THE MAGIX FOCAL PLANE TPC

An open-cage TPC for the MAGIX experiment

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MAINZ ER SUPERCONDUCTIVE ACCELERATOR

Multi-turn, superconducting ERL

Energy recovery mode

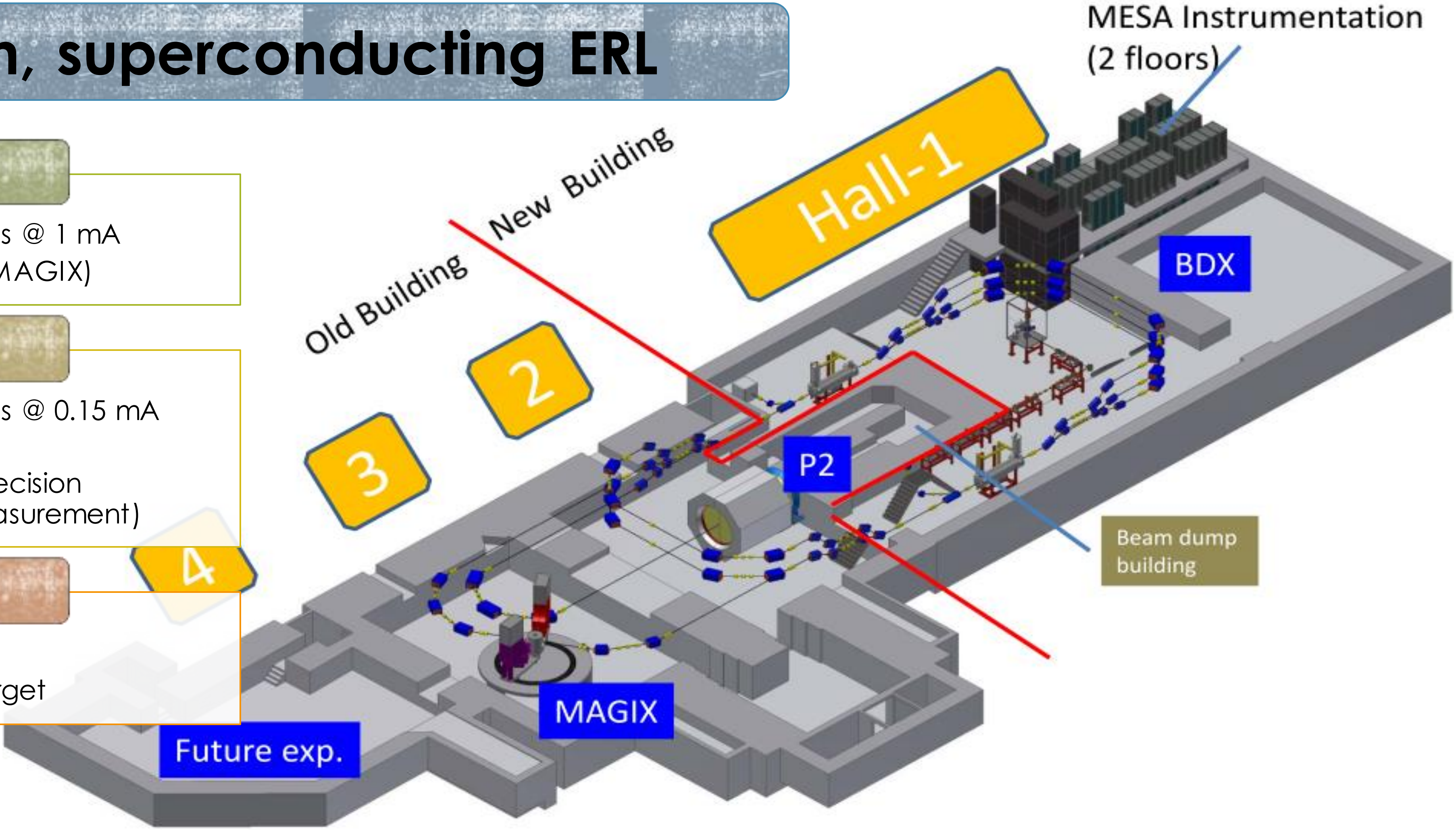
- 105 MeV polarized electrons @ 1 mA
- Internal target scattering (MAGIX)

External beam

- 155 MeV polarized electrons @ 0.15 mA
- Dedicated experiment (P2)
- Electroweak asymmetry precision measurement (10000 h measurement)

DarkMESA (BDX)

- Behind the P2 beam dump
- About 10^{23} electrons on target



MAGIX EXPERIMENT

A versatile experiment for precision measurements at low energy

EXTENSIVE PHYSICS PROGRAM

Hadronic structure

- Proton form factors (electric and magnetic)
- Nuclear polarizabilities
- Light nuclei form factors (Deuteron and helium)

Precision measurement of a differential cross-section

Few-body physics

- Deuteron and ^{3}He breakup
- ^{4}He monopole transition factors
- Test of effective field theories
- Inclusive electron scattering

Non-gaseous targets and complex observables

Precision cross-sections

- $^{16}O(e, e'a)^{12}C$ S-factor

Detection of the low energy recoil products

Search for exotic particles

- Direct dark photon search
- Invisible decaying dark photon search

Identification of a narrow resonance on a large background

THE MAGIX SETUP

A high-precision multi-purpose experimental setup

Internal Gas Target

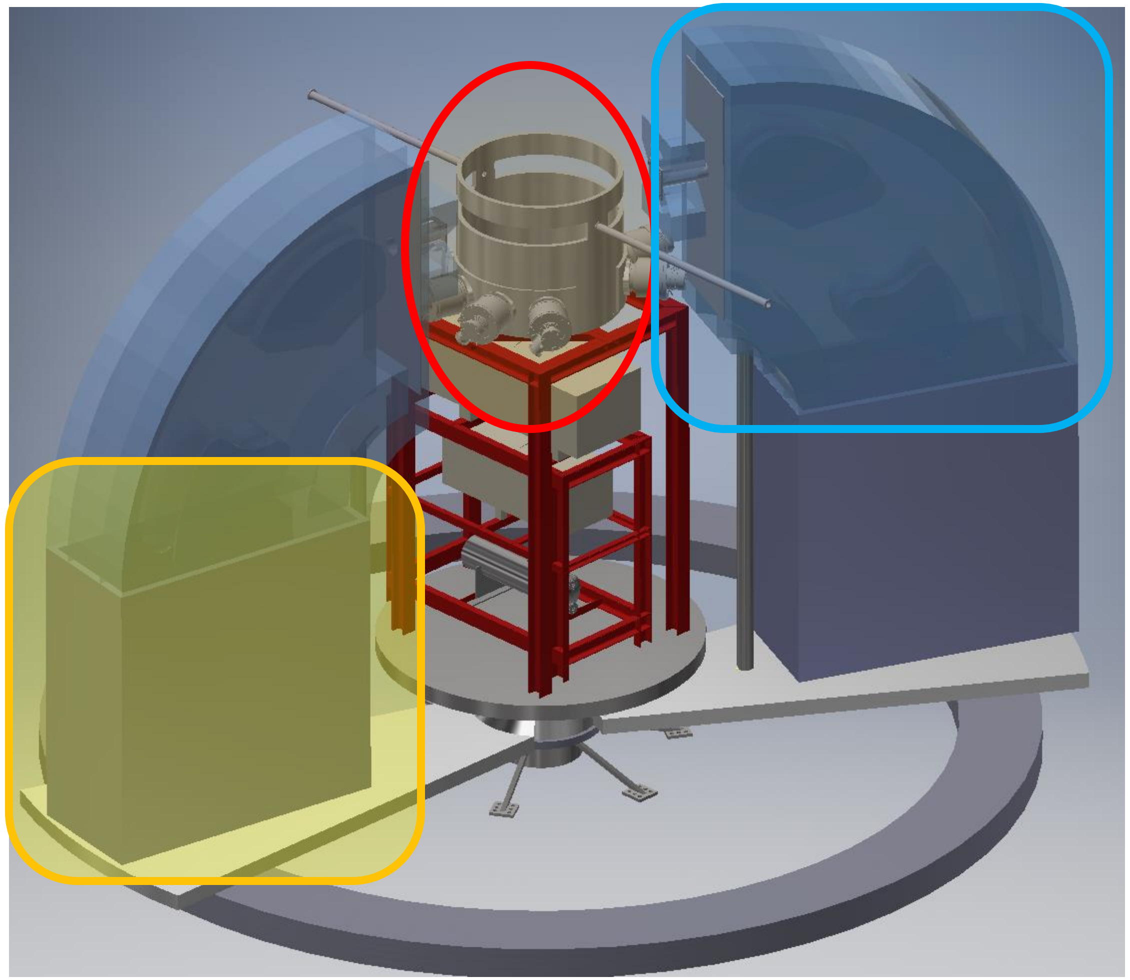
- Windowless gas target
- Integrated recoil silicon detectors
- Forward luminosity monitors

