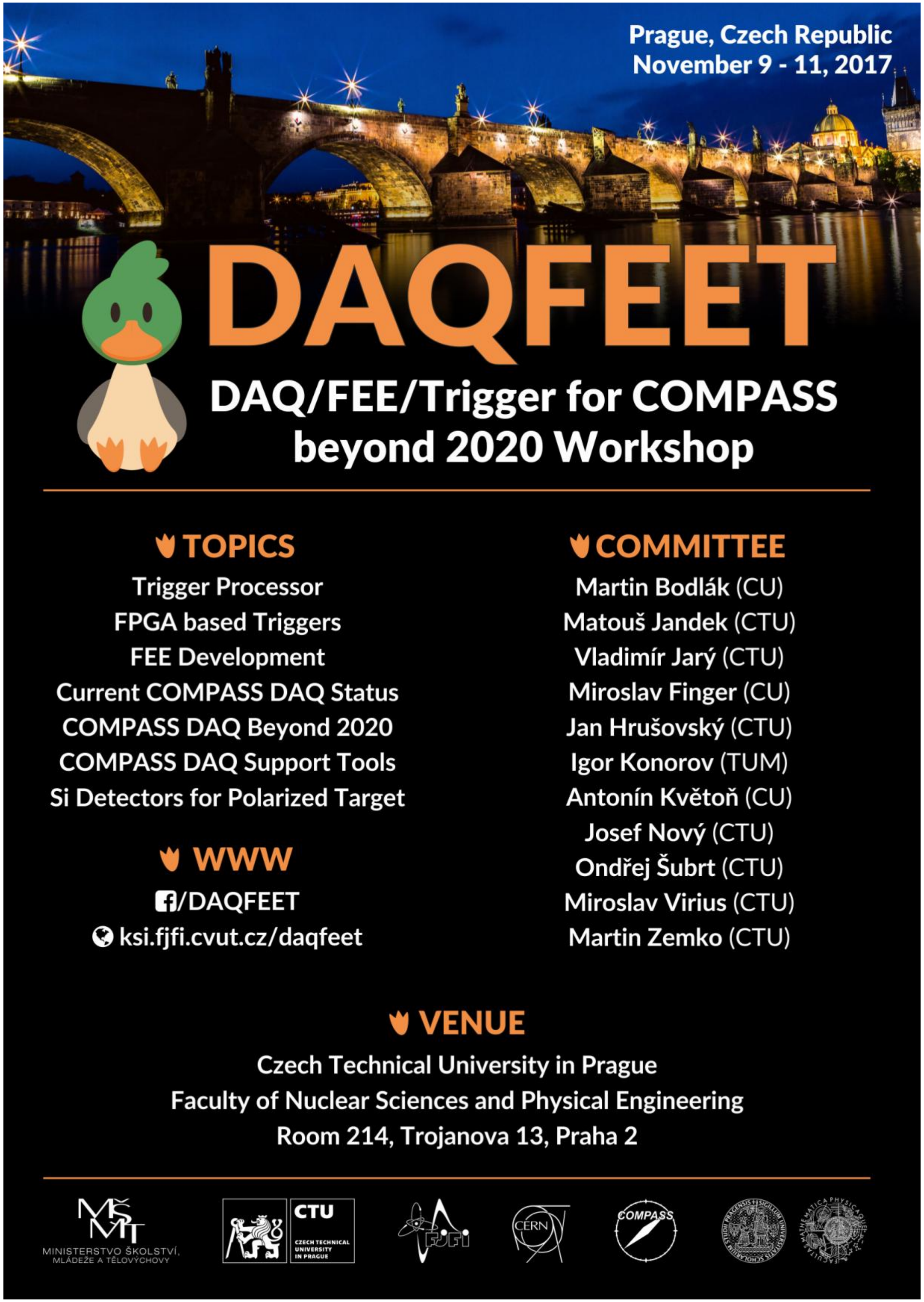


This workshop is focused on development needed for COMPASS beyond 2020.

We will discuss required performance and architecture of FEE and DAQ components, unify serial interfaces and protocols, discuss trigger processor hardware, and distribution of workload.

One of the topics will be also development of Si detector systems for polarized target.

35 participants, 33 talks,
4 talks from JINR

https://ksi.fjfi.cvut.cz/daqfeet/#Home
https://indico.cern.ch/event/673073/

COMPASS & a COMPASS-like experiment

DAQFEET
DAQ/FEE/Trigger for COMPASS beyond 2020 Workshop

CTU FNSPE Prague
November 9-11, 2017

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Caroline Riedl
CERN

On behalf of the COMPASS proposal- and LoI-writing teams

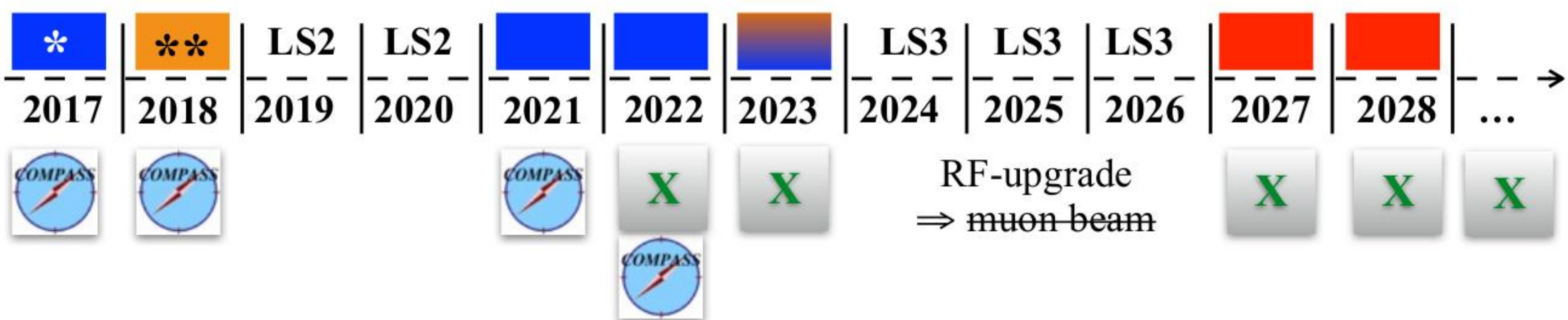
The M2 beamline: a unique hadron & muon facility

hadron & muon beams
two charges
high energy (100 GeV++)
high intensity (1e08/sec)

- Starting point: March 2016 "COMPASS beyond 2020" workshop https://indico.cern.ch/event/502879
- **2021 (/ 22): Proposal** submitted to SPSC in October 2017 for the extension of the COMPASS-II program.
- **2022++: Letter of Intent (LoI)** in preparation for a new COMPASS-like experiment at the M2 beam line.

conventional muon beams

A) conventional pion & muon beams
B) RF-separated anti-proton- and kaon-enhanced beams

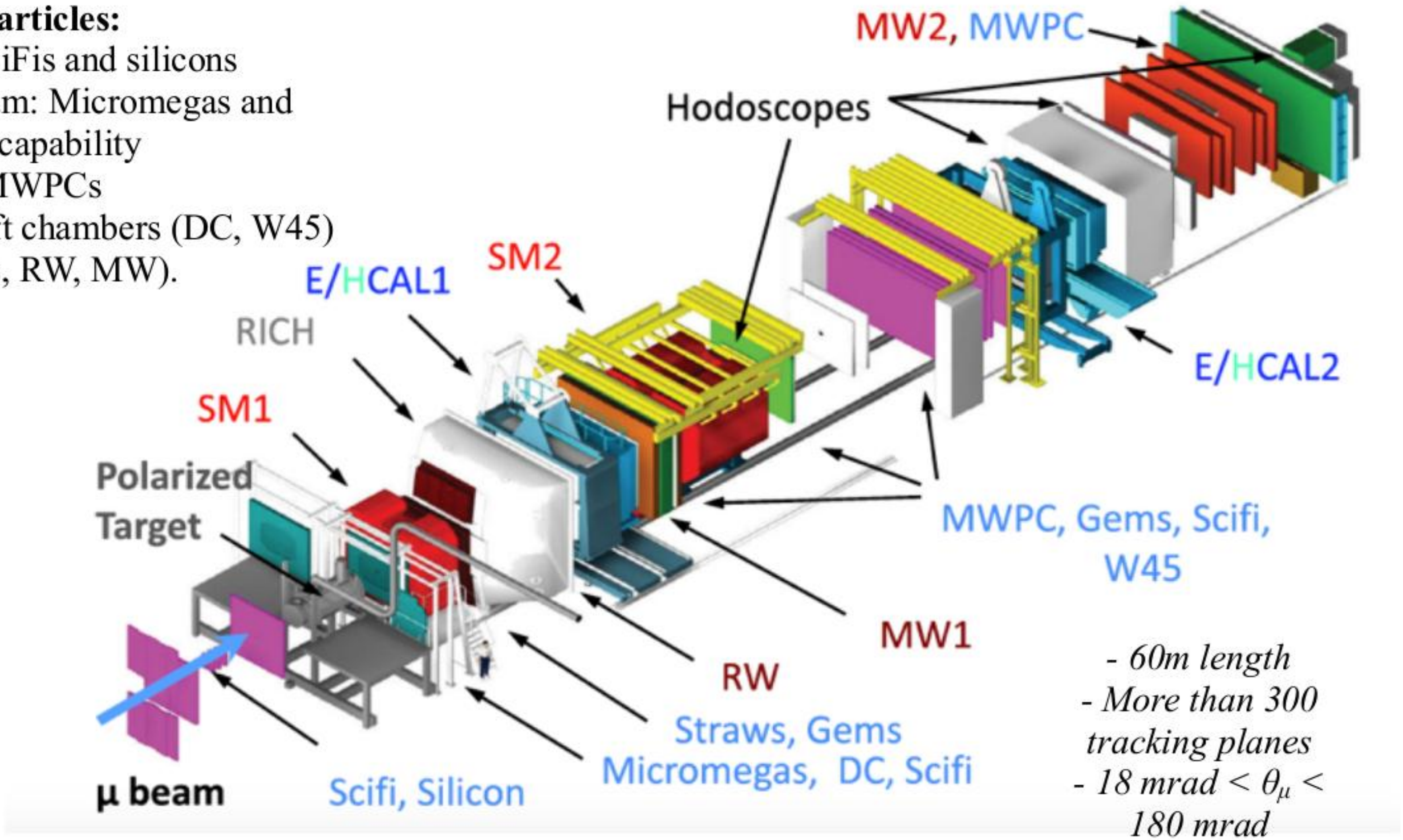


* COMPASS-II DVCS, completed

** COMPASS-II spin-dependent Drell-Yan to start on April 9, 2018

Existing COMPASS spectrometer

- **Tracking of charged particles:**
  - in the beam region: SciFis and silicons
  - region close to the beam: Micromegas and GEMs with high-rate capability
  - intermediate region: MWPCs
  - large-are tracking: drift chambers (DC, W45) and drift tubes (Straws, RW, MW).



- 60m length
- More than 300 tracking planes
- 18 mrad < θ_μ < 180 mrad

- **Separation of produced pions & kaons:** RICH with multianode-photomultiplier tubes and MWPCs with photosensitive CsI cathodes in the periphery

- **Energy measurement:**
  - charged particles: sampling hadron calorimeters (HCAL)
  - neutral particles, in particular high-energy photons: electromagnetic calorimeters (ECAL)

The mission: exploring hadron structure at ENH2

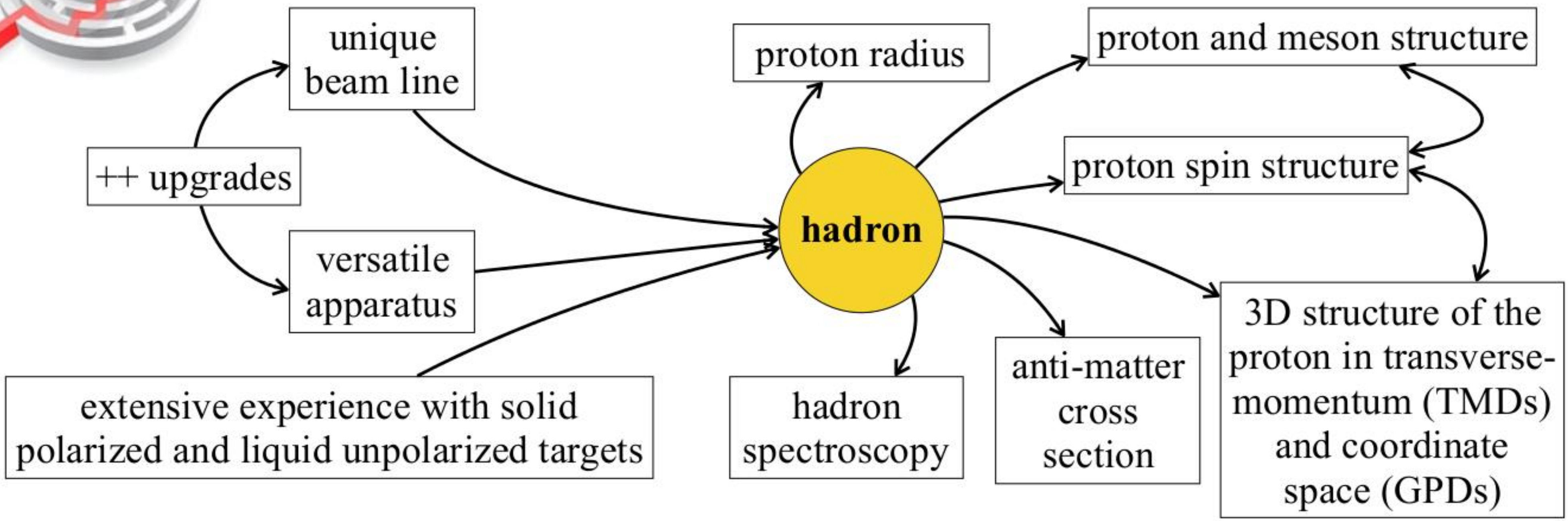
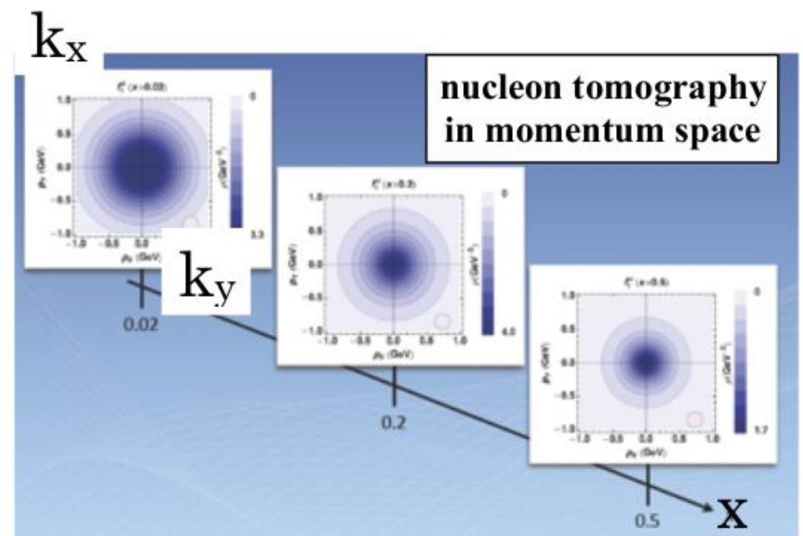


Table of TMD PDFs

- nucleon (**N**)
- unpolarized quark (**Q**)
- nucleon spin
- quark spin
- quark k_T

N \ Q	U	L	T
U	f_1 number density		$h_1^\perp$ Boer-Mulders
L		g_1 helicity	$h_{1L}^\perp$ worm-gear
T	$f_{1T}^\perp$ Sivers	$g_{1T}^\perp$ worm-gear	h_1 transversity; $h_{1T}^\perp$ pretzelosity



Drell-Yan with kaon and anti-proton beams

LoI (draft)

RF-separated beams

- Pion (*ud*) vs. kaon (*us*): presence of the heavier valence strange-quark might alter kaon properties.
- Kaon s-quark carries larger fraction of kaon momentum:
  ⇒ Valence distributions differ kaon vs. pion.
  ⇒ Less gluons in kaon than in pion (heavier quarks radiate softer gluons).
- Only experimental information on valence kaon PDF 30 years old: NA3. Sea unknown.
- Valence and sea separation in kaons using isoscalar targets and high-intensity K^+ and K^- beams.
- Kaon-induced J/ψ production to map kaon u-quark distribution
- Nucleon spin structure with anti-proton beams: measurements of observables related to proton TMDs with reduced systematic uncertainties. Example for Boer-Mulders TMD (BM):
  πp scattering: $(BM)_p \otimes (BM)_\pi$
  $\bar{p}$p scattering: $(BM)_p \otimes (BM)_{\bar{p}}$
  ⇒ Access to valence-quark TMDs of the proton only.

Drell-Yan with K^+, K^- and $\bar{p}$-beams on targets:
- liquid deuterium
- polarized ^{6}LiD
- nuclear

Conditions for future programs

Additional questions: trigger latency?
Hardware (FPGA) or software trigger?
Earliest possible realization?

(*) or list of detectors to be included in trigger logic

Program	Type / set of detectors baseline: COMPASS w/o RICH1	Beam energy [GeV]	Rate on target [sec^{-1}]	Trigger rate (est.) [kHz]	Trigger signature (*)	Trigger challenge factor
d-quark Transversity	RICH1	160	3×10^6	25	As 2010: IT, MT, LT, OT, CT, LAST	
Proton radius	active hydrogen target, silicon (2+1) or SciFi (2+2) telescopes	100	4×10^6	<= 100	~~beam trigger?~~ scattered-muon trigger? (recoil-proton trigger?)	
GPD E	recoil detector around transpol polarized target	160	10^7	10	MT, LT, OT, LAST. If higher beam intensity: photon or proton trigger?	
Drell-Yan conventional	vertex detector	190	$0.2\text{-}6.8 \times 10^7$	25	As 2015: MT+LAST, OT +LAST, LAST 2mu	
Drell-Yan RF-separated	vertex detector, larger tracking detectors?	~100	10^8	25-50	As above + ? new hodoscopes for SAS-SAS trigger	
Primakoff RF-separated	RICH1	~100		>> 10	ECal2 ΔE>threshold	
Prompt photon prod.		>= 100	5×10^6	10-100	ECal0, ECal1 ΔE>threshold, or “true pT” trigger	
Anti-matter x-section	RICH1 (RICH0?)	50 100 190,..	5×10^5	25	As 2012 Primakoff: (a)BT, VI, ΔECals>threshold	
Spectroscopy anti-p	target spectrometer: tracking & calorimetry, RICH (RICH0?)	12 20			CEDARs?	

Where we are and where we want to go ?

