SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

FROM QUARKS AND GLUONS TO HADRONS AND NUCLEI

PRECISE MAGIX

Challenges and opportunities for precision physics with the MAGIX experiment at MESA

MAGIX IN THE SFB1044

A multipurpose experiment for MESA

- Versatile experimental program using the 105 MeV MESA beam
- Includes dark photon searches whether it decays visibly or not

An internal (gas) target system

- Crucial to reduce backgrounds and systematics in the MESA energy range
- Allows to use MESA energy recovery mode

A GEM based focal plane detector

- A large area, high accuracy, ultra-thin detector
- Keystone to precision physics in this experimental environment

Project P1

Preparation of the internal target experiment MAGIX at MESA

A recent search for the dark photon at A1/MAMI was able to set stringent limits for the existence of this hypothetical particle. Since the mass region below 50 MeV is not accessible at MAMI **a new multi-purpose spectrometer, MAGIX**, will be developed and used to **search for dark photons** in this mass region. MAGIX will operate as the **internal target setup** at the new MESA accelerator. Within project P1 we will develop **a GEM-based focal plane detector** for MAGIX.

MAINZ ER SUPERCONDUCTIVE ACCELERATOR

Multi-turn, superconducting ERL

Energy recovery mode

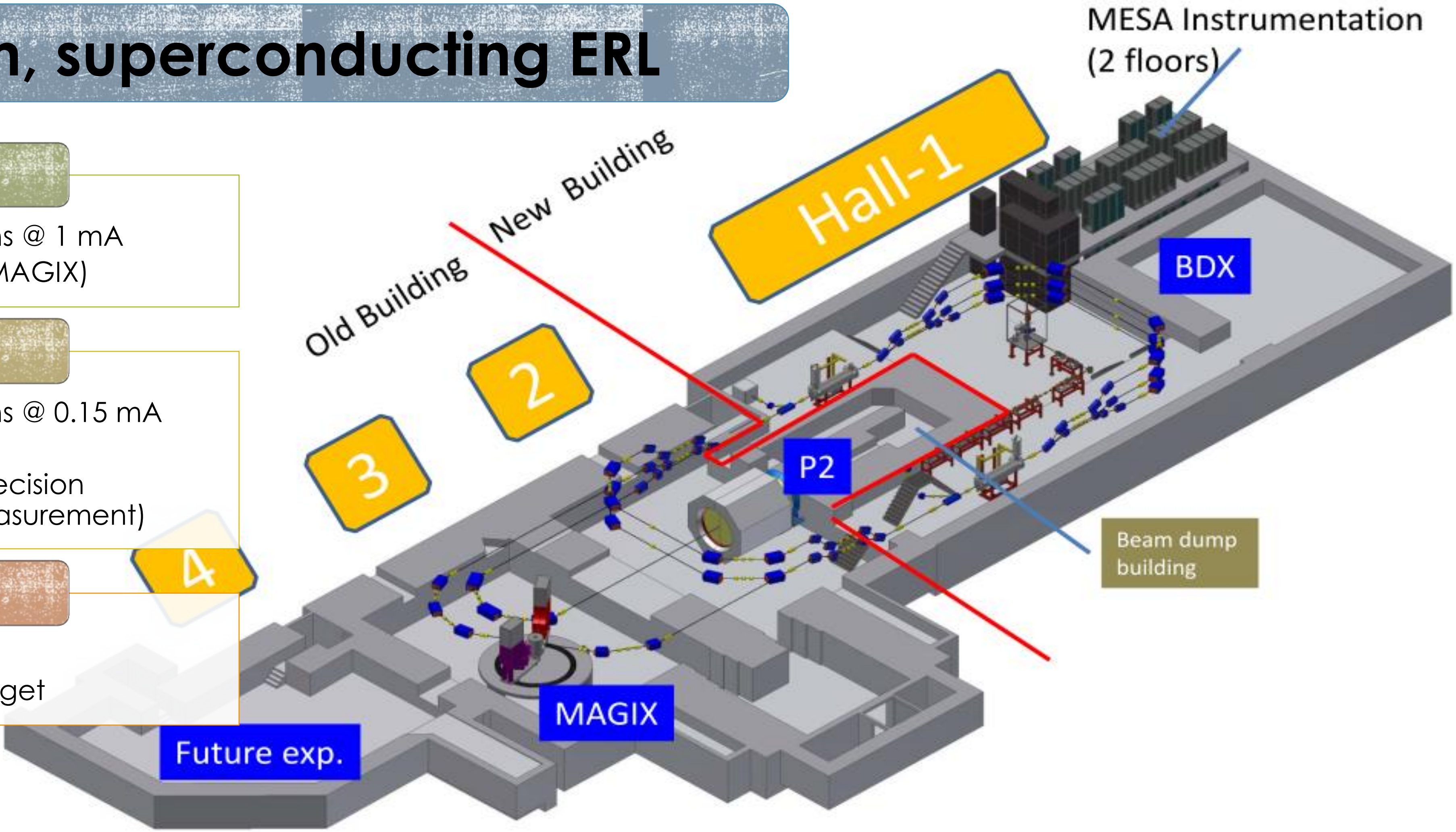
- 105 MeV polarized electrons @ 1 mA
- Internal target scattering (MAGIX)

