Comments on a possible physics program at PERLE

- Disclaimer : comments only, very partial view mostly reflecting my ignorance

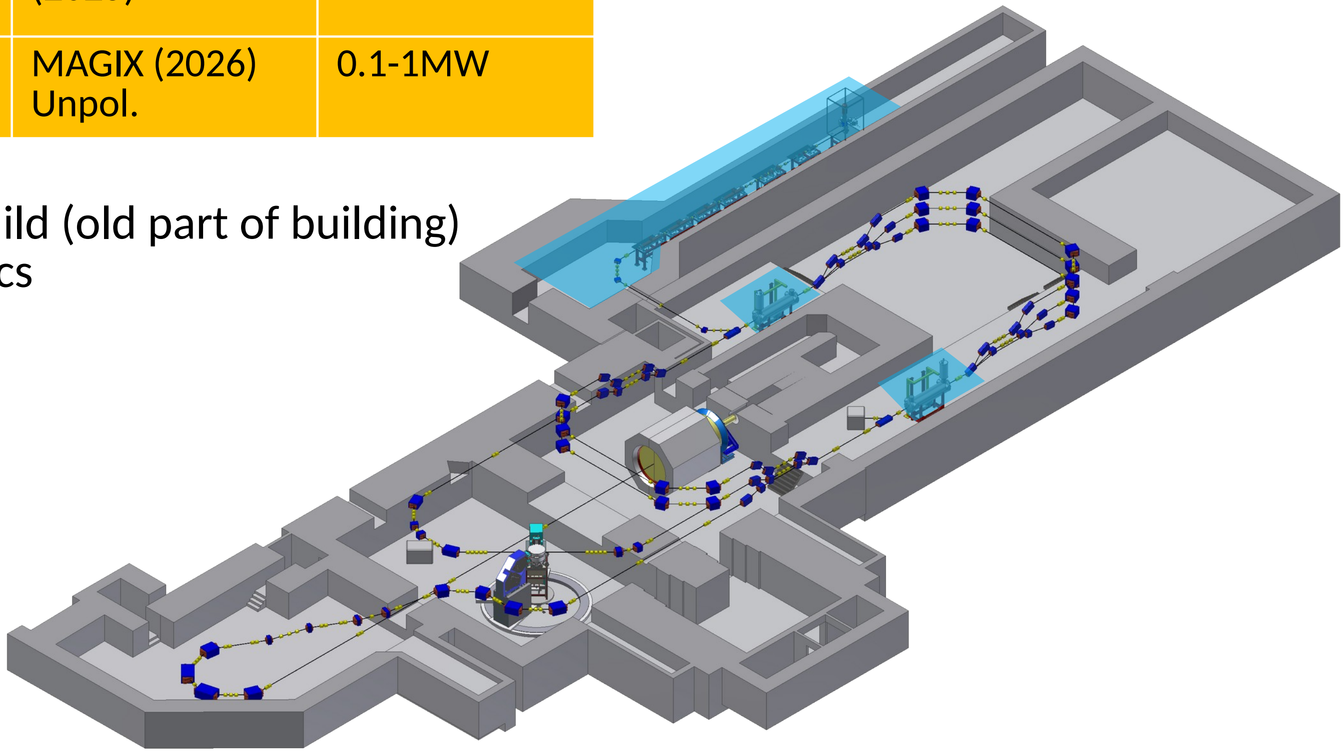
- Low-energy physics program at MESA and MAMI; comments for PERLE
  - Polarized and unpolarized scattering
  - Standard Model and BSM physics
  - “support” physics : application to neutrino physics, precision measurements

Maarten Boonekamp, IRFU
Material from K.Aulenbacher, P2, Magix, MAMI/Primakoff teams

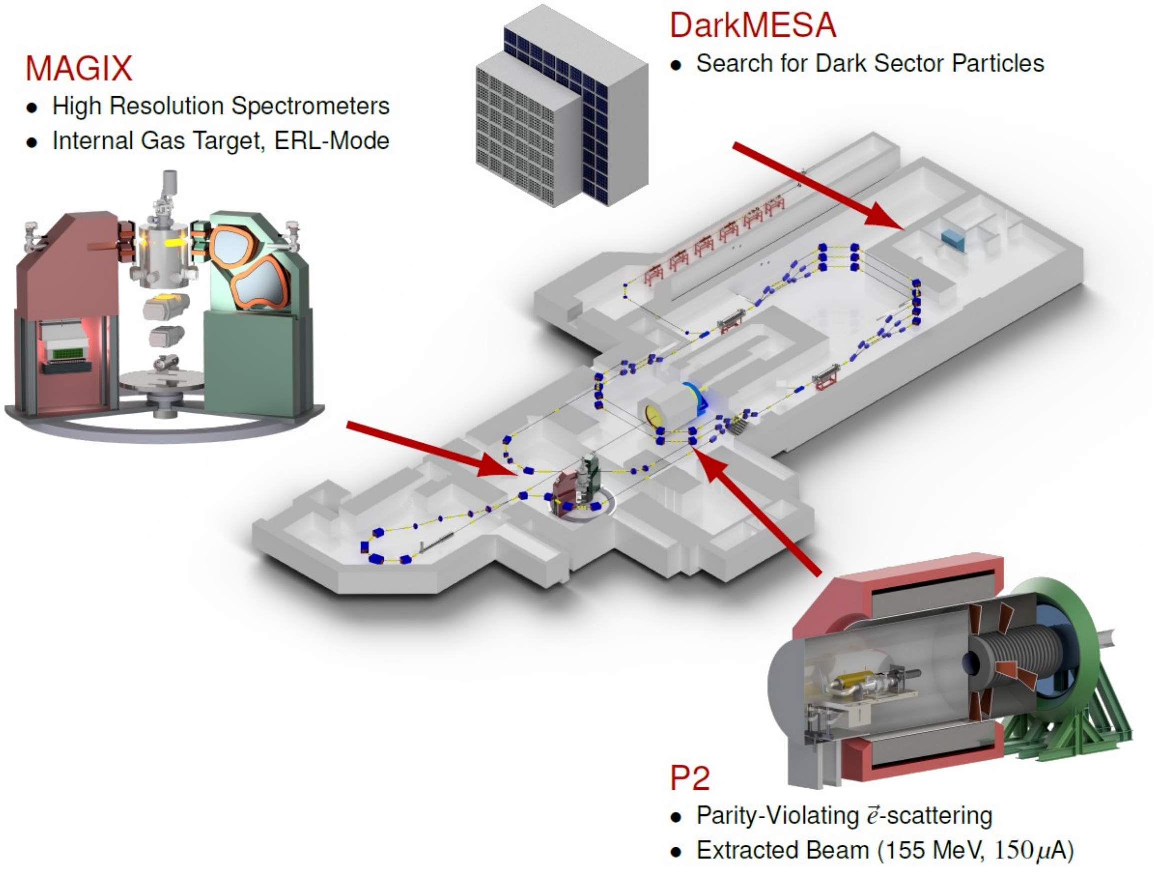
MESA Operational modes

Op-mode	Target	Current/ Energy	Experiment Beam pol.	Beam power@targe t
Ext. Beam (EB)	Solid/ Liquid	0-1mA/ 55-105 MeV	P2, unpol (2025)	0-25kW
Energy recovery (ERL)	Gas-jet	1-10mA/ 55-105MeV	MAGIX (2026) Unpol.	0.1-1MW

