7th Roma International Conference on AstroParticle Physics

*Rome, Italy, Sept. 4th - 7th 2018*

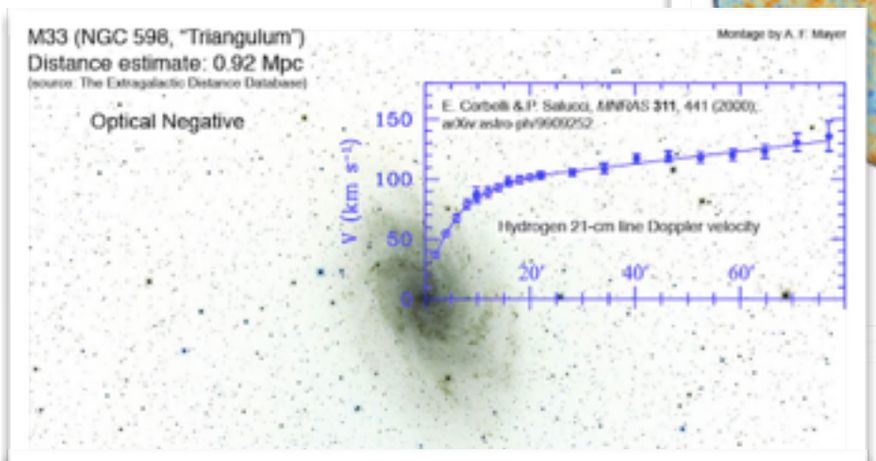
# ReD Status and Prospects

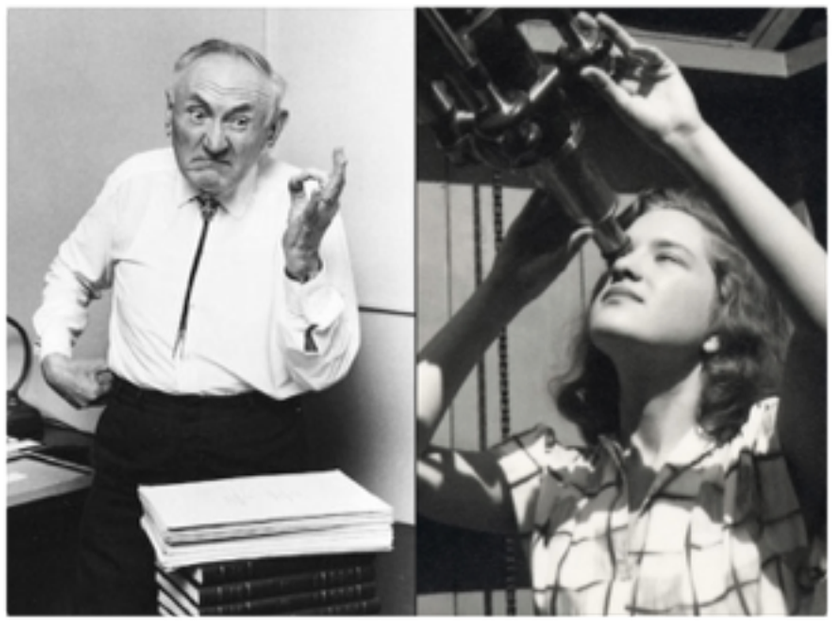
**Simone Sanfilippo**
Univ. & INFN Roma Tre
on behalf of ReD Working Group (DarkSide Collaboration)

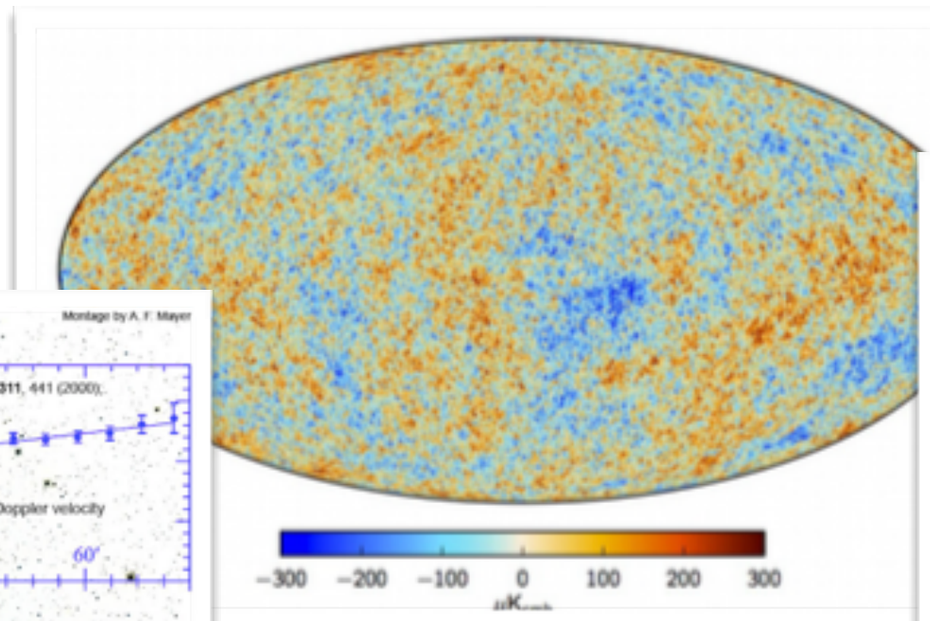
# Outline

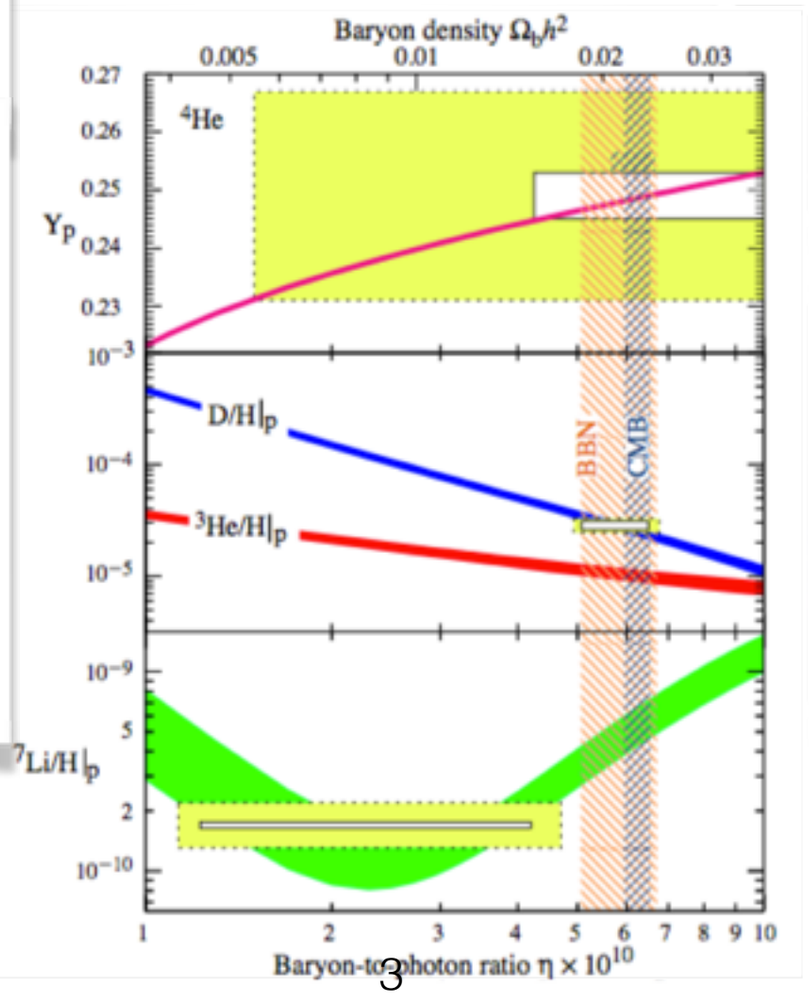
- **Dark matter on one slide**;
- The **DarkSide** program:
  - **Recoil Directionality** in Liquid Argon (LAr);
    - **SCENE**: a hint for directionality;
- The **ReD** experiment:
  - **installation at INFN - LNS** & alignment procedures;
  - **preliminary analysis**;
- **Conclusions**.

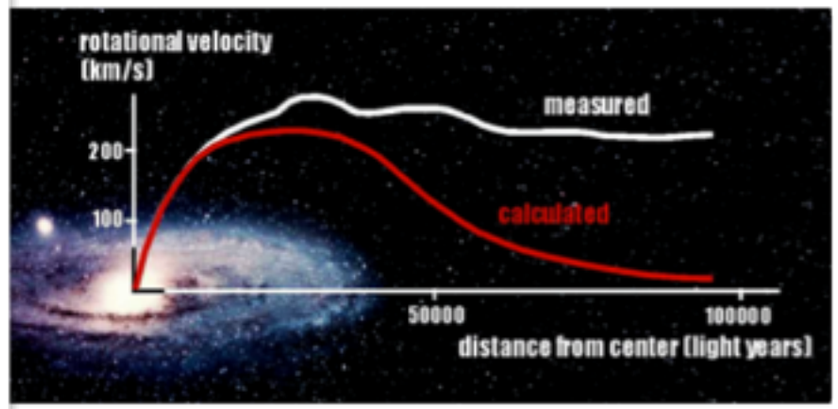
# Dark Matter on one slide



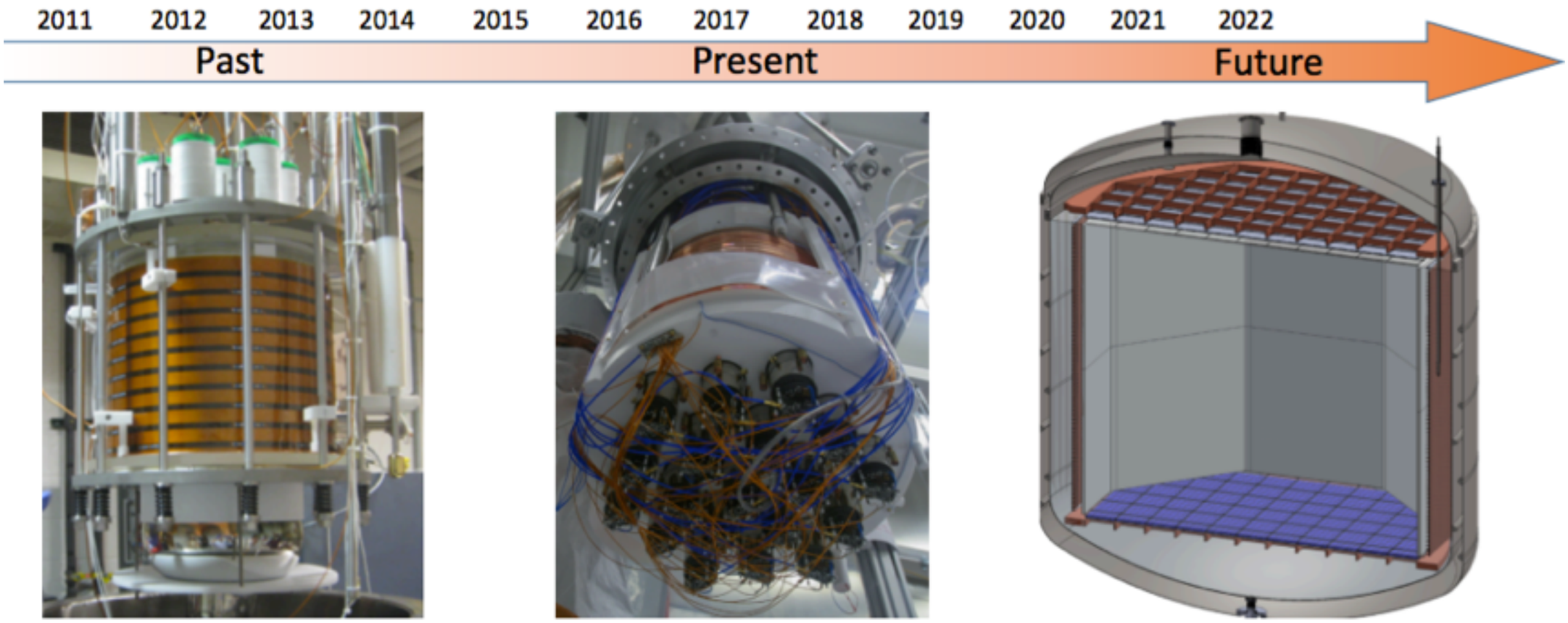





# The DarkSide program at LNGS

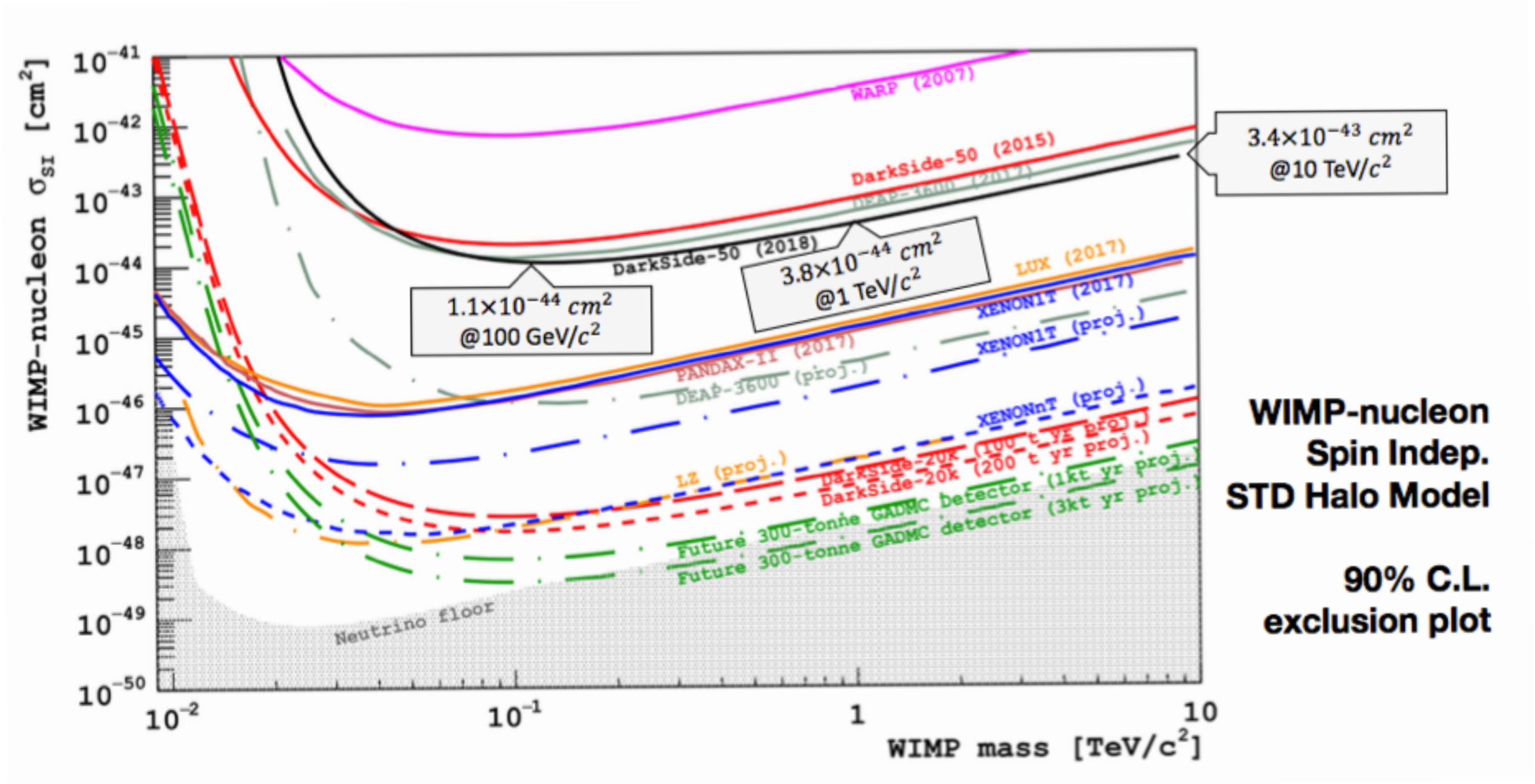



**DS-10**
technical prototype

**DS-50**
dark matter runs ongoing
$\sigma(\chi N) \sim 10^{-44}$ cm$^2$ @
WIMP mass 100 GeV/c$^2$

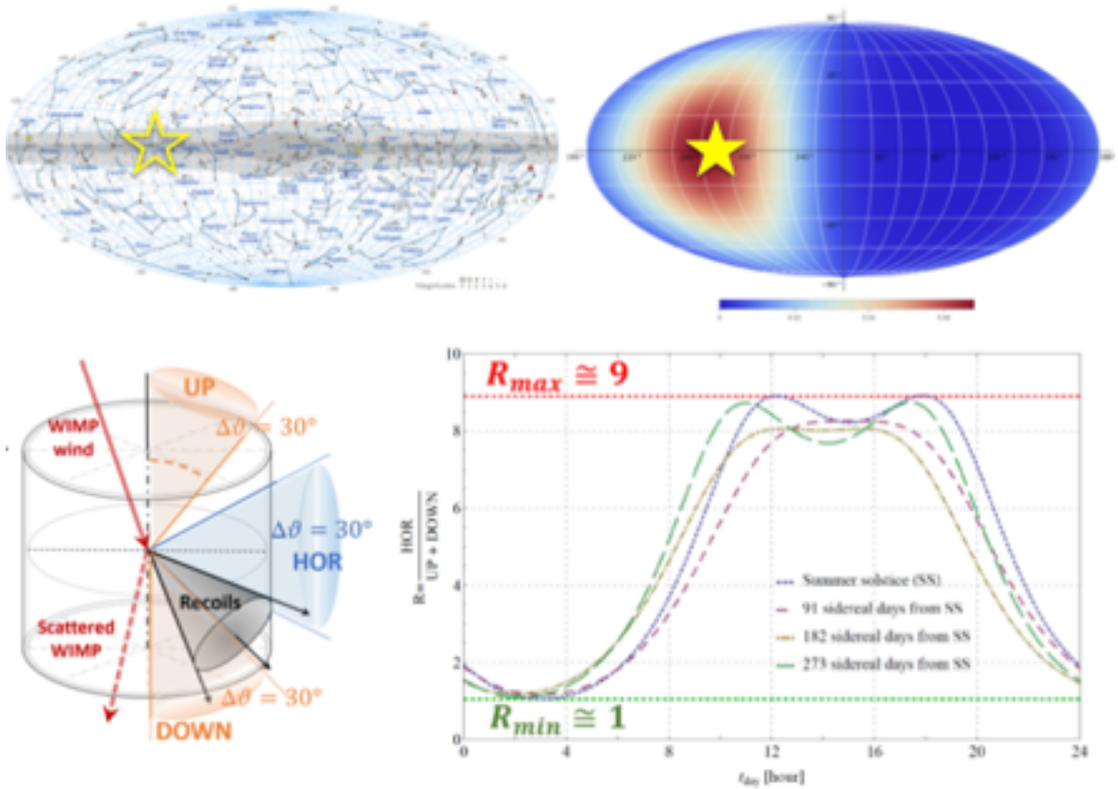
**DS-20k**
projected sensitivity
$\sigma(\chi N) \sim 10^{-48}$ cm$^2$ @
WIMP mass 100 GeV/c$^2$

# DarkSide recent results




arXiv:1802.07198v2 (submitted to Phys. Rev. D)

# ReD: Recoil Directionality in LAr

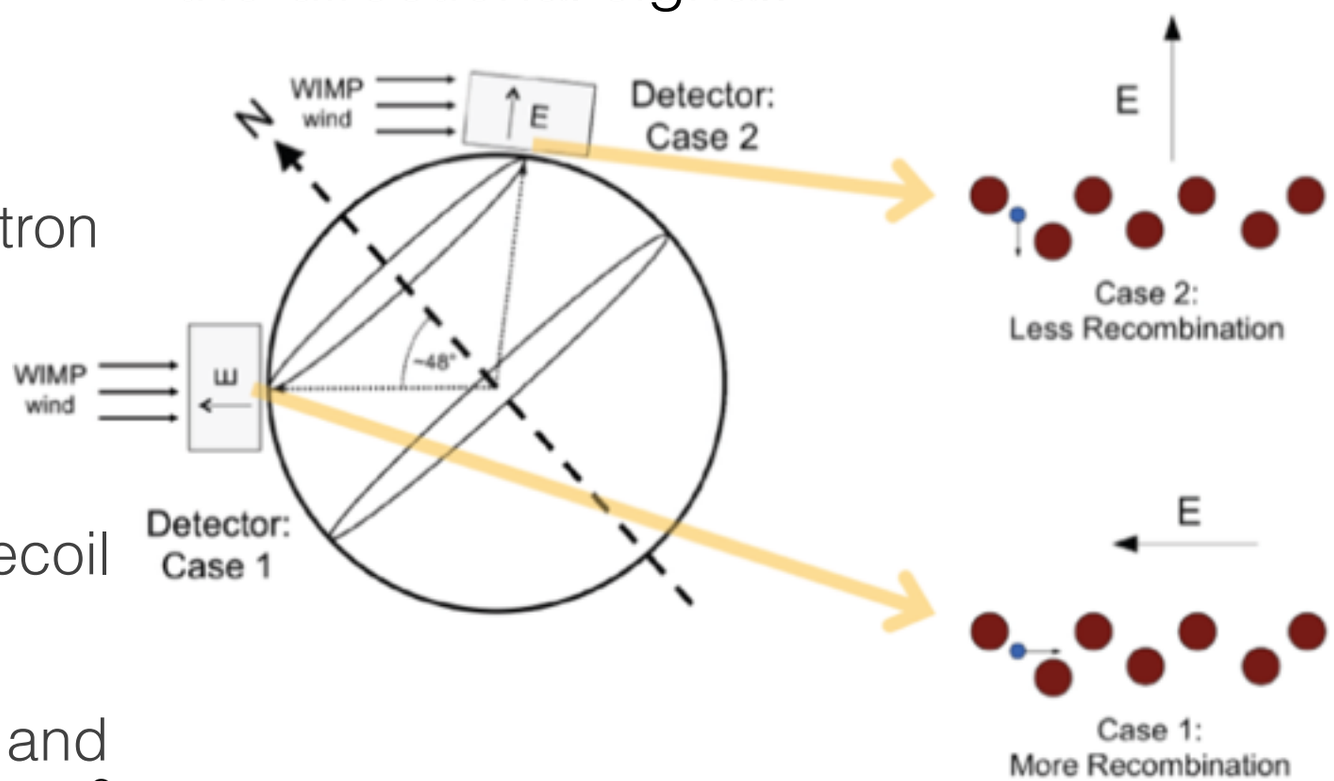



When a nuclear recoil is **parallel** to the electric field (Case 1), there will be **more** electron-ion recombination since the electron passes more ions as it drifts through the chamber.