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



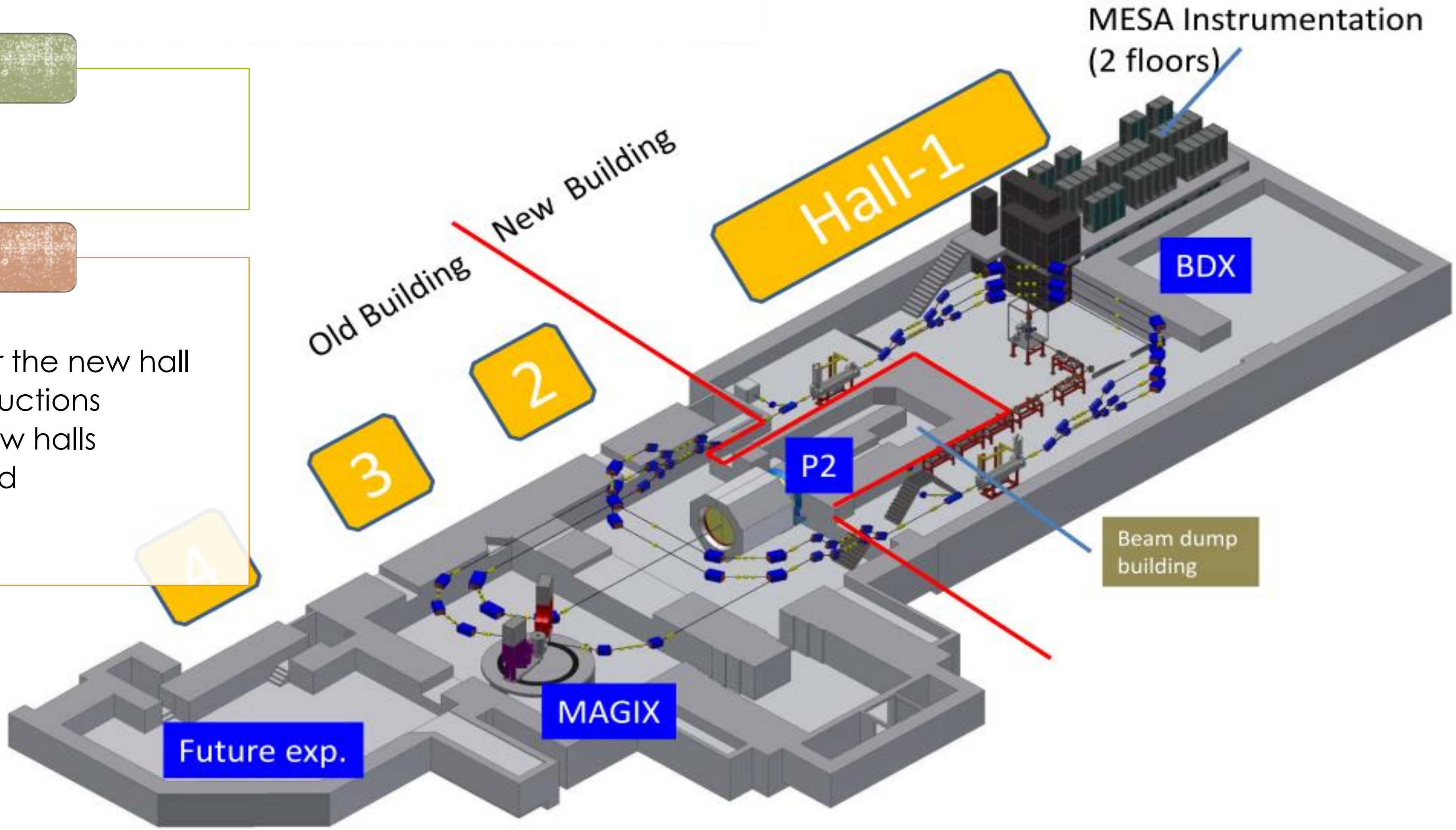
MESA SCHEDULE

Additional extension hall

- More space
- Delayed schedule

Construction schedule

- 2017 Ancillary buildings
- 2018 Ground breaking for the new hall
- 2019 Underground constructions
- 2020 Hand over of the new halls
- 2021 MESA installation and commissioning
- 2022 Start of operation



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

PRECISION PHYSICS WITH MAGIX

Experimental constraints

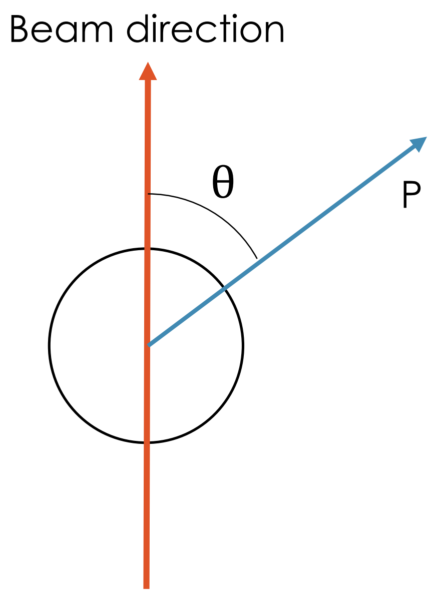
- Beam energy (E): 105 MeV
- Beam current (I): up to 1 mA
- Available space: 3-4 m radius around the target
- ERL mode: minimal energy losses in the interaction region ($\frac{dE}{E} < \approx 10^{-4}$)

Basic observables

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

Statistics

- Luminosity: $I \times \rho \times L$ ← Target thickness
- Geometric acceptance
- Detector efficiency



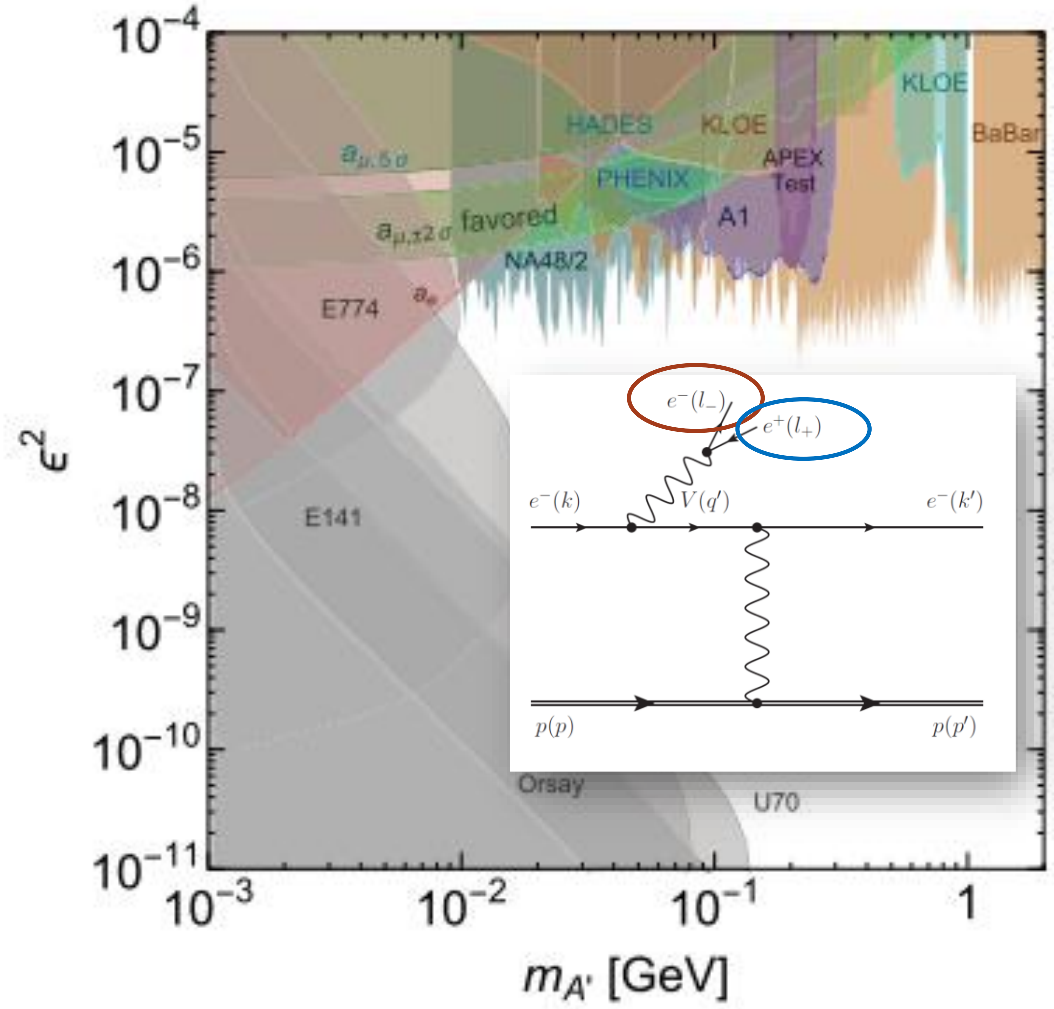
LUMINOSITY REQUIREMENTS: DP CASE

Cross-section

- $\sigma \approx \epsilon^2 \times \sigma_{QED}$
- σ_{QED}@100 MeV $\approx \mathcal{O}$(1 mb)
- $\epsilon \approx 10^{-4}$
- $\sigma \approx 10$ pb

