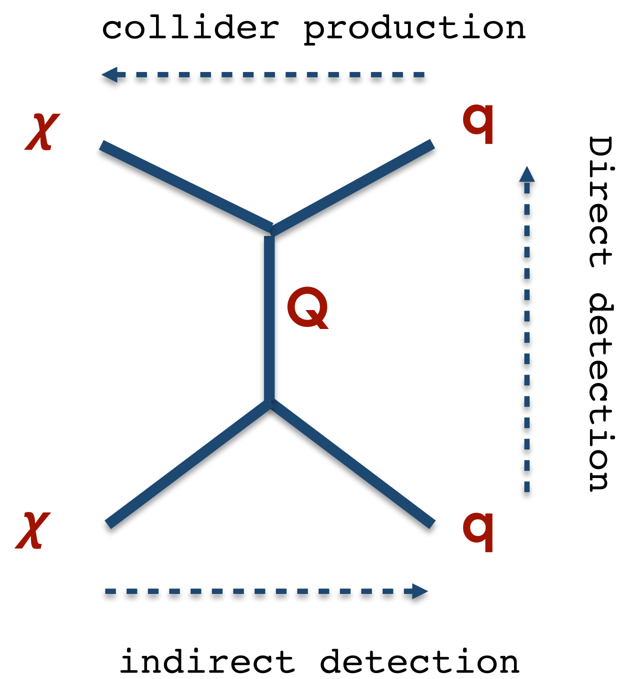
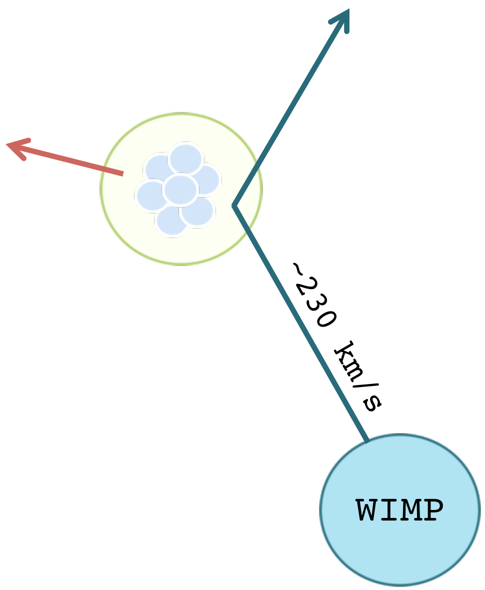
Calibrating detectors for dark matter search at ALTO

D. Franco

Dark Matter Particles

A number of indirect observations:
- Galaxy clusters
- Galactic rotation curves
- Weak lensing
- Strong lensing
- Hot gas in clusters
- Bullet Cluster
- Supernovae
- CMB
- …





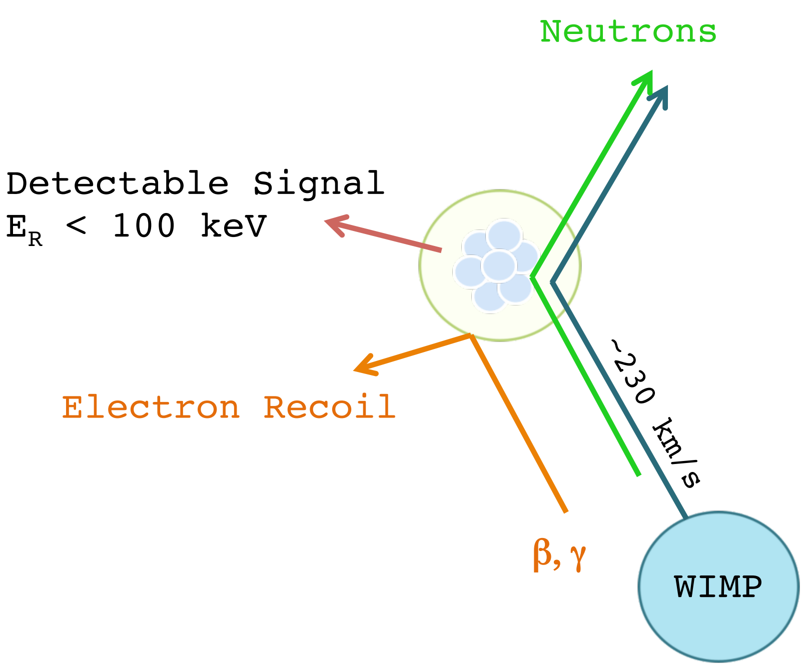
Dark Matter particle properties:
- Cold
- Gravitational force
- No electric charge or color
- No strong and em interactions
- Stable or very long lived

Backgrounds and Detector Requirements

Cosmic rays and cosmogenic isotopes

Natural (^{238}U, ^{232}Th, ^{235}U, ^{222}Rn,…) and anthropogenic (^{85}Kr, ^{137}Cs,…) **radioactivity**

Neutrinos (solar, atmospheric, diffuse supernovae)



WIMP detector requirement:

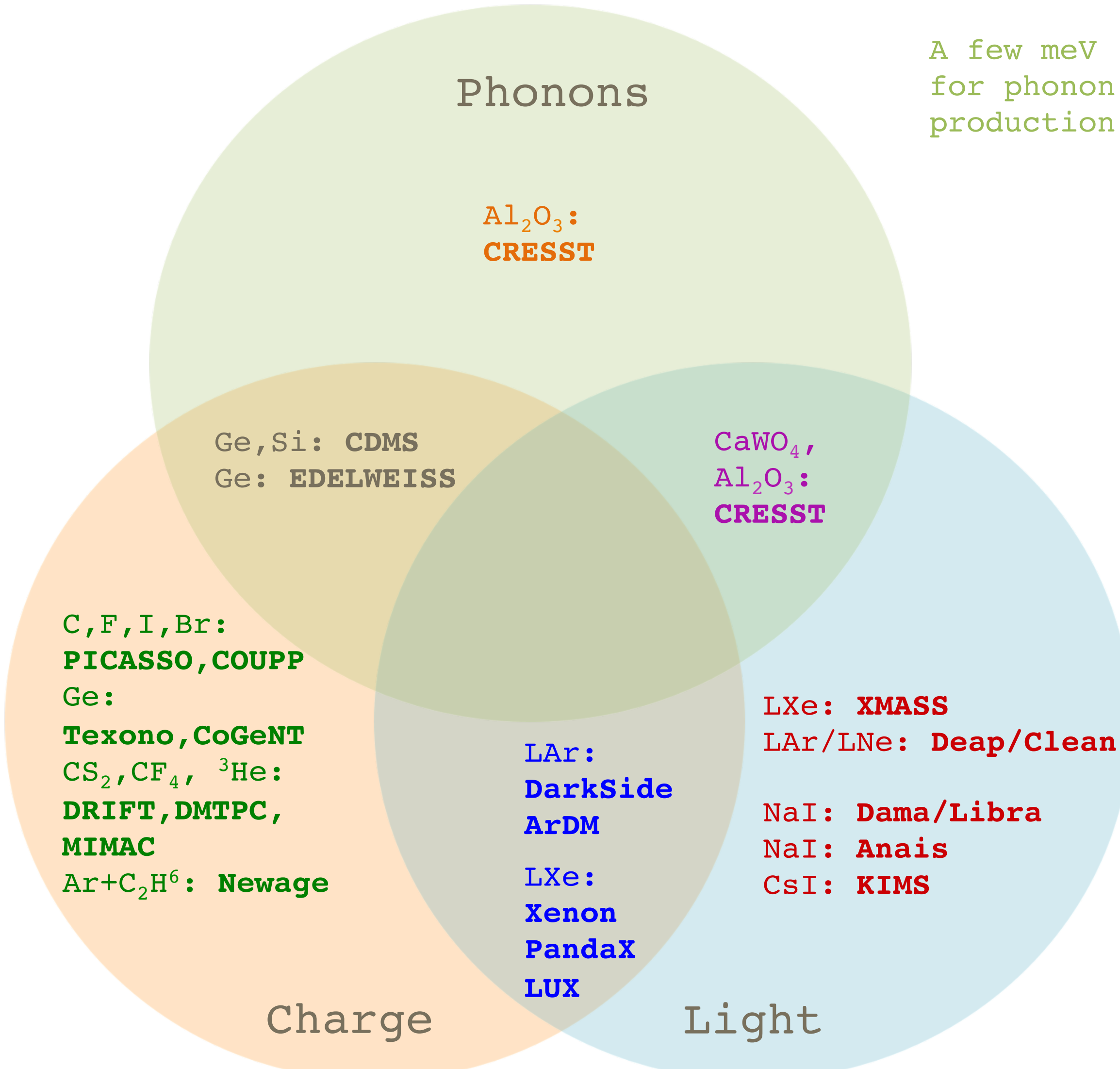
- Large mass
- Low energy threshold
- Ultra-low background
- Signal/background discrimination

