Time Assisted Energy Reconstruction in the AHCAL

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Virtual CALICE Meeting

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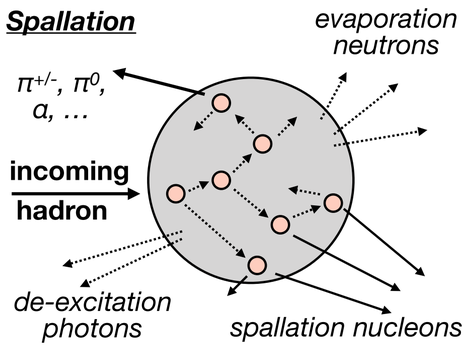
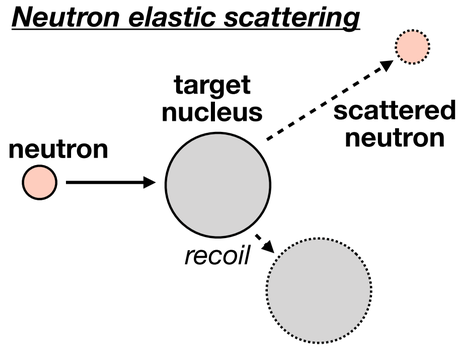
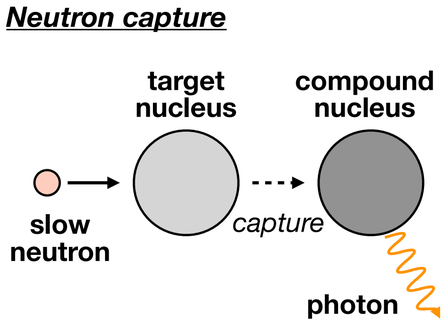
Time Structure of Hadronic Showers



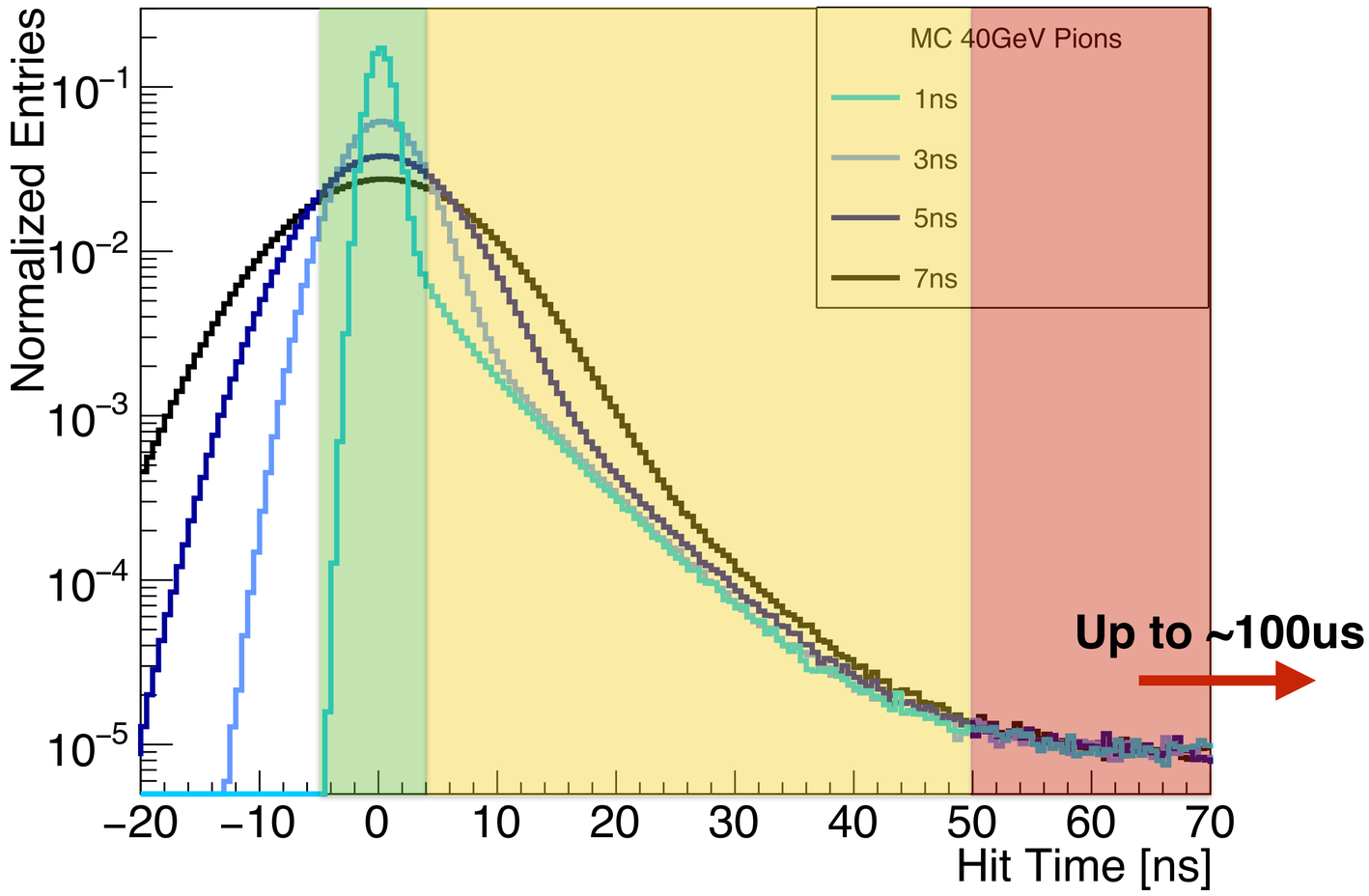
Instantaneous



Neutron elastic sc.



Neutron capture



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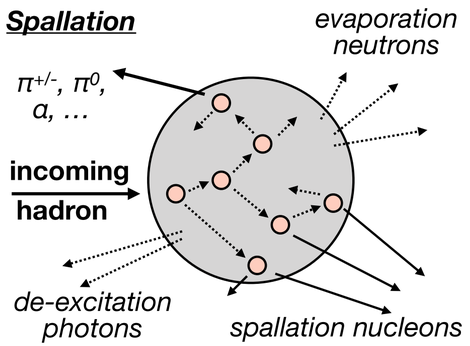
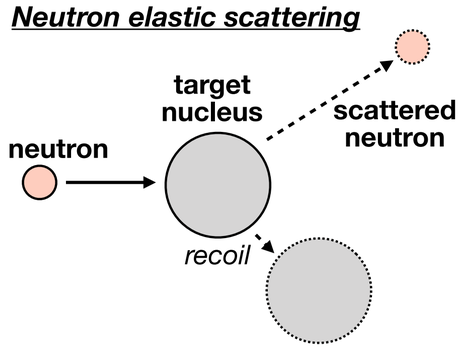


