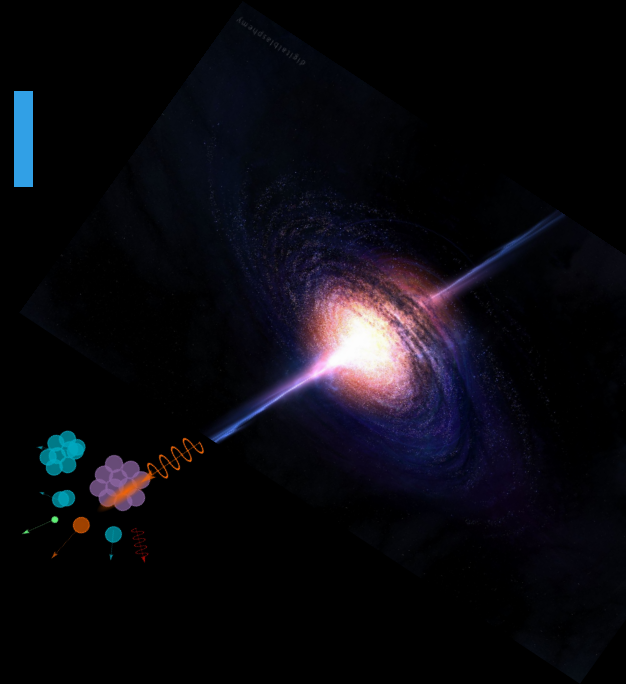


An improved model of UHECR nuclei photomeson interactions



...beyond a superposition of nucleons

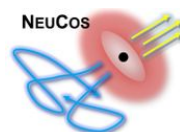
TeV Particle Astrophysics 2019

Leonel Morejon

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Contributing Authors: A. Fedynitch, D. Boncioli, D. Biehl, W. Winter

HELMHOLTZ SPITZENFORSCHUNG FÜR
GROSSE HERAUSFORDERUNGEN

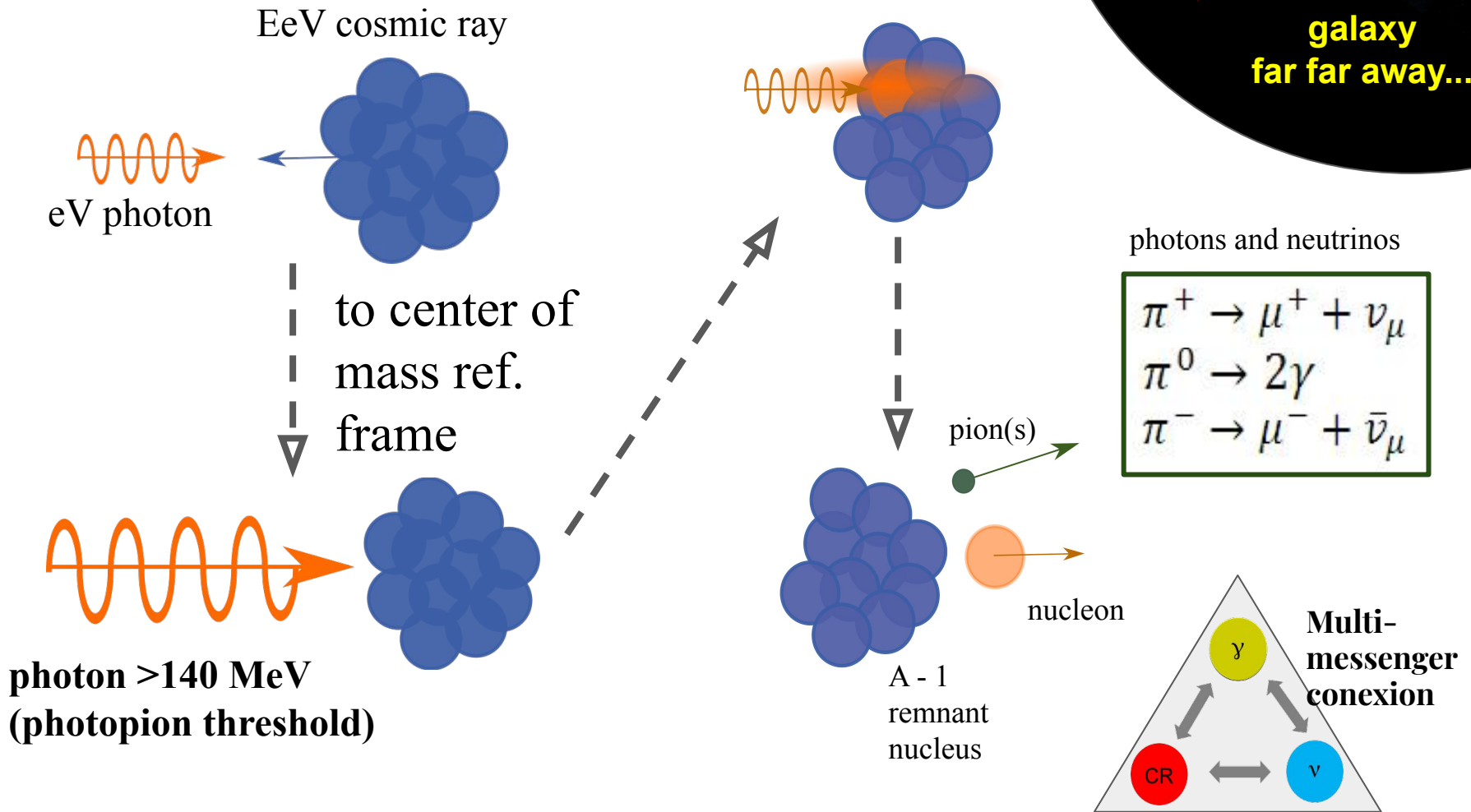


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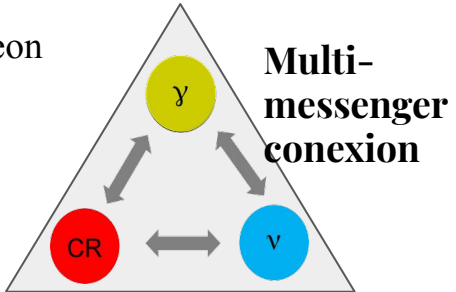
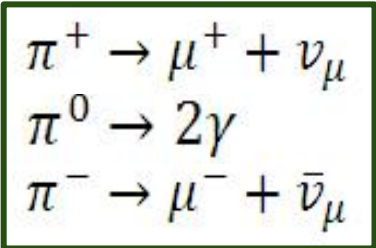


Photomeson interactions briefly...

...photoproduction of pions resulting in neutrinos



photons and neutrinos



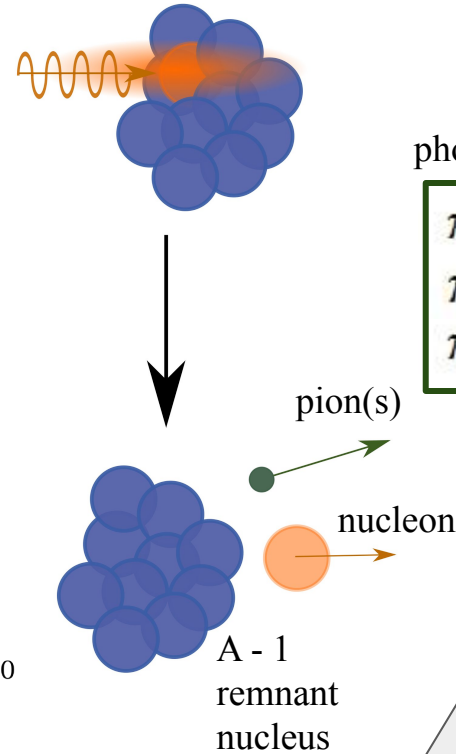
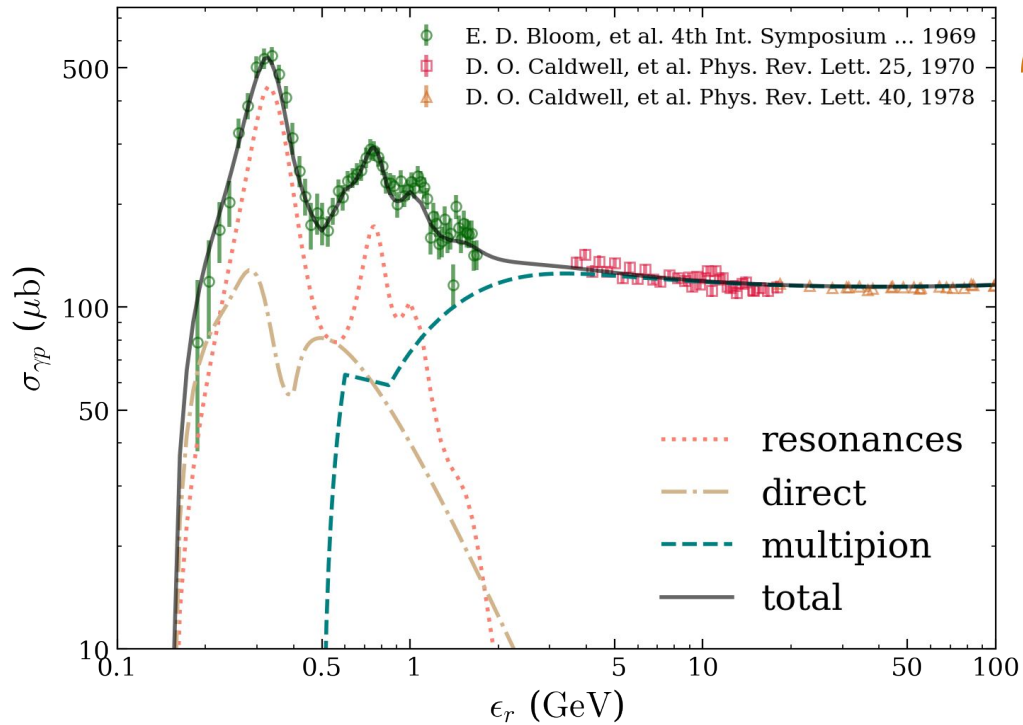
Single-particle model for nuclei

in short: nucleons in nuclei are considered free

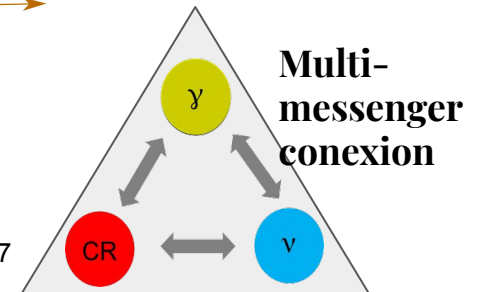
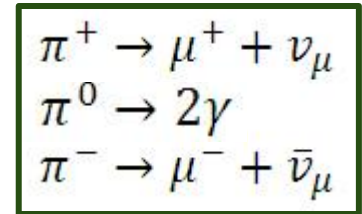


In a galaxy far far away...

