International Conference on Science and Technology for FAIR in Europe 2014

# Development of the Time-Of-Flight System for the CBM Experiment

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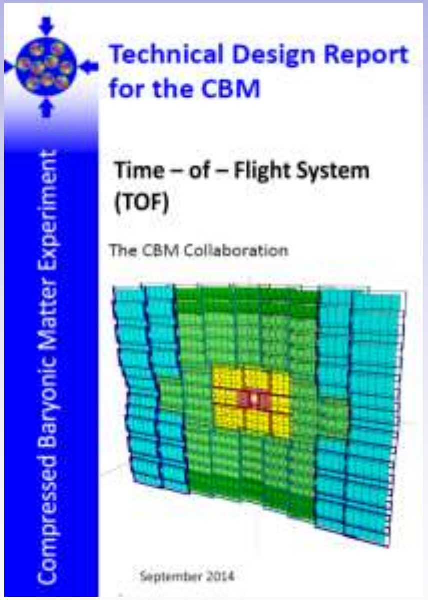
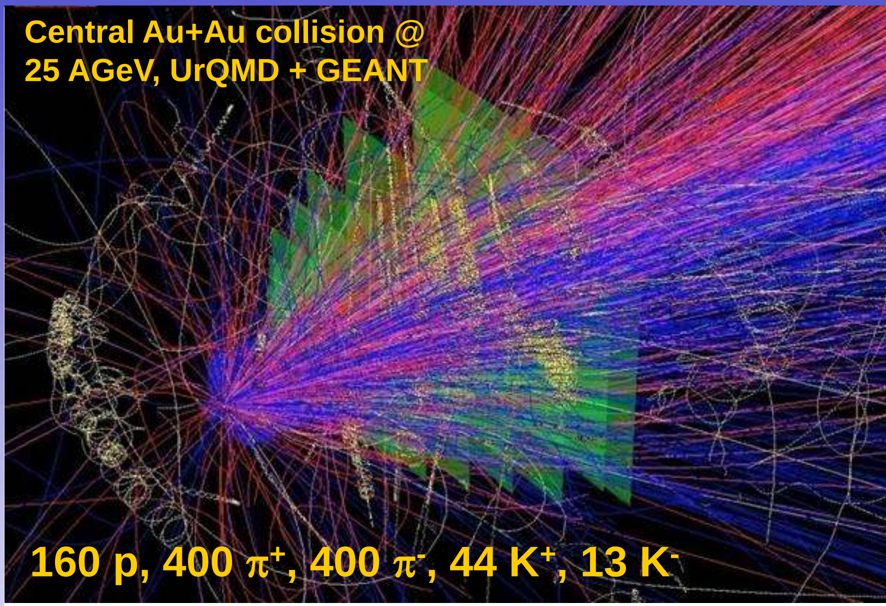
**Outline:**

- Motivation / CBM-ToF Requirements
- Working principle of Resistive Plate Chambers
- Rate capability of MRPCs
- Low resistive glass
- Conceptual design of the ToF wall
- MRPC description and test result
- ToF project time table
- Summary / Next Steps



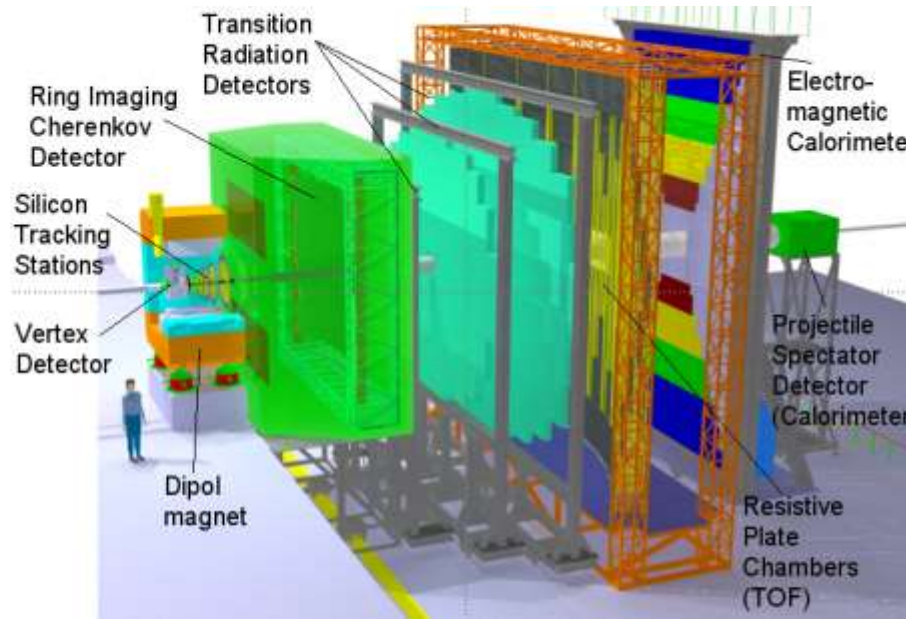
# Motivation and Requirements

CBM ToF




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

**Compressed Baryonic Matter Experiment at FAIR facility @ GSI**



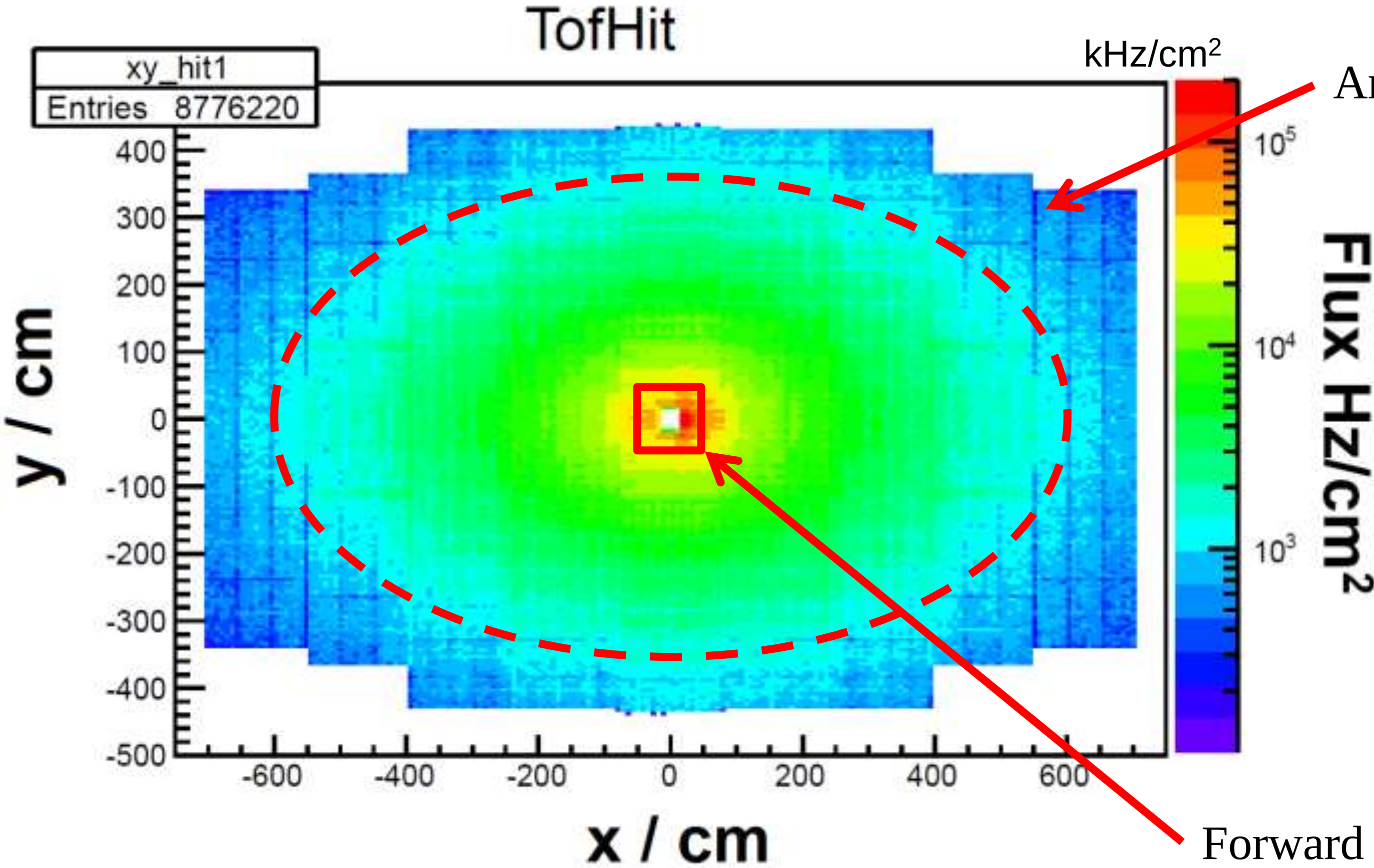

**CBM-ToF Requirements**

- **full system time resolution $\sigma_T$ ~ 80 ps**
- **Efficiency > 95 %**
- **Rate capability ≤ 25 kHz/cm²**
- **Free streaming DAQ**
- **Polar angular range 2.5° – 25°**
- **Low power electronics (~100.000 channels).**
- **Pile-up < 5%**
- **Occupancy < 5 %**
  **(for Au-Au(central) at E=25 GeV/A)**

**Maximal interaction rate for heavy systems is 10 MHz**

# Incident particle flux

**URQMD simulated charged particle flux for Au + Au (minimum bias) events at 25 AGeV assuming an interaction rate of 10 MHz**

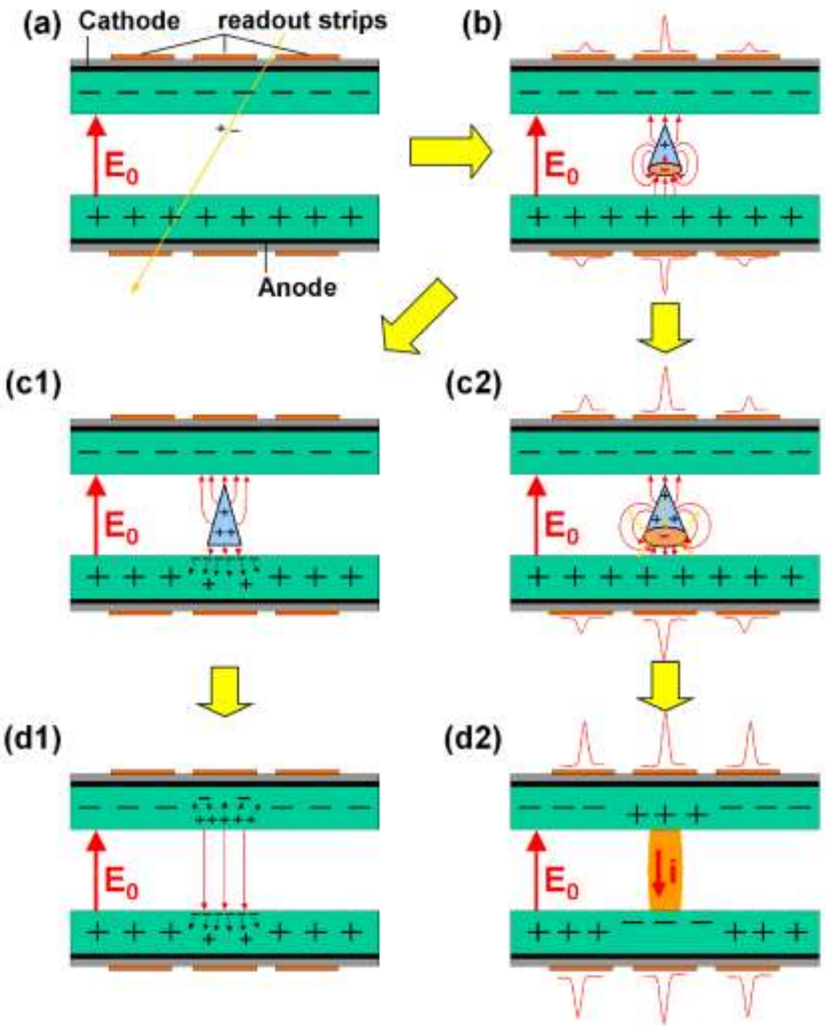



Area with < 1 kHz/cm$^2$

- Flux ranging from 0.1 to 100 kHz/cm$^2$
- At different regions MRPC counters with different rate capabilities are needed

Forward zone > 25 kHz/cm$^2$

# Working principle of an RPC



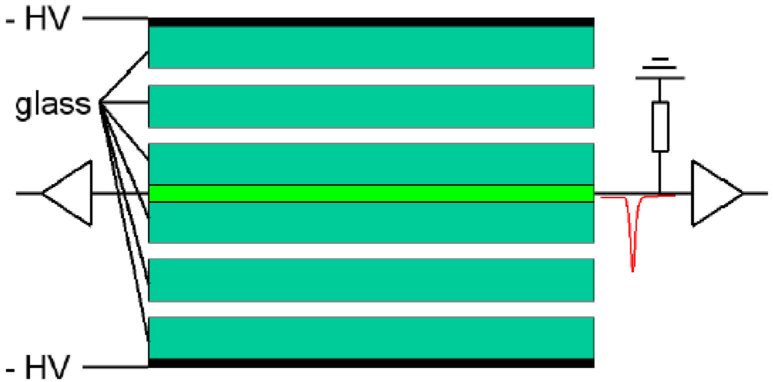

(a) A traversing particle (thin yellow arrow) ionizes the gas in the gap.
(b) Electrons and ions drift towards the electrodes developing an avalanche and inducing a signal in the readout electrode.
(c1) Since the drift velocity of the ions is much smaller than for the electrons their contribution to the signal is negligible.
(d1) The charges are deposited on the surface of the resistive material building up an opposite electric field. This temporarily leads to a blind spot in the counter which is limiting the rate capability.

