MPGD DEVELOPMENT AT THE UNIVERSITY OF MAINZ

GEMs and MicroMegas at the Instiutes for nuclear physics and high energy physics

(SUB)NUCLEAR PHYSICS IN MAINZ

Experimental particle and astroparticle physics group

- Several active collaborations: ATLAS, D0, NA62/NA48, IceCube, XENON, Calice, Borexino

Institute for nuclear physics

- MAMI:1.5 GeV 0.1 mA electron accelerator on site
- Long term experiments (A1, A2, X1)
- User test-beam line for detector development
- International collaborations: COMPASS, PANDA, BaBar, BESIII

Mainz Institute for Theoretical Physics

- Founded in 2013
- Active in both high energy and nuclear physics

PRISMA CLUSTER OF EXCELLENCE

Multidisciplinary consortium of leading scientific groups within the University of Mainz

http://www.prisma.uni-mainz.de/index.php

Research Areas

- Fundamental Interactions
- Origin of Mass and Physics beyond the Standard Model
- Structure of Matter
- Theoretical Concepts and Mathematical Foundations

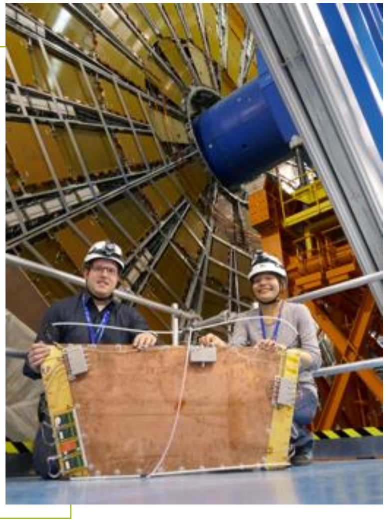
Common infrastructures

- Mainz Institute for Theoretical Physics (MITP)
- Mainz Energy-recovering Superconducting Accelerator (MESA)
- TRIGA User Facility (Research nuclear reactor)
- Detector Lab

MPGD DEVELOPMENT IN MAINZ

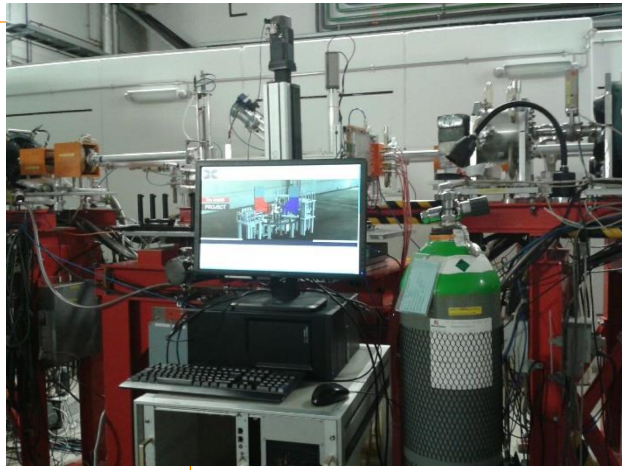
Micromegas

- Lichtenberg research group
- Forward muon detectors for the ATLAS upgrade
- General detector R&D



GEM

- MAGIX experiment @ MESA
- Low-mass and high-rate detectors for the MAGIX focal plane
- General detector R&D



MICROMEGAS DEVELOPMENT

NEW SMALL WHEEL (NSW) MASS PRODUCTION

Multilayer tracker

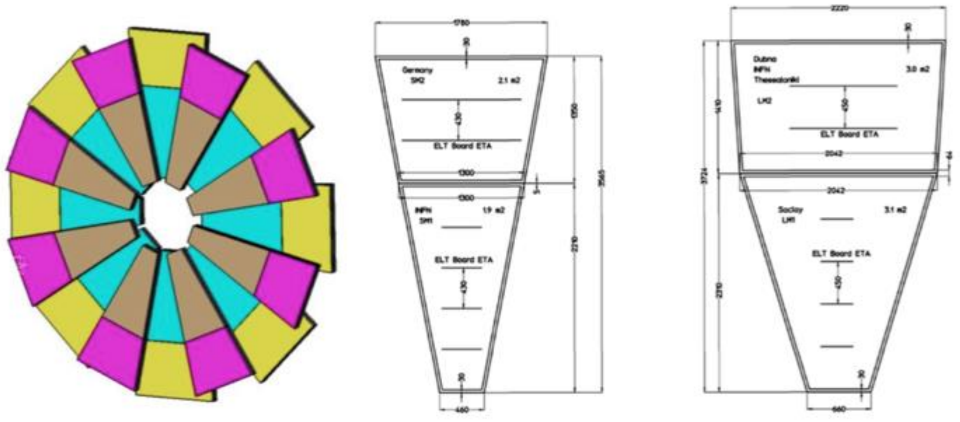
- Each layer shares the readout and the cathode supports with the neighbors

Tight mechanical requirements

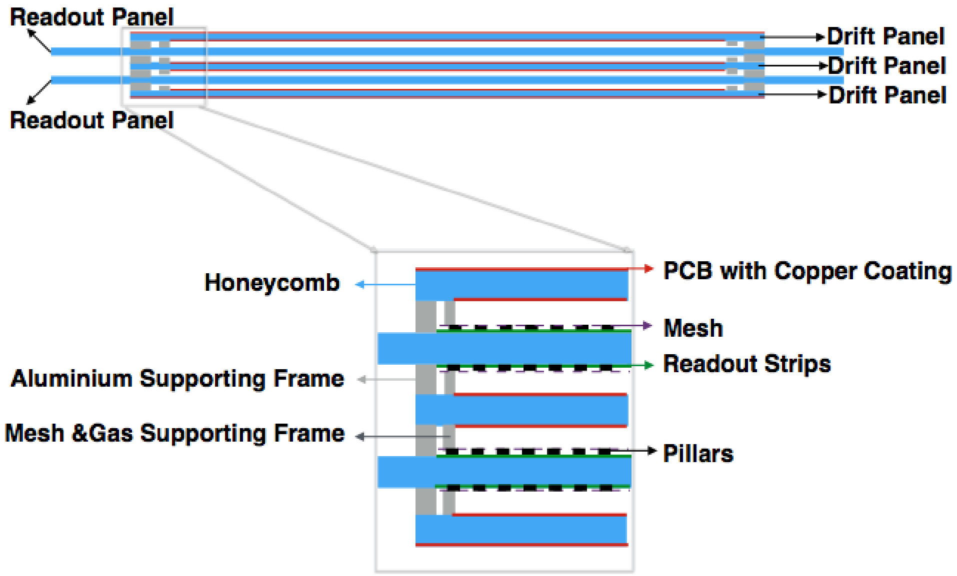
- 30 μm planar deviations over 2 m^2
- Gas tightness
- Quality control with a 5 μm resolution displacement sensor

Already an RD51 project

- Collaboration between the ATLAS groups in RD51 and in Mainz



arXiv: 1310.0734v1



PROTOTYPE TESTING

Resolution and efficiency measurement

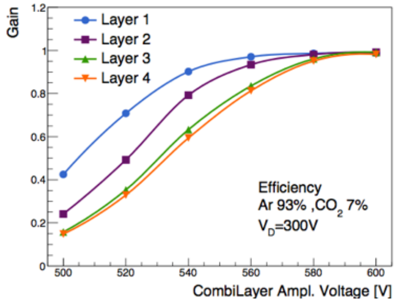
- MAMI test beam in Mainz
- RD51 Cosmic test bench

