Update on 3d-topological reconstruction

Presented by

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on behalf of

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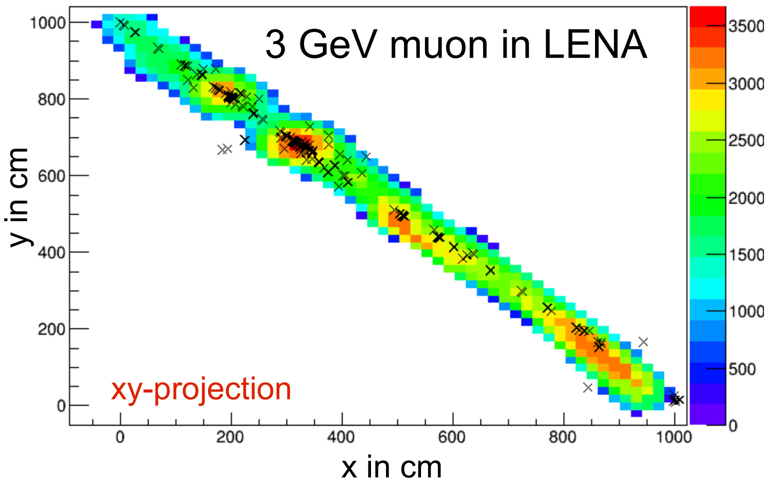
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

PRISMA Cluster of Excellence

- **Short overview**
- **Some new details** (preliminary results)
- **Separation of Cherenkov light**
- **Other relevant points**

WonsakReco: Overview

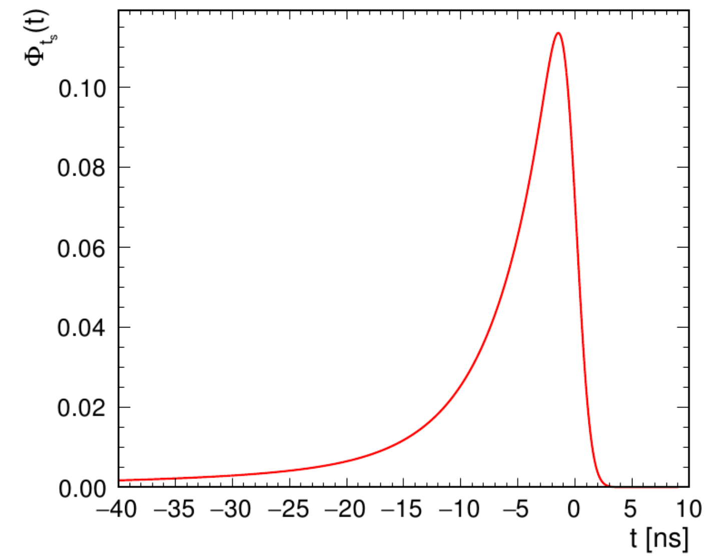
- 3D toplogical reconstruction
  → Spatial distribution of emission density
- Using full time information
- Iterative process
  - Using a probability mask (PM)
  - Usually result of previous iteration
- Operating on a grid → bin size is important
- Only assumptions:
  - One known reference point (in space and time)
  - Single photon hit times available



- **Potential at high (GeV) and low (MeV) energies**

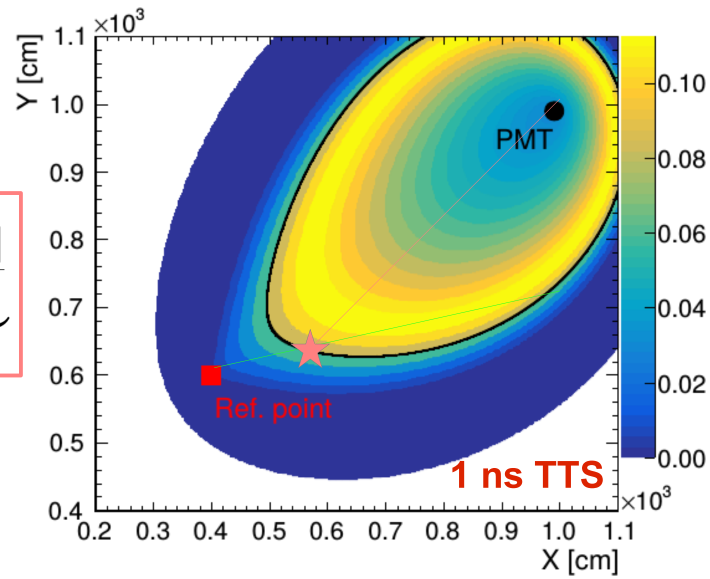
Working Principle

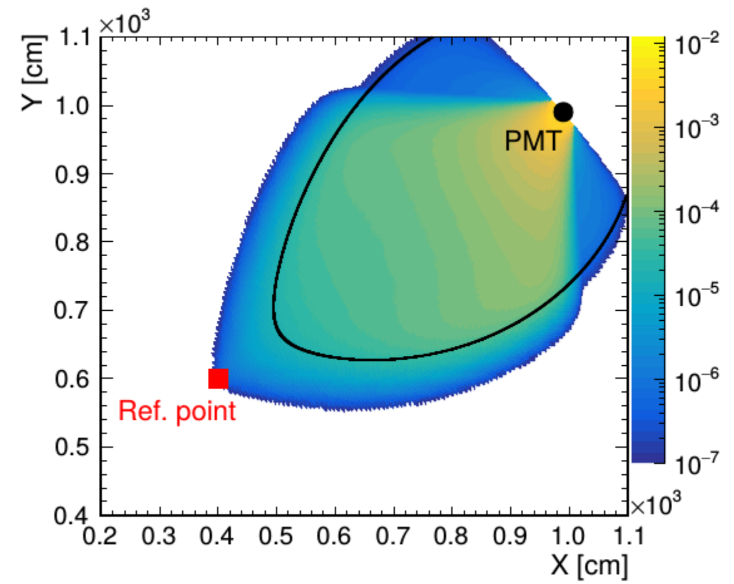
- For each signal:
  - Time defines drop-like surface
  - Gets smeared with time profile
    (scintillation & PMT-timing)
  - Weighted due to spatial constraints
    (acceptance, optical properties, light concentrator, …)