**$E_0$ = 120 kV/cm**

# Structure of Multi-gap RPCs

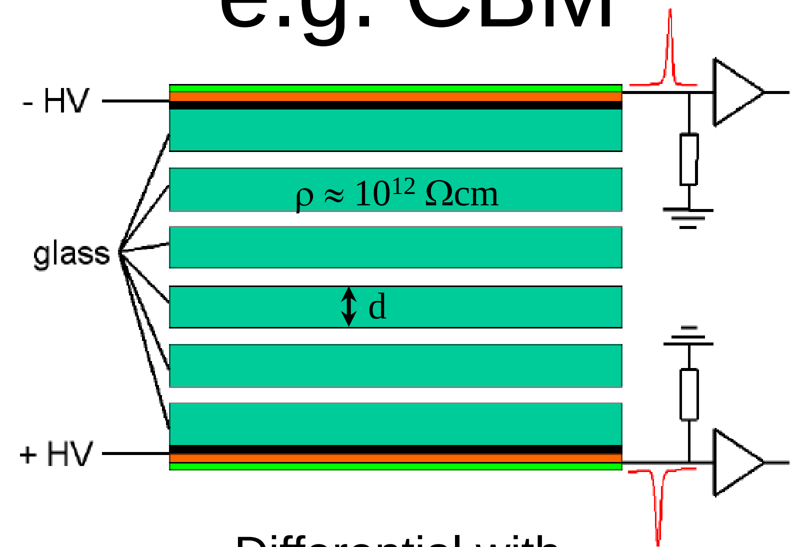
CBM ToF

## e.g. FOPI




Single ended with
double stack
configuration

## e.g. CBM




Differential with
single stack
configuration

**First MRPC 1996**

E. Cerron Zeballos, I. Crotty, D. Hatzifotiadou, J. Lamas Valverde, S. Neupane, M.C.S. Williams, A. Zichichi
**Nucl.Instrum.Meth. A374 (1996) 132-136**

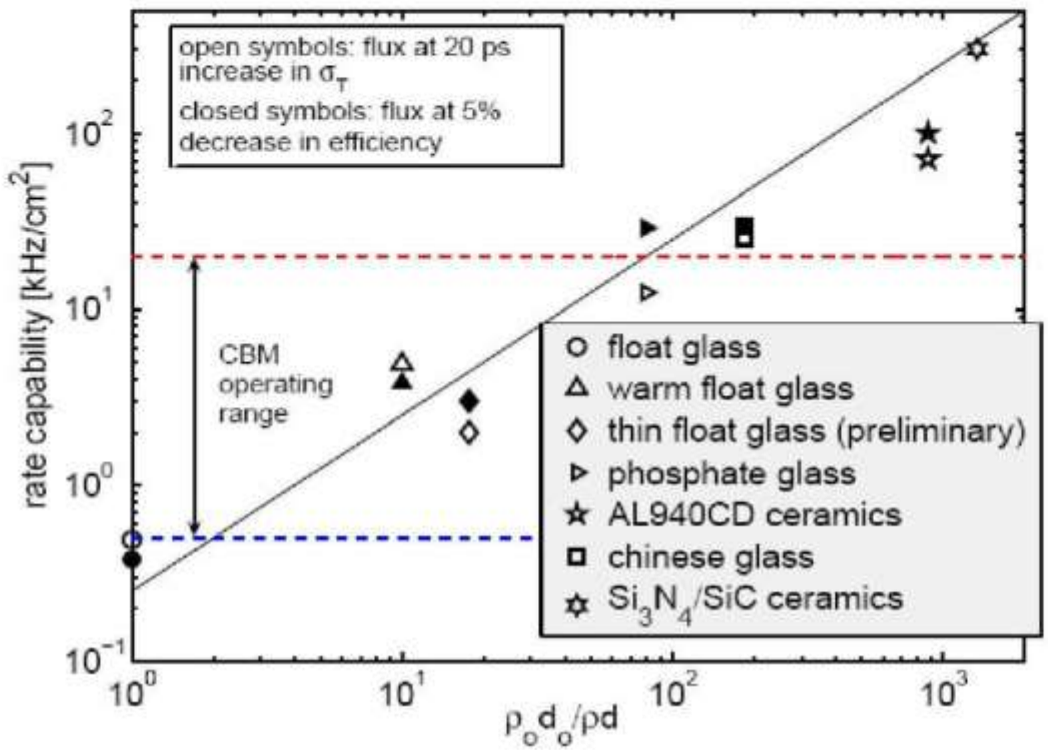
# Rate capability of MRPCs

CBM ToF

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

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

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




How to increase the rate capability?

- Lowering the resistivity of the electrode material
  - different materials
    1) float glass: $\rho = 3\times10^{12}$ Ωcm
    2) low resistive glass: $\rho \approx 10^{10}$ Ωcm
    3) ceramics: $\rho \approx 10^{9}$ Ωcm
  - warming the electrodes

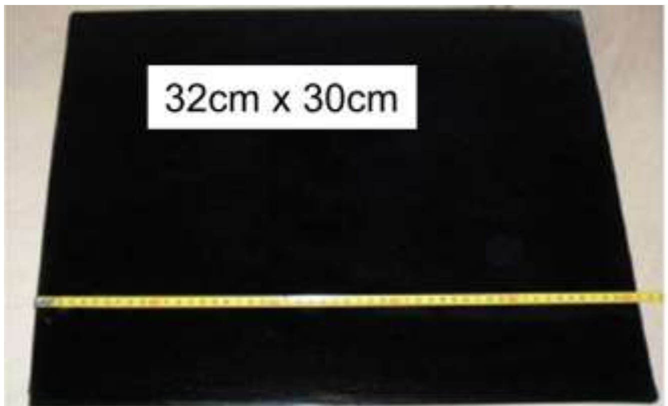
$$\rho \cong \rho_{T_0} 10^{(T_0 - T)/\Delta T}$$

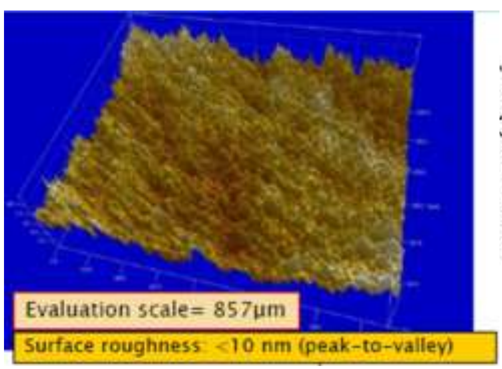
- Decreasing the electrode thickness

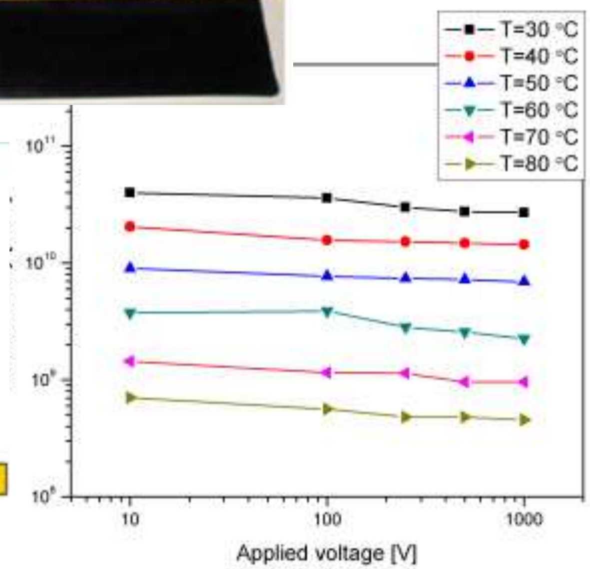
# Low resistive glass

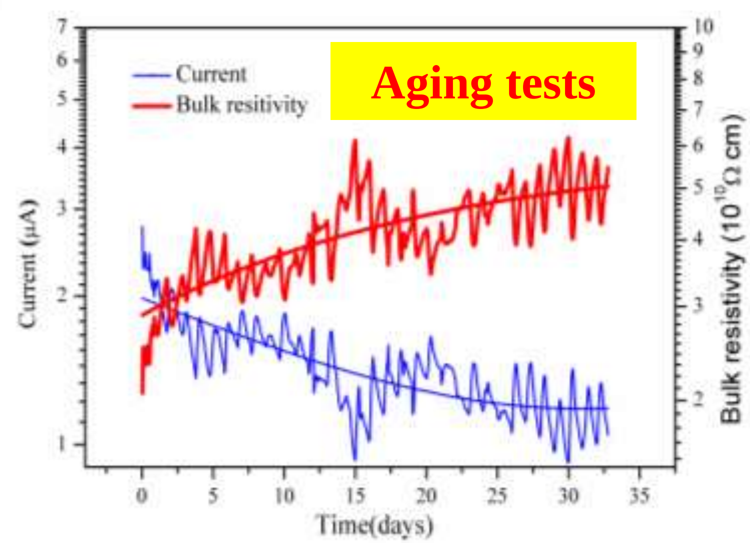
**Low resistive glass for high-rate MRPCs is developed in Beijing, China (Yi Wang)**

