The CBM Time-of-Flight wall

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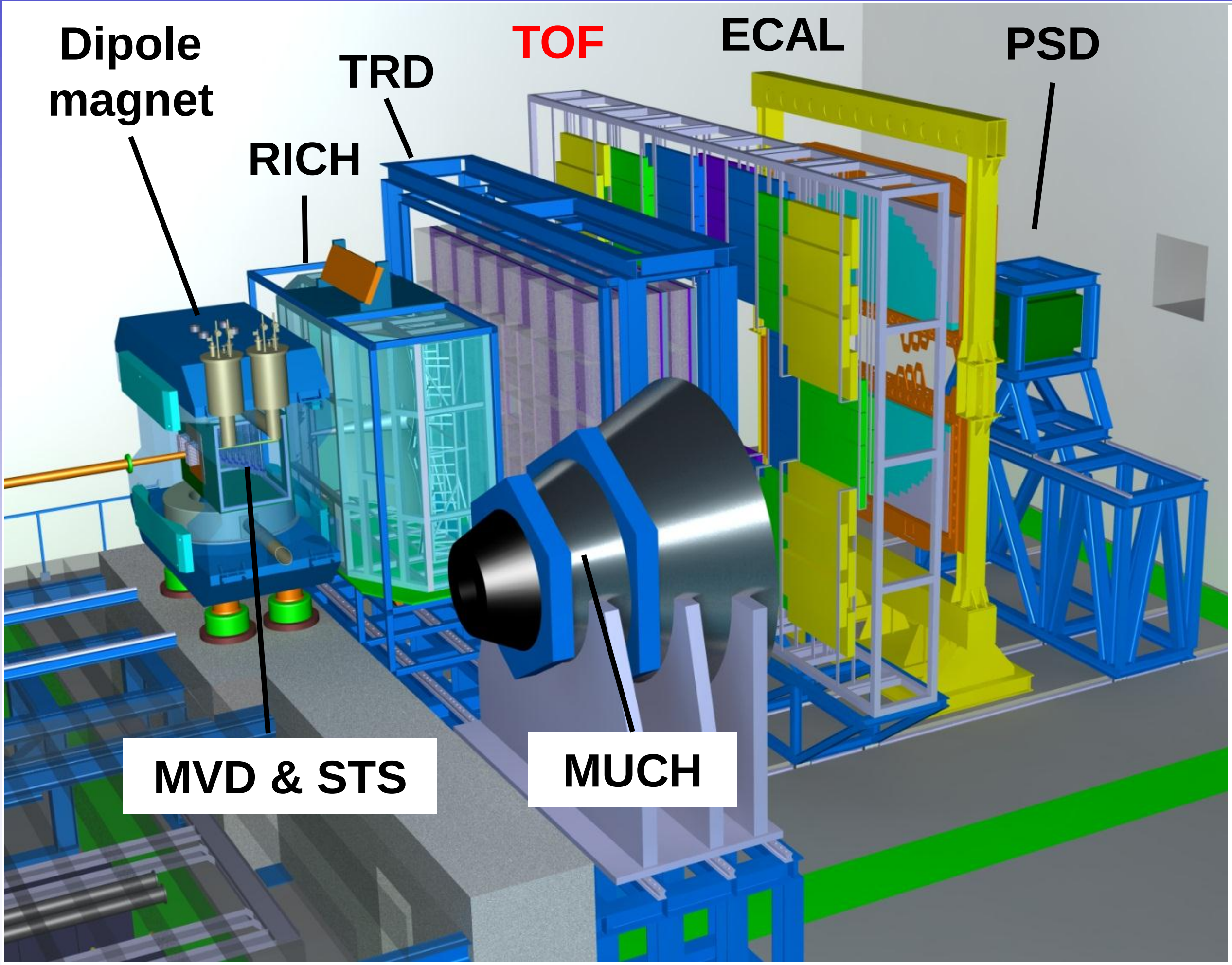
Outline:

- CBM-ToF requirements
- What is an (M)RPC?
- Tof wall arrangements
- Ceramics RPC and the central region of the ToF wall
- Low resistive glass as resistive electrodes for MRPCs
- Single stack vs. double stack
- Performance study from test beam time at GSI and SPS
- Time Table
- Summary / Next steps

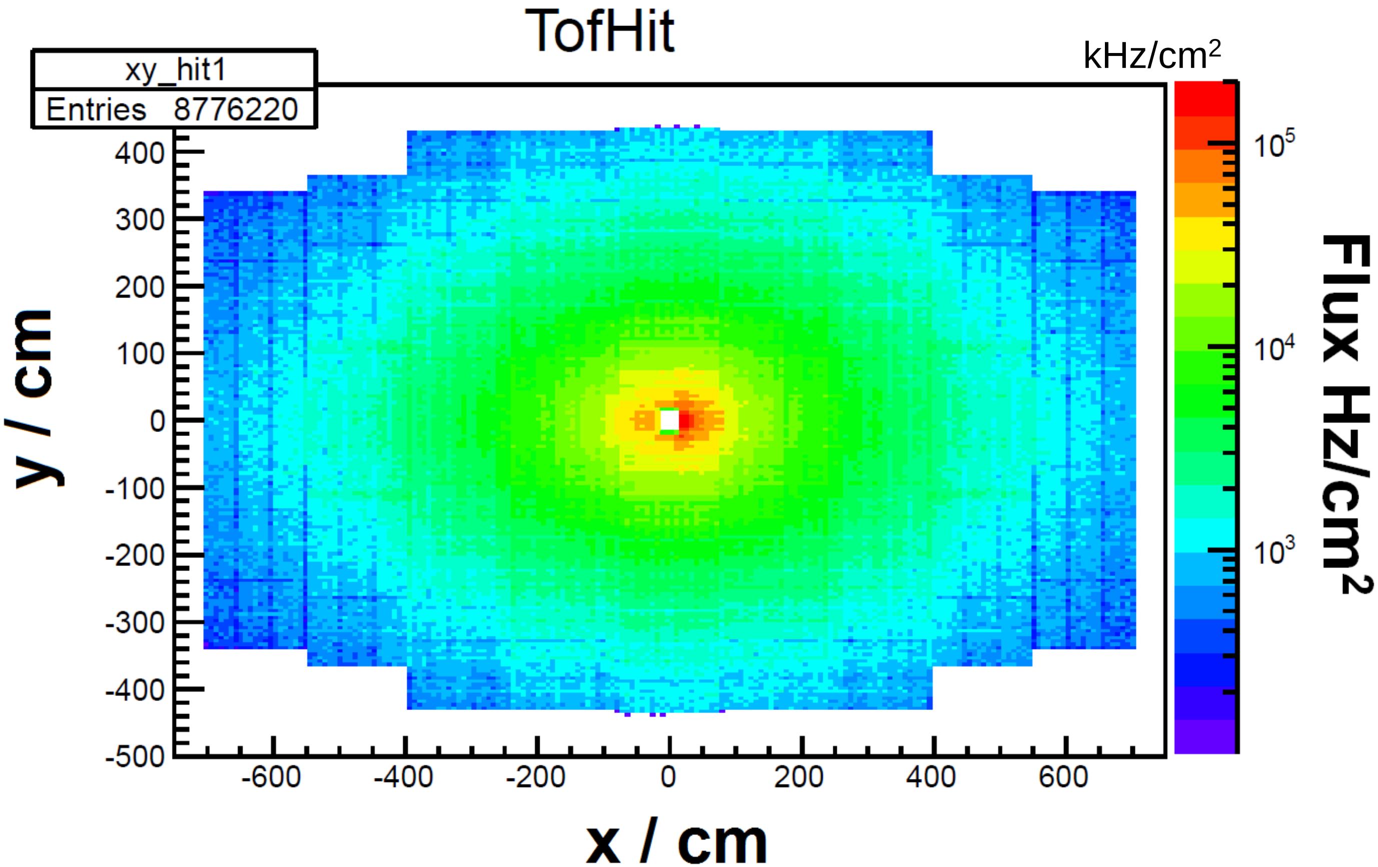
Introduction



CBM talks: HK7.1, HK7.3, HK7.4, HK7.5, HK8.3, HK8.4, HK10.5, HK14.1, HK14.2, HK14.3, HK14.7, HK15.1, HK15.2, HK15.3, HK17.4, HK21.2, HK21.3, HK21.4, HK24.1, HK24.2, HK25.2, HK25.4, HK25.5, HK26.7, HK29.4, HK29.7, HK38.1, ← we are here HK40.7, HK44.1, HK44.2, HK44.3, HK44.6, HK45.9, HK45.20, HK45.49, HK45.63, HK45.73, HK48.7, HK54.5, HK59.2, HK59.3, HK59.4, HK60.2, HK60.3, HK60.6, HK60.7, HK56.2, HK66.1

Incident particle flux

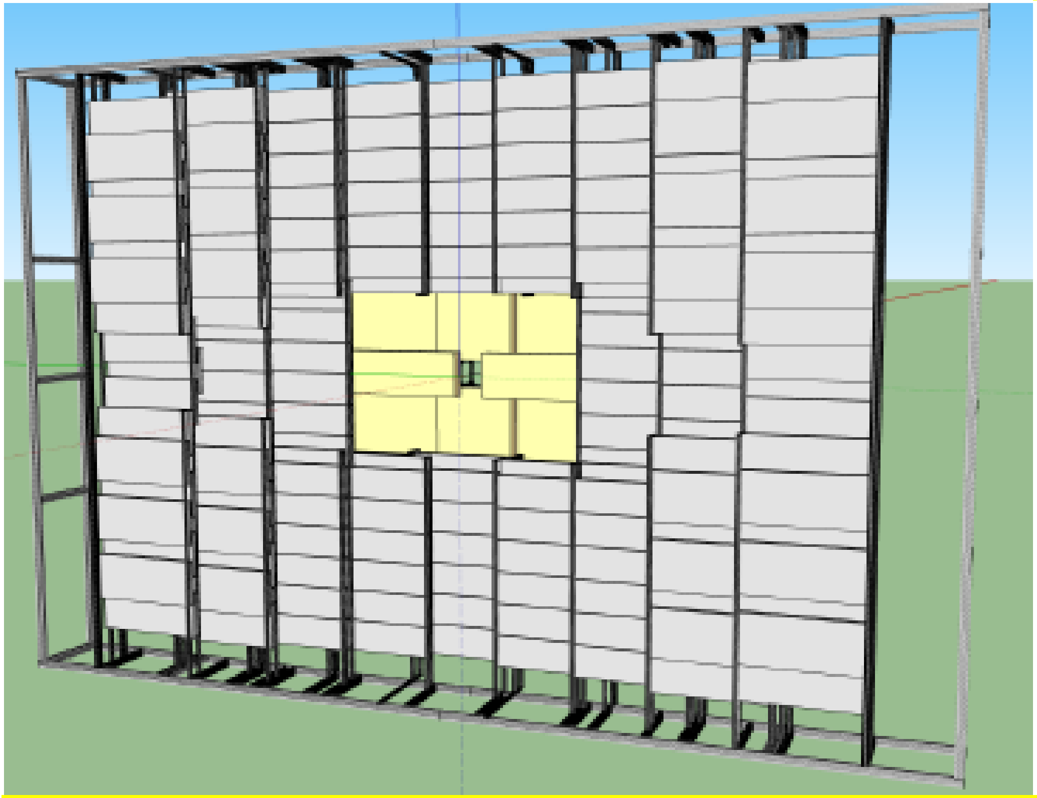
URQMD simulated charged particle flux for Au + Au (central) events at 10A GeV assuming an interaction rate of 10 MHz



- Flux ranging from 0.1 to 100 kHz/cm^2
- At different regions Time-of-Flight detectors with different rate capabilities are needed

Requirements

Charged hadron identification is provided by Time-of-Flight (ToF) measurement

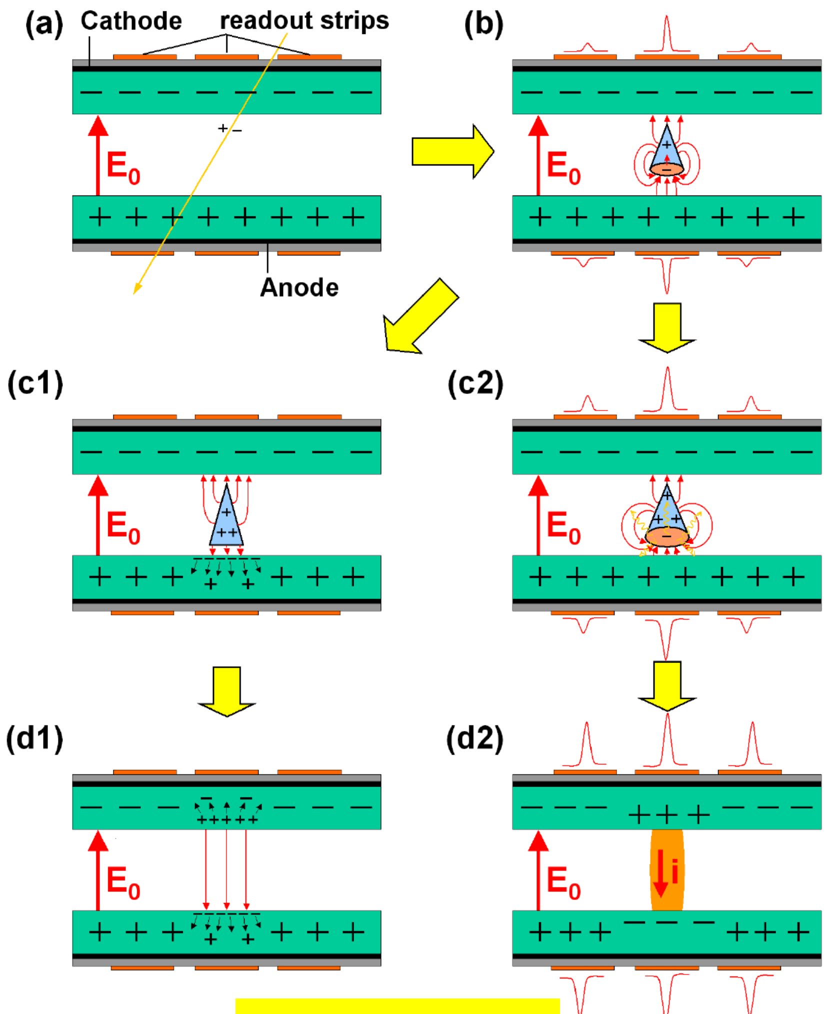


CBM-ToF Requirements

- **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**

Multi-gap Resistive Plate Chambers (MRPC) are the most suitable ToF detectors fulfilling our requirements

