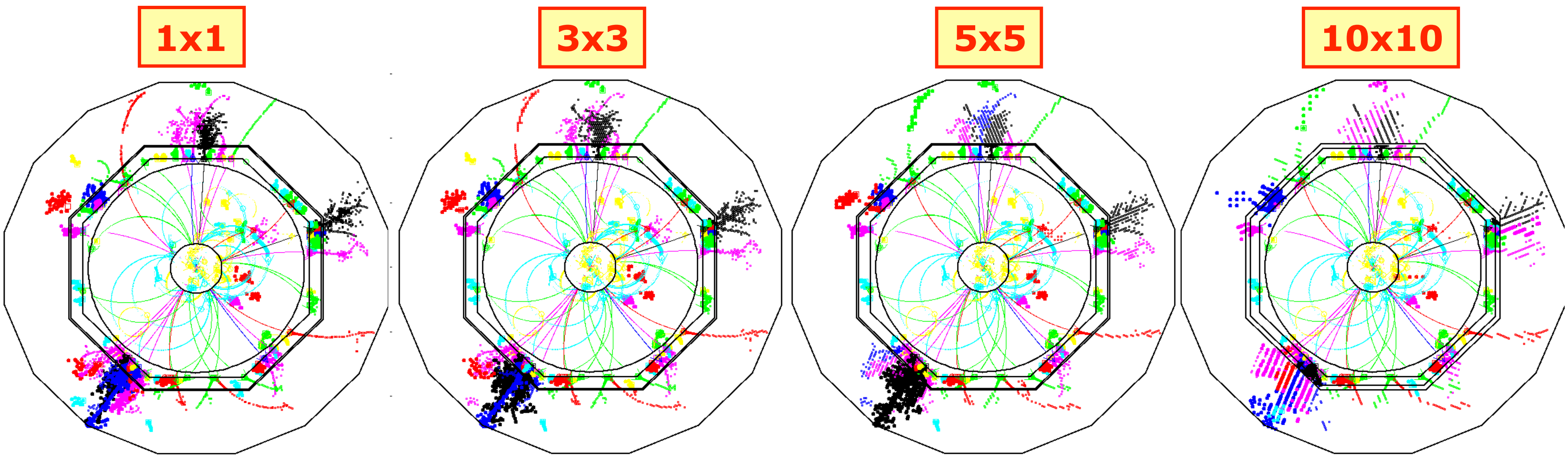
Granularity and Energy Resolution

Katja Krüger, Coralie Neubüser, Felix Sefkow, Huong Lan Tran

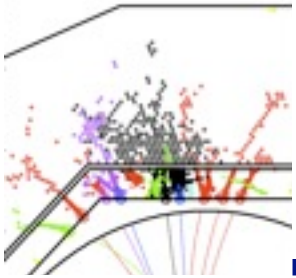
LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

DESY

CALICE

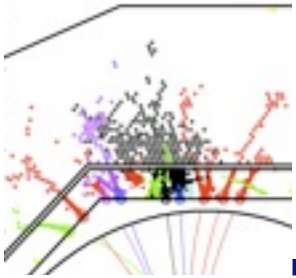


ILD software and optimisation workshop
DESY, Feb 25, 2016



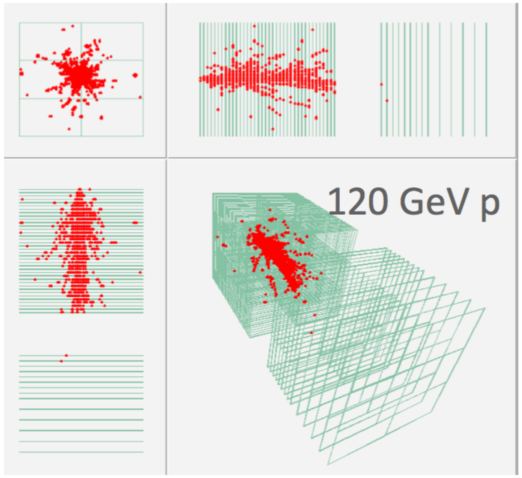
Outline

- Introduction: effects of granularity
- Reconstruction schemes for single particles and software compensation
- Energy resolution and granularity
- AHCAL optimisation
- Studies done at DESY, in co-operation with **Argonne**, **Cambridge** and **CERN**
  - see also talks by S.Green and H.L.Tran



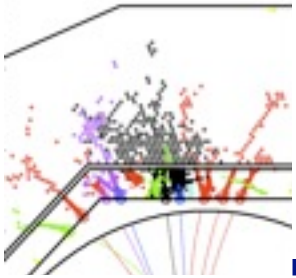
Energy and Granularity

- A central theme in jet calorimetry since the times of H1 and ZEUS



“Energy resolution is everything!”

“Granularity is everything!”



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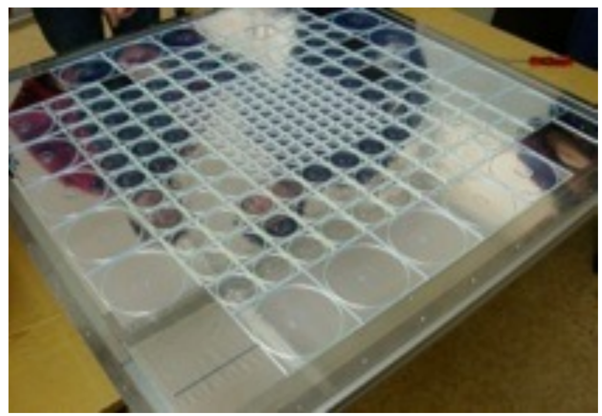
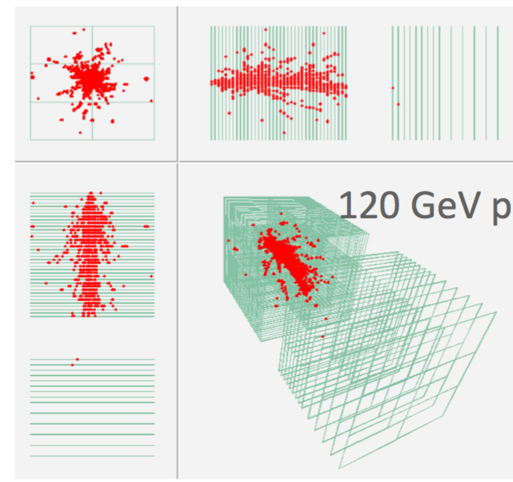
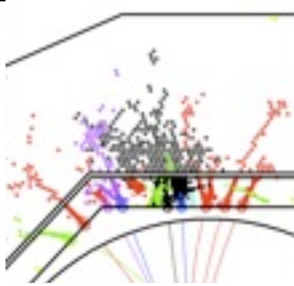




“Energy resolution is everything!”

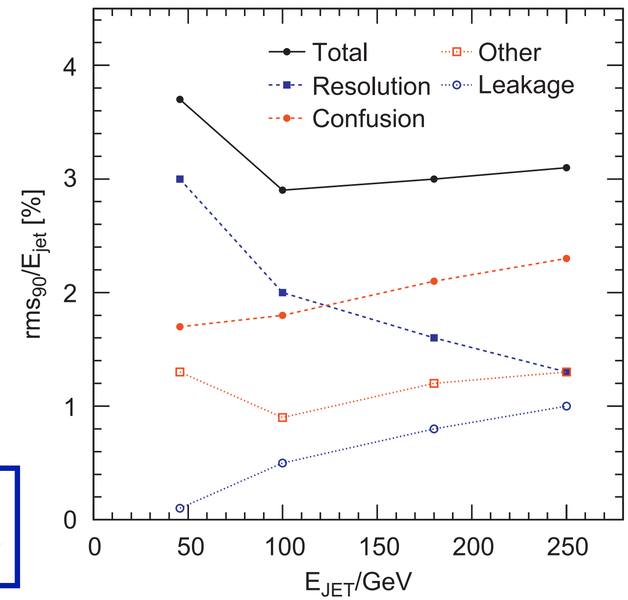
“We need enough of both!”

“Granularity is everything!”



Particle flow performance

M.Thomson, Nucl.Instrum.Meth. A611 (2009) 25-40

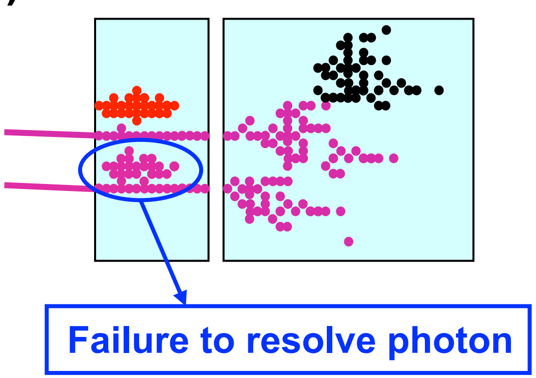


- Separating the energy depositions of individual particles requires high granularity
- Calorimeter resolution still does matter
  - dominates for jets up to ~ 100 GeV
  - contributes to resolve confusion

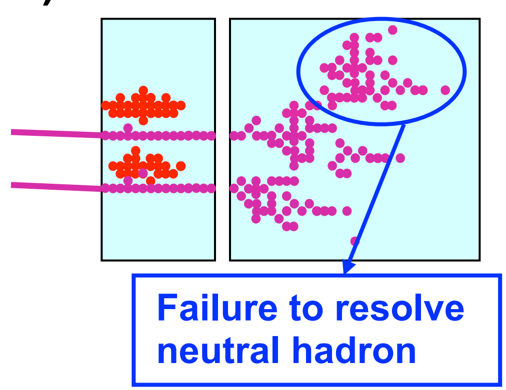
Pattern recognition
based on topology **and** energy

Types of confusion:

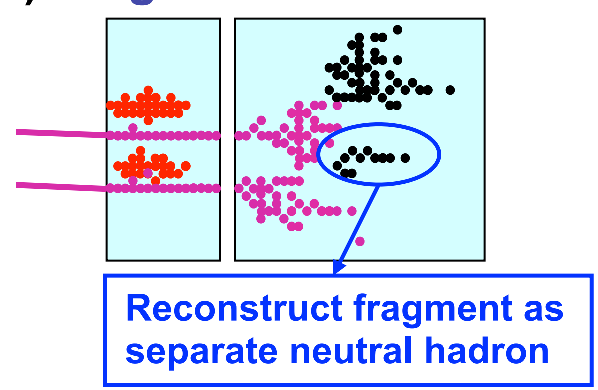
i) Photons



ii) Neutral Hadrons

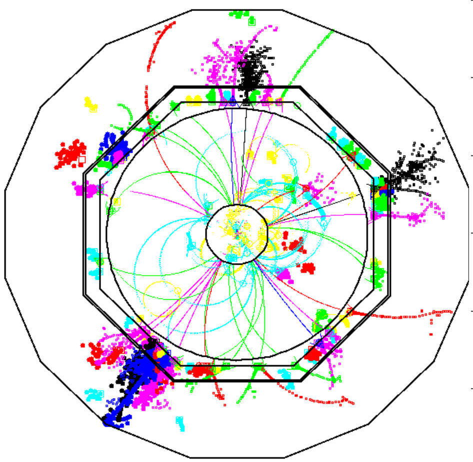


iii) Fragments

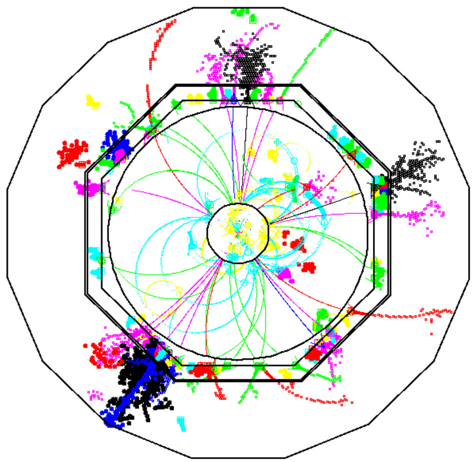


Make your choice…

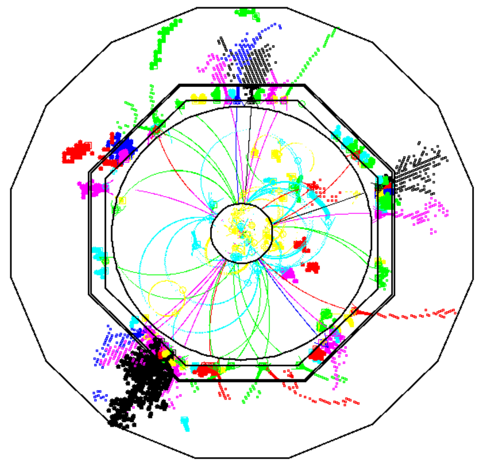
1x1



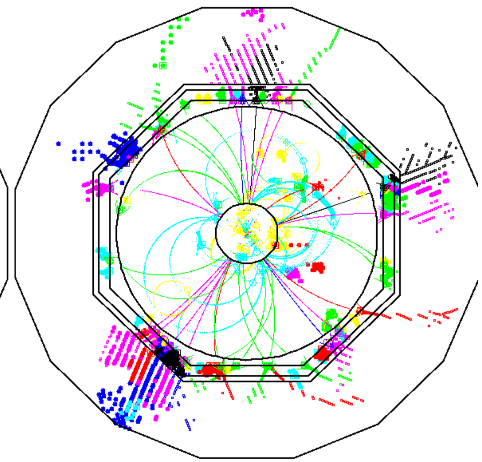
3x3

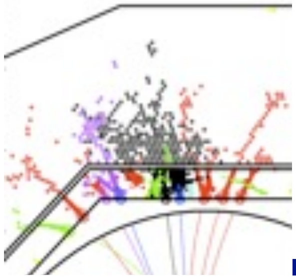


5x5

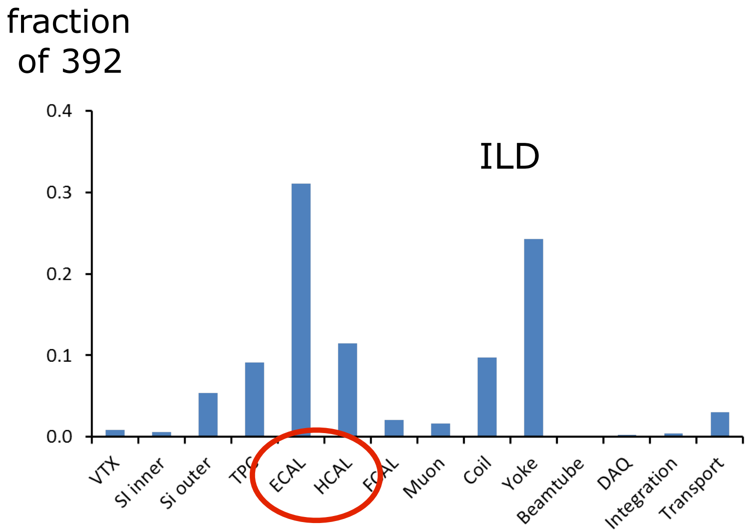


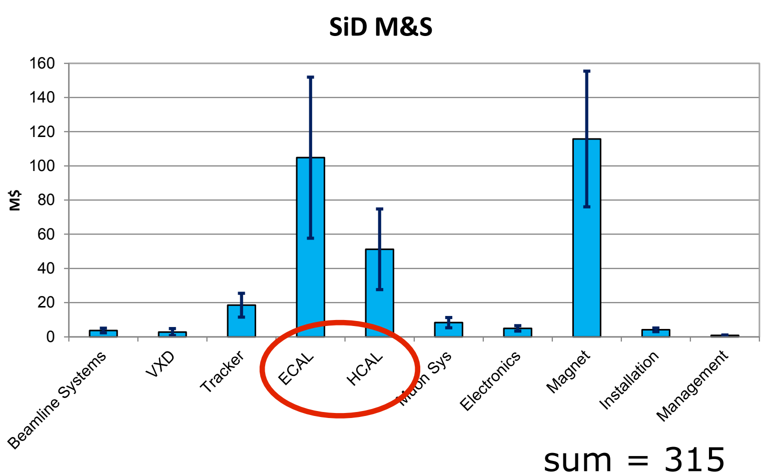
10x10



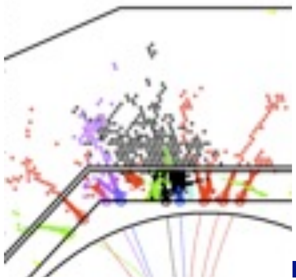


Calorimeter cost



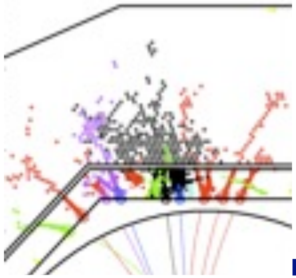


- Costing is at a very early stage
- Yet, many lessons learnt from 2nd generation prototypes
- Example ILD scint HCAL: 45M
  - 10M fix, rest ~ volume
  - 10M absorber, rest ~ area (n_{Layer})
  - 16M PCB, scint, rest ~ channels
  - 10 M SiPMs and ASICs
- HCAL cost is rather driven by instrumented area then by cell size
- ECAL cost driver: silicon area
- Still, high granularity drives the design and needs to be justified



Gaseous calorimeters

- Gaseous HCAL with **analogue** readout would have poor resolution
  - small sampling, large Landau fluctuations
- **Digital** calorimeter idea: count particles, ignore fluctuations
  - $1cm^2$ cells: saturate above 30 GeV
- **Semi-digital** idea: mitigate saturation using several thresholds and weights
  - assumes signal prop. to E deposition



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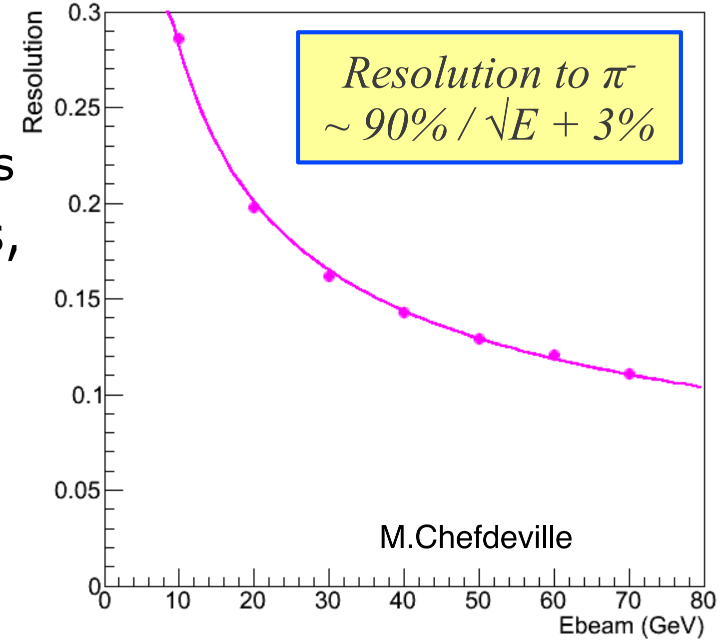

