Light Dark Matter Searches at MESA: Progress Report

Mirco Christmann

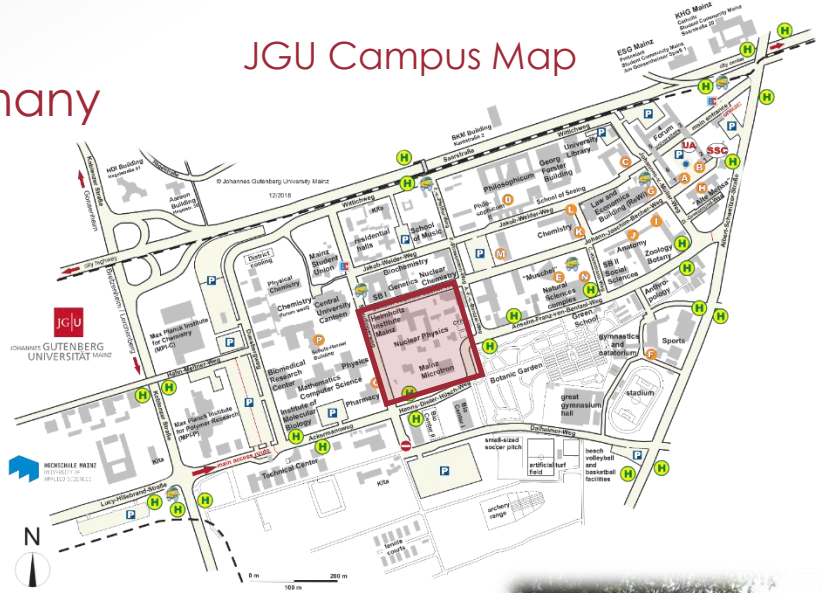
Institute for Nuclear Physics, Johannes Gutenberg-University Mainz, Germany

LDMA'19 – Venice – 21 November 2019

Introduction

Institute for Nuclear Physics, Mainz, Germany

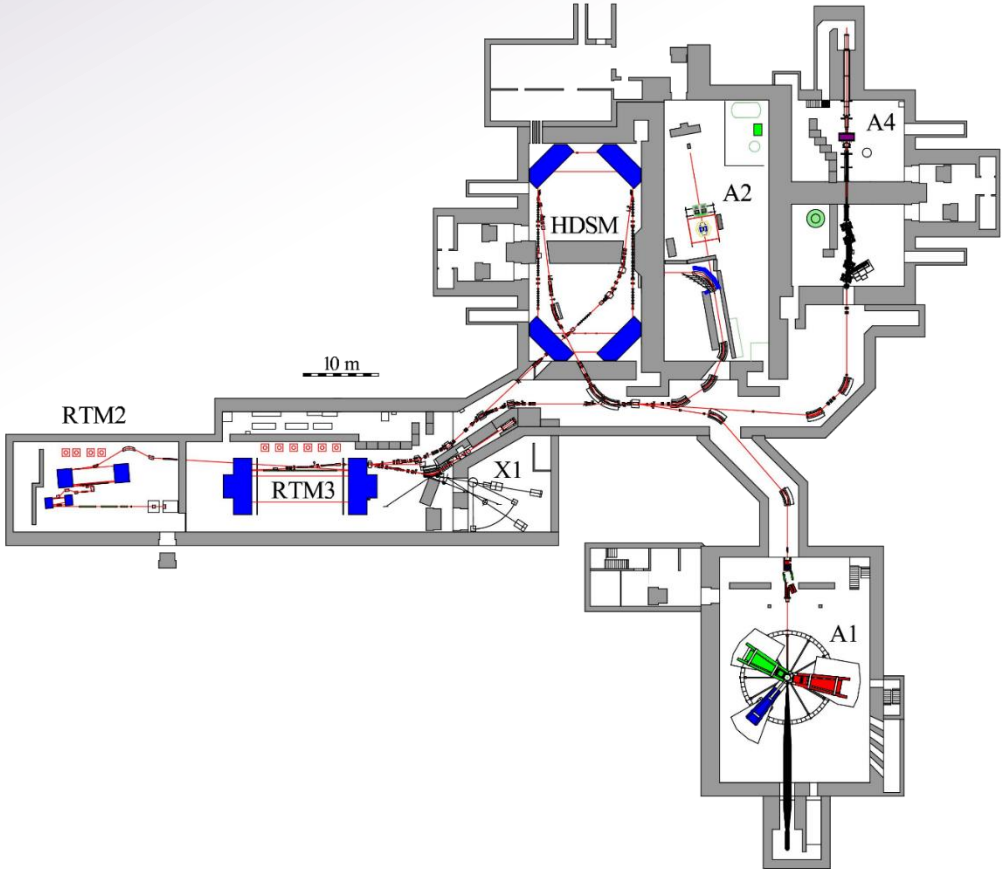
JGU Campus Map



MAMI
MAINZER MIKROTRON

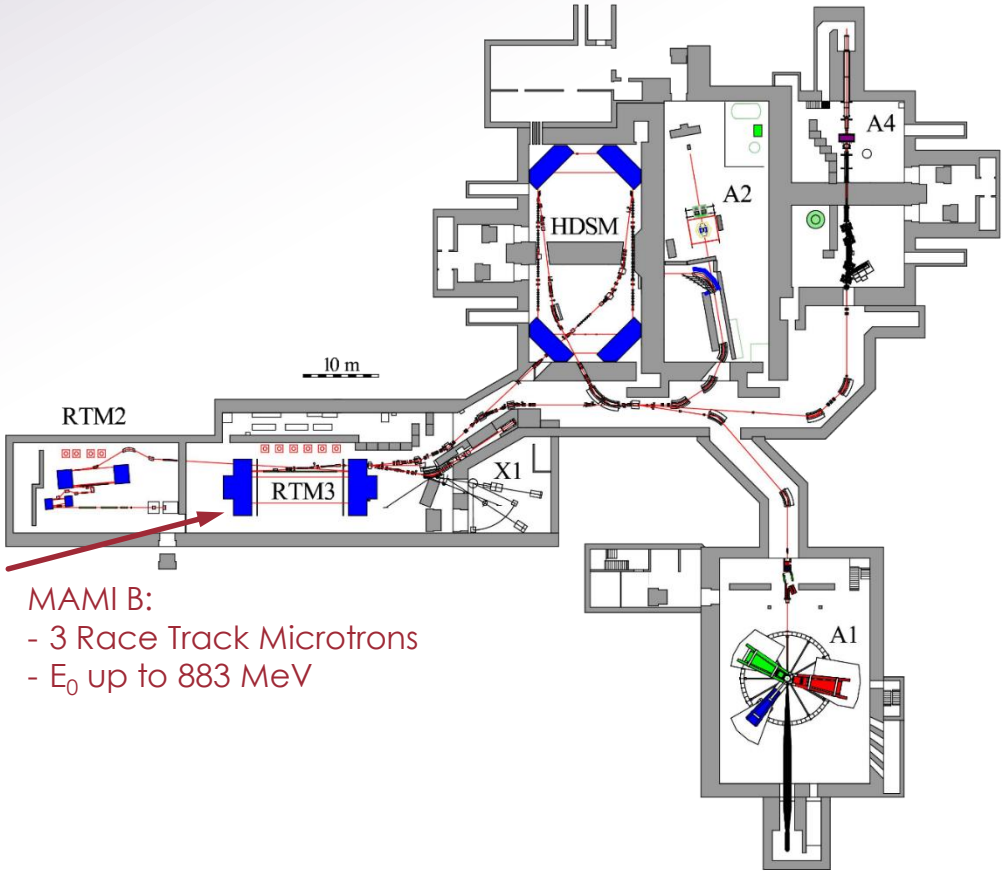
Introduction

Underground Floorplan Nuclear Physics



Introduction

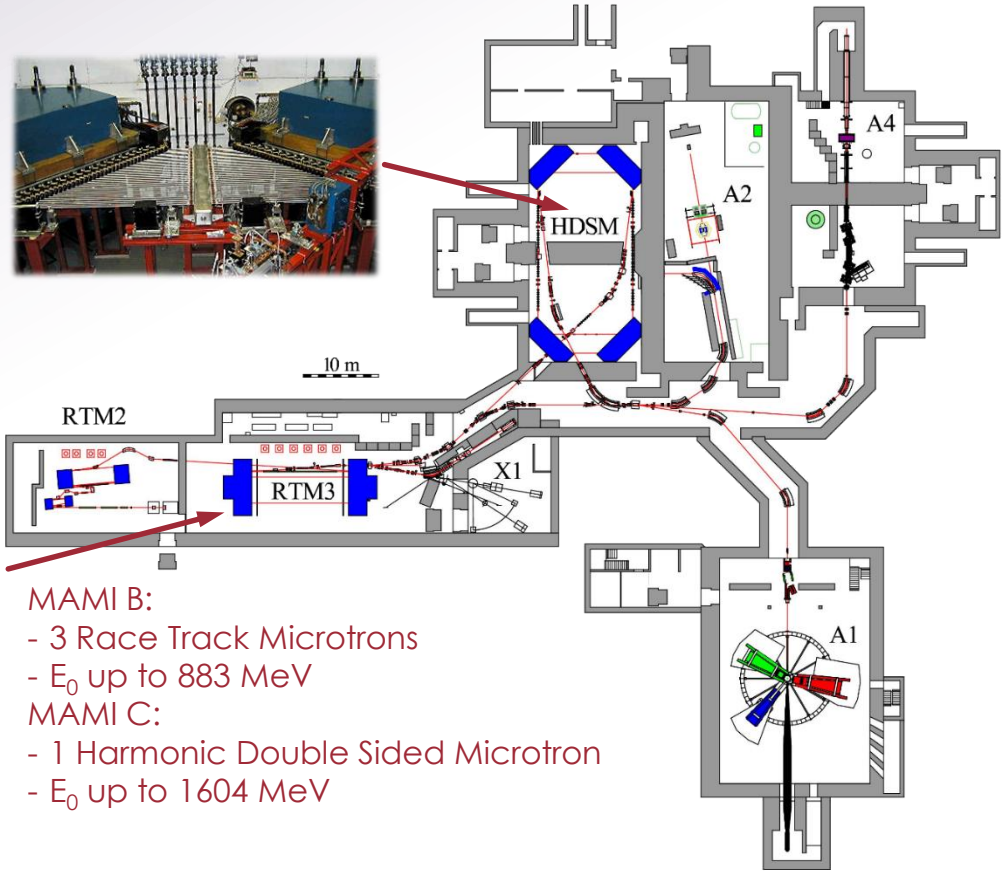
Underground Floorplan Nuclear Physics



MAMI B:
- 3 Race Track Microtrons
- E_0 up to 883 MeV

Introduction

Underground Floorplan Nuclear Physics

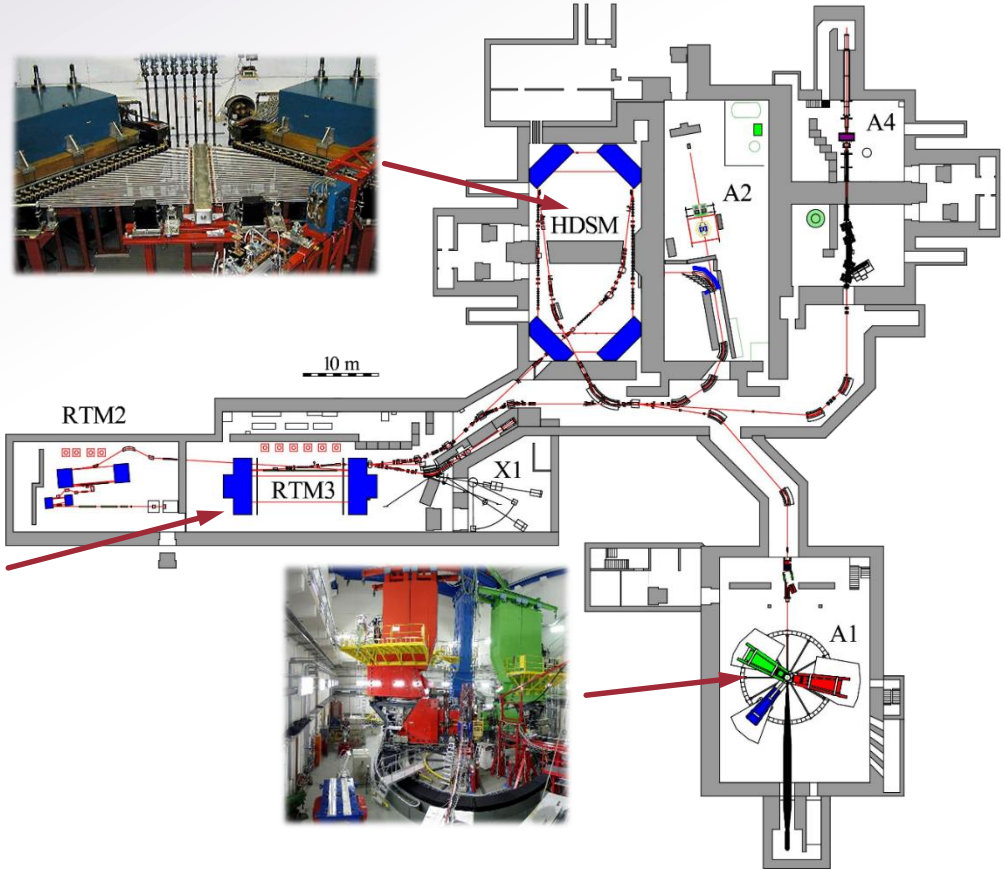


MAMI B:
- 3 Race Track Microtrons
- E_0 up to 883 MeV

MAMI C:
- 1 Harmonic Double Sided Microtron
- E_0 up to 1604 MeV

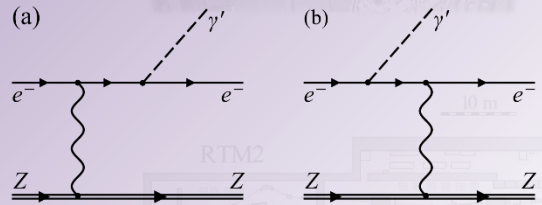
Introduction

Underground Floorplan Nuclear Physics

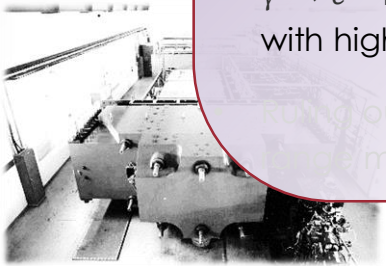


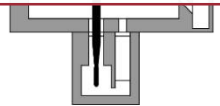
Dark Photon Searches with A1

- Dark photon produced radiatively:



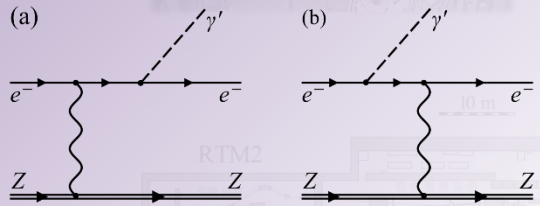
- $\gamma' \rightarrow e^+ + e^-$: detection of lepton pair with high resolution spectrometers



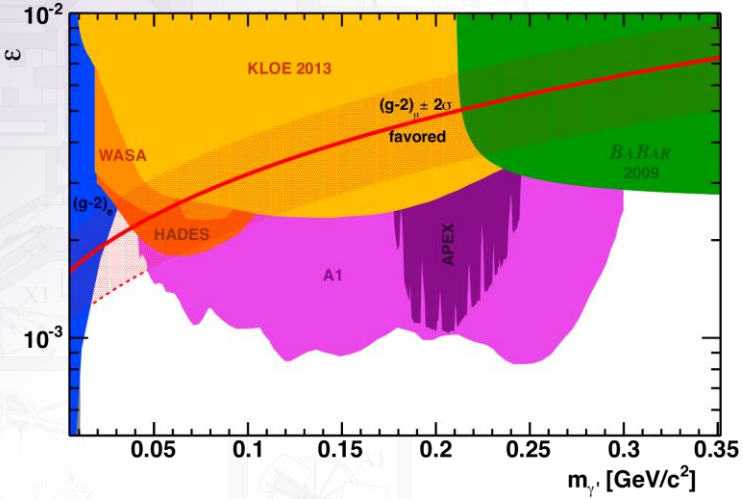


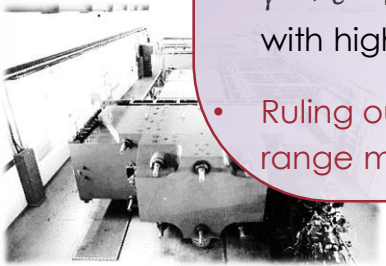
Dark Photon Searches with A1

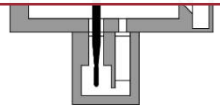
- Dark photon produced radiatively:



- $\gamma' \rightarrow e^+ + e^-$: detection of lepton pair with high resolution spectrometers
- Ruling out major part of the parameter range motivated by $(g\text{-}2)_\mu$

