Investigation of ceramic based Resistive Plate Chambers for high rate applications

MT Meeting Darmstadt 2017

Lothar Naumann

Outline

1. Prototype development of Resistive Plate Chambers (RPC) with low resistive ceramic electrodes for high rate capability

2. A Beam Fragmentation T_0 Counter (BFT_0C) in the framework of the Compressed Baryonic Matter (CBM) Experiment

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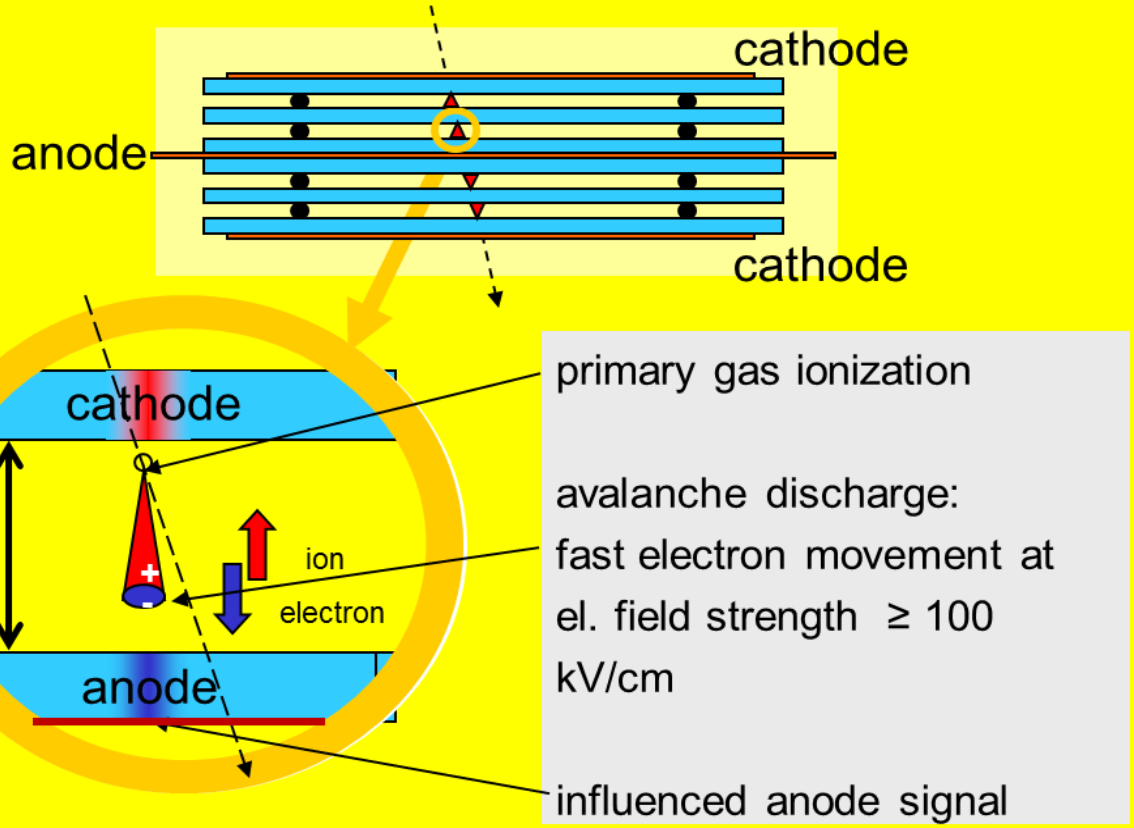
RPC mode of operation

- time resolution $\sigma \leq 100$ ps → gap ≤ 300 µm; el. field ≥ 100 kV/cm
- rate capability ≥ 100 kHz/cm² → bulk resistivity ≤ 10^{10} Ω cm



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Ceramic electrodes

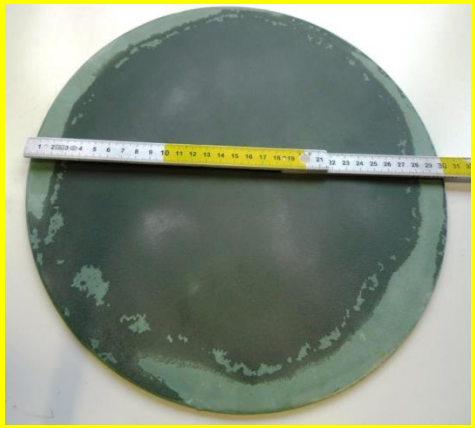
Fraunhofer IKTS Dresden –

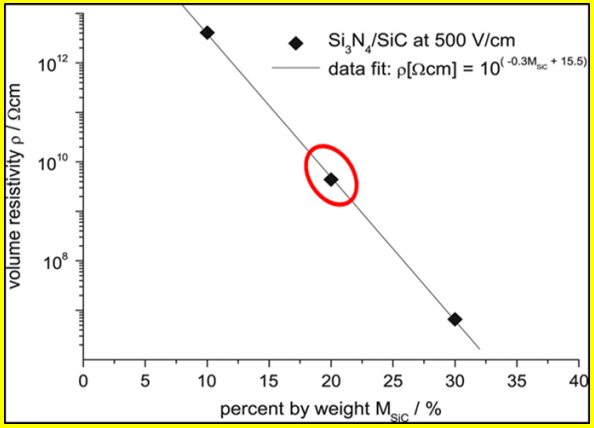
rough ceramics as sintered:

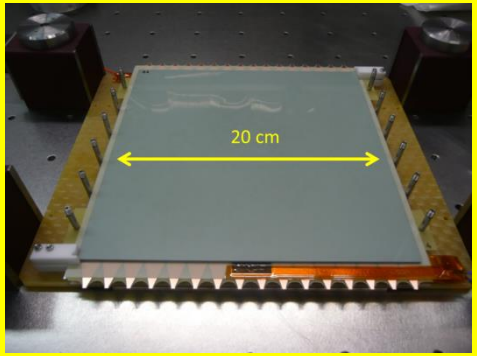
- Ø ≈ 30 cm
- d ≈ 3.5 mm

mixing ratio:

