DAQ at Spin Physics Detector

Leonid Afnasyev

on behalf of SPD DAQ group, JINR, Dubna

The NICA project at JINR, Dubna

Nuclotron-based
Ion **C**ollider f**A**cility
in the **Joint Institute for Nuclear Research** (JINR),
Dubna, Russia

circumference	- 503 m,
number of collision points (IP)	- 2,
beta function β_{min} in the IP	- 0.35 m,
number of protons per bunch	- $\sim 1 \cdot 10^{12}$,
number of bunches	- 22,
RMS bunch length	- 0.5 m,

Ion beams from *p* to *Au*

Two interaction points:
MPD -**M**ulti**P**urpose **D**etector for heavy ion physics
SPD - **S**pin **P**hysics **D**etector for physics with polarized beams

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SPD at NICA

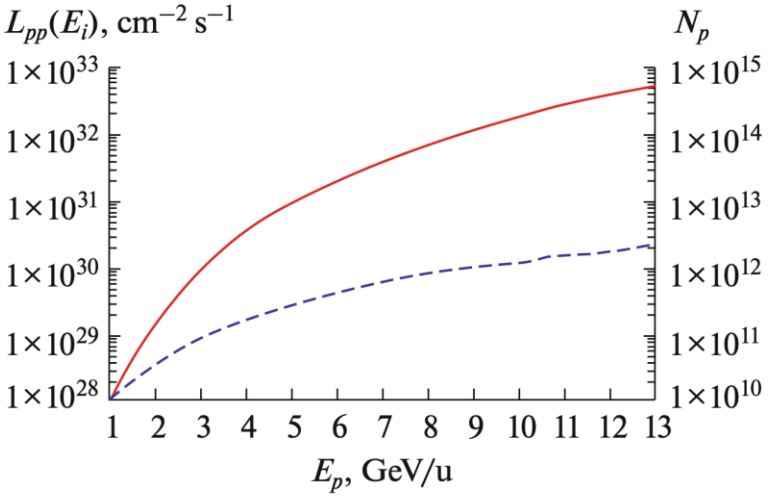
$p^{\uparrow}p^{\uparrow}: \sqrt{s} \leq 27 GeV$ $\quad L \leq 10^{32}$ cm^{-2}s^{-1}

$d^{\uparrow}d^{\uparrow}: \sqrt{s} \leq 13.5 GeV$

$d^{\uparrow}p^{\uparrow}: \sqrt{s} \leq 19 GeV$

U, L, T

|P|>70%



All combinations of polarization in colliding beams will be possible:

LL, TT, UU, UL, UT, LT

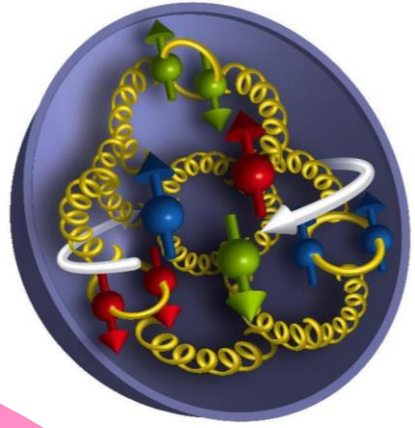
L – longitudinal

T – transversal

U - unpolarized

SPD experiment *will be used for a comprehensive study of the proton and deuteron spin structure. Special attention will be paid to the study of the polarized and unpolarized gluonic component in inclusive reactions of charmonia, open charm and prompt photon production, and other spin-related phenomena in polarized collisions of proton and deuteron beams at the center-of-mass energy up to 27 GeV and luminosity up to* 10^{32} *cm^{-2} s^{-1}.*

CONCEPT OF THE SPD PHYSICS PROGRAM



SPD - a universal facility for comprehensive study of gluon content in proton and deuteron at large x

Charmonia

Prompt photons

Open charm

Other spin-related phenomena

Other physics

SPD Conceptual Design Report

CDR was presented on the meeting of the JINR Program Advisory Committee for particle physics on Jan, 18 by A. Guskov

JOINT INSTITUTE FOR NUCLEAR RESEARCH

February 3, 2021

arXiv:2102.00442

Conceptual design of the Spin Physics Detector

Version 1.0

The SPD proto-collaboration*

The next step is the Technical Design Report

SPD Physics Program

JPPNP: 103858 Model 3G pp. 1–43 (col. fig: NIL)

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journal homepage: www.elsevier.com/locate/ppnp

Review

On the physics potential to study the gluon content of proton and deuteron at NICA SPD

A. Arbuzov [a], A. Bacchetta [b,c], M. Butenschoen [d], F.G. Celiberto [b,c,e,f], U. D'Alesio [g,h], M. Deka [a], I. Denisenko [a], M.G. Echevarria [i], A. Efremov [a], N.Ya. Ivanov [a,j], A. Guskov [a,k,*], A. Karpishkov [l,a], Ya. Klopot [a,m], B.A. Kniehl [d], A. Kotzinian [j,o], S. Kumano [p], J.P. Lansberg [q], Keh-Fei Liu [r], F. Murgia [h], M. Nefedov [l], B. Parsamyan [a,n,o], C. Pisano [g,h], M. Radici [c], A. Rymbekova [a], V. Saleev [l,a], A. Shipilova [l,a], Qin-Tao Song [s], O. Teryaev [a]

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Accepted for publication to PPNP

arXiv:2011.15005

SPD Physics Program

Prepared for Physics of Elementary Particles and Atomic Nuclei. Theory

Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams

V.V. Abramov[1], *A. Aleshko*[2], *V.A. Baskov*[3], *E. Boos*[2], *V. Bunichev*[2], *O.D. Dalkarov*[3], *R. El-Kholy*[4], *A. Galoyan*[5], *A.V. Guskov*[6], *V.T. Kim*[7,8], *E. Kokoulina*[5,9], *I.A. Koop*[10,11,12], *B.F. Kostenko*[13], *A.D. Kovalenko*[5], *V.P. Ladygin*[5], *A. B. Larionov*[14,15], *A.I. L'vov*[3], *A.I. Milstein*[10,11], *V.A. Nikitin*[5], *N. N. Nikolaev*[16,26], *A. S. Popov*[10], *V.V. Polyanskiy*[3], *J.-M. Richard*[17], *S. G. Salnikov*[10], *A.A. Shavrin*[18], *P.Yu. Shatunov*[10,11], *Yu.M. Shatunov*[10,11], *O.V. Selyugin*[14], *M. Strikman*[19], *E. Tomasi-Gustafsson*[20], *V.V. Uzhinsky*[13], *Yu.N. Uzikov*[6,21,22,*], *Qian Wang*[23], *Qiang Zhao*[24,25], *A.V. Zelenov*[7]

