Geant 4

1) The Geant4 Toolkit
2) Functionality and "Plug-in"-ability
3) Geometry
4) Physics Processes
   a) Neutron scattering – elastic
   b) Neutron HP extension to Geant4
   c) Electromagnetic Physics
   d) Adding your own physics models
5) Summary and Conclusions

Alexander Howard, CERN

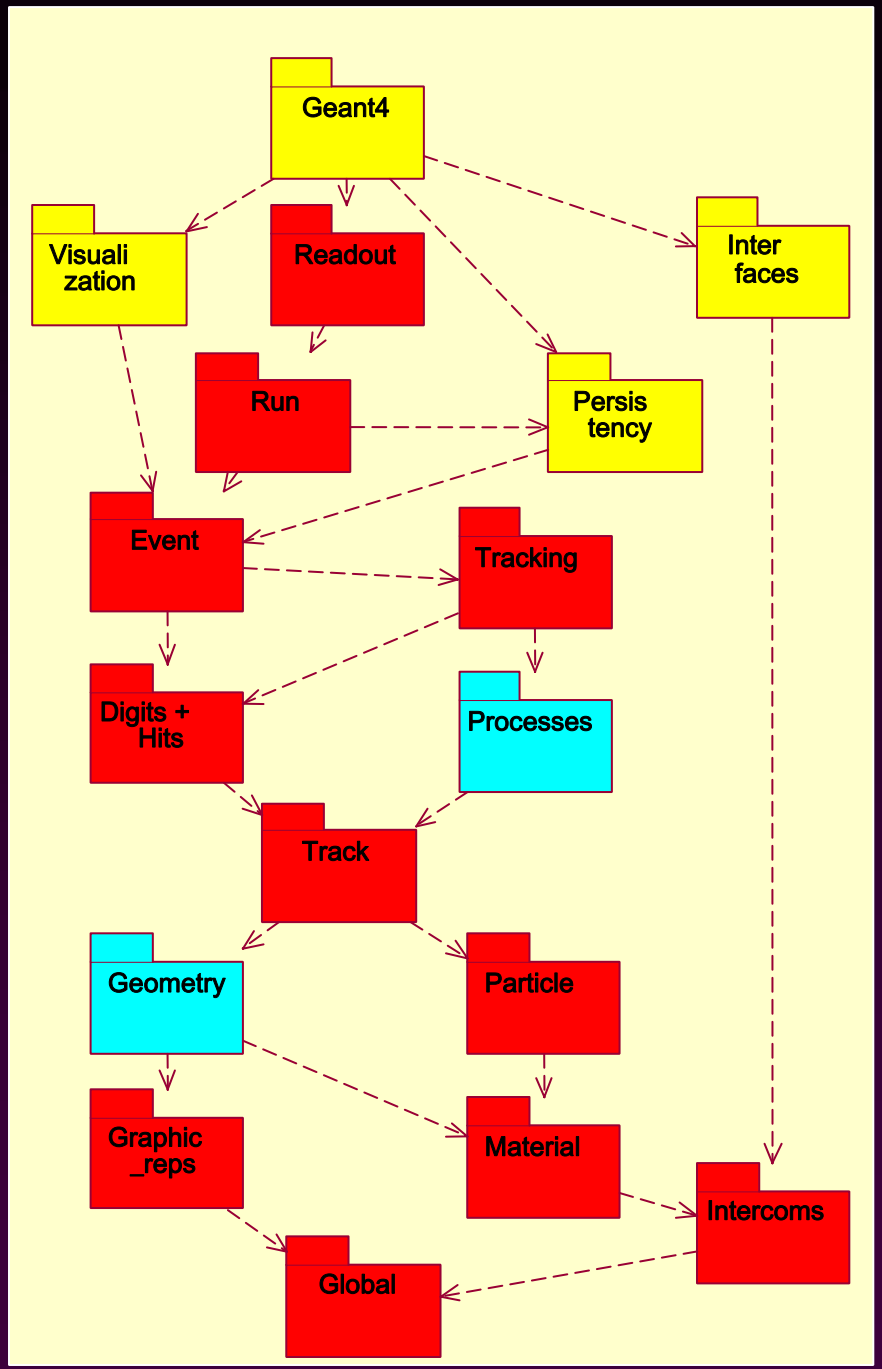
on behalf of the Geant4 Collaboration

The Geant4 Toolkit

- Geant4 is a software toolkit for the simulation of the passage of particles through matter
  - Has been developed over the last 12 years by over 100 developers (both computer scientists and physicists)
  - Adopts object-oriented technology
- Used by a large number of experiments, in a variety of application domains, including: high energy physics, astrophysics and space science, medical physics and radiation protection
- It provides comprehensive detector and physics modelling capabilities embedded in a flexible structure
- Its kernel encompasses tracking (including fields); geometry; material specification; physics processes; digits + hits; flexible graphics and UI; biasing and variance reduction; scoring and user defined possibilities

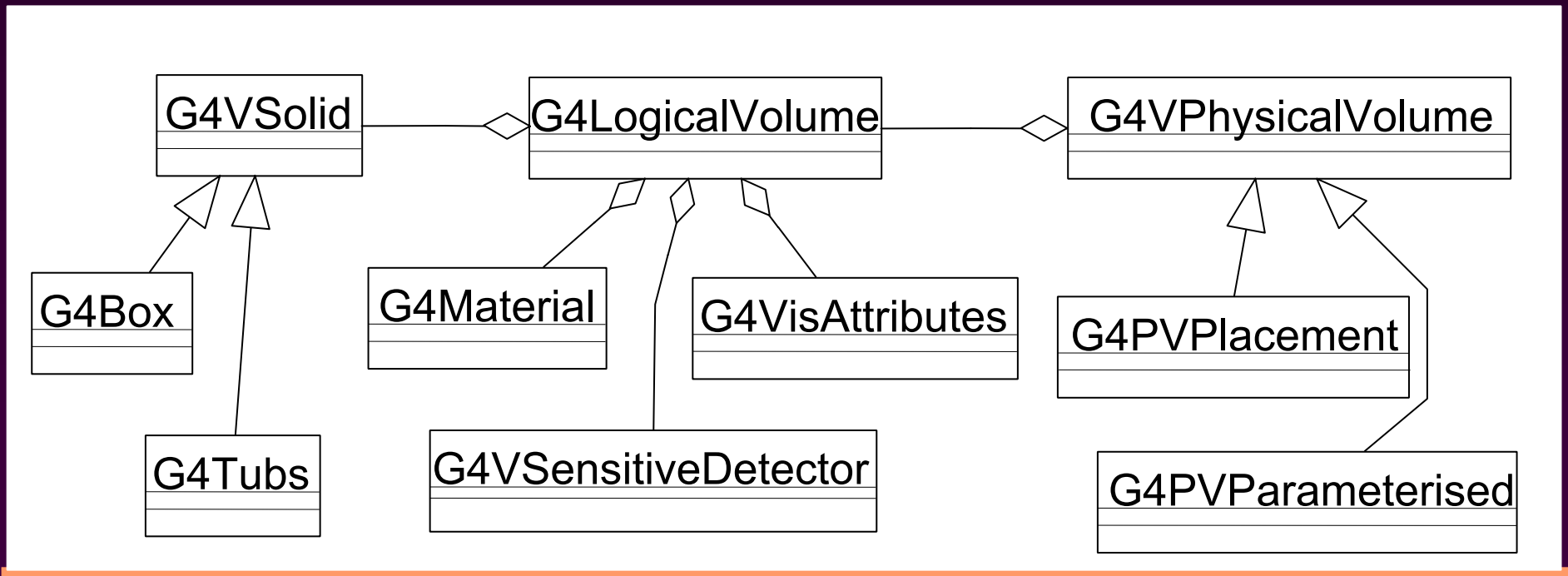
Geant4 Structure

- Geant4 consists of 17 categories
  - Largest categories are physics and geometry
  - Tracking provides engine used for all particles and physics choices
  - Toolkit with component design
  - Interfaces between categories are stable long-term
    → plug-in ability

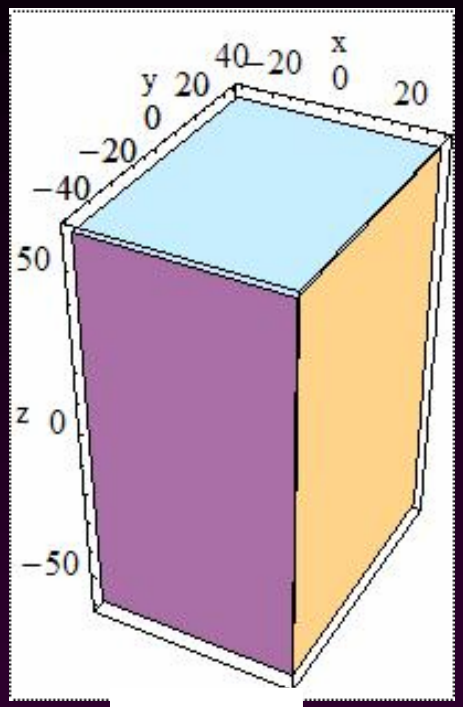


Detector Description

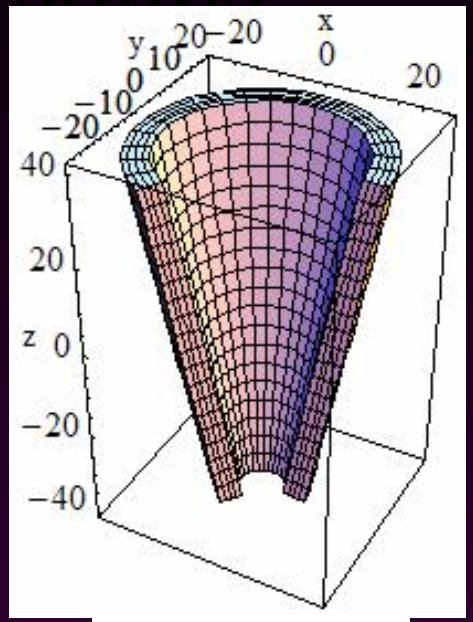
- Within Geant4 there is a defined geometrical hierarchy
  1. Solid – shape of object
  2. Logical Volume – material properties, sensitivity, daughters
  3. Physical Volume – placement, position, rotation
- There a number of pre-defined shapes (constructed solid geometry), boundary representations and also boolean operations (union, subtraction, intersection)



