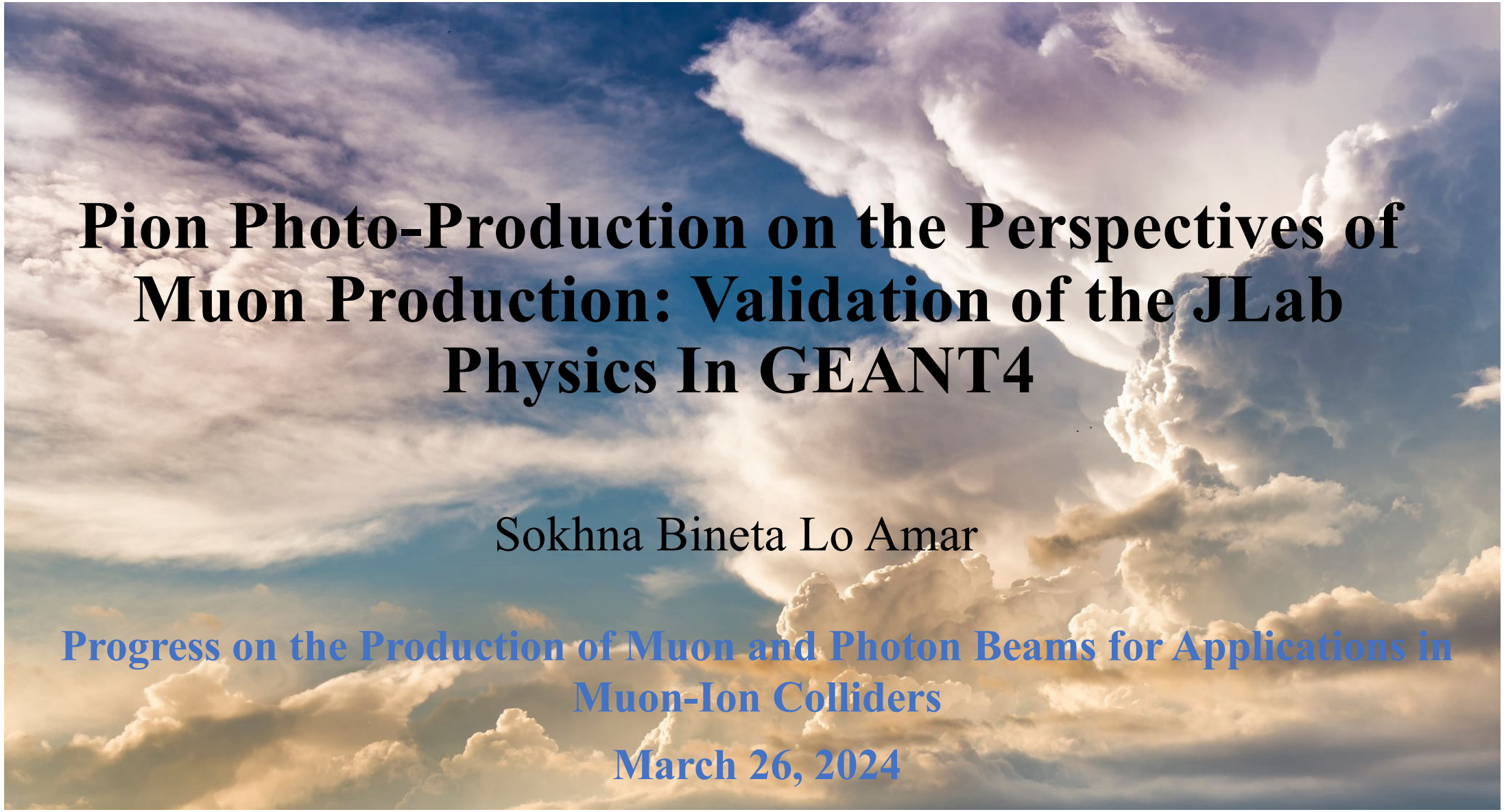


Pion Photo-Production on the Perspectives of Muon Production: Validation of the JLab Physics In GEANT4

Sokhna Bineta Lo Amar

Progress on the Production of Muon and Photon Beams for Applications in Muon-Ion Colliders

March 26, 2024

Perspectives of muon production via charged pions

- Importance of muon beams in Nuclear Physics, deserved to be studied. It is therefore crucial to study the charged pion decay into muon and its neutrino.

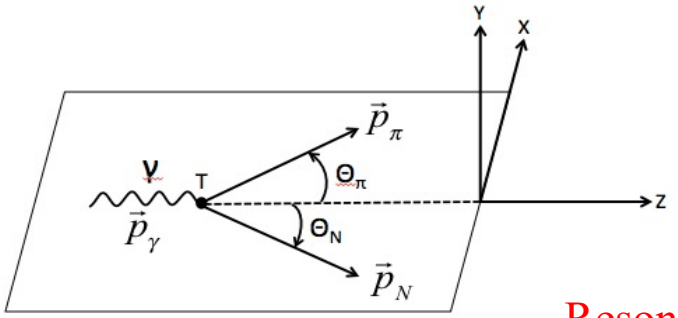
$$\Longrightarrow \quad \pi^{\pm} \longrightarrow \mu^{\pm} + \nu_{\mu}$$

- Good understanding of pion photo-production using GEANT4 tool required
- Identification and validation of GEANT4 hadronic models for pion photo-production reactions

Introduction

❑Pion photo-production: good alternative to probe matter

- Electromagnetic and Hadronic interactions combined



Resonances identified

❑CLAS, CEBAF Large Acceptance Spectrometer

- Experiences performed with the CLAS detector, located in the hall B of JLab
- CLAS, detector allowing to probe deeply the nucleons with high statistics

❑GEANT4, GEometry ANd Tracking 4

- Tool dedicated for simulation between particle and matter and for data analysis
- Applications, high energy, nuclear energy, space and materials sciences to medical physics

