Achim Denig

Institute for Nuclear Physics

Johannes Gutenberg University Mainz

JG|U

SFB 1044
THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

Cluster of Excellence
PRISMA+
Precision Physics, Fundamental Interactions and Structure of Matter

Precision Physics at the future MESA accelerator

February 25, 2019
BINP Novosibirsk, Russia
Intl. Workshop on e+e- Physics from Phi to Psi

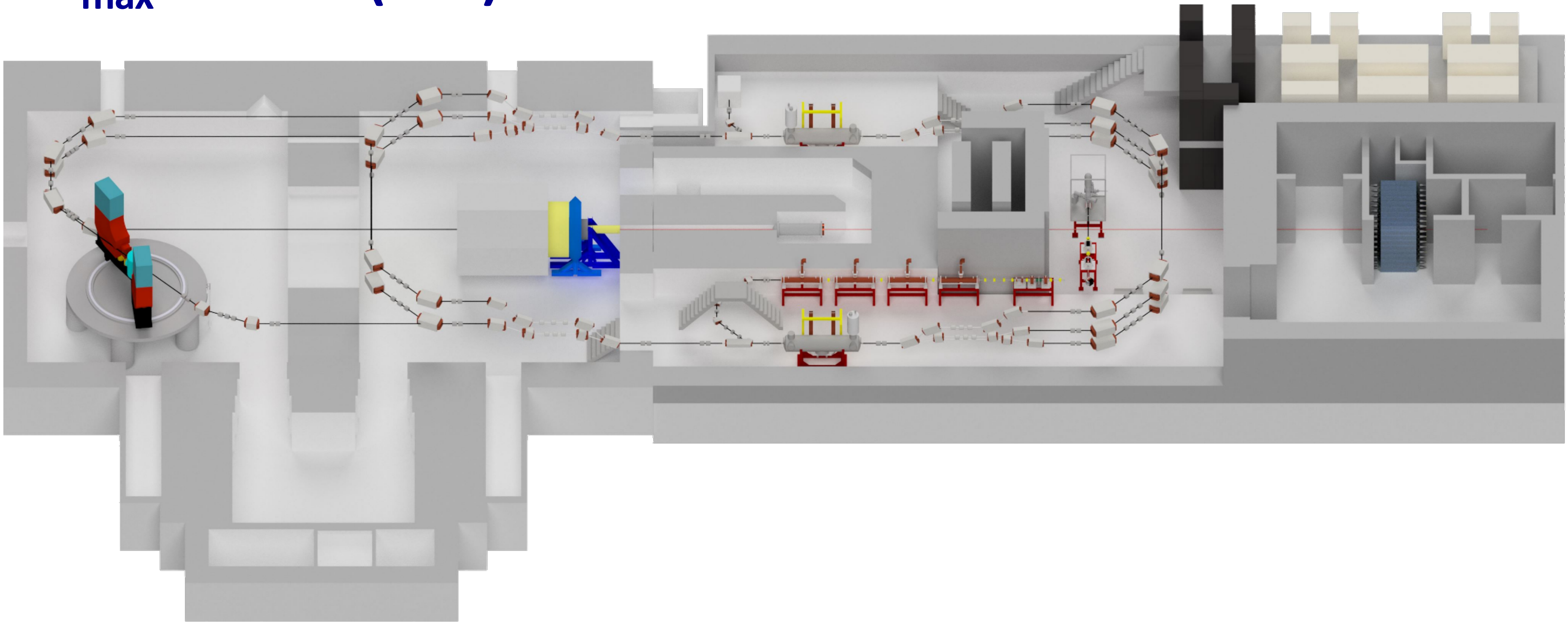
Novosibirsk State University
*THE REAL SCIENCE

Mainz Energy-Recovering Superconducting Accelerator

Recirculating ERL

E_{max} = 105/155 MeV

I_{max} > 1 mA (ERL)



MESA commissioning 2022

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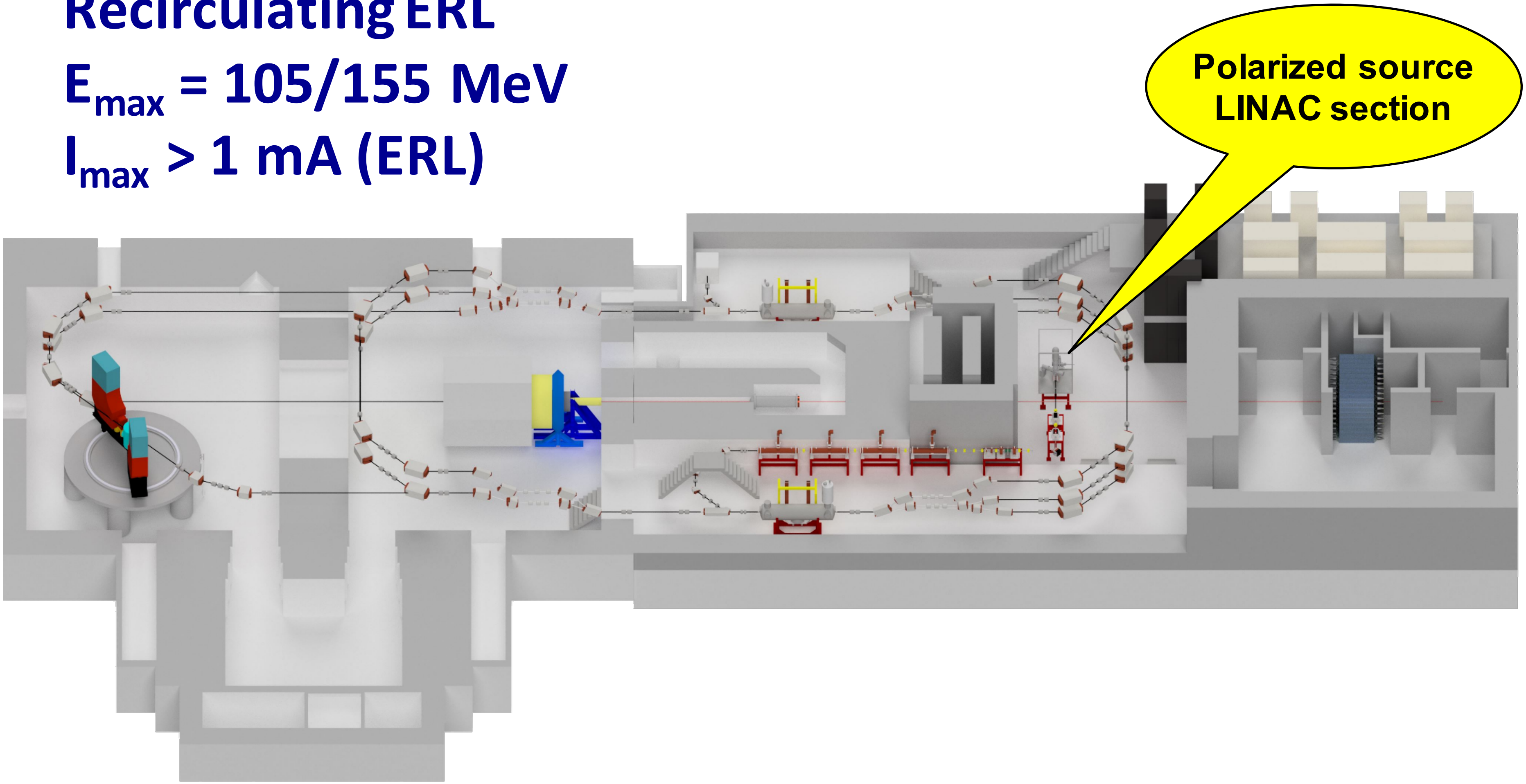

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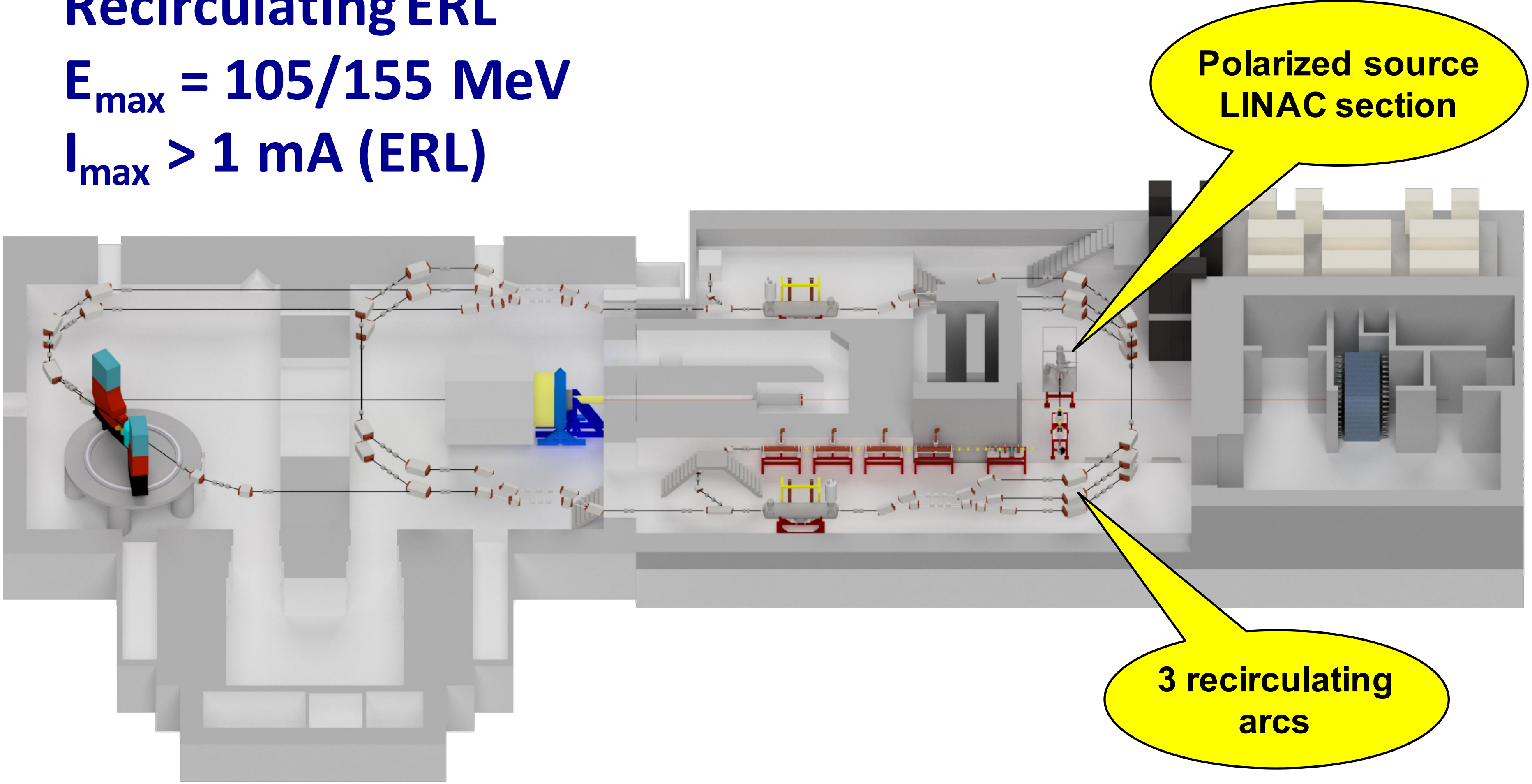
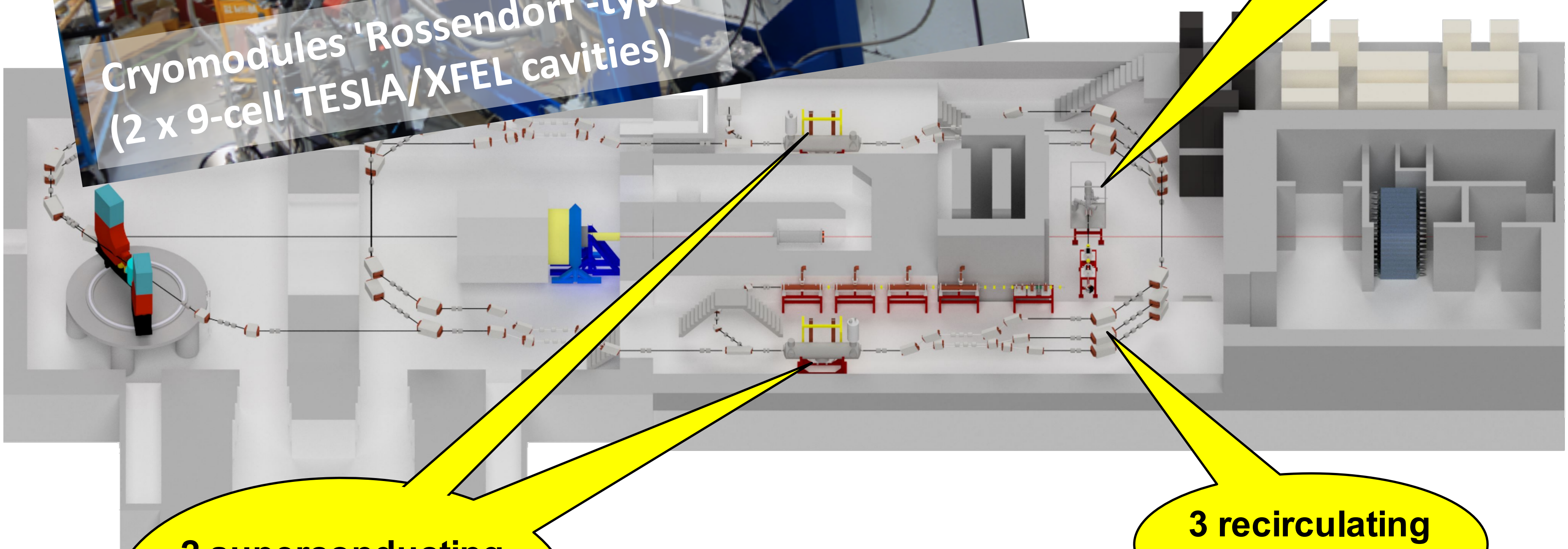


