The DarkMESA Experiment in Mainz

Light Dark Matter 2025 @ Genova, Italy

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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

HIM Helmholtz-Institut Mainz

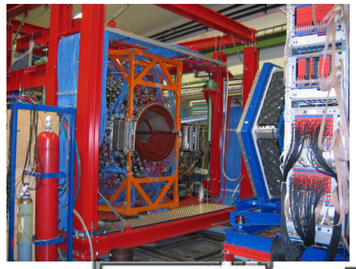
Overview

- The new MESA facility
- Beam Dump experiments
- DarkMESA - overview
- DarkMESA - detector technology
- Sensitivity
- Summary

The MESA Facility

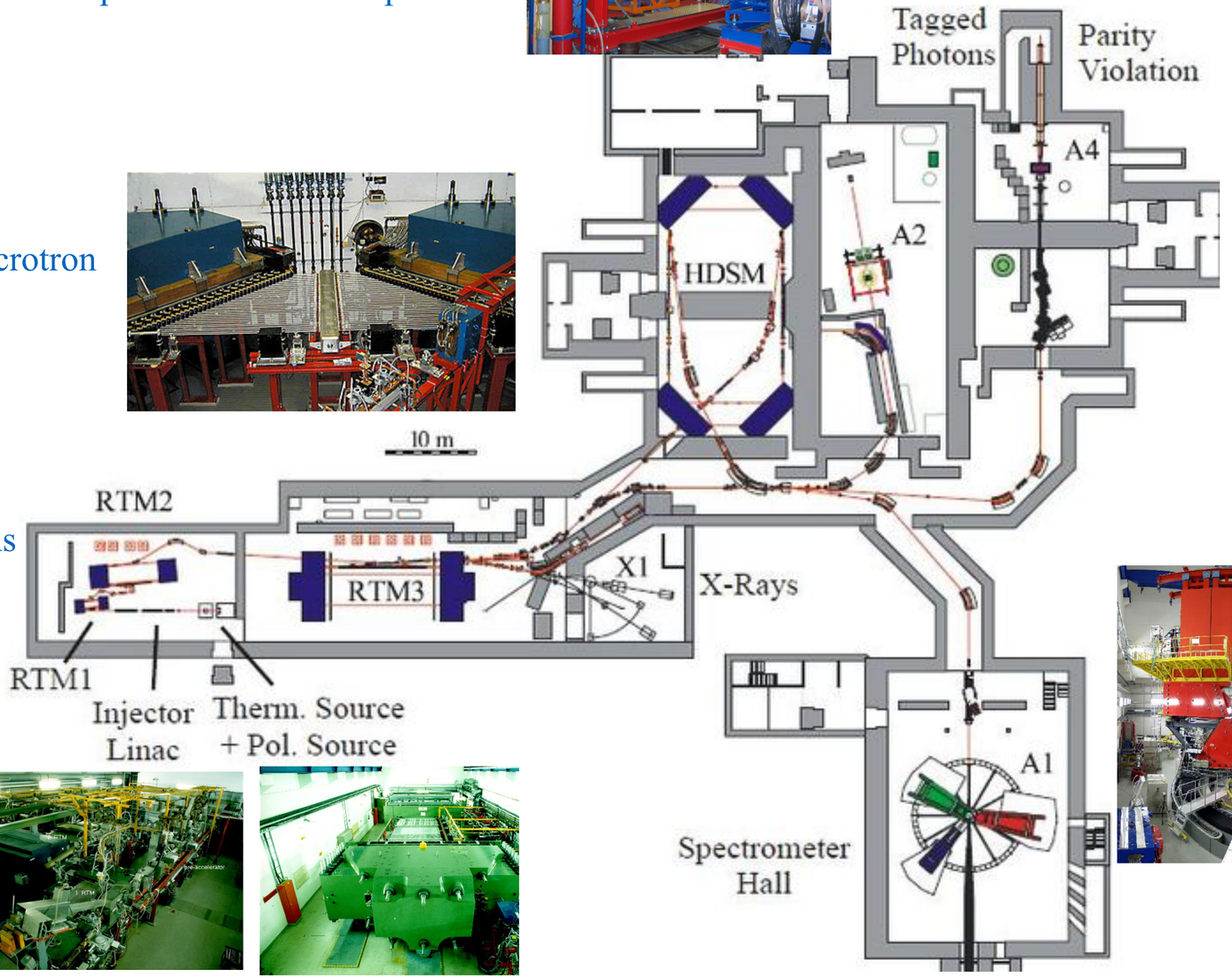
The MAMI Facility

A2 Collaboration
Experiments with real photons



MAMI-C (since 2007)
Harmonic Double-sided Microtron
E= 1.6 GeV

MAMI-B
3 cascaded Racetrak Microtrons
E=180-883 MeV
Max beam current 100 uA c.w.



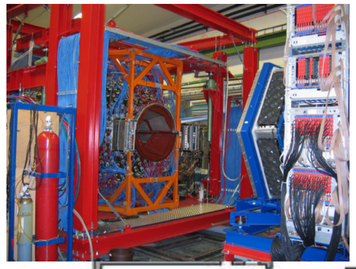
Existing High-power Beam Dump

Existing Halls cleared for MESA

A1 Collaboration
3-spectrometer setup
Experiments with electrons

The MAMI Facility

A2 Collaboration
Experiments with real photons



New MESA Hall and Building

Existing High-power Beam Dump

Existing Halls cleared for MESA

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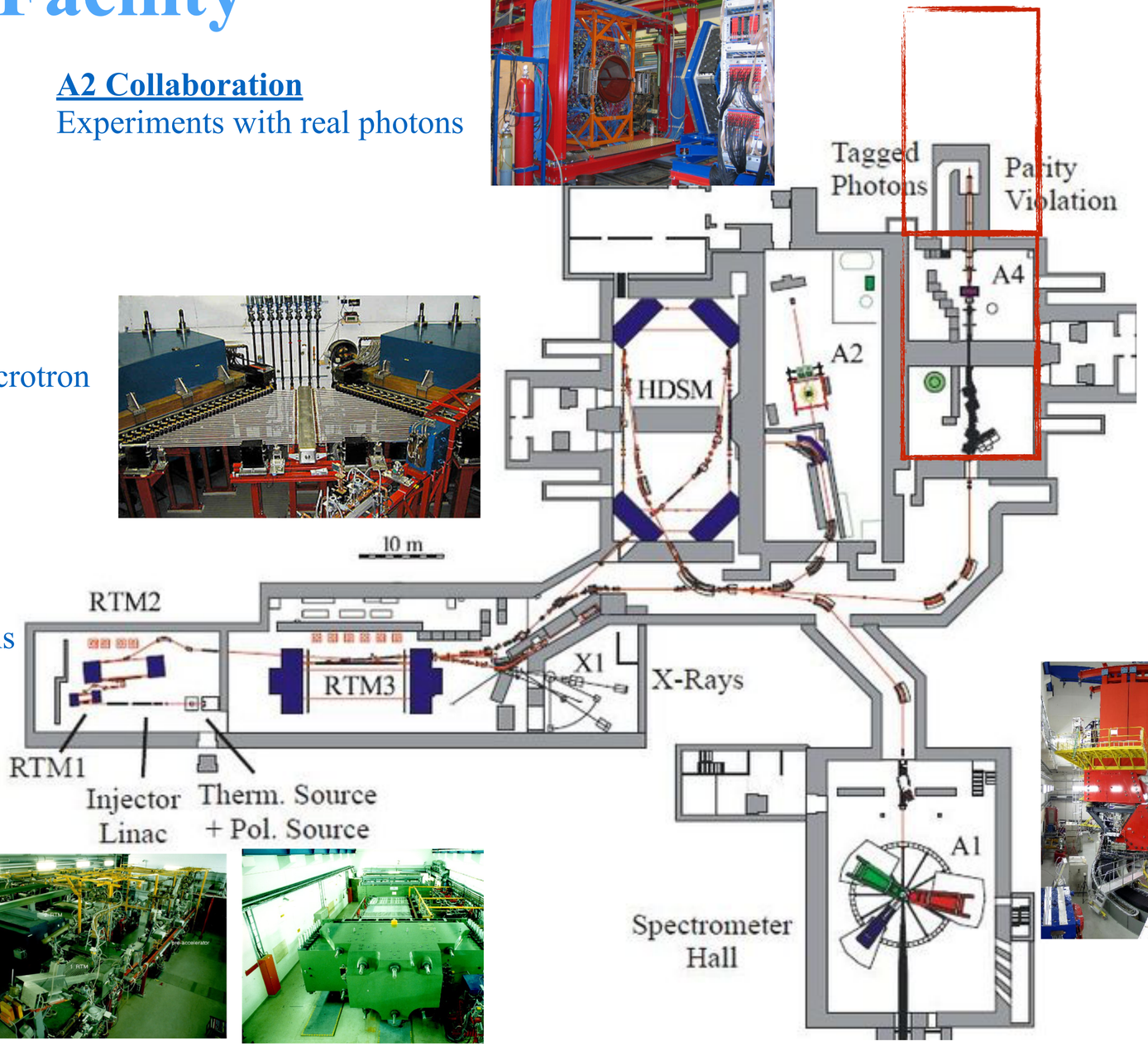