Cross section for photon - proton interactions vs photon energy (as in SOPHIA)



photons and neutrinos



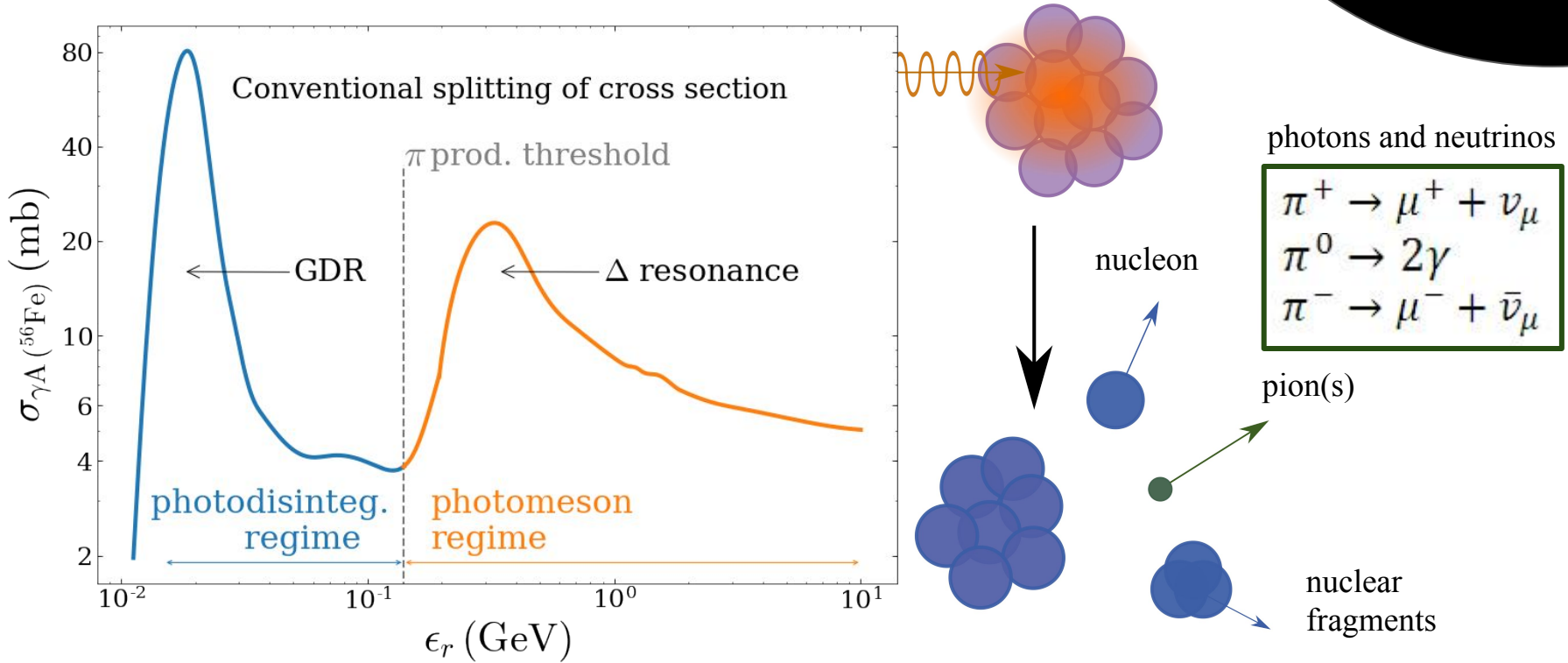
Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

Photomeson interactions for nuclei

Nuclear medium effects not negligible



Schematic cross section for photonuclear interactions vs photon energy



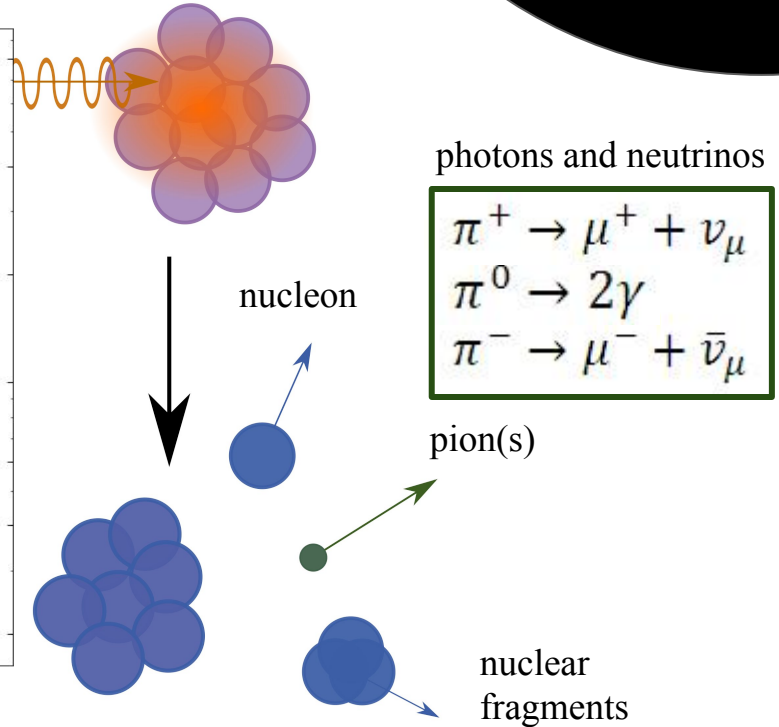
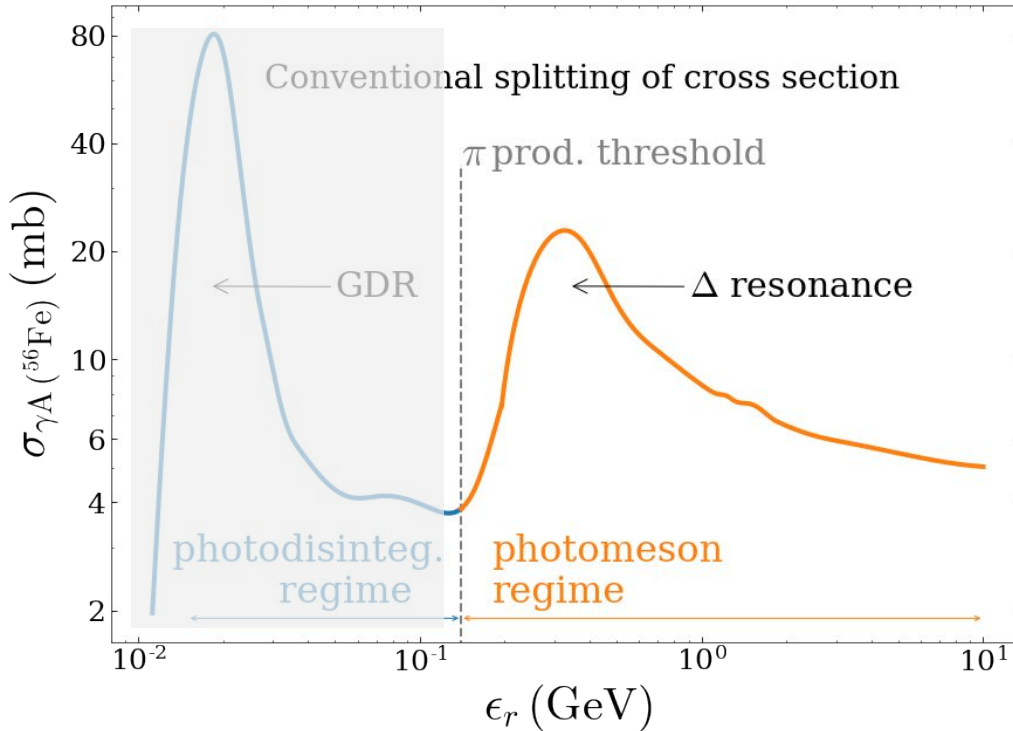
Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