Working principle of an RPC



E_0 = 120 kV/cm

First Multi-gap RPC 1996

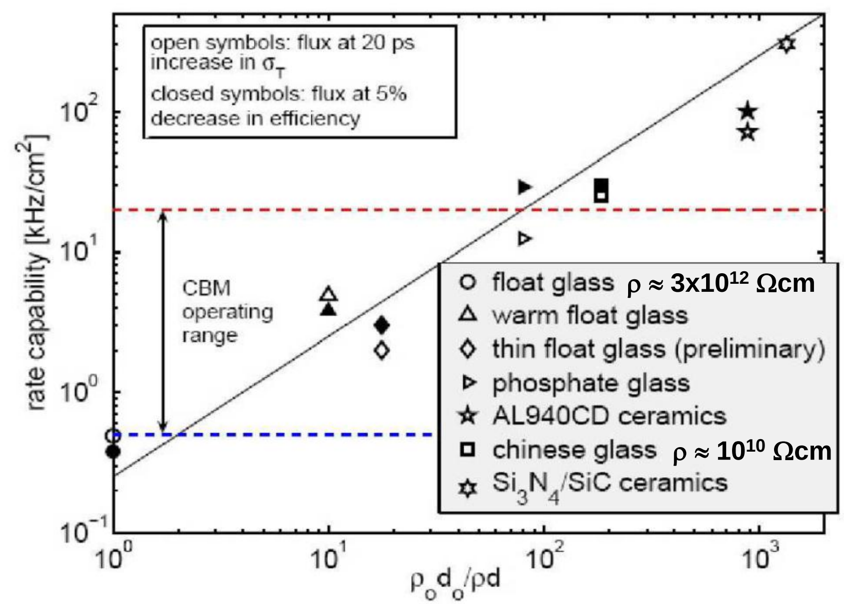
E. Cerron Zeballos et al., **Nucl.Instrum.Meth. A374 (1996) 132-13**

$$\text{Time resolution:} \quad \sigma_T = \sigma_0 + K_T \bar{q}\phi \boxed{\rho d}$$

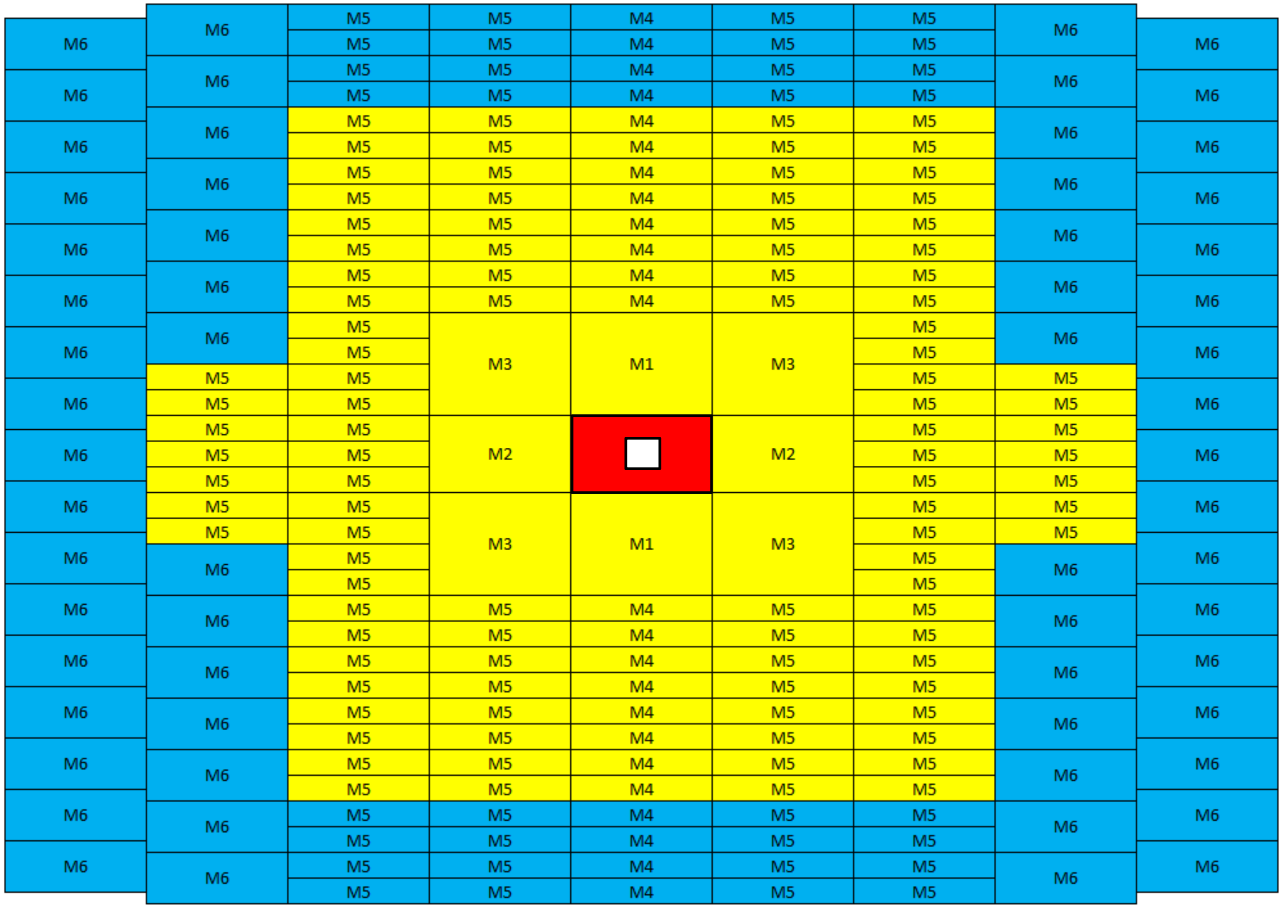
$$\text{Efficiency:} \quad \epsilon = \epsilon_0 - K_\epsilon \bar{q}\phi \boxed{\rho d}$$

ϕ: incident ch. particle flux, ρ: electrode bulk resistivity, d: electrode thickness

How to increase the rate capability?



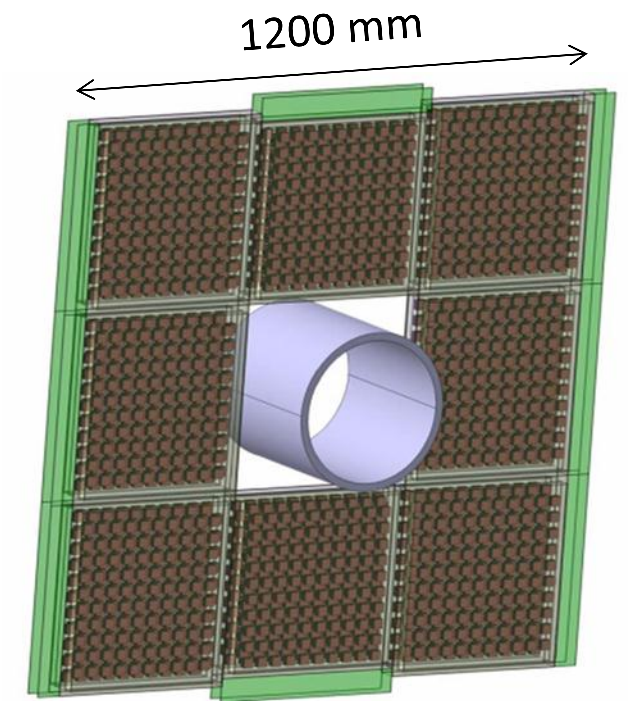
TDR ToF wall layout



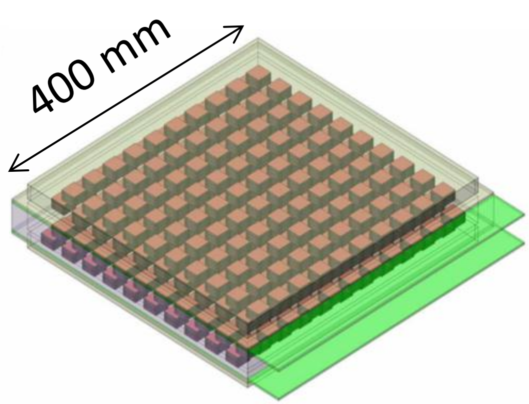
- 6 types of modules (M1 – M6) only
- A module contains several MRPC counters
- Region containing counters equipped with float glass
- Region containing counters equipped with low resistive glass
- Region containing counters equipped with ceramic material

Ceramic RPCs

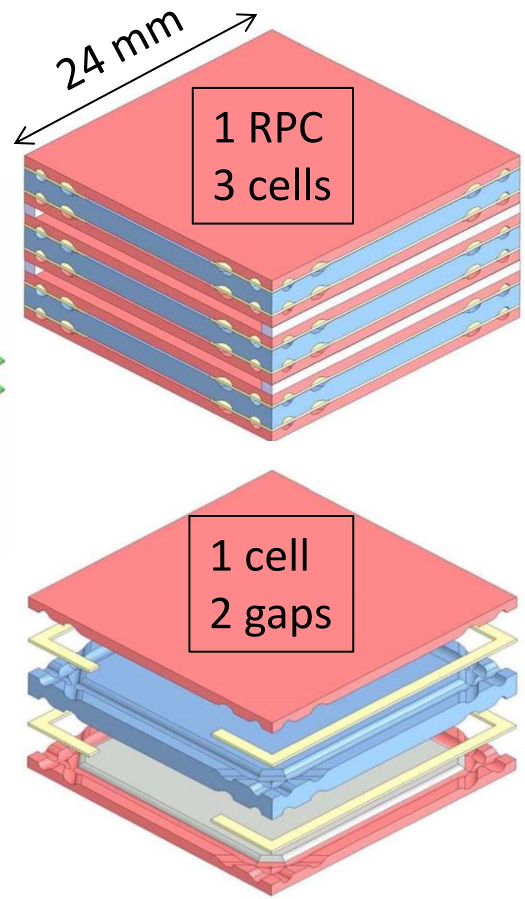
Important scopes of High Energy Heavy Ion experiments are the start-time and the reaction-plane determination. For CBM the use of RPC for the Beam Fragmentation T_0 Counter (BFT$_0$C) with low resistive radiation hard ceramics electrodes and small chess-board like single cells is under consideration.



BFT$_0$C = 8 modules

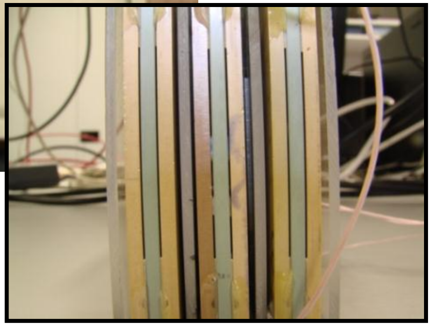


1 module
400 RPC

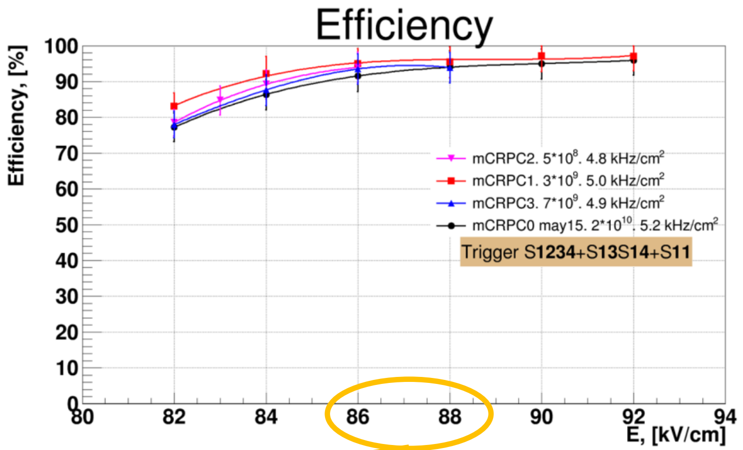


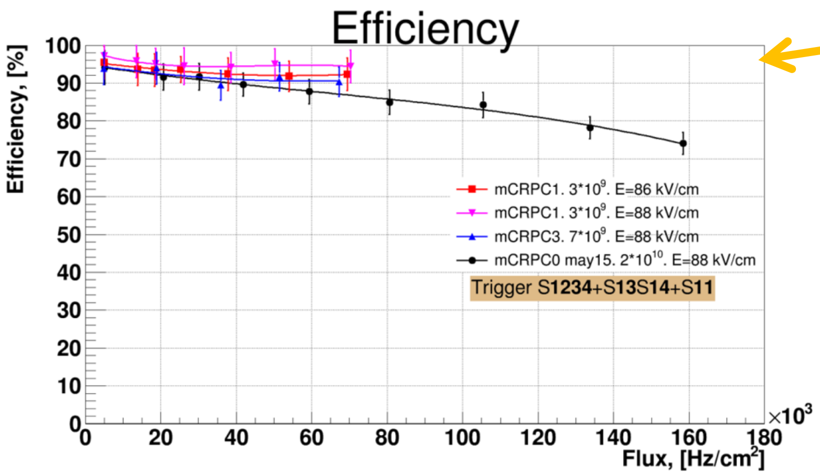
Ceramic RPCs

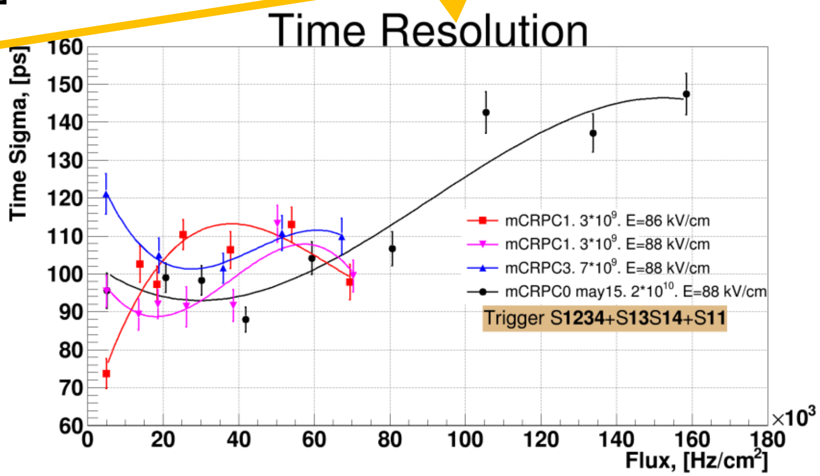
electrodes



RPC







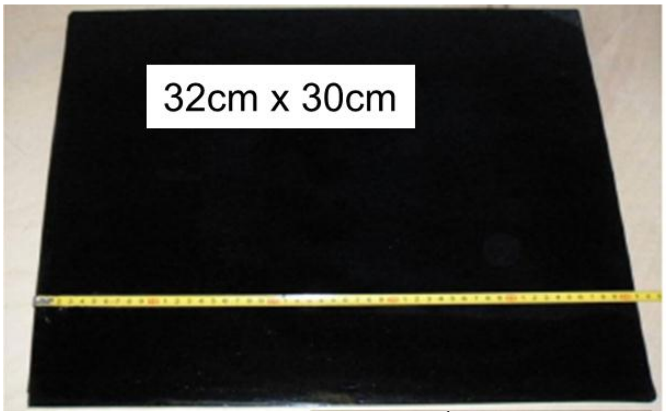
$10^9\ \Omega$cm: most suitable resistivity order for our aims