Igor Konorov

COMPASS Beyond 2020

DAQ/FEE/Trigger Workshop

Prague November 9-th

COMPASS

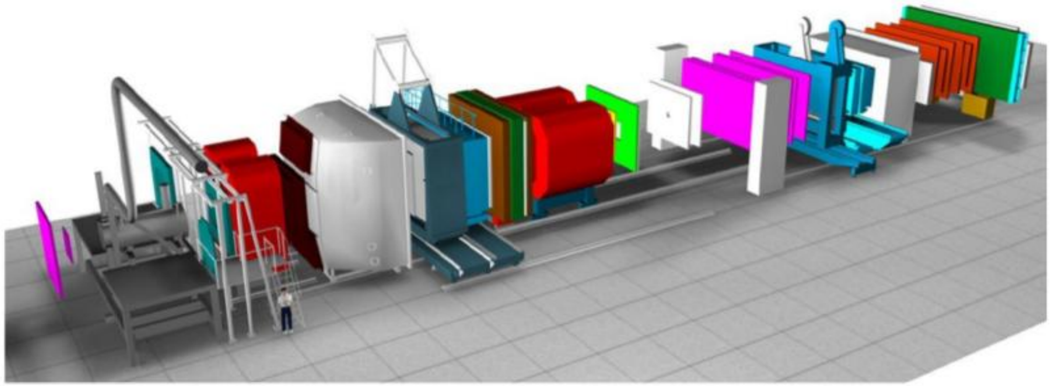
Micro pattern detectors
- Silicon Detectors
- GEM, PGEM, PMM

Scintillating Detectors
- SciFi, BMS, Hodoscopes, CAMERA

Wire Chambers
- DC, Straw, W45
- MWPC, RW, MW1, MW2
- DC05

Calorimeters
- HCAL1,2
- ECAL0,1,2

RICH
- MAPMT
- MWPC, THGEM



Front-End and DAQ Electronics

DAQFEET workshop, Prgue 2017

Detector type	# of channels	Required out electronics	
Calorimeters ECAL0, ECAL2	4.800	12b ADC@80MHz	
Calorimeters HCALs, ECAL1	2.200	10b ADC@80MHz	
Silicon, GEM, PGEM, PMM	~100.000	APV25 ASIC	
RICH, MWPC	60.000	APV25 ASIC	
RICH, MAPMT	12.000	F1 TDC	
SciFi	~2.600 ?	F1 TDC GANDALF TDC	
Beam Momentum Station	640	F1 TDC	
Hodoscopes, VETO	500	F1 TDC	
Wire Chambers	~60.000	F1+FPGA TDC	
Recoil Detector	96	14b ADC@0.5(1.0)GHz	

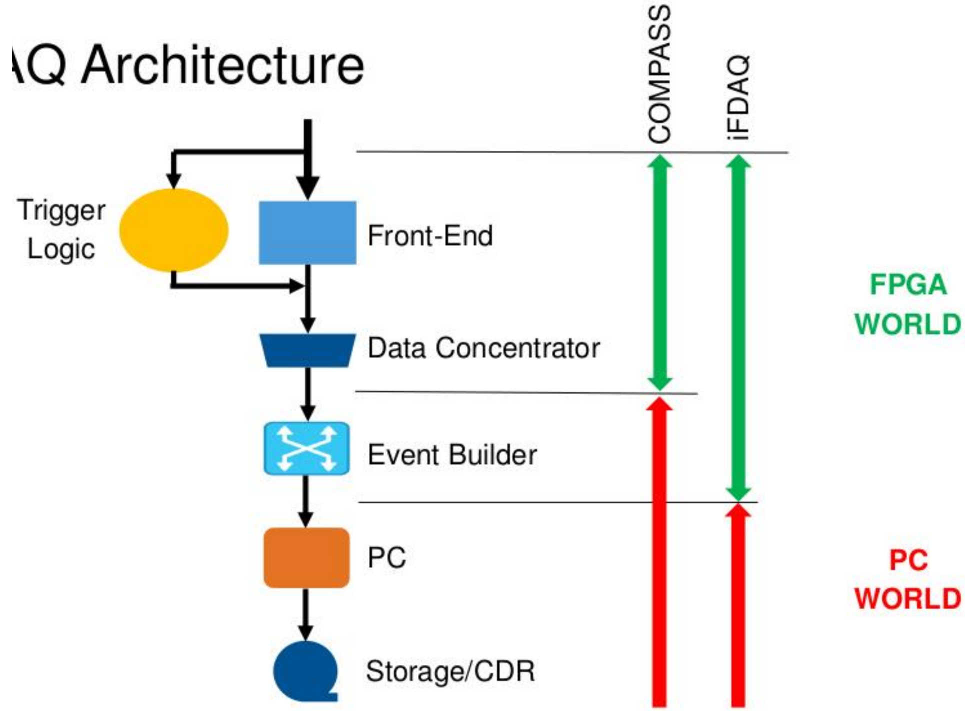
Front-End and DAQ Electronics

FEEs and DAQs electronics developed by COMPASS collaboration !!!

Adoption of LHC technology :

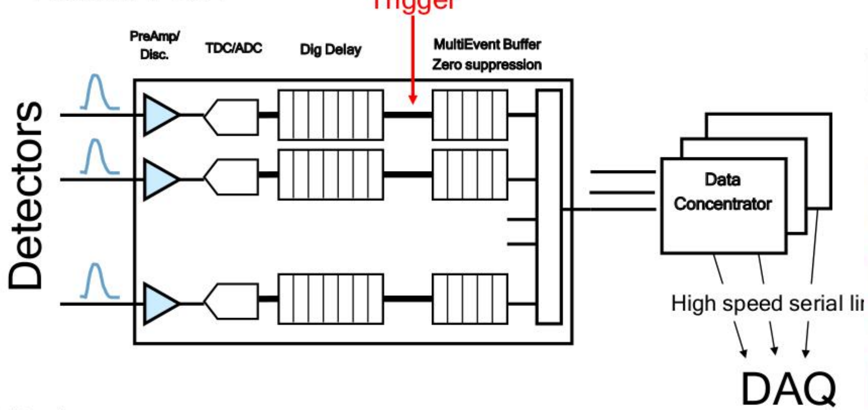
- APV25 developed for CMS silicon detectors => **Silicon, GEM, PGEM, PMM, RICH**
- Passive optical splitter and Time Division Multiplex encoding of TTC(Time Trigger Control) developed for LHC experiments => **Trigger Control System**
- Slink serial interfaces – optical interface with160 MB/s bandwidth

AQ Architecture



Pipe-Line Read out Architecture

First run : 2002



FEE Performance :

Trigger rate	aimed :100kHz	real : 40kHz
Dead time	0 %	10-20%

Read Out Electronics

Micro pattern detectors
- Silicon Detectors
- GEM, PGEM, PMM

APV25

Scintillating Detectors
- SciFi, BMS, Hodoscopes — F1
- CAMERA — GANDALF

Wire Chambers
- DC, Straw, W45
- MWPC, RW, MW1, MW2

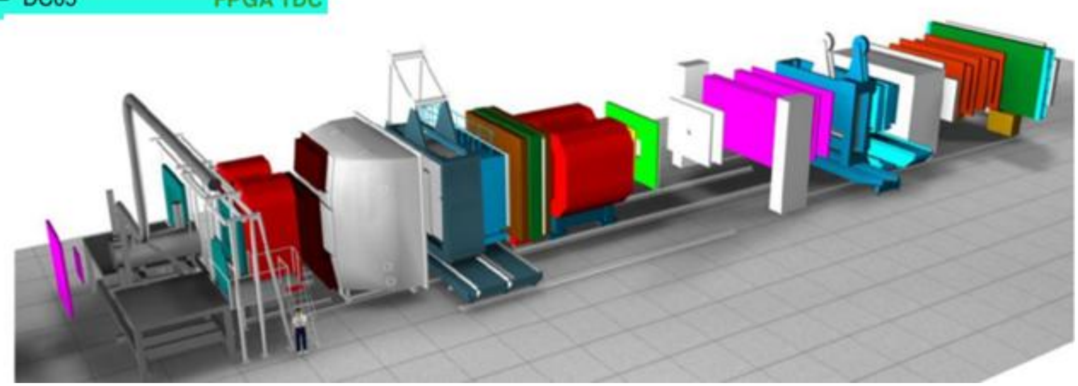
F1

- DC05 — FPGA TDC

Calorimeters
- HCAL1,2
- ECAL0,1,2

MSADC

RICH
- MAPMT — F1
- MWPC, THGEM — APV25



New Developments

DAQ Upgrade
IPBUS interface developed for CMS

- UDP based protocol
- Direct Ethernet connection to FPGA to access internal registers , memories
- Requires little FPGA resources

UCF (Unified Communication Framework)

- Protocol for serial links
- Universal protocol for all types of communications between FPGAs
- Single link for trigger, slow control(IPBUS) and data
- Supports point-to-point and start like topology

FPGA TDC - iFTDC

New Kintex Ultrascale FPGA module for DAQ and Trigger Processor

Summary

Limitations of present readout system :

- 2us trigger latency, 40 kHz trigger rate

Possible improvements :

- upgrade of Silicon and GEM firmware to 40 MHz => 90 kHz trigger rate
- Change 3 sample read out to one sample => 200 kHz trigger rate
- Implement feature extraction algorithm in SADC and MSADC to over come bandwidth limits

Hardware upgrade to build trigger less FEEs

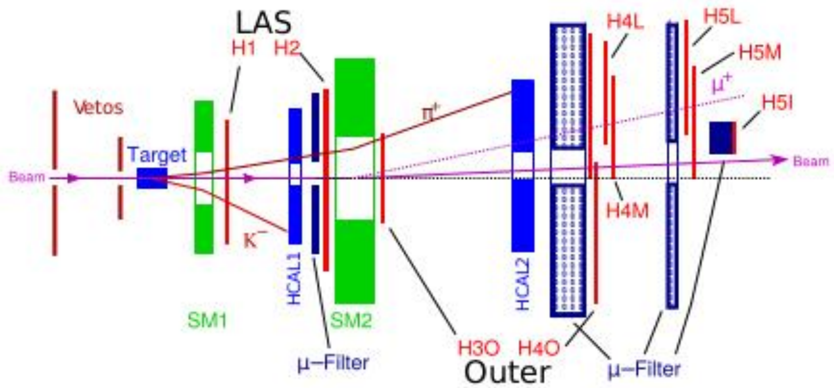
- exchange F1 TDC by iFTDC
- exchange SGADC by new ADC

Investigate a possibility to substitute APV25 by trigger less or high trigger rate ASIC

COMPASS Trigger Hardware Overview

Benjamin Moritz Veit

COMPASS Trigger



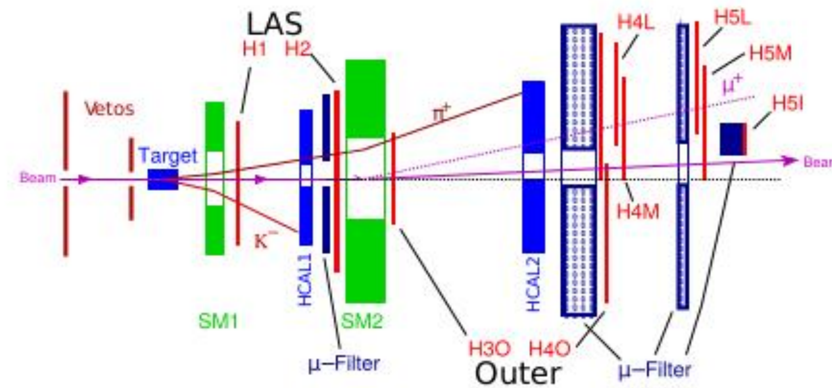
Identification of muons via absorber.

Two independent trigger systems:

- Muon Trigger (Target Pointing / Energy Loss)
- Calorimeter Trigger (Energy threshold)

+ Veto System

COMPASS Trigger



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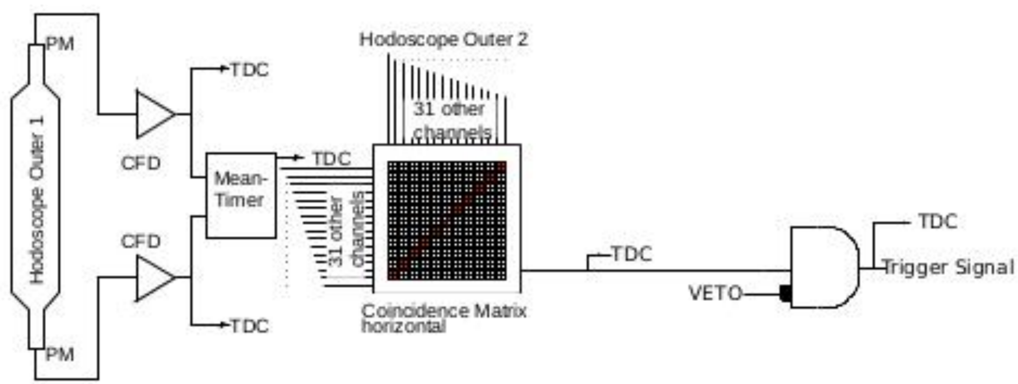
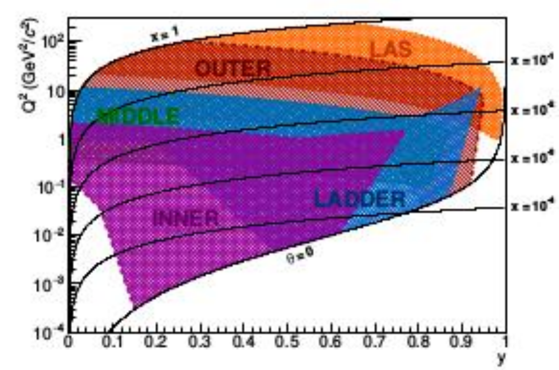


Trigger Subsystems

4 different trigger subsystems with different acceptance.

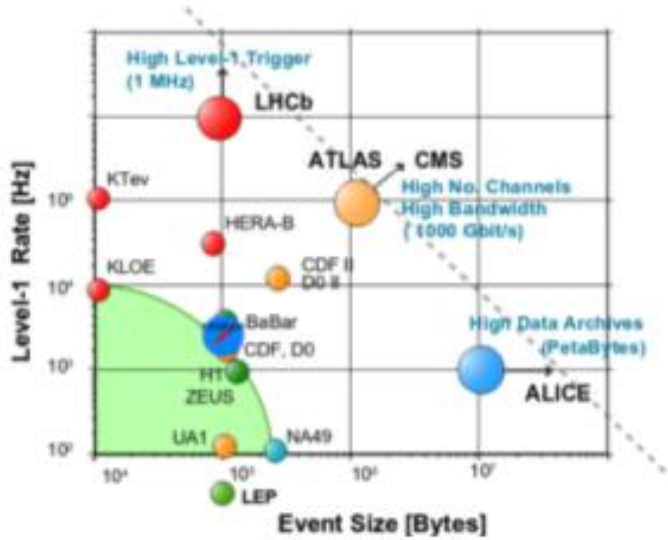


No INNER since 2012.

- Middle (HM04/05Y/X)
  - 8 Hodoscopes with 144 Slabs
- Ladder (HL04/05X)
  - 2 Hodoscopes with 64 Slabs
- Outer (HO03/4Y)
  - 2 Hodoscope with 50Slabs
- LAS (HG01/2Y)
  - 2 Hodoscopes with 96Slabs
- Inner (HI04/05)
  - 2 Hodoscopes with 128Slabs

+ calibration trigger (BeamT, Halo, Random)

L1 Trigger Rate vs. Event Size



Maximum allowed trigger rate determined by typical event size:

DAQ Bandwidth = Maximum Trigger Rate × Event Size

L0 Rate = Sum of Beam Trigger, Inner Veto and Halo.

Transversity 2010 250E11 pot on T6

Prescaler setup for run 89064

Trigger element	Short name	Division factor	In rate (1st spill)	Out rate (1st spill)
Inner Trigger	IT	1	[illegible]	[illegible]
Middle Trigger	MT	1	[illegible]	[illegible]
Ladder Trigger	LT	1	[illegible]	[illegible]
Outer Trigger	OT	1	[illegible]	[illegible]
Calorimeter Trigger	CT	1	[illegible]	[illegible]
Inner Veto	VI	40000	[illegible]	[illegible]
Halo Trigger [illegible]	Halo	10000	[illegible]	[illegible]
Beam Trigger	BT	99999	[illegible]	[illegible]
Middle Trigger Inclusive	MTincl	1	[illegible]	[illegible]
Large Angle Spectrometer Trigger	LAST	1	[illegible]	[illegible]
True Random	TRand	1	[illegible]	[illegible]
Noise Random	NRand	0	[illegible]	0

≈ 13 MHz

DY 2015 120E11 pot on T6

Prescaler setup for run 263045

Trigger element	Short name	Division factor	In rate (1st spill)	Out rate (1st spill)
Dimuon Trigger (Middle and LAS)	MT+LAST	1	[illegible]	[illegible]
Single muon Middle Trigger	MT	100	[illegible]	[illegible]
Dimuon Trigger (Outer and LAS)	OT+LAST	1	[illegible]	[illegible]
Single muon Outer Trigger	OT	100	[illegible]	[illegible]
Calorimeter Trigger	CT	0	[illegible]	0
Inner Veto	VI	0	[illegible]	0
Halo Trigger [illegible]	Halo	0	[illegible]	0
Beam Trigger	BT	[illegible]	[illegible]	[illegible]
Dimuon Trigger LAS	LAST [illegible]	1	[illegible]	[illegible]
Single muon Trigger LAS	LAST [illegible]	[illegible]	[illegible]	[illegible]
True Random	TRand	1	[illegible]	[illegible]
Noise Random	NRand	0	[illegible]	0

≈ 16 MHz

DVCS 2017 150E11 pot on T6 mu+ 500mm Be Target

Prescaler setup for run 279166

Trigger element	Short name	Division factor	In rate (1st spill)	Out rate (1st spill)
[illegible]	[illegible]	0	[illegible]	0
Middle Trigger	MT	1	[illegible]	[illegible]
Ladder Trigger	LT	1	[illegible]	[illegible]
Outer Trigger	OT	1	[illegible]	[illegible]
Calorimeter Trigger	CT	10	[illegible]	[illegible]
Inner Veto	VI	10000	[illegible]	[illegible]
Halo Trigger [illegible]	Halo	500	[illegible]	[illegible]
Beam Trigger	BT	[illegible]	[illegible]	[illegible]
ECAL0 trigger	ECAL0	0	0	0
LAS Trigger	LAST	1	[illegible]	[illegible]
True Random	TRand	1	[illegible]	[illegible]
Noise Random	NRand	0	[illegible]	0

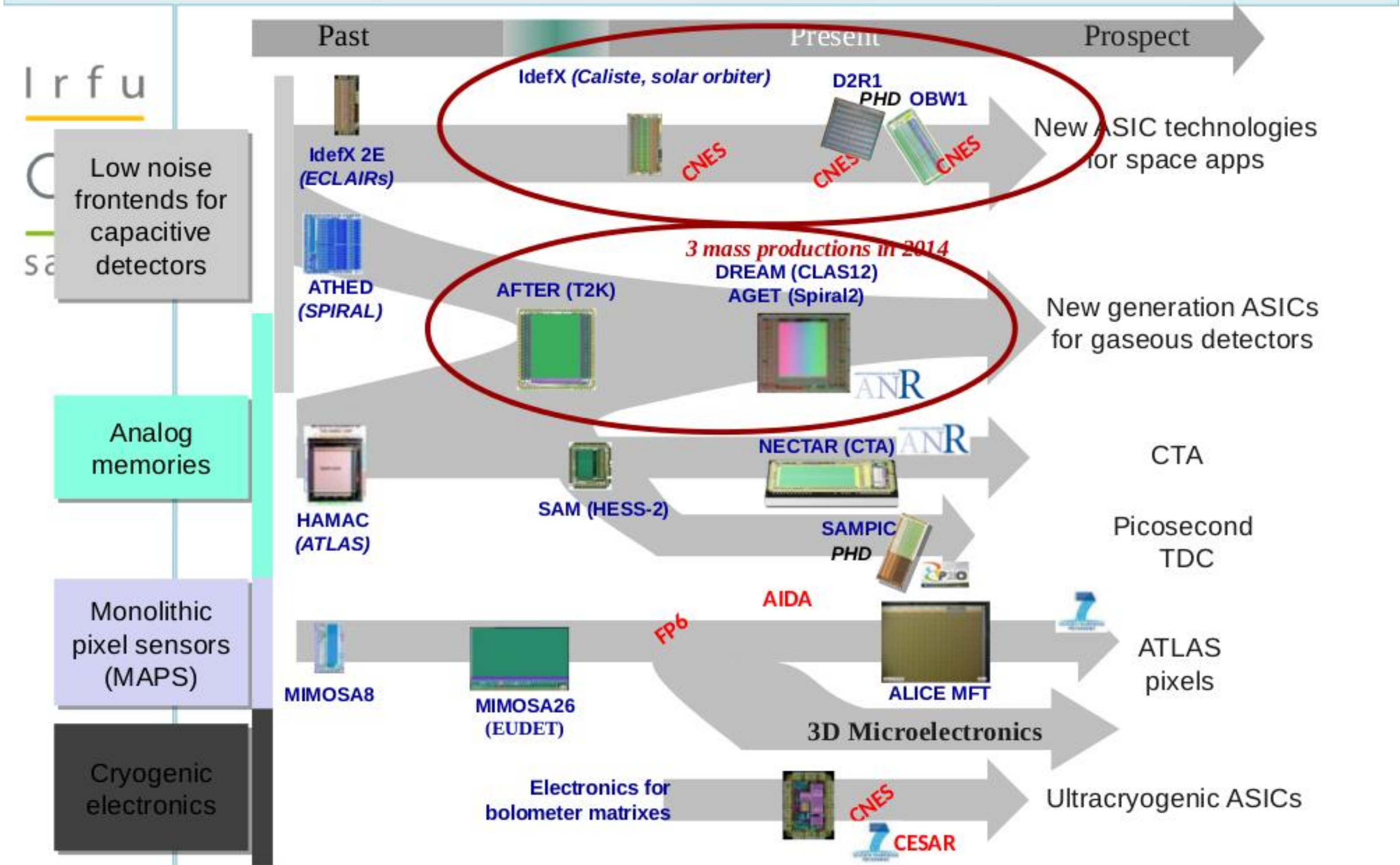
≈ 15 MHz

Latency of current system max 3 μs.

