Investigation of ceramic based Resistive Plate Chambers for high rate beam environments

GDS Meeting Legnaro 2017

Lothar Naumann

Outline

1. Resistive Plate Chambers (RPC) with low resistive ceramic electrodes for high rate capability
2. The Beam Fragmentation T_0 Counter (BFT_0C) in the framework of the Compressed Baryonic Matter (CBM) Experiment
3. RPC tests with electrons and pions for BFT_0C

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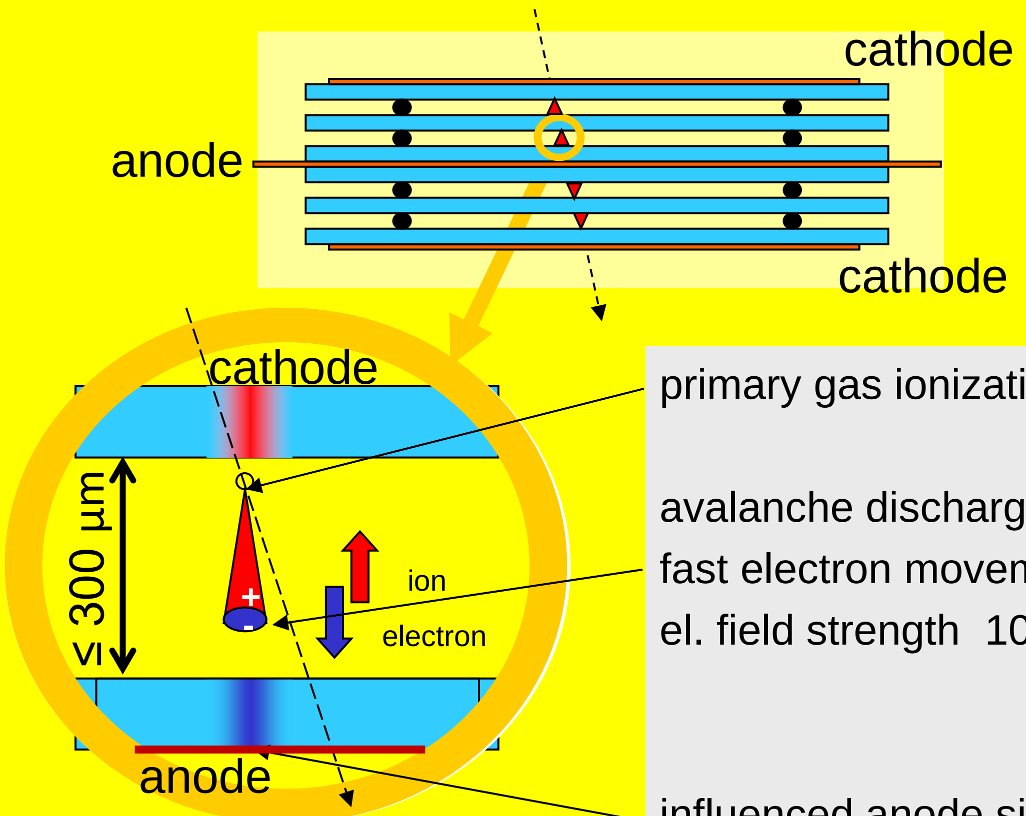
RPC mode of operation

RPC with time resolution ≤ 100 ps



primary gas ionization

avalanche discharge -
fast electron movement
el. field strength 100 kV/cm

influenced anode signal

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Ceramics

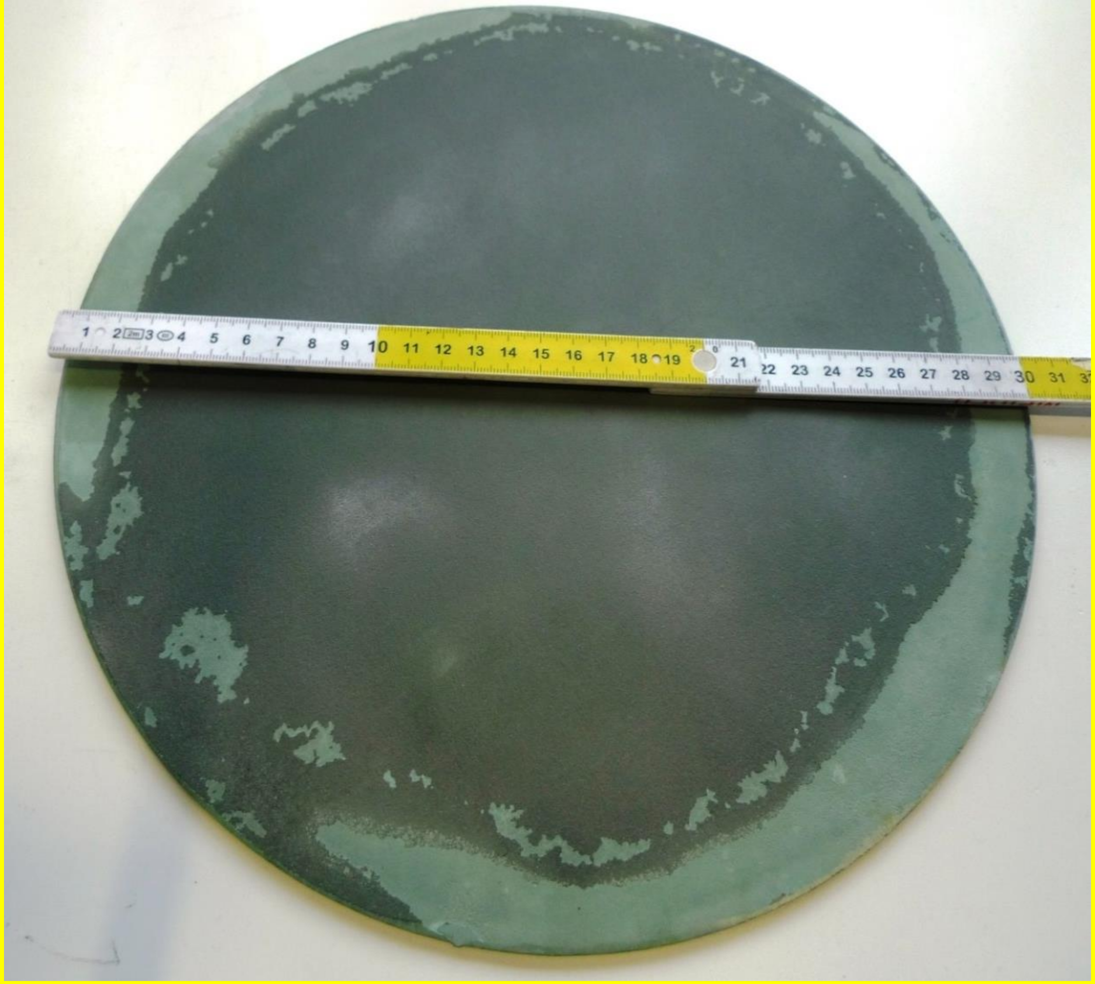
rough ceramics

as sintered:

- Ø ≈ 30 cm
- d ≈ 3.5 mm

mixing ratio:

- Si_3N_4/SiC (80%/20%)



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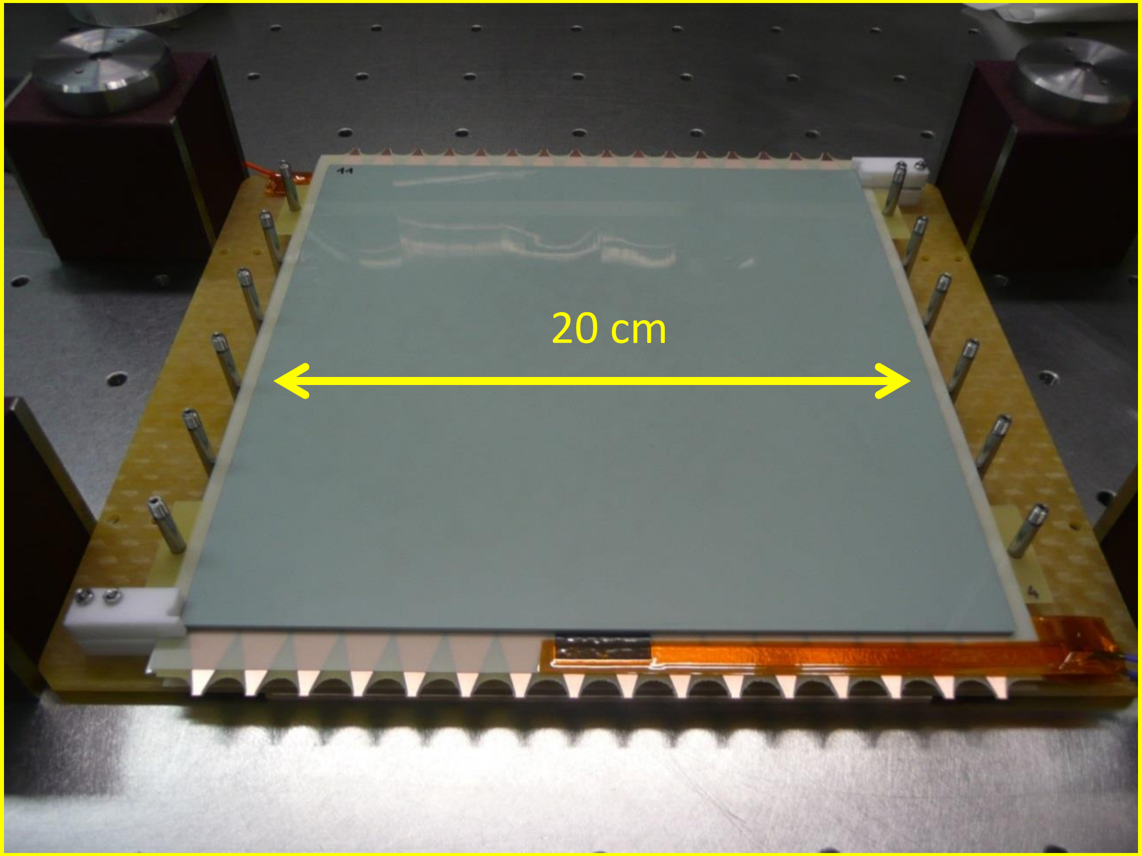
Ceramics

