Experiments with Internal Targets at the Mainz Energy-Recovering Superconducting Accelerator

Harald Merkel
Johannes Gutenberg-Universität Mainz

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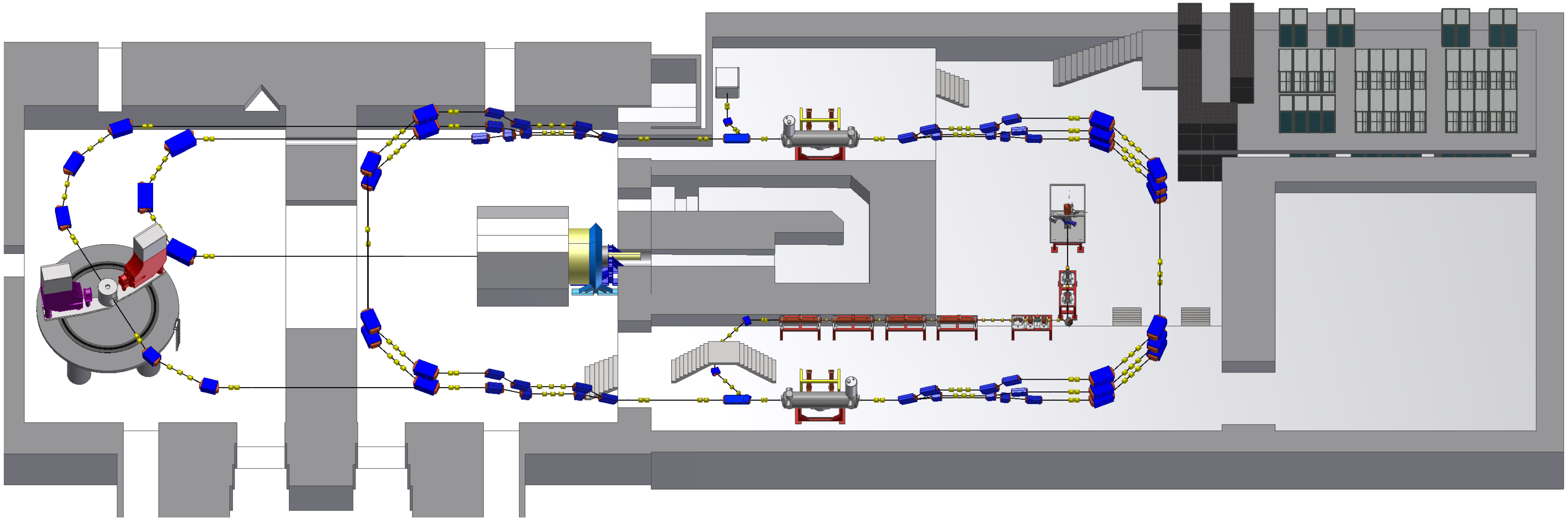
- The MESA Accelerator
- MAGIX
  - High resolution magnetic spectrometers
  - Internal targets: Gas Jet Target or Polarized Target
- Physics program
  - Magnetic radius of the proton
  - Astropyhsical S-Factor
  - Few body physics
  - Search for exotic particles
- Summary

MESA - Mainz Energy Recovery Superconducing Acclerator



- Super-conducting, recirculating LINAC
- Energy of up to 155 MeV
- Operation for external targets, 1 mA, polarized beam
- Operation in ENERGY RECOVERY MODE (up to 105 MeV)
  - Recirculating with $\lambda/2$ phase shift in last return path
  - Deceleration in cavities recovers energy from the beam
    $\Rightarrow$ High beam current (up to 10 mA)
  - Large fraction of the beam can be used for an INTERNAL TARGET

...funded, under construction!

Magix - Design Considerations

Using the full power of the MESA beam quality

- Beam intensity

$\Rightarrow$ High count rate capability (MHz)

- Nuclear Physics: Separate energy levels at 100 MeV at 100keV distance

$\Rightarrow$ momentum resolution $\frac{\delta p}{p} < 10^{-4}$

- Precision measurement of electron scattering cross sections proportional to Mott cross section

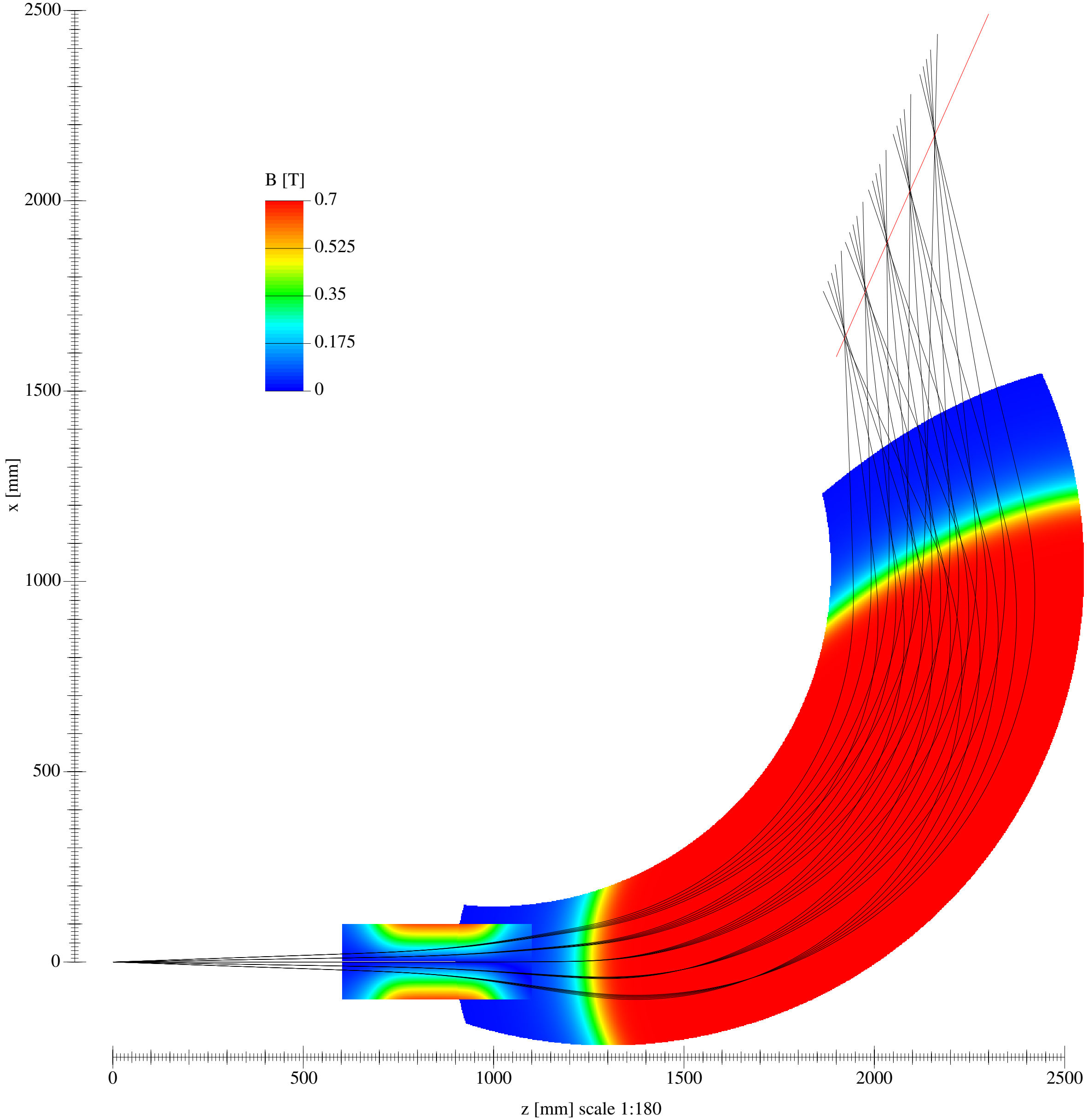
$$\frac{d\sigma}{d\Omega} \approx \frac{1}{Q^4} \approx \frac{1}{\sin^4 \theta/2}$$