Luminosity

- To have rates of the order of 1 Hz we need a luminosity of the order of $10^{35}\text{cm}^{-2}\text{s}^{-1}$



THE MAGIX TARGET

REQUIREMENTS

Limited material thickness

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

High luminosity

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

Gas polarization

- Optional requirement for some process

Flowing gas tube

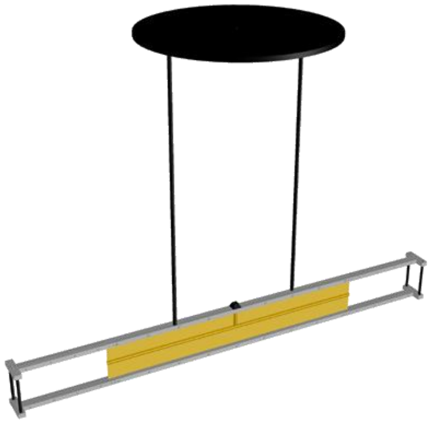
- 30 cm open mylar tube
- Usable for polarized gases
- Lower luminosity

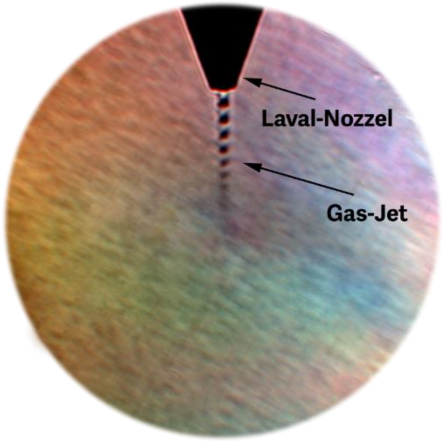
Supersonic jet

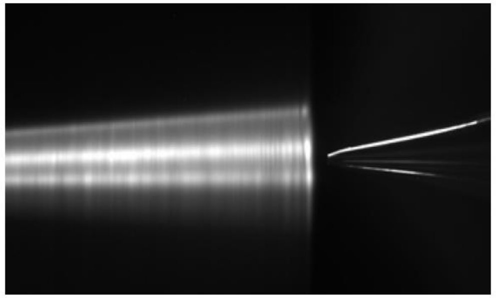
- 2 mm wide jet stream in vacuum
- 10^{19}atoms / cm^2

Cluster-Jet

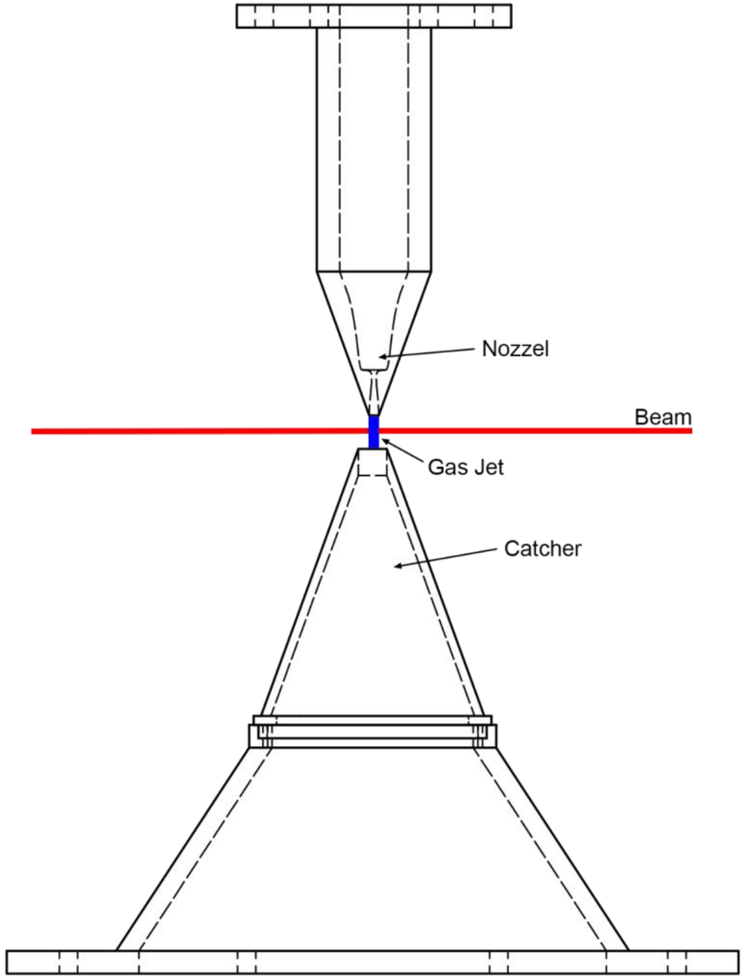
- Molecular clustering @ 40K
- Increase self-containment







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

Angular measurement

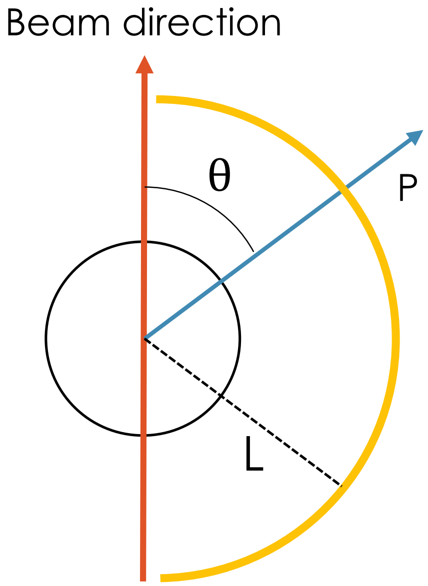
- Define the required angular resolution, e.g 10^{-3}rad
- Position resolving detector at distance L from the interaction point

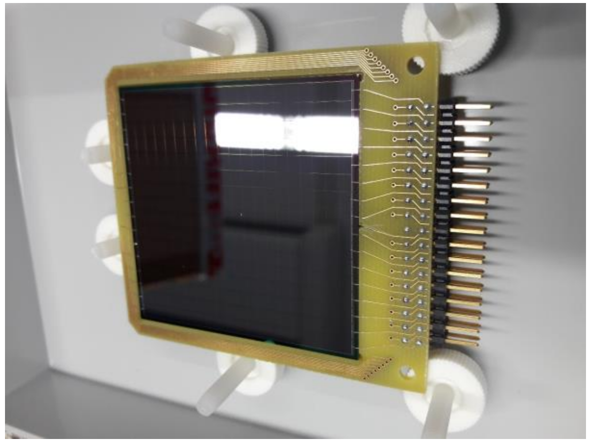
Coarser or closer?