5 MeV Injector is currently being build (old part of building)
Cryomodules tested and within specs
Completion of building end 2022
Experiments begin in 2025

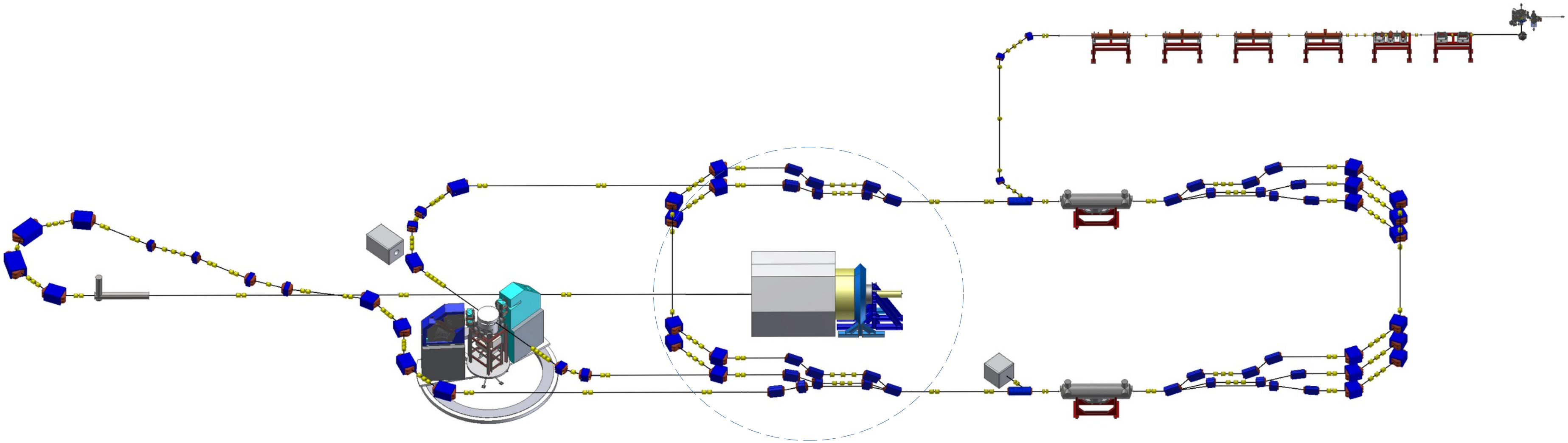


MESA- fixed target experiments

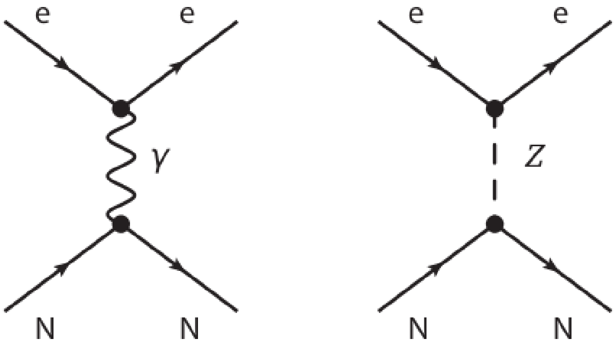


- P2 experiment:
  High target density, 0.15mA
  External beam mode (EB)
  Luminosity >10^{39} cm^{-2}s^{-1}
- MAGIX experiment:
  low target density, 1mA
  Energy recovery mode (ERL)
  Luminosity >10^{35} cm^{-2}s^{-1}
- DarkMESA:
  beam-dump experiment
  measures recoil from elastic scattering of weakly-interacting particles

