A combined energy scale for WIMP searches in LAr with the DarkSide-50 detector

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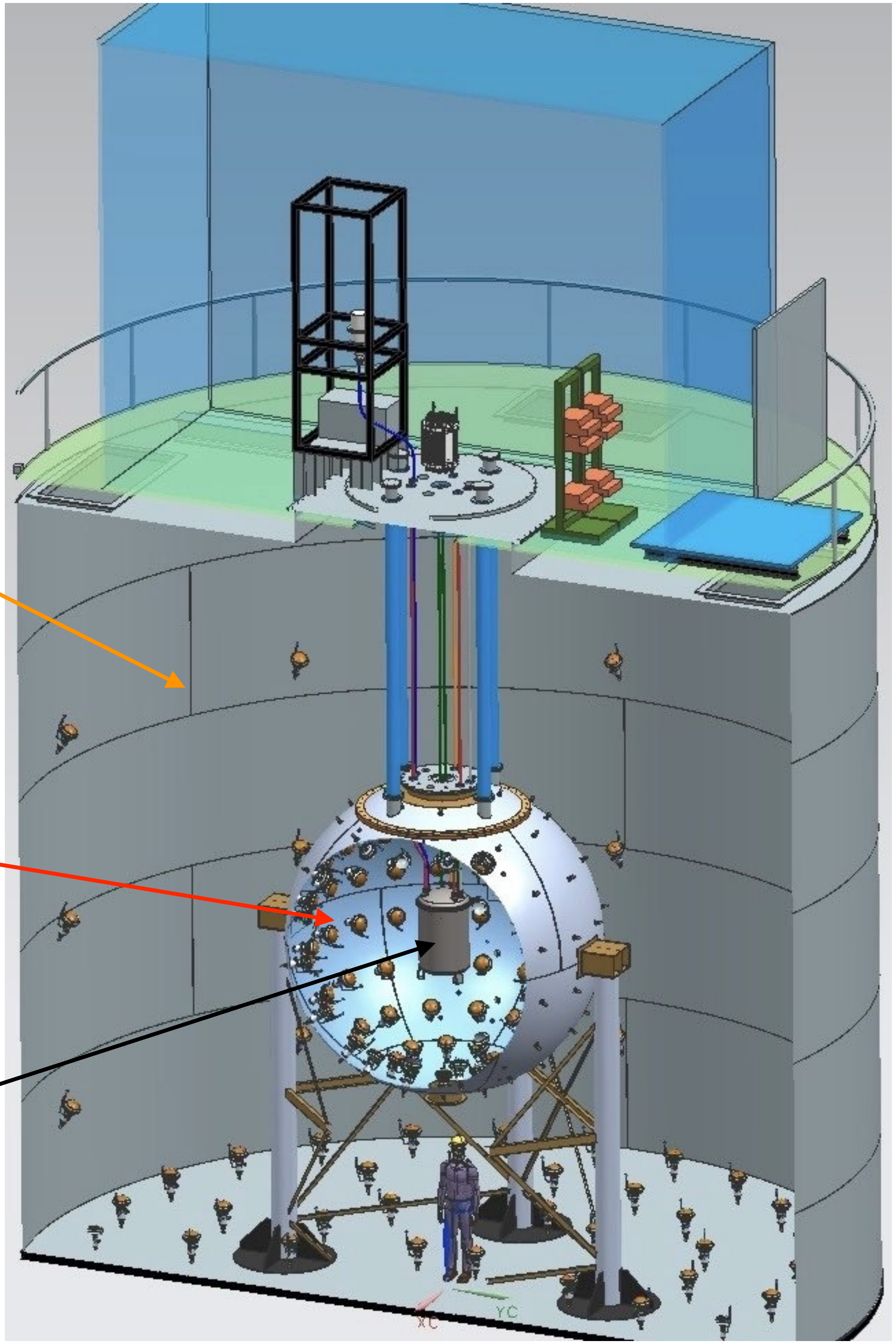
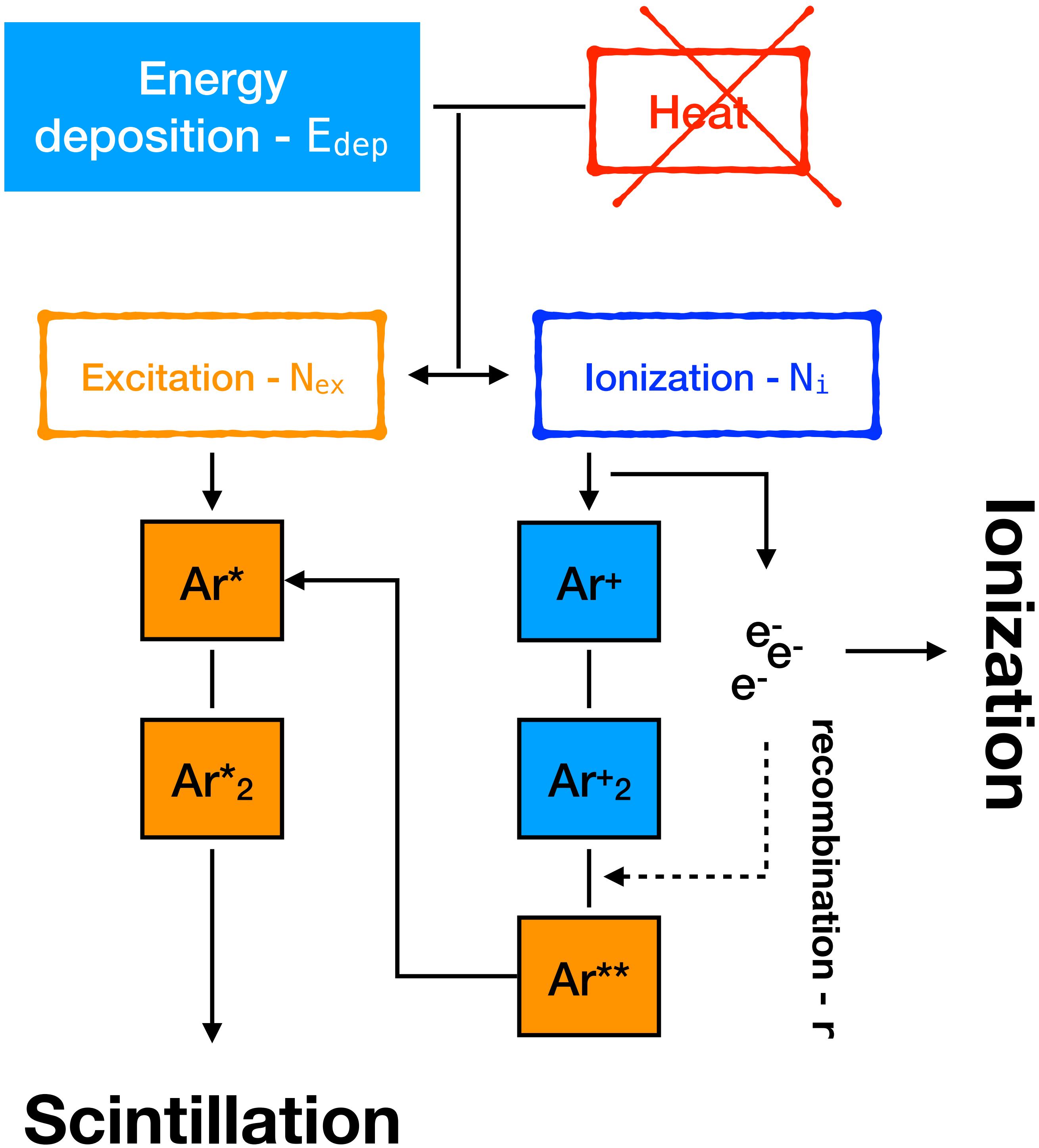
DarkSide-50 detector overview

- **Water Cherenkov** detector (1,000 tons of ultra pure water): active veto for μ and passive shield for external radiation
- **Liquid scintillator** detector (30 tons of PC+PPO+TMB): active ɣs and neutron detector (^{10}B loading)
- **LAr TPC** detector (current phase ~50 kg of Ar fiducial): inner detector for WIMP searches