Photomeson interactions for nuclei

Nuclear medium effects not negligible



Schematic cross section for photonuclear interactions vs photon energy

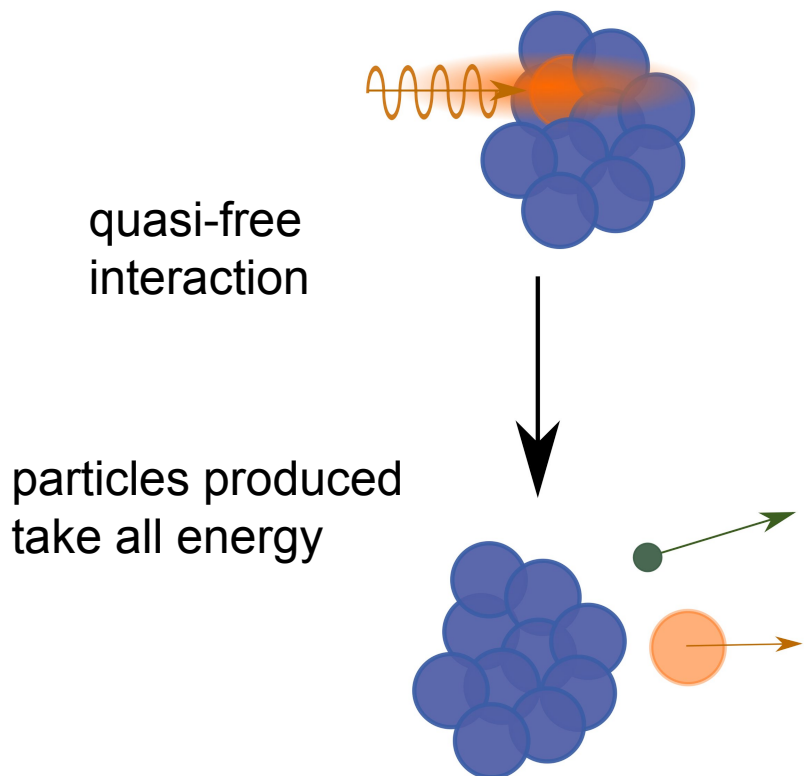


Ref: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

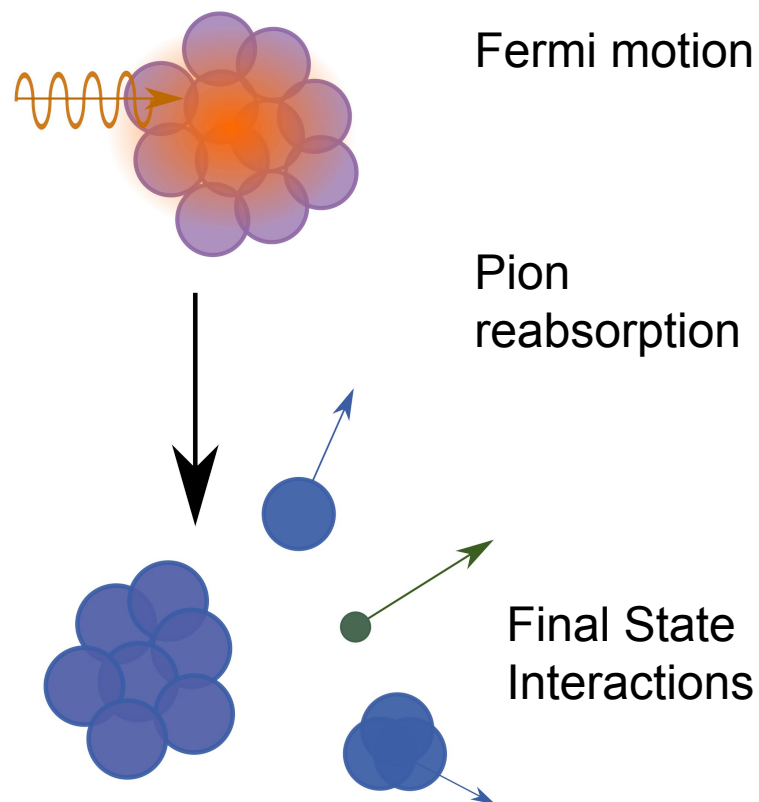
Old vs New model in schematics

Conventions used in what follows

Single Particle Model (SPM)



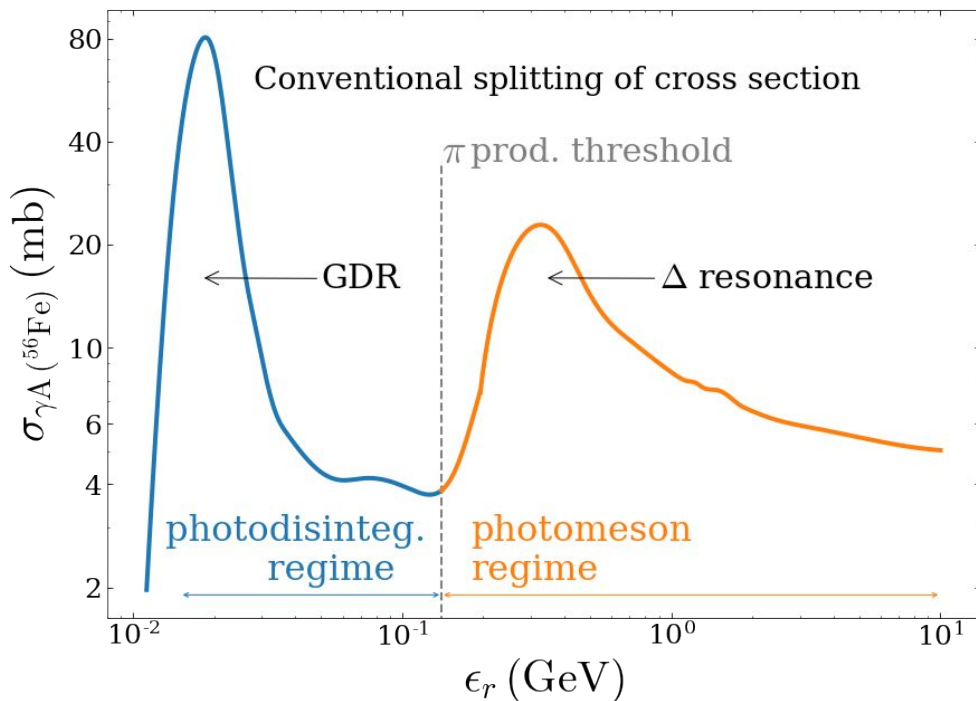
Empirical Model (EPM)



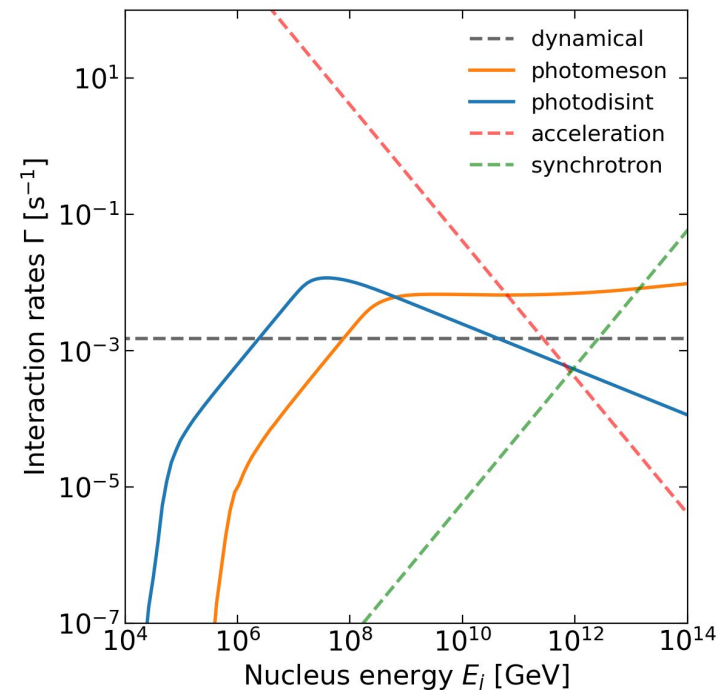
Cross section imprints on interaction rates

In scenarios where photomeson interactions are dominant

Photonuclear interactions with broken power law photon fields



Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

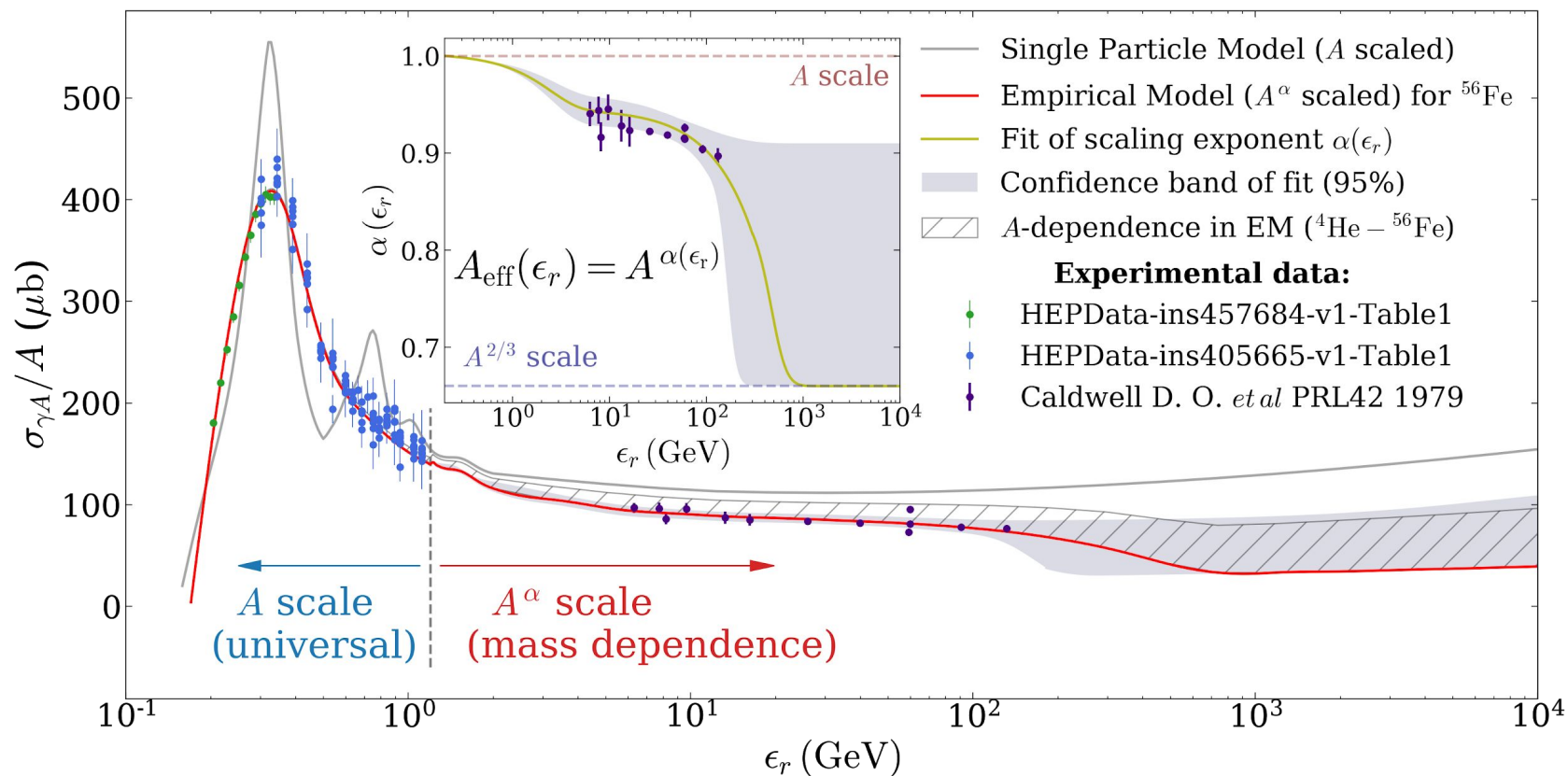


Ref: LM, Poster Presentation TeVPA(2018)

Total cross section

General differences with the free nucleon interaction

Resonances are smeared and shadowing effects occur.