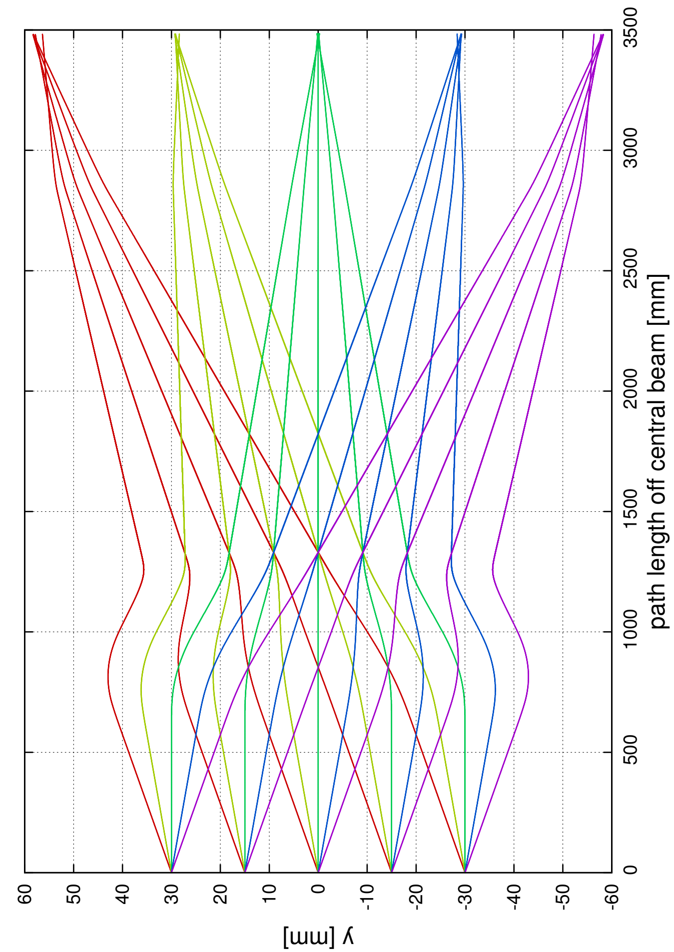
$\Rightarrow$ angular resolution $\delta\theta < 0.05^\circ$

- Low energetic particles (e, p, below π threshold)
  - Negligible energy loss in window-less gas target
  - Vacuum until first detector layer
  - Excellent position detection in first layer, modest angular detection later

