Geant4 for the ATLAS electromagnetic calorimeter

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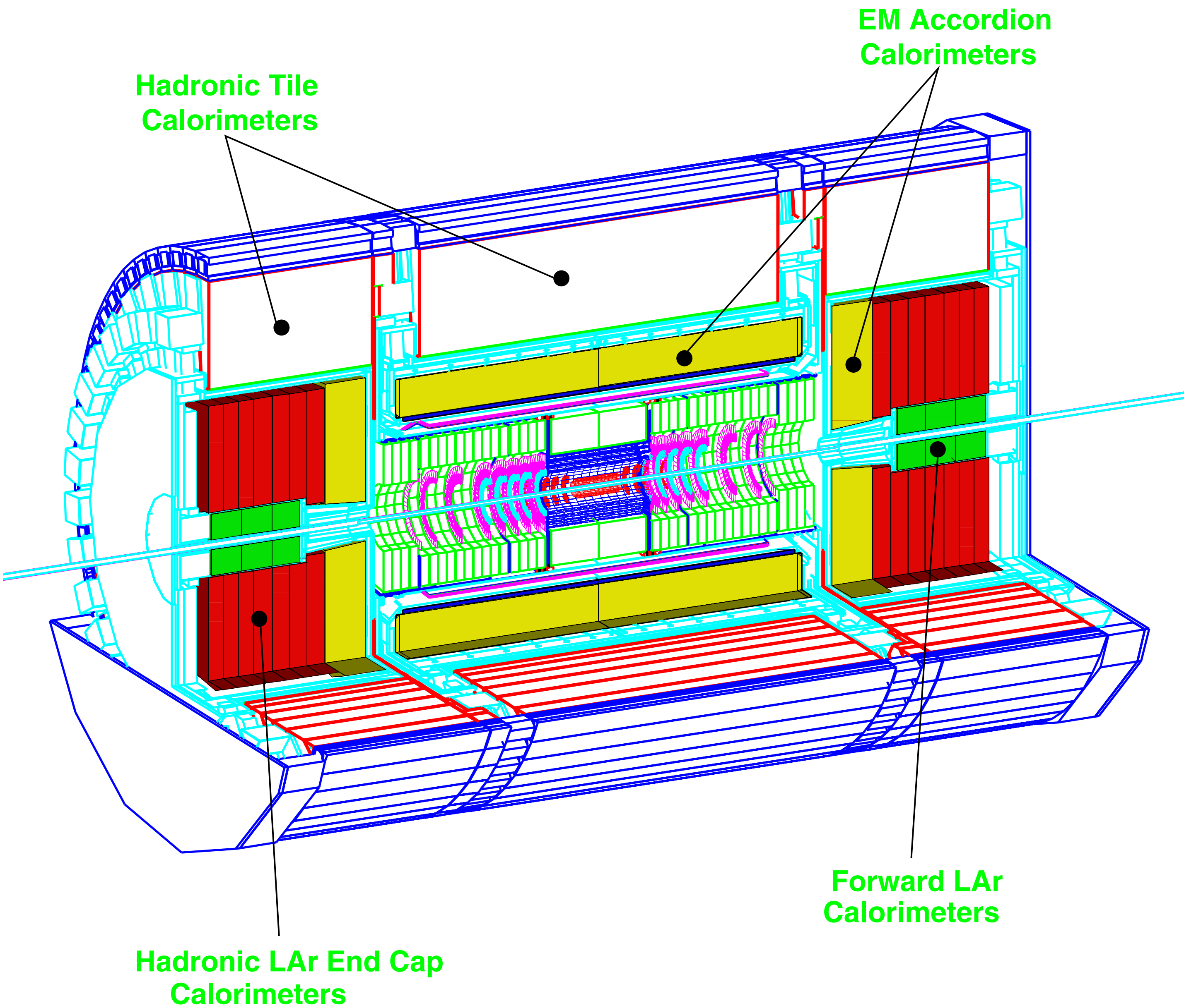
1. The ATLAS calorimeters



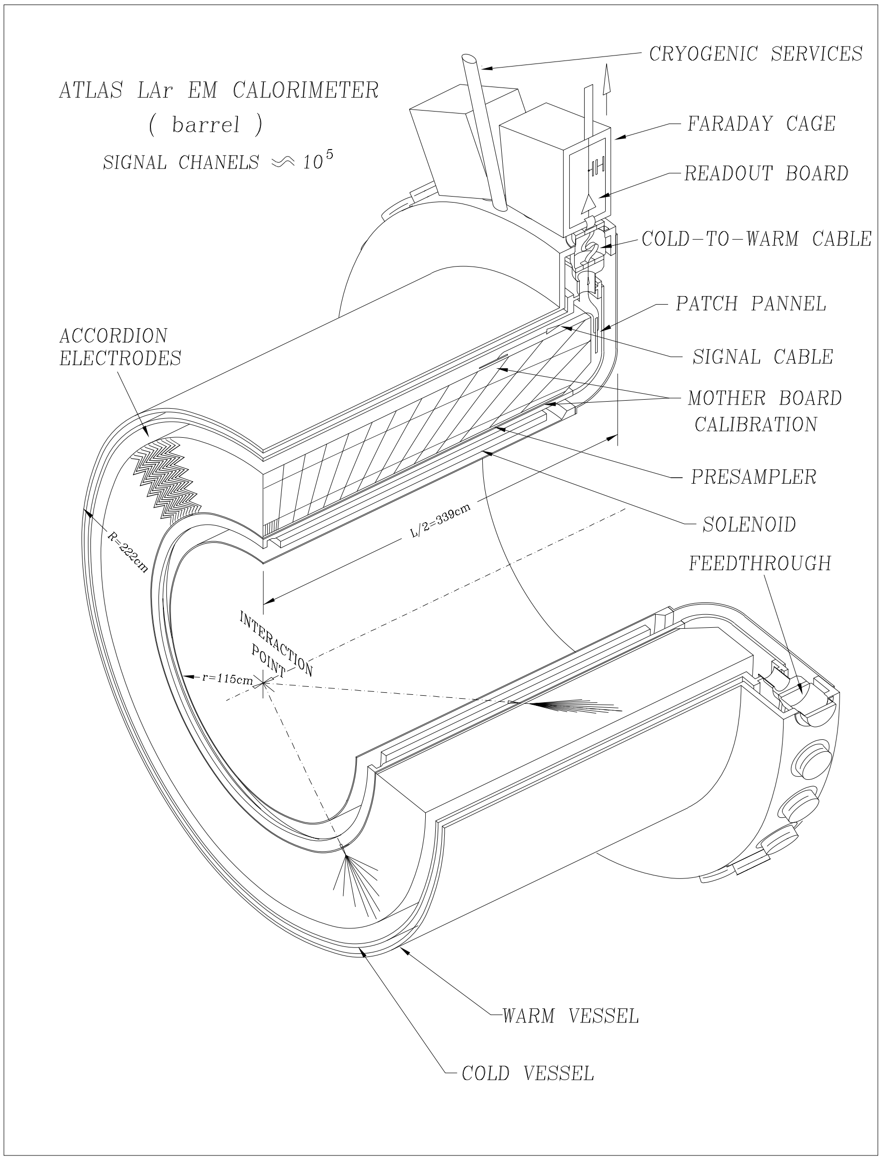
The EM barrel calorimeter

Absorber plates: 1024 Accordion-shaped Pb+Fe for full 2π

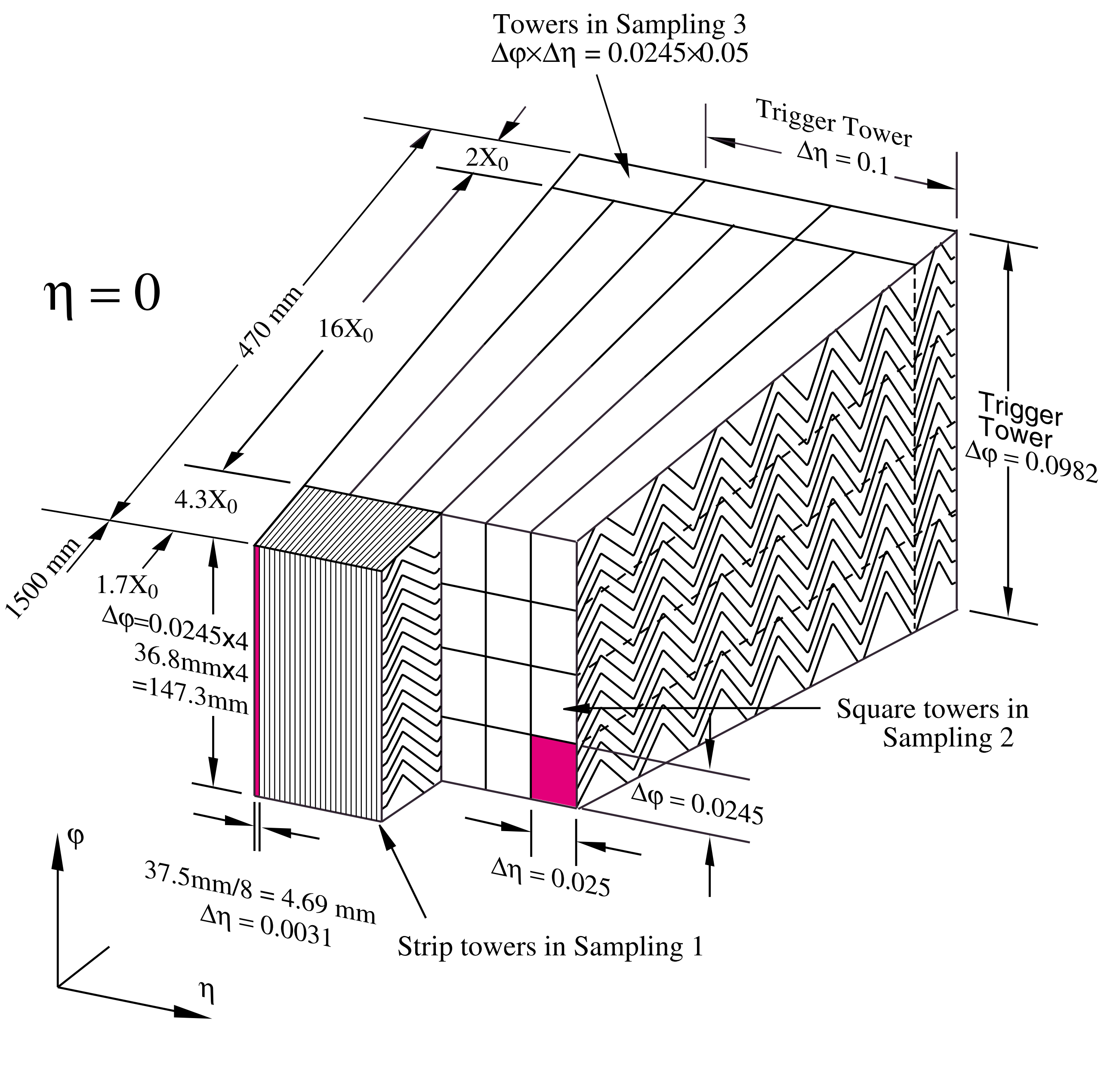
spaced ~ 4.5mm apart, with electrodes in mid-distance

Pb thickness: 1.5mm ($\eta < 0.8$) and 1.1mm ($\eta > 0.8$)