Fraunhofer Institute:

- cutting
- grinding
- polishing
- rounding



HZDR:

- cleaning
- drying
- ρ-measurement

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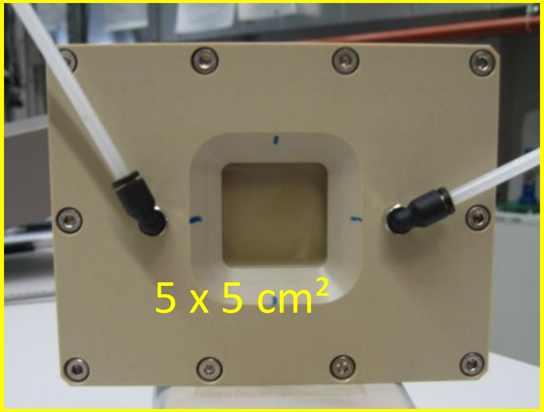
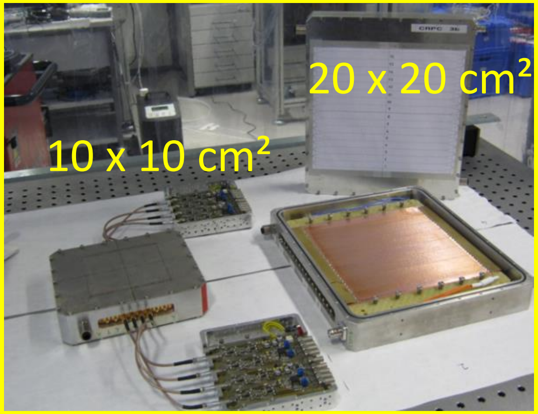
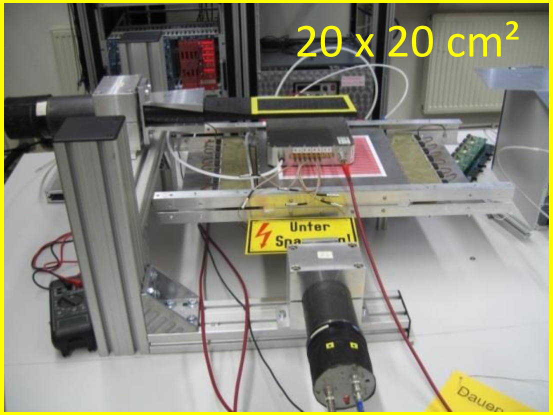
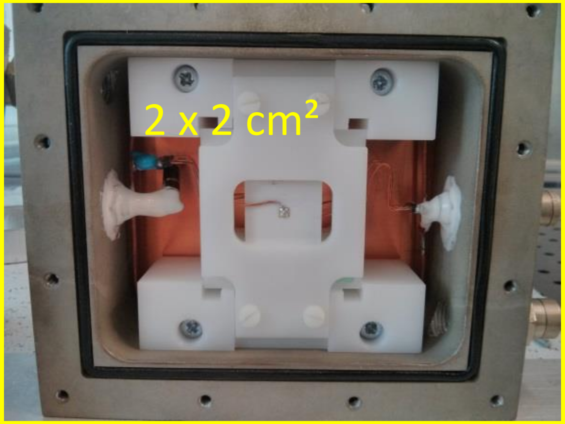
Resistive Plate Chambers @ HZDR



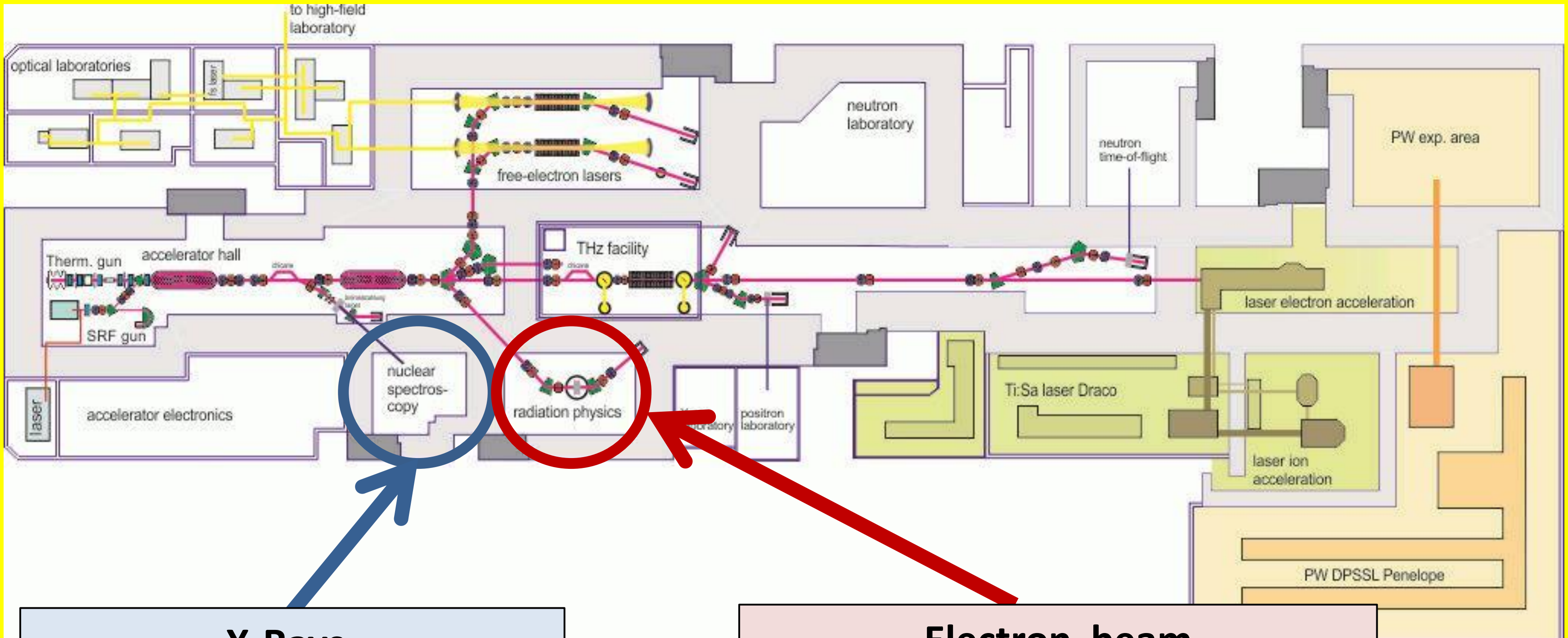






RPC area [cm²]	gas gap design			anode design		
	number	size [µm]	separator	number	length [cm]	width [cm]
2x2	3x2	250	ceramics	1	2	2
5x5	2	300	kapton	1	5	5
5x5	3x2	250	ceramics	1	5	5
10x10	2x2	250	fishing line	8	10	1
10x10	2x2	300	mylar	8	10	1
20x20	2x2	250	fishing line	16	20	1.125
20x20	2x2	300	mylar	16	20	1.125
20x20	6	250	fishing line	32	20	0.375