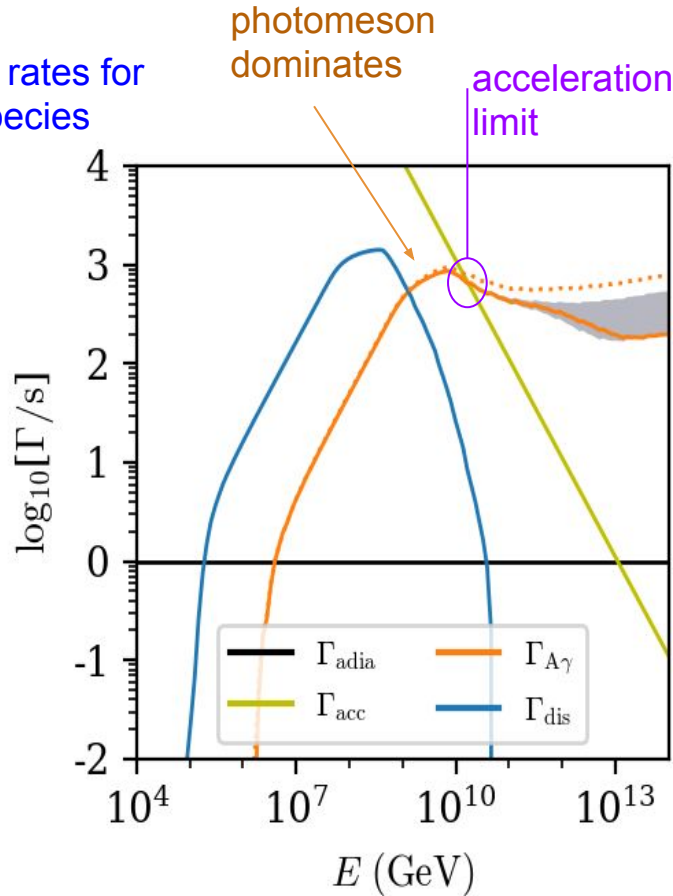


Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

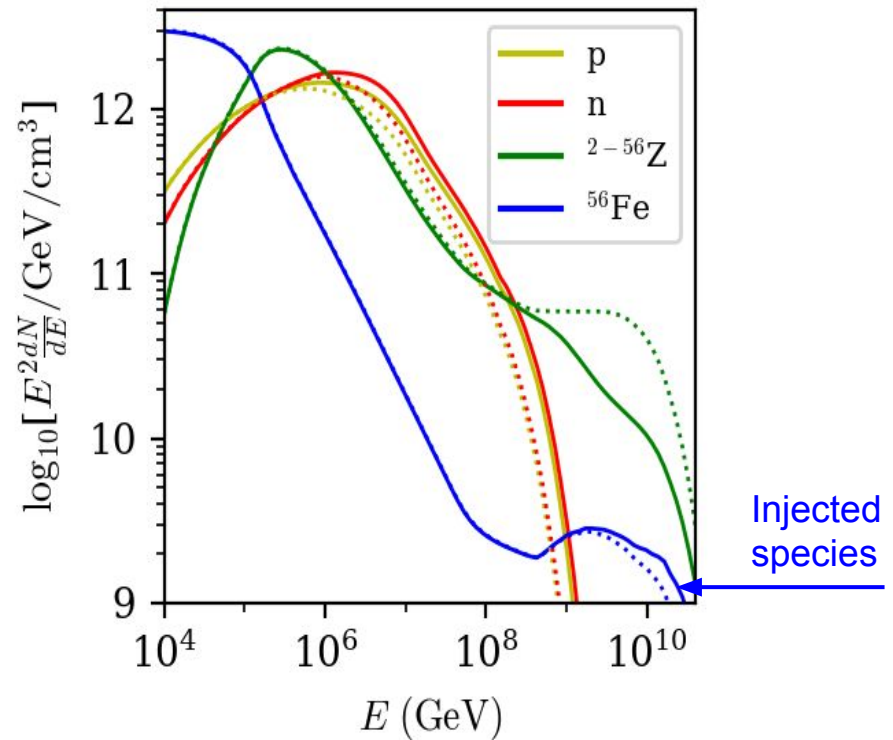
Gamma-Ray Burst source

Impact of the cross section

Interaction rates for injected species



Lower interaction rates at higher energies!



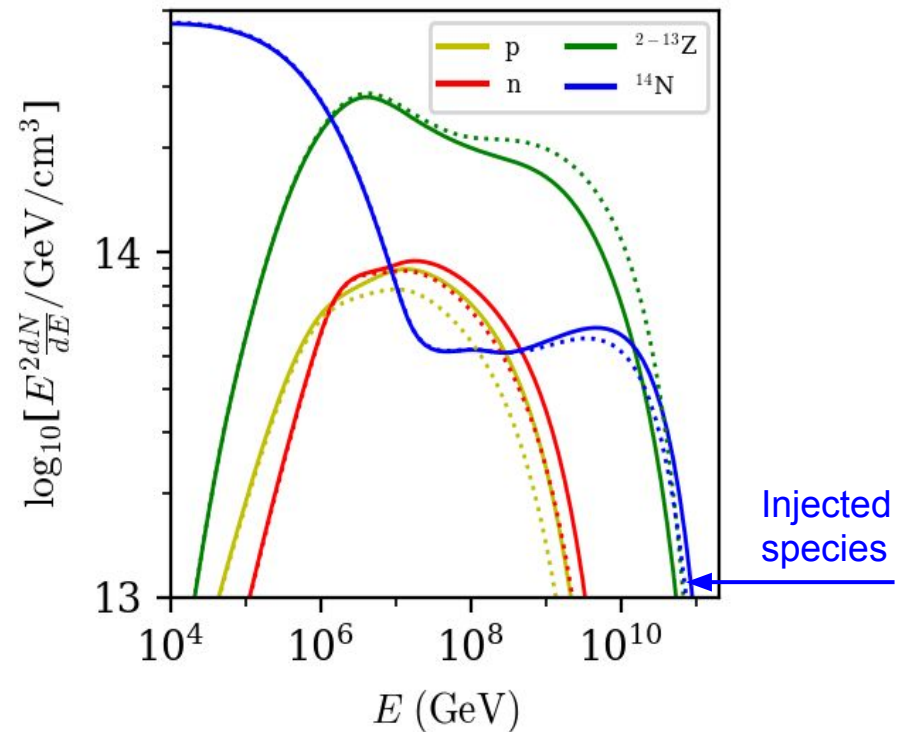
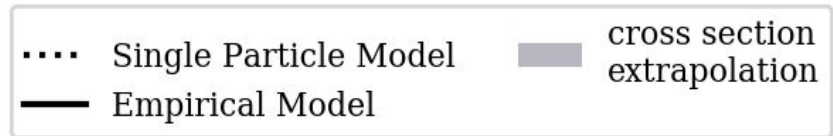
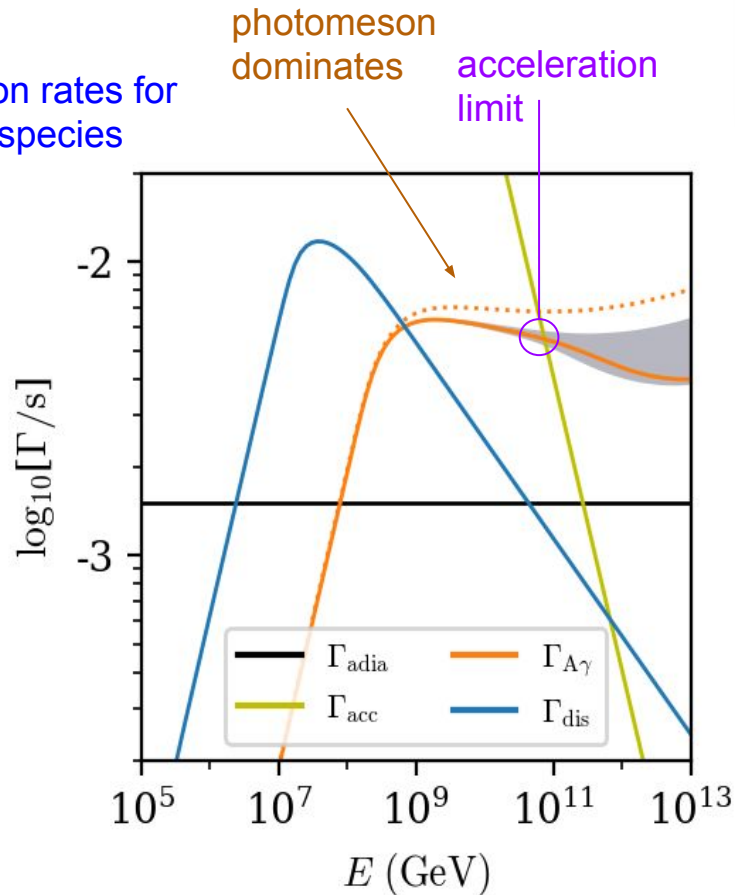
Refs: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 (2019) 007
 D. Biehl, D. Boncioli, A. Fedynitch and W. Winter, A&A 611, A101 (2018)

Tidal Disruption Event source

Slightly higher maximal energies!