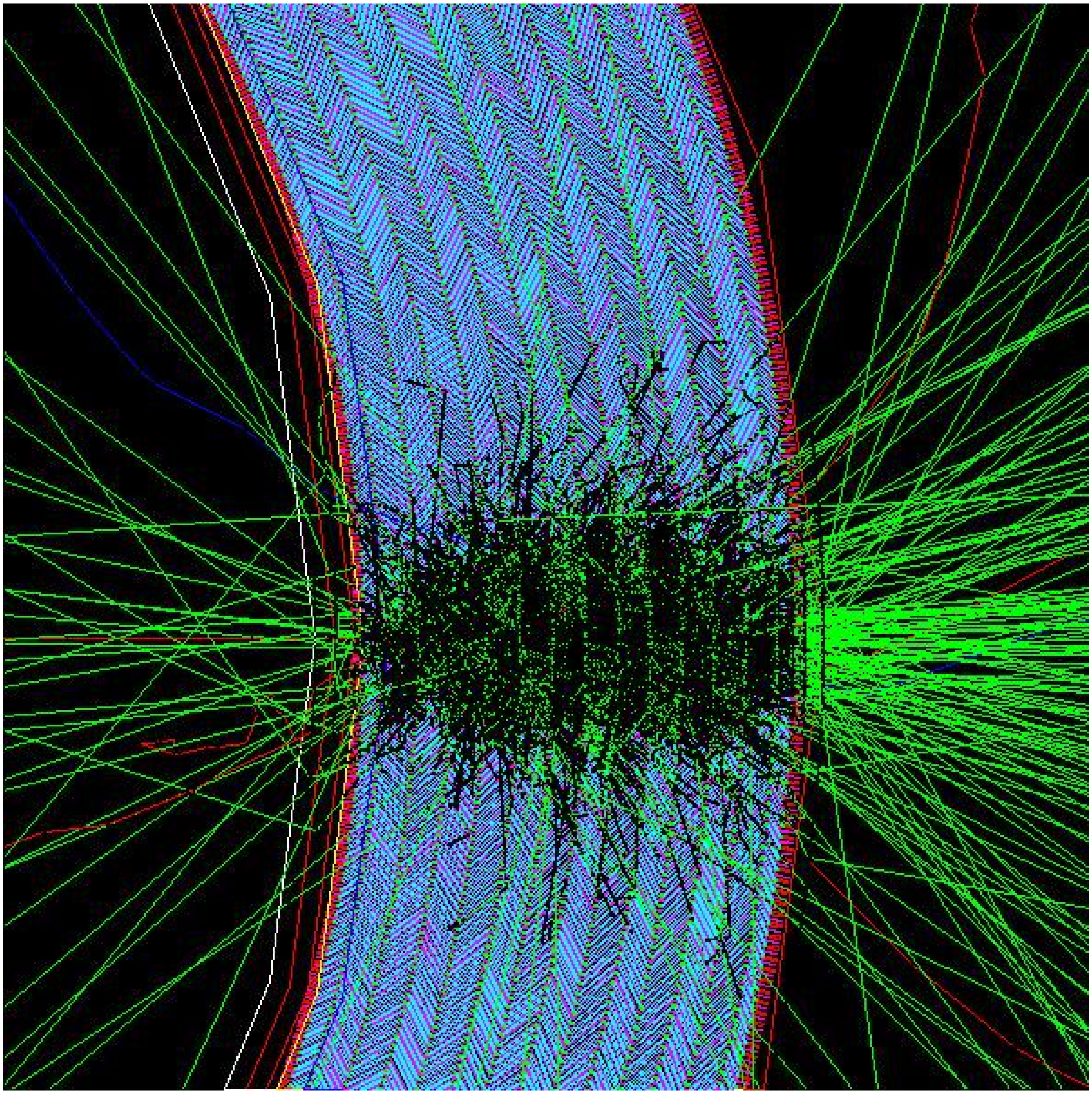
The whole thing in liguid Argon (sensitive medium in the 2.1mm electrode-absorber gaps)



Segmentation of the EM barrel calorimeter



A 50 GeV e^- in the EM barrel calorimeter



2. EM barrel description with Geant4

"Static" model: (by Gaston Parrour)

Geometry as in Geant3: Defines all elementary volumes for each part of the accordion ($\sim$ 100 k volumes)

$\Rightarrow$ $\sim$ 120 Mbytes of memory to run the simulation$^{(*)}$

"Tailored" model: (by Stefan Simion)

Uses Geant4 toolkit to define a new shape (G4Accordion) and constructs the geometry of one 2-D abstract Accordion line-shape ("neutral-fibre") and the positions/thicknesses of the absorber, Kapton and LAr layers, relative to this neutral-fibre.

Then, define the (1024) ϕ positions of the "real" neutral-fibres in the global ATLAS coordinates

$\Rightarrow$ Given the particle direction, its hit-position relative to the closest neutral-fibre is calculated

$\Rightarrow$ Only the relevant Accordion volumes occupy the memory

$\Rightarrow$ $\sim$ 19 Mbytes of memory to run the simulation$^{(*)}$

Both models take the same time per event for $e^{\pm}/\gamma$

(~ 0.55 sec/GeV for $e^{\pm}/\gamma$ at CERN & Lyon Linux clusters)

Comparing the two geometry models

Shoot 50 GeV e^- towards various detector regions
(of greater interest: $\eta \sim 0.0, 0.8, 1.4$)

(1) Record: E_{LAr}, $E_{Absorbers}$, $E_{electrodes}$, E_{G10}, E_{Air}, etc.

Q: Does the sum equal the incident energy E_{inc}?
A: Yes.

Q: Are the fractions E_x/E_{inc} the same?
A: Close, but not exactly.

(2) Compare: $f_1 = \frac{E_{LArg} \text{ in the 1st sampling}}{E_{LArg} \text{ total in all samplings}}$
$\Rightarrow$ Agreement.

(3) Find incident ϕ direction using the 2^{nd} LAr sampling:

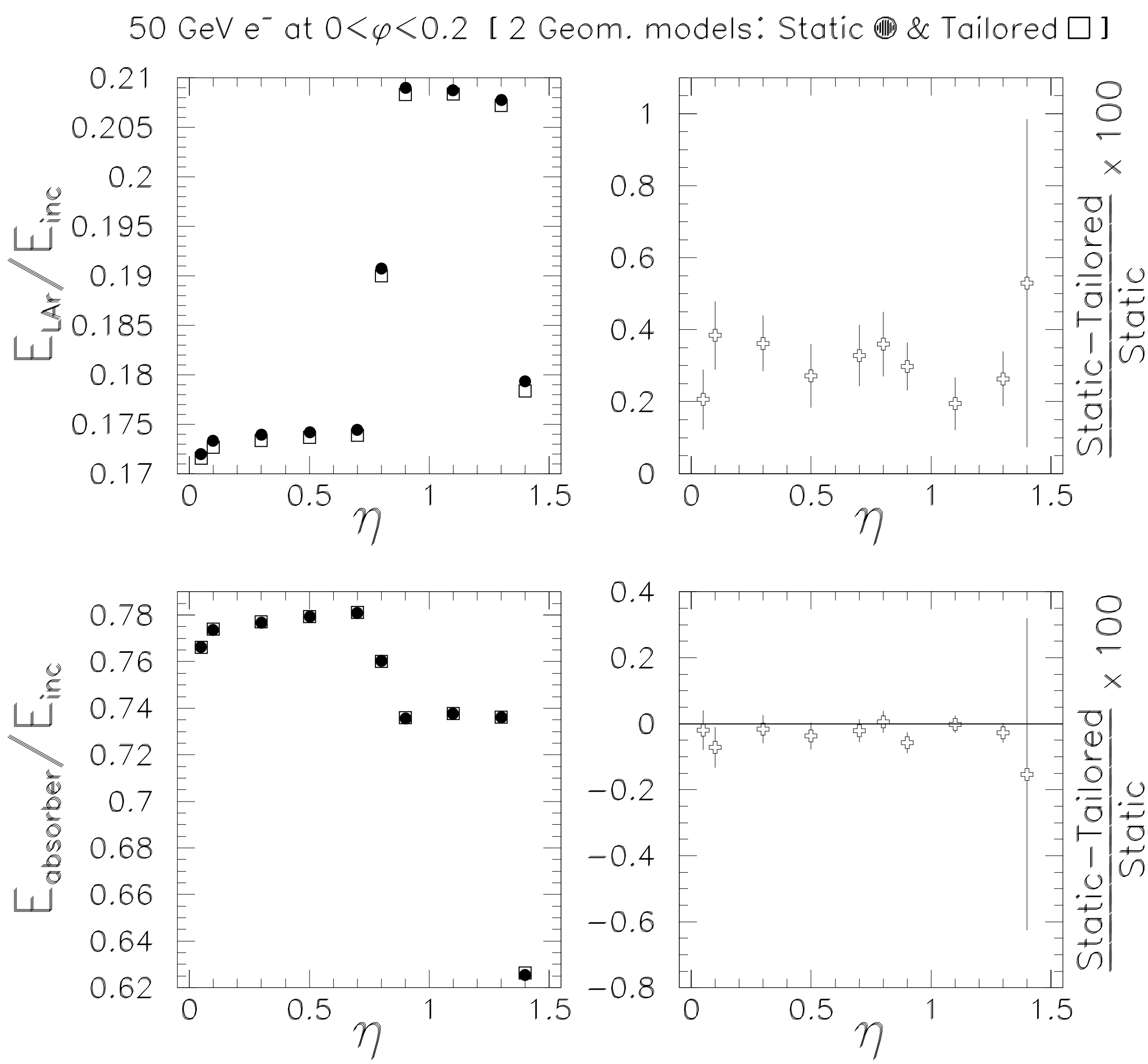
$$\phi_{barycenter} = \frac{\sum E(i)\phi(i)}{\sum E(i)}$$

$\Rightarrow \Delta\phi = \phi_{barycenter} - \phi_{incident} = f(\eta)$

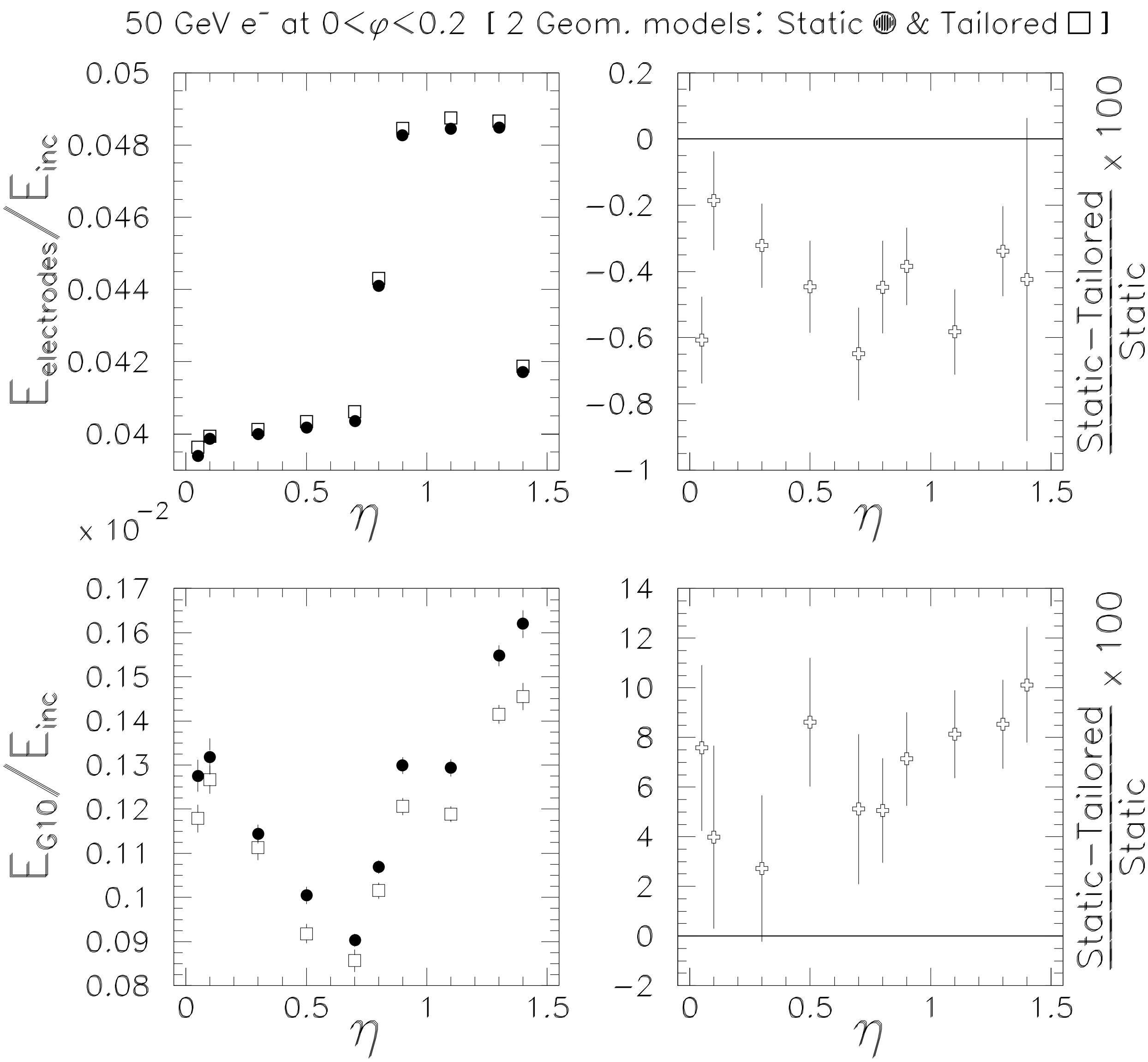
NOTE: Not done yet. Will be, after the clustering is complete. For the moment get the energy-weighted ϕ of each Geant4 step.

