Topological Track Reconstruction:
Adaptation to JUNO and Latest Studies

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on behalf of

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The Topological Reconstruction was developed for LENA.
But: The principle is adaptable to **any** large volume LSc detector.
→ Use it for JUNO!

Adaptation of Reconstruction to JUNO

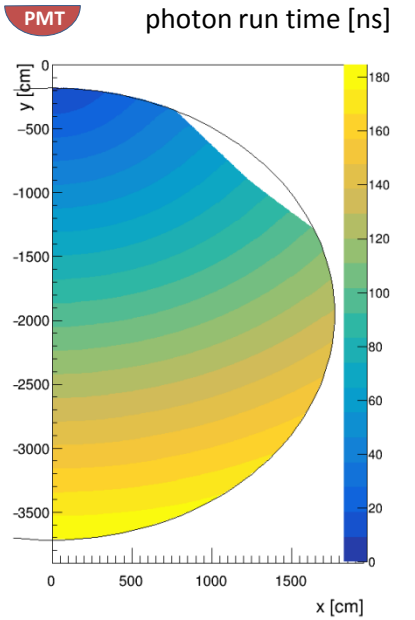
- adapt software framework: JUNO geometry, PMT positions, PMT types, …

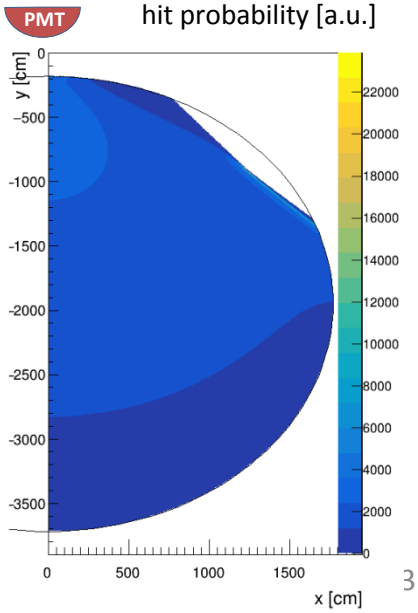
- pre-computation of **look-up tables** for spatial distriution of
  - photon run times
  - hit probability

  → consider **refraction** at acrylic sphere (tricky!)
  - extension of optical model: take into account wavelength dependence of optical parameters

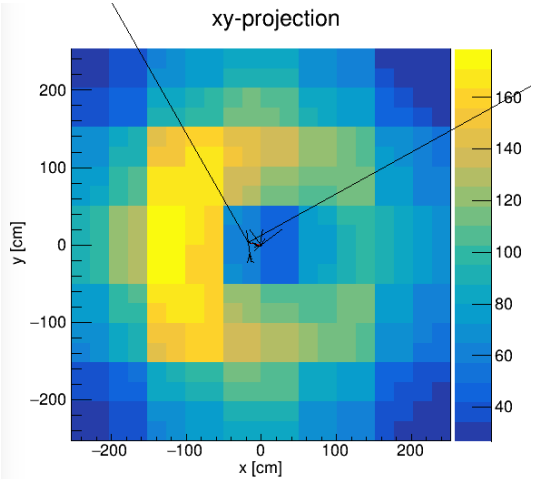
- **interfacing** between output from JUNO MC and topological reconstruction framework, adaptations in MC-output

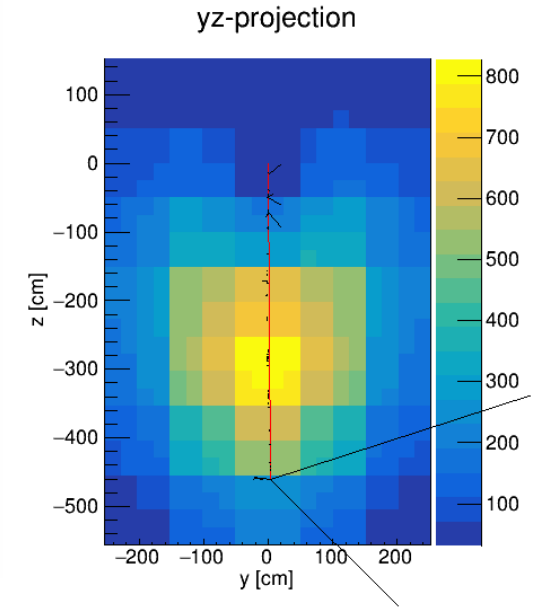
Software now ready to use for JUNO!





