TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Accelerator-Based Dark Sector Searches

Luca Doria
TRIUMF

July 2017

Outline

- Physics Motivation
- Dark Sector Models
- Experimental Technique
- Planned Experiments
- Any opportunity for ARIEL?

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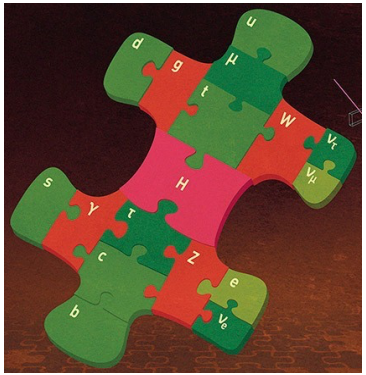
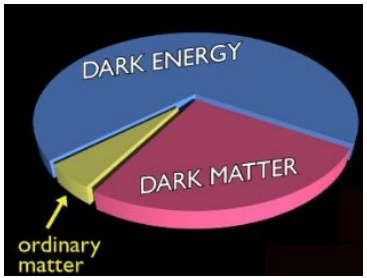
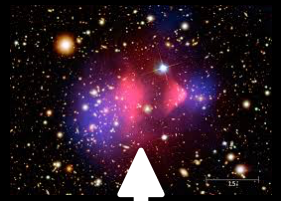
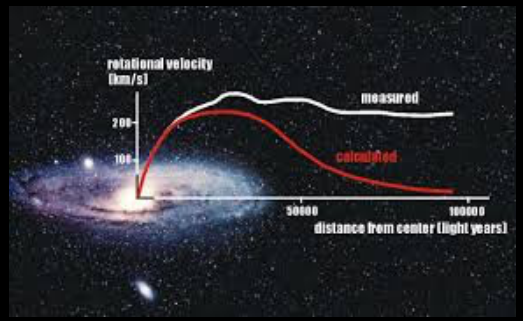


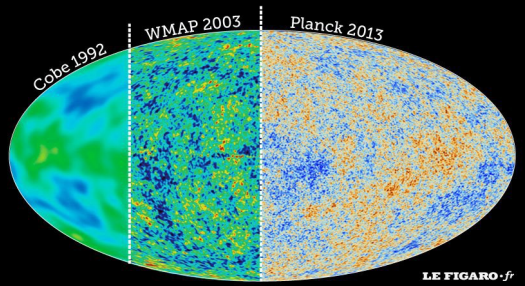


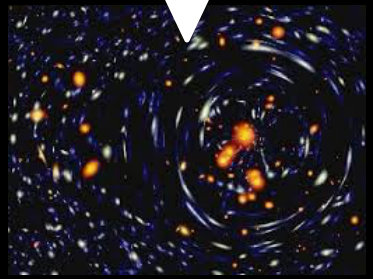
Physics Motivation





Dark Matter





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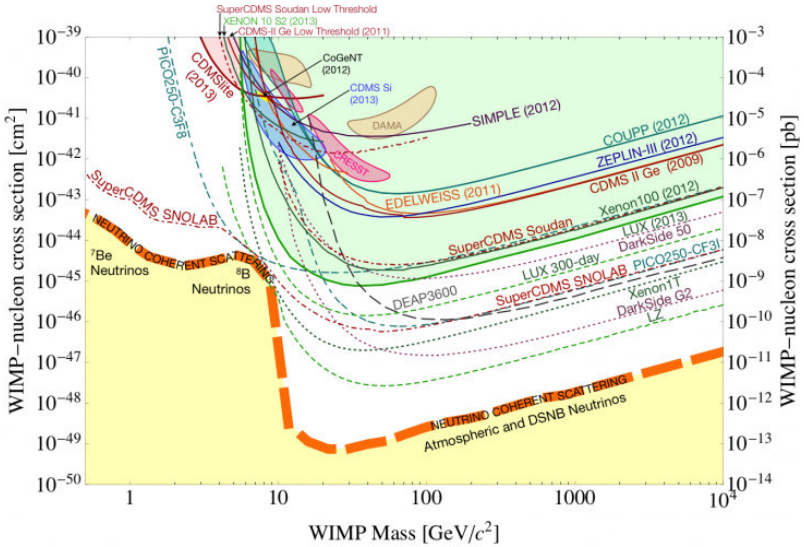
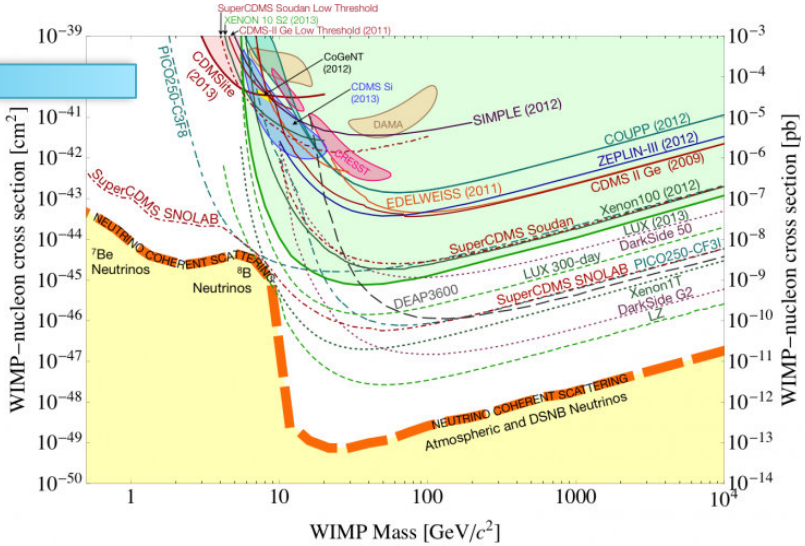


The WIMP Paradigm $\sigma \sim 1pb \Rightarrow \Omega_D M \sim 0.25$

Lee-Weinberg Window

$$\sigma_{\text{ann}} \propto \begin{cases} G_F^2 m_\chi^2 & \text{for} \quad m_\chi \ll m_W \\ 1/m_\chi^2 & \text{for} \quad m_\chi \gg m_W \end{cases} \Rightarrow \text{GeV} < m_\chi < \text{TeV}$$

Dark Matter



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Light Dark Matter Paradigm

- If light, smaller annihilation CS
- DM overproduction
- “Overclosed" Universe
- In contrast with cosmological data.

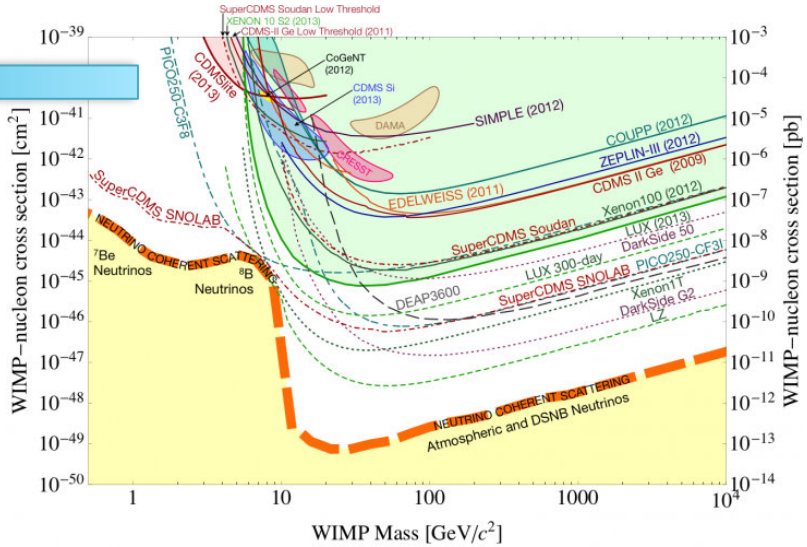
The way out:
- postulate a new interaction
- annihilation via a new force carrier

If coupling small enough, DM can be light!

$$MeV \lesssim m_\chi \lesssim GeV$$

Example: $\chi\chi \to e^+e^-$

$$\sigma \sim \alpha\alpha_D\epsilon^2 v^2 \frac{m_\chi^2 + 2m_e^2}{(m_{A'}^2 - 4m_\chi^2)^2}\sqrt{1 - \frac{m_e^2}{m_\chi^2}}$$