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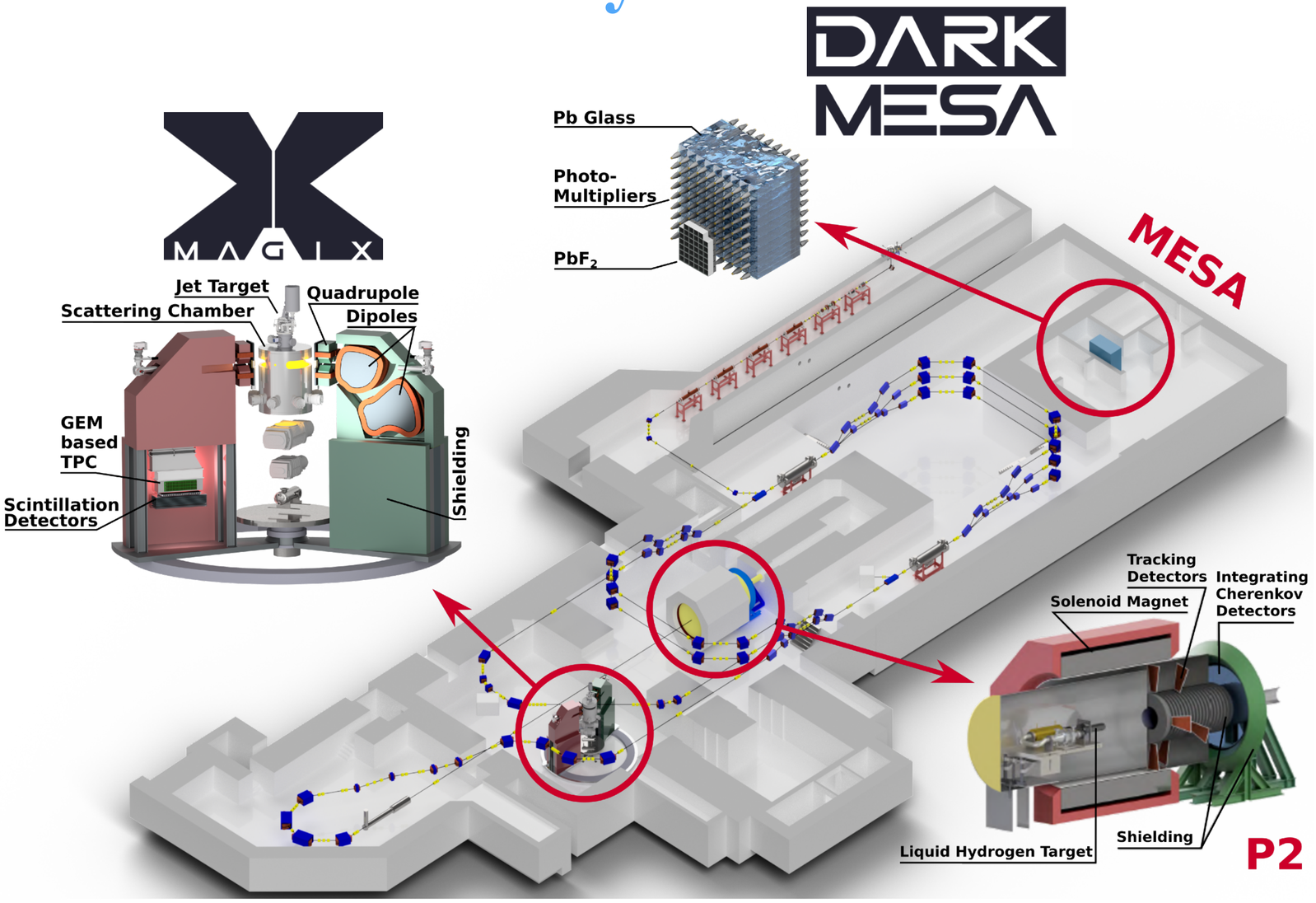
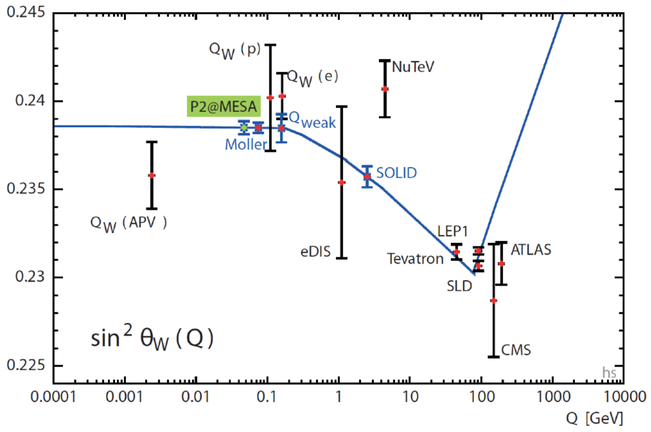
The MESA Facility



The MESA Accelerator

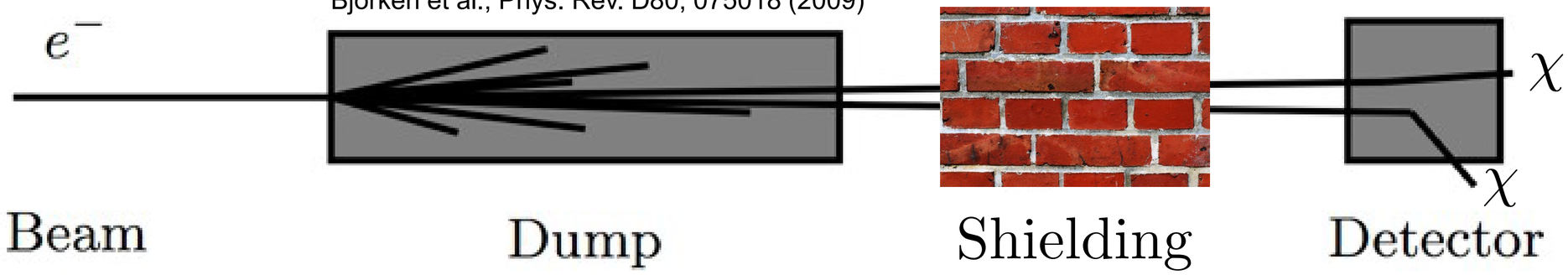
- 155 MeV max. beam energy
- 2 SC TESLA-like cavities
- >1mA beam current
- Operation:
- Extracted beam mode
- Energy recovery/3x recirculation



Beam-Dump Experiments

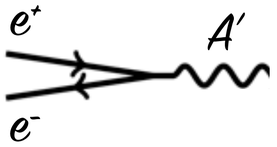
The DarkMESA experimental principle

Bjorken et al., Phys. Rev. D80, 075018 (2009)

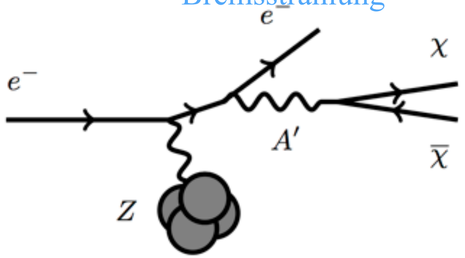


Production

Annihilation



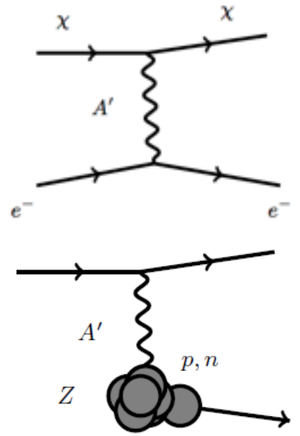
Bremsstrahlung



$$\theta_{A'\,\max} \sim \max\left(\frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}}\right)$$

$$\frac{d\sigma}{dx} \approx \frac{8Z^2\alpha^3\epsilon^2 x}{m_{A'}^2}\left(1 + \frac{x^2}{3(1-x)}\right)\mathcal{L}og$$

Detection

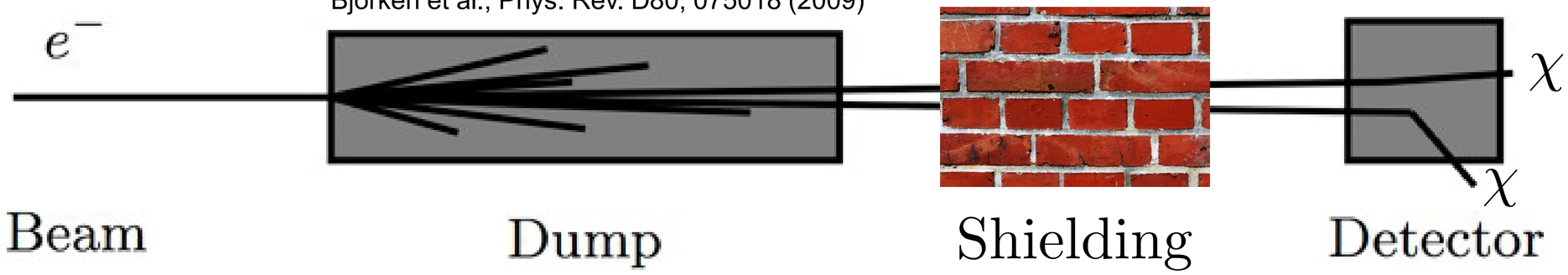


$$Y_{Prod} \sim \epsilon^2/m_A^2$$

$$Y_{Det} \sim \epsilon^2\alpha_D/m_A^2$$

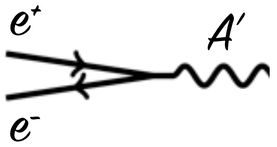
The DarkMESA experimental principle

Bjorken et al., Phys. Rev. D80, 075018 (2009)



Production

Annihilation



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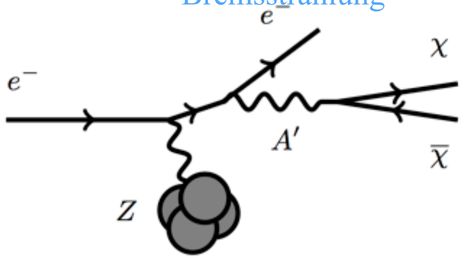

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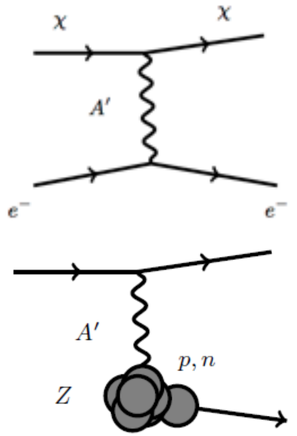
Detection



