DPG Frühjahrstagung 2018, Würzburg 2018-03-20

T 32.3:

Topological Track Reconstruction in Liquid Scintillator Neutrino Detectors for MeV Events

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on behalf of

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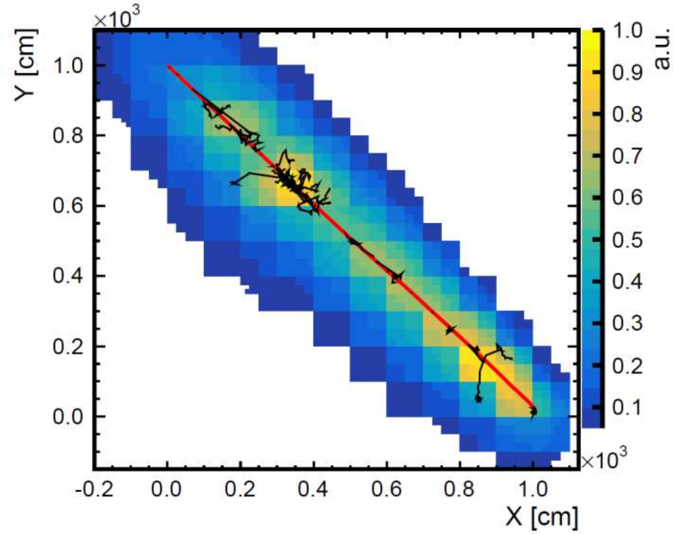
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Gefördert durch DFG Deutsche Forschungsgemeinschaft

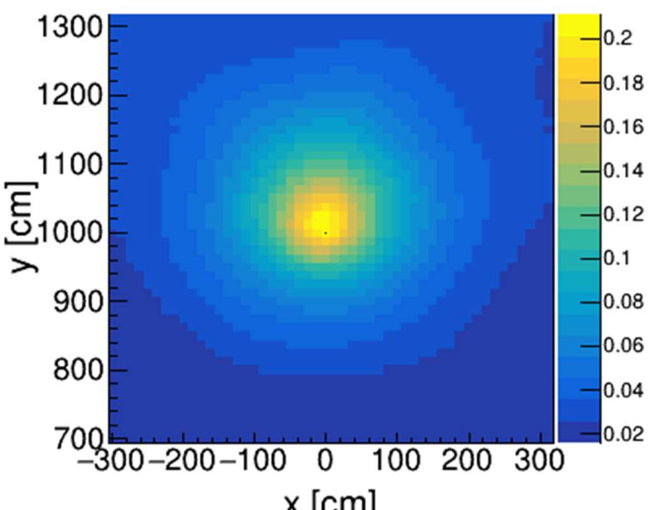
JUNO

Motivation

- topological reconstruction designed to resolve tracks of high energy particles ($\mathcal{O}$(GeV)), e.g. muons
- low energy (LE) events ($\mathcal{O}$(MeV)), e.g. IBD signal, considered as point-like
- LE: well established methods exist to resolve vertex and energy



topological reconstruction of a 3 GeV muon

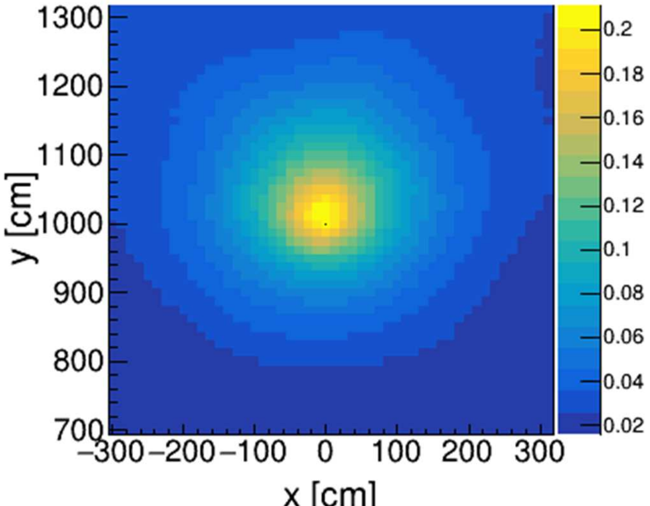


topological reconstruction of a 3 MeV electron

… so why do we even care?

Motivation

- LE events: no clear topology recognizable
- but: **contrast** can give rise to event discrimination



topological reconstruction of a 3 MeV electron

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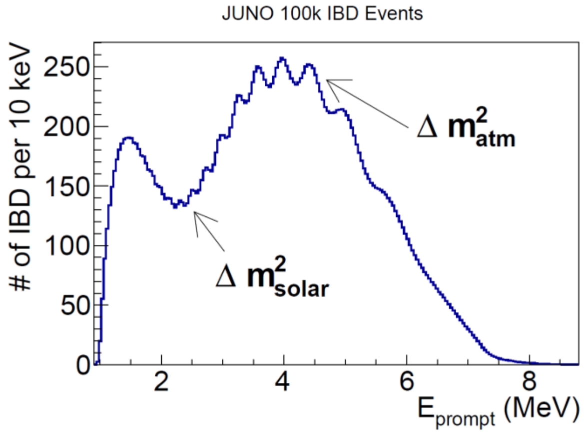
positrons