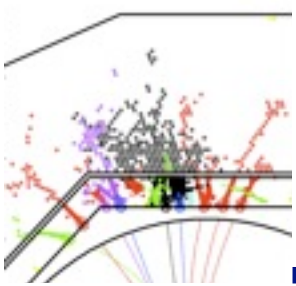

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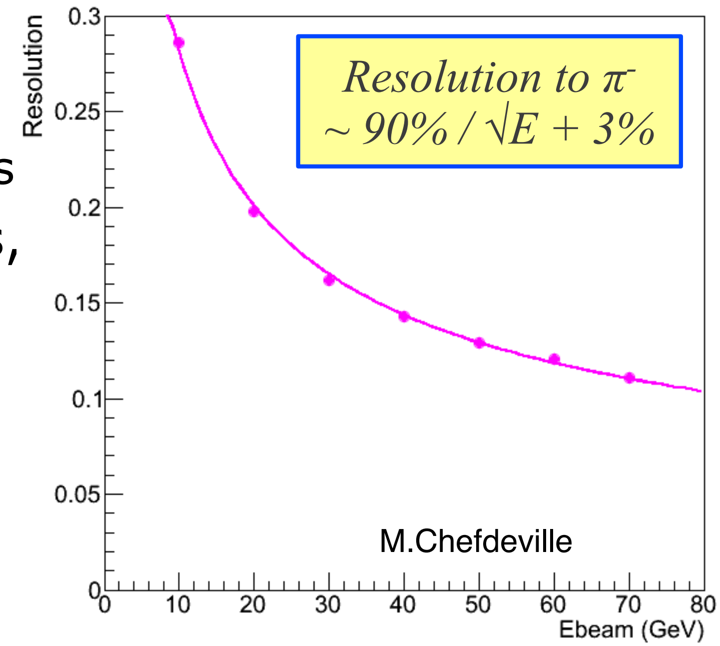

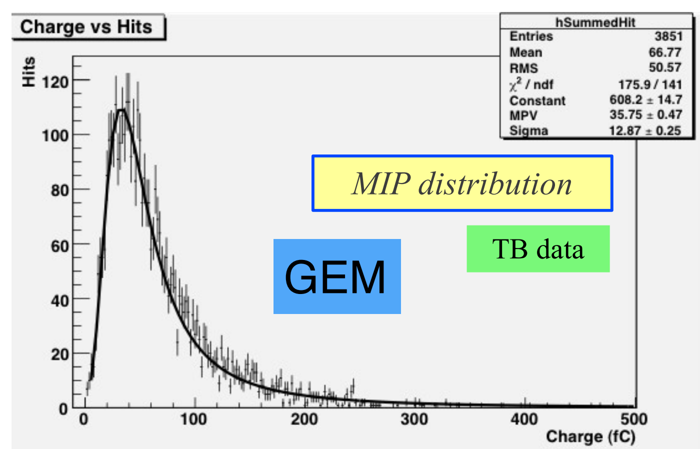

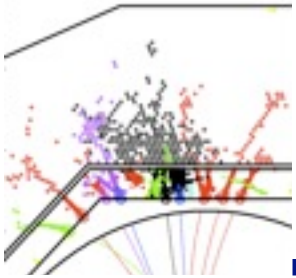

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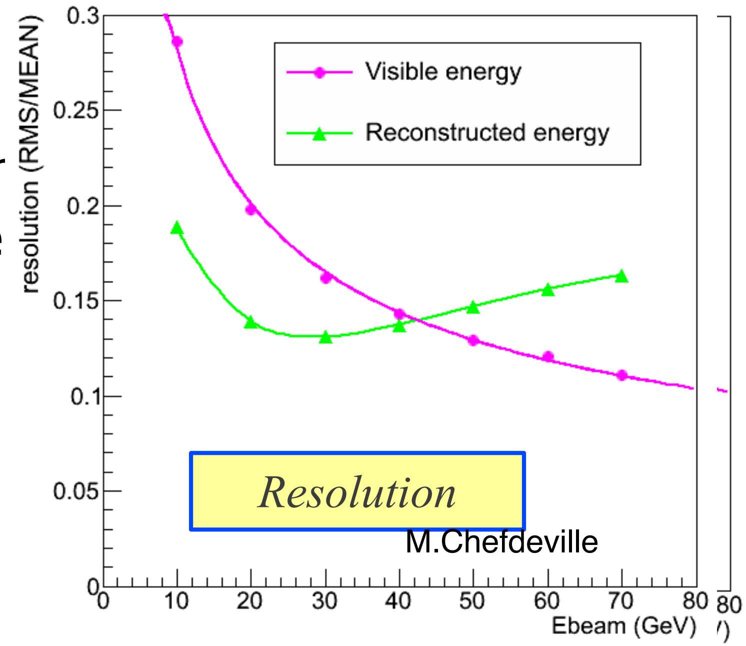

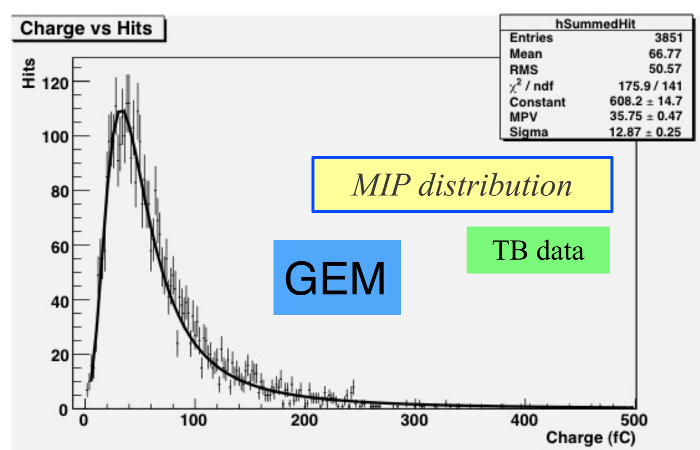

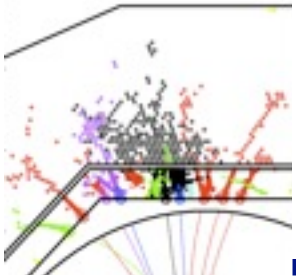

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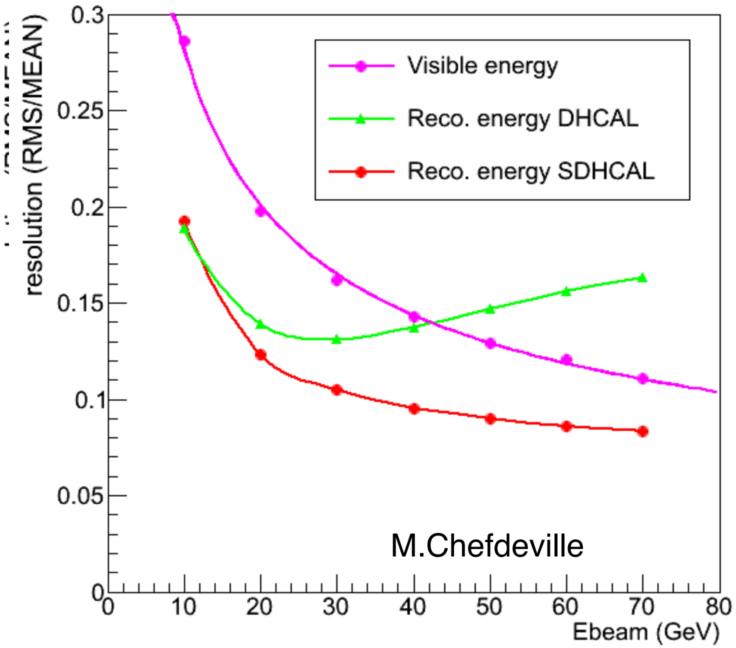

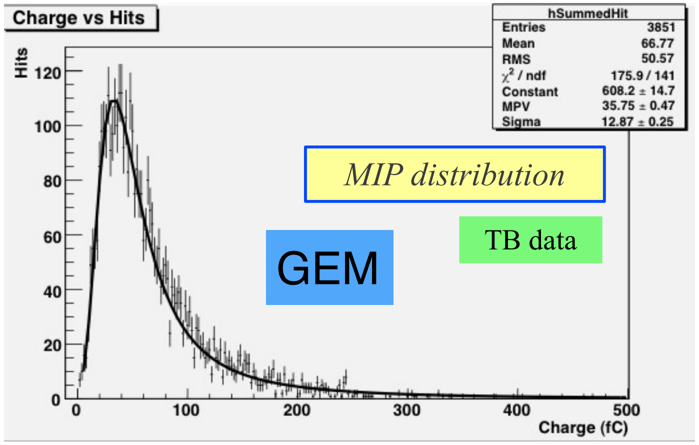

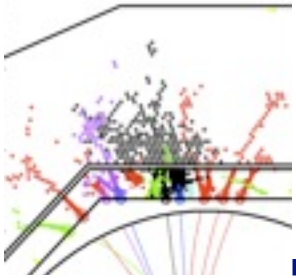

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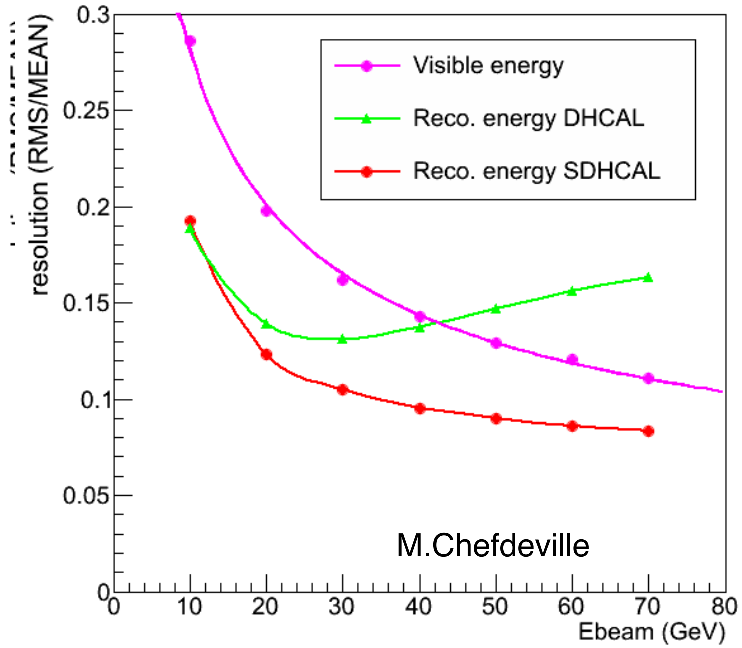
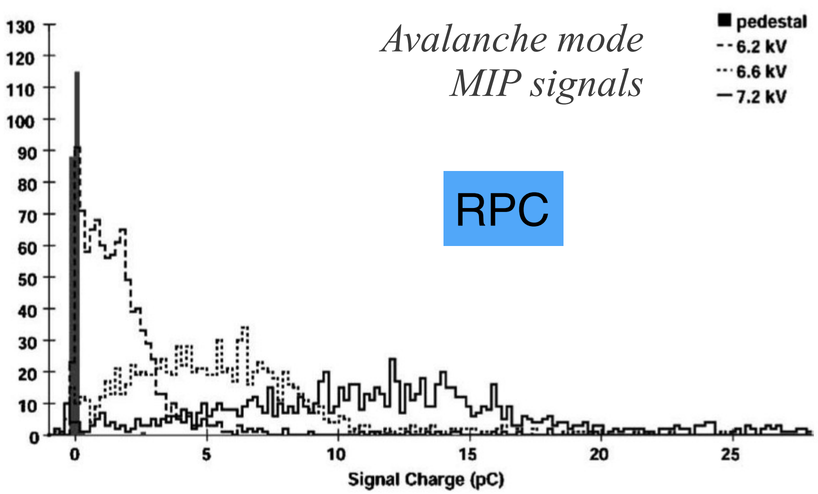
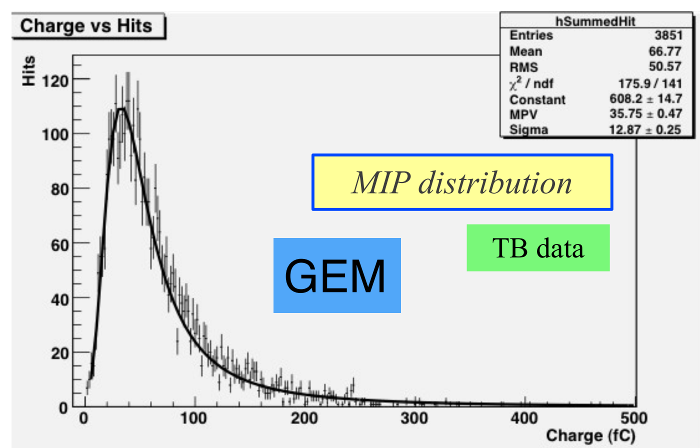
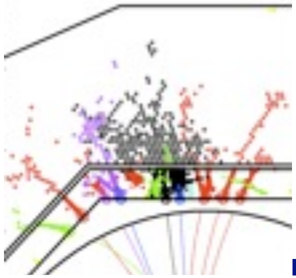




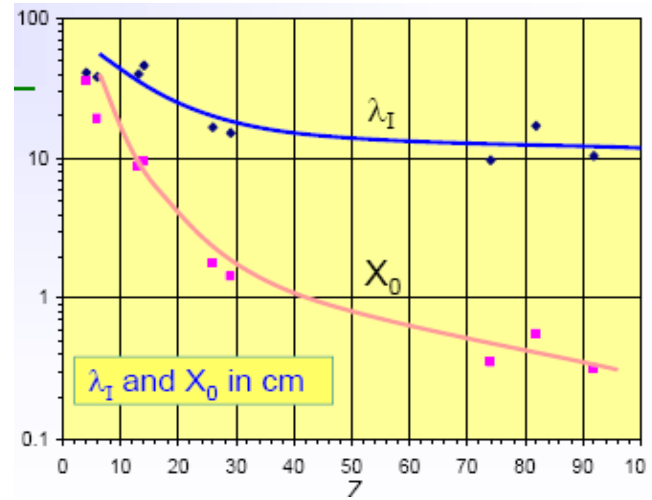


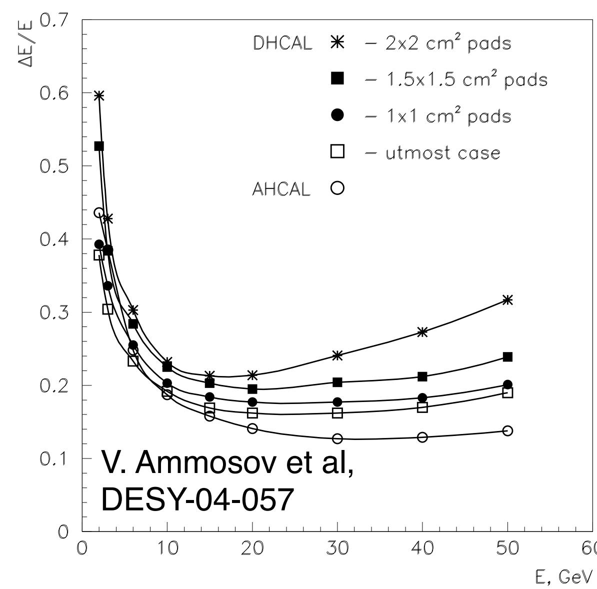


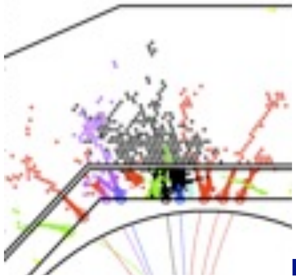
Initial choices

- Analogue:
- 3cm x 3cm at ~ 3cm sampling pitch
- corresponds to Molière radius and X_0; hadron shower sub-structure scale
- small effect on plain energy response and resolution, only via threshold
- more direct effects when software compensation methods are applied

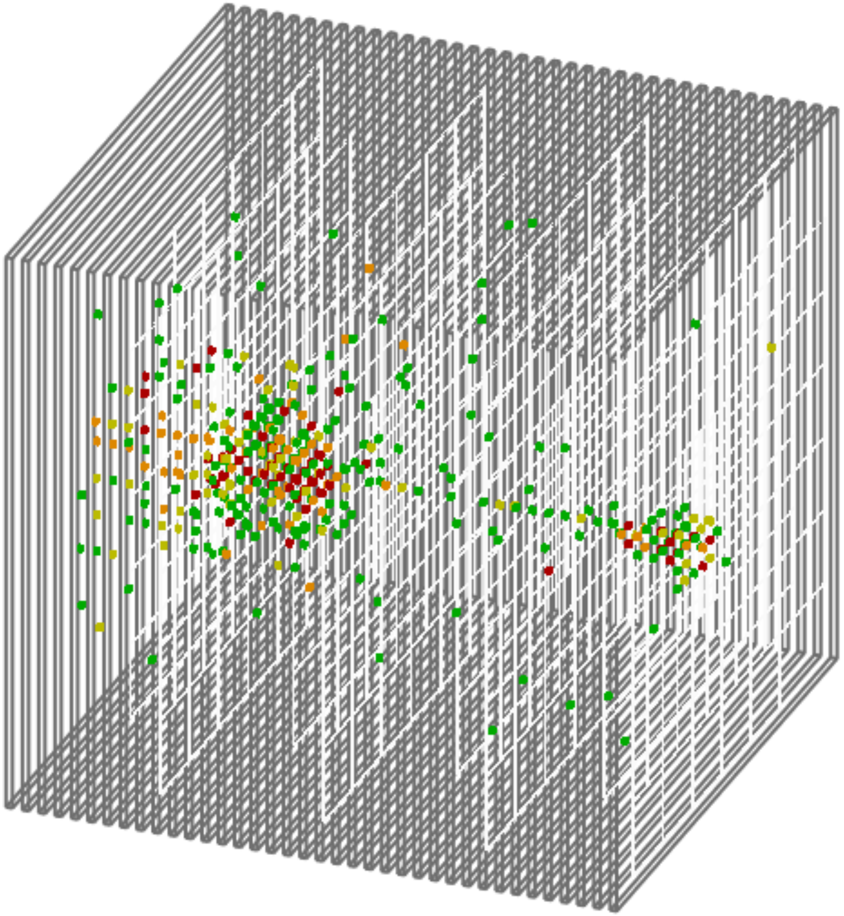
- Digital:
- 1cm x 1cm at ~ 3cm sampling pitch
- to limit saturation effects
- affects single particle linearity and resolution directly



