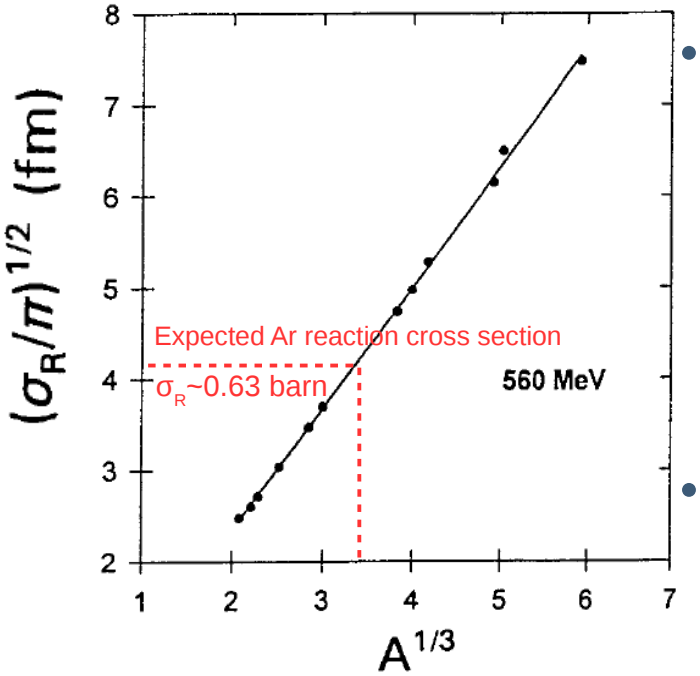
Study of Proton-Argon Cross Section

Heng-Ye Liao, Glenn Horton-Smith, Tingjun Yang
ProtoDUNE sim/reco Meeting
Mar 06, 2019

Motivation & Outline



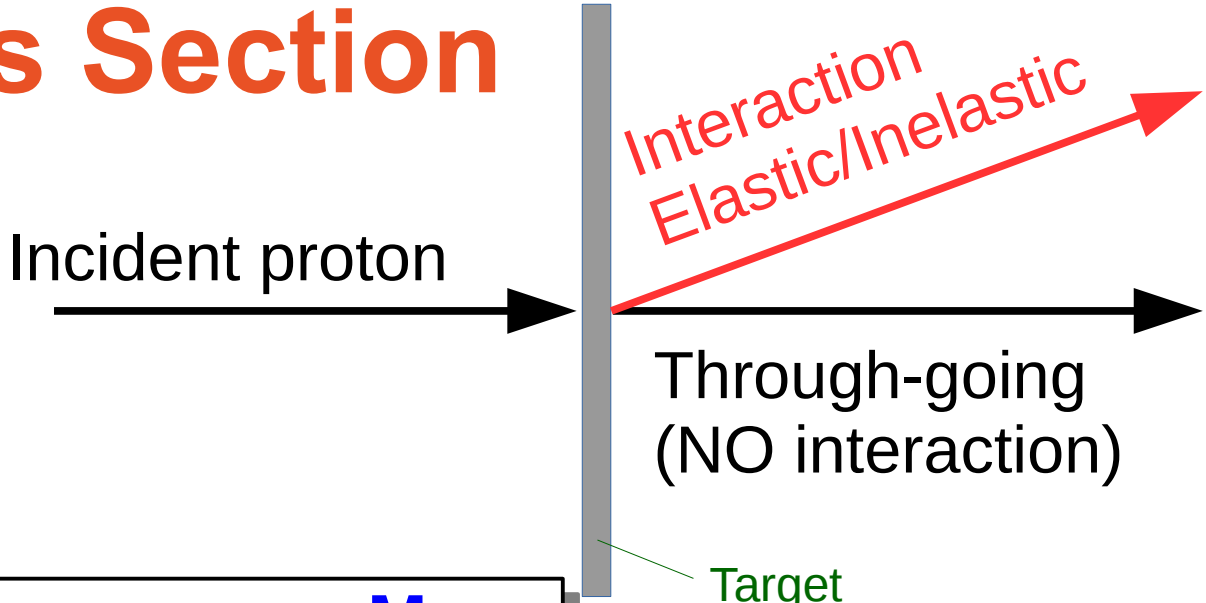
R. F. Carlson, "Proton-nucleus total reaction* cross sections and total cross sections up to 1 GeV", Atomic data and nuclear data tables 63, 93-116 (1996)

- Motivation of proton-argon cross section (XS)
  - Hardly find any proton-argon measurement in our energy region (~400 MeV - ~6.2 GeV)†
  - Predictions come from interpolation between heavier and lighter nuclei
  - Test nuclear structure models
- Outline
  - Method to measure proton-argon XS
  - Proton-argon XS (MC-truth)

* "Reaction" XS in literature = "Inelastic" XS in Geant4

† See page 15 for more references

Cross Section



$$XS = \frac{N^{interacting}}{N^{incident}} \cdot \frac{M_a}{d \cdot L \cdot N_a}$$

- $N^{interacting}/N^{incident}$: "Profile" of cross section
- Scaling factor $(S_f := M_a/d \cdot L \cdot N_a)$: constant

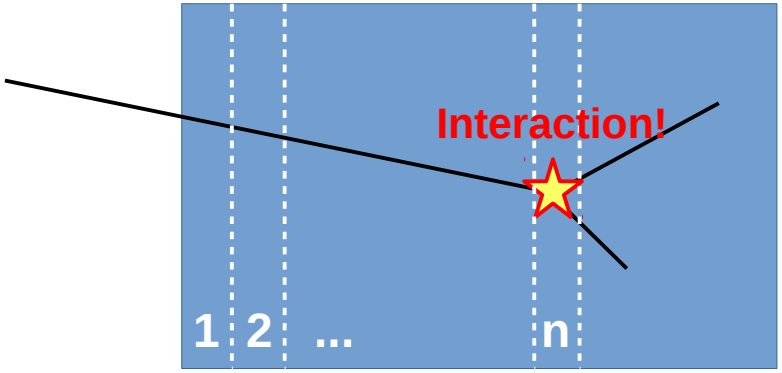
  $N^{incident}/N^{interacting}$: Number of incident/interacting protons