Columnar recombination may display a sensitivity to the angle between nuclear recoil direction $\theta_R$ and drift field **E** in a LAr TPC:

- S1 and S2 expected to depend on **E** and $\theta_R$.

- **Sideral variation** of WIMP wind from Cygnus, results in a substantial **anisotropy** in nuclear recoils;
- Ratio of **horizontal** WIMP induced Ar recoils to **vertical** ones, varies of a factor 10 over the day;
- Hard for the background to mimic the directional signal.



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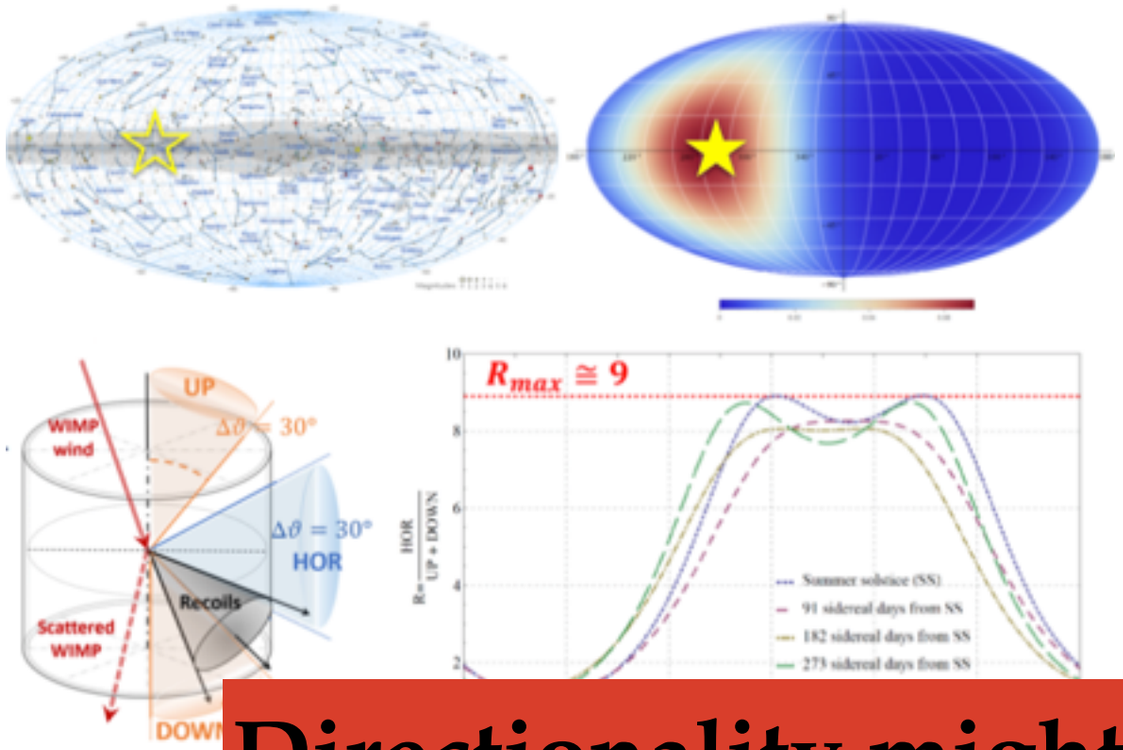





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**Directionality might be the key to discovery!**

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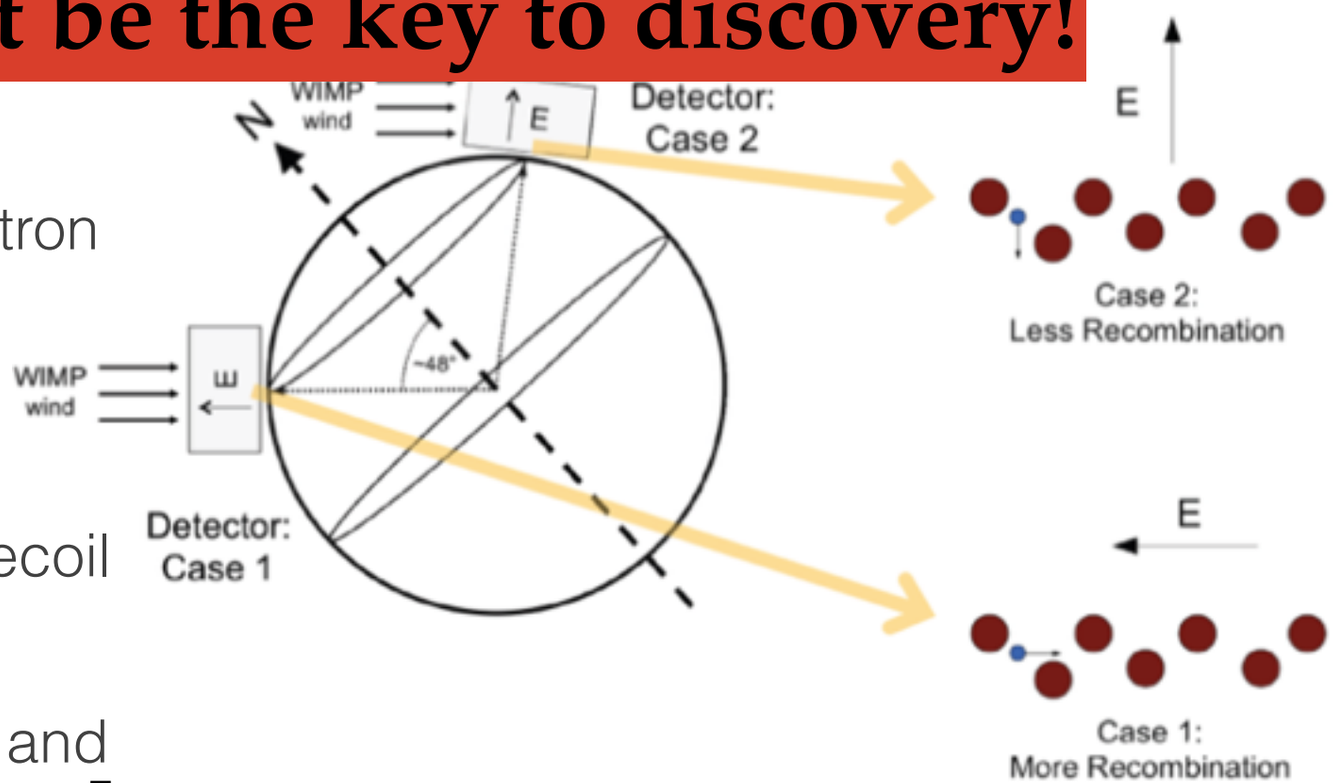
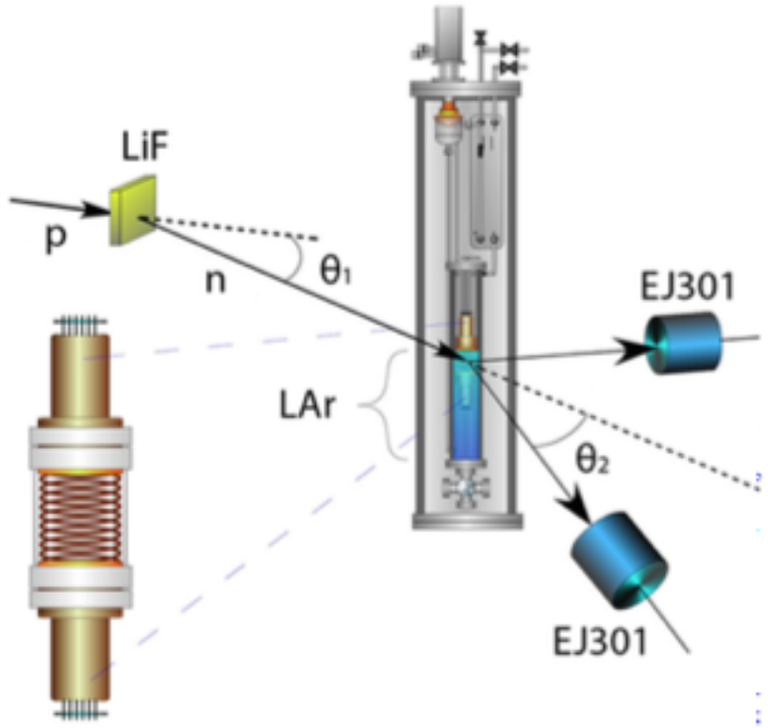


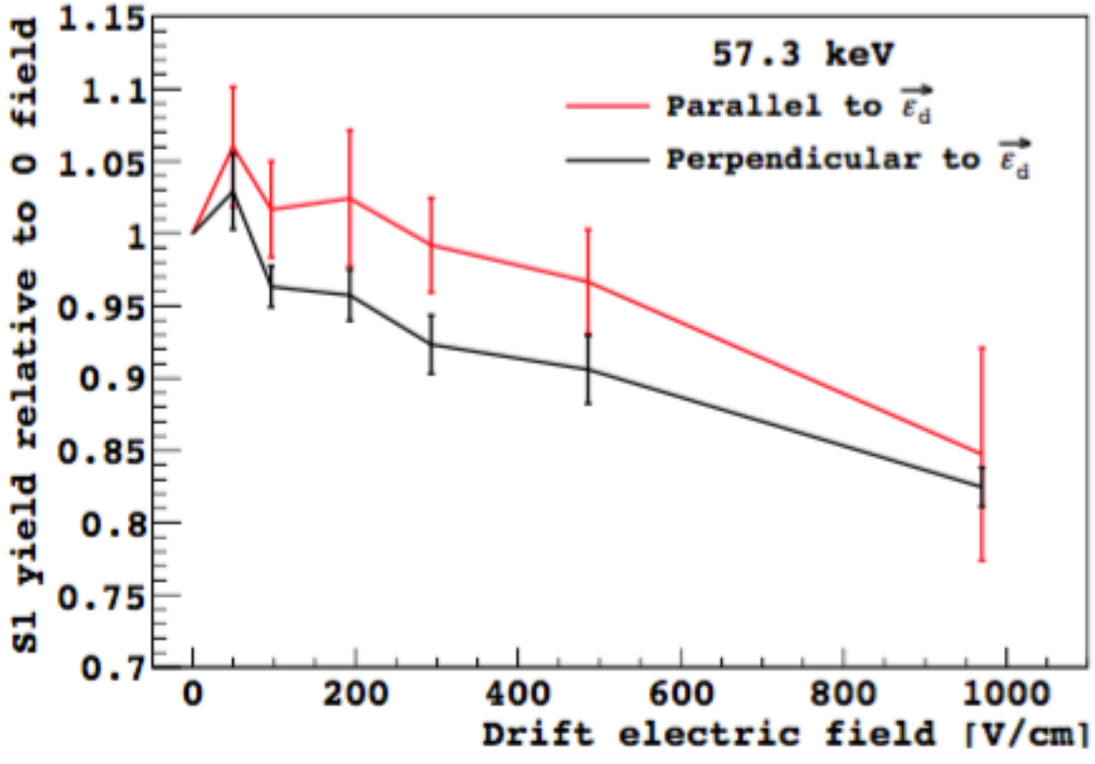
# SCENE: a hint for directionality

- **Main goal: characterize scintillation (S1) and ionization (S2) signals** produced by nuclear recoils **between 10.3 keV and 57.3 keV**;

- **How:** using a **monoenergetic neutron beam** impinging **on a small dual phase** Liquid Argon (**LAr**) Time Projection Chamber (**TPC**) with and without an applied electric field;

- **Bonus: for the first time the comparison of the light and charge yield of recoils parallel and perpendicular wrt electric field (direction sensitivity)**.




H. Cao et al. (The SCENE Collaboration), arXiv:1406.4825v4 (2015)

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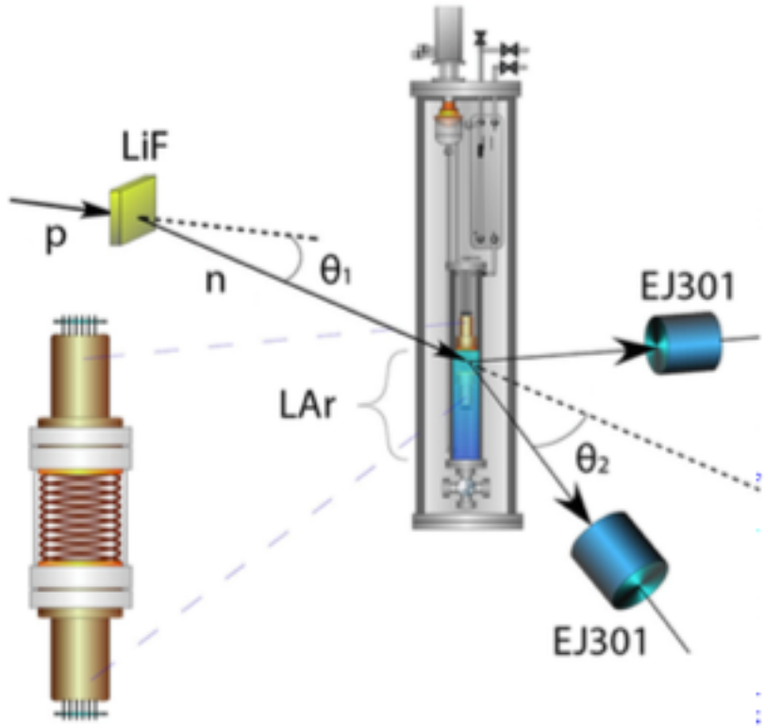
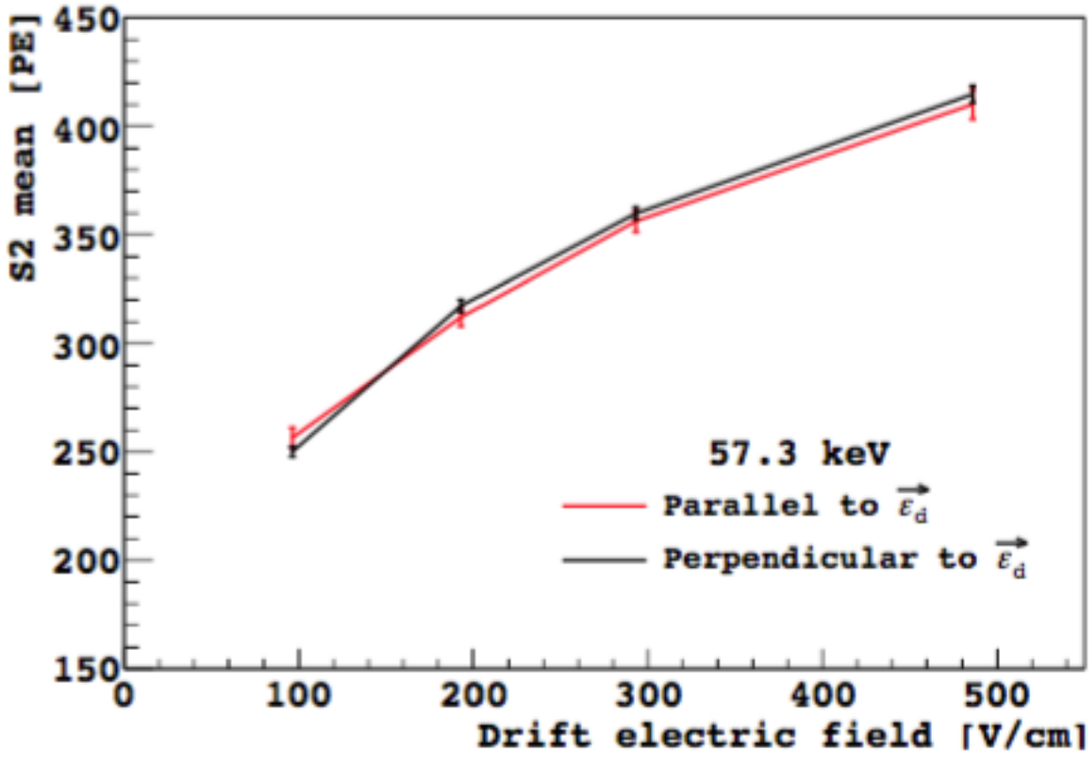
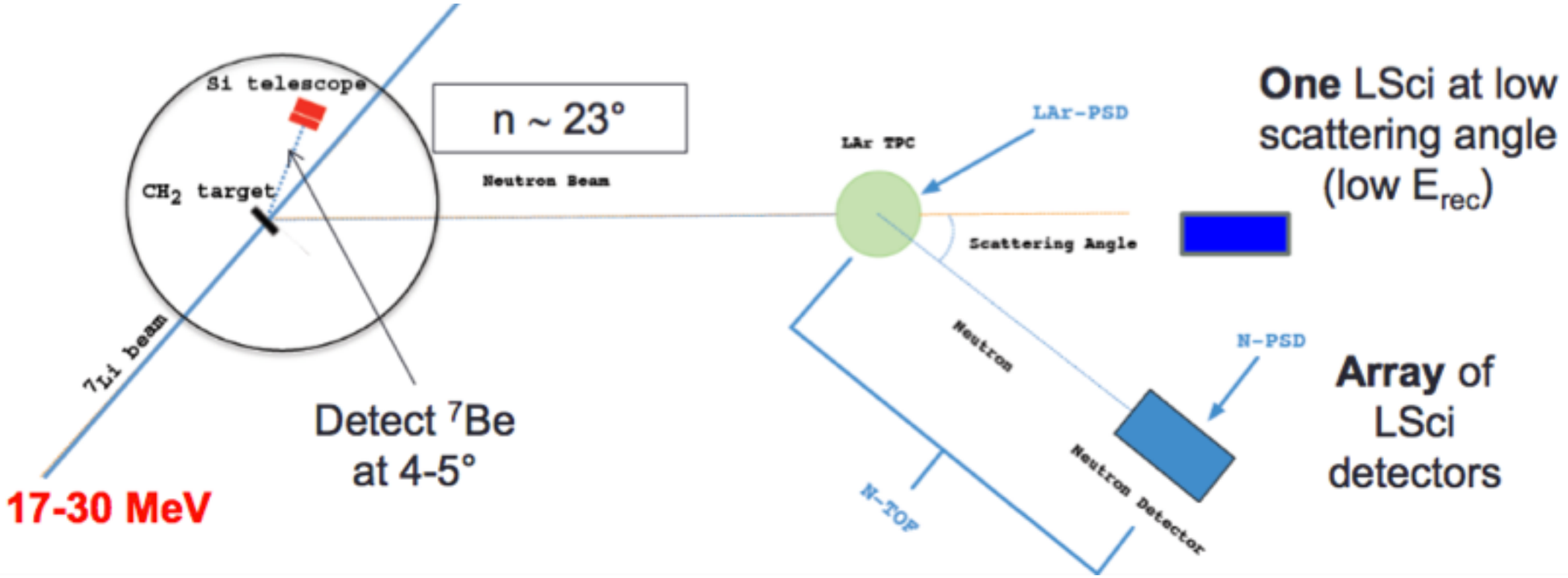


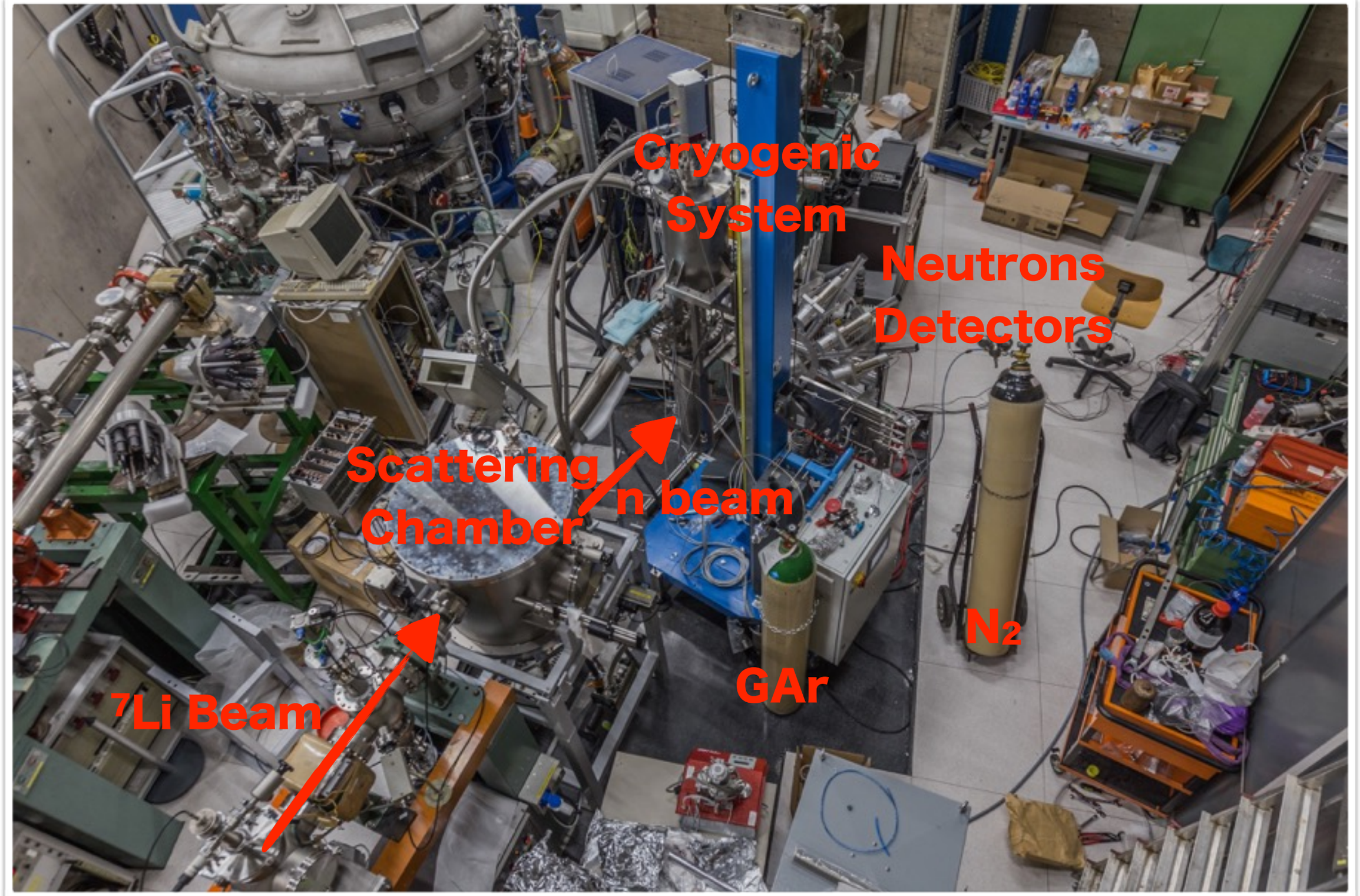

H. Cao et al. (The SCENE Collaboration), Phys. Rev. D 91 (2015) 092007

# The ReD experiment

- **Main goal:** irradiate a small LAr TPC with neutrons and produce **recoil parallel or orthogonal wrt the E field** in order to probe the **directionality of NR** in liquid argon;
- **How:** neutron beam is produced at **INFN - Laboratori Nazionali del Sud (LNS)** in Catania by the **15 MV Tandem** via the **p($^7$Li,$^7$Be)n** reaction;
- **Bonus: direct measurement of low energy nuclear recoil** with the same TPC by tuning appropriately the beam and the geometry setups.