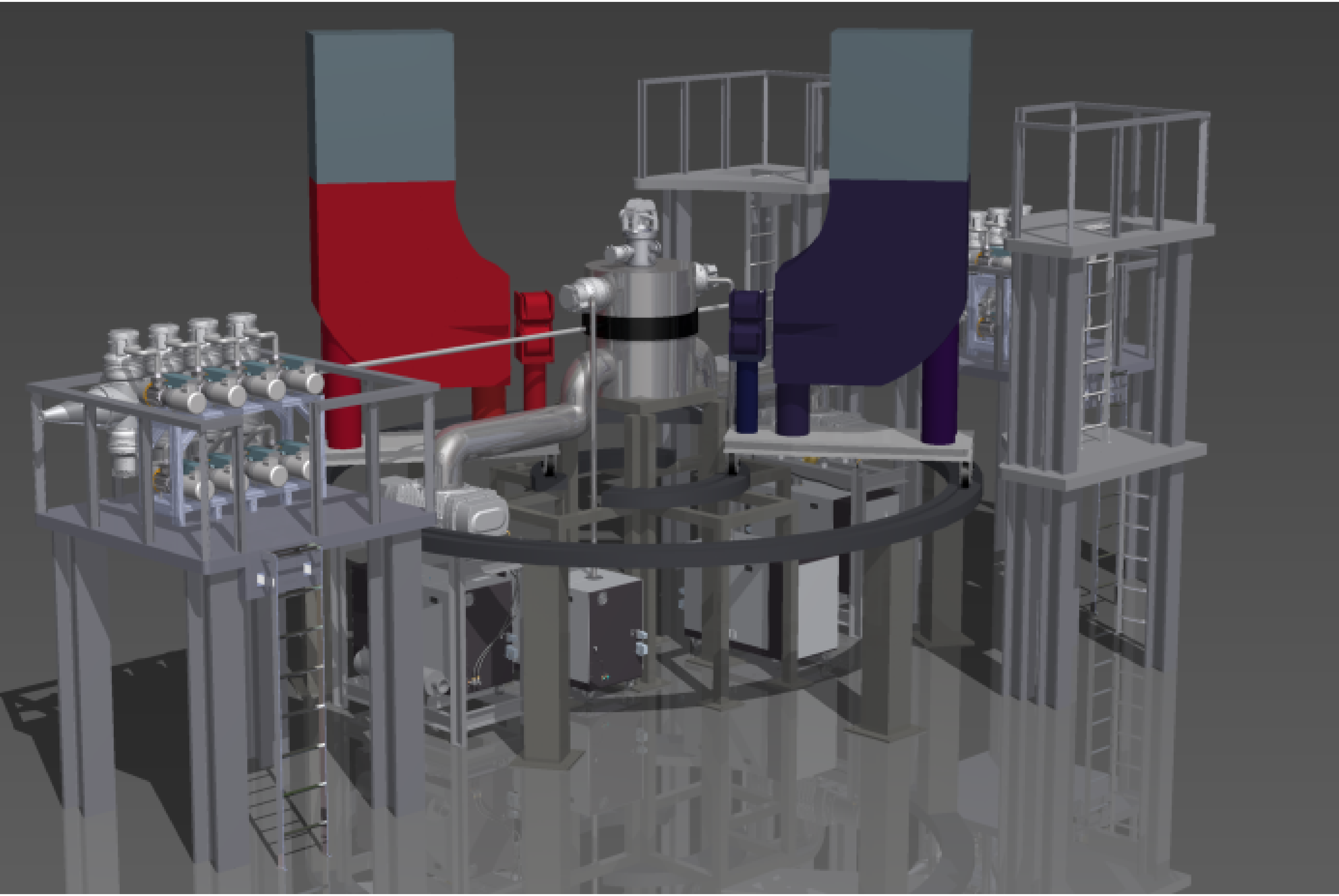
$\Rightarrow$ Focussing spectrometers

Magix - Optics





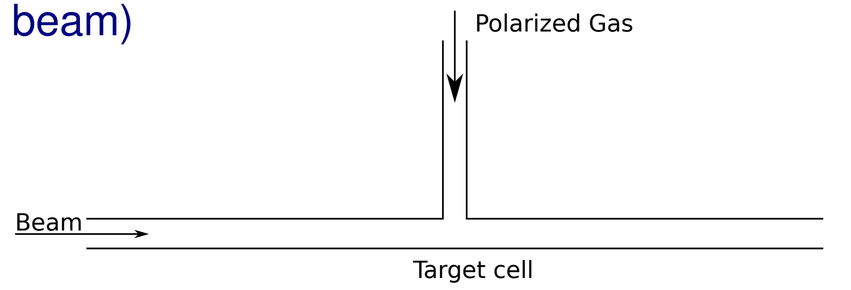
Magix



Magix - Targets

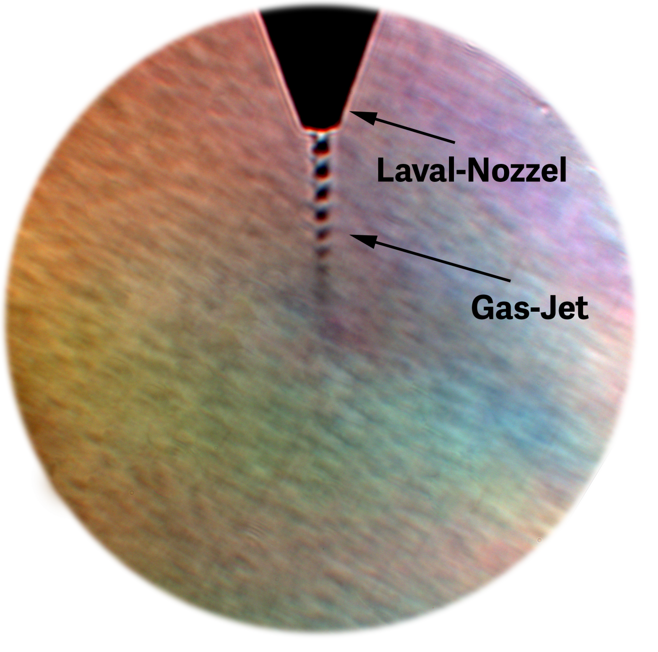
1. Polarized Target

- Polarized Hydrogen target
- Flow is limited by polarizator (Laser driven/Atomic beam)
- Luminosities of up to $L = 2 \times 10^{31}\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$
- Polarization $|\vec{P}_e| \approx 80\%$



2. Gas Jet Target

- Hypersonic gas jet by Laval nozzle
- Gas jet caught
- Expensive part: Pumping system mbar $\to 10^{-11}$ mbar
- Beam quality: narrow flow delimiters
- Luminosities of up to $L = 10^{36}\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$ at 10 mA



Physics Program at Magix

Physics Program to employ the strenghtes of MESA and Magix

- High beam intensity $\leftrightarrow$ low target density
- Excellent beam quality $\Rightarrow$ Precision physics
- High degree of beam/target polarization
- Tuneable to very low energies

Selected Examples:

- Magnetic Radius
- Tests of ab-initio Calulations in Few-Body Physics
- Astrophysical S-Factors
- Search for exotic particles:
  - Search for Dark Photons
  - Invisible Decay of Dark Photons
  - Dark matter beam

Magnetic Radius of the Proton

Magnetic Radius from limit $Q^2 \to 0$

- Suppressed by $\tau = \frac{Q^2}{4m_p^2}$ in cross section

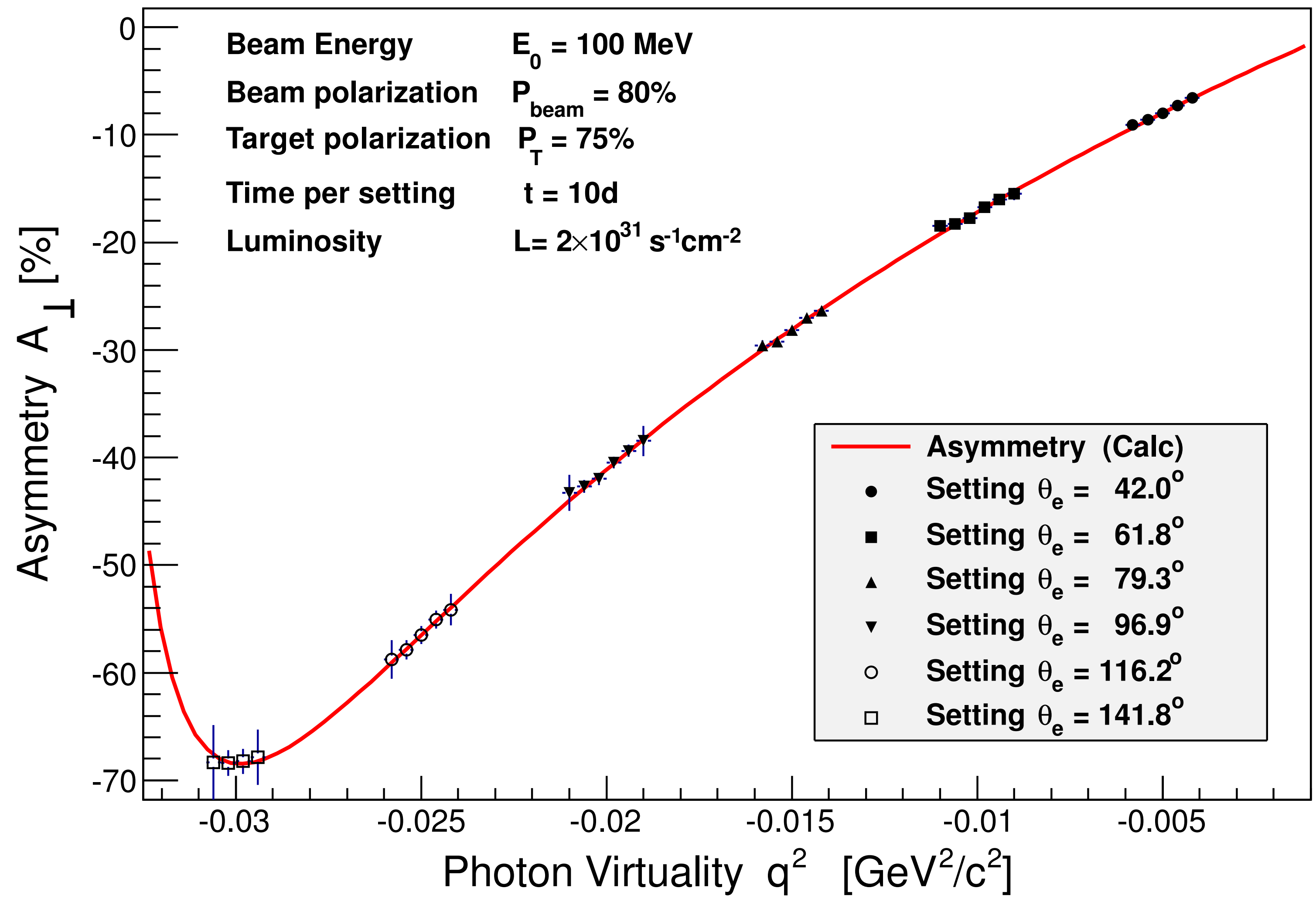
$$\frac{d\sigma}{d\Omega_e} = \left(\frac{d\sigma}{d\Omega_e}\right)_{\text{Mott}} \frac{1}{\varepsilon(1+\tau)} \left[\varepsilon\, G_E^2(Q^2) + \tau\, G_M^2(Q^2)\right]$$

