The PixelGEM Central Tracking System of COMPASS

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Overview

1. The COMPASS Experiment

2. Motivation

3. The PixelGEM Detector
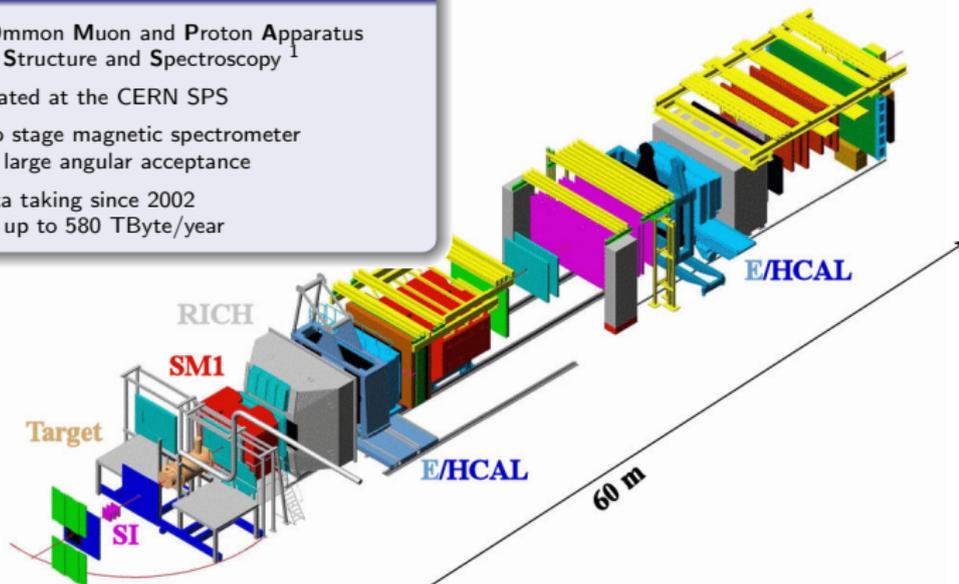
4. Detector Performance

5. Conclusions

The COMPASS Experiment

The COMPASS Experiment

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- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy [1]
- located at the CERN SPS
- two stage magnetic spectrometer
  → large angular acceptance
- data taking since 2002
  → up to 580 TByte/year

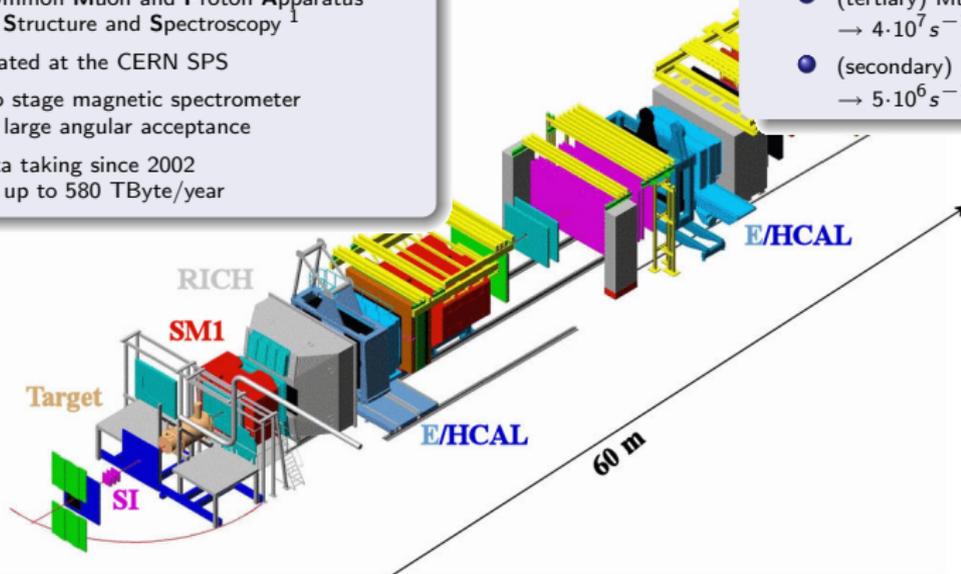[1][Nucl. Instr. and Meth. A 577 (2007) 455]

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Beam Rates

- (tertiary) Muon:
  $\rightarrow 4 \cdot 10^7 \, s^{-1}$
- (secondary) Hadron (π, K, ...):
  $\rightarrow 5 \cdot 10^6 \, s^{-1}$

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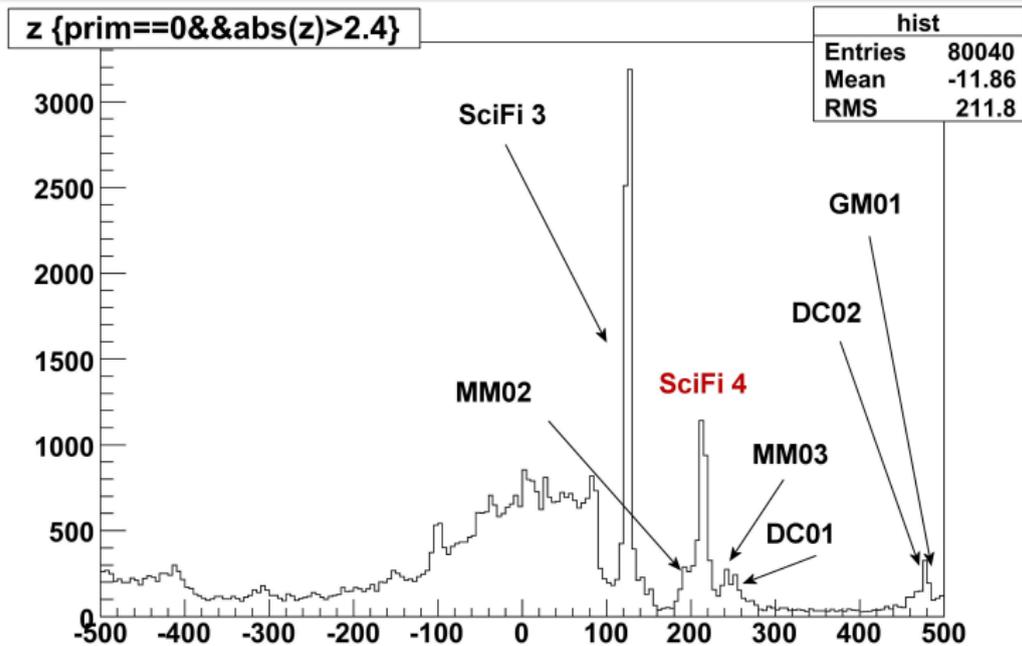 → $5 \cdot 10^6 \, s^{-1}$