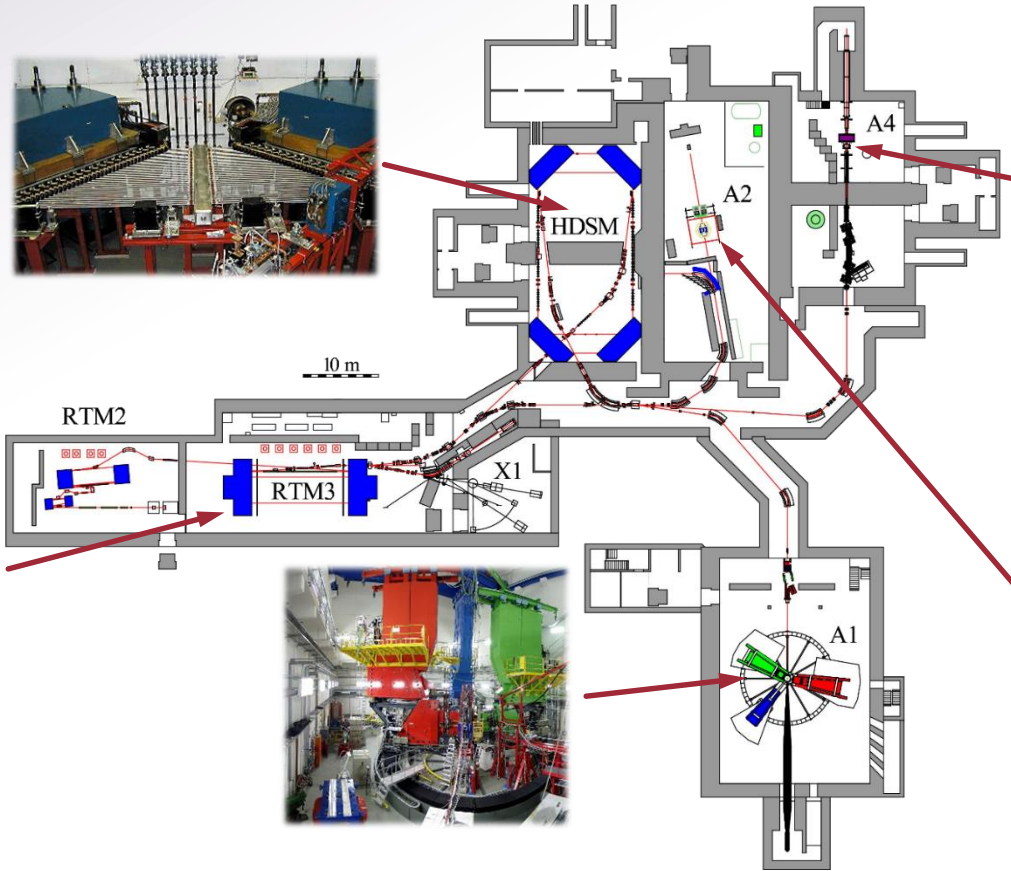


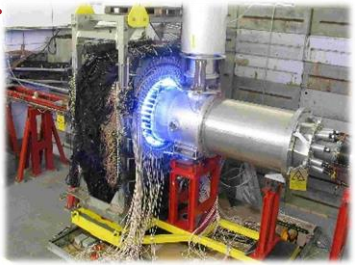


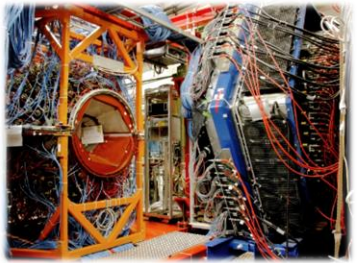


Introduction

Underground Floorplan Nuclear Physics

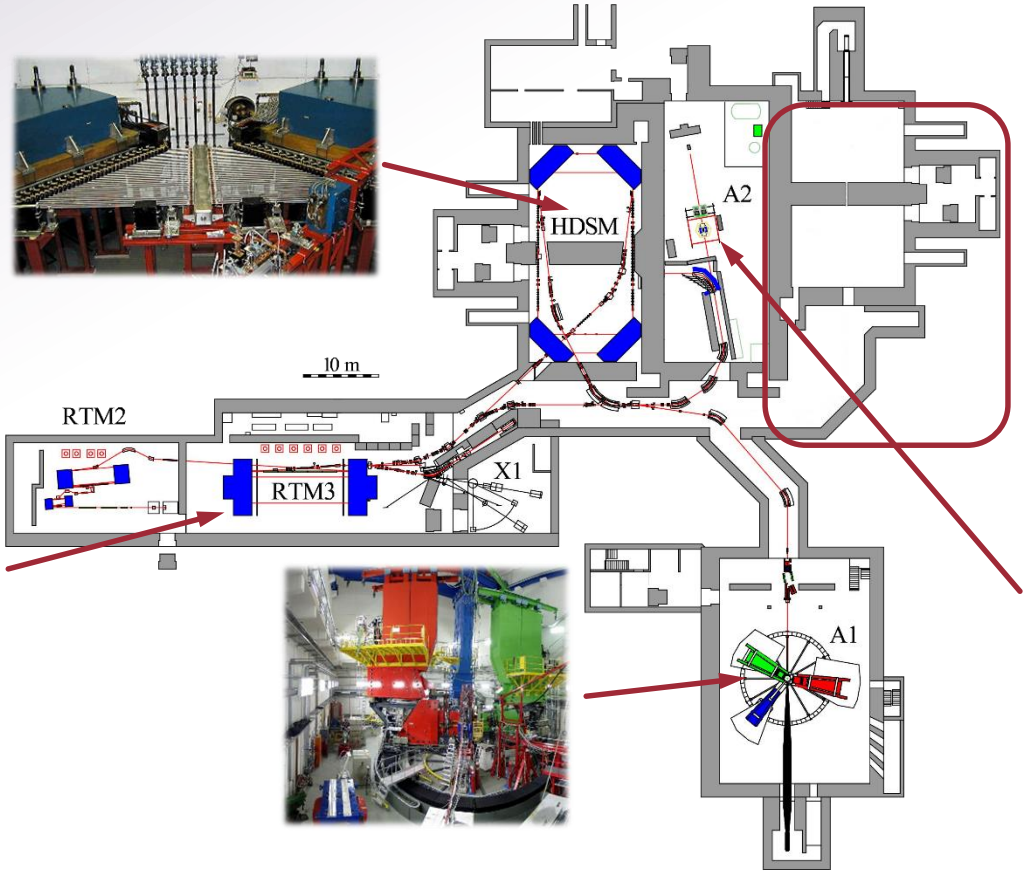


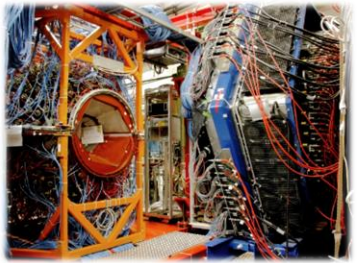




Introduction

Underground Floorplan Nuclear Physics

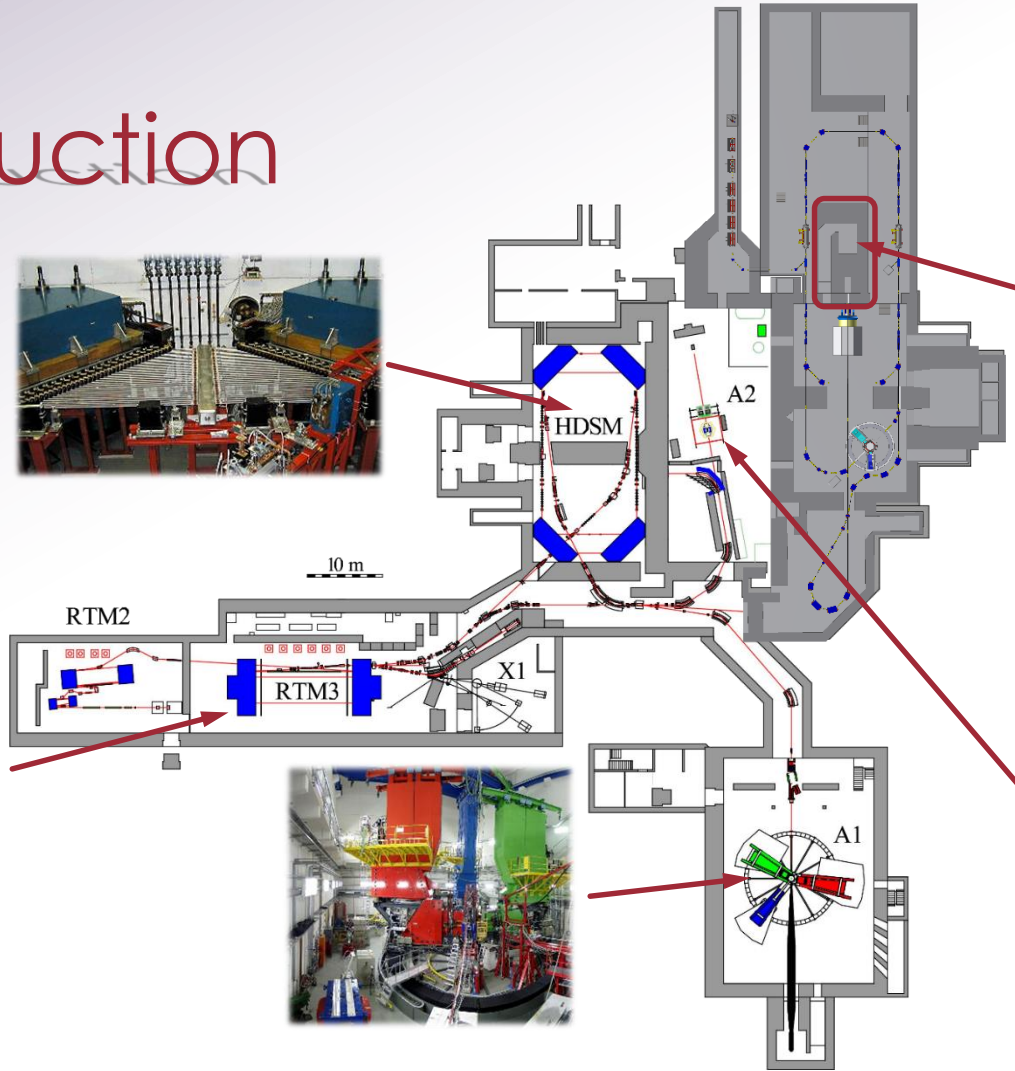




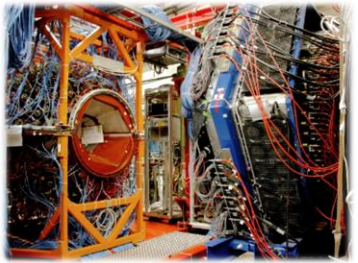
- Halls cleared for MESA

Introduction

Underground Floorplan Nuclear Physics

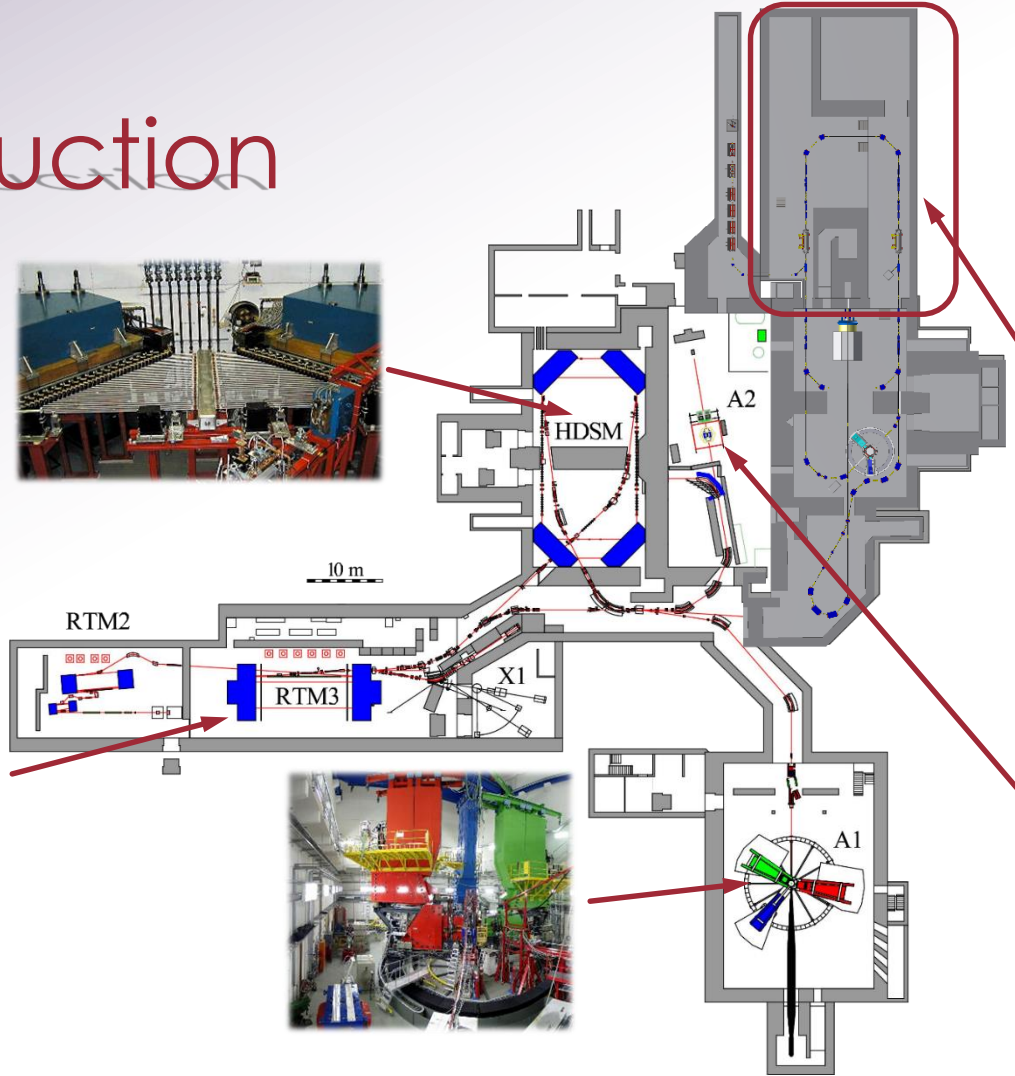


- Halls cleared for MESA
- Existing high-power beam dump

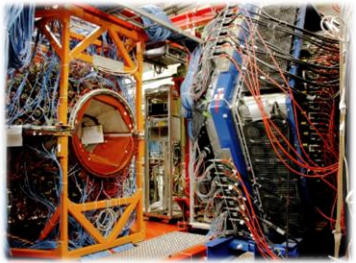


Introduction

Underground Floorplan Nuclear Physics

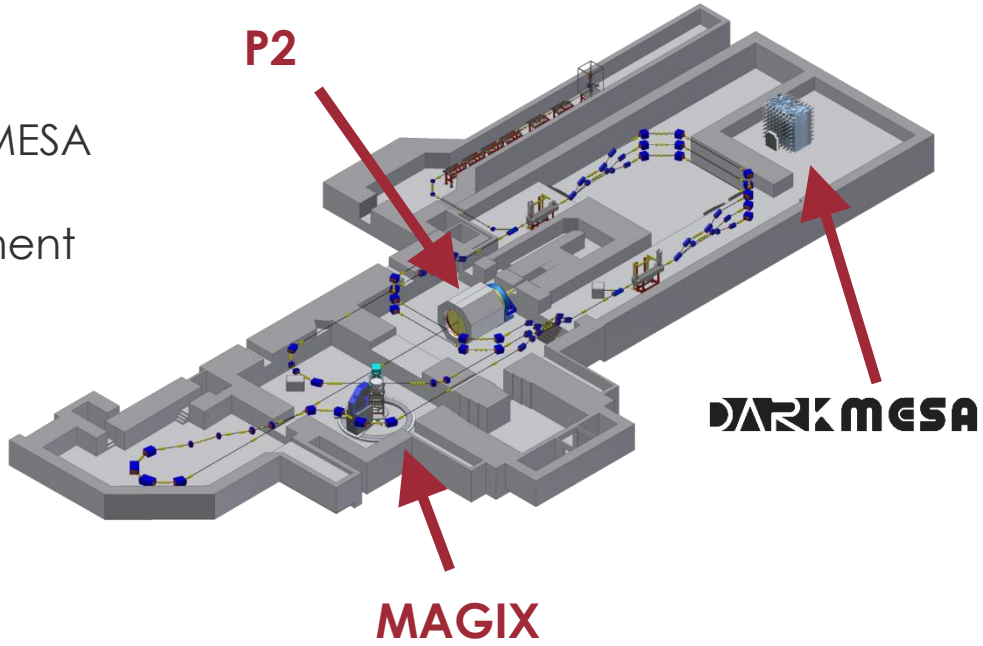


- Halls cleared for MESA
- Existing high-power beam dump
- New MESA hall and building



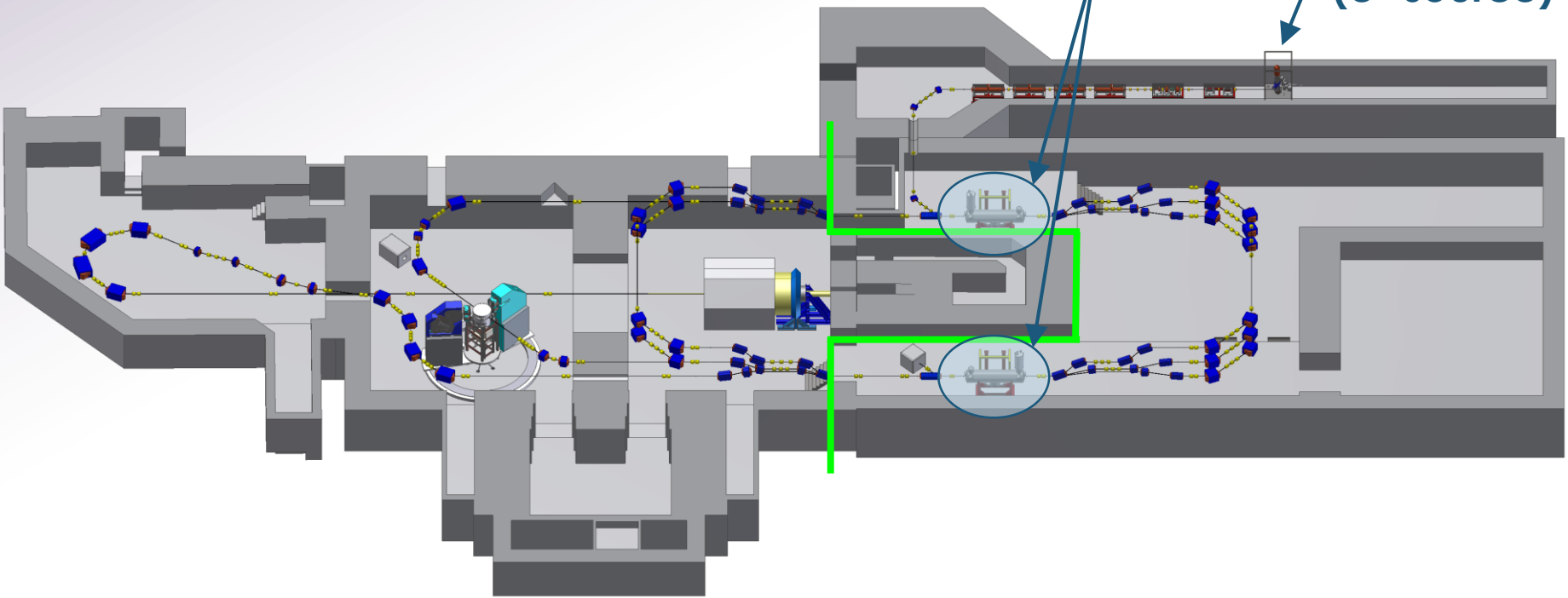
Outline

- The upcoming MESA accelerator
- MAGIX – A versatile experiment @ MESA
- DarkMESA – A beam dump experiment
  - Concept
  - Simulation and optimization studies
  - Material studies at MAMI
  - Veto prototype system
- Summary

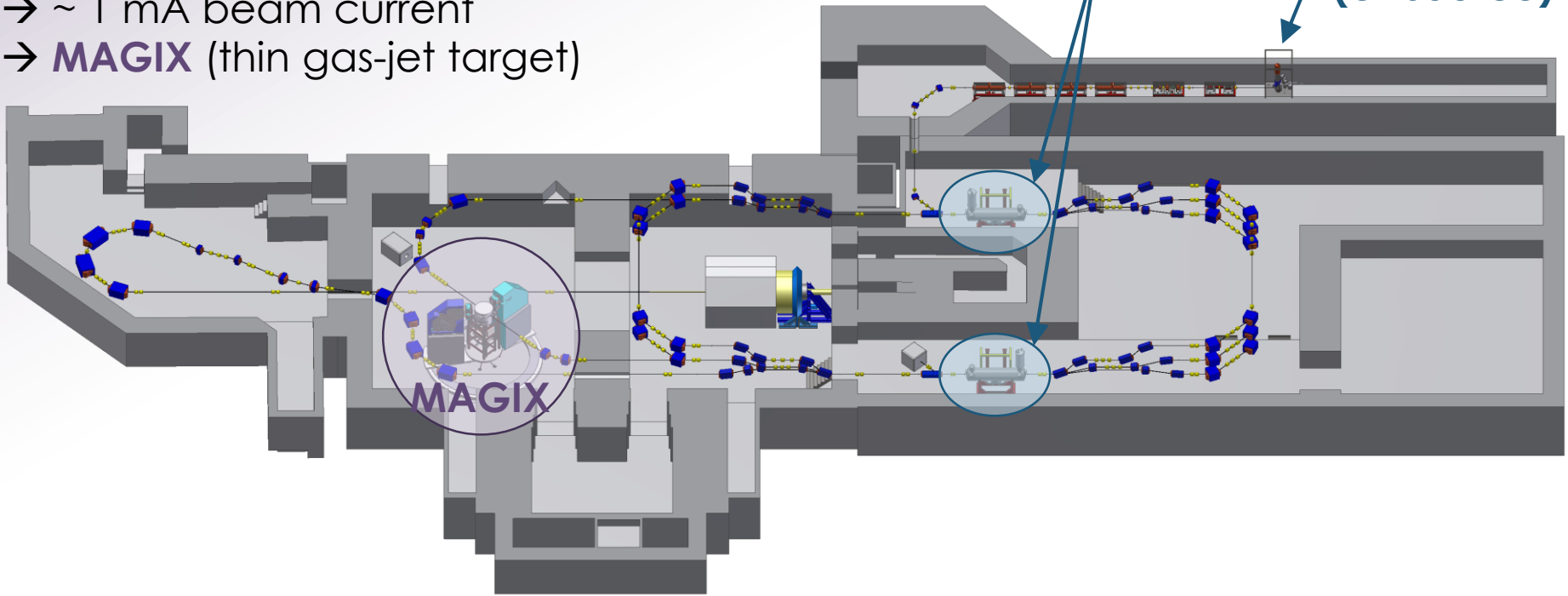


Mainz Energy recovering Superconducting Accelerator

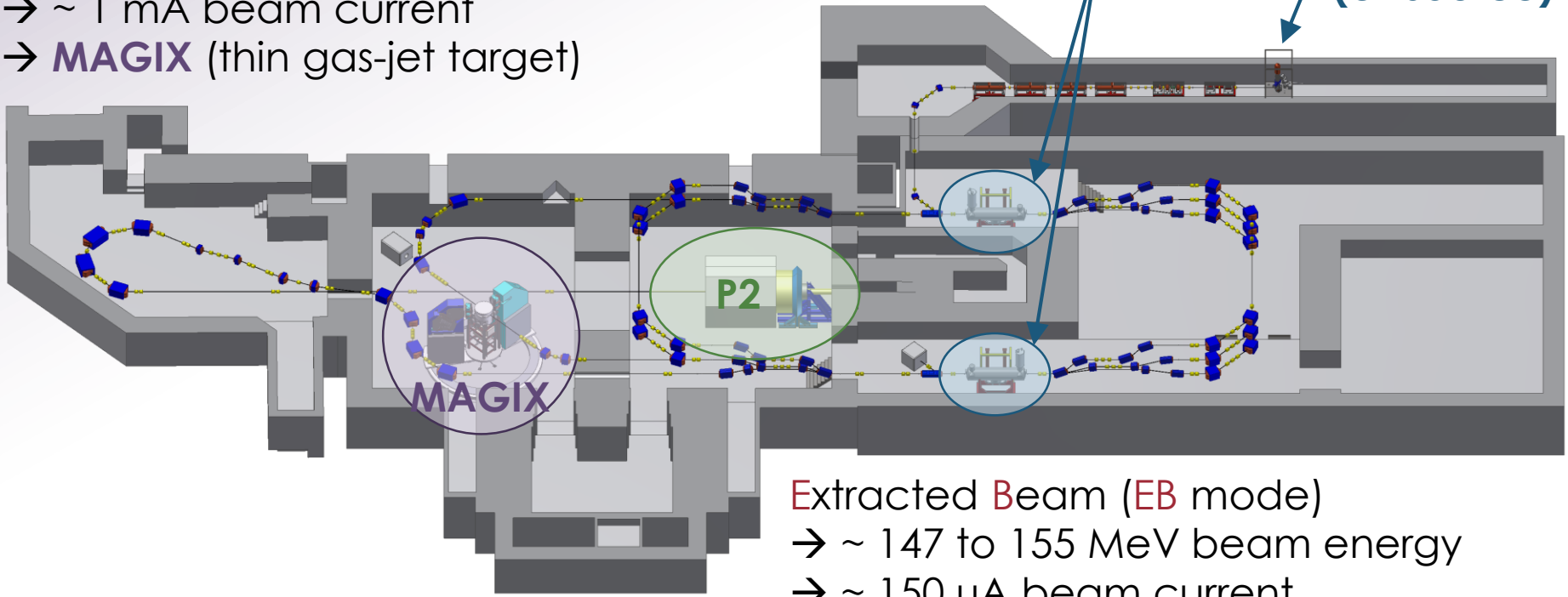
MESA – An upcoming electron accelerator in Mainz


Superconducting cryomodules
Injection (e⁻ source)
existing halls
new hall

Energy Recovery Linac (ERL mode)
→ ~ 5 to 105 MeV beam energy
→ ~ 1 mA beam current
→ **MAGIX** (thin gas-jet target)



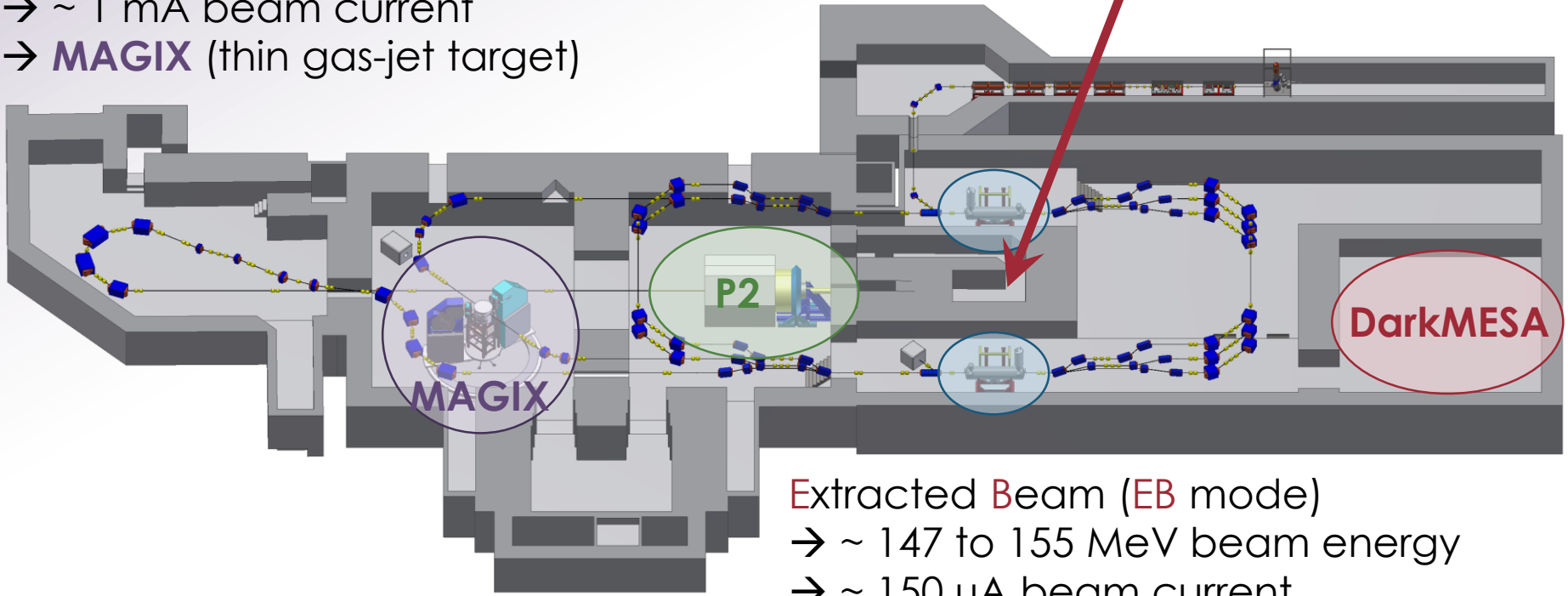
Energy Recovery Linac (ERL mode)
→ ~ 5 to 105 MeV beam energy
→ ~ 1 mA beam current
→ **MAGIX** (thin gas-jet target)



Extracted Beam (EB mode)
→ ~ 147 to 155 MeV beam energy
→ ~ 150 µA beam current
→ **P2** (liquid hydrogen target)

Energy Recovery Linac (ERL mode)
→ ~ 5 to 105 MeV beam energy
→ ~ 1 mA beam current
→ **MAGIX** (thin gas-jet target)

