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

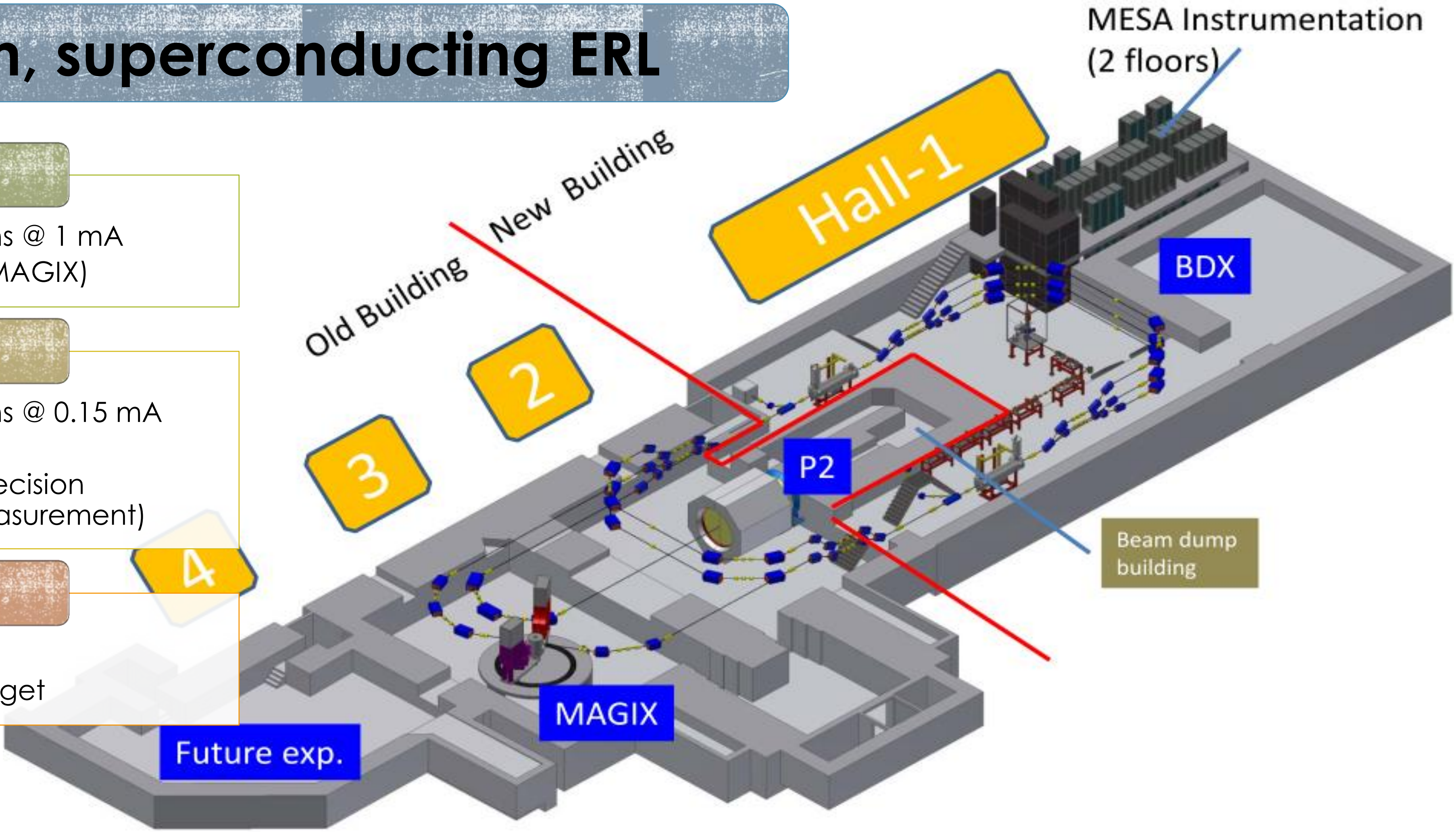
- 105 MeV polarized electrons @ 1 mA
- Internal target scattering (MAGIX)

External beam

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

Beam dump experiment

- 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 exotica

- 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

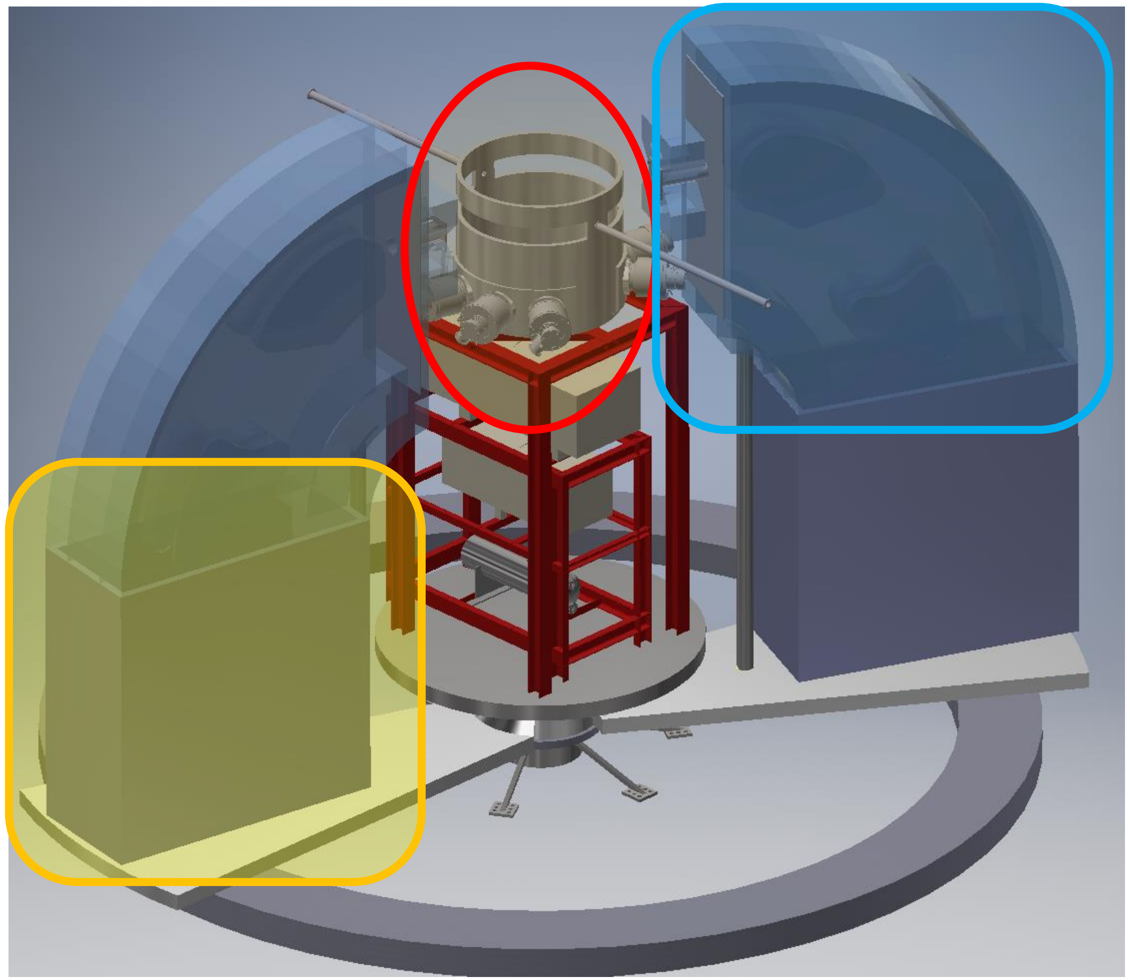
- Windowless gas target
- Integrated recoil silicon detectors
- Forward luminosity monitors