MESA Accelera…

…ducting Accelerator



MESA commissioning 2022

Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter PRISMA

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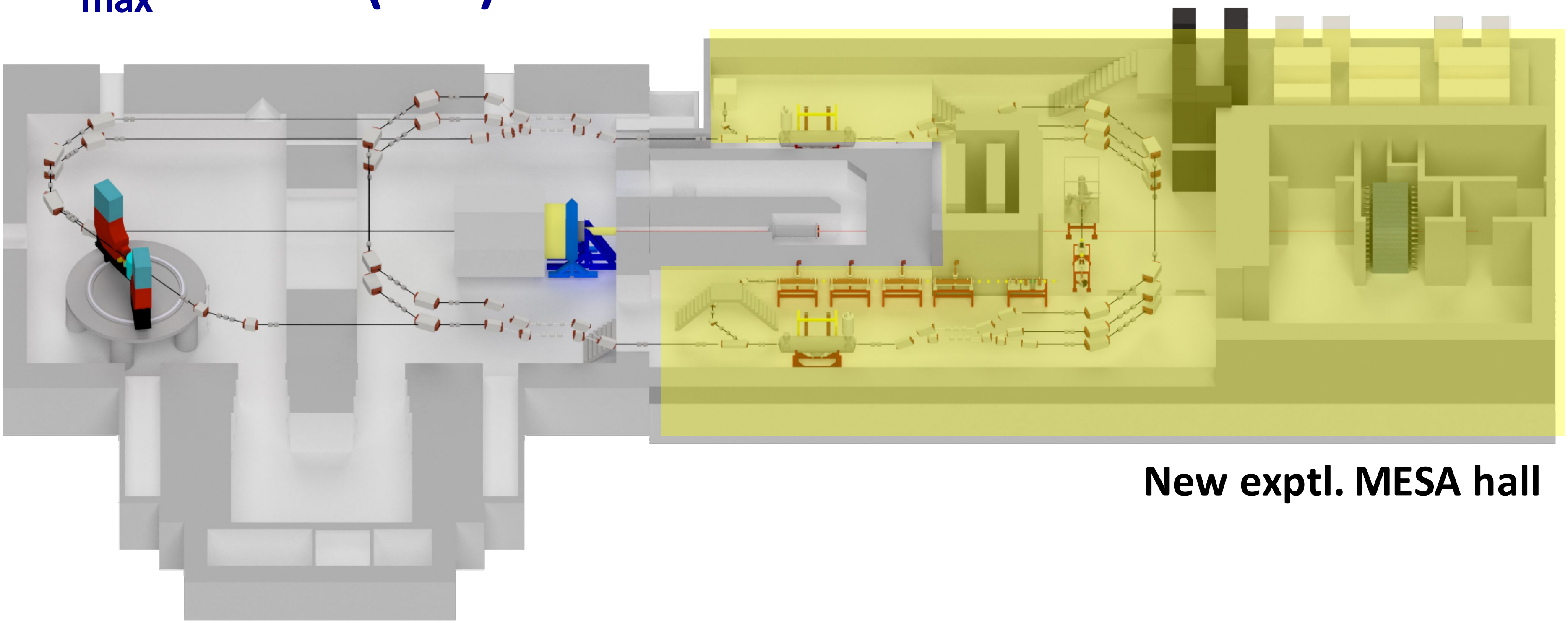

New exptl. MESA hall

MESA commissioning 2022

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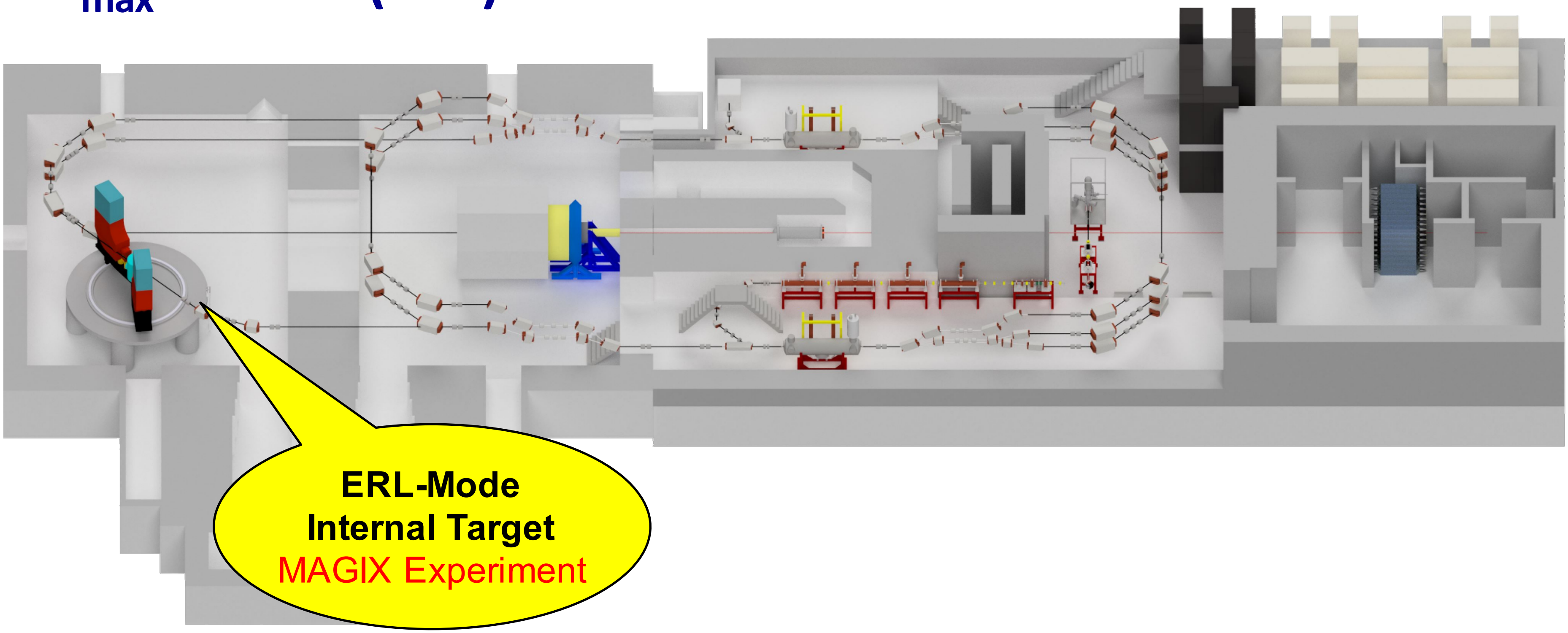

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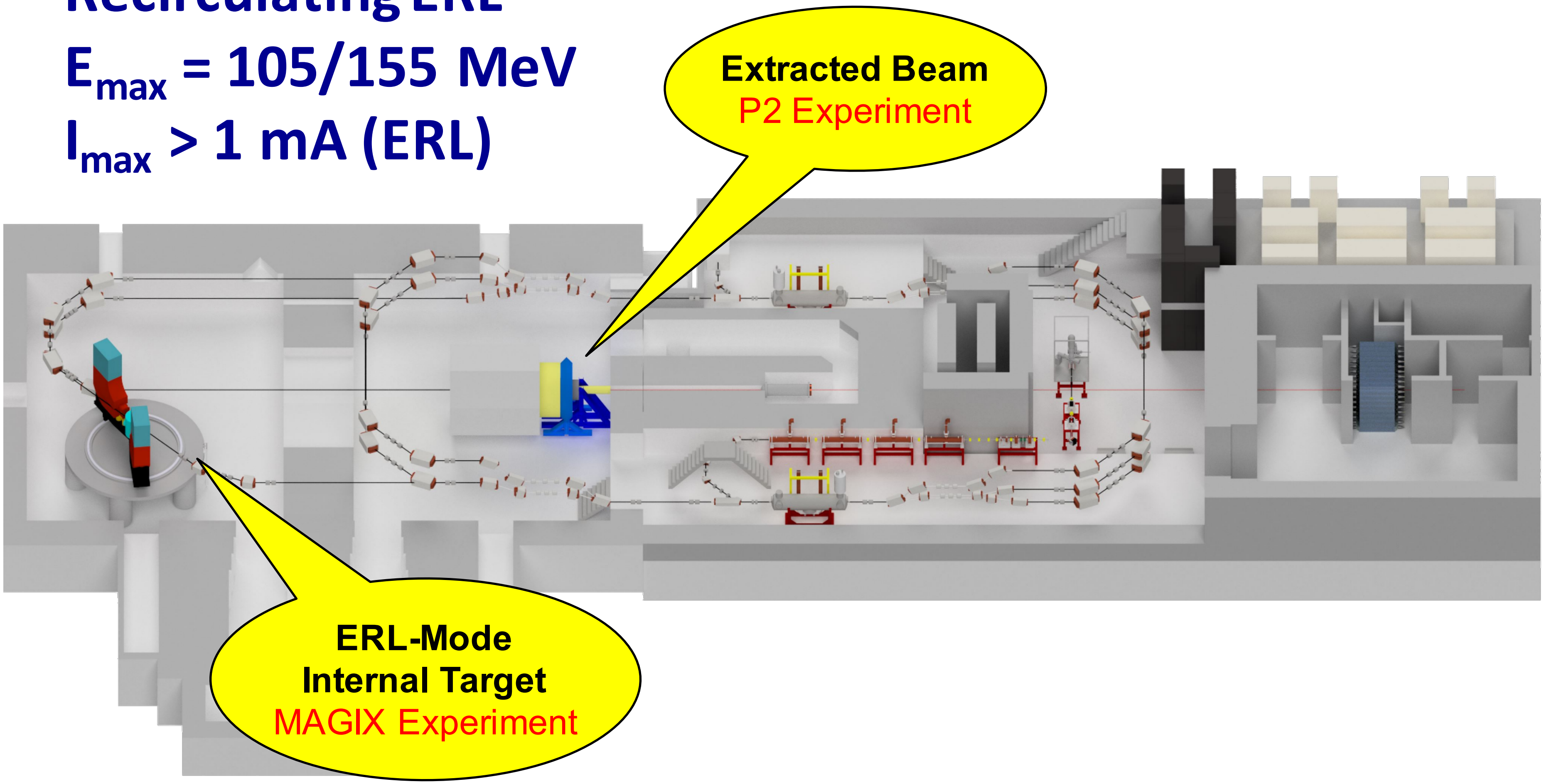