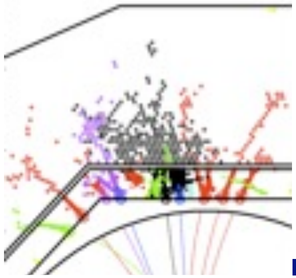




Event displays: Analogue HCAL



- pions 80 GeV
- W absorber
- 3cm scintillator + SiPM



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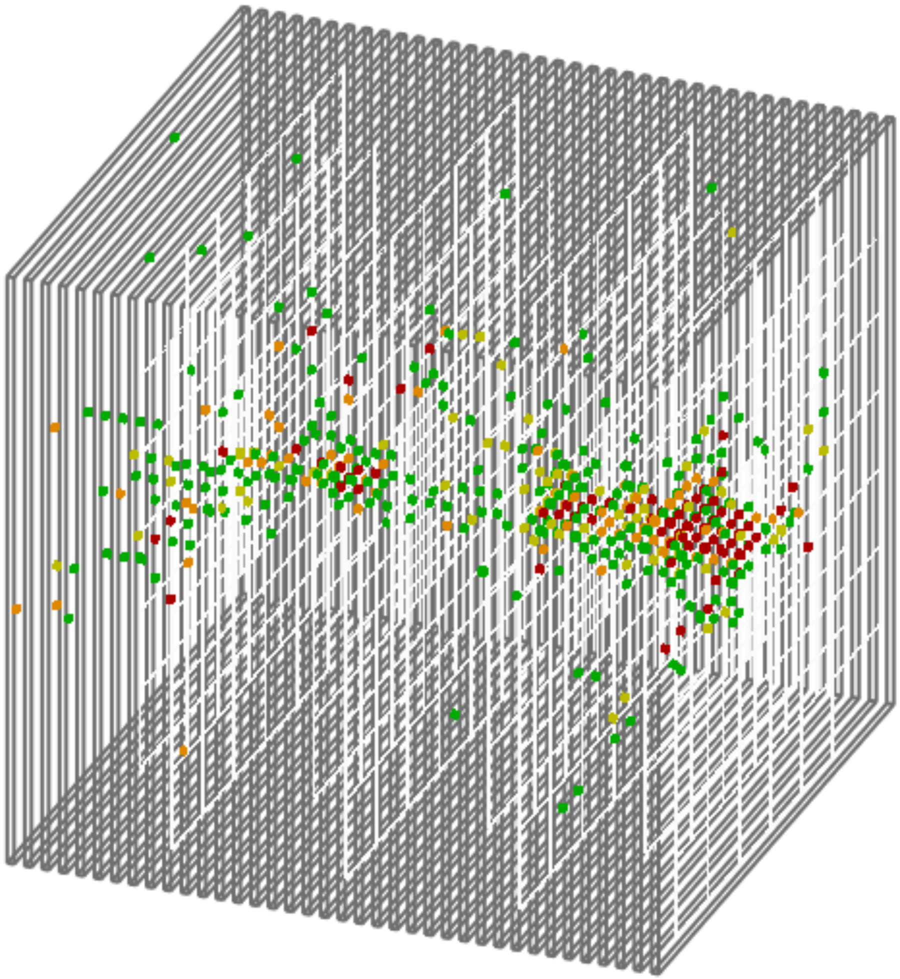

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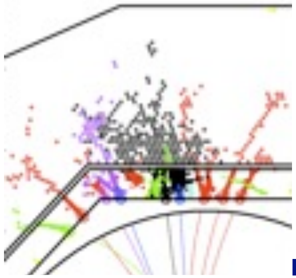

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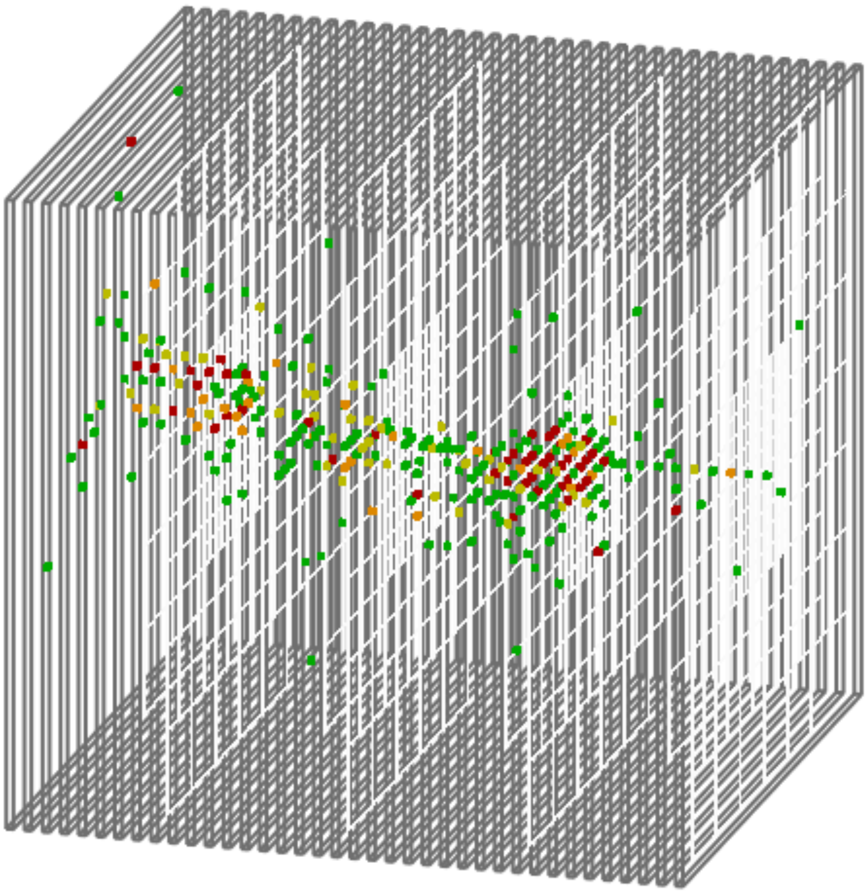

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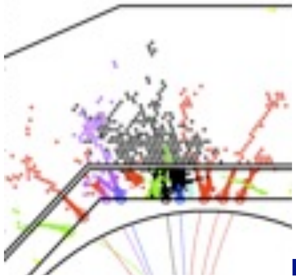
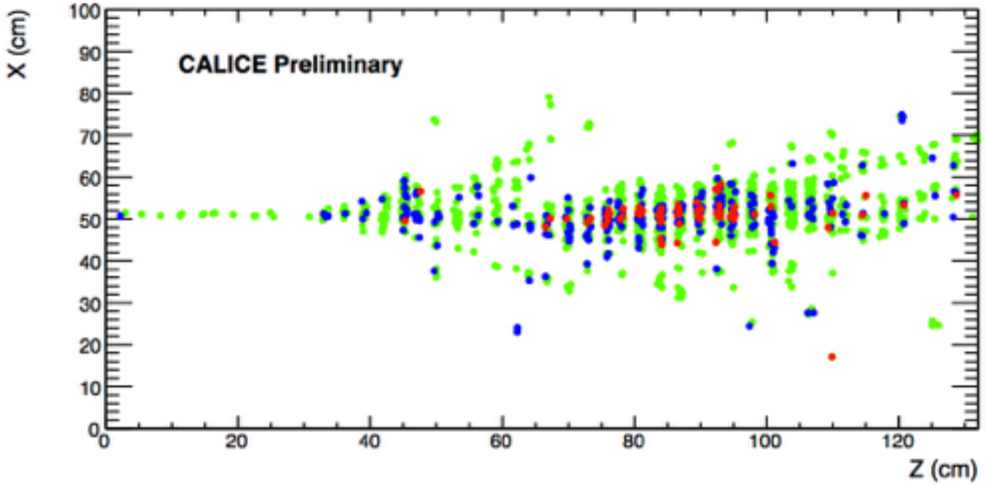
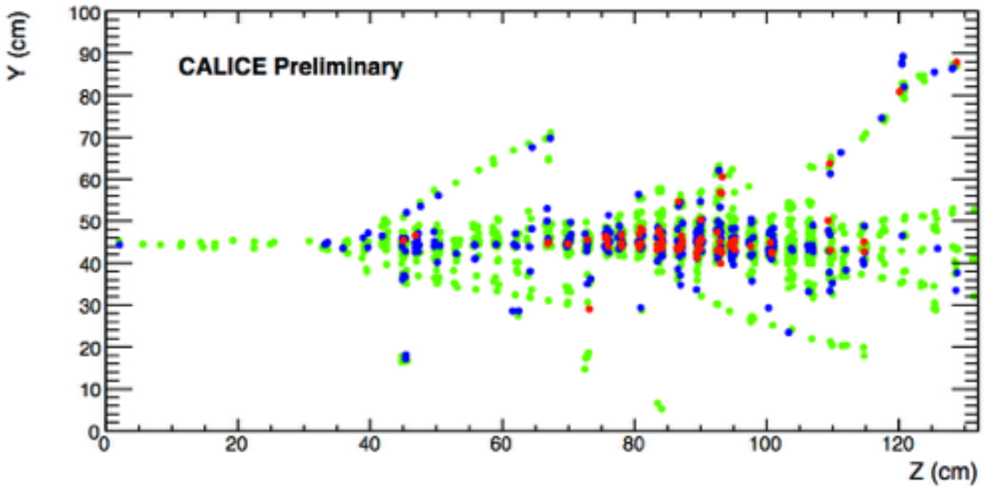
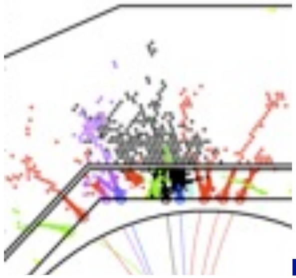


Semi-digital RPC HCAL

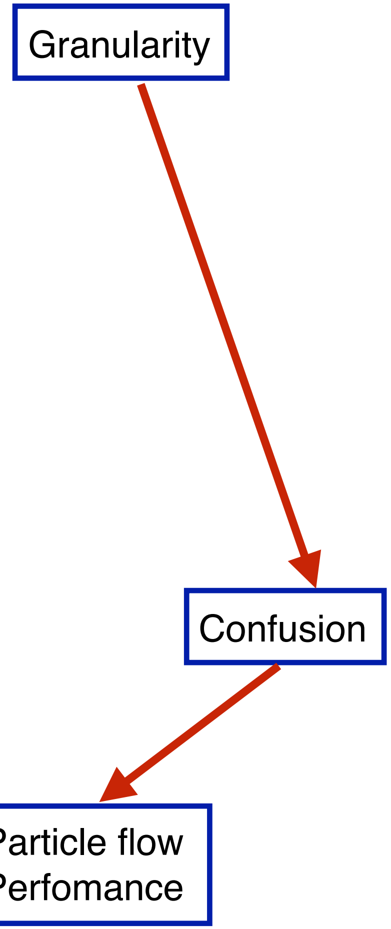


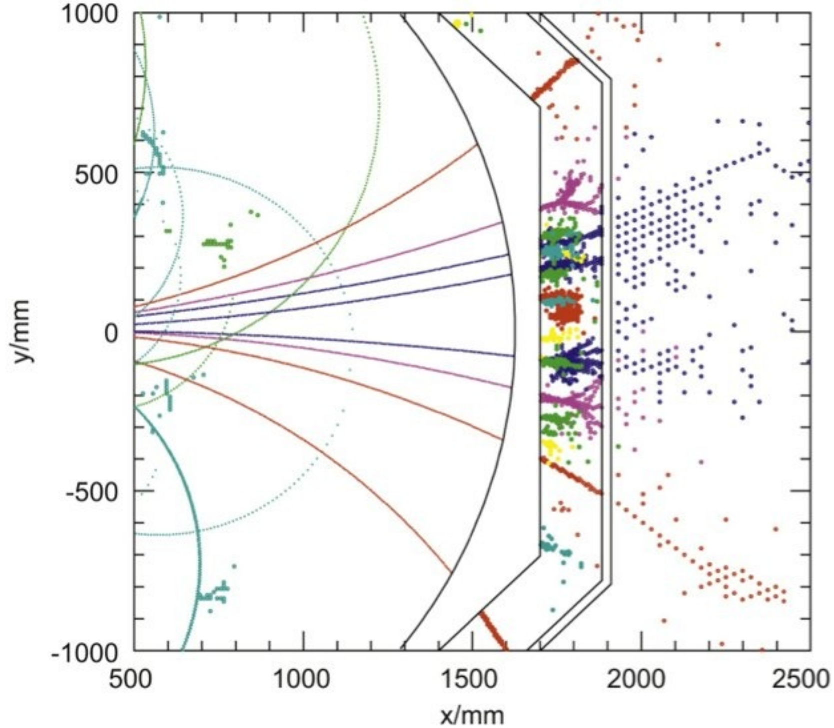


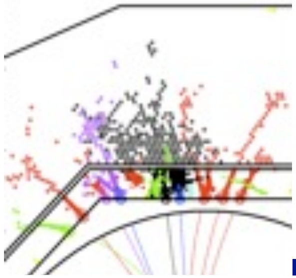
- pions 80 GeV
- Fe absorber
- 1 cm RPC, 3 thresholds



Effects of high granularity







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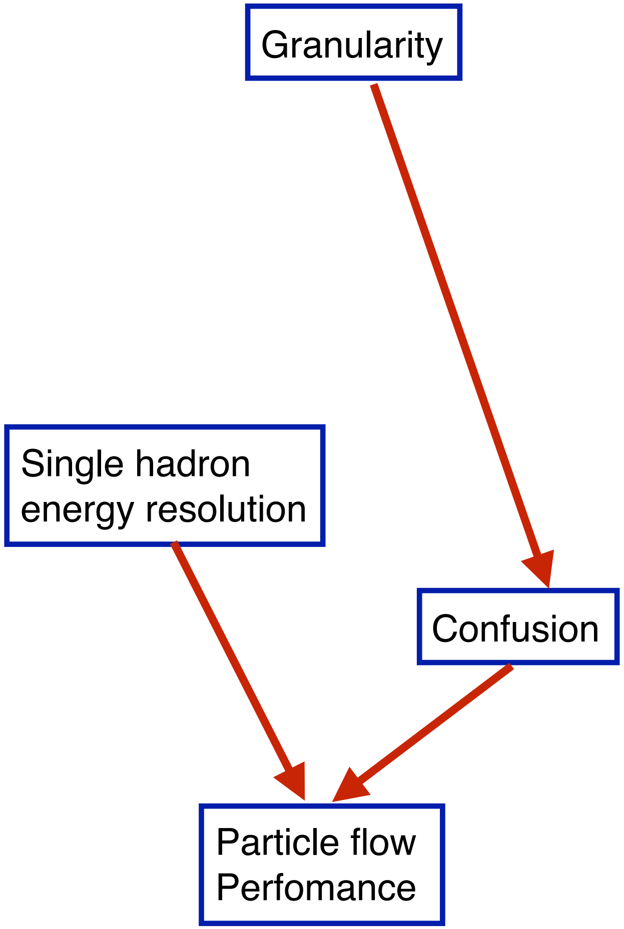

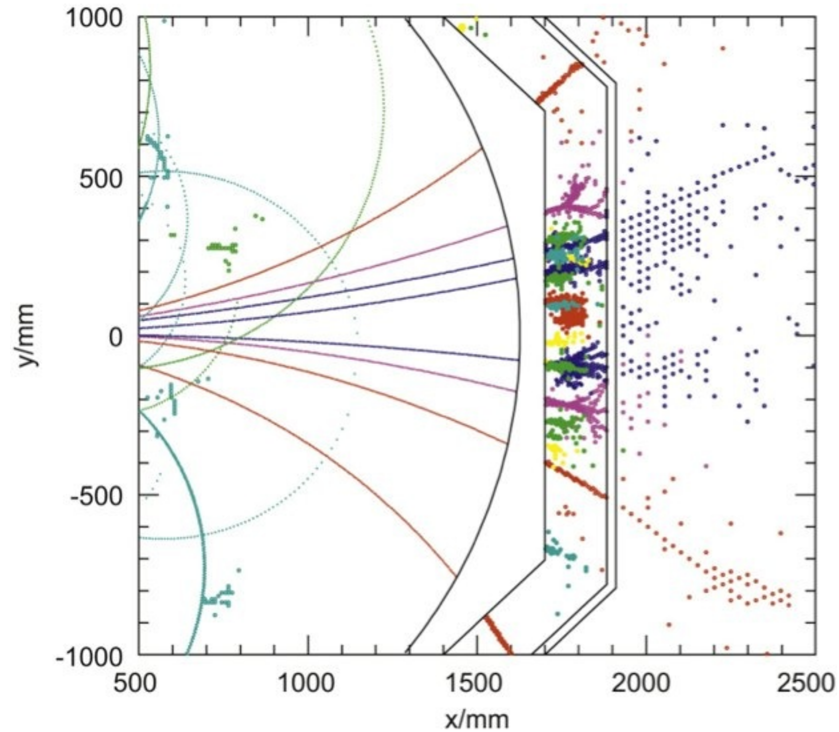

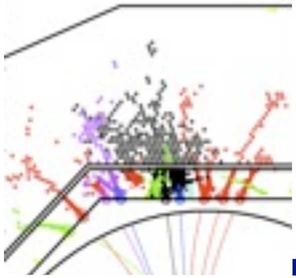

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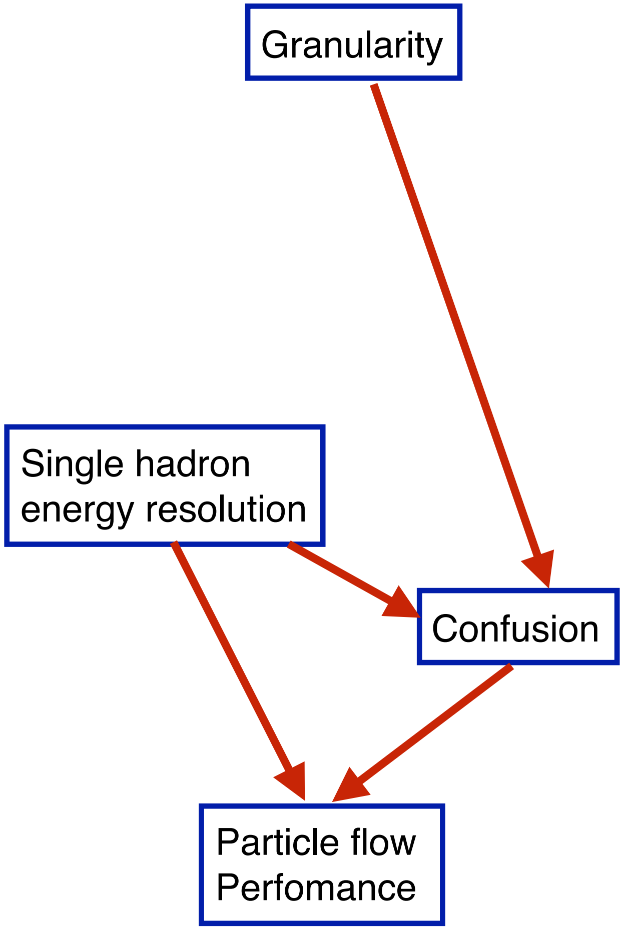