RICH

SM1

Target

E/HCAL

E/HCAL

SI

60 m

Tracking
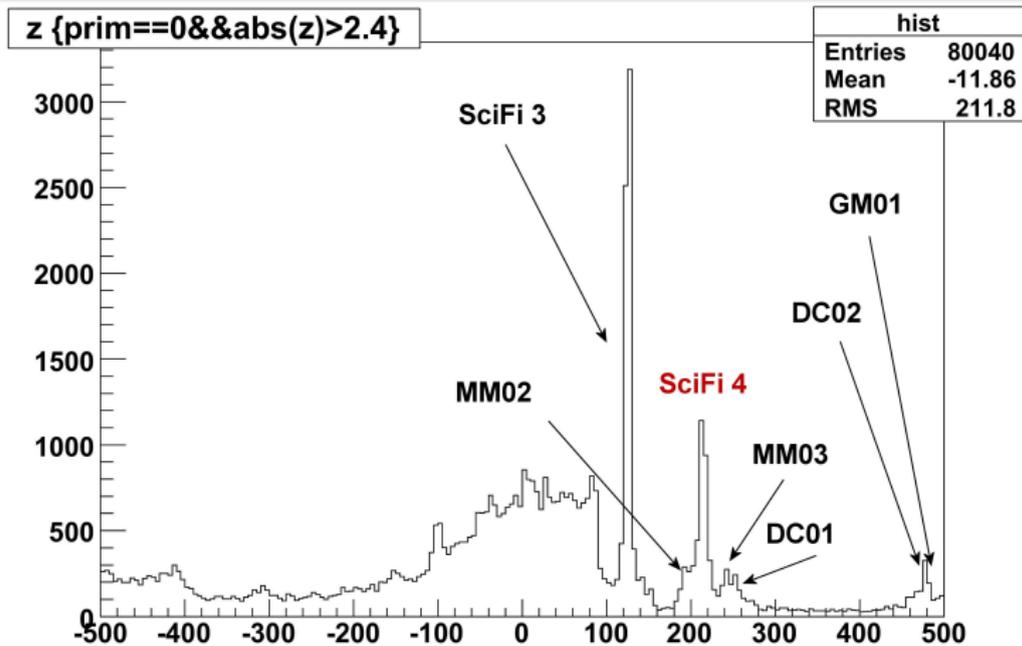
- Silicons ($\sigma_x \sim 10 \mu m$), SciFis ($\sigma_t \sim 0.4 ns$)
- GEMs ($\sigma_x \sim 70 \mu m$), MicroMegas ($\sigma_x \sim 90 \mu m$)
- Drift Chambers ($\sigma_x \leq 200 \mu m$)

[1][Nucl. Instr. and Meth. A 577 (2007) 455]

Motivation

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- SciFis act as secondary targets in hadron beam
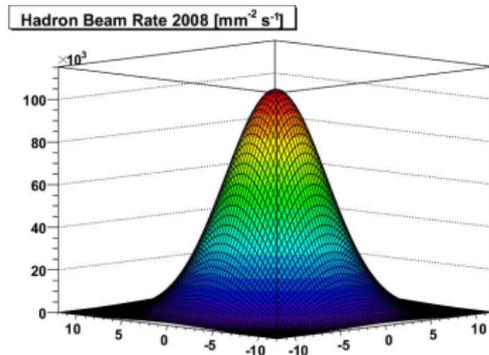- Thickness SciFi: $x/X_0 = 1.6$-2.8 %

Motivation

Triple-GEM Detectors:

- high rate capability [1,2]
  COMPASS requirements:
  - beam rates: $\lesssim 10^5$ mm^{-2} s^{-1}
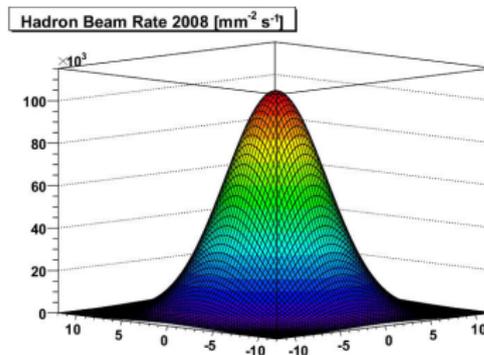

Hadron Beam Rate 2008 [mm^{-2} s^{-1}]

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[1] [S. Bachmann, A. Bressan, B. Ketzer et al., Nucl. Instr. and Meth. A 470 (2001) 548.]

[2] [S. Bachmann, S. Kappler, B. Ketzer et al., Nucl. Instr. and Meth. A 478(2002) 104.]

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- small material budget[3]
  center: $x/X_0 =$ 0.4 %

Hadron Beam Rate 2008 [mm^{-2} s^{-1}]

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[3][C. Altunbas et al., Nucl. Instr. and Meth. A 490 (2002) 177]

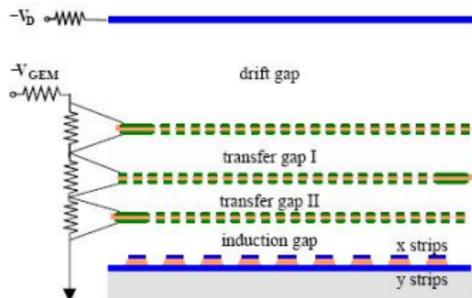## Motivation

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Strip Readout

- strip occupancy too high
- no sufficient beam tracking with strip readout

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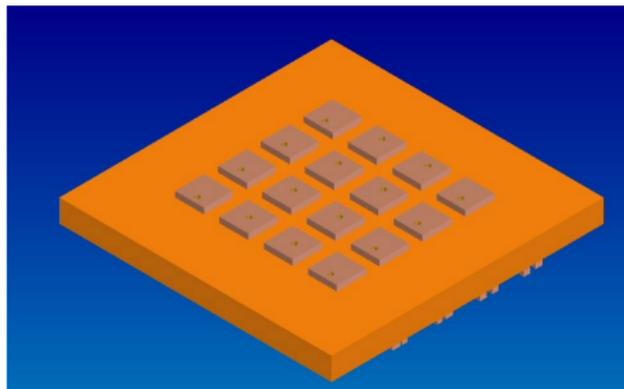**GEM detector with combined pixel/strip readout**

