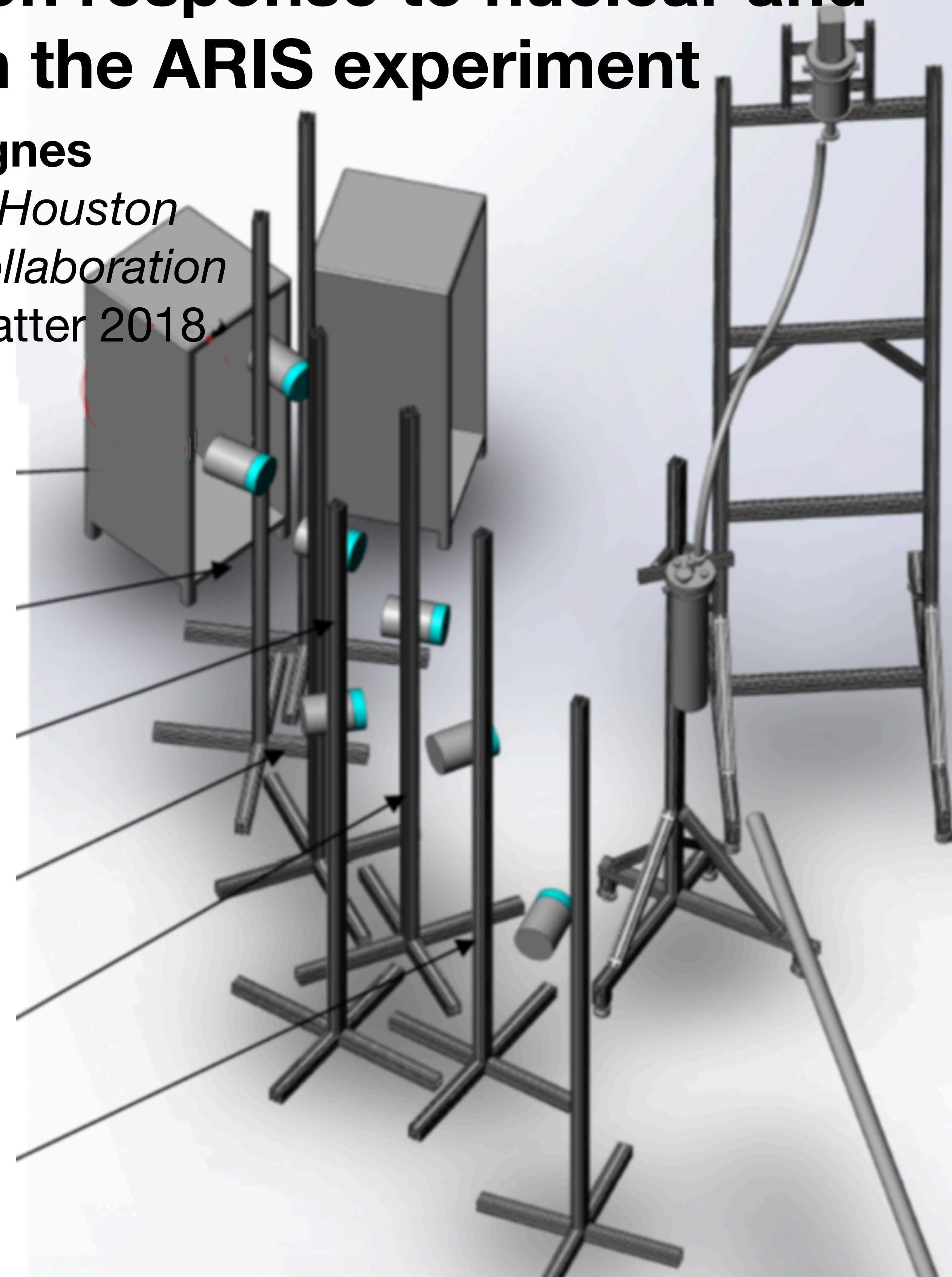
Measurement of liquid argon response to nuclear and electronic recoils with the ARIS experiment

Paolo Agnes
University of Houston
for the *ARIS Collaboration*
UCLA Dark Matter 2018



Overview

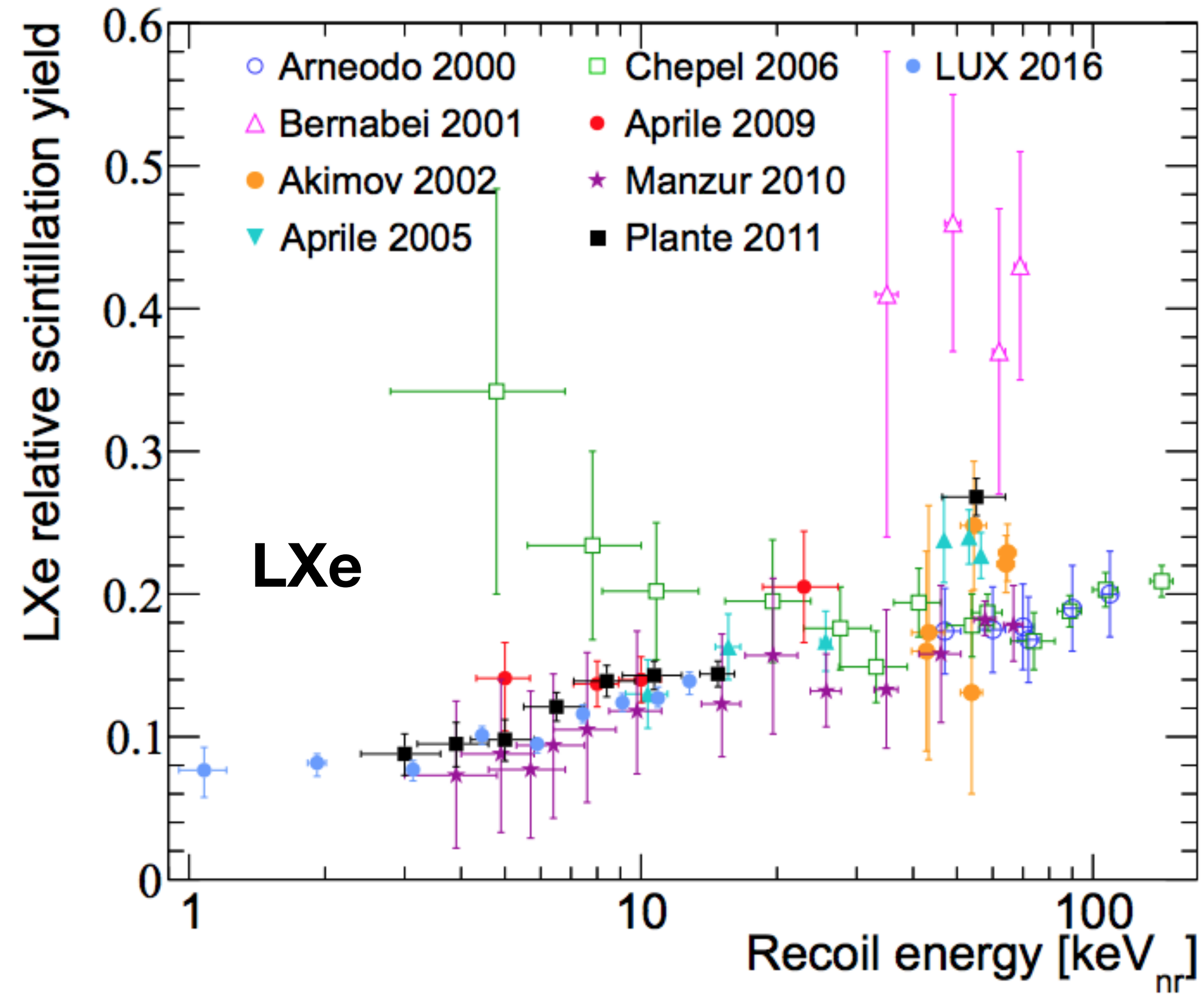
Noble liquids are convenient targets for **direct dark matter searches** (single- and dual-phase TPCs ⇨ **DarkSide**)

Systematics of WIMP search are dominated by uncertainties at low energies:

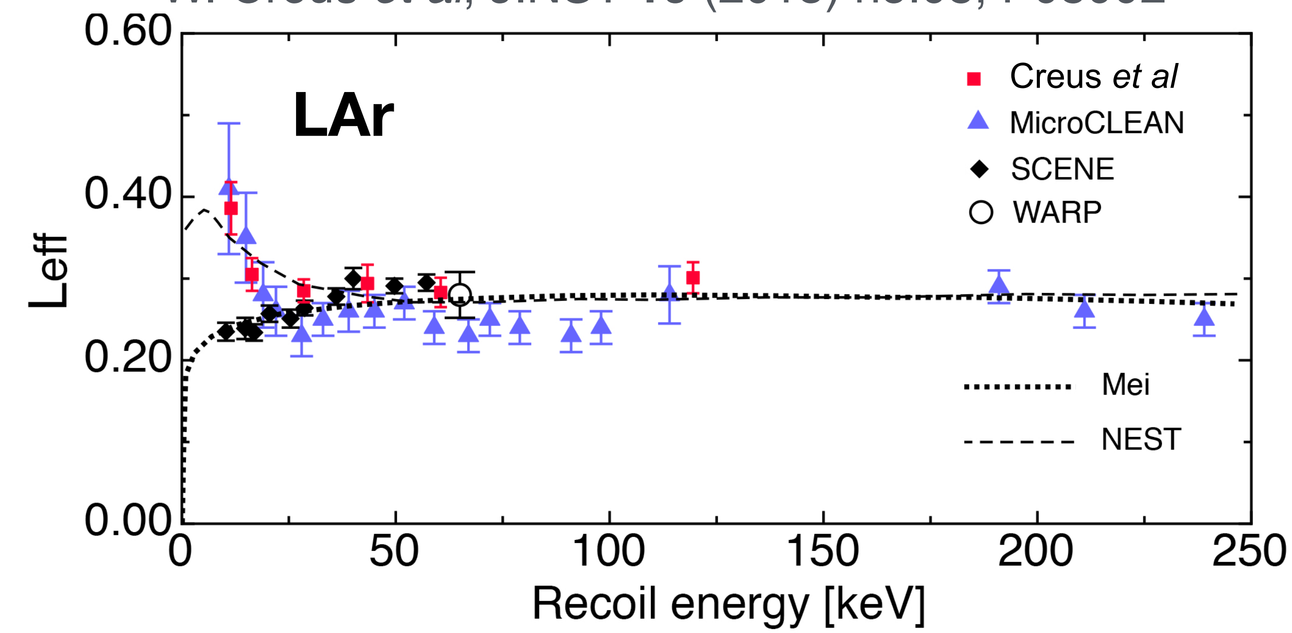
- relative scintillation efficiency of NR compared to ER (**L_{eff}**)
- effect of the drift electric field (recombination of e^-/ion pairs)

Internal calibrations are limited by
- geometry (spatial distribution)
- source dynamics (few gamma lines or non monochromatic neutrons)

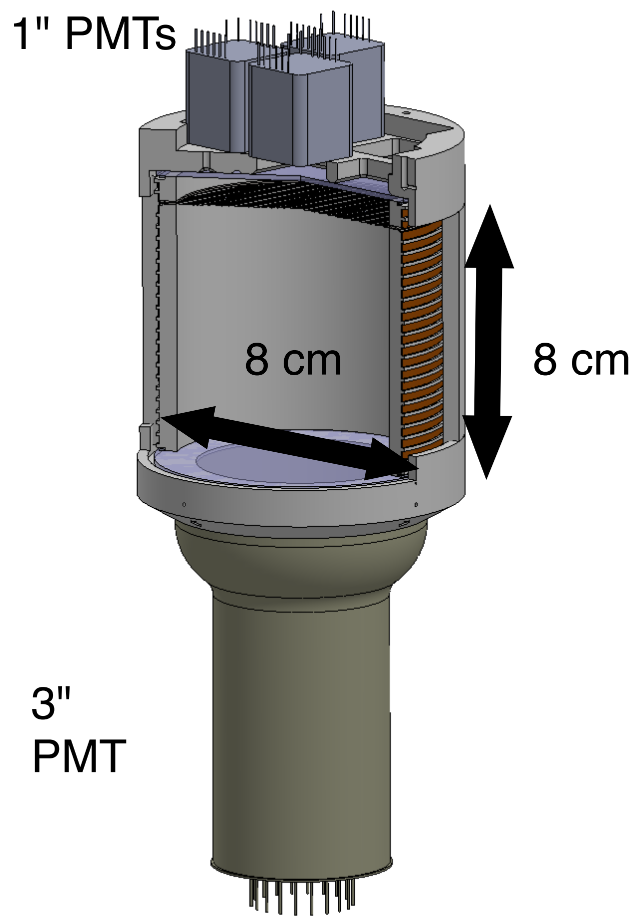
==> **External calibrations**
Small scale dedicated detectors operated under controlled conditions