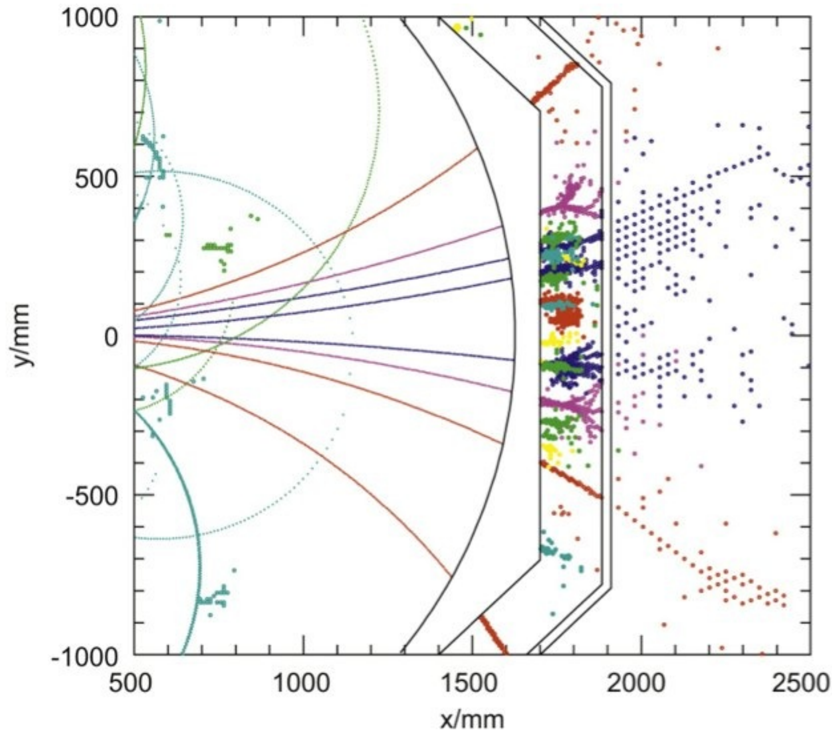

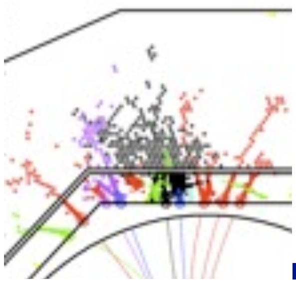

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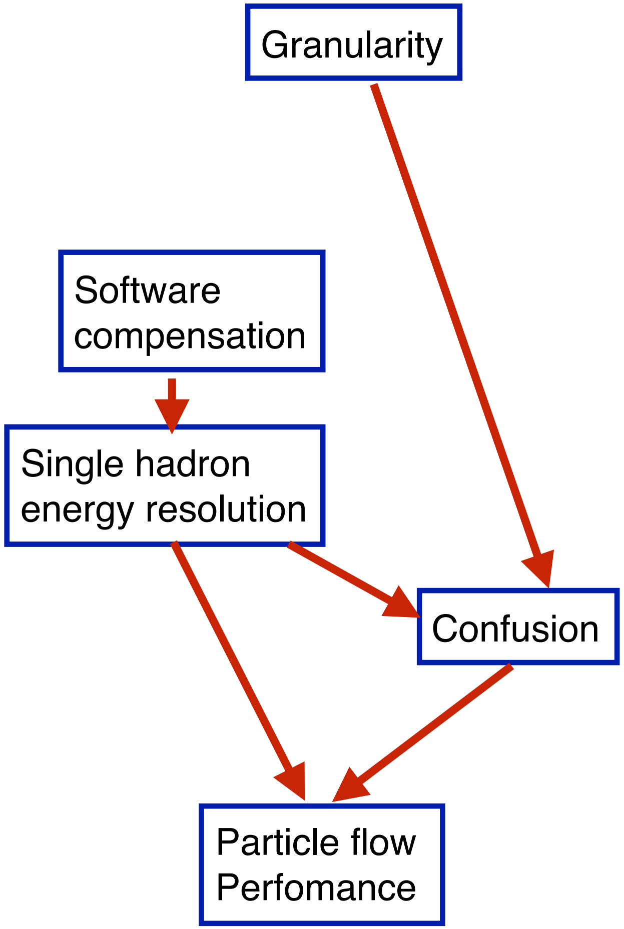

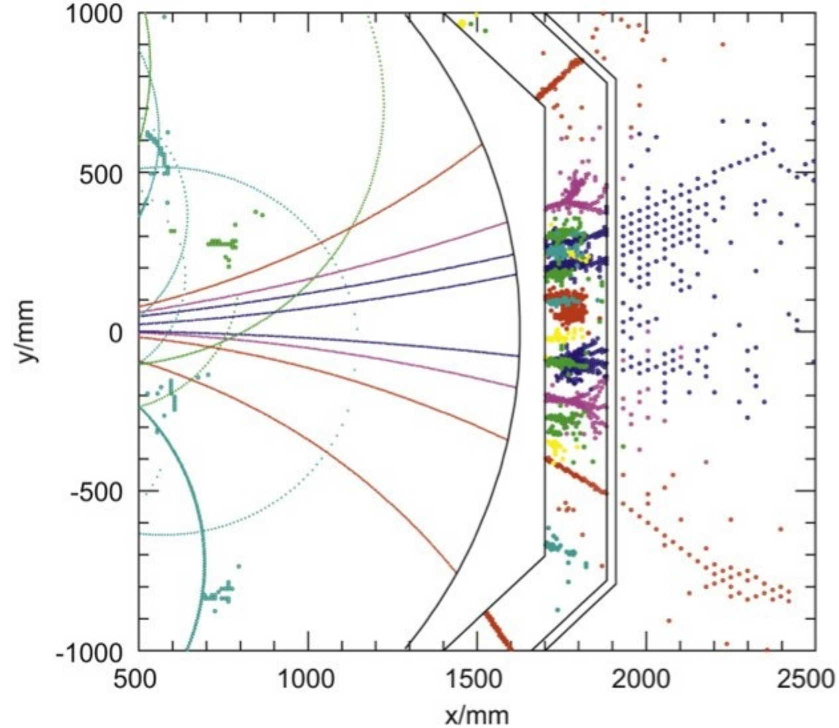

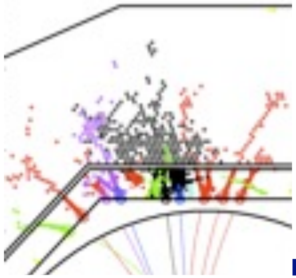

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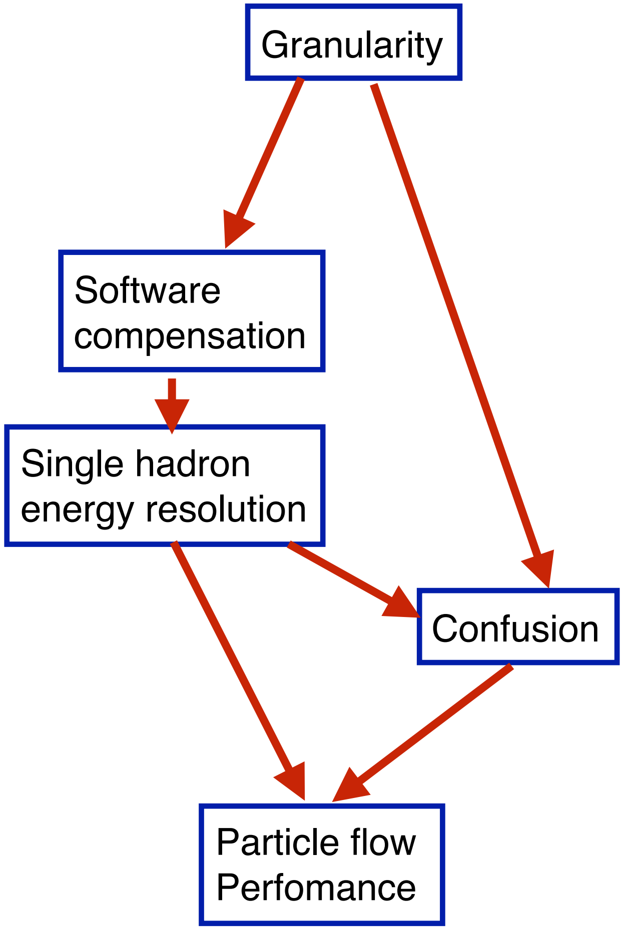

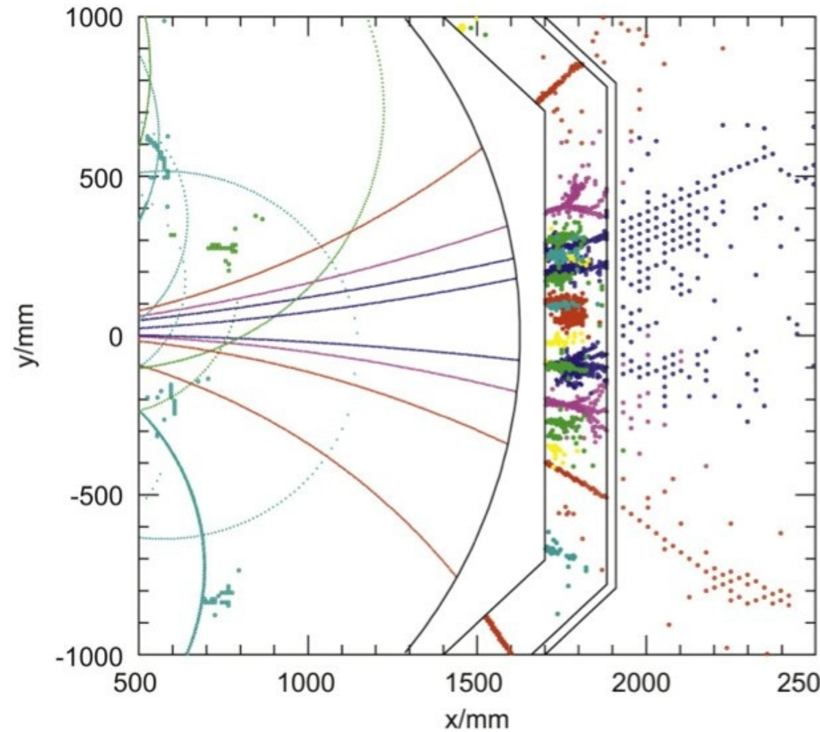

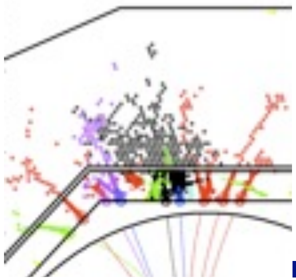

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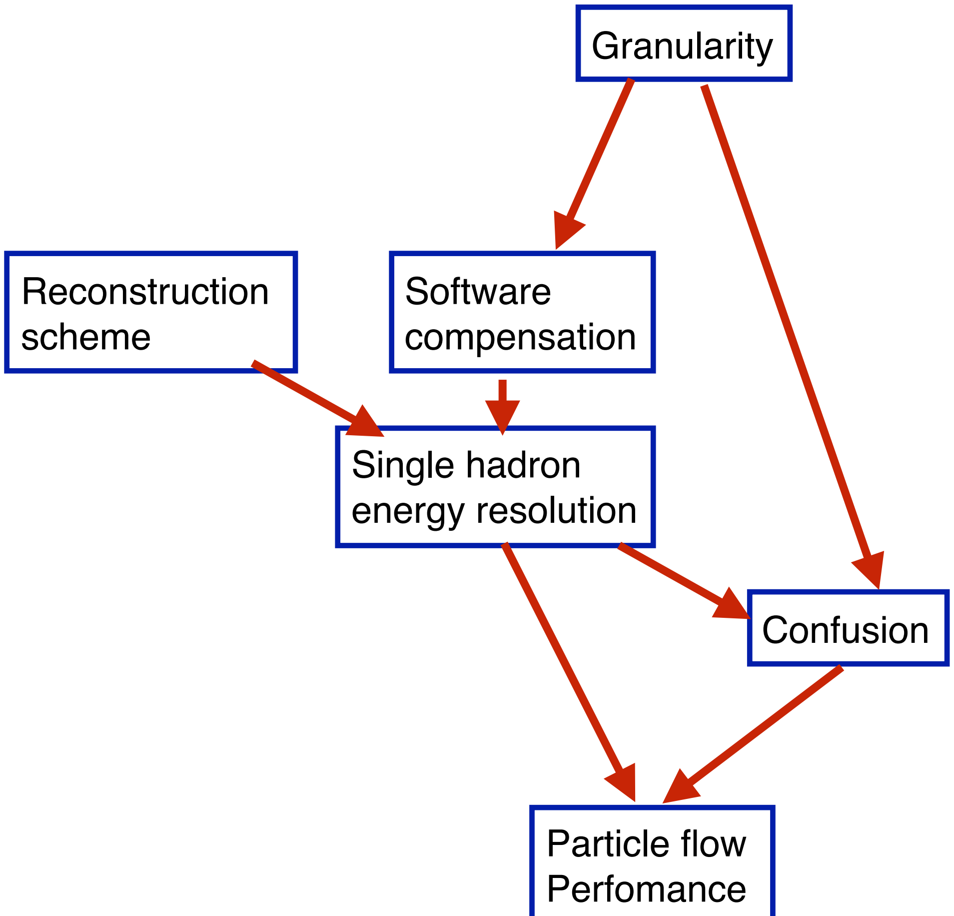
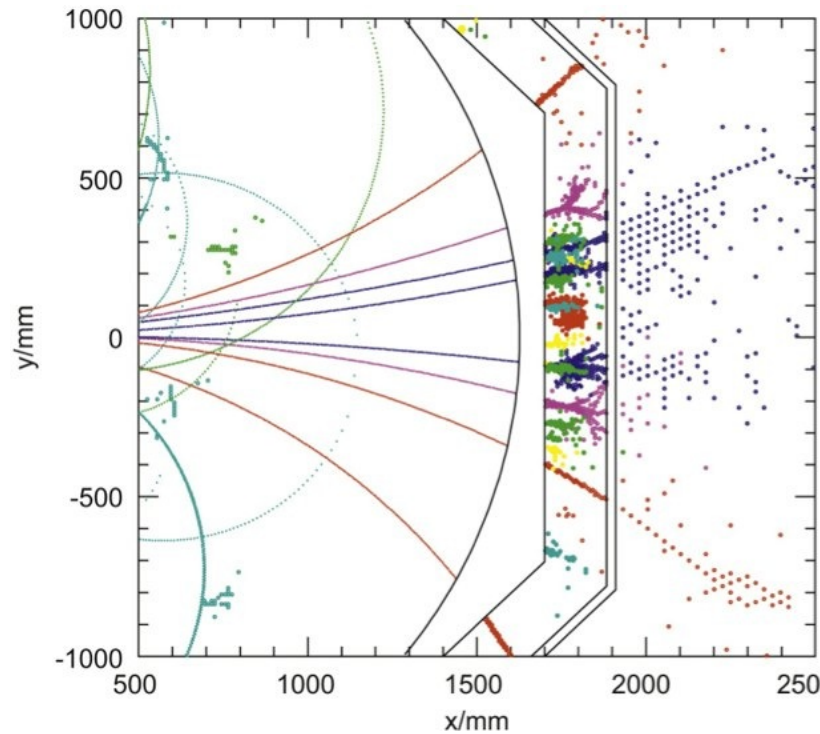
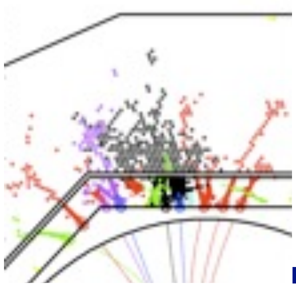
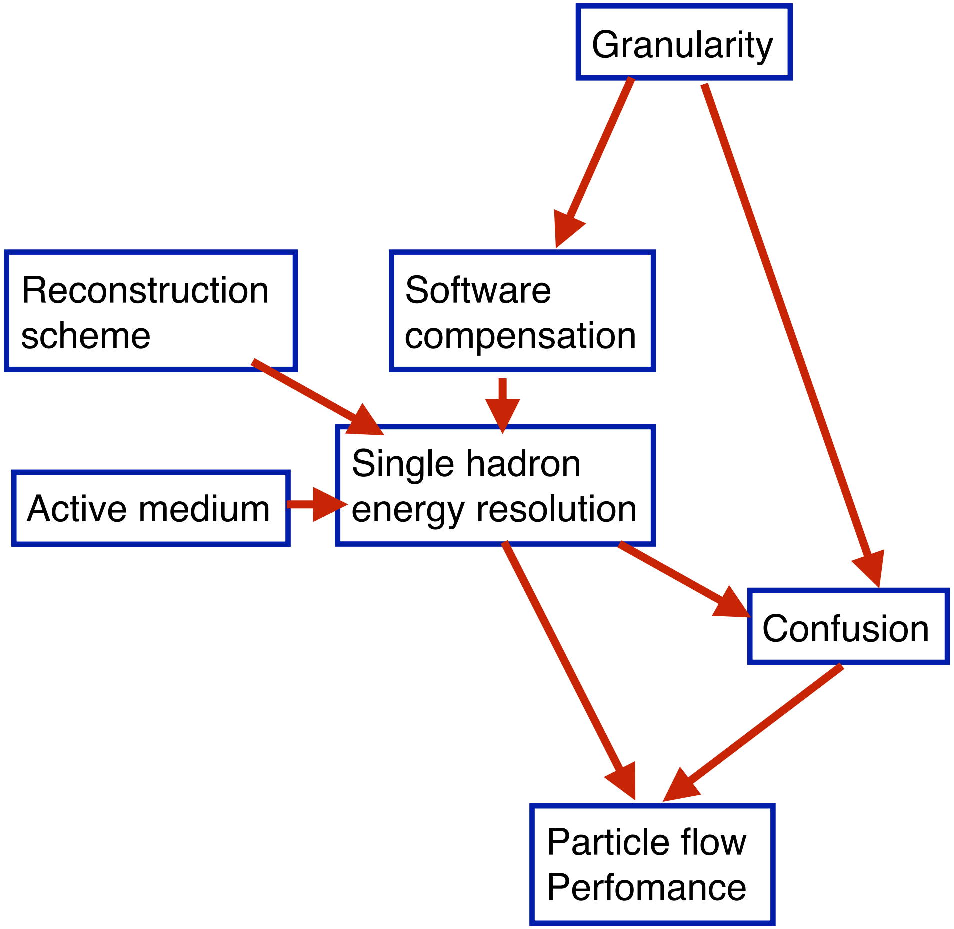
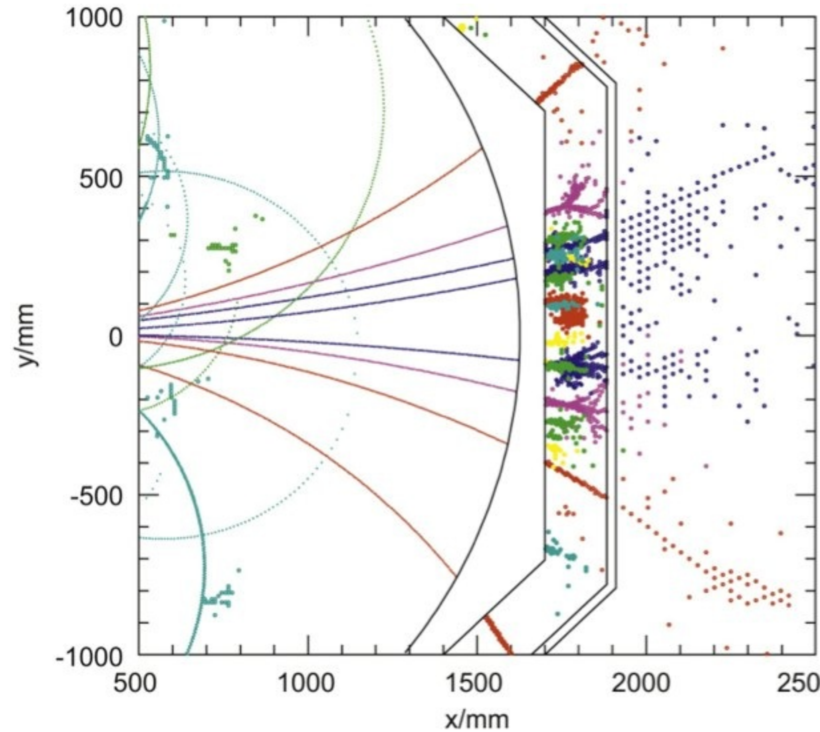






