# Overview of hadronic physics ‘upgrades’ in Geant4 9.4

John Apostolakis
CERN, PH/SFT

# Overview:

- Context
- Improvements of FTF/Fritiof model
- Physics list: updates and new option
- First plans for 2011

- Note
  - Used extensively Slides/material from
    - Dennis Wright's talk at Geant4 Technical Forum (16 November 2010)
    - Vladimir Uzhinskiy's talk on FTF at SNA+MC2010 Conf. (Oct 2010, Tokyo)

# Context

- Work of the hadronic group over the past years has been driven by requests from HEP detectors (esp. LHC) needs for
  - better hadronic shower shapes
  - better energy response and resolution
    - good progress, but still work to do
  - improved kaon interactions
    - models extended to handle this
  - ion-ion interactions
    - development ongoing
  - anti-nucleon and anti-ion reactions
    - development program recently begun

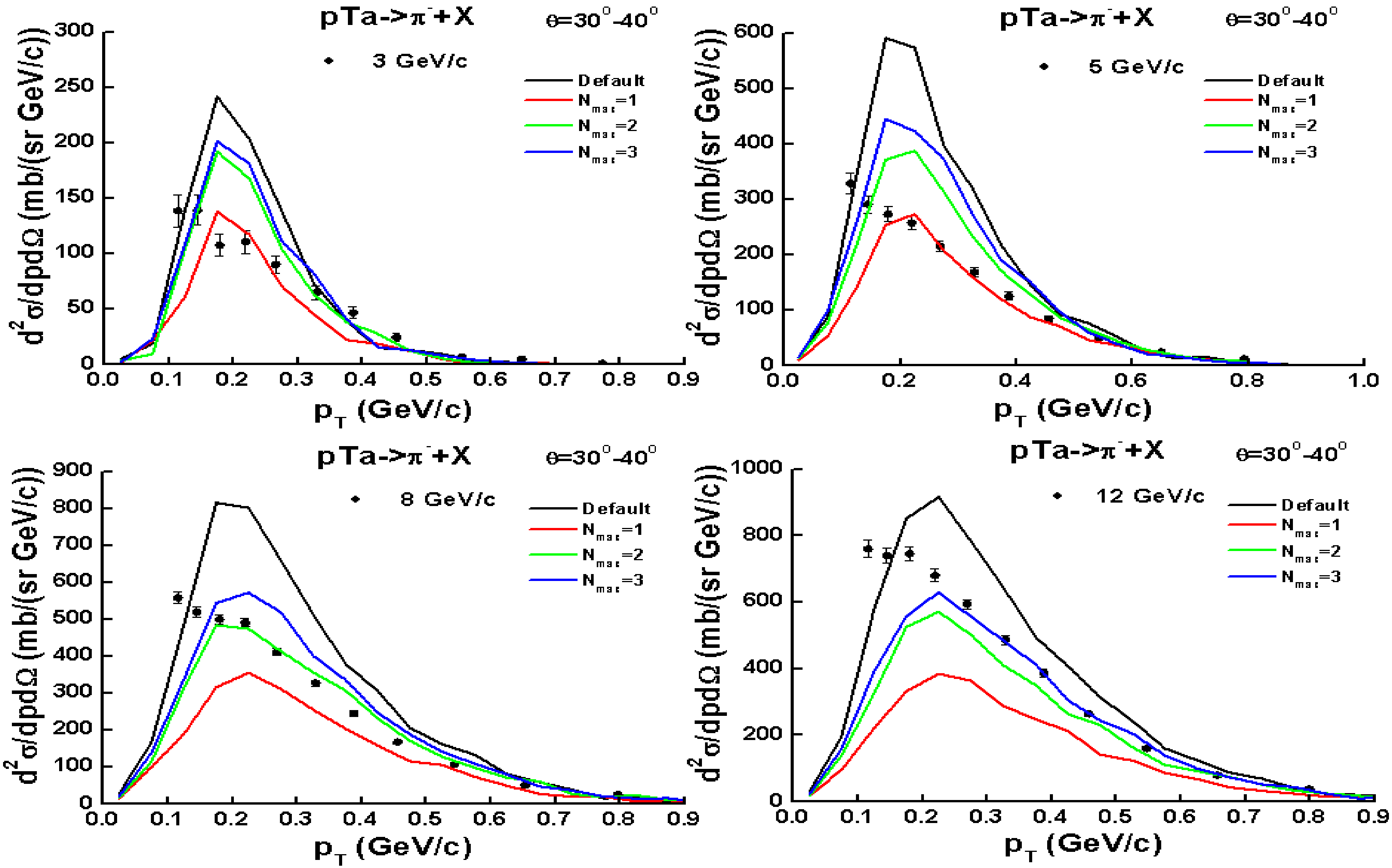
# Summary of Major Improvements in 9.4

- FTF model
  - added excitation energy calculation and introduced Reggeon cascading
    - resulted in extension of applicability to lower energies
    - smoother transition to cascade possible
  - improved pion absorption
- Bertini-style cascade
  - full review of pi-nucleon and nucleon-nucleon partial cross sections
    - many corrections made

# Improvement of FTF model

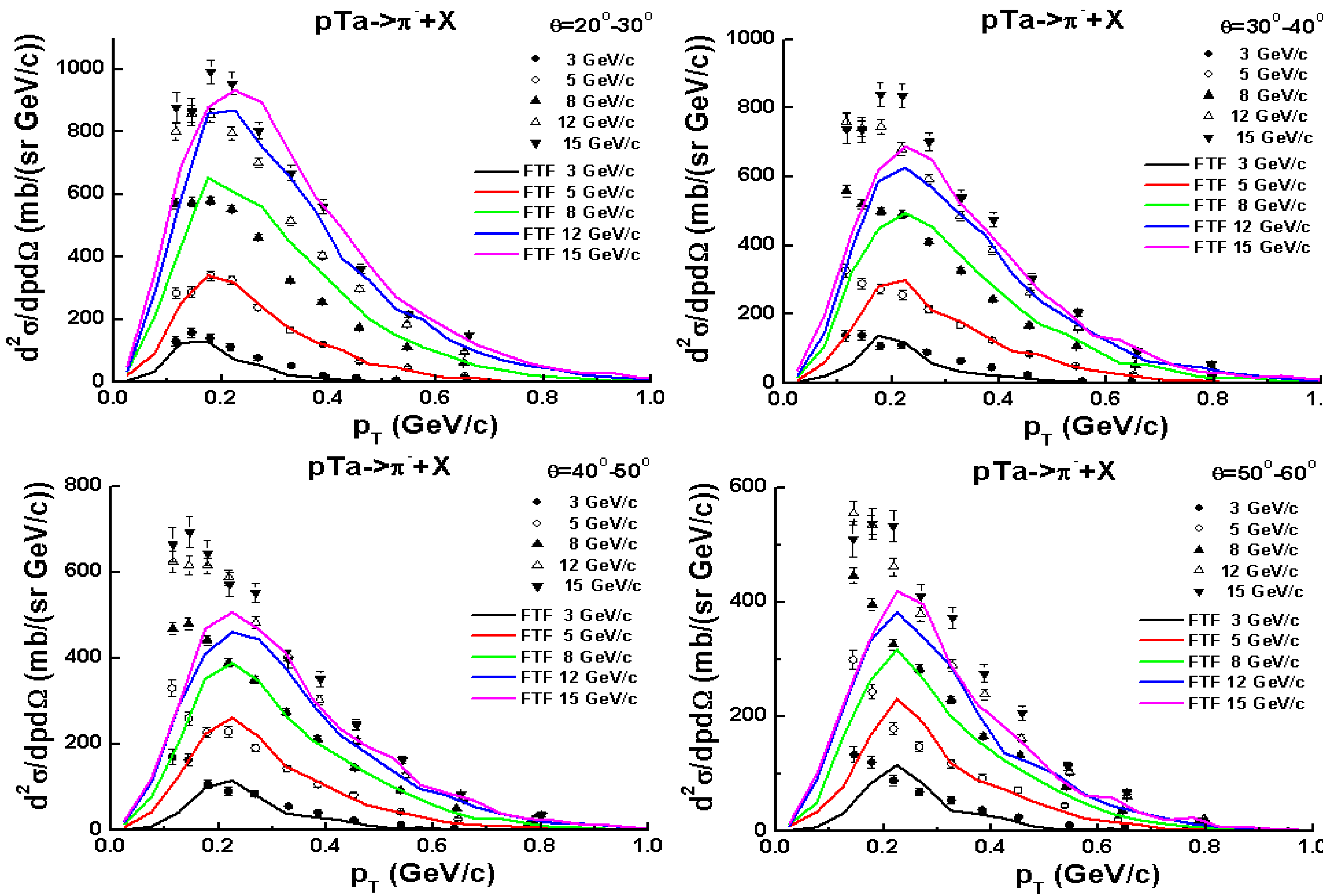
- Extension of FTF model down to 3-5 GeV for hadron-nucleus scattering
  - tuned parameters of Reggeon cascading
  - improved fragmentation of small-mass strings
- As a result, improved behavior below 8 GeV
  - smoother transition from cascade to string model in physics lists (e.g. FTFP_BERT)
  - transition from cascade to string model now possible at lower energies
    - can now consider using Binary cascade as alternate to Bertini

