Hadronic highlights in G4 9.6

A. Ribon CERN PH/SFT

CHIPS package decoupling

CHIPS package is very difficult to maintain, therefore we decided to extract only the minimum which is really needed; the CHIPS package is now deprecated and removed in G4 10

- Quasi-elastic scattering
 - Both cross sections and final states (used in QGS-based P.L.)
- Elastic scattering
 - Both cross sections and final states
- Hadron nucleus inelastic cross sections
 - Kaons and hyperons cross sections used in most physics lists
- Gamma- and electro-nuclear
 - Cross sections of γ A interactions
 - Virtual photon generation and conversion to real photon (for electro-nuclear)

CHIPS replacement

CHIPS nuclear capture at rest and final-state gamma- and electro-nuclear (which cannot be decoupled from the CHIPS package) have been replaced by Bertini + Fritiof:

- Nuclear capture at rest
 - **Bertini** is used for π^- , K^- , Σ^- , Ξ^- and Ω^-
 - Fritiof (+ Precompound) is used for \underline{p} , $\underline{\Sigma+}$, \underline{d} , \underline{t} , $\underline{3He}$, and $\underline{\alpha}$
- Gamma- and lepton-nuclear
 - Bertini & Fritiof (+ Precompound) is used

Checking energy conservation

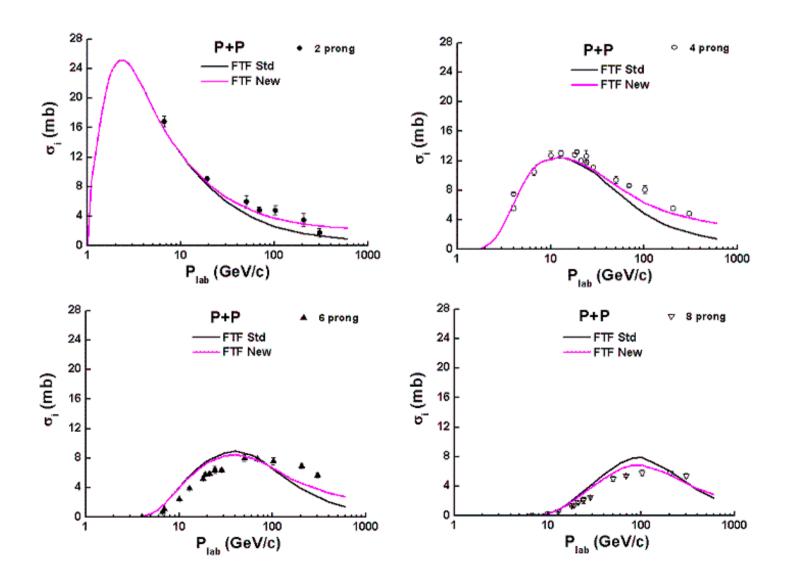
Introduced a new check against "catastrophic" energy violations

- Default limits: relative = 10%, absolute = 5 GeV
 - Models may provide different limits,
 e.g. (10%, 250 GeV) for HP
 - The check fails if both relative and absolute fail
- If check fails:
 - Raise G4Exception "JustWarning"
 - Re-sample the interaction
 - If more than 100 consecutive re-samplings, "FatalException"

Fritiof

Improved diffraction dissociation of:

protons, pions and kaons



Bertini

- Added capability to handle nuclear capture at rest
 - For π^- , K^- , Σ^- , Ξ^- and Ω^-
- Added capability to handle direct photo-nuclear
 - y n and y p final-state reaction
- Lepto-nuclear interactions via virtual photon
 - Models used to generate virtual photon, then to convert to on-shell gamma projectile
 - Bertini used below 10 GeV
 - FTF used above 10 GeV, photon converted to π°
- Changed internal nucleon-nucleon cross sections
 - Driven by the SATIF benchmark
 - Use Stepanov's cross section values up to 420 MeV

INCL++

- C++ full redesign of Fortran INCL
 - Liège Intranuclear Cascade model
- According to IAEA spallation benchmarks, one of the best intra-nuclear cascades
 - For π, p, n, d, t, 3He, α on nuclei
 - From threshold (~ 100 MeV) up to ~ 3 GeV
- INCL++5.1: ahead of current Fortran INCL4.6
 - Can handle light-ion projectiles up to A=18
- Physics list QGSP_INCLXX
 - Similar to QGSP_BERT, with INCL below 3 GeV

Inelastic cross sections in G4 9.6

Consistent set of inelastic hadron-nucleus cross setions used across all physics lists

- Except LHEP and CHIPS physics lists
- Replaced Wellisch nucleon-nucleus inelastic cross sections with Barashenkov-Glauber-Gribov
- Kept Barashenkov-Glauber-Gribov for pions
- CHIPS-extracted kaons and (anti-)hyperons cross sections
- Galoyan-Uzhinsky anti-baryon cross sections
 - Based on Glauber, and already used in FTFP_BERT
- Nucleus-nucleus Glauber-Gribov-Grichine inelastic xsection
 - Replacing Tripati (in 9.5) or Shen (in 9.6.beta)
 - As model, use Binary (< 4 GeV) and FTFP (> 2 GeV) everywhere

New hadronic data libraries

- Hadronic physics now requires the new G4SAIDDATA data file, pointed by the new environmental variable G4SAIDXSDATA
 - Total, elastic and inelastic hadron-nucleon cross sections from SAID database
 - Used for Barashenkov-Glauber-Gribov cross sections
- New neutron HP library G4NDL4.2 distributed without ThermalScattering data
 - Reduced size: 1.7 -> 1.2 GByte
 - Download ThermalScattering separately if you need

New physics lists

- FTFP_BERT_HP
 - as FTFP_BERT, with neutron HP for precise treatment of low-energy neutrons (Ekin < 20 MeV)
- QGSP_BERT_95, QGSP_FTFP_BERT_95
 - Same physics components as in G4 9.5 (and before)
 - CHIPS stopping and lepto-nuclear
 - Wellisch nucleon-nucleus inelastic cross sections
- QGSP_BERT_95XS, QGSP_FTFP_BERT_95XS
 - Same inelastic cross sections as in G4 9.5 (and before)
 - Bertini & Fritiof stopping and lepto-nuclear
 - Wellisch nucleon-nucleus inelastic cross sections
 - NB) **_95(XS)** are **deprecated**, created only for "backward ₁₀ compatibility" for ATLAS and CMS

Warnings from deprecated classes

In G4 9.6, several **CHIPS** and **LEP/HEP** classes, and physics lists which use them, warn the user that they are deprecated and will be removed in G4 10

- Currently, only FTF-based physics lists are free of LEP
- For the QGS-based physics lists LEP is used to bridge the gap between QGS and the cascade models, so for G4 10:
 - Either extend QGS to lower energies
 - Work is undergoing on this
 - Or replace LEP with FTFP (as in QGSP_FTFP_BERT)
 - Or remove these physics lists

Hadronic showers (see plots in backup slides)

- For hadronic showers in G4 **9.6**, significant changes only for lateral shapes w.r.t. G4 9.5 and 9.4
 - Wider showers in Fe and Cu
 - Narrower showers in W and Pb
- Likely in better agreement with data
 - to be confirmed by experiments (especially CALICE)
- FTFP_BERT our recommended HEP physics list
 - To consider also the variant FTFP_BERT_TRV
 - Smoother (because of the wider transition region 3 12 GeV)
 - Significantly different in \mathbf{W} (because of the different neutron treatment)
 - Important feedback expected from CALICE W-Sci

Hadronic interactions for short-lived particles

- For hyperons, Geant4 is already offering something expected to be "reasonable" (but need validation)
- For taus, no yet tau-nuclear interactions, but it should be feasible, if needed, for Geant4 10
 - Similar to electro- and muon-nuclear
- For charm and bottom hadrons, no yet hadronic interactions in Geant4: it would require at least a few years of work to provide something "not crazy"
 - Final-state models already present in MC Event Generators
 - Cross sections are the major problem

Summary

Significant progress in hadronics achieved in G4 9.6

- Decoupling from CHIPS package
- New nuclear capture at rest and gamma- & lepto-nuclear based on Bertini + Fritiof
- Consistent set of inelastic cross sections used in physics lists (improved nucleon-nucleus)
- Improvements and extensions in Bertini and Fritiof
- State-of-the-art INCL++ now available
- Expected improvements in hadronic shower lateral shapes

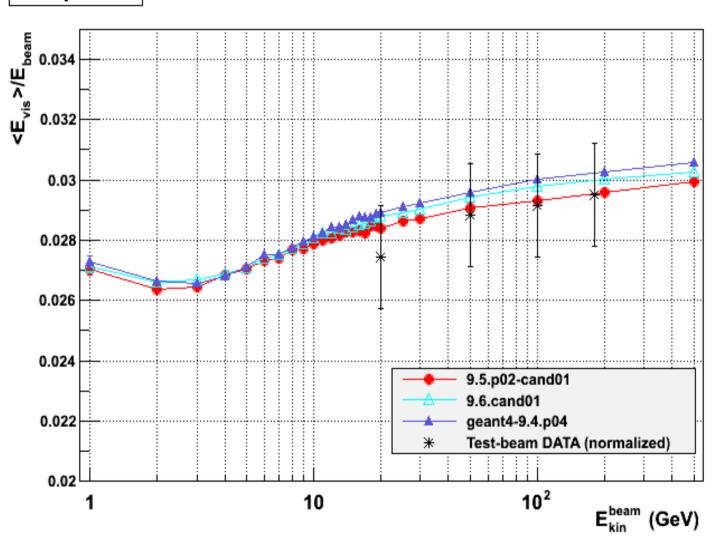
Backup slides

Comparing G4 versions:

