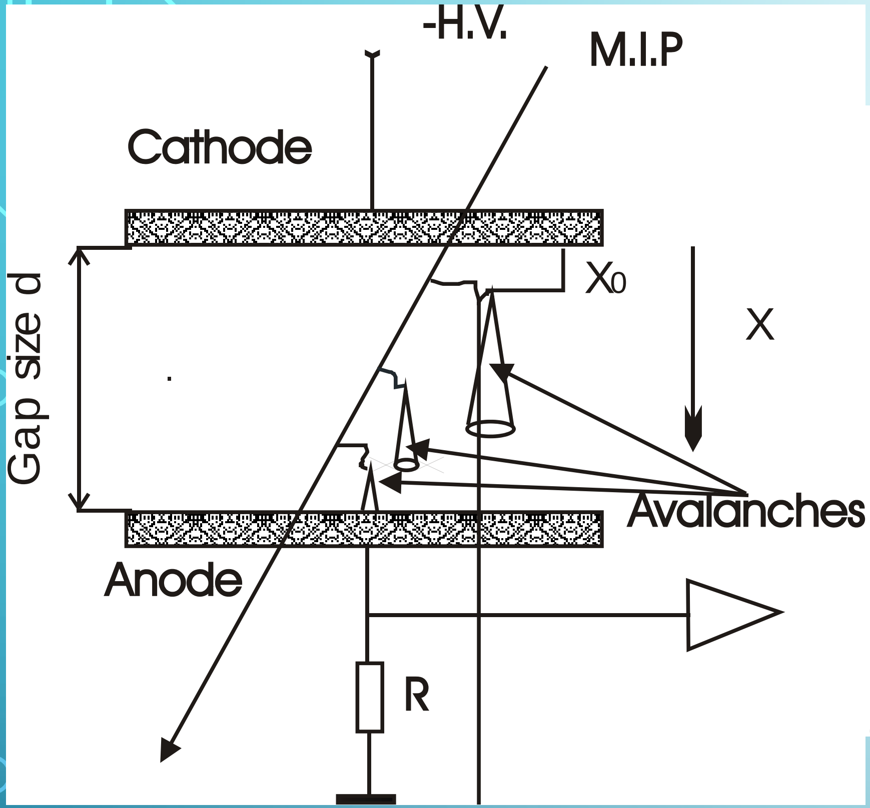
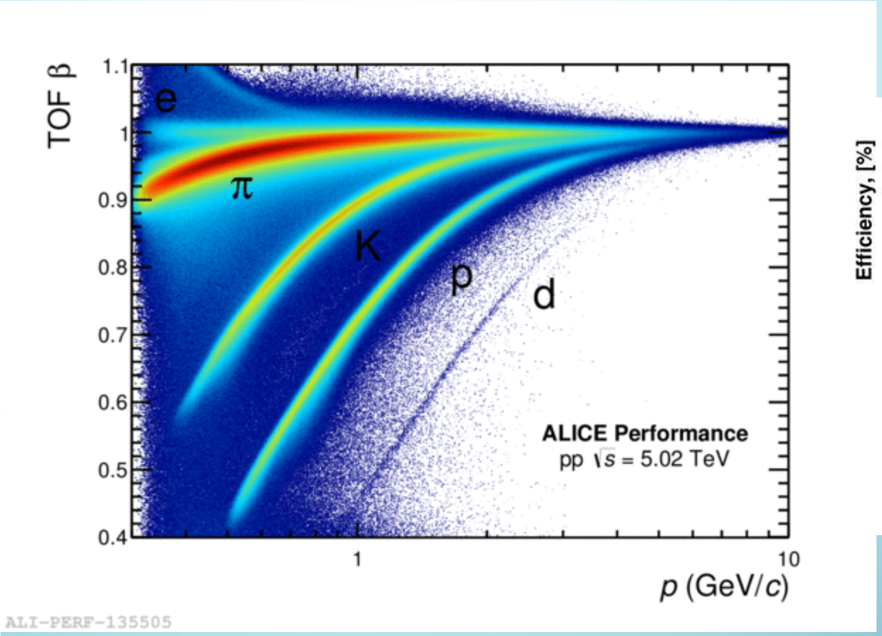
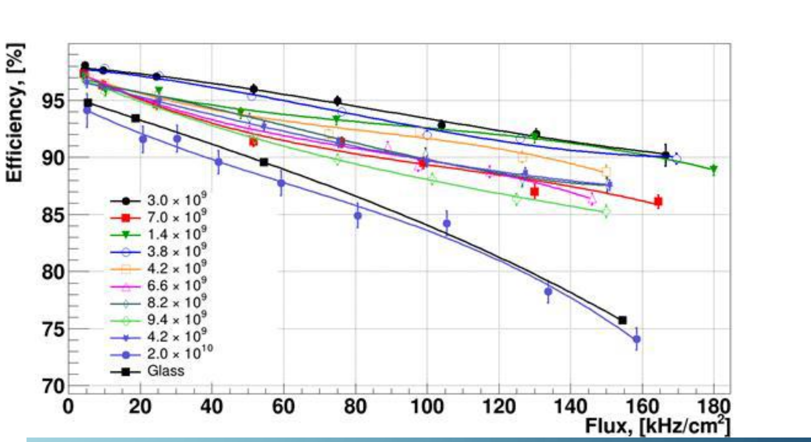






ITEP

Progress in the development of high-rate and radiation hard RPC for Time-of-Flight systems

Alexander Akindinov, NRC «Kurchatov Institute» - ITEP

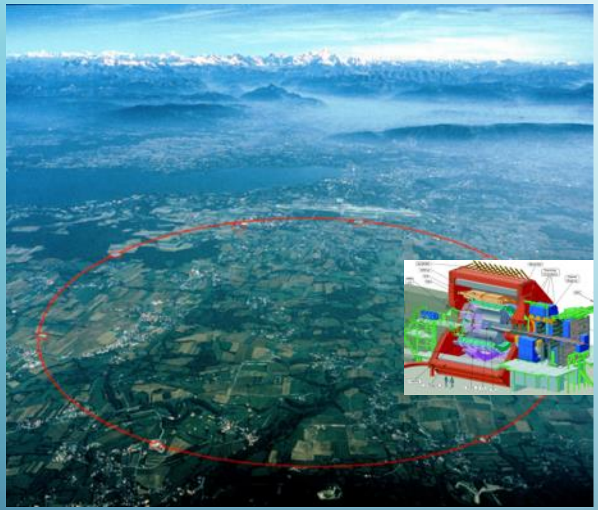
SPD meeting, 05 March, 2018

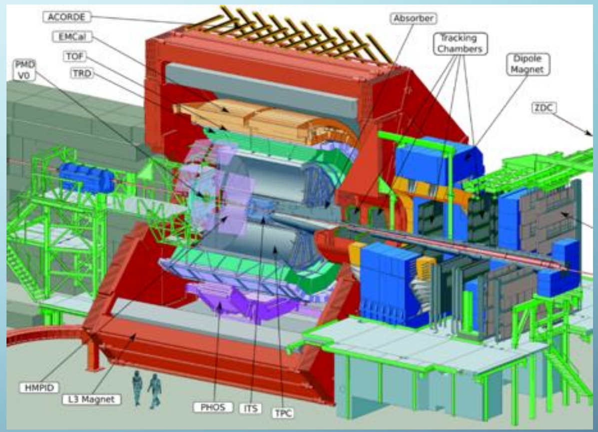
Outlook

- Brief results of ALICE TOF R&D
- Some remarks about detector design and output charge.
- Key point for high-rate RPC – new low resistive material with high surface quality
- CMB R&D results for semiconductive ceramics and low resistive glass
- Search for optimal resistance using ceramic electrodes.
- Data with low resistive glass
- Conclusion

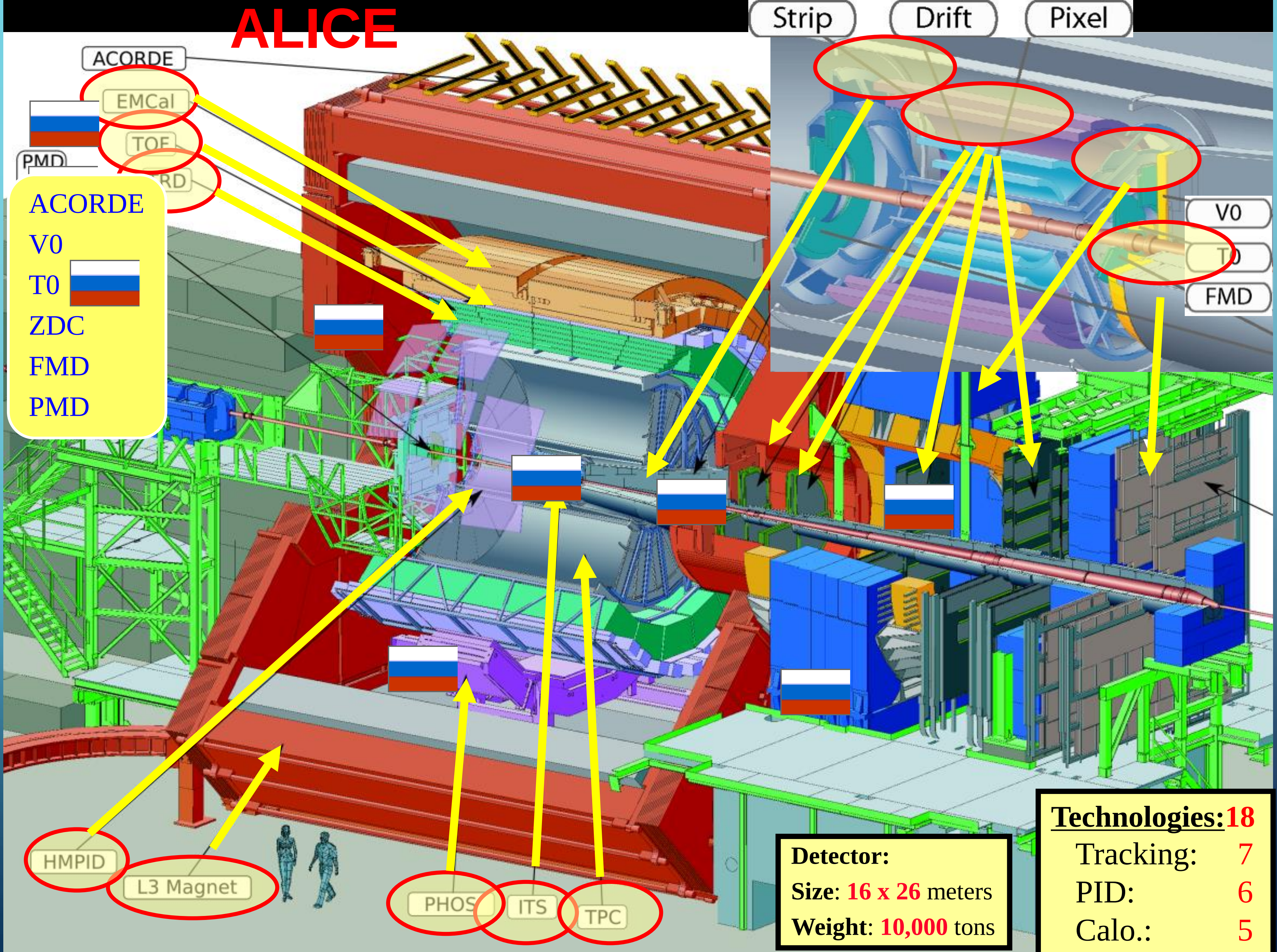
ITEP

Brief results of ALICE TOF R&D





ALICE



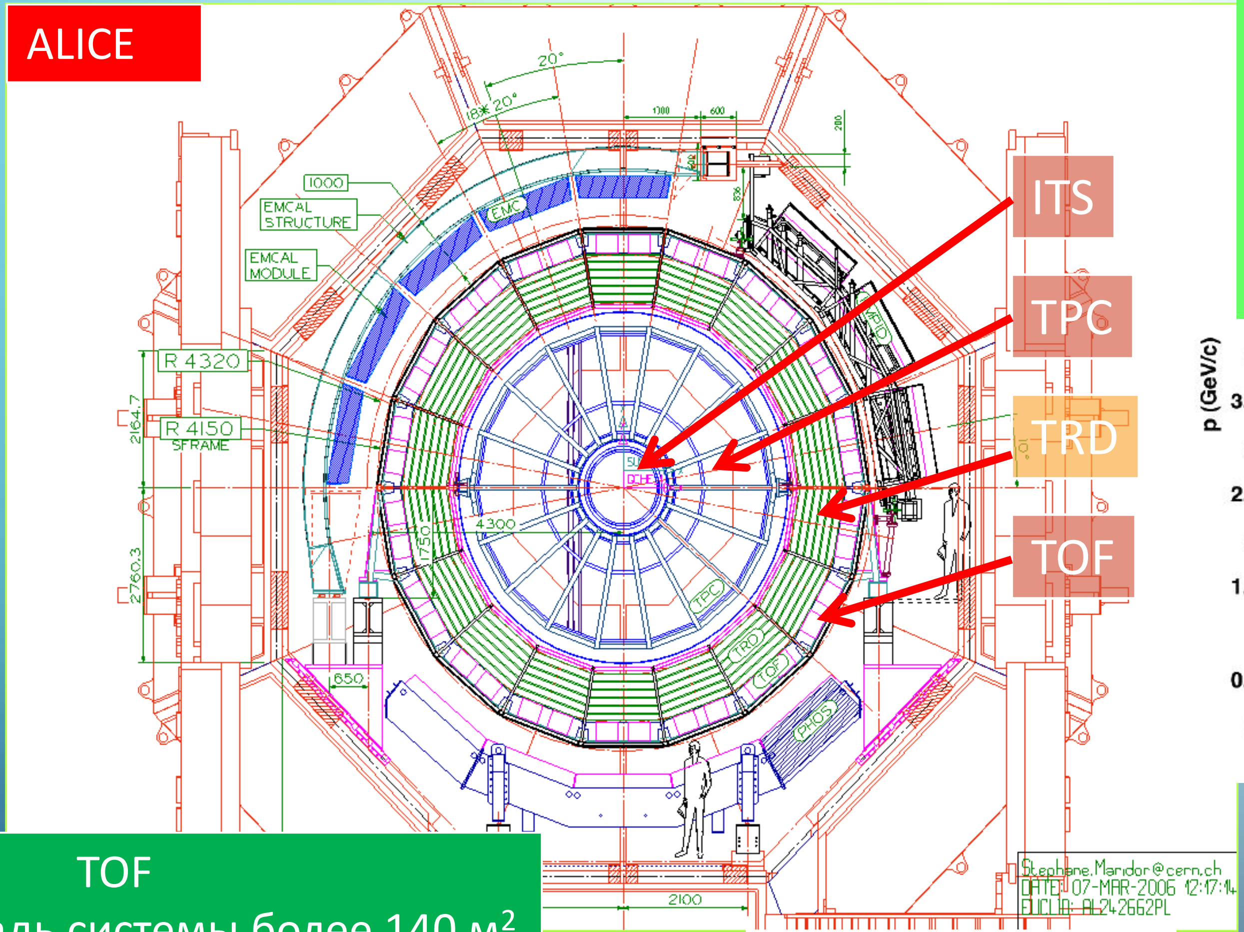
ACORDE
V0
T0
ZDC
FMD
PMD

Detector:
Size: 16 x 26 meters
Weight: 10,000 tons

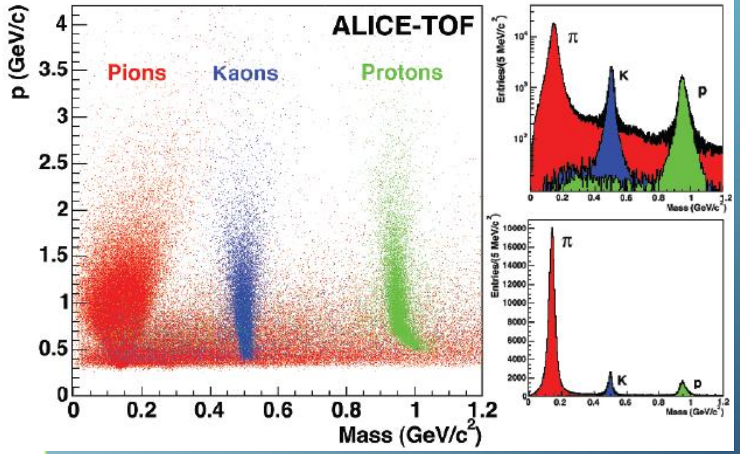
Technologies: 18
Tracking: 7
PID: 6
Calo.: 5

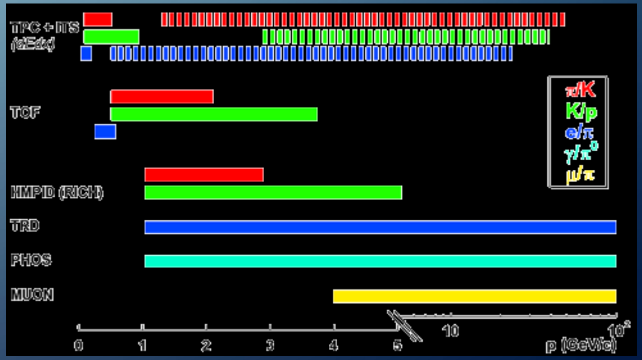
ITEP

TOF ALICE – наиболее масштабная времяпролетная система



Моделирование идентификации частиц при временном разрешении 100 псек.





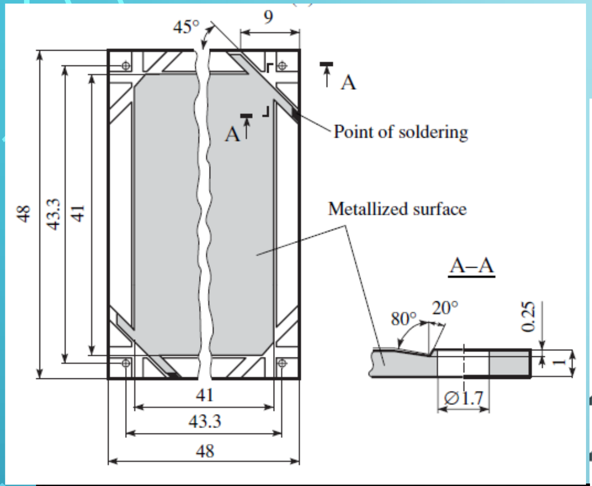
$$m = \frac{p}{c}\sqrt{\frac{c^2t^2}{L^2} - 1}$$

$$\left(\frac{\delta m}{m}\right)^2 = \left(\frac{\delta p}{p}\right)^2 + \left(\gamma^2\frac{\delta L}{L}\right)^2 + \left(\gamma^2\frac{\delta t}{t}\right)^2$$

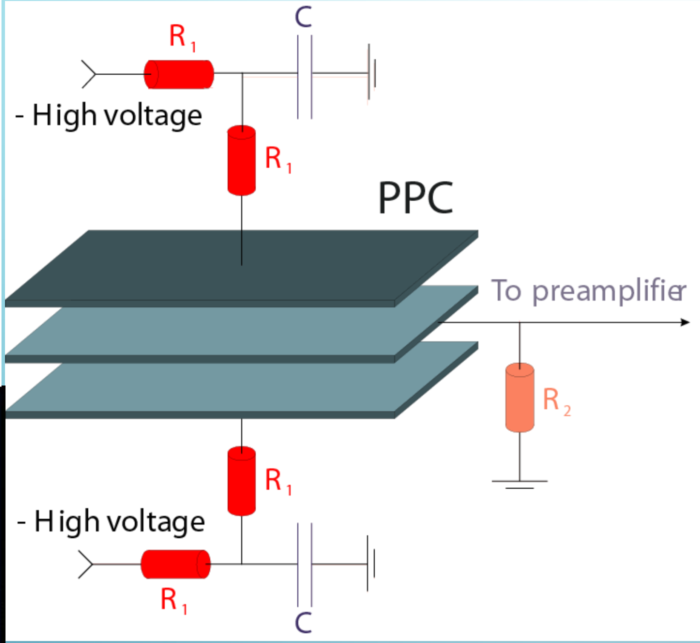
TOF

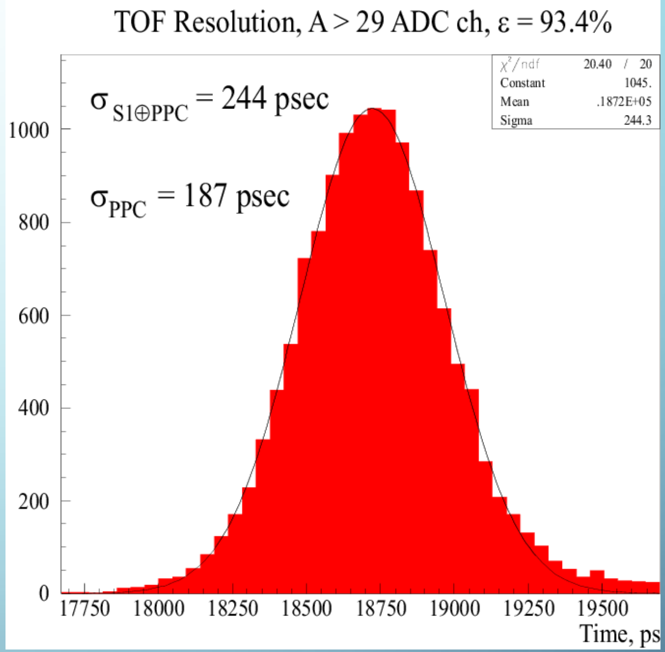
- Общая площадь системы более 140 м^2
- общее число каналов 150 000 (гранулярность ≈4x4 см)
- от 0.5 до 2.5 ГэВ/с на базе в 3.8 метра
- σ ~100 псек.