The combined Pixel-Strip-Readout

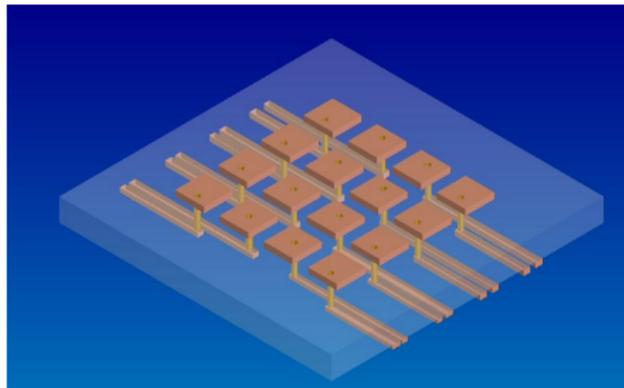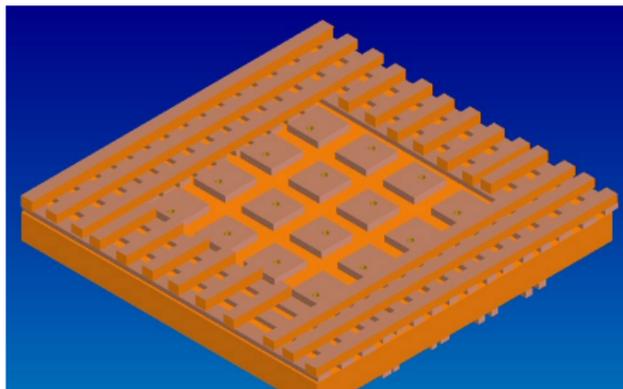- 3-layer foil
  (base material: Kapton)
- thickness: 100 μm

