TRIUMF

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

Opportunities for Dark Sector Searches with ARIEL

Luca Doria
TRIUMF & JGU-Mainz
(luca@triumf.ca / doria@uni-mainz.de)

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Outline

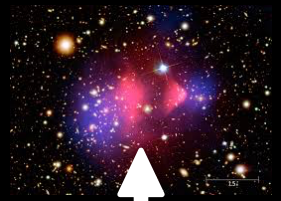
- Motivation

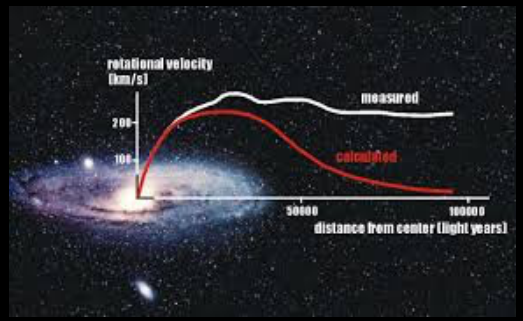
- Experimental Technique

- Proposed Experiments

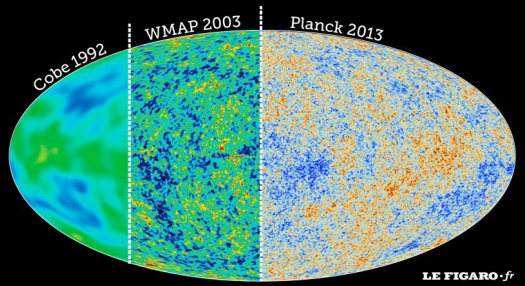
- Opportunities for ARIEL

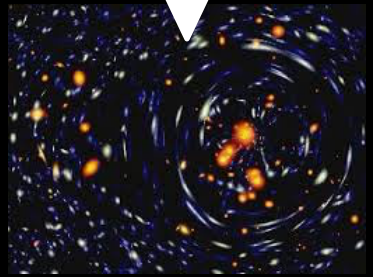
Physics Motivation



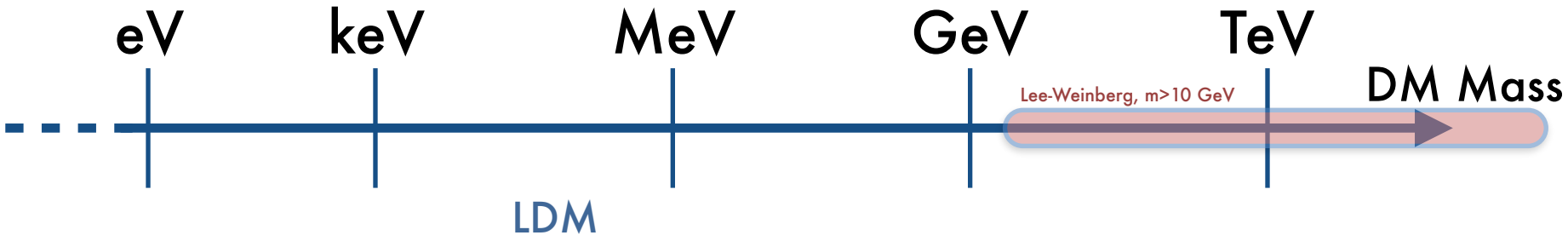


Dark Matter





(Light) Dark Matter



Visible Decays

Invisible Decays

(Light) Dark Matter

eV keV MeV GeV TeV DM Mass

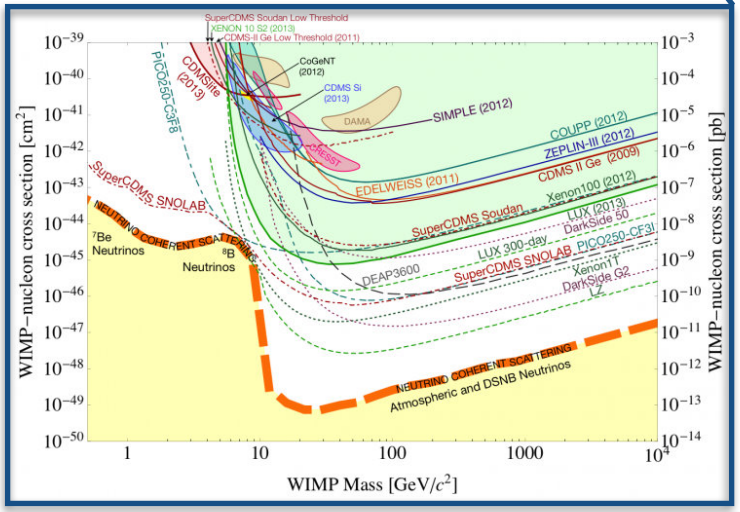
Lee-Weinberg, m>10 GeV

LDM

WIMPS

Visible Decays

Invisible Decays



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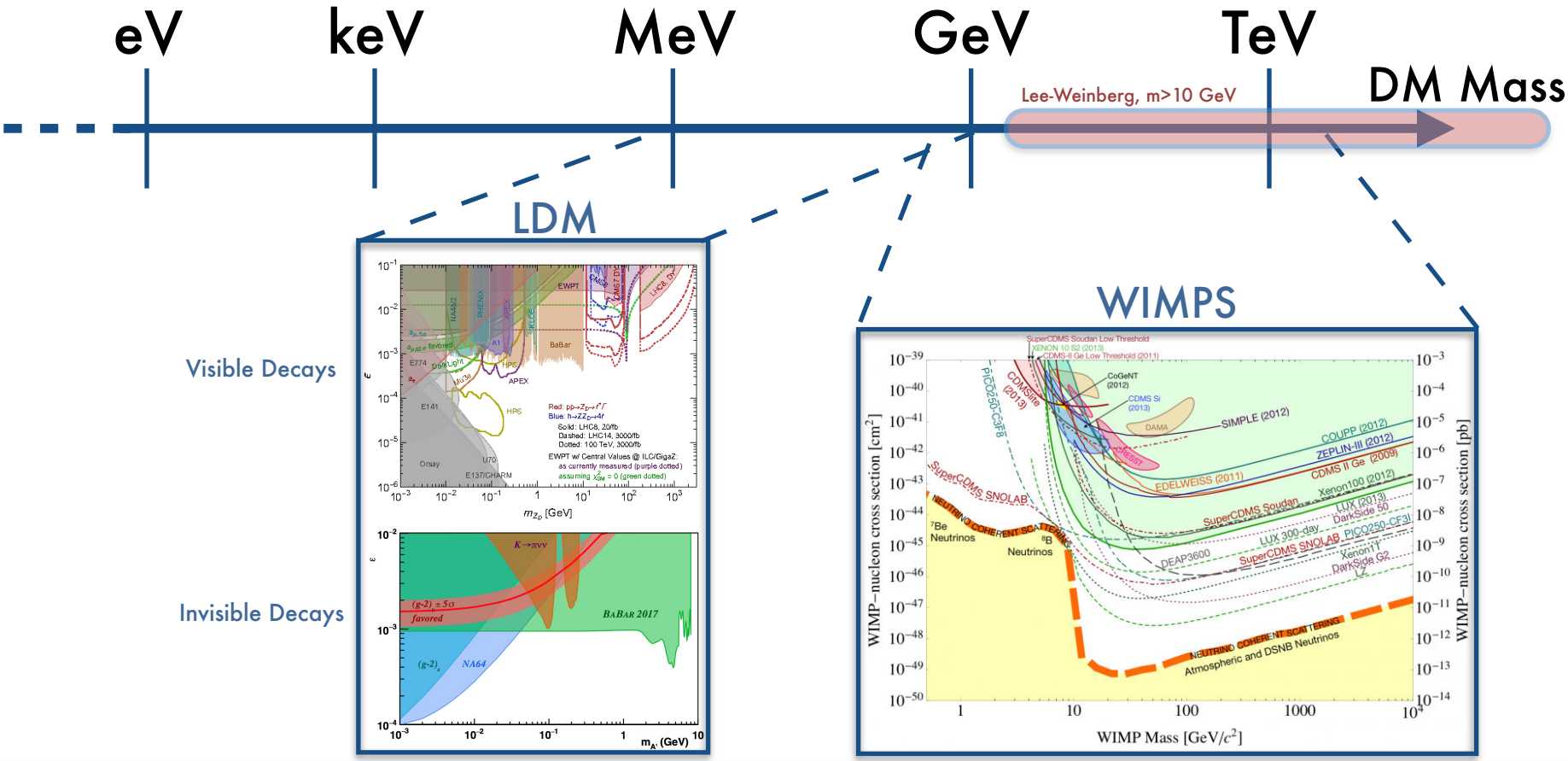
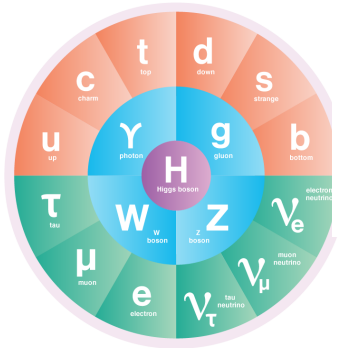
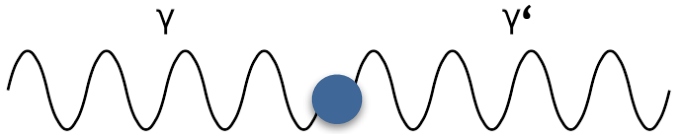


The Dark Sector





Different possible portals to the DS:
Scalar/vector particles, the Higgs, (heavy/sterile) neutrinos, axions.

Experimental benchmark scenario: minimal dark photon model