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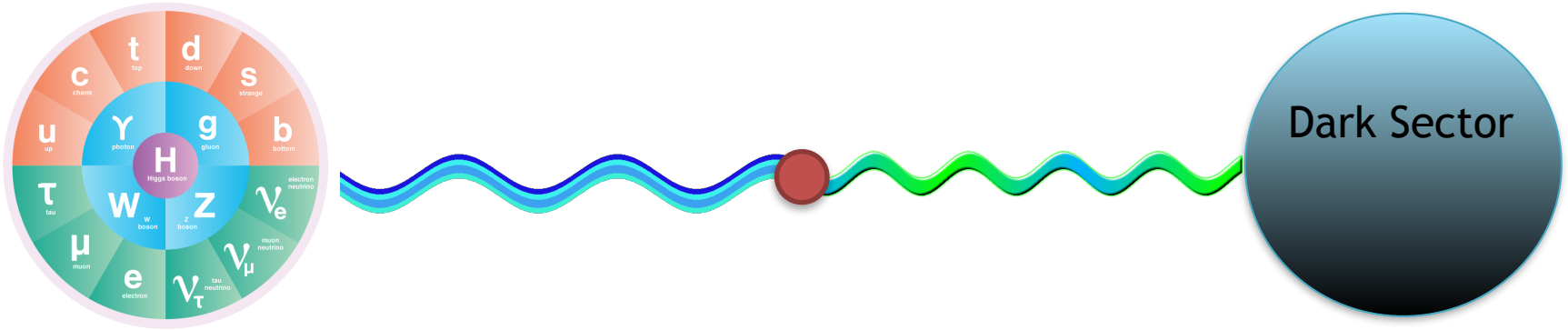
The Dark Sector



The Dark Sector

Vector Portal $\frac{1}{2}\epsilon_Y F_{\mu\nu} F'^{\mu\nu}$

Higgs Portal $\epsilon_h |h|^2 |\phi|^2$ Precision Higgs Physics

Neutrino Portal $\epsilon_\nu h L \psi$ New Neutrino States

Axion Portal $\frac{G_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$

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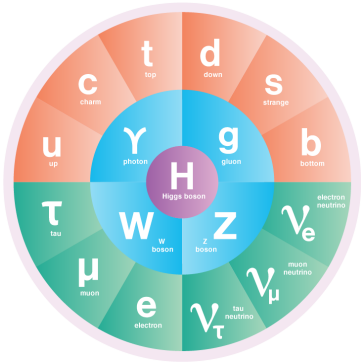

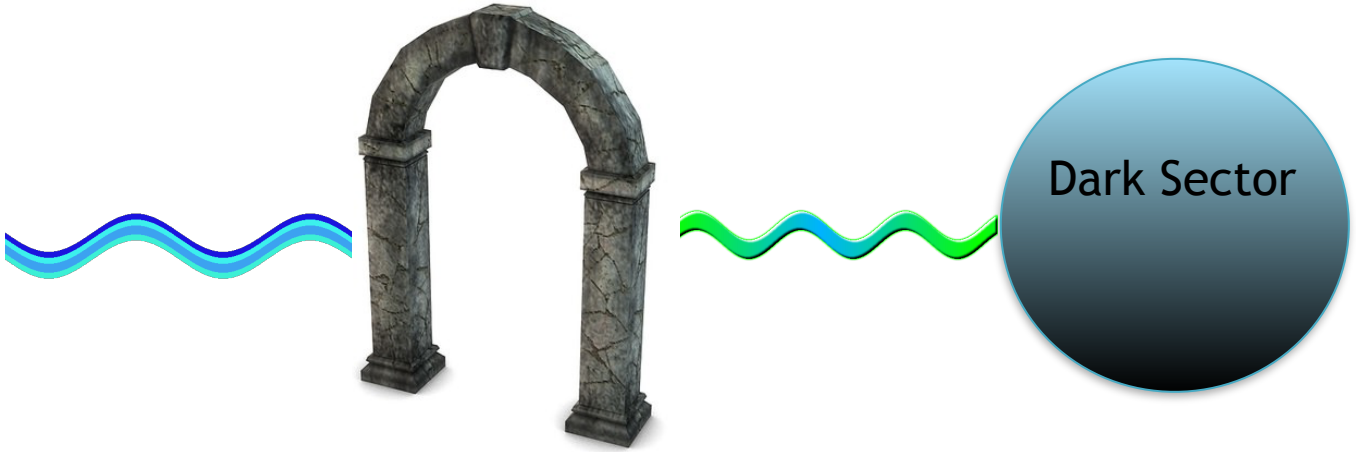

$$\mathcal{L} \sim \bar{\chi}(i\not{D} - m_\chi)\chi + \frac{1}{2}\epsilon_Y F'_{\mu\nu} B_{\mu\nu} + \frac{1}{2} m^2_{A'} A'_\mu A'^\mu$$

$$D_\mu = \partial_\mu + i g_D A'_\mu$$ New U(1) massive gauge boson

4 parameters: $m_{A'}$ $\alpha_D = \frac{g_D^2}{4\pi}$ m_χ ϵ_Y

Vector Portal $\frac{1}{2}\epsilon_Y F_{\mu\nu} F'^{\mu\nu}$

Higgs Portal $\epsilon_h |h|^2 |\phi|^2$ Precision Higgs Physics

Neutrino Portal $\epsilon_\nu h L \psi$ New Neutrino States

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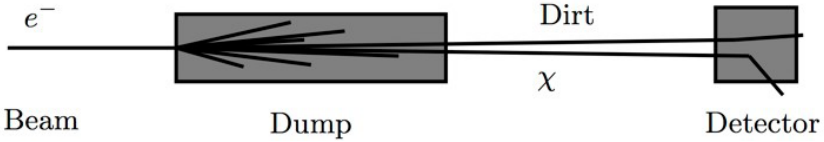
After EW Symmetry Breaking:

$$\epsilon = \epsilon_Y \cos\theta_W \ll 1$$

$$\frac{1}{2}\epsilon F'_{\mu\nu} F_{\mu\nu}$$

Beam Dump (Invisible Decays)



Neutrino Experiments, Proton BD Experiments
Possible future locations: JLab, MESA, …
Re-analysis of old experiments

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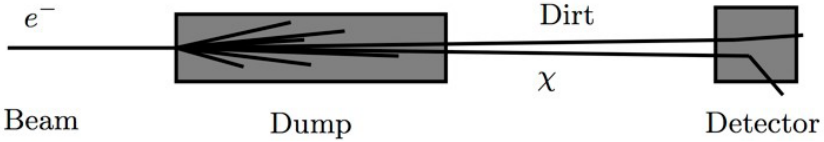

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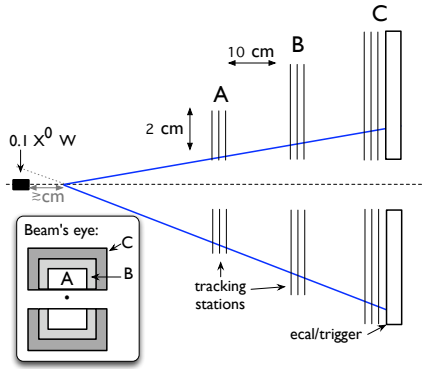
Thin/Thick Target + Vertexing (Visible Decays)



Intense Experimental Activity:

DarkLight: FEL 200MeV beam (JLab)
APEX: e+e- pairs (JLab)
HPS: e+e- pairs + displaced vertex (JLab)
A1@MAMI: e+e- pairs (Univ. Mainz)

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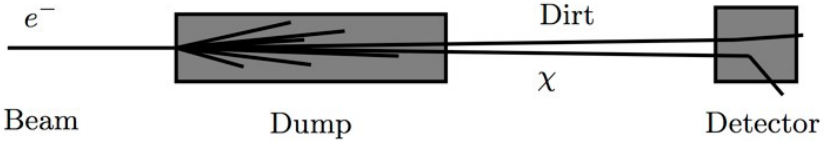

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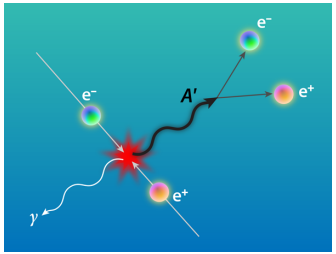
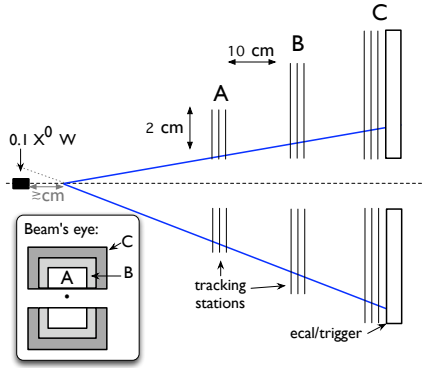
Collider (Visible/Invisible)



B-Factories (BaBar/Belle/Belle II)
LHC Experiments
Meson Decays

Thin/Thick Target + Vertexing (Visible Decays)