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

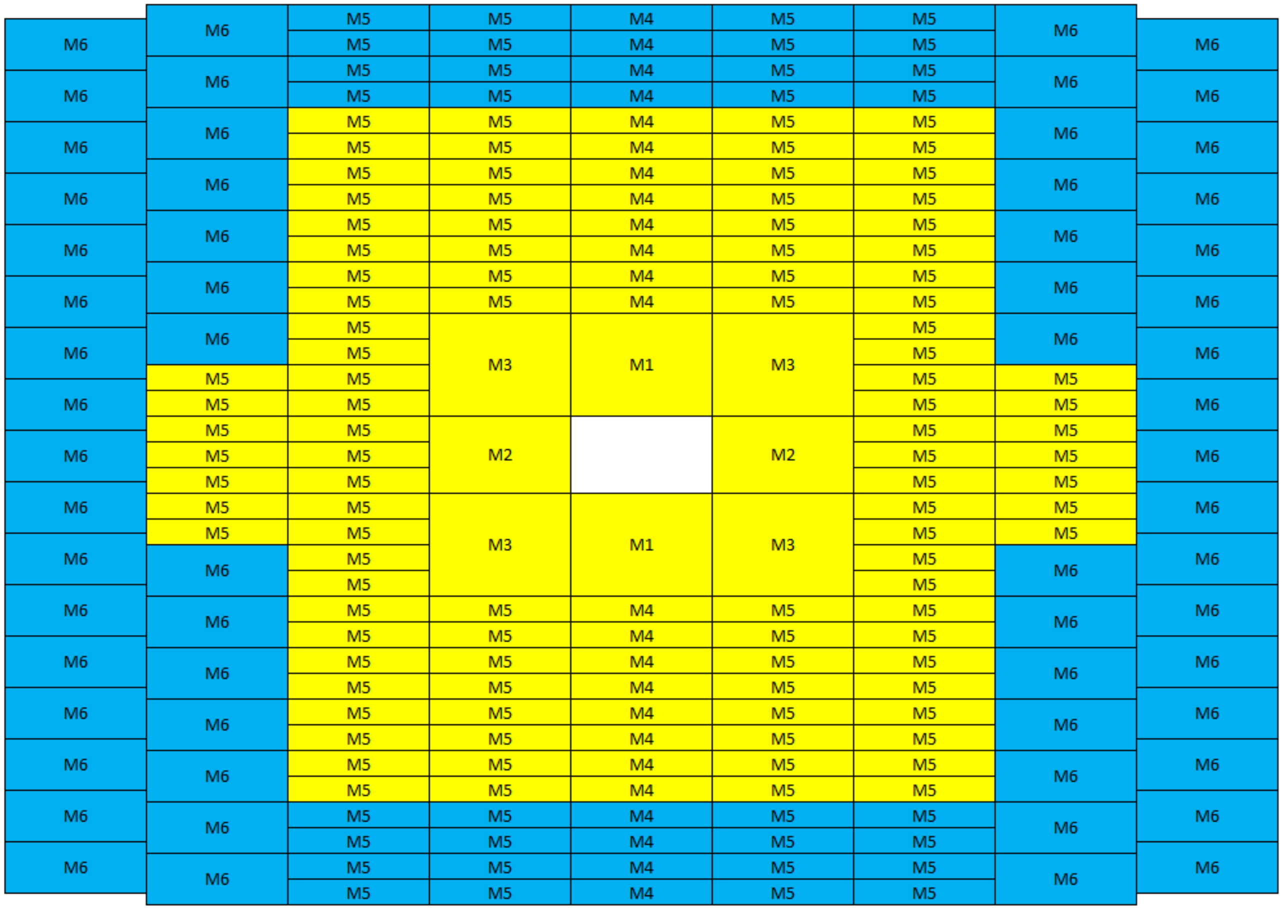


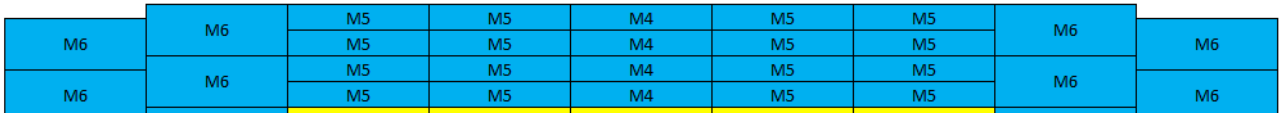



# ToF wall layout




- **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**

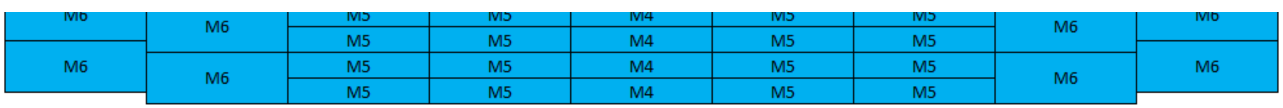
# ToF wall layout




- **6 types of modules (M1 – M6) only**

| Module notation | Number of modules | Module size mm$^3$ | Number of MRPCs per module | Number of MRPCs in total | Number of cells per module | Number of cells in total |
|---|---|---|---|---|---|---|
| M1 | 2 | $1270 \times 1417 \times 239$ | 32 | 64 | 2048 | 4096 |
| M2 | 2 | $2140 \times 705 \times 239$ | 27 | 54 | 1728 | 3456 |
| M3 | 4 | $1850 \times 1417 \times 239$ | 42 | 168 | 2688 | 10752 |
| M4 | 24 | $1802 \times 490 \times 110$ | 5 | 120 | 160 | 3840 |
| M5 | 132 | $1802 \times 490 \times 110$ | 5 | 660 | 160 | 21120 |
| M6 | 62 | $1802 \times 740 \times 110$ | 5 | 310 | 160 | 9920 |
| Sum | 226 | | | 1376 | | 53184 |

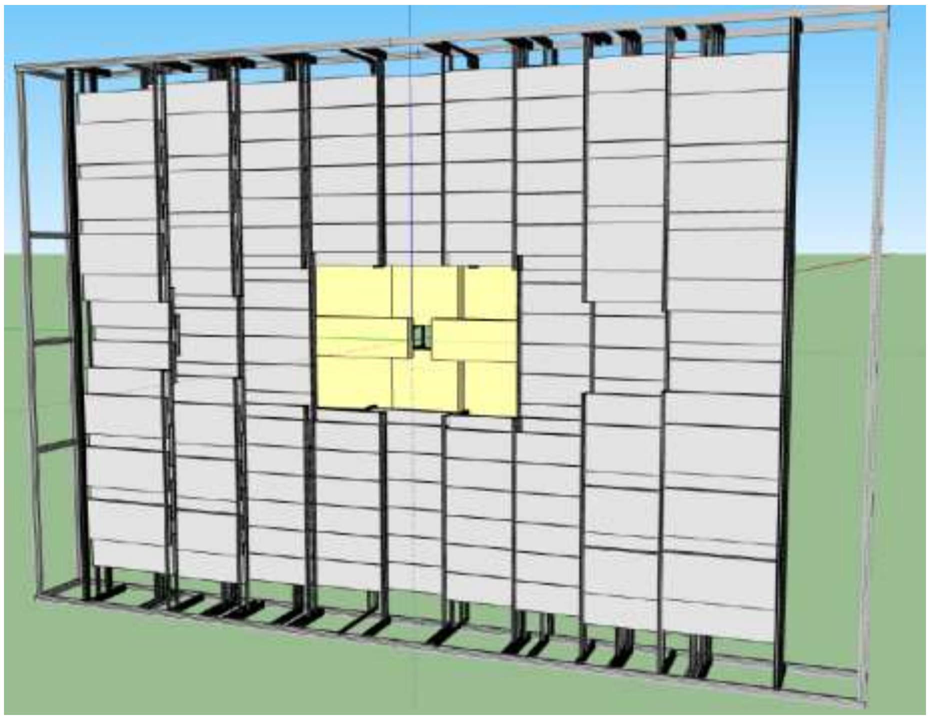
***Table 3.1:*** *Numbers and dimensions of the modules.*