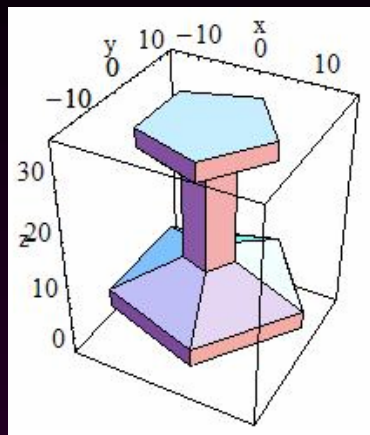
solids



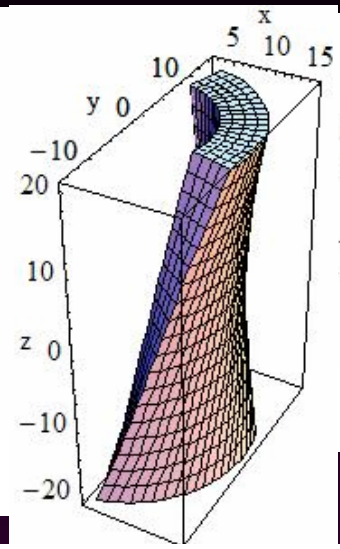
G4Box



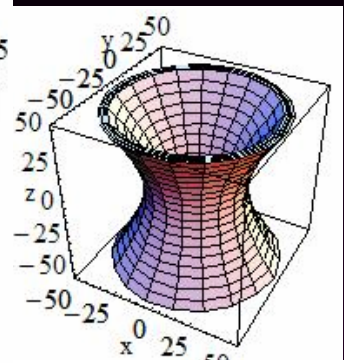
G4Cons



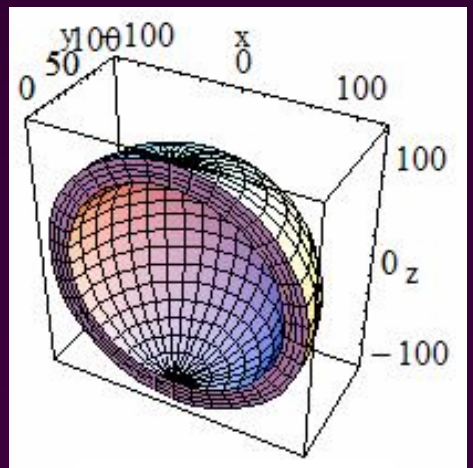
G4Polyhedra



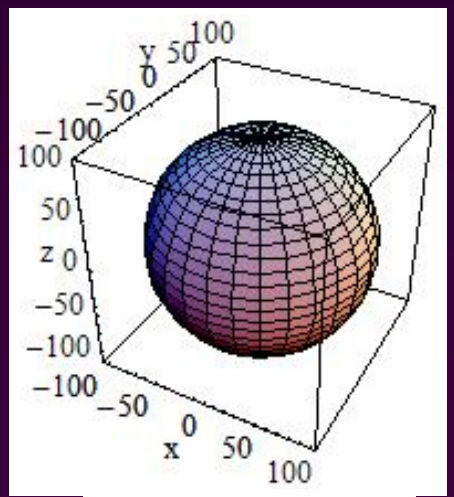
G4TwistedTubs



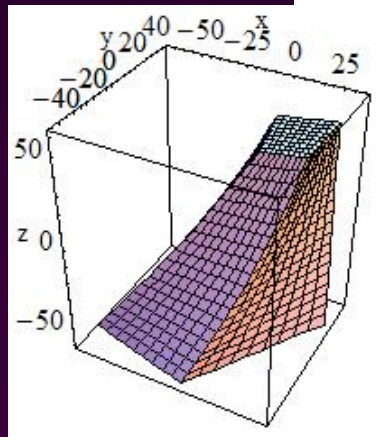
G4Hype



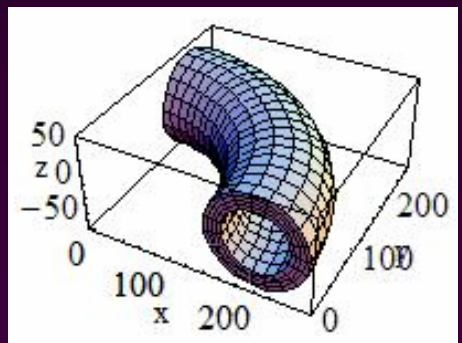
G4Sphere



G4Orb

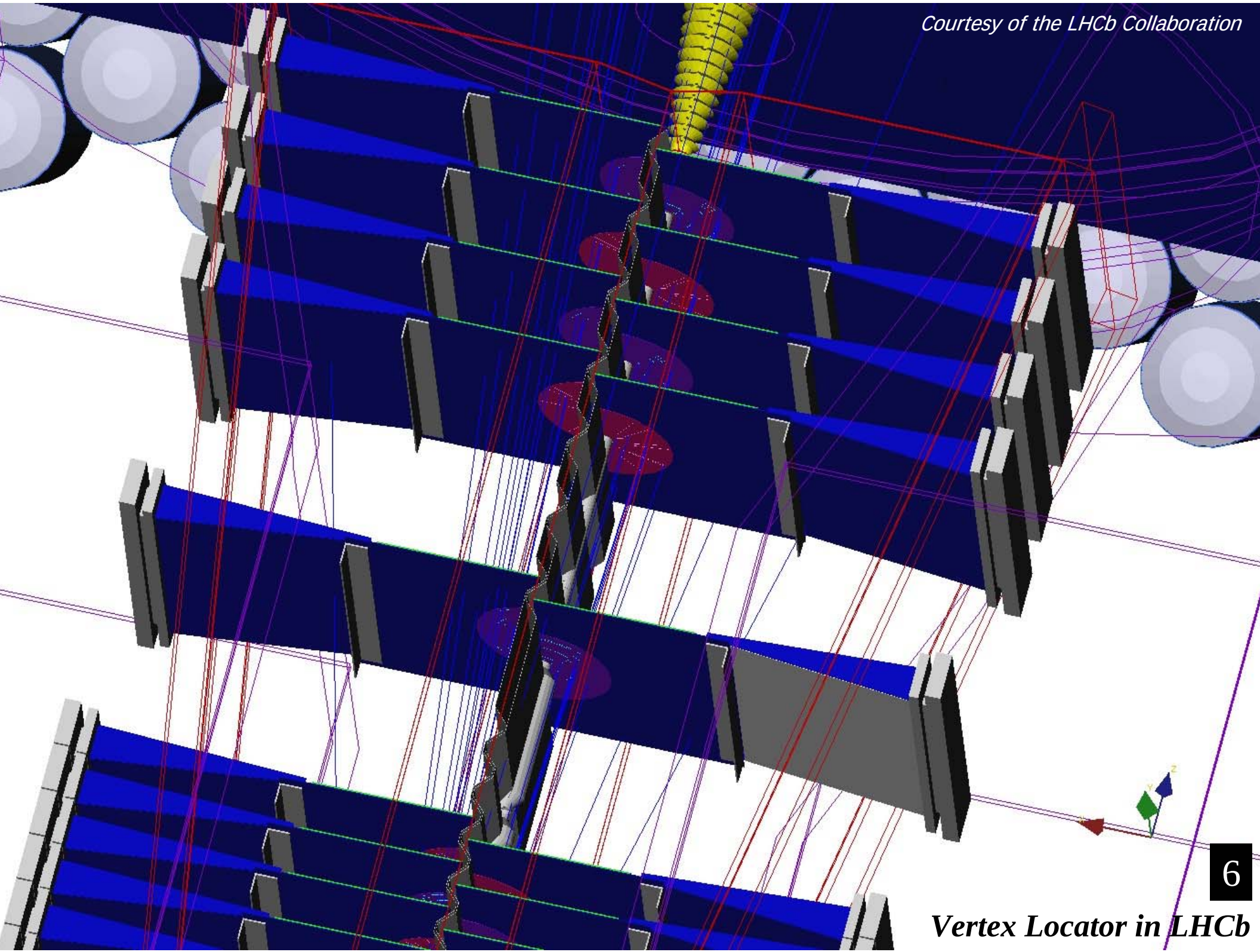


G4TwistedTrap

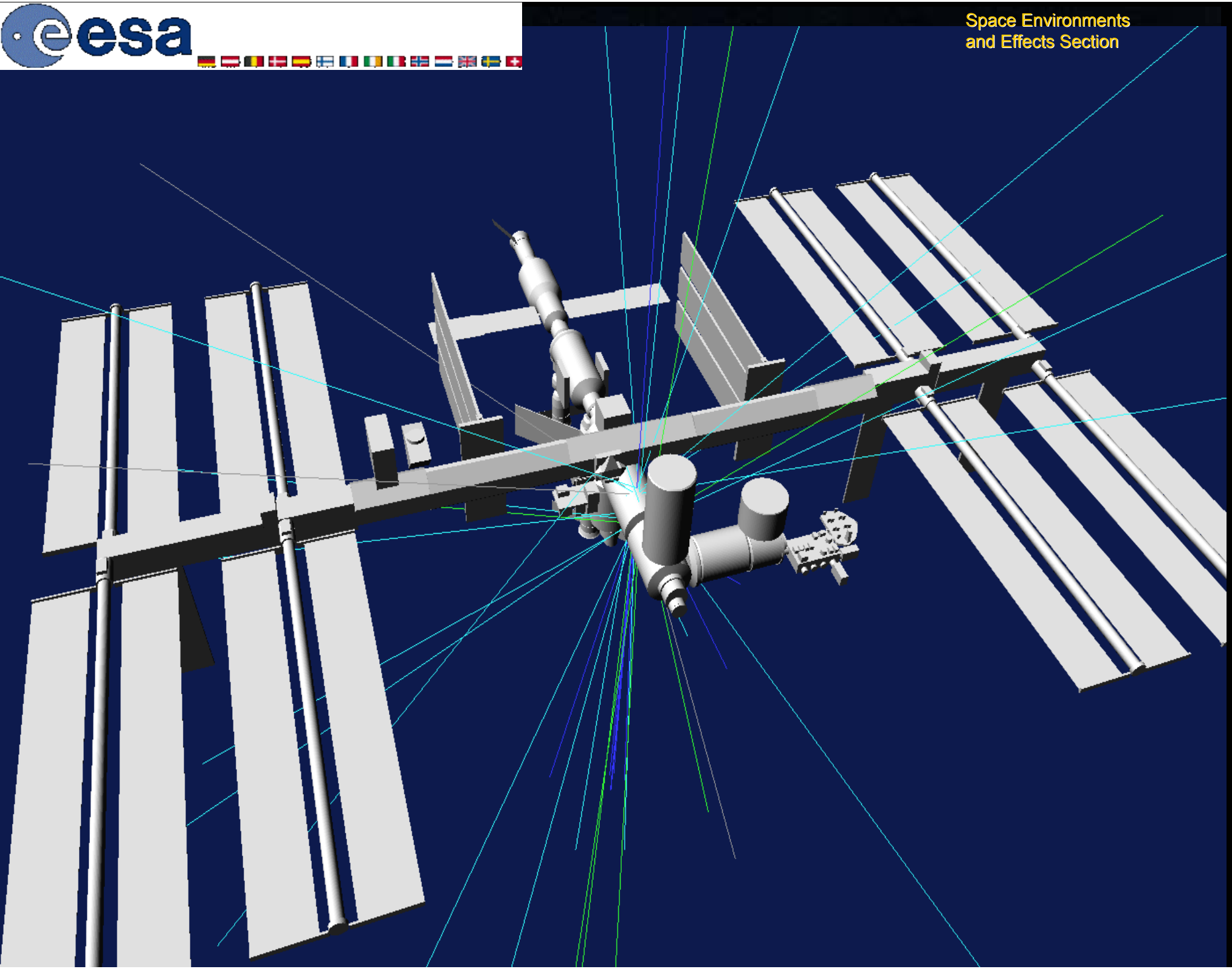


G4Torus

Consult Section 4.1.2 of Geant4 Application Developers Guide for full description of available shapes.



Vertex Locator in LHCb



Courtesy T. Ersmark, KTH Stockholm

Geant4 Physics

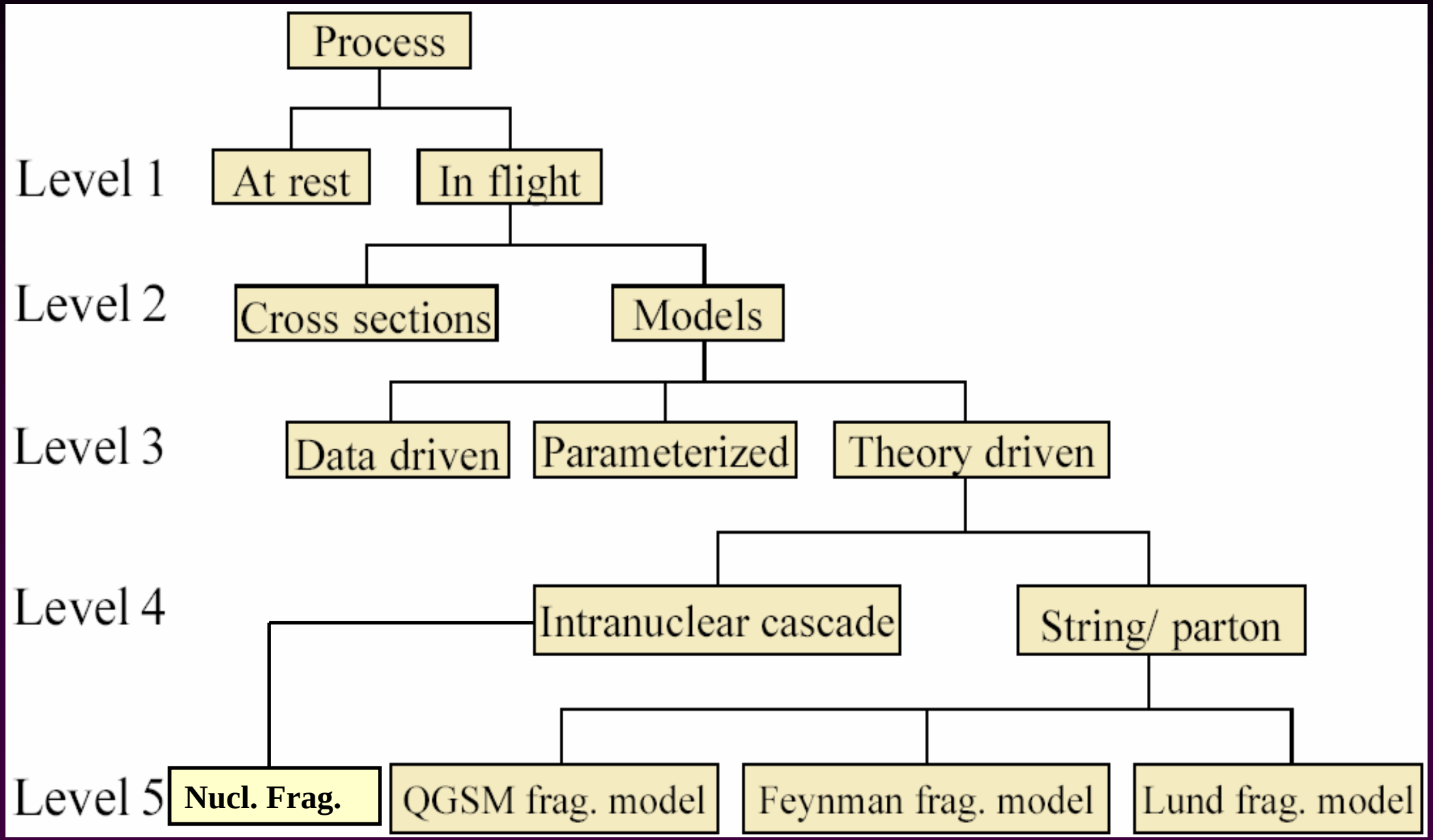
- Physics processes are grouped into 3 main categories:
  - Electromagnetic (EM) including optical ray-tracing
  - Hadronic
  - Decay

- Particle interaction is simulated using an abstract interface → *process*
- A whole range of physics modelling is included in Geant4
- The toolkit nature means that user defined physics processes can be included and easily interfaced to Geant4

Running Geant4 - configurability