- Beam-Recoil polarization is limited by proton recoil momentum $|\vec{p}_p| > 300\,\frac{\text{MeV}}{c}$
- Beam-Target polarization:

$$\begin{aligned}
A(\theta^*, \phi^*) &= A_I \sin\theta^* \cos\phi^* + A_S \cos\theta^* \\
A_I &= -2\sqrt{\tau(1+\tau)}\,\tan\frac{\theta}{2}\,\frac{G_E\, G_M}{G_E^2 + \left(\tau + 2\tau(1+\tau)\tan^2\frac{\theta}{2}\right) G_M^2} \\
A_S &= -2\,\tau\,\sqrt{1+\tau+(1+\tau)^2\tan^2\frac{\theta}{2}}\,\tan\frac{\theta}{2}\,\frac{G_M^2}{G_E^2 + \left(\tau + 2\tau(1+\tau)\tan^2\frac{\theta}{2}\right) G_M^2}
\end{aligned}$$

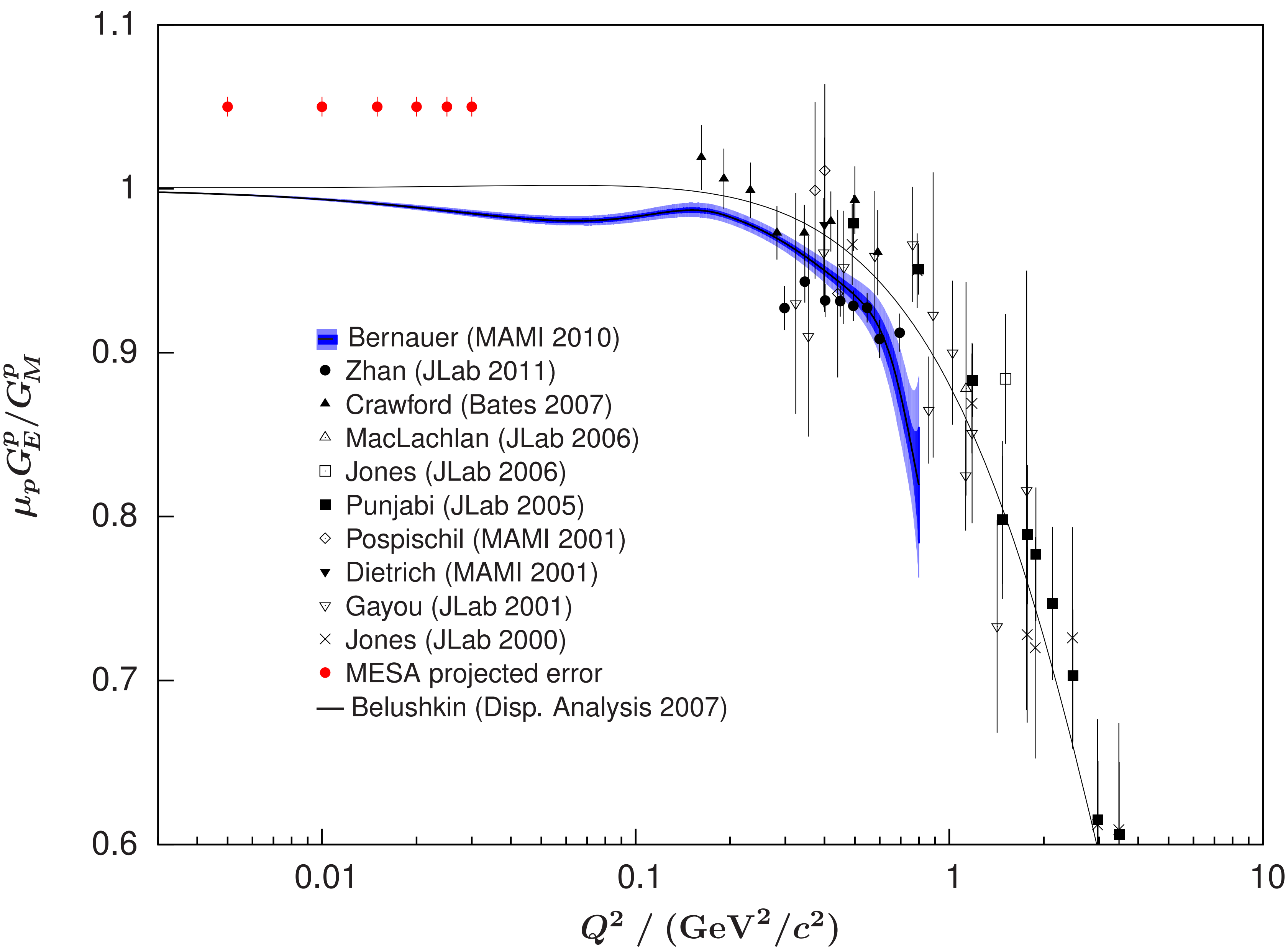
$$\left.\begin{aligned}\phi^* &= 0\\ \theta^* &= 0, \tfrac{\pi}{2}\end{aligned}\right\} \Rightarrow \quad A_\perp = \frac{A_I}{A_s} \sim \frac{G_E}{G_M}$$