[1] NRC "Kurchatov Institute" - IHEP, Protvino 142281, Moscow region, Russia

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[3] P.N. Lebedev Physical Institute,Leninsky prospect 53, 119991 Moscow, Russia

arXiv:2102.08477

SPD Collaboration formation

— proto-collaboration meeting in June 2019 (Dubna)
— remote proto-Collaboration Board meeting 27.10.2020
— remote proto-Collaboration Board meeting 10.03.2021

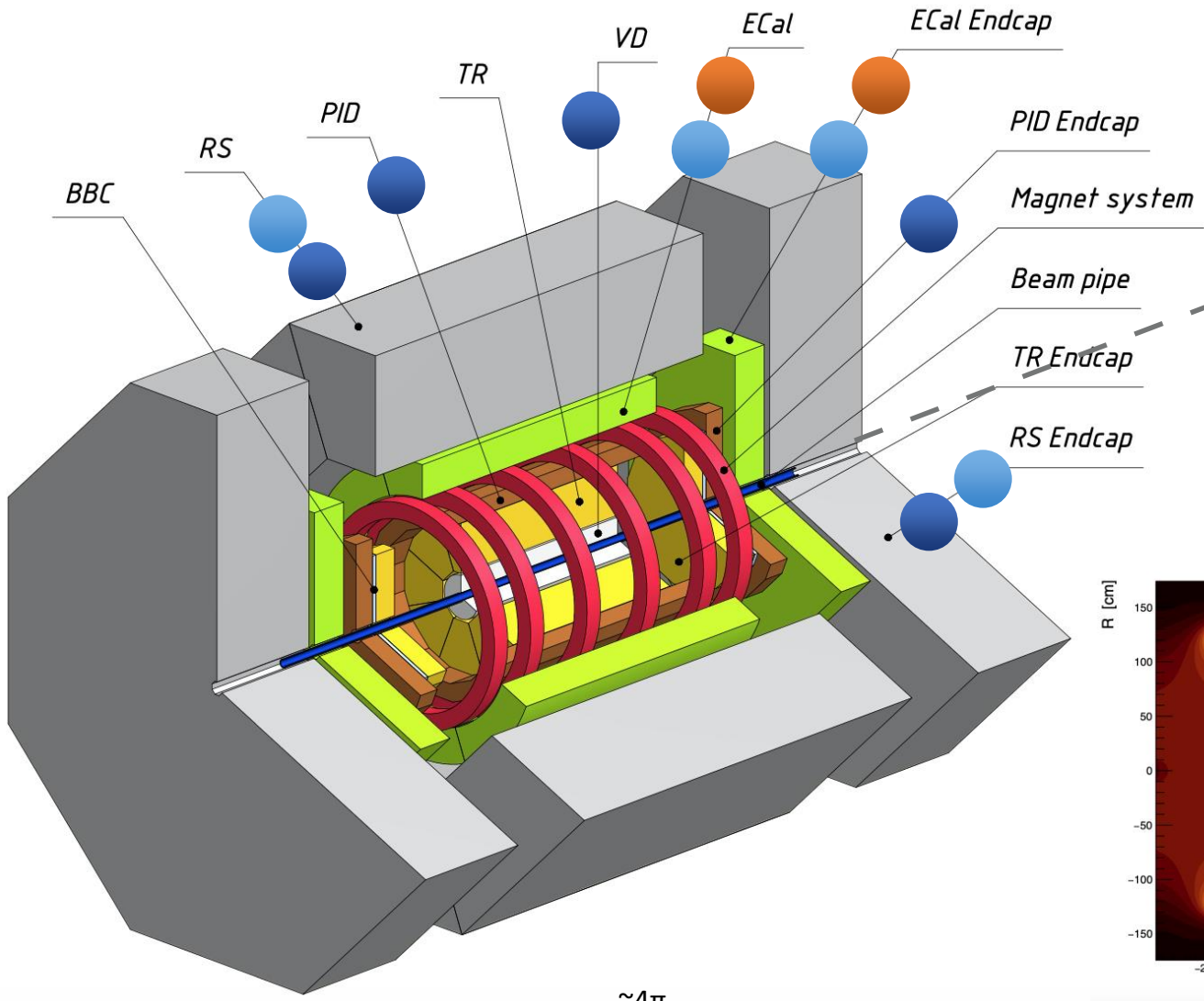
about 30 institutes from 12 states

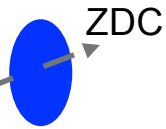
DETECTOR: general overview

Charmonia

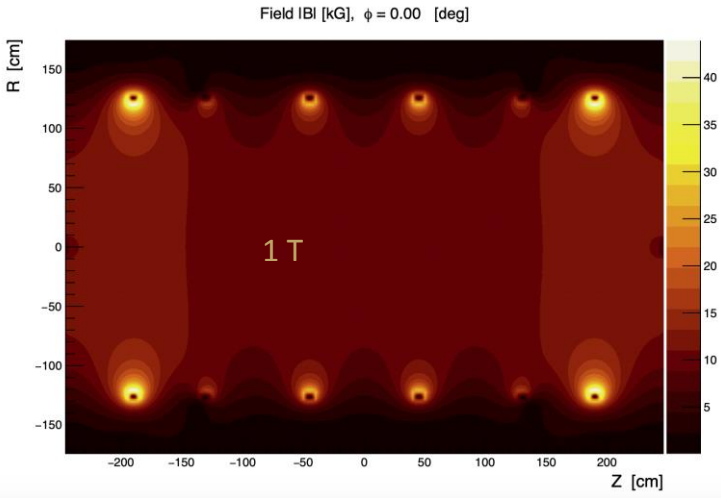
Prompt photons

Open charm





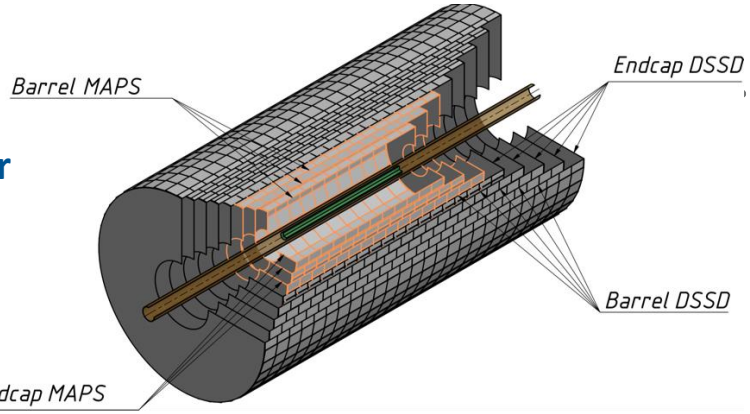
6 superconductive solenoidal coils



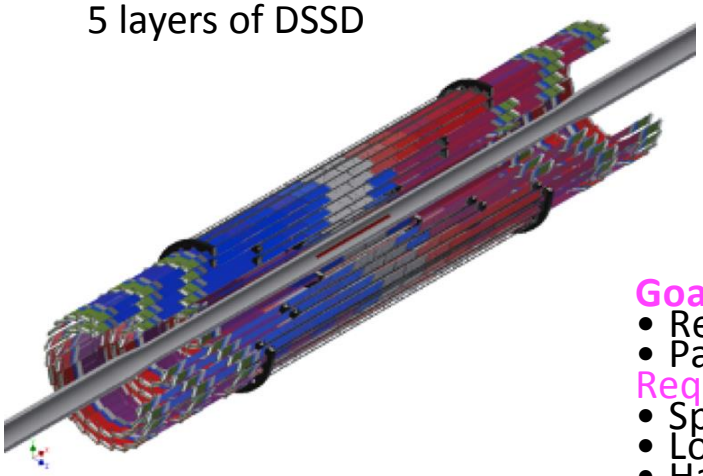
~4π

Tracking system

3 internal layers in barrel replaced by MAPS



5 layers of DSSD



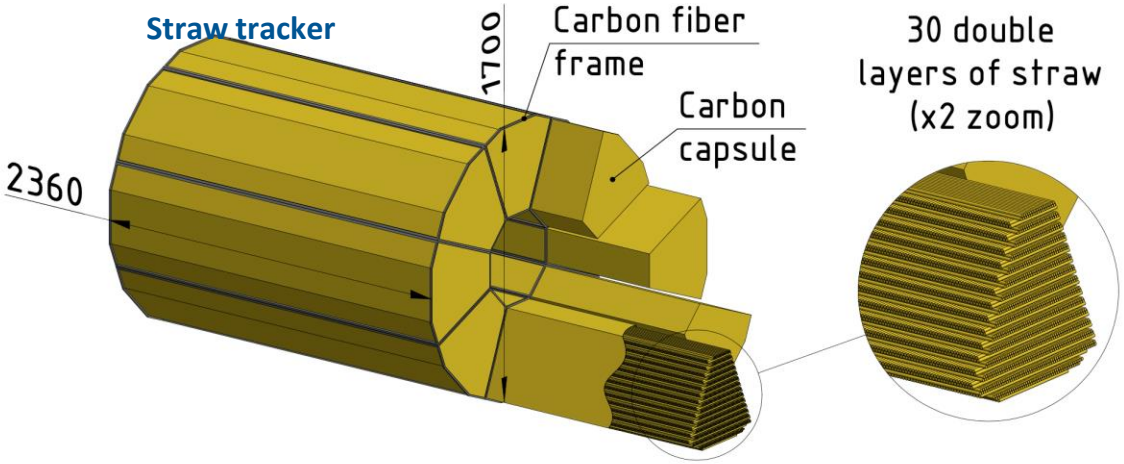
