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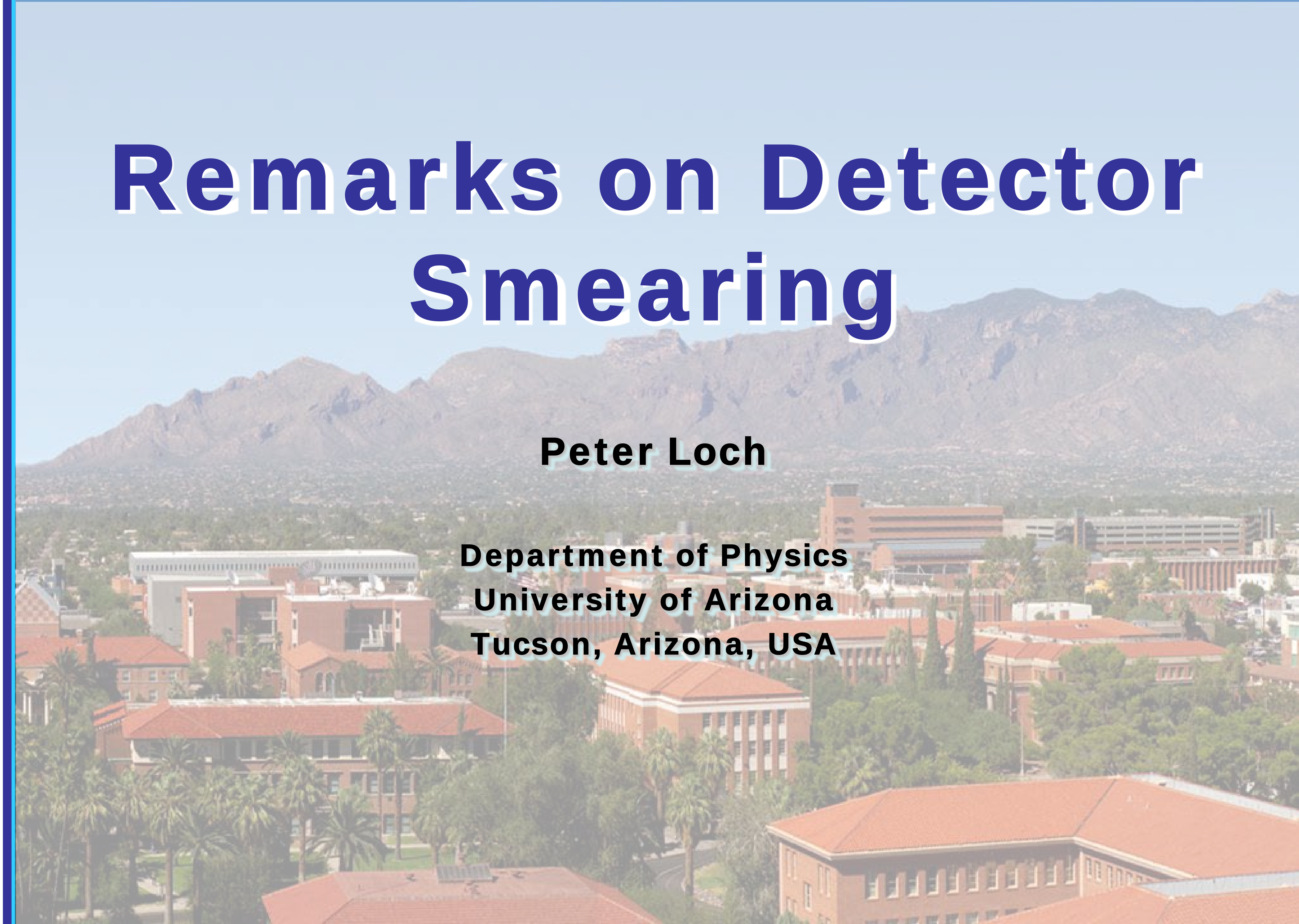

Remarks on Detector Smearing

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Boost 2011

BOOST2011
May 22-26,2011

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Scope

Detector smearing as a tool for phenomenology

- Useful to understand principal limitations induced by detectors on an theoretically well motivated analysis
  - Generic discovery potential for new physics – rough signal & background estimates
  - General limitations introduced by resolution effects for jet sub-structure analysis
- Pretty much a calorimeter business for jets
  - Unfortunately the detector with the most complex smearing function!

Limitations

- Realistic performance evaluation is detector specific
  - Sorry, you need to call your favorite experimentalist from your favorite experiment (no offense)!
  - Needs detailed detector simulation with input from collision & test beam data, sometimes even electronic readout characteristics (signal transfer functions) and digitization…
- Level of details
  - Pretty straight forward if spatial signal distributions not so much of an issue
  - Use for more detailed jet (sub)structure analysis is a new challenge!
- Don’t ask for too much!
  - Smearing can help you to increase the level of measurement reality and produce rough estimates – but will likely still be optimistic!

Response

Scale

- Assume linearity & uniformity on average
  - Means experimentalists have done their job for a specific experiment

$$\left\langle E_{\text{jet}}^{\text{smeared}} \right\rangle (p_{\text{T,jet}}^{\text{true}}, \eta_{\text{jet}}^{\text{true}}, \ldots)$$

$$= \left\langle E_{\text{jet}}^{\text{true}} \right\rangle (p_{\text{T,jet}}^{\text{true}}, \eta_{\text{jet}}^{\text{true}}, \ldots)$$

Resolution

- Fluctuations: assume Gaussian
  - Non-Gaussian tails in response function are a detector feature you need to assume to be corrected
    - Again, you don't want to study a specific detector – if you wanted to that, you need detailed simulation/data
  - You may want to study a precise scenario and a not-so-precise senario
    - E.g. LHC vs ILC

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$e^{\pm}, \gamma$ precise (e.g., ILC):

$$\frac{\sigma}{E} = \frac{3\%}{\sqrt{E}} \oplus 0$$

$e^{\pm}, \gamma$ typical (e.g., LHC):

$$\frac{\sigma}{E} = \frac{10\%}{\sqrt{E}} \oplus 0$$

jets/hadrons precise (e.g., ILC):

$$\frac{\sigma}{E} = \frac{35\%}{\sqrt{E}} \oplus 1\%$$ (ZEUS w/ e-flow)

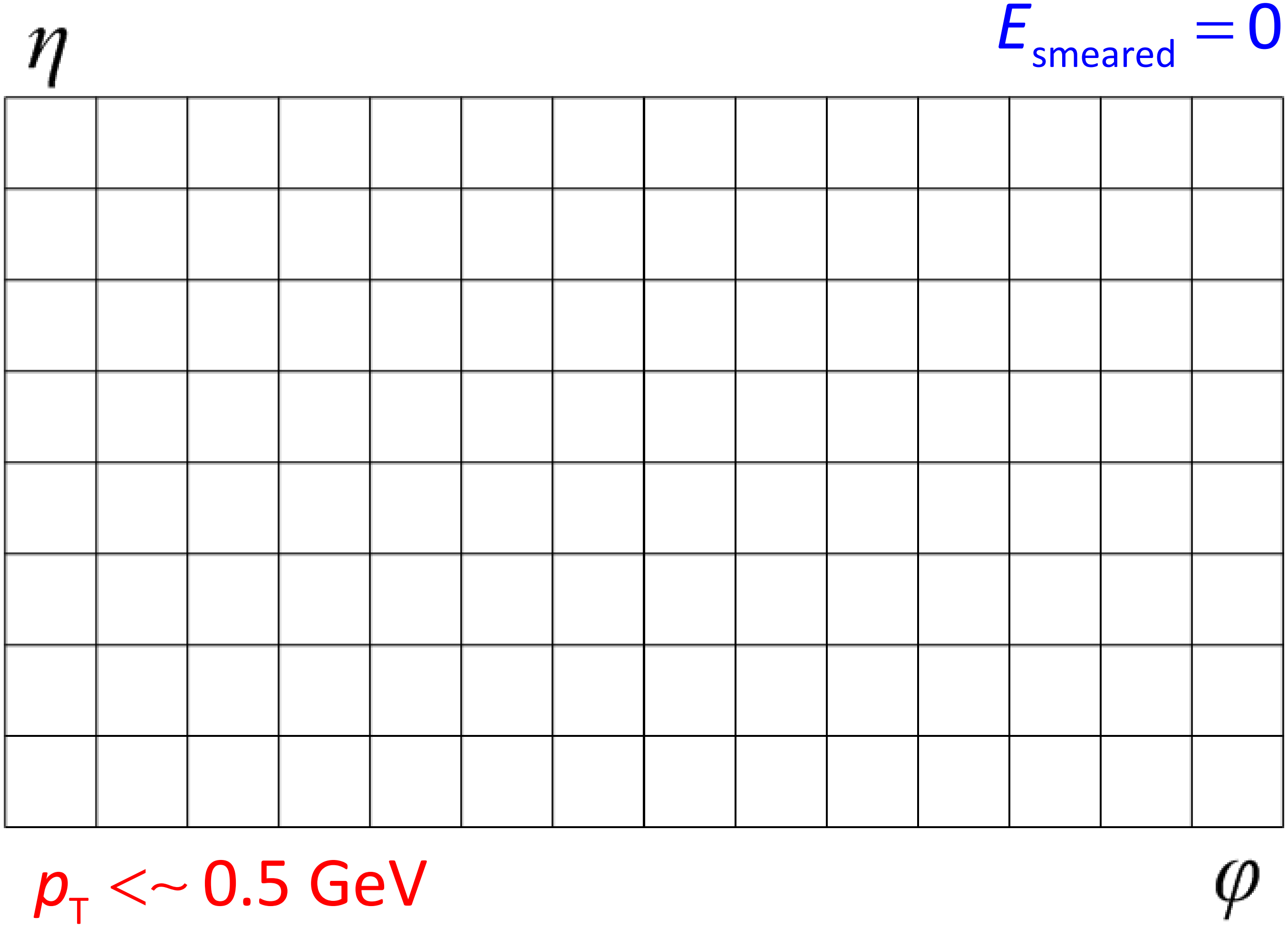
jets/hadrons typical (e.g., LHC):