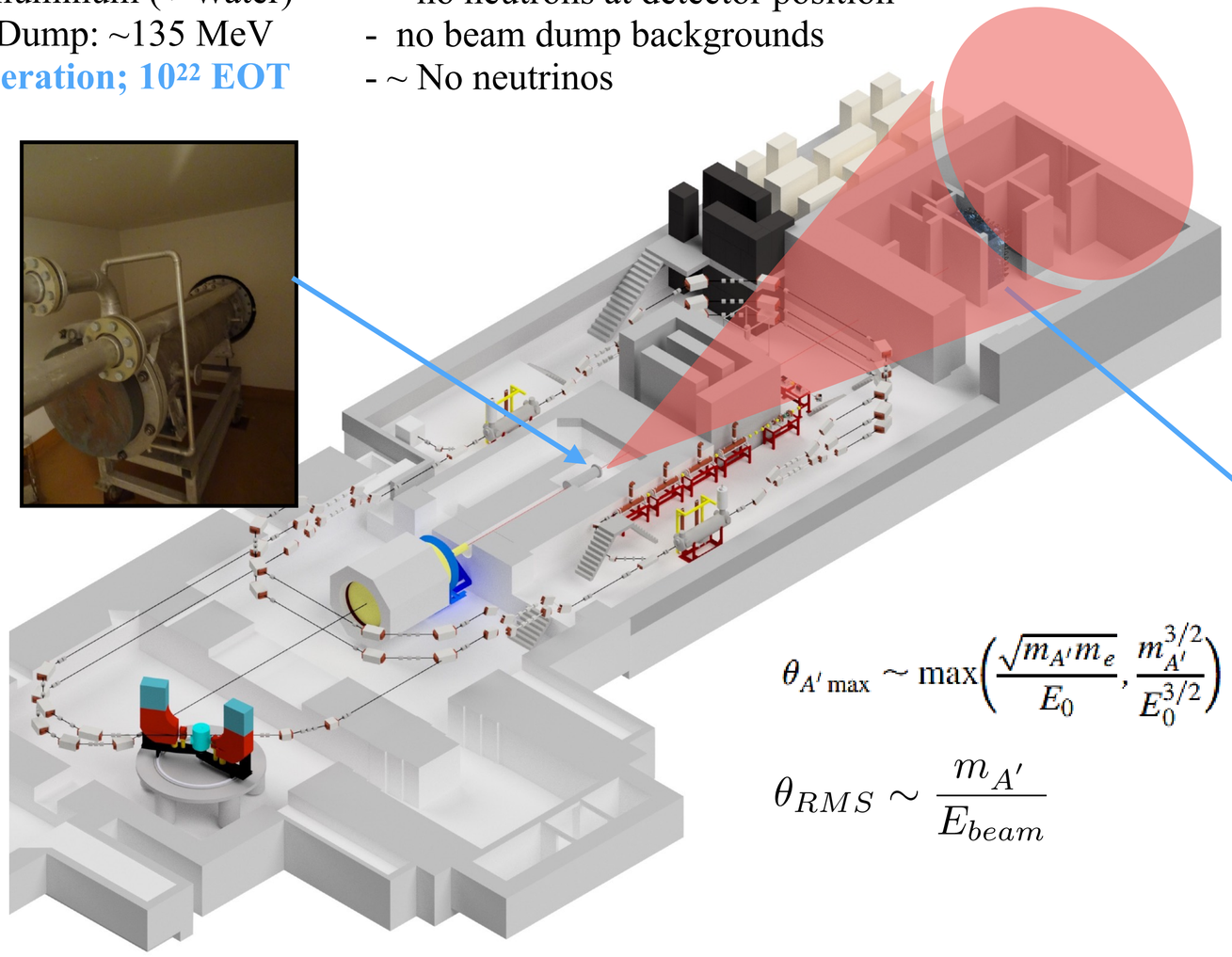
Total Yield

$$Y_{Prod} \sim \epsilon^2/m_A^2 \rightarrow Y_{TOT} \sim \epsilon^4\alpha_D/m_A^4 \leftarrow Y_{Det} \sim \epsilon^2\alpha_D/m_A^2$$

The DarkMESA experimental principle

Beam Dump
- 20 X_0 Beam Dump
- Material: Aluminum (+ Water)
- Energy on Dump: ~135 MeV
- **10^4 h of operation; 10^{22} EOT**

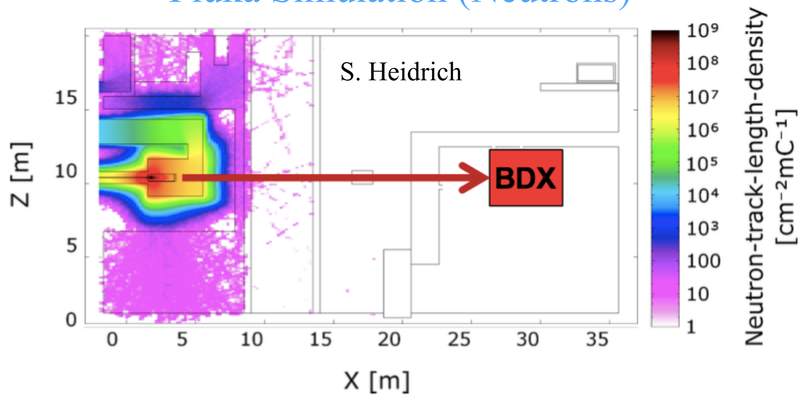
Experimental Area
- 70 X_0 (~8m) barite concrete
- ~ no neutrons at detector position
- no beam dump backgrounds
- ~ No neutrinos

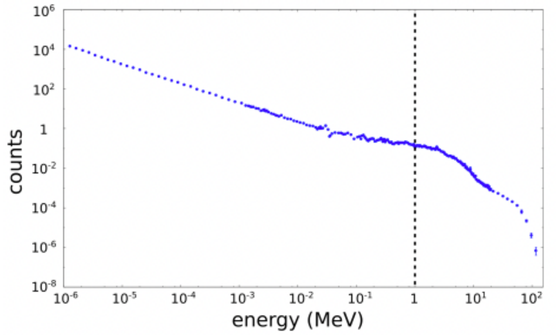


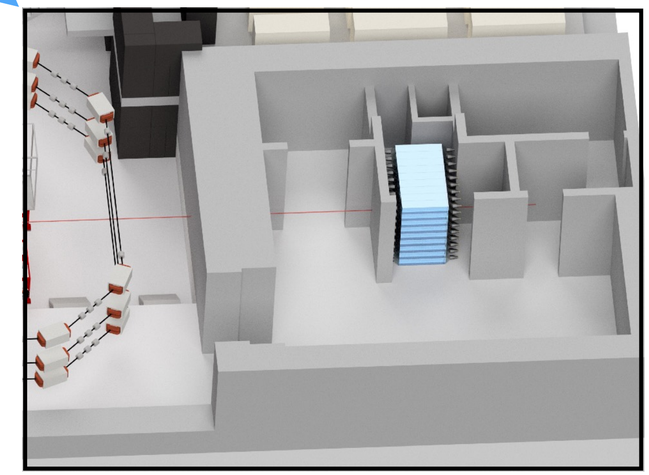
$$\theta_{A' \max} \sim \max\left(\frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}}\right)$$

$$\theta_{RMS} \sim \frac{m_{A'}}{E_{beam}}$$

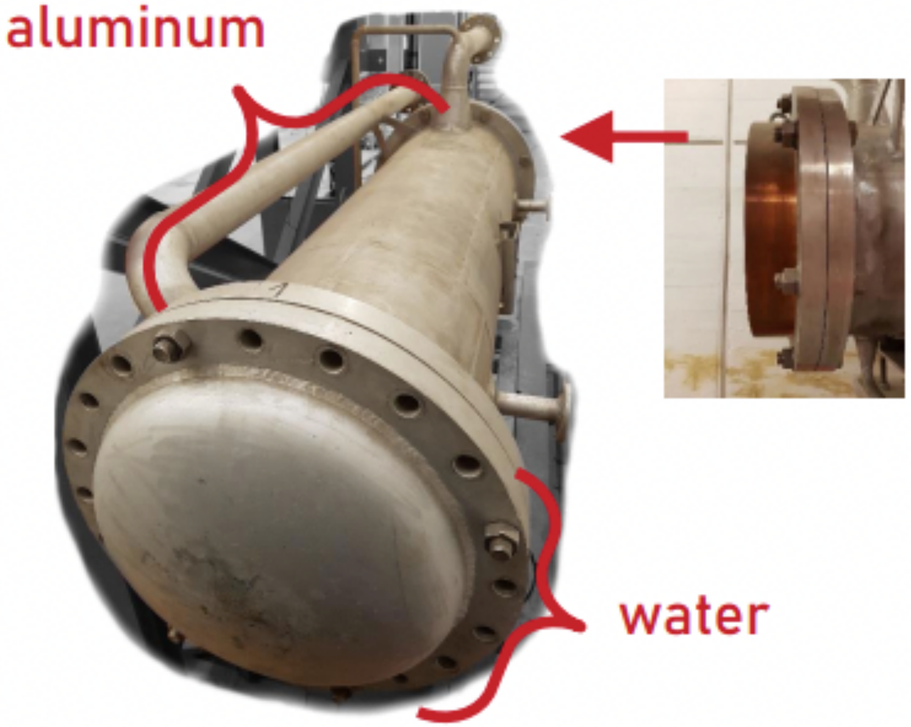
Fluka Simulation (Neutrons)

