A Triple-GEM Detector with Pixel Readout for High-Rate Beam Tracking in COMPASS

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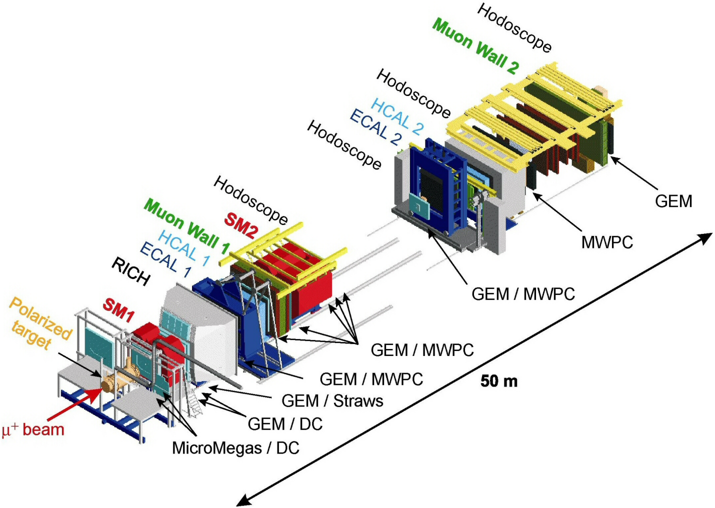
Outline

1. COMPASS-Experiment
2. PixelGEM Detector
3. Characterisation
4. Conclusion

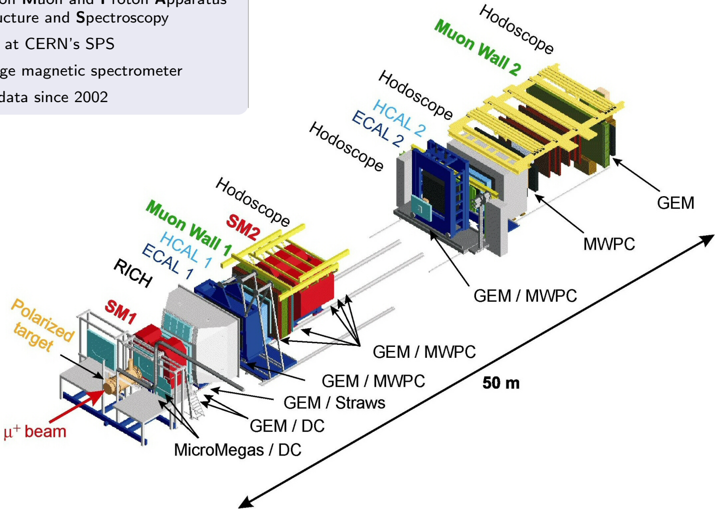
The COMPASS-Experiment



The COMPASS-Experiment

Overview

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- located at CERN's SPS
- two-stage magnetic spectrometer
- taking data since 2002



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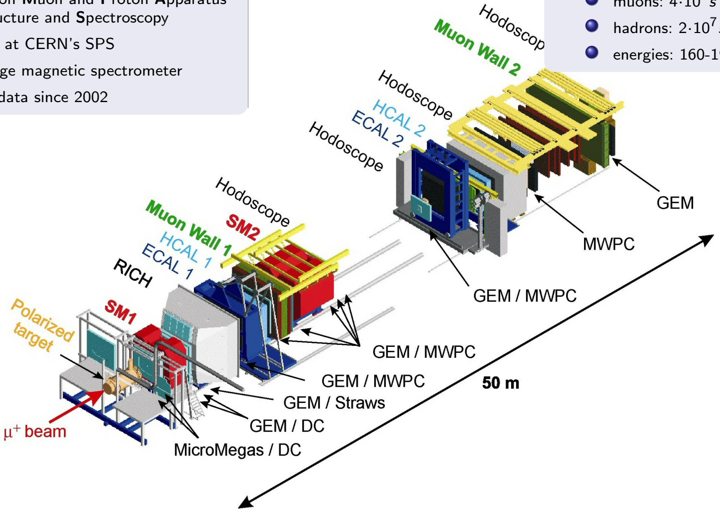
2 types of beam

- muons: $4{\cdot}10^7 s^{-1}$
- hadrons: $2{\cdot}10^7 s^{-1}$
- energies: 160-190 GeV



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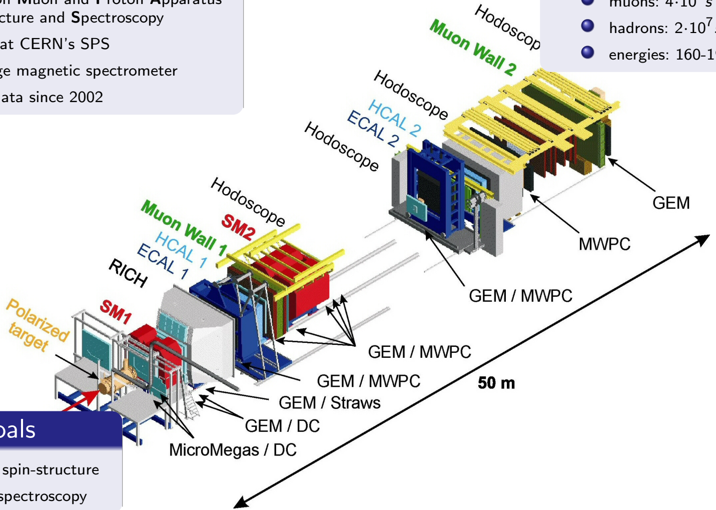