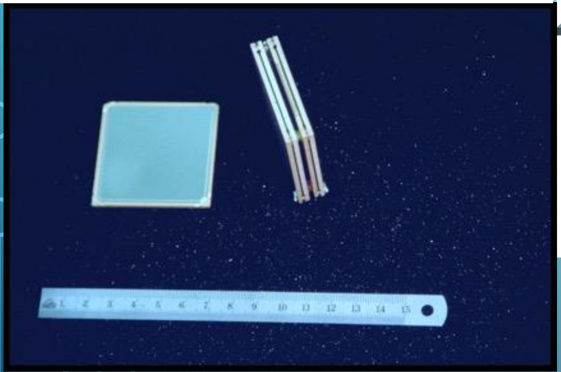
DOUBLE GAP PPC WITH 0.63 MM GAP SIZE

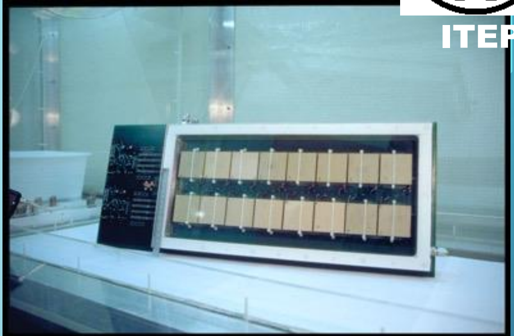


95% DME + 5% CF_4Br





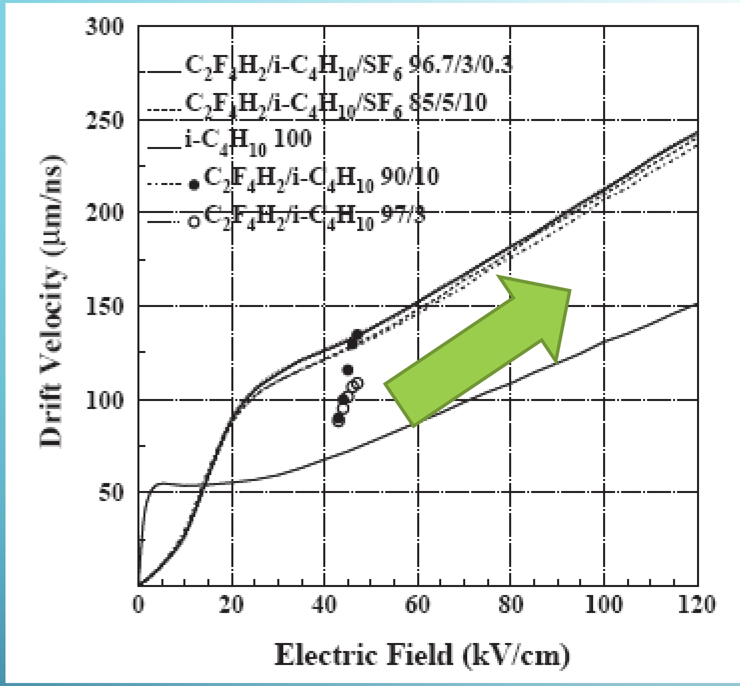


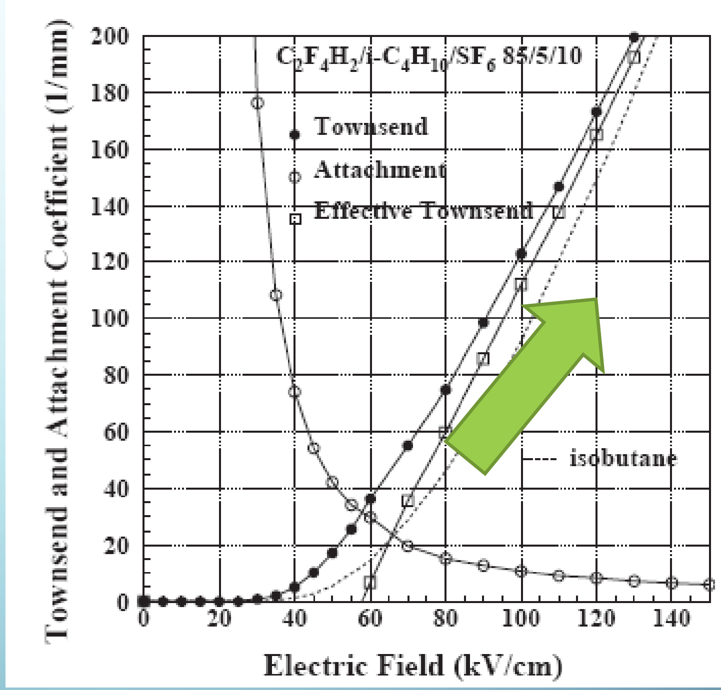


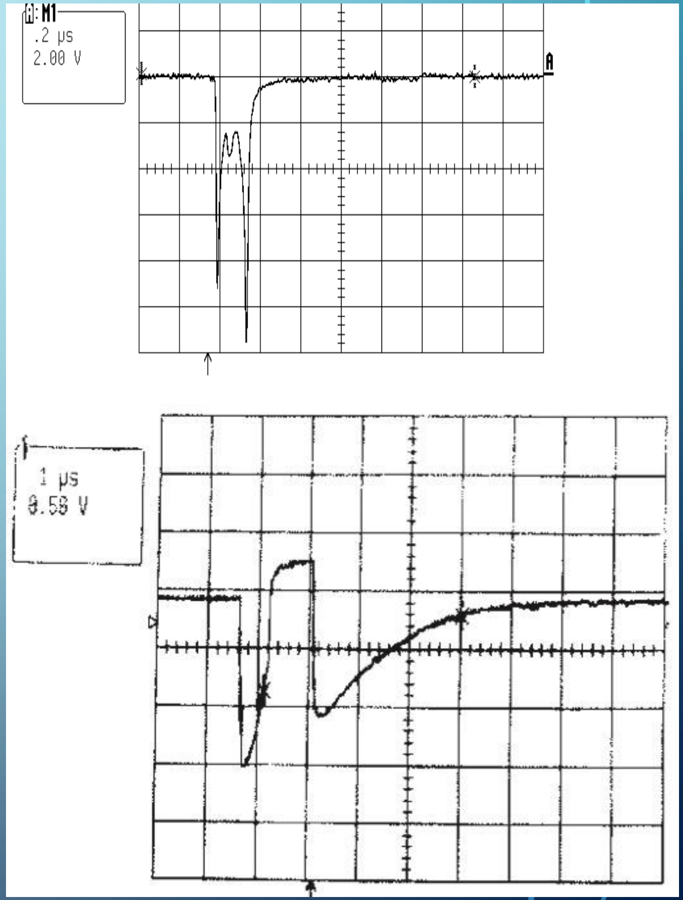
ITEP

!!!First demonstration of new technology!!!!

WHAT WE HAVE TO DO TO IMPROVE TIME RESOLUTION?







E ↑

$$1/(\alpha - \eta) * v_{dr}$$

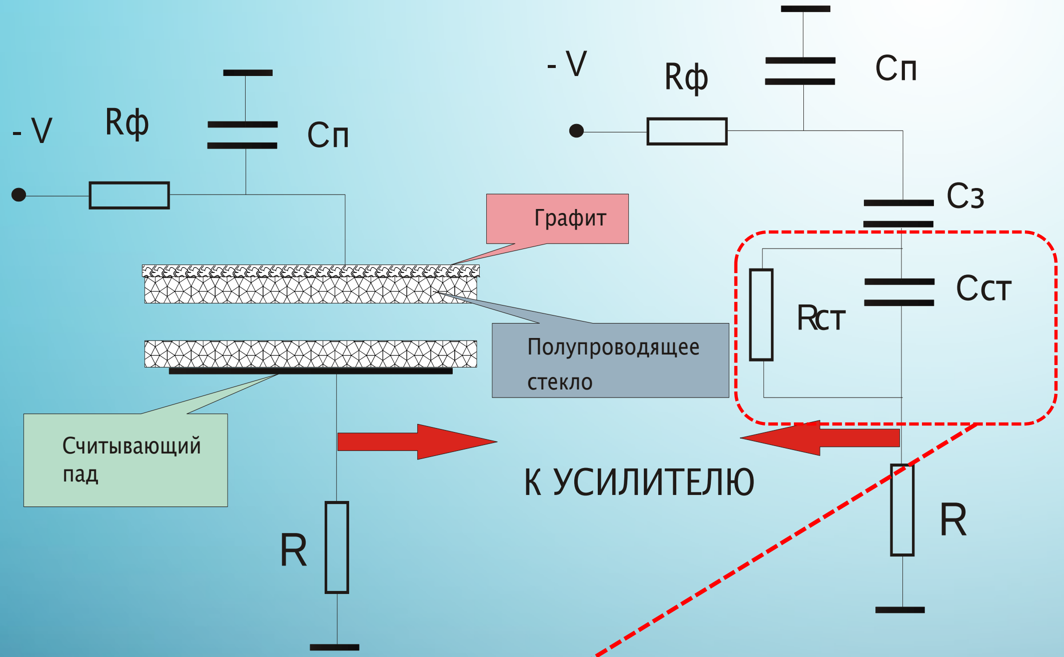
$$\sigma(t) \sim \frac{k}{(\alpha - \eta)v},$$

↓

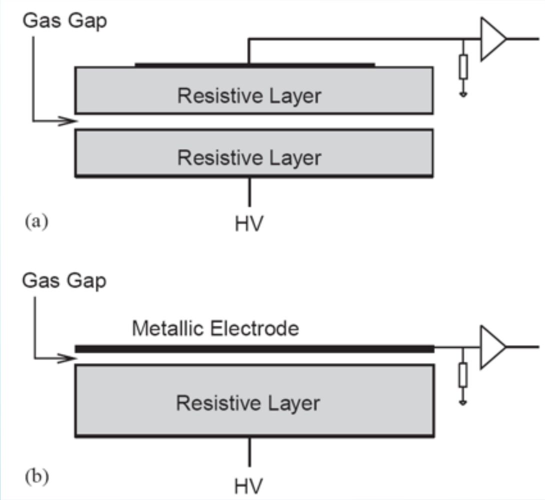
(α-η)*d≈20
Spark discharge

Idea of Local Quench

ITEP



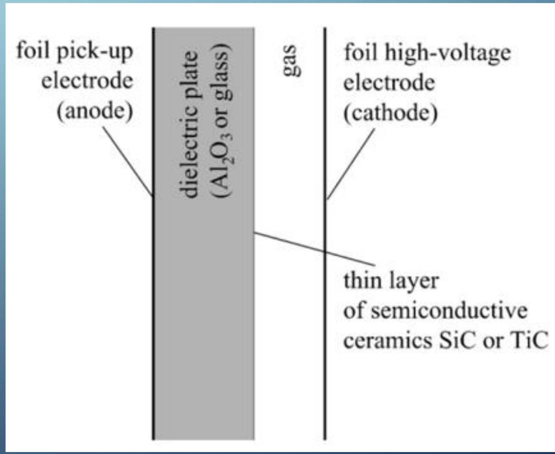
RPC



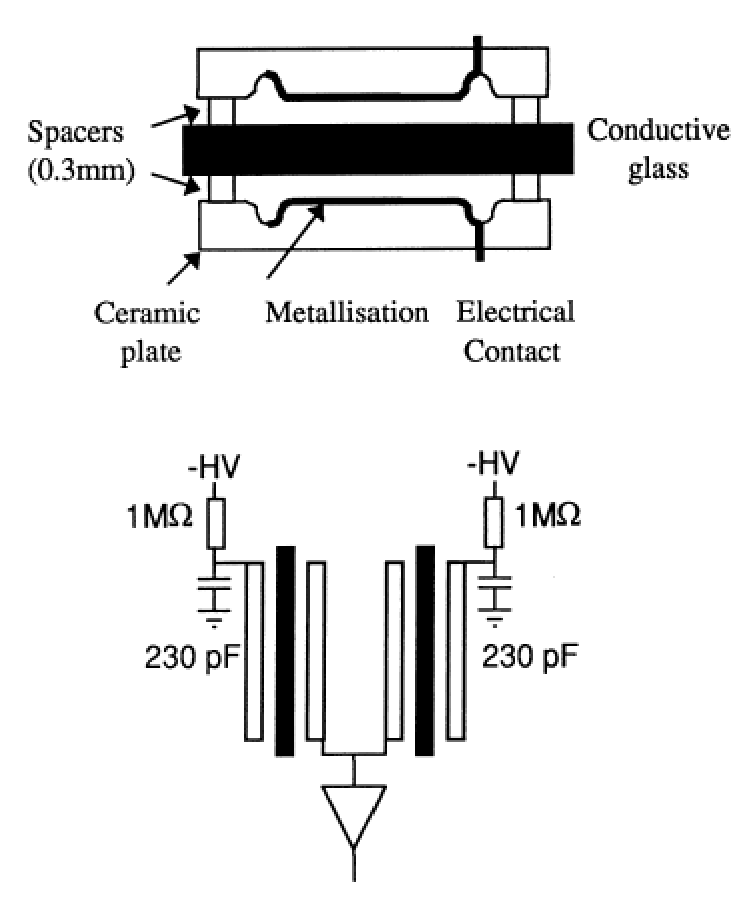
DRPC

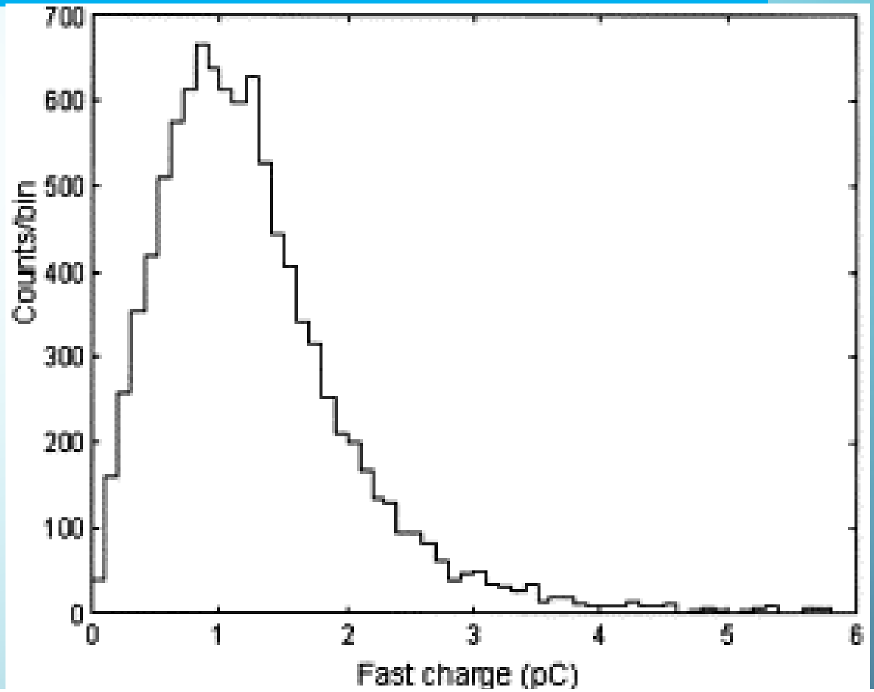
Local quenching

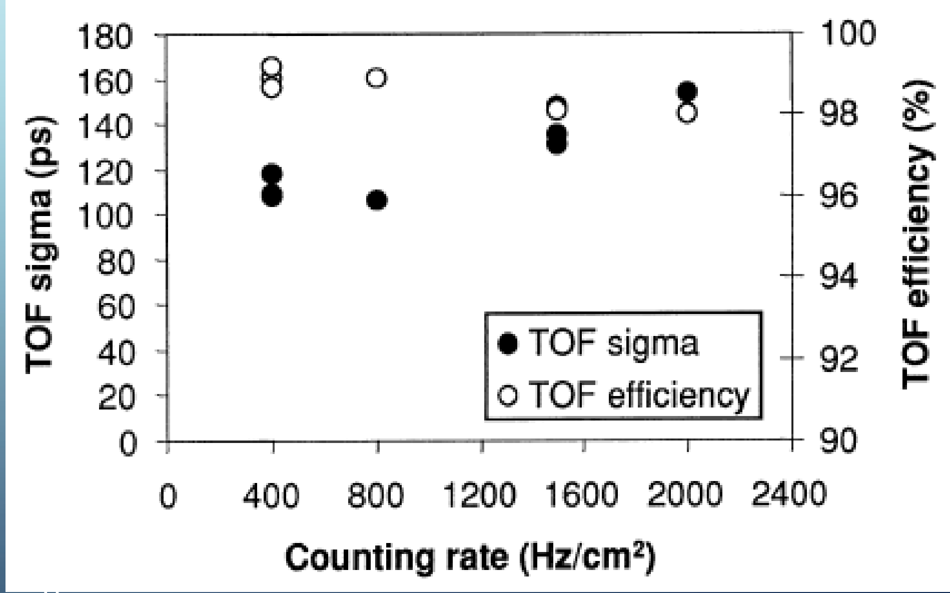
$E=(U-\langle I\rangle R)/d$



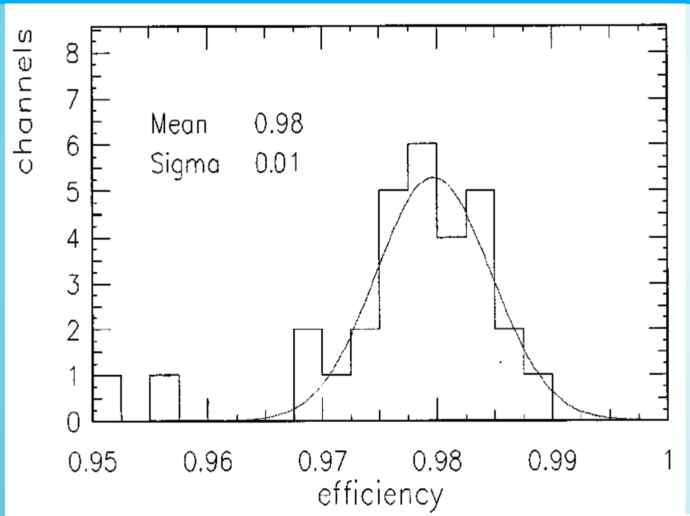
Вариант РППК(P. Fonte) для системы для ALICE-TOF

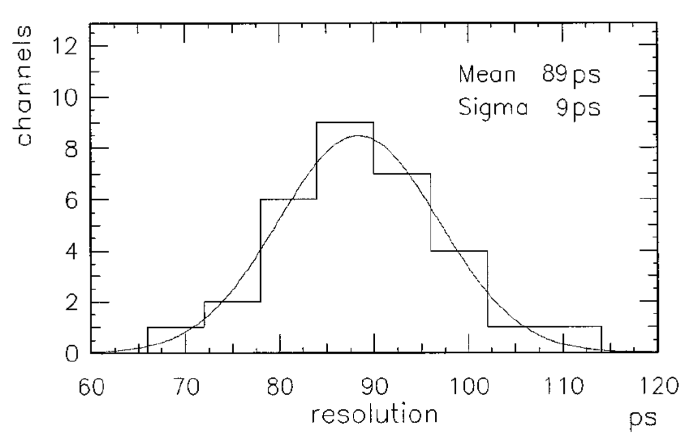


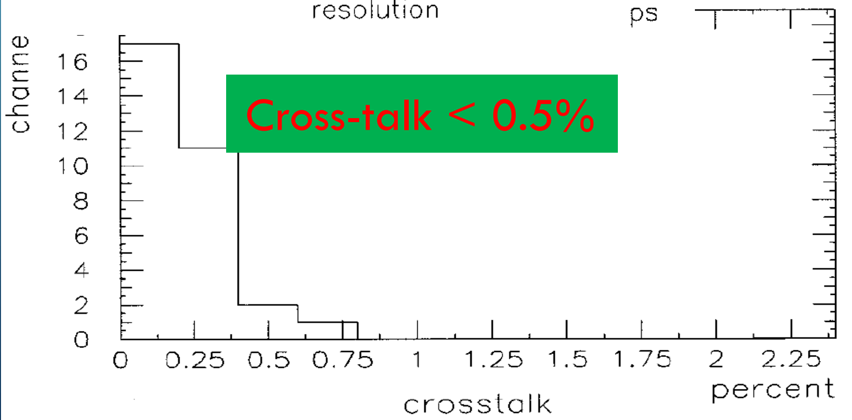


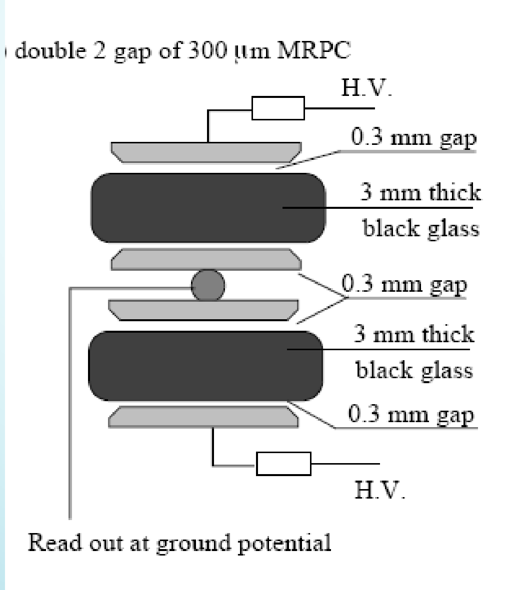


SINGLE CELL MODULE WITH DOUBLE GAP RPC (ITEP + COIMBRA +CERN)