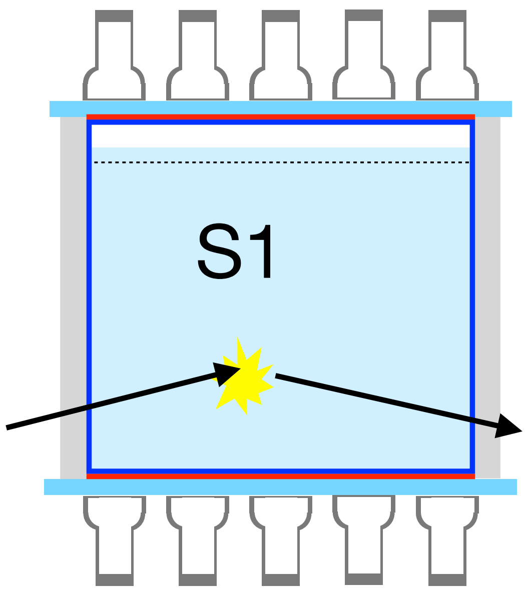


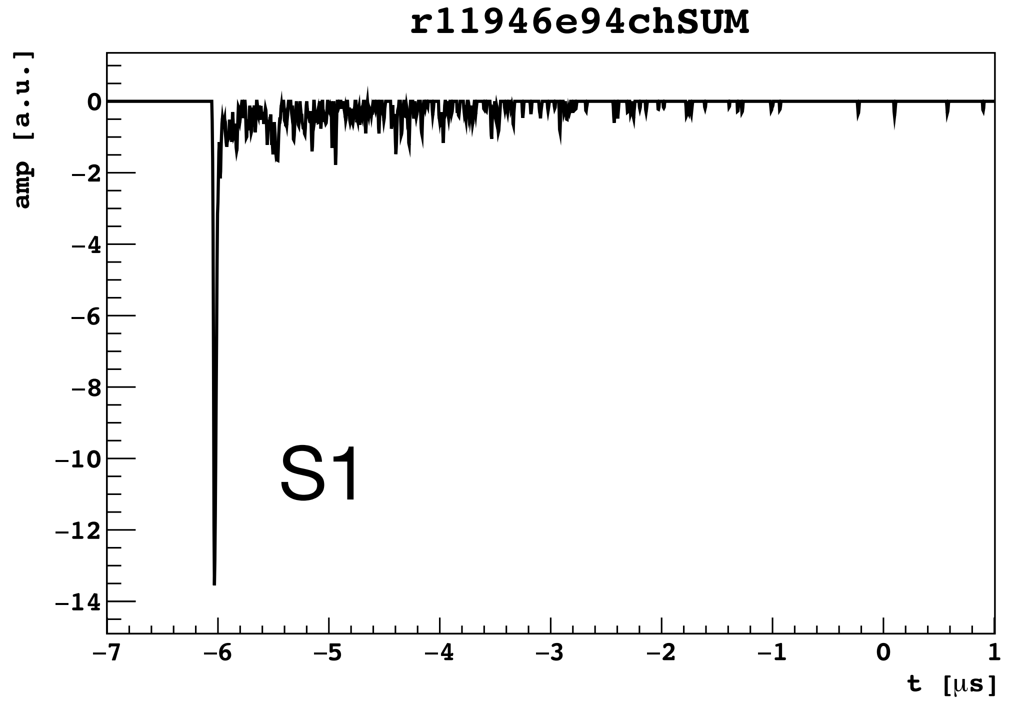
Scintillation in noble liquids

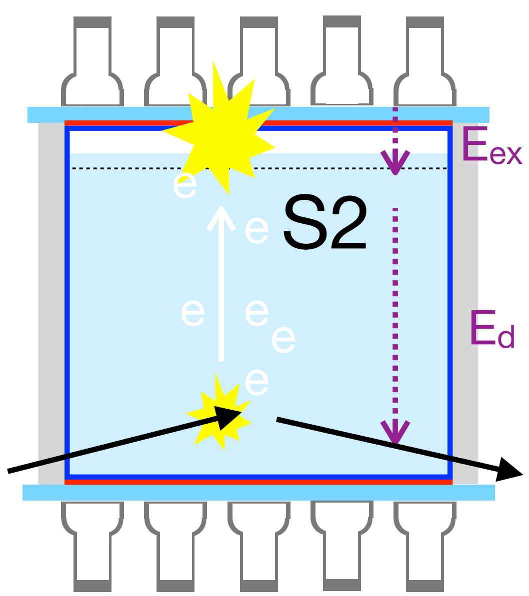


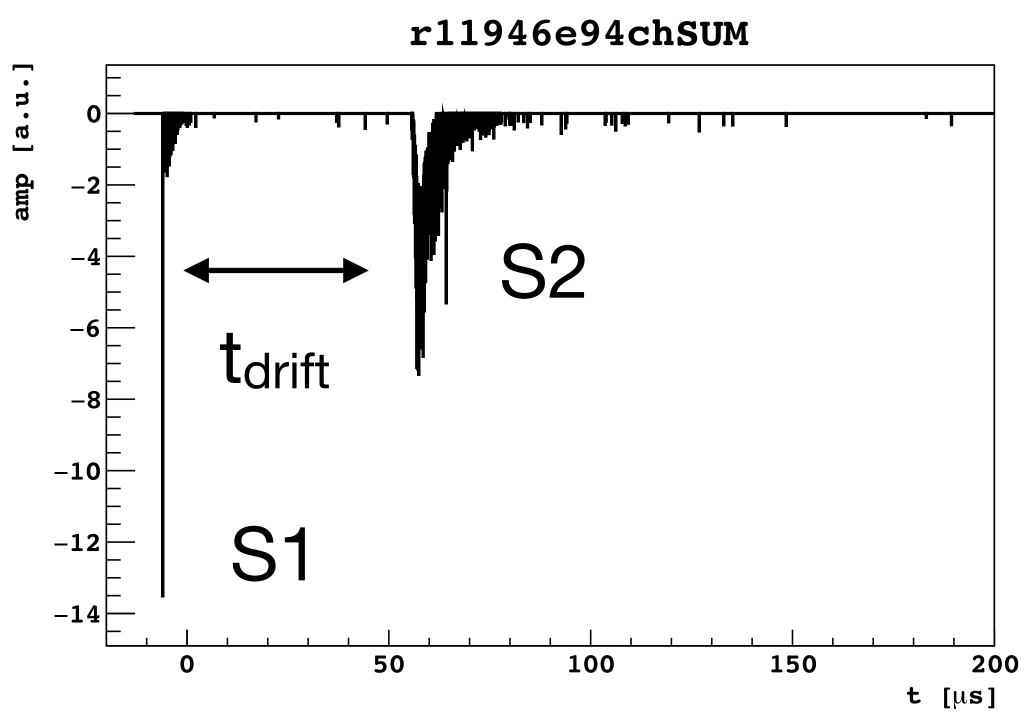
- A particle interaction produces **excited (excitons)** and **ionized (ions)** and **heat** (soft elastic recoils which dominant for NRs - visible light quenched by factor ~3-5 in LAr - while negligible for ERs)
- Excitons produced either directly or through recombined electrons
  - Excitons → Excited dimer decay producing photons (λ=128nm for Ar)
- If electric field ≠0, electrons can avoid recombination and collected

Two-phase Argon TPC









- S1 (primary scintillation) and S2 (ionization signal) give:
  - Energy estimation
  - 3D position of the event (t_{drift}→z and light pattern on PMTs→xy)
  - Particle discrimination: PSD and S2/S1 can distinguish between electron (ERs - β/ɣ) and nuclear recoils (NRs - n/WIMPs)

A combined energy frame

- Why? WIMP's interactions will deposit only small amounts of energy and dR/dE exp falling - **IMPORTANT:** understand energy scale since directly maps WIMP sensitivity

- How? Exploit anti-correlation between S1 and S2 signals → energy scale independent from recombination (Doke et al. (2002))

  - $\mathbf{E_{dep}} = W (N_{ex}+N_i) = \mathbf{W (S1/\varepsilon_1+S2/\varepsilon_2)}$

  - Being $S1 \equiv \varepsilon_1 (N_{ex}+r N_i)$ $S2 \equiv \varepsilon_2 (1-r) N_i$, $N_{ex}/N_i=0.21$ (ERs - Doke et al. (2002)) and W=19.5eV (Doke et al. (2002) and Takahashi et al. (1975)) is average work function to create electron-ion pair and r is recombination prob.