Spectrometers

- Twin Arm Dipole Spectrometer
- Zero-degree tagger spectrometer

Focal Plane Detectors

- GEM-based TPC tracker
- Timestamping trigger



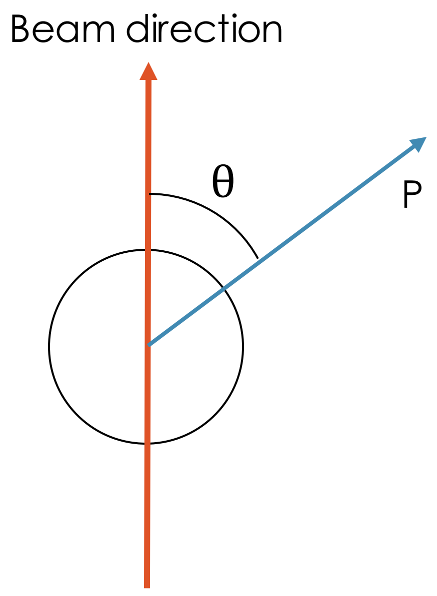
MAGIX PARAMETER SUMMARY

Experimental constraints

- Beam energy (E): 105 MeV
- Beam current (I): up to 1 mA
- Possible beam and target polarization
- ERL mode: minimal energy losses in the interaction region ($\frac{dE}{E} < \approx 10^{-4}$)
- Luminosity of the order of $10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Basic observables

- Scattered particle momentum (P)
- Scattering angle (θ,φ)



MAGNETIC SPECTROMETERS

Momenta and angles

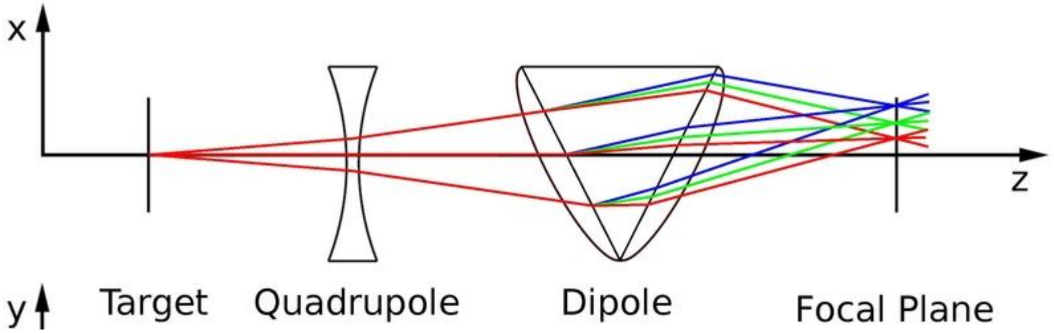
- Linear mapping of momenta to one coordinate in a focal plane
- Mapping of the scattering angles to the second coordinate and angle at the focal plane
- Momenta and angular resolution depend on the magnification properties as well as the detector resolution

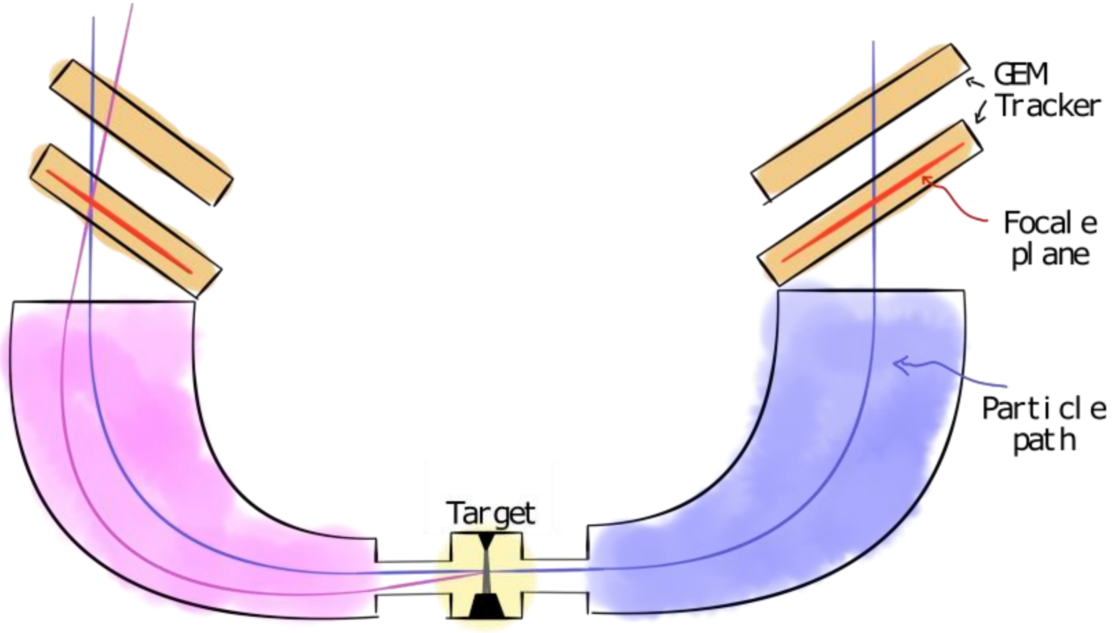
Advantages

- Extremely good momentum and angular resolution

Disadvantages

- Limited geometric acceptance
- Compensated by the high luminosity





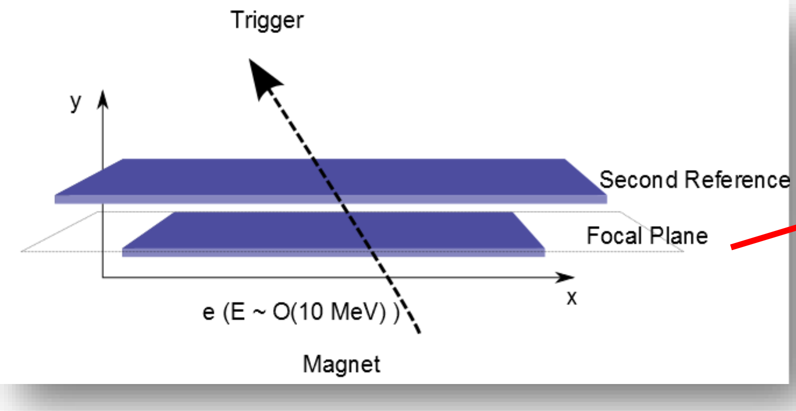
FOCAL PLANE DETECTORS

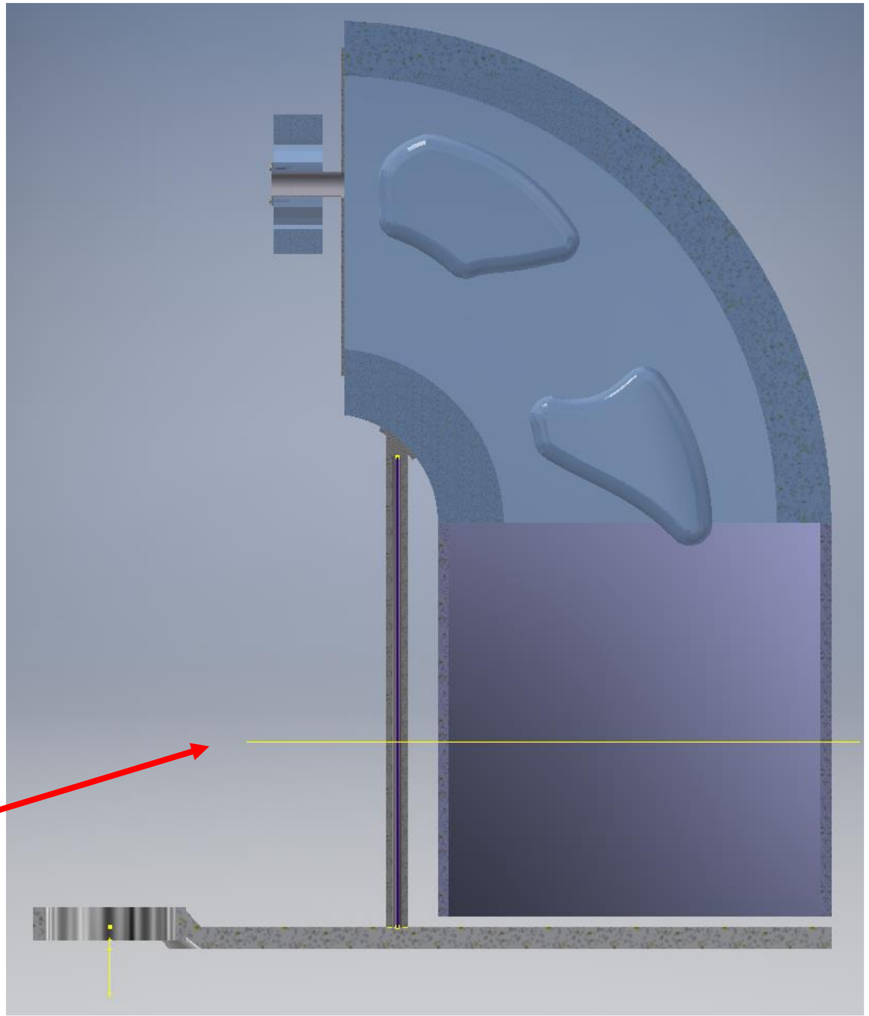
Momentum measurement

- Momentum range: $\approx 100\ \mathrm{MeV}$
- Momentum resolution: $\frac{\delta P}{P} \approx 10^{-4}$
- Focal plane length: $\approx 1\ \mathrm{m}$
- Required position resolution: $\approx 100\ \mathrm{\mu m}$

