Direct detection of dark matter

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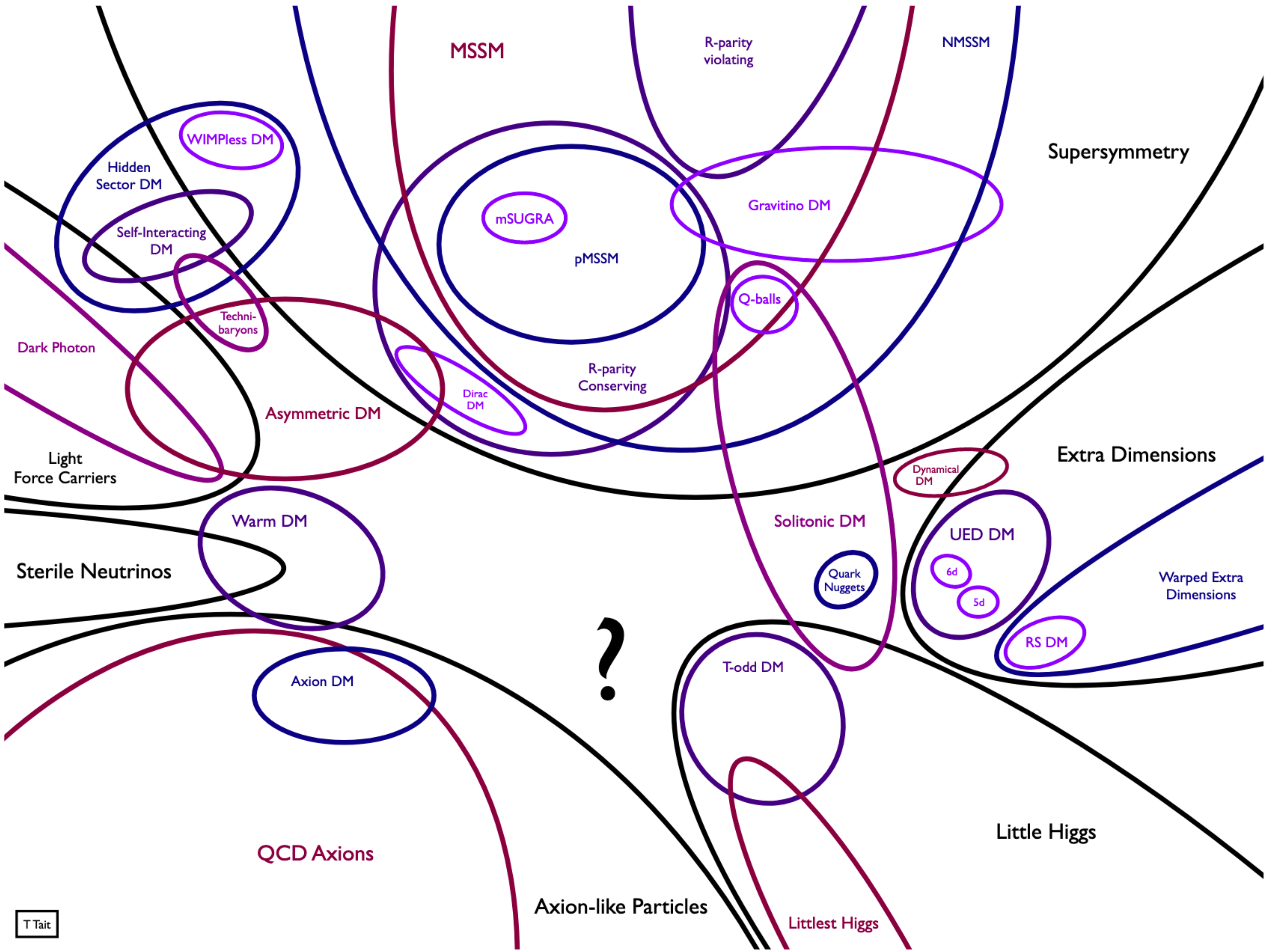
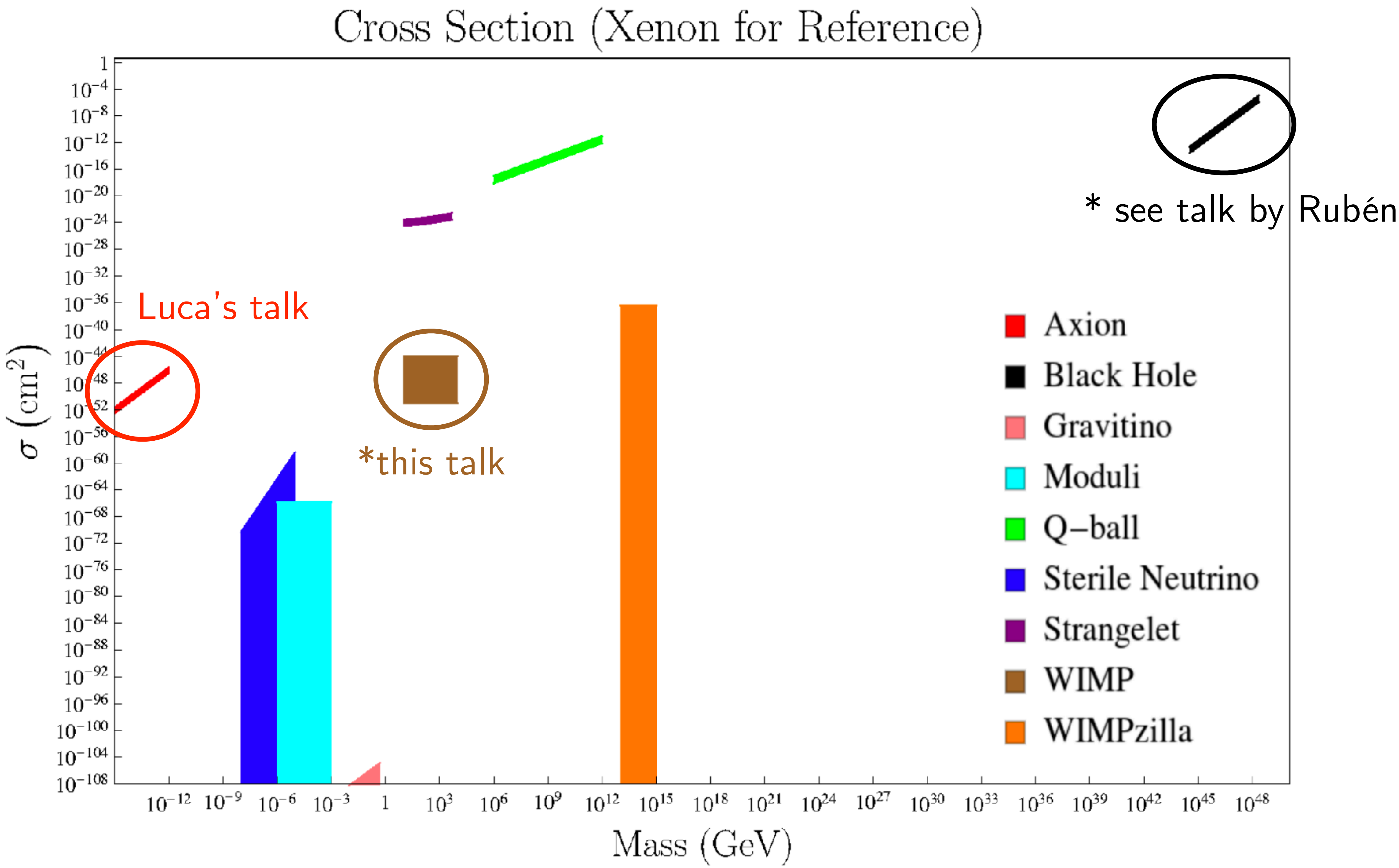
DM theories


MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
mSUGRA
pMSSM
Gravitino DM
Q-balls
R-parity Conserving
Dirac DM
Dark Photon
Asymmetric DM
Light Force Carriers
Extra Dimensions
Dynamical DM
Warm DM
Solitonic DM
UED DM
Sterile Neutrinos
Quark Nuggets
6d
5d
Warped Extra Dimensions
RS DM
?
T-odd DM
Axion DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs
T Tait