- Si_3N_4/SiC (80%/20%)
- cutting
- grinding
- polishing
- rounding







HZDR:

cleaning

drying

ρ, ε - measurement

detector assembling

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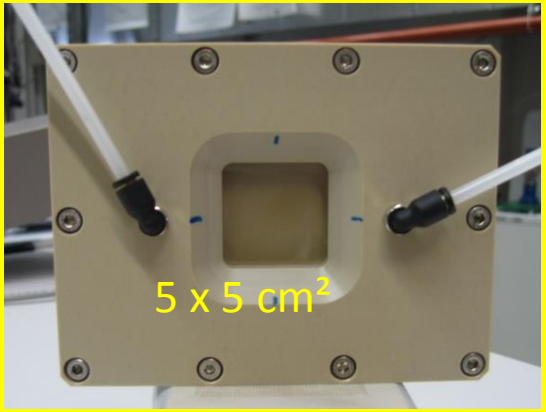
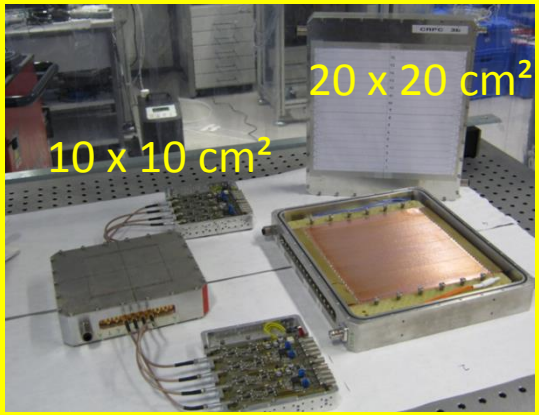
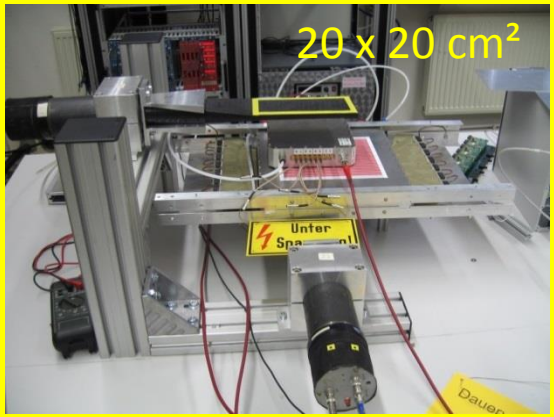
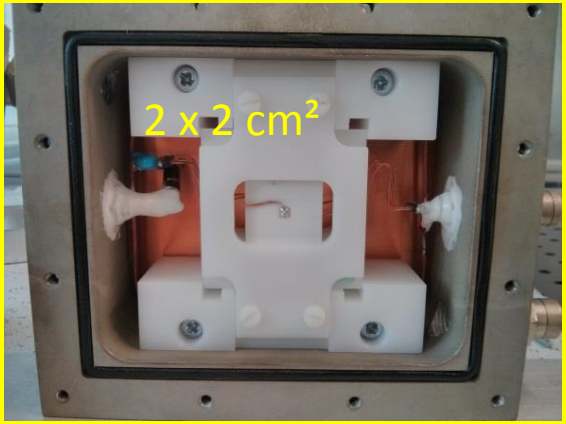
Resistive Plate Chambers @ HZDR



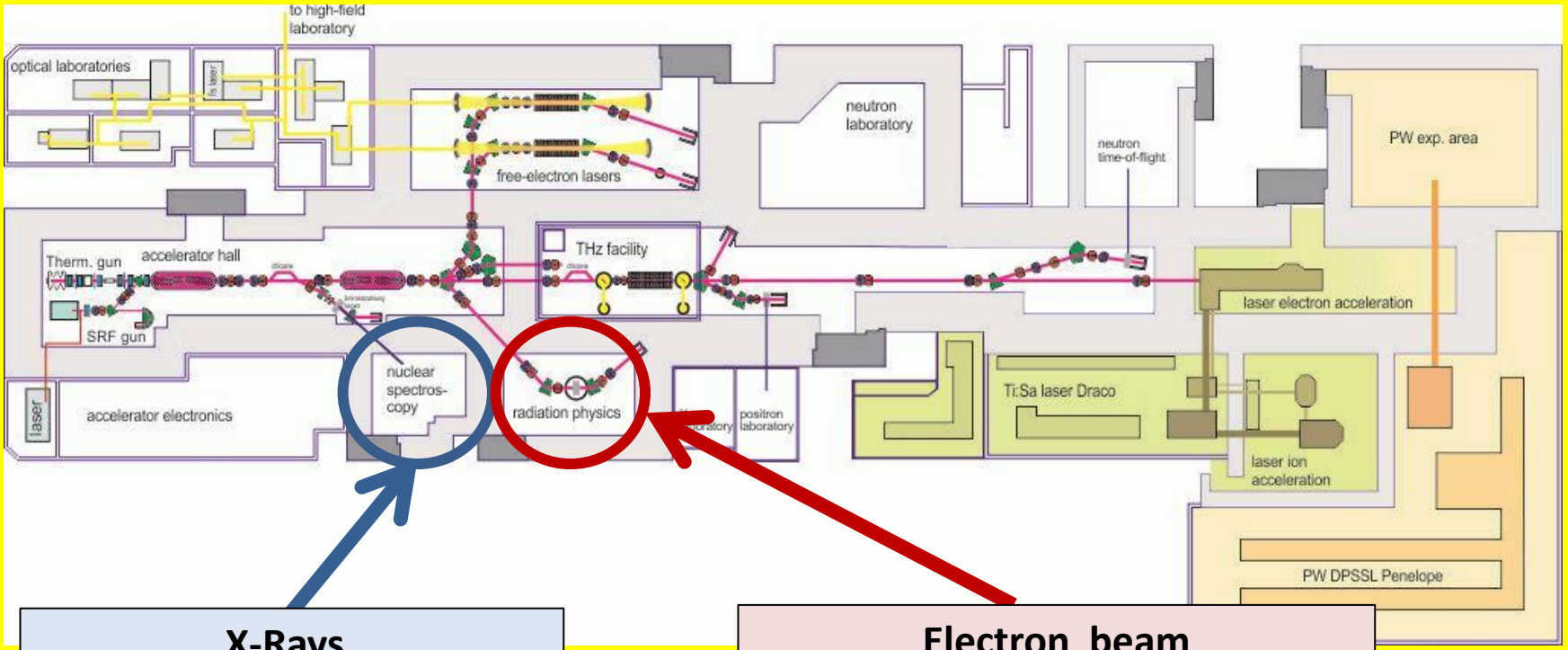






RPC area [cm²]	gas gap design			anode design		
	number	size [µm]	separator	number	length [cm]	width [cm]
2x2	3x2	250	ceramics	1	2	2
5x5	2	300	kapton	1	5	5
5x5	3x2	250	ceramics	1	5	5
10x10	2x2	250	fishing line	8	10	1
10x10	2x2	300	mylar	8	10	1
20x20	2x2	250	fishing line	16	20	1.125
20x20	2x2	300	mylar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