Recent Front-end developments at Saclay

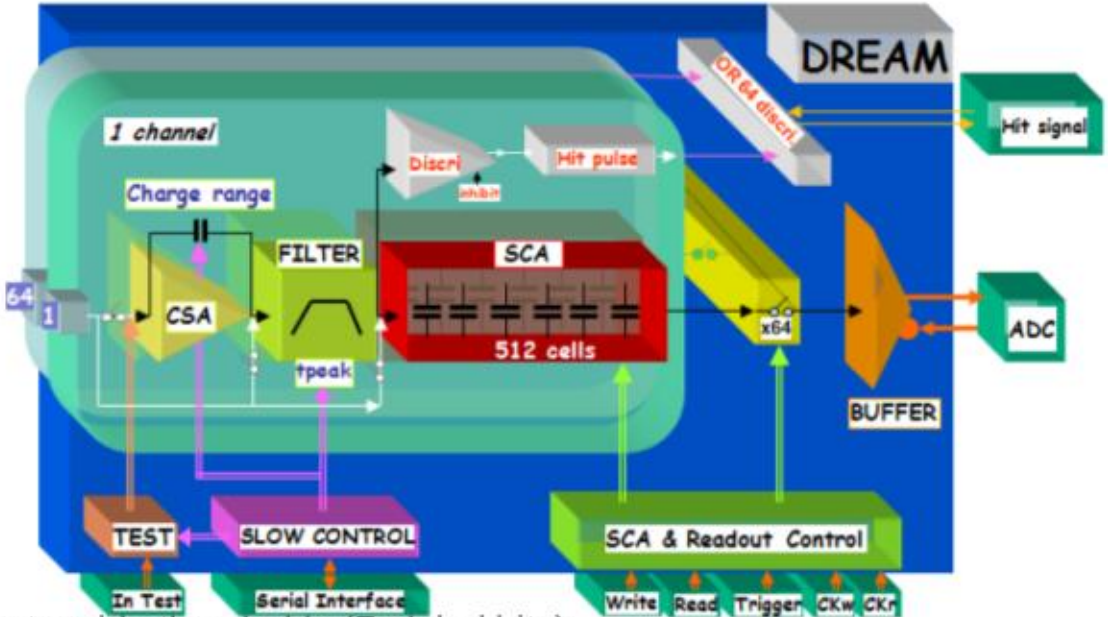
Damien Neyret, on behalf of the SEDI Microelectronics group
(particularly O. Gevin, P. Baron)
CEA Saclay IRFU/SPhN

Front-end chips road-map



DREAM front-end chip

- 64 channels
- 4 gains / channel: 50 fC, 100 fC, 200 fC, 600fC
- 16 peaking times: 50 ns to 1 µs
- **512**(511) analog memory cells
- Sampling rates: 1MHz to 50 MHz
- Read-out rate: 20 MHz

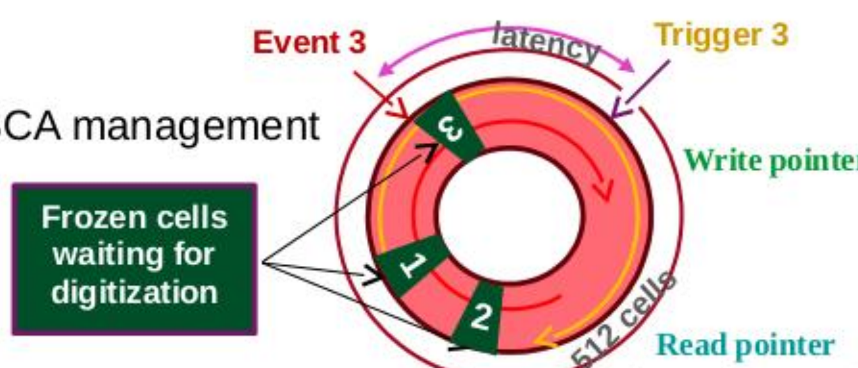


- Auto trigger: discriminator + tunable thresholds (7 global bits)
- Multiplicity information: digital signal (LVDS); 8 multiplicity levels
- SCA read-out: only “trigged” cells of the 64 channels
- Possibility to short the CSA and input directly into RC2 filter or into SCA

DREAM ASIC

- developed for CLAS12 Micromegas
- stand high input capacity (> 200pF)
- large trigger and counting rates

SCA management



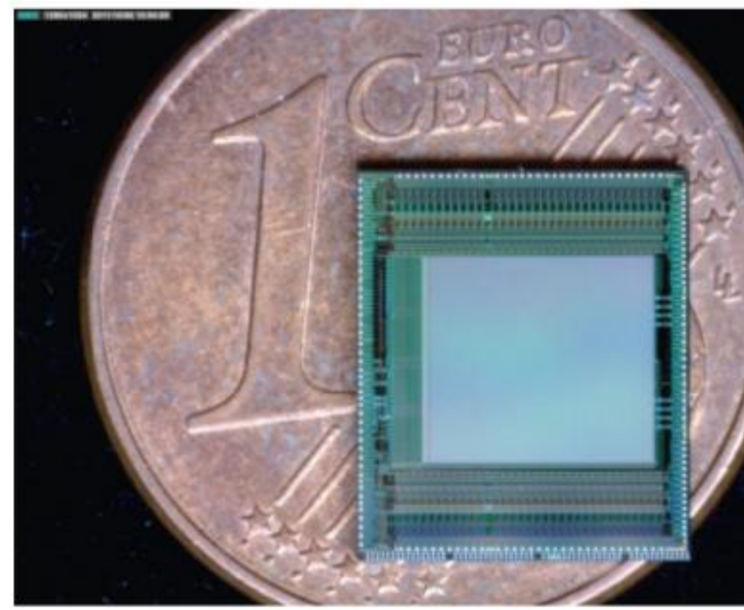
DREAM front-end chip

Specifications

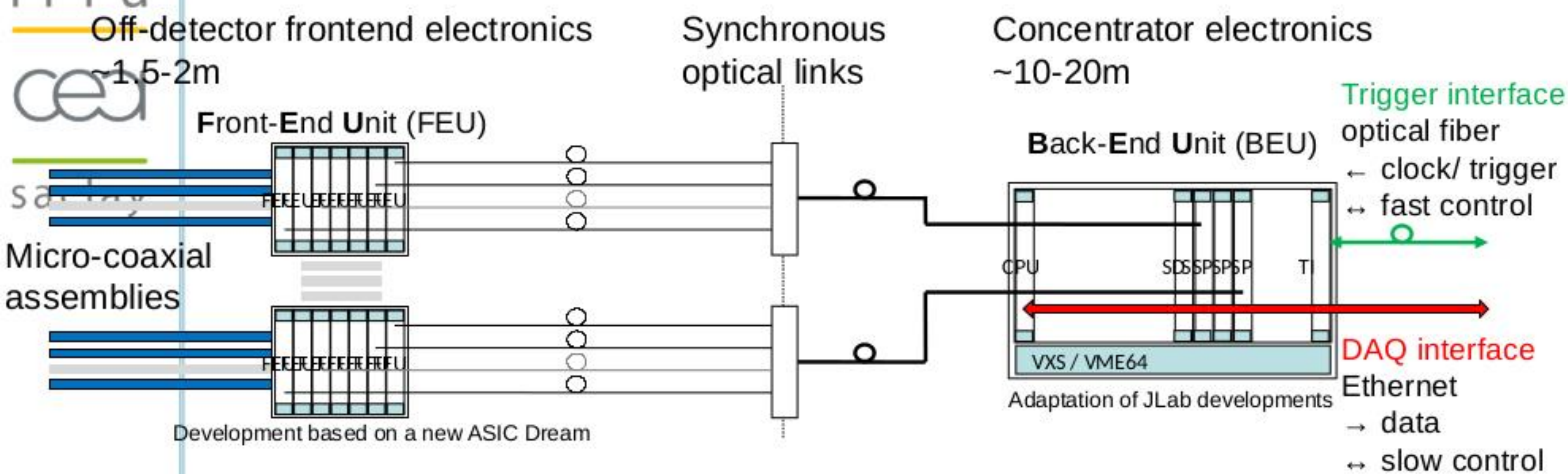
Parameter	Value
Polarity of detector signal	Negative or Positive
Channels number	64
External Preamplifier	Yes; access to the filter or SCA input (external CSA)
Charge measurement	
Input dynamic range	50 fC, 100 fC, 200 fC, 600 fC
Gain	Adjustable per channel
Output dynamic range	2V p-p (differential)
I.N.L	< 2%
Resolution	< 2500 e- (Gain: 200fC; Peaking Time: 180ns; Cinput < 200pF)
Sampling	
Peaking time	50 ns to 900 ns (16 values)
SCA time bin number	512
Sampling Frequency	1 MHz to 50 MHz
Multiplicity	
Multiplicity signal	LVDS signal; 8 multiplicity levels
Input dynamic range	5% or 17.5% of input channel input charge range
I.N.L	< 5%
Threshold value	7-bit DAC + polarity bit
Readout	
Readout frequency	20 MHz
Channel Readout mode	All channels
SCA Readout mode	Triggered columns only
Test	
calibration	1 channel among 64; 1 external test capacitor
test	1 channel among 64; internal test capacitor (1 among 4)
functional	1 to 64 channels; 1 internal test capacitor per channel
Counting rate	< 50 kHz / channel
Trigger rate	Up to 20 kHz (4 samples read/trigger)
Power consumption	< 10 mW / channel @ 3.3V

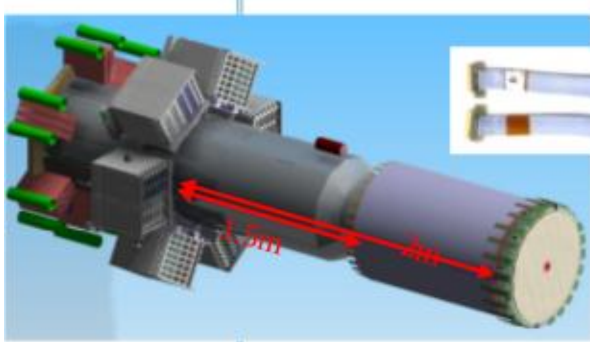
Layout & package

- Technology: AMS CMOS 0.35 µm
- Surface: 8,6 x 7,5 mm²
- Number of transistors:# 700 000
- Package: LQFP 128 (14 x 14 x 1,4 mm)
- 2014: end of test production (1600)

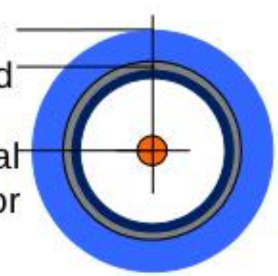


DREAM front-end chip

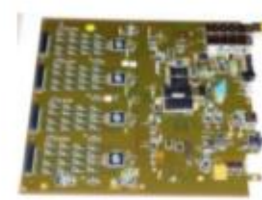




Micro-coax flat cable



FEU



SSP

Comparison between chips

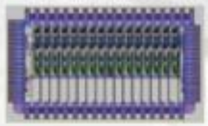
Parameter	AFTER	AGET	DREAM
Polarity of detector signal	Negative or Positive	Negative or Positive	Negative or Positive
Number of channels	72	64	64
External Preamplifier	No	Yes; access to the filter or SCA inputs	Yes; access to the filter or SCA inputs
Charge measurement			
Input dynamic range/gain	120 fC; 240 fC; 360 fC; 600 fC	120 fC; 240 fC; 1 pC; 10 pC /channel	50 fC; 100 fC; 200 fC; 600 fC /channel
Gain v.s Cdet (200pF)			
200 fC; tp = 230 ns	- 13%	- 13%	-0,9%
Sampling			
Peaking time value	100 ns to 2 µs (16 values)	50 ns to 1 µs (16 values) (ASTRE : 8µs)	50 ns to 900 ns (16 values)
Number of SCA Time bins	511	512	512
Sampling Frequency (WCk)	1 MHz to 100 MHz	1 MHz to 100 MHz	1 MHz to 50 MHz
Triggering			
Discriminator solution	No	Leading edge	Leading edge
HIT signal		OR of the 64 discri. outputs in LVDS level	OR of the 64 discri. outputs in LVDS level; 8 multiplicity levels
Threshold Range		5% or 17.5% of the dynamic range	5% or 17.5% of the dynamic range
Threshold value		(3-bit + polarity bit) common DAC + 4-bit DAC / channel	(7-bit + polarity bit) DAC common to all channels
Readout			
Readout frequency	20 MHz	25 MHz	Up to 20 MHz
Channel Readout mode	all channels	All, hit or selected	all channels
SCA cell Readout mode	all	1 to 512	Triggered columns only
Trigger rate			Up to 20kHz (4 samples read/trigger).
Counting rate	< 0.3 Hz / channel	< 1 kHz / channel	< 50 kHz / channel
Power consumption	< 10 mW / channel	< 10 mW / channel	< 10 mW / channel
Status	Production	Production	Production
Noise 120 fC; 200 ns peaking time	370 e- + 14.6 e- / pF (measured)	580 e- + 9 e- / pF (measured)	
Noise 200 fC; 200 ns peaking time	700 e- + 8.5 e- / pF (measured)		610 e- + 9 e- / pF (measured)
Electronics	T2K (AFTER + FEC + FEM) AFTER + FEC + evaluation kit AFTER + FEC + STUC AFTERSED	GET AGET + AsAd + rCoBo FEMINOS	DREAM + FEU + SSP DREAM + FEU + TCM

IDeF-X ASIC family

Very low noise chips for solid detectors, to be considered for ionization detection ?

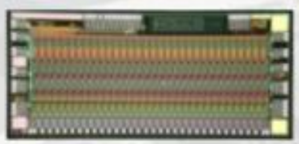
AMS 0.35µm — **IDeF-X :spectrometry channel**

V0, Chip test, CSAs



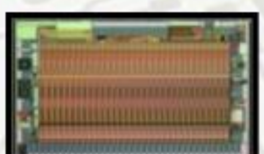
V1.0 Full analog chains

V1.1 Analog + Mux / Caliste64
System approach
Radiation evaluation



V.2 – ECLAIRs / Caliste 256
Fully programmable
Space qualified

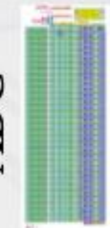
BD – SSL/CINEMA
Fully programmable
Si or DSSD adapted



HD – Caliste HD
Low Power
Fully programmable
HD-BD upcoming

HD-LXE–
Low Power
Fully programmable
// outputs

ADC



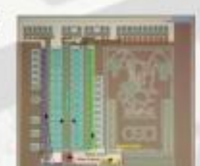
OWB-1 – ADC //
32 channel
13 bits
Low power
SEL hardened

XFAB 0.18µm — **IDeF-X :spectrometry channel**

Caterpylar
Chip test
Very low noise
Very low power

D^2R_1, 256 Pixels
$300 \times 300\ \mu m^2$
Auto-trigger
very low power.

AMS 0.18µm



Caterpylar AMS
Chip test
Very low noise
Very low power

INFN TORINO
ELECTRONICS SERVICE

DAQ/FEE/Trigger workshop for COMPASS beyond 2020
Prague 9-11 November 2017
Giulio Dellacasa

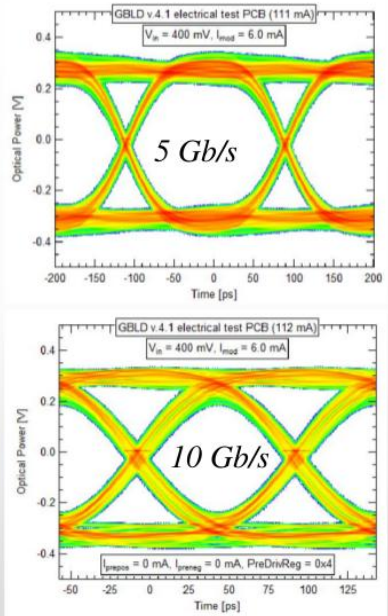
Who we are

- INFN Torino personnel consists of 87 staff members and 275 associated members (students and researcher from University and other institutions)
- Electronics Laboratory at INFN Torino is made up of 14 staff members
  - 2 Postdoc and more than 10 PhD students involved in IC design. Big resource!
- The Electronics Laboratory fulfils all the requests made by different physics research groups providing both design, systems realization and test capabilities of discrete electronics and microelectronics devices
- Design activities range from the very front-end electronics to the development of full read-out and data acquisition systems

IC design - contributions

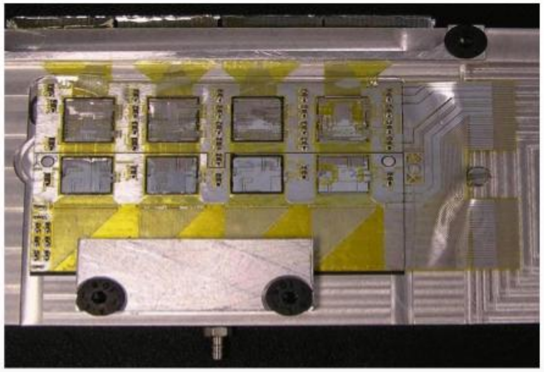
INFN Istituto Nazionale di Fisica Nucleare

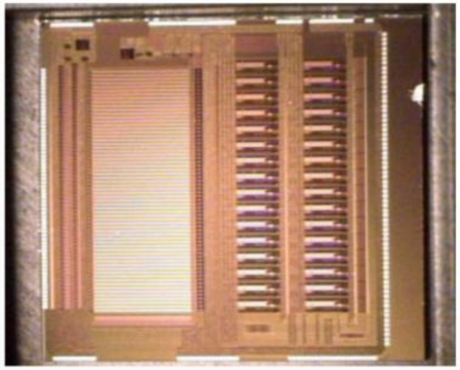
- ALICE ITS upgrade: ALPIDE Monolithic Pixel Sensor chip (TowerJazz 180 nm)
  - 1.2 Gb/s Data Transmission Unit (DTU) DDR mode with SEU protection. PLL design x15 clock multiplication (40 -> 600 MHz)
- GBLD: Laser Driver for the CERN's GBT project. 4.8 Gb/s, radiation tolerant in CMOS 130 nm (IBM). R_j<1 ps rms
- HL-LHC CMS ECAL upgrade:
  - 12-bit ADC 160 Ms/s, developed by private company
  - chip integration (2 ADC per ASIC), data compression and readout logic development (E-DTU) in CMOS TSMC 65 nm



IC design – system level ALICE

INFN Istituto Nazionale di Fisica Nucleare



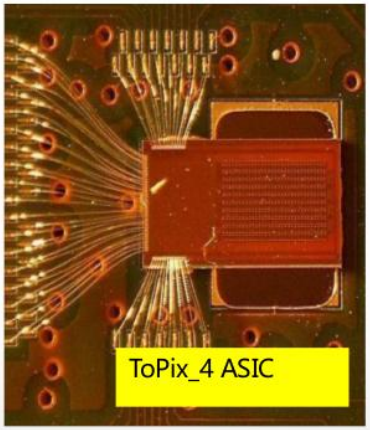


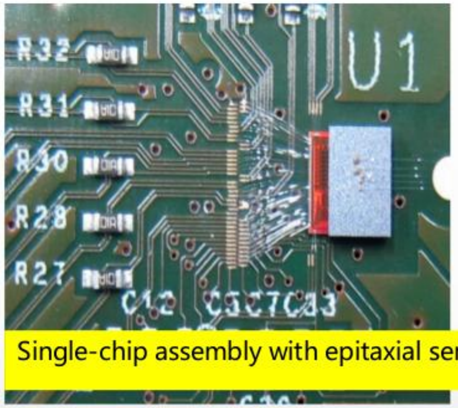
- ALICE ITS Silicon Drift Detector: development, test production and assembly of the readout electronics for the SDD detector
  - PASCAL: 64 channels analogue frontend. Preamp. and analogue storage. 10-bit SAR ADC 40 Ms/s
  - AMBRA: digital 4-events buffer, data compression from 10 to 8 bits
  - CMOS 0.25 μm

IC design – R&D

- Timing application:
  - TOFEE: amplifier-discriminator chip for timing measurement of Ultra Fast Silicon Detector (resolution required ~30 ps per detector layer in CMS-TOTEM PPS). 8 channels, CMOS 110 nm (UMC), ToT time walk correction
  - TOF-PET: analogue CMOS front-end for silicon photomultiplier (SiPM) for time-of-flight measurement in compact Positron Emission Tomography medical imaging. CMOS 130 nm, 64 channels, 100 kHz per channel, 50ps TDC time binning, ToT time walk correction
  - NA62: development of a prototype for the readout of Gigatracker detector of the NA62 experiment. CMOS 130 nm, 4 TDC per channel (Wilkinson ADC), CFD time walk correction, 100 ps time binning
- SEED: Sensor with Embedded Electronics Development. Study of a innovative technology HVCMOS 130 nm for monolithic sensors
- Starting development 16 nm FIN-FET (technology evaluation studies on F/E design and radiation tolerance)
- Technology transfer: frontend and readout ASIC, with time measurement per channel less than 100 ps rms of a 1024 channels hybrid pixels sensor (CMOS 110 nm)

IC design – R&D - PANDA


ToPix_4 ASIC

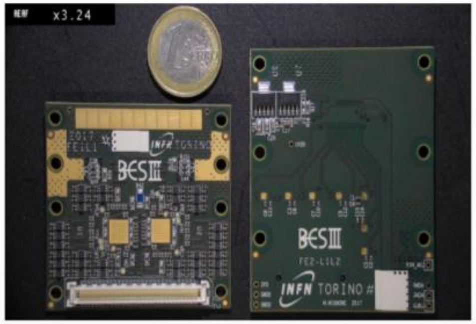


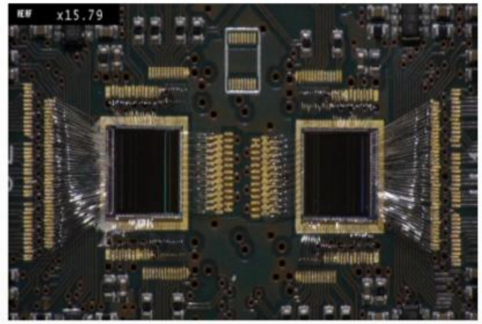
Single-chip assembly with epitaxial sensor