DM candidates

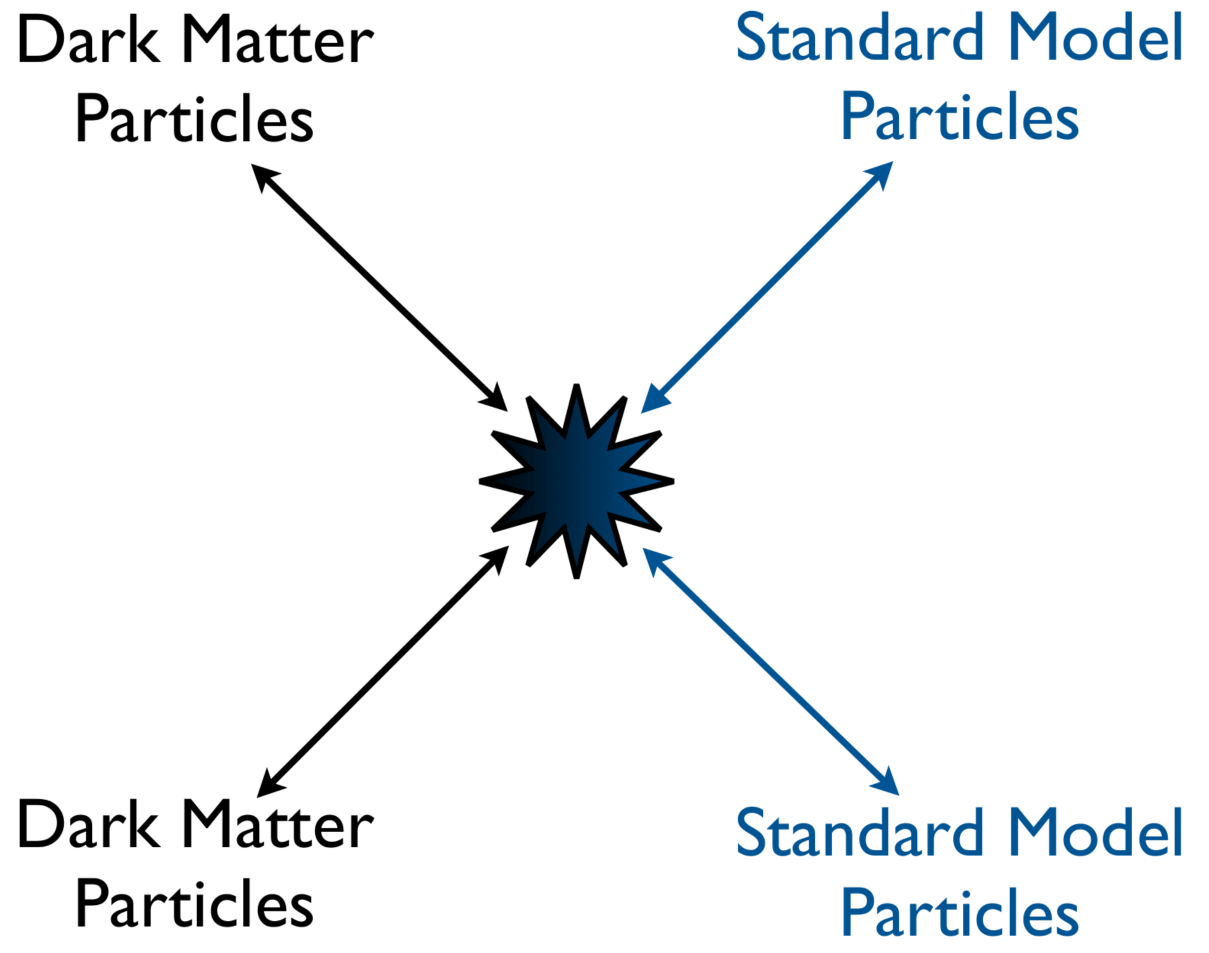


Credit: Snowmass-2013 CF 3, 1310.8642

DM detection

Production

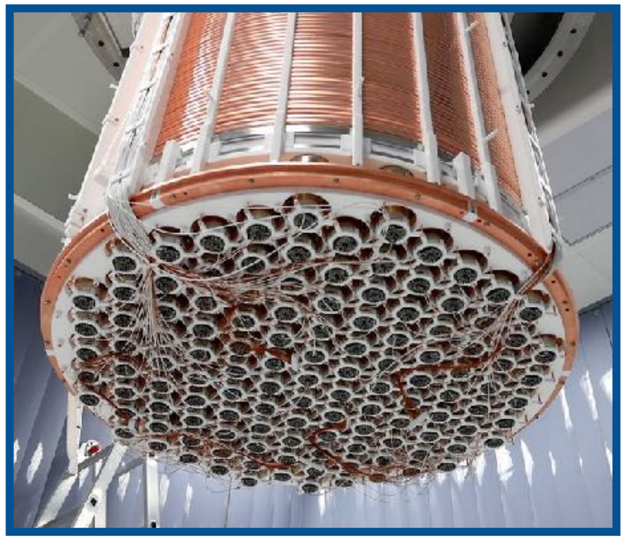
time ←



time ↑ **Scattering**

*this talk

Direct detection



→ time

Annihilation

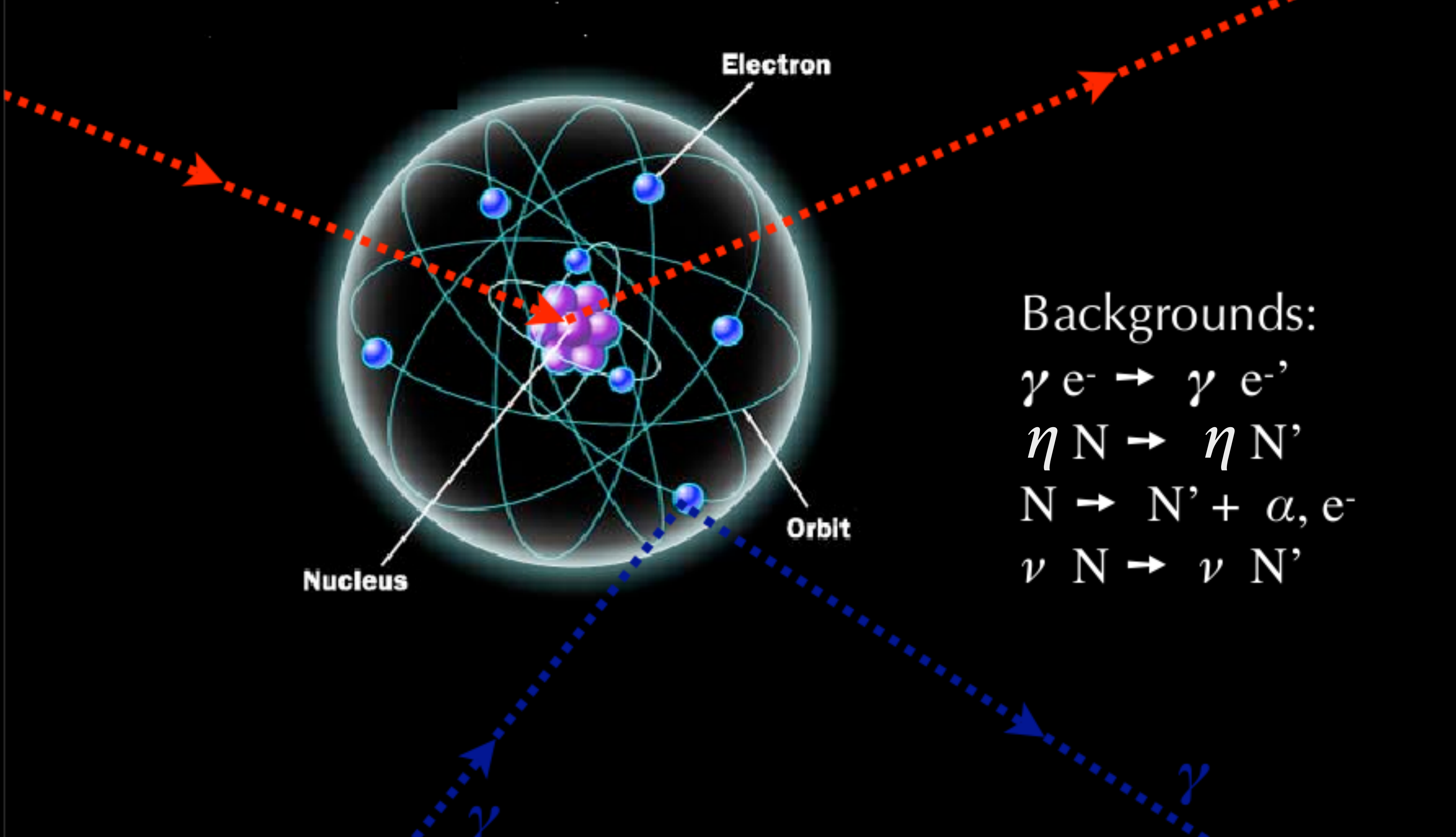
Indirect detection

* see talks by Mattia and Rubén

Direct detection

Signal: $\chi\, N \rightarrow \chi\, N$

- DM mass range: GeV — TeV
- Isothermal velocity distribution: $v_0 \sim 220$ km/s
- Nuclear recoil (NR) vs. electronic recoil (ER)



Backgrounds:

$\gamma\, e^- \rightarrow \gamma\, e^{-\prime}$

$\eta\, N \rightarrow \eta\, N'$

$N \rightarrow N' + \alpha, e^-$

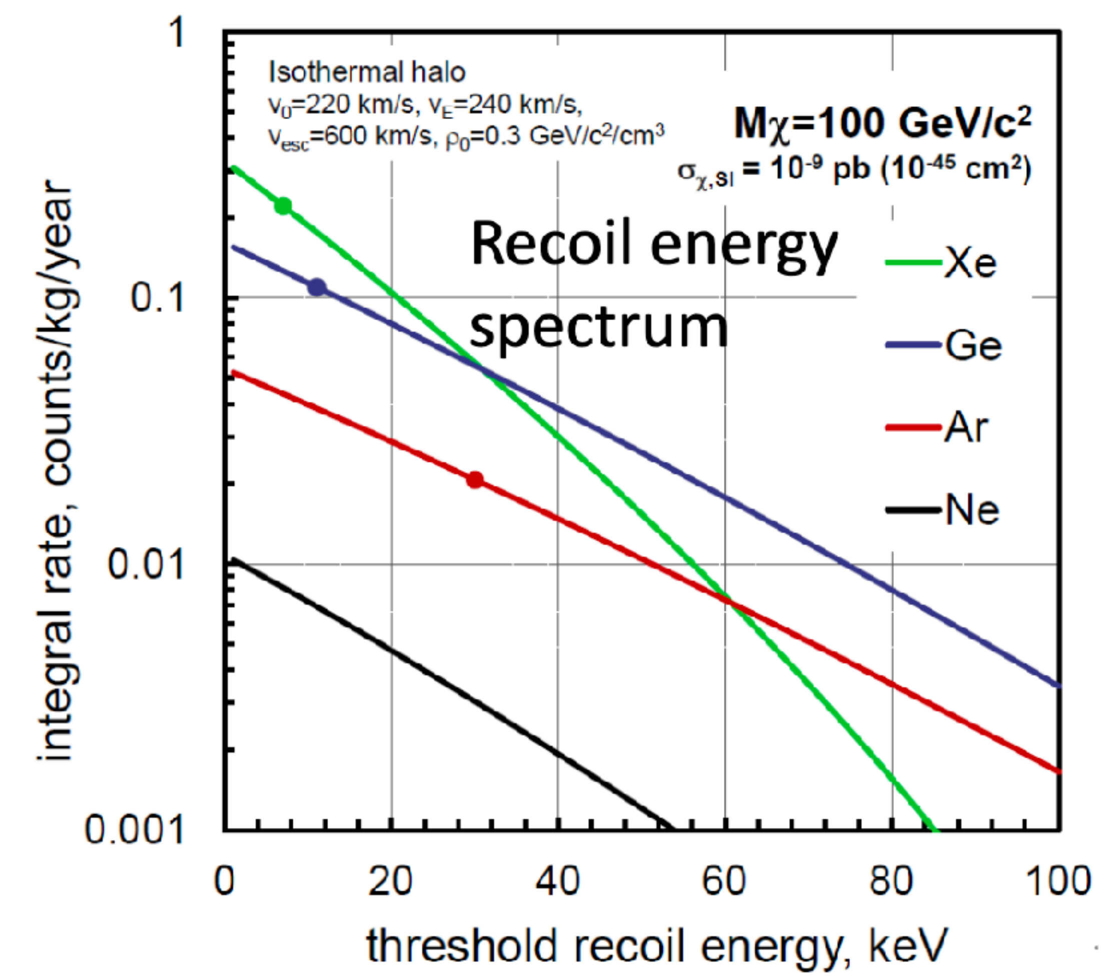
$\nu\, N \rightarrow \nu\, N'$

DM signals

- Scattering cross section on nuclei:

$$\frac{dR}{dE_{\rm nr}} = \frac{\rho_0 M}{m_N m_\chi} \int_{v_{\rm min}}^{v_{\rm esc}} v f(v) \frac{d\sigma}{dE_{\rm nr}}\, dv.$$