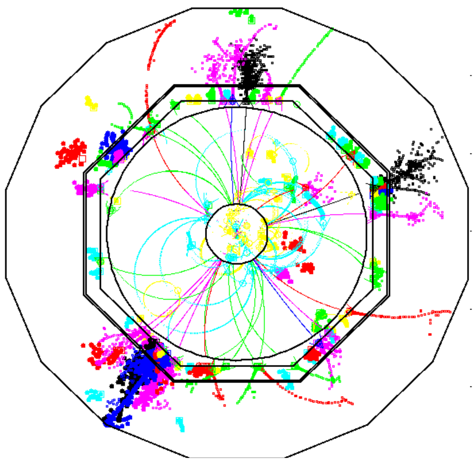
Effects of high granularity



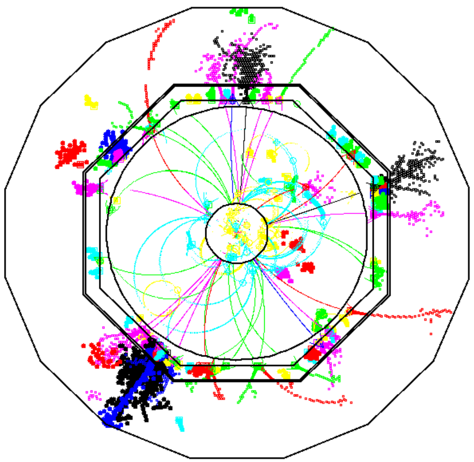


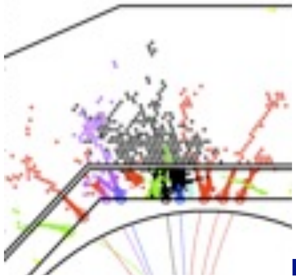
Analogue and (semi-) digital reconstruction of single hadrons

1x1



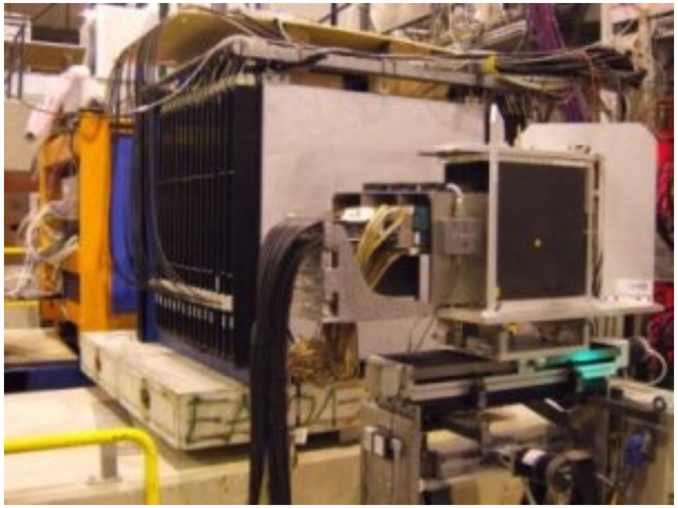
3x3

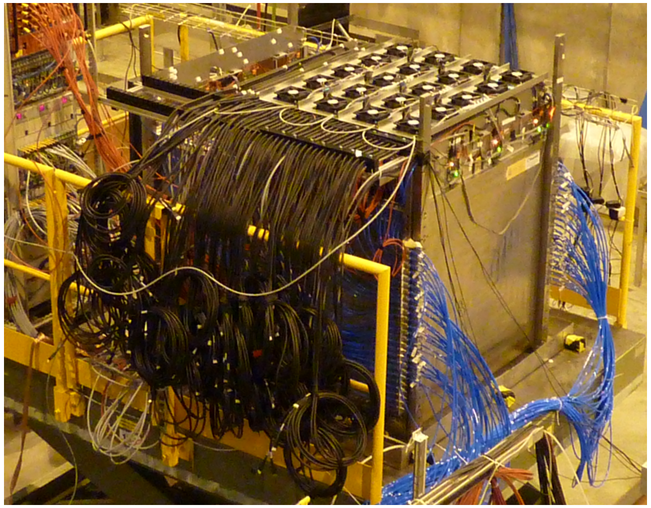


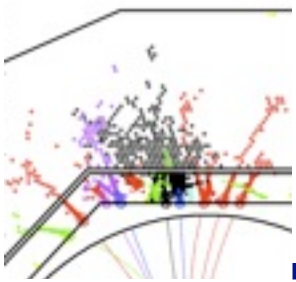


AHCAL and SDHCAL

- Scint and gas prototypes differ in medium, cell size and read-out scheme
- All of them affect single hadron and jet energy resolution
- Disentangle with validated simulations, and optimise, incl. s/w comp







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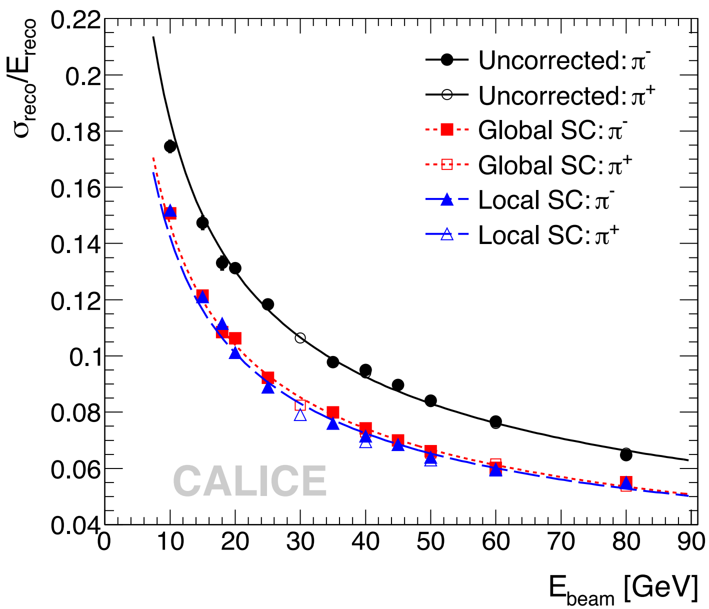
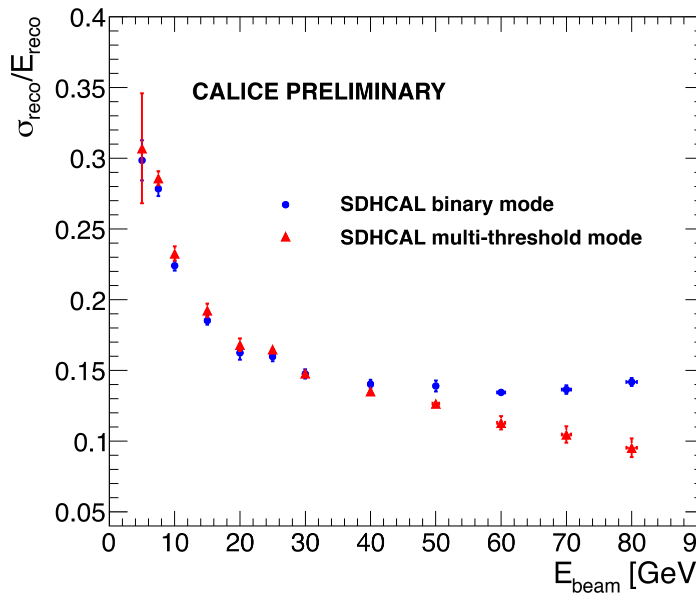
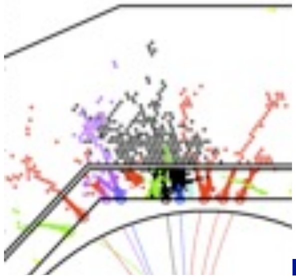
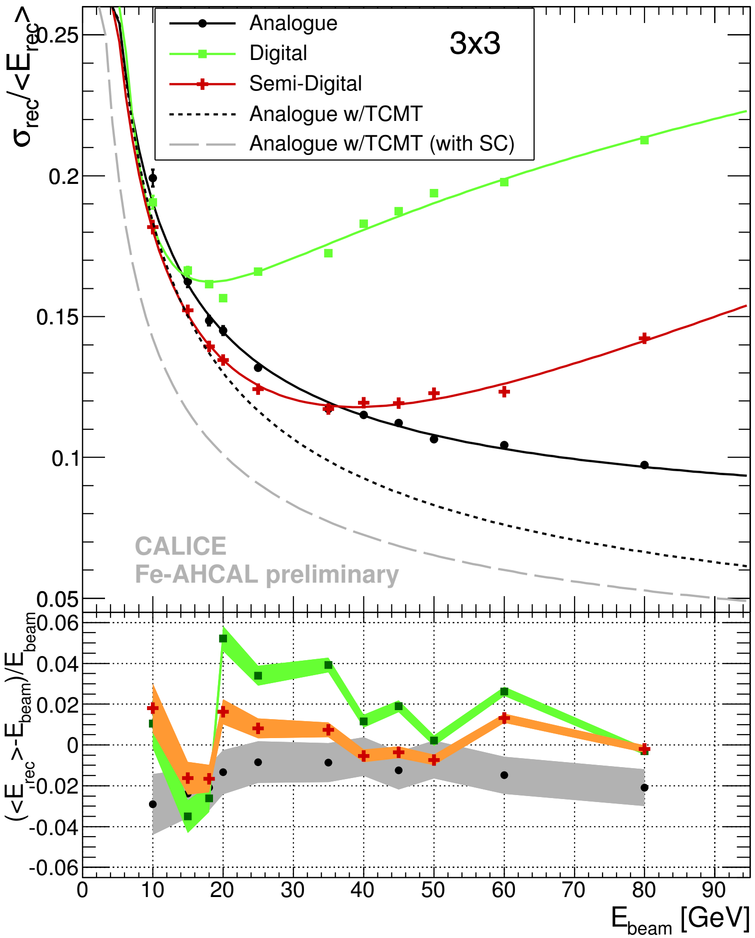
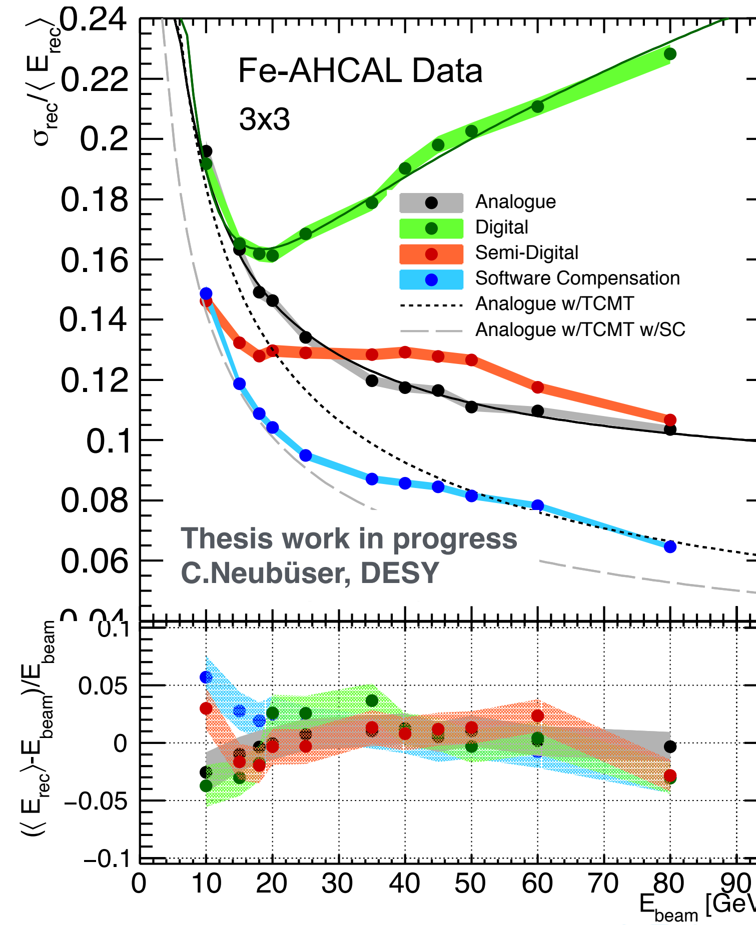




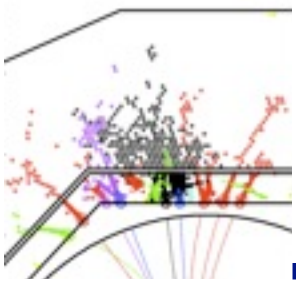


(Semi-) digital reconstruction of AHCAL





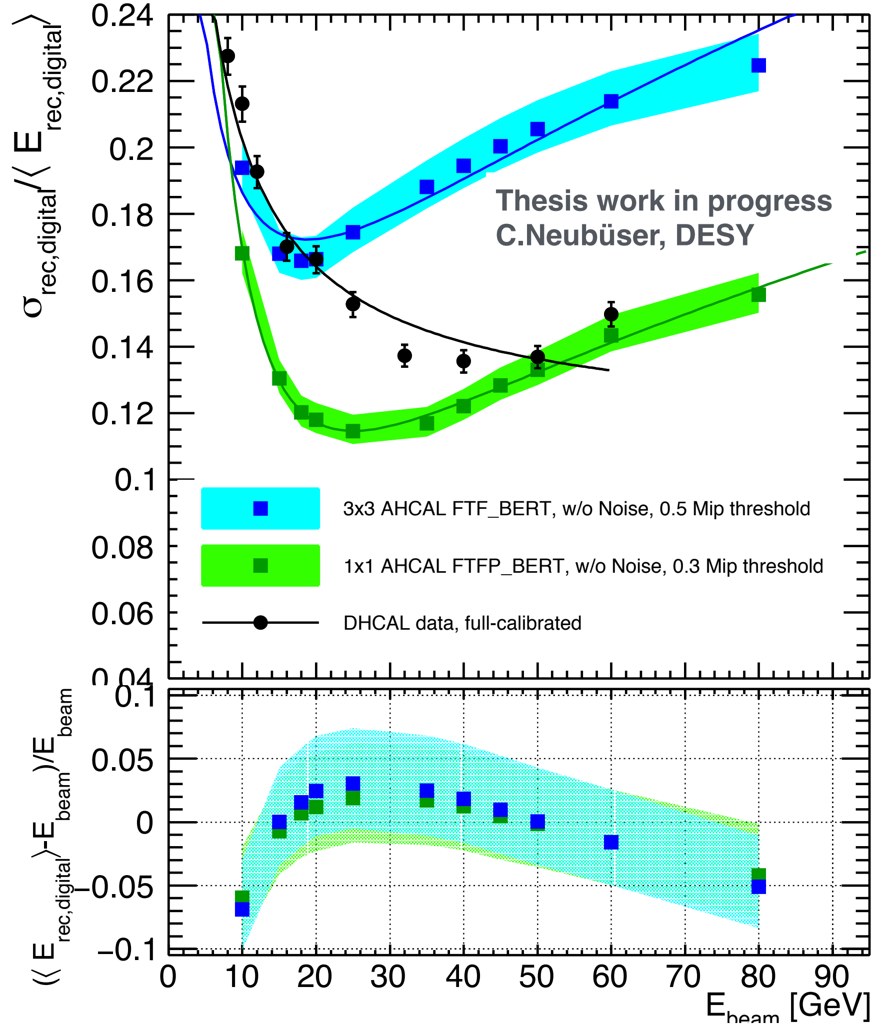
- Update of CAN-049 in preparation
  - optimise semi-digital weights, add software compensation