→ ionization
→ annihilation
→ two 511 keV gammas

- IBD signal

E_{prompt}: 0 – 8 MeV

$\overline{E_{prompt}} \approx 2.6$ MeV



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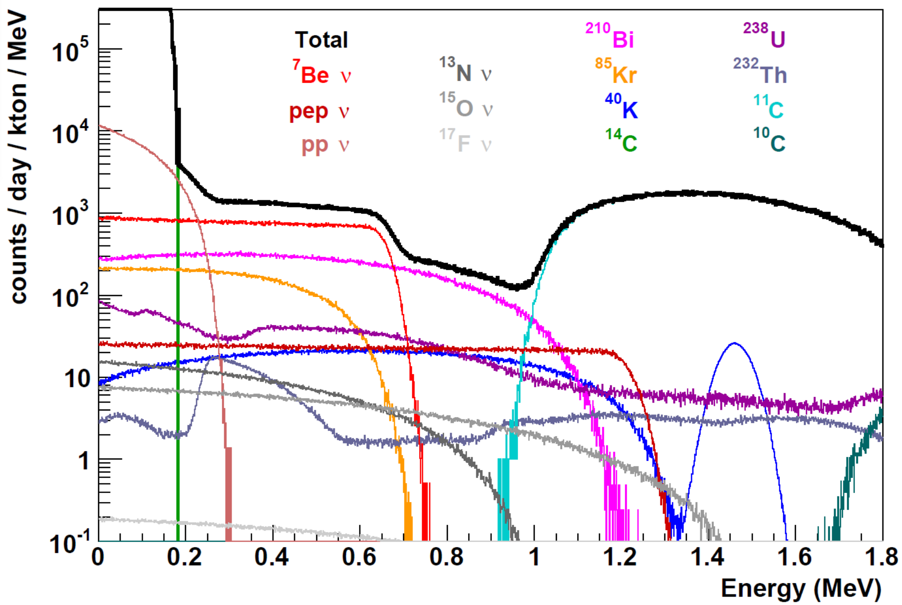
gammas

→ Compton scattering
→ $range_\gamma$: $\mathcal{O}$(50 cm)

- natural decay chains

$E_\gamma < 3$ MeV



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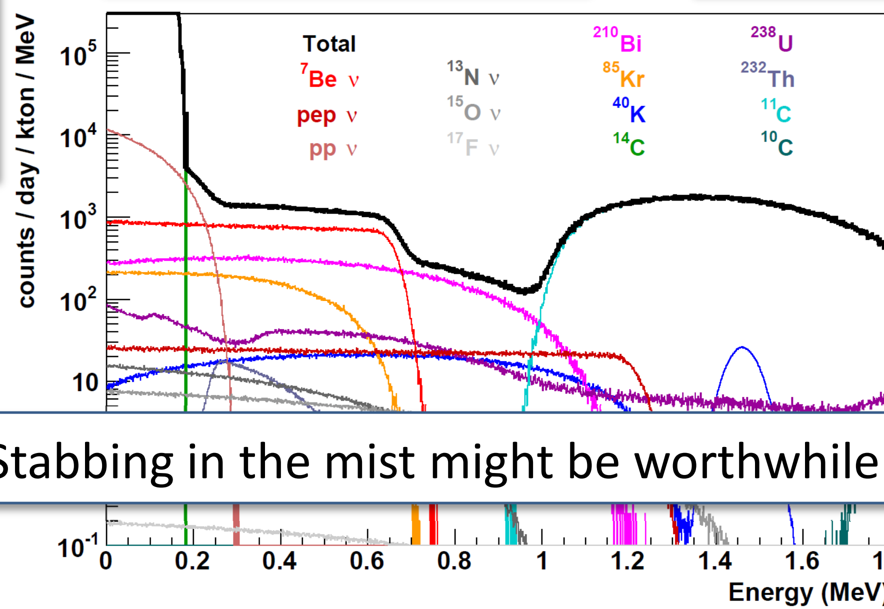
electrons

→ ionization
→ range$_e$: $\mathcal{O}$(cm)