Either **background free** or perfectly constrained background

Or **clear signature** (annual modulation, directionality)

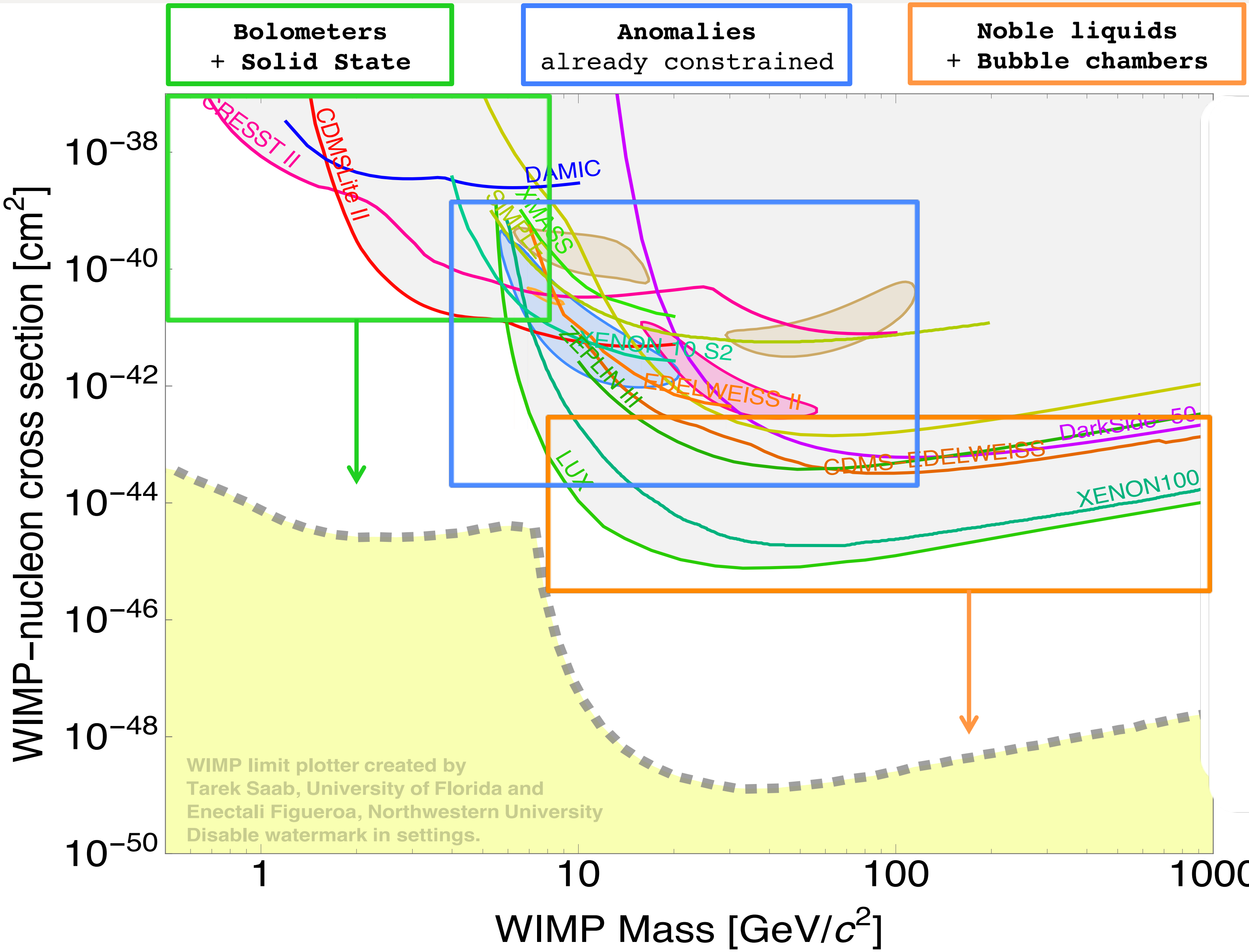
Direct Detection Techniques

A few meV for phonon production



A few eV for ion-electron production

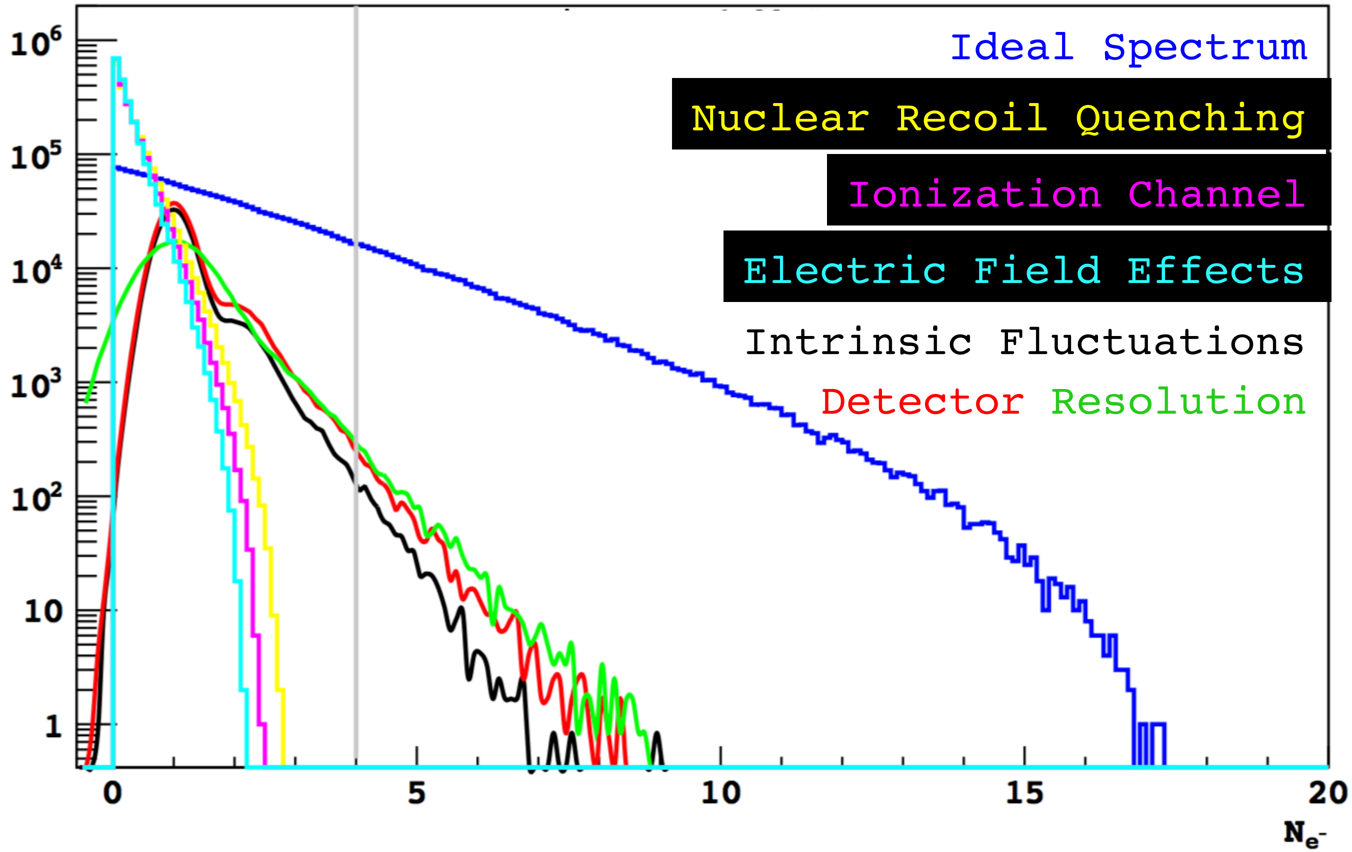
10-100 eV for light production in noble liquids and in scintillators


Bolometers
+ Solid State
Anomalies
already constrained
Noble liquids
+ Bubble chambers
CRESST II
CDMSLite II
DAMIC
XMASS
SIMPLE
XENON 10 S2
ZEPLIN III
EDELWEISS II
LUX
CDMS–EDELWEISS
DarkSide–50
XENON100
WIMP–nucleon cross section [cm²]
WIMP Mass [GeV/c²]
10⁻³⁸
10⁻⁴⁰
10⁻⁴²
10⁻⁴⁴
10⁻⁴⁶
10⁻⁴⁸
10⁻⁵⁰
1
10
100
1000
WIMP limit plotter created by
Tarek Saab, University of Florida and
Enectali Figueroa, Northwestern University
Disable watermark in settings.