Instantaneous

Nuclear binding energy lost



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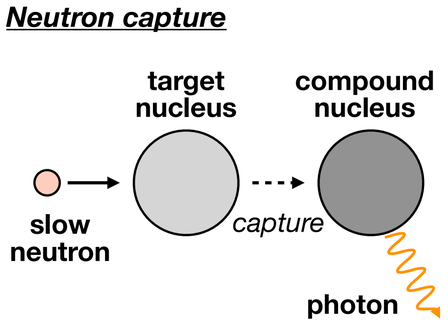
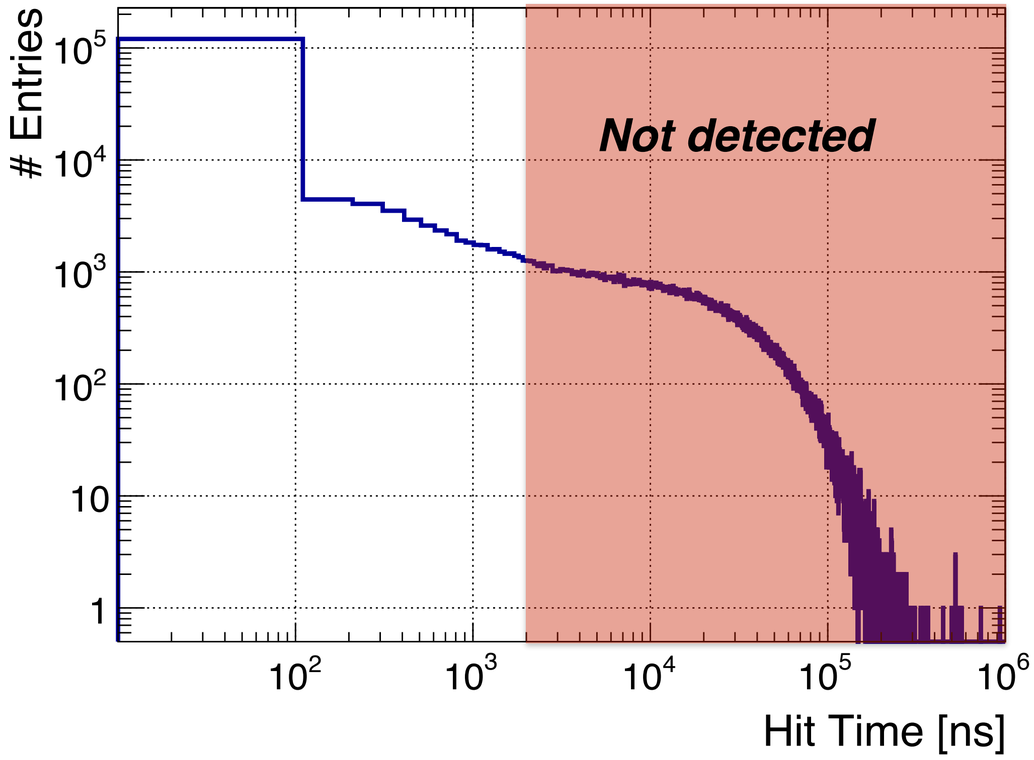


Neutron capture

Binding energy gained back



Neutrons are an indication for:

Electromagnetic fraction

Lost binding energies

Most neutron captures too late for TB mode

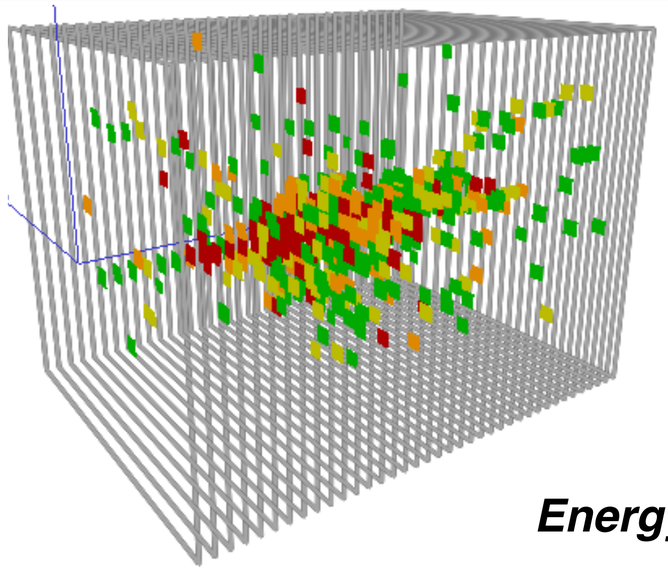
Time Structure of Hadronic Showers

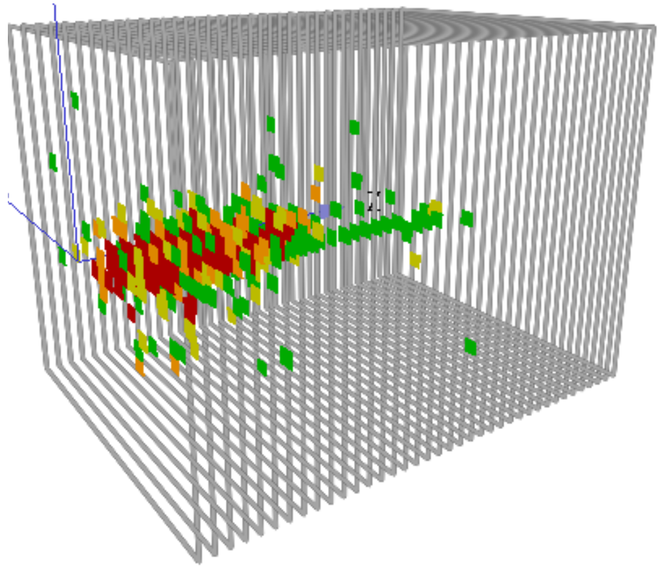
< 1.65 MIP

… < 2.9 MIP

… < 5.4 MIP

> 5.4 MIP





Simulations

Energy

Time Structure of Hadronic Showers

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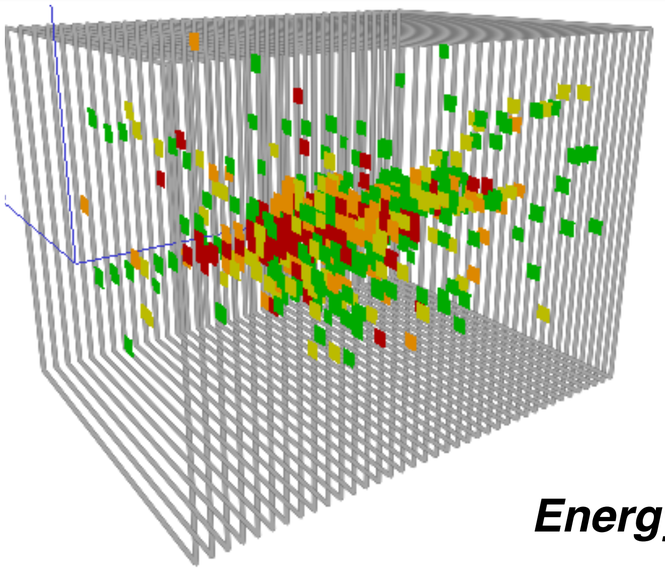

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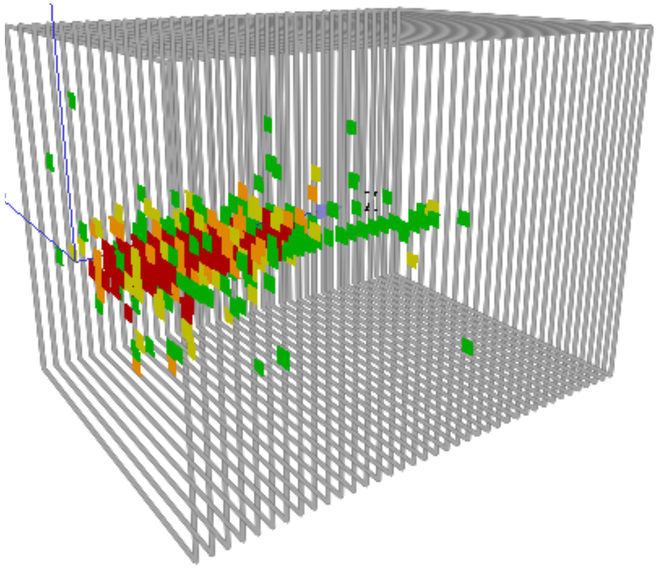