  - Unknowns: ε_1, ε_2 and $r=r(E_{dep},E_d)$ being E_d the strength of the drift field

- Combined energy has access to micro-physics parameter to better understand detector response: light and charge yield (L_y, Q_y) and recombination (r)

Calibration data

- Idea: since $r=r(E_{dep},E_d)$, then ε_1 and ε_2 can be determined looking at S1 and S2 from different calibration sources with data taken at different drift fields

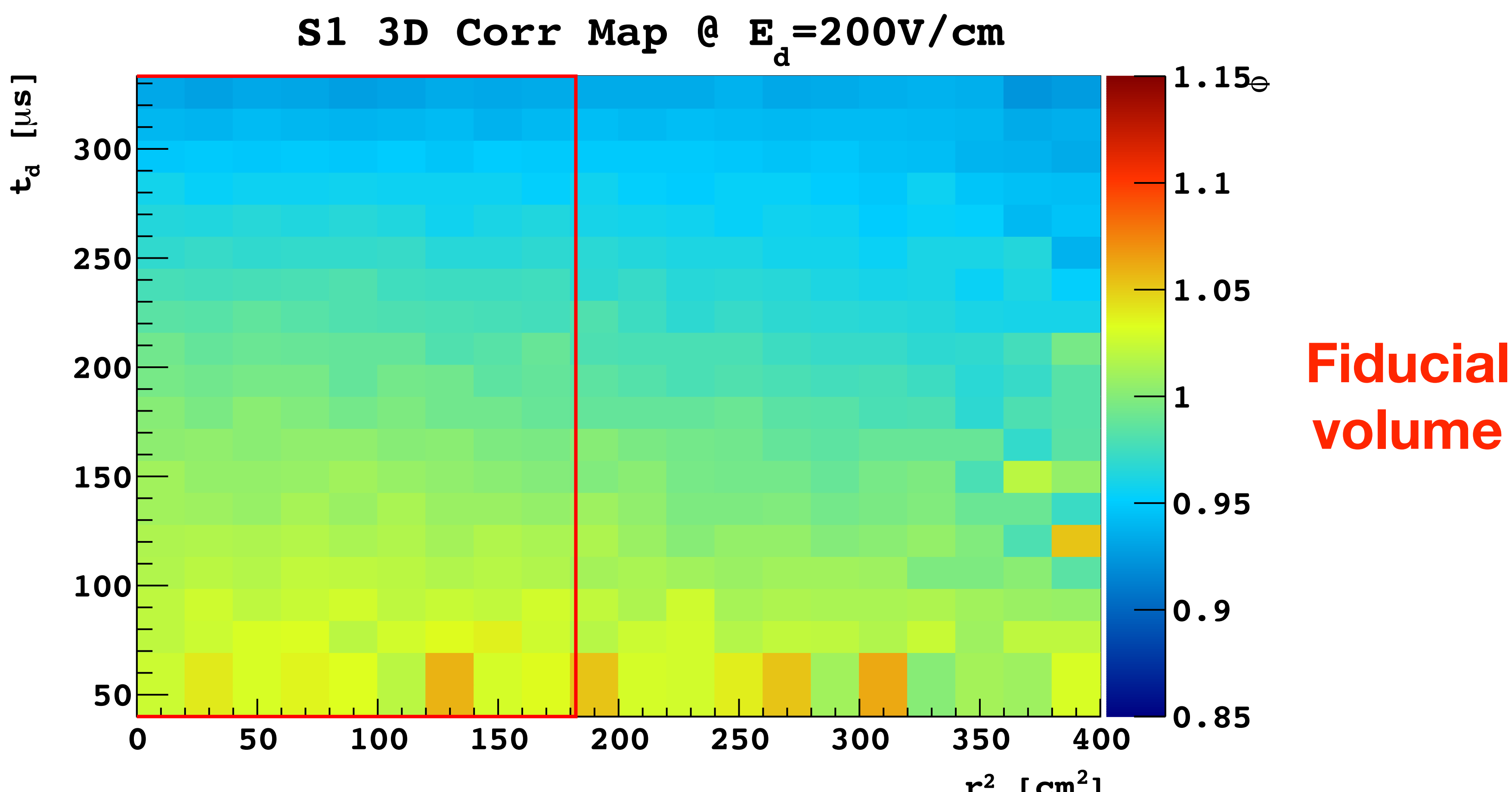
	E [keV]	type	Edrift [V/cm]
^{57}Co	122.1 (86%) 136.5 (11%)	External AAr	200 150 100
^{83m}Kr	9.1+32.4	Internal Periodic calib.	200 150 100 50
^{37}Ar	2.82	Internal Inherent UAr	200 150 100 50

Data selection criteria and corrections

- Data quality cuts are applied (check sanity of the detector in terms of performances and completeness of information)
  - Single scatter events (S1+S2) considered only
  - **3D fiducial** (~0.5cm top and bottom and events radius <13.5cm)
- Corrections: 3D correction for both S1 and S2

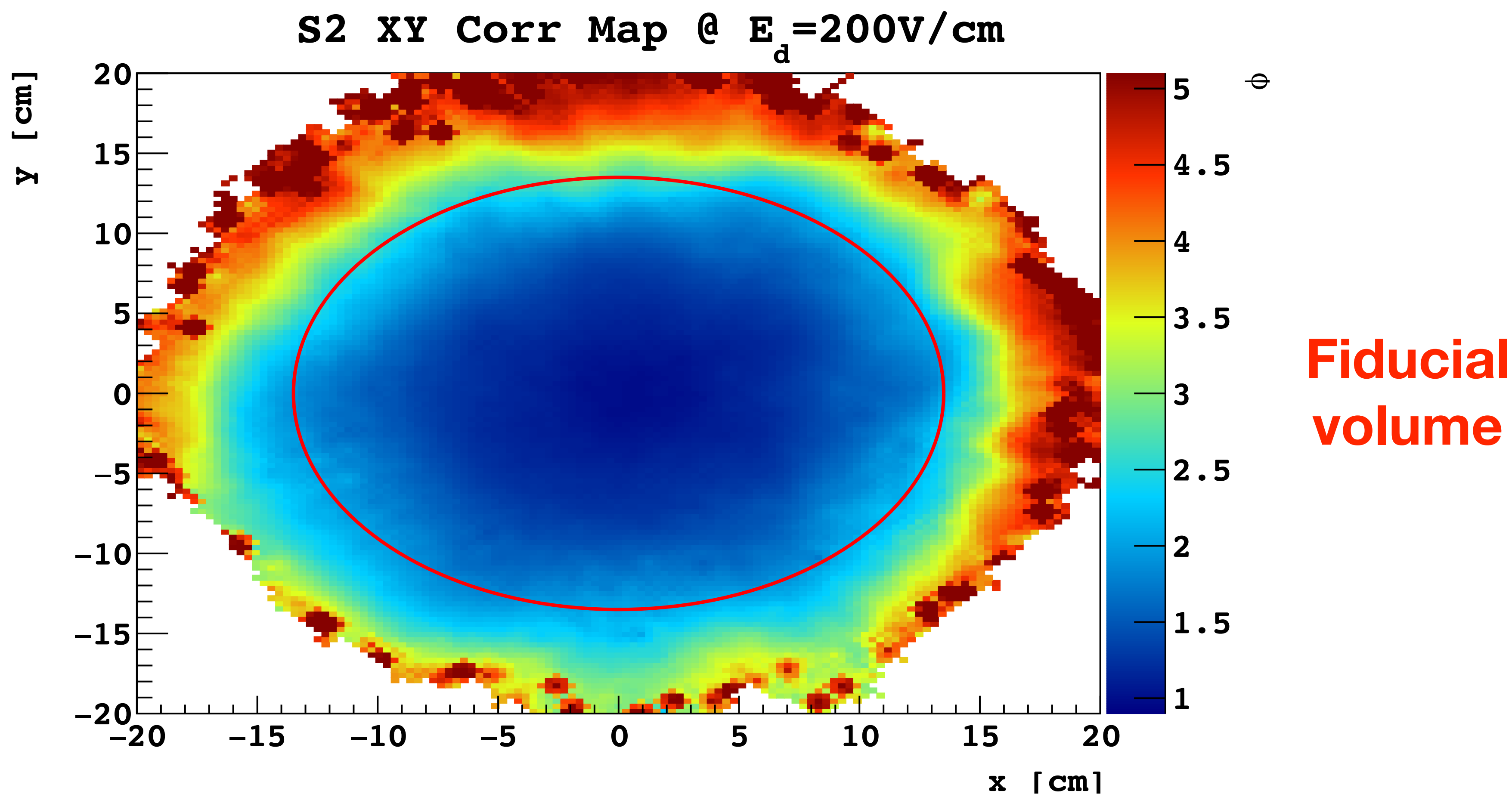
S1 corrections

- **S1=S1(t_{drift})** - bottom PMTs see more light than top (total internal reflection liquid-gas interface, grid not transparent) - effect up to ~14%
- **S1=S1(x,y)** - parts have better light collection (cylindrical shape, different QE PMTs, non uniformity of TPB) - effect up to ~3% (less severe)



S2 corrections

- **S2=S2(x,y)** - central PMT sees x3 more light than corners (possible cause is anode sagging or grid deflection) - effect up to ~300%

