Geant4 models for anti-protons, positrons, and gamma

V.N.Ivanchenko, CERN, G4AI
For Geant4 Collaboration

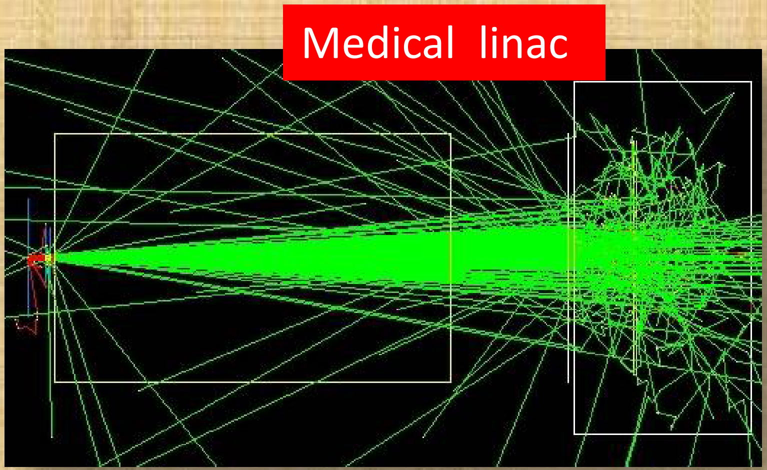
Nuclear physics for Galactic Cosmic Raysin the AMS-02 era
Grenoble, France, 3-4 December 2012

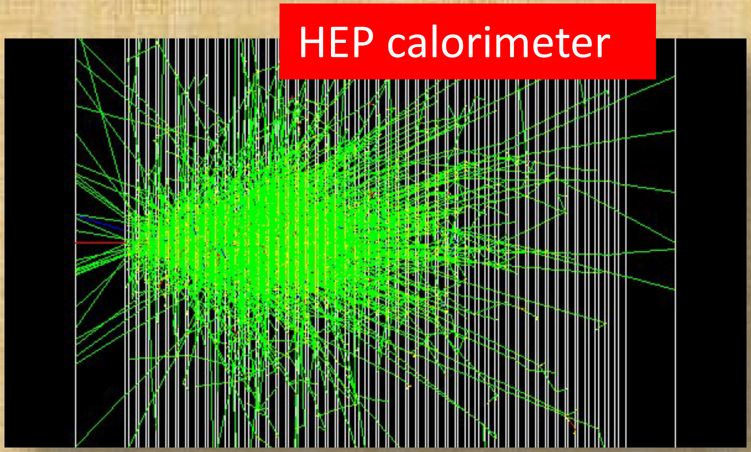
Outline

- Overview of Geant4 Electromagnetic (EM) physics
  – EM sub-packages
  – EM physics constructors in 9.6
  – Gamma and positron production
- Physics of anti-protons and light anti-ions
  – Cross sections
  – Secondary generators
  – Anti-proton production
- Summary

Main electromagnetic processes

- Photon processes
  - γ conversion into e+e- pair
  - Compton scattering
  - Photoelectric effect
  - Rayleigh scattering
  - *Gamma-nuclear interaction in hadronic s*
- Electron and positron processes
  - Ionisation
  - Coulomb scattering
  - Multiple scattering
  - Bremsstrahlung
  - Positron annihilation
  - *Nuclear interaction in hadronic s*
- Muon, hadron and ion processes
  - Ionisation
  - Coulomb scattering
  - Multiple scattering
  - Bremsstrahlung
  - E+e- pair production





Geant4 EM sub-packages

- Standard
  - γ, $e^{\pm}$ up to 100 TeV
  - hadrons up to 100 TeV
  - ions up to 100 TeV
- Muons
  - up to 1 PeV
  - energy loss propagator
- X-rays
  - X-ray and optical photon production proc.
- High-energy
  - processes at high energy (E>10GeV)
  - physics for exotic particles
- Polarisation
  - simulation of polarized beams
- Optical
  - optical photon interactions
- Low-energy
  - Livermore library γ, $e^{\pm}$ from 10 eV up to 1 GeV
  - Livermore library based polarized processes
  - PENELOPE code rewrite , γ, $e^{\pm}$ from 100 eV up to 1 GeV (2008 version)
  - hadrons and ions up to 1 GeV
  - atomic de-excitation (fluorescence + Auger)
- Geant4-DNA
  - microdosimetry models for radiobiology (Geant4-DNA project) from 0.025 eV to 10 MeV
- Adjoint
  - Sub-library for reverse Monte Carlo simulation from the detector of interest back to source of radiation
- Utils
  - general EM interfaces
  - helper classes

Unification of EM physics interfaces

- Standard EM developments was concentrated on HEP and in a great part to LHC experiments
  - LHC experiments are successfully taking and analyzing data n
- For many years EM low-energy sub-package was developed separately
  - Focused on medical and space science requirements
- The were many recommendation extend Geant4 EM physics using the best features of both packages
  - Previously there were technical limitations to use in one run both standard and low-energy models
- Migration to common design for the low-energy package was done for Geant4 9.3 (December 2009)
  - It has been completed for Geant4 9.6

Geant4 9.6: EM Physics builders for HEP

- Used by Geant4 validation suites
  - Are robust due to intensive tests by Geant4 team
  - well known precision and limitations
- May be used in any application domain