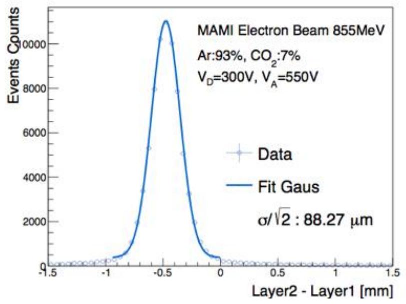
Irradiation and ageing

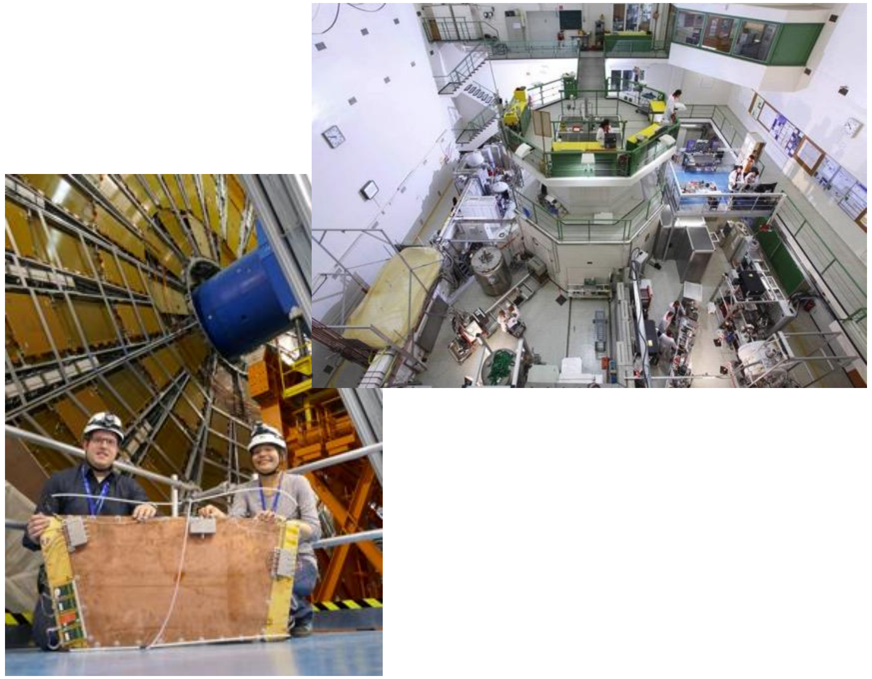
- TRIGA reactor in Mainz (1kW Neutron irradiation)
- GIF++ at CERN with RD51 support

Test and installation in the ATLAS cavern

- 1.8 m away from the MDT outer wheel







Nucl.Instrum.Meth. A767 (2014) 281-188

Nucl.Instrum.Meth. A814 (2016) 117-130

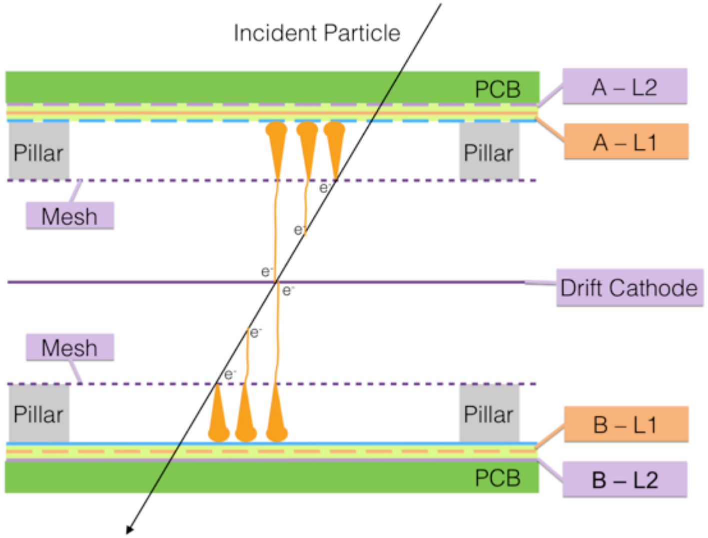
DOUBLE SIDED MICROMEGAS

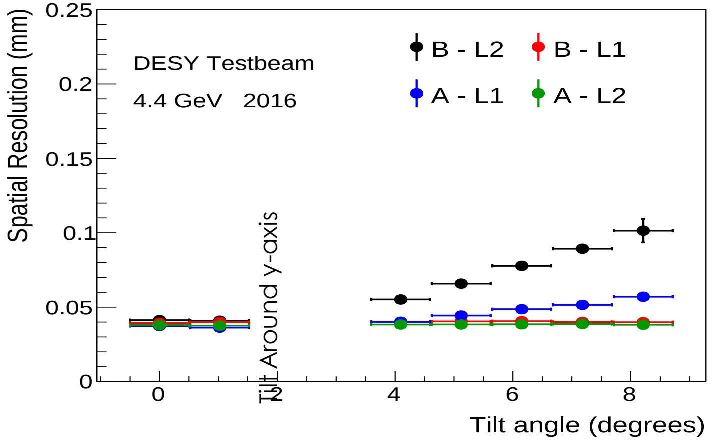
Specifications	
Size	90x90x14 mm^3
Drift region	7 mm
Pillar size	H:128 µm, Ø:350 µm
Distance between pillars	2.5 mm
Pitch size (X and Y)	250 µm
Thickness of strips	X:200 µm, Y:80 µm

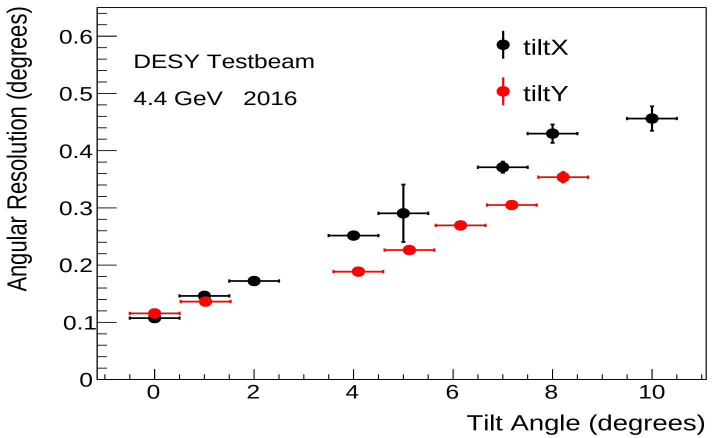
Double 2D readout

Common drift region separated by a cathode mesh

Separate amplification region







Presented by E. Yildirim at RD51 Workshop in Aveiro
https://arxiv.org/abs/1610.09539

MICROMEGAS PAD READOUT

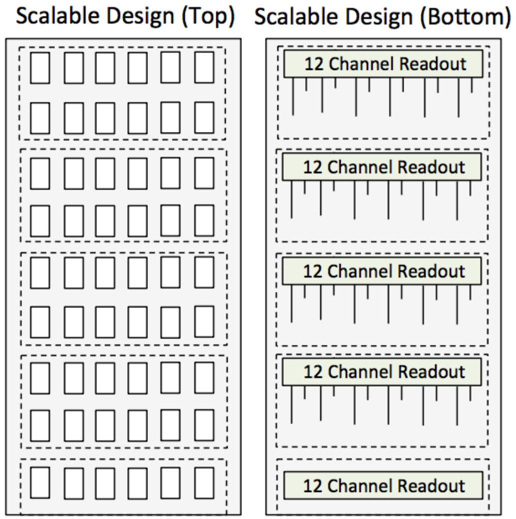
Scalable design layout
- Modular connection layout
- Scalable with the module size