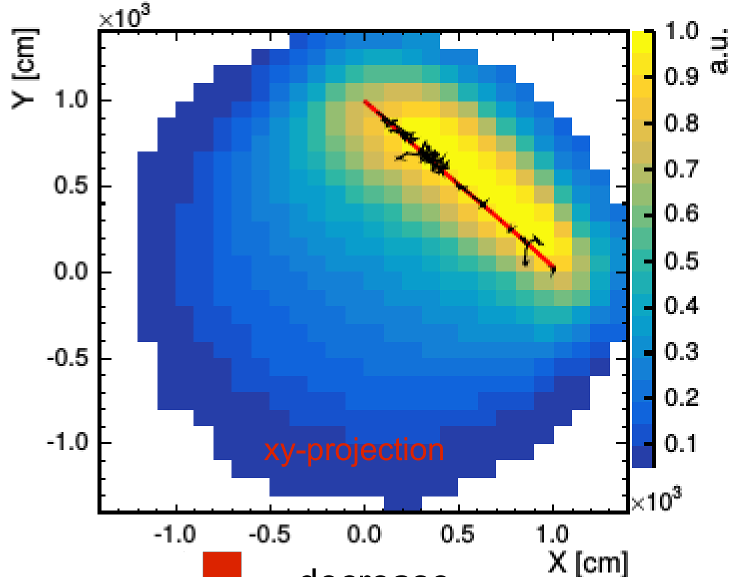
- → spatial p.d.f. for photon emission points

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





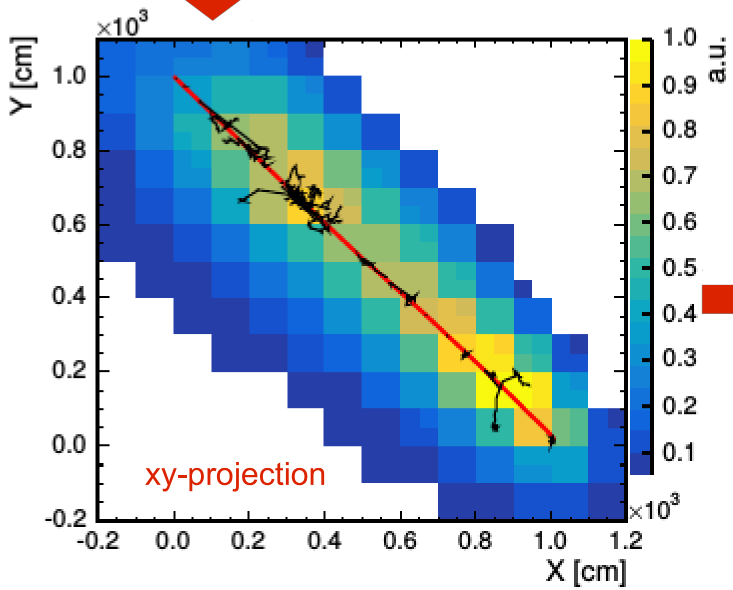
Working Principle II



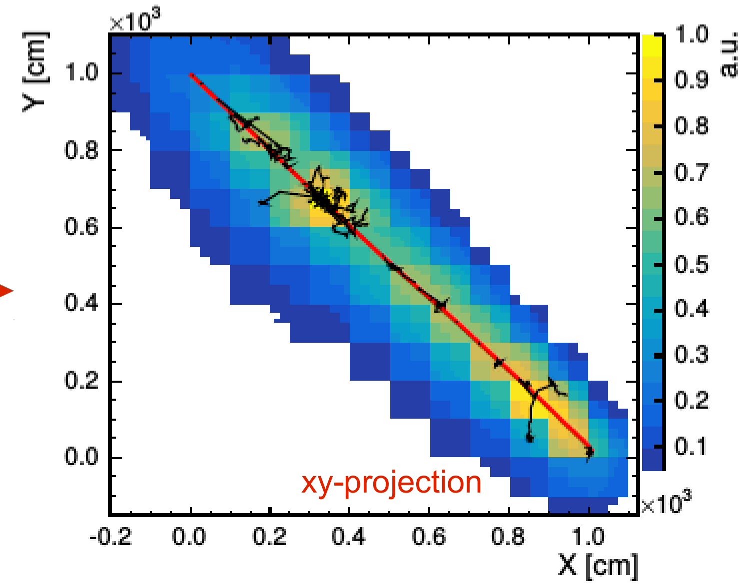
- Add up all signals
- Divide result by local detection efficiency
  → Number density of emitted photons
- Use knowledge that all signals belong to same topology to 'connect' their information
  → Use prior results to re-evaluate p.d.f. of each signal

That is what I call probability mask (PM)

decrease cell size



decrease cell size

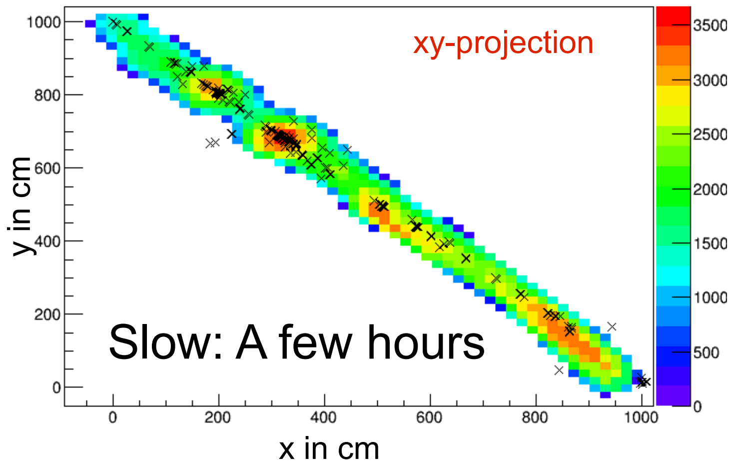


dE/dx accessible

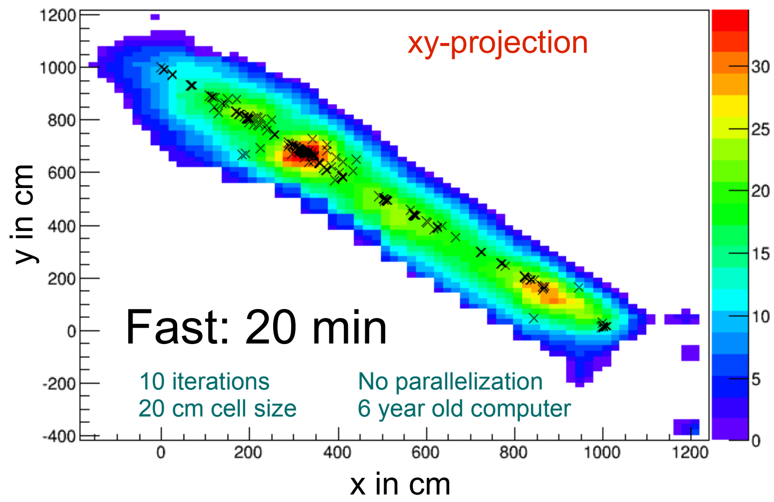
Computing Time

- **Full fine grained reconstruction is very time consuming**

  (21 iterations, 12.5 cm binning → a few hours for a few GeV muon in LENA)
- **However:**
  - Easy to implement parallel computing techinques (already some success)
  - Reconstruction strategy can be adapted with a configuration file
  - Can use prior track information
  - Already the first iteration with coarse grains includes a lot of information
- **→ Need to find balance for a given question**
  - Cell Size, number of iterations and number of PMTs used



GPU could help a lot !