Magnetic Radius of the Proton - Asymmtry



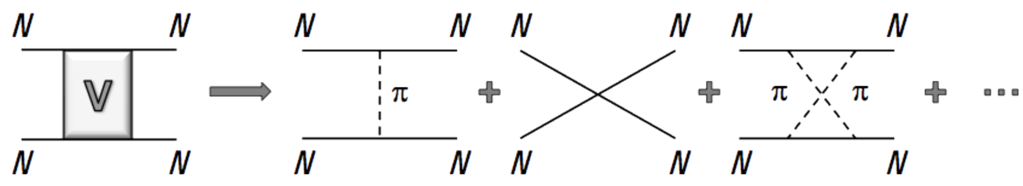
- (Conservative) assumptions for target ≈ Blast target
- Statistical error only (systematic error should be small!)

Magnetic Radius of the Proton - Errors

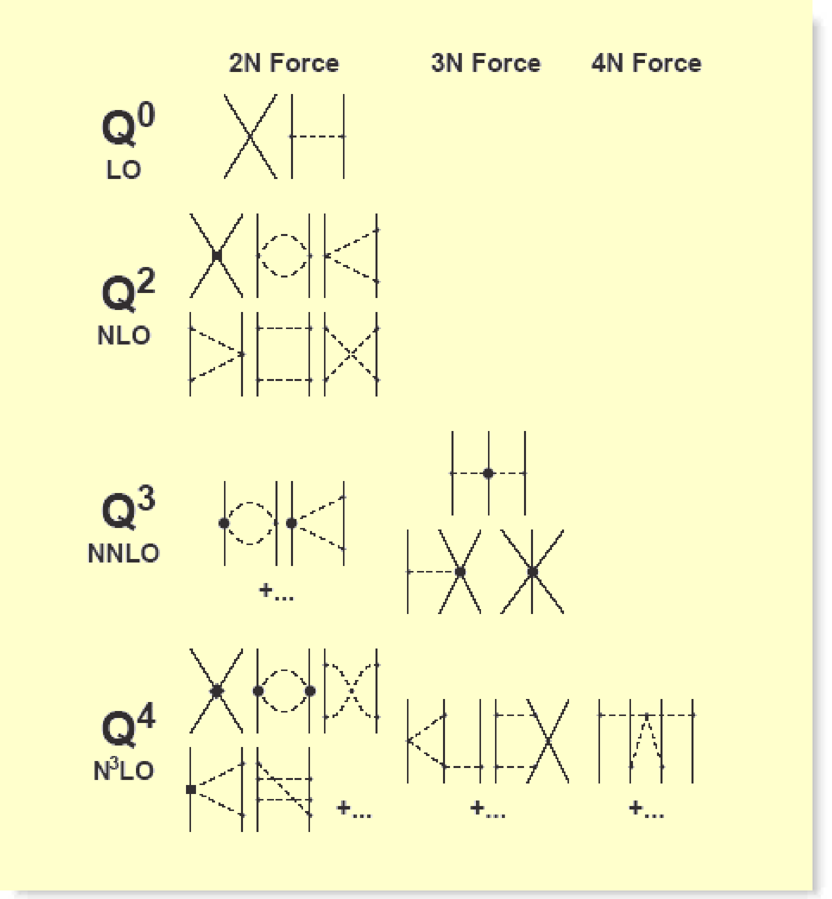


Tests of ab-initio Calulations in Few-Body Physics

- Ab initio calculations e.g. with Effective Field Theory
- Consistent chiral expansion of elementary NN-interaction



- Consistent expansion of Few-Body-Systems
- Very promising, but



How can we test this?

How can we test Ab-Initio-Calculations?

- Challenge for theory: Reaction dynamics

  Possible solution:

  - Use EFT input for potentials
  - Faddeev Calculations for dynamics (J. Golak, H. Witała, ...)
  - Prediction of dynamic observables
  - Promising: Polarization observables

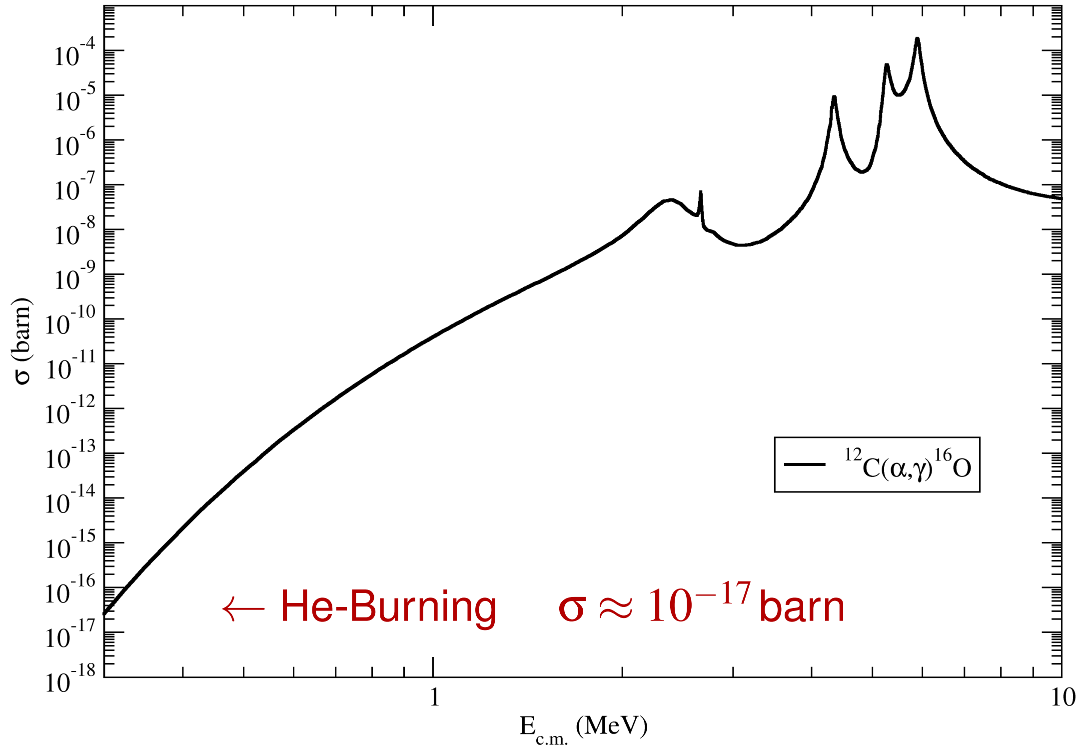
- Challenge for experiments: Low Momentum Region

  Needed:

  - High resolution (separate excited states!)
  - Low momentum (use gas targets!)
  - High luminosity (in spite of gas target!)
  - High degrees of beam and target polarization (in spite of high luminosity!)