Capacitive-coupled readout
- Maze-like resistive tracks
- Increase the charge localization

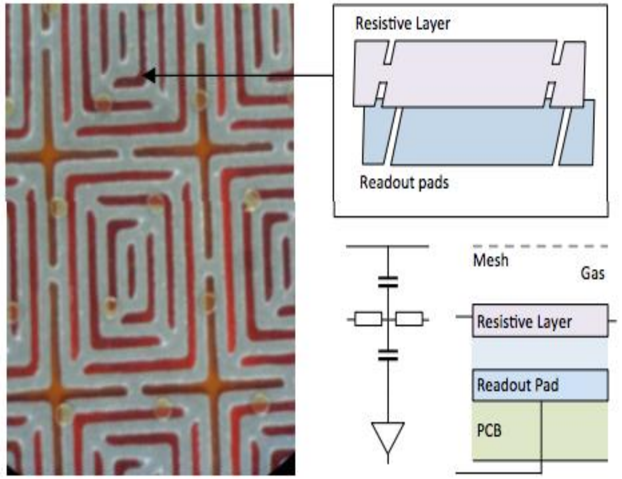
Resistive-coupled readout
- Direct resistive connection between resistive and readout layer
- Increase of the charge localization

Specifications	
Size	10x10 cm^2
N pads	500
Pad size	5x4 mm^2
Distance between pads	300 µm

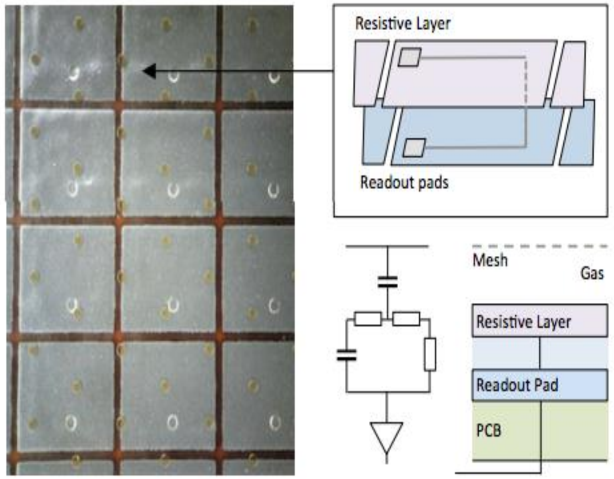
Nucl.Instrum.Meth. A803 (2015) 29-35
Nucl.Instrum.Meth. A824 (2016) 526-527



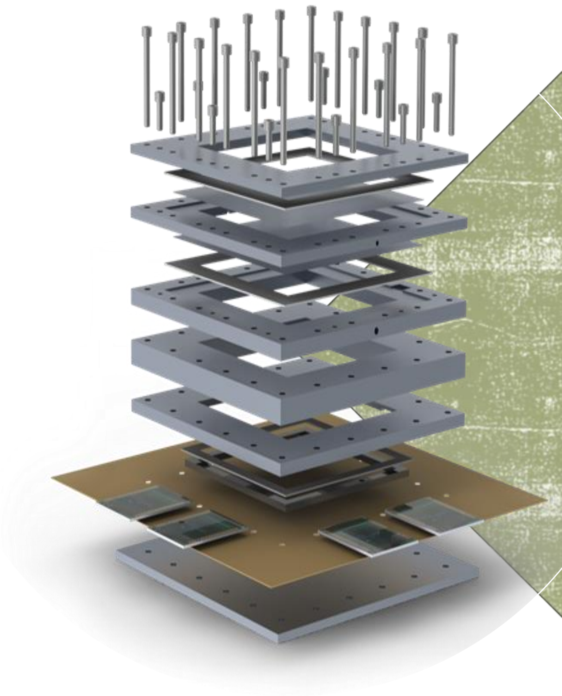
Capacitive - Coupled (CC)



Resistive - Coupled (RC)



OTHER DETECTOR CONCEPTS

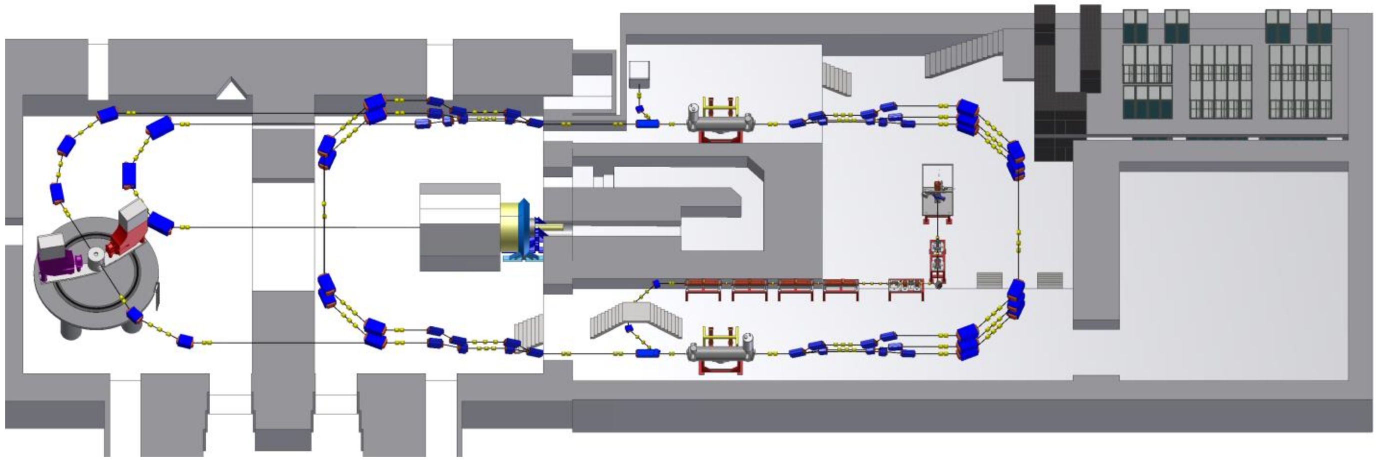


Xenon Micromegas

- Optimized for the detection of low energy X-Rays (1-10 keV)
- No gas flushing to increase portability
- Controlled materials to avoid outgassing
- Detector simulation with GEANT4 and Garfield++
- Measurements with ^{55}Fe

GEM DEVELOPMENT

Multi-orbit recirculator with energy recovery



Energy recovery

- External loop of half-wave length
- Electron energy transferred back to the cavity

Experiment on the recirculating beam (MAGIX) @105 MeV

- External loop after two recirculation
- Thin gas target on the beam path with a dedicated detector