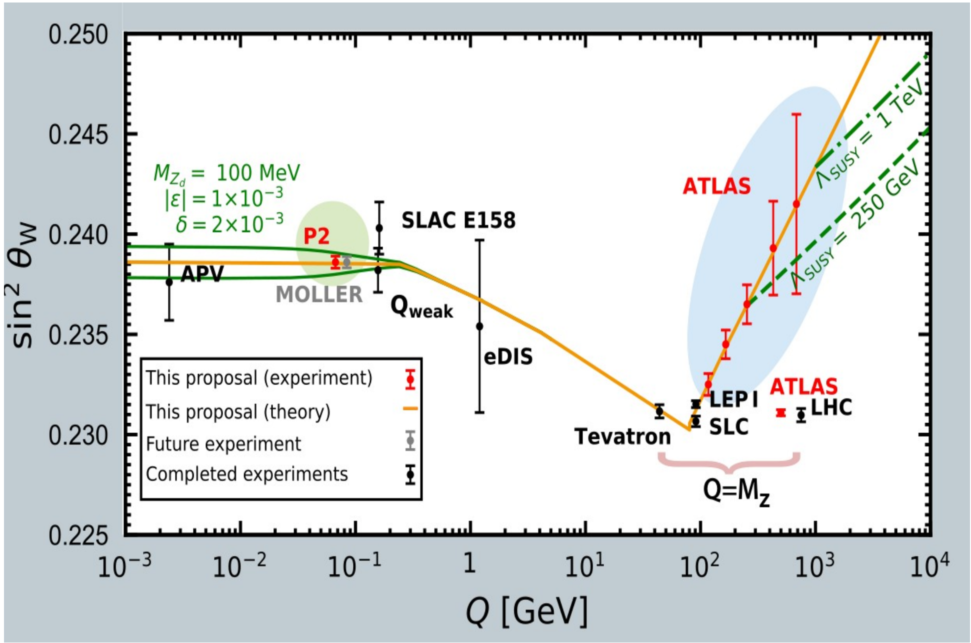
Physics in EB mode – P2



The P2 experiment



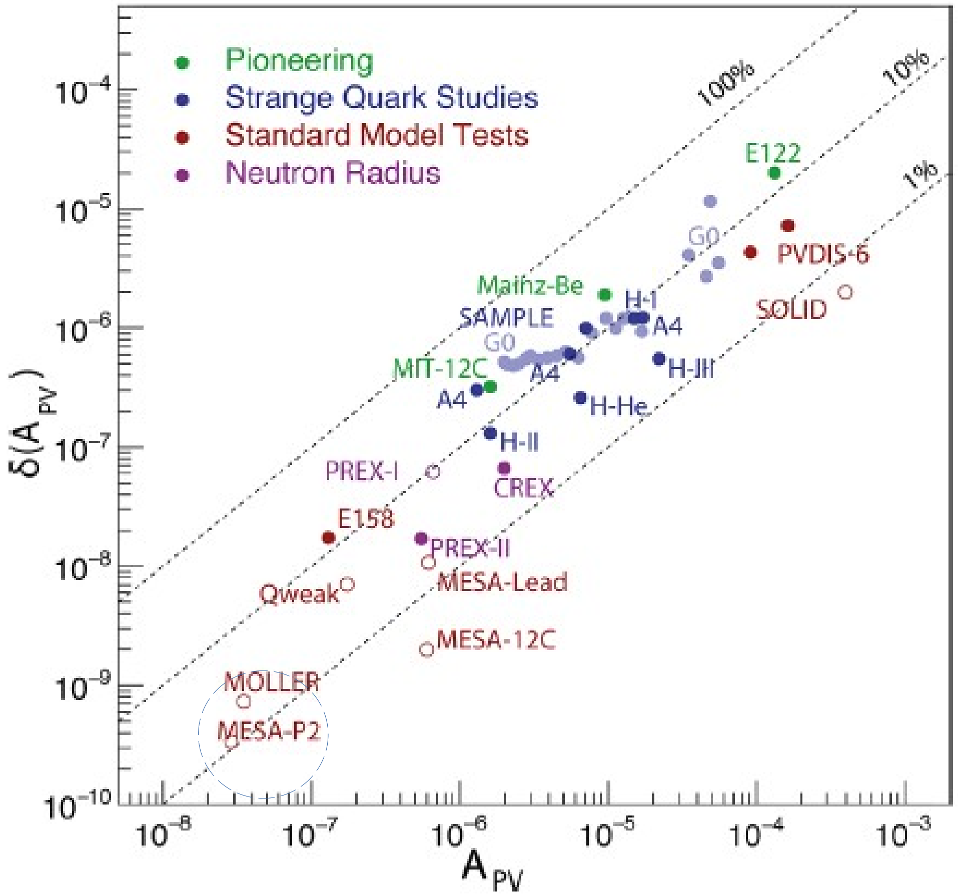
$$A^{\mathrm{PV}} \equiv \frac{\mathrm{d}\sigma_{\mathrm{ep}}^{+} - \mathrm{d}\sigma_{\mathrm{ep}}^{-}}{\mathrm{d}\sigma_{\mathrm{ep}}^{+} + \mathrm{d}\sigma_{\mathrm{ep}}^{-}}.$$



$$\text{weak charge } \; Q_W(p) = 1 - 4\sin^2\theta_W$$

Q_W to 1.4% ↔ $\sin^2(\theta_W)$ to 0.15%

The P2 experiment



$A_{PV} \sim 3\ 10^{-8}$ → $\delta A_{PV} \sim 4.5\ 10^{-10}$
→ $N \sim 10^{19}$

Beam current 150 μA
LH_2 target, 60 cm
→ $L = 2.4\ 10^{39}$ /cm²/s
→ Rate ~100 GHz
Integrating detectors
Quartz bars + PM tubes
10000 hours of running

The P2 experiment

- Parity-violating asymmetries, the weak mixing angle, and the proton form factors

- Measurement :

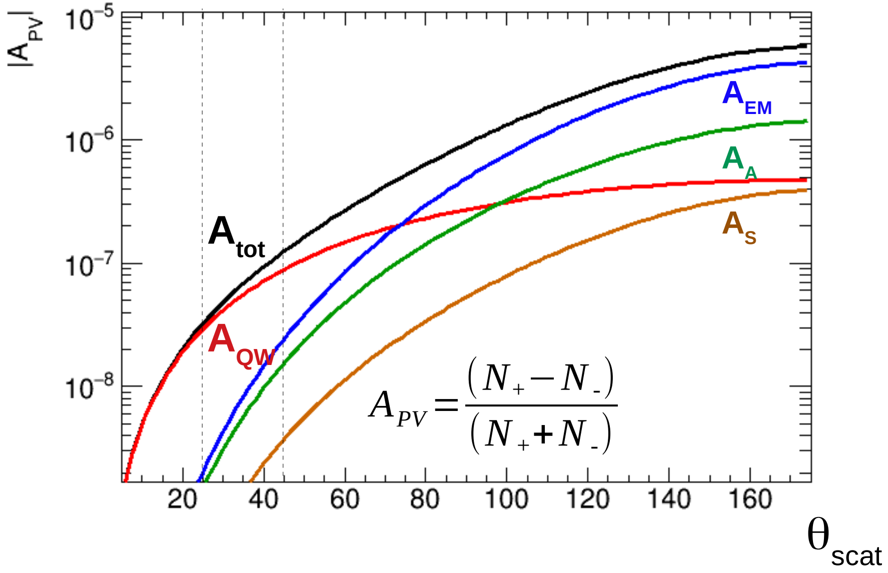
$$A_{PV}^{\exp} = \frac{N^+ - N^-}{N^+ + N^-}$$

- Prediction:

$$A_{PV} = \frac{-G_F Q^2}{4\pi\alpha_{em}\sqrt{2}}\left[Q_W^p - F(Q^2)\right]$$

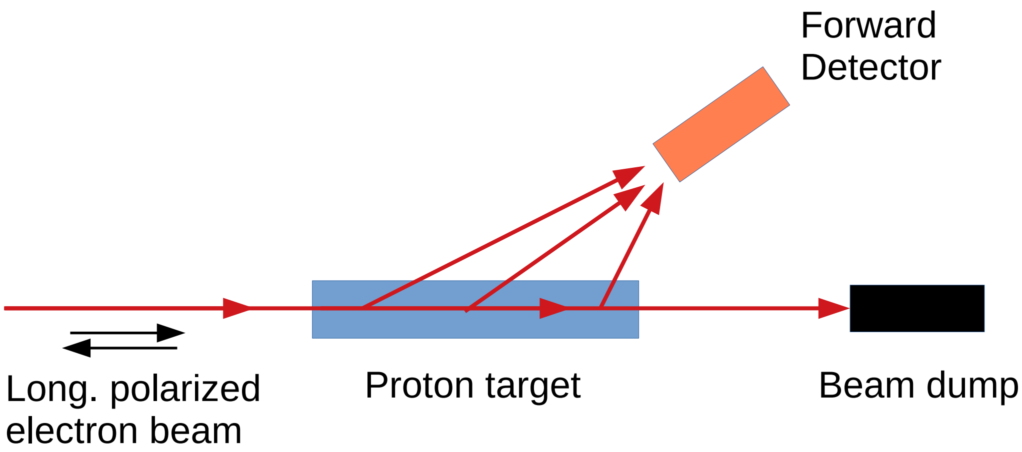
$$Q_W^p = 1 - 4\sin\theta_W.$$

$$F(Q^2) = F_{EM}(Q^2) + F_A(Q^2) + F_S(Q^2)$$

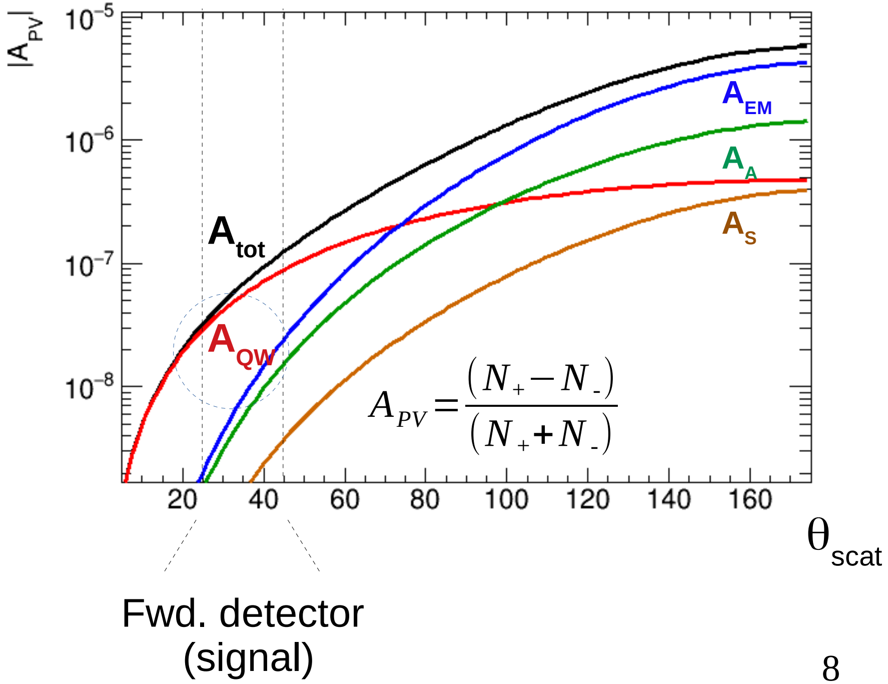


The P2 experiment

- An accepted project, in construction (Mainz):



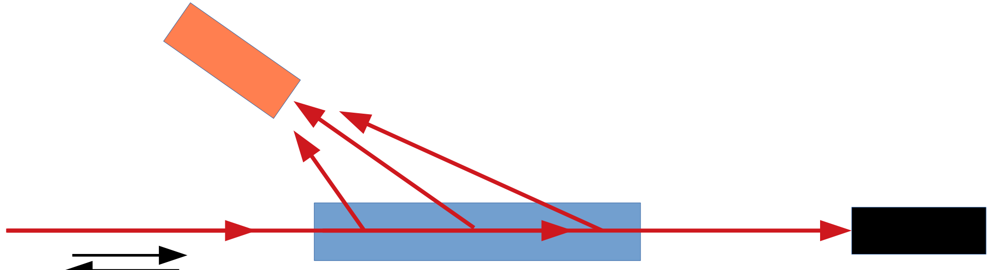
A_{QW} : "signal", "feels" $\sin^2\theta_W$
A_{EM} : known
A_A, A_S : systematics!!



25 < θ < 45 deg.
Total signal rate ~ 100 GHz
→ integrating detectors

The P2 experiment

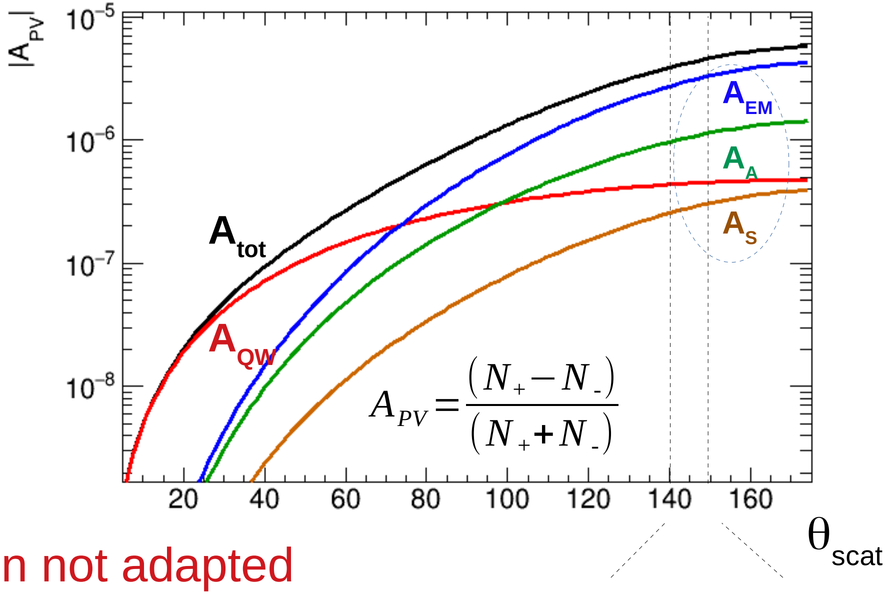
- Required ancillary measurements:



A_{QW} : "signal", "feels" $\sin^2\theta_W$

A_{EM} : known

A_A, A_S : systematics!!