(pre-) Preliminary Results





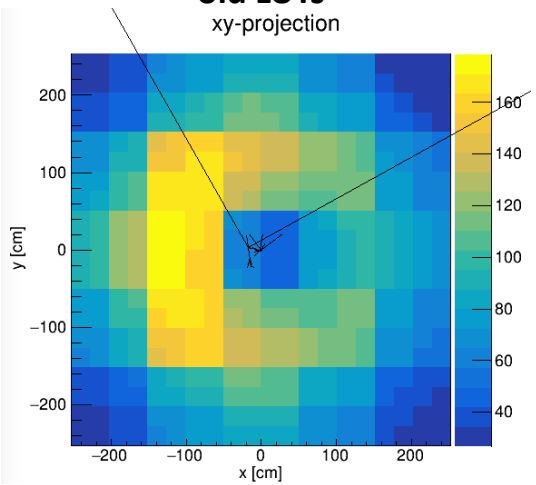
central event:
- 3 GeV muon
- starting from (0,0,0) cm
- 21 iterations
- 12.5 cm binning

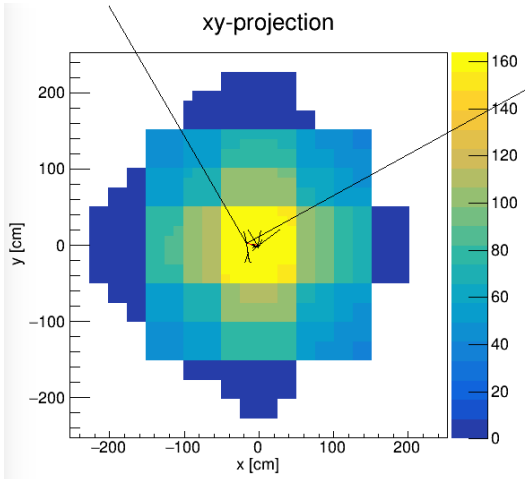
- observed strange patterns and shifts

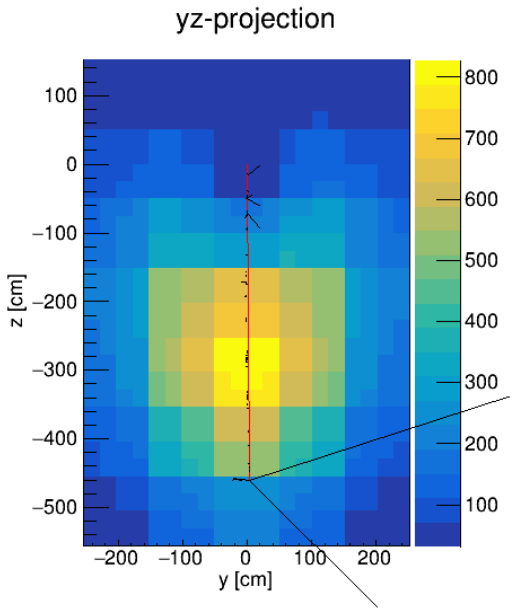
→ faulty photon run times. Offline simulation uses group velocity!