Electron accelerator ELBE @ HZDR

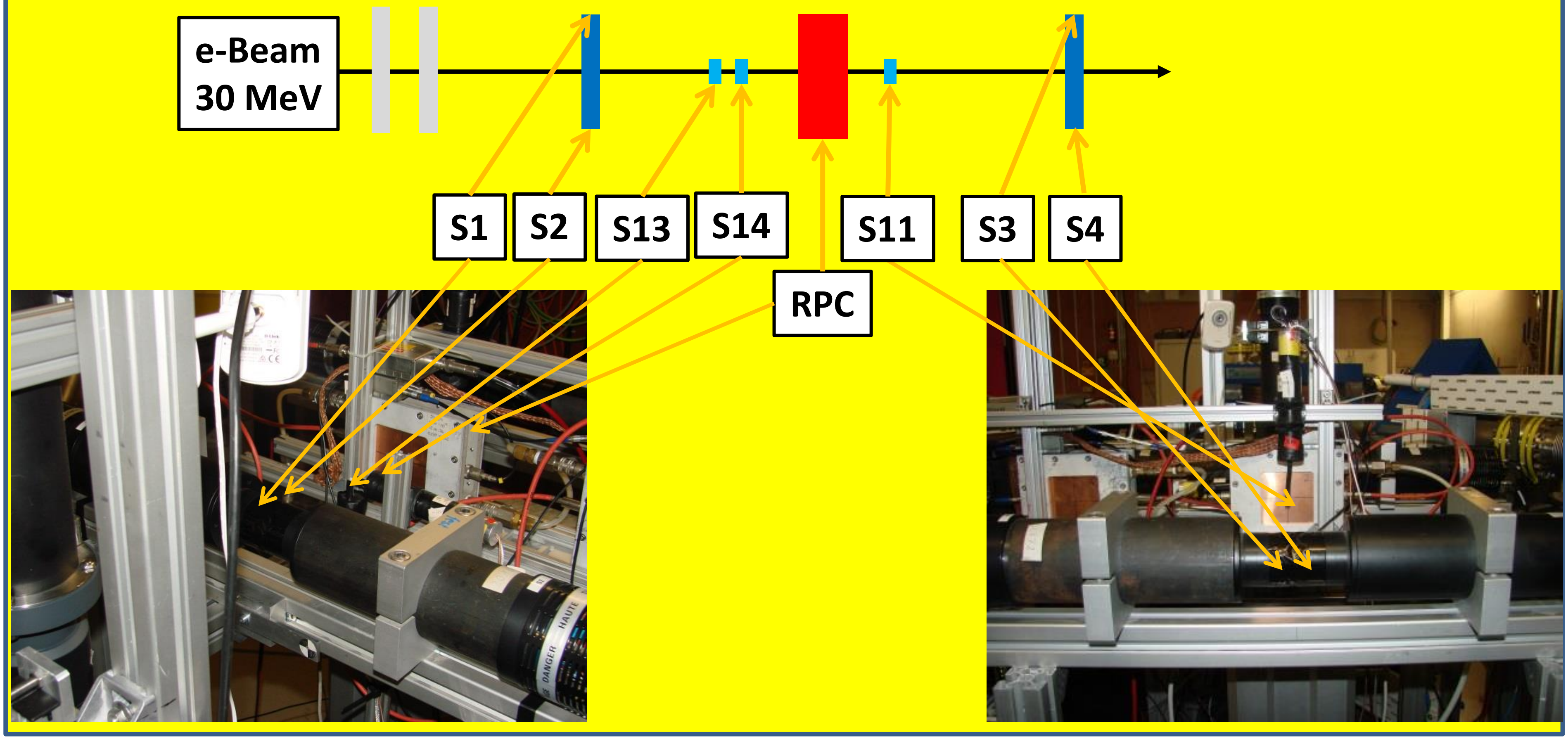


X-Rays
energy spectra ≤ 20 MeV
pulse duration 5 ps
flux ≤ 500 kHz/cm^2

Electron beam
monoenergetic , single electrons
energy 12 - 40 MeV
pulse duration 5 ps
flux ≤ 500 kHz/cm^2

Detector test facility @ ELBE

Gas: Freon /SF_6 /isobutan
Start system: σ_{RF} = 35 ps
Trigger scint. size: 5x5 to 20x20 mm^2



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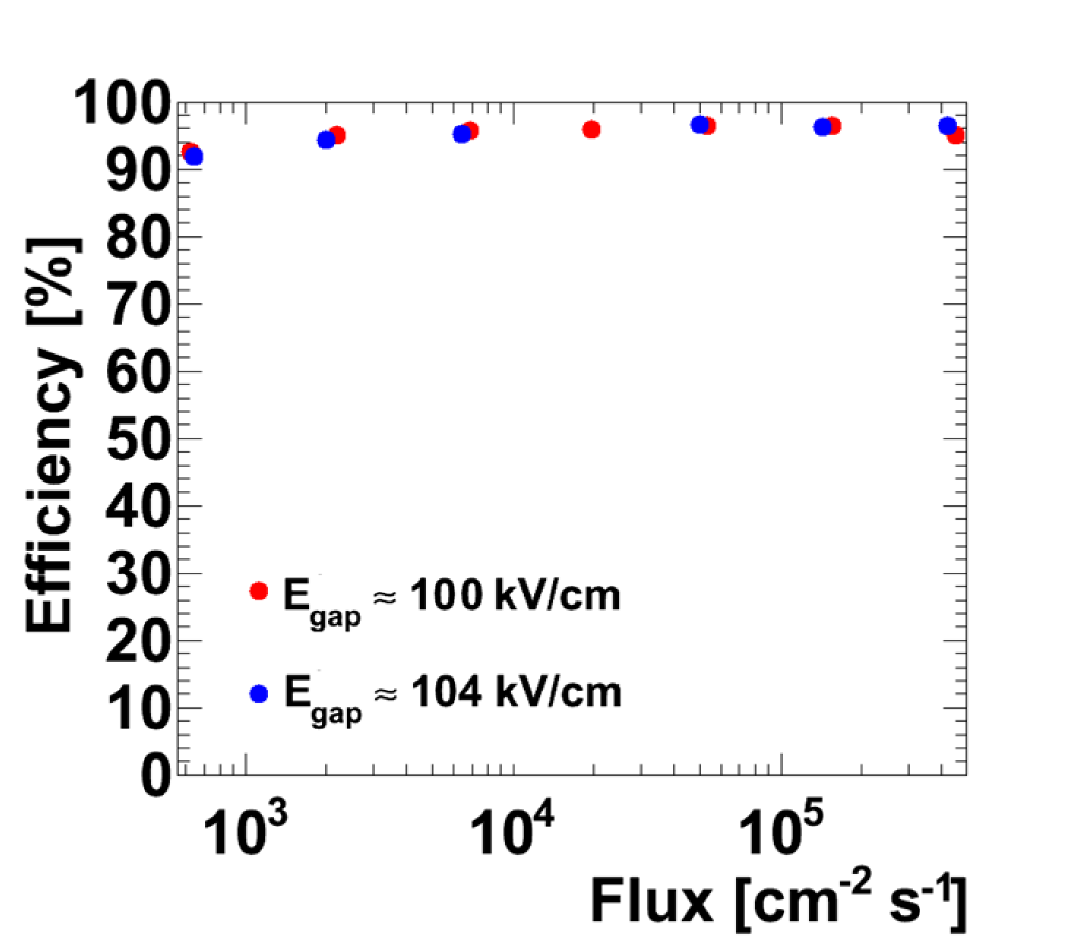
RPC – efficiency (e)

Ceramics RPC

- 10 x 10 cm²
- 2 x 2 x 300 µm

Electrons

- 30 MeV
- $A_{beam} \geq 10\ cm^2$



RPC – timing (e, p)

