The Monte Carlo event generator DPMJET-III

8th International Workshop on Multiple Partonic Interactions at the LHC

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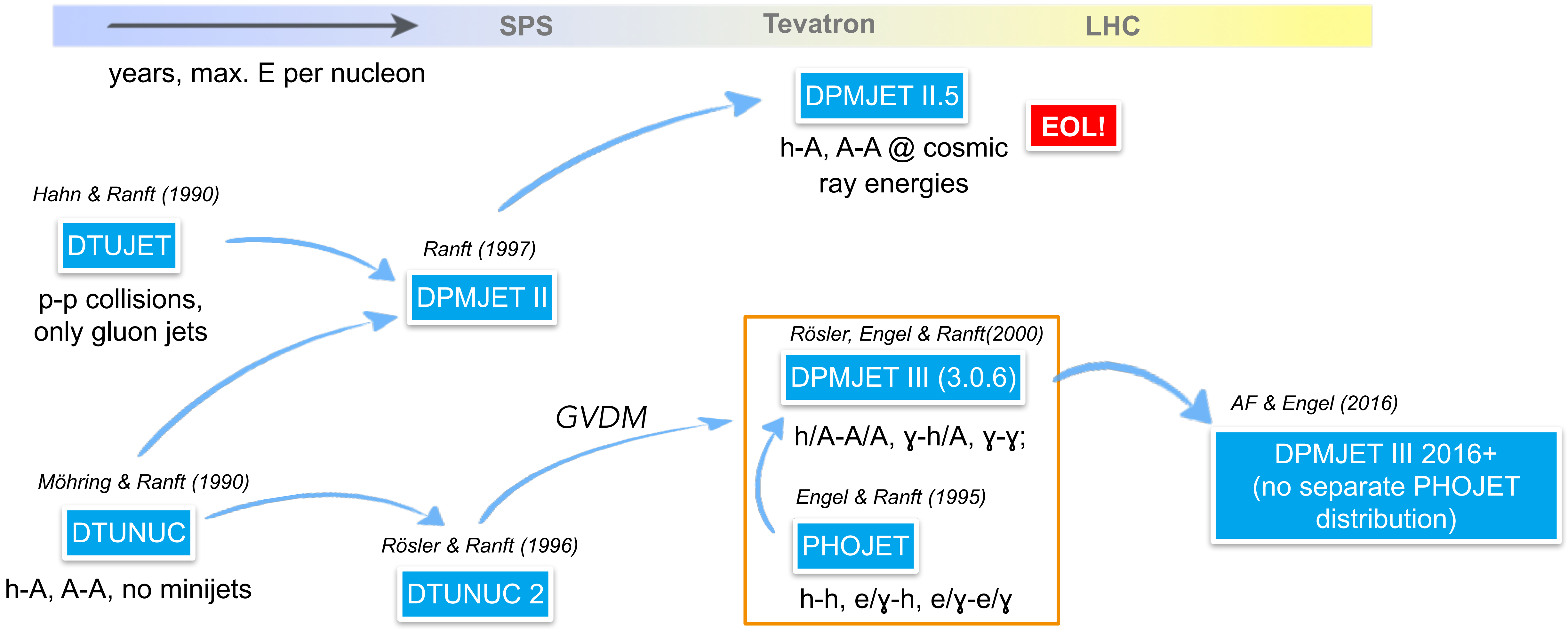
HELMHOLTZ | ASSOCIATION

DESY

DPMJET-III



SPS
Tevatron
LHC
years, max. E per nucleon
DPMJET II.5
h-A, A-A @ cosmic ray energies
EOL!
Hahn & Ranft (1990)
DTUJET
p-p collisions, only gluon jets
Ranft (1997)
DPMJET II
Rösler, Engel & Ranft(2000)
DPMJET III (3.0.6)
h/A-A/A, ɣ-h/A, ɣ-ɣ;
GVDM
Engel & Ranft (1995)
PHOJET
h-h, e/ɣ-h, e/ɣ-e/ɣ
AF & Engel (2016)
DPMJET III 2016+ (no separate PHOJET distribution)
Möhring & Ranft (1990)
DTUNUC
h-A, A-A, no minijets
Rösler & Ranft (1996)
DTUNUC 2