2a) 50 GeV e^- at exact η's, $0 < \phi < 0.2$

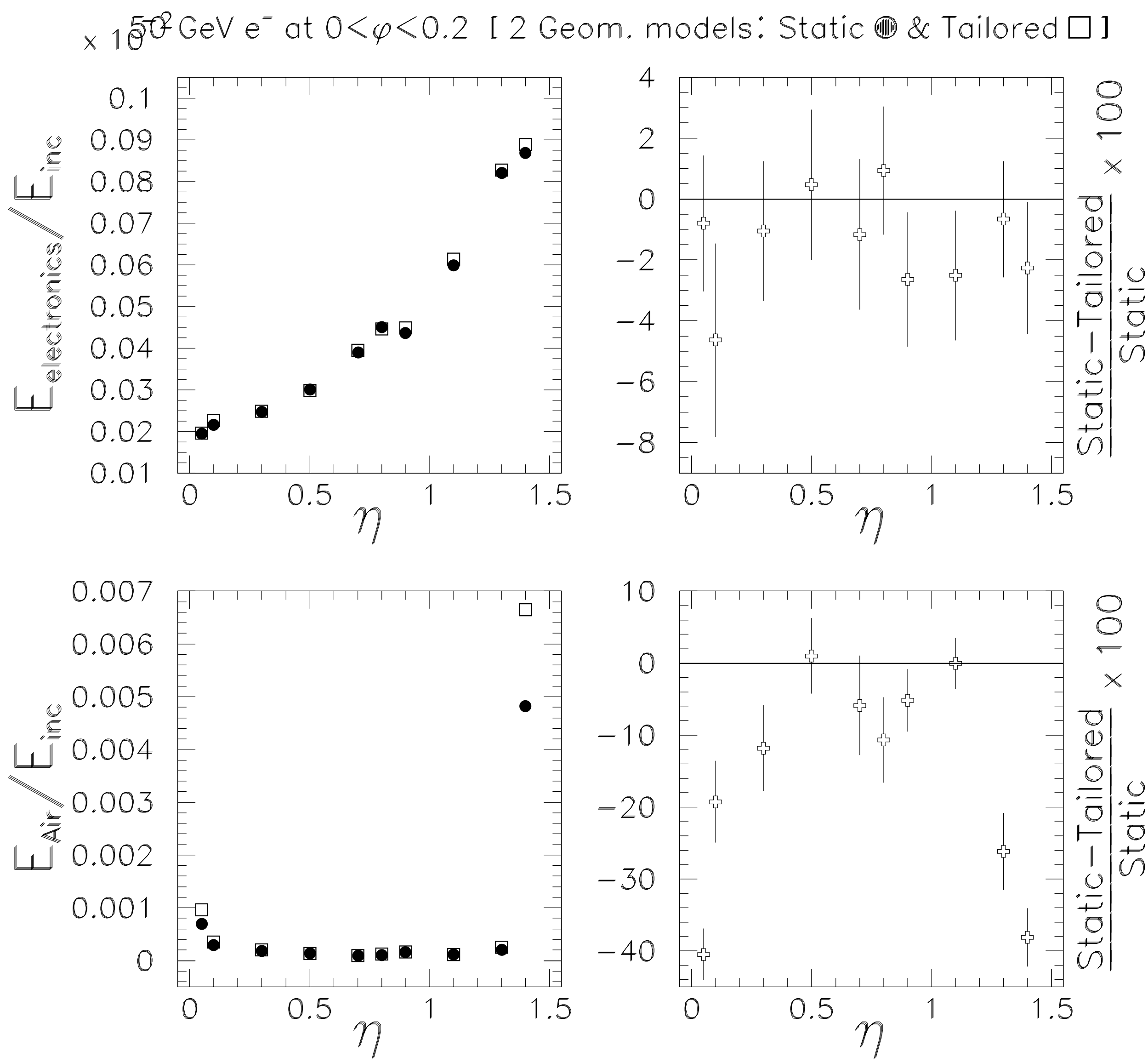
($\simeq 500$ events at each η value)



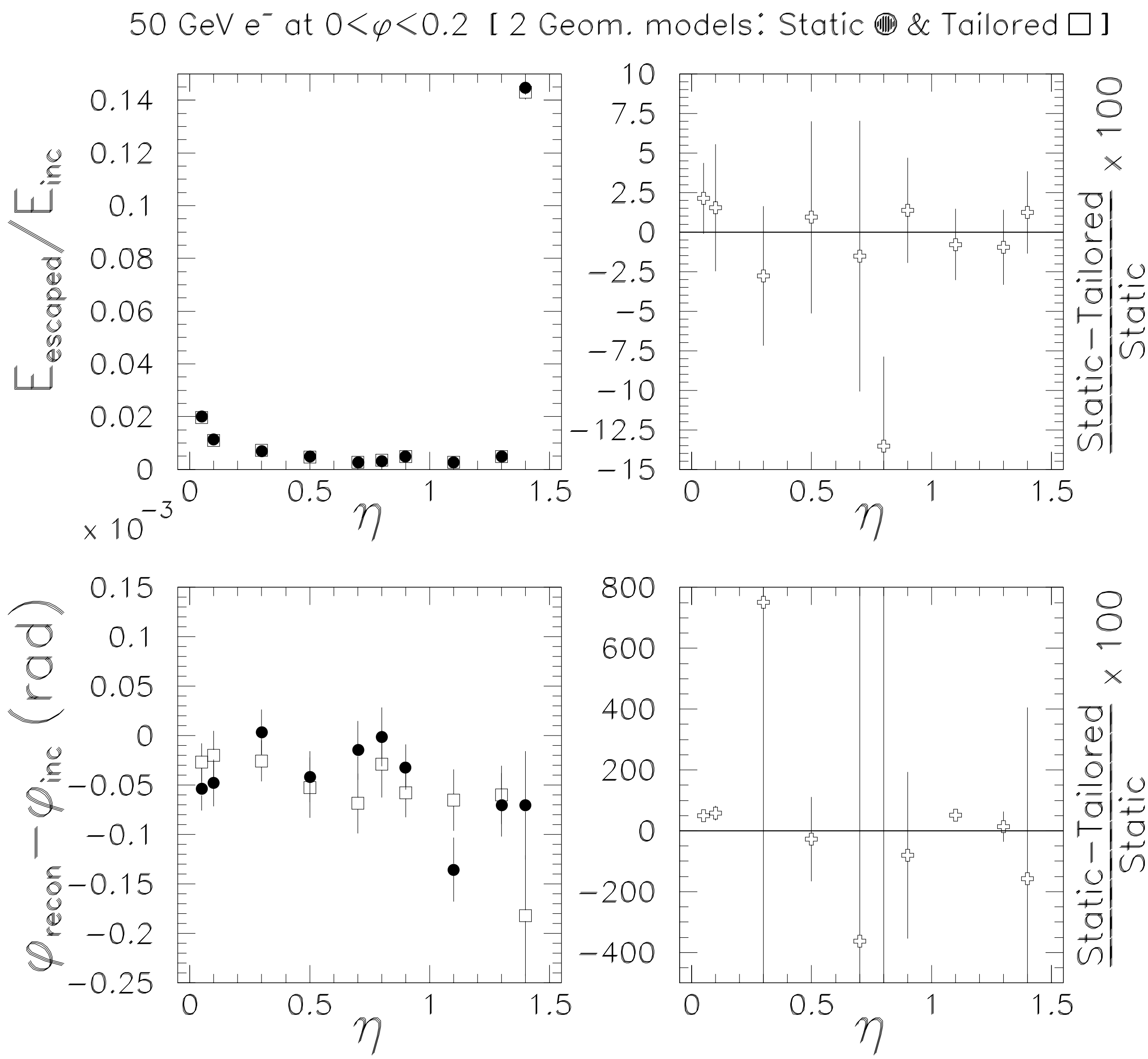
Fraction of energy into electrodes and G10 bars



Fraction of energy into electronics and Air



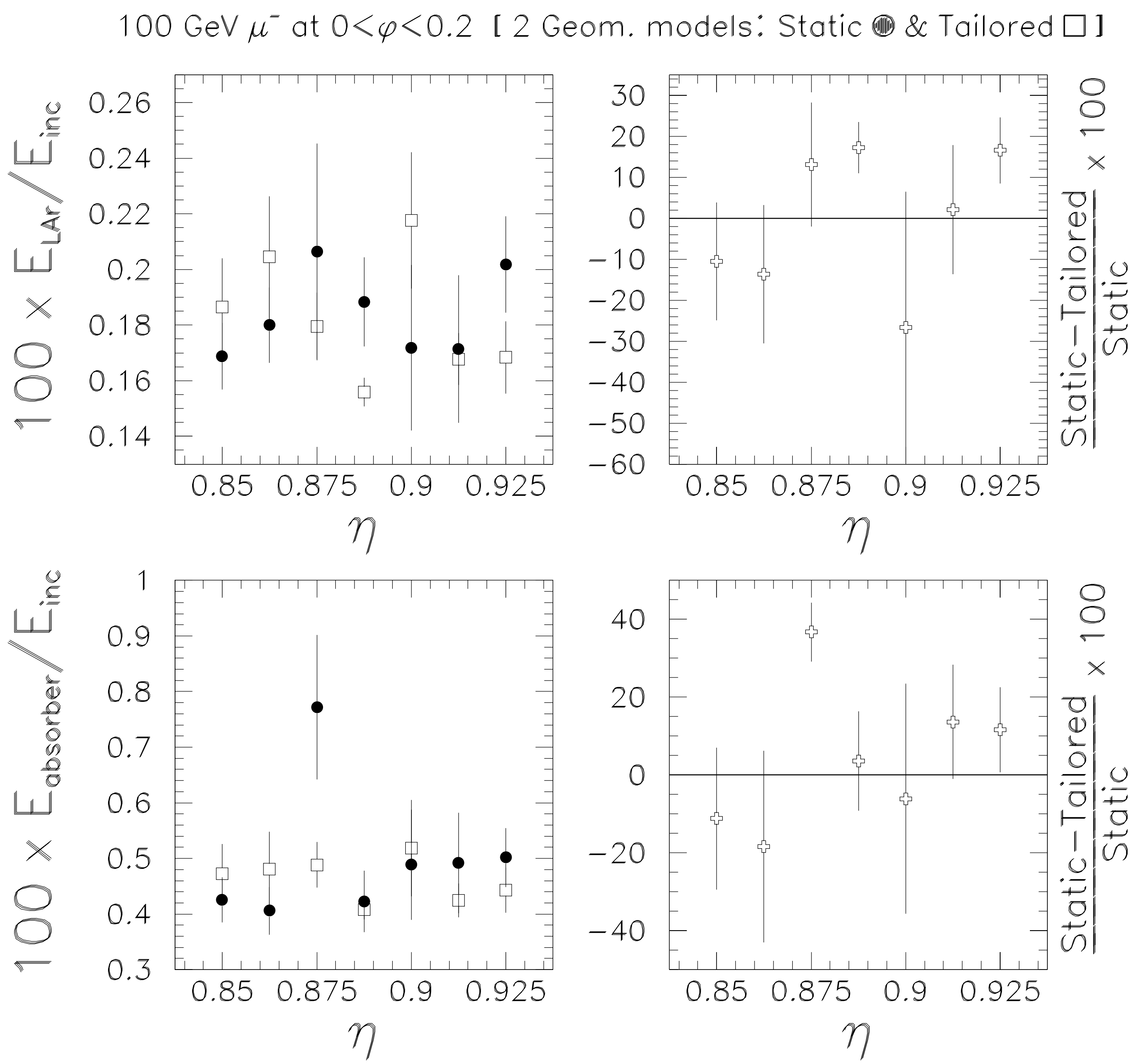
Fraction of energy escaping and recosnstructed$^{(*)}$ ϕ