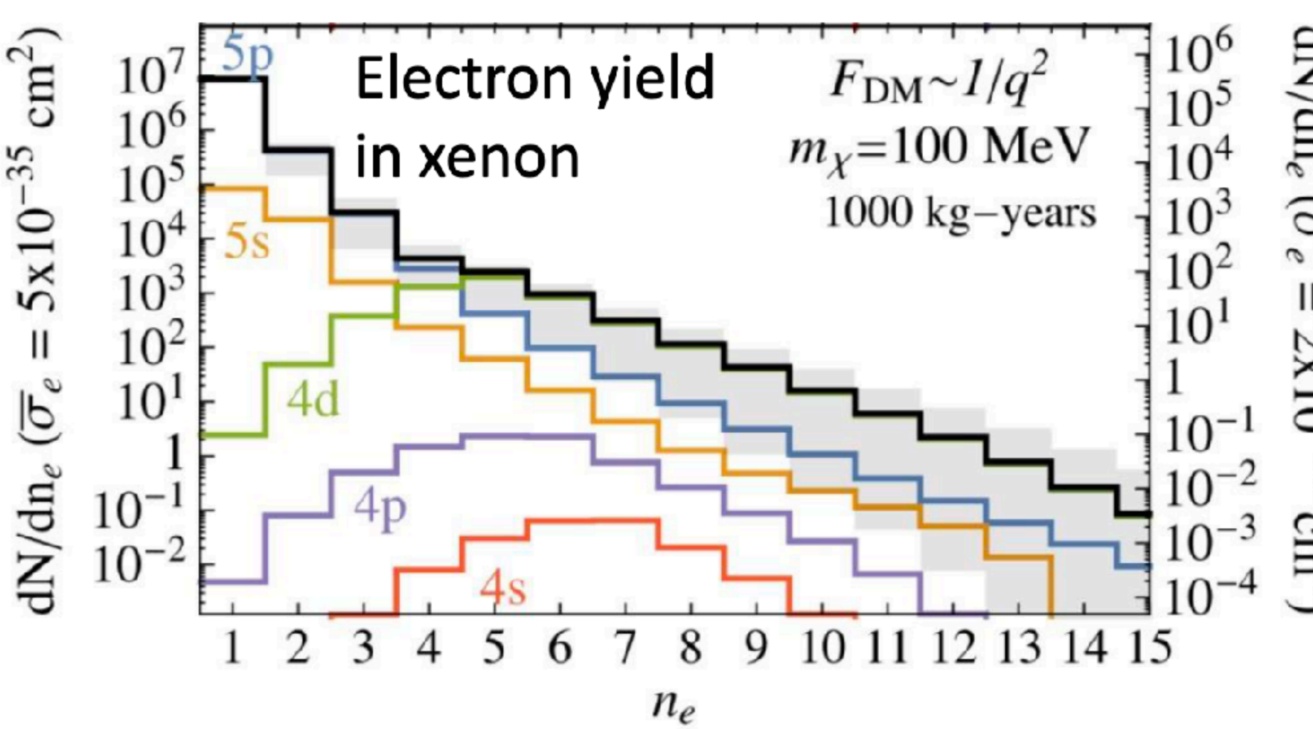
$$\frac{d\sigma}{dE_{\rm nr}} = \frac{m_N}{2v^2\mu^2}\left(\sigma_{SI}F_{SI}^2(E_{\rm nr}) + \sigma_{SD}F_{SD}^2(E_{\rm nr})\right)$$



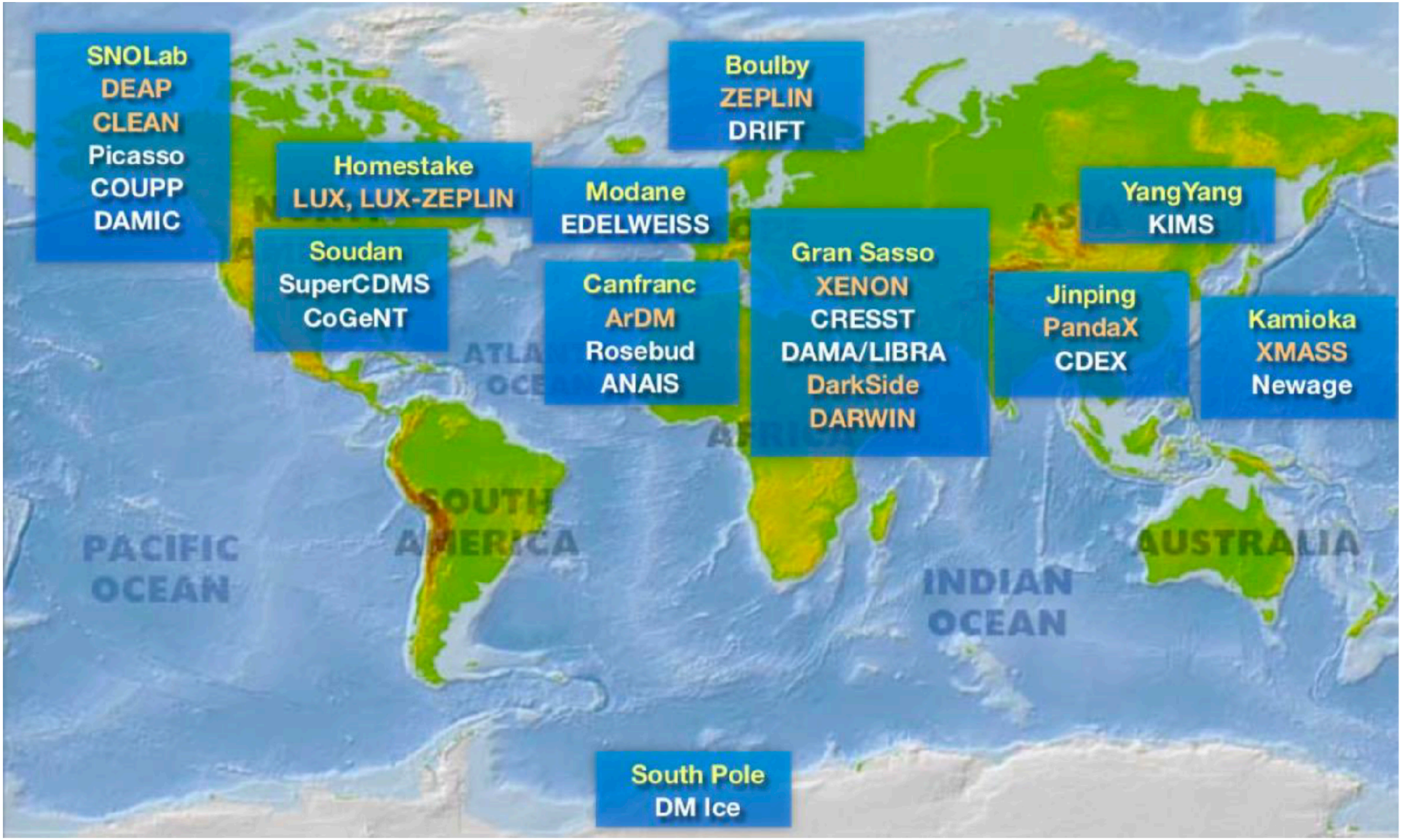
- Scattering cross section on electrons

$$\frac{d\langle\sigma_{\rm ion}^{nl}v\rangle}{d\ln E_{\rm er}} = \frac{\overline{\sigma}_e}{8\,\mu_{\chi e}^2}\int dq\, q\, |f_{\rm ion}^{nl}(k',q)|^2\, |F_{\rm DM}(q)|^2\, \eta(v_{\rm min})$$

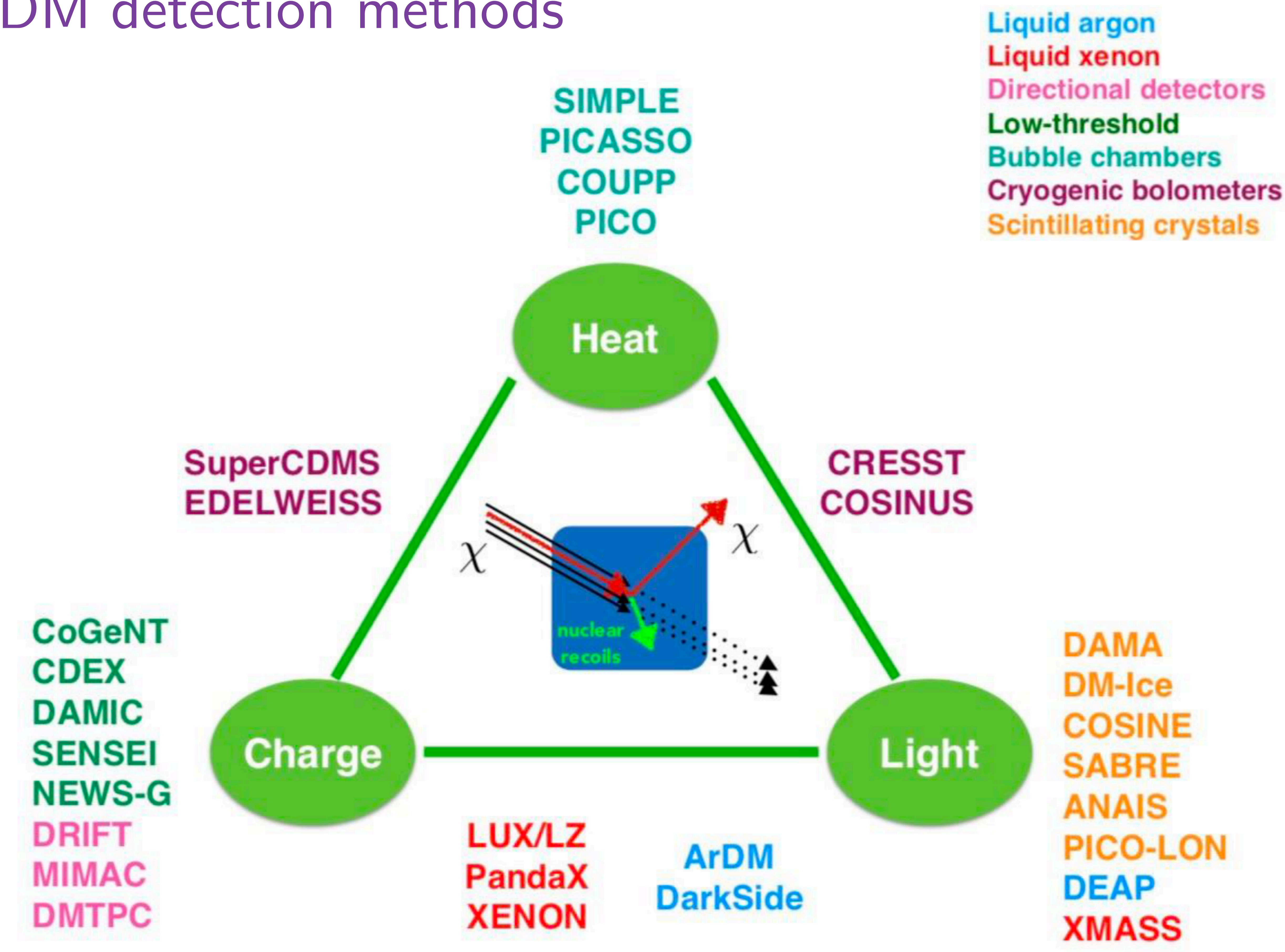
$$\frac{dR}{d\ln E_{\rm er}} = N_T \frac{\rho_\chi}{m_\chi}\sum_{nl}\frac{d\langle\sigma_{\rm ion}^{nl}v\rangle}{d\ln E_{\rm er}}$$