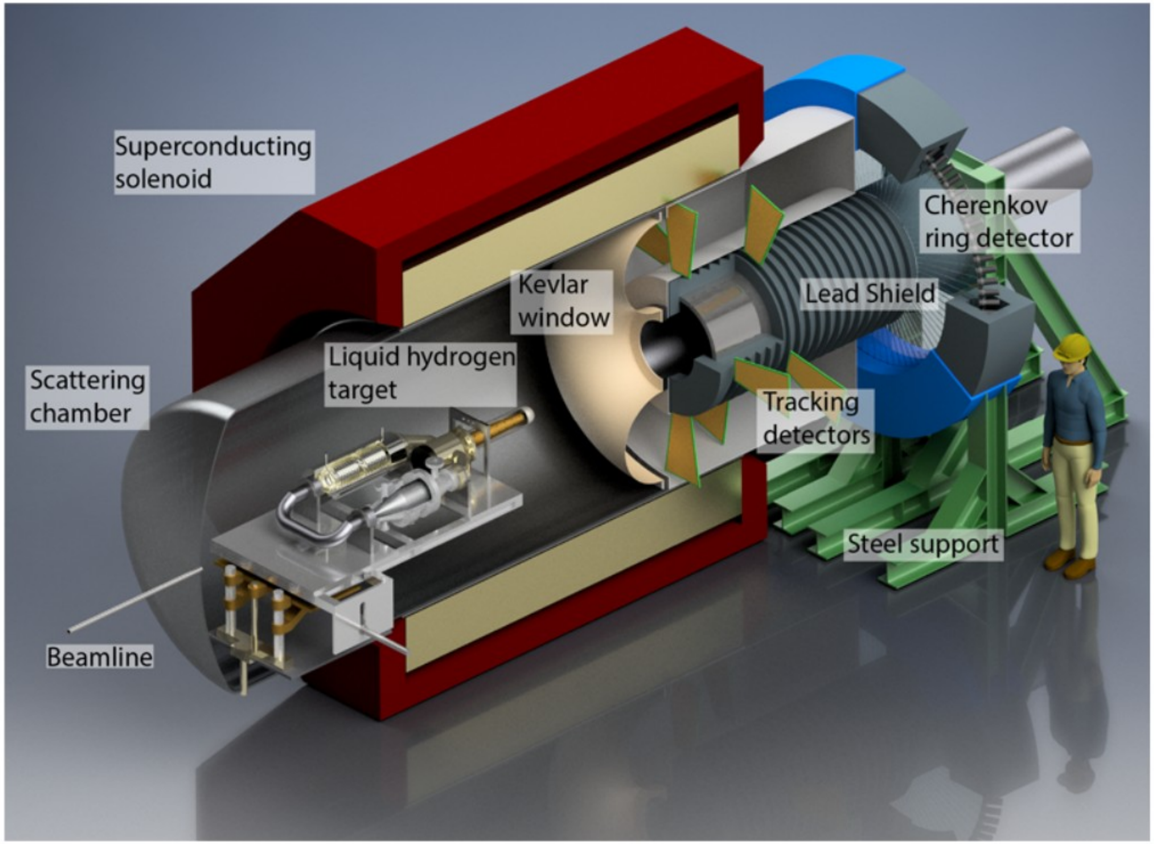
eg. $140 < \theta < 150$ deg: Total signal rate ~ 100 MHz

→ counting detectors possible

→ always flagged as a requirement, but initial design not adapted
(target, vacuum chamber, background shielding)