$$\frac{\sigma}{E} = \frac{(50-60)\%}{\sqrt{E}} \oplus 3\%$$

Single particle response modification

Magnetic field in front of calorimeter

Charged particles may not reach calorimeter at all



$E_{\text{smeared}} = 0$

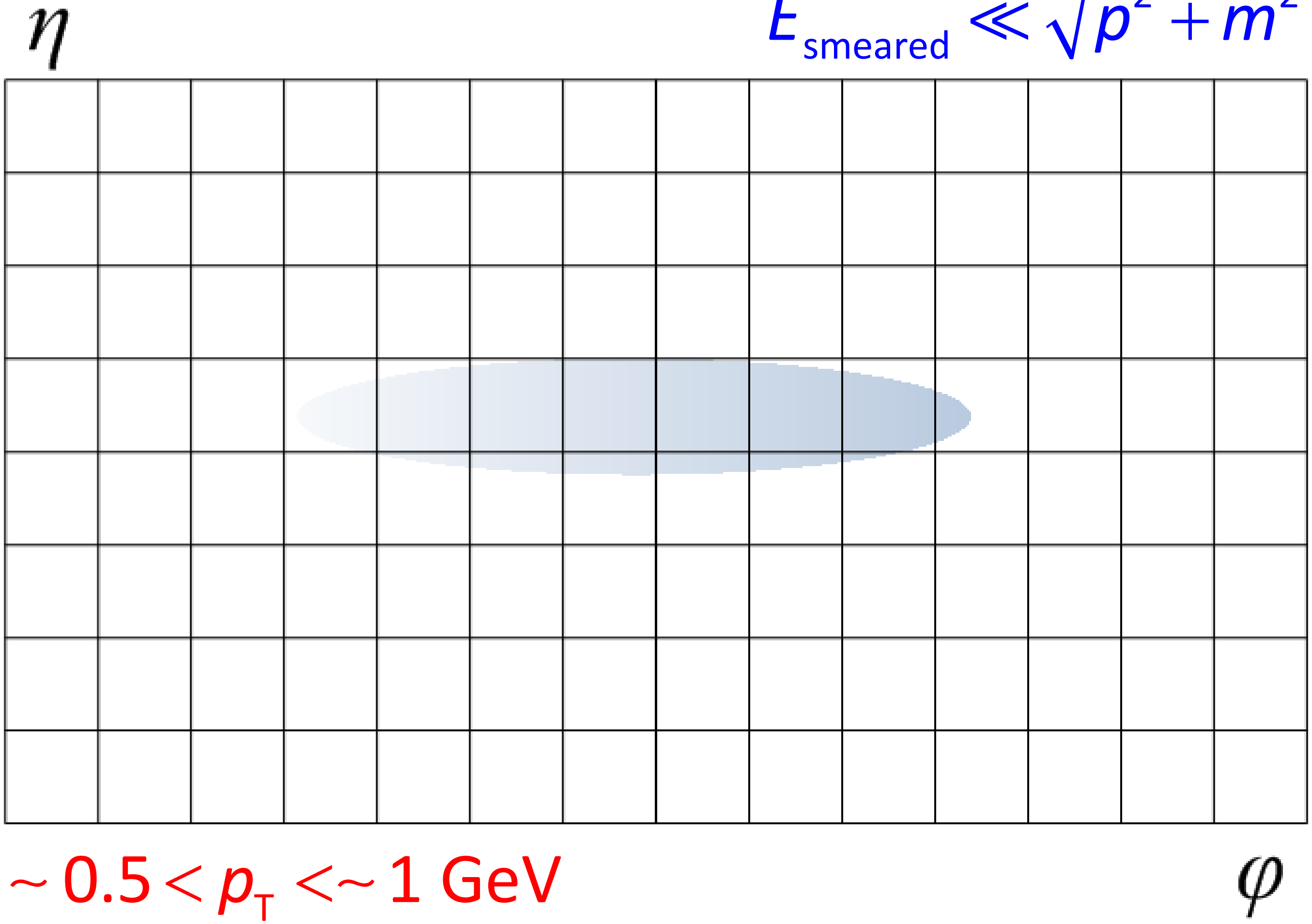
$p_{\mathrm{T}} <\sim 0.5$ GeV

Single particle response modification

Magnetic field in front of calorimeter

Charged particles may not reach calorimeter at all

$$E_{\text{smeared}} \ll \sqrt{p^2 + m^2}$$

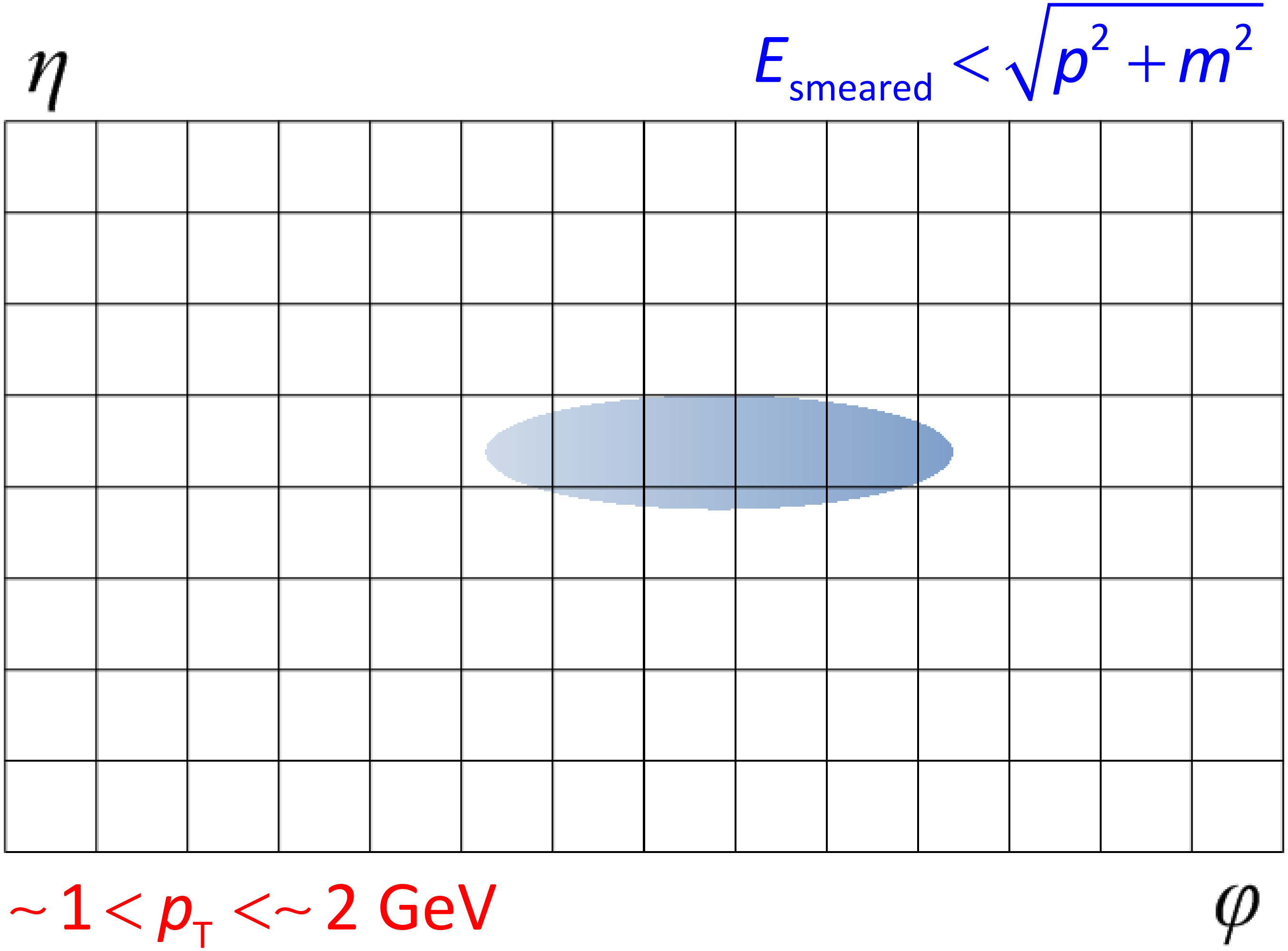


$\sim 0.5 < p_{\mathrm{T}} < \sim 1\ \mathrm{GeV}$

Single particle response modification

Magnetic field in front of calorimeter

Charged particles may not reach calorimeter at all