Focal plane angle measurement

- Sample the particle trajectory in at least two points and perform a linear fit
- E.g. required angular resolution: $\approx 10^{-3}\ \mathrm{rad}$
- Position resolution: $\approx 100\ \mathrm{\mu m}$
- Minimum plane distance: $\approx 10\ \mathrm{cm}$





FOCAL PLANE DETECTORS

Gas detectors

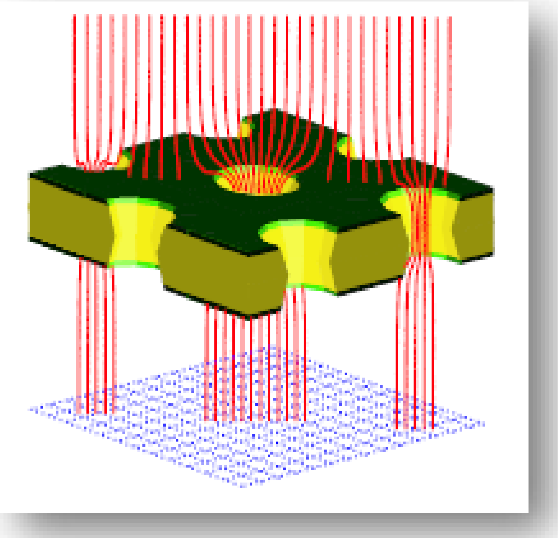
- Low material budget
- Low cost for large area coverage

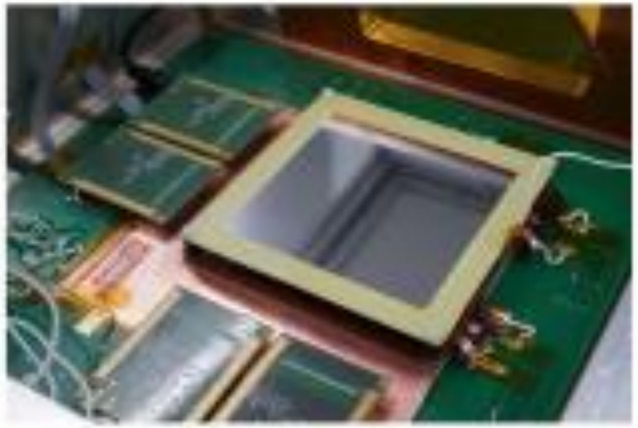
MPGD

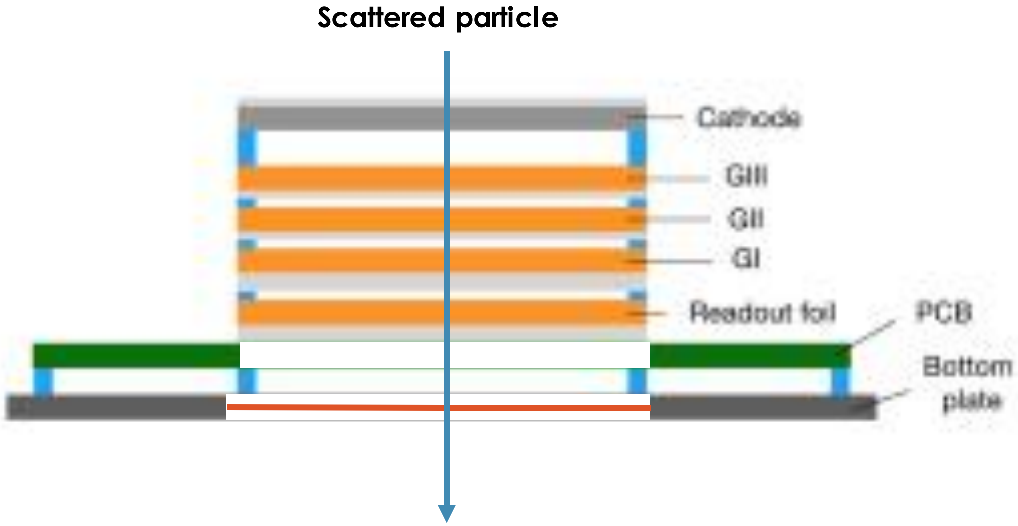
- Modern gas amplification systems
- Resolutions of the order of 50 µm achieved by several detectors

GEM

- Simple to design and setup
- Good stability at high rate
- Adaptable to many exp. needs

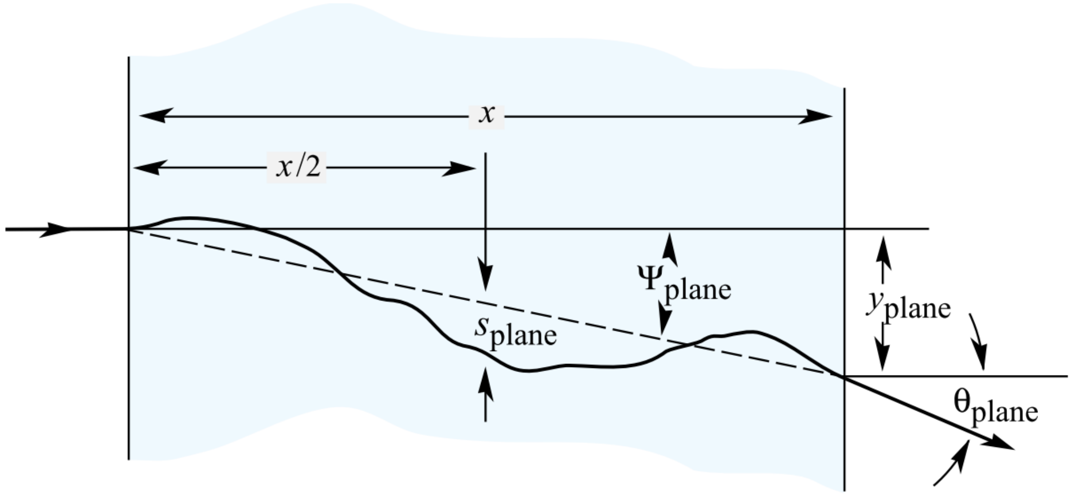






MULTIPLE SCATTERING

Angular error introduced by the foil separating the spectrometer vacuum and the detector volume

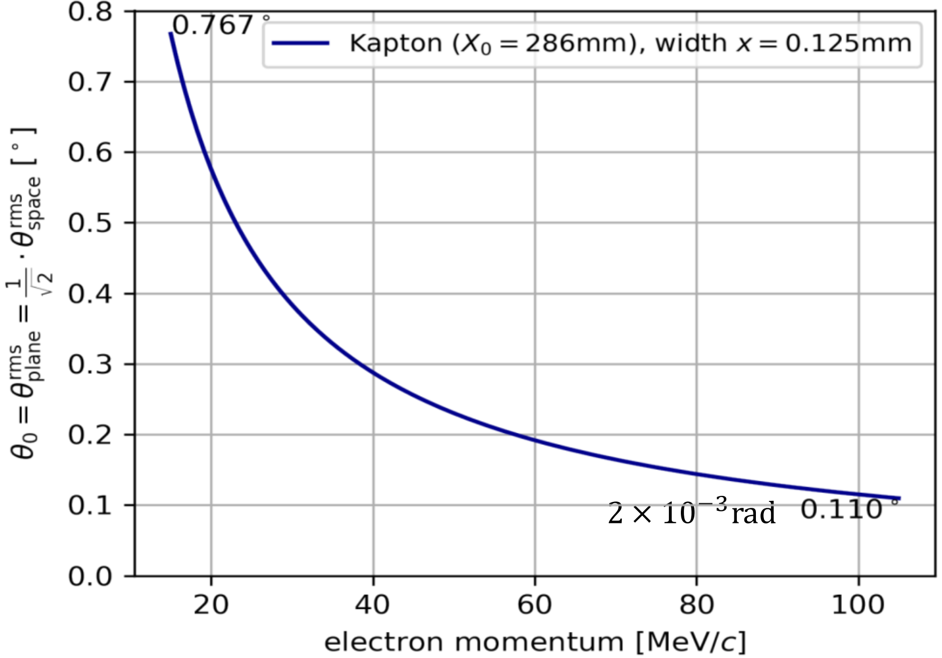


$$\theta_0 = \delta\theta_{plane} = \frac{1}{\sqrt{2}}\delta\theta_{space}$$

$$\theta_0 = \frac{13.6}{\beta\, c\, p} z \sqrt{\frac{x}{X_0}}\left[1 + 0.38\ln\left(\frac{x\, z^2}{X_0 \beta^2}\right)\right]$$