# FTF Correction of multiplicity of intra-nuclear collisions - BEFORE




Nmax=1, Plab=3, 5 GeV/c: Nmax=2, Plab=8 GeV/c: Nmax=3, Plab=12

# FTF Correction of multiplicity of intra-nuclear collisions - AFTER

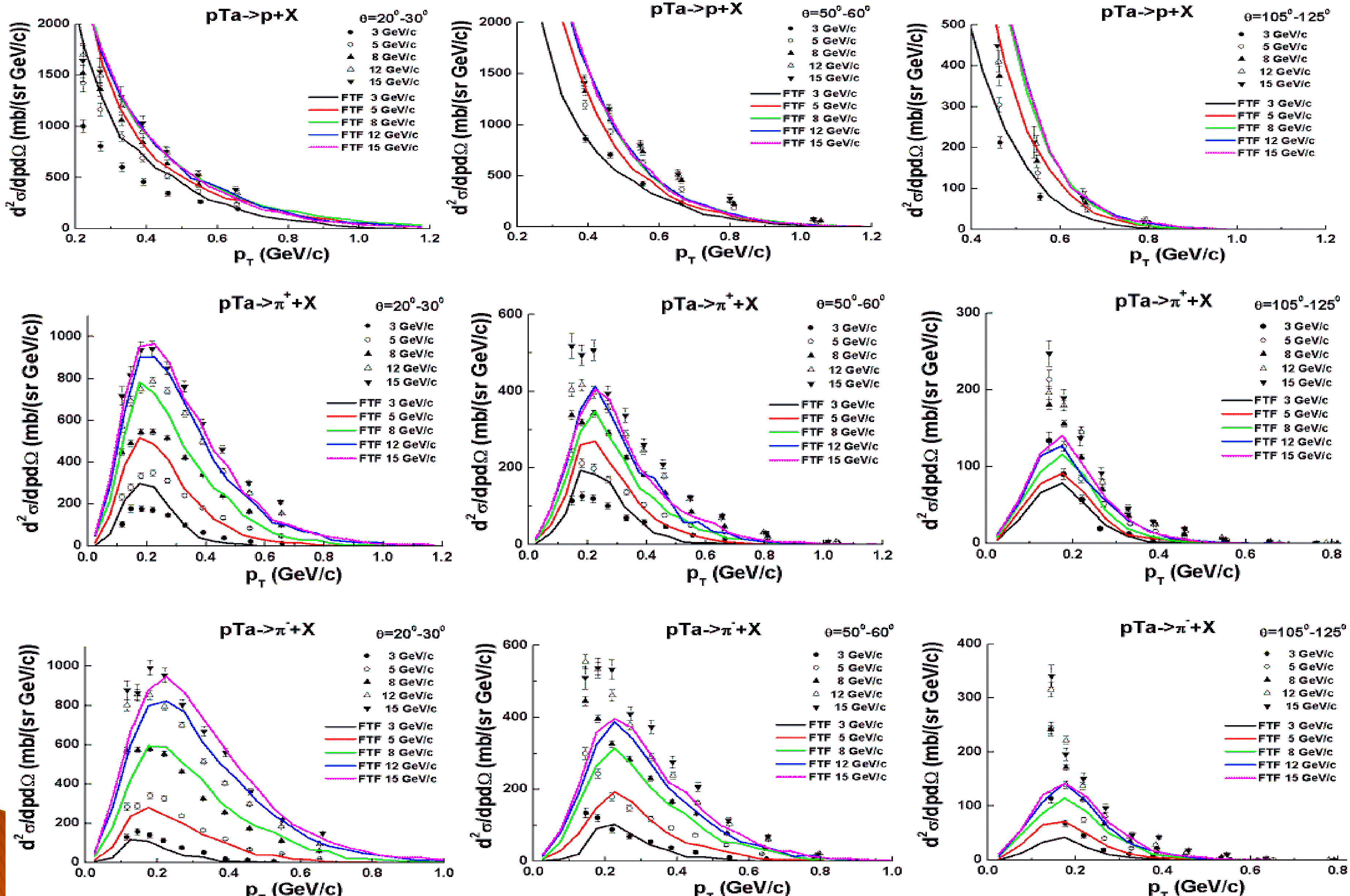



All O.K. with Pi-mesons!

Nmax=Plab/4 (GeV/c)

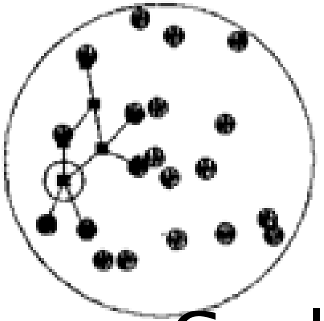
# Results – Description of the HARP-CDP exp. data






Better Agreement!

J. Apostolakis 2011



# Tuning of parameters of reggeon cascading

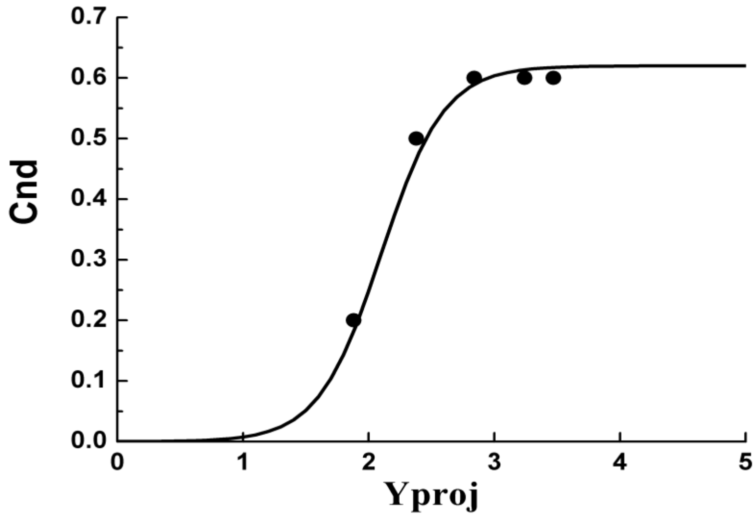
- Goal: to determine momentum spectra of nucleons
  - Complex analysis of gold interactions with photoemulsion nuclei at 10.7-GeV/nucleon within the framework of cascade and FRITIOF models. By EMU-01 Collaboration (M.I. Adamovich *et al.*). 1997. Zeit. fur Phys.A358:337-351,1997
- Longditudinal light-cone momentum fraction

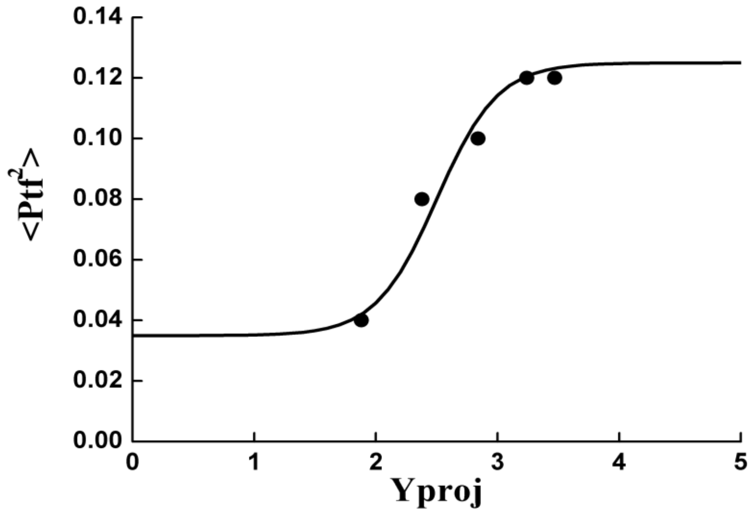
$$dW \propto \exp[-(x_i^+ - 1/A)^2/(d_x/A)^2]dx_i^+, \quad d_x = 0.05.$$

- Main parameters tuning:
  - Cnd, $d_x$, $p_T^2$

# tuning the reggeon cascading parameters :Results

Unexpected result !




$$C_{nd} = 0.62 \frac{e^{4(y-2.1)}}{1 + e^{4(y-2.1)}}$$

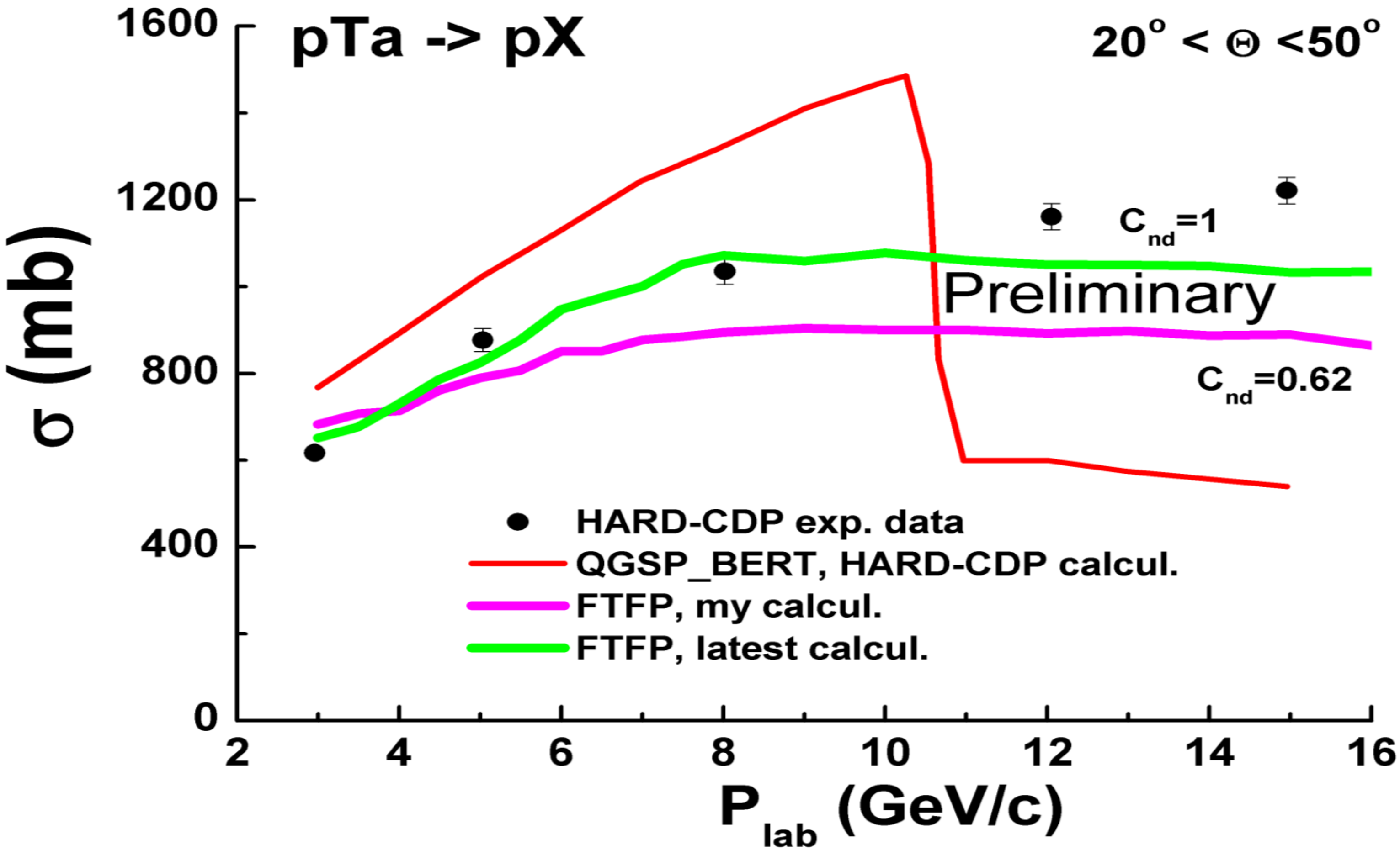
$$y = 2.1 \ at \ p_{lab} \simeq 4 \ GeV/c$$

$$< P_T^2 >= 0.035 + 0.09 \frac{e^{4(y-2.5)}}{1 + e^{4(y-2.5)}} \ (GeV/c)^2$$

$$y = 2.5 \ at \ p_{lab} \simeq 5.5 \ GeV/c$$

Parameters carry Signal of a transition!
The transition takes place at Plab= 4-5 GeV/c