9.6, 9.5.p02, 9.4.p04

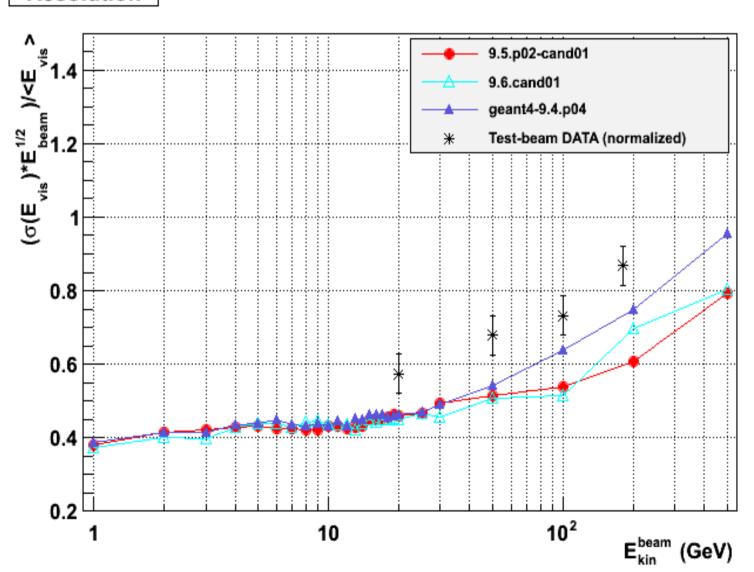
π on **Fe-Sci**

Response



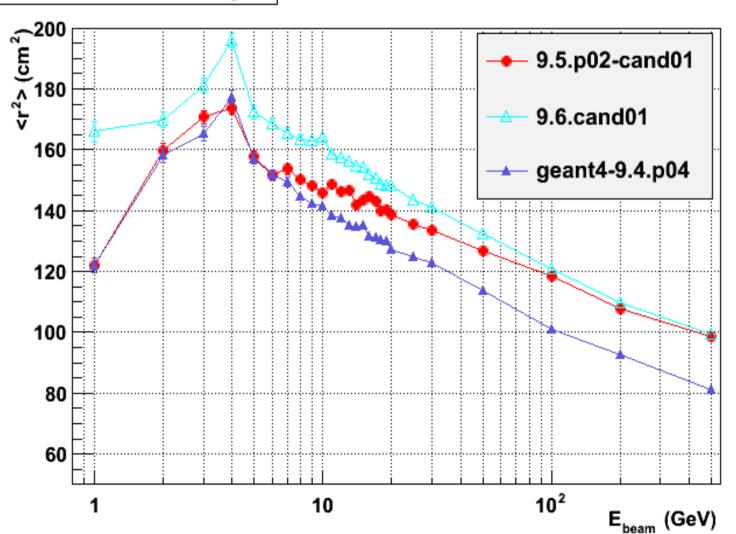
π^- on **Fe-Sci**

Resolution



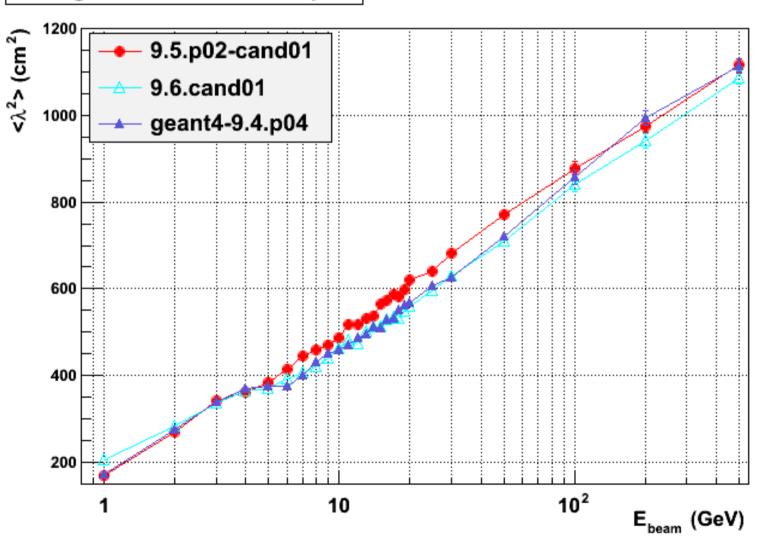
π^- on Fe-Sci

Lateral shower shape

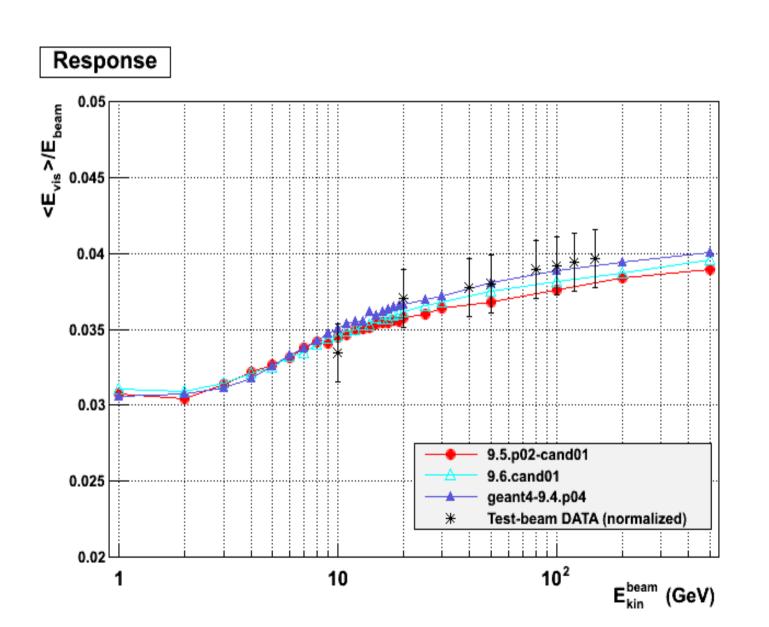


π on Fe-Sci

Longitudinal shower shape

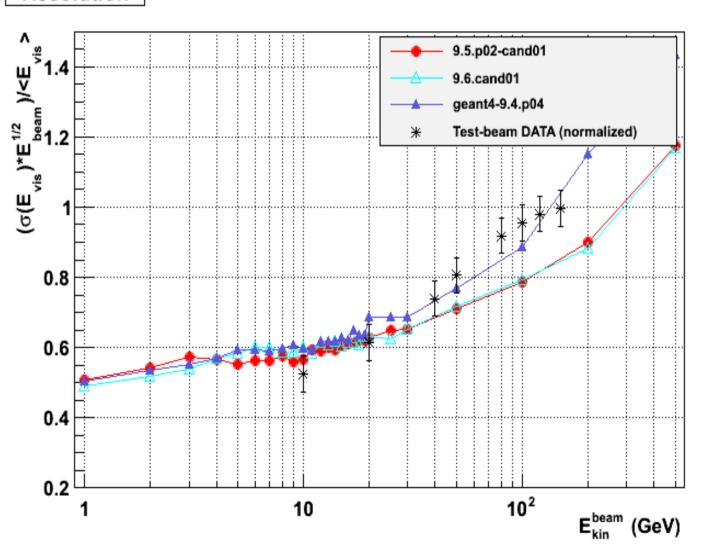


π^- on Cu-LAr



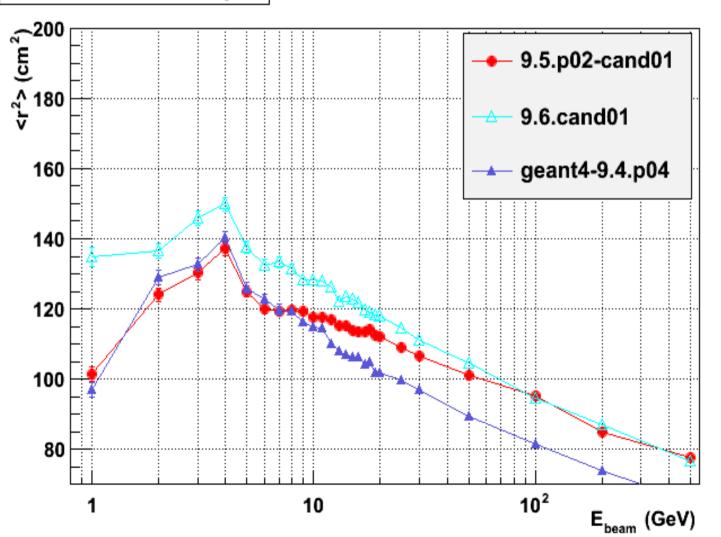
π^- on Cu-LAr

Resolution



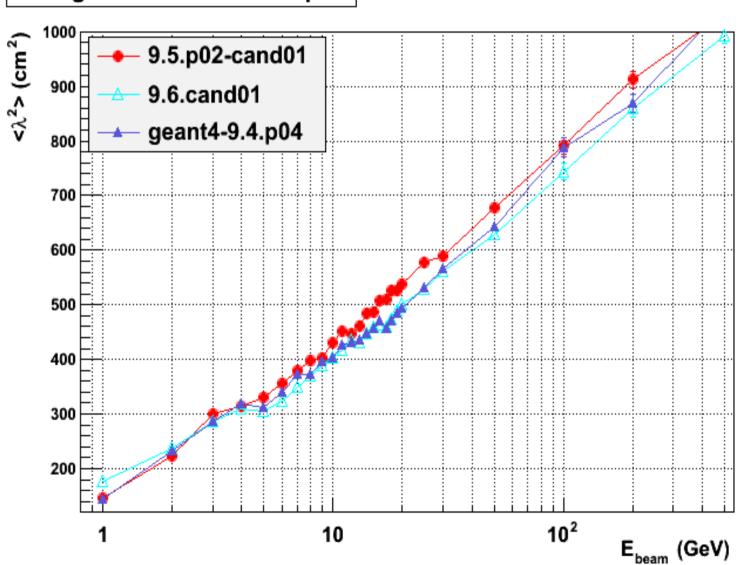
π^- on Cu-LAr

Lateral shower shape

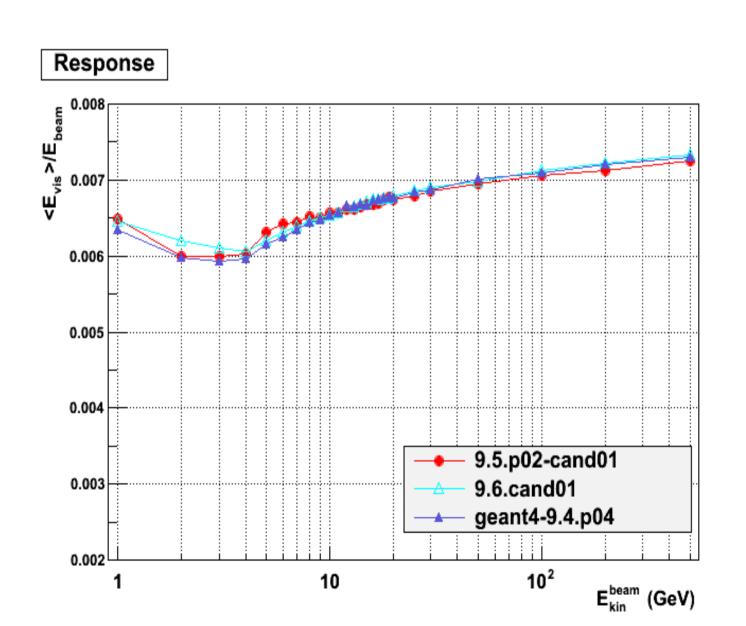


π^- on Cu-LAr

Longitudinal shower shape

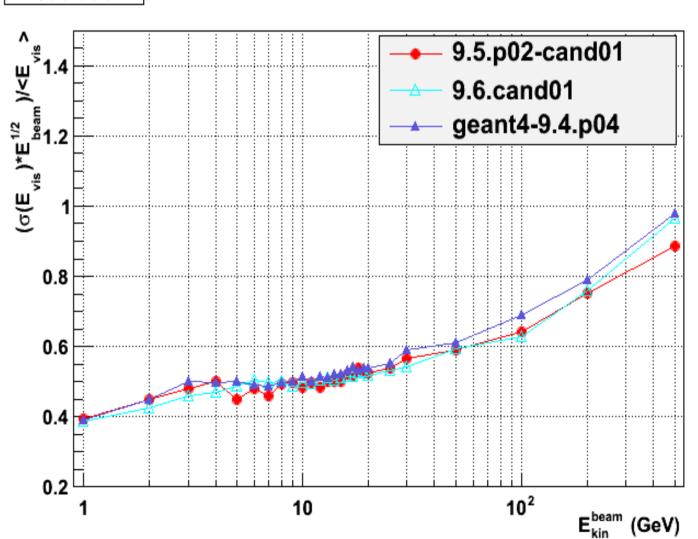