W. Creus *et al*, JINST **10** (2015) no.08, P08002

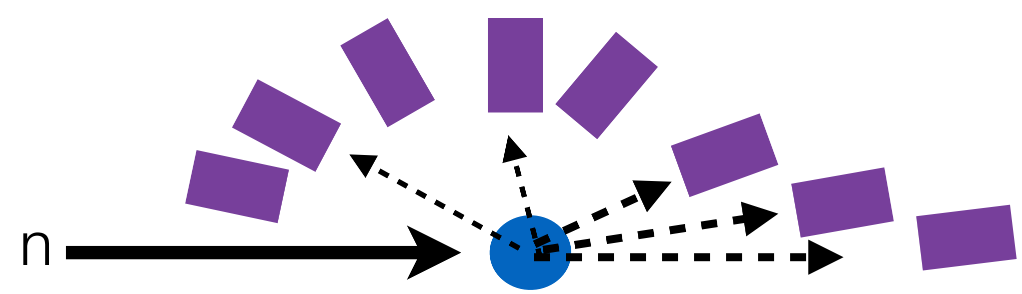


The **ARIS** experiment



Measure L_{eff} down < 10 keV_{NR}
Small size to minimize multiple scatters

Collimated and mono-energetic neutron beam coupled with a set of neutron detectors



TPC (built at UCLA):

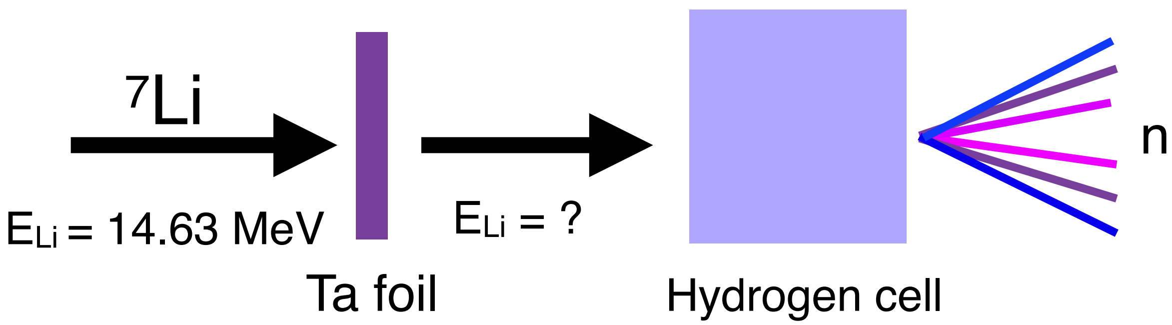
- ~0.5 kg of LAr
- PTFE reflector with TPB coated surface
- 7 Hamamatsu 1” PMTs on top, one 3” PMT on bottom
- Anode/Cathode created with ITO plated fused-silica windows
- Grid 1 cm below the anode (extraction field)
- Ability to create a gas pocket for dual-phase running
- Operated in SINGLE PHASE

8 neutron detectors:

- NE213 liquid scintillator
- 20 cm diameter
- 5 cm height
- Signal pulse shape discrimination available

The **LICORNE** Beam (IPNO, Orsay)

Inverse $^{1}H(^{7}Li, n)^{7}Be$ **Reaction**



Advantages:

Lithium energy near production threshold

⇨ **highly collimated beam**

⇨ high neutron flux on the TPC

Beam characteristics:

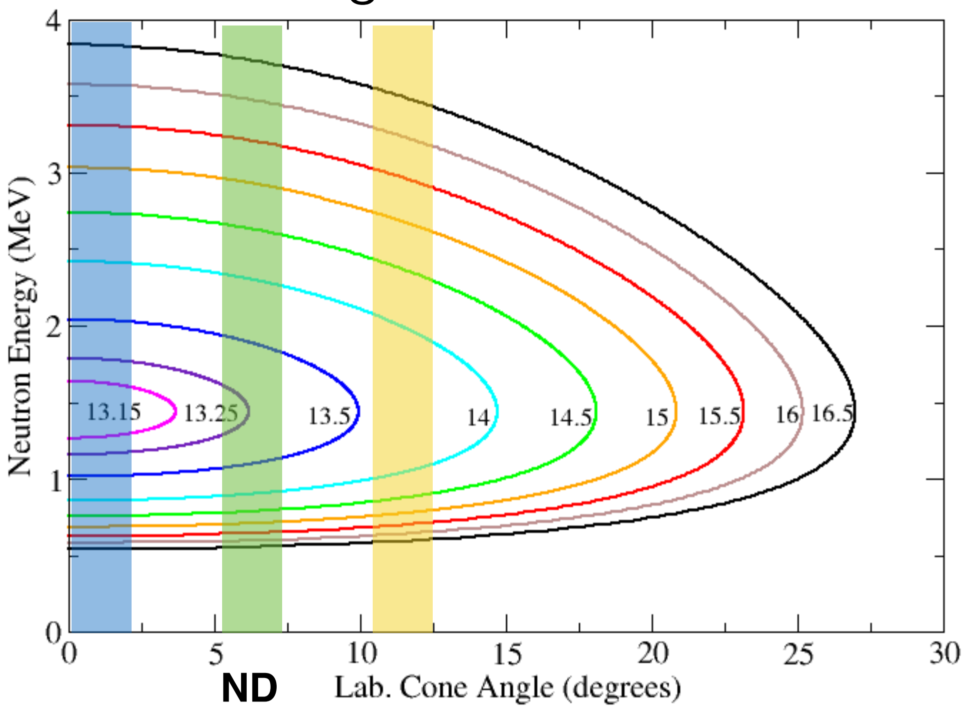
⇨ Neutron flux on TPC : ~ 10^4 Hz

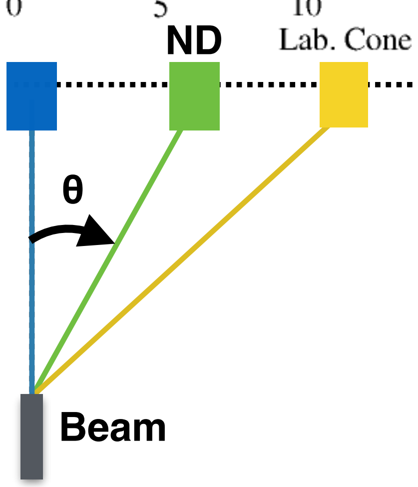
⇨ 1 pulse / 400 ns

⇨ Beam pulse width: 1.5 ns

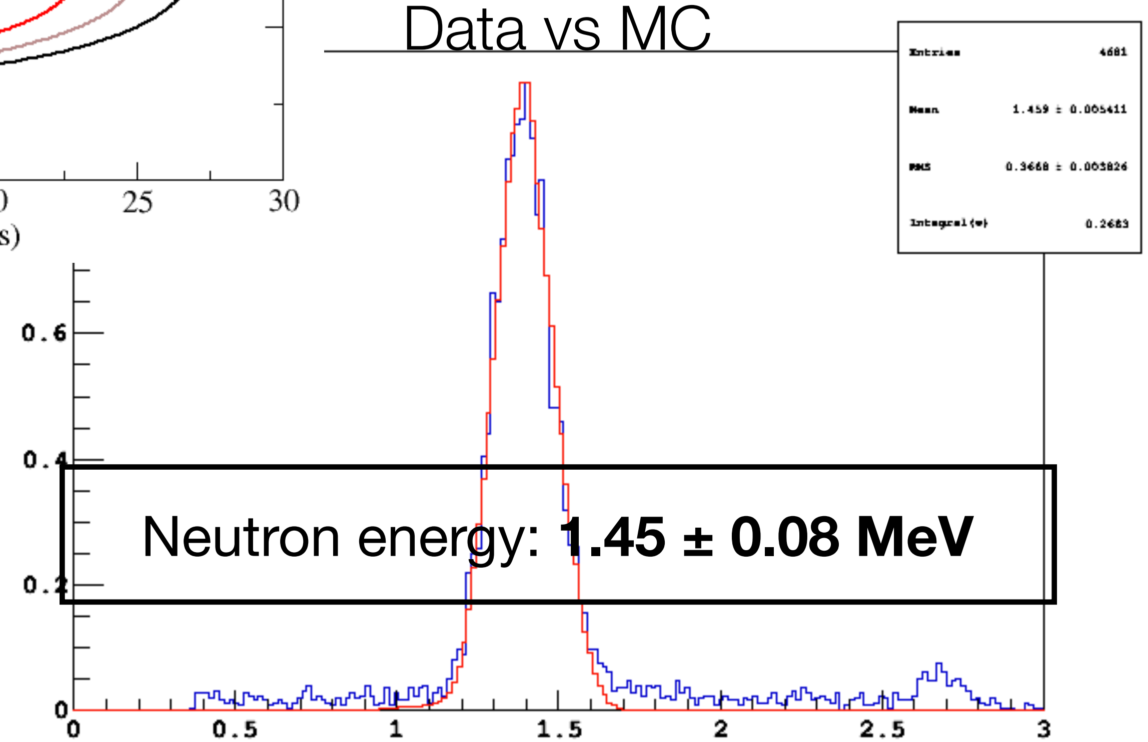
(Coincidence-TOF)

TPC solid angle is 2°





Data vs MC



Neutron energy: **1.45 ± 0.08 MeV**

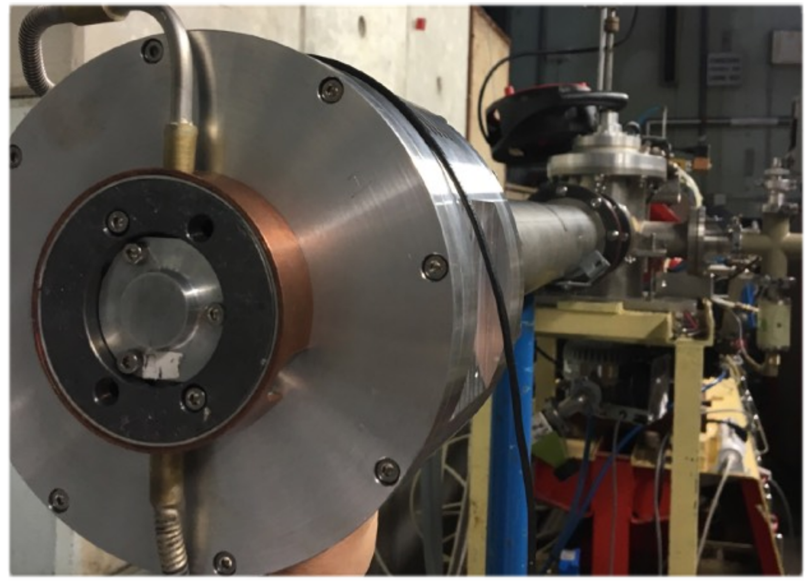
	Scattering Angle [deg]	Mean NR Energy [keV]
A0	25.5	7.1
A1	35.8	13.7
A2	41.2	17.8
A3	45.7	21.7
A4	64.2	40.5
A5	85.5	65.4
A6	113.2	98.1
A7	133.1	117.8

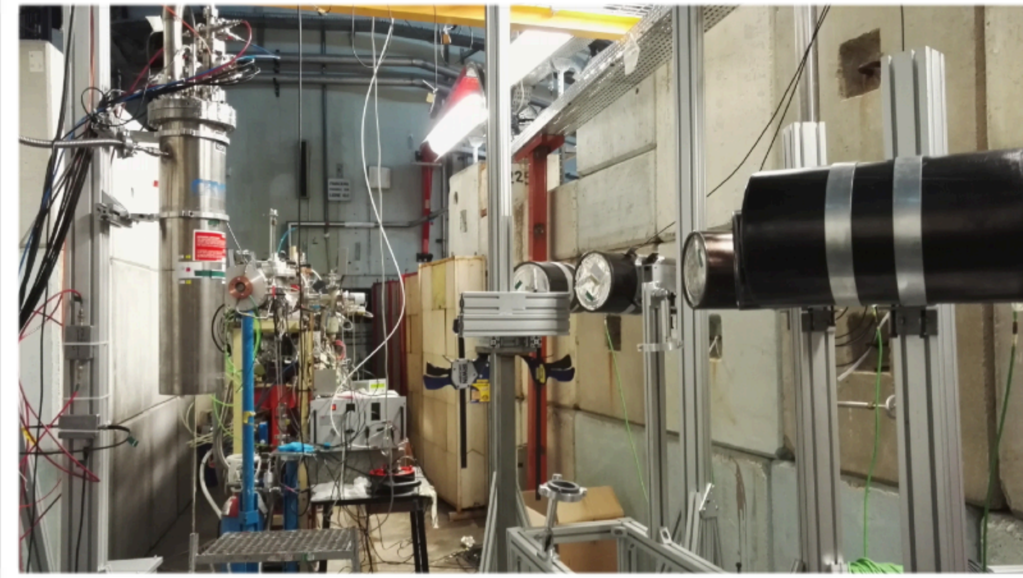
Triangulation (~cm error)