Spectrometers

- Twin Arm Dipole Spectrometer
- Zero-degree tagger spectrometer

Focal Plane Detectors

- GEM-based TPC tracker
- Timestamping trigger



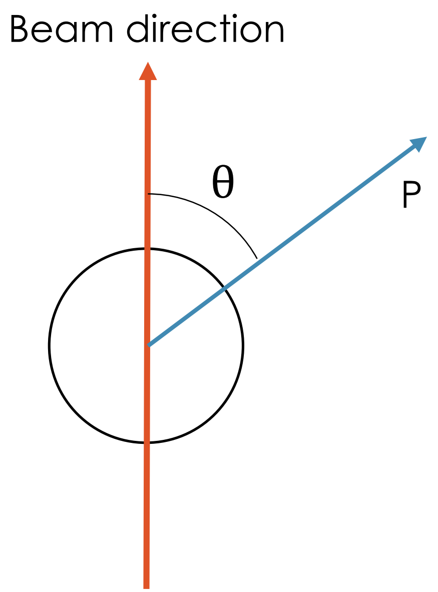
MAGIX PARAMETER SUMMARY

Experimental constraints

- Beam energy (E): 105 MeV
- Beam current (I): up to 1 mA
- Possible beam and target polarization
- Available space: 3-4 m radius around the target
- ERL mode: minimal energy losses in the interaction region ($\frac{dE}{E} < \approx 10^{-4}$)
- Luminosity of the order of $10^{35}\text{cm}^{-2}\text{s}^{-1}$

Basic observables

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



MAGNETIC SPECTROMETERS

Momenta and angles

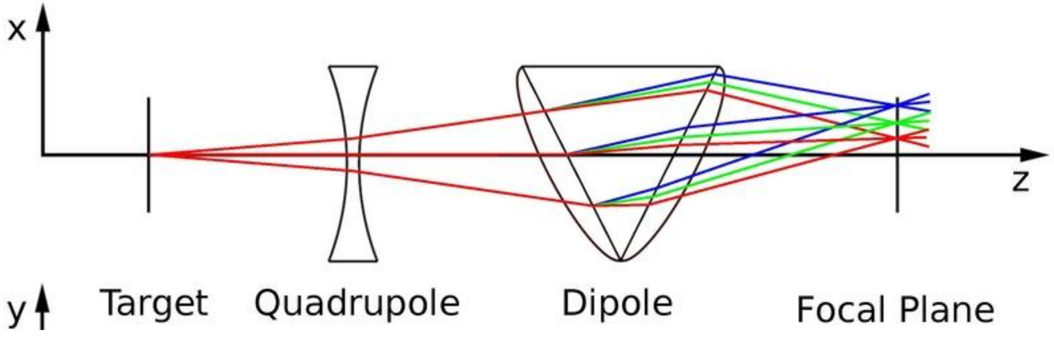
- Linear mapping of momenta to one coordinate in a focal plane
- Mapping of the scattering angles to the second coordinate and angle at the focal plane
- Momenta and angular resolution depend on the magnification properties as well as the detector resolution