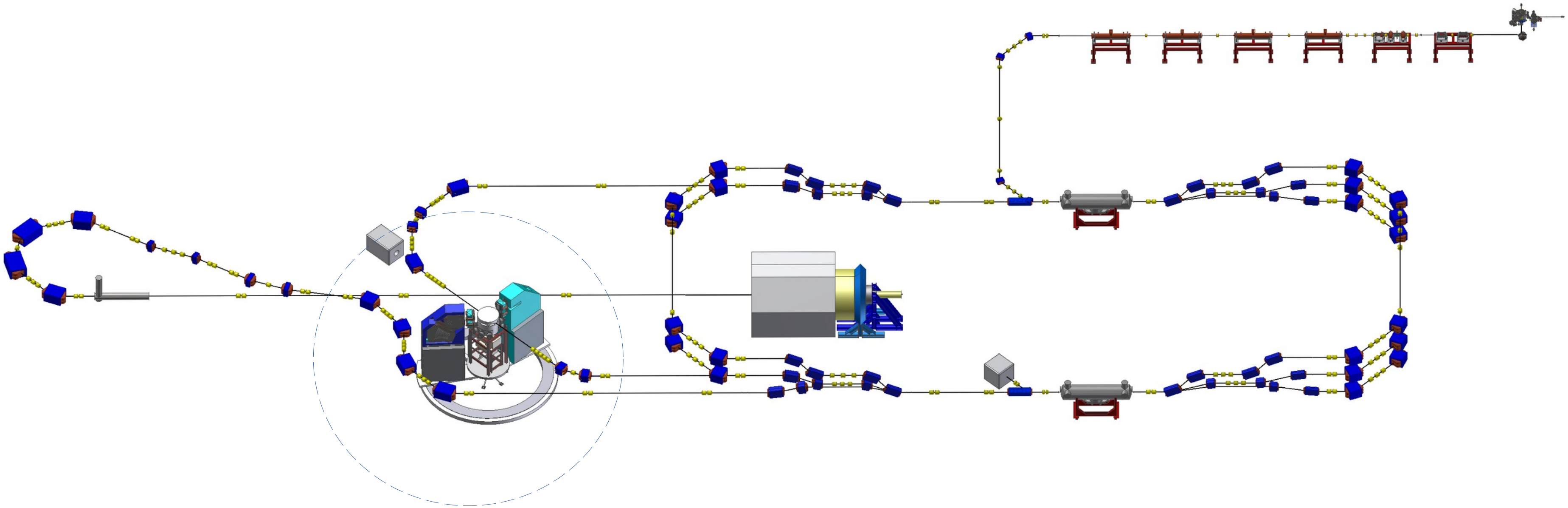
→ keep in mind for future experiments

The P2 experiment

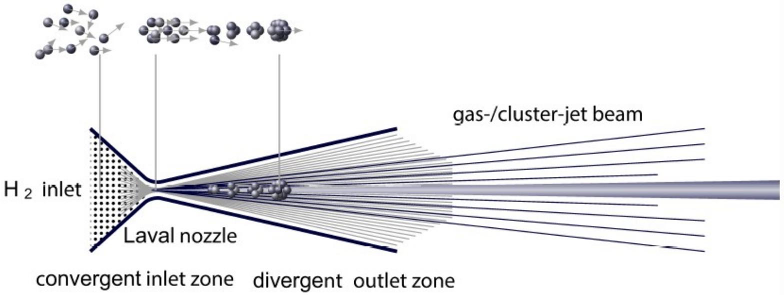


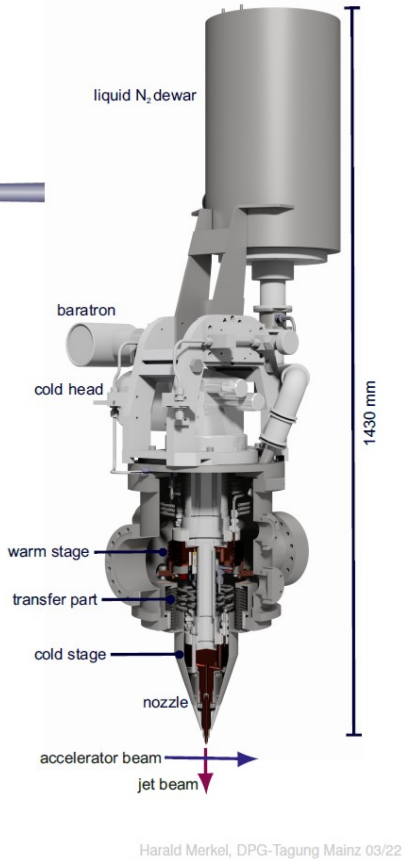
E_{beam}	155 MeV
$\bar{\theta}_{\text{f}}$	35°
$\delta\theta_{\text{f}}$	20°
$\langle Q^2 \rangle_{L=600\,\text{mm},\ \delta\theta_{\text{f}}=20^\circ}$	$6 \times 10^{-3}\,(\text{GeV/c})^2$
$\langle A^{\text{exp}} \rangle$	-39.94 ppb
$(\Delta A^{\text{exp}})_{\text{Total}}$	0.56 ppb (1.40 %)
$(\Delta A^{\text{exp}})_{\text{Statistics}}$	0.51 ppb (1.28 %)
$(\Delta A^{\text{exp}})_{\text{Polarization}}$	0.21 ppb (0.53 %)
$(\Delta A^{\text{exp}})_{\text{Apparative}}$	0.10 ppb (0.25 %)
$\langle s^2_{\text{W}} \rangle$	0.231 16
$(\Delta s^2_{\text{W}})_{\text{Total}}$	3.3×10^{-4} (0.14 %)

Physics in ERL mode – Magix



Gas Jet target at MAMI A1 /MAGIX

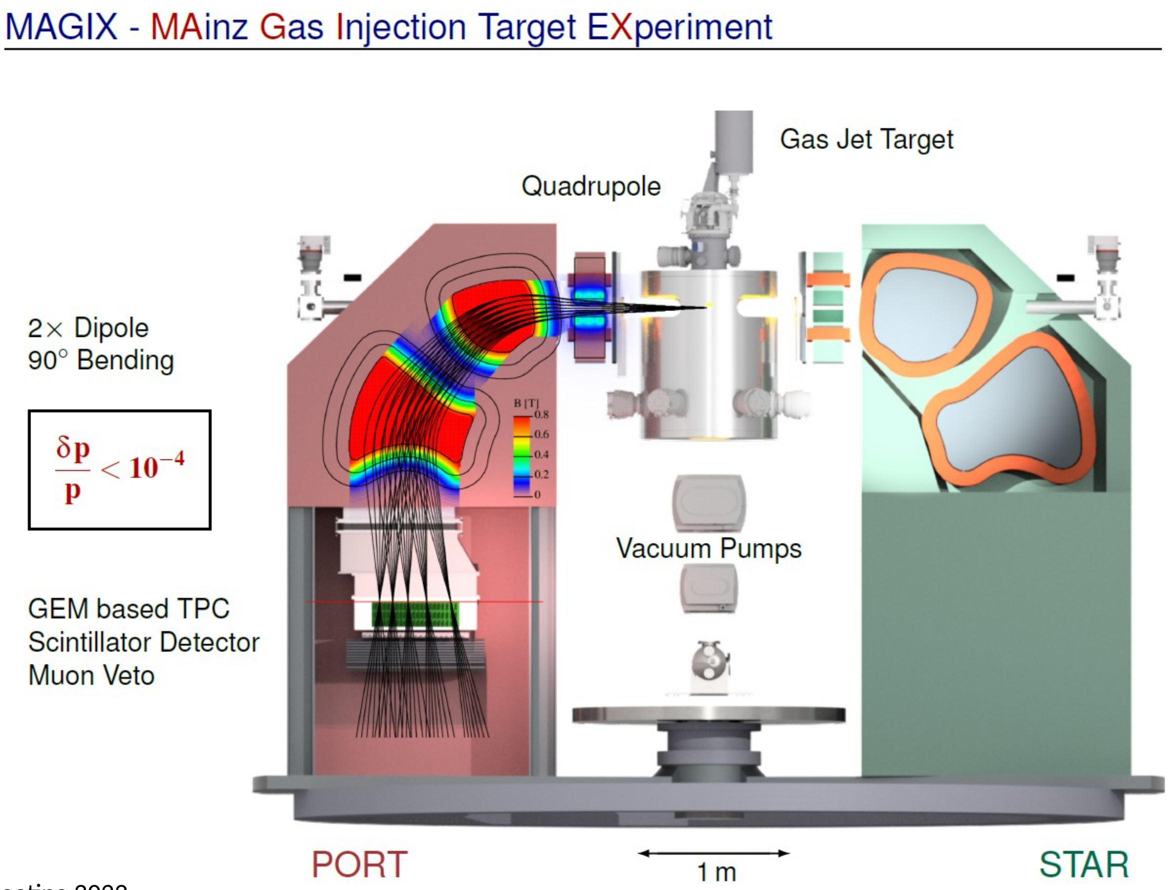




Gas jet target in operation at MAMI

H.Merkel Talk at DPG Springmeeting 2022

MAGIX spectrometers



Spectrometers are ordered, expected delivery
March 23

Experimental program at MAGIX

Hadron Structure

Topic	Reaction	Jet	Observables
p Formfactor	$H(e,e')p$	H	$G_E(Q^2)$, $G_M(Q^2)$, r_E, r_M
d Formfactor	$D(e,e')d$	D	$A(Q^2)$, $B(Q^2)$, r_d
^{3}He Formfactor	$^3\mathrm{He}(e,e')^3\mathrm{He}$	^{3}He	r_E
^{4}He Formfactor	$^4\mathrm{He}(e,e')^4\mathrm{He}$	^{4}He	r_E

Few-Body Systems

d Breakup	$D(e,e'p)$	D	$\mathrm{d}\sigma/\mathrm{d}\Omega$, polarizabilities
^{3}He inclusive	$^3\mathrm{He}(e,e')$	^{3}He	Structure functions, R_L
^{4}He inclusive	$^4\mathrm{He}(e,e')$	^{4}He	Structure functions, R_L
^{4}He monopole	$^4\mathrm{He}(e,e')^4\mathrm{He}^*$	^{4}He	Transition Formfactors $E(^4\mathrm{He}^*)$, $\Gamma(^4\mathrm{He}^*)$
^{16}O inclusive	$^{16}\mathrm{O}(e,e')$	^{16}O	Structure functions, R_L
^{40}Ar inclusive	$^{40}\mathrm{Ar}(e,e')$	^{40}Ar	Structure functions, R_L
^{3}He exclusive	$^3\mathrm{He}(e,e'p/d)d/p$	^{3}He	$\mathrm{d}\sigma/\mathrm{d}\Omega$
^{4}He exclusive	$^4\mathrm{He}(e,e'p/d)$	^{4}He	$\mathrm{d}\sigma/\mathrm{d}\Omega$