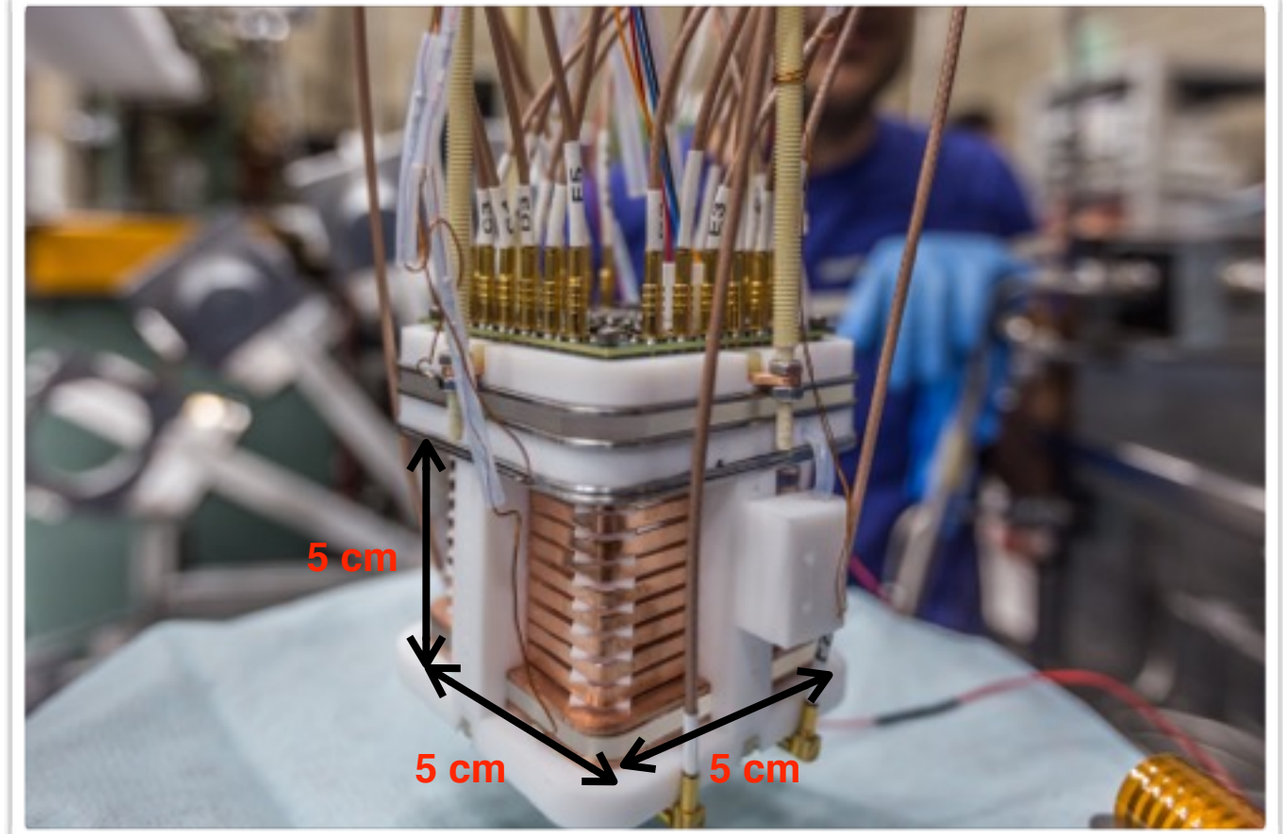


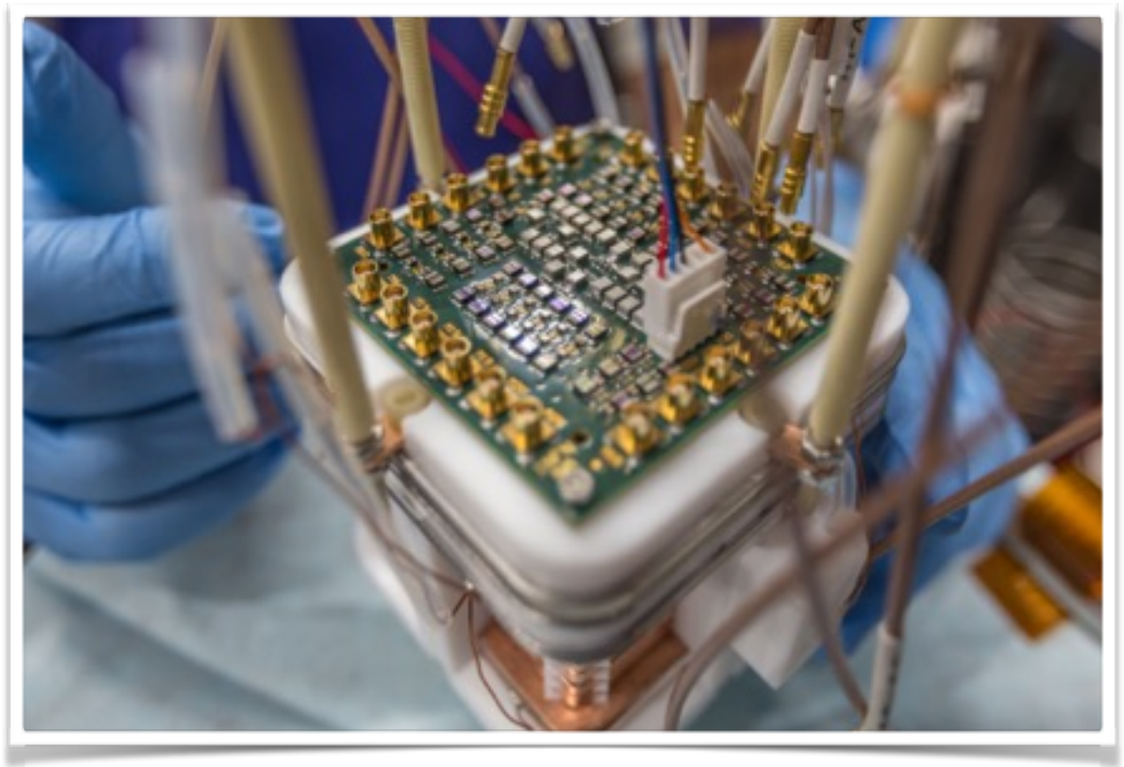
# The LNS setup



# The TPC

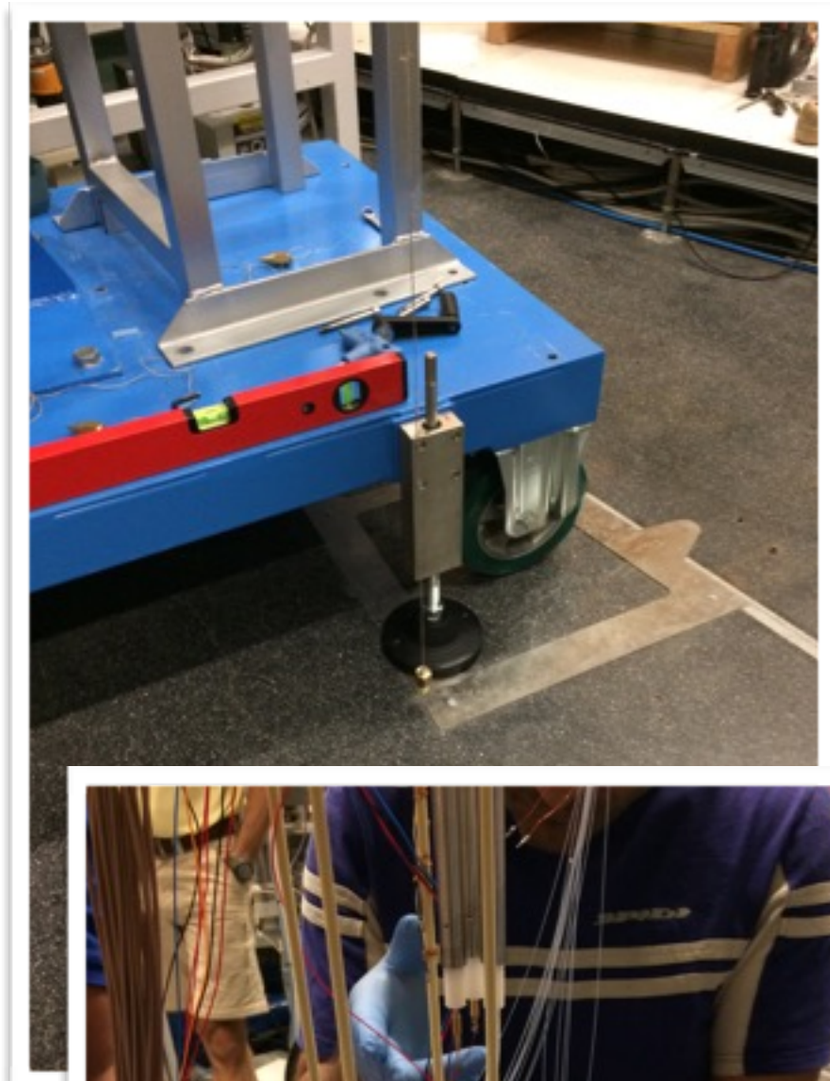
- **Explicitly designed for ReD at UCLA** (CA,US);
- **5x5x5 cm dual-phase LAr TPC**:
  - Teflon with 3M Reflector + TPB coating;
- **New SiPMs light readout** at cryogenic temperatures:
  - **key test for future DarkSide-20k detector**

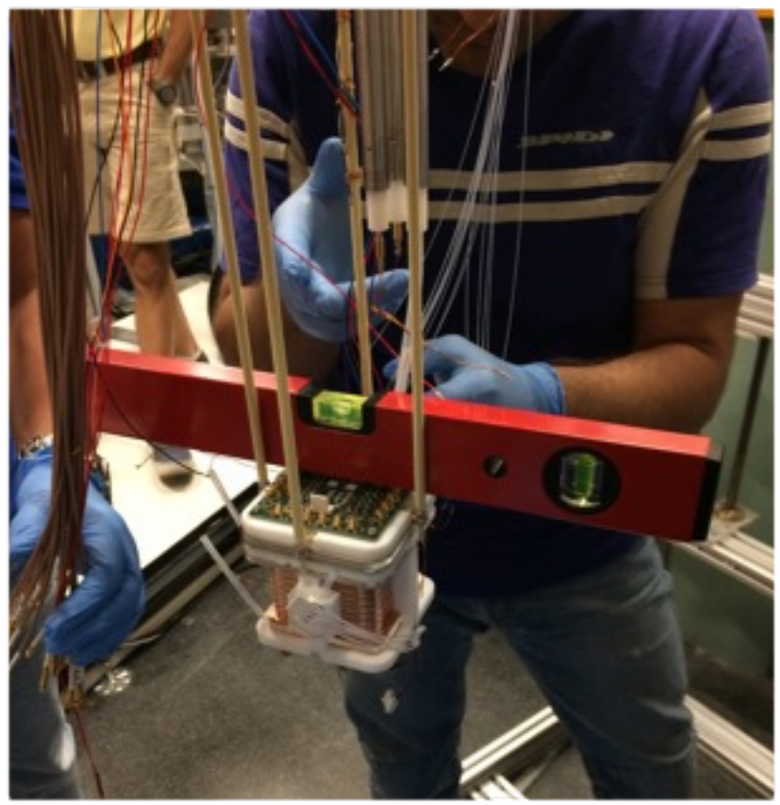


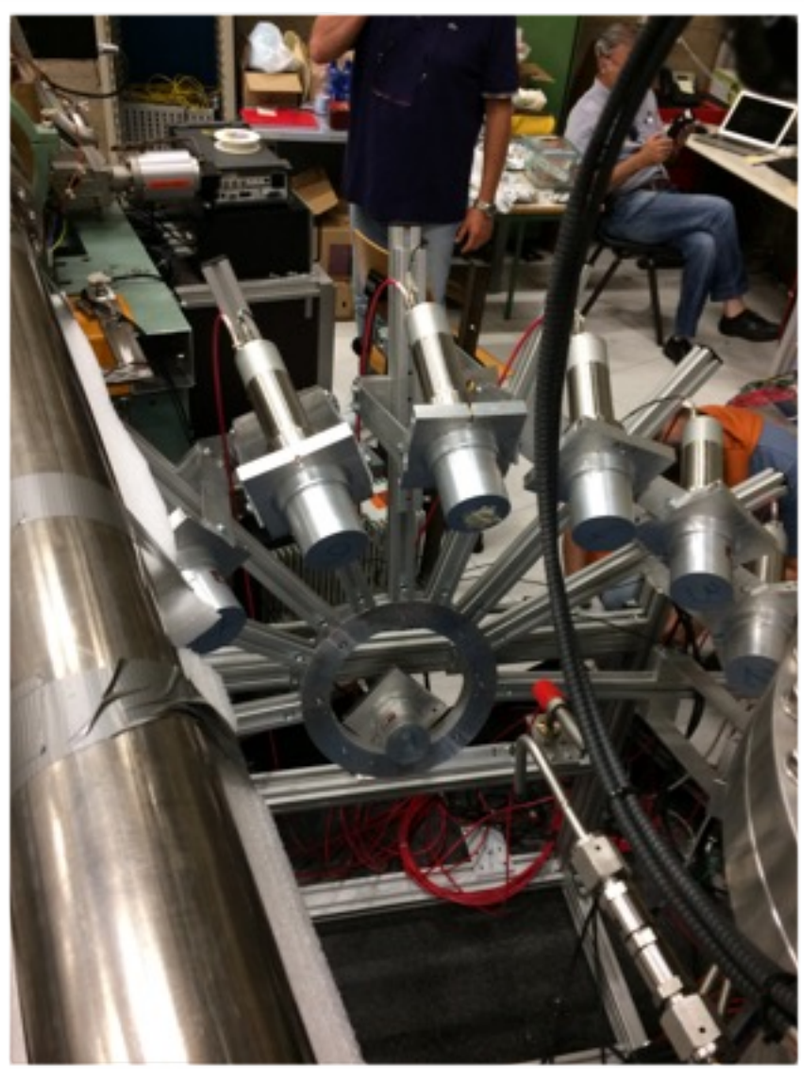



- 24 x 1 $cm^2$ **FBK** SiPM with **24ch readout** on the **TOP** of the TPC
  - **Readout board made by INFN-NA**, with the collaboration of **INFN-BO** and **LNGS**
- 24 x 1 $cm^2$ **FBK** SiPM with **4ch readout** on the **BOTTOM** of the TPC