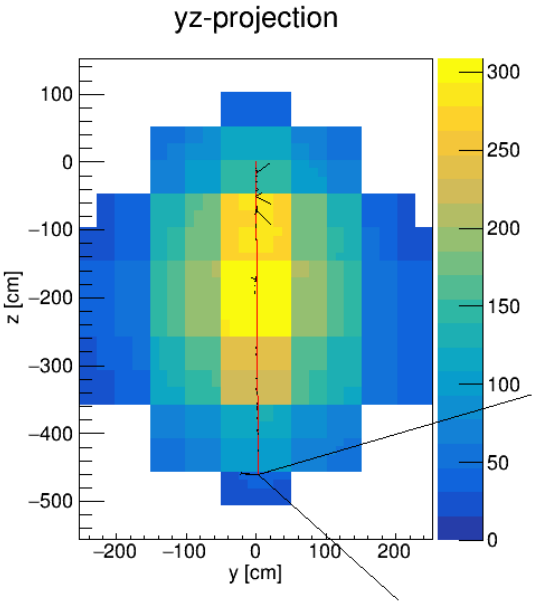
(pre-) Preliminary Results

old LUTs







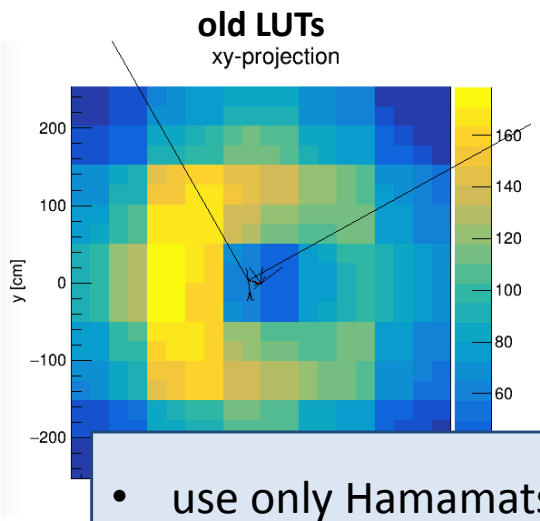


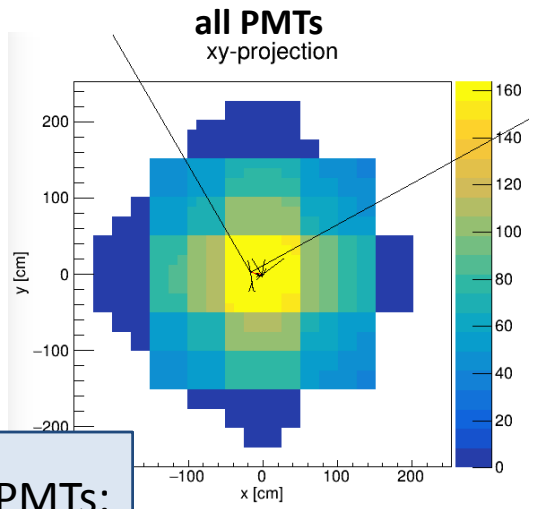
central event:
- 3 GeV muon
- starting from (0,0,0) cm
- 21 iterations
- 12.5 cm binning

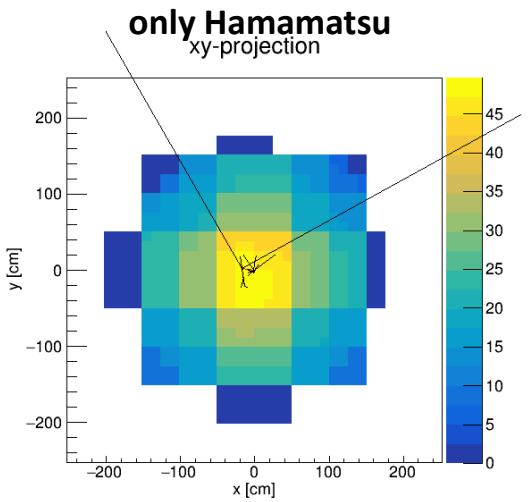
- with correct LUT's:

→ Track is reconstructed much better!