Extracted beam @ 155 MeV

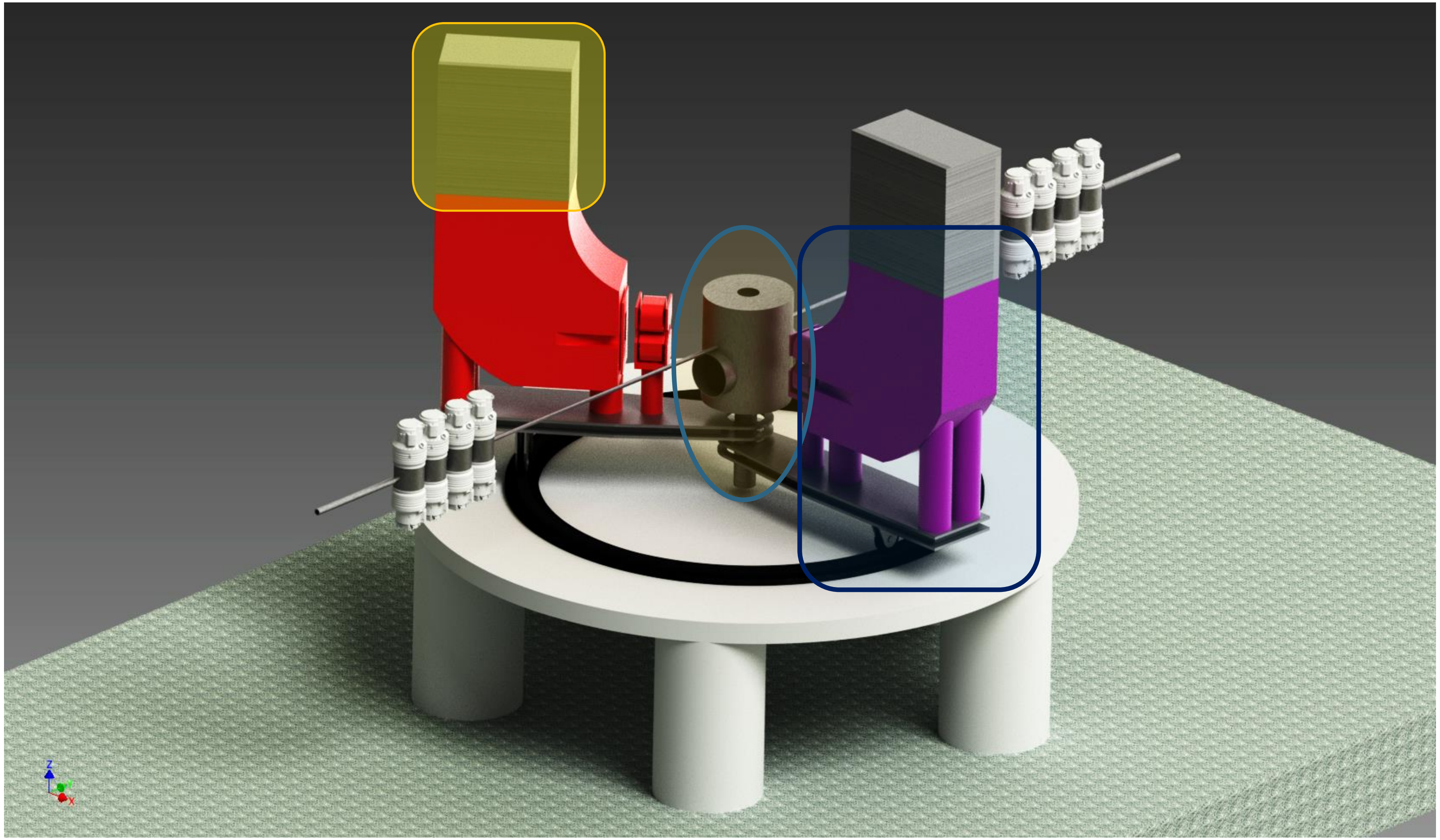
- After a final recirculation, then dumped
- Dedicated experiment (P2)

MAGIX COMPONENTS

Internal Gas Target

Twin ARm DIpole Spectrometer

Focal Plane Detectors



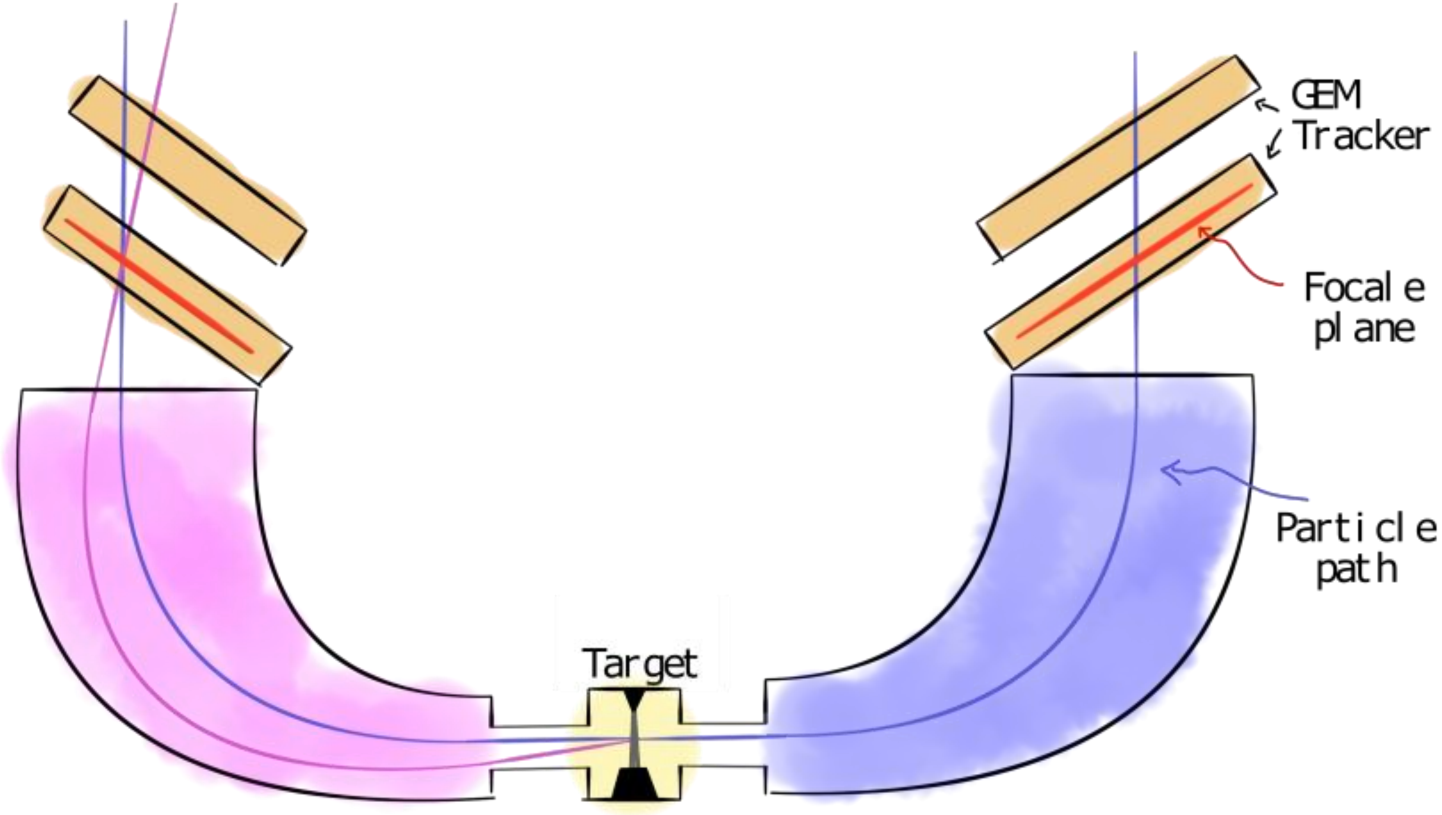
THE SPECTROMETER CONCEPT

Momentum focusing

- Particles of different momenta at different positions
- Mapping of momenta to position