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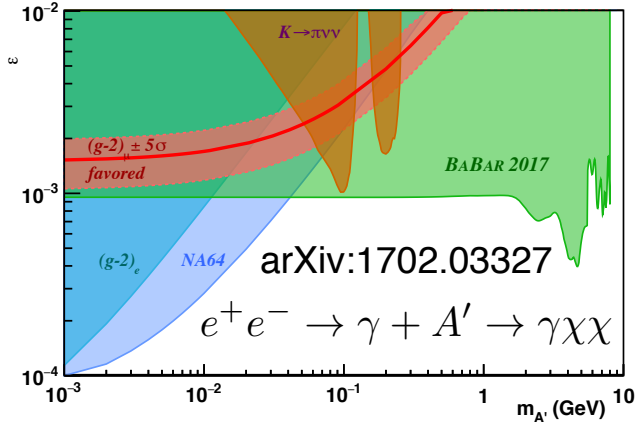
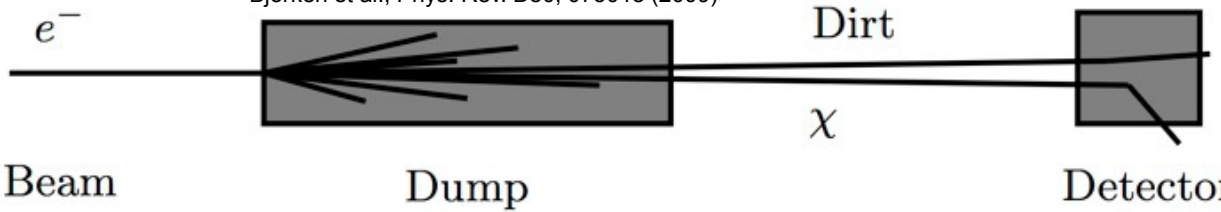
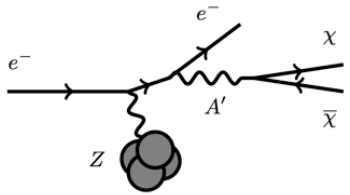
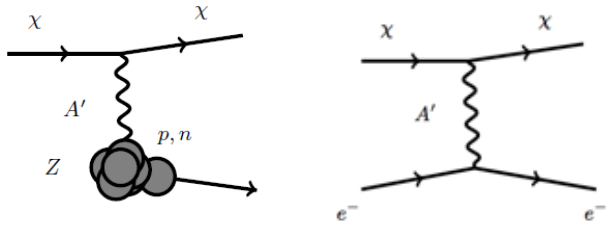


Beam-Dump Experiments

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



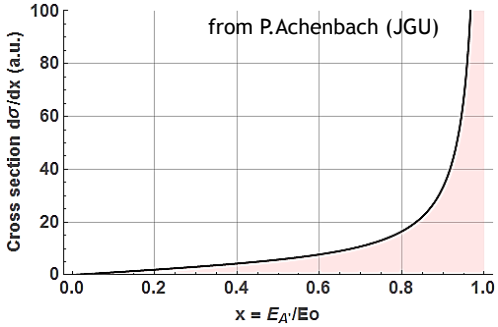




Production Mechanism:

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

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

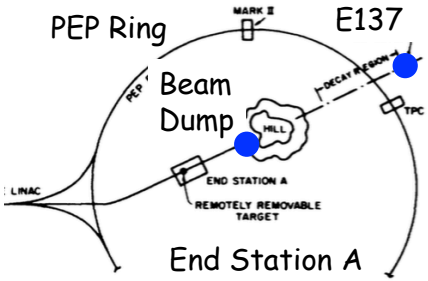


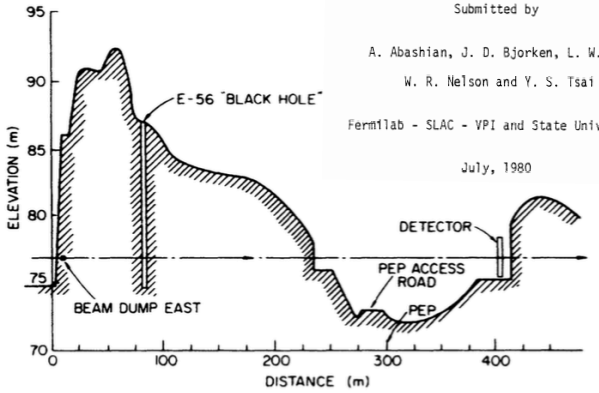
Detection Mechanism:

- Nuclear Recoil
- Electron Recoil

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

SLAC E137 Experiment





Proposal To Search For Low Mass,
Metastable, Neutral Particles at SLAC

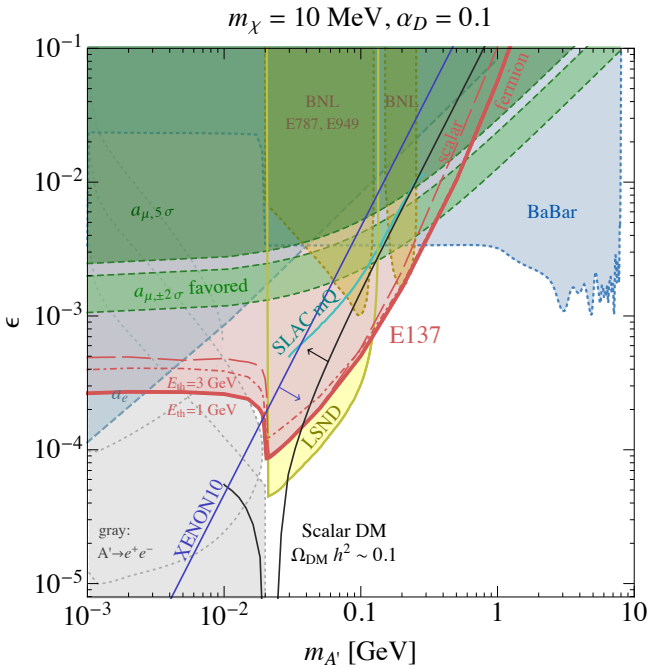
Submitted by

A. Abashian, J. D. Bjorken, L. W. Mo*,
W. R. Nelson and Y. S. Tsai

Fermilab - SLAC - VPI and State University

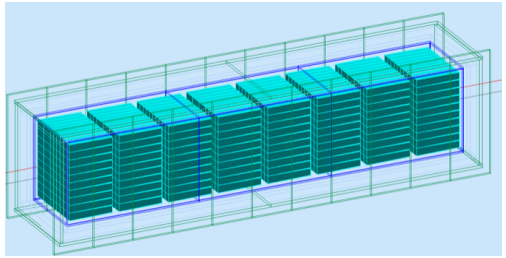
July, 1980

Axions, Heavy neutrinos from Z decays, photinos, other neutrals.
20GeV electron beam, 10^{20} EOT accumulated.
Mass range: 1-200 MeV.
EM Cal + Wire Chambers: Detect EM showers + Direction.
Distance from beam dump: 383m.
Operation: 1980-1982.
No events observed.

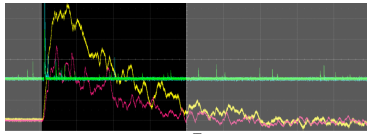


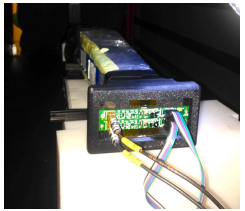
B.Batell et. al, Phys. Rev. Lett. **113**, 171802

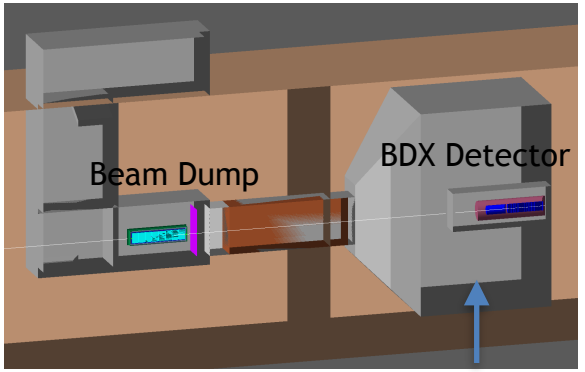
Proposed Detector:
820 CsI(Tl) BaBar EM Cal
Crystals: 32x5x5 cm
8 Modules, 10x10 crystals
SiPM readout
3m length, 0.5x0.5m CS



