Performance in heavy -ion beam tests of a high time resolution and two-dimensional position sensitive MRPC with transmission line impedance matched to the FEE

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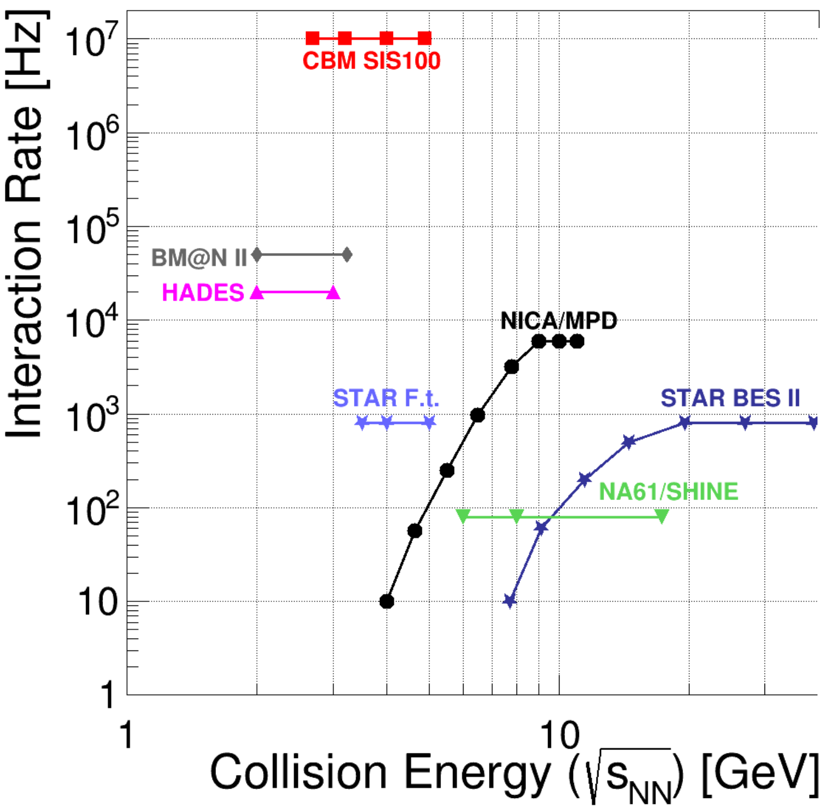
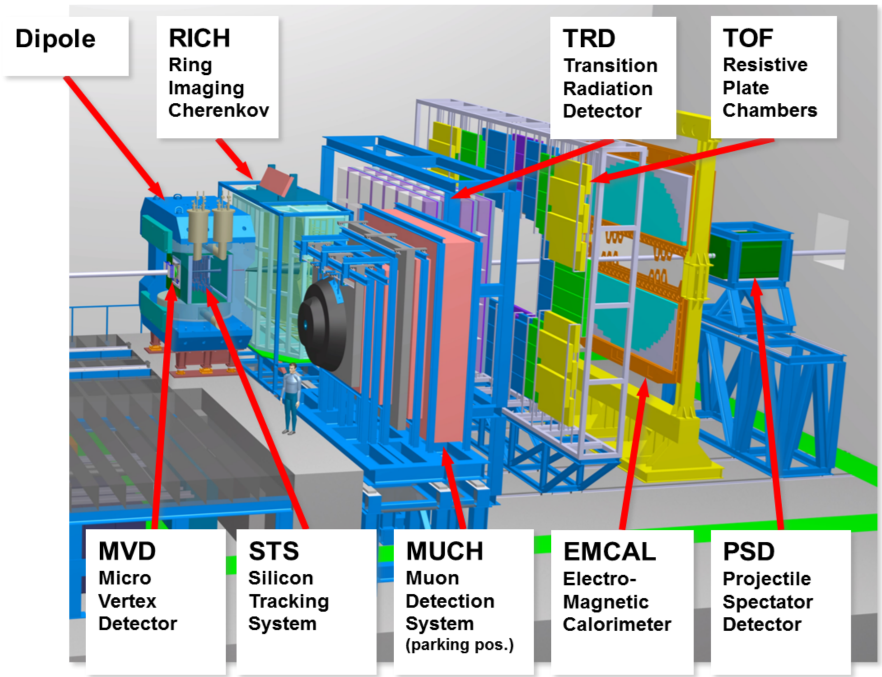
Outline

- Motivation – high counting rate, high multiplicity experiments, (e.g. CBM@FAIR, Darmstadt ->TOF inner wall)
- MSMGRPC with a high granularity and impedance matching to FEE
- Performance in the CERN SPS in-beam tests in triggered and trigger-less mode operation
- Conclusions and Outlook

CBM experiment @ SIS100



CBM experimental set-up



- **Tracking acceptance: $2° < \theta_{lab} < 25°$**
- **Free streaming DAQ**

  R_{int} = 10 MHz (Au+Au)

  except: R_{int} (MVD)=0.1 MHz
- **Software based event selection**

CBM: is a high rate experiment!

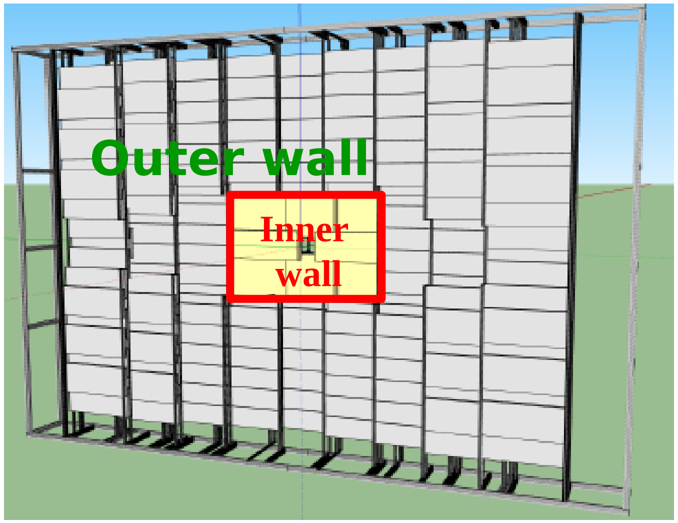
Opens up new possibilities!

- ✓ **Electromagnetic observables, charm production**
- ✓ **High statistics and good systematics on hadronic observables: multi-strange baryons, flow, fluctuations**
- ✓ **New (exotic) observables: kaonic clusters, hypernuclei**

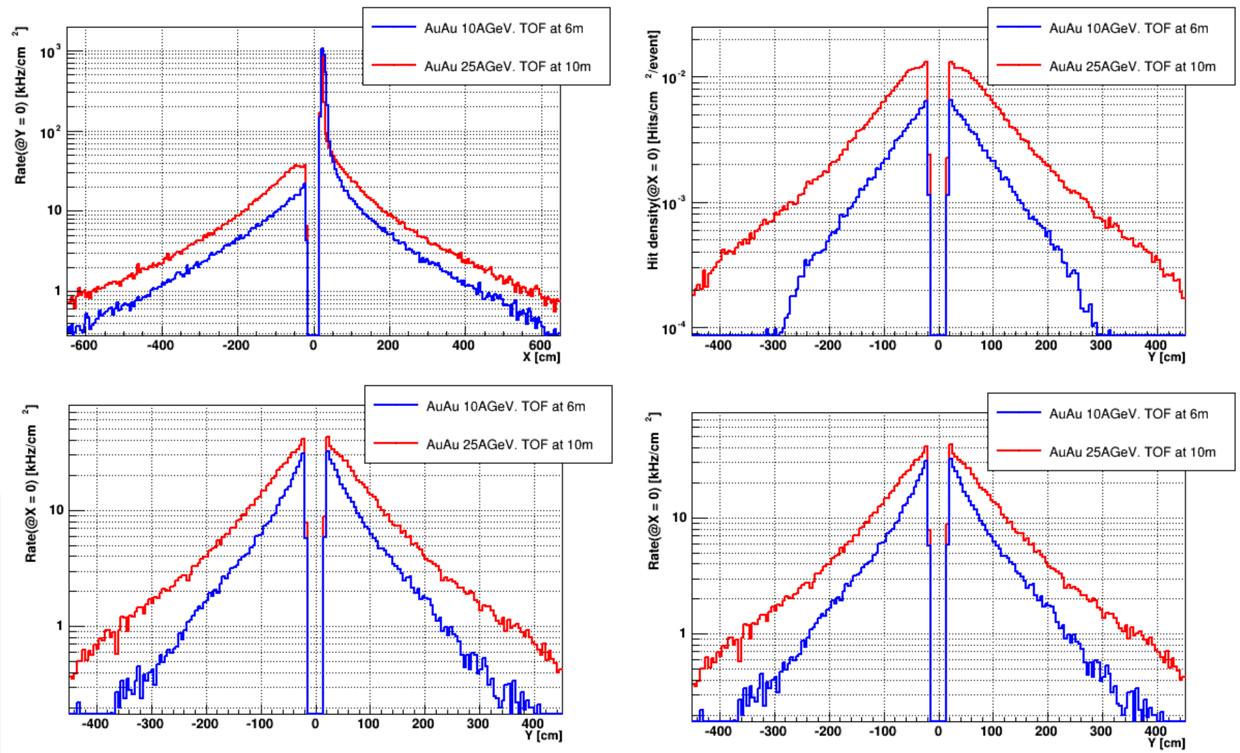
CBM Collaboration, Eur. Phys. J. A (2017) 53: 60