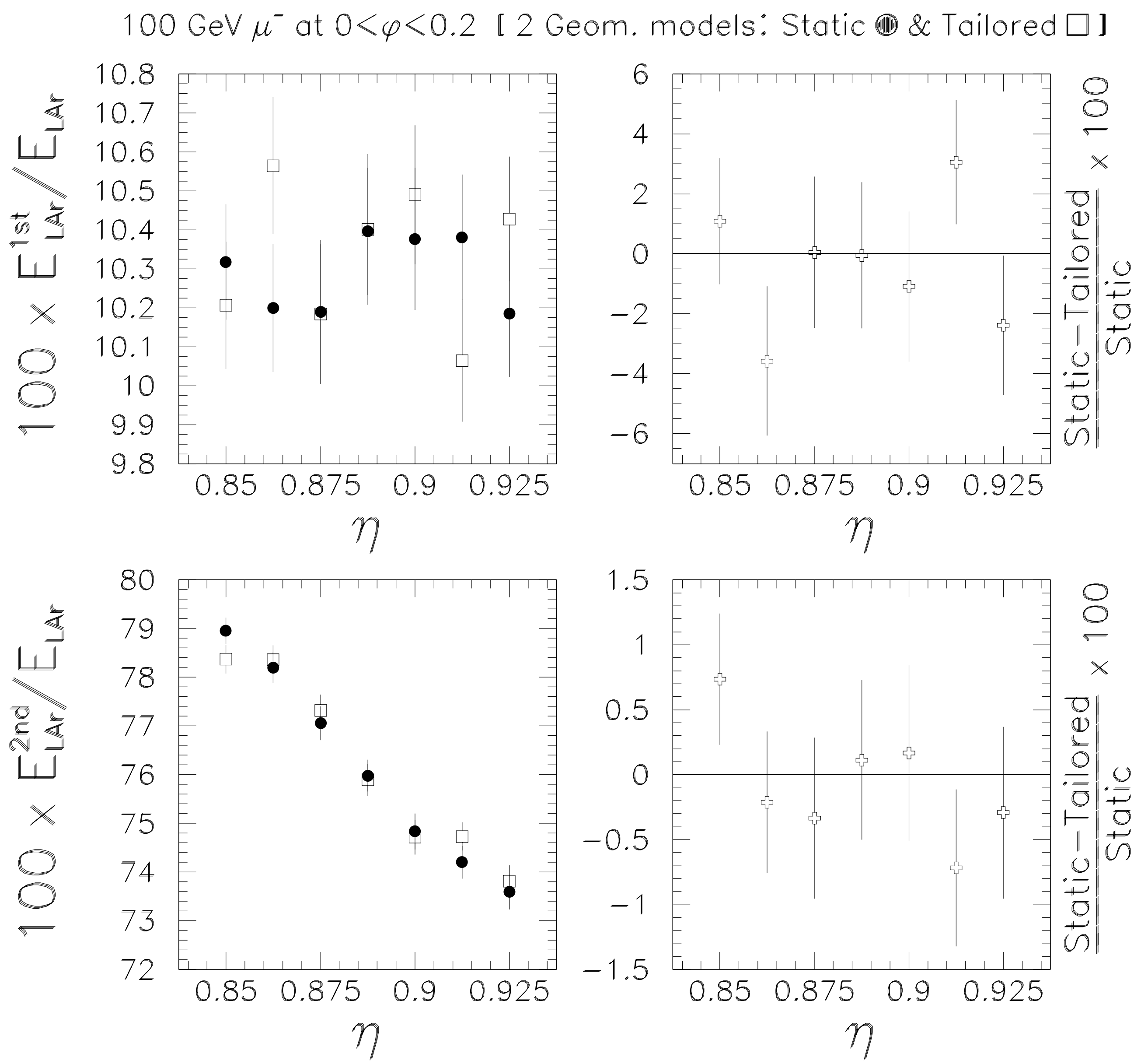
(*) Energy-weighted ϕ from Geant4 steps

2b) 100 GeV μ^- at $\eta \sim 0.9$, $0 < \phi < 0.2$

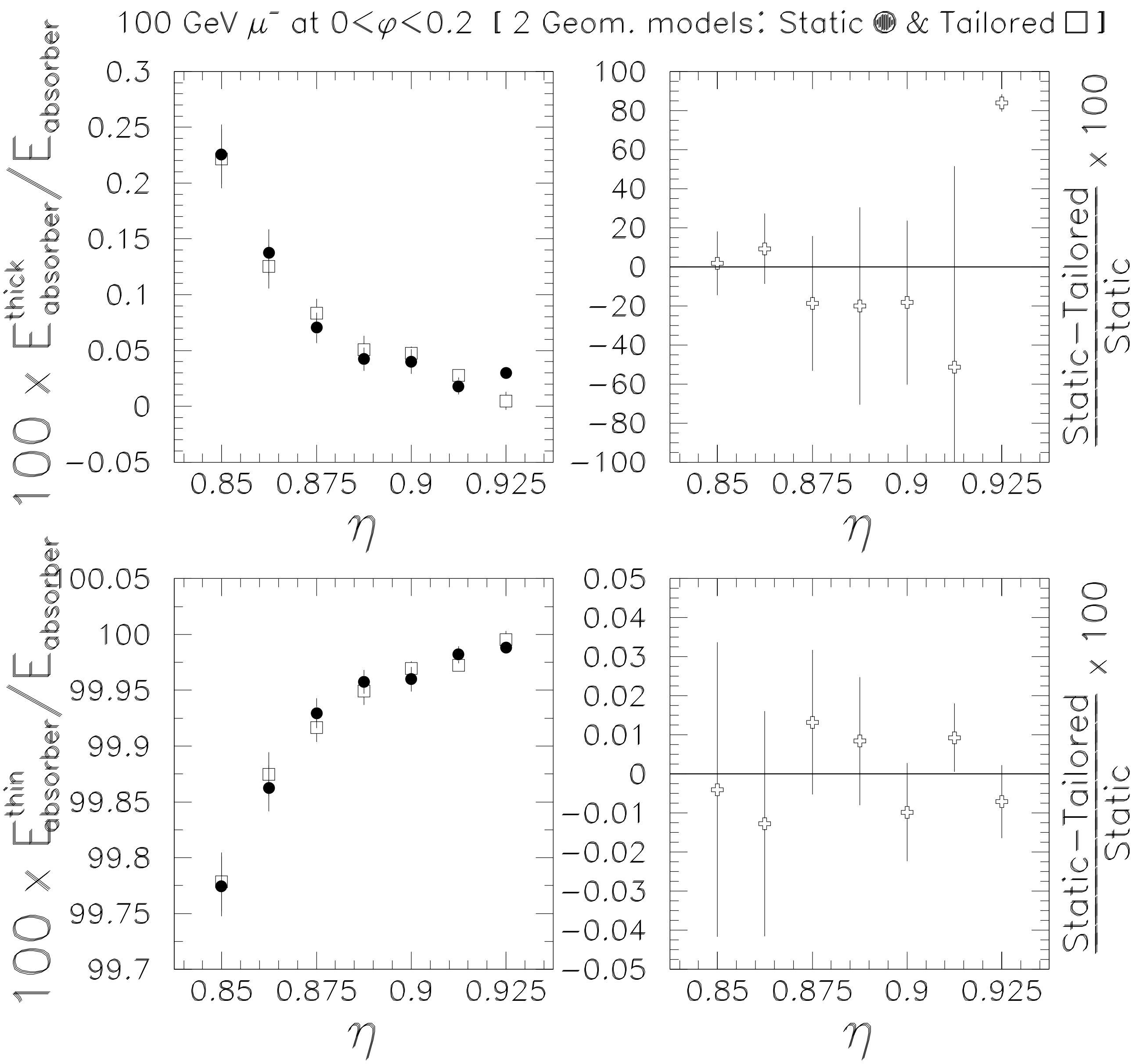
($\simeq 500$ events at each η value for each model)



Fraction of LAr energy into the 1^{st} and 2^{nd} samplings



Fraction of Absorber energy at $\eta < 0.8$ (thick) and $\eta > 0.8$ (thin)



Results on comparison of geometry models

1) No big differences between the two models, but not perfect agreement either.
$\Rightarrow$ Use "static" model for now, and
we'll re-do the comparison with:

(i) smearing in η as well as in ϕ,

(ii) small Geant4 steps compared to volume thicknesses.

2) Time consumed for simulation of electrons is the same

Memory saving with "smart" use of voxels

Q: Can we do anything about the memory usage with the "Static" model?

A: Yes. One can optimize the tracking by deviding the geometry into "voxels" and checking in which voxel the track is, instead of in which real volume.

E.g., `Volume_log->SetSmartless(Value);`

$\Rightarrow$ With decreasing Value get fewer voxels, but may take more time to find the real volume inside each voxel.

RESULTS:

1) Can get a factor of ~ 3.5 reduction in memory usage (35 $\rightarrow$ 10 Mbytes for EM barrel testbeam setup) by applying
`Volume_log->SetSmartless(0.2);` (lowest*)
comparing to using
`Volume_log->SetSmartless(2.0);` (default)

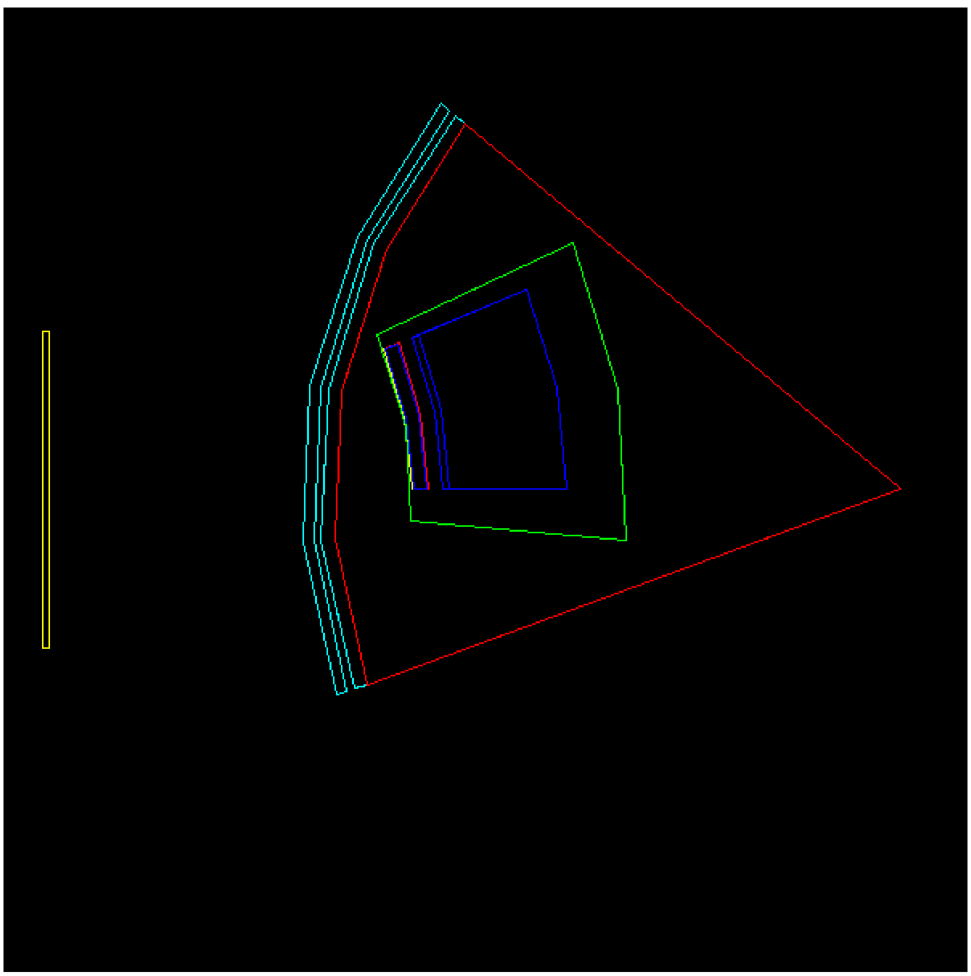
2) The execution time increases by $< 5\%$

Geant4 physics

ATLAS started a collaboration with the Geant4 team in order to validate the physics of the Geant4 product, by comparisons with Geant3 and TestBeam data

Order of comparison project (EM barrel): μ, e

Test beam geometry in Geant4 is very similar to Geant3*



3a) Geant4 vs. Geant3: E_{LAr} for μ^-

Compare Geant4.1.0 vs. Geant3.