Ceramics RPC

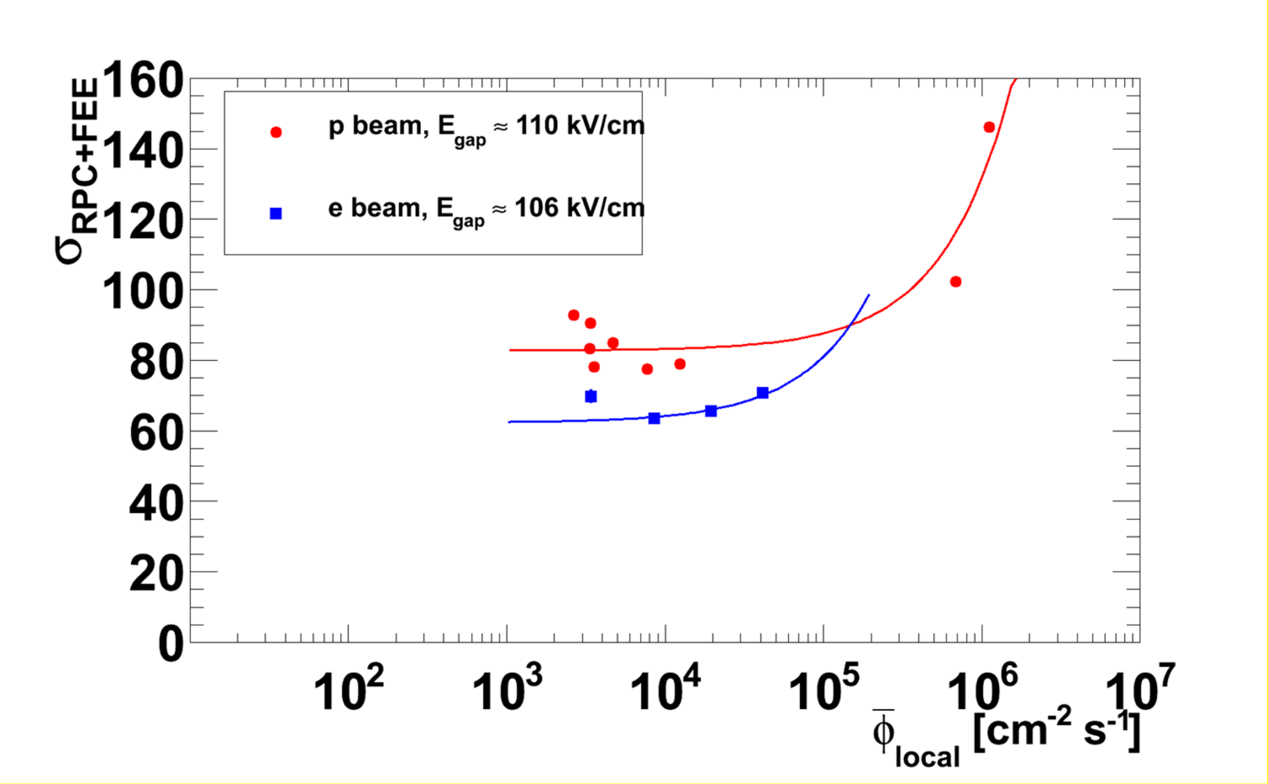
- 20 x 20 cm²
- 2 x 2 x 250 µm

Electrons

- 30 MeV
- $A_{beam} \geq 10$ cm²

Protons

- 2.7 GeV
- $A_{beam} \leq 1$ cm²



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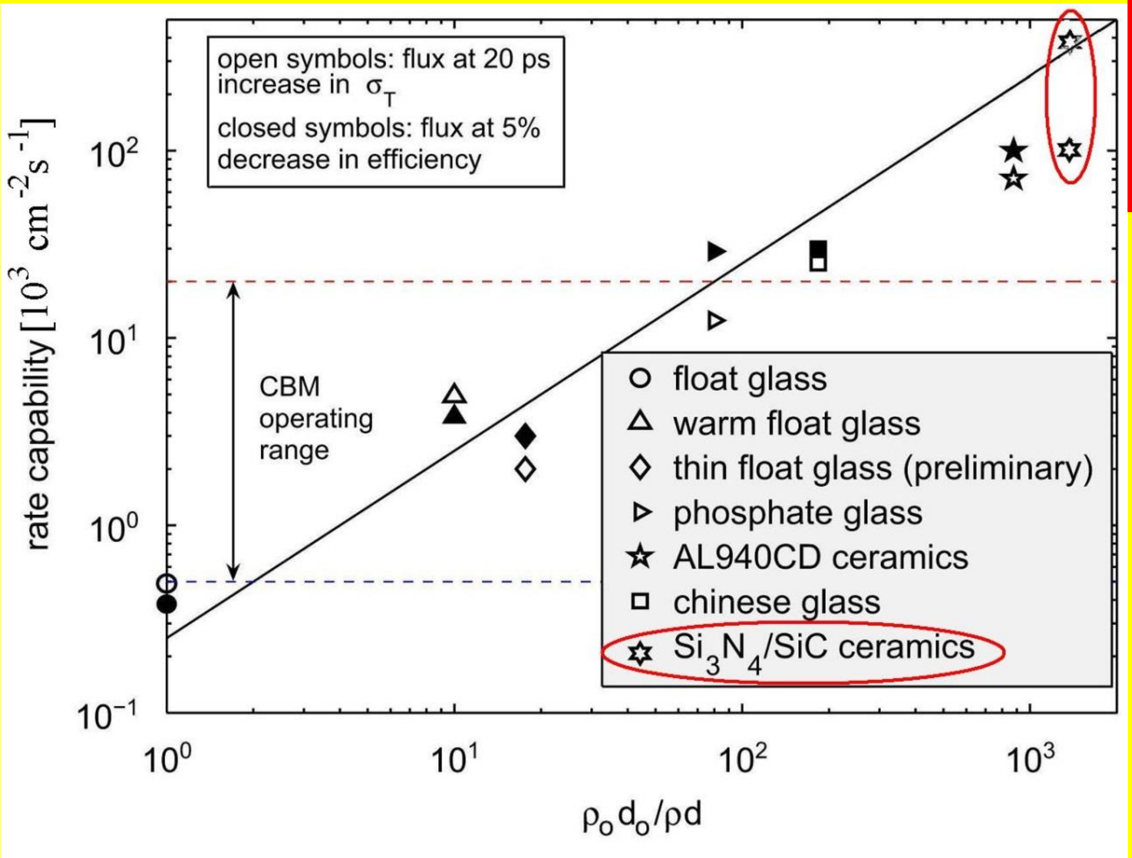
RPC rate capability



2x2 cm²

10x10 cm²

20x20 cm²

normalized to the value of float glass: 300 GΩ·cm²

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Beam Fragmentation T_0 Counter

- Important scopes of High Energy Heavy Ion experiments are start-time and reaction-plane determination.
- For the Compressed Baryonic Matter Experiment (CBM) at FAIR the use of RPC with low resistive radiation hard ceramics electrodes and small chess-board like single cells is under consideration for the Beam Fragmentation T_0 Counter.

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Beam Fragmentation T_0 Counter

Challenges of the BFT$_0$C region:

- High-rate capability up to **$\geq 2x10^5 cm^{-2} \cdot s^{-1}$**

  → one floating electrode per cell
- Timing resolution: **$\sigma \leq$ 60 ps**
- Efficiency: **≥ 98 %**
- Double-hit suppression: **≤ 2 %** → cell size 20x20 mm^2
- Cross-talk suppression: **≤ 1 - 2 %**

→ RPC with low resistive ceramics electrodes and chess-board like single cell design are under consideration

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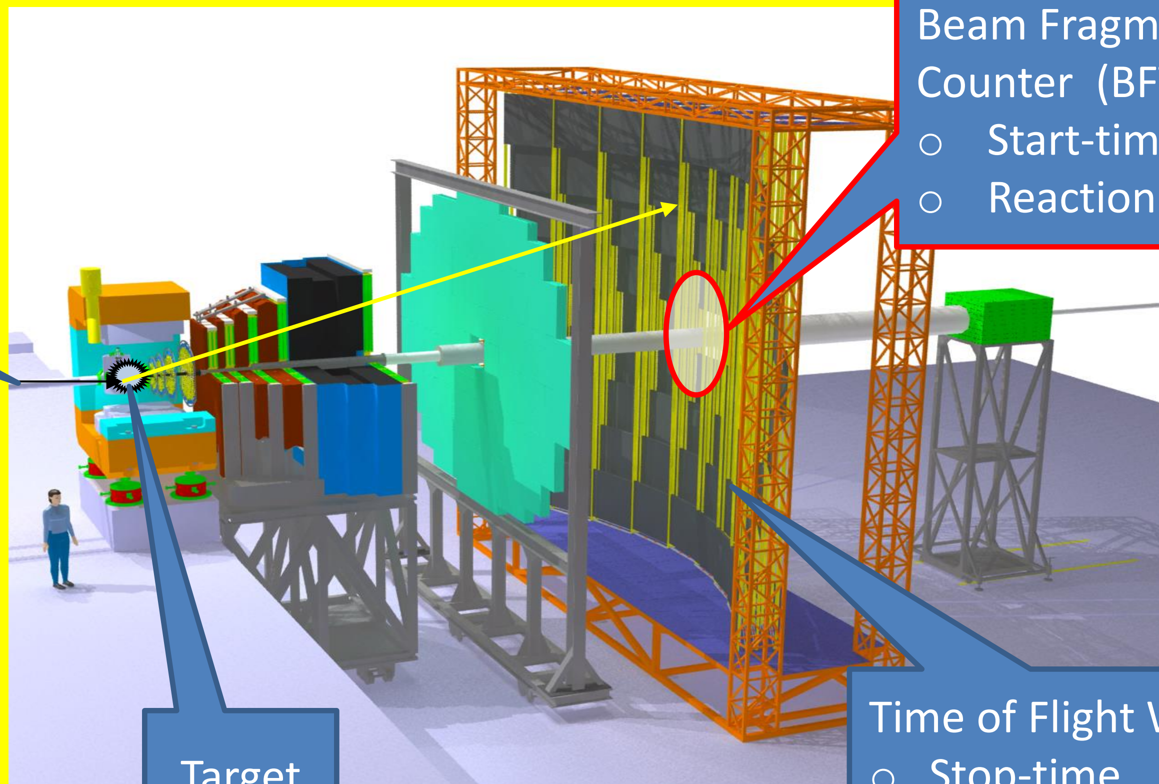
Beam Fragmentation T_0 Counter