Detector Prototyping in progress.
Beam/Cosmics tests at INFN-Catania







New Infrastructure

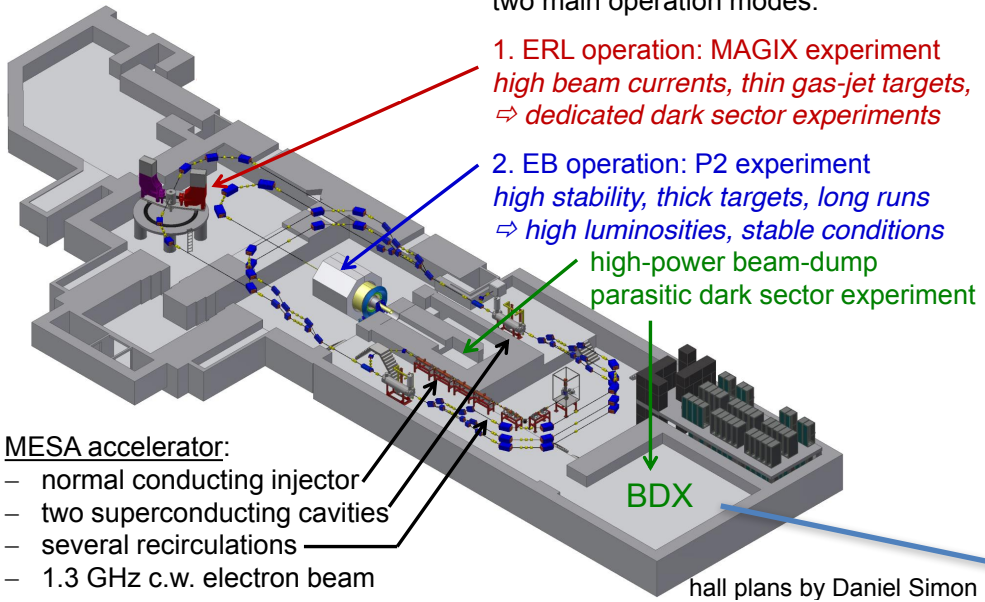
Beam:
E = 11GeV
I =100uA
10^{22} EOT/yr

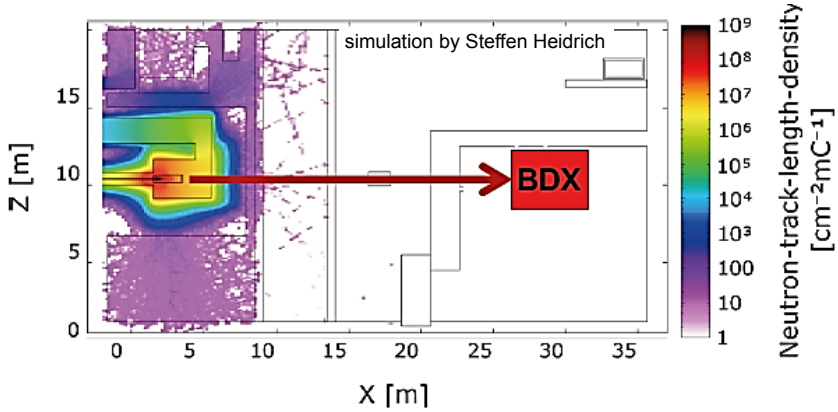
Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab

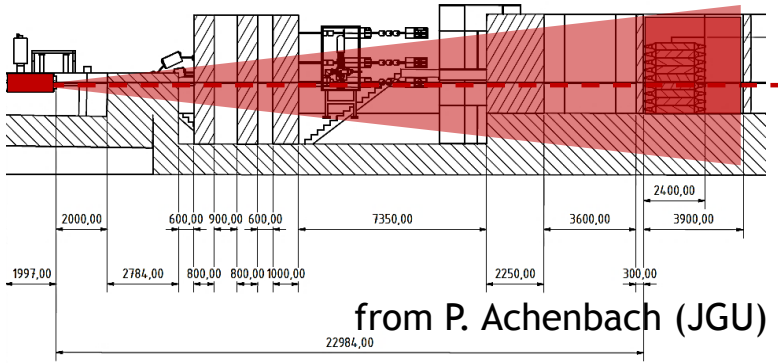
The BDX Collaboration

arXiv:1607.01390

BDX @ MESA





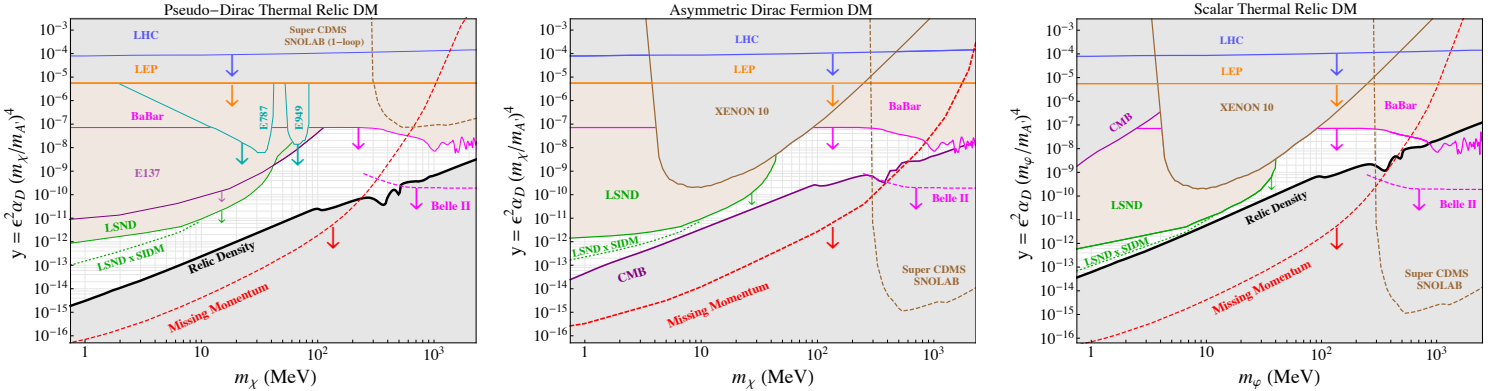


from P. Achenbach (JGU)

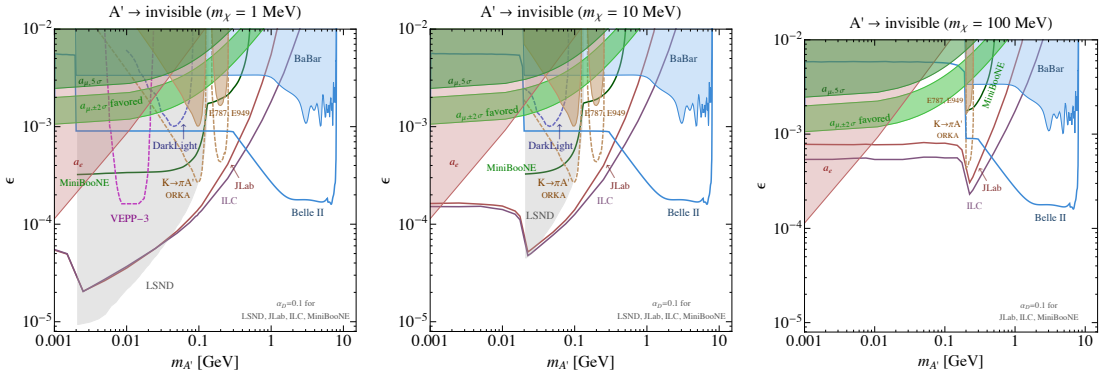
Electron Beam: 150MeV / 100uA (~20 kW)
In 10.000h operation ~3x1022 EOT / 5400C
Dark Matter "Beam": ~10deg opening angle
Distance from the dump: 23m —> +/- 4m @ detector