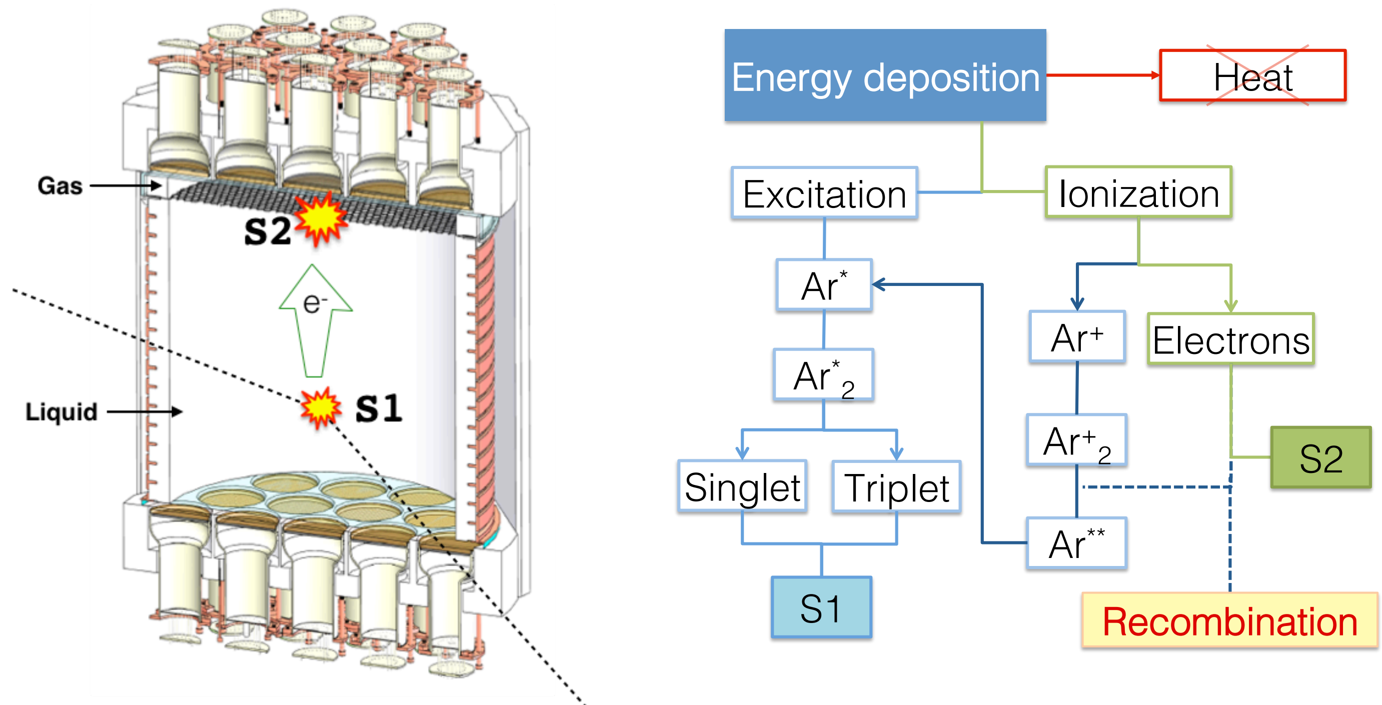
Sensitivity Enhancement

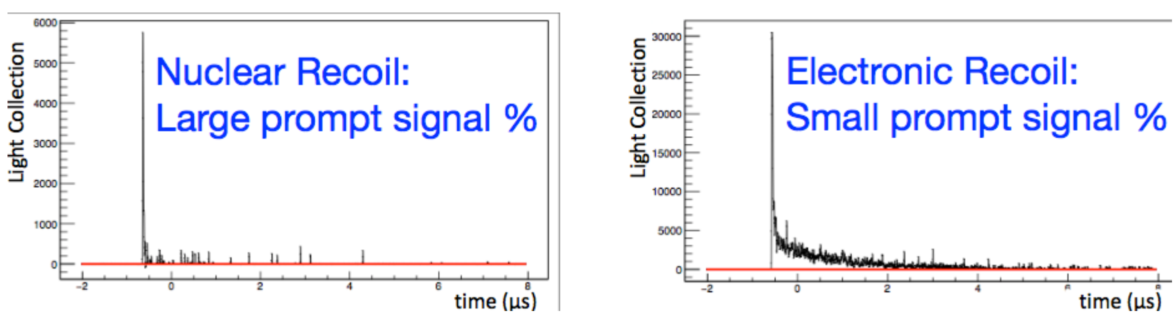
Strategies:
1) Increasing target **mass**
2) Lowering the analysis/trigger **threshold**
3) Constraining the **response**

Ionization Signal in a Liquid Argon Target at 1 GeV WIMP Mass



Noble Liquid TPCs





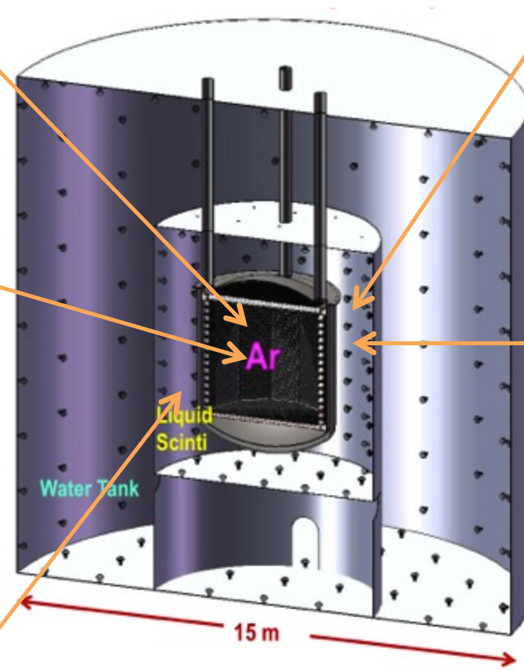
In Argon: powerful **pulse shape discrimination** in primary scintillation channel

Calibration Methods

Natural internal source
(^{39}Ar, ^{127}Xe)
Uniformly distributed
Limited number of sources

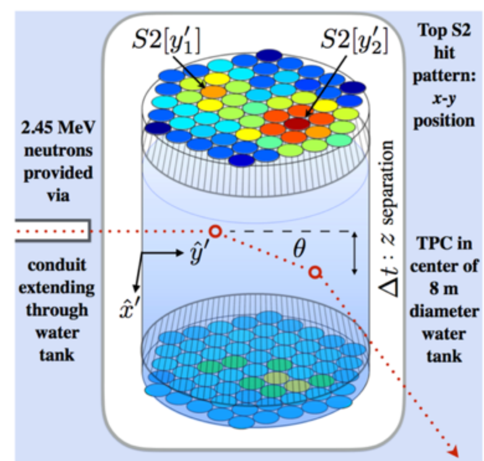
Injected gaseous source
(^{83m}Kr)
Direct measurement
Limited number of sources
Electron Recoil only

External gamma source
(^{241}Am, ^{133}Ba)
Known energy
Events close to the borders