Looking for Shower in Cosmic Events I

- **Motivation:**
  - Reduce veto volume for cosmogenics
  - Important for large detctors with shallow overburden

- **Difficulties:**
  - Reconstruction time very long

- **Solution:**
  - Use information from fast reconstructions
    → Generate probability mask
    → **Danger:** Introduces additional error sources

Looking for Shower in Cosmic Events II

- **Two sources for lack of robustness**
  - Scattered light that is wrongly attributed
  - Influence of binning in the near field region

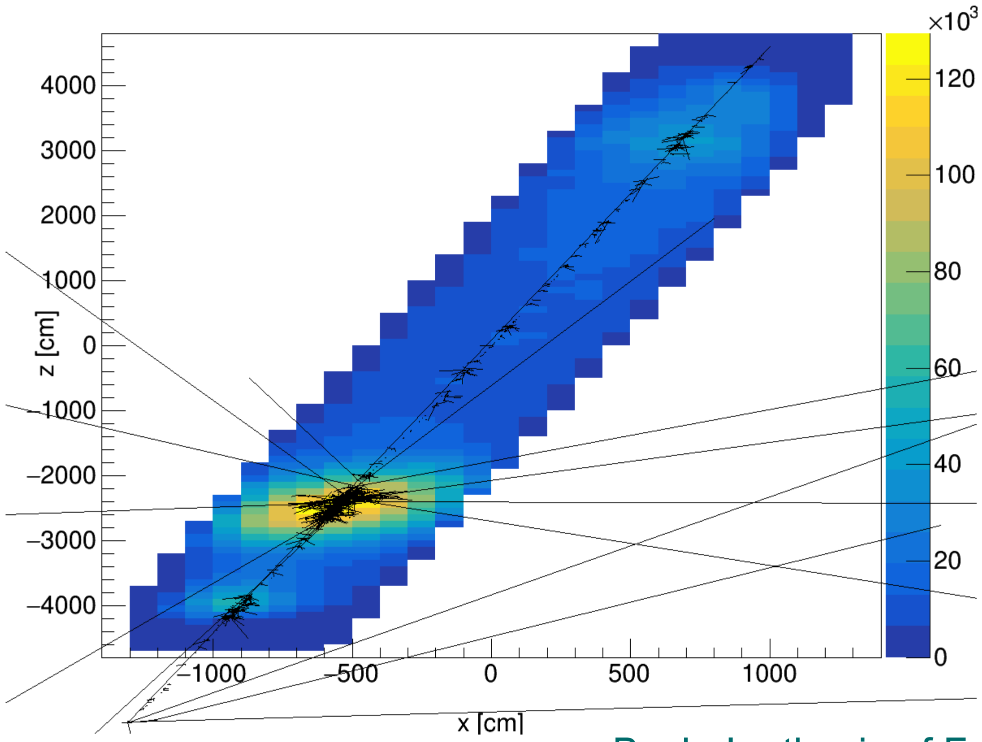
    (large bins are dangerous in general)

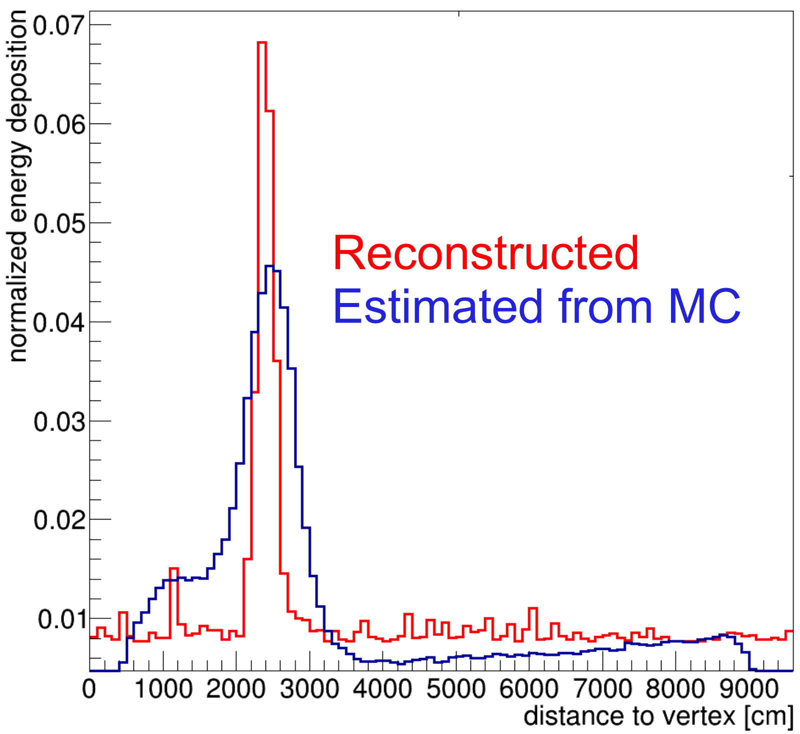
- **Solution for robustness:**
  - Eliminate scattered light based on probability mask

    (each signal gets a probability for beeing scattered)
  - Obmit PMTs that are to close to event topology

Looking for Shower in Cosmic Events III

- **Result:**
  - 40 GeV muon crossing the whole detector
  - With hadronic shower
  - 1 Iteration only → much faster reconstruction





Bachelor thesis of Felix Benckwitz

Vertex Reconstruction

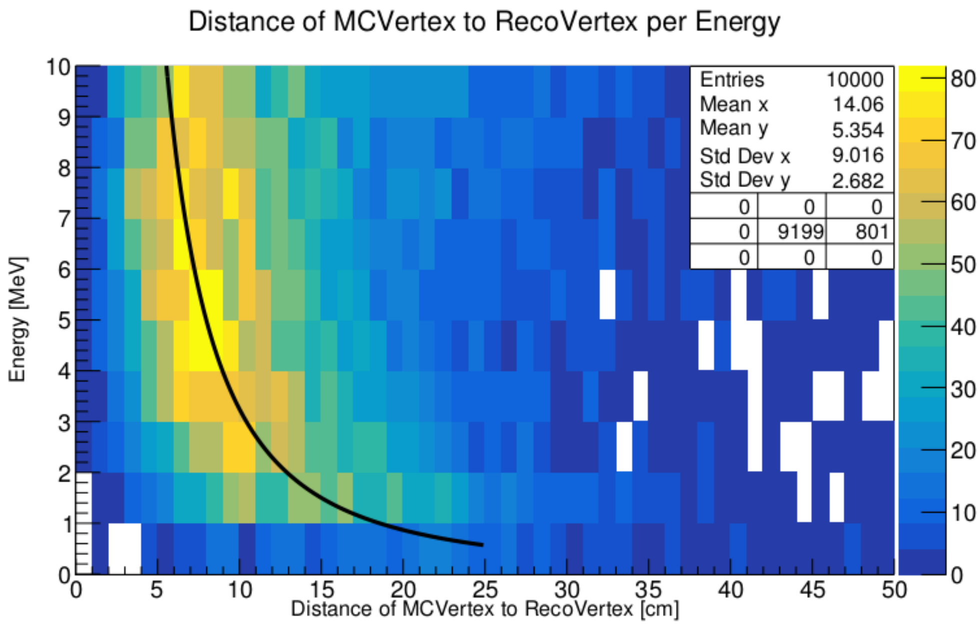
- Use backtracking-like algorithm to find primary vertex