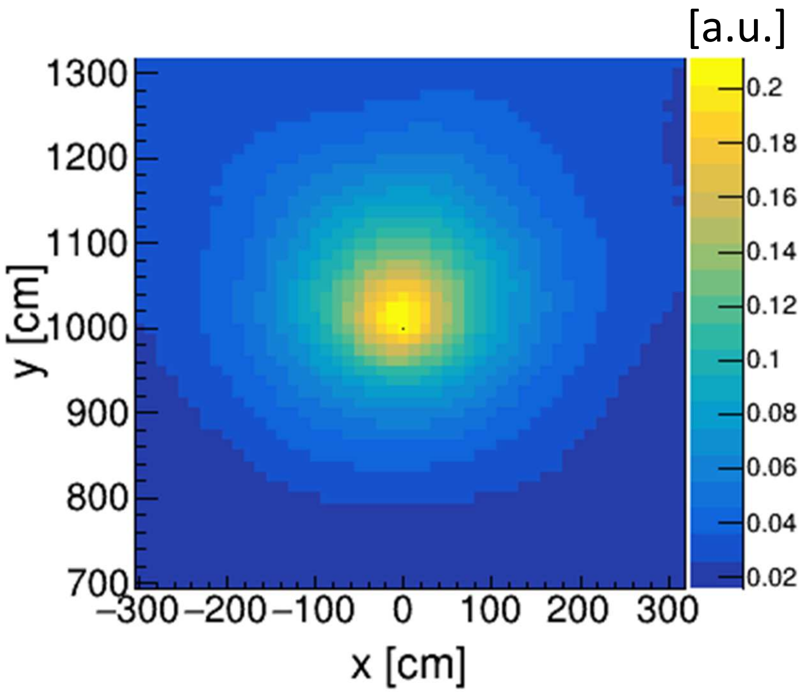
- solar neutrinos
- βn from ^8He, ^9Li

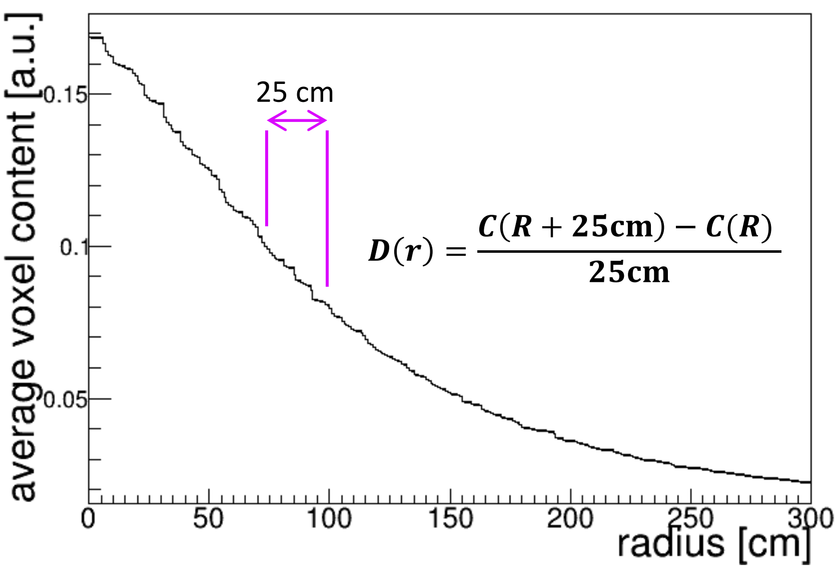


Stabbing in the mist might be worthwhile!

Development of a Discrimination Parameter

- LE: a few thousand photo electrons (PE)
- reconstruction output: number density distribution of photon emissions



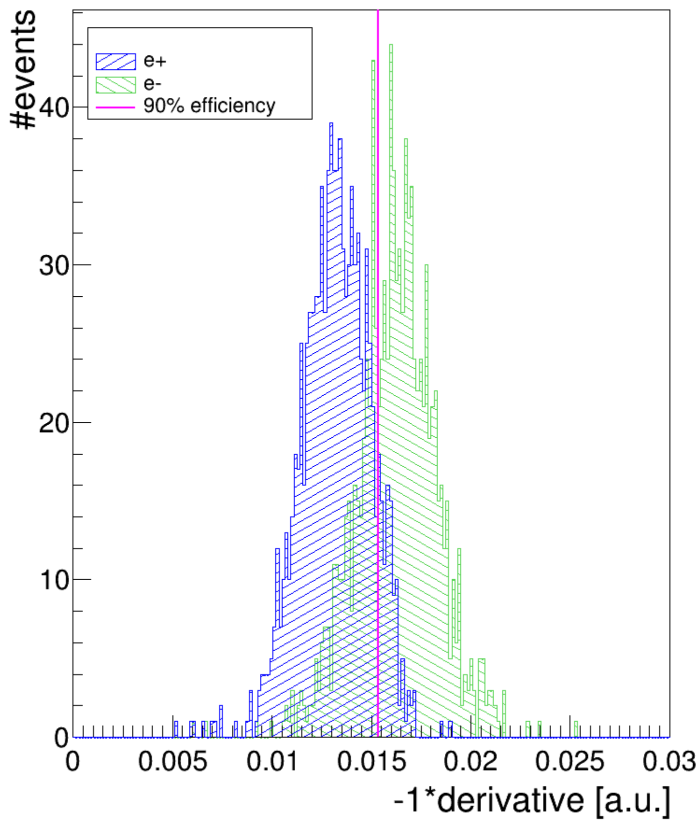


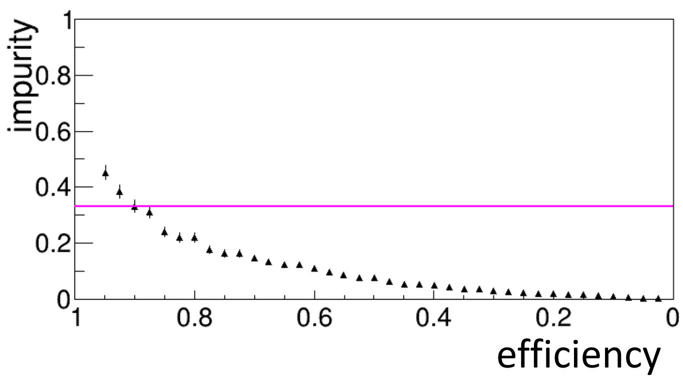
$$D(r) = \frac{C(R + 25\text{cm}) - C(R)}{25\text{cm}}$$