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

Mixing with SM

Fermion DM

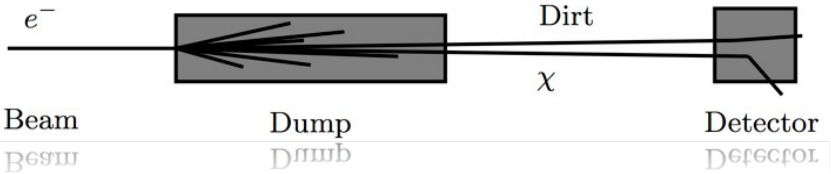
massive dark photon

4-parameter model

m_χ	DM mass
$m_{A'}$	Dark photon mass
$\alpha_D = \frac{g_D^2}{4\pi}$	DM coupling
ϵ_Y	SM coupling

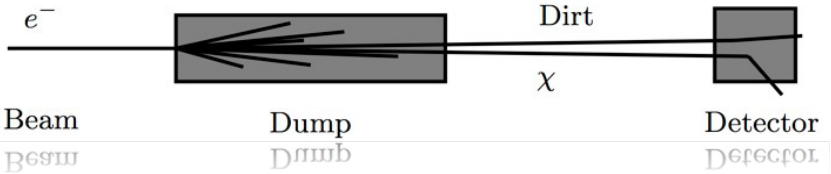
$$y = \epsilon^2 \alpha_D \left(\frac{m_\chi}{m_{\gamma'}}\right)^4 \qquad y \propto \langle \sigma v \rangle$$

Beam Dump (Invisible Decays)



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

Beam Dump (Invisible Decays)



Neutrino Experiments, Proton BD Experiments
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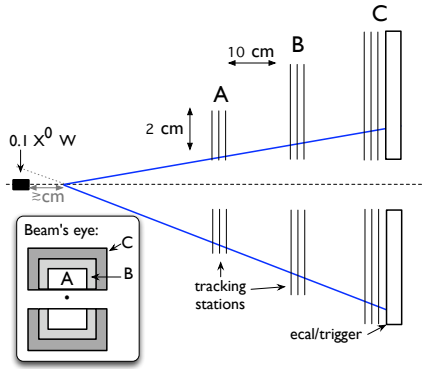
Thin/Thick Target + Vertexing (Visible Decays)

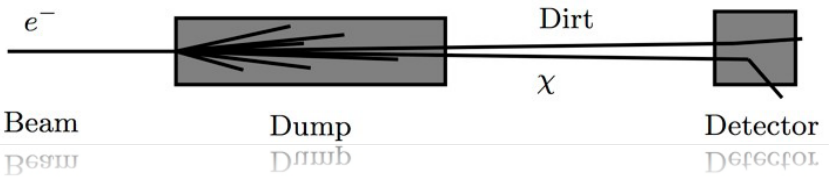


Intense Experimental Activity:

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

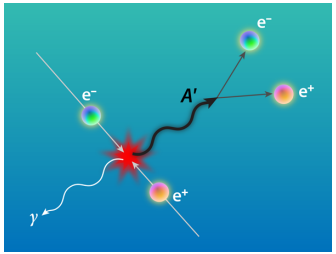
Accelerator-Based Approaches

Beam Dump (Invisible Decays)

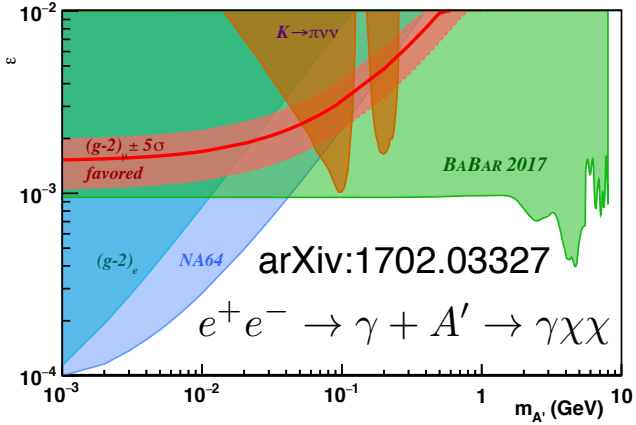


Neutrino Experiments, Proton BD Experiments
Possible future locations: JLab, MESA, ...
Re-analysis of old experiments