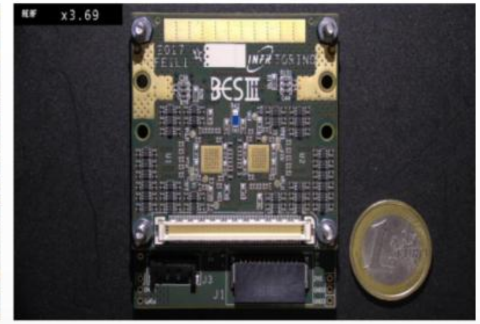

Tracking station: pixel and strips

- Responsibility of the Micro Vertex Detector (MVD): ~11 millions of pixels and 200k micro strips
- High speed trigger less readout for both the systems ToPix (pixels) and PASTA (strips)
- ToPix: first CMOS 130nm (IBM) prototype tested at INFN with intensive studies of radiation damages
- Development with FBK of epitaxial silicon sensors

PCB design – BES III

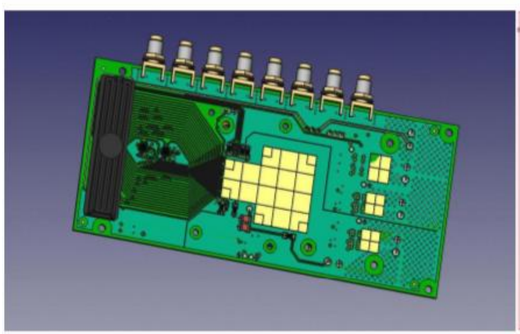


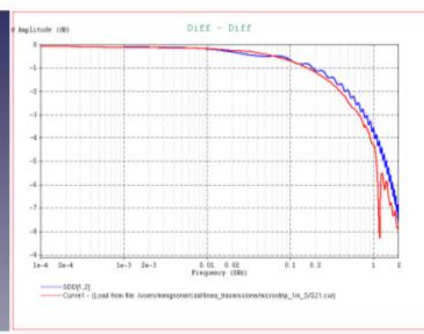




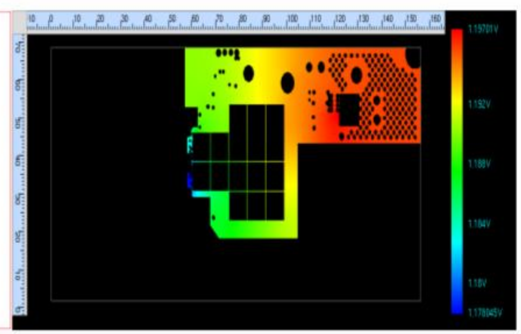
- Torino involved in the construction of the Cylindrical GEM detector for the inner tracker of the BES III experiment
- VFE CGEM readout developed in Torino (TIGER ASIC)
- On detector readout electronics: 10000 channels, 160 ASIC, 80 FE boards

PCB design – test boards





S parameters measurements vs simulation

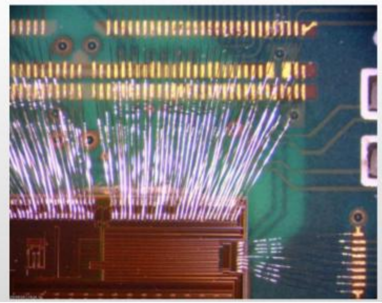


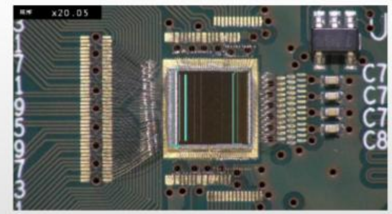
Voltage drop simulation

- Each ASIC designed in Torino requires a dedicated PCB test board
- Each board is designed by our PCB expert staff
- Signal and power integrity simulations are performed when required

Wire Bonding facility

- Up to 100 μm pitch
- AL wire up to 17 μm





Conclusion – recent activity

- BELLE II
- BES III
- CMS DT
- CMS ECAL
- CMS TK
- COMPASS
- NA62
- AUGER
- JEM-EUSO
- ALICE ZDC
- ALICE ITS
- NUMEN
- CHIPIX65
- e-LIBANS
- INSIDE
- SEED
- UFSD
- WHIN
- PANDA
- DARKSIDE
- DIESIS
- MOVE-IT
- LHAASO
- TOTEM
- SCALTECH28
- SYNCFEL
- TIMESPOT
- EEE
- FOOT
- DIACELL
- ASIDI
- FINFET16
- TRIMAGE

DAQ/FEE/Trigger for COMPASS beyond 2020 workshop

Experience and developments in ASIC design at INFN Torino

G. Mazza

INFN sez. di Torino

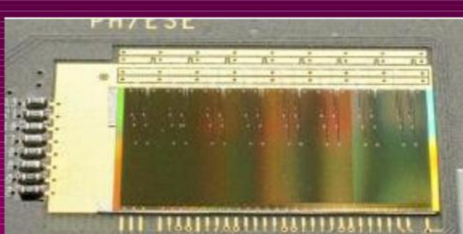
INFN Torino VLSI lab

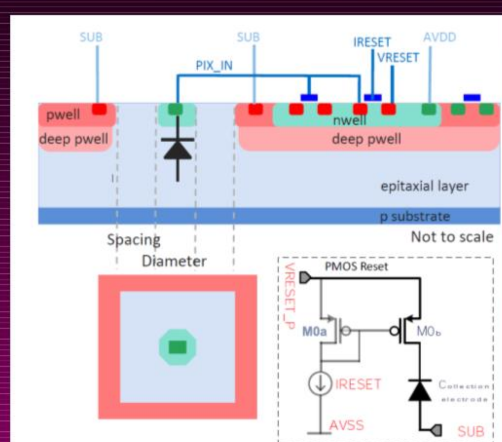
- Part of INFN Torino electronic laboratory
- Activity started in 1995
- 4 senior designer + 1 senior test engineer
- 3 MSc students + 9 PhD students + 2 Post Doc
- Design in CMOS technologies from 1.2 μm to 65 nm
- R&D ongoing in 28 nm and 16 nm technologies
- Main design experiences :
  - *silicon detector readout*
  - *precise time measurements*
  - *clock multiplication and high speed data transmission*
  - *design for medical application*
  - *radiation tolerant design*

ALICE ITS upgrade

ALPIDE ASIC

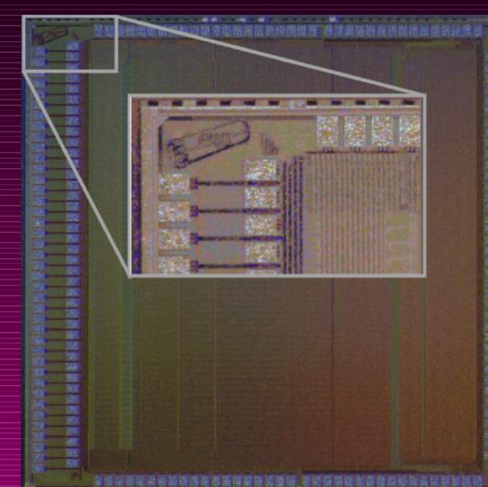
- *Chip size* : 15×30 mm^2
- *Chip thickness* : 50 μm
- *Detection efficiency* : >99%
- *Integration time* : < 10 μs
- *Power density* : ~35 mW/cm^2
- *Readout rate* : 100 kHz
- *Technology* : CIS 0.18 μm





TIGER : ASIC for the BES III CGEM readout

- 64 channels : VFE, signal conditioning, TDC/ADC, local controller
- SEU protected digital backend
- on-chip bias and power management
- on-chip calibration circuitry
- fully digital output (LVDS)
- 4 Tx SDR/DDR links with 8b10b encoding
- configuration via SPI interface
- Power : < 10 mW/channel
- System clock : 160 MHz
- Chip size : 5×5 mm^2
- Technology : UMC 0.11 μm



Ongoing and future activities

✔ Ultra high rate (500 MHz) pulse counting circuit for medical application in 0.11 μm CMOS technology

✔ Readout ASICs in 0.11 μm CMOS technology for DarkSide (SiPM @ 77° K) and PANDA (SSD) experiments

✔ HVCMOS 0.13 μm R&D program for MAPS

✔ CMS Tracker pixel chip in 65 nm

✔ CMS ECAL data conversion and transmission ASIC in 65 nm

✔ Timing electronics in 28 nm technology

✔ Evaluation of finFET 16 nm technology for HEP experiments

DAQ and FEE Architecture for COMPASS Beyond 2020

Igor Konorov

COMPASS Beyond 2020

DAQ/FEE/Trigger Workshop

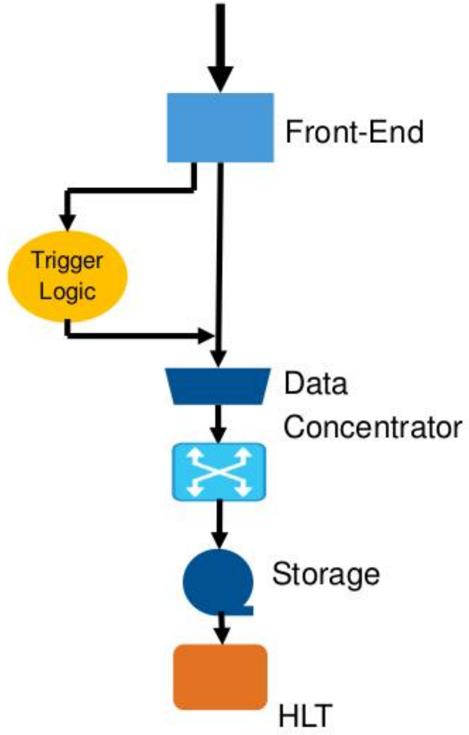
Prague November 9-th

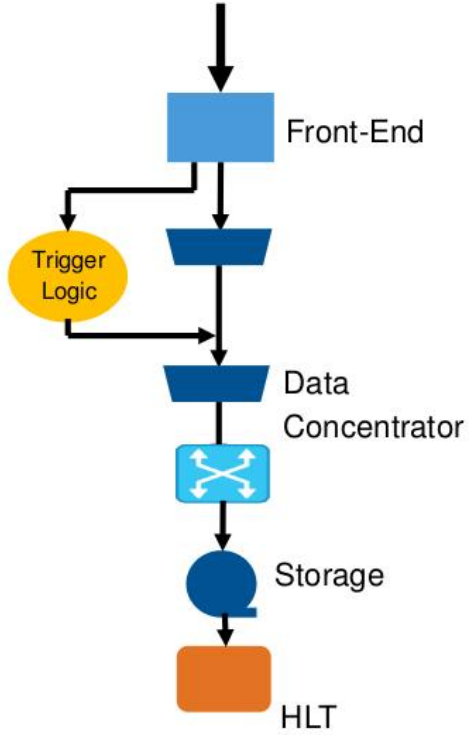
General Comments

Requirements for new developments of DAQ, FEE and Trigger
- Most of foreseen measurements require 100kHz trigger rate capable DAQ
- Proton radius measurement requirements are tuned towards DAQ capability and
- We may get new requirements

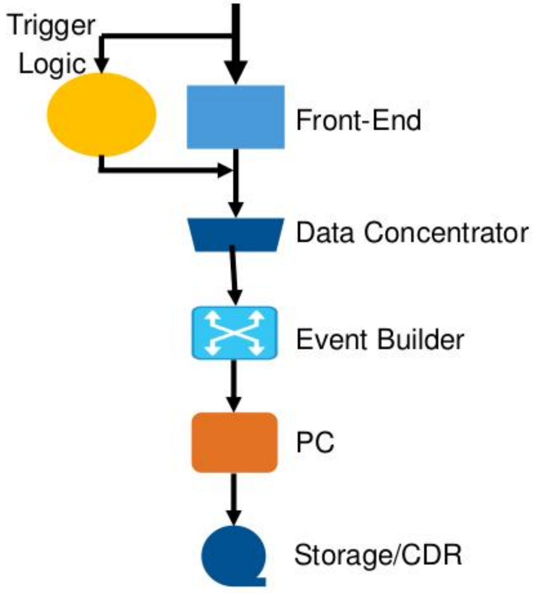
New FEE hardware developments can be done to fulfill trigger less requirements without big cost penalty … I think

Possible DAQ Architecture





COMPASS 2 DAQ Architecture



Strategy for New Developments

FEE :

- Trigger less capability : triggered and not triggered read out streams
- Data of any detector can be used for triggering
- Local buffering limited in size to overcome data rate fluctuations, no requirements to store data for trigger decision
- FEE Interface based on Serial links with UCF protocol
- IPBUS for slow control and monitoring

Strategy for Trigger Logic

Switch to Digital Trigger Processor

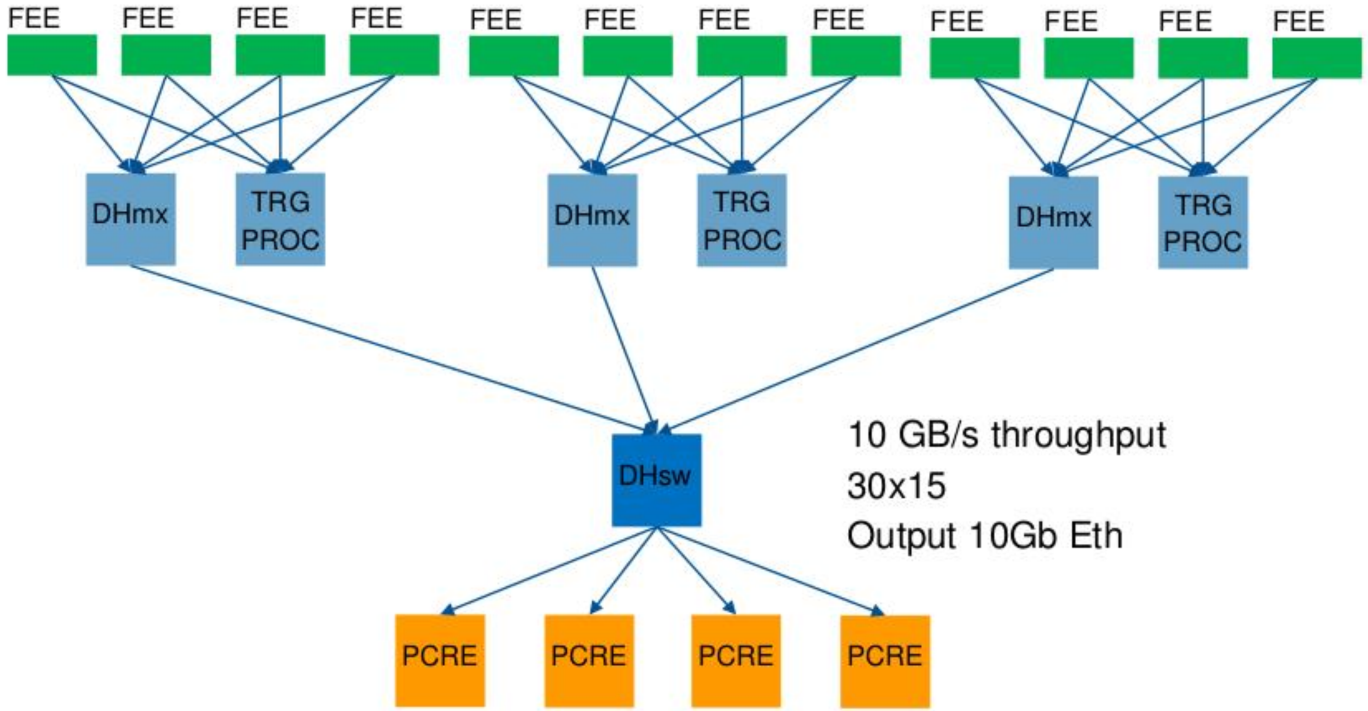
Complete development of configurable digital trigger logic

Use UCF protocol for data transmission

IPBUS for configuration

Common hardware between DAQ and Trigger Logic

Read Out Architecture



10 GB/s throughput

30x15

Output 10Gb Eth

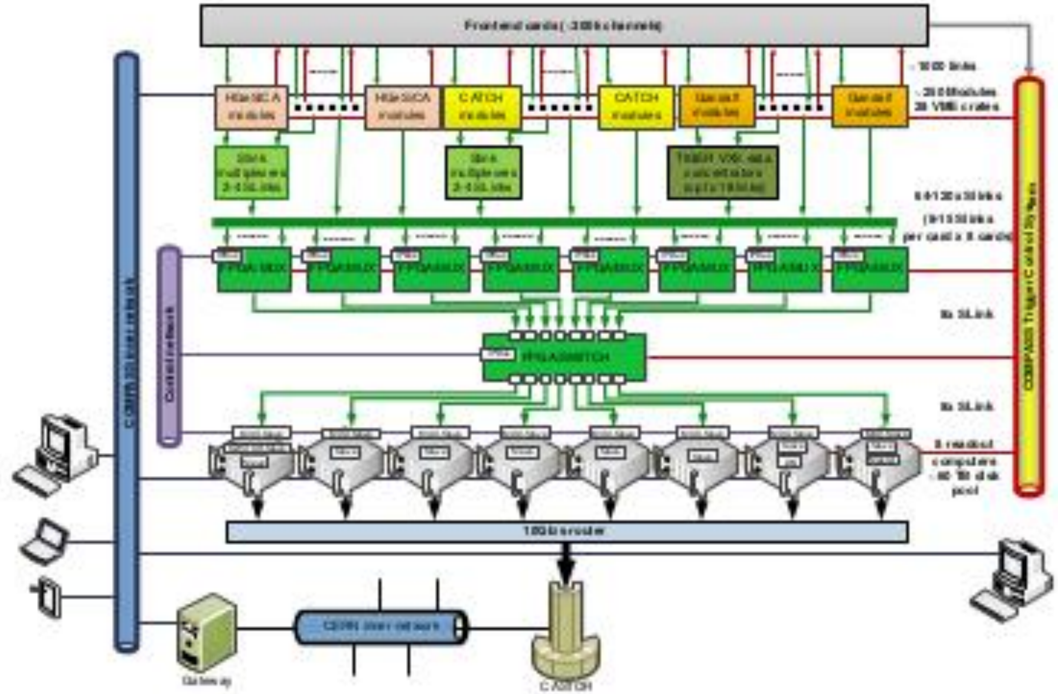
COMPASS DAQ Beyond 2020

J. Novy

Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague

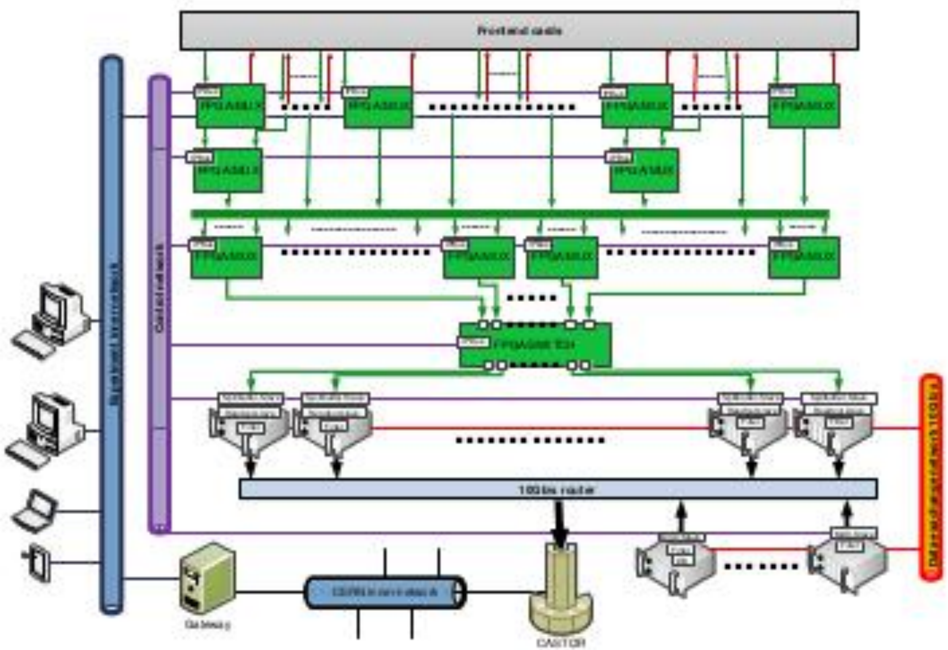
Present DAQ structure

- Avg. 50 kHz trigger
- Avg. 36 kB events
- Slink header, DATE data format
- Theoretical maximum speed 8*150 MB/s
- Not optimal format ~ 30 % empty data



New DAQ structure

- Trigger-less
- 15x server - 64 GB memory, 2xCPU, 16 TB RAID 10
- 10 Gb/s communication and data exchange network
- All data concentrators monitored
- New data format



Letter of Intent on the Common R&D project to upgrade the COMPASS Polarized Target with Recoil Detectors.