- Geant4 includes transportation in fields/potentials
- Parameterisation / fast- simulation
- Event Biasing/Variance Reduction
  - At the process level (forced cross-section/final state) e.g. RDM
  - Russian roulette
  - Weight window
  - Geometrical importance sampling
- Different configuration of physics processes can be applied to the same experimental setup
  - Trade precision vs performance
  - Different strengths and weaknesses in physics models

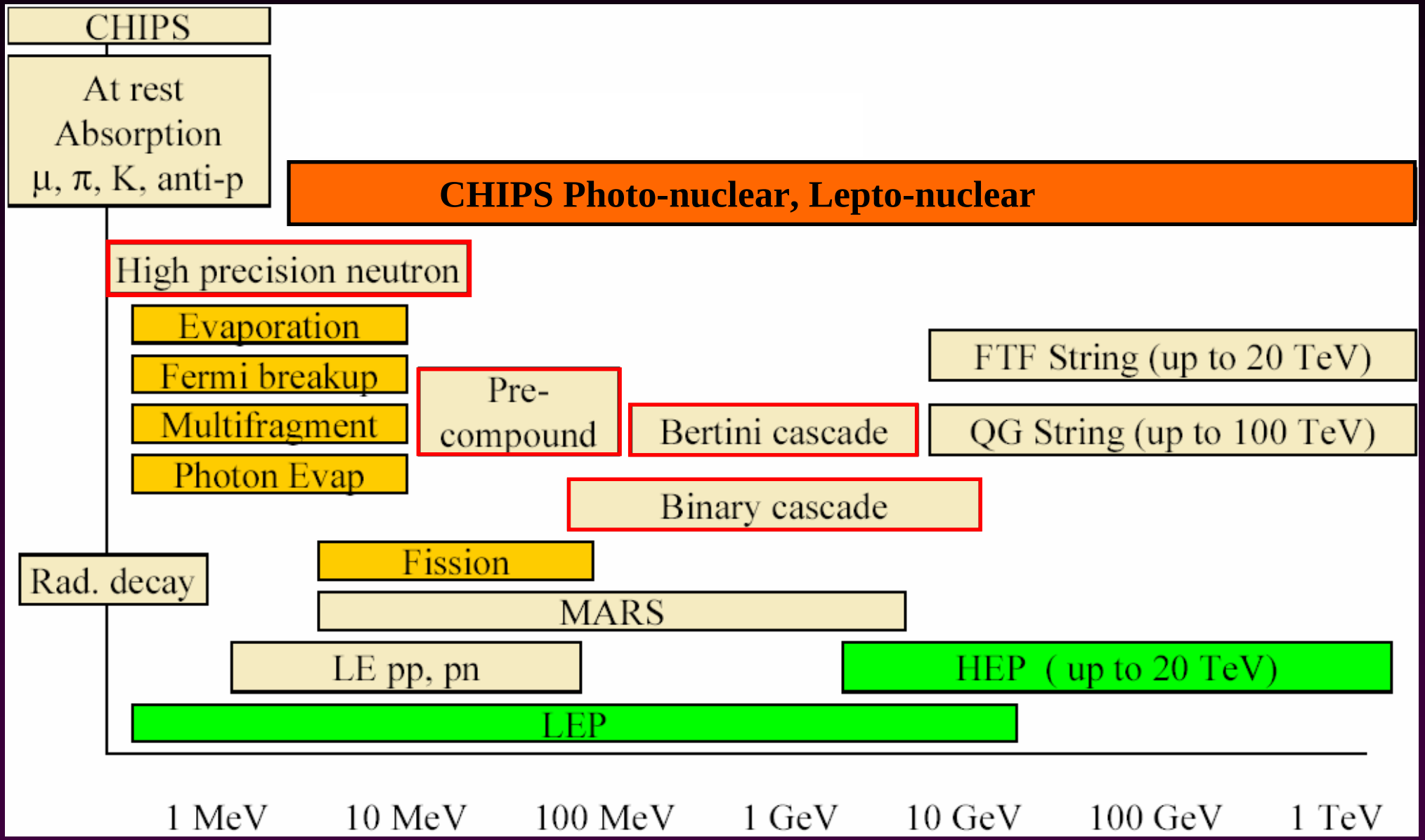
Models in hadronic framework



Hadronic Physics Models

- There are 3 types of models in Geant4 hadronic physics:
  - Data driven (cross-sections, angular distribution, multiplicity)
    - Coherent elastic scattering
    - Radioactive decay
    - High precision neutrons (E < 20MeV)
  - Parameterisation (semi-empirical/data and theory formulae)
    - Fission
    - Capture
    - LEP, GHEISHA based HEP models
  - Theoretical (true hadronic models)
    - Phenomenological (Quark Gluon Strings, CHIPS)
    - Intra-nuclear cascades, de-excitation and break-up
    - Final states determined by sampling theoretical distributions