Collider (Visible/Invisible)



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



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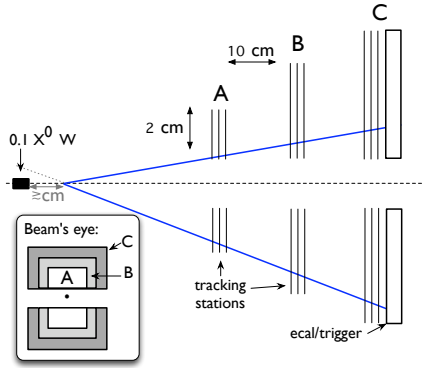

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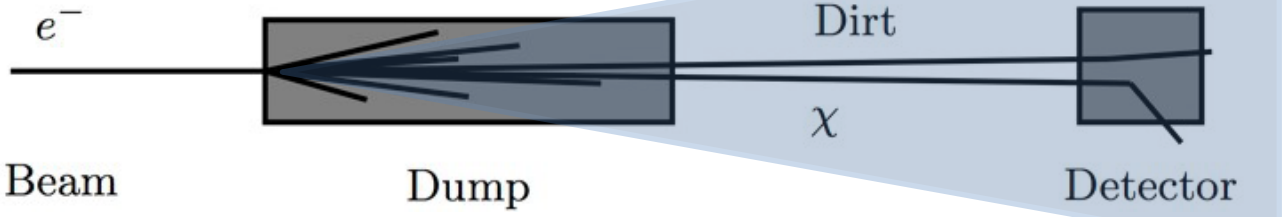
Beam-Dump Experiments

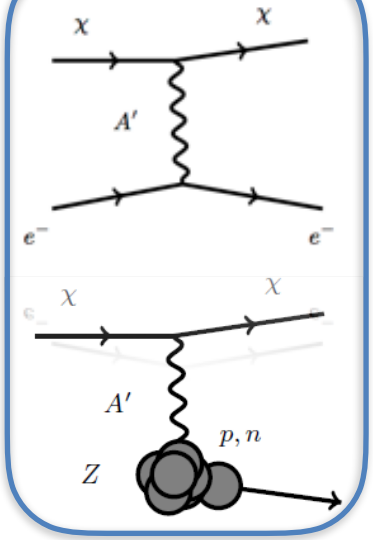
Bjorken et al., Phys. Rev. D80, 075018 (2009)

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

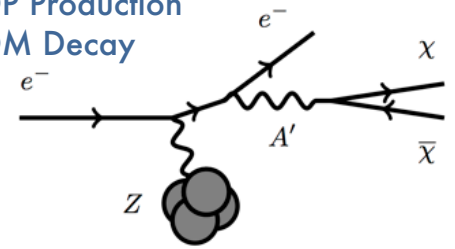
$$\theta_{RMS} \sim \frac{m_{A'}}{E_{beam}}$$



DM Detection



DP Production
DM Decay

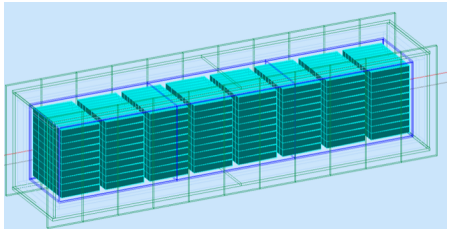


$$\frac{d\sigma}{dx} \approx \frac{8Z^2\alpha^3\epsilon^2 x}{m_{A'}^2}\left(1 + \frac{x^2}{3(1-x)}\right)\mathcal{L}og$$

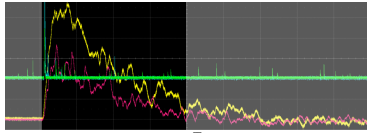
- Bremsstrahlung-like dark photon production.
- DM detection via re-scattering in the detector.
- Production and detection in the same experiment.
- Generic setup for dark sector particles.

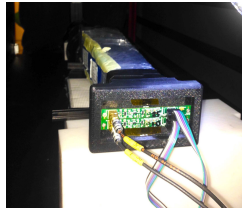
PROPOSED EXPERIMENTS

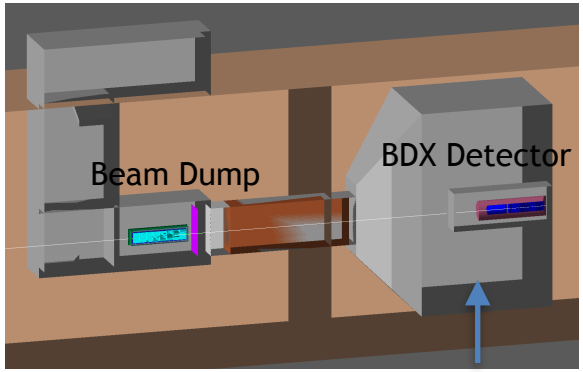
Proposed Detector:
820 CsI(Tl) BaBar EM Cal
Crystals: 32x5x5 cm
8 Modules, 10x10 crystals
SiPM readout
3m length, 0.5x0.5m CS



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







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

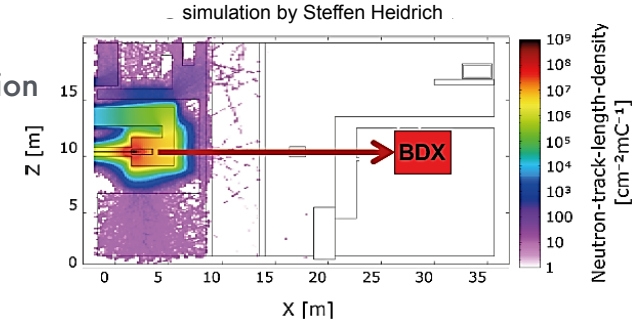
arXiv:1607.01390

Beam Dump

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

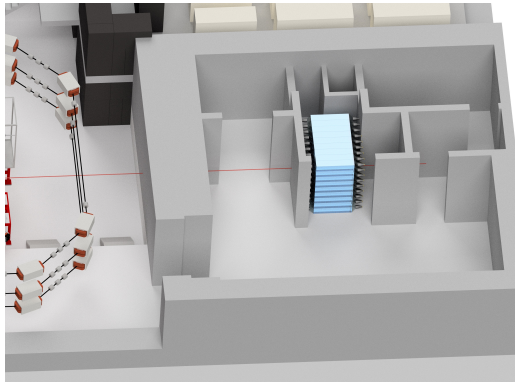
Experimental Area

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



Detector Concept:

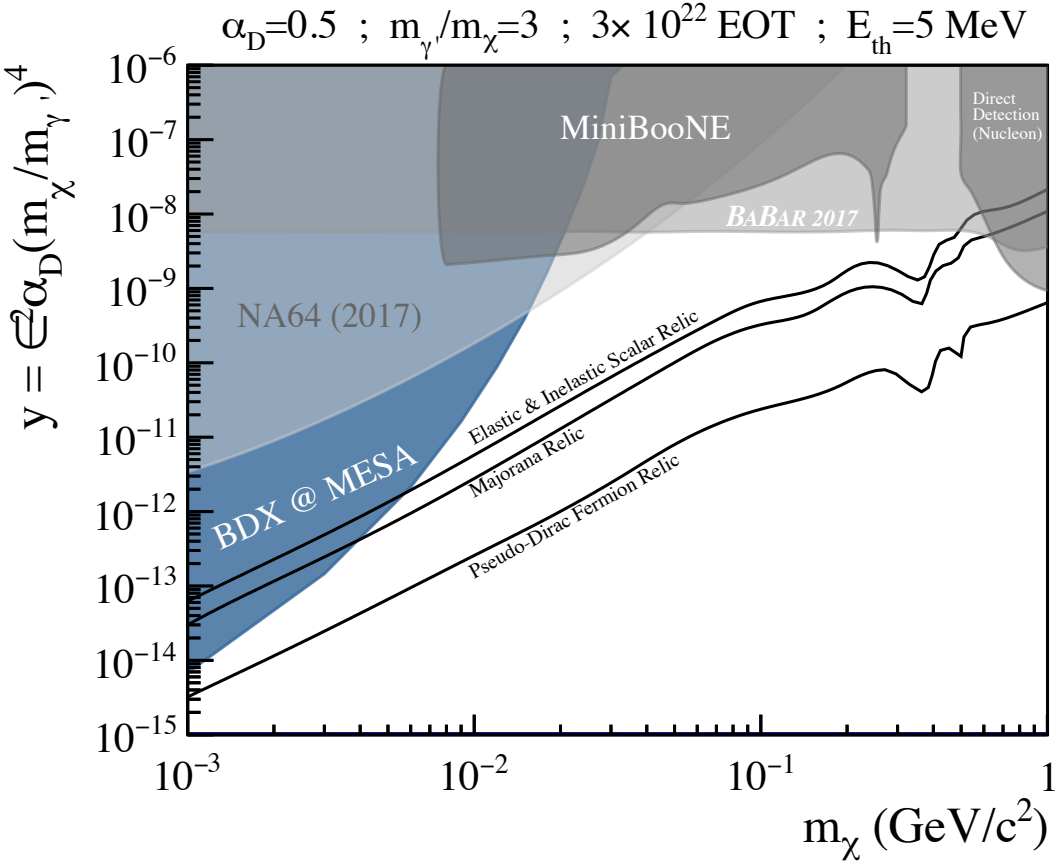
- 81 lead glass blocks
- 30x30x150cm each
- 5'' PMTs or SiPM readout
- Other crystals under study



Background Rejection

- Beam on/off
- Comics Veto
- Segmentation

BDX @ MESA



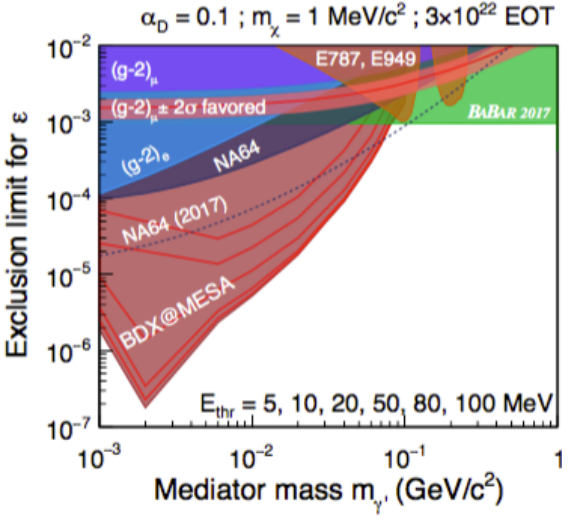
Simulation

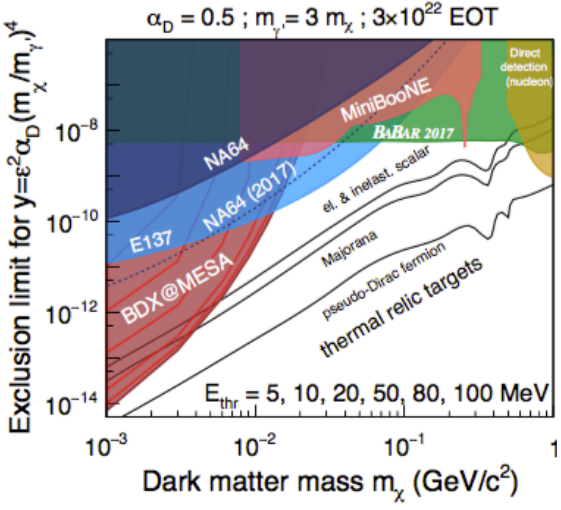
- GEANT4
  - Experimental Halls
  - Beam Dump
  - Detector
  - DM/e DM/p interaction
- MadGraph-4
  - Dark Photon Production
  - Input to GEANT4

Results

- Competitive sensitivity
  - Better than BDX@JLAB but..
  - ...lower mass reach
- Reaches the thermal targets

Detector Threshold

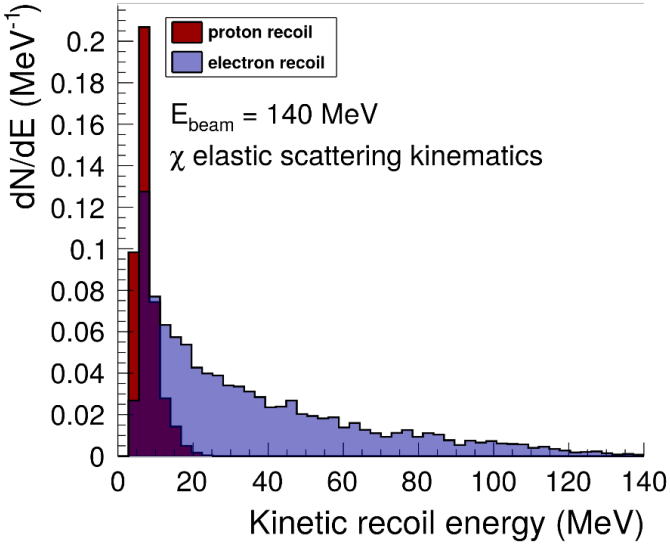




- 10 MeV threshold
  - Still good sensitivity
  - Rejects most backgrounds

- e/p recoils
  - ER most promising
  - need ER/NR discrimination?