Physics Goals

- nucleon spin-structure
- hadron spectroscopy

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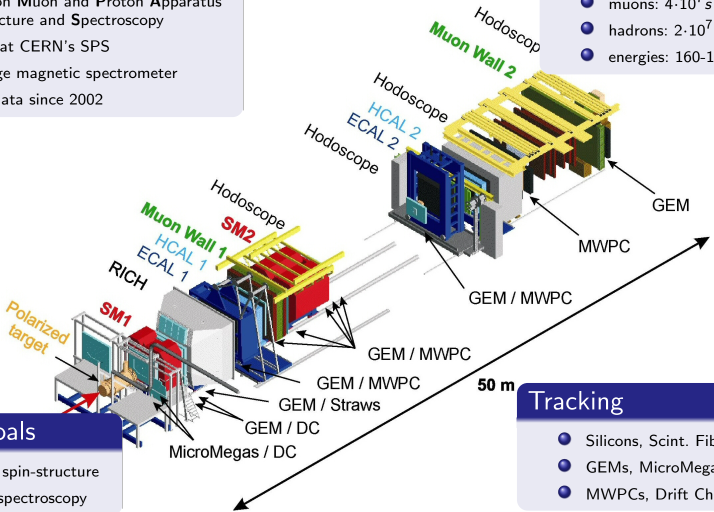


Physics Goals

- nucleon spin-structure
- hadron spectroscopy

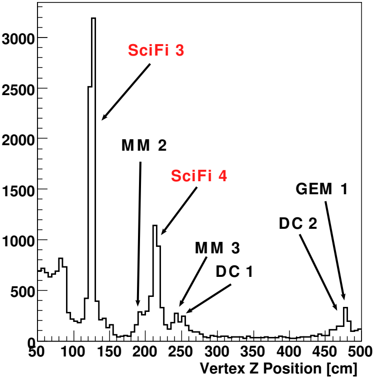
Tracking

- Silicons, Scint. Fibres
- GEMs, MicroMegas
- MWPCs, Drift Chambers

Motivation for PixelGEM

Hadron Beam 2008

- intensity up to $2 \cdot 10^7\,s^{-1}$
- flux density $> 10^5\,mm^{-2}s^{-1}$
- SciFi act as secondary target: $x/X_0 = 1.8 - 2.6\,\%$



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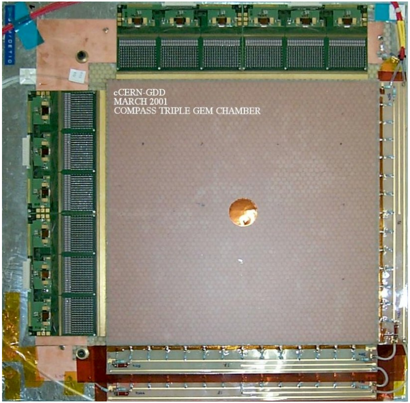
COMPASS GEMs

- $x/X_0 = 0.4\,\%$
- no gain drop due to space charge
  $\Rightarrow$ high inherent rate capability
- strip readout
  $\Rightarrow$ occupancy too high
  $\Rightarrow$ centres deactivated



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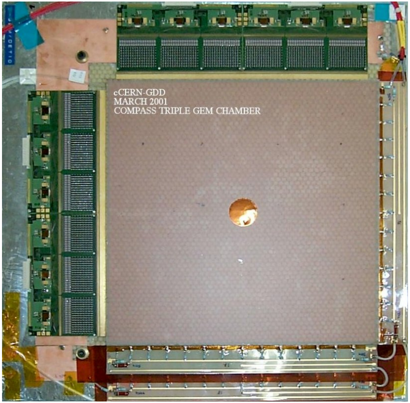
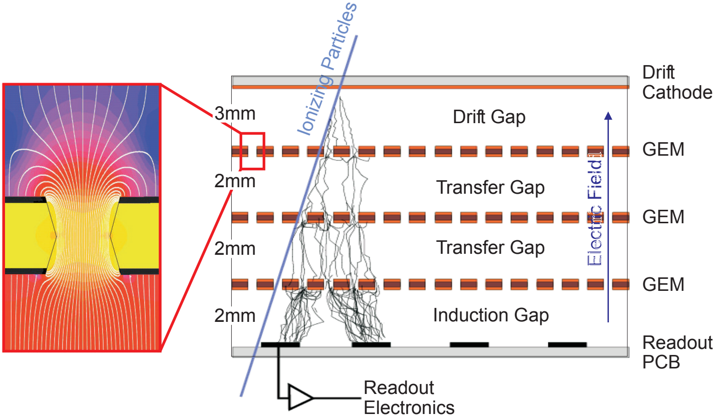