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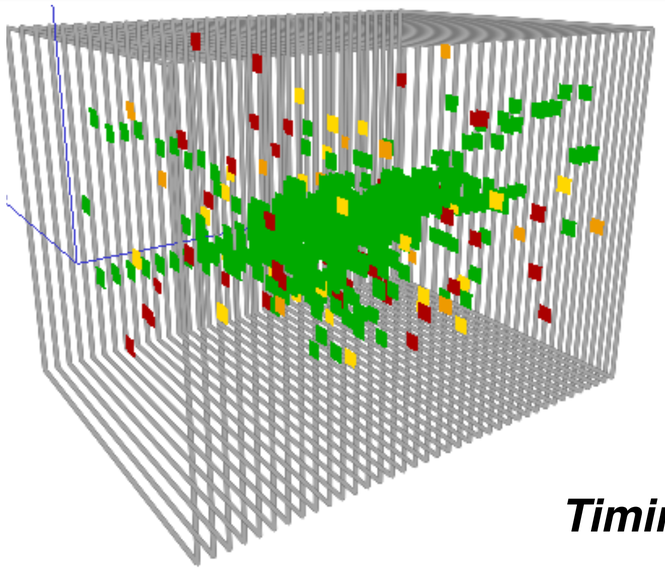
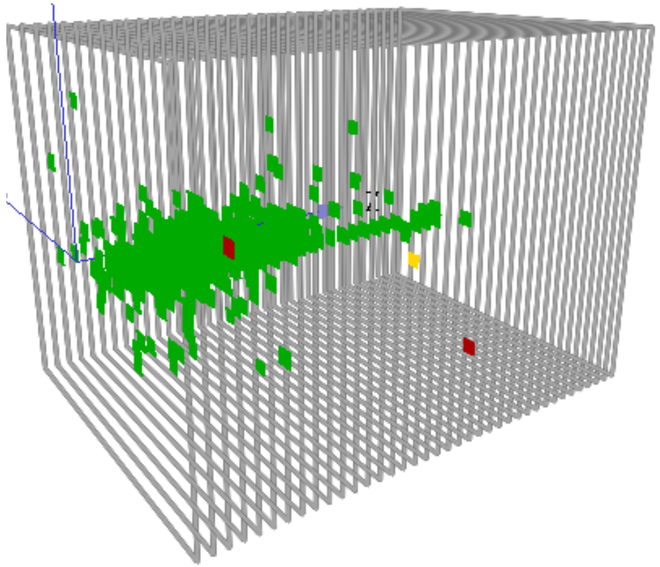


Timing



< 5 ns

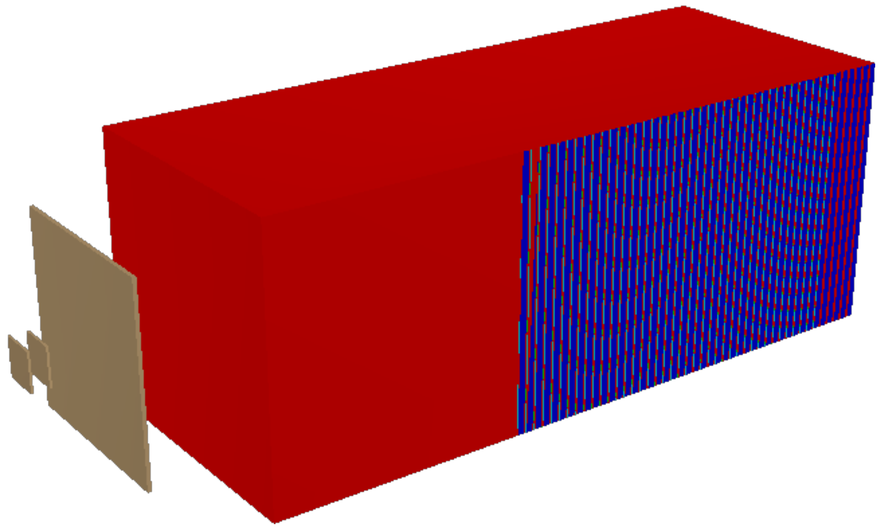
… < 15 ns

… < 50 ns

> 50 ns

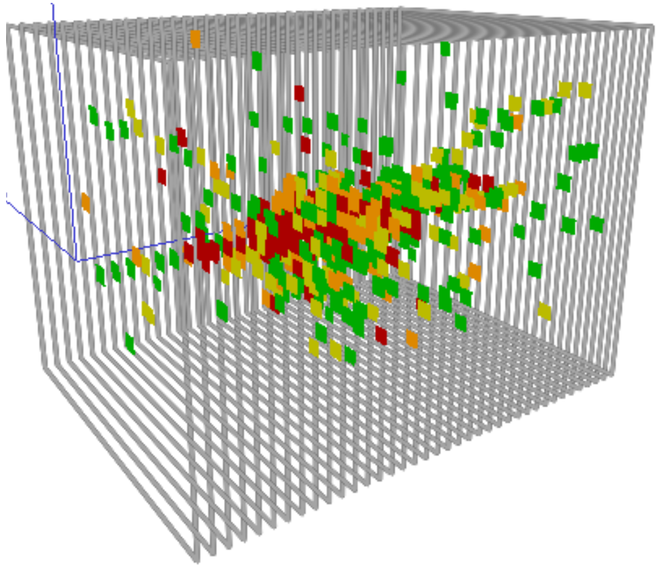
Simulation

- CALICE AHCAL test beam geometry with 60 layers (to avoid leakage)
- *QGSP_BERT_HP*
- 10 - 80 GeV Pions
- 1ns gaussian time smearing
- Integration time: 2000ns



- Minimal event selection:
  - Shower start: first 10 layers

Software Compensation



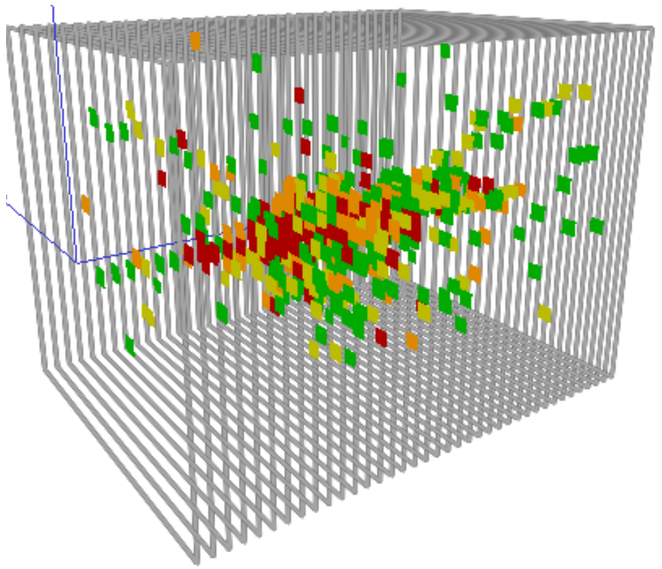
Global

$$E^{\text{global}}_{\text{reco},i} = E_{\text{std},i} \cdot (a + b\,\theta_i + c\,\theta_i^2)$$

$$C_{global} = \frac{C_{thr}}{C_{av}}$$

- C_{thr}: Fraction of hit energies above *thr*
- C_{av}: Fraction of hit energies above average

Software Compensation



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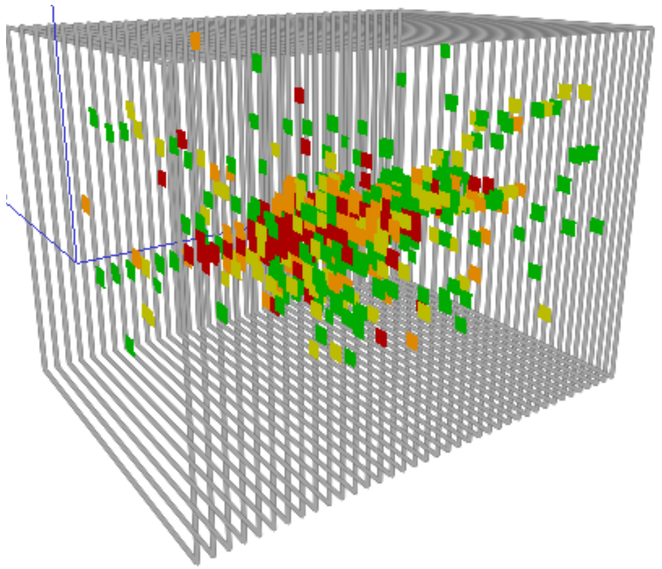