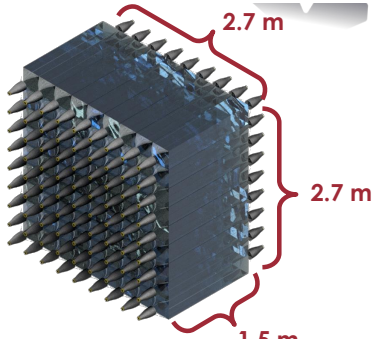
Nucleon / Electron Recoil



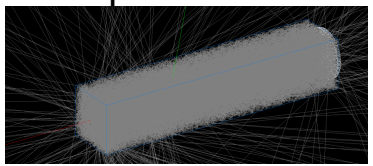
Preliminary Detector Concept

1) Lead Glass Blocks –> Cherenkov Calorimeter –> Directionality + no NR
2) Scintillation Crystals
5'' Photomultipliers available (move to SiPMs ?)
Materials available:

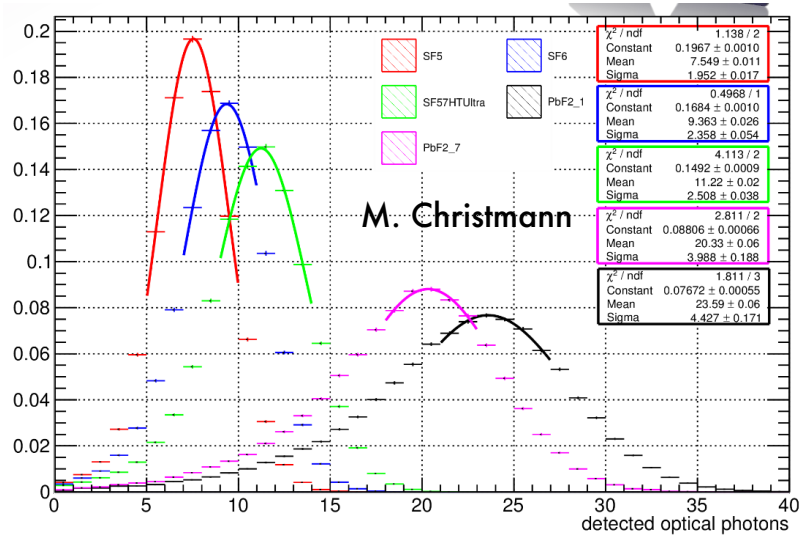
	X [mm]	Y [mm]	Z [mm]	Density [g/cm³]
SF 5	70	55	160	4.07
SF 6	30	55	160	5.18
SF 57 HTultra	40	55 (180)	160	5.51
BGO	21	21	230	7.13
PbF_2 (1)	Frustum of a pyramid		150	7.77
PbF_2 (7)	(30x30 / 26x26)		185.4	7.77



G4 Optical Simulation



\+ Quantum Efficiency
Refraction Index
Emission spectra

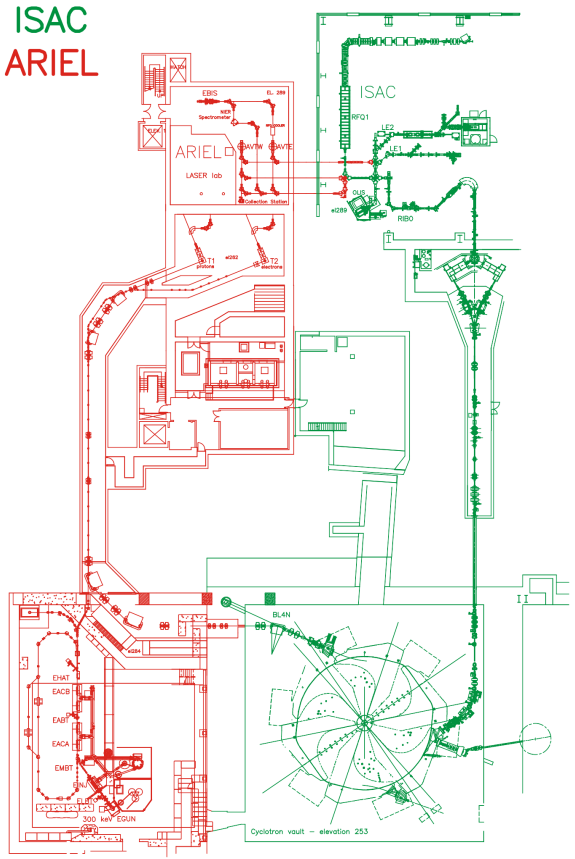


THE ARIEL CASE

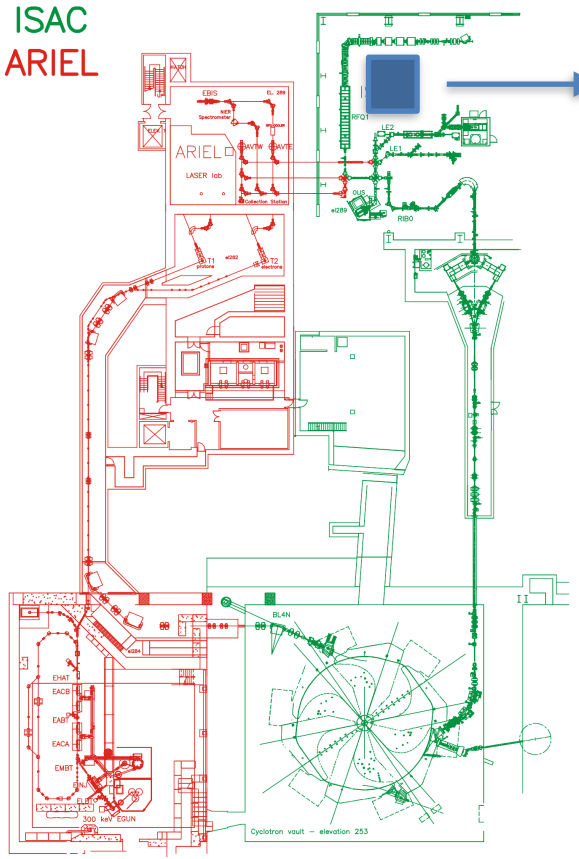
- Where to locate the experiment?
- Sensitivity?
- Integration into the existing infrastructure?
- Detector technology?

- Full Simulation needed (complex, time consuming for different scenarios)
- For now: fast calculation implemented in C++ code (starting from Mathematica code from P. Achenbach, JGU Mainz).
  - Implement Bjorken et al. PRD 80 075018 (2009) formulas.
  - Parameterized nuclear form factors and other small approximations.
  - Optimistic scaling of exclusion limits with DM mass but highest sensitivity about right.