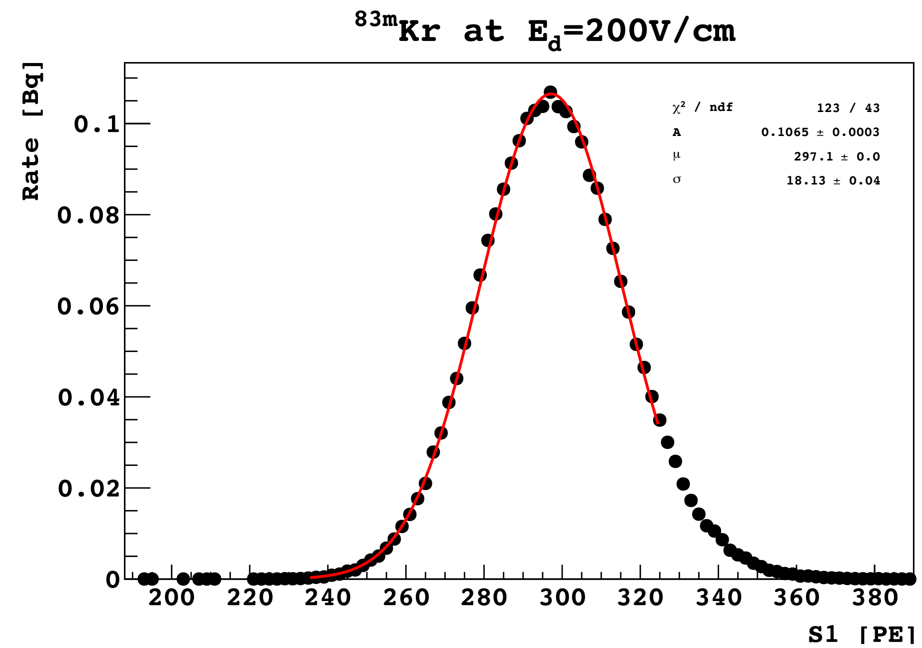


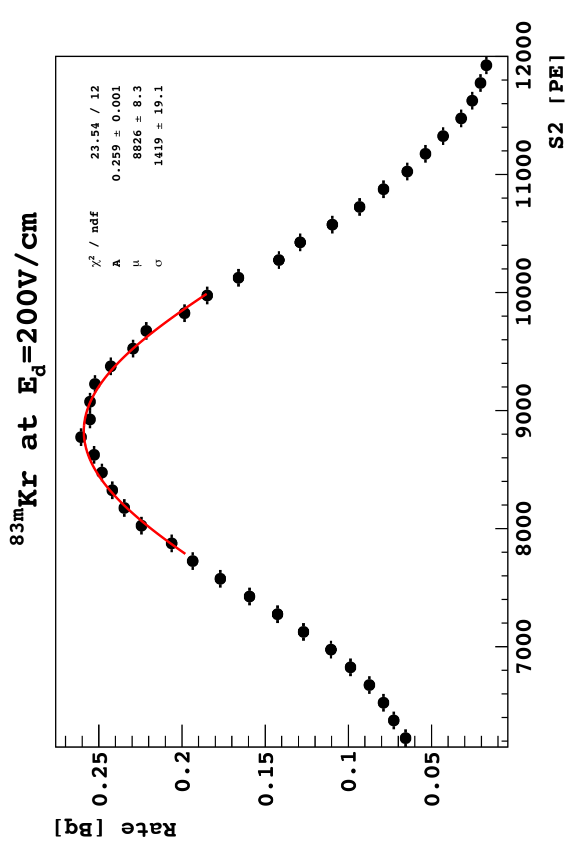
- **S2=S2(t_{drift})** - impurities can "eat" electrons during drift: survival probability ~exp($-t_{drift}/T_e$) where $T_e \simeq$5ms is electron lifetime - effect up to ~7%

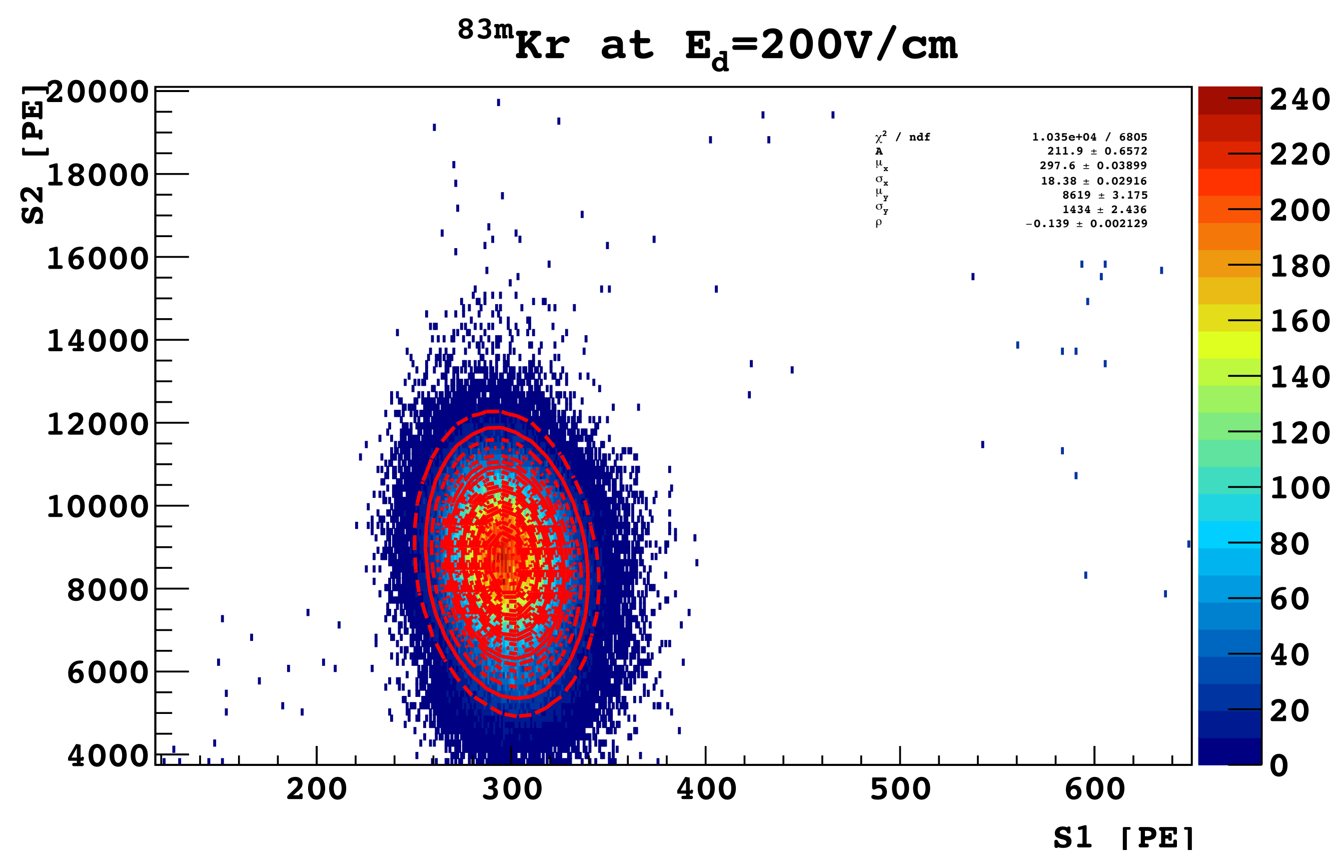
Data analysis

- Each mono-energetic source generates a fixed mean amount of light and charge: **signals** appear as **elliptical over-densities** in (S1,S2)-space

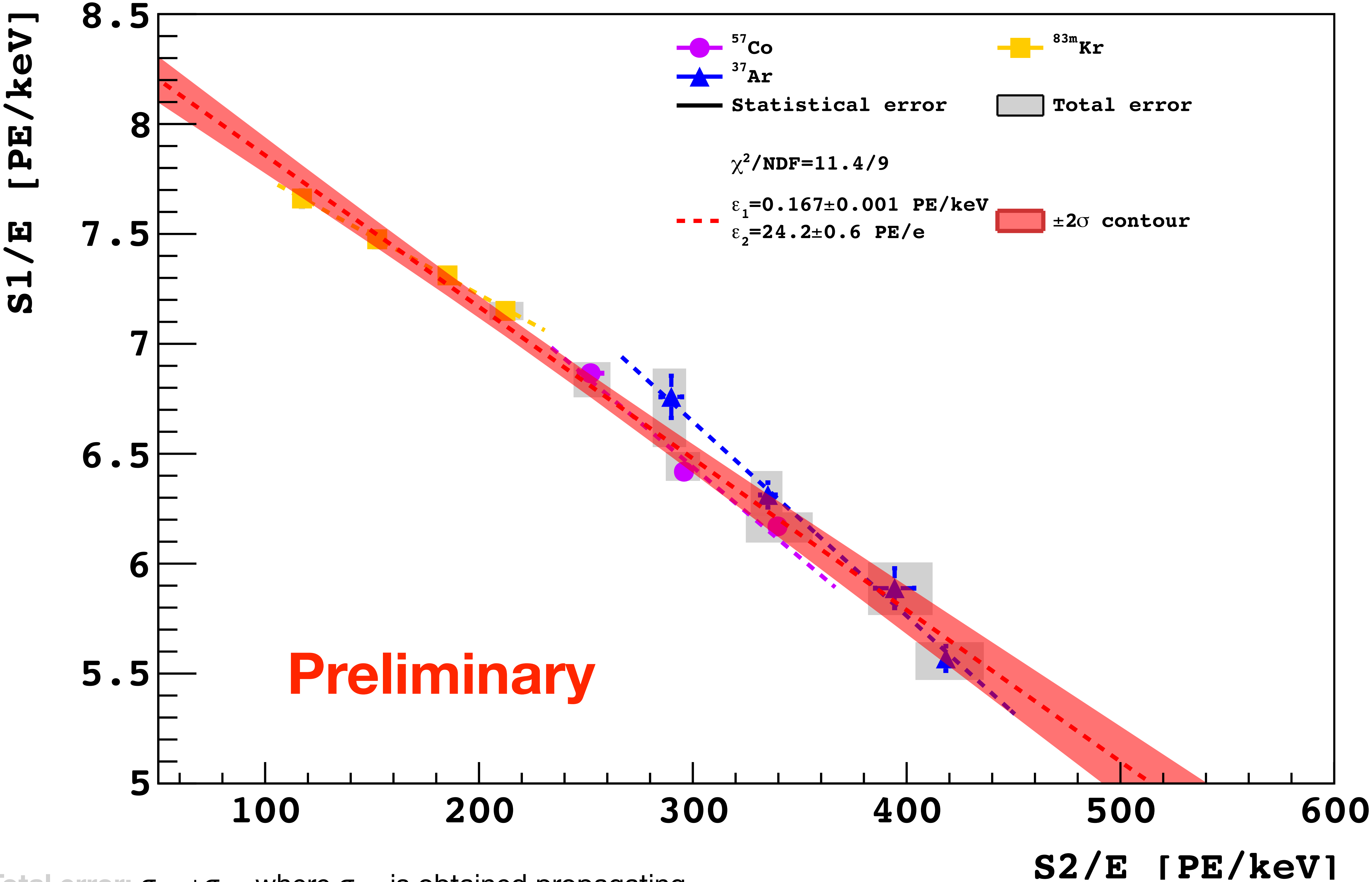
- Measurements of the light and charge yields follow directly from Gaussian fits (1D and 2D) for the mean S1 and S2