Beam dump

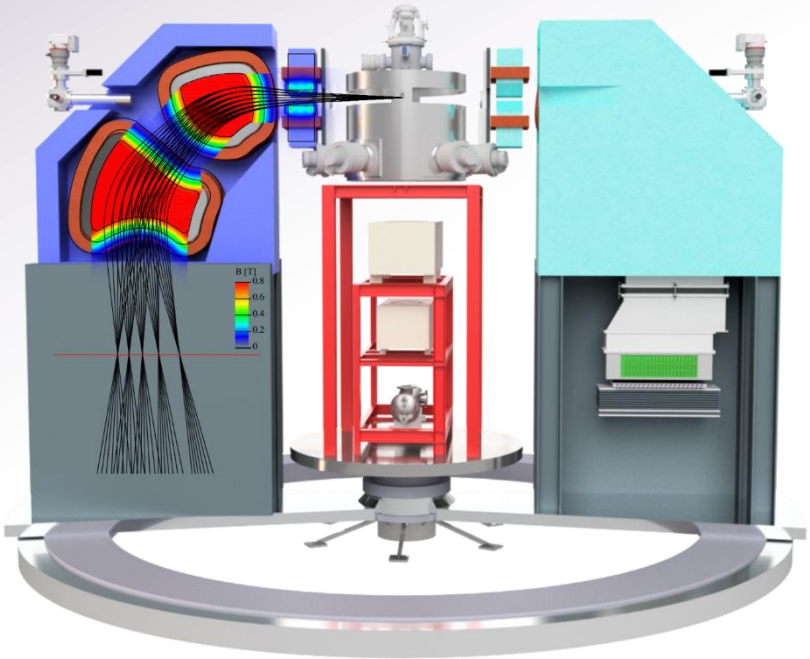


Extracted Beam (EB mode)
→ ~ 147 to 155 MeV beam energy
→ ~ 150 µA beam current
→ **P2** (liquid hydrogen target)

MESA Gas Internal target eXperiment

MAGIX – A versatile fixed target experiment @ MESA

MAGIX – Setup & Physics



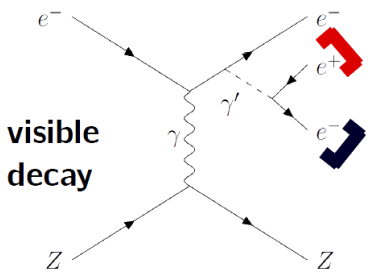
- Gas-jet target inside of a windowless chamber
- Two magnetic spectrometers
- Focal plane detectors (low material budget)
- Trigger and cosmics veto system
- Precision measurements in a variety of fields

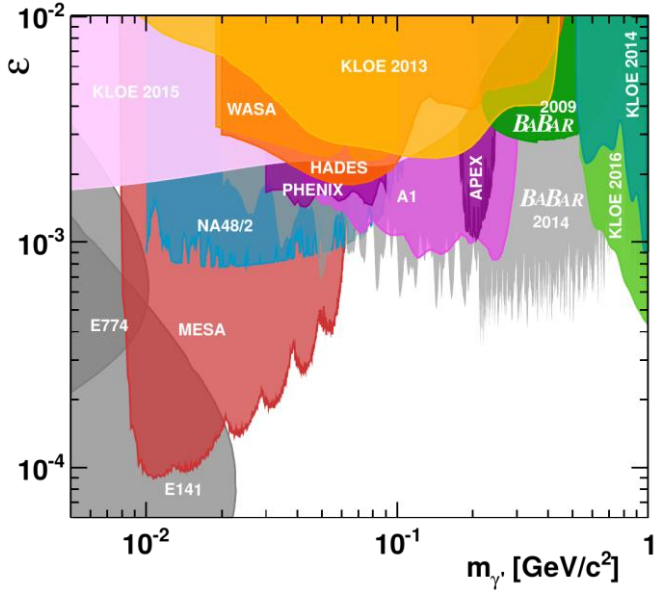
MAGIX – Search for Dark Photons

- Dark photon produced radiatively:

$$e^- + Z \rightarrow e^- + Z + \gamma'$$
$$\hookrightarrow e^+ + e^-$$

- **Visible decay**, if γ' decays into SM particles, e.g. $\gamma' \rightarrow e^+ + e^-$:
  - Final state can be detected in coincidence in the spectrometers





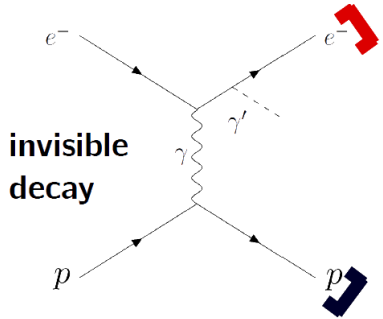
Exclusion limits for detecting the lepton pair at different beam energies (visible)

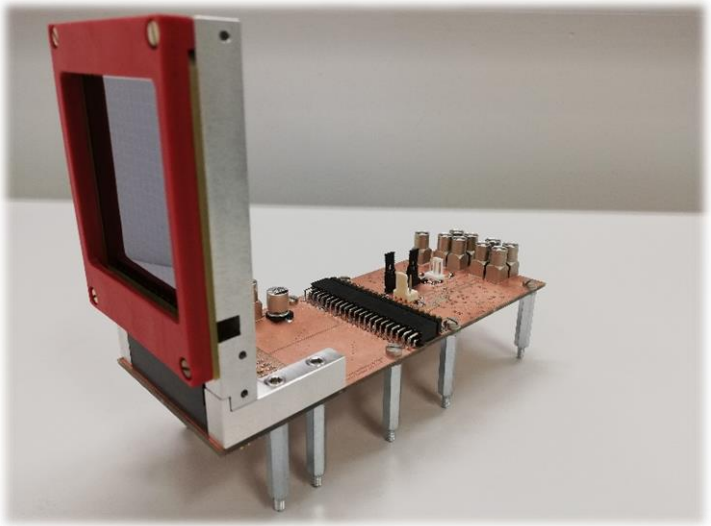
MAGIX – Search for Dark Photons

- Dark photon produced radiatively:

$$e^- + p \rightarrow e^- + p + \gamma'$$
$$\hookrightarrow \chi + \bar{\chi}$$

- **Invisible decay**, if γ' decays into light dark matter particles $\gamma' \rightarrow \chi + \bar{\chi}$:
  - Measure recoil target nucleus with additional detector (missing mass)





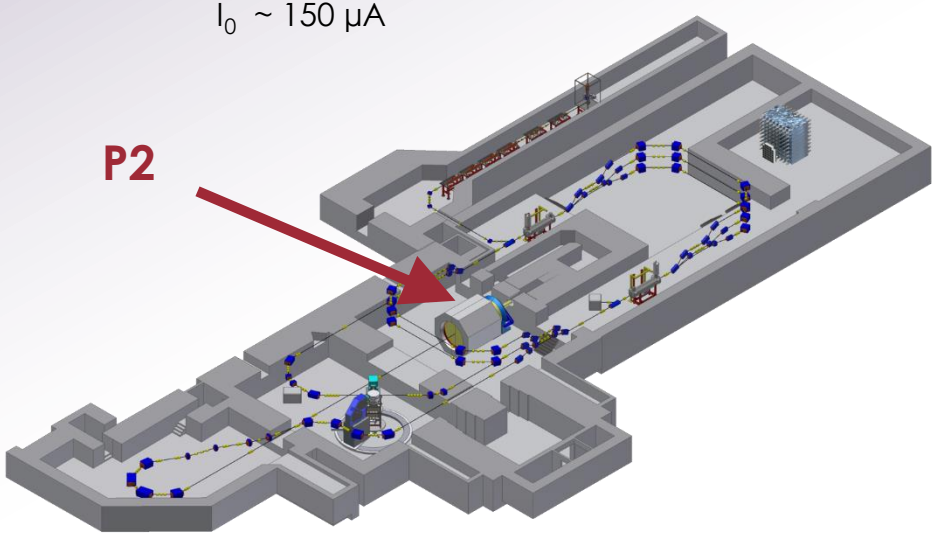
Silicon strip detector: *Micron Semiconductor X1*

DarkMESA

– A parasitic dark sector experiment –

The P2 Experiment…

E_0 ~ 147 - 155 MeV
I_0 ~ 150 µA



- Parity violating asymmetry
- 60 cm liquid hydrogen target

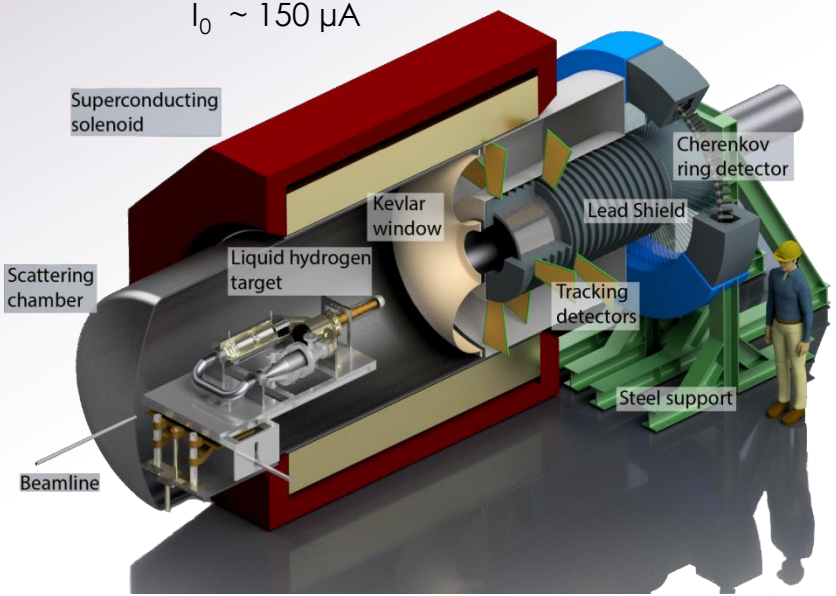
  → energy loss ~ 17 MeV
- Solenoid spectrometer
- 10,000 h measurement time needed

  → ~ 3.37 · 10^{22} electrons

  → ~ 5400 C dumped

The P2 Experiment…

E_0 ~ 147 - 155 MeV
I_0 ~ 150 µA



- Parity violating asymmetry
- 60 cm liquid hydrogen target

  → energy loss ~ 17 MeV
- Solenoid spectrometer
- 10,000 h measurement time needed

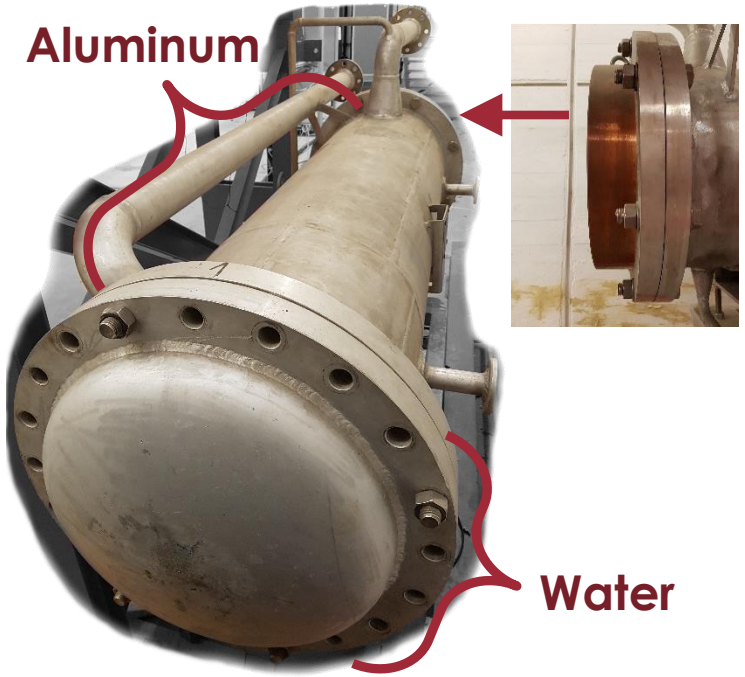
  → ~ $3.37 \cdot 10^{22}$ electrons

  → ~ 5400 C dumped

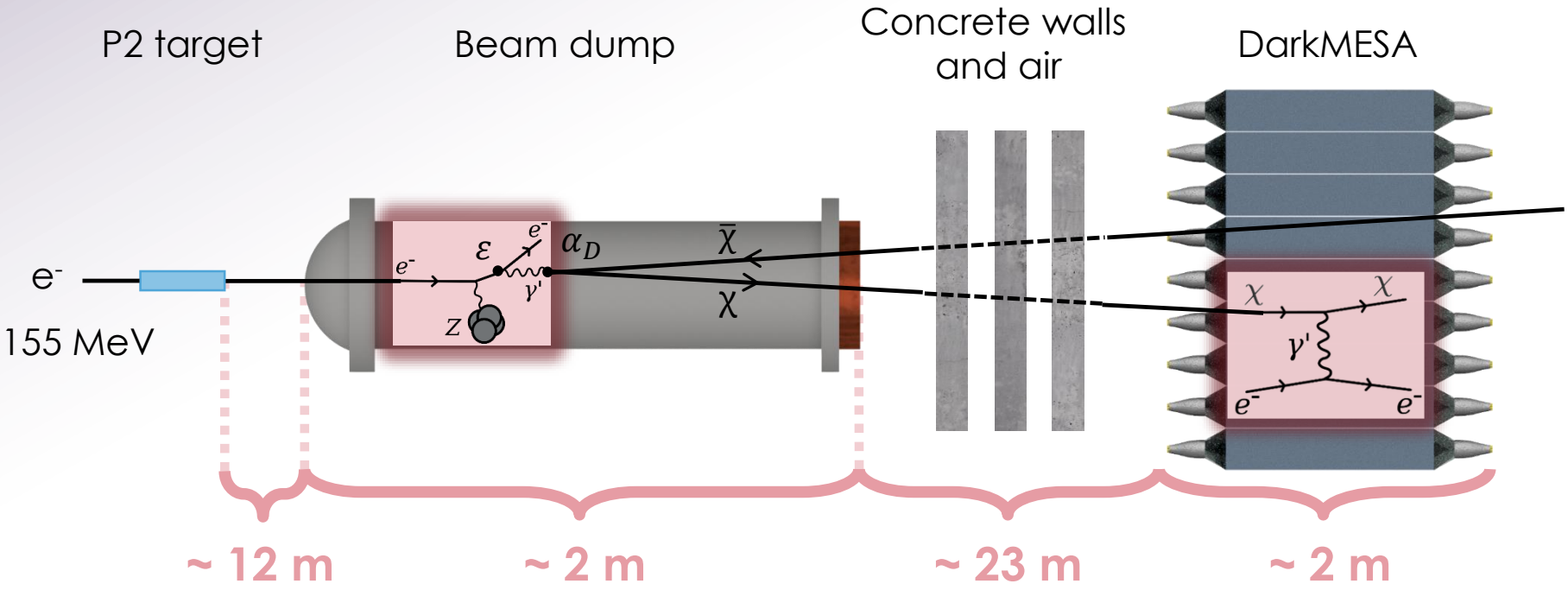
...and the Beam Dump

- Beam dump 12 meter after P2 target
- Water for cooling (~ 0.4 X_0)
- Aluminum (~ 16.5 X_0)
- Copper plate (~ 9.5 X_0)

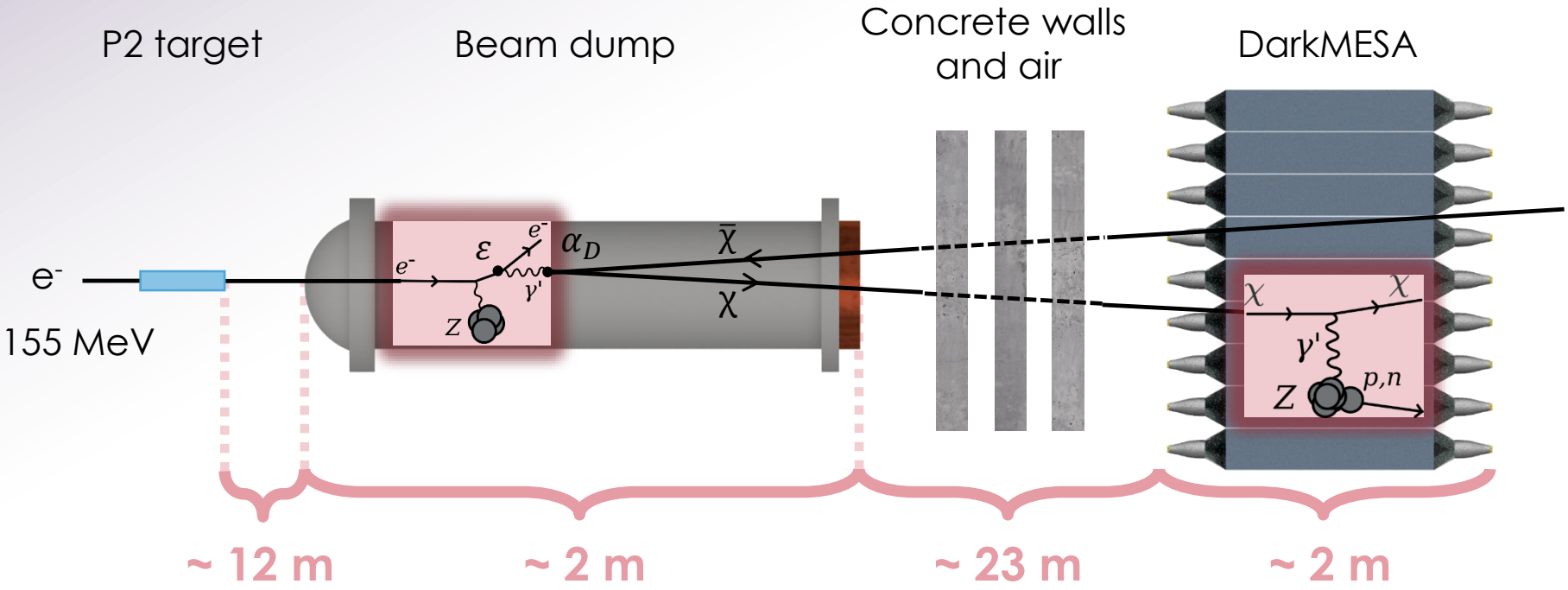
➡ Ideally suited for a parasitic dark sector experiment



Experimental Concept



Experimental Concept

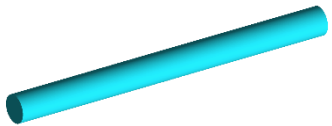


Simulation Studies for DarkMESA

Using Geant4 and MadGraph

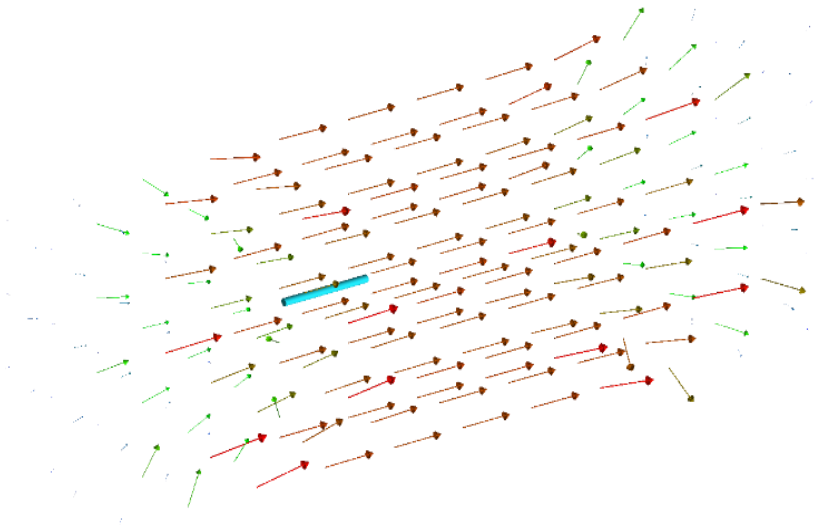
What we simulate with Geant4

- P2 target
- Magnetic field of the solenoid
- Beam dump
- DarkMESA detector volume
- Hall and rooms



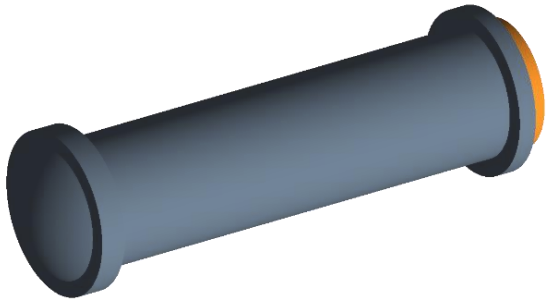
What we simulate with Geant4

- P2 target
- Magnetic field of the solenoid
- Beam dump
- DarkMESA detector volume
- Hall and rooms



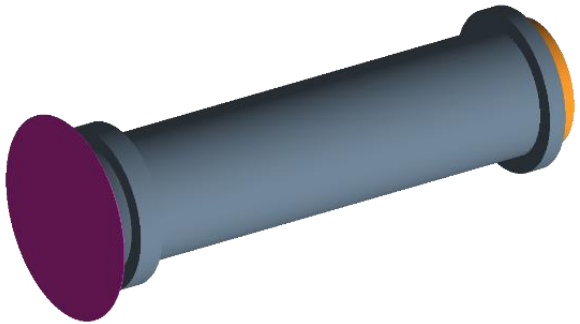
What we simulate with Geant4

- P2 target
- Magnetic field of the solenoid
- Beam dump
- DarkMESA detector volume
- Hall and rooms



What we simulate with Geant4

- P2 target
- Magnetic field of the solenoid
- Beam dump
- DarkMESA detector volume
- Hall and rooms

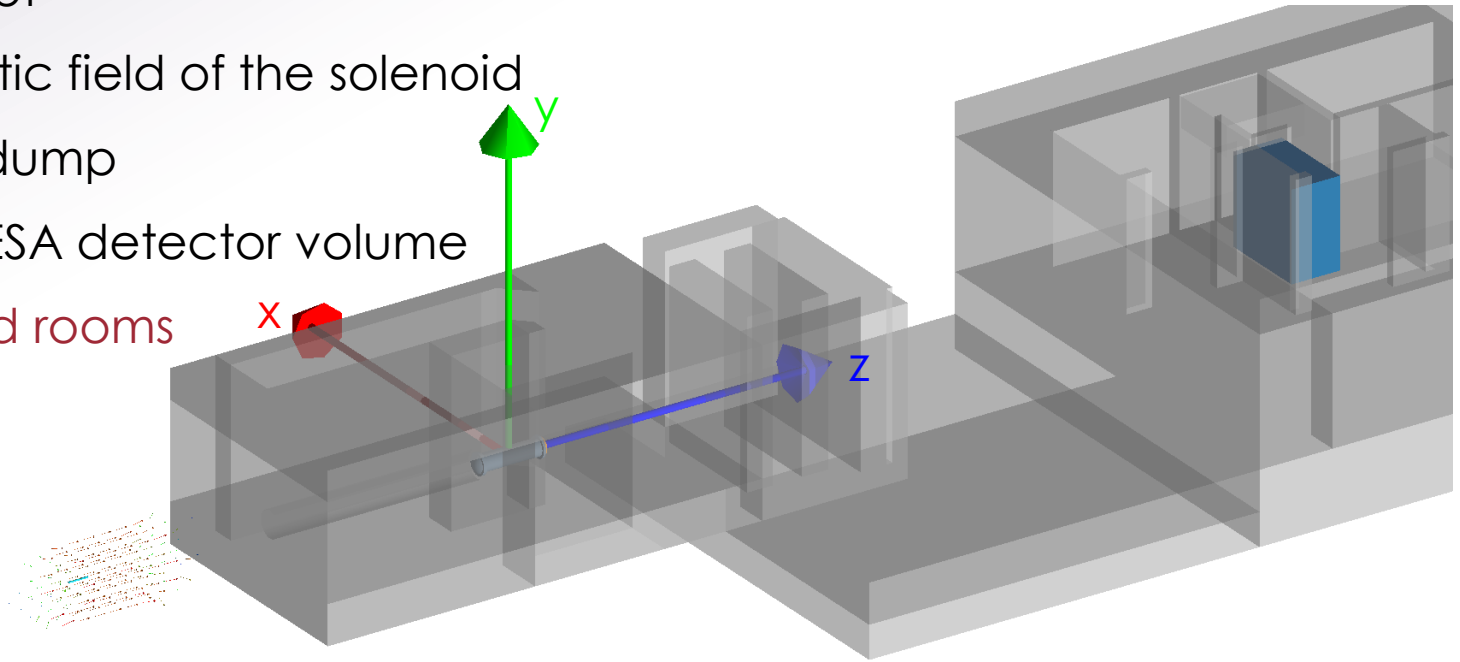


What we simulate with Geant4

- P2 target
- Magnetic field of the solenoid
- Beam dump
- DarkMESA detector volume
- Hall and rooms