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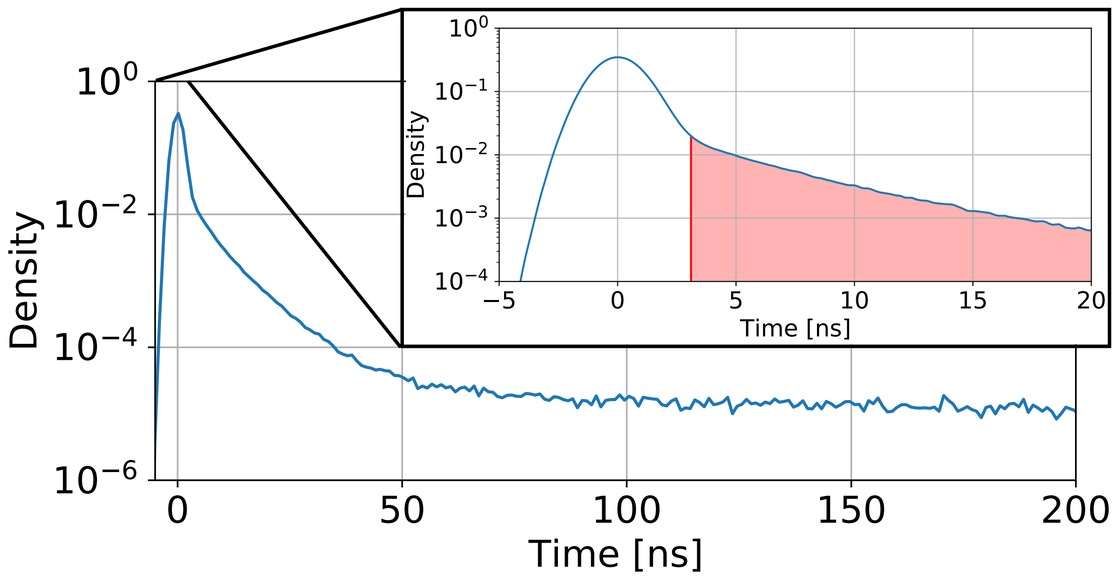
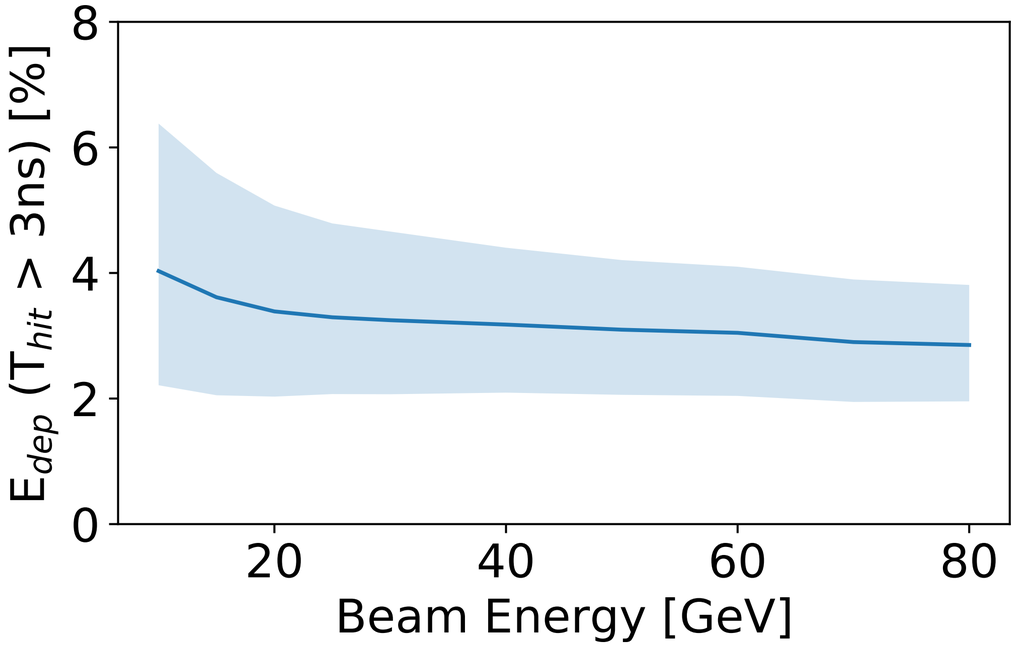
How can we introduce the time measurement?

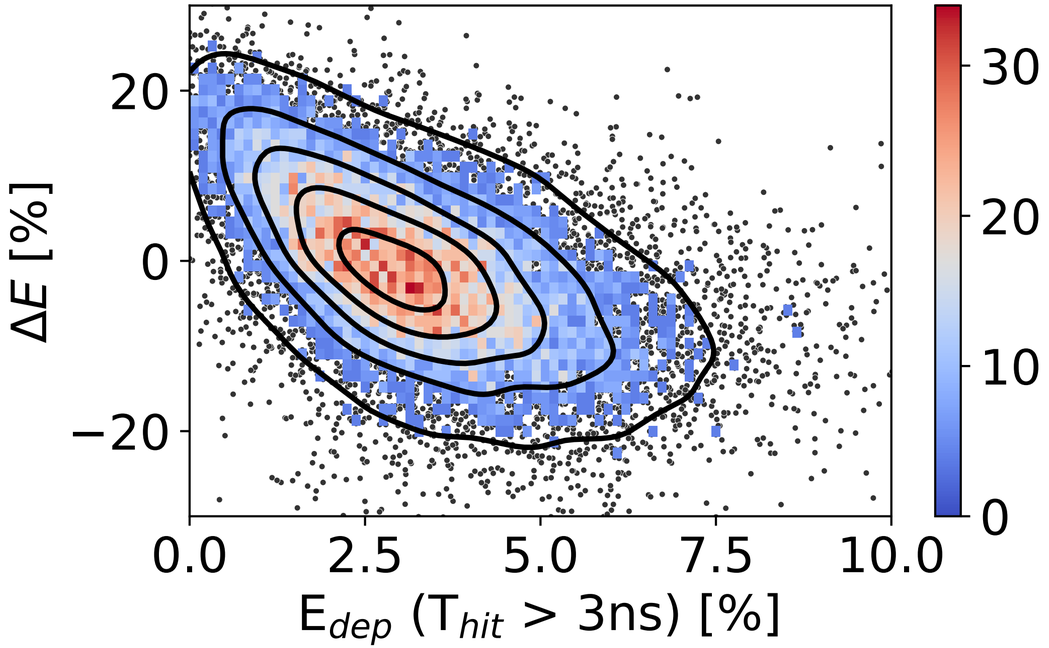
Global Timing

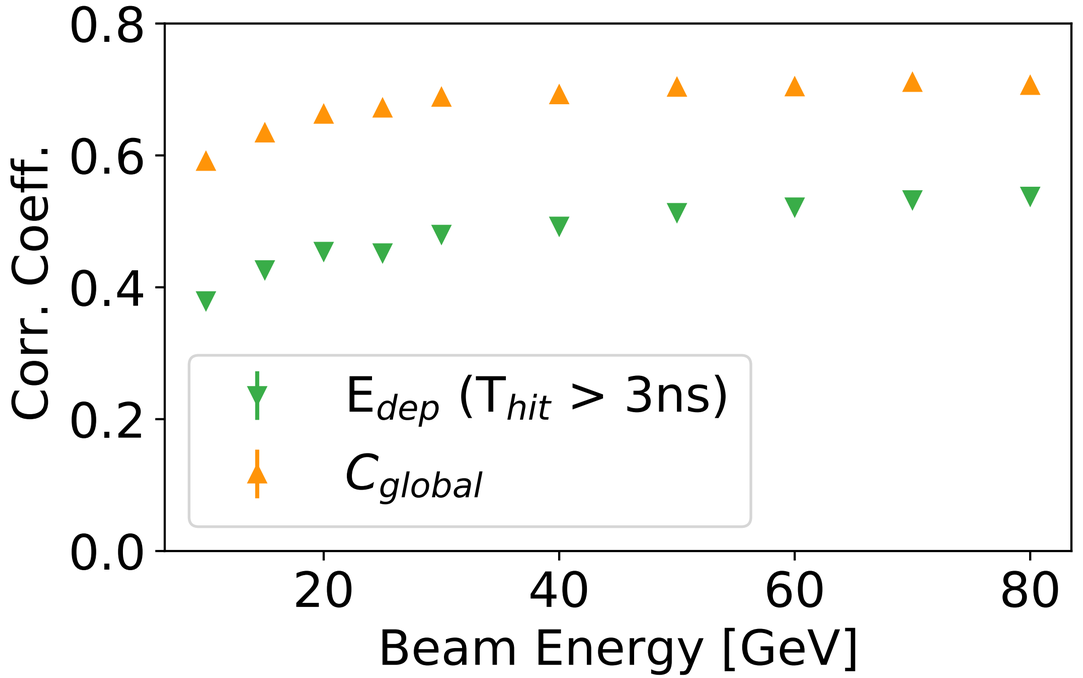




- Easiest way to quantify timing as a global observable: Energy deposited later than a certain threshold
- About 3-4% of the energy is deposited later than 3ns