**⇒ 106368 read-out channels**

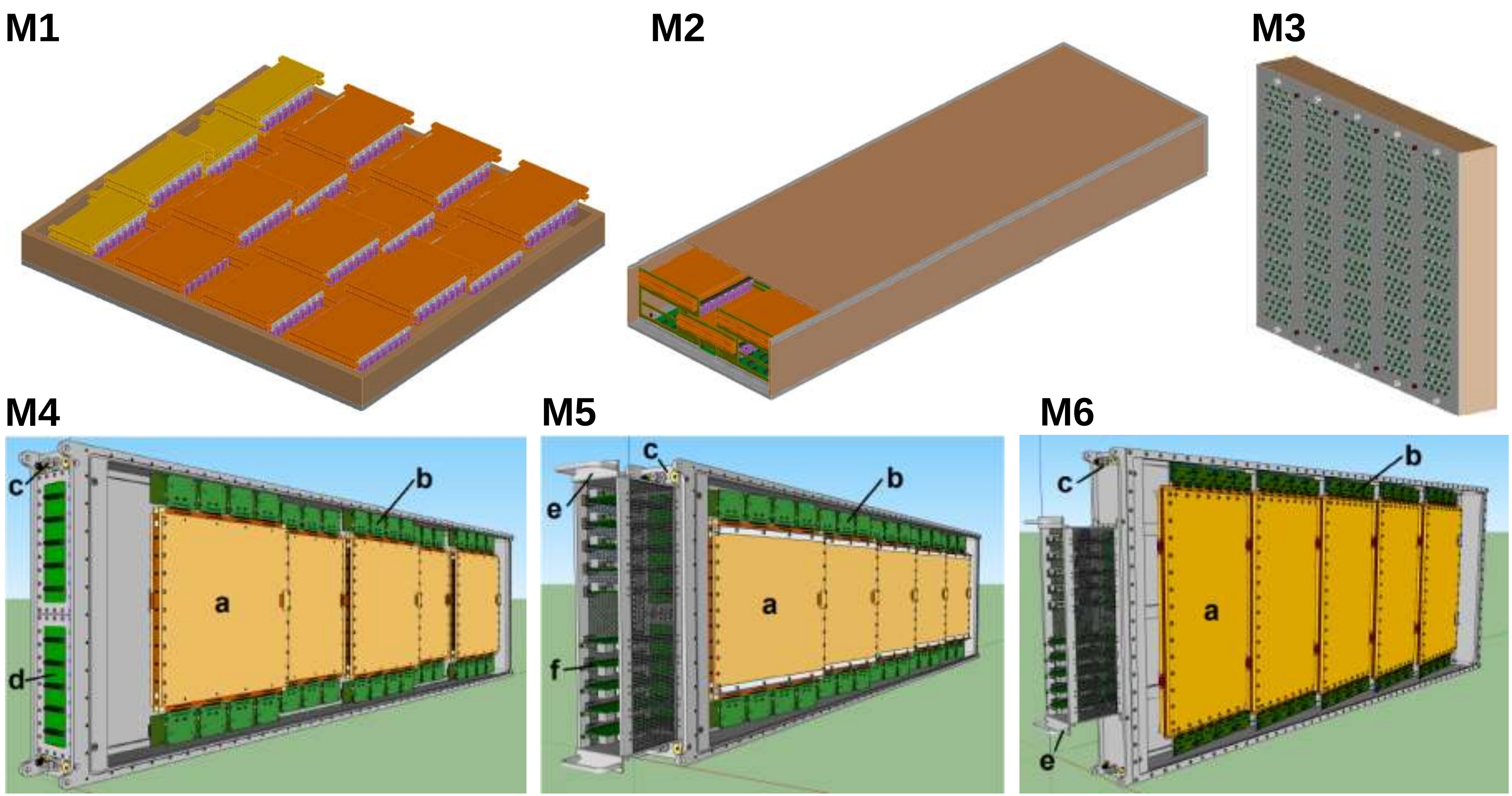
# ToF wall layout

## More realistic layout



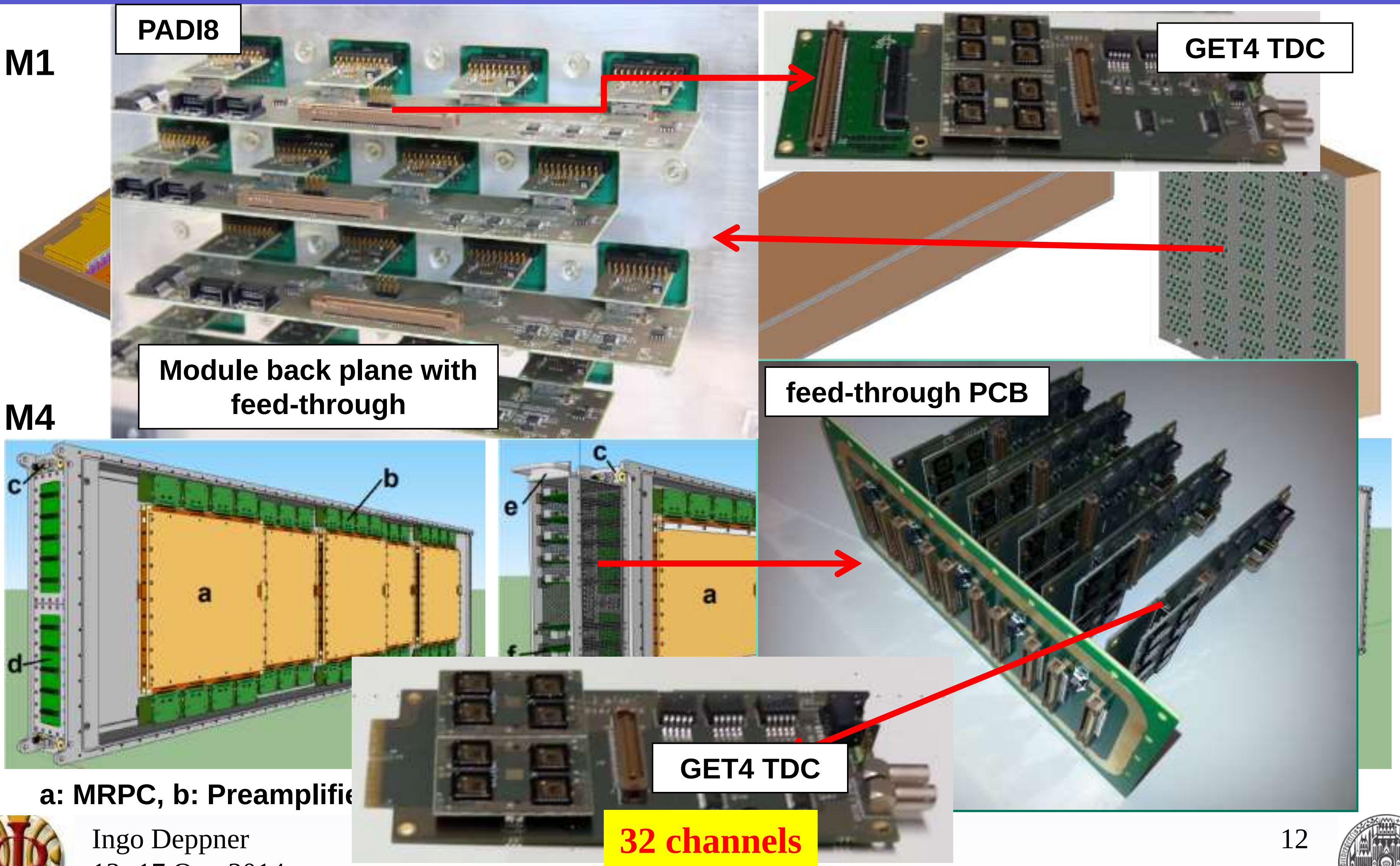
- Frame is constructed out of industrial aluminum profiles (company: Item)
- Thick profiles are used only for the outer frame and one bar behind each column ( ≈ 30 % of a radiation length ( $X_{0,Al}$ = 8,72cm))
- Modules are screwed on thin profiles of 80 mm x 16 mm cross section with a typical radiation length of 6%
- About 250 kg of material is placed in front of the counters
- Module are mounted without electrical connection to the frame (Teflon spacers)
- Wall is movable in beam direction from 6 m to 12 from the target

# Modules



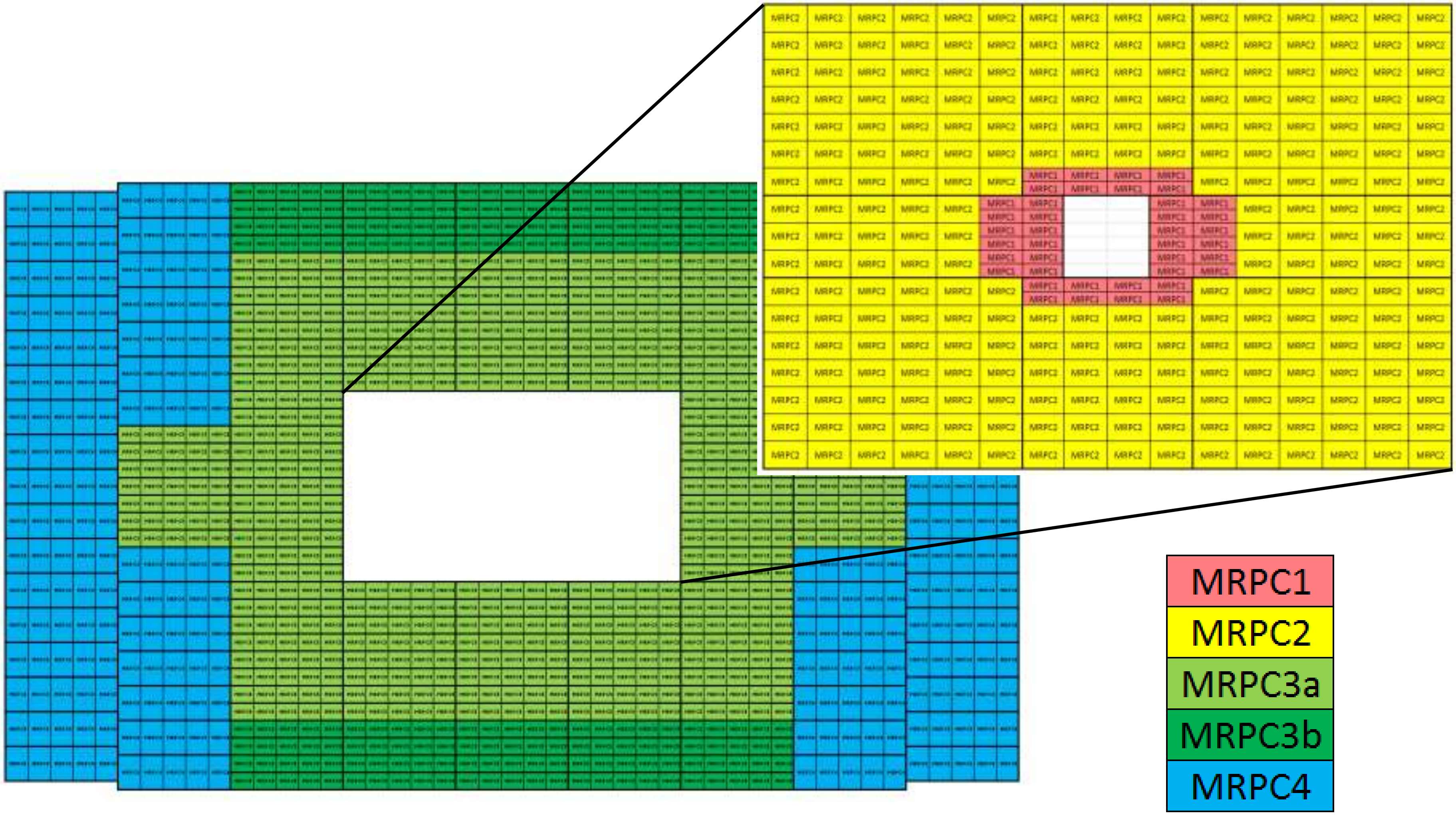

**a: MRPC, b: Preamplifier (PADI), c: feed-through PCB, d: connectors, e: crate, f: TDC and read out**

# Modules

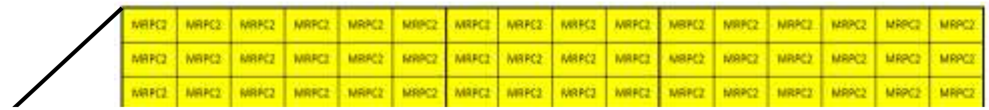



a: MRPC, b: Preamplifie

# MRPC arrangement



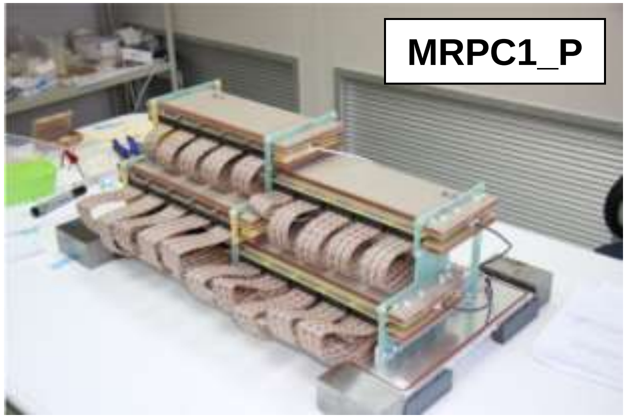
# MRPC arrangement

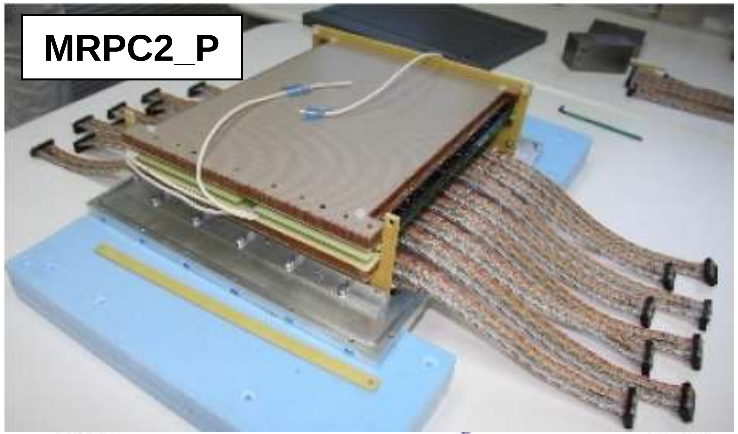


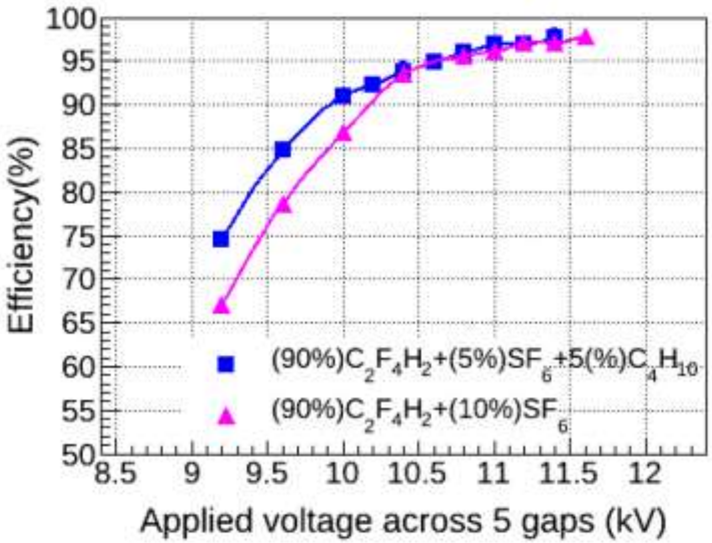
| MRPC notation | MRPC1 | MRPC2 | MRPC3a | MRPC3b | MRPC4 |
|---|---|---|---|---|---|
| Number of MRPCs | 40 | 246 | 580 | 200 | 310 |
| Active area [mm$^2$] | 300 × 100 | 300 × 200 | 320 × 270 | 320 × 270 | 320 × 530 |
| Number of Strips per MRPC | 64 | 64 | 32 | 32 | 32 |
| Strip length [mm] | 100 | 200 | 270 | 270 | 530 |
| Granularity (cell size) [mm$^2$] | 472.4 | 944.8 | 2700 | 2700 | 5300 |
| Number of gas gaps | 10 | 10 | 8 | 8 | 8 |
| Gap size $\mu$m | 140 | 140 | 220 | 220 | 220 |
| Glass size [mm$^2$] | 320 × 100 | 320 × 200 | 330 × 280 | 330 × 280 | 330 × 540 |
| Glass thickness [mm] | 0.7 | 0.7 | 1.0 | 0.5 | 0.5 |
| Number of glass plates | 12 | 12 | 9 | 9 | 9 |
| Glass type | low res. | low res. | low res. | float | float |
| Total glass surface [m$^2$] | 15.36 | 188.93 | 482.33 | 166.32 | 497.18 |

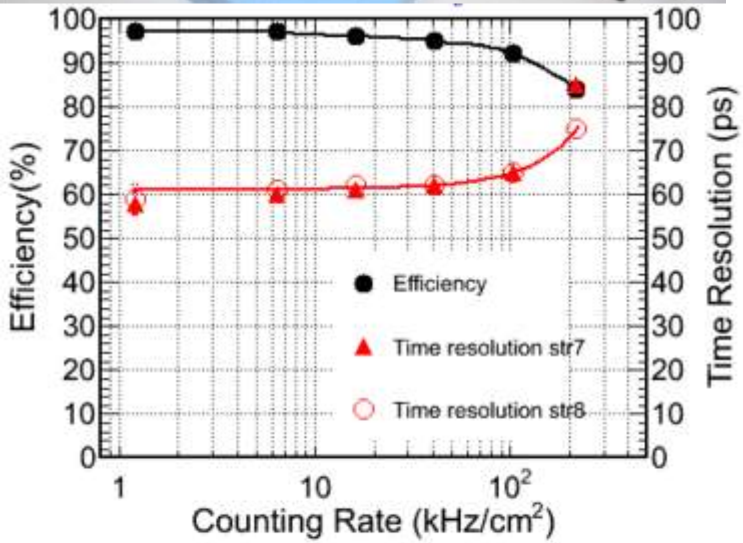
***Table 3.2:*** *Numbers and dimensions of different MRPC counters.*