Impact of the cross section

Interaction rates for injected species



Ref: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, *JCAP* 11 (2019) 007
 D. Buehl, D. Boncioli, C. Lunardini and W. Winter *Sci Rep* 8, 10828 (2018)

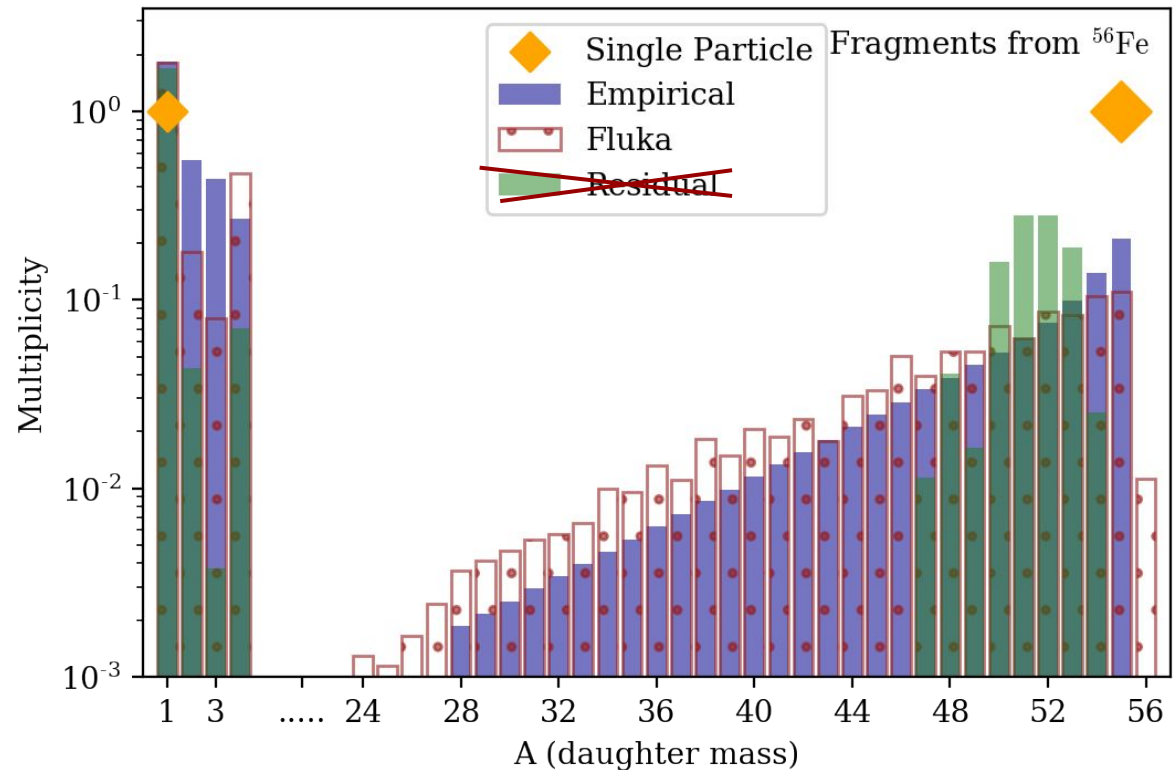
Nuclear breakup: mass distributions

Impact of the nuclear cascade

Larger variability of fragment masses!

Features of the model...

- Fragment production from empirical relations
- Thermostatistics criteria for low-mass fragments
- Insensitive to isotopic charge differences

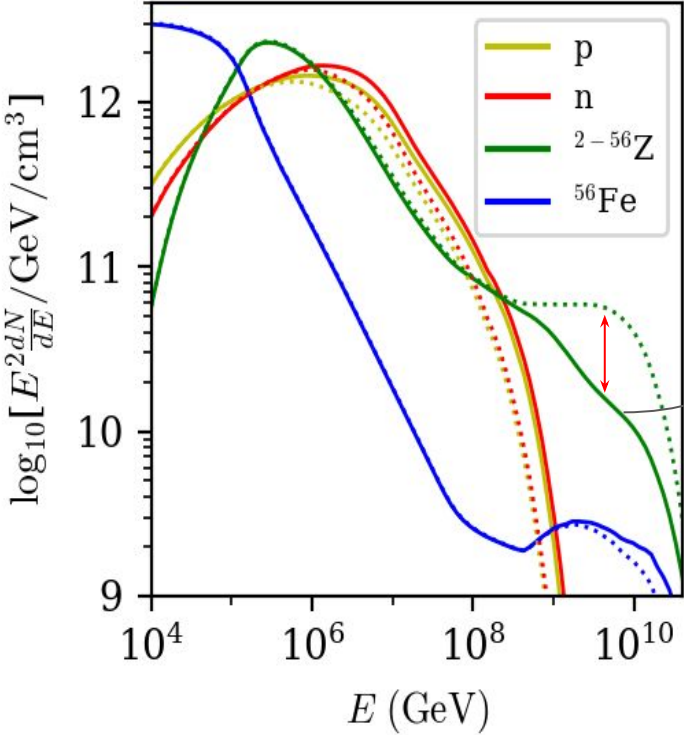


Ref: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

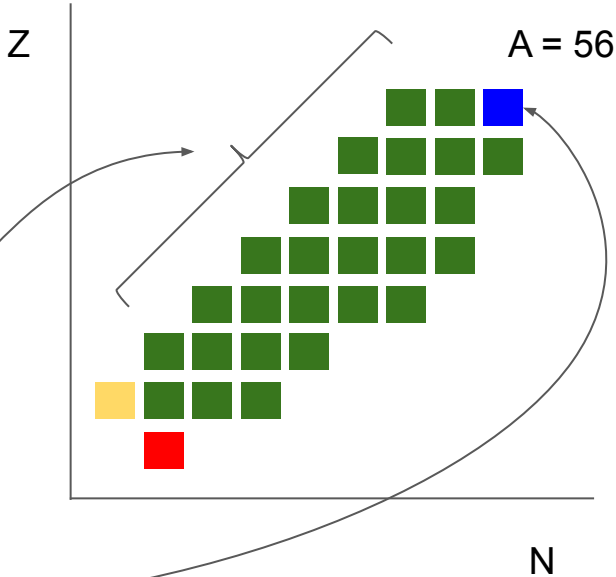
Gamma-Ray Burst source

Impact of the nuclear cascade

..... Single Particle Model cross section extrapolation
 — Empirical Model



Marked differences in cascade composition!

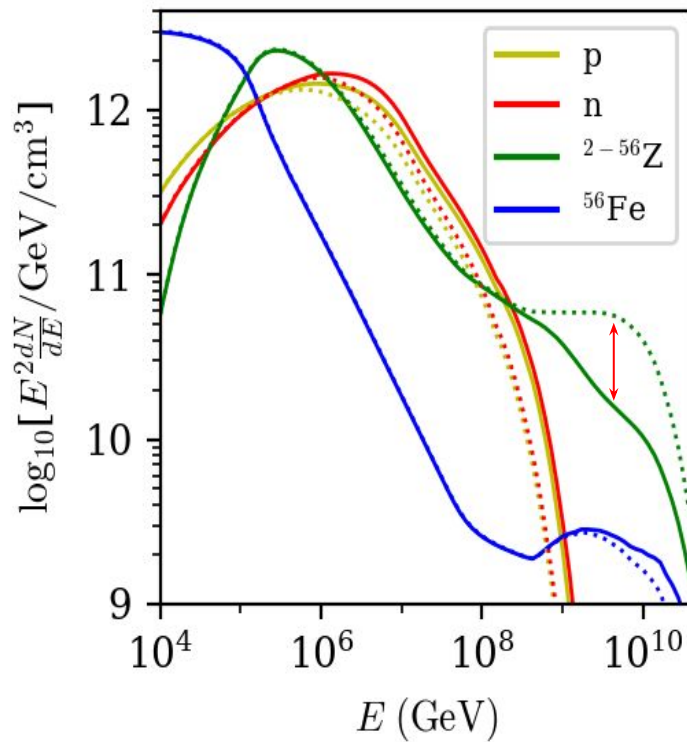


Refs: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 (2019) 007
 D. Biehl, D. Boncioli, A. Fedynitch and W. Winter, A&A 611, A101 (2018)

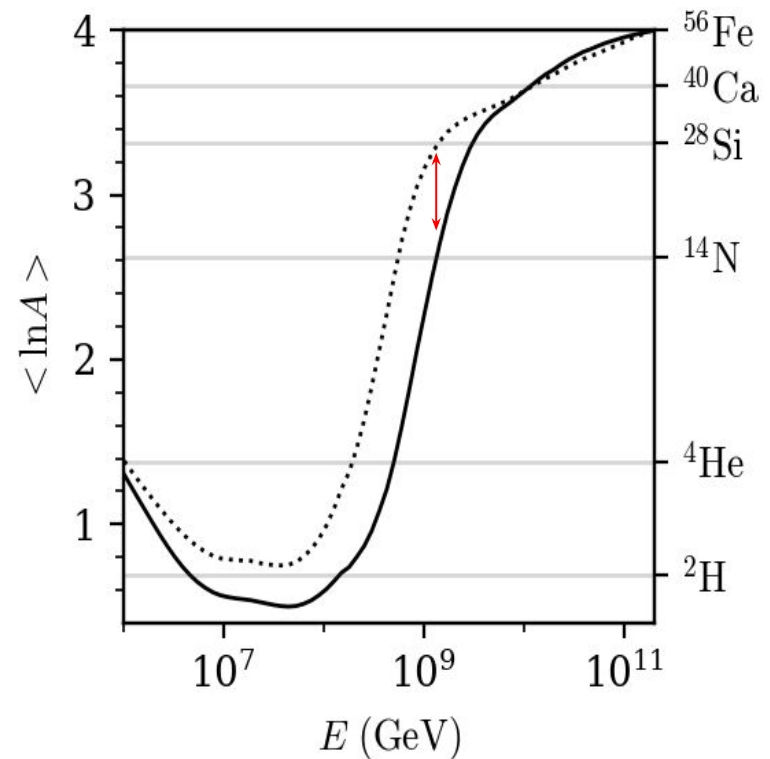
Gamma-Ray Burst source

Impact of the nuclear cascade

..... Single Particle Model  cross section extrapolation
 — Empirical Model



Marked differences in cascade composition!