Global Timing: Correlations





- Clear correlation visible with reconstructed energy

Global Software Compensation

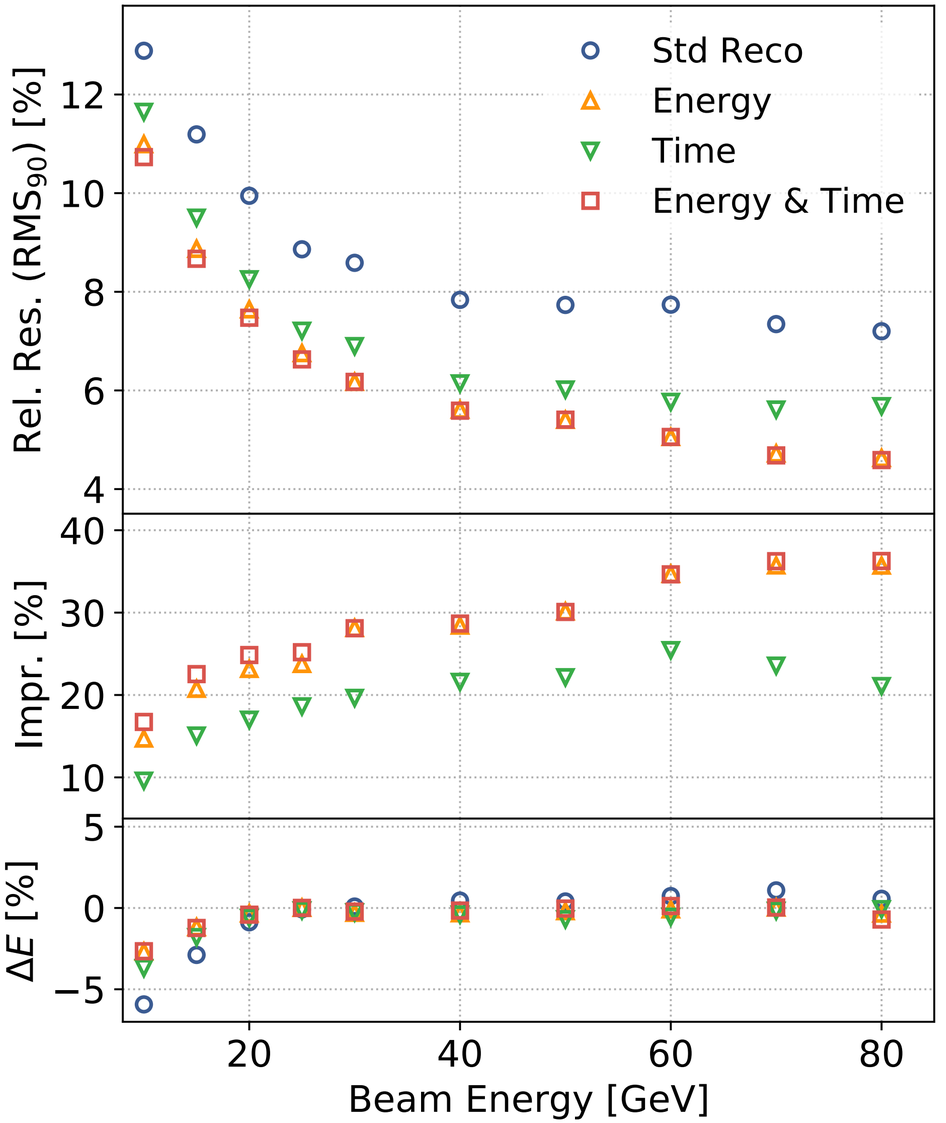
- Correct the standard energy reconstruction with a polynomial fit over some observable

$$E_{\mathrm{reco},i}^{\mathrm{global}} = E_{\mathrm{std},i} \cdot (a + b\,\theta_i + c\,\theta_i^2)$$

- Can be extended to two observables (C_{global} and time)

$$E_{\mathrm{reco},i}^{\mathrm{global}} = E_{\mathrm{std},i} \cdot (a + b\,\theta_i + c\,\phi_i + d\,\theta_i\phi_i)$$

- Parameters a-d are energy dependent



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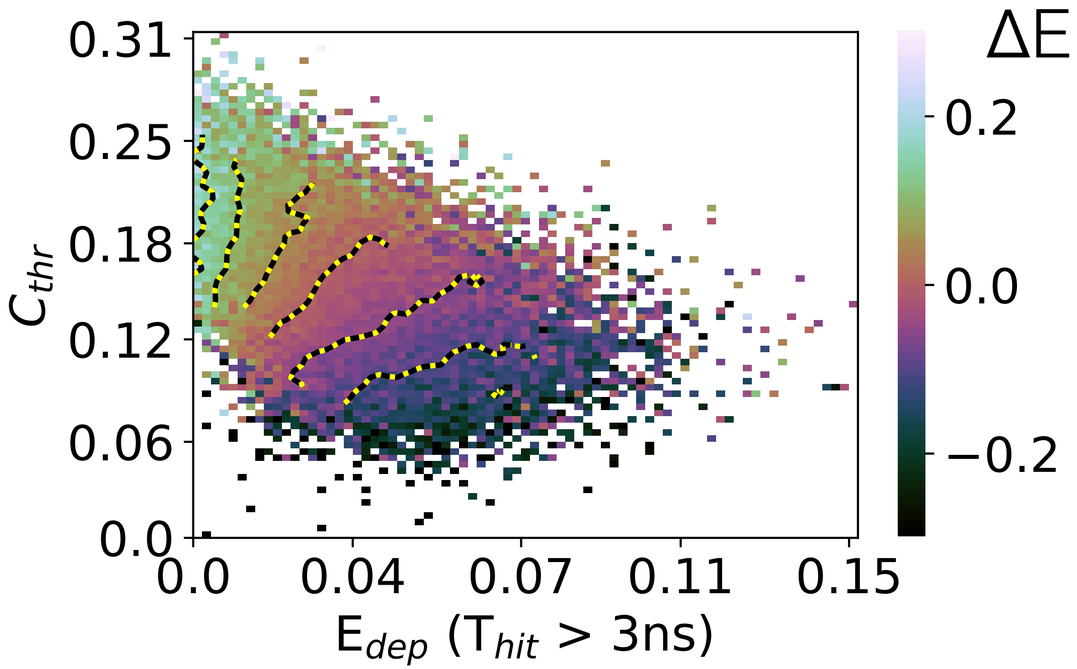

- Time information seems to be complementary to energy density
- But not to C_{global}

- C_{thr}: Fraction of hit energies above *thr*
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$$C_{global} = \frac{C_{thr}}{C_{av}}$$

