New Bertini-based Processes

Michael H. Kelsey
SLAC GEANT4 Group

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Introduction

Three new kinds of processes using Bertini-esque cascade model available in 9.5 and 9.6-beta

- Absorption of stopped (negative) hadrons on nuclei
- Direct photonuclear interactions
- Leptonuclear interactions via indirect photonuclear

Validation ongoing, expect to deploy in reference physics lists with 9.6 release

Recent issue: SATIF benchmarks show degradation in performance since SATIF 10 (GEANT4 9.2); study underway

Hadron Capture Process

Any "stable" negative hadron, including hyperons ($\pi^-, K^-, \Sigma^-, \Xi^-$)

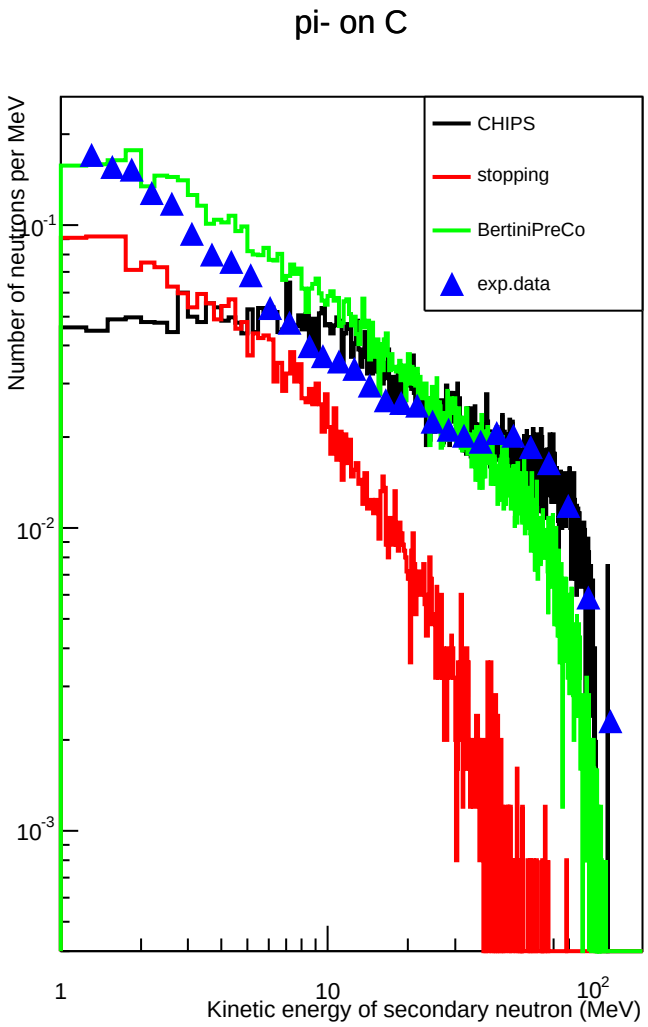
- `source/processes/hadronic/stopping/G4HadronicAbsorptionBertini`
- 9.5, 9.6-beta **G4QandFTFStoppingPhysics**
- For 9.6 **G4BertiniAndFritiofStoppingPhysics**
- $\bar{p}$, $\overline{\Sigma^+}$ handled with FTF

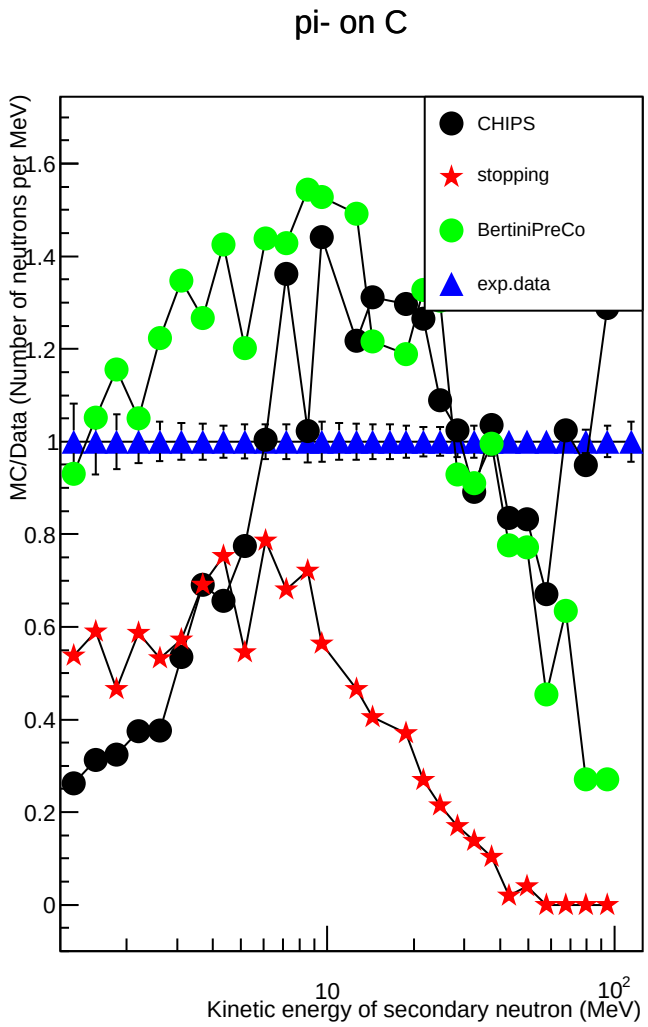
Tested with 5 MeV K^- on iron-scintillator stack