$p =$ particle momentum
$z =$ charge of the projectile

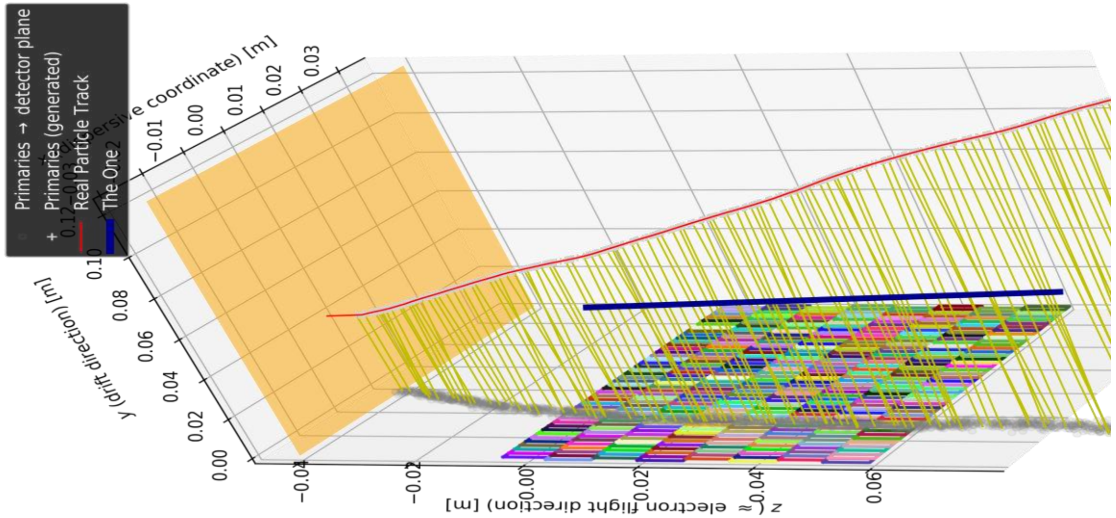
Multiple scattering in the MAGIX vacuum window



Materials in the particle path

- Multiple scattering in the window is already enough to introduce a sizeable systematic error
- Any other material on the particle path should be sensitive

ULTIMATE MATERIAL REDUCTION – GEM TPC

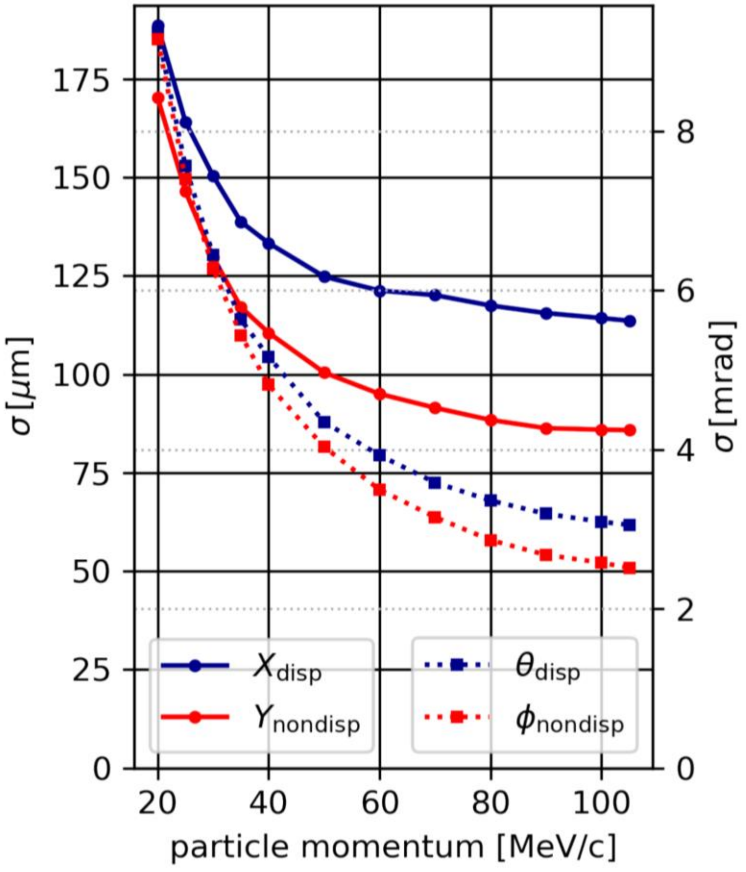


Relevant requirements

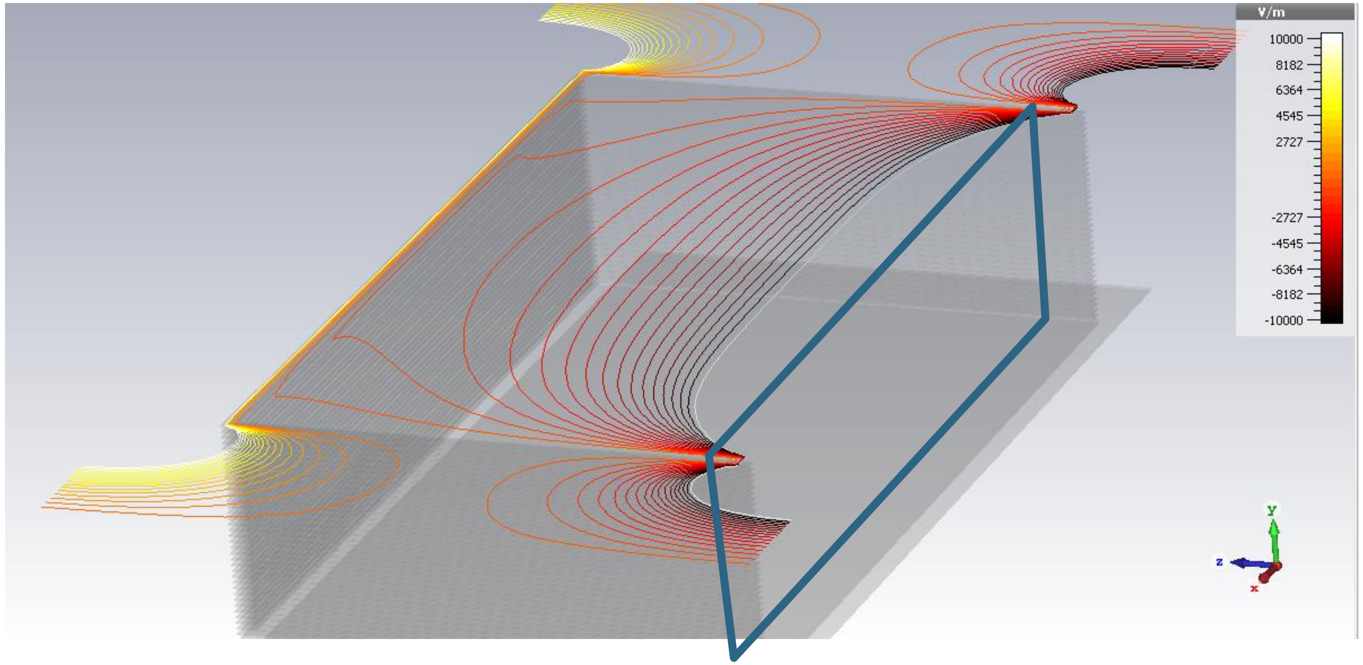
- Focal plane as close as possible to the first sensitive row to limit the lever arm from the main source of the MS
- Sensitive volume starting immediately after the vacuum window
- High uniformity of the angle and momentum measurement to limit position dependent position errors