50 GeV and 100 GeV μ^-, towards various η values.

In each η region, incident μ^- cover $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ (one middle-size cell)

Geant4 cut: 2.0, 1.0, 0.5, 0.05 mm

Geant3 cuts:

BCUTE (γ) = 10 keV, DCUTE ($e^{\pm}$) = 100 keV

Note:

→ 0.05 mm cut in Geant4 corresponds to
1.4 (18) keV for γ and 55 (154) keV for $e^{\pm}$ in LAr (Pb)

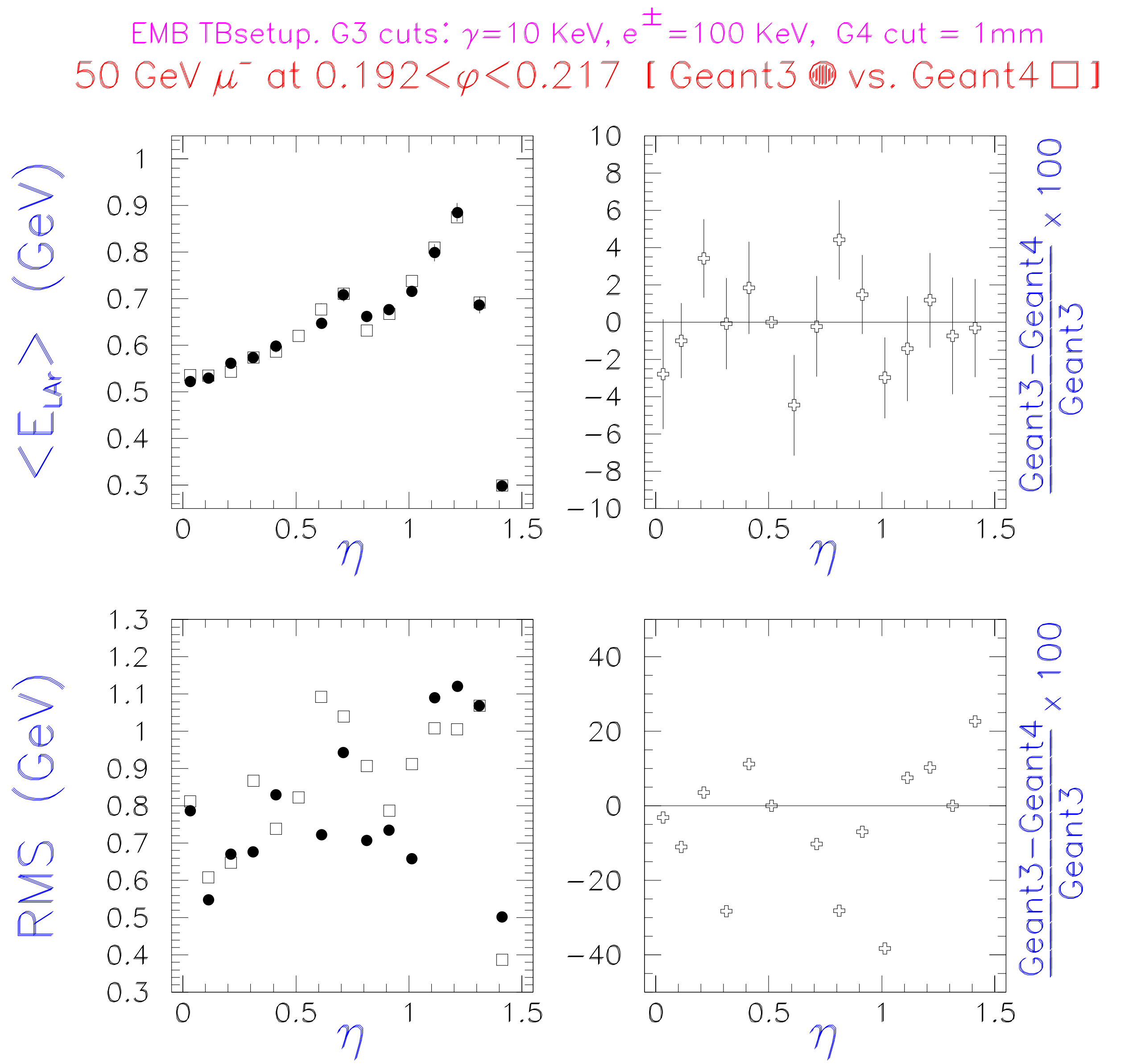
→ 2 mm cut in Geant4 corresponds to
9 (121) keV for γ and 568 (2614) keV for $e^{\pm}$ in LAr (Pb)

In order to compare Geant4 with test beam data, we must have realistic energy clustering, and also add noise (the Geant3 description is complete).

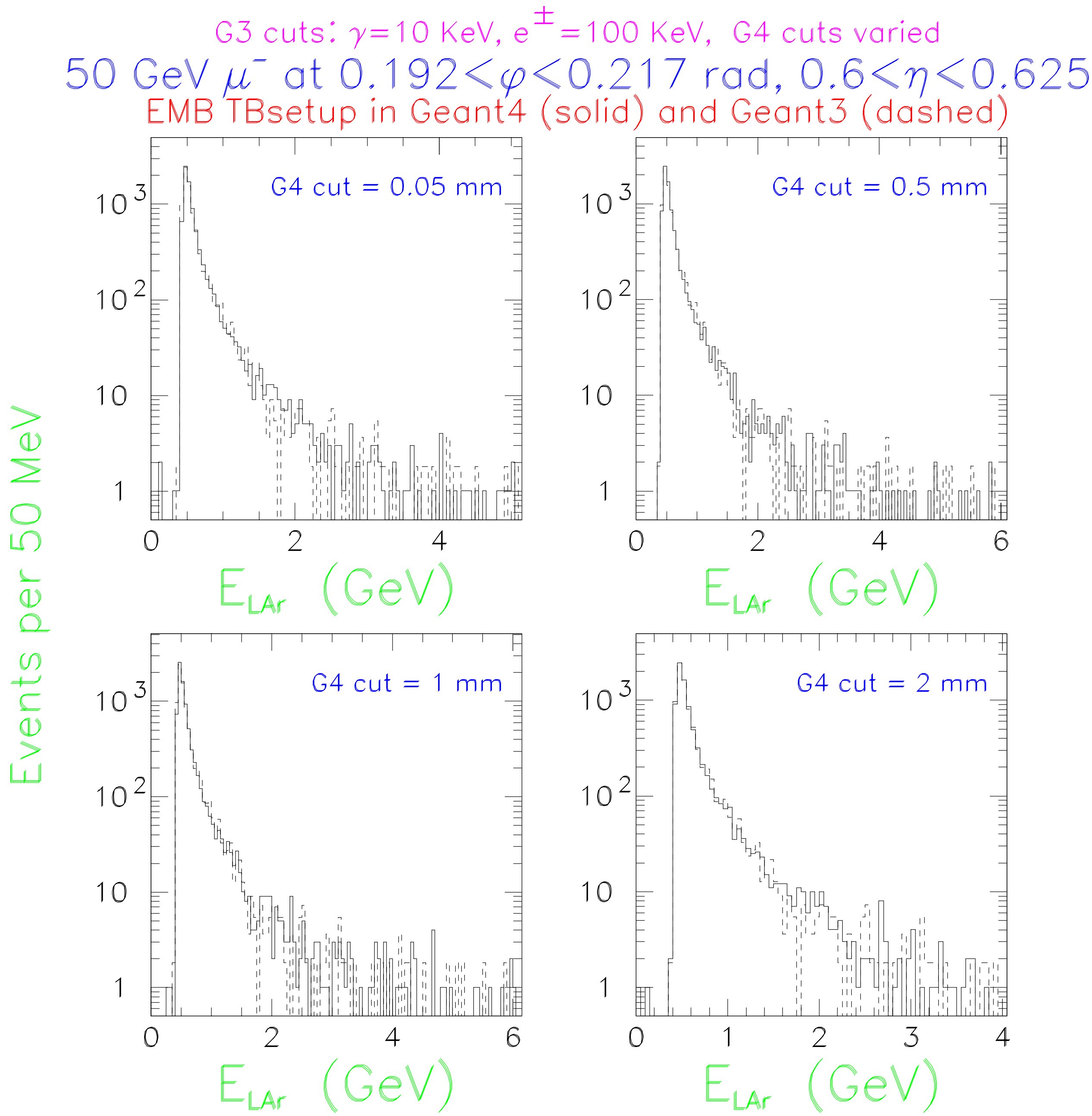
Geant4: no energy clustering, no noise for following results

50 GeV μ^-: energy in LAr vs. η

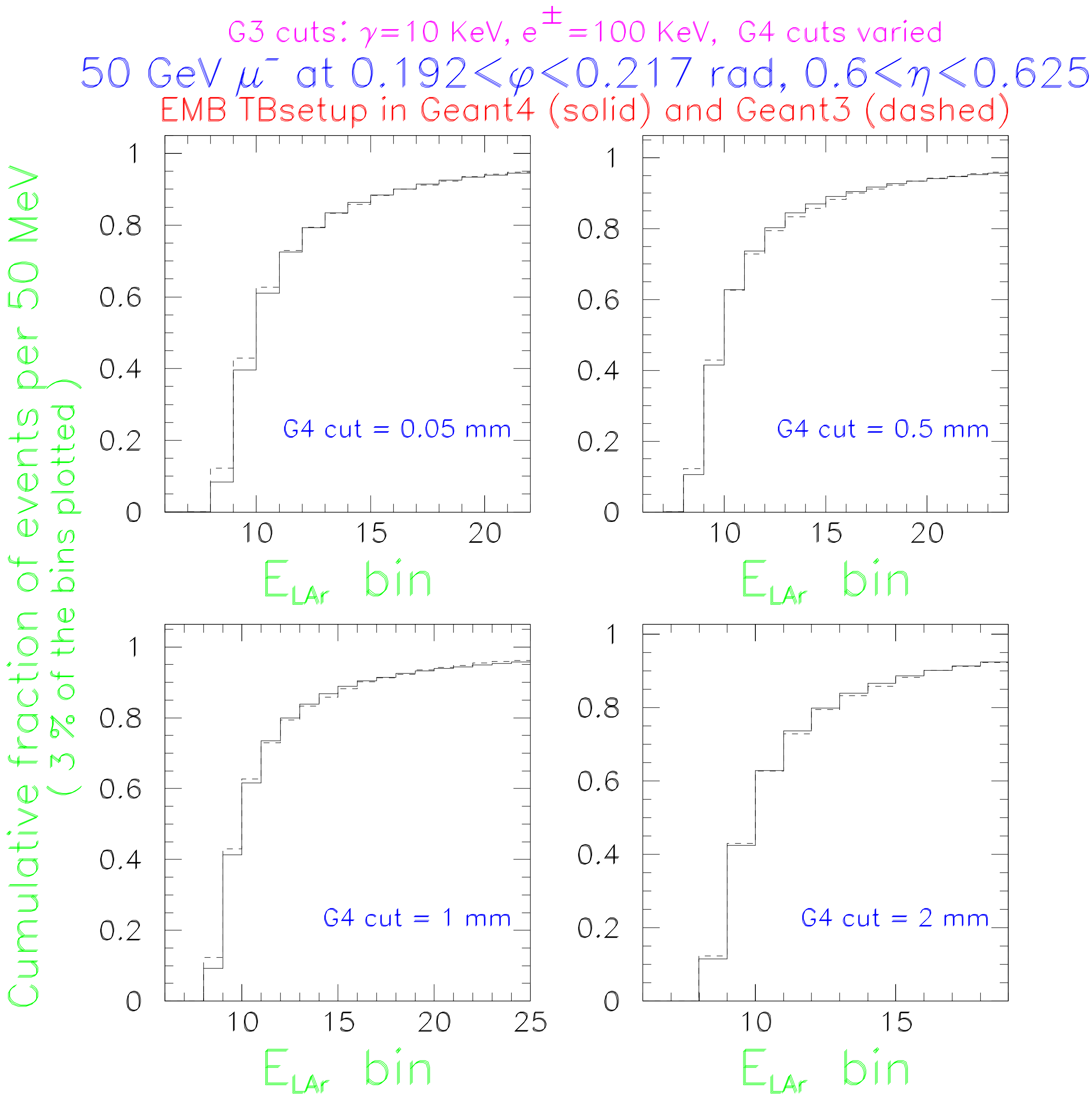
Geant4.1.0: ~ 8000 (Geant3: ~ 4000) events at each η value