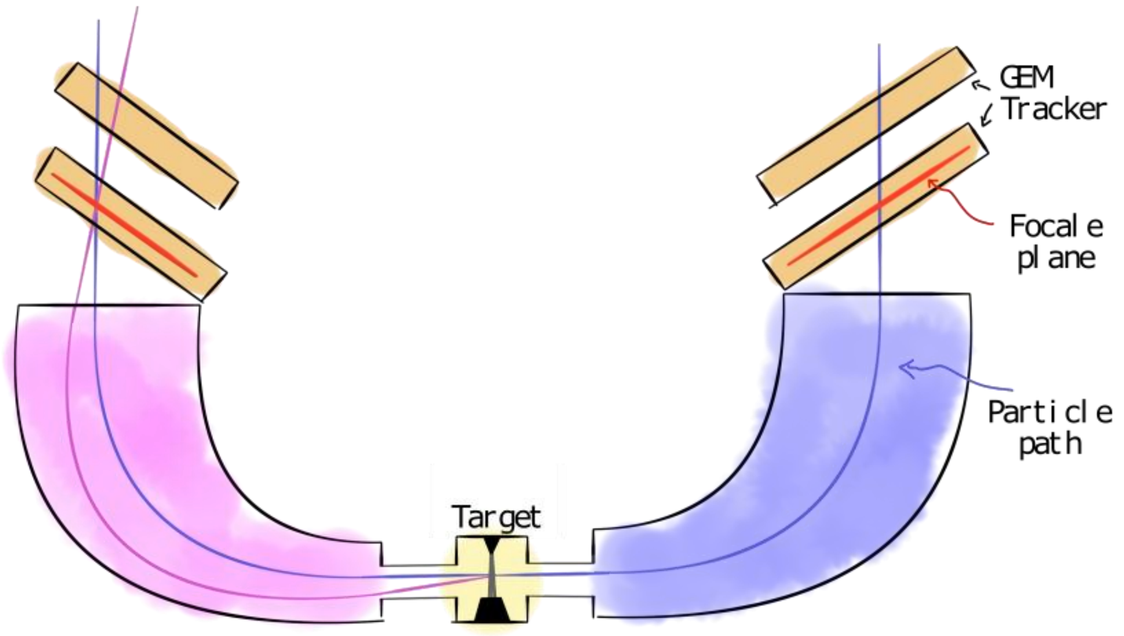
Advantages

- Extremely good momentum and angular resolution

Disadvantages

- Limited geometric acceptance
- Compensated by the high luminosity





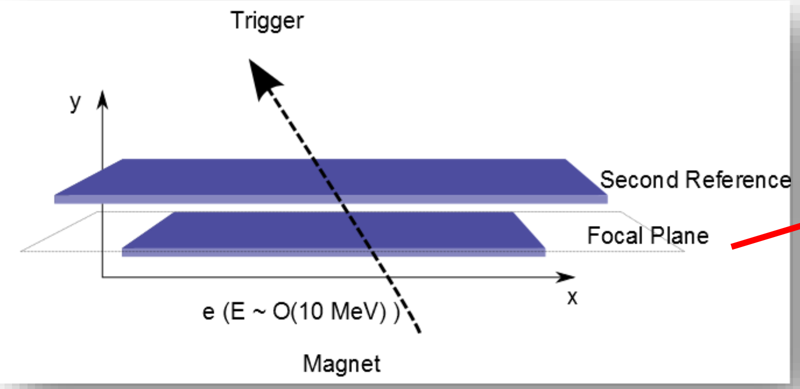
FOCAL PLANE DETECTORS

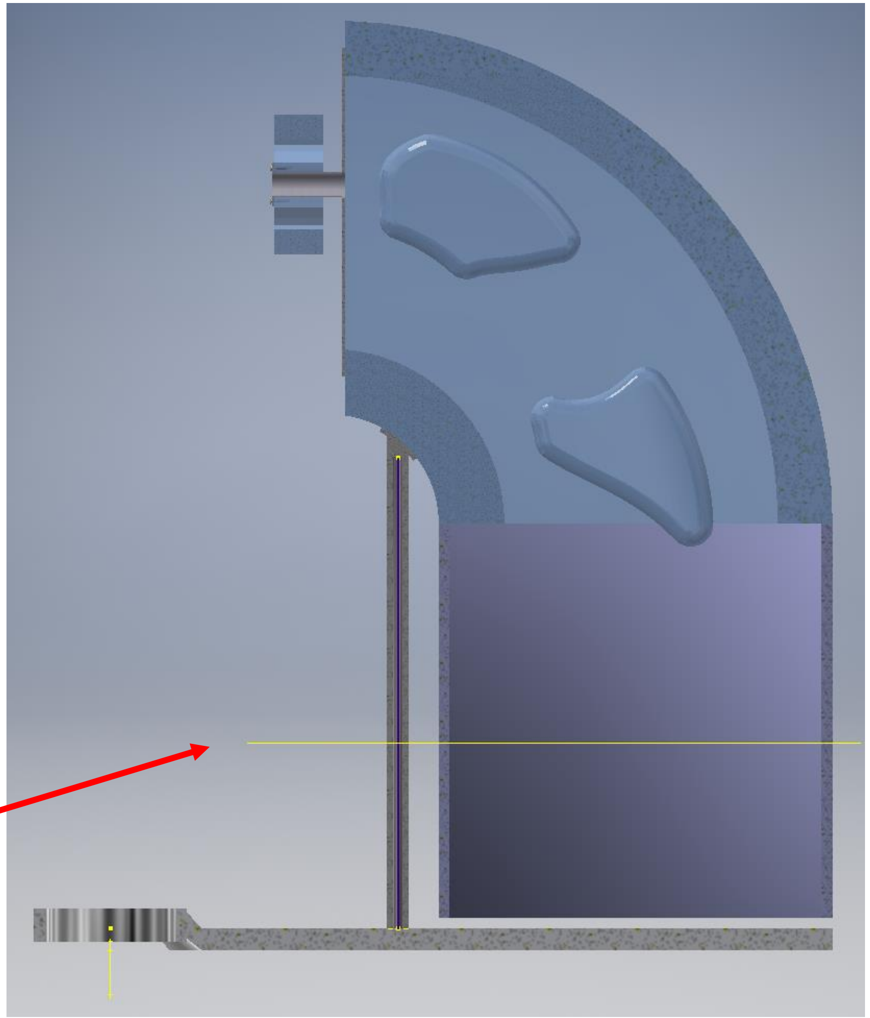
Momentum measurement

- 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: $\approx 100\ \mu\mathrm{m}$