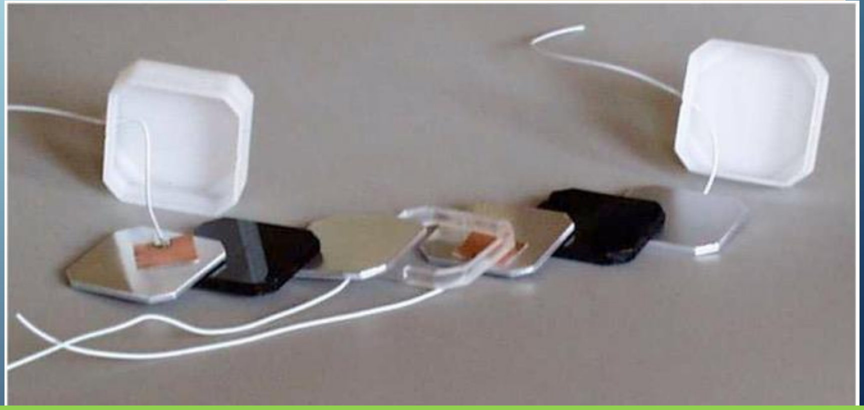






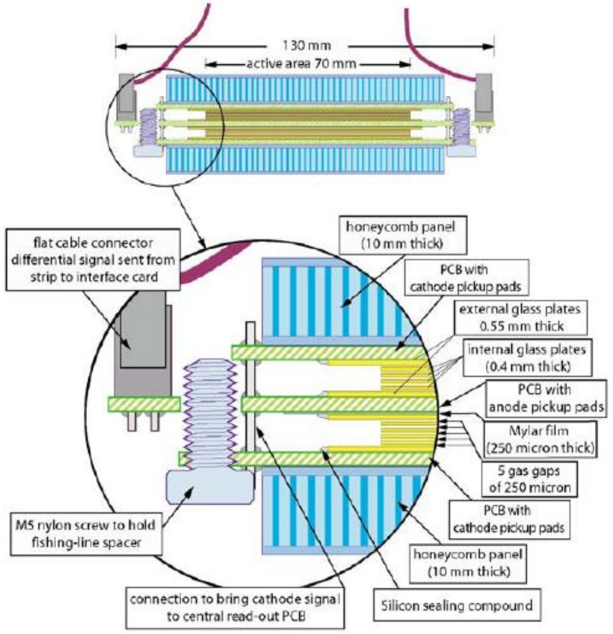


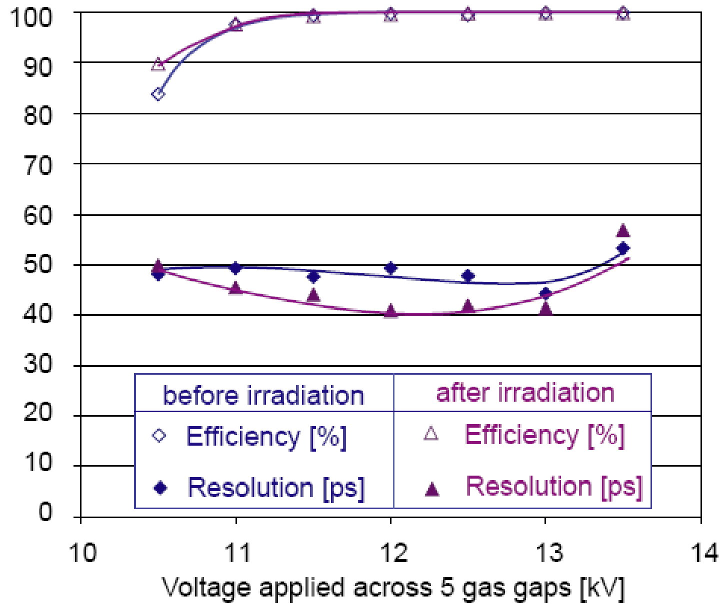
Single cells 4 gaps

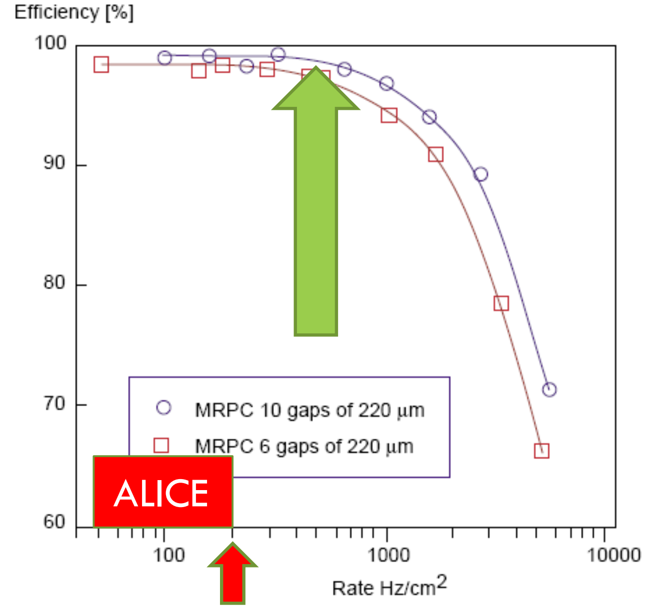


A. Akindinov, P. Fonte, F. Formenti, et al., IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 48, NO. 5, pp. 1658-1663, 2001

Bologna design for ALICE TOF







Float glass
~10^{13} Ohm*cm

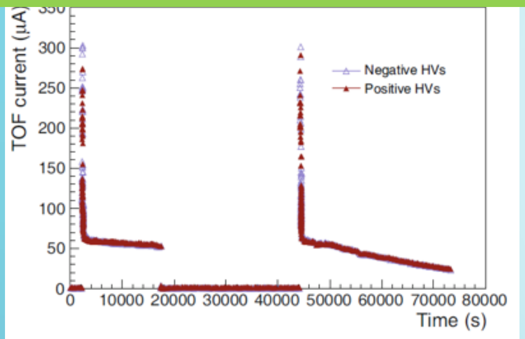



Creation of new technology and its adaptation for mass production
The detector is recognized as the main technological success of the ALICE collaboration

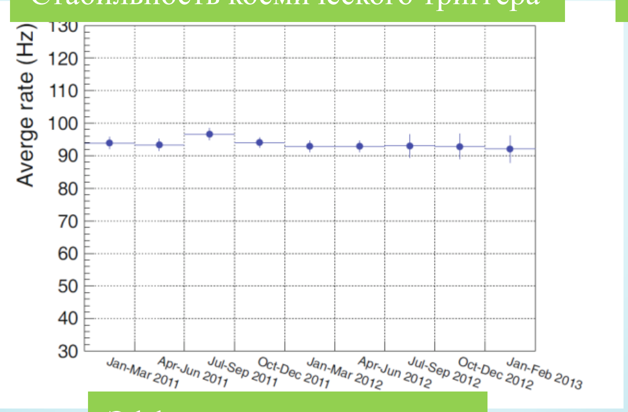
Performance of the ALICE Time-Of-Flight detector at the LHC

ITEP

Величина тока системы в течение набора

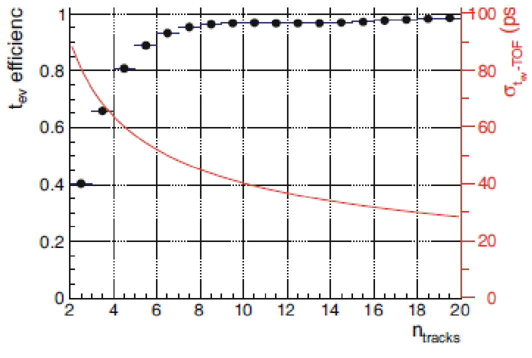


Стабильность космического триггера

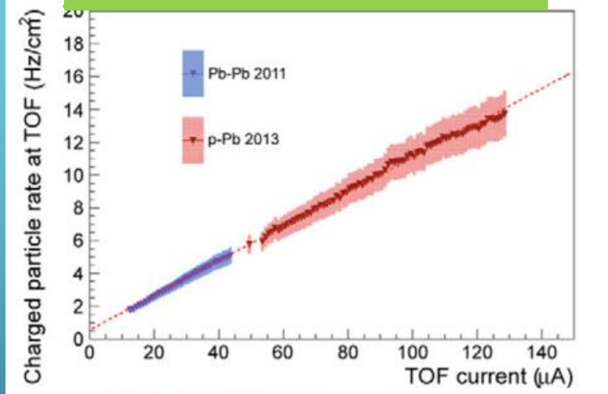


Стартовое время и временное разрешение

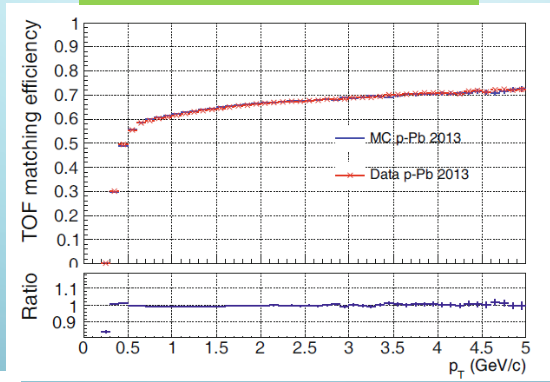
$$\chi^2 = \sum_{n_{\mathrm{tracks}}} \frac{((t_{\mathrm{TOF}} - t_{ev}) - t_{\mathrm{exp}}(m_i))^2}{\sigma^2_{\mathrm{TOF}} + \sigma^2_{t_{\mathrm{exp}}}},$$

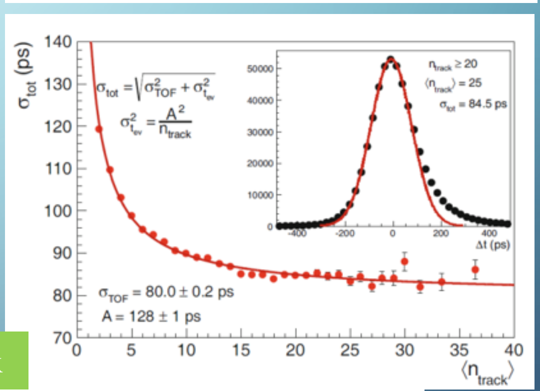


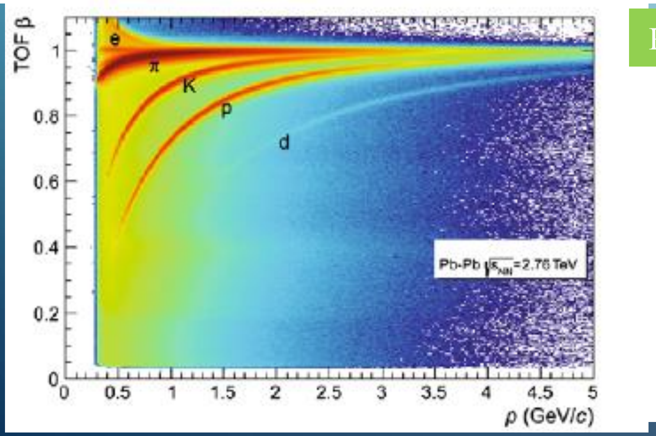
Величина тока и величина счета



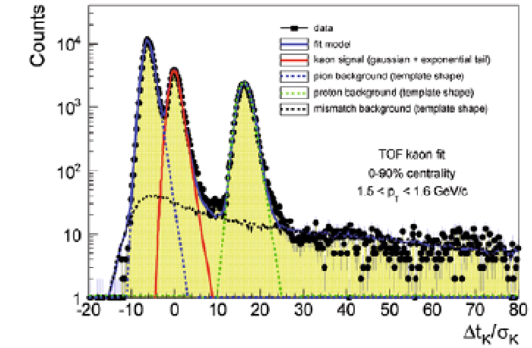
Эффективность детектора

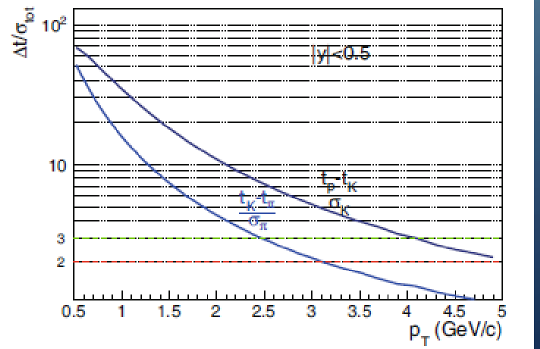






Разделение частиц в ион-ионных столкновениях



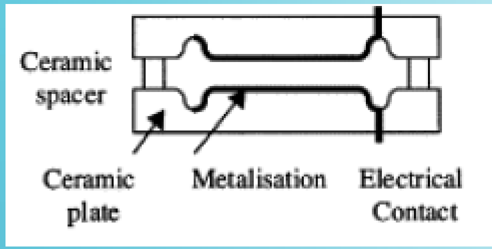


Some remarks about detector design and output charge.

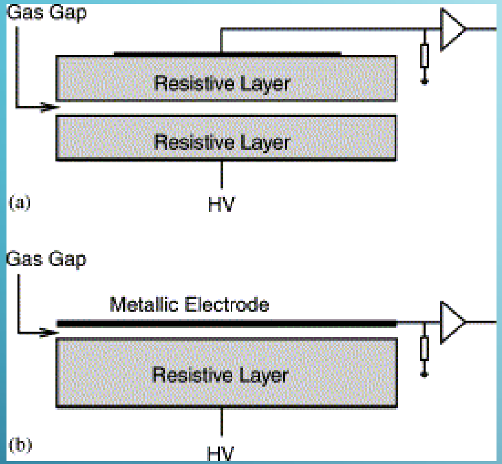
Detector design and output charge

$$i(t) = \frac{\vec{E}_w * \vec{v}_{dr}}{V_w} * q(t)$$

ε – The dielectric constant
d – Gap size
s – Resistive electrode thickness



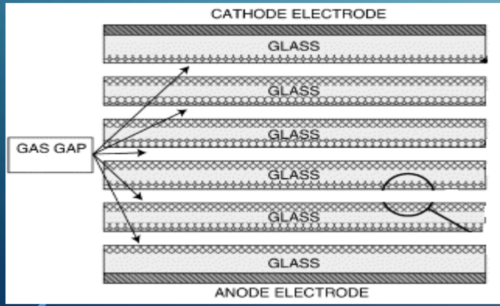
$$\left|\frac{\vec{E}_w}{V_w}\right| = \frac{1}{d}$$



$$\left|\frac{\vec{E}_w}{V_w}\right| = \frac{1}{d} * \frac{\varepsilon d/s}{\varepsilon d/s + 2}$$

$$\left|\frac{\vec{E}_w}{V_w}\right| = \frac{1}{d} * \frac{\varepsilon d/s}{\varepsilon d/s + 1}$$

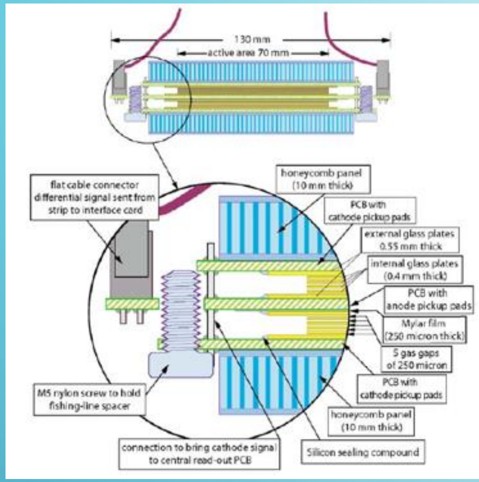
Resistive material	ε	d	s	ε*d/s
Glass	5	0.3	1	5/3
Bakelite	5	0.3	2	5/6
Ceramic	11	0.3	1	11/3

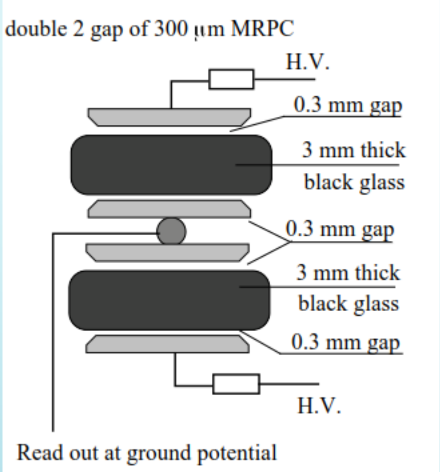


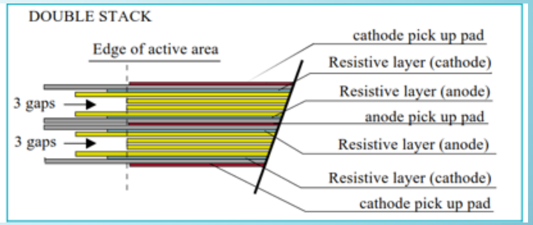
$$\left|\frac{\vec{E}_w}{V_w}\right| = \frac{1}{d} * \frac{\varepsilon d/s}{\varepsilon d/s + (n+1)}$$

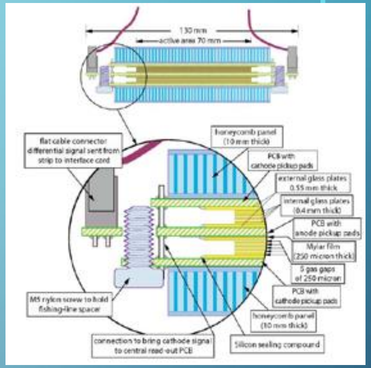
$$q = \sum_{i=1}^{n} Q_{1gap}^{i} * \left|\frac{E_w}{V_w}\right| = Q_{1gap} * \frac{\varepsilon d/s}{\varepsilon d/s + (n+1)} * n$$

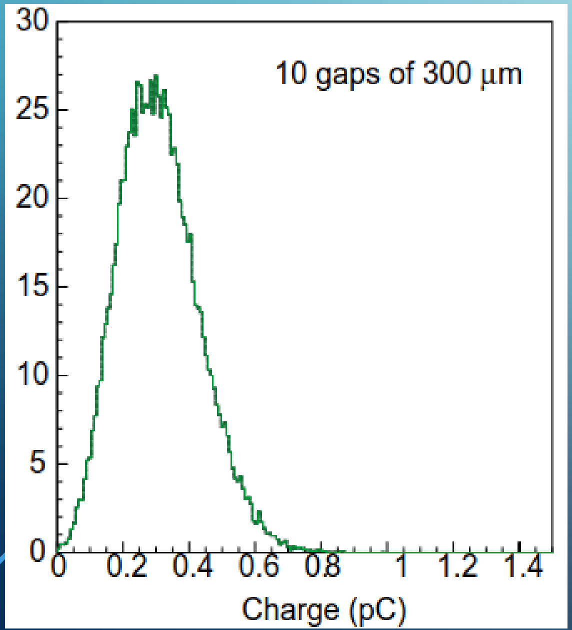
Fast charge comparison for different constructions and gap number