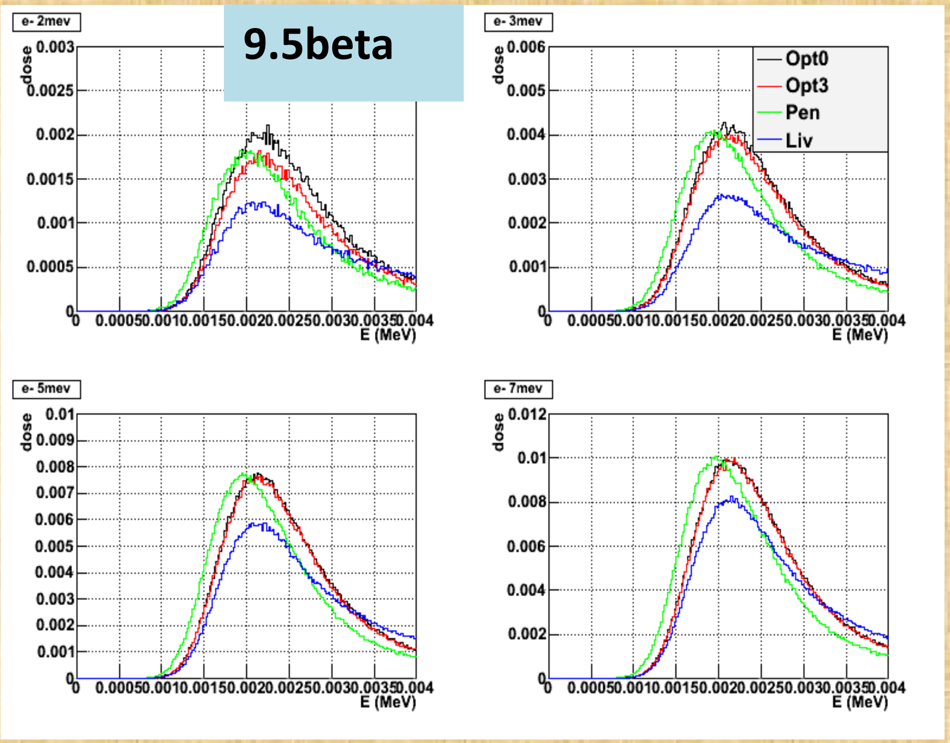
Constructor	Components	Comments
G4EmStandardPhysics	Default (QGSP_BERT, FTFP_BERT…)	ATLAS, and other HEP productions, other applications
G4EmStandardPhysics_option1	Fast due to simple step limitation, cuts used by photon processes (QGSP_BERT_EMV)	CMS production, good for crystals, not good for sampling calorimeters
G4EmStandardPhysics_option2	Experimental: WentzelVI model of multiple scattering (QBBC, …)	Used for testing of new models, LHCb production

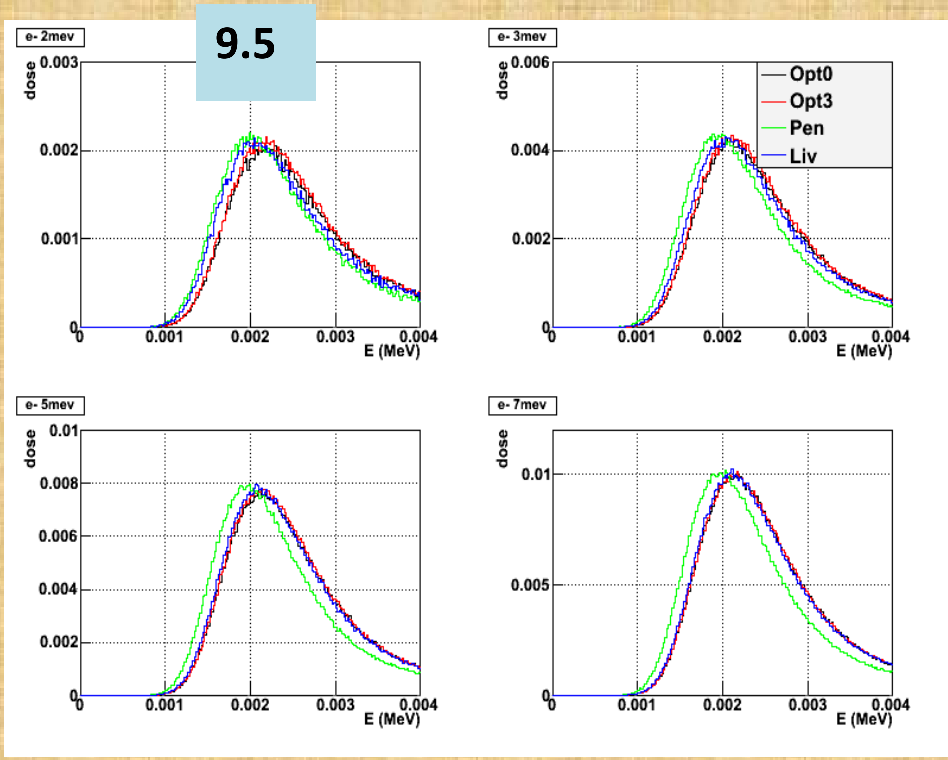
Geant4 9.6: extra EM Physics builders

- Focus more on accuracy than on maximum simulation speed
- Ion stopping model based on the ICRU’73 data
- Strong step limitation from ionisation and multiple scattering per particle type
- Recommended for hadron/ion therapy, space applications

Constructor	Components	Comments
G4EmStandardPhysics_option3	QGSP_BIC_EMY, Shielding	Proton/ion therapy
G4EmStandardPhysics_option4	The best combination of standard, Livermore, and Penelope models	New EM builders
G4EmLivermorePhysics	Livermore models for γ, e^- below 1 GeV, Standard models above 1 GeV	Livermore low-energy electron and gamma transport
G4EmPenelopePhysics	Penelope models for γ, $e^\pm$ below 1 GeV, Standard models above 1 GeV	Penelope low-energy $e^\pm$ and gamma transport