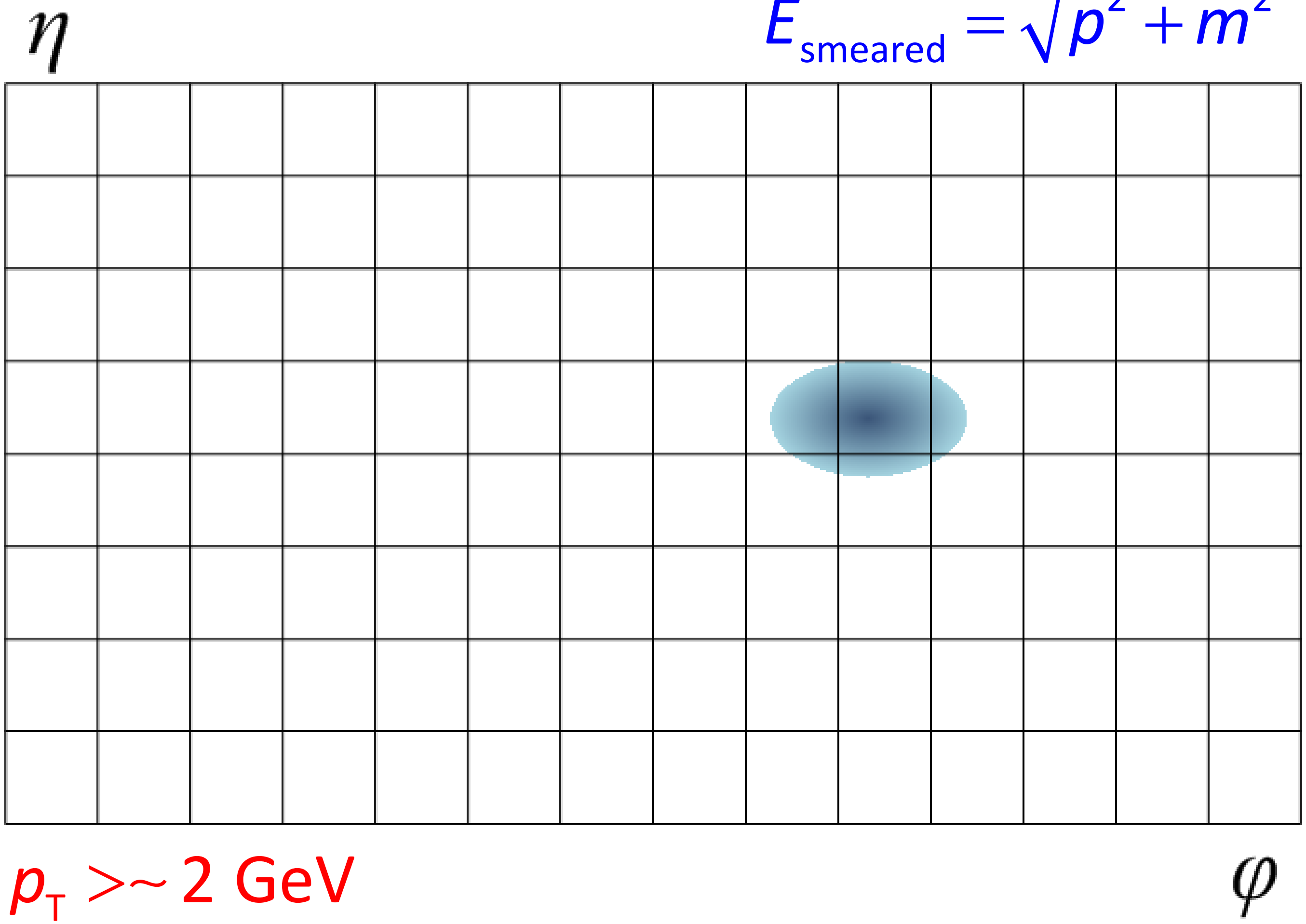


Acceptance

Single particle response modification

- Magnetic field in front of calorimeter
  - Charged particles may not reach calorimeter at all

$$E_{\text{smeared}} = \sqrt{p^2 + m^2}$$



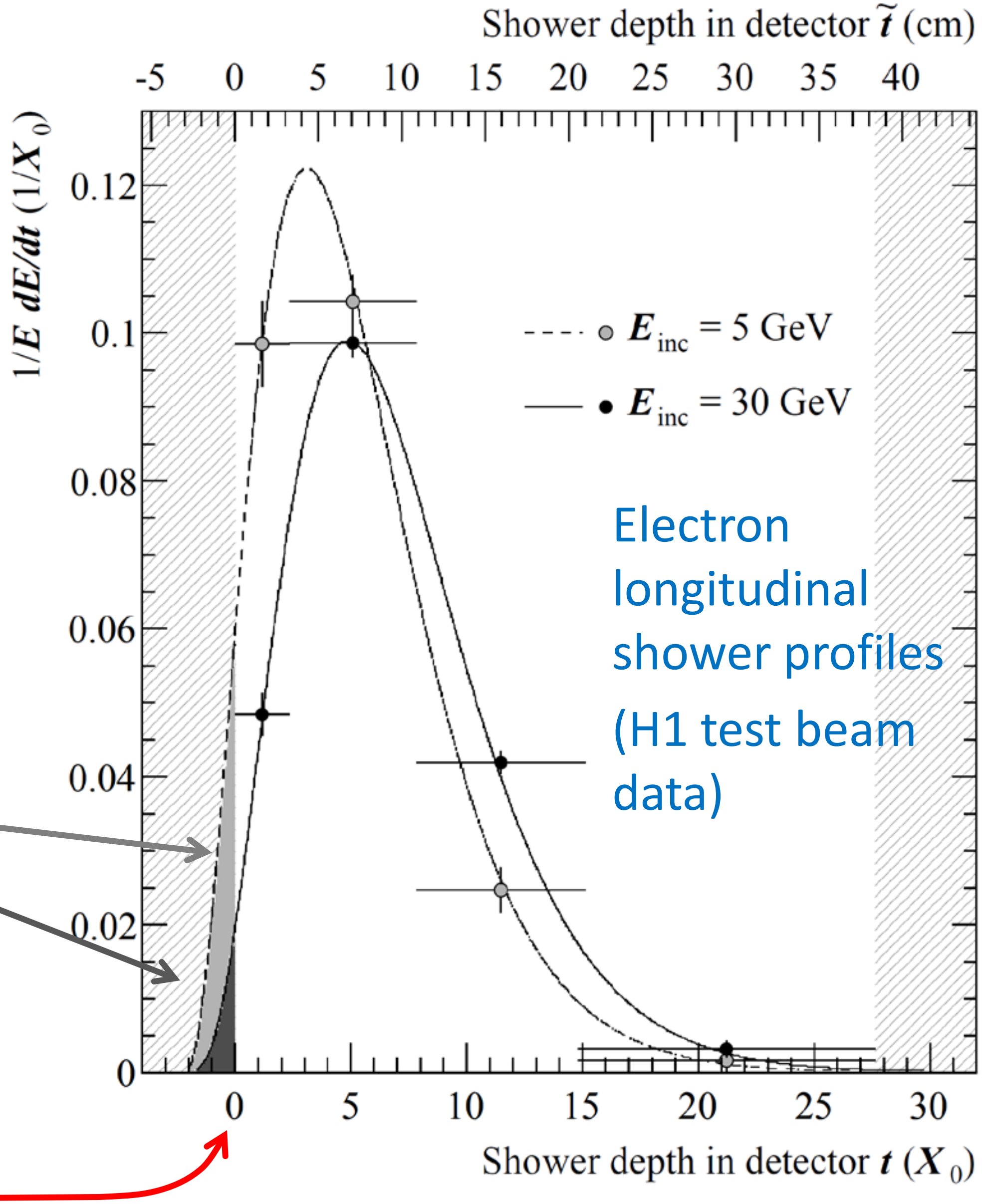
$p_{\mathrm{T}} >\sim 2$ GeV

Acceptance

Single particle response modification

- Inactive material in front of calorimeter
  - Charged and neutral particle energy partly or completely lost
- Affects the response in a complex way

Shaded areas indicated energy loss in front of detector



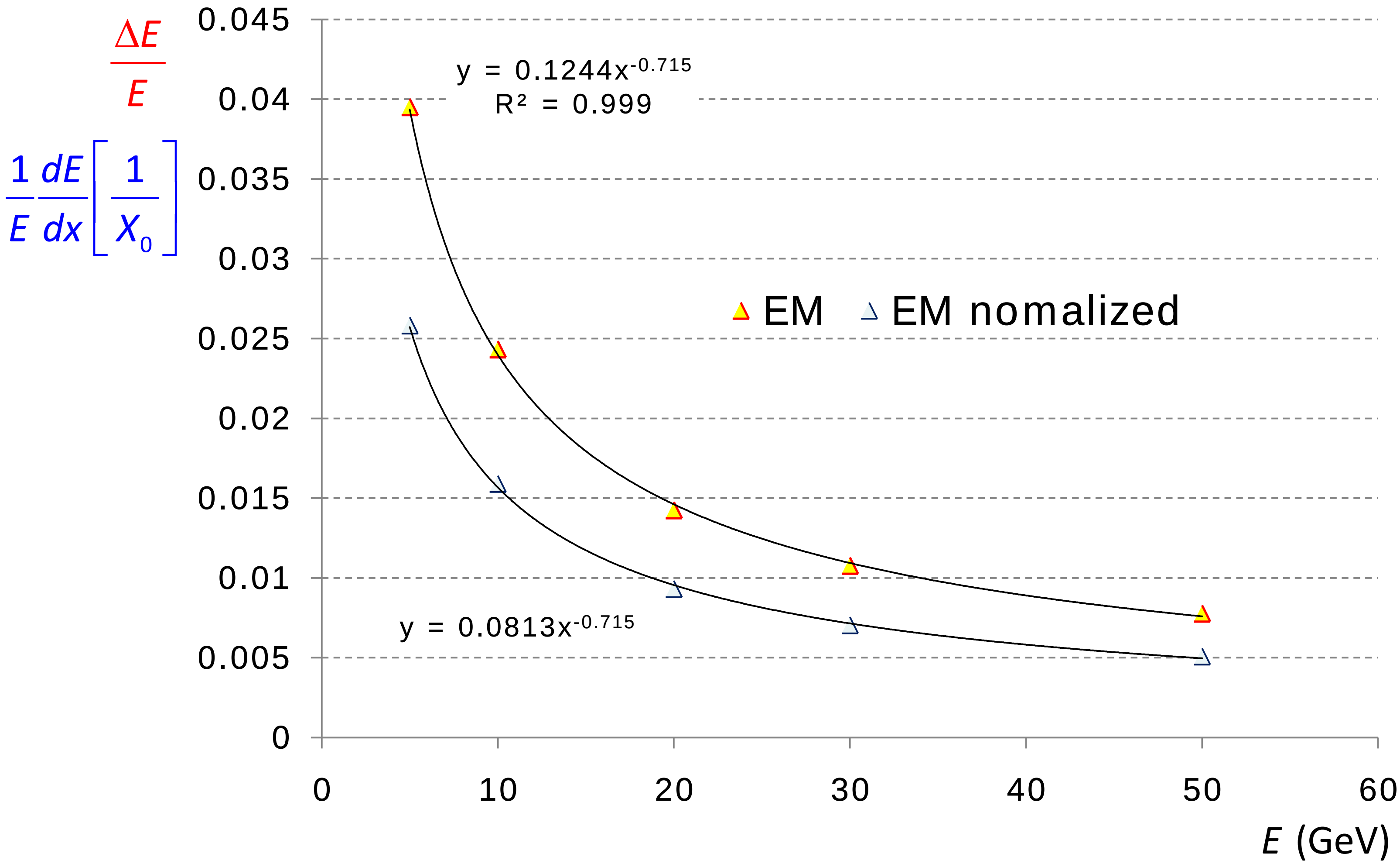
Electron longitudinal shower profiles

(H1 test beam data)