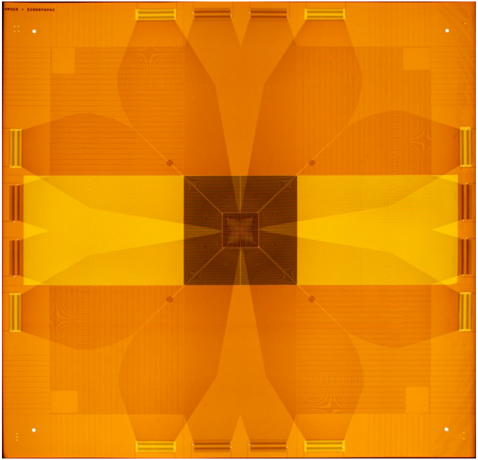
Solution: GEM with pixel read-out

PixelGEM Overview



- **G**as **E**lectron **M**ultiplier: avalanche amplification in holes
- 3-fold staggered design to increase gain and avoid discharges

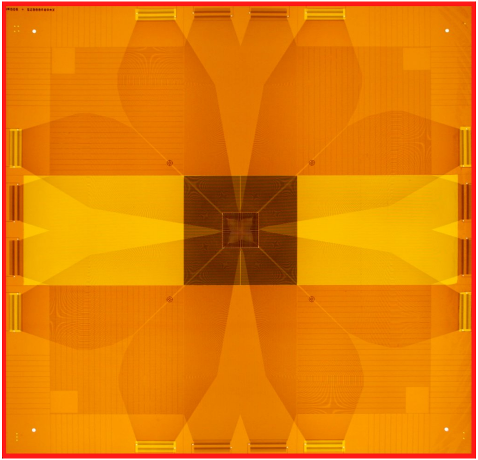
Read-out Circuit



Read-out Circuit

Read-out: $450 \times 450\,\mathrm{mm}^2$

- 3 conducting layers
  Cu 5 μm
- 2 intermediate layers
  Kapton 50 μm



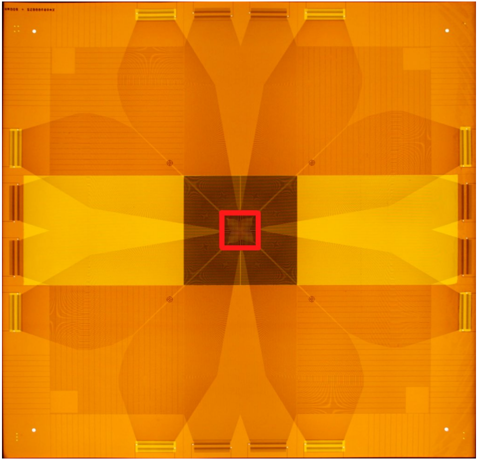
Read-out Circuit

Read-out: $450 \times 450\,mm^2$

- 3 conducting layers
  Cu 5 μm
- 2 intermediate layers
  Kapton 50 μm

Centre: $32 \times 32\,mm^2$

- 32×32 Pixels
- pitch: 1 mm



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- 3 conducting layers
  Cu 5 μm
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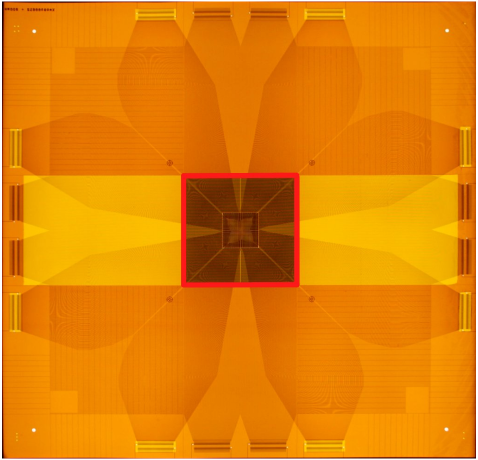
  Kapton 50 μm