A.P.Nagaytsev JINR, Dubna

The COMPASS Polarised Target, equipped with Recoil Detector (PT with RD), can be used for the polarized GPDs studies:
- via the exclusive DVCS mechanism, in the muon beam;
- via the Exclusive DY mechanism in the pion beam .

One of the major goals of the forthcoming worldwide GPD physics programs will be the precise mapping of the GPDs H and E, which enter in the "Ji sum rule" and provide access to the total parton angular mometum:

$$J^f(Q^2) = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx\, x\left[H^f(x,\xi,t) + E^f(x,\xi,t)\right]$$

$$\frac{1}{2} = \sum_{q=u,d,s} J^q(Q^2) + J^g(Q^2)$$

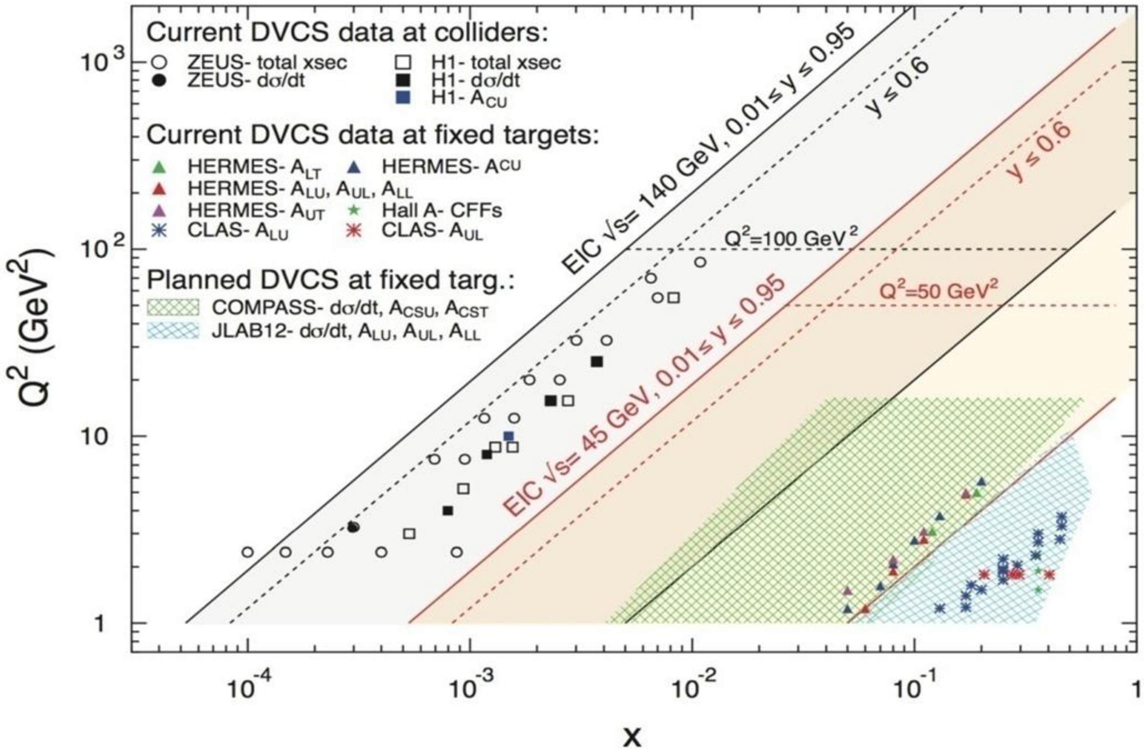
While some information on the GPD H is already provided by the existing data, the GPD E is basically unknown. The most promising DVCS observables that are sensitive to E are the transverse target spin asymmetry in the case of proton targets, and the longitudinal beam spin asymmetry with neutron targets.

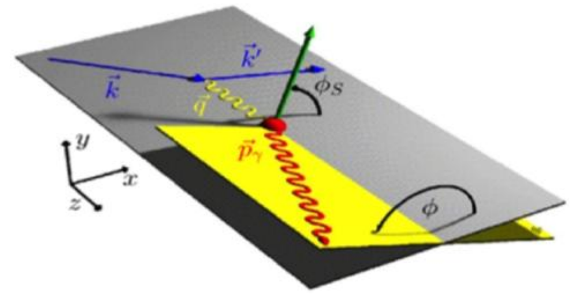
Since at COMPASS both beam and target are polarized, the relevant observables for accessing the GPD E are represented by the transverse beam charge & spin difference and sum of the m p mg p cross section, respectively defined as follows:

$$\mathscr{D}_{CS,T} \equiv \left(d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S) - d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S+\pi)\right) - \left(d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S) - d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S+\pi)\right).$$

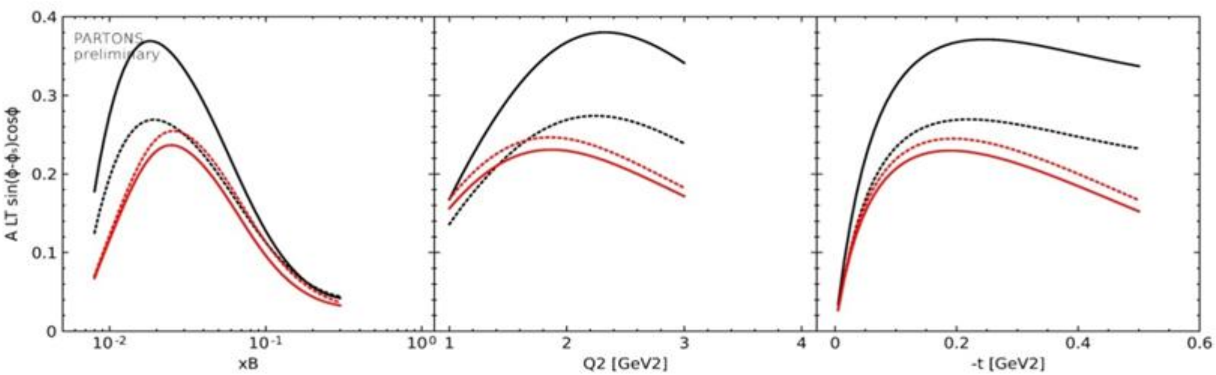
$$\mathscr{S}_{CS,T} \equiv \left(d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S) - d\sigma^{\overset{+}{\leftarrow}}(\phi,\phi_S+\pi)\right) + \left(d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S) - d\sigma^{\overset{-}{\rightarrow}}(\phi,\phi_S+\pi)\right).$$

$$\mathscr{A}^D_{CS,T} = \frac{\mathscr{D}_{CS,T}}{\Sigma_{unpol}} \text{ and } \mathscr{A}^S_{CS,T} = \frac{\mathscr{S}_{CS,T}}{\Sigma_{unpol}}.$$

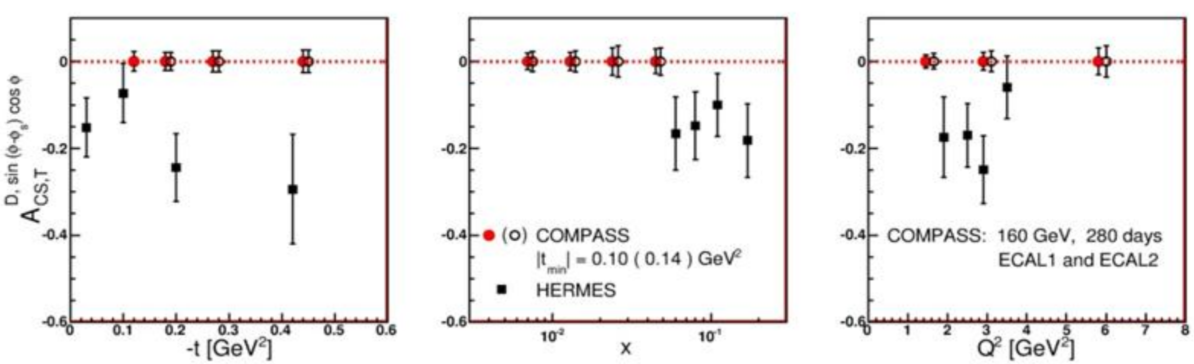




Estimation of the amplitude of the [sin(φ-φ$_S$)cos(φ)] modulation in the COMPASS kinematics, based on predictions from the VGG (red) and GK [(black) models at leading order (solid lines) and with the additional assumption of E = 0 (dashed lines). The estimates have been obtained in the context of the PARTONS framework.



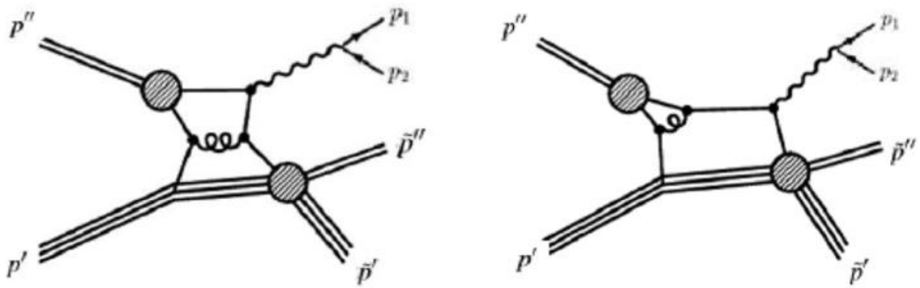
Expected statistical accuracy of $A^{D[sin(φ-φ_S)cos(φ)]}_{CS,T}$ as a function of -t, x_B and Q_2 from a measurement in 140 days with the COMPASS spectrometer, using a 160 GeV muon beam and a transversely polarized NH_3 target. Solid and open circles correspond to a minimum detectable |t| of 0.10 GeV² and 0.14 GeV², respectively. Also shown is the asymmetry $A^{sin(φ-φs)cosφ}_{U,T}$ measured at HERMES.



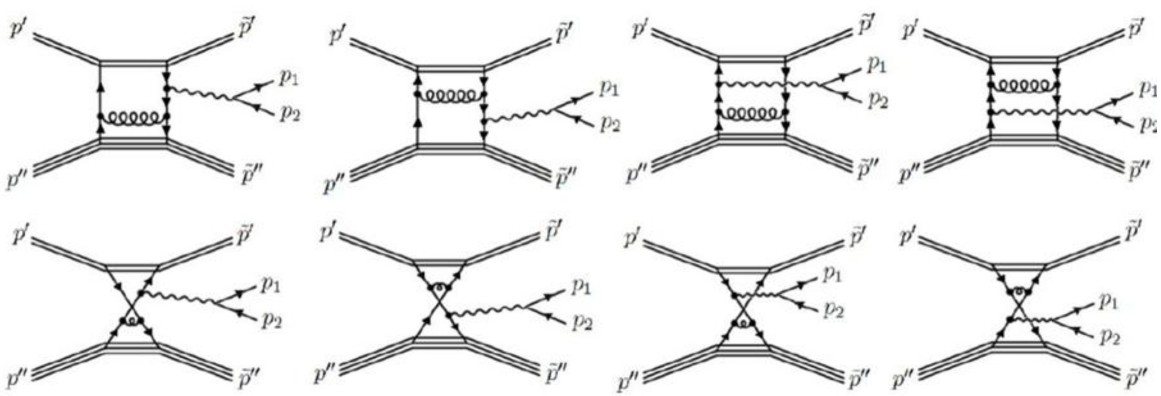
The COMPASS data could therefore provide a measurement of the [sin(φ-φ$_S$)cos(φ)] modulation with a statistical accuracy of approximately 2.5% in the so far uncharted region of $5\ 10^{3} < x_B < 5\ 10^{2}$.

A.A.Pivovarov, O.V.Teryaev (JINR,Dubna), QCD mechanisms of (semi)exclusive Drell-Yan processes,Published in AIP Conf. Proc. 1654 (2015) 070008.

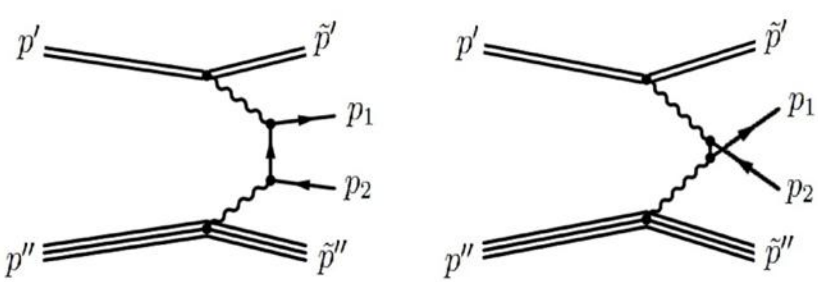
The exclusive DY formalism of the lepton pair's production in pion-nucleon interactions can be represented by a combination of two mechanisms: (i) a classical mechanism and (ii) so called GPD·GPD-mechanism.



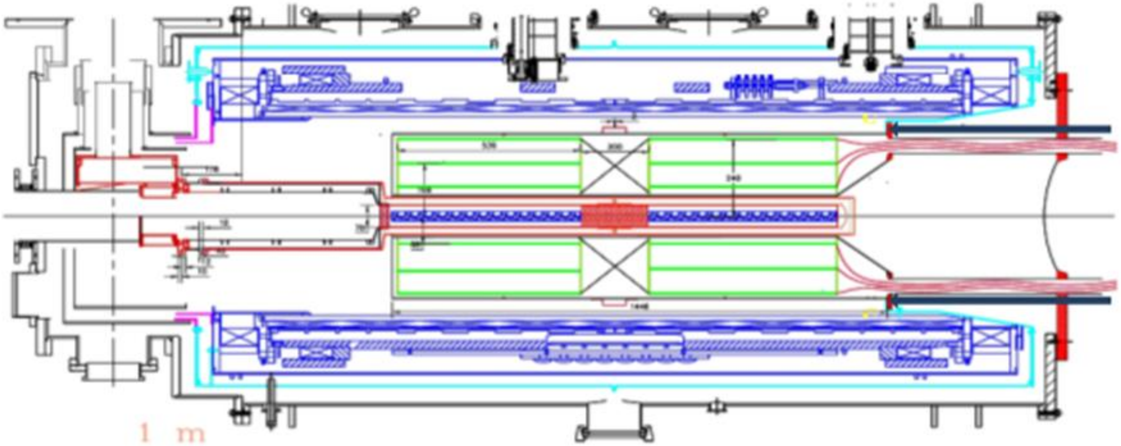
The classical mechanism of the DY pair's production in pion-nucleon interactions.



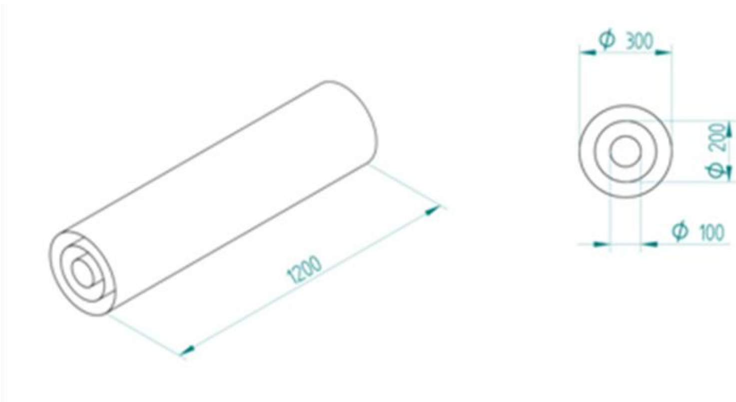
GPD·GPD-mechanism of the DY lepton pair's production in pion-nucleon interactions.



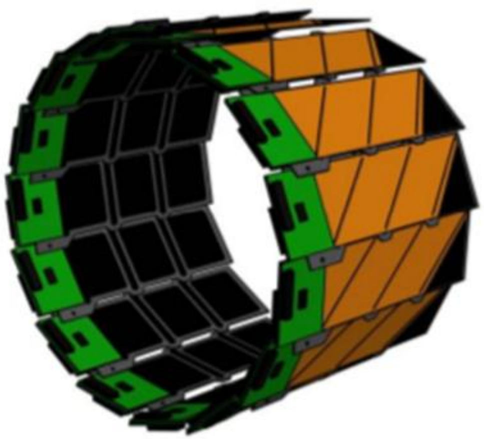
The EM-diagrams which can interfere with those shown in Figure above.

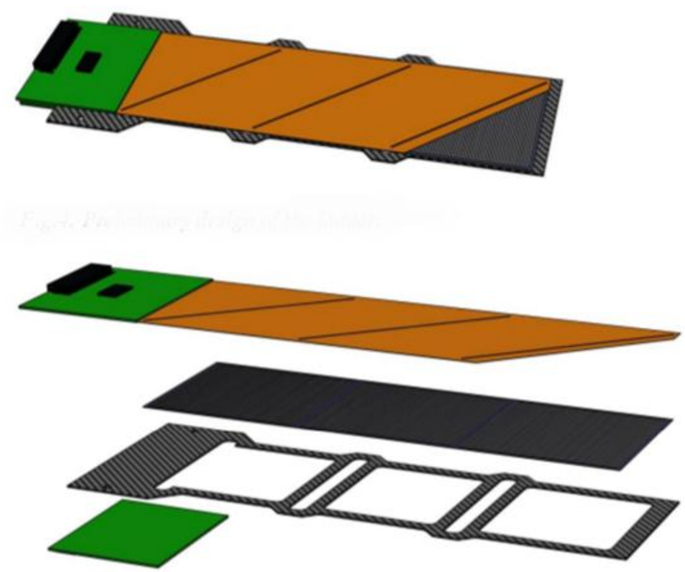


The last modification is preferable:
(i) it does not limit the acceptance in the forward direction,
(ii) the length of cables will be minimised,
(iii) “worm” chips can be fixed on the outside surface of the flange at the room temperature,
(iv) lengths of the target cells can be increased up to 75 cm each. (The 3-cells option is to be considered).

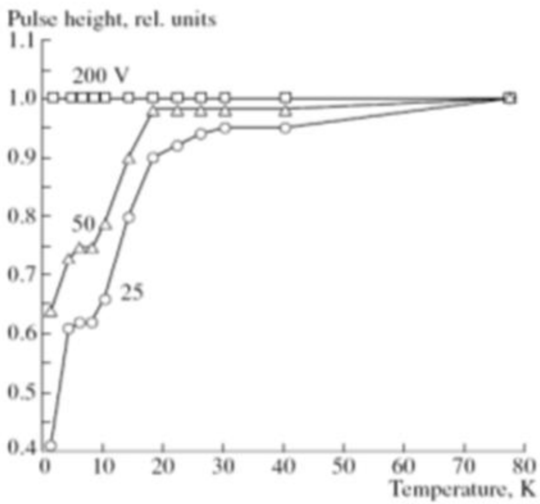


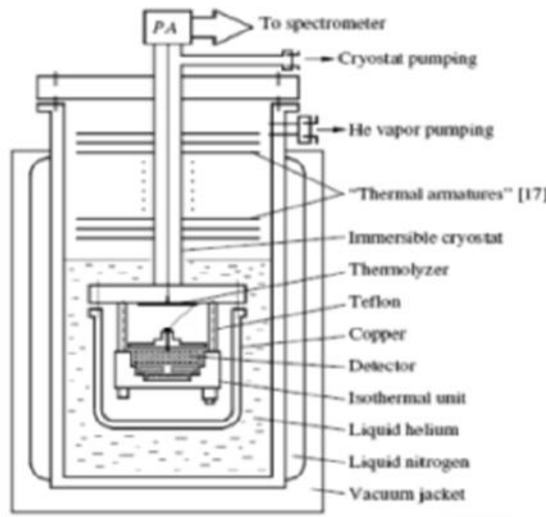
Each layer contains a number of ladders. The ladder supporting the double-sided Silicon strip detectors, 63x63 mm each, with a ~ 0.5 mm pitch should be made of a low-Z material

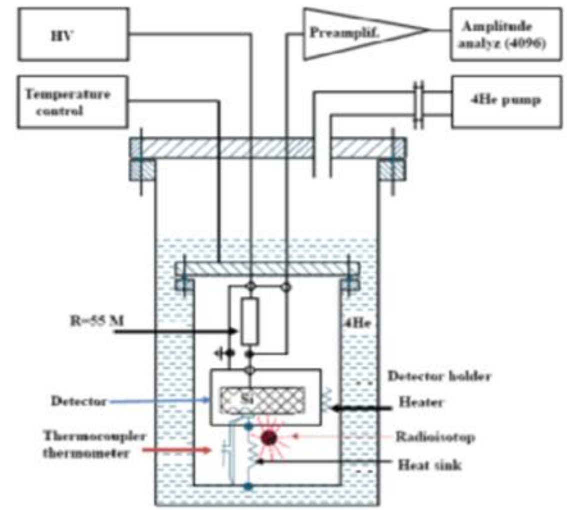




Performance of silicon detectors is studied in a number of papers (see [1] and references therein). An example of the pulse height dependence on temperature for the n-Si detectors is shown in Figures below.