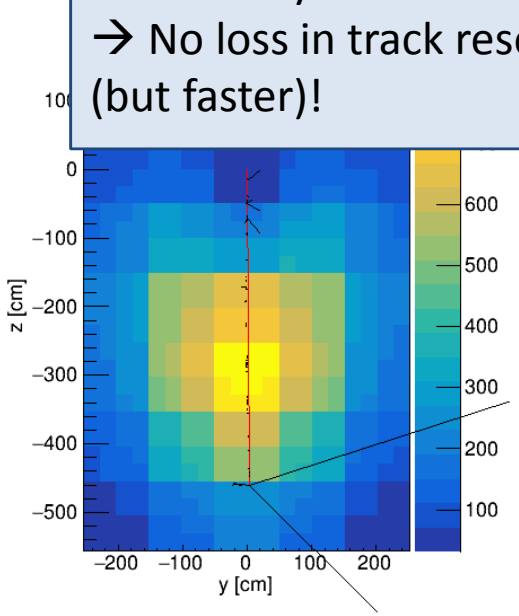
(pre-) Preliminary Results

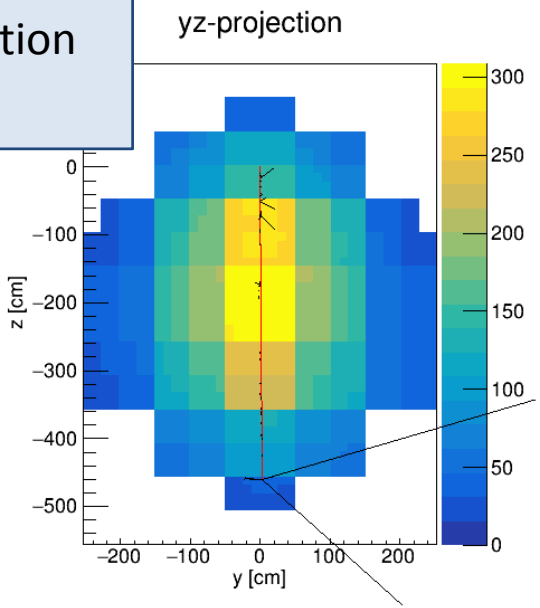


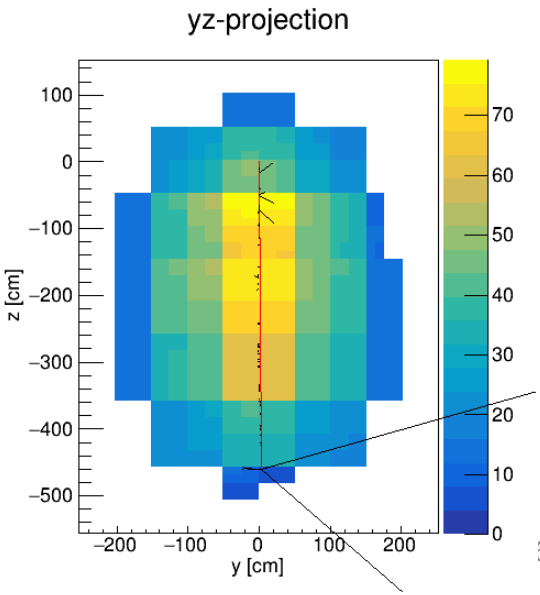




- use only Hamamatsu PMTs:
→ No loss in track resolution (but faster)!