Centre: $32 \times 32\,\text{mm}^2$

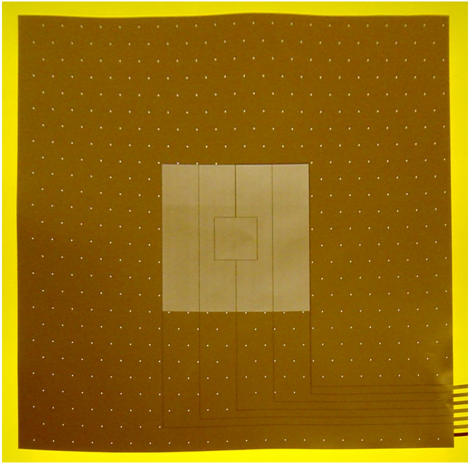
- 32×32 Pixels
- pitch: 1 mm

Periphery: $100 \times 100\,\text{mm}^2$

- 512 crossed (2D) strips
- equal charge-sharing
- pitch: 400 μm



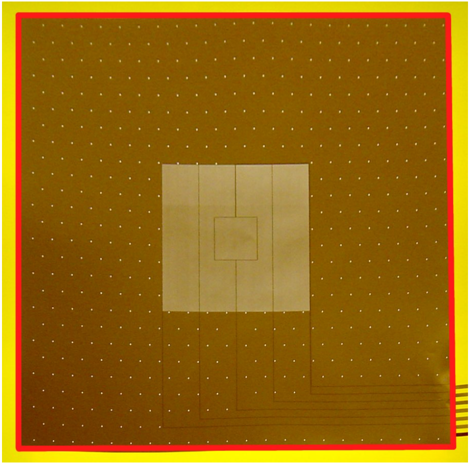
GEM Foil



GEM Foil

Foil: $330 \times 330\,\text{mm}^2$

- Kapton $50\,\mu$m
- Cu cladding: $5\,\mu$m or $1\,\mu$m
- gas circulation holes: diameter $0.5\,$mm



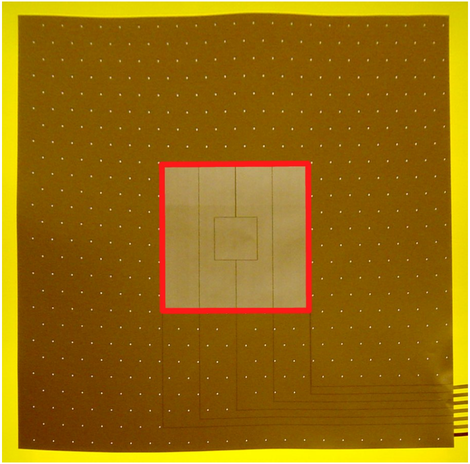
GEM Foil

Foil: $330 \times 330\,\mathrm{mm}^2$

- Kapton $50\,\mu$m
- Cu cladding: $5\,\mu$m or $1\,\mu$m
- gas circulation holes: diameter 0.5 mm

Active Area: $100 \times 100\,\mathrm{mm}^2$

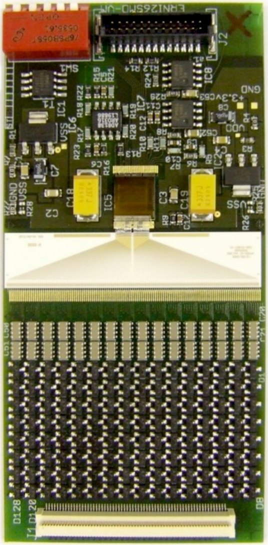
- segmented amplification region
- double-conical holes
- GEM hole diameter: $70\,\mu$m
- pitch: $140\,\mu$m



Front-End Electronics

APV card

- analogue APV25 S1 ASIC[1]
- 38.88 MHz sampling frequency
- 128 channels
- 160 samples pipeline:
  up to $\sim 4\,\mu s$ trigger latency



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

Front-End Electronics

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- analogue APV25 S1 ASIC[1]
- 38.88 MHz sampling frequency
- 128 channels
- 160 samples pipeline:
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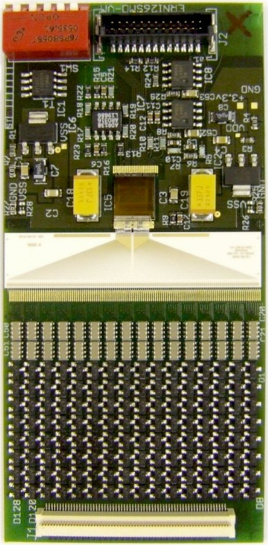
Read-out Scheme

- 16 APV cards per detector
- bus card to 12 bit ADC
- total equiv. noise charge:
  1300-1500 electrons



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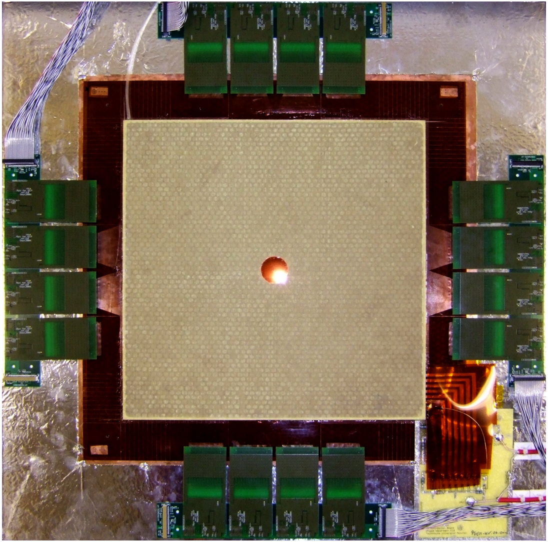
The fully assembled Detector