$\Rightarrow$ Magix @ MESA

Astrophysical S-Factor for $\alpha(^{12}C,^{16}O)\gamma$



How to overcome limits:

1. Timereversal (enhancement by factor 10 due to spin weight):

$$\gamma + ^{16}O \rightarrow ^{12}C + \alpha$$

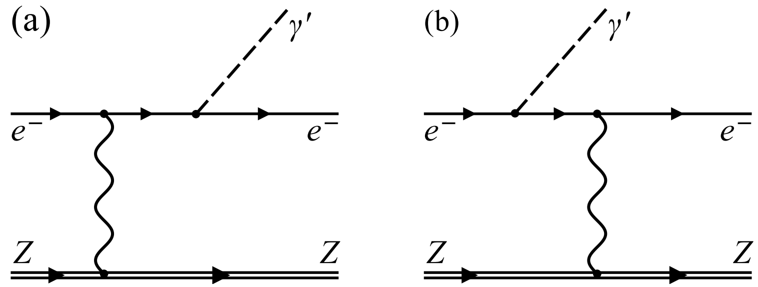
2. Covering the Threshold: Electroproduction in limit $Q^2 \rightarrow 0$

$$e + ^{16}O \rightarrow e' + ^{12}C + \alpha \quad \Leftrightarrow \quad \gamma^* + ^{16}O \rightarrow ^{12}C + \alpha$$

   Electron has large momentum, but virtual photon energy goes to zero!

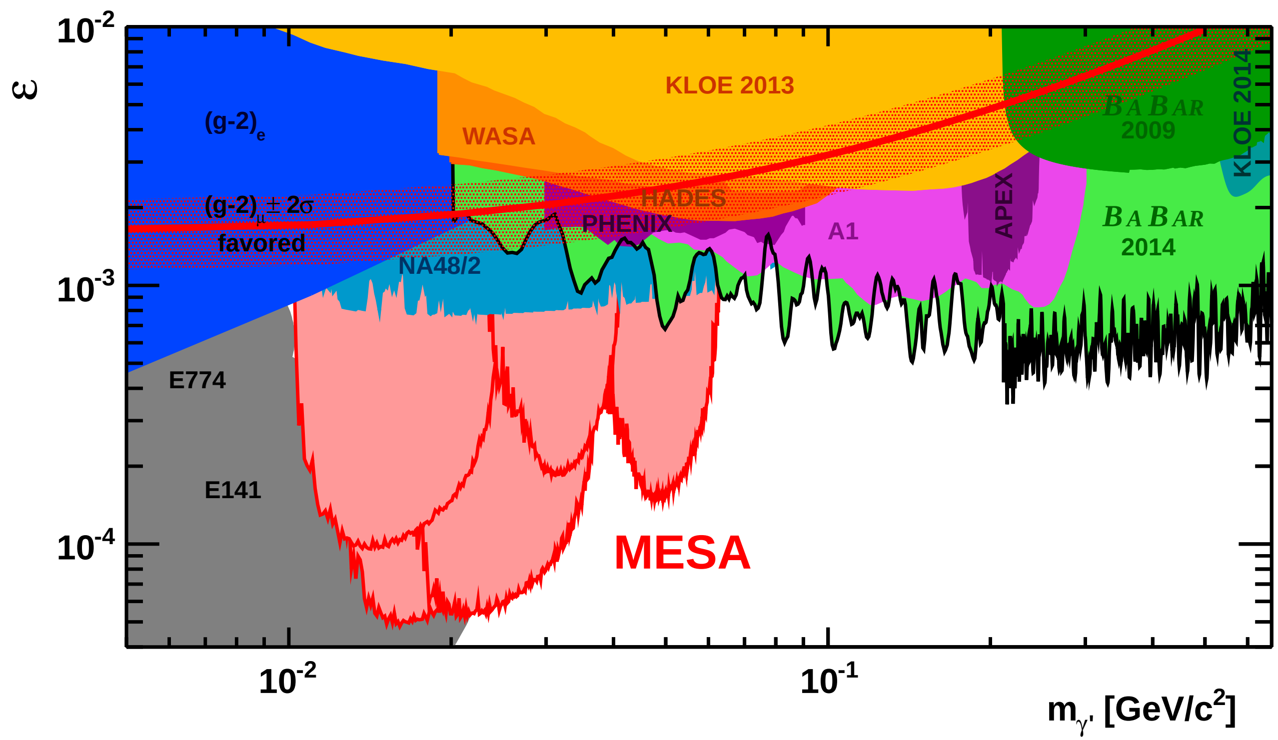
3. Detection of slow recoil $\alpha \Rightarrow$ gas target, recoil detector