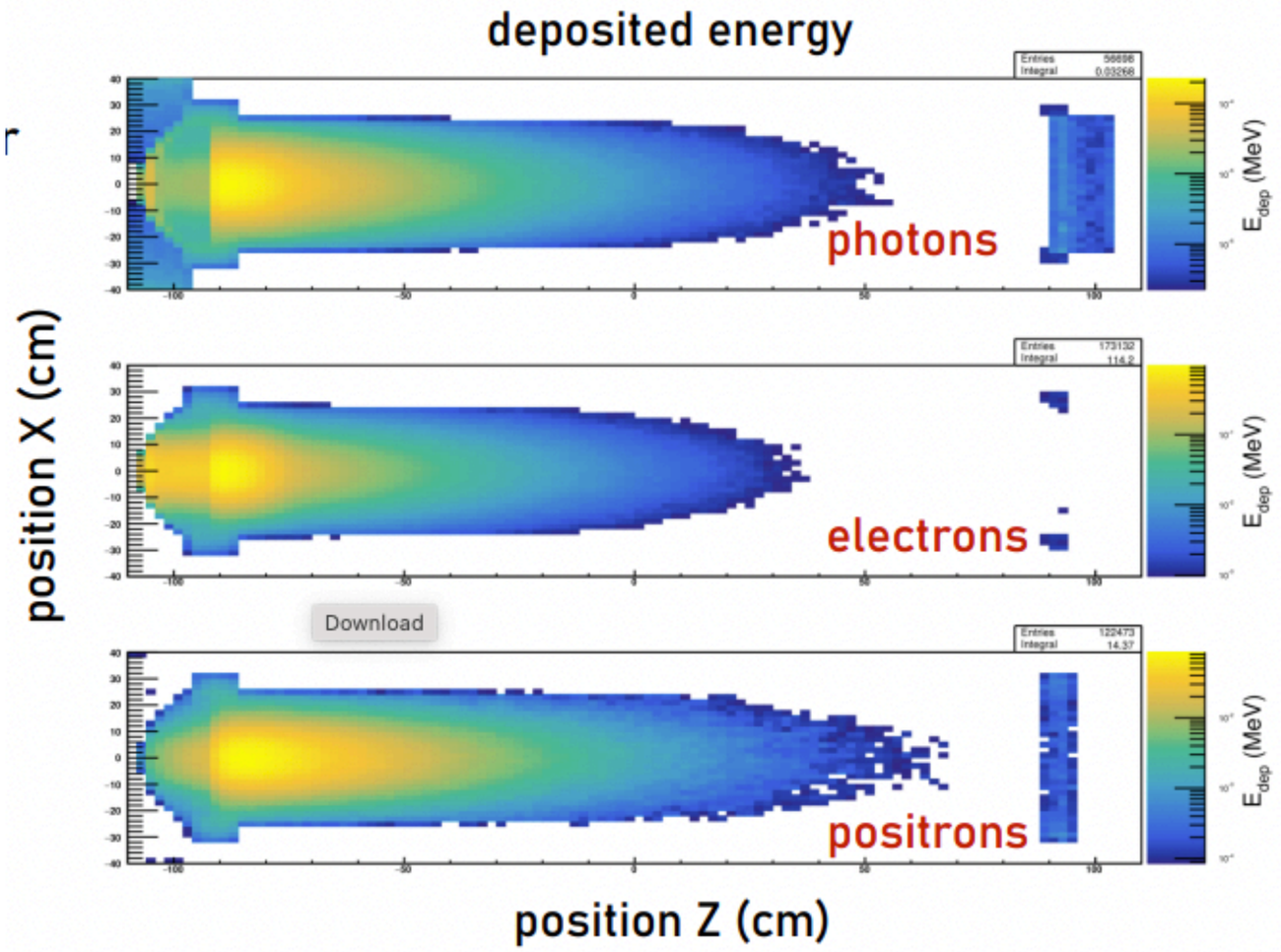






The “Target”

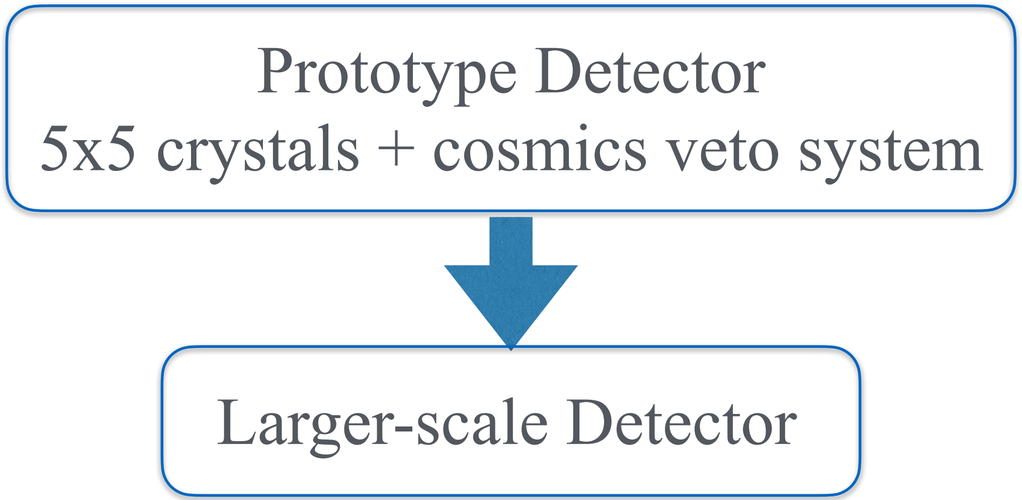

aluminum
water


deposited energy
photons
electrons
positrons
position X (cm)
position Z (cm)
E_dep (MeV)
Download

Detector Technologies

M. Lauß *et al.*, Nucl. Instr. Meth. A, 1012, 165617 (2021)
M. Christmann *et al.*, Nucl. Instr. Meth. A, 960, 163665 (2020)
M. Christmann *et al.*, Nucl. Instr. Meth. A, 958, 162398 (2020)

Staged Approach to the final detector



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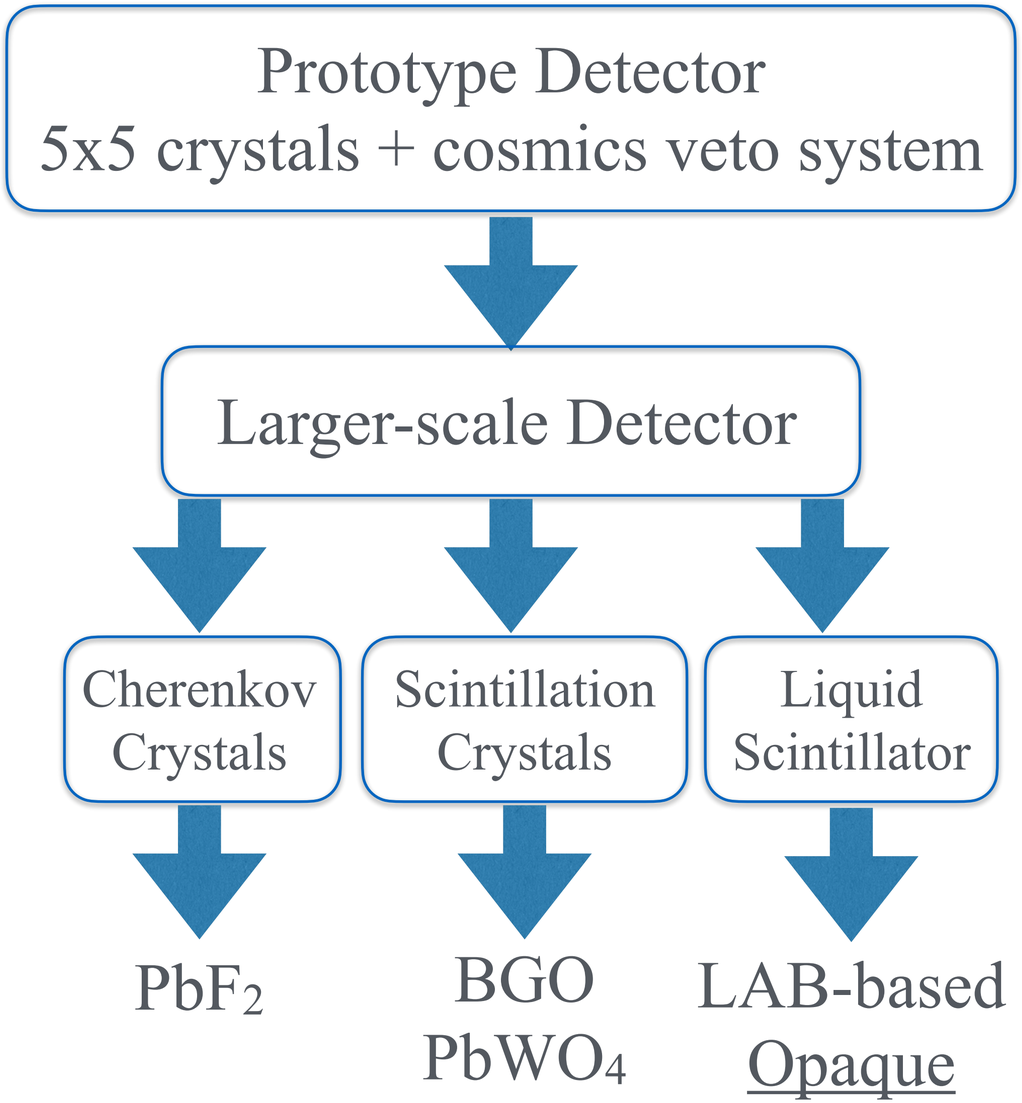

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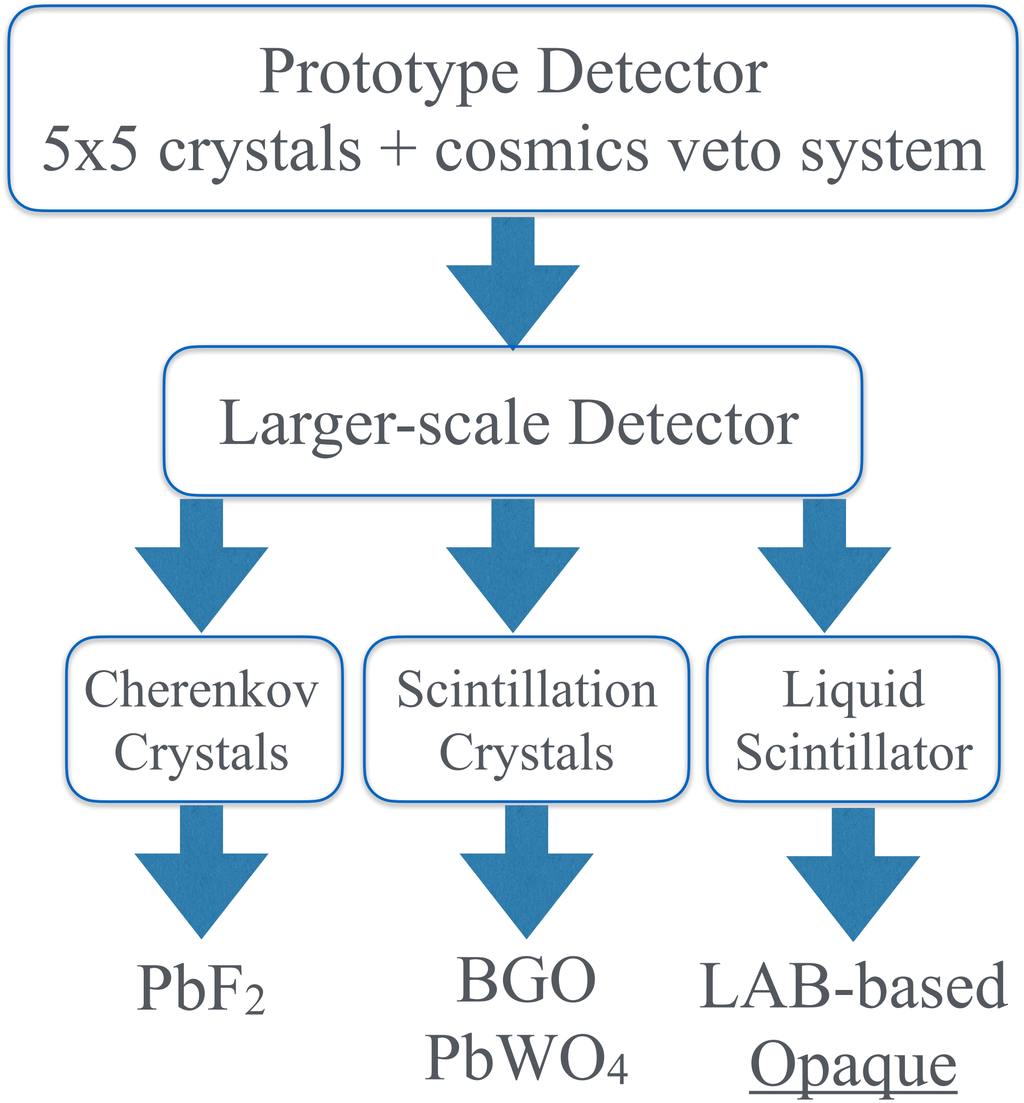