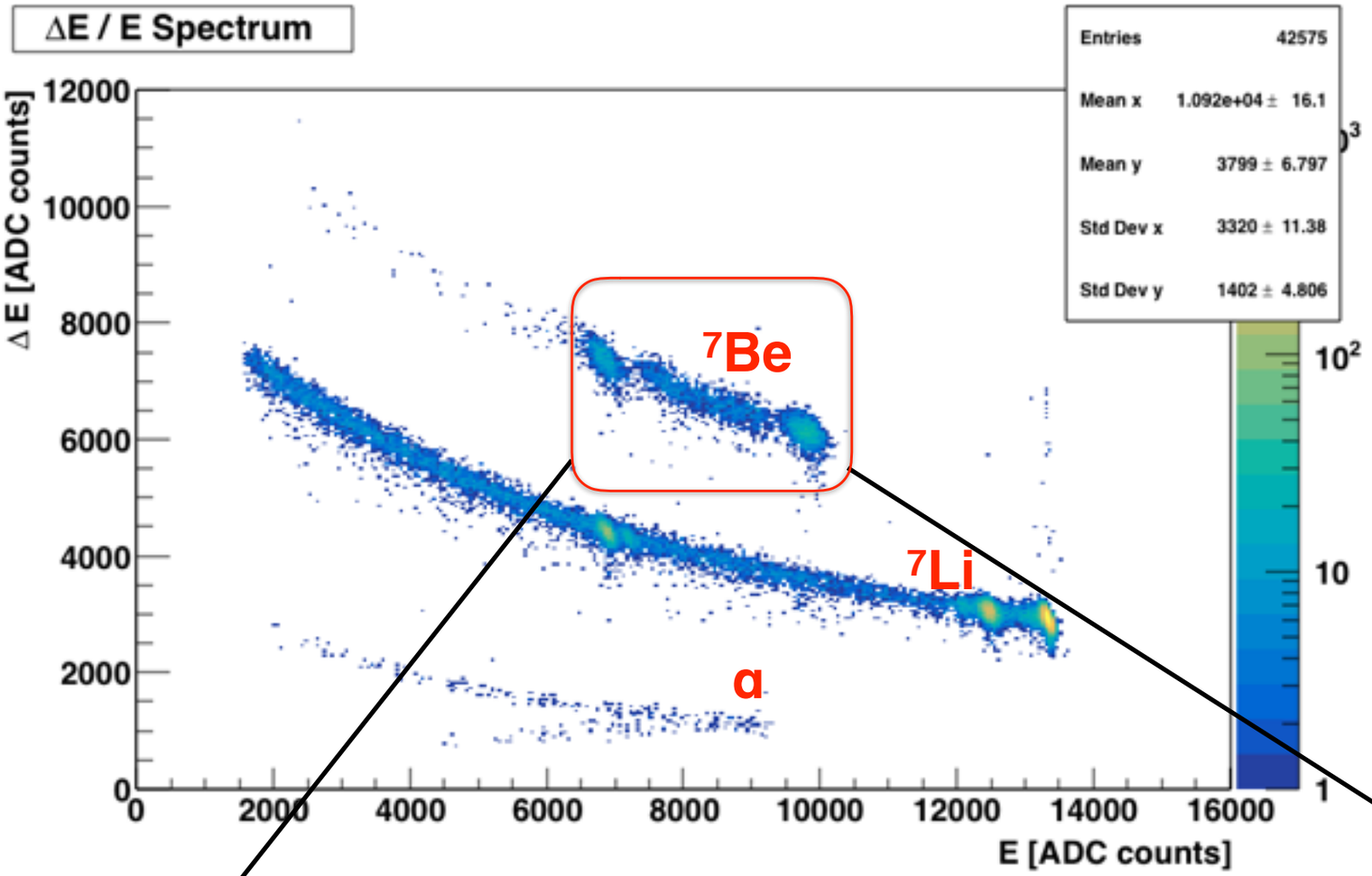
# Alignment procedures



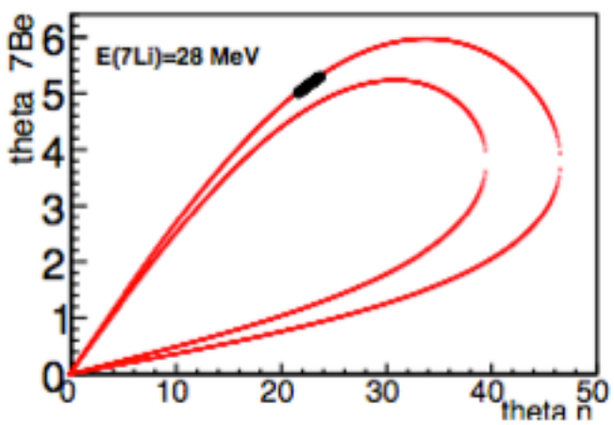


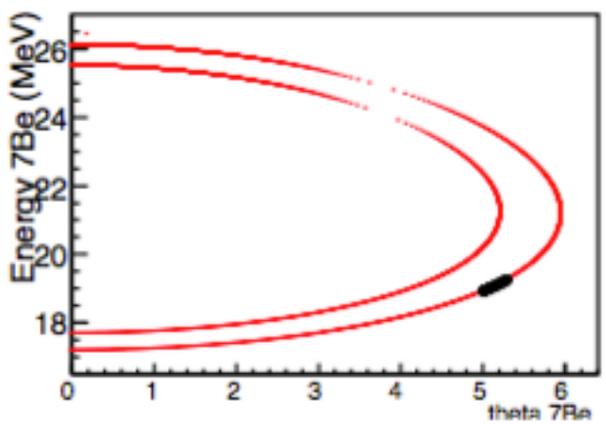


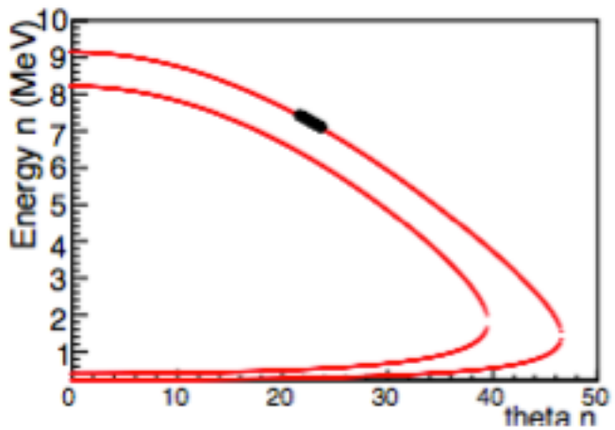
# Preliminary Analysis



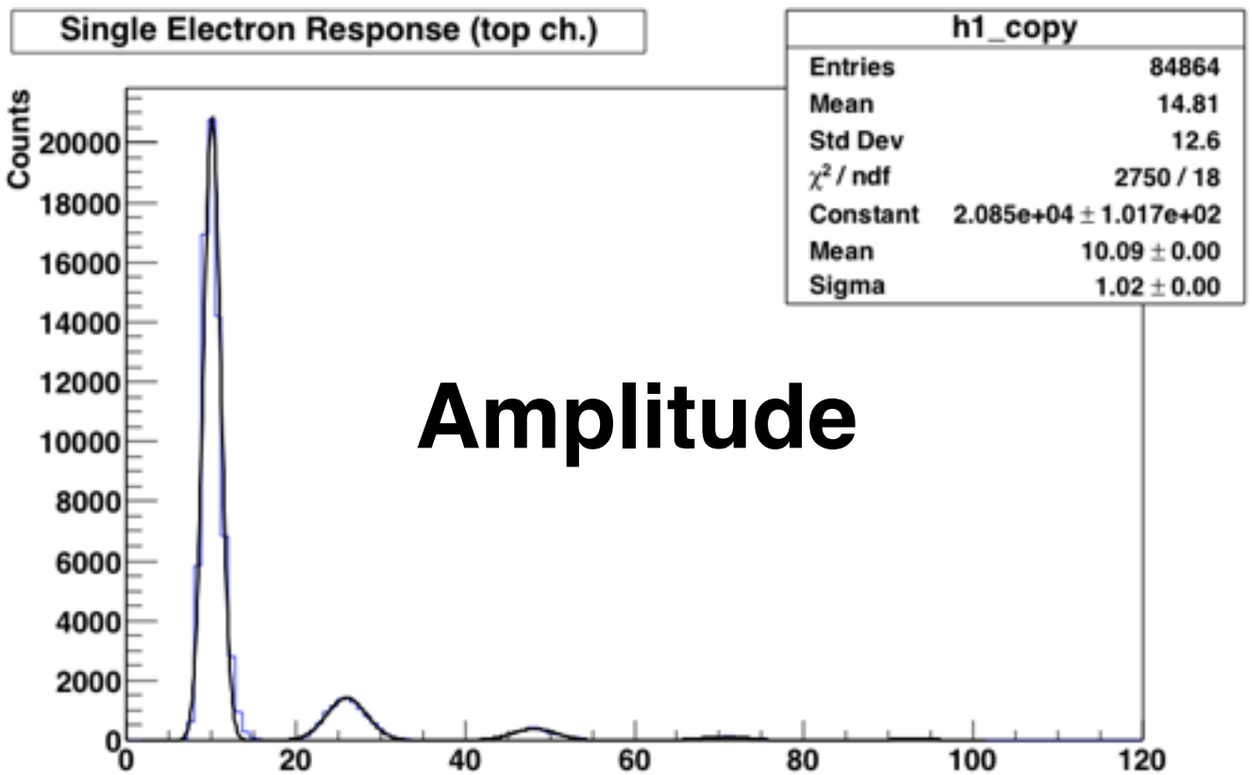

- **p(⁷Li,⁷Be)n @ 28 MeV ⁷Li**
- **tag ⁷Be @ 5 deg** in order to be sure to select **neutrons** with selected energy (**~ 7 MeV**) wrt TPC position (~ 22 deg)

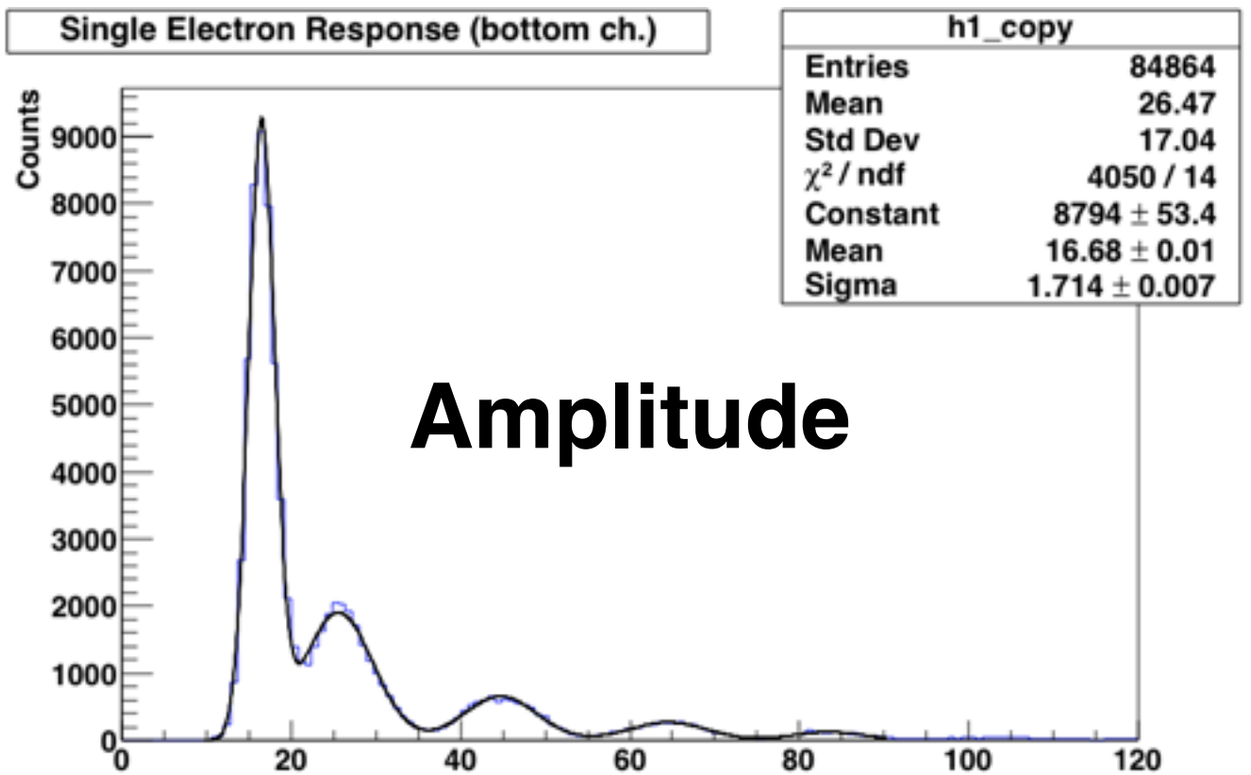


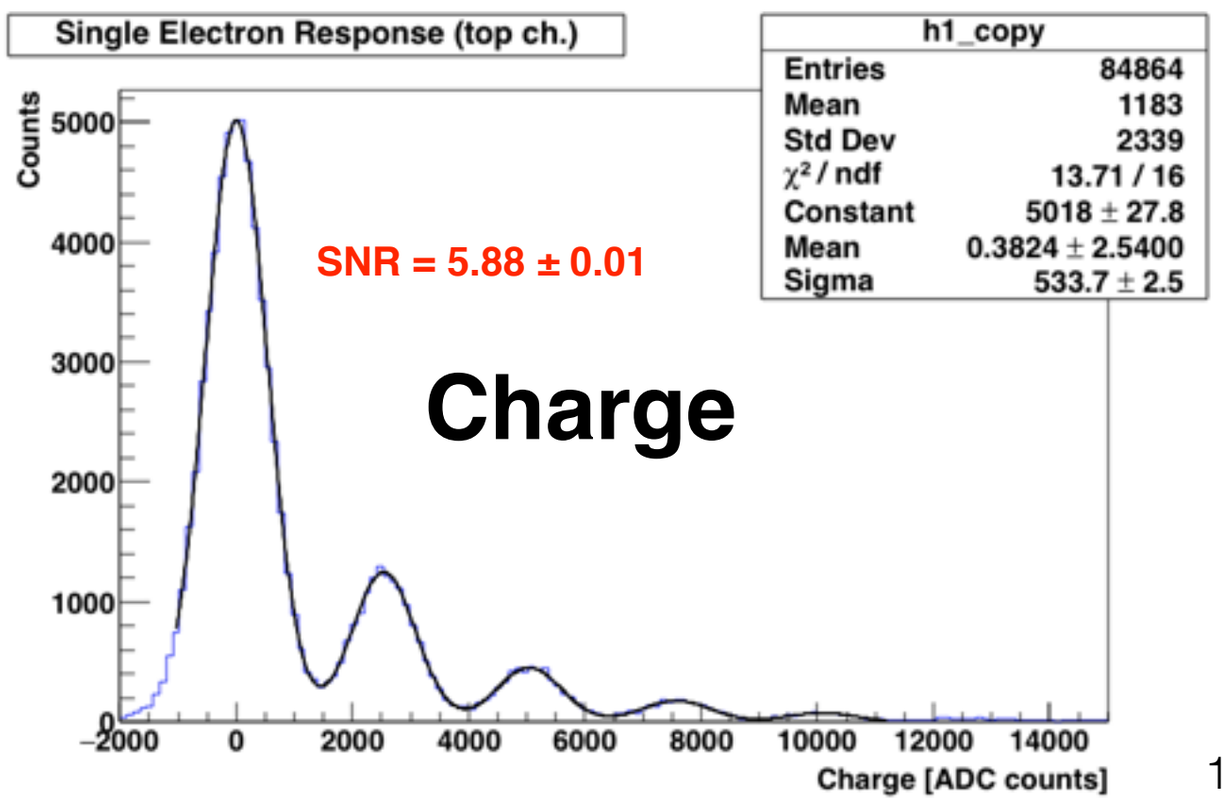



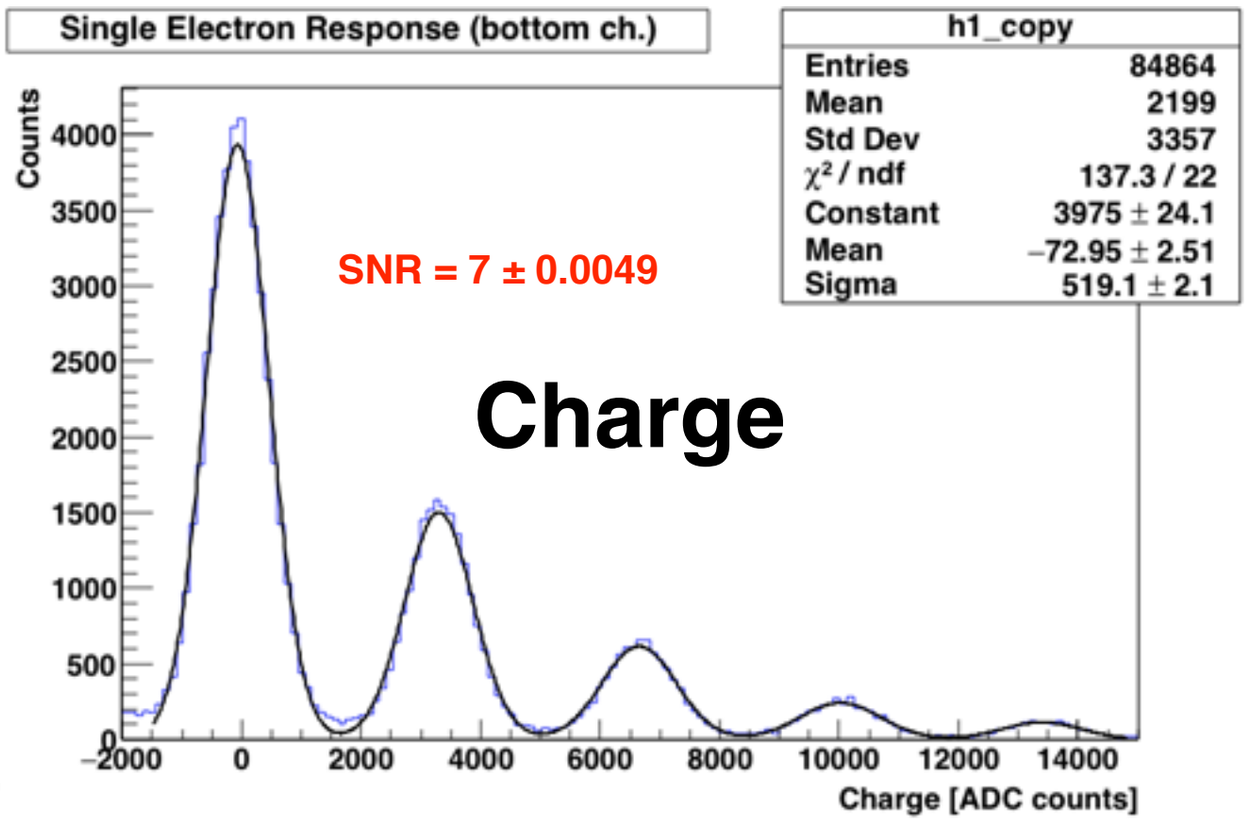



# Preliminary Analysis: Single Electron Response



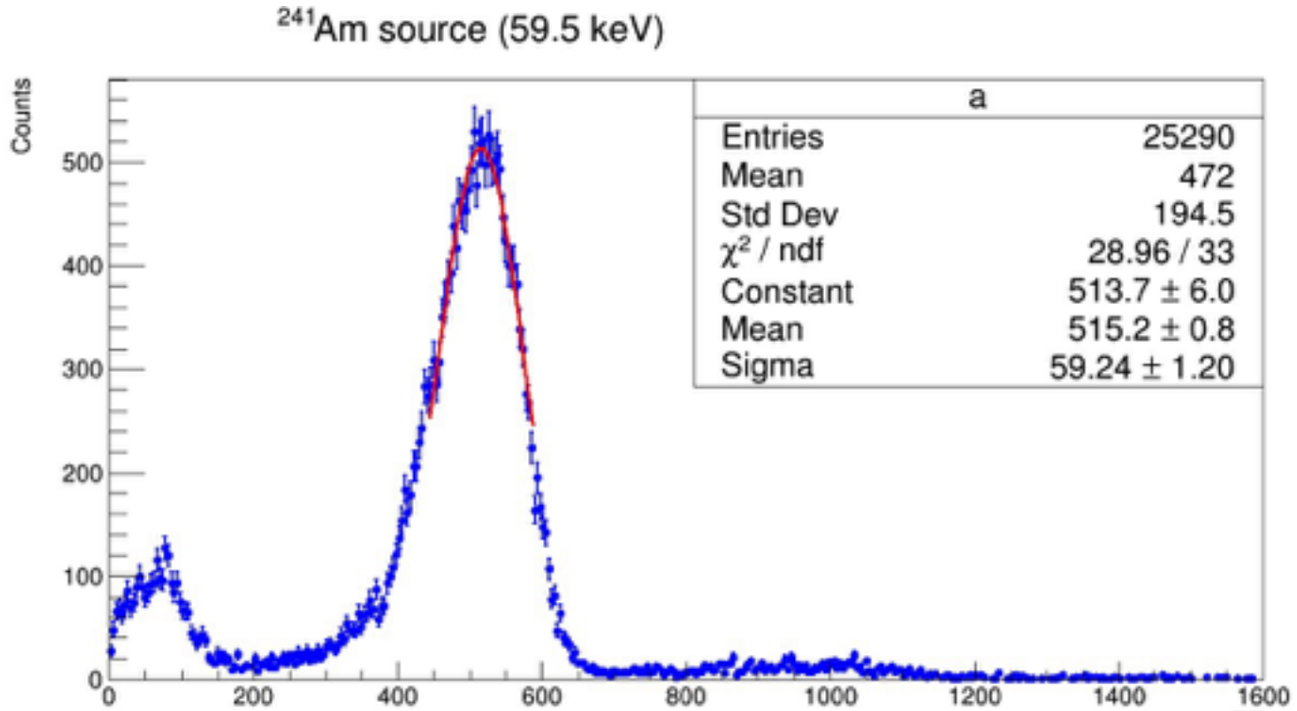



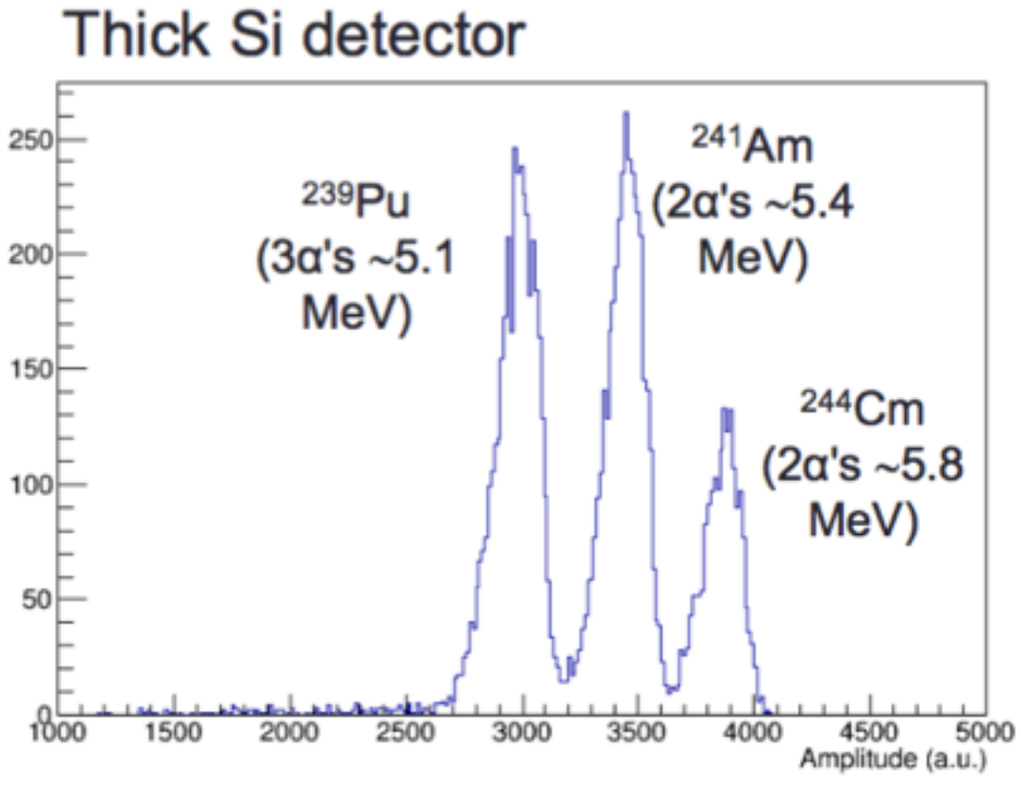



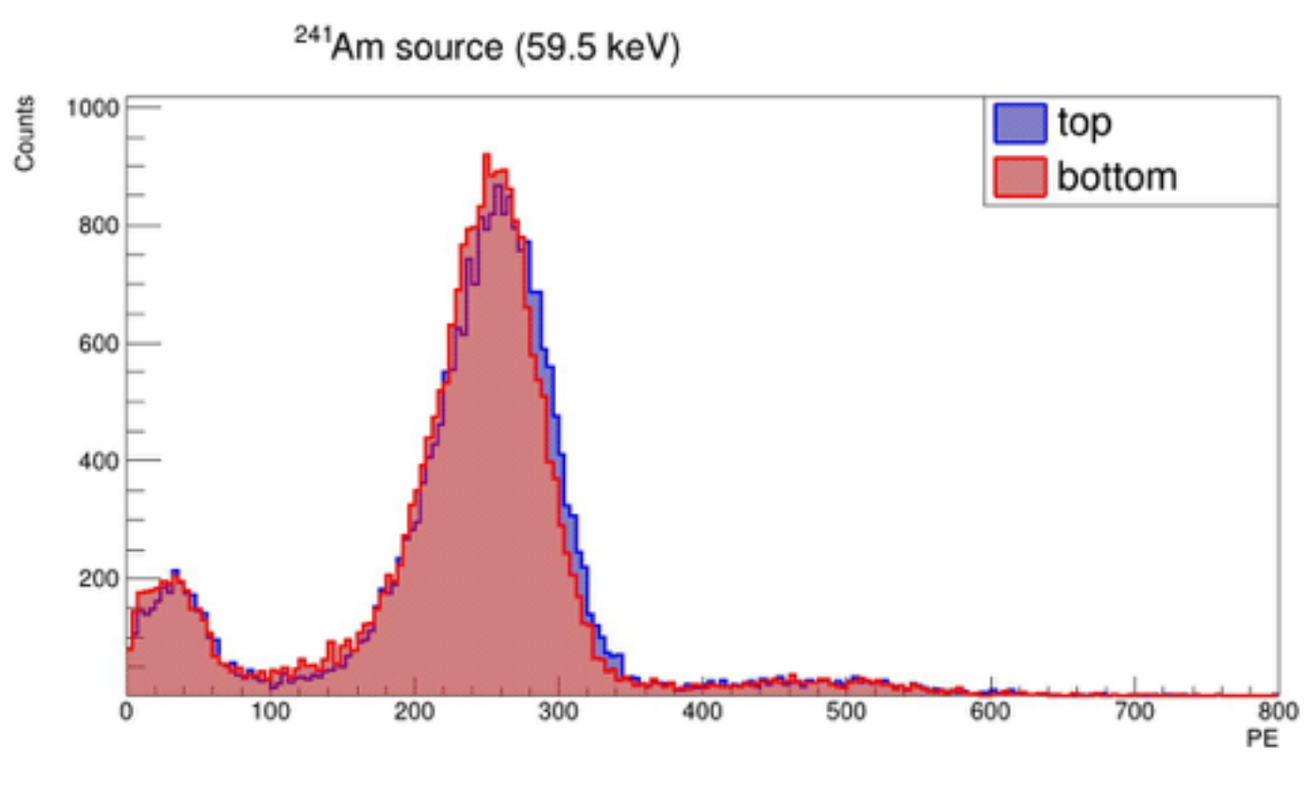



# Preliminary Analysis: Calibration Sources

- **$^{241}$Am source** (59.5 keV):
  - **Total light yield** at null field **8.6 phe/keV**;
  - Top/bottom spectra are **OK**;
- **3 peaks α source**.