- Lower resolution → larger distance → larger surface → greater costs

Magix recoil detectors

- Measure the direction of scattered nucleons with kinetic energy lower than 100 keV
- Multichannel silicon strip detector inside the scattering chamber ($L \approx 30$ cm)





E or P measurement

- Define the required resolution, e.g $\frac{\delta P}{P} 10^{-4}$
- Calorimetry not good enough at low energy
- Measure the particle curvature in a magnetic field
- The magnetic field cannot deflect the beam which should be recaptured

MAGNETIC SPECTROMETERS

An optical analogy

- A microscope with a prism
- Image magnification and wavelength dispersion

Momenta and angles

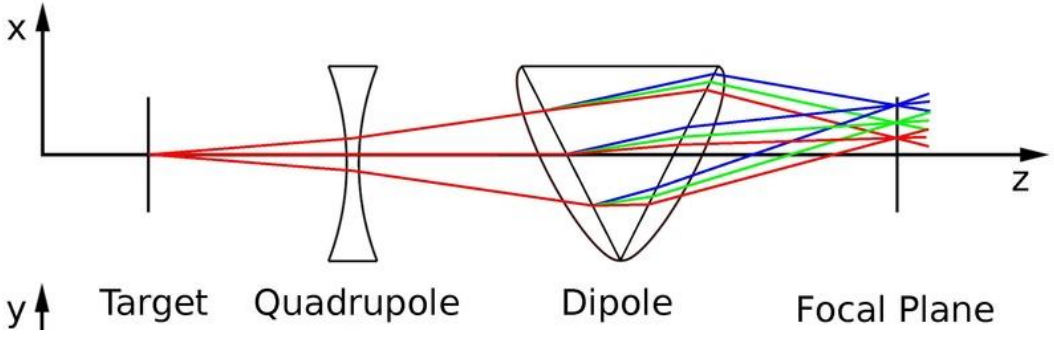
- Linear mapping of momenta to one coordinate in a focal plane
- Mapping of the scattering angles to the second coordinate and angle at the focal plane
- Momenta and angular resolution depend on the magnification properties as well as the detector resolution