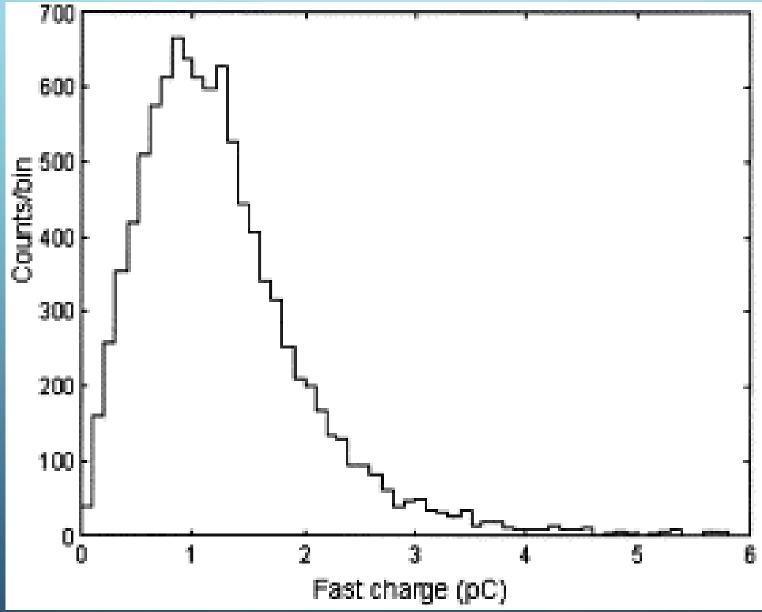


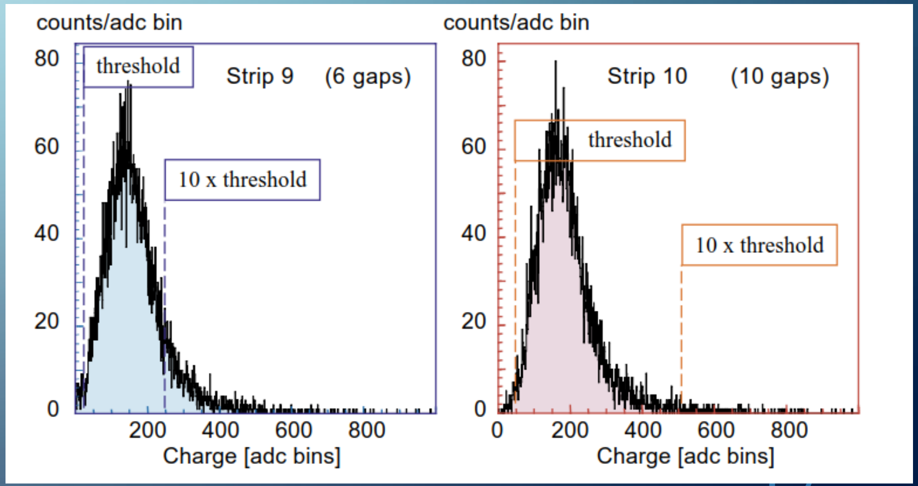






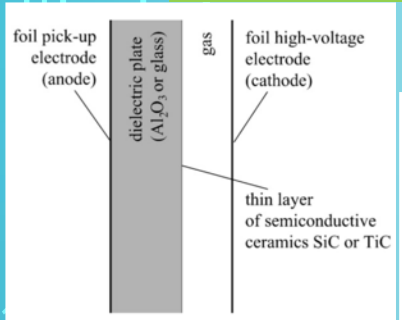


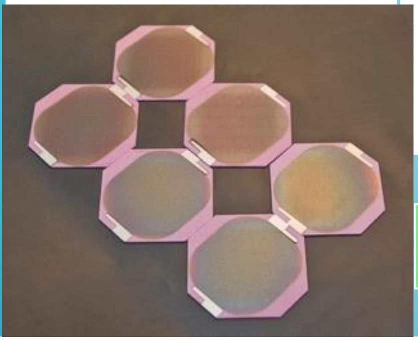




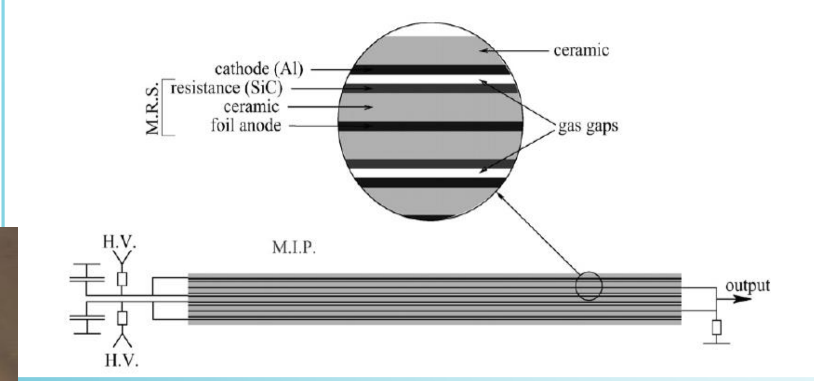
Key point for high-rate RPC – new low resistive material with high surface quality

New Low resistive Material Search

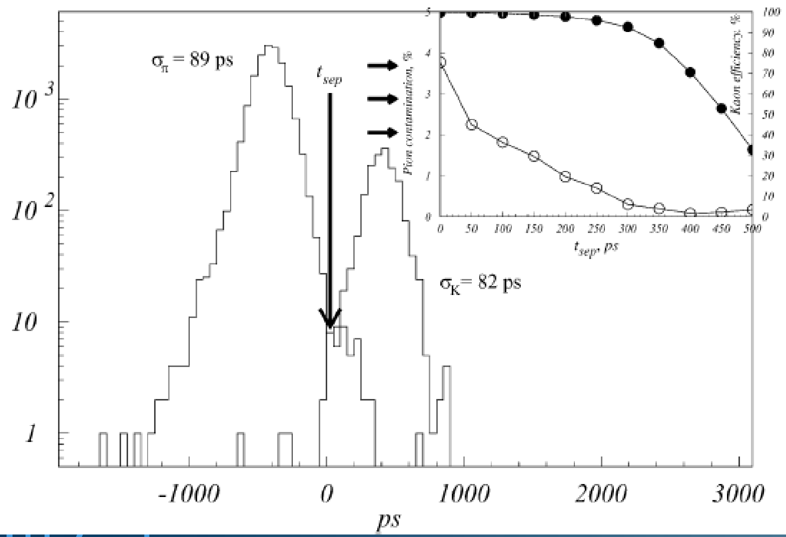


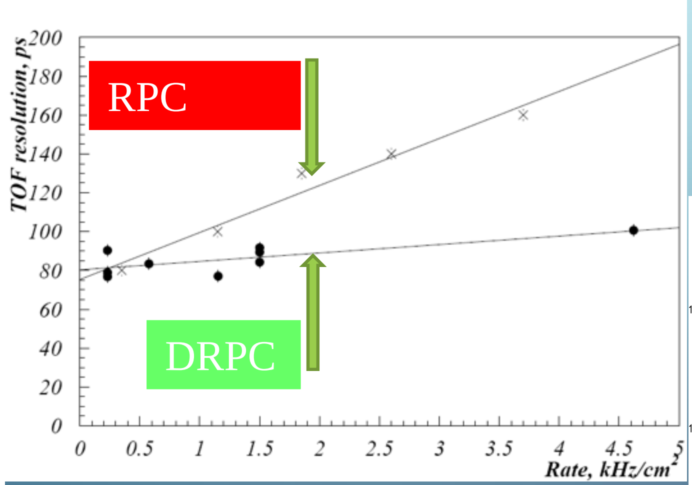


Ceramic



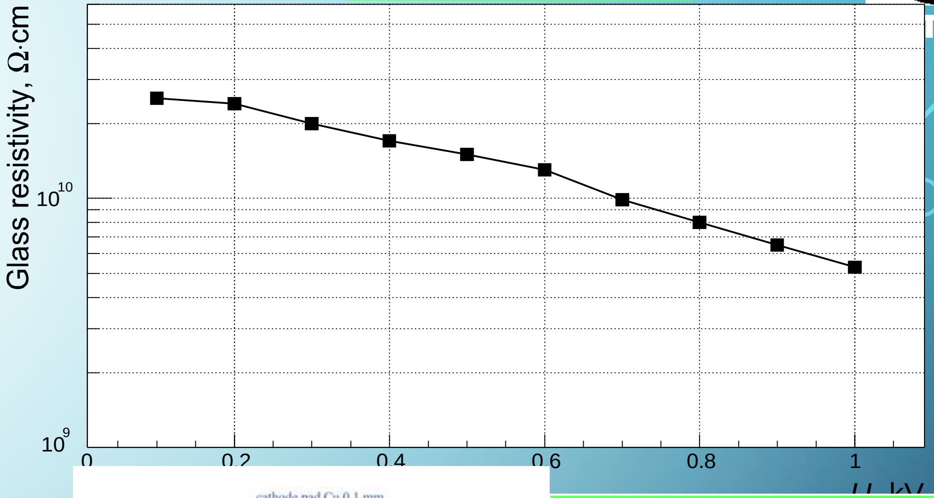
4 gaps (300 μm) ρ= 10^{11} Ohm/□ SiC

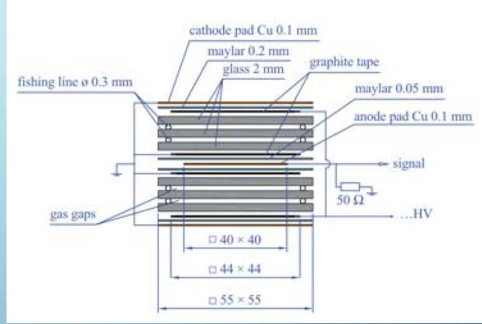




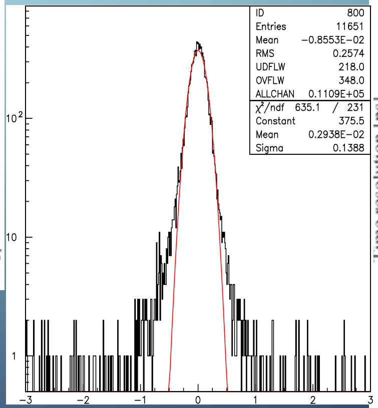
A. Akindinov, V. Golovine, A. Martemianov, et al., Nucl. Instr. and Meth. A 494 (2002) 474-479

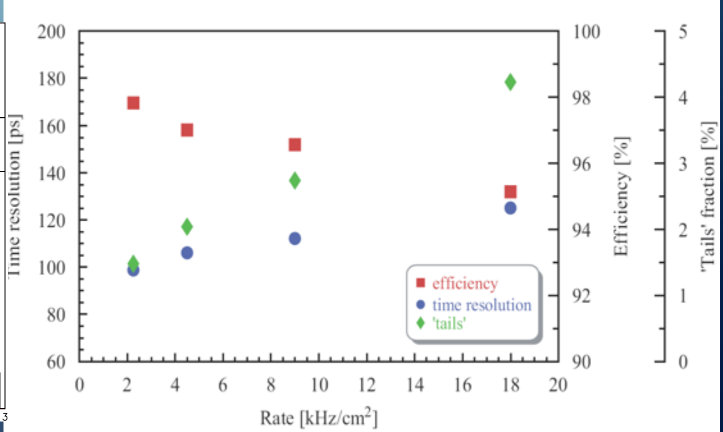
Phosphate glass





4 gaps (300 μm) ρ= 3*10^{10} Ohm*cm

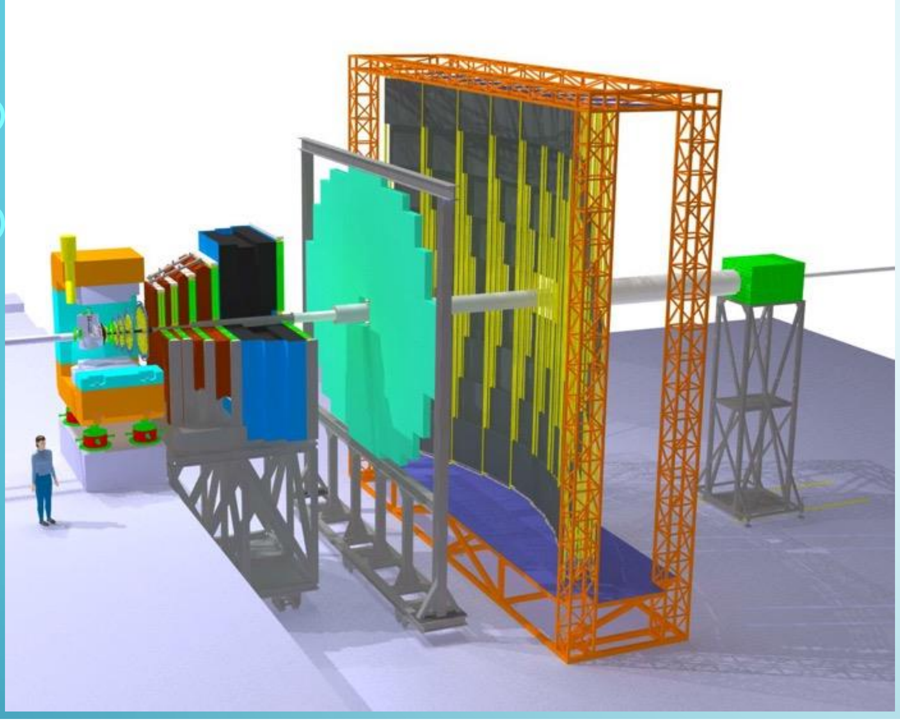


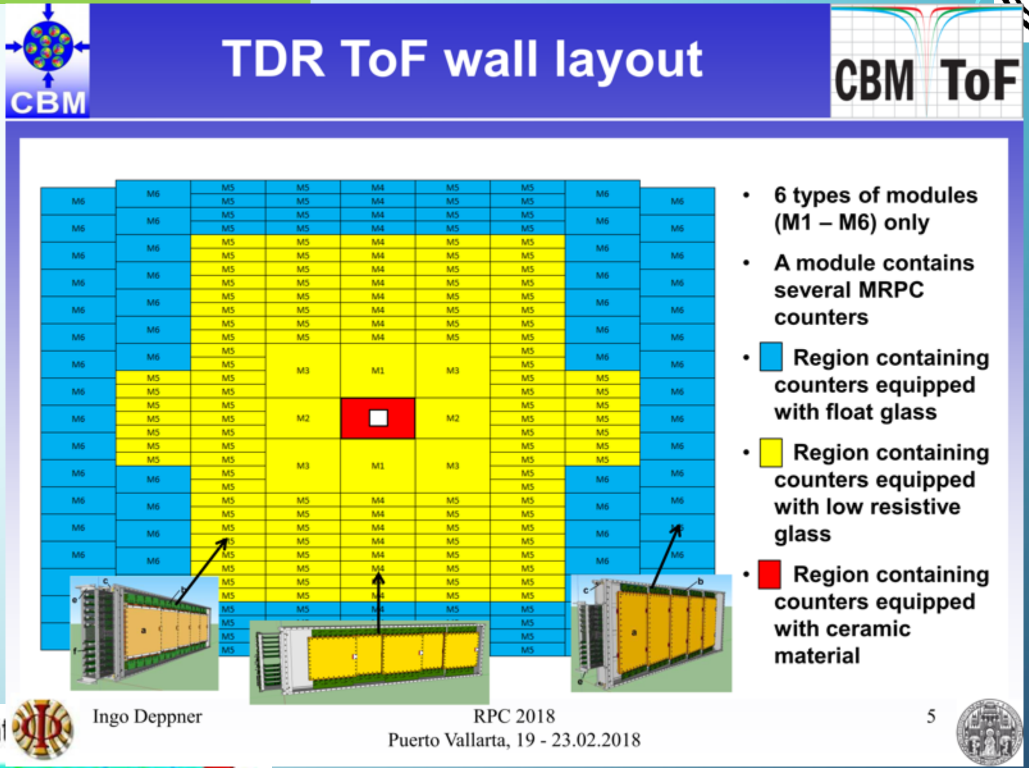


A. Akindinov, V. Ammosov, V. Gapienko, et al., Nucl. Instr. and Meth. A 572 (2007) 676-681

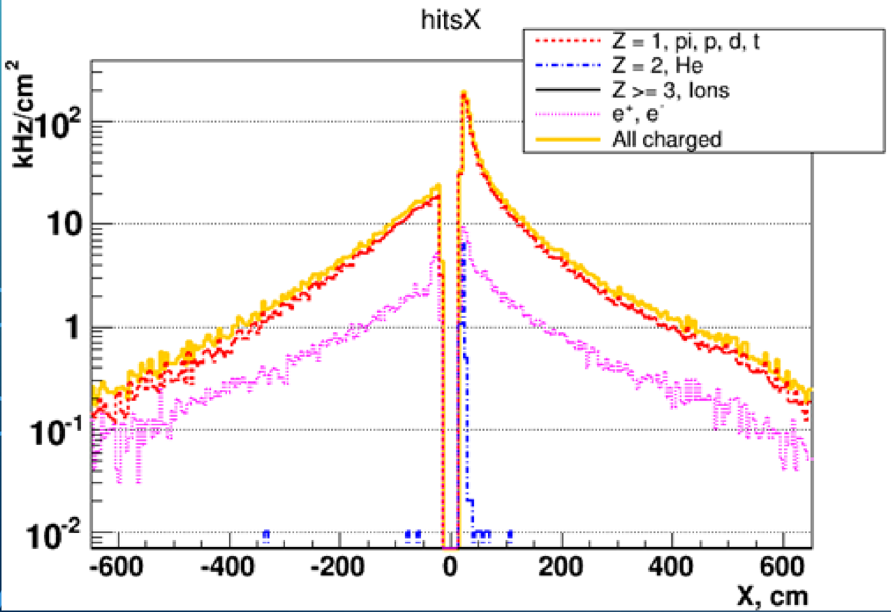
CMB TOF R&D results for semiconductive ceramics and low resistive glass

CBM TOF

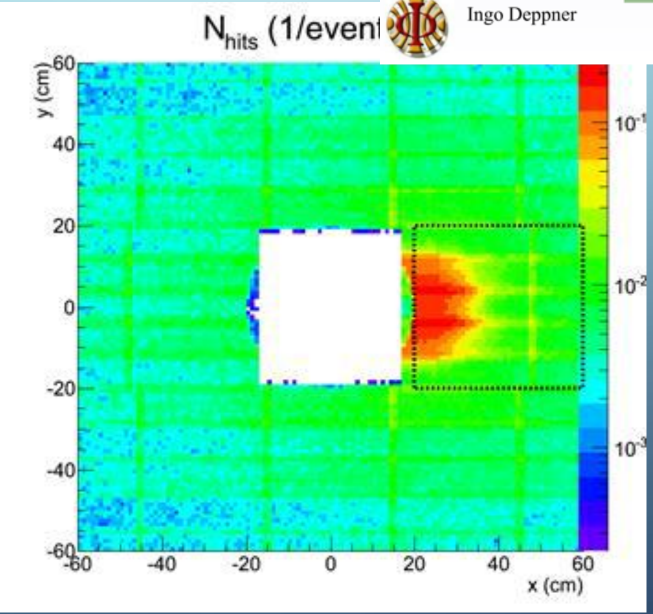




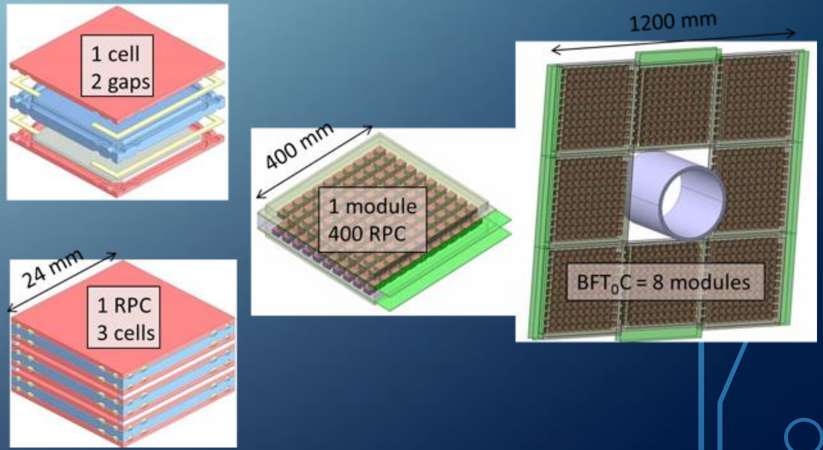
CBM
TDR ToF wall layout
CBM ToF
6 types of modules (M1 – M6) only
A module contains several MRPC counters
Region containing counters equipped with float glass
Region containing counters equipped with low resistive glass
Region containing counters equipped with ceramic material
Ingo Deppner
RPC 2018
Puerto Vallarta, 19 - 23.02.2018
5



hitsX
Z = 1, pi, p, d, t
Z = 2, He
Z >= 3, Ions
e⁺, e⁻
All charged
kHz/cm²
X, cm



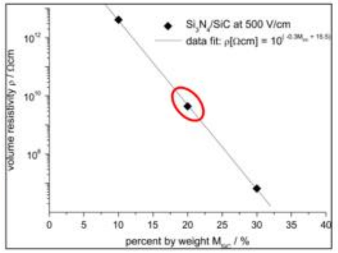
Nhits (1/event
y (cm)
x (cm)



1 cell
2 gaps
24 mm
1 RPC
3 cells
400 mm
1 module
400 RPC
1200 mm
BFT₀C = 8 modules

Si_3N_4/SiC ceramic

- Size ≤ 20 x 20 cm²
- Thickness d = 2 mm
- Thickness uniformity 10 μm
- Surface roughness 100 nm
- Bulk resistivity $\rho = 10^7 - 10^{12}\ \Omega\cdot$cm
- Permittivity ε_r = 10 - 20
- Rad. hardness proved at $10^{13}\ n_{eq}$/cm²
- DC measurement (> 1 C/cm²) shows non-ohmic behavior



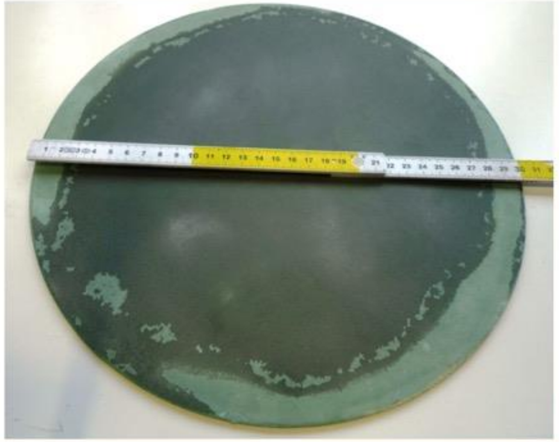
L. Naumann et al., NIM A 628 (2011) 138
A. Laso Garcia et al., JINST 7 (2012) 10012