π^{-} on W-LAr



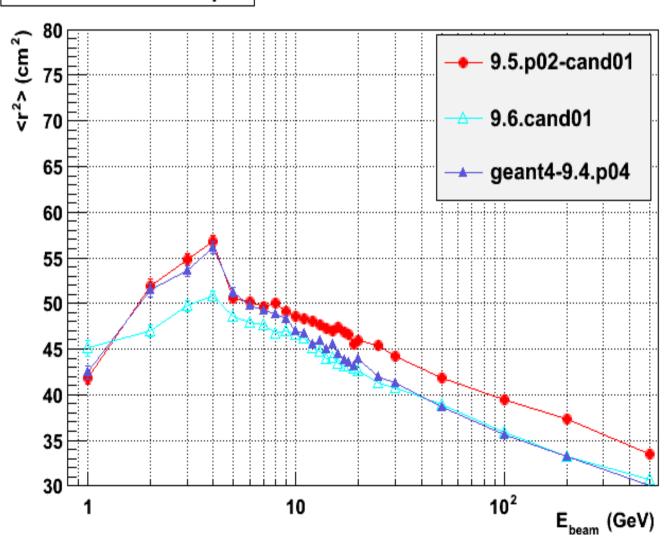
π on W-LAr

Resolution



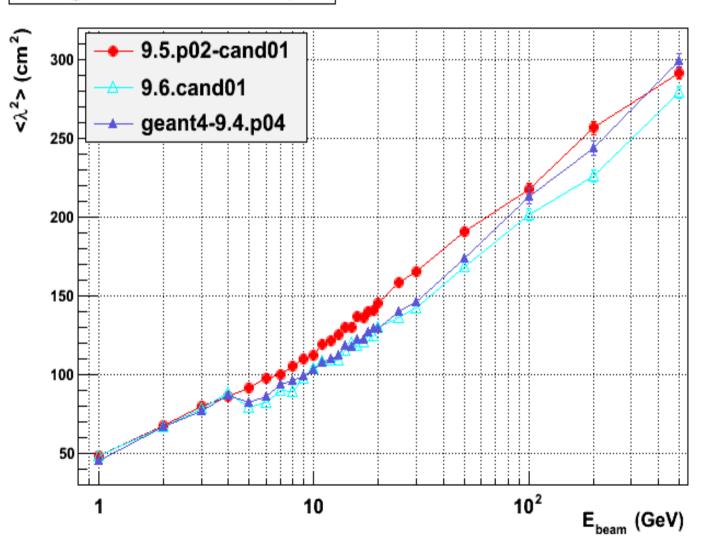
π on W-LAr

Lateral shower shape

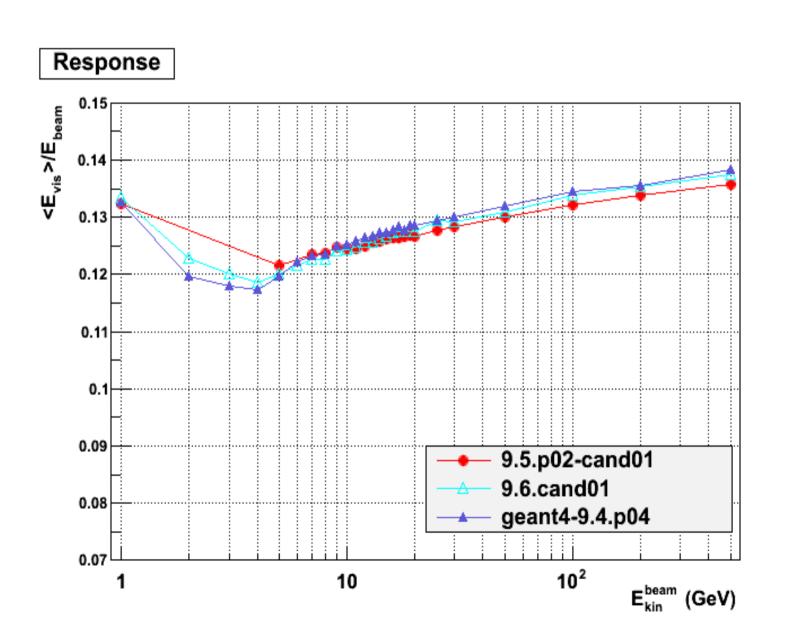


π on W-LAr

Longitudinal shower shape

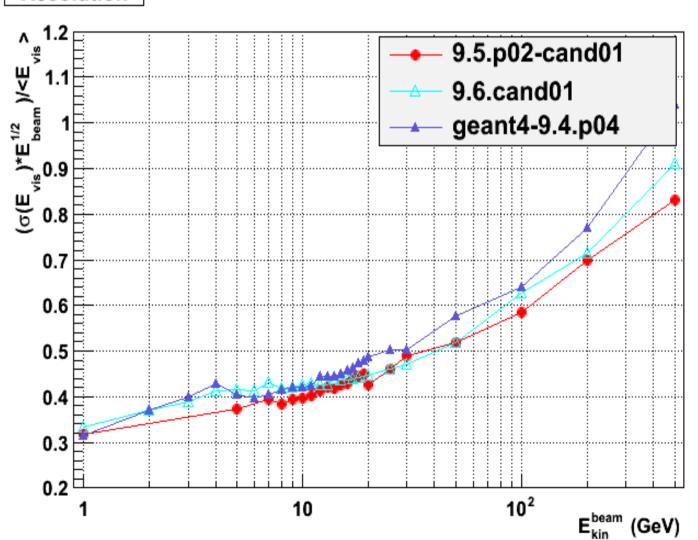


π on Pb-LAr



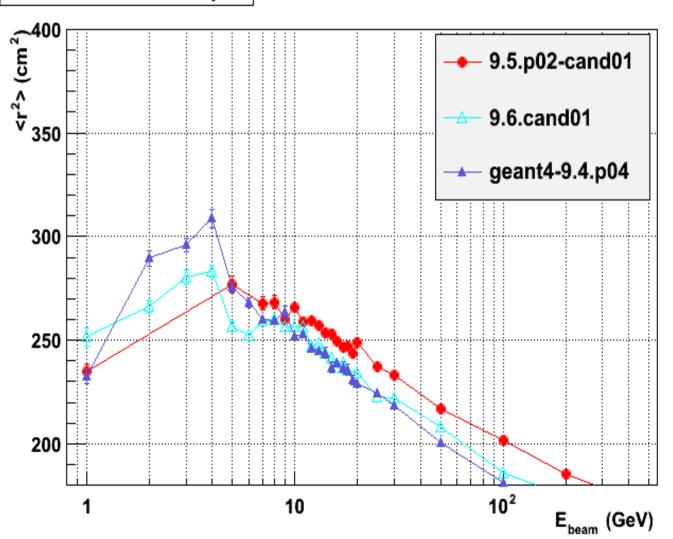
π^- on Pb-LAr

Resolution



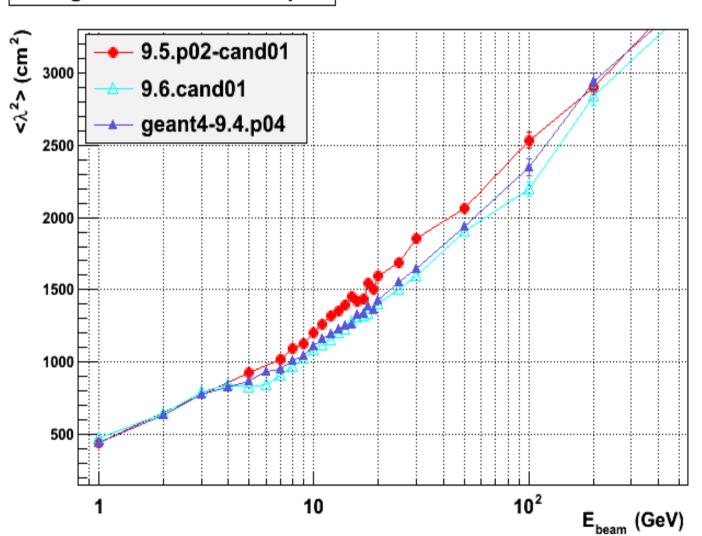
π^- on Pb-LAr

Lateral shower shape



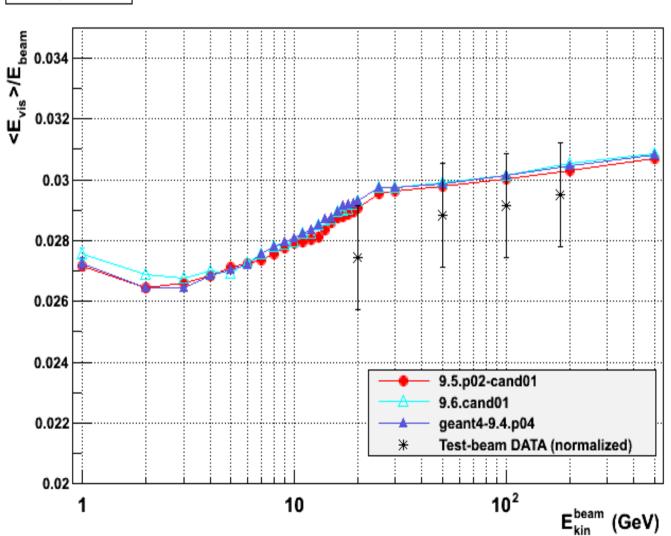
π on Pb-LAr

Longitudinal shower shape



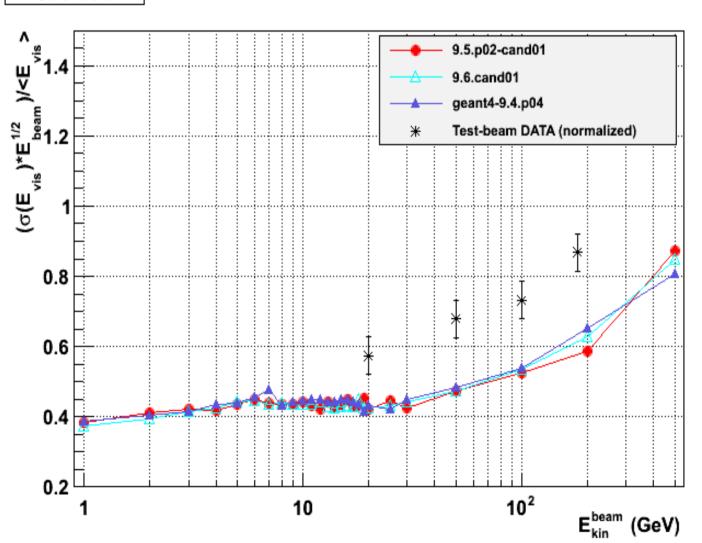
π on Fe-Sci



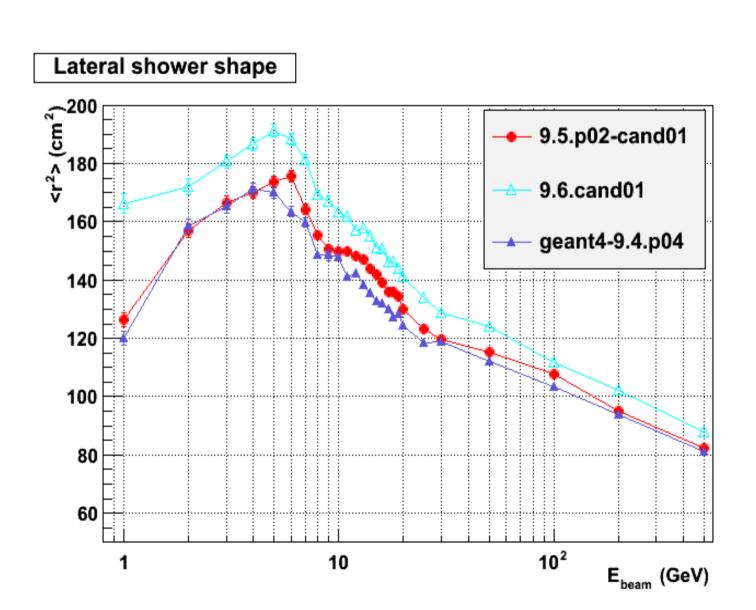