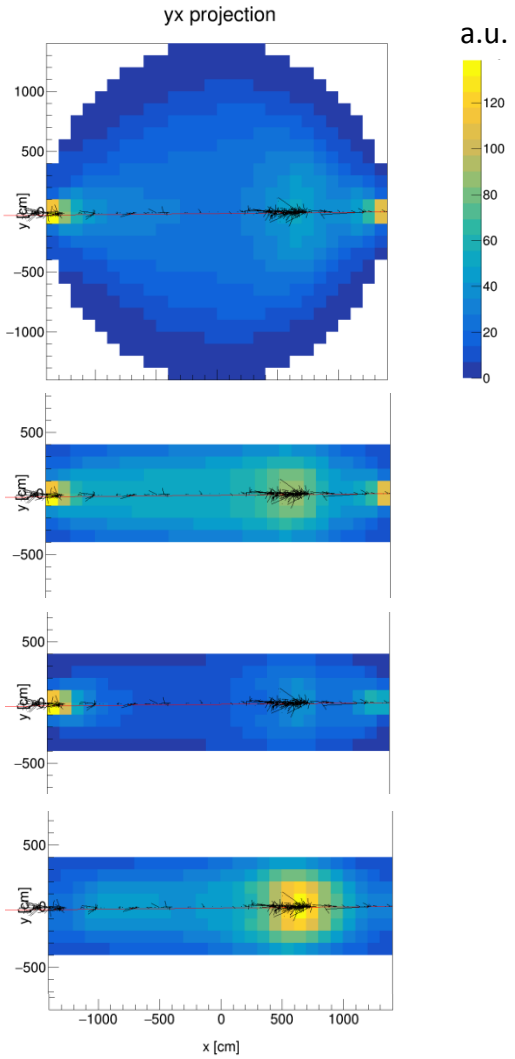






Improving the Algorithm (LENA framework)

LENA event:
- 20 GeV muon
- horizontally crossing the detector
- 1 iteration
- 100 cm binning

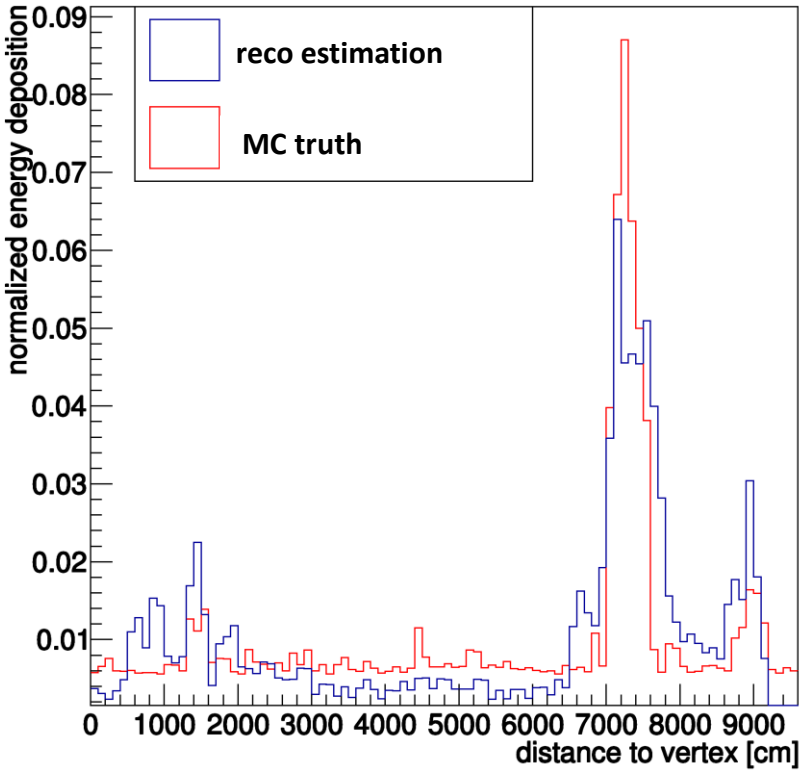


- external knowledge on the event allows to **confine the probability mask**
  → save computation time
- **optical scattering** can be treated statistically
  → better localize the event
- **exclude PMTs** near entry and exit point
  → remove artifacts

[work by Felix Benckwitz]