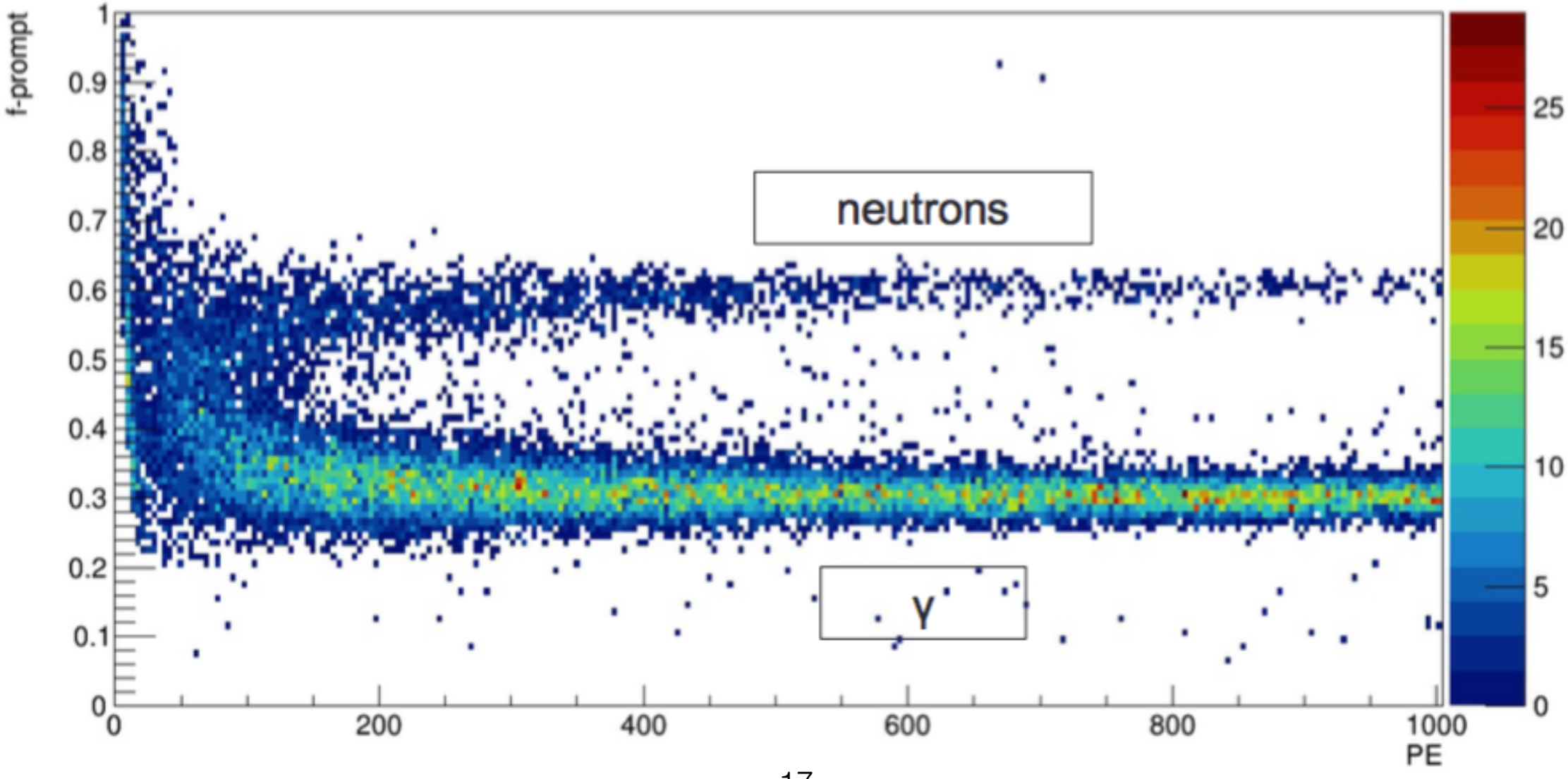


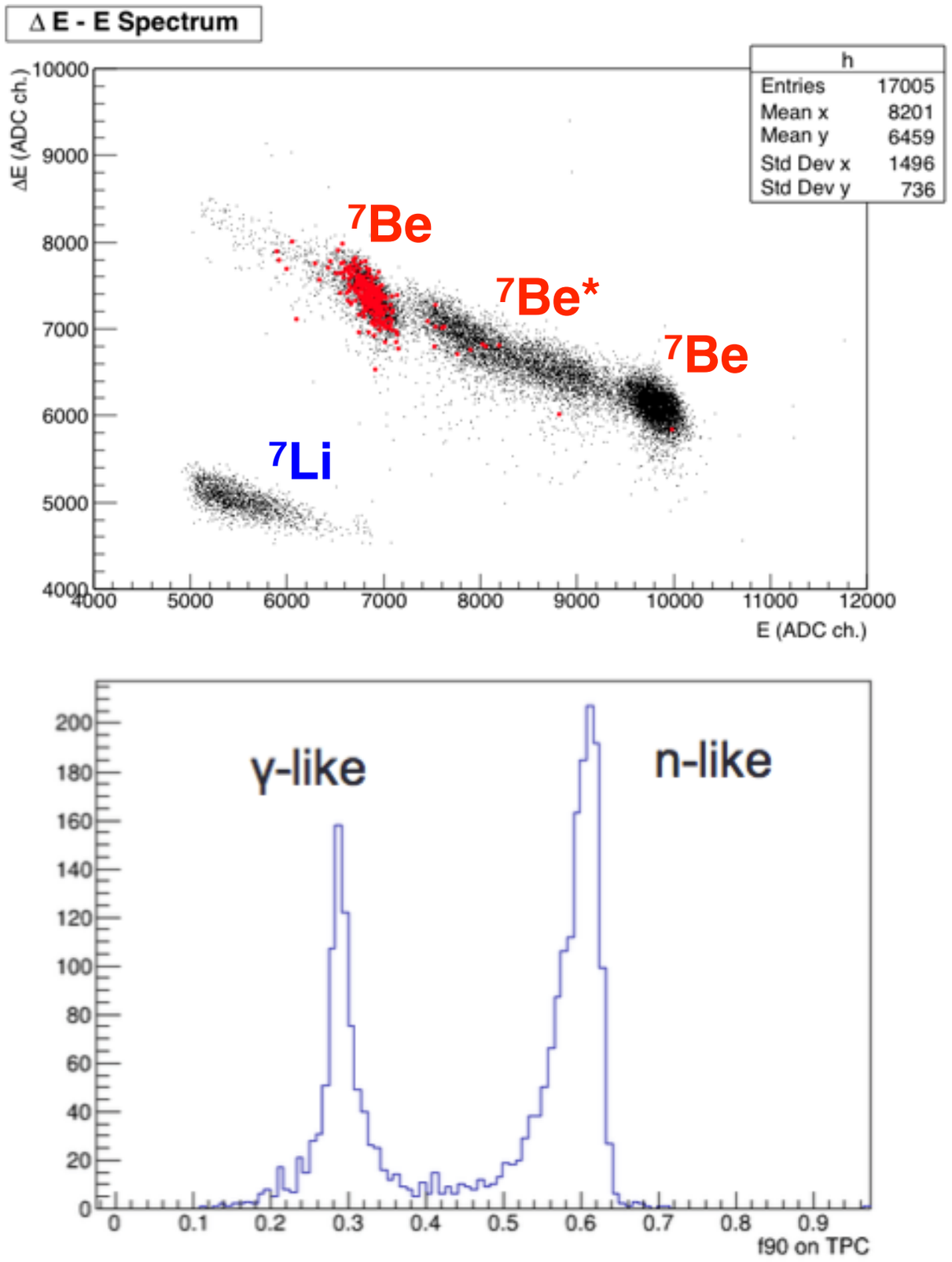
# Preliminary Analysis: Calibration Sources

- Calibration with a **$^{252}$Cf neutron source**:
  - Check of **LAr Pulse Shape Discrimination (PSD)**



# Preliminary Analysis: Si AND TPC

- Runs in **sigle phase**;
- events in **coincidence** between **Si and TPC** are mostly associated with the **"proper"** $^{7}$Be locus:
  - **a few accidentals** in the other $^{7}$Be and in the $^{7}$Li blobs;
- events in the TPC are largely due to **neutron-induced recoils** (based on LAr PSD).



# Conclusions

- **Successful installation and alignment** of the entire ReD setup at INFN - Laboratori Nazionali del Sud (LNS) in Catania (thanks to all the technicians involved during the operations, too);

- **More than 12 people** from different INFN sections **involved** for a total period of 3 weeks (installation + data taking);

- **About 100 runs taken** in different conditions  (beam ON/OFF, calibration sources, laser):

  - ~ **6 TB** of data on disk;

- **Analysis in progress**;

- **Next scheduled beam time: 24 September - 01 October 2018**;

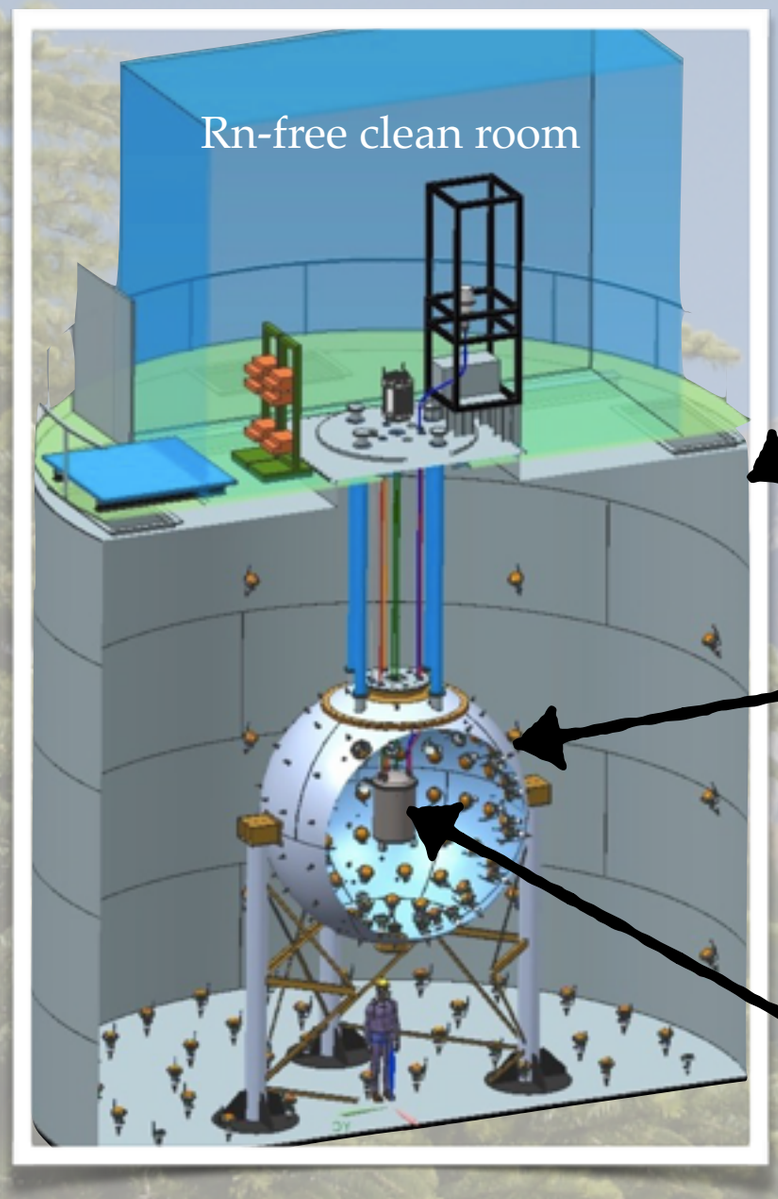
  - last slot for 2018;

  - going to ask for beam time in 2019.

ENJOY THE DARK SIDE!

# Backup

# DarkSide-50



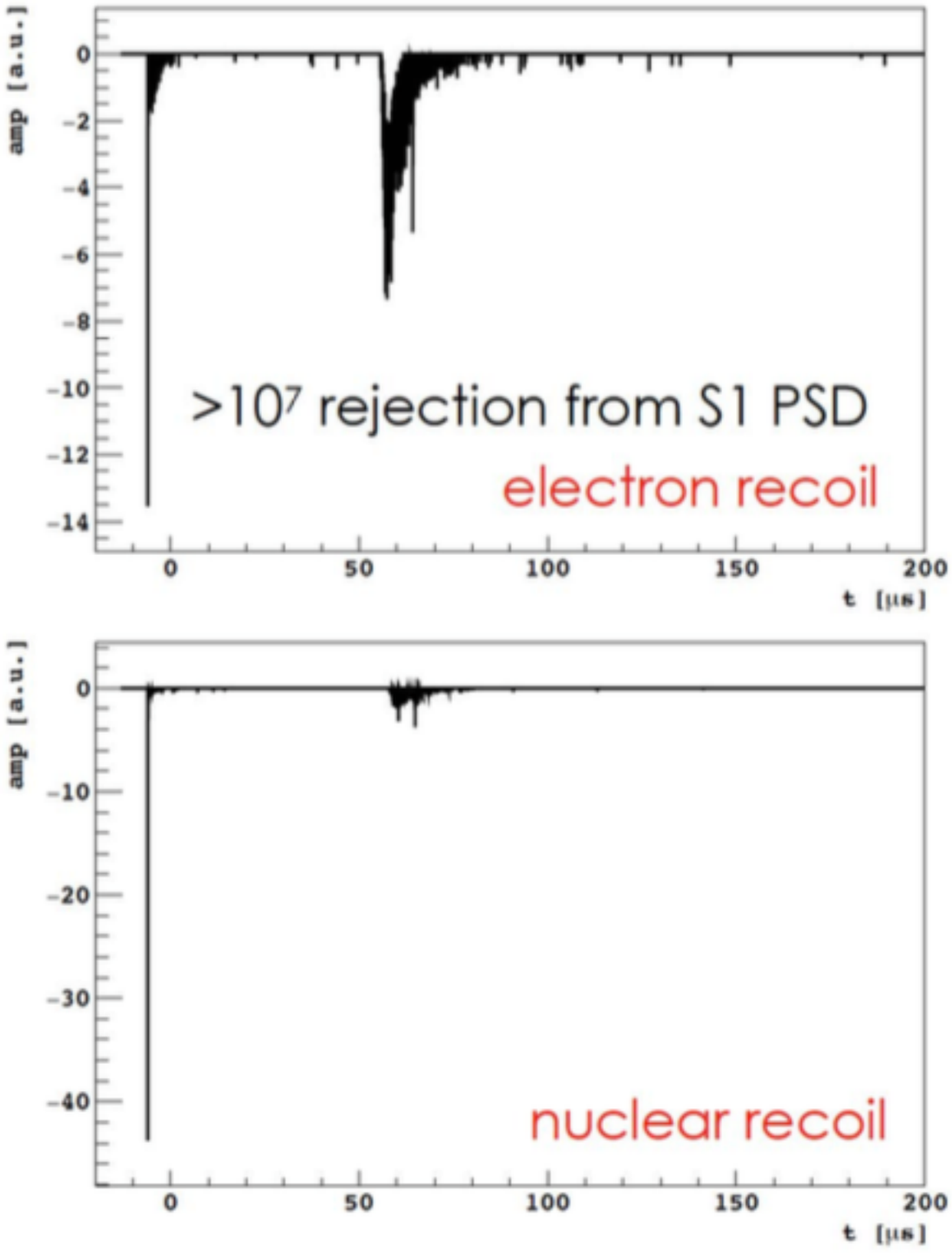

The Gran Sasso massif provides 3800 m.w.e. passive shielding against cosmic rays

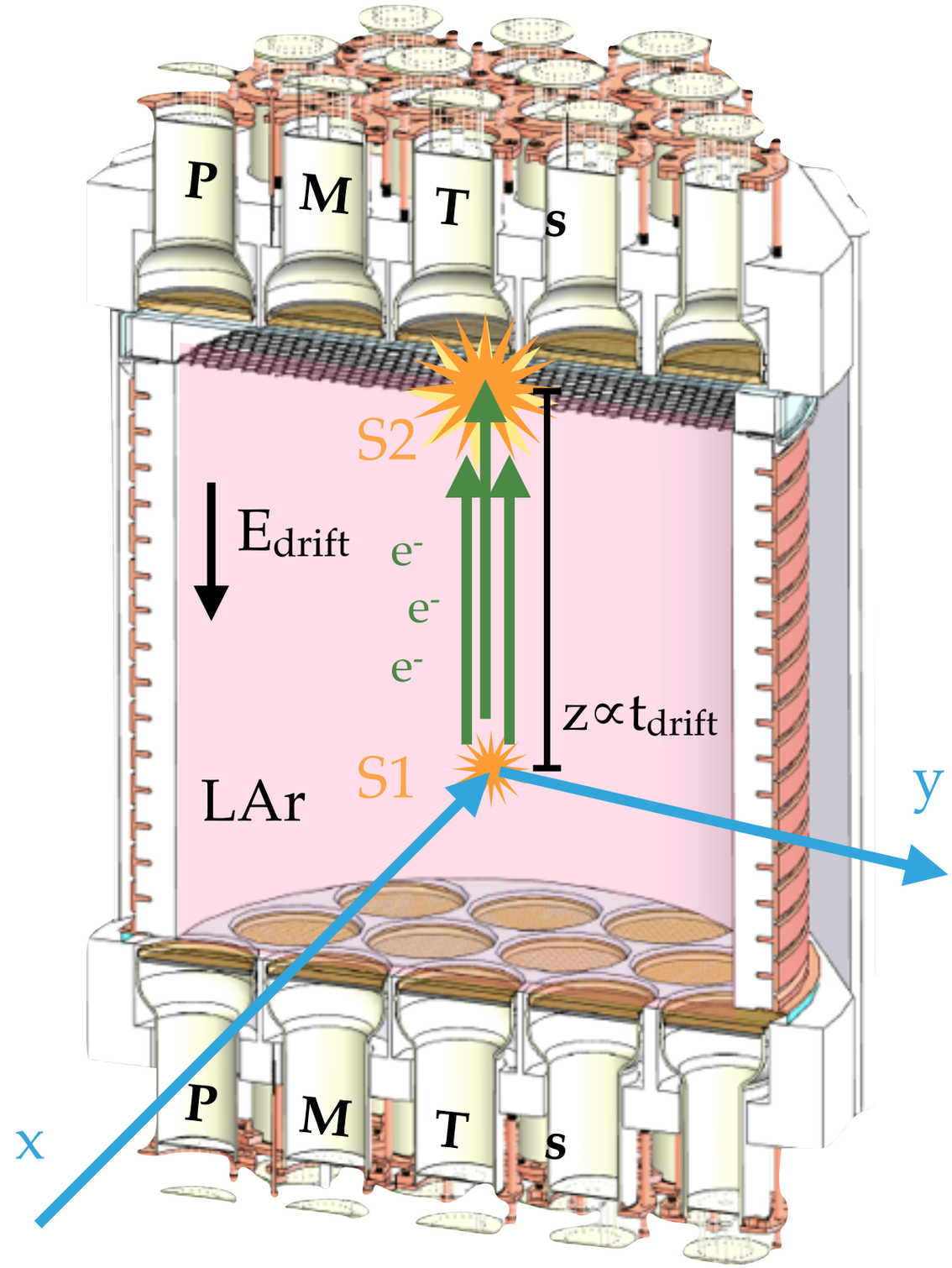
11m-diameter, 10m-tall, 1 kt Water Čerenkov Detector (WCD) instrumented with 80 8”-PMTs provides active shielding against μ’s

4m-diameter 30 t borated Liquid Scintillator Veto (LSV) instrumented with 110 8”-PMTs provides additional active shielding against γ’s, n’s and μ’s