Compressed Baryonic Matter Spectrometer



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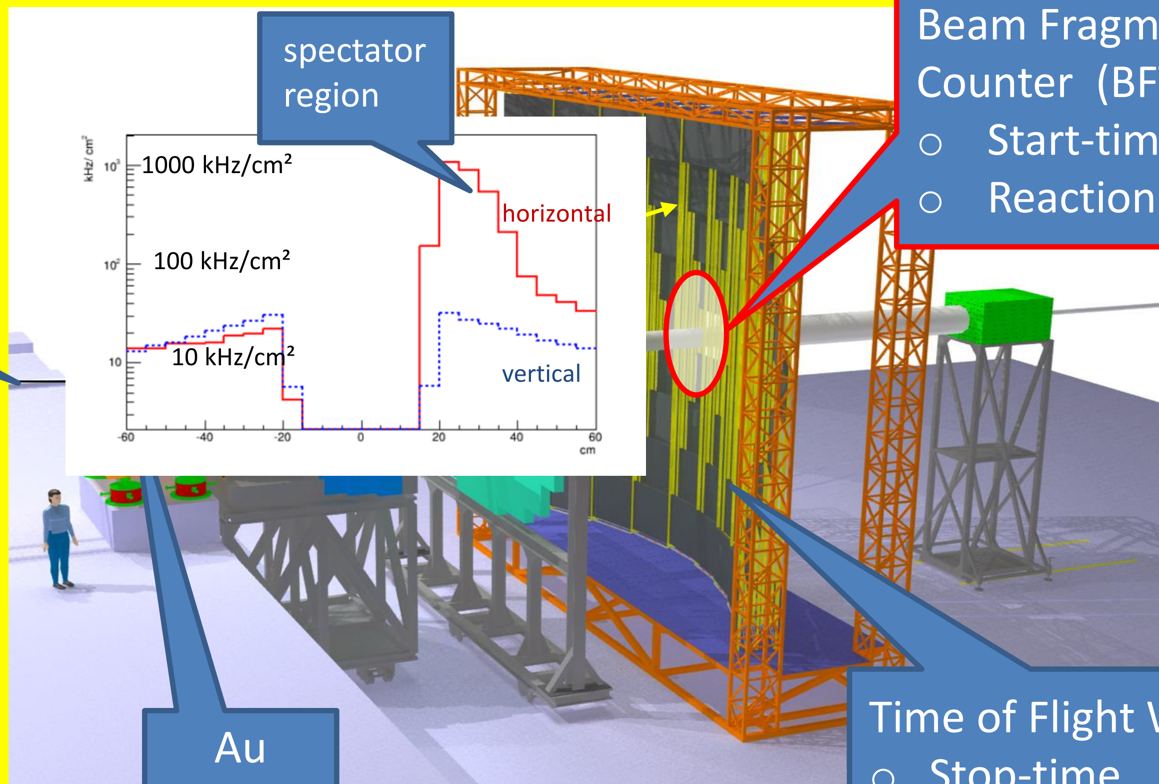
Beam Fragmentation T_0 Counter

Particle flux (UrQMD) 6 m behind the target on the BFT_0C



Beam Fragmentation T_0 Counter (BFT_0C):
- Start-time T_0
- Reaction plane

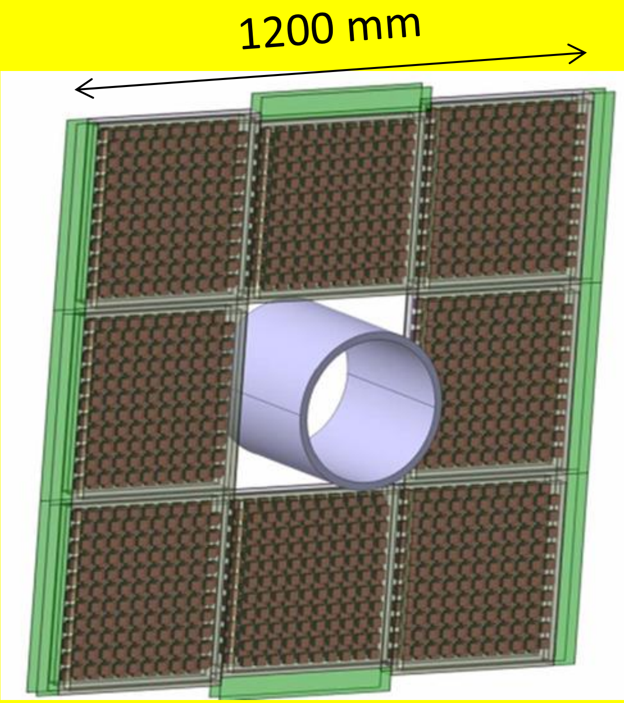
Au 10 GeV

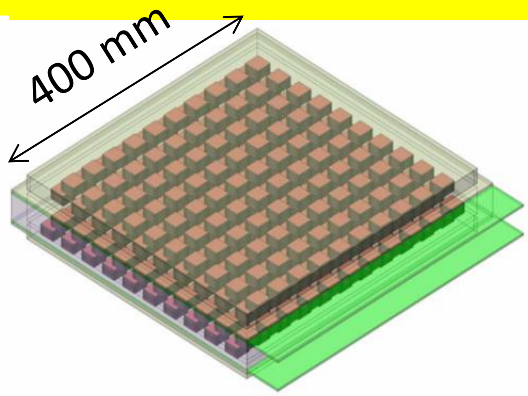
Au Target

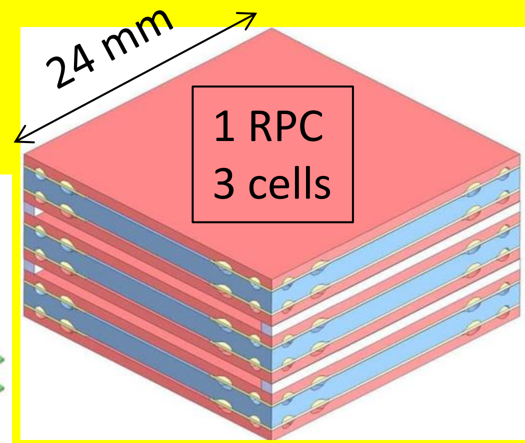
Time of Flight Wall
- Stop-time

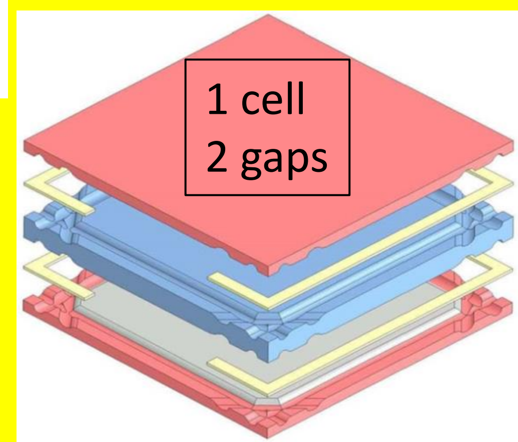
Beam Fragmentation T_0 Counter

BFT_0C design









1 module
400 RPC

BFT_0C = 8 modules

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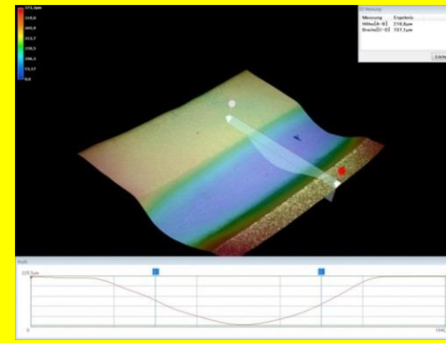
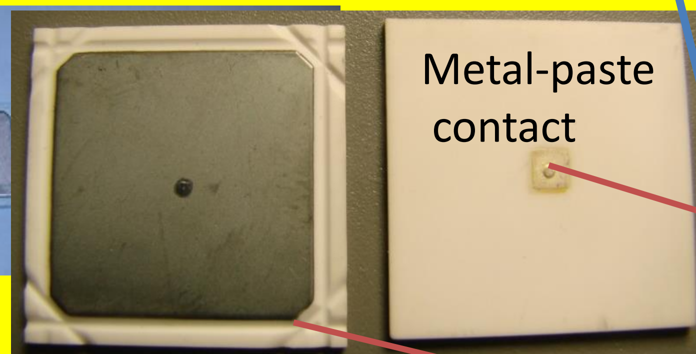
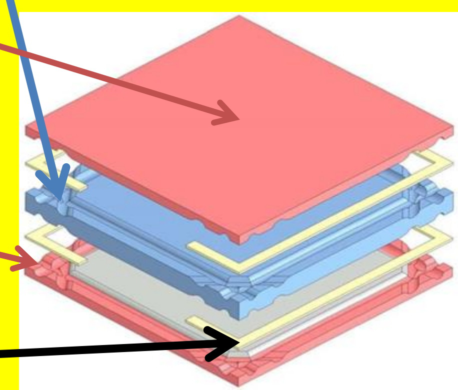
Ceramics for RPC