Vertex Detector

Two variants:

Goals:
- Reconstruction of secondary vertices for D-mesons decay
- Participation in track reconstruction and momentum measurement

Requirements:
- Spatial resolution <100 µm
- Low material budget
- Has to be installed as close as possible to the IP

Straw tracker



Goals:
- Track reconstruction and momentum measurement
- Participation in PID via dE/dx measurement

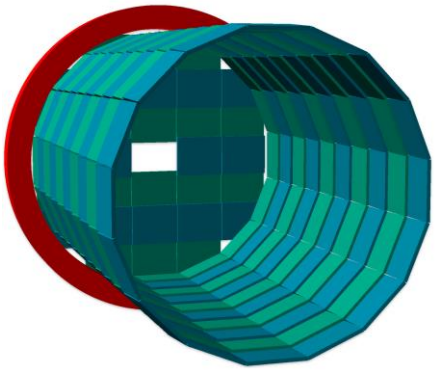
Requirements:
- Spatial resolution ~150 µm
- Low material budget
- Operation in magnetic field of about 1 T

some R&D is still needed

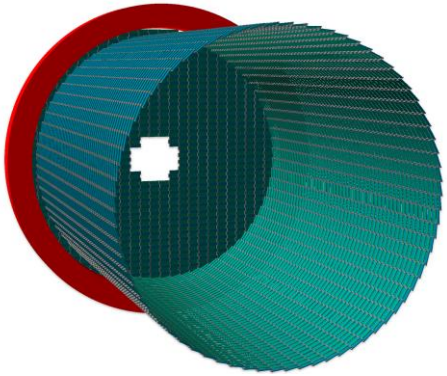
PARTICLE IDENTIFICATION SYSTEM

TOF system

mRPC-based



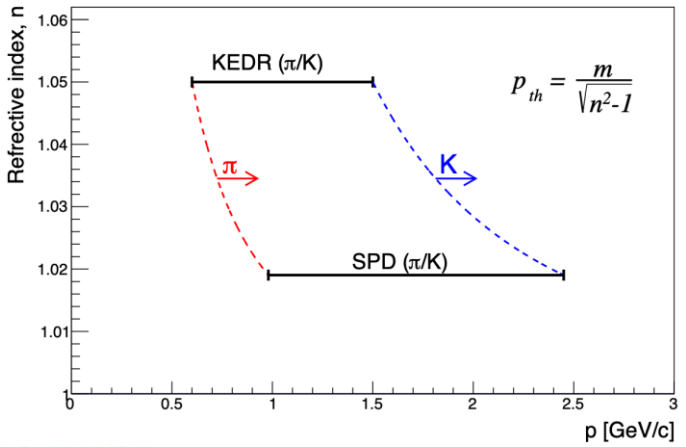
Scintillator-based

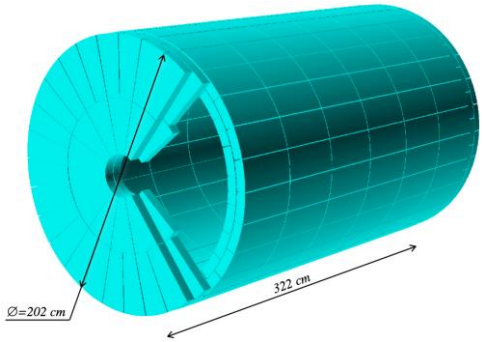


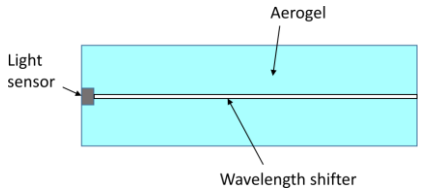
Goals:
- π/K separation up to ~1.5 GeV
- K/p separation
- t_0 determination