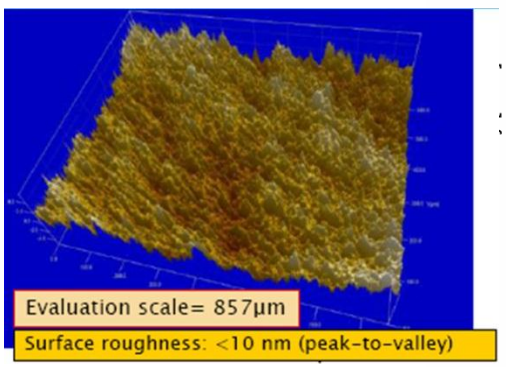
Resistive Glass Development

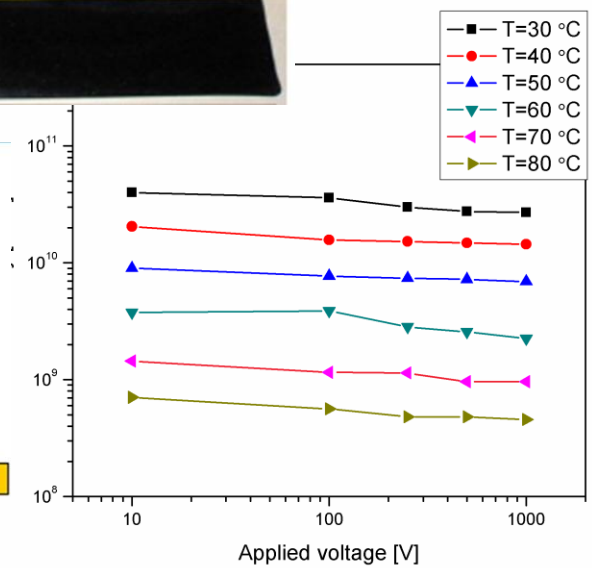
CBM ToF

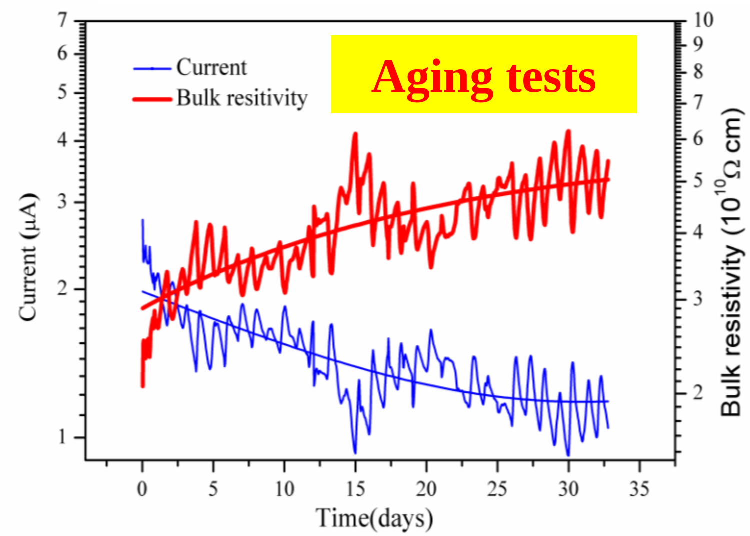
Resistive glass for high-rate MRPCs is developed in Beijing, China

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

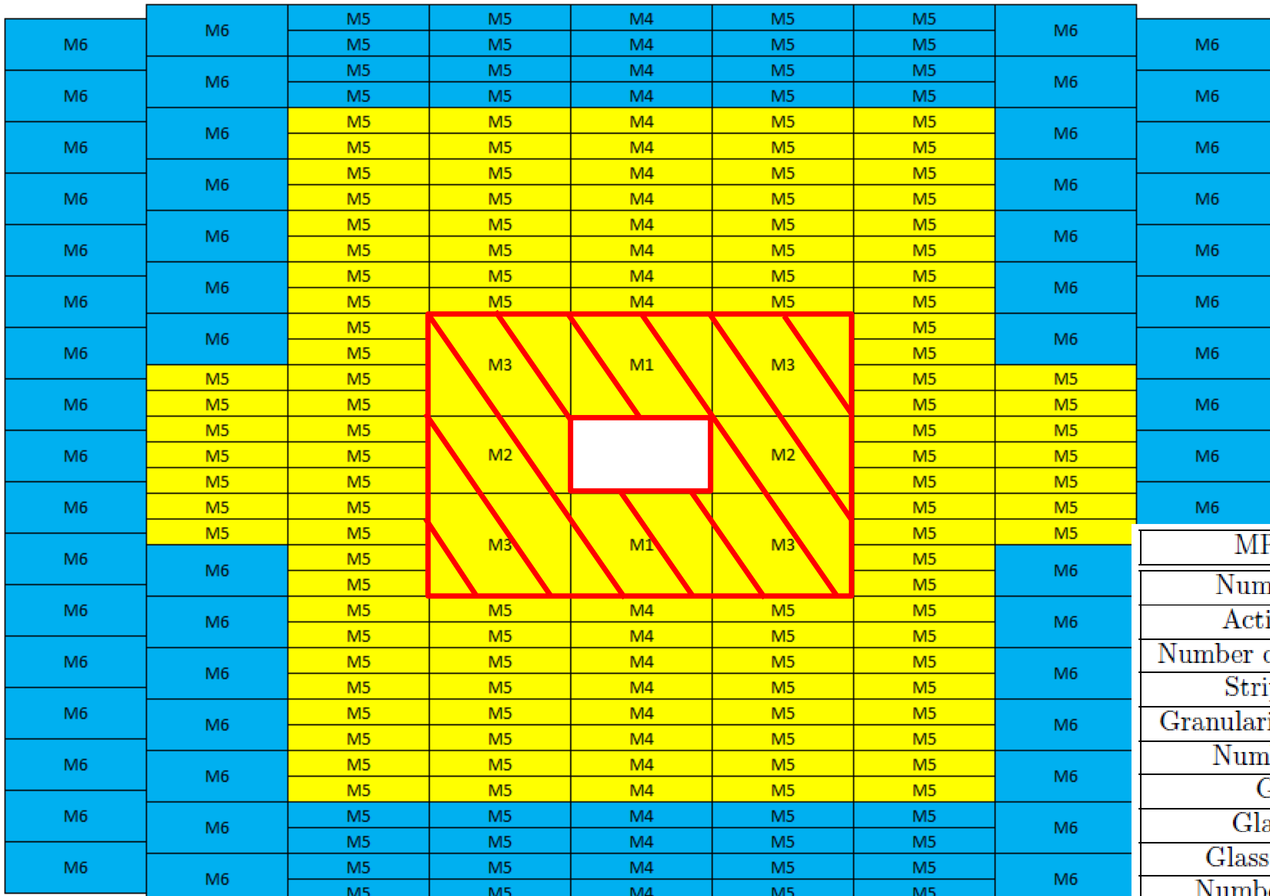


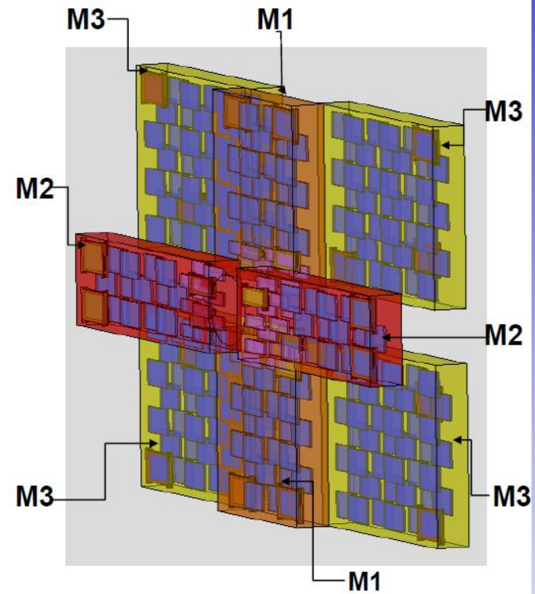






TDR ToF wall layout

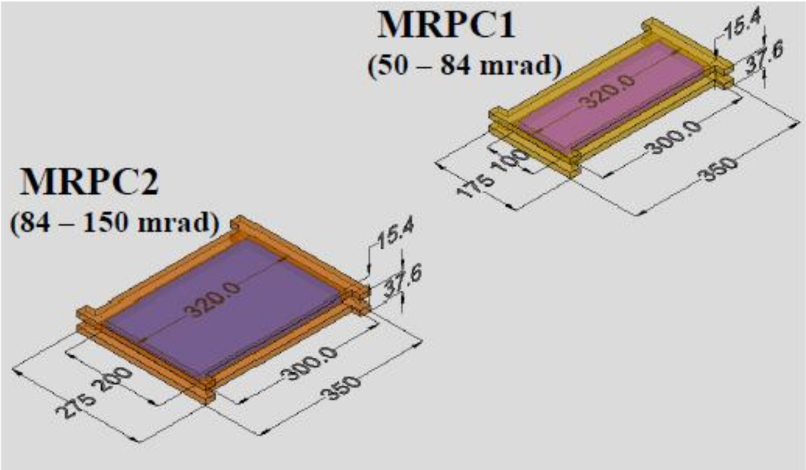


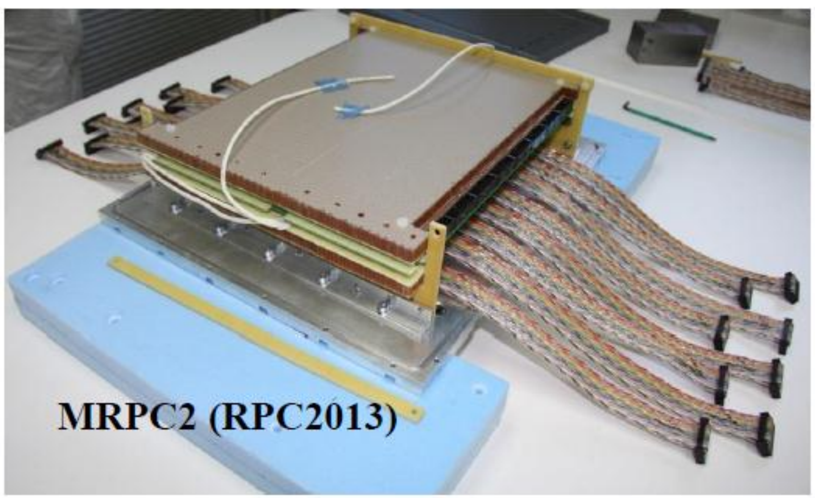


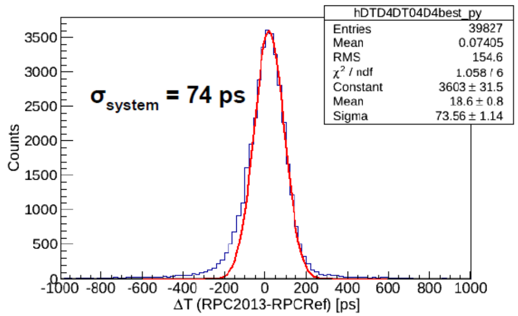
MRPC notation	MRPC1	MRPC2
Number of MRPCs	40	246
Active area [mm^2]	300×100	300×200
Number of Strips per MRPC	64	64
Strip length [mm]	100	200
Granularity (cell size) [mm^2]	472.4	944.8
Number of gas gaps	10	10
Gap size μm	140	140
Glass size [mm^2]	320×100	320×200
Glass thickness [mm]	0.7	0.7
Number of glass plates	12	12
Glass type	low res.	low res.
Total glass surface [m^2]	15.36	188.93

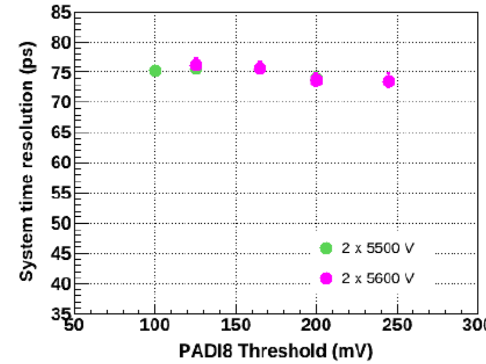
Alternative solution with Pad-MRPCs is available

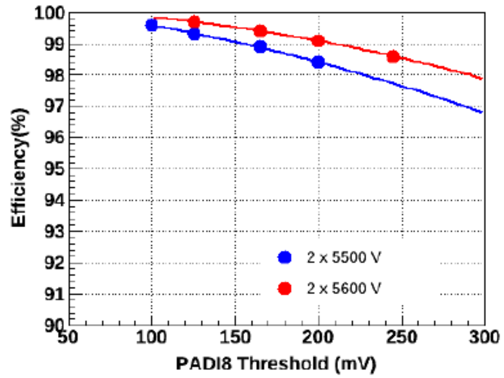
Beam-time @ SIS18

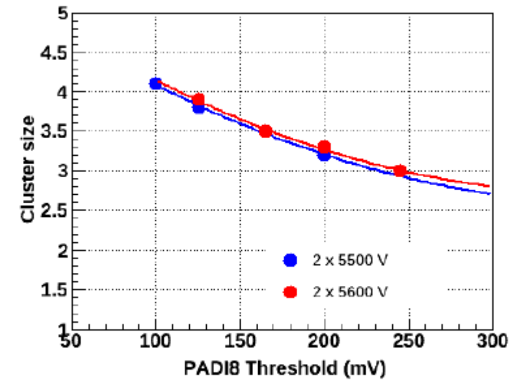










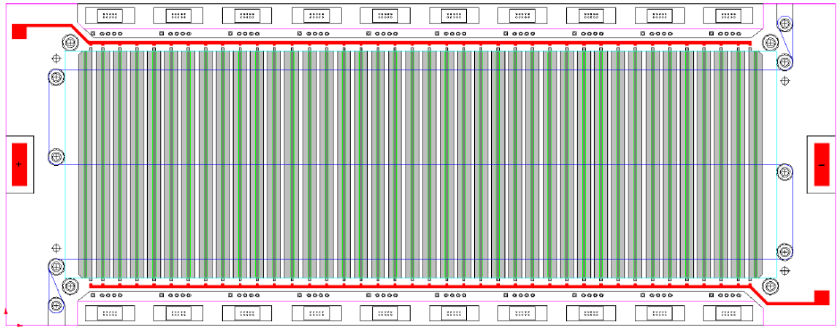


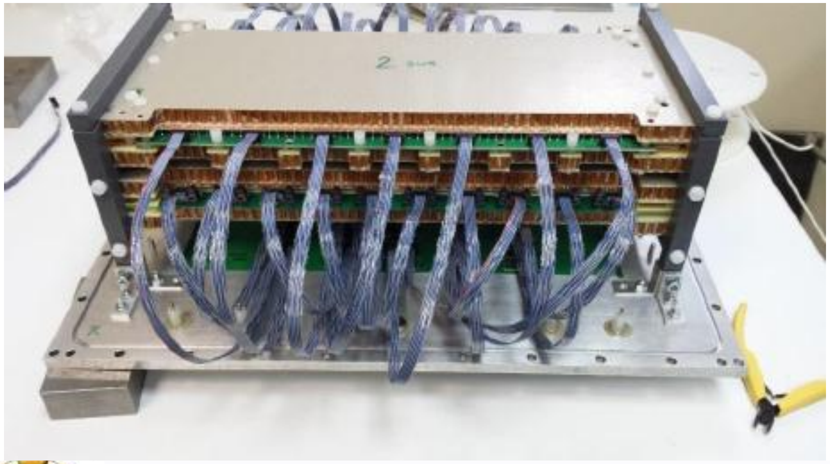
Counter time resolution about 53 ps
Efficiency about 99 %
Cluster size > 3 (due to a strip pitch of 4.2 mm)
Particle flux only a few hundred Hz/cm^2