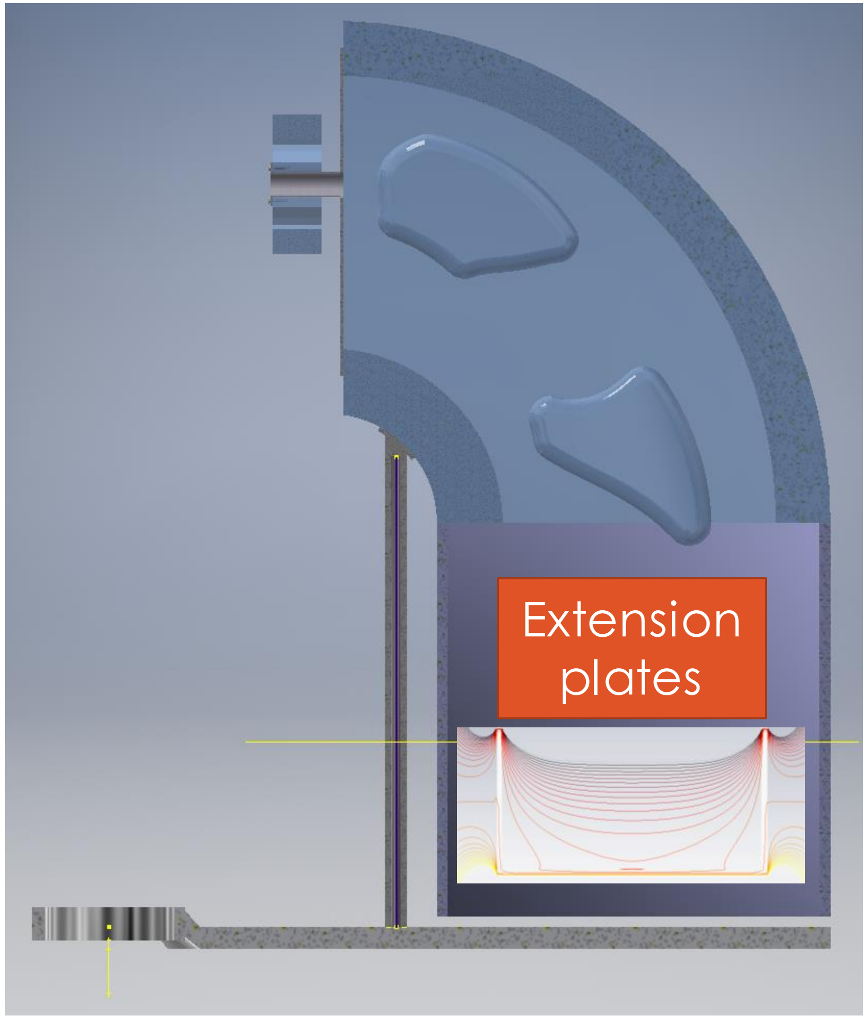
No field cage parallel to the vacuum window

- No field shaping parallel to the vacuum window
- No additional material in the particle path



OPEN FIELD CAGE





Field distortions

- Large field distortions especially near the opening where we need the higher precision

Extension plates

- Extending the TPC in the vacuum behind the field cage

OPEN FIELD CAGE SIMULATION

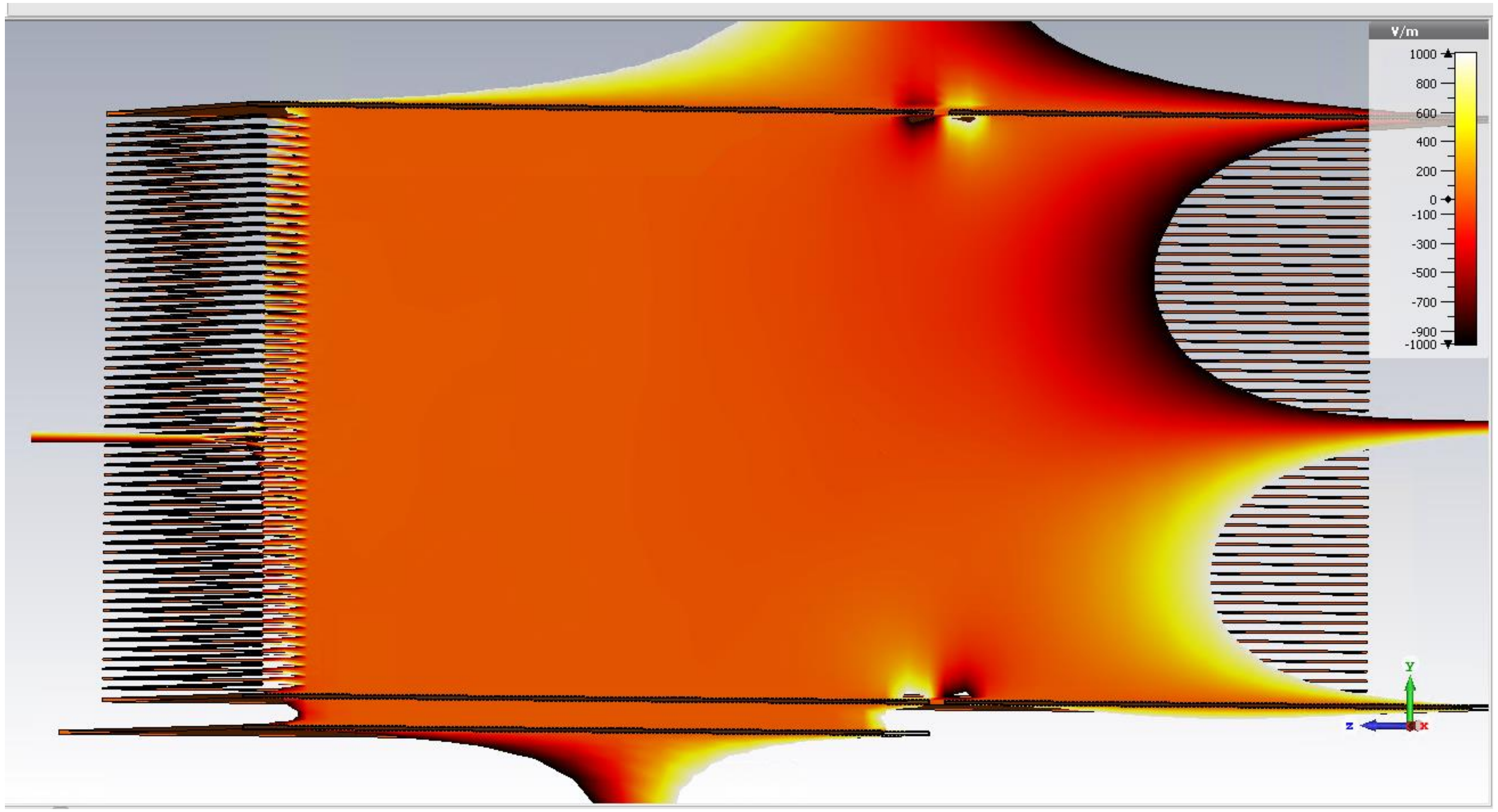
Field cage

- 2 mm element spacing, no mirror strips on 3 sides
- 15 cm drift length
- 20x8 mm pad rows
- 1 cm gap between TPC and extension plates
- 15 cm extension plate in the magnet vacuum
- Field cage extending on the two sides
- Fully parameterized simulation in CST

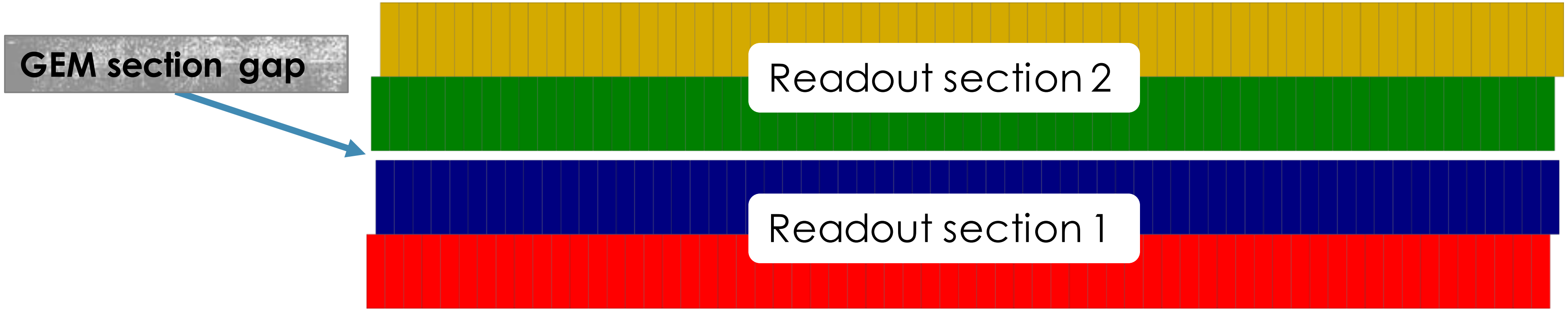
Results

- Distortions < 0.1% in the focal plane
- Relevant distortions due to the gap between the TPC and the extension cage