Calorimeter starts here

Single particle response modification

Electron energy loss in material in front of calorimeter (H1 test beam data)



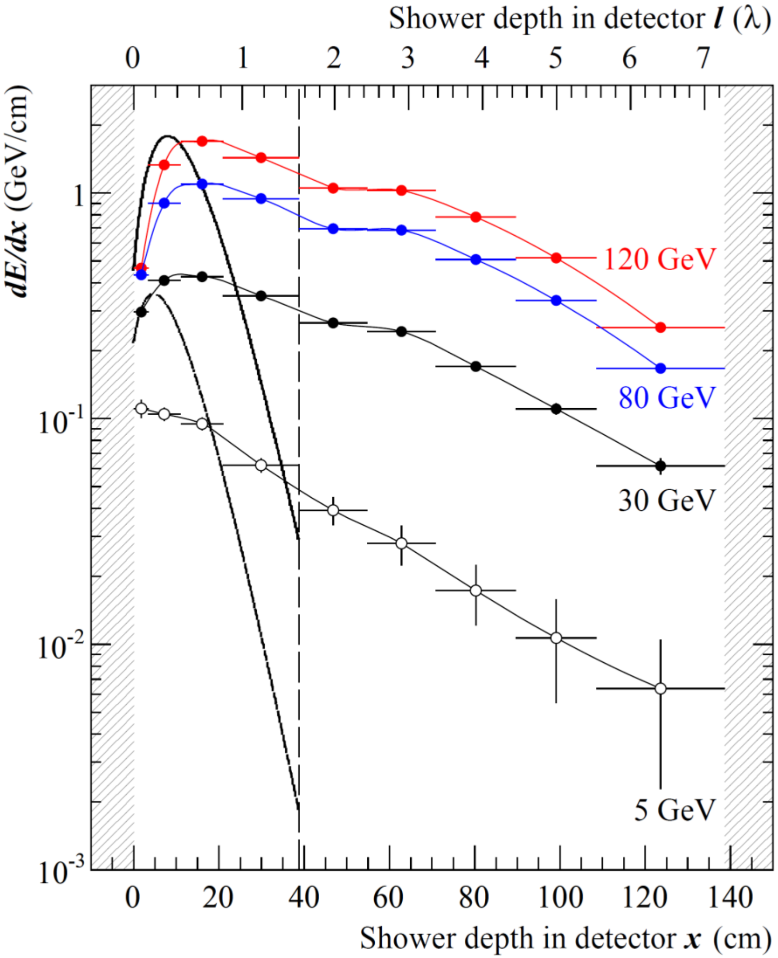
Spatial Smearing Models

Shower profiles

- Longitudinal & radial profiles
  - Analytically well described for EM particles – including fluctuations
  - Also possible for HAD showers – very detector dependent features, hard to model fluctuations numerically!
- Correlations in profiles – shower shapes
  - Radial profile depends on shower starting point/shower depth
  - EM showers – strong correlation between profiles and fluctuations, can be modeled
    - E.g., GFLASH approach for H1 physics simulation
  - HAD showers – very hard to model correlations in profiles and fluctuations, attempt to model often very unsatisfactory in general
    - Some success for specific calorimeters (CDF, ATLAS – ATLFAST2)

Smearing particle energy spatially

- Simple ansatz
  - Only radial smearing
    - Longitudinal profile assumed to be not important for pseudo-particles
  - Problems with longitudinal coupling of projective calorimeter readout segments in case of curved particle trajectory (magnetic field)
    - Can chose to ignore… See later!

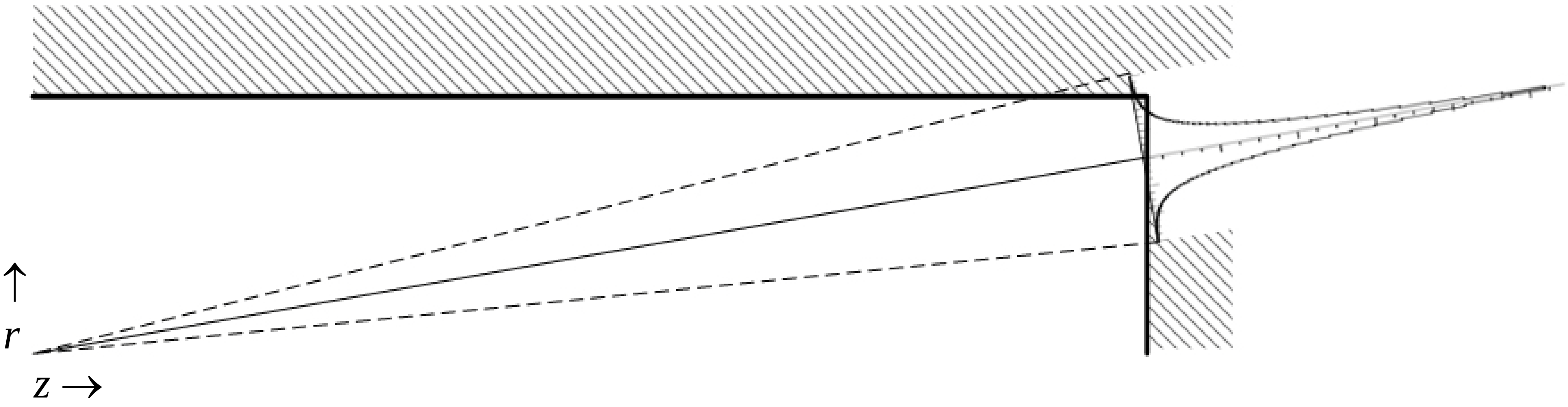


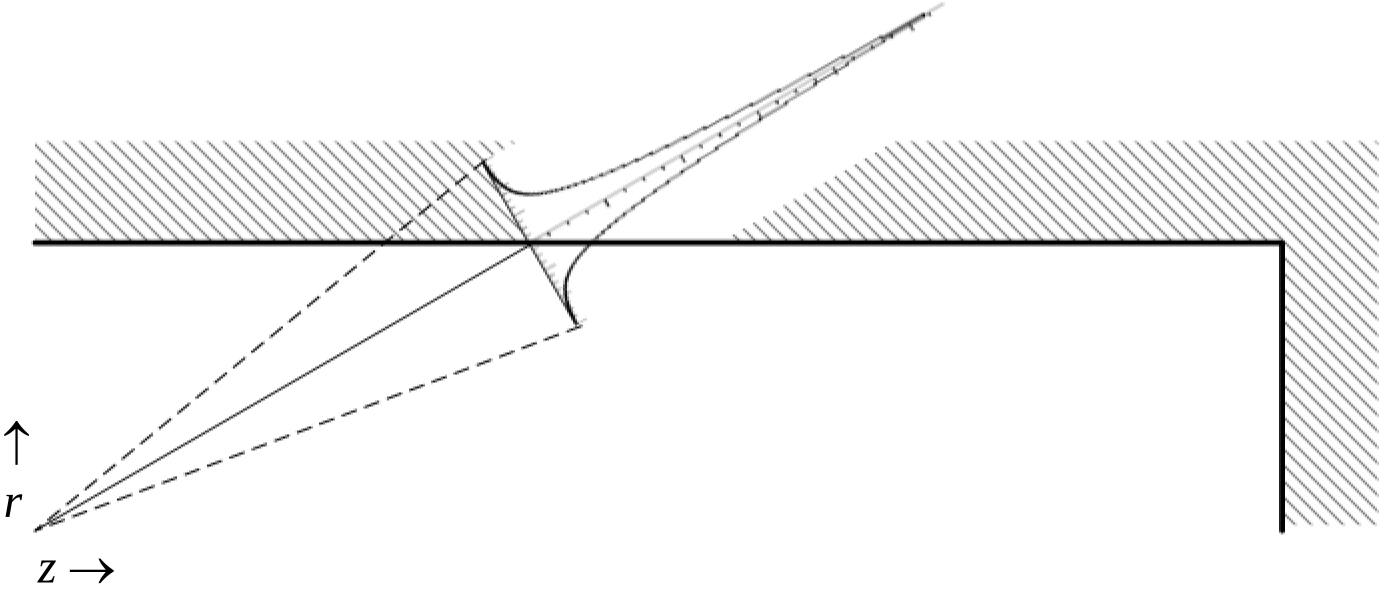
Radial Smearing

Simple radial energy distribution in tower grids

- Ignore longitudinal development
  - Particle energy distributed transverse to direction of flight of particle in a plane through the particle impact point into the calorimeter
  - Shape of distribution from experiment/full simulation
- Integrated energy in profile is the same as particle energy
  - No calibration/acceptance/smearing of energy
- Distributed energies projected into regular eta/phi grid within modeled detector acceptance
  - Fakes calorimeter tower signal definition, including high eta losses
  - Different grid and eta acceptance for EM particles

Radial Energy Projection





Modeling

Toy detector defaults

- EM acceptance -2.5 < eta < 2.5
  - Photons/electrons outside are mapped onto HAD towers
- HAD acceptance -5.0 < eta < 5.0
  - Particles outside are ignored completely
- Cylindrical calorimeter
  - R = 1200 mm, -2500 mm < z < 2500 mm
- High granularity
  - 0.025 x 0.025 (EM)
  - 0.1 x 0.1 (HAD)