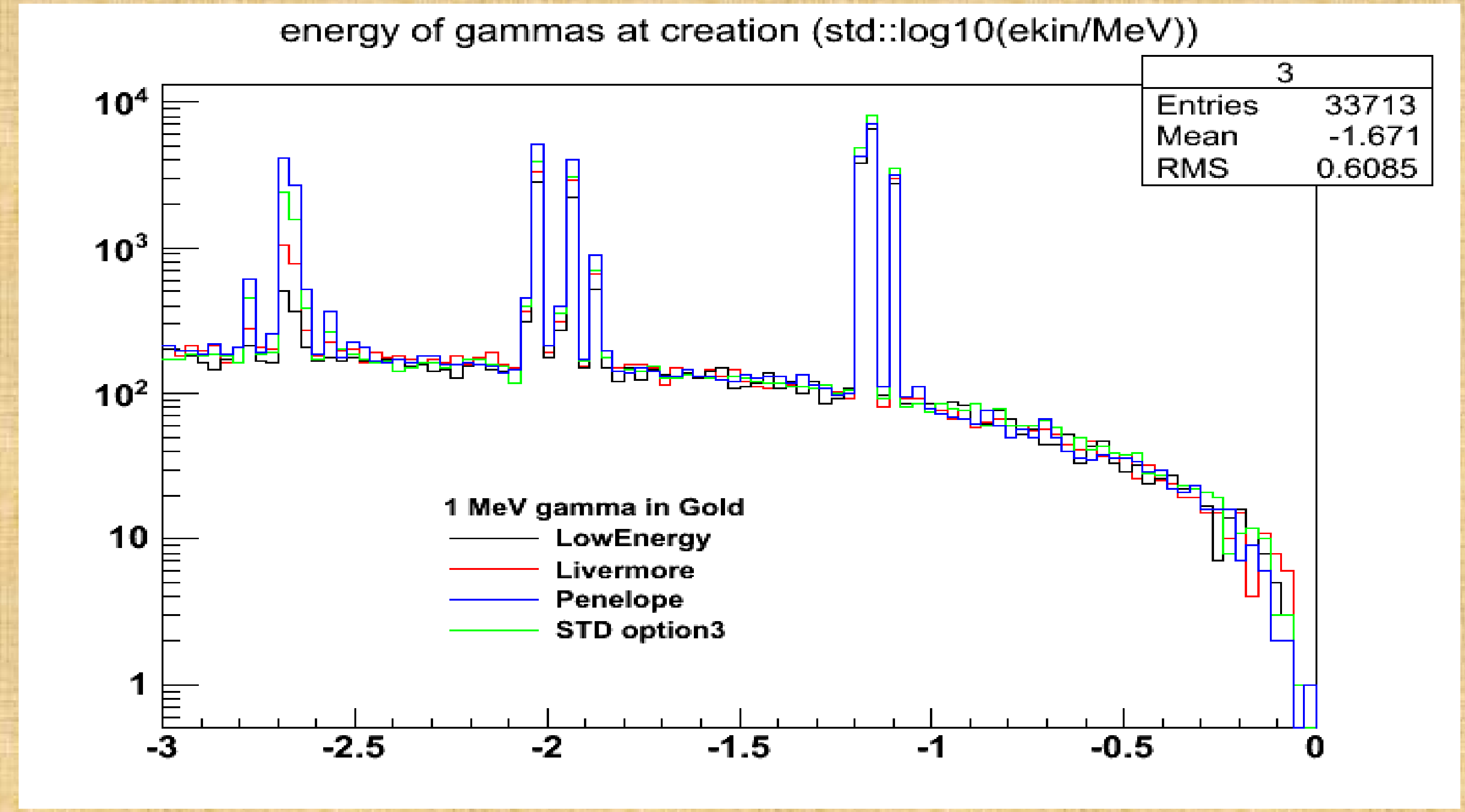
ELSHIELD 1-D Benchmark: Comparison of Geant4 EM physics lists





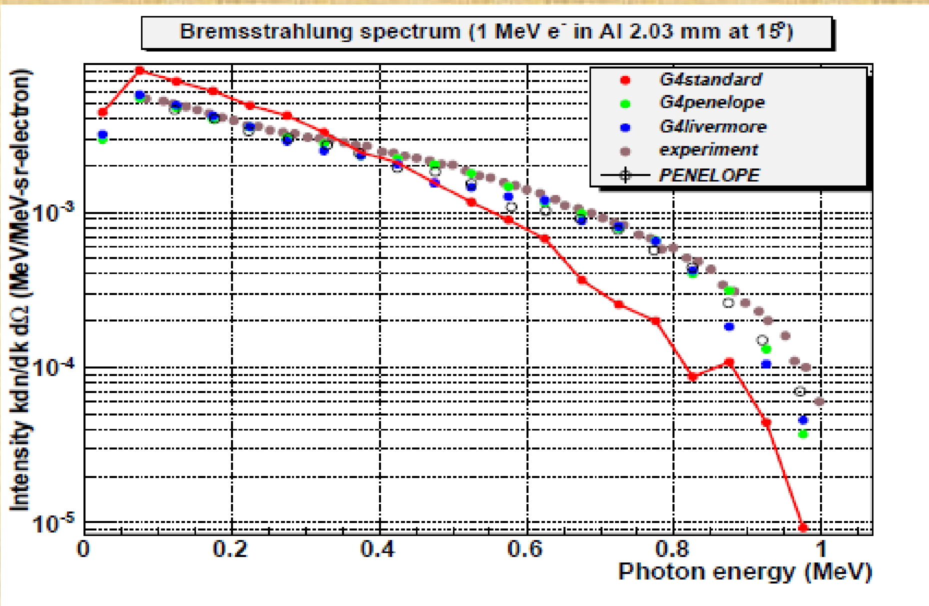
- Dose deposition in 10 um Si layer by 2, 3, 5, 7 MeV electron beams and 2 mm Al shielding
- Penelope predicts a bit lower peak position – difference in model of fluctuations
- In general all Physics Lists of 9.5 predicts the same dose