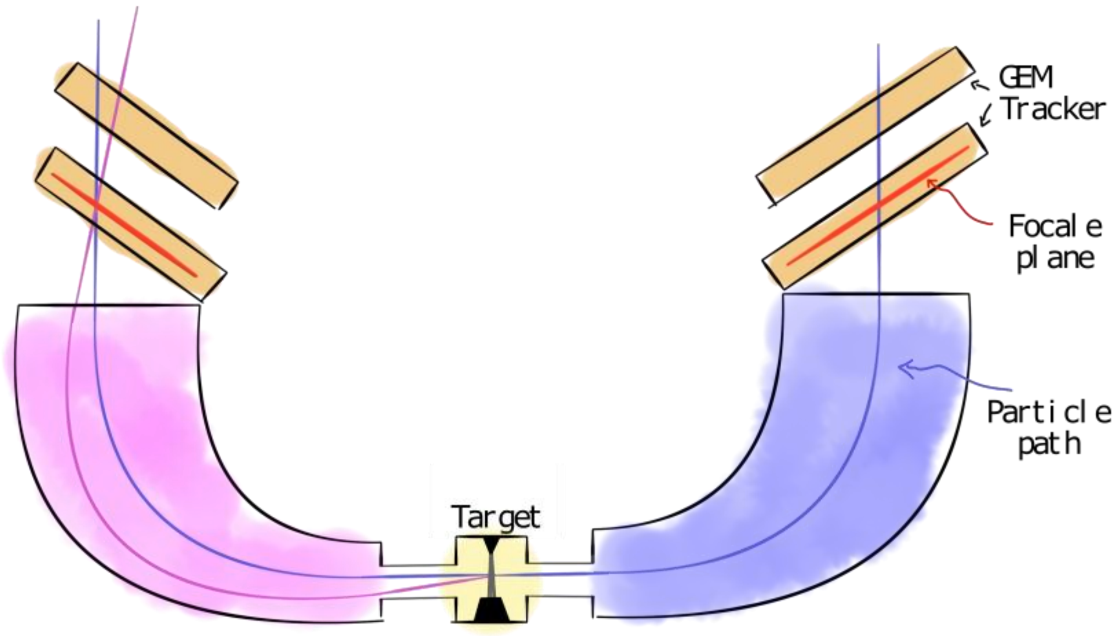
Advantages

- Extremely good momentum and angular resolution

Disadvantages

- Limited geometric acceptance
- Compensated by the high luminosity





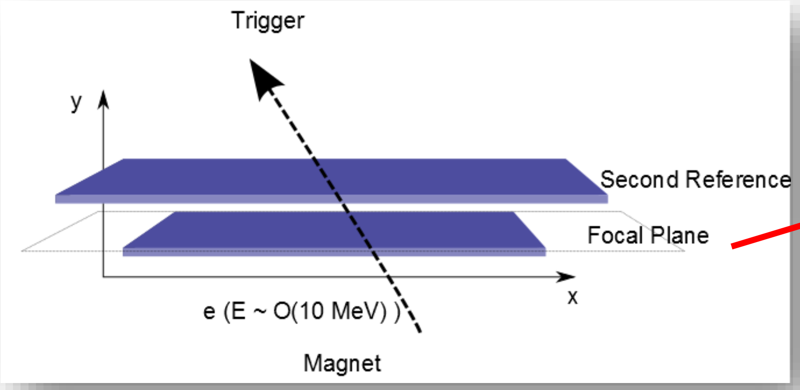
FOCAL PLANE DETECTORS

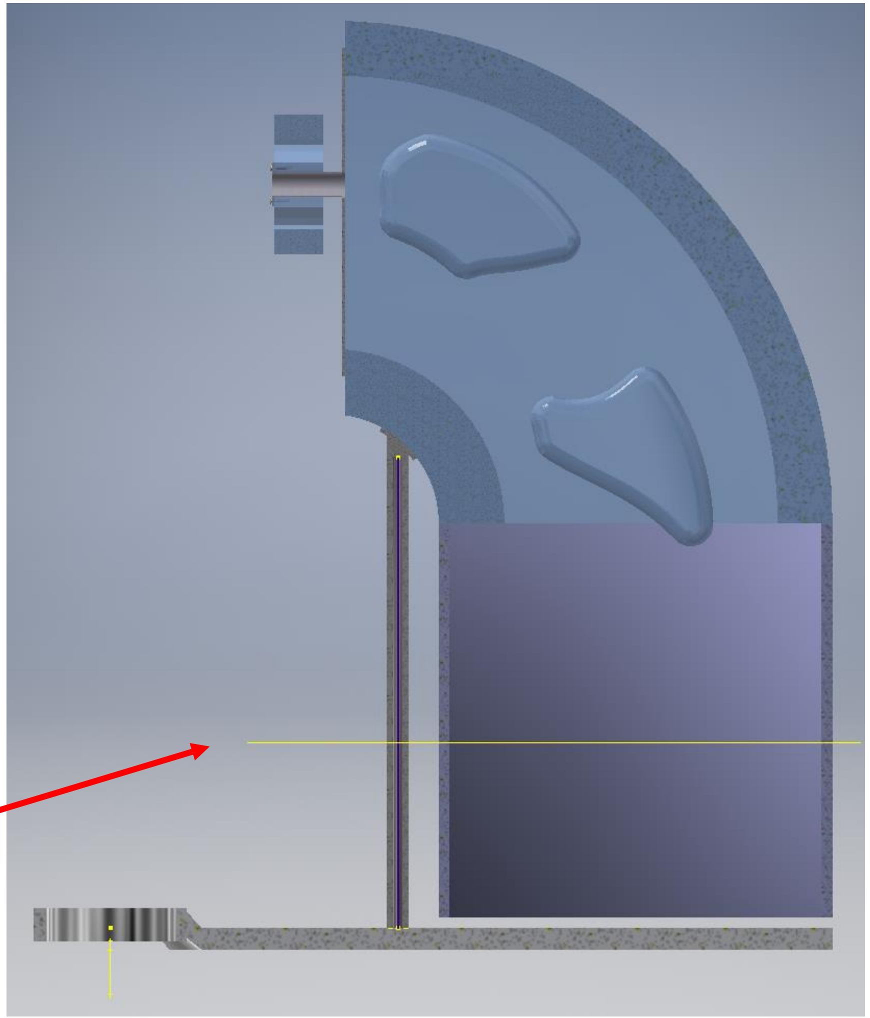
Momentum measurement

- 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: $\approx 10\ \mathrm{cm}$



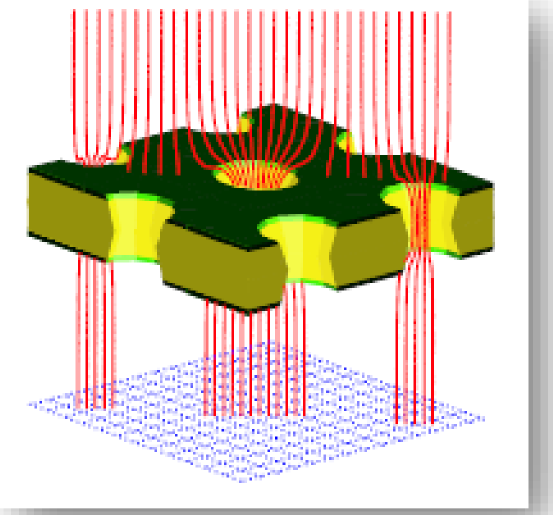


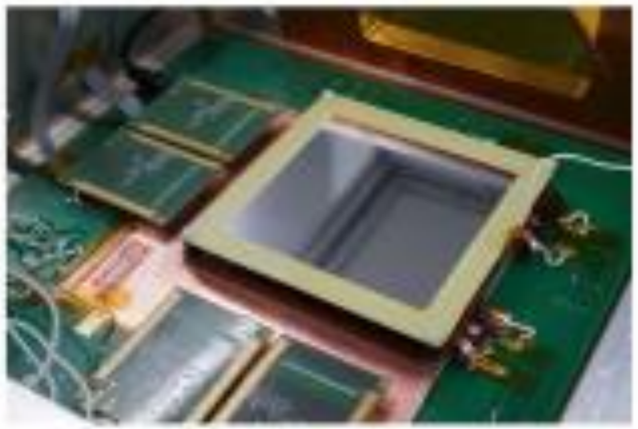
FOCAL PLANE DETECTORS

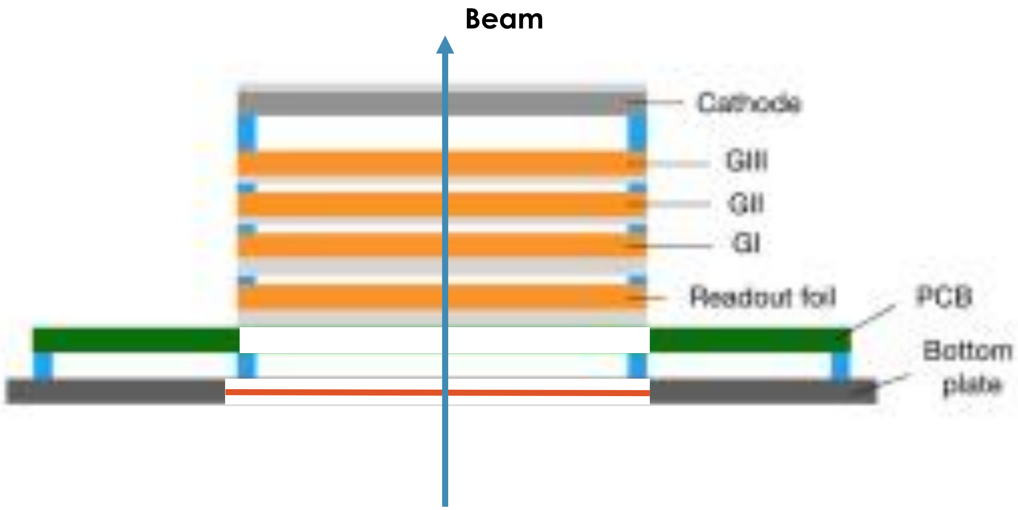
Gas detectors
- Low material budget
- Low cost for large area coverage

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







GAS ELECTRON MULTIPLIERS

Mechanical structure

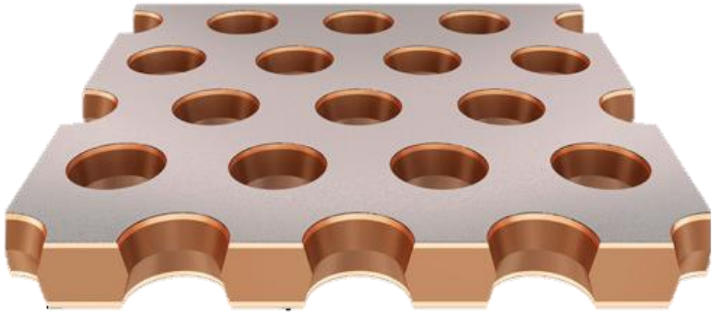
- Dielectric foil (Kapton) coated with a conductive material (Copper)
- Chemically etched holes in the foils