E-field, Z component.
Nominal drift field: 100 V/mm parallel to Y
Color map range: -1:1 V/mm



READOUT PLANE



Readout pads

- Rectangular 2x8 mm^2
- Small enough to achieve a good charge sharing
- Large enough to integrate the electronics behind the readout
- We may test and compare the zigzag design

Pad rows

- Minimum 17 rows to achieve optimal resolution
- 20 or 24 rows with 0.5 mm staggering (4 rows repetition)
- A gap of ~1 mm between each couple of rows matching the GEM sectioning scheme

Other features

- Integrated HV distribution
- Gas tight
- Integrated electronics behind each readout section
- 128 pads per readout section for compatibility with VMM and APV
- 60-72 readout sections

THE GEM STACK

Up to 4 GEM stack

- Unknown whether the IB will be a major factor in such a short drift (15 cm)
- Simulations and measurements are programmed
- Designing to support up to 4 GEMs allows freedom of choice

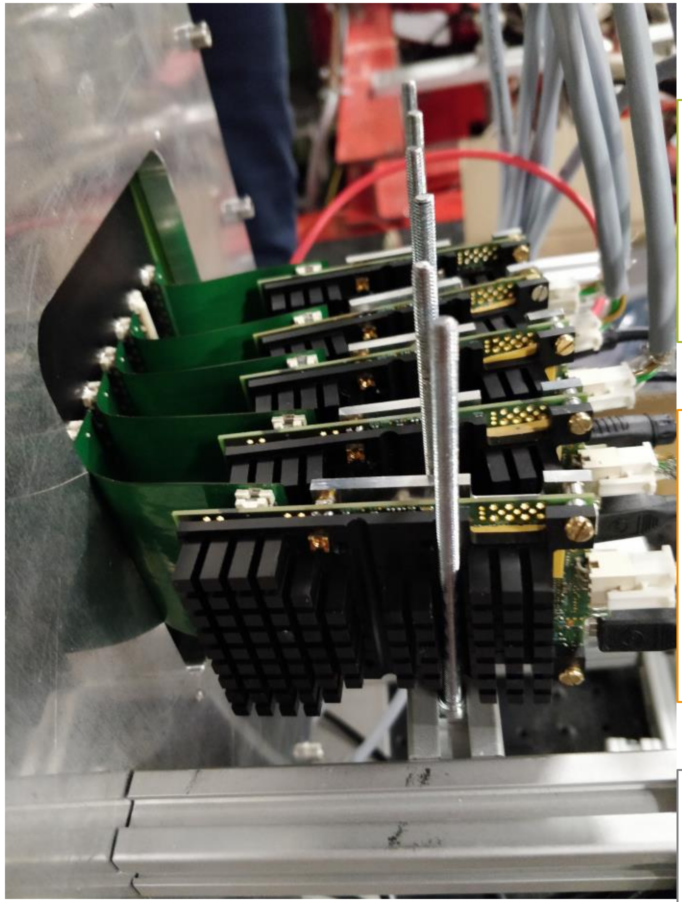
Sectioning

- Each section matching 2 readout rows
- Section size is 800x17 mm^2
- Single side sectioning with bottom facing sections
- To evaluate the possibility of double side sectioning – more complex power distribution vs increased robustness

Support structure

- Need to choose between self-stretching or pre-stretched foils

ELECTRONICS



One of the main users of SRS VMM

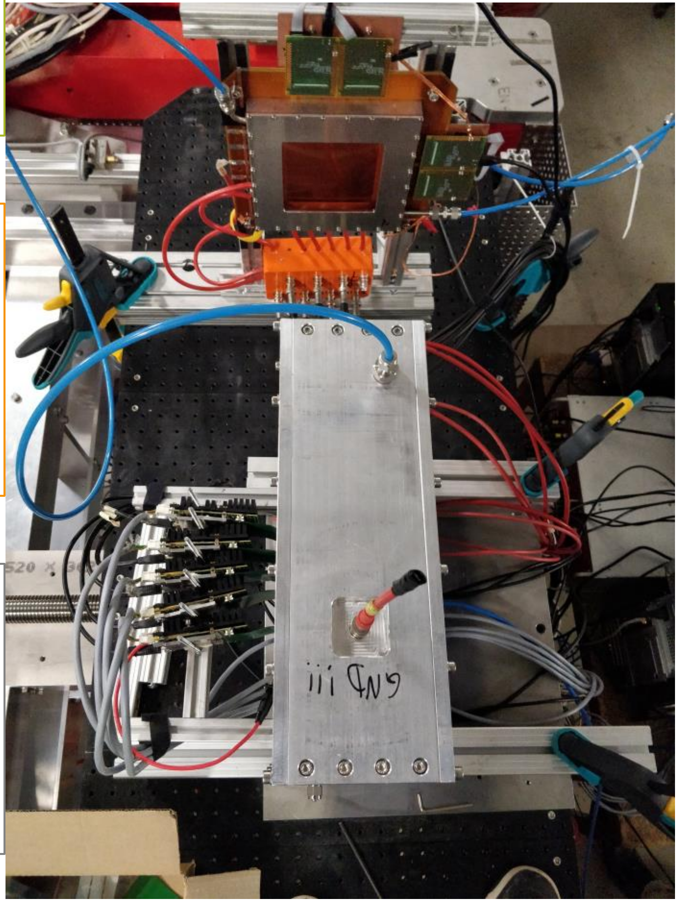
- Each detector needs at least 7680 channels
- 120 VMM3a per detector in 60 hybrids

VMM development

- First test-beam with TPC and VMM completed on May 4th at MAMI in Mainz
- SRS DAQ software to share within RD-51 under development

Radiation hardness

- Is the radiation environment harmful to the hybrid FPGA?
- Test in a compatible environment could be performed in the next months



TPC DESIGN FEATURES

Field cage and window

- Open field cage with minimal in-beam material
- Thin field cage in the back to maximize trigger efficiency
- Field plates extensions in the spectrometer vacuum to improve the field quality

Anode

- Gas tight with integrated high-voltage distribution and GEM support system for up to 4 GEMs
- VMM3 hybrids mounted directly on the back of the readout plane with SRS readout (15-20 k channel SRS system)
- Integration with the field cage to be defined

Other features

- Independent cathode plate that can be aligned with the anode
- Integrates an emission pattern to use in the detector calibration
- Laser and source based calibration system
- Trigger scintillators behind the field-cage back side to efficiently detect electron of energies of the order of 1 MeV

CURRENT STATUS AND FUTURE OUTLOOK

Small prototype

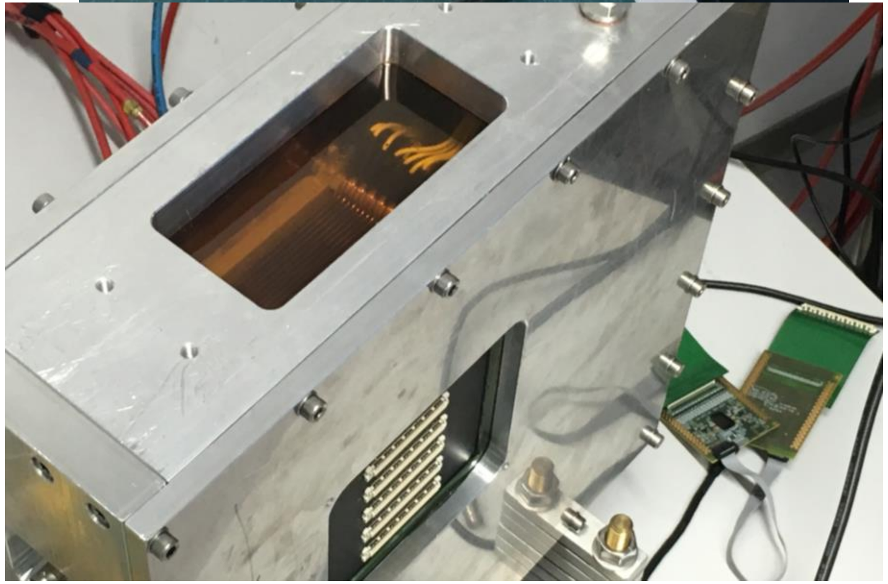
- 10x10 cm^2 for basic physics test, electronics integration, readout development, GEM stack integration and IBF measurements
- Already used in the lab and for the last test-beam

Final prototype

- Finalize design in May 2019 and start the production of a full-size prototype of the detectors
- Test the integration with the vacuum window, connected with a vacuum box that can be directly installed on the test-beam line
- Measure all the distortions and find hardware and software methods to mitigate possible issues
- Tweak the design of the production detectors

Milestone

- Build the final detectors for the commissioning of the experiment in 2022



SFB 1044

PRISMA+

THANK YOU FOR YOUR ATTENTION!