Beam-time @ SPS

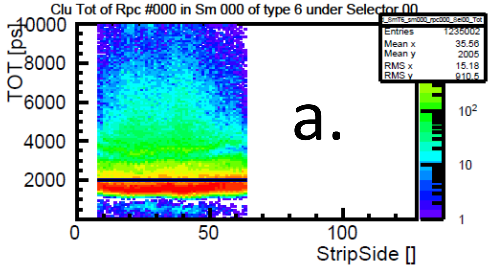
CBM ToF

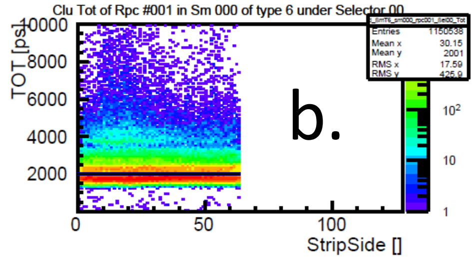
2 new types of counters designed
a. Single stack with pitch of 10.1 mm
b. Double stack with pitch of 7.2 mm



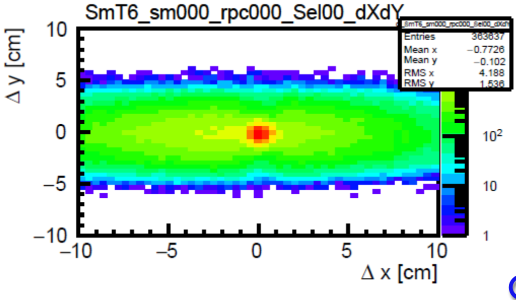


Time over Threschold distribution

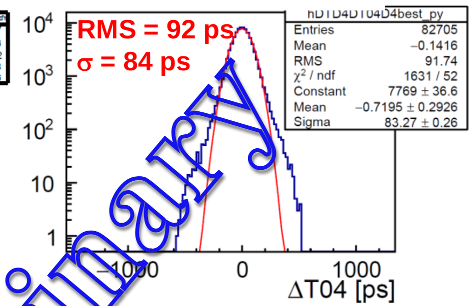


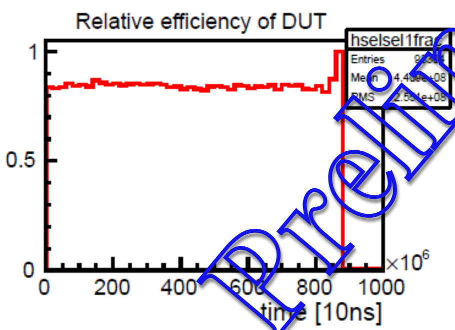


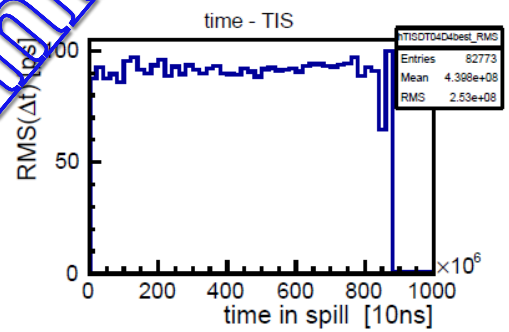
Cluster matching



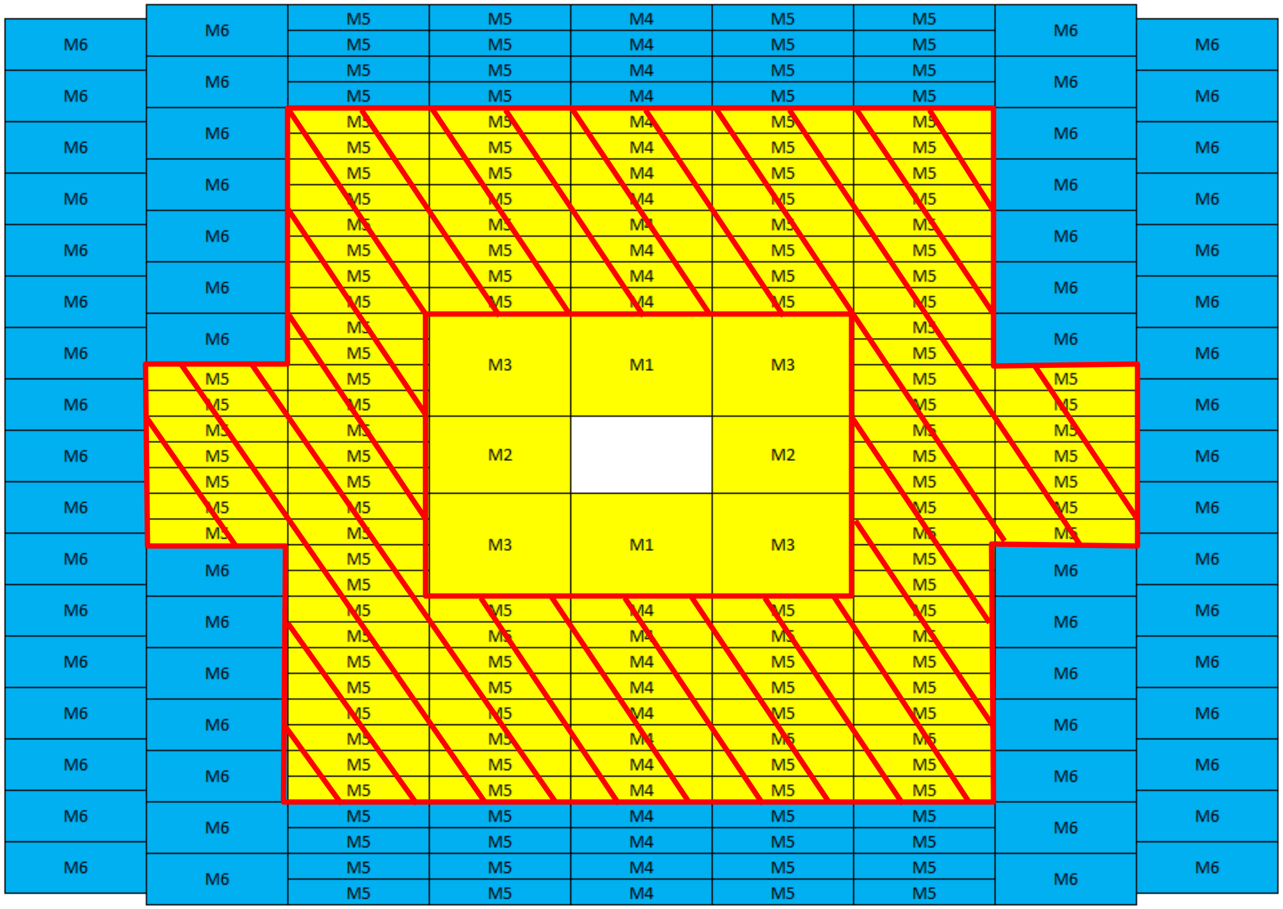
System time resolution



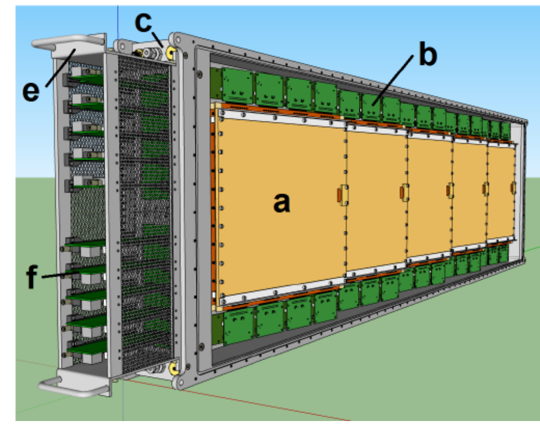




TDR ToF wall layout



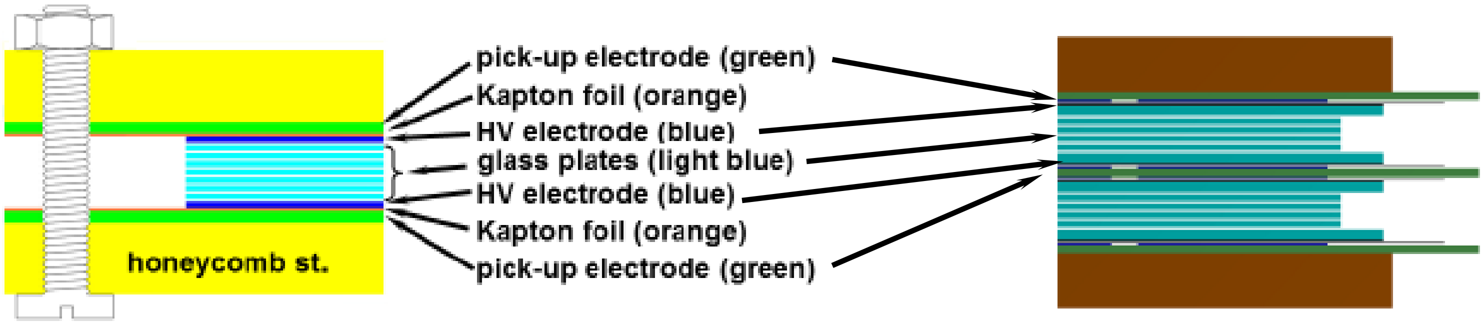
Module M5



MRPC notation	MRPC3a
Number of MRPCs	580
Active area [mm^2]	320×270
Number of Strips per MRPC	32
Strip length [mm]	270
Granularity (cell size) [mm^2]	2700
Number of gas gaps	8
Gap size μm	220
Glass size [mm^2]	330×280
Glass thickness [mm]	1.0
Number of glass plates	9
Glass type	low res.
Total glass surface [m^2]	482.33

2 MRPC concepts

Differential singel stack MRPC with 8 gaps vs. Differential double stack MRPC with 2 x 5 gaps



Differential singel stack MRPC with 8 gaps

Advantages
- simpler construction
- symmetric signal path
- fewer glass plates (#9)
- lower weight
- impedance matching easy possible (100Ω)

Disadvantages
- higher High Voltage (> ±10 kV)
- bigger cluster size

Differential double stack MRPC with 2 x 5 gaps

Advantages
- lower High Voltage (< ±6 kV)
- smaller cluster size

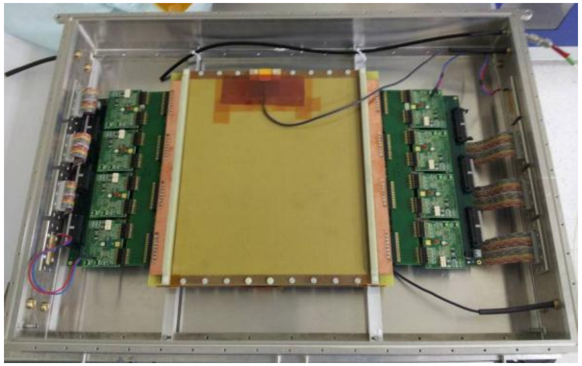
Disadvantages
- more complex construction
- more glass plates (#12)
- impedance matching hardly possible (100Ω)

Beam-time @ GSI

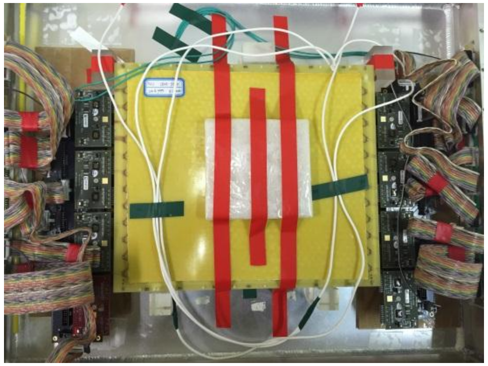
Full size demonstrator and reference MRPC used for the performance analysis

	MRPC-P2 (HD)	THU-strip (Beijing)	MRPC-P5 (HD)
MRPC	differential	differential	differential
glass stack	single	double	single
active area	32 x 27 cm^2	24 x 27 cm^2	15 x 4 cm^2
strips	32	24	16
strip / gap	7/ 3	7/ 3	7.6 / 1.8 mm
glass type	low resistive glass	low resistive glass	low resistive glass
glass thickness	0.7 mm	0.7 mm	1.0 mm
number of gaps	8	2 x 4	6
gap width	220 μm	220 μm	220 μm