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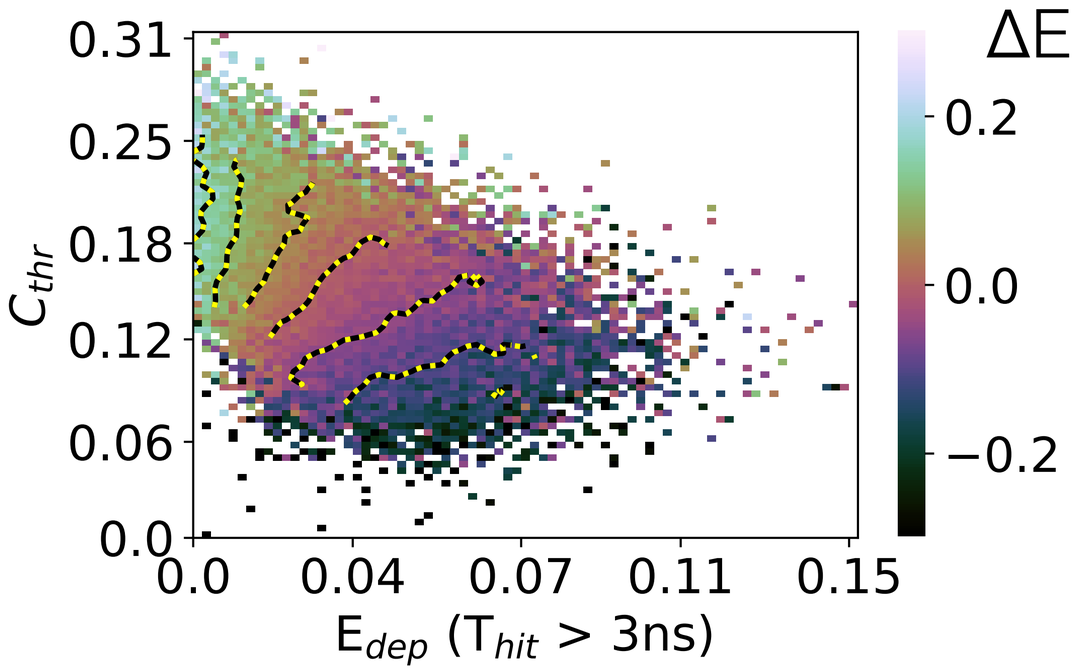

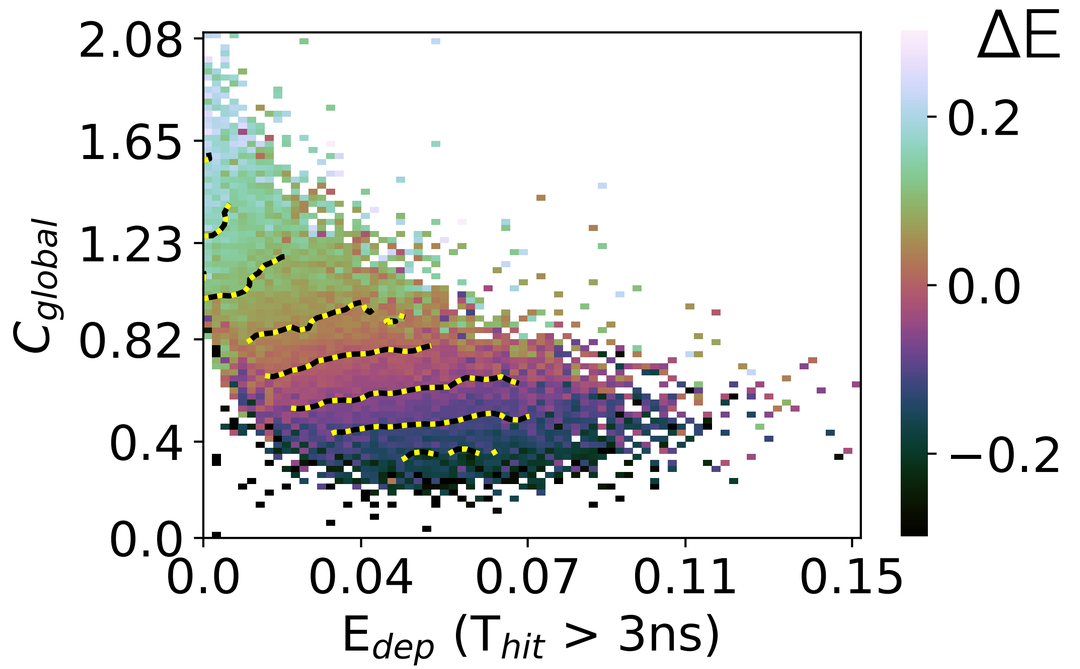

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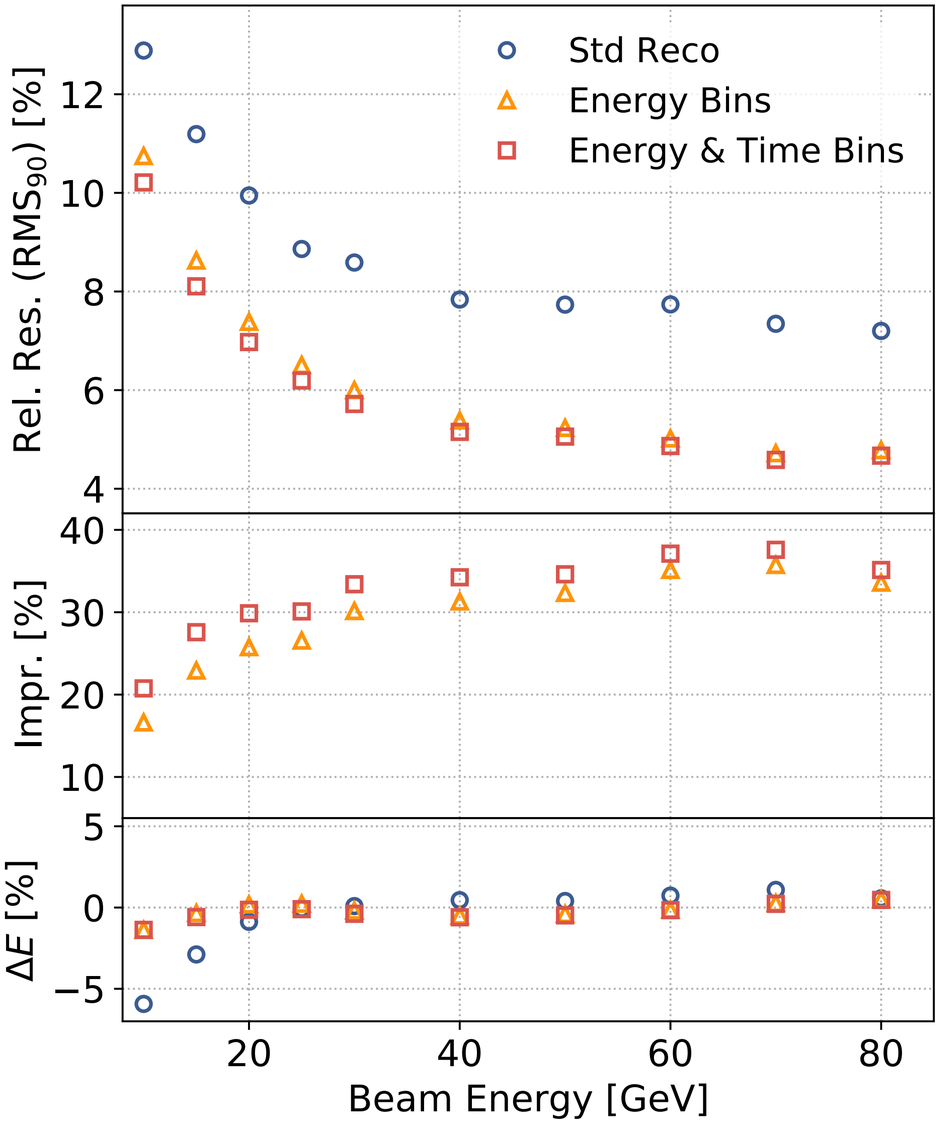
Local Software Compensation