Detector Location



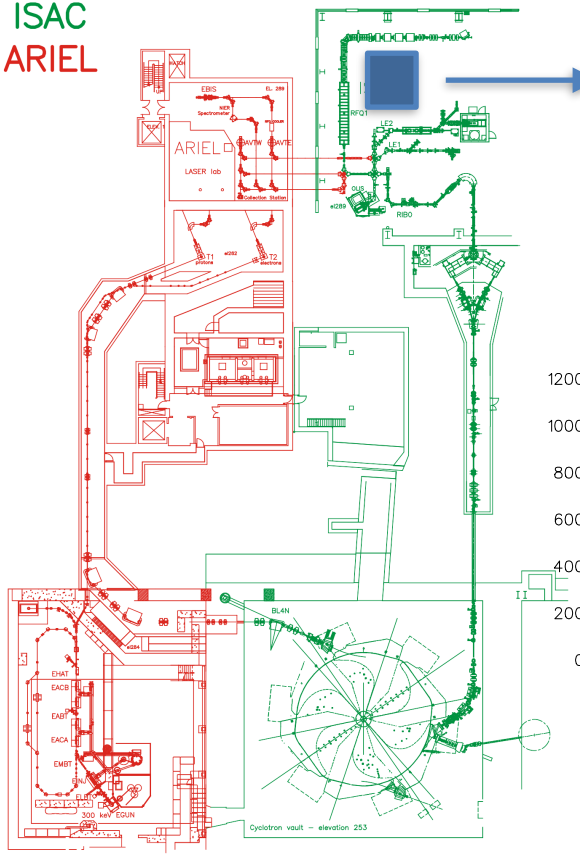
Detector Location



Option 1
- ARIEL targets + Separator room.
- Parasitic operation possible.
- Backgrounds from ISAC targets?
- Enough space? –> Room available.
- Distance: ~20m

Detector Location

ISAC
ARIEL



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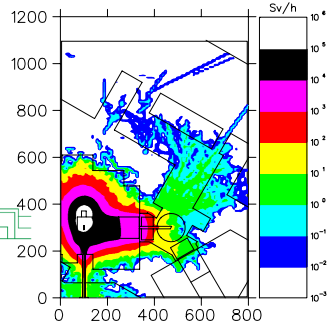
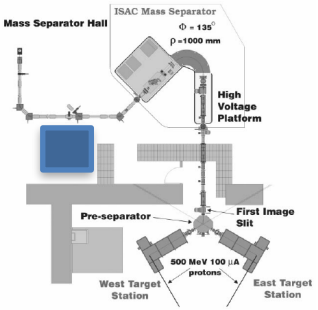
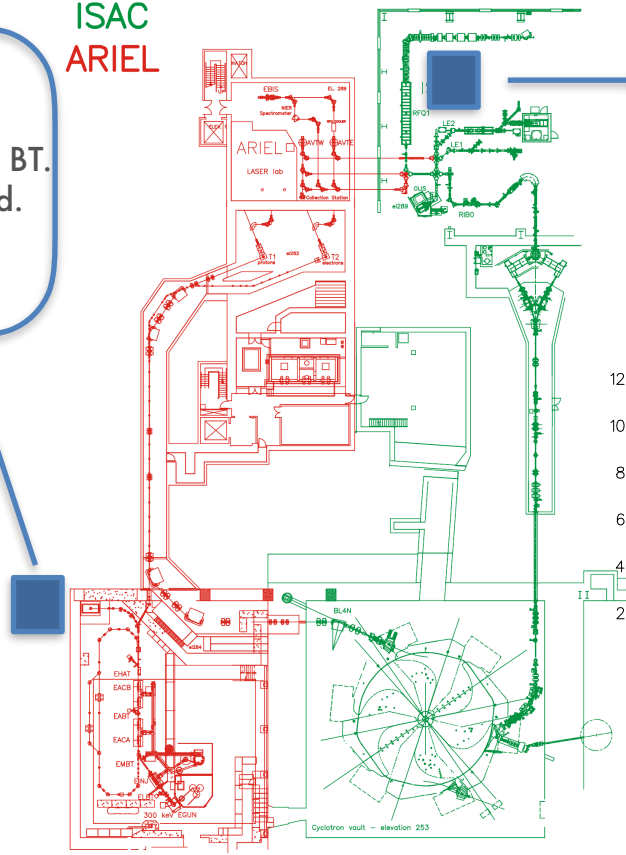




Detector Location

Option 2
- ARIEL beam-dump
- Less beam time available + dedicated BT.
- Cavity still present? If not, new needed.
- Distance: ~3m

ISAC
ARIEL



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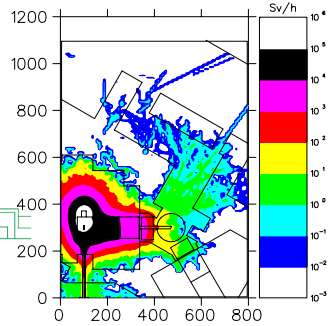
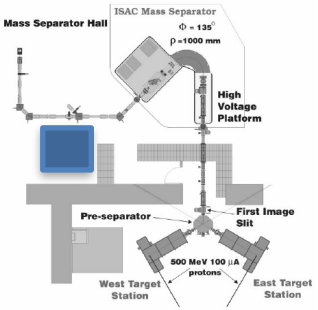