Angular focusing

- Parallel-to-point focusing
- Mapping of angles to position



DETECTOR CHALLENGES

High resolution on low momentum electrons

- 1 < p < 100 MeV
- $\frac{\Delta p}{p} \approx 10^{-4}$
- $\Delta\theta \cong 5 * 10^{-2}\,{}^{\circ}$

Material reduction

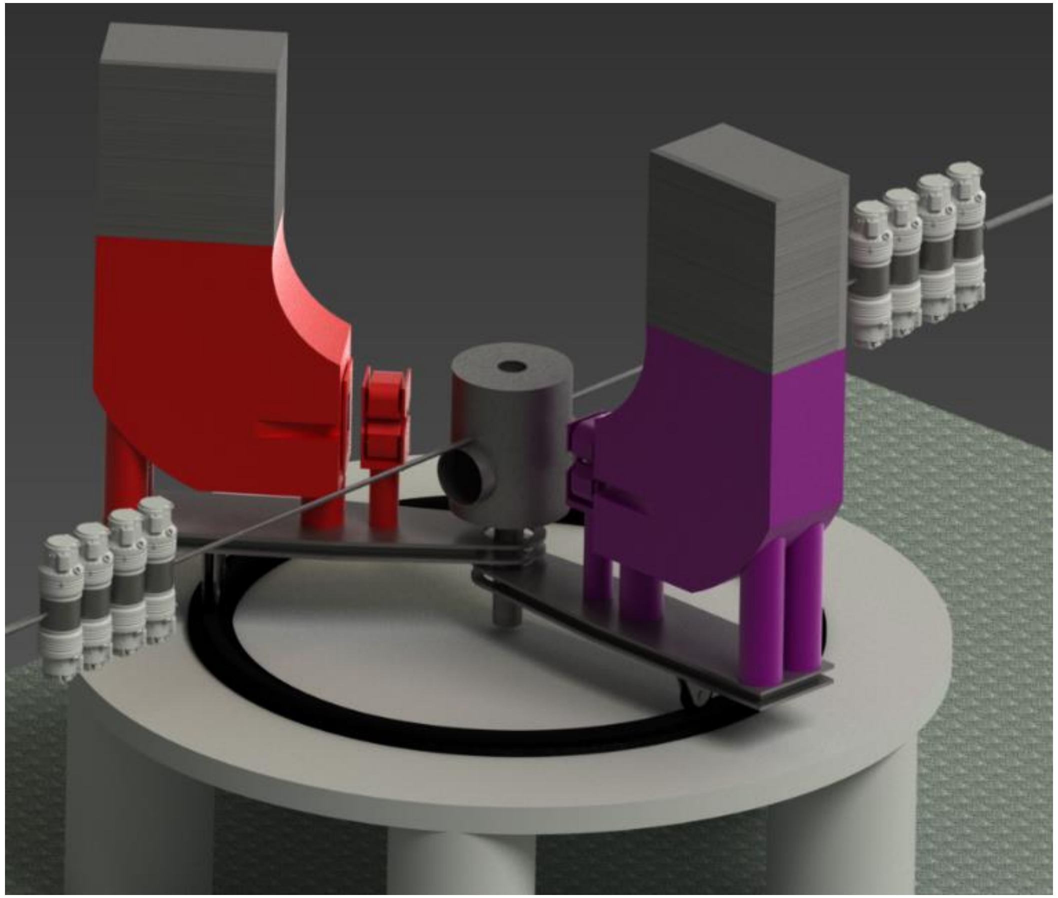
- Thin detector design
- Reduce electron multiple scattering
- Detect proton with momentum less than 50 MeV

Large sensitive surface

- $120 * 30\ cm^2$ focal plane surface
- $50\ \mu m$ point resolution in the focal plane
- At least 2 samples to reconstruct the full kinematics

High rate capability

- With a CW operation rates up to $O(1\ MHz)$
- Count rates of $O(100\ KHz)$



MATERIAL MINIMIZATION

Challenges

- Multiple scattering of 10 – 100 MeV electrons between layers less than $\Delta\theta \cong 5 * 10^{-2}$ °
- Detection of protons of momentum < 50 MeV in the first tracking layer

Foil readout

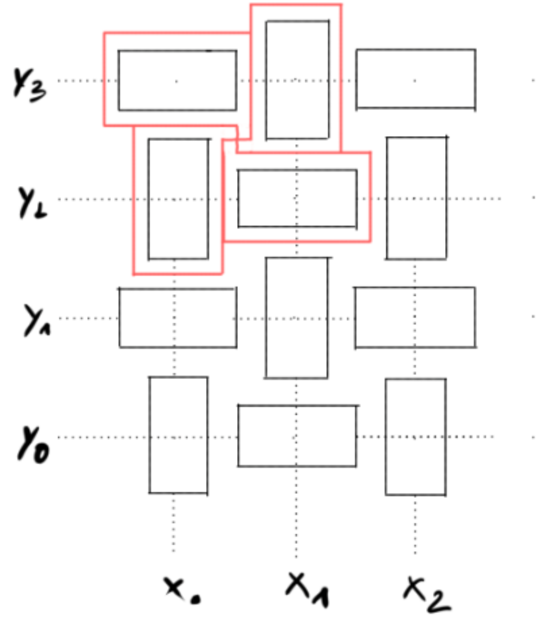
- Kapton foil readout planes in the first hodoscope layer
- Single layer padded strip layout

Thin GEM

- Thin copper coating or chromium coating
- Some chromium coated GEM ordered and to be delivered

Inert material reduction

- Vacuum membrane has cathode
- Single gas volume for the two layers



HIGH RATES CAPABILITY

Expected MESA rates

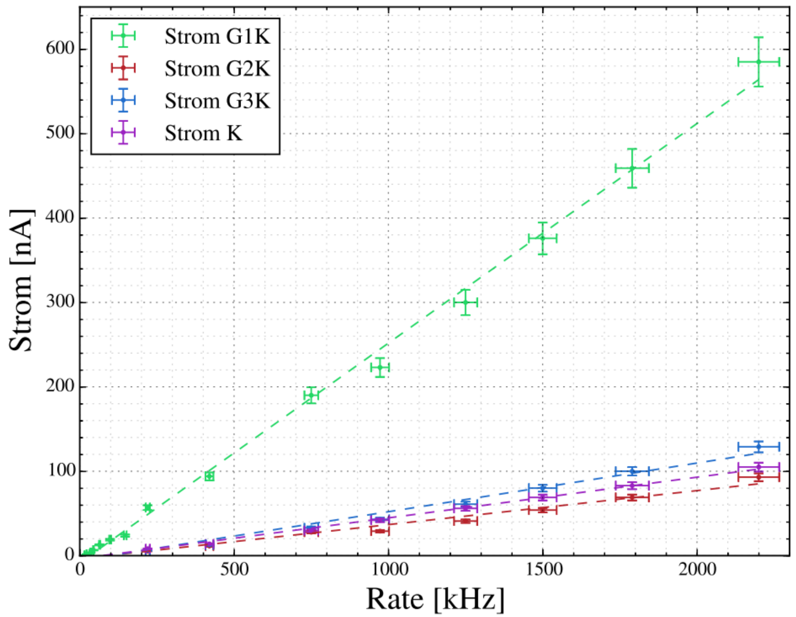
- 1.3 GHz bunch rate – 1mA current (10 mA upgrade)
- Up to $O\left(1\frac{MHz}{cm^2}\right)$ detector rate
- Up to $O(100\ KHz)$ trigger rate

High-rate prototype tests

- $100\ \mathrm{cm}^2$ standard CERN GEMs on the MAMI test beam
- Up to 2.2 MHz trigger rates
- Readout with SRS and APV25 (limited to about 600 Hz)
- Borrowed from the ATLAS MM Group

DAQ optimization

- Understand and optimize the SRS system to achieve higher rates.
- New system just ordered.