Shower shapes

- Started with Gaussian within cylinder
  - Lateral extend /cylinder radius 80 mm for EM particles (also in HAD grid!)
  - 160 mm for all others
  - Gaussian showers are too wide, this was just a simplification!
- Now experimental electromagnetic and hadronic shower shapes
  - H1 data easily available (with some help) – representative for ATLAS (CMS?)-like calorimeters
- Energy distributed in small "spots"

Electron Lateral Profile (H1)

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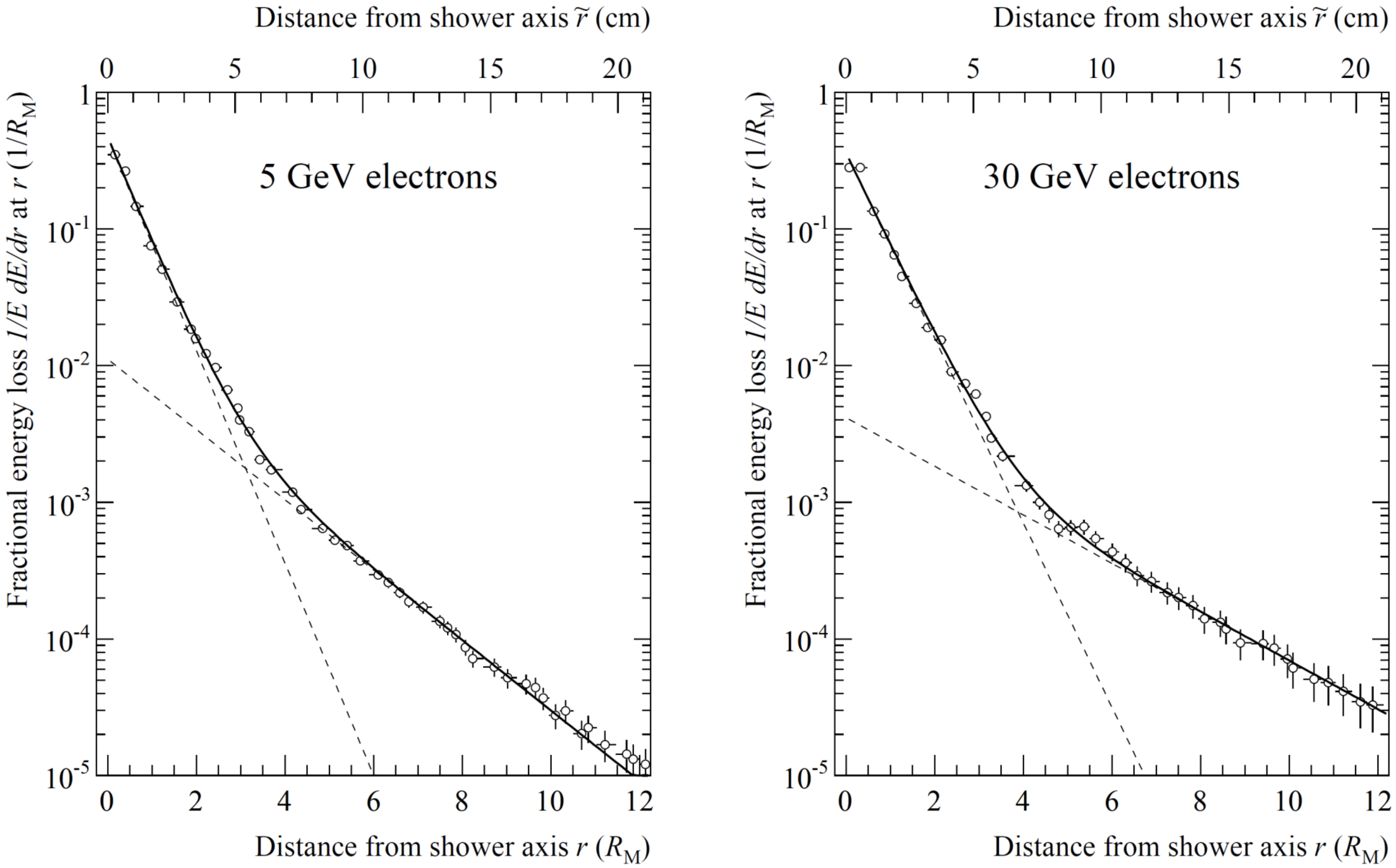
U of Arizona
May 22, 2011

Radial (transverse) electron shower profile in H1 calorimeter (test beam data)



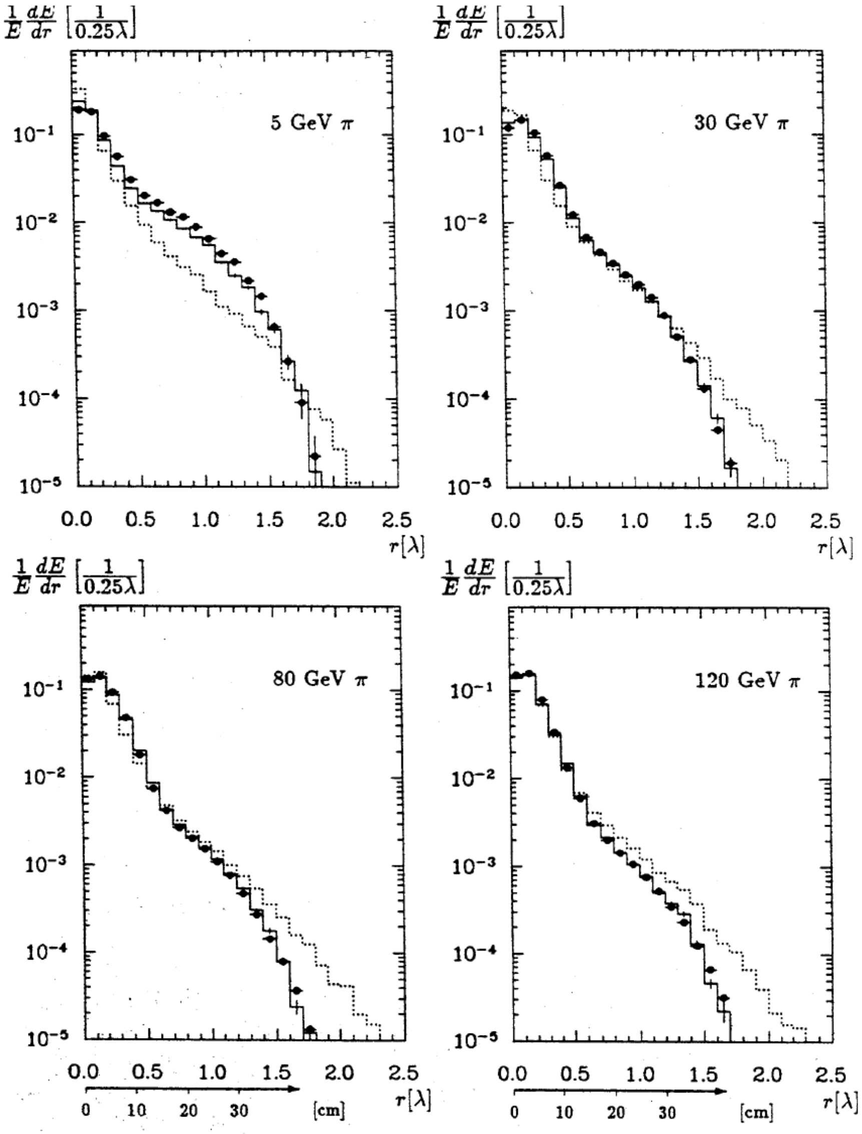
$$\frac{dE}{dr}(r) = E\left(a(E)e^{-\alpha(E)r} + b(E)e^{-\beta(E)r}\right)$$

PL Thesis, 1992

Hadronic Lateral Profile (H1)

Points/solid line histogram: data + simulated signal with noise cuts

Dashed line histogram: simulated shower development, no noise or cuts



PL Thesis, 1992

Software

Two files needed:

- DetectorModel.h and DetectorModel.cxx
  - Uses fastjet/PseudoJet.h and STL – nothing else!
- Compile DetectorModel.cxx

Usage (default):

```
#include "DetectorModel.h"
...
// default smearing module
DetectorModel::RadialSmearing smear;
... fill std::vector<PseudoJet> input with final state particles and set
the user_index of each of those to the particle pdg code!!
// retrieve pseudo-particles after smearing
const std::vector<PseudoJet>& smeared = smear.smear(input);
// do your thing...
```