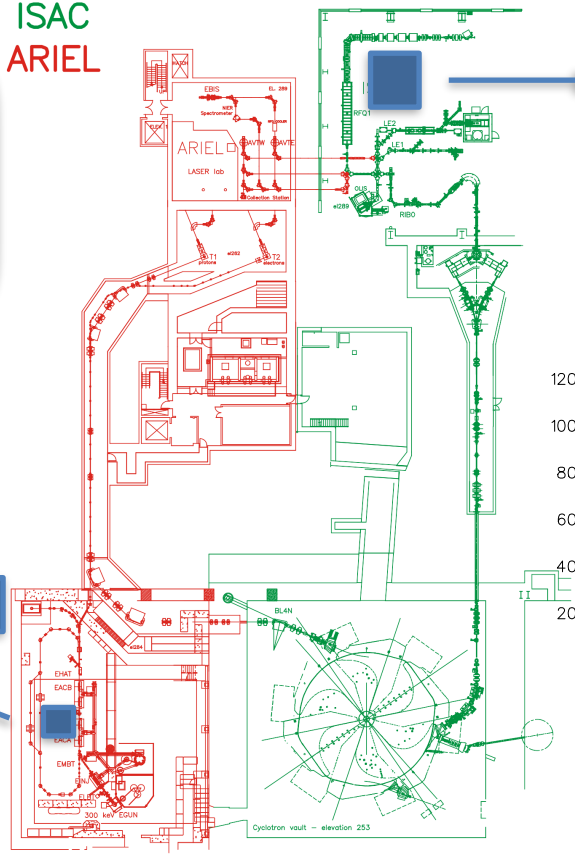
Detector Location

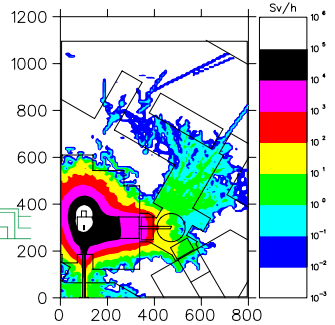
ISAC
ARIEL

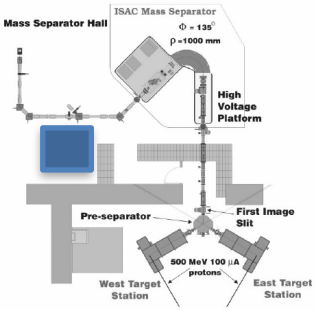
Option 2
- ARIEL beam-dump
- Less beam time available + dedicated BT.
- Cavity still present? If not, new needed.
- Distance: ~3m

Option 1
- ARIEL targets + Separator room.
- Parasitic operation possible.
- Backgrounds from ISAC targets?
- Enough space? –> Room available.
- Distance: ~20m

Option 3
- Dedicated beam line in E-Hall
- Dedicated BT or split the beam.
- Less beam time available.
- Distance: ~1.5m



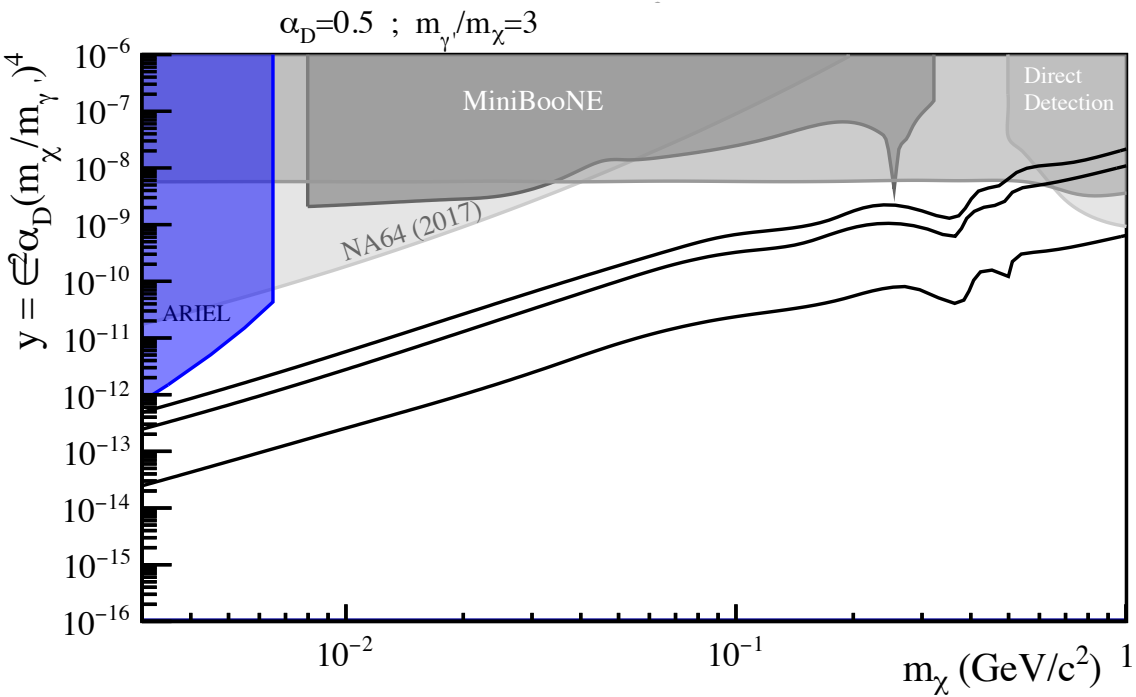




Option1 (ARIEL Target + Separator Room)

Beam
- E= 35MeV, 3mA
- 5000 h/year
- –> $3x10^{23}$ EOT

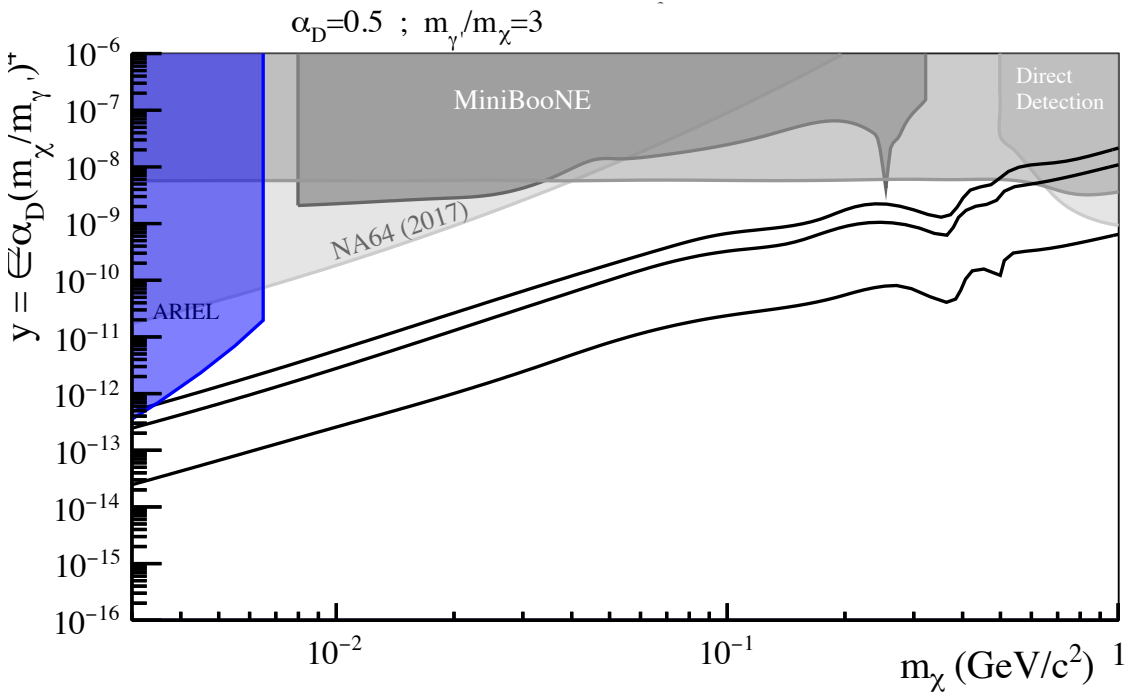
Detector
- 2x2x2 m
- 20m distance
- avg inorg. crystal density 4g/cm3
- 10 MeV threshold