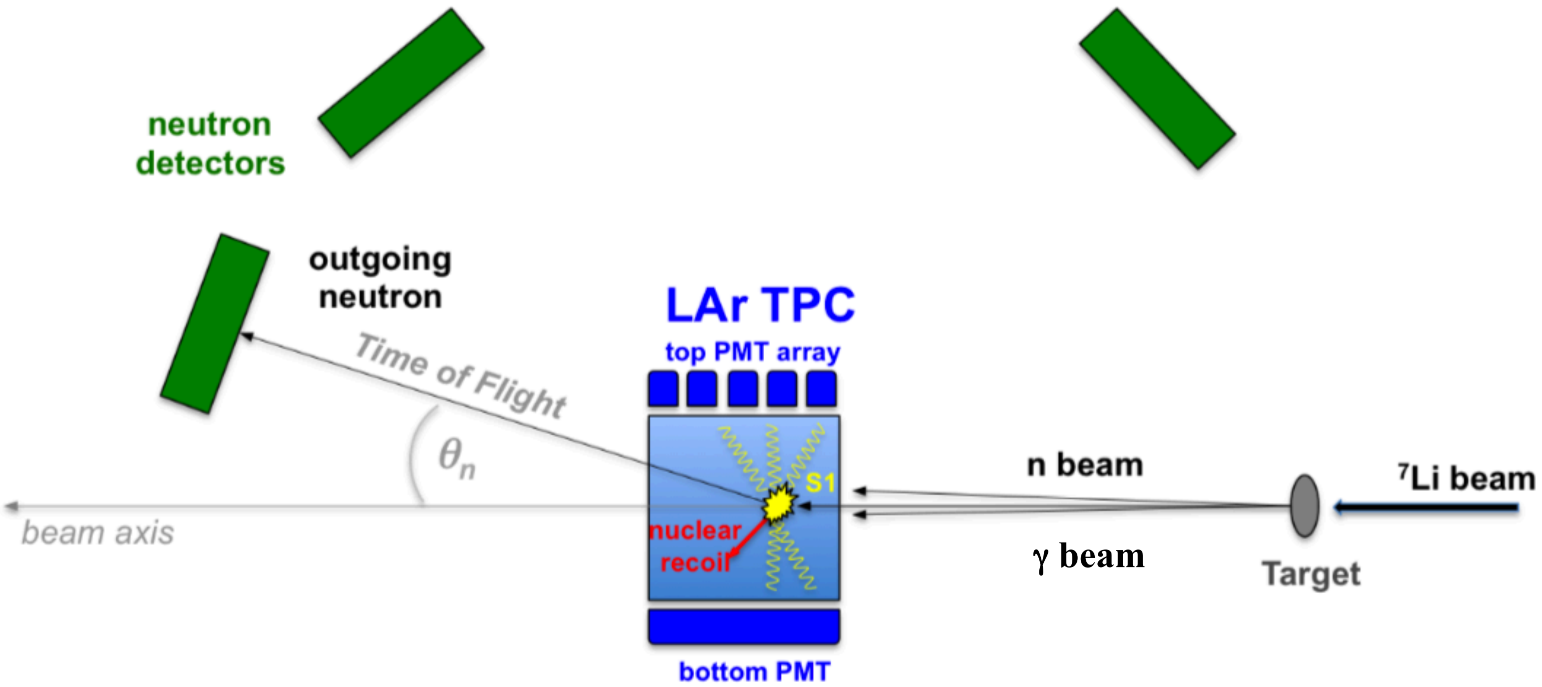
External neutron source
(AmBe, AmC)
Direct measurement in nuclear recoil mode
Non-monochromatic

D-D gun in the veto
Monochromatic neutrons
Recoil energy reconstruction



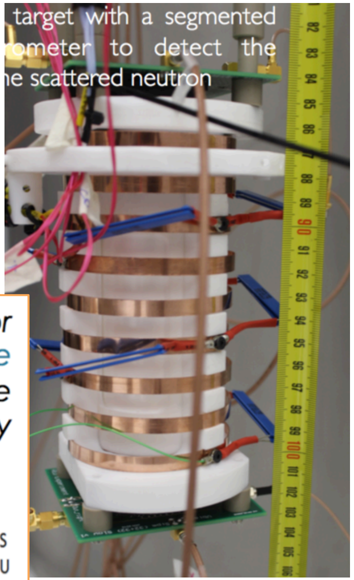
Cross Calibrations

- Response of **noble liquids** depends on the purity level only
- **Bolometers** and **solid state** detectors can be “moved” for lab tests

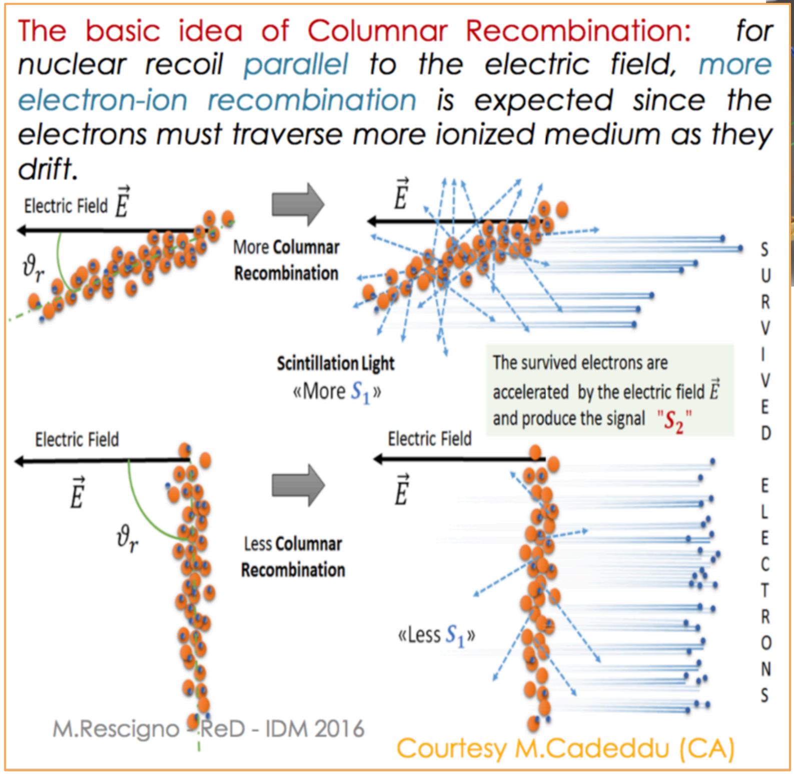


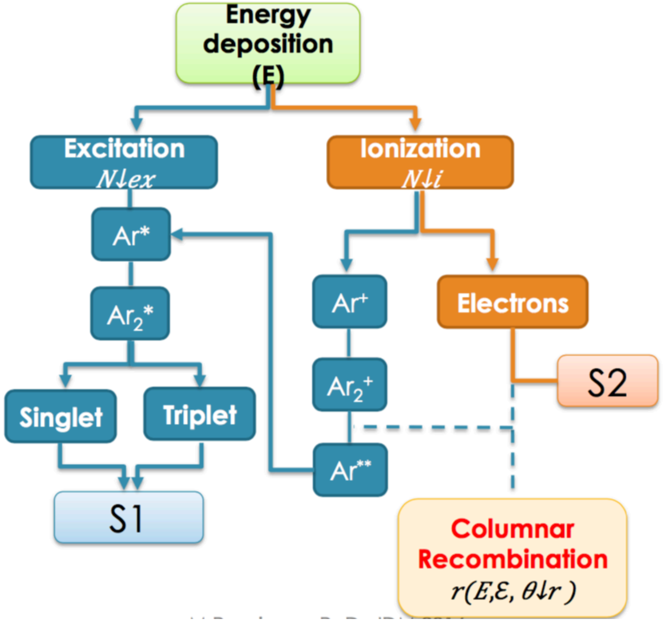
Recoil Directionality Studies in Two-Phase Liquid Argon TPC Detectors

Beam:
- **Continuous**
- p(^{7}Li,^{7}Be)n
- Tagging of ^{7}Be



TPC:
- equipped with SiPM
- High segmentation
- Large PDE (~40%)