- ✔ **Fast and radiation hard detectors**
- ✔ **Novel readout system**
  - **no hardware trigger on events,**
  - **free streaming/trigger-less data**
  - **detector hits with time stamps**
  - **full online 4-D track and event reconstruction**

CBM – TOF requirements



URQMD simulated charged particle flux from Au + Au events for an interaction rate of 10 MHz



CBM-ToF Requirements

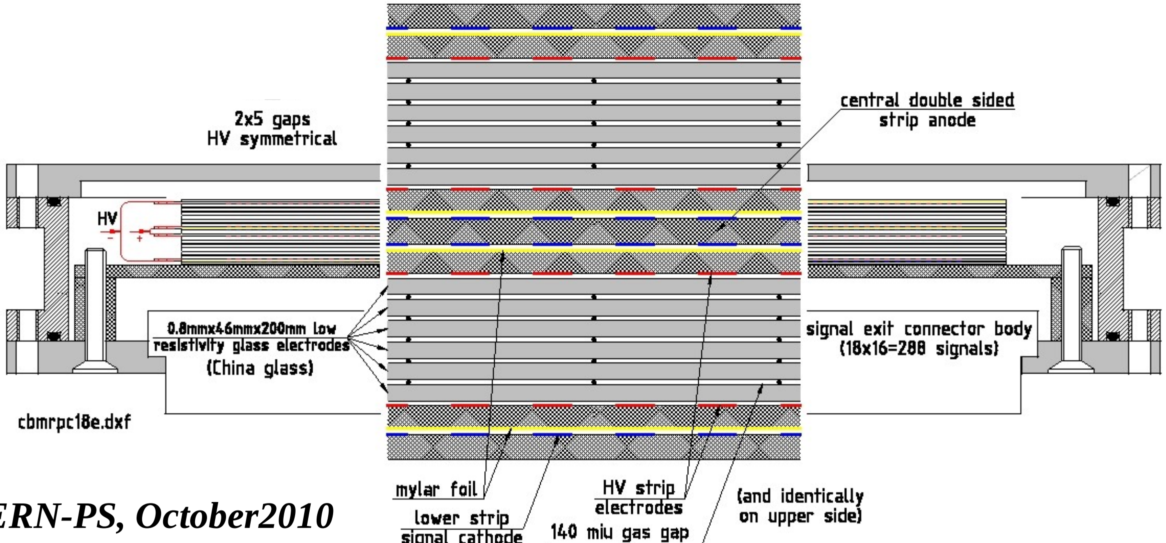
- Full system time resolution σ_T ~ 80 ps
- Efficiency > 95%
- Rate capability ≤ 30 kHz/cm^2
- Polar angular range 2.5° – 25°
- Active area of 120 m^2
- Occupancy < 5%
- Low power electronics (~120.000 channels)
- Free streaming data acquisition

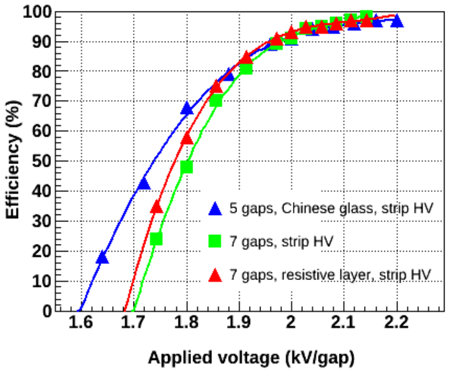
CBM Collaboration, "CBM – TOF Technical Desing Report", October 2014

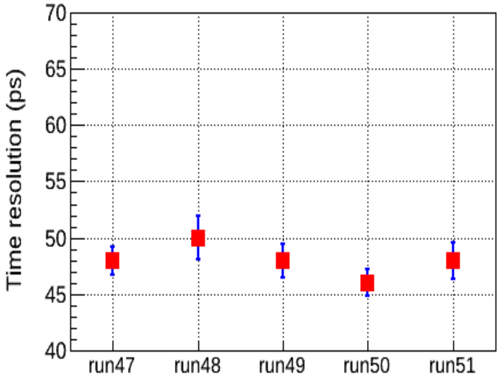
Detectors with different rate capabilities are needed as a function of polar angle

Our R&D activity addresses the CBM-TOF inner wall:
- highest counting rate
- highest occupancy
- ~15 m^2 active area

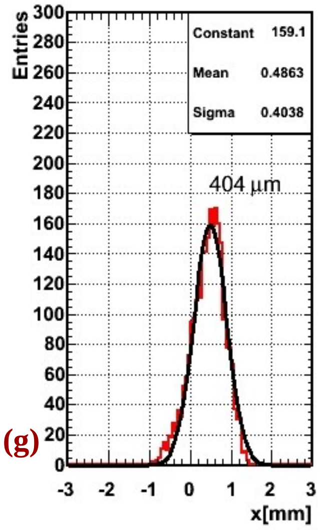
Double stack, strip readout, multigap, timing RPC concept - MSMGRPC

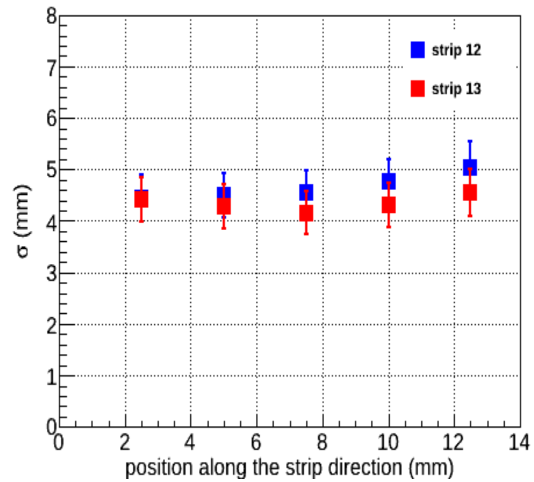


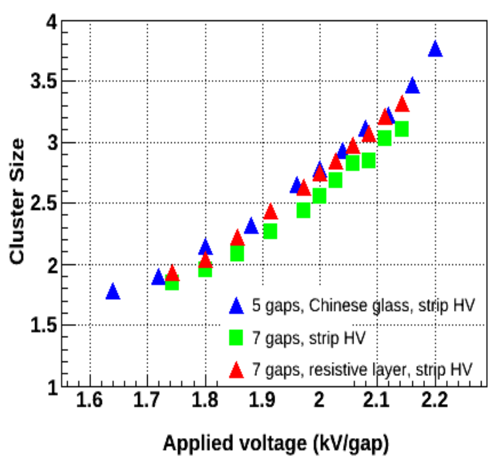




CERN-PS, October2010
Pion beam 6 GeV/c







Differential strip readout

2.54 mm pitch =1.1 mm(w)+1.44 mm (g)