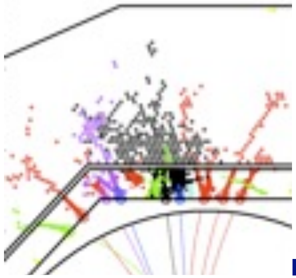


Simulate smaller granularities

- Simulate with same degree of realism as in AHCAL test beam
  - except noise (not an issue with present SiMs)
  - and adjust threshold in order to obtain similar linearity
- Apply digital and (re-optimised) semi-digital reconstruction

- Differences between gas and scintillator to be understood
  - validated simulations on their way





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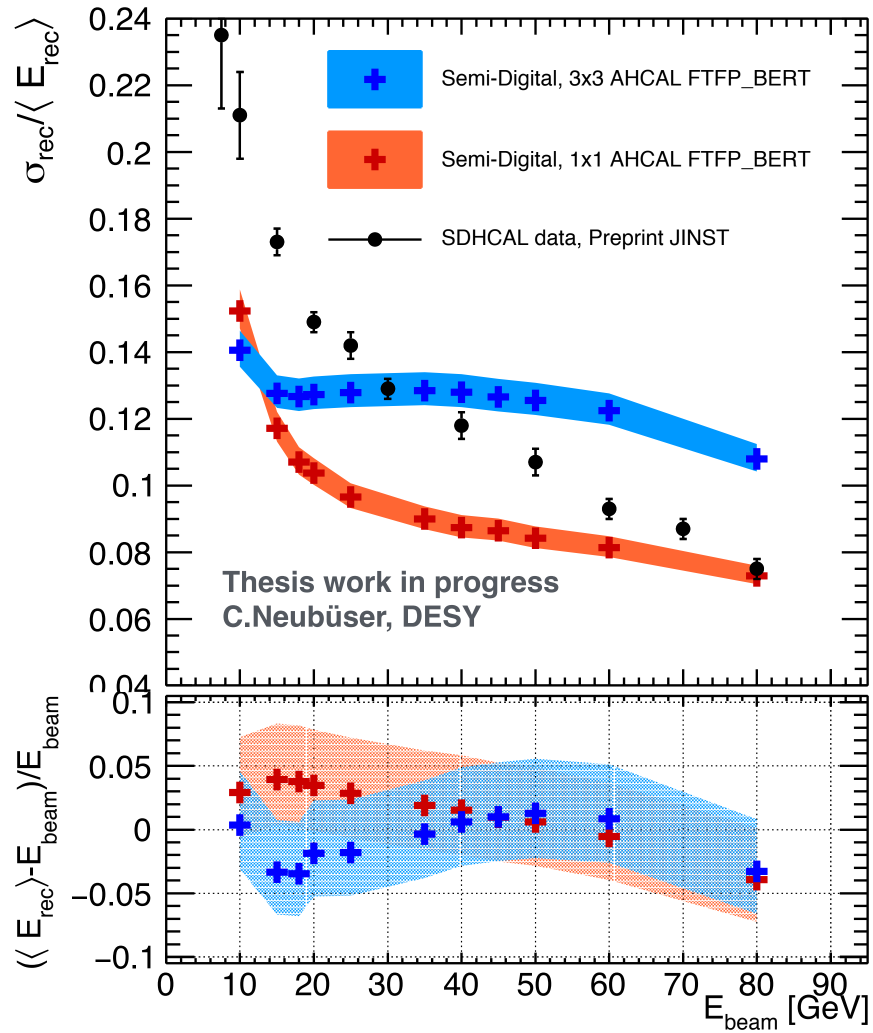
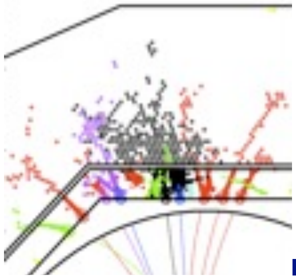
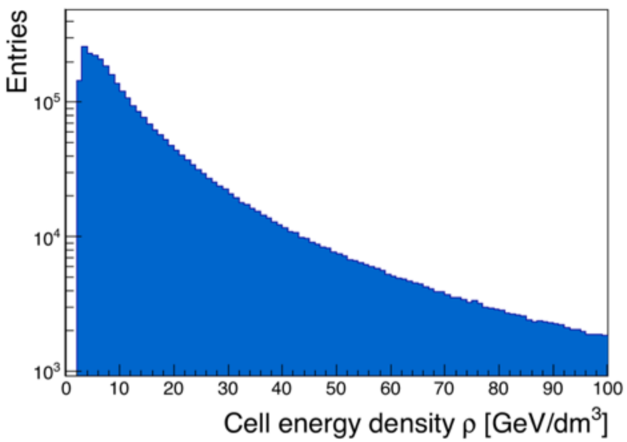
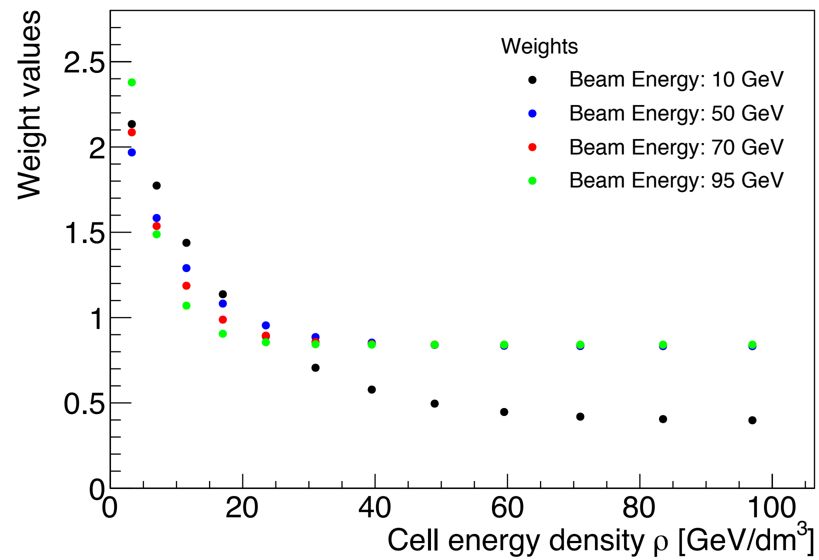




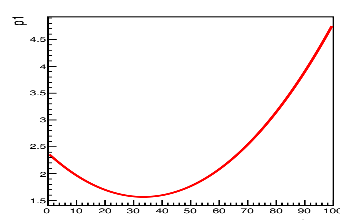
Software compensation

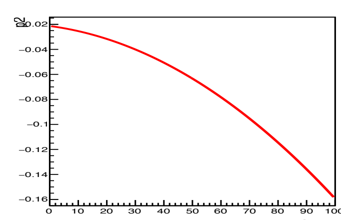
- Electromagnetic showers: higher density, larger response
- Software compensation: weight has according to cell energy

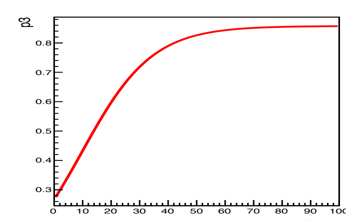




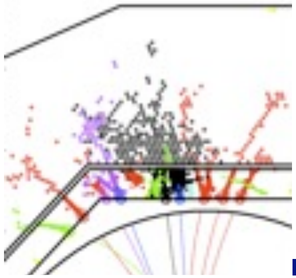
$$\omega(\rho) = p_1.exp(p_2.\rho) + p_3$$







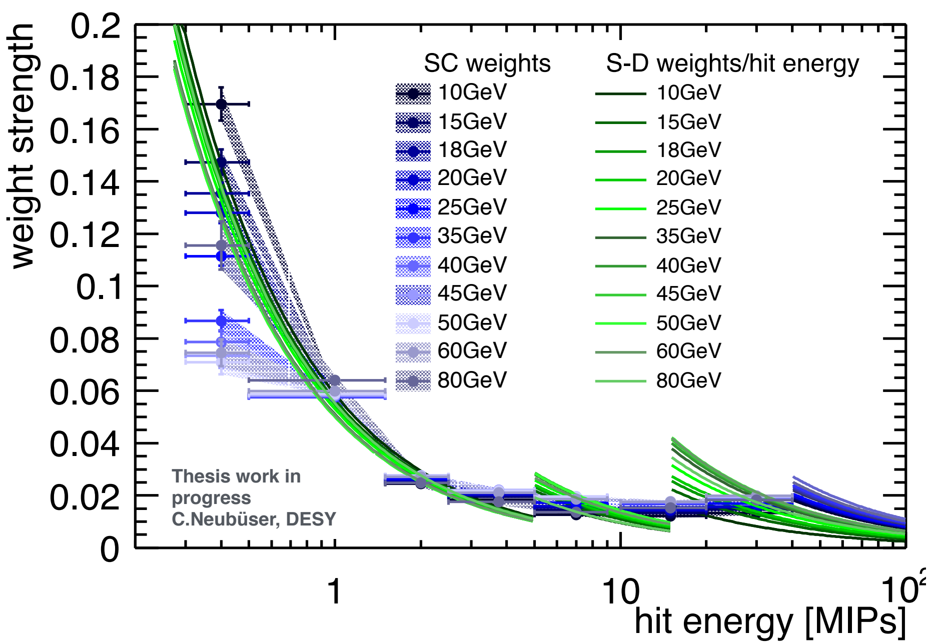
→ E_{beam}



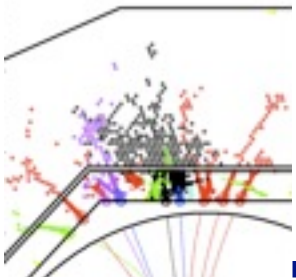
Analogue and digital weighting

- Analogue: $E_{rec,SC} = \sum_i \omega_{SC,i} \cdot E_i$ ω = ω(E_i, E_{tot})
- Semi-digital: $E_{rec,semi-digital} = \alpha \cdot N_1 + \beta \cdot N_2 + \gamma \cdot N_3$ α = α(N_{tot}), N_{tot} ~ E_{tot}^{α}

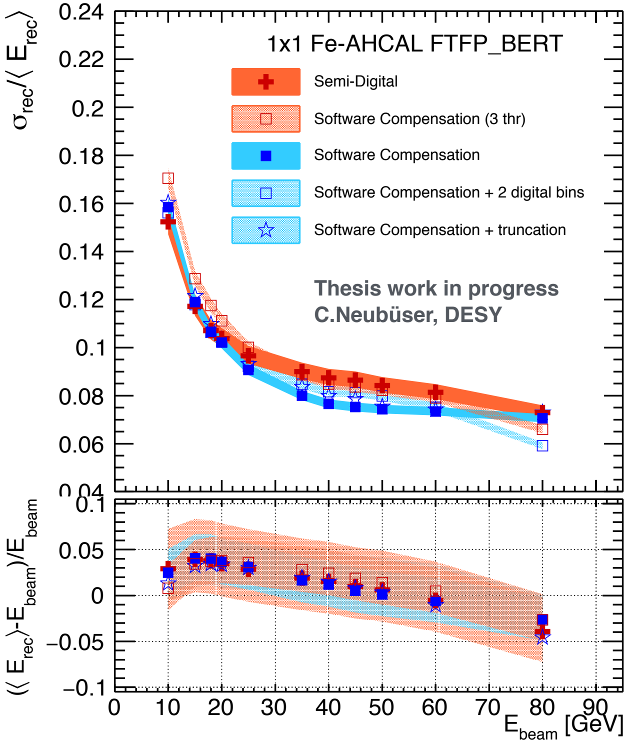
- Counting is equivalent to weighting with 1/E_{hit}: ω = α/E_{hit}
- Use common formalism and learn from each other



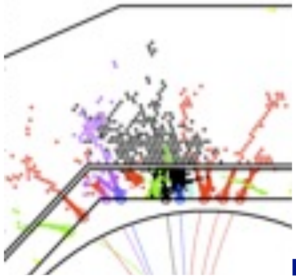
in principle the same
differences in detail



Read-out scheme and resolution



- vary number of bins and energy dependence within bins
- small differences once some weighting is applied



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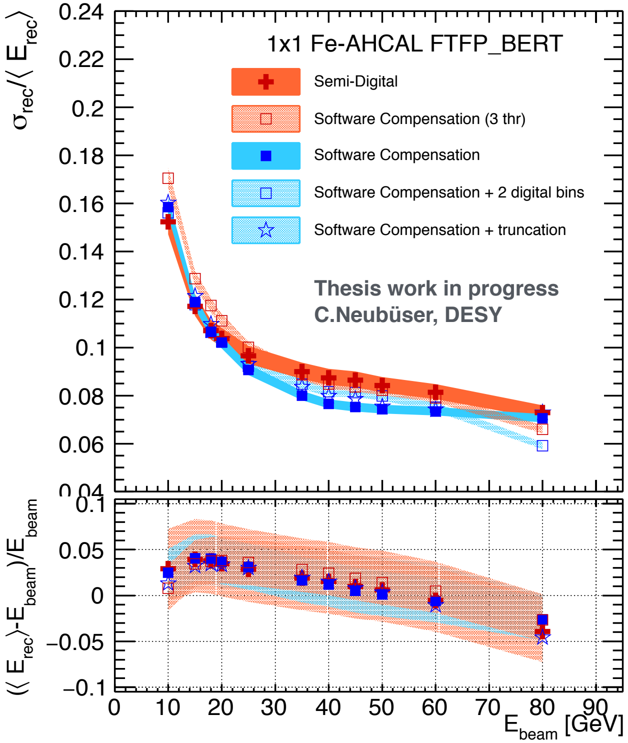

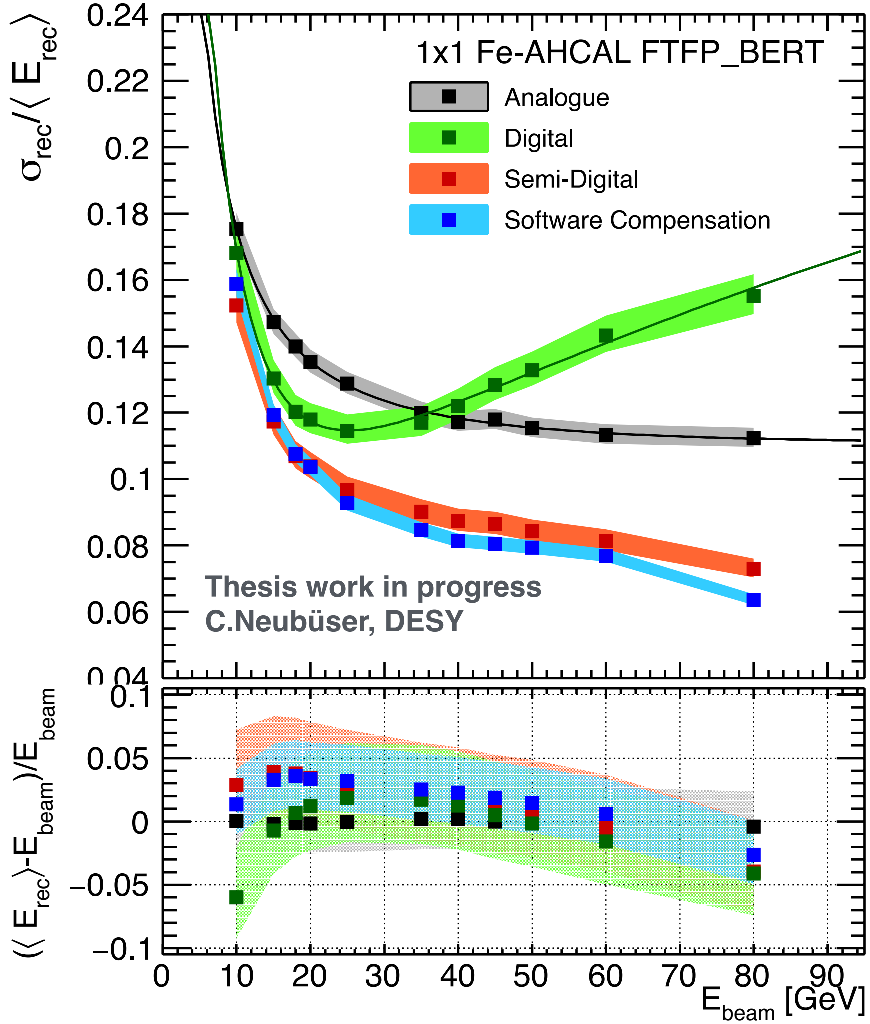

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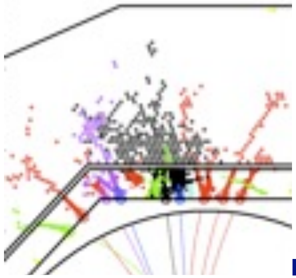
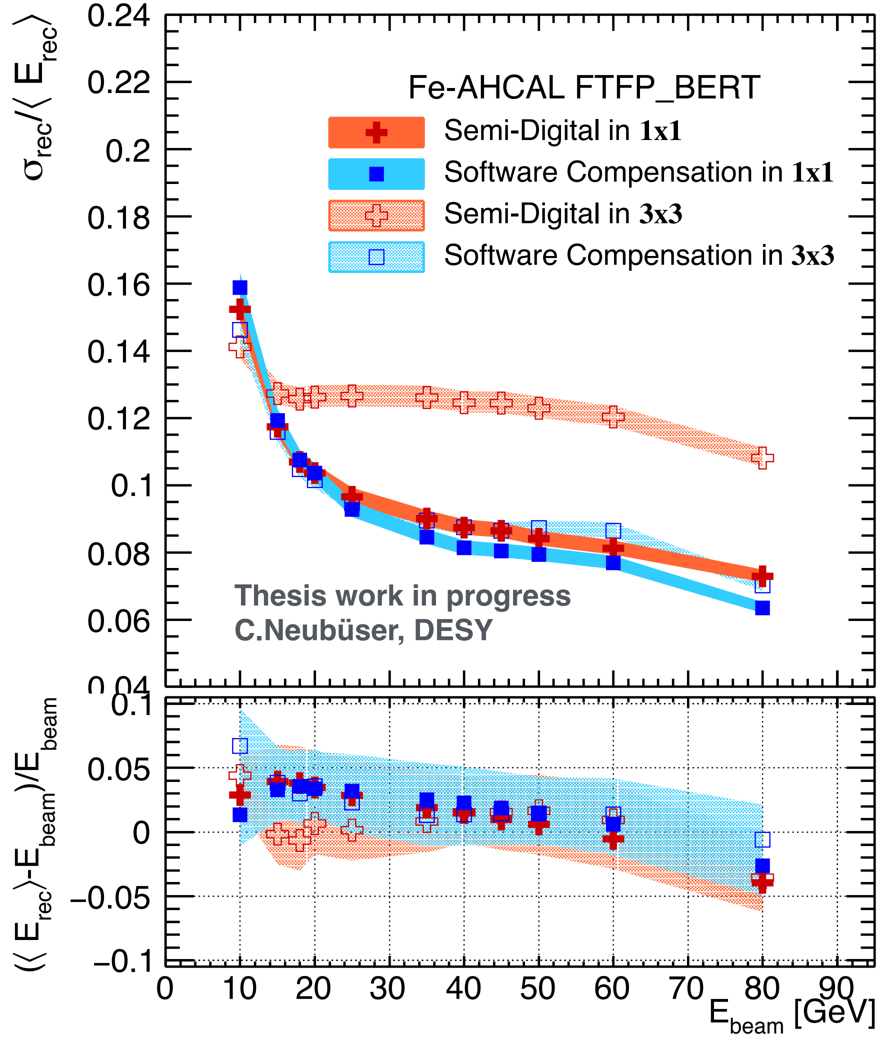
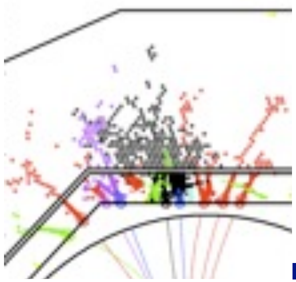