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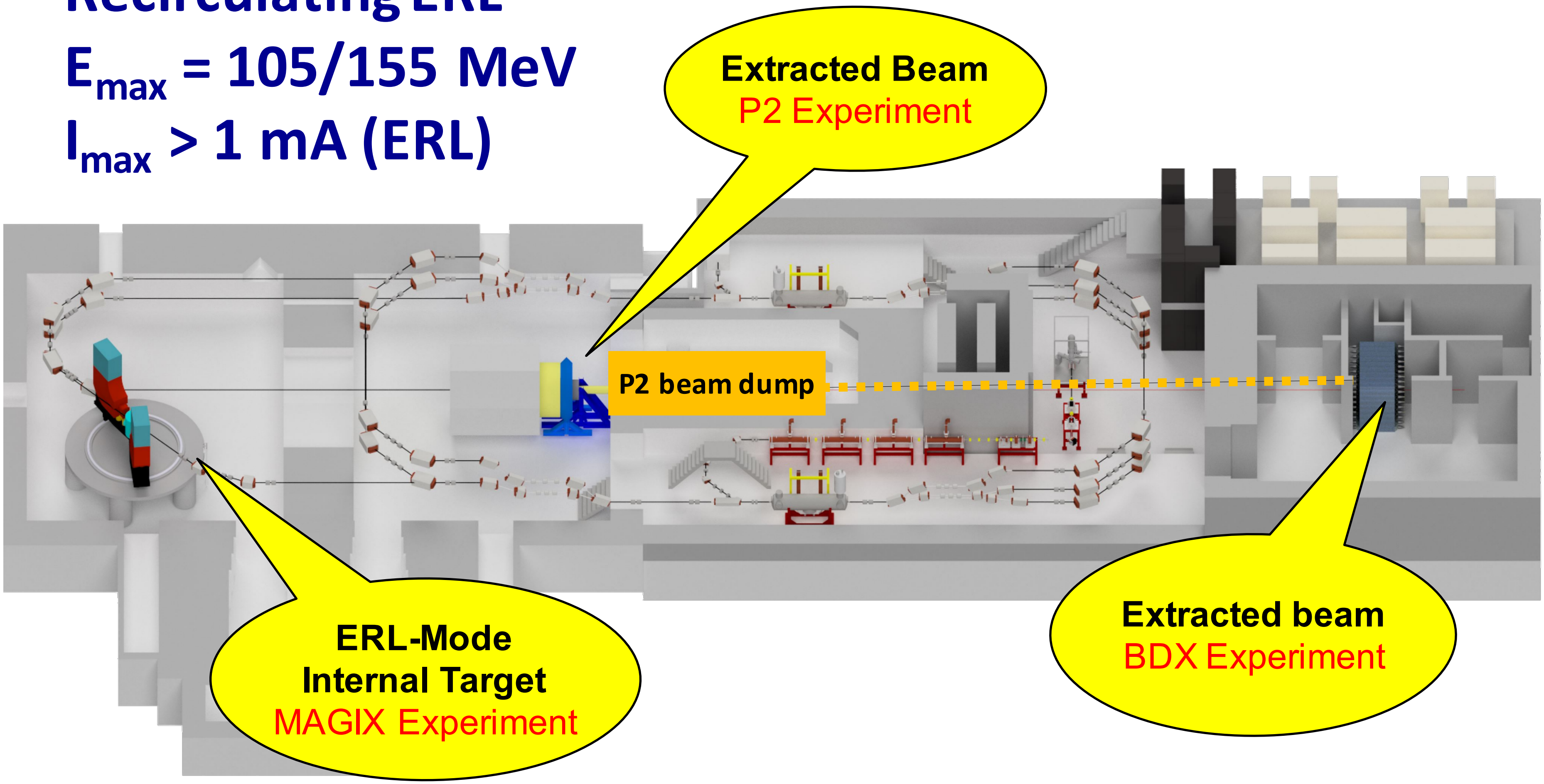
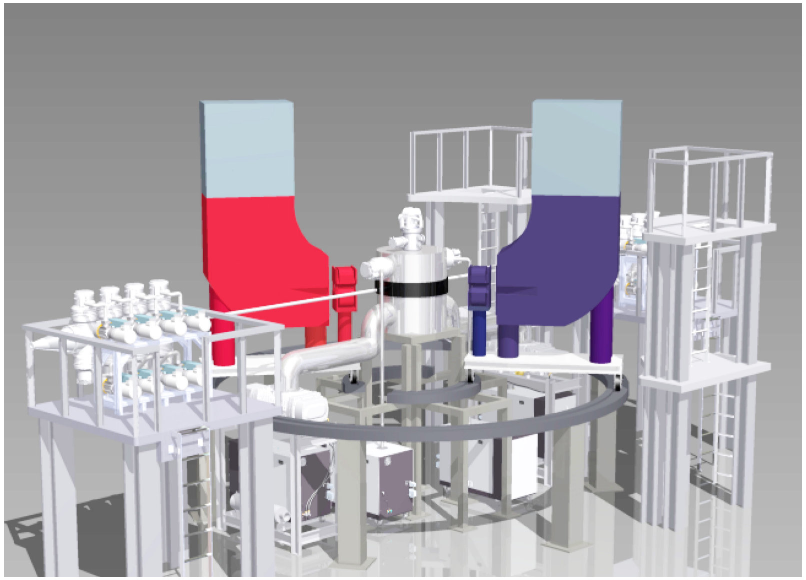


MESA Physics Programme

	ERL Mode MAGIX expt.	Extracted Beam Mode P2 expt.	Extracted Beam Mode BDX expt.
Nucleon From Factors	✔		
EW Mixing Angle		✔	
Nuclear Astrophysics	✔	neutron skin of nuclei ✔	
Few Body Physics	✔		
Light Dark Matter Search	✔		✔

Internal Gas Target Experiment MAGIX



in MESA ERL Mode

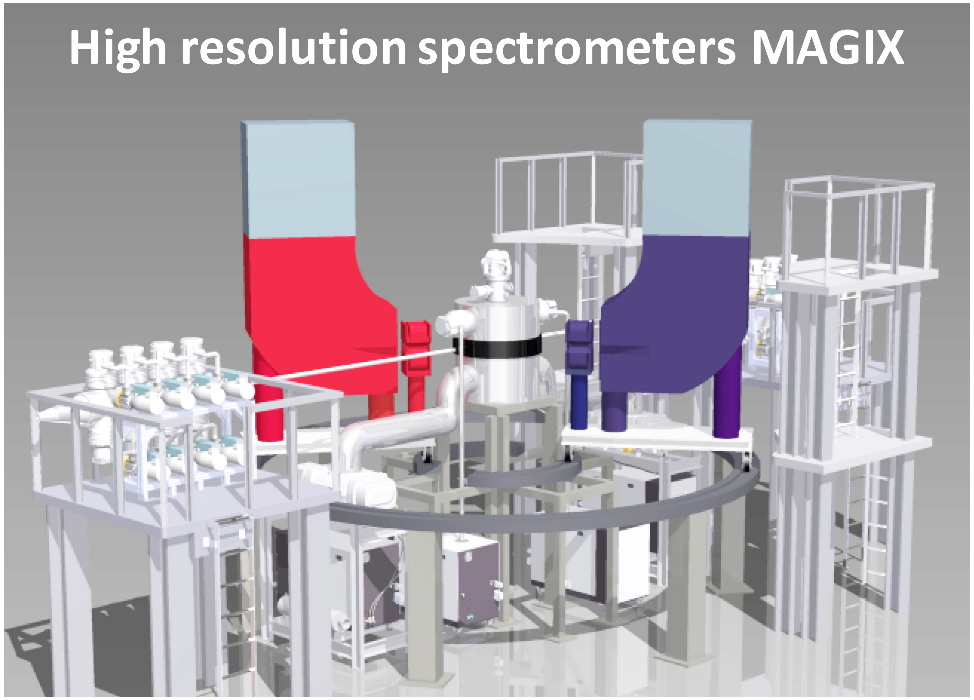
MAinz **G**as **I**nternal **EX**periment

Operation of a high-intensity (polarized) ERL beam (1mA) in conjunction with light internal target

→ **a novel technique in nuclear and particle physics**

→ **measurement of low momenta tracks with high accuracy**

→ **competitive luminosities ~ 10^{35} / cm^2 / s**



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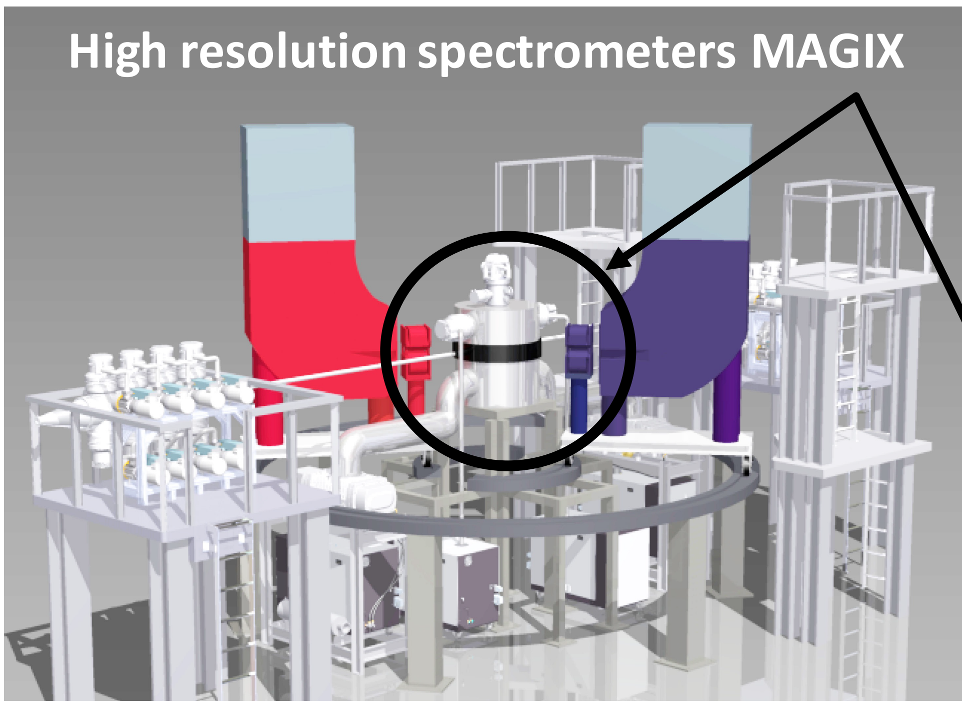
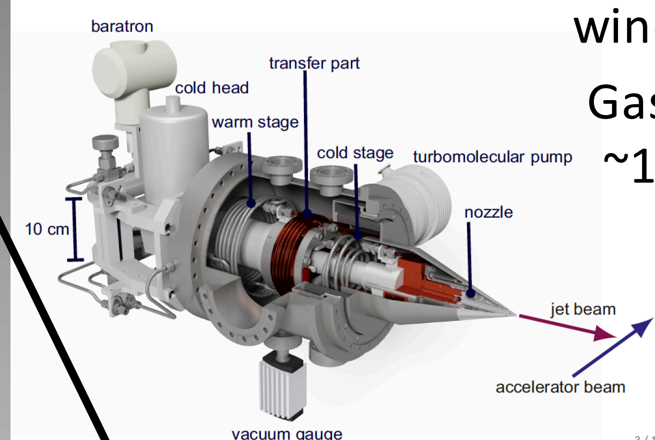
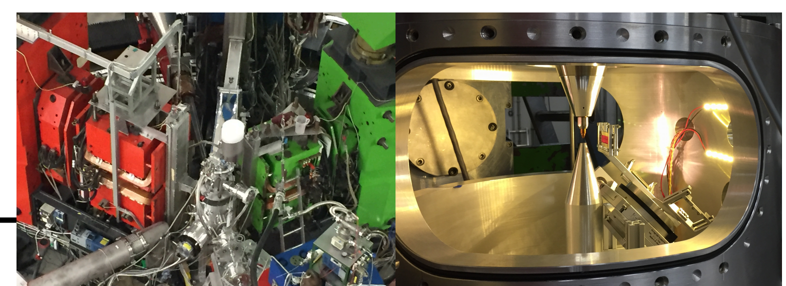


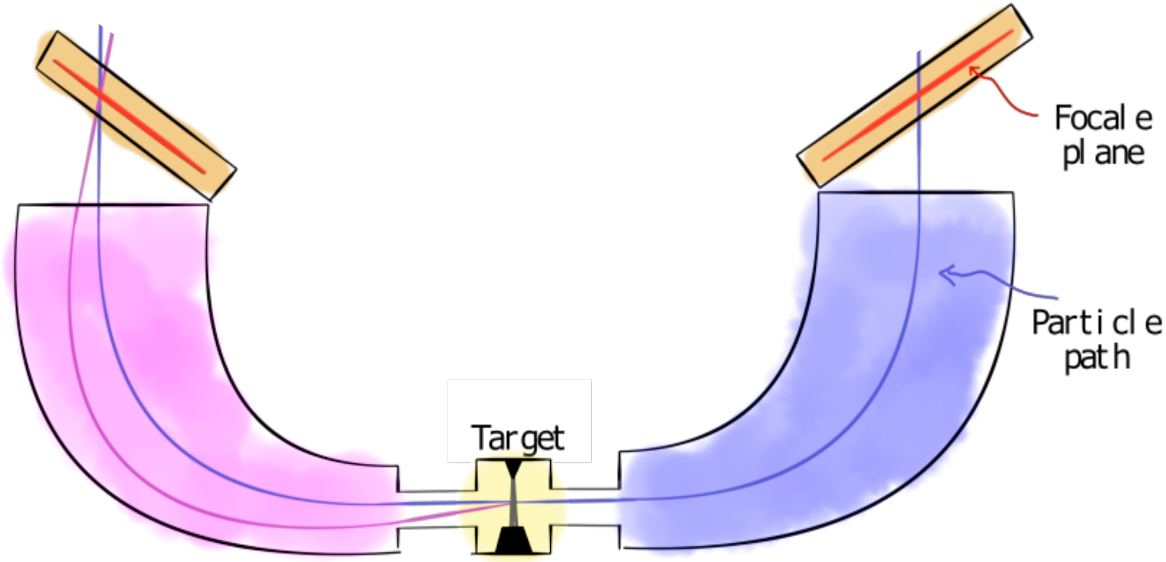
Gas jet target already commissioned windowless

Gas density ~$10^{19}/cm^2$





Focal Plane Detector for MAGIX



Focal plane:

- spatial measurement of particle track
- resolution of $\Delta p/p < 10^{-4}$
  → spatial resolution of 50 µm
- O(1 MHz) rate