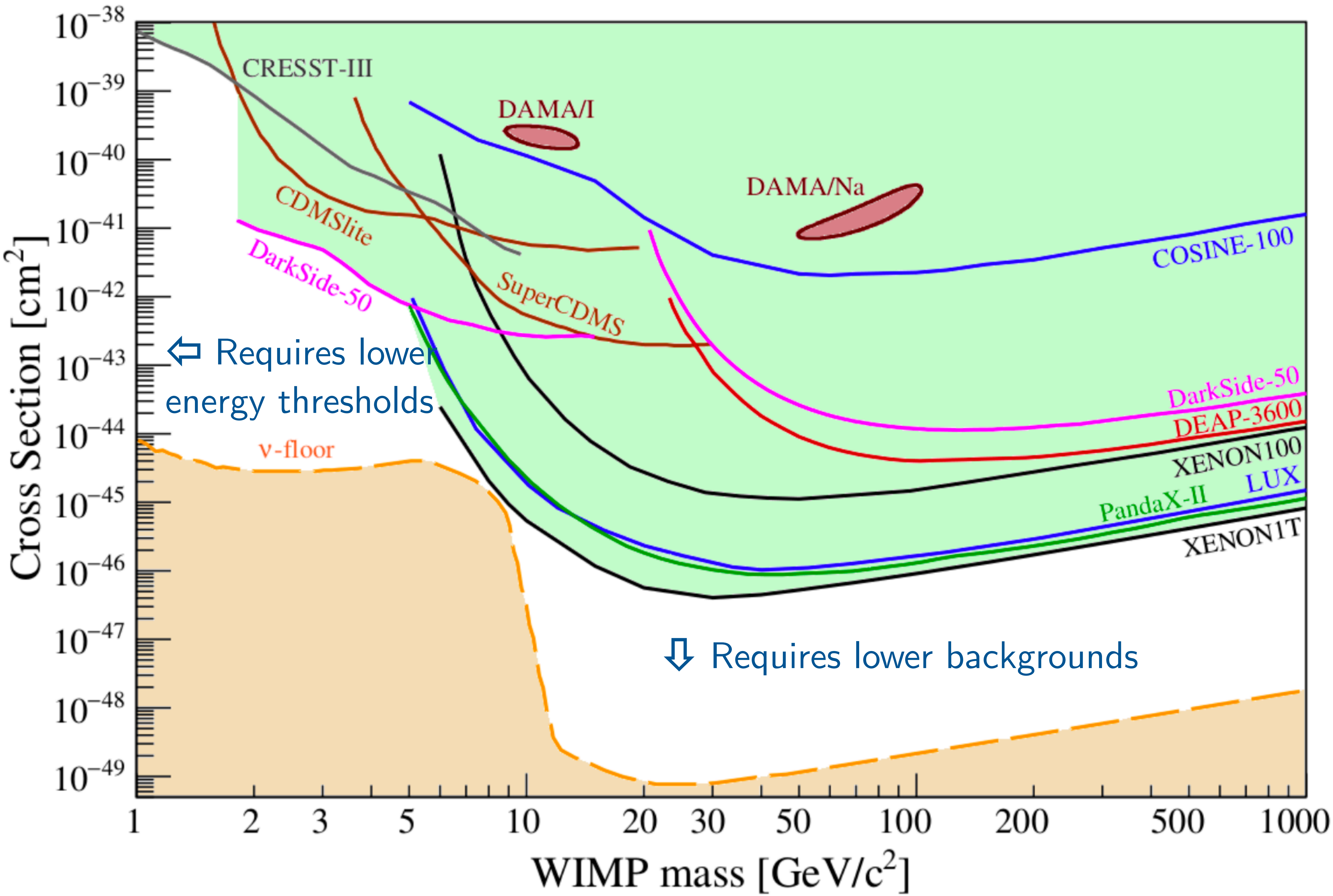
DM experiments worldwide



DM detection methods

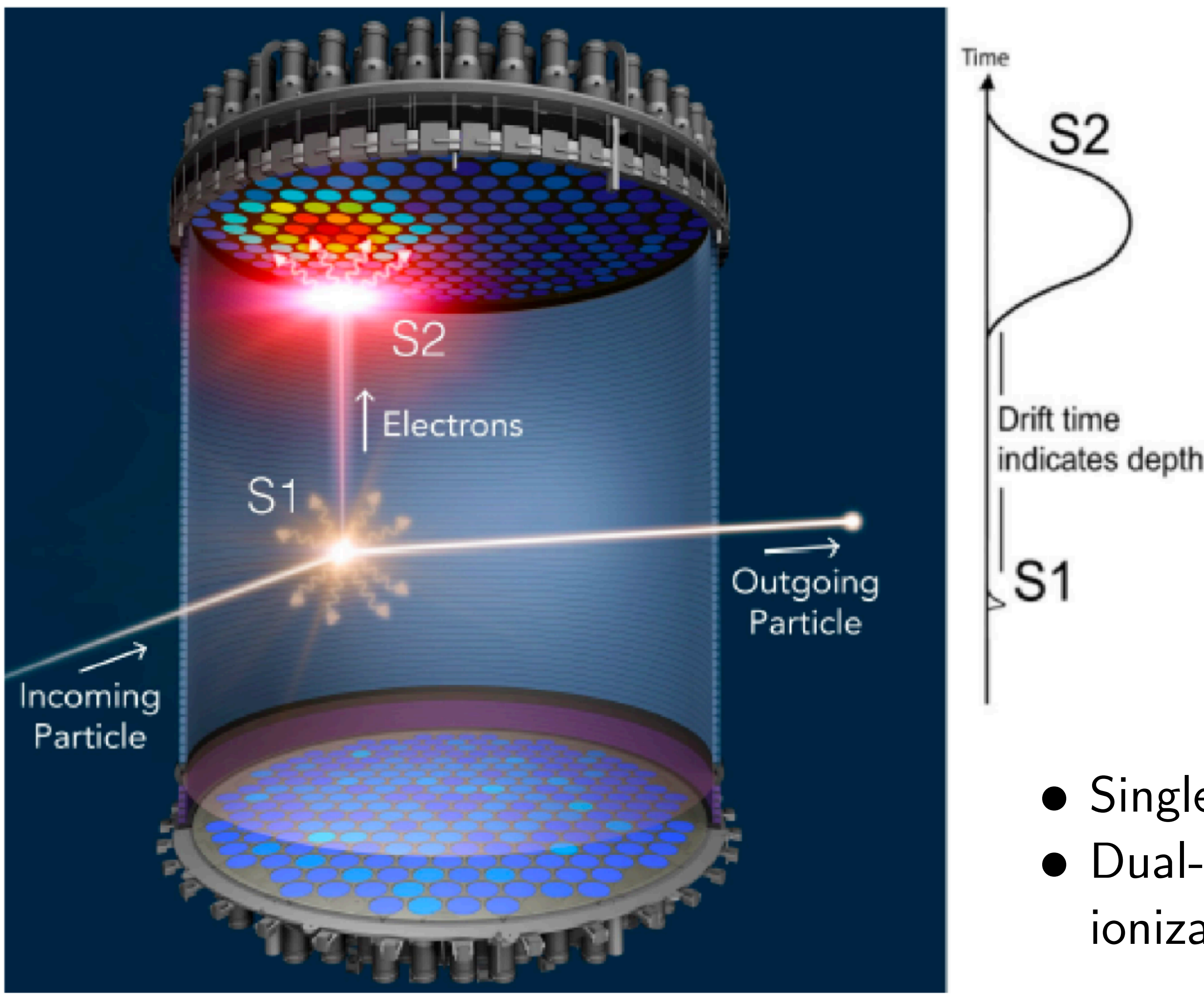


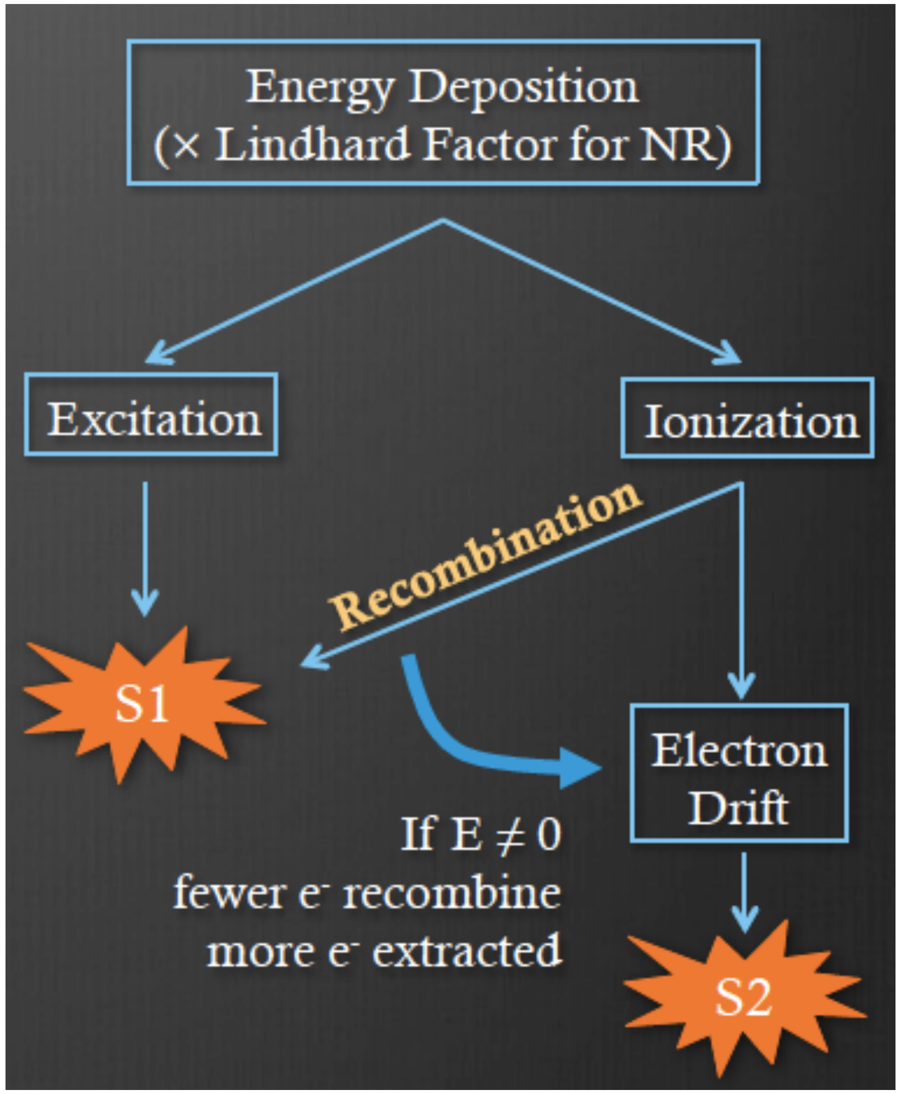
Current constraints



Noble liquid TPCs

- Dense and homogeneous target (e.g. LXe or LAr)
- Self-shielding
- High light and charge yields