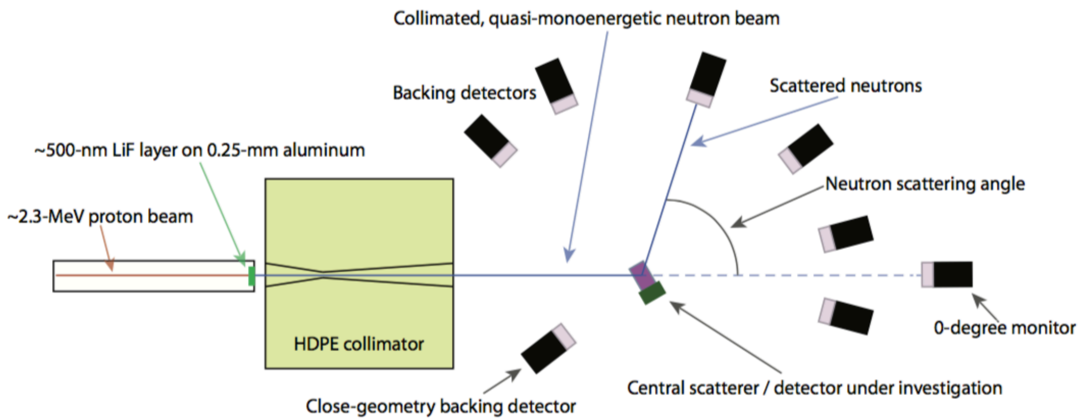


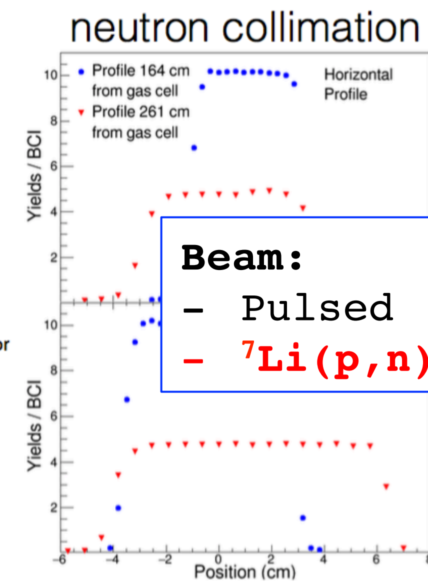


From M. Rescigno at IDM 2016

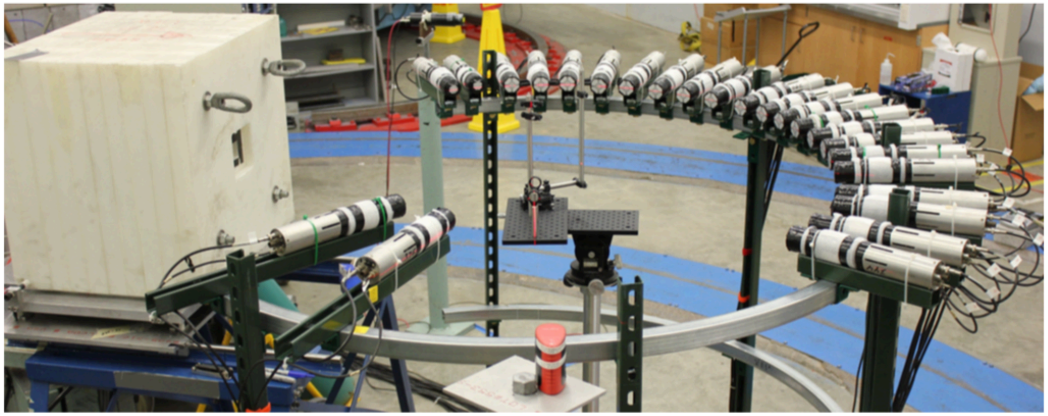
TUNL

Reaction	Q-value (MeV)	Mono-energetic neutron energy range (MeV)	Off-energy reactions	Threshold (MeV)
^{7}Li(p,n)^{7}Be	−1.644	0.1–0.65	^{7}Li(p,n)^{7}Be*	2.372
^{3}H(p,n)^{3}He	−0.763	0.5–7.7	^{3}H(p,np)^{2}H	8.348
^{2}H(d,n)^{3}He	+3.269	4.0–7.7	^{2}H(d,np)^{2}H	4.449
		4.0–5.5	X(d,np)X	2.249
	+17.589	14.8–20.5	^{3}H(d,np)^{3}H	3.710
^{3}H(d,n)^{4}He	+17.589	14.8–21.9	^{3}H(d,2n)^{3}He	4.984
	+17.589	14.8–18.6	X(d,np)X	2.249





Beam:
- Pulsed
- ^{7}Li(p,n)^{7}Be

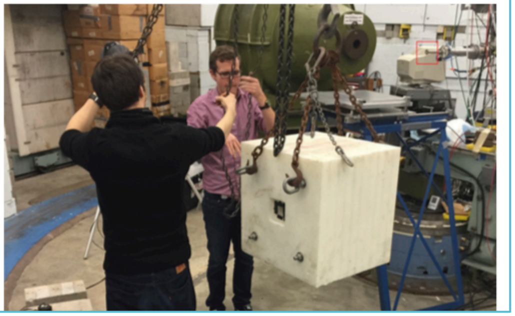


From P. S. Barbeau @ US Cosmic Visions 2017

A nice philosophy!

There ain't no such thing as a free lunch…
…it's just cheap

- TUNL provides the beam-time at no cost
- There is an $80 setup fee for technical support on the front end.
- The graduate students operate the beam. If they collaborate on the effort (and if they are interested in the project, or it aligns well with already funded effort) then the time they spend on the beam is free.
  - All of them have experience measuring these parameters
- If the students are just acting as operators then the cost is ~$3k per week per 8 hour shift when the beam is running.
  - so 24 hour per day runs are ~$9k/week.
  - No setup/takedown costs



From P. S. Barbeau @ US Cosmic Visions 2017

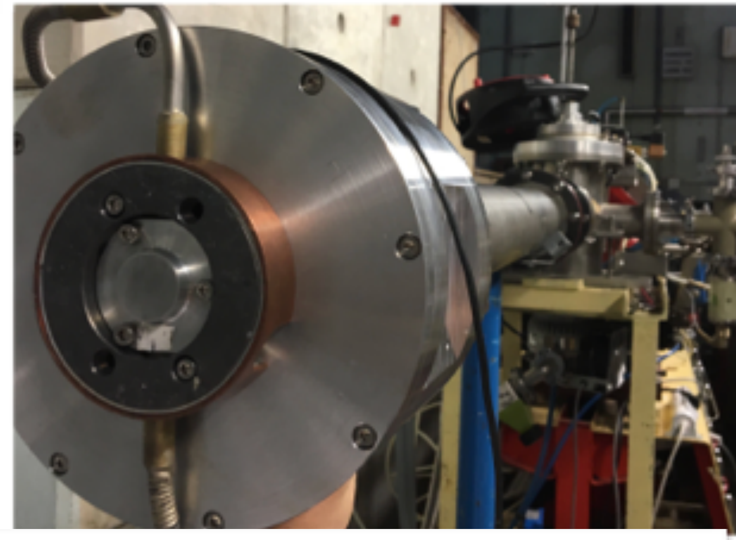
Several experiments are already planning on coming to TUNL

- Planning a campaign can be straightforward
  - Usually we will run 7-10 days at a time
  - Scheduled ~ 2 months in advance
  - More involved deployments have required more coordination
  - Typically schedule 1.5-2 months per year for these activities, but this could be increased.

- A number of groups have plans for QF measurements at TUNL, have measured in the past, or have plans to be visiting soon to investigate firsthand. (visits can be arranged with Seminars to defer costs)
  - LXe measurement for Dark Matter (Luca Grandi—UofC)
  - Si recoils for DAMIC and CONNIE (Juan Estrada—FNAL & Paolo Privatera—UofC)
  - LAr and LXe for Dark Matter and Coherent Neutrino Scattering (Adam Bernstein & Jingke Xu—LLNL)
  - Stilbene channeling (John Mattingly—NCSU & CNEC)
  - SuperCDMS (Tali Figueroa— NWU and Tarek Saab—UFL)
  - ANAIS Dark Matter (Clara Cuesta—U Madrid)
  - HPGe (Juan Collar—UofC, Dave Reyna—Sandia)
  - Stockpile Stewardship Program (Alex Glaser—Princeton)
  - Micro-Chandler (John Link—VaTech)
  - Pure NaI cooled (Liu Jing—USD)
  - Water Bubble chambers (Matt Szydagis—SUNY Albany)
  - Gas detectors (Sven…I'm looking at you!)
  - + Barbeau Group: isobutane, He, CO_2, CF_4, N_2, CaF2, NaI[Tl] channeling, BGO, CeBr3…

From P. S. Barbeau @ US Cosmic Visions 2017

ARIS @ LICORNE



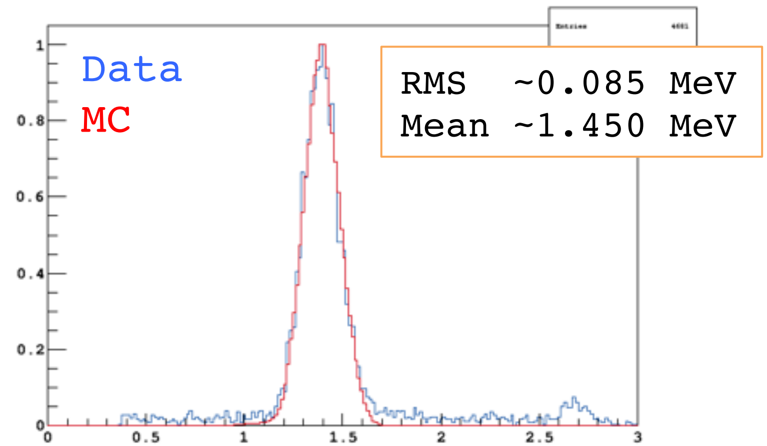
LICORNE: inverse $^7Li(p,n)^7Be$

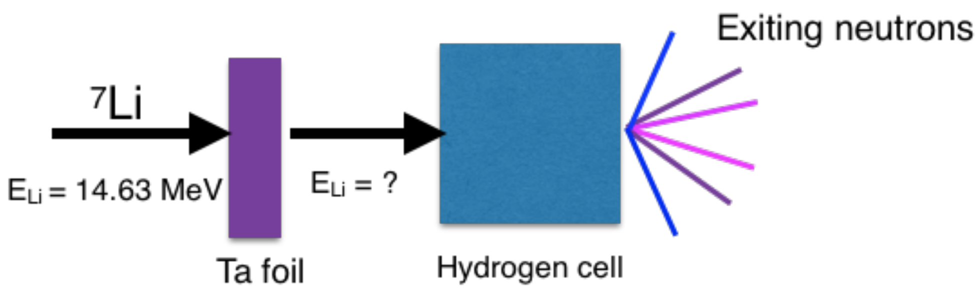
LICORNE is **ideal** because:

- Pulsed (1.5 ns width)
- Monochromatic
- Collimated
- Emits also correlated 478 keV gammas

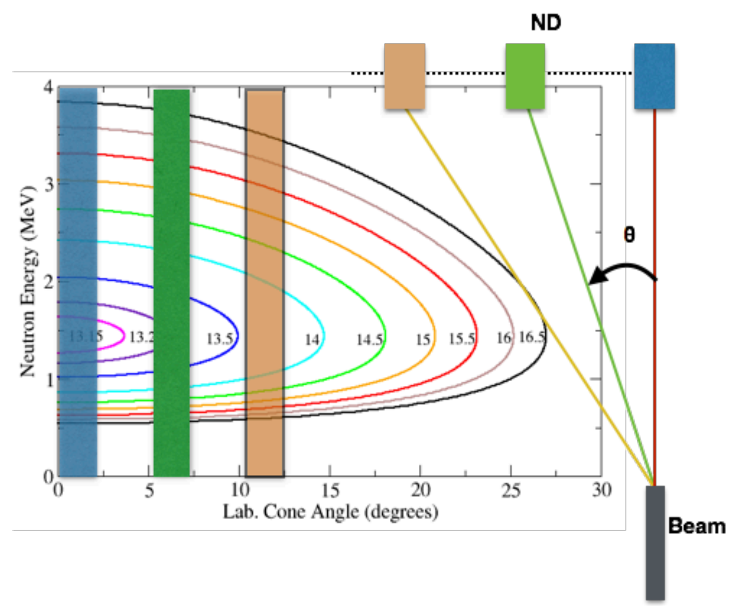
But

- Close to the reaction threshold (~13.096 MeV)
- Need specific calibration at each run

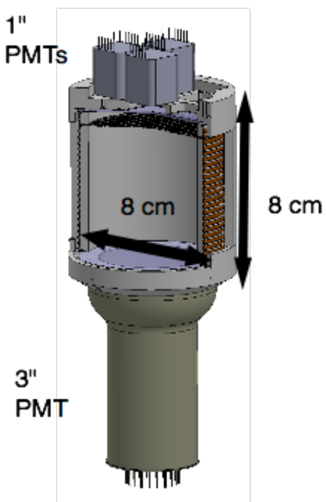


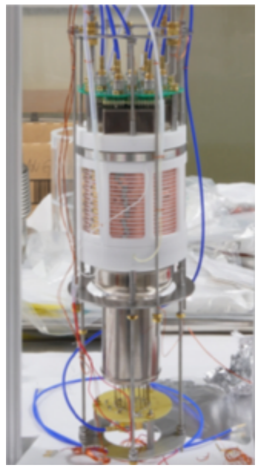


Lithium energy : $13.13^{+0.02}_{-0.01}$ MeV



Small-scale: ideal for single scatters

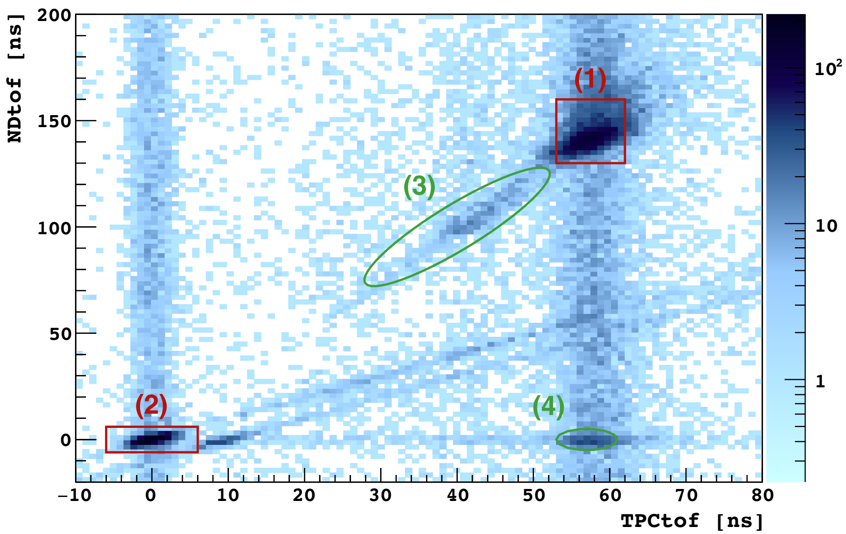


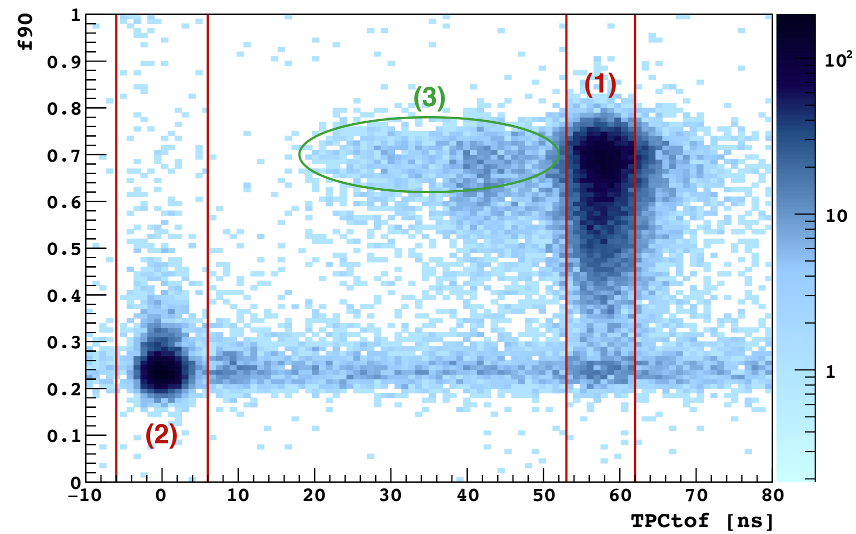


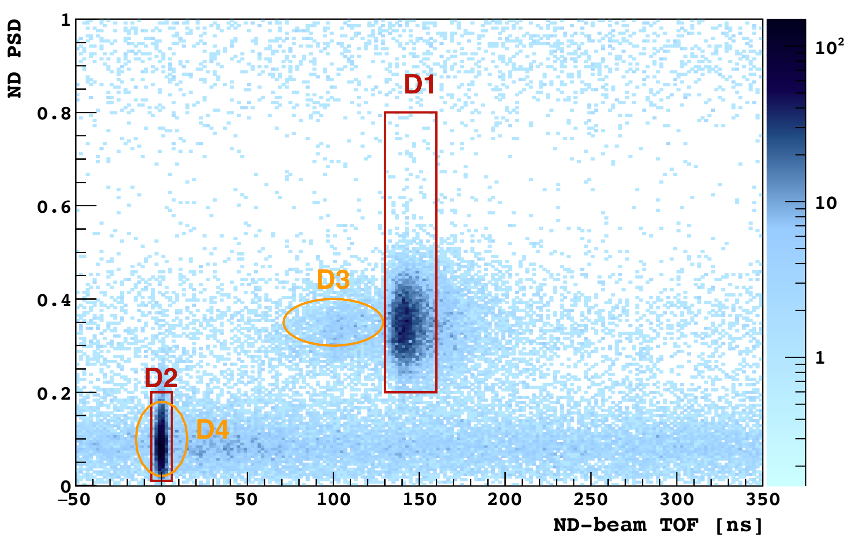
	Scattering Angle [deg]	MC Determined Mean NR Energy [keV]
A0	25.5	7.14
A1	35.8	13.72
A2	41.2	17.78
A3	45.7	21.69
A4	64.2	40.45
A5	85.5	65.37
A6	113.2	98.14
A7	133.1	117.78

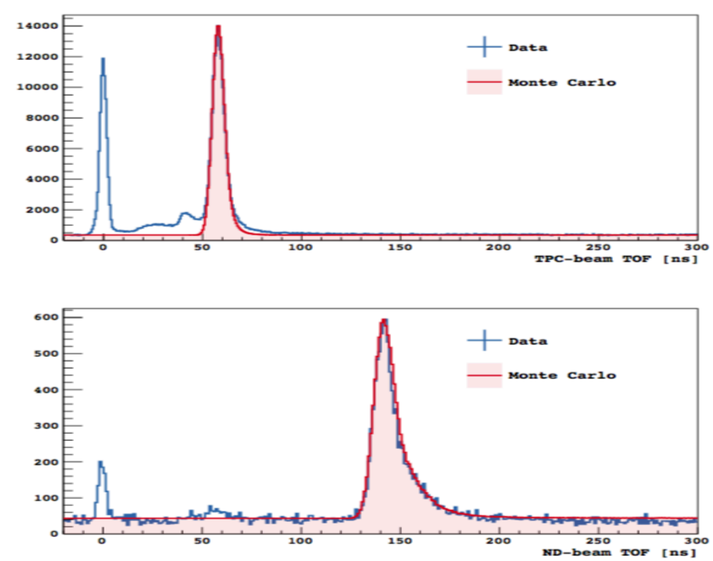
- ~0.5 kg of LAr
- PTFE reflector with TPB coated surface
- 7 Hamamatsu 1’’ PMTs on top, one 3’’ PMT on bottom
- Ability to create a gas pocket for dual-phase running
- Anode/Cathode created with ITO plated fused-silica windows
- Grid 1 cm below the anode provides bias for electron extraction