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: $\approx 100\ \mu\mathrm{m}$
- Minimum plane distance: $\approx 10\ \mathrm{cm}$



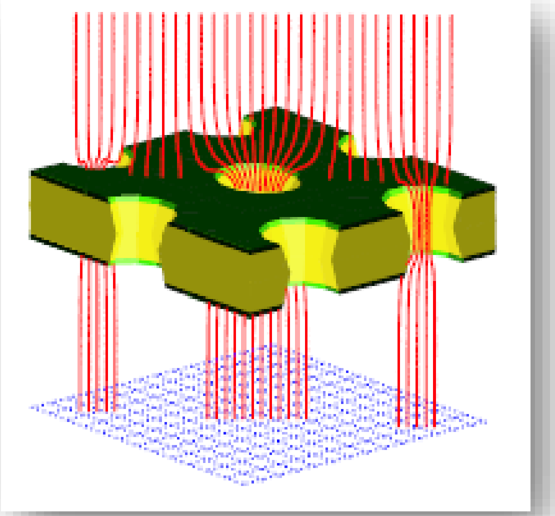


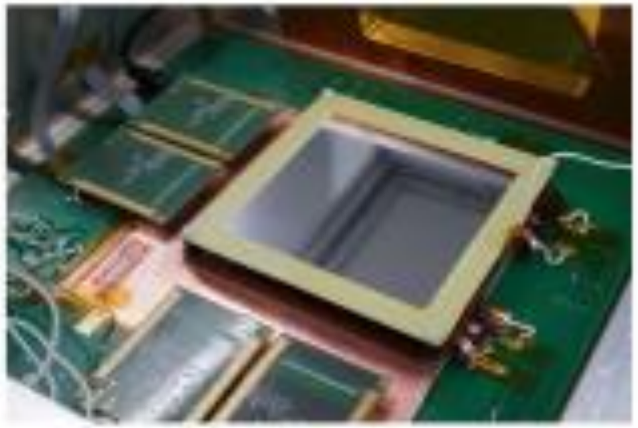
FOCAL PLANE DETECTORS

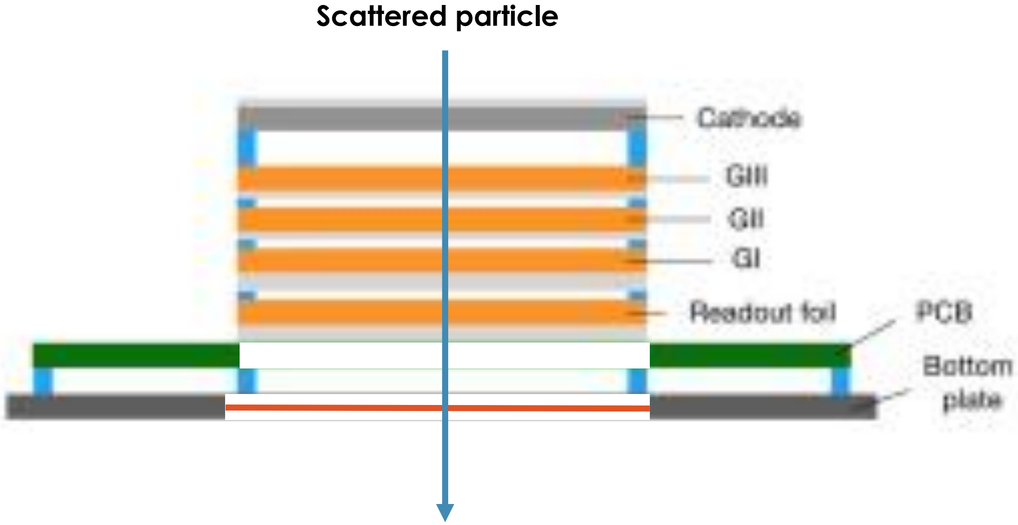
Gas detectors
- Low material budget
- Low cost for large area coverage