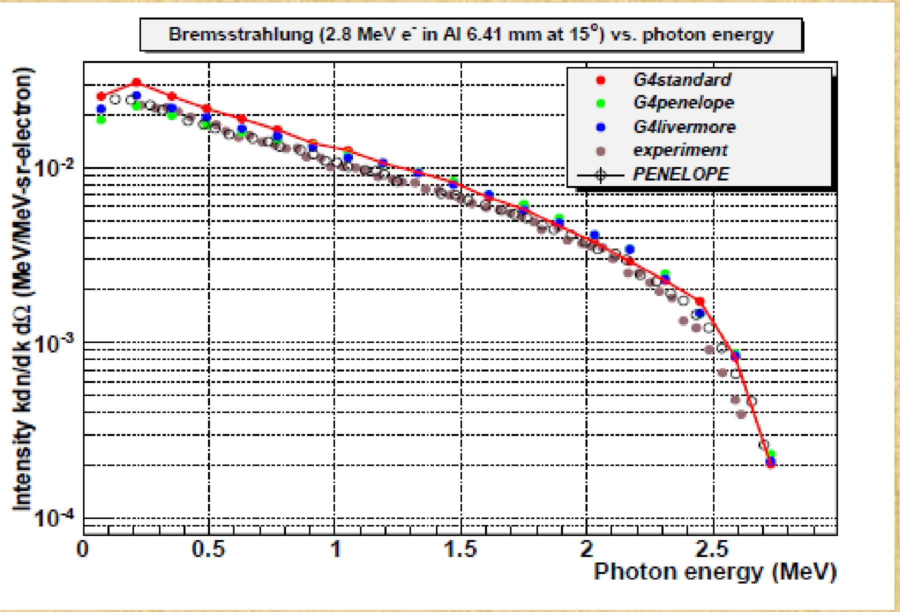
Geant4 9.6: unified deexitation module



- As a result of ELSHIELD project in all EM Physics Lists de-excitation module can be enabled to sample K- L- M- shell gamma emission and Auger electrons
- Old low-energy model was less accurate

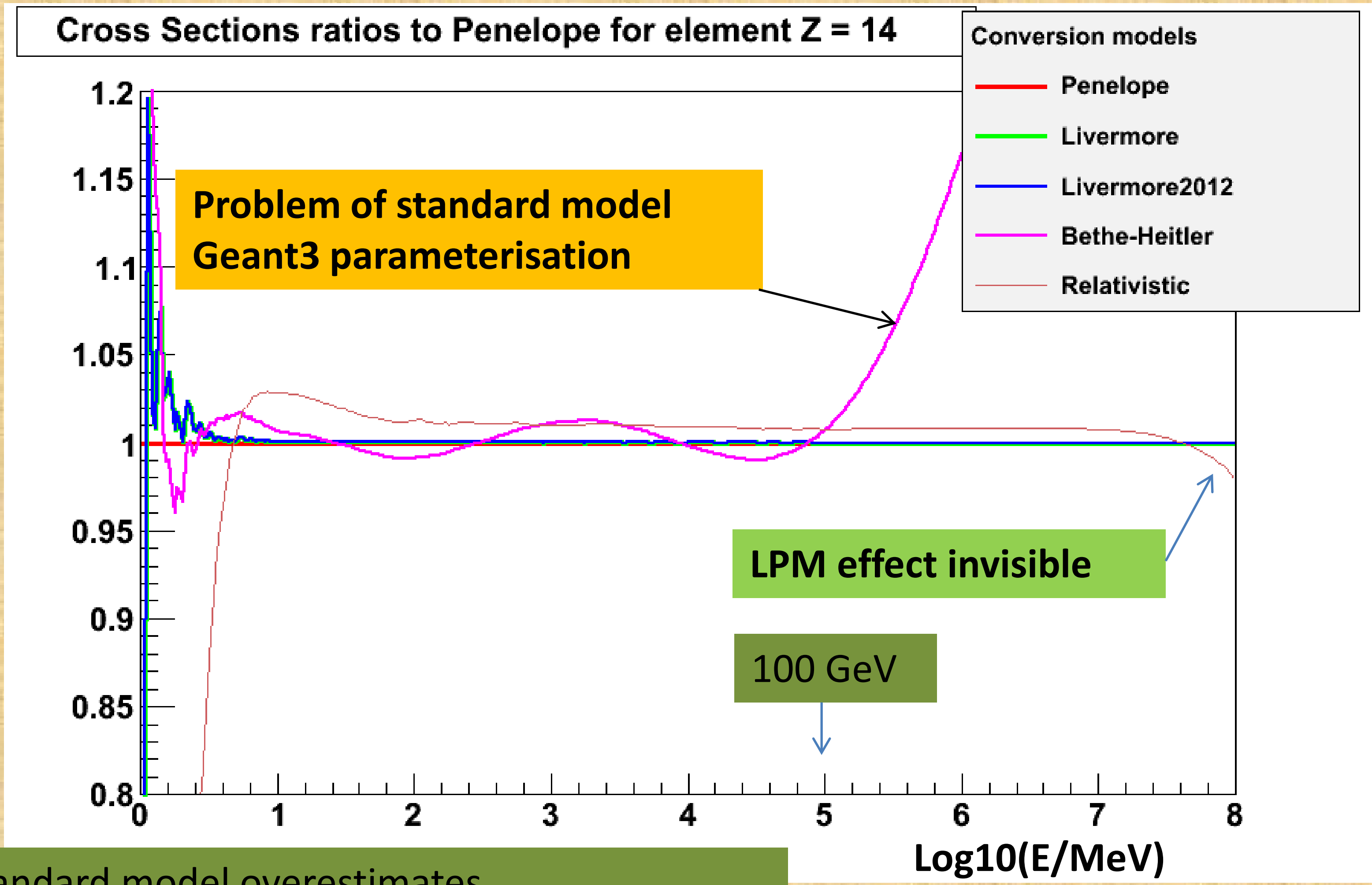
Bremsstrahlung energy spectrum





- Standard bremsstrahlung model had limitations in accuracy of energy spectra for 1 and 2.8 MeV benchmark data
- Original FORTRAN Penelope and Geant4 Penelope models were in better agreement with the data