Material Thickness in ‰ of radiation length X_0

	centre $[X_0/1000]$	periphery $[X_0/1000]$
Honeycomb Support	0.0	2.9
Drift Foil	0.5	0.5
3 GEM Foils	2.1	2.1
Readout Circuit	1.0	1.3
Shielding	0.2	0.2
Gas	0.1	0.1
Total Thickness	**3.8**	**7.1**

centre: $r < 15\,\text{mm}$, periphery: $r > 15\,\text{mm}$

Cu layer thickness 5 μm

Material Thickness in ‰ of radiation length X_0

	centre $[X_0/1000]$	periphery $[X_0/1000]$
Honeycomb Support	0.0	2.9
Drift Foil	0.5 / 0.3	0.5 / 0.3
3 GEM Foils	2.1 / 0.8	2.1 / 0.8
Readout Circuit	1.0	1.3
Shielding	0.2	0.2
Gas	0.1	0.1
Total Thickness	**3.8 / 2.2**	**7.1 / 5.5**

centre: $r < 15\,\text{mm}$, periphery: $r > 15\,\text{mm}$

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

Material Thickness in ‰ of interaction length λ_I

	centre $[\lambda_I/1000]$	periphery $[\lambda_I/1000]$
Honeycomb Support	0.0	1.1
Drift Foil	0.1	0.1
3 GEM Foils	0.4	0.4
Readout Circuit	0.4	0.5
Shielding	0.1	0.1
Gas	0.0	0.0
Total Thickness	**0.9**	**2.1**

centre: $r < 15$ mm, periphery: $r > 15$ mm

Cu layer thickness 5 μm

Material Thickness in ‰ of interaction length λ_I

	centre $[\lambda_I/1000]$	periphery $[\lambda_I/1000]$
Honeycomb Support	0.0	1.1
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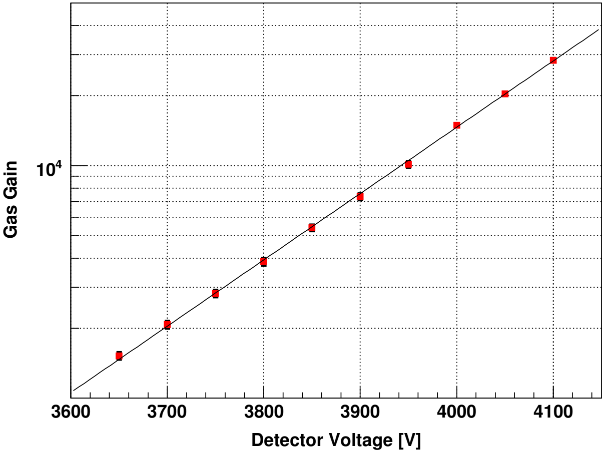
3 GEM Foils	0.4 / 0.2	0.4 / 0.2
Readout Circuit	0.4	0.5
Shielding	0.1	0.1
Gas	0.0	0.0
Total Thickness	**0.9 / 0.8**	**2.1 / 2.0**

centre: $r < 15\,\mathrm{mm}$, periphery: $r > 15\,\mathrm{mm}$

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

Gain-Voltage-Dependency

measured with ^{55}Fe source for 5 μm Cu GEM



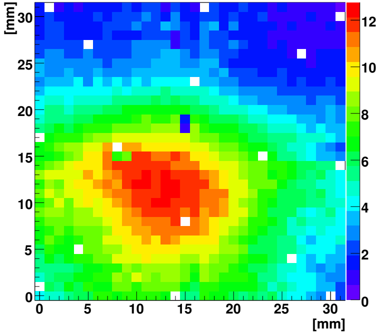
selected 3900 V for a gain of ~7500

Setup in COMPASS

Beams from SPS

SPS Tunnel

Occupancy [%]



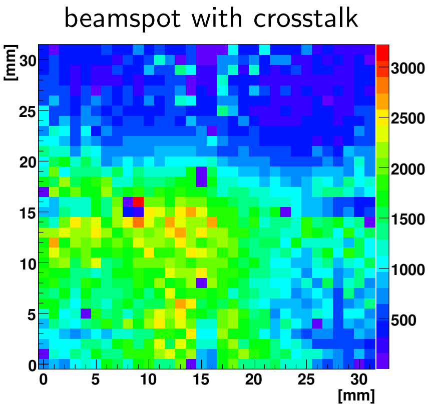
Low Intensity μ^- Beam

total flux: $1.1 \cdot 10^6\,\mathrm{s}^{-1}$
max. density: $2.5 \cdot 10^3\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$

High Intensity μ^- Beam

total flux: $4.8 \cdot 10^7\,\mathrm{s}^{-1}$
max. density: $1.2 \cdot 10^5\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$