Granularity and resolution 1

- 1x1: semi-digital as good as analogue with s/w comp
  - 2 bits are enough
- 3x3: analogue with s/w comp better than SD, as good as 1x1
  - for analogue read-out 3x3 is enough





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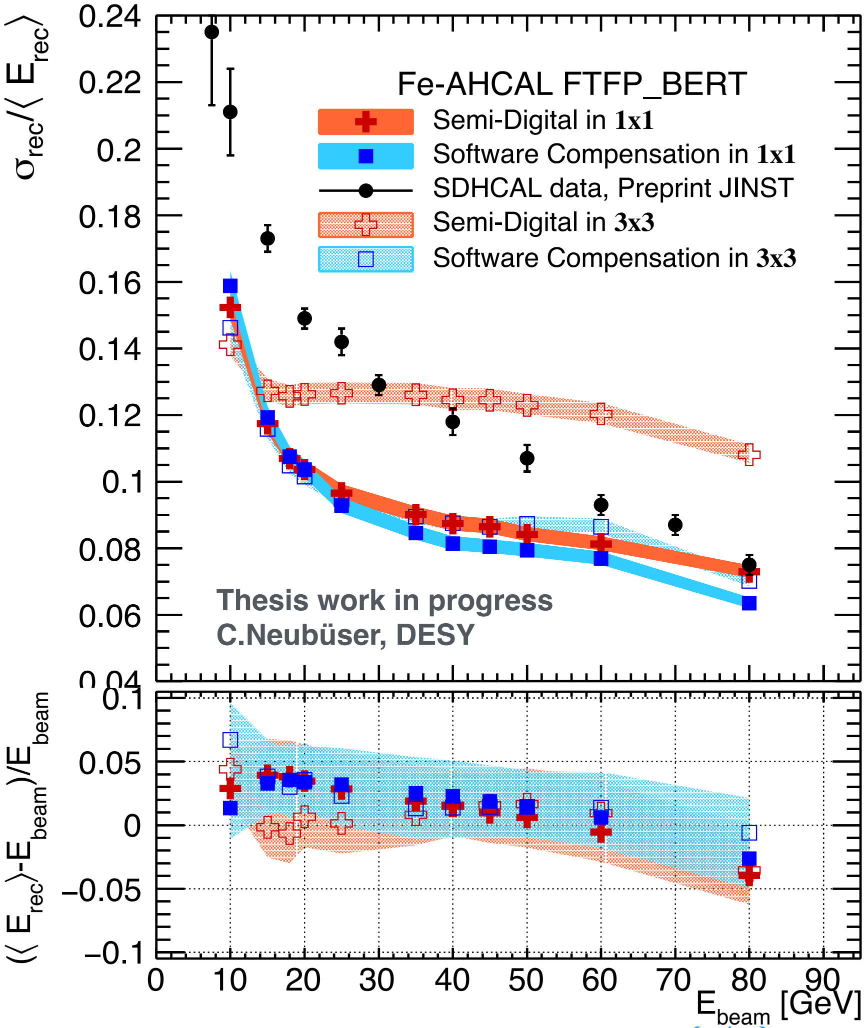
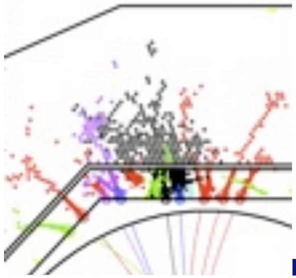
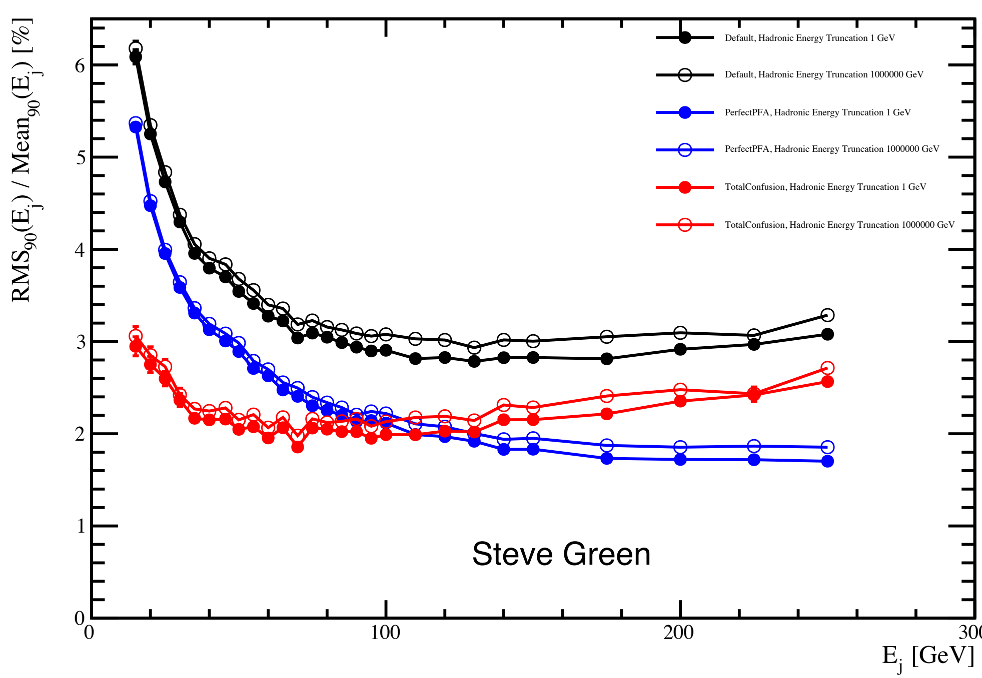


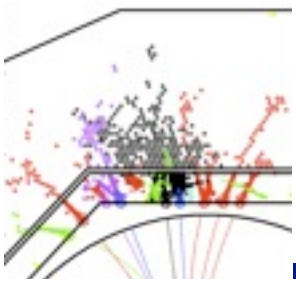


s/w compensation and PFLOW

- Jet energy resolution is the goal
- In principle can benefit in two-fold way:
  - improve resolution for neutral objects - done
  - improve cluster energy estimators for track-cluster association - on its way

studies with Pandora PFA





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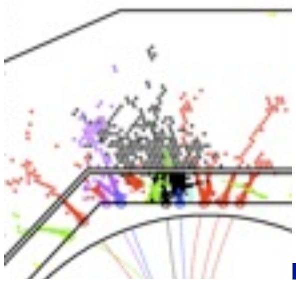

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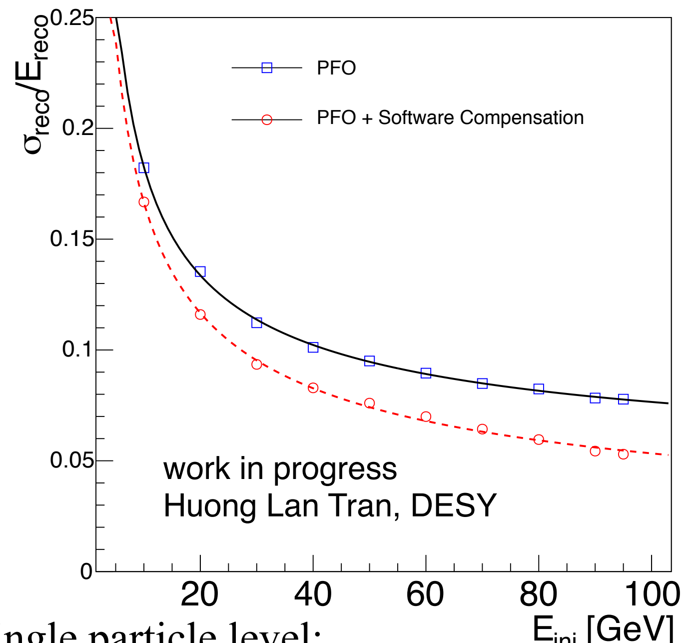
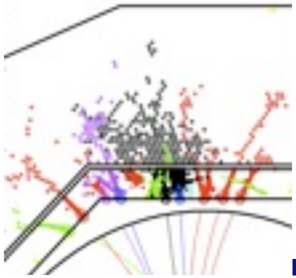
Single particle level:





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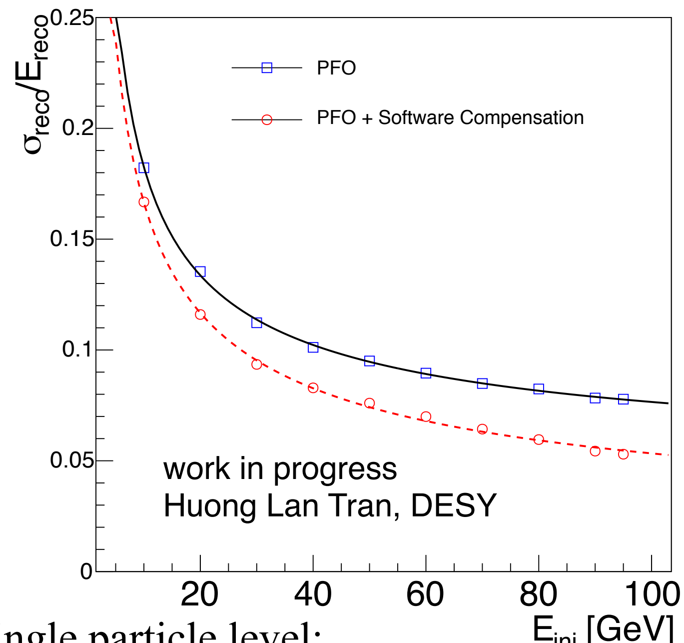
studies with F



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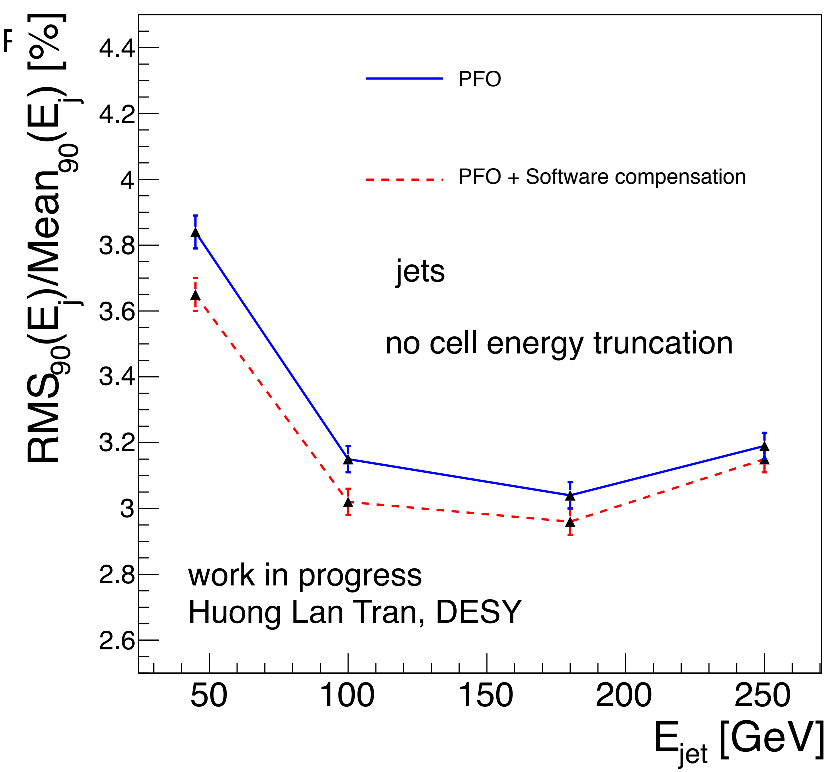
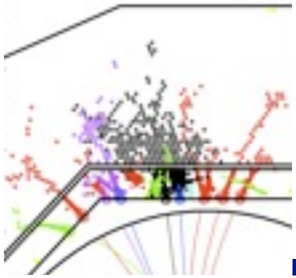
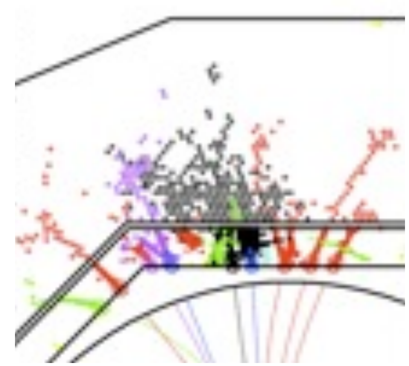


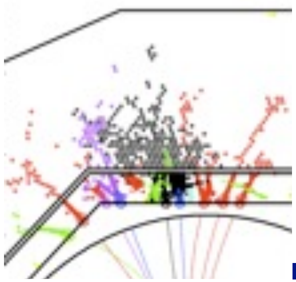


s/w compensation and clustering

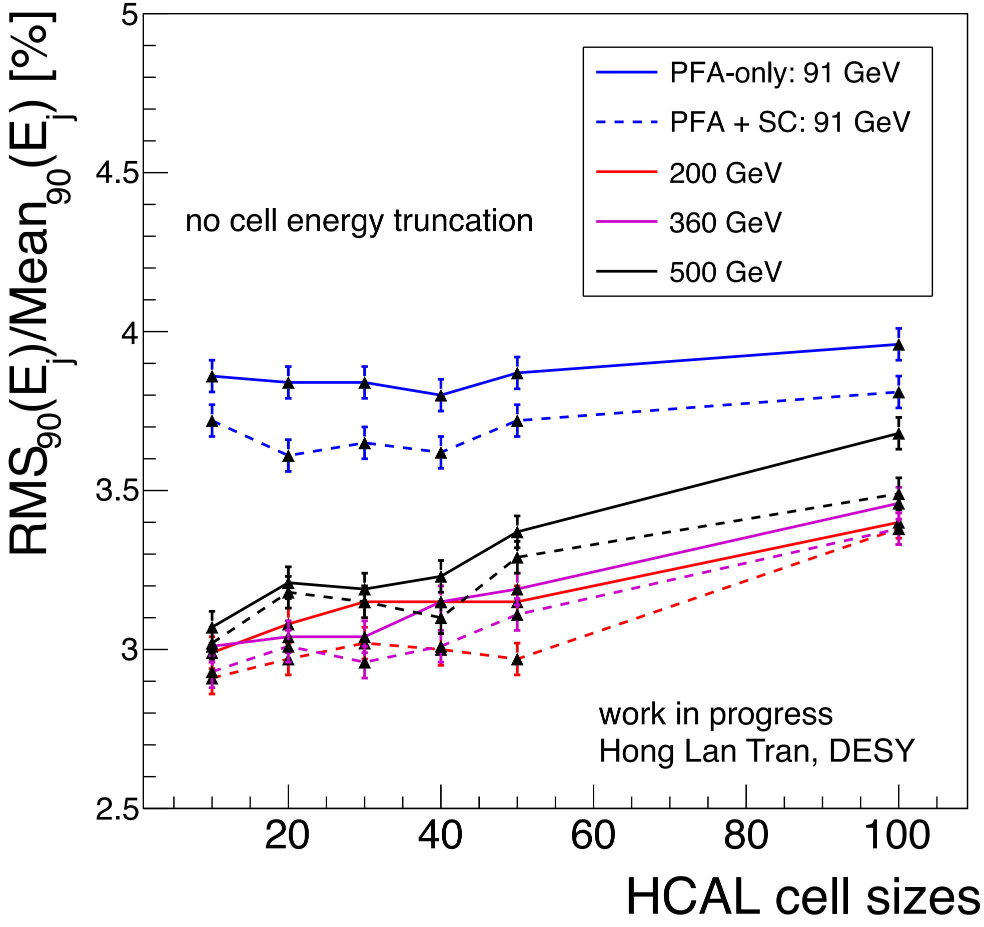
- Hypothesis testing at re-clustering stage
  - use track energy
  - benefits demonstrated earlier (fractal dim.)
- However: Weighting the energy before or during the clustering stage of particle flow reconstruction is not straightforward
  - In general $\omega = \omega(E_i, E_{tot})$
  - Easy only for truncation

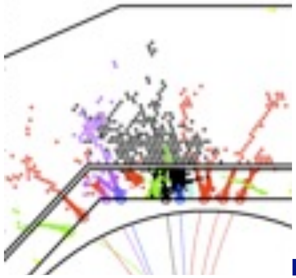


- General issue for all weighting schemes, inevitable for digital and semi-digital reconstruction
- Non-linear response: cannot revert to plain E flow in dense environments
  - $\omega E_1 + \omega E_2 \neq \omega (E_1 + E_2)$