- determine maximum voxel V_{max}
- plot **average voxel content** *C* over radius *R* around V_{max}
- build **derivative** *D* (25 cm binning)

→ expect *C*(*R*) to decrease faster for electrons than for positrons

e^+/e^- Discrimination





Cut Performance

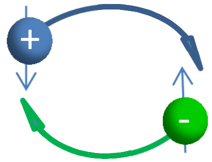
- simulation of each 1000 positron and electron events (*Geant4*)
- energy:
  $E_{e+} = 2.6\ \text{MeV}, \quad E_{e-} = E_{e+} + 2 \cdot 511\ \text{keV}$
- position: (0,0,10) m from JUNO center
- direction: random
- assumed vertex uncertainty: 10 cm in *x*, *y*, *z*
- topological reconstruction and determination of derivative

→ plot with two populations, just as expected!

→ distributions show some overlap

… can we do better?

Considering
Positronium Lifetime



- before annihilation, e^+ and e^- generally build positronium
- two possible spin states:
    - singlet: **para-positronium** (p-Ps), lifetime $\tau_{pPs}{\sim}100$ ps
    - triplet: **ortho-positronium** (o-Ps), lifetime $\tau_{oPs}{\sim}140$ ns (in vacuum)
- spin flips cause o-PS lifetime to shorten
- effective τ_{oPs} in liquid scintillator from measurements:
    - τ_{oPs}= (2.97 $\pm$ 0.04) ns, ratio > 48%

- not considered in official *Geant4* simulation for JUNO detector
- **Delayed photons should blur out reconstruction result even more!**

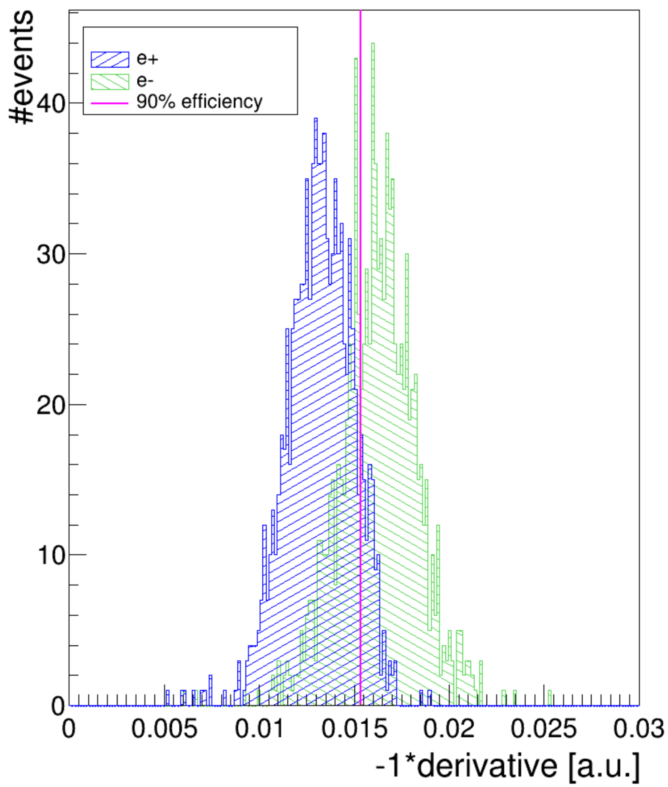
→ for given ratio of e+ events, introduce **artificial PE delay** w.r.t. τ_{oPs}

(only for 511keV-daughters)

→ *T 9.1 "First Measurements of Lifetime and Formation Probablility of Orthopositronium in the LAB Based Scintillator of JUNO" by M. Schwarz*