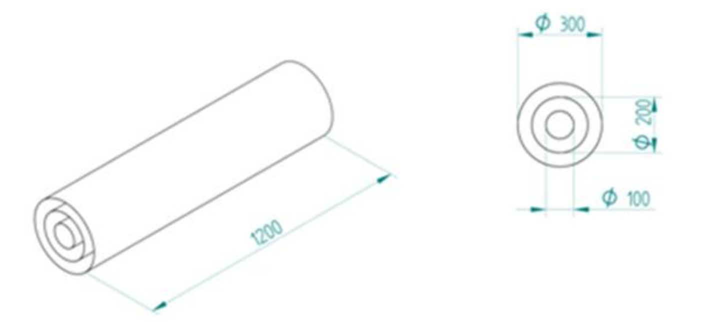


Stable performance of this and other type of detectors at the temperature up to 1K ° requires higher working voltages.

[1] K.N. Gusev et al., A study of the performance characteristics of silicon and germanium semiconductor detectors at temperatures below 77K, Instruments and Experimental Techniques, 2007, Vol.50, No.2, pp 202.

PID inside the COMPASS Polarized Target.

Gleb Meshcheryakov, JINR, Dubna



To exploit the both mechanisms at COMPASS, one needs:
(i) to accommodate RDs inside the target magnet volume,
(ii) to use the dE/dx technique for PID.

In order to use the dE/dx technique for PID distinguishing protons, kaons and pions, detectors should be able to measure:
(i) space coordinates of the recoil particles with a precision of about 1 mm at least in 3 space points,
(ii) momentum of each recoil particle in the region of about 100-1000 MeV/c with a precision of about 5-10% and
(iii) dE/dx for each recoil particle with precision of about 10%.

- MC studies - to the estimation of opportunities for identification of particles with application of a technique of dE/dx.
- Two types of particles were generated – protons DVCS (HepGen) and protons and pions of SIDIS (Pythia),
- Settings of both are specified in tables 1 and 2.

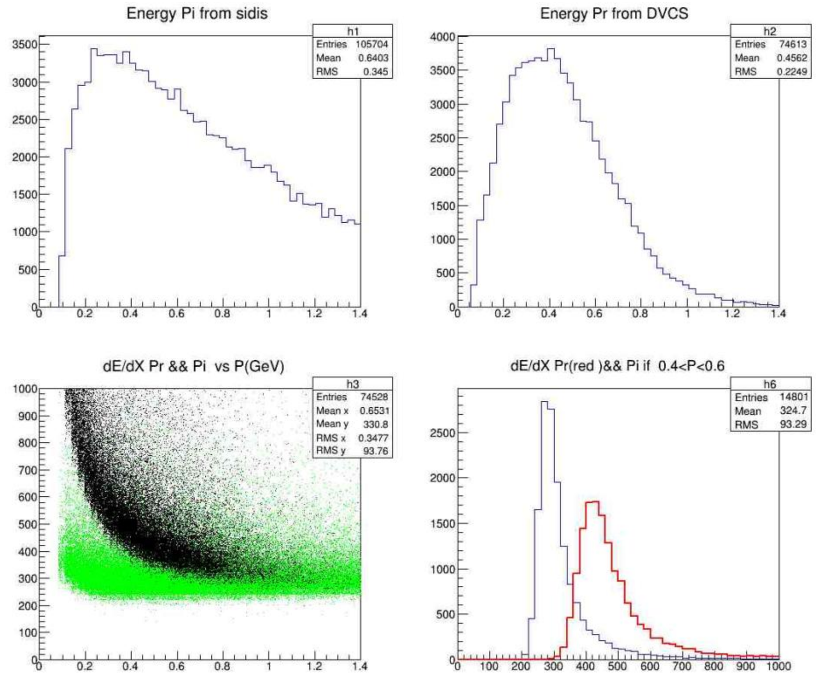
Table 1. Settings of the PYTHIA generator

MSEL=2 OFF global process selection
MSUB(1)=0 Off q+qb -> gamma*/Z0 mu+mu- (DrellYan process)
MSTP(43)=0 ! OFF only gamma* included (DrellYan process)
MSTP(51)=1 ! structure function for GRV 94
LMDME(174,1)=0 ! Z0 -> dd~ turned OFF
pz=160.0
call pyinit('fixt','mu-','p+', pz)
nev=50000

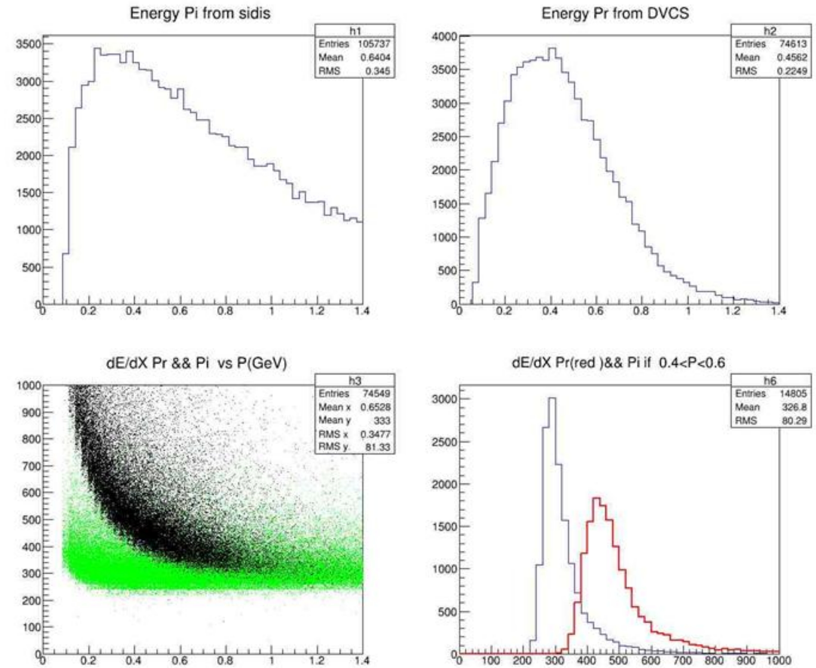
Table 2. Settings of the HepGen generator

NGEV 50000
* Colliding particles: ELEPT, EHADR, ILEPT, AHADR, ZHADR - PARL(1), PARL(2)
BEAM 160.0 0.9382723 -13 1 1
* Read beam external file: 0-nothing, 1-beam only, 2-halo only, 3-beam+halo
BMRD 0
* Physics process: 1 gamma, 2 W ex., 3 Z, 4 full NC - LSTHFL(4), 5 HiExcProd
PROC 5
* LEPTO 'soft' cuts: x, y, Q2, W2, nu, E', phi (min/max) - CUT(1-14)
CUTL 0.0001 1.0 0.0 1.0 0.5 80.0 0.00 1000.0 5.0 155.0 0.0 200.0 0.00 6.28318
- limits for tprim generation
- * Scattered muon acceptance - theta_max(rad)

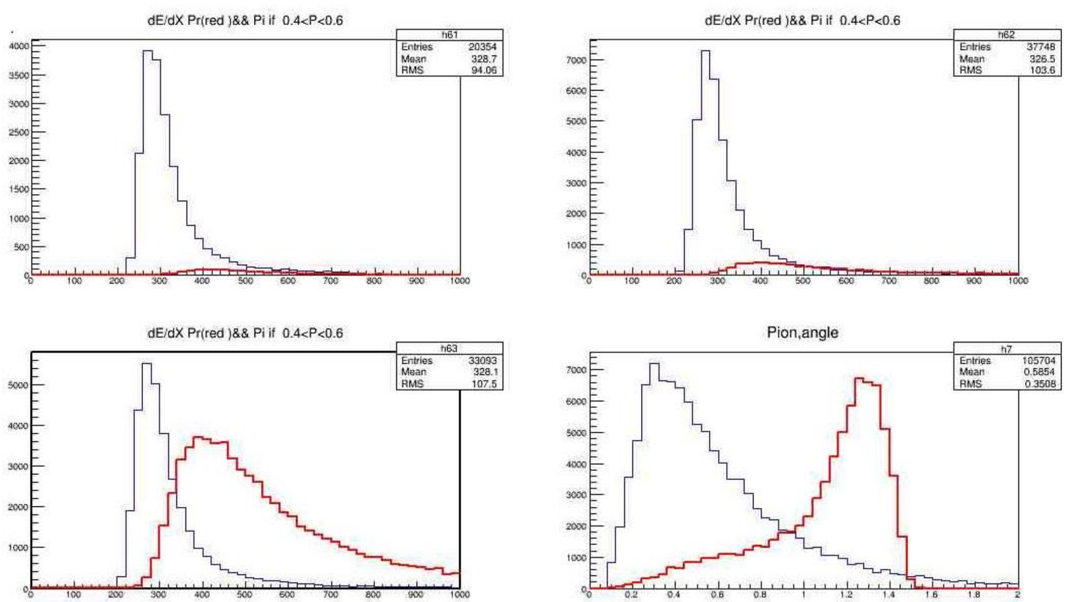
MACC 0.050
* Select produced particle and its decay mode (DVCS: ivecm=0)
VMES 0 0
- Swich to turn diffractive dissociation ON (1) or OFF (0)



The results for protons (red line) from HepGen (DVCS) and pions from PYTHIA (SIDIS) and thickness of the silicone detector – 0.3 mm

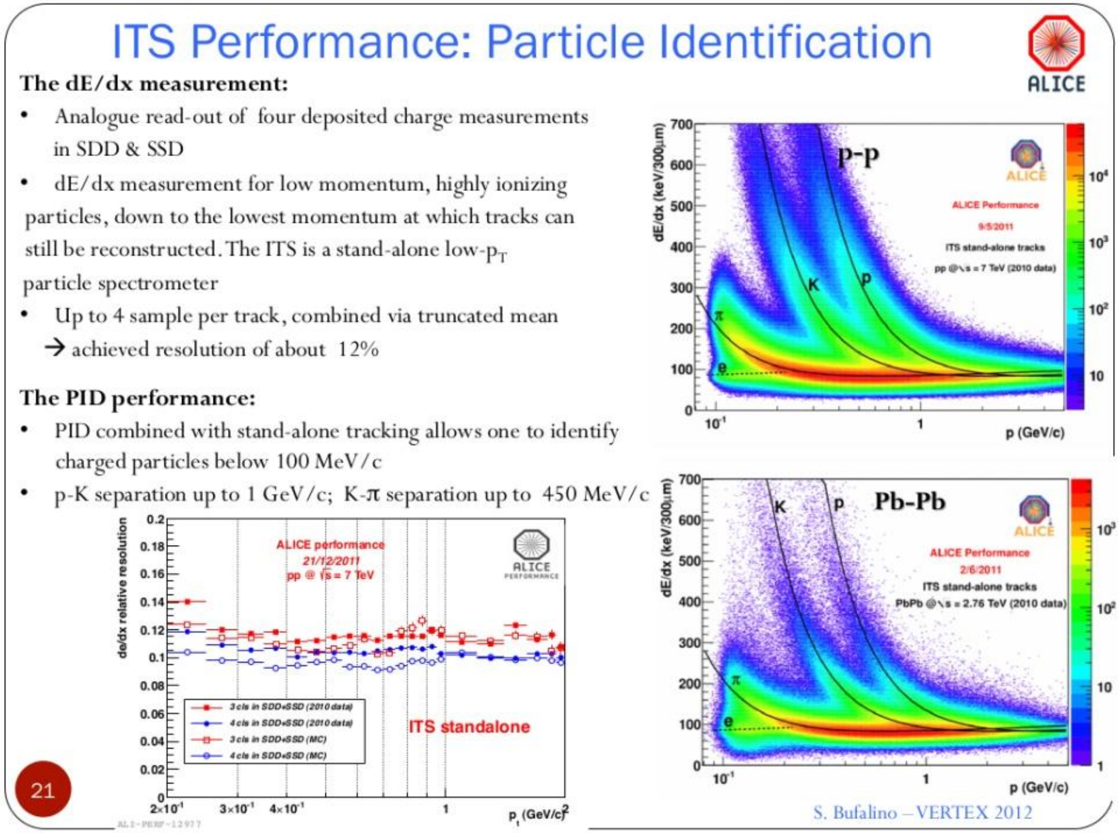


The results for protons (red line) from HepGen (DVCS) and pions from PYTHIA (SIDIS) and thickness of the silicone detector – 0.5 mm



The total energy loss for protons from HepGen (DVCS) and pions from Pythia(SIDIS) and thickness of the silicone detector – 0.3 mm and for three ranges of scattering angles, 0.24-0.36 rad. (the left-hand top schedule), 0.36-0.64 rad. (the right top schedule) and 0.64-1.57 rad. (the left-hand lower schedule). The right lower panel shows the scattering angle

distributions of pions and protons (red line



From this analysis it is possible to make the following conclusions:
- for this configuration of the detector (3 layers of a silicon) of dE/dx the technique allows to separate pions and protons for the range of momentum lower than 0.5 GeV;
- effeciency of identification – 0.8-0.9;
- taking account a scattering angle improve effeciency;
- the received results are comparable with data from ALICE.

The aims of the present R&D project are as follows:

(1) to study the engineering problems connected with a detector's insertion inside the inner volume of the target;
(2) tests of the silicon detectors in the environment close to that of the present PT, consideration of alternatives to silicon detectors;
(3) tests of the Silicon detectors and associated electronics in the environment close to that of the present PT.
(4) tests of the Silicon detectors can be performed partially in the laboratory using the specialized set-up and partially in a beam.

MC studies are very important.

The list of measurements with the test set-up, first of all can include:
- responses and resolutions of available Silicon detectors,
- operation of the FE-electronics (preamplifiers) and cables in the environments close to that of the PT,
- tests of materials which will be used in mechanical supports of Silicon detectors,
- tests of the multilayer flexible buses of different length at different temperatures.

DAQ/FEE/Trigger
for COMPASS beyond 2020 workshop,
CTU FNSPE Prague, November 9-11, 2017

Activities of LTU for high energy physics experiments

LED Technologies of Ukraine:
Slava Borshchov
<u>Maksym Protsenko (speaker)</u>
Ihor Tymchuk

viatcheslav.borshchov@cern.ch, maksym.protsenko@cern.ch, ihor.tymchuk@cern.ch

Activities for physics experiments

- Designing detector modules
- Designing components of the modules (single- and multilayered flexible cables and flexible-rigid boards etc.)
- Designing photomasks
- Manufacture of the components
- Developing assembly procedures for detector modules and their components
- Developing, designing and manufacturing precise assembly jig
- Implementing assembly processes at assembly sites (if necessary)
- Reliability tests of the components

Notes:

- ✓ ***work „Development and implementation in industry of newest technologies of ultramodern detector modules creation on the basis of hi-tech base components with aluminium interconnection for particles detector systems in high energy physics experiments" submitted by Kharkiv team was awarded by the Ukrainian Government for the development and implementation of innovative technologies (April 6, 2016)***
- ✓ ***More then 80 papers on activities for physics experiments are published***

Features & advantages of „full-aluminium" approach

Features:

▪ *Materials for the components:*	
- conductive layers -	*aluminium-polyimide adhesiveless foiled dielectrics*
- dielectric spacer –	*Kapton or polyimide*
▪ *Layers manufacture techniques:*	*photolithography &chemical wet etching*
▪ *Assembly techniques:*	*SpTAB&gluing*

Advantages:

- *approach **is verified** in practice in existing ALICE ITS strip and drift detector modules*
- *conductive layer **is aluminium***
- ***lower material budget** (compared to Cu)*
- ***absence of heavy metals** (Au, Sn) on the flex and on the chip (soldering is not needed)*
- *connection of aluminium leads of the flex to aluminium contact pads of the chip that ensure **high-reliable and mechanically stable connections**;*
- *possibility to realize **3-D (volumetric) design** of the module/component*
- *high-precise and high-throughput standard **automated equipment** can be used for assembly (Delvotec G4, G5 bonders etc.). Tune of the bonder is very simply and can be done in few hours!*

Feature of the approach: chipcable

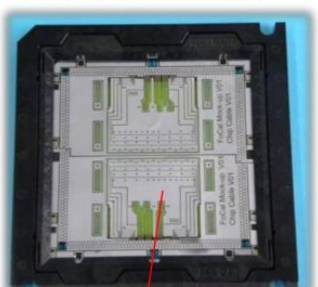
Chipcable- cable welded to chip/sensor for further connection to flex.
Cable allows to test chip/sensor after welding.
Plastic frame (TAB-35, TAB-70) for cable and chip+cable tests is using
Usage of chipcables allow to use for further assembly only good chips/sensors.

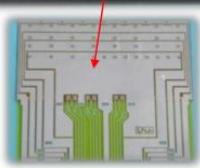
TAB-35 (1xALICE chipcable)

Framed cables

Cut-off work areas with chips

TAB-70 (2xFoCal chipcable)



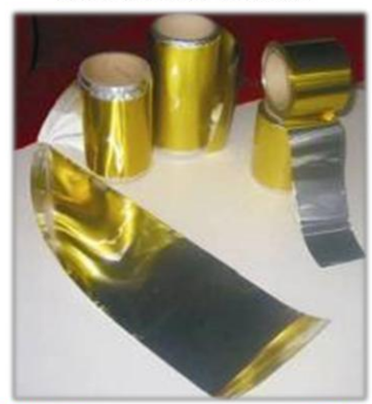


Test Socket (TAB-70)

FoCal chipcables in test Socket (TAB-70)

Materials and technological level

Main materials for flexible layers are aluminium-polyimide adhesiveless foiled dielectrics FDI-A type



❖ **FDI-A-24**
polyimide – 10 um
aluminium foil – 14um

❖ **FDI-A-50**
polyimide – 20 um
aluminium foil – 30 um

Fine-pitch cables FDI-A-24	pitch of traces	45÷60 um
	width of traces	20 ÷ 30 um
	length of cable	10 ÷ 20 mm
	quantity of traces	128÷1024
Connecting cables, flexes FDI-A-24 FDI-A-50	pitch of traces	100÷200 um
	width of traces	40 ÷ 100 um
	length of cable	up to 600 mm
	quantity of traces	up to 512

Some features of assembly process

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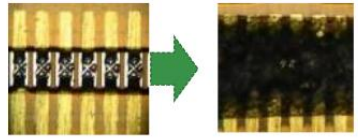
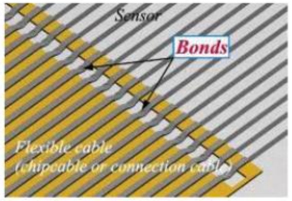
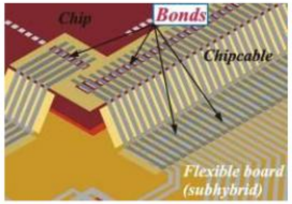
Main process at modules components assembling is an ultrasonic TAB bonding (manual or automatic) of aluminium traces to contact pads on chip, sensor or flexible cable with encapsulating by glue

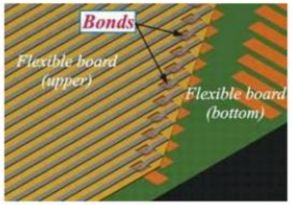


Schematic close-up view of some different connection areas

cable-to-sensor	chipcable-to-chip & chipcable-to-subhybrid	flexible board-to-flexible board (inside subhybrid)







Note: for SpTAB techniques two times less bonds are required- higher reliability

Features of typical multilayered flex

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- Flex consist of three layers: top, spacer, bottom
- Layers of the flex are manufactured based on photolitography and chemical wet etching technological processes
- Typical assembly sequence includes following main operations: multilayered flexible board gluing and bonding (TAB), board-to-chip bonding (TAB), bond joints protecting by glue
- Typical flex might includes following types of TABed joints:

- *Top layer-to-chip*

- *Bottom layer-to-chip*

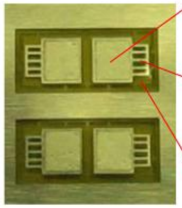
- *Interlayer connection*

Some features of SMD components and SMT connectors mounting

10

For manufacturability increasing SMD components and SMT connectors are mounting on flexible carriers (flex-mounts) by soldering and after that connecting to board or cable by ultrasonic bonding

Flex-mounts for SMD component

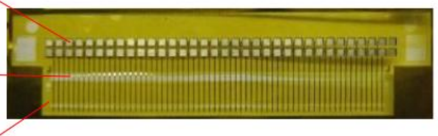


Ni + SnBi layer (pads for soldering)
Thickness ~ 3+8 um

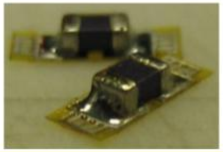
Aluminum layer (traces for bonding)
Thickness ~ 30 um

Polyimide layer
Thickness ~ 20 um

Flex-mount for SMT connectors



SMD resistor on flex-mount



Dual row connector on flex mount

Background: ALICE ITS SSD&SDD detector modules

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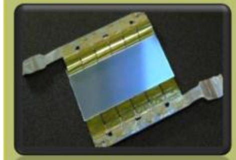
For existing ALICE ITS by Kharkov team more than 200 types of module components developed and more than 50000 components manufactured and delivered for SSD and SDD modules creation

SSD (&CERN, NIKHEF, IN2P3, HIP)



SDD (&CERN, INFN)

For both module types were done :