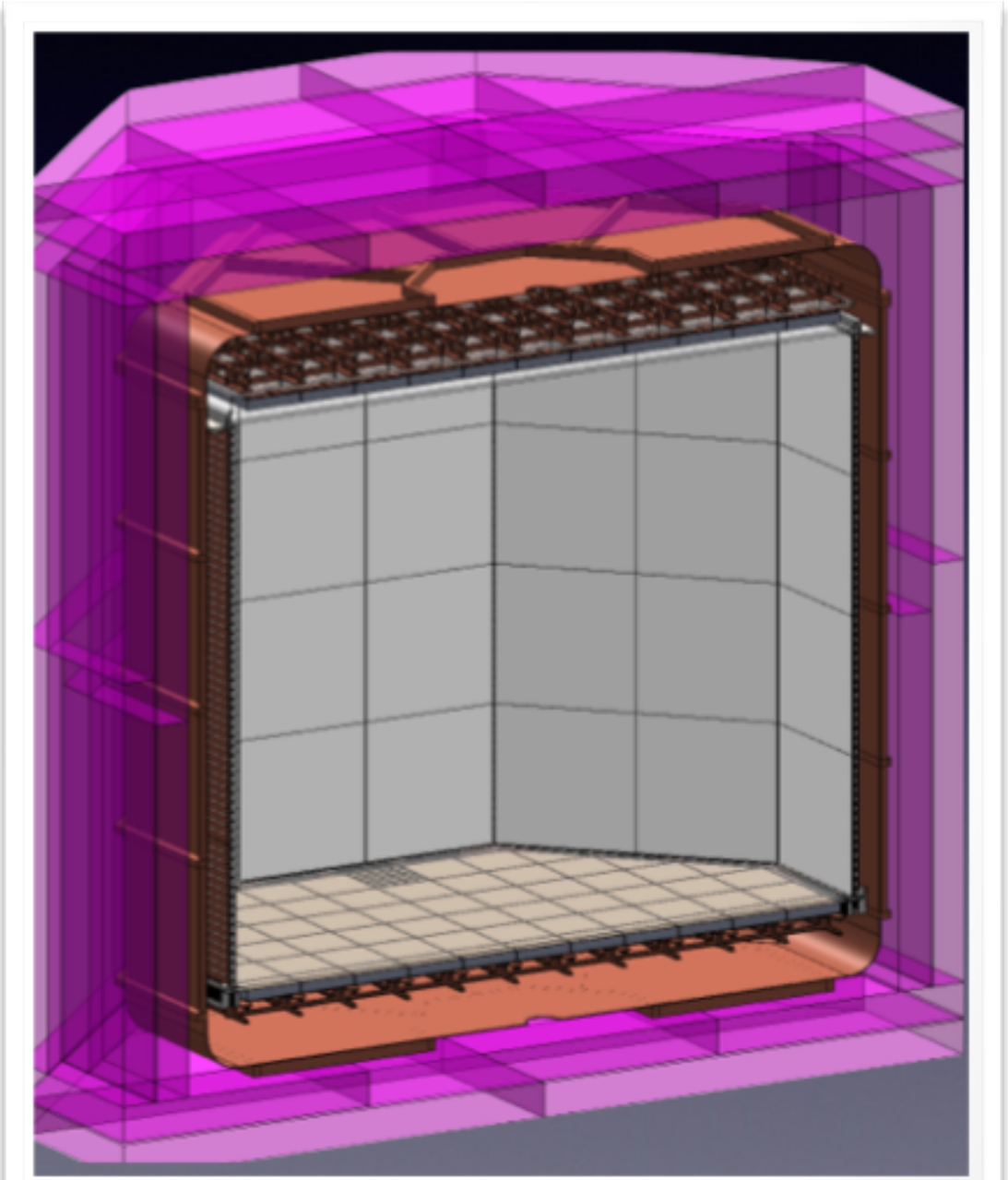
…these all surround the inner detector, the Time Projection Chamber (TPC)

# DarkSide-50 Two phase TPC



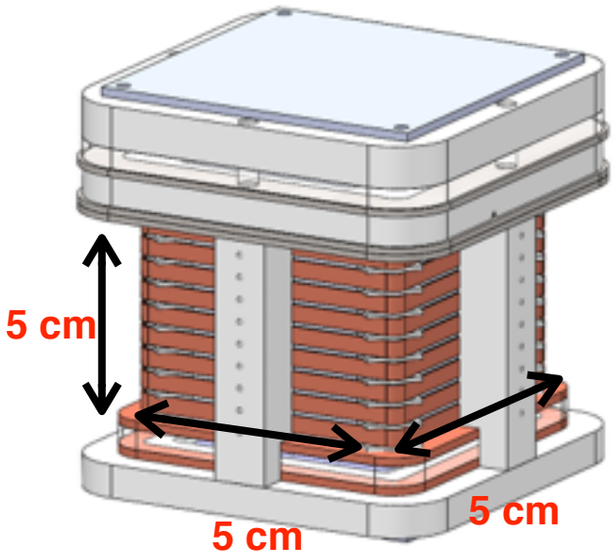



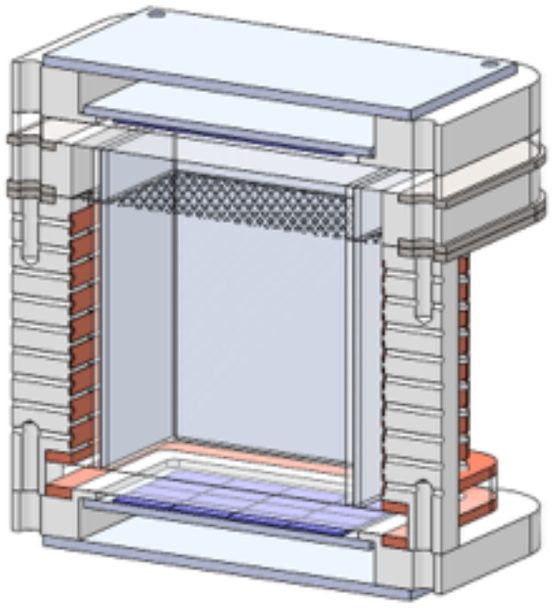
# The future of DarkSide: DS-20k

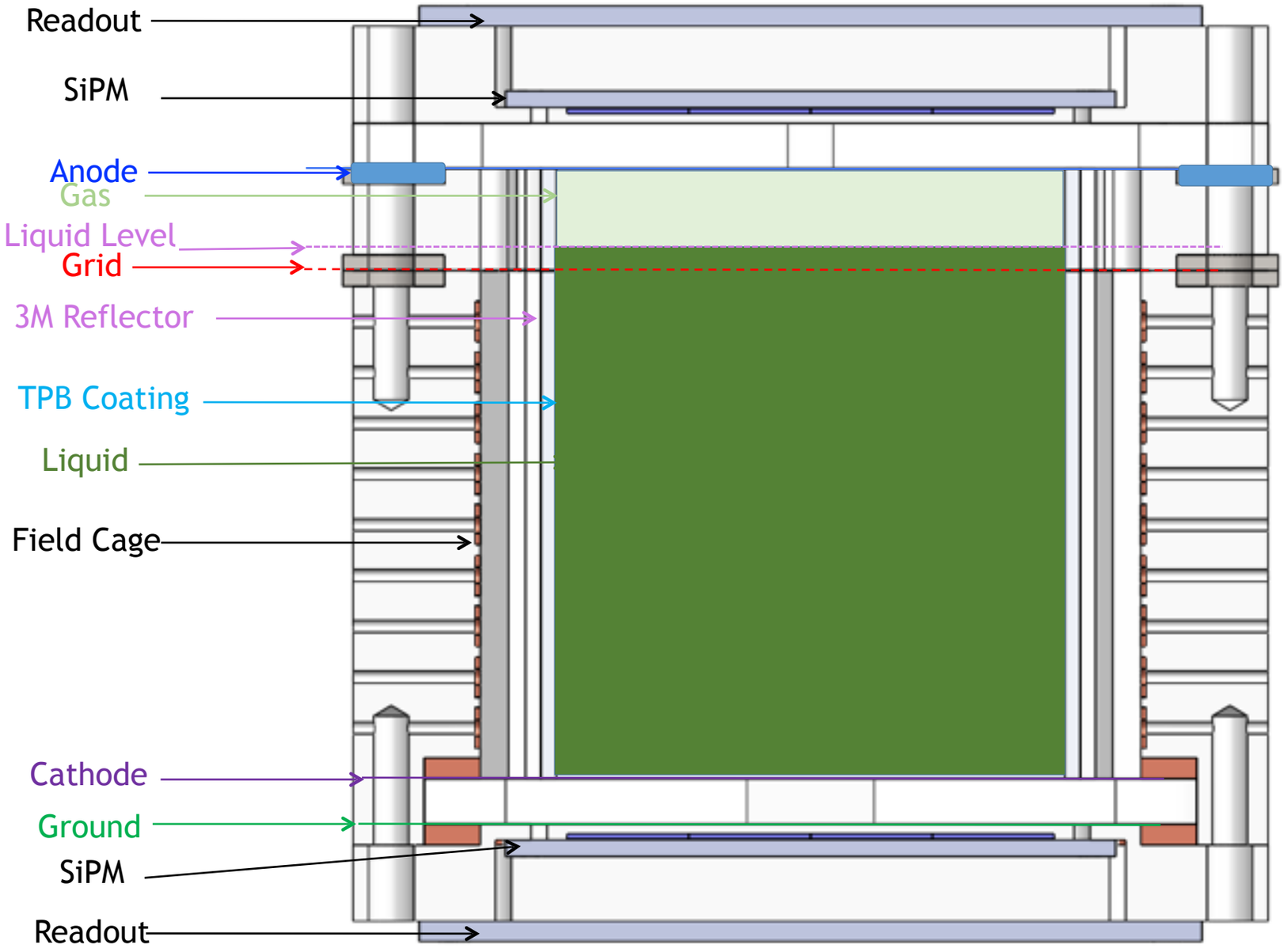


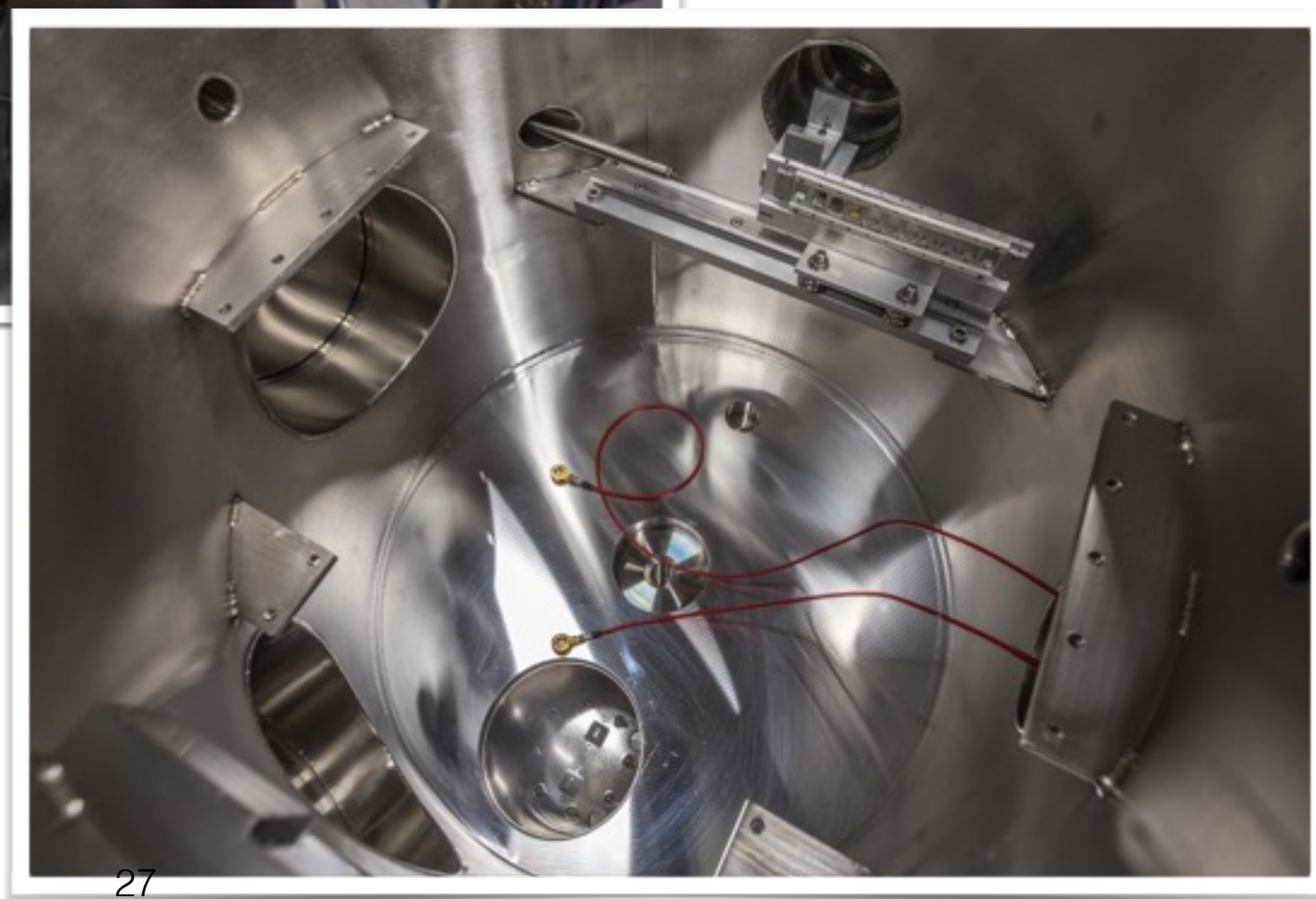
- 50 tons LAr two phase TPC;
- 30 tons fiducial volume;
- 20 $m^2$ of SiPM scintillation detecting surface;
- TPC thin copper vessel to be surrounded by an active plastic scintillator layer as neutron veto;
- detector concept minimize internal neutron background sources and allow easier scaling for bigger target mass.

# The TPC

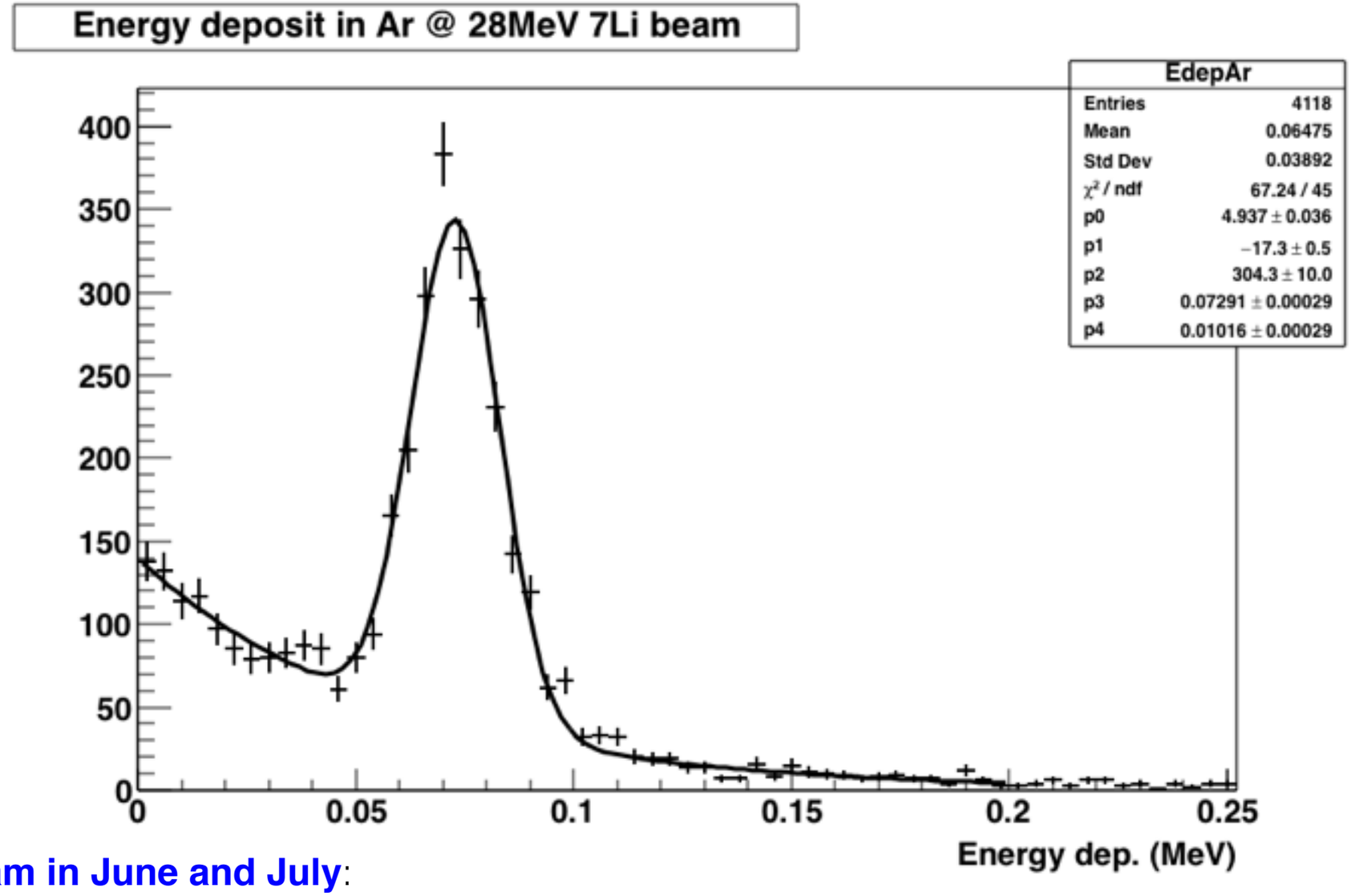

5 cm
5 cm
5 cm




Readout
SiPM
Anode
Gas
Liquid Level
Grid
3M Reflector
TPB Coating
Liquid
Field Cage
Cathode
Ground
SiPM
Readout



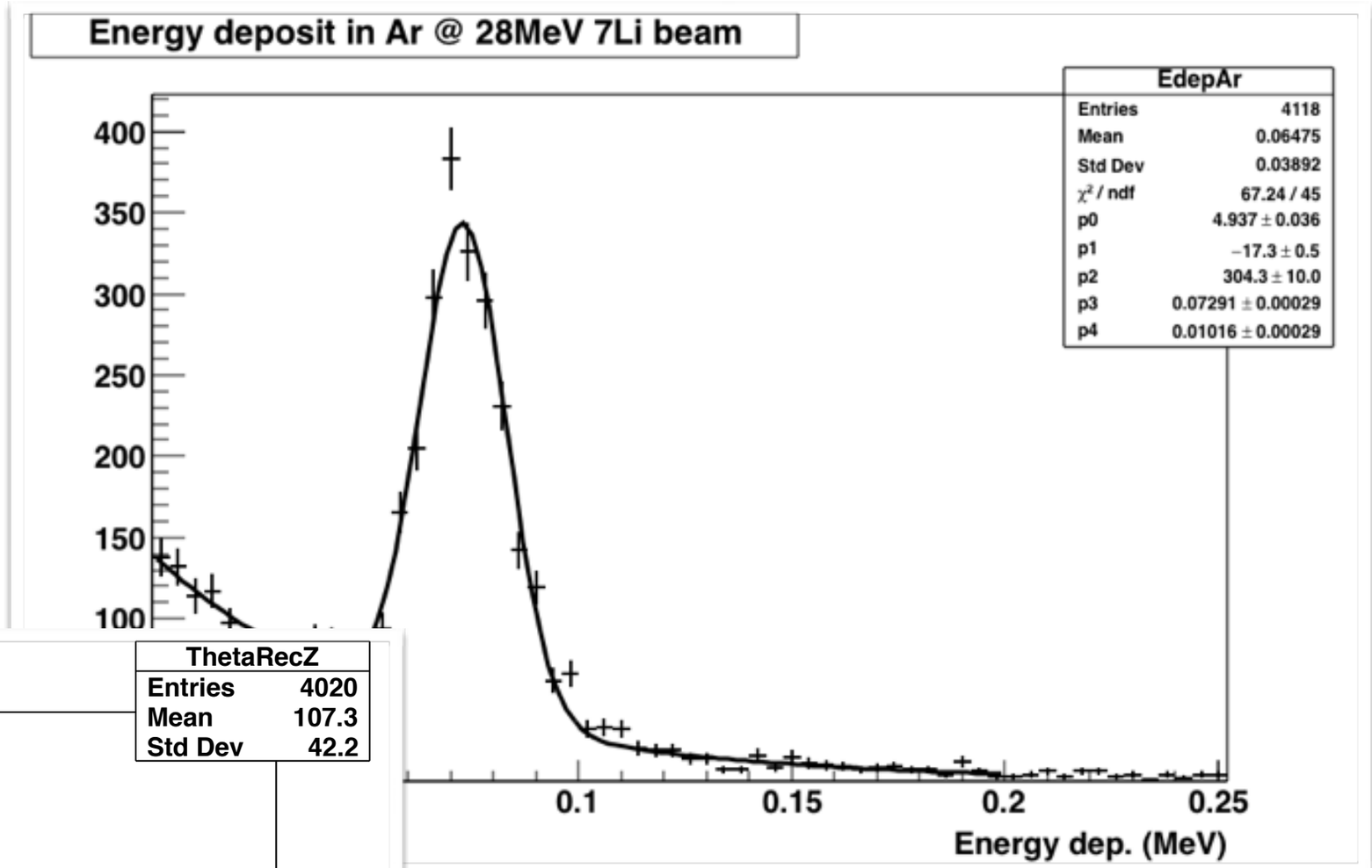
# Monte Carlo simulations: Selected output