LARGE AREA DESIGN

Sensitive surface

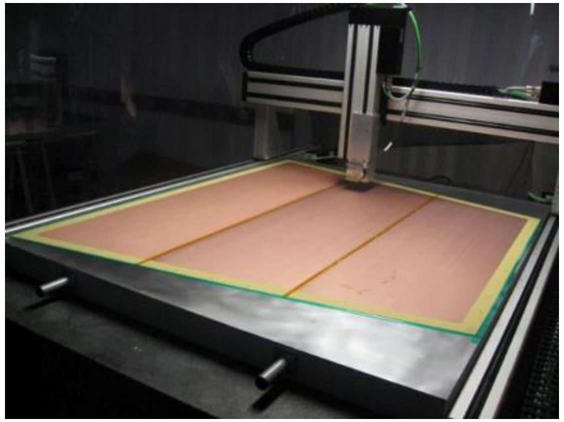
- $120 \cdot 30\ \mathrm{cm}^2$ sensitive surface
- Reduced dead areas on the sensitive surface

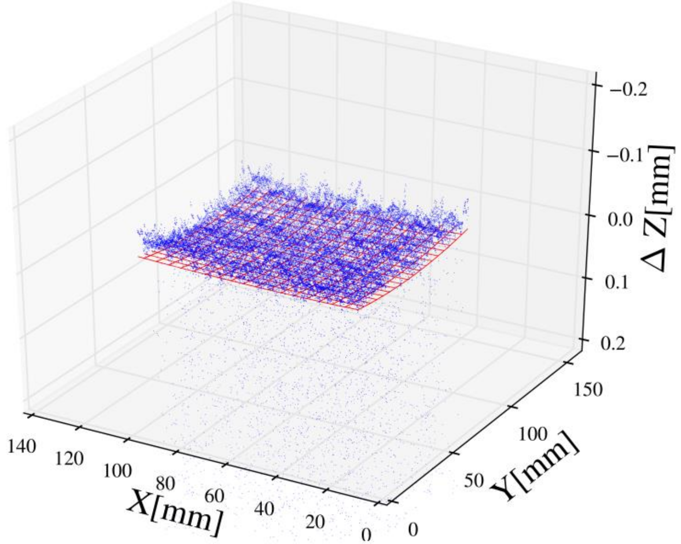
Incremental development

- Standard $10 \cdot 10\ \mathrm{cm}^2$ detectors for generic GEM testing and student training
- $30 \cdot 30\ \mathrm{cm}^2$ prototypes for readout and assembly testing
- Full size detector for the final experiments

Stretching and flatness measurements

- Mechanical stretching device under design for $30 \cdot 30\ \mathrm{cm}^2$ prototypes
- Laser displacement system developed together with the ATLAS group for the quality control





SHORT DRIFT TPC

Conceptual design

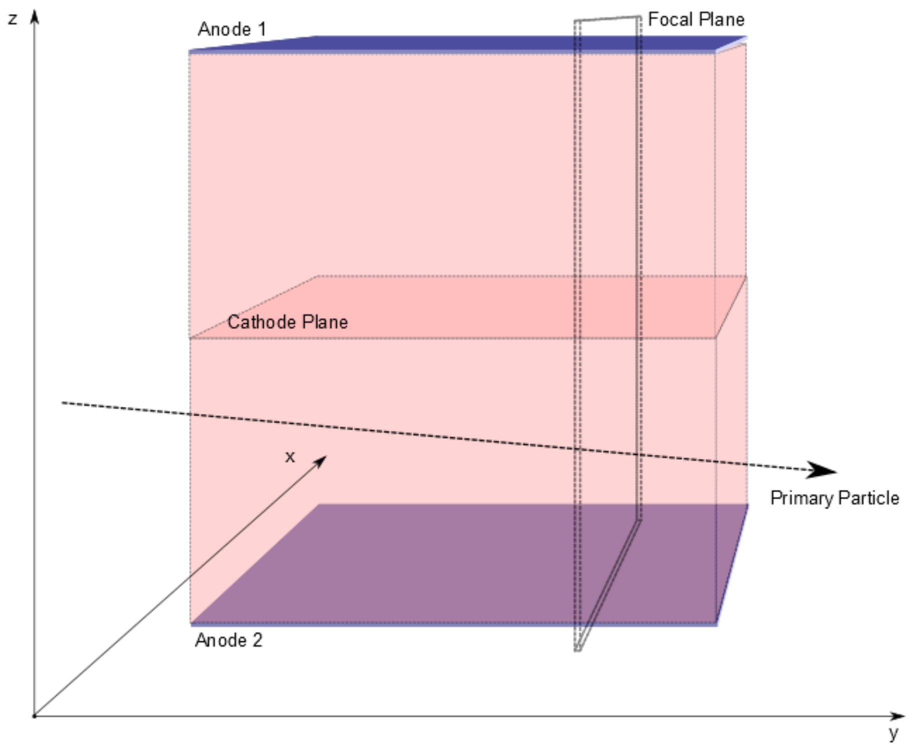
- $120 \cdot 30\ \mathrm{cm}^2$ entry window
- Mirror drift volumes to reduce the drift length to 15 cm
- 15 cm depth (y in the picture)

Advantages

- Full tracking
- Minimal material
- No constraint on GEMs and readout

Disadvantages

- Slower readout, can only be used at lower rates
- Need an extension of the spectrometer magnets to take advantage of the magnetic field
- Probably needs a pad readout (more expensive)



CONCLUSIONS

CONTRIBUTIONS TO MPGD DEVELOPMENT

General detector R&D

- MPGD readout structure
- High rate DAQ matching the high-rate potential of the MPGDs
- Contribute to the VMM3 development

New detector setup

- Full-foil, lightweight GEM detector
- XENON Micromegas for X-Ray detection
- Short drift TPC for high rate environments

Detector characterization

- Variable gap Micromegas
- Test beam activities
- Assembly quality control

CONCLUSION

Well established MPGD programs

- Micromegas for ATLAS
- GEM for MAGIX
- General detector R&D supporting both

Expanding the envelope

- Detector optimization and characterization
- New detector designs and new features
- Improving performances