Dark Sector

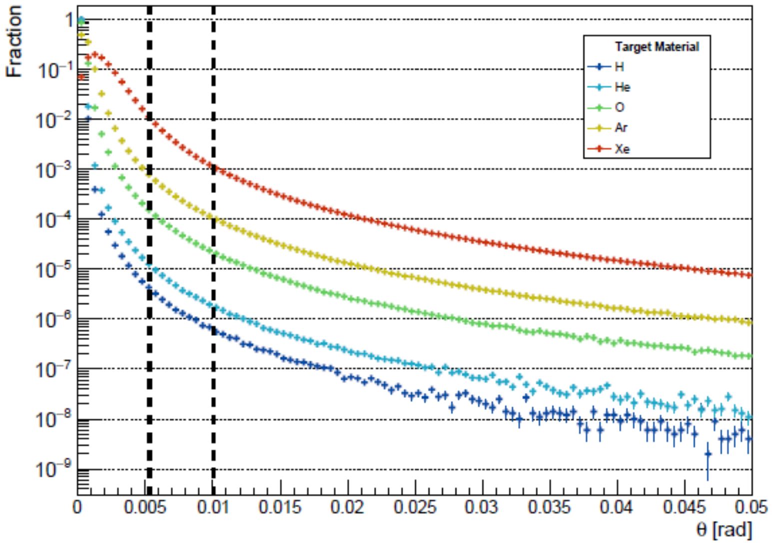
Leptonic Decay	$Ar(e,A' \rightarrow e^+e^-)$	^{40}Ar, Xe	Lepton pair mass $m_{A'}$ peak search
Invisible Decay	$p(e,e'p)A'$	H	Missing mass $m_{A'}$ peak search

Astrophysical Reactions

S-Factor Phase 1	$^{16}\mathrm{O}(e,e'\alpha)^{12}\mathrm{C}$	^{16}O	$S_{E1}(E)$, $S_{E2}(E)$
S-Factor Phase 2	$^{16}\mathrm{O}(e,e'\alpha)^{12}\mathrm{C}$	^{16}O	$S_{E1}(E)$, $S_{E2}(E)$

Luminosity limitation ERL gas jet target

Coulomb scattering - expect for fixed power loss and geometry:
Losses can be concentrated in collimator region separeted from experiment and accelerator

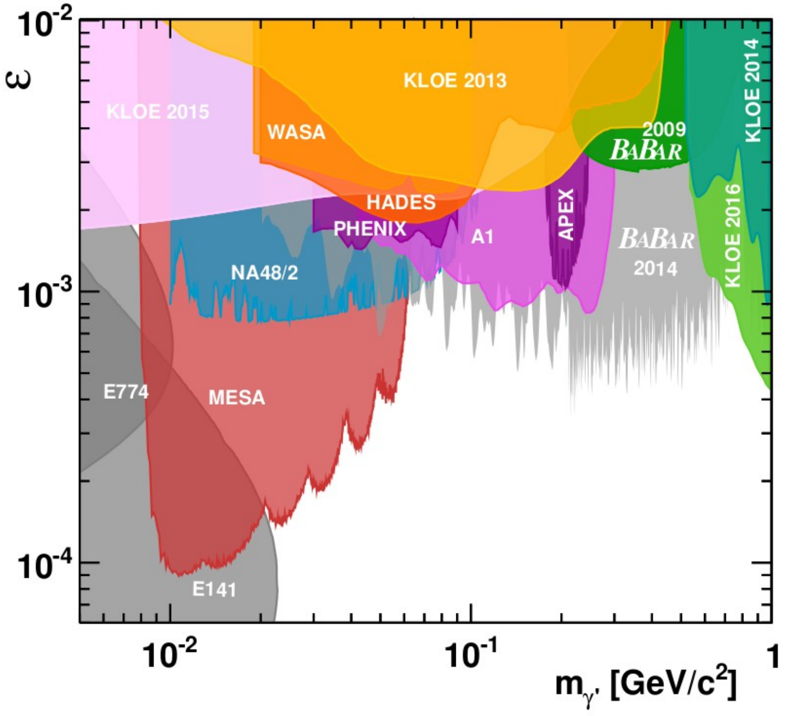


http://doi.org/10.25358/openscience-5808

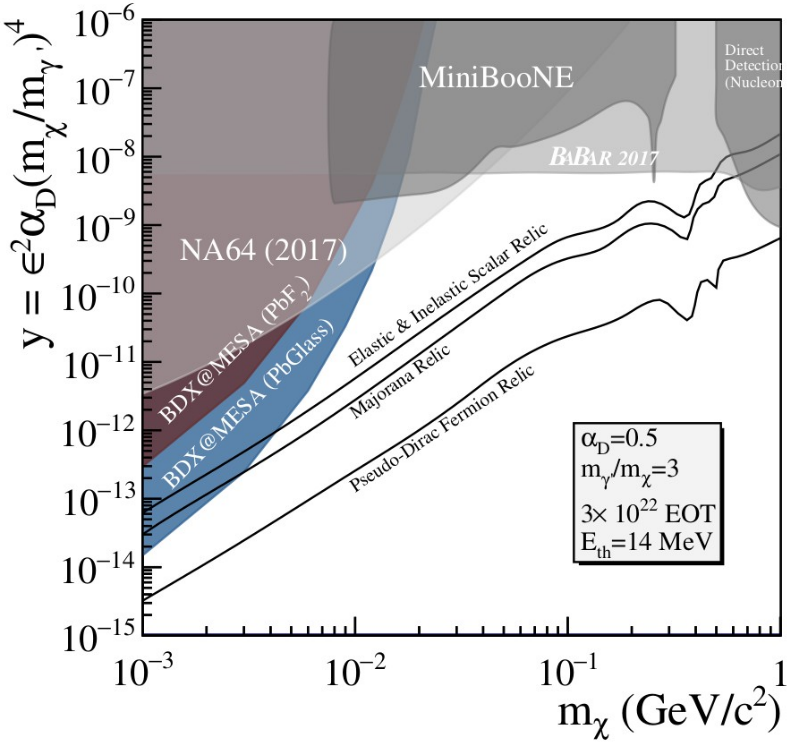
Results for „two collimator“ system
Total loss <100 Watt, loss in accelerator <0.05 W.