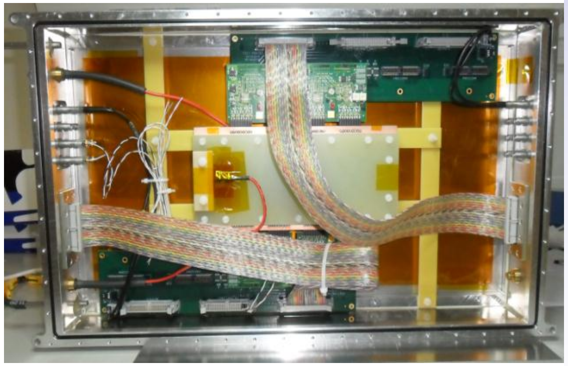
MRPC-P2



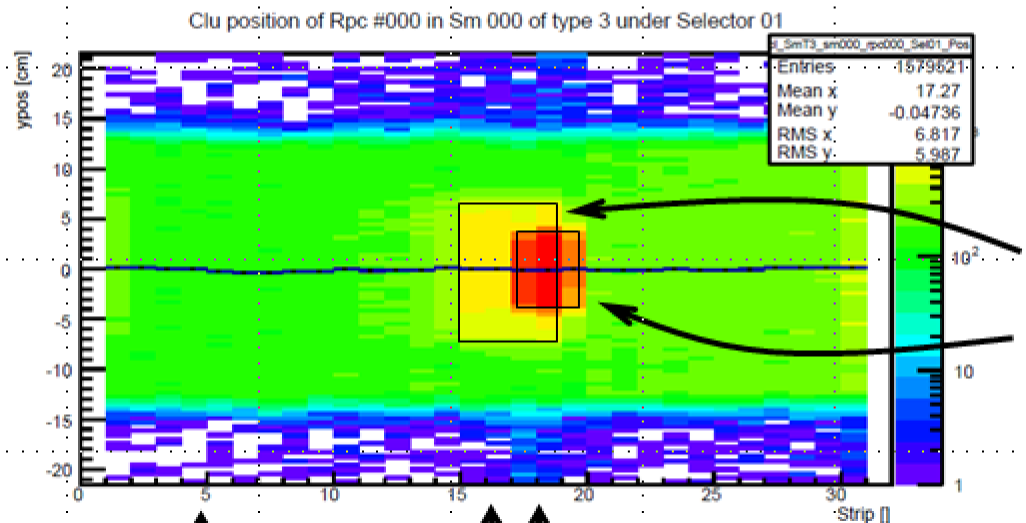
THU-strip



MRPC-P5



Beam-time @ GSI

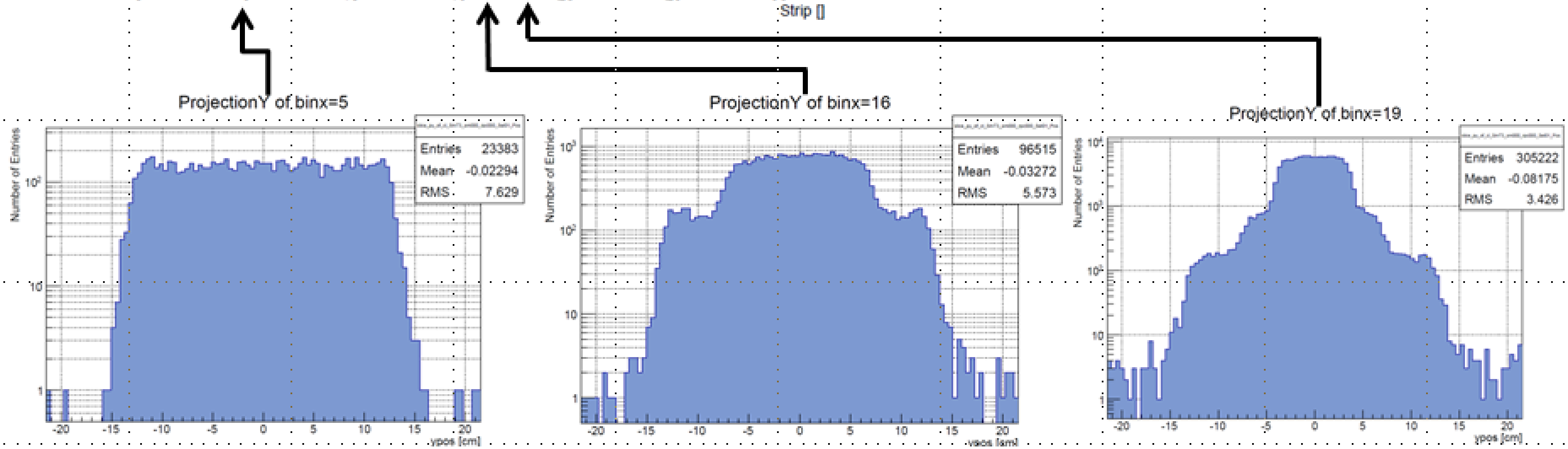


Active area of overlain counters

D.u.t. MRPC-P2: 32 x 27 cm^2

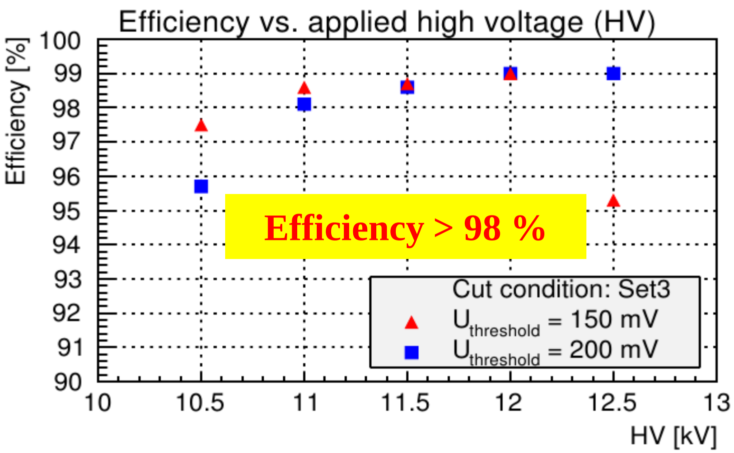
Reference MRPC-P5: 15 x 4 cm^2

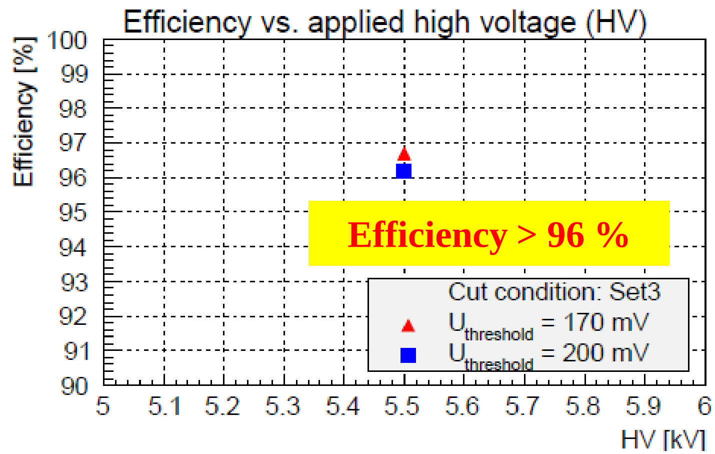
Plastic: 8 x 2 cm^2

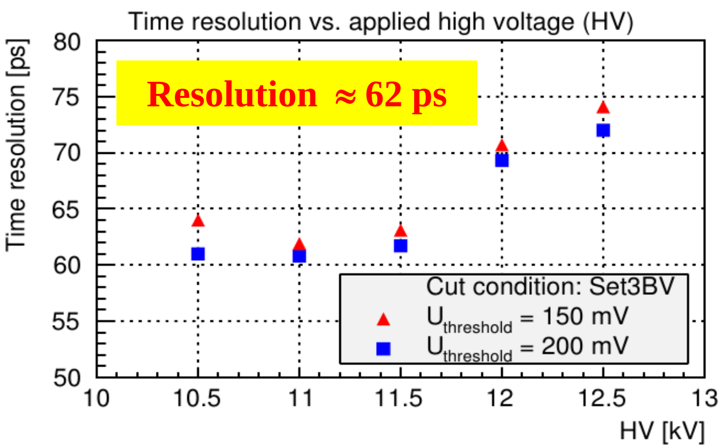


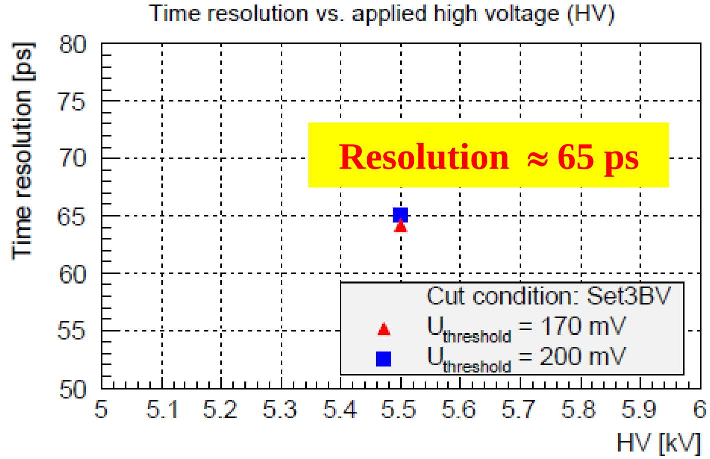
Beam-time @ GSI

Differential singel stack MRPC with 8 gaps vs. Differential double stack MRPC with 2 x 4 gaps





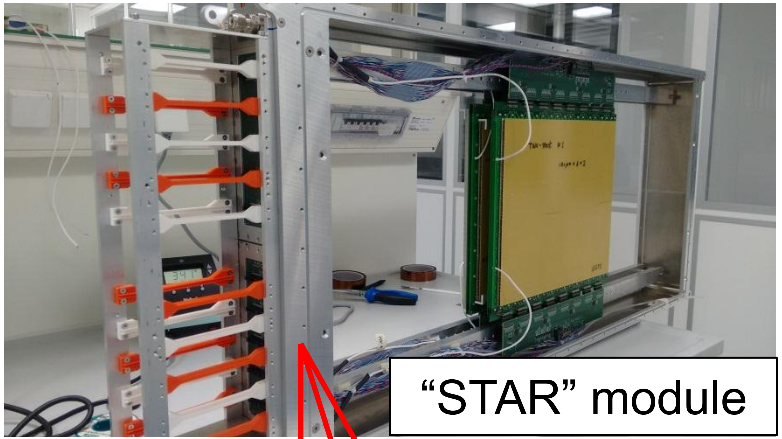


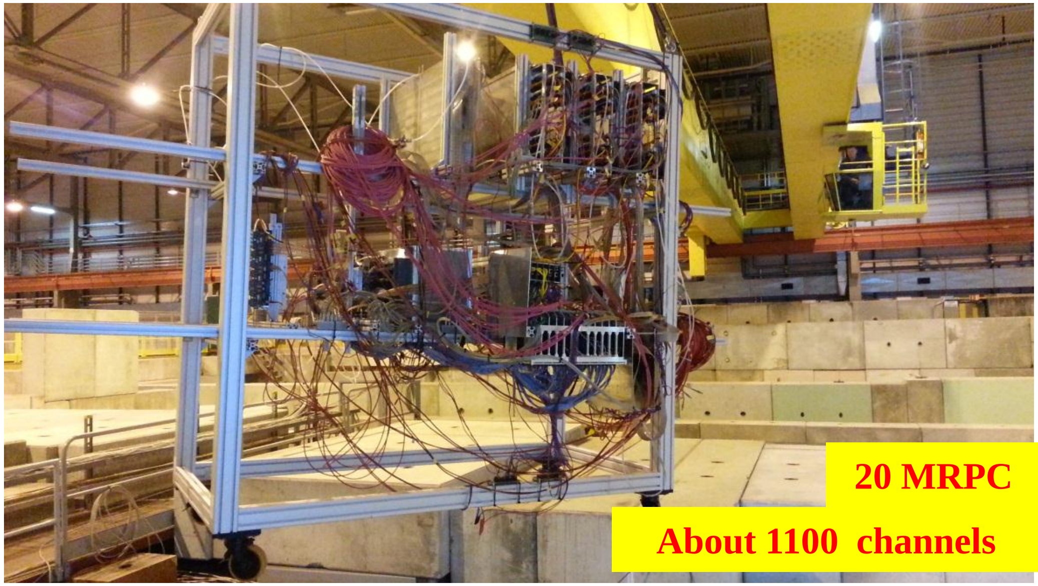


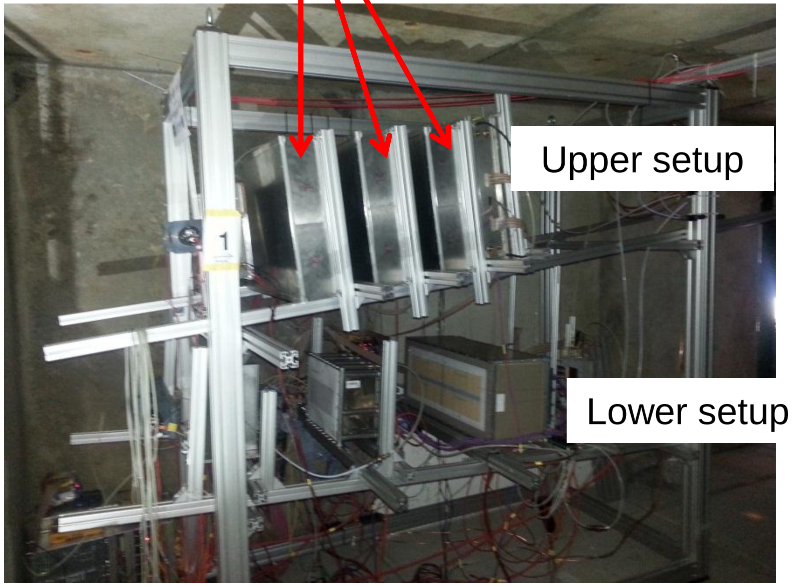
- Data points at ±11 kV in the left plot can be compared with ±5.5 kV in the right plot.
- Single stack MRPC shows slightly better efficiency and time resolution.
- Single counter resolution is in the order of 45 ps including all electronic components.