  (i.e. signals matching in time corresponding to position)

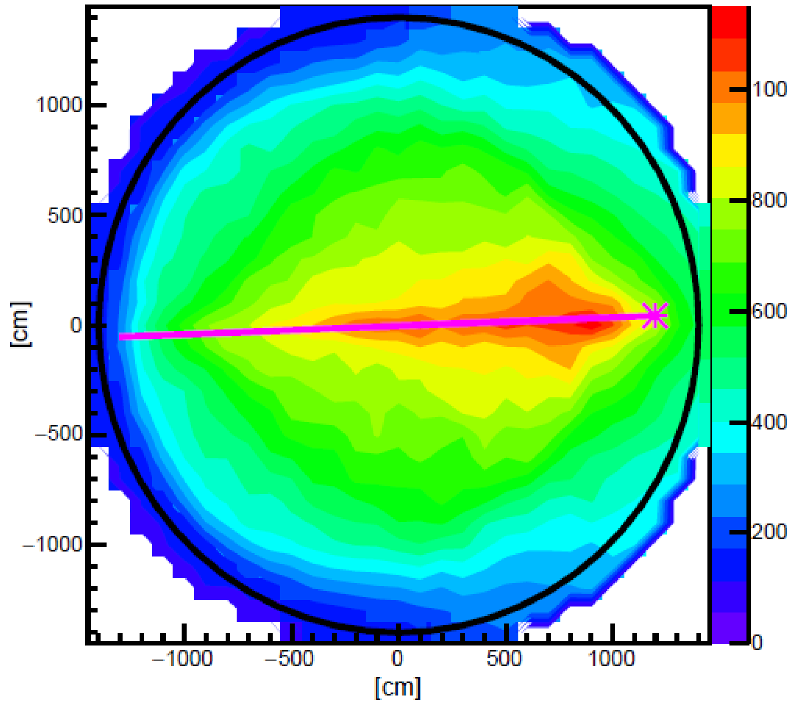
- Results for low energies already within expectations
- For high energy: Average distance to track 30 cm

  → Room for improvement

  (likelyhoods methods in LENA yielded <10 cm vertex resolution)



XY-projection

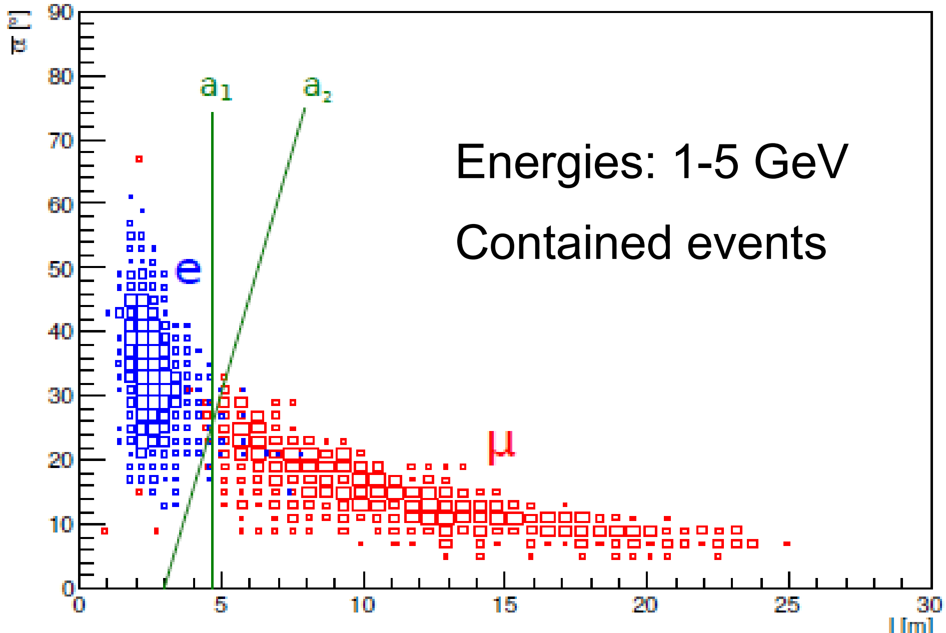


Master thesis of David Meyhöfer

Electron/Muon Separation

- **Used two parameters:**
  - Length of track
  - Angular width of track
    (with respect to reference point)

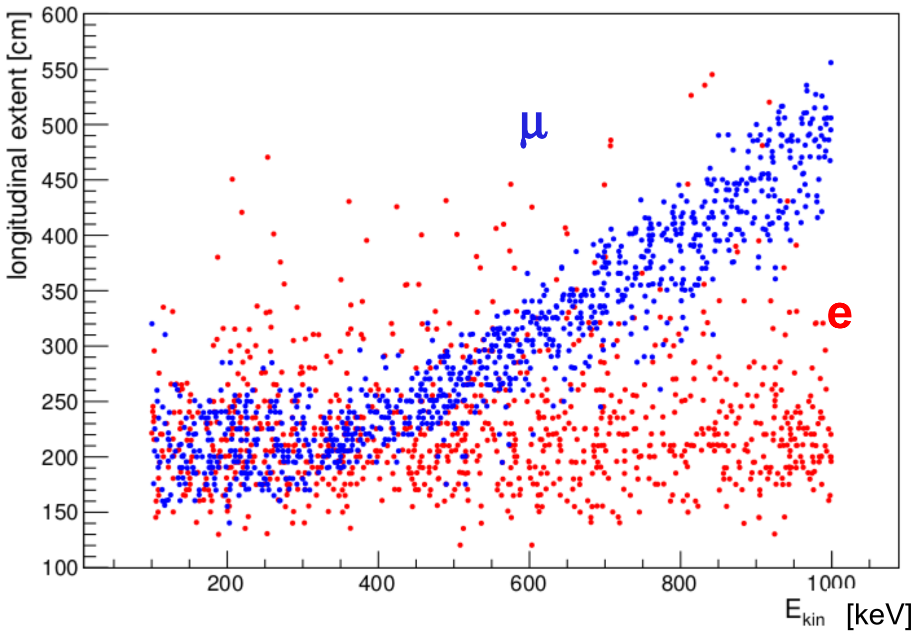
- **Result:** 1.5% impurity, 98% efficiency