→ Drift Chamber or GEM solutions not feasible

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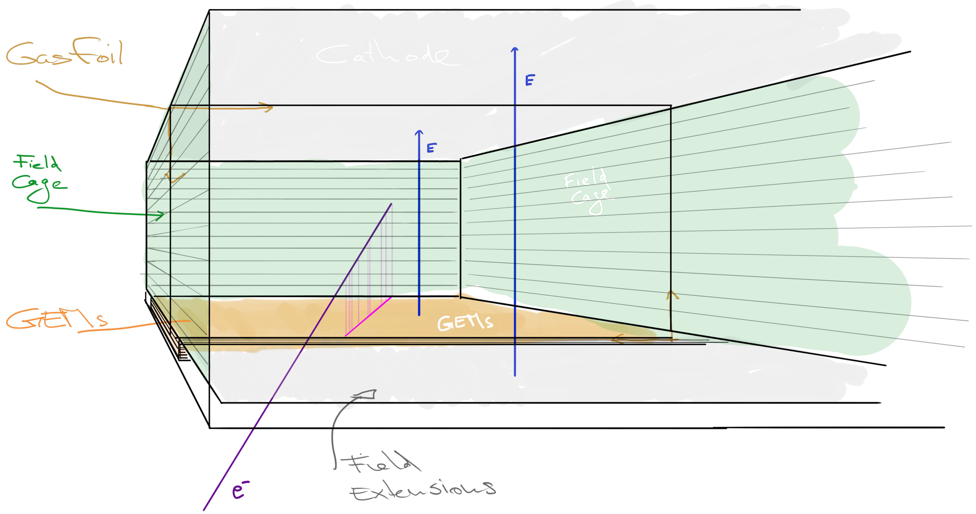
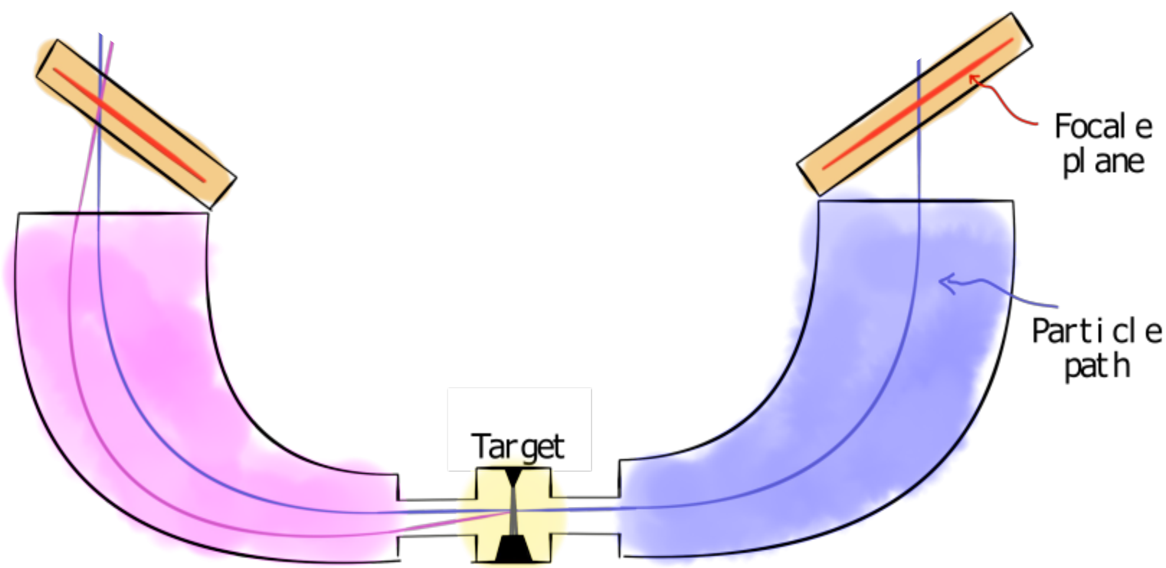


Baseline solution:

- Time Projection Chamber (TPC) open field cage and GEM readout
- VMM electronics read out
- Prototype currently operational



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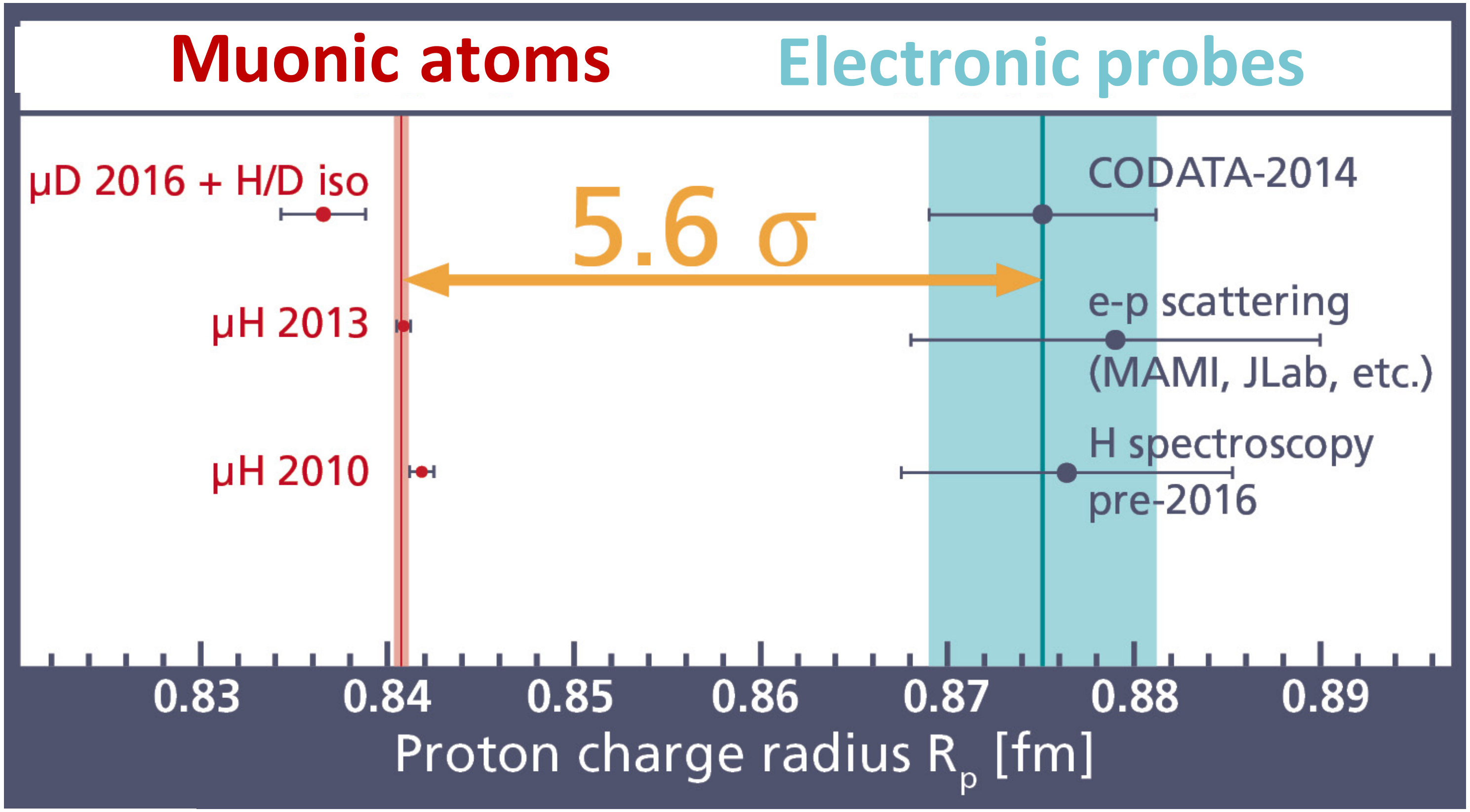
Electromagnetic Form Factors at MAGIX

The Proton Radius Puzzle



EM Form Factors of the Proton

Elastic form factors in ep scattering:

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

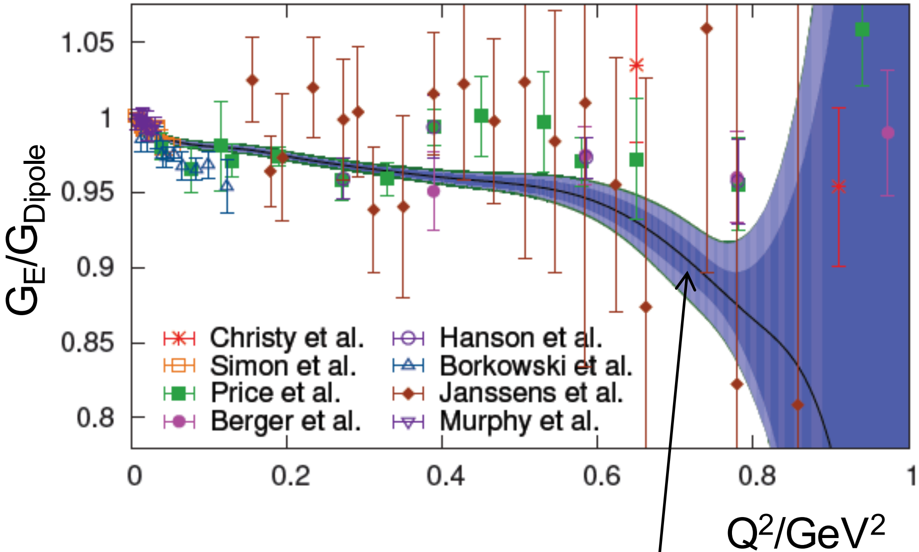
$$\varepsilon = \left(1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}\right)^{-1}$$

$$\tau = \frac{Q^2}{4m_p^2}$$

G_E: spatial electric charge distribution

G_M: distribution of magnetic moments

Super-Rosenbluth measurement



Mainz measurement average of all fit models with uncertainties

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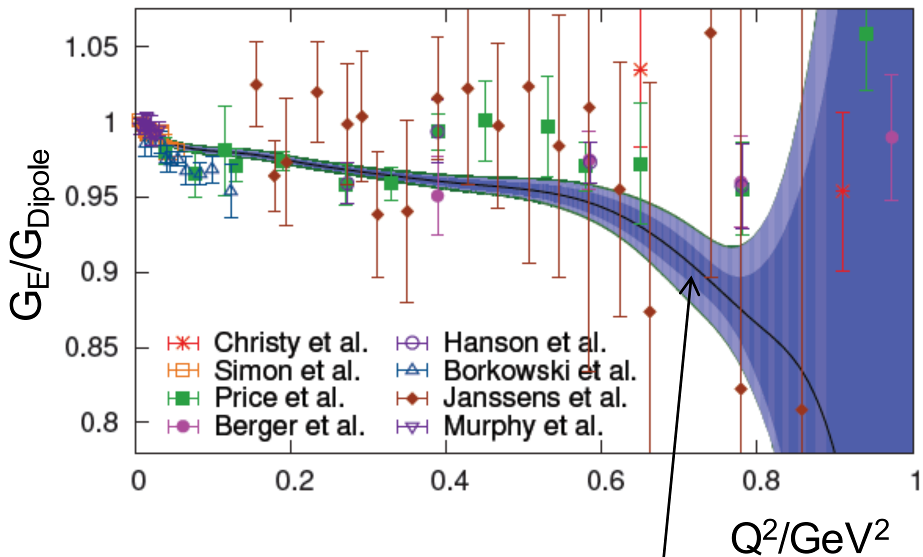