e^+/e^- Discrimination

w/o ortho positronium



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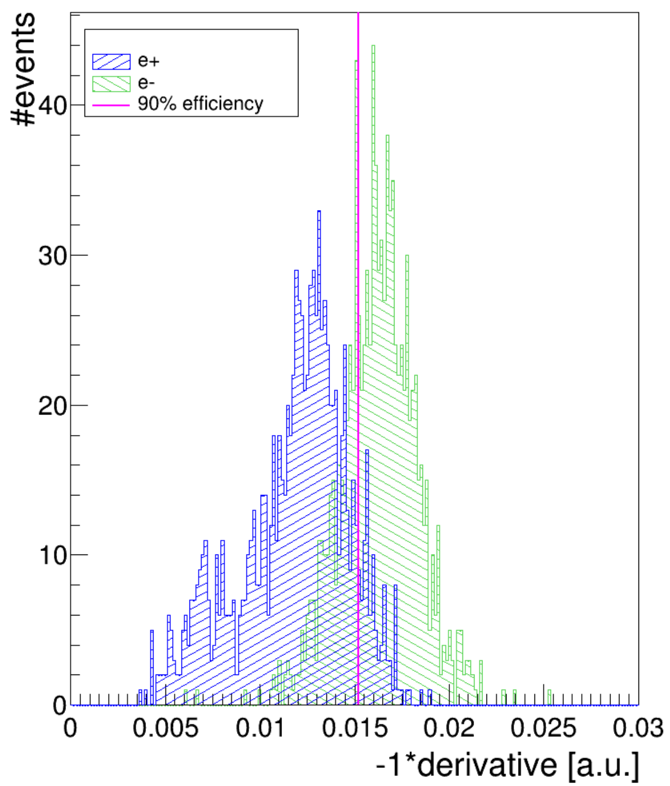
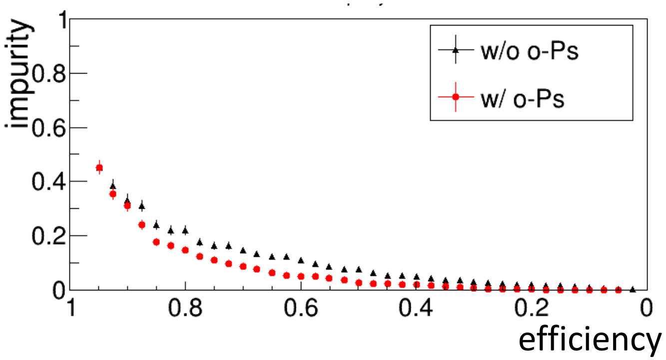


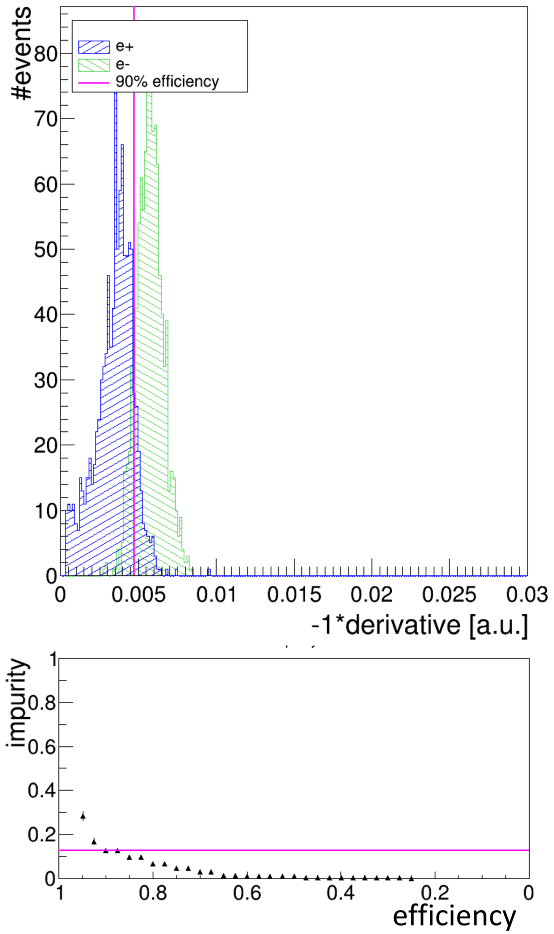


- realistic treatment of o-Ps favors e^+/e^- discrimination
- high signal to noise ratio towards low efficiencies

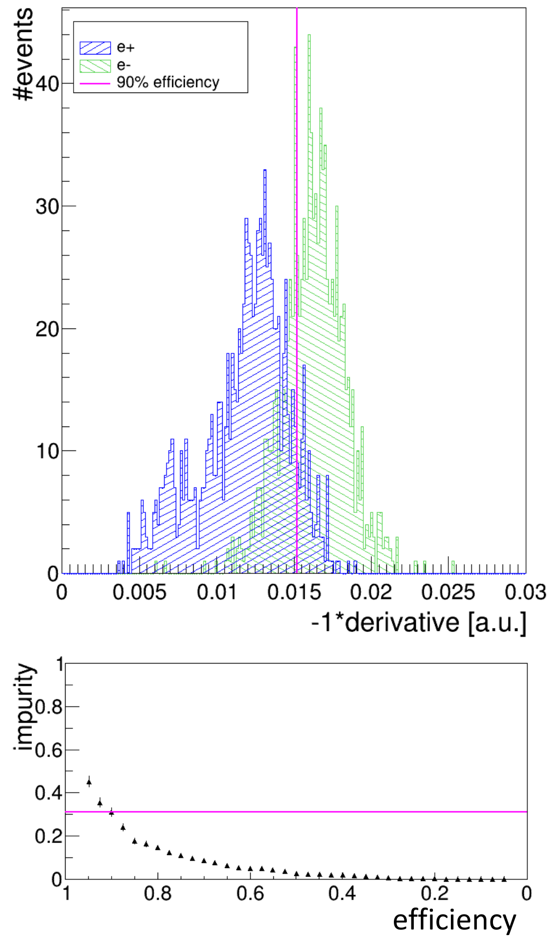
Comparing Different Energies

- cut performance improves strongly towards lower energies
- discrimination potential fades beyond 7.5 MeV