What's new in DPMJET 2016

> DPMJET III at cosmic ray energies

- Extrapolation up to PeV (center-of-mass)
- Simultaneous handling of multiple projectile-target combinations (cascade codes)

> Minimum bias

- New PDF (GRV94 -> CT14 LO)
- Re-tune
- More accurate MPI behavior
- Cross section fits

> Untouched:

- Nuclear phenomenology
- Heavy-Ions

> Distributed in

- FLUKA 2017
- CORSIKA 2017
- CRMC, standalone in progress
- Will become available at https://dpmjetiii.hepforge.org

Hadron – hadron amplitudes in DPMJET (identical to PHOJET)

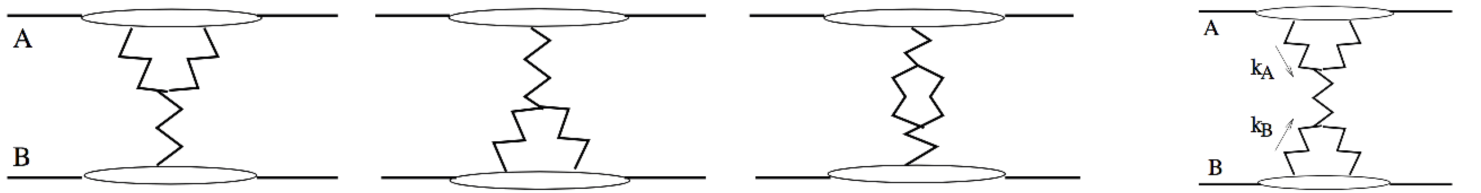
- Unitarization of soft, hard and diffractive amplitudes (together) via Eikonal scheme (AGK cutting rules)

$$a(s,\vec{B}) = \sum_{n=1}^{\infty} a^{(n)}(s,\vec{B}) = \frac{i}{2}\left(1 - \exp\left[-\chi(s,\vec{B})\right]\right)$$

$$\chi(s,\vec{B}) = \chi_{\mathrm{S}}(s,\vec{B}) + \chi_{\mathrm{H}}(s,\vec{B}) + \chi_{\mathrm{TP}}(s,\vec{B}) + \chi_{\mathrm{LP}}(s,\vec{B}) + \chi_{\mathrm{DP}}(s,\vec{B})$$

Lowest order enhanced graphs

Triple-Pomeron side 1 | TP side 2 | pomeron loop | double pomeron scattering



Single Diffraction side 1 | SD side 2 | double diffraction | central diffraction

Cross sections from optical theorem

- Free Regge parameters are fitted to data using total, elastic, inelastic and *t*-slope

$$\sigma_{\rm tot} = 2\int \mathrm{d}^2\vec{B}\ \Im m(a(s,\vec{B})) = 2\int \mathrm{d}^2\vec{B}\ (1 + e^{-\chi_{\rm R}}\sin\chi_{\rm I})$$

$$\sigma_{\rm el} = 2\int \mathrm{d}^2\vec{B}\ |a(s,\vec{B})|^2 = \int \mathrm{d}^2\vec{B}(1 + 2e^{-\chi_{\rm R}}\sin\chi_{\rm I} + e^{-\chi_{\rm R}})$$

$$\sigma_{\rm inel} = \sigma_{\rm tot} - \sigma_{\rm el} = \int \mathrm{d}^2\vec{B}(1 - e^{-2\chi_{\rm R}})$$

- From $2\int \mathrm{d}^2\vec{B}\ \chi(s,\vec{B}) = \sigma^{\rm Born}(s)$ we identify following relationships

soft:

$$\sigma_{AB}^{I\!P_s}(s) \sim \left(\frac{s}{s_0}\right)^{\Delta_{I\!P_s}(0)}$$

diffractive (e.g.):

$$\frac{\mathrm{d}\sigma^{\rm TP}}{\mathrm{d}M_{\rm D}^2} \sim \left(\frac{s}{s_0}\right)^{2\Delta_{I\!P}}\left(\frac{s_0}{M_D^2}\right)^{\alpha_{I\!P}(0)}$$

hard:

$$\sigma_{\rm QCD} = \sum_{i,j,k,l}\frac{1}{1+\delta_{kl}}\int dx_1\, dx_2 \times$$