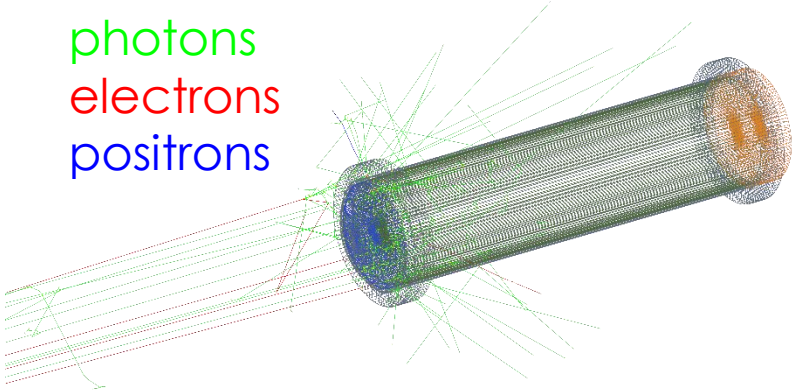
What we simulate with Geant4

- P2 target
- Magnetic field of the solenoid
- Beam dump
- DarkMESA detector volume
- Hall and rooms



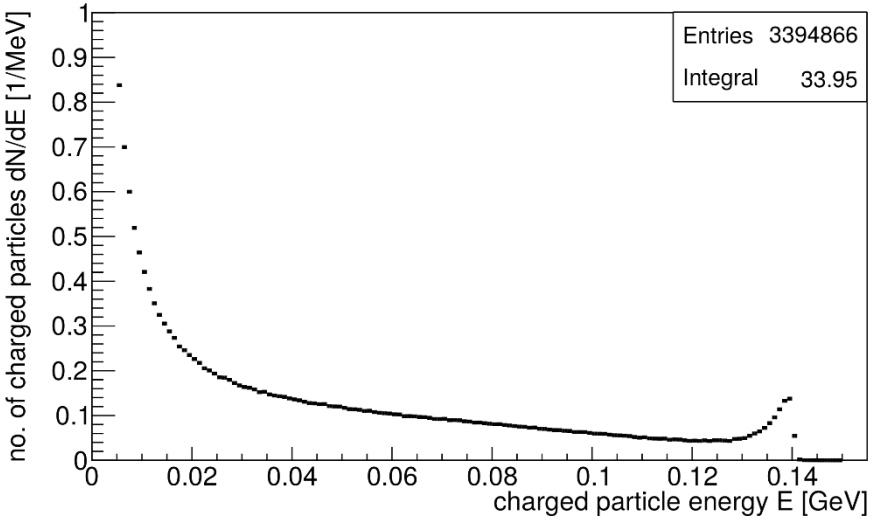
Simulation Outline

- First primary generator: 155 MeV electrons before P2 target
- e^+e^- energy distribution in the dump
- External: MadGraph simulation of dark photon decay
- Second primary generator: χ's at first radiation length of beam dump
- Cross section calculation



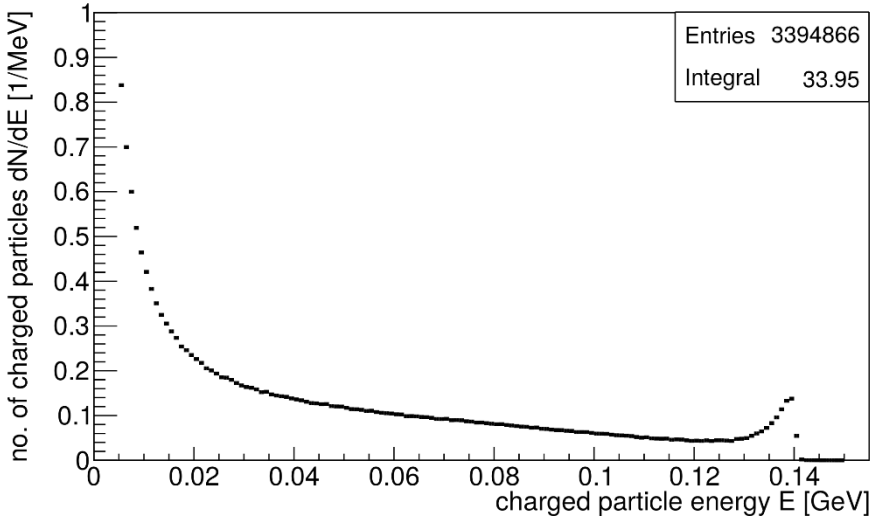
Simulation Outline

- First primary generator: 155 MeV electrons before P2 target
- e^+e^- energy distribution in the dump
- External: MadGraph simulation of dark photon decay
- Second primary generator: χ's at first radiation length of beam dump
- Cross section calculation



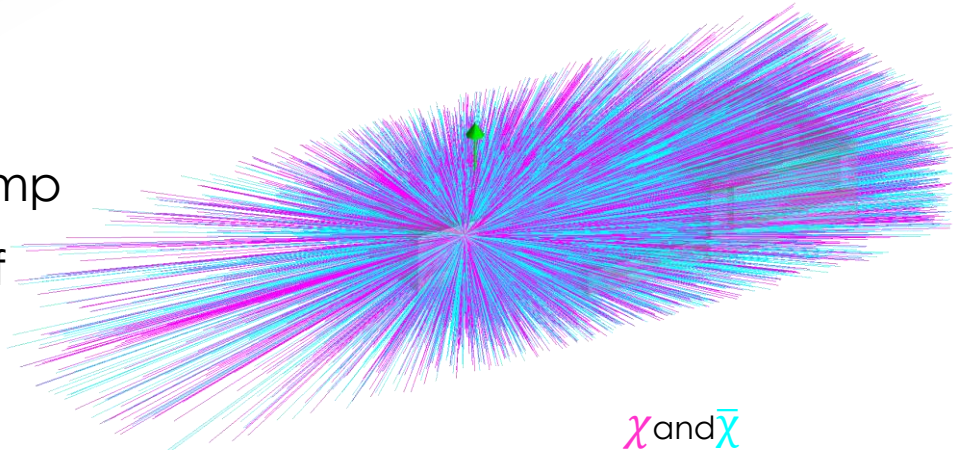
Simulation Outline

- First primary generator: 155 MeV electrons before P2 target
- e^+e^- energy distribution in the dump
- External: MadGraph simulation of dark photon decay
- Second primary generator: χ's at first radiation length of beam dump
- Cross section calculation



Simulation Outline

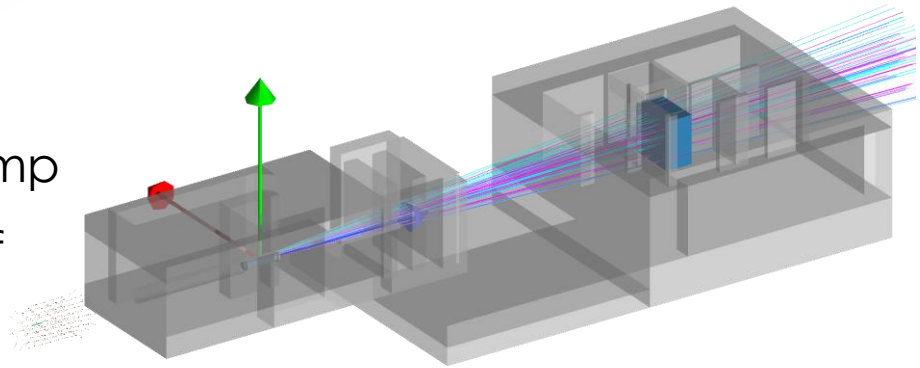
- First primary generator: 155 MeV electrons before P2 target
- e^+e^- energy distribution in the dump
- External: MadGraph simulation of dark photon decay
- Second primary generator: χ's at first radiation length of beam dump
- Cross section calculation



χ and $\bar{\chi}$
(example for
$m_{\gamma'} = 100$ MeV
and $m_\chi = 1$ MeV)

Simulation Outline

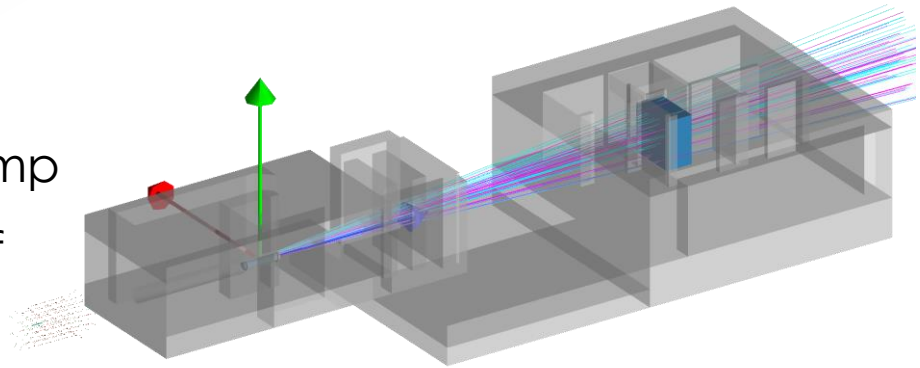
- First primary generator: 155 MeV electrons before P2 target
- e^+e^- energy distribution in the dump
- External: MadGraph simulation of dark photon decay
- Second primary generator: χ's at first radiation length of beam dump
- Cross section calculation



χ and $\bar{\chi}$
(example for
$m_{\gamma'}$ = 100 MeV
and m_χ = 1 MeV)

Simulation Outline

- First primary generator: 155 MeV electrons before P2 target
- e^+e^- energy distribution in the dump
- External: MadGraph simulation of dark photon decay
- Second primary generator: χ's at first radiation length of beam dump
- Cross section calculation



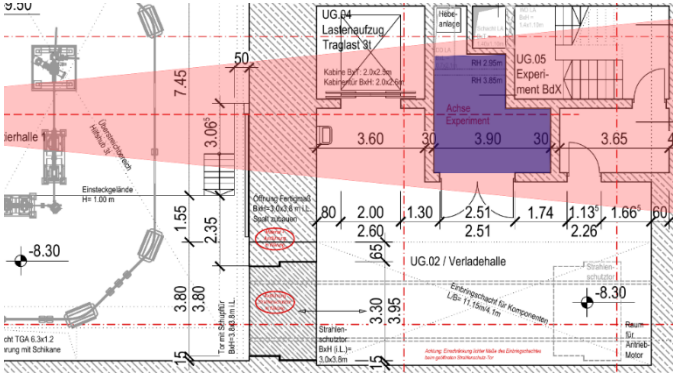
χ and $\bar{\chi}$
(example for
$m_{\gamma'} = 100$ MeV
and $m_\chi = 1$ MeV)

What about the DarkMESA detector?

DarkMESA – Detector Concept

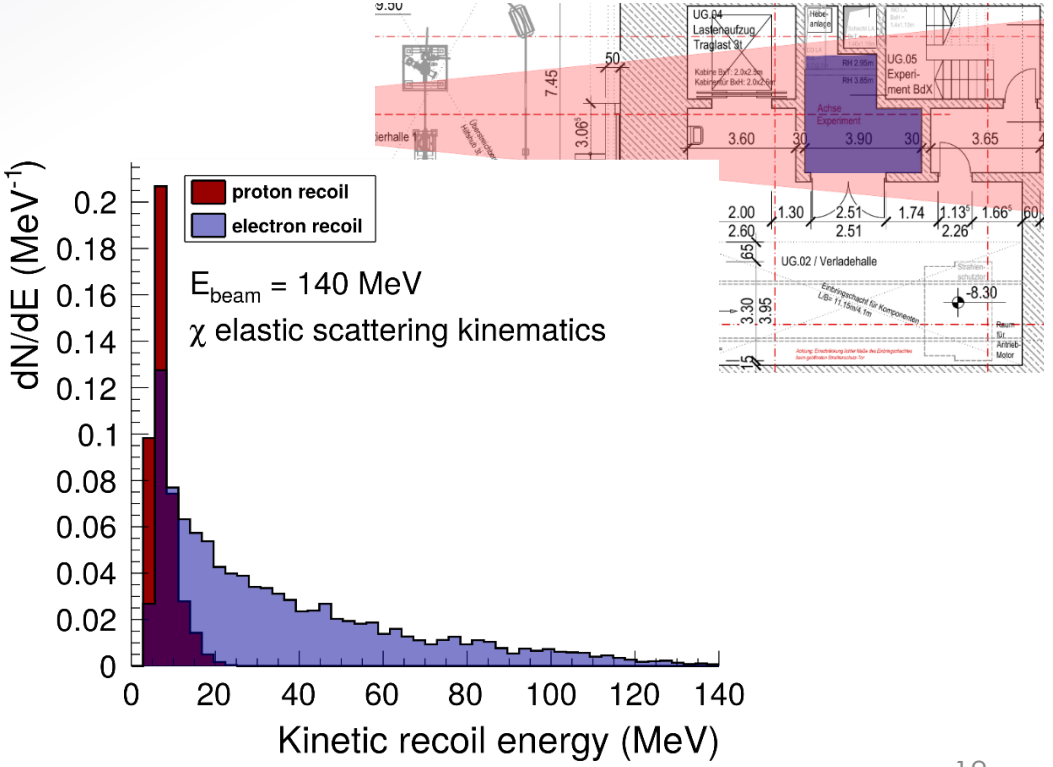
- Limited but dedicated space for DarkMESA (floorspace ~ 12 m^2)
- Detector sensitive for electrons

  ➡ Calorimeter

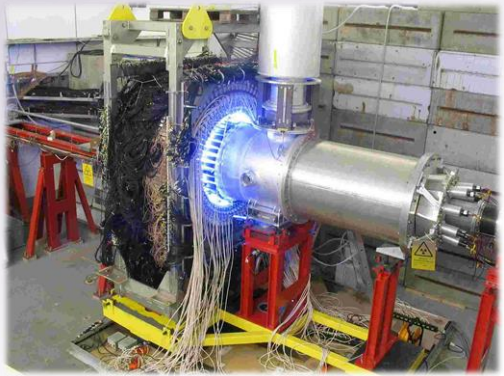


DarkMESA – Detector Concept

- Limited but dedicated space for DarkMESA (floorspace ~ 12 m^2)
- Detector sensitive for electrons
  - ➡ Calorimeter

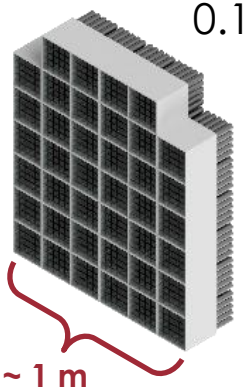


DarkMESA – Detector Concept



~1000 crystals and photomultipliers from the former A4 experiment

PbF_2 crystals



0.13 m^3 PbF_2

+ additional Pb glass

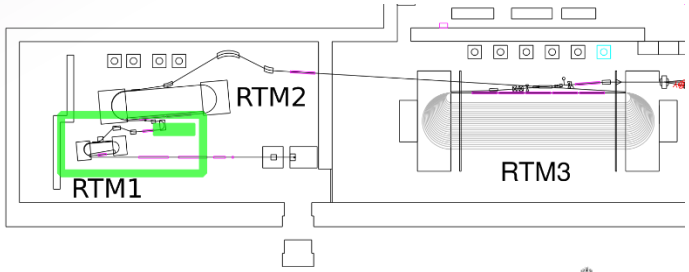
Material Studies for the DarkMESA Calorimeter

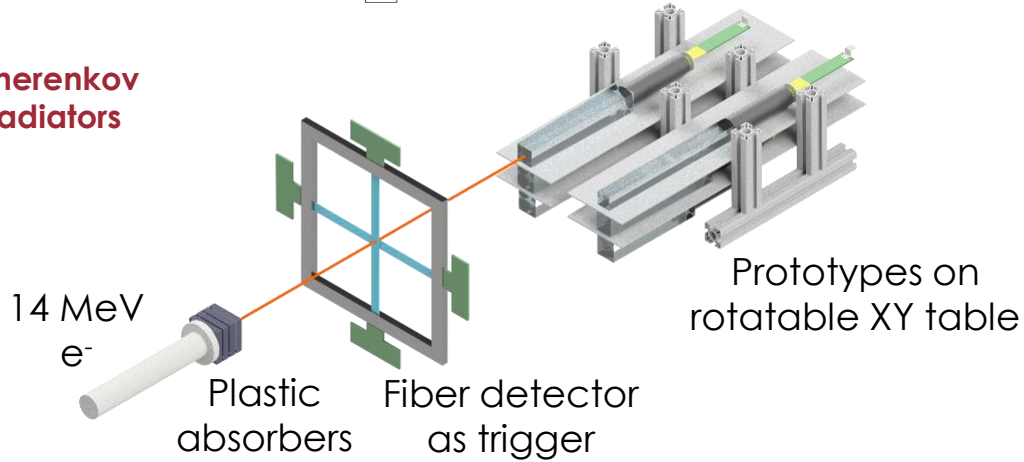
Beam time at MAMI in July & December 2018

Experimental Setup

- 6 - 14 MeV electron beam at MAMI
- Fiber detector as trigger system
- Prototype detectors
  - ➡ PbF_2 in different lengths
  - ➡ Pb glasses from Schott: SF5, SF6 & SF57 HTUltra
  - ➡ BGO as reference

  } **Cherenkov radiators**
- XY and angular scans

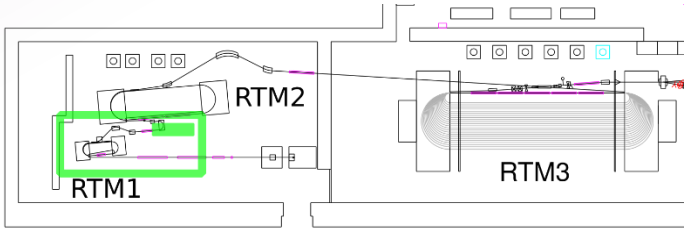


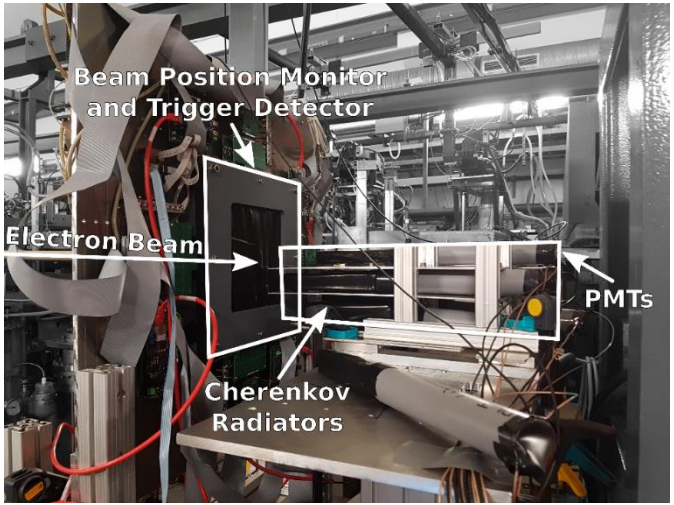


Experimental Setup

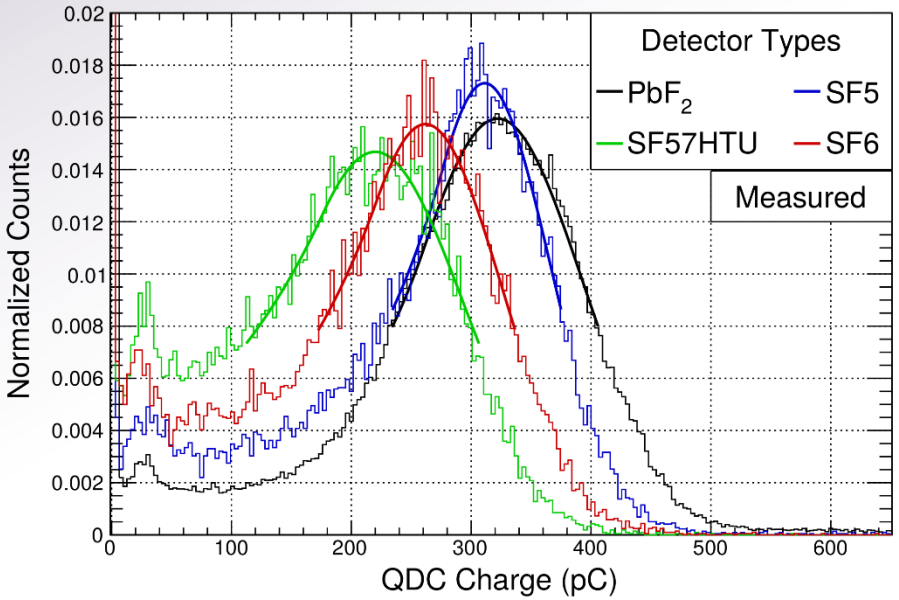
- 6 - 14 MeV electron beam at MAMI
- Fiber detector as trigger system
- Prototype detectors
  - ➡ PbF_2 in different lengths
  - ➡ Pb glasses from Schott: SF5, SF6 & SF57 HTUltra
  - ➡ BGO as reference