Mainz measurement
average of all fit models
with uncertainties

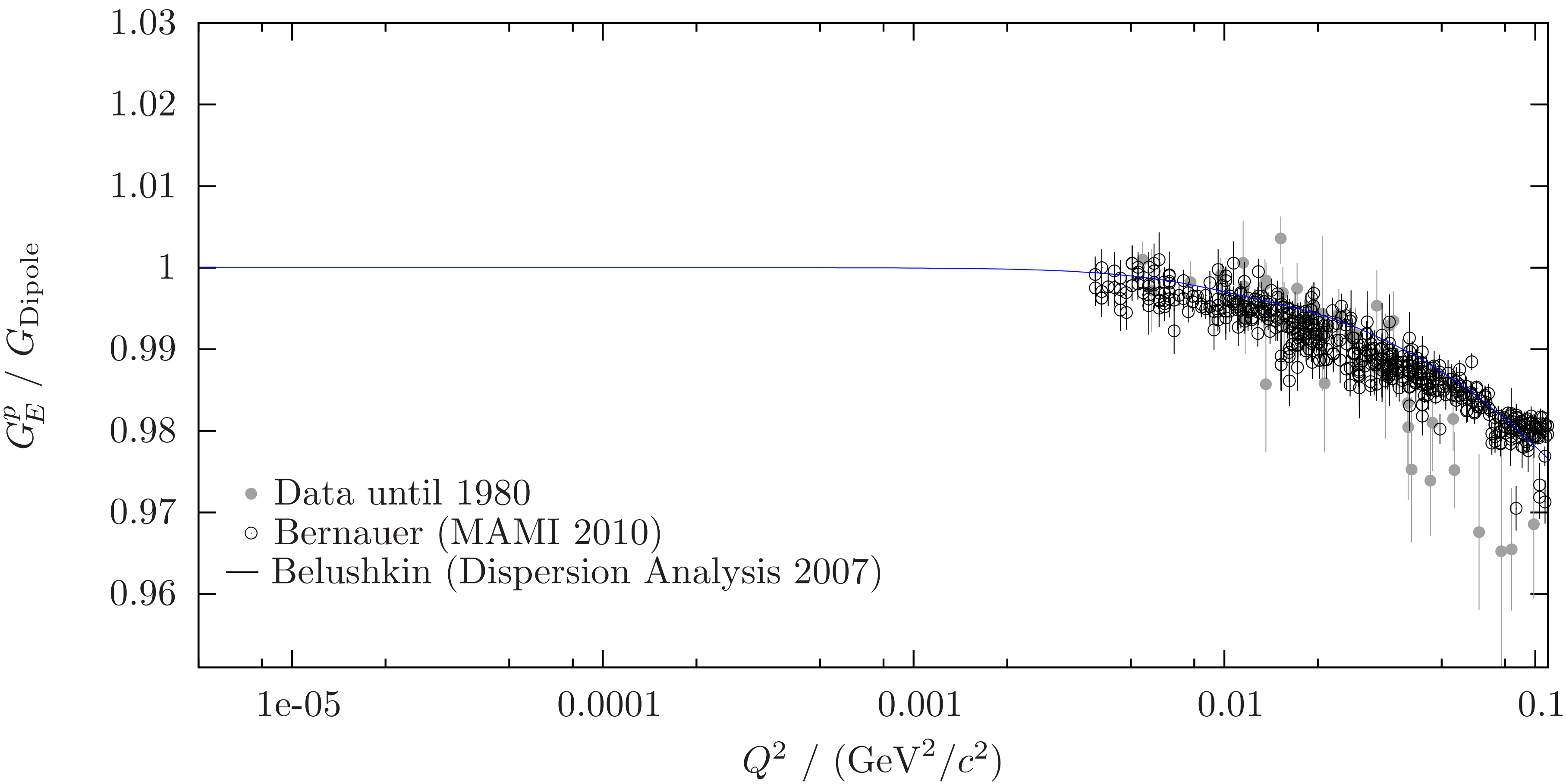
Proton charge radius:

$$\left\langle r_{E/M}^2 \right\rangle = -\frac{6\hbar^2}{G_{E/M}(0)} \frac{dG_{E/M}(Q^2)}{dQ^2}\bigg|_{Q^2=0}$$

PRL10 (A1): $\langle r_E \rangle$ = 0,879(8) fm

PRL '10, 242001: Bernauer et al.
PRC '14 015206: Bernauer et al.

Low-Q^2 Scattering Data with MAGIX



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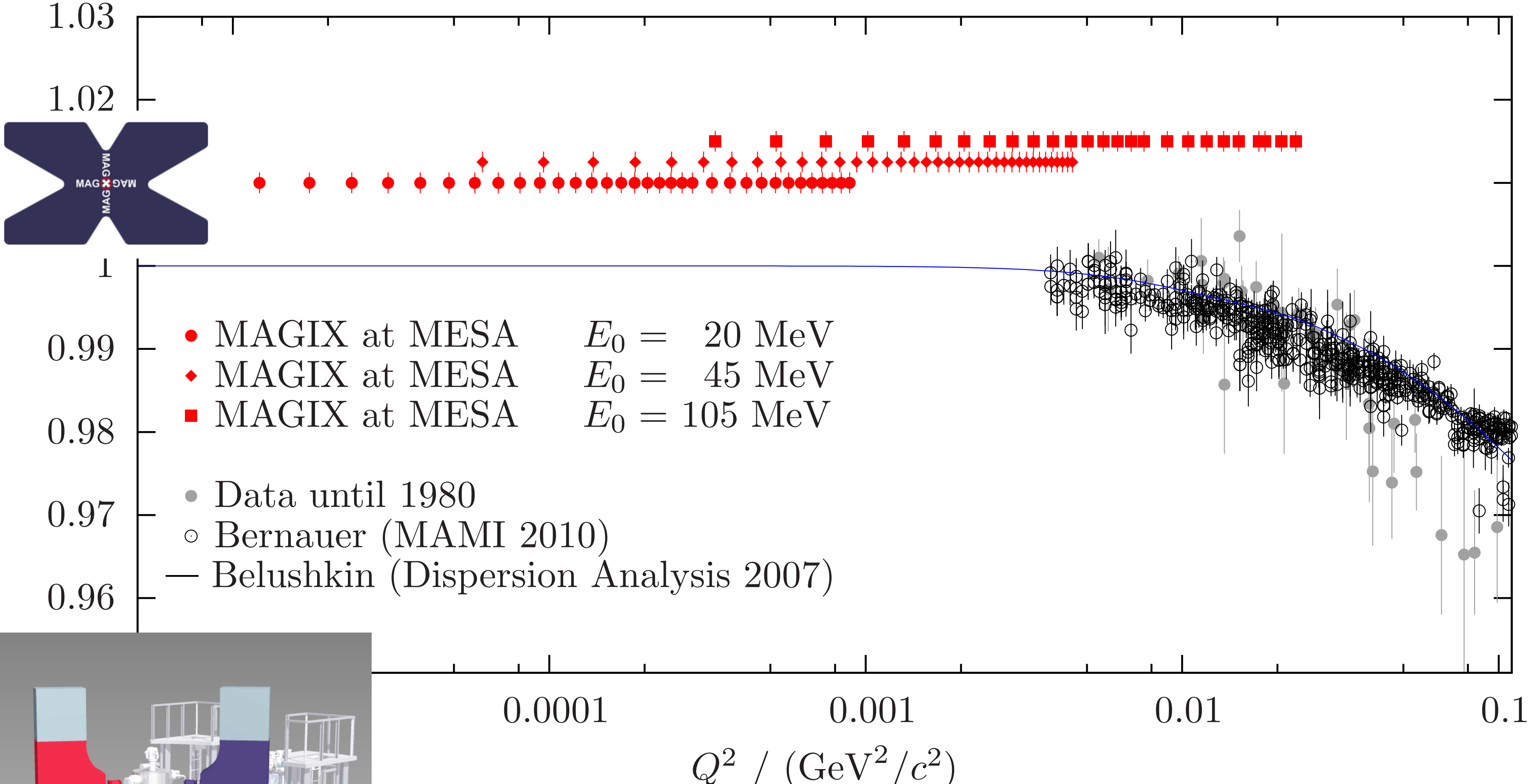

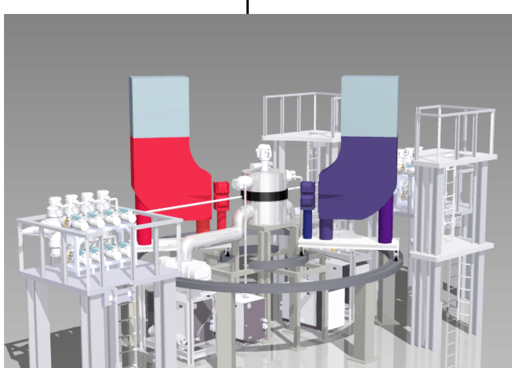

Magnetic Form Factor @ MAGIX

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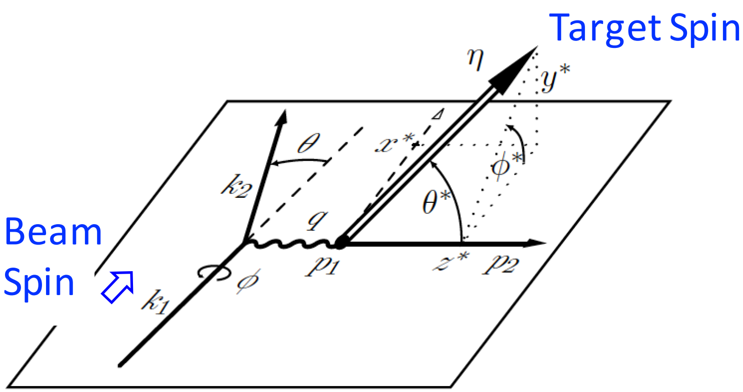
$$\varepsilon = \left(1 + 2(1+\tau)\tan^2\frac{\theta_e}{2}\right)^{-1}$$

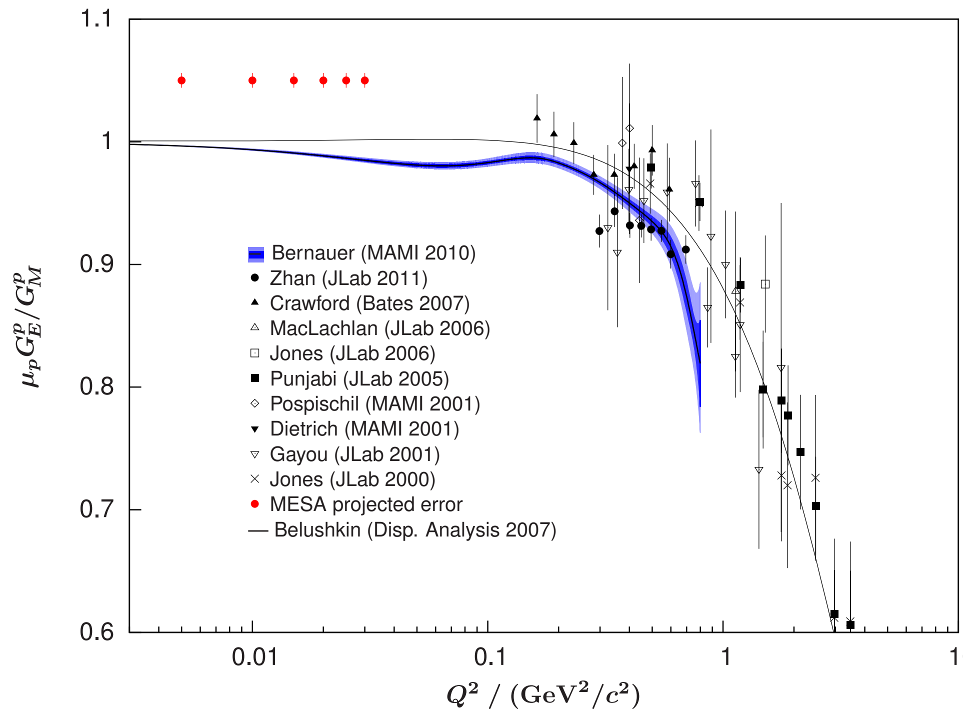
long. polarization of virtual photon

Low Q^2 accessible with low E_{beam}

Suppressed at low Q^2 due to τ

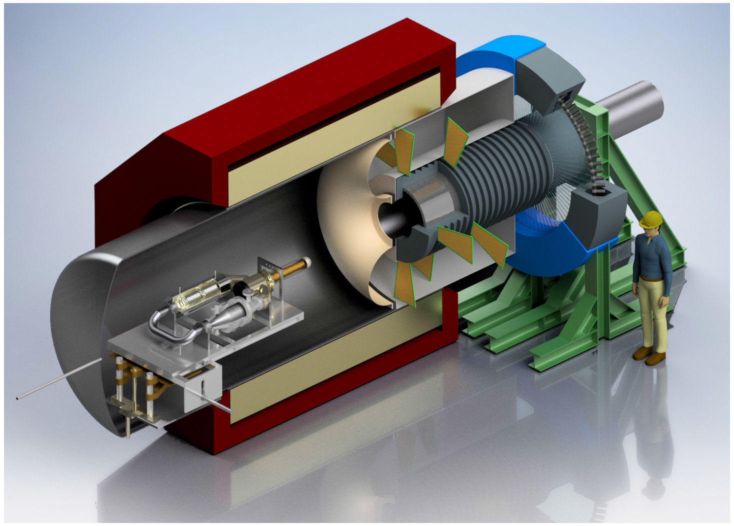
→ Double polarization measurement
Beam Target Asymmetry !