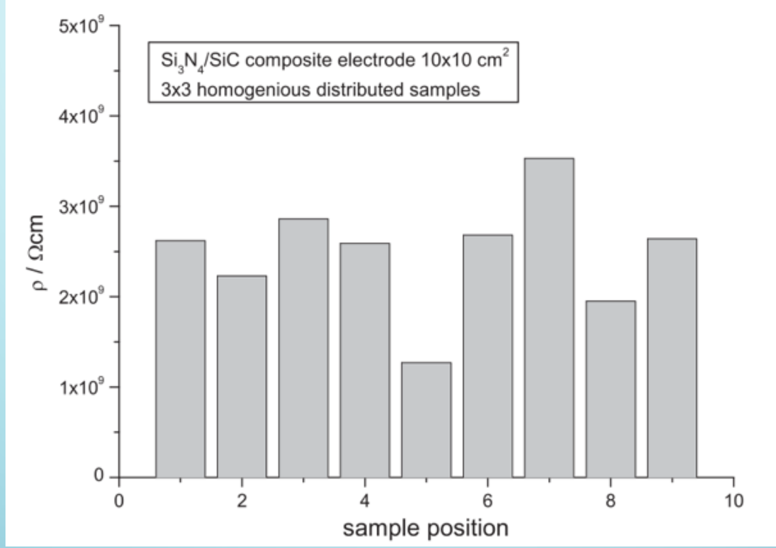
rough ceramics as sintered:

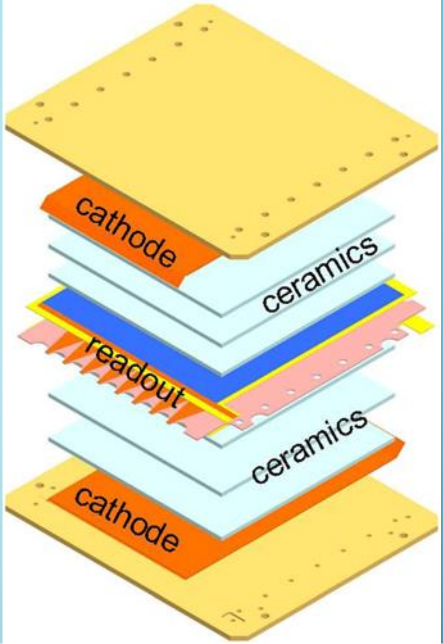
- Ø ≈ 30 cm
- d ≈ 3.5 mm

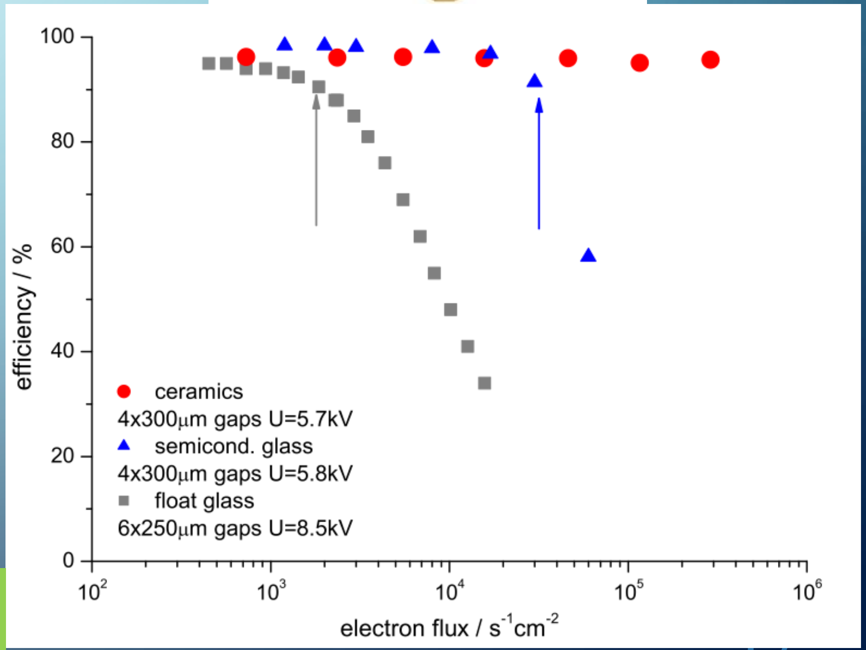
mixing ratio:

- Si_3N_4/SiC (80%/20%)







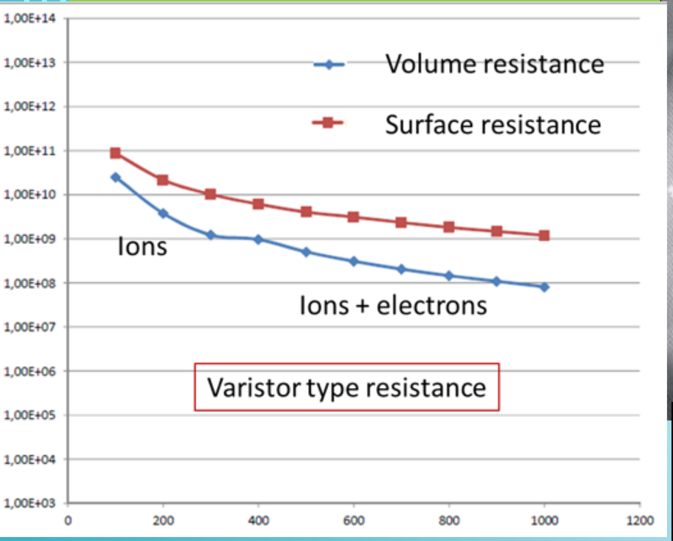


Four-gap device with 300 mm gas gaps. Resolution 110 ps for U=5.7 kV
!!!But very high level of dark current > 100 μA!!!

L. Naumann , R. Kotte, D. Stach, J. Wustenfeld Nuclear Instruments and Methods in Physics Research A 635 (2011) S113–S116

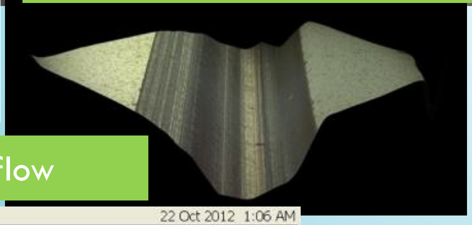
From 2012 joint group ITEP+HZDR (high current problem investigation)

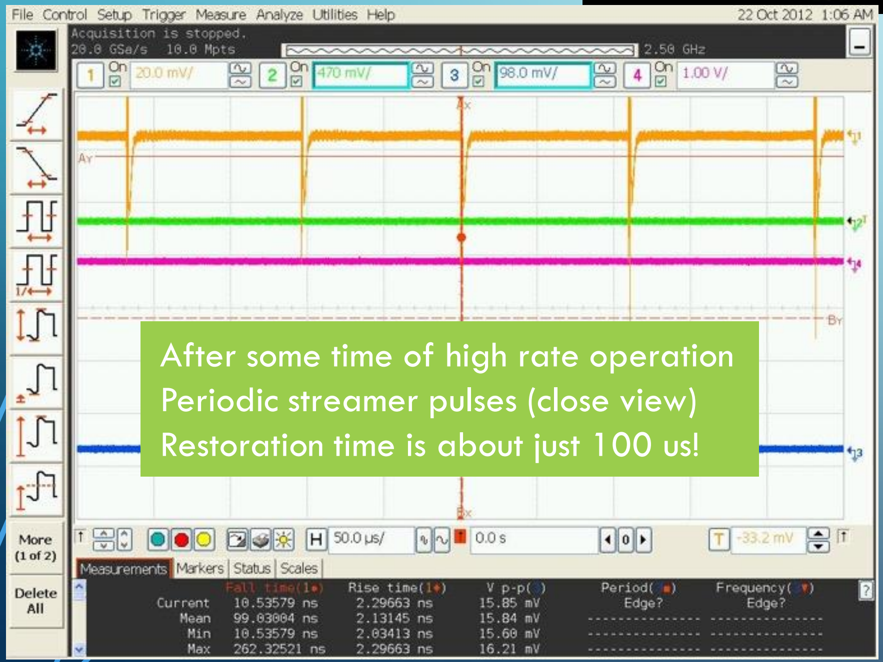
ITEP



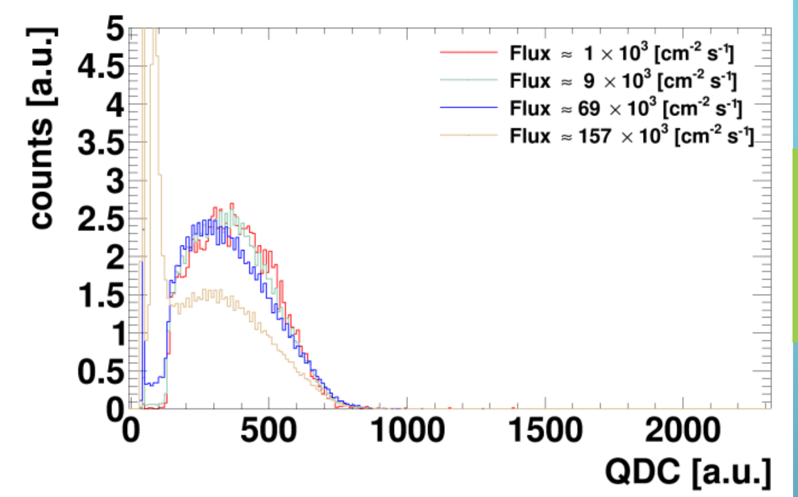
Proved to be stable after 2 C/cm^2 charge flow

One electrode with Rogowsky shape

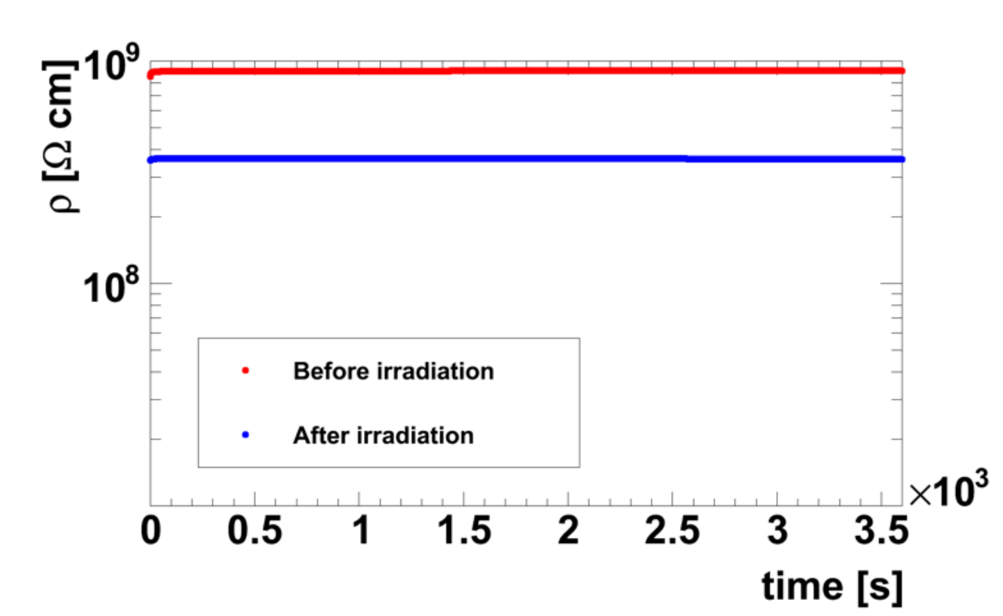




After some time of high rate operation
Periodic streamer pulses (close view)
Restoration time is about just 100 us!

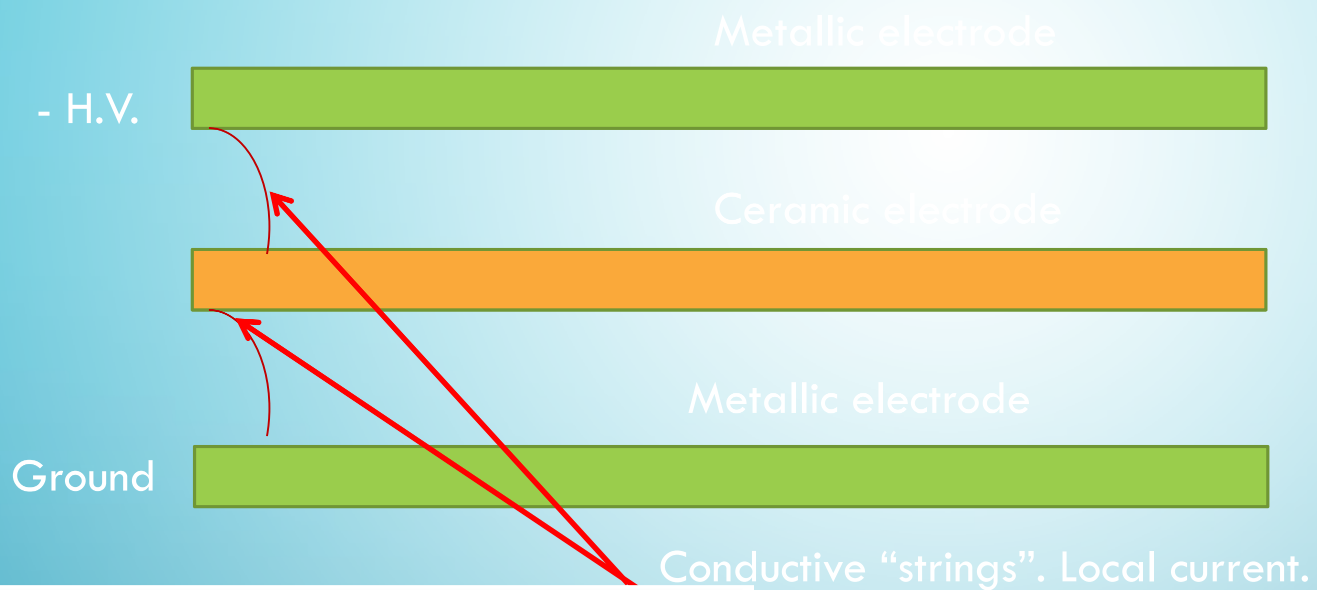


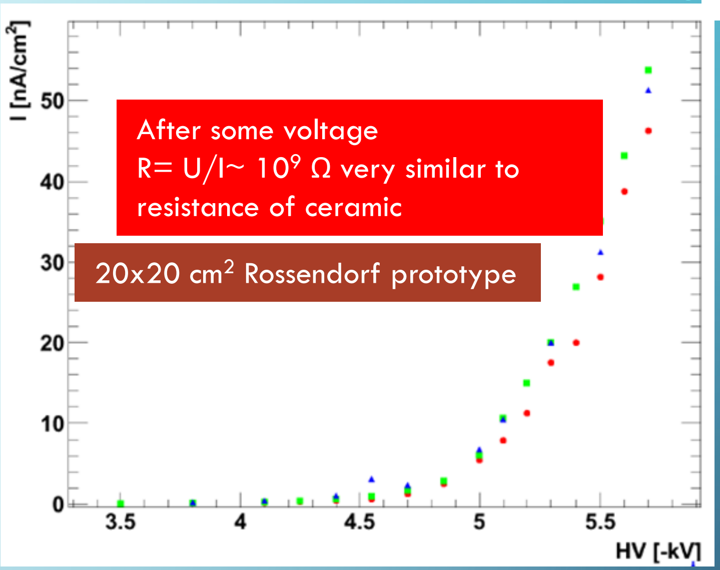
Small charge degradation was confirmed

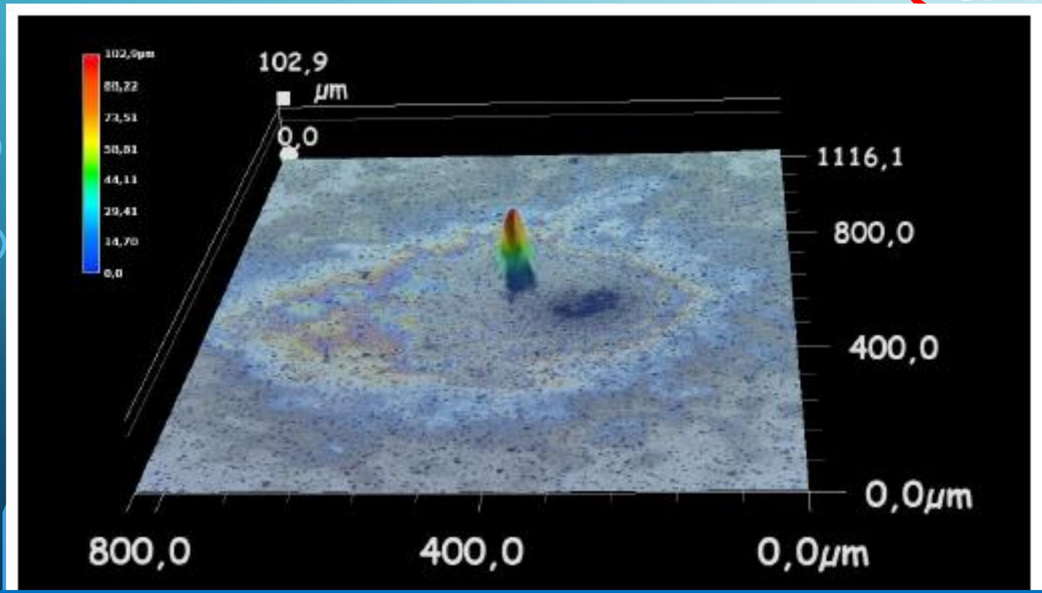


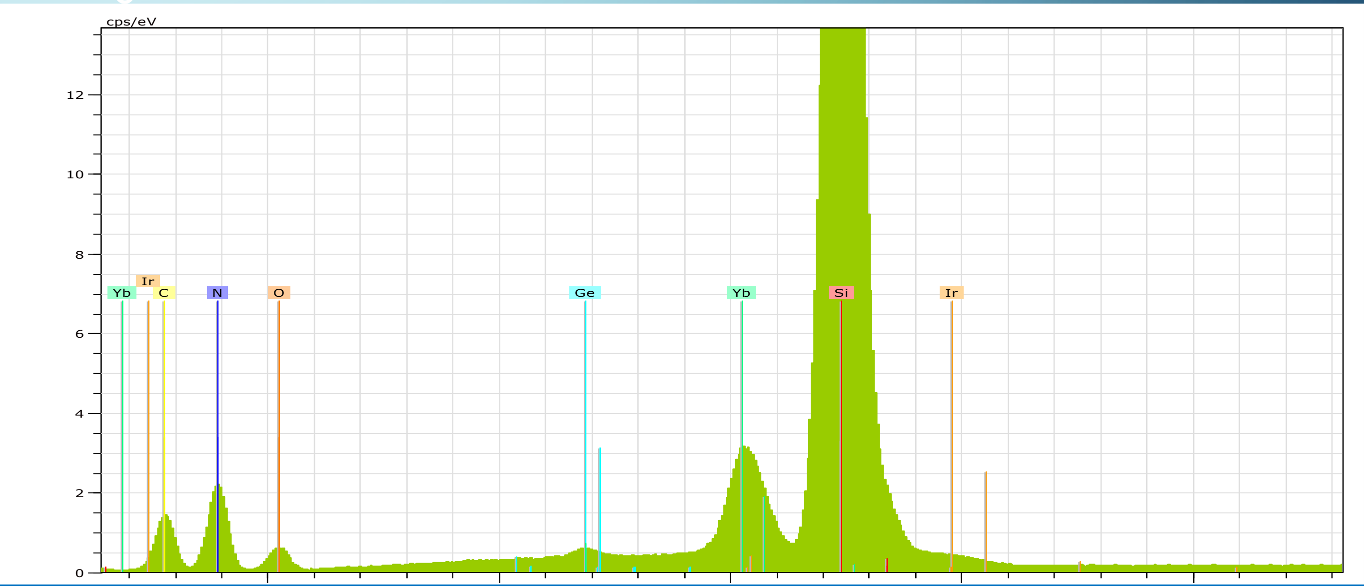
Two probes of low bulk resistive plates have been exposed to non-ionizing radiation doses in the order of 10^{13} n_{eq}/cm^2 at the neutron beam of MEDAPP at FRM II in Munich. The bulk resistivity of both probes was measured before and after the irradiation. A factor of 2 decrease of the bulk resistivity has been observed. This decrease has no impact on efficiency and time resolution. For the Al_2O_3 electrodes an irradiation with fluxes up to $10^{15}n_{eq}/cm^2$ is possible without any degradation of the detector performance.

Possible explanation for leakage current phenomenon





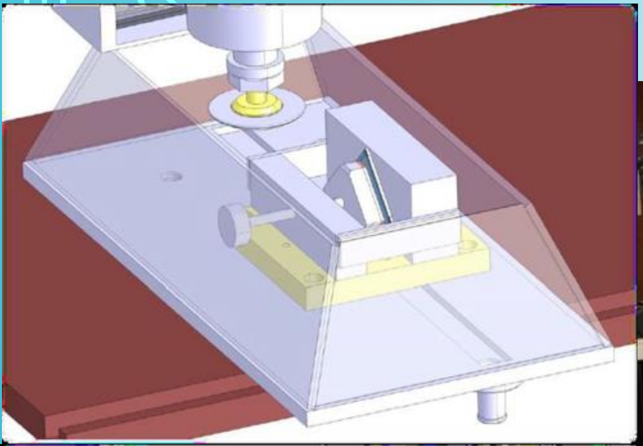


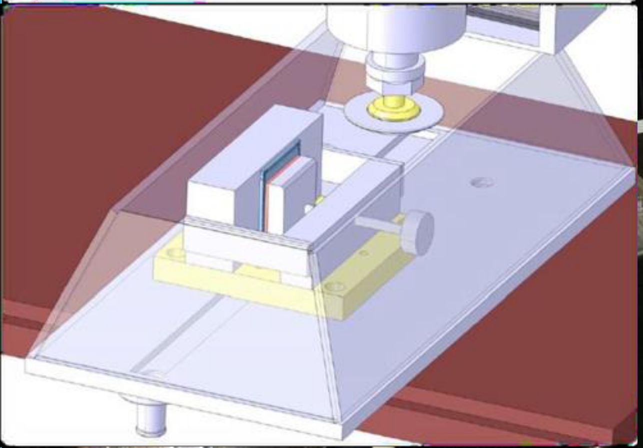


The 90%$C_2H_2F_4$/10%SF_6 or 95%$C_2H_2F_4$/5%SF_6 binary gas mixtures were used, since the formerly used iso-butane was found to be responsible for whisker formation (photo).