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

GEM
- High rate capability
- Good stability at high rate
- Adaptable to many exp. needs

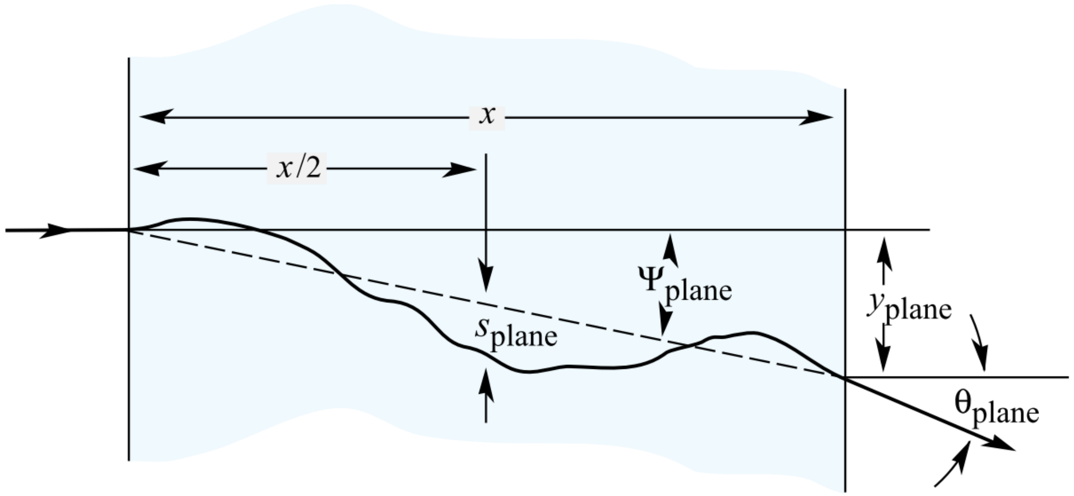






MULTIPLE SCATTERING

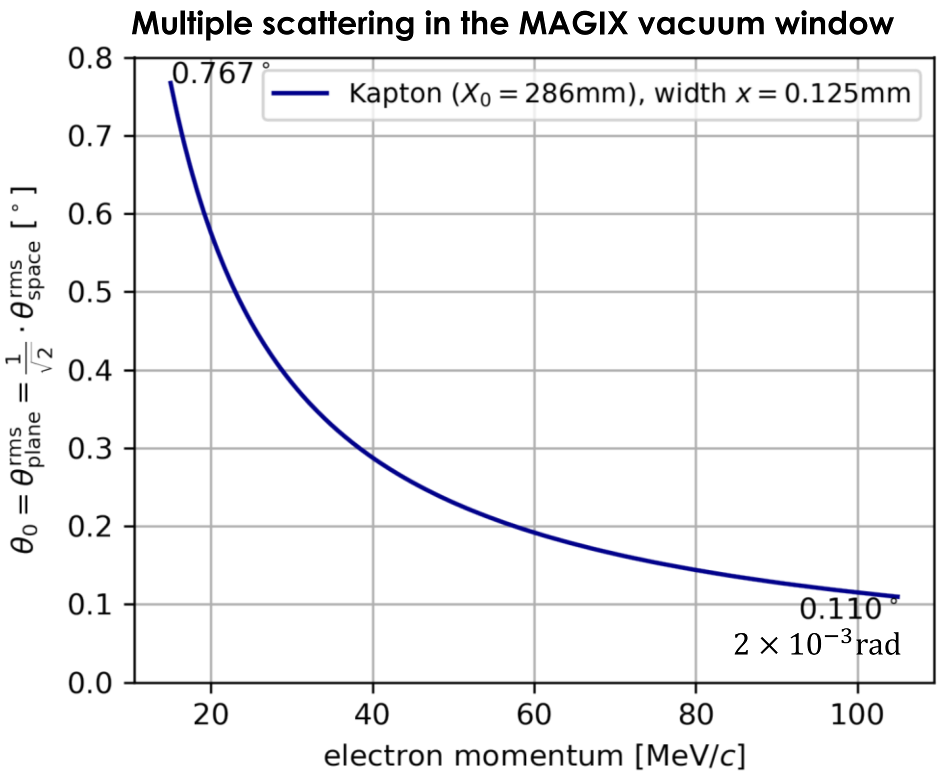
Small uncorrelated deflection of a particle passing through a material



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

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

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



ULTRA-THIN GEM DETECTORS FOR MAGIX

Experimental challenge

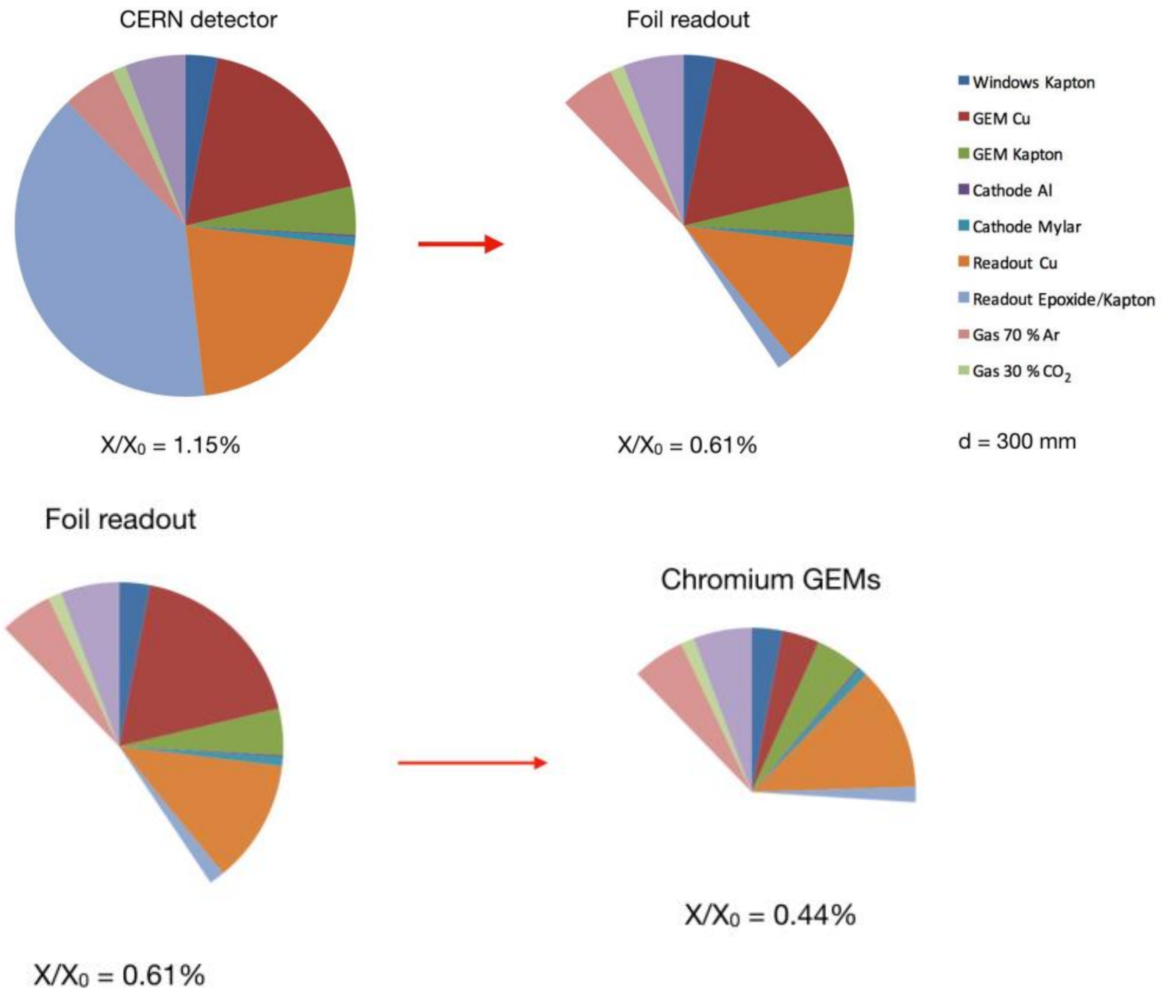
- Minimize the multiple scattering of electrons of 10-100
- Detecting 50 MeV protons