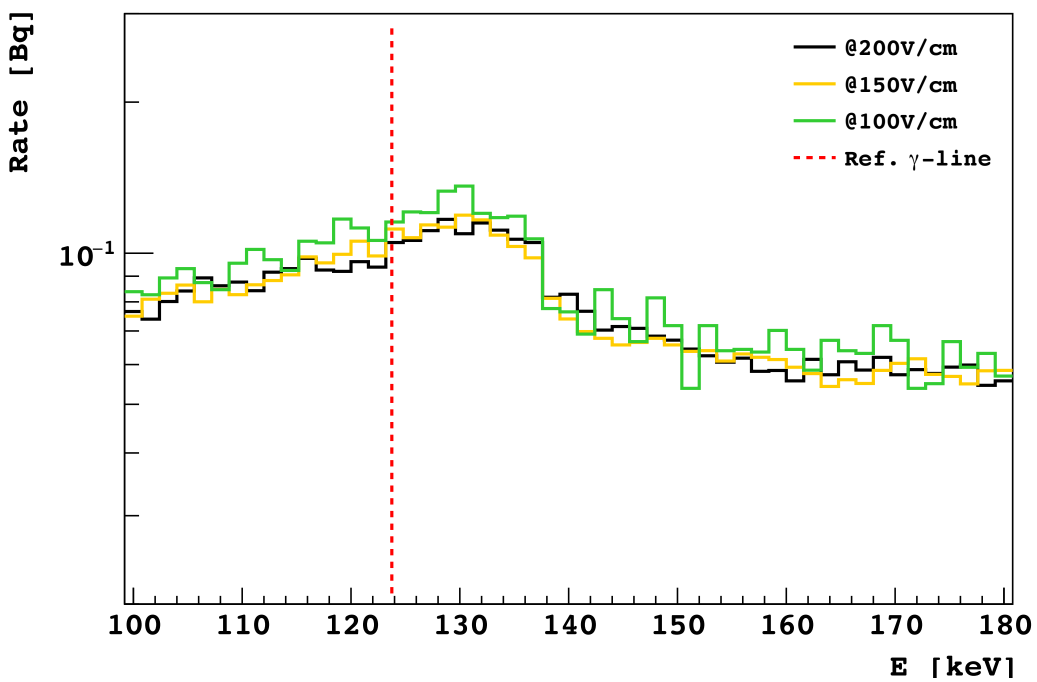


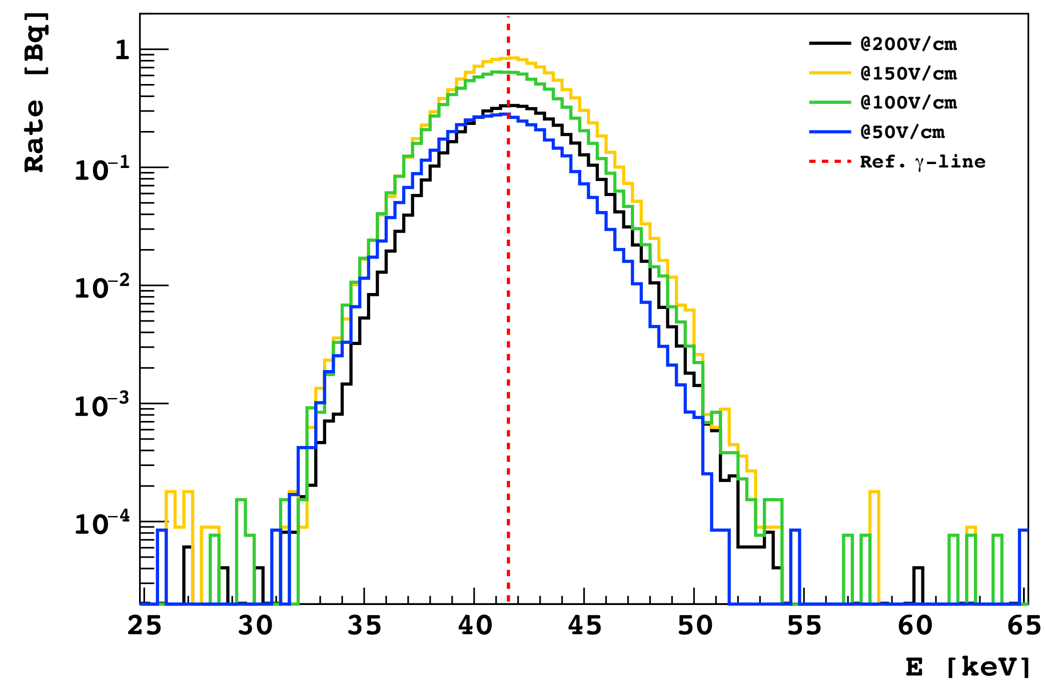
Results

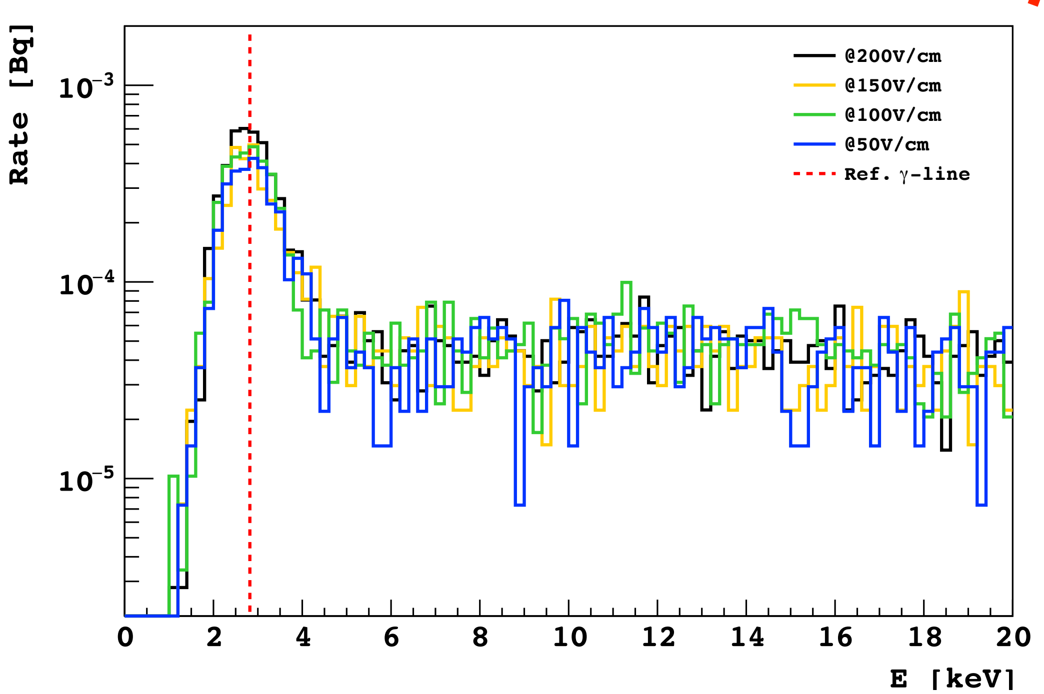


Total error: $\sigma_{stat}+\sigma_{sys}$ where σ_{sys} is obtained propagating uncertainties of the various corrections on S1 and S2