Experimental Reach / Complementarity

E. Izaguirre et al.: Phys.Rev.Lett. 115 (2015) no.25, 251301



R. Essig *et al.*, arXiv:1311.0029



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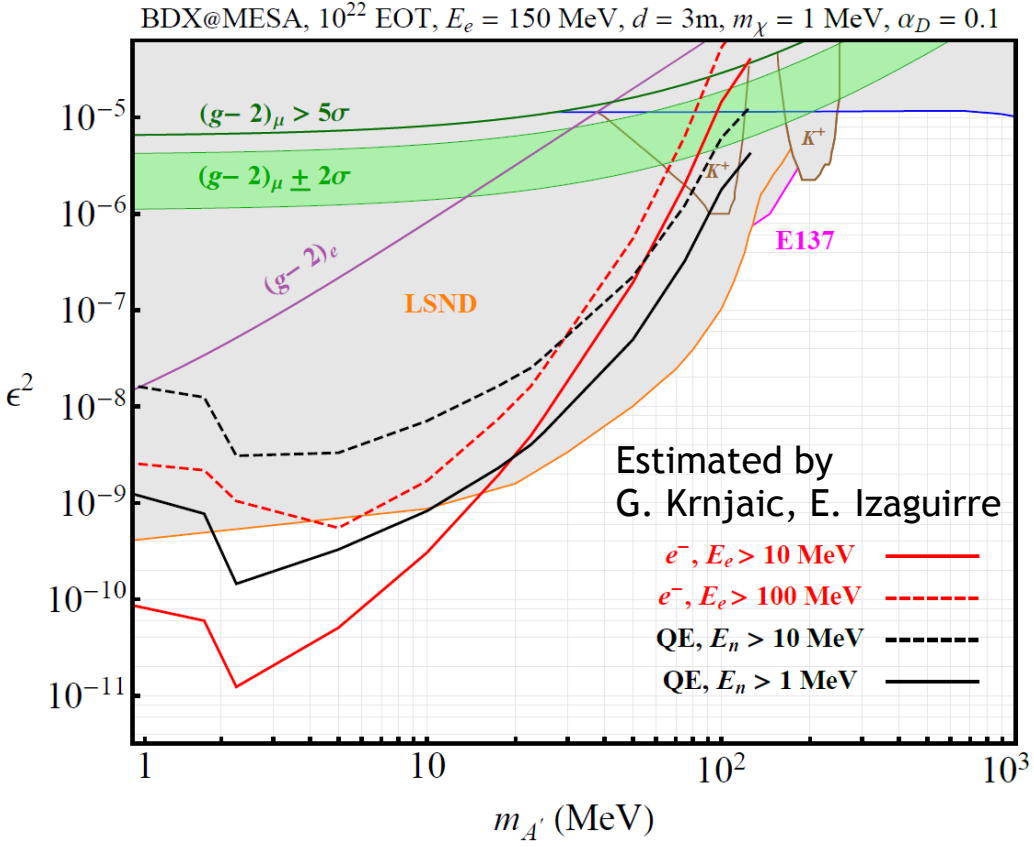

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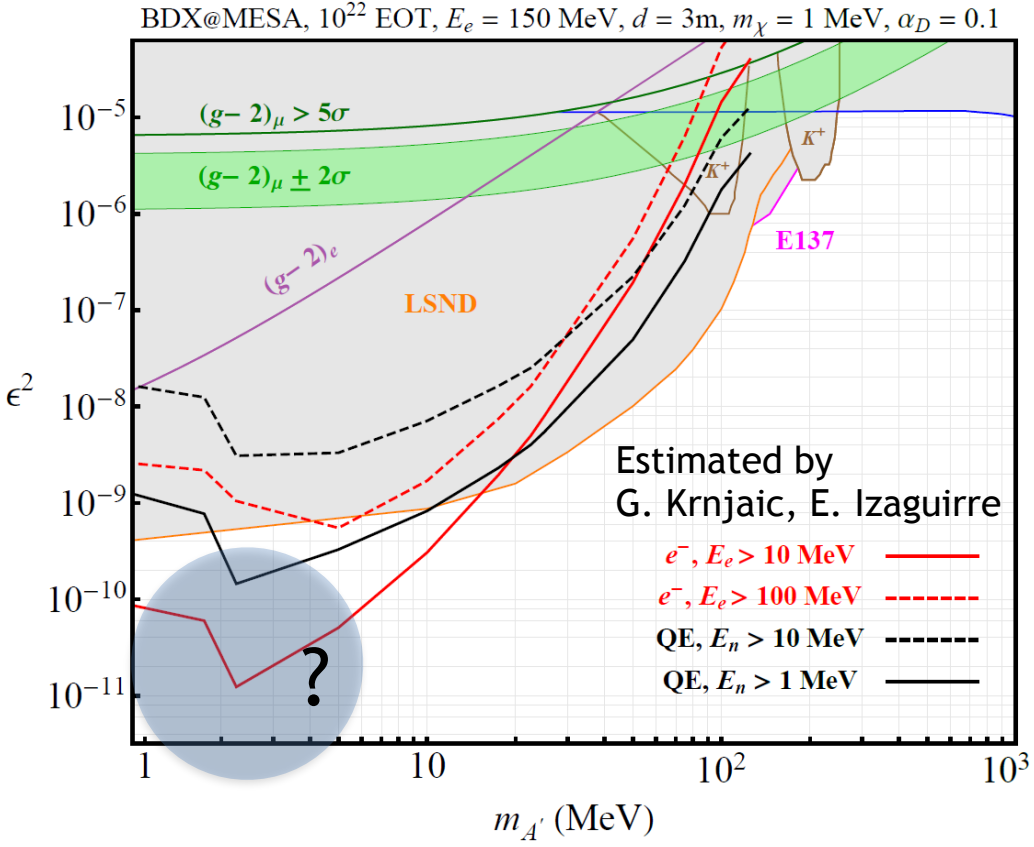
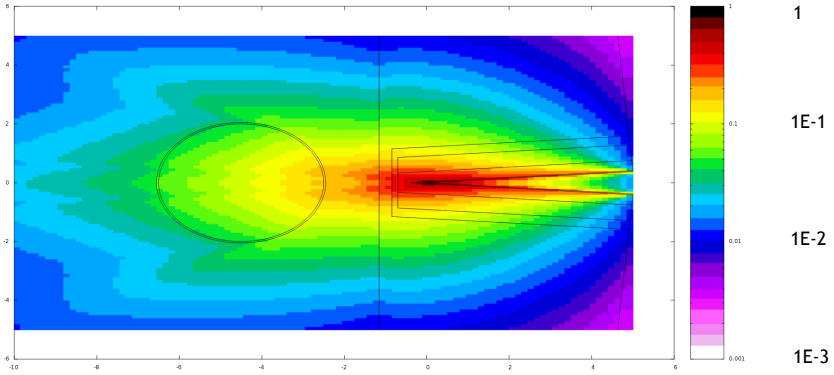
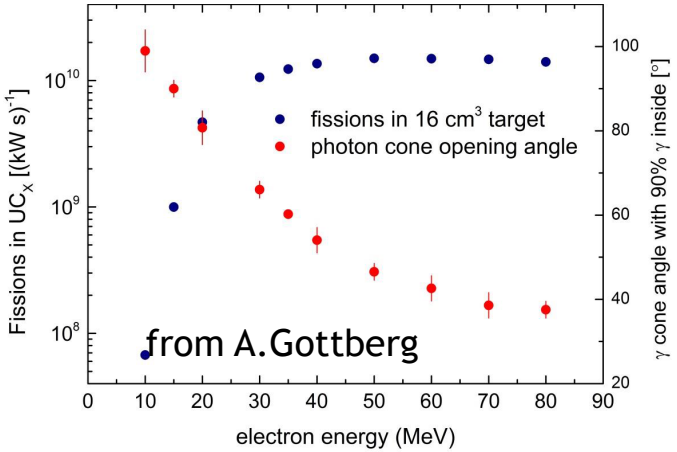


The ARIEL Electron Target

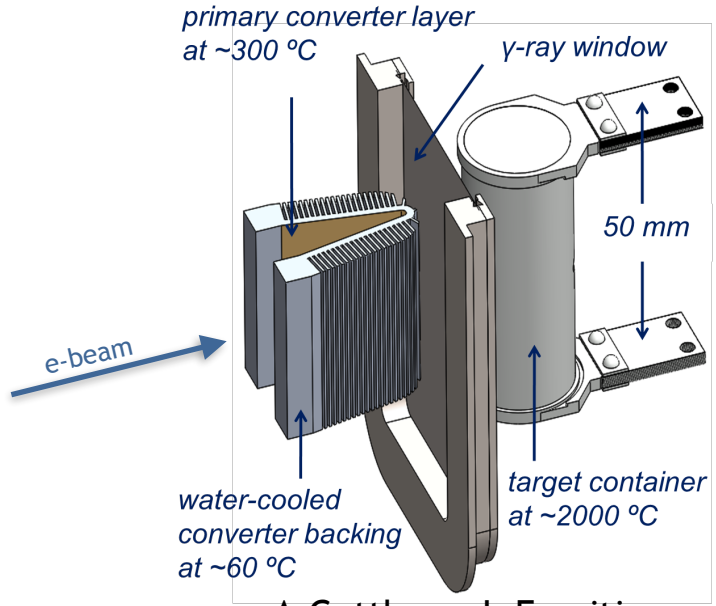
Photon Flux





Conical Trench Converter

- Beam rastered over 5x5x2 = 50 cm²
- Finned, water-cooled backing
- Max beam power = 60 kW
- Vertical target
- Gold-Aluminum