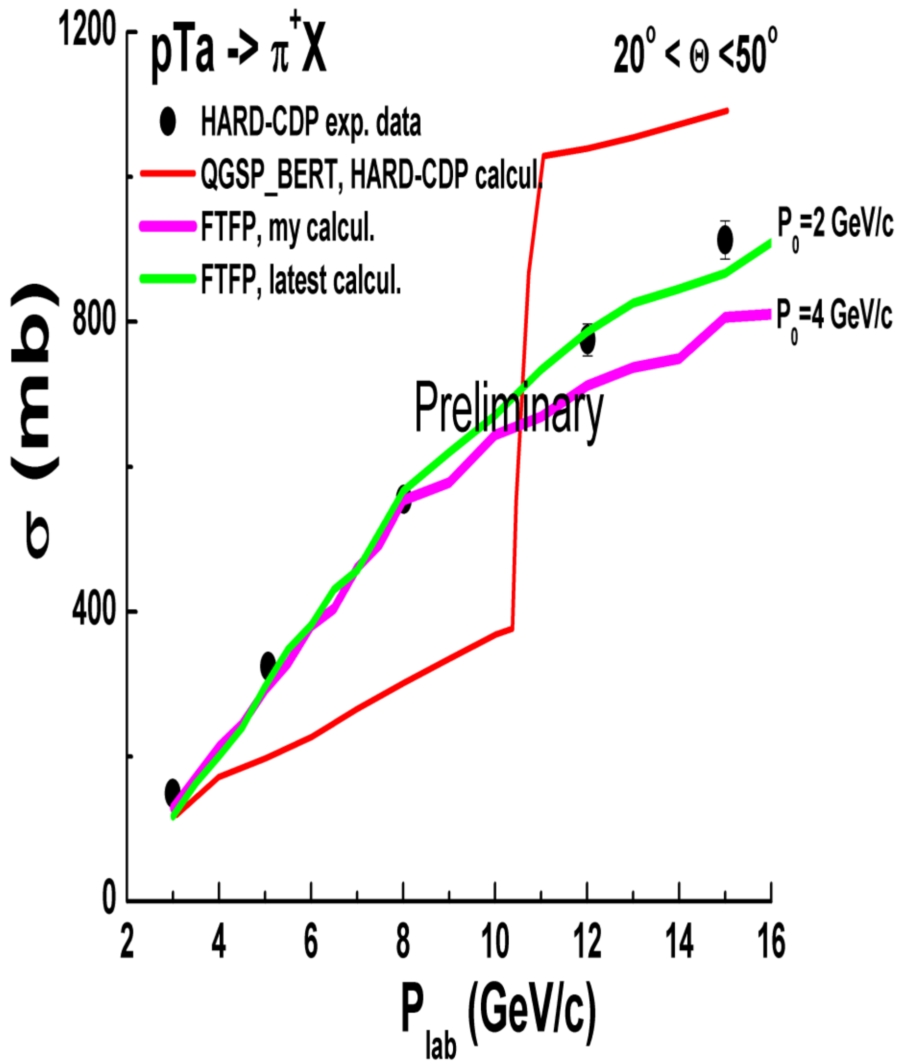
# Comparison with HARP Results

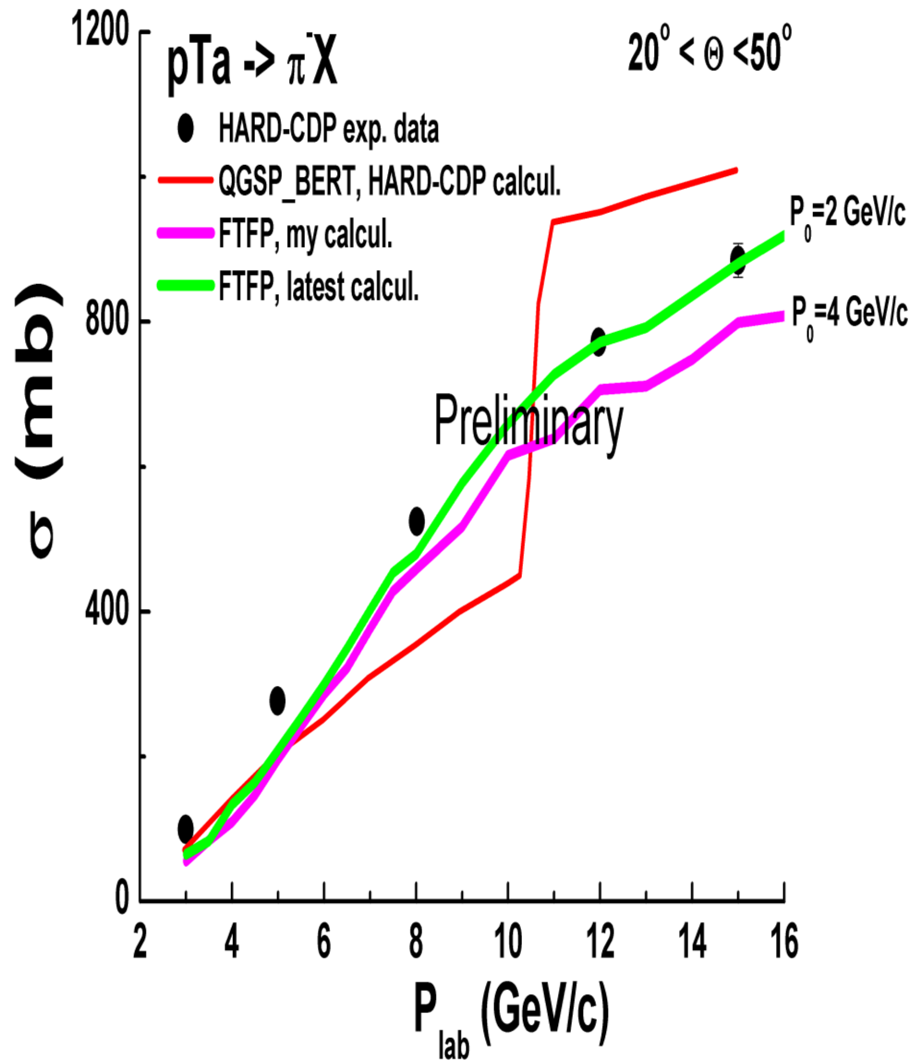



Smooth transition!

HARP-CDP hadroproduction data: Comparison with FLUKA and GEANT4 simulations.
HARP-CDP Collaboration (A. Bolshakova *et al.*) CERN-PH-EP-2010-017, Jun 2010. 21pp.
Submitted to Eur.Phys.J.C, e-Print: arXiv:1006.3429 [hep-ex]

# Comparison – More detail



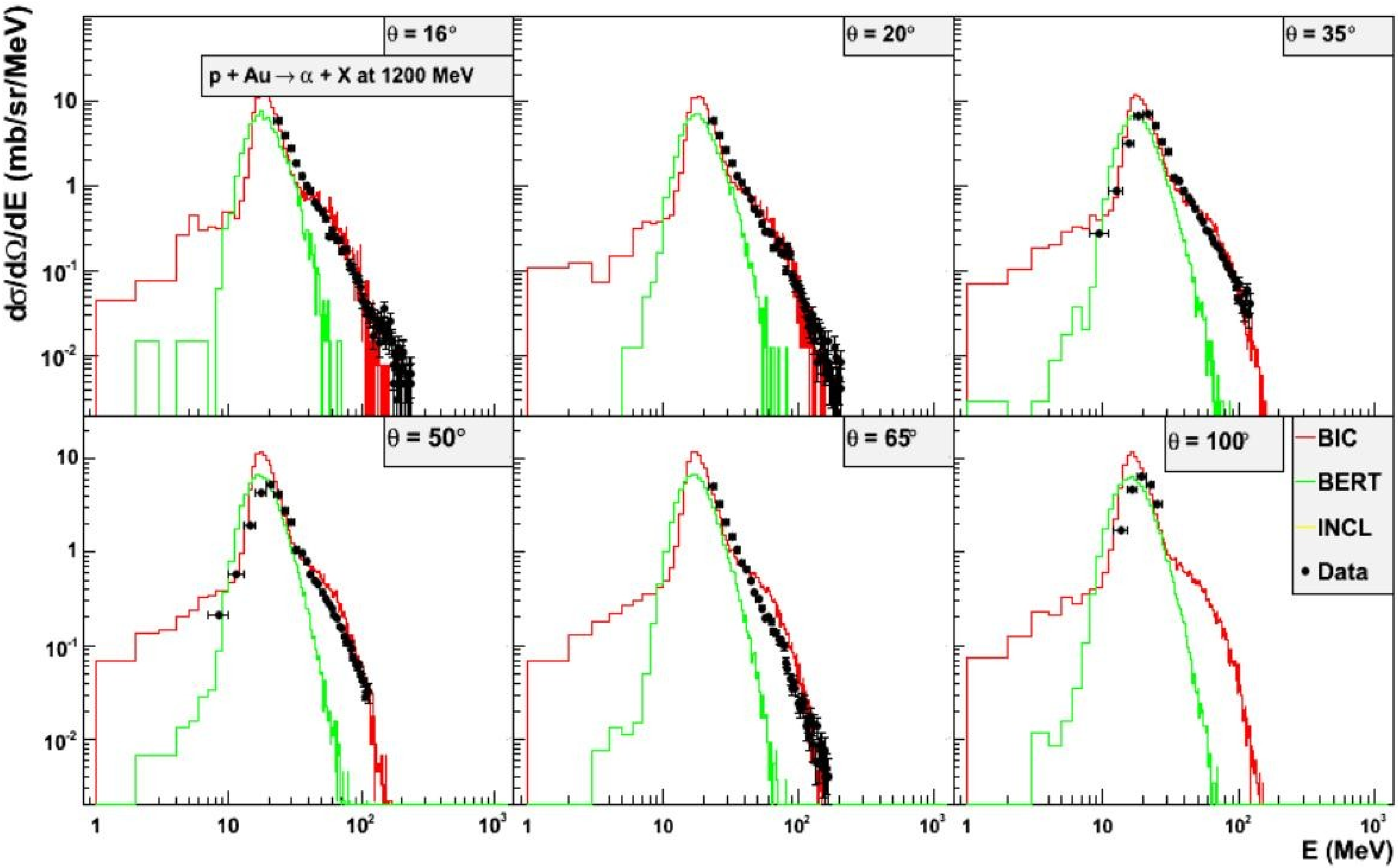




Smoothed transition!