π on Fe-Sci

Resolution

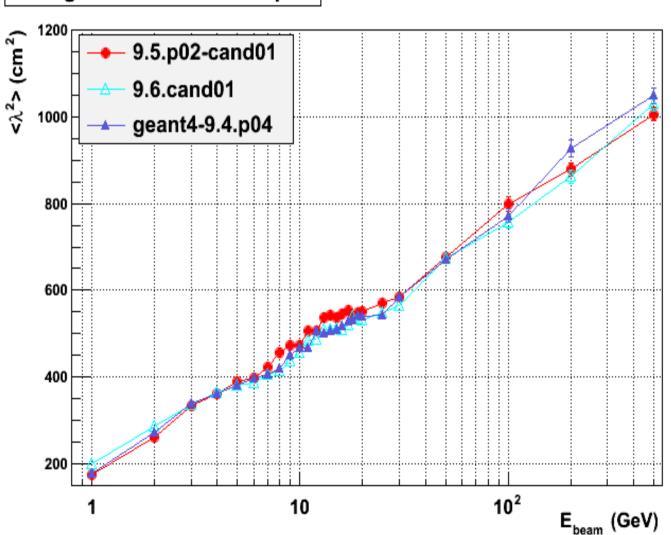


π on **Fe-Sci**

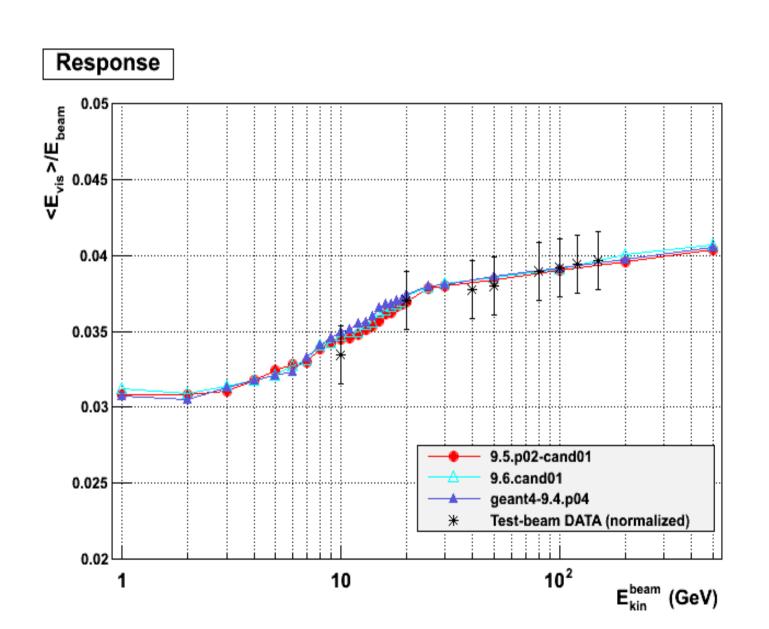


π on Fe-Sci

Longitudinal shower shape

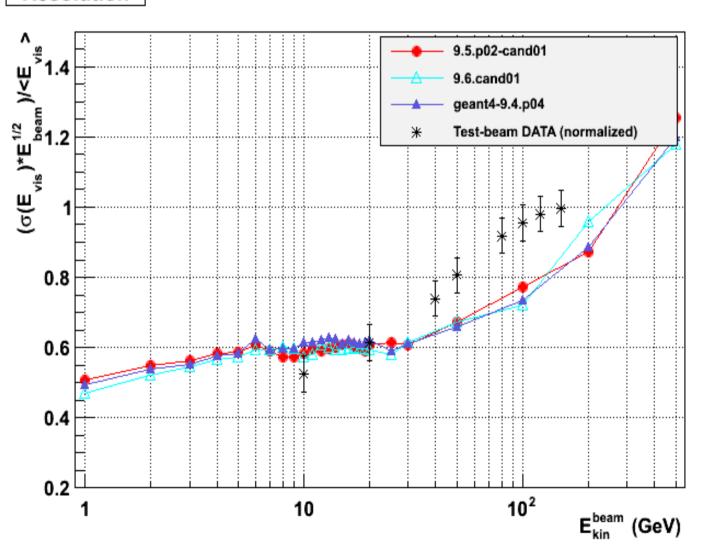


π^- on Cu-LAr

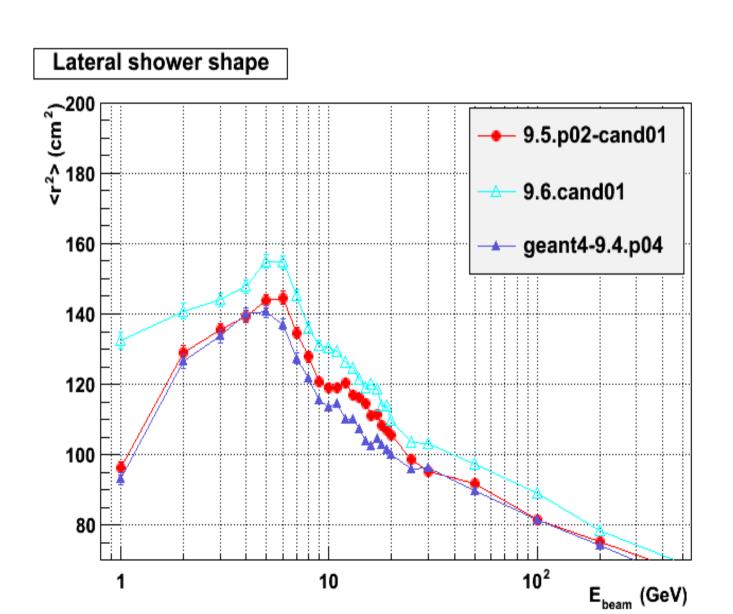


π on Cu-LAr

Resolution

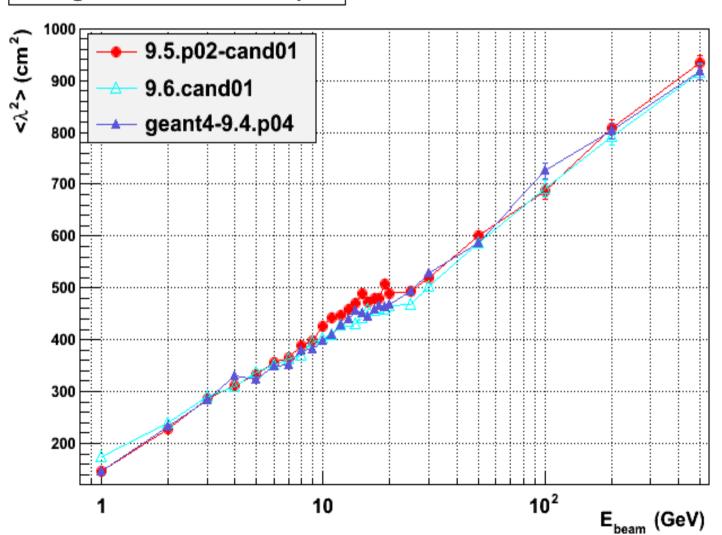


π^- on Cu-LAr

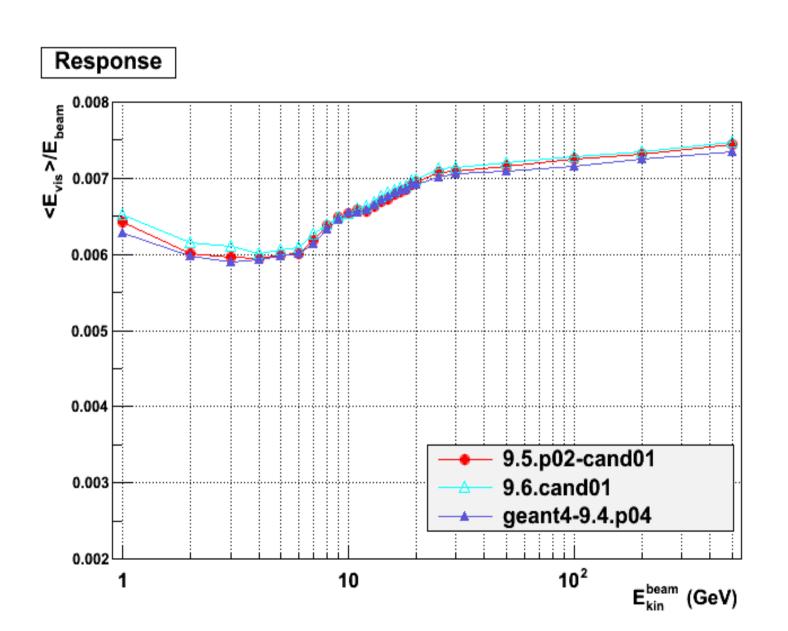


π^- on Cu-LAr

Longitudinal shower shape

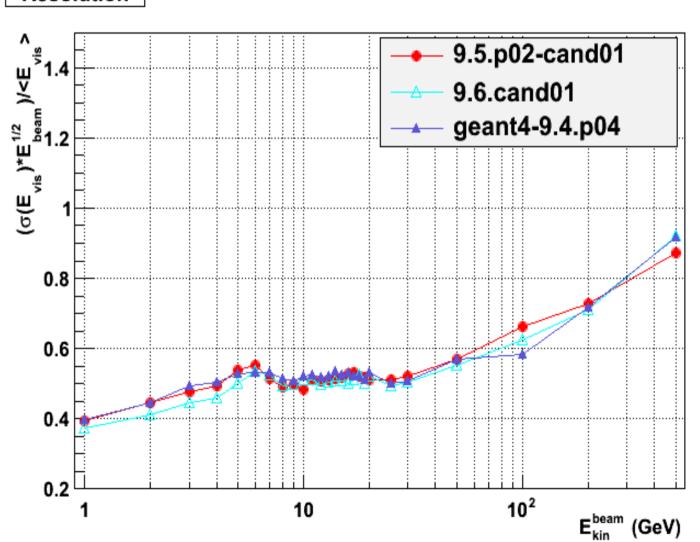


π^- on W-LAr

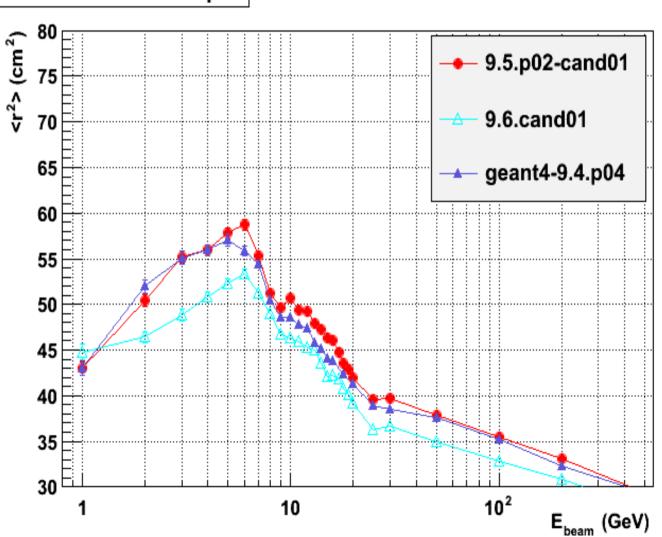


π on W-LAr

Resolution

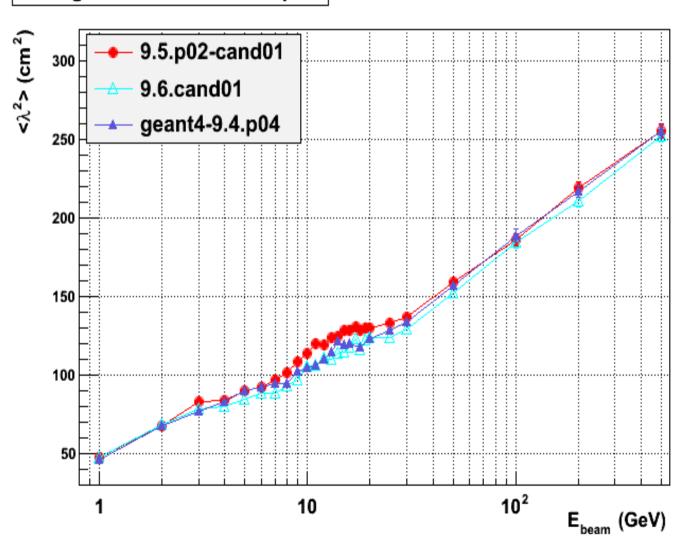


π^- on W-LAr

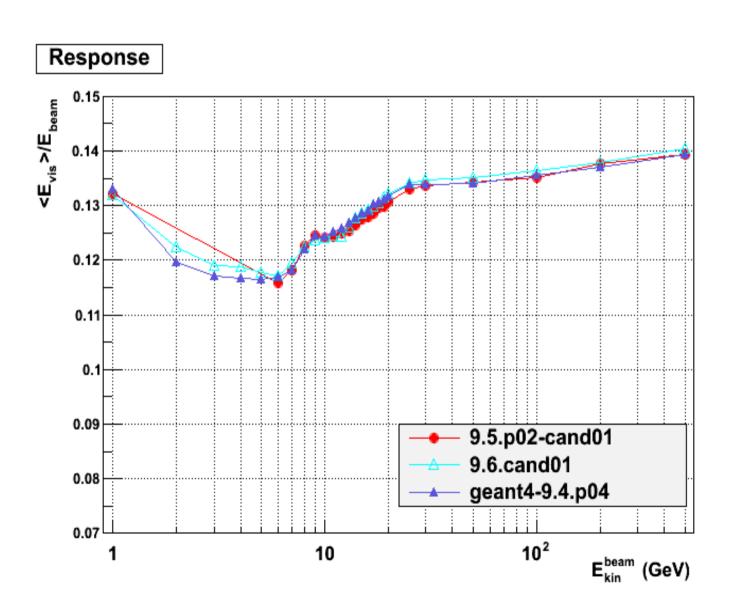