- Direct K^- captures, as expected (133/2000)
- π^- captures, from K^- decays in flight (90/2000)
- Σ^- captures, from secondaries after K^- capture (2/2000)

test48 (Julia Yarba) exercises different stopping models

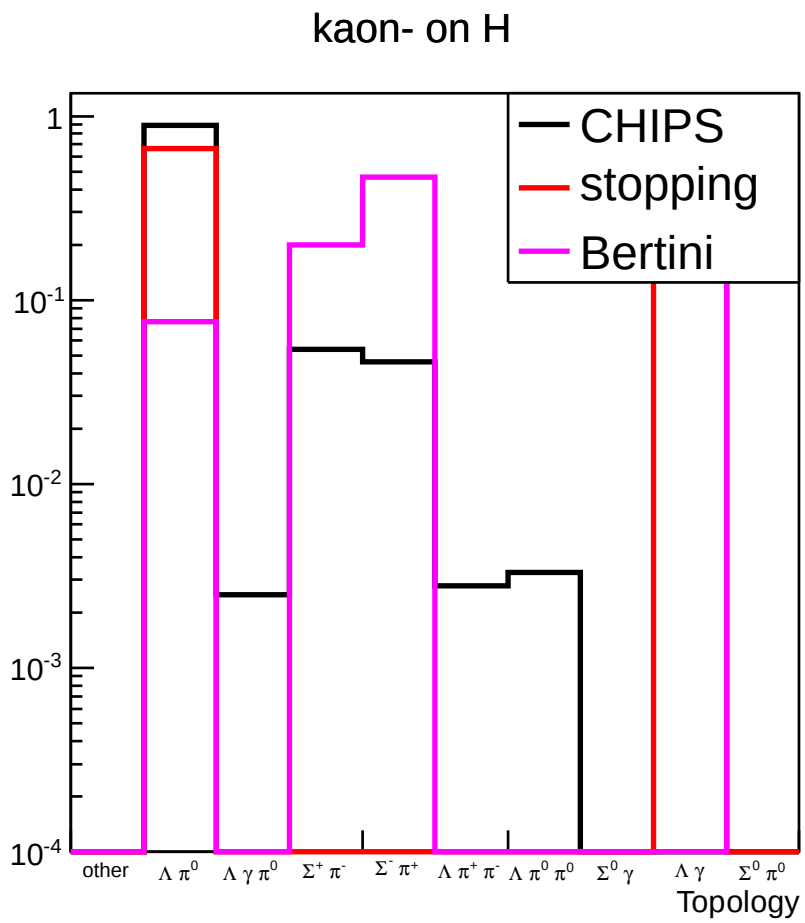
π^- Capture on Carbon