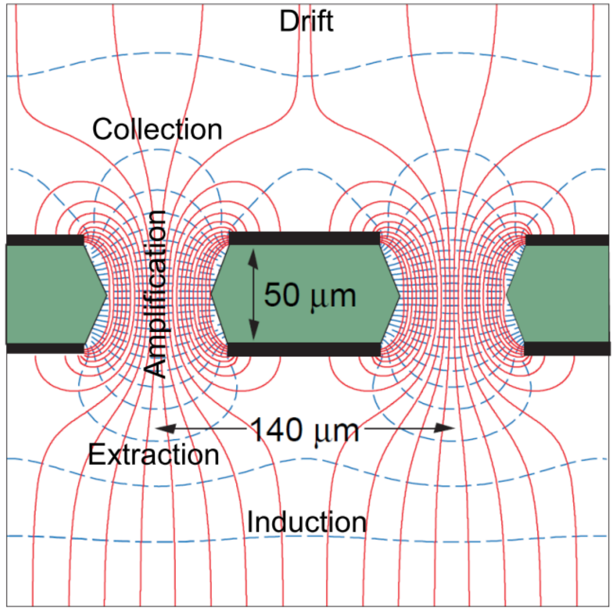
Electrical features

- Parallel plate capacitor pierced by many holes
- Characteristic structures size of $\mathcal{O}(100\ \mu m)$
- Field distortions of the same magnitude

Physical characteristics

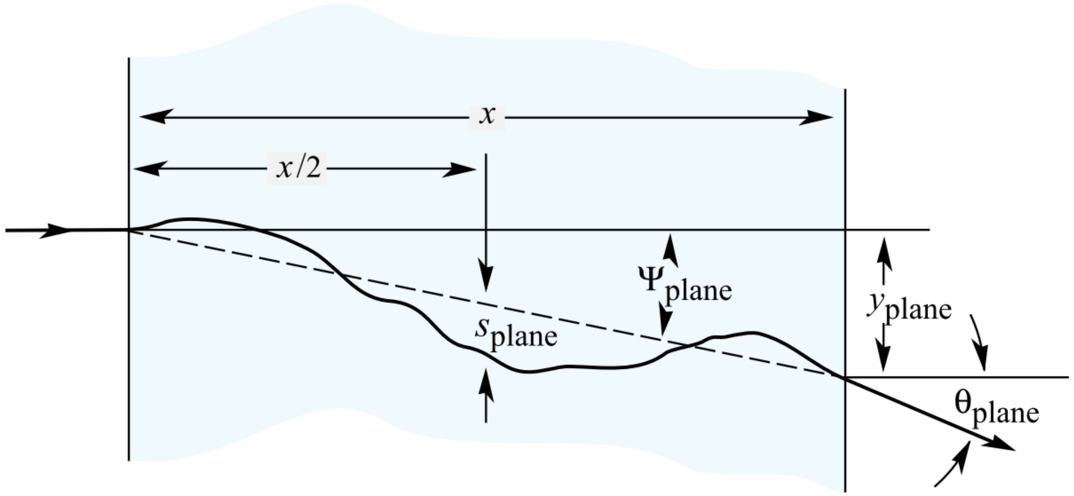
- Gas amplification localized in the holes
- Single layer gain of the order of 100





MULTIPLE SCATTERING

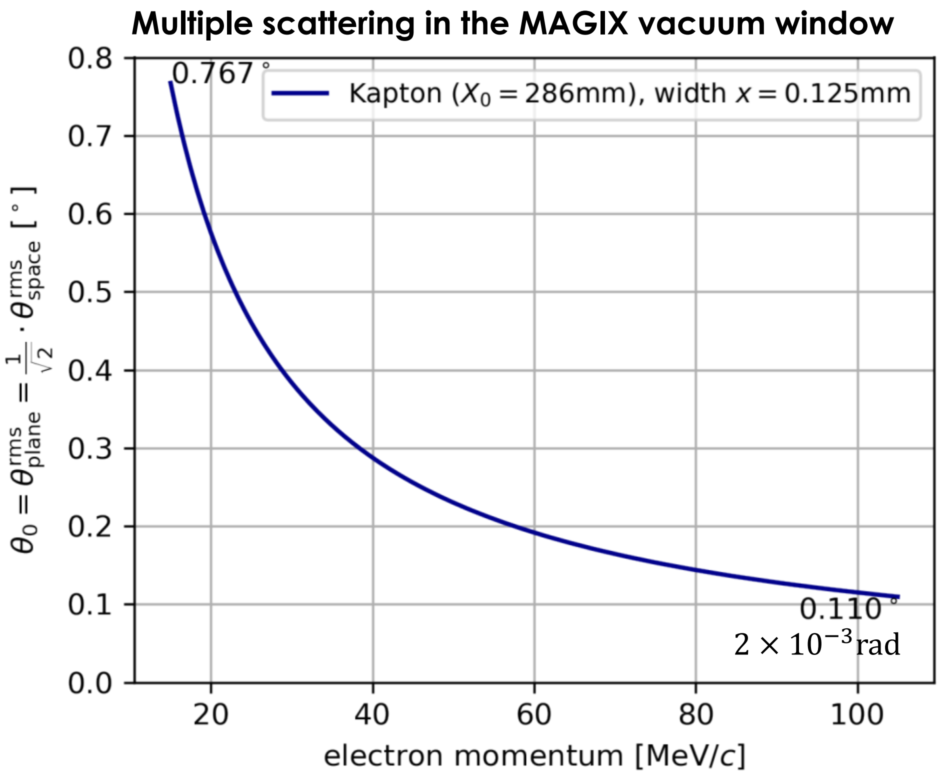
Small uncorrelated deflection of a particle passing through a material