A.Gottberg, L.Egoriti

The ARIEL Electron Target

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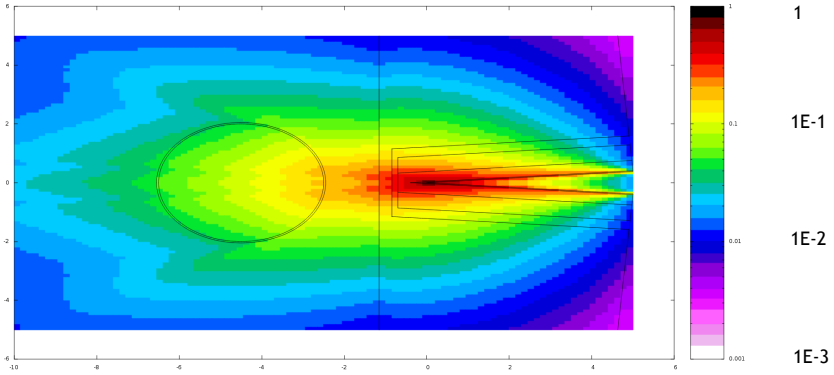

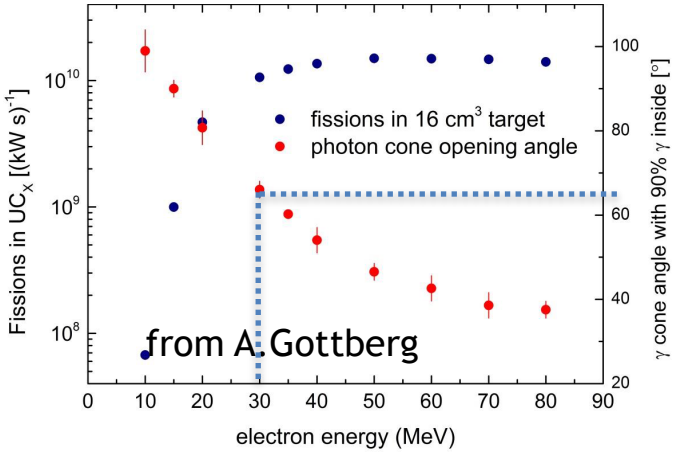

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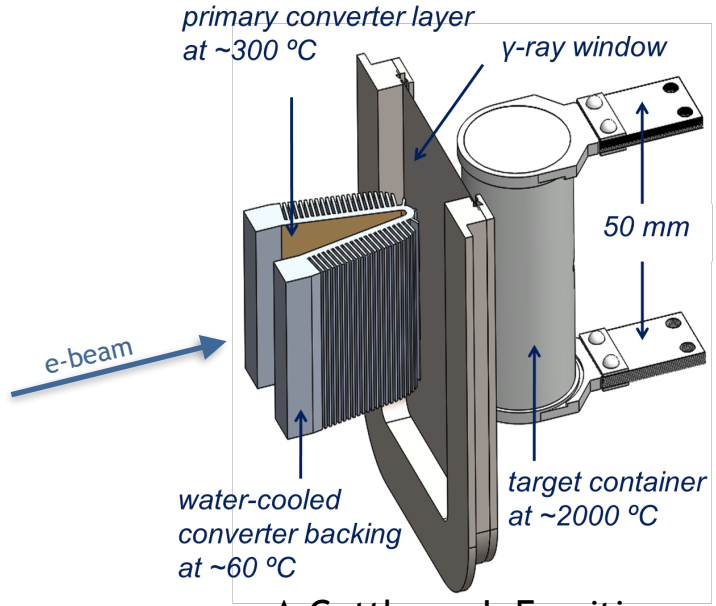
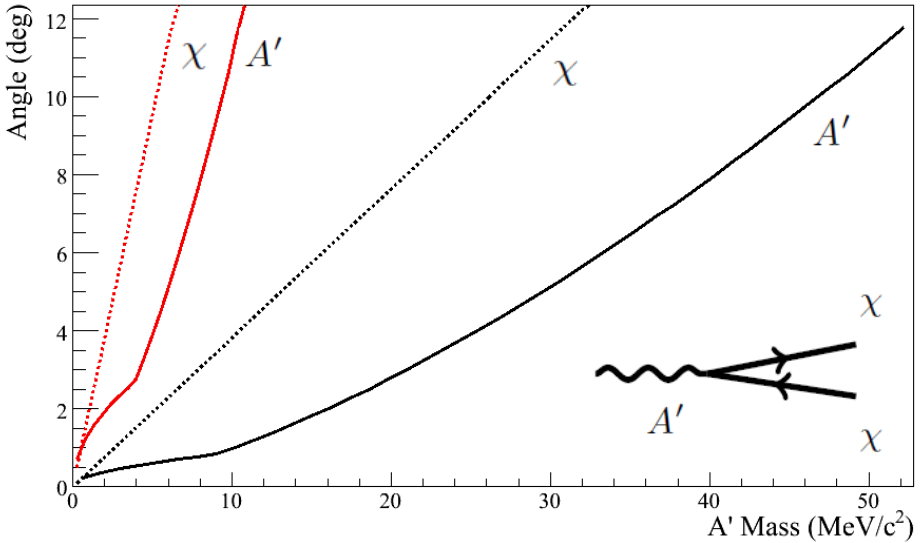


A.Gottberg, L.Egoriti

Low Energy Beams Kinematics

$$2m_\chi < m_{A'}$$



E_0 = 150 MeV

E_0 = 30 MeV

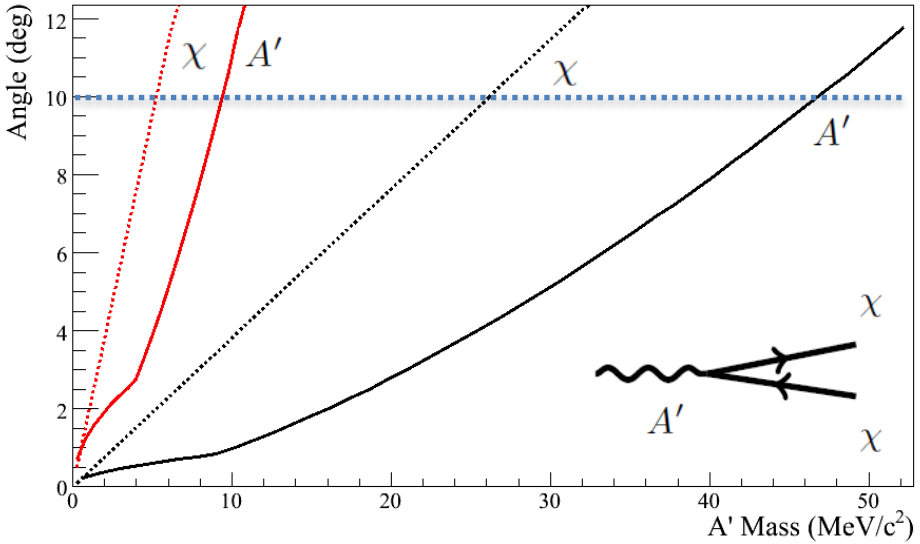
A' production angle smaller wrt angle between decay products.

A' rate: $R_{A'}/R_{bs} \sim \epsilon^2 \frac{m_e^2}{m_{A'}^2}$

A' lifetime: $c\tau \sim 1/(\epsilon^2 m_{A'})$

Low Energy Beams Kinematics

$$2m_\chi < m_{A'}$$



E_0 = 150 MeV

E_0 = 30 MeV

A' production angle smaller wrt angle between decay products.

A' rate: $R_{A'}/R_{bs} \sim \epsilon^2 \frac{m_e^2}{m_{A'}^2}$

A' lifetime: $c\tau \sim 1/(\epsilon^2 m_{A'})$

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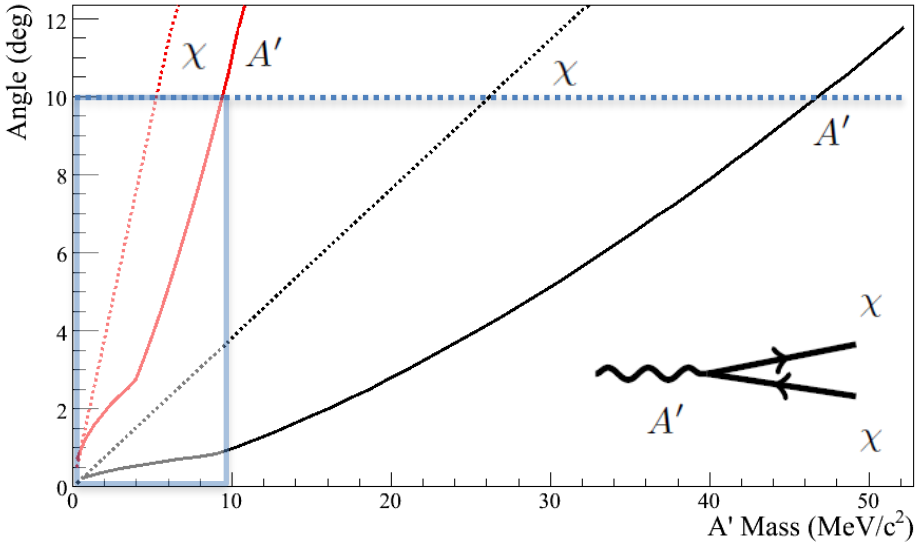

