Quenching measurements in noble liquids

Anyssa Navrer-Agasson
LPNHE

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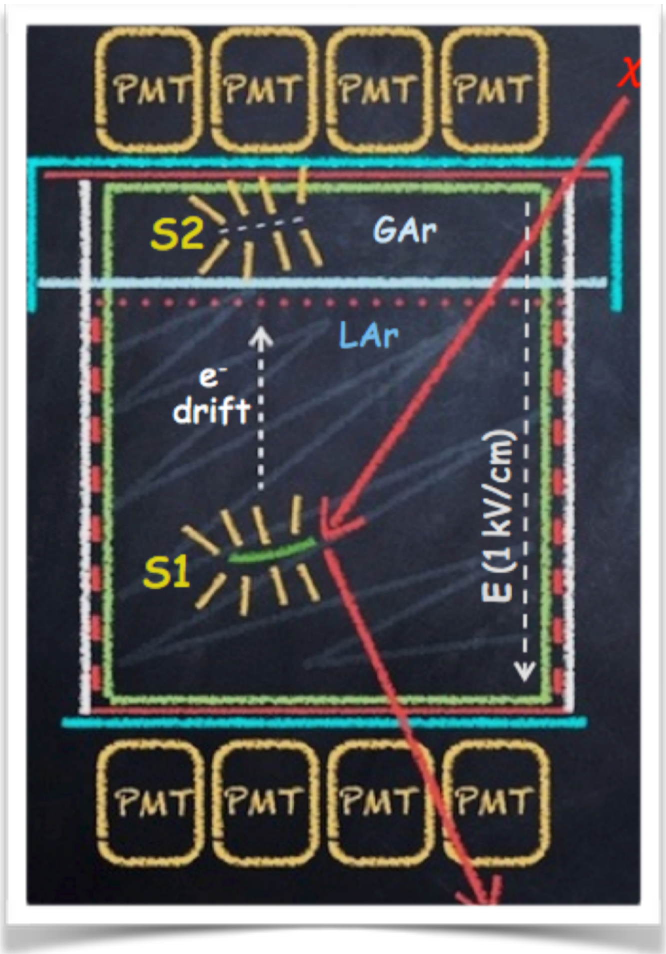
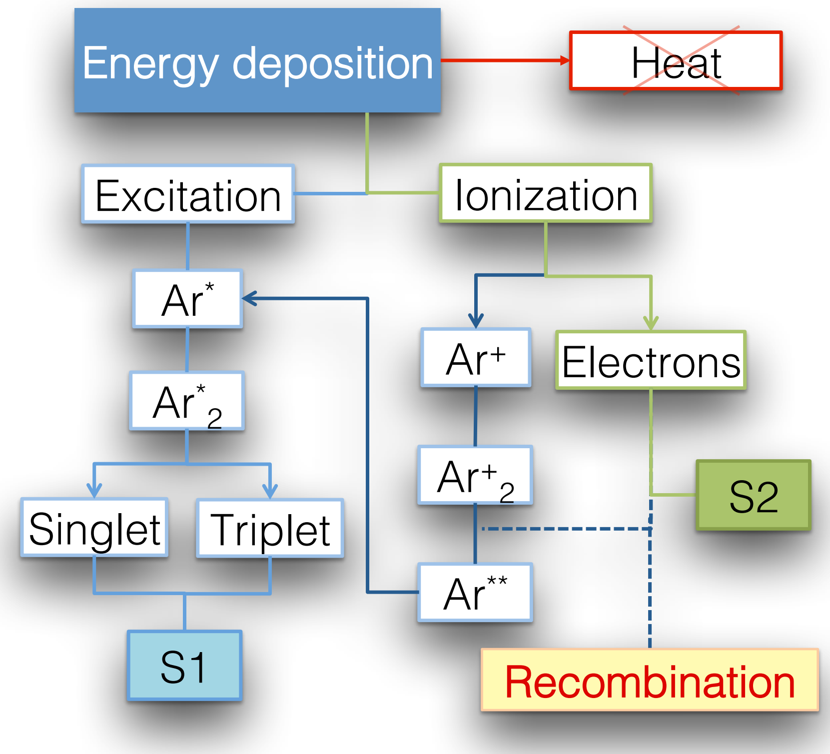
Noble liquid dual-phase TPC





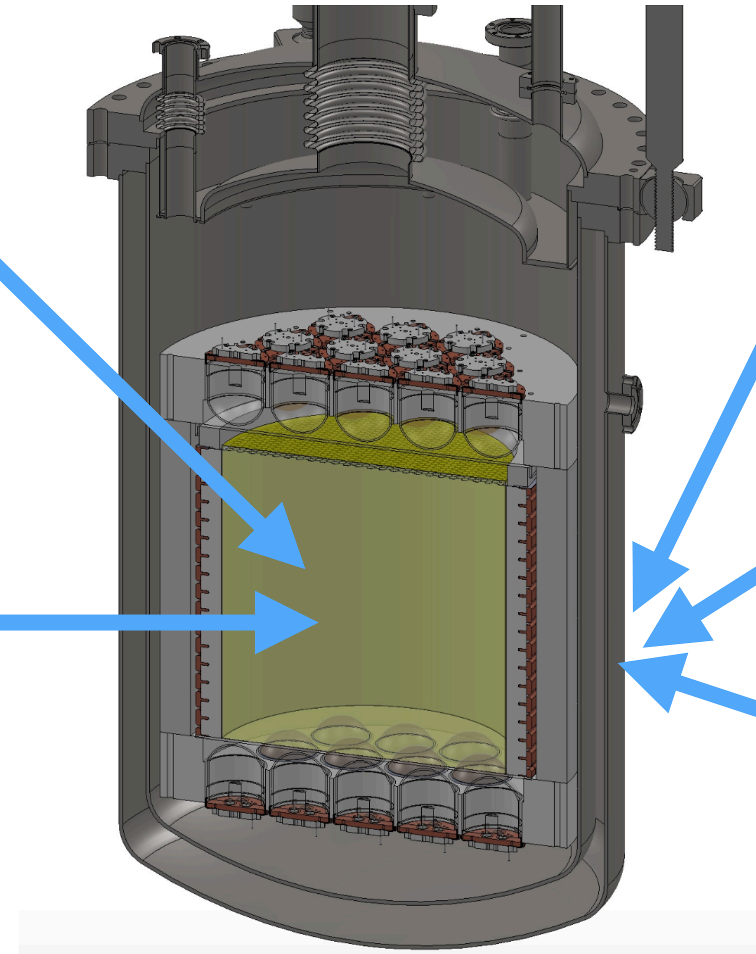
Uncertainties on the response of noble liquids to nuclear and electronic recoils is a major systematics in dark matter searches

- **Photoelectron yield** of electronic recoils as a function of energy
- **Effect of electric field** on scintillation output
- **Relative scintillation efficiency** (L_{eff}) between electronic and nuclear recoils

Measurement methods

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

<u>Injected gaseous source</u>
<u>(^{83m}Kr)</u>
Direct measurement
Limited number of sources

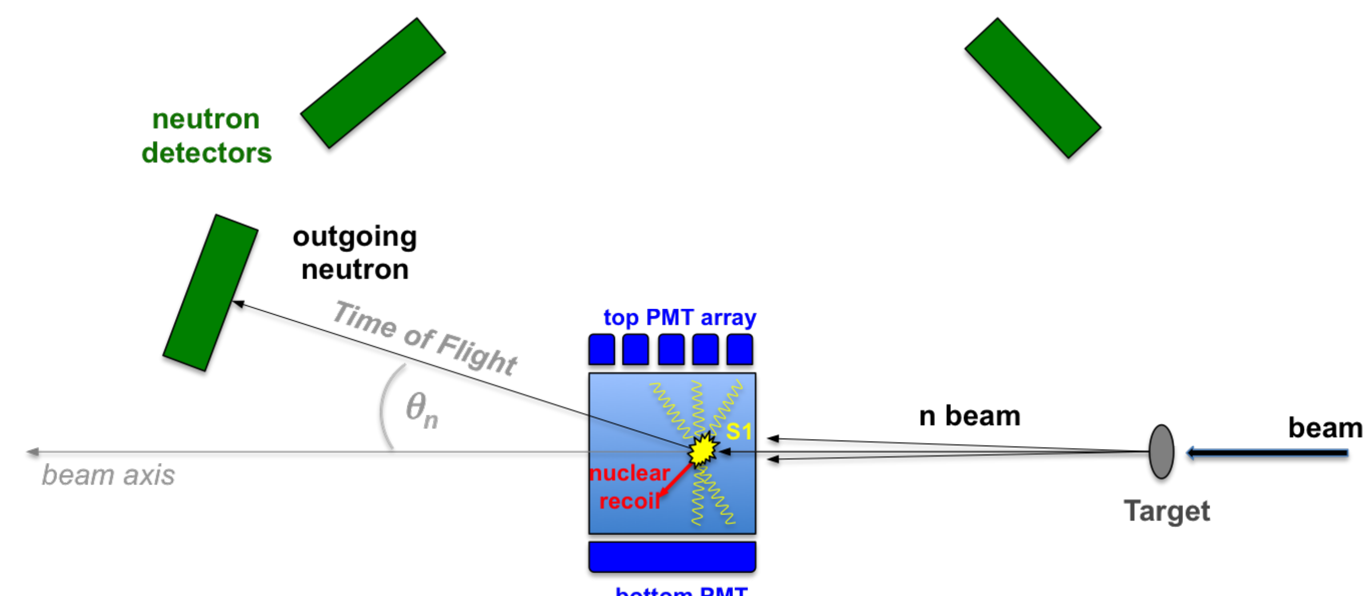


<u>External neutron source</u>
<u>(AmBe)</u>
Direct measurement
Non-monochromatic

<u>D-D gun in the veto</u>
Monochromatic neutrons
Recoil energy reconstruction

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

<u>External calibration</u>
Precise recoil energy reconstruction
Indirect measurement

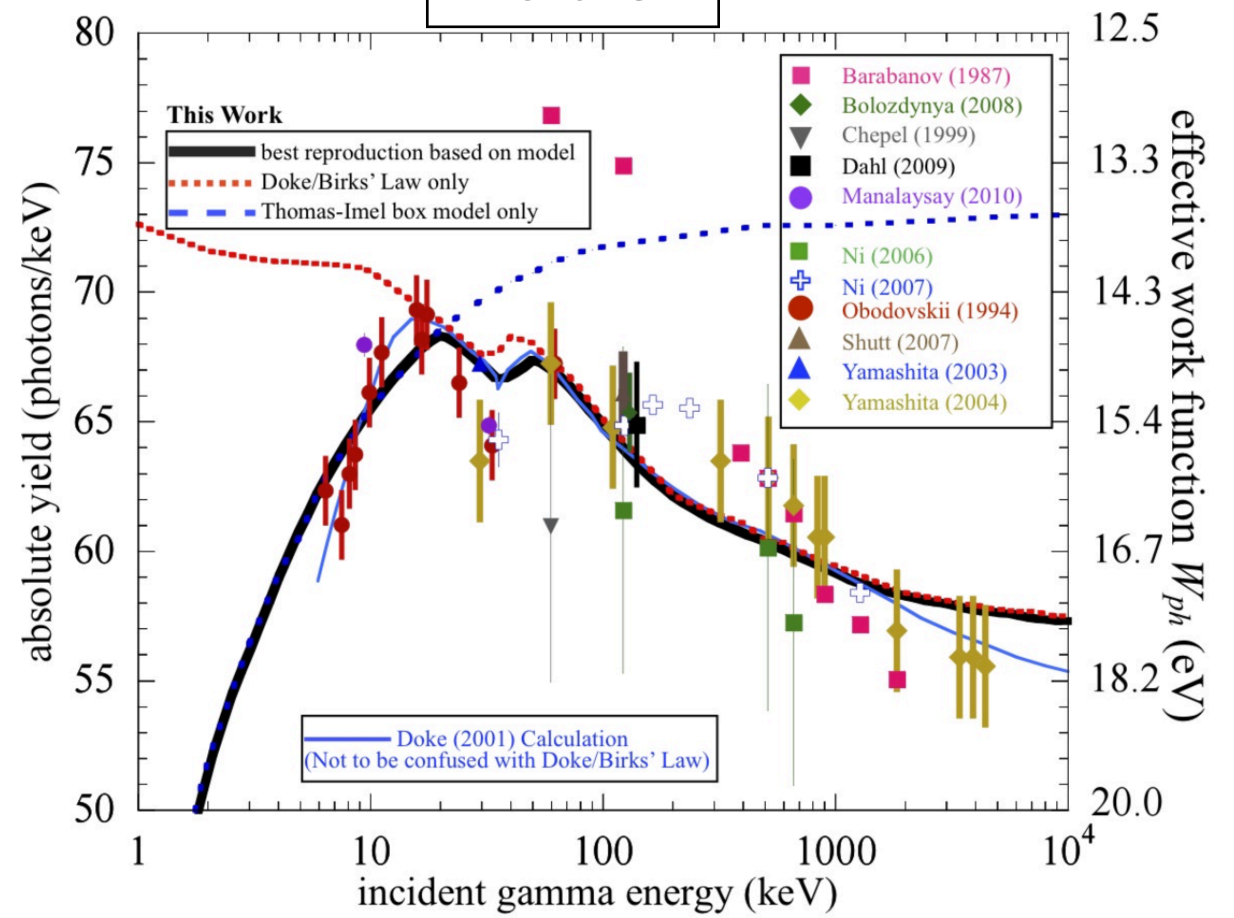


LXe response to electron recoils

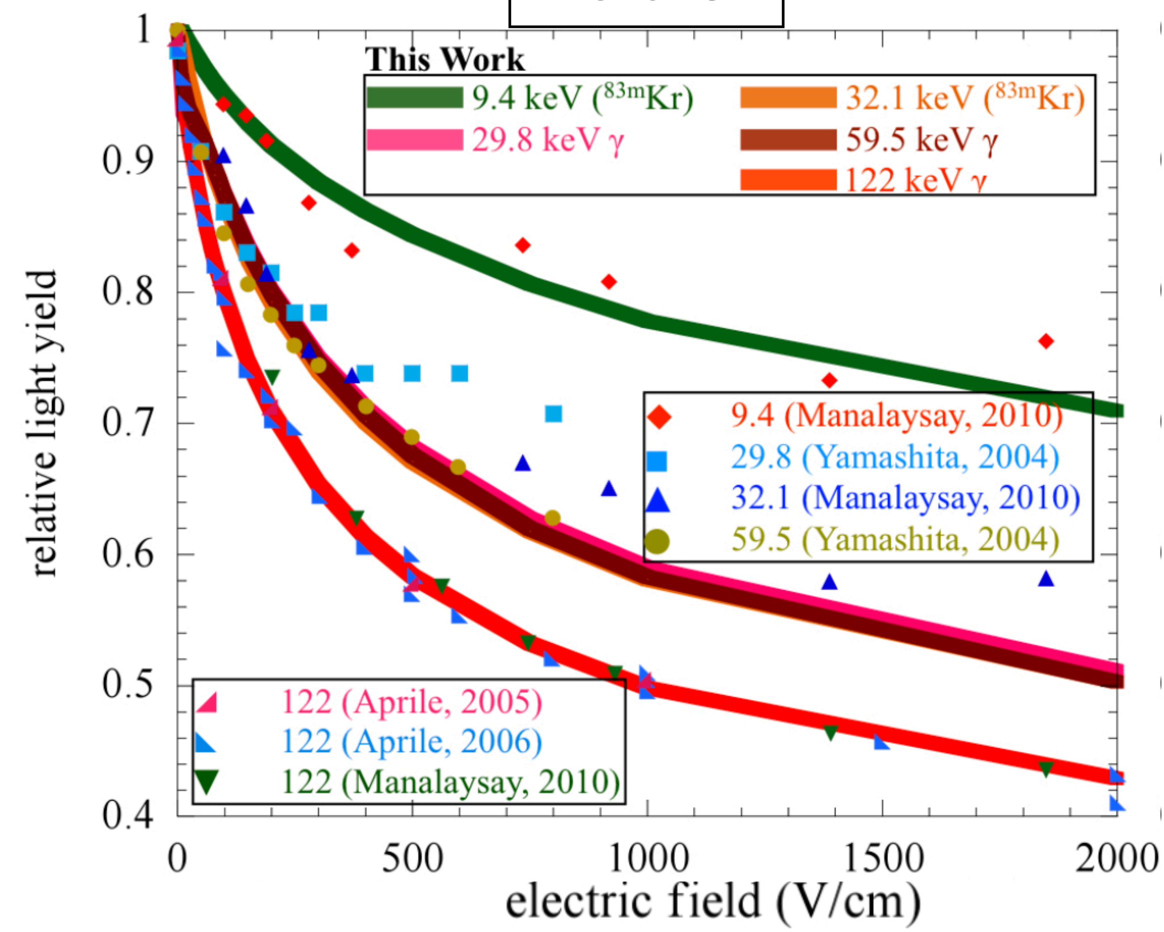
LXe response to ER is non-linear at null field

Dependance of the scintillation yield on the drift field

Field off



Field on



LXe response modeled by the NEST package : simulation based on Thomas-Imel (low energy) and Doke-Birks(high energy) models

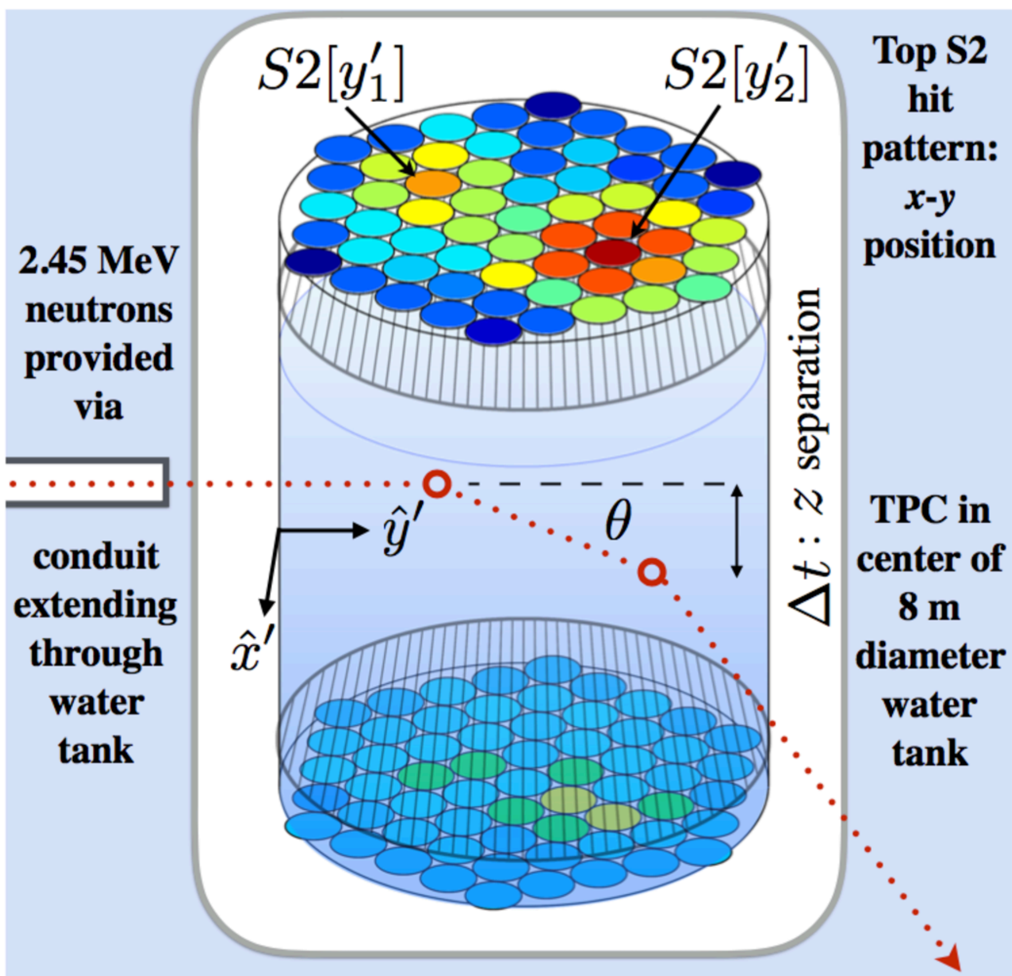
LXe response to nuclear recoils

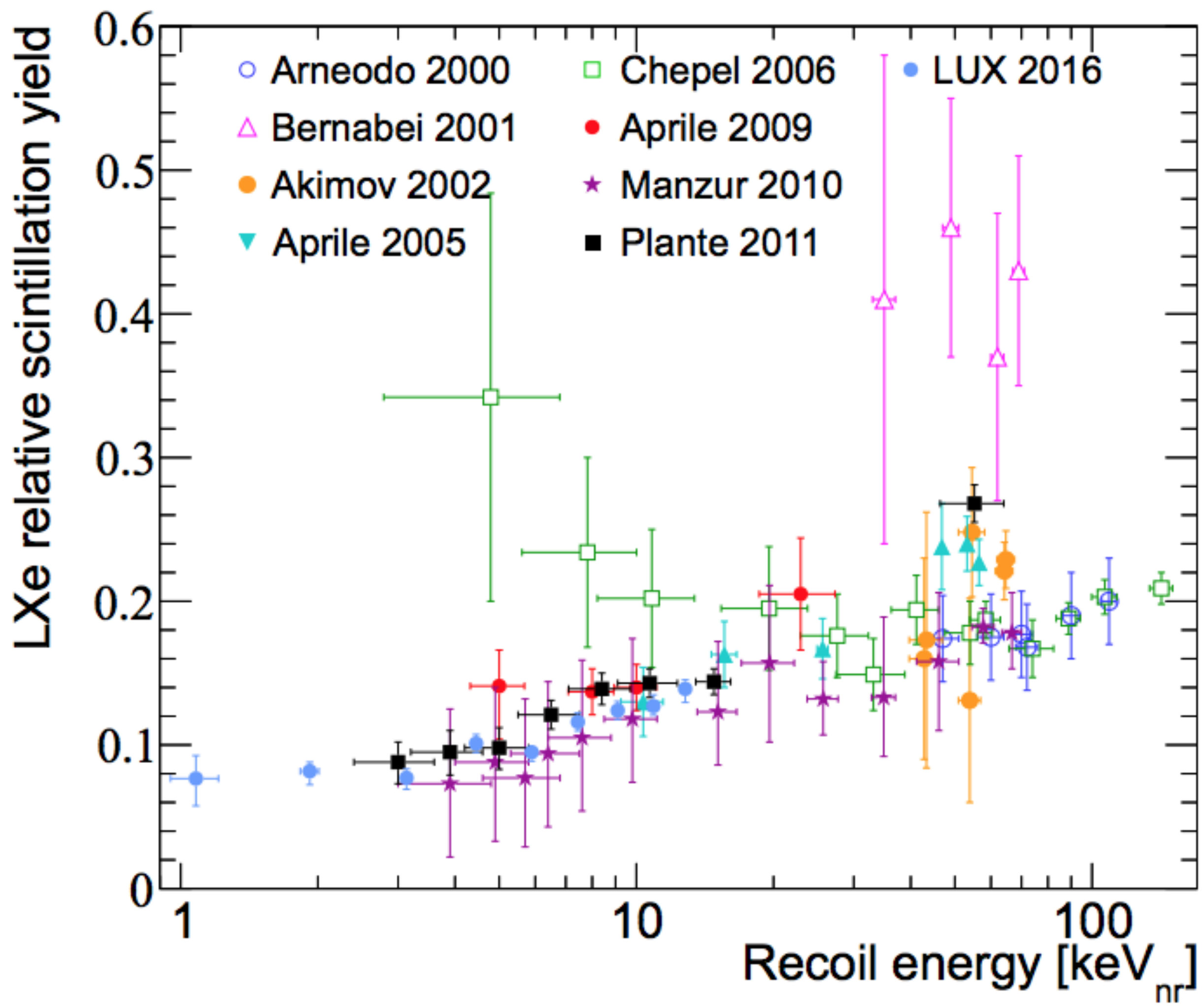
New method proposed by LUX:

Neutrons provided by a D-D neutron gun and directly introduced in the LUX TPC

➡Exploit double-scatter events to calibrate S2 response

➡Use single scatters to calibrate S1 yield, using S2 as a measure of the recoil energy





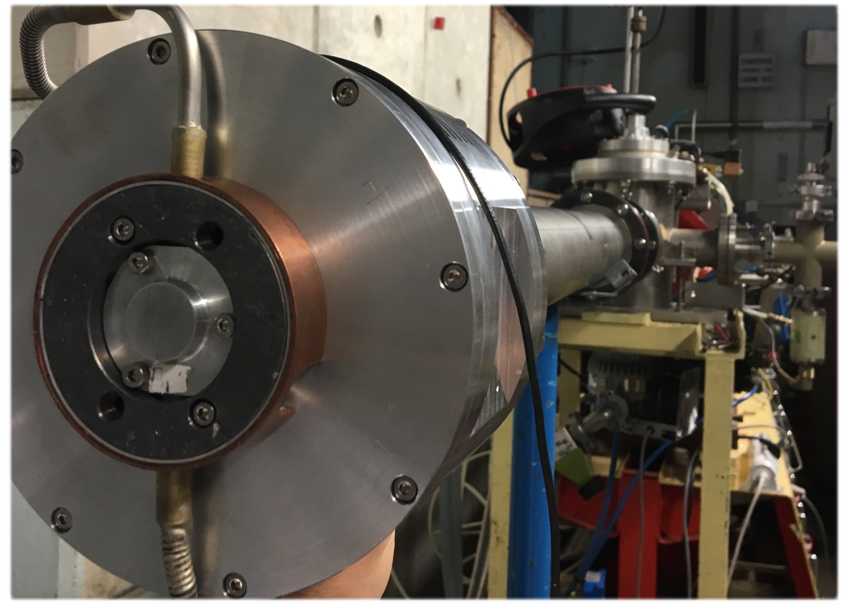
L_{eff} measured down to 1.08 keV_{nr}

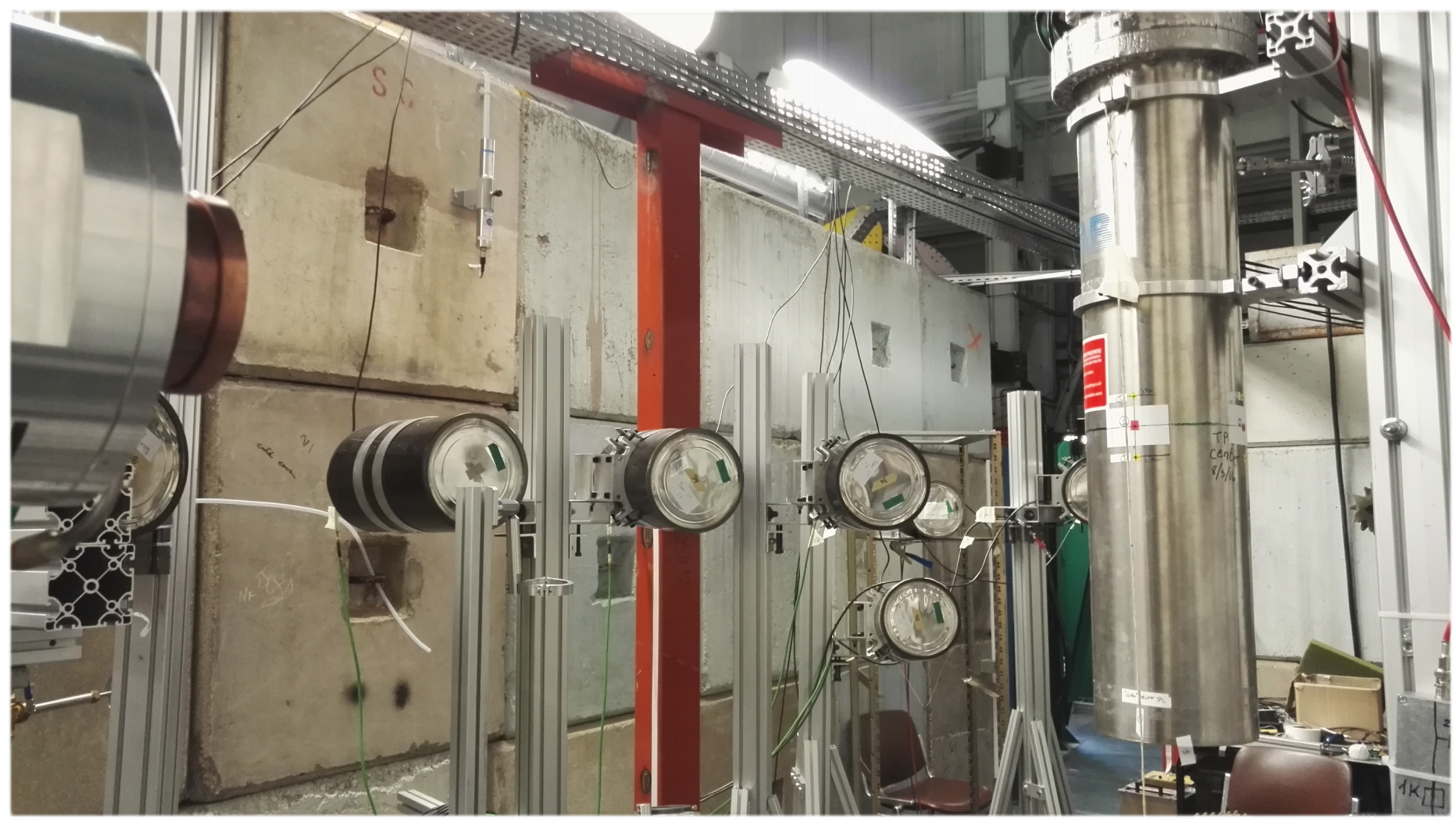
http://aris.in2p3.fr

The ARIS experiment

ARIS experiment: data taking at Licorne

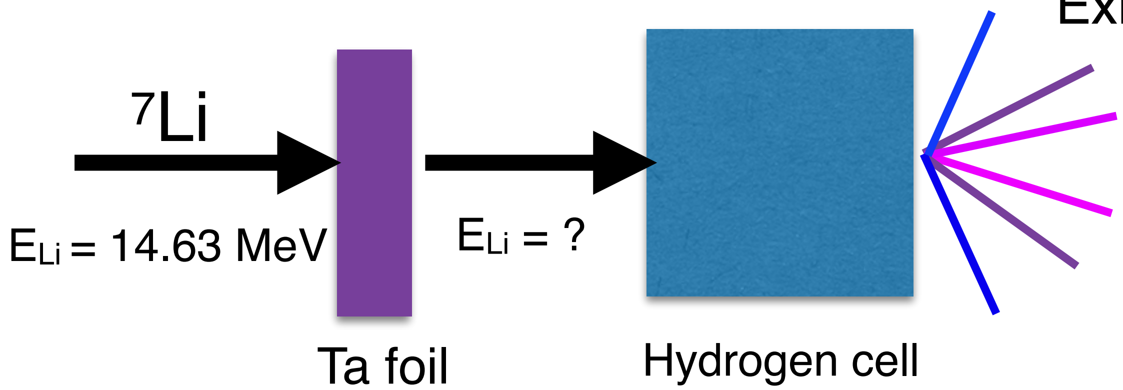
12 days of data taking
in October 2016



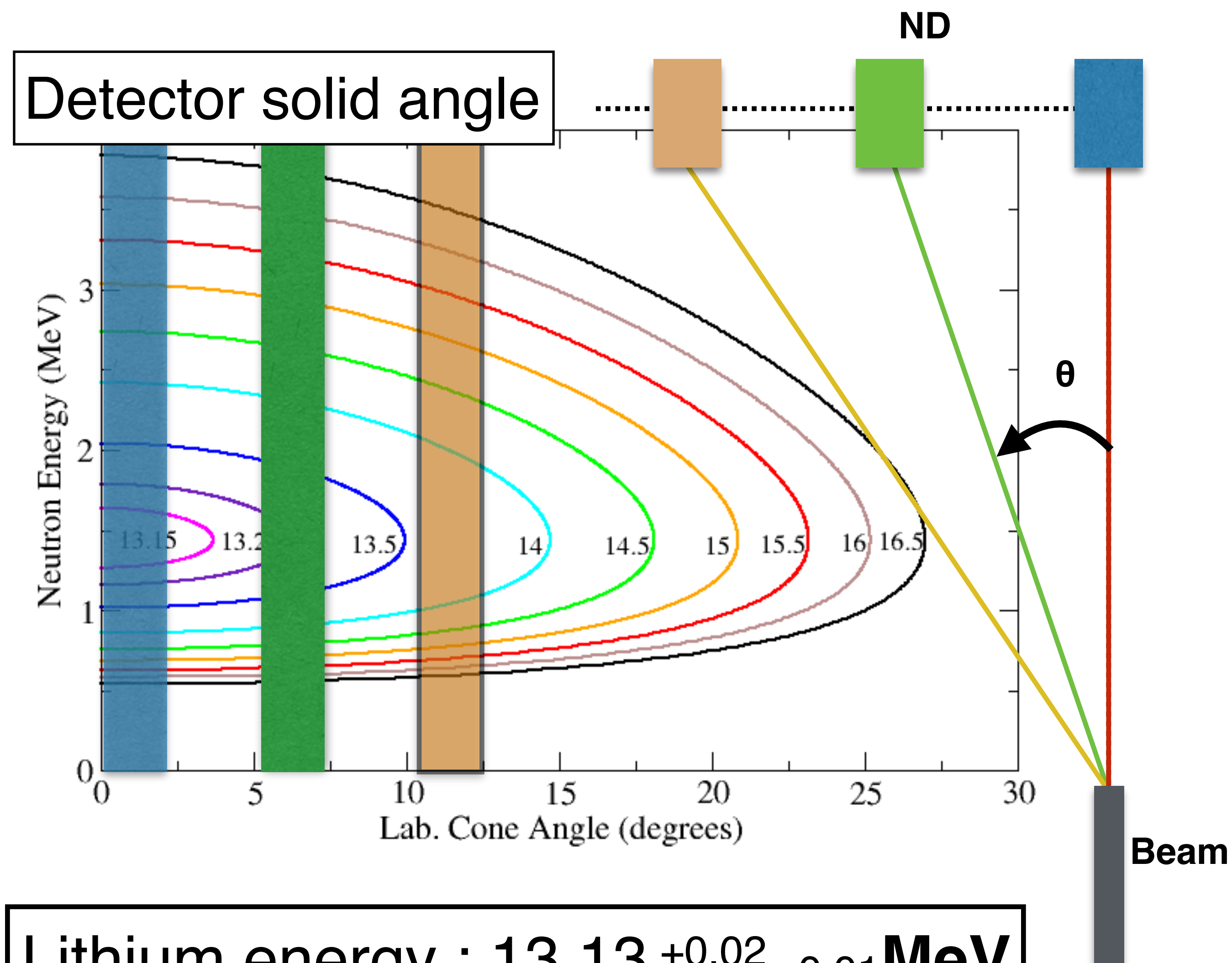


Neutron kinematics

Neutron production $^{7}\mathrm{Li}(p.n)^{7}\mathrm{Be}$

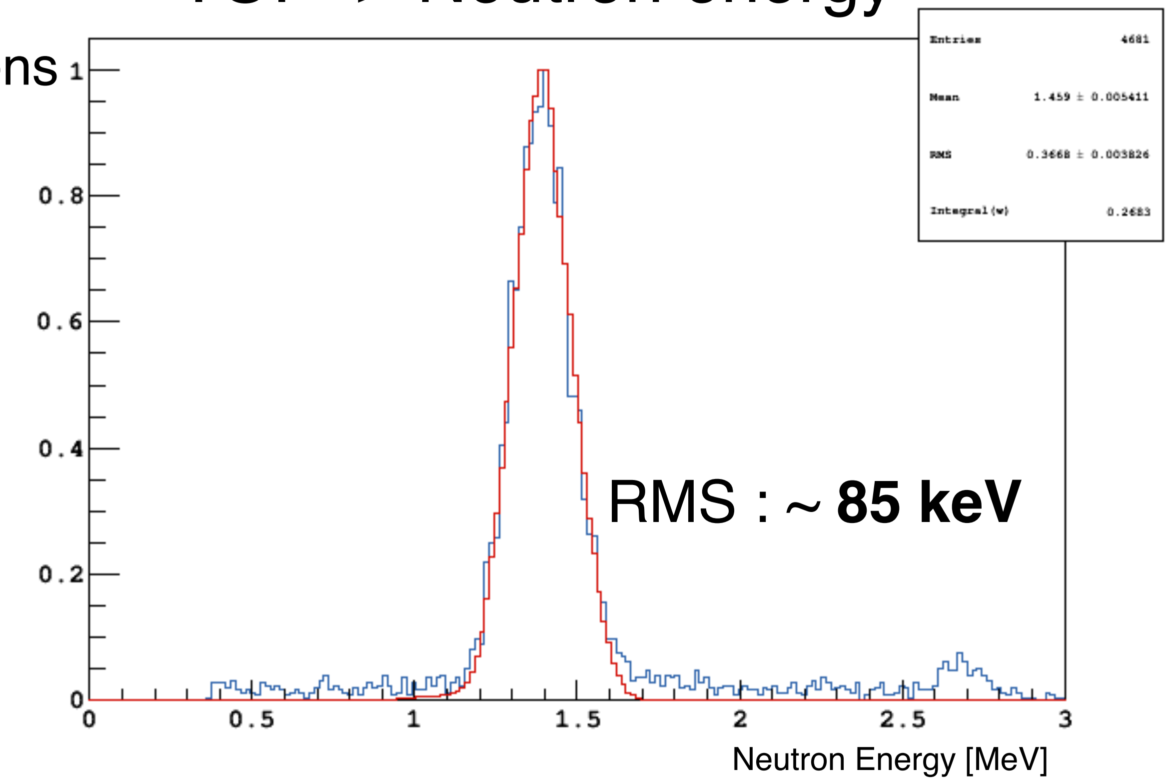


Detector solid angle



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

TOF -> Neutron energy



Neutron mean energy: **1.45 MeV**

Beam characteristics:

- ⇨1 pulse / 400 ns
- ⇨Beam pulse width: 1.5 ns
- ⇨Neutron flux on TPC : ~ 10^4 Hz

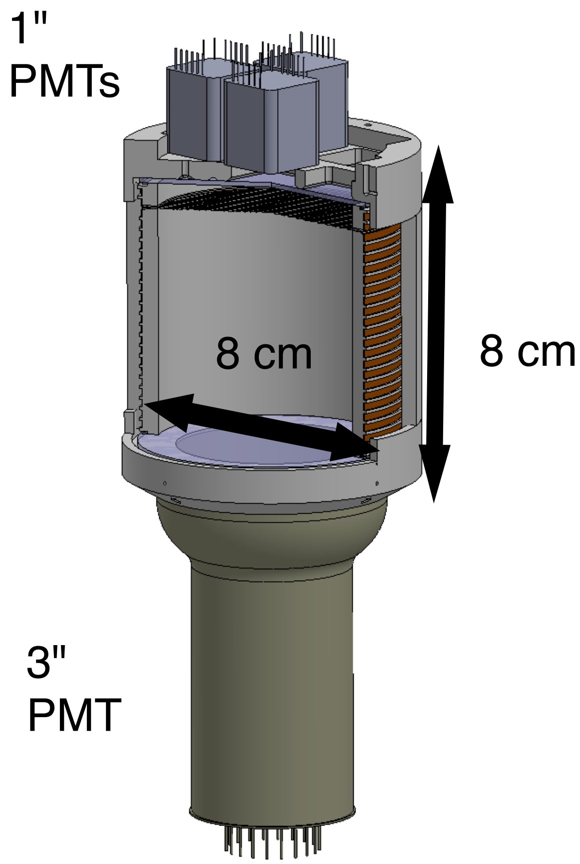
Advantages:

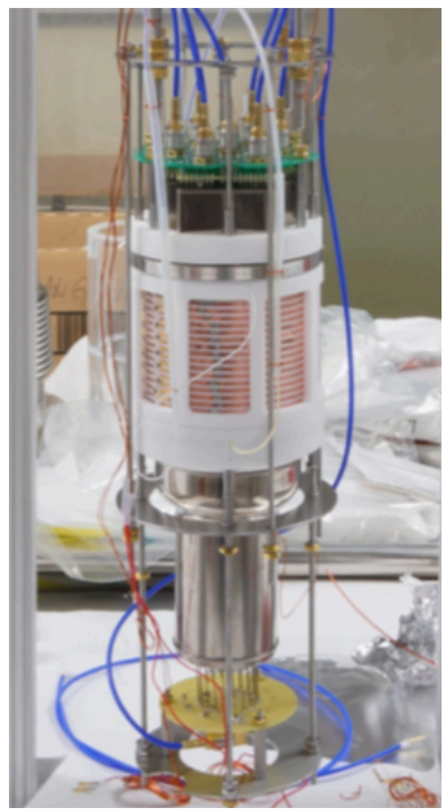
Lithium energy near production threshold

- ⇨ highly collimated beam
- ⇨ high neutron flux on the TPC

The ARIS setup

Small scale TPC ⇨single scatters





TPC:

- ~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

8 neutron detectors:

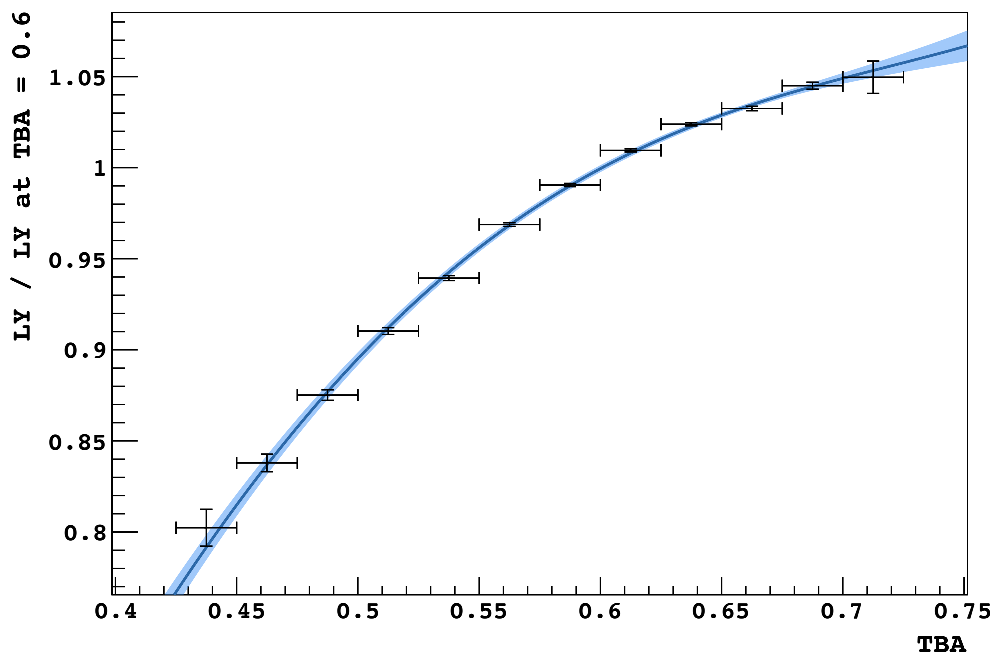
- NE213 liquid scintillator
- 20 cm diameter
- 5 cm height
- Signal pulse shape discrimination available