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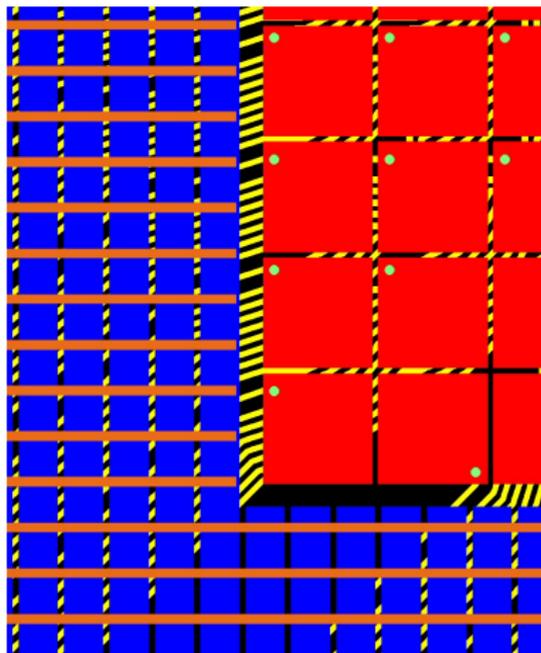
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- pitch: 1 mm
- 1024 strip channels
  (512 x, 512 y)
- pitch: 400 μm
- equal charge sharing
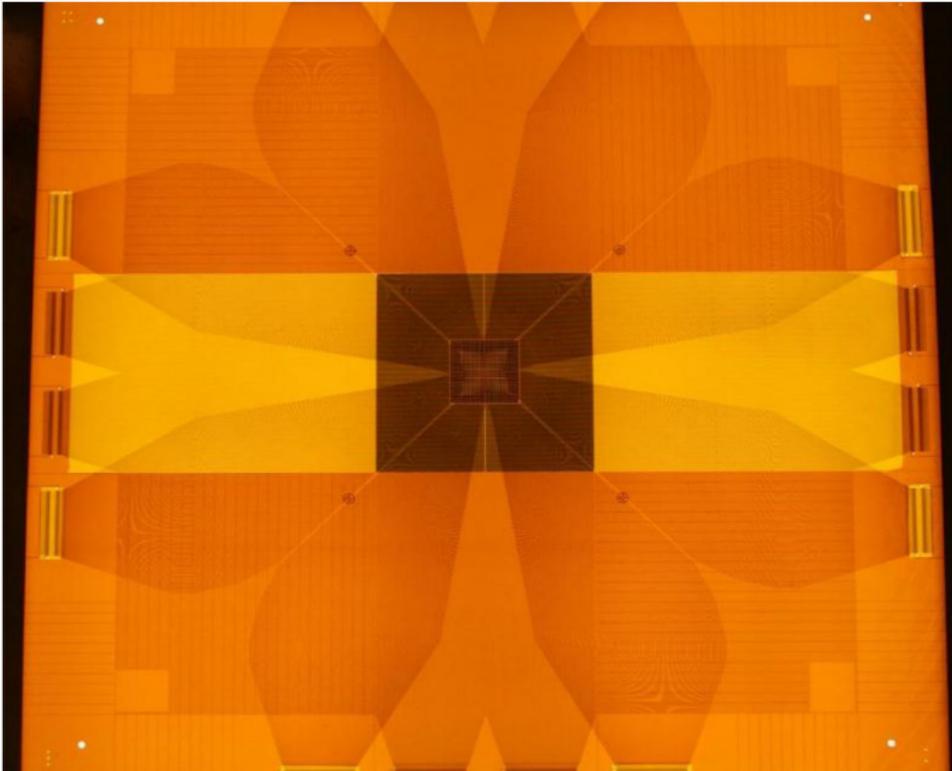
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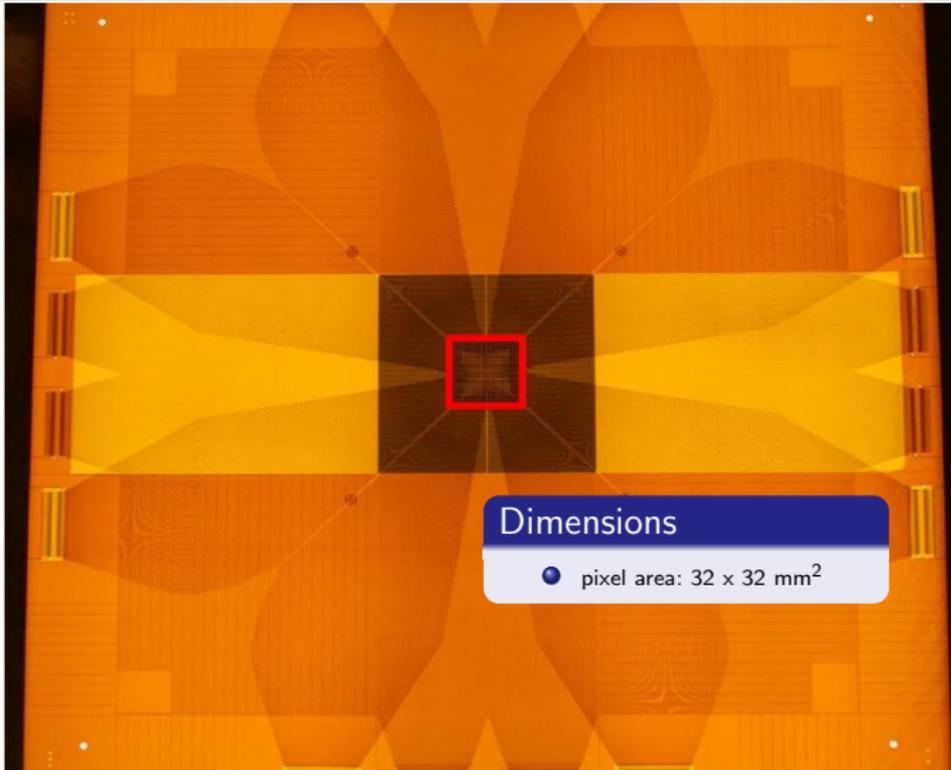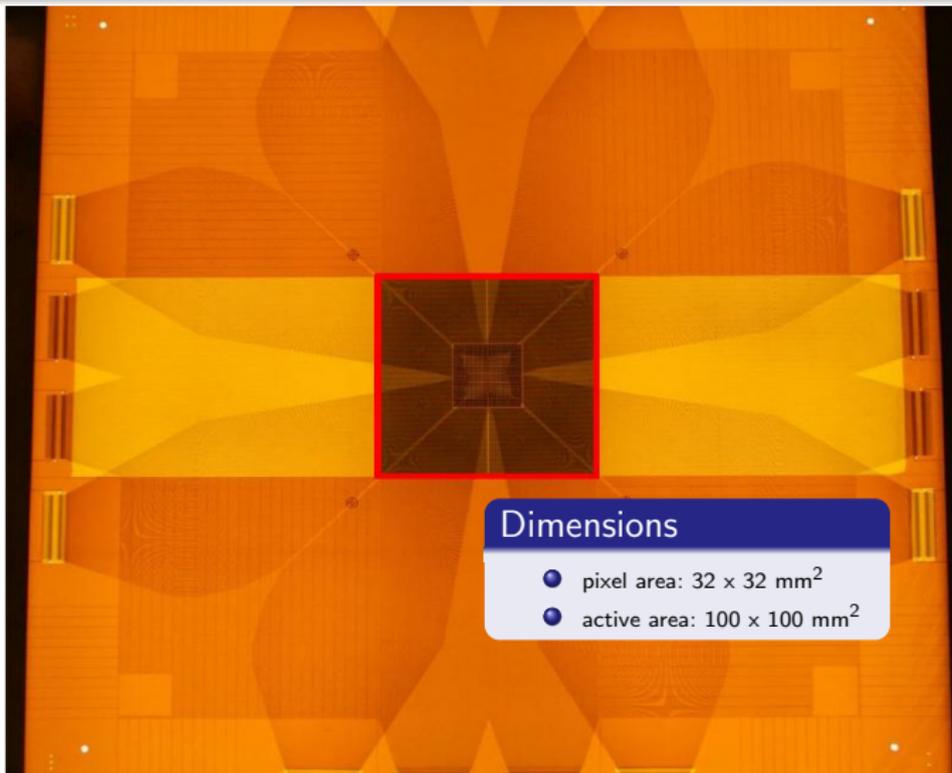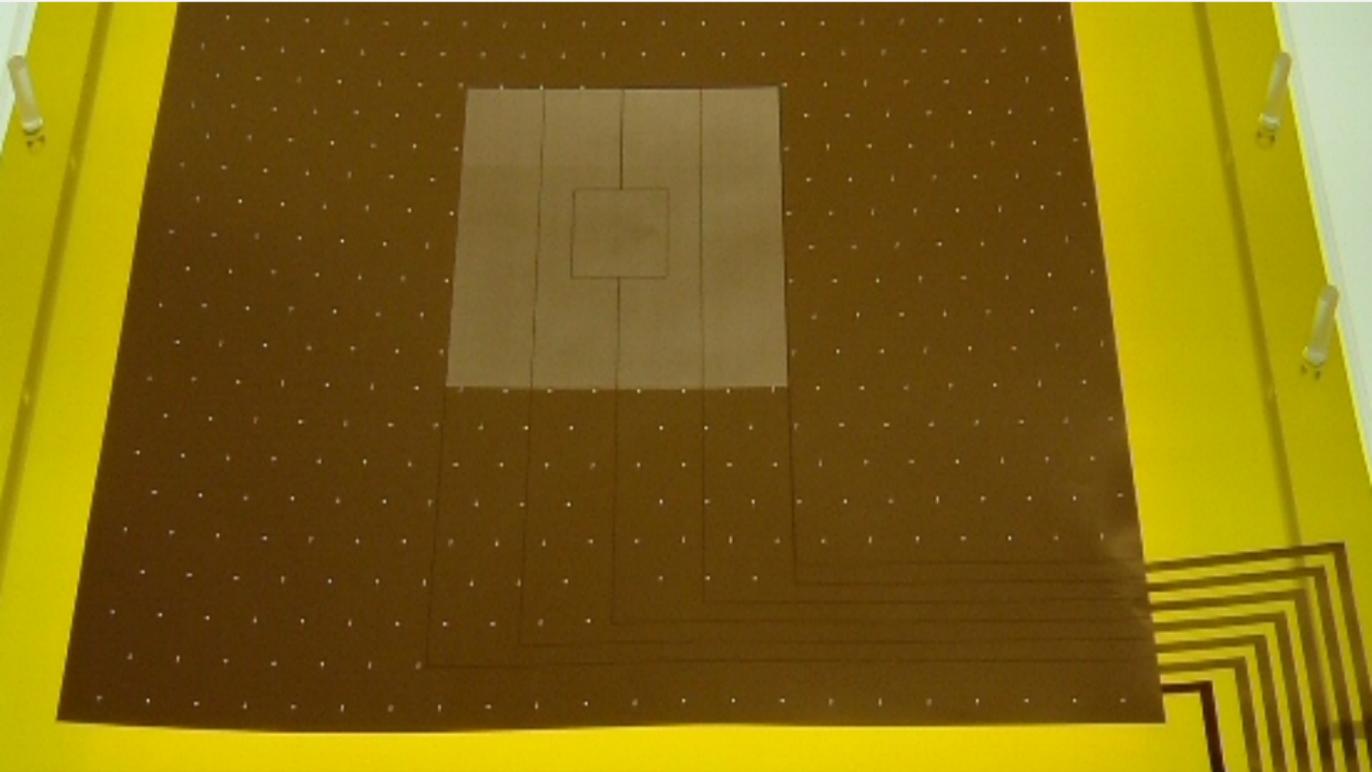# The combined Pixel-Strip-Readout