Combined energy spectra





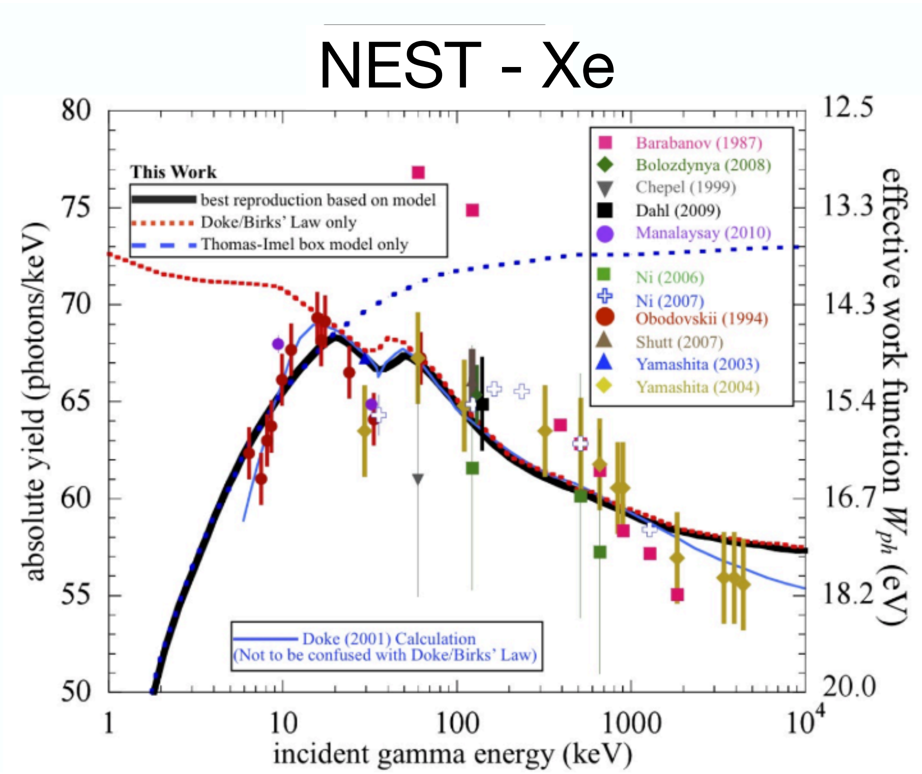


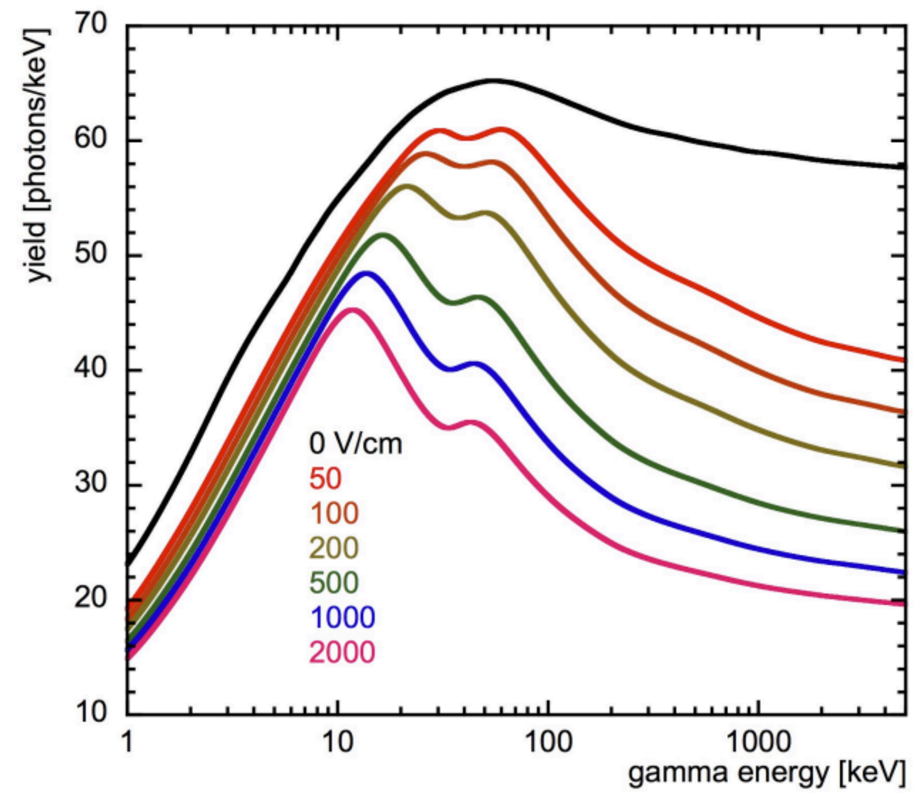
Preliminary

- Spectra taken at different E_d overlap → **energy scale** is **independent from recombination probability**
- Improvement in the peak resolution (σ/μ): *e.g.* for ^{37}Ar from 24% for S1 to 17% for E
- New energy scale is in good agreement with reference ɣ-lines at low energy. At high energy (>40keV) discrepancy of ~5%

PARIS model (I)

- Several models developed to describe recombination probability as function of energy and drift field
  - NEST approach combines Thomas-Imel and Doke-Birks models by constraining associated parameters using exp. data. Data set abundant for Xe but for Ar limited at some energies
- Other approach: **P**recision **A**rgon **R**esponse **I**onization (and) **S**cintillation
- Simplify embedding an **effective model** to parametric effects inducing S1 and S2 signals:
  - Empirical parametrization: $r(E) = \mathrm{erf}(E/p_0)\,(p_1 \exp(-E/p_2) + p_3)$
  - p_i i=0,..3 tuned on DarkSide-50 data @ E_d=200V/cm

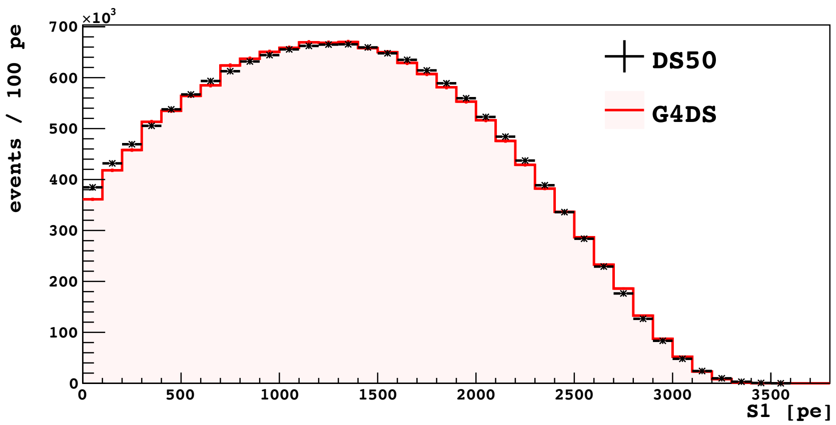


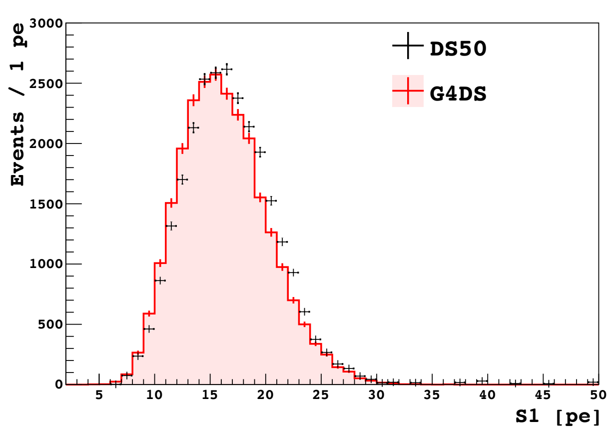


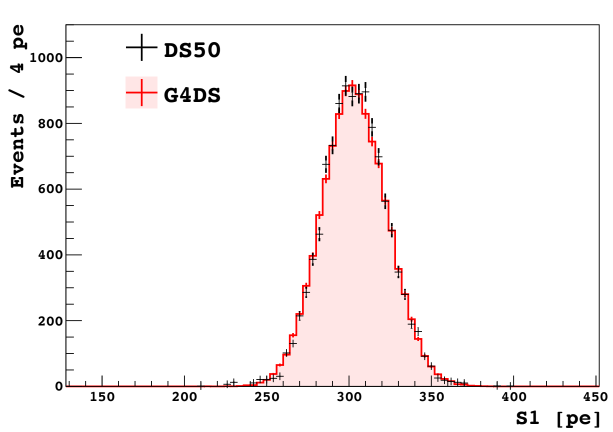
See reference JINST 12 P10015

PARIS model (II)