# Summary of Major Improvements in 9.4

- Precompound and de-excitation models
  - GEM model fixed and re-introduced
  - replaced old-style emission probabilities (based on pre-1960's data) with new parameterization
- Binary Light Ion cascade
  - improvements to allow de-excitation of smaller fragments
- QMD model (ion-ion collisions) extended up to 5 GeV/n
- CHIPS models extended to all particles, all energies
  - validation in progress, some problems found

# Precompound and De-excitation Models vs. IAEA Data for p+Au -> ♋ 🖃 X



# Features in Geant4 9.4 beta

- Bertini-style cascade (M. Kelsey, D. Wright)
  - old pion-nucleon and nucleon-nucleon angular distributions replaced (for two-body final states)
  - Removed almost all energy-momentum non-conservation
  - Reduced memory churn by factor ~10
- Transitioning to using integer A and Z exclusively in hadronic code (G. Folger)
  - now require use of specific isotopes - no effective Z or average A allowed
    - can no longer use materials with average Z and A

# Features in Geant4 9.4 beta

- Extensive improvements in G4Precompound model and de-excitation code
  - hybrid use of Weisskopf-Ewing and GEM models to improve nuclear fragment spectra from decay
  - improved inverse capture cross sections
  - enabled use of multi-fragmentation model for light nuclei
  - numerous bug fixes and improvements in logic

  - J.M. Quesada & V. Ivantchenko

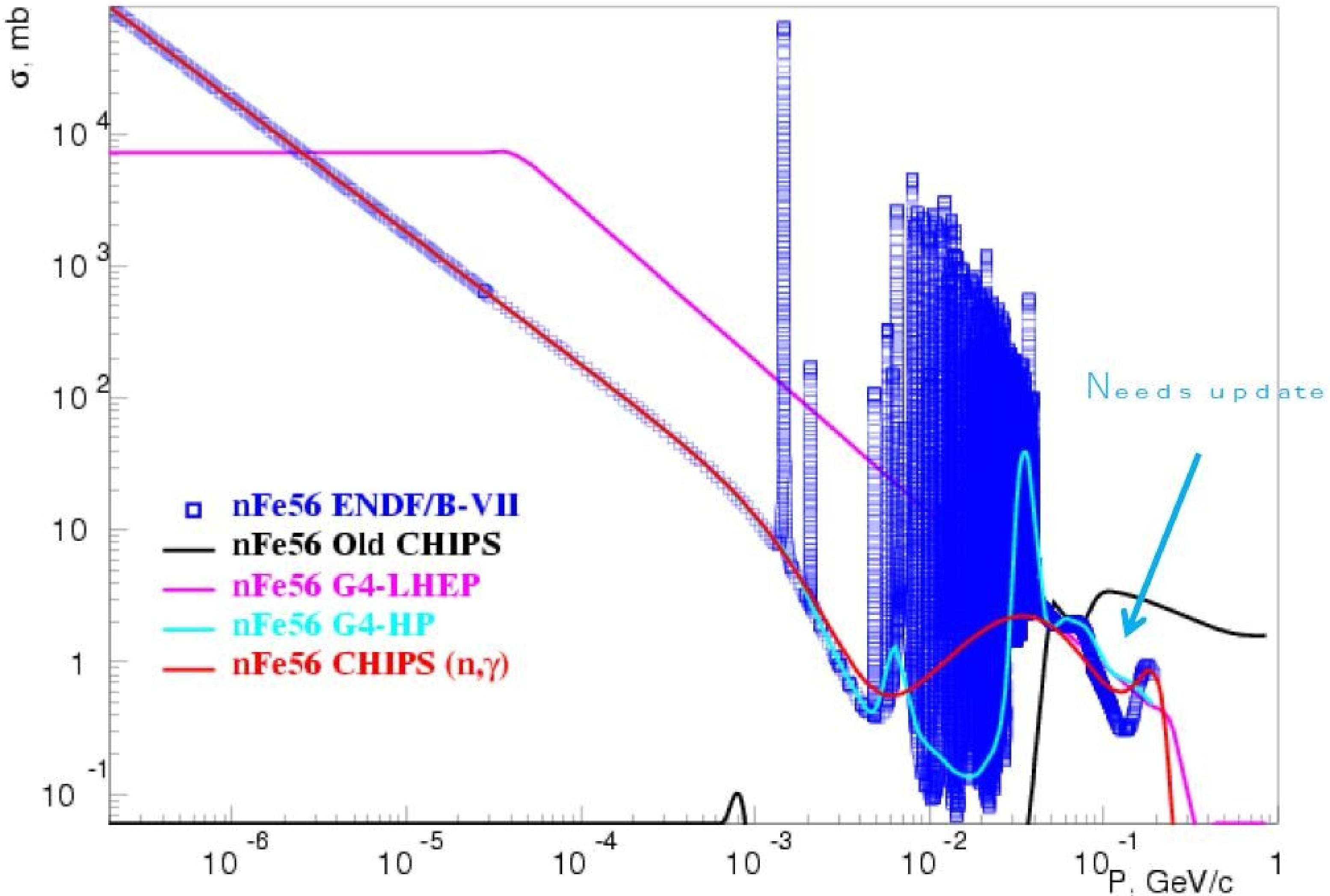
# New Features in Geant4 9.4

- Faster neutron capture 'XS' model
  - includes some of the detail found in HP neutron models

V. Ivantchenko and A. Ivantchenko

    - old GHEISHA-based model too simple
    - high precision neutron model too slow

# n + Fe Cross Section Data vs CHIPS, LHEP, and FastHP Parameterizations



# New Features in Geant4 9.4

- Interfaces from Bertini/INCL cascade models to G4Precompound model (optional)
  - allows our best de-excitation model to be used in a uniform way with existing cascade codes
    - Bertini-style cascade (J. Yarba/FNAL)
    - already used by Binary cascade
- Anti-p, n, d, t, 3He, ♋ – nucleus cross sections
  - first step in expanding hadronic models to handle incident anti-nucleons and anti-light ions
    - Simplified Glauber parameterization (Grichine)
    - New Glauber calculation – improved parameterisations (Galoyan, Uzhinskiy)

# Draft Plans for 2011

- Shower shape and calorimeter response improvements
  - develop and validate new physics lists to exploit recent model extensions
  - try new implementation of nuclear trailing effect in Bertini cascade
- Completed implementation of hadronic cross section de-design
  - developed plan last year to treat large number of cross section data sets uniformly
  - will allow smoother joining of one set to another

# Draft Plans for 2011 (cont.)

- Revised anti-nucleon, and new anti-nucleus interactions
  - Bertini-style cascade
  - FTF model
- Cross section improvement for kaons, hyperons
  - Kaon oscillation: a first treatment
- Installation of alternatives to current HP neutrons
  - Conversion of latest neutron library data to G4NDL format (CIEMAT)
    - Allows use of full ENDF-VII, Jeff 3.1, ..
    - Existing HP implementation, with improvements
  - ENDL: based on Livermore neutron DB
    - With new implementation

Both to offer more isotopes than HP models

# Draft Plans for 2011(cont.)

- Add initial and final state clustering models to Bertini
  - to improve light ion production at cascade energies
- Interface of G4Precompound and de-excitation to INCL cascade

# Draft Plans for 2011(cont.)

- Nucleus-nucleus scattering
  - currently our models do not perform well above ~5 GeV/c
    - extend them: FTF, RQMD
  - low energy scattering
    - current models do not go below ~100 MeV
    - will then have complete coverage of nucleus-nucleus A and incident energy
    - develop and validate new physics lists to use new ion-ion models and cross sections

# Backup slides (EM+)

# Updates on Electromagnetic Physics for Geant4 9.4

Borrowed from presentation of V.Ivanchenko
for Geant4 EM standard group
( Geant4 Technical Forum – 16 November 2010 )

# Outline

- Main activities of EM standard physics working group in 2010
- EM standard modifications for Geant4 9.4
  - Models of ionisation
  - Multiple scattering
  - Physics Lists
  - Helper classes
- Draft plan for 2011

# Main activities for Electromagnetic Physics in 2010

- Ionisation
  - Improved parameterization of density effect
  - Addition of anti-deuteron, anti-triton, anti-He3, anti-alpha are included in all Physics Lists
  - Addition of the new model for low-energy ionization of negatively charged particles
  - Improved models of ionization for monopoles and heavy exotic objects
  - Upgraded model of fluctuations of energy loss
- Bremsstrahlung
  - Alternative angular distribution
- Multiple scattering
  - Urban93 model substitute Urban92 for $e^{\pm}$
  - WentzelVI model of multiple scattering for muons
  - New tests for multiple scattering of high energy particles
- Infrastructure upgrades
  - Physics Lists
  - Helper classes
- Regular activity on validation
  - Testing suite run for each reference tag and any significant change of software
  - CPU performance profiling

# Ionisation Model Developments

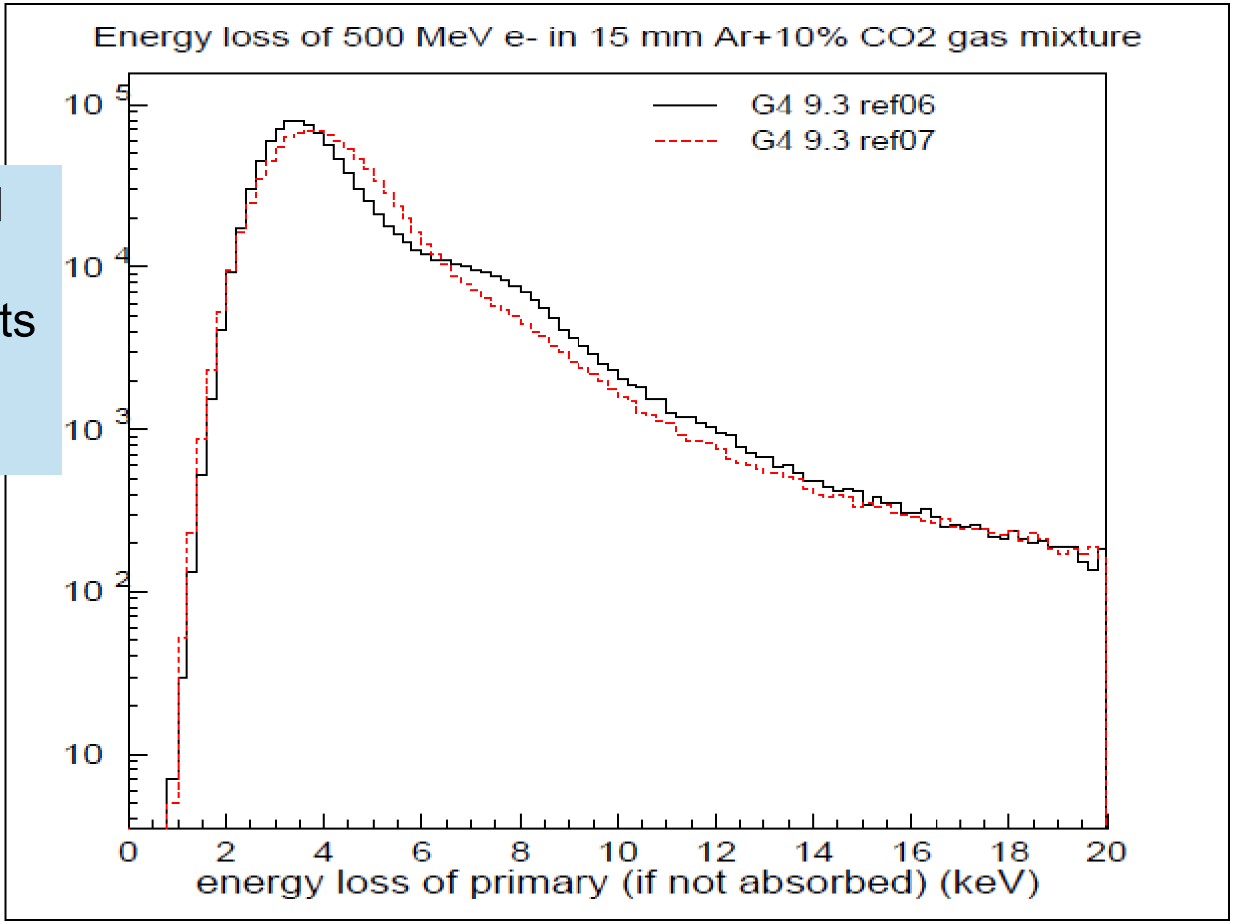
- Review and upgrade of parameterisation (A.Bagulia)
  - Density effect
  - Shell Correction
  - Barkas Corrections
- Ionisation of magnetic monopole
  - Transportation of monopoles in field is added (J.Apostolakis, B.Bozsogi)
  - Delta-electron production is added
- Ionisation of heavy highly charged objects
  - Fixed low-energy behaviors