Si_3N_4/SiC resistive electrode shaped both sides



Al_2O_3 evaporated with Cu/Cr





Al_2O_3 250 µm spacers

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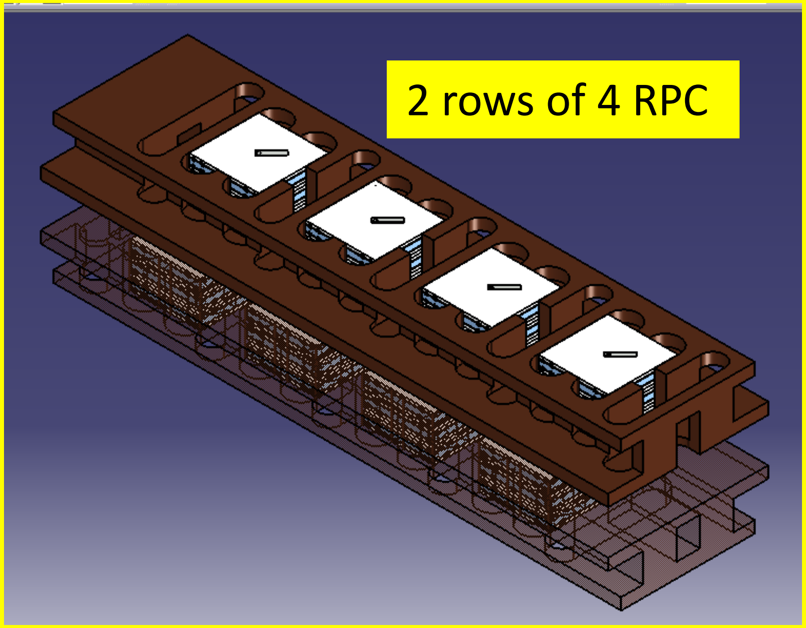
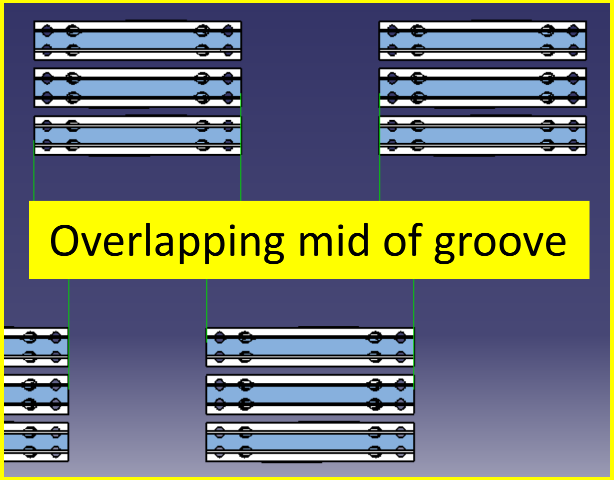
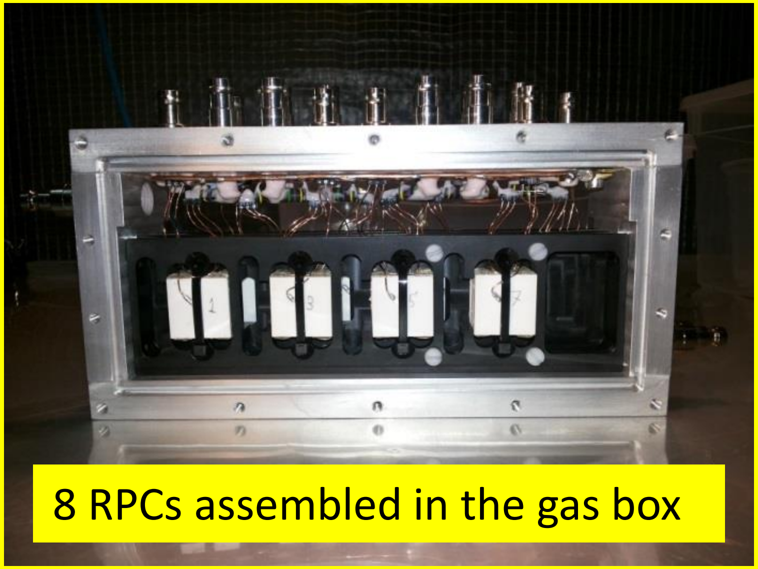
Demonstrator design

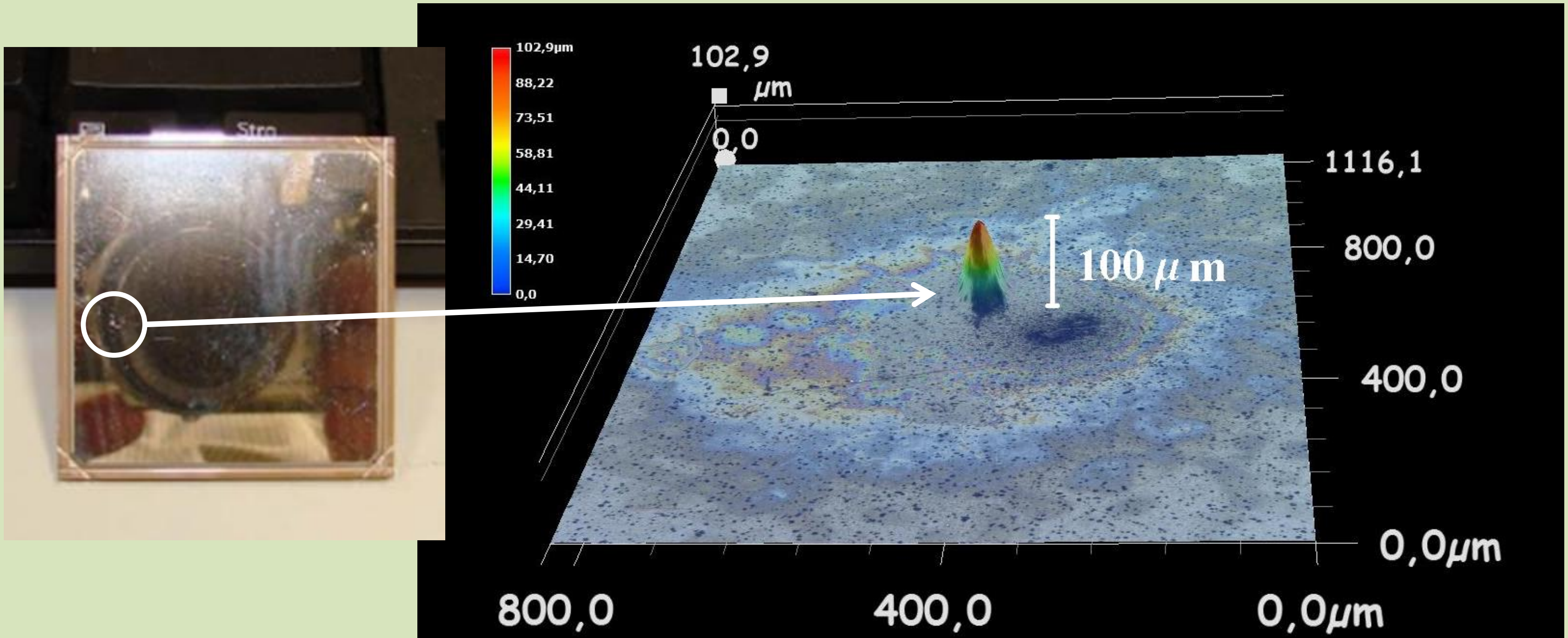






In order to find optimal resistivity value for BFT_0C conditions and requirements Si_3N_4/SiC floating electrodes with a bulk resistivity from 10^7 to $10^{12}\Omega\cdot cm$ were tested.

Gas mixture



Intense discharges combined with isobutane provokes whisker generation at Cr-surface