❑Goal

- Validate GEANT4 physics using JLab data in the GeV range

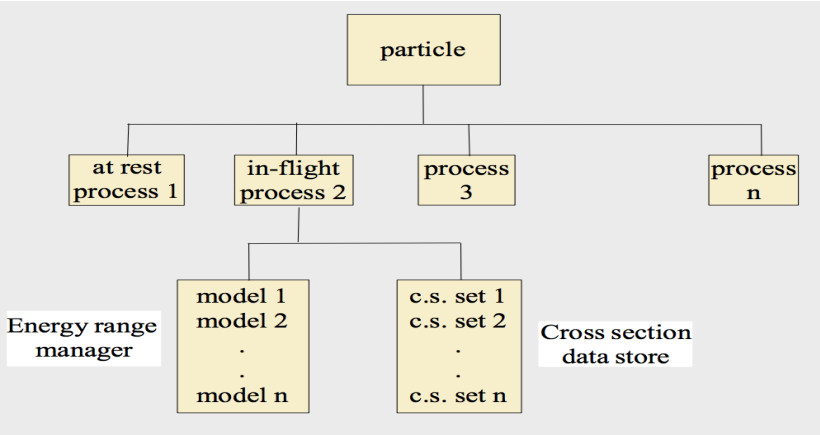
Outline

- GEANT4
- Cross-sections and Comparison
- Results
- Conclusion
- Perspectives

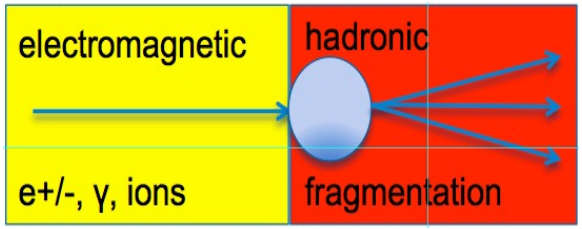
GEANT4

Physics implementation and Photo-production reaction

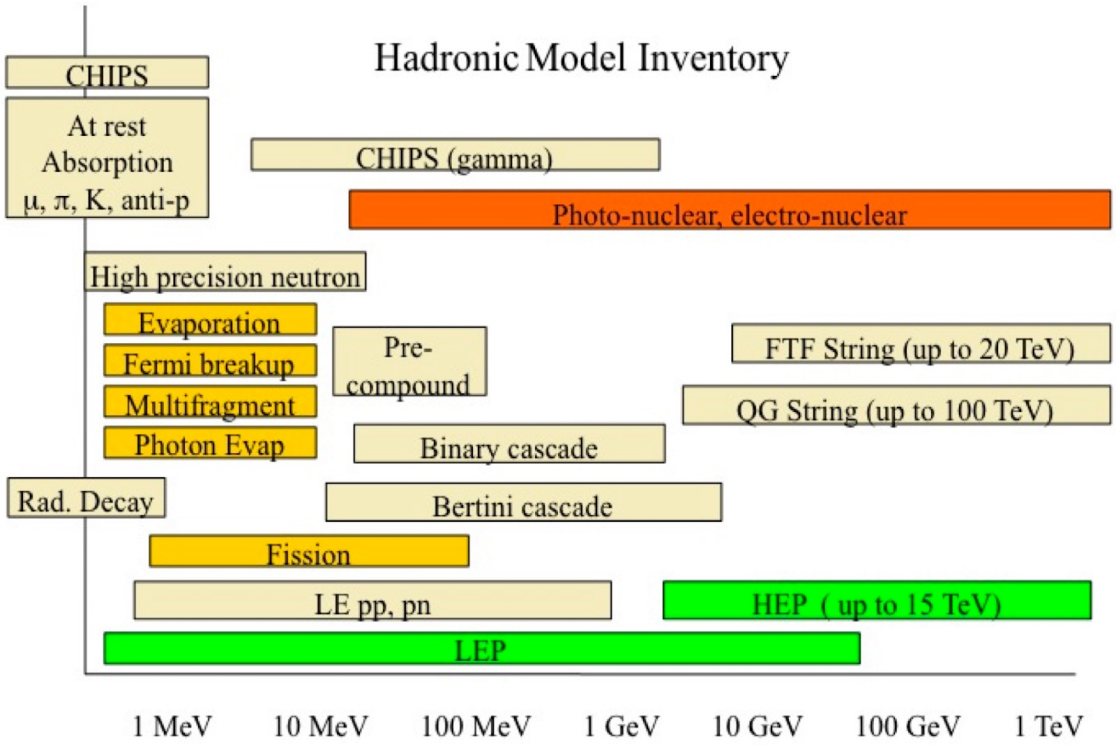
❑Interactions in GEANT4 as a physics processes



❑Two distinct packages: EM and Hadronic physics



❑Tens of categories of hadronic models (GEANT4 9.6.p02 version)



GEANT4

Physics implementation and Photo-production reaction

Models	Incident particles	Incident energies	Applications
String models: Quark-Gluon-String (QGS) Fritiof (FTF)	p, n, K, π.	>~20 GeV >~5 GeV	Radioprotection and high energy
Cascade models: **Bertini (BERT)** Binary Invariant Cascade (BIC)	p, n, π, K, Λ, Σ^+, Σ^- L, Ω^-, Ξ^-, Ξ^0, γ p, n, γ p, n, π^+, π^-	<~10 GeV	Intermediate energies
Chiral Invariant Phase Space (CHIPS)	μ, π, K, anti-p, anti-baryon, γ	~1 MeV → ~10 GeV	Intermediate to high energies
Pre-compound model (P or PRECO)	p, n	< 20 MeV	Low energy nucleon-nuclei interaction Nuclear de-excitation
High Precision Neutron (HP)	Neutrons	0→170 MeV	Detail neutron transport Radioprotection

Models in function of incidents particles, energy range, applications

Tens of models but users interesting in a restricted number, regularly tested and validated by GEANT4

Only two, potentially suitable for photo-production reactions in the: **BERT** and **CHIPS**

Cross-sections and Comparison
Generalities

❑Cross-sections

- GEANT4, interactions between particle and matter quantified by exclusive/inclusive cross-sections
- Cross-sections data tabulated for each hadronic model

❑Comparison: PDG and GEANT4 (BERT & CHIPS)