# Model for low-energy negatively charged particles (A.Bagulia)

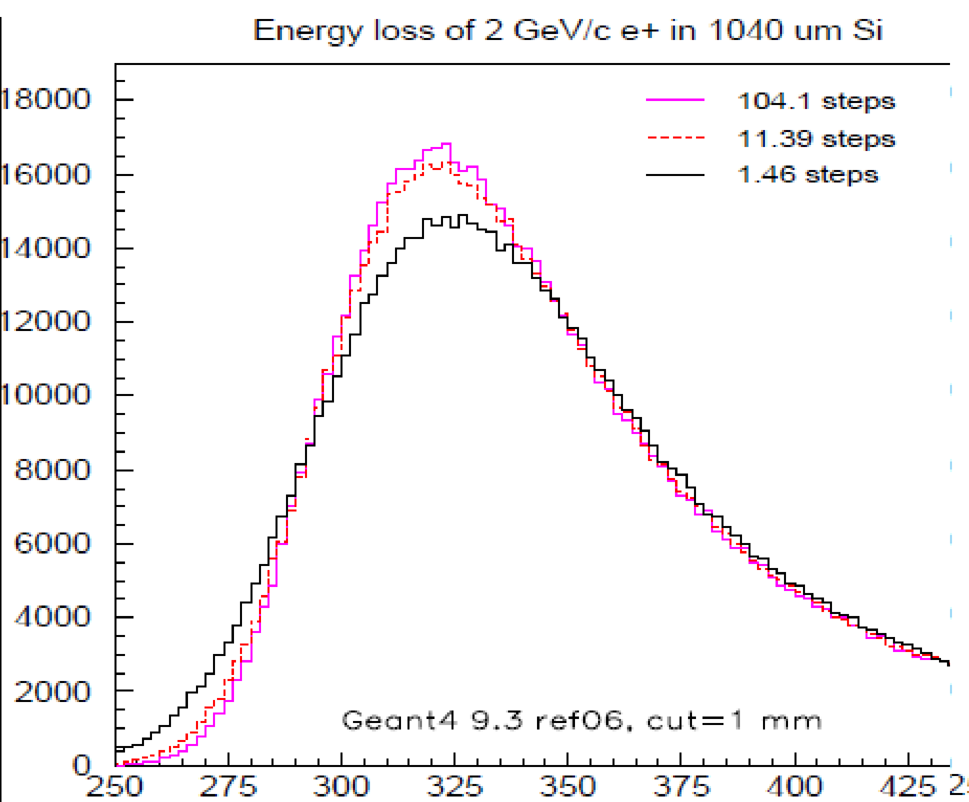
- A model for a calculation of the stopping power by regarding the target atom as an assemble of quantum harmonic oscillators is implemented
- ICRU'73 data for oscillator strengths
- Used for new anti-particles and other particles with negative charge

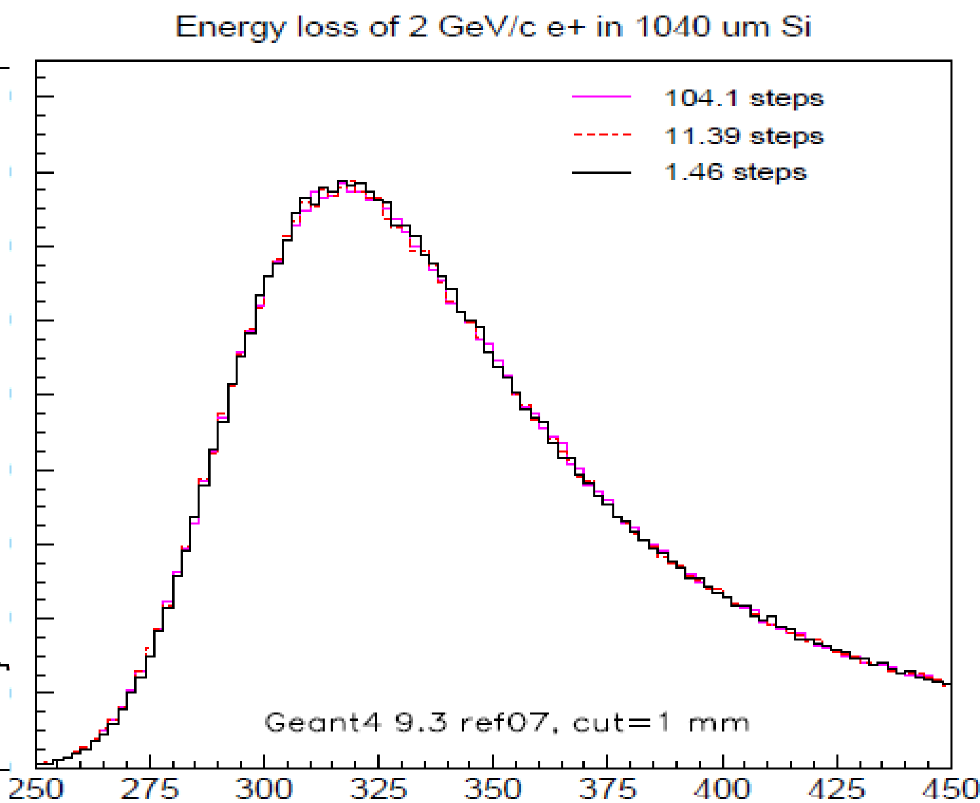
# Upgrade of the Model of Fluctuations (L.Urban)

Problem was observed
for tail of energy l
deposition in thin targets
- gaseous detectors
- Si trackers (?)