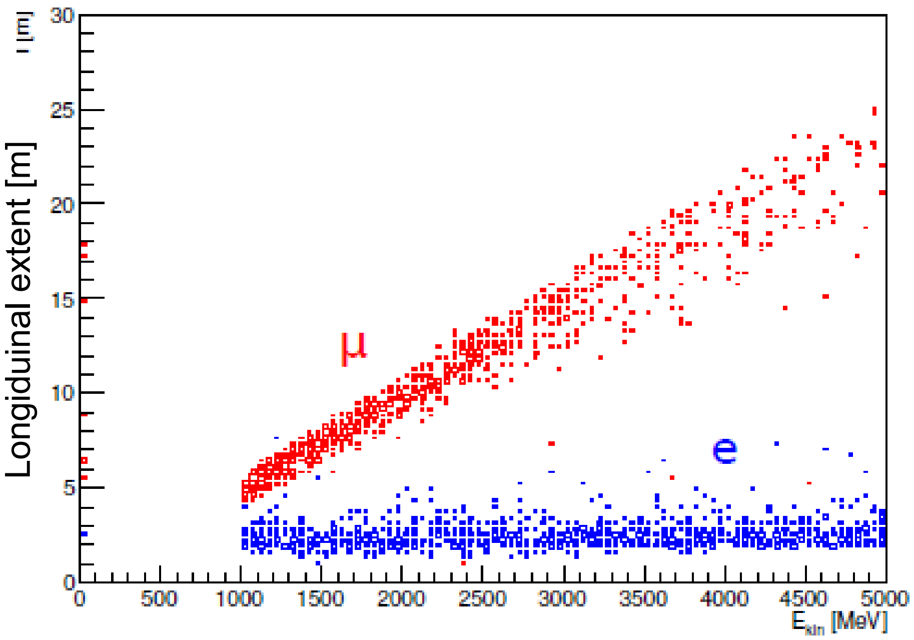


Bachelor thesis of Daniel Hartwig

Electron/Muon Separation

- **Energy dependents of separation**





Maybe other variables like dE/dx distribution could improve this
Or the clearness of Cherenkov rings!

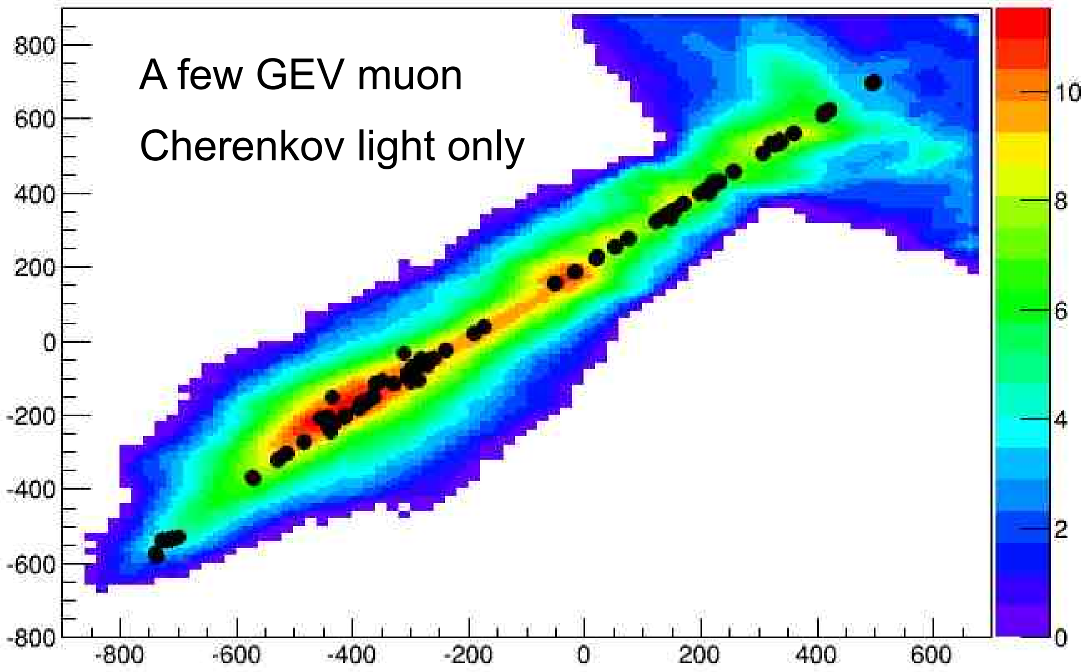
Bachelor thesis of Daniel Hartwig

Consequence of THEIA Properties

- Working well with scintillation light only or Cherenkov light only
- Dedicated reconstruction mode needed if both are present:
  - Need to asign each signal a probability to be one or the other!

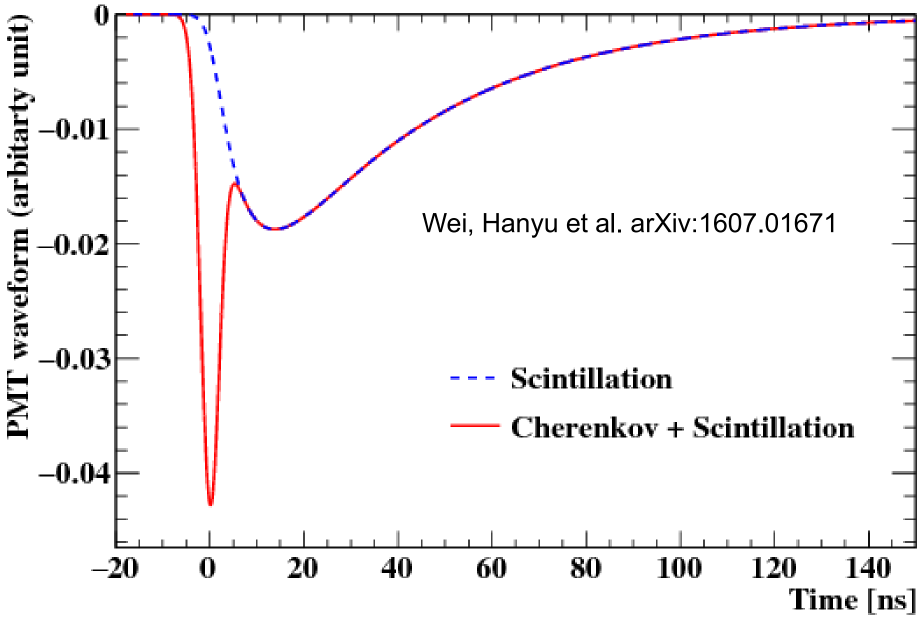
→ Separation of both light sources

This will be on of our priorities!