Detector test facility @ ELBE



X-Rays

energy spectra ≤ 20 MeV
pulse duration 5 ps
flux ≤ 500 kHz/cm²

Electron beam

monoenergetic , single electrons
energy 12 - 40 MeV
pulse duration 5 ps
flux ≤ 500 kHz/cm²

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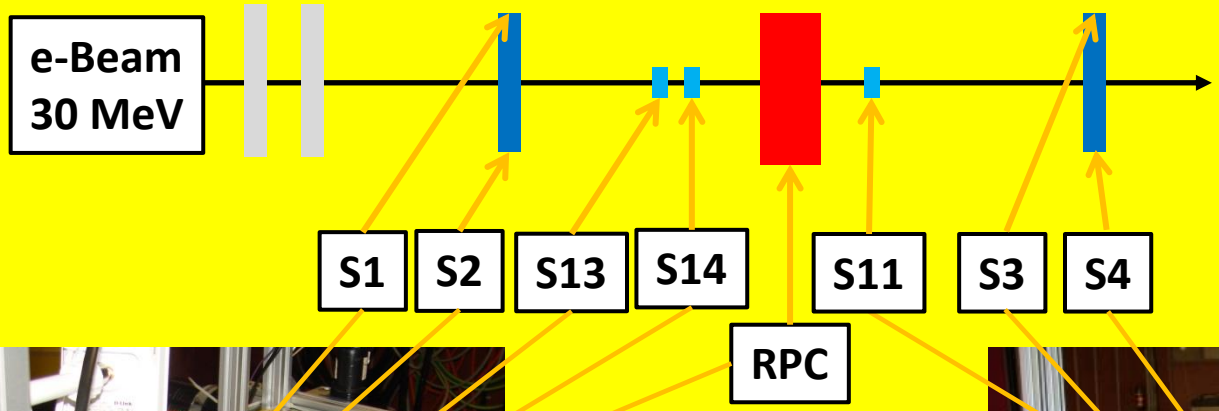
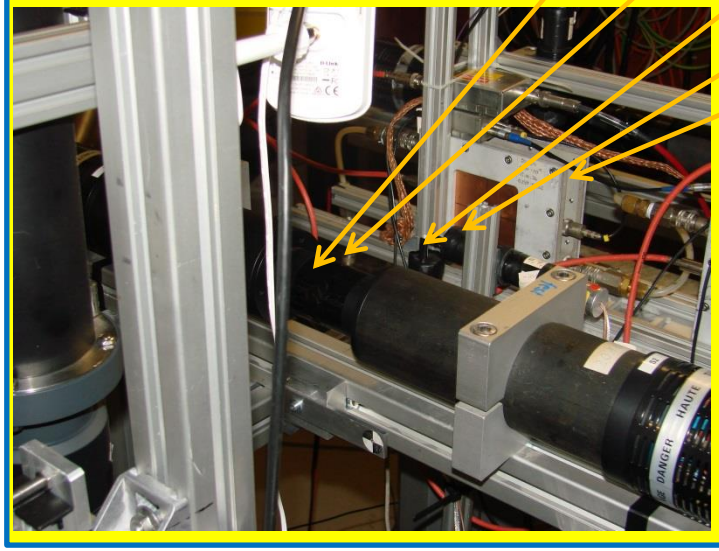
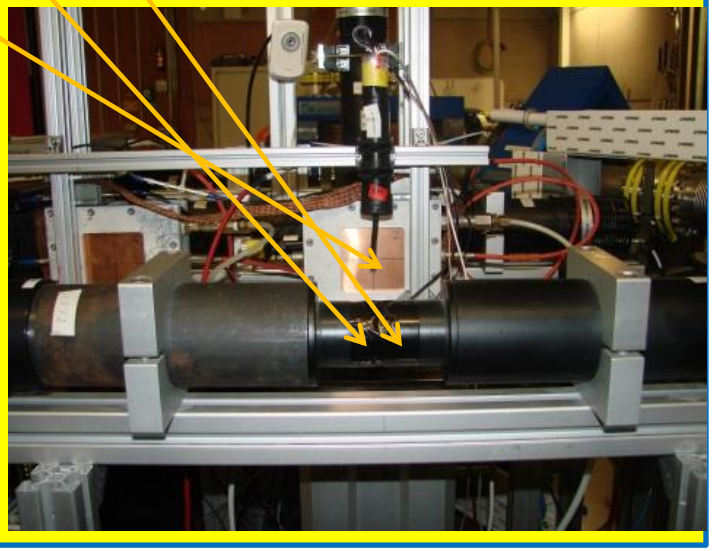
Detector test facility @ ELBE

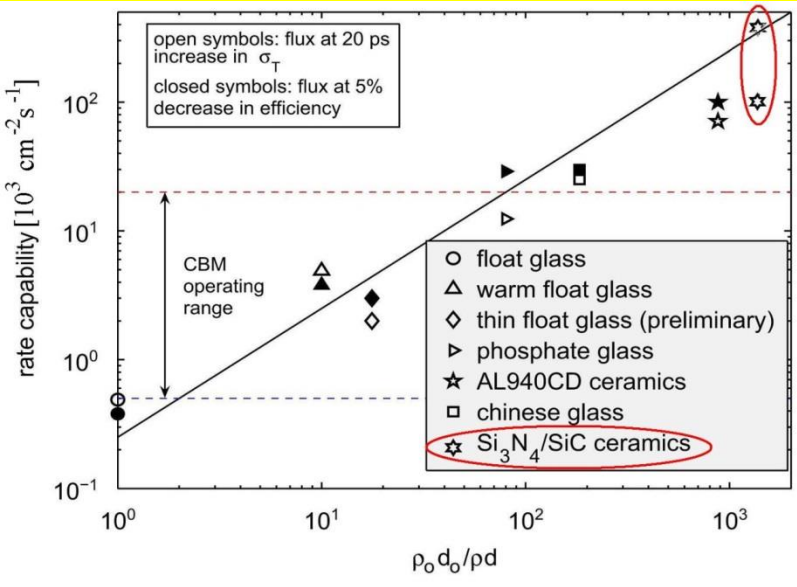
Gas: Freon /SF_6 /isobutan
Start system: σ_{RF} = 35 ps
Trigger scint. size: 5x5 to 20x20 mm^2