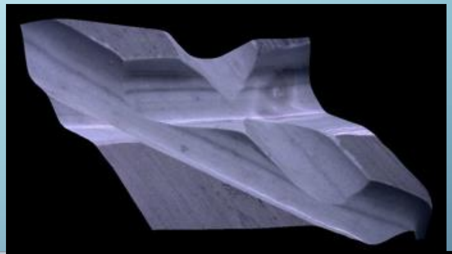
Reason is a few free carbon inside ceramics.

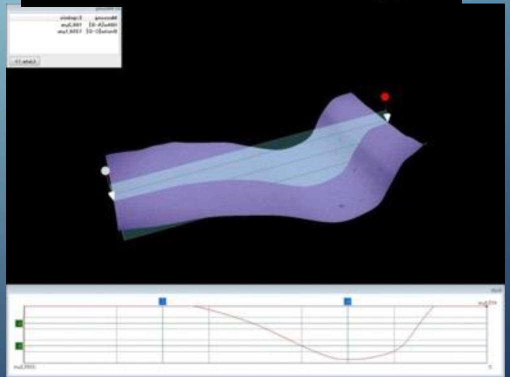
Improve of technology



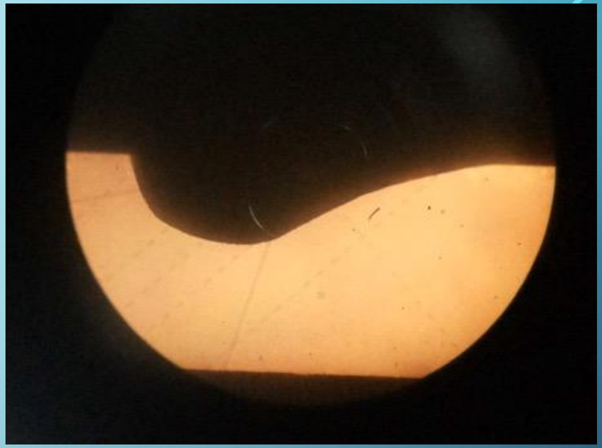


20 000 r.pm. rotation speed and 15 mm/min processing speed

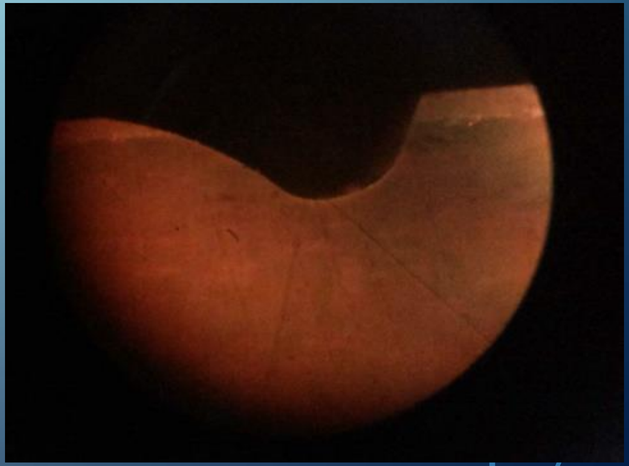




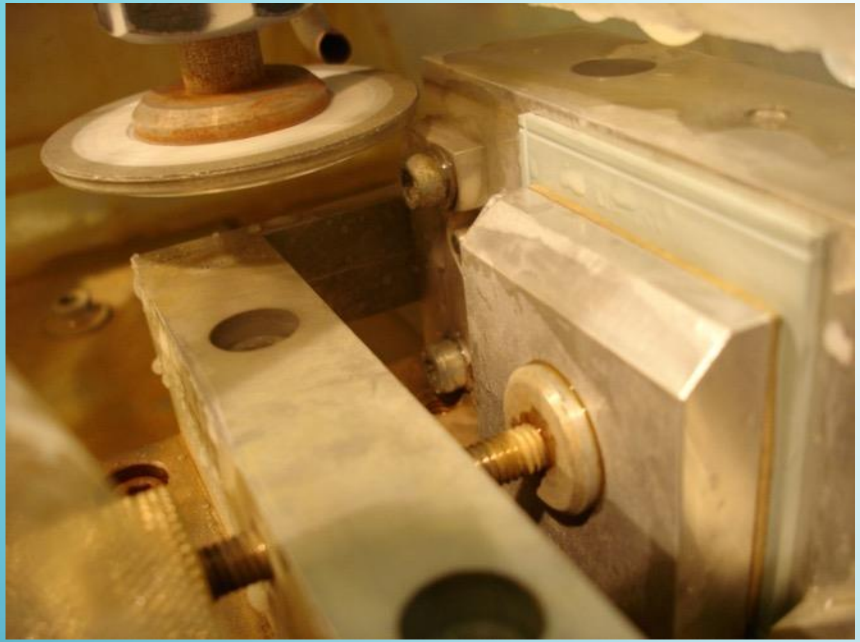
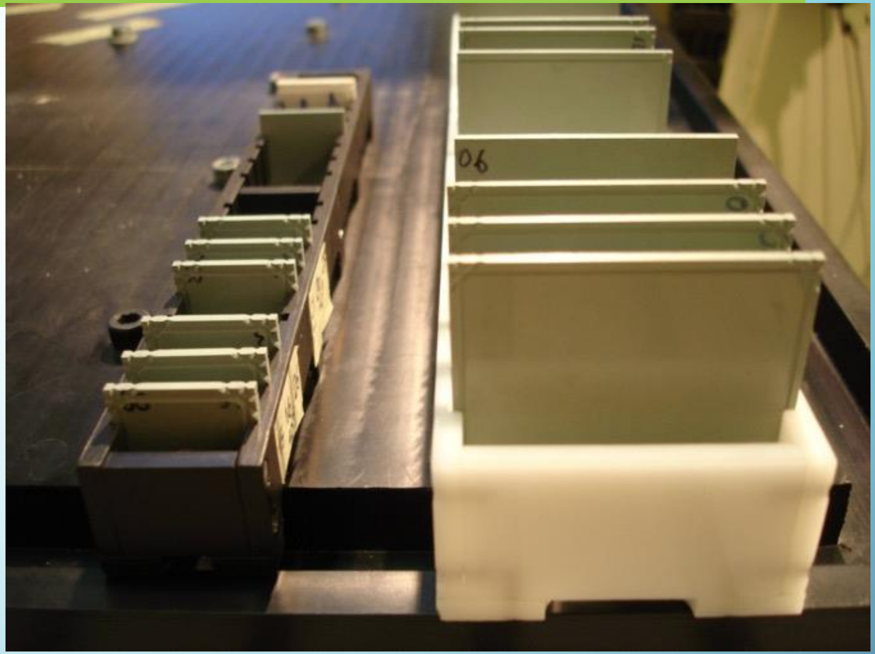
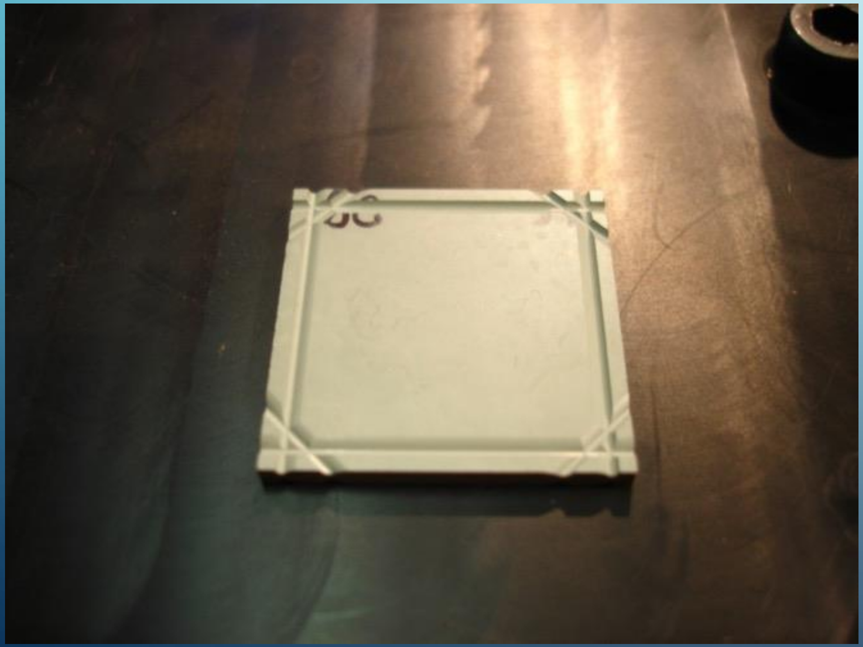
Al_2O_3



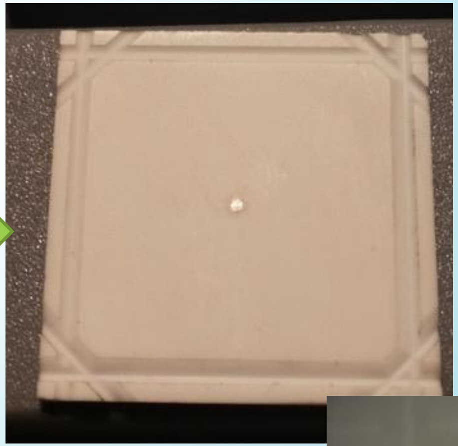
Si_3N_4/SiC

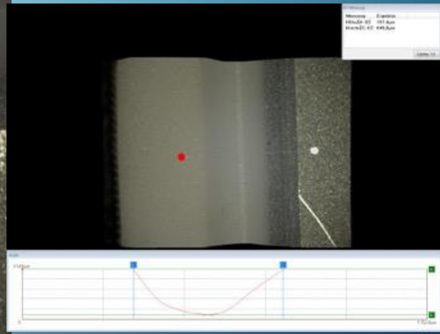


Rossendorf electrodes 24x24 mm^2 and 50x50 mm^2


New Al_2O_3 electrodes 24x24 mm^2(active size 20x20 mm^2)

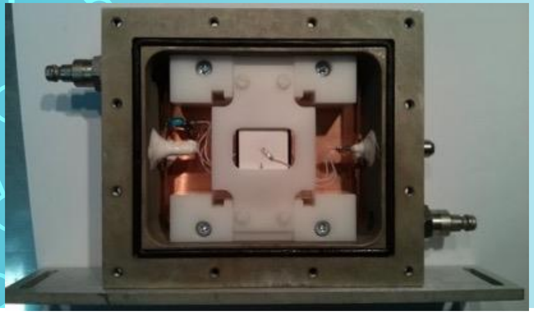




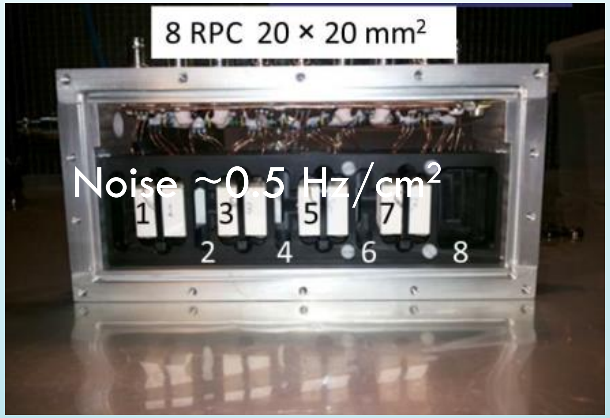
Al_2O_3 250 µm spacers

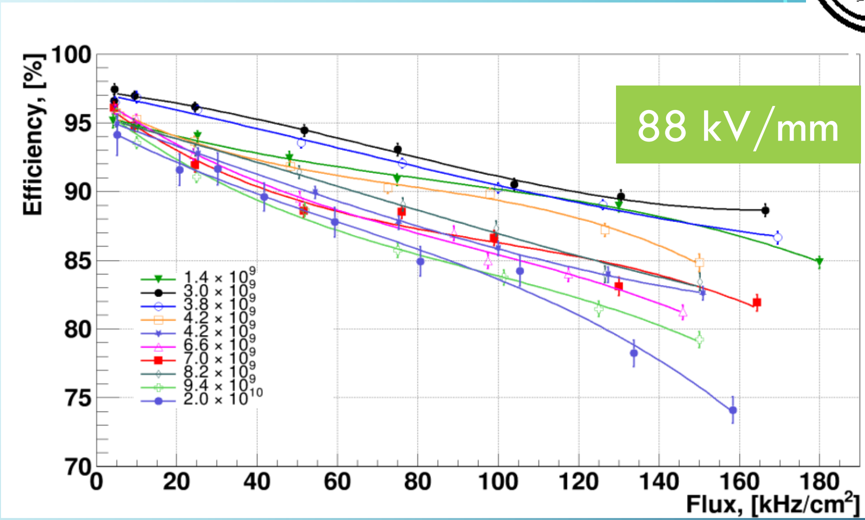
Search for optimal resistance using ceramic electrodes

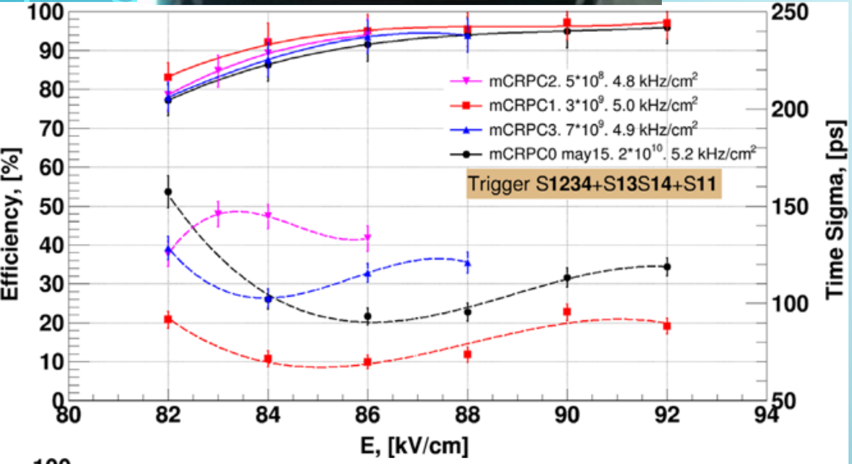
Search for minimal possible resistance

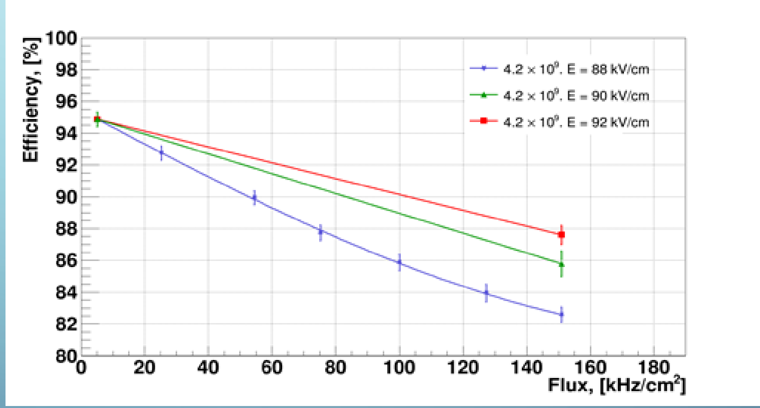


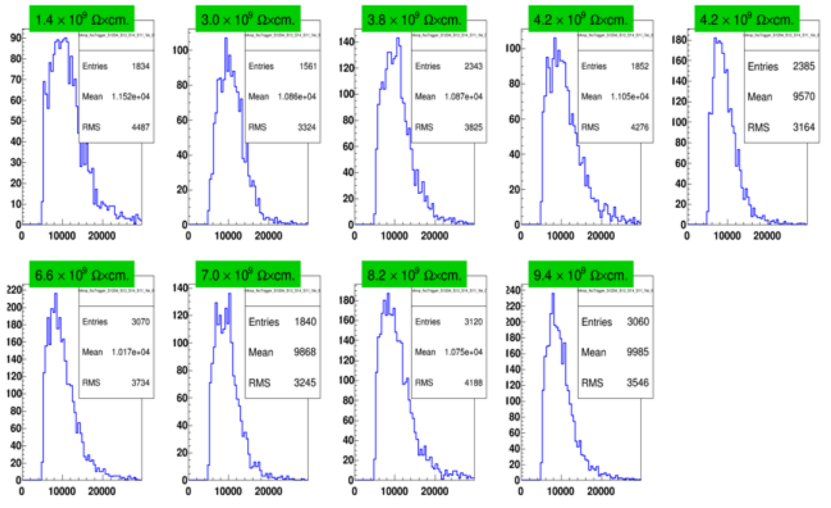
Measurements done with MAX3760

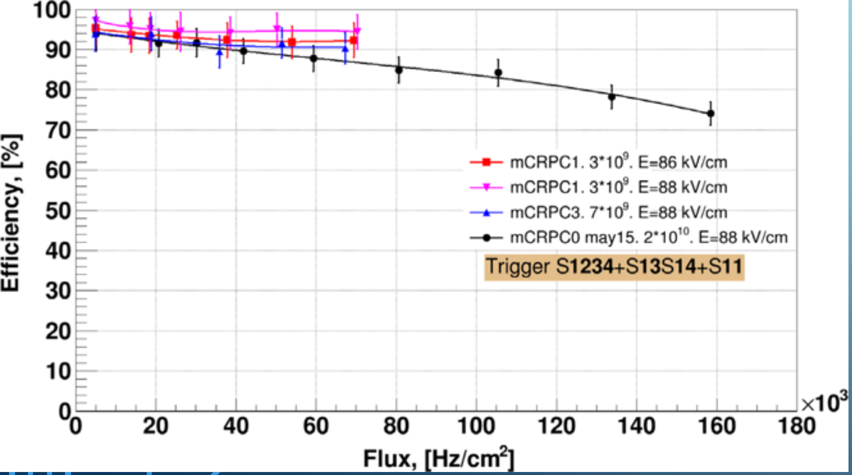












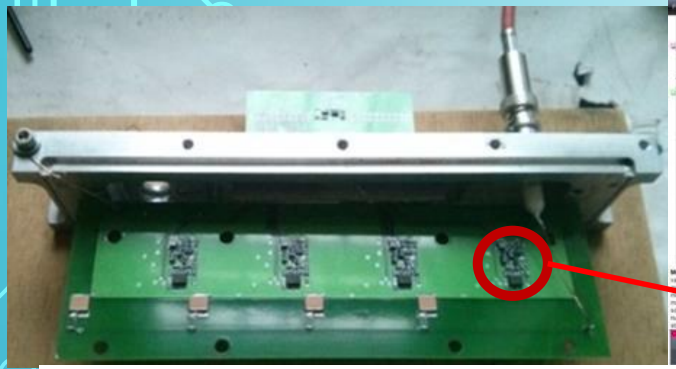
We selected value of resistance 4*10^9 Ohm*cm as minimal

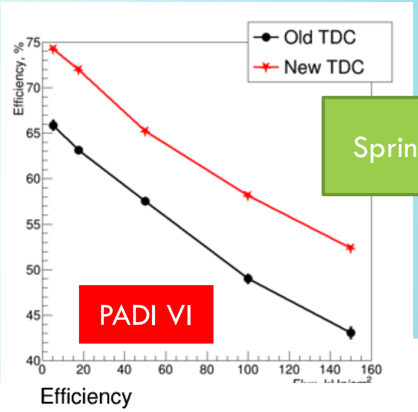
Nuclear Instruments and Methods in Physics Research A 845 (2017) 203–205

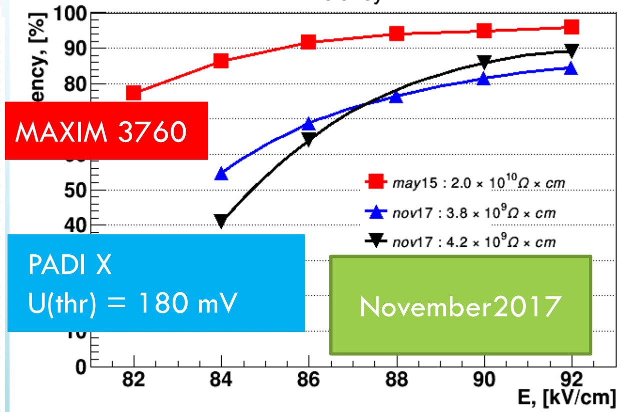
Journal of Physics: Conf. Series 798 (2017) 012136