→ **No isobutan!**

Gas-mixture for RPC: 90% Freon + 10% SF_6

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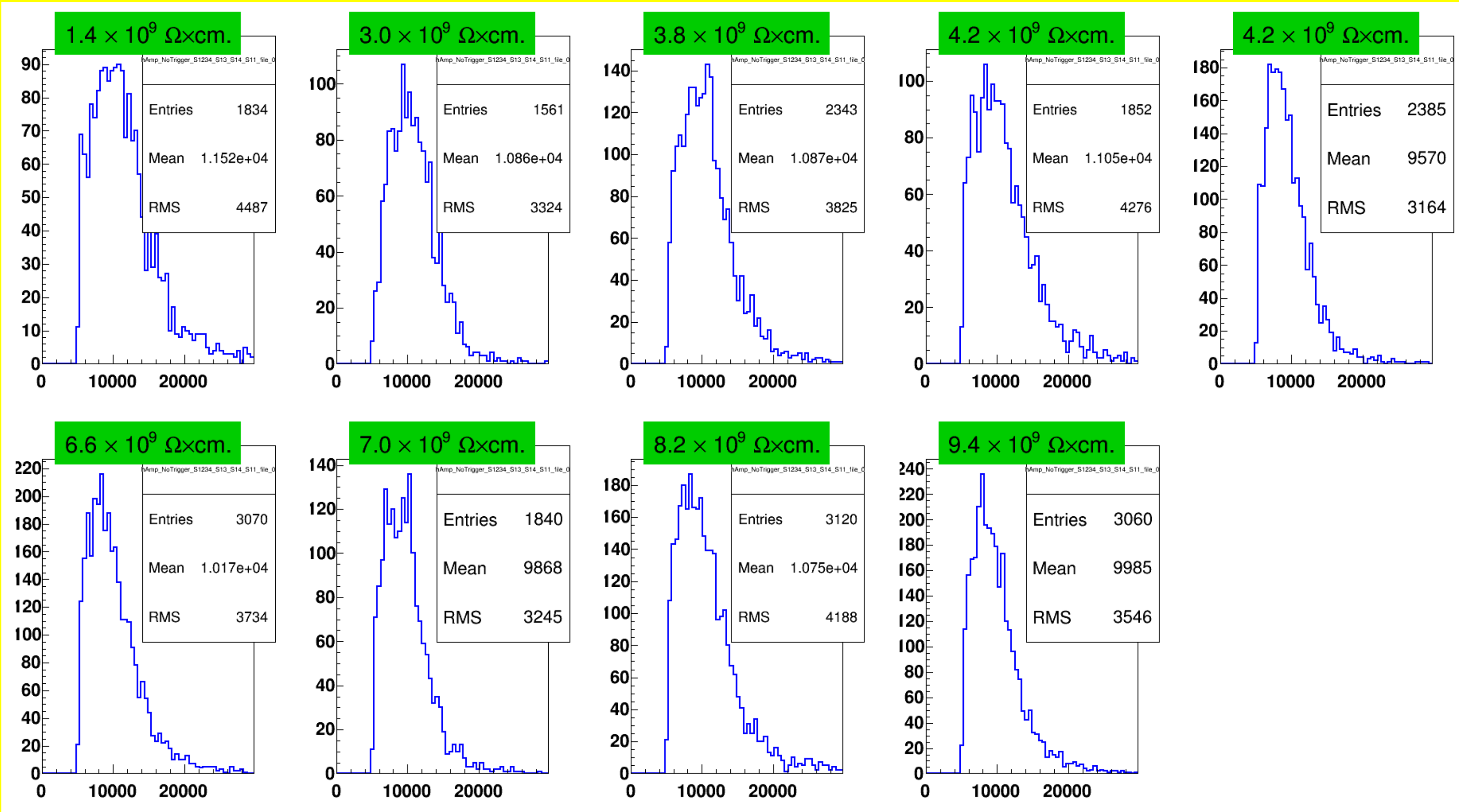
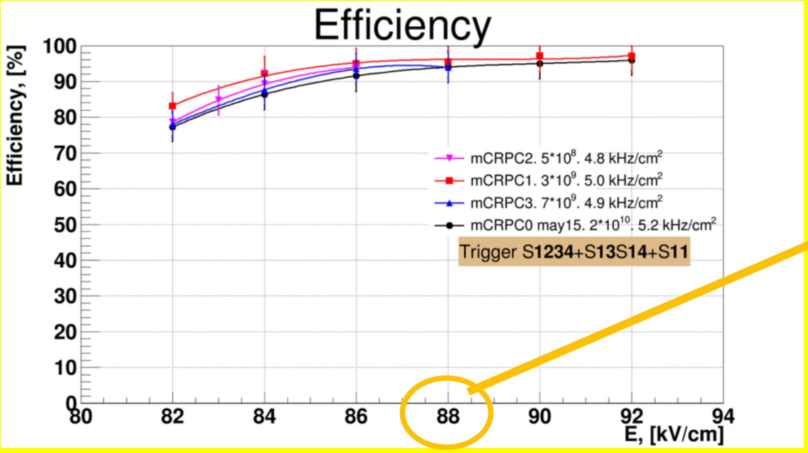
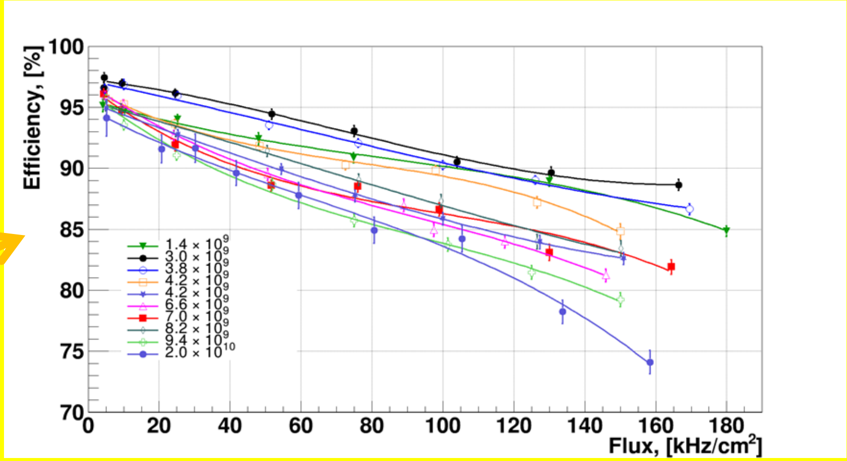
BFT$_0$C – signal amplitudes

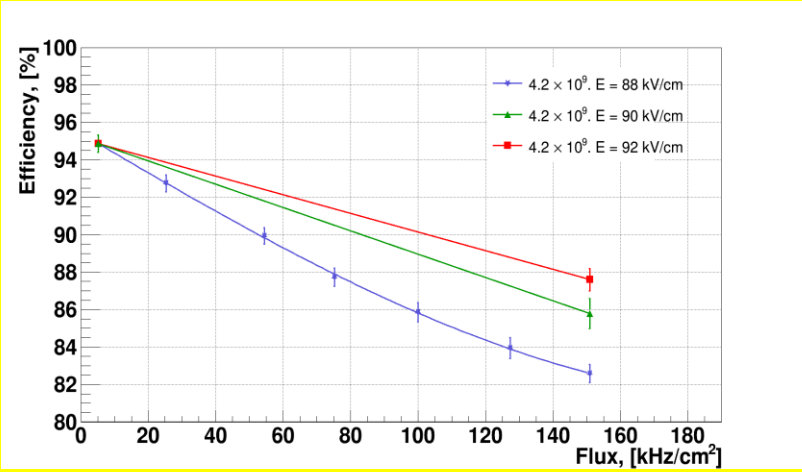


Quite uniform RPC construction →
all chambers in mini-module can be put under the same voltage

BFT_0C – efficiency (electrons)

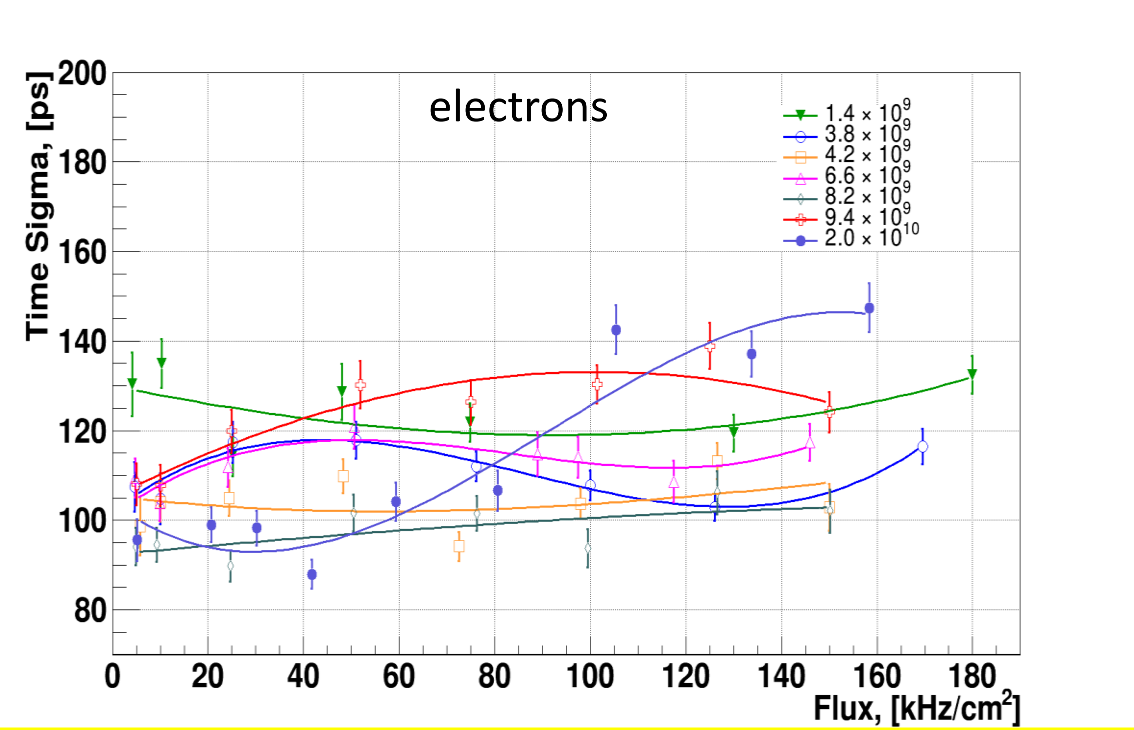






- 2×10^{10} Ωcm: ε fast degrease with flux
- 5×10^{8} Ωcm: ε is not capable to get on the efficiency plateau: unstable work and lots of streamers starting from 87-88 kV/cm
- 3×10^{9} Ωcm: most suitable resistivity order for our aims