Dimensions

- pixel area: 32 x 32 mm^2

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- active area: 100 x 100 mm^2
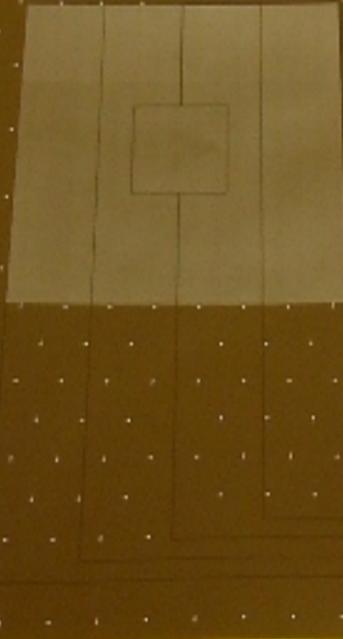
GEM Geometries and Settings

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- foil size: 330 x 330 mm^2
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- big holes ($\varnothing$ 0.5 mm) only for gas exchange

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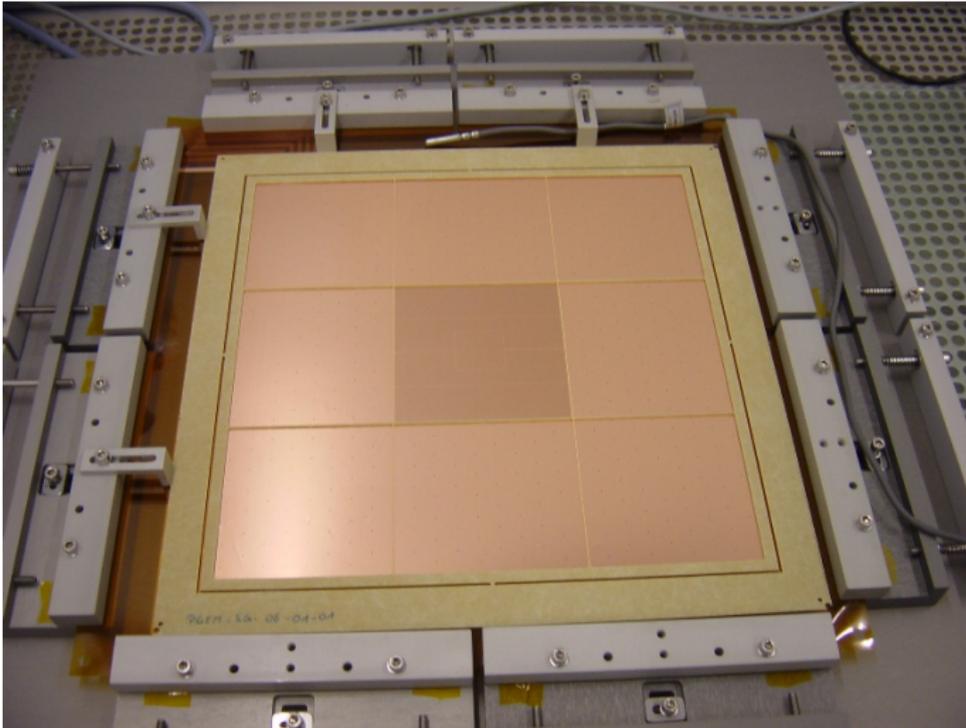- asymmetric gain sharing

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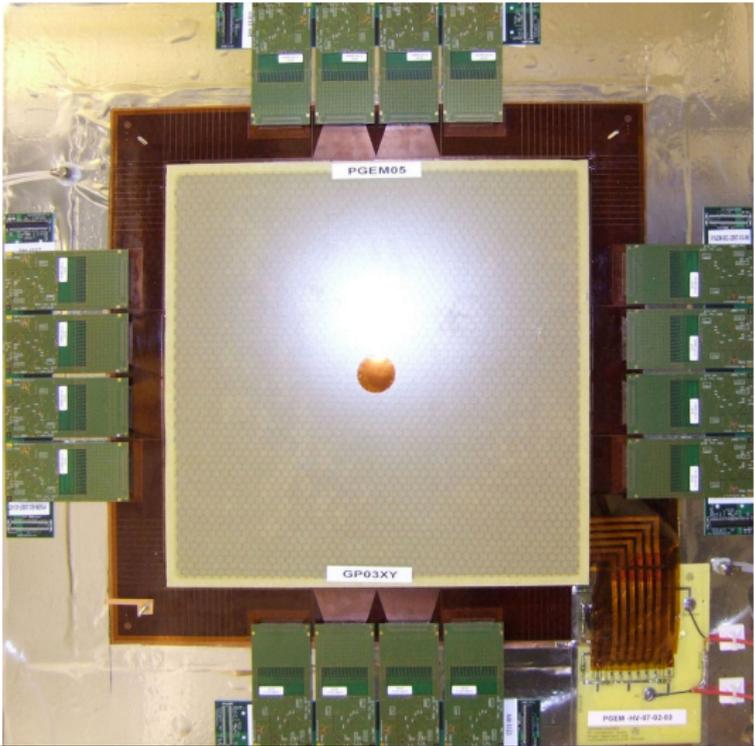
thin copper

- foils with only 1-2 μm thick copper[1]