π on W-LAr

Longitudinal shower shape

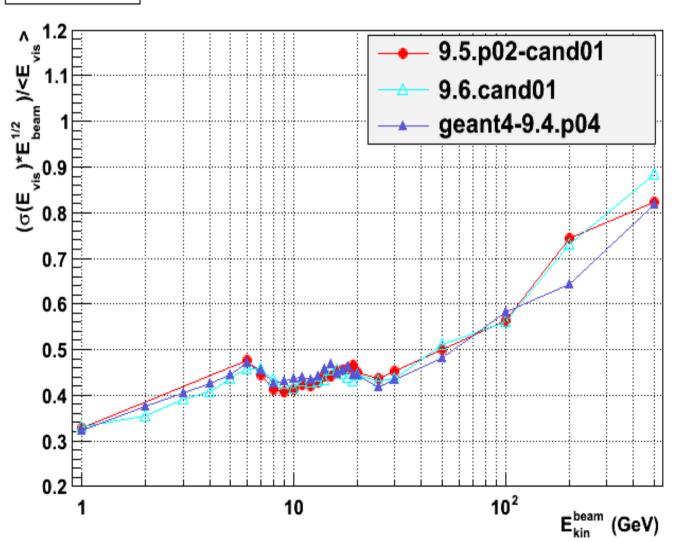


π on Pb-LAr

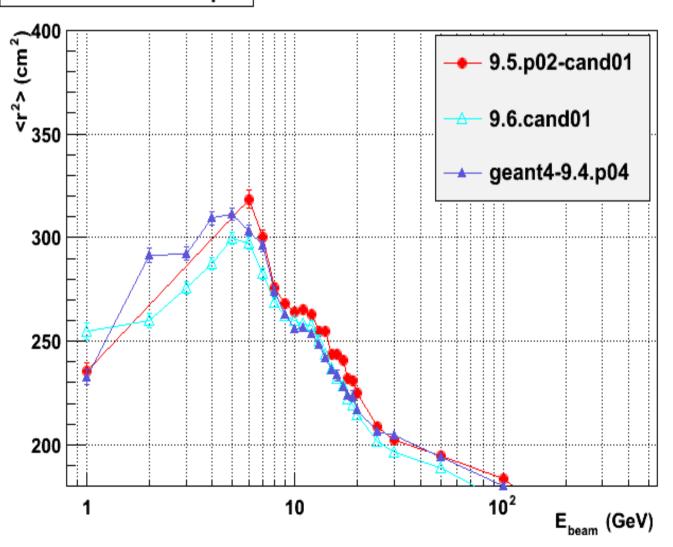


π on Pb-LAr

Resolution

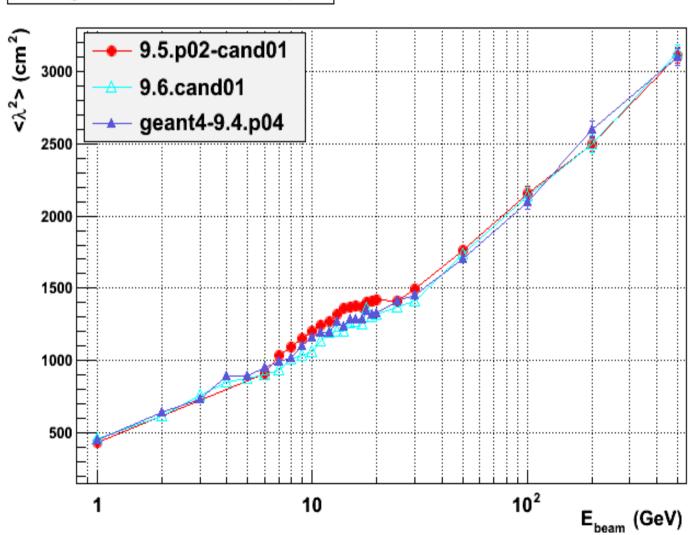


π on Pb-LAr



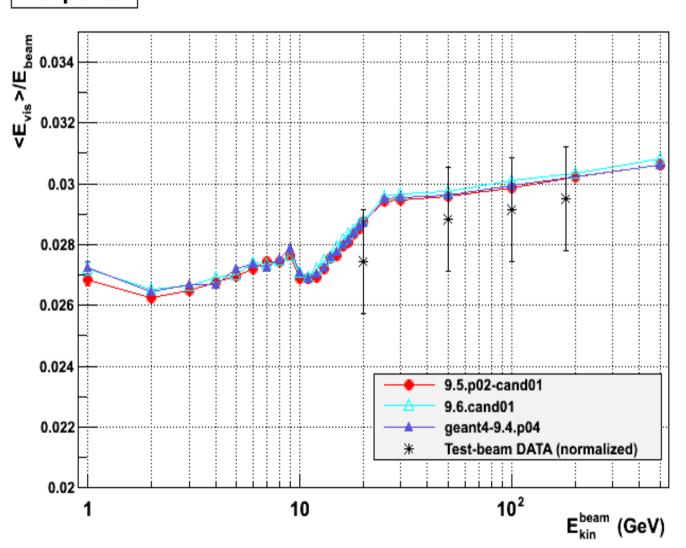
 π on Pb-LAr

Longitudinal shower shape



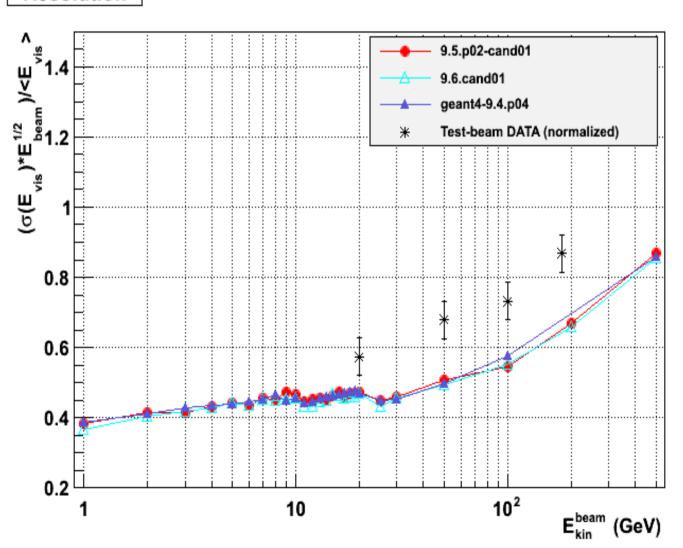
π^- on Fe-Sci

Response

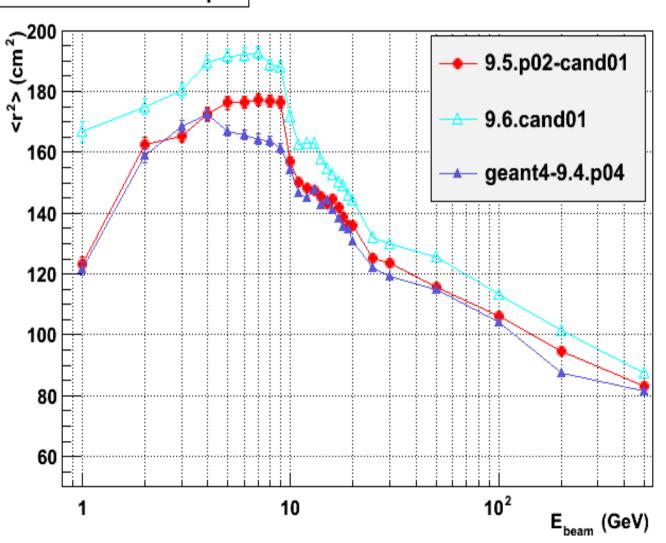


π^- on Fe-Sci

Resolution



π^- on Fe-Sci



π^- on Fe-Sci

Longitudinal shower shape 1200 $<\chi^2>$ (cm²) 9.5.p02-cand01 9.6.cand01 1000 geant4-9.4.p04 800 600 400

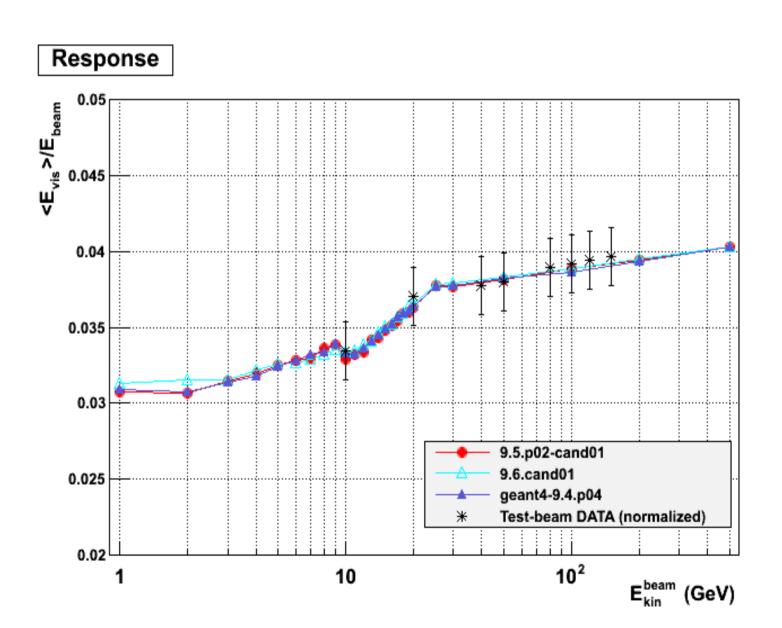
10

10²

E_{beam} (GeV)