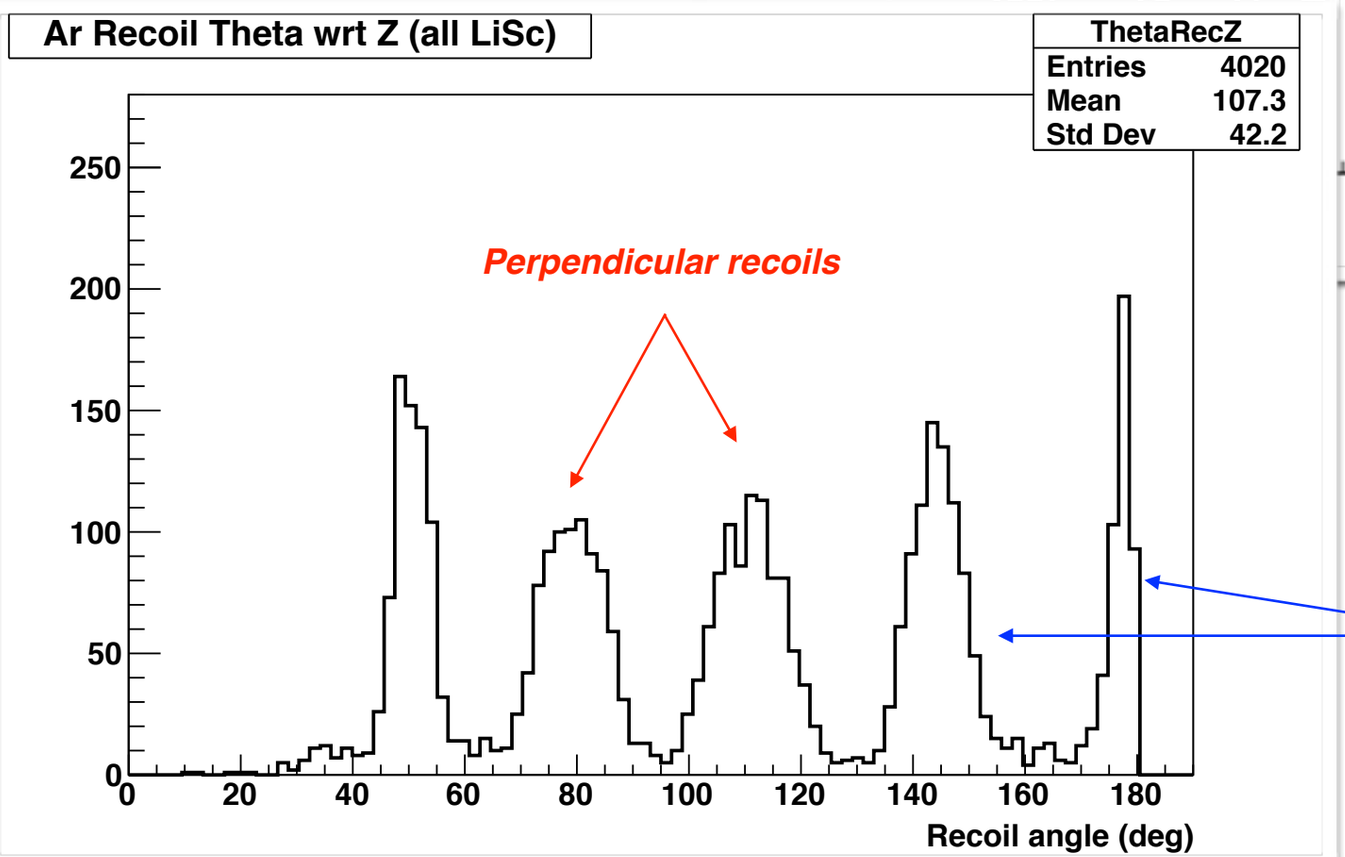



- ReD saw **beam in June and July**:
  - for 6 nA of $^{7}$Li and 0.2 mg/cm$^{2}$ target of $CH_2$: **~10$^{5}$ n/s (expected)**;
  - TPC-beam: 22°, TPC-LSci: 37°;
  - **TPC rate: ~Hz**;
  - **TPC+LSci: a few 100's of ev/day/nA expected**;

# Monte Carlo simulations: Selected output

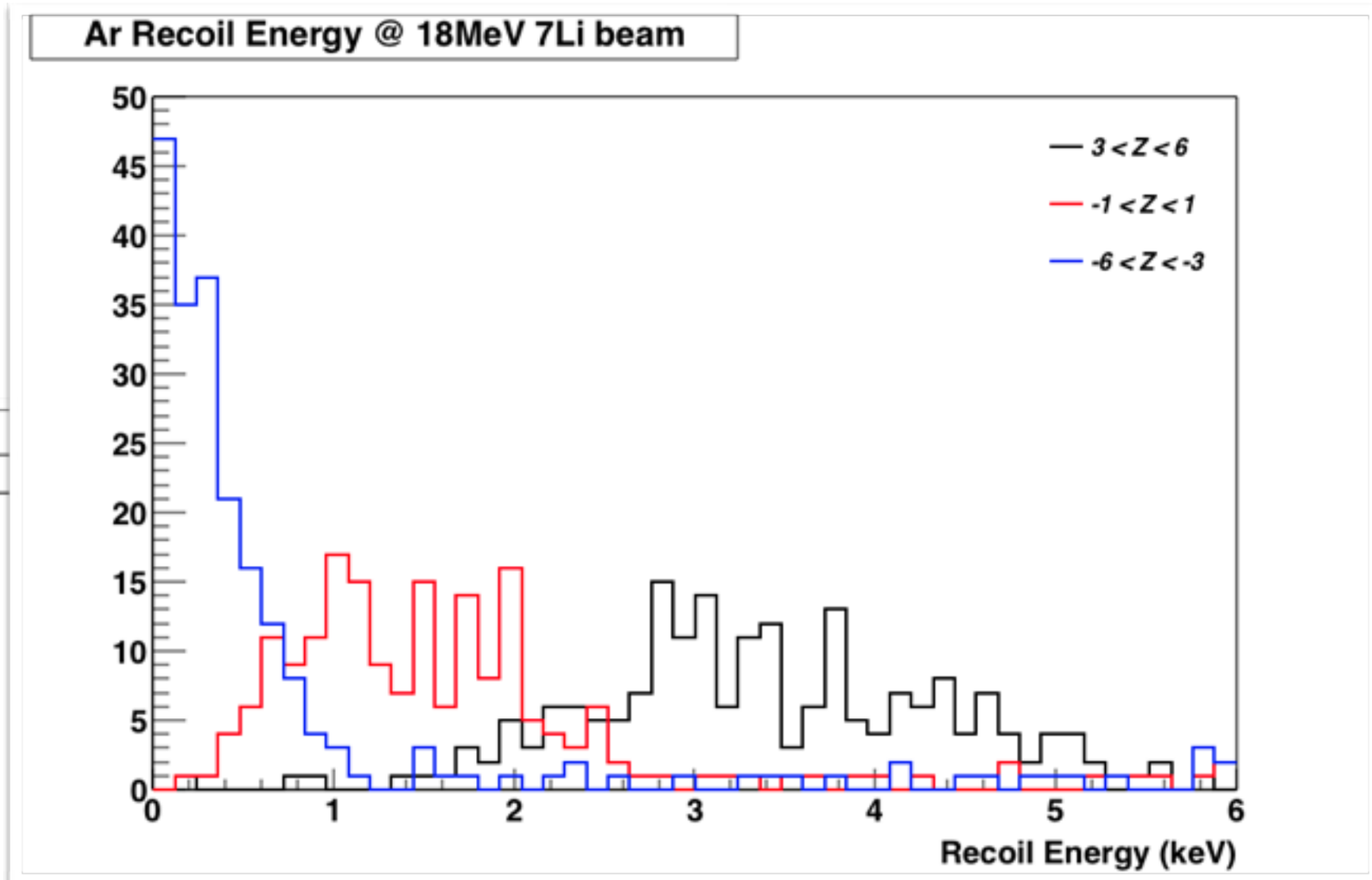
**$E_k$ ($^7$Li) = 28 MeV**
**TPC @ 22.35 deg wrt**
**$^7$Li beam**
**$E_k$ (n) = ~ 7 MeV**

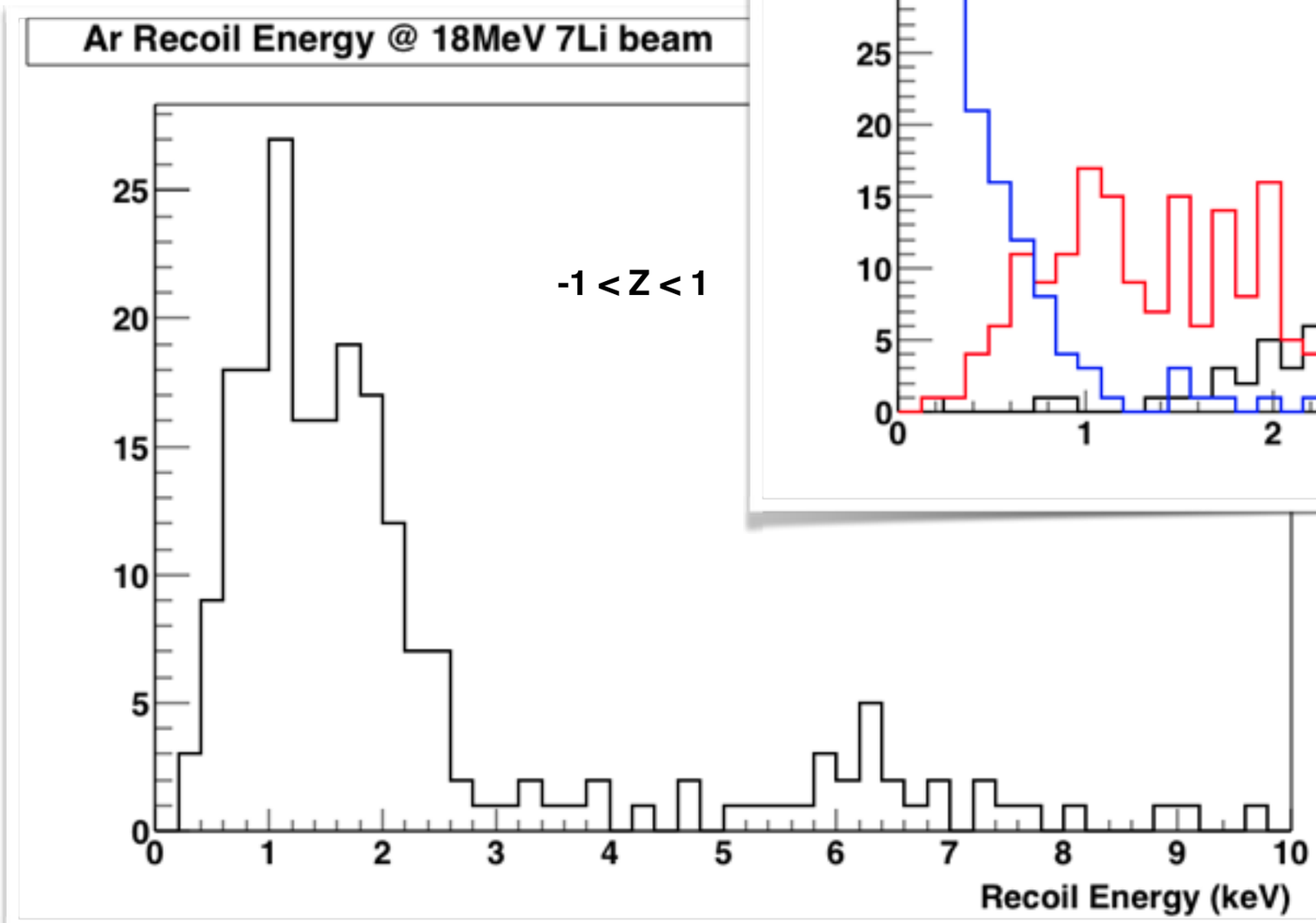


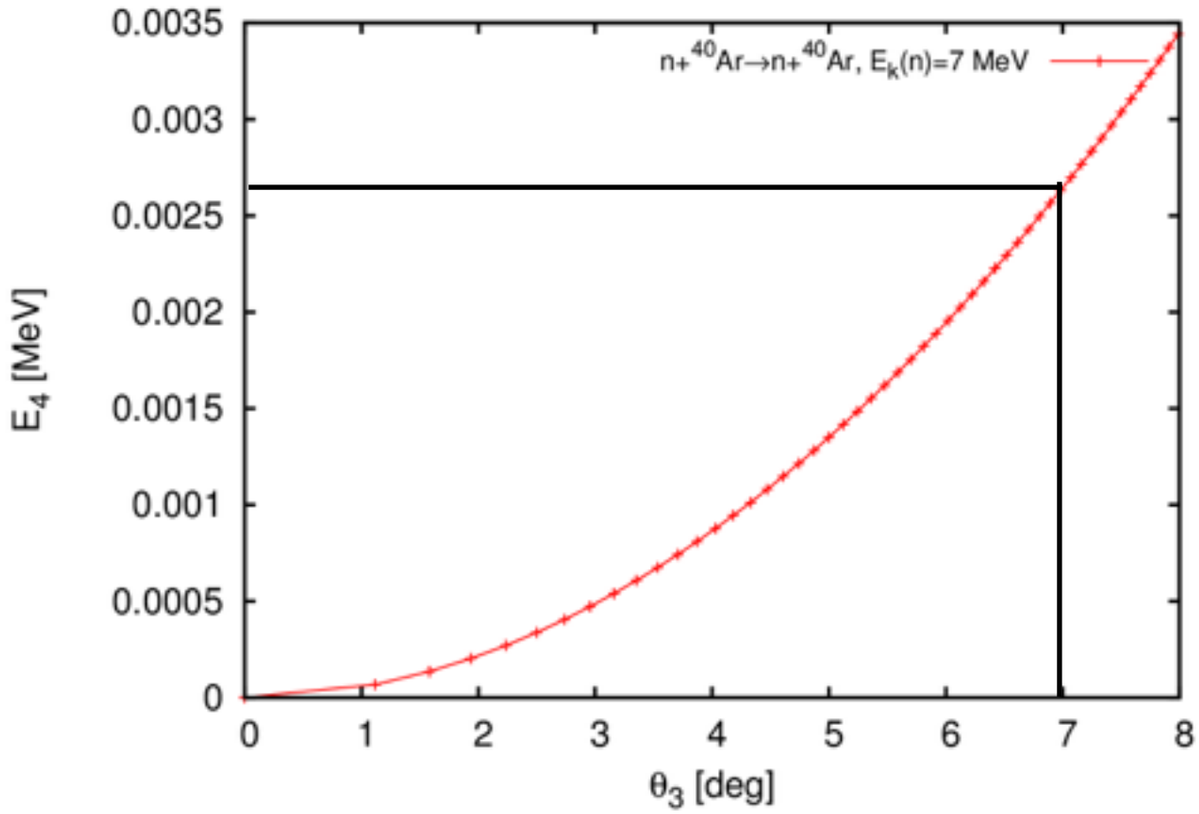
# MC: Low energy recoils

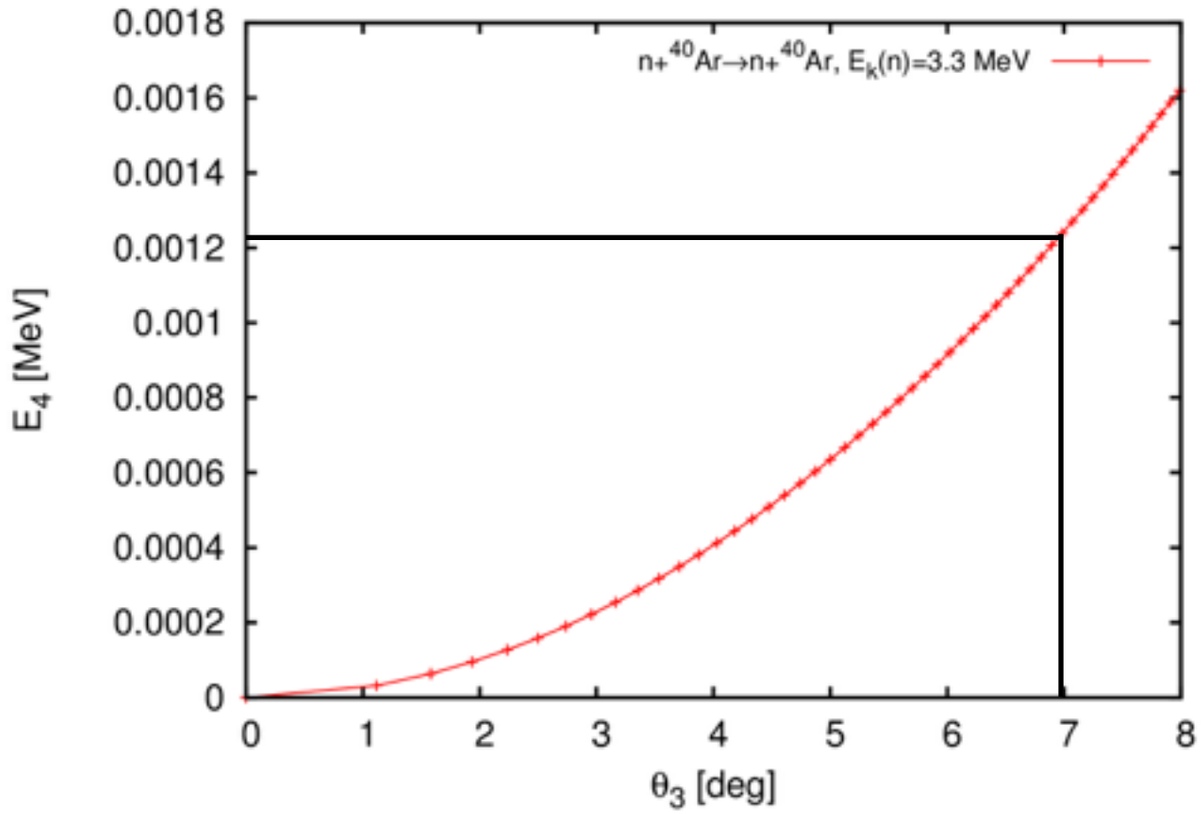
**$E_k$ ($^7$Li) = 18 MeV**
**TPC @ 22.35 deg wrt**
**$^7$Li beam**
**$E_k$ (n) = ~3 MeV**