Crosstalk Suppression



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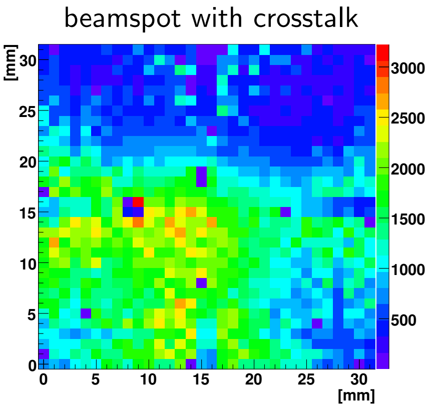

- tag channels with high-amplitude neighbours
- after clustering: remove clusters containing mostly tagged pixels

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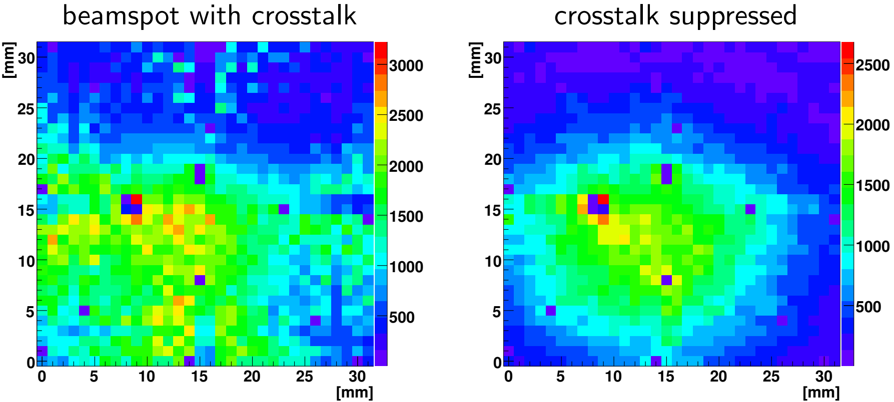

- tag channels with high-amplitude neighbours
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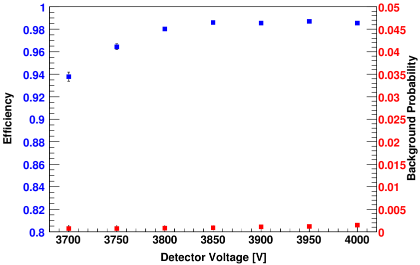
Efficiency Scan

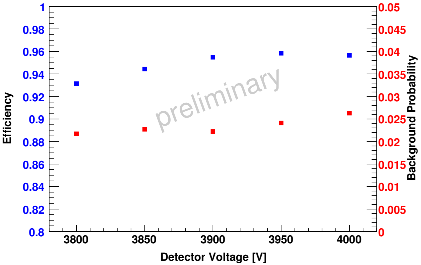
Low Intensity: $\sim 2 \cdot 10^3\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$



efficiency plateau: $\sim 98.5\,\%$
bg prob. per pixel: $\sim 0.1\,\%$

roadwidth used: 0.6 mm

High Intensity: $\sim 1 \cdot 10^5\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$

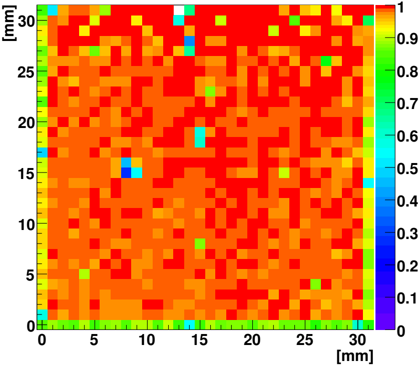


efficiency plateau: $\sim 95.5\,\%$
bg prob. per pixel: $\sim 2\,\%$

roadwidth used: 1 mm

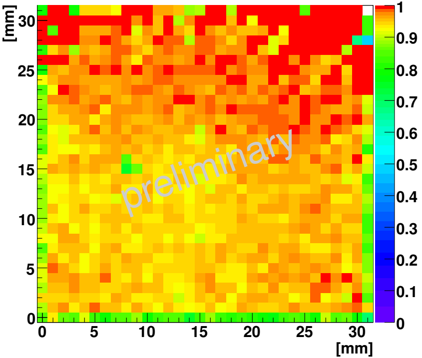
Efficiency Map

Low Intensity: $\sim 2 \cdot 10^3\ \mathrm{mm}^{-2}\mathrm{s}^{-1}$



average efficiency: $\sim 98.5\,\%$

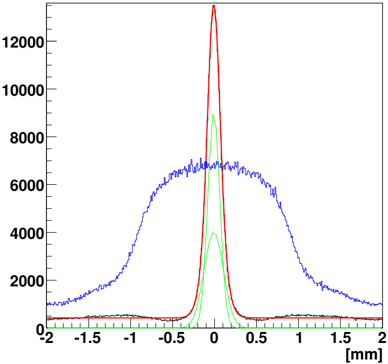
High Intensity: $\sim 1 \cdot 10^5\ \mathrm{mm}^{-2}\mathrm{s}^{-1}$