ARIS Performance

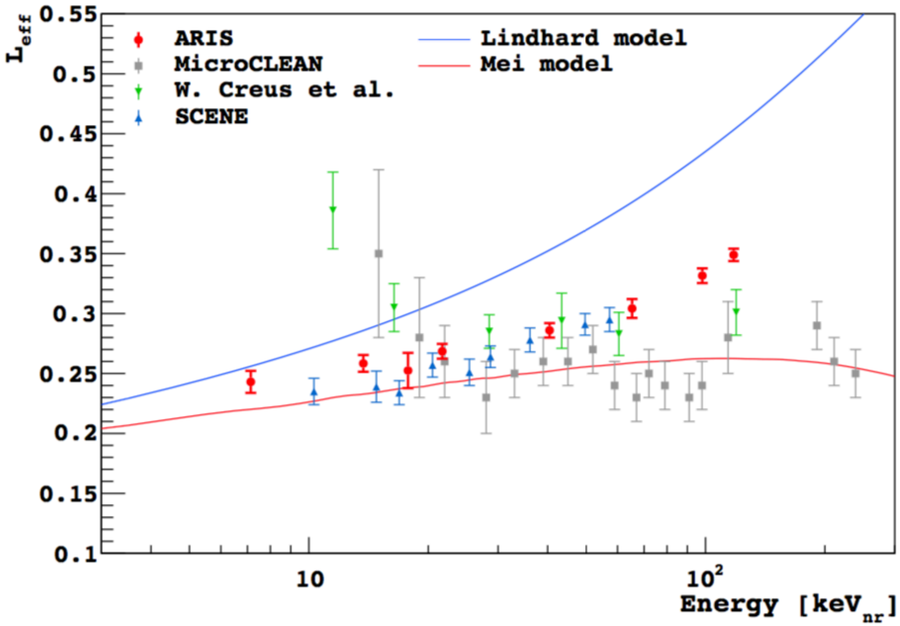






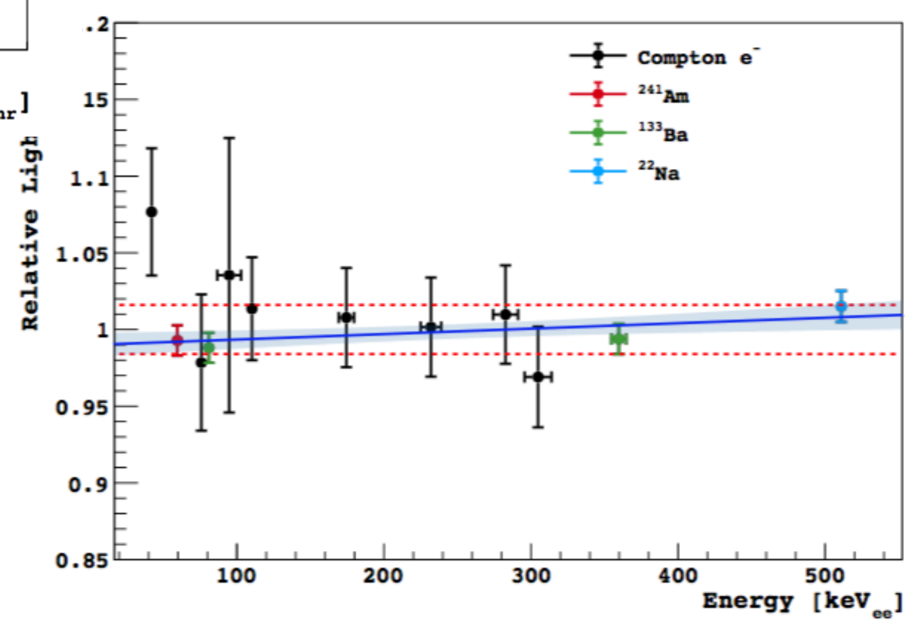


ARIS Results at Field Off



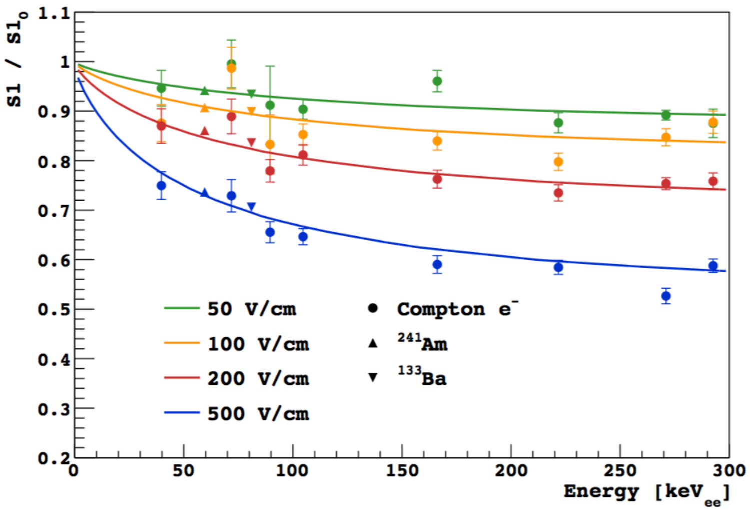
Most accurate measurement of the **nuclear recoil quenching** at field off

First experimental proof of the **linearity of the LAr scintillation at field off** at 1.6% level (90% CL) between 40 and 500 keV