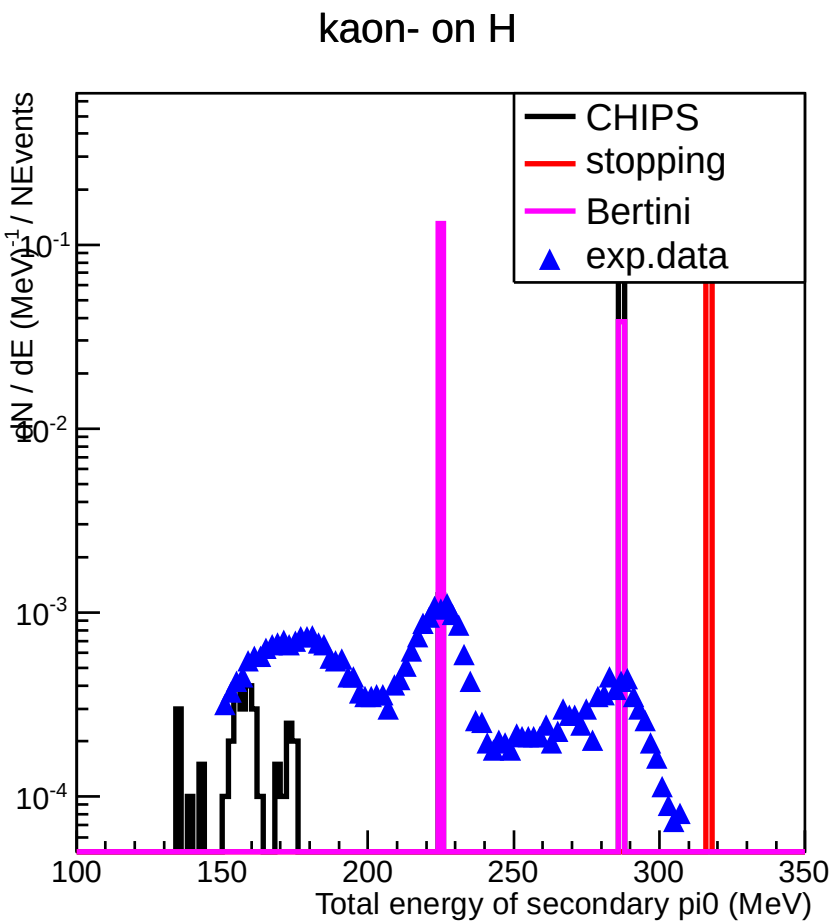




Bertini handles low-energy well, kinematic limit too soft

K^- Capture on Hydrogen

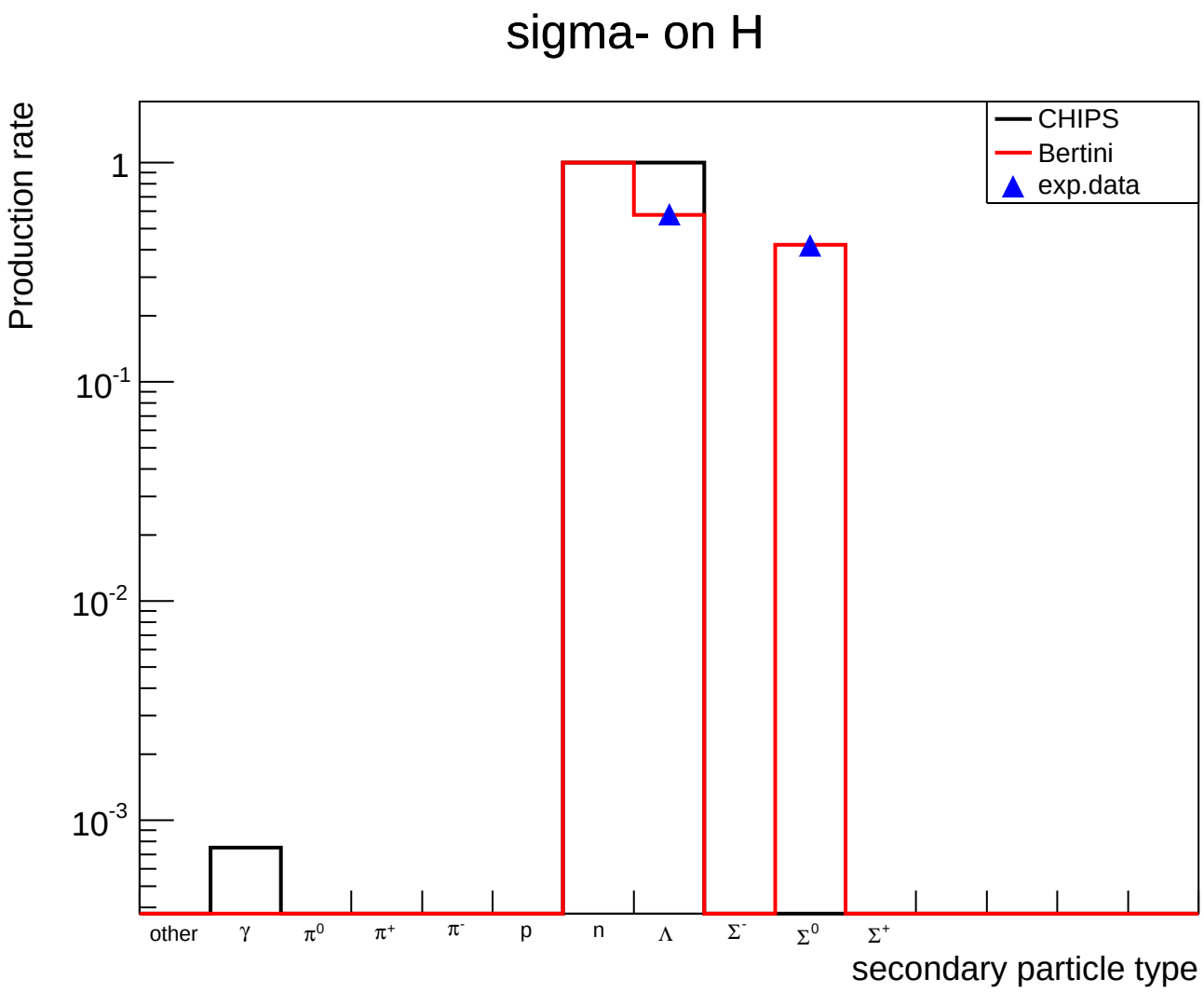




Zero-energy cross-sections fixed to match data

Two-body π^0 peaks match data; continuum from hyperon decays?

