THE MAGIX FOCAL PLANE TPC

An open-cage TPC for the MAGIX experiment
Stefano Caiazza
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

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A versatile experiment for precision measurements at low energy
### Hadronic structure
- Proton form factors (electric and magnetic)
- Nuclear polarizabilities
- Light nuclei form factors (Deuteron and helium)

### Few-body physics
- Deuteron and $^3$He breakup
- $^4$He monopole transition factors
- Test of effective field theories
- Inclusive electron scattering

### Precision cross-sections
- $^{16}$O(e, e' $^\alpha$)$^{12}$C S-factor

### Search for exotic particles
- Direct dark photon search
- Invisible decaying dark photon search

### Non-gaseous targets and complex observables
- Detection of the low energy recoil products

### Precision measurement of a differential cross-section

### Identification of a narrow resonance on a large background
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
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 \( \left( \frac{dE}{E} < \approx 10^{-4} \right) \)
- Luminosity of the order of \( 10^{35}\text{cm}^{-2}\text{s}^{-1} \)

Basic observables

- Scattered particle momentum (P)
- Scattering angle (\(\theta, \varphi\))
Magnetic Spectrometers

Moments 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: \(\approx 100\ \text{MeV}\)
- Momentum resolution: \(\frac{\delta p}{p} \approx 10^{-4}\)
- Focal plane length: \(\approx 1\ \text{m}\)
- Required position resolution: \(\approx 100\ \mu\text{m}\)

**Focal plane angle measurement**

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

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**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

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Scattered particle

Cathode
GIII
GII
GI
Readout foil
PCB
Bottom plate
Angular error introduced by the foil separating the spectrometer vacuum and the detector volume

\[ \theta_0 = \delta \theta_{\text{plane}} = \frac{1}{\sqrt{2}} \delta \theta_{\text{space}} \]

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

- 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

\[ \theta_0 = \theta_{\text{max}} = \frac{1}{\sqrt{2}} \theta_{\text{max}} \text{ne} \]

Multiple scattering in the MAGiX vacuum window

- Kapton \((X_0 = 286\text{mm})\), width \(x = 0.125\text{mm}\)

- \(2 \times 10^{-3} \text{rad} = 0.11^\circ\)
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
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
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 mm²
- 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
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 mm²
- 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
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 cm² 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

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25-Sep-18
THANK YOU FOR YOUR ATTENTION!

http://magix.kph.uni-mainz.de
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
- $10^{19}\text{atoms} / \text{cm}^2$

**Cluster-Jet**
- Molecular clustering @ 40K
- Increase self-containment

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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 injector

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

Jet catcher

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

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

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

Replacing the copper layer with an atomic layer of Chromium 0.61% → 0.44% $X_0$
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
**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

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First 30 minutes

After 1 hour
Facing the drift
2MHz electron beam

Last 60 minutes