Beam-time @ SPS

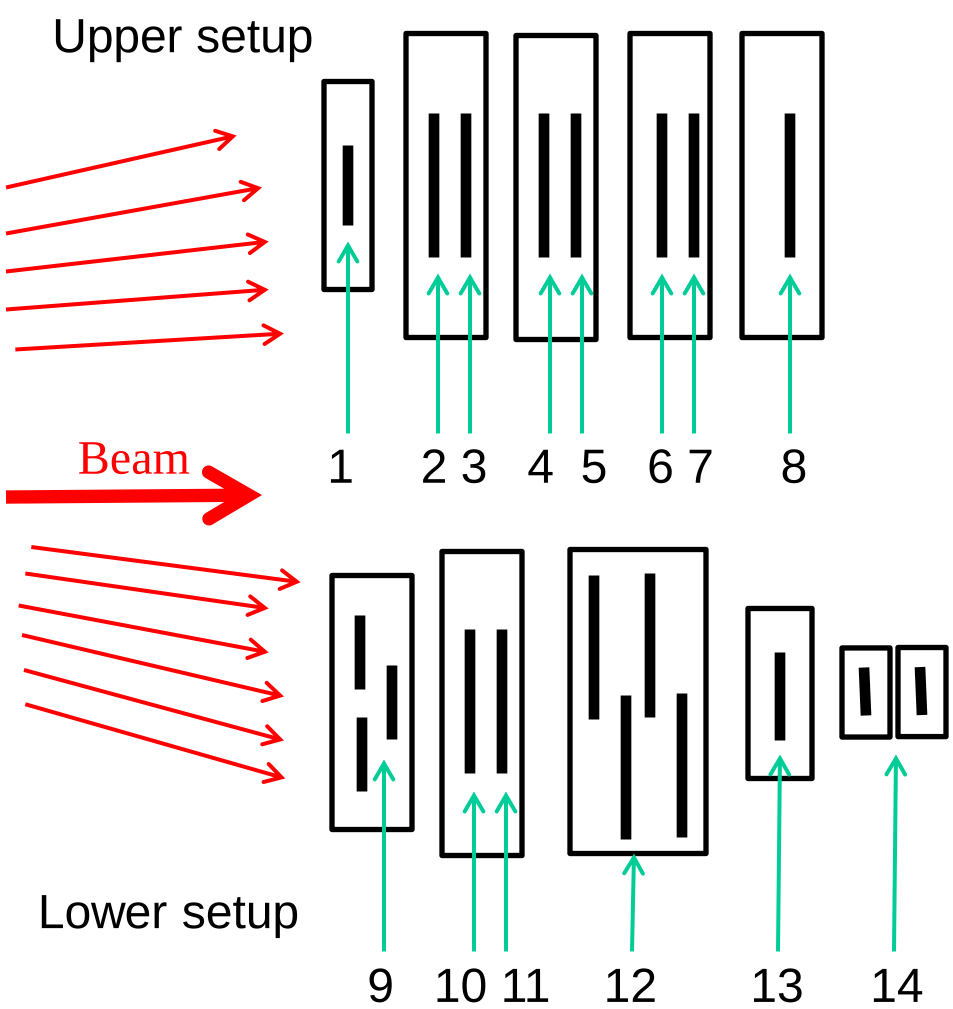
Beam-time @ SPS North Area in Nov. 2015
Beam: Lead @ 30A GeV
Target: Lead 1 mm
Intensity: 10^7 / spill
Spill length: 8 s
Rates: few kHz/cm^2
Energy close to SIS300 conditions







Beam-time @ SPS



Impedance matching

1. Heidelberg-P5 ✗
2. USTC-SSS (Ω^-) (✓)
3. USTC-SSU (Ξ^0) (✓)
4. USTC-DSU (Λ) (✓)
5. Tsinghua-SU (K^+) ✓
6. Tsinghua-DS (K^0) ✓
7. Tsinghua-DU (π^+) ✓
8. Heidelberg-P2 ✓

9. Tsinghua-PAD (3 counter) ✗
10. Bucharest2015-SS (φ) ✓
11. Bucharest2015-DS (K^{0*}) ✓
12. Bucharest2012 (4 counter) (✓)
13. Bucharest-Reference ✓
14. CRPC (2 counter) ✗

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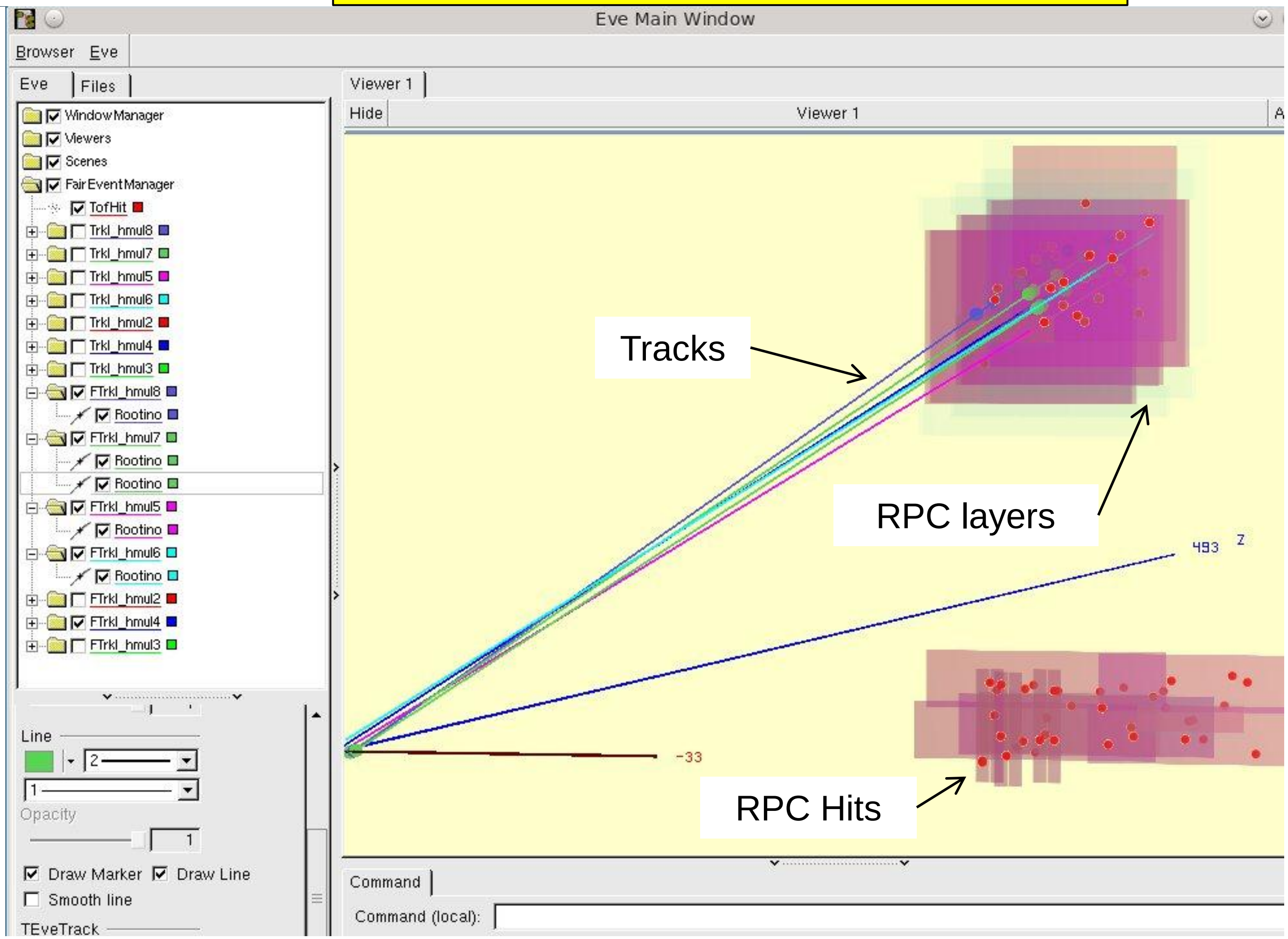
Beam-time @ SPS

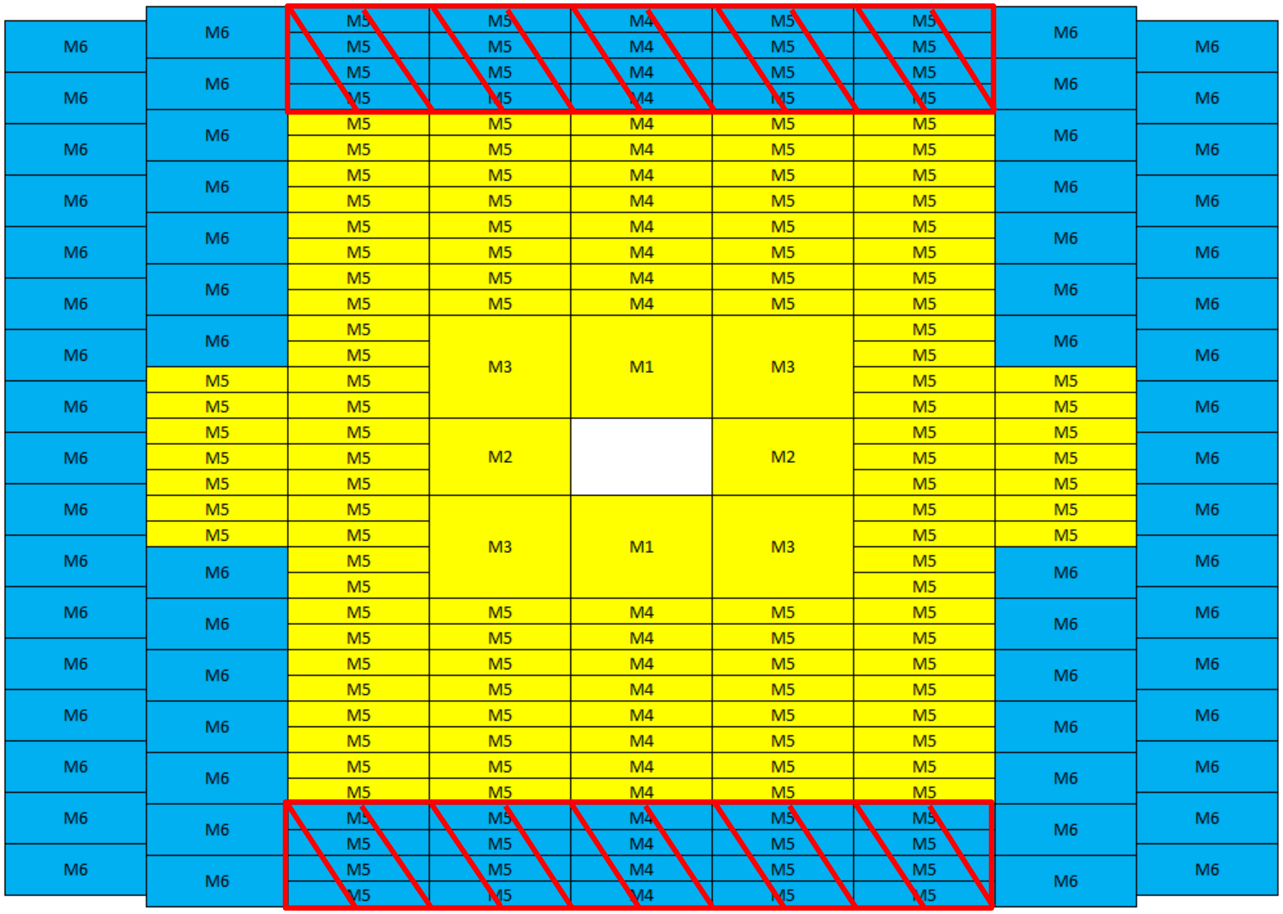
Event display after position calibration



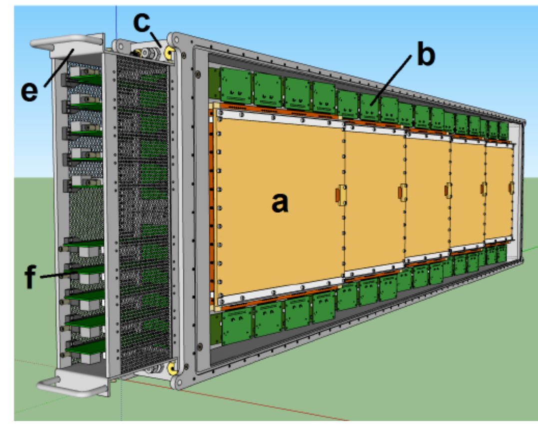
- 1 Track (blue) with hit multiplicity 8
- 2 Tracks (green) with hit multiplicity 7
- 1 Track (light blue) hit with multiplicity 6
- 1 Track (pink) with hit multiplicity 5

The opportunity to construct tracks offers new possibilities to analyze and study the counters in much greater detail

TDR ToF wall layout



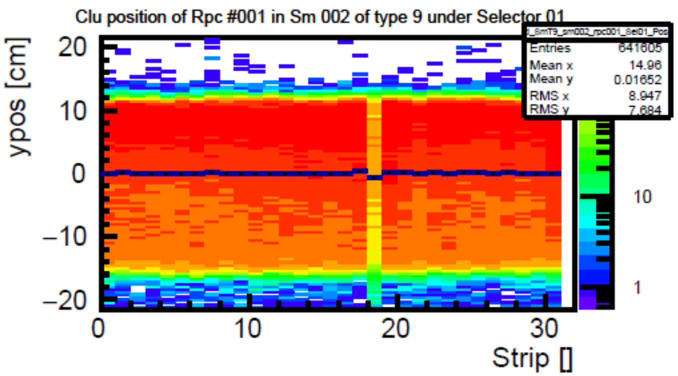
Module M5



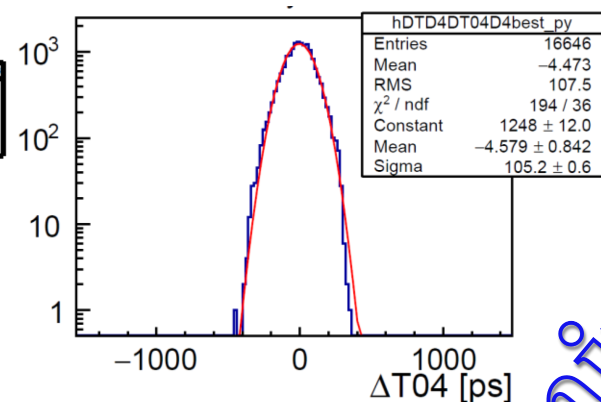
MRPC notation	MRPC3b
Number of MRPCs	200
Active area [mm^2]	320×270
Number of Strips per MRPC	32
Strip length [mm]	270
Granularity (cell size) [mm^2]	2700
Number of gas gaps	12
Gap size μm	140
Glass size [mm^2]	330×280
Glass thickness [mm]	0.28
Number of glass plates	13
Glass type	float
Total glass surface [m^2]	166.32