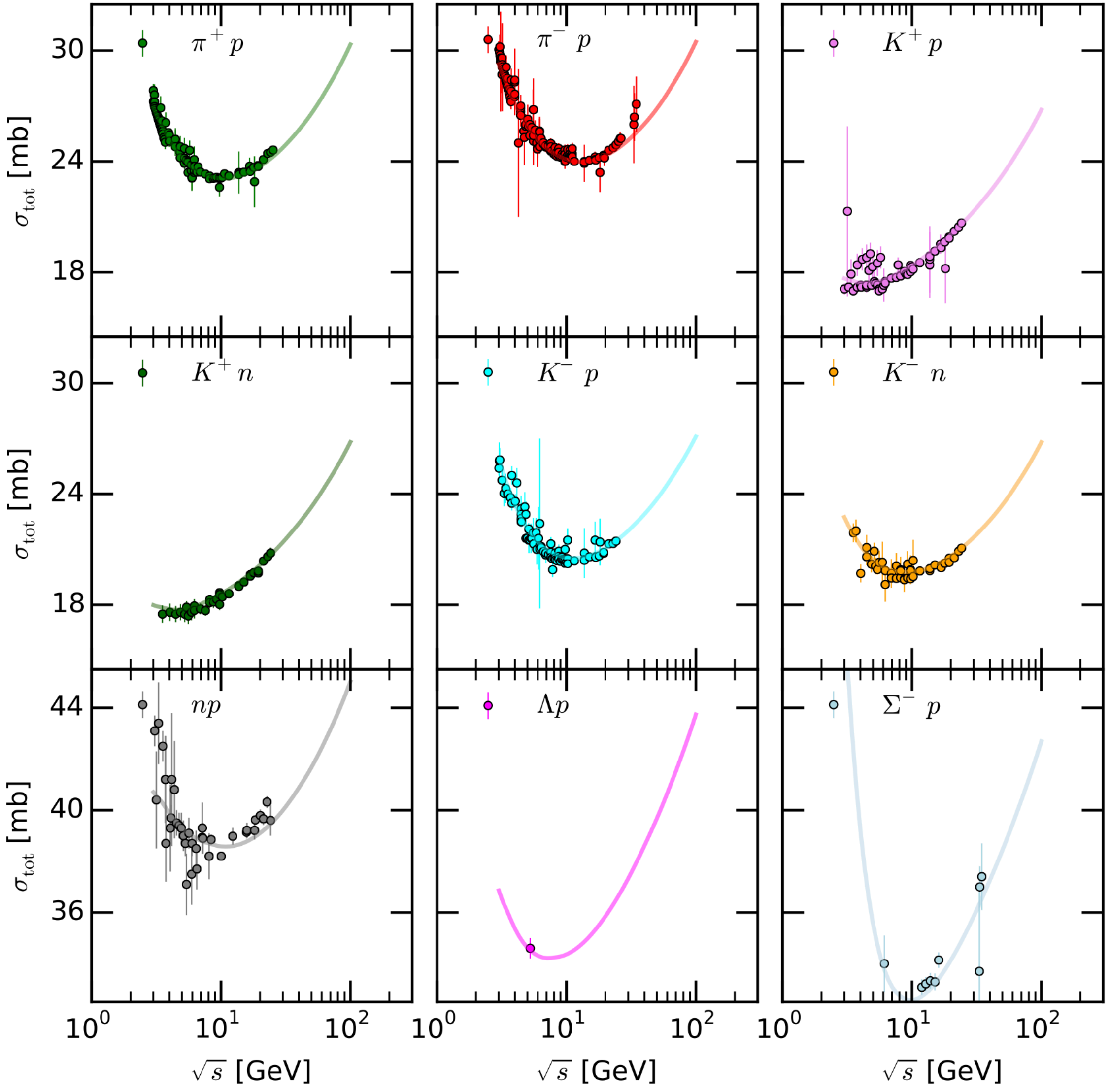
$$\times \int_{Q_{min}\propto p_\perp^{\rm cutoff}} dQ^2\ f_i(x_1,Q^2)\ f_j(x_2,Q^2)\ \frac{d\sigma_{i,j\to k,l}}{dQ^2} \sim \left(\frac{s}{s_0}\right)^{\Delta_{\rm hard}}$$

“free”?