$PbWO_4$

Density ~8.3 g/cm³
Output 50-200 ph./MeV
Fast (~10 ns)

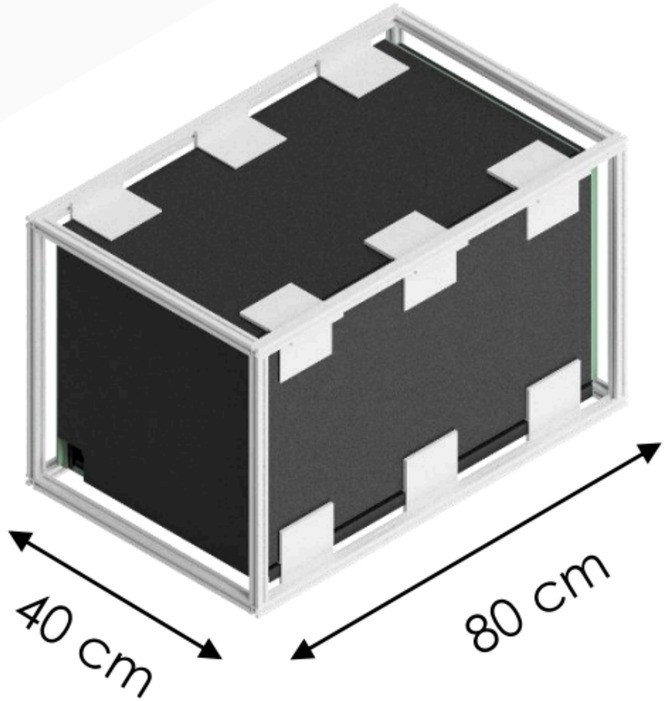
BGO

Density ~ 7.1 g/cm³
Output ~10,000 ph./MeV
Slow (~300-600 ns)

PbF_2

Density ~8.4 g/cm3
Output ~16 ph./MeV
Fast (~10ns)

Prototype Detector





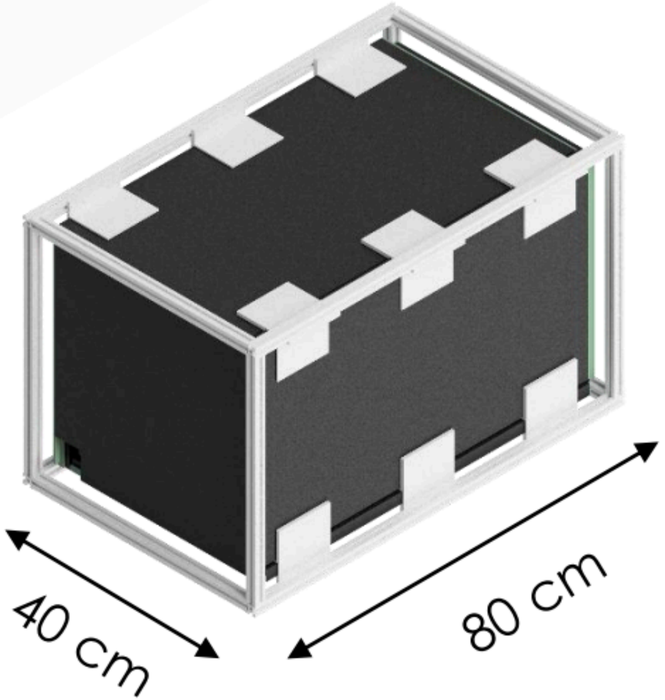
Mirco Christmann

Matteo Lauss

Christian Stoss

Michail Kontogoulas

Prototype Detector



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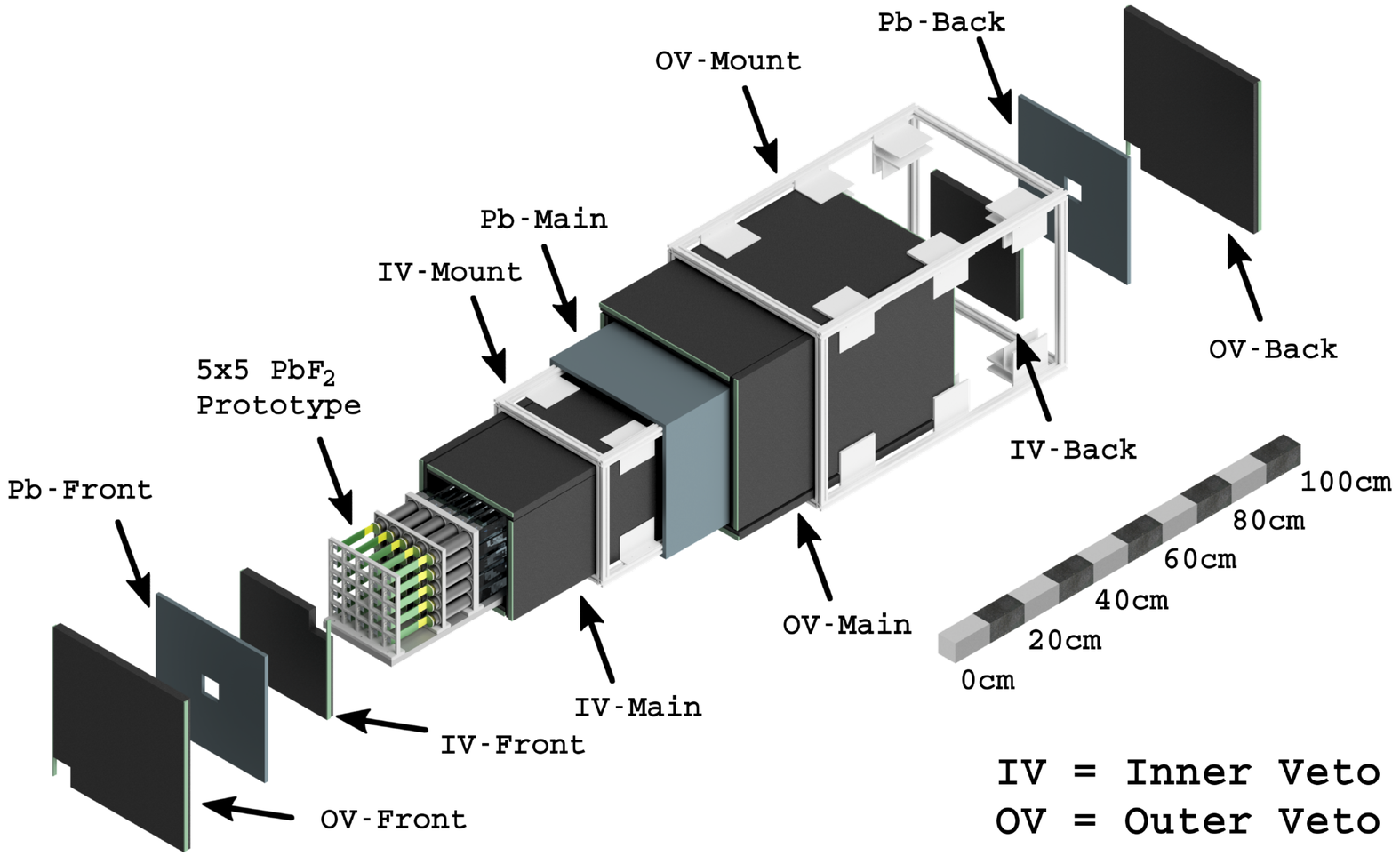
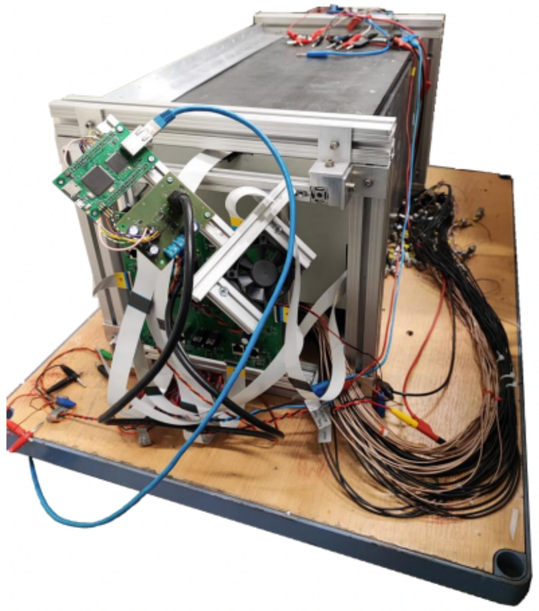