Requirements:
- Time resolution ~60-70 ps

Aerogel-based PID



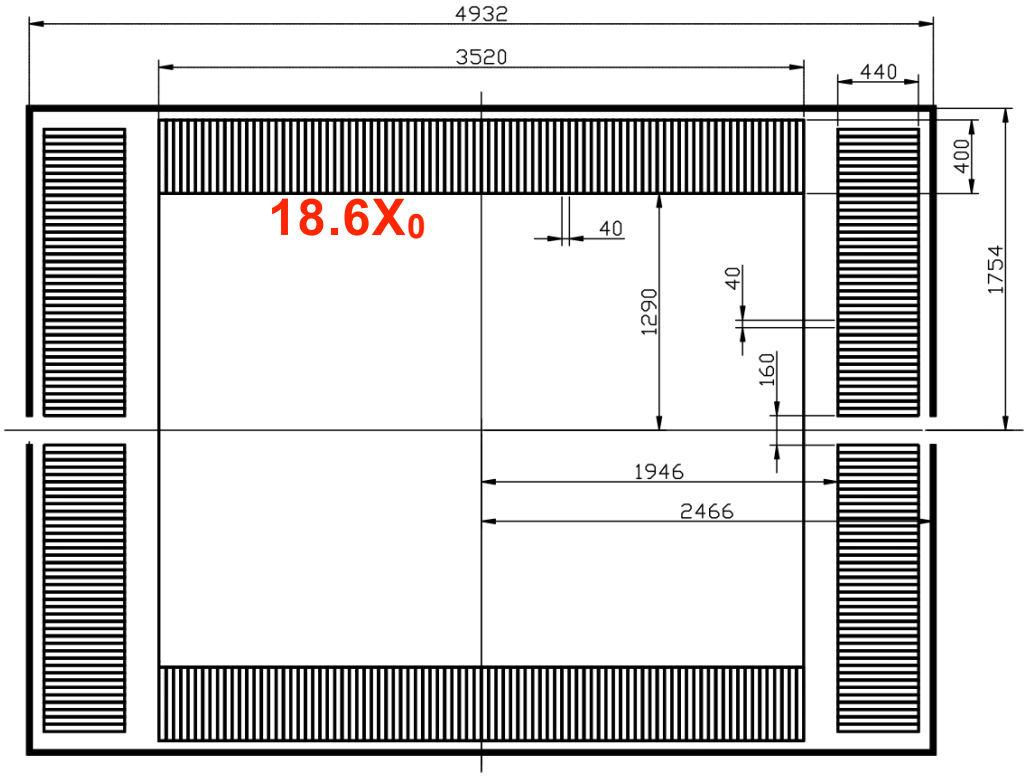


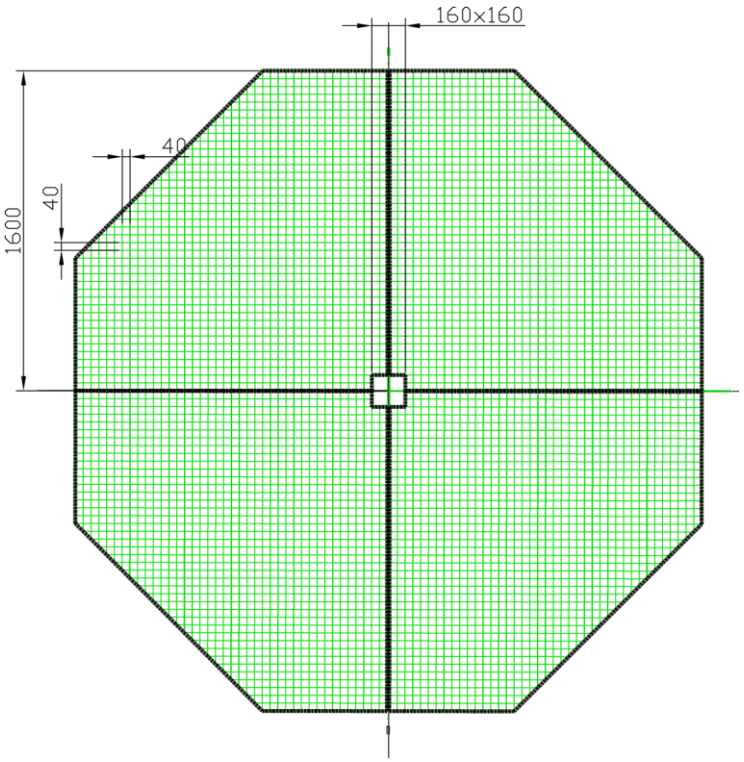


Goals:
- π/K separation up to 2.5 GeV range

Requirements:
- We should have enough light!

ELECTROMAGNETIC CALORIMETER

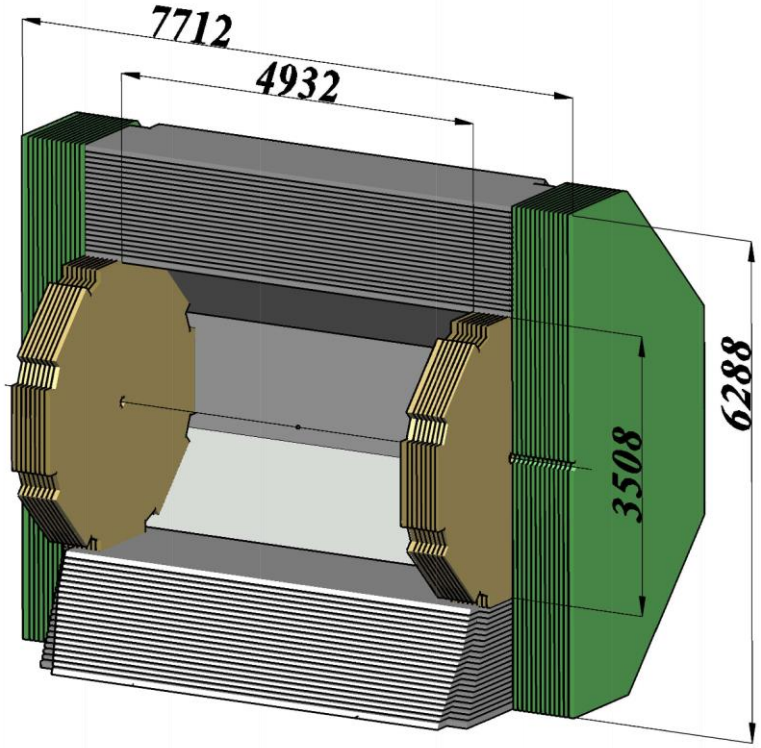


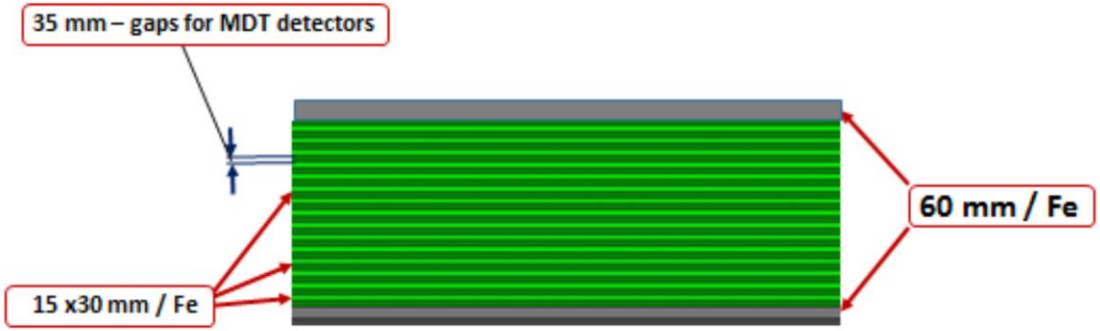


Goals:
- Detection of prompt photons, photons from π^0, η and χ_c decays
- Identification of electrons and positrons, participation in muon identification