Option2 (ARIEL beam-dump in eHall)

Beam
- E= 35MeV, 3mA
- 5000 h/year
- –> 3×10^{23} EOT / 10.0

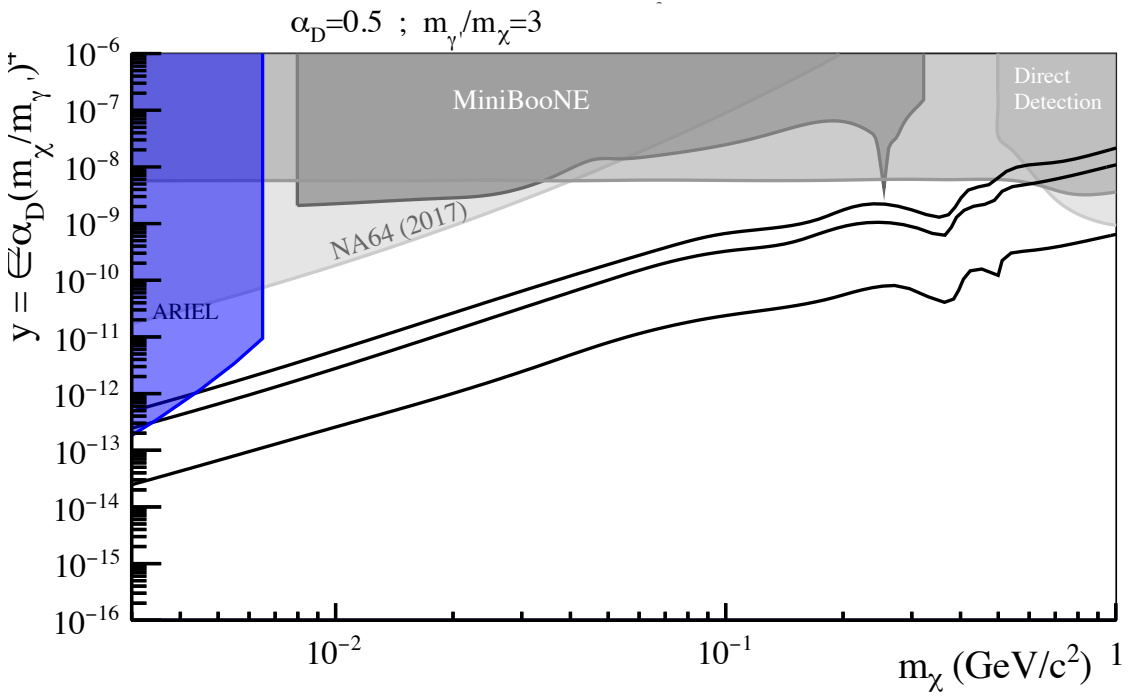
Detector
- 2x2x2 m
- 3m distance
- avg inorg. crystal density 4g/cm3
- 10 MeV threshold



Option3 (Dedicated beamline)

Beam
- E= 35MeV, 3mA
- 5000 h/year
- –> 3x10^{23} EOT * 50% duty cycle

Detector
- 2x2x2 m
- 1.5m distance
- avg inorg. crystal density 4g/cm3
- 10 MeV threshold



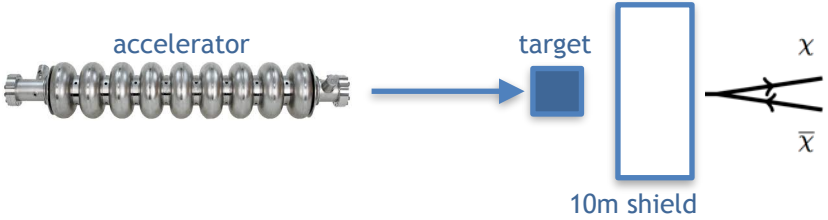
Option X

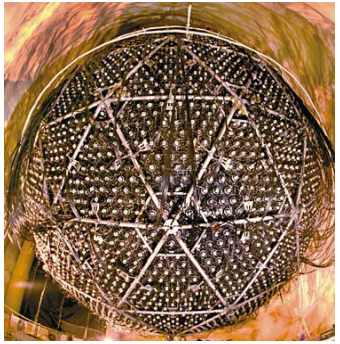
E.Izaguirre, G. Krnjaic, M. Pospelov PRD 92 095014 (2015)

Do not build a detector at a good accelerator, but build an accelerator close to a good detector.

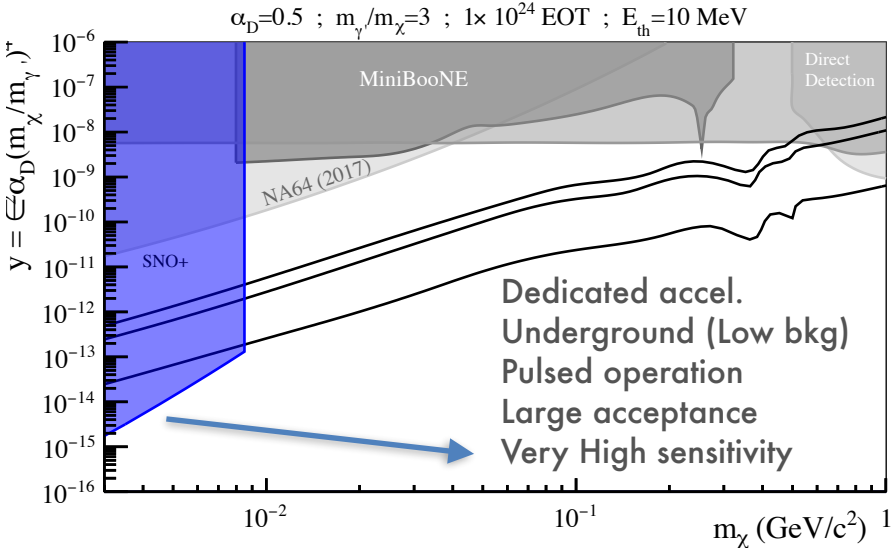
Beam
- E= 100MeV
- 3×10^{24} EOT

Detector
- 12m sphere
- 10m distance
- 0.9 g/cm^3 (~liquid scint.)
- 10 MeV threshold (SNO+ has 200keV)





The SNO+ Detector @ SNOLab



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
Have to stay close to BD for good acceptance -> backgrounds?
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Tracking calorimeter / high segmentation / Noble liquid detector / .. ?
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Other:

Complex logistics: where to place the detector (separtor room, new cave, new beamline, …)?
Enough space in the separator room?
Radiation levels low enough?

Conclusion

- 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, …
- BD-type experiments have the potential to explore unique parameter regions.
- An opportunity for the TRIUMF beams (protons could also be an option…)
- Full simulation study needed: beam dump + detector technology

TRIUMF

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

Thank you!
Merci!

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