  N_a: Avogadro's number

  M_a: Atomic mass of argon

  d/L: Density/thickness of argon target

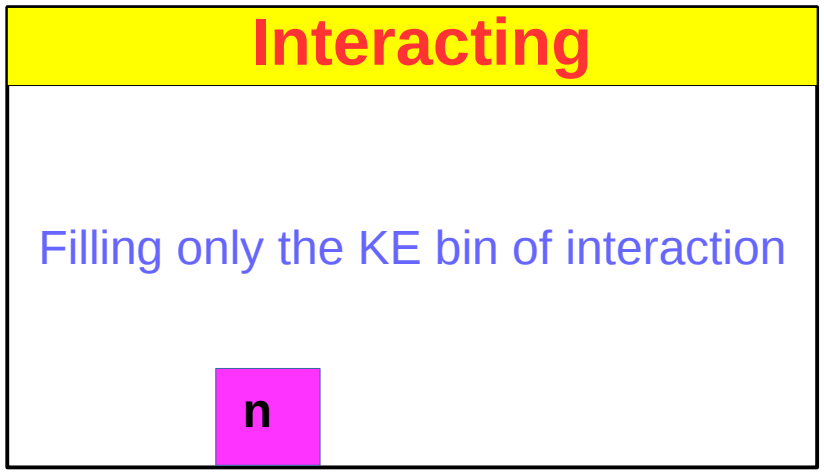
Thin Slice Method

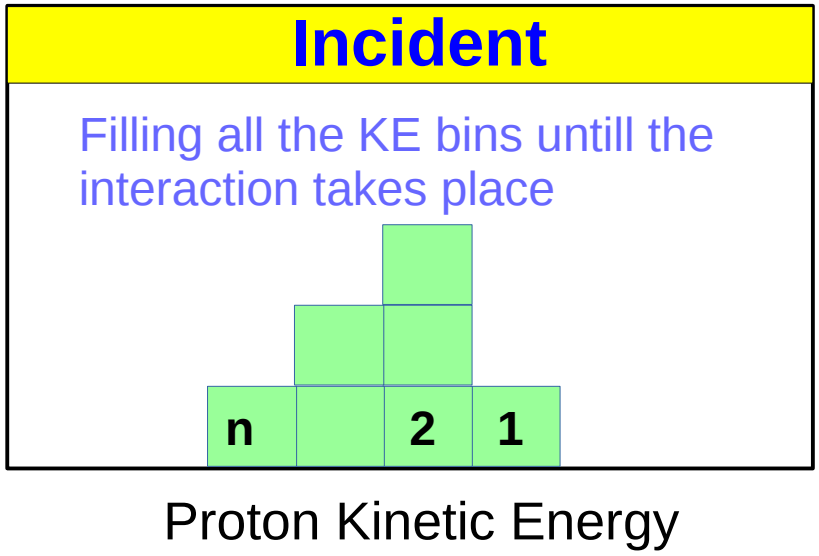


- The thin slice method was developed by the LArIAT experiment
- Use the granularity of LArTPC
  → Treat wire-to-wire spacing as a series of "thin-slab" targets.
  Each thin-slab is an independent measurement.
- Cross section

$$XS(KE) = S_f \cdot \frac{N(KE)^{interacting}}{N(KE)^{incident}}$$

* S_f ~ 100 barn in our case
(Argon, slab thickness~0.5 cm)





MC Setup

- Ajib and I have developed the XS module together since the general purpose is the same for both proton and pion analysis

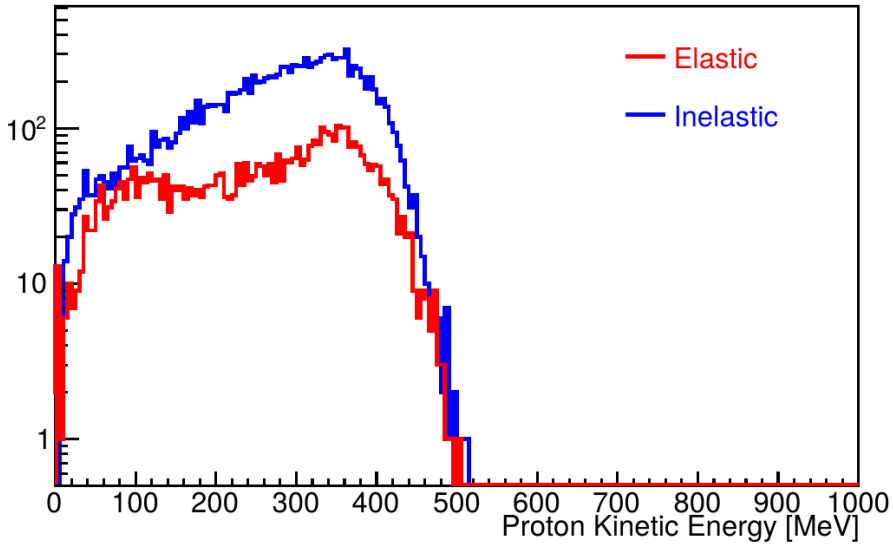
- Thanks to Flavio, Elena, and Hans for many helpful suggestions, valuable experience sharing and technical supports for the XS study!