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

Measurement of the electroweak mixing angle with P2



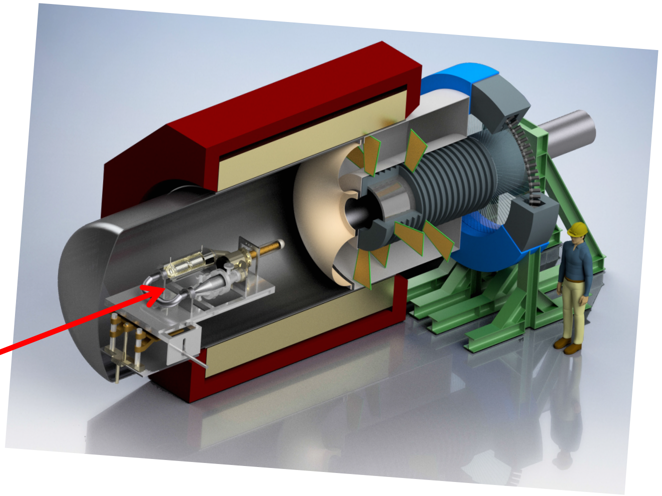
in MESA Extracted Beam Mode

A Low-Q^2 Measurement of $\sin^2\theta_W$ @ P2

Scattering of longitudinally polarized electrons on unpolarized protons

→ **Z boson exchange** in electron-proton scattering introduces **parity-violating effect**

→ Measure **parity-violating Left-Right cross section asymmetry A_{LR} (= 40 x 10^{-9})**



155 MeV
150 µA
Polarized
Electron Beam

weak charge

$$A_{LR} = \frac{\sigma(e\uparrow) - \sigma(e\downarrow)}{\sigma(e\uparrow) + \sigma(e\downarrow)} = -\frac{G_F Q^2}{4\sqrt{2}\pi\alpha}(Q_W - F(Q^2))$$

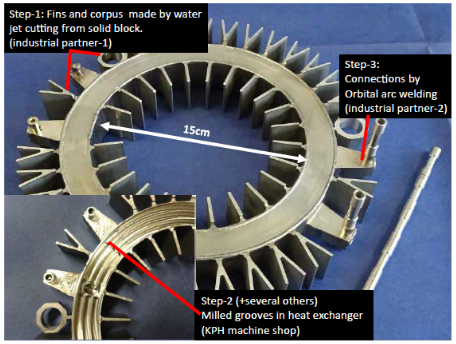
$$Q_W = 1 - 4\sin^2\theta_W(\mu)$$

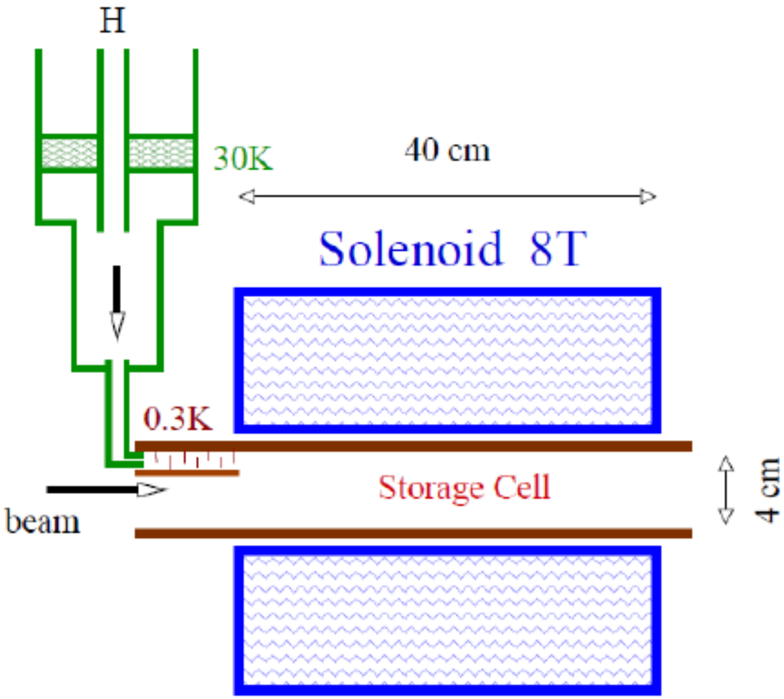
hadron structure

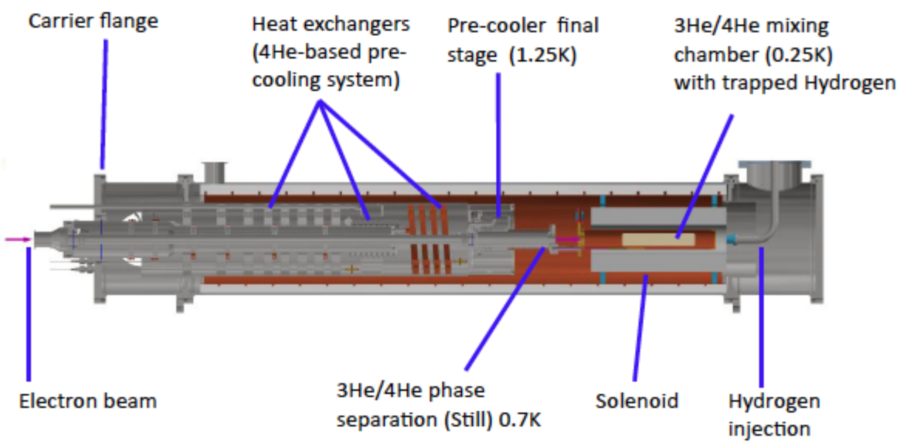
Beam Polarimetry @ MESA

Strategy: Redundant measurement of beam polarization with < 1% accuracy each

- Double scatter Mott polarimeter @ 100 keV
- Single scatter Mott polarimeter @ 5 MeV
- Hydro Moeller Polarimeter @ 155 MeV (in situ)
  exchange ferromagnetic probe by trapped polarized hydrogen atoms (engineering challenge)
  → expected accuracy <0.5%

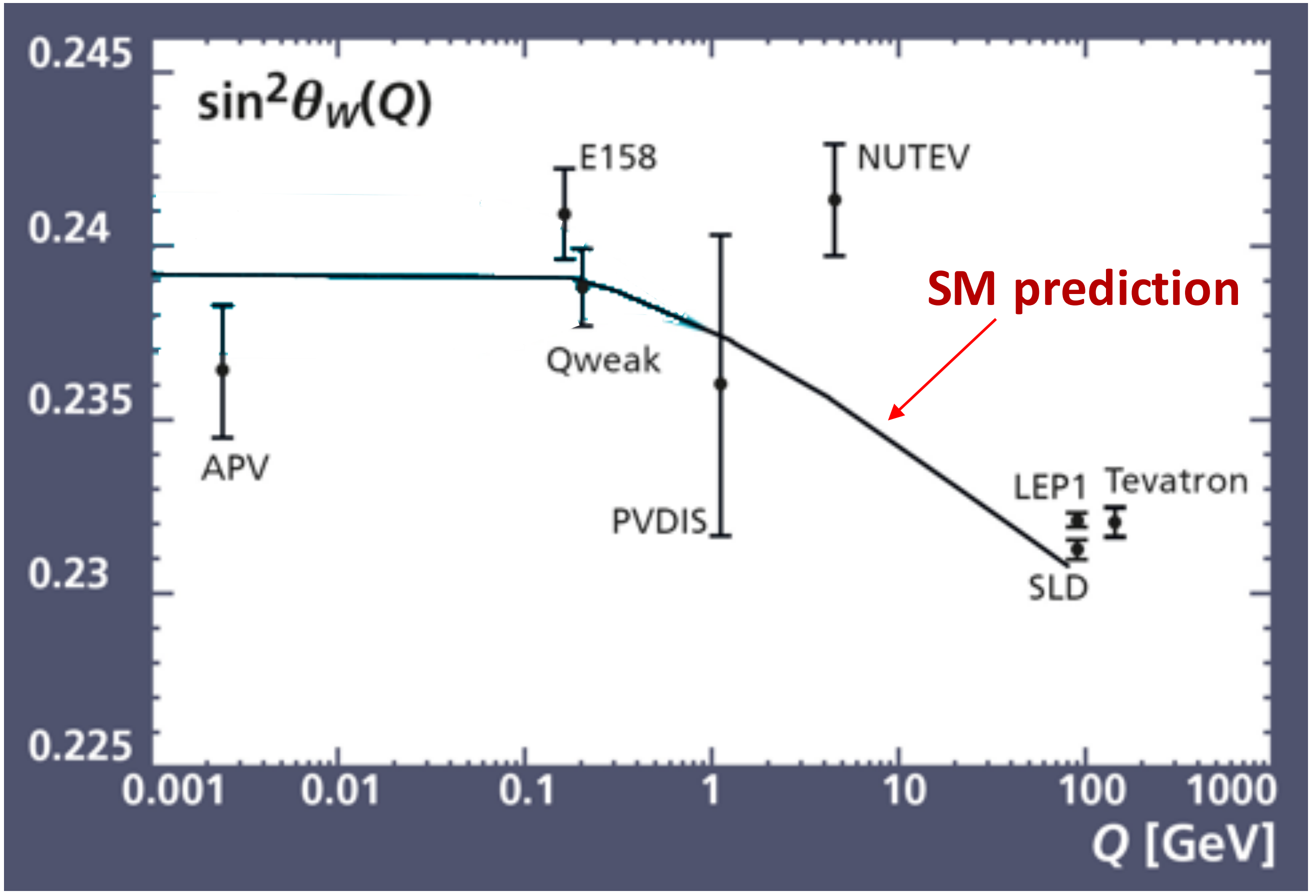






$$A_m = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}} = P_T P_B \frac{\sin^2\theta(7+\cos^2\theta)}{(3+\cos^2(\theta))^2}$$

A Low-Q^2 Measurement of $sin^2\theta_W$ @ P2



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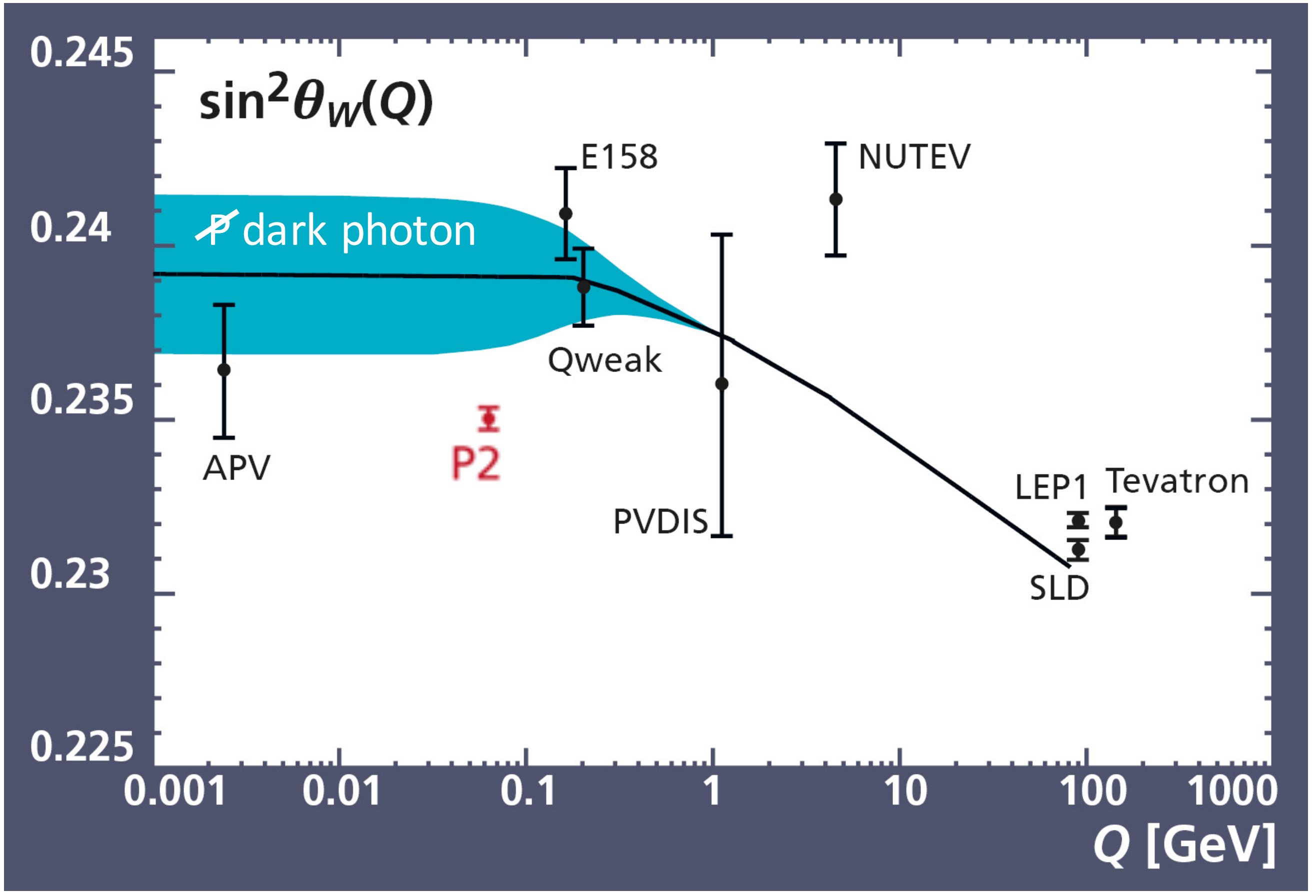