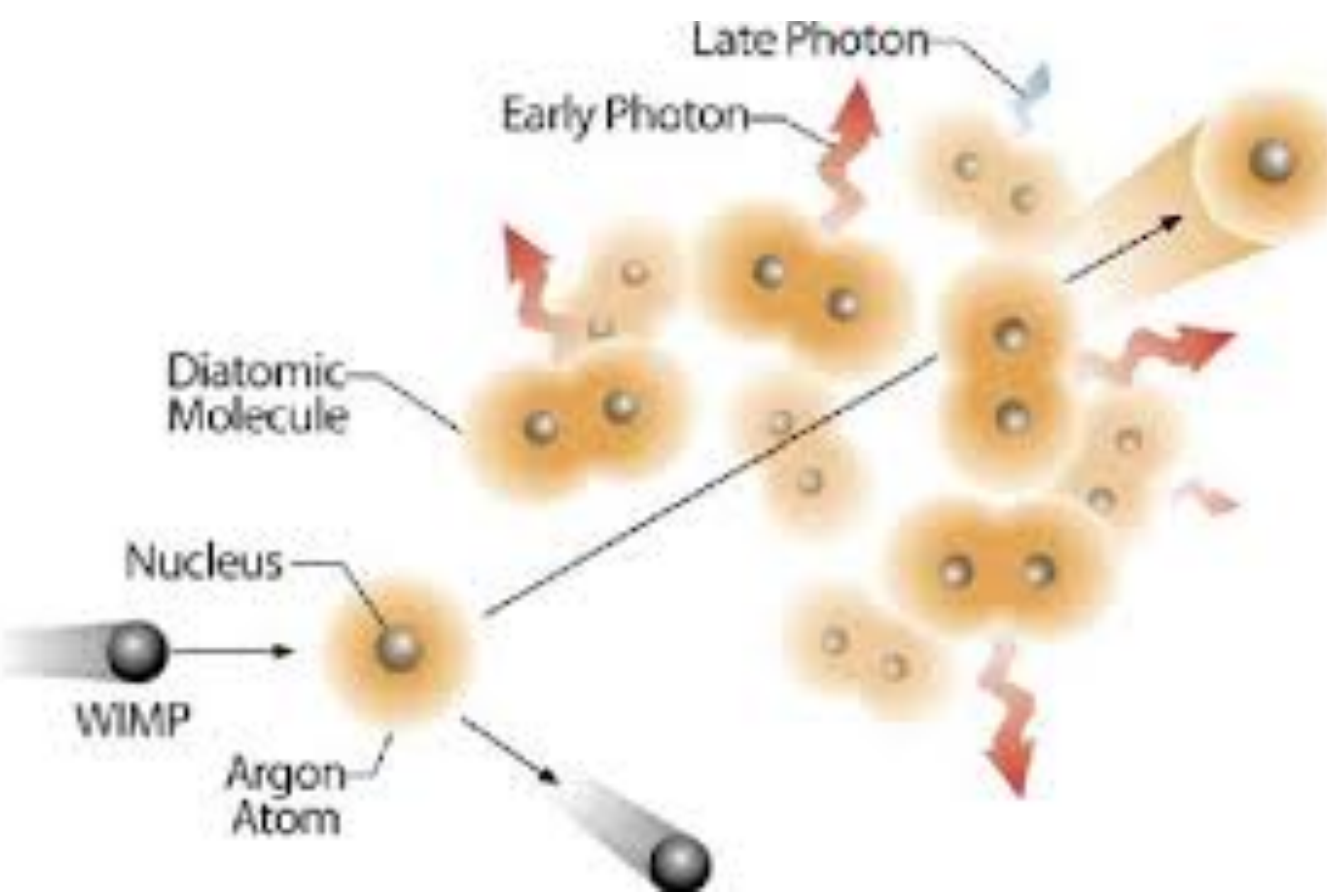


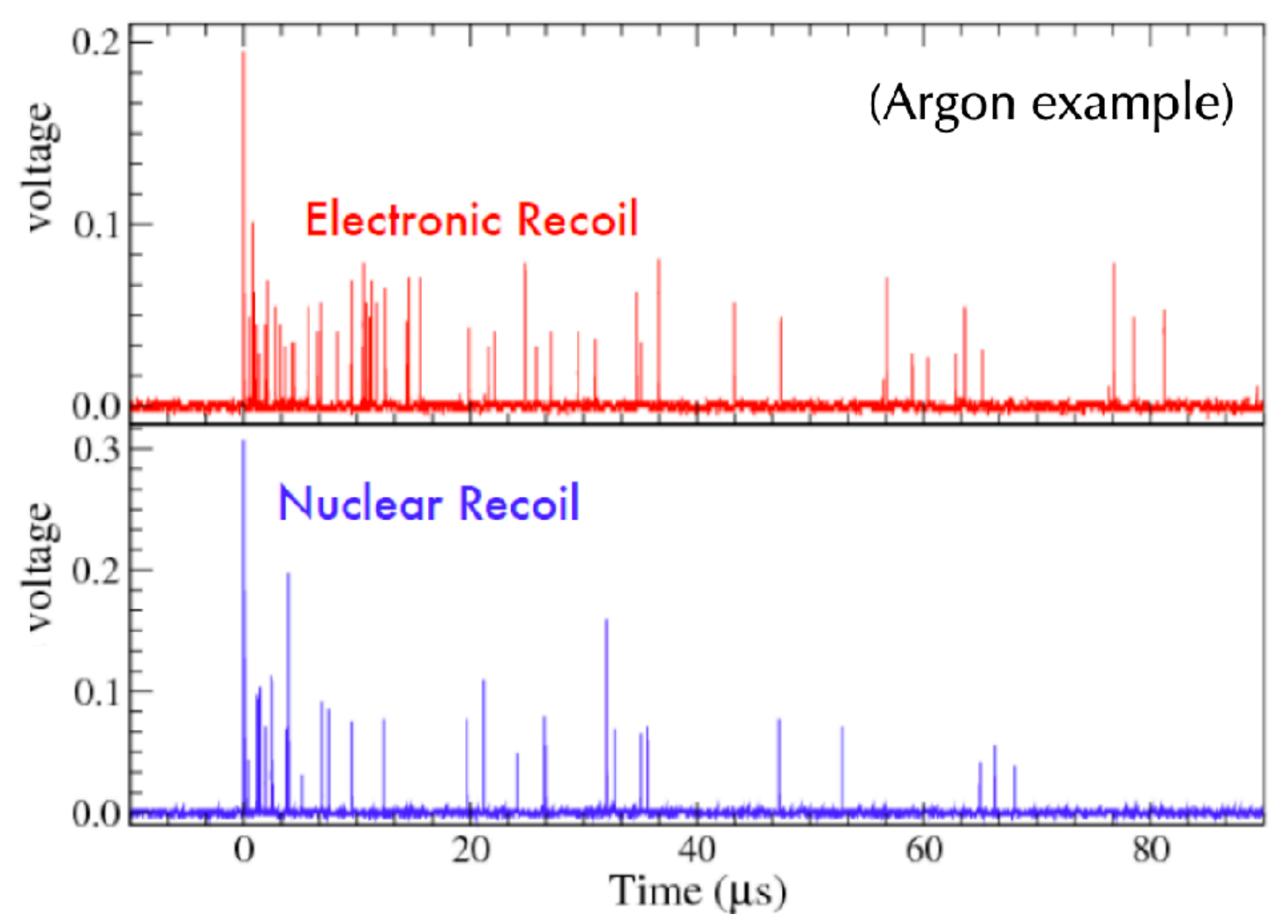


- Single-phase: scintillation light only
- Dual-phase: scintillation light + ionization charge

Why Argon?

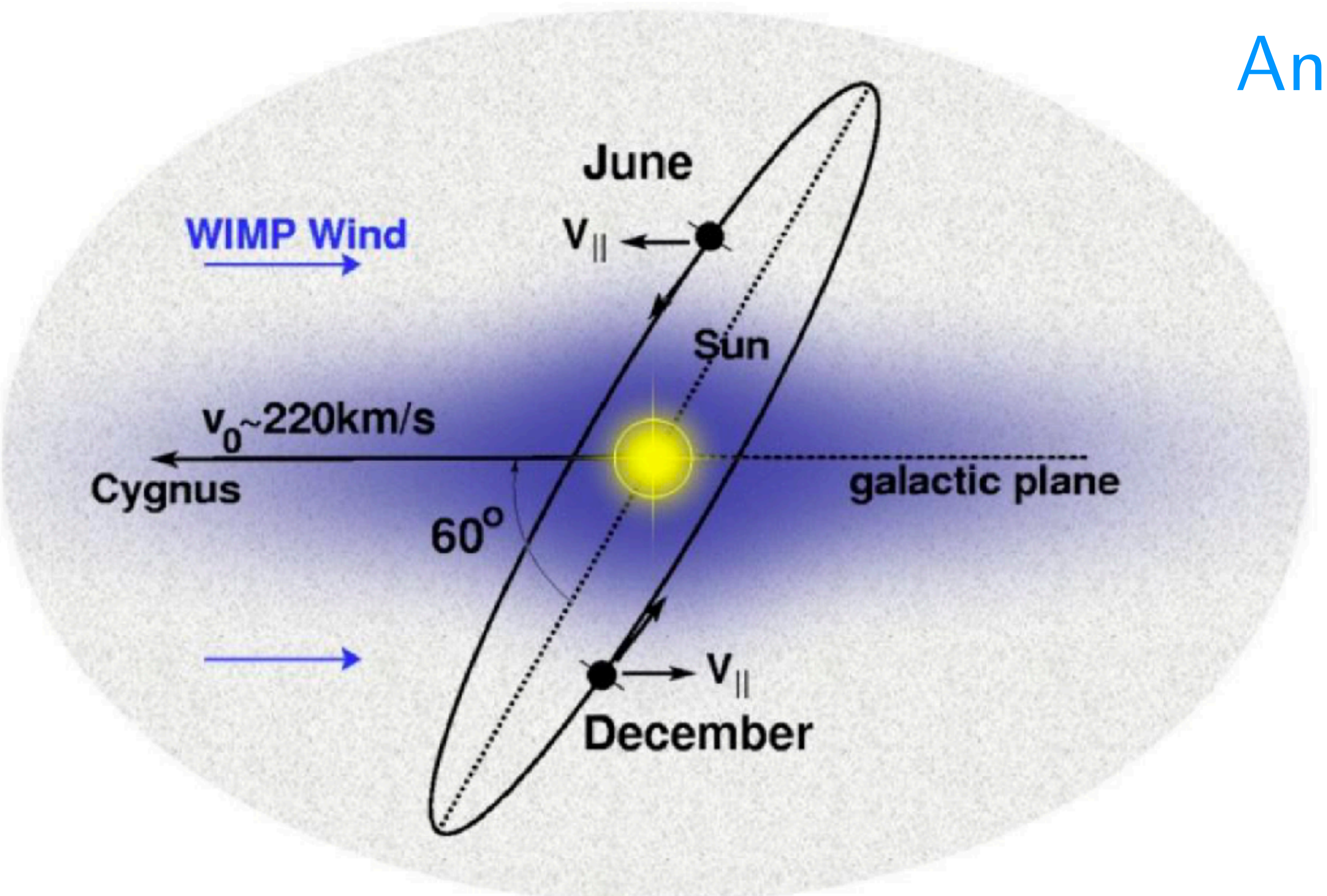
- High ionization yield (S2/S1) relative to LXe
- Powerful PSD for background rejection $> 10^8$
- Availability and low cost: scalability
- Potential to extract radiopure target from underground
- Nuclear form factor: better sensitivity in Ar at high mass for non-standard DM
- Transparent to VUV scintillation
- Particle identification: light vs. time depends on ionization density
- Easily purified: long electron lifetime