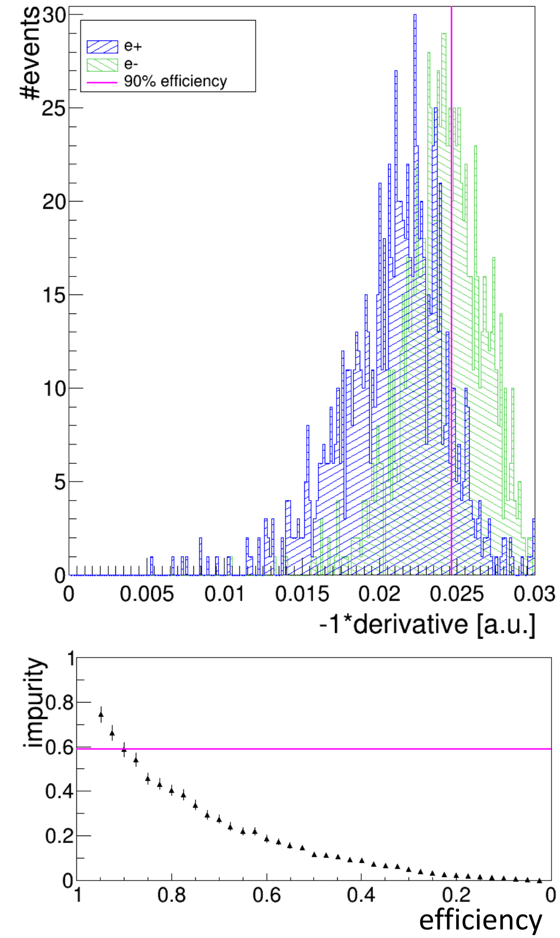
$E_{e+} = 1.0\ \mathrm{MeV}$



$E_{e+} = 2.6\ \mathrm{MeV}$



$E_{e+} = 7.5\ \mathrm{MeV}$



Summary

- **topological 'track' reconstruction** used on LE events in JUNO
- **e^+/e^- discrimination** based on contrast in topology
- feasibility successfully demonstrated

→ full potential yet to be determined

Outlook

- short term:
  - detailed analysis of position and energy dependencies
  - use of **multivariate methods** (TMVA)
  - perform cut on **e-/γ samples**
- mid term:
  - compare closely to alternative discrimination techniques, investigate possible gain by combination

→ AKPIK 1.7 "e + /e - Discrimination with Deep Learning Method" by Y. Xu
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Thank you for your attention!

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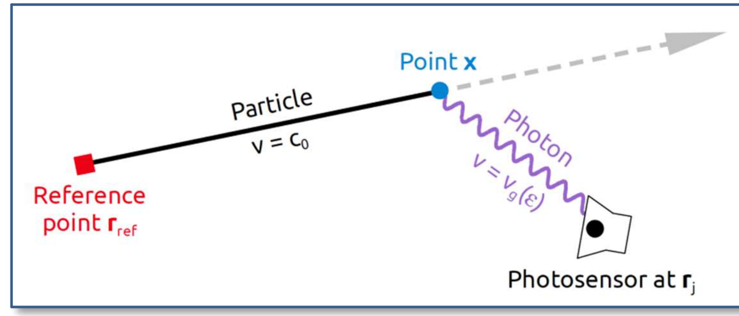
How to reconstruct a track

Assume simple model:

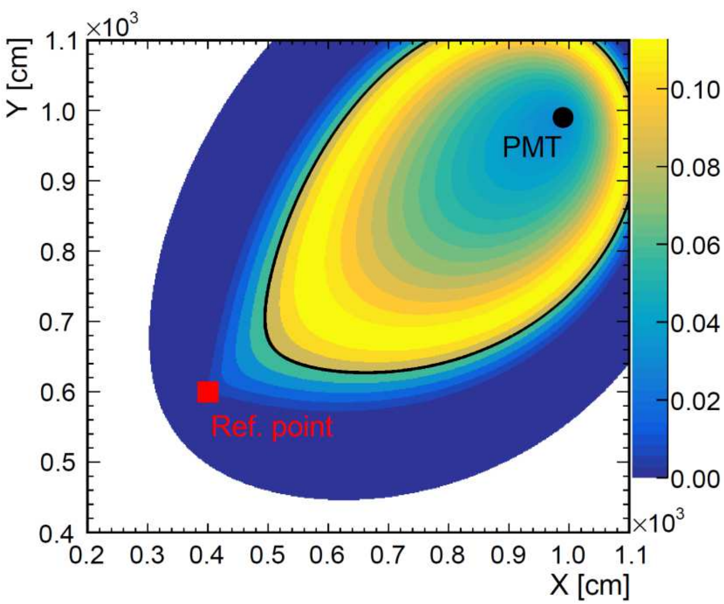
- clearly defined **reference point** and **time**
- p.d.f. for timing uncertainty and scintillation process