- PDG: Particle data Group, large database including diverse compilations

❑Comparison: GEANT4 and SAID + experimental data of JLab

- SAID: Scattering Analysis Dial-in

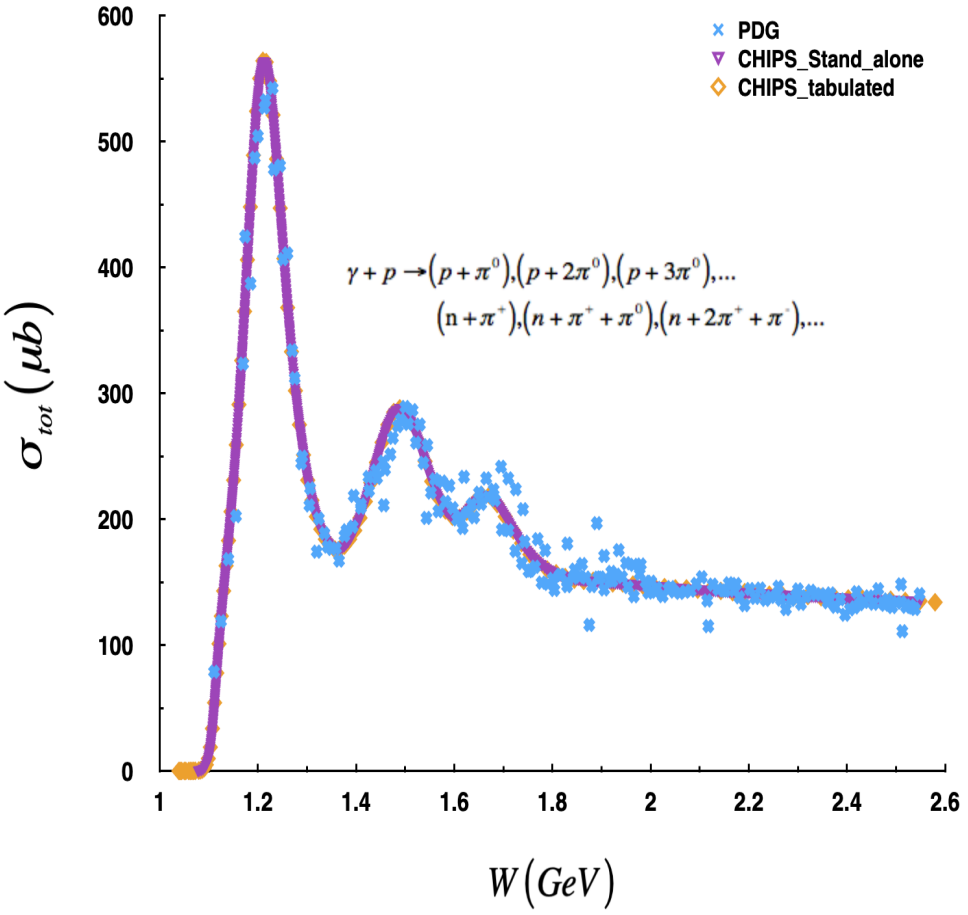
(Phenomenological model based on word-wide experimental data and maintained by GWU)

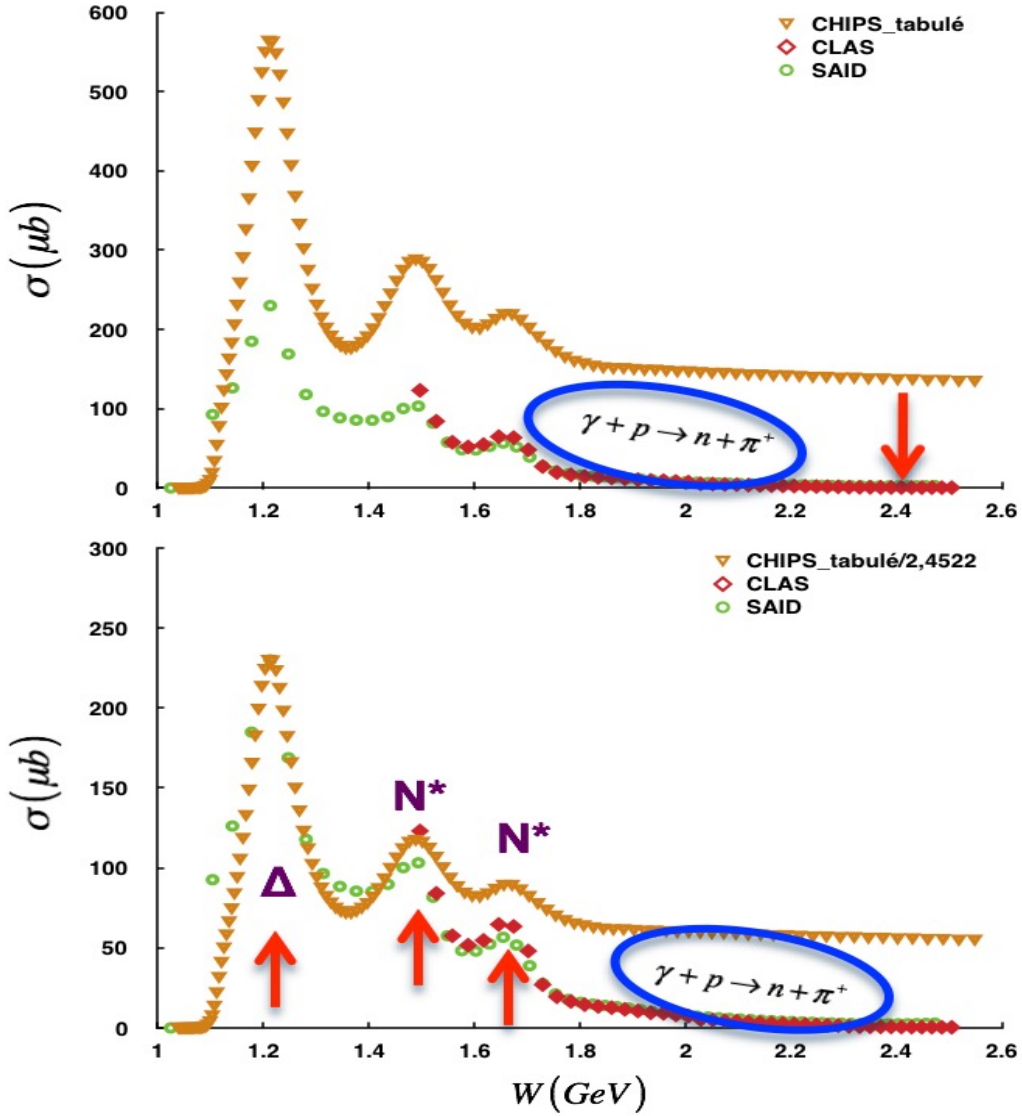
- Missing data from CLAS below 600 MeV

Cross-sections and Comparison

GEANT4 (CHIPS) vs PDG

- ❑CHIPS_Stand_alone allows to verify the tabulated data
  - Superimpose perfectly
- ❑CHIPS_tabulated
  - fits correctly with PDG data