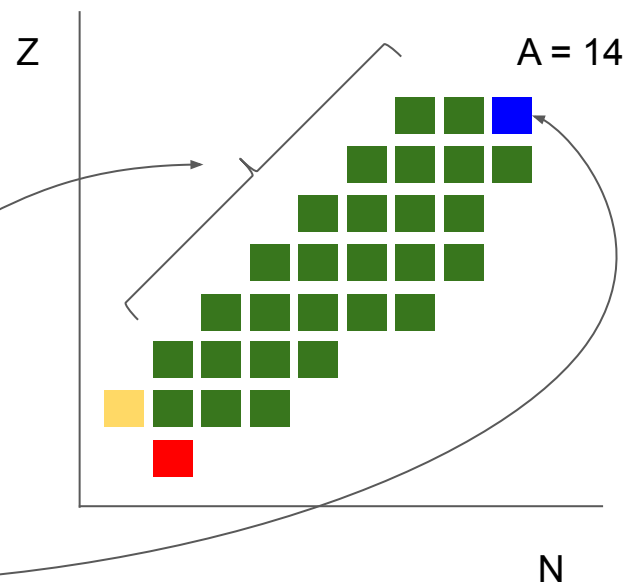
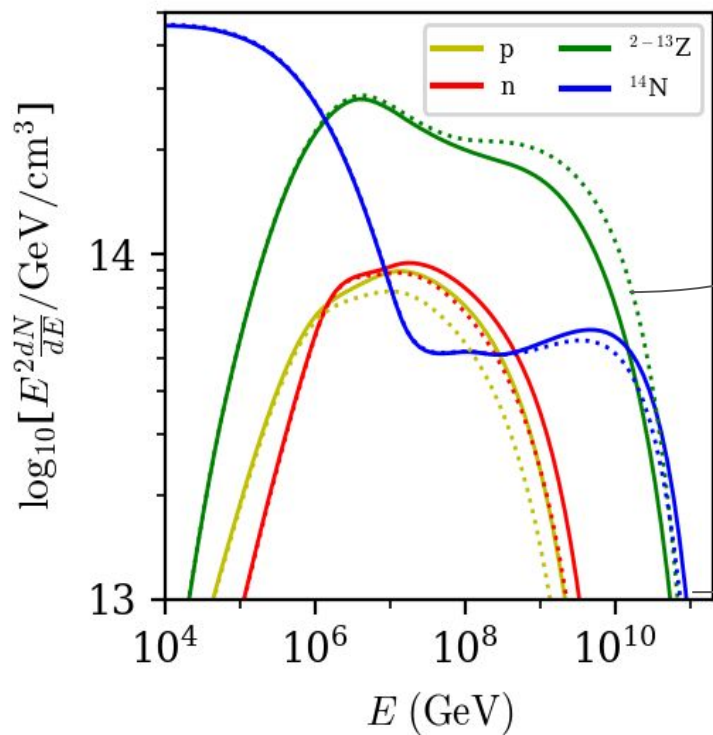
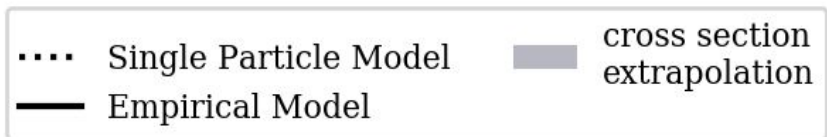


Refs: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 (2019) 007
 D. Biehl, D. Boncioli, A. Fedynitch and W. Winter, A&A 611, A101 (2018)

Tidal Disruption Event source

Impact of the nuclear cascade

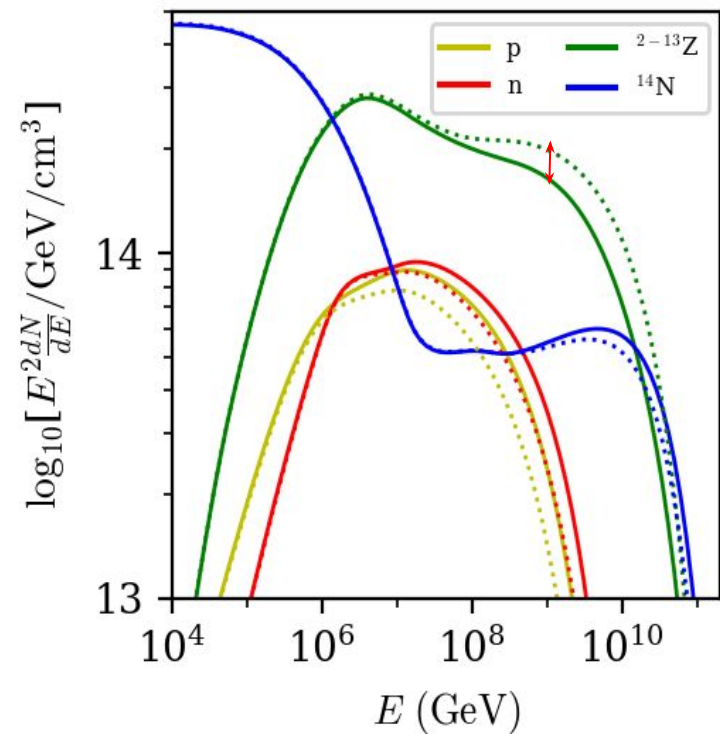
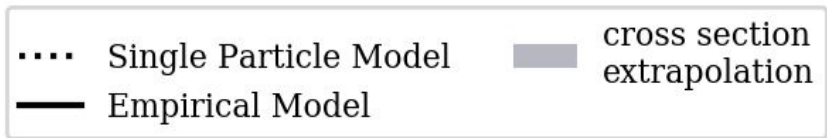
Marked differences in cascade composition!



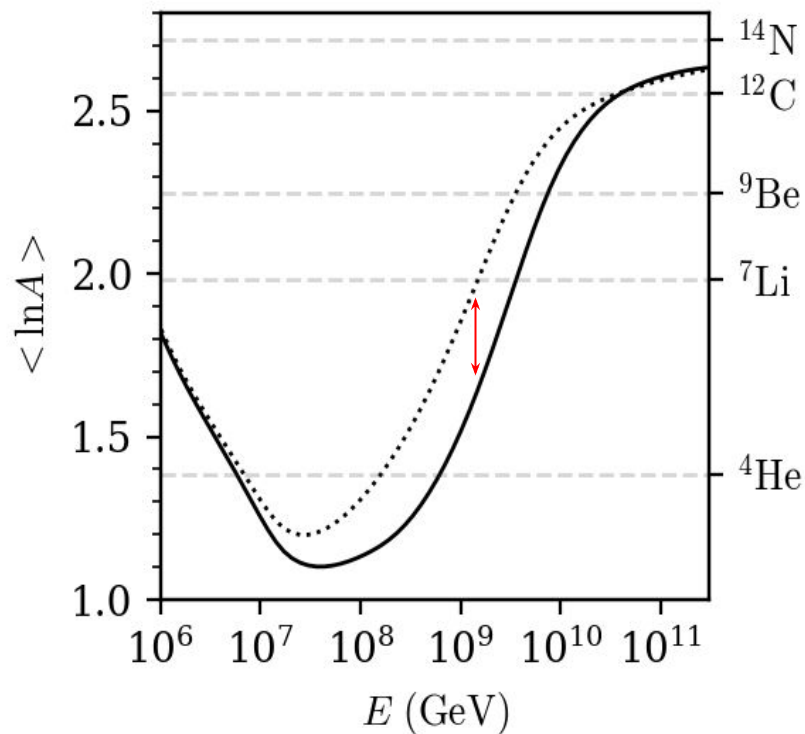
Ref: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, *JCAP* 11 (2019) 007
D. Buehl, D. Boncioli, C. Lunardini and W. Winter *Sci Rep* 8, 10828 (2018)

Tidal Disruption Event source

Impact of the nuclear cascade



Marked differences in cascade composition!

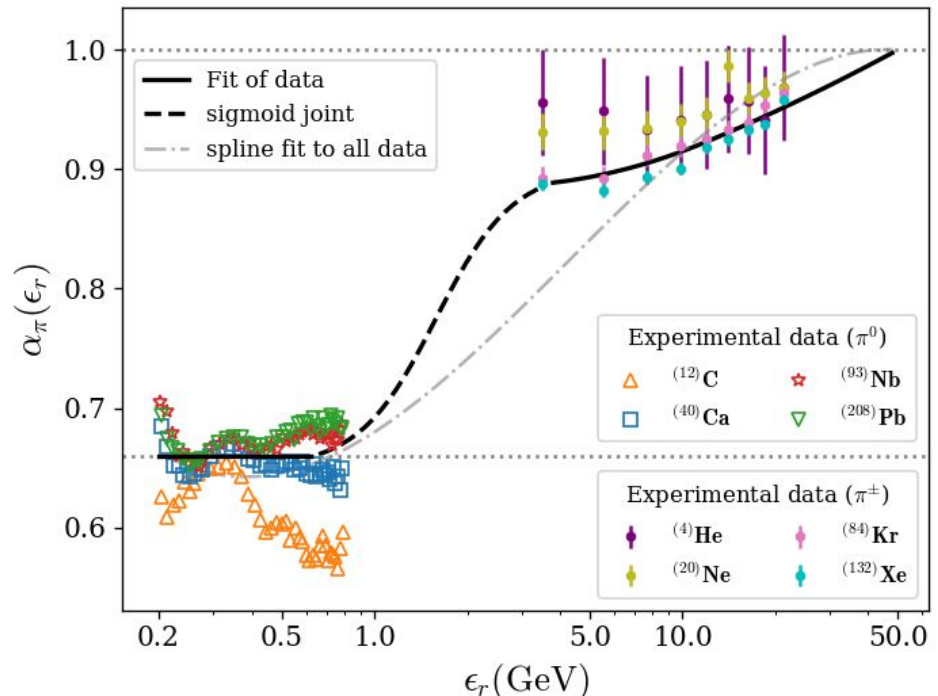
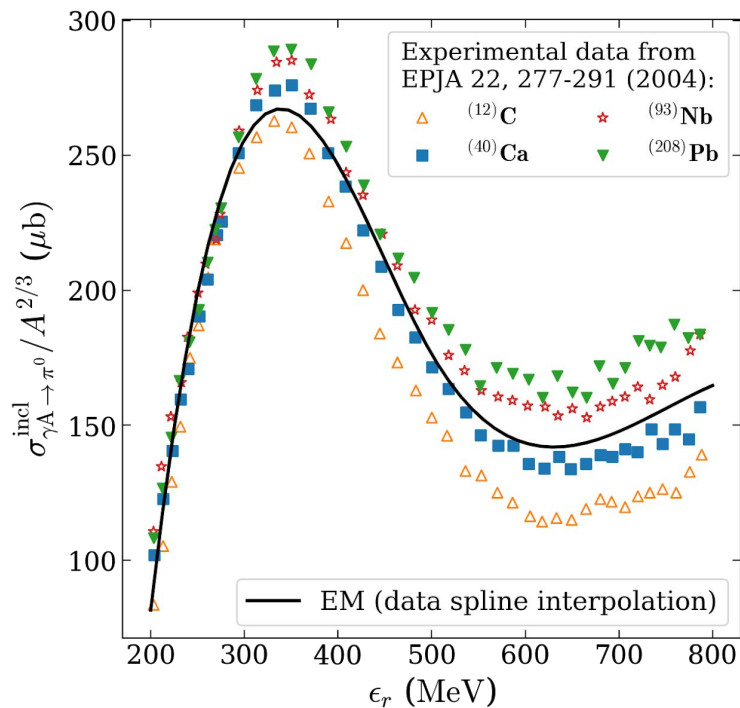


Ref: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, *JCAP* 11 (2019) 007
 D. Buehl, D. Boncioli, C. Lunardini and W. Winter *Sci Rep* 8, 10828 (2018)

Pion production cross section

Impact of the nuclear cascade

Pion production per nucleon is reduced in nuclei compared to the proton.