→ spatial p.d.f. for emission point



[1]

$$t(\mathbf{x}) = t_{\mathrm{ref}} \pm \underbrace{\frac{|\mathbf{x} - \mathbf{r}_{\mathrm{ref}}|}{c_0}}_{\text{particle}} + \underbrace{\frac{|\mathbf{r}_j - \mathbf{x}|}{v_g(\epsilon)}}_{\text{photon}}$$



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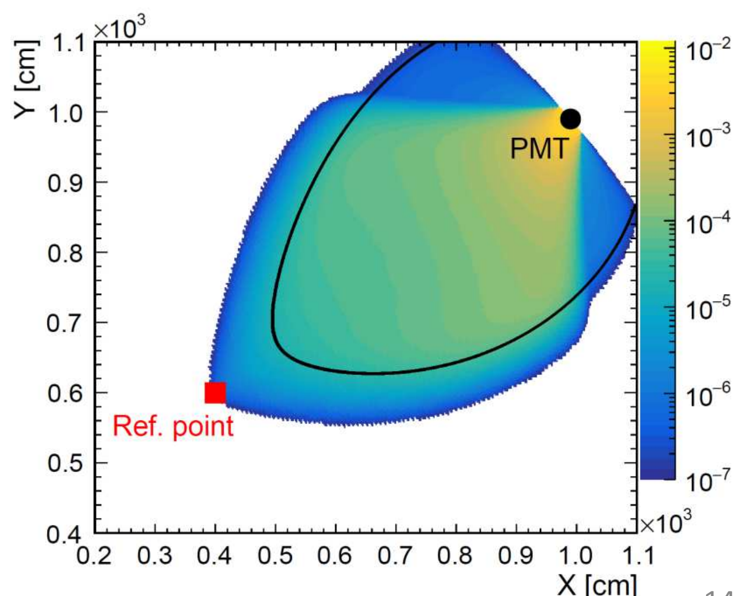


[1]

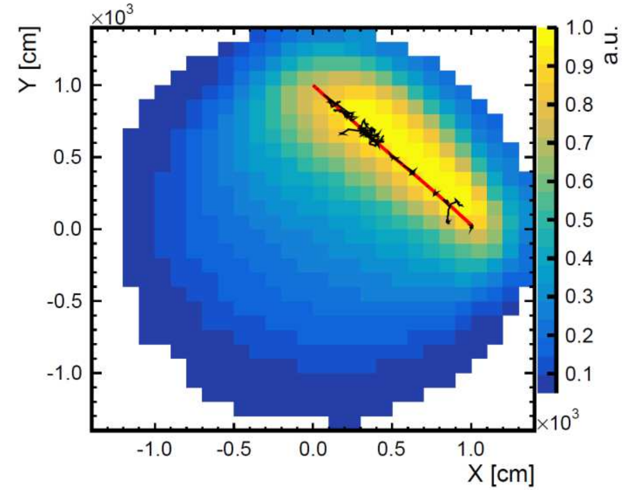
Backup

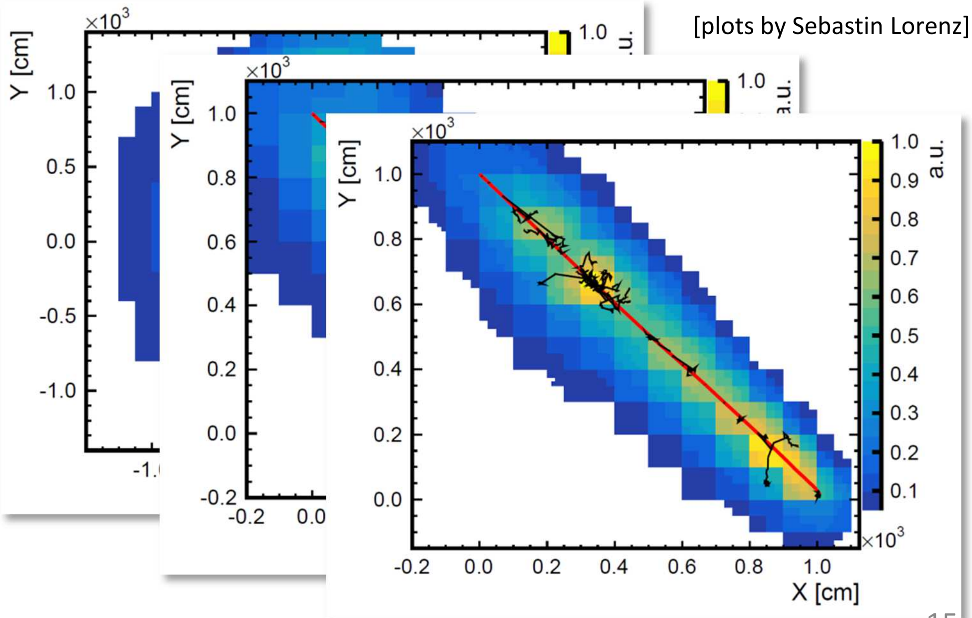
put together **all hits** from **all PMTs**