Cherenkov vs. Scintillation Separation

- **Critical point:**
  - Both light sources have very different timing behaviours
  - The whole reconstruction is based on good time information
  - Attributing the wrong time distribution to a signal will automattically introduce a bias



Cherenkov vs. Scintillation Separation

- **Two situations:**
  - 1) One light source is dominante
    - → Can ignore the second component as a first step
    - Then use the resulting topology to evaluate the typ of each signals (using time and angular information)
  - 2) Comparable light contributions
    - → Do two separate reconstructions
    - Combine them by normalising each signal over both grids and find persistant topological features present in both grids
    - Disadvantage: More time consuming, maybe less robust

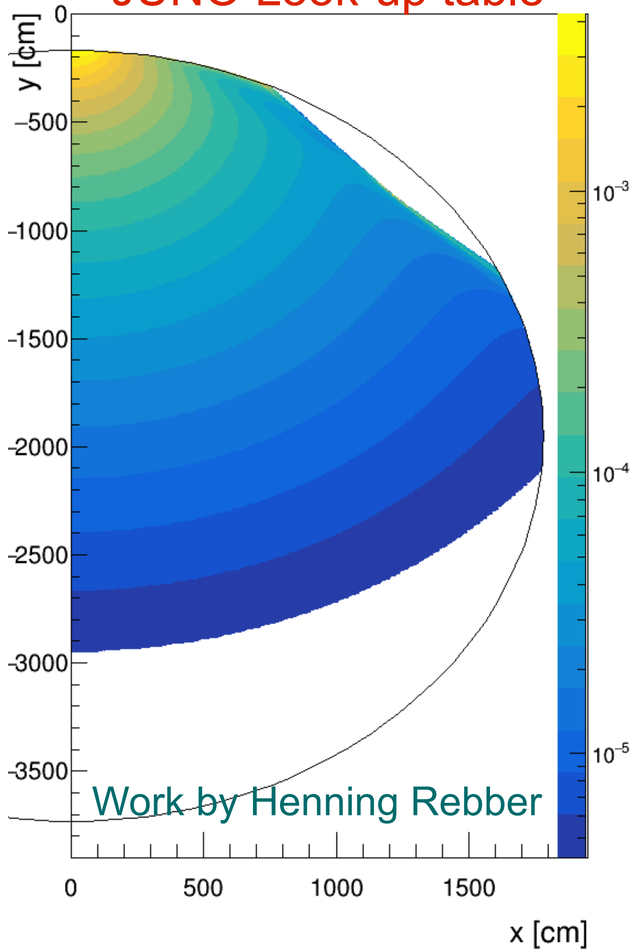
Remarks:

- In both cases the iterative structure will help
- Finally every signal gets a probability for beeing scintillation, Cherenkov or scattered

Technical Aspects of Detector Integration

- **Written as its own software package**
- **Implementation of specific detector needs:**
  - Position and orientations of light sensors
  - Basic geometry
  - Time responds of electronics and scintillator
  - Look-up tables (LUT) based on optical model

JUNO Look-up table



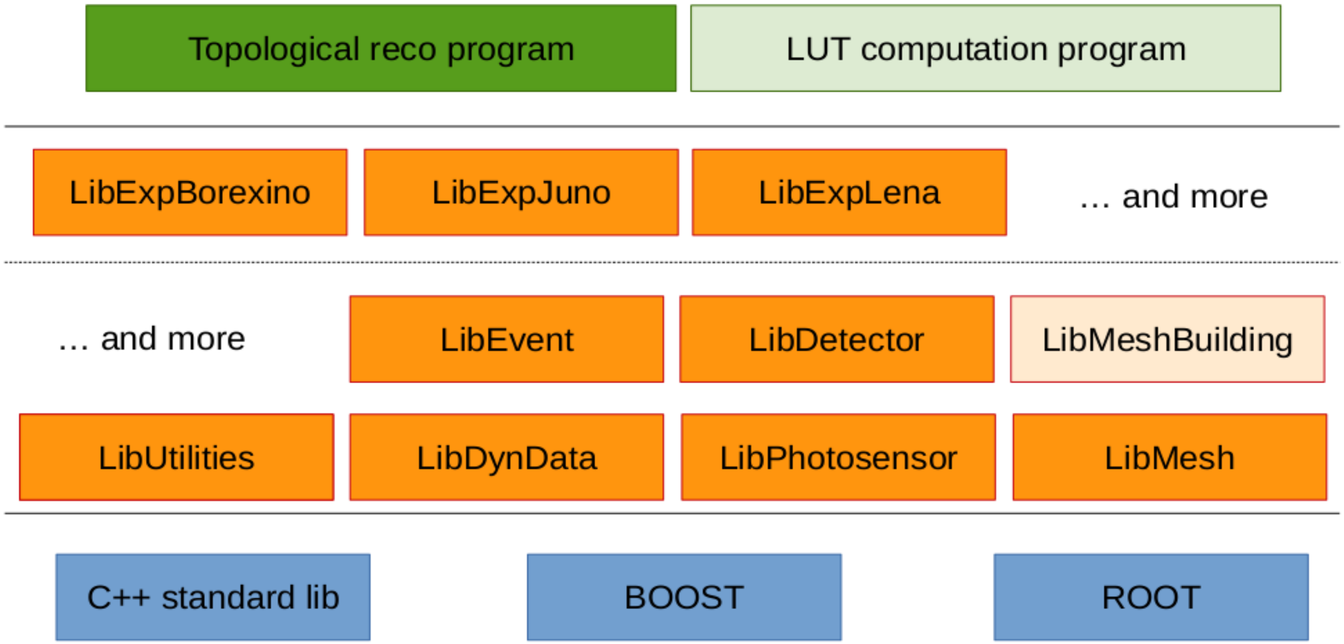
Generating the LUTs needs special care!

Technical Aspects of Detector Integration

- Still in the development phase
- Will be used for other experiments

  → No direct implementation into RAT-PAC

Envisioned software structure



+ other external libs, e.g., LibLena

Work by Sebastian Lorenz

Prospects

- Making it faster
- Separation of Cherenkov light
- Maybe muon bundles
- Study impact of waveform

Already part of our JUNO effort

- **Applied for THEIA related funding together with Michi and Zhe**

→ Hope to get a Phd who can do the integration of THEIA

Summary/Conclusion

- **3d topological reconstruction**
  - Versatile tool
  - A lot of potential
  - Needs to get faster (working on it)
- **Cherenkov separation**
  - Non-trivial
  - Seams to be feasable
  - Would have a lot of advantages

Working Group/Strategy

- **What we want to achieve:**
  - Official MC for all physics analysis
  - Develop tools for reconstruction
  - Optimise THEIA design (also task of physics group)
- **Biggest Question: Which liquid will be used?**
  - THEIA "main fill" WbLS or lightly doped Oil based Liquid Scintillator (ObLS)
  - Need a scheme how to decide this!