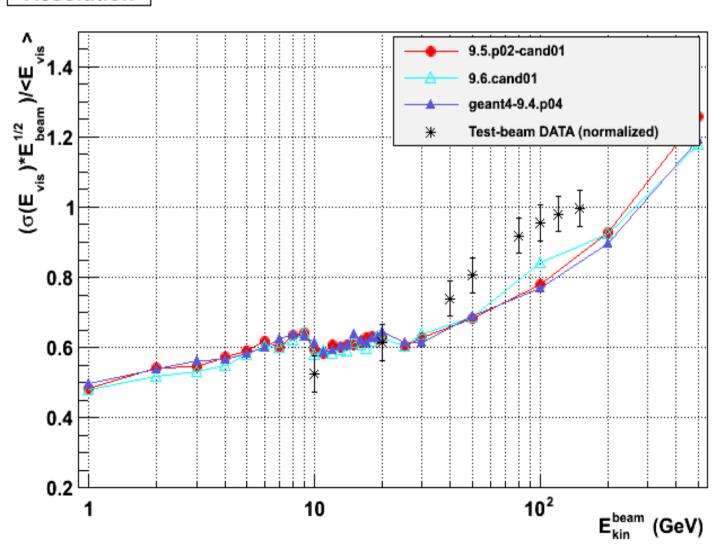
200

π^- on Cu-LAr

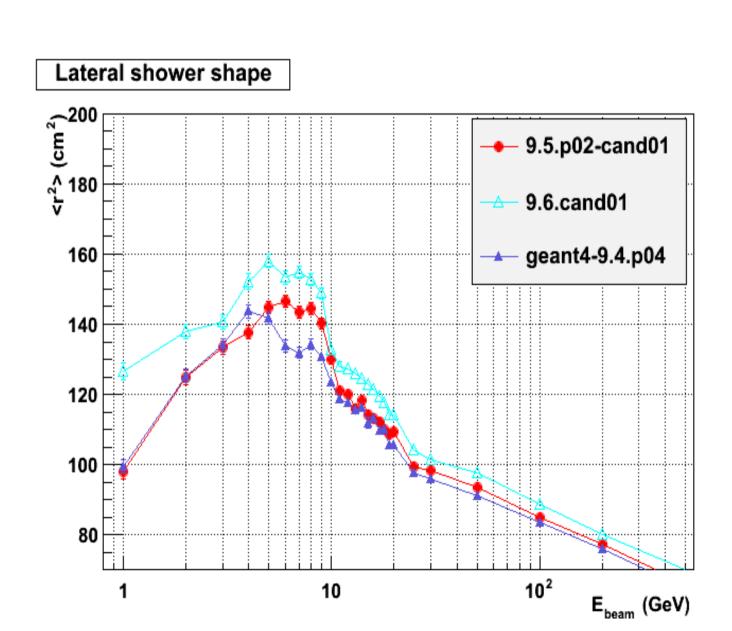


π^- on Cu-LAr

Resolution

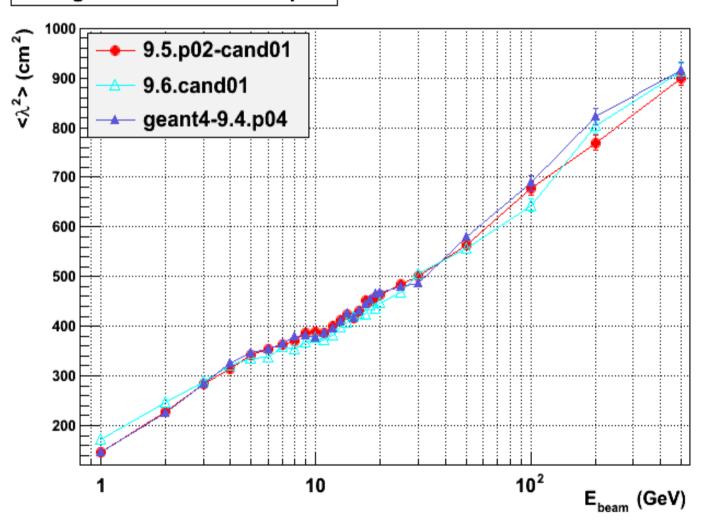


π on Cu-LAr

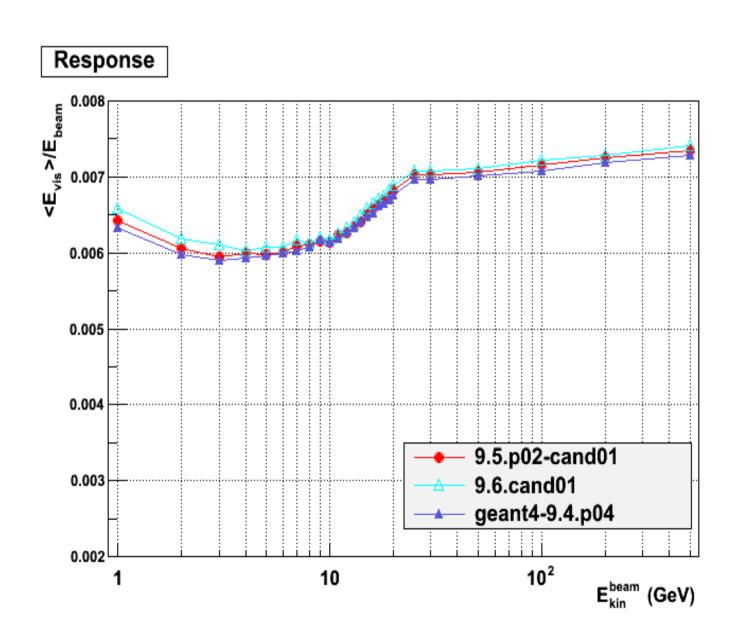


π on Cu-LAr

Longitudinal shower shape

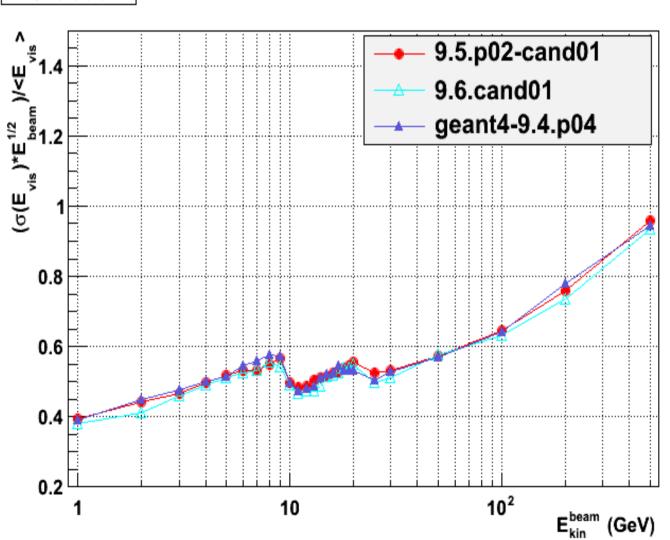


π on W-LAr

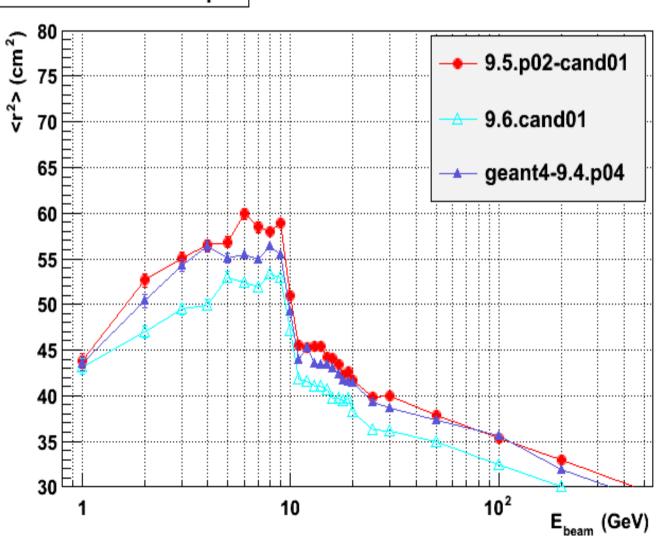


π on W-LAr

Resolution

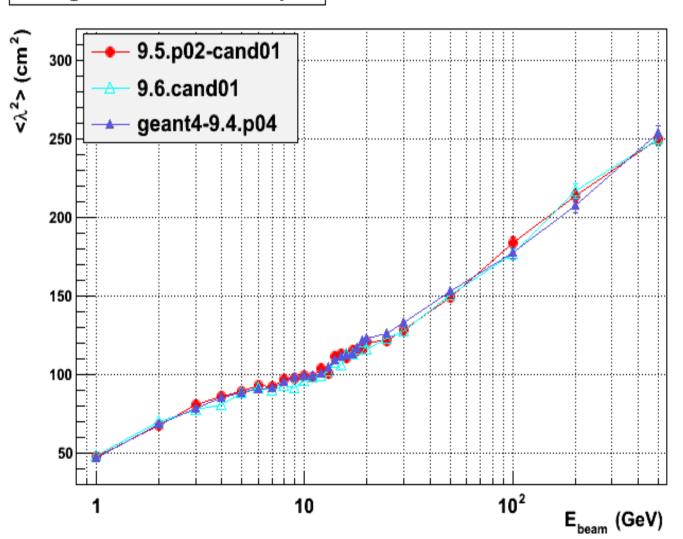


π on W-LAr

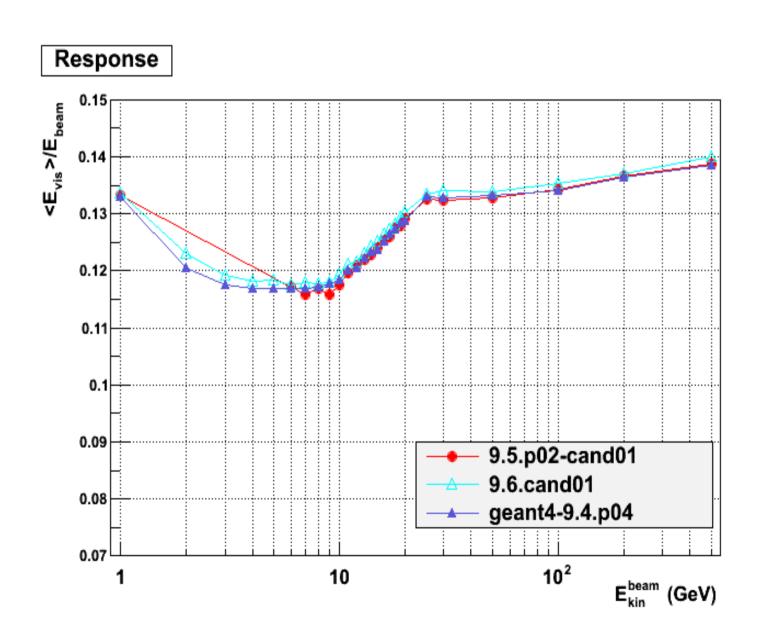


π on W-LAr

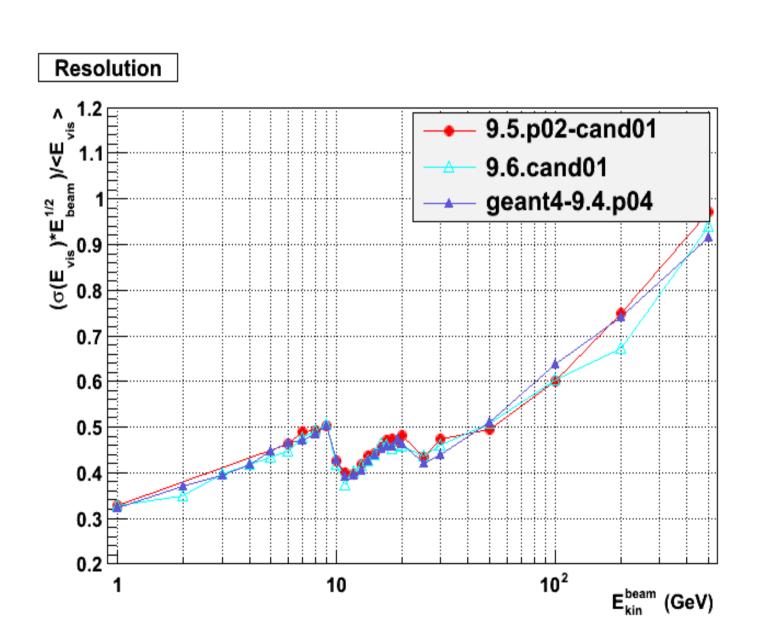
Longitudinal shower shape



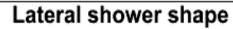
π on Pb-LAr

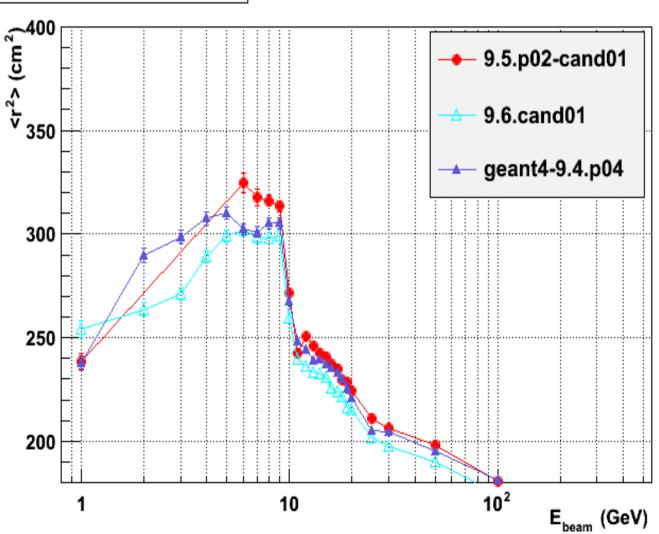


π^- on Pb-LAr



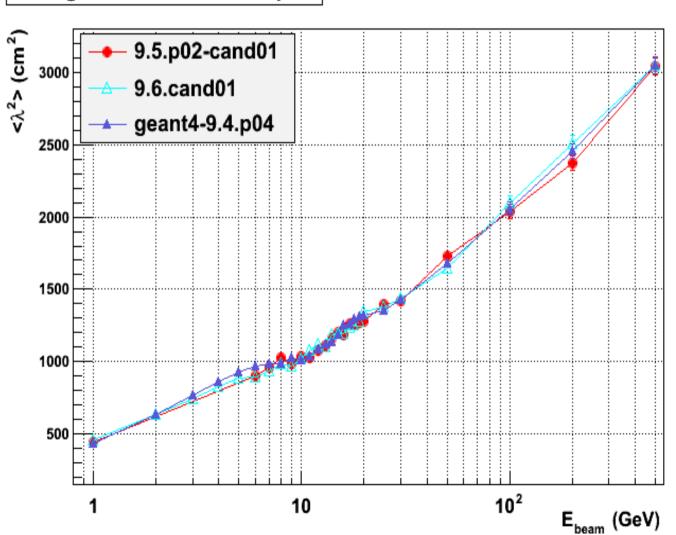
π on **Pb-LAr**





π^- on Pb-LAr

Longitudinal shower shape



Comparisons with _95(XS)

QGSP(_FTFP)_BERT_95(XS)

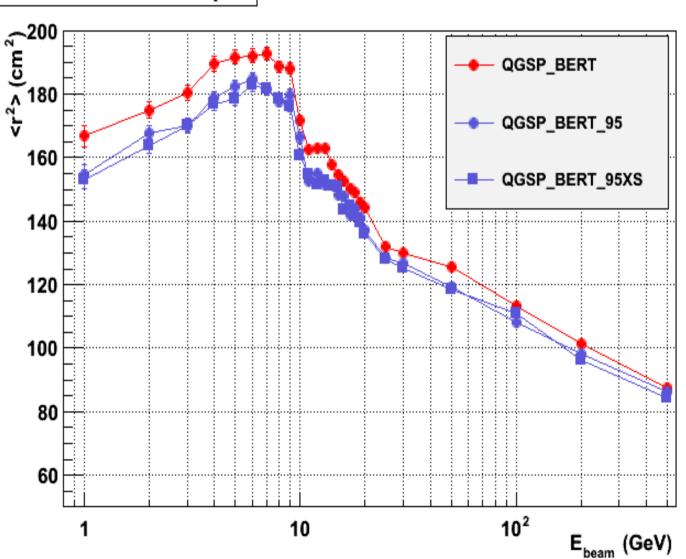
For hadron showers in simplified calorimeters

- General trend: the three variants of the same type of physics list are nearly identical
- Exception: lateral shape in Fe or Cu absorbers
 - The G4 9.6 variant is wider than "95" and "95XS"
 - Due to the replacement of Wellisch nucleon-nucleus inelastic cross sections with Barashenkov-Glauber-Gribov
- Confirmation that:
 - nuclear capture
 - lepto-nuclear
 - ion physics

have a very small impact in hadronic showers!

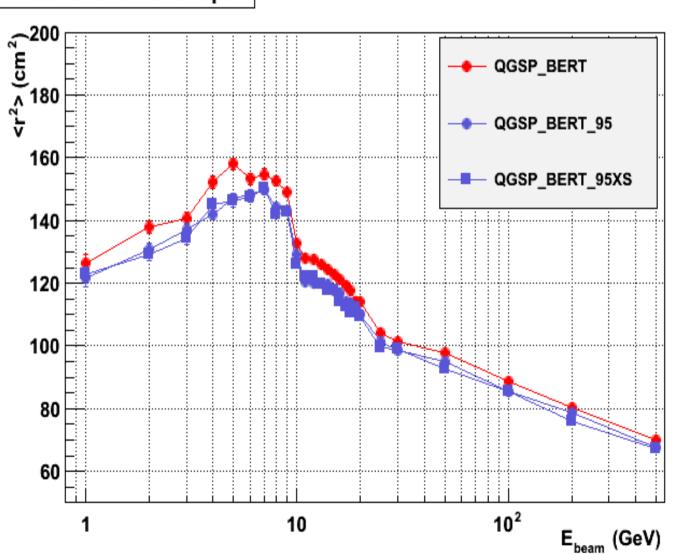
QGSP_BERT_95(XS)

π^- on **Fe-Sci**



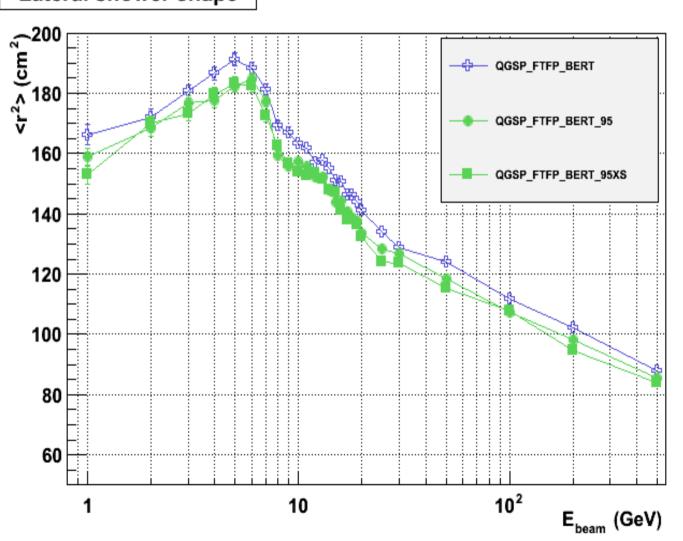
QGSP_BERT_95(XS)