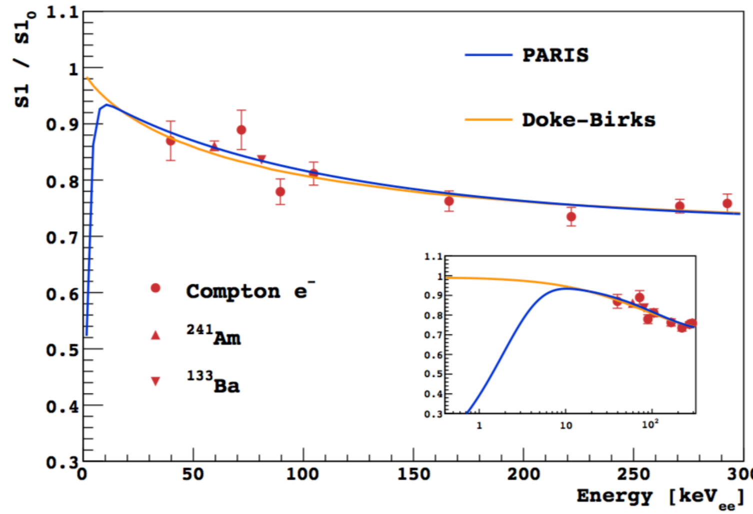


ARIS Results at Field On

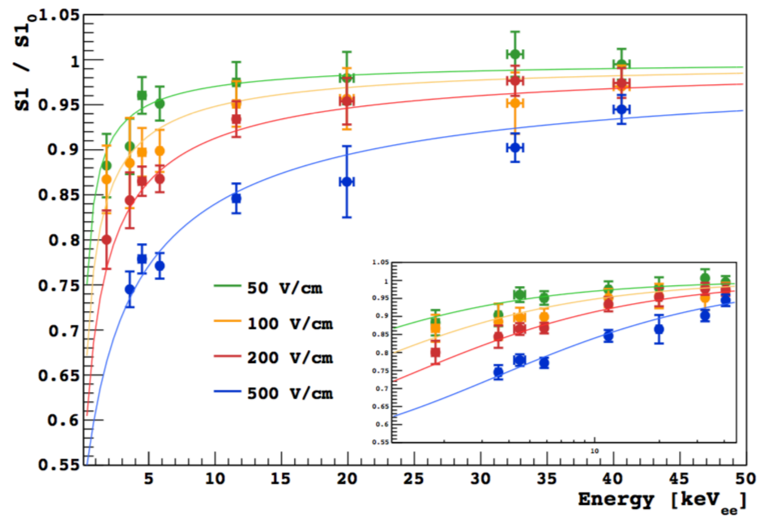
Electron Reoils: Doke-Birks Model



Electron Reoils: PARIS Model

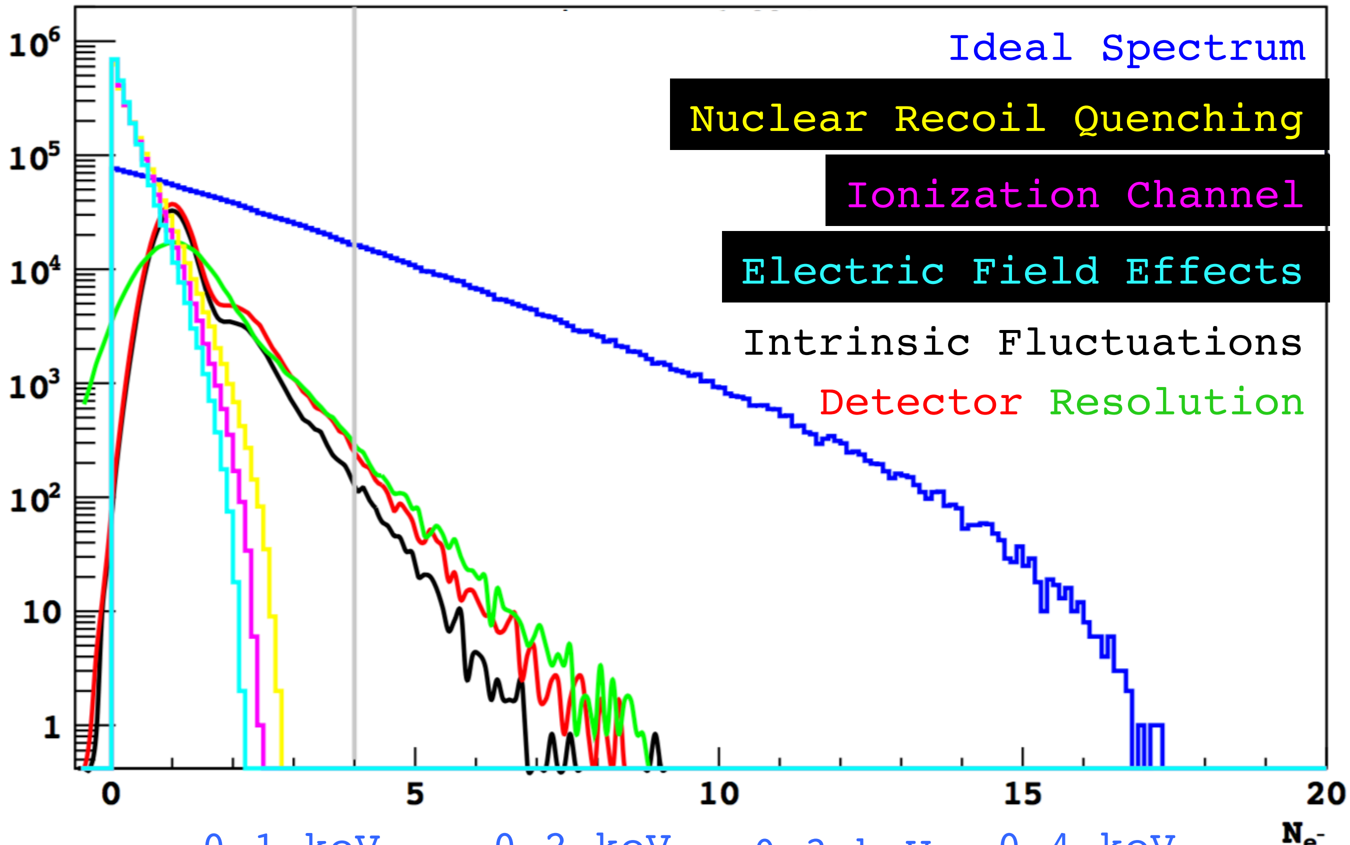


Nuclear Reoils: Thomas-Imel Model



What's next?

Ionization Signal in a Liquid Argon Target at 1 GeV WIMP Mass



Next Frontier:

- Ionization scale down to sub-keV
- Fluctuation models
- Recombination probability

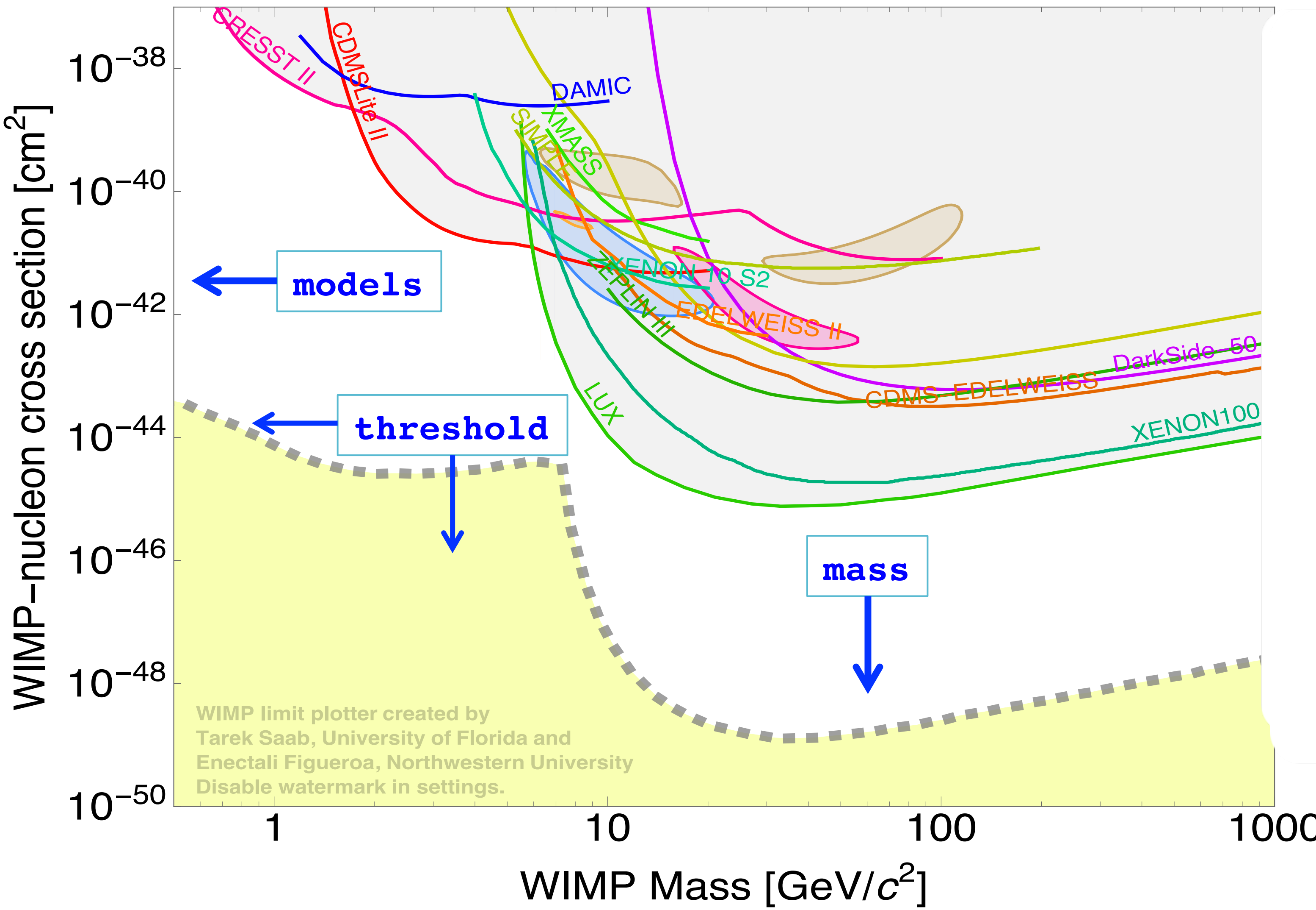
0.1 keV 0.2 keV 0.3 keV 0.4 keV

Visible Energy

0.6 keV 1.0 keV 1.7 keV 2.5 keV

Nuclear Recoil Energy

How to improve



Why Dark Matter @ ALTO?

Dark matter detectors need more and more accurate constraints of the different detector responses at lower and lower energies.

From my personal experience with ARIS, **ALTO is the ideal facility** for Dark Matter detector calibrations

- The **perfect beam**: pulsed
- The **perfect source**: p(^{7}Li,^{7}Be)n
- Add on of correlated **478 keV gammas**
- A **great team of engineers and physicists**: experienced and willing to help
- **Available equipment**: neutron detectors and electronics
- Plus a **mechanical workshop**

ALTO may play a major role in the dark matter field