CT14 LO

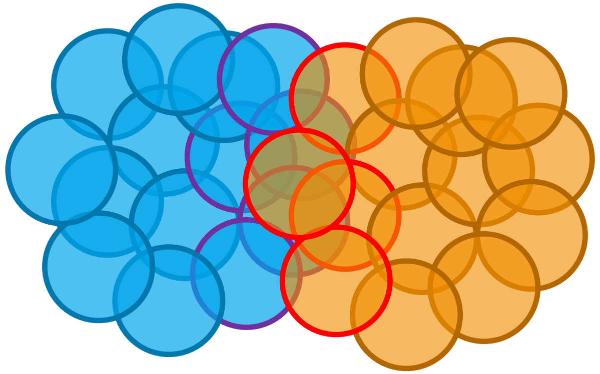
not free!

Accurate fits for hadron-nucleon cross sections



- In an air-shower cascade all kinds of hadrons can re-interact
- DPMJET is the **only model** working from particle production threshold up to highest cosmic ray energies (10^{21} GeV)

DPMJET III in hA/AA/γA

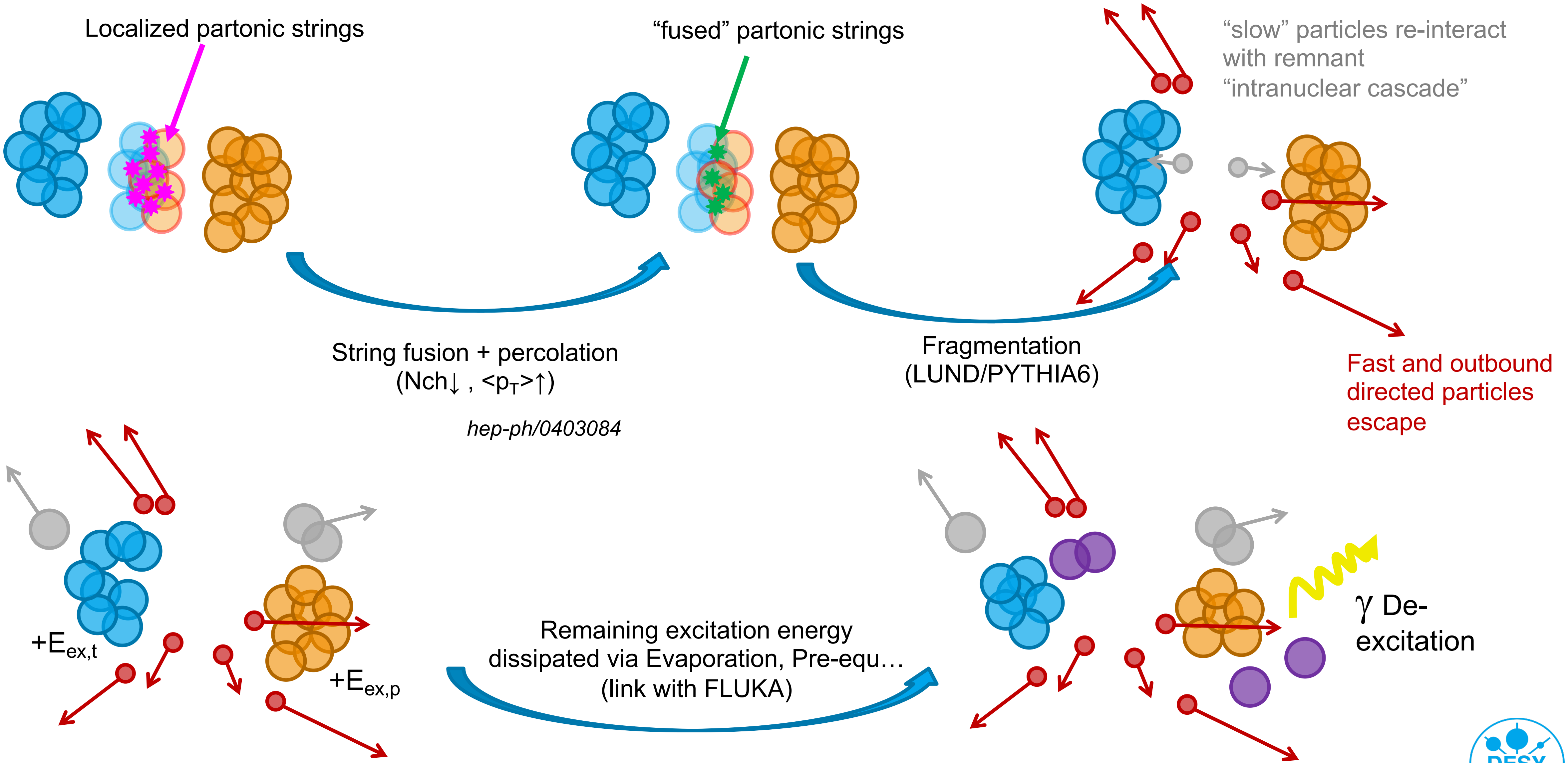


- Each individual NN interaction is simulated with PHOJET (for A = 1 identical to PHOJET)
- DPMJET tracks if valence quarks were involved (re-interaction of remnants)