π^- on Cu-LAr



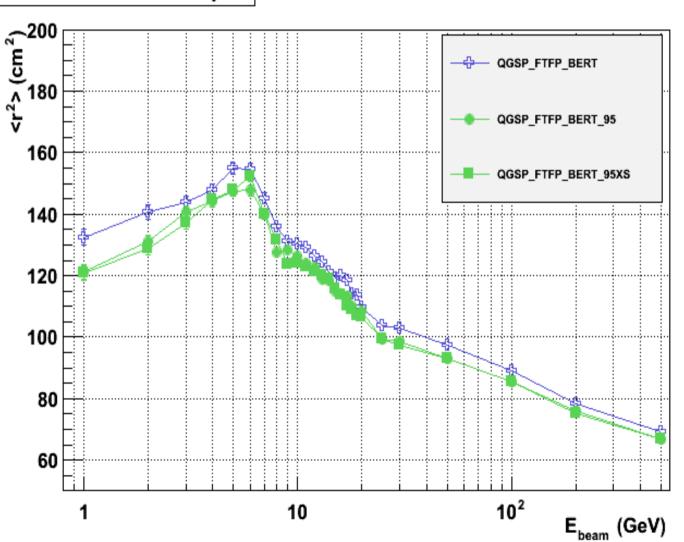
QGSP_FTFP_BERT_95(XS)

π on Fe-Sci



QGSP_FTFP_BERT_95(XS)

π^- on Cu-LAr

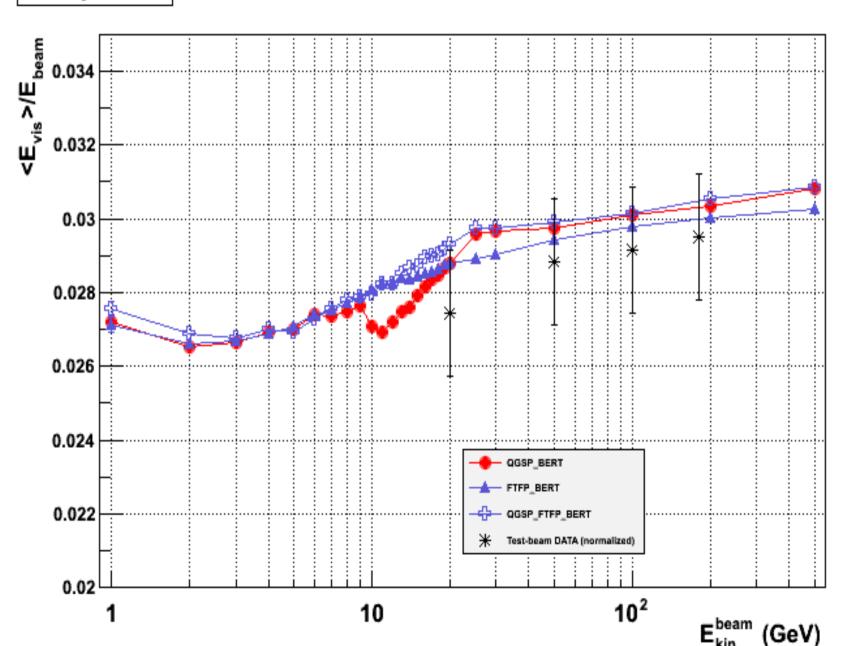


Comparing Physics Lists in G4 9.6

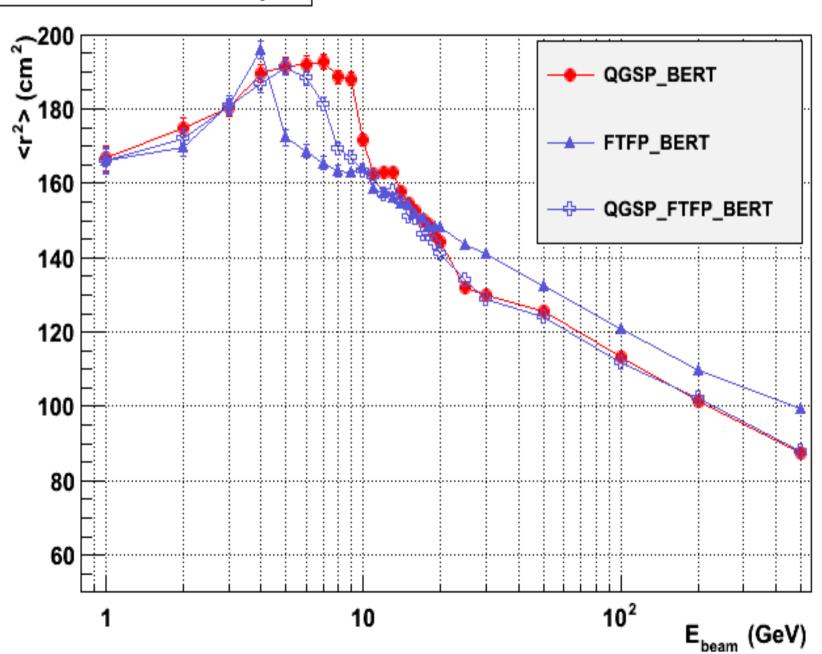
Comparing the 3 main physics lists for HEP

- 1. FTFP_BERT: our recommended physics list
- 2. QGSP_FTFP_BERT: used by CMS
- 3. QGSP_BERT: used by ATLAS
- For hadron showers in simplified calorimeters
 - Energy response: FTFP_BERT slightly lower for ≥ 20 GeV
 - Energy resolution: very similar
 - Longitudinal shape: FTFP_BERT longer for ≥ 20 GeV
 - Lateral shape: FTFP_BERT wider for ≥ 20 GeV