- ***Modules and components design developed***
- ***Prototypes assembled and tested***
- ***Full-scale production organized***
- ***Assembly technologies developed and implemented at foreign assembly sites***
- ***Components for more than 2000 SSD and 400 SDD modules manufactured and delivered***
- ***Two foreign assembly sites organized for modules assembling***

Developed and manufactured components for the modules

Type	Brief description	Manufactured components quantity	
		SSD	SDD
Chipcables	*Single- and twochip single- and double layer ultralight flexible cables with min. pitch of traces 80-100um*	~35000pcs	~3000pcs
Subhybrids	*Flexible-rigid multilayered boards on the carbon fiber heat sink*	~4500pcs	~700pcs
Long connecting cables	*Connecting multilayered LV & HV cables (length up to 600mm, operating voltage up to 5kV)*	~4500pcs	LV~1500pcs HV~500pcs

Activities for other experiments

15

- ALICE ITS upgrade
- LHCb IT upgrade
- CBM
- NICA/MPD
- PANDA
- Mu3e

Activities for CERN: ALICE ITS upgrade

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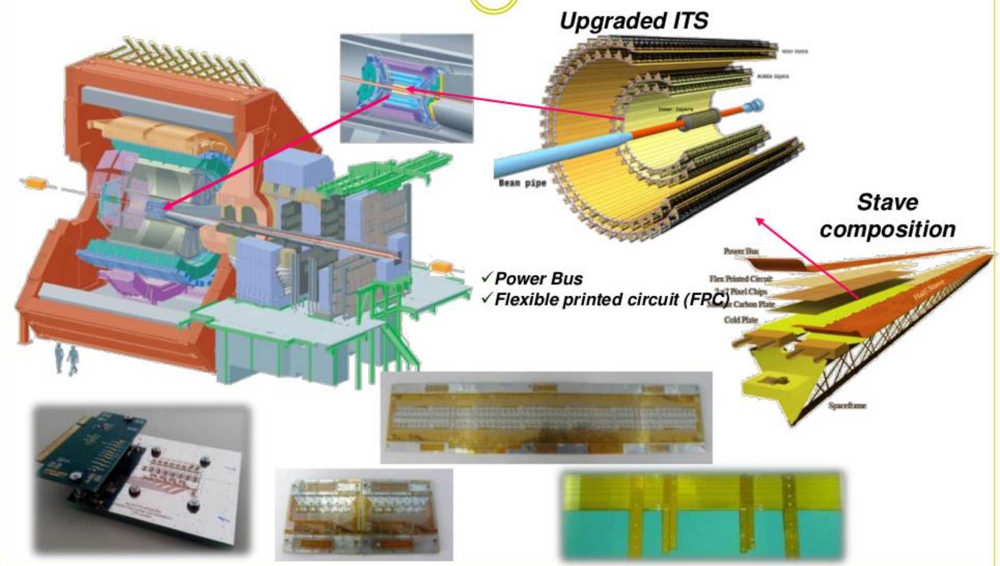
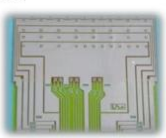


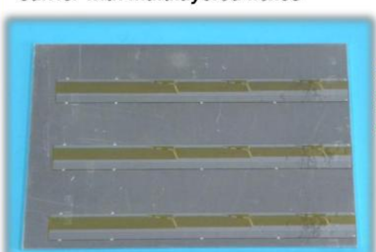
Activities for CERN FoCal experiment

19

Cutout cable

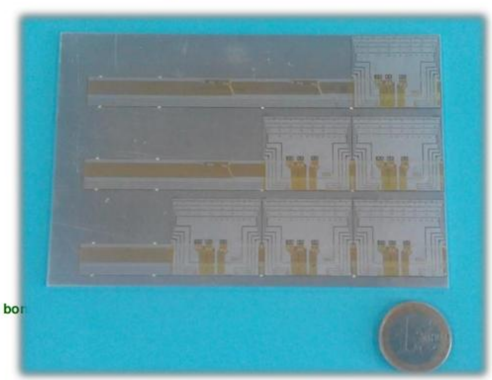


Carrier with multilayered flexes



Aligning,
Gluing,
SpTAB,
Testing,
Protecting bo[...]

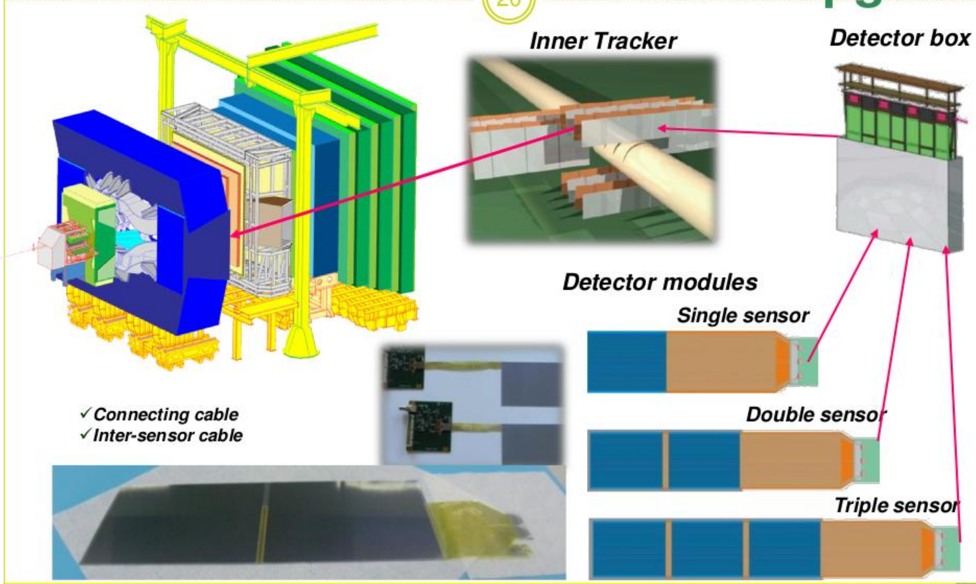
Assembled slab mock-up



Joint activity with NIKHEF

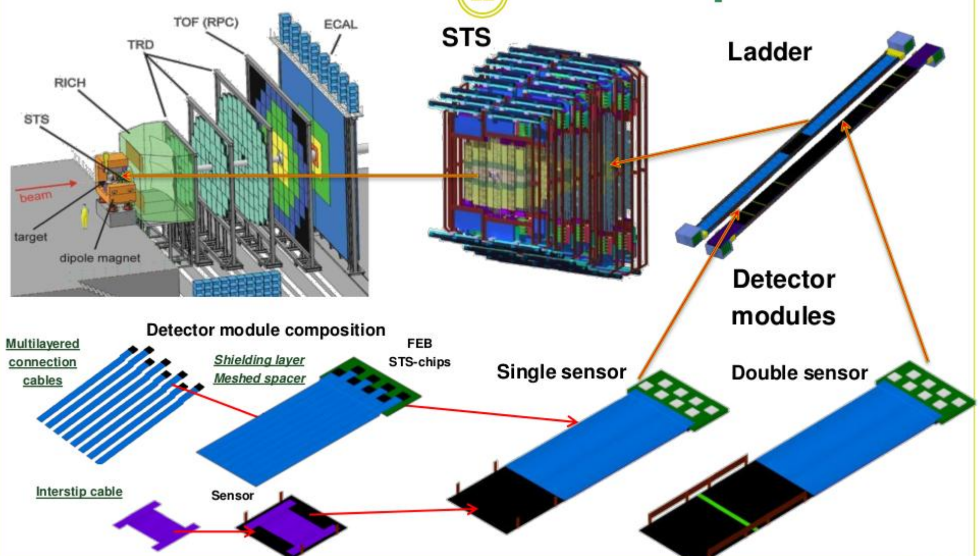
Activities for CERN: LHCb IT upgrade

20



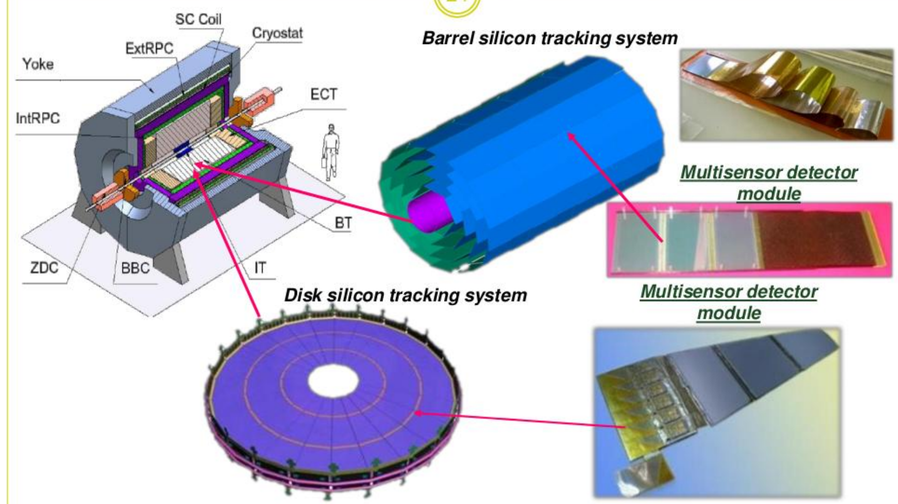
Activities for GSI: CBM experiment

22



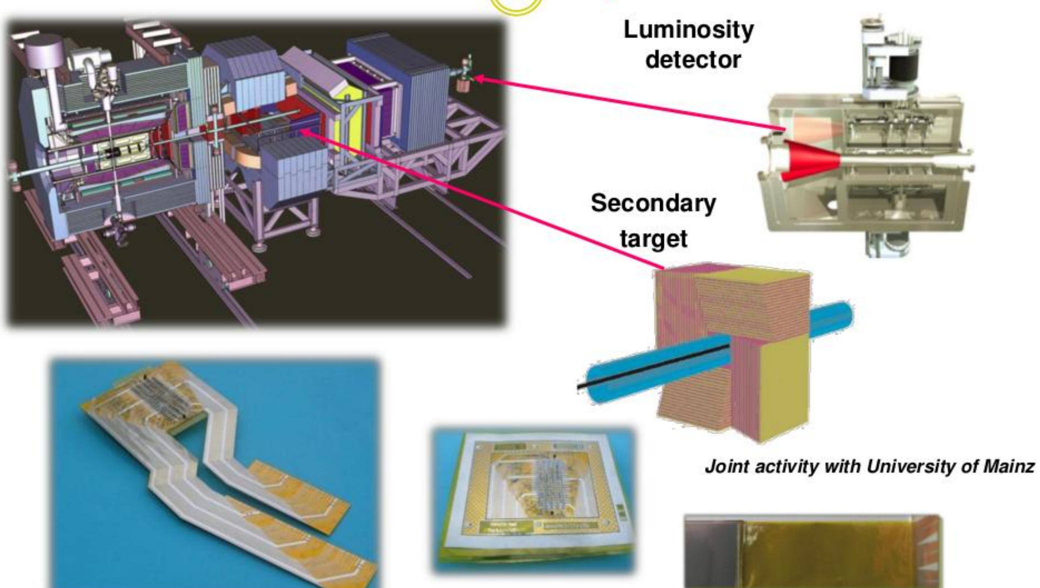
Activities for JINR: NICA experiment

24



Activities for GSI: PANDA experiment

25



Activities for PSI: Mu3e experiment

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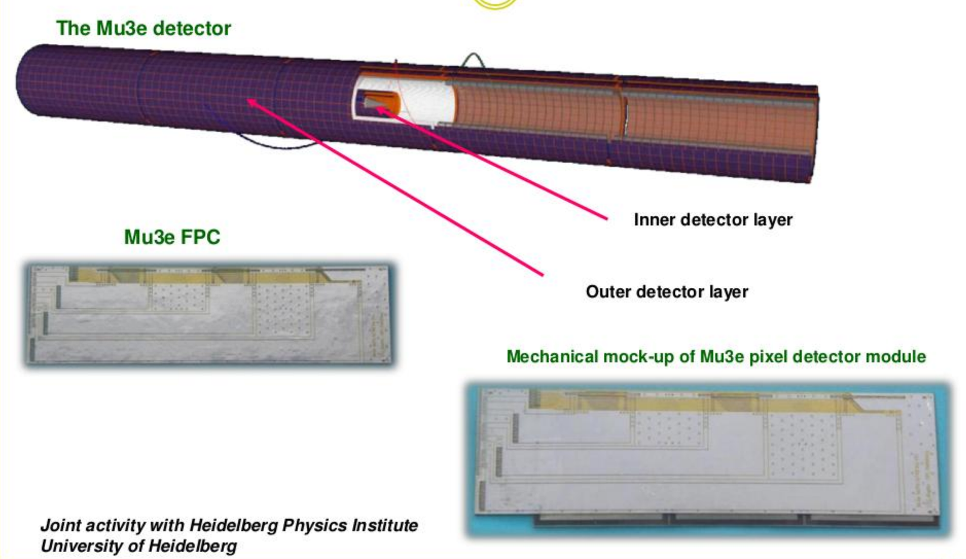


RUHR-UNIVERSITÄT BOCHUM

panda

RUB

The PANDA Experiment and the Electromagnetic Calorimeter

Fritz-Herbert Heinsius

RUHR-UNIVERSITÄT Bochum
FAKULTÄT FÜR PHYSIK UND ASTRONOMIE
Experimentelle Hadronenphysik

DAQFEET
DAQ/FEE/Trigger for COMPASS beyond 2020 Workshop

Content

- FAIR
- PANDA Physics
- PANDA Detector
- PANDA EMC
- EMC Readout
- EMC Cooling

bmb+f
Großgeräte der physikalischen Grundlagenforschung

Prague 9.-11.11.2017

The FAIR Project at Darmstadt

RUB

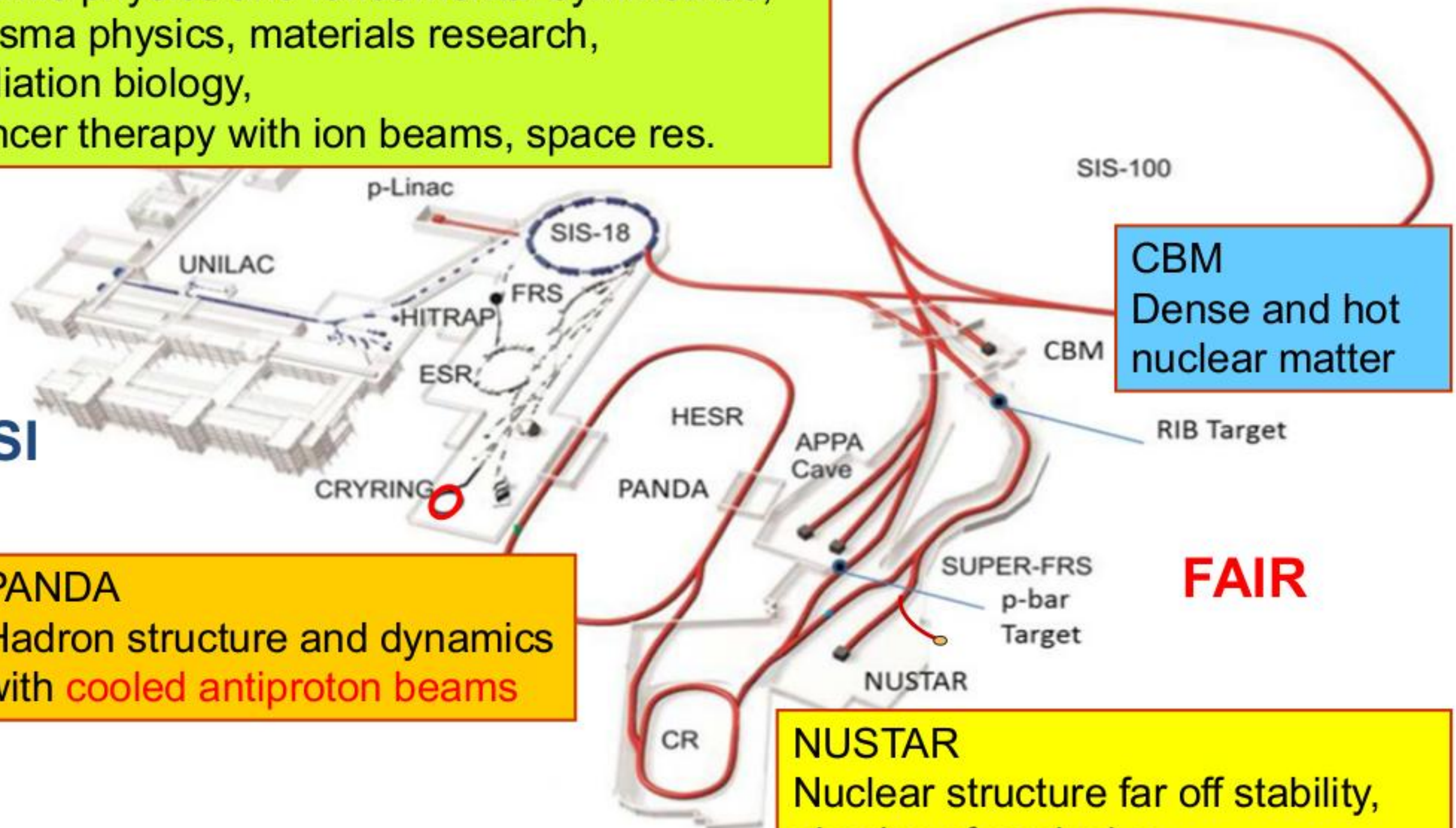
FAIR

GSI

Finland France Germany India Poland Romania Russia Slovenia Sweden UK

FAIR Accelerator Complex

APPA
Atomic physics and fundamental symmetries, plasma physics, materials research, radiation biology, cancer therapy with ion beams, space res.



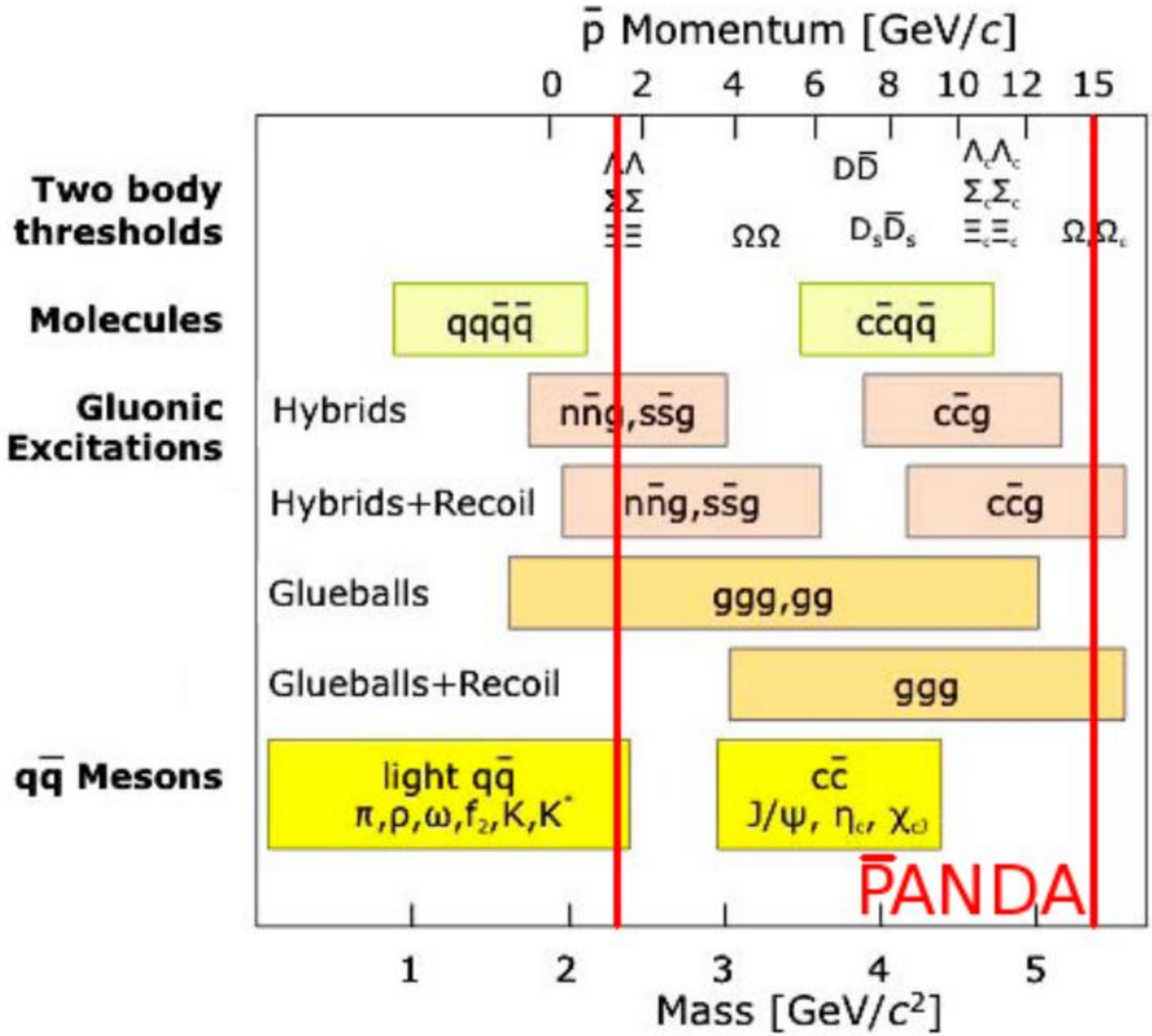
CBM
Dense and hot nuclear matter

PANDA
Hadron structure and dynamics with cooled antiproton beams

NUSTAR
Nuclear structure far off stability, physics of explosive nucleosynthesis (r process)