- MC setup for the XS study
  [1] Generate the proton beam close to the TPC front face
  - Incident proton beam: P=1 GeV/c; σP=0.05 GeV/c
  - (Θ_{xz}, Θ_{yz})=(0°, 0°) & (x_0, y_0, z_0)=(-80, 420, -10) cm
  - 50,000 events generated
  - Electron lifetime: 3 ms
  - Only the truth info, no reconstruction

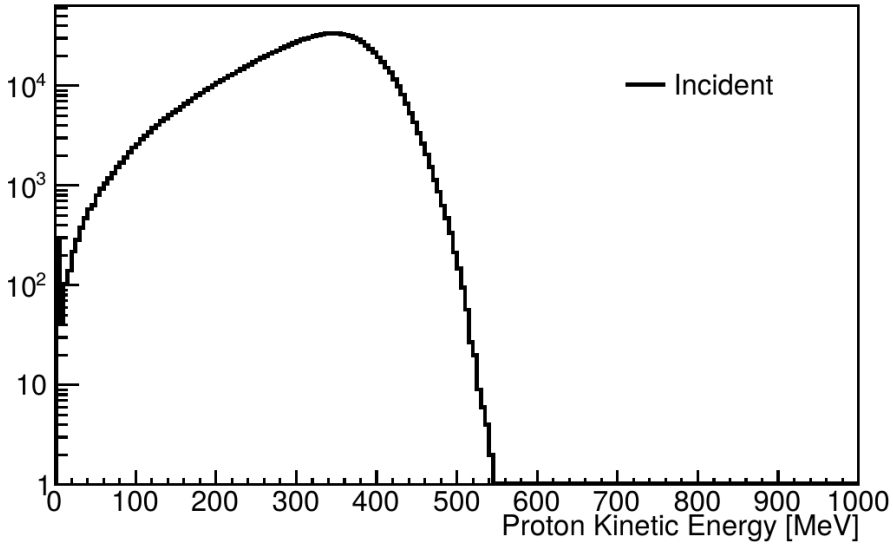
  [2] Apply the thin slice method to derive the proton-argon XS (collection plane only)

Proton Kinetic-Energy Distributions (MC)

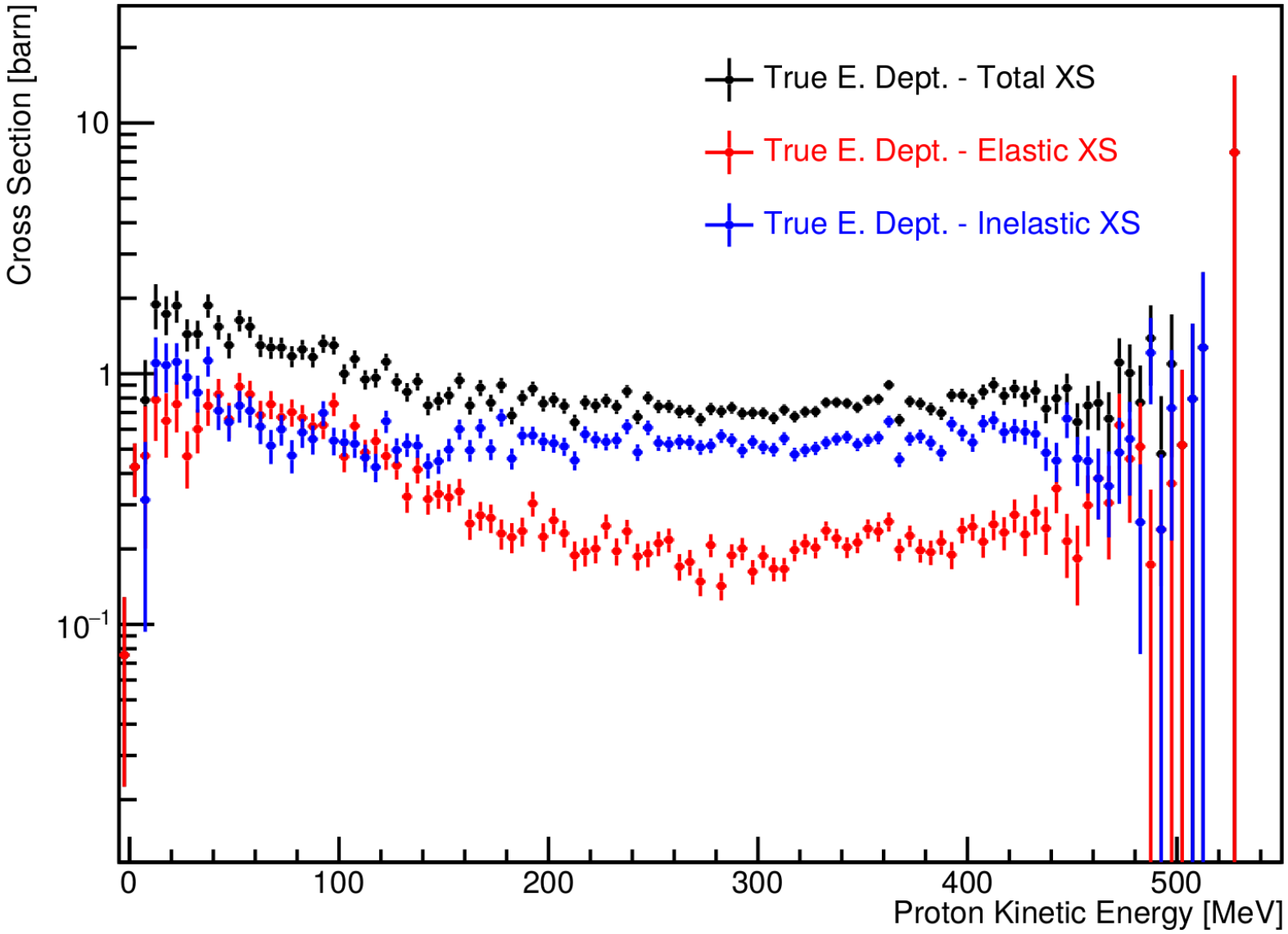
Interacting



Incident



Proton-Ar Cross Sections (MC Truth)