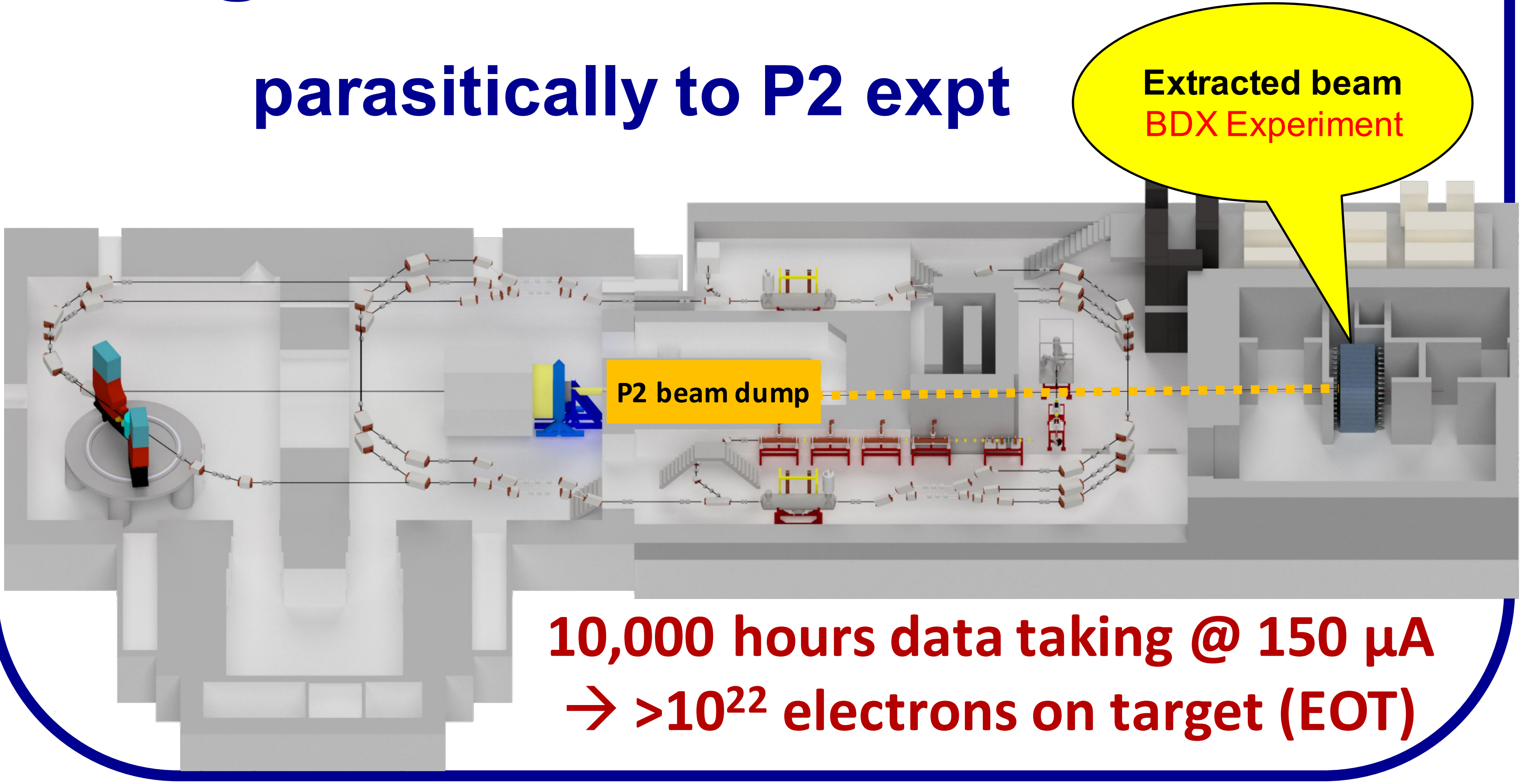
<u>P2 goal</u>: Measure parity-violating Left-Right asymmetry A_{LR} of 39 x 10^{-9} with 1.4% accuracy

→ Comparison with SM prediction probes NEW PHYSICS UP TO 49 TeV

BDX:

Light Dark Matter Search

parasitically to P2 expt

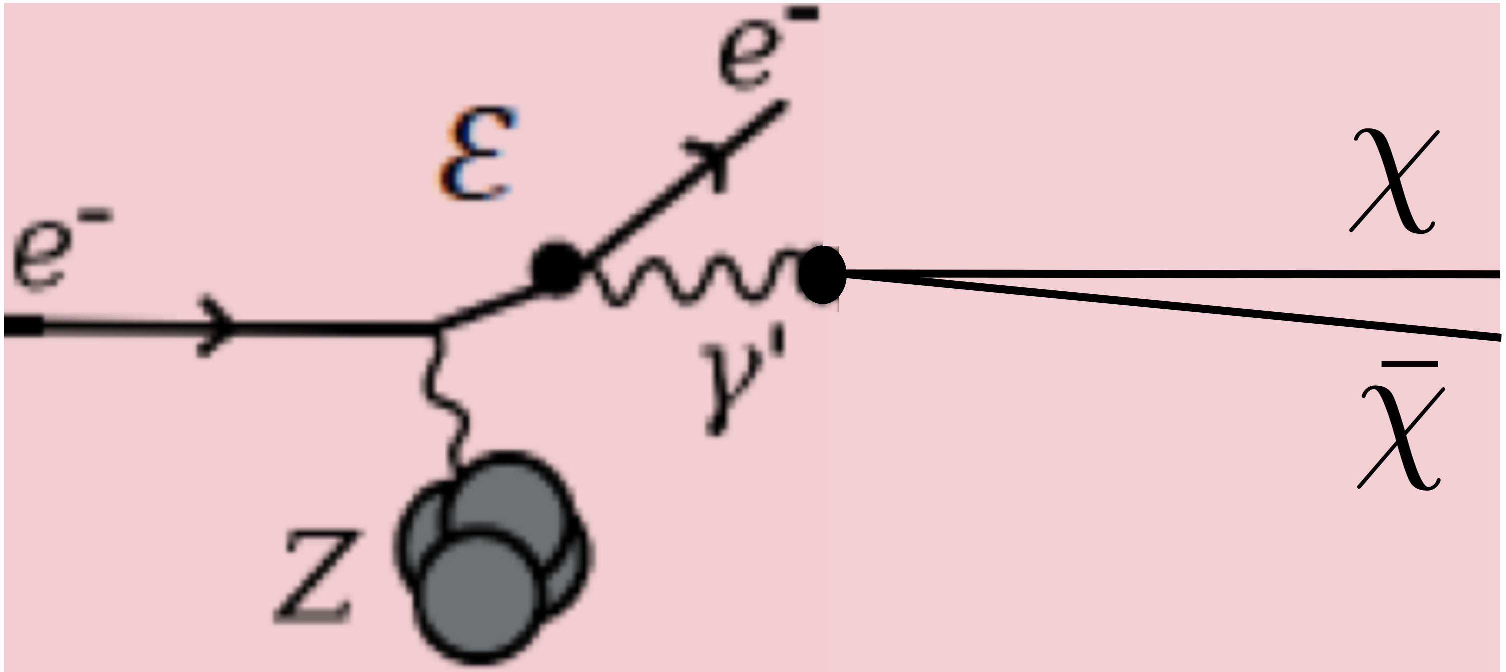


10,000 hours data taking @ 150 μA

→ $>10^{22}$ electrons on target (EOT)

Beam Dump Experiment (BDX) @ MESA

Light Dark Matter (LDM) : $m_{\gamma'} > 2m_{\text{DM}}$



Electron Scattering (MESA) on Beam Dump
→ Collimated pair of Dark Matter particles !

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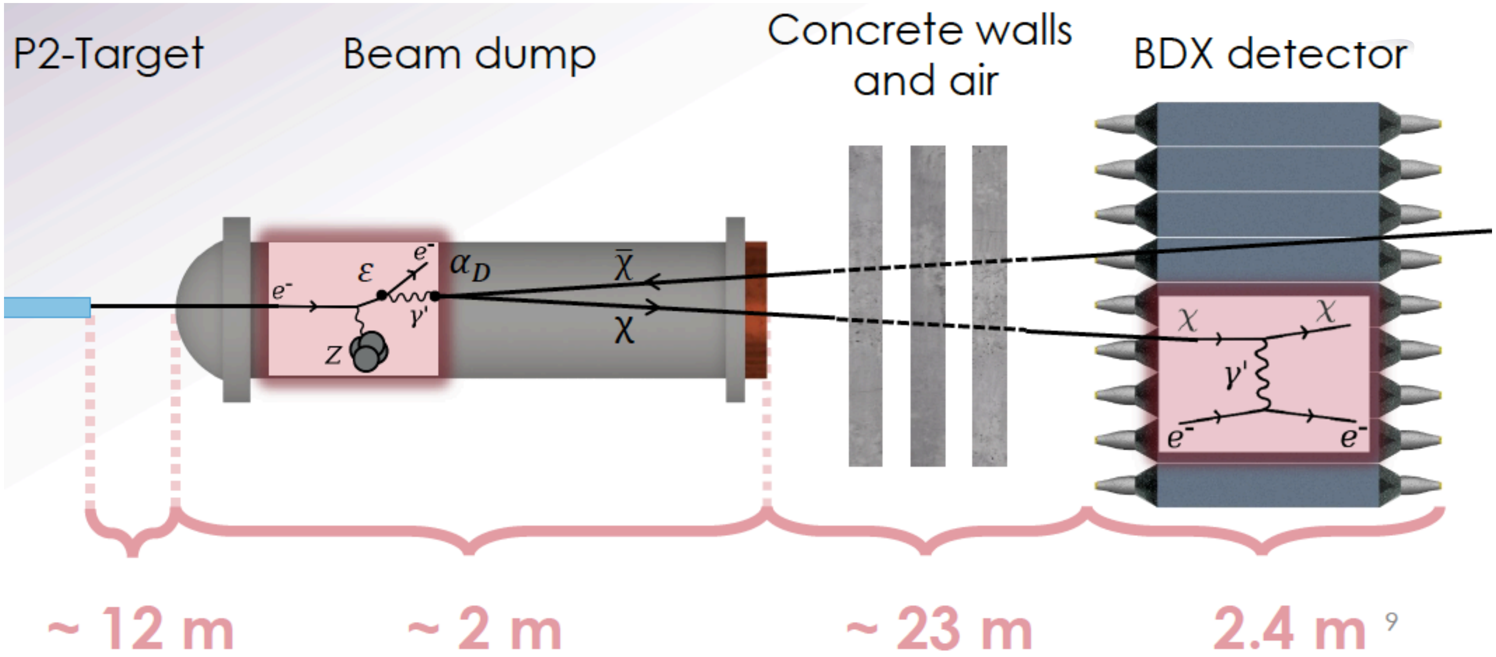

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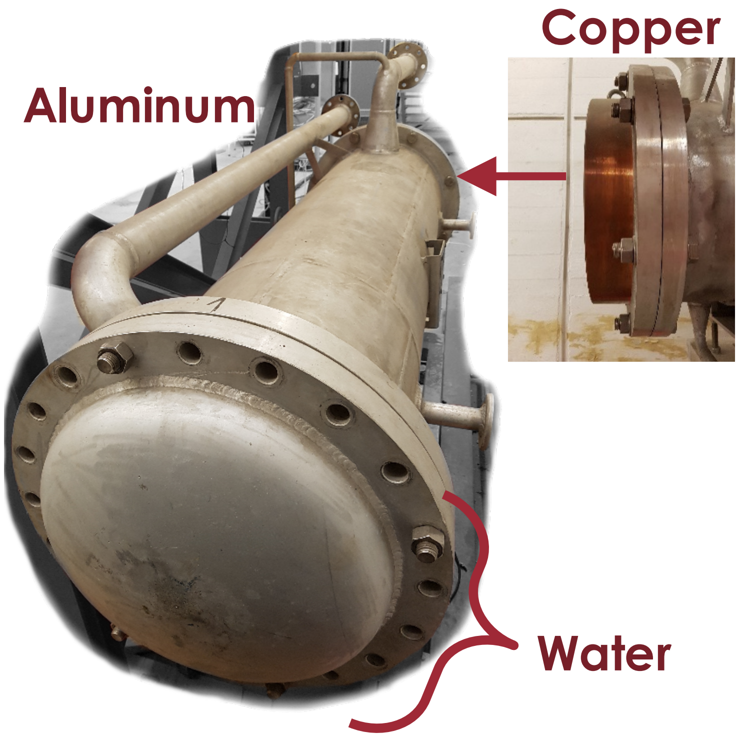
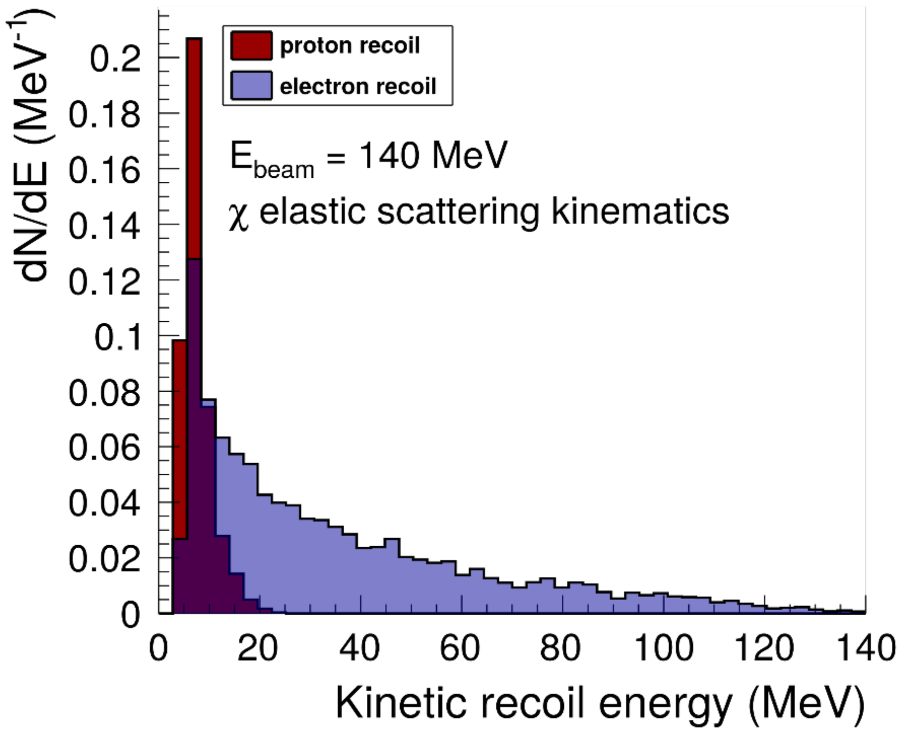
Simulation BDX @ MESA

Full GEANT4 simulation:
P2 target, beam dump, BDX detector volume, walls etc.