average efficiency: $\sim 95.5\,\%$

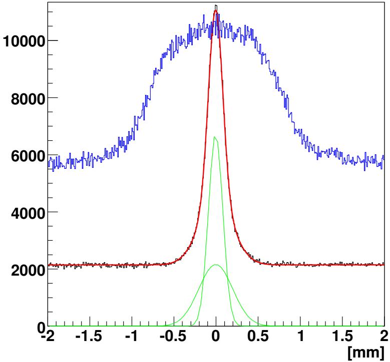
Spatial Residuals

Low Intensity: $\sim 2 \cdot 10^3\ \mathrm{mm}^{-2}\mathrm{s}^{-1}$



weighted mean: $\sigma_x = 90\mu m$

High Intensity: $\sim 1 \cdot 10^5\ \mathrm{mm}^{-2}\mathrm{s}^{-1}$

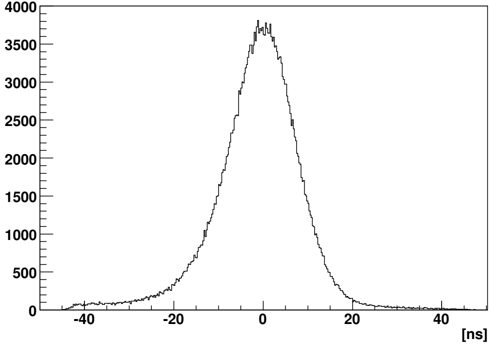


weighted mean: $\sigma_x = 135\mu m$

black/blue: with/without clustering, green: Gaussian components

Temporal Residual

Low Intensity: $\sim 2 \cdot 10^3\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$



rms $= 9.9\,\mathrm{ns}$

Conclusion and Outlook

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Conclusion

- GEM with pixel read-out
- radiation-hard in-beam tracker
- stable operation in muon beams up to $1.2 \cdot 10^5\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$
- extremely thin: $x/X_0 = 0.2\,\%$ and $\lambda/\lambda_I = 0.07\,\%$

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Outlook

- ongoing work on analysis/reconstruction
- deployment of 5 PixelGEM detectors in COMPASS in 2007/2008

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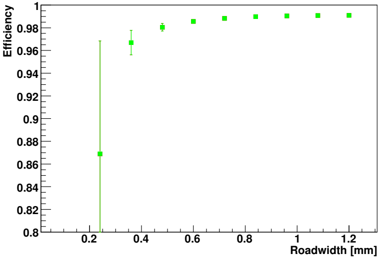
Acknowledgements

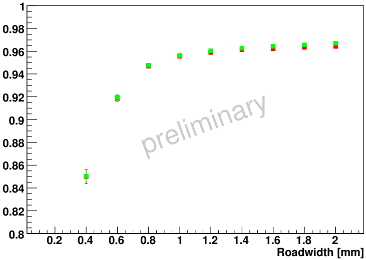
- Rui de Oliveira (CERN TS-DEM-PMT)
- Christian Joram, Eric David, Miranda van Stenis (CERN PH-DT2)
- Ian McGill (CERN PH-DT2)
- Workshops of CERN and TU München

Efficiency: Roadwidth Scan

Low Intensity: $\sim 5 \cdot 10^3\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$