→ get number density distribution of photon emissions

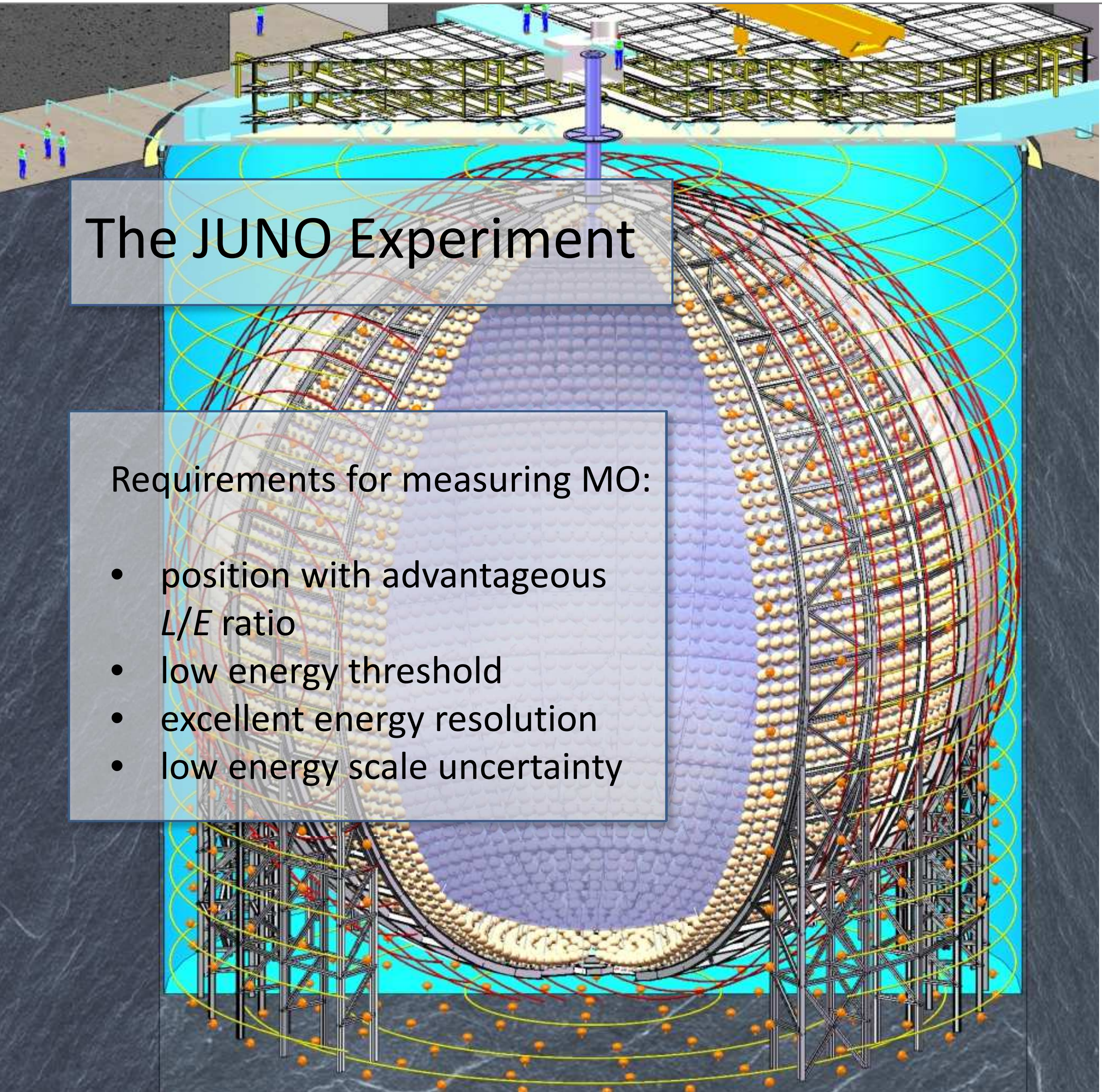
so far: PMT information used independently
but: emissions are correlated!

→ use result as prior information for iterative process





[plots by Sebastin Lorenz]



The JUNO Experiment

Requirements for measuring MO:

- position with advantageous L/E ratio
- low energy threshold
- excellent energy resolution
- low energy scale uncertainty

- ~53 km distance to two nuclear power plants (35.8 GW P_{th})
- 20 kt liquid scintillator
- acrylic tank: Ø 35.4 m (PMT sphere: Ø 40.1 m)
- ~18,000 20” PMTs, ~25,000 3” PMTs
  → 77% coverage
- $QE \approx 30\%$
- coils to shield EMF

→ $\Delta E/E = 3\%/\sqrt{E(\mathrm{MeV})}$

- energy scale uncertainty < 1%