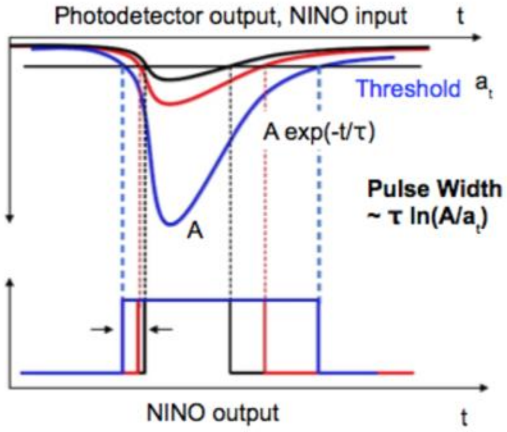
Tests with PADI electronics

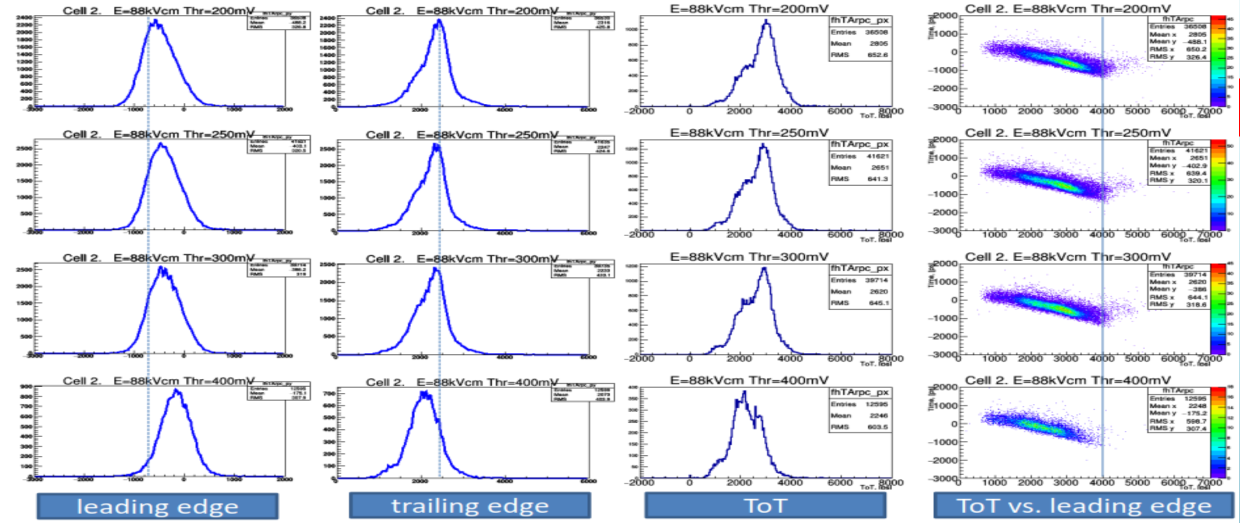
ITEP

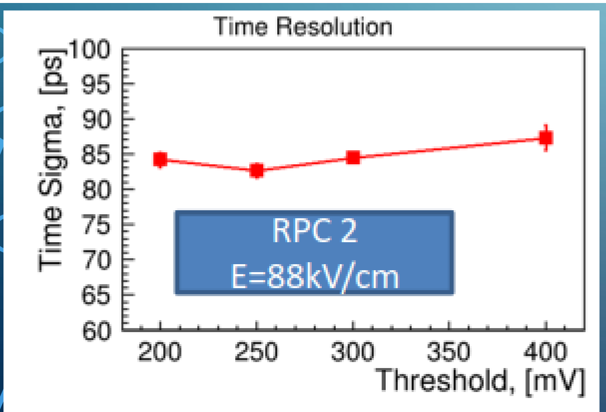


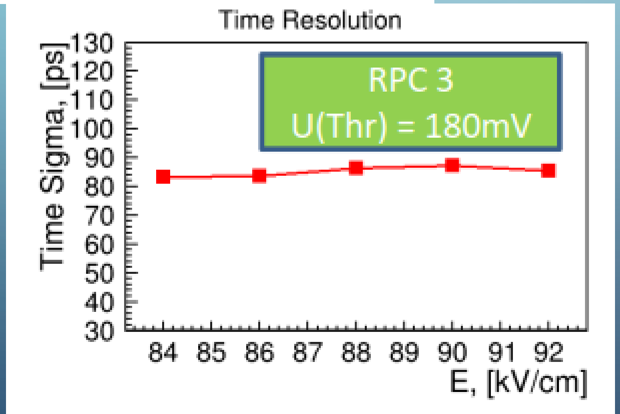


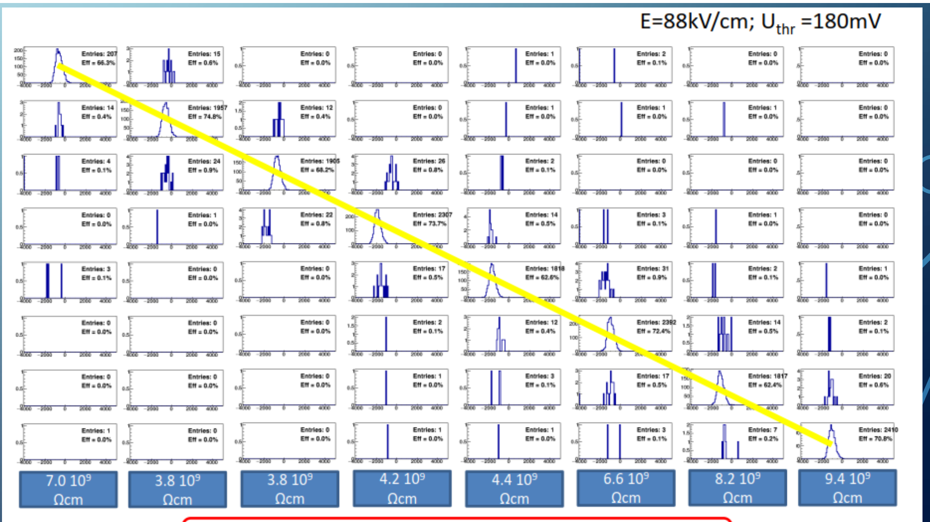










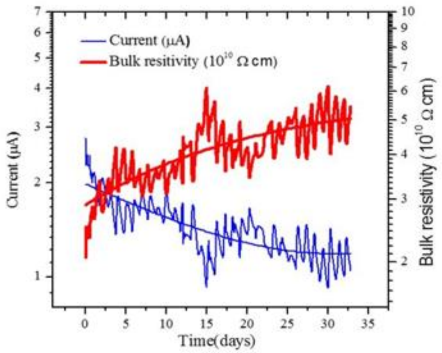


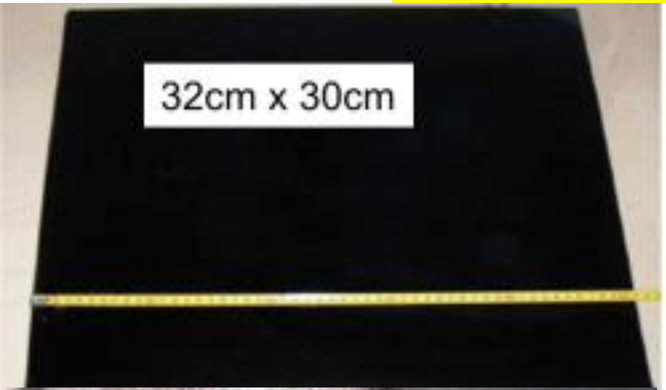
ToT cross-talk probability in all 8 RPCs ≤ 1.2%

Data with low resistive glass

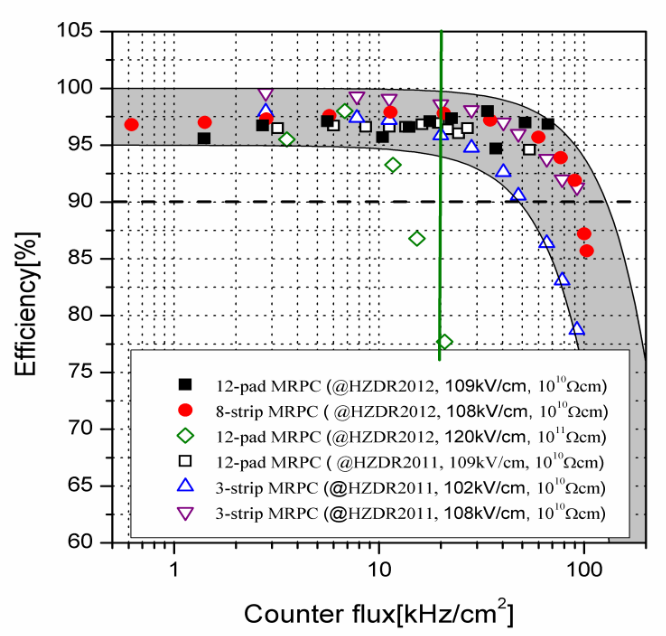
Resistive glass for high-rate MRPCs is developed in Beijing, China

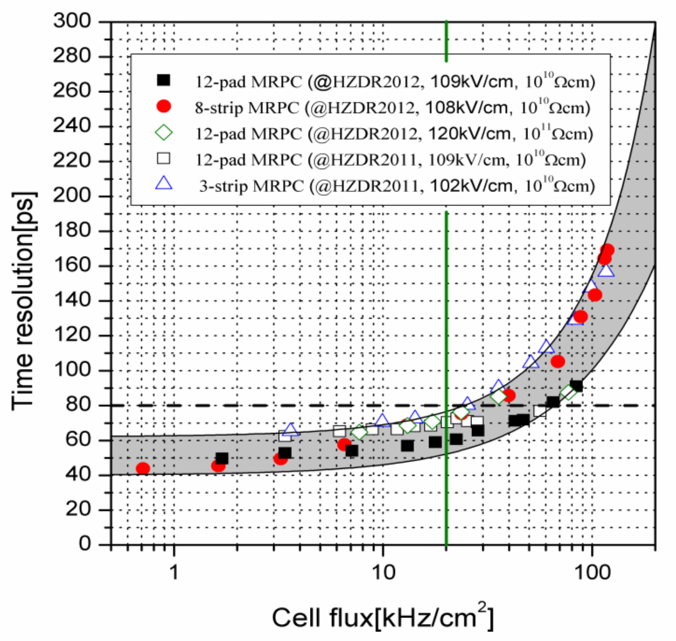
Maximal dimension	32cm × 30cm
Bulk resistivity	10^{10} Ωcm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20 μm
Surface roughness	< 10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic bebavior stable up to 1 C/cm^2





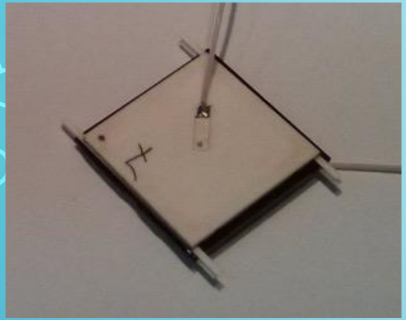
Raw resistive glass material for 400 m²

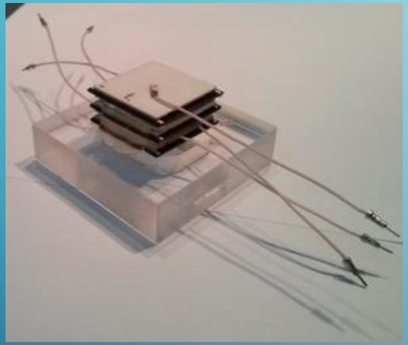


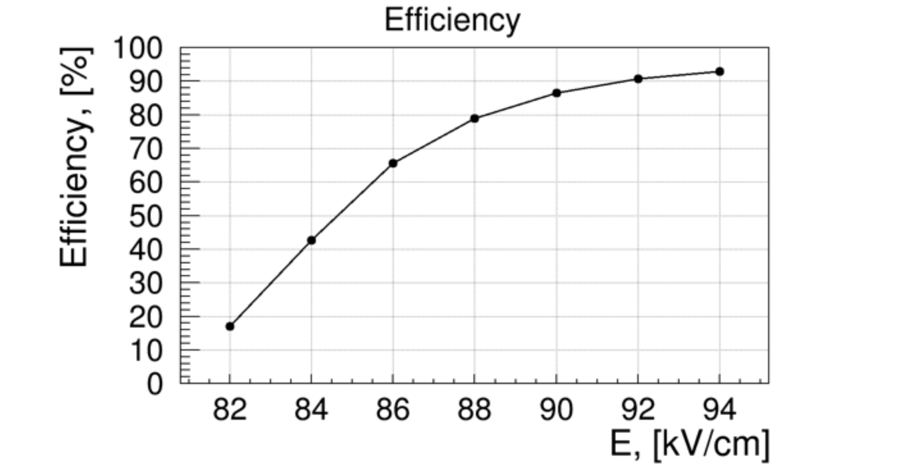


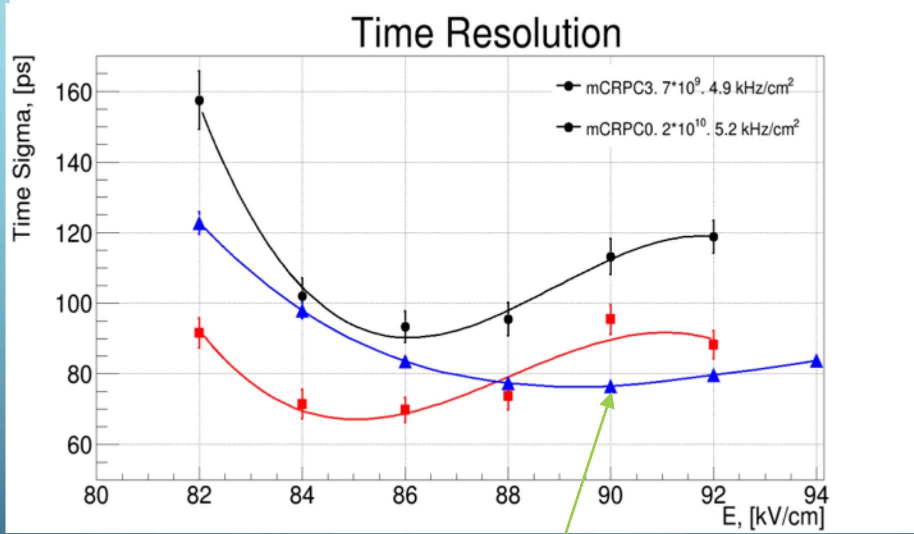
ITEP

Glass chamber control test

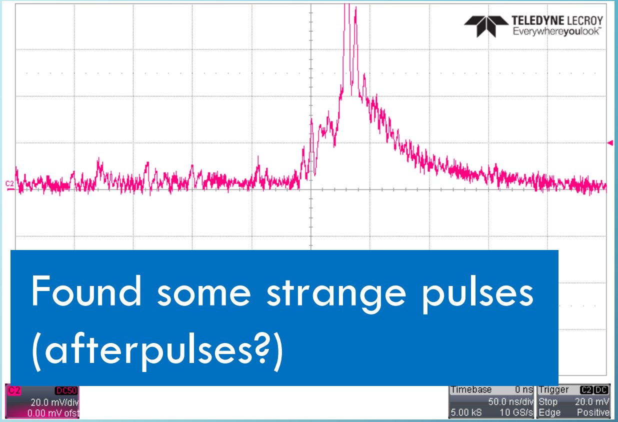




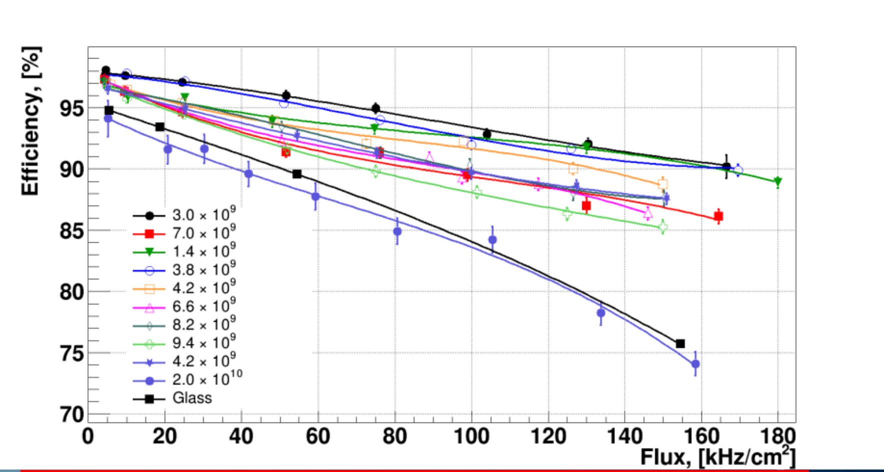




Glass RPC. 5 kHz/cm2



Found some strange pulses (afterpulses?)



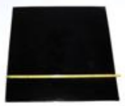
Glass thickness = 0.7 mm
Ceramic thickness = 2 mm
Glass resistance ~(5-6)*10^{10} Ohm*cm

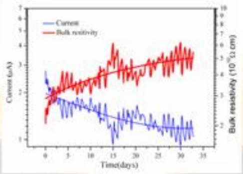
Lagarde François on behalf CMS Muon group

ITEP

Characteristics

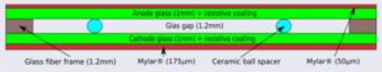
- Bulk resistivity : $10^{10}\ \Omega\,\mathrm{cm}$
- Thickness : 0.5 mm to 2 mm
- Thickness Uniformity : 0.02 mm
- Roughness : <10 nm
- Ohmic behavior : stable ($1\,\mathrm{C\,cm^{-2}}$)
- Maximal sizes : 32 cm×30 cm





Single Gap Chamber

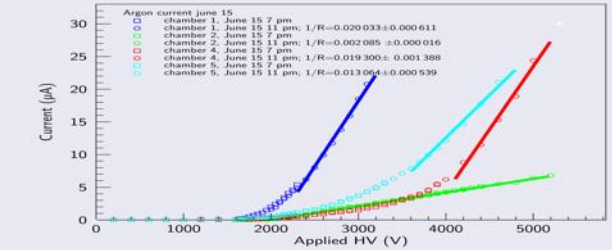
- Electrode Thickness 1 mm
- Gas gap 1.2 mm



Electronics

- HARDROC2 (64 channels)
- 3 thresholds
- Dynamical range : 10 fC-15 pC
- 1 cm×1 cm Pads

Resistivity measurement with Argon



Resistivity estimation

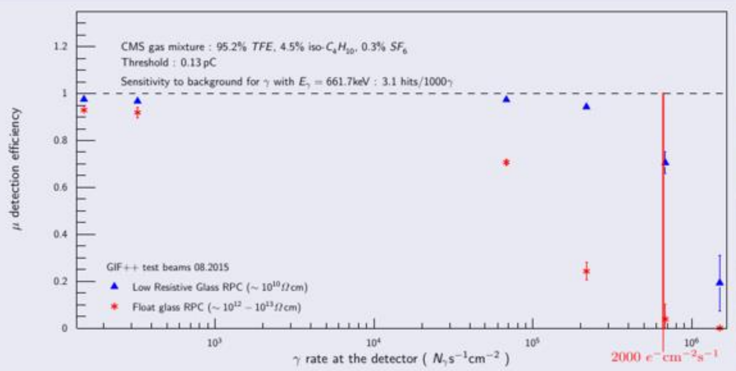
$$\rho = \frac{RS}{e}$$

R : electrode Resistivity
S : surface of the electrodes
e : electrode thicknesses.

Low Resistivity 1	$2.4 \times 10^{11}\ \Omega\,\mathrm{cm}$
Float Glass	$3.60 \times 10^{12}\ \Omega\,\mathrm{cm}$
Low Resistivity 4	$2.49 \times 10^{11}\ \Omega\,\mathrm{cm}$
Low Resistivity 5	$3.94 \times 10^{11}\ \Omega\,\mathrm{cm}$

Resistivity is much higher than expected $\sim 1 \times 10^{10}\ \Omega\,\mathrm{cm}$ to $5 \times 10^{10}\ \Omega\,\mathrm{cm}$. Resistivity mesurement in laboratory on bare electrode increased by $\sim \times 2$ after $1\,\mathrm{C\,cm^{-2}}$

Efficiency vs γ flux (Single Gap)



Efficiency is better than 70% for a flux of $\sim 2\,\mathrm{kHz\,cm^{-2}}$

Conclusion

ITEP

After finishing ALICE TOF:

➢A few attempts were done with low resistive materials:

1.Ceramic - SiC evaporated layer – DRPC with 10^{11} Ohm/□ (too high capacitance and some problem with groove)

2.Glass – phosphate glass 10^{11} Ohm*cm (some tail due to resistance non uniformity and fast surface degradation)

➢At next step mostly for CBM TOF R&D two types of technology were developed:

❑Ceramic – chambers based on Si_3N_4/SiC:

1.Problem with aging was confirmed and solved

2.Radiation hardness was proved

3.New technology for mass production of electrodes was established (possible to produce single cell and common substrate)

4.Minimal resistance value for stabile operation (maximal rate – 160 kHz/cm^2 for 6-gaps chamber) was found to be $4*10^9$ Ohm*cm.