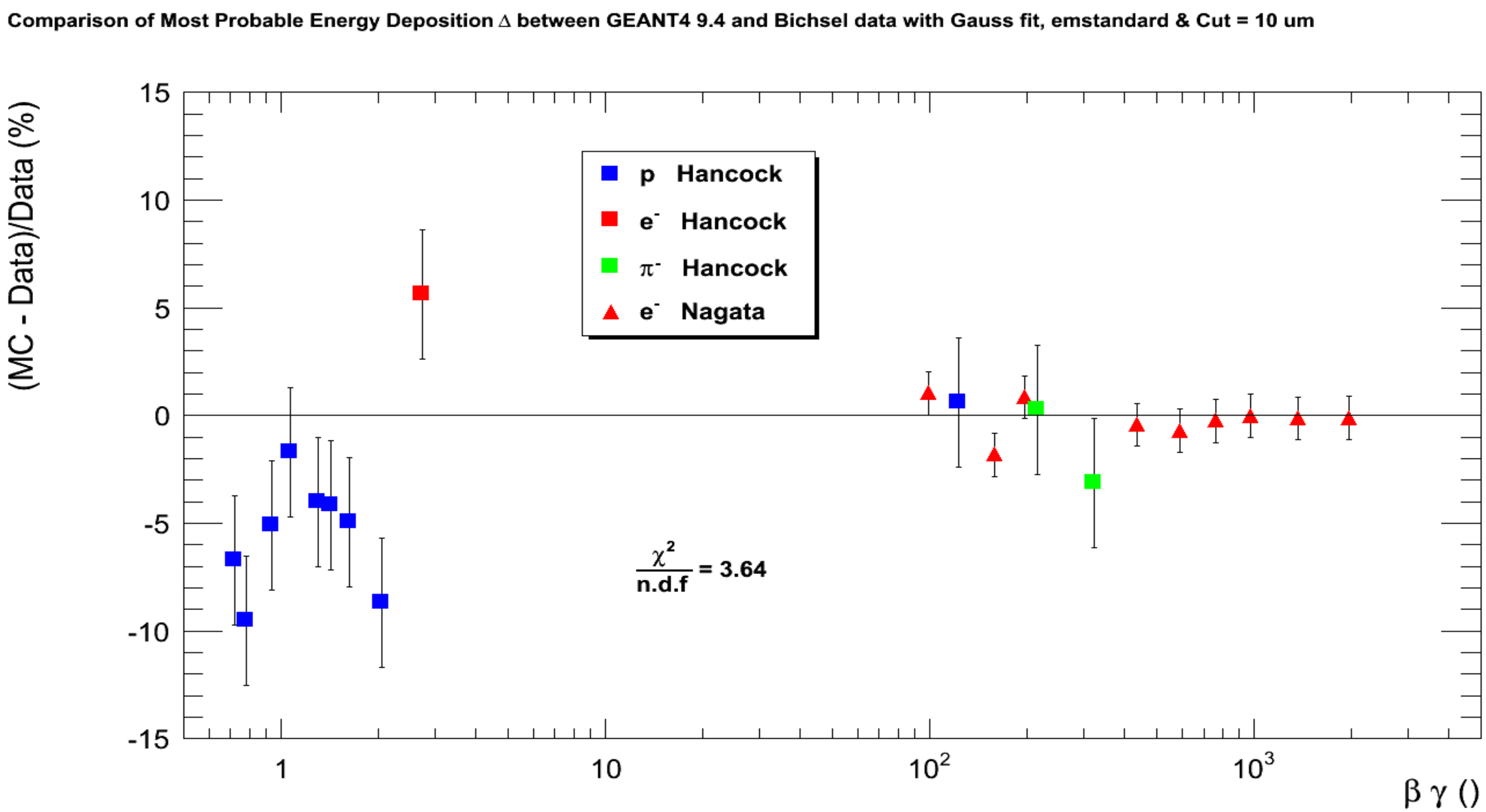


# Stability of the upgraded fluctuation model versus step limit



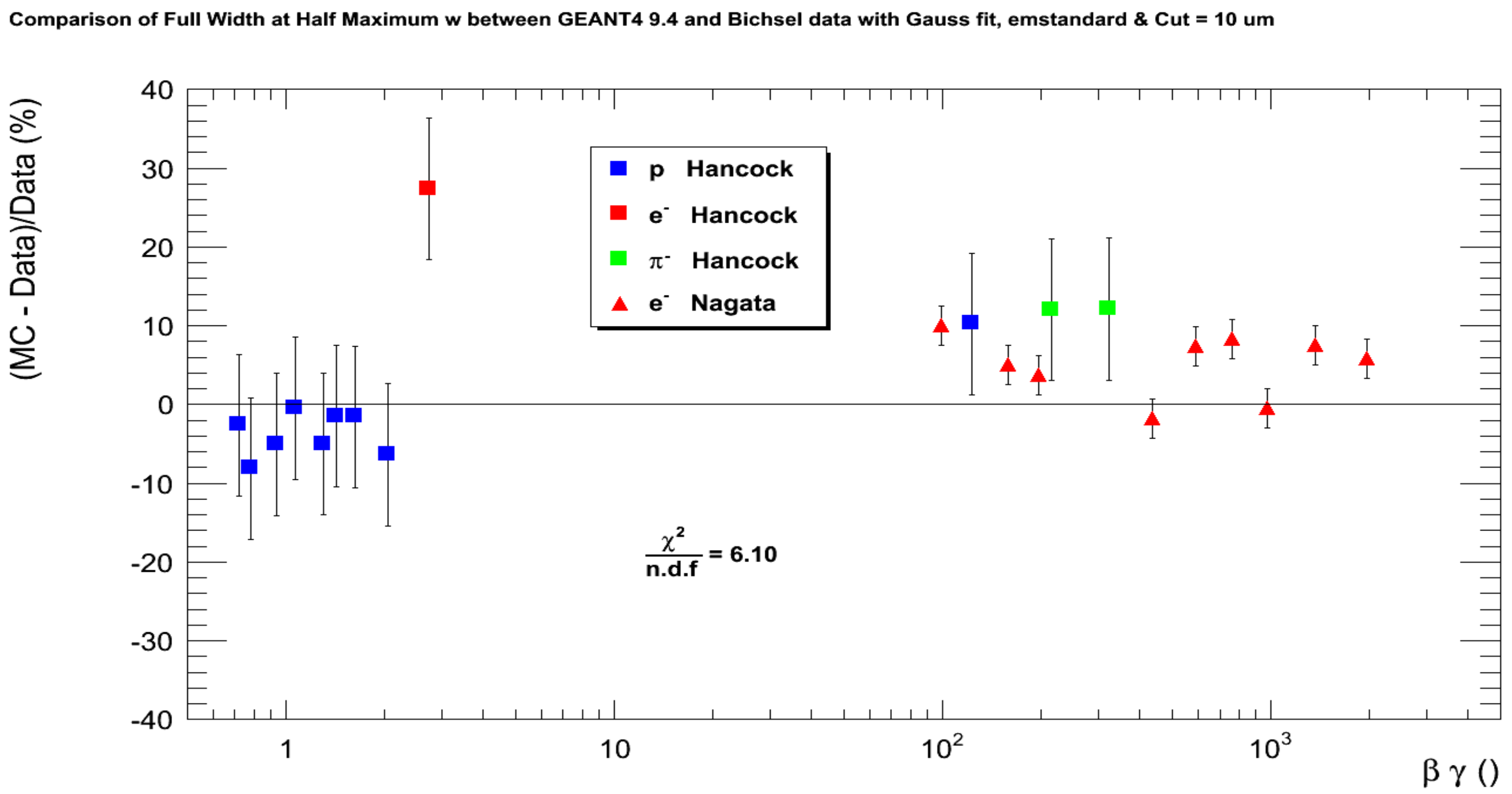



# Accuracy of simulation of peak of energy deposition in 0.3 mm Silicon for 9.4




In 9.3 $\chi^2$ was 3.2

# Accuracy of simulation of FWHM of energy deposition in 0.3 mm Silicon for 9.4



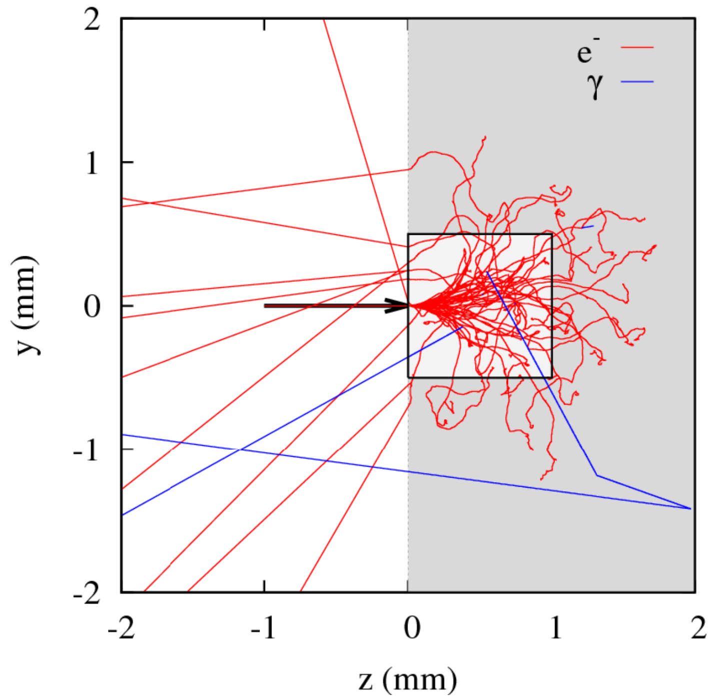

In 9.3 $\chi^2$ was 17.4

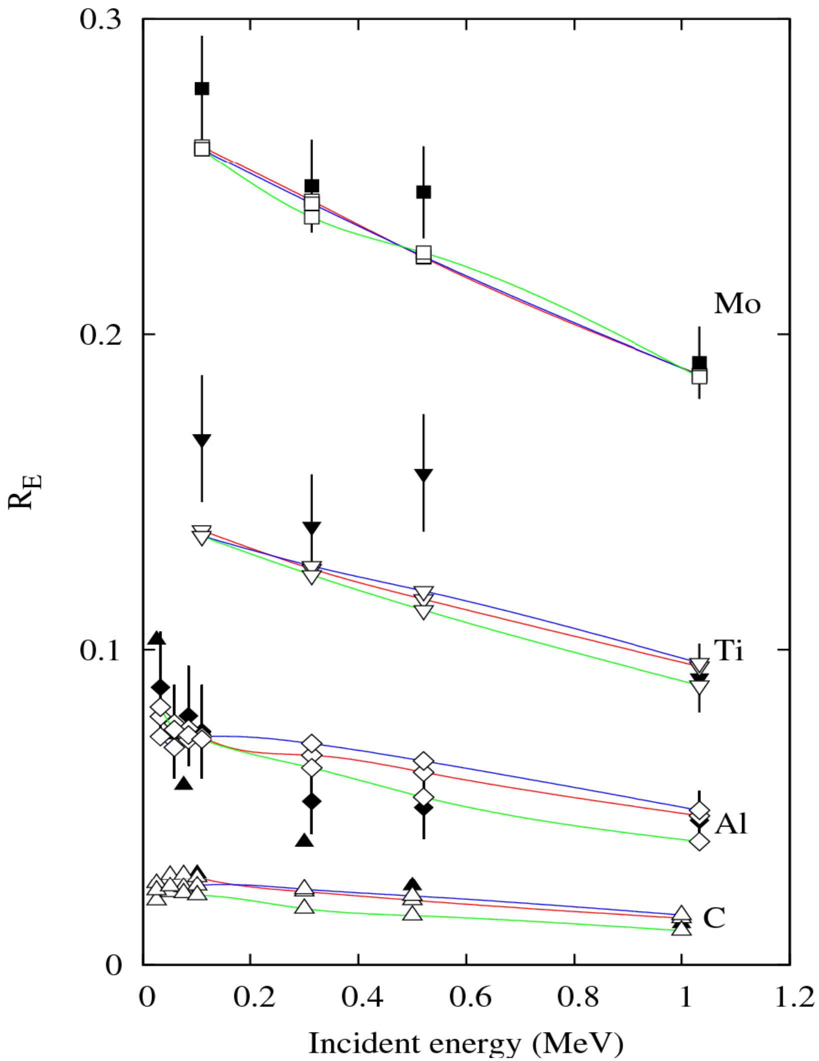
# Multiple scattering developments

- Several validation of electron scattering confirms that **G4UrbanMscModel93** is more precise than G4UrbanMscModel92
  - Urban93 model become the default for 9.4
  - Optimized for electrons and positrons
- Number of new tests for high energy particles confirms that WentzelVI model is better for muons than Urban90 model which was used for a long time
  - G4WentzelVIModel become the default

# New Backscattering simulation with L.Urban model (A.Lechner)

- Electron Energy and Charge Albedos SANDIA Report SAND80-0573 (1984)
- Electron energy 0.1 – 1 MeV