Search for exotic particles: Dark Photons

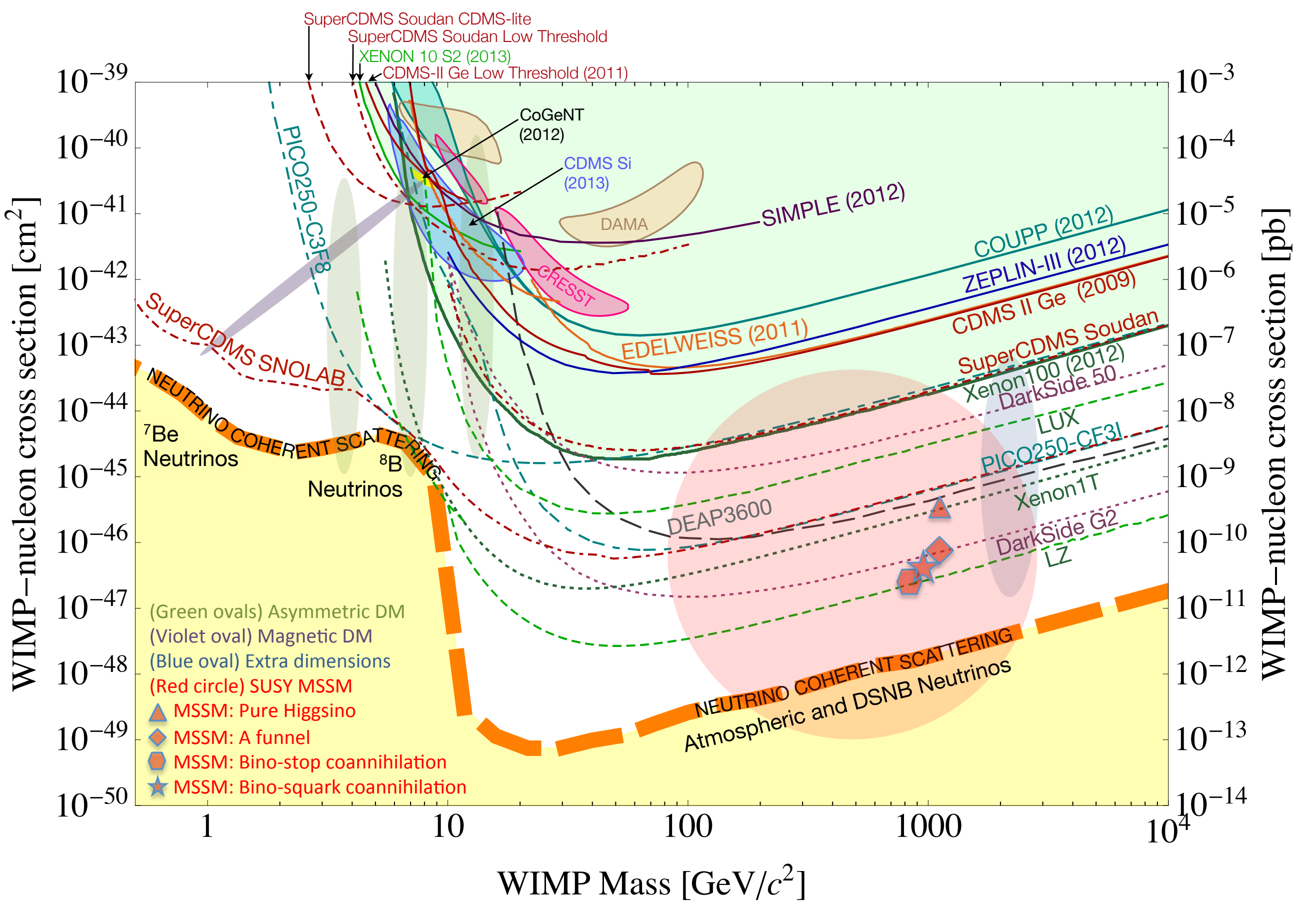


- Dark photon: Force carrier of the Dark Sector
- Radiative production

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



Beam-Dump Experiments: Motivation

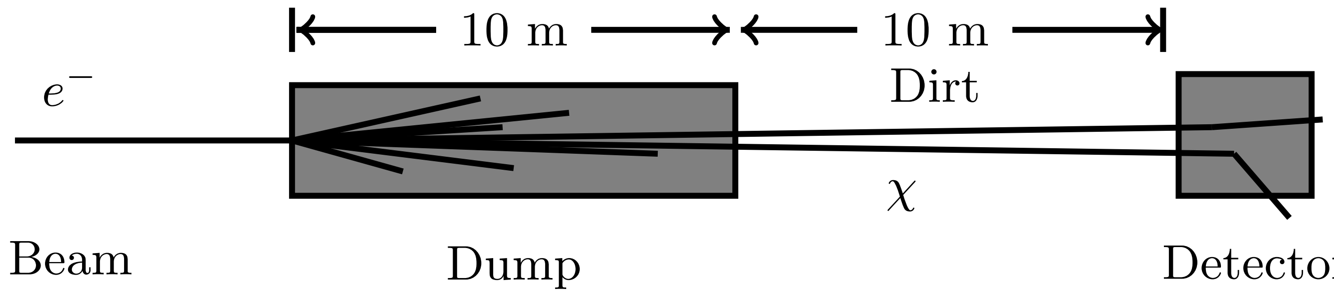


Direct detection experiments:

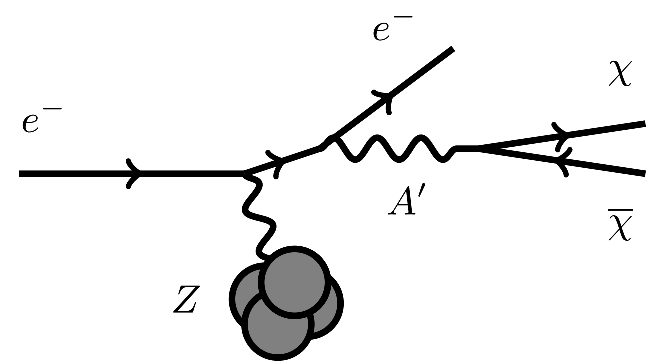
- No clear signal yet
- Limit of sensitivity (solar ν background) will be reached soon
- Lower masses (*i.e.* low recoil energy) not accessible