# MRPC1/2 prototypes



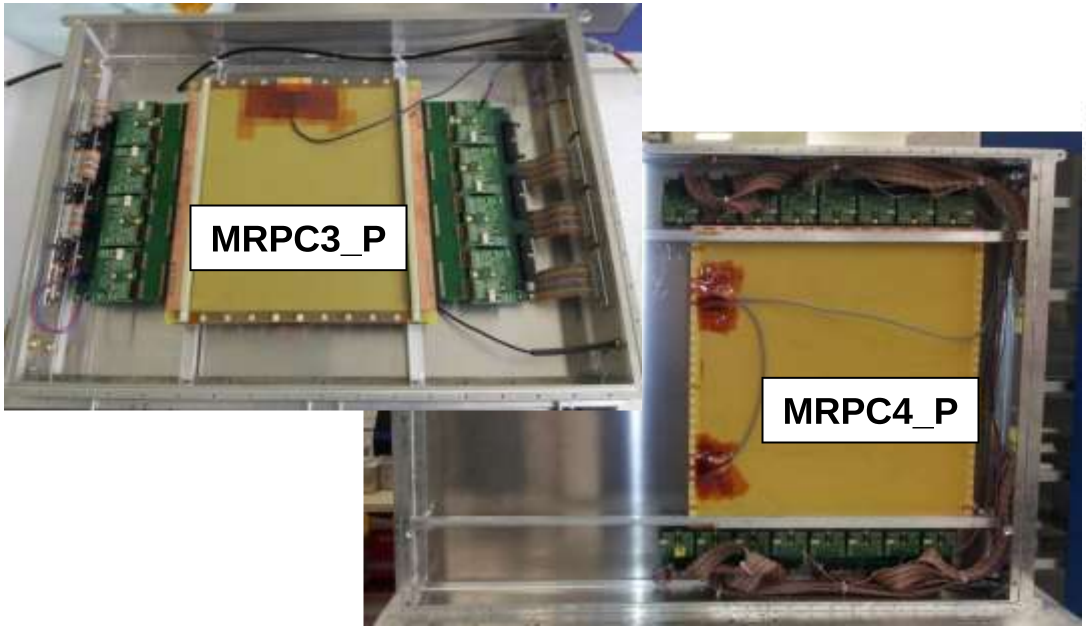



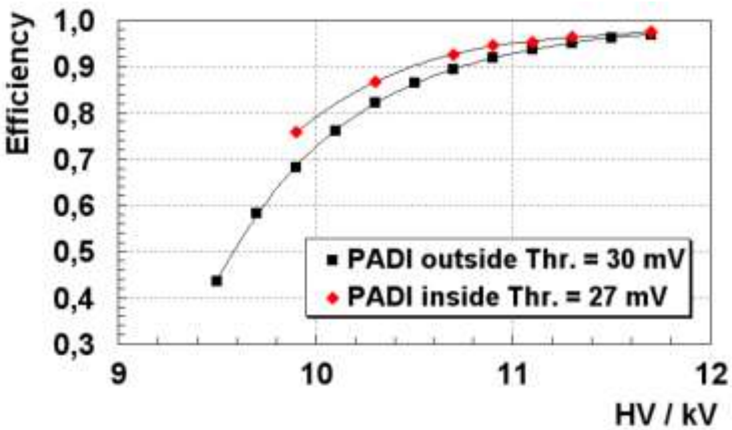




**MRPC1/2 prototypes are developed in NIPNE Bucharest**

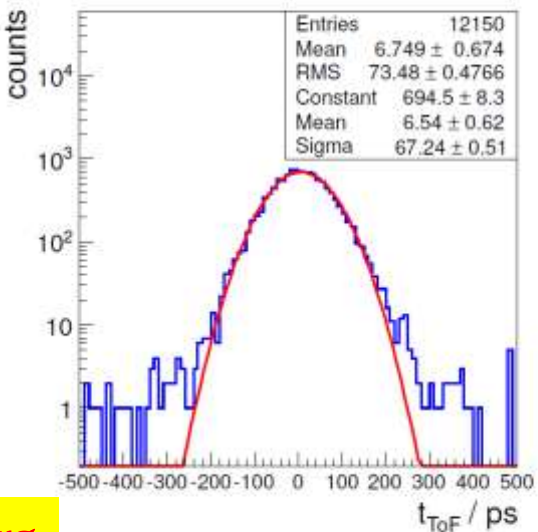
# MRPC3/4 prototypes




| | | |
|---|---|---|
| Applied high voltage | ±10.2 kV | ±11.0 kV |
| Efficiency | (94.4 ± 0.2) % | (98.5 ± 0.1) % |
| RPC time resolution | (43.5 ± 1.2) ps | (39.0 ± 1.0) ps |
| Mean cluster size | 1.24 | 1.39 |
| Mean cluster multiplicity | 1.26 | 1.26 |

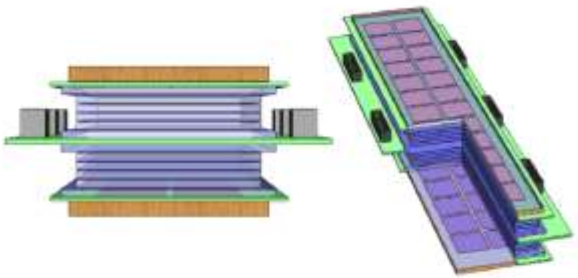
**Table 5.1:** Results obtained in the cosmic ray test for RPC-P3.

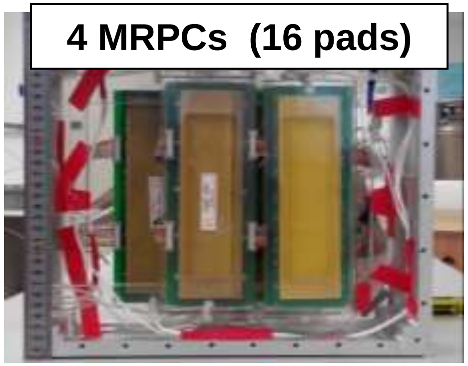


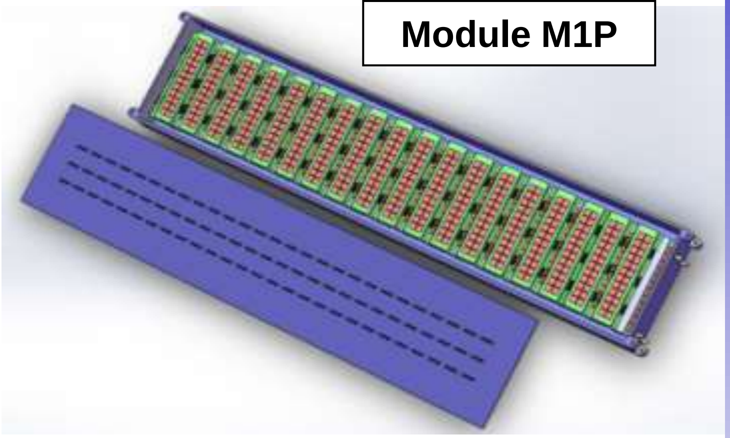

**MRPC3/4 prototypes are developed at PI Univ. Heidelberg**

# Alternative solution for M1 to M3

**Pad MRPC**






| Module notation | Number of modules | Module size mm$^3$ | Number of MRPCs per module | Number of MRPCs in total | Number of cells per module | Number of cells in total |
|---|---|---|---|---|---|---|
| M1P | 24 | $1802 \times 370 \times 110$ | 38 | 912 | 912 | 21888 |
| M2P | 6 | $1802 \times 370 \times 110$ | 41 | 246 | 984 | 5904 |
| Sum | 30 | | | 1158 | | 27792 |

***Table E.1:*** *Numbers and dimensions of the modules.*

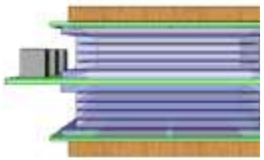
**Pad MRPC prototypes are developed in Tsinghua-Univ. Beijing**

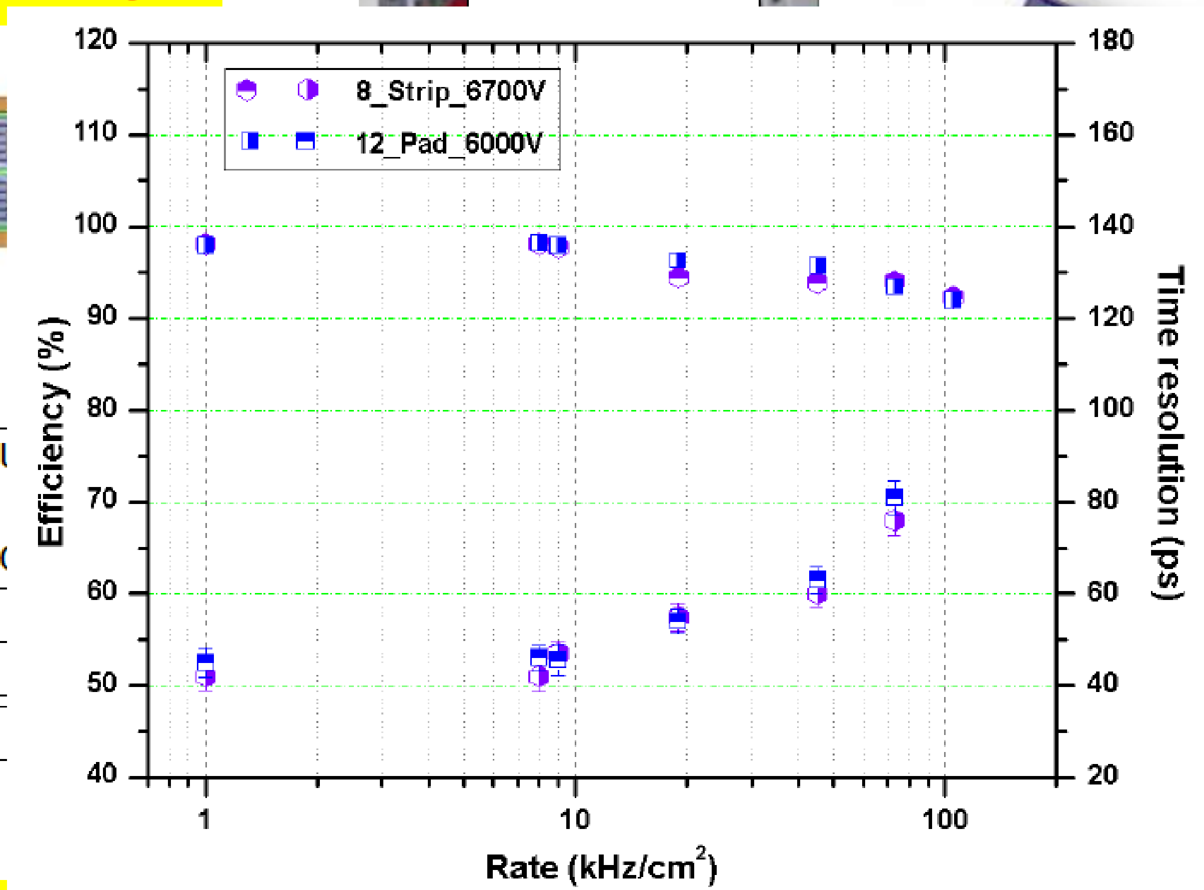
# Alternative solution for M1 to M3

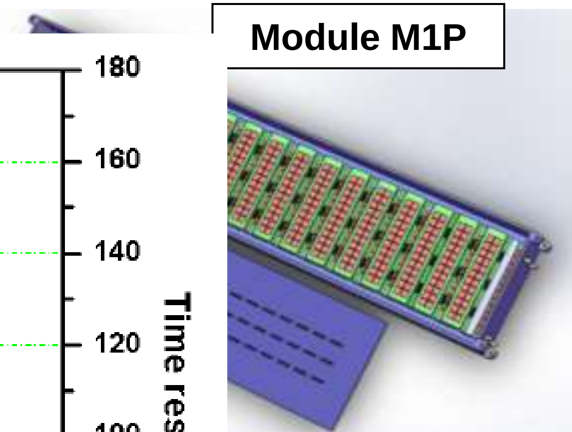
## Pad MRPC

4 Pad MRPC

Module M1P





| Module notation | Nu... m... | ...ber of ...s per ...dule | Number of cells in total |
|---|---|---|---|
| M1P | | ...12 | 21888 |
| M2P | | ...34 | 5904 |
| Sum | | | 27792 |