Probed recoil energies

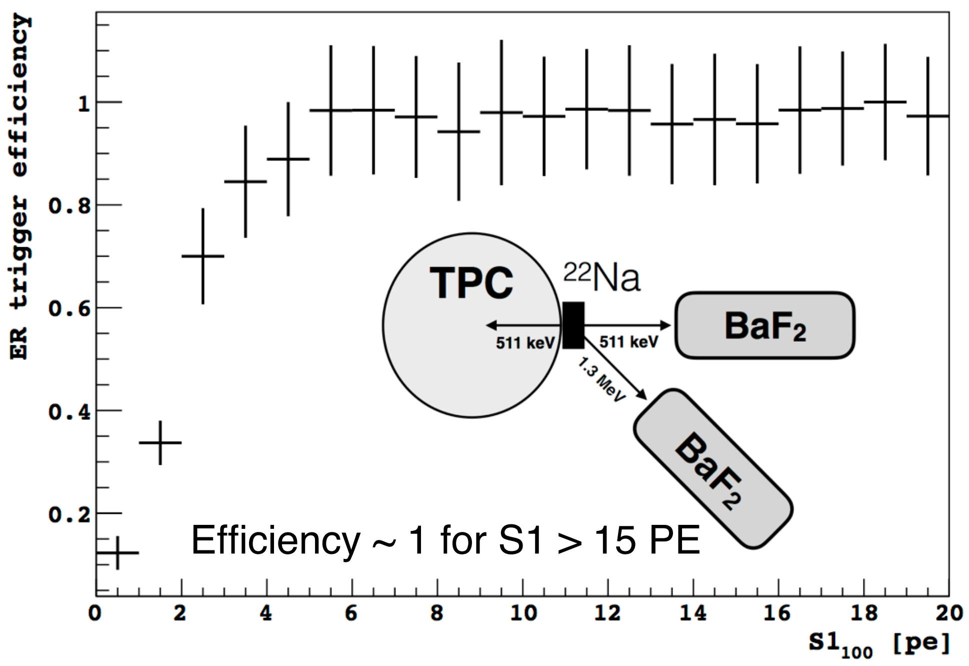
	Scattering Angle [deg]	MC Determined Mean NR Energy [keV]
A0	25.5	7.14
A1	35.8	13.72
A2	41.2	17.78
A3	45.7	21.69
A4	64.2	40.45
A5	85.5	65.37
A6	113.2	98.14
A7	133.1	117.78

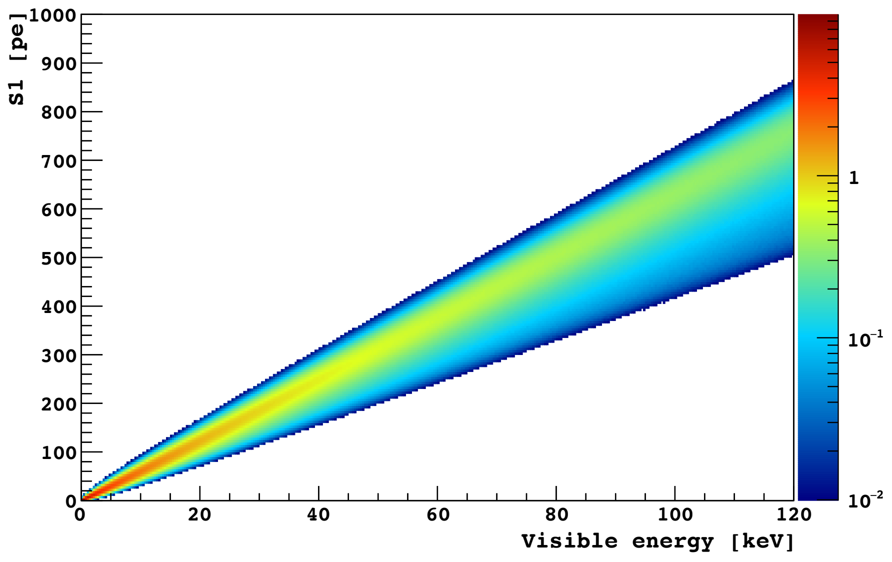
TPC calibration

Top/bottom asymmetry



Trigger efficiency

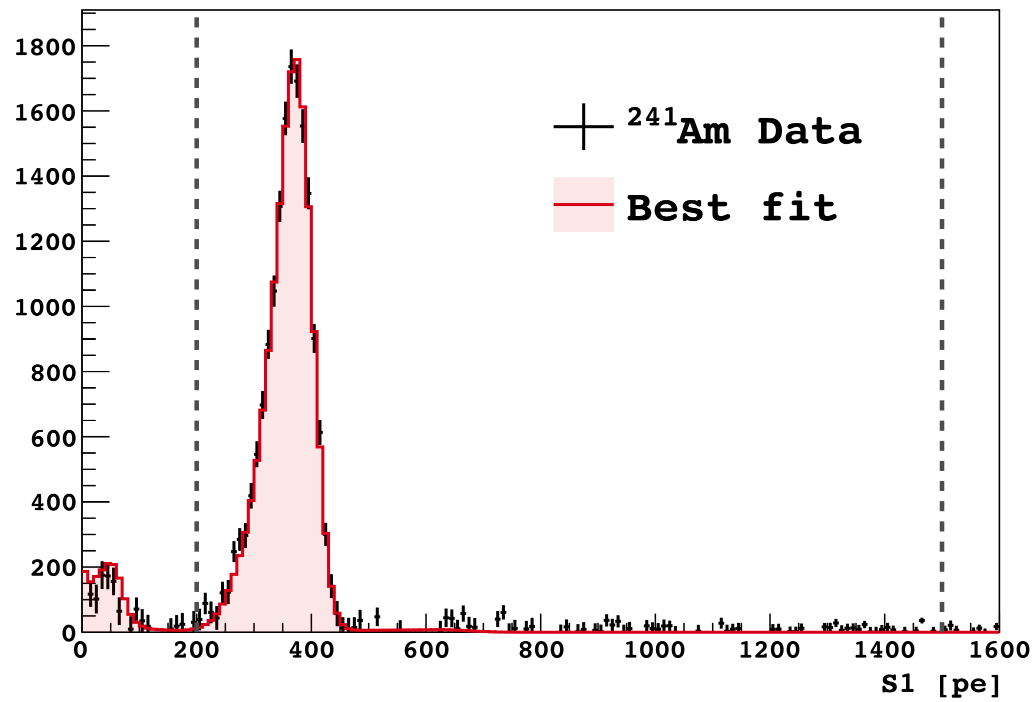


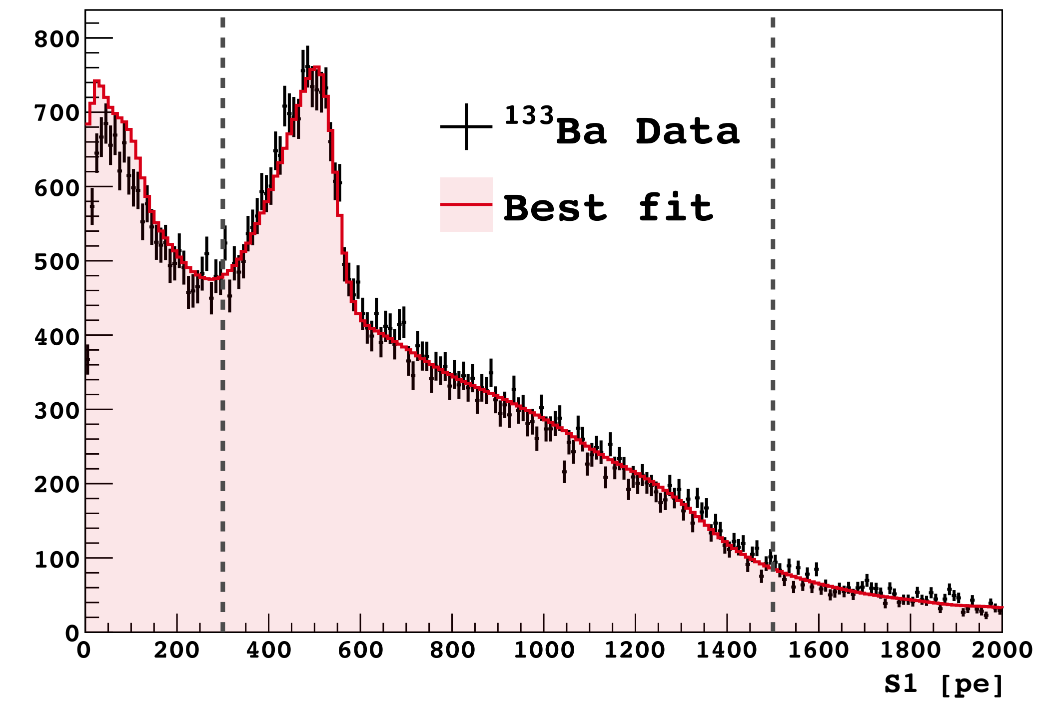


Response map to model detector response

Light yield in LAr

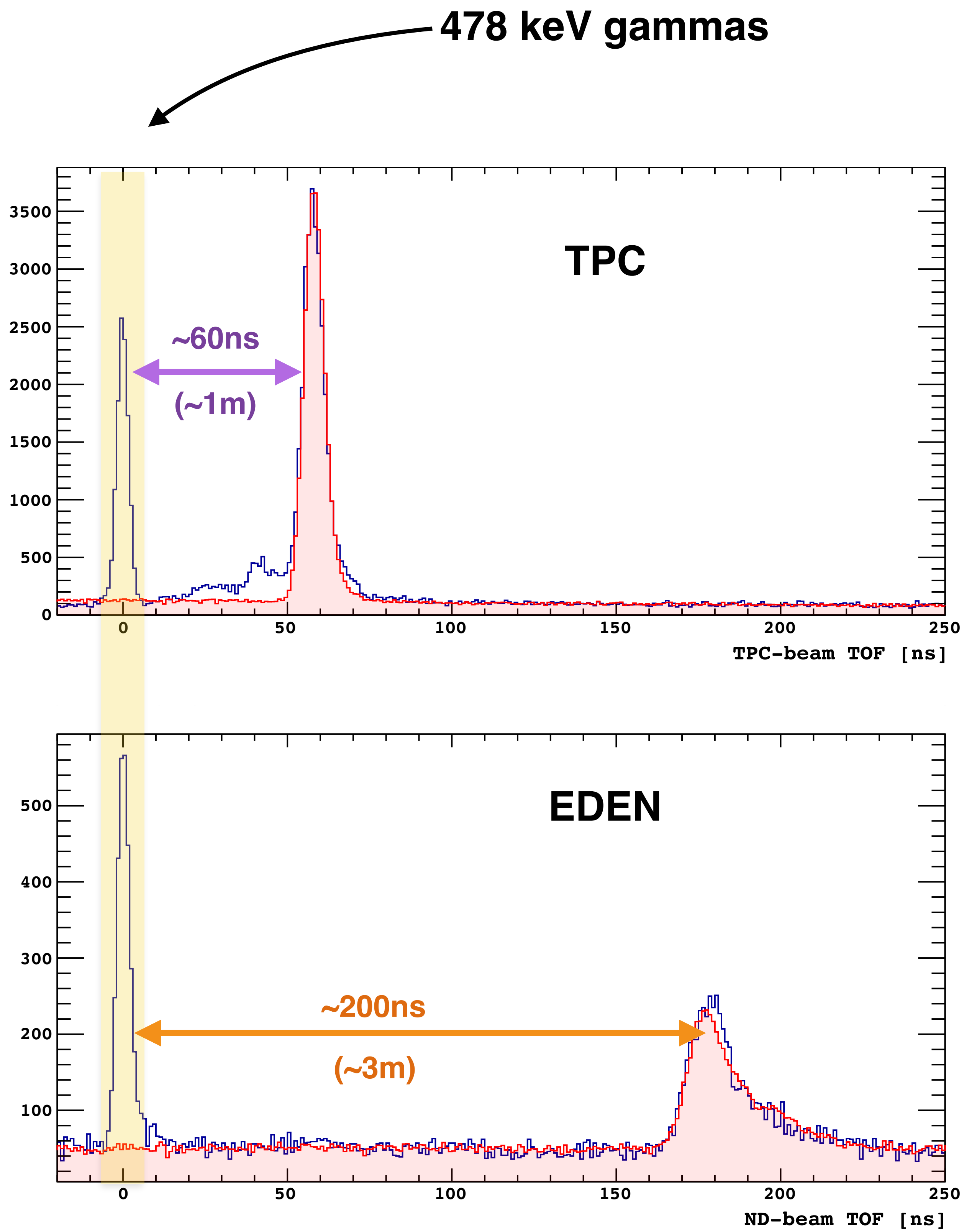
Light yield extracted using data from ^{241}Am and ^{133}Ba sources

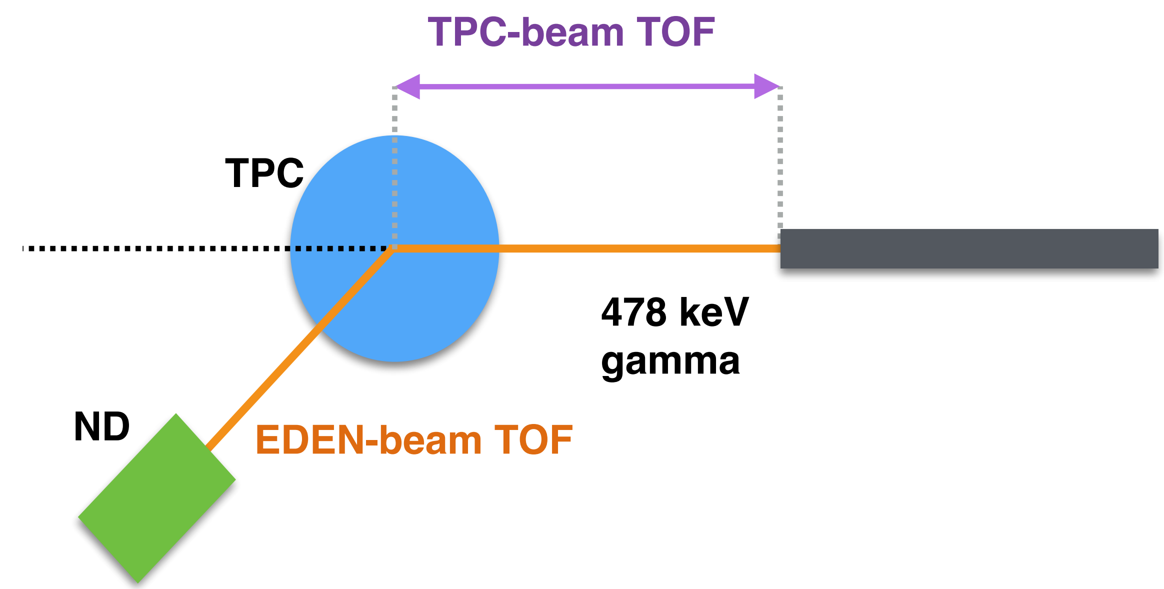




Final average light-yield: 6.35 ± 0.05 pe / keV

TOF resolution



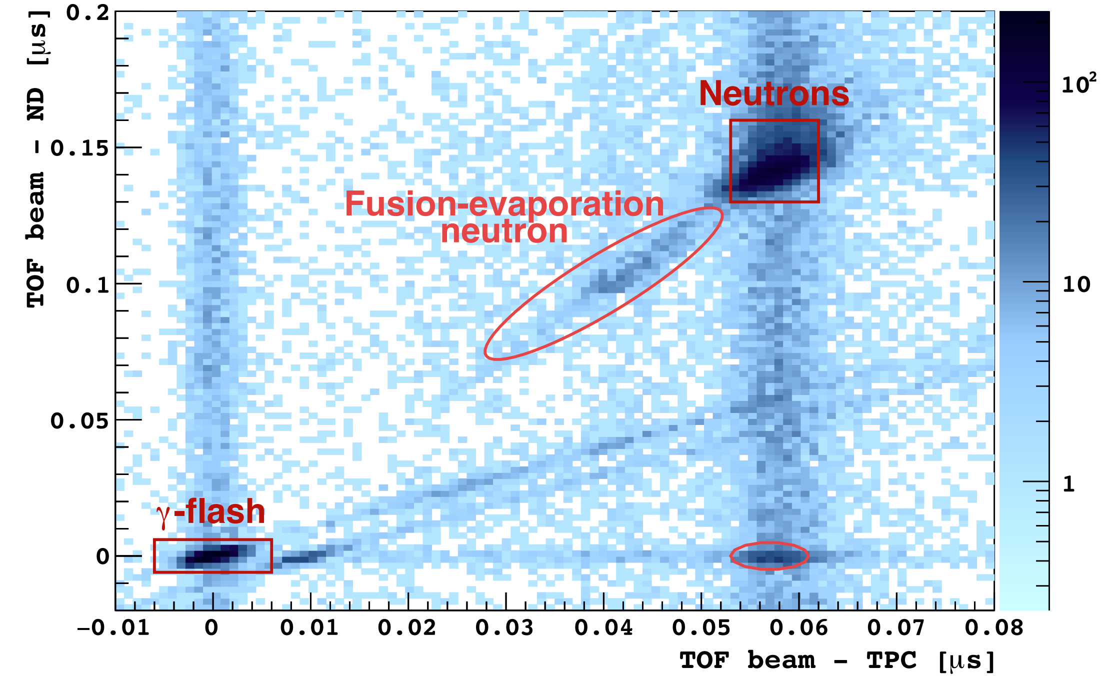


Emission of 478 keV gammas
($^7Li^*$ de-excitation)

TOF Resolutions:

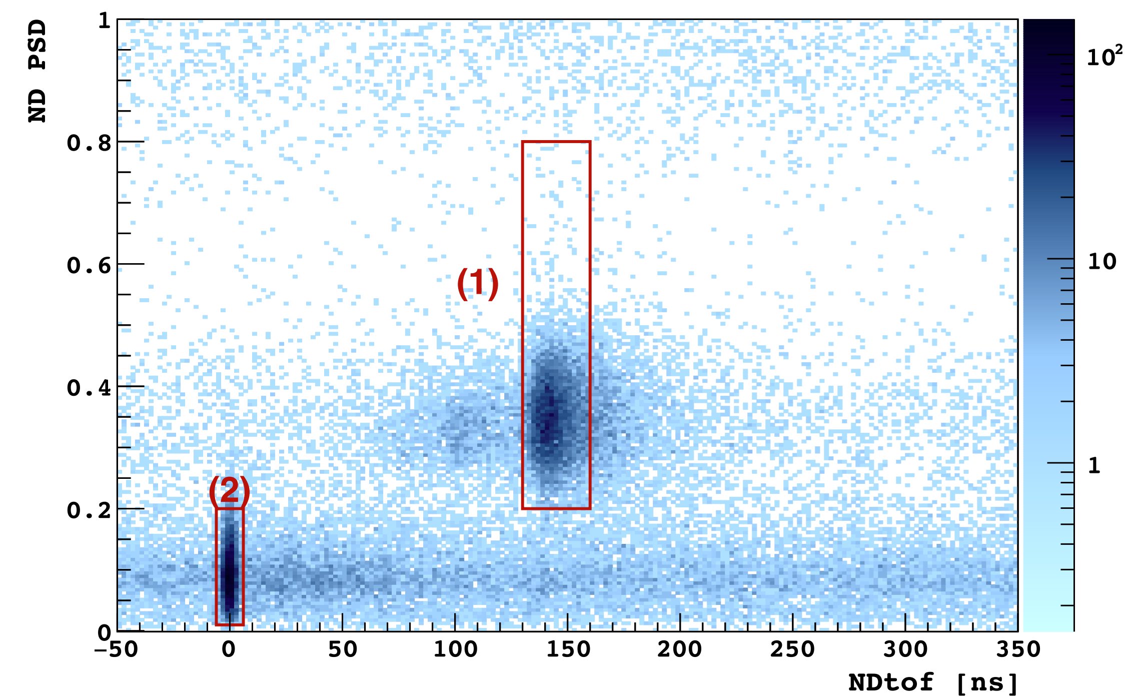
TPC: ~1.8 ns
EDEN: ~1.6 - 3 ns

Data selection



4 populations

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



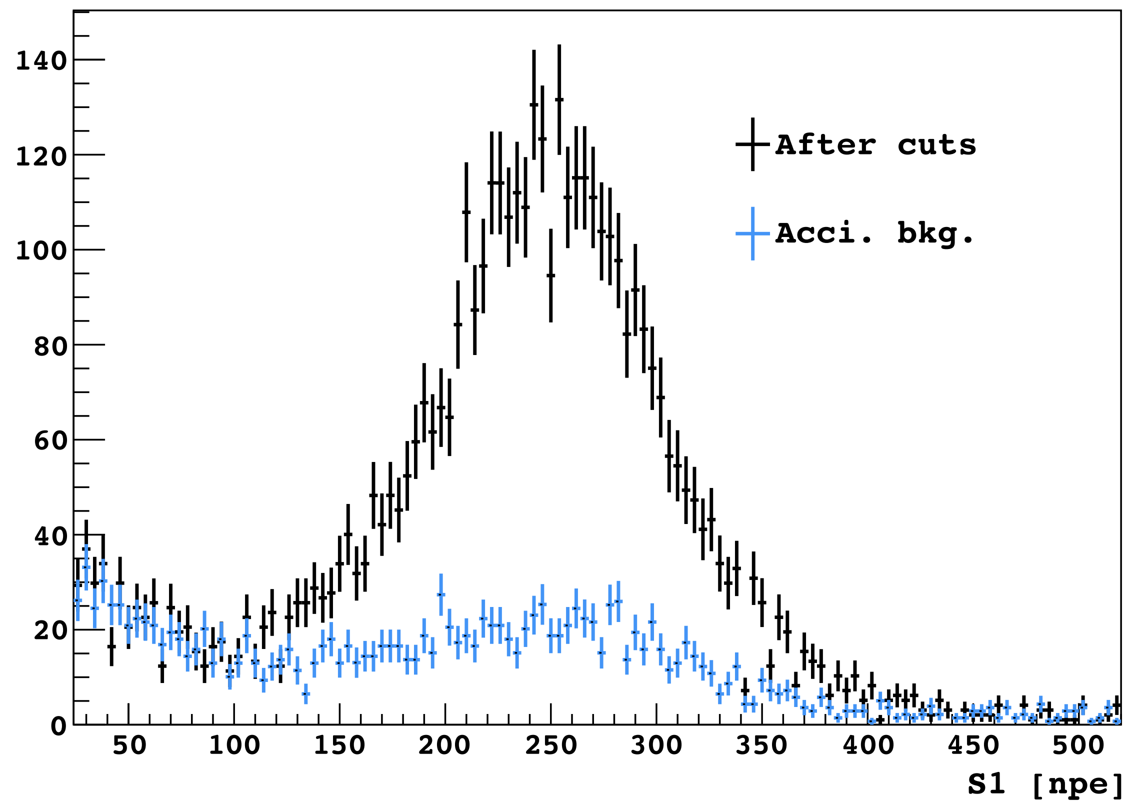
4 cuts

- Beam-TPC TOF
- Beam-ND TOF
- Charge collection in the ND
- PSD in the ND

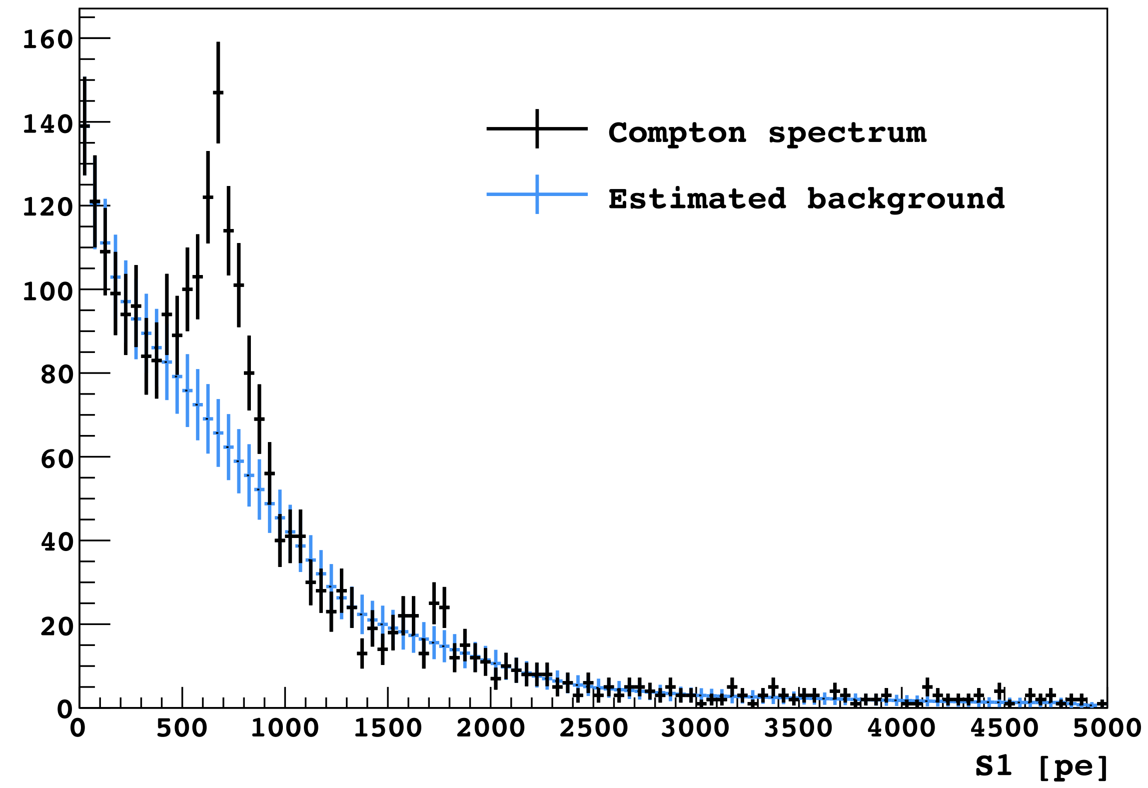
Exploitable samples of both ER and NR with well defined energies