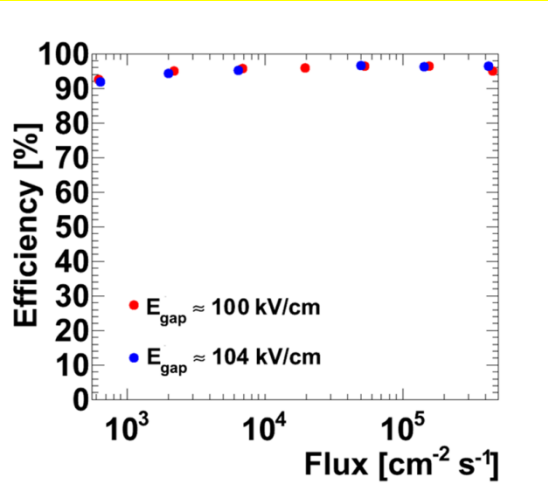


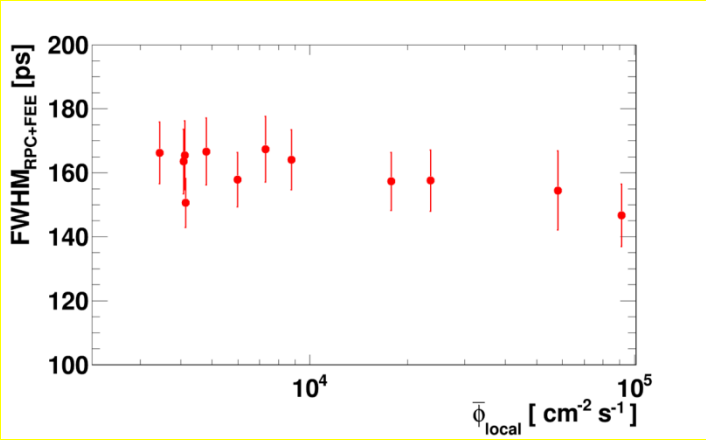


RPC rate capability results



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





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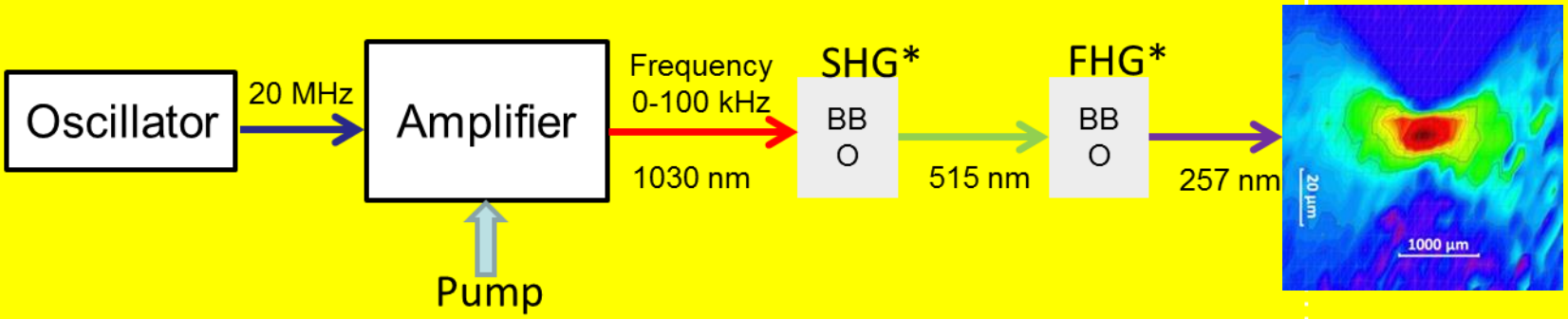
Laser facility for gaseous detectors

- Application of UV laser beams for calibration and surveying of gas filled detectors since 1979
  [MDC: M. Anderhub et al. NIM 166 (1979); RPC: E. Gorini et al. NIMA 425 (1999)]
- Micro-plasma creation inside a sub-millimeter narrow gas gap is up to now a technical challenge
  [RPC: Fonte et al. NIMA 613 (2010); L. Naumann et al., JINST V.9 (2014)]
- Townsend coefficient in a RPC gap

Laser facility for gaseous detectors



Laser parameters

- wavelength: 257 nm → 4.8 eV
- pulse repetition rate: ≤ 100 kHz
- pulse length: 2.5 ps
- beam envelope: r_{min} ≤ 10 µm, l_{Debye} = 300 µm
- beam flux density: ≤ 10^{11} W/cm²

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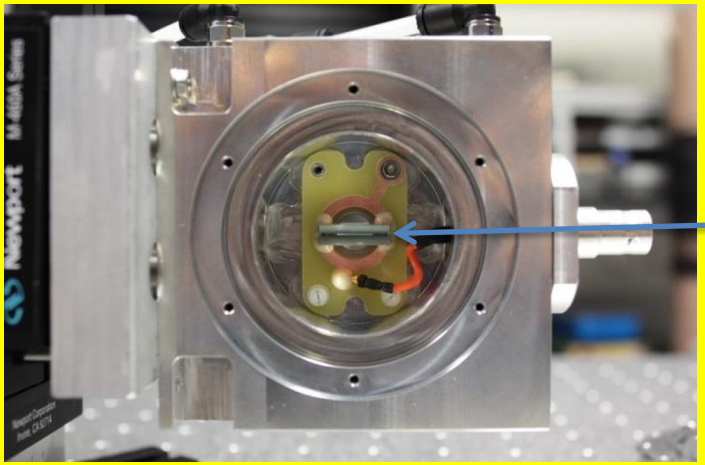
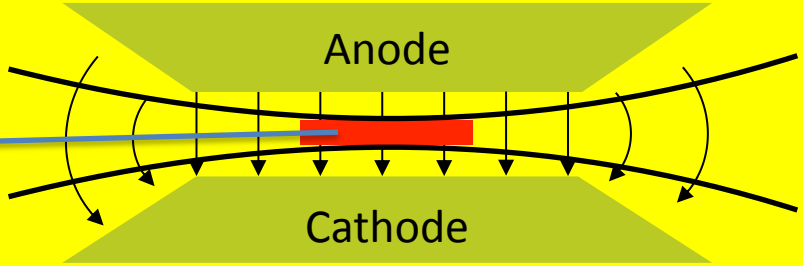
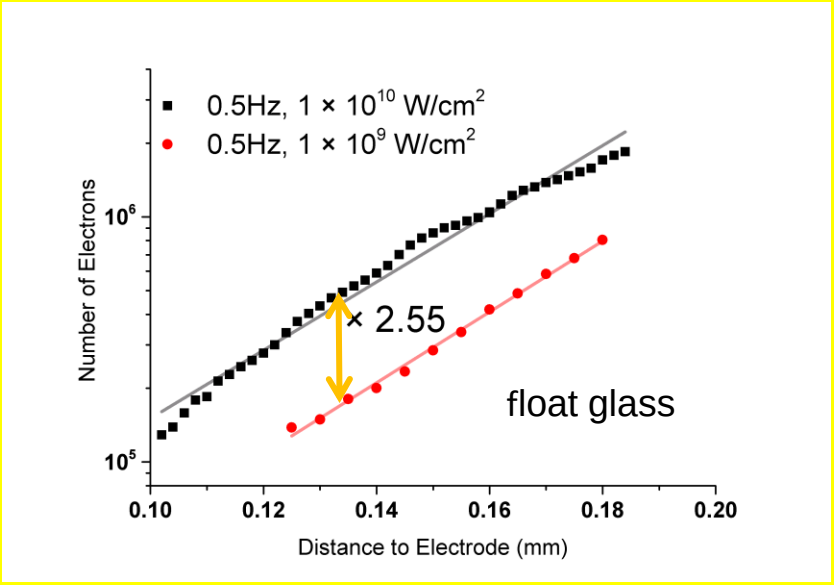
Laser facility for gaseous detectors