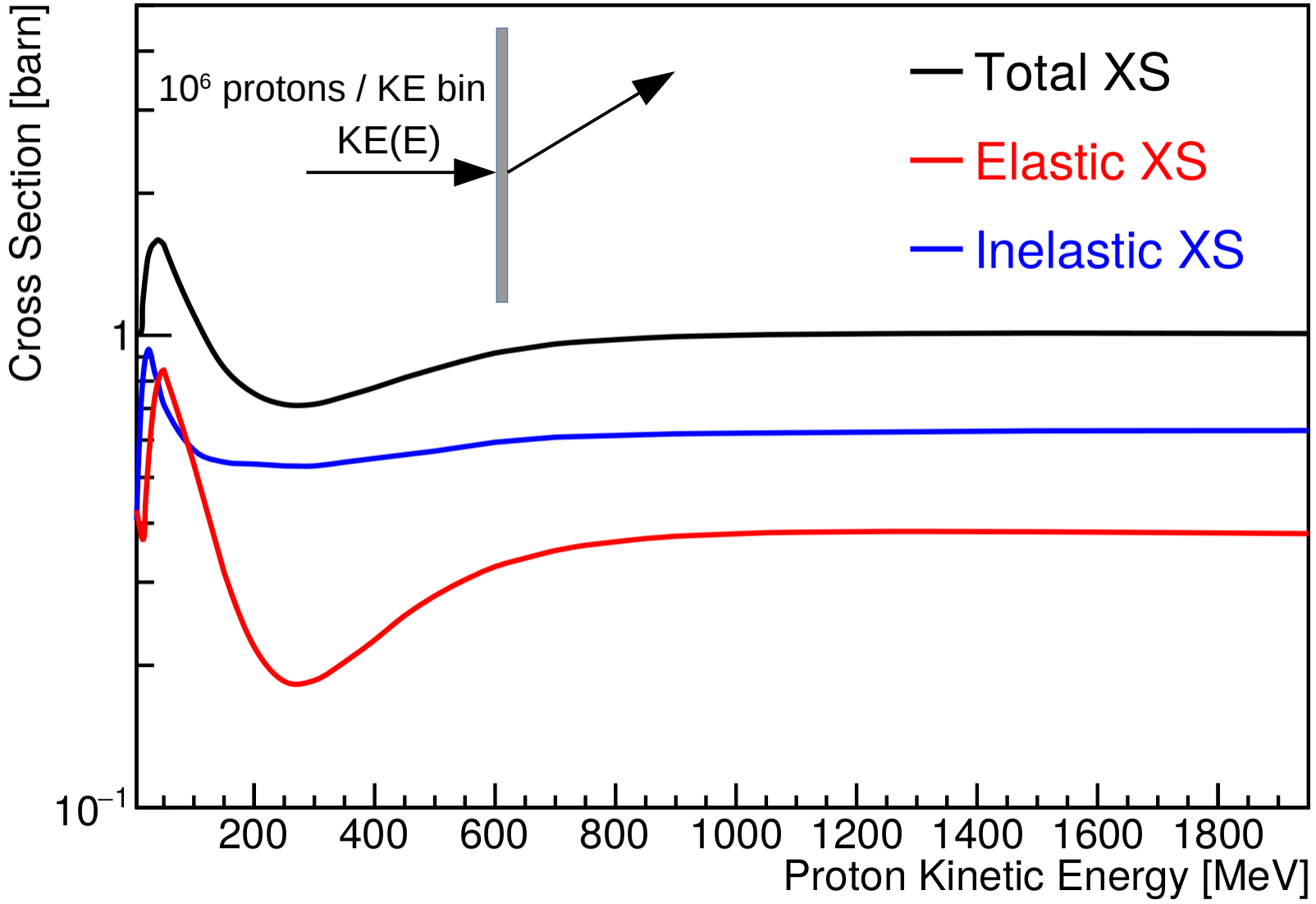
LArSoft Geant4 version: 10.3

Geant4 Application (G4HadStudies)

- Proof-of-principle of the thin slice method
  - Use a stand-alone Gean4 application to test if the method works
  - To verify the cross section result from the implemented LArSoft module