Algorithm Improvements

- binwise **projection of d*E*/d*x*** onto the track
- comparison to MC truth shows that d*E*/d*x* is reproduced well
- features like **hadron showers** become visible
- not studied quantitatively yet

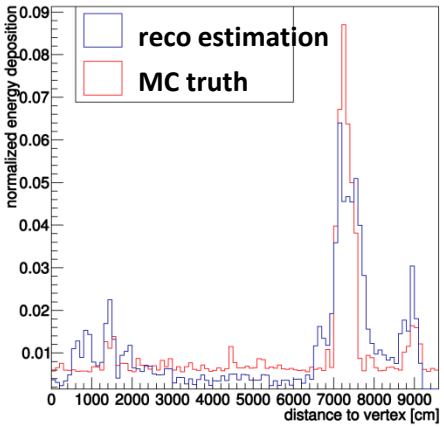


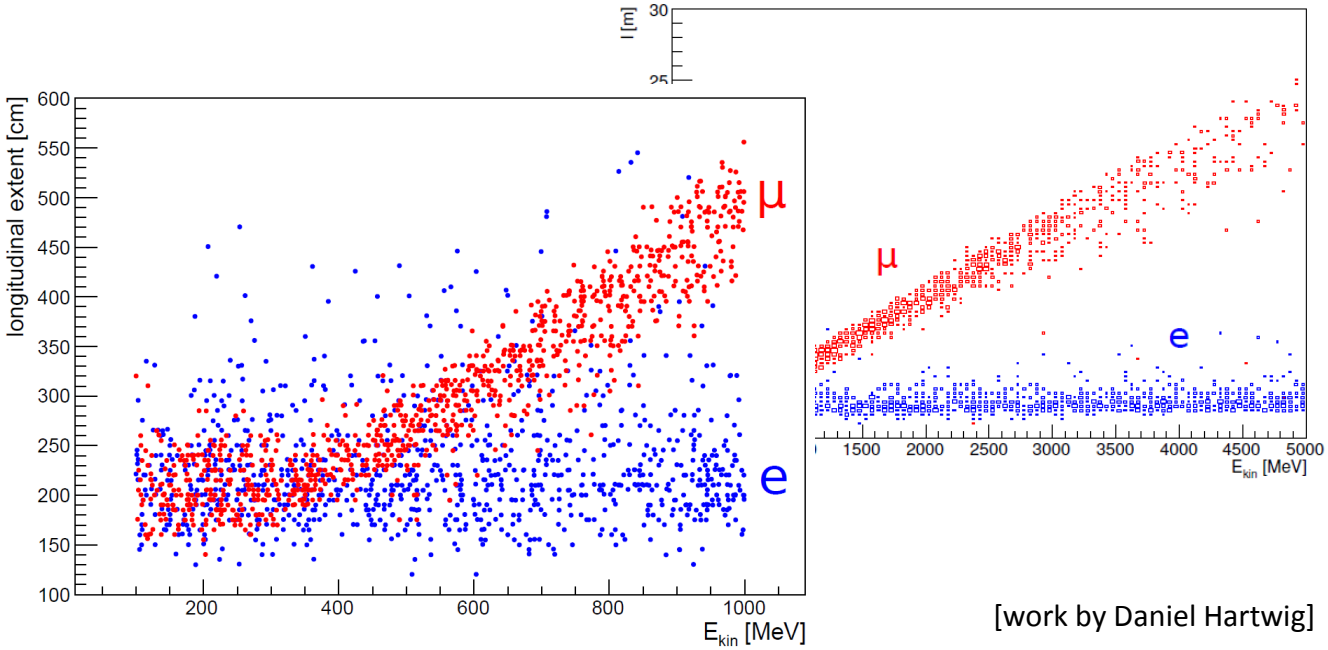
[work by Felix Benckwitz]