RPC probe



gap width 300 µm
el. field 100 kV/cm



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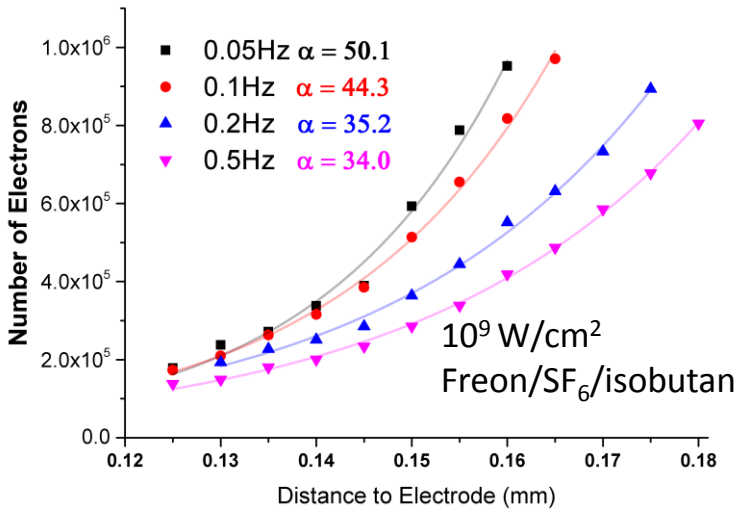
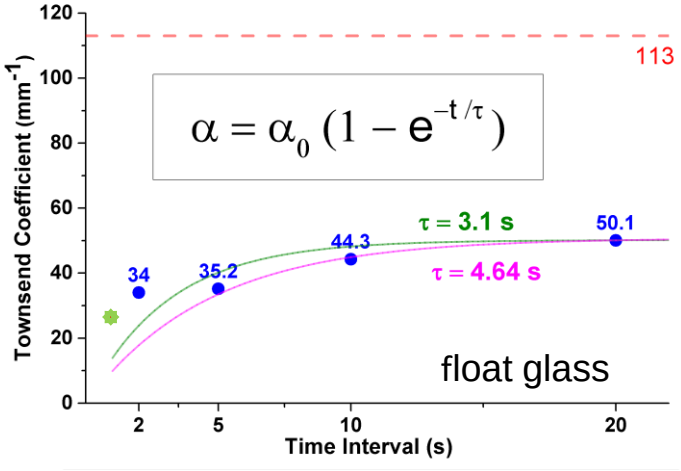
Laser facility results





- strong dependence on the laser rep. rate
- recovery time for float glass RPC is in the order of several seconds
- the Townsend coefficient follows a horizontal asymptote with $\alpha \approx 50\ mm^{-1}$

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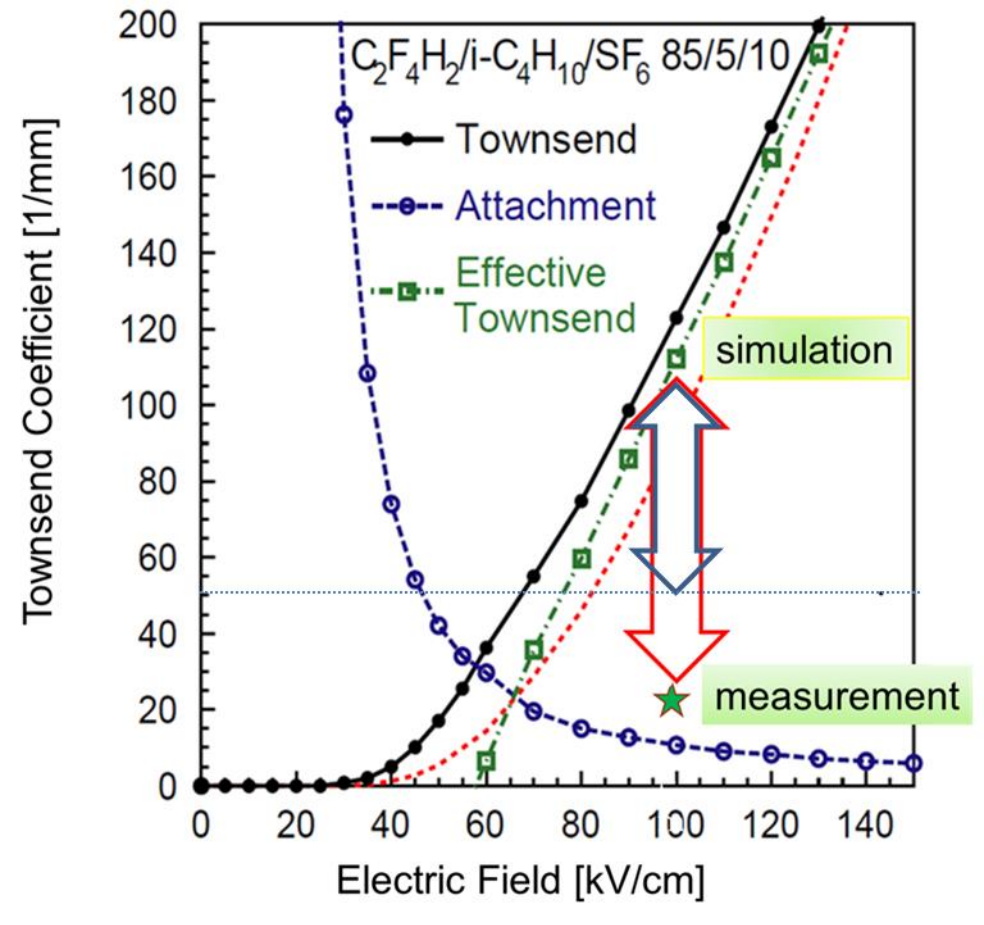
Laser facility result