Cross-sections and Comparison

GEANT4 (CHIPS) vs CLAS/SAID

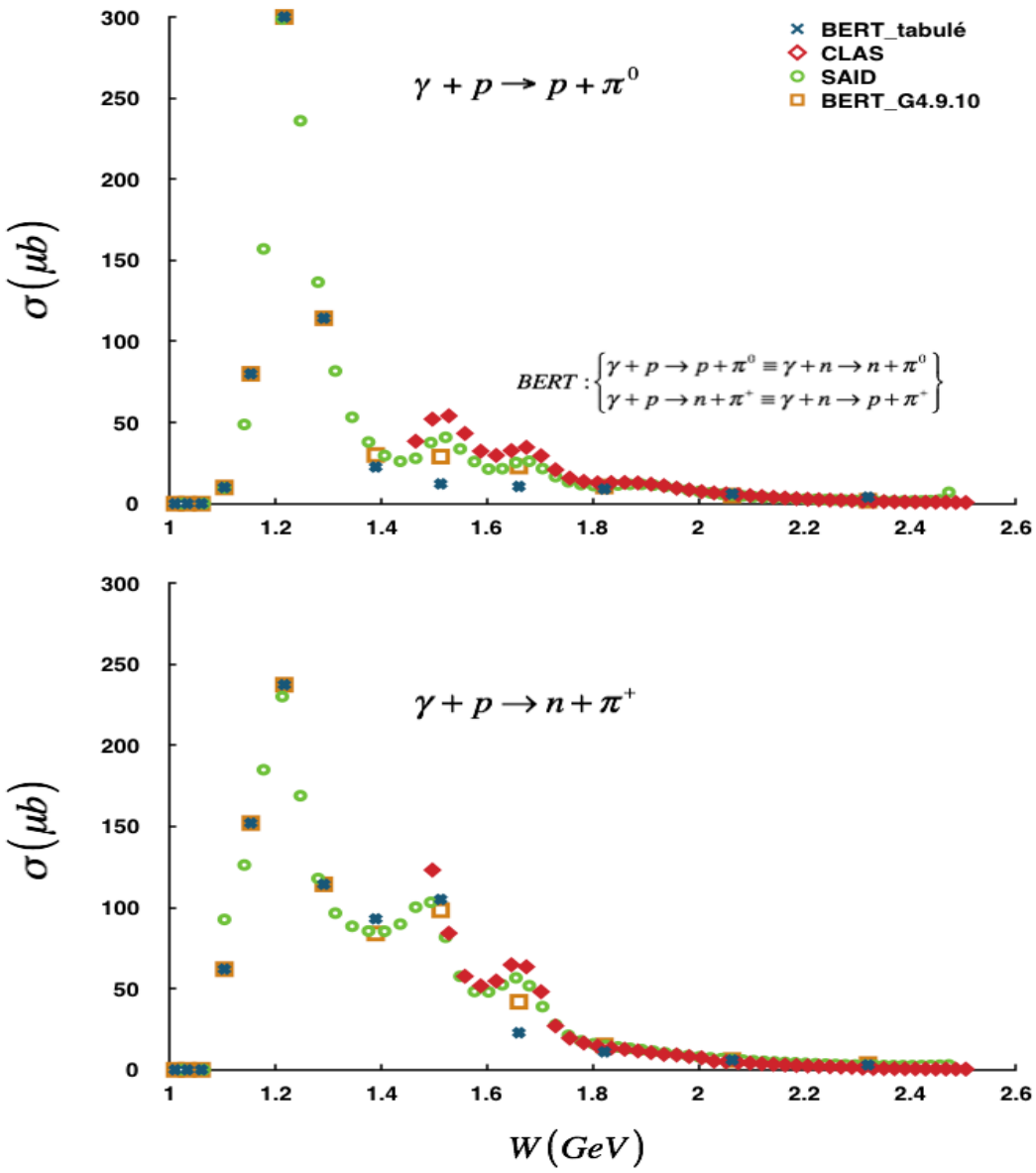
- GEANT4_CHIPS
  - Reproduce experimental resonances (Δ resonance of CHIPS normalized to SAID)

Cross-sections and Comparison

GEANT4 (BERT) vs CLAS/SAID

❑GEANT4_BERT

- Correctly describe the Δ resonance of SAID for the π^0 and π^+ channels
- Not enough data around the 2nd and the 3rd resonances
- Revised in version 10: Slightly improved but more needed