  } Cherenkov radiators
- XY and angular scans

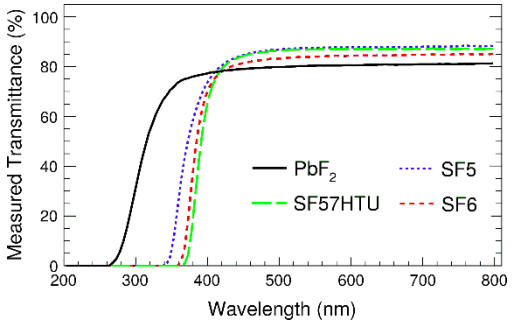




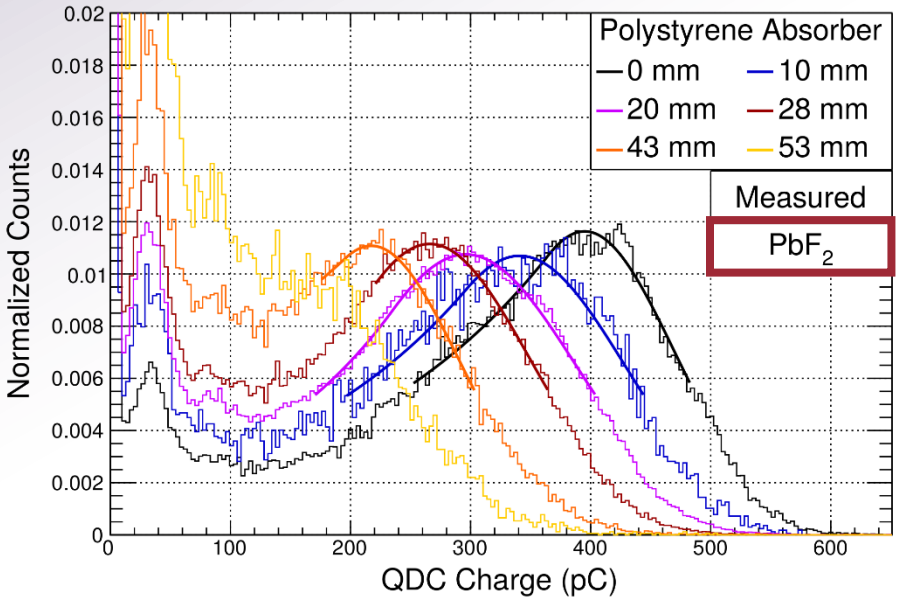
Experimental Results



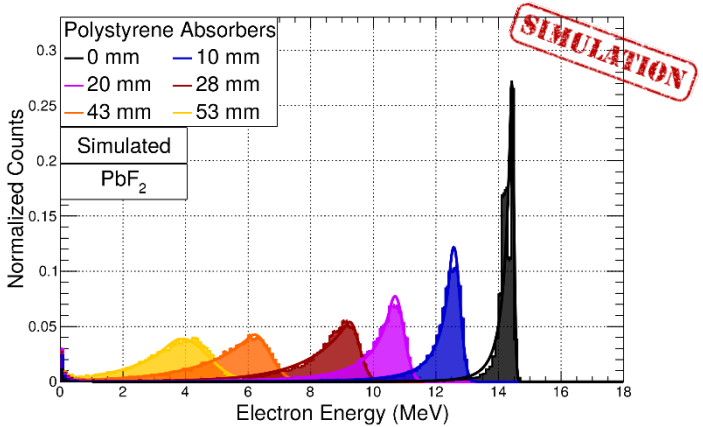
- Three different Pb glass detectors and PbF_2 with almost same crystal sizes ($\sim 30 \times 30 \times 150\ mm^3$)
- PbF_2 has the highest light yield
- Out of the Pb glasses SF5 performs best
- This sequence was expected due to the transmittance spectra



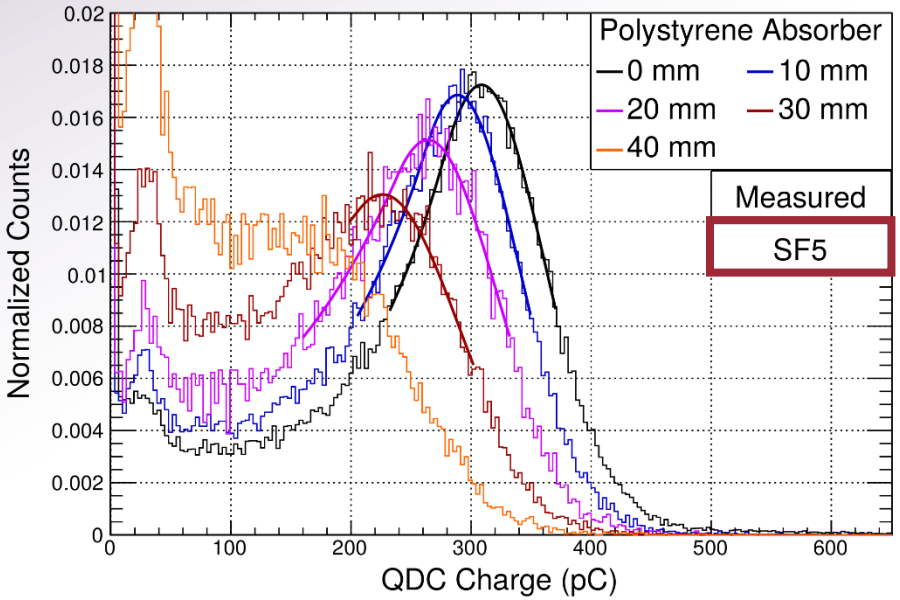
Experimental Results



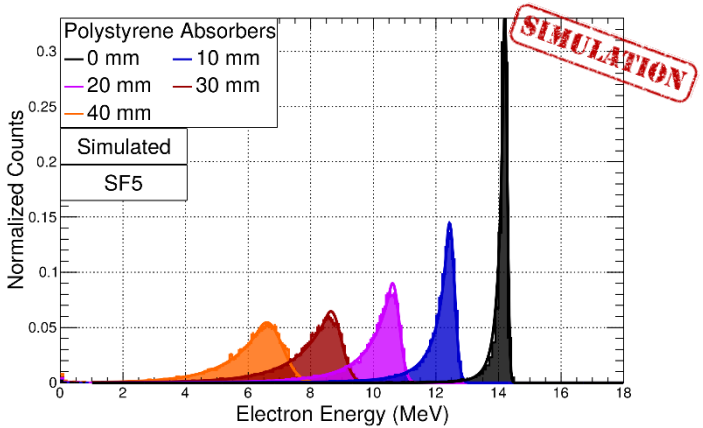
- Varying absorber thicknesses
  - ➡ Different beam energies
- Signals can be resolved even for beam electrons below 10 MeV



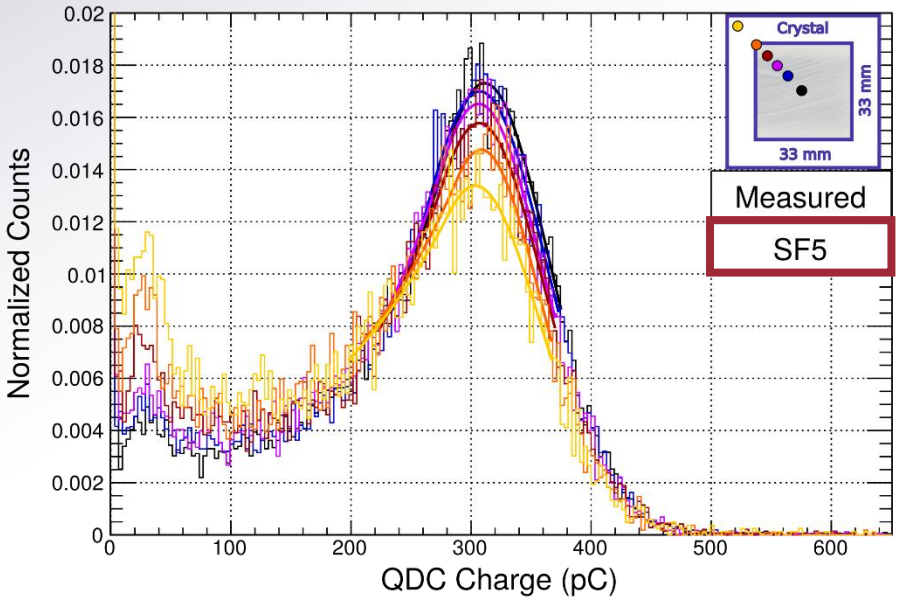
Experimental Results



- Varying absorber thicknesses
  - ➡ Different beam energies
- Signals can be resolved even for beam electrons below 10 MeV

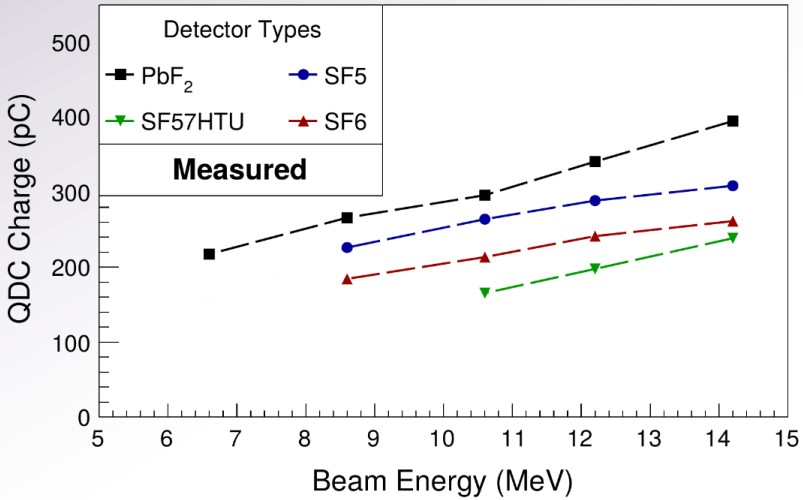


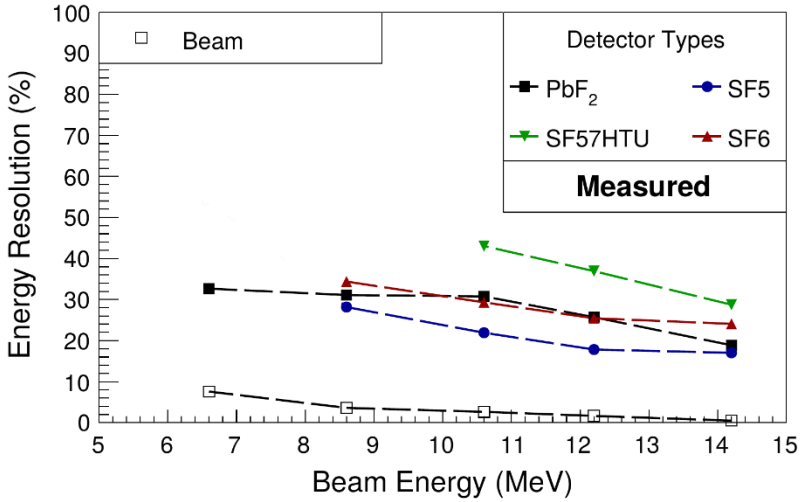
Experimental Results



- Varying absorber thicknesses
  - ➡ Different beam energies
- Signals can be resolved even for beam electrons below 10 MeV
- Good homogeneity over the entire front surface

Experimental Results

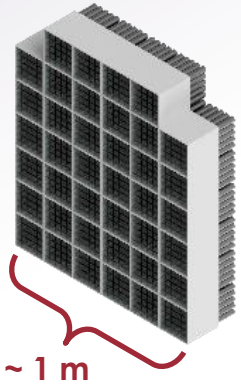




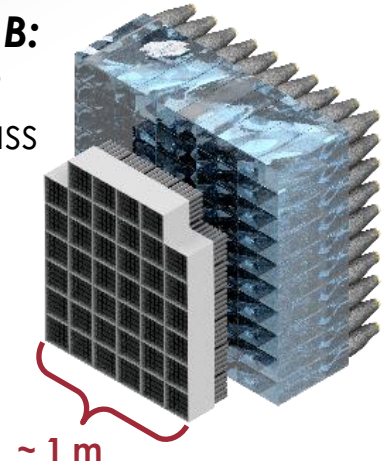
- PbF_2 and SF5: best light yield & energy resolution for e^- below 14 MeV

DarkMESA – Staged Approach

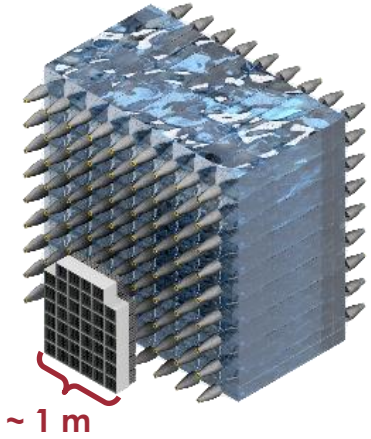
Stage A:
0.13 m^3
PbF_2



Stage B:
+ 1 m^3
Pb glass



Stage C:
+ 10 m^3
Pb glass

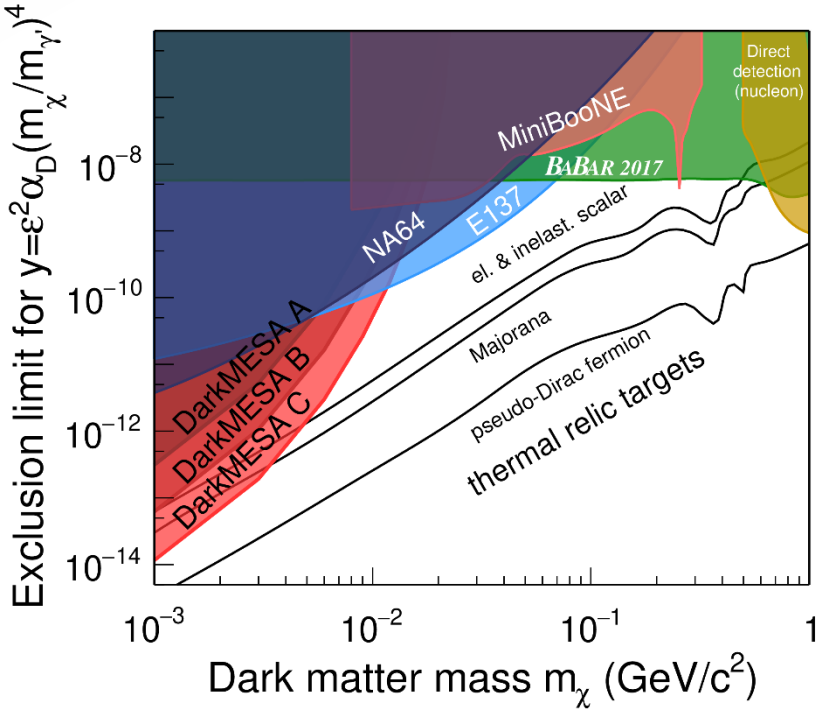


~1000 crystals and photomultipliers from the former A4 experiment

Expansion of the active volume

DarkMESA – Simulation Results

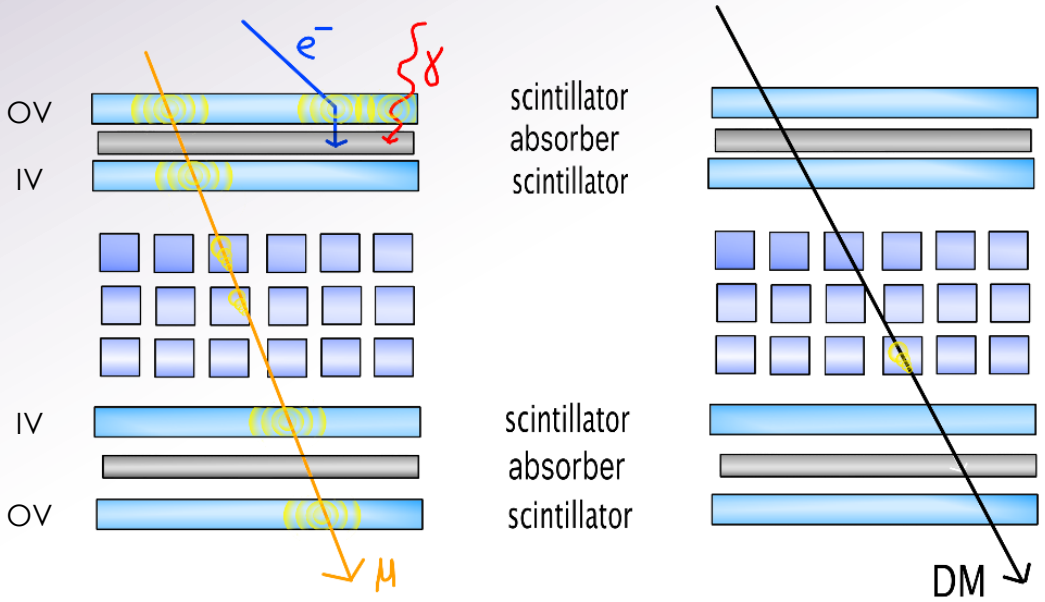
- Further assumptions made:
  - Additional 2.5 mm Tungsten target
  - $\alpha_D = 0.5$ and $m_{\gamma'} = 3 \cdot m_\chi$
  - $3 \cdot 10^{22}$ EOT
  - Energy detection threshold 14 MeV
  - Detector efficiency 90%
  - No backgrounds
- Touch thermal relic targets



Prototype for a Calorimeter with a Veto Detector System

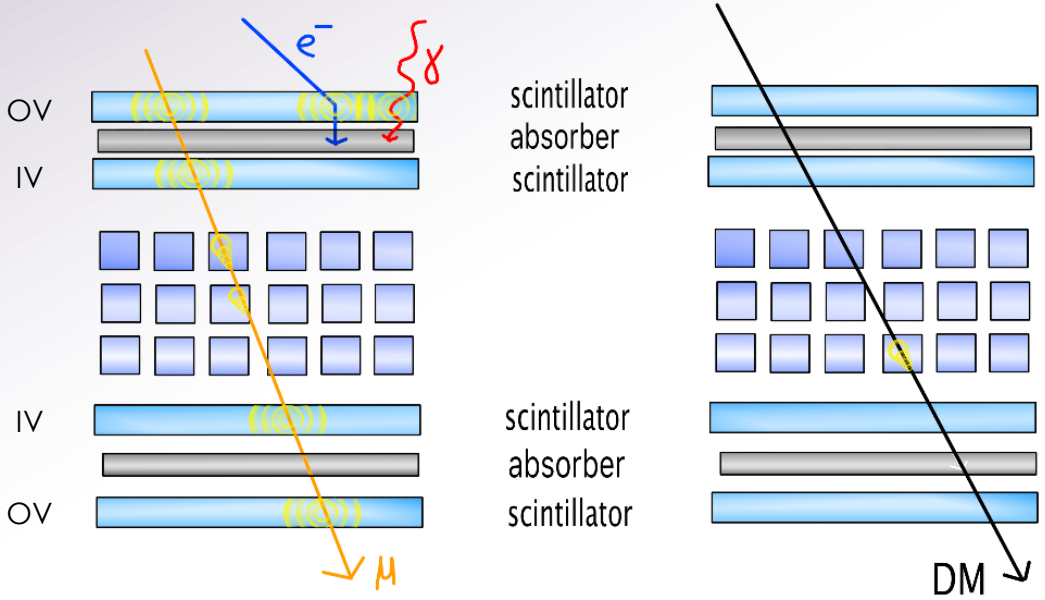
Construction & Outlook

Prototype – Concept



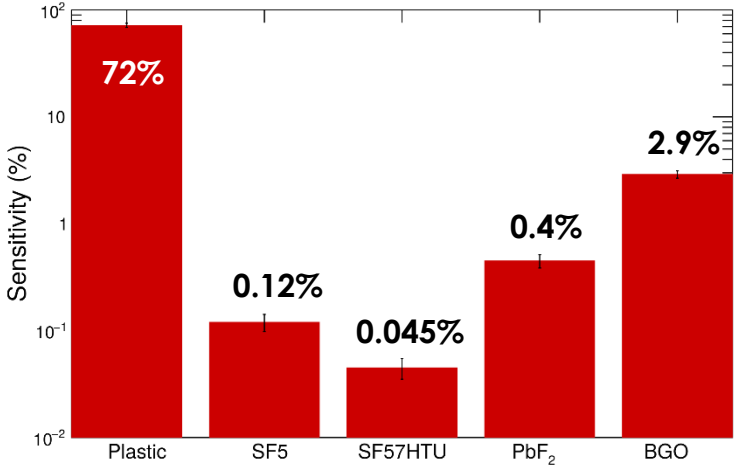
OV = Outer Veto
IV = Inner Veto

Prototype – Concept

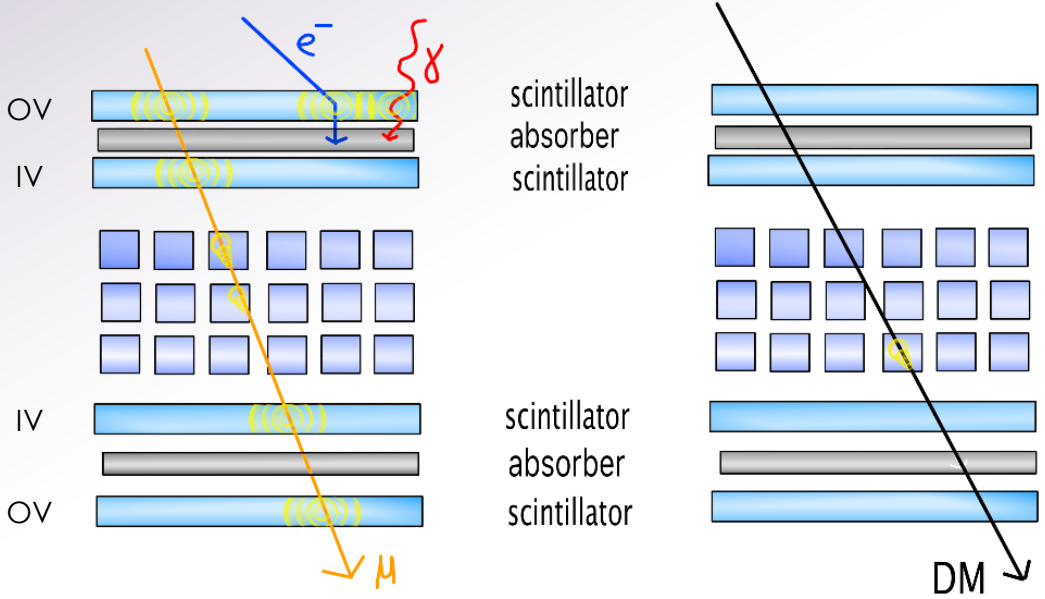


OV = Outer Veto
IV = Inner Veto

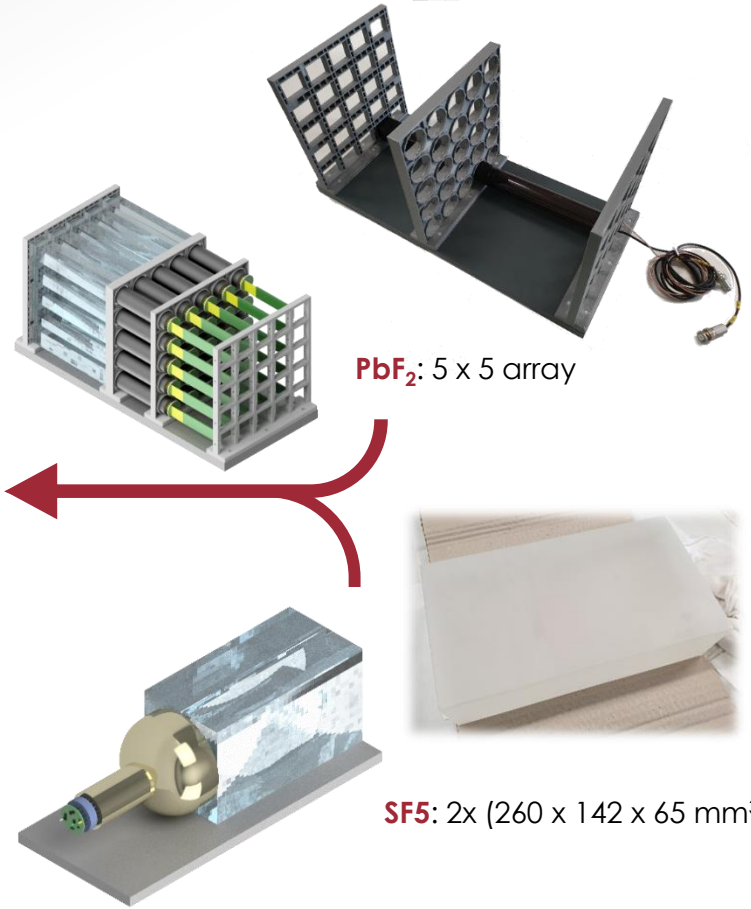
- Cosmic ray induced neutrons?
- Sensitivity to neutrons was studied in a bachelor thesis