W. Riegler et al., NIM A 500 (2003) 144

0.05 Hz rep. rate/ glass electrode / HZDR 2016

1.0 Hz rep. rate/ glass electrode / HZDR 2014
L. Naumann et al., JINST V.9 (2014)

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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_0C 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: **$\leq 1 - 2$ %**

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

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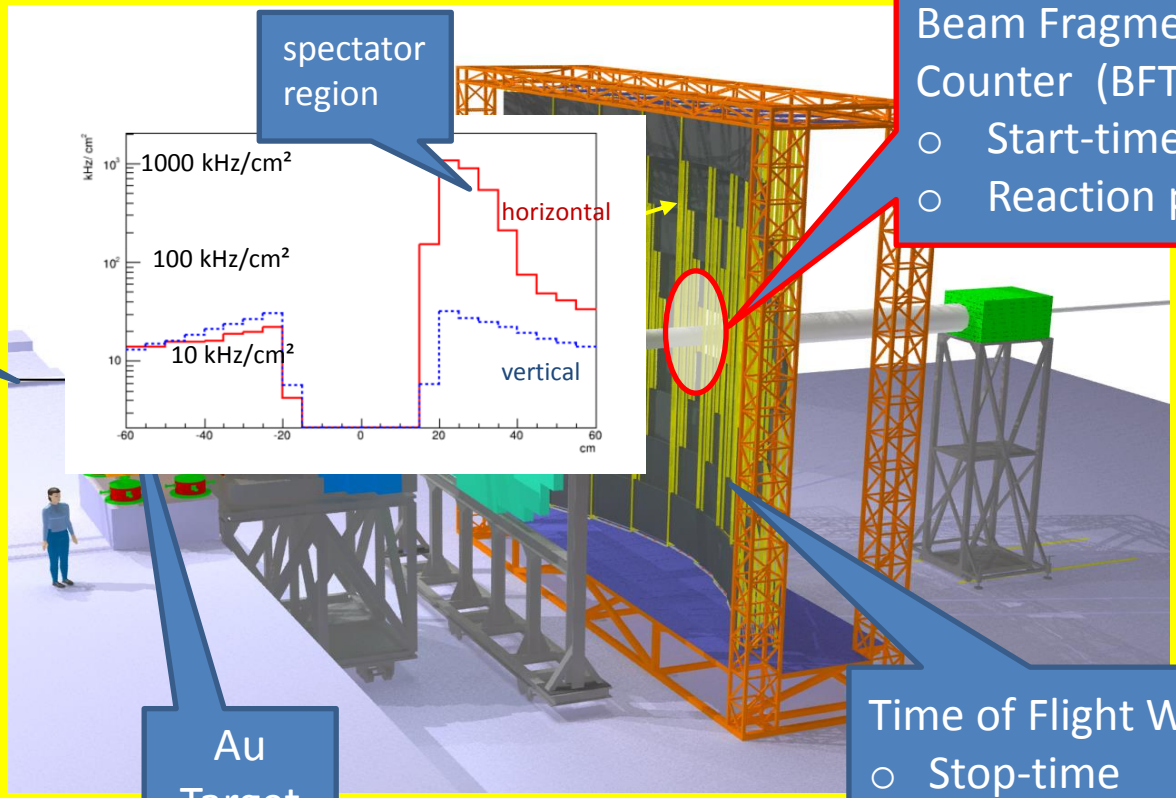
Beam Fragmentation T_0 Counter

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



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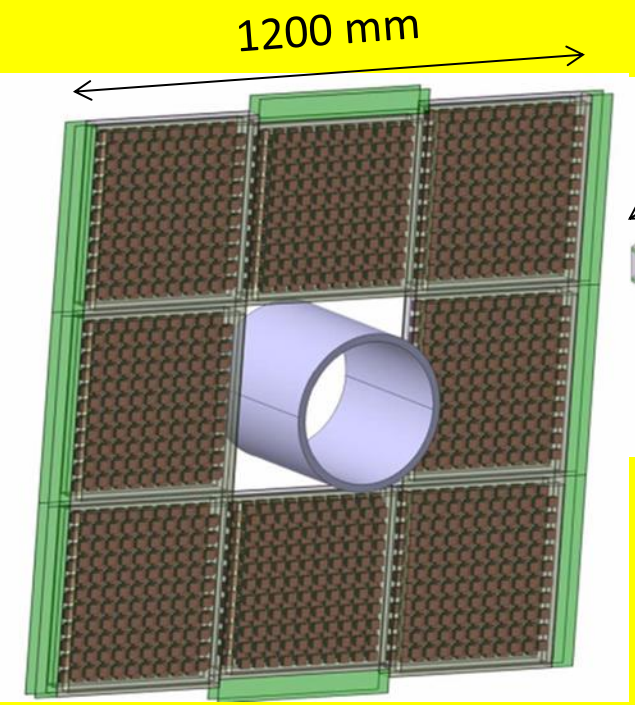
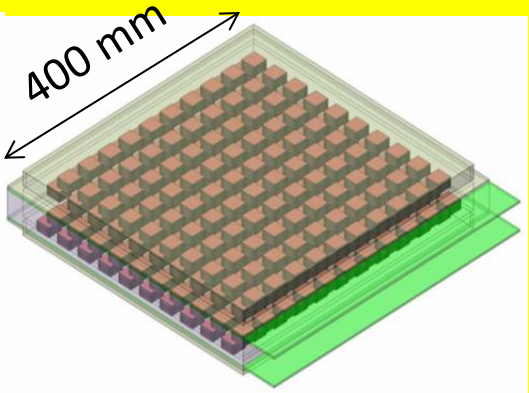
Beam Fragmentation T_0 Counter