Gamma conversion cross section ratio for Silicon between different Geant4 models



Standard model overestimates probability of gamma conversion in tracker

Simulation of light antinucleus-nucleus interactions

A.Galoyan and V. Uzhinsky, 22/06/2012

Anti-Matter at Accelerators

Anti-Proton 1955, Emilio Segre and Owen Chamberlain (Nobel Prize in Physics)-

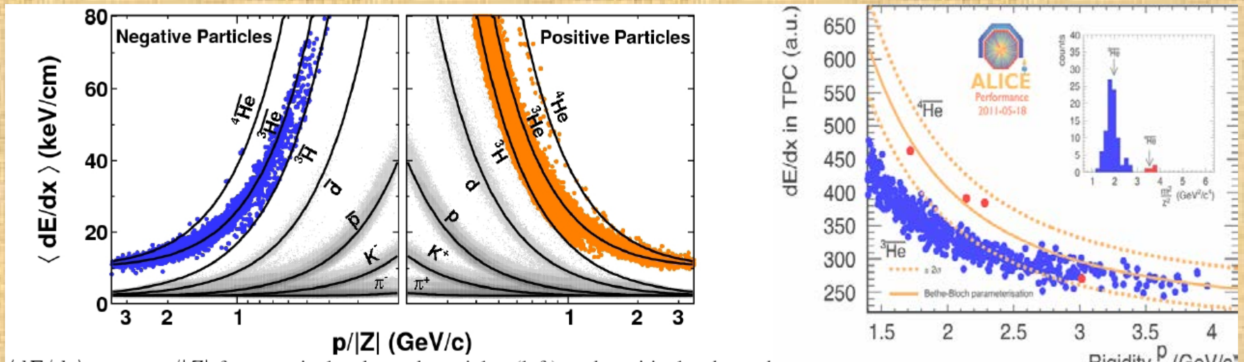
Anti-Neutron, 1956, Bruce Cork and colleagues (BNL)

Anti-Deuterium, 1965, Antonino Zichichi et al. (CERN), D.E. Dorfan et al. (BNL)

Anti-Helium-3, 1974, Y.M. Antipov et al. (IHEP)

Anti-Helium-4, March 2011, Star Collab, H. Agakishiev et al. (RHIC)
Observation of the antimatter helium-4 nucleus, arXiv:1103.3312, Au+Au, 200

18 Anti-He-4



$\langle dE/dx \rangle$ versus $p/|Z|$ for negatively charged particles (left) and positively charged

ALICE Collab.
LHC
5 Anti-He-4

ALICE Experiment at CERN

Anti-nucleus nucleus interaction cross sections, elastic scattering and multi-particle production

- Apply of **the Glauber theory** for the cross section calculations
- Apply **the Glauber amplitudes** and **black disk** model with diffuse boundary for a simulation of the elastic scattering
- Apply **the Quark-Gluon String Model** for a simulation of the multi-particle production processes

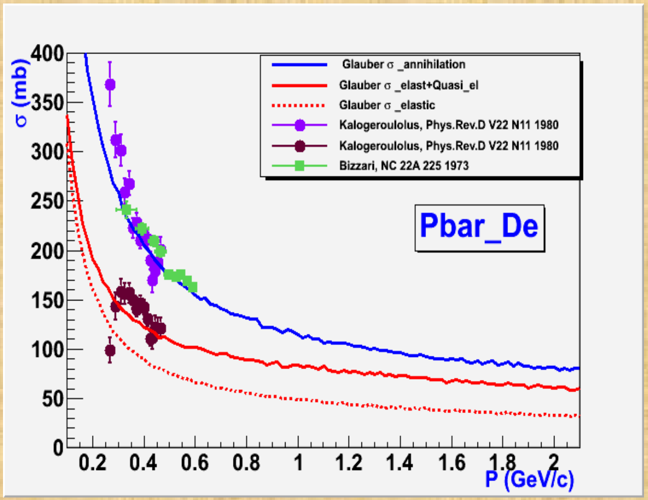
- Our parametrization of **Pbar-P** **total and elastic** cross sections
- Our parametrization of **antinucleus-nucleus** **total and elastic** cross sections
- Results of simulation of inelastic **Pbar-P, Pbar-A** interactions
- Our parameterization of **Anti-P P Elastic Scattering, Imaginary and Real** parts of the Elastic Scattering Amplitude
- Description of recent **Totem** data on elastic **pp-interactions at 7 TeV !**

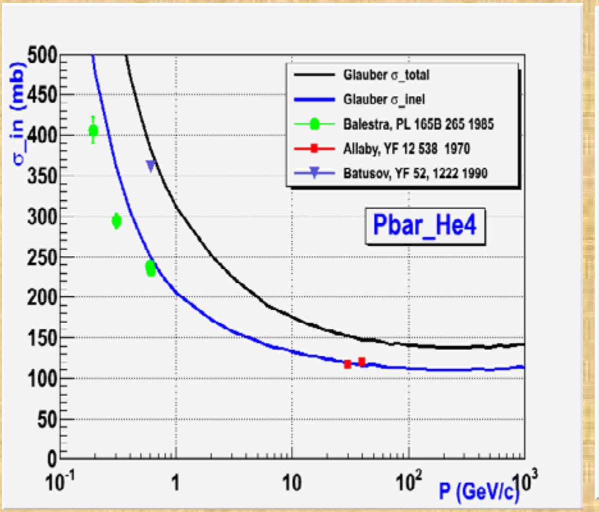
We use well known Glauber theory

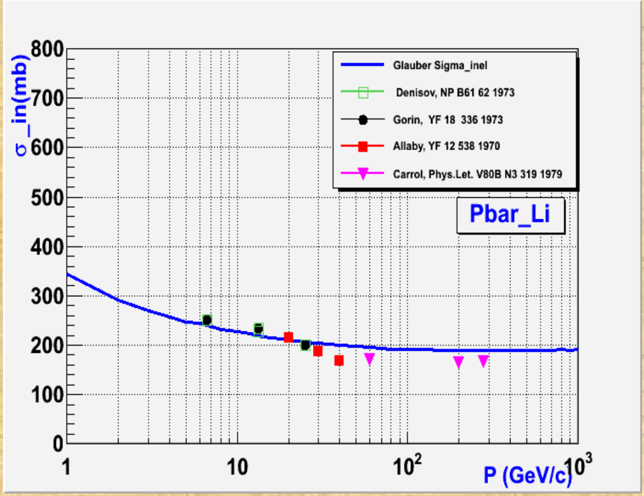
V. Franco, R.J. Glauber// Phys. Rev. **142** (1966) 142.