- Bookkeeping of used momentum fractions *x* for subsequent interactions
- Partonic state from PHOJET is color connected but not fragmented
- Strings localized between interaction partners in b-space

Glauber approximation

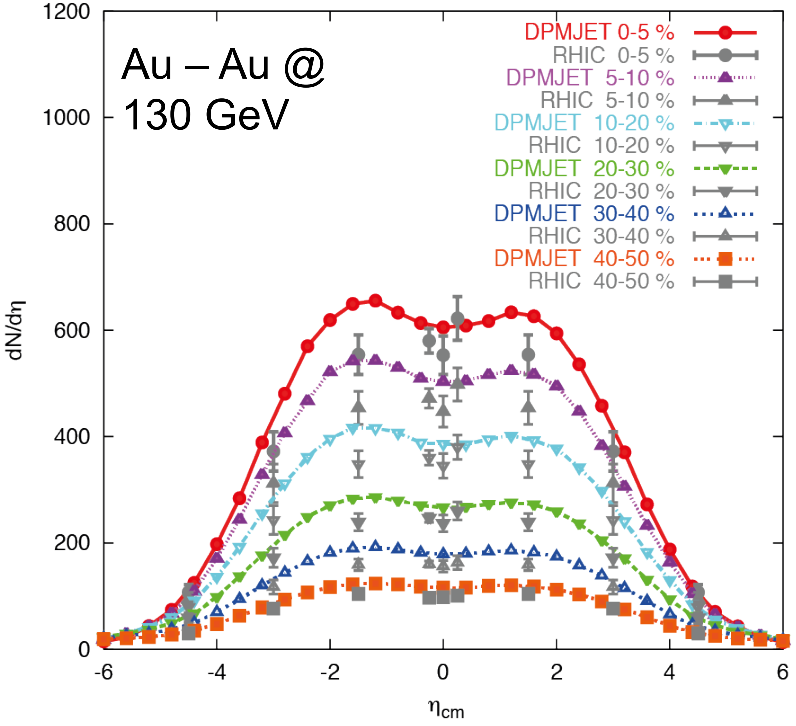
$$\sigma_{\mathrm{inel}} = \int d^2\vec{b}\left[1-\prod_{k=1}^{A}\left(1-\sigma_{\mathrm{tot}}^{NN}T_N(\vec{b}-\vec{s}_k)\right)\right] \approx \int d^2\vec{b}\left[1-\exp\left\{-\sigma_{\mathrm{tot}}^{NN}T_A(\vec{b})\right\}\right]$$