→ **LDM interaction with BDX material (electron recoil)**

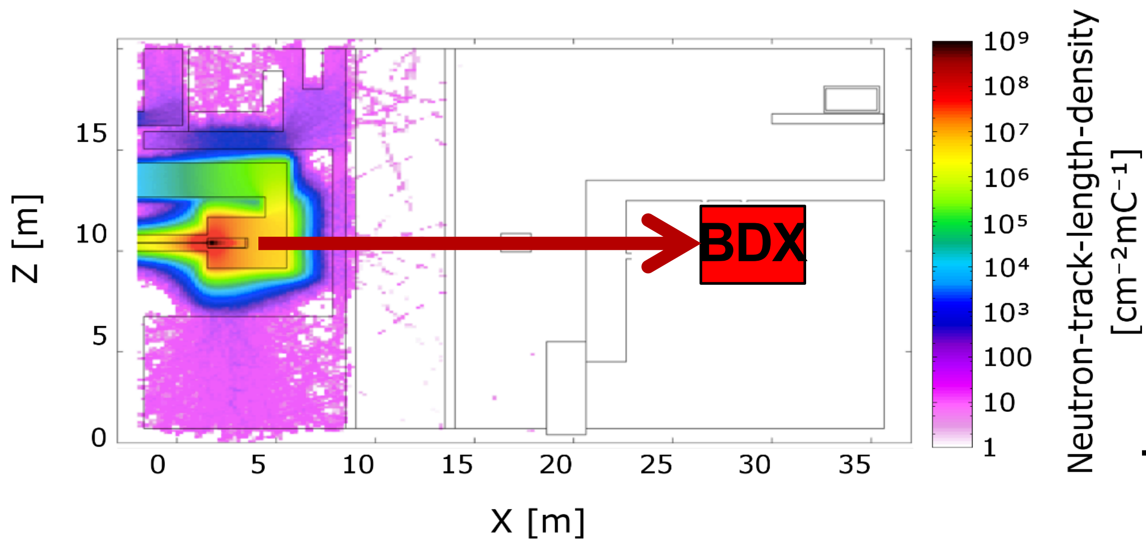


Detector Concept for BDX @ MESA

Ideal Requirements:

1. Electron Detection > few MeV
2. Large Surface (Acceptance)
3. Large thickness (Int. Prob.)
4. Reliability (long running time)
5. Background rejection

- Cosmics
- Natural Backgrounds
- Beam Backgrounds (Neutrons)



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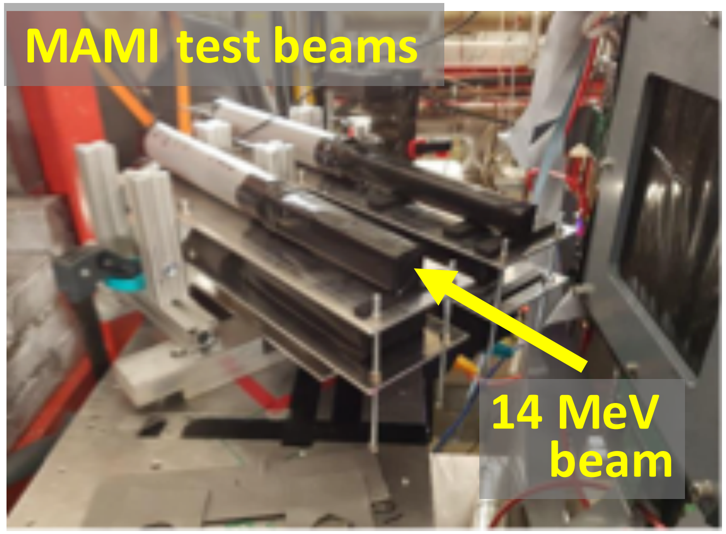
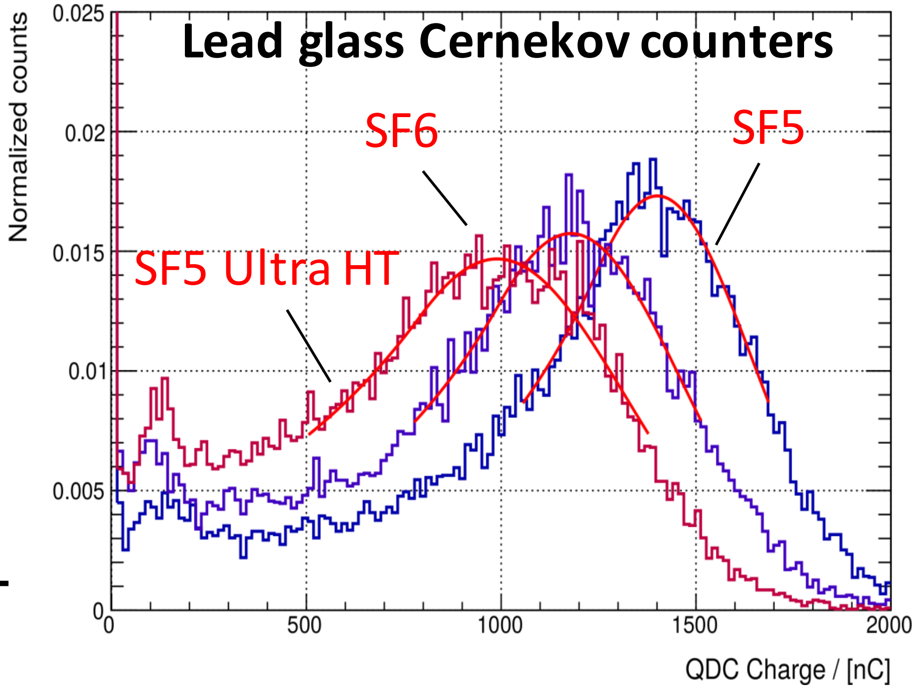
Baseline Concept

Inorganic crystal calorimeter
- Cherenkov (fast, no neutrons)
- Scintillator (higher light yield)





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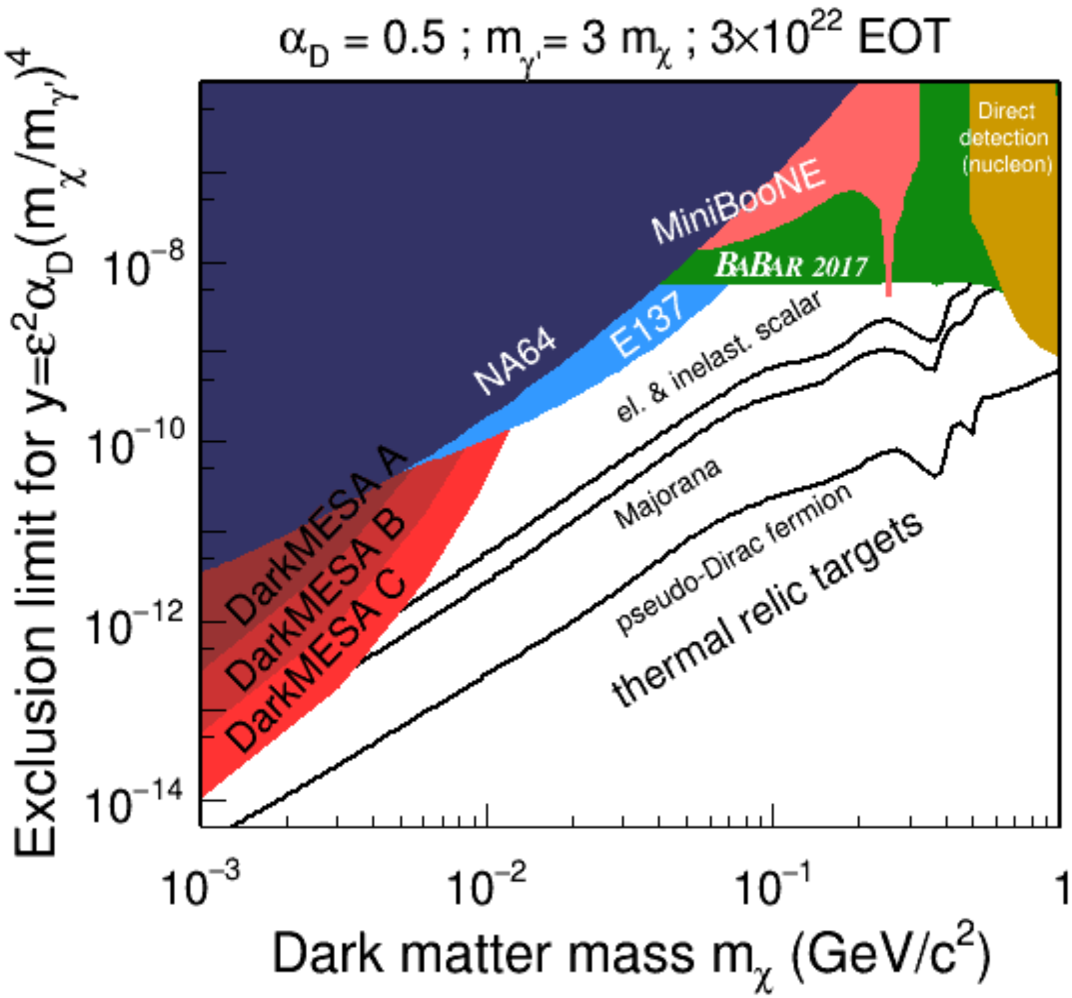
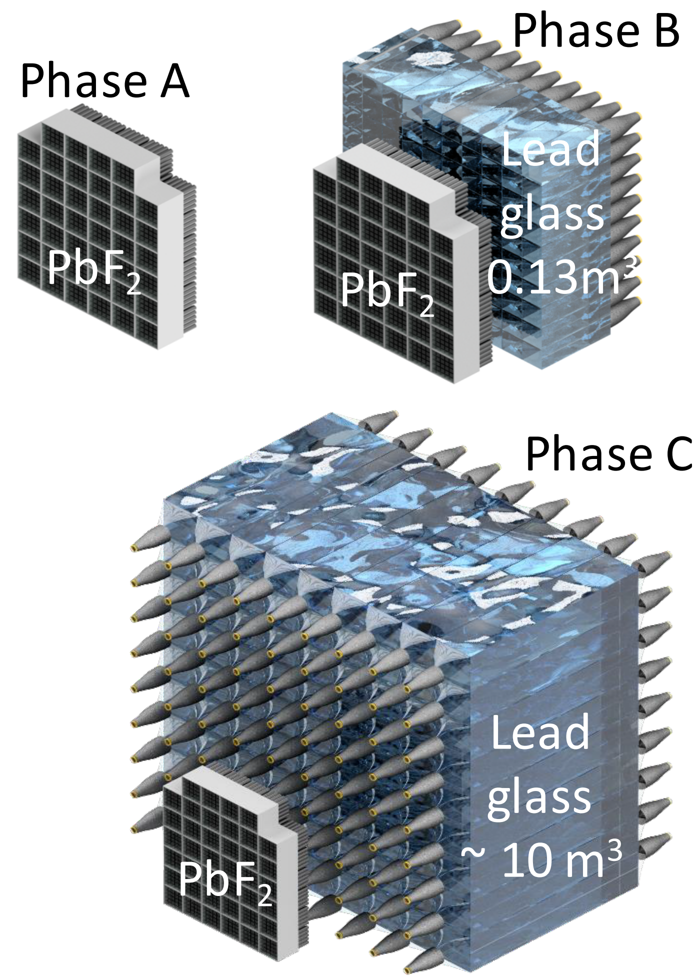


Detector layouts:



Conclusions

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- New MESA electron accelerator (increase of intesity x 10) under construction at Mainz, commissioning in 2022

- Experiments MAGIX, P2, and BDX currently under construction

- Exciting physics topics at the intensity / precision frontier

  - Proton Radius
  - EW Mixing Angle
  - Dark Sector
  - Nuclear Astrophysics
  - Few Body Physics
  - ....

- Go beyond state of the art in many technological aspects: ultralight detectors, beam polarization, low energy detection, ...

- Competitive programme in nuclear, hadron, and particle physics

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THANK YOU !

NEW COLLABORATORS WELCOME !

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