Float glass counters A and B and a reference counter C with low res. glass

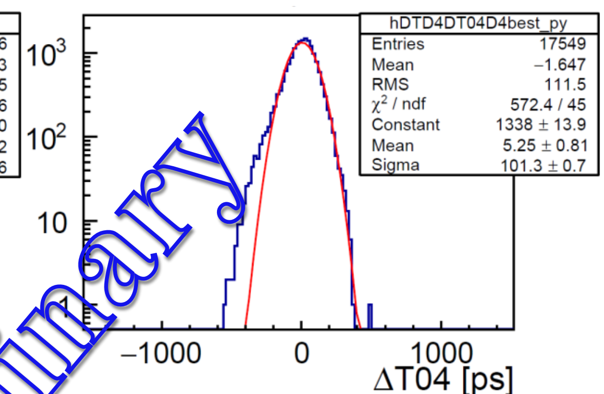
Spacial distribution



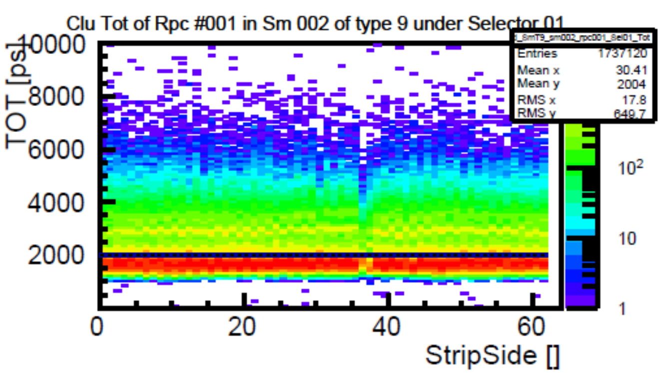
Timediff. A and B



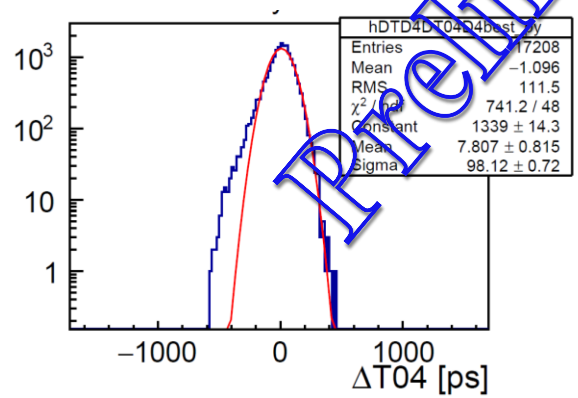
Timediff. B and C



ToT distribution



Timediff. A and C



Preliminary

Individual counter time resolution

$\sigma_A = 72.2$ ps

$\sigma_B = 75.5$ ps

$\sigma_C = 66.4$ ps

ToF – Project Timeline

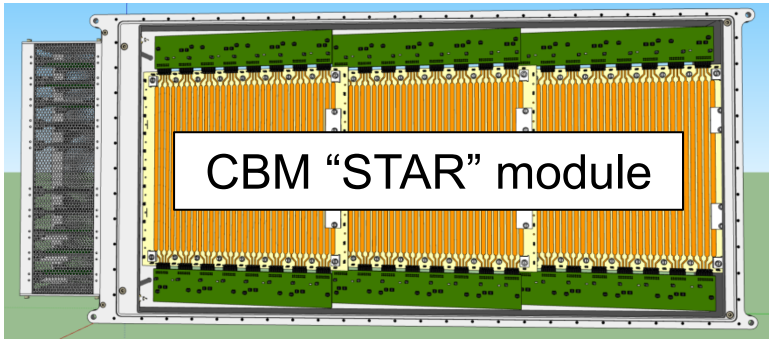
RPC type	res. material	efficiency	time resolution	rate capability
Ceramic MRPC	Ceramic	≈ 90 %	≈ 90 ps	≈ 500 kHz/cm^2
Pad MRPC	sem. glass	≈ 95 %	≈ 50 ps	> 30 kHz/cm^2
Strip	sem. glass	> 95 %	≈ 50 ps	> 30 kHz/cm^2
Strip	float glass	> 95 %	60 ps – 70 ps	≈ 1.5 kHz/cm^2

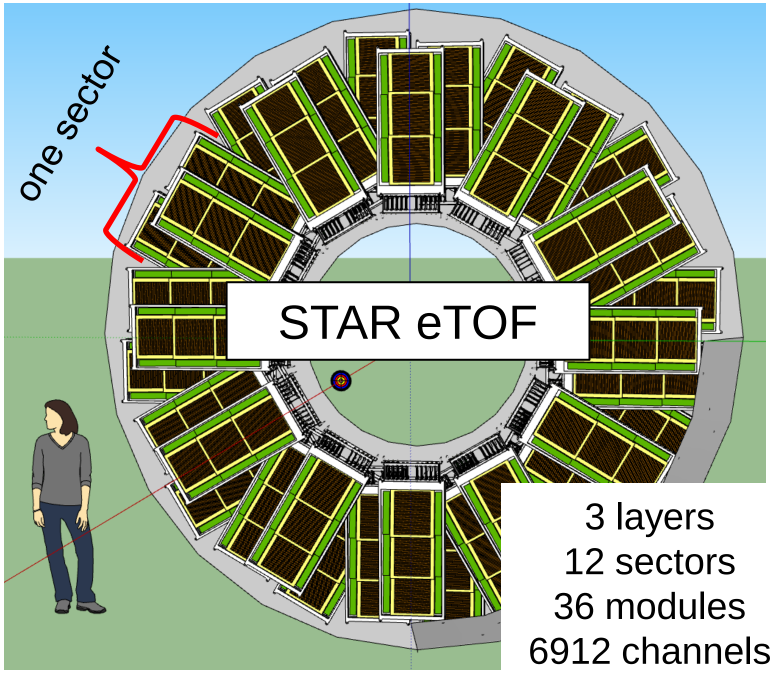
The CBM requirements are fulfilled.

Time line

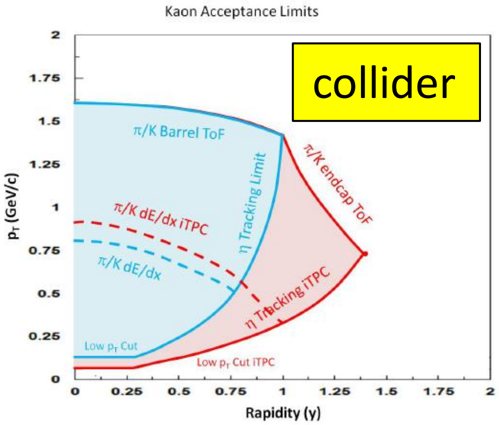
✓ **Full-size demonstrator**	**end 2012**
✓ **TDR approved**	**mid. 2015**
✓ **Full-size modules**	**mid. 2015**
➢ **Full-size modules with 'final' electronics**	**mid. 2016**
➢ **Construction of the modules**	**2016- 2020**
➢ **Integration in STAR@RHIC@BNL**	**2017- 2018**
➢ **eTOF ready for beam**	**01.01.2019**
➢ **Integration in CBM@SIS100@FAIR**	**2019- 2021**
➢ **ToF ready for beam**	**01.06.2021**

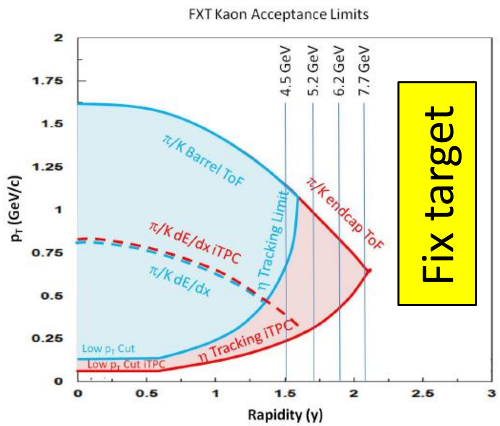
CBM-ToF @ STAR

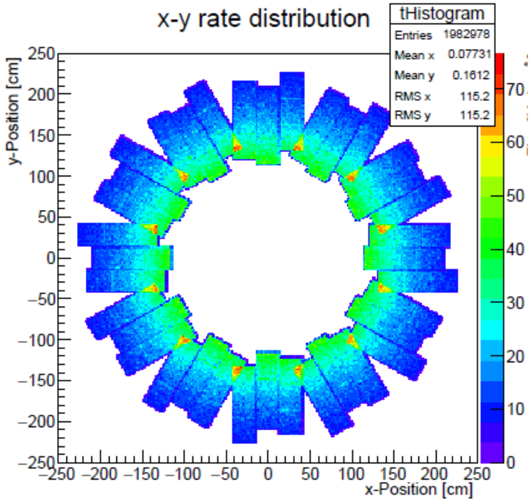


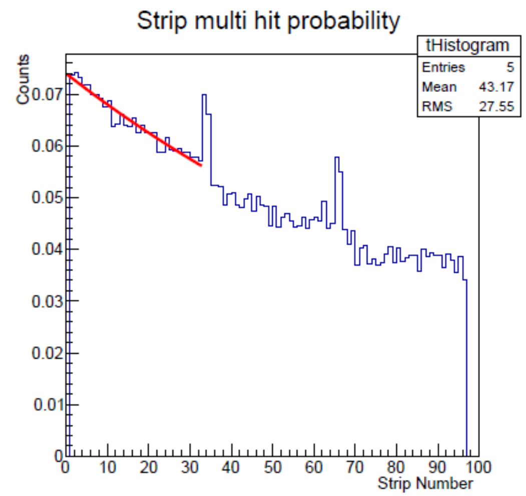


3 layers
12 sectors
36 modules
6912 channels









Particle flux < 45 Hz/cm^2, Multi-hit probability < 7.4%

Summary / Next steps

Summary

- The high rates in CBM require a special materials for MRPC electrodes $\Rightarrow$ Ceramics and Low resistive glass from Beijing, China
- MRPC solutions for all rate conditions available.
- The design of the MRPC are driven by the free-streaming readout $\Rightarrow$ impedance matching is realized.
- The single stack MRPC shows slightly better efficiency and time resolution in comparison to a double stack MRPC.
- Single counter resolutions are in the order of 50 ps to 70 ps including all electronic contributions.
- All types of MRPC detectors fulfill the CBM ToF requirements.
- Results of the last CERN beam time are still preliminary and analysis is ongoing.
- A participation in BES II of STAR @ BNL with about 10% of the full CBM Tof wall is being planned.

Next steps

- Selection of the final layout and counter configurations this year based on the last SPS beam time results.
- Integration of the final electronics and readout until summer this year.
- Load test for all available full size prototypes in Nov. 2016 with final electronics with heavy ions at SPS CERN.
- Integration and beam time test of one module at BNL in Feb. 2017

Thank you for your attention

CBM ToF

Contributing institutions:

Tsinghua	Beijing,
NIPNE	Bucharest,
GSI	Darmstadt,
IRI	Frankfurt
USTC	Hefei,
PI	Heidelberg,
ITEP	Moscow,
HZDR	Rossendorf,
CCNU	Wuhan,

Special thanks go to:

Norbert Herrmann

bmb+f

Großgeräte der physikalischen Grundlagenforschung

SEVENTH FRAMEWORK PROGRAMME

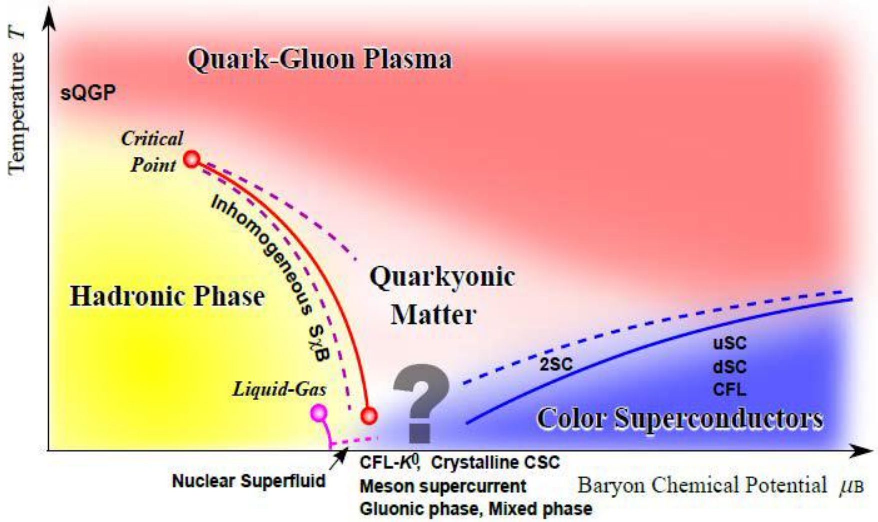
AIDA 2020

Backup Slides

Backup Slides

CBM Physics topics

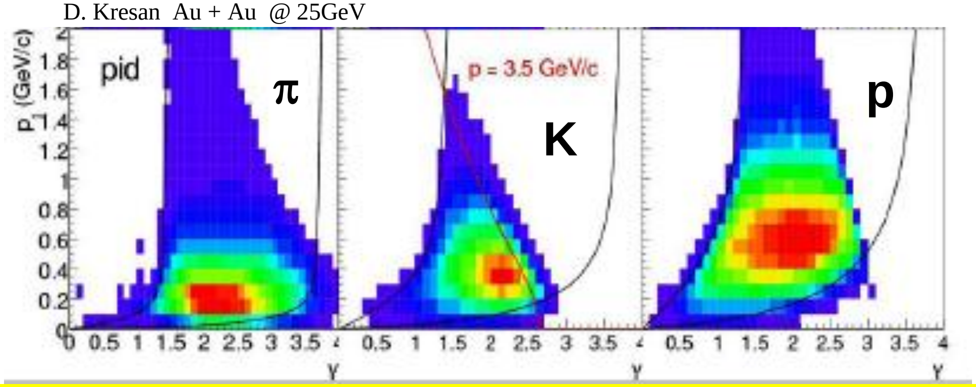
- Deconfinement / phase transition at high ρ_B
- QCD critical endpoint
- The equation-of-state at high ρ_B
- chiral symmetry restoration at high ρ_B



Observables

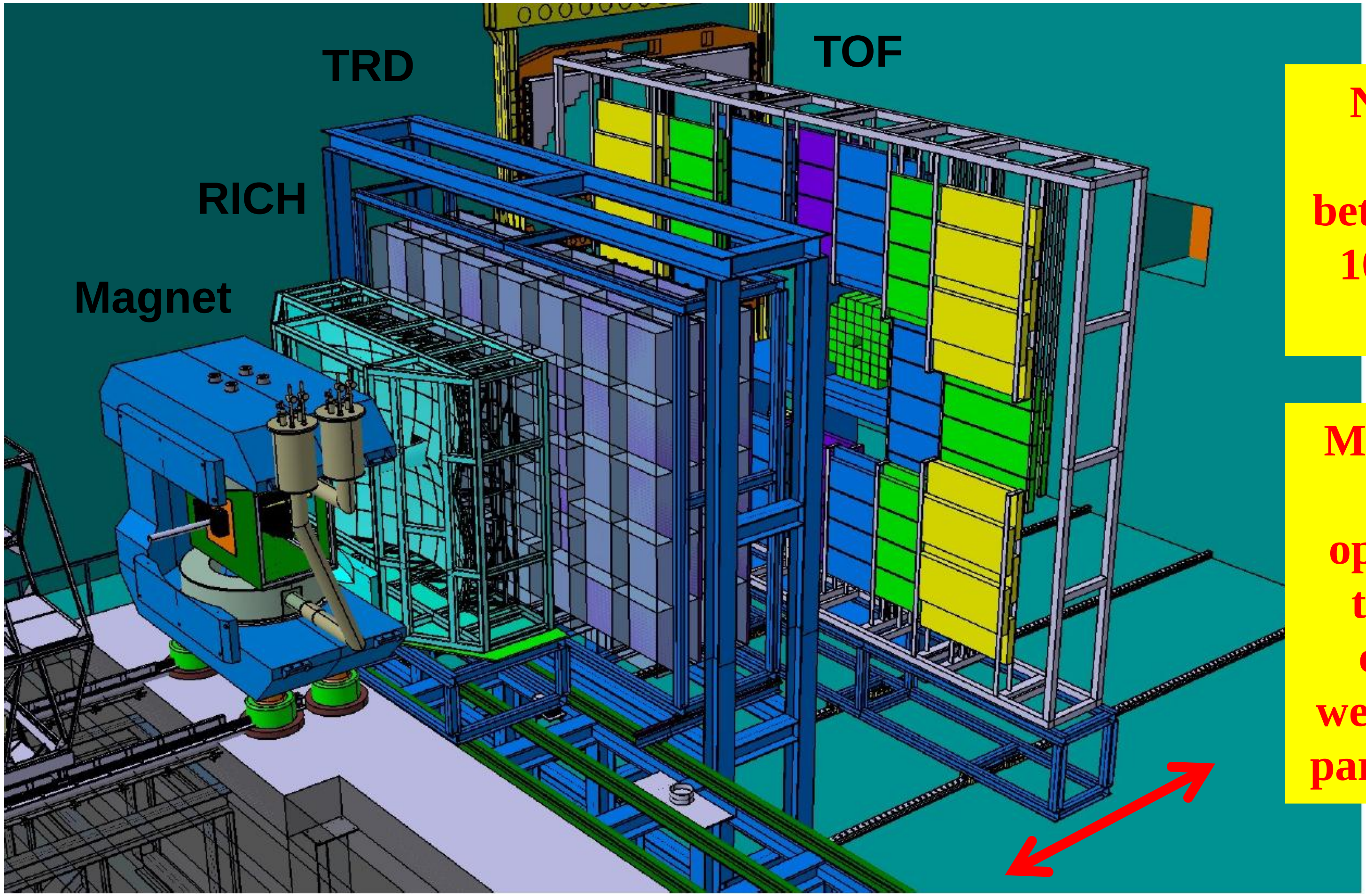
- excitation function and flow of strangeness and charm
- collective flow of hadrons
- particle production at threshold energies
- excitation function of event-by-event fluctuations
- excitation function of low-mass lepton pairs
- in-medium modifications of hadrons ($\rho,\omega,\varphi \rightarrow e+e-(\mu+\mu-)$, D)