Σ^- Capture on Hydrogen



Zero-energy cross-sections fixed to match data

Photonuclear Process

In 9.5 release, introduced γp and γn interactions

- Exclusive final states: elastic, multipion and $K\overline{K}$
- Free-nucleon cross sections
- No γ production (radiative states) in other channels
- Currently in **G4BertiniElectroNuclearBuilder**

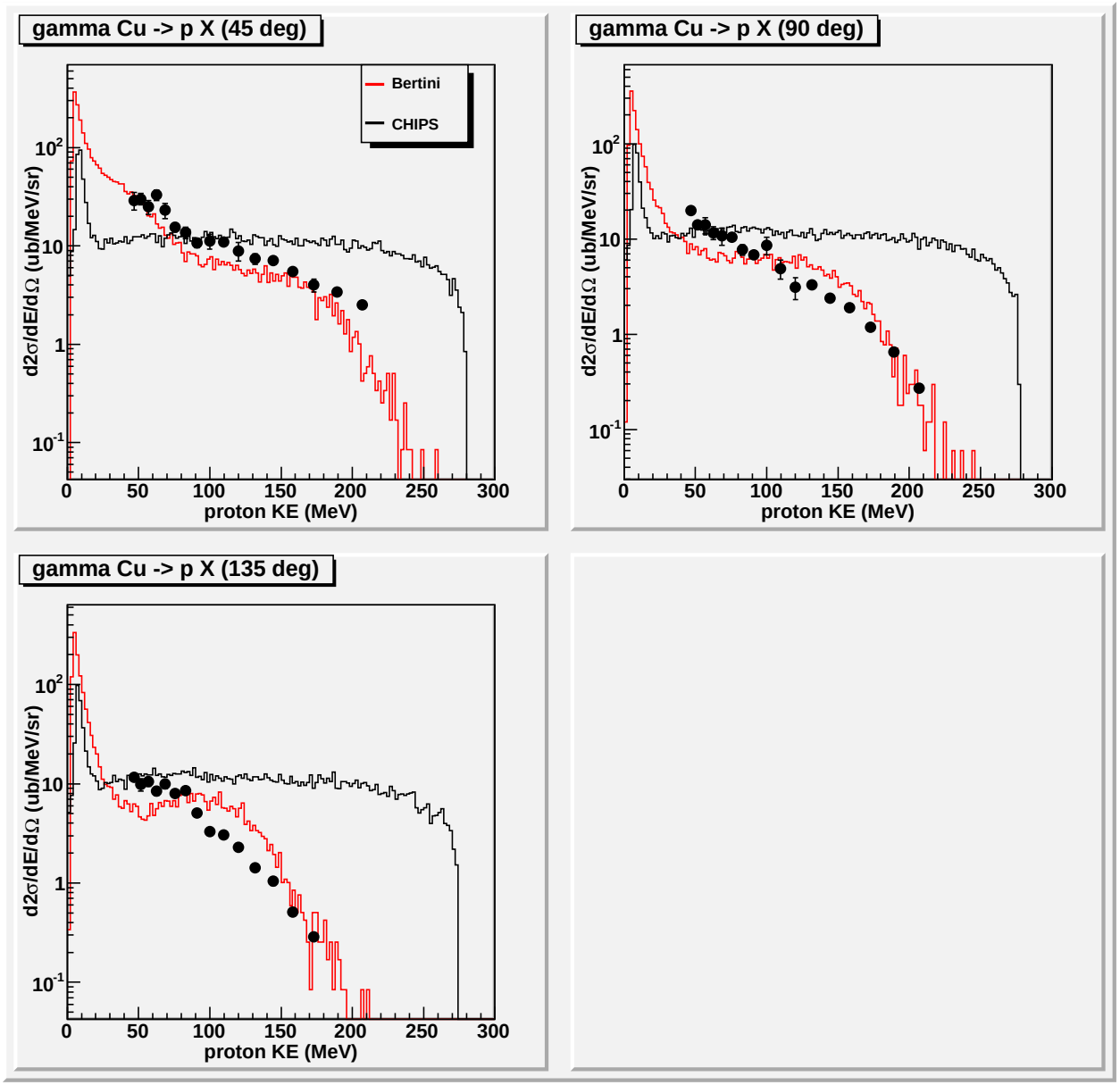
CERN-HERA 87-01, Feb 1987