Granularity and resolution 2





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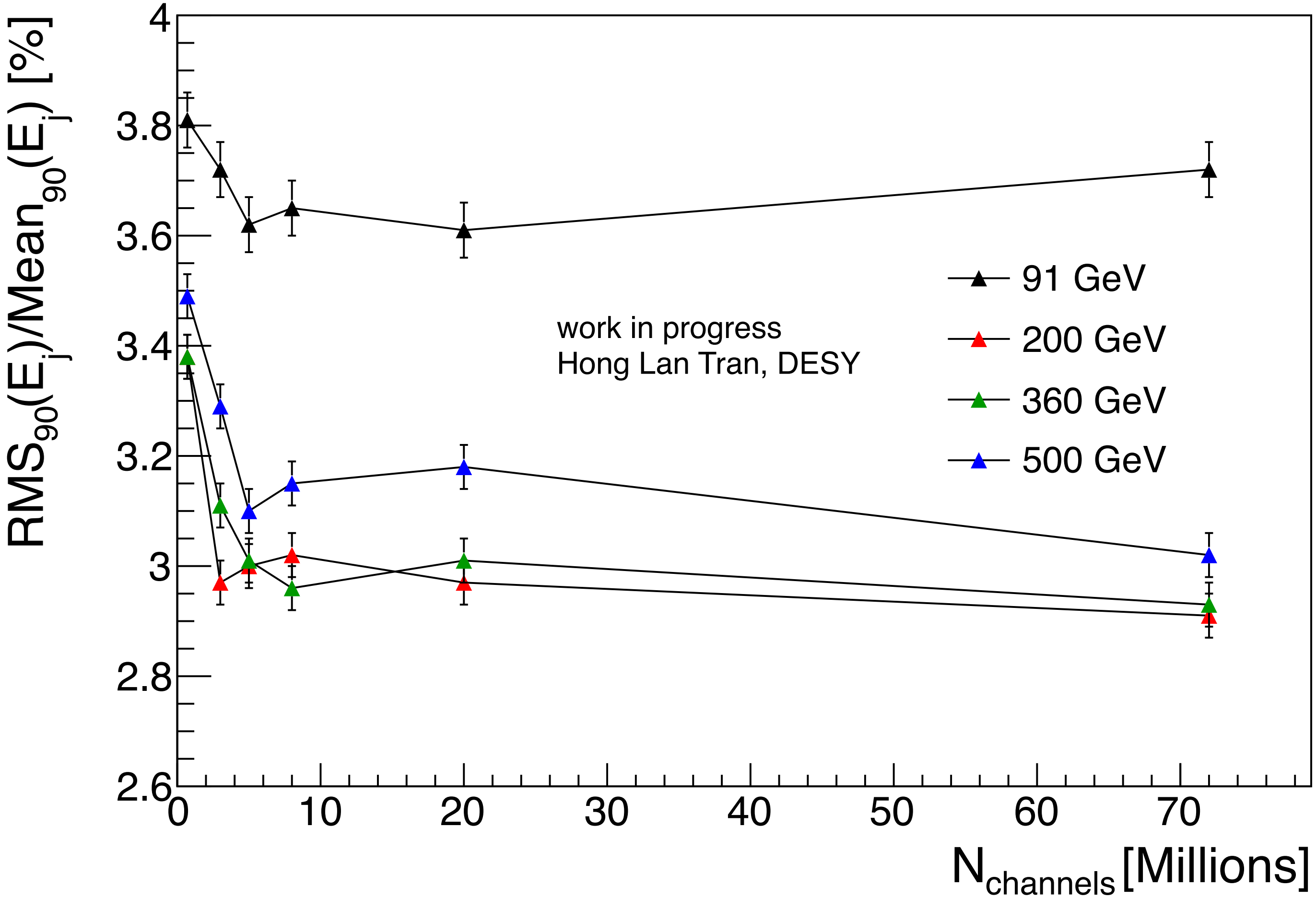
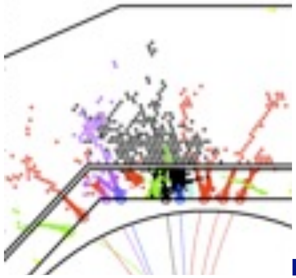


- 3 cm still a very reasonable choice



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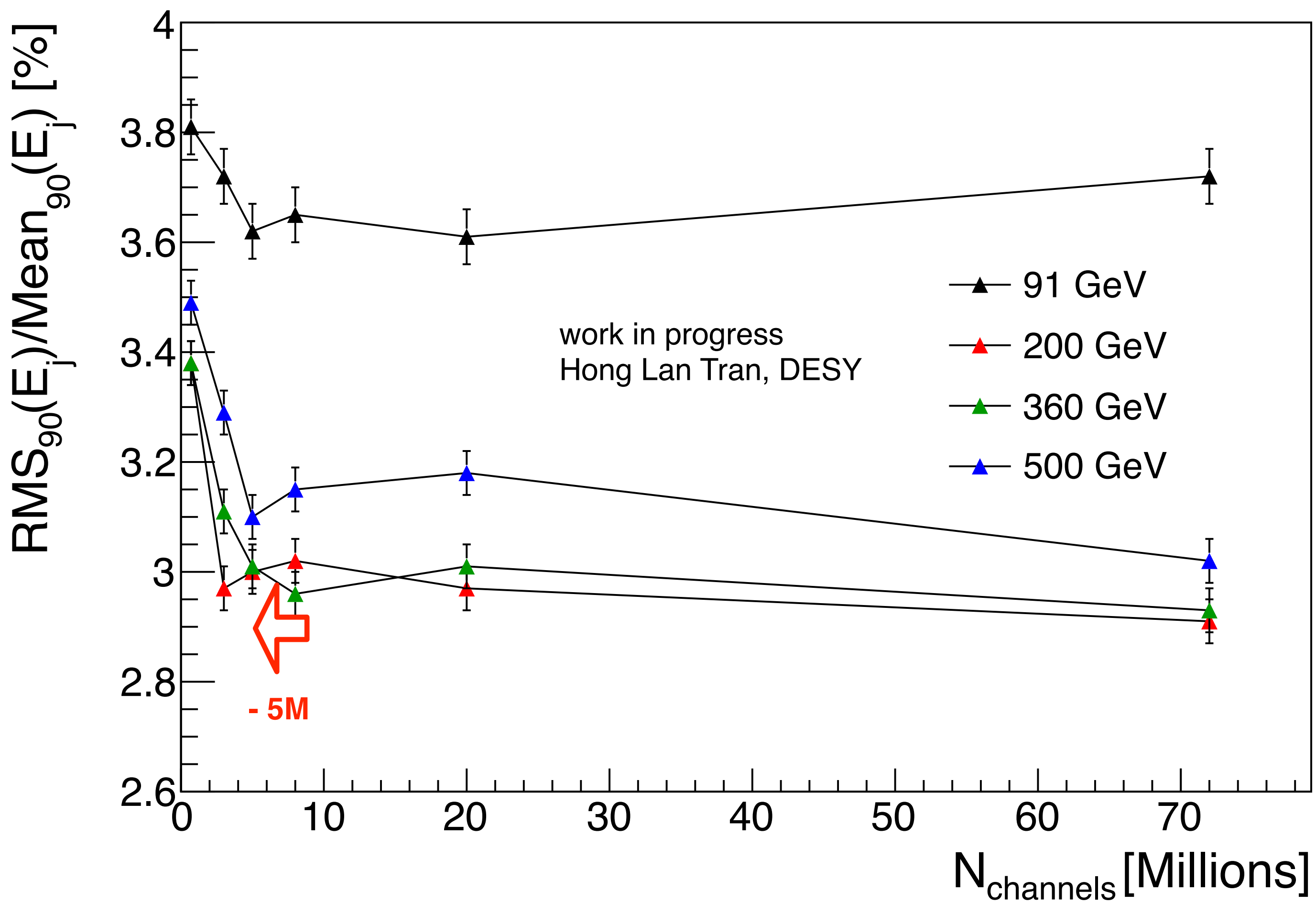

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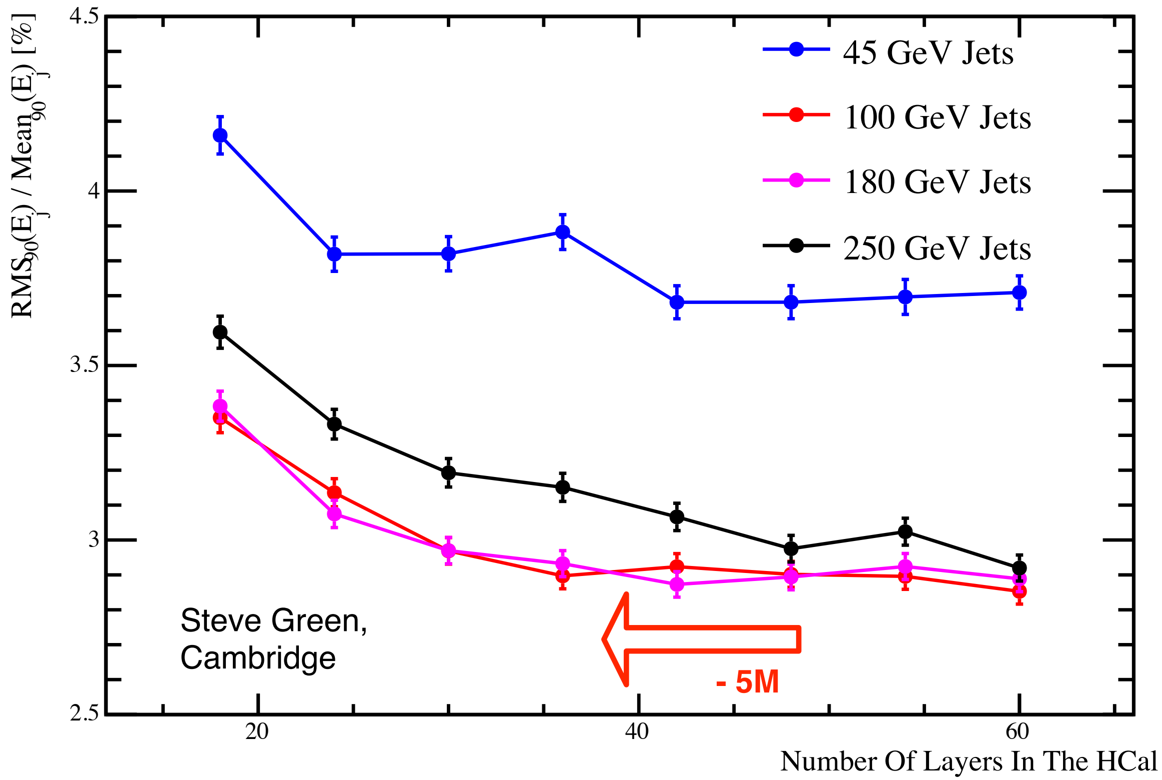
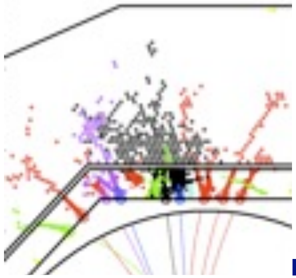
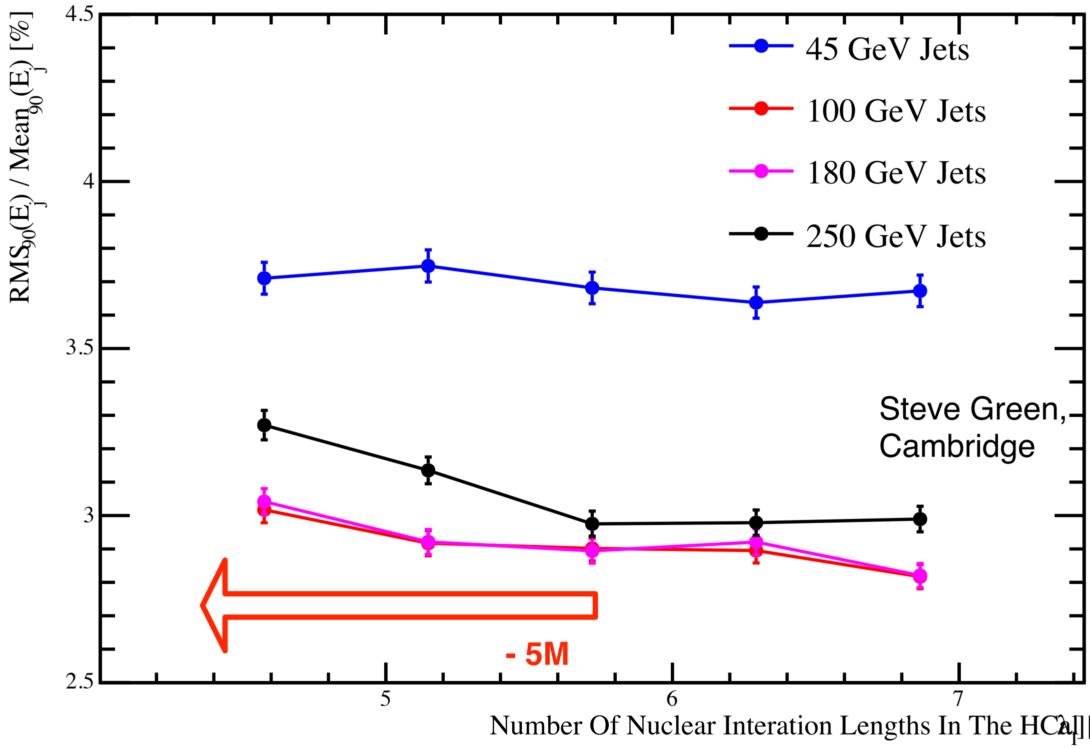
Cost optimisation: long. sampling



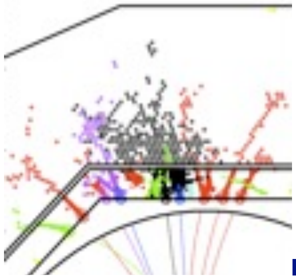
- fewer layers: not for free, but at least no knee
- not necessarily the same for SDHCAL



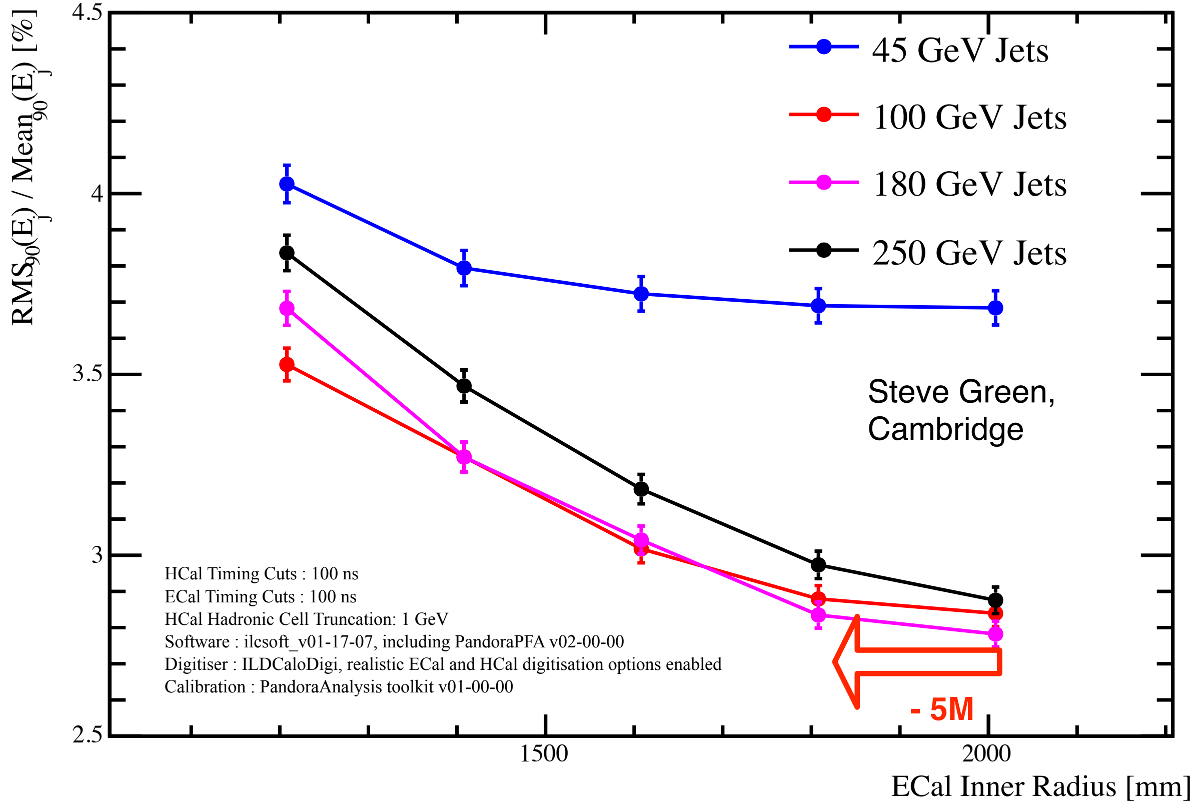
Cost optimisation: depth



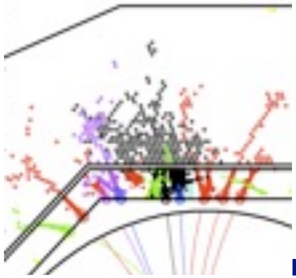
- this plot n(layers) = const; should have constant pitch also
- additional savings from coil and yoke - or smaller reduction
- but should be studied with missing energy performance



Cost optimisation: inner radius



- shown: cost variation is for 18 cm smaller HCAL inner radius
- additional savings from coil and yoke - or smaller reduction



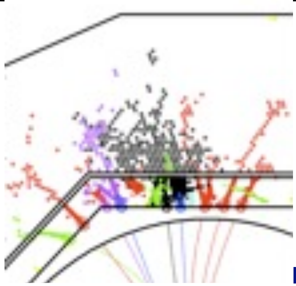
Conclusion

- We are getting close to collecting the remaining pieces for the complete picture
- Still some way to finalise these studies

- More to come:
- Scintillator and gaseous comparison
  - finalise data and simulation
- Timing cuts for energy reconstruction and pattern recognition
- Integration of ARBOR and its new algorithms

- Cost optimisation: from HCAL point of view smaller radius is safest way

Back-up slides



Granularity optimisation

- Based of Pandora PFA
- Large radius and B field drive the cost
- Both ECAL and HCAL segmentation of the order of X_0
    - longitudinal: resolution
    - transverse: separation
- Cost optimisation to be done