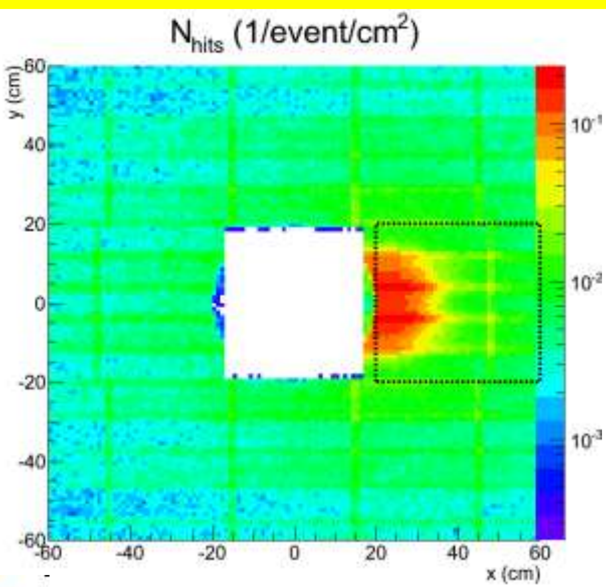
**Pad MRPC prototypes are developed in Tsinghua-Univ. Beijing**

# Forward Zone

## Beam fragmentation counter in the central zone

Can be used for:
- T0 calculation from fast beam fragments
- reaction plane determination for non-central events

**Au + Au mbias events at 10 AGeV @ 10 MHz**




3 x 2 gap ceramic counter

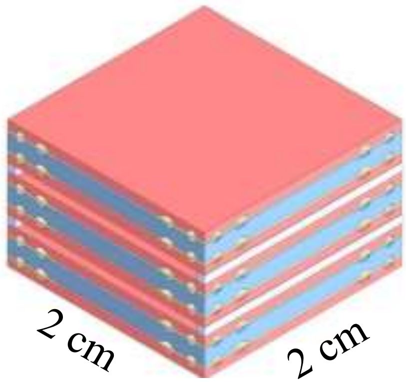
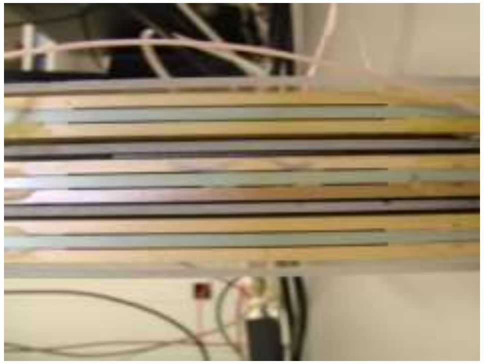
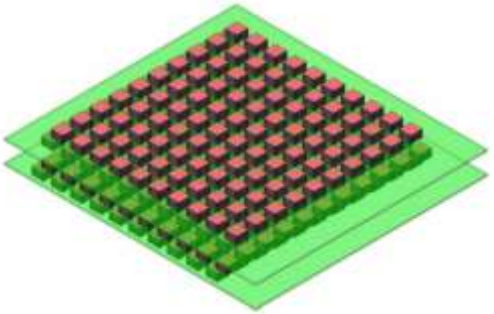


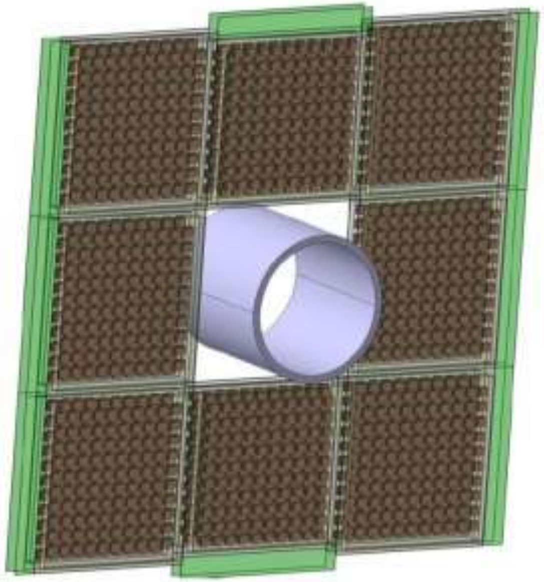

Photo of one cell



Module



Central Zone



# ToF – Project Timeline

| RPC type | res. material | efficiency | time resolution | rate capability |
|---|---|---|---|---|
| Ceramic MRPC | Ceramic | ≈ 90 % | ≈ 70 ps | ≈ 500 $kHz/cm^2$ |
| Pad MRPC | sem. glass | ≈ 95 % | ≈ 50 ps | > 30 $kHz/cm^2$ |
| Narrow strip RPC | sem. Glass | > 95 % | ≈ 50 ps | > 30 $kHz/cm^2$ |
| Wide Strip (Beijing) | sem. glass | > 95 % | ≈ 60 ps | > 30 $kHz/cm^2$ |
| Wide Strip (HD) | float glass | > 95 % | ≈ 40 ps | 1 – 10[1)] $kHz/cm^2$ |
| Wide Strip (Hefei) | float glass | > 95 % | ≈ 60 ps | ≈ 1 $kHz/cm^2$ |

**The CBM requirements are fulfilled, however only in the spot response of the counters**

[1)] rate capability of float glass can be improved by warming up by a ~ factor 10/ 26 K

## Time line

- ✓ **Demonstrators** — **end 2010**
- ✓ **Electronics chain** — **end 2011**
- ✓ **Full-size demonstrator** — **end 2012**
- ✓ **TDR submission** — **16.12.2013**
- ✓ **TDR re-submission** — **soon**
- ➢ **Full-size modules with 'final' electronics** — **mid. 2015**
- ➢ **Construction** — **2015-2017**
- ➢ **Integration** — **2017-2018**
- ➢ **ToF ready for beam** — **01.05.2019**

# Summary / Next steps

## Summary

- Rate capability of MRPC can be increased by using low resistive electrode material.
- For the inner part (M1 to M3) of the wall two different concepts are available.
- The design of all MRPC types are driven by the free- streaming readout
  $\Rightarrow$ impedance matching is realized.
- All available types of MRPC detectors fulfill the CBM ToF requirements in a spot response.
- Since the gas exchange in the gas gaps of the counters is dominated by diffusion, the performance of all MRPC types has to be tested under full load conditions only available with heavy ion beams.

## Next steps

- Building a complete module M6 incl. electronics till summer 2015.
- Load test for all available full size prototypes in spring 2015 with heavy ions at SPS.
- Selection of the different layouts and counter configurations next year based on system aspects.

# Thank you for your attention

CBM ToF Group:

- **Beijing, China, Department of Engineering Physics, Tsinghua University (THU):**
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- **Moscow, Russia, Institute for Theoretical and Experimental Physics (ITEP):**
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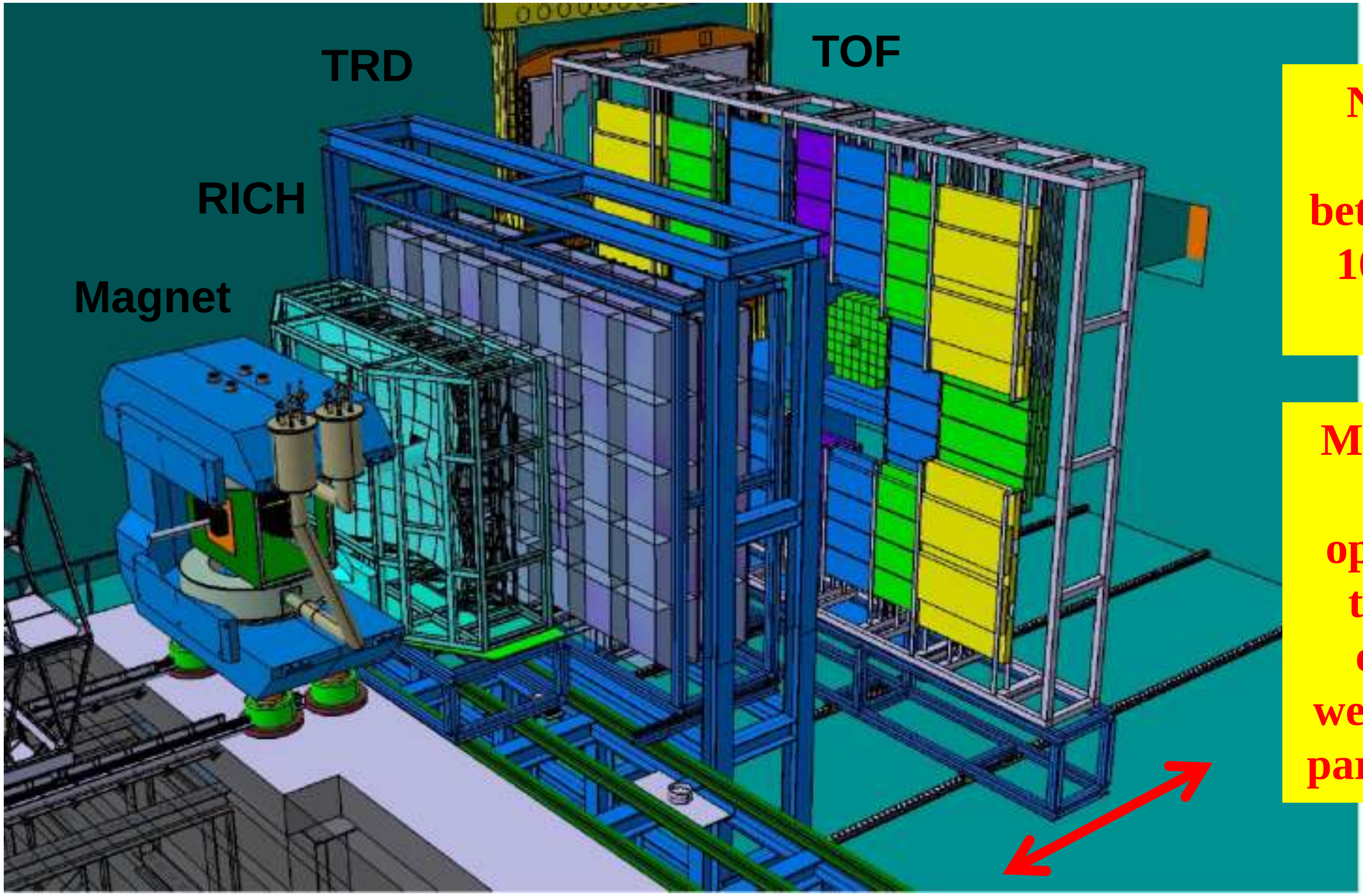
- **Wuhan, China, Institute of Particle Physics, Hua-zhong Normal University (CCNU):**
Changzhou Xiang, Nu Xu, Daicui Zhou