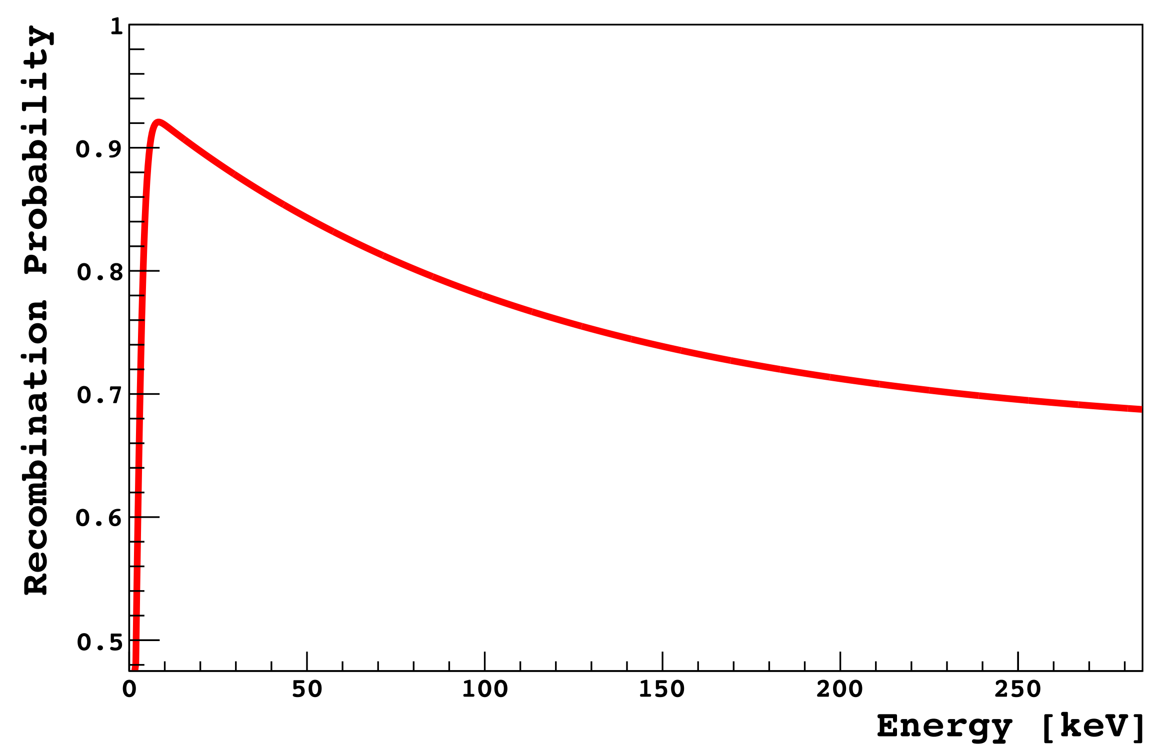
Note: ^{39}*Ar beta decay is forbidden*
(uncertainty at low energy)



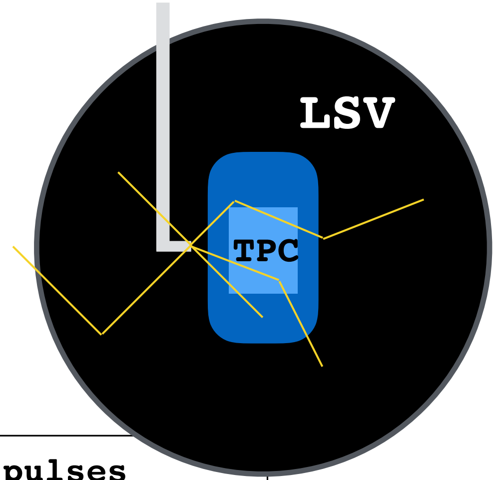


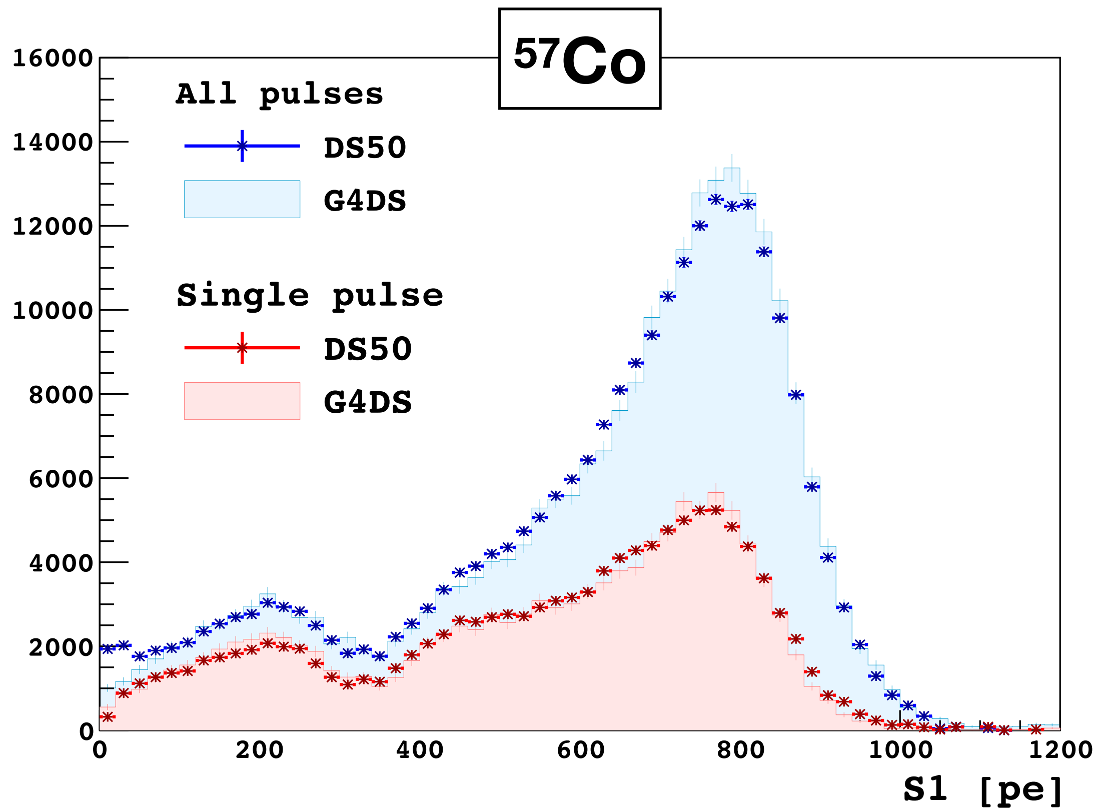


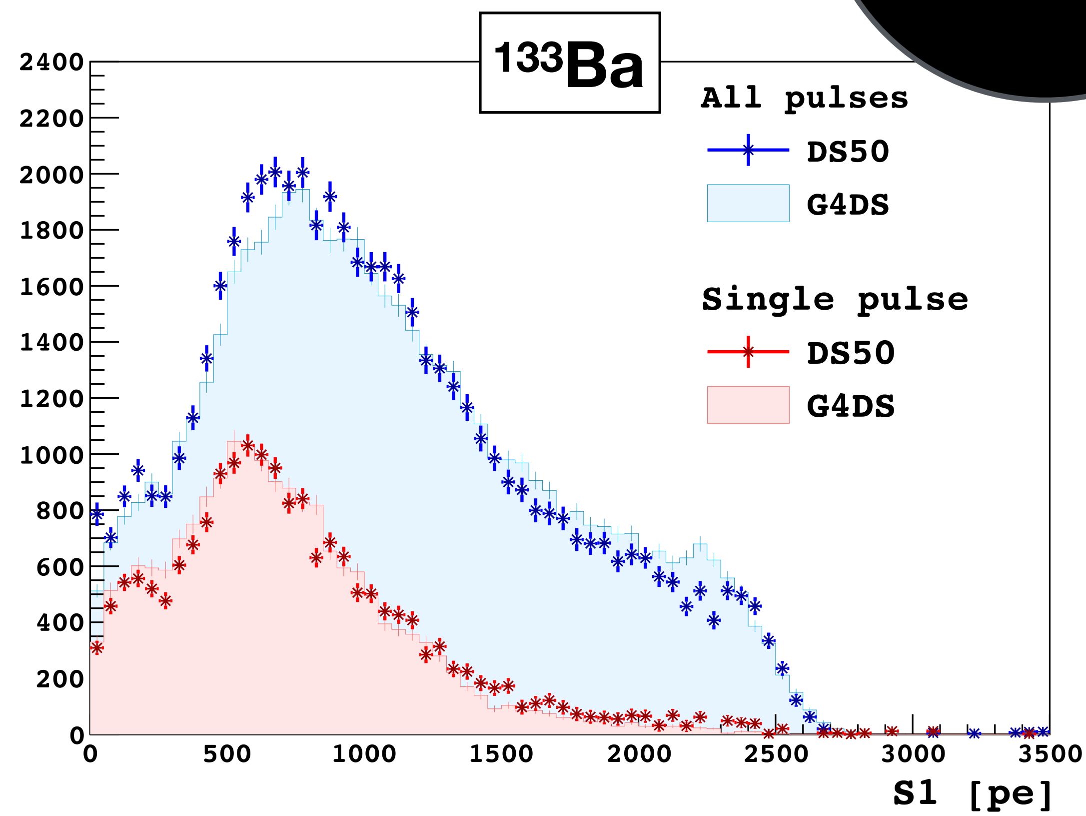
- Extraction of the recombination probability from comparing DS50 data vs. G4DS and considering only single scatter events
- Determine **r(E)** by simultaneous fit of S1 spectra of:
    - endpoint of ^{39}**Ar** spectrum (565 keV)
    - ^{37}**Ar** peak (2.82 keV) peak
    - ^{83m}**Kr** (9.4+32.1 keV) peak