PANDA Physics Program

- $\bar{p}p$- and $\bar{p}A$-annihilation: beam momentum 1.5-15 GeV/c



PANDA Physics Program

RUB

HEP: interference of coupled channels

HEP: underlying elementary

Spectroscopy

New narrow XYZ: Search for partner states

Production of exotic QCD states: Glueballs & hybrids

Bound States of Strong Interaction

Nucleon Structure

Generalized parton distributions: Orbital angular momentum

Drell Yan process: Transverse structure, valence anti-quarks

Timelike formfactors: Low and high E, e and μ pairs

HI collisions comparing QGP to elementary reactions

Strangeness

Strange baryons: Spectroscopy Polarisation

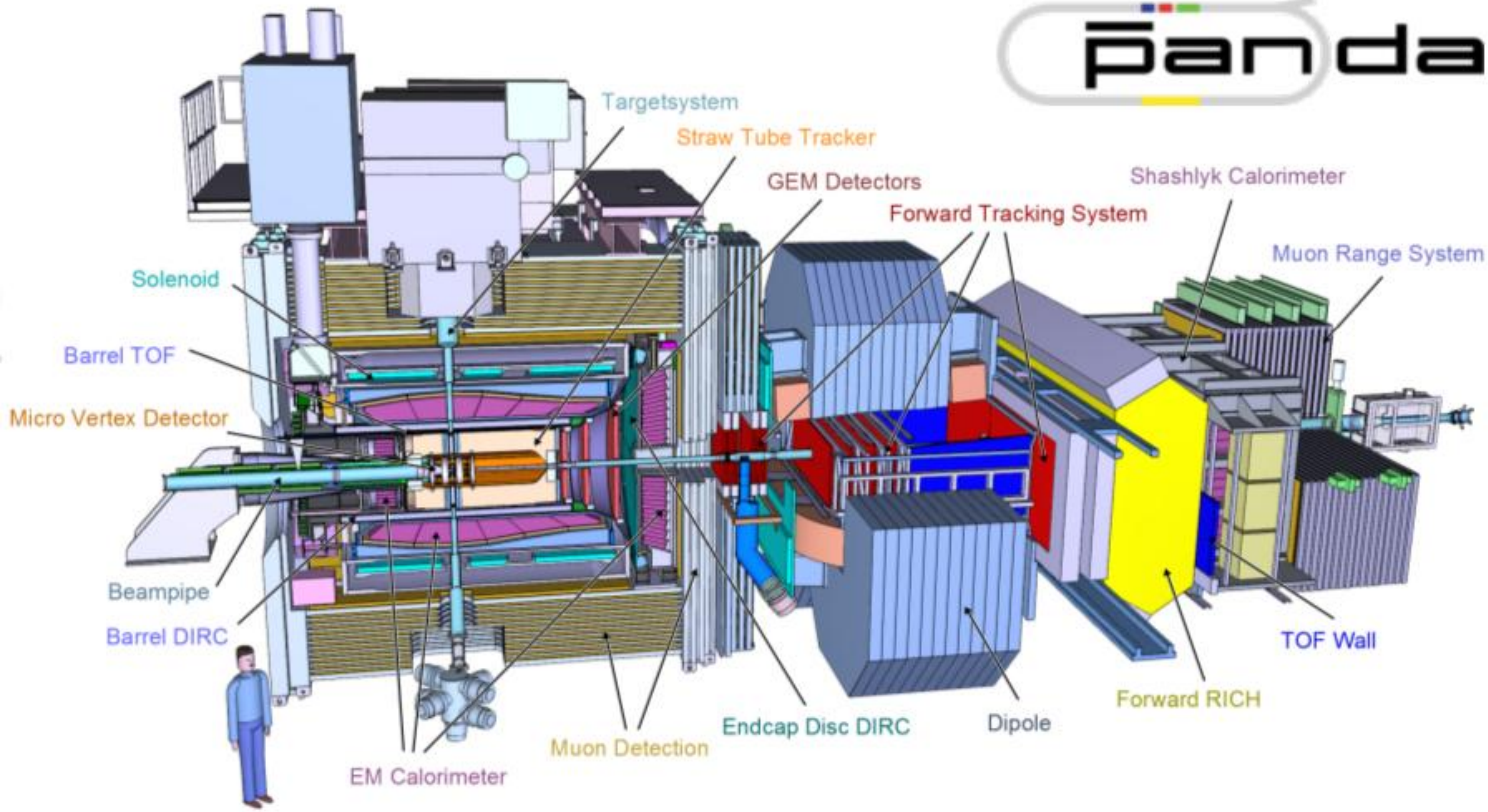
Astro physics: Strange n-stars

Nuclear physics: Hypernuclear spectroscopy

Nuclear Physics

Hypernuclear physics: Double Λ hypernuclei Hyperon interaction

Hadrons in nuclei: Charm and strangeness in the medium



Exclusive measurements

- Almost 4π coverage
- Target and forward spectrometer

High event rate (10^7/s)

- Sophisticated online processing
- Detection of rare decay modes

Charged particle tracking (p<15 GeV/c)

- Good momentum / vertex resolution
- Good PID capabilities

Photon detection (E=0.02-15 GeV)

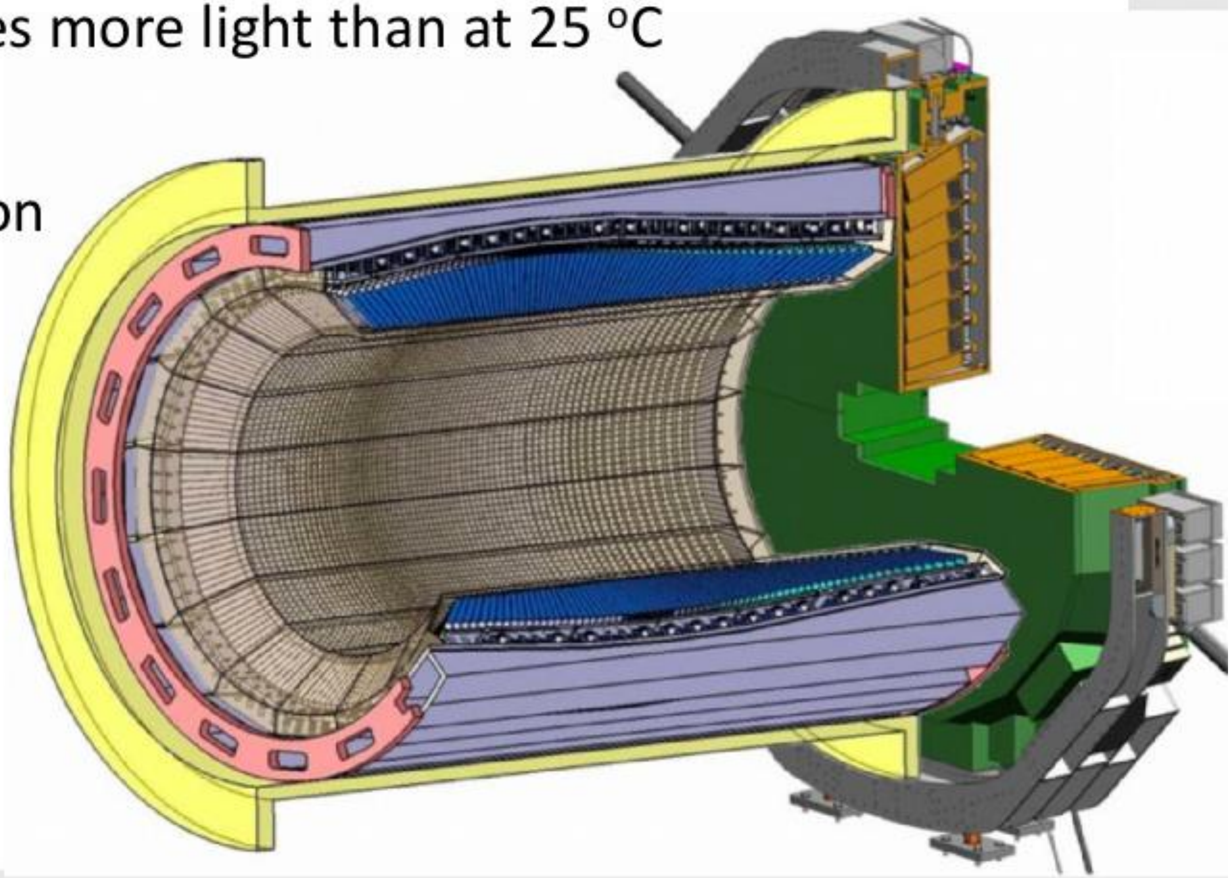
- Excellent energy / angular resolution
- Detection of low energetic photons

Electromagnetic Calorimeter (EMC)

- Sampling calorimeter in forward spectrometer
- Homogeneous crystal calorimeter in target spectrometer: Barrel and two end caps
- 15 552 $PbWO_4$ crystals (20 cm ≈ 22 X_0)
- Operating at -25 °C: 4 times more light than at 25 °C
- Time resolution < 2 ns
- Envisaged energy resolution

$$\leq 1\% \oplus \frac{\leq 2\%}{\sqrt{E/\text{GeV}}}$$

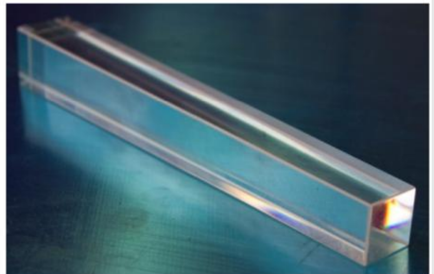
- 99.8% of 4π
- B = 2T



Lead tungstate (PWO) Crystals

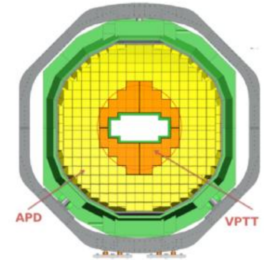
RUB

- Partly produced at BCTP (Russia)
- Production now at Crytur (Czech Republic)

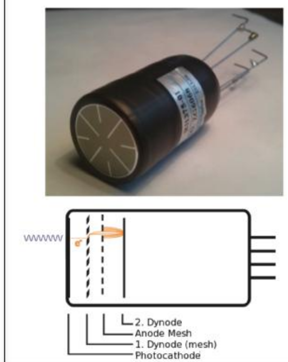


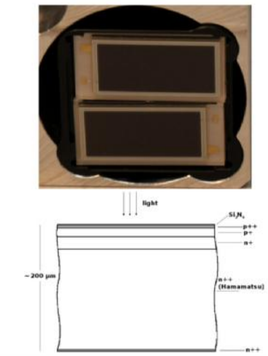
Photodetectors

RUB



APD: 80 % fw endcap
100 % barrel
100 % bw endcap

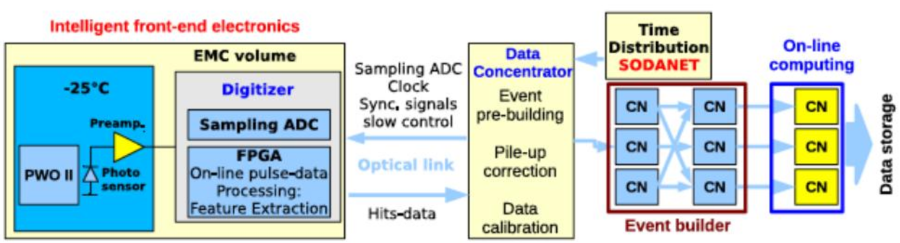




	VPTT (Hamamatsu)	APD (Hamamatsu)
Quantum eff. (typ.)	≈ 23 %	≈ 80 %
Active area	200 mm^2	6.8 x 14 = 95.2 mm^2
Gain	typ. 50	200 / 150
Dark current (Anode)	< 1 nA	1 pA – max 40 nA
Capacity	≈ 22 pF	≈ 270 pF

Electronics and Readout System

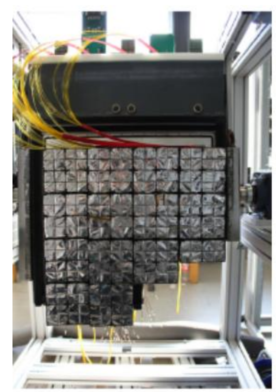
RUB



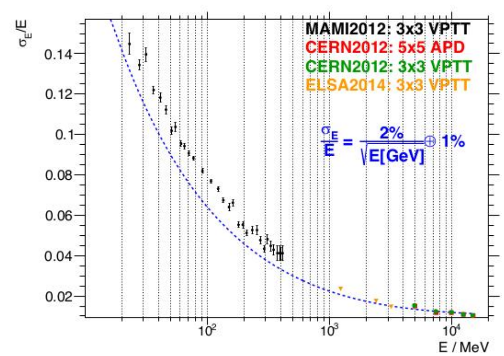
- APFEL-ASIC / Basel low noise preamplifier
- Intelligent front-end: SADC
- Time-distribution system: SODANET
- Triggerless DAQ
- Data concentrators
- Burst-building network
- On-line computing

Test Beam Results

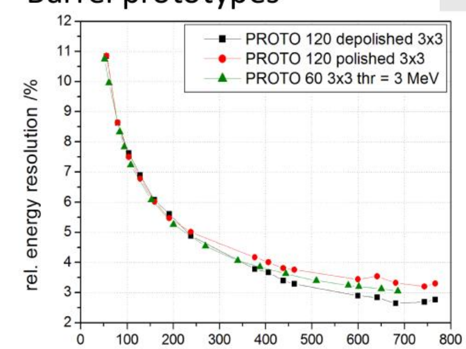
RUB

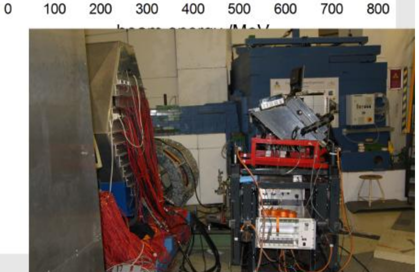


Forward endcap prototype

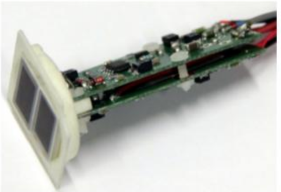


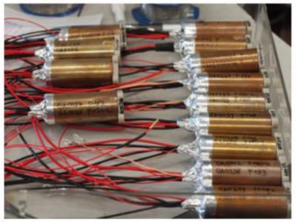
Barrel prototypes

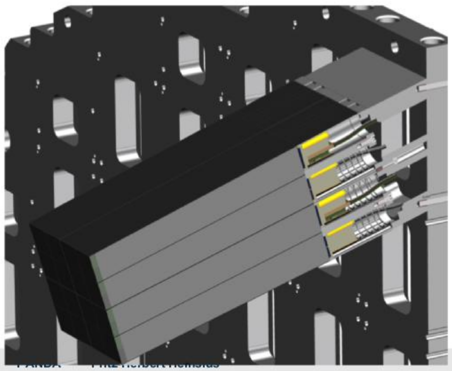


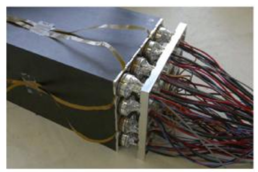


Production of Forward Endcap

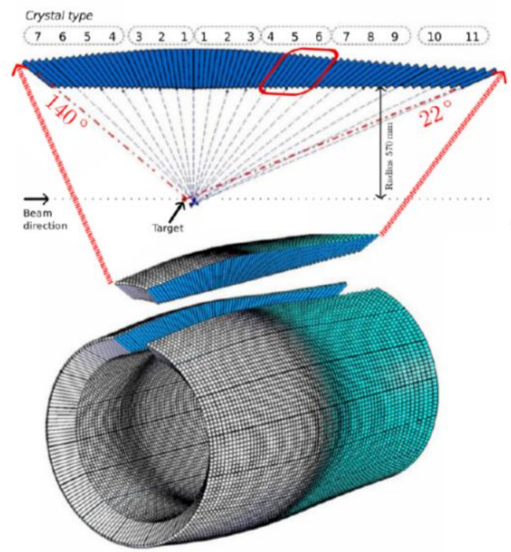




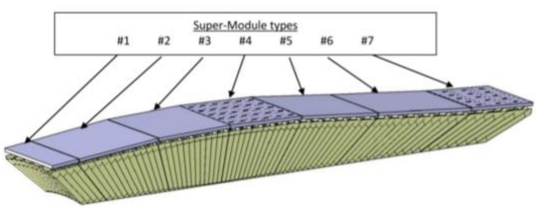


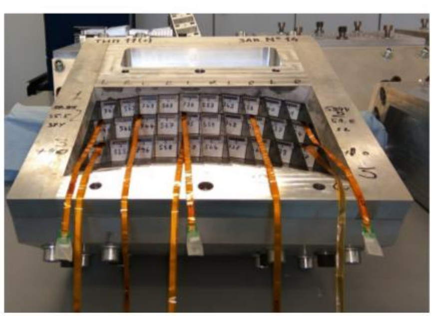


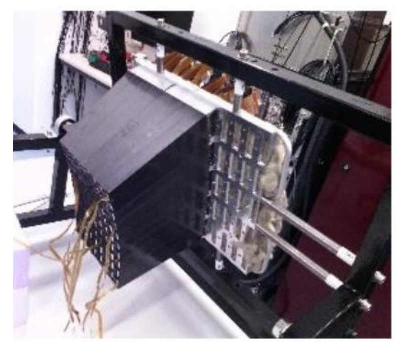
Production of Barrel Slice

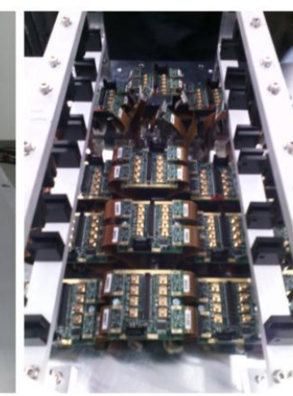


- 710 crystals in 11 different geometries
- Assembly of first slice in 2017





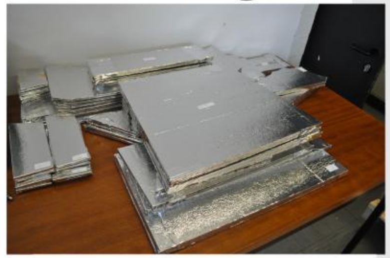


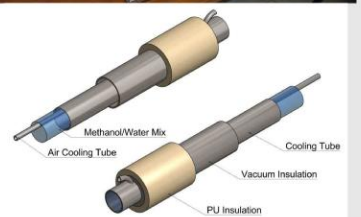


Forward Endcap EMC Cooling

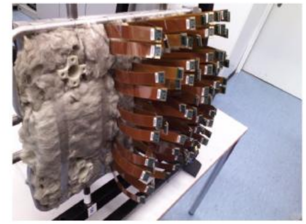
Cooling and Insulation

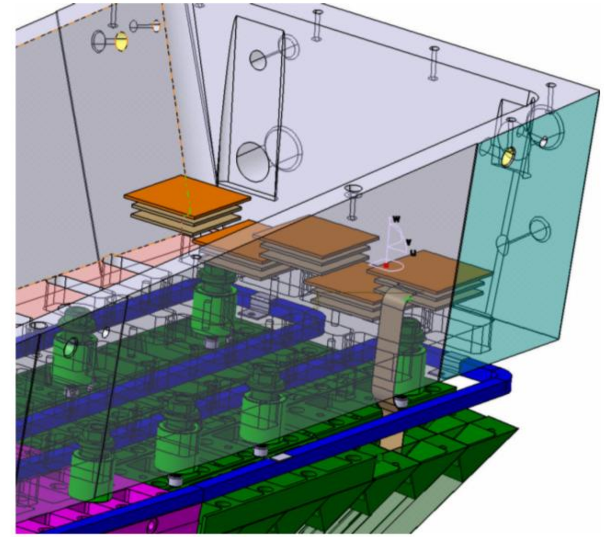
- Cooling lines through drilled holes in backplate support
- Low mass Vacuum Isolation Panels
- Vacuum insulation of cooling lines through solenoid magnet





Barrel EMC Cooling





Summary

- HESR provides an antiproton beam with 1.5 – 15 GeV/*c* momentum
- The PANDA detector covers almost 4π around a fixed target
- PANDA experimental program is covering the three pillars of hadron physics
  - Hadron spectroscopy
  - Hadron structure
  - Hadron interaction
- Lead tungstate crystals enable a compact EMC design, capable of resolving a high hit rate
- Assembly of the forward endcap calorimeter and slice
- Looking forward to produce excellent physics results at the beginning of the next decade