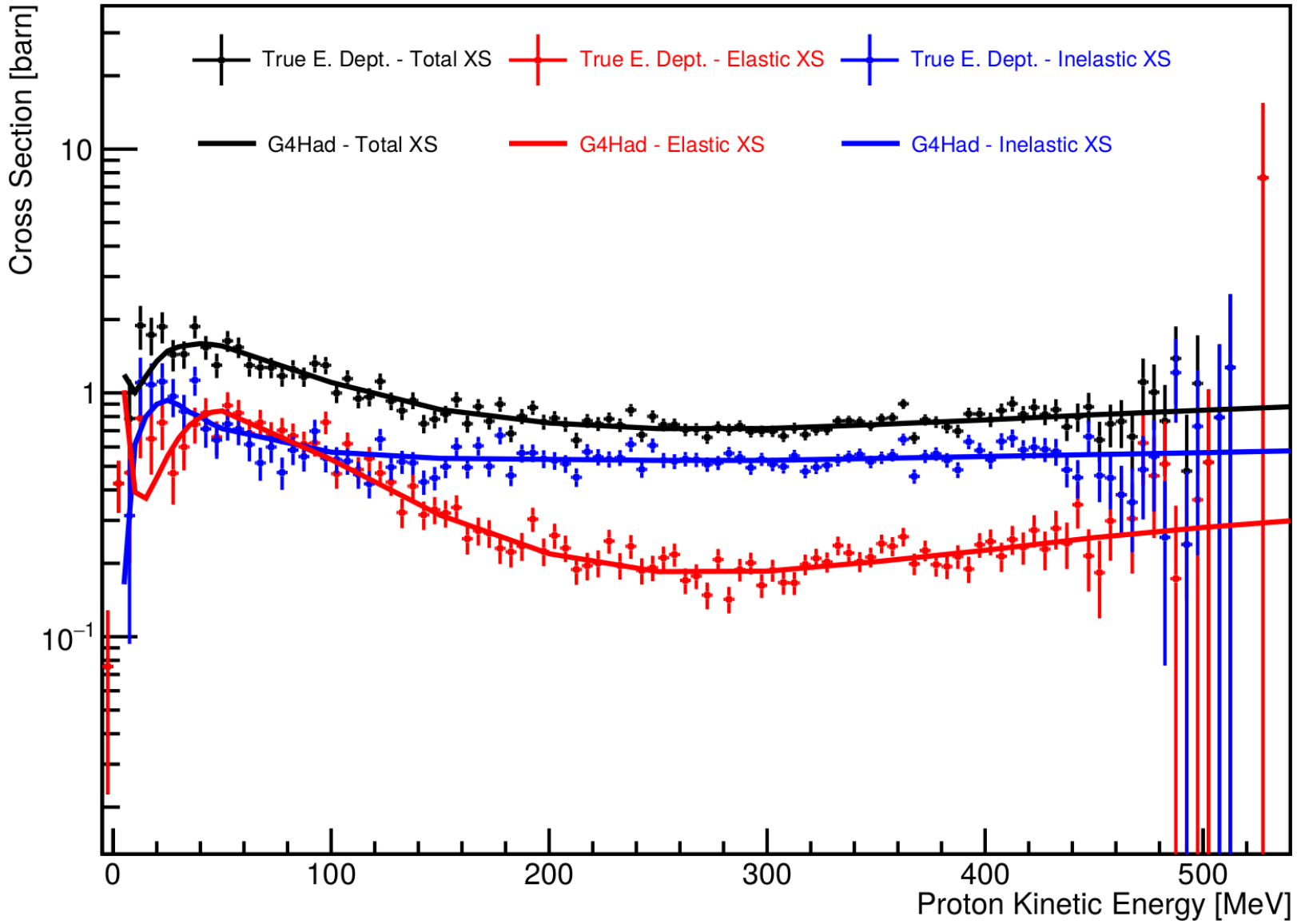
- G4HadStudies (Developed by Hans Wenzel):
  - A very nice Geant4 application to calculate the hadronic cross sections
    + Easy to install & run
    + Details of the truth information can be extracted easily
    + Hadronic models can be plug in/out in a painless way
  - Github link
    https://github.com/hanswenzel/G4HadStudies

Geant4 Cross Sections (G4HadStudies)



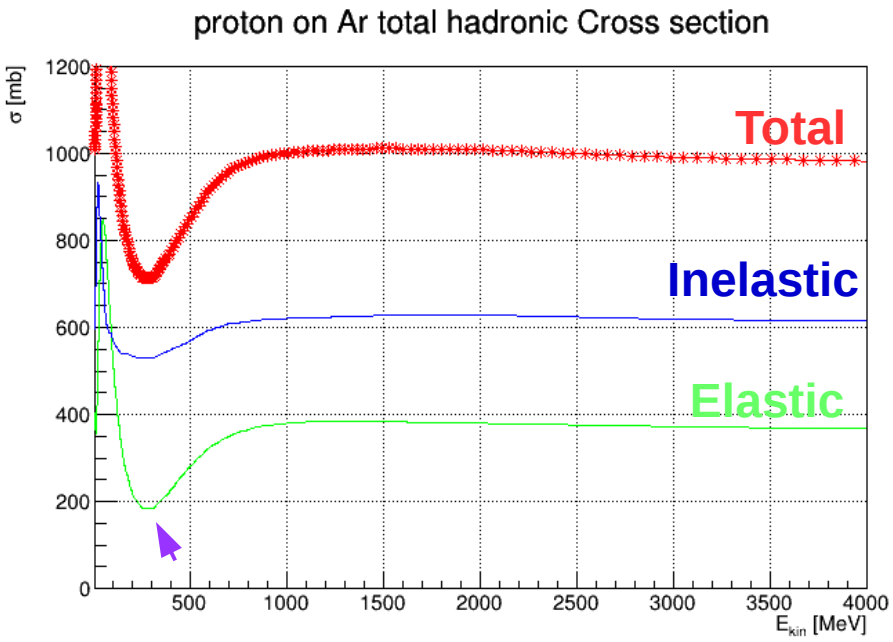
Geant4 version: 10.4

Cross Sections - Comparison



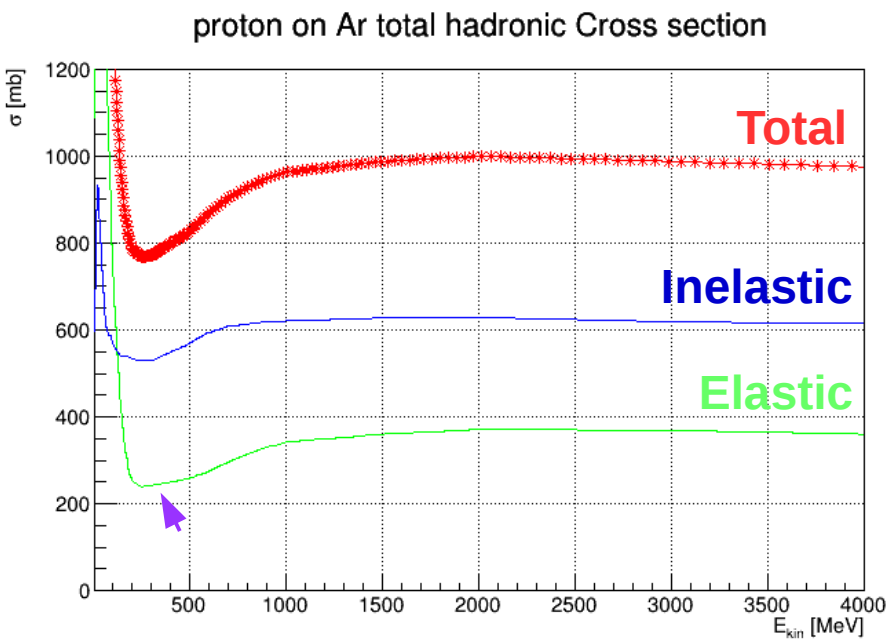
*Geant4 versions: LArSoft: 10.3 <> G4Had: 10.4

XS: Geant4 Versions



Version 10.4

(Figure credit: Hans Wenzel)



Version 10.5
(latest version*)

- Geant4 version matters
- Discrepancy in the low energy region
- Provide a validation of Geant4 models using our data!