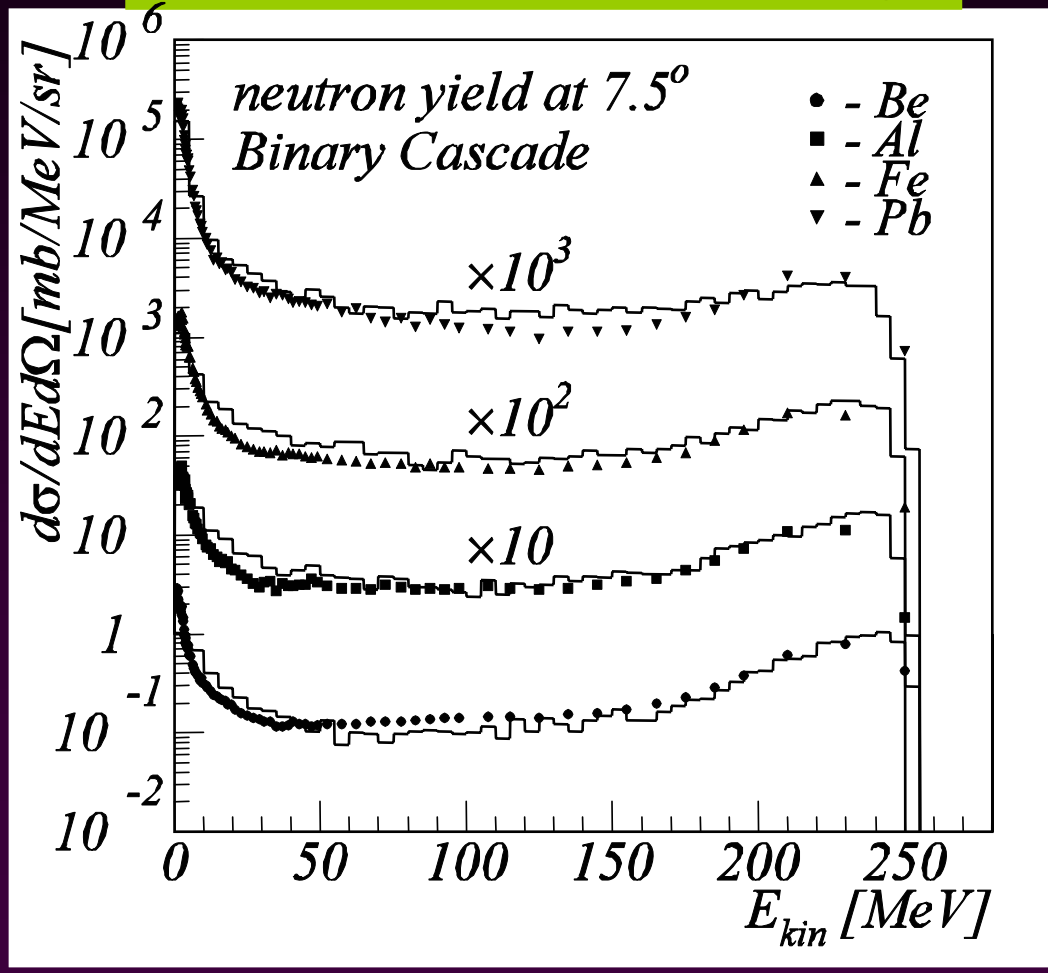
Hadronic model inventory



Hadronic Processes

- At Rest:
  - Capture of μ^-, π^-, K^-, anti-p, Σ^-, anti-Σ^+ …
  - radioactive decay
- Elastic:
  - π, K, p, n, hyperons
- Inelastic:
  - different models for π, K, p, n, hyperons
  - photo-nuclear, lepton-nuclear neutrino-nuclear
  - Ions
  - Capture in flight (n,γ), π^-
  - neutron-induced fission