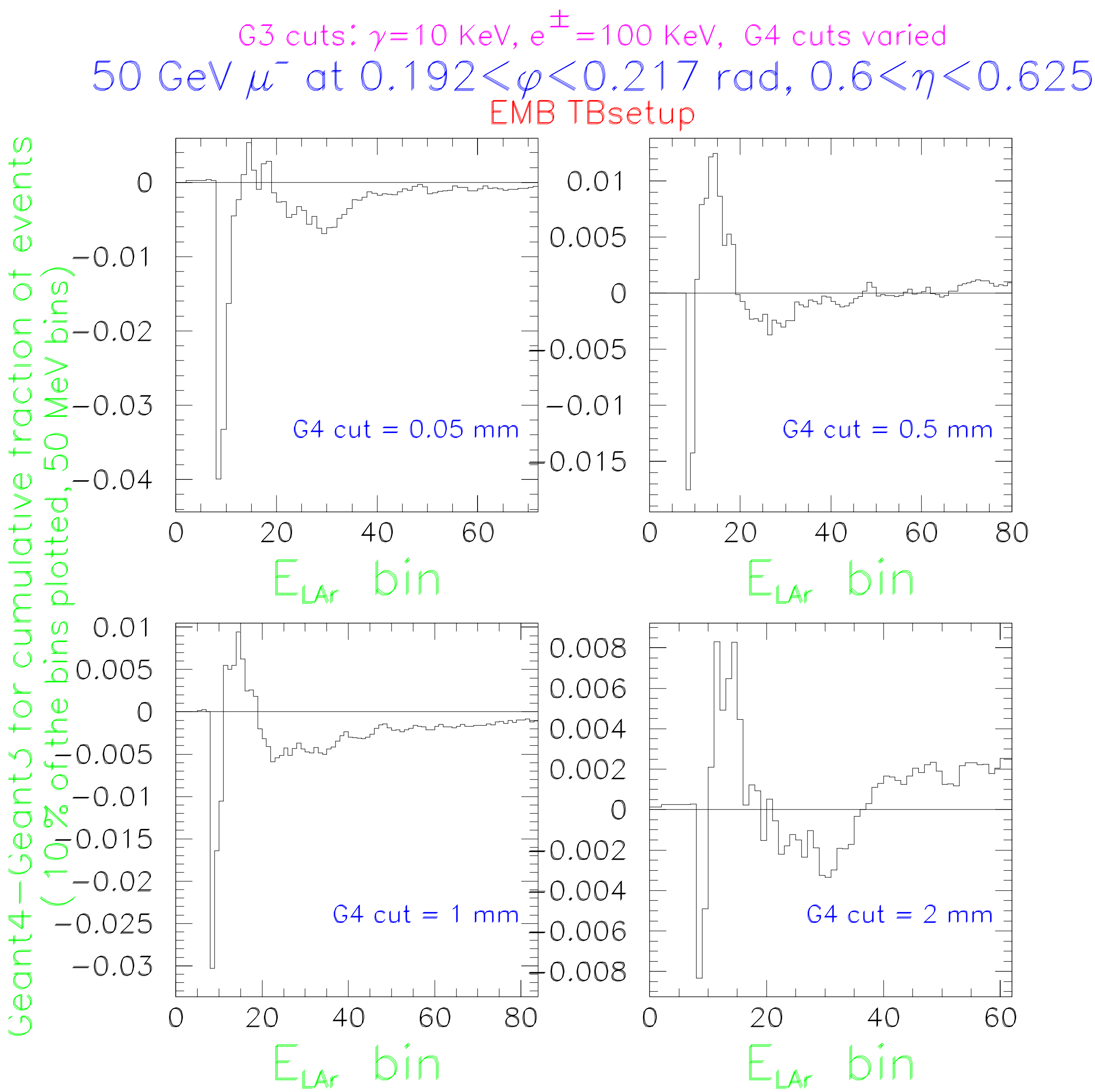
50 GeV μ^-: energy in LAr (shapes 1)



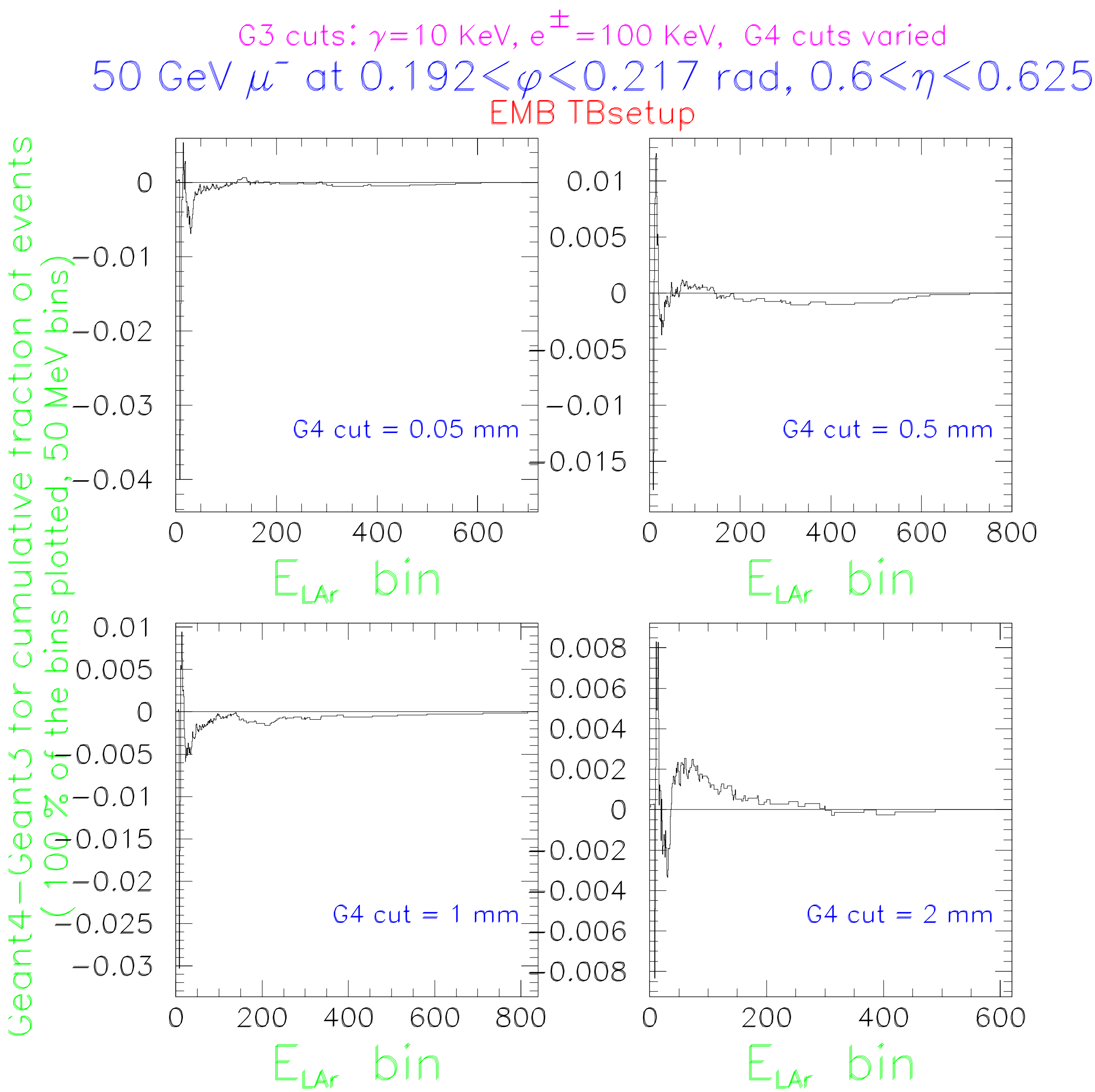
50 GeV μ^-: energy in LAr (shapes 2)



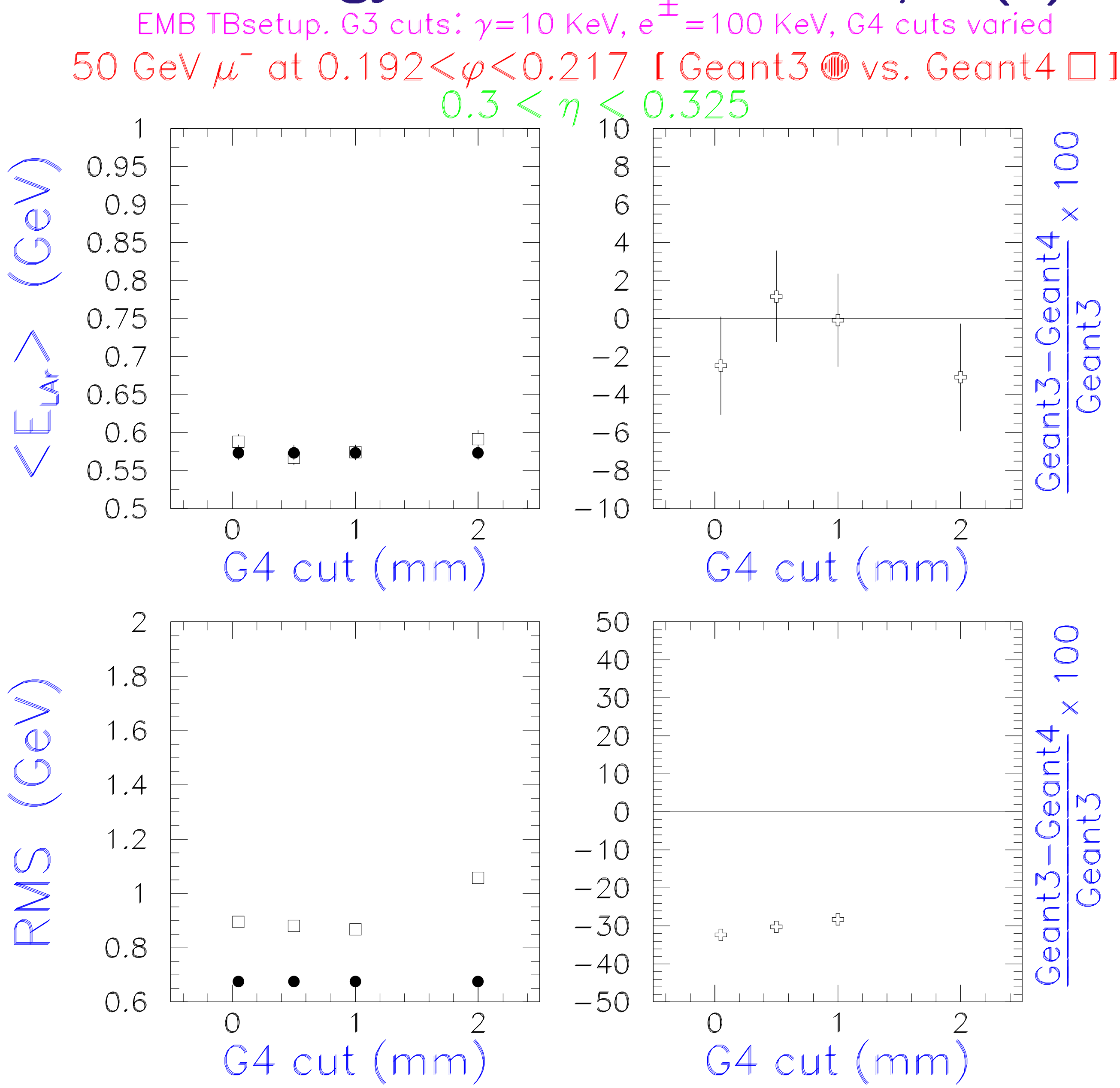
50 GeV μ^-: energy in LAr (shapes 3)