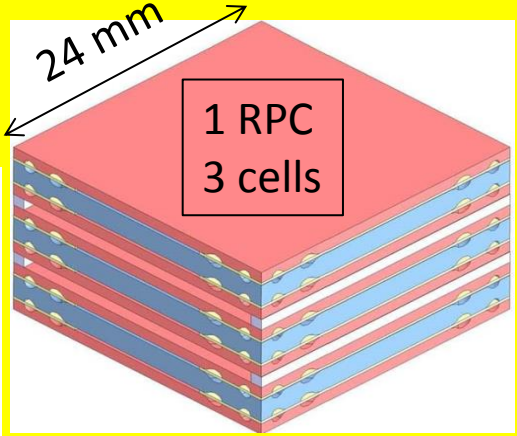
BFT_0C design

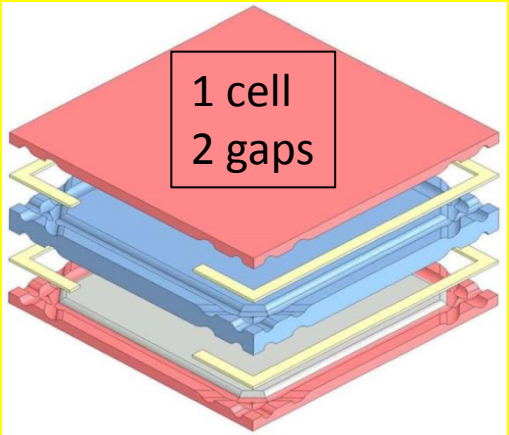


BFT_0C = 8 modules



1 module
400 RPC





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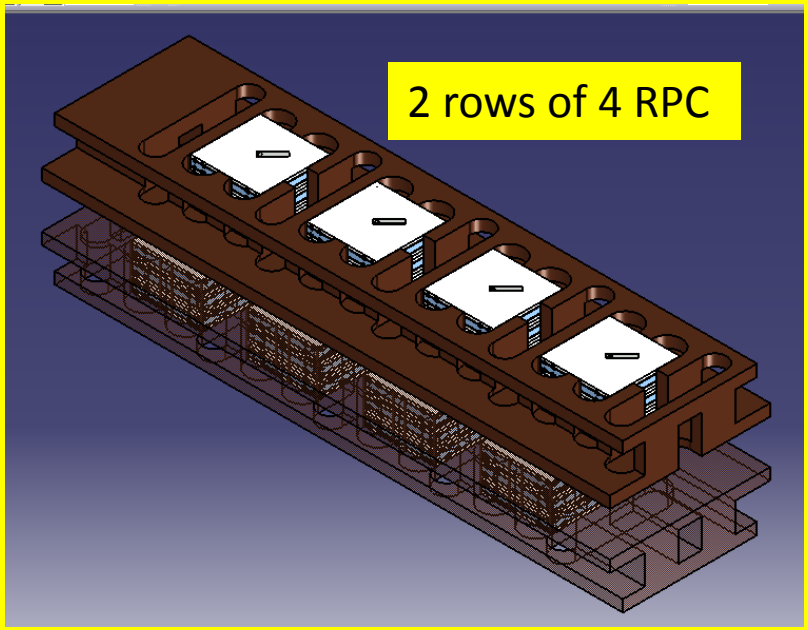
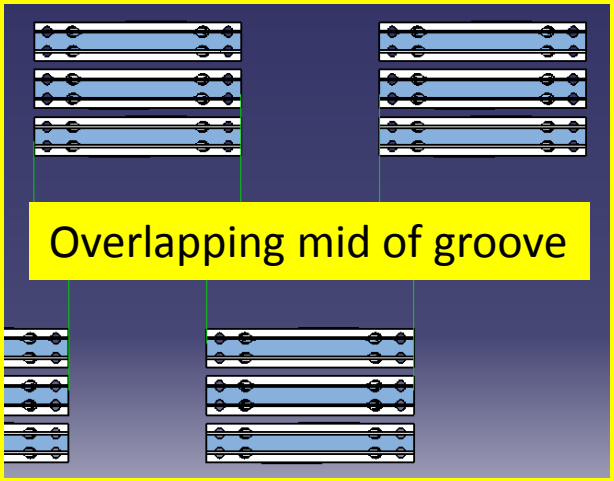
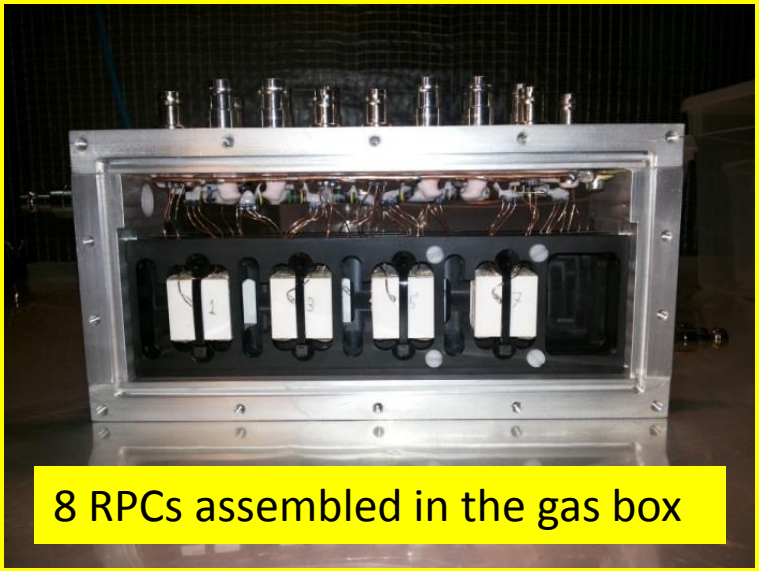
Demonstrator design





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} Ω·cm were tested.