- Binning of the hit energies. Weight hit energy bins differently

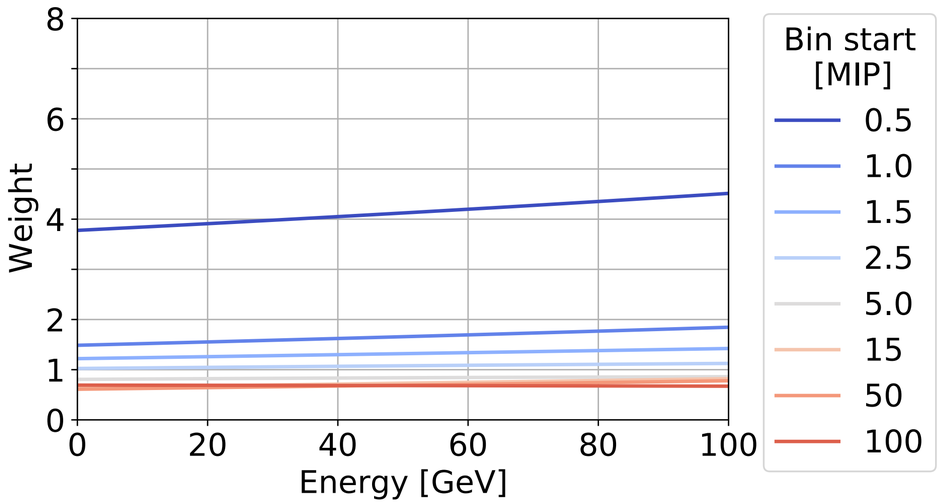
$$E_{\text{reco}}^{\text{local}} = \sum_{j \in \text{hits}} e_j \cdot w(e_j, E_{\text{std}})$$

- To include time: Double the bins. One set of bins for early hits, one set of bins for late hits.

- —> Significant improvement over standard local SC method.

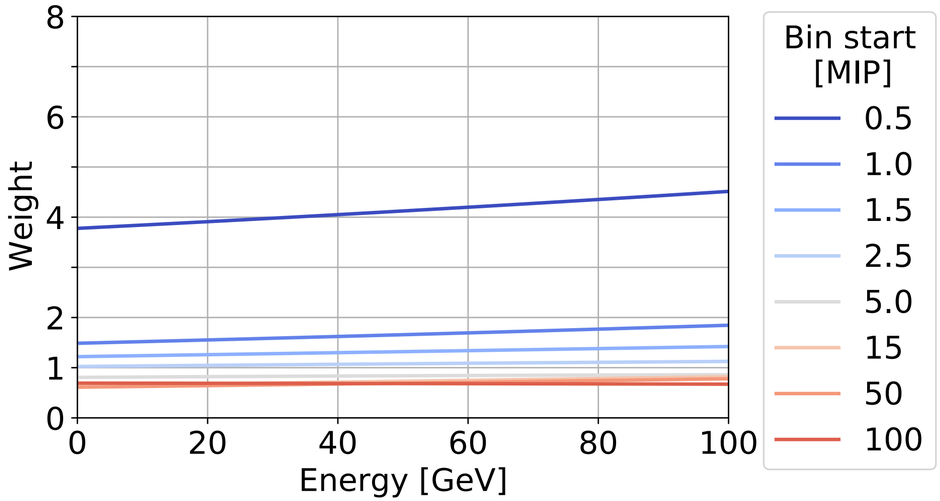


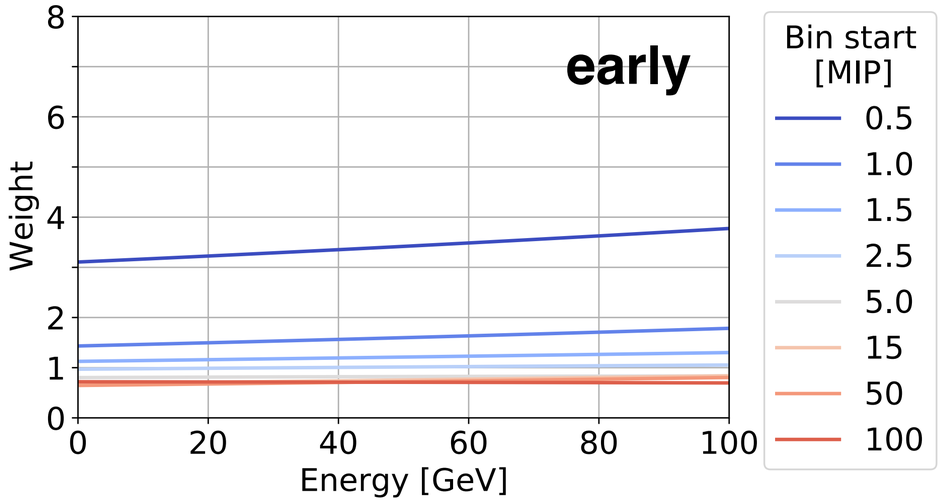
Local Software Compensation: Weights

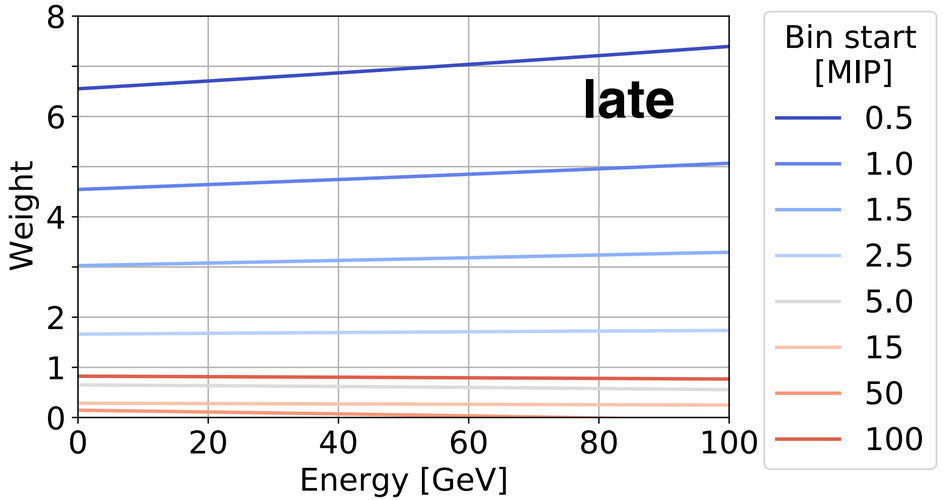


- Low energy hits are weighted up while high energy hits are weighted down

Local Software Compensation: Weights







- Low energy hits are weighted up while high energy hits are weighted down
- Late, low energy hits are weighted up significantly more. While early, low energy hits are weighted up less.

Outlook: Neural Network Extensions

Global

$$E_{\mathrm{reco},i}^{\mathrm{global}} = E_{\mathrm{std},i} \cdot (a + b\,\theta_i + c\,\theta_i^2)$$

Local

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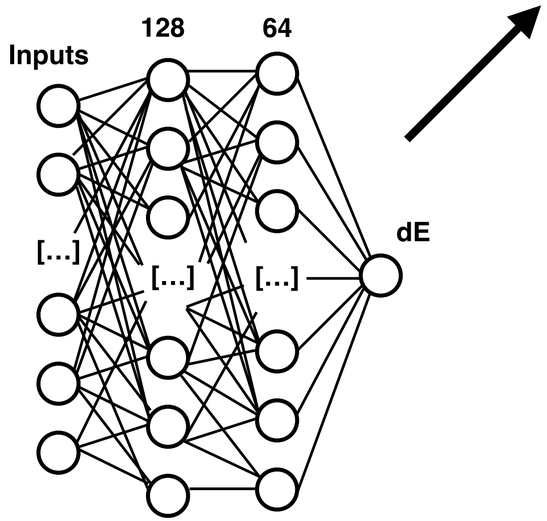

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- Using longitudinal shower shape information seems to be beneficial
- Reported in my PhD Thesis

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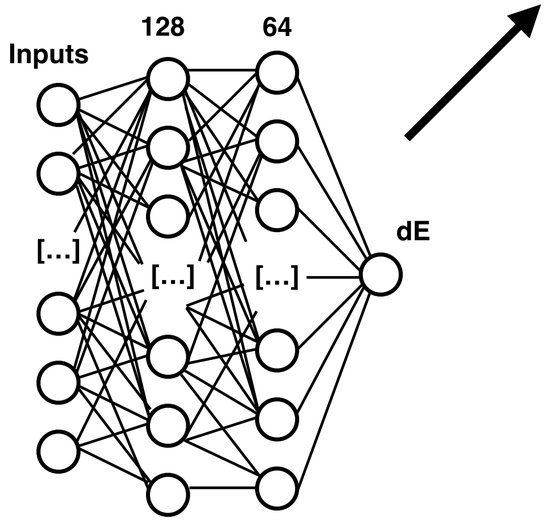