D. Kresan Au + Au @ 25GeV



Kaon acceptance depends critically on TOF resolution

Engineering design of the CBM experiment



Nominal ToF position is between 6 m and 10 m from the target

Movable design allows for optimization of the detection efficiency of weakly decaying particles (Kaons)

Backup Slides

T0 – determination

Diamond start counter

- use HADES development,
- develop DAQ interface,
- limited to reaction rates ~ 100kHz

Software solution

- available for all systems
- needs fast particles from reaction
- demonstrated to work for central and semi-central heavy system

Beam fragmentation counter

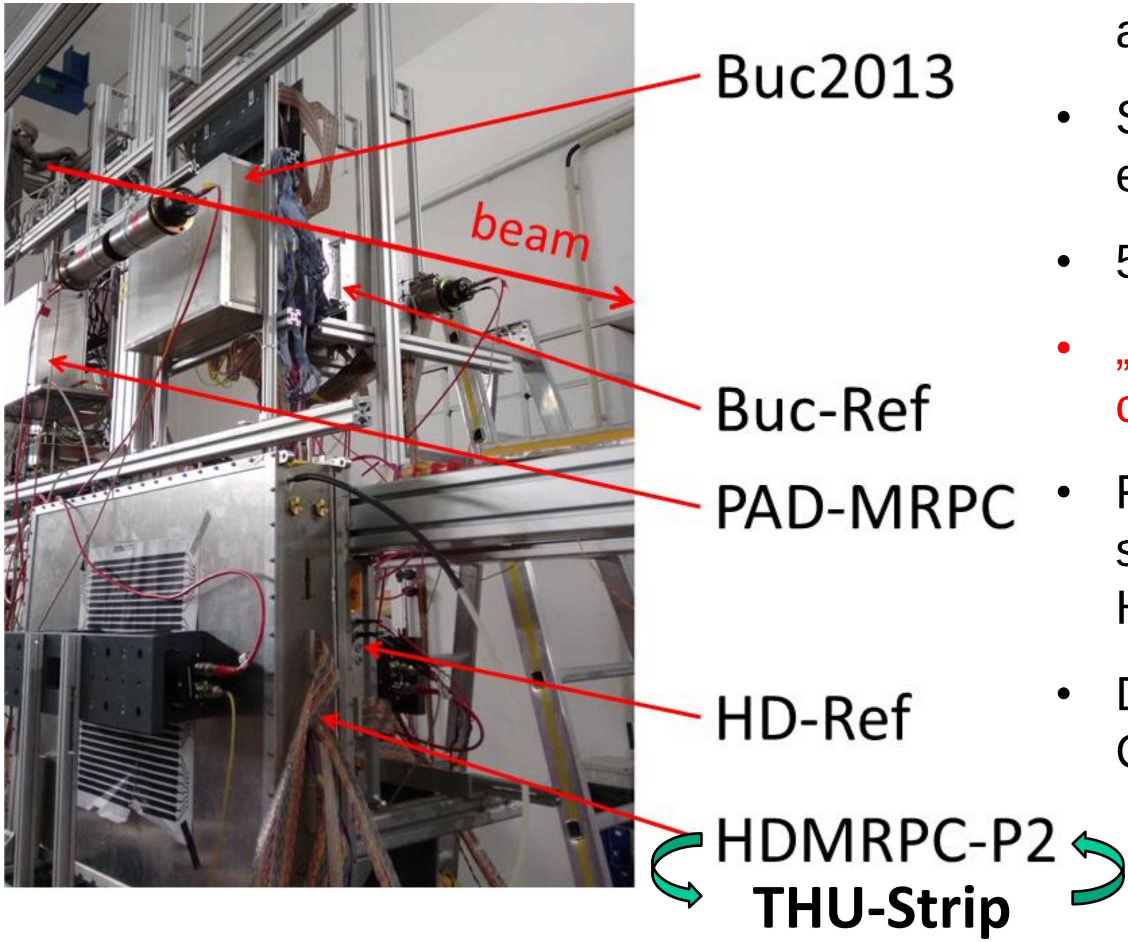
- peripheral HI – reaction have fast particles from projectile fragmentation
- equip region E with timing counters (BFTC)

Reaction counter

- needed for high rate pA – reactions (charm at SIS 100)
- reaction counter at polar angles 35° < θ < 60°.

Beam-time @ GSI

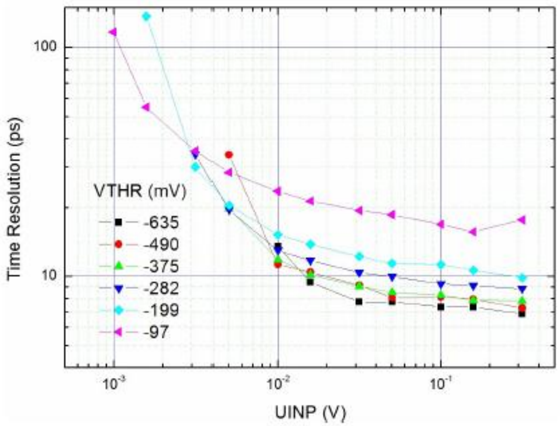
Setup

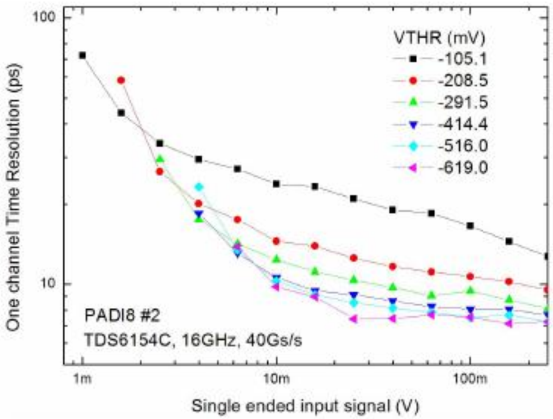


- Test beam time in October 2014 at GSI (Hades cave)
- Sm beam with 1.2A GeV kin. energy
- 5 mm thick lead target
- „Uniform“ illumination of the counter surface
- Flux on the lower part of the setup was about few hundred Hz/cm^2
- Delivered flux does not meet the CBM requirements

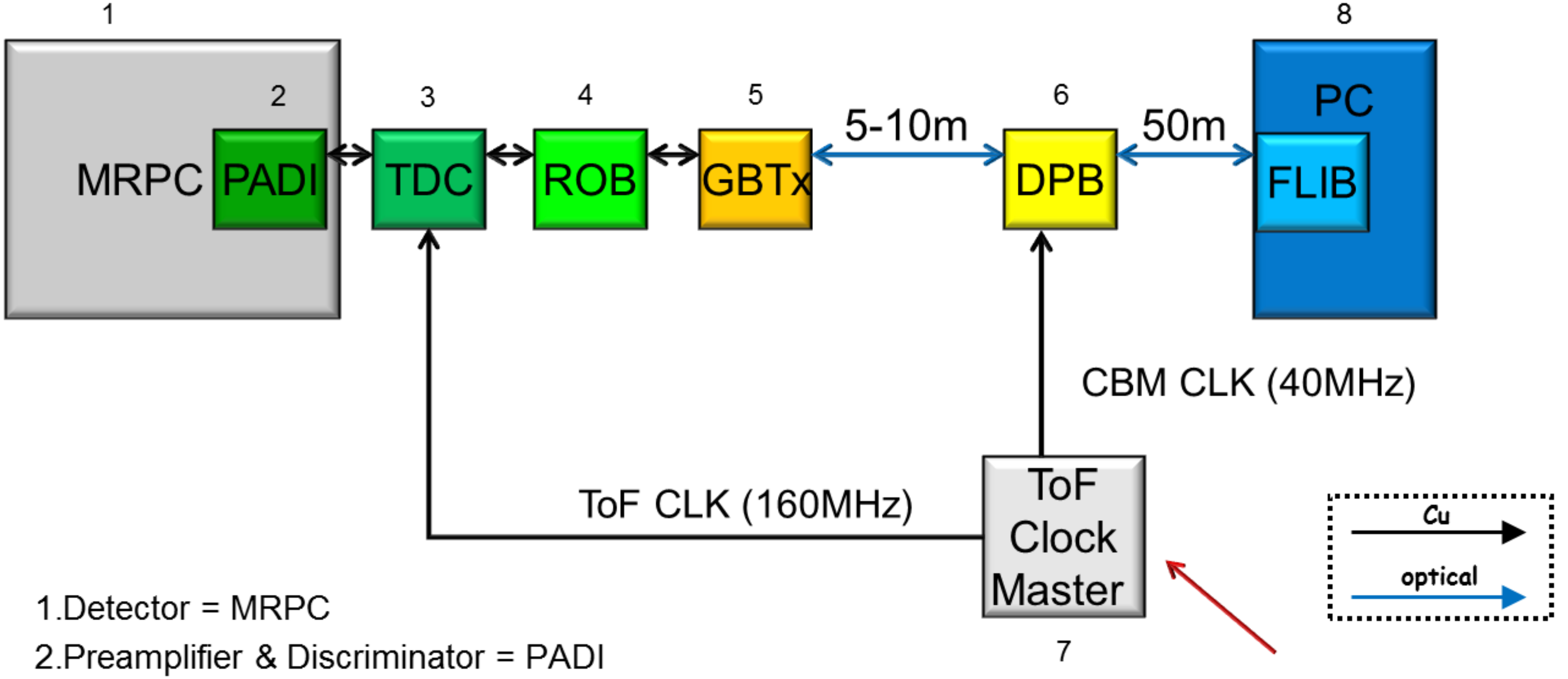
Backup Slides

Main parameters comparison	PADI-1	PADI-2	PADI-6	PADI-8
Channels per chip	3	4	4	8
PA Bandwidth (MHz)	280	293	416	411
PA Voltage Gain	74	87	244	251
Conversion Gain (mV/fC)	6.3	7.8	35	30
Baseline DC offset σ (mV)	6.7	21.9	5.9	1
PA Noise (mV_{RMS})	3.37	2.19	5.82	5.5
Equivalent Noise Charge (e_{RMS})	3512	1753	1039	1145
Threshold type	Extern	Extern	Ext. & DAC	DAC
Threshold dynamics ($\pm$ mV)	Non.lin. 280	Non.lin. 300	Lin. 500	Lin. 750
Input Impedance Range (Ω)	30-450	37 - 370	38 - 165	30 - 160
Power consumption (mW/channel)	21.6	17.4	17.7	17





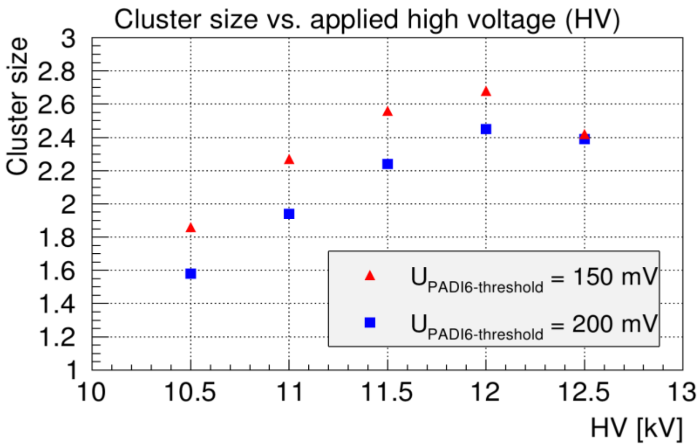
Backup Slides

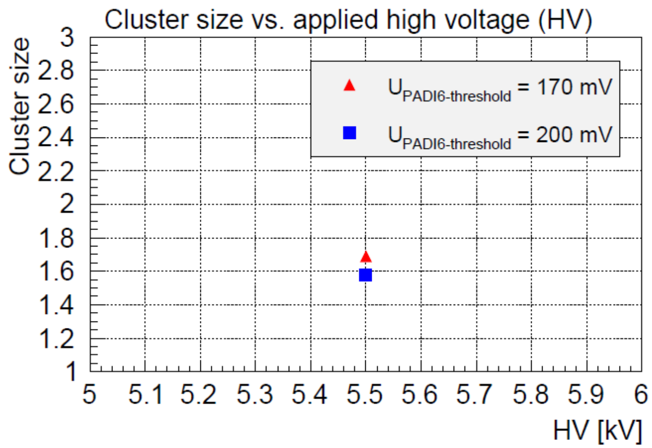


1. Detector = MRPC
2. Preamplifier & Discriminator = PADI
3. Time to Digital Converter (TDC) = GET4 or FPGA TDC
4. Readout board for TDC = **1st concentrator stage**
5. GBTx = Data Concentrator ASIC from CERN = **2nd concentrator stage**
6. Data Processing Board = **3rd concentrator stage**
7. Clock Master (CLOSY) & Clock Distribution for ToF
8. PC = storage Device

Results

Differential single stack MRPC with 8 gas gaps vs. Differential double stack MRPC with 2 x 4 gas gaps





- In a triggered setup there is no major difference in the performance between both counter types.
- However, in a free running mode an impedance matched MRPC should give a better performance due to minimized signal reflections.