Astropart. Phys. 85 (2016)

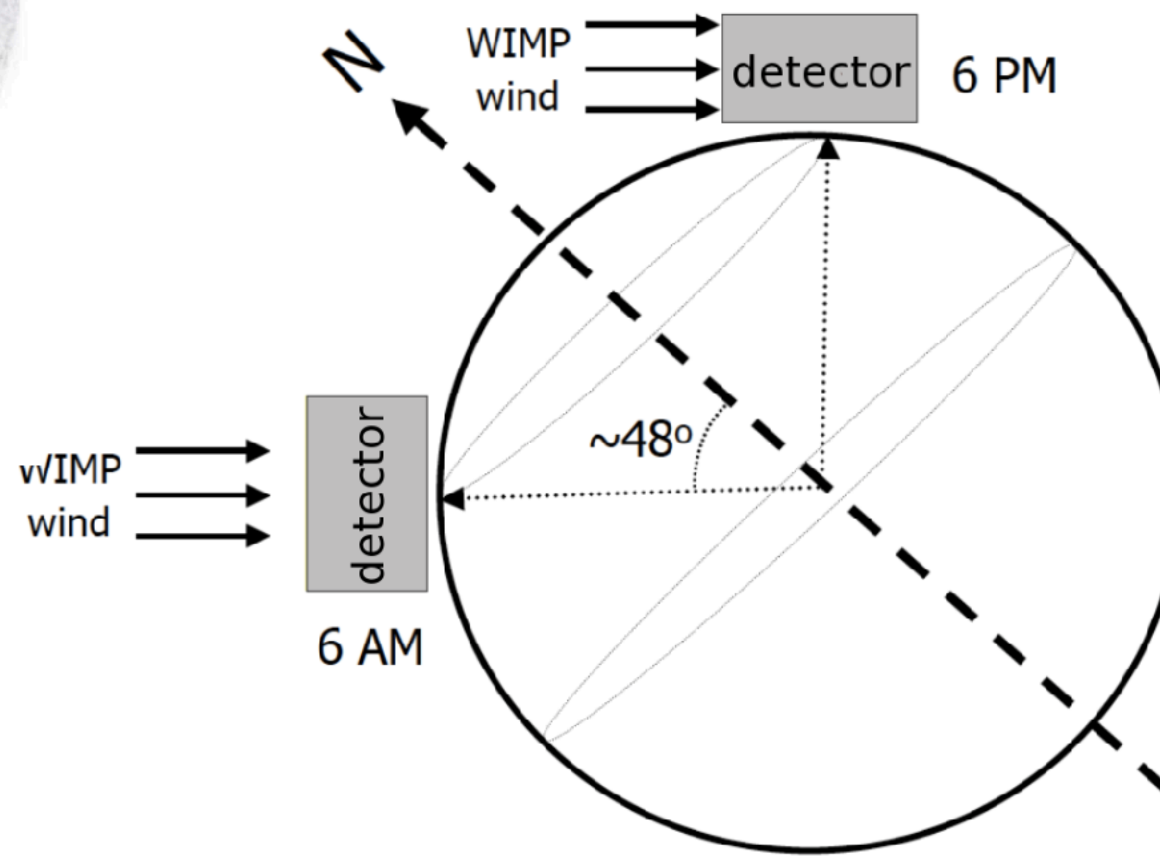
Modulation signatures



Annual event rate modulation:

June-December asymmetry ~2-10%

Phys. Rev. D33:3495 (1986)



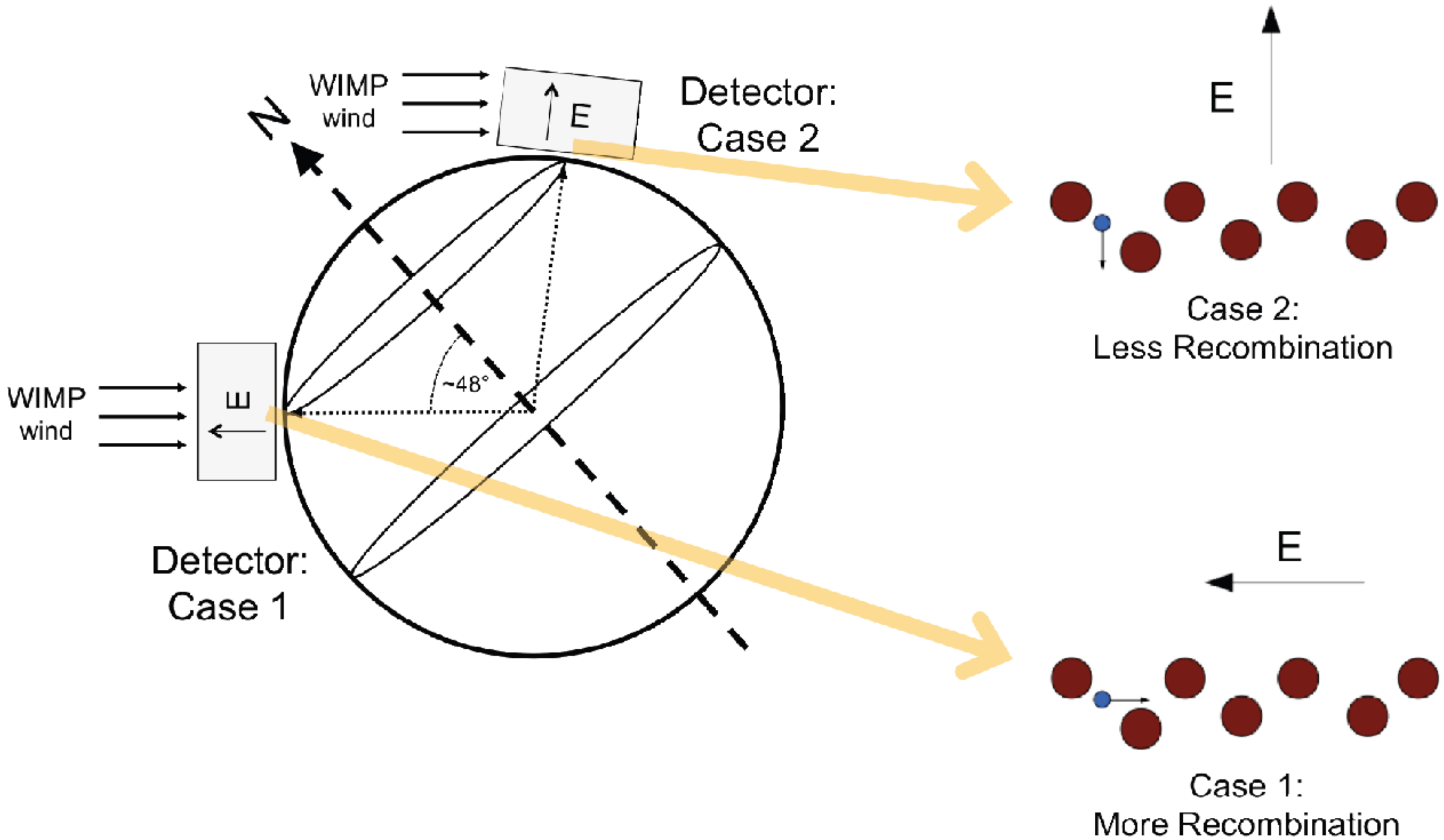
Sidereal direction modulation:

asymmetry ~20-100% in forward-backward event rate

Phys. Rev. D36:1353 (1988)

⇒ Need detector stability + readout capable of directional measurement

Columnar recombination



Nuclear recoils perpendicular to electric field exhibit less electron-ion recombination

Nuclear recoils parallel to electric field exhibit more electron-ion recombination since drifting electrons traverse ion cloud

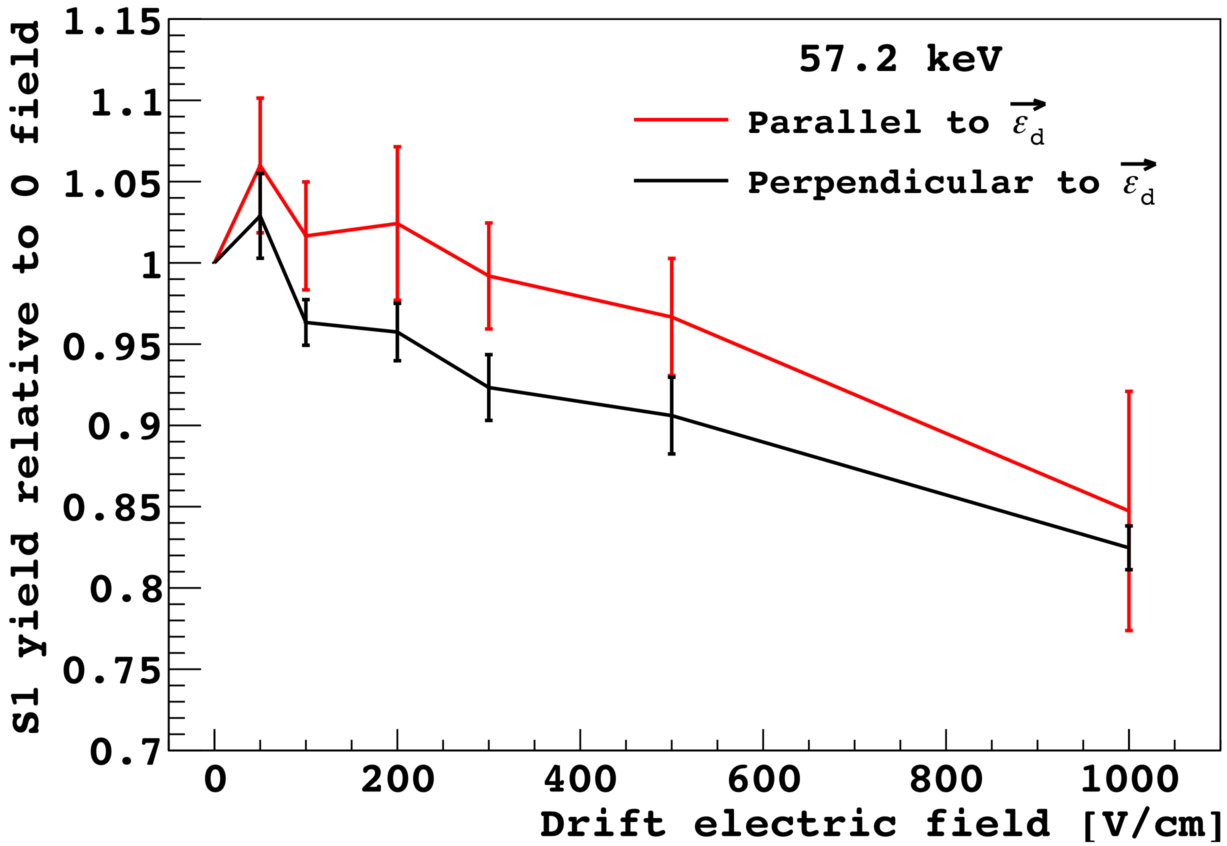
Columnar recombination may be sensitive to the angle θ_R between recoil direction and drift field in a noble liquid TPC