Spectra after selection cuts

NR spectrum



ER spectrum



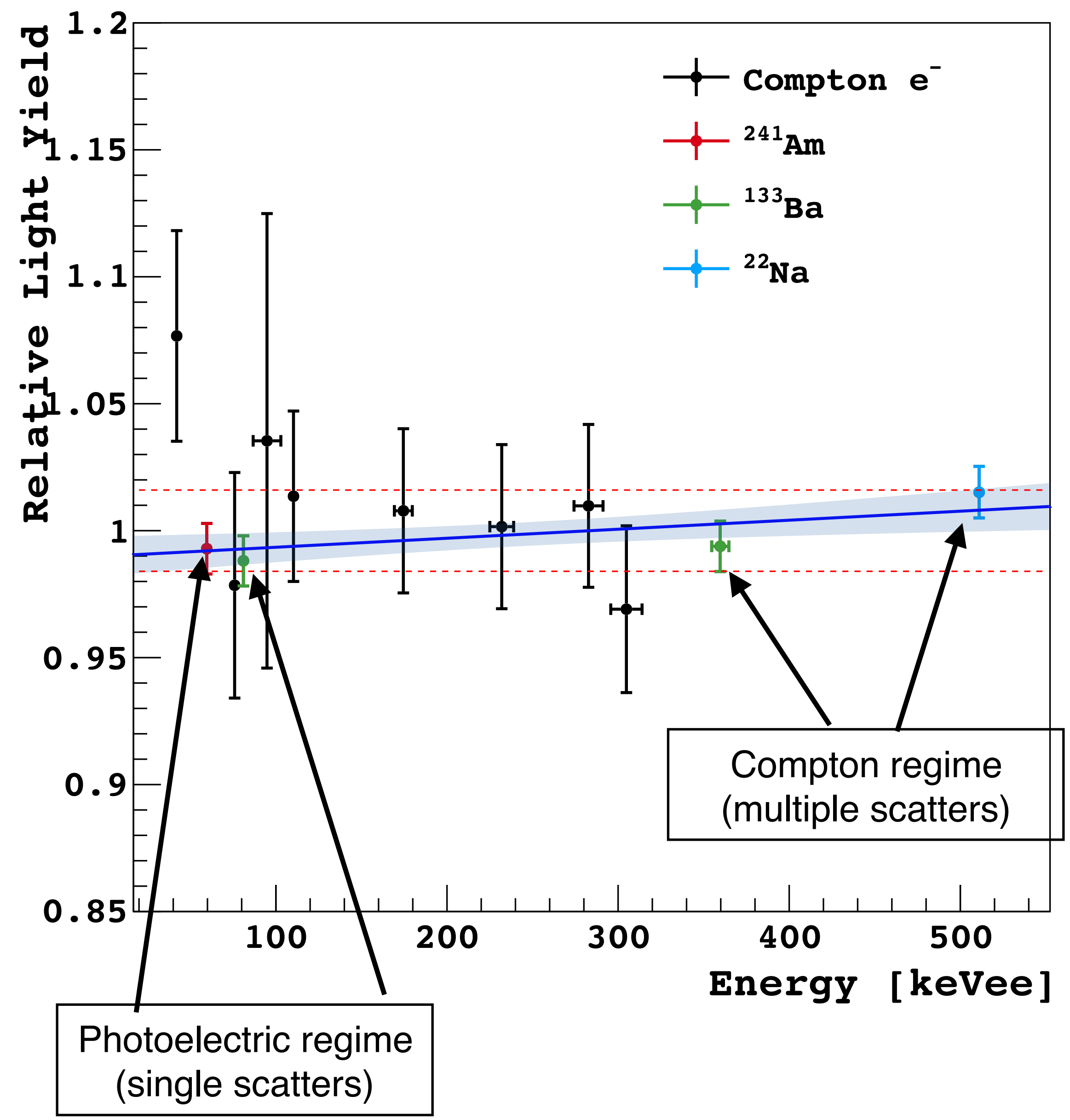
Light yield linearity at null field in LAr

$$Q = \Sigma q_{ei}$$

Total quenching

Single electron quenching

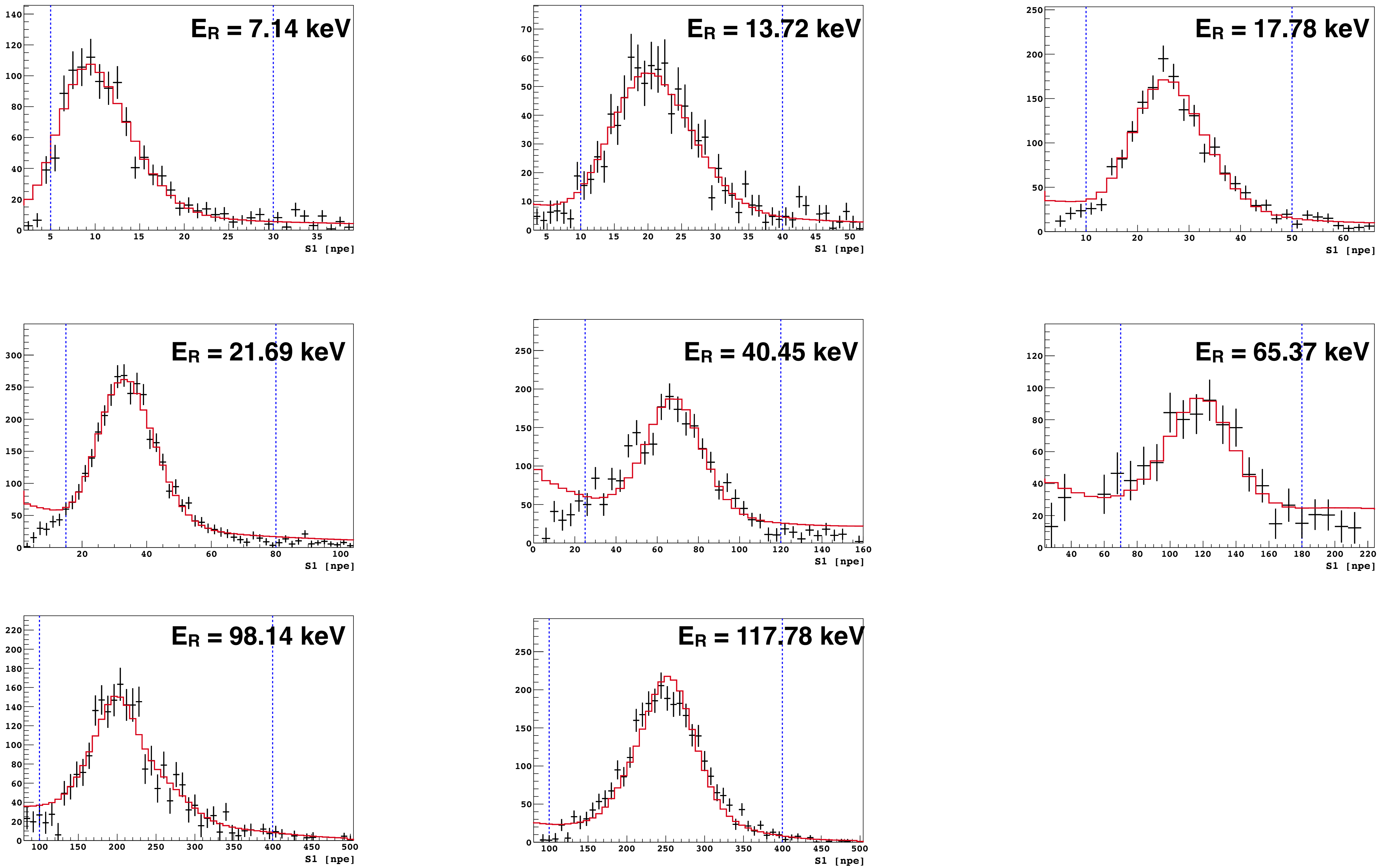
Quenching effect expected to be amplified for multiple scatter with respect to single scatters



Light yield proven to be constant within 1.6% fitting all sources

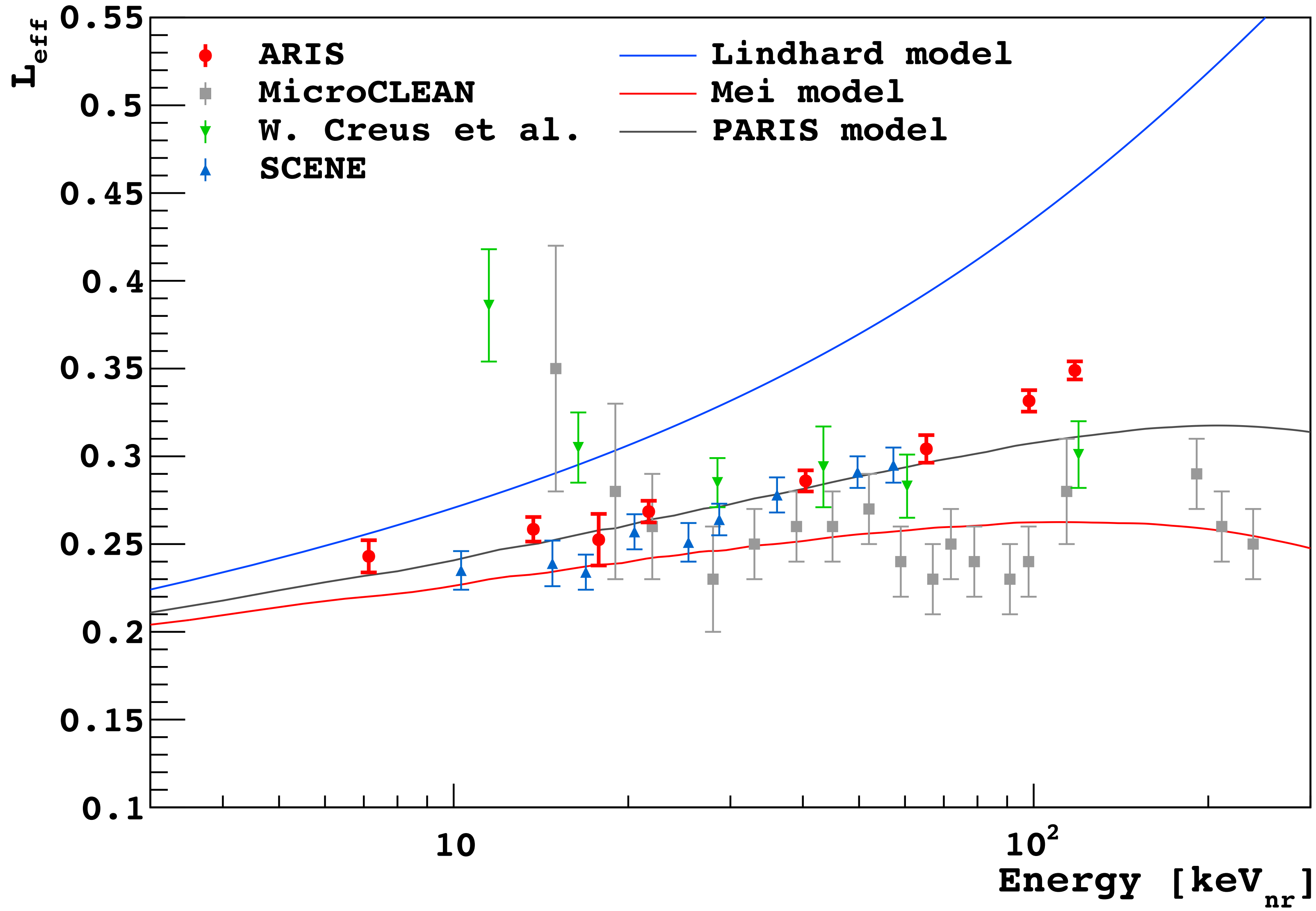
No evidence for a strong ER quenching at null field

Fitted NR spectra



Quenching of NR in LAr

Most precise measurement of L_{eff} and lowest energy point



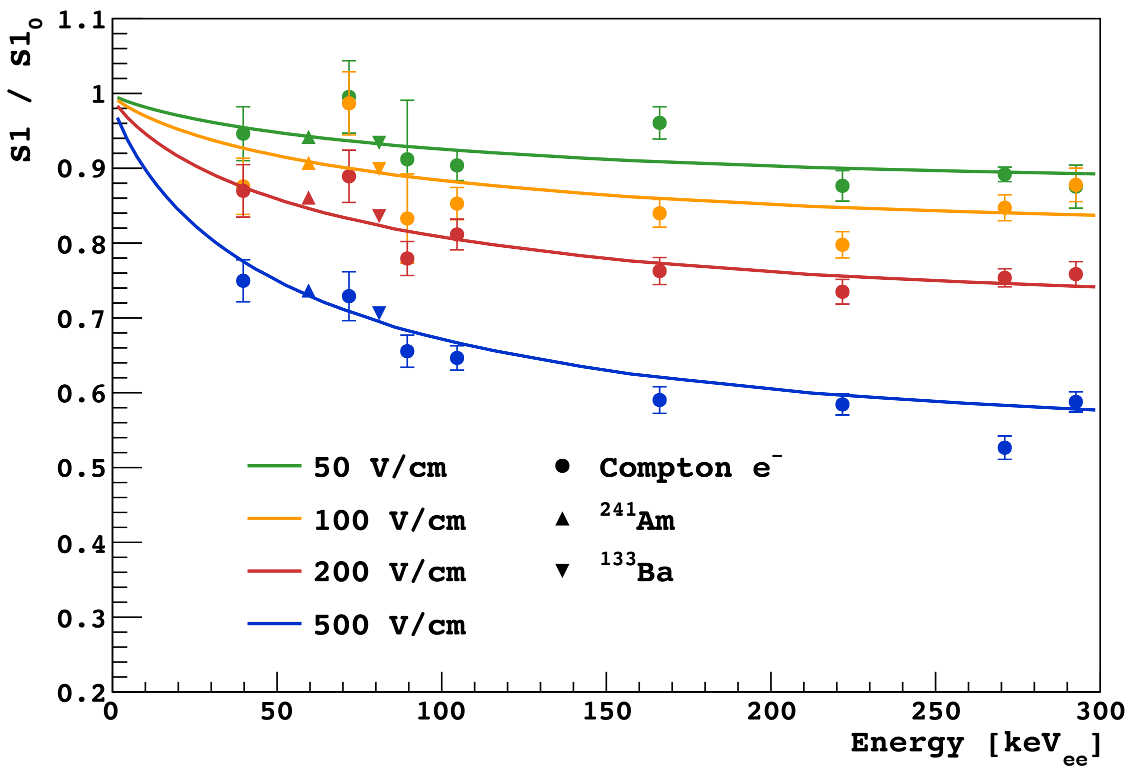
Good agreement with PARIS model (modified Mei model) up to 60 keV_{nr}

Recombination probability in LAr: ER

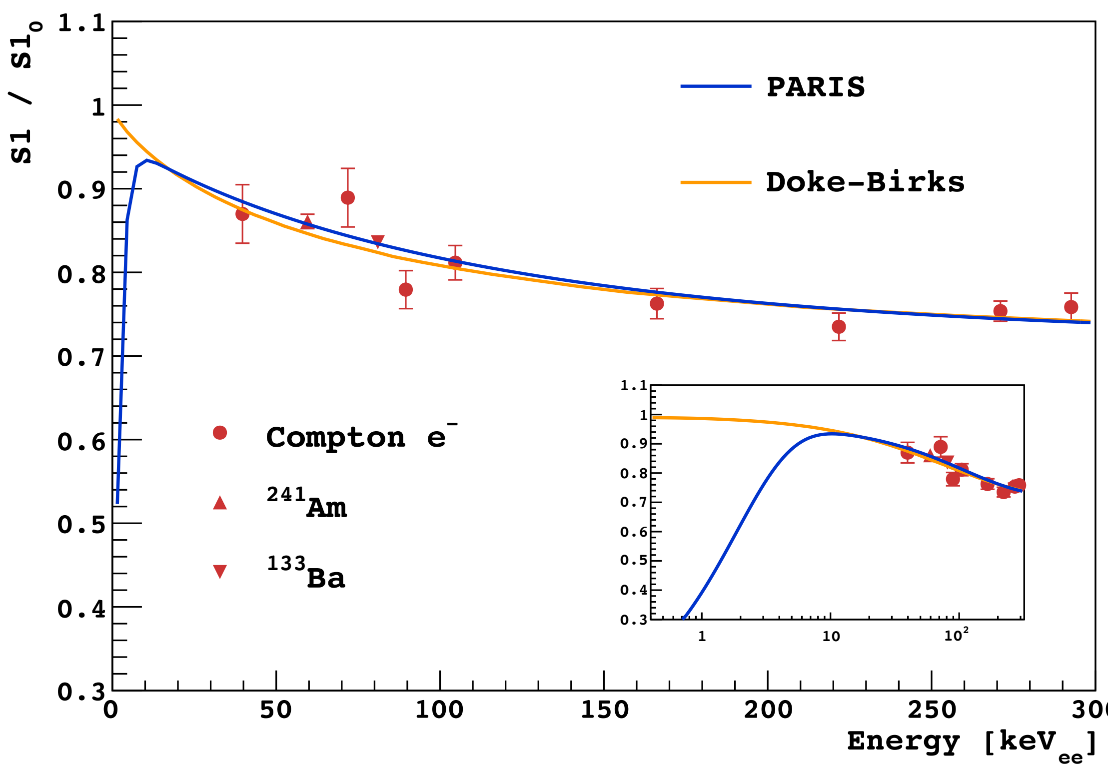
$$\frac{S1_{field}}{S1_{null\_field}} = \frac{R+\alpha}{1+\alpha}$$ extracted from **ER** data $\left(\alpha = \frac{N_{ex}}{N_i} = 0.21 \text{ for ER}\right)$

Fit by Doke-Birks model

(tuned to account for field dependance)