γD partial cross-sections used for dibaryon clusters

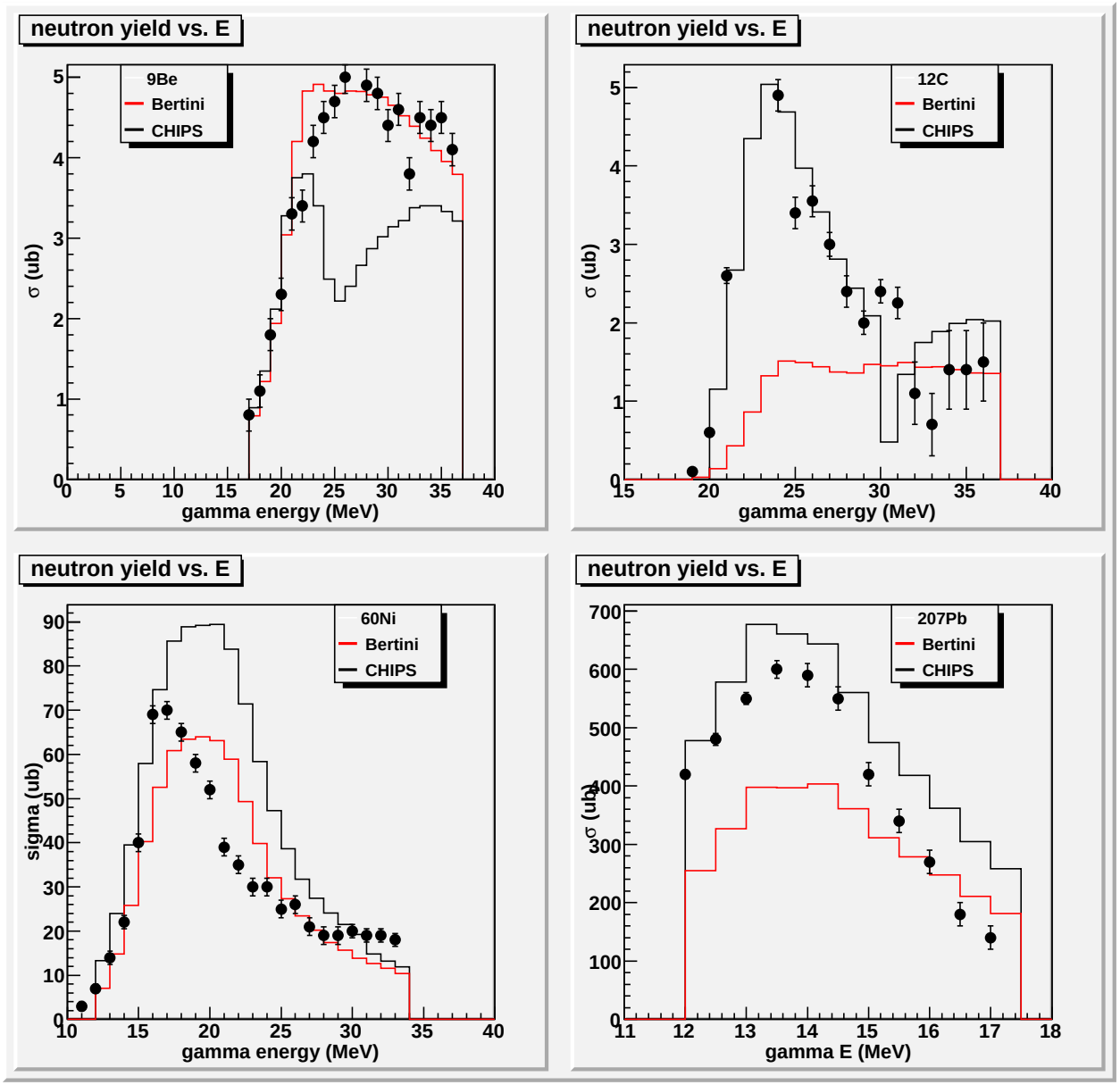
Two-body angular distributions parametrized from data

- $\gamma p \rightarrow \pi^+ n$, $\gamma p \rightarrow \pi^0 p$, and isospin partners
- All other final states use phase-space calculation

Photonuclear Validation



Photonuclear Validation



Leptonuclear Processes

Lepto-nuclear interactions implemented 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^0