*Released on Dec/07/2018 (v10.4: Dec/08/2017; v10.3: Dec/09/2016)

Geant4 10.4 & 10.5: Model Comparison

10.5	10.4
Process: ***hadElastic*** Model: hElasticCHIPS: 0 eV - 100 TeV Cr_sctns: Barashenkov-Glauber: 0 eV - 100 TeV	Process: ***hadElastic*** Model: hElasticCHIPS: 0 eV - 100 TeV Cr_sctns: ChipsProtonElasticXS: 0 eV - 100 TeV Cr_sctns: GheishaElastic: 0 eV - 100 TeV
Process: ***protonInelastic*** Model: FTFP: 3 GeV - 100 TeV Model: BertiniCascade: 0 eV - 12 GeV Cr_sctns: Barashenkov-Glauber: 0 eV - 100 TeV	Process: ***protonInelastic*** Model: FTFP: 3 GeV - 100 TeV Model: BertiniCascade: 0 eV - 12 GeV Cr_sctns: Barashenkov-Glauber: 0 eV - 100 TeV Cr_sctns: GheishaInelastic: 0 eV - 100 TeV

Credit: Hans Wenzel

- According to the release notes, there were a lot of changes to the cross sections between 10.4 and 10.5. (see “Hadronic Physics” & “Physics Lists” in: http://geant4-data.web.cern.ch/geant4data/ReleaseNotes/ReleaseNotes4.10.5.html)

*Note. Unlike the EM physics in Geant4, 1 process has 1 model and 1 cross section, the Hadronicphysics in Geant4 has many possible models, cross sections (Cr_sctns).

Summary & Outlook

- MC-based study on the proton-argon cross section
- Applied the thin slice method to the Monte Carlo data
- The cross section results from the two MC-based methods are in close agreement with each other
- Geant4 version matters

- Work in progress:
  - Comparison of the reconstructed and the true end-points of the primary proton tracks (preparation before looking at the real data)