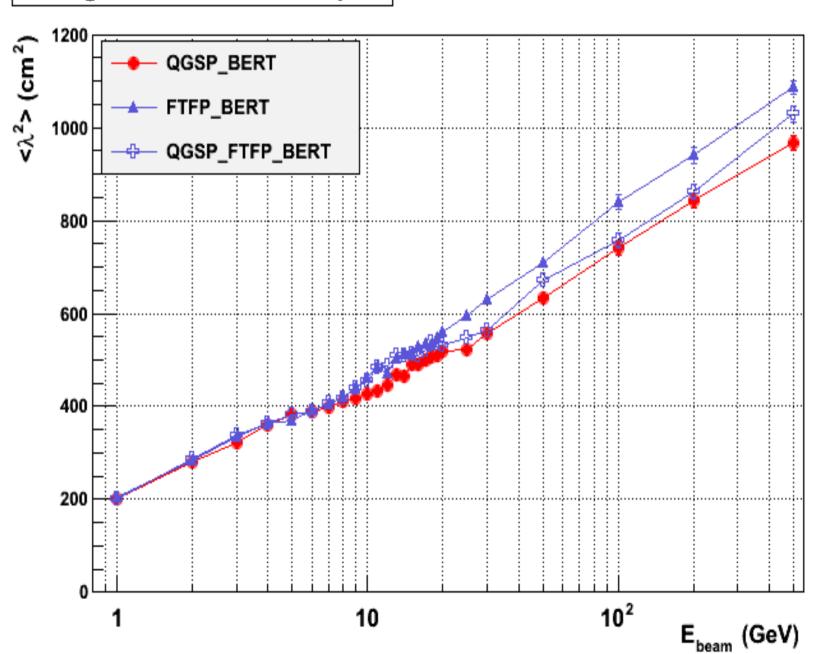
π^- on Fe-Sci



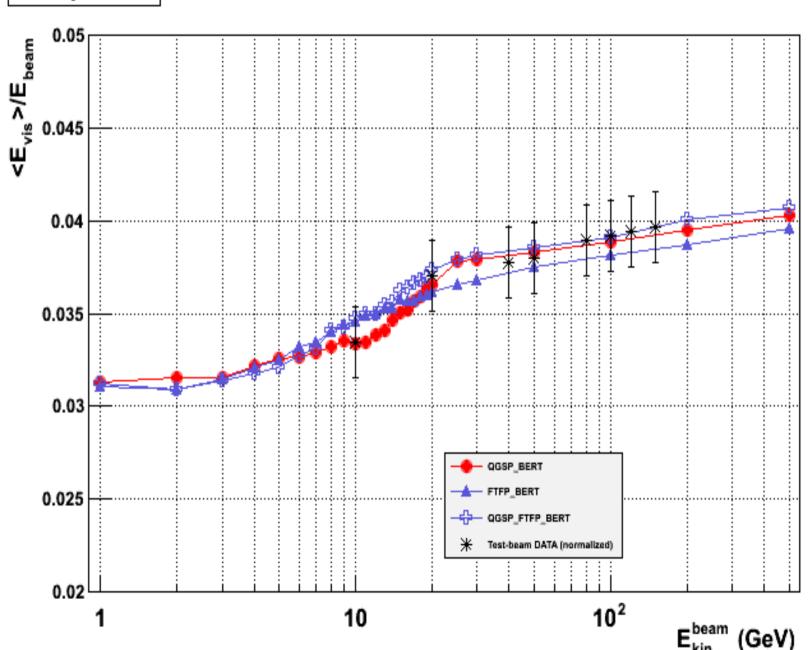
π on **Fe-Sci**



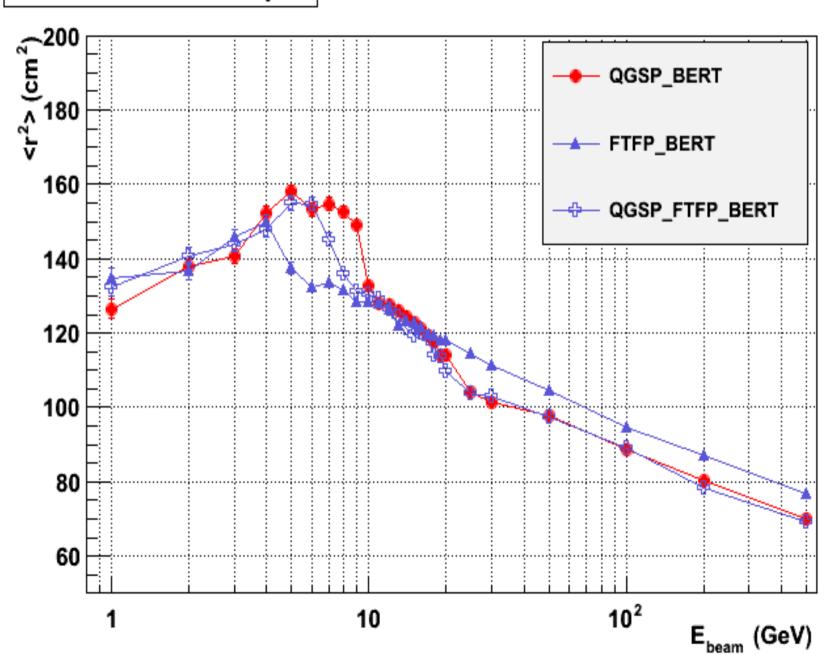
π^- on Fe-Sci



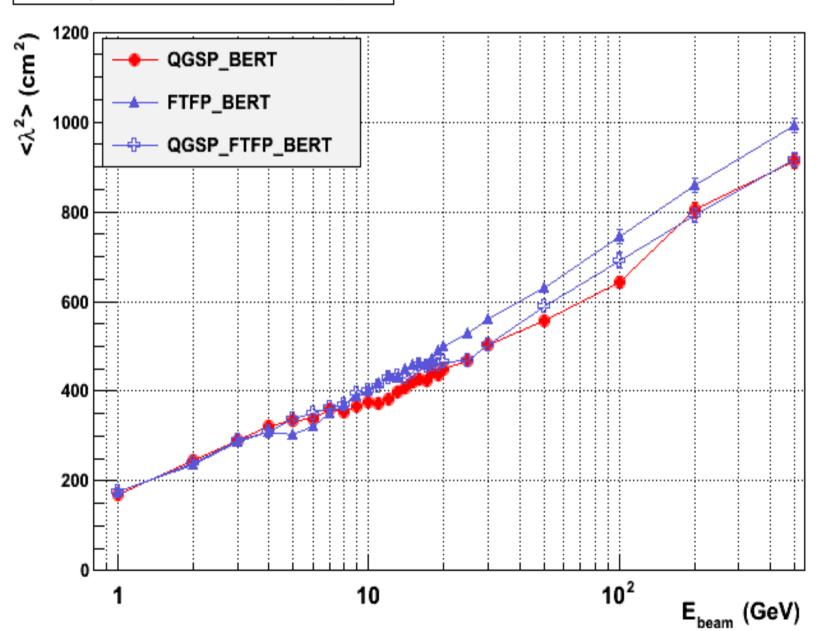
π^- on Cu-LAr



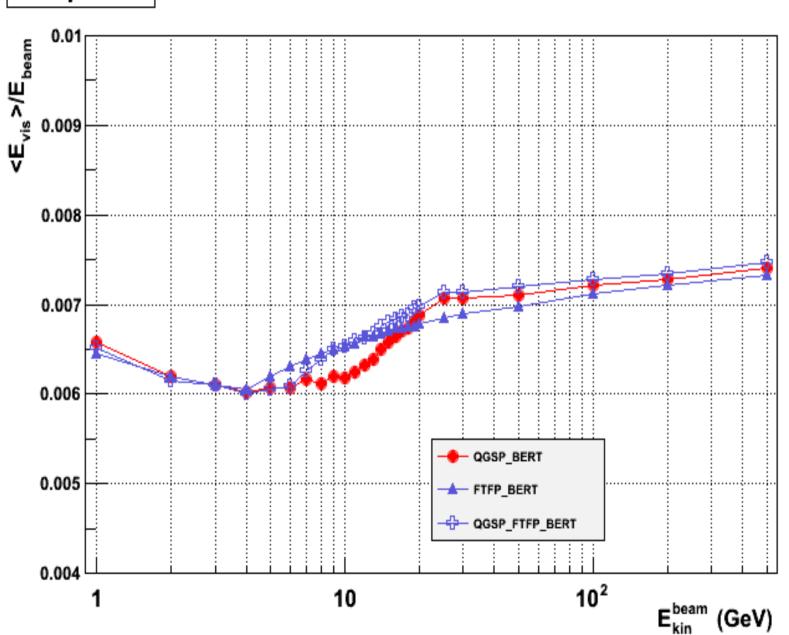
π^- on Cu-LAr



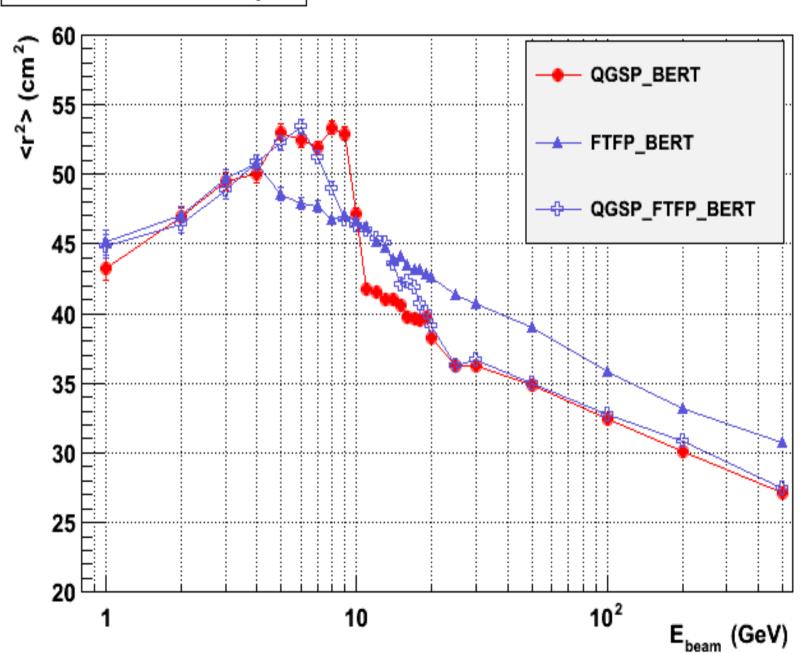
π^- on Cu-LAr



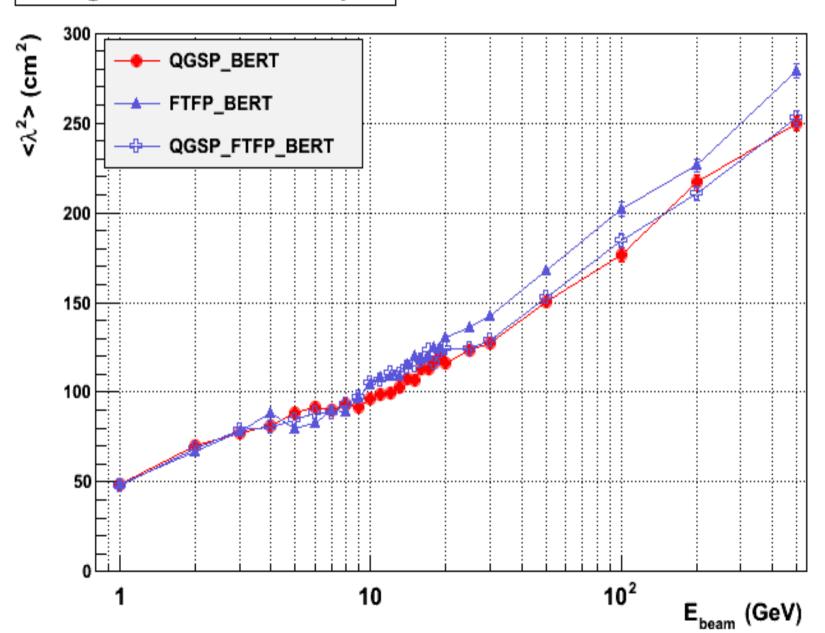
π^- on W-LAr



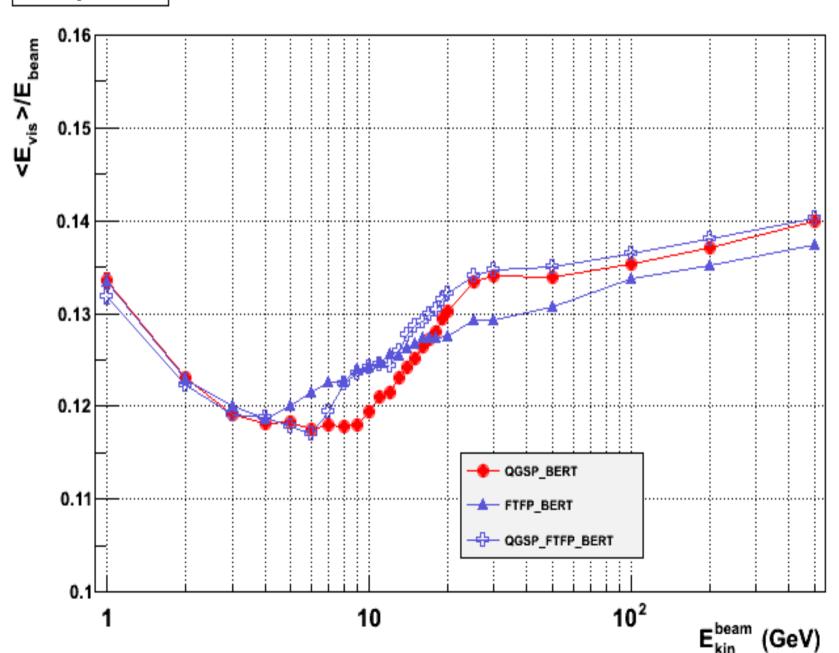
π on W-LAr



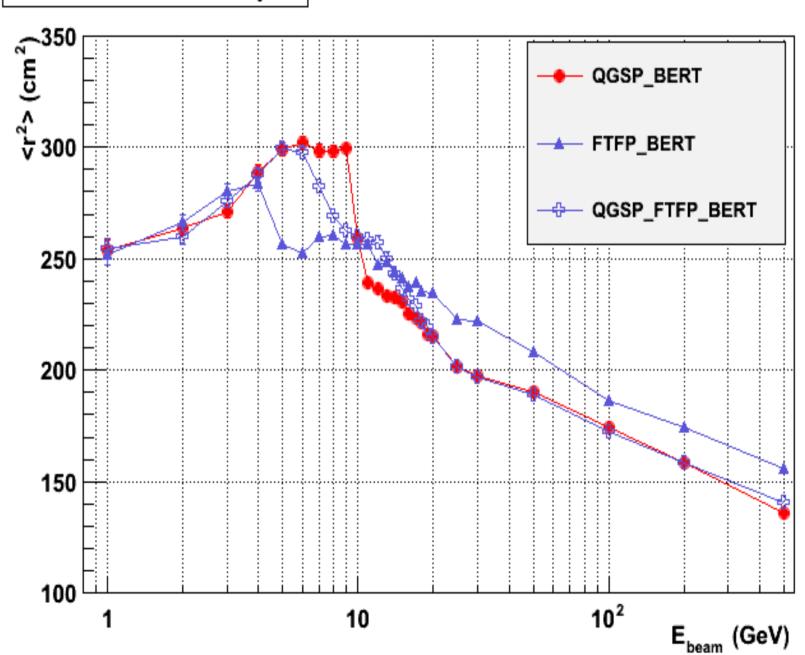
π^{-} on W-LAr



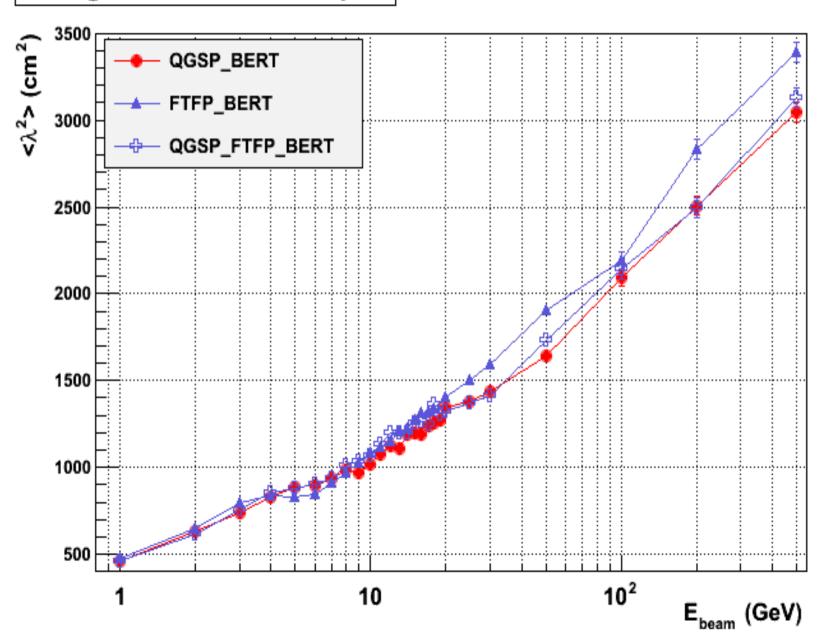
π on **Pb-LAr**



π on **Pb-LAr**



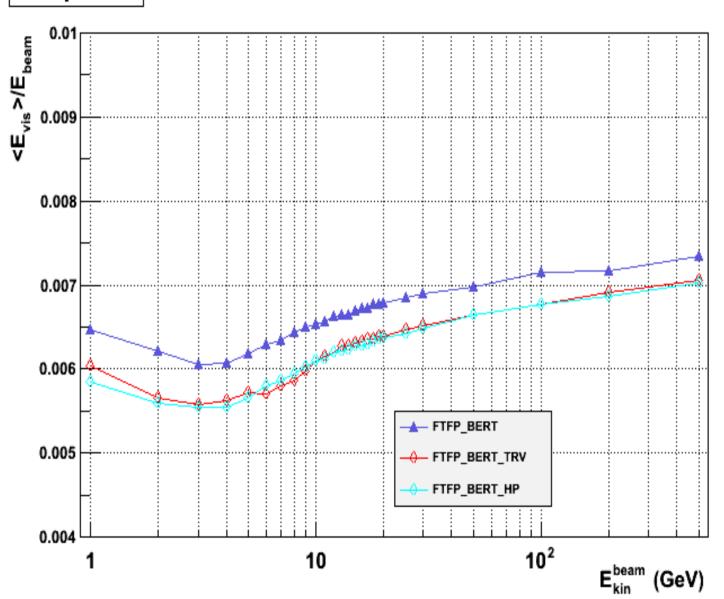
π on **Pb-LAr**



Comparing FTFP_BERT variants

- FTFP_BERT
- FTFP_BERT_TRV
- FTFP_BERT_HP
- For hadron showers in simplified calorimeters
 - Nearly the same
 - Except in W
 - Higher response and wider shapes for FTFP_BERT, whereas
 FTFP BERT TRV and FTFP BERT HP are similar
 - It could be an hint that getting narrower showers in G4 9.6 for W goes in the right direction (i.e. closer to the data)
 - Need feedback from CALICE W-Sci

π on W-LAr



π^{-} on W-LAr