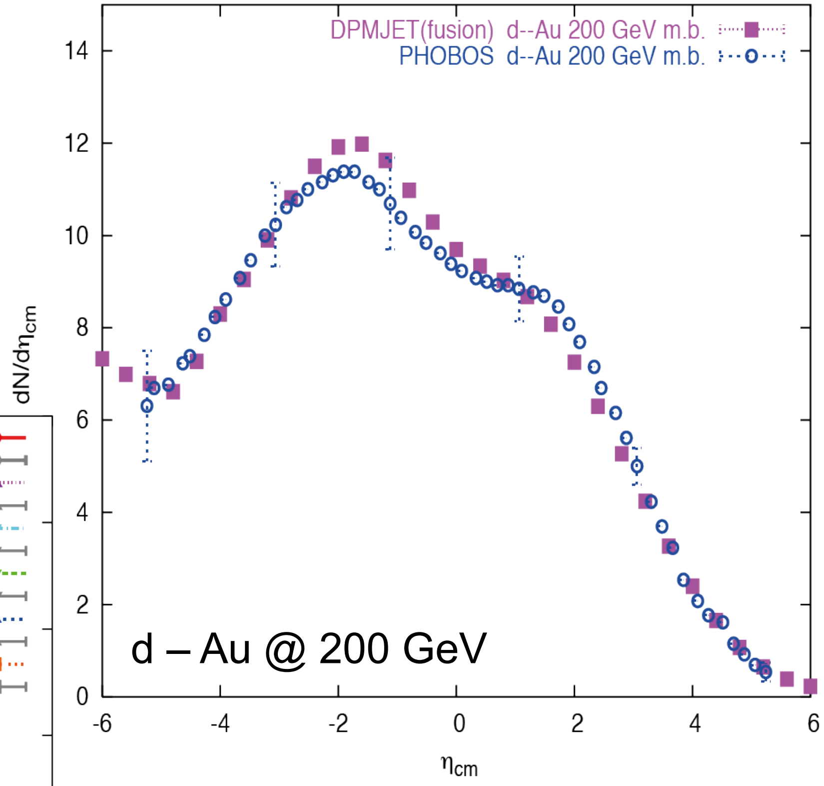
Nuclear phenomenology and construction of (nuclear) remnants



Some AA results

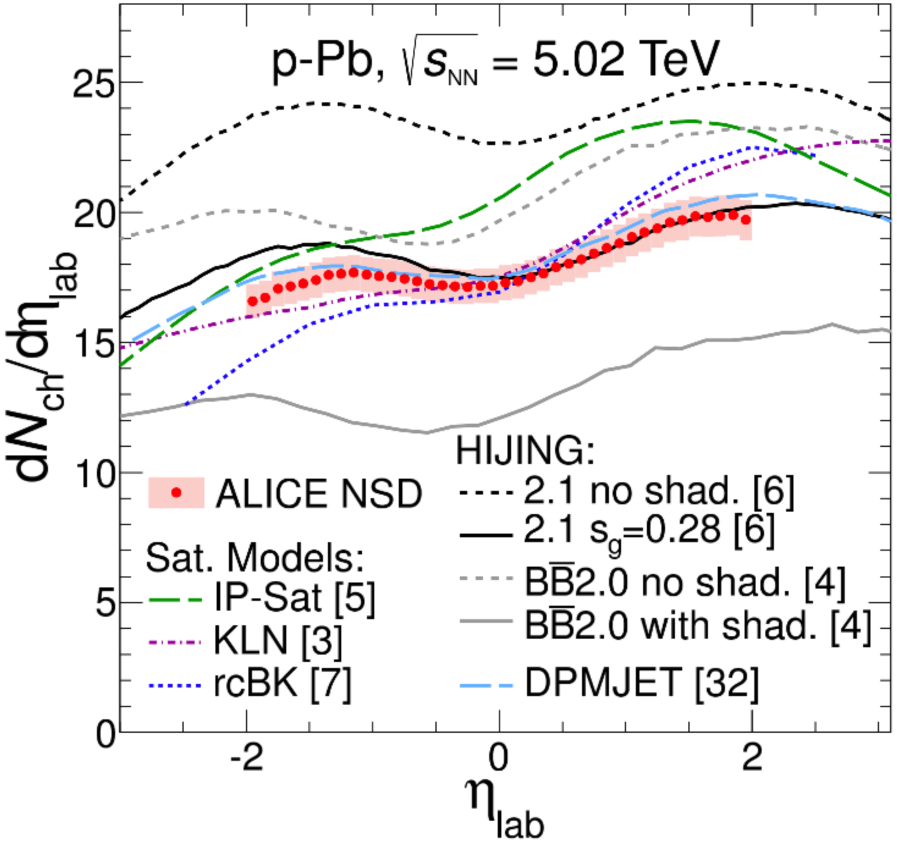
F.W.Bopp, J. Ranft, R.Engel, S.Roesler
arXiv:hep-ph/0403084v1