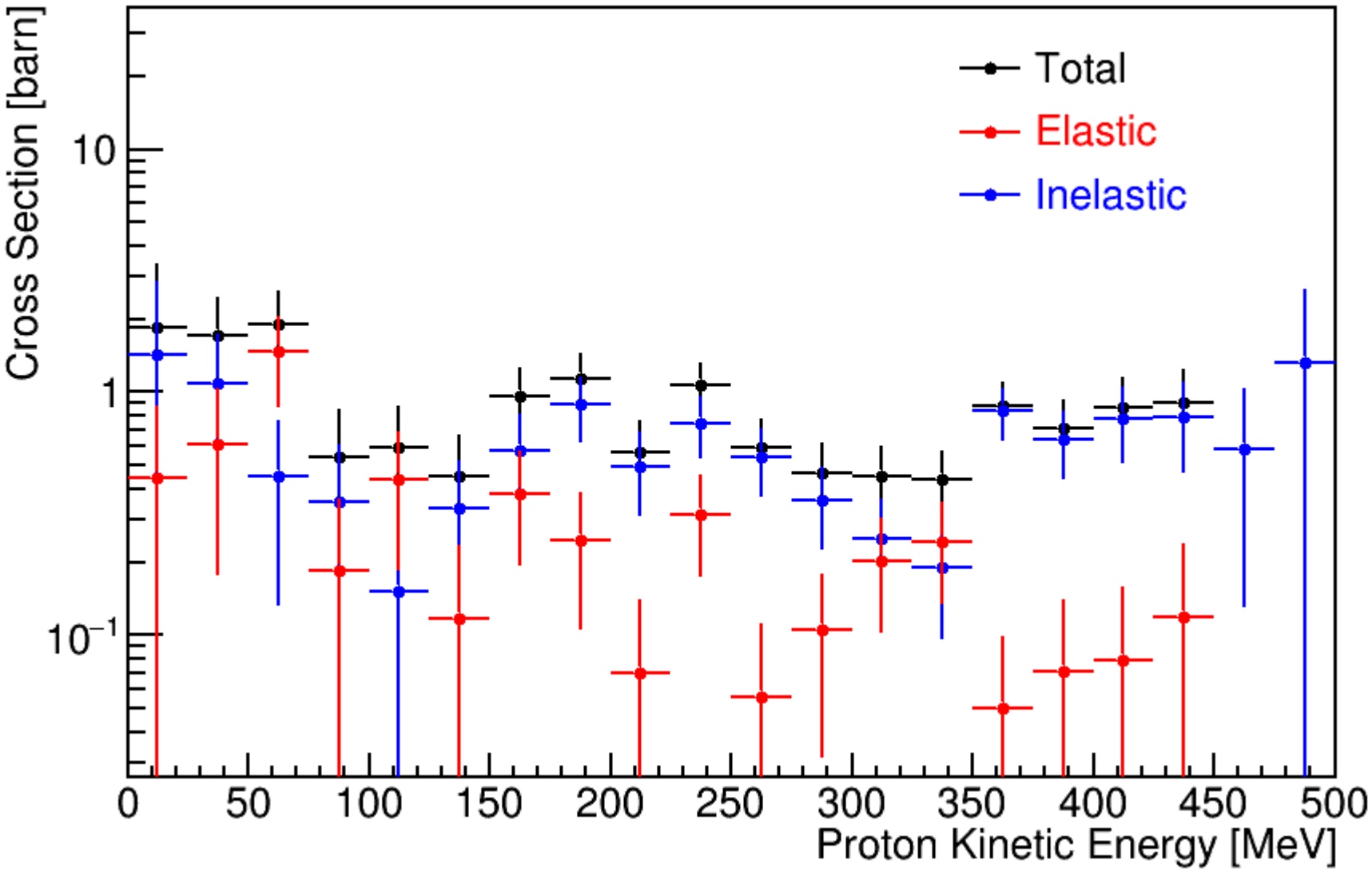
Backup

Literature Survey on Proton XS

#	Title of Paper	Author(s)	Journal
1	Measurements of the proton total reaction cross section for light nuclei between 20 and 48 MeV	McGill, W.F. et al.	Phys.Rev. C10 (1974), p2237-2246
2	Proton Total Reaction Cross Sections in the 10-20-MeV Range: Calcium-40 and Carbon-12	J.F. Dicello, G. Igo	Phys.Rev.C2 (1970) , p488-499
3	Reaction cross sections for protons on C-12, Ca-40, Zr-90 and Pb-208 at energies between 80-MeV and 180-MeV	A. Auce, A. Ingemarsson et al.	Phys.Rev.C71 (2005) , p: 064606
4	Reaction cross sections for protons in the energy range 220-570 MeV	P.U.Renberg, D.F.Measday et al.	Nuclear Physics Al83 (1972) 81-104
5	Proton-nucleus total reaction cross sections and total cross sections up to 1 GeV	R. F. Carlson	Atomic data and nuclear data tables 63,93 – 116 (1996)
6	Proton-argon elastic scattering at 9.8MeV	T. HonJeong, L. Johnston et al.	Nuclear and Instruments and methods volume 28, Aug. 1964, 325-329
7	Total Reaction Cross-Section Measurements With 60 MeV Protons	J. J. H Menet, E. E. Gross et al.	Phys. Rev. Lett. 22, 1128 – Published 26 May 1969
8	Cross sections for reactions with 593 and 540 MeV protons in aluminium, arsenic, bromine, rubidium and yttrium	A. Grütter	The International Journal of Applied Radiation and Isotopes, volume 33, Issue 9, September 1982, 725-732
9	Reactions of Protons with Ni58 and Ni60	Sheldon Kaufman	Phys. Rev. 117, 1532 – Published 15 March 1960
10	Reaction Cross Sections for 30- to 60-MeV Protons on Various Elements: Comparison of Theoretical Results with Experiment	H. W. Bertini	Phys. Rev. C 5, 2118 – Published 1 June 1972
11	Proton-nucleus total crosssections in the intermediate energy range*(100-2200 MeV)	L. Ray	Physical Review C, 1979 - APS
12	Nuclear reactions of tantalum with 5.7-Gev protons	J. R. Grover	Physical Review, 1962 - APS
13	A study of proton total reaction cross sections for several medium-mass nuclei between 20 and 48 MeV	R. H. McCamis, et al	Canadian Journal of Physics, 1986, Vol. 64, No. 6 : pp. 685-691
14	A Direct Measurement of the Proton Total Reaction Cross Section for Copper at 9.3 Mev	G. W. Greenlees and O. N. Jarvis	Proceedings of the Physical Society, 1961
15	Energy dependence of proton-nucleus reaction cross sections	A. Ingemarsson and M. Lantz	PHYSICAL REVIEW C 72, 064615 (2005)
16	Total cross section measurements with π− , Σ− and protons on nuclei and nucleons around 600 GeV/c	SELEX Collaboration	Nuclear Physics B Volume 579, Issues 1–2, 17 July 2000, Pages 277-312
17	Measuring system of proton total reaction cross-sections at tandem energy region	Nokumura, et al	Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Volume 487, Issue 3, 21 July 2002, Pages 565-570

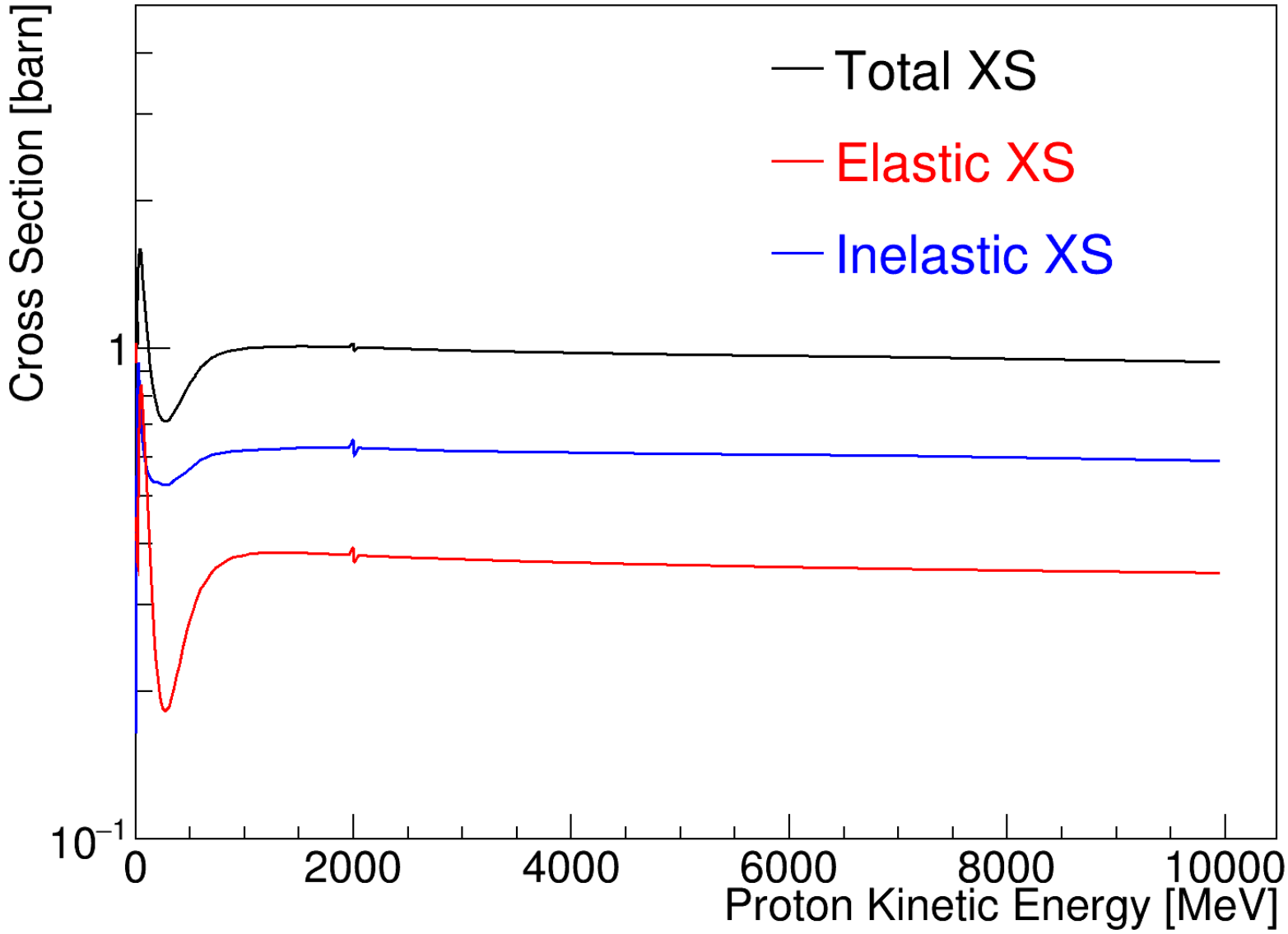
* "Reaction" XS in literature = "Inelastic" XS in Geant4