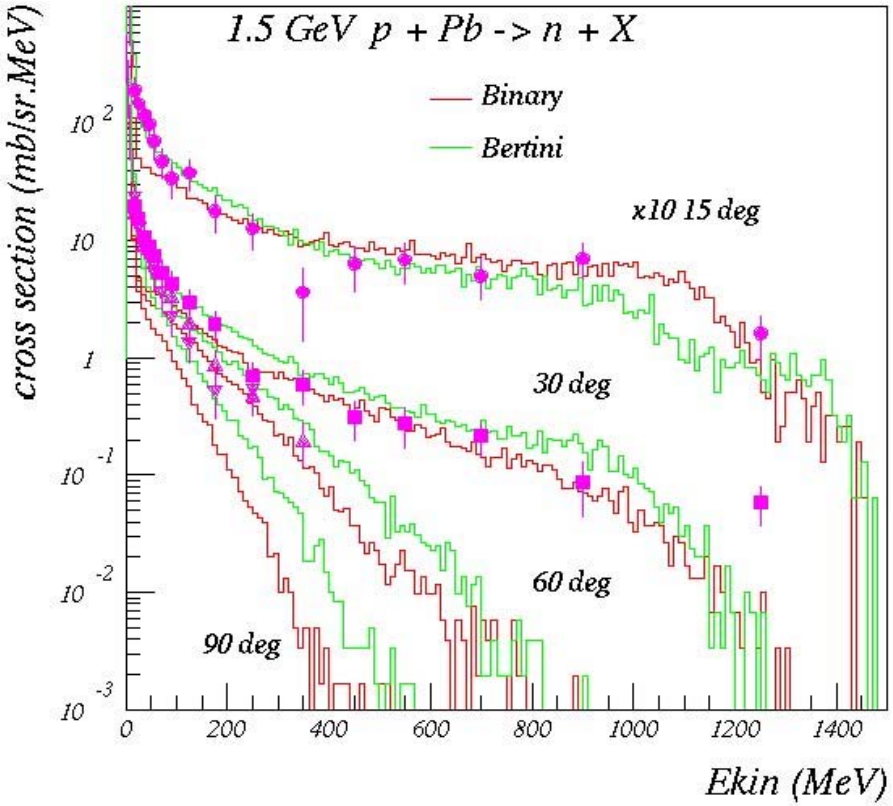
Protons of 256 MeV on thin target

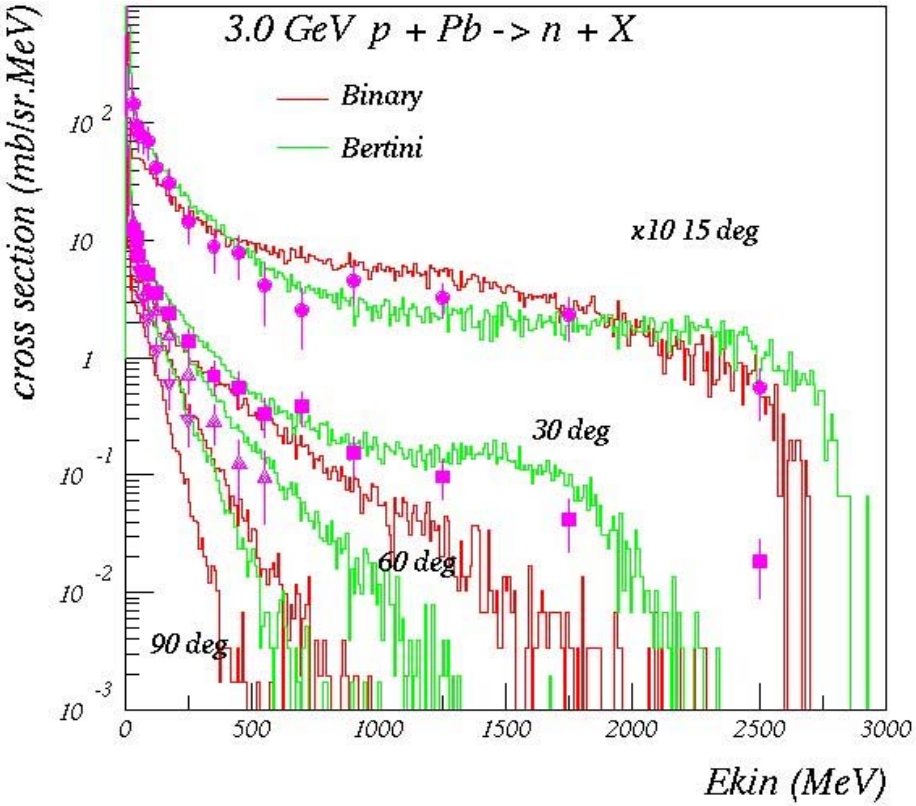


Neutron spectra by 1.5 and 3 GeV protons

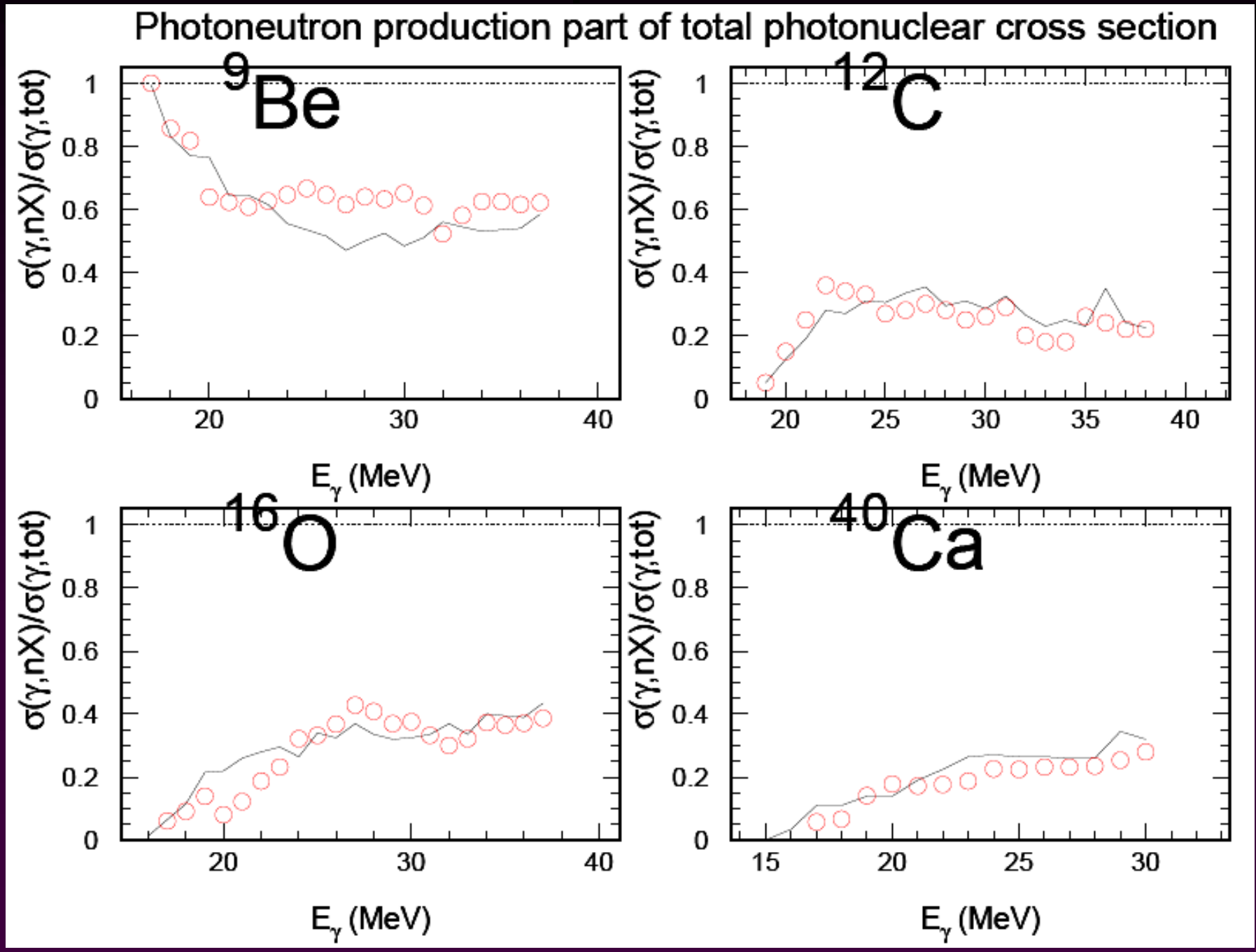
Preliminary

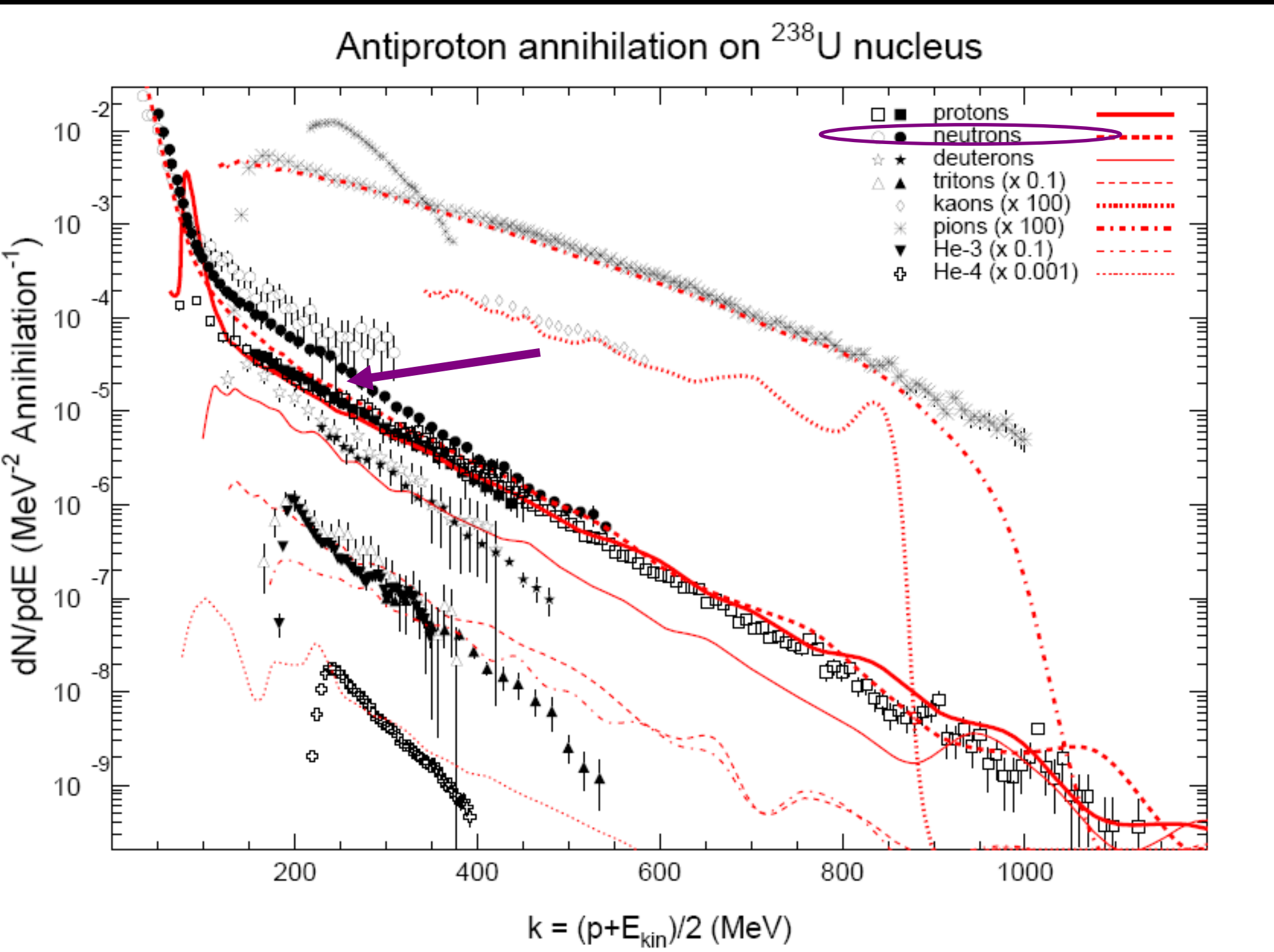
K. Ishibashi et al., J,NST,34,(6),529,199706