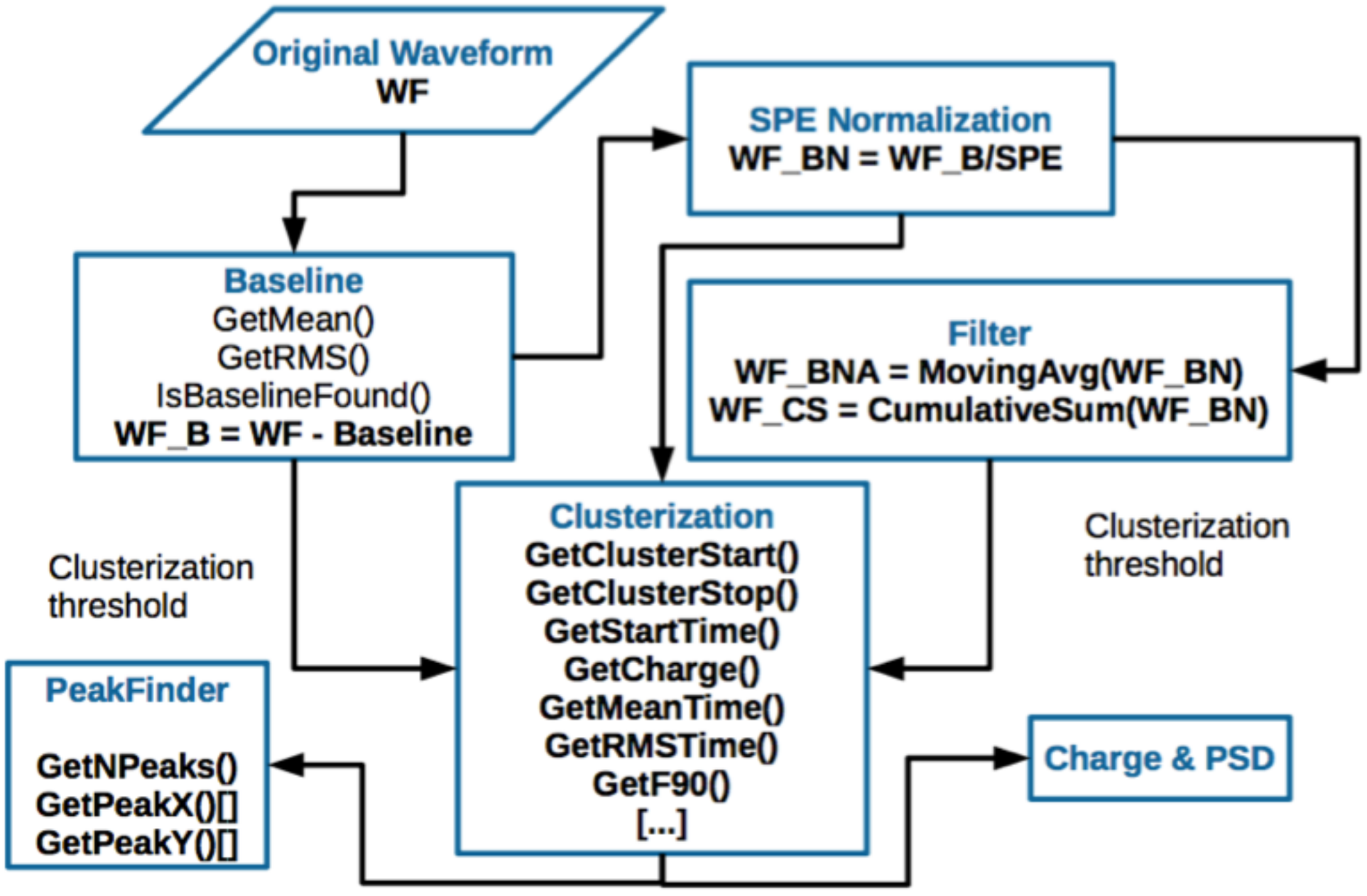



# Neutron recoil angle vs Argon recoil energy

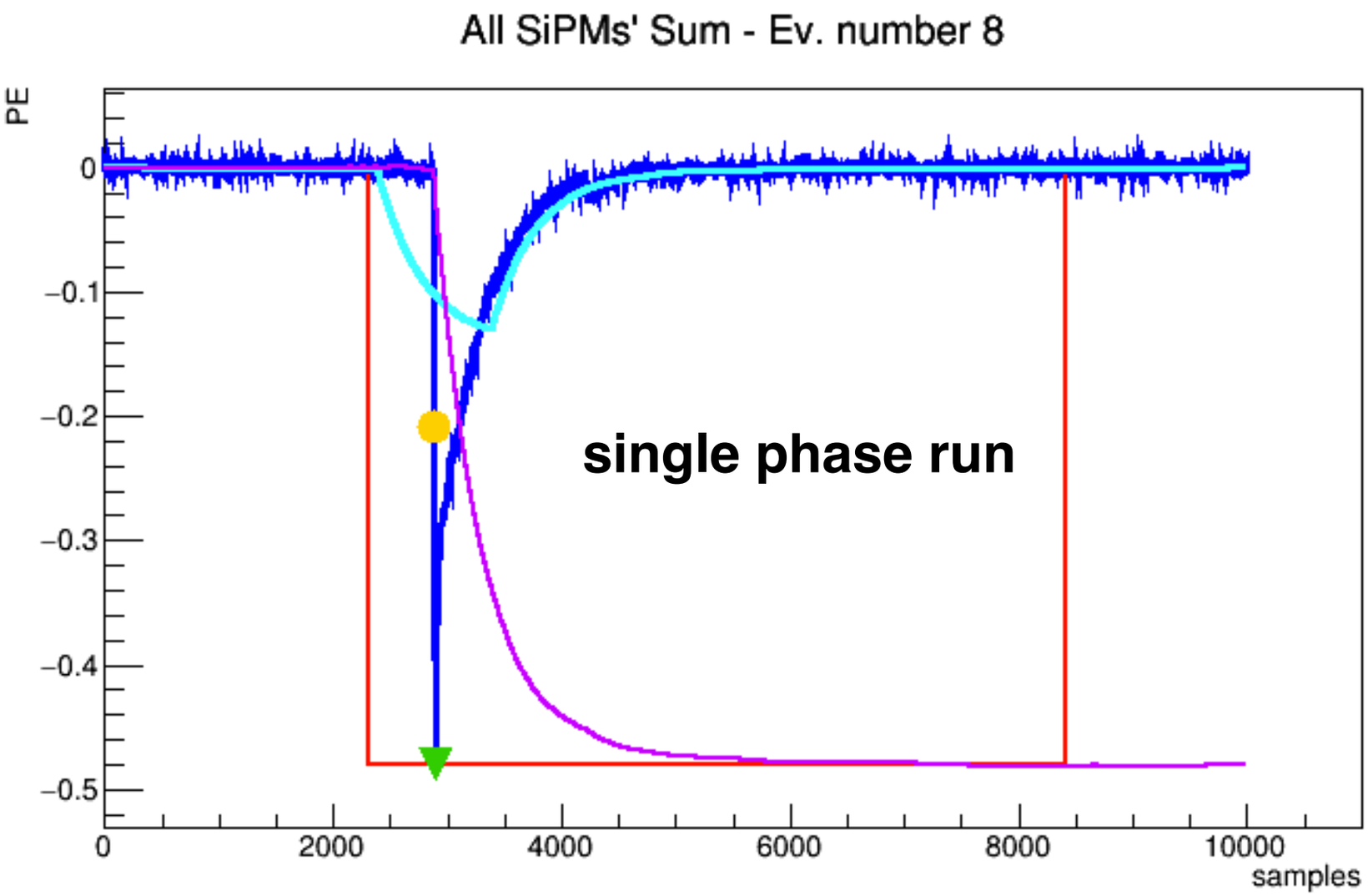


# Reconstruction: flow diagram



# Reconstruction: raw waveforms




**Cluster window**

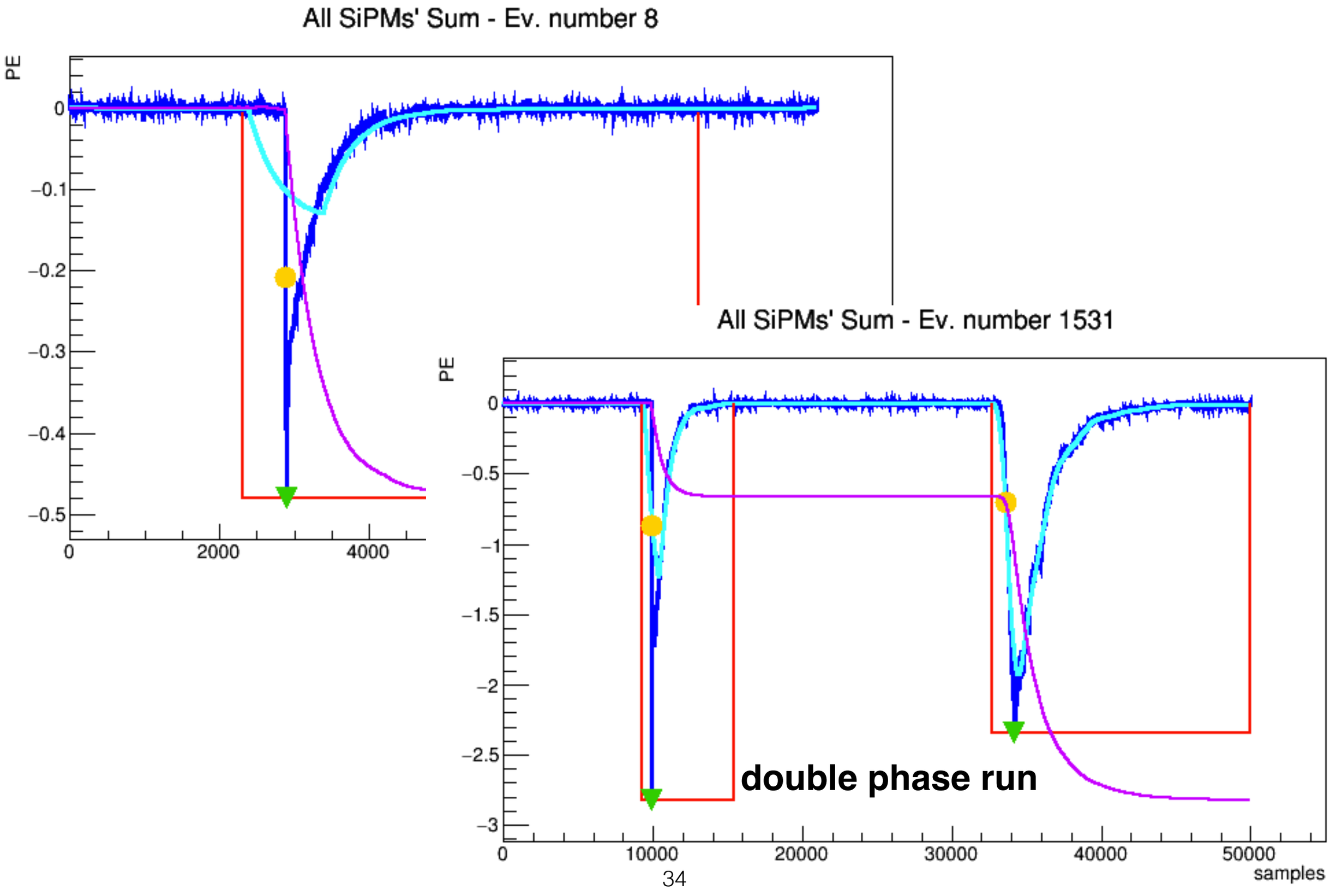
**cumulative sum**

**moving average**

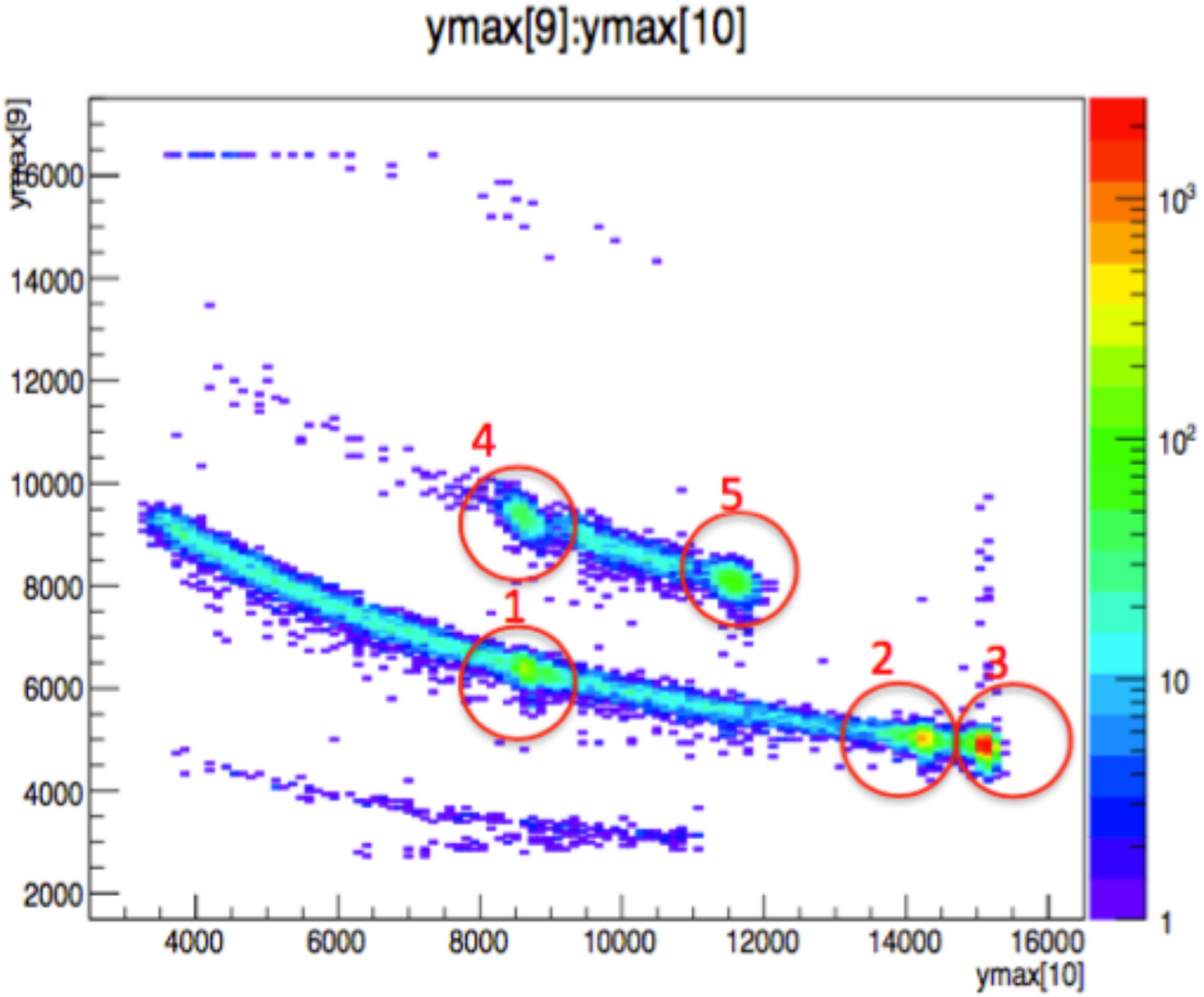
**pulse finder**

**constant fraction discriminator**

# Reconstruction: raw waveforms



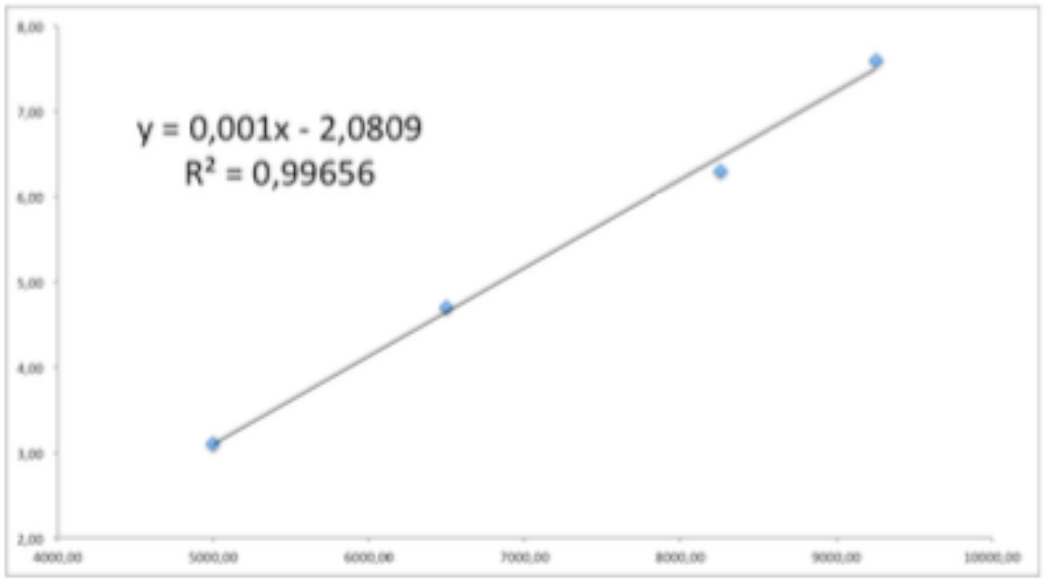
# Silicon telescope energy calibration



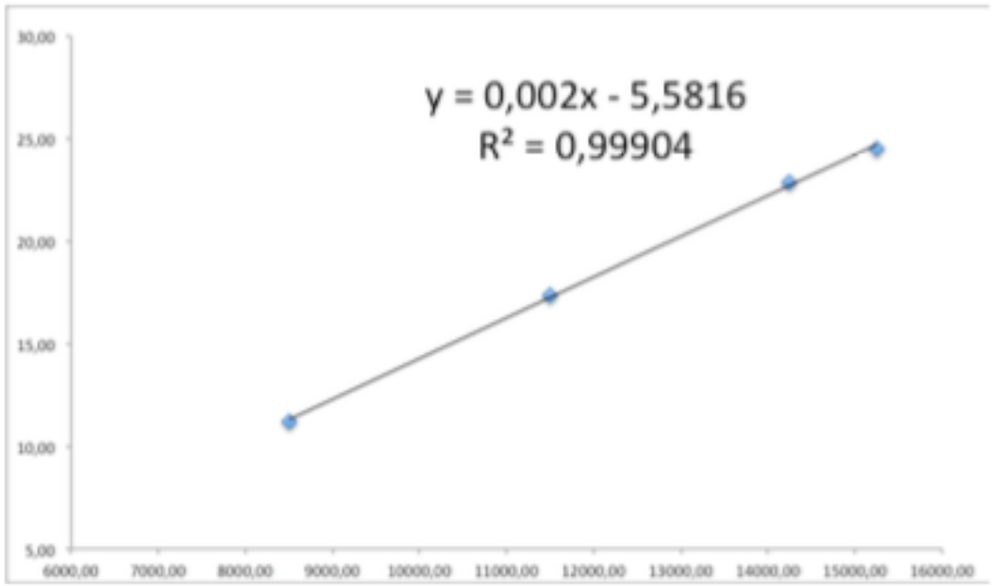

- **5 calibration points**:
  - p($^{7}$Li,$^{7}$Li)p (**1,2**)
  - $^{12}$C($^{7}$Li,$^{7}$Li)$^{12}$C (**3**)
  - p($^{7}$Li,$^{7}$Be)n (**4,5**)

| Reazione | angolo | cerchio | Energia (MeV) | Eloss 20 um Si (MeV) | Eloss 200 um Si (MeV) |
|---|---|---|---|---|---|
| 7Li+p→7Li+p | 5° | 1 | 16,5 | 4,7 | 11,8 |
| " | " | 2 | 26,2 | 3,3 | 22,9 |
| 7Li+12C→7Li+12C | " | 3 | 27,6 | 3,1 | 24,5 |
| 7Li+p→7Be+n | " | 4 | 18,8 | 7,6 | 11,2 |
| " | " | 5 | 23,7 | 6,3 | 17,4 |

# Silicon telescope energy calibration

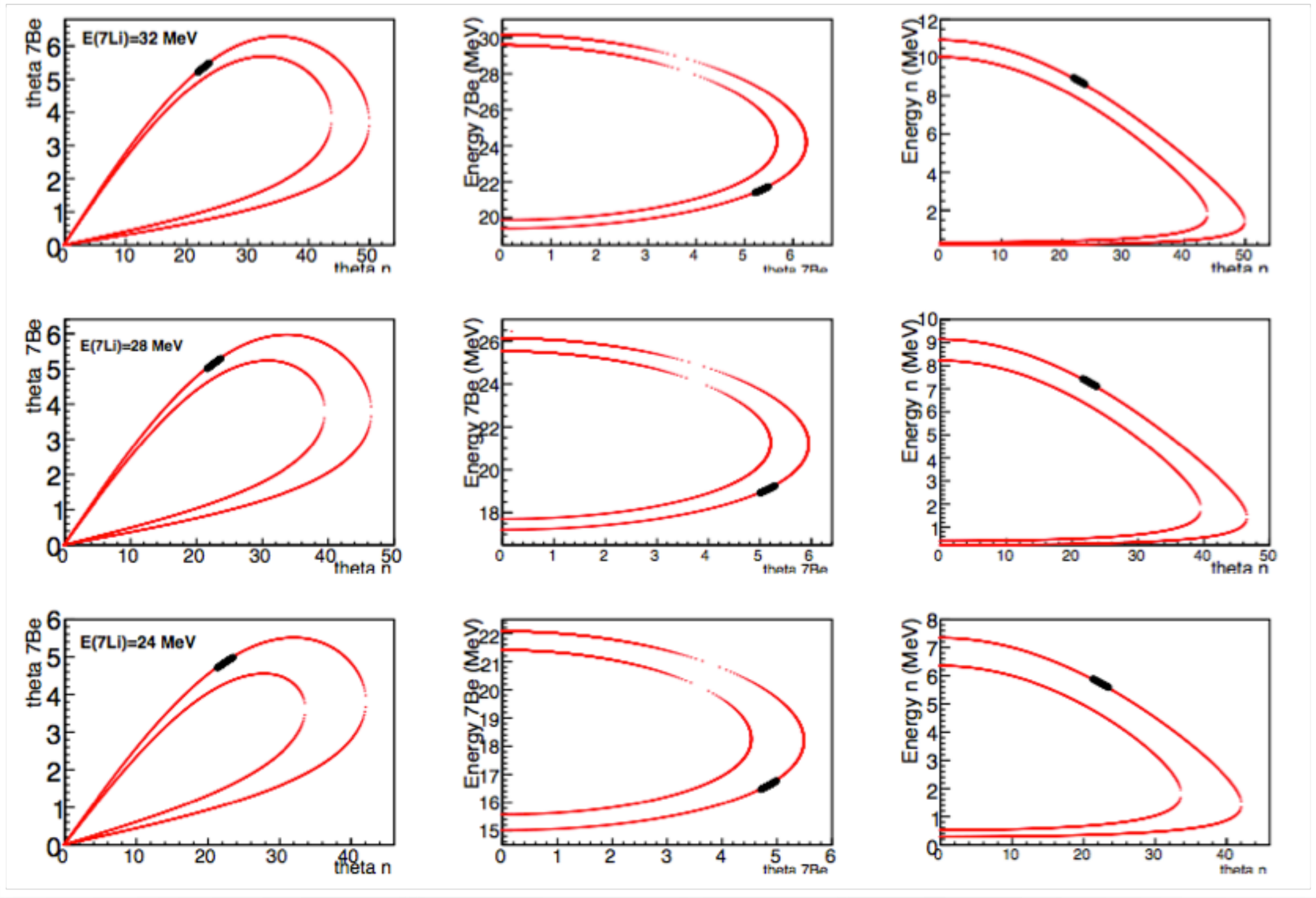



| Channel | DE (MeV) |
|---|---|
| 5000,00 | 3,10 |
| 6500,00 | 4,70 |
| 8250,00 | 6,30 |
| 9250,00 | 7,60 |




| Channel | E (MeV) |
|---|---|
| 8500,00 | 11,20 |
| 11500,00 | 17,40 |
| 14250,00 | 22,90 |
| 15250,00 | 24,50 |

# Kinematical plots for the proposed $^{7}$Li beam energies



## KINEMATICAL CALCULTIONS

… to have Ar recoil energies > 50 keV @ recoil angle // **E**

| E_7Li (MeV) | θ (7Be) | θ (n) | E_n (MeV) | E_Ar @72° (keV) |
|---|---|---|---|---|
| 24 | 4.85 ± 0.15 | 21 - 23.6 | 5.7 ± 0.15 | 51 |
| 28 | 5.15 ± 0.15 | 21.5 – 23.8 | 7.3 ± 0.15 | 66 |
| 32 | 5.35 ± 0.15 | 21.5 - 24 | 8.8 ± 0.15 | 79 |

# n+Ar ELASTIC SCATTERING CROSS SECTION for different energies of incident neutron

The scattering cross section for the proposed energies of neutrons (6,7,8 MeV) is of the same order of magnitude of that used by SCENE.