5.Mass-production of Si3N4/SiC has to be confirmed this year! MISiS(Moscow) – electrosintering, IKT(Dresden) – hot pressing

❑Glass - Low resistive glass made by China

1.Fixed value of resistance $2*10^{10}$ Ohm*cm (not confirmed!) and maximal size 30x32 cm^2

2.Chamber design almost ALICE TOF type (strips or pads)

3.For 10 gaps chambers maximal rate ~ (40-50) kHz/cm^2

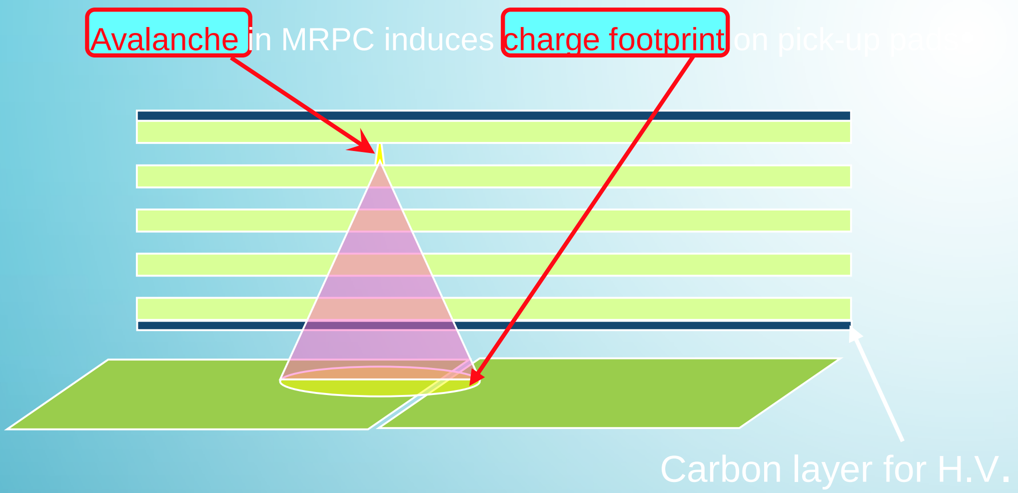
4.Well established mass production – first results from STAR E-TOF expected to be end of this year

➢Both technologies accepted for inner and very forward parts of CBM TOF

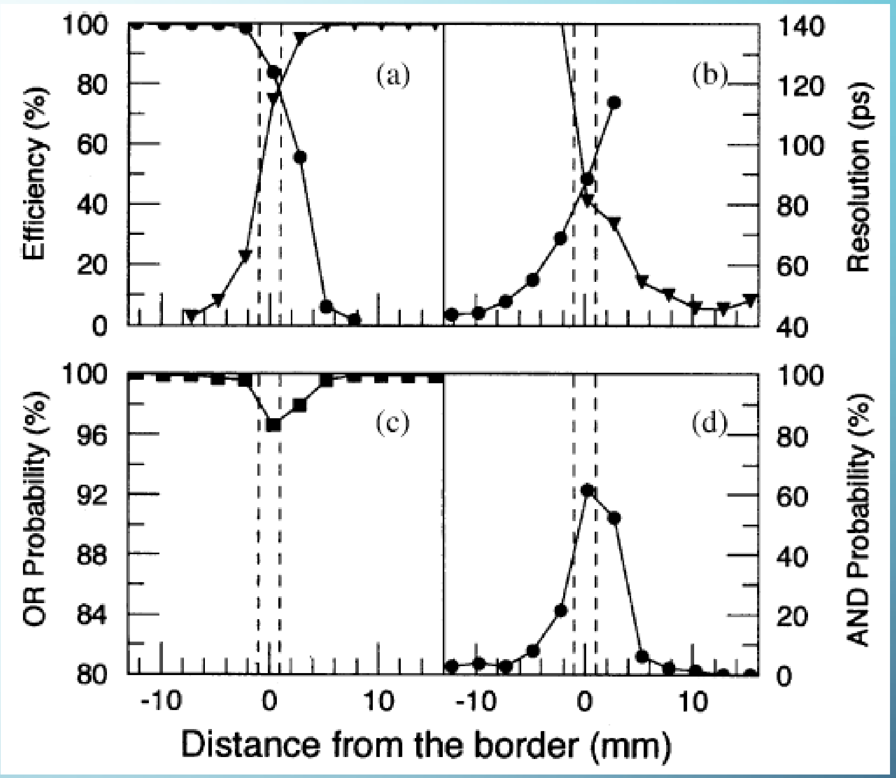
THANK YOU FOR ATTENTION!

Charge induction for pad readout

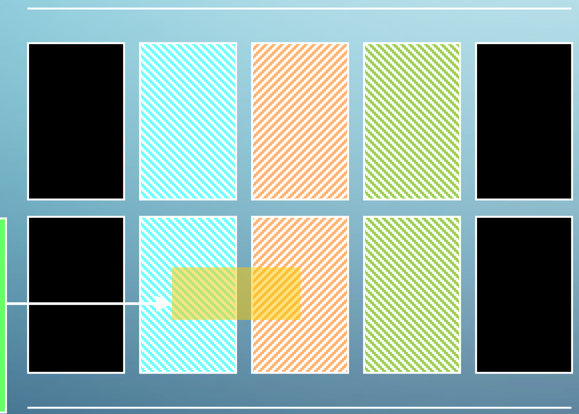
Перераспределение заряда



Высокий процент «cross-talk»

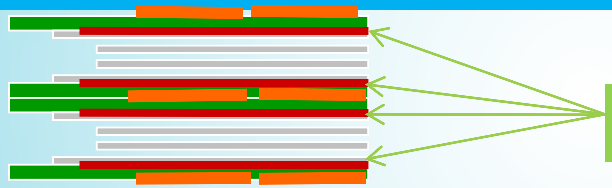


Сканирование между центрами падов 25x35 мм

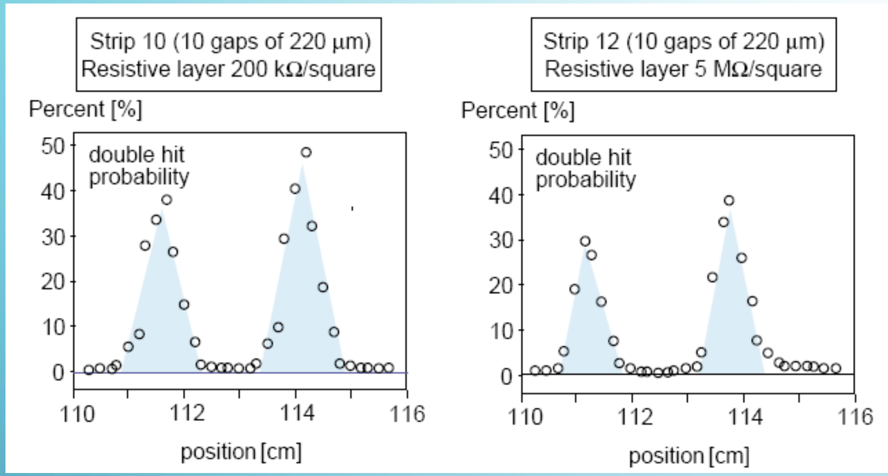


Влияние краевых эффектов:
На эффективность – мало
На разрешение – мало
Но «cross-talk» ~ 16% для соседних ячеек

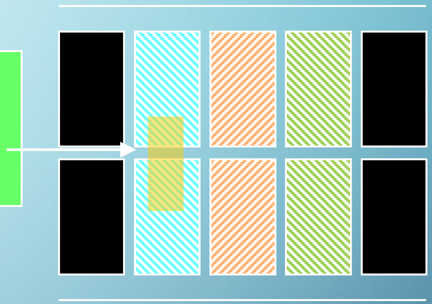
Зависимость величины cross-talks от сопротивления резистивного слоя для подачи напряжения

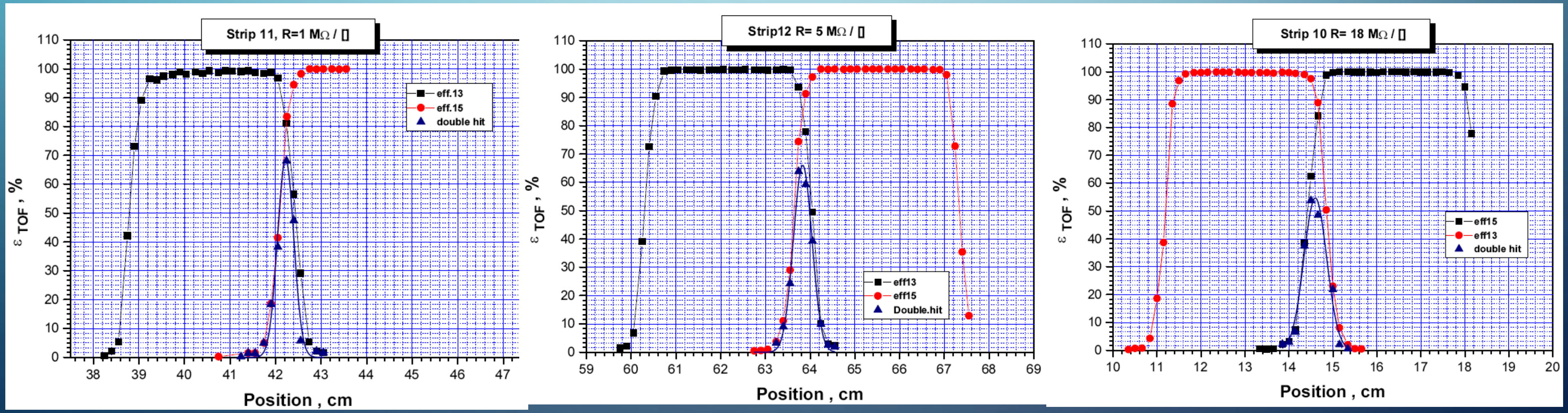


Резистивный слой для подачи напряжения

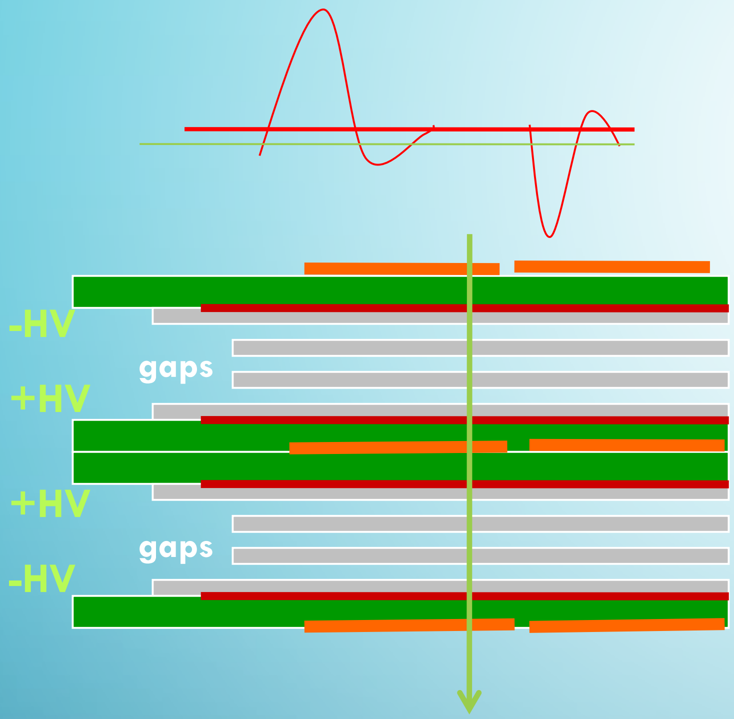


Вертикальное сканирование 35 мм

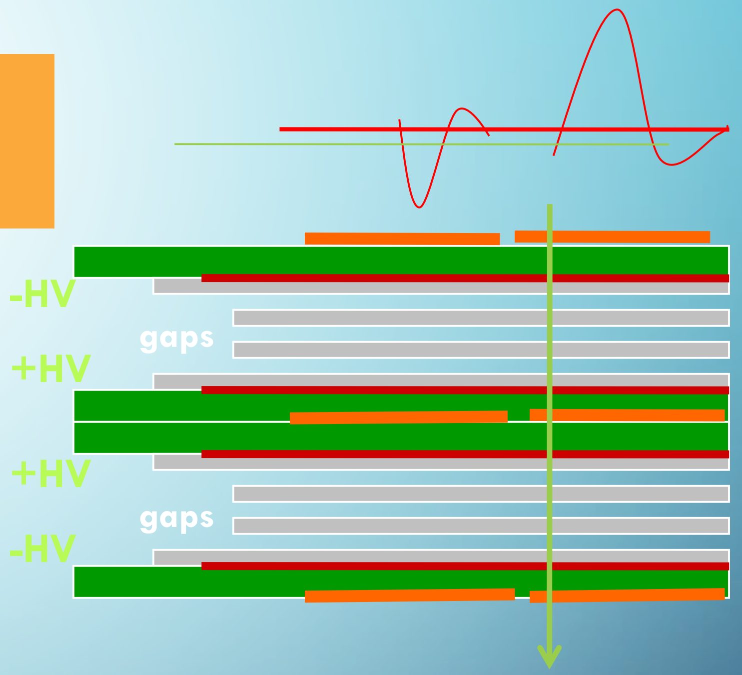




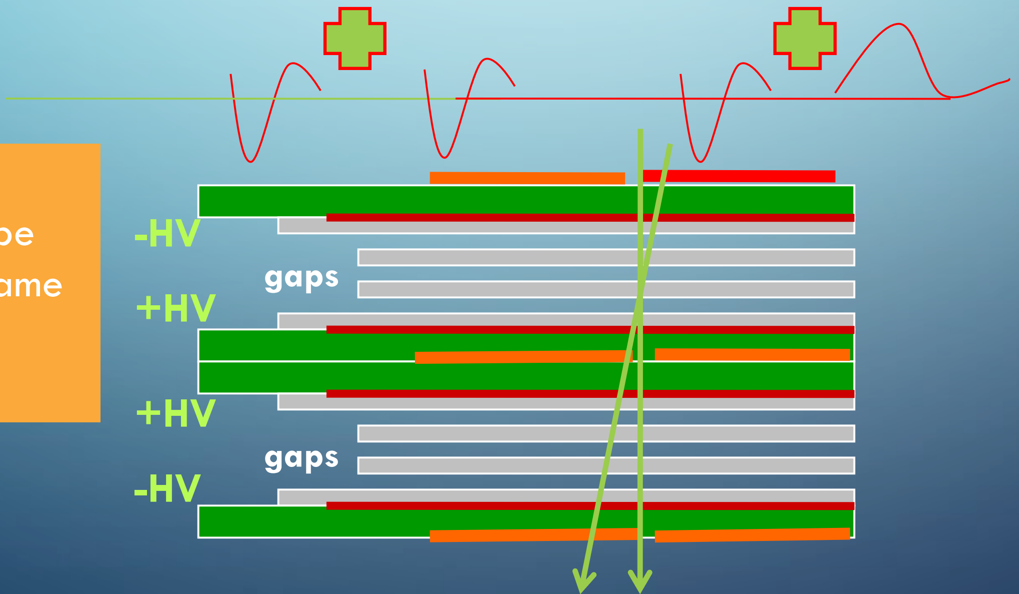
PROBLEM WITH HIGH CROSS-TALK LEVEL



Signal on neighboring pad has inversed polarity



For different particle trajectories signal can be sum of two signals of same polarity or direct and inversed polarities



Attempts to averaged time from a few pads/strips can even degrade PID performance

GLOBAL TIME RESOLUTION

$$\sigma^2_{TOT} = \sigma^2_{MRPC} + \sigma^2_{T0} + \sigma^2_{CLK} + \sigma^2_{CLK-TRM} + \sigma^2_{CAL}$$

MRPC + ELEC. (50 ps)

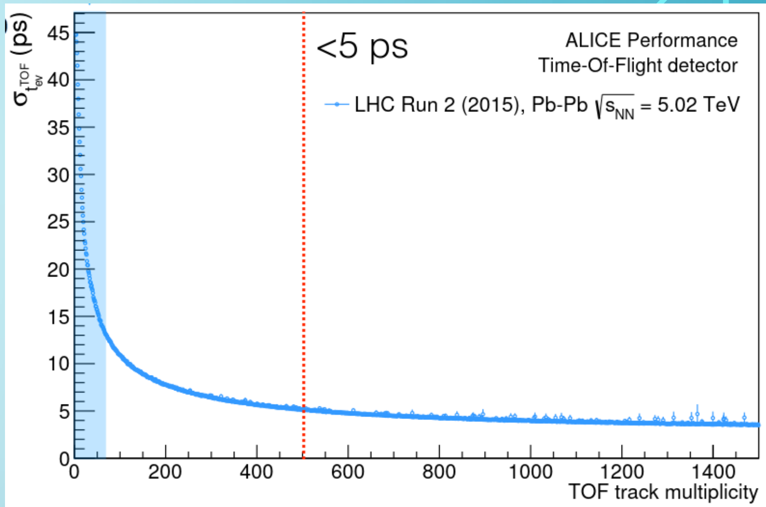
(50 ps) For Pb-Pb by TOF for 2000-3000 charged particles (5 – 10 ps)

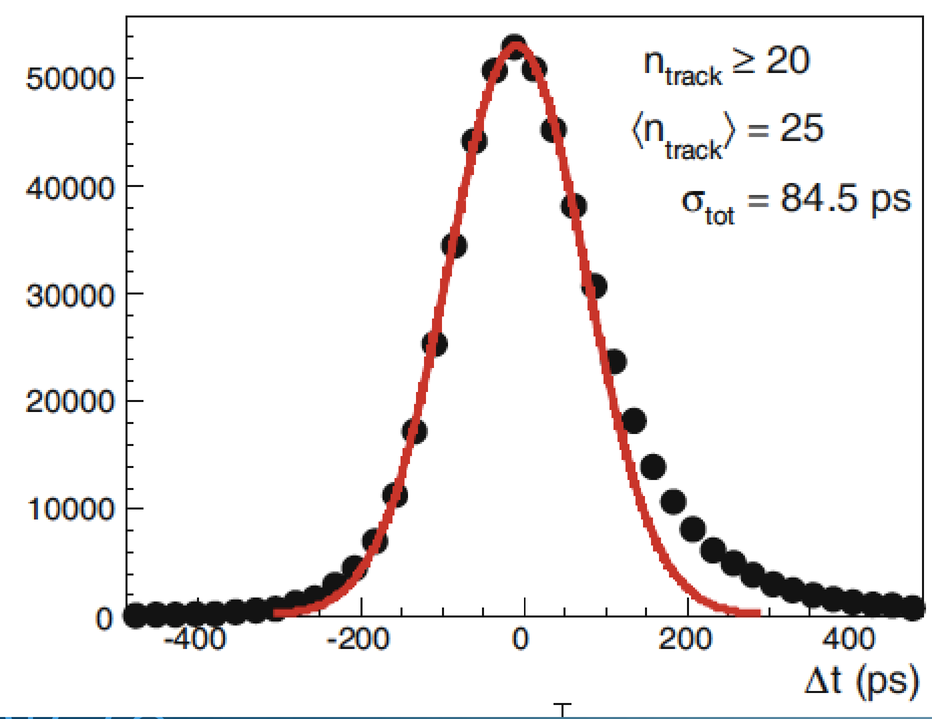
Clock from LHC to crates (15 ps)

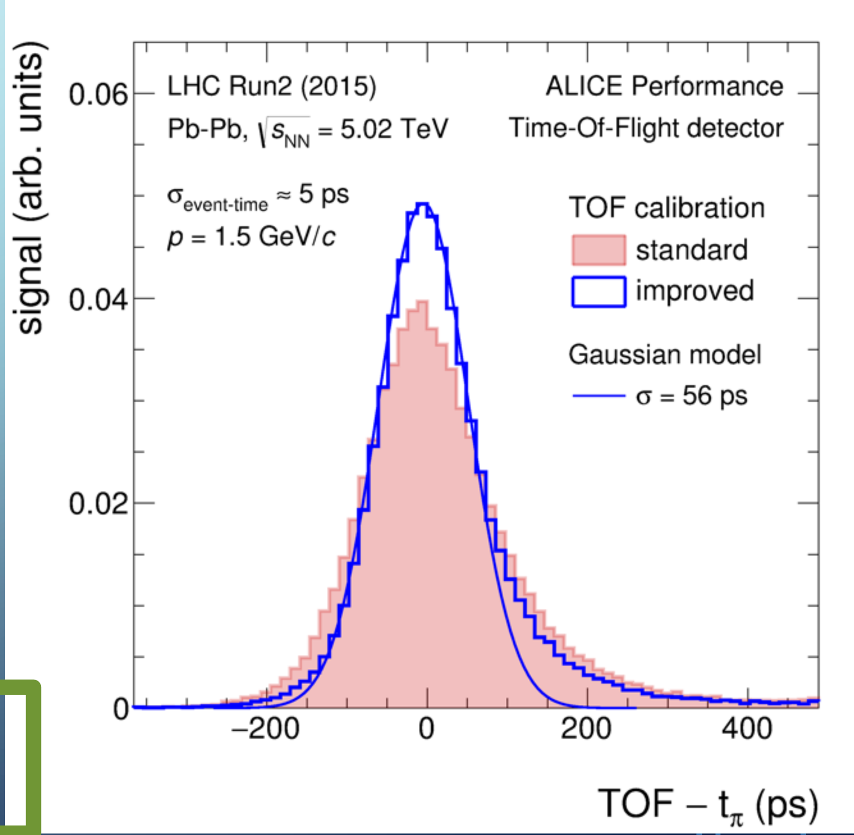
(10 ps)

Different time delay of different channels (cable lengths and time slewing) (30 ps)

ALICE TOF Time of flight spectrum







$$\sigma^2_{TOF} = \sigma^2_{MRPC} + \sigma^2_{TDC} + \sigma^2_{FEE} + \sigma^2_{Clock} + \sigma^2_{Cal}$$