`source/processes/hadronic/models/photolepton_hadron/muon_nuclear`

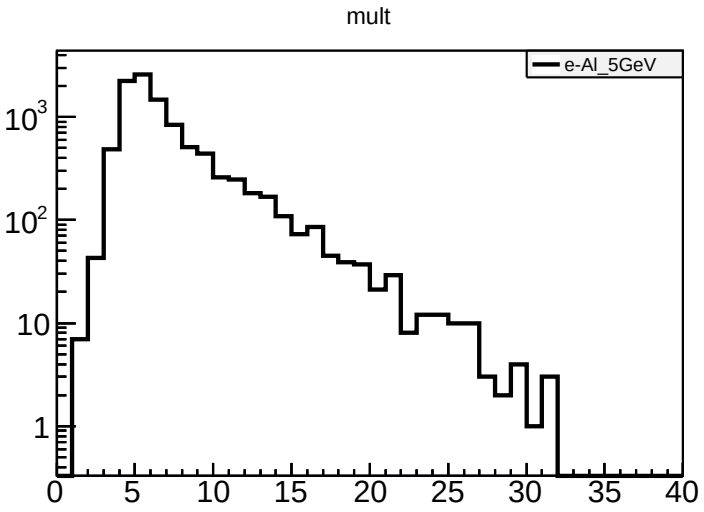
eN: G4ElectroVDNuclearModel

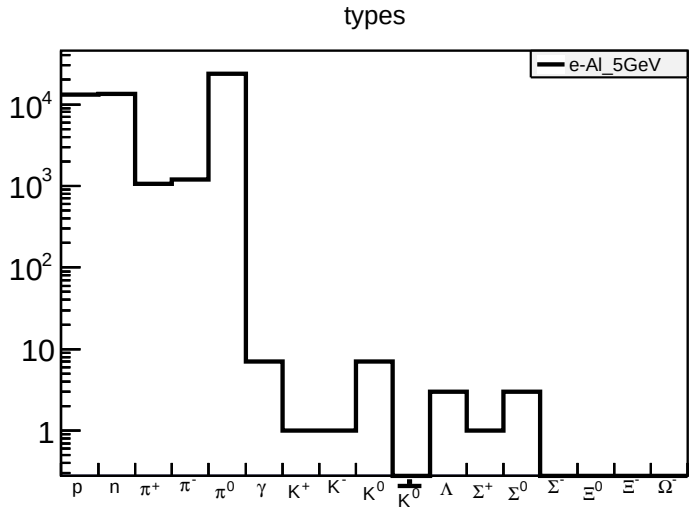
- CHIPS code for photon generation and conversion
- CHIPS electro-nuclear cross-sections used
- Currently in **G4BertiniElectroNuclearBuilder**

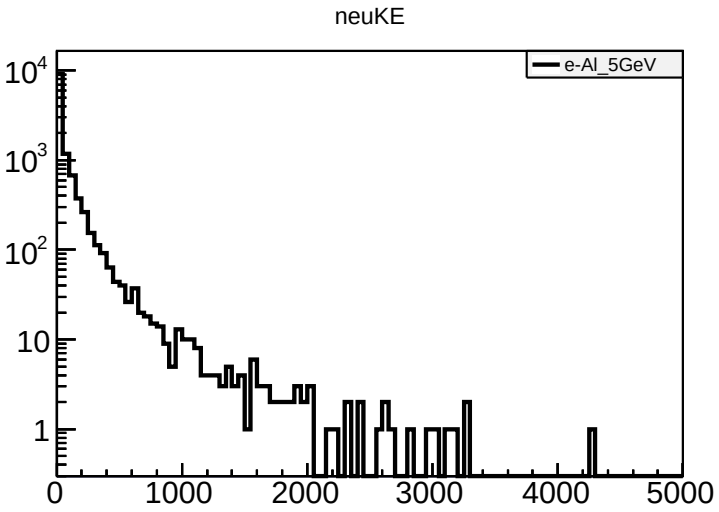
μN: G4MuonVDNuclearModel

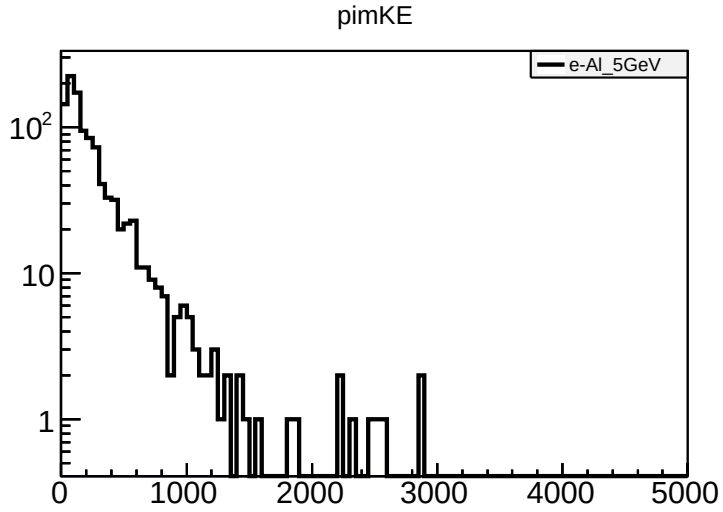
- Kokoulin model for photon generation and conversion
- Old GHEISHA model (**G4MuNuclearInteraction**) should be deprecated
- Currently in **G4EmExtraPhysics, G4EmExtraBertiniPhysics**