O.D. Dalkarov, V.A. Karmanov// Nucl. Phys. **A445** (1985) 579.

Pbar – nucleus and light anti-nucleus – nucleus cross sections. V. Uzhinsky et al., Phys. Lett B705 (2011) 235

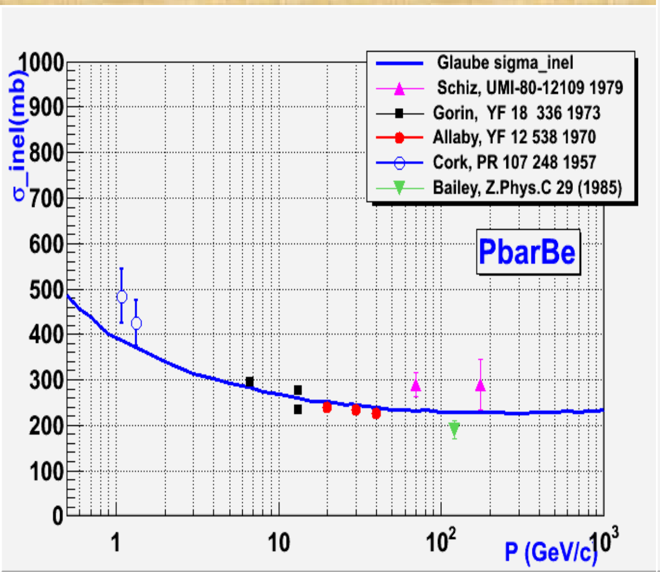


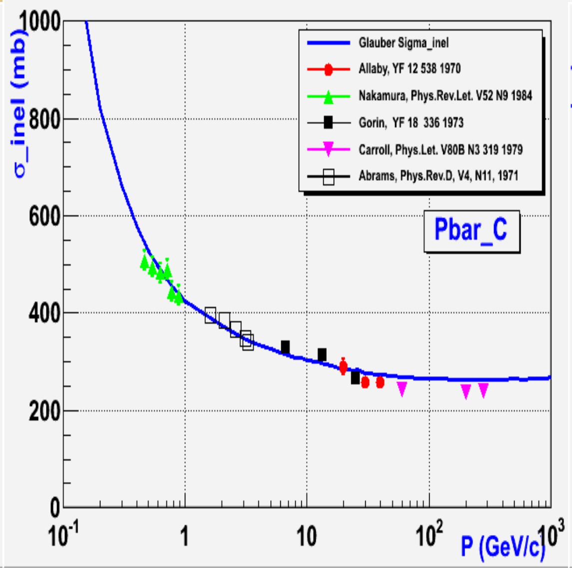


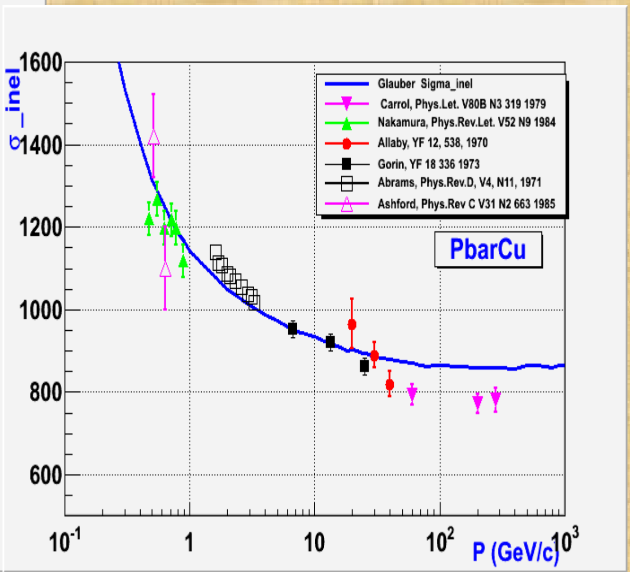


The Glauber approach works well!