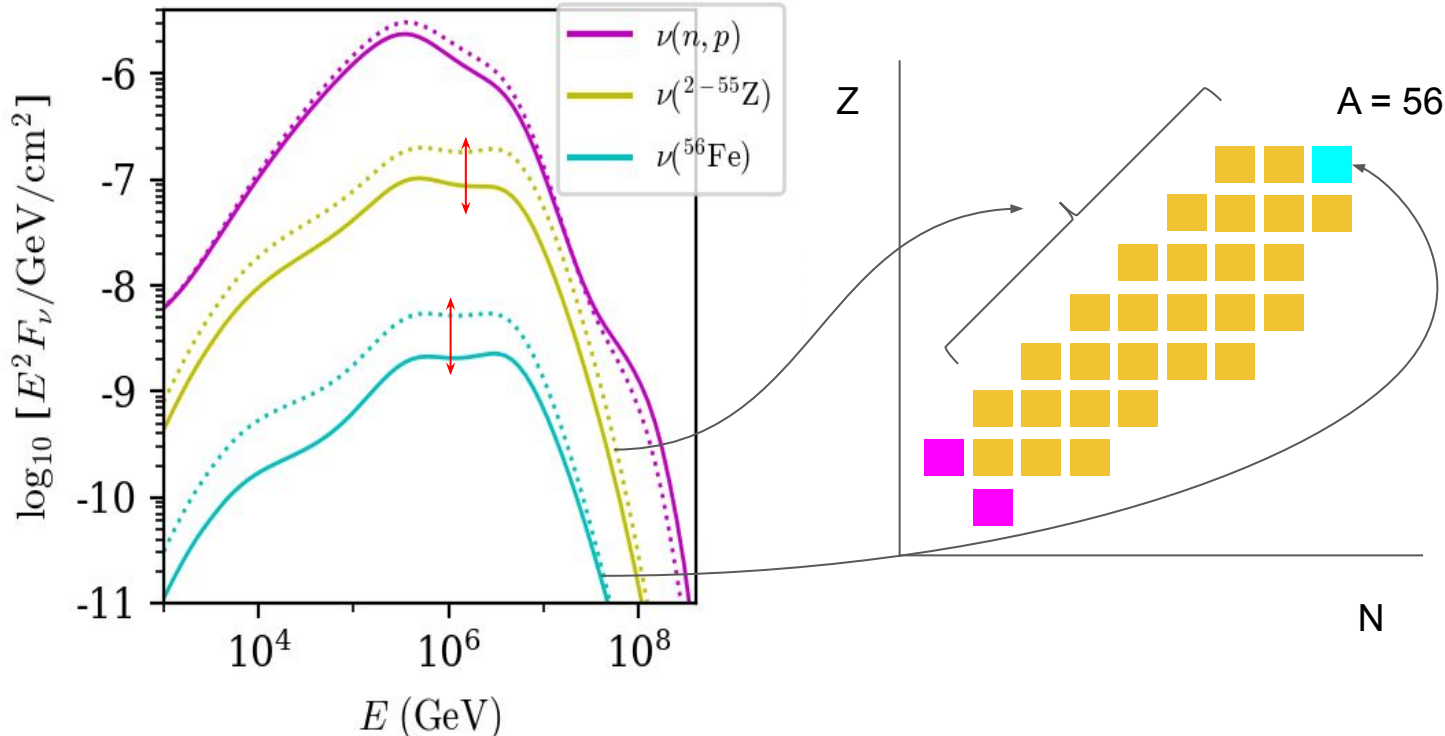
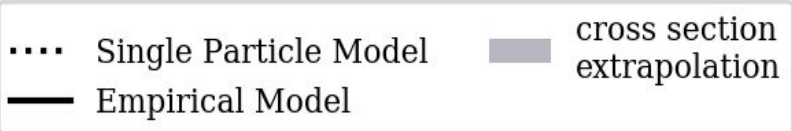


Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

Gamma-Ray Burst source

Impact of the nuclear cascade

Nuclei contribute less to neutrino flux!

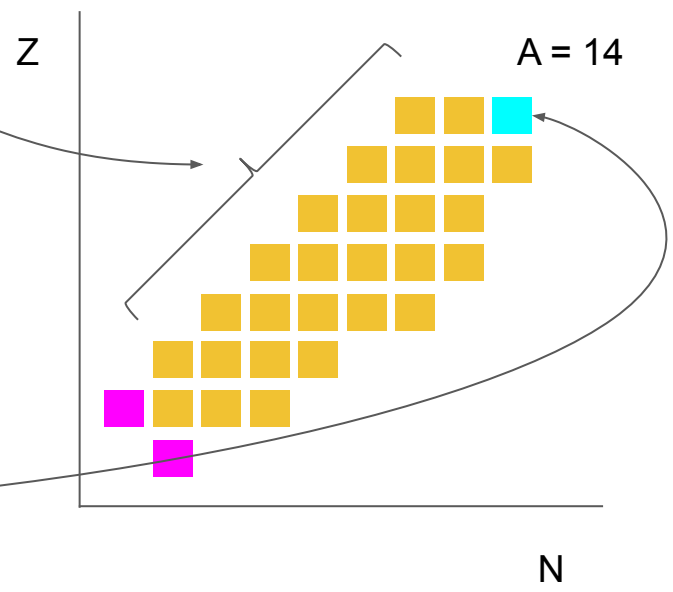
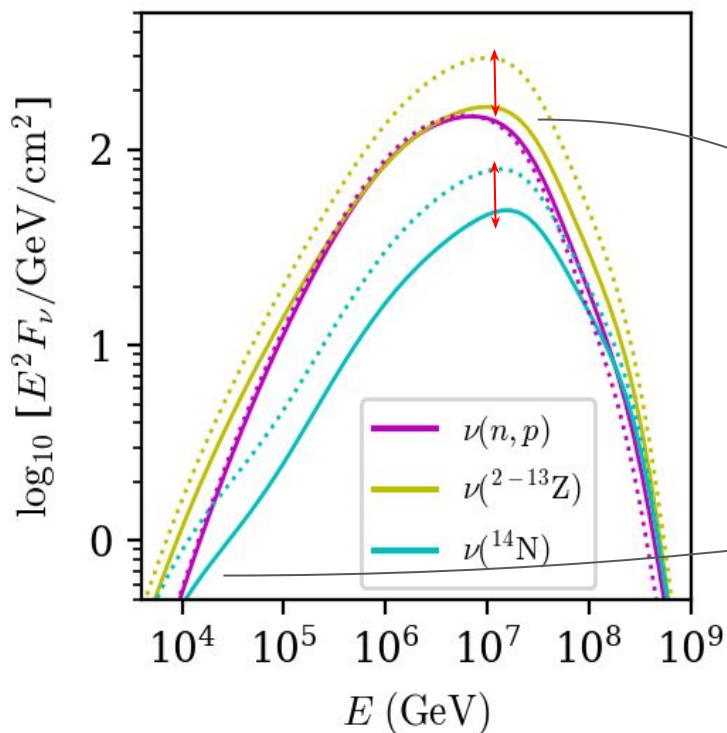
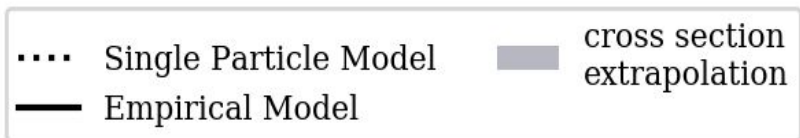


Refs: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP 11 (2019) 007
 D. Biehl, D. Boncioli, A. Fedynitch and W. Winter, A&A 611, A101 (2018)

Tidal Disruption Event source

Impact of the nuclear cascade

Nuclear contribution is not the dominant!



Ref: **LM**, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, *JCAP* 11 (2019) 007
 D. Buehl, D. Boncioli, C. Lunardini and W. Winter *Sci Rep* 8, 10828 (2018)

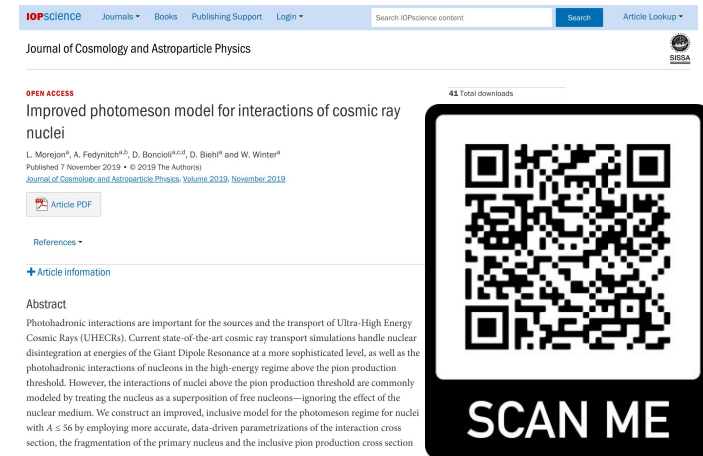
Summary

Nuclear photomeson improved model ...