Electronuclear Validation

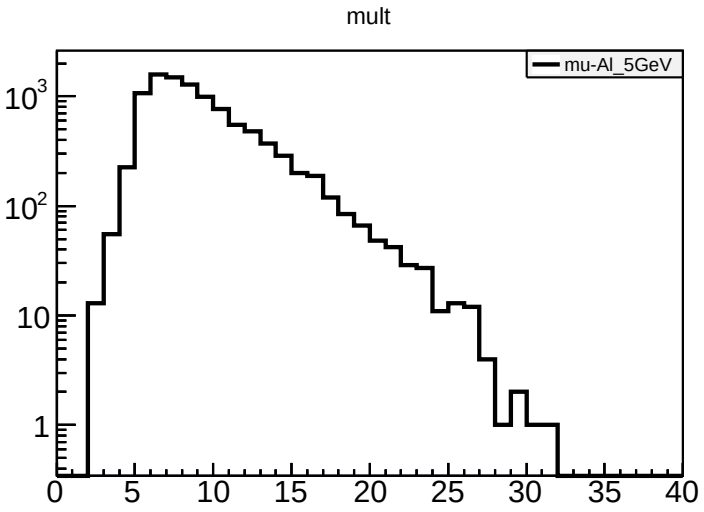


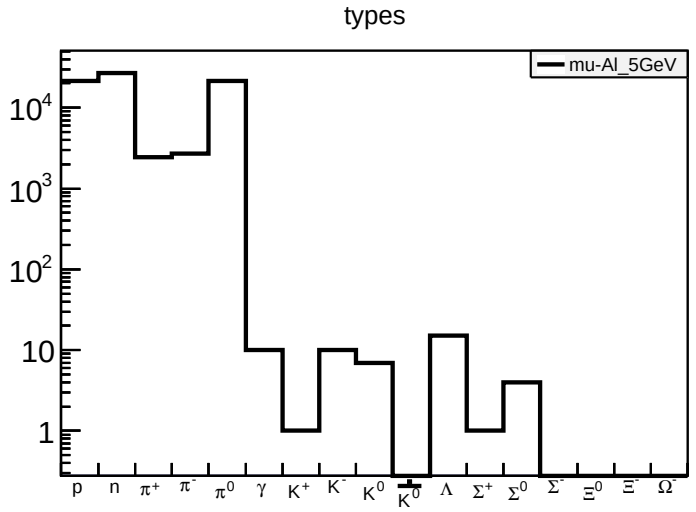


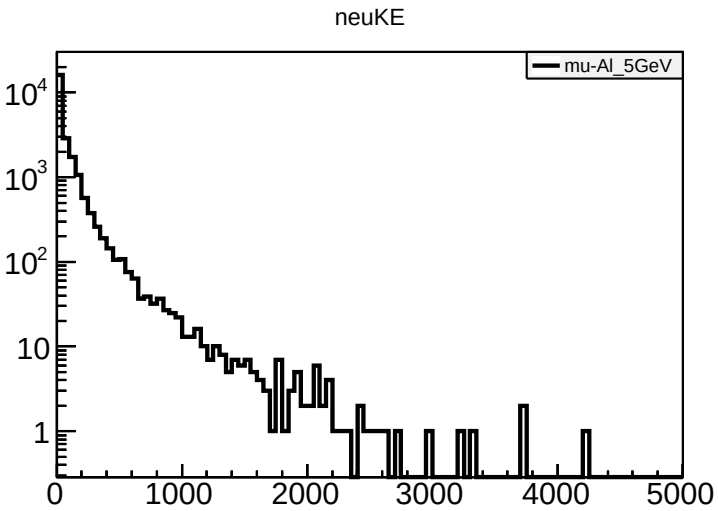


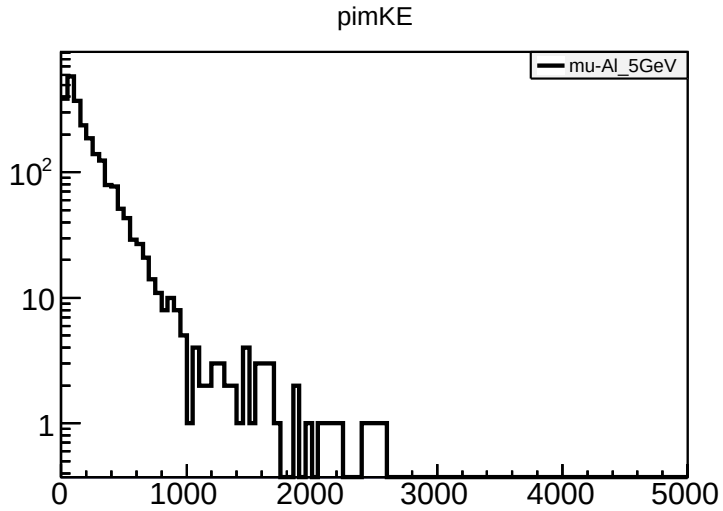


Muon-nuclear Validation









SATIF Benchmarks

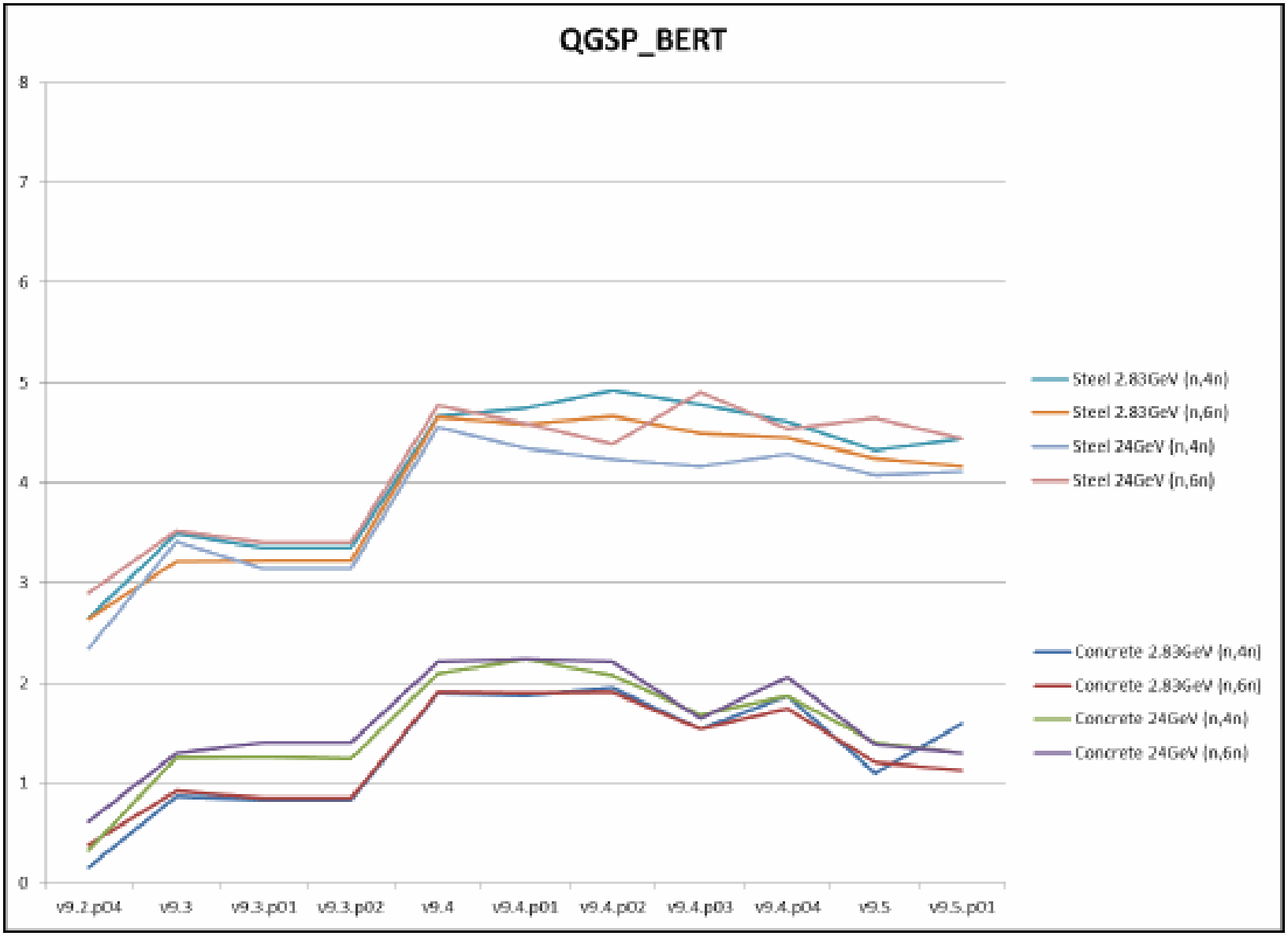
"Drift" of SATIF benchmarks (neutron-induced spallation) with Bertini since 9.2

General trend: reduction in multiplicity, energy of secondary neutrons in concrete(n,4n), steel(n,4n), etc.

Smaller step when NN cross-sections changed from 9.2 to 9.3

Large step between 9.3 and 9.4, when Bertini "remodelled" to conserve four-momentum stepwise throughout cascade

SATIF Benchmarks



Possible Solution

Bertini 9.3 replaced pp, nn and pn cross-section tables with versions consistent with PDG

Verified in 9.6-beta that reverting NN cross-section tables to old version improved benchmarks

For the steel target, using "old" tables for pn improved things

Plan to split pp and nn cross-section tables (currently combined with enforced isospin symmetry), revert only nn to "old" version

Summary

Bertini ready to handle general hadronic capture on nuclei

G4QandFTFStoppingPhysics

Bertini ready to handle direct photonuclear interactions

G4BertiniElectroNuclearBuilder

Bertini photonuclear interface suitable for low to medium energy electron- and muon-nuclear interactions

G4BertiniElectroNuclearBuilder