# Backup Slides

## Engineering design of the CBM experiment

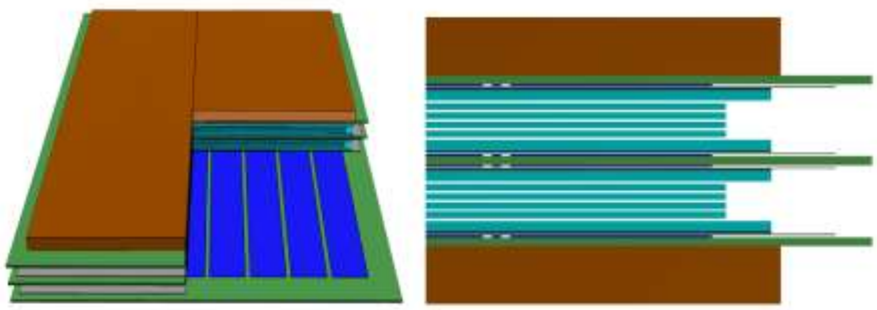



Nominal ToF position is between 6 m and 10 m from the target

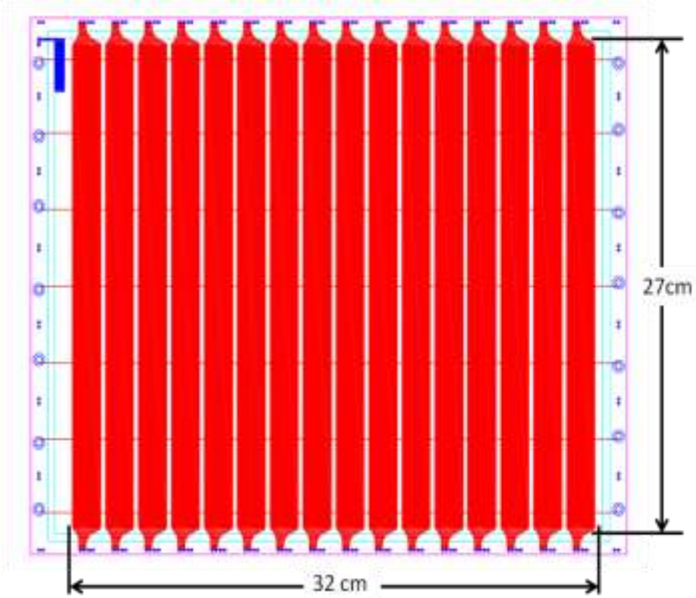
Movable design allows for optimization of the detection efficiency of weakly decaying particles (Kaons)

# Backup Slides

**Beijing Multi-strip MRPC design**



**Hefei Multi-strip MRPC design**

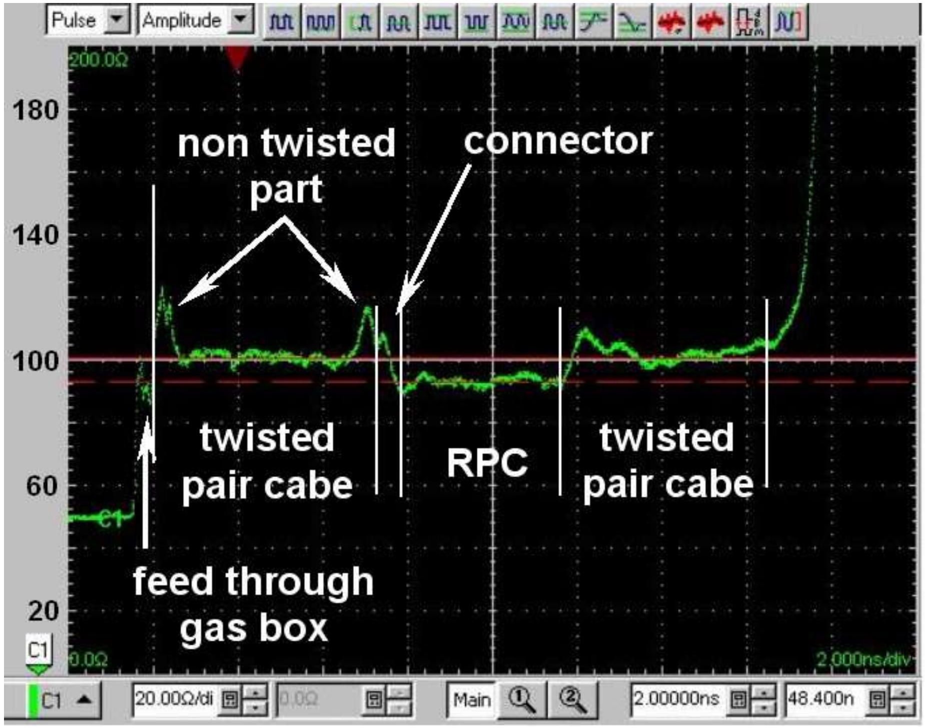



## Parameters

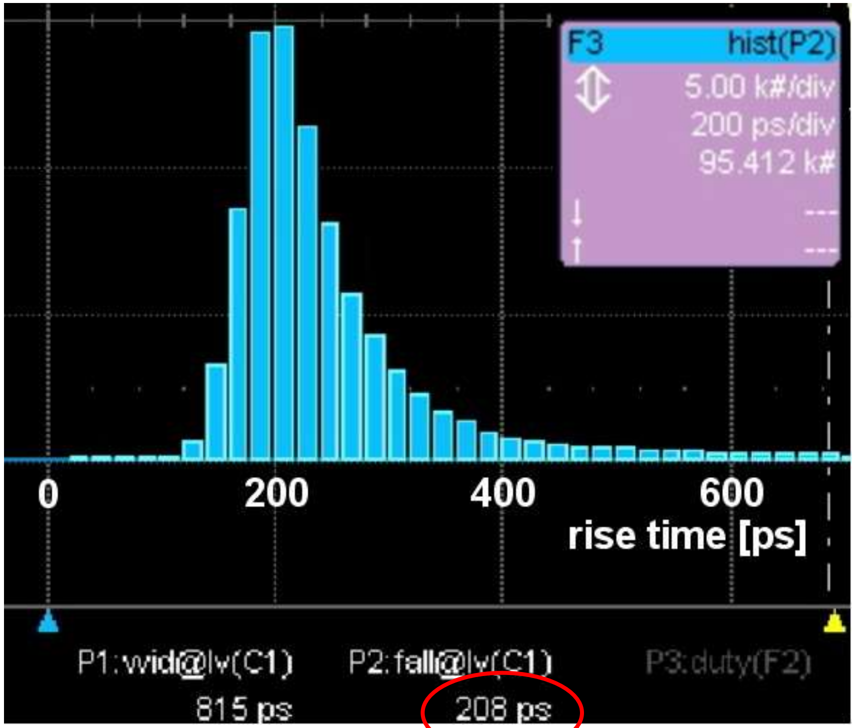
| | Beijing MRPC | Hefei MRPC |
|---|---|---|
| active area | 20 x 12.5 $cm^2$ | 32 x 27 $cm^2$ |
| # strips | 8 | 16 |
| strip / gap | 22 / 3 mm | 17 / 3 mm |
| glass type | float glass | float glass |
| glass thickness | 0.35 mm | 0.33 mm |
| number of gaps | 10 | 10 |
| gap width | 250 $\mu$m | 220 $\mu$m |