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

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

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



ULTRA-THIN GEM DETECTORS FOR MAGIX

Experimental challenge

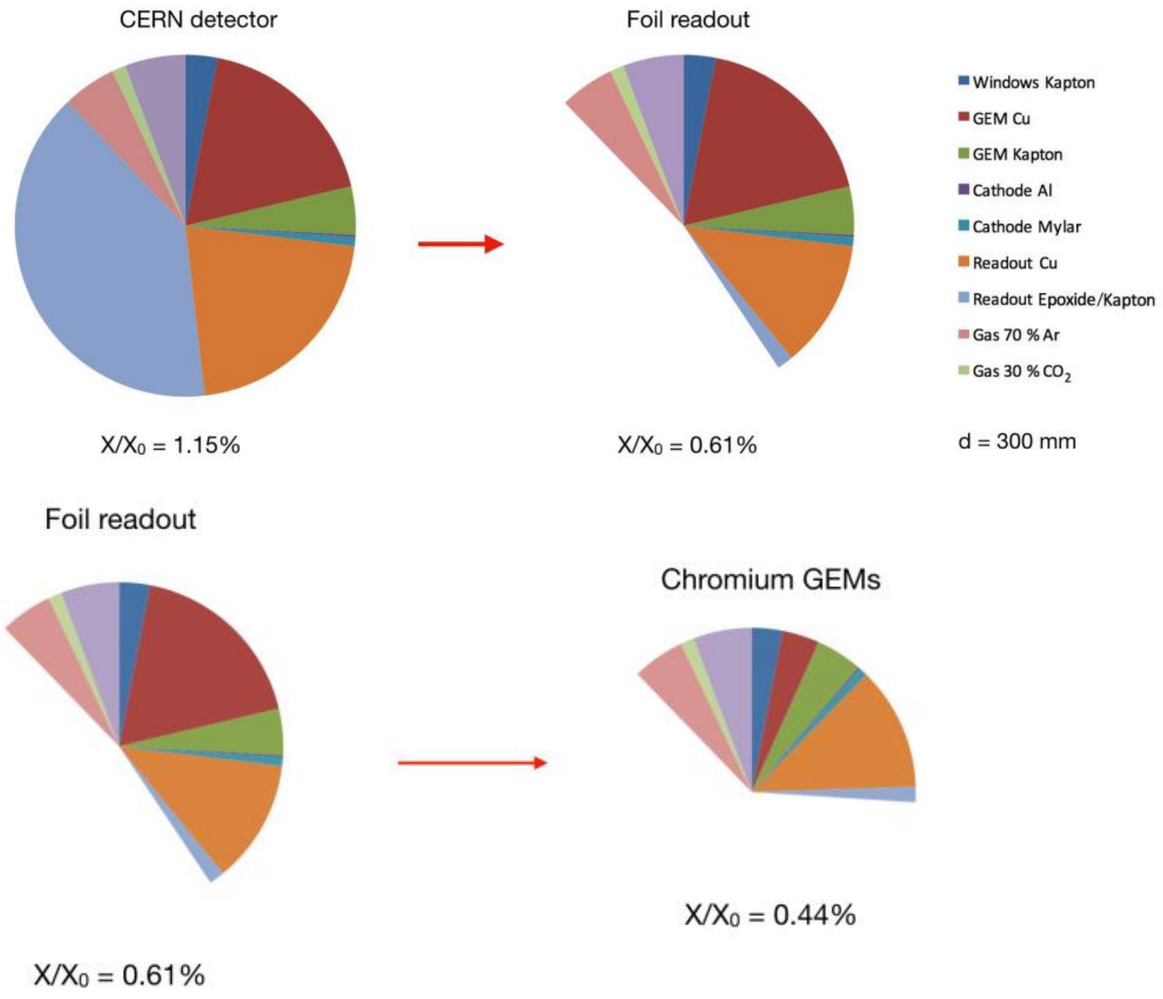
- Minimize the multiple scattering of electrons of 10-100
- Detecting 50 MeV protons

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

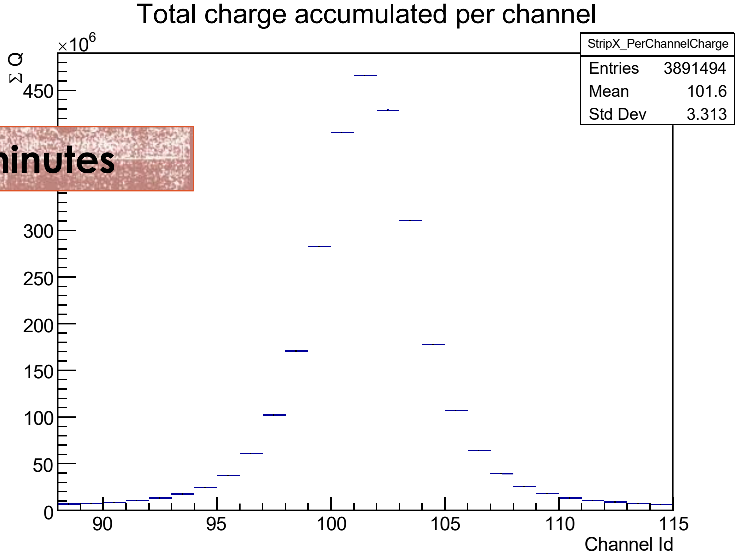
- 100 nm chromium layer always present between copper and Kapton in a standard GEM
- Etch all the copper away. Small copper strips to increase conductivity
- Discharge probability and energy resolution as standard GEMs
- Higher gain than normal GEMs (to be investigated further)

The long term reliability issue

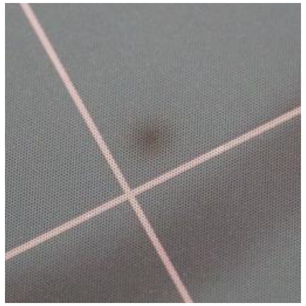
- Measured efficiency drop by other groups as a function of accumulated charge
- How long can we efficiently use a chromium GEM in the different stack layers in beam conditions?

MAMI test-beam (Nov 2017)