WHO ARE WE

Lichtenberg group

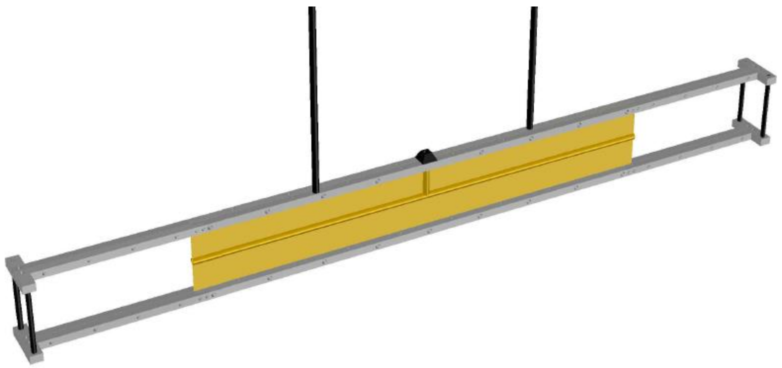
- Matthias Schott (Principal Investigator)
- Eda Yildrim (ATLAS NSW)
- Andreas Düdder (ATLAS NSW)
- Tai-Hua Lin (ATLAS NSW)
- Bernard Brickwedde (Pad Detectors)
- Robert Westenberg (Xenon-Based detectors)
- Friedemann Neuhaus (Micromegas R&D)

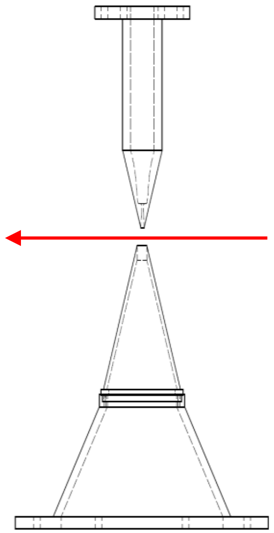
MAGIX group

- Achim Denig (Group Leader)
- Harald Merkel
- Patrick Achenbach
- Stefano Caiazza
- Pepe Gülker
- Mirco Christmann
- Stephan Aulenbacher
- Stefan Lunkenheimer
- Matthias Klein
- Yasemin Schelhaas
- Manuel Mauch
- Nicolas Emig

BACKUP

TARGET LAYOUT





Foil-thin tube

- To be used with polarized gases
- Moderate gas density $O(10^{22}/m^3)$
- Length (~ 30 cm)
- Estimated luminosity with polarized beam $O(10^{32}\ cm^{-2}s^{-1})$

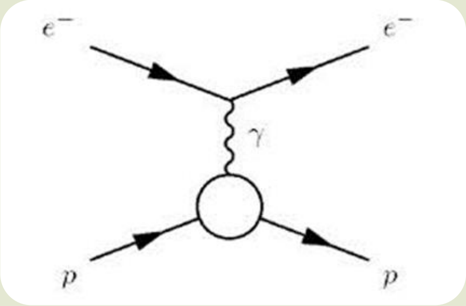
Jet Target

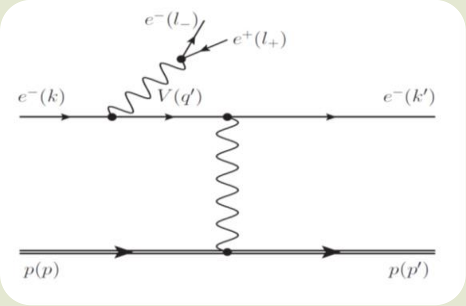
- Supersonic gas jet
- Higher gas density $O(10^{26}/m^3)$
- O(mm) target length
- Estimated luminosity $O(10^{35}cm^{-2}s^{-1})$

THE PHYSICS

LOW ENERGY ELECTRON SCATTERING

Electron scattering on fixed target below the pion threshold





E-Nucleon scattering

- Elastic or inelastic
- Form factor measurements
- Proton radius

Pair production

- $e^+ e^-$ coincidence
- With SM or dark U(1) photons

Low momentum electron coincidence
- On the scale of the bunch frequency (ns timestamping)

High acceptance
- To improve the statistics on rare event searches

Good momentum resolution
- For high precision measurements
- Low momentum

Good angular resolution
- For background rejection and vertex reconstruction

DARK PHOTON SEARCH

What is a dark photon

- Force carrier in the dark sector
- Kinematic mixing with the SM photon
- U(1) interaction with SM particles with reduced coupling

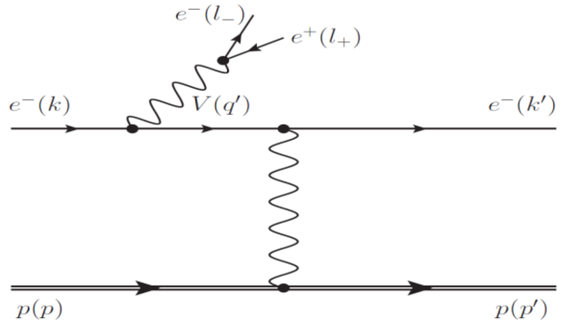
Measurable effects

- Decay of the DP to SM fermions
- $\Gamma = \sigma(10\ KeV)$
- Dark sector particles with a fractional QED charge
- Hidden sector contribution to SM diagrams

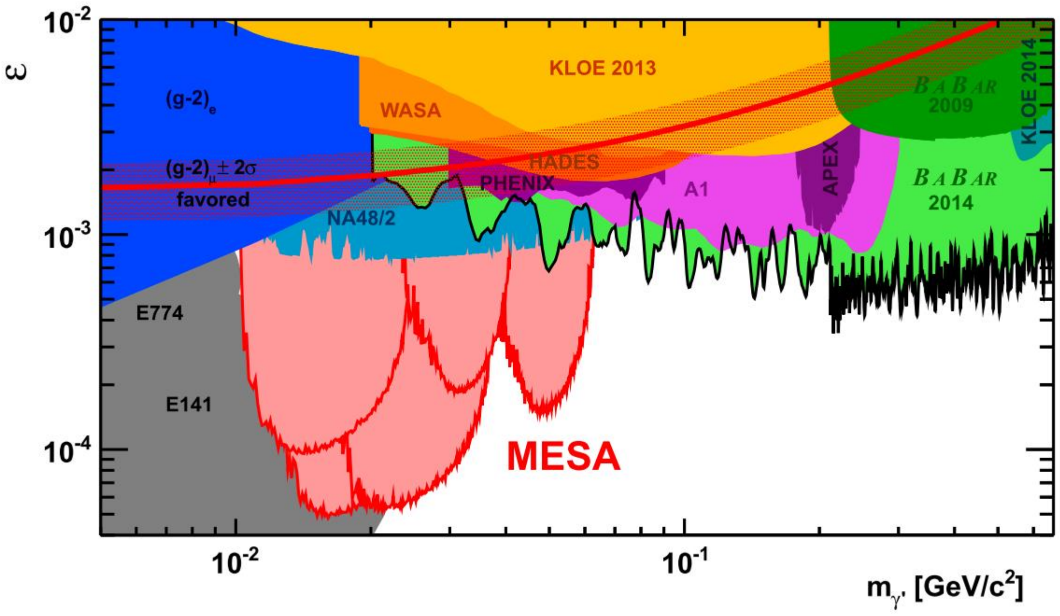
Requirements

- High luminosity (rare process)
- High momentum resolution $\frac{\Delta p}{p} \approx 10^{-4}$