IV = Inner Veto
OV = Outer Veto

First Tests



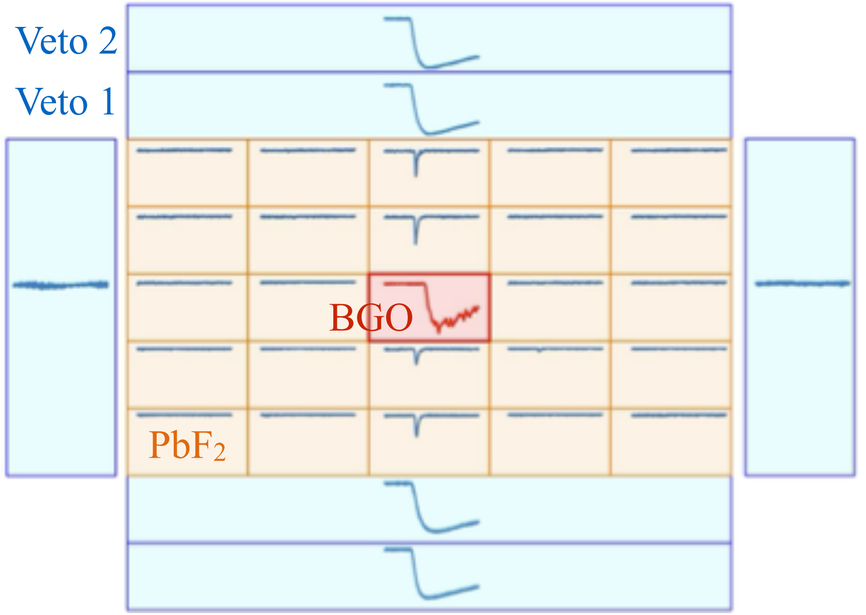
Electronics/DAQ

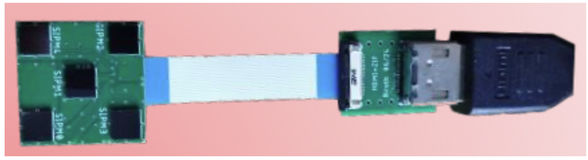
CAEN V1742 (5GHz, 32ch, sigle ended)
- Fast, more expensive

PANDA sADC (80 MHz, 64ch, diff.)
- Slower, cheaper, shaping required.

Operation with cosmics started:

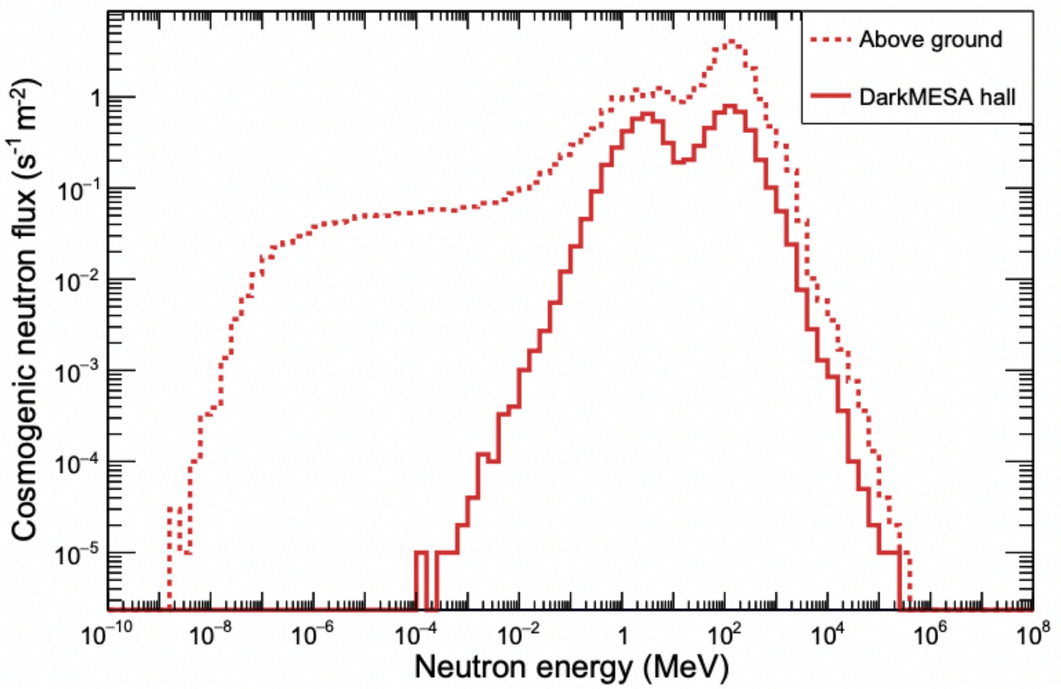
Central BGO crystal for test.
Surrounding crystals: PbF_2.





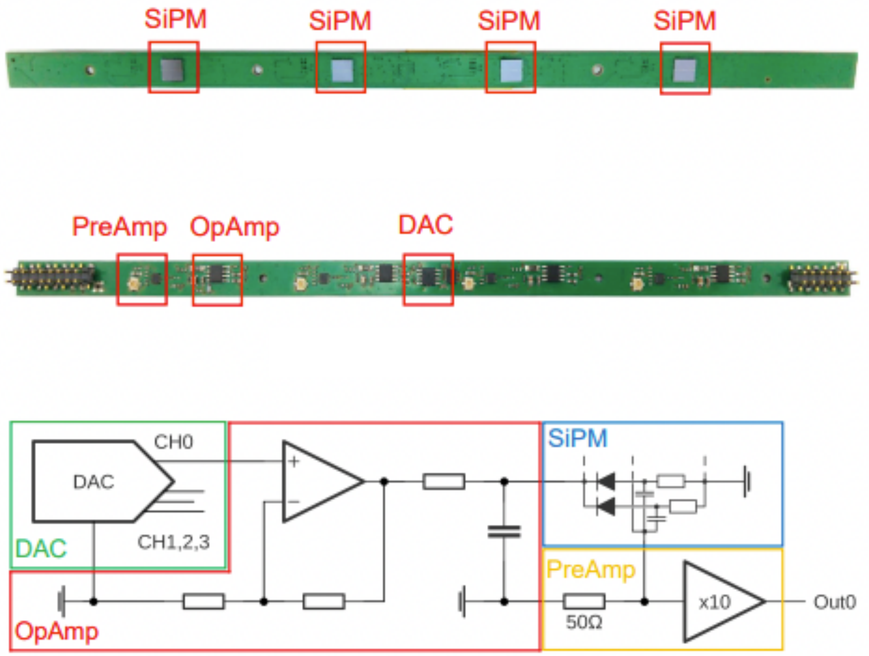
SiPM readout

Background Studies



Cosmic Rays Simulation

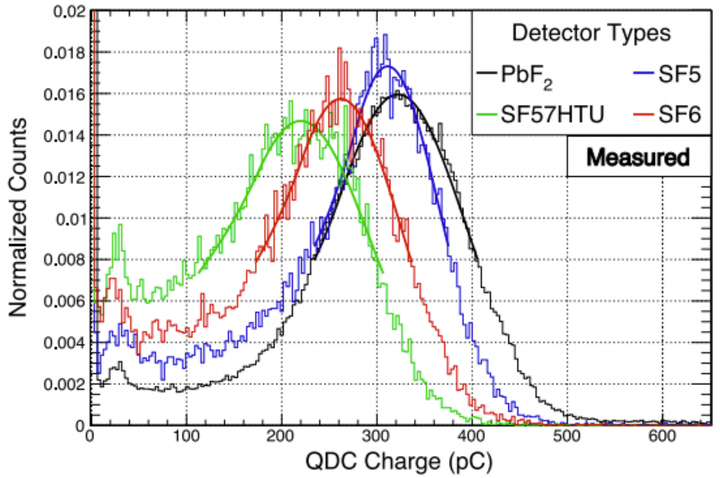
- CRY Library (LANL)
- Overburden
- Neutrons

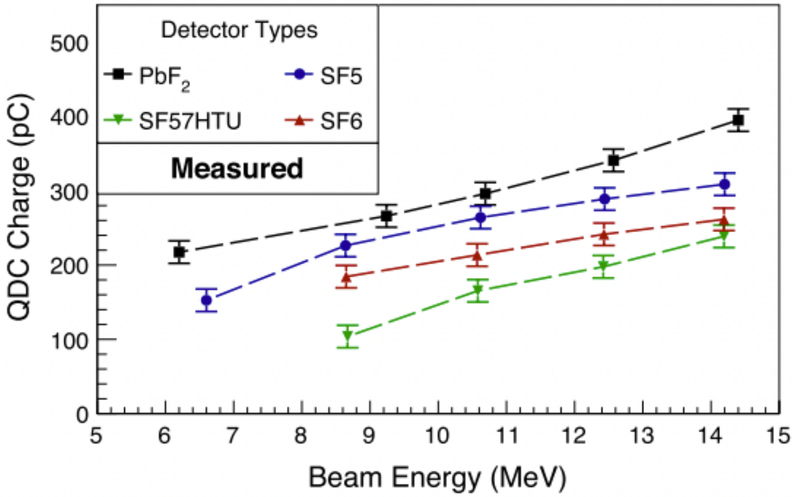


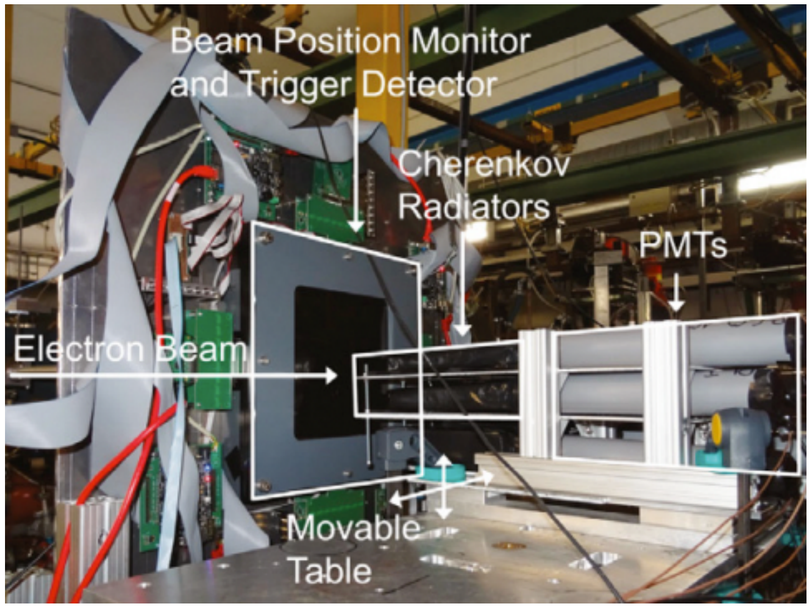
Cosmic Rays Veto Detector

- Plastic Scintillators
- SiPM readout
- Custom electronics

Beam Tests (Cherenkov Radiators)