# Backup Slides

Reflectometer measurement on the small RPC



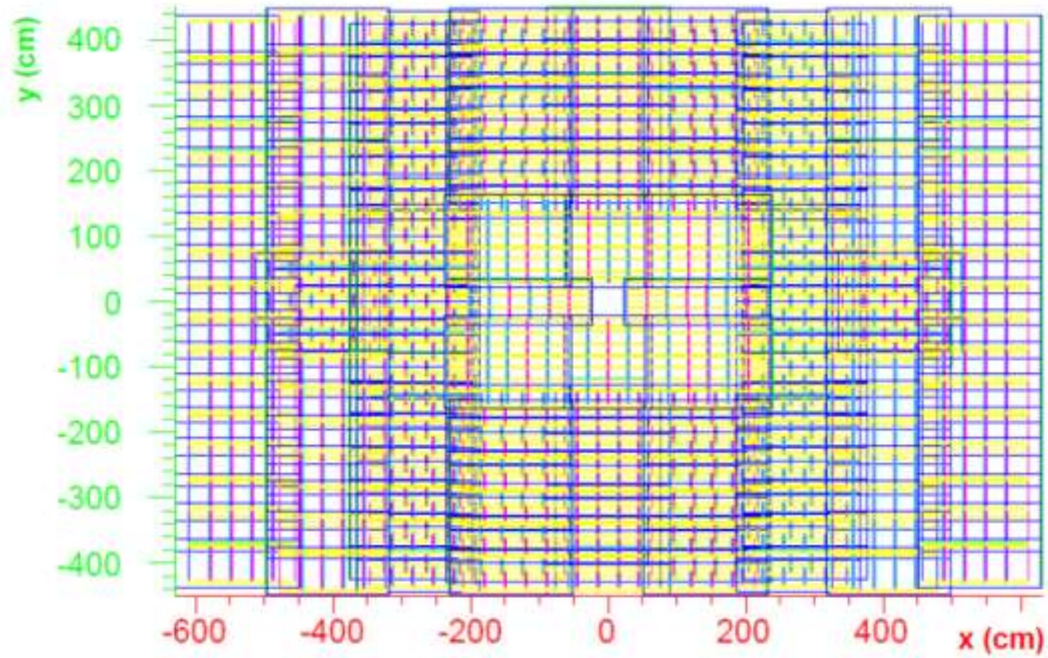

Rise time measurement on the small RPC

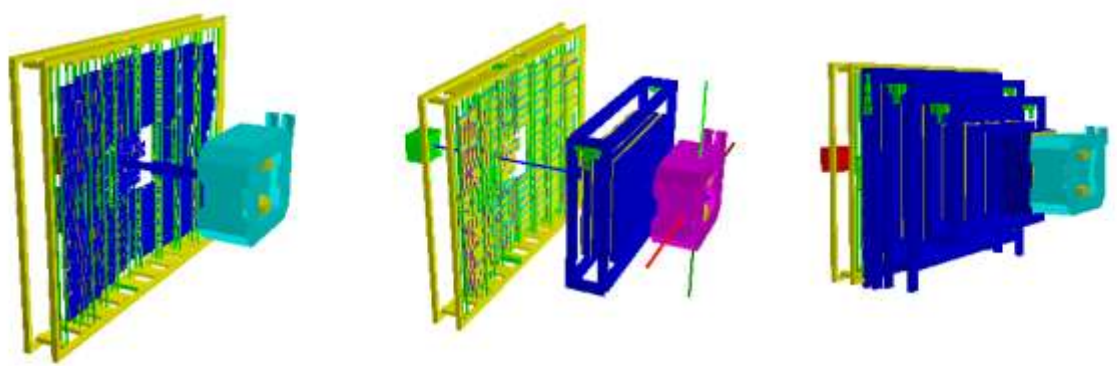



Impedance = 93 Ω

# Backup Slides





~ 100000 timing channels

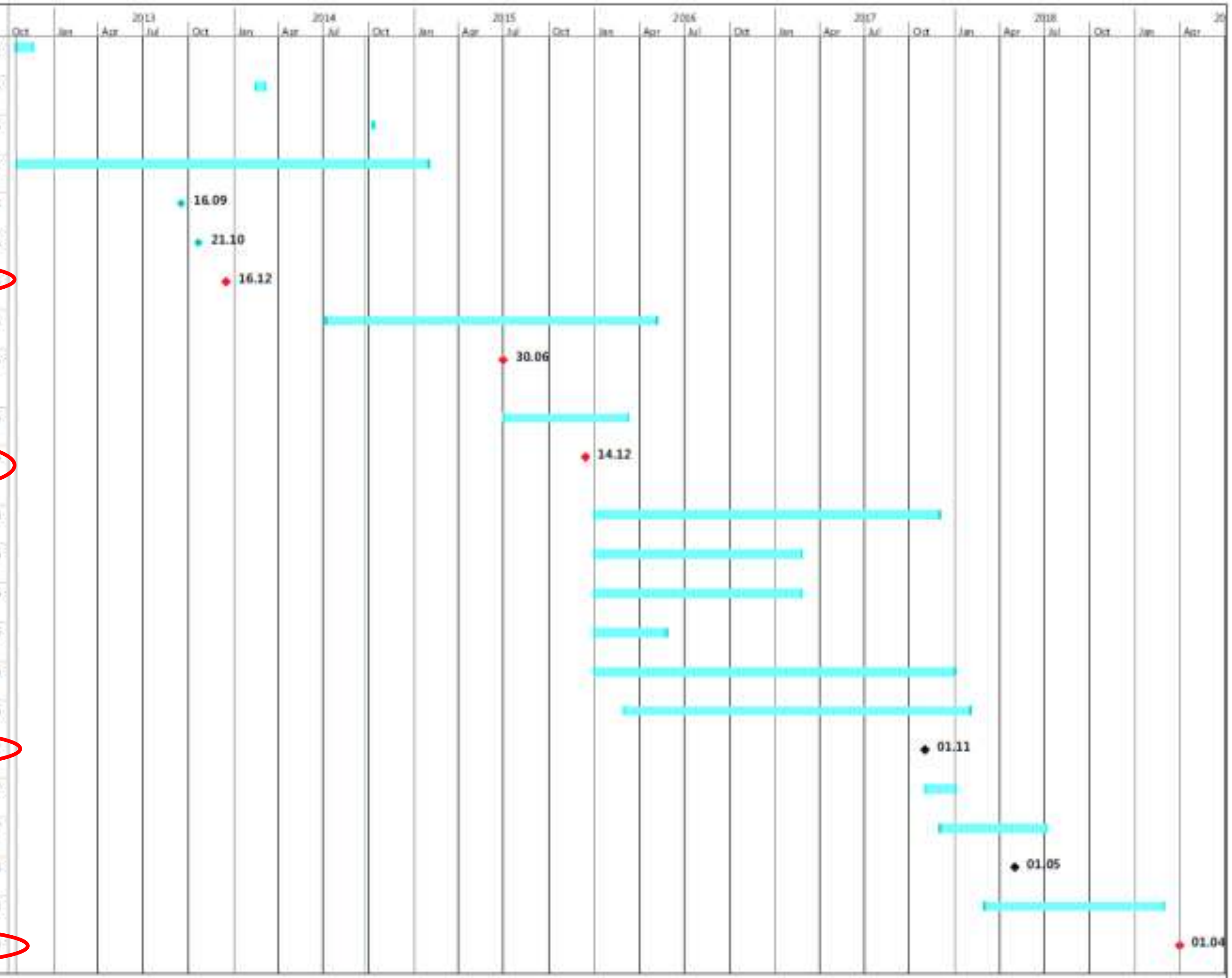
Realistic material budget

Parameterization of measured detector response

Software reconstruction chain prepared

# Backup Slides

| ID | Task Name | Start |
|---|---|---|
| 1 | HI - Run(GSI) | 16.10.12 |
| 2 | HI - Run(GSI) | 14.02.14 |
| 3 | HI - Run(GSI) | 10.10.14 |
| 4 | Test beam analysis | 17.10.12 |
| 5 | Int. TDR - submission | 16.09.13 |
| 6 | Int. Review | 21.10.13 |
| [illegible] | TDR submission | 16.12.13 |
| 8 | Glass production | 07.07.14 |
| 9 | production readiness ASICs (PADI, GET4) | 30.06.15 |
| 10 | PADI/GET4 production | 01.07.15 |
| 11 | production readiness counters & FEET | 14.12.15 |
| 12 | Counter production | 01.01.16 |
| 13 | FEET production | 01.01.16 |
| 14 | TDC board prod. | 01.01.16 |
| 15 | ROC/DPB production | 01.01.16 |
| 16 | Module - production | 01.01.16 |
| 17 | Module - testing (offsite) | 01.03.16 |
| 18 | Cave ready | 01.11.17 |
| 19 | Installation of space frame | 01.11.17 |
| 20 | Delivery of SMs | 01.12.17 |
| 21 | Start of comm wo beam | 01.05.18 |
| 22 | Installation in cave | 01.03.18 |
| [illegible] | TOF ready for beam | 01.04.19 |




Page 1

# 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°.

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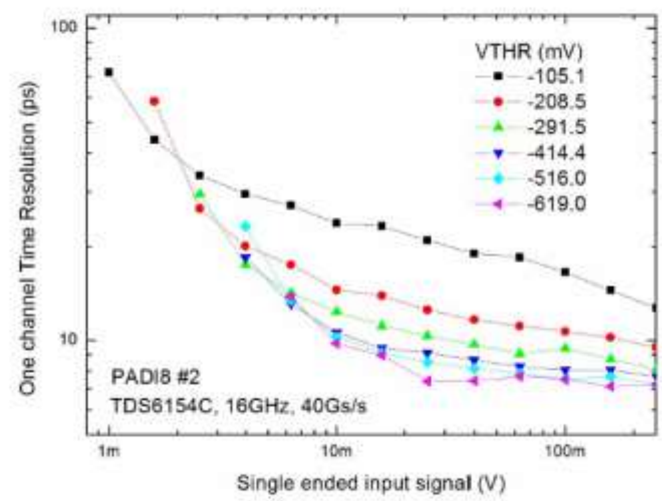
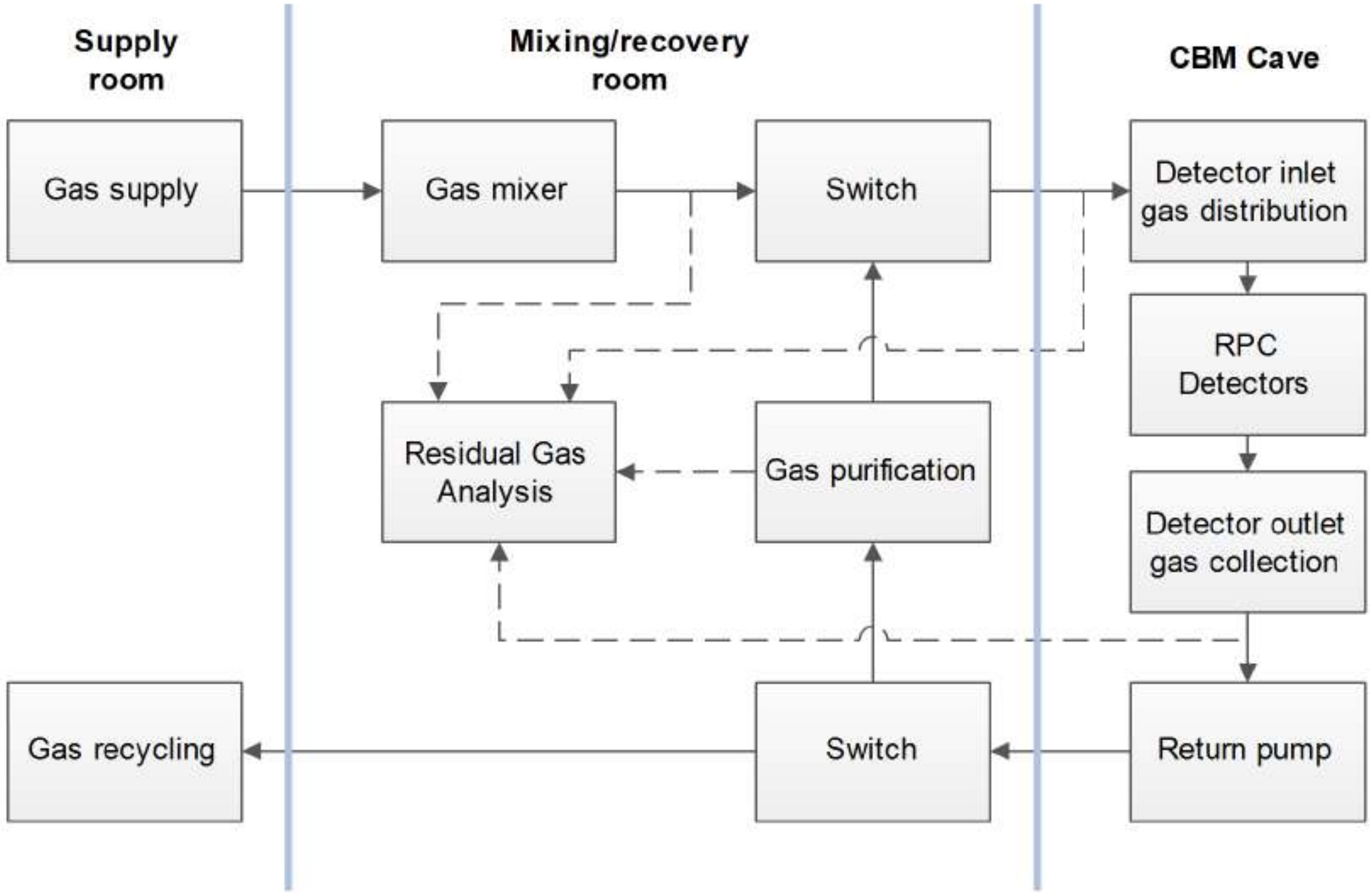
# Backup Slides

| 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 $\sigma$ (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 ($\Omega$) | 30-450 | 37 - 370 | 38 - 165 | 30 - 160 |
| Power consumption (mW/channel) | 21.6 | 17.4 | 17.7 | 17 |

***Table 3.4:*** *Main parameters of the PADI chip family.*



Gas system: closed loop,



# Backup Slides

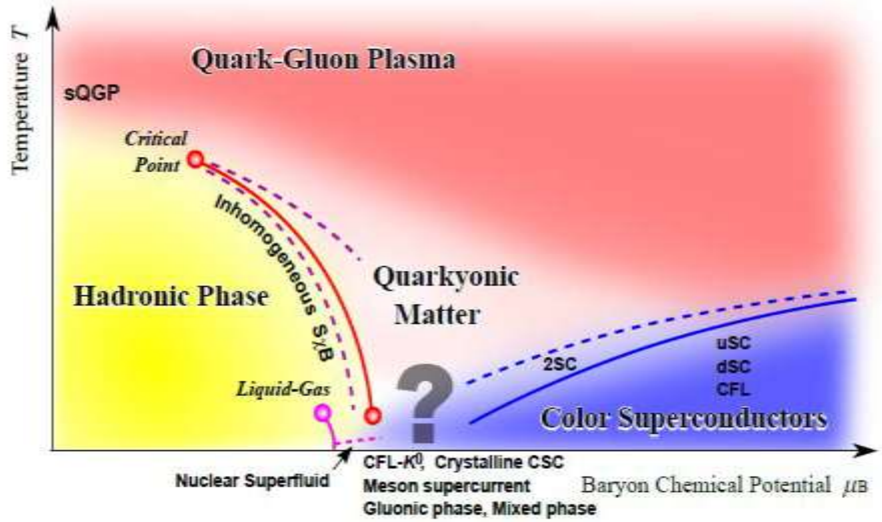
| CBM ToF Wall: Gas-System Parameters | |
|---|---|
| detector surface | 120 $m^2$ |
| gas volume in the whole system | 7.2 $m^3$ |
| gas volume in the detectors | 6 $m^3$ |
| gas mixture ($CH_2FCF_3$:$C_4H_{10}$:$SF_6$) | 85:5:10 vol. % |
| gas-exchange rate relative to full volume | 1/day |
| maximum flow (purging) | 15 l/min |
| nominal flow (recirculating) | 4 l/min |
| detector leakage-rate | $<$ 0.1 slm |
| max. water vapor level | 1000 ppm |
| max. oxygen level | 100 ppm |

# Backup Slides

CBM ToF

## CBM Physics topics

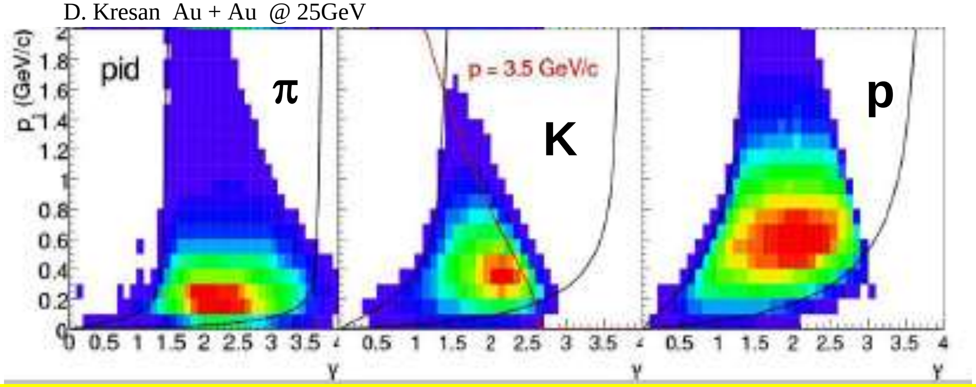
- Deconfinement / phase transition at high $\rho_B$
- QCD critical endpoint
- The equation-of-state at high $\rho_B$
- chiral symmetry restoration at high $\rho_B$




## 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**