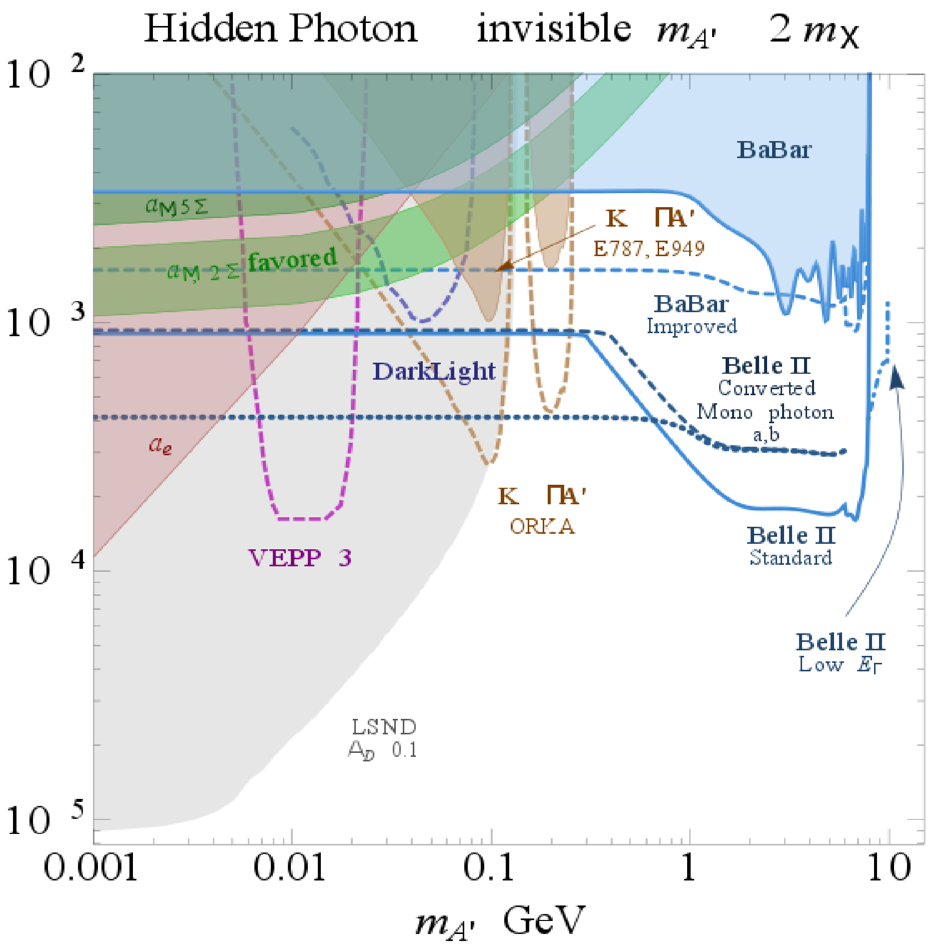
$$\varepsilon^2 = \frac{\alpha'}{\alpha}$$



$e + Z \rightarrow e + Z + \gamma'$
$\hookrightarrow e^+ + e^-$ (detected in Magix)



DARK PHOTON INVISIBLE DECAY

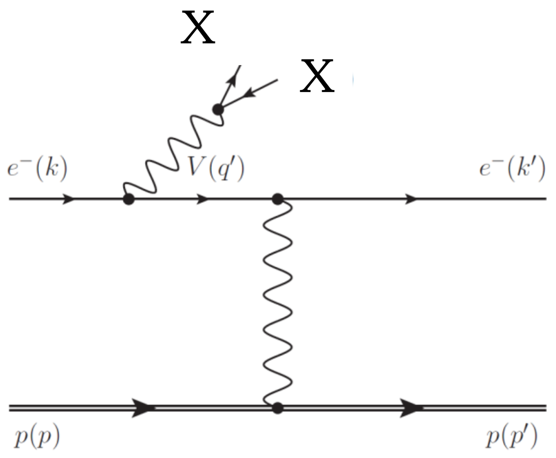


Dominant decay in the dark sector

- Wide space for improving the current limits

Missing mass on a tagged event

- Tag the recoil proton
- Challenging due to the low energy of the proton
- Scenario evaluation in progress



PROTON RADIUS PUZZLE

Electronic measurements

- Hydrogen hyperfine structure
- Electron scattering
- $r_e = 0.8775(51)$

Muonic measurements

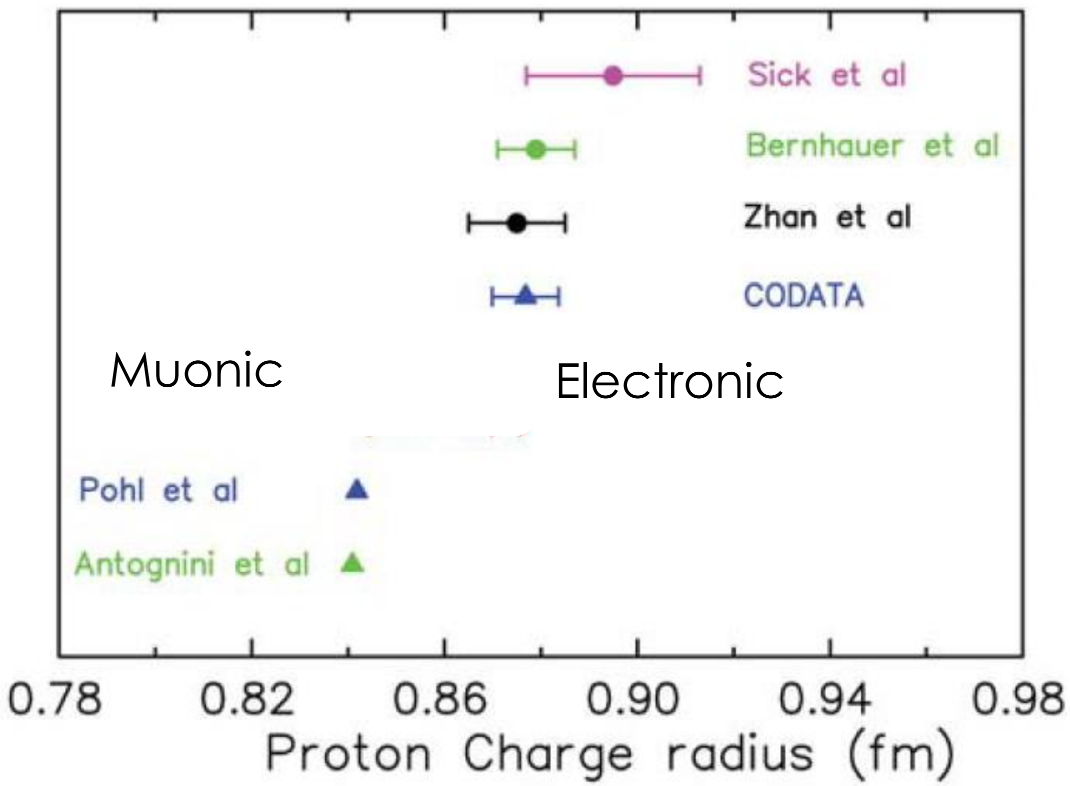
- Lamb shift of a muonic hydrogen
- $r_\mu = 0.84087(39)$

7σ discrepancy of unknown origin

- Neglected theoretical contributions?
- BSM phenomena (dark photon)?
- Incorrect extrapolations at low Q^2?

Requirements

- Low Q^2 - Small angles
- Minimal multiple scattering



SOME MORE IDEAS

Polarizabilities

- Photon tagging
- Proton recoil measurement

Test of chiral effective theories

- High resolution @ low momenta
- High luminosity with highly polarized beam and targets

Nuclear cross-section of astrophysical relevance

- Measure cross-sections of processes like $^{12}C(\alpha,\gamma)^{16}O$
- Can be derived from the cross-section of the related process $^{16}O(e, e' \, ^{12}C) \, \alpha$
- Flexible gas target design to inject different elements

To be studied also with the collaboration of SFB1044

- Included in the projects of the collaboration