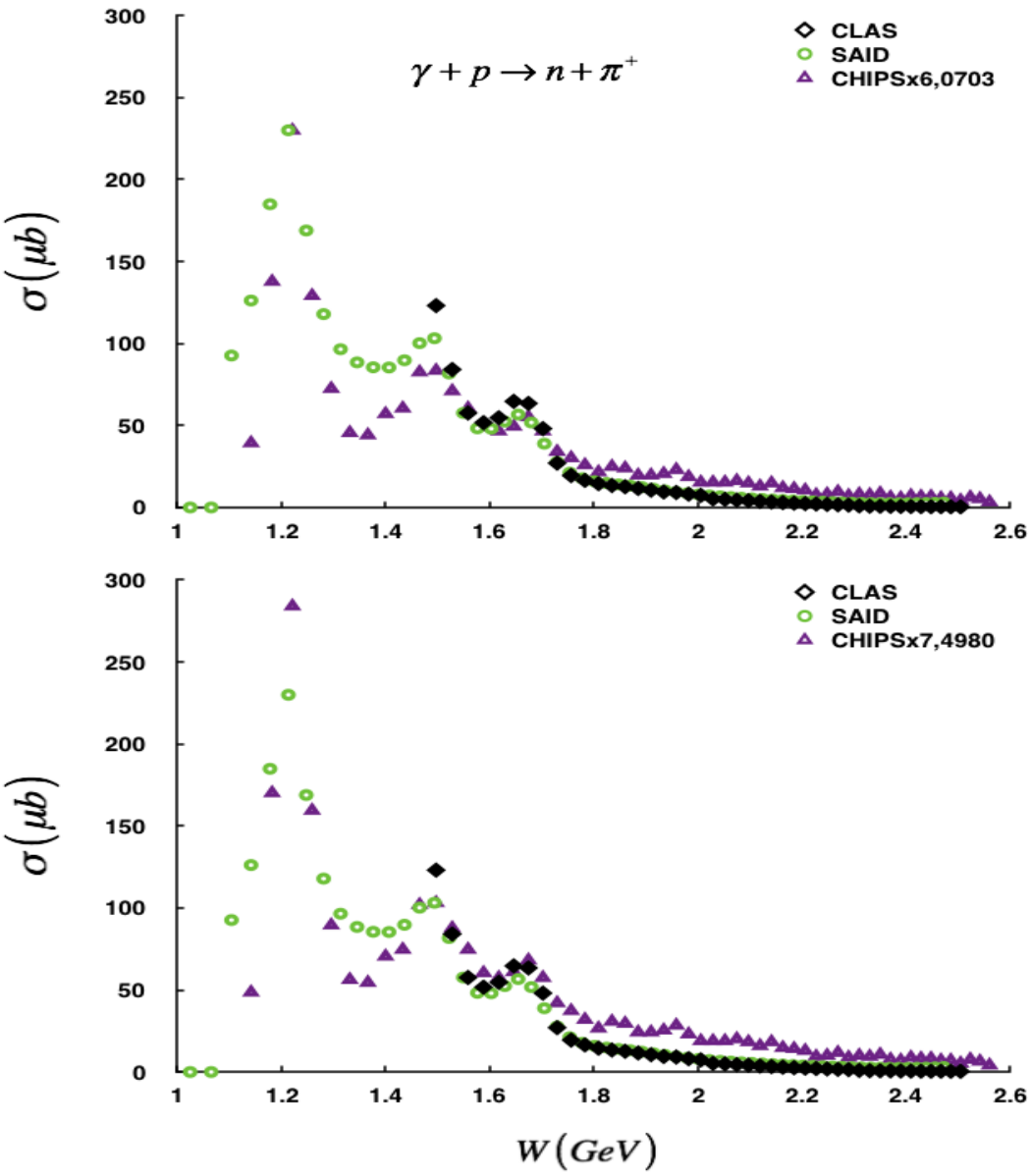


Results

Total cross-sections

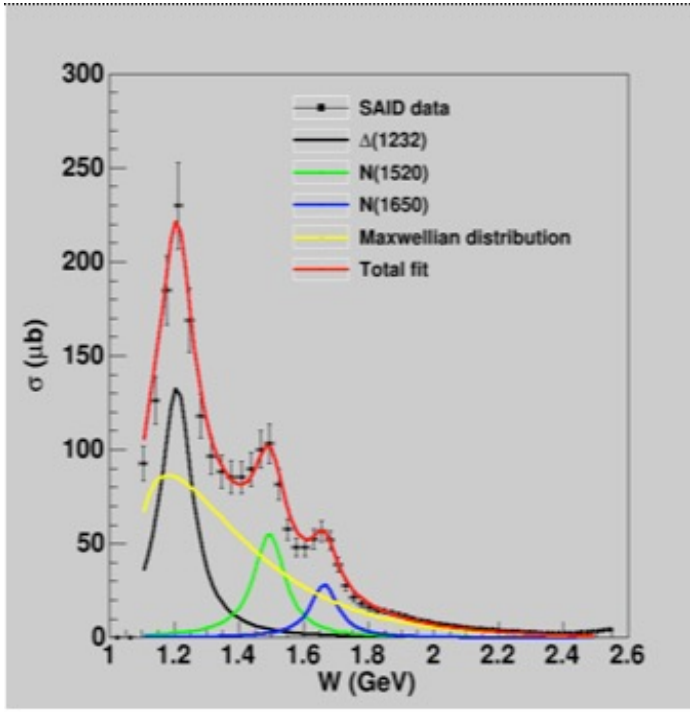
❑**CHIPS_nπ^+ :**

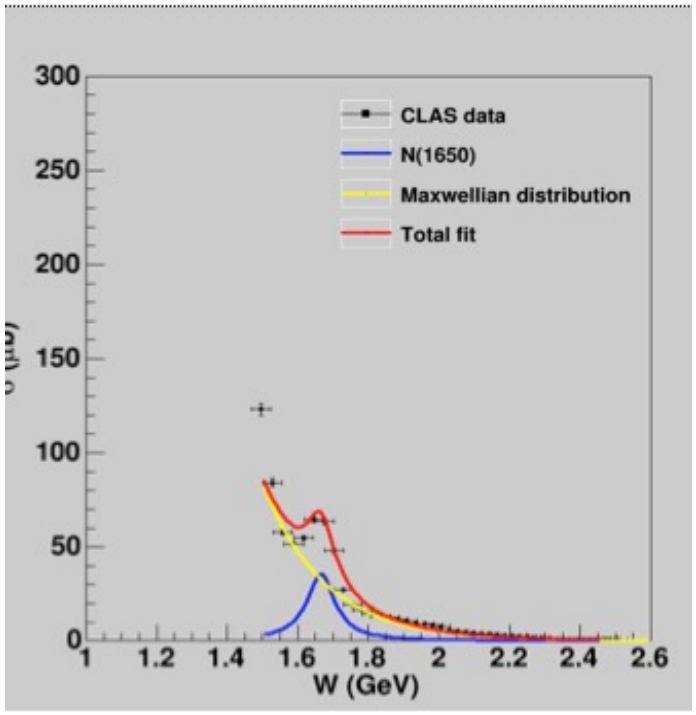
- Data normalized to the 1st and 2nd resonances of SAID in the top and bottom figure respectively
- Correct description of the physics behind the experimental data by the model