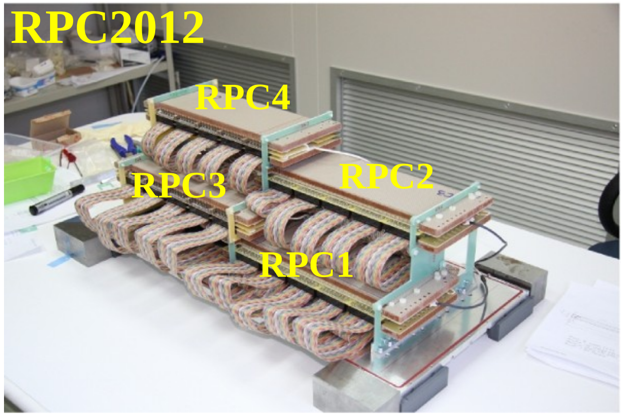
100 Ω transmission line impedance

Active area: 46 x 180 mm²

FEE based on NINO chip (ALICE-TOF Collaboration)

M.Petrovici et al. JINST 7 P11003, 2012

Basic architecture for MSMGRPC implementation in the inner zone of the CBM-TOF wall

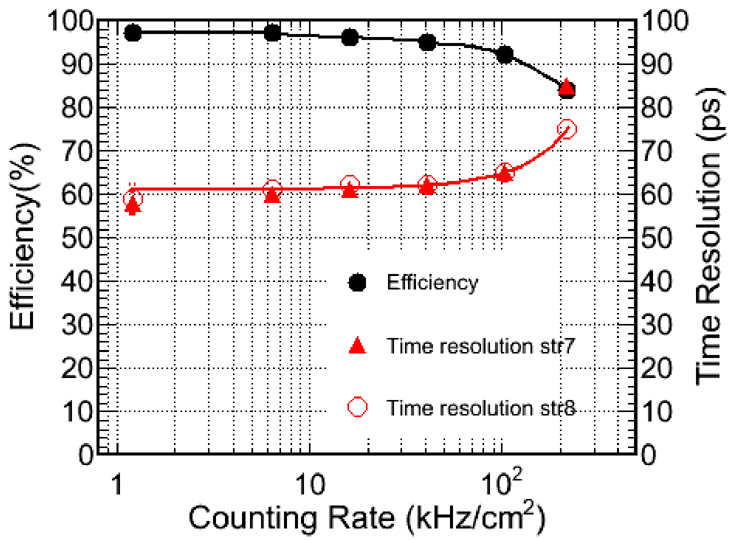


Counter architecture:

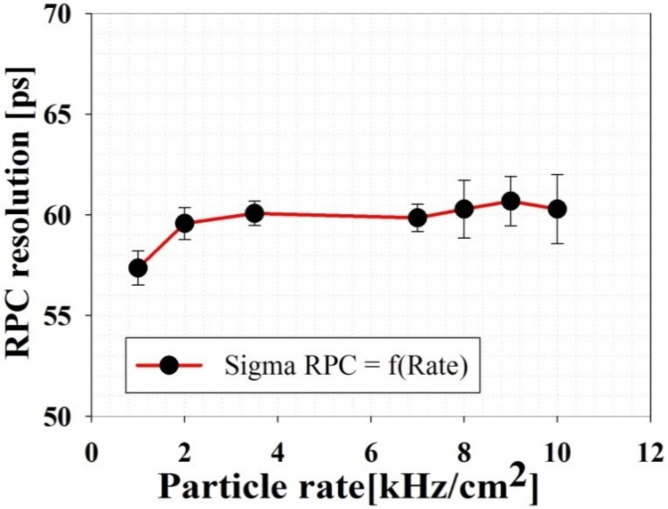
Electrodes: 0.7 mm low resistivity (~10^{10}Ωcm) Chinese glass (with a maximum size of ~30 cm x 30 cm)
Gap size: 140 μm thickness
Symmetric two stack structure: 2 x 5 gas gaps
Strip geometry for both readout and high voltage electrodes
7.4 mm strip pitch = 5.6 mm width + 1.8 mm gap
Differential readout, 50 Ω impedance
Active area: 96 (strip length) x 300 mm^2

Staggered configuration on both x and y directions with an overlaps of the strips along and across the strip direction

Focused proton beam, 2.5 GeV/c @ COSY Jülich



Ni beam 1.9A GeV on Pb target, GSI Darmstadt , exposure of whole active area

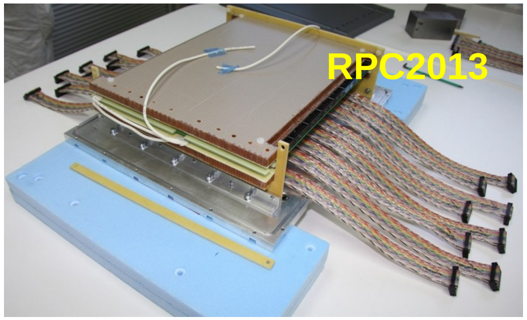


FEE based on NINO chip (ALICE-TOF Collaboration)

M. Petris et al., Journal of Phys: Conf. Series 533 (2014) 012009

M. Petris et al., Journal of Phys: Conf. Series 724 (2016) 012037

Performance in multi-hit environment



- ✓ Active area 200 (strip length) x 266 mm^2
- ✓ Pitch=2.16 mm (w) +2.04 mm (g) = 4.2 mm
- ✓ Differential readout, 100 Ω impedance
- ✓ Anode architecture: Cu strips between two FR4 layers of 0.25 mm

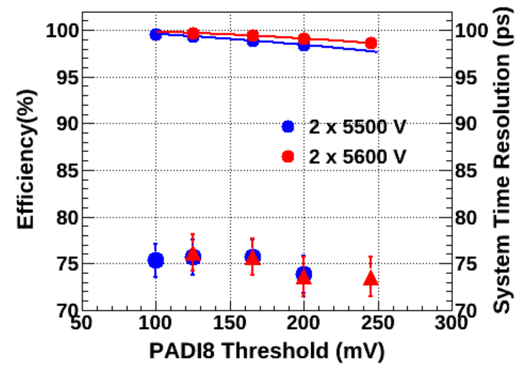
CERN SPS, February 2015
13A GeV Ar on Pb target

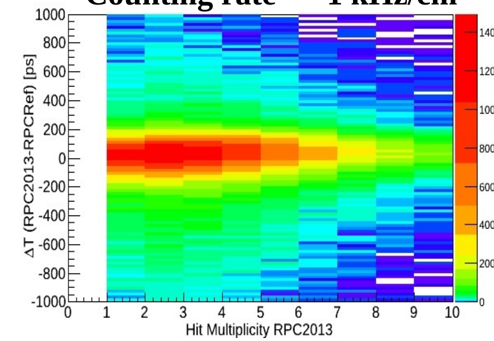
FEE based on PADI chip (CBM-TOF Collaboration)
(IEEE Trans. Nucl. Sci. 61 (2014), 1015
DAQ: FPGA TDC (GSI Scientific Report 2014 (2015), 121
+ TRB3 data hubs (http://trb.gsi.de/)