Prototype – Concept



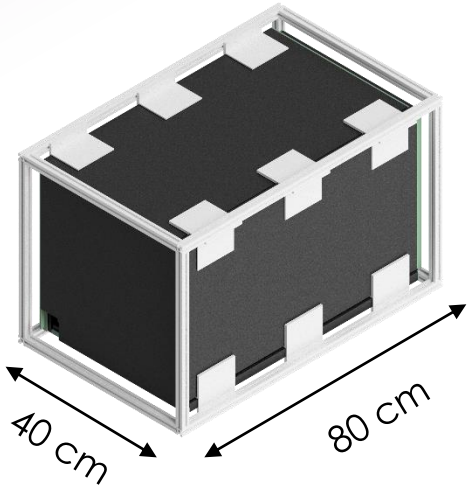
OV = Outer Veto
IV = Inner Veto



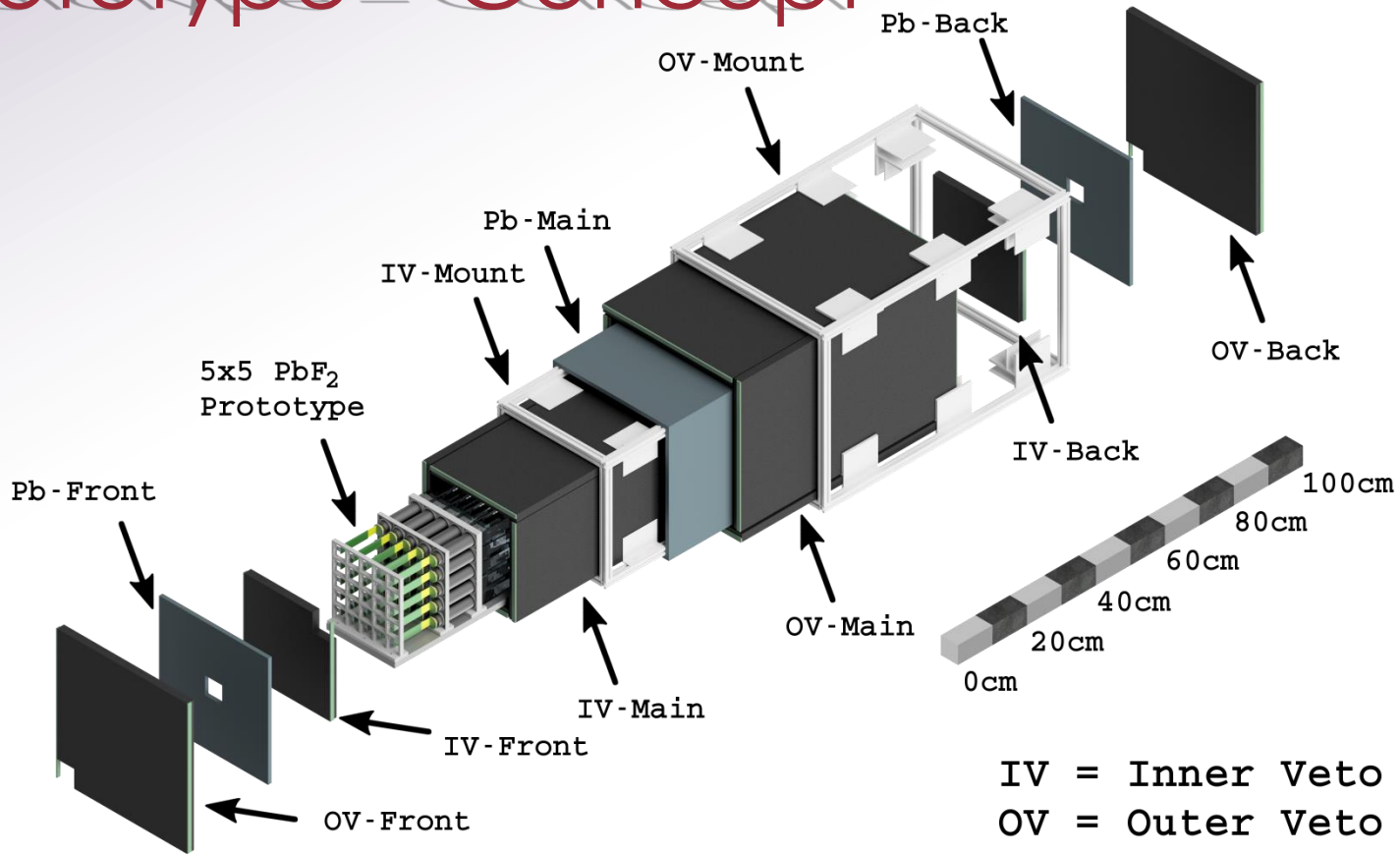
PbF_2: 5 x 5 array

SF5: 2x (260 x 142 x 65 mm^3)

Prototype – Concept

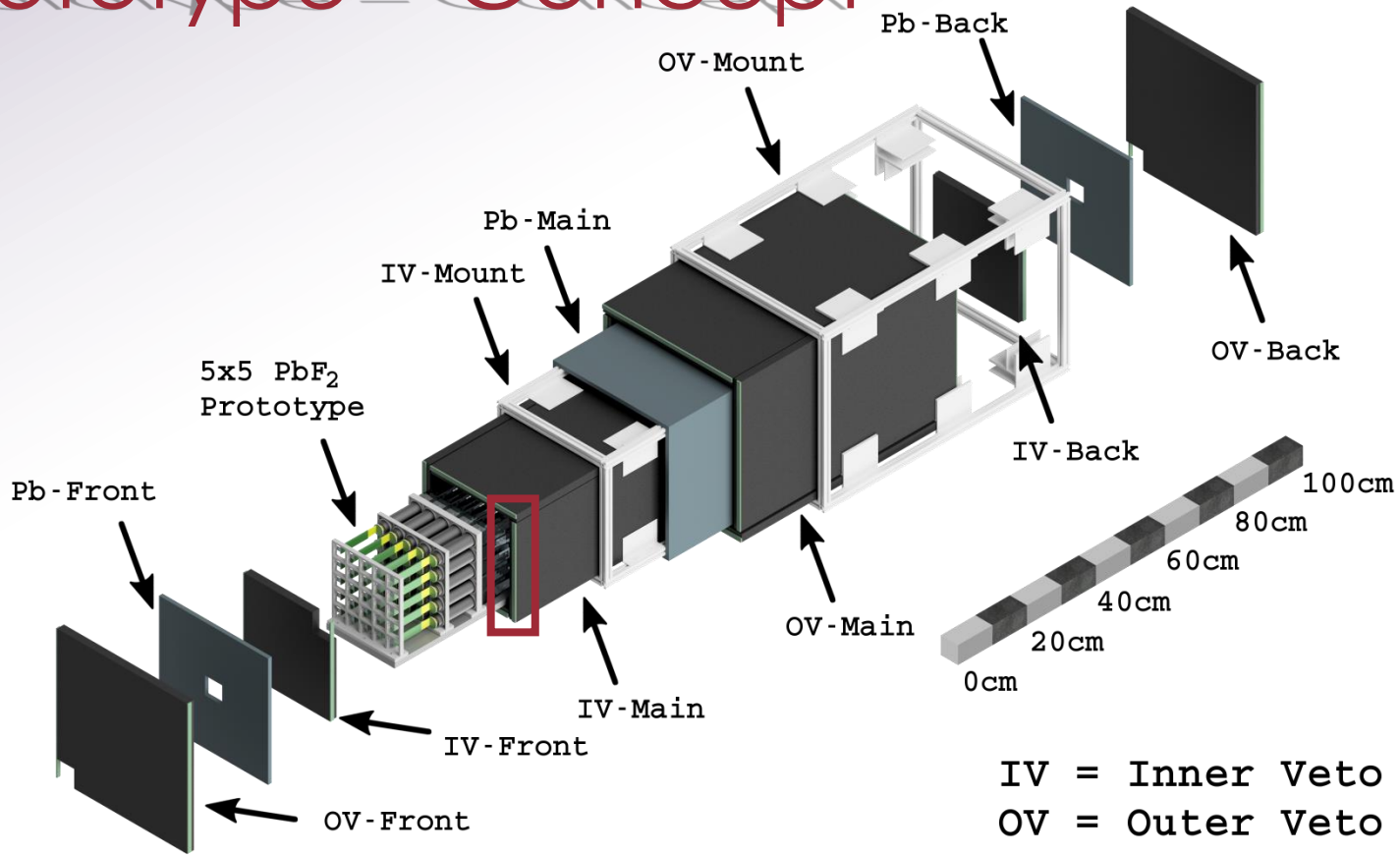


Prototype – Concept



IV = Inner Veto
OV = Outer Veto

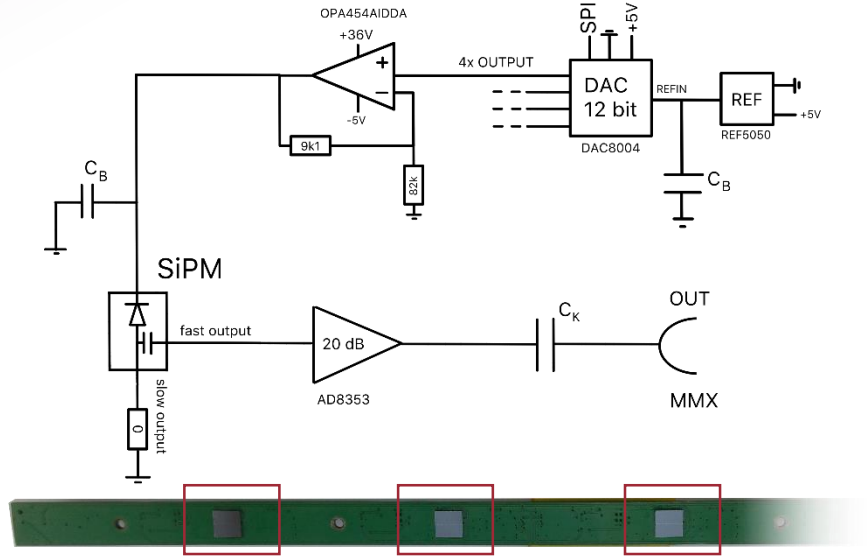
Prototype – Concept



IV = Inner Veto
OV = Outer Veto

Prototype – Readout System

- SensL SiPM
  - 6 x 6 mm^2
  - Peak wavelength at 420 nm
- EJ-200 plastic scintillators
  - 20 mm thick
  - 10,000 photons/MeV
  - Maximum emission at 425 nm



OP Amplifier

DAC

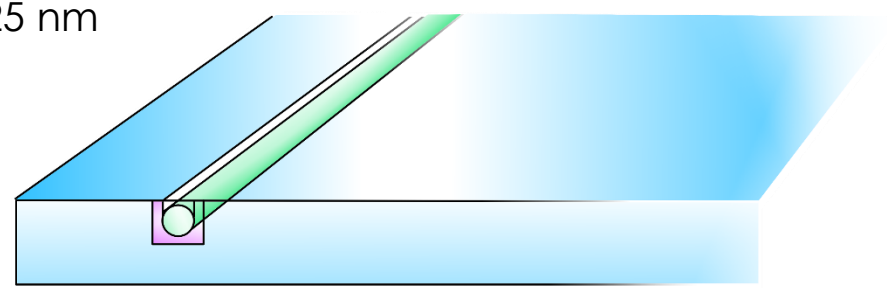
4 SiPMs per card

Amplifier
Analog Output

Prototype – Readout System

- SensL SiPM
  - 6 x 6 mm^2
  - Peak wavelength at 420 nm
- EJ-200 plastic scintillators
  - 20 mm thick
  - 10,000 photons/MeV
  - Maximum emission at 425 nm

- Light collection:
  - About 10 photons/SiPM
  - Increase light yield with wavelength-shifting fibers
  - MAMI beamtime last week, analysis ongoing (master thesis)



Summary

- MESA and the three experiments (MAGIX, P2 & DarkMESA) could be operational 2022
- DarkMESA can achieve stronger dark photon exclusion limits
- Calorimeter materials were studied experimentally at MAMI
- PbF_2 and the Pb glass Schott SF5 showed the most promising results ➡ Background studies started
- DarkMESA readout electronics developed

  ➡ Short-term goal: Completion of a prototype for DarkMESA Stage B

Open For Registration

721. WE-Heraeus-Seminar
„Light Dark Matter Searches“
23 – 25 Apr 2020
Physikzentrum Bad Honnef, Germany

www.we-heraeus-stiftung.de/veranstaltungen/seminare/2020/light-dark-matter-searches

Students Welcome
No Conference Fee & Full-board Accomodation

provided by the Wilhelm und Else foundation

Open For Registration

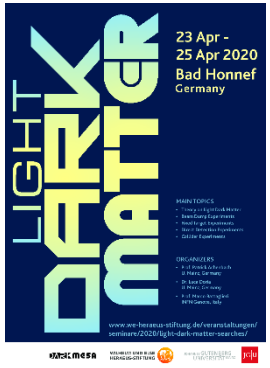
721. WE-Heraeus-Seminar
„Light Dark Matter Searches“
23 – 25 Apr 2020
Physikzentrum Bad Honnef, Germany

www.we-heraeus-stiftung.de/veranstaltungen/seminare/2020/light-dark-matter-searches

Students Welcome
No Conference Fee & Full-board Accomodation

provided by the Wilhelm und Else foundation

Thank you for your attention!



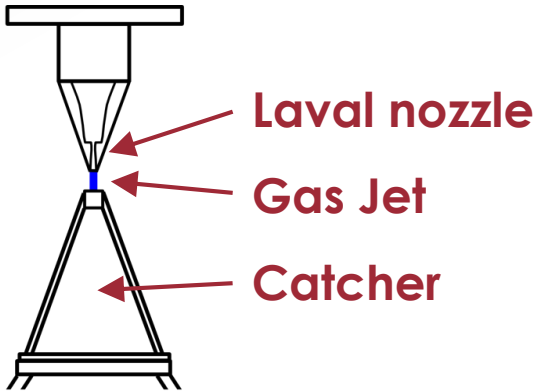
BACKUP SLIDES

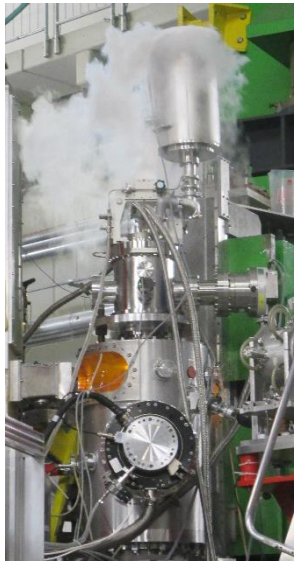
Backup: MAGIX

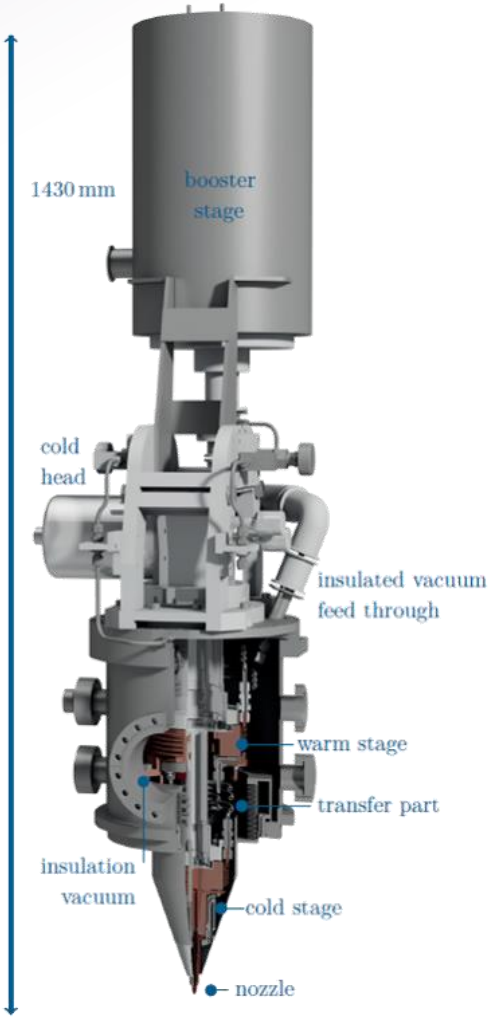
Gas Jet Target, Spectrometers, Time Projection Chamber, Trigger and Cosmic Veto System

MAGIX Gas Jet Target

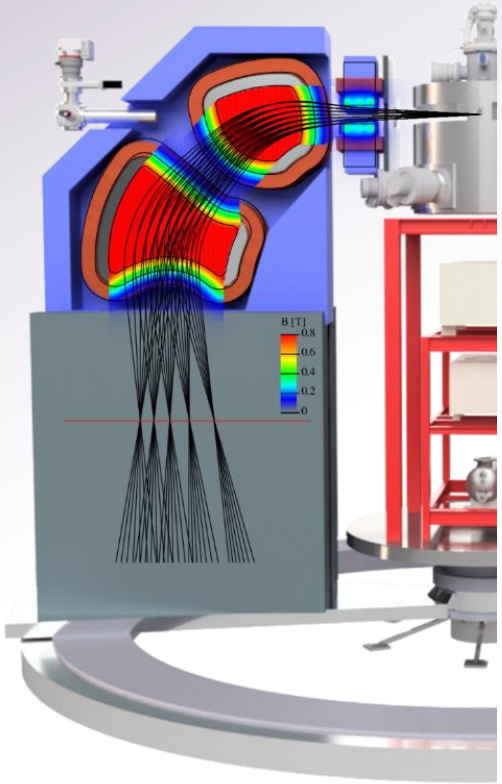
- Directive gas beam in vacuum (point-like)
- Different gas types possible
- $>10^{18}$ atoms / cm²
- Low energy high precision electron scattering ($\mathcal{L} \sim 10^{35}$ cm^{-2} s^{-1})







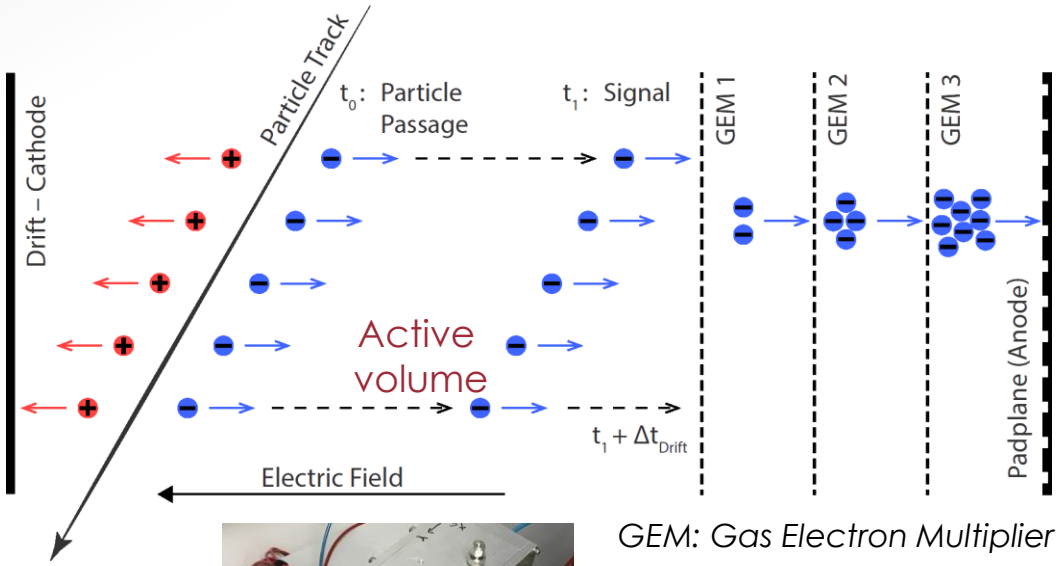
MAGIX Spectrometers

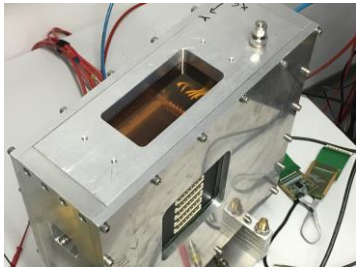


- Quadrupole and two dipoles
- High momentum resolution $\frac{\Delta p}{p} < 10^{-4}$
- Angular resolution $\Delta\theta < 0.05°$
- Dipole edges designed to focus all particles with same momentum to same point in a horizontal focal plane

MAGIX Time Projection Chamber

- Minimal radiation thickness
- Tracking multiple trace points
- Working principle:
  - Particle transition
  - Ionisation of counting gas
  - Electron drift
  - Amplification with GEMs
- 3D track reconstruction





GEM: Gas Electron Multiplier

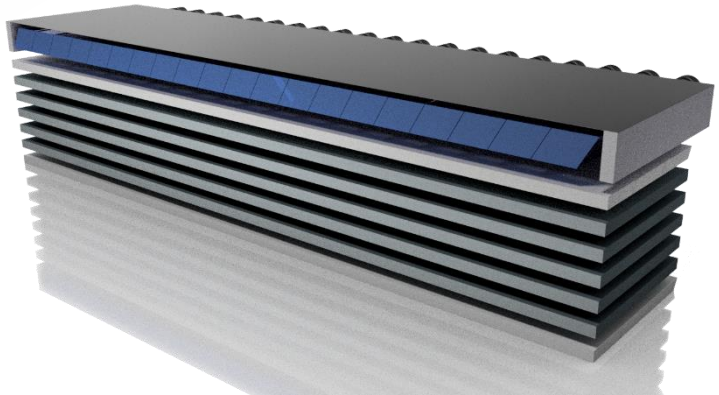
MAGIX Trigger and Cosmic Veto

Requirements:

- Scattered beam electrons
  - Trigger efficiency ~10^{0}
  - Veto response probability < 10^{-4}
- Cosmic muons
  - Veto response probability ~10^{0}