[1][A. Bondar, et al., Nucl. Instr. and Meth. A 556 (2006) 495]
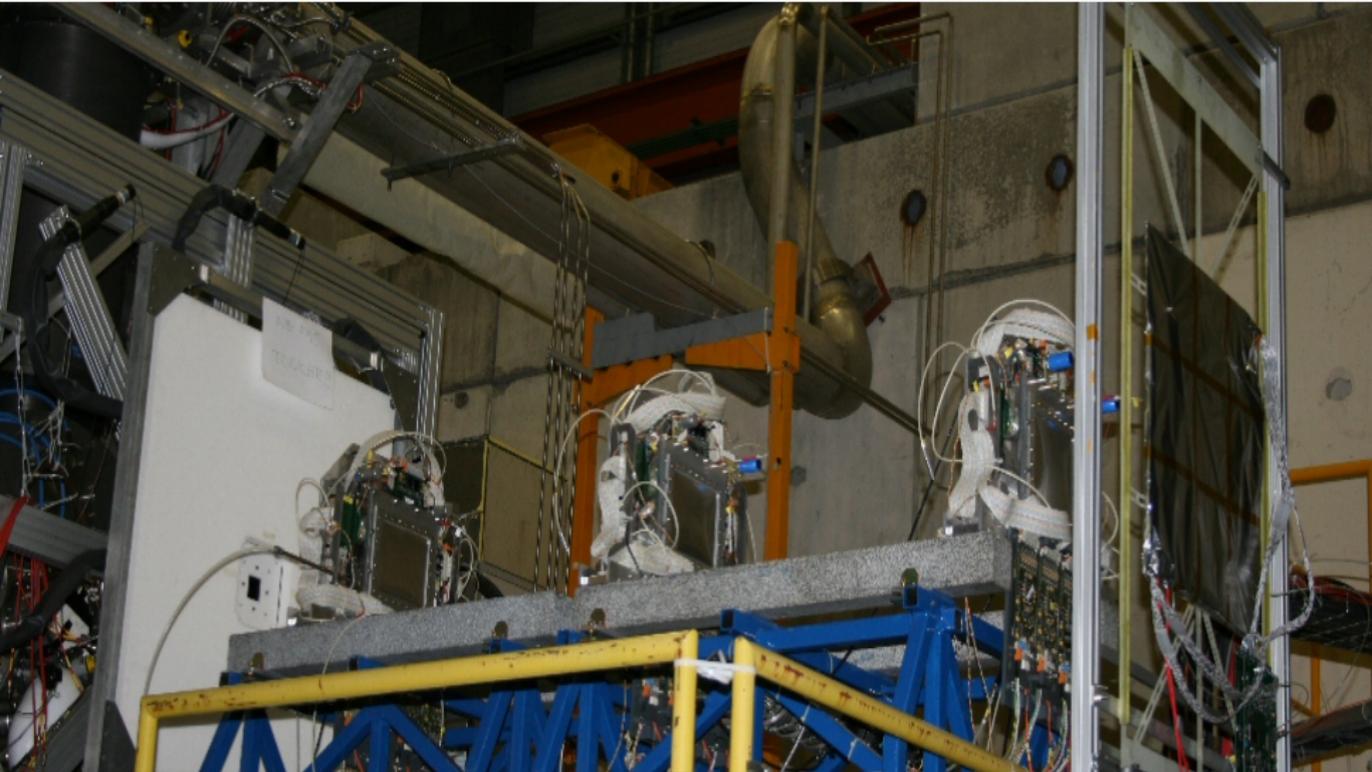
Assembly

Complete Detector

FrontEnd-Electronics

- APV25 S1 ASIC[1]

- 128 channels per APV

- 160 samples pipeline

- 40 MHz sampling frequency

- average noise:
  $\sim$ 1300 - 1500 electrons

- used for Silicon, GEM and RICH at COMPASS

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[1] M.J. French, et al. Nucl. Instr. and Meth. A 466 (2001) 359
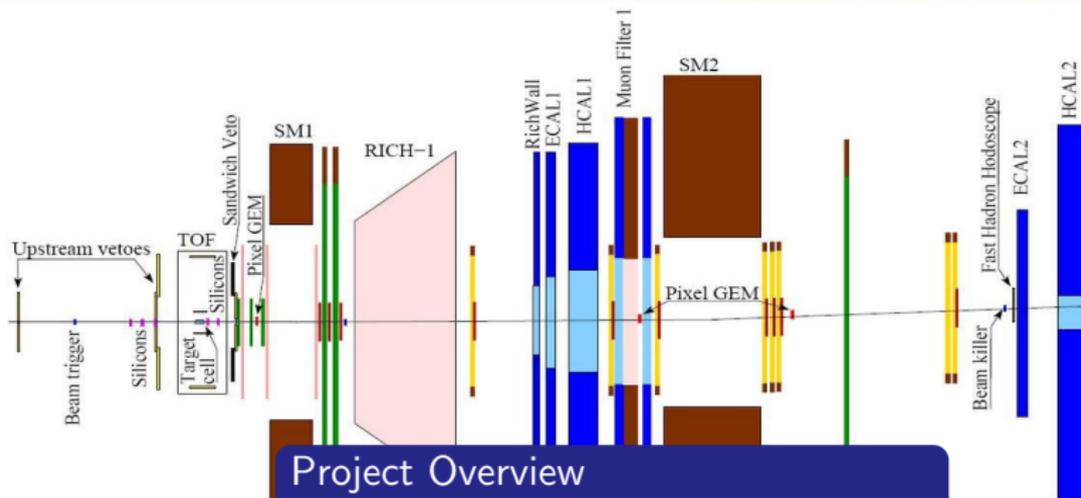
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Project Overview