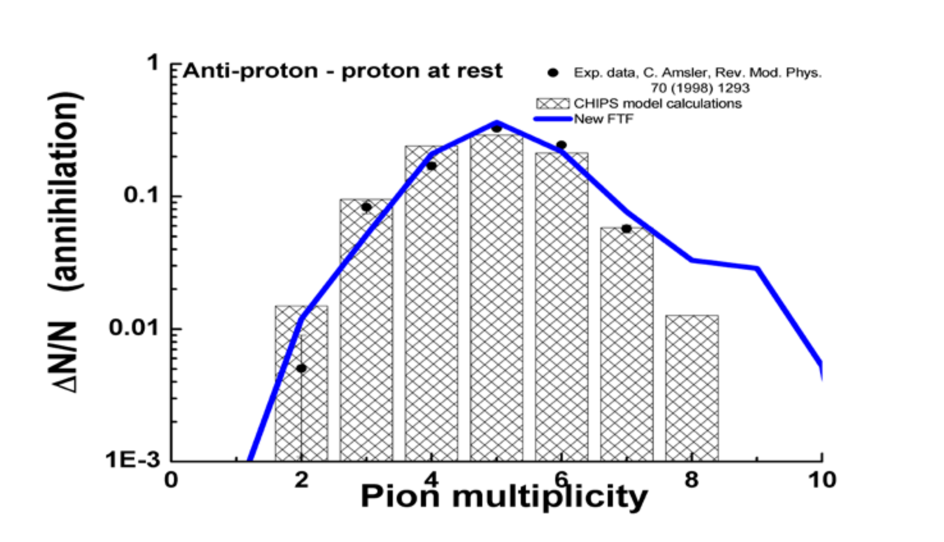
FTFP_BERT

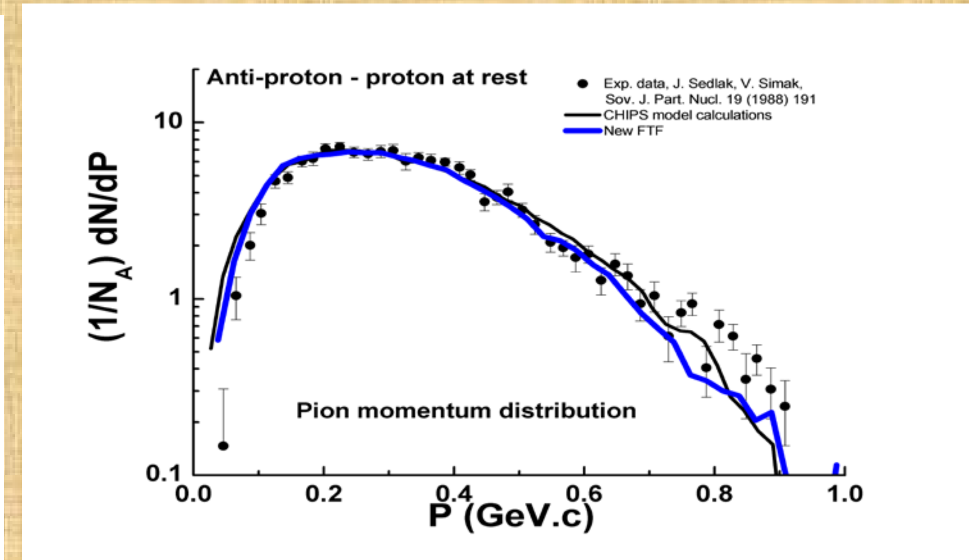


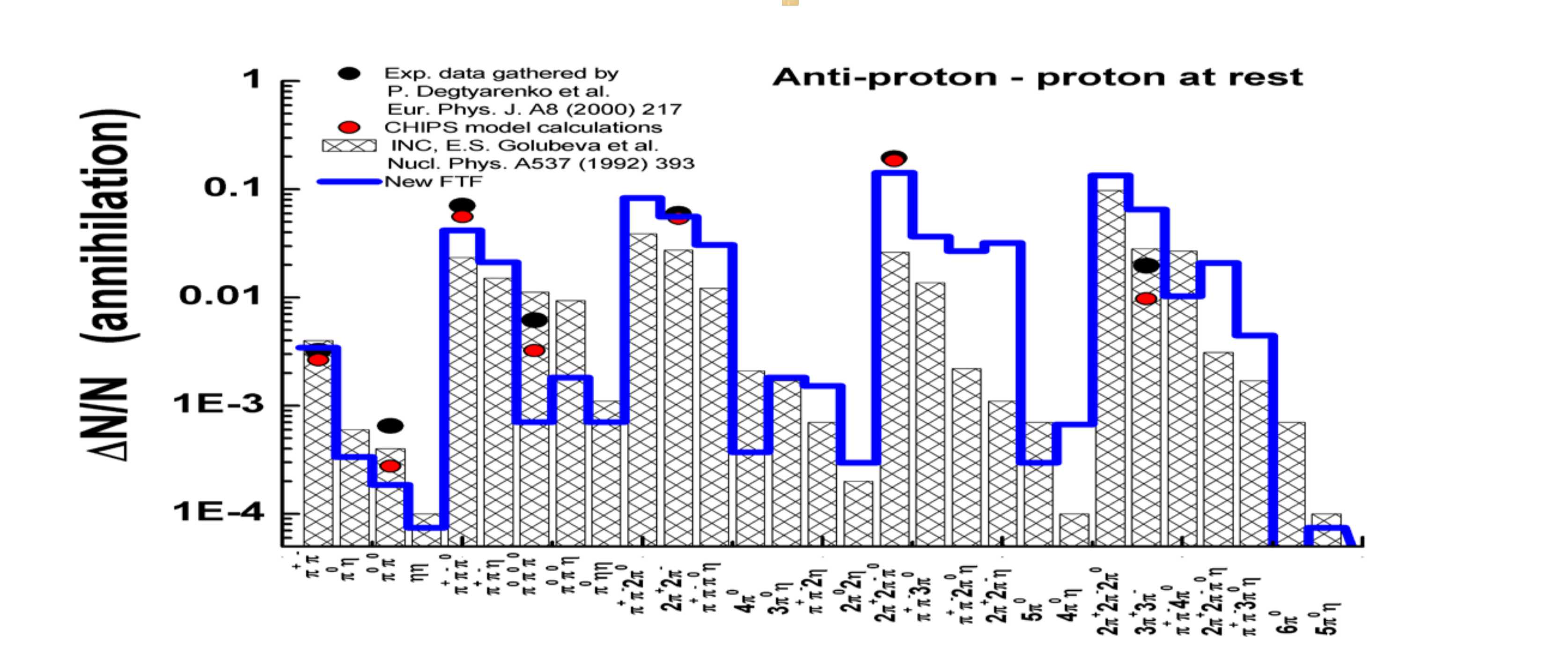




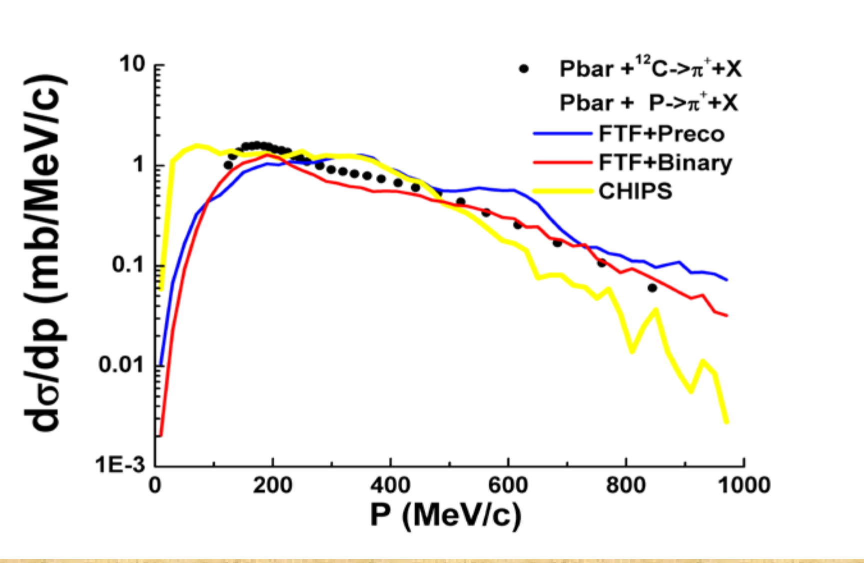
Annihilation at rest

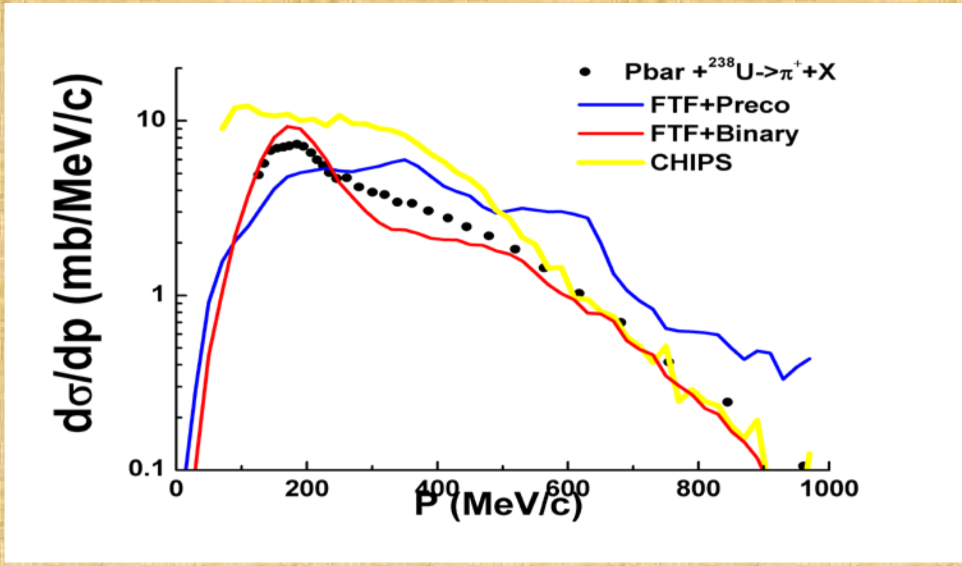




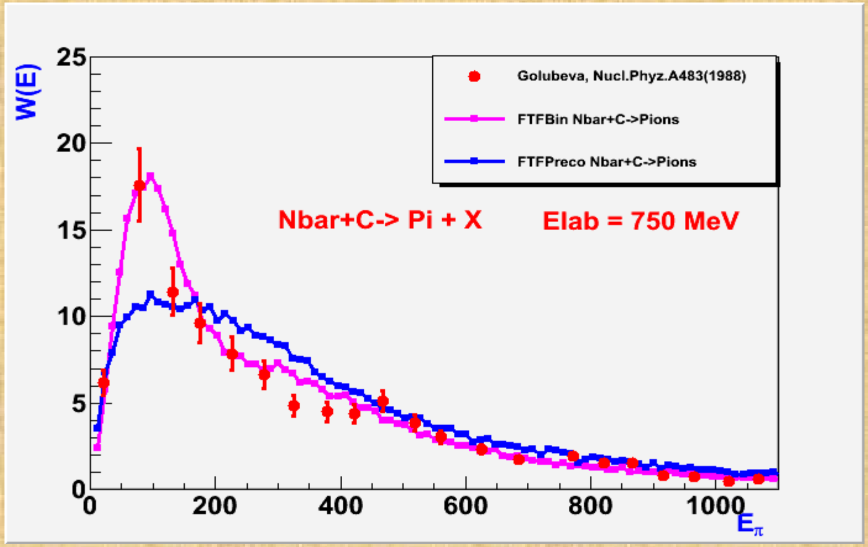


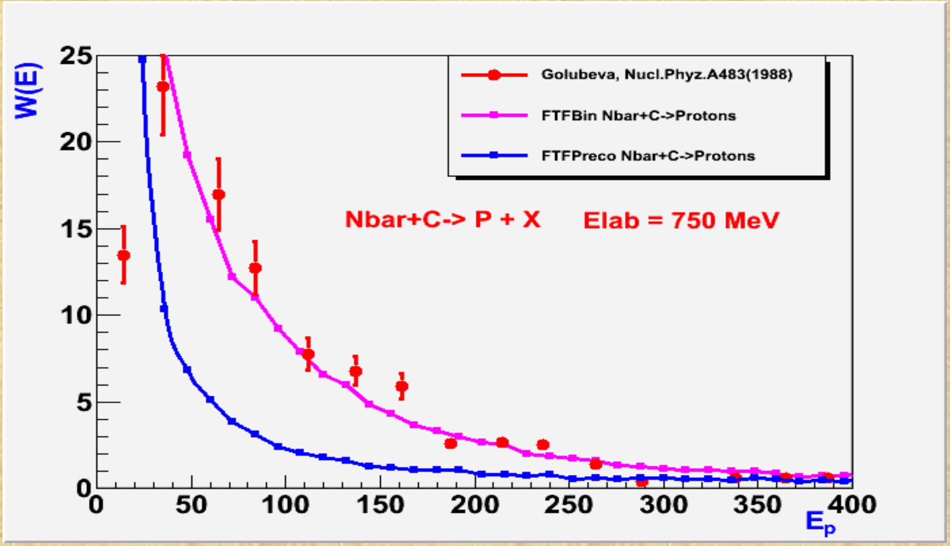
Simulation of pbar-A at Plab= 608 MeV/c





Annihilation of antineutrons at Plab=1.4 GeV/c





Production of anti-protons

- Geant4 models providing anti-protons in final state: QGS and FTF
- Spectra and yield of anti-protons may be tested at LHC

Summary

- In new Geant4 version 9.6 gamma, positron, and anti-proton interactions are improved
- For all EM builders cross sections and final states are similar within few %
- Anti-proton and anti-light ion cross sections and final states have been improved significantly

Differential Cross sections of Elastic Pbar Nucleus interactions