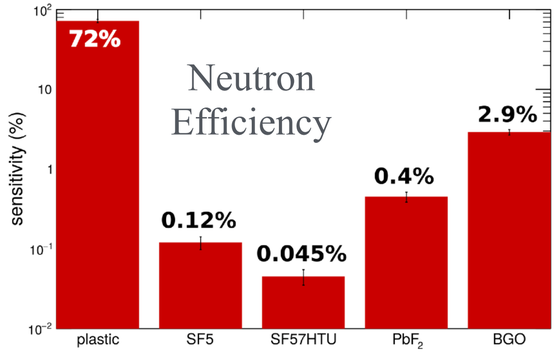


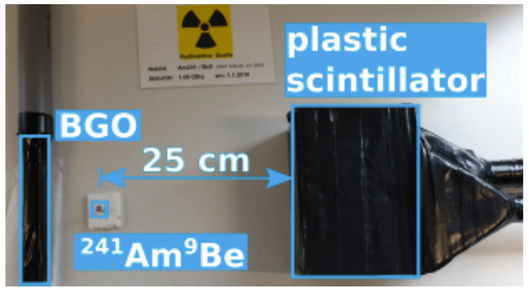




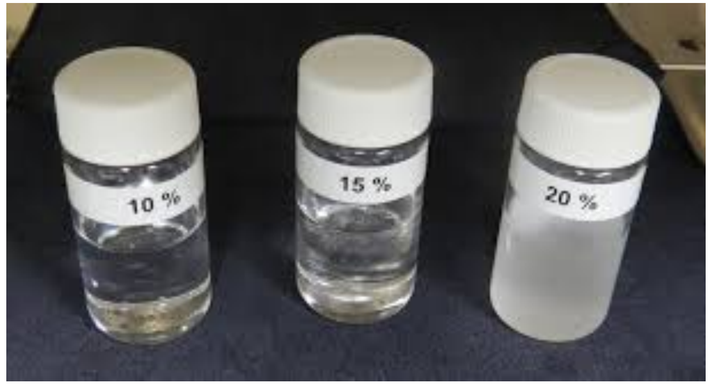
MAMI Beam (6-14 MeV)

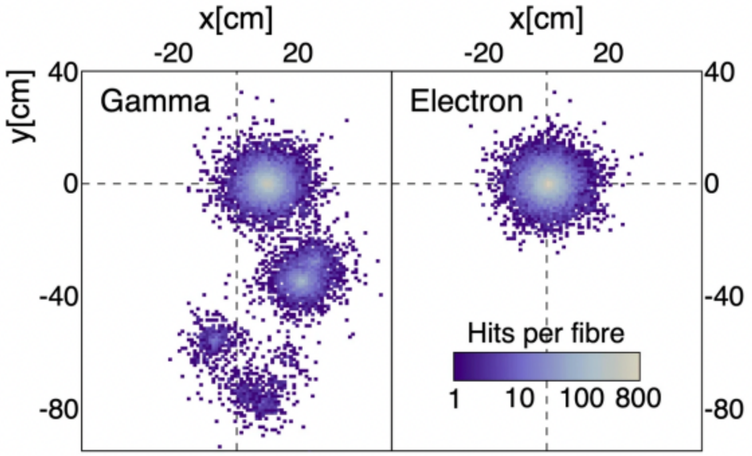
- Produced PEs
- Lower Threshold
- Neutron efficiency (source)

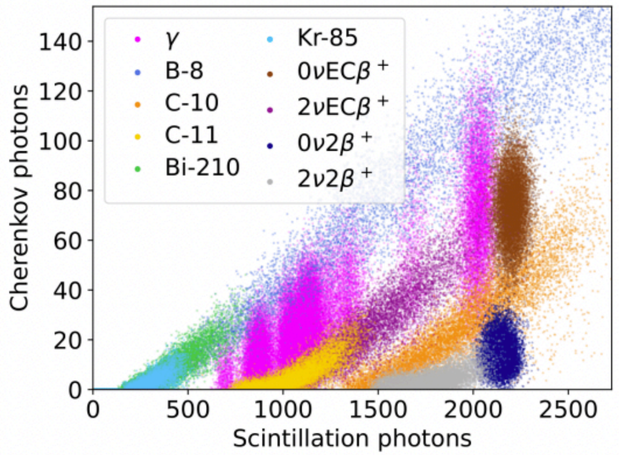




Liquid Scintillators







<u>Opaque Scintillators</u>

Load LS with wax (e.g. 80%-20%)

Opaqueness: scattering w/o absorption

PID: topology of vertices

Readout: optical fibres.

Stefan Schoppann et al. (JGU)

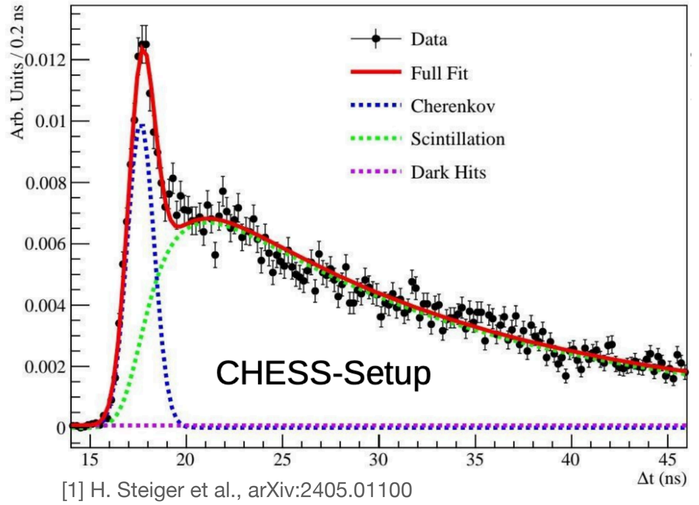
arXiv:2407.05999

<u>Water-Based Scintillators</u>

1%-10% scintillator

Long time component > 10ns

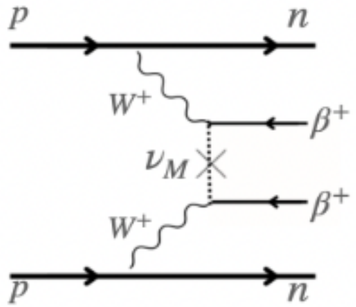
PID: Cherenkov/Scint ratio



[1] H. Steiger et al., arXiv:2405.01100

Detector Concept

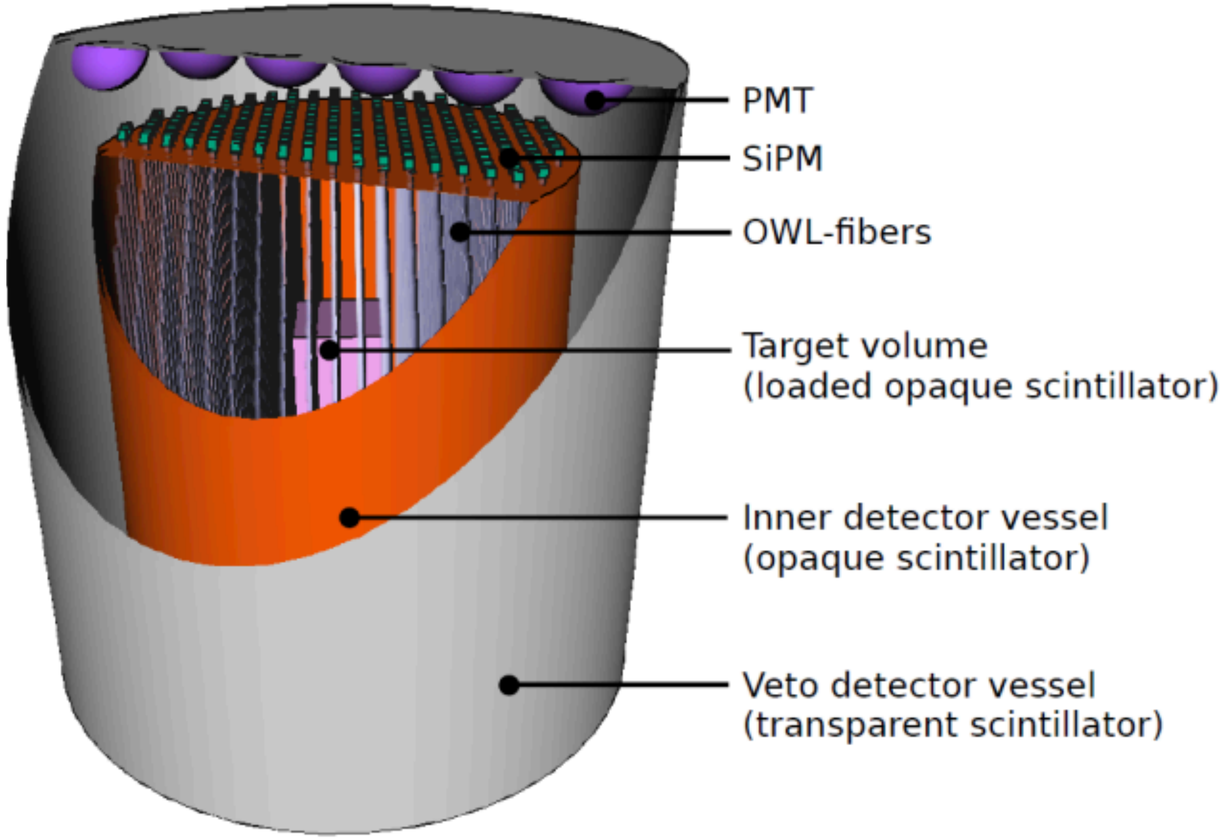
Prototype of a $0\nu\beta\beta$ experiment (NuDoubt^{++})
Test isotopes: ^{78}Ke, ^{124}Xe, ^{106}Cd
Aim: observe $0\nu\beta\beta$+ in p-rich isotopes:



No only a detector test: DarkMESA .