$\Rightarrow$ S1 and S2 expected to depend on E and θ_R

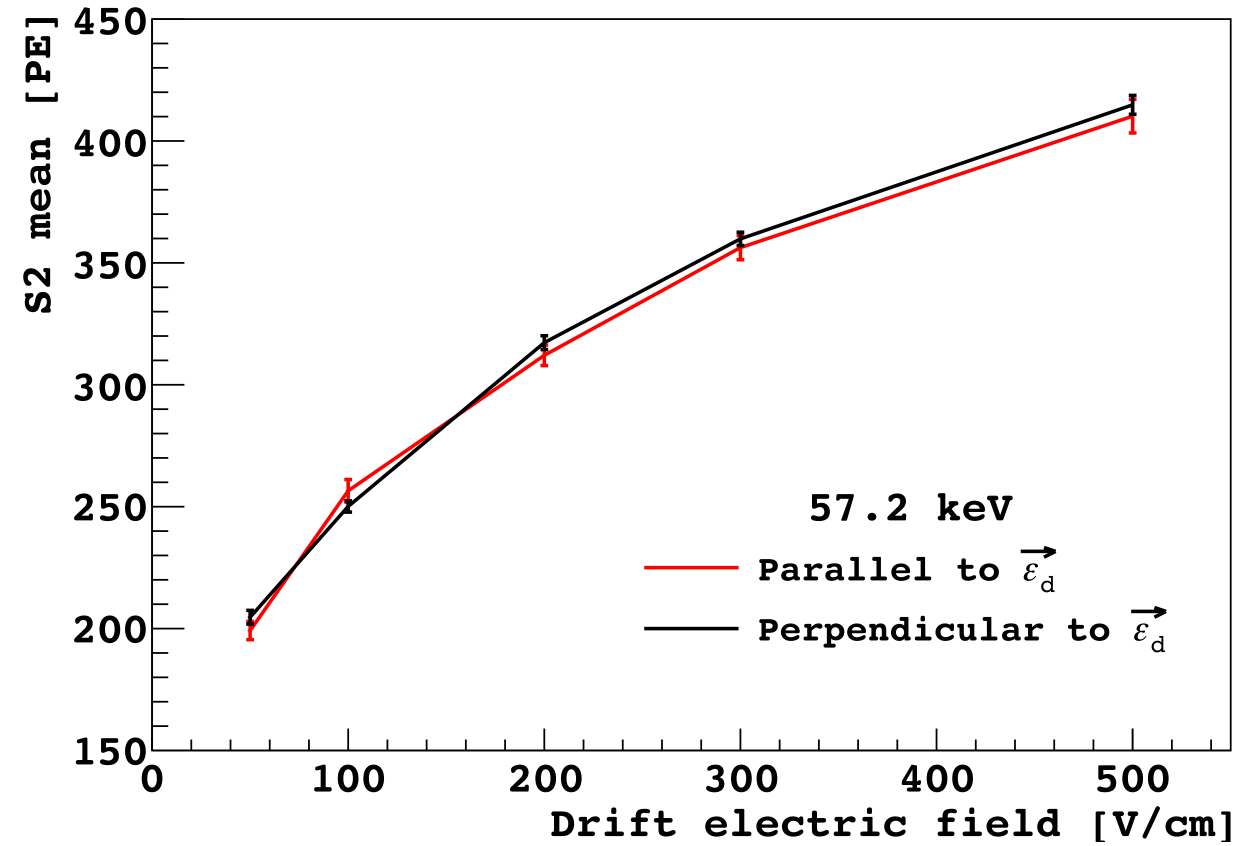
A hint from the SCENE experiment

Phys. Rev. D91:092007 (2015)

Scintillation (S1)



Ionization (S2)

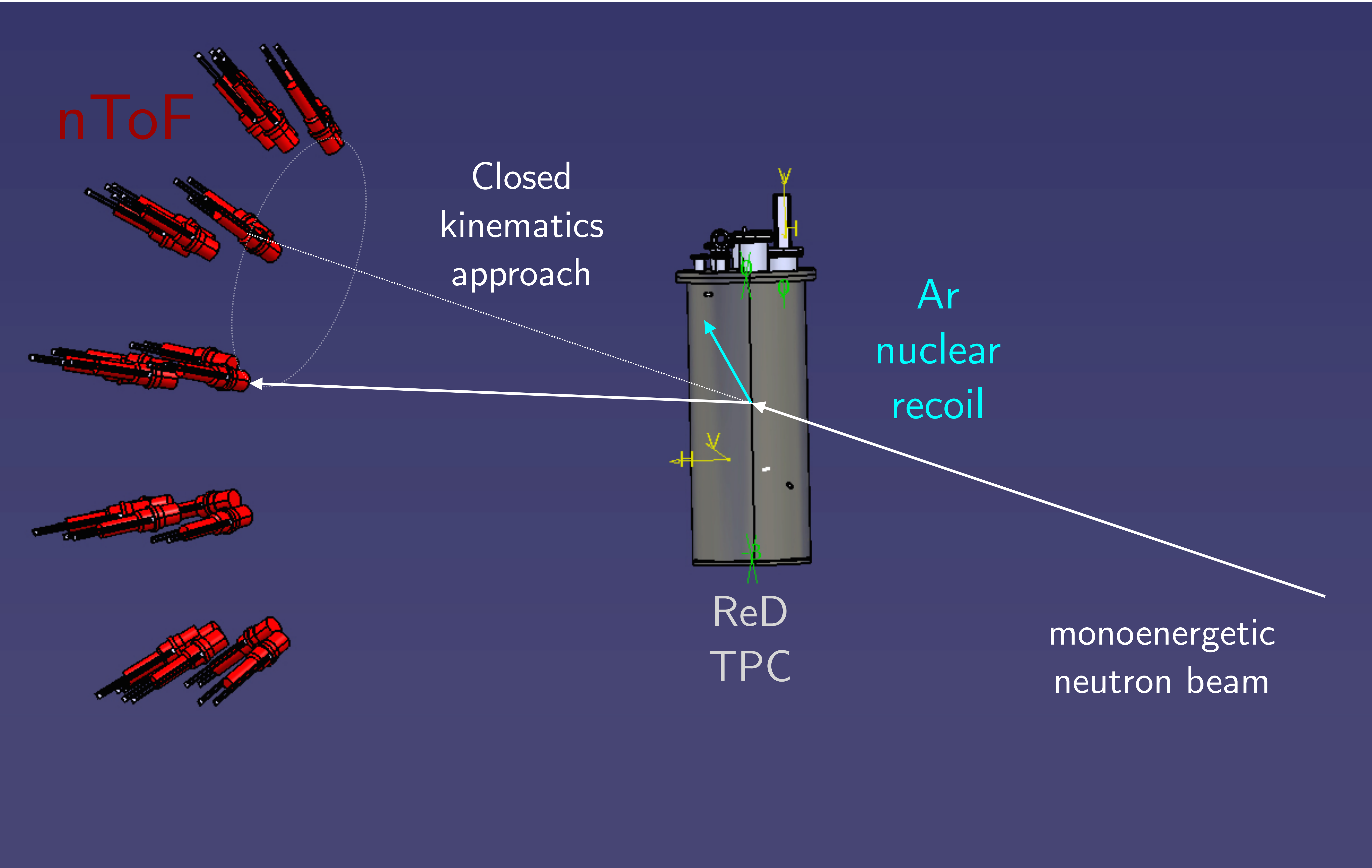


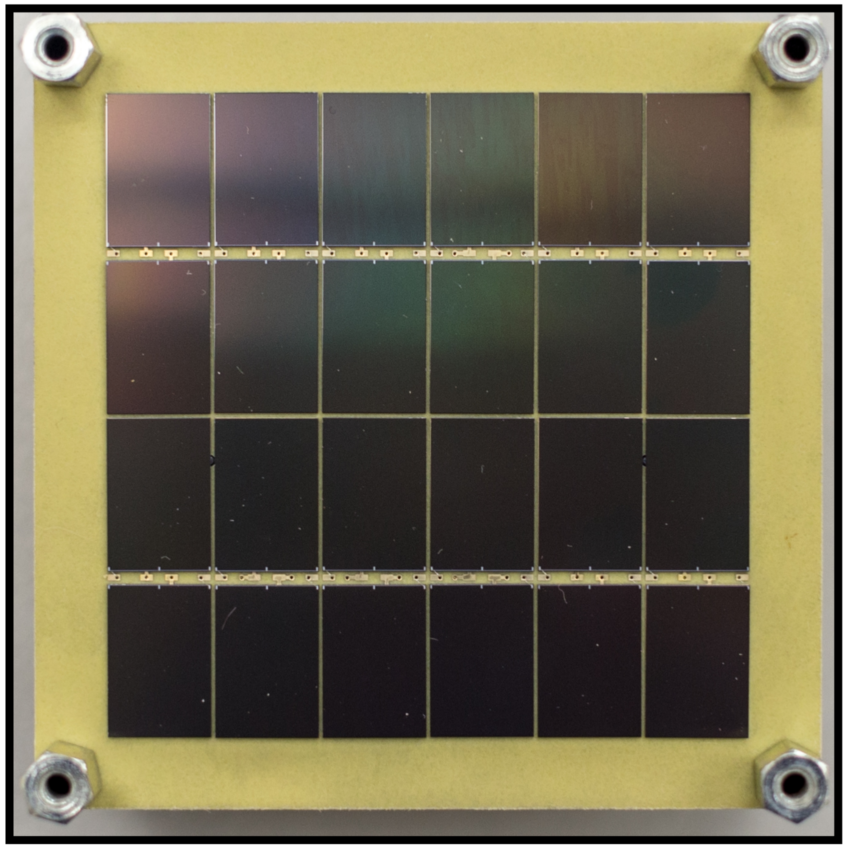
⇒ Hint of anisotropy in 57.2 keV_{nr} recoils