- **Need people for all three of these tasks**
- **Optical models will be key to all tasks**

Organisation of the WG

- **A couple of people are already interested**

  (John Learned, Martin Tzanov, Andrey Elaghin, Nuno Barros, Javier Caravaca, Sebastian Lorenz, B.W., more?)
- **Propose to have regular video meetings** (once a month)
- **Email list:** theiaMC@lists.lbl.gov
- **Instruction for signing up:** http://theia.berkeley.edu/index.php/Help

- **Page for this WG on the THEIA website:**

  http://theia.berkeley.edu/index.php/Monte_Carlo,_Reconstruction_and_Particle_ID

  (to keep track of progress, ideas, documents etc.)

Remark: The generic "theia" user doesn't have write privileges so people will need to request accounts on the wiki to add to the page.

Points to Discuss: MC

- We have a nominal detector model for THEIA (50kt etc) and a rough model for WbLS optics.

- Do we want more details in the detector model?
  - I don't think we should worry about e.g. a realistic DAQ at this stage
  - Maybe we want more options for PMT types etc

- What options do we want for the detector model? e.g. size, coverage, target LS fraction
  - Should we fix as many points as possible now (or as soon as possible)?

- Are we satisfied with the WbLS model?
- Do we want LAPPDs (presumably yes!) and how should we go about including them?
- Need to agree a default detector model for all the sensitivity studies to use

Points to Discuss: Reconstruction

- Do we want this to be at a stage that it is actually used in the physics studies?
- My leaning here is no: We should develop the algorithms independently.

  I completely agree!

- For the physics studies I propose that the goal should be to show the sensitivity in terms of resolution (energy, position, directional - whatever is relevant for the physics in question).
- That then provides goals for the reconstruction.

  (e.g. to get a good DBD measurement we might need directional resolution of X degrees in order to reject solar neutrino backgrounds)

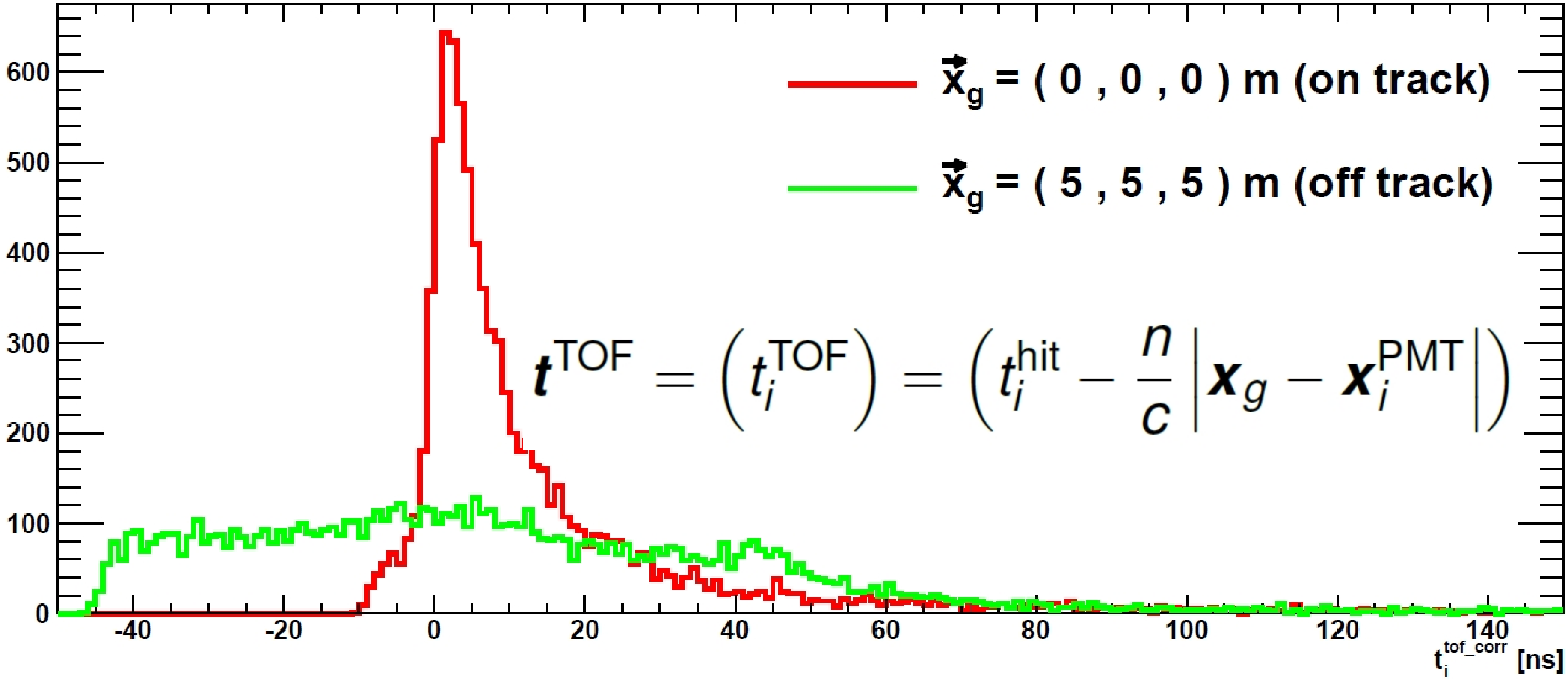
Backup slides

Vertex Finding/Backtracking

Basic idea:

from Domenikus Hellgartner

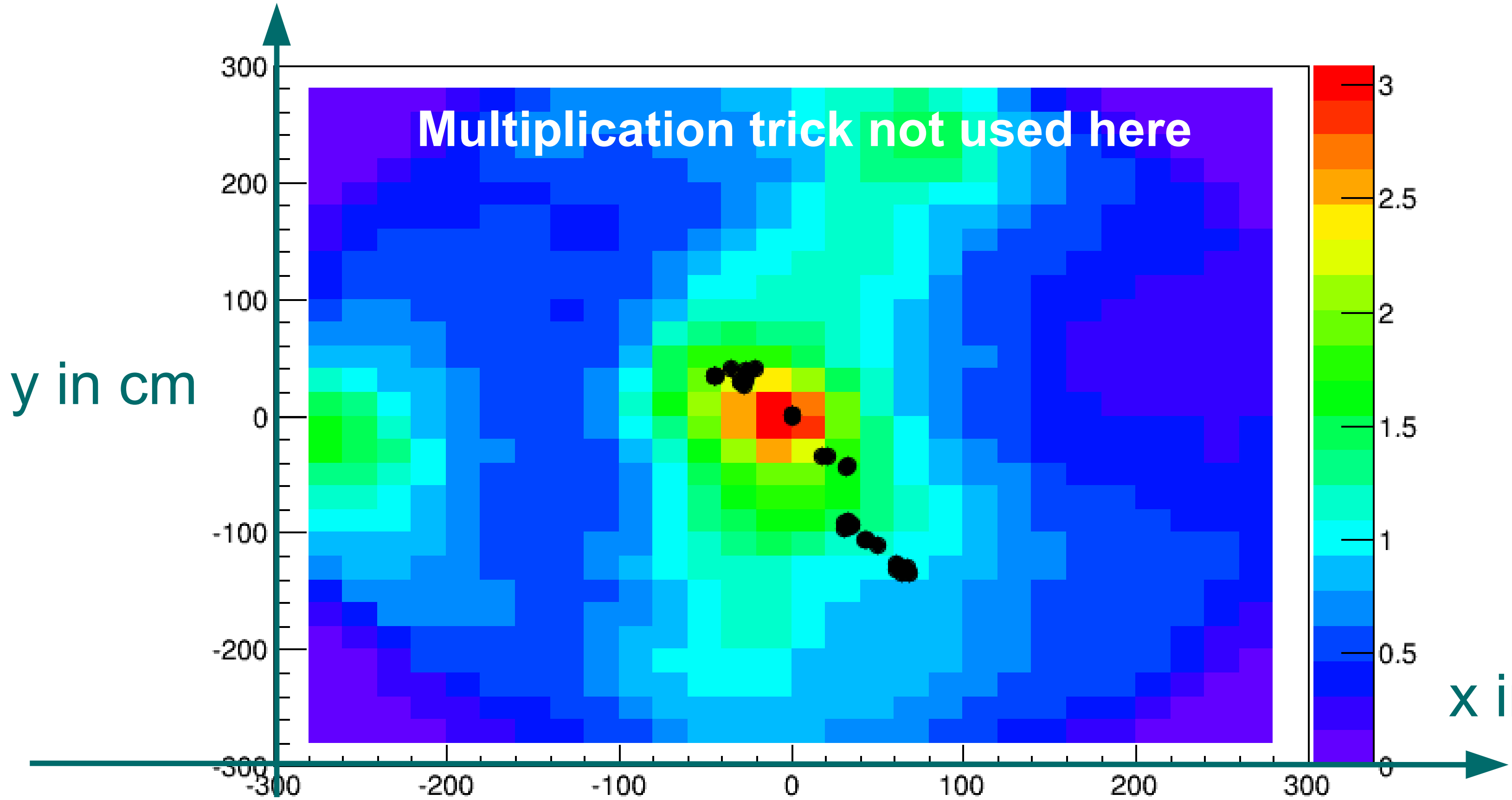
- Calculate at every point the time correction needed for each first hit signal to match the flight time to that point
- Then look for peaks in this time distribution



Eliminating Influence of Scattered Light

- **Idea:** Use probability mask and lookup tables to calculate for each signal the probability to be scattered

  → reweigh signals after each iteration



Result **before** removal of scattered light!

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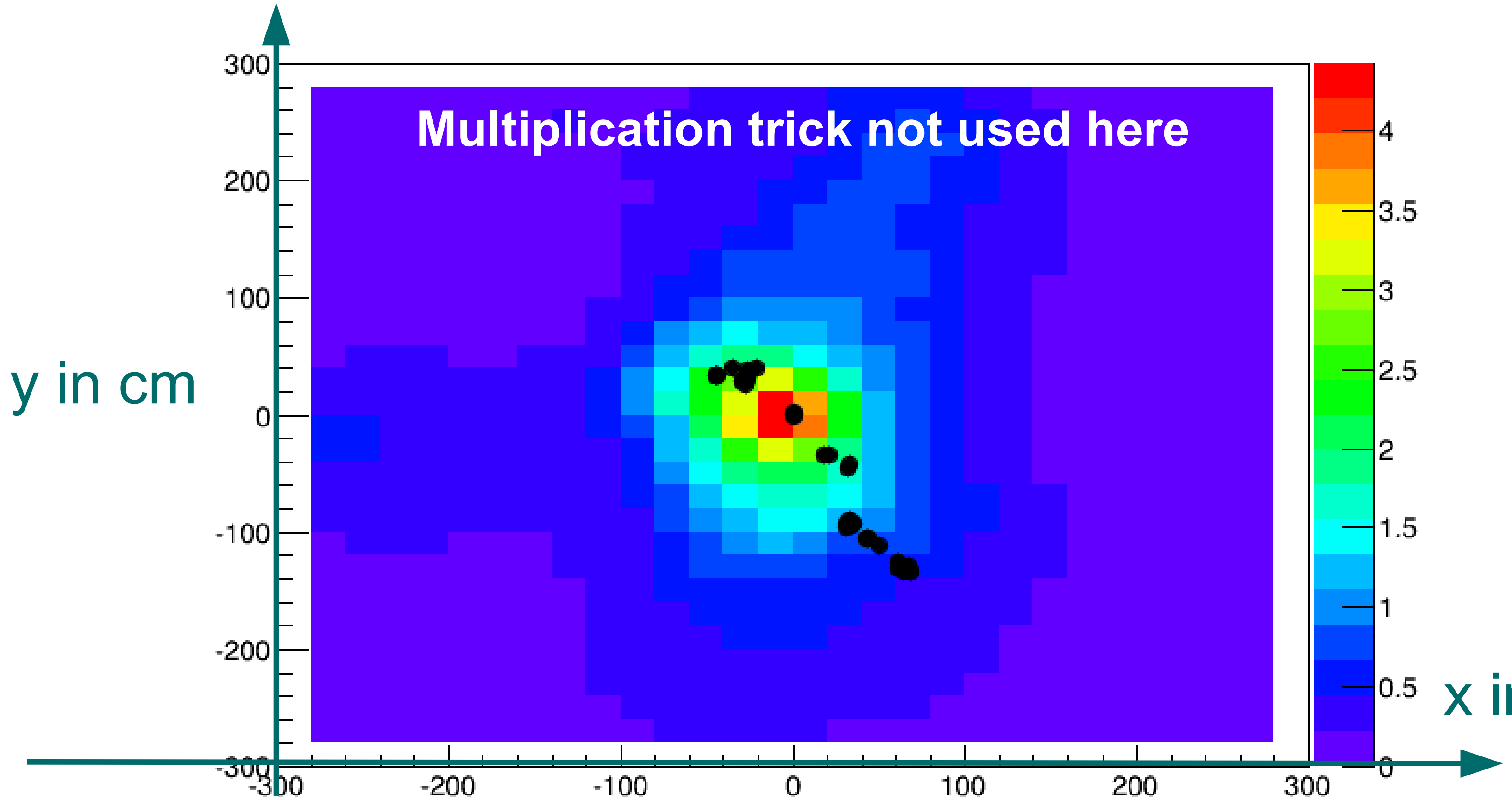

Result **after** removal of scattered light!

Mu/e-Separation: Angular Width