e/μ-Discrimination

- compare longitudinal extend (**'track length'**) of electrons and muons

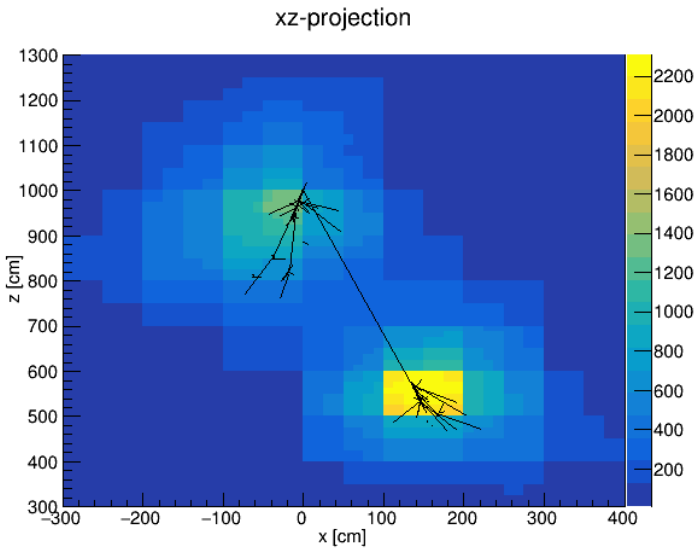
→ very clean discrimination above 1 GeV
→ effective down to 500 MeV





[work by Daniel Hartwig]

e^-/π^0-Discrimination



Reconstruction of a 500 MeV π^0 starting from (0,0,1000) (LENA)

- current study to discriminate **e^-/π^0**
- development of discrimination parameters:
  - features in **d*E*/d*x*** projection
  - **track length**
  - asymmetry in **lateral distribution**
- some encouraging first results (see picture), but still challenging task
- quantitative study ongoing

[work by Katharina Voss]

Summary and Outlook

- **migration to JUNO** complete!
  → more validation required
- use in other experiments in progress: **Borexino** [B. Opitz] and **THEIA** [B. Wonsak]
- JUNO: 5-10% of light from **Cherenkov** rather than scintillation:
  → expect improvement if separation could be done in future
- ongoing studies investigating potential of **particle discrimination**:
  - e/μ
  - e^-/π^0
- work on statistical treatment of scattering
- my work: concentration on **low energies (MeV)**, investigate e^+/γ, e^+/e^-

Staff (JUNO)

Björn Wonsak Sebastian Lorenz	Postdoc
David Meyhöfer Henning Rebber	PhD students
Felix Benckwitz Katharina Voss	Bachelor students / student assistants

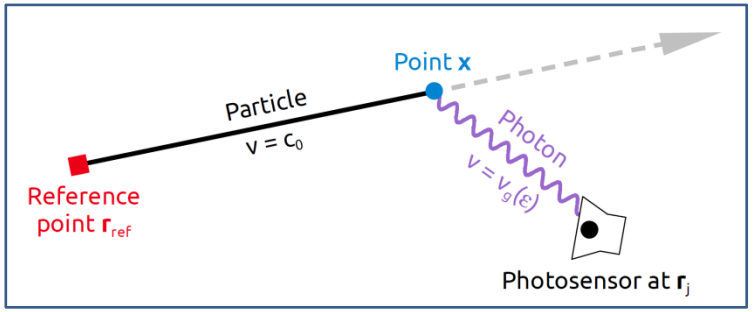
Thank you for your attention!