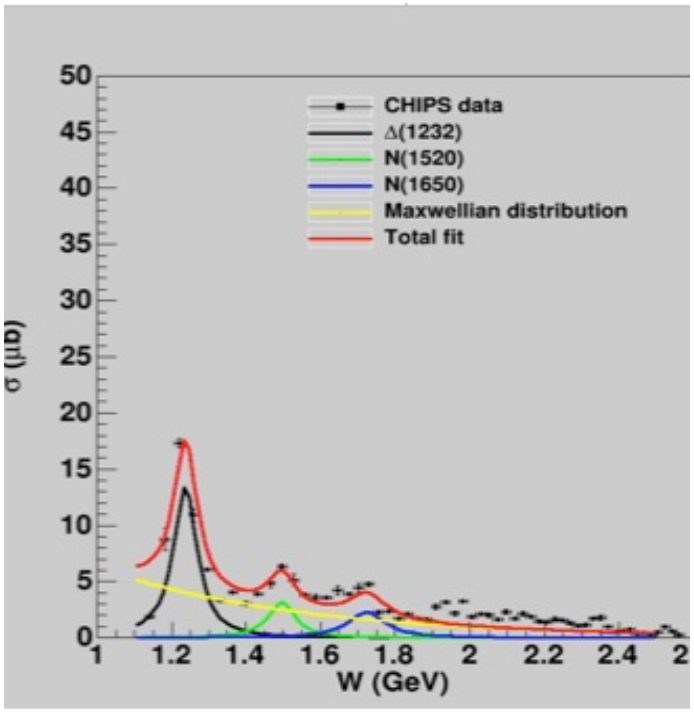


Results
BW fits

- Relativistic BW fits of π^+ cross-sections from CLAS data, the phenomenological model SAID and the simulated data of CHIPS







Results

BW parameters fits comparison

$N\pi^+$	Parameters	1st Peak Δ (1232)	2nd Peak $N^*(1440)$ - $N^*(1520)$	3rd Peak $N^*(1650)$ – $N^*(1720)$
CLAS	σ_0 (μb)	-	-	5.442 5± 4.324
	M (GeV)	-	-	1.666 ± 0.019
	Γ (GeV)	-	-	0.097 ± 0.083
SAID	σ_0 (μb)	24.817 ± 2.498	10.026 ± 2.755	4.574 ± 0.825
	M (GeV)	1.208 ± 0.007	1.494 ± 0.019	1.664 ± 0.010
	Γ (GeV)	0.119 ± 0.002	0.115 ± 0.035	0.102 ± 0.023
CHIPS_simu	σ_0 (μb)	1.602 ± 0.113	0.429 ± 0.091	0.430 ± 0.043
	M (GeV)	1.237 ± 0.005	1.496 ± 0.009	1.724 ± 0.006
	Γ (GeV)	0.076 ± 0.007	0.087 ± 0.020	0.120 ± 0.016

Results

BW parameters fits comparison

$$M_{Peak} = \frac{\sum_{i=1}^{N=3} \omega_i M_i}{\sum_{i=1}^{N=3} \omega_i}$$

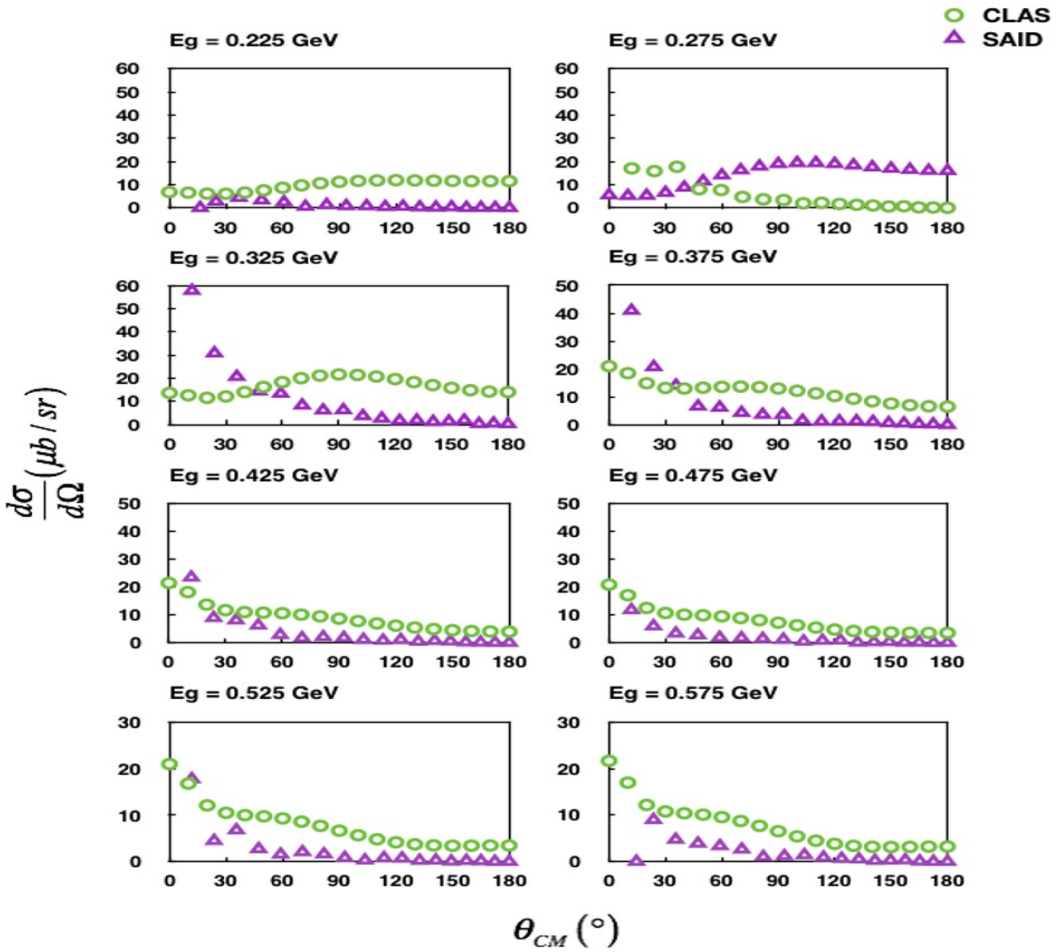
$$\Gamma_{Peak} = 2M_{Peak} \sqrt{\frac{1}{N-1} \sum_{i}^{N} \left(\frac{\Gamma_i/2}{M_i}\right)^2}$$