string fusion was needed, otherwise multiplicity 30-40% too high

Best description of first p-Pb data



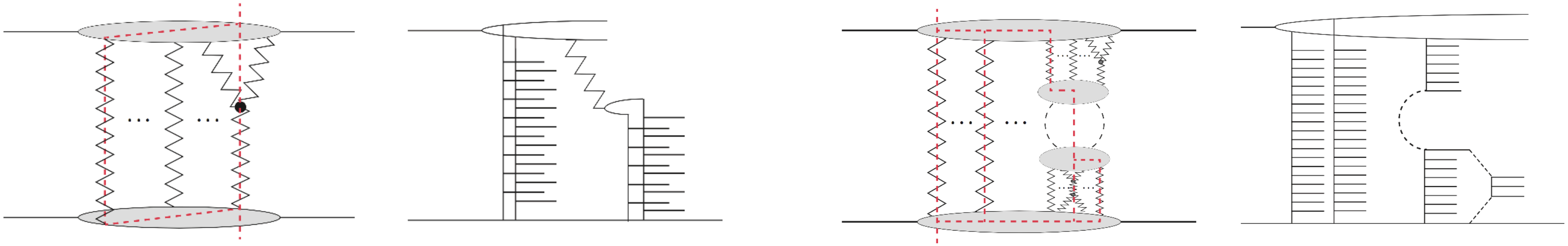
*ALICE Coll.,PRL **110**, 032301 (2013)*

MPI

- MPI (uncorrelated) from

$$\sigma(n_{\mathrm{S}}, n_{\mathrm{H}}, \dots) = \int \mathrm{d}^2\vec{B}\, \frac{(-2\chi_{\mathrm{S}})^{n_{\mathrm{S}}}}{n_{\mathrm{S}}!}\, \frac{(-2\chi_{\mathrm{H}})^{n_{\mathrm{H}}}}{n_{\mathrm{H}}!} \dots\; e^{-2\chi}$$

- Pomeron has its own partonic structure, i.e. pomeron-hadron, pomeron-pomeron scattering can have multiple parton interactions (recursion)



Arbitrary complex topologies

New energy dependence of p_T-cutoff

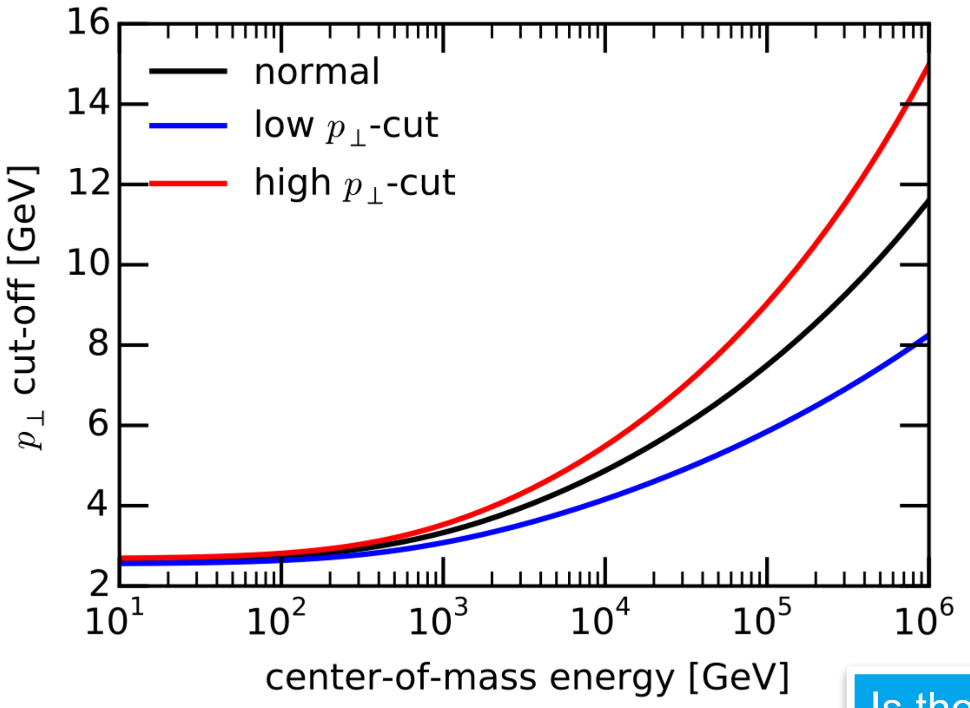
- Somewhat artificial separation of soft and hard interactions
- Inspired by saturation in dipole models, e.g. *Golec-Biernat and Wusthoff, PRD 59(1) 014017 (1999)*