BFT_0C - time resolution



Time resolution : σ_{RPC} = 90-140 ps
Time start stamp: σ_{RF} = 35 ps

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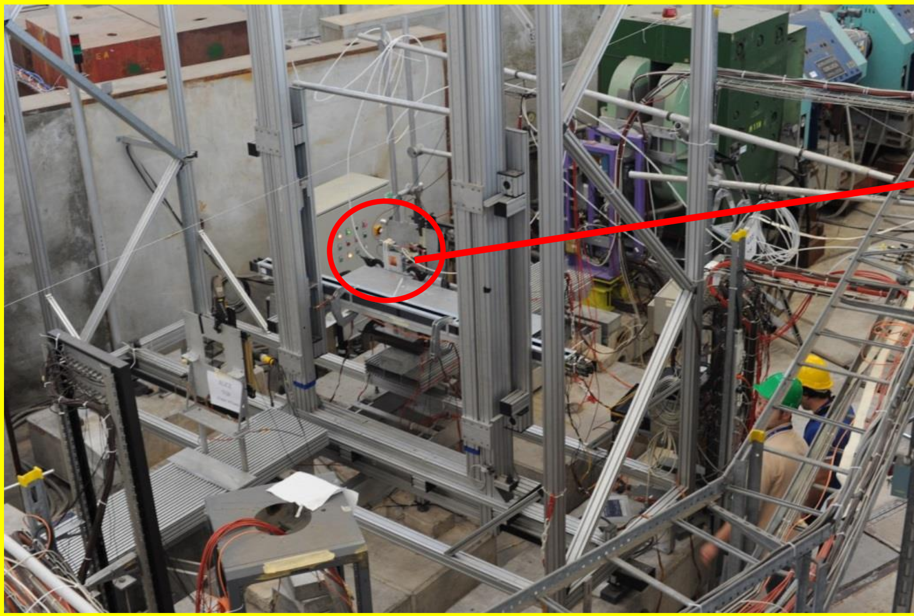
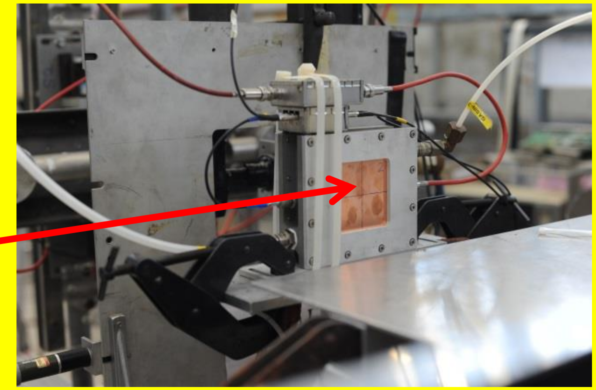
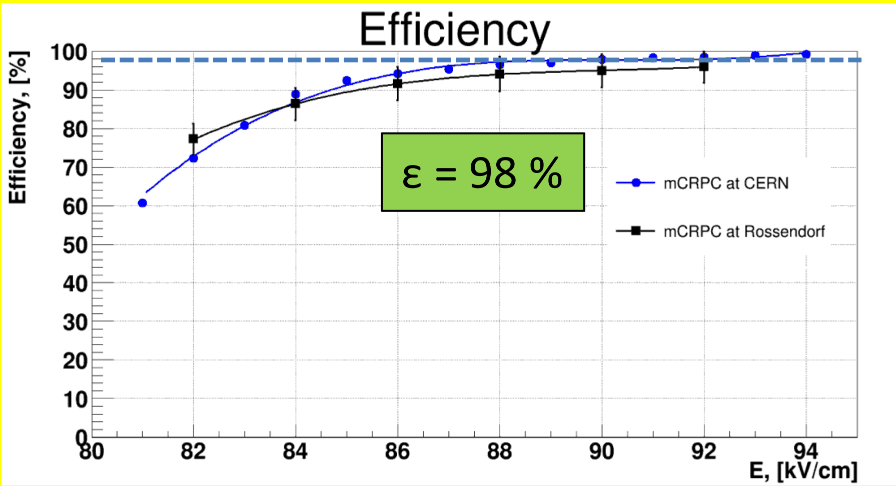
Pion test facility @ CERN

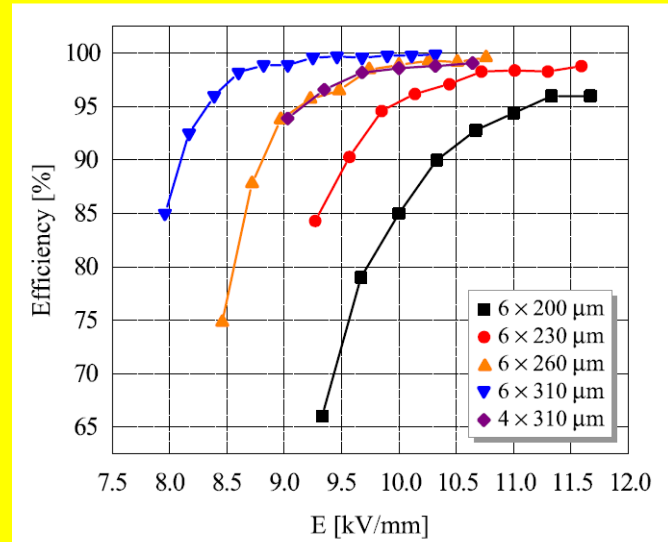


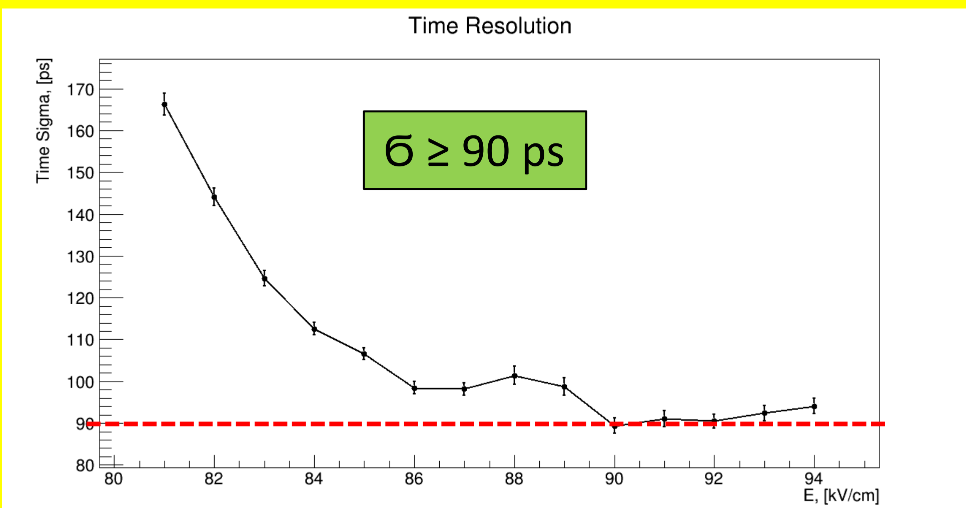


Beamline: T10
Pion rate: few kHz/cm^2
Gas: 90% Freon + 10% SF_6
Electronics: MAX376012
Trigger scint. size: 20x20 mm^2
Start system: σ_{RF} = 50 ps

BFT$_0$C - test @ CERN (pions)







- Pion efficiency ε ≈ 98 %
3% higher than for 30 MeV electrons

- Time resolution σ ≥ 90 ps
comparable with electron results

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Summary

- A Beam Fragmentation T_0 Counter of 120x120 cm^2 in the innermost region of the CBM TOF wall with 2x2 cm^2 chess-board like single RPC cells is under consideration.
- Radiation hard low resistive Si_3N_4/SiC composite is a candidate for the floating electrodes of the RPC cells.
- A manufacturing process has been developed to produce ceramic electrodes with a bulk resistivity varying between 10^8 and 10^{10} Ω cm.
- The outer electrodes are Cr-plated Al_2O_3 sheets with a central contact pin.
- The dark count rate has been reduced to 0.5 Hz/cm^2 by special material treatments .
- To define the most suitable bulk resistivity for the BFT_0C, eight RPC cells of different bulk resistivity have been investigated. 3 – 5x10^9 Ω cm is the most suitable resistivity order for our aims.
- RPC tests with relativistic electron beam fluxes of up to 2x10^5 $cm^{-2}s^{-1}$

  have been provided.
- The detection efficiency amounts to 98 % and is sufficient for CBM, while the time resolution amounts to 90 ps and needs still further improvement.

Outlook

- Estimation of streamer excitation
- Implementation of PADI-FEE
- Radiation hardness test of powered RPC cells with fast neutrons
- Cost reduction by modern technology employment for Si_3N_4/SiC ceramics composite production
- Assembling of a 32-modular demonstrator with 3 – $5x10^9$ Ω cm electrodes

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