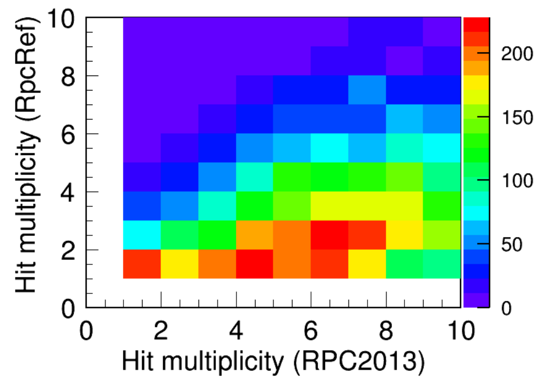
GSI Darmstadt, October 2014

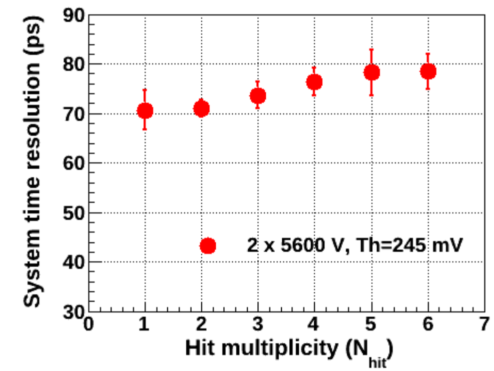
1.1 GeV/u ^{152}Sm beam on Pb target

Counting rate = ~1 kHz/cm^2





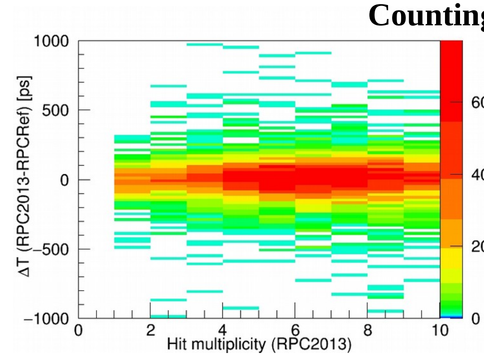


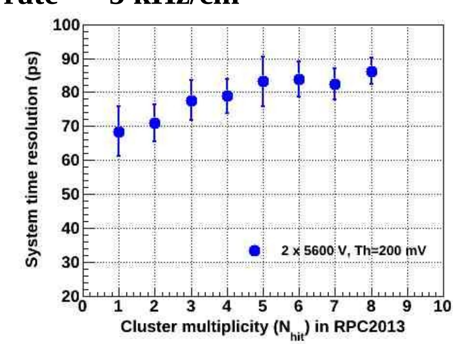


Goal – compatibility with PADI FEE developed within CBM-TOF Collaboration

CERN SPS, February 2015, 13 GeV/u Ar on Pb target

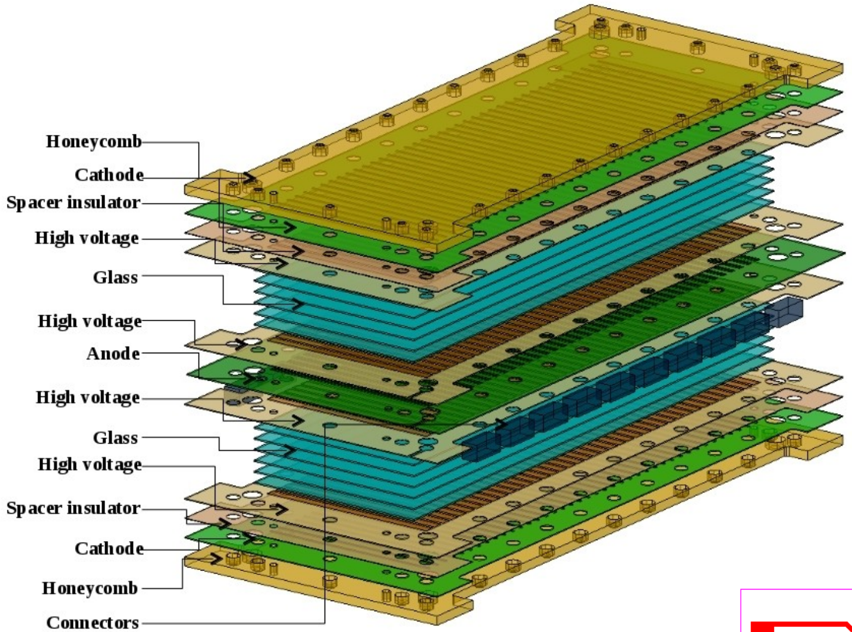
Counting rate = ~5 kHz/cm^2

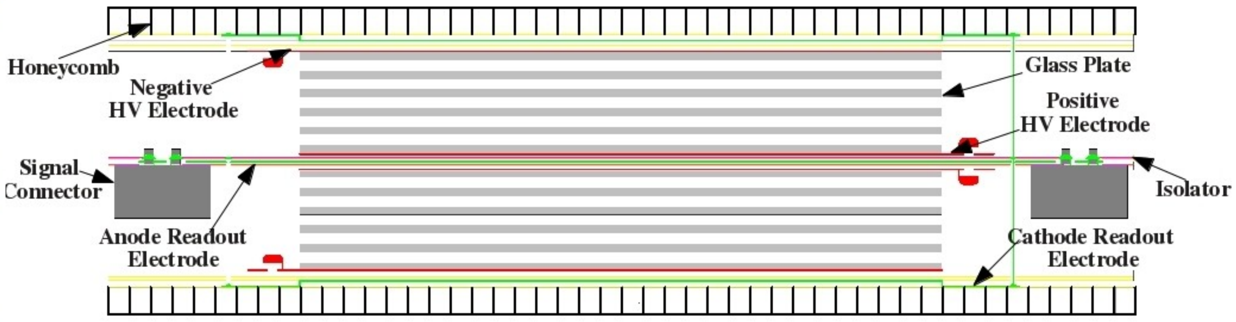




M.Petris et al. JINST 11 C09009, 2016

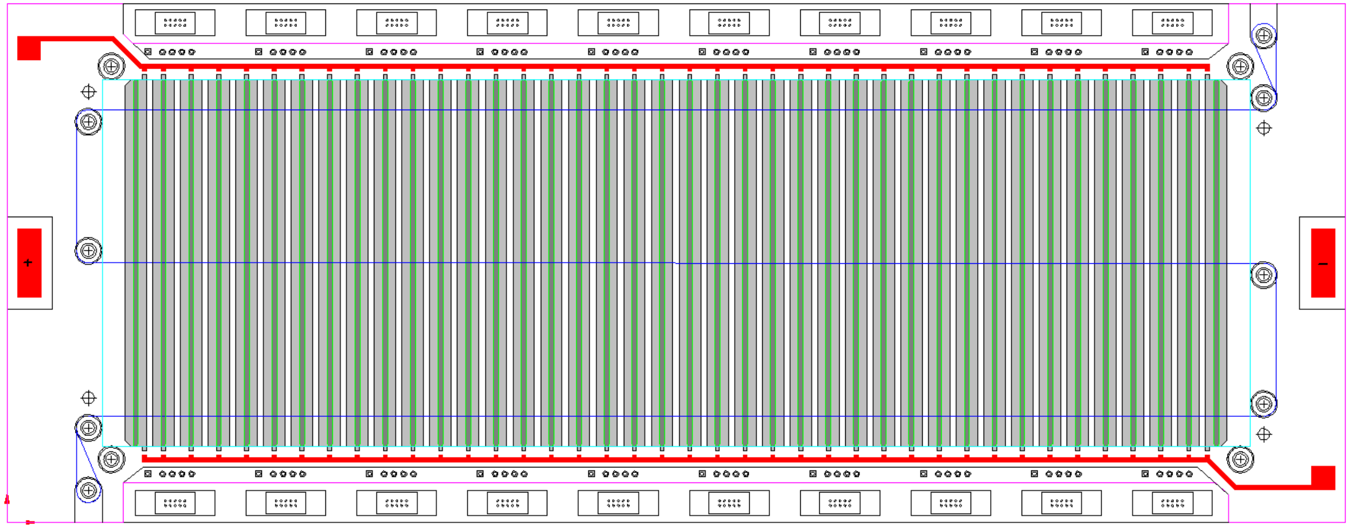
RPC2015DS prototype - strip impedance tuned through the readout strip width





Goal – perfect matching of the impedance of the signal transmission line to the imput impedance of the FEE, in order to reduce the amount of fake information resulted from reflections.