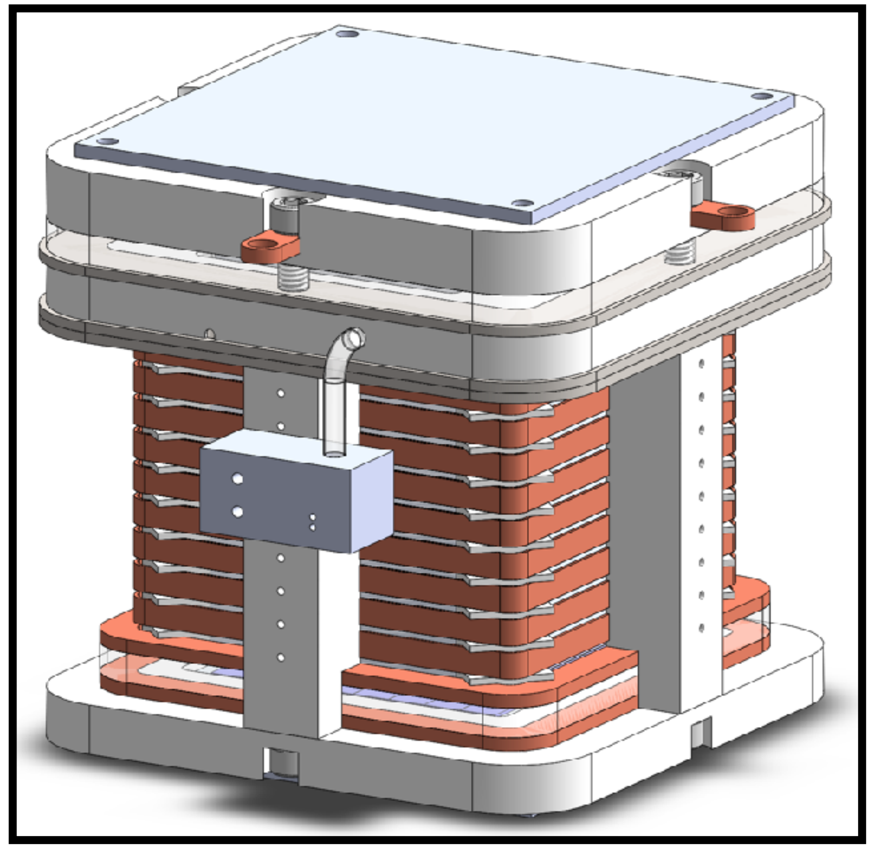
⇩

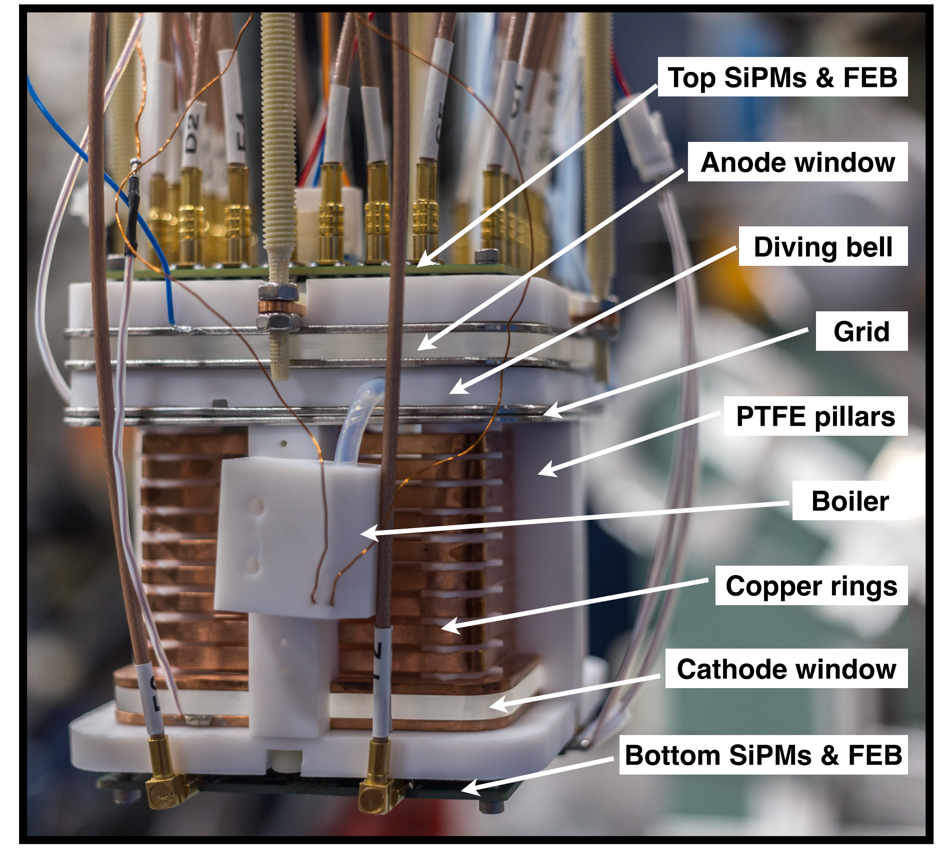
My project: investigate the directional sensitivity of LAr TPCs using an improved detector (ReD) and an optimized experimental setup

Experimental setup

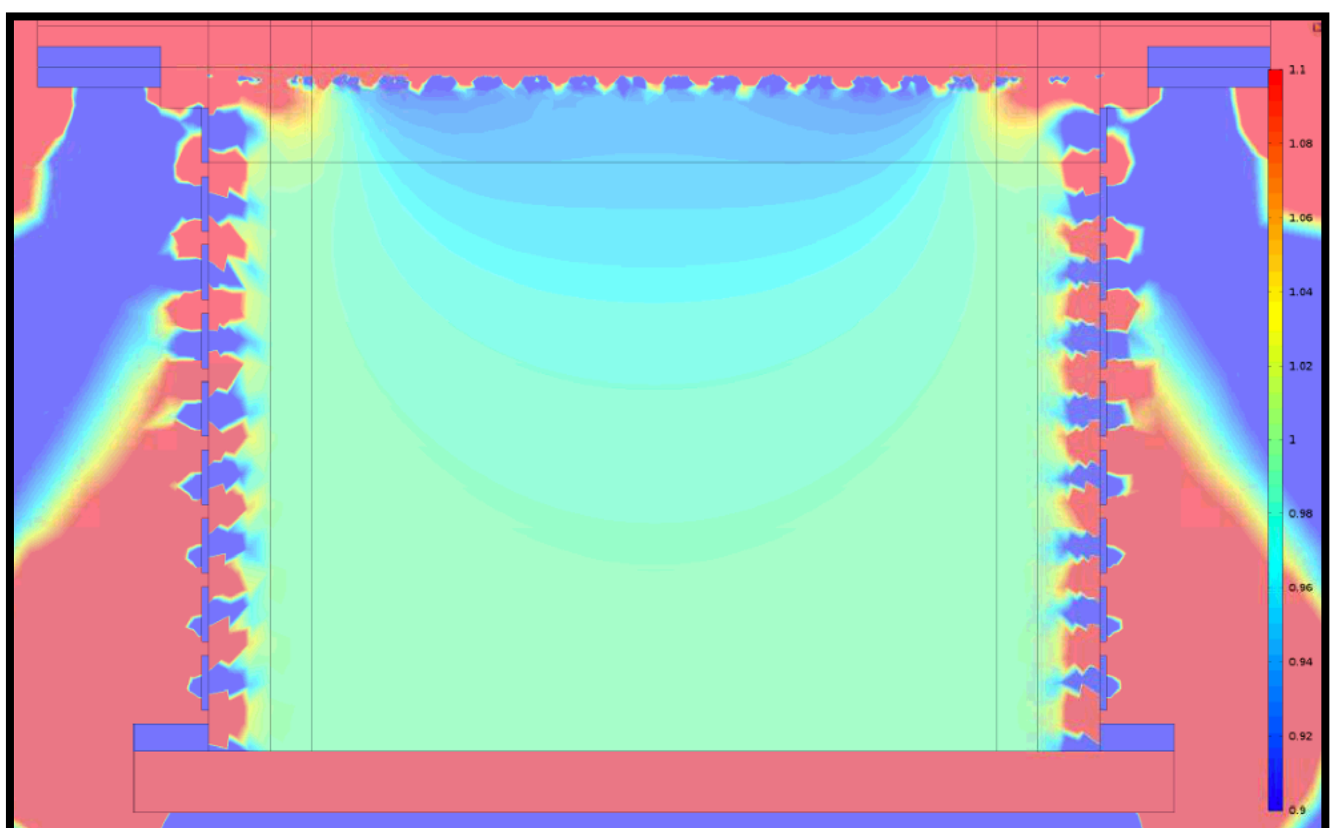


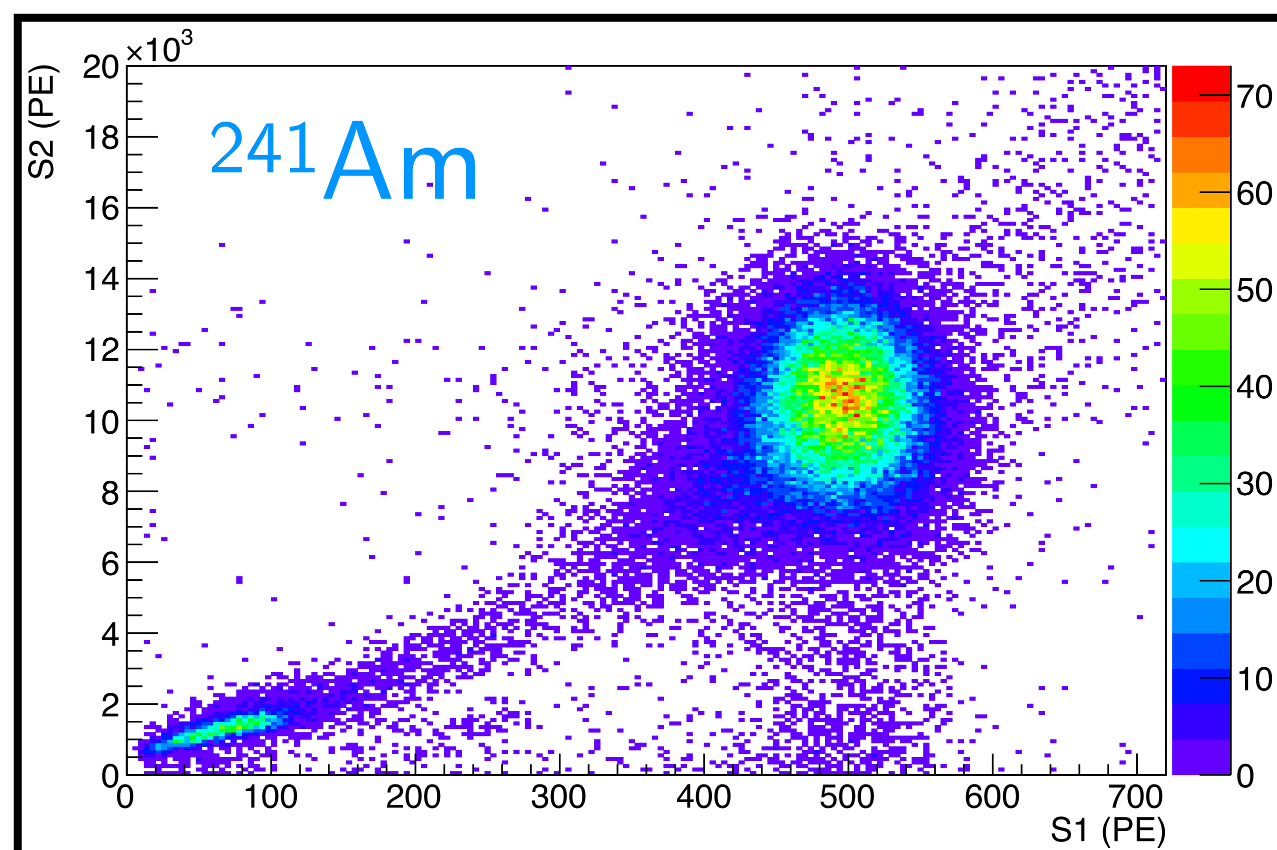





Top SiPMs & FEB
Anode window
Diving bell
Grid
PTFE pillars
Boiler
Copper rings
Cathode window
Bottom SiPMs & FEB

ReD TPC




^{241}Am
S2 (PE)
×10^3
S1 (PE)
0
100
200
300
400
500
600
700
2
4
6
8
10
12
14
16
18
20
10
20
30
40
50
60
70