How to reconstruct a track

Assume simple model:

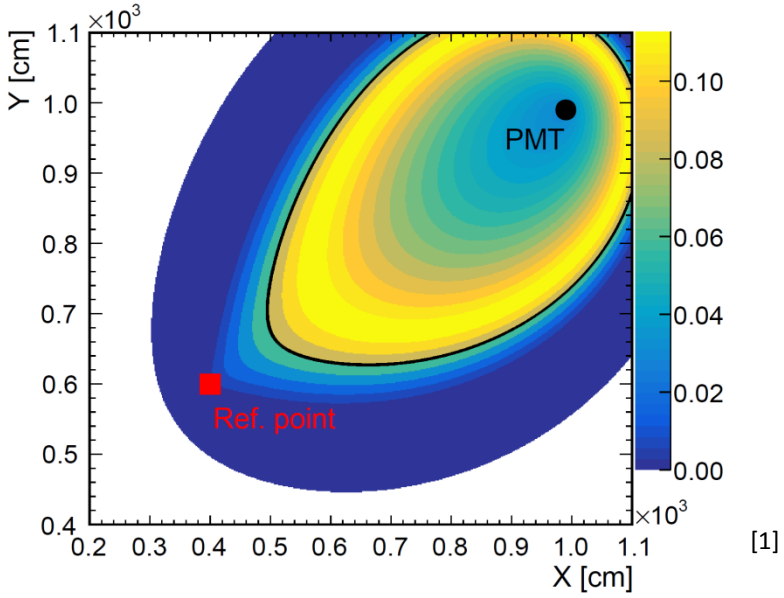
- clearly defined **reference point** and **time**
- p.d.f. for timing uncertainty and scintillation process

→ spatial p.d.f. for emission point



[1]

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



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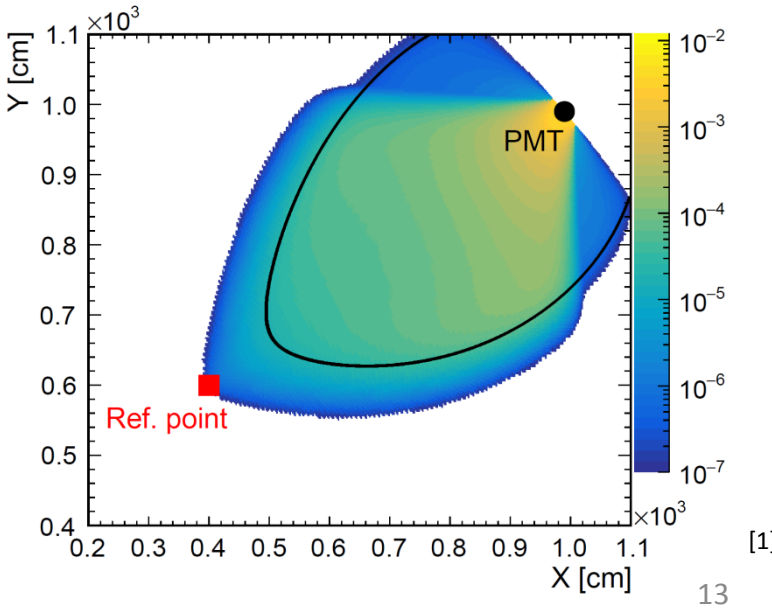


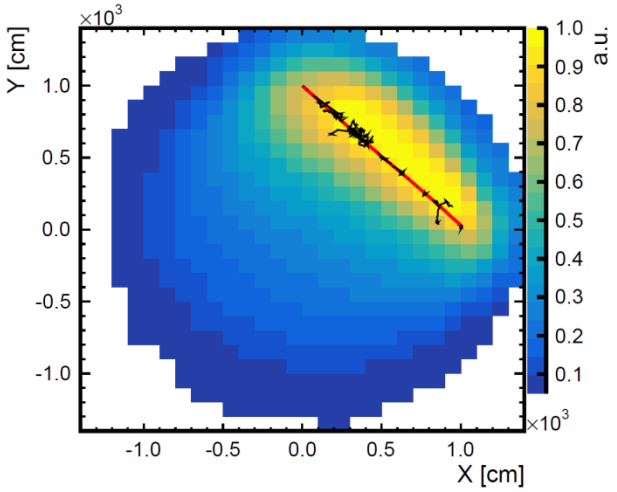
[1]

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]