G4EmExtraPhysics

Validation with leptonuclear data required

Bertini nucleon-nucleon cross-section tables under revision in light of SATIF benchmark studies

Ξ^- Capture

Zero-energy cross-sections set by consistent scaling from known hyperon interactions, symmetry relations

Only elastic and charge-exchange interactions have non-zero cross-section

Need data for validation and to adjust cross-sections

Indian J. Pure Appl. Phys., **12** 1(1974) 51-56
`http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=4282561`

Xi^- D capture, E813, Report BNL–60355
`http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=10150900`

Xi^- capture may produce hypernucleus pairs

Progr. Theoret. Phys. **89** 2(1993) 493-500
`http://adsabs.harvard.edu/abs/1993PThPh..89..493A`

Not possible in GEANT4 (yet?)

Ω^- In Bertini

Bertini will have $\Omega^- N$ cross-sections and final-state tables (2–7 body channels) for 9.6 release

No data available: estimates based on "reasonableness"

- charge, baryon, strangeness conservation
- isospin invariance
- thresholds for multi-particle production
- characteristic shapes of non-resonant partial cross sections (rapid rise vs. E up to some peak, followed by slow exponential)
- combinatoric suppression with identical final states
- OZI suppression
- Absolute scale estimated from scaling other hyperons $\Sigma^- p \Rightarrow \Xi^- p \Rightarrow \Omega^- p$