Comparison to prediction of PARIS model



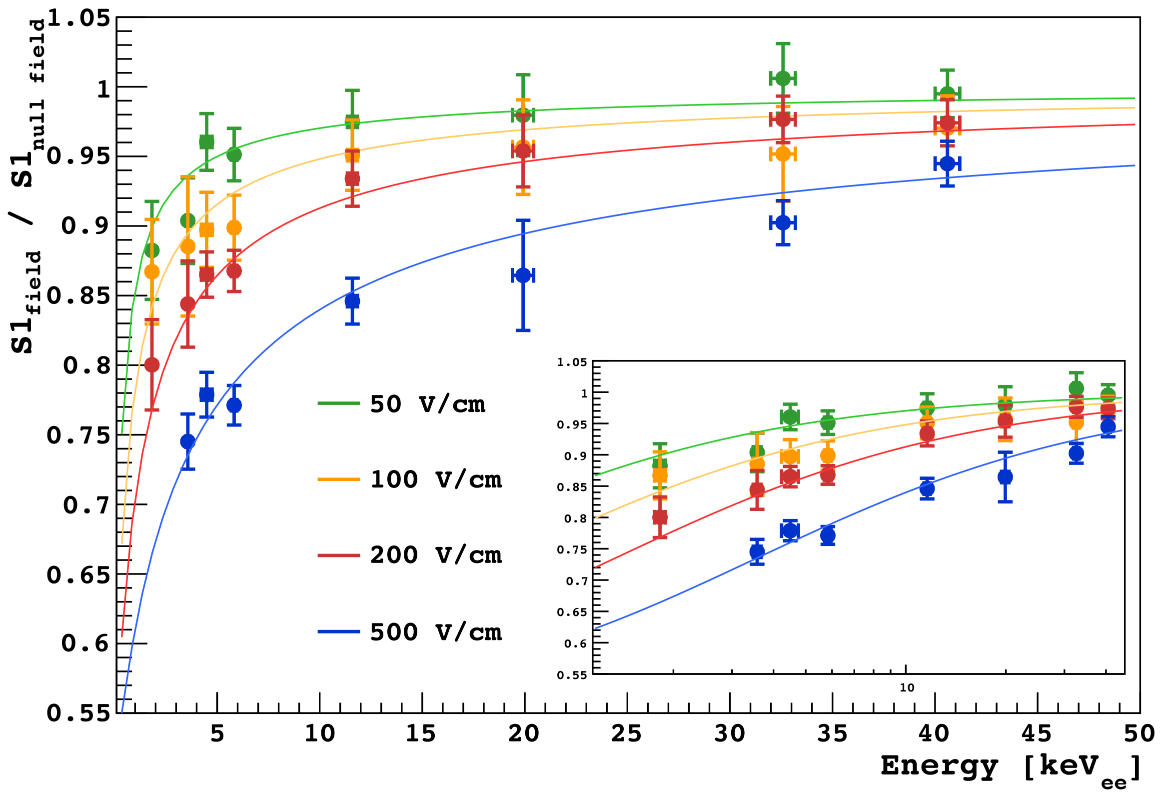
Doke-Birks' R goes to 1 at low energies while data shows that R should decrease

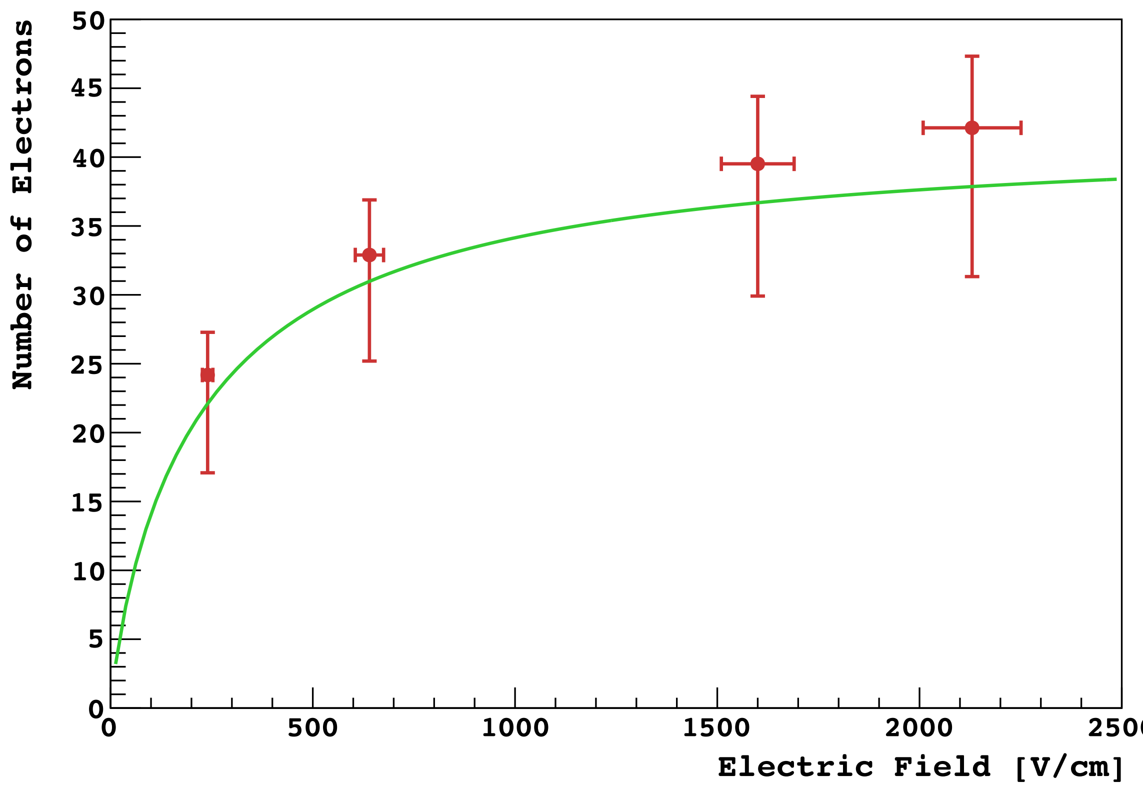
PARIS model consistent with ARIS ER data at 200 V/cm

Recombination probability in LAr: NR

Fit $S1_{null}/S1_{null\_field}$ data for NR with Thomas-Imel model (assuming α = 1)

Tuned model compared to S2 at 6.7 keV data from Joshi et al. as a cross check





Thomas-Imel model reproduces both NR S1 and S2 (6.7 keV) at different drift fields

Conclusions

Xenon

- Response of LXe to ER proven to be non-linear
- Quenching of NR well constrained over the WIMP search range
- LUX innovative method allows access to very low energy (~ 1 keV_{nr})
- Leff ranging from ~ 0.2 to ~ 0.1

Argon

- Precise measurement of LY linearity

  ➡ Linear within 1.6% above 40 keV
- NR quenching measured down to 7 keV_{nr}
- Fully comprehensive modeling of recombination for ER (PARIS) and NR (Thomas-Imel) at 200 V/cm

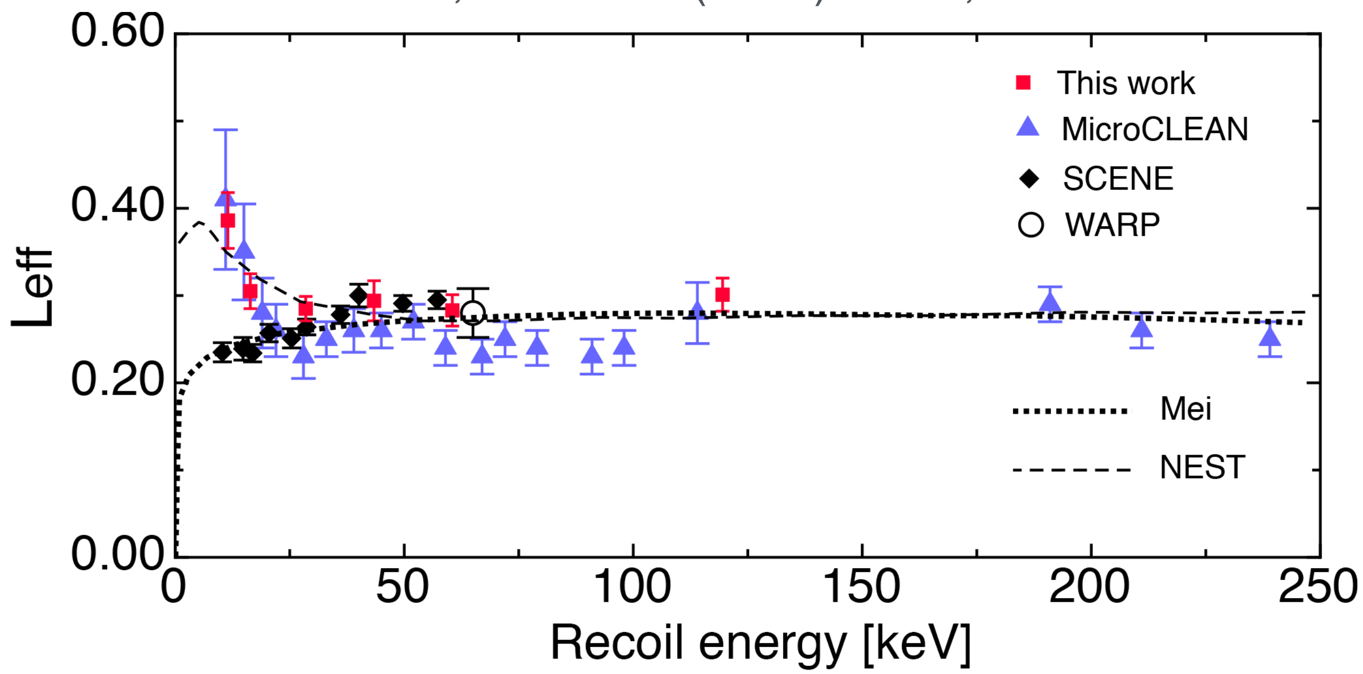
Backup

Physics goals

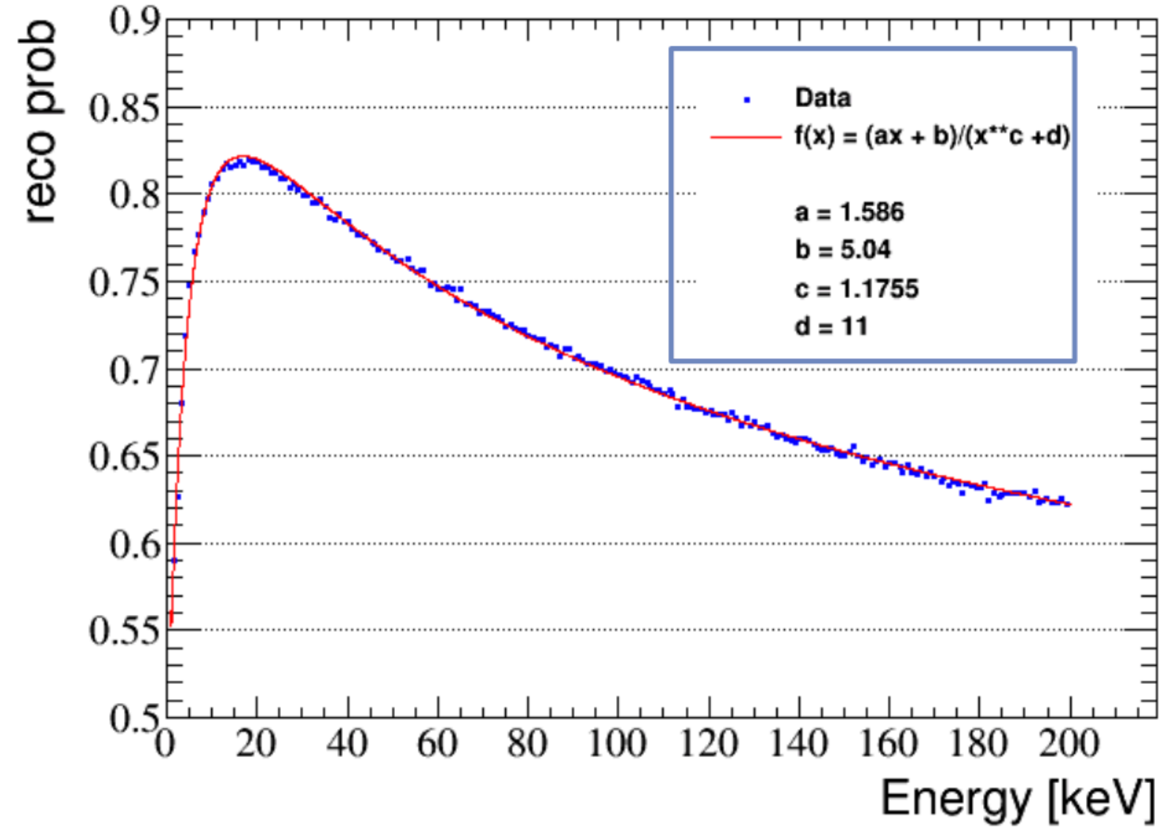
Argon **R**esponse to **I**onization and **S**cintillation

NR quenching

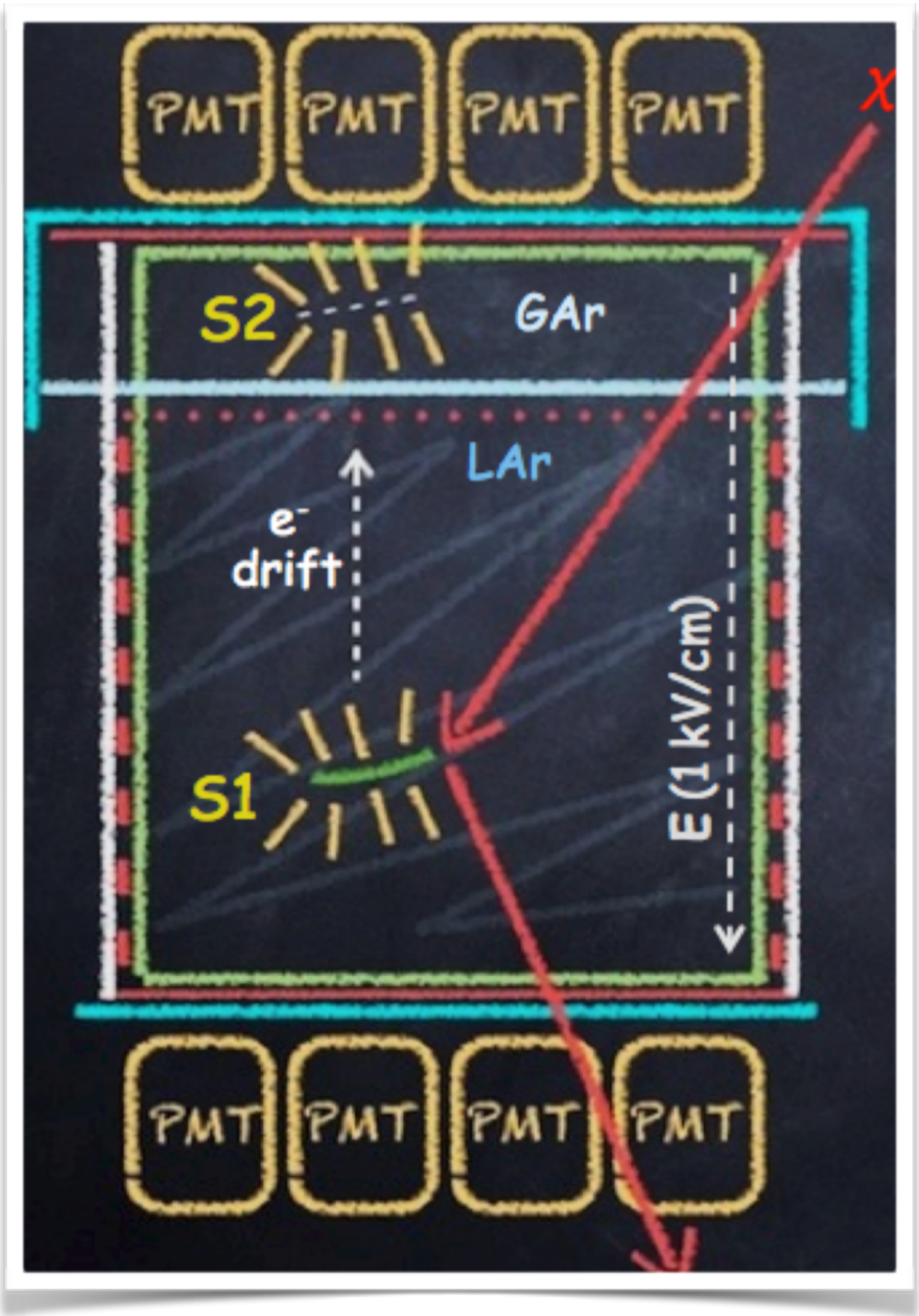
W. Creus *et al*, JINST **10** (2015) no.08, P08002

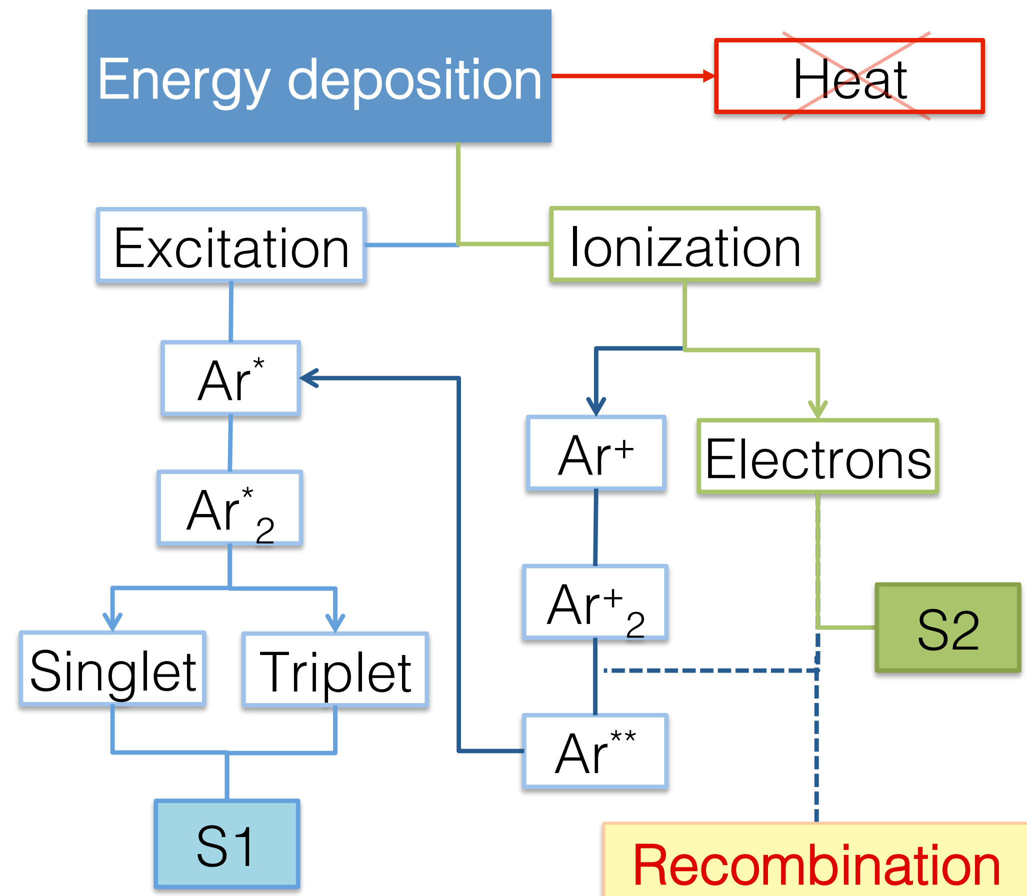


Recombination probability

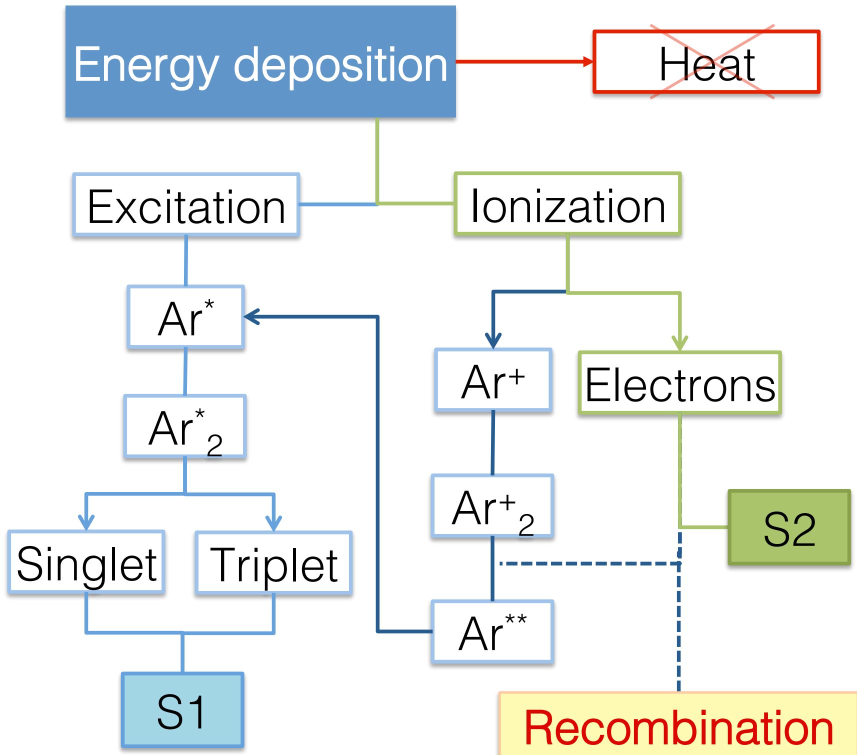


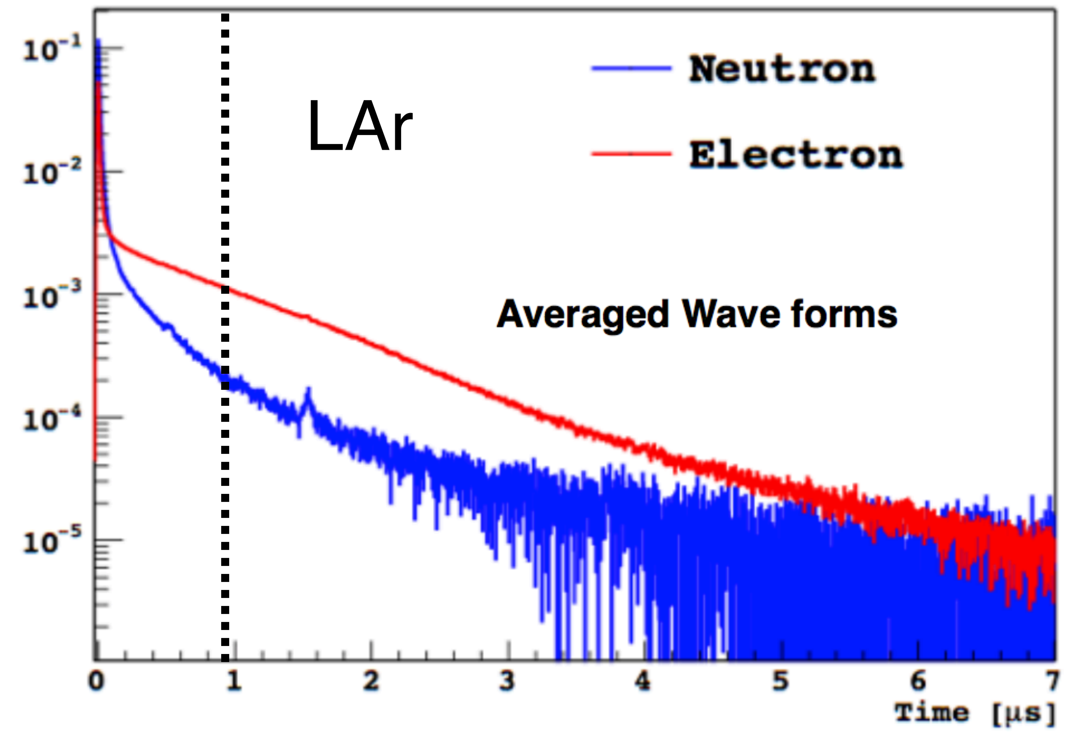
Noble liquid dual-phase TPC



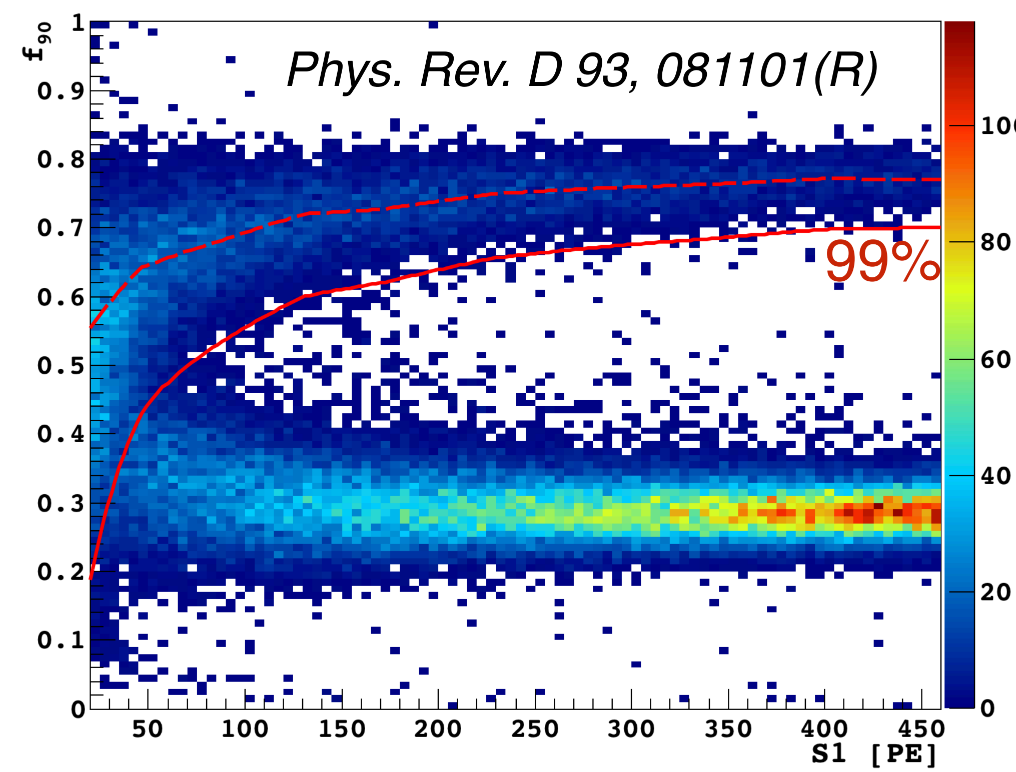


ER/NR discrimination

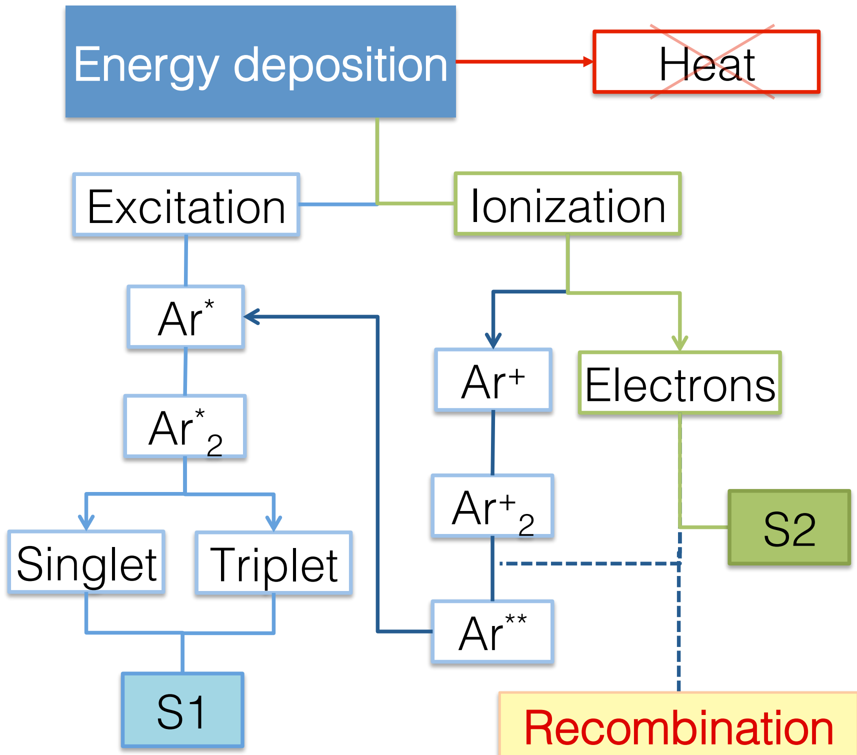


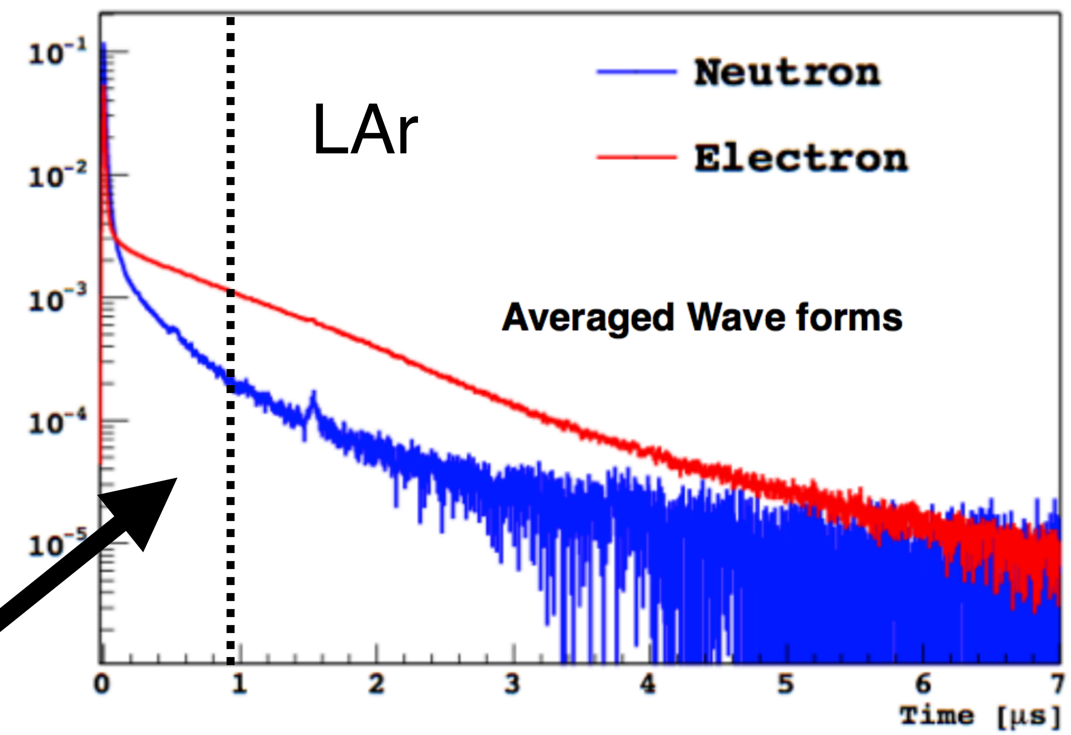


	$t_{singlet}$	$t_{triplet}$
Argon	7 ns	1600 ns
Xenon	4.3 ns	22 ns



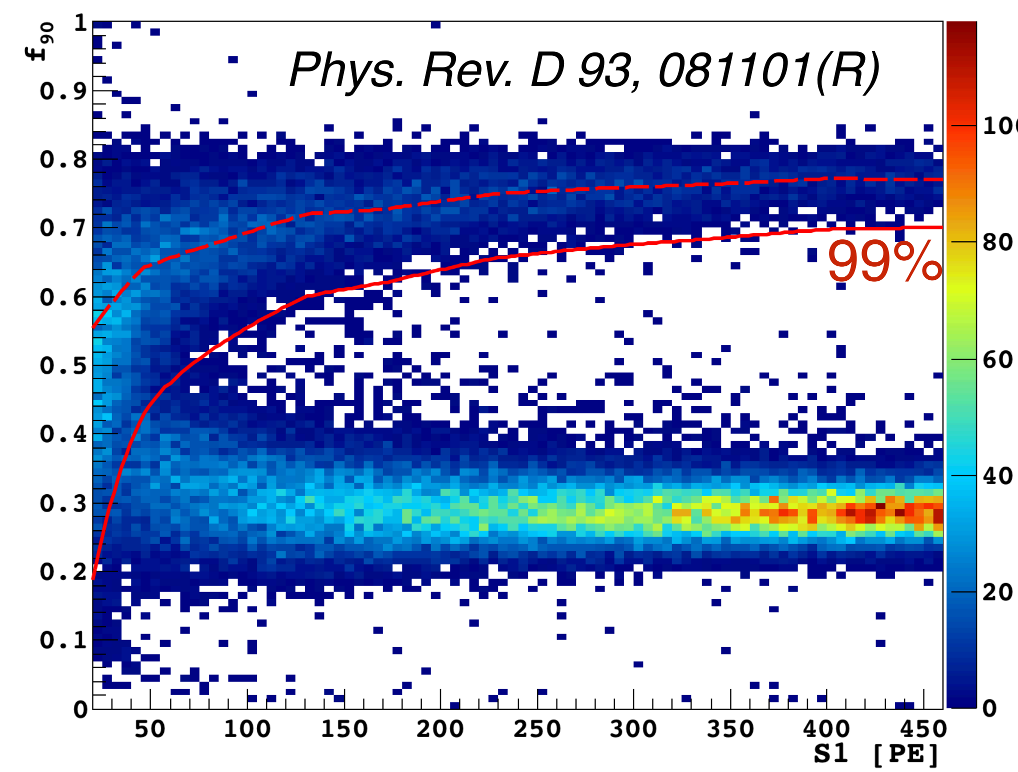
ER/NR discrimination





PSD parameter f_{90} :
fraction of light seen in the **first 90 ns**

	$t_{singlet}$	$t_{triplet}$
Argon	7 ns	1600 ns
Xenon	4.3 ns	22 ns

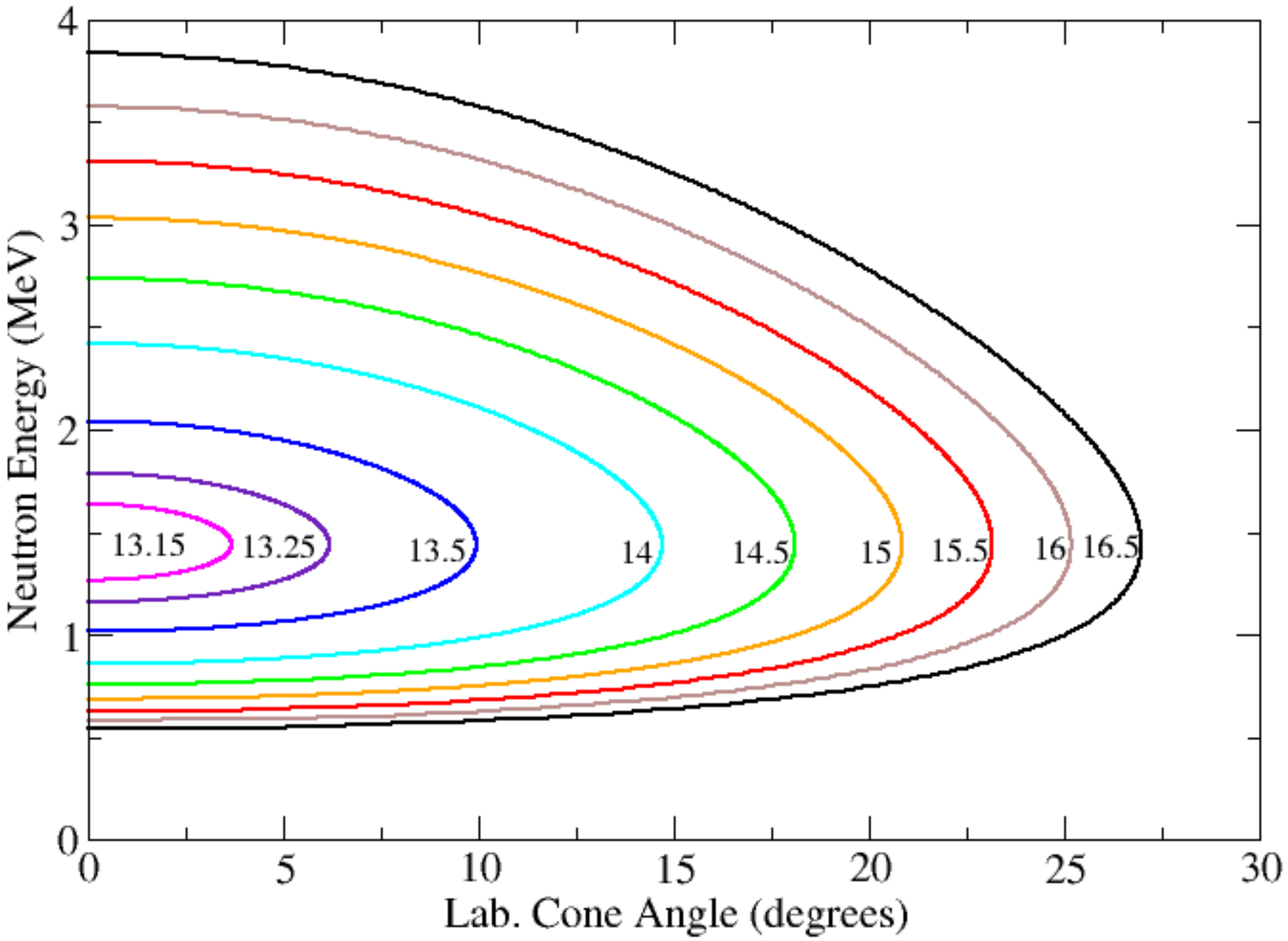


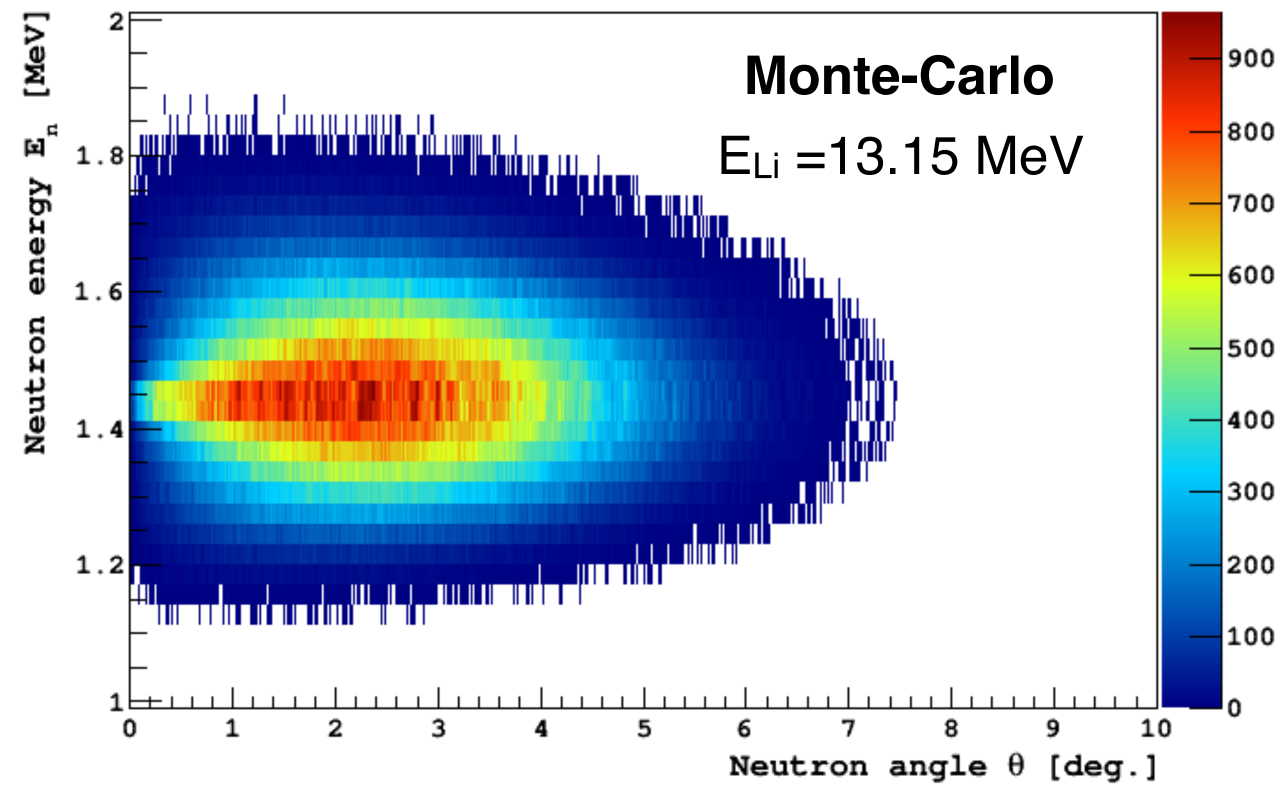
Liquid Ar ER rejection factor: ~10^8

WARP Astr. Phys 28, 495 (2008)

Licorne beam

Lithium Inverse Cinematique ORsay Neutron source



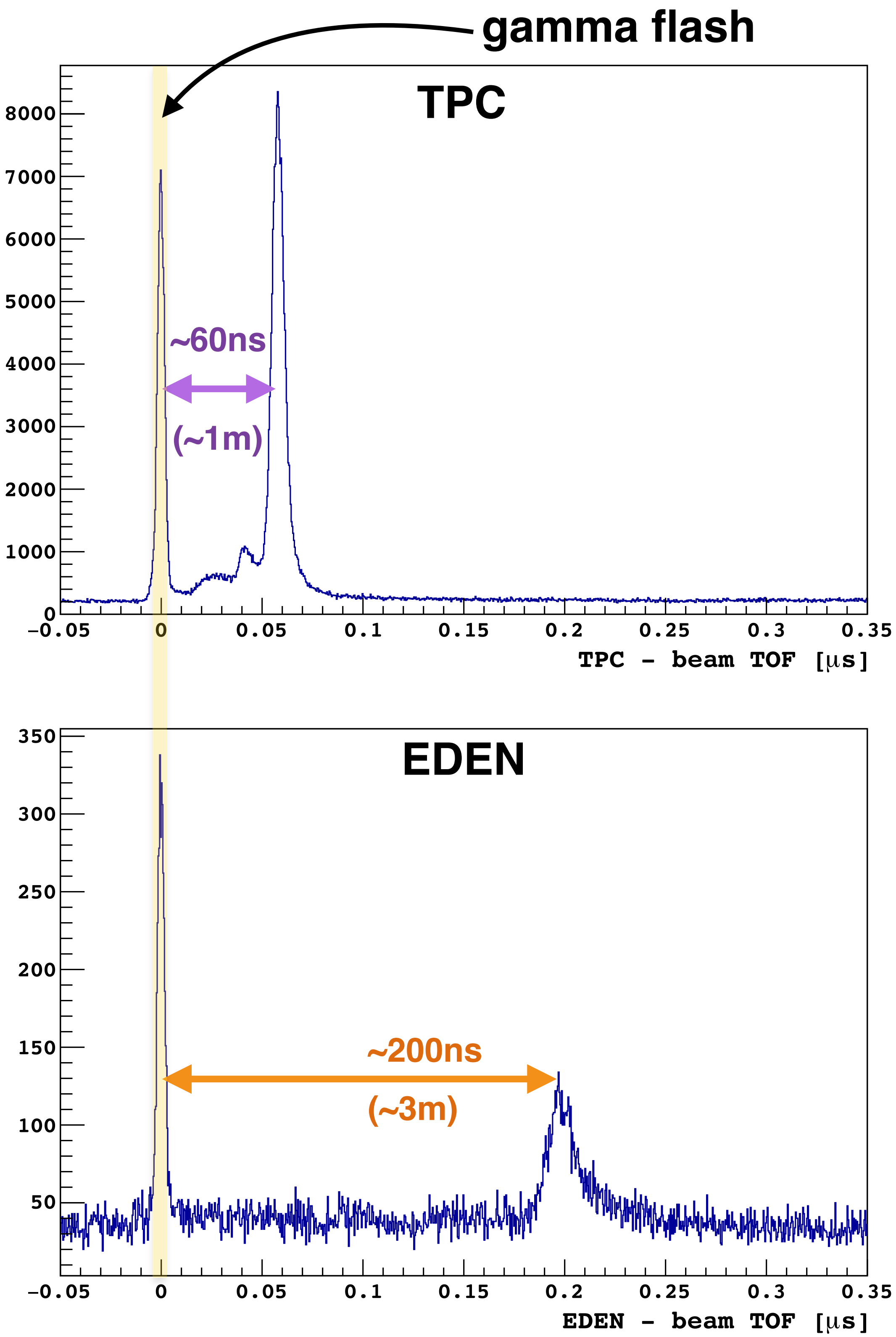


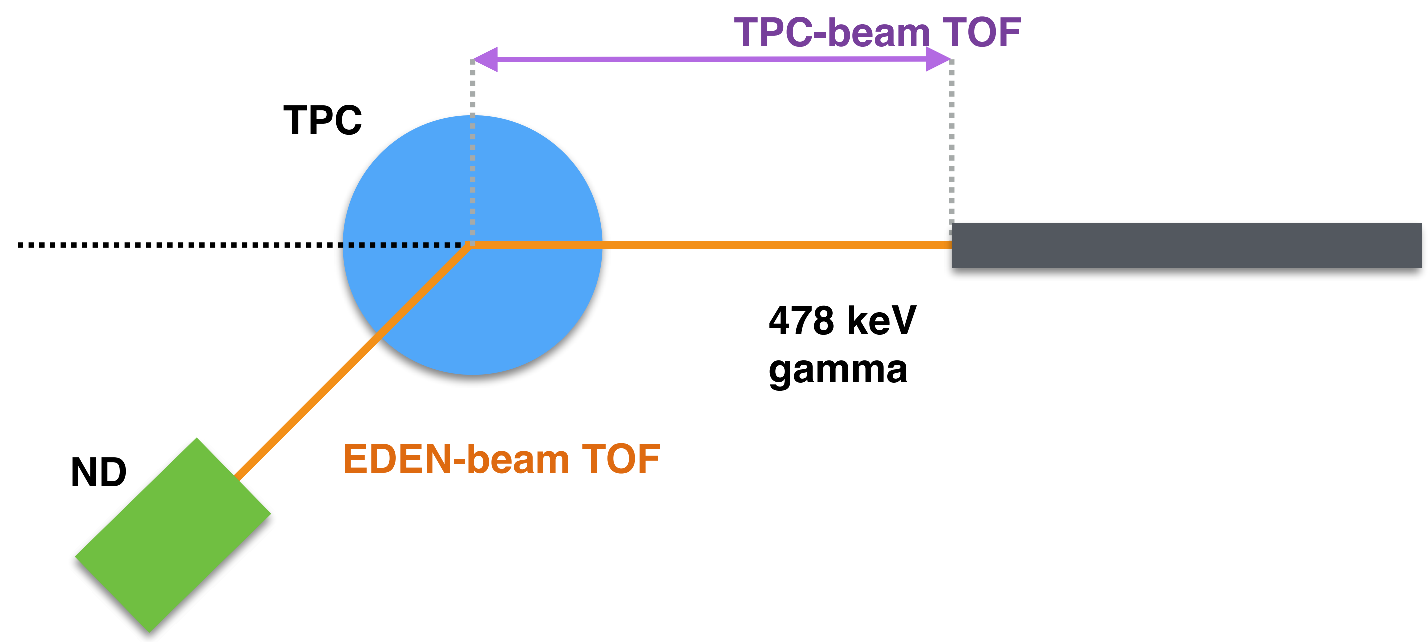
Neutron production: inverse $^7\mathrm{Li}(p.n)^7\mathrm{Be}$

➡ Monochromatic

➡ Collimated beam

TOF resolution



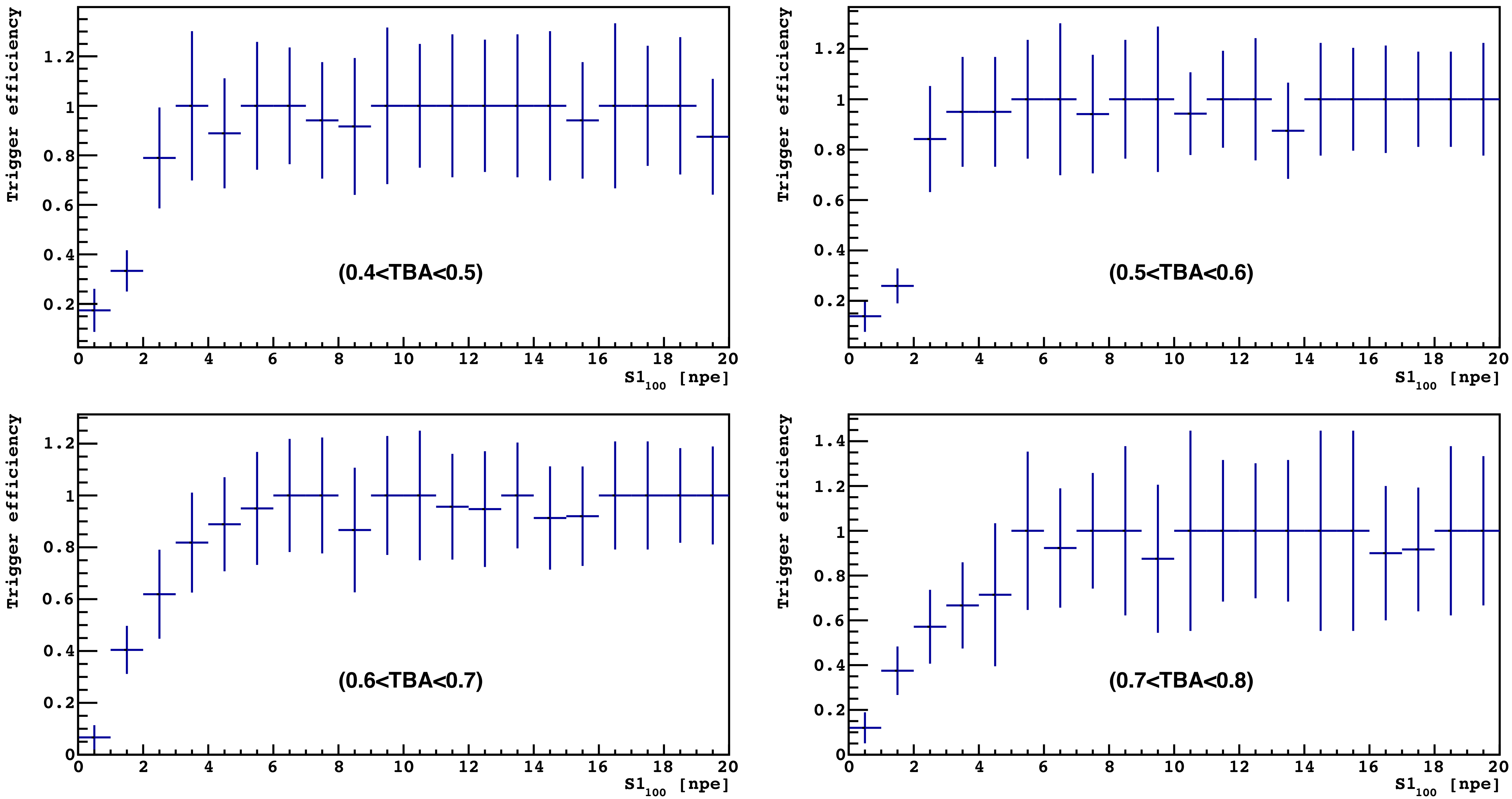


Emission of 478 keV gammas ($^{7}Li^{*}$ de-excitation)
⟶ γ-flash

TOF Resolutions:

TPC = ~1.8 ns
EDEN: ~1.6 - 3 ns (depending on the detector)

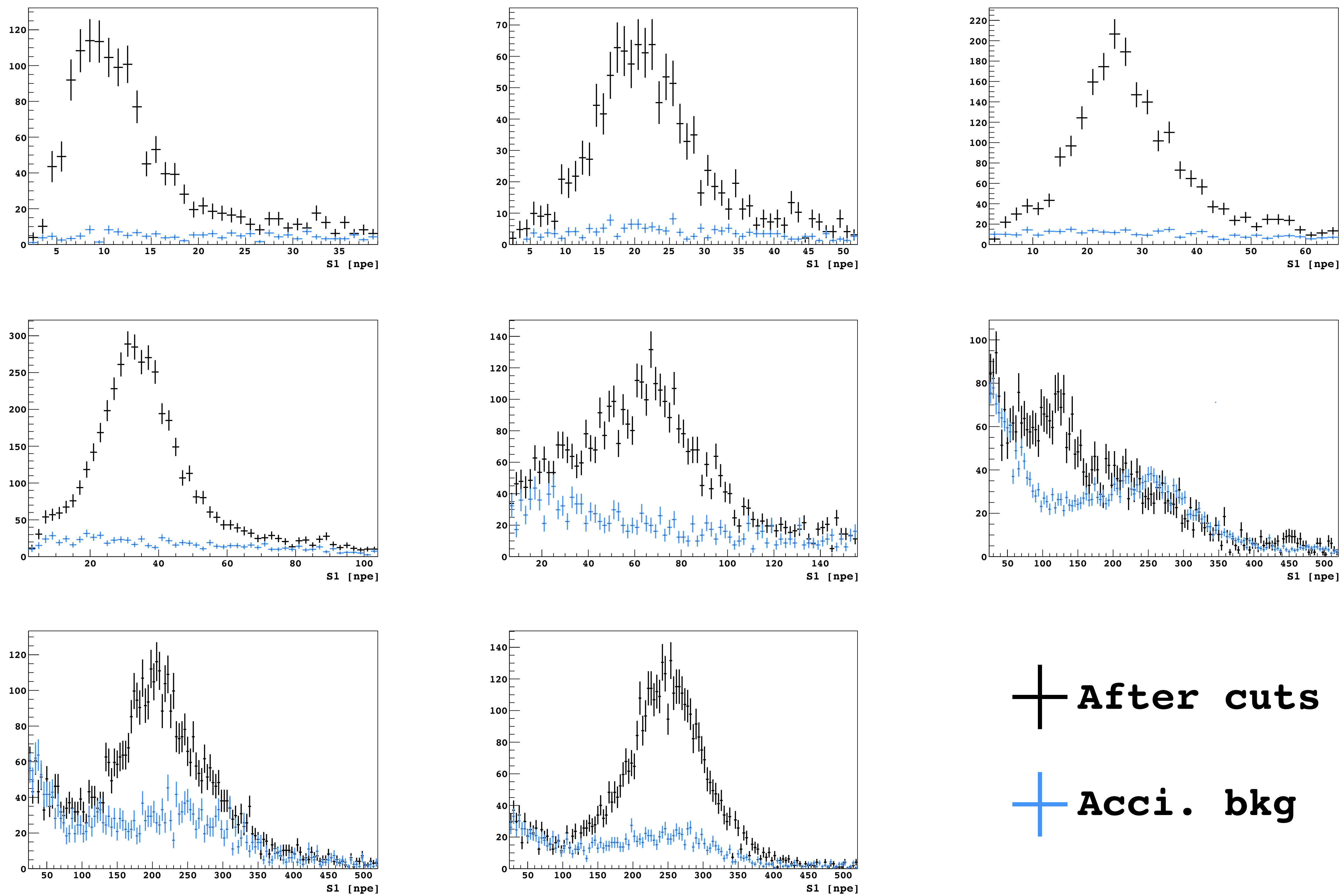
Trigger efficiency



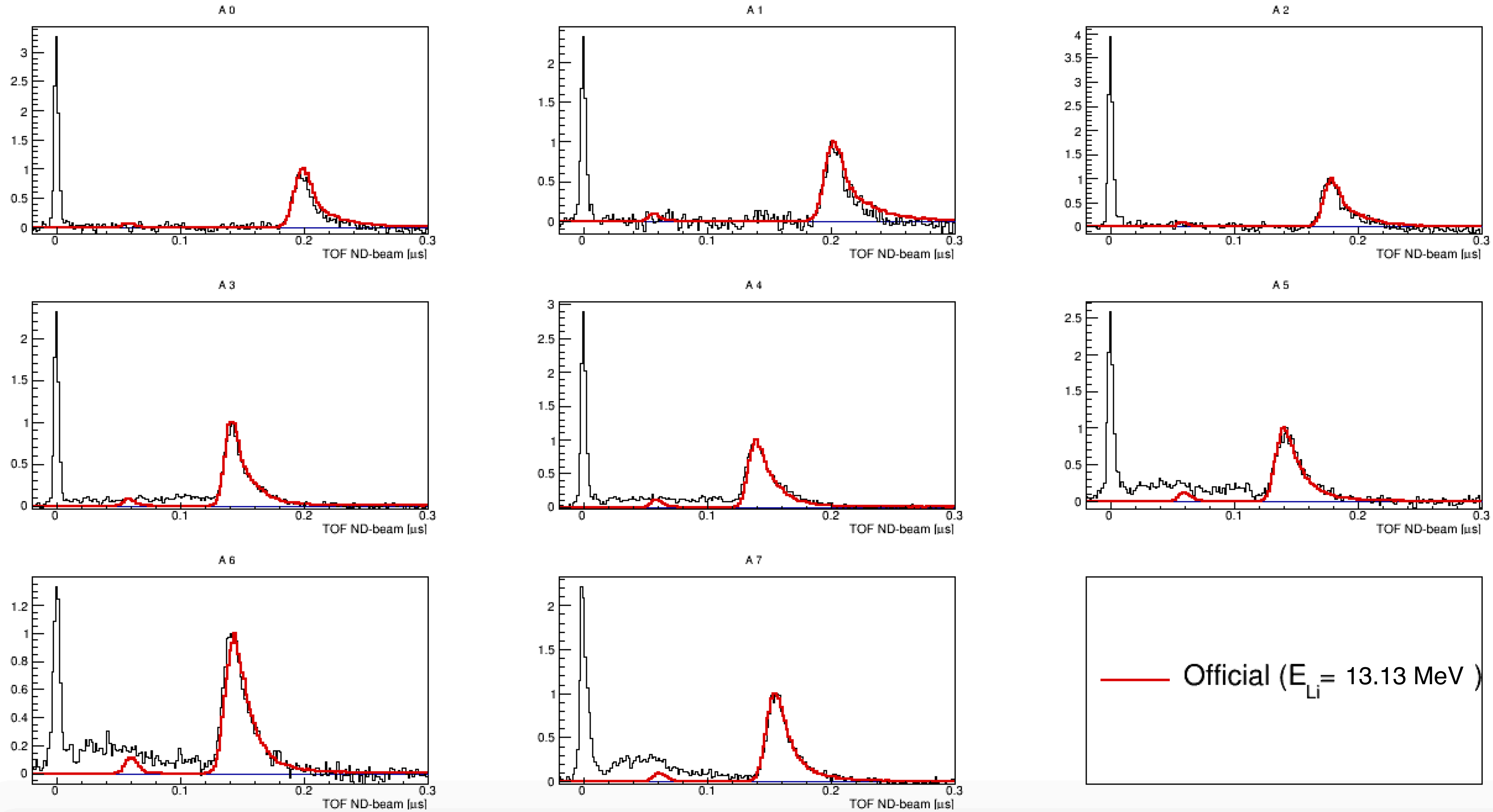
Efficiency **varies with the TBA**

→ Extracted and **fitted for different TBA regions**

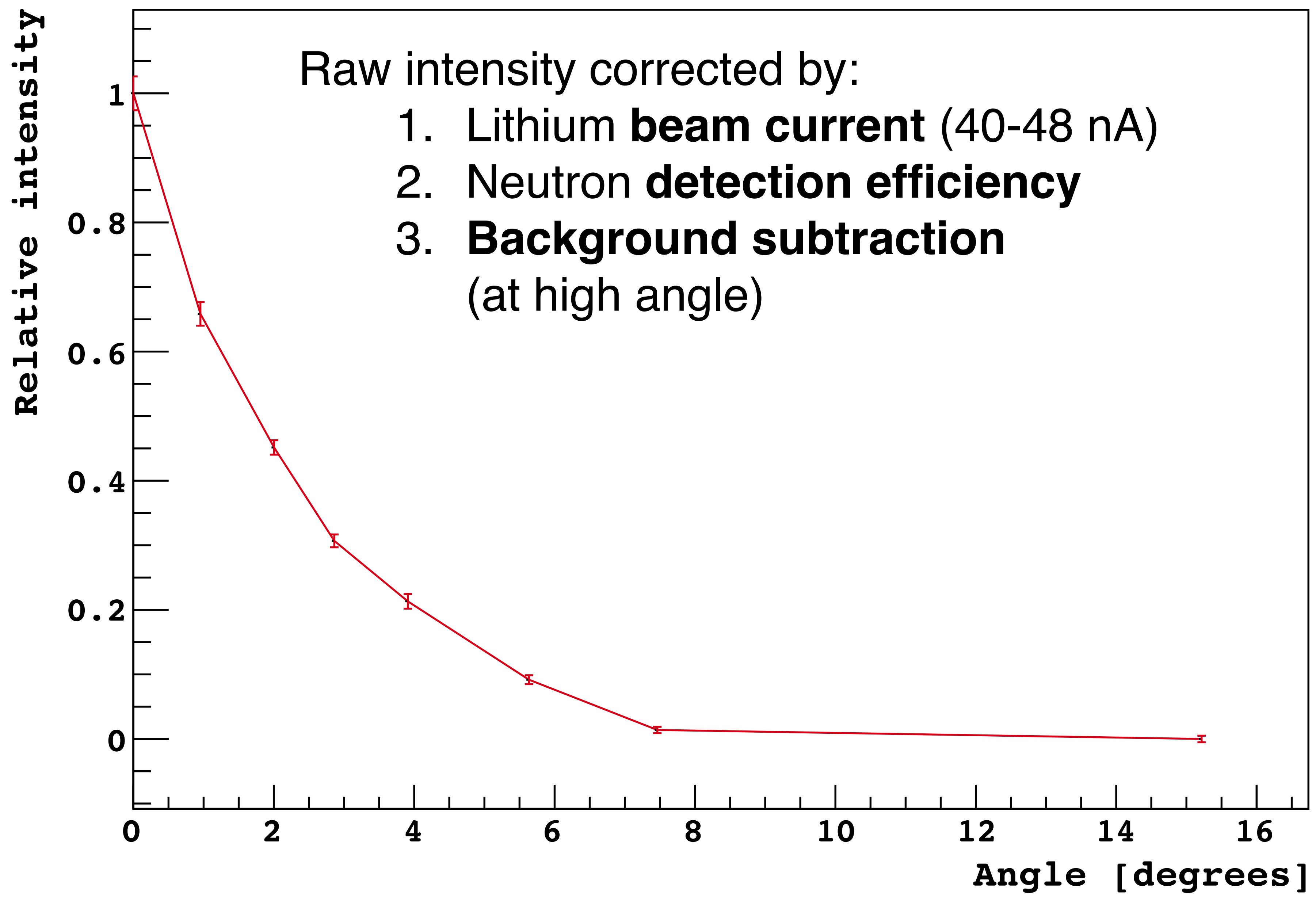
NR energy spectra



TOF : data/MC comparison



Angular distribution data

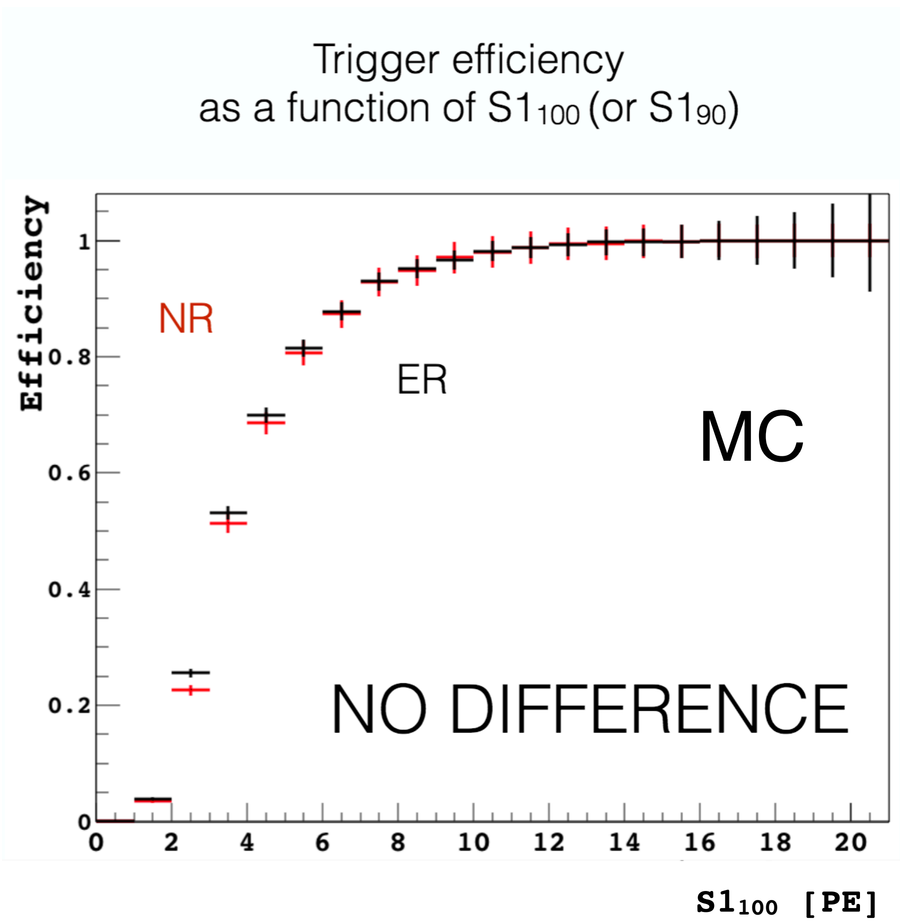


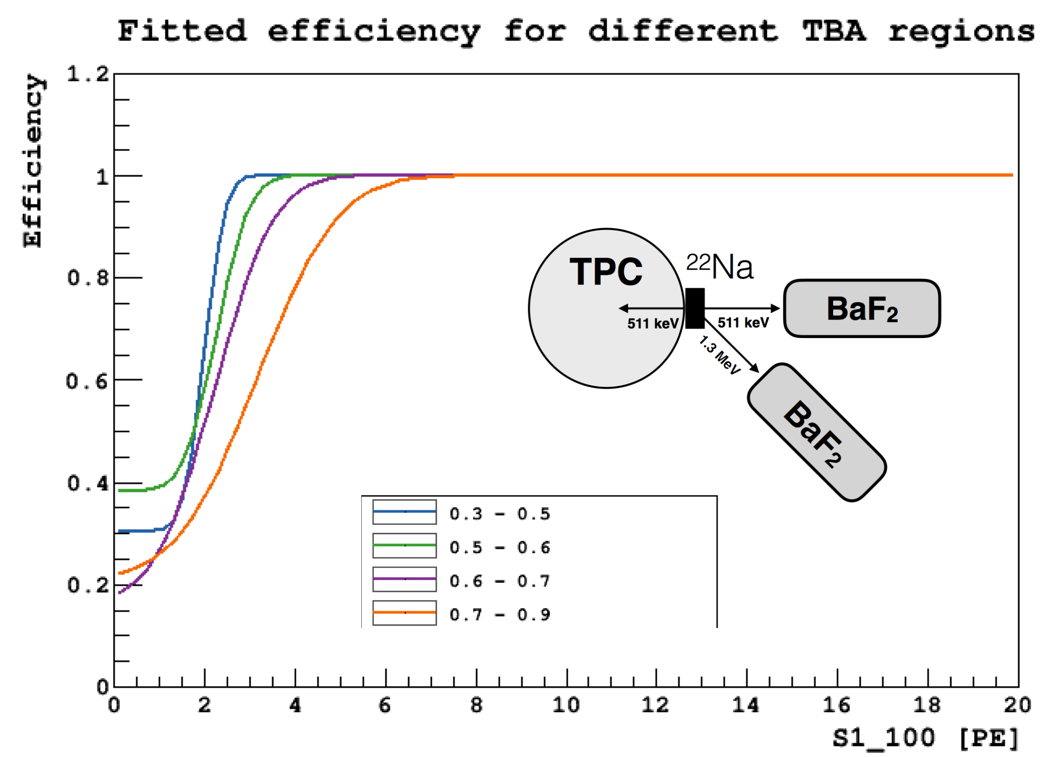
See Davide presentation: https://arisanalysis.slack.com/files/dfranco/F2P5AC2AH/kinematics.pdf

Trigger efficiency

NR an ER have different trigger efficiency due to the different S1 pulse profiles

TPC trigger: **Two PMTs** fired in **100 ns** window

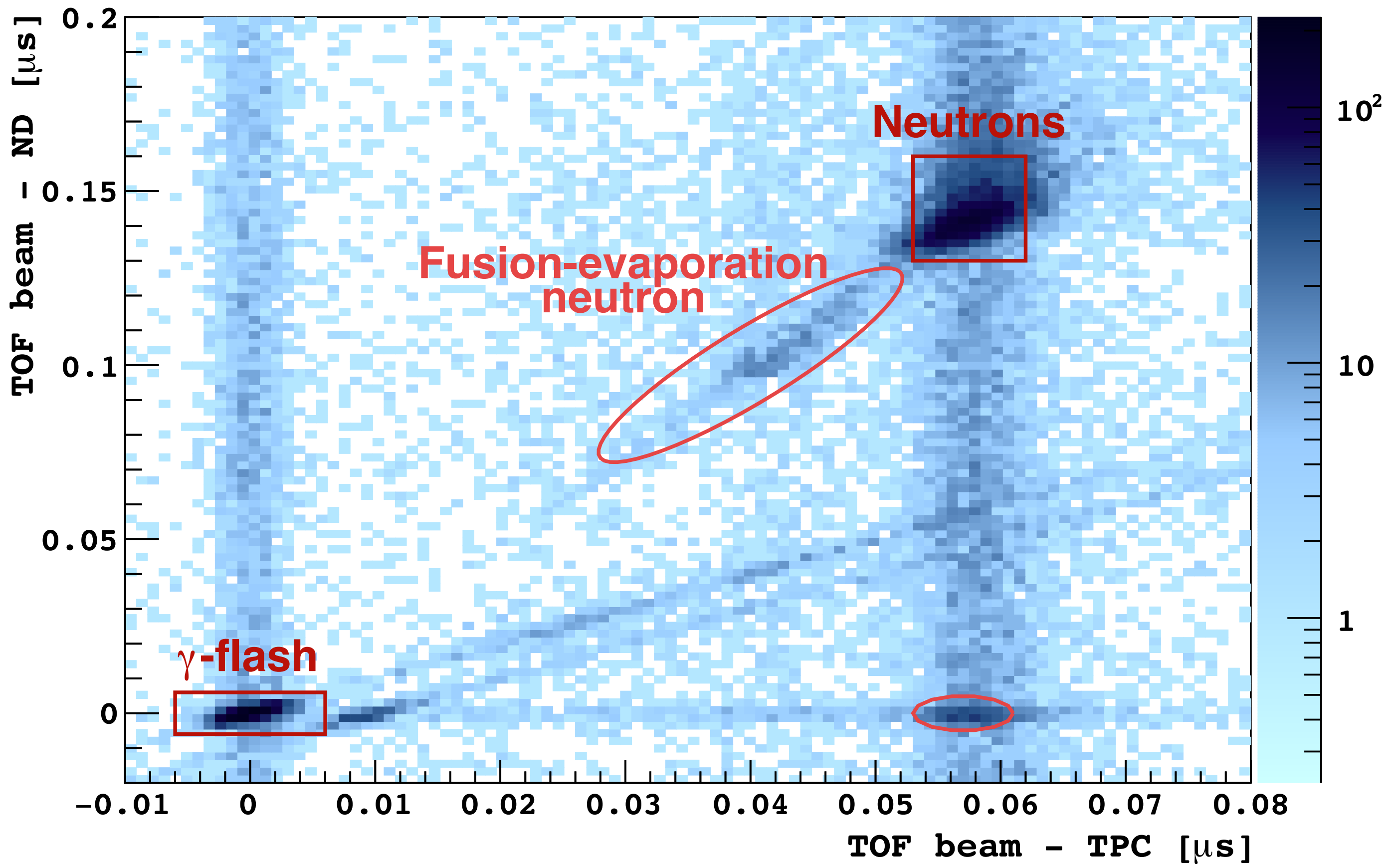


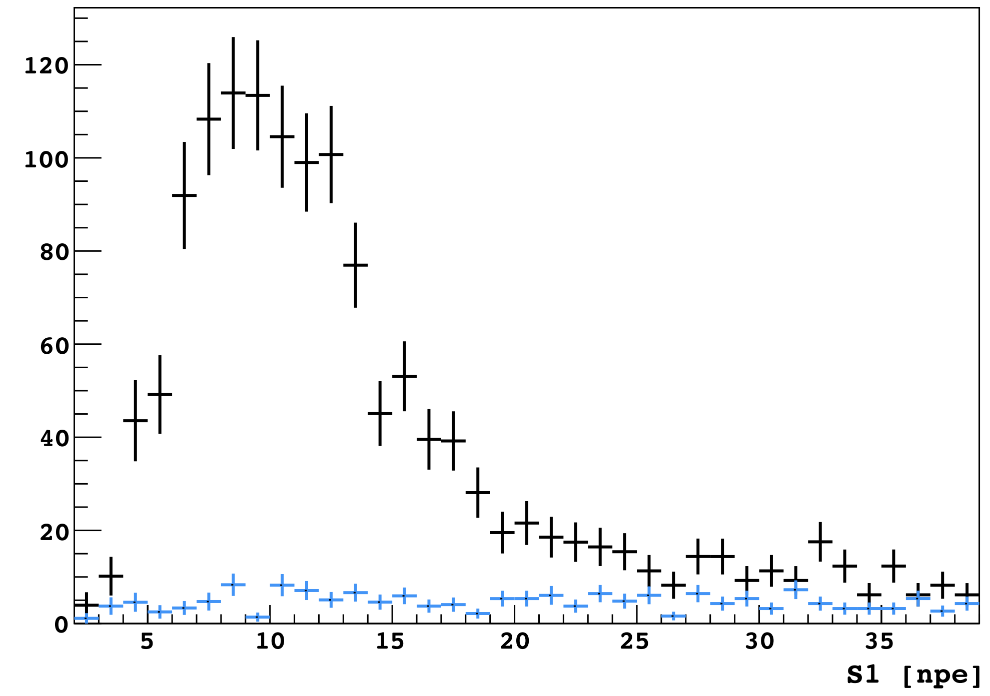


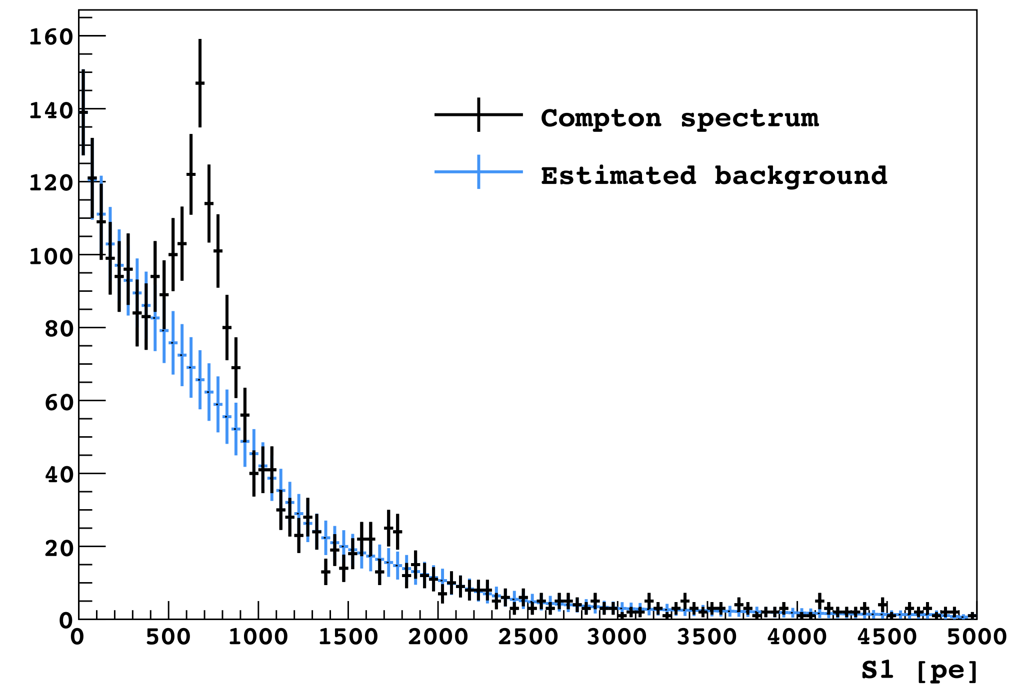
The efficiency given as function of the prompt part is insensitive to the recoil nature (checked with toy MC)

Efficiency fitted on $S1_{100}$ for ER and **directly applied to NR**

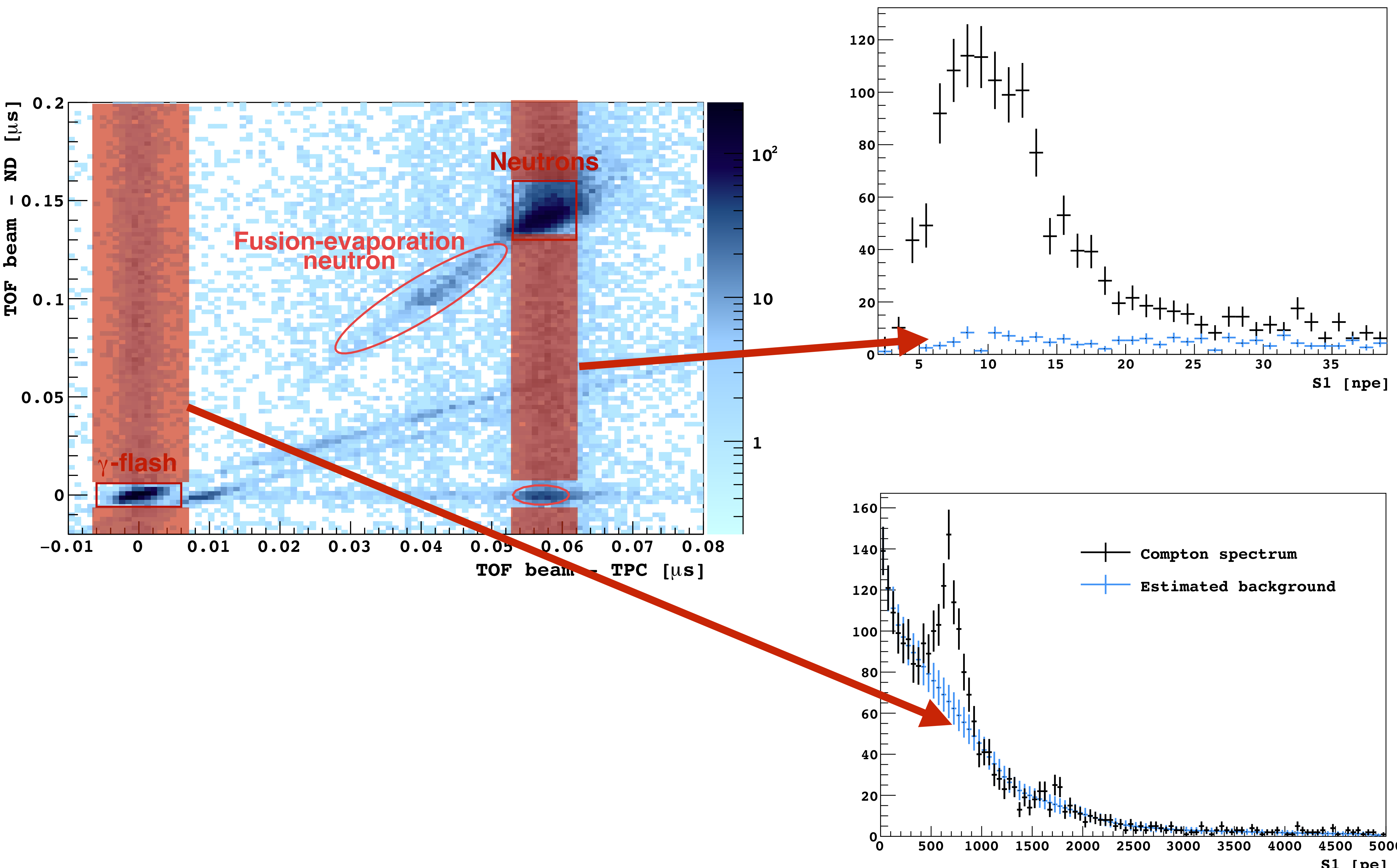
Background subtraction





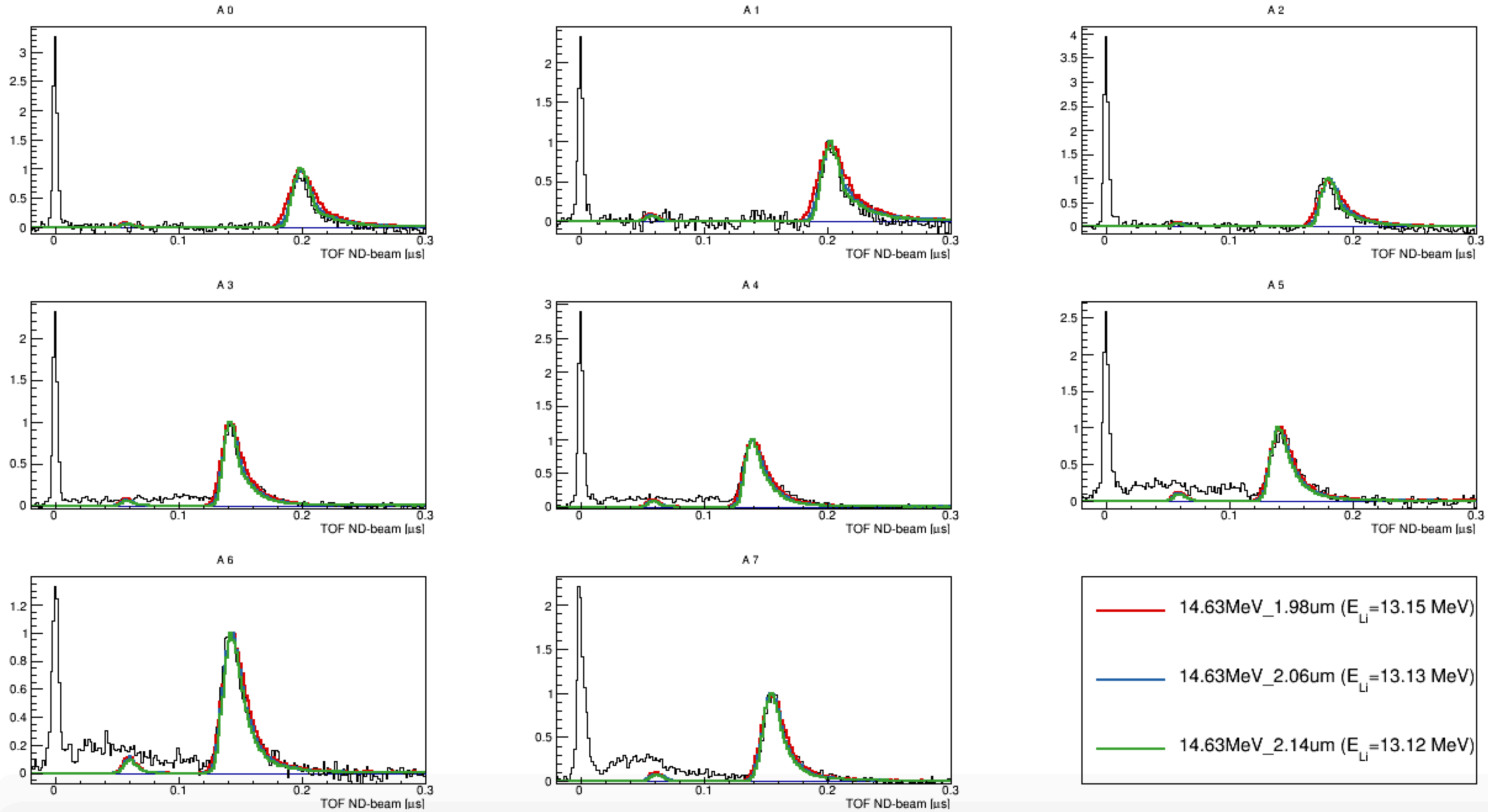


Background subtraction

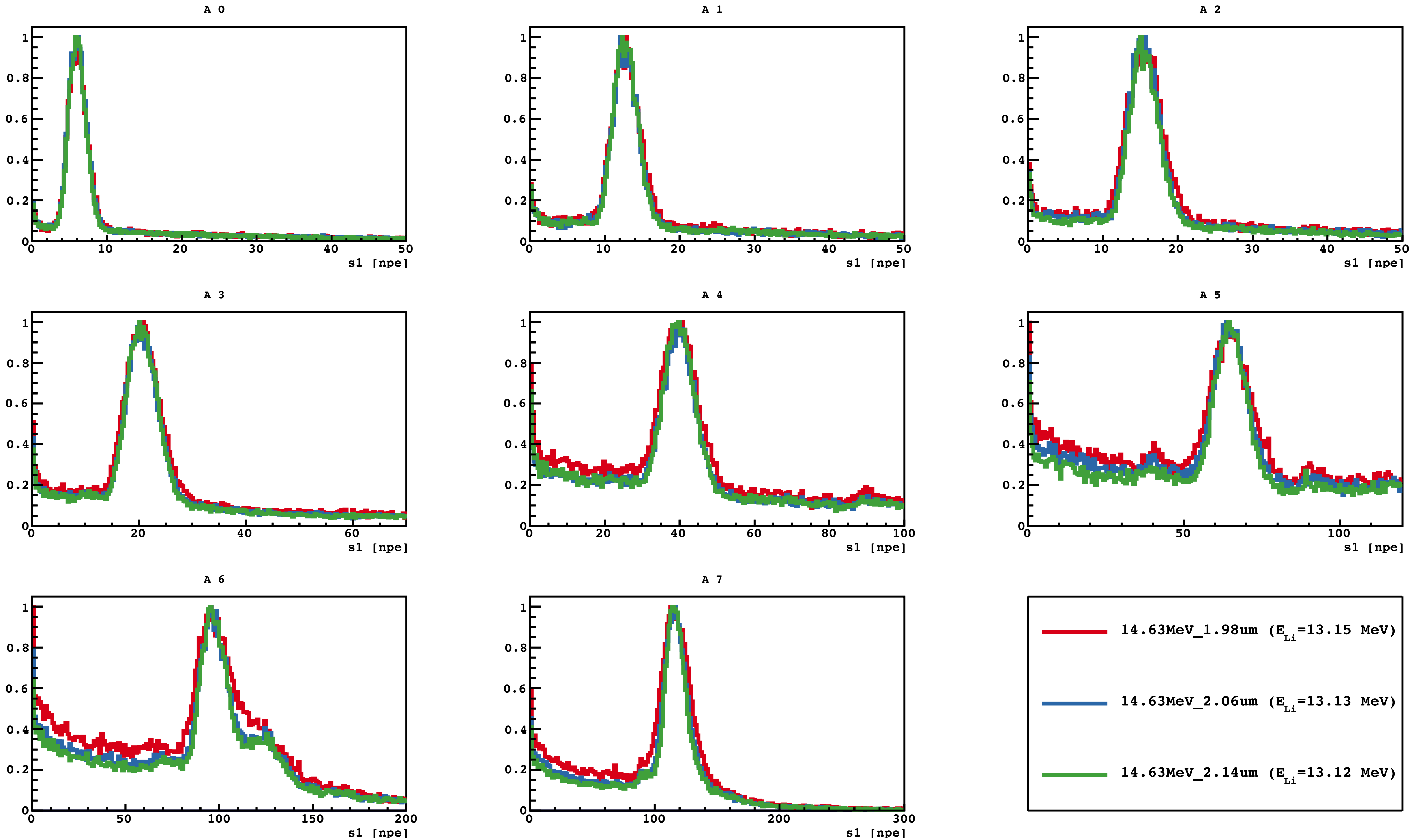


TOF: Data-MC comparison

No real differences in the TOF spectra for all kinematics



S1: MC-MC comparison



No real differences in the S1 spectra for all kinematics

PARIS model

Precision **A**rgon **R**esponse to **I**onization and **S**cintillation

Modification of Mei's model relying on an empirical parametrization of the recombination probability.
Tuned on DS-50 200 V/cm data.