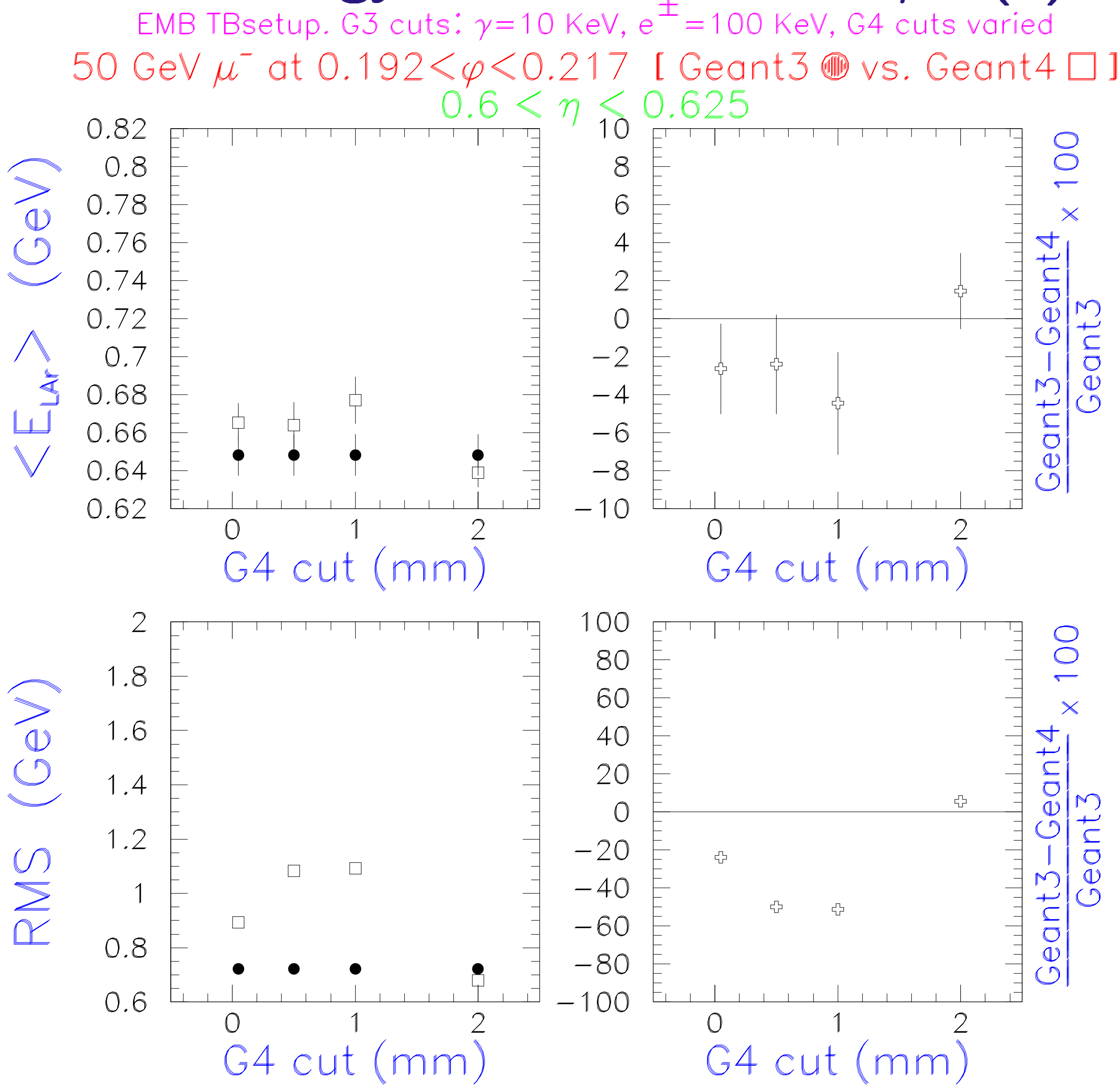
50 GeV μ^-: energy in LAr (shapes 4)



G4 cuts: energy in LAr for 50 GeV μ^- (1)



G4 cuts: energy in LAr for 50 GeV μ^- (2)



⇒ ELAr depositions do not depend strongly on G4 cut

Remarks on Geant4 vs. Geant3 muons

Mean ELAr depositions do not depend strongly on G4 cut

The ELAr depositions in G4 are distributed differently than in G3, even though the mean values are in agreement.

The differences are not large, but in general one can say that G4 puts more events in the central part of the distribution, and less in the "near-tails" (both low-end and high-end tails, up to Mean + 1 RMS).

In the "far" high-end tail ($>$ Mean + 2 RMS), G4 agrees with G3.

When we add noise ($\sim 15\%$ of mean E_{LAr} for muons) differences are smaller, but this is not a comparison between Geant4 and Geant3 anymore...

BUT do not forget:

1) The real test is the Test Beam (Next project)
2) Geant4 is not merely Geant3 re-written in C++

VERY PRELIMINARY:
Geant4 vs. Geant3: E_{LAr} for e^-

Compare Geant4 (4.2.0-ref-02) vs. Geant3.

10, 25, 50, 80 and 100 GeV e^-, towards $\eta \simeq 0.6, 0.9$.

In each η region, incident e^- cover $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ (one middle-size cell)

Geant4 cut: 0.03 mm

Geant3 cuts:

BCUTE (γ) = 10 keV, DCUTE ($e^{\pm}$) = 100 keV

Note:

0.03 mm cut in Geant4 corresponds to
1.1 (13) keV for γ and 41 (112) keV for $e^{\pm}$ in LAr (Pb)

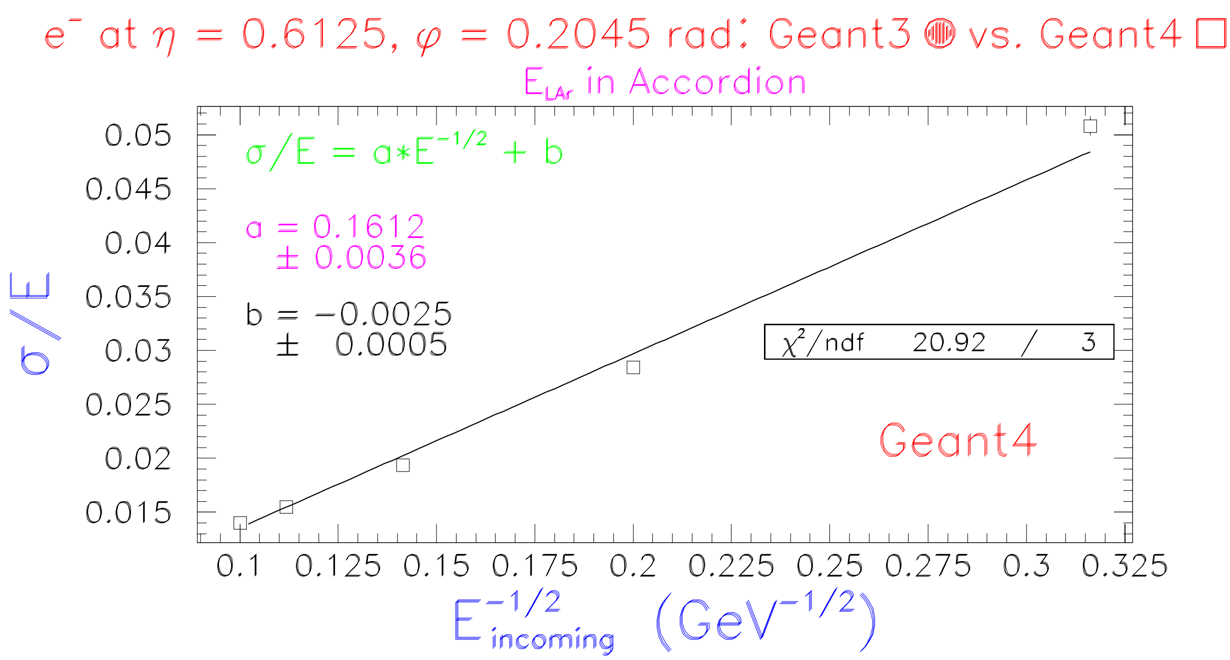
In order to compare Geant4 with test beam data, we must have realistic energy clustering, and also add noise (the Geant3 description is complete).

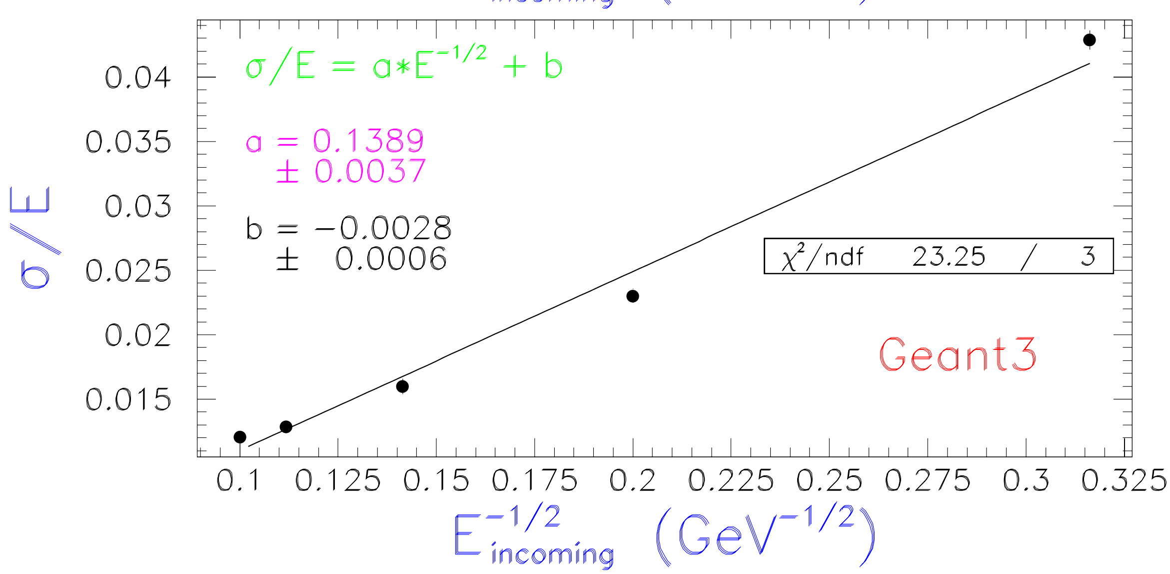
Geant4: no energy clustering, no noise for following results