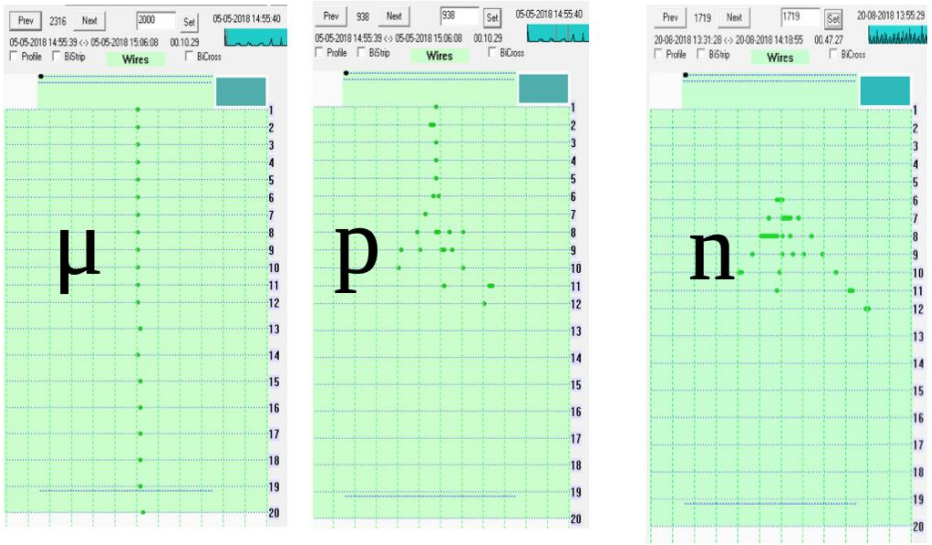
Requirements:
- Granularity ~4 cm
- Low energy threshold (~50 MeV)
- Energy resolution $\sim 5\%/\sqrt{E}$

RANGE (MUON) SYSTEM





Event examples at 5 GeV/c



Goals:
- Muon identification
- Rough hadron calorimetry

Requirements:
- should have at least $4\lambda_I$

Front-End electronics for free running DAQ

- Silicon vertex detector – TDC/ADC: few promising options is developing for PANDA front-end electronics. No final decision yet.
- Electromagnetic calorimeter (SiPMs) – ADC: No final decision yet.
- Straw tracker: iFTDC developed for COMPASS, NA64 is planned for SPD or VMM3 based TDC/ADC.
- Range system – TDC: The SPD range system closely follows the design of the range system of PANDA, which is in a well-advanced state. The digital part of the PANDA front-end electronics is very closed to what we want for the SPD-DAQ.

Estimation of raw data flow

Bunch crossing each 80 ns; crossing rate 12.5 MHz,
Collision rate ~3–4 MHz →
Triggerless DAQ to avoid any hardware biases

Data flux was estimated for the maximum luminosity $L = 10^{32}$ $cm^{-2}c^{-1}$ and maximum energy $\sqrt{s} = 27$ GeV.

Within simplified simulation and some safety margin the data flux is estimated as 20 GBytes/s.

Front-end electronics for the free-running DAQ-SPD

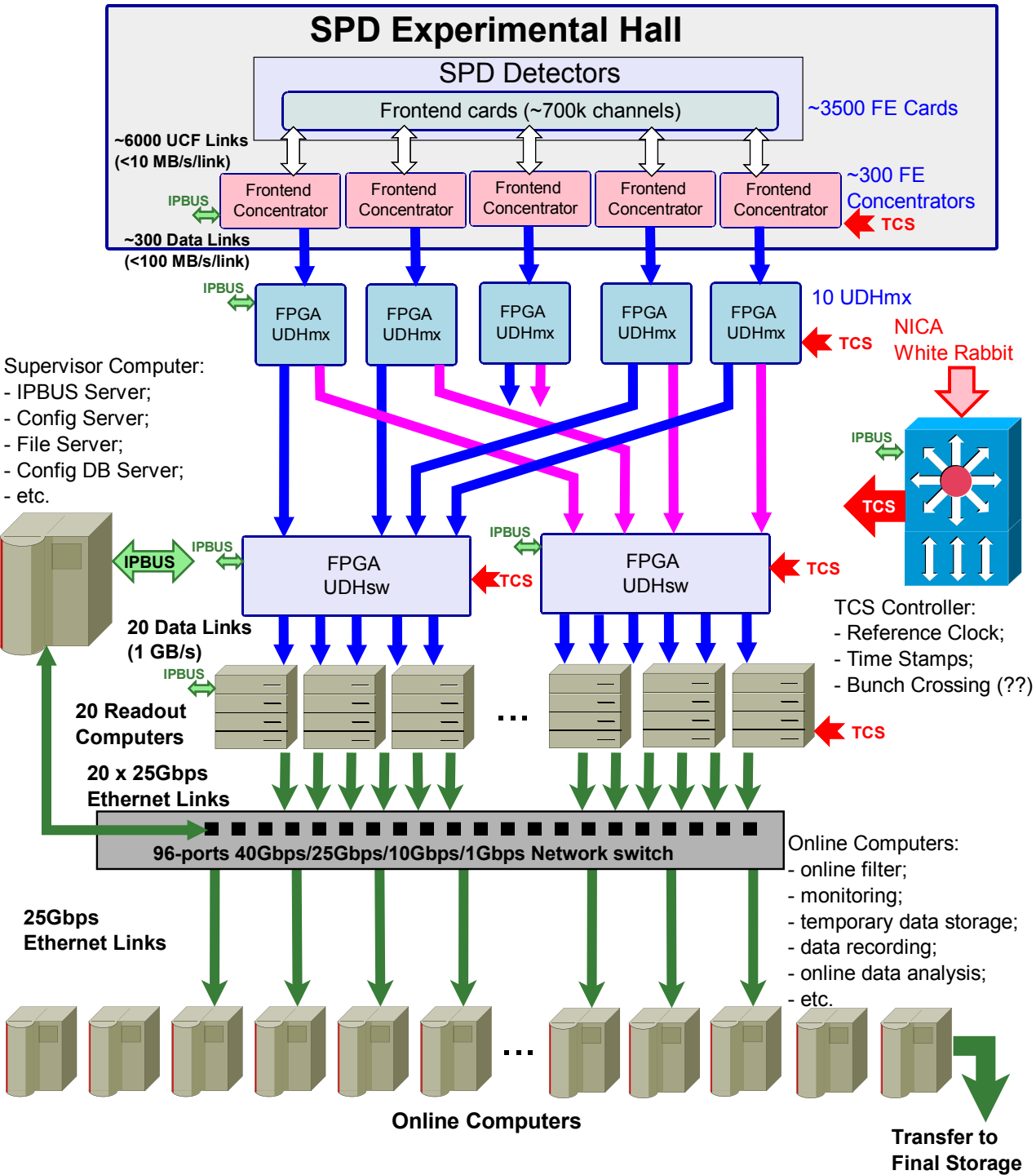
Front-end electronics of the detectors has to meet the requirements of a free-running DAQ