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 $0.61\% \rightarrow 0.44\%\ X_0$



CHROMIUM GEMS RELIABILITY

What is a chromium GEM

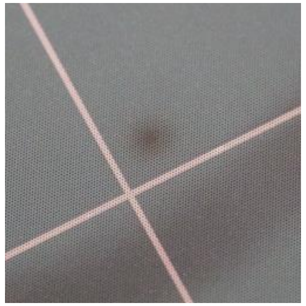
- 100 nm chromium layer always present between copper and Kapton in a standard GEM
- Etch all the copper away. Small copper strips to increase conductivity
- Discharge probability and energy resolution as standard GEMs

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

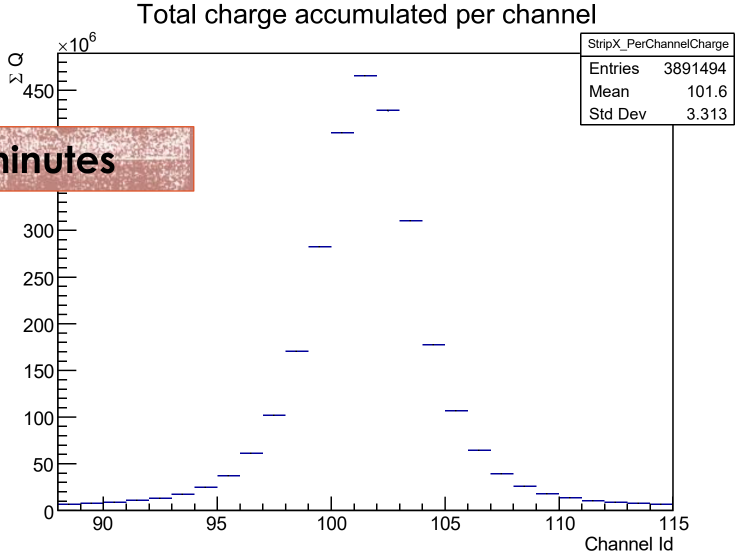


After 1 hour

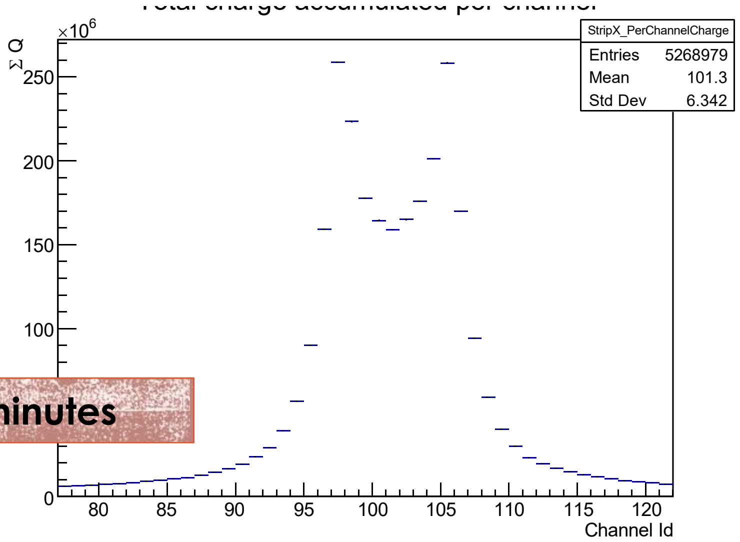
Facing the drift

2MHz electron beam

First 30 minutes



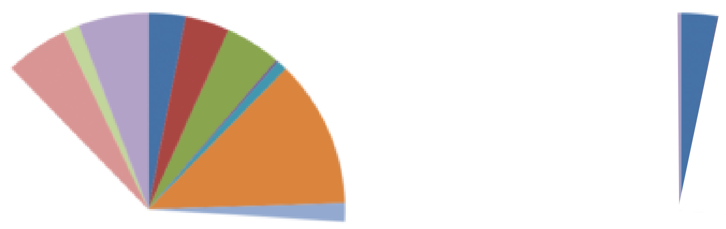
Last 60 minutes



ULTIMATE MATERIAL REDUCTION – WINDOW ONLY