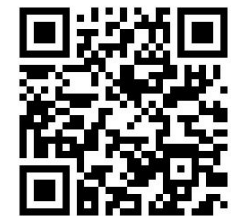
- ... impacts in-source nuclear cascade
- ... impacts in-source neutrino production
- ... might impact propagation (ongoing work)

The improved photomeson model

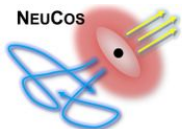
- Available software to compute interaction tables
- Available in PriNCE code (effects under study)
- Soon to be included in CRPropa interactions



The screenshot shows the IOPscience website interface. At the top, there are navigation links for 'Journals', 'Books', 'Publishing Support', and 'Login'. A search bar is present with the text 'Search IOPscience content'. The article title is 'Improved photomeson model for interactions of cosmic ray nuclei'. Below the title, the authors are listed: 'L. Morejon^a, A. Fedynitch^{a,b}, D. Boncioli^{a,c,d}, D. Bleh^a and W. Winter^a'. The publication date is 'Published 7 November 2019 • © 2019 The Author(s)'. There is a link for 'Article PDF' and a 'References' section. An 'Abstract' section follows, starting with 'Photohadronic interactions are important for the sources and the transport of Ultra-High Energy Cosmic Rays (UHECRs)'. To the right of the article information is a large QR code with the text 'SCAN ME' below it.



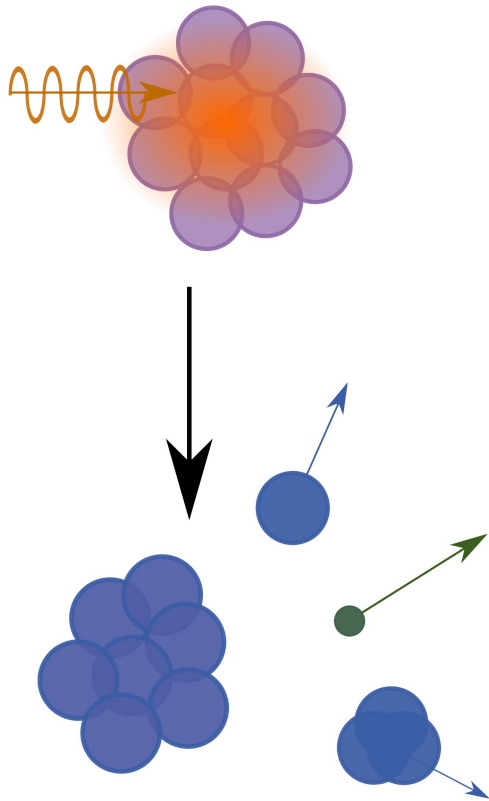
zenodo / 2600177
(also on github)



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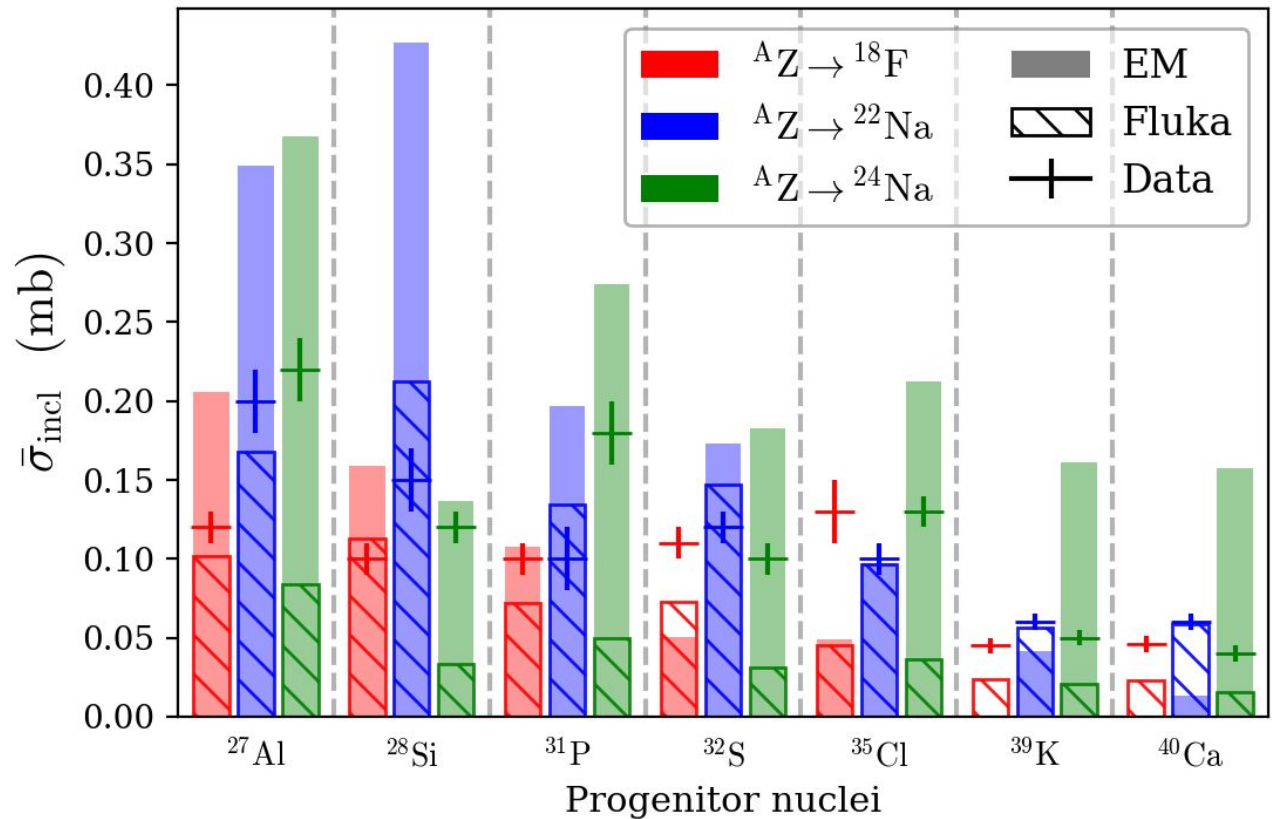
Additional slides

Nuclear breakup: mass distributions

Comparison to data and detailed code

Within order of magnitude without tuning for individual species!

- Within factor ~3 from the data
- Performs similarly as Fluka detailed modelling
- Insensitive to isotopic charge differences

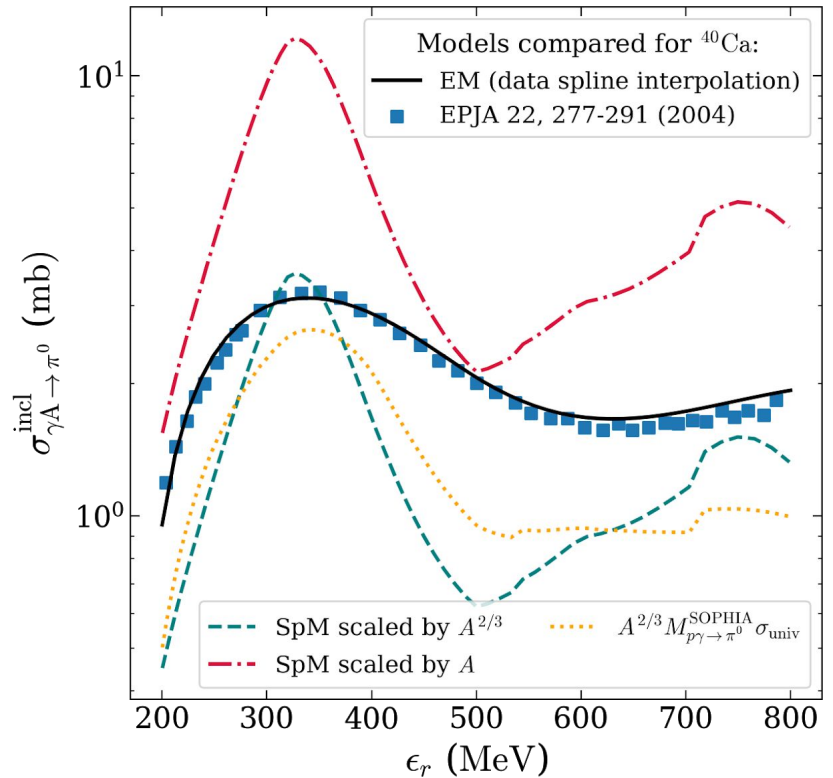
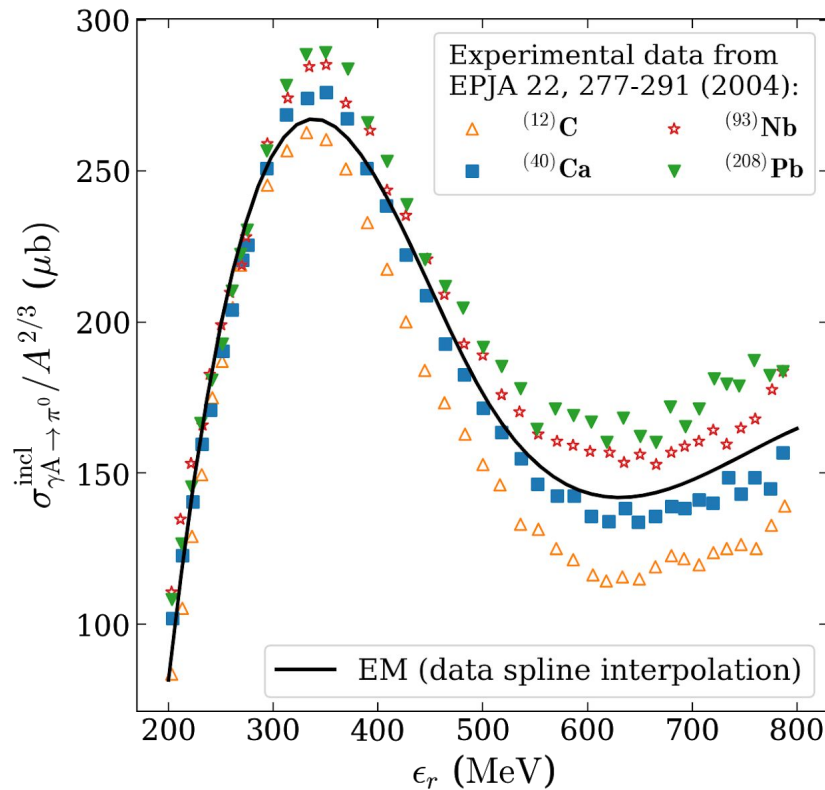


Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007

Pion production at threshold

Nuclear medium effects are relevant.

Reabsorption of pions lead to less production. Quasi-free production disfavoured.



Ref: LM, A. Fedynitch, D. Boncioli, D. Biehl and W. Winter, JCAP11(2019)007