General FEE requirements from the DAQ system:

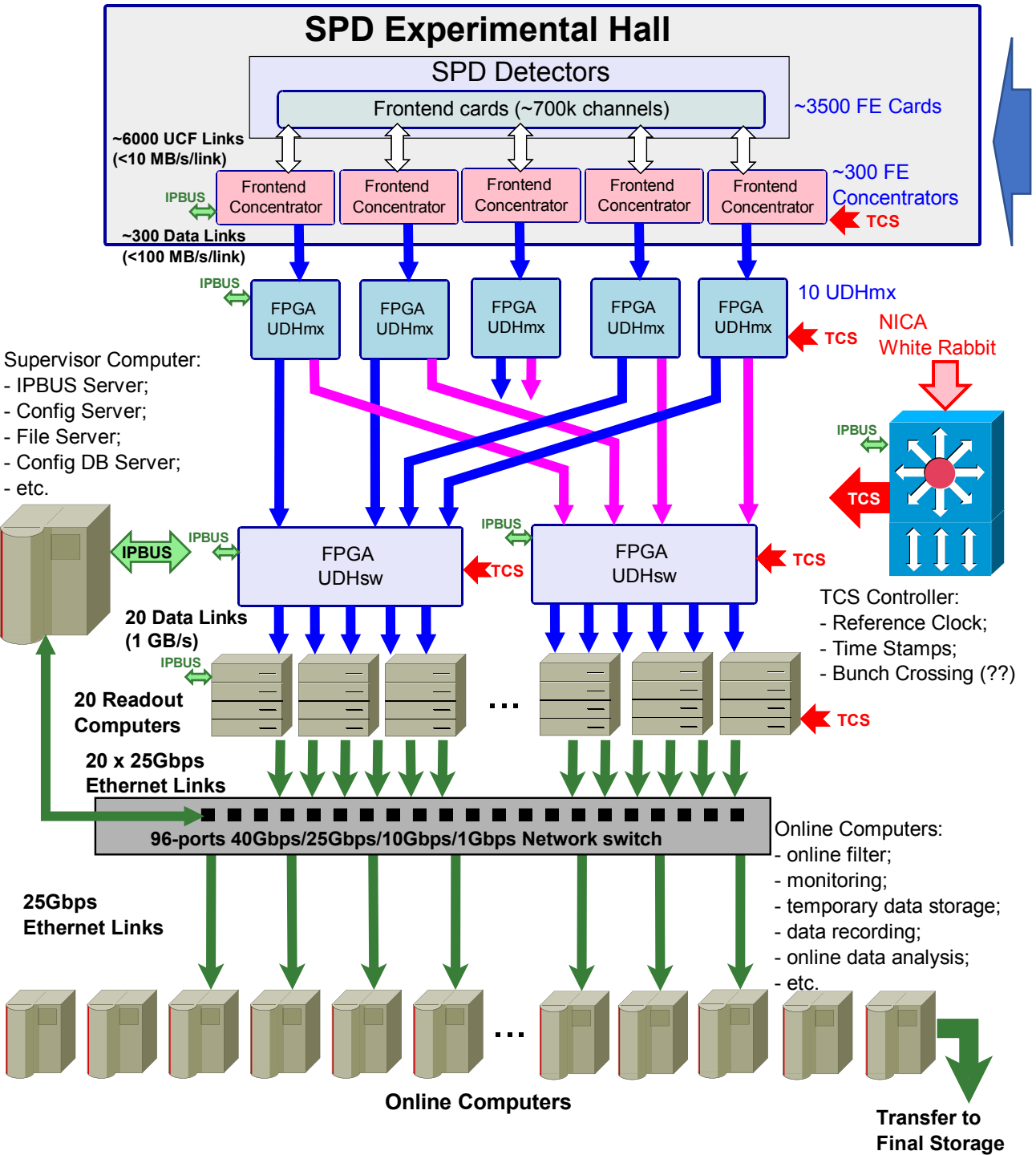
- Self-triggered (*trigger-less*) FEE operation
- Digitizing on-board
- Zero suppression
- Large memory to store the data accumulated in a time slice
- Timestamp included in the output format

Compatibility with DAQ (AMBER)