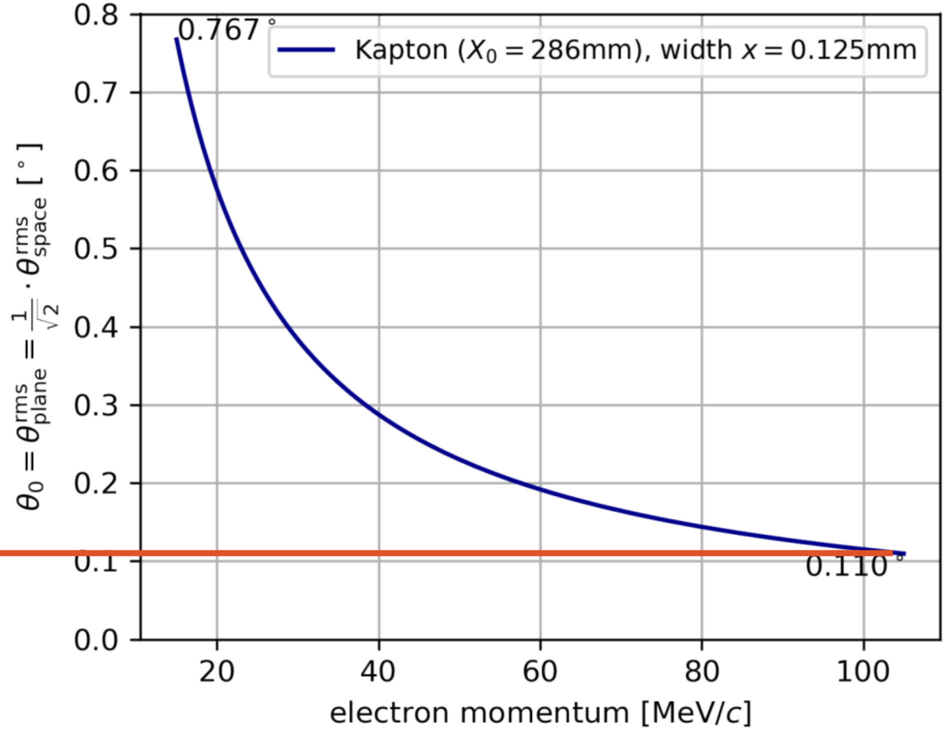
Chromium GEMs

Vacuum foil only



$X/X_0 = 0.44\%$

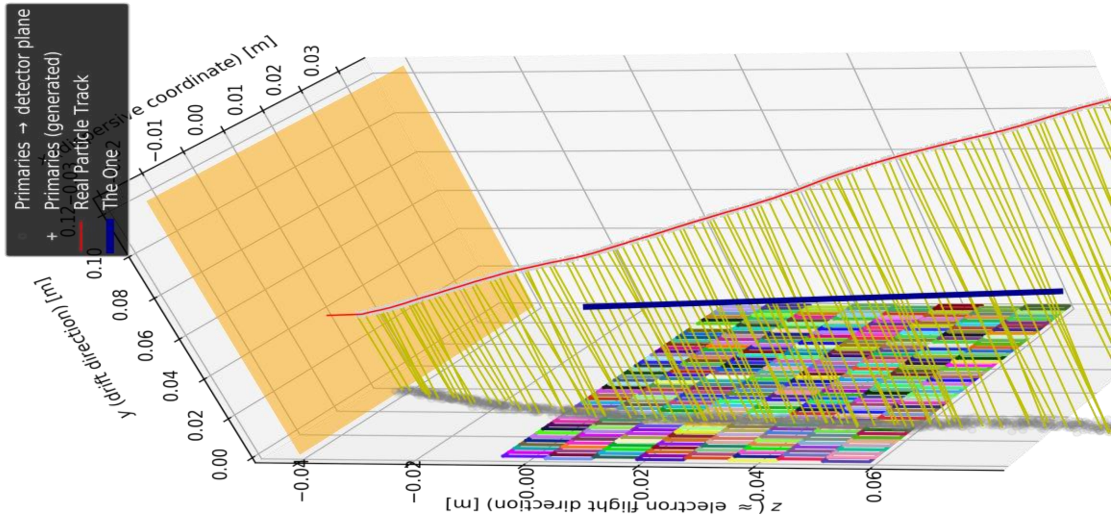
$X/X_0 = 0.04\%$

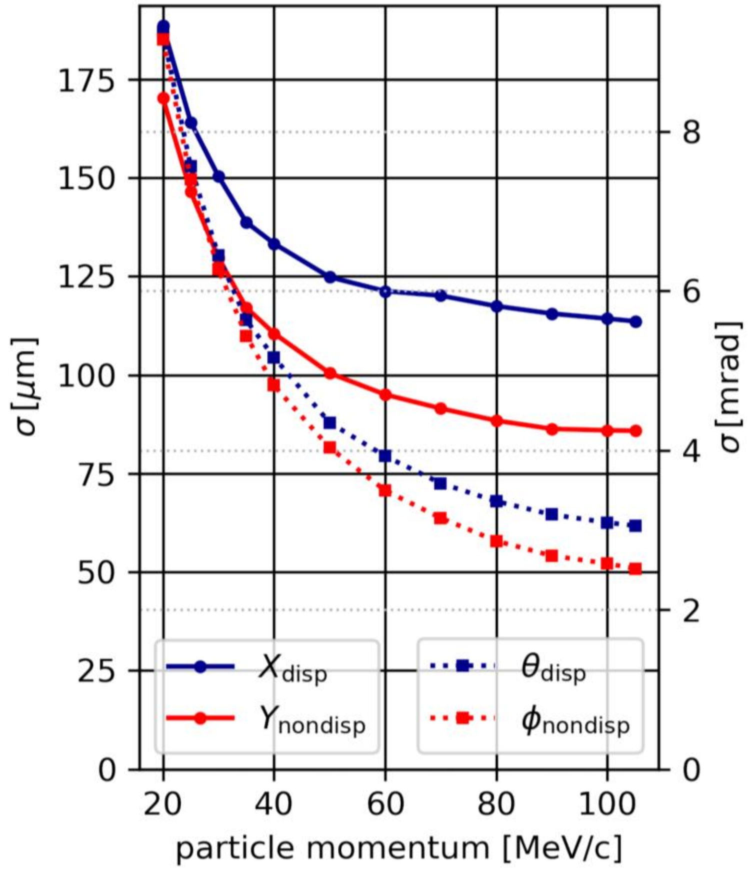


Reduction to essentials

- 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

ULTIMATE MATERIAL REDUCTION – GEM TPC





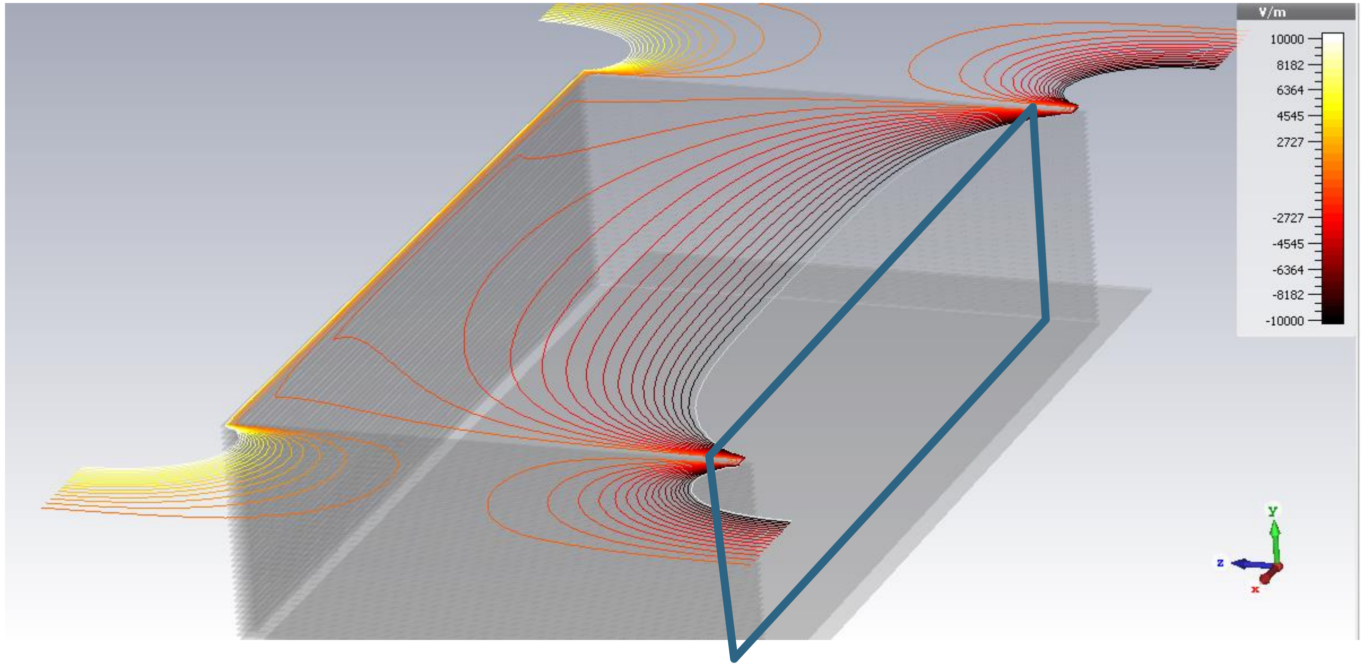
Relevant requirements

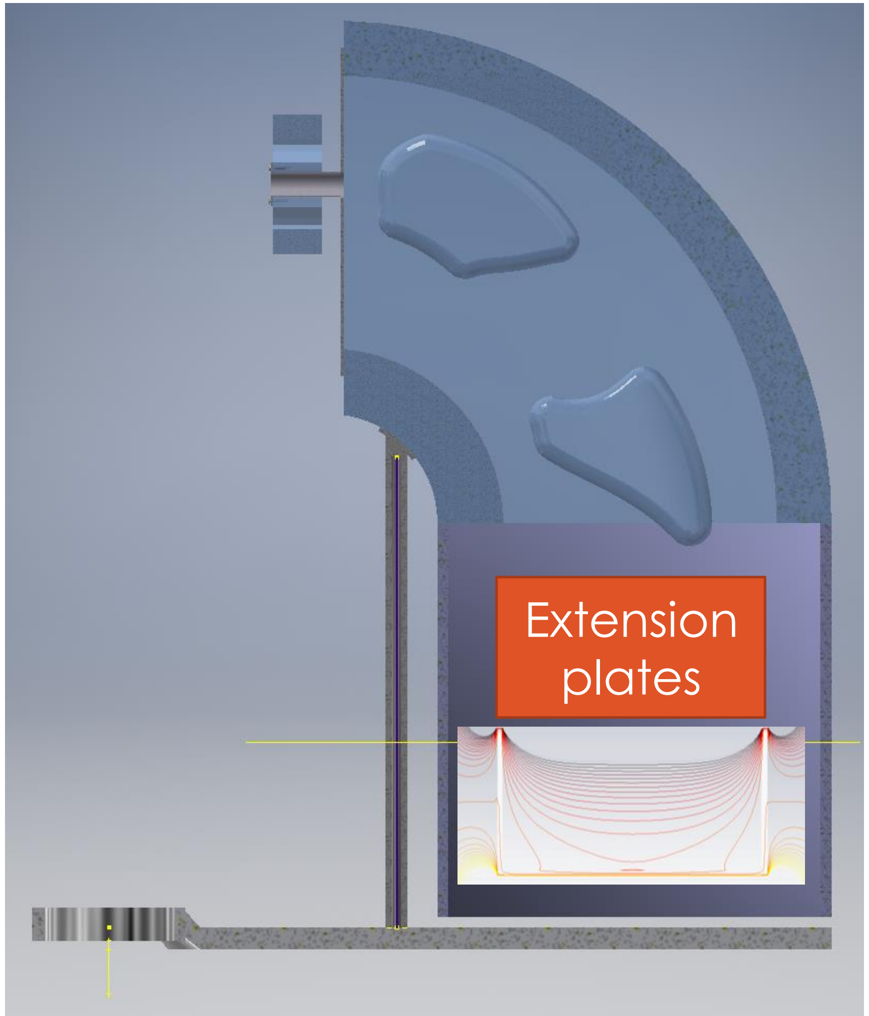
- Focal plane as close as possible to the first sensitive row to limit the lever arm from the source of the MS
- Sensitive volume starting immediately after the vacuum window
- High uniformity of the angle and momentum measurement to limit position dependent position errors