- ✓ Symmetric two stack structure: 2 x 5 gaps
- ✓ Active area 96 x 300 mm^2
- ✓ Gas gap thickness: 140 µm thickness
- ✓ Readout electrode = 40 strips
- ✓ Differential readout = 100 Ω impedance
- ✓ Resistive electrodes: low resistivity glass

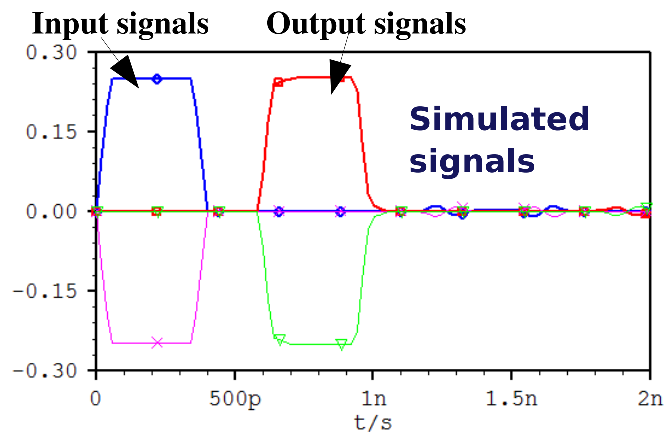


Readout electrode: 7.2 mm pitch= 1.3 mm width + 5.9 mm gap – define impedance

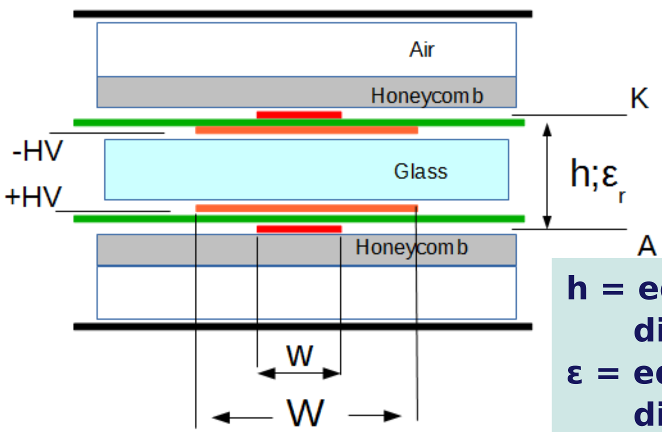
High Voltage electrode: 7.2 mm pitch= 5.6 mm width + 1.6 mm gap – define granularity

Simulation of the transmission line impedance

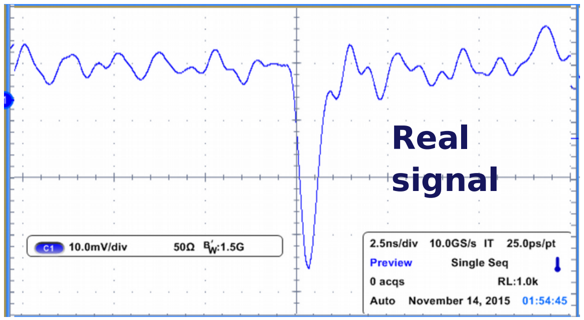
- The readout strips overlapped with the corresponding anode and cathode HV ones define a signal transmission line (STL)
- STL impedance depends on the readout strip width and the properties of the material layers in between.



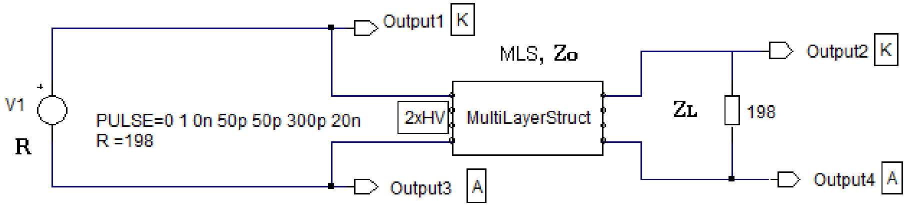
Input/Output signals are simulated using APLAC software for different values of the readout strip width

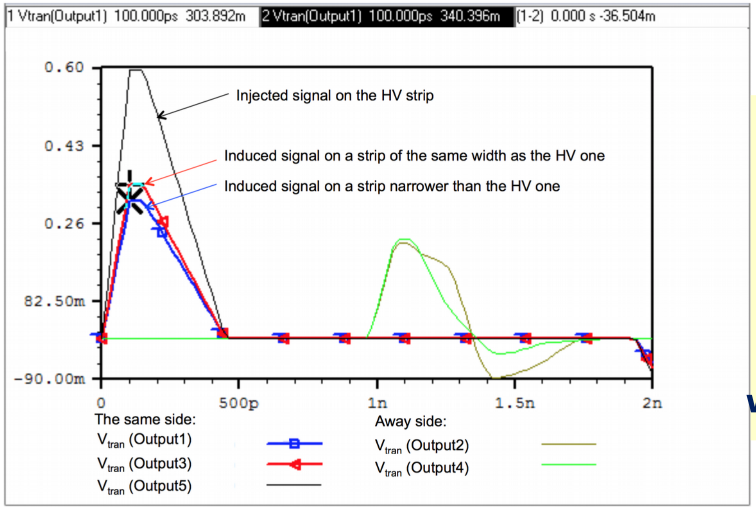


h = equivalent dielectric thickness
ε = equivalent dielectric constant



Simulations predicted 99 Ω impedance for 1.3/5.9 mm readout/HV strip widths





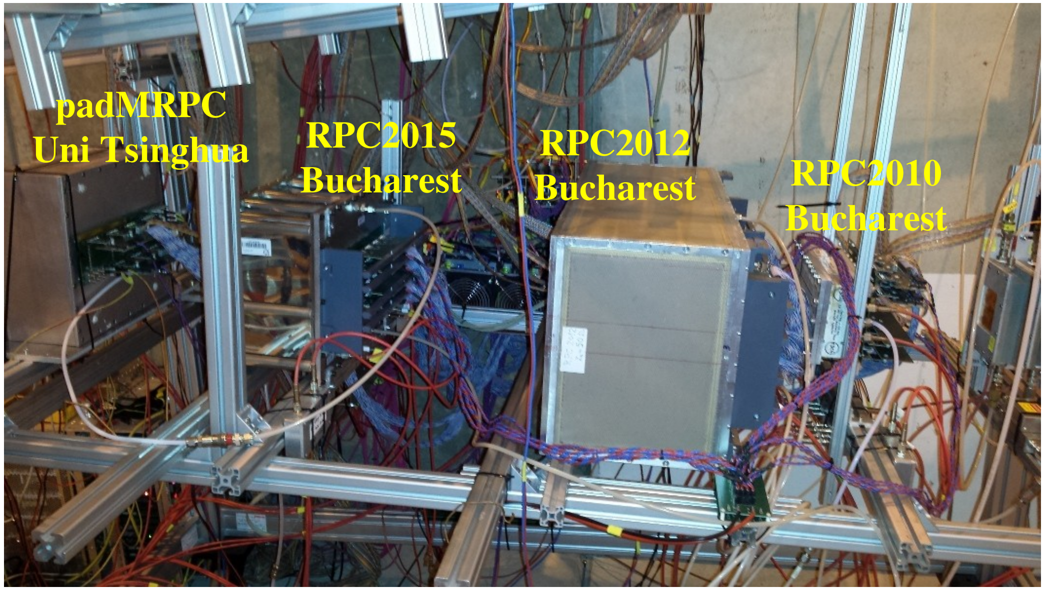
No significant signal loss occurs due to the narrow readout strip in comparison with the HV one

If R = Z_0= Z_L the transmission line is matched;
Z_0 = characteristic impedance of a transmission line
Z_L = load resistor connected to the transmission line
R = internal resistance of the pulse generator