- Optic output
- Protocols: S-link, Aurora, UCF
- White Rabbit input

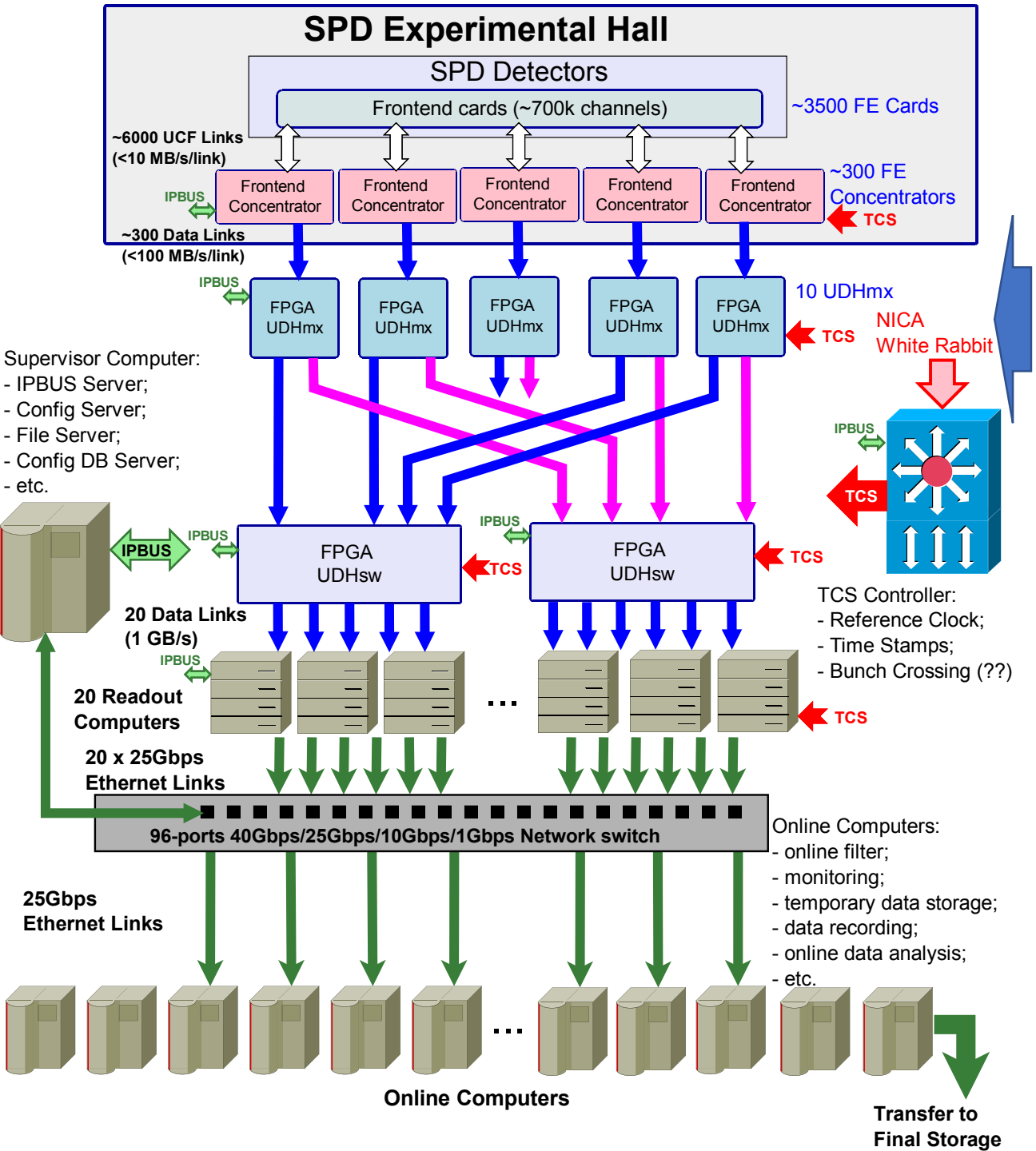


In DAQ of SPD we are planning to employ the ideas developed for the modernized DAQ of COMPASS/AMBER by Igor Konorov group from the Technische Universität of München (TUM). His conception of SPD DAQ is accepted with minor modifications.



Slow control accesses FE cards via the FE Conccentrators using UDP-based IPBus protocol.

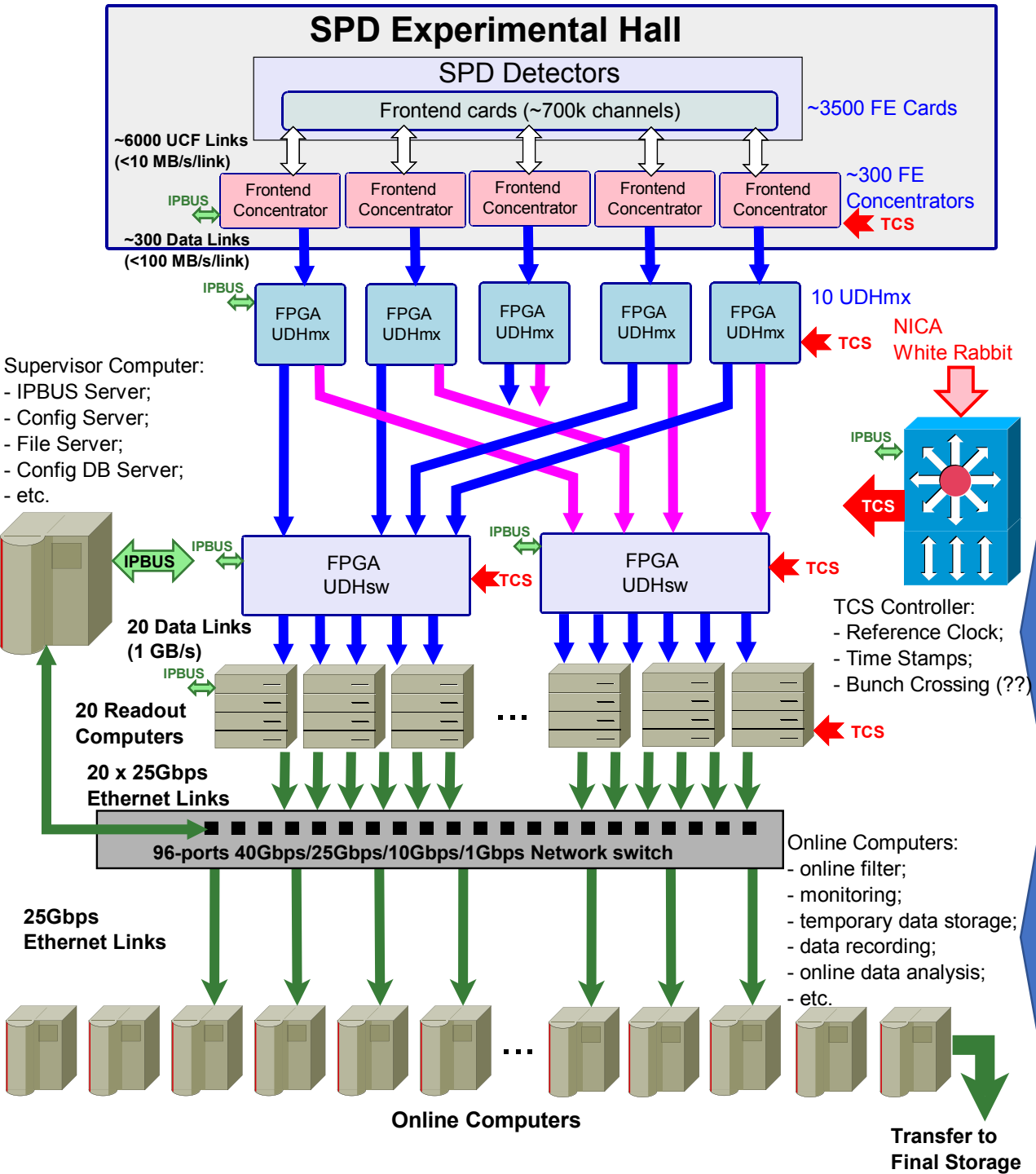
FE Conccentrators retransmit clock signals to FEE and convert detector information to a high speed serial interface running over an optical link.
UCF (*Unified Communication Framework*) protocol will be a standard high speed link protocol within the DAQ.



The multiplexer (UDHmx) modules receive detector information via serial links, verify consistency of data, and store them in DDR memories.

The multiplexer is equipped with 32 GBytes of memory.

All accepted data are assembled in sub-slice and distributed to two switches. Each multiplexer has a bandwidth of 2 GBytes/s.



The switches (UDHsw) perform the final level of slice building and distribute the assembled slices to 20 (?) on-line computers.