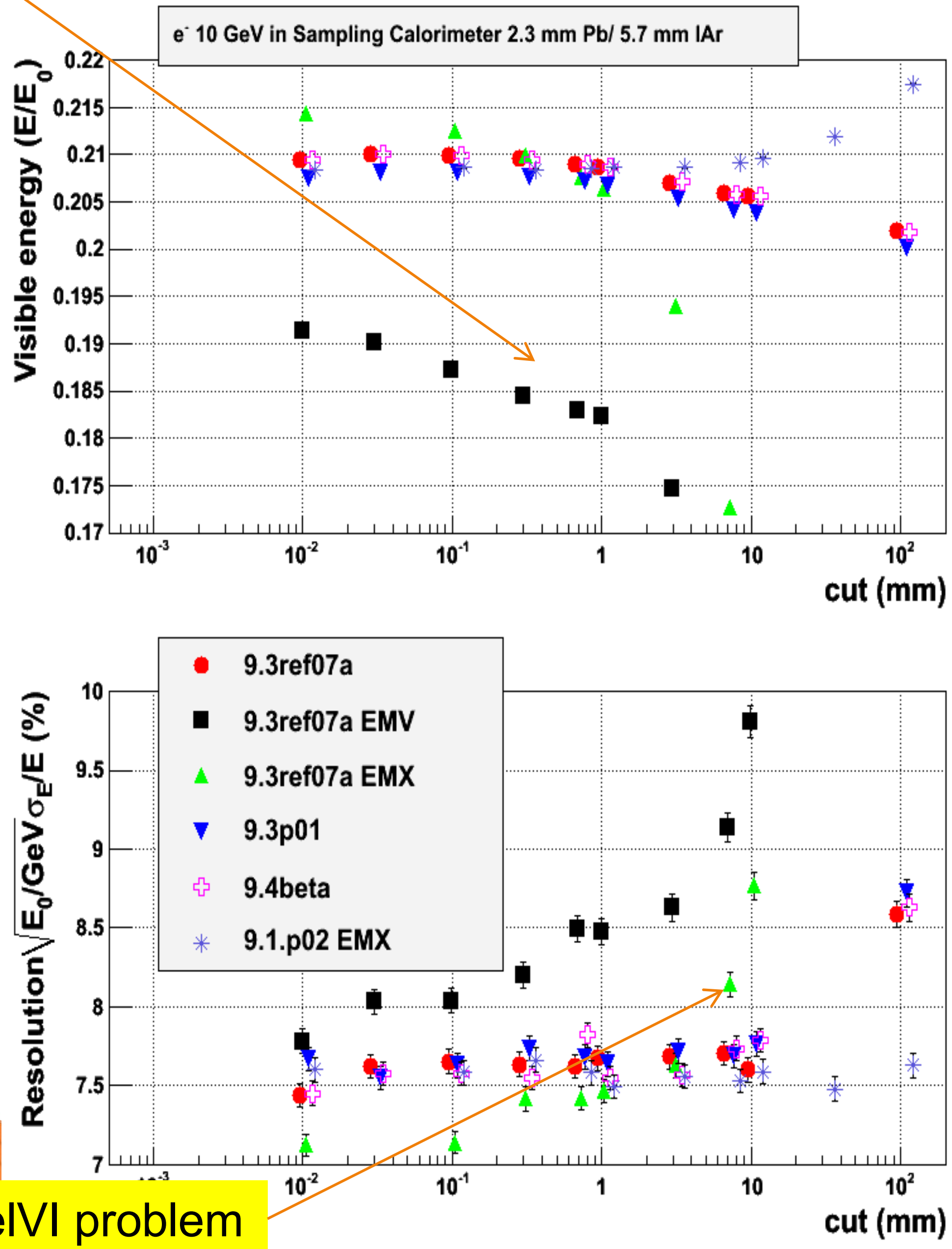


# Calorimeter response

Effect of MSC

ATLAS-HEC like setup



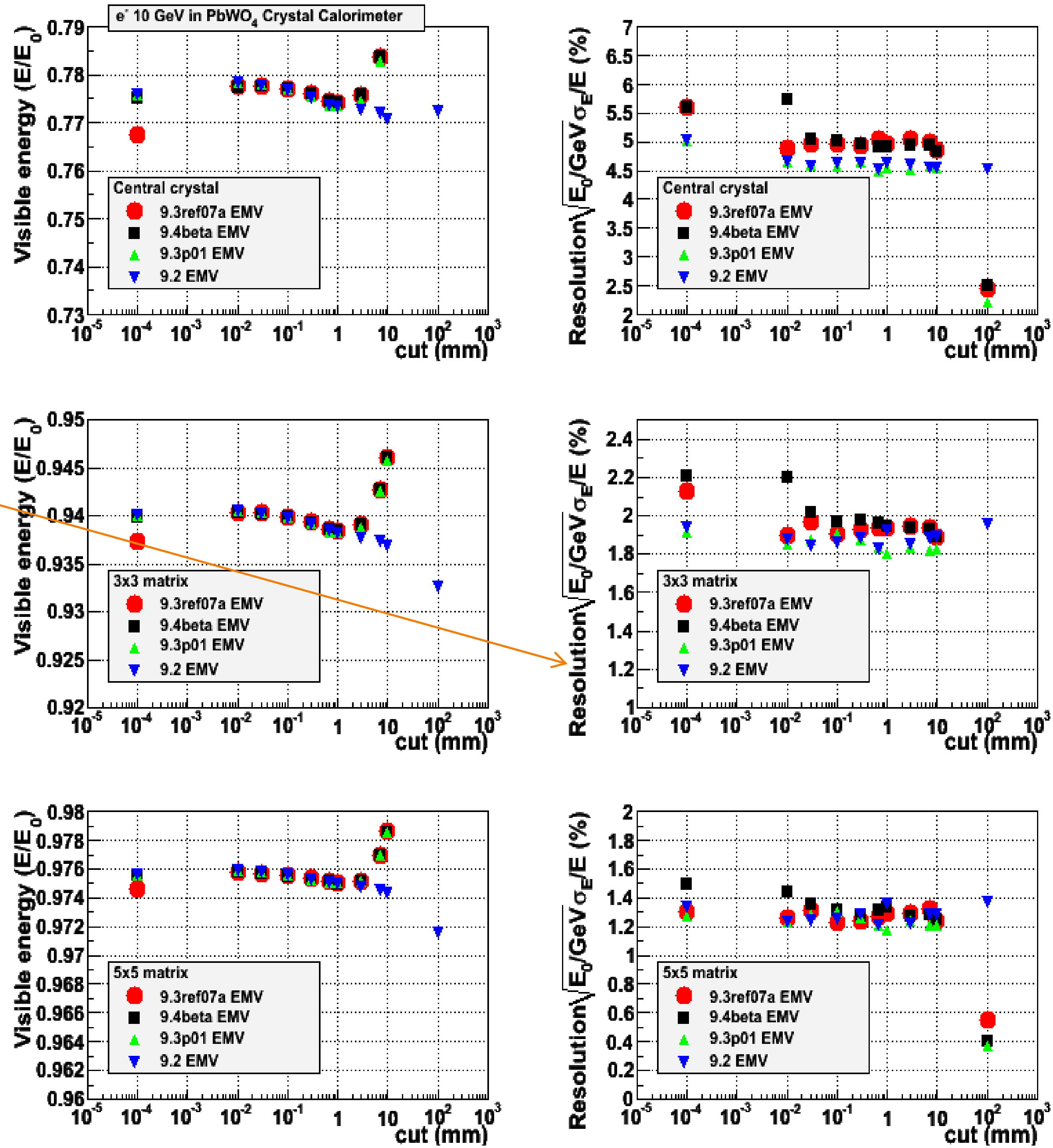

WentzelVI problem

20

# Calorimeter response

Effect of MSC

CMS-like $PbWO_4$

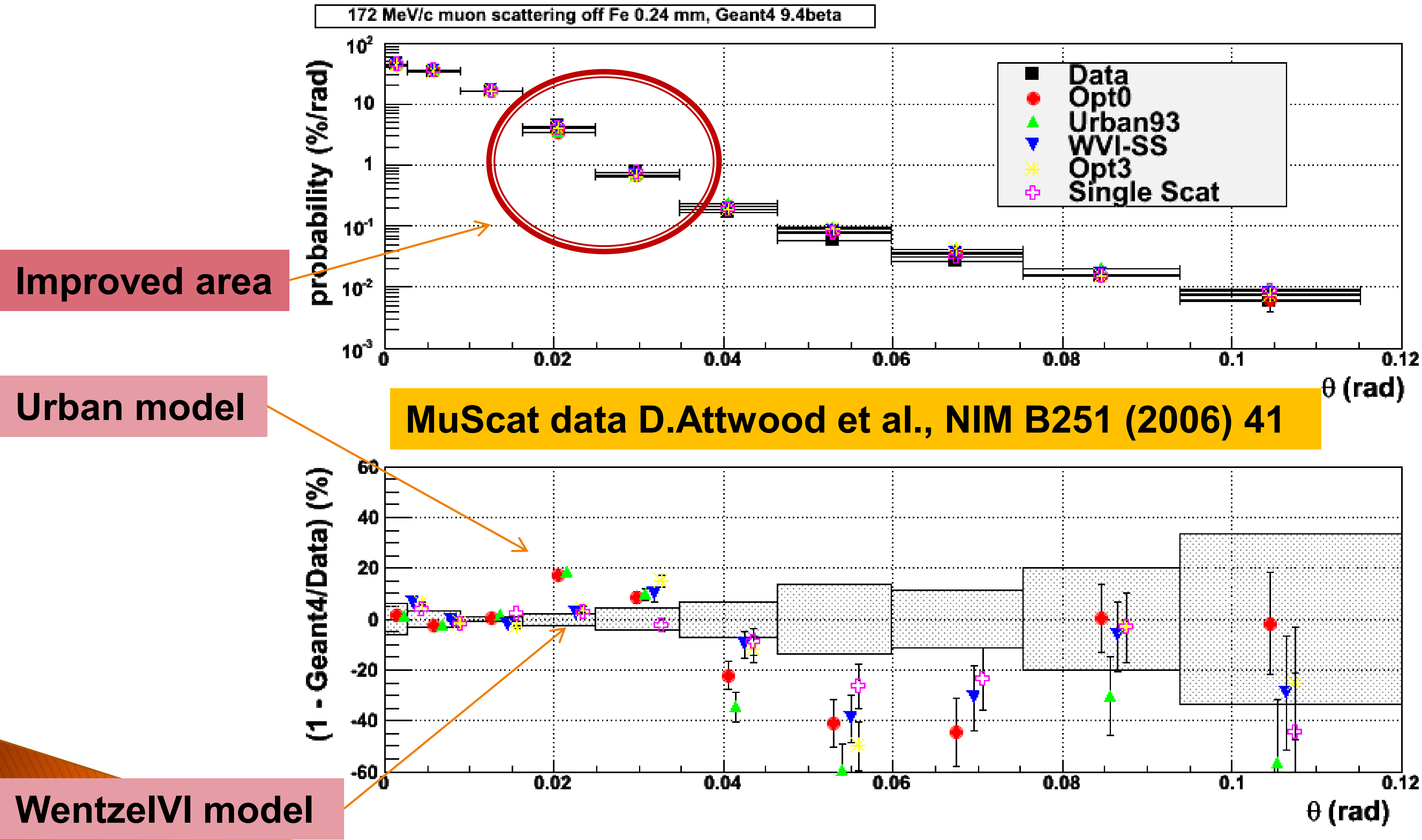


# New WentzelVI model

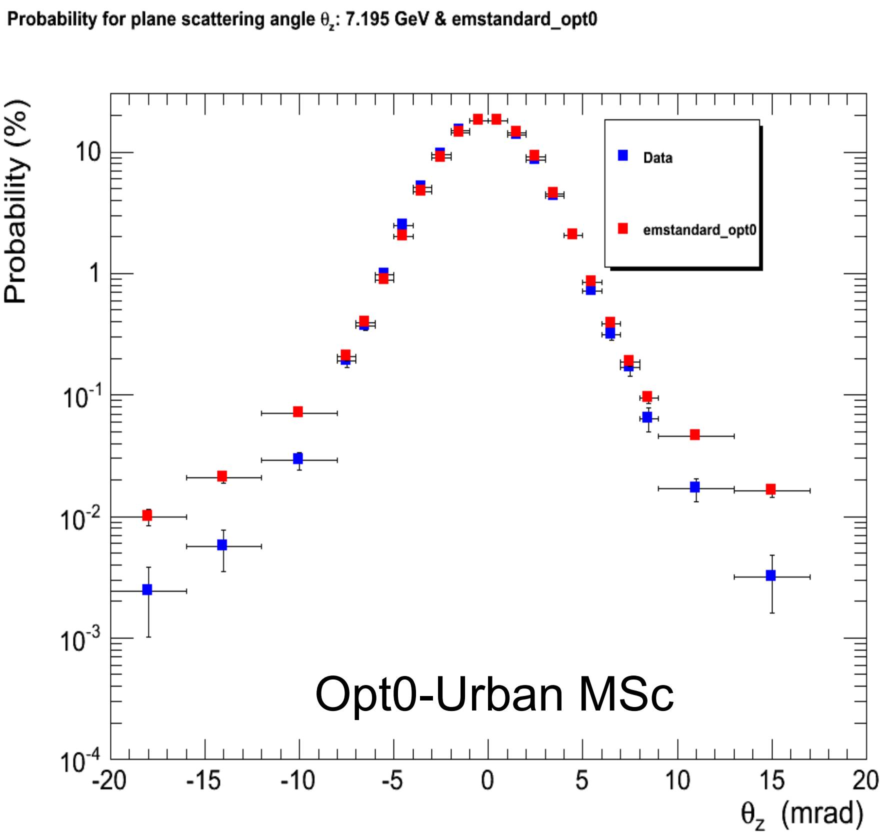
*J. Phys: Conf. Ser. 219 (2010) 032045*

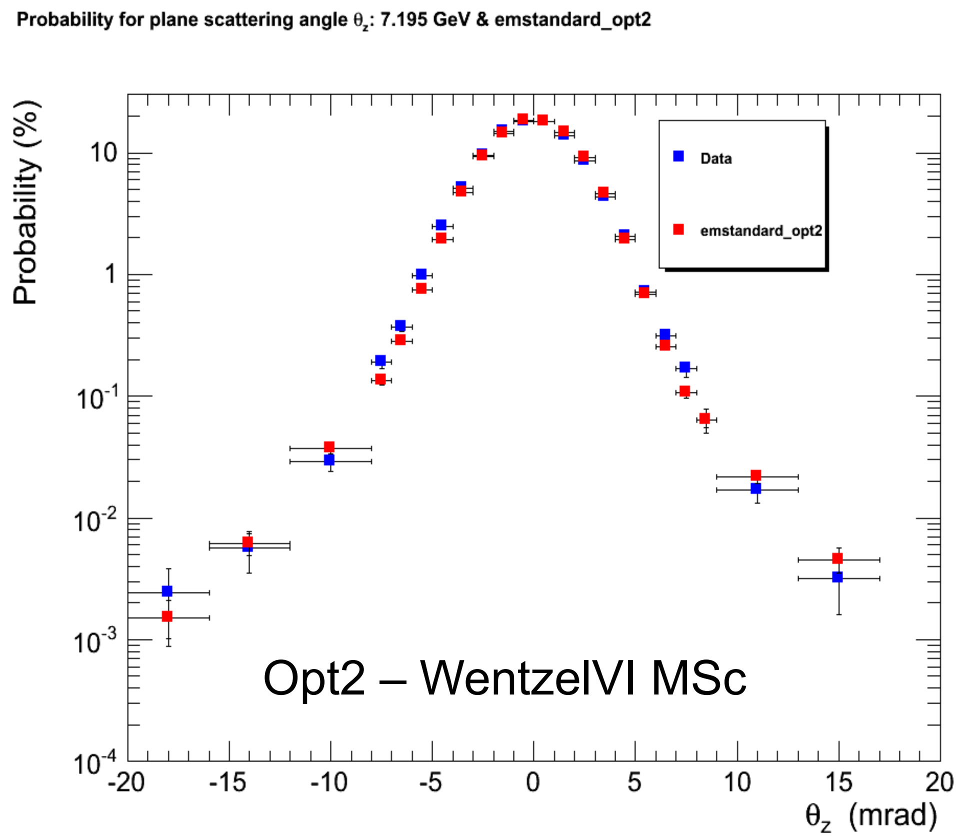
- Is much simpler, but fully theory based
  - Wentzel differential cross section with mass, spin and form-factor corrections
  - Separate, original step limitation
  - Limit step of high energy particles in extended media (LHCb request)
- **Angular limit** between the single and multiple scattering is selected **dynamically**, depending on momentum and step size
  - May be applied for transportation in vacuum or low-density media
  - Can be used together with the hadron elastic scattering process

# MuScat test results for 9.4



# New test of high energy MSC CERN summer student (O.Dale)

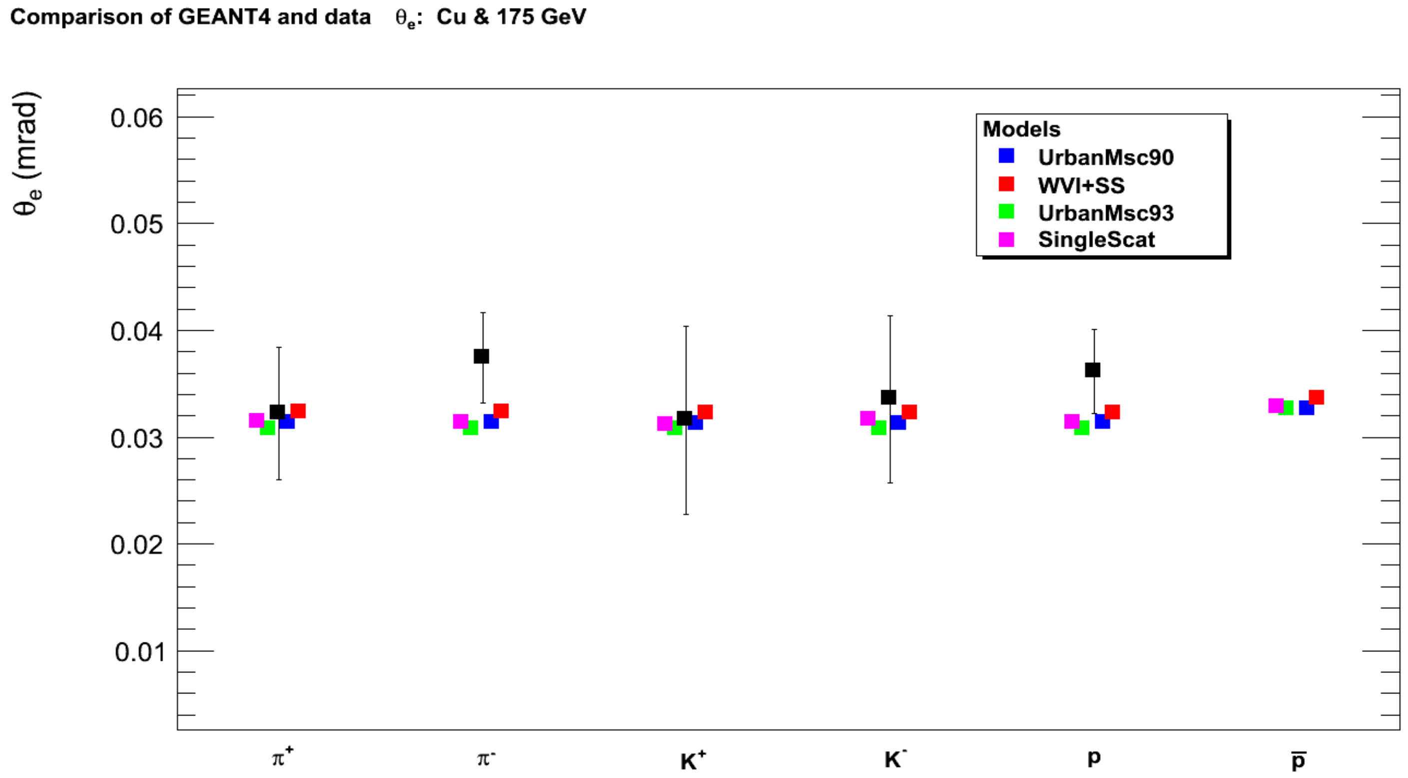



7.195 GeV

- Urban model overestimates tail
- WentzelVI and single Coulomb scattering models fit the data

# High energy multiple scattering: 175 GeV beams off Cu target (O.Dale)




- Central part of distribution reproduced by all models within data uncertainty and agree with Moliere theory
- Data available for 50 – 200 GeV for various targets (Be, Al, Cu, Sn, Pb)
- G.Shen et al., Phys. Rev. D20 1584 (1979)

# EM Physics List constructors for 9.4

| Constructor | Components | Comments |
|---|---|---|
| G4EmStandardPhysics | Default (QGSP_BERT, FTFP_BERT…) | ATLAS and other HEP productions, other applications |