Open field cage

- 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

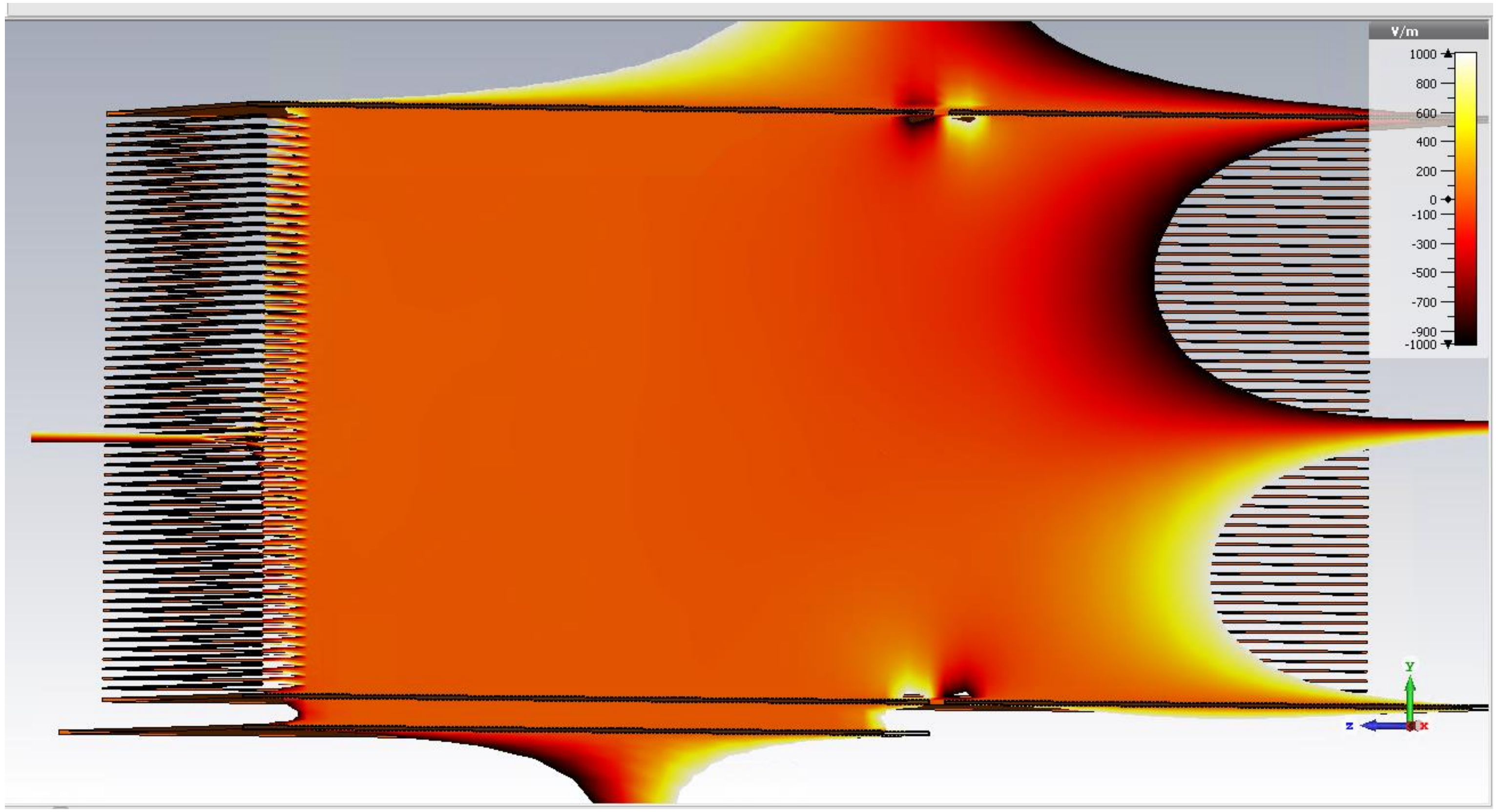
Field cage

- 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



MAIN 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 back-side electronics
- Integrated high-voltage distribution and GEM support system
- Integration with the field cage to be defined

Cathode

- Independent field plate that can be aligned with the anode
- Integrates an emission pattern to use in the detector calibration

Other features

- 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

DEVELOPMENT PLANS

Small prototype

- $10x10\ cm^2$ sensitive surface, 7 cm drift length
- Traditional field cage with variable spacing
- Only a new readout board is needed to build this detector. Modular design that can be extended to larger surfaces
- VMM compatible detector interface
- Test-beam planned 8-11 November 2018 at MAMI in Mainz (more in WG5 session)

Small prototype goals

- Build a simple benchmark prototype to be easily used at test-beams and in the laboratory
- Test the quality of the readout board and validate the usage of the VMM for such a detector

Large prototype and validation

- $30x30\ cm^2$ sensitive area, 15 cm drift length with thin field cage and extension module
- Measure distortions, establish calibration procedure, test all the necessary technologies
- First results need to be available by June 2019

BACKUP

REQUIREMENTS

Limited material thickness

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

High luminosity

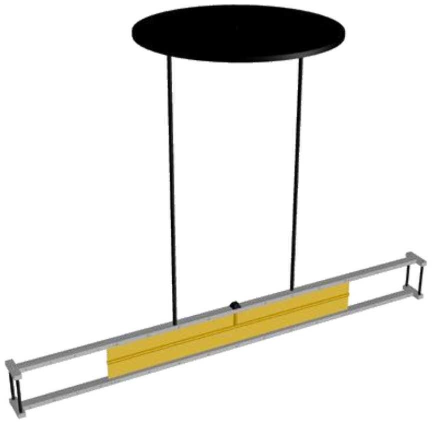
- Target luminosity $10^{35} \text{cm}^{-2} \text{s}^{-1}$ @ 1mA
- Target thickness 10^{19} cm^{-2}

Gas polarization

- Optional requirement for some process

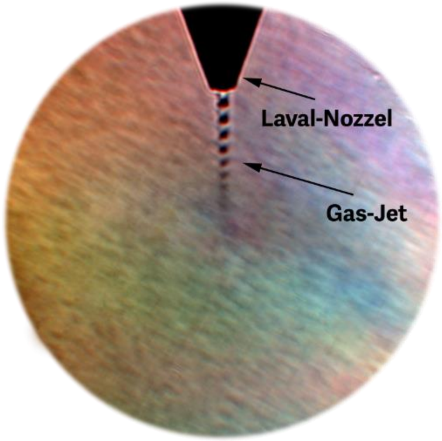
Flowing gas tube

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



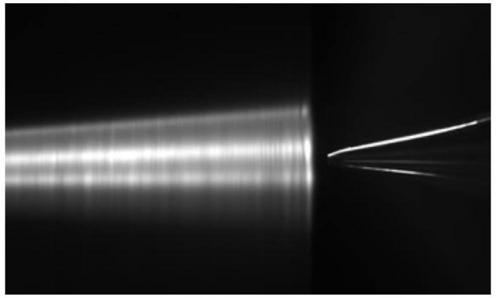
Supersonic jet

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

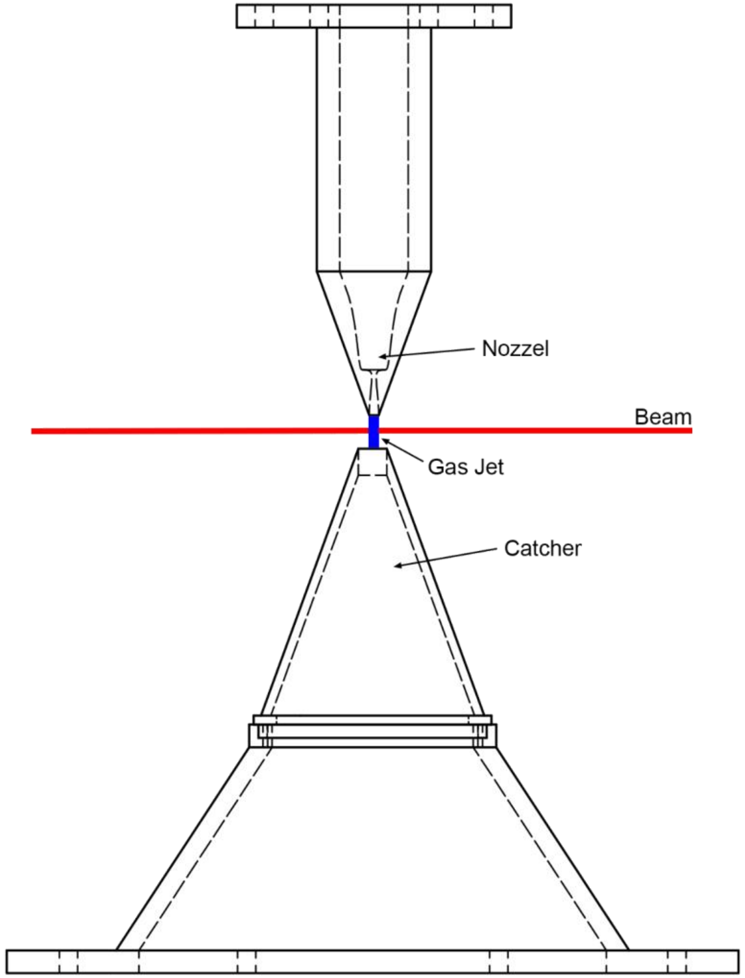


Cluster-Jet

- 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