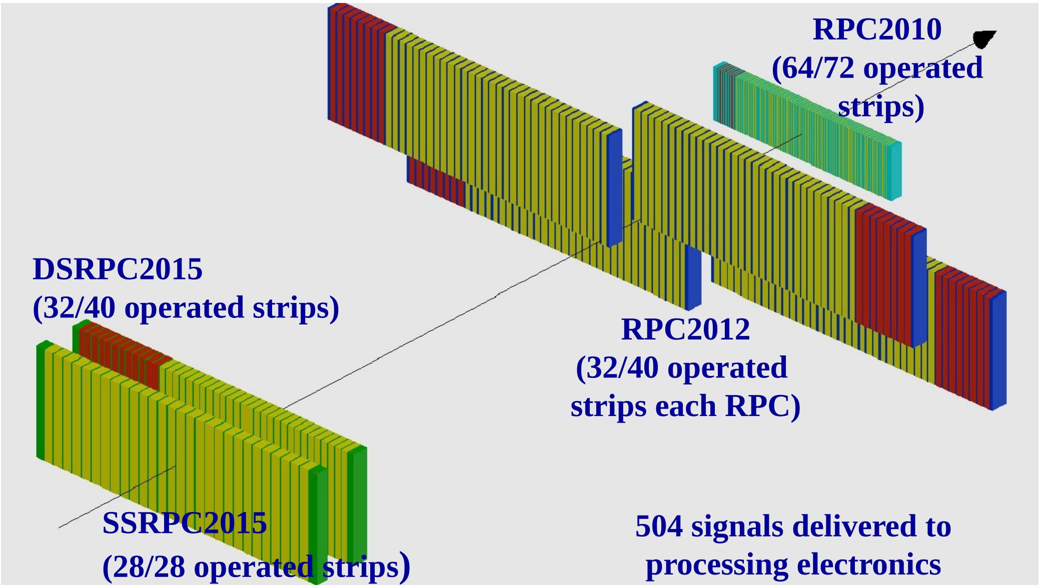
D. Bartos et al. Romanian Journal of Physics 63, 901 (2018)

November 2015 CERN - SPS in-beam tests

Pb beam of 30A GeV on a Pb target



Spatial overlap of the RPCs active area

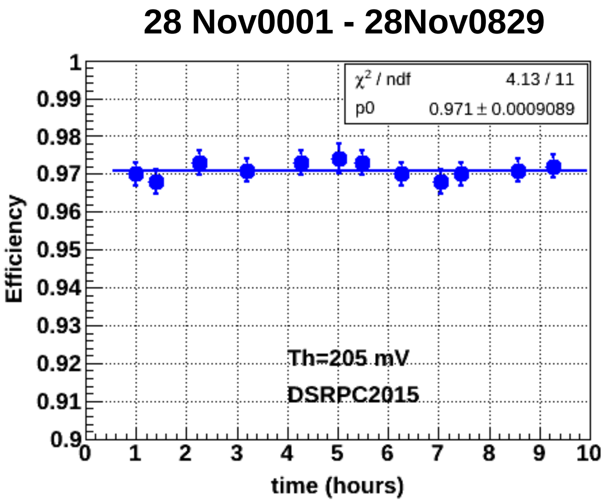


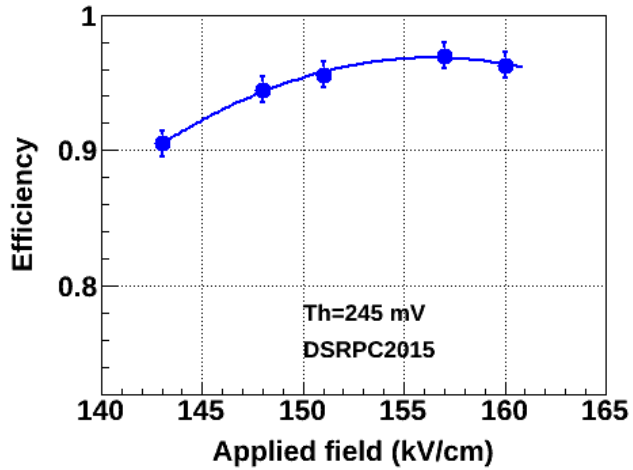
Gas mixture: 85%$C_2H_2F_4$ + 5%iso-C_4H_{10} +10%SF_6

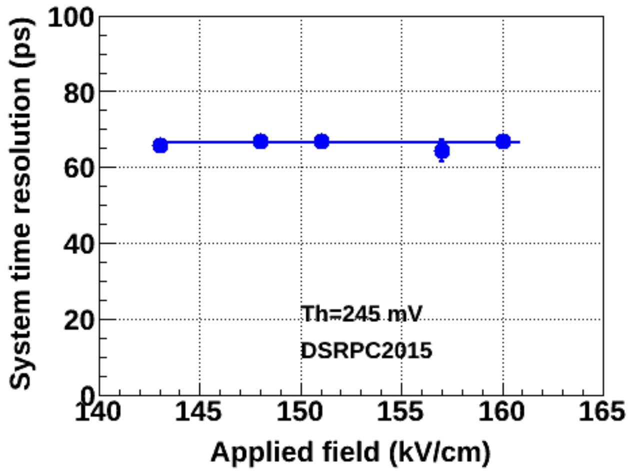
Experimental set-up – ~3.0 relative to the beam line

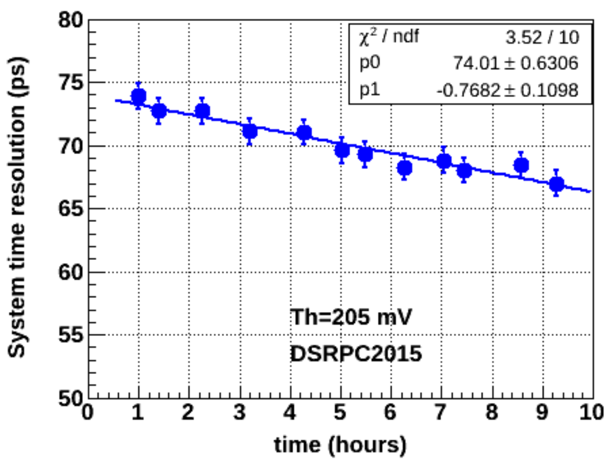
- ***RPC2015 Bucharest – 2 MRPCs***
  - ***SS. 10.1 mm strip pitch (see next slide) – 28 operated strips out of 28/RPC – 100% active area***
  - ***DS. 7.2 mm strip pitch (see next slide) – 32 operated strips out of 40/RPC – 80% active area***
- ***RPC2012 Bucharest – 4 MRPCs – 32 operated strips/RPC out of 40/RPC – 80% active area***
- ***RPC2010 Bucharest – 1 MRPC – 64 operated strips out of 72/RPC - 89% active area***
- ***FEE based on PADI chip (CBM-TOF Collaboration)***
- ***Triggered DAQ based on FPGA TDCs & TRB3 data hub***

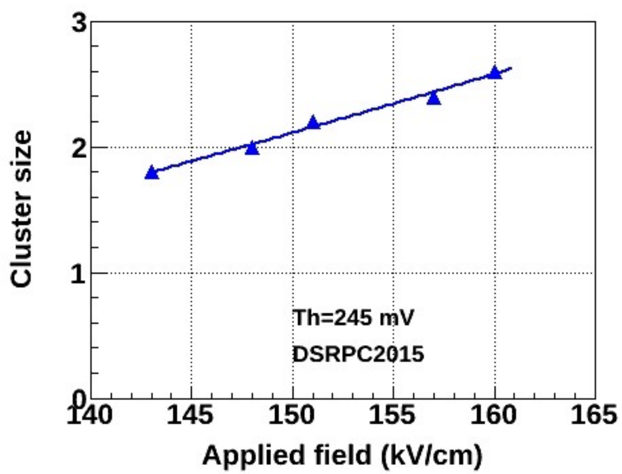
Efficiency and time resolution in high multiplicity environment











System time resolution

(including electronics contribution)

$$\sigma_{TOF} = \sqrt{\left(\left(\sigma_{RPC\,2015}\right)^2 + \left(\sigma_{RPCRef}\right)^2\right)}$$