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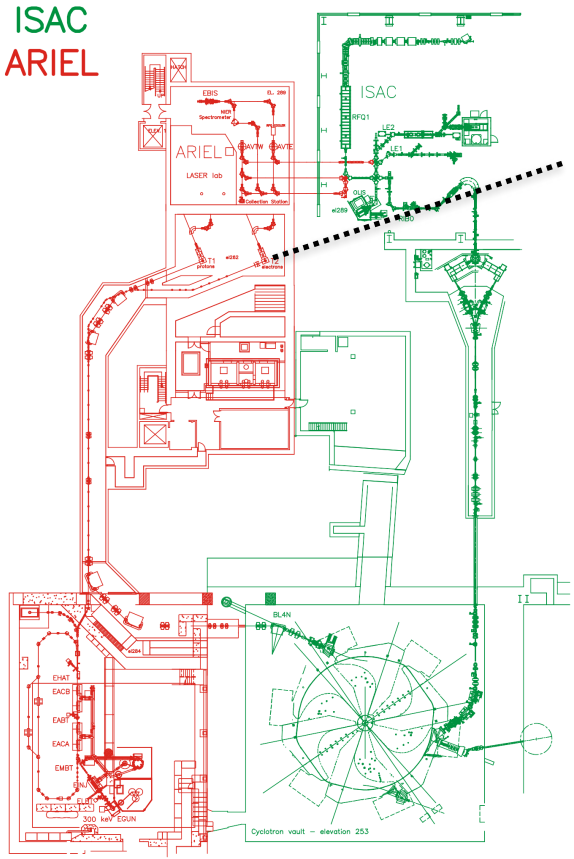
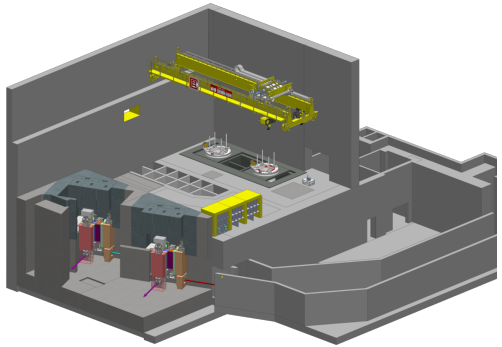
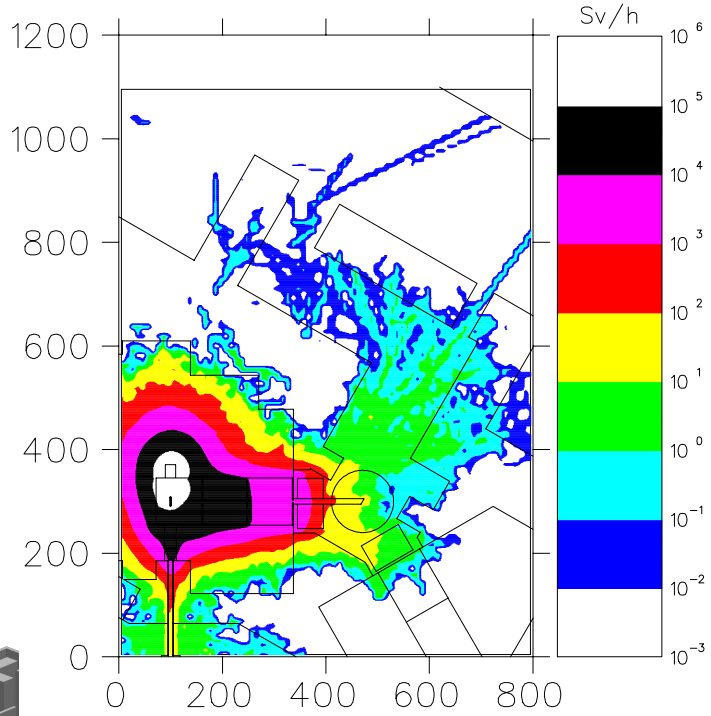


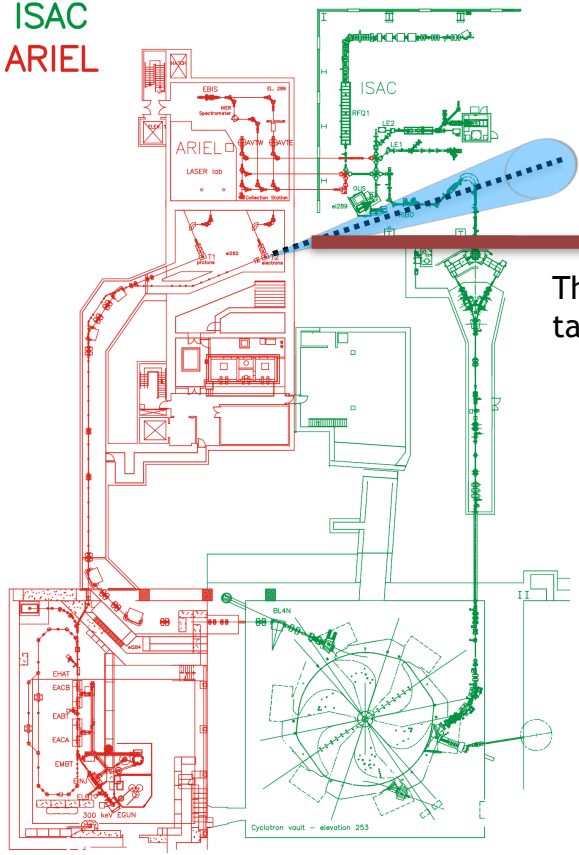




FLUKA99 simulation of neutrons from the pre-separator maze to the separator vault.

~mSv/h radiation level during operation.

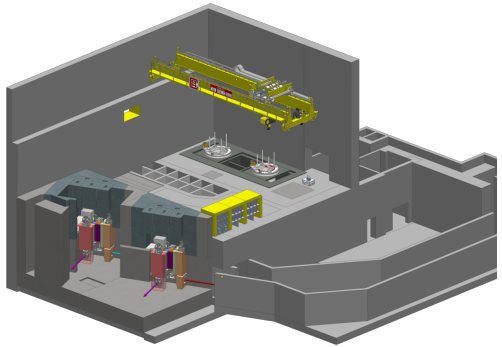
ISAC
ARIEL

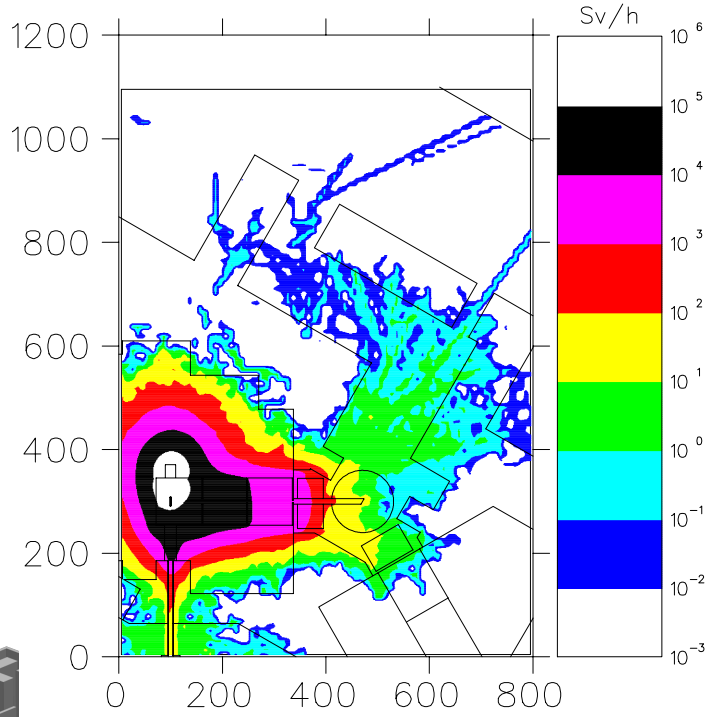


$\theta = 10°$

Thick concrete wall between target and separator hall.