old (empirical)

$$p_\perp(s) = p_\perp^0 + 0.12\mathrm{GeV}\left(\log_{10}\frac{\sqrt{s}}{50\mathrm{GeV}}\right)^3$$

new GBW-type

$$p_T^{\mathrm{cutoff}} = p_0\left(\frac{\sqrt{s}+p_1}{p_2}\right)^\lambda$$

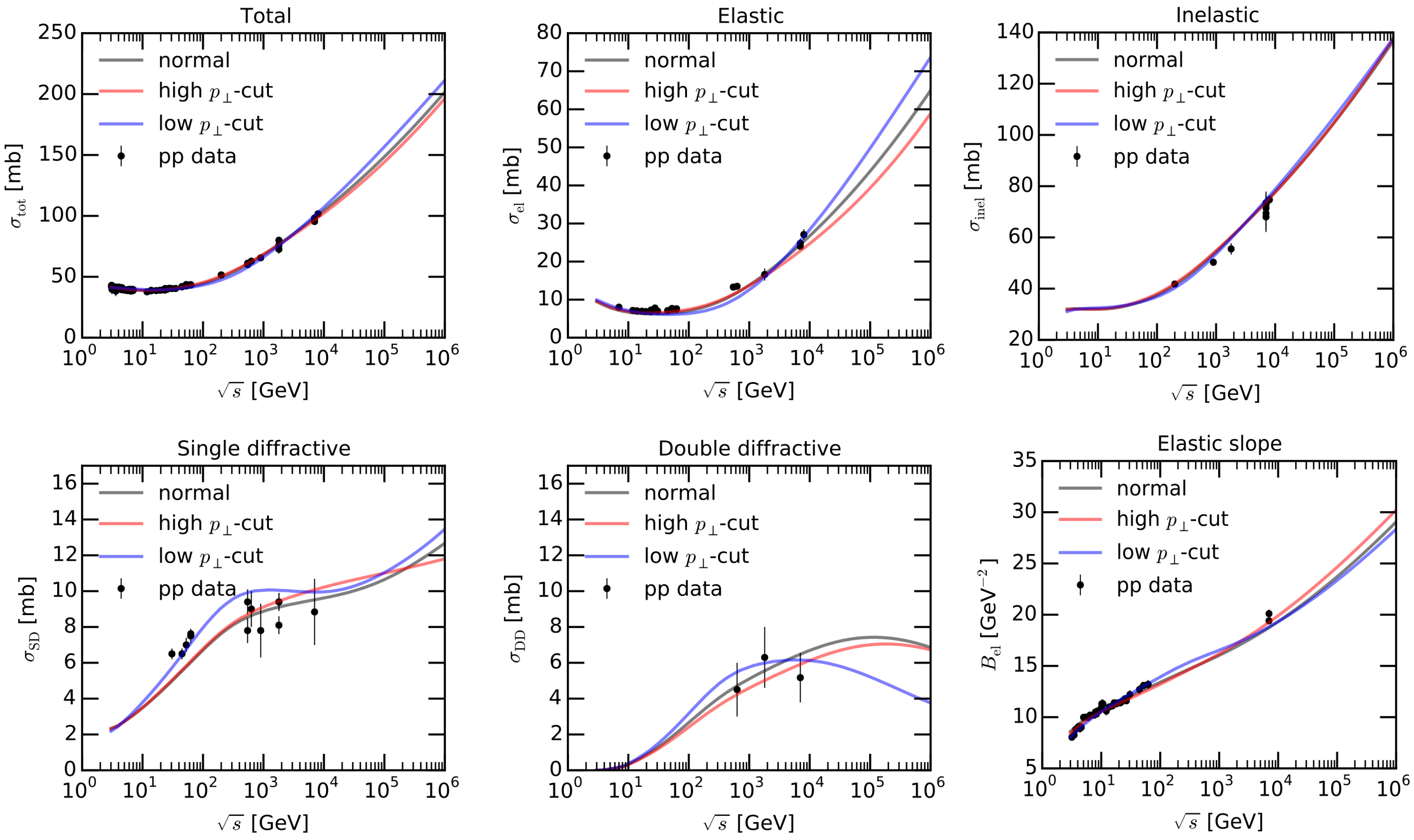


Is there a choice?