- 2006 Development and first prototype (5 μm) in the COMPASS spectrometer
- 2007 Improvements in design and electronics, second prototype (1-2 μm)in the spectrometer
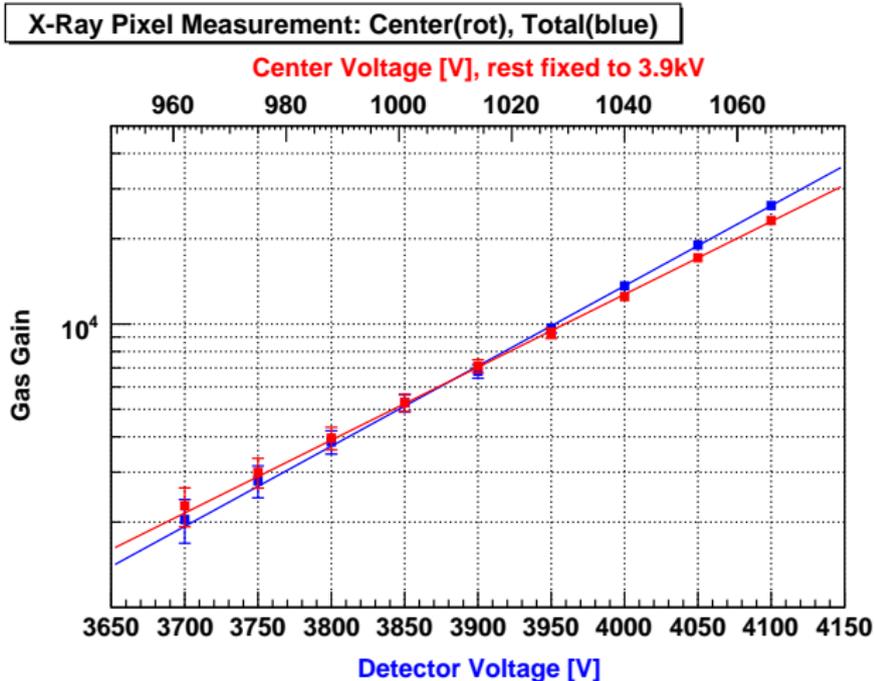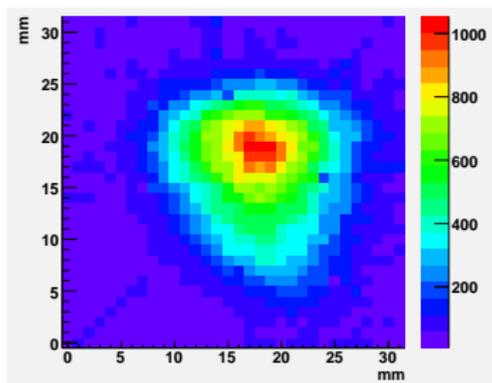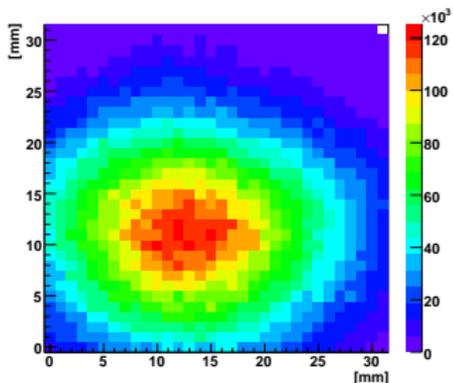
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- 2008 Five PixelGEMs installed

Gain

Beam Intensities

Estimations of particle flux in the pixel region

Myon beam

- $4.8 \cdot 10^7/s$
- $\leq 1.2 \cdot 10^5/s/mm^2$

Pion beam

- $5 \cdot 10^6/s$
- $\leq 1.6 \cdot 10^4/s/mm^2$

Spatial Resolution

Low Intensity: $\leq 2\cdot 10^3/\text{s}/\text{mm}^2$ **High Intensity**: $\leq 1\cdot 10^5/\text{s}/\text{mm}^2$

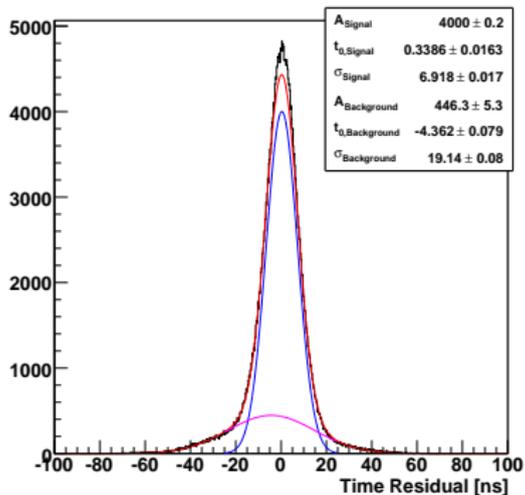$\bar{\sigma} = 90\mu\text{m}$ $\bar{\sigma} = 135\mu\text{m}$

with/without Clustering, green: Gauss fit components

Time Resolution

Low Intensity: $\leq 2 \cdot 10^3/\text{s/mm}^2$ **High Intensity**: $\leq 1 \cdot 10^5/\text{s/mm}^2$

$\sigma_t \leq 7\text{ns}$ $\sigma_t \leq 8\text{ns}$

blau: Signal,   magenta: Underground

Efficiency Plateau

Low Intensity: $\leq 2 \cdot 10^3 / \text{s/mm}^2$

High Intensity: $\leq 1 \cdot 10^5 / \text{s/mm}^2$

Efficiency Plateau: 98.5 %

Efficiency Plateau: 95.5 %

Background per pixel: $\leq 0.1\,\%$

Background per pixel: $\approx 2\,\%$

Background: probability to find uncorrelated clusters within a certain roadwidth around a track

Detector Efficiency

Low Intensity: $\leq 2 \cdot 10^3 / s / mm^2$

Mean Efficiency $\approx 98.5\%$

High Intensity: $\leq 1 \cdot 10^5 / s / mm^2$

Mean Efficiency $\approx 95.5\%$

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- stable operation in high intensity muon/hadron beam
  $\rightarrow 4 \cdot 10^7 \, s^{-1}$
- Pixel readout allows tracking in a high rate beam
  $\rightarrow \lesssim 10^5 \, mm^{-2} \, s^{-1}$
- spatial resolution $\leq 135 \, \mu m$
- thin GEM detecors: $x/X_0 = 0.2 \, \%$
- $5 + 1$ PixelGEM detectors for COMPASS

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Acknowledgements

- Rui de Oliveira (CERN TS-DEM-PMT)
- Christian Joram, Eric David, Miranda van Stenis (CERN PH-DT2)
- Ian McGill (CERN PH-DT2)
- workshops at CERN and TU München

Readout Chain

Spatial/Time Resolution COMPASS Triple GEM Detectors

Spatial resolution

- Test beam/low intensity:

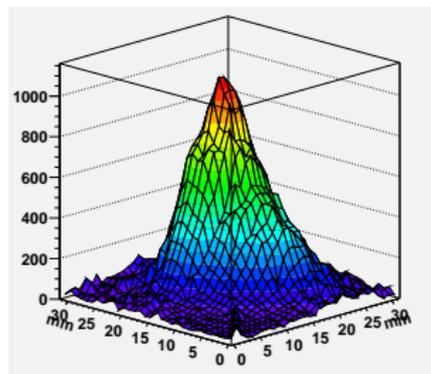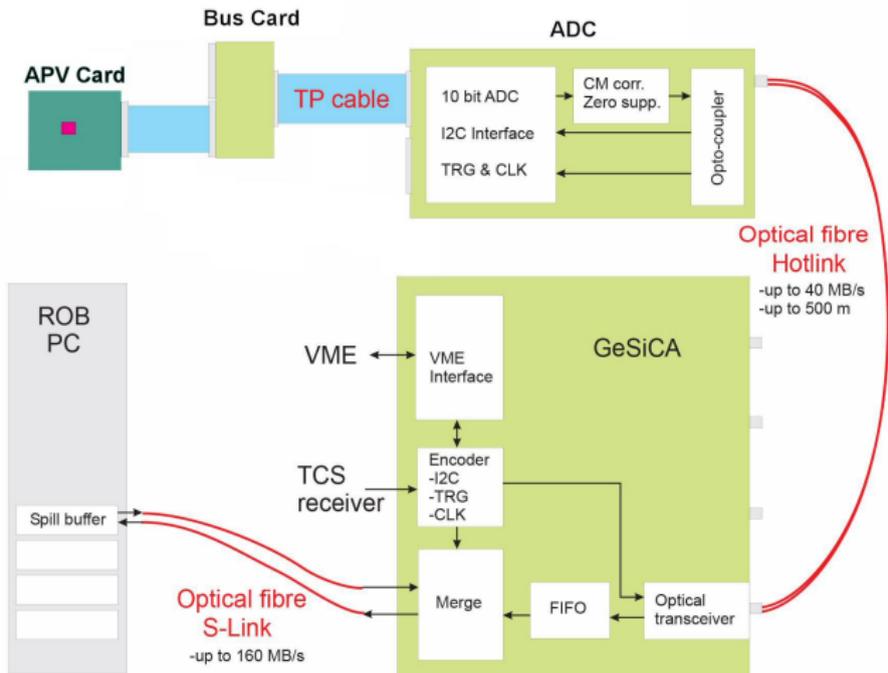$$\langle \sigma_x \rangle \approx 50\,\mu m$$

- Standard physics run: $4 \cdot 10^7\ \mu^+/s$:

$$\langle \sigma_x \rangle \approx 70\,\mu m$$

Time resolution

- 3 analog samples per trigger
- Rising edge of signal
- Reconstruct t_0 from known pulse shape

$$\langle \sigma_t \rangle \approx 12\,ns$$

Entries	416305
χ^2 / ndf	299.9 / 80
p0	1469
p1	-0.04564
p2	0.1697
p3	2.048e+04
p4	-0.01413
p5	0.06035
p6	64.16

Entries	176090
χ^2 / ndf	862.7 / 100
Constant	5247
Mean	-4.724
Sigma	12.33

[B. Ketzer et al., NIM A535, 314 (2004)]

Efficencies COMPASS Triple GEM Detectors

Low intensity beam: $5 \cdot 10^6$ μ^+/s
- All detectors reach plateau ($\varepsilon > 98\%$)
- Gain ~8000
- SNR ~18
- Losses due to spacer grid: 1.2-1.5%

Standard physics beam: $4 \cdot 10^7$ μ^+/s
- Background correction
  $$\varepsilon_{app} = \varepsilon + (1 - \varepsilon) \cdot b$$
- Single plane: $\langle \varepsilon_{1D} \rangle = 97.2\%$
- 2D (space point): $\langle \varepsilon_{2D} \rangle = 95.6\%$

[B. Ketzer et al., Nucl. Phys. B 125C, 368 (2003)]

[B. Ketzer et al., NIM A535, 314 (2004)]

Front-End Electronics

Readout Scheme

- 16 front-end cards per detector
- bus-cards to 12 bit ADC

3 Sample Amplitude Information

⇒ clustering
⇒ time reconstruction

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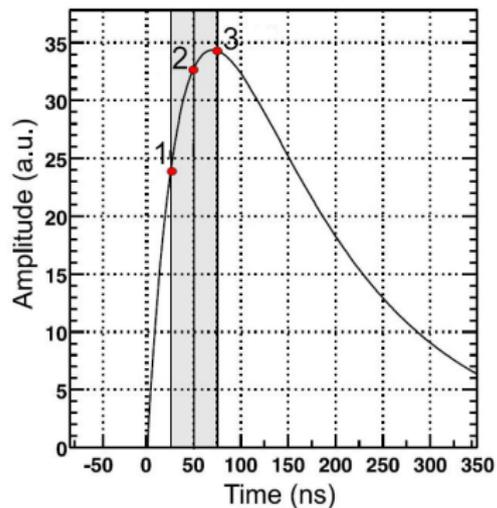
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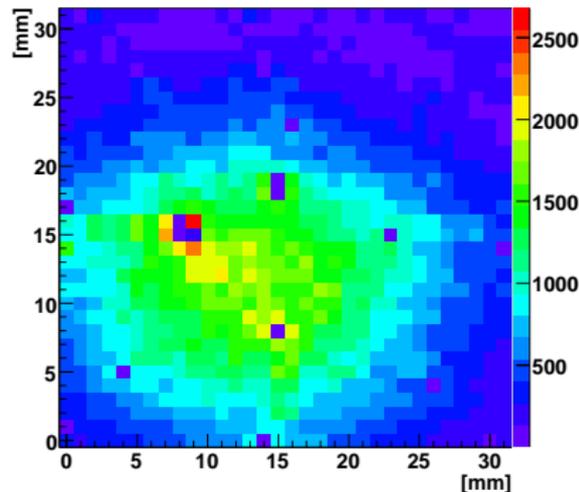
crosstalk suppression

beamspot with crosstalk   crosstalk suppressed

- tag channels with high-amplitude neighbours
- after clustering: remove clusters containing mostly tagged pixels

Material Budget

	Centre $[X_0/1000]$	Periphery $[X_0/1000]$
Support	0.0	2.9
Driftfoil	0.5	0.5
3 GEM-Foils	2.1	2.1
Readout Foil	1.0	1.3
Shielding	0.2	0.2
Gas	0.1	0.1
Sum	**3.9**	**7.1**

Centre: $r < 15\,\mathrm{mm}$, Periphery: $r > 15\,\mathrm{mm}$

Cu layer $5\,\mu\mathrm{m}$

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3 GEM-Foils	2.1 / 0.8	2.1 / 0.8
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Shielding	0.2	0.2
Gas	0.1	0.1
Sum	**3.9 / 2.4**	**7.1 / 5.6**

Centre: $r < 15\,\mathrm{mm}$, Periphery: $r > 15\,\mathrm{mm}$

Cu layer $5\,\mu\mathrm{m}$ / $1\,\mu\mathrm{m}$

Modifications Prototype - Prototype II

prototype design   *final design*