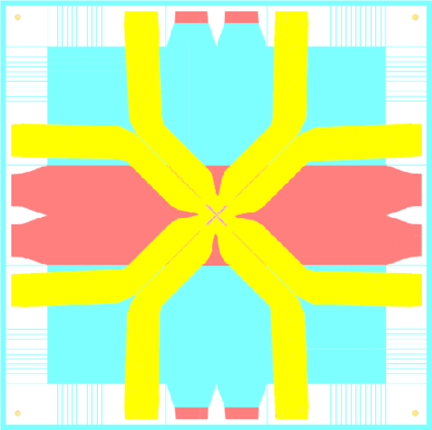


High Intensity: $\sim 2 \cdot 10^5\,\mathrm{mm}^{-2}\mathrm{s}^{-1}$



Crosstalk: Design of Read-out Circuit

first version



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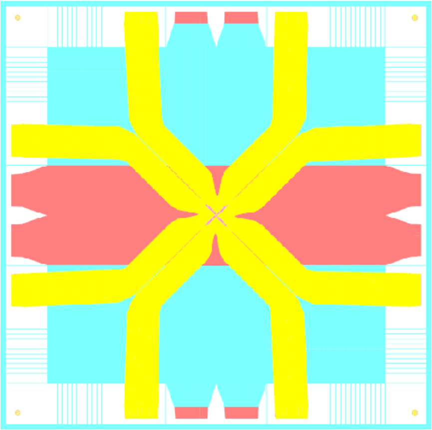
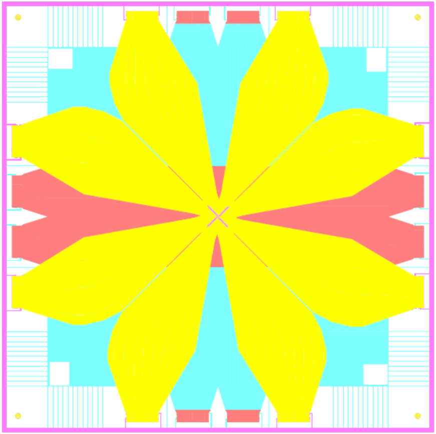
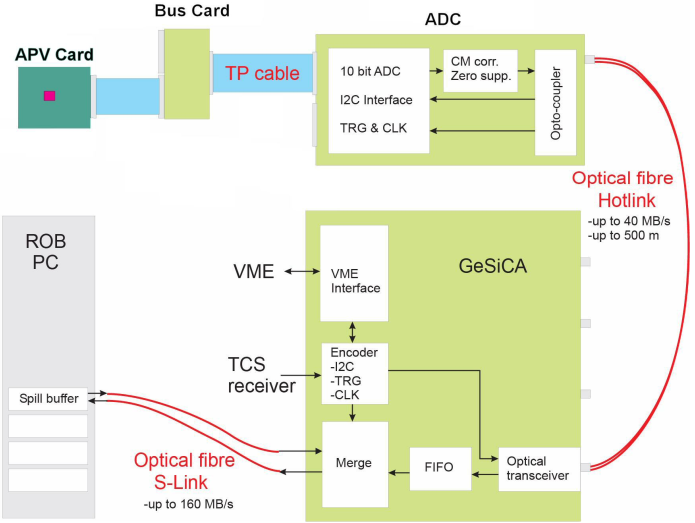


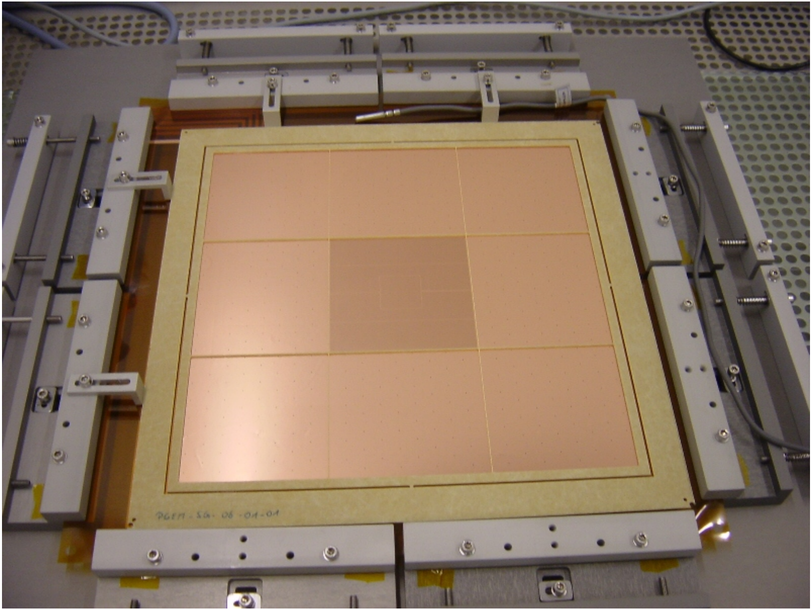
improved layout



Readout Chain



Production: Gluing GEM foil onto Spacer Grid



Spatial/Temporal Resolution Strip-GEMs

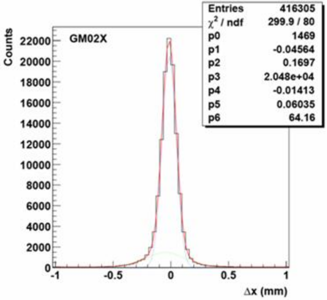
Spatial resolution

- Test beam/low intensity:

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

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

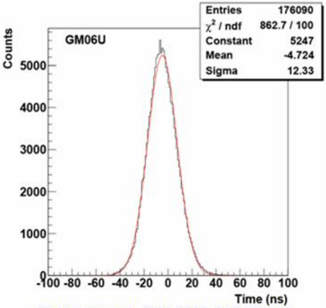
$$\langle \sigma_x \rangle \approx 70\mu m$$



Time resolution

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

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



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

Efficiencies Strip-GEMs

Low intensity beam: $5 \cdot 10^6$ μ^+/s

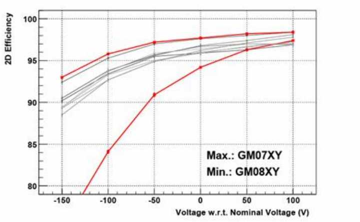
- All detectors reach plateau (ε>98%)
- Gain ~8000
- SNR ~18
- Losses due to spacer grid: 1.2-1.5%

Standard physics beam: $4 \cdot 10^7$ μ^+/s

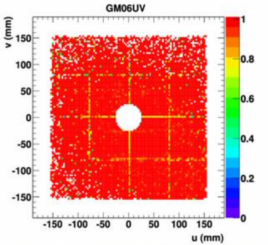
- Background correction

$$\varepsilon_{app} = \varepsilon + (1-\varepsilon)\cdot b$$

- 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)]