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



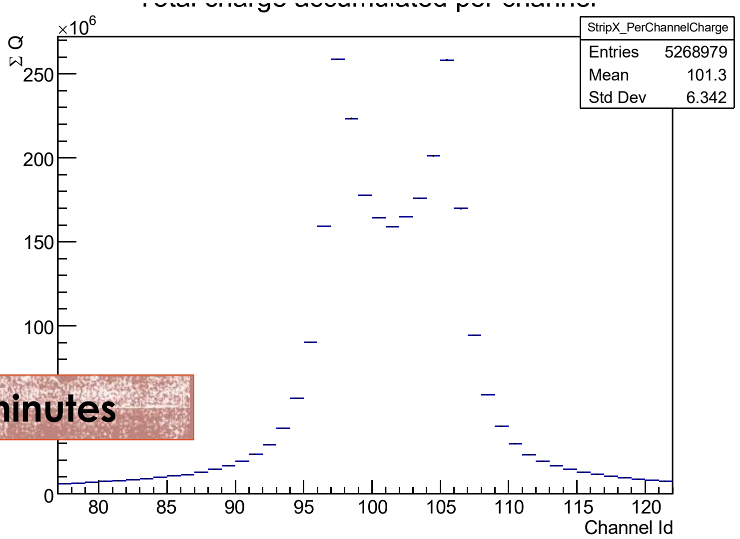
First 30 minutes



After 1 hour

Facing the drift

2MHz electron beam

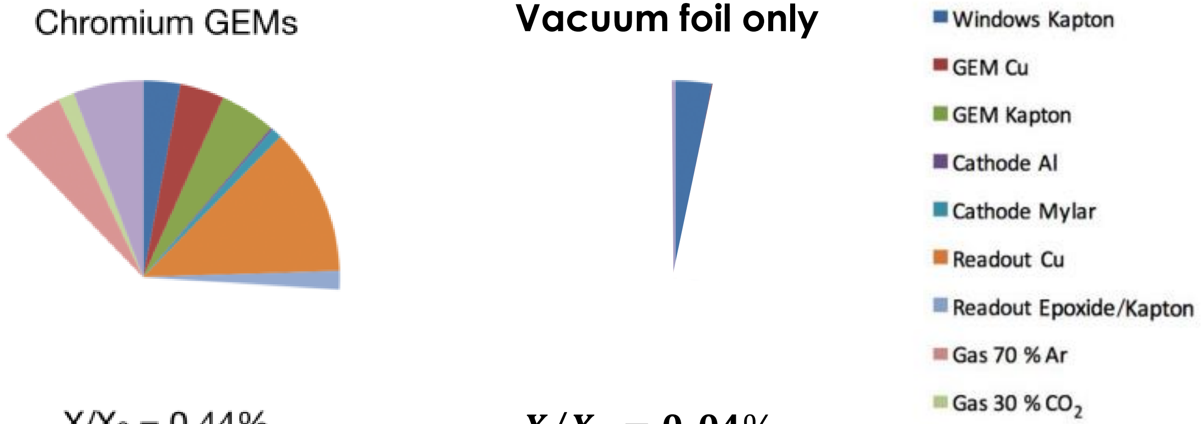


Last 60 minutes

ULTIMATE MATERIAL REDUCTION – FOIL ONLY

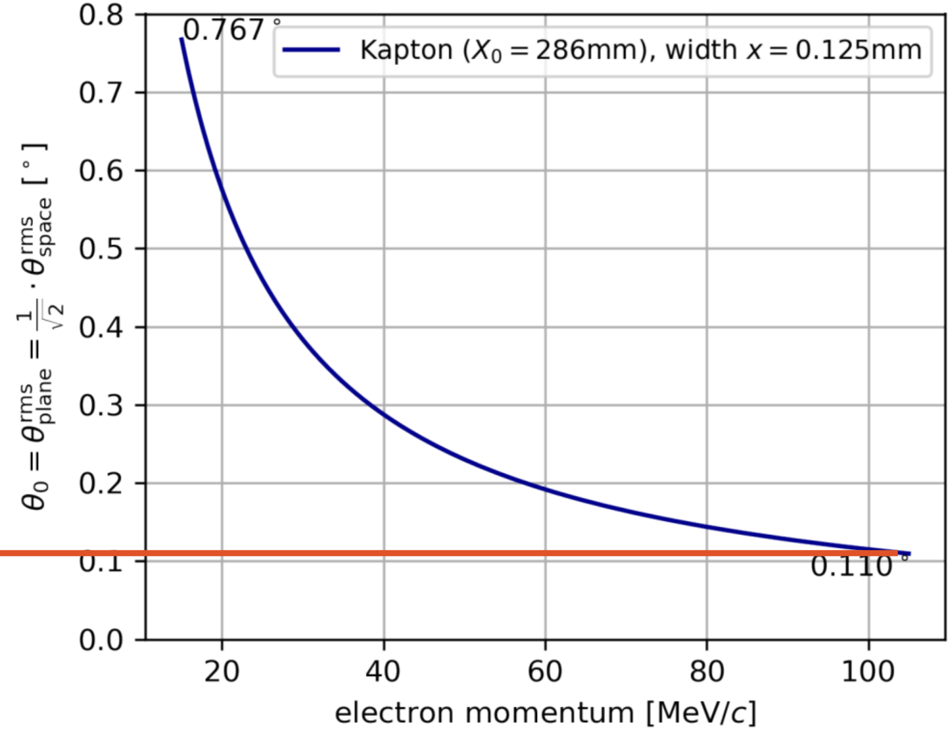
Chromium GEMs

Vacuum foil only



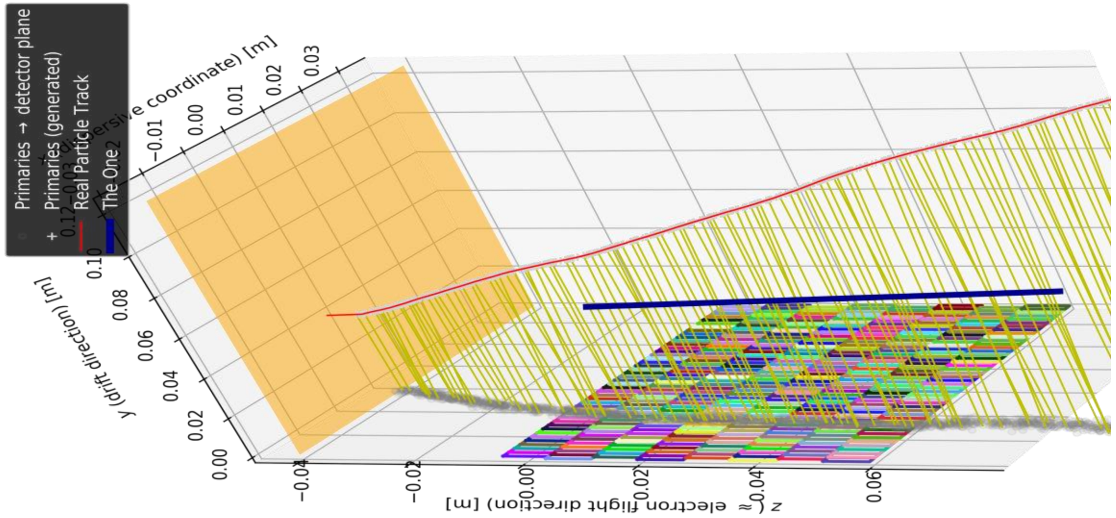
$X/X_0 = 0.44\%$

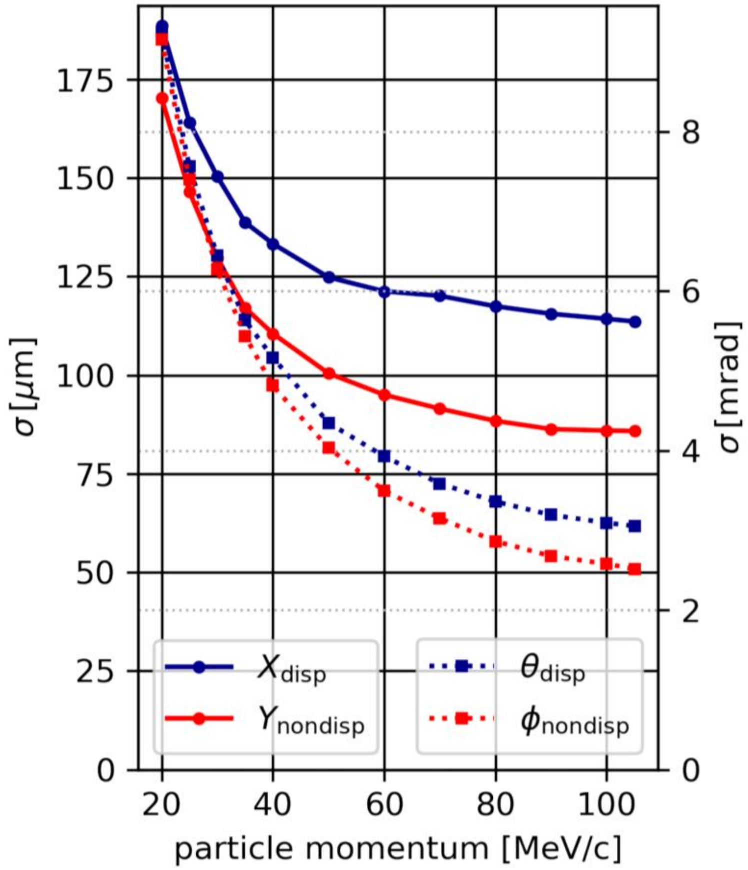
$X/X_0 = 0.04\%$



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





Projected performances

- Sensitive volume starting immediately after the vacuum window with an open field cage on the window side
- Possibility to measure some recoil products
- Position and angular resolution within the target range
- Extremely high efficiency and uniformity

THE MAGIX SETUP

A high-precision multi-purpose experimental setup

Internal 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