VERY PRELIMINARY:

e^- energy scan at $\eta = 0.6$

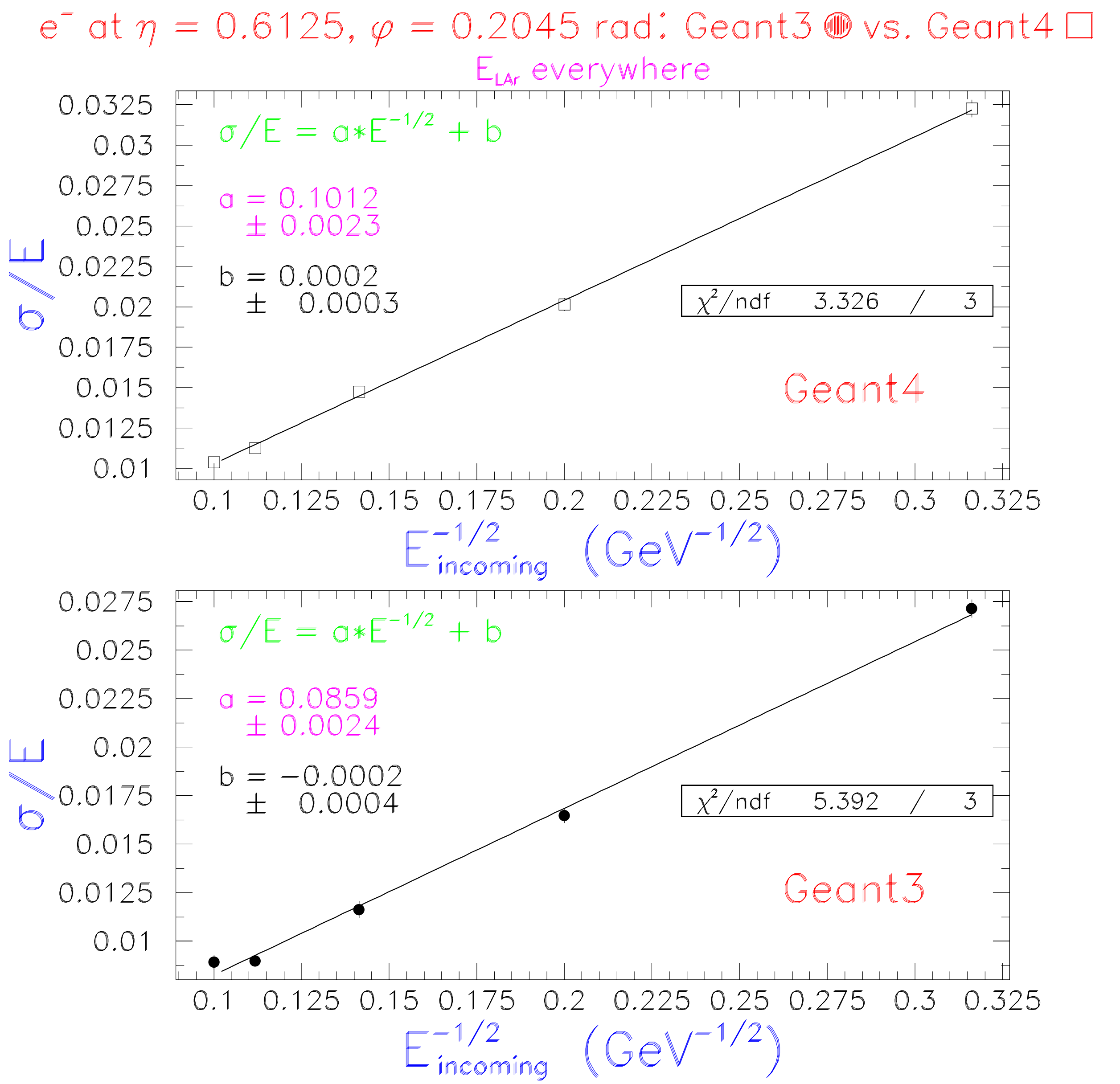
2000 events per (η, E) for G4. $550 - 2000$ for G3





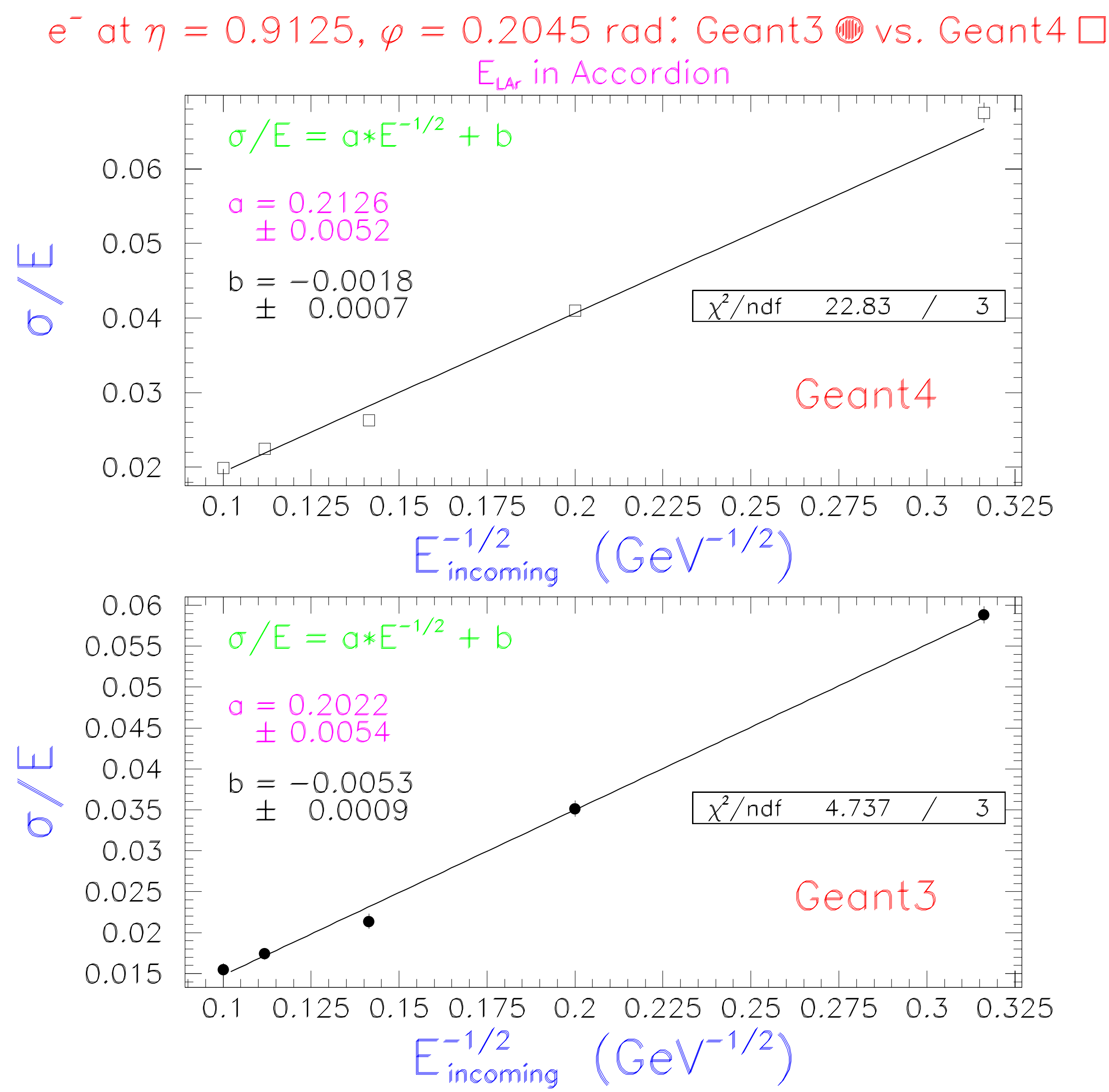
VERY PRELIMINARY:

e^- energy scan at $\eta = 0.6$



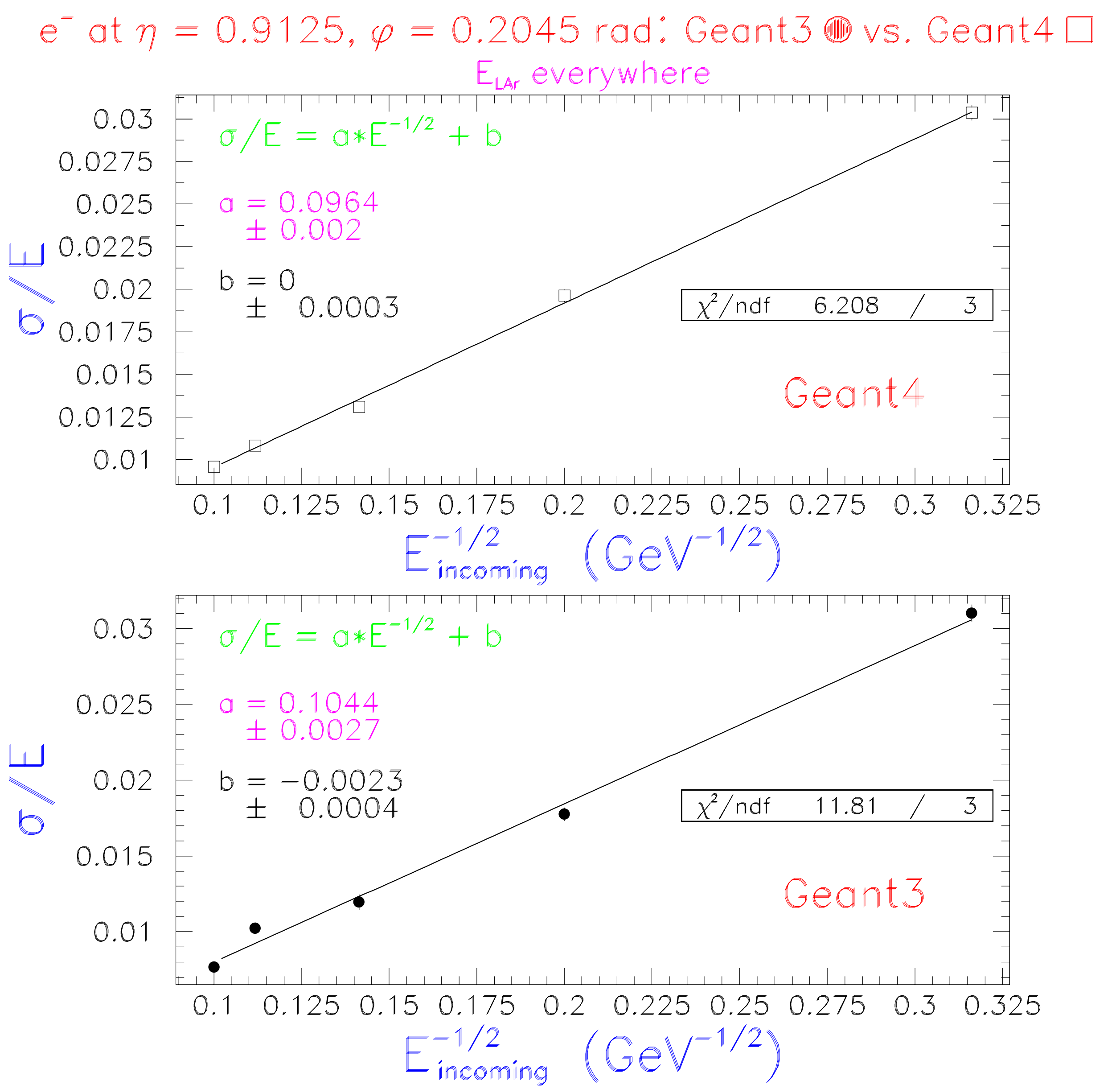
VERY PRELIMINARY:

e^- energy scan at $\eta = 0.9$



VERY PRELIMINARY:

e^- energy scan at $\eta = 0.9$



VERY PRELIMINARY:

Remarks on Geant4 vs. Geant3 electrons

σ/E is similar between Geant3 and Geant4. Good enough, given the small diffrences in the geometry (extra copper between presampler and Accordion volume in Geant4)

The Presampler is important. It sees the begining, and most uncertain, part of the shower, and taking its measurement into account improves the energy resolution

Summary/Next

A first comparison between the two geometry models has shown that there are some small differences
$\Rightarrow$ Use "static" model for now, and will repeat comparison in greater detail.

One can reduce significantly the memory usage of the straight-forward "static" geometry description. Nevertheless, the "tailored" description is unbeatable in memory usage, but mathematical description of neutral fibers is hard to develop, in general

Mean energy depositions for muons are in agreement between Geant4 and Geant3. Some differences in shapes are observed. Comparison with test beam will come next, and the addition of noise will be a crucial factor

VERY PRELIMINARY results with e^- show that σ/E is similar between Geant3 and Geant4.2.0-ref-02

And do not forget:

1) The real test is the Test Beam (Next project)

2) Geant4 is not merely Geant3 re-written in C++