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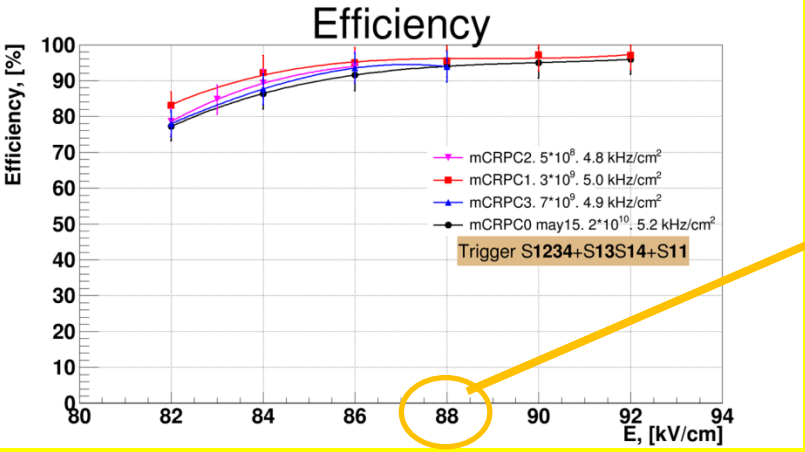
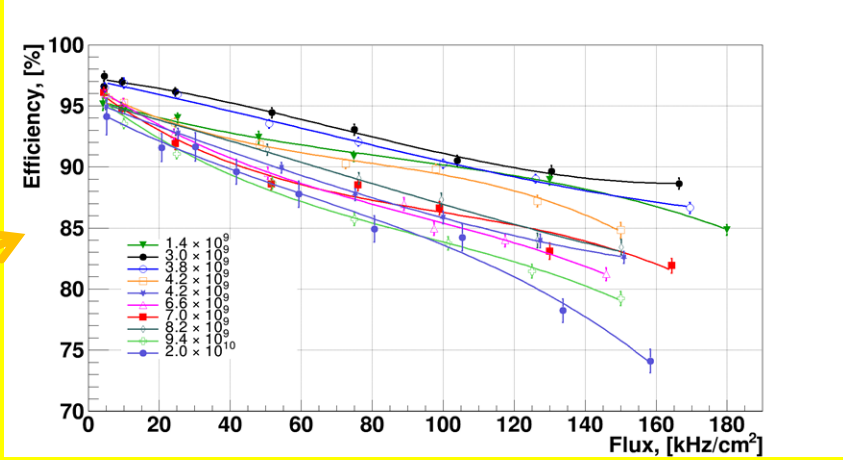
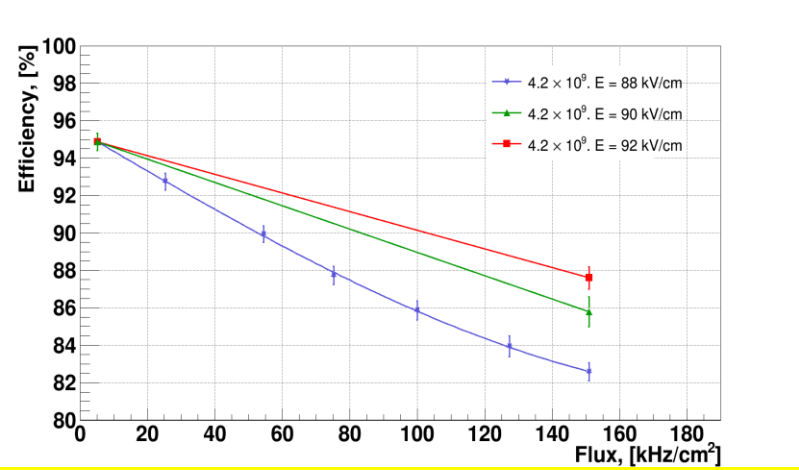
BFT_0C – efficiency (electrons)







- $2x10^{10}$ Ωcm: ε fast degrease with flux
- $5x10^{8}$ Ωcm: ε is not capable to get on the efficiency plateau: unstable work and lots of streamers starting from 87-88 kV/cm
- $3x10^{9}$ Ωcm: most suitable resistivity order for our aims

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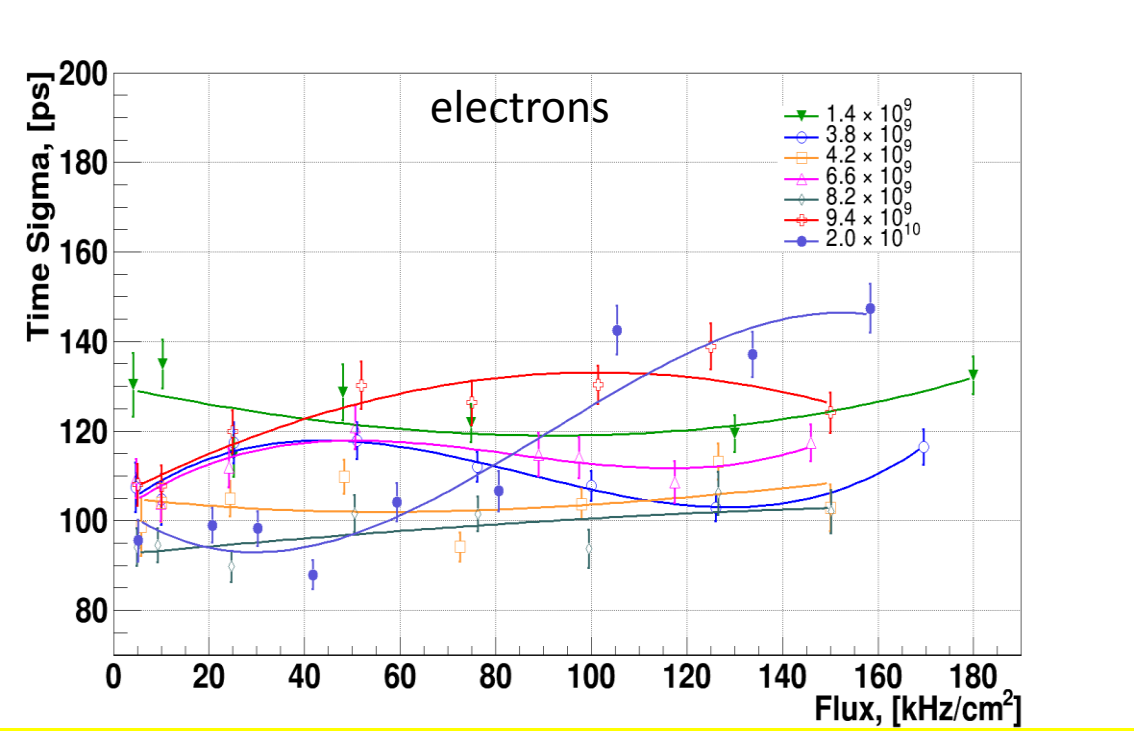
BFT_0C - time resolution



Time resolution : σ_{RPC} = 90-140 ps

Time start stamp: σ_{RF} = 35 ps

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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 and manufacturing process has been developed to produce ceramic electrodes with $3 - 5 \cdot 10^9$ Ω cm.
- The dark count rate has been reduced to 0.5 Hz/cm^2 by special material treatments .
- 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.

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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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