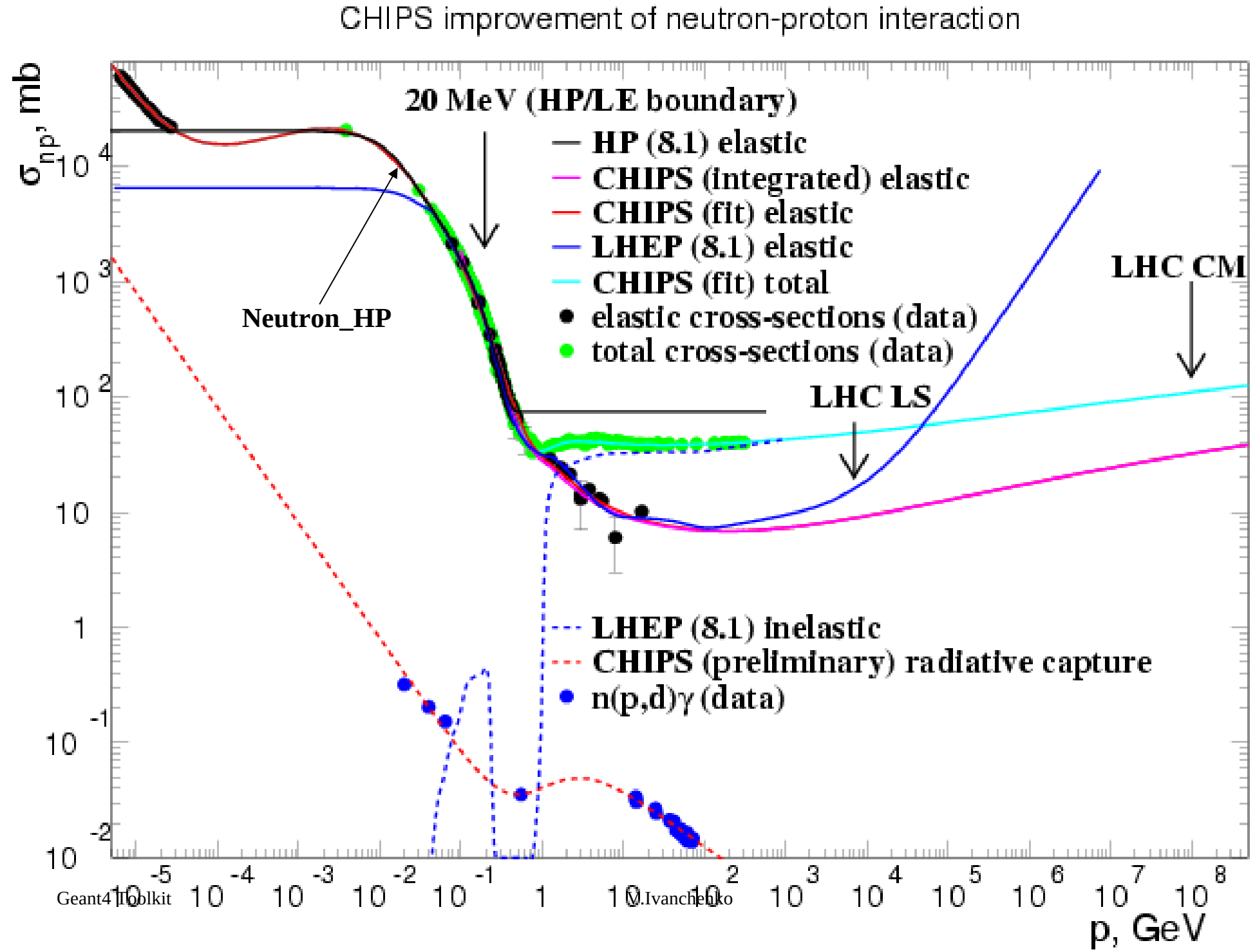


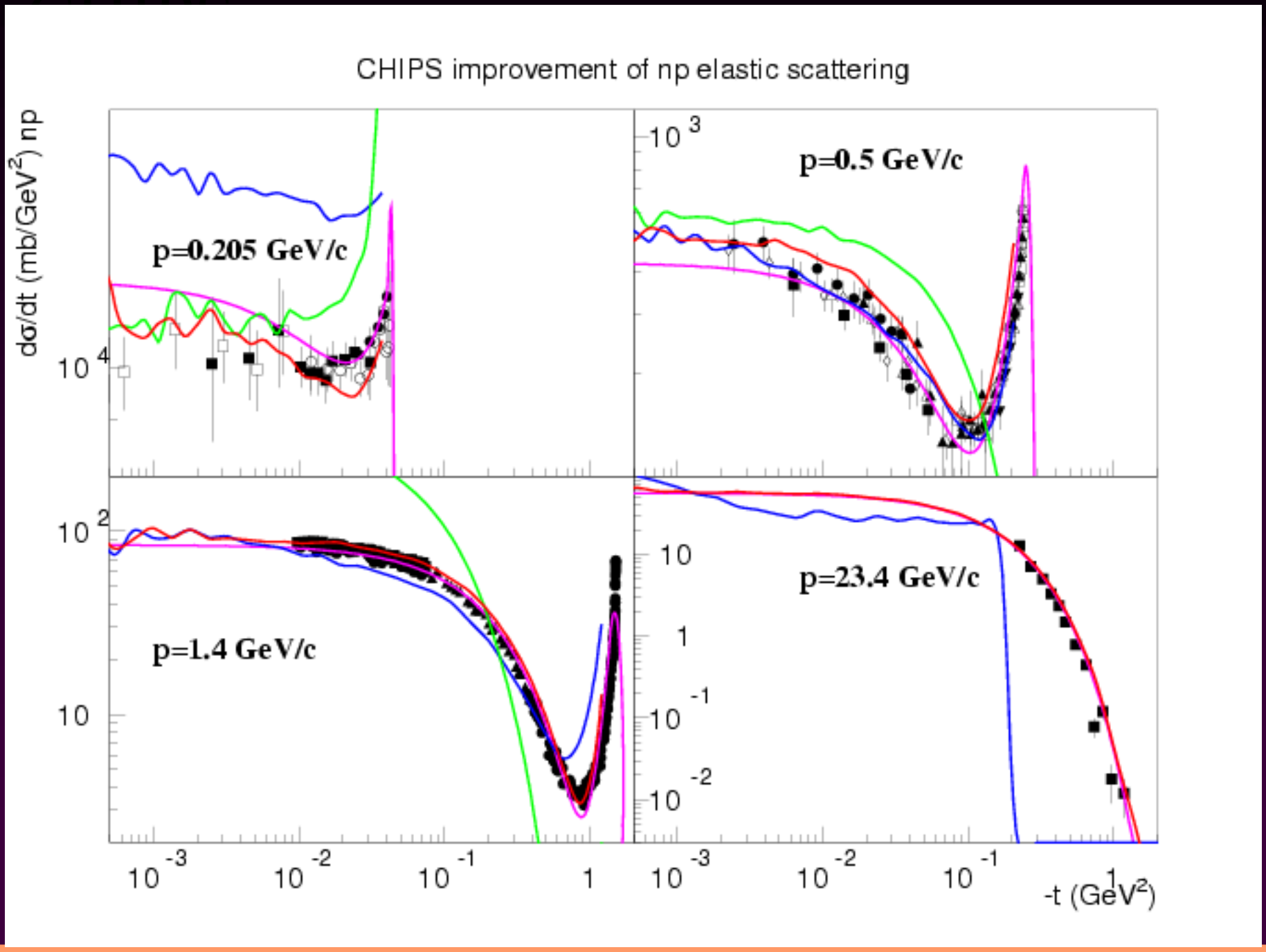


Photoneutron production - CHIPS




Antiproton annihilation on ^{238}U nucleus
protons
neutrons
deuterons
tritons (x 0.1)
kaons (x 100)
pions (x 100)
He-3 (x 0.1)
He-4 (x 0.001)
dN/pdE (MeV^{-2} Annihilation^{-1})
k = (p+E$_{kin}$)/2 (MeV)
200
400
600
800
1000


CHIPS improvement of neutron-proton interaction
σnp, mb
20 MeV (HP/LE boundary)
HP (8.1) elastic
CHIPS (integrated) elastic
CHIPS (fit) elastic
LHEP (8.1) elastic
CHIPS (fit) total
elastic cross-sections (data)
total cross-sections (data)
Neutron_HP
LHC CM
LHC LS
LHEP (8.1) inelastic
CHIPS (preliminary) radiative capture
n(p,d)γ (data)
p, GeV

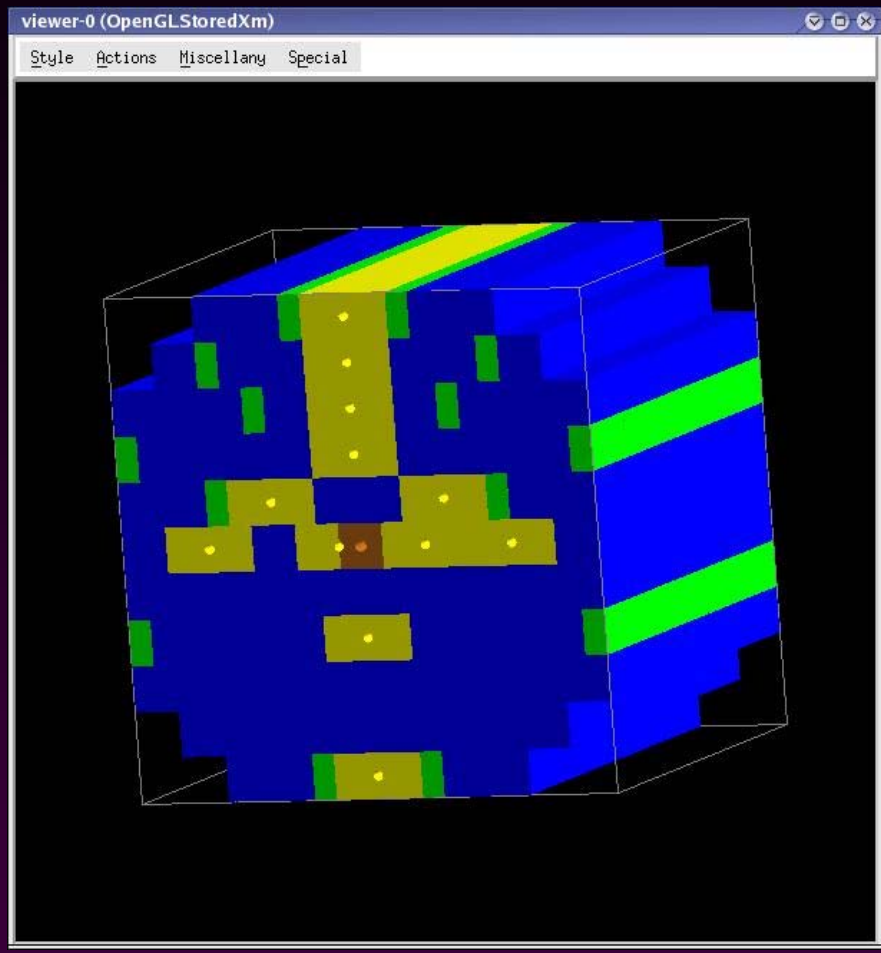

CHIPS improvement of np elastic scattering
dσ/dt (mb/GeV²) np
p=0.205 GeV/c
p=0.5 GeV/c
p=1.4 GeV/c
p=23.4 GeV/c
-t (GeV²)