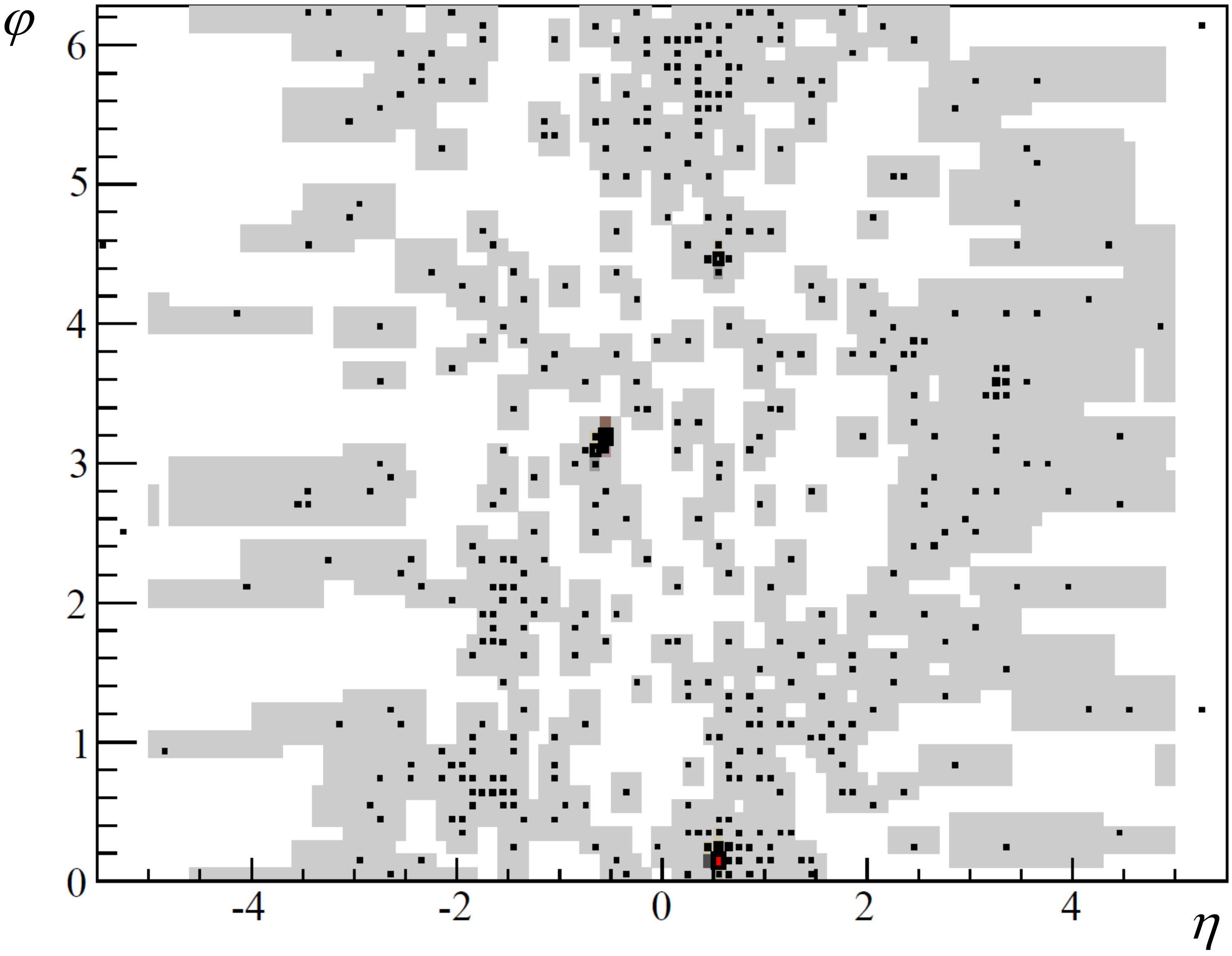
Observations:

- Expect about 20 x more particles than in the generator final state
  - Topology dependent, here Pythia QCD di-jets
- Slow execution
  - Needs much more optimization

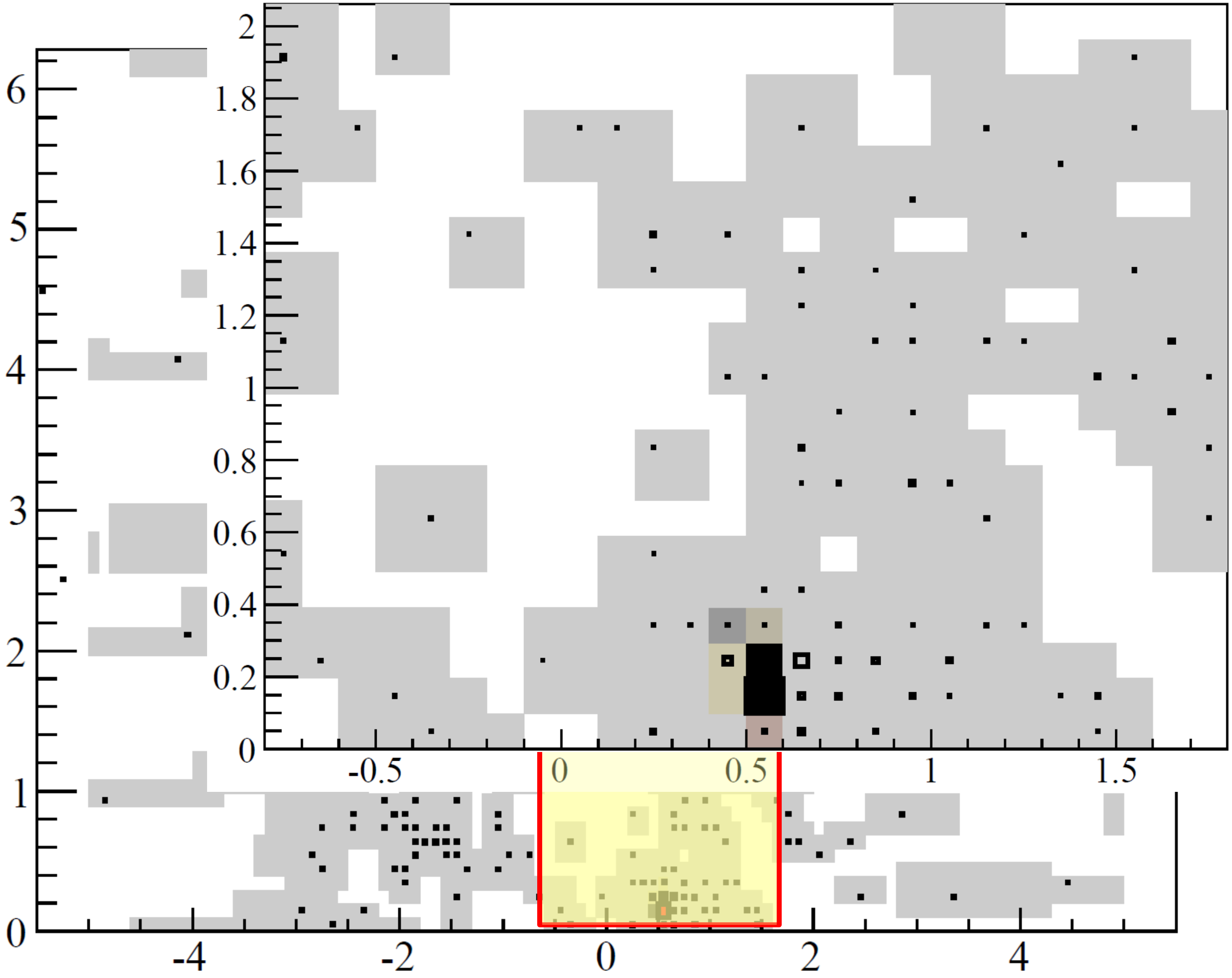
Source:

- Link to archive at http://atlas.physics.arizona.edu/~loch/index.html#Material

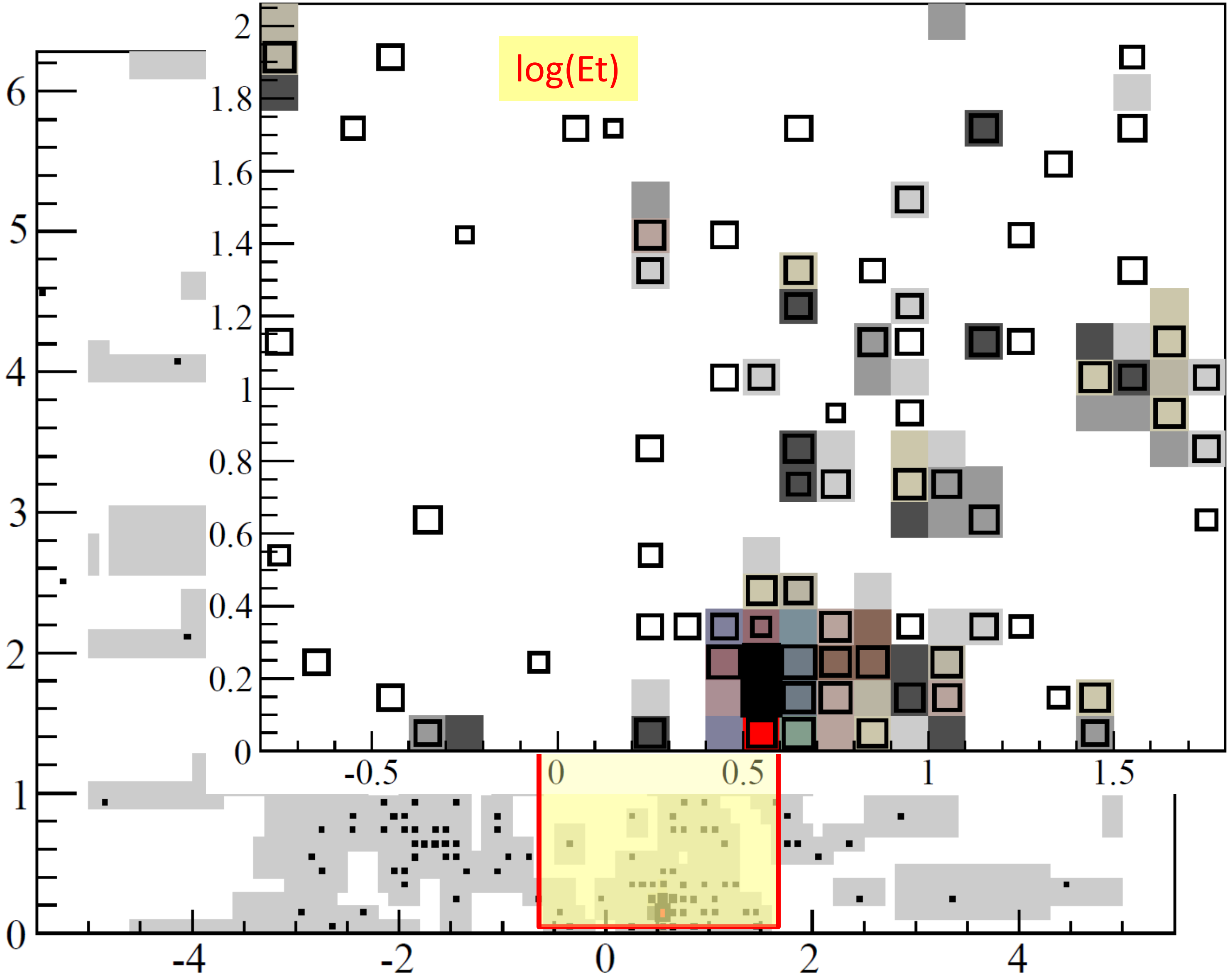
Pythia8 QCD Di-jets



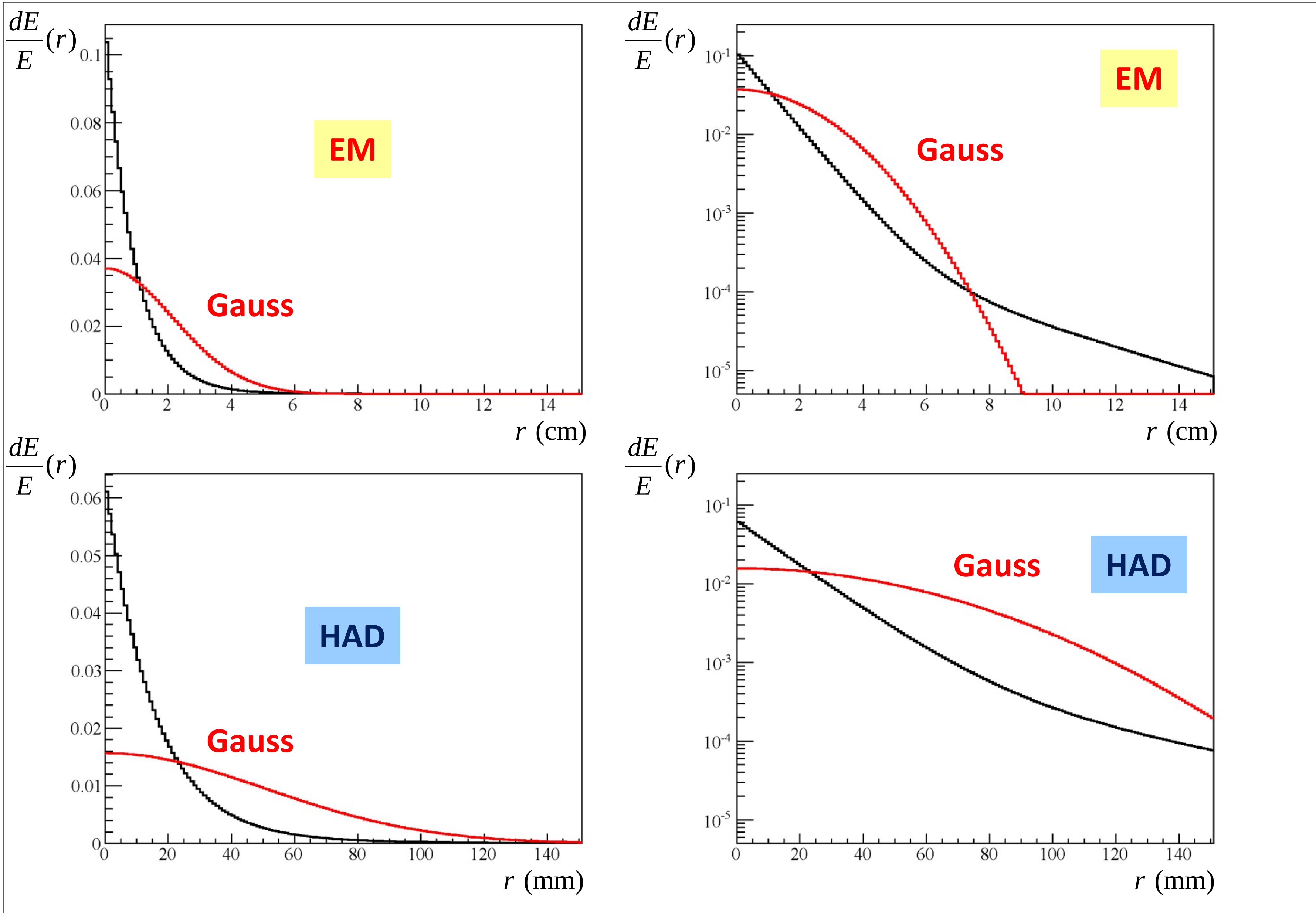
Pythia8 QCD Di-jets



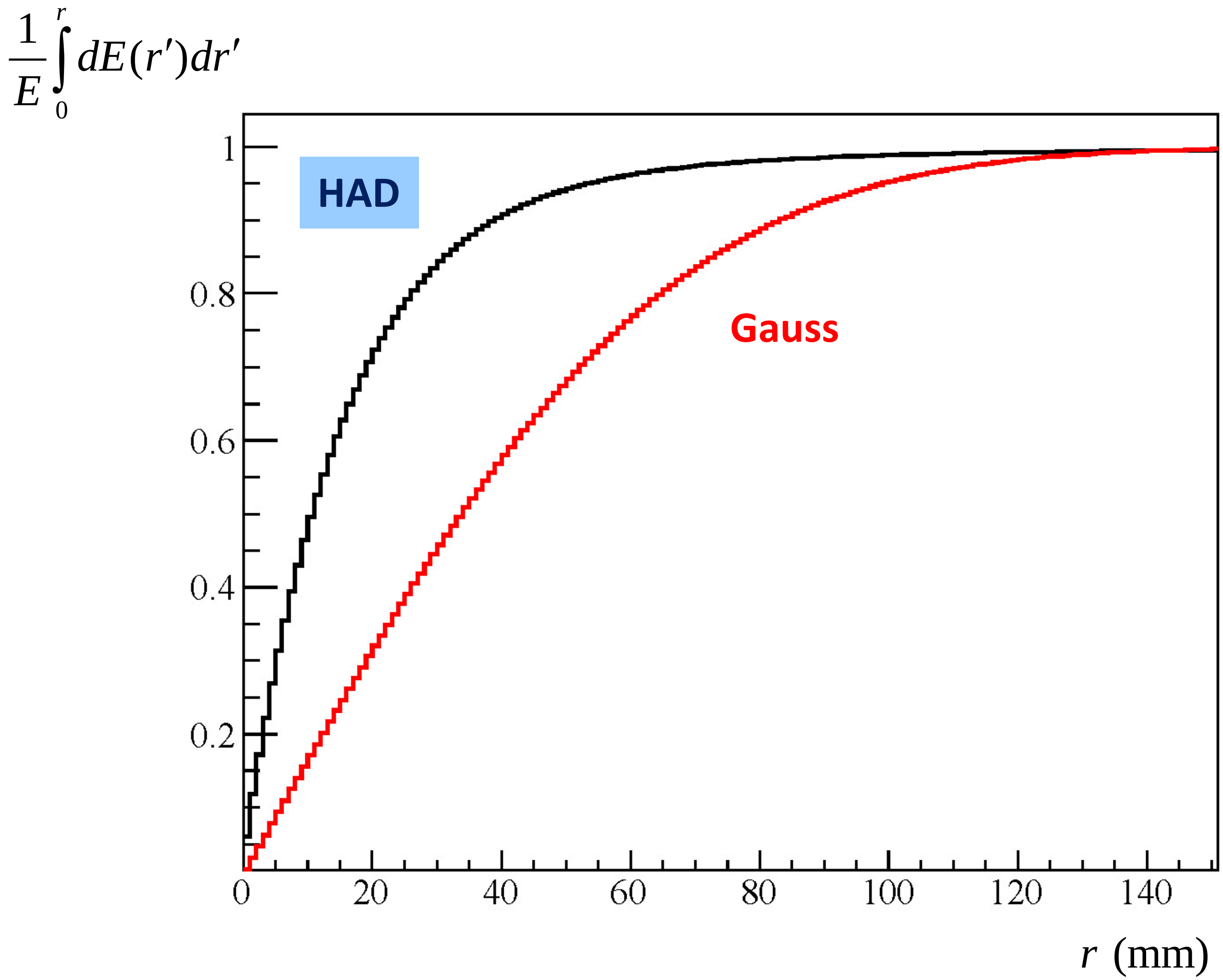
Pythia8 QCD Di-jets



Input Shapes Fits To Data



HAD Integrated



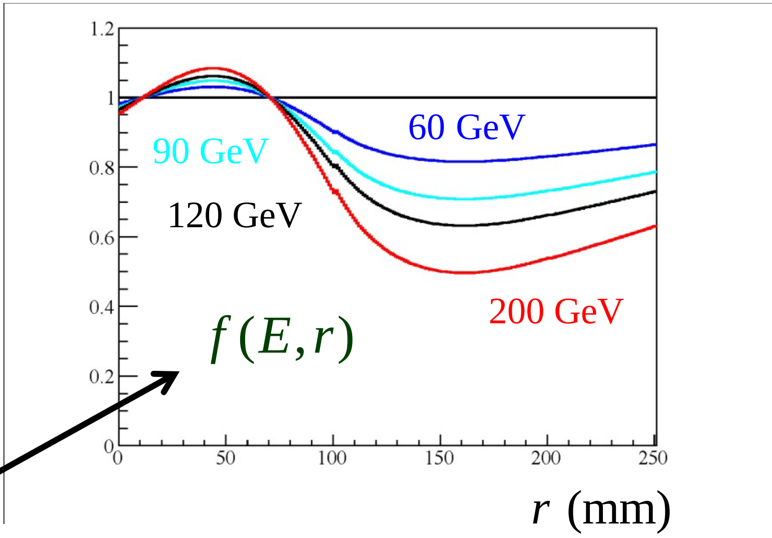
HAD Energy Dependence

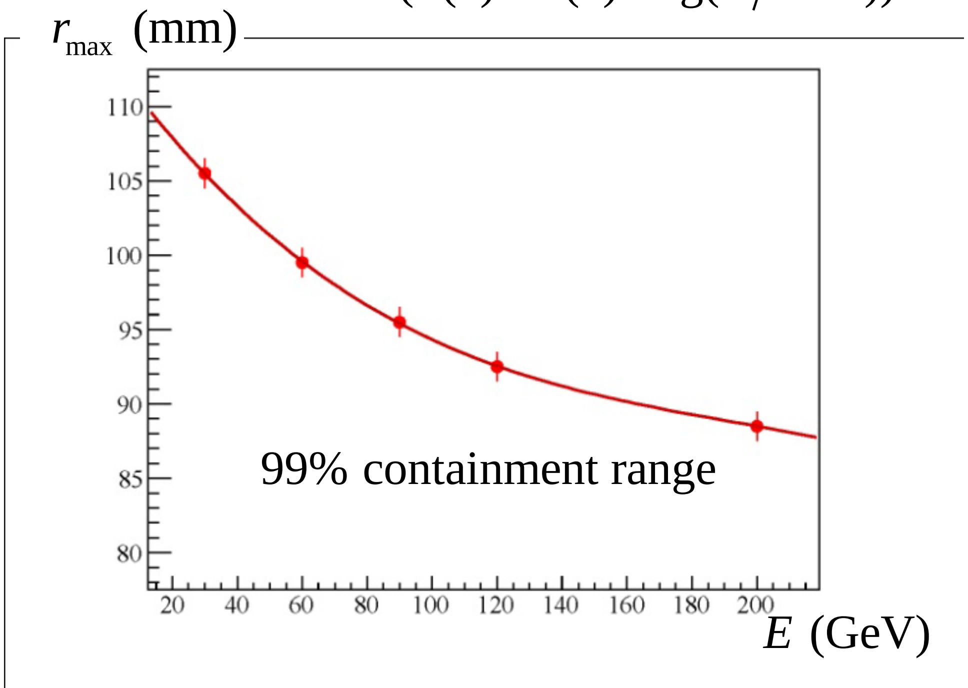
Some energy dependence observed

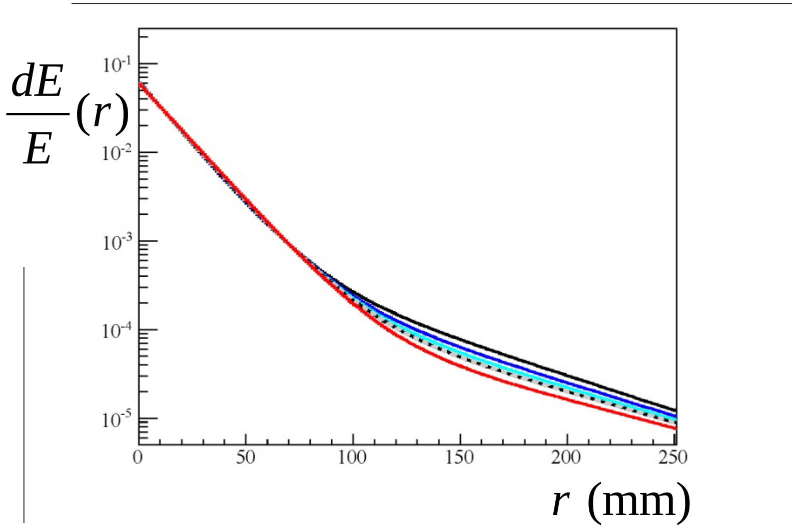
- Not very significant
  - Implemented it anyway
- Only two profiles used
  - E = 30, 120 GeV
- Log-like interpolation between those

200 GeV

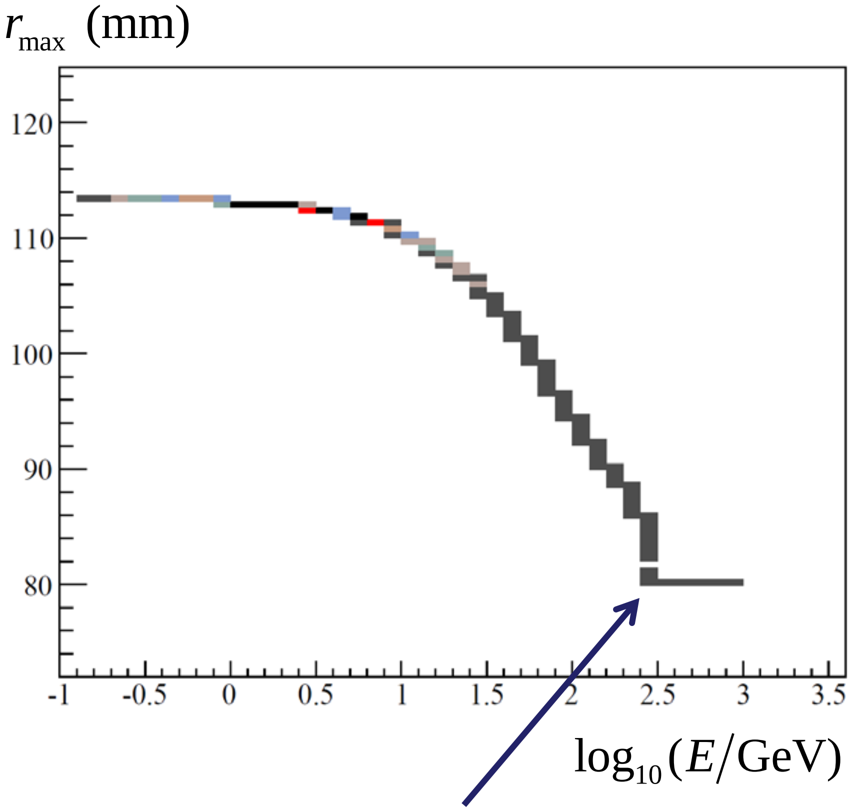
$$S(E,r) = S(30\text{ GeV},r)\cdot f(E,r)$$
$$= (a(r) + b(r)\cdot\log(E/\text{GeV}))$$



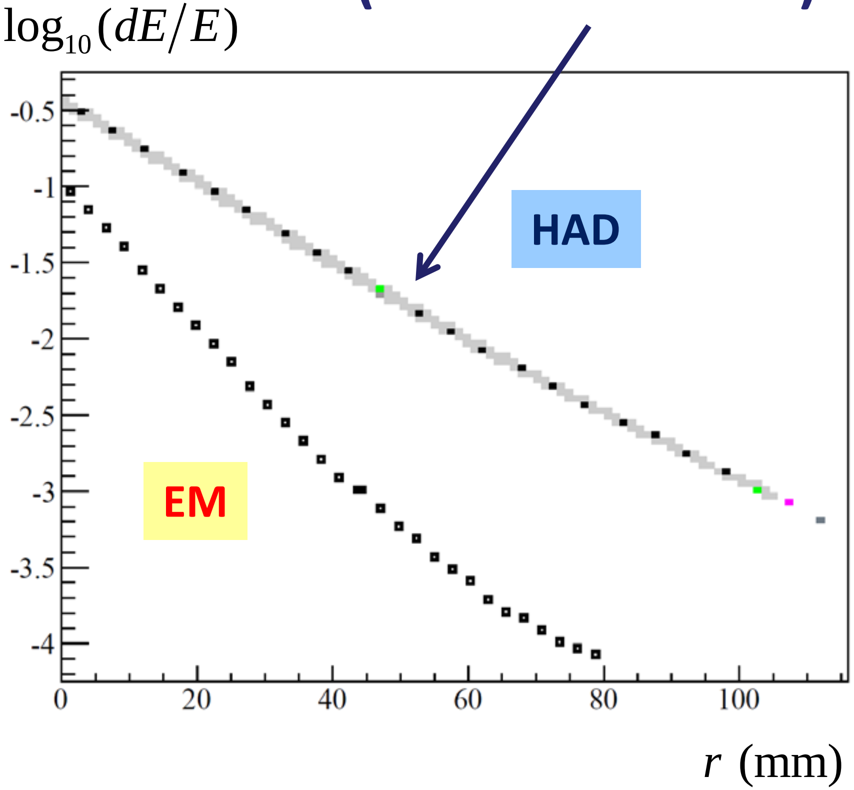




SW Performance Snapshots



(r_{max} = 80 mm for E>200 GeV)



(not normalized!)

Future Development

Concern

- Any improvement in smearing becomes more detector specific
  - Radial profiles themselves fairly general – not too different event for very different calorimeters

Acceptance before radial smearing

- Add magnetic field for charged particles
  - Changes in calorimeter impact direction (azimuth) changes jet (sub)structure!
  - Complete loss of particles
  - Relatively easy if longitudinal shower couplings are ignored
    - Assume projective impact and use same radial smearing as for straight tracks
- Reduce particle energies to model inactive material
  - Useful?
    - Requires inactive material model - very detector dependent, not a general feature
  - Parameterization for EM and HAD available
    - Energy loss per radiation/interaction length

Acceptance/response after smearing

- Could apply minimum signal cut
  - Model minimum measurable energy per grid bin
    - Removes pseudo-particles from grid/output list
  - Most realistic with respect to an assumption for calorimeter noise
    - Electronic and pile-up (if any)
- Signal fluctuations in grid bin
  - Simple assumptions possible
    - Most interesting in connection with noise modeling
    - Note that nominal resolution is for complete (single particle) showers or full jet response – local fluctuation are larger but energies are smaller
  - Should then consider spatial fluctuations as well
    - Shower starting point etc.
    - Not impossible, but it gets complex…

For Discussions…

Limiting the scope?

- Extensions of smearing model academically interesting but little practical use?
  - How detector specific do we want to get?
- Many features possible but not helpful?
  - All this requires some work – don’t want to embark on another semi-useless adventure to provide detector smearing (too unrealistic, too optimistic, too pessimistic, …)
- Collaboration with similar projects?
  - E.g., think about integrating with/providing extension for PGS?

…