Target	$n_{spoiler}$	n_{col}	$\mathcal{L}_{max}$ [$cm^{-2}\,s^{-1}$]
H	13	13	7.595×10^{35}
He	13	13	2.505×10^{35}
O	14	14	2.408×10^{34}
Ar	18	18	7.916×10^{33}
Xe	18	20	5.959×10^{32}

Dark sector



$\gamma' \rightarrow$ e+e- in MAGIX

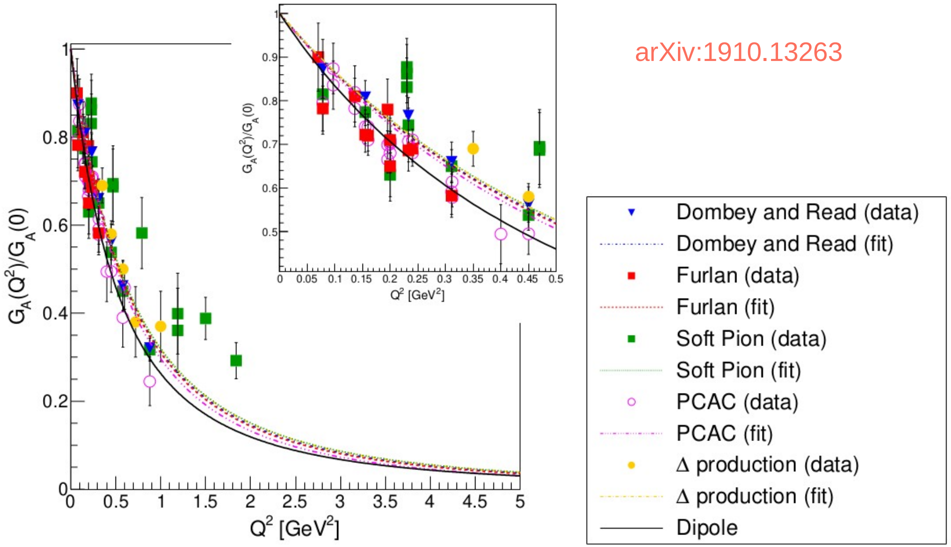


γ'e- $\rightarrow \gamma$'e- in DarkMESA

measurable recoil

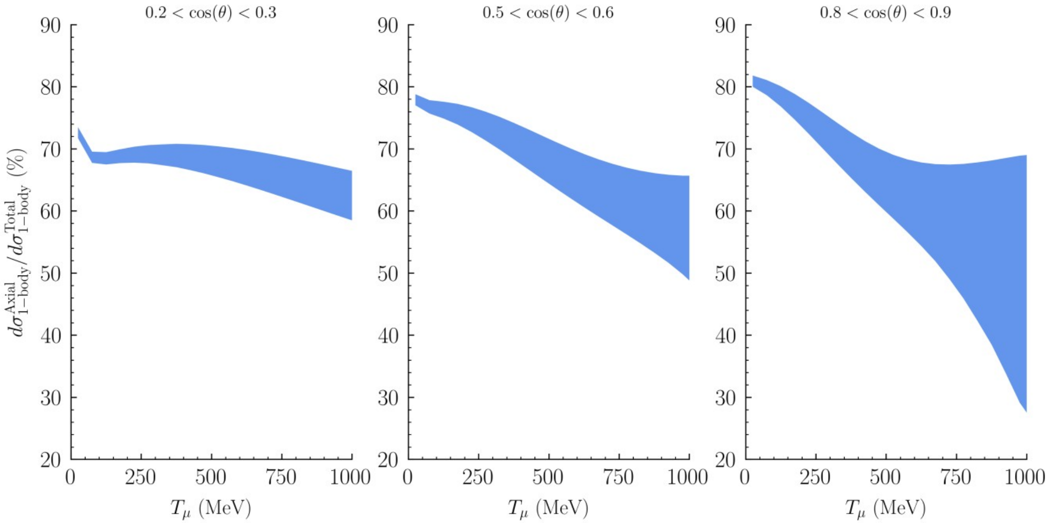
Applications – neutrino physics

arXiv:1910.13263



F_A data

FERMILAB-PUB-22-745-T

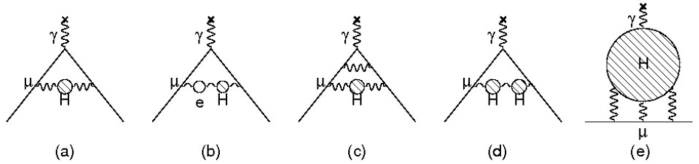


F_A -induced neutrino scattering cross section uncertainties (MiniBoone kin.)

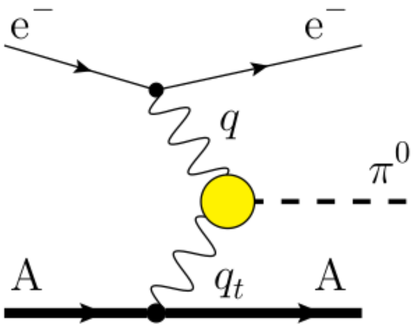
MESA, PERLE can help populate the low-Q^2 region, of particular importance for reactor neutrinos

Applications – Muon g-2

Muon anomaly (had. Contributions):

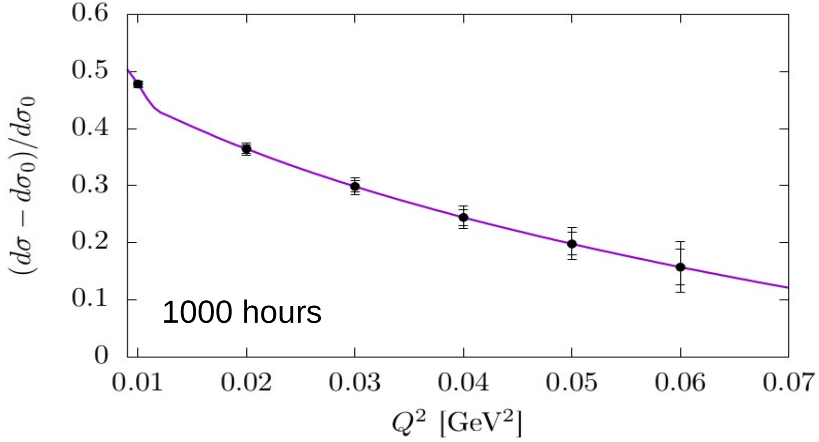


Experimental probe : Primakoff process



Proposed setup (@MAMI)

Beam	energy	1.2 to 1.5 GeV
	current	0.1 to 1.0 μA
	polarisation	unpolarised
Target material		^{181}Ta
Detector systems		EMC (new)
		plastic scintillator (new)
		A1 spectrometer A



→ PERLE lower energy, but above threshold - can contribute

Comments and conclusions

- Described a small selection of experiments at a low-energy electron-proton or electron-atom scattering experiment
- Luminosities
  - Dense targets ↔ extracted beams. I_{max} ~ 0.1-0.2 mA $L_{max} \sim 10^{40}$ $cm^{-2}s^{-1}$
    - EM backgrounds
    - Target design a challenge in itself (heat load, interactions with final state electron)
  - Physics in ERL mode ↔ gas targets I_{max} ~ 10-20 mA $L_{max} \sim 10^{35}$ $cm^{-2}s^{-1}$
- PERLE will gain a factor 2 – 4 in energy compared to MESA
  - Specific opportunities
  - Hadronic backgrounds

→ time to collect concrete ideas!