Low energy (< 20MeV) neutrons physics

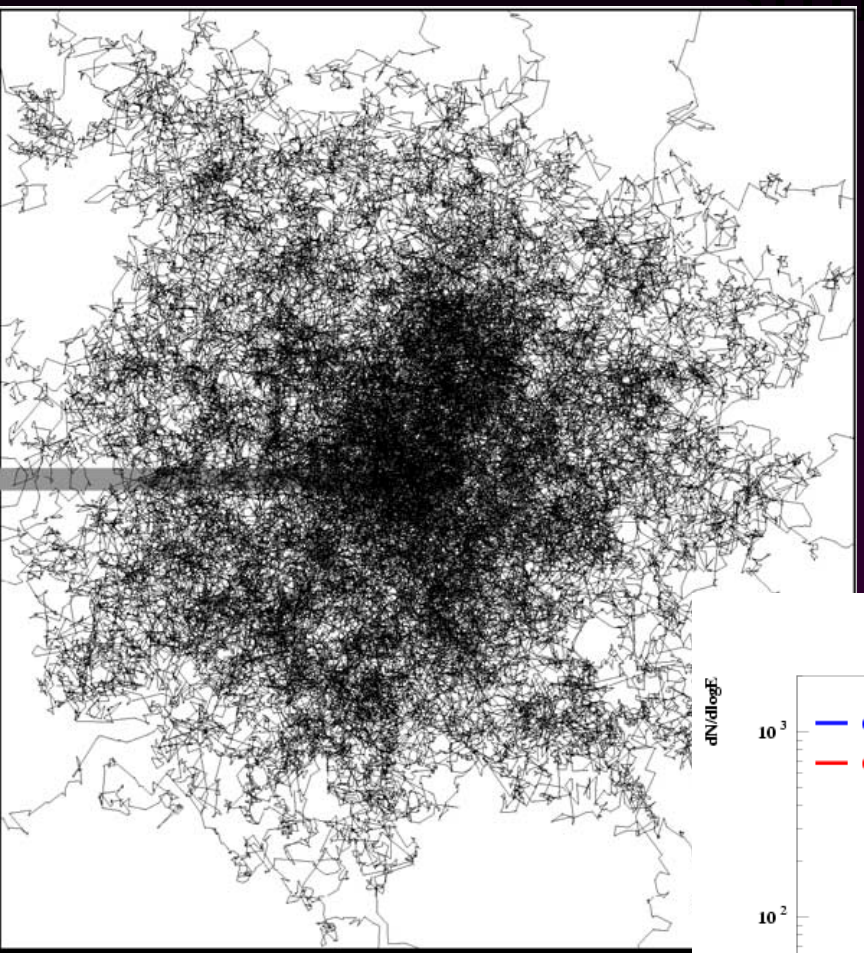
- High Precision Neutron Models (and Cross Section Data Sets)
  - G4NDL
    - Elastic
    - Inelastic
    - Capture
    - Fission
- A data-base driven model
- The data are including both cross sections and final states.
- Derived evaluations based on the following evaluated data libraries (in alphabetic order)
  - Brond-2.1; CENDL2.2; EFF-3; ENDF/B-VI.0, 1, 4; FENDL/E2.0; JEF2.2; JENDL-FF; JENDL-3.1,2; MENDL-2
- The data format is similar to ENDF, however it is not equivalent

Simulation of the TARC experiment - neutrons

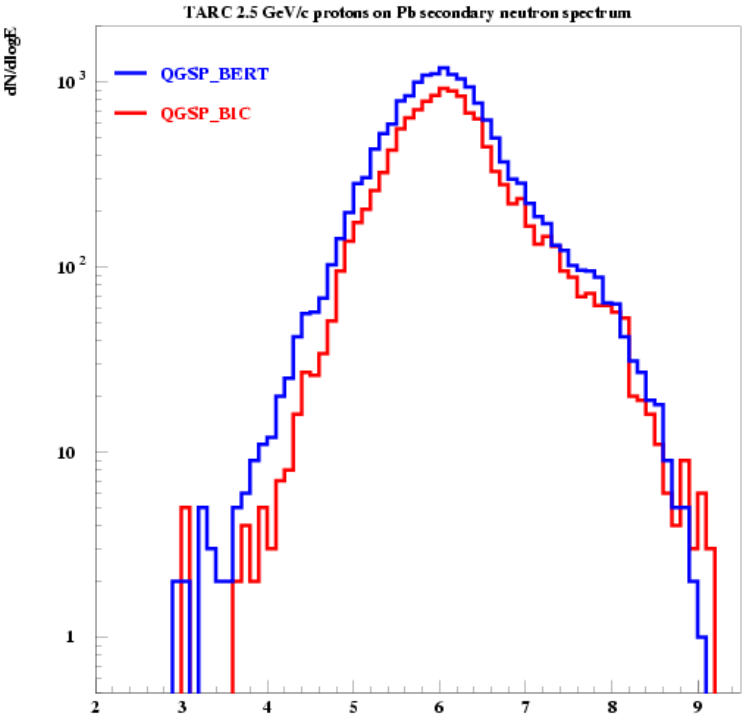
- Neutron Driven Nuclear Transmutation by Adiabatic Resonance Crossing (Cern 96-97)
- 334 tons of pure Pb in cylindrical 3.3m x 3.3m x 3m block.
- 12 sample holes are located inside the volume to measure capture cross-sections on some isotopes.
- 2.5 or 3.5 GeV/c proton beam.

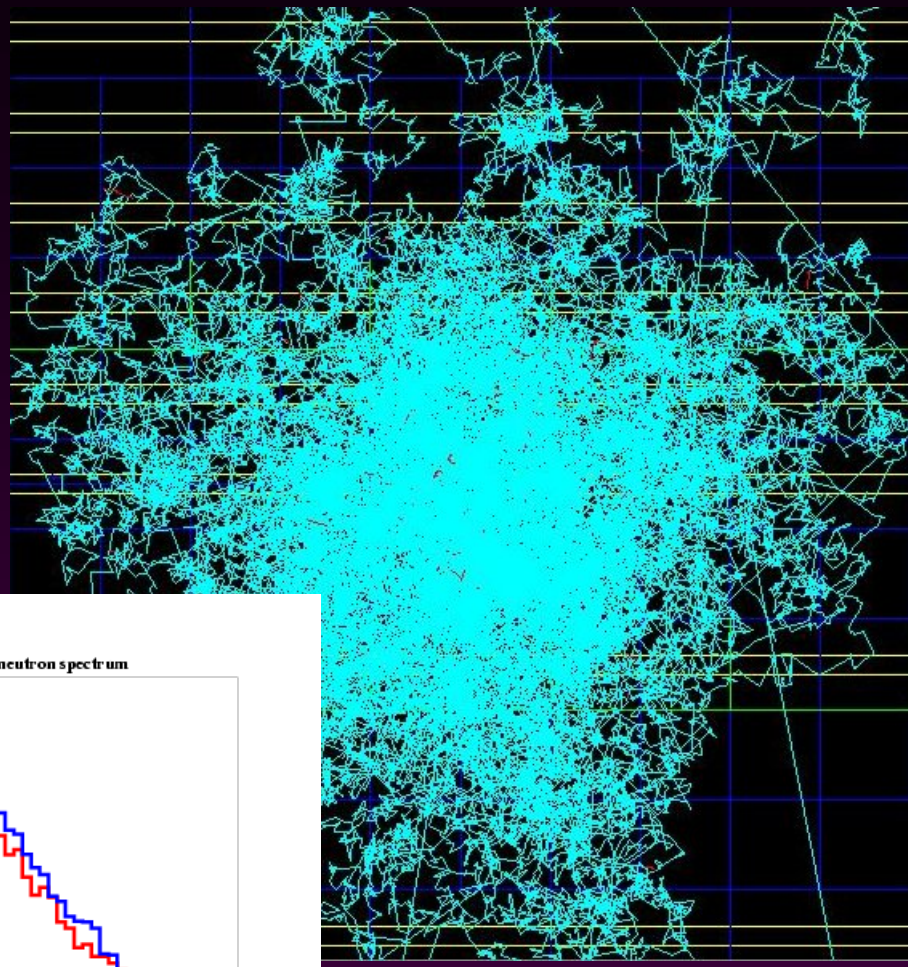


simulation



TARC original simulation





Geant4

Electromagnetic Physics Packages

- ***Standard***
  - γ, e from 1 keV to 1 TeV
  - hadrons from 1 keV to 1 TeV
  - ions up to 100 GeV
- ***Muons***
  - from 1 keV up to 1 PeV
  - high energy processes – large energy transfer
  - absoption at rest
- ***Xrays***
  - xray and optical proton production

- ***Low energy*** : alternative set of processes
  - for gamma, electron down to 250 eV
  - Hadrons down to 250 eV
  - Fluorescence
  - Auger electrons
- ***Optical***
  - Optical photon interaction

User implemented physics process

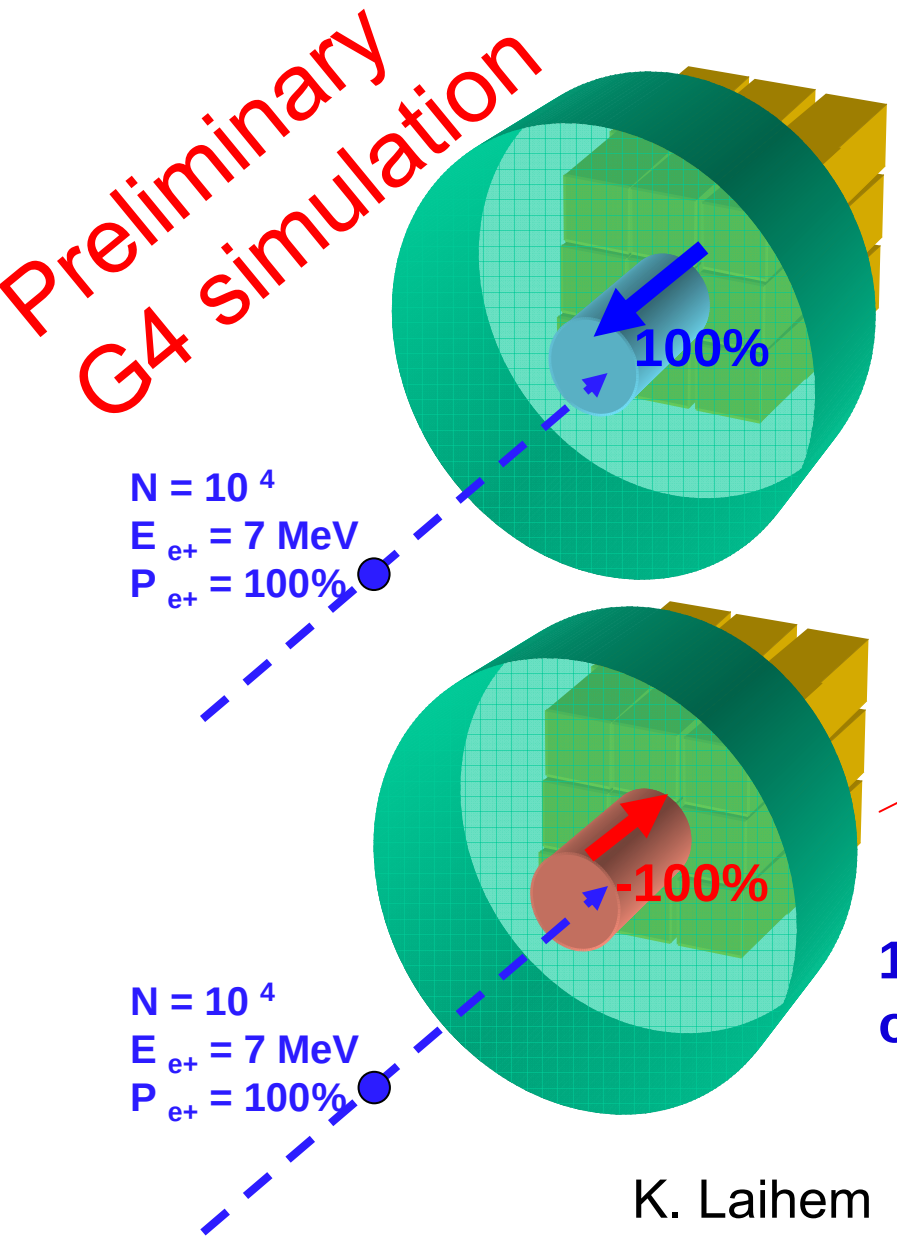
- For example a group from DESY in Berlin introduced a high energy polarisation of electrons physics model
  - Polarised target and projectile