http://magix.kph.uni-mainz.de

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BACKUP

THE MAGIX TARGET

REQUIREMENTS

Limited material thickness

- Low energy electrons and recoil nuclei to measure
- Beam recapture after the interaction

High luminosity

- Target luminosity $10^{35}\text{cm}^{-2}\text{s}^{-1}$ @ 1mA
- Target thickness $10^{19}\ \text{cm}^{-2}$

Gas polarization

- Optional requirement for some process

Flowing gas tube

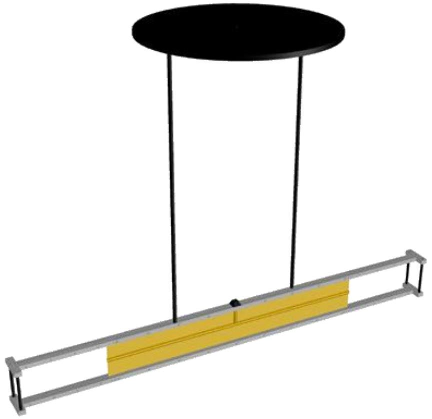
- 30 cm open mylar tube
- Usable for polarized gases
- Lower luminosity

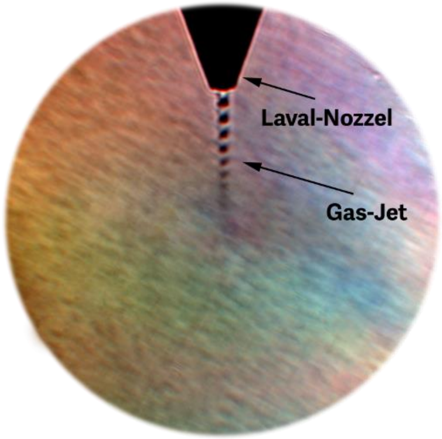
Supersonic jet

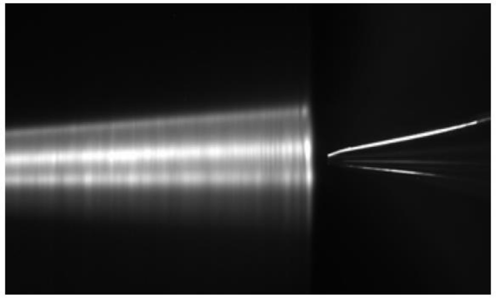
- 2 mm wide jet stream in vacuum
- 10^{19}atoms / cm^2

Cluster-Jet

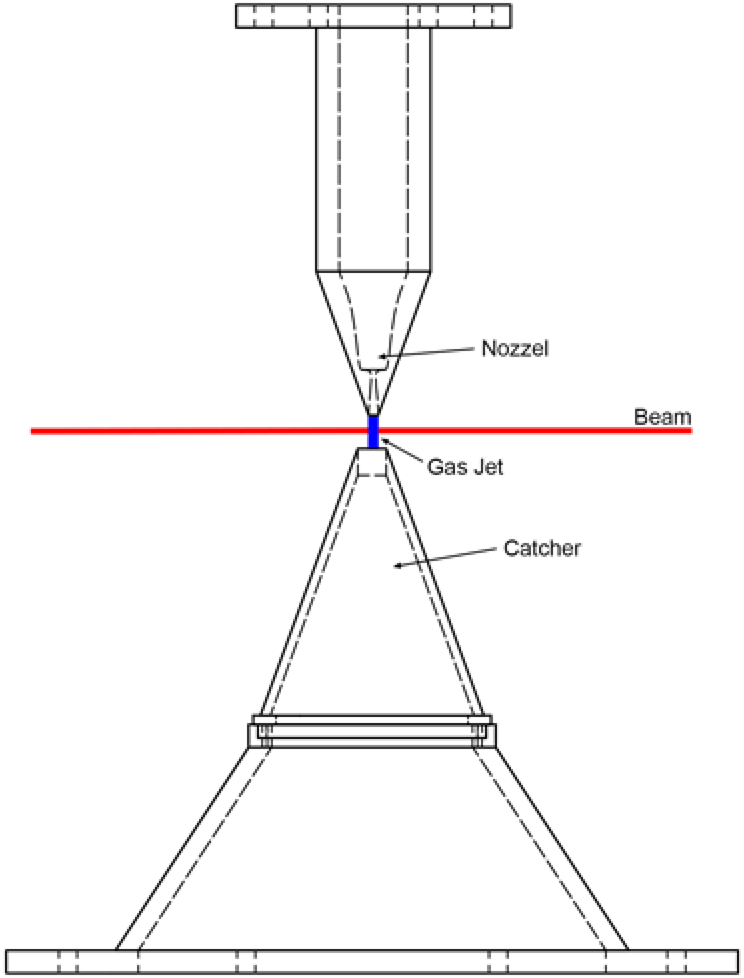
- Molecular clustering @ 40K
- Increase self-containment







JET TARGET



Jet injector

- Supersonic gas flow generated by a miniaturized Laval nozzle
- Supersonic shockwaves and molecular clustering at cryogenic temperatures limit the gas diffusion
- 2 mm wide collimated gas stream

Jet catcher

- Captures the gas stream limiting its diffusion in the scattering chamber
- Massive pumping system to reduce any backflow in the chamber vacuum

Performances

- Core stream pressure about 1 bar
- Scattering chamber pressure < 10^{-4} mbar

ULTRA-THIN GEM DETECTORS FOR MAGIX

Experimental challenge

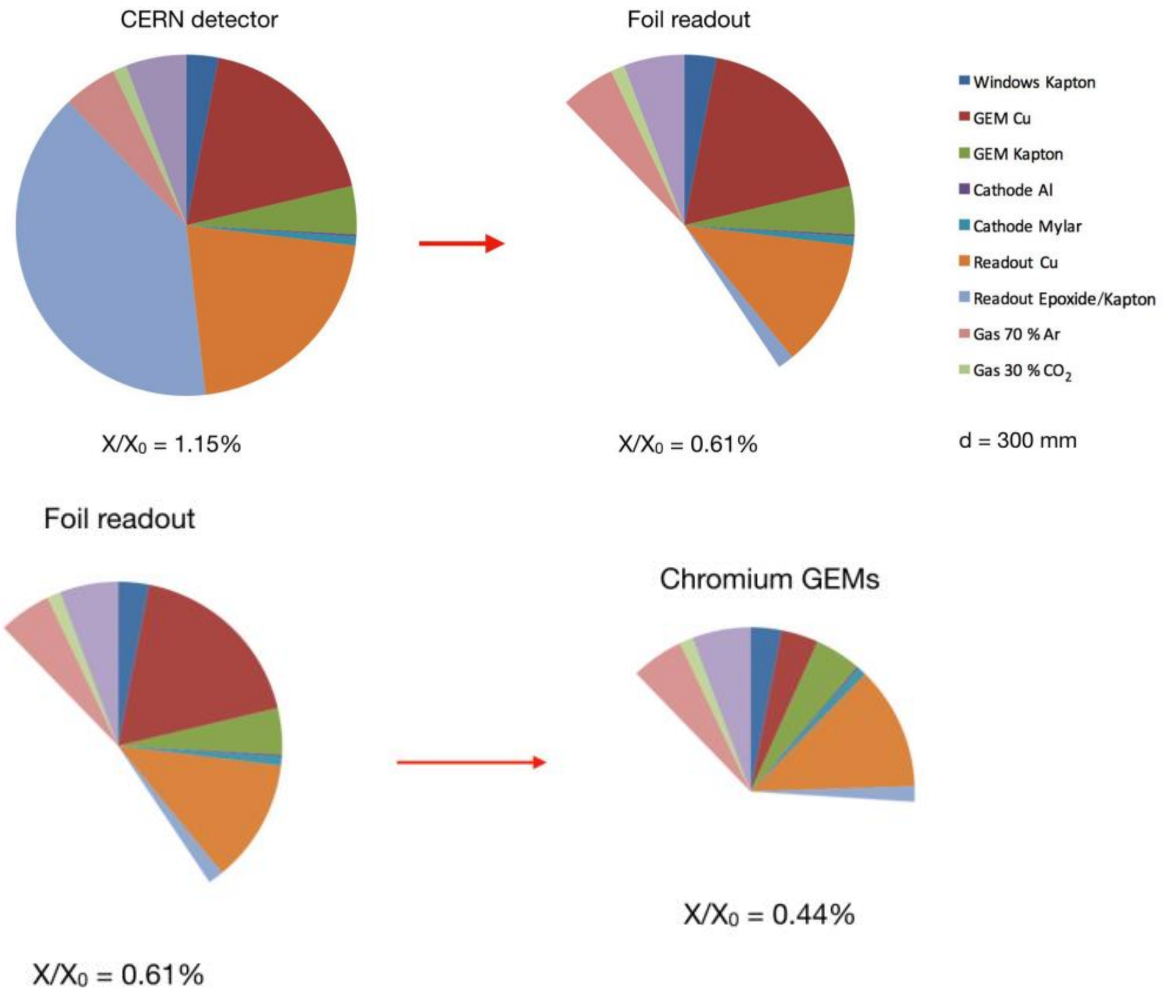
- Minimize the multiple scattering of electrons of 10-100
- Detecting 50 MeV protons