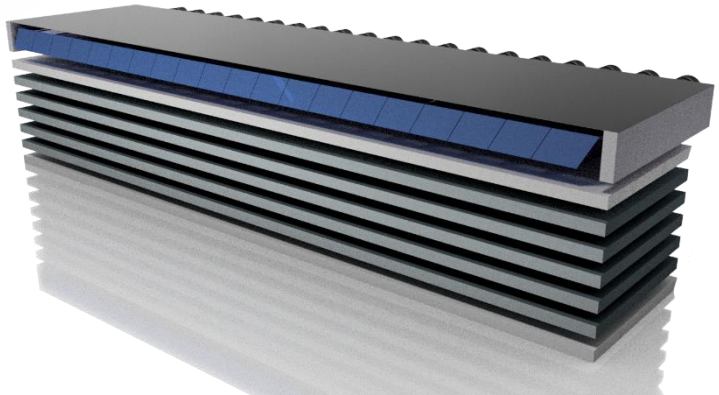
MAGIX Trigger and Cosmic Veto

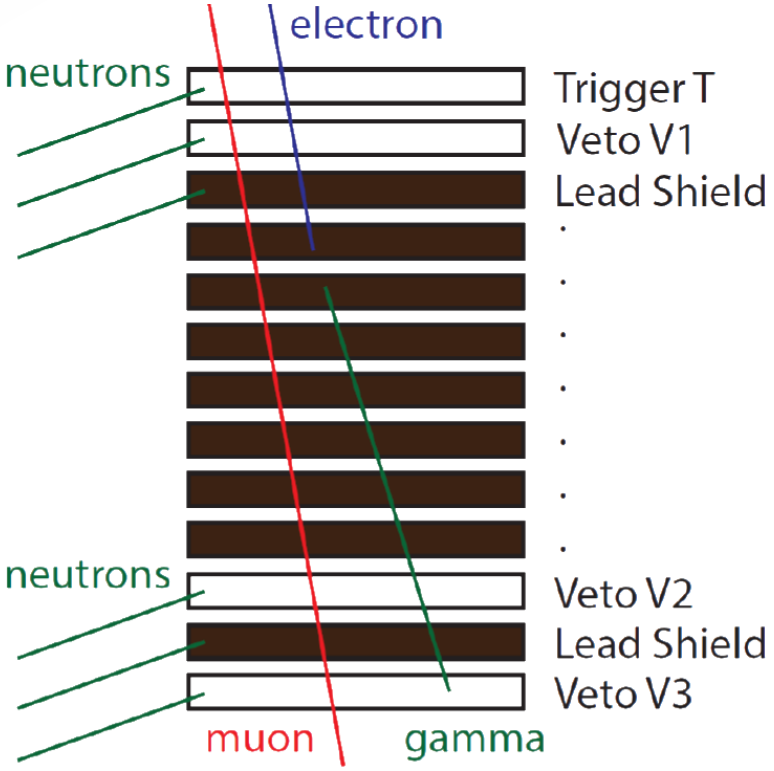
- 4 active segmented scintillator layers
- Lead shield in between
- 60° between scintillators



MAGIX Trigger and Cosmic Veto

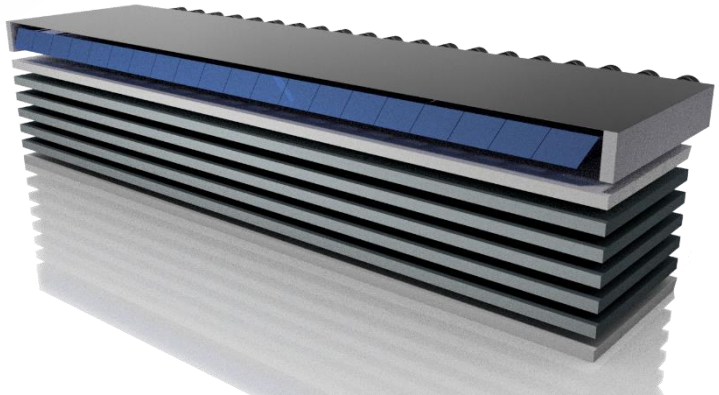
- 4 active segmented scintillator layers
- Lead shield in between
- 60° between scintillators

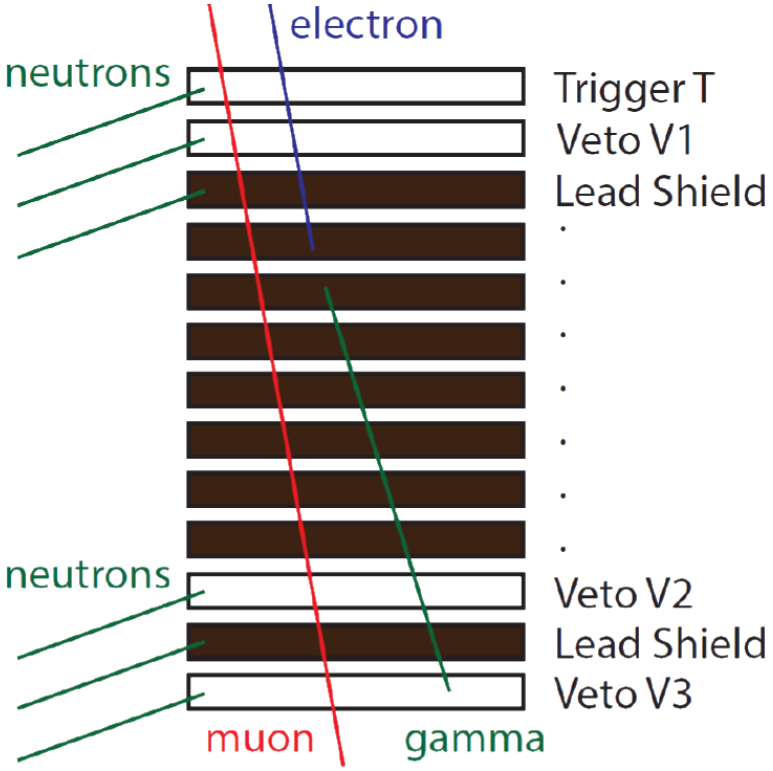




MAGIX Trigger and Cosmic Veto

- Electron Trigger:
  - T & !(V1 & V2 & V3) or
  - T & V1 & !(V2 & V3)
- Muon Veto:
  - T & (V1 & V2 & V3) or
  - T & (V2 & V3)



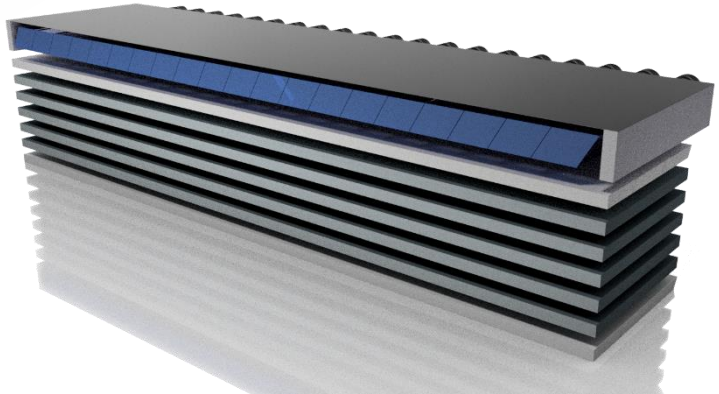


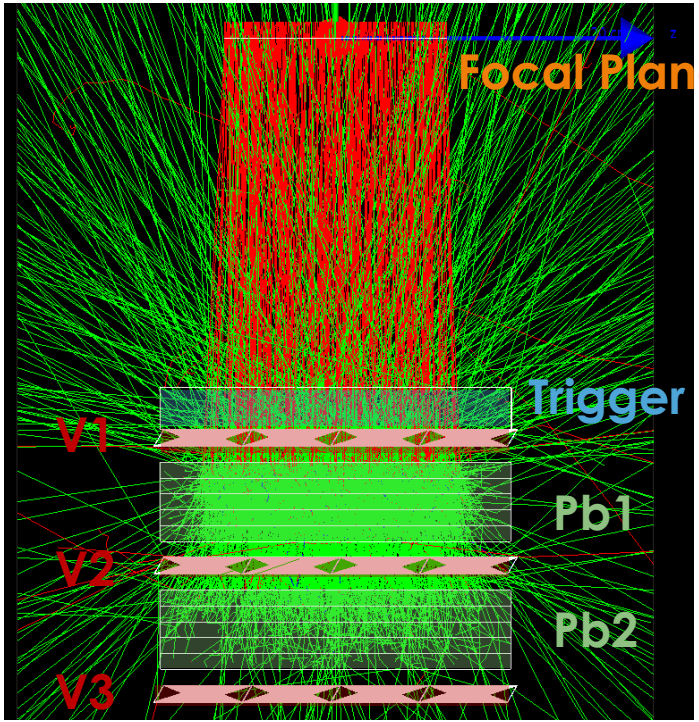
MAGIX Trigger and Cosmic Veto

Veto response for

Pb1 = 11 cm and **Pb2** = 1 cm

- Electrons: $1.28 \cdot 10^{-4}$
- Muons: $>9.999 \cdot 10^{-1}$

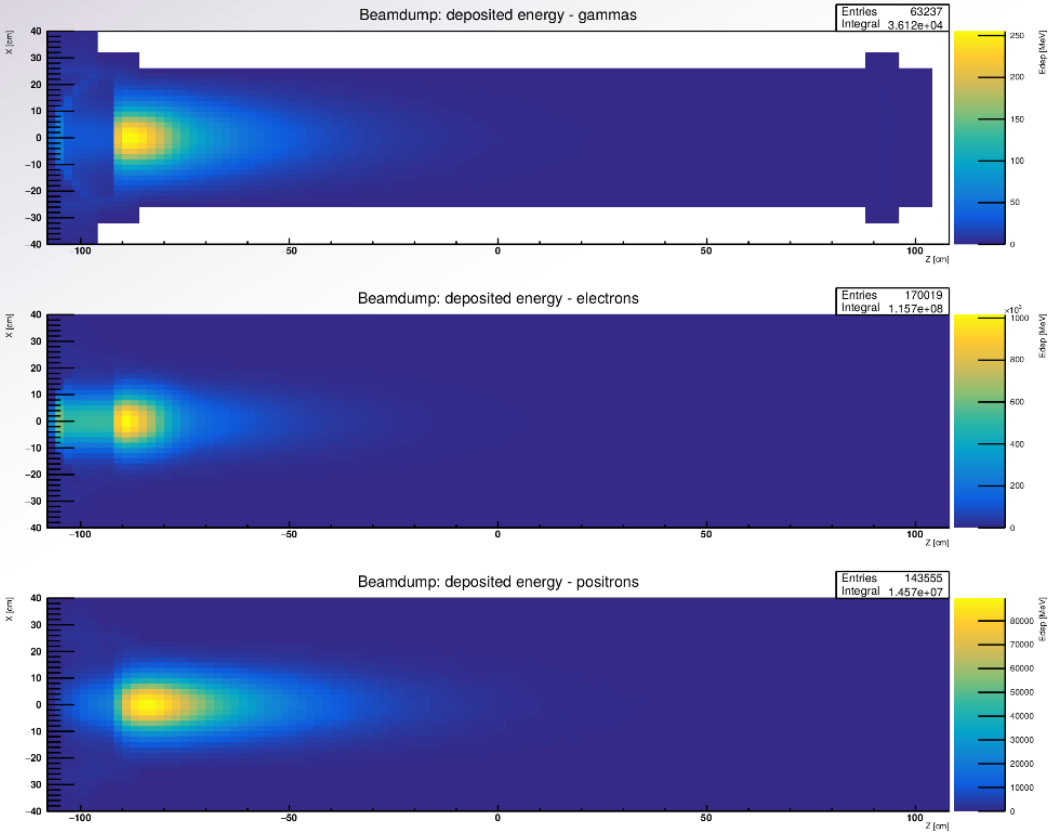




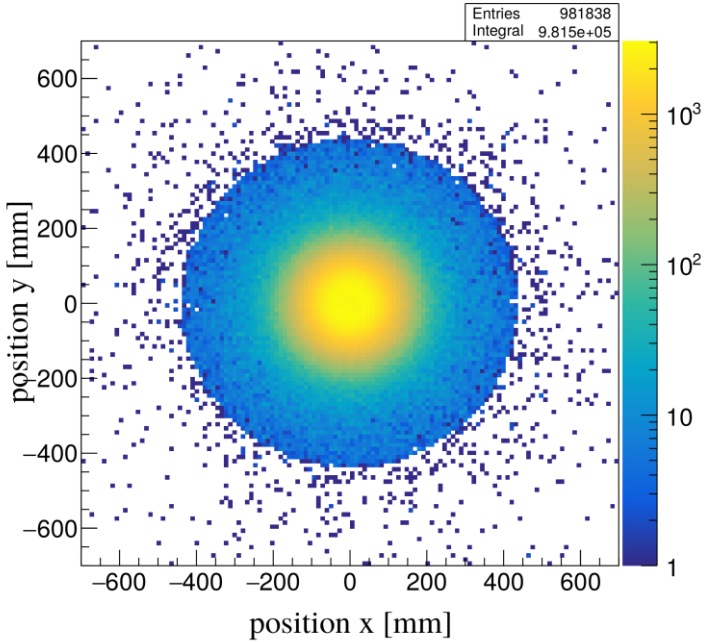
Backup: Simulation Studies

Energy Deposition, Additional Target, Geometrical Studies, Angular Distribution, Exclusion Limits with Threshold Dependence, Detection Efficiency

Energy Deposition

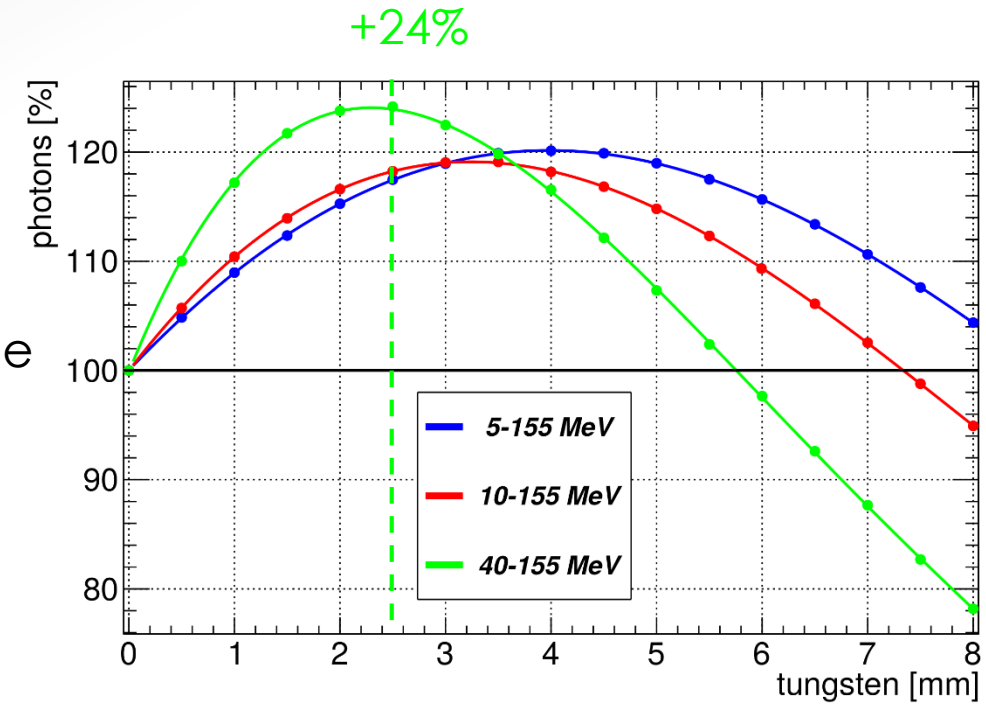


Lateral width of electron beam at dump

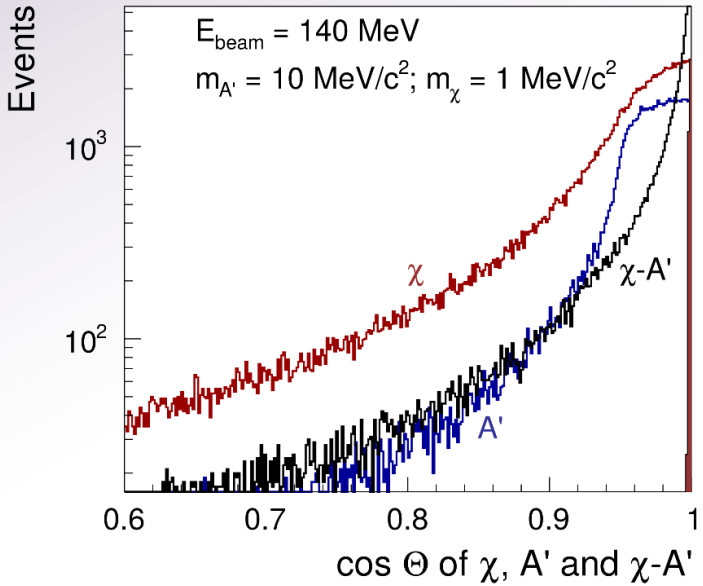


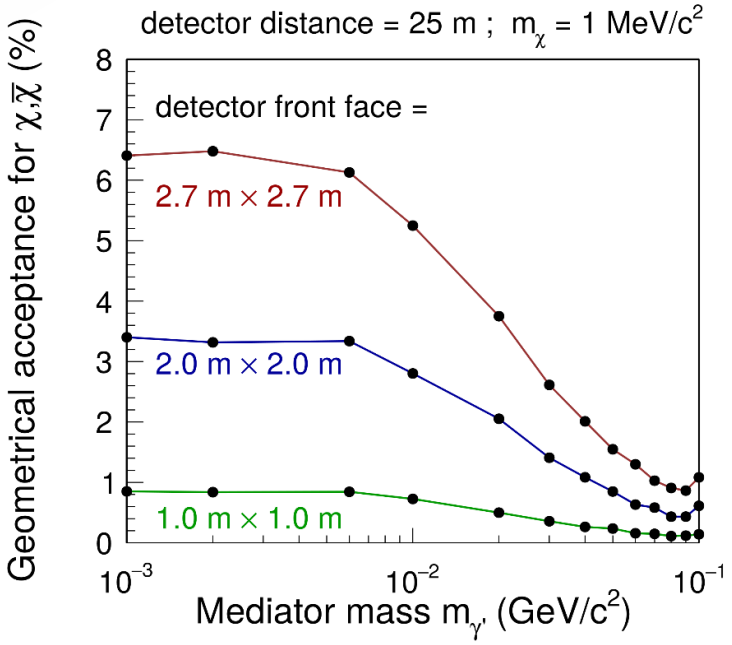
Additional Target

- Increase quantity of high energy photons
- W-Target (Z=74) in front of Al beam dump (Z=13)
- Choose 2.5 mm W plate in the following simulations



Geometrical Studies

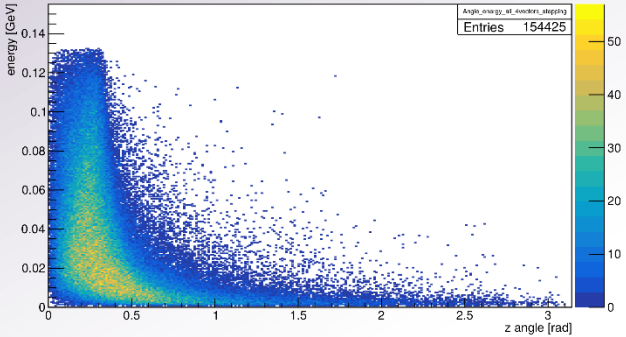




- Geometrical acceptance → maximize front face

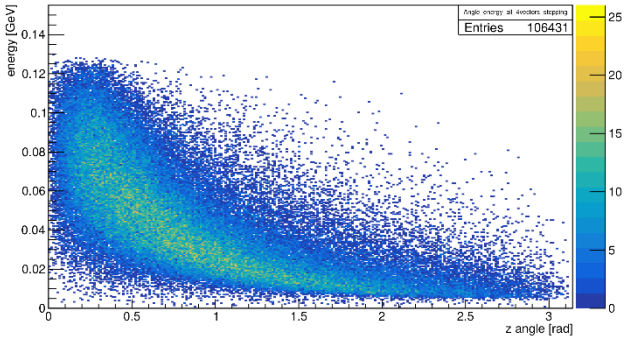
Angular Distribution of χ's

$m_{\gamma'} = 10$ MeV / $m_{\chi} = 1$ MeV



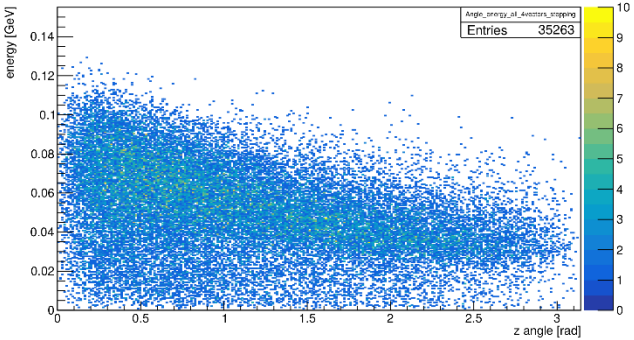
5.24 %

$m_{\gamma'} = 50$ MeV / $m_{\chi} = 1$ MeV



1.54 %

$m_{\gamma'} = 100$ MeV / $m_{\chi} = 1$ MeV

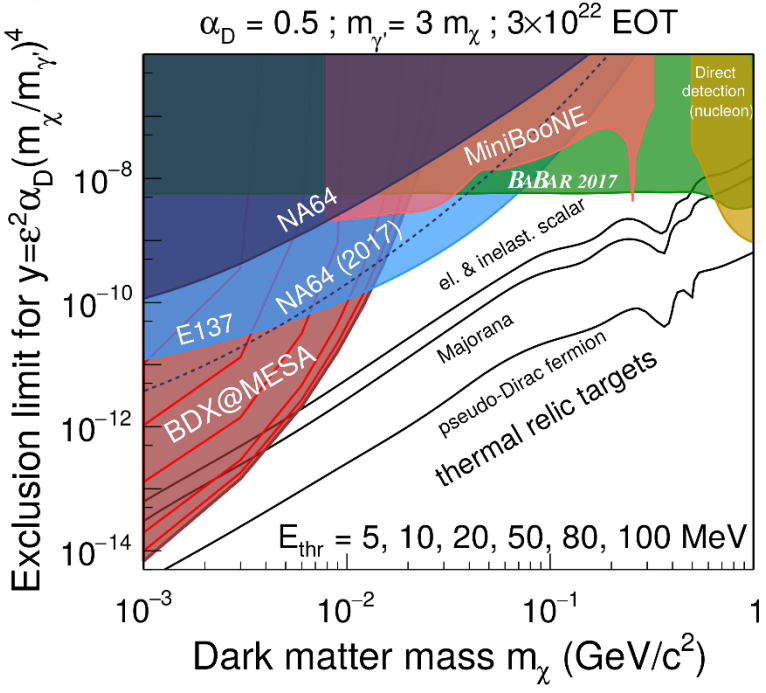


1.20 %

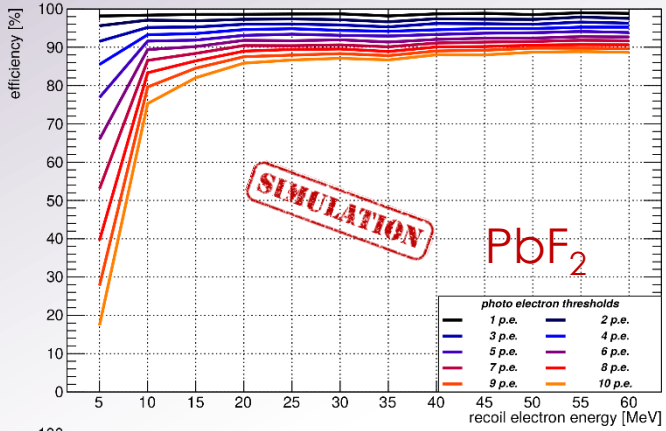
- Higher dark photon mass → wider distribution
- Geometric acceptances for reference detector
  - 2.7 × 2.7 m^2 surface
  - 23.5 m distance