| G4EmStandardPhysics_option1 | Fast due to simple msc step limitation, cuts used by photon processes (QGSP_BERT_EMV, …) | CMS & LHCb prod., good for crystals – not accurate for sampling EM calos |
| G4EmStandardPhysics_option2 | Experimental: WentzelVI model for hadron msc, BS angular distribution for bremsstahlung (QBBC, …) | Used for testing of new models |

- Main user interface
- Used by Geant4 validation suites
  - Are robust due to intensive tests by Geant4 team
- Oriented on HEP applications

# Helper classes in 9.4

- Easy access to cross sections and stopping powers (G4EmCalculator)(shown on TestEm0)
- C++ interface to EM options alternative to UI commands (G4EmProcessOptions)
- G4EmSaturation – Birks effect
- G4ElectronIonPair – sampling of ionisation clusters in gaseous or silicon detectors
- G4EmConfigurator – add models per energy range and geometry region

# Geant 4 Draft plan for 2011

- Ionisation
  - finalize tuning of ICRU73QA model (for negatively charged projectiles)
    - Improved ionisation for highly changed objects including high energy ions
  - Specialization of the fluctuation model for electrons and positrons
- Multiple scattering
  - Provide combined model for hadrons where Coulomb and strong scattering consistently taken into account
- Bremsstrahlung
  - Increase precision of computation of total cross section
  - Improve sampling (including angular distributions)
- Pair production
  - Add triple final state; improve angular distribution
- Polarisation
  - Implement spin precession in field using Stokes vector formalism
- Validation
  - Regular run existing testing suite
  - Extend tests for extra thin target data
  - Follow up issues from LHC experiments' observations
  - Interact with CALICE and other experiments, test-beam