DUT = DSRPC2015, Ref = SSRPC2015

HV DSRPC2015 = 157 kV/cm, Th = 205 mV

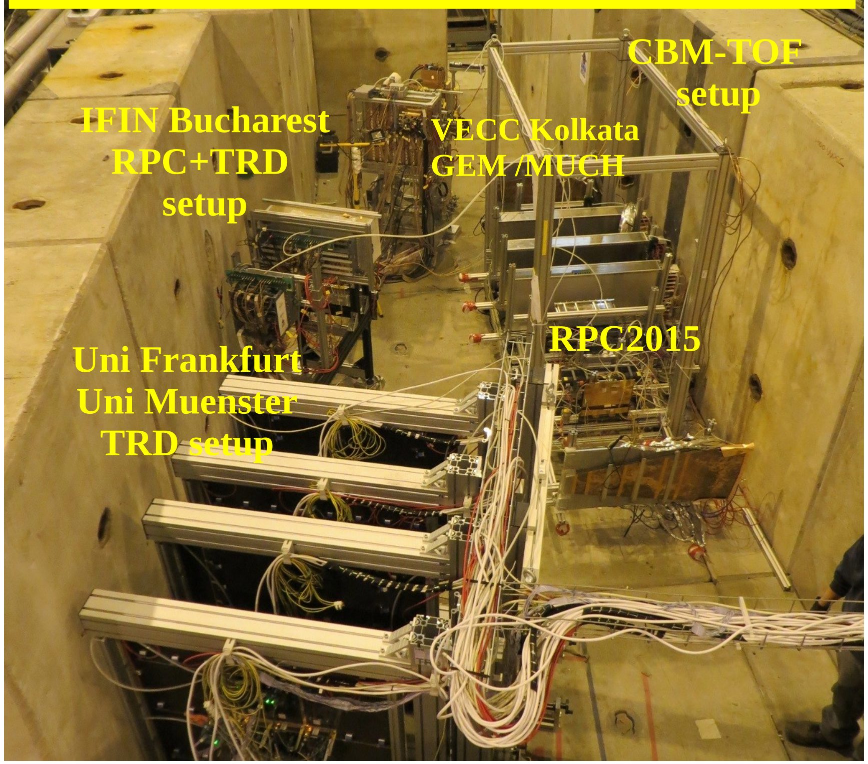
HV SSRPC2015 = 157 kV/cm, Th = 205 mV

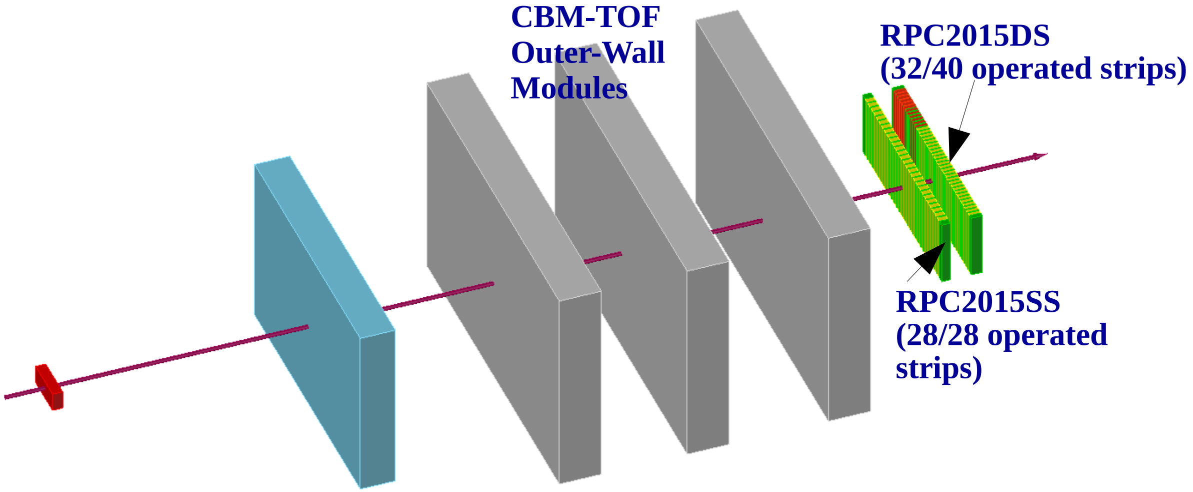
- ✓ **System time resolution = 66 ps**
- ✓ **The efficiency plateau is reached @ 96% -97%**
- ✓ **The cluster size is 2.2 – 2.6 @ efficiency plateau**

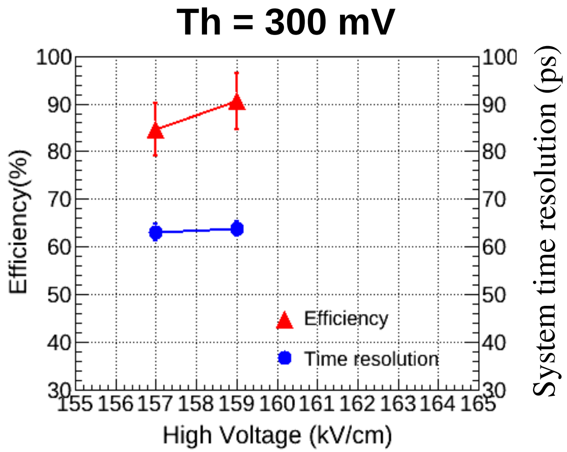
First operation of a free streaming/trigger-less DAQ in a CBM-TOF in-beam test

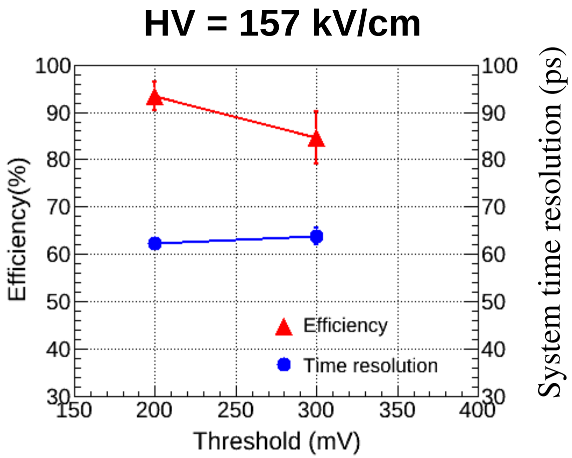
CERN-SPS Fall 2016 in-beam test

Pb beam of 13/30/150 AGeV on a Pb target









CBM-TOF readout:

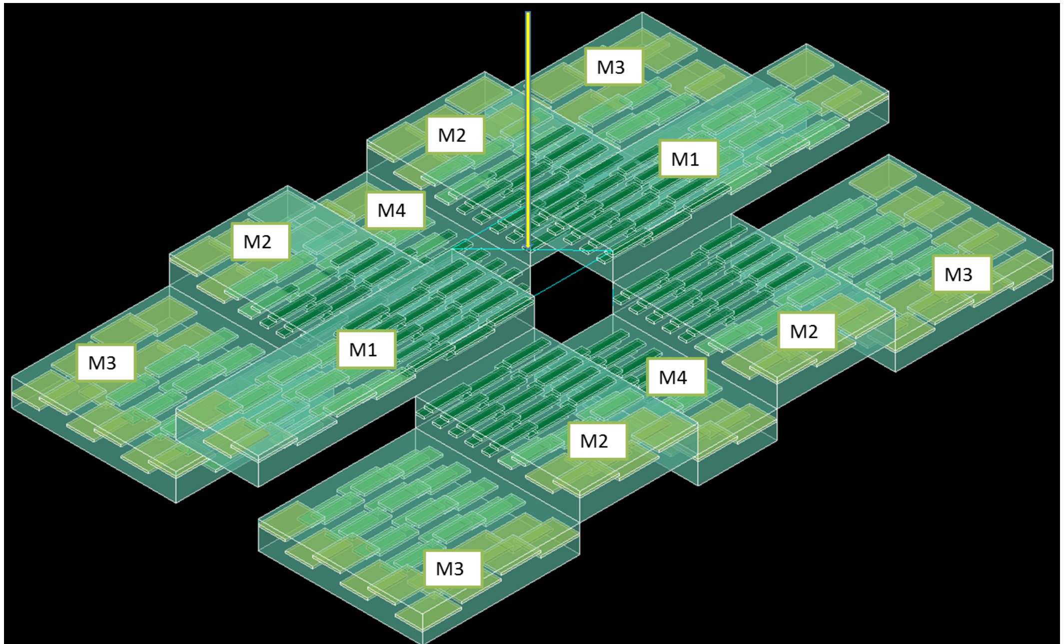
~ 500 Channels with a new readout-chain based on:

PADI + GET4 TDC (https://wiki.gsi.de/pub/EE/GeT4/get4.pdf)

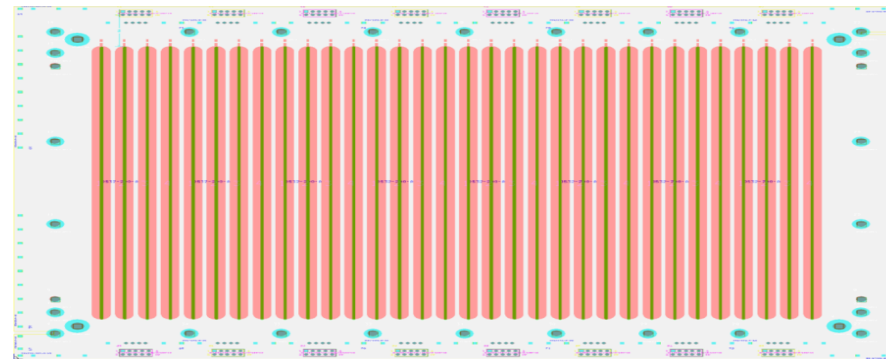
DAQ: AFCK board (Data Processing Board) + FLIB (First Level Interface Board)

The slightly lower efficiency using PADI-GET4 TDC readout relative to PADI-FPGA-TDC is under investigation

Inner Wall Design



Based on a new RPC2018 prototype – the same principle and inner geometry as RPC2015, but with 32 strips instead of 40 → further reduction of number of readout electronic channels



Readout electrode: 9.02 mm pitch= 1.27 mm width + 7.75 mm gap

HV electrode: 9.02 mm pitch= 7.37 mm width + 1.65mm gap

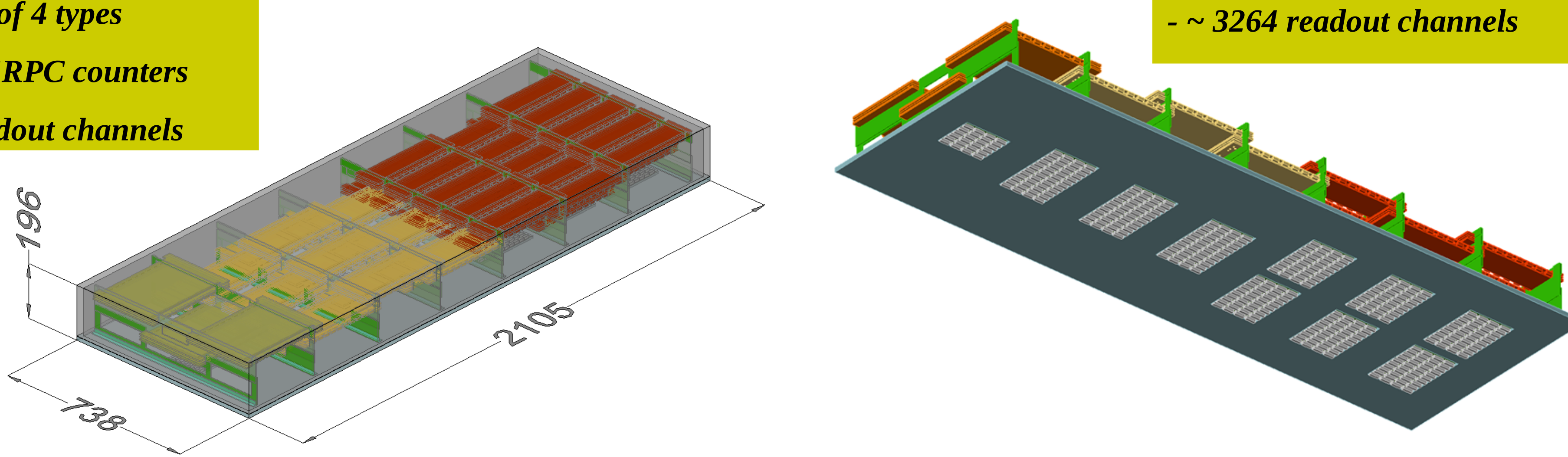
CBM-TOF inner zone

- *~15 m² active area*
- *12 modules of 4 types*
- *~470 MGMSRPC counters*
- *~ 30 080 readout channels*

Module M1

Module M1:

- *~51 MGMSRPC counters*
- *~ 3264 readout channels*



Outlook of the next activities

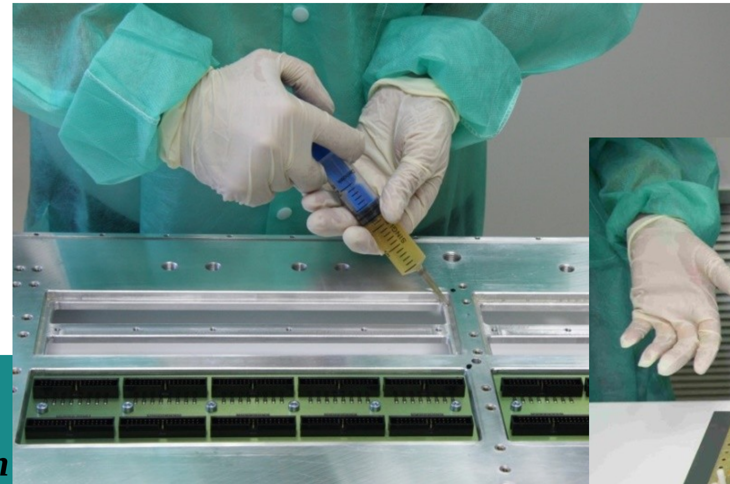
2019 – construction of the first module for CBM-TOF inner zone

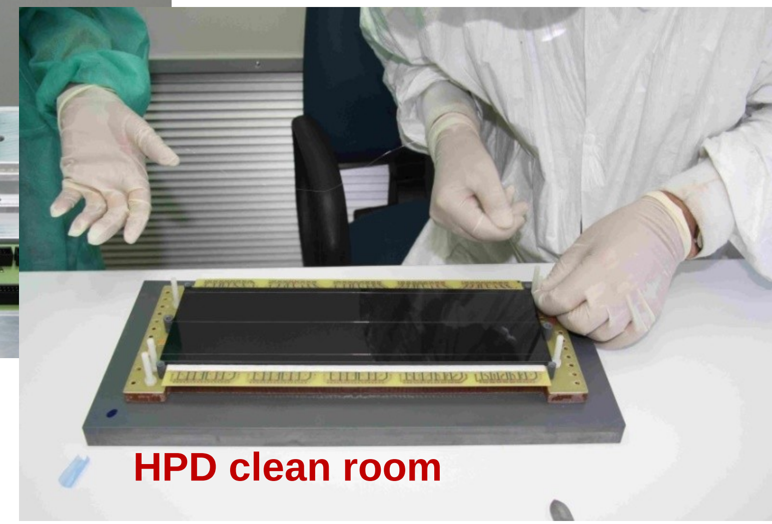
CBM-TOF inner zone

- *~15 m^2 active area*
- *~470 MGMSRPC counters*
- *~ 30 080 readout channels*

HPD main infrastructure:

- *<10 000 part/ft^3 clean room for construction*
- *dedicated RPC test laboratory*





Conclusions & Outlook

- **A method to tune the MSMGRPC signal transmission line impedance such to match the input impedance of the corresponding front-end electronics was developed, exploiting the original MSMGRPC architecture developed in our group. The required matching can be achieved independent on the adjustment of the MSMGRPC granularity.**
- **Performance of the prototype based on this method was confirmed by the in-beam test results.**
- **Inner-zone CBM-TOF subsystem will be based on such architecture.**
- **A full size module of the inner zone of the CBM-TOF will be build in 2019.**