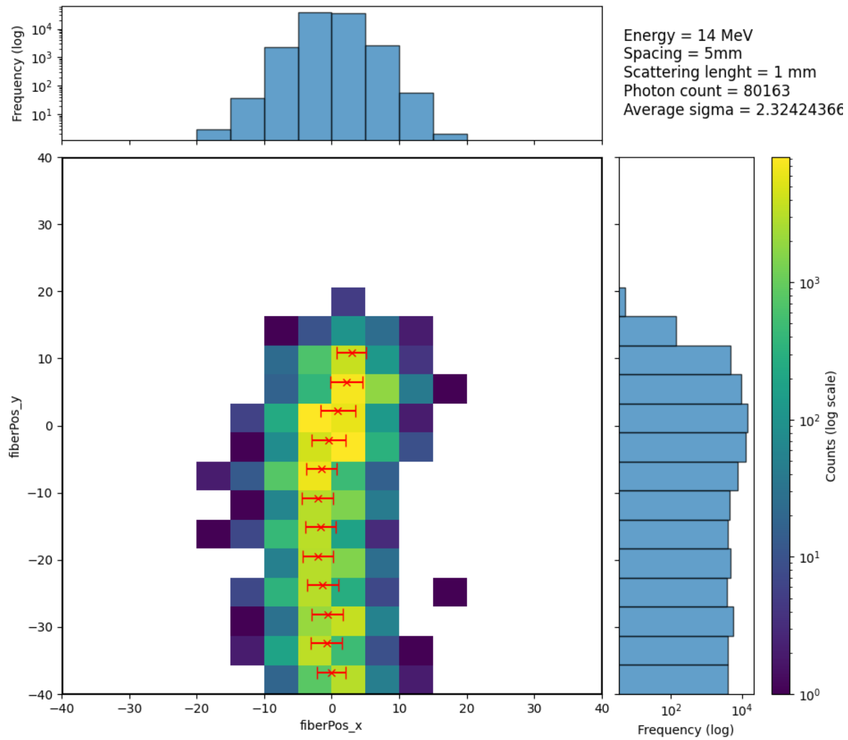
Technology:
Liquid Scintillator (Opaque/W-based)
Optimised WLS Fibres (OWL)
Readout: SiPMs

Concept for NuDoubt^{++}/DarkMESA



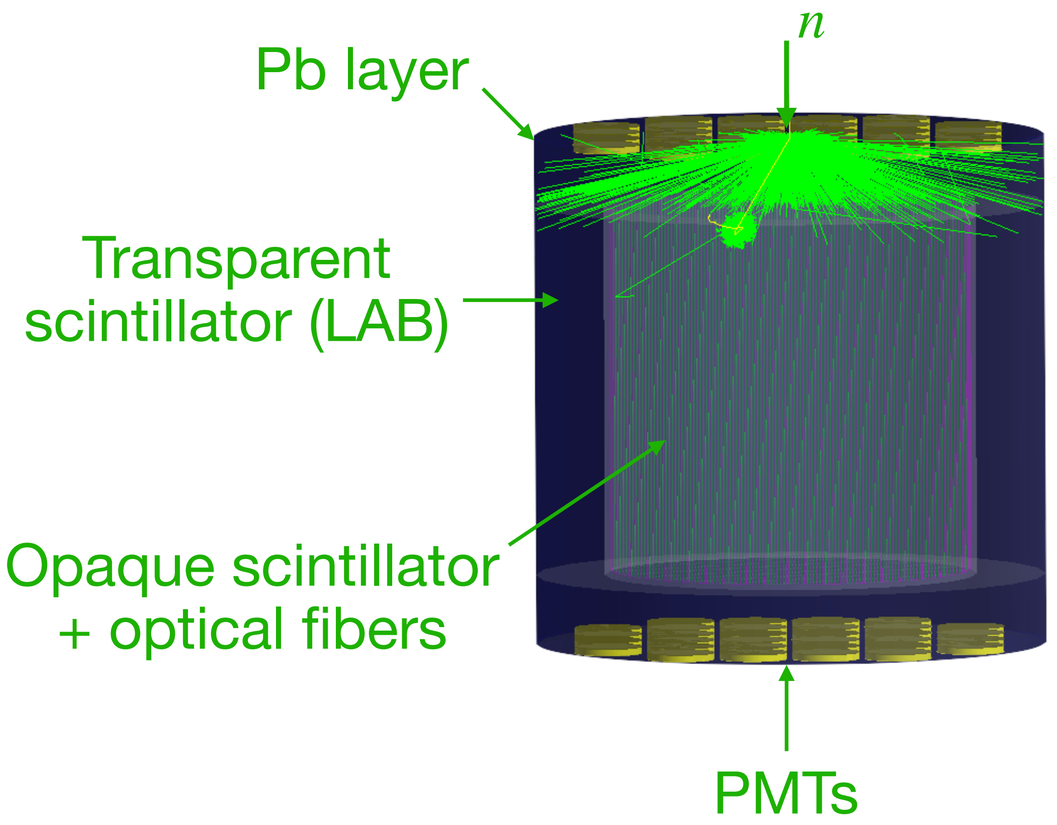
Detector Concept

Simulation towards a ~10cm³ prototype.
To be tested at MAMI accelerator (JGU).
Key point: threshold, tracking, PID.



Jonas Pätschke

Simulation of neutron background



Michail Kontogoulas

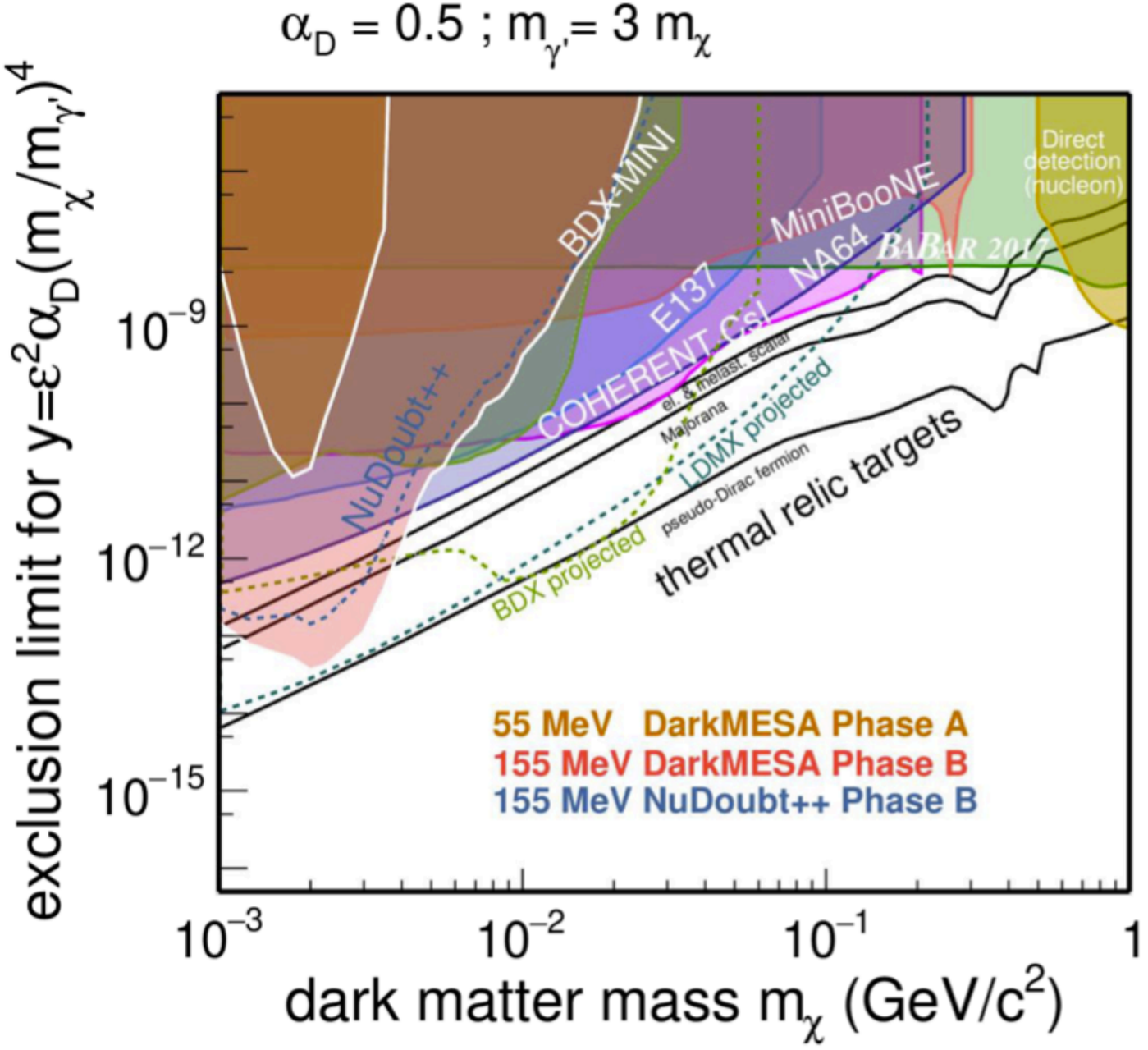
Projected Limits

Moving from G4+MadGraph to full G4 simulation (A. Celentano).

Add background contributions.

Simulate other physics models:
- Z’
- axions
- …

Saskia Plura



Summary

- MESA finally under construction: first 55 MeV beam in 2025.
- Beam Dump experiments: a lot of EOTs, sensitivity, direct measurement.
- DarkMESA: sensitivity to DM < 10MeV
- Investigation of different technological options underway.

Summary

- MESA finally under construction: first 55 MeV beam in 2025.
- Beam Dump experiments: a lot of EOTs, sensitivity, direct measurement.
- DarkMESA: sensitivity to DM < 10MeV
- Investigation of different technological options underway.
- Thank you!