P. Cushman, *et al.*, arXiv:1310.8327

Beam-Dump Experiments: Idea

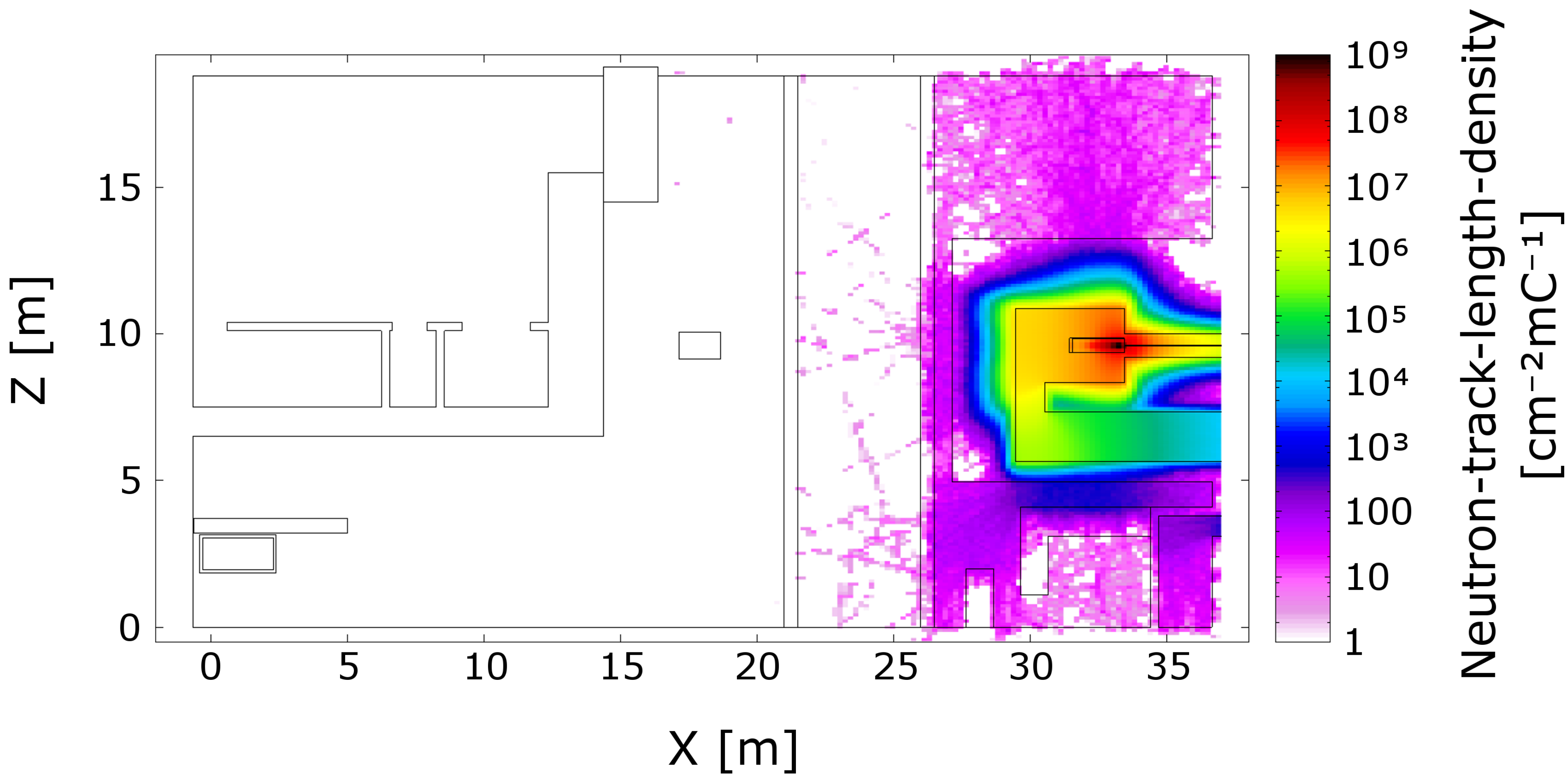


- Production in beam dump, *e.g.* via pair production



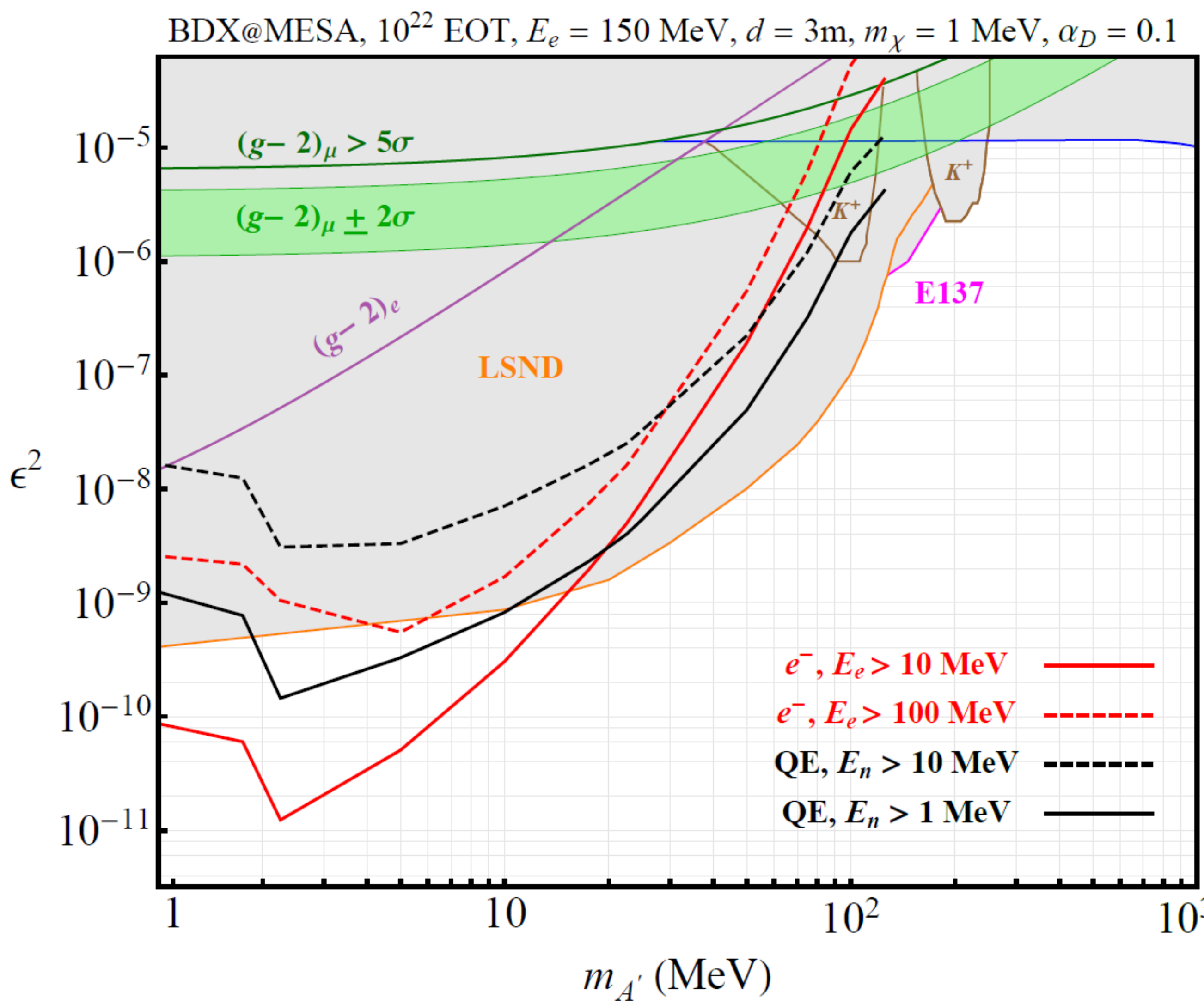
- We now have a Dark Matter Beam!
- Dark Matter particles have enough recoil energy!
- Detection with simple detector, *e.g.* scintillator cube
- ... or with sophisticated DM Detector ...

FLUKA Simulation



- Neutrons can be shielded
- Below pion threshold: negligible ν background
- Clean conditions, detailed layout of hall needed for further design

Magix Sensitivity



- Reasonable sensitivity for low mass region
- Multidimensional plot: Assumptions for dark photon mass, m_χ

Calculations: G. Krnjaic

Summary

MESA:

- High beam current in Energy Recovery mode
- Excellent beam quality

MAGIX:

- High Resolution Spectrometers
- High density or high polarization internal target
- Multi-purpose setup for precision physics

Physics Program

- Precision form factors: Magnetic Radius of the Proton
- Nuclear Astrophysics: S-Factor measurements
- Few-Body physics
- Search for exotic particles
- ... Contributions from other groups are welcome!