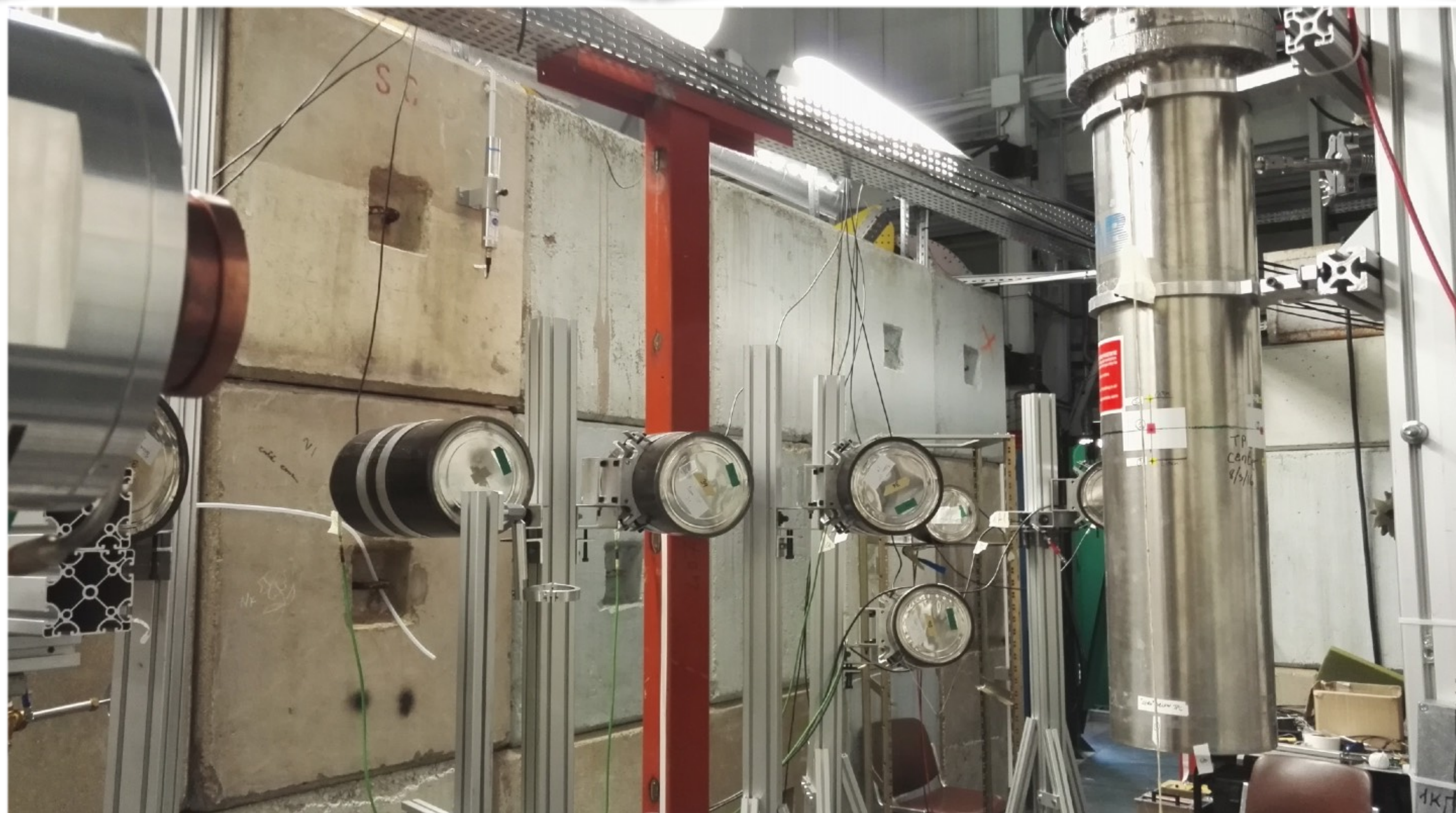
Data taking

12 days of data taking in Oct 2016 at IPN, Orsay

IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY



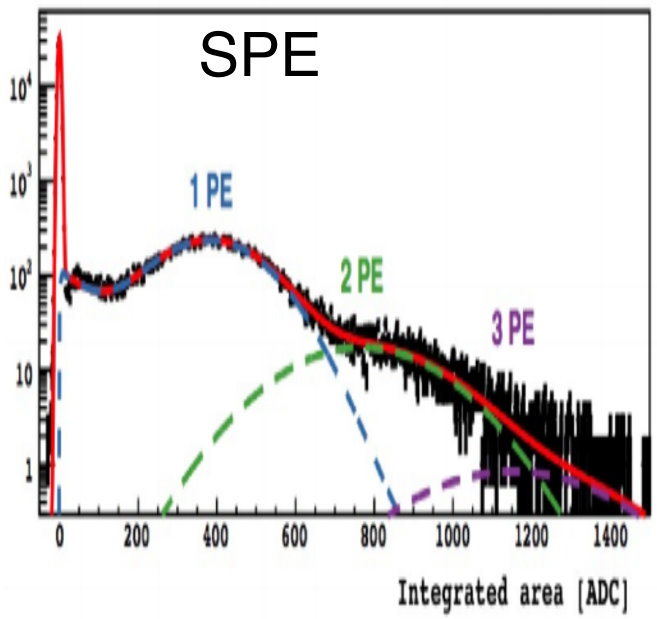


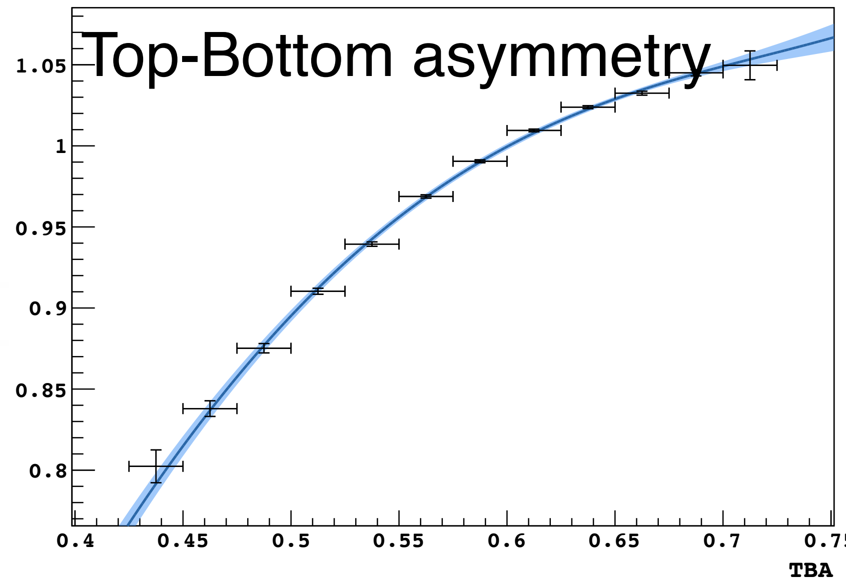


Modeling the TPC response

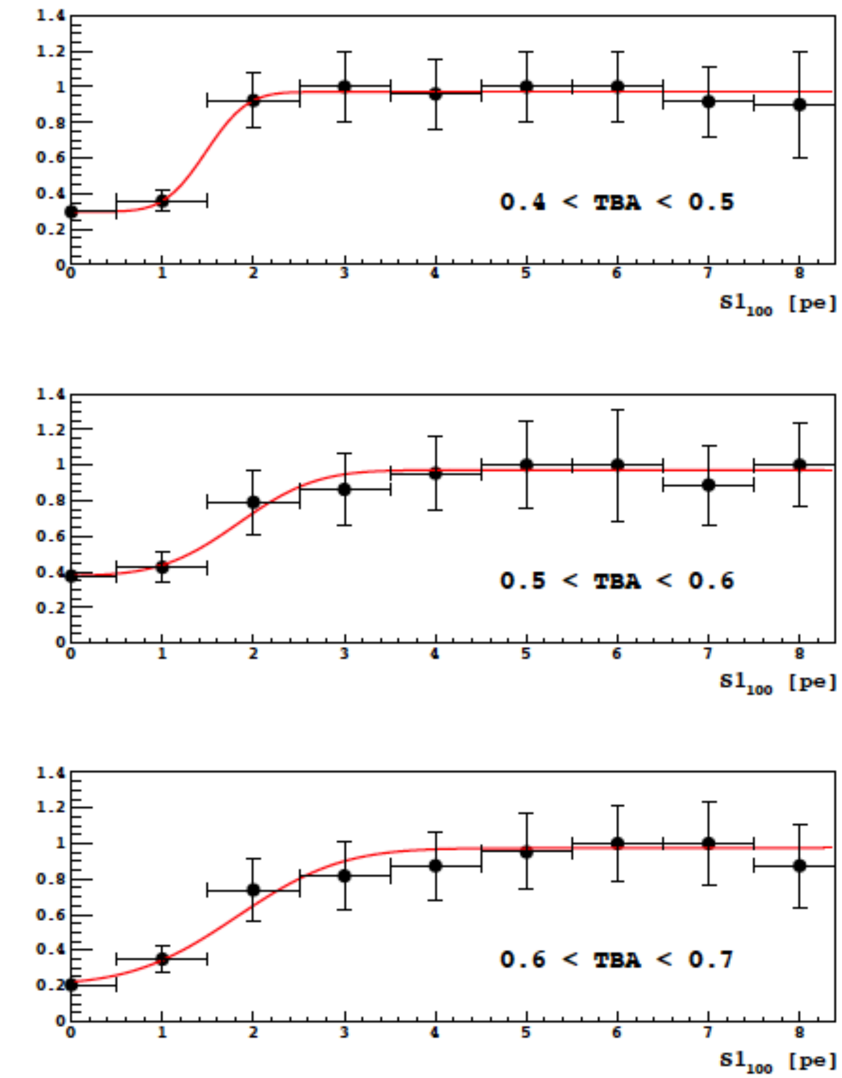
Take into account TPC the non-uniformity of the TPC response (top/bottom asymmetry)

The TPC trigger logic requires 2 PMTs firing in 100 ns

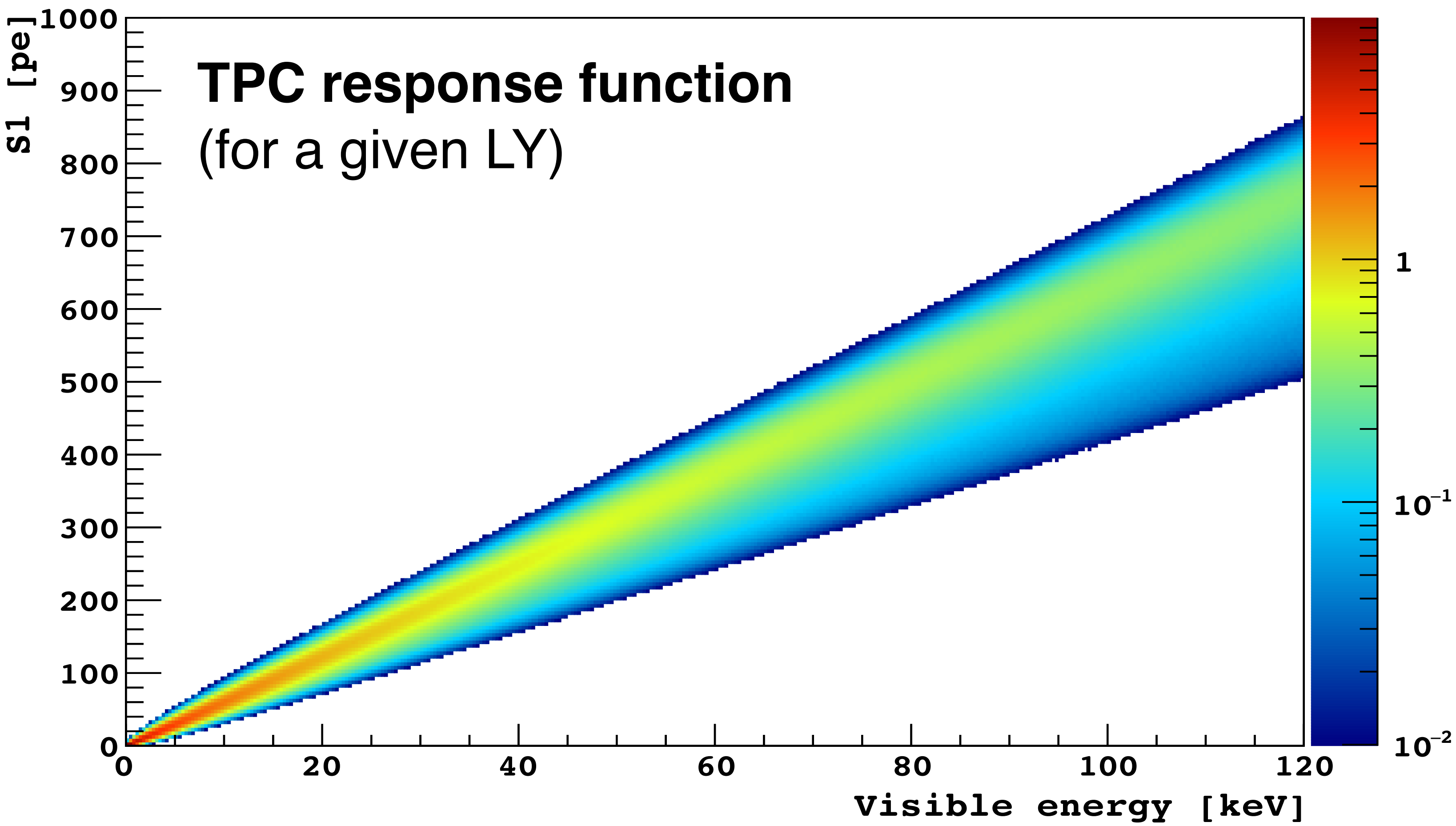


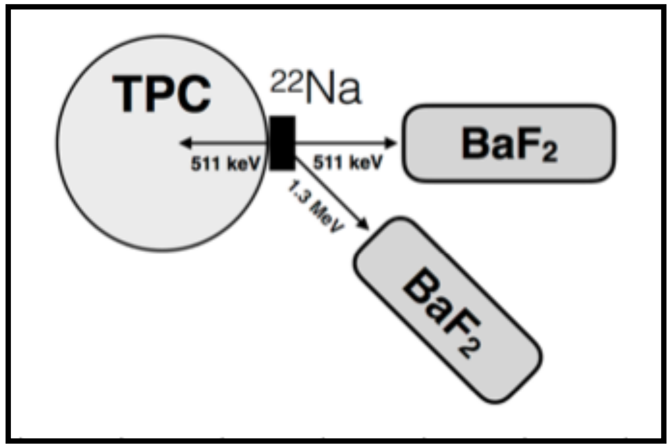


Includes Poisson statistics



Measured Trigger efficiency to correct real data

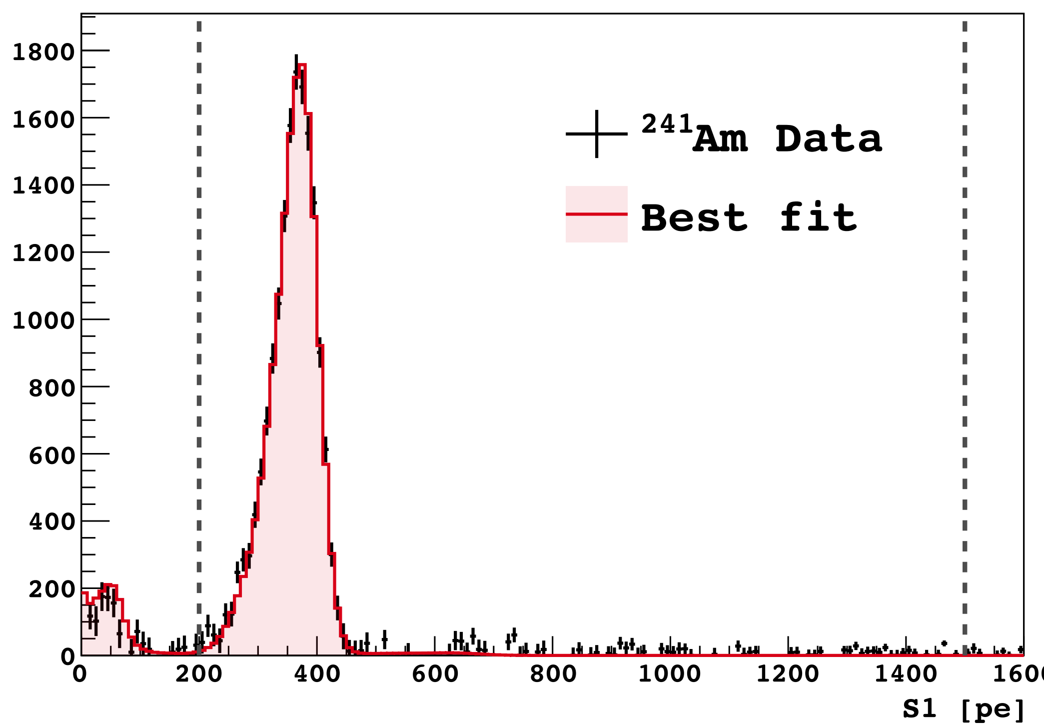


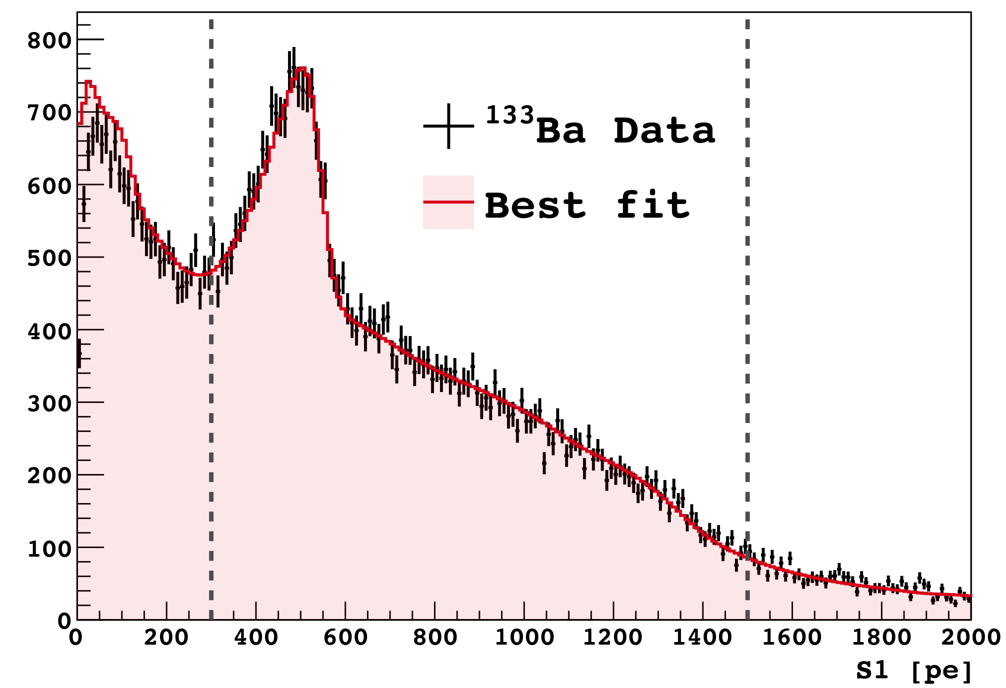


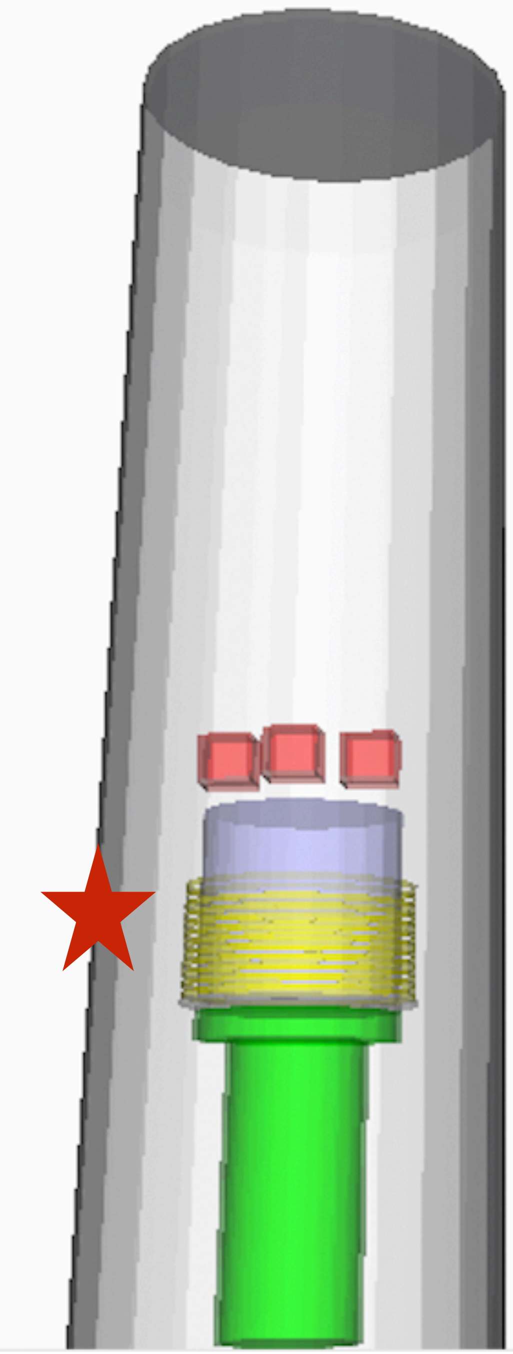
Calibration of the TPC

Simulation of the TPC geometry and response:
High precision geometry implemented in a GEANT4-based MC (**G4DS framework** ⇨ **DarkSide**, see JINST12,10(2017))

Convolute MC spectra with response map
Determine average light yield and related systematics (1.8% decrease of the full data-taking)

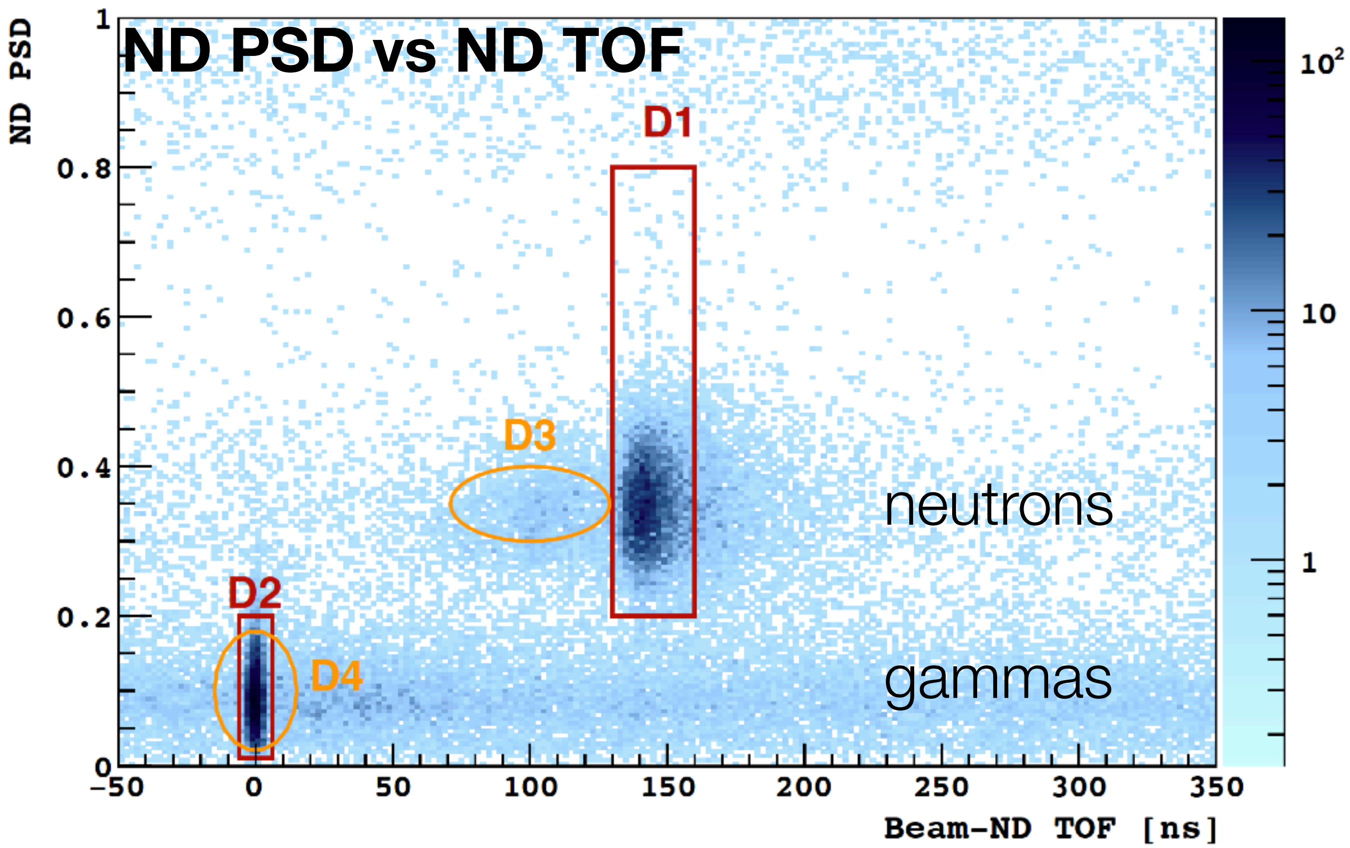


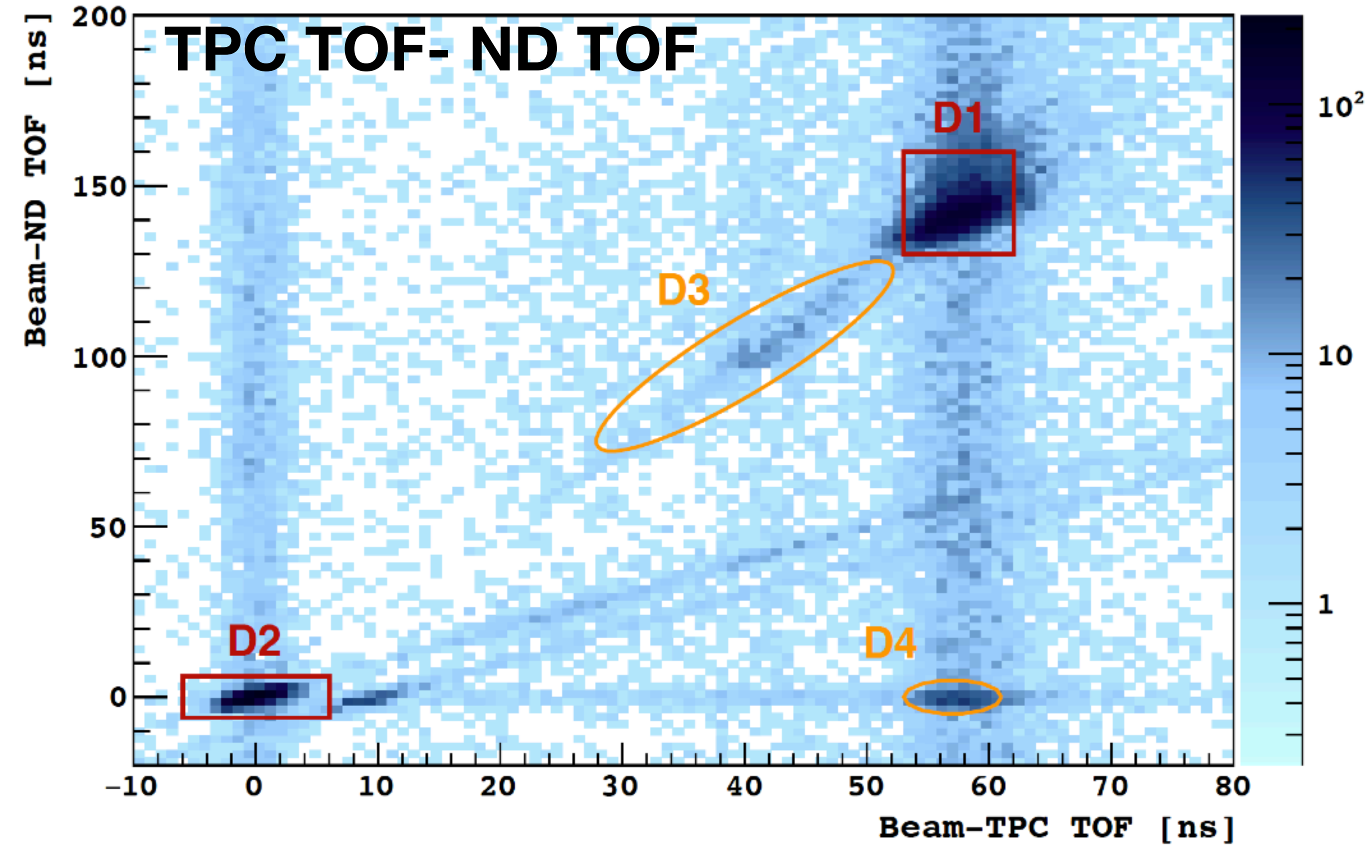




Average light-yield: 6.35 ± 0.05 pe / keV @ null-field

Beam data selection





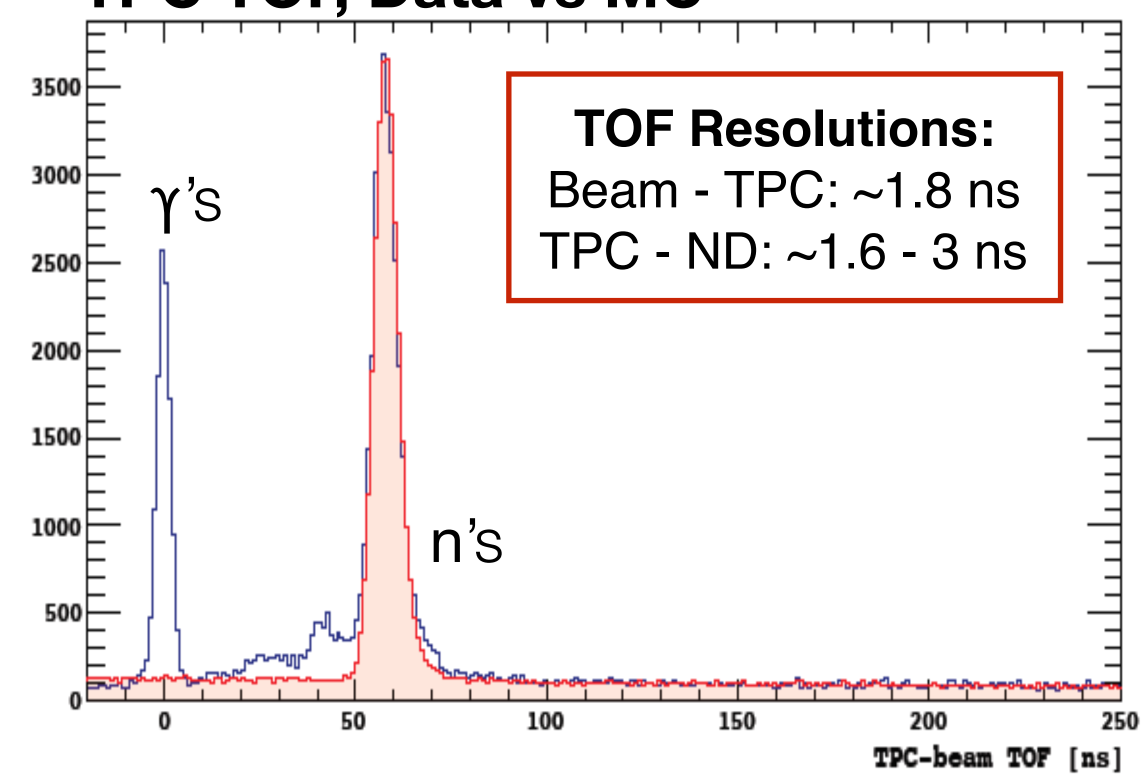
4 populations:

- Neutrons from ^{7}Li(p,^{7}Be)n reaction (D1)
- Compton scattered beam-correlated γ from 7Li* de-excitation (D2)
- Neutrons from fusion evaporation reactions (D3)
- Accidental coincidences between a neutron in the TPC and a γ in the ND (D4)

Cut based on **TOF**, **ND PSD** and **ND charge**.

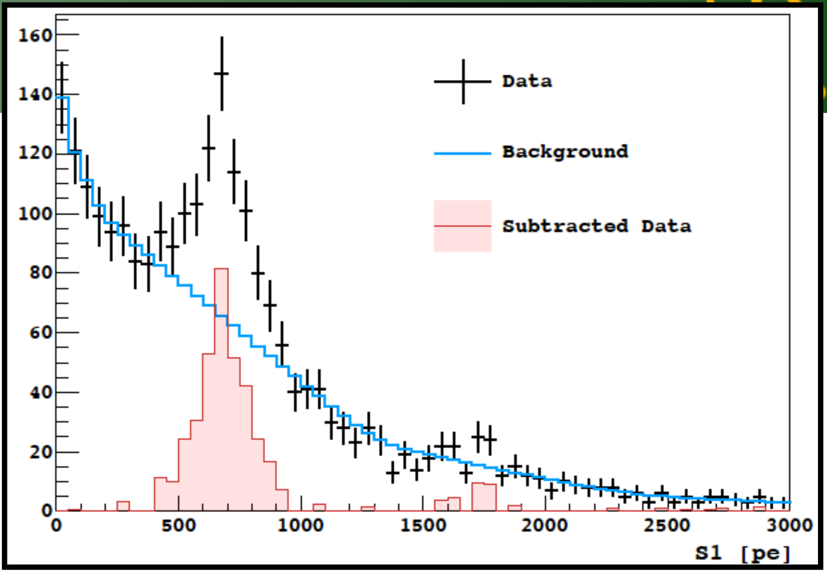
Do NOT exploit PSD in LAr (NR and ER overlap at low E)

TPC TOF, Data vs MC

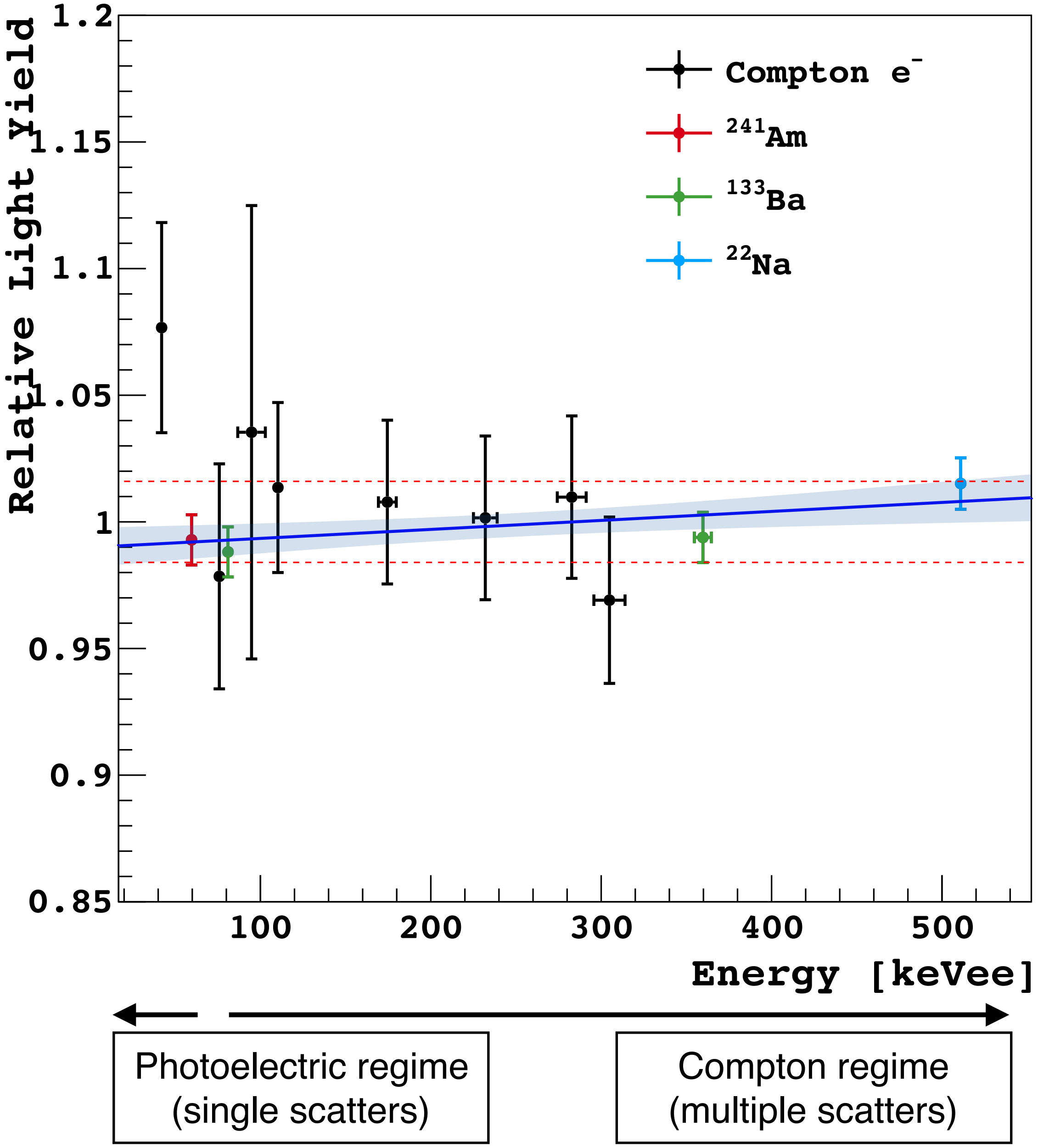


ER response linearity

478 keV γ's from **^{7}Li* de-excitation** for time-alignment and ER analysis. Mean energy (from full MC) is affected by **relativistic boost**, up to 6% (large systematics). **Pure sample of single ER's** in the Compton dominated region. Coupled with γ sources allows determination of LAr **response linearity** at null field.

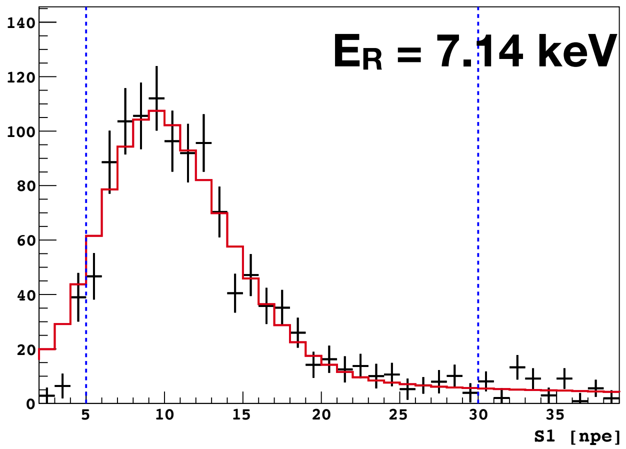


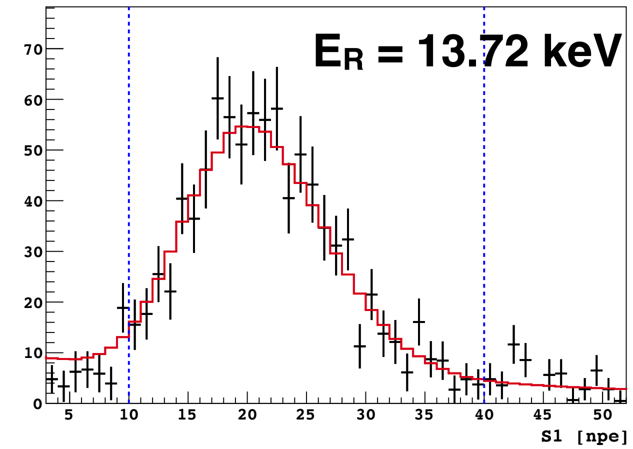
	Scattering Angle [deg]	Mean NR Energy [keV]	Mean ER Energy [keV]
A0	25.5	7.1	42.0
A1	35.8	13.7	75.9
A2	41.2	17.8	85.8
A3	45.7	21.7	110.3
A4	64.2	40.5	174.5
A5	85.5	65.4	232.0
A6	113.2	98.1	282.7
A7	133.1	117.8	304.9

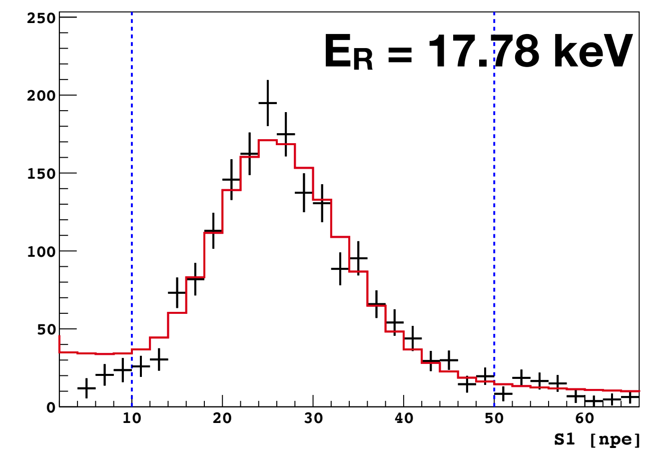


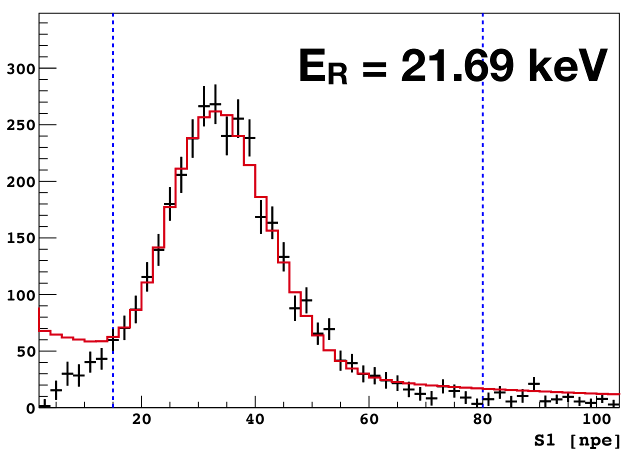
Light yield proven to be **constant at 1.6%** fitting all sources (**42 to 511 keV**)

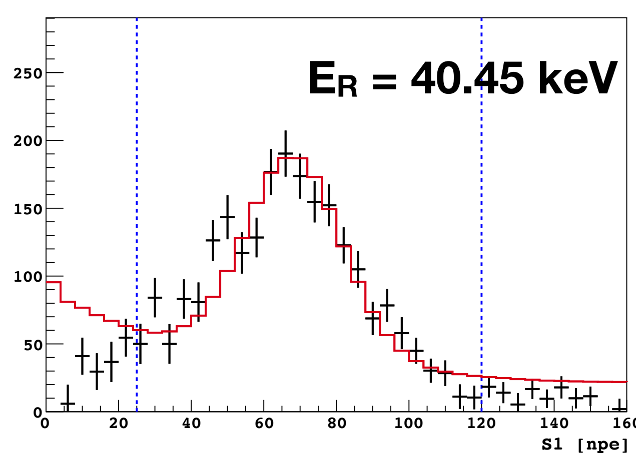
NR fitted spectra

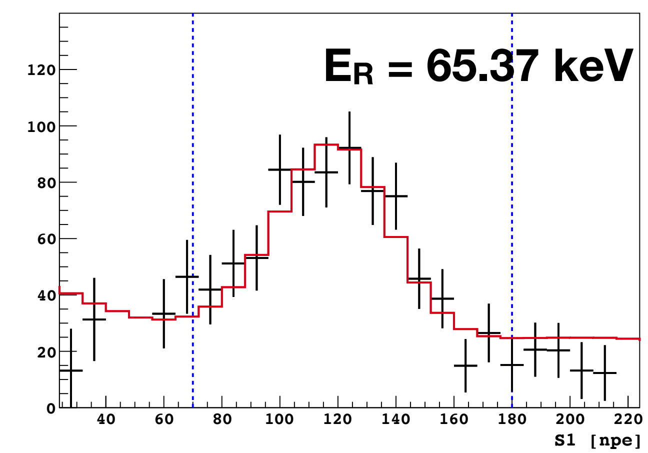


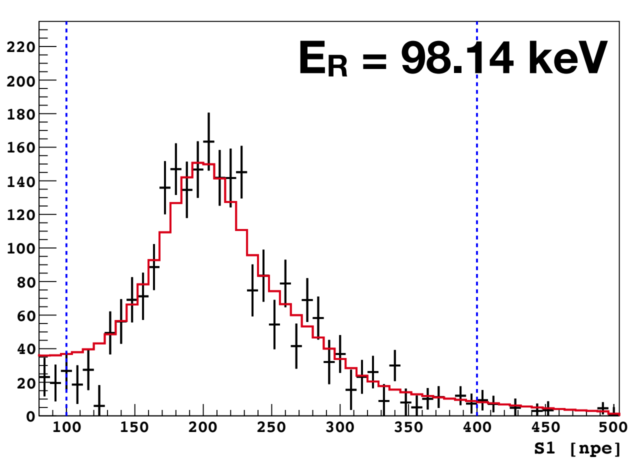


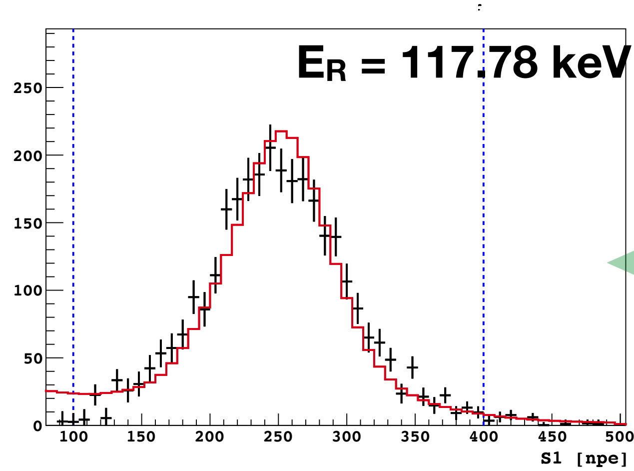




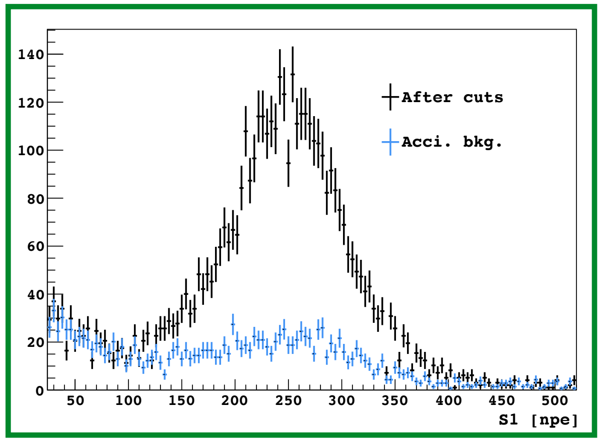








A7 before bg subtraction:



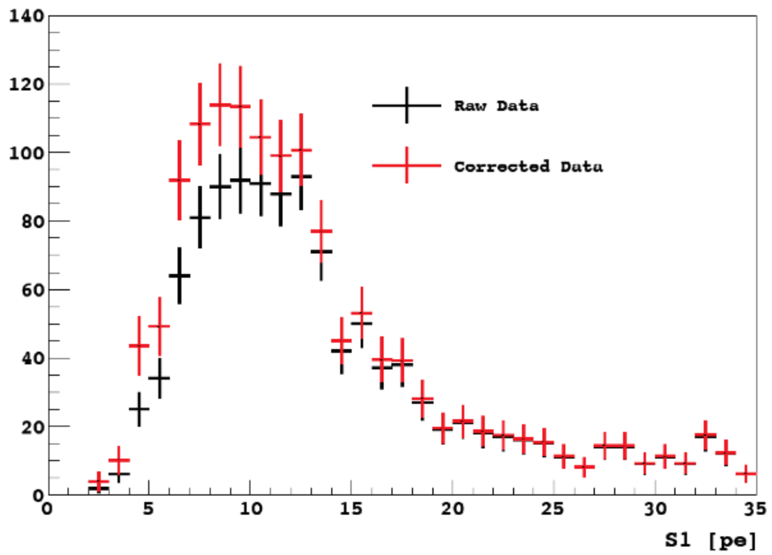
Data is **background subtracted**. MC spectra are convoluted with TPC response map. **LY is fixed** from ER's. Fit performed with **L_{eff} as free parameter**

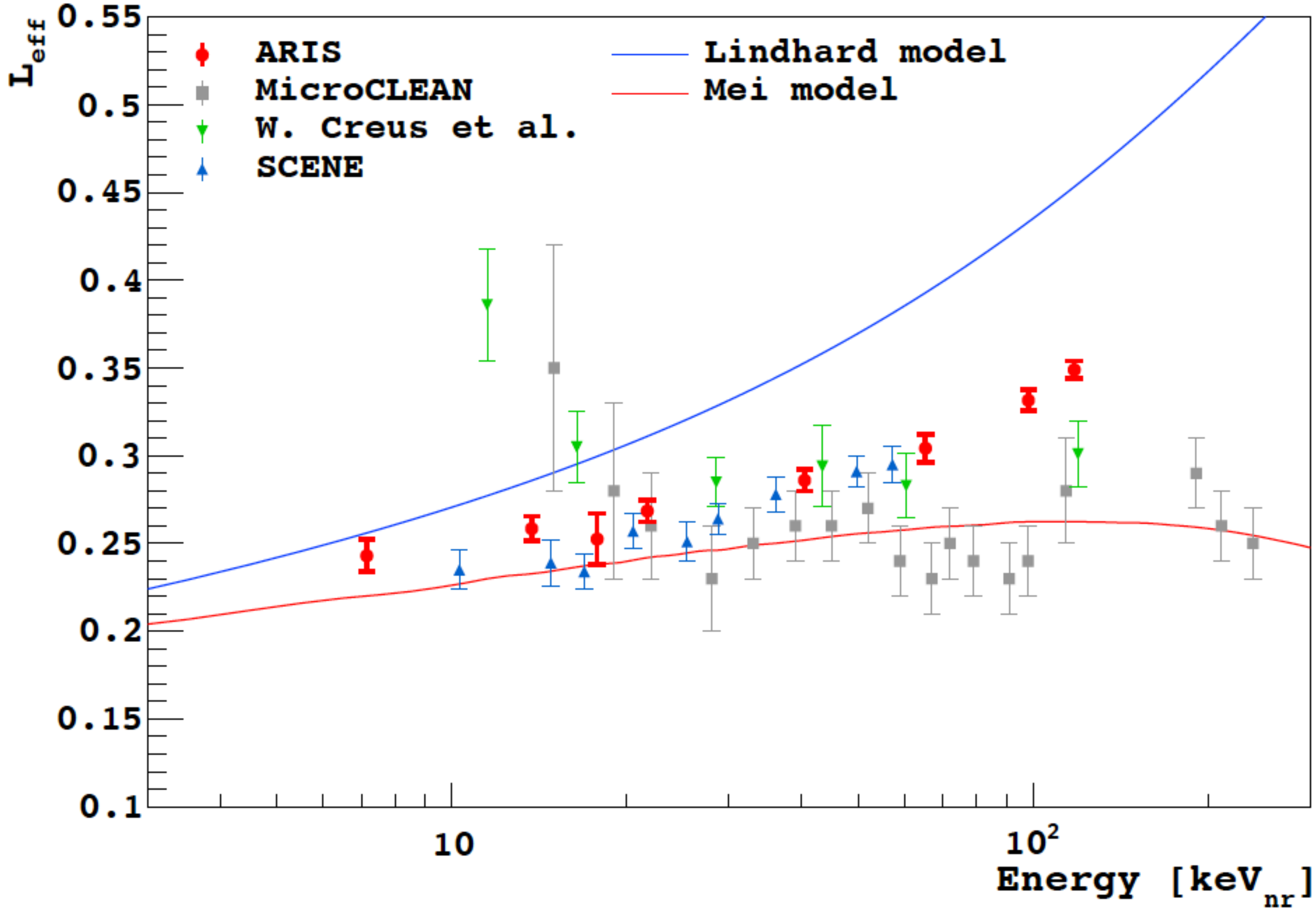
L_{eff} at null field and systematics

ARIS

	A0
NR energy [keV]	7.1
$\mathcal{L}_{eff}$	0.243
Light-yield	0.002
Beam kinematic	0.001
A0–A7 position	0.006
TPC position	$o(10^{-3})$
A0–A7 TOF	$o(10^{-3})$
TPC TOF	0.002
Trigger efficiency	$o(10^{-3})$
Total Syst.	0.007
Stat.	0.005
Combined	0.009
Combined relative [%]	3.8

Trigger efficiency correction to A0



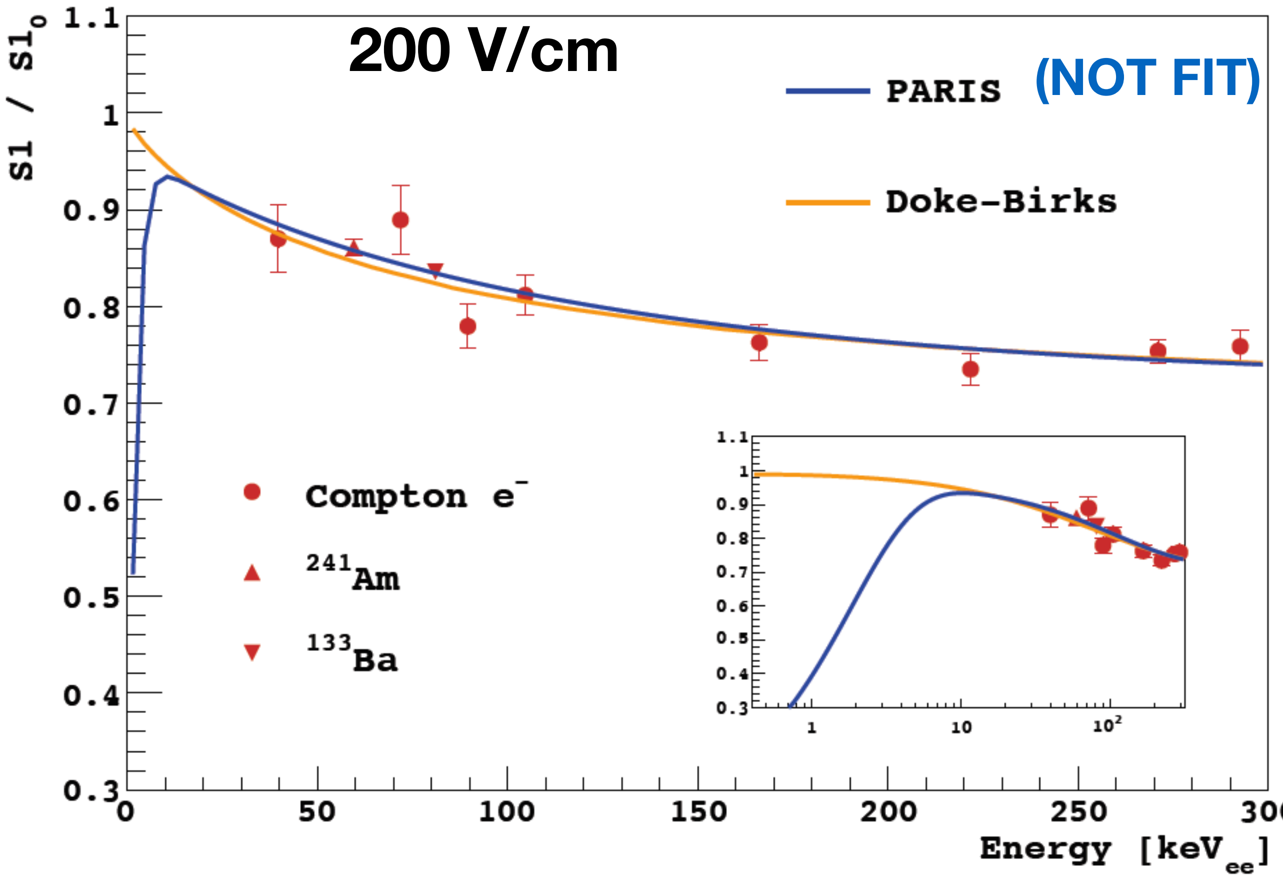


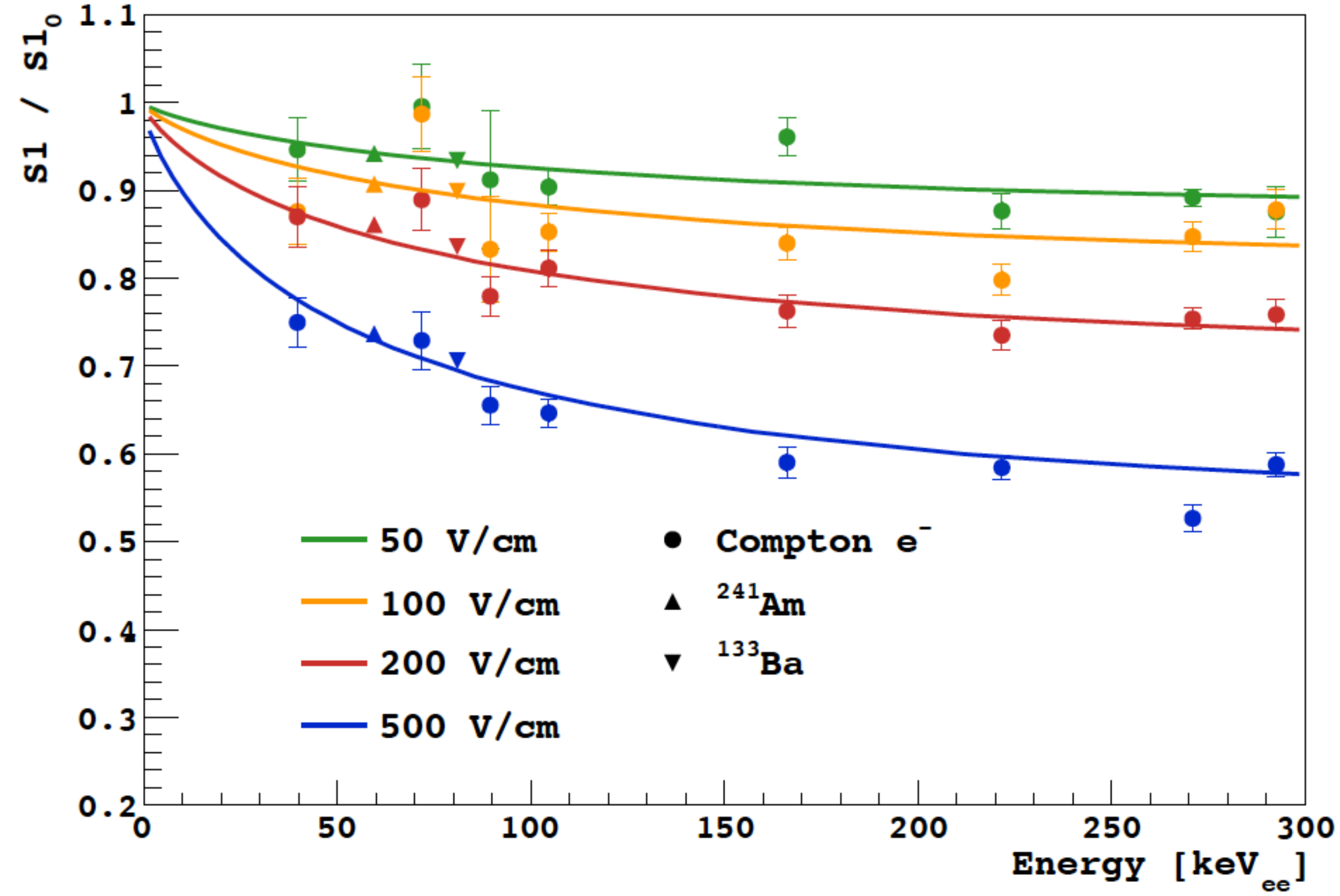
Pure Lindhard: $$L^{L}_{eff} = \frac{kg(\epsilon)}{1 + kg(\epsilon)}$$

Mei Model: $$L^{M}_{eff} = L^{L}_{eff} \times \frac{1}{1 + k_B \frac{dE}{dx}}$$

Parameterization provided with modified Mei model
arXiv:1801.06653

Field dependence: ER





$S1^F / S1^0 (E) = (\alpha + R(E)) \;/\; (1 + \alpha)$

PARIS model developed for **DarkSide**. Extraction of recombination probability at 200 V/cm field from ^{39}Ar, ^{83m}Kr and ^{37}Ar ERs. Underlying assumptions are W = 19.5 eV (effective work function) and α = 0.21 (excitation/ionization).

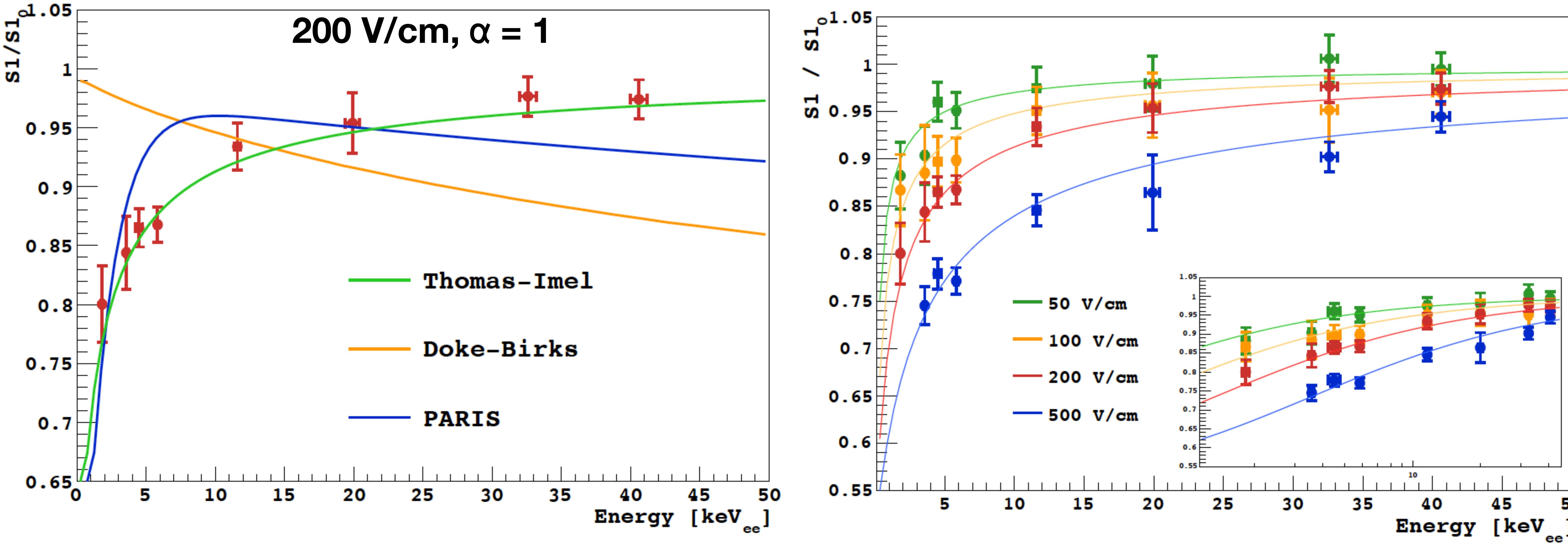
For **E >20 keV, Doke-Birks** model fits well (fails at low E) and describes field dependence.

$$R = \frac{A\ dE/dx}{1 + B\ dE/dx} + C\, e^{-D \times F}$$

A ~ 2.5E-3 cm/MeV
C ~ 0.77
B ~ A/(1-C)
D ~ 3.5E-3 cm/V

dE/dx: e⁻ StP
F: field

Field dependence: NR



S1^F/ S1^0 (E) = (α + R(E)) / (1 + α)

Fixing α = 1 to break the degeneracy between **R** and **α** (do not measure charge).
Under this assumption the Thomas-Imel model is favored (Doke-Birks and PARIS rejected at 5σ)
Thomas-Imel also describes the field induced scintillation quenching with **b ~ 1** and **C ~ 18.5.**
N_i is given by assumptions on W and a. The goal is to **provide a consistent framework for both ER and NR.**

$$R = 1 - \frac{ln(1+\xi)}{\xi}$$

$$\xi = C_{box}\frac{N_i}{F^{\beta}}$$

F: field

Conclusions and outlook

The ARIS external calibration experiment provides a **precision measurement of L_{eff}** as a function of the recoil energy at the lower energy (7 keV_{NR}).

It provides evidence for the **ER response linearity at null field** within 1.6%.

It provides a cross check of the ER S1 energy scale extracted from DarkSide-50 (**the PARIS model** JINST12,10(2017))

It provides a **comprehensive model** for the scintillation response of LAr in the range of interest for the dark matter searches for **both ER and NR**.

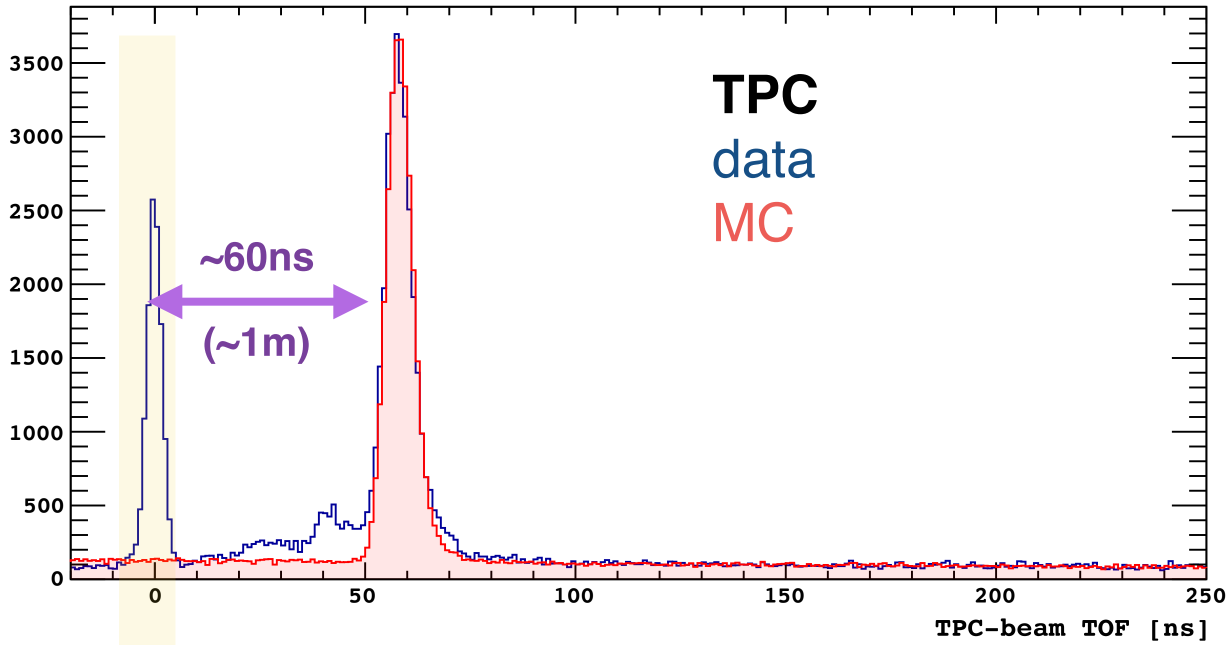
All these results are discussed in arXiv:1801.06653, a second set of analysis is in preparation (LAr time response profile)

The ARIS TPC was operated in single-phase configuration. The recent developments highlight the need to for measurement of the **ionization yield** at very low recoil energy.

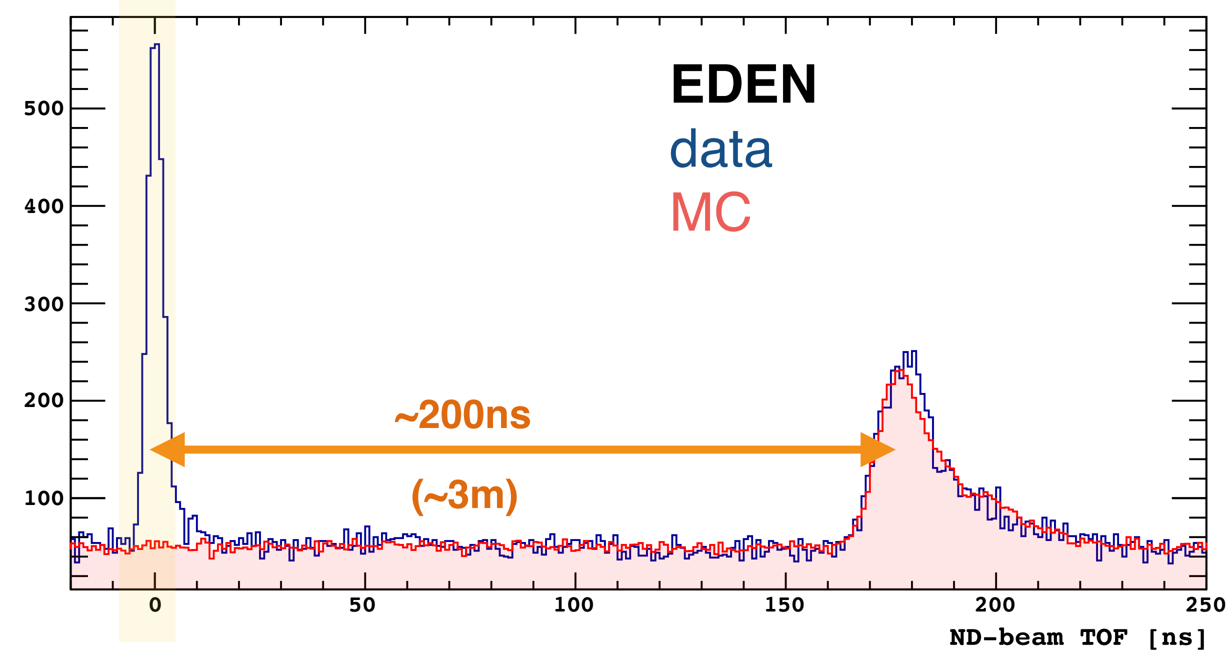
Additional slides

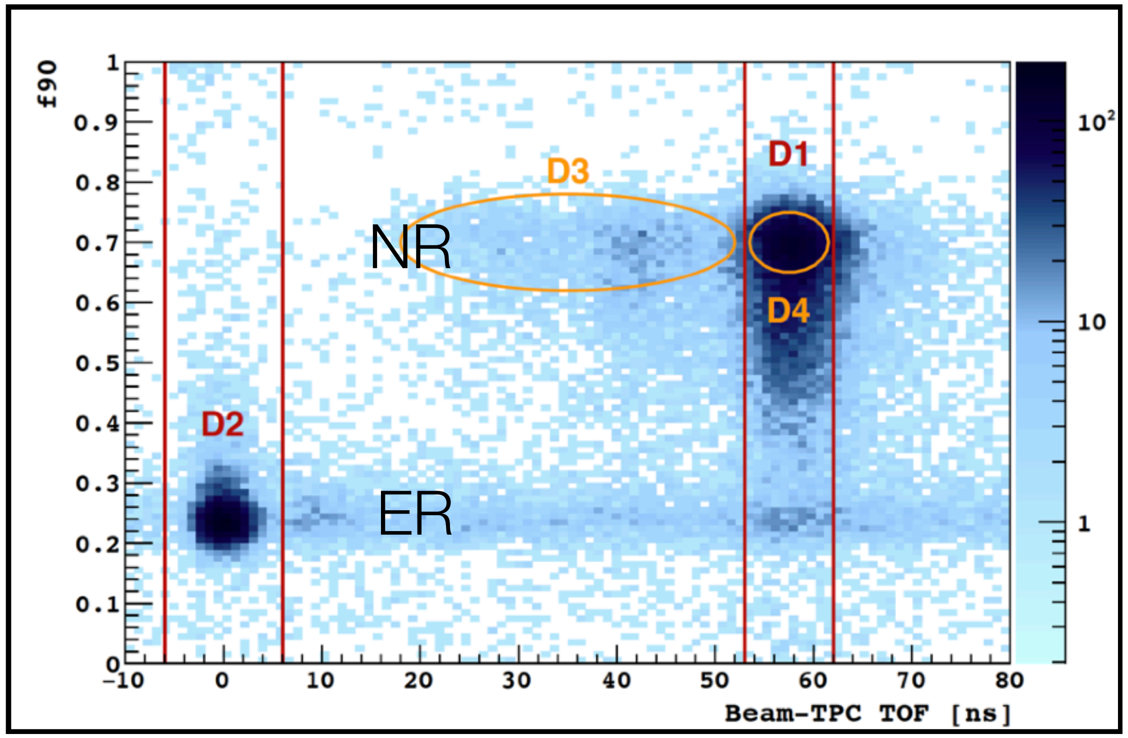
Beam data: time resolution

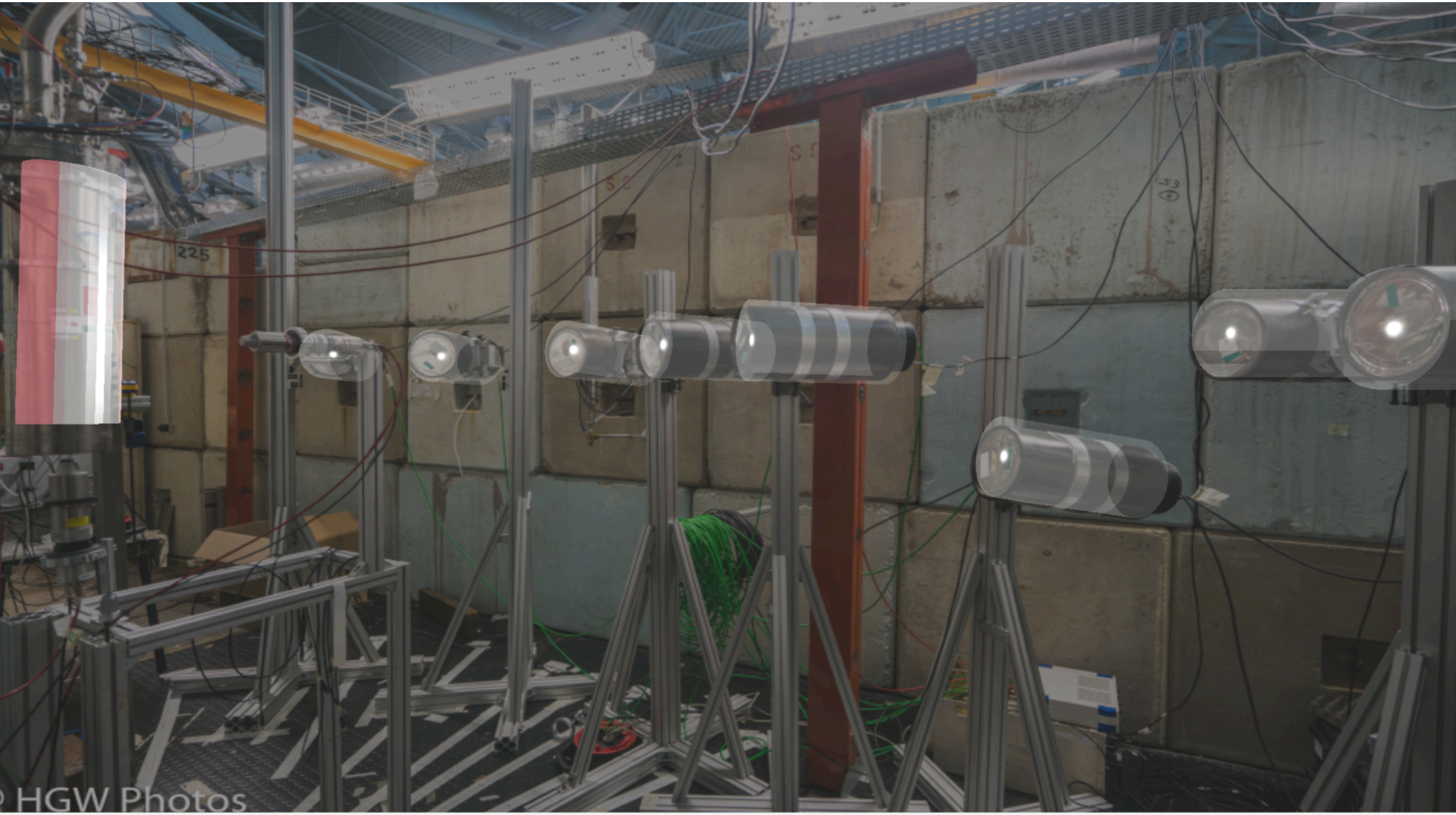
Trigger condition requires TPC, beam and one ND triggered in 100 ns.
Use the **478 keV** gamma from **^{7}Li* de-excitation** for time-alignment



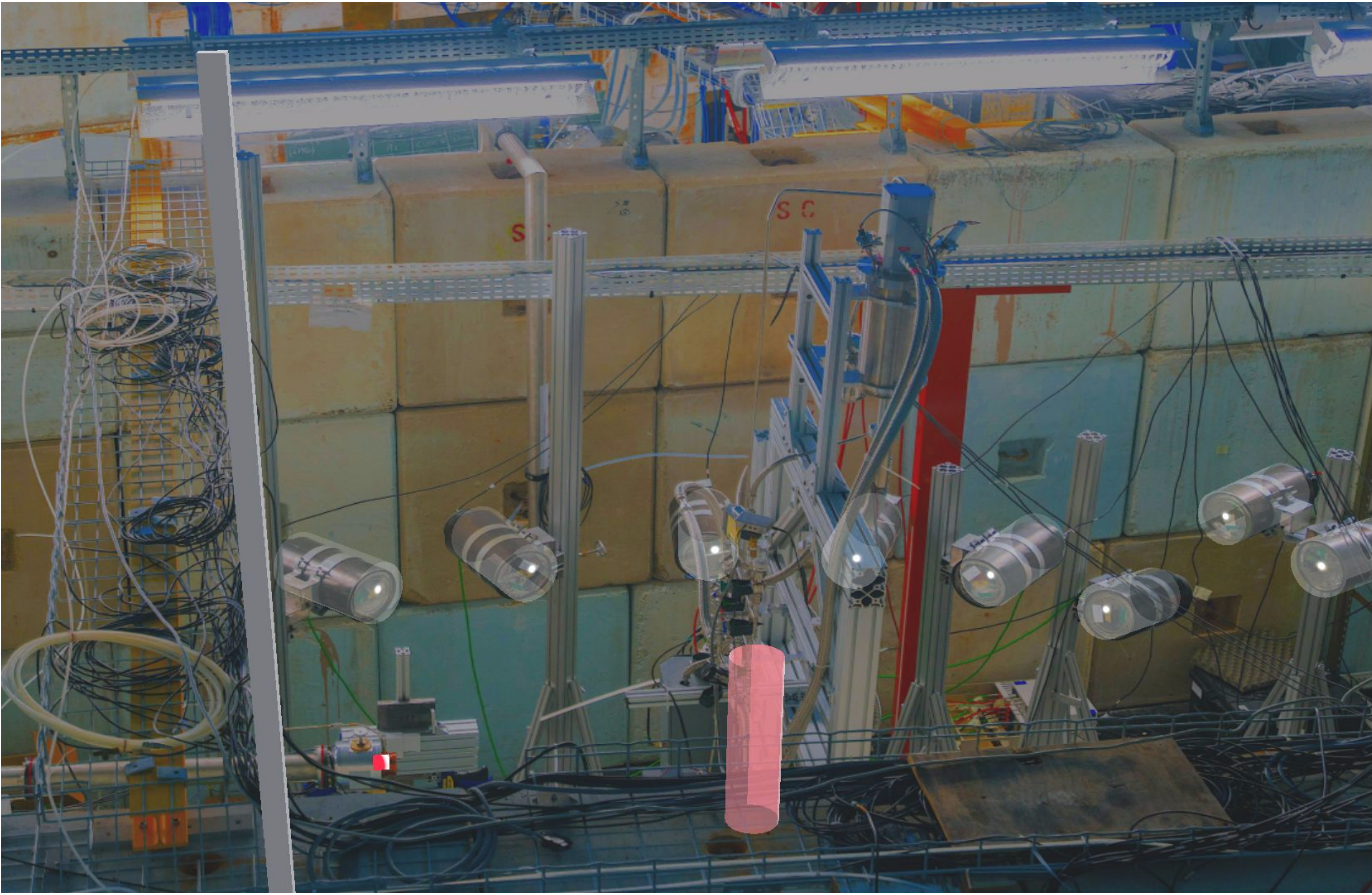
TOF Resolutions:
TPC: ~1.8 ns
EDEN: ~1.6 - 3 ns






225
© HGW Photos

A2 position



Background subtraction