Finally, the continuous sequence of slices is built with Network Switch in each PCs

DAQ hardware

Near detector

Mechanics:

- 374 Front End Concentrators - VME 6U double width 12 inputs, 1 outputs
- 43 VME crates, 0.5kW → 9-10 racks
- Option with ATCA crates < 20

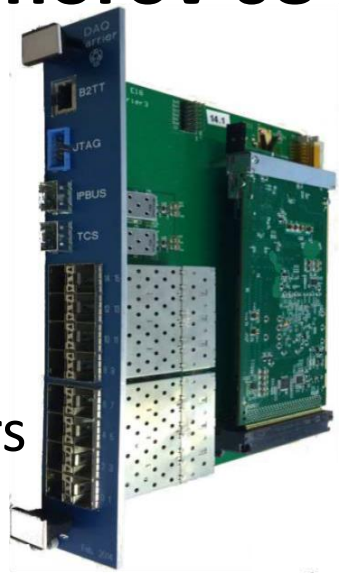
Cables:

- From detectors to DAQ: 4436 optic links
- From DAQ to control room: 374 optic links (double), max 480 links

In barrack

3 VME crates (1kW)
20 DAQ computers (1kW) → 3-4 racks

Migration to ATCA (Igor Konorov 08-02-2021)



ATCA Carrier Card :

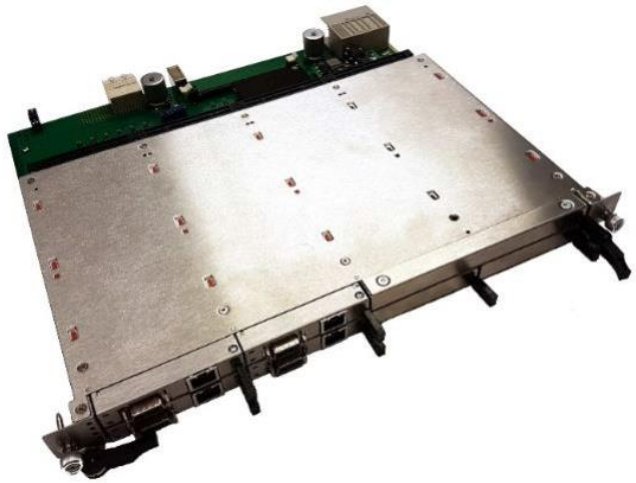
- 4 DHmx/DHsw modules
- 4 Optical interface AMC cards
- 16 links between A ⍰ B connectors

Rear interfaces

- 8 x Ethernet for IPBus
- USB for JTAG
- SFP+ for TCS interface + 1:8 fanout

Optical Interface AMC card

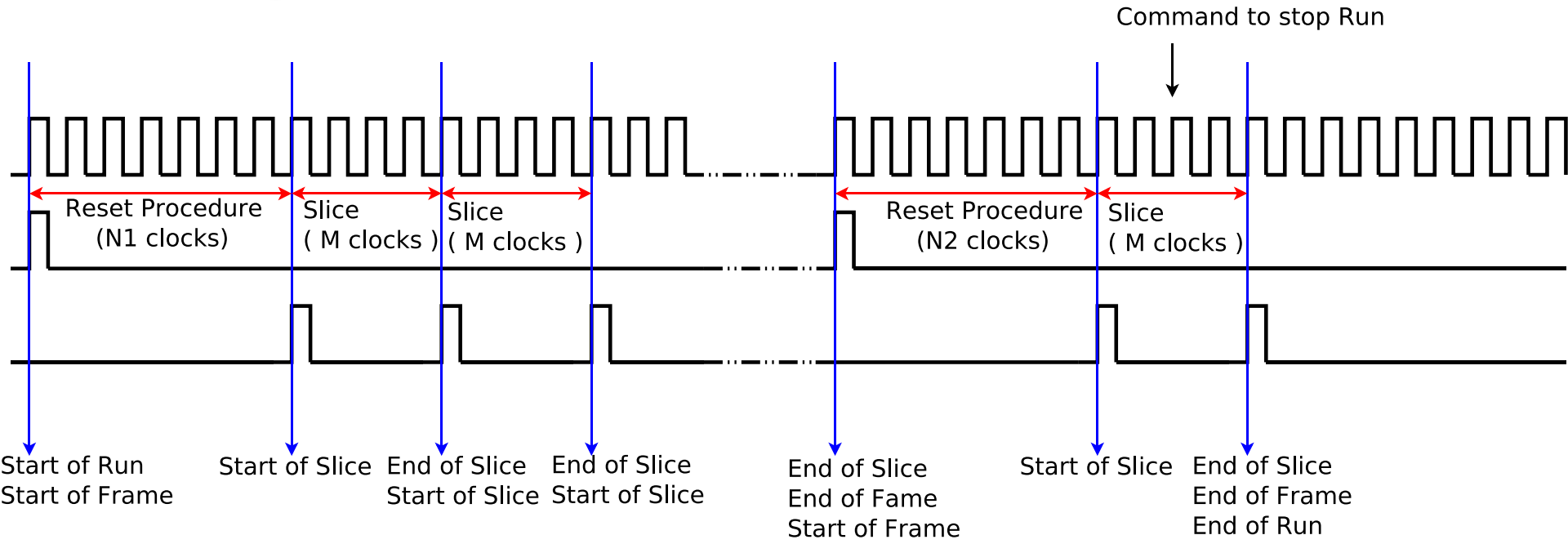
- 8 + 4 FireFly Transceivers



Computer input / PCI Express buffer

- Based on commercial hardware
  – Nereid Kintex 7 PCI Express
  – Trenz FMC – SFP adapter
  Kintex 7 XC7K160T FBG676
- 4x PCIe-Gen2 interface
- 4 GB DDR3 memory
- No dedicated TCS interface

Time diagrams



Tclock = 8ns (125 MHz) from White Rabbit;
Reset Procedure <= 300 ms (depends on electronics);

Slice Number: 24 bits (1 us - 8.3ms)
Data Size: max 16GB (real size < 160MB (20GB/s limit));

Frame: starts by Reset procedure, width 16 bits (min: 65ms, max: 549.7s),
Data Size: max 1PB (real size < 10TB (20GB/s limit))

SUMMARY

- SPD is a new experimental project at the NICA collider at JINR intending to study the spin structure of nucleon with polarized proton and deutron beams at $\sqrt{s}$ up to 27 GeV and at high luminosity.

  All polarization modes will be available as well as combinations of $p\uparrow p\uparrow$, $d\uparrow d\uparrow$ and $p\uparrow d\uparrow$ colliding beams.

- The SPD detector is planned as a universal multipurpose 4π detector including the vertex detector, tracking system, time-of-flight system, electromagnetic calorimeter and muon identification system.

  The free-running DAQ is foreseen for SPD.

- The SPD project is opened for new ideas and collaborators.

New participants are welcome!

Some slides are provided by courtesy of Alexei Guskov

Thank you for attention