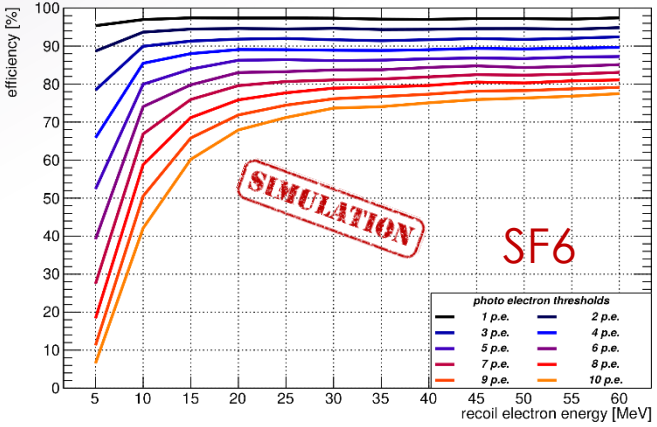
Exclusion Limits

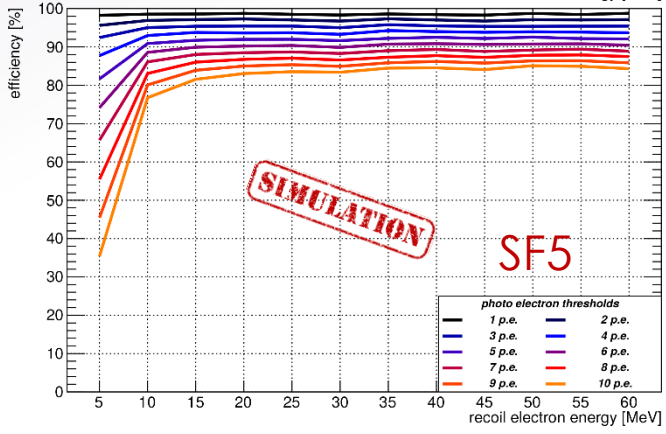
- Assumptions made for the BDX@MESA projection:
  - $\gamma' - \chi$ coupling α_D = 0.5
  - $m_{\gamma'} = 3 \cdot m_\chi$
  - 3×10^{22} EOT
  - 2.5 mm Tungsten target
  - Detector material: lead glass, 11 m^3
  - Detector efficiency 100%
  - No backgrounds
  - Energy detection threshold 5 MeV
- Touch thermal relic targets
- Dependence on detection thresholds

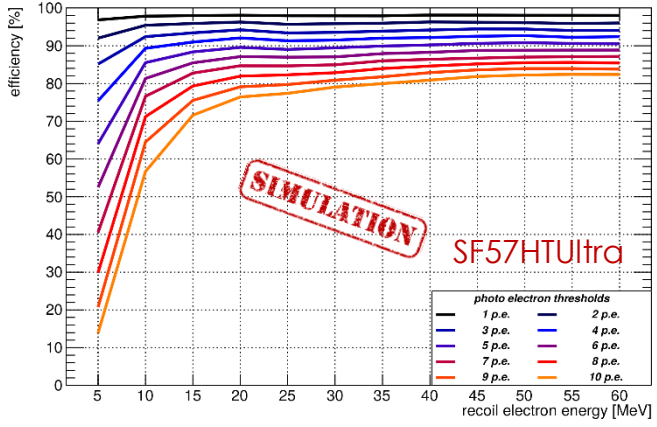


Detection Efficiency







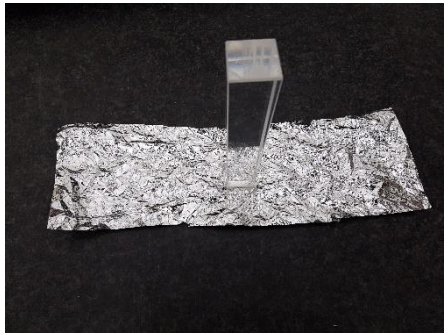


Backup: Experimental Studies

Prototype Detector Construction, BGO Spectra, MAMI Beamtime July 2018, Photonis XP2900 PMT, Calorimeter Material Properties & Pictures

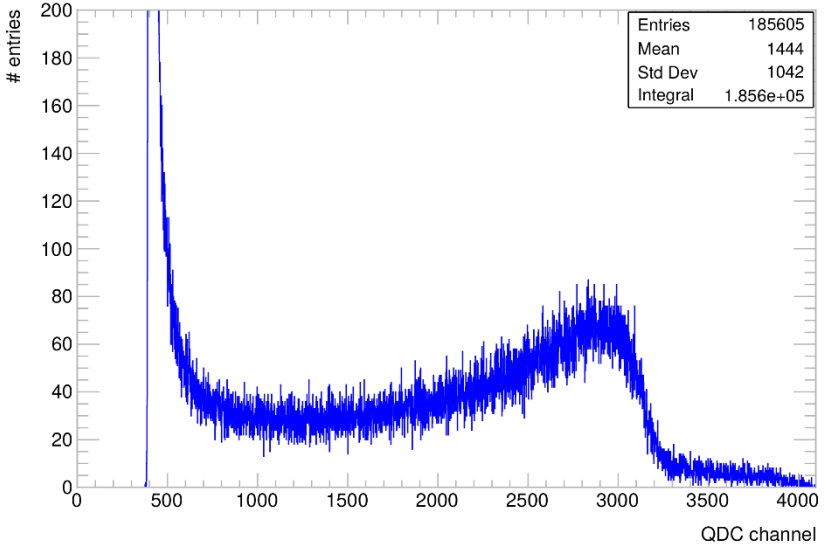
Prototype Detector Construction

- Grinding, polishing and cleaning
- Taking transmittance spectra
- Crystals in aluminum foil
- Photonis XP2900/01 Ø 29mm
- Lightproof black foil and tape
- Plastic tube with cable pull protection



BGO Spectra

- For BGO:
  - No optical photon simulation yet
  - Much more light → no amplifier could be used for full spectra → single p.e. peak not resolvable (lies in pedestal peak)
  - Determine the single p.e. peak in additional laboratory measurements



BGO 10322 (1 µs gate)

MAMI July 2018 Beamtime

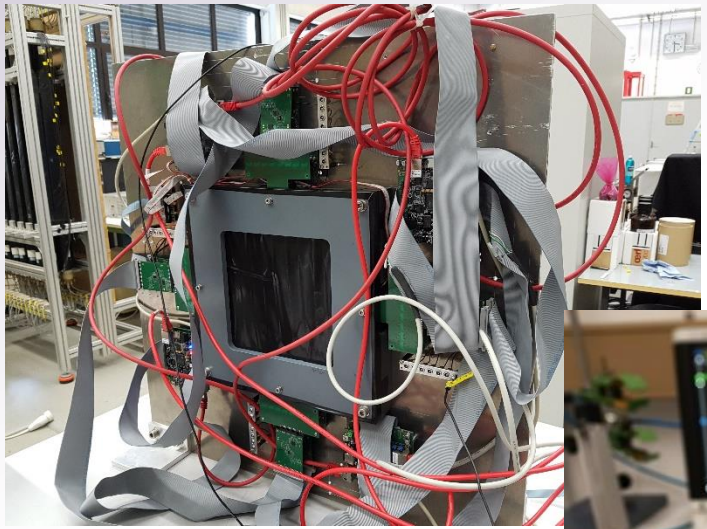
- Different sizes and densities of the lead glass blocks and crystals

	X [mm]	Y [mm]	Z [mm]	Density [g/cm³]
SF 5	70	55	160	4.07
SF 6	30	55	160	5.18
SF 57 HTultra	40	55 (180)	160	5.51
BGO	21	21	230	7.13
PbF_2 (1)	Frustum of a pyramid		150	7.77
PbF_2 (7)	(30x30 / 26x26)		185.4	7.77

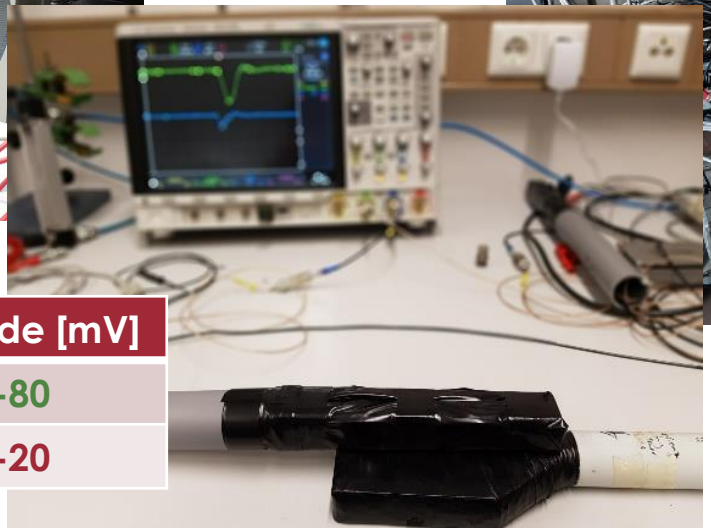
- Photonis XP2900/01 Ø 29mm

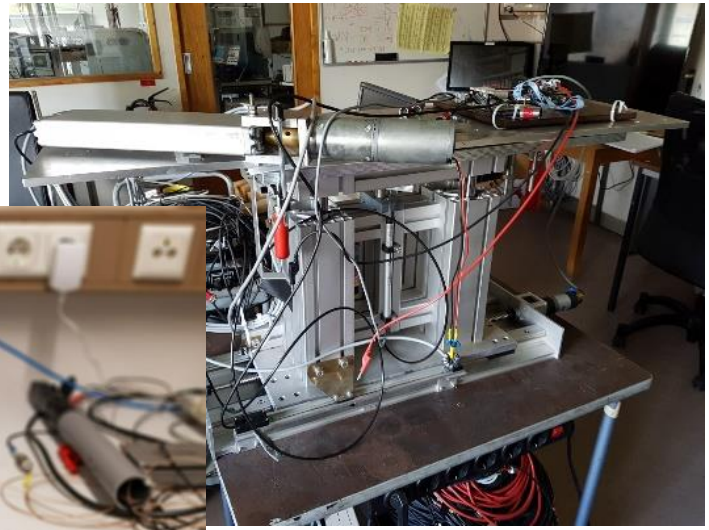
→ No optimal combination for lead glass and BGO

MAMI Beamtime Preparations



Fibre detector as trigger



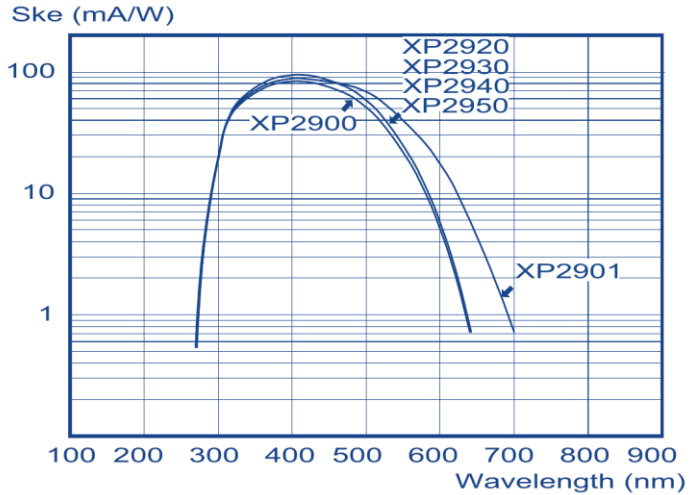


Rotatable XY table

	time [ns]	amplitude [mV]
BGO	> 500	20-80
PbF_2	~ 20	10-20

PMT Characteristics

Photonis XP2900/01 Ø 29mm



wavelength [nm]	800	600	400	350	300	290	280	270	260	253	250
quantum efficiency [%]	0.001	4.1	26.9	24.4	25.4	21.0	16.9	18.1	7.2	5.1	4.2

Calorimeter Material Properties

Material	CsI(Tl)	PbF_2	BGO	SF-5 (51% PbO)
Origin	BaBar at SLAC	A4 at MAMI	L3 at CERN	e.g. CERN, Schott
No. of blocks	820 (end-cap)	1 022	11 488	
Avg. size of blocks (cm^3)	$4.7 \times 5.4 \times 32.5$	$(2.6^2/3^2) \times 16.6$	$(2^2/3^2) \times 24$	$17.5^2 \times 30$
Shape of blocks	tapered	tapered	tapered	cuboid
Alveolus size (cm^3)	$5 \times 5.5 \times 33$	$3^2 \times 19$	$3.5^2 \times 24.5$	$18^2 \times 30.5$
Detector volume (m^3)	0.82	0.13	0.15	9.2
Density (g/cm^3)	4.53	7.77	7.13	4.08
Radiation length (cm)	1.85	0.93	1.13	2.54
Light yield (photons/MeV)	50 000	$\sim$ 300 (?)	10 000	$\sim$ 300 (?)
Peak emission (nm)	565	350	480	450
Signal decay time (ns)	680 (64%)	< 20	300	< 20
	3 340 (36%)			
Index of refraction	1.80	1.85	2.19	1.67
References	[1, 2]	[3, 4]	[5, 6]	[7]

*for 1000 blocks

Calorimeter Material Properties

References

[1] J. Brose, G. Dahlinger, K. R. Schubert, Properties of CsI(Tl) crystals and their optimization for calorimetry of high-energy photons, Nucl. Instrum. Methods Phys. Res. A 417 (1998) 311–324. doi:10.1016/S0168-9002(98)00765-7.

[2] B. Aubert, et al., The BaBar detector, Nucl. Instrum. Methods Phys. Res. A 479 (2002) 1–116. doi:10.1016/S0168-9002(01)02012-5.

[3] D. Anderson, M. Kobayashi, C. Woody, Y. Yoshimura, Lead fluoride: An ultra-compact Cherenkov radiator for em calorimetry, Nucl. Instrum. Methods Phys. Res. A 290 (2) (1990) 385–389. doi:10.1016/0168-9002(90)90553-I.

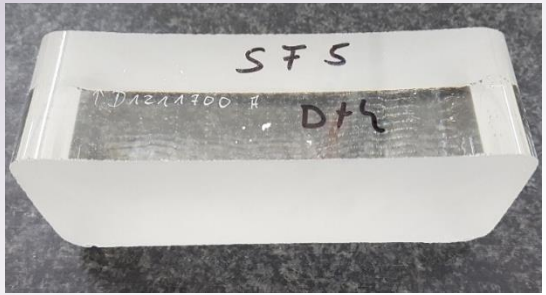
[4] S. Baunack, et al., Real-time calibration of the A4 electromagnetic lead fluoride (PbF_2) calorimeter, Nucl. Instrum. Methods Phys. Res. A 640 (1) (2011) 58–68. doi:10.1016/j.nima.2011.02.099.

[5] R. Sumner, The L3 BGO electromagnetic calorimeter, Nucl. Instrum. Methods Phys. Res. A 265 (1–2) (1988) 252–257. doi:10.1016/0168-9002(88)91078-9.

[6] F. Ferroni, The L3 BGO electromagnetic calorimeter at LEP, Nucl. Phys. B (Proc. Suppl.) 23 (1) (1991) 100–106. doi:10.1016/0920-5632(91)90036-E.

[7] U. Buchner, J. P. Donker, B. Spaan, J. Spengler, G. Schweda, D. Wegener, W. Schmidt-Parzefall, Performance of a scintillating glass calorimeter for electromagnetic showers, Nucl. Instrum. Methods Phys. Res. A 272 (1988) 695. doi:10.1016/0168-9002(88)90750-4.

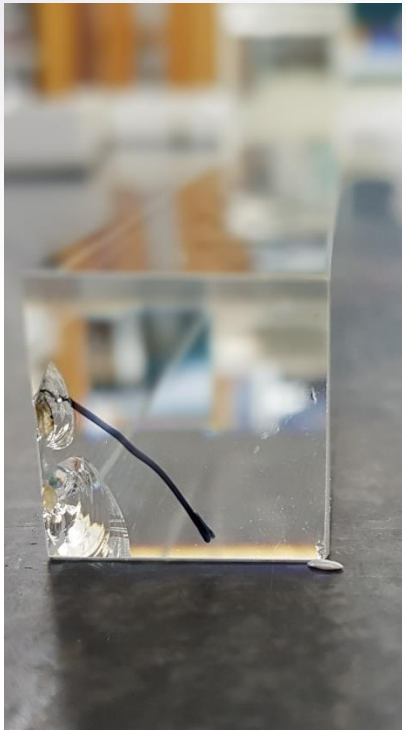
Lead Glass Blocks



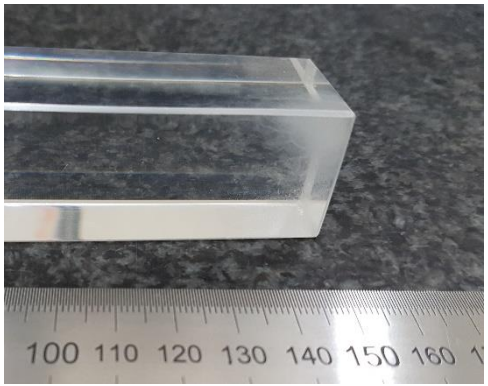
SF57 HTultra

SF 6

Crystal Damages



Physical damage (BGO)



Radiation damage (PbF_2)

SF5 673322.407

SCHOTT

Refractive Indices		
	λ [nm]	
$n_{2325.4}$	2325.4	1.63289
$n_{1970.1}$	1970.1	1.63785
$n_{1529.6}$	1529.6	1.64359
$n_{1060.0}$	1060.0	1.65104
n_t	1014.0	1.65206
n_s	852.1	1.65664
n_r	706.5	1.66327
n_C	656.3	1.66661
$n_{C'}$	643.8	1.66756
$n_{632.8}$	632.8	1.66846
n_D	589.3	1.67252
n_d	587.6	1.67270
n_e	546.1	1.67764
n_F	486.1	1.68750
$n_{F'}$	480.0	1.68876
n_g	435.8	1.69986
n_h	404.7	1.71069
n_i	365.0	1.73056
$n_{334.1}$	334.1	
$n_{312.6}$	312.6	
$n_{296.7}$	296.7	
$n_{280.4}$	280.4	
$n_{248.3}$	248.3	

Internal Transmittance τ_i		
λ [nm]	τ_i (10mm)	τ_i (25mm)
2500	0.847	0.660
2325	0.887	0.740
1970	0.959	0.900
1530	0.995	0.987
1060	0.998	0.996
700	0.998	0.996
660	0.998	0.995
620	0.998	0.995
580	0.998	0.996
546	0.998	0.996
500	0.997	0.993
460	0.995	0.988
436	0.993	0.982
420	0.989	0.973
405	0.983	0.959
400	0.980	0.950
390	0.967	0.920
380	0.950	0.880
370	0.915	0.800
365	0.882	0.730
350	0.626	0.310
334	0.200	
320		
310		
300		
290		
280		
270		
260		
250		

$$\rho = 4.07 \frac{g}{cm^3}$$

SF6 805254.518

SCHOTT

Refractive Indices		
	λ [nm]	
$n_{2325.4}$	2325.4	1.75302
$n_{1970.1}$	1970.1	1.75813
$n_{1529.6}$	1529.6	1.76444
$n_{1060.0}$	1060.0	1.77380
n_t	1014.0	1.77517
n_s	852.1	1.78157
n_r	706.5	1.79117
n_C	656.3	1.79609
$n_{C'}$	643.8	1.79750
$n_{632.8}$	632.8	1.79884
n_D	589.3	1.80491
n_d	587.6	1.80518
n_e	546.1	1.81265
n_F	486.1	1.82775
$n_{F'}$	480.0	1.82970
n_g	435.8	1.84707
n_h	404.7	1.86436
n_i	365.0	1.89703
$n_{334.1}$	334.1	
$n_{312.6}$	312.6	
$n_{296.7}$	296.7	
$n_{280.4}$	280.4	
$n_{248.3}$	248.3	

Internal Transmittance τ_i		
λ [nm]	τ_i (10mm)	τ_i (25mm)
2500	0.887	0.740
2325	0.910	0.790
1970	0.971	0.930
1530	0.996	0.991
1060	0.999	0.999
700	0.999	0.996
660	0.998	0.996
620	0.998	0.995
580	0.999	0.996
546	0.998	0.996
500	0.996	0.991
460	0.991	0.978
436	0.982	0.955
420	0.967	0.920
405	0.933	0.840
400	0.915	0.800
390	0.847	0.660
380	0.720	0.440
370	0.442	0.130
365	0.246	0.030
350		
334		
320		
310		
300		
290		
280		
270		
260		
250		

$$\rho = 5.18 \frac{g}{cm^3}$$

SF57HTultra 847238.551

SCHOTT

Refractive Indices		
	λ [nm]	
$n_{2325.4}$	2325.4	1.79026
$n_{1970.1}$	1970.1	1.79539
$n_{1529.6}$	1529.6	1.80187
$n_{1060.0}$	1060.0	1.81185
n_t	1014.0	1.81335
n_s	852.1	1.82038
n_r	706.5	1.83102
n_C	656.3	1.83650
$n_{C'}$	643.8	1.83808
$n_{632.8}$	632.8	1.83957
n_D	589.3	1.84636
n_d	587.6	1.84666
n_e	546.1	1.85504
n_F	486.1	1.87204
$n_{F'}$	480.0	1.87425
n_g	435.8	1.89393
n_h	404.7	1.91366
n_i	365.0	
$n_{334.1}$	334.1	
$n_{312.6}$	312.6	
$n_{296.7}$	296.7	
$n_{280.4}$	280.4	
$n_{248.3}$	248.3	

Internal Transmittance τ_i		
λ [nm]	τ_i (10mm)	τ_i (25mm)
2500	0.914	0.798
2325	0.930	0.835
1970	0.980	0.951
1530	0.998	0.994
1060	0.999	0.999
700	0.999	0.998
660	0.999	0.997
620	0.999	0.997
580	0.999	0.997
546	0.999	0.997
500	0.996	0.990
460	0.991	0.978
436	0.985	0.962
420	0.971	0.930
405	0.941	0.860
400	0.924	0.820
390	0.831	0.630
380	0.621	0.304
370	0.250	0.029
365	0.100	
350		
334		
320		
310		
300		
290		
280		
270		
260		
250		

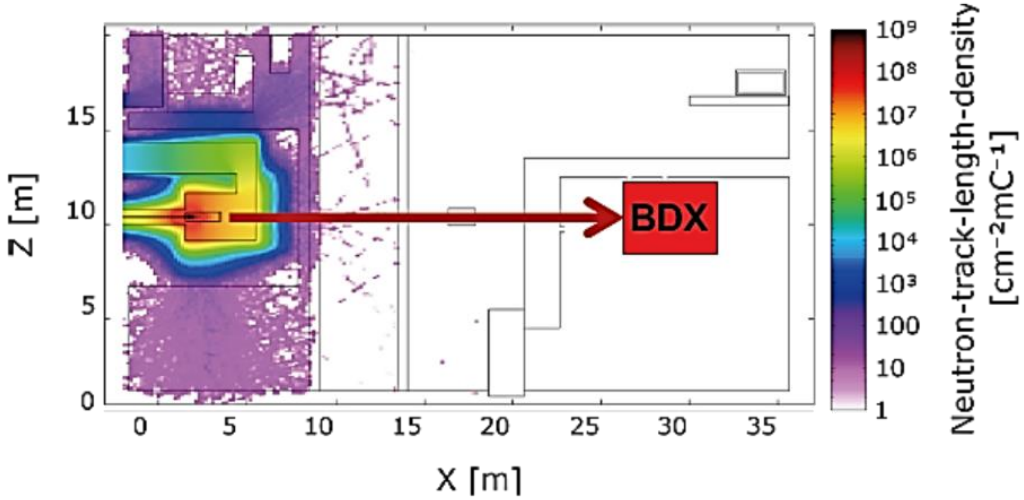
$$\rho = 5.51 \frac{g}{cm^3}$$

Backup: Background Studies

FLUKA Neutron Background, Neutron Studies by P. Burger

Backgrounds

- FLUKA simulation of neutron background looks promising
- "Response characteristics of high dense Cherenkov radiators to low-energy neutrons"
  - ➡ Bachelor thesis by P. Burger
- Threshold energy for pion production is 152 MeV
  - ➡ No beam related neutrinos at MESA



by Steffen Heidrich