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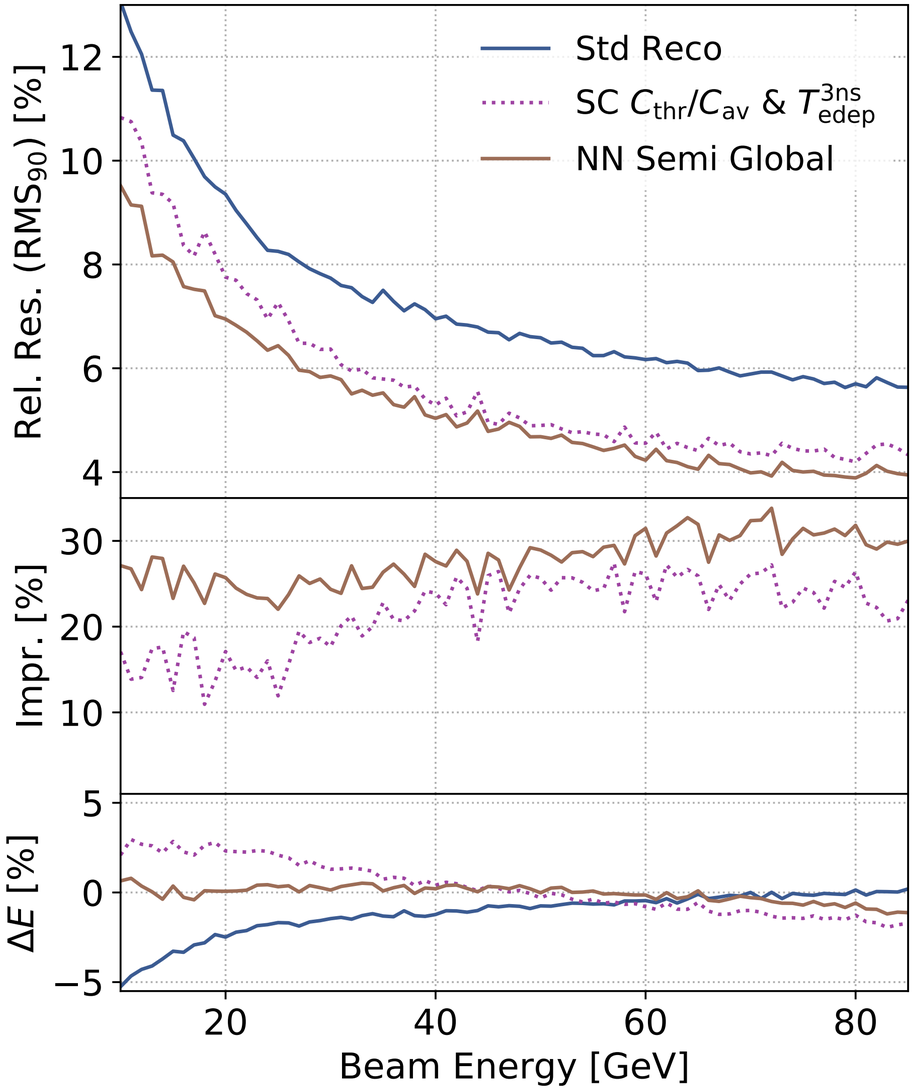

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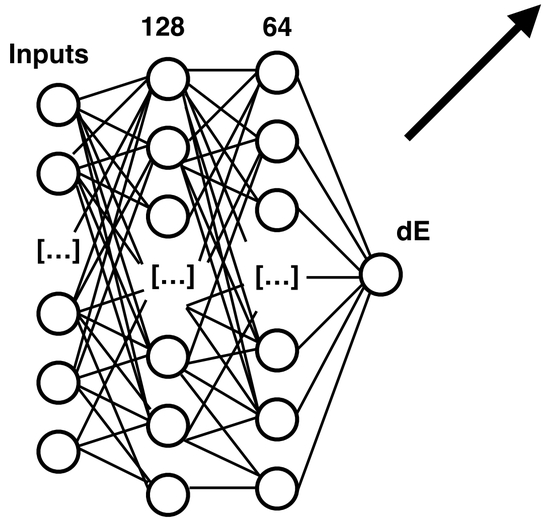

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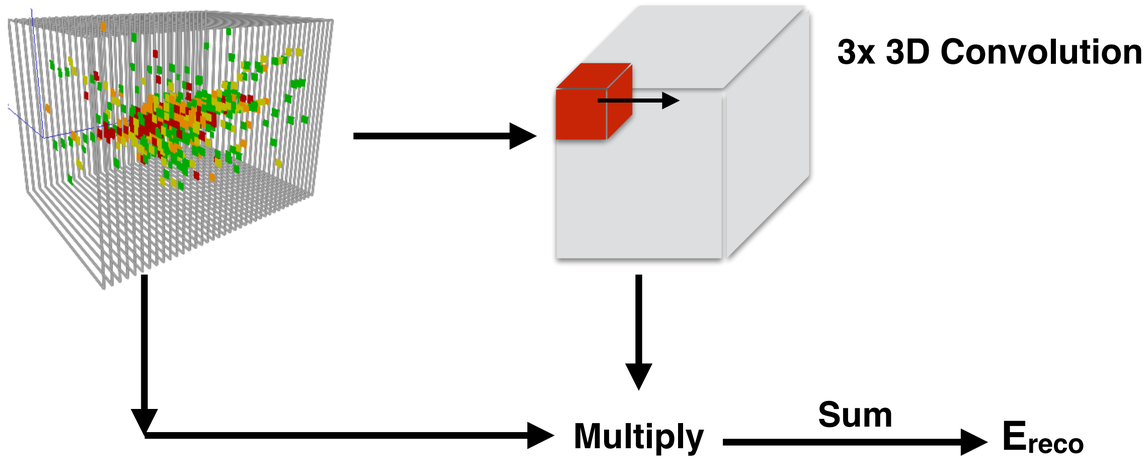
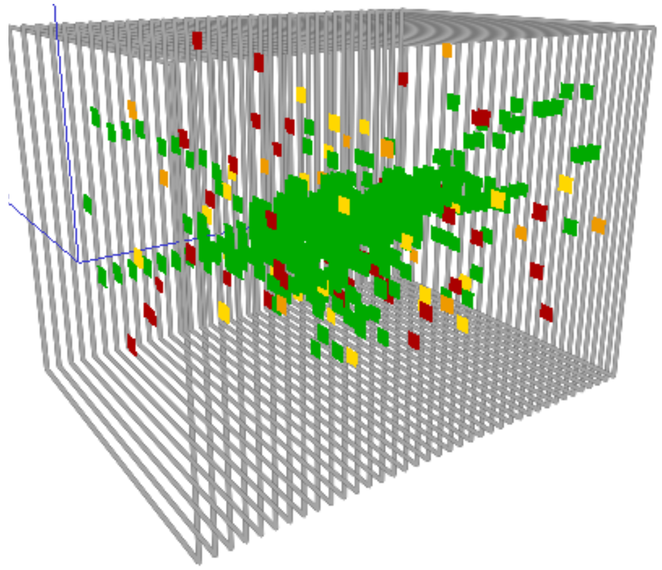


- Include information about neighbouring cells
- Work in progress

Conclusion

What have we learned?

- Studied two ways of including time information in the energy reconstruction process
- Correlation of global time observable with reconstructed energy visible
- Global SC: No improvement over using C_{global}
- C_{global} is doing more than only being sensitive to the em-part of the shower
- Local SC: Significant improvement visible if early and late hits are treated differently
- Neural Network extensions that allow an incremental increase in complexity



Writing a paper