Proton-Ar Cross Section (MCC11)



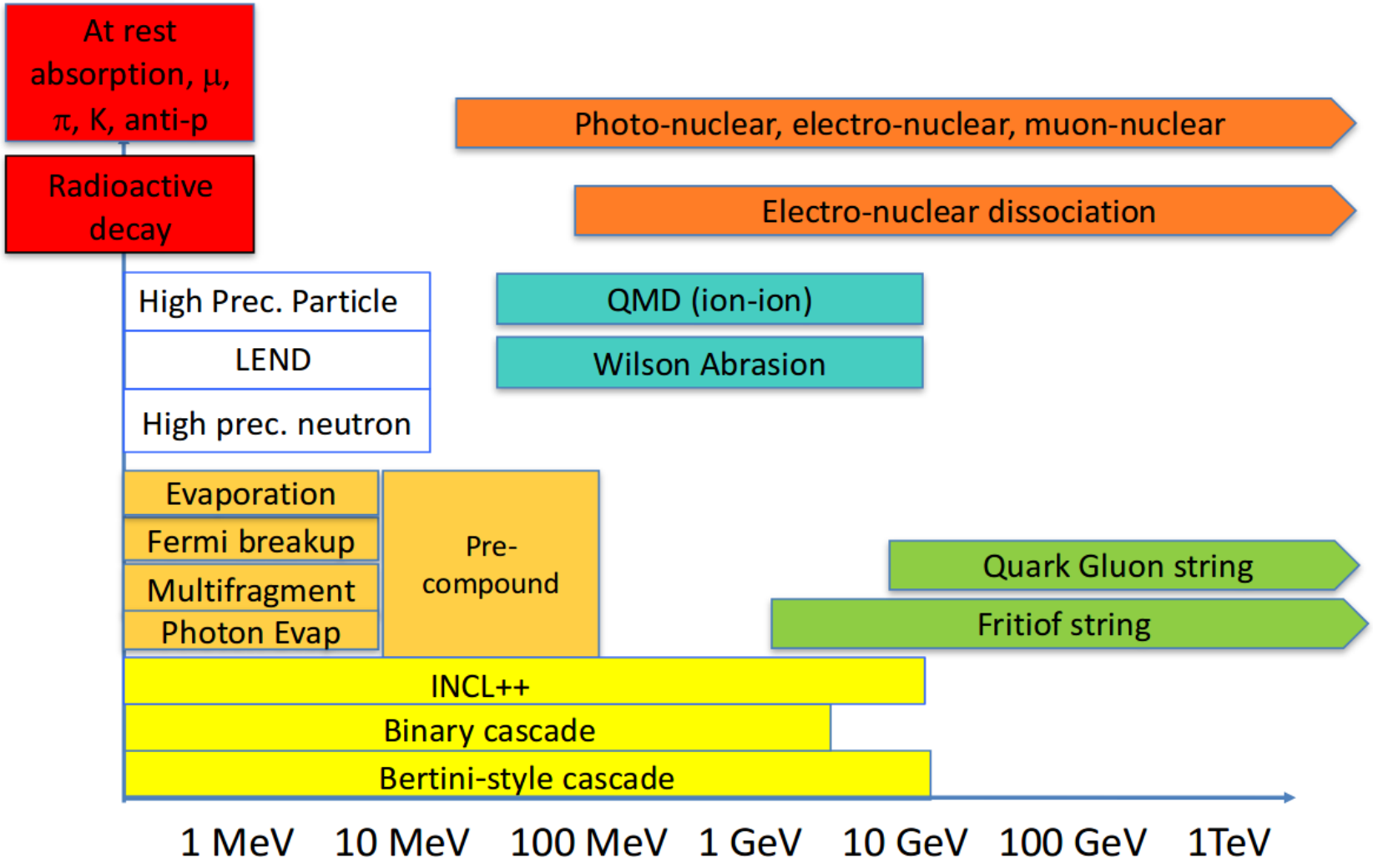
Geant4 version of MCC11: 10.3

Proton-Ar XS (g4Had): High Energy Region



Geant4 version: 10.4

Partial Hadronic Model Inventory



Credit: Dennis Wright, “Geant4 Tutorial at Lund University”, 09/06/2018