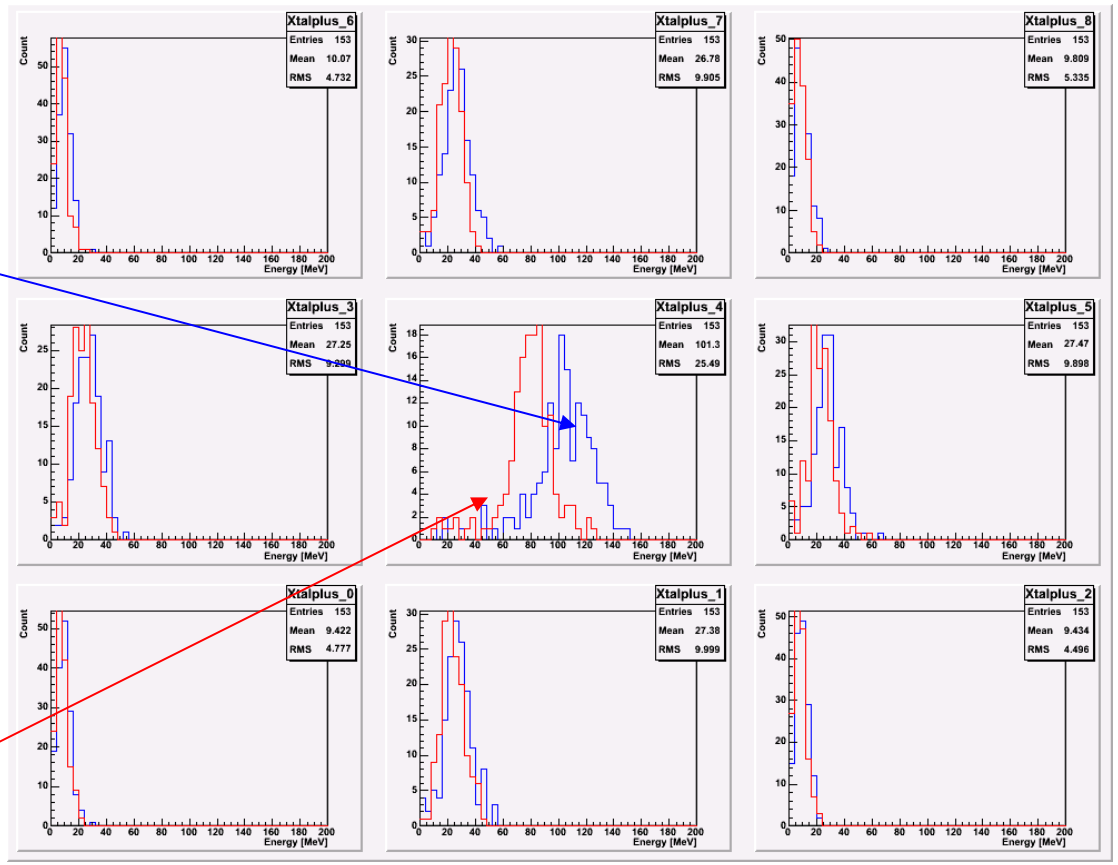
Geant4 Simulation for E166 Experiment at SLAC

Karim Laihem, Andreas Schaelicke,
and Pavel Starovoitov for E166 collaboration
DESY, Zeuthen

Measure Positron polarization by Compton transmission polarimetry

Preliminary
G4 simulation





150 bunches of 10k e+ each

Asymmetry % = 13 ± 1.4

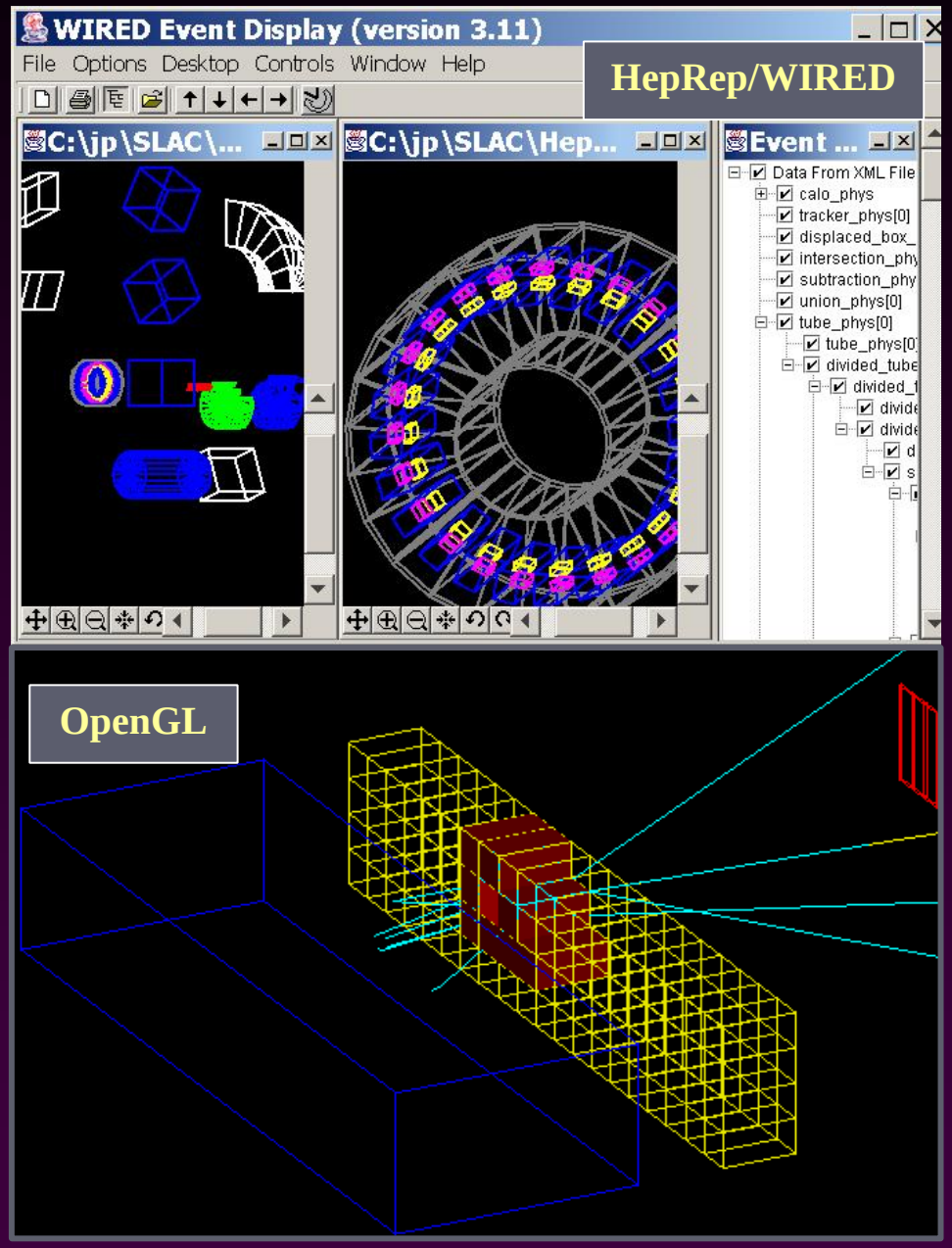
K. Laihem

Scoring and Storing Information

- Given geometry, physics and primary track generation, Geant4 usually simulates physics "silently"
  - You have to choose or add user code to extract observables
- There are two ways:
  - Use user hooks (G4UserTrackingAction, G4UserSteppingAction, …)
    - Straight-forward, but "do-it-yourself"
    - You have full access to almost all information
  - Use Geant4 scoring from G4VSensitiveDetector in a volume
    - Store hits. A hit is a snapshot of the physical interaction of a track or an accumulation of interactions of tracks in the sensitive part of your detector.
    - New Geant4 scorers provide standard implementation of fluence, dose, equivalent dose, ..

Visualization

- Quick response to study geometries, trajectories and hits
- High-quality output for publications
- Flexible camera control to debug complex geometries
- Tools to show volume overlap errors in detector geometries
- Interactive picking to get more information on visualized objects



User Support

- Geant4 web page http://cern.ch/geant4 include important links to
  - Installation guide
  - Application developer manual
  - Physics Reference Manual
  - FAQ
  - HyperNews forum for user/developer and user/user communications
  - Bug report system

Summary and Conclusions

- Geant4 is powerful toolkit allowing the simulation of complex geometries with the physics of particle interactions and tracking
- A full-range of physics is included ranging from very low energy eletromagnetic processes to very high energies
- A selection of hadronic physics models are included with applicability of different energy ranges/use cases
- Neutrons are handled in a selection of hadronic models from high precision data-base driven to intra-nuclear cascades and string-parton models
- The toolkit design allows plug-ability and user defined physics processes (e.g. See the very next talk)

Thanks to the collaboration for providing material for this presentation