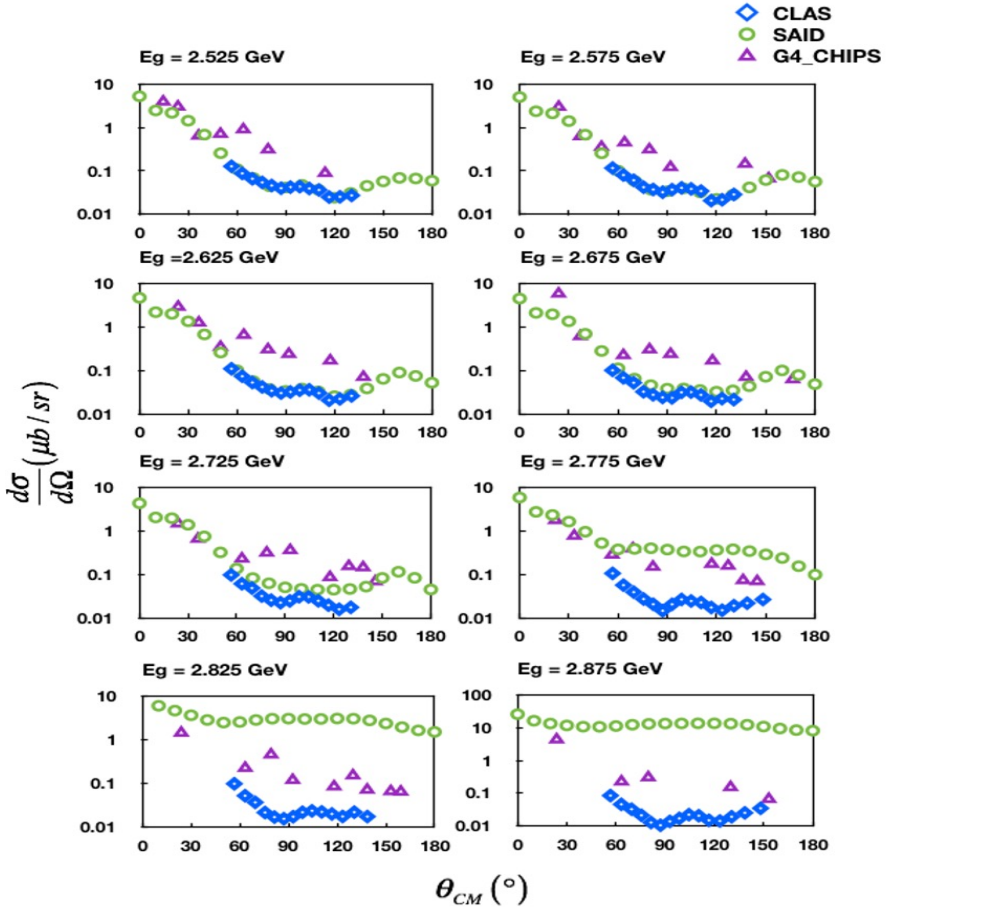
$$\omega_i = \frac{\Gamma_i/2}{M_i}$$

SAID-CHIPS : the agreement the effective masses (widths) are within 2.4% (36.16%) for the (1232), 0.13% (32.18%) for the 2nd peak and 3.61% (17.65%) for the 3rd peak, respectively.