GEM readout on a Kapton foil

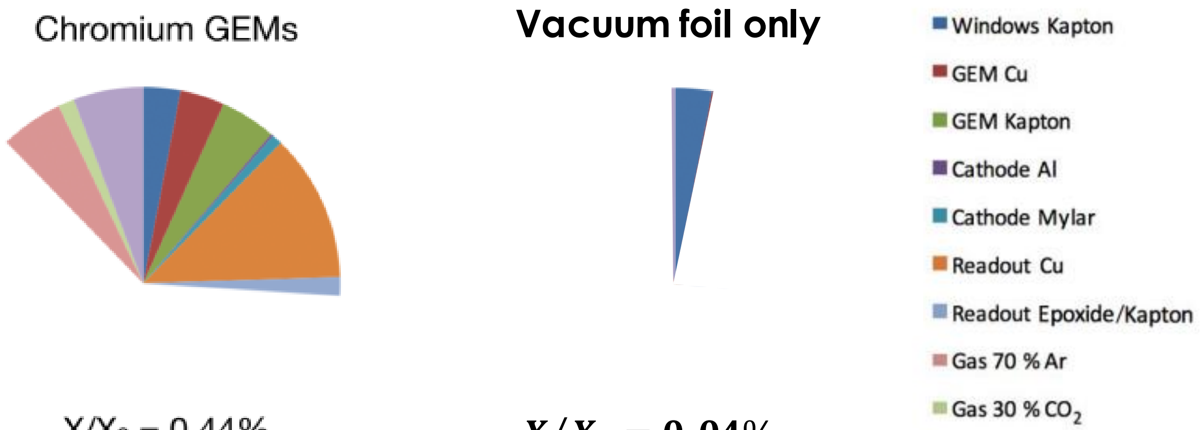
- PCB substrate is the main contributor to the detector thickness
- Replace the substrate with a Kapton foil $0.96\% \rightarrow 0.61\%\ X_0$

GEM copper reduction

- Replacing the copper layer with an atomic layer of Chromium $0.61\% \rightarrow 0.44\%\ X_0$

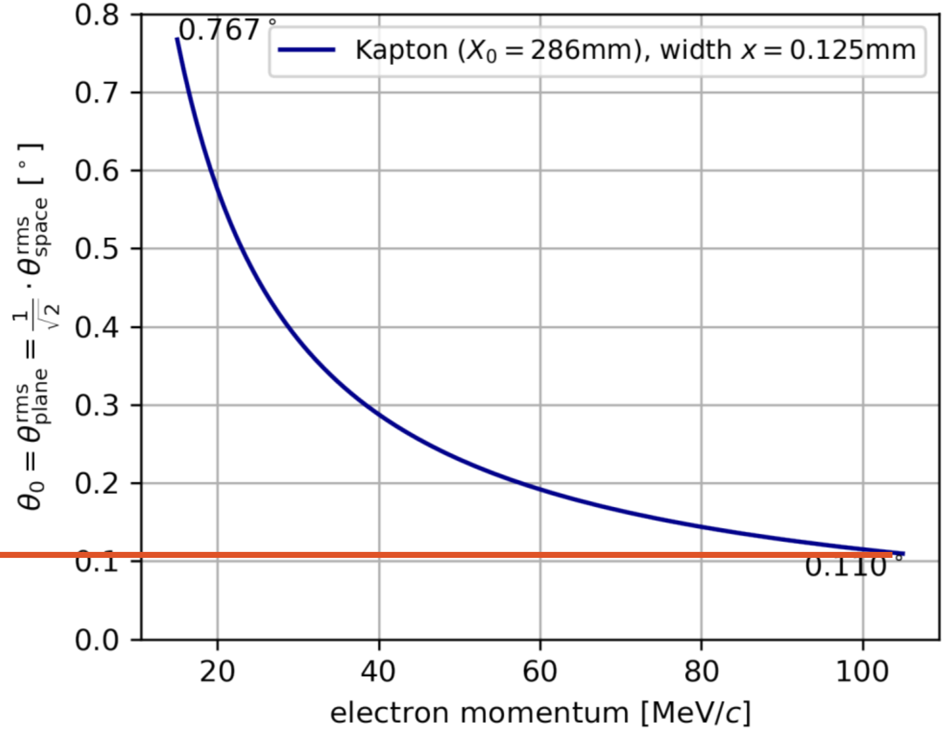


ULTIMATE MATERIAL REDUCTION – WINDOW ONLY



$X/X_0 = 0.44\%$

$X/X_0 = 0.04\%$



Reduction to essentials

- The vacuum window is the only passive material we cannot eliminate
- Multiple scattering in the window is already enough to introduce a sizeable systematic error
- Any other material on the particle path should be sensitive

CHROMIUM GEMS RELIABILITY

What is a chromium GEM

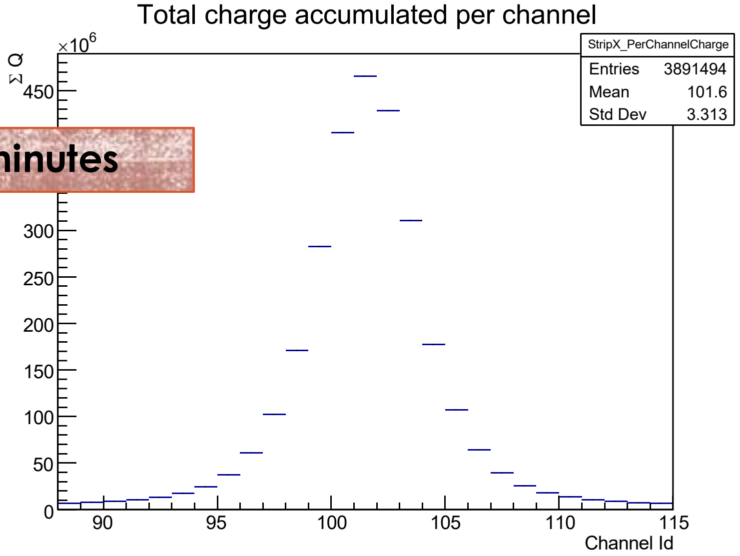
- 100 nm chromium layer always present between copper and Kapton in a standard GEM
- Etch all the copper away. Small copper strips to increase conductivity
- Discharge probability and energy resolution as standard GEMs

The long term reliability issue

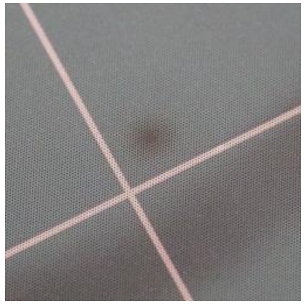
- Measured efficiency drop by other groups as a function of accumulated charge
- How long can we efficiently use a chromium GEM in the different stack layers in beam conditions?

MAMI test-beam (Nov 2017)

- 5 hours at 1.4 MHz with 885 MeV electrons from MAMI
- Stress-test setup: chromium layer facing the readout
- Clear efficiency drop at the end of the test period



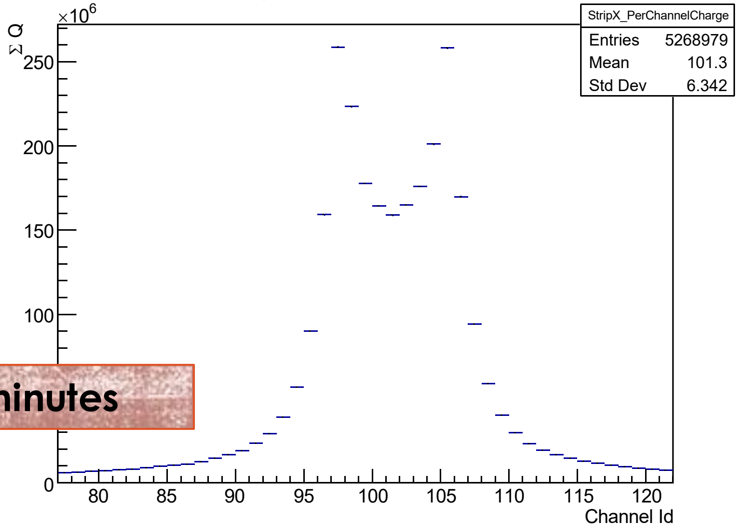
First 30 minutes



After 1 hour

Facing the drift

2MHz electron beam



Last 60 minutes