~20m —> ~3x3m detector





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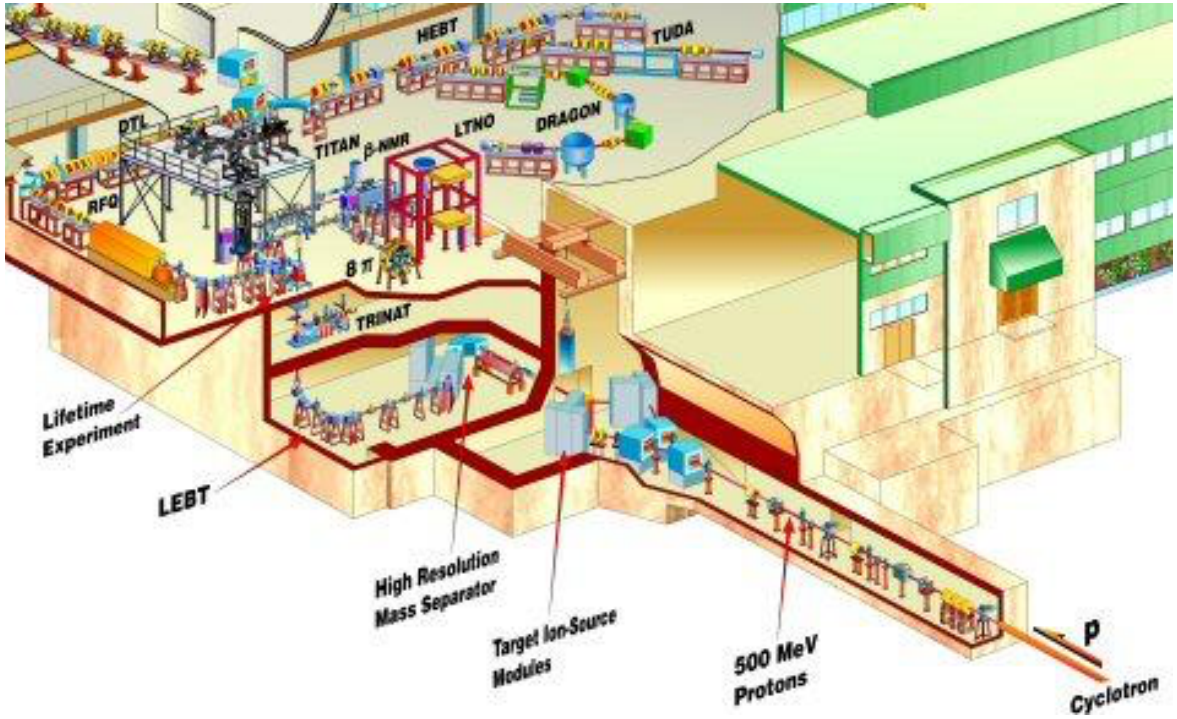

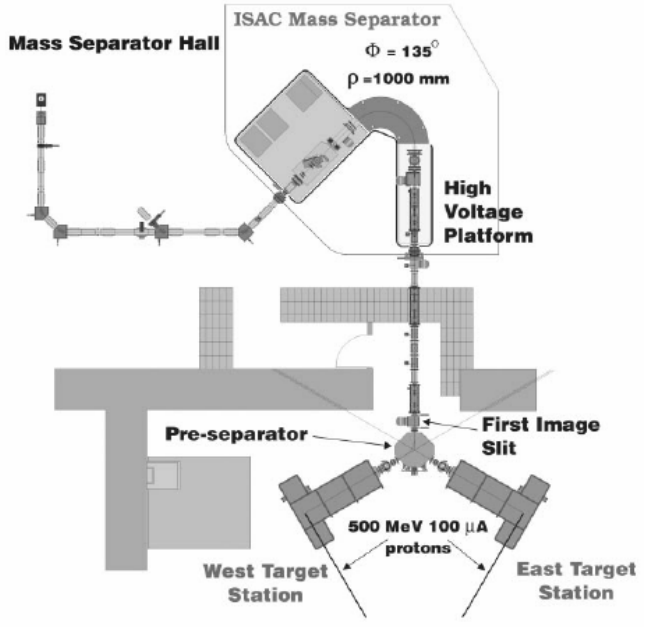

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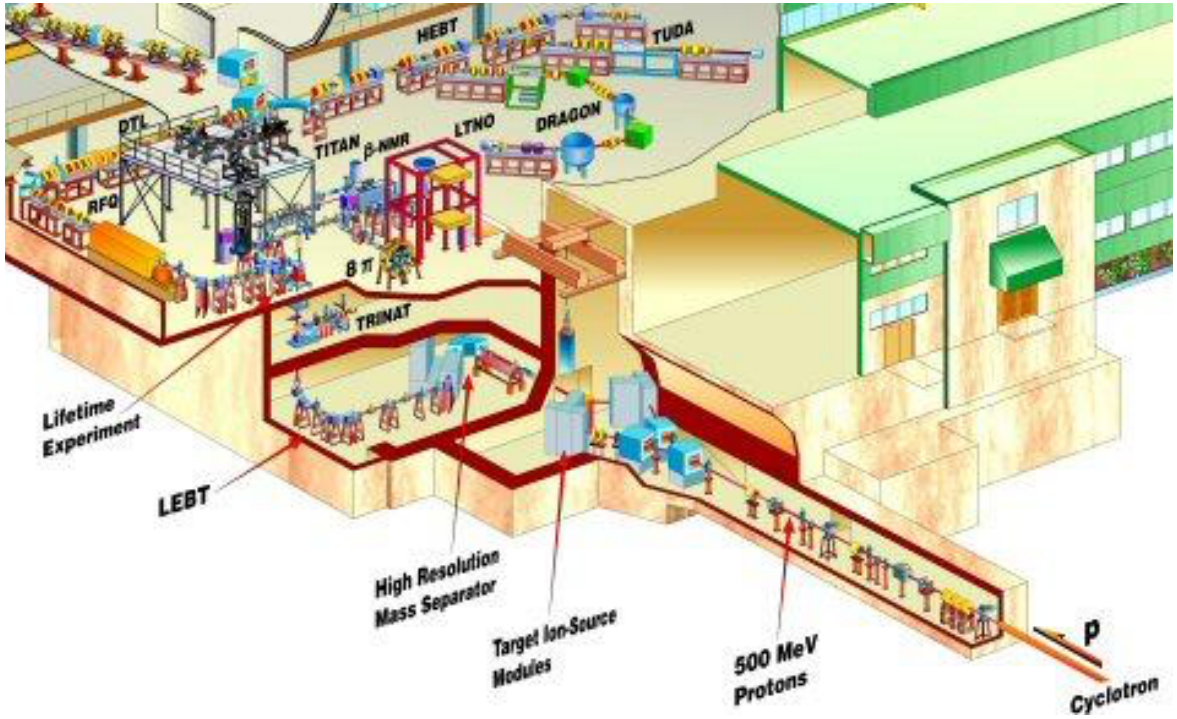

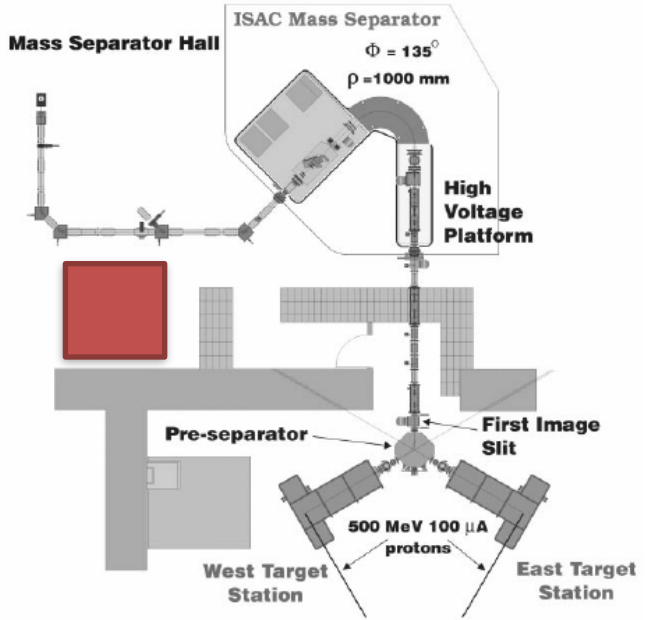

Considerations for ARIEL

Beam Properties:

High power BD (~100kW expected, more w/o ISOL target..500kW?) , bremsstrahlung on Au (+Al)
Low beam energy (30 MeV): wide A'/DM beam
Nuclear effects: issue to study
Have to stay close to BD for good acceptance -> backgrounds?
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Alternatives to a BD experiment?

Dedicated beam needed?
High-power BD needed?

Conclusion

- DM constitutes ~25% of the Universe's energy balance. LDM is a quite generic possibility and there are minimal models (which are also UV complete).
- With a rapidly "heavy" DM window closing, "light" DM searches are gaining a lot of interest.
- Dark sector experiments discussed at major labs equipped with electron machines: SLAC, Cornell, DESY, ELSA, MAMI/MESA, Frascati, KEK, …
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A Dark Matter beam at TRIUMF !

TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Thank you!
Merci!

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