Results

Angular distribution



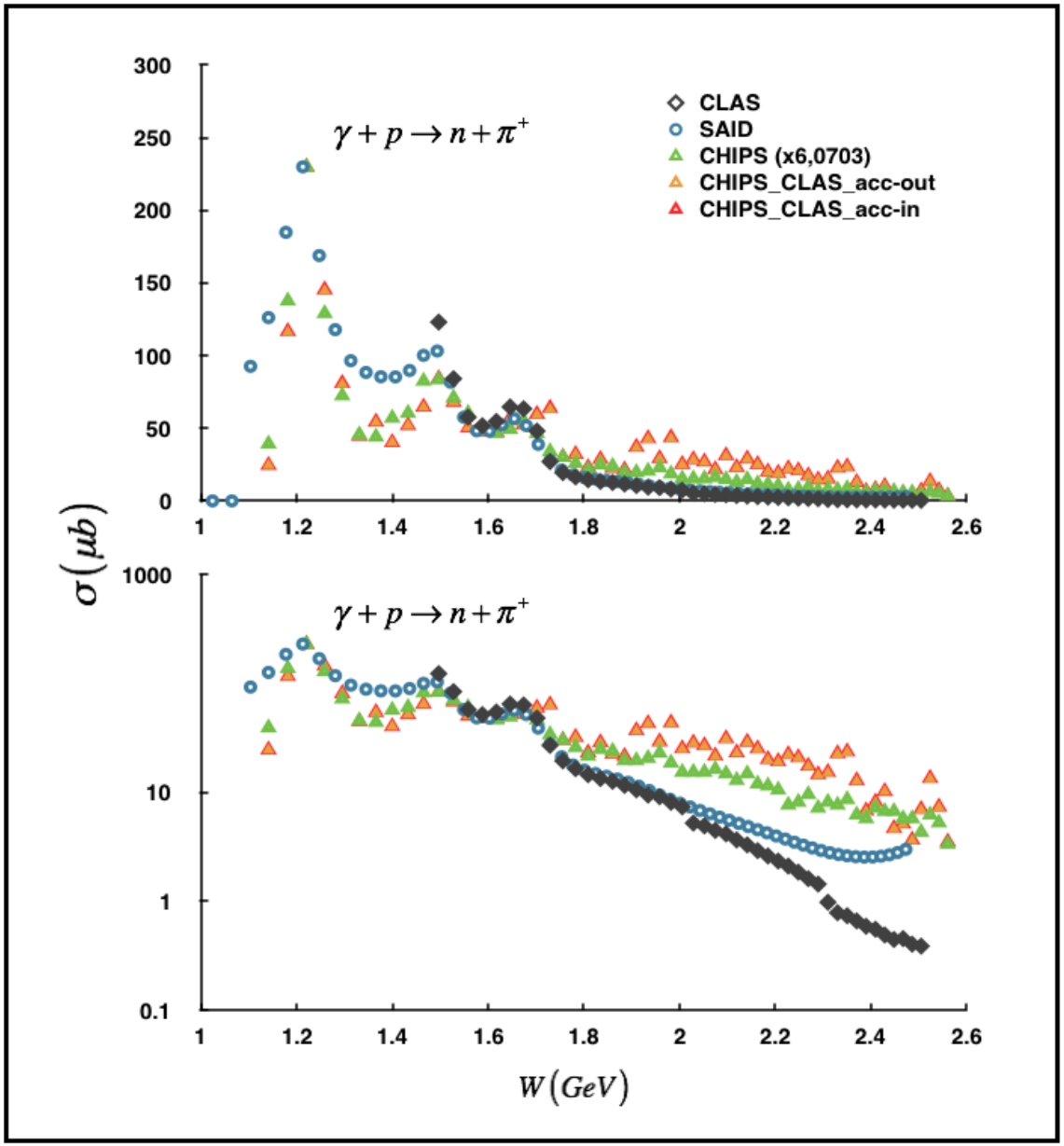


- Angular distributions very different
- No agreement between CLAS and SAID from 2.775 GeV

Results

Cross-sections integrated

- Differential cross-sections of GEANT4 integrated on all the scattering angle (0 - 180º) or according the CLAS acceptance (8 – 140º) overlap perfectly the total cross-sections data.



Summary

- Study the validity of JLab physics in GEANT4 for the pion photo-production reactions off proton
  - CHIPS (Chiral Invariant Phase Space)
  - BERT (BERTini Cascade).
- Verification of tabulated photo-production cross-sections through the Stand-alone code.
- Comparison of tabulated data with experimental data (CLAS/SAID) and PDG
- Simulation of the exclusive pion production reactions via an incident photon beam, using the CHIPS model.

Perspectives

- Calculate the individual contribution of resonances under the 2nd and 3rd peak
- Improved performance of CHIPS for describing differential cross sections
- Take back the CHIPS hadronic model into GEANT4 tool!

References

https://doi.org/10.1140/epja/s10050-021-00640-3

https://link.springer.com/article/10.1140/epja/i2019-12732-4

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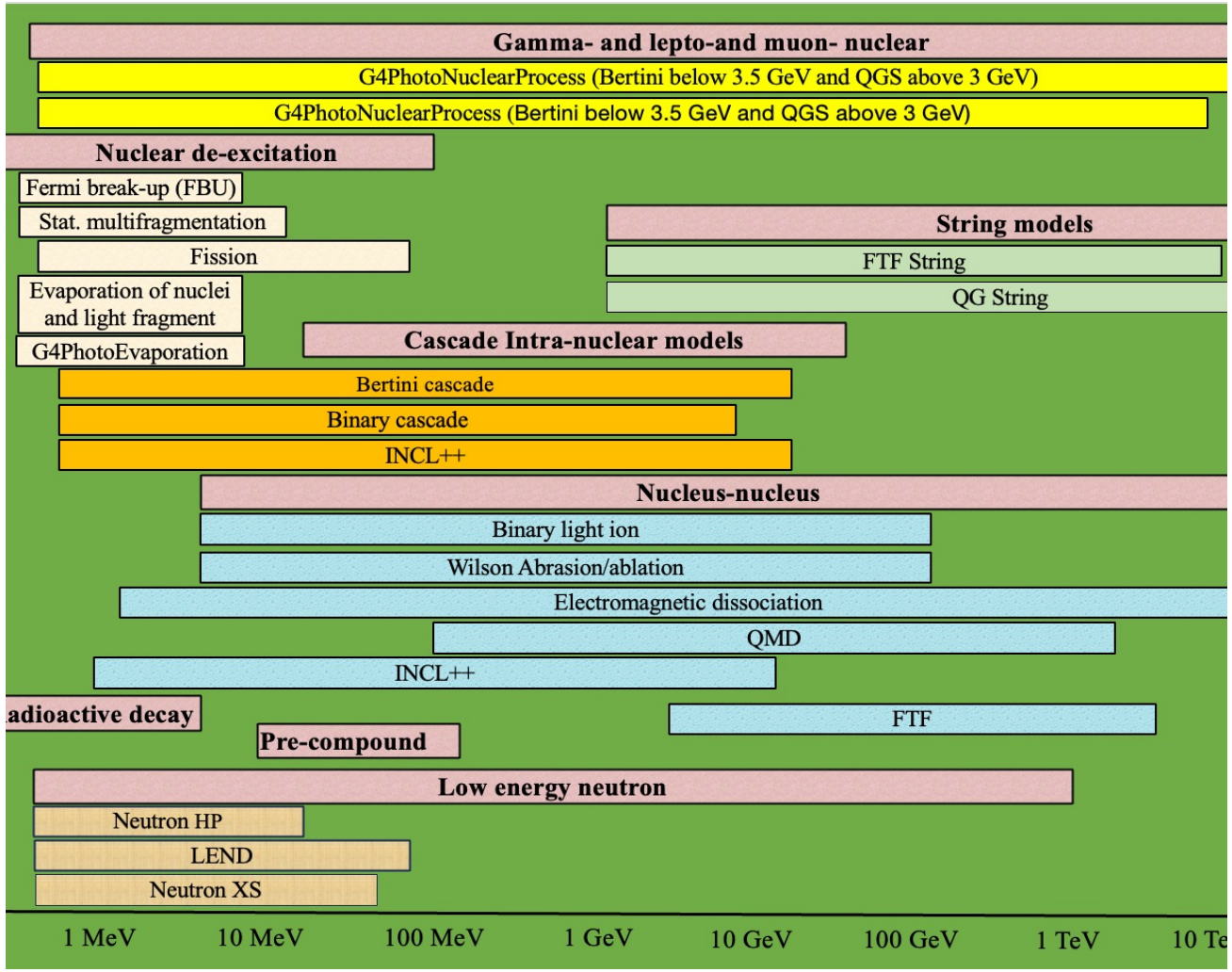
Perspectives

- Study of the muons photo-production via pion decay using the hadronic models;
- Comparison with the GEANT4 EM models;
- Validation with experimental data.



- **References**
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- https://link.springer.com/article/10.1140/epja/i2019-12732-4

- **E-mail:** sokhnabinetalo.amar@ucad.edu.sn

Update of the GEANT4 Hadronic Physics models inventory from 10.07 version

Thank you so much!