PARIS model (III)



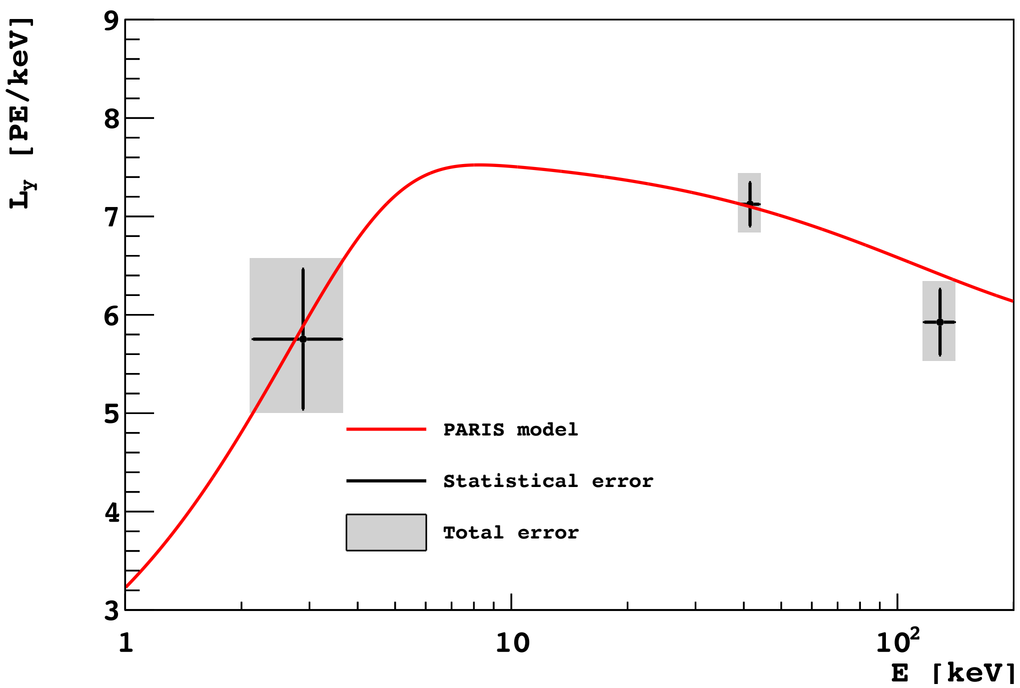


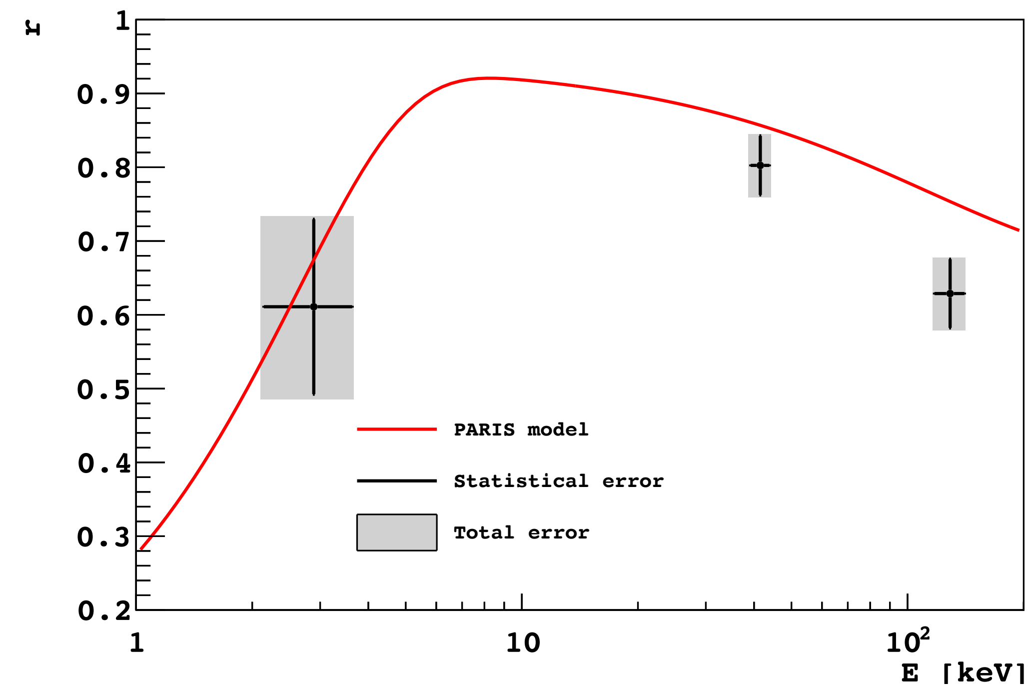


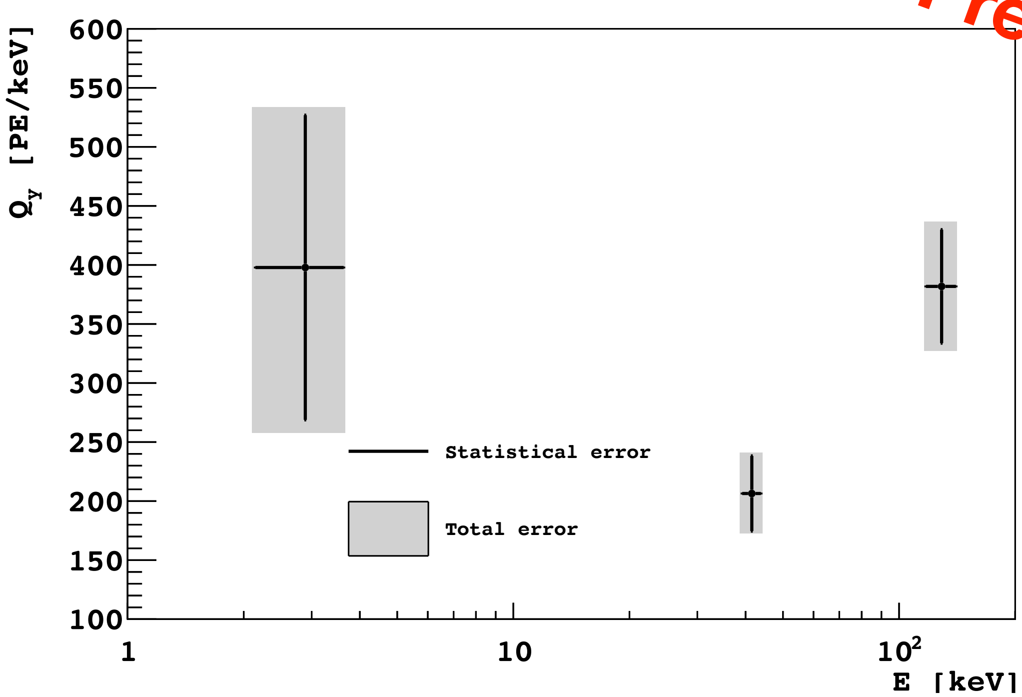
- Recombination probability from PARIS - cross check with external calibration ɣ sources (^{57}Co and ^{133}Ba)

- Very good agreement between data and Monte Carlo G4DS, both for single-scatter and multiple-scatters events

Combined Energy Scale vs. PARIS model







Preliminary

- Light yield (L_y) for electron increases at low energy where there is more recombination (due to higher stopping power). Complementary behavior for charge yield (Q_y)
- **Good agreement between L_y derived with combined energy scale and PARIS**
- ~5-10% discrepancy at high energy (>40keV) for recombination probability: expected since PARIS is 1) tuned only on S1 signal and not on both S1 and S2 and 2) full recombination is assumed at zero field

Conclusions and future development

- Conclusions:
  - New energy framework allows better energy resolution at low energy and agrees with PARIS model
  - Combined energy frame used to achieve recent results in arXiv 1802.07198: useful for detailed studies of ER backgrounds (See G. Giovanetti's talk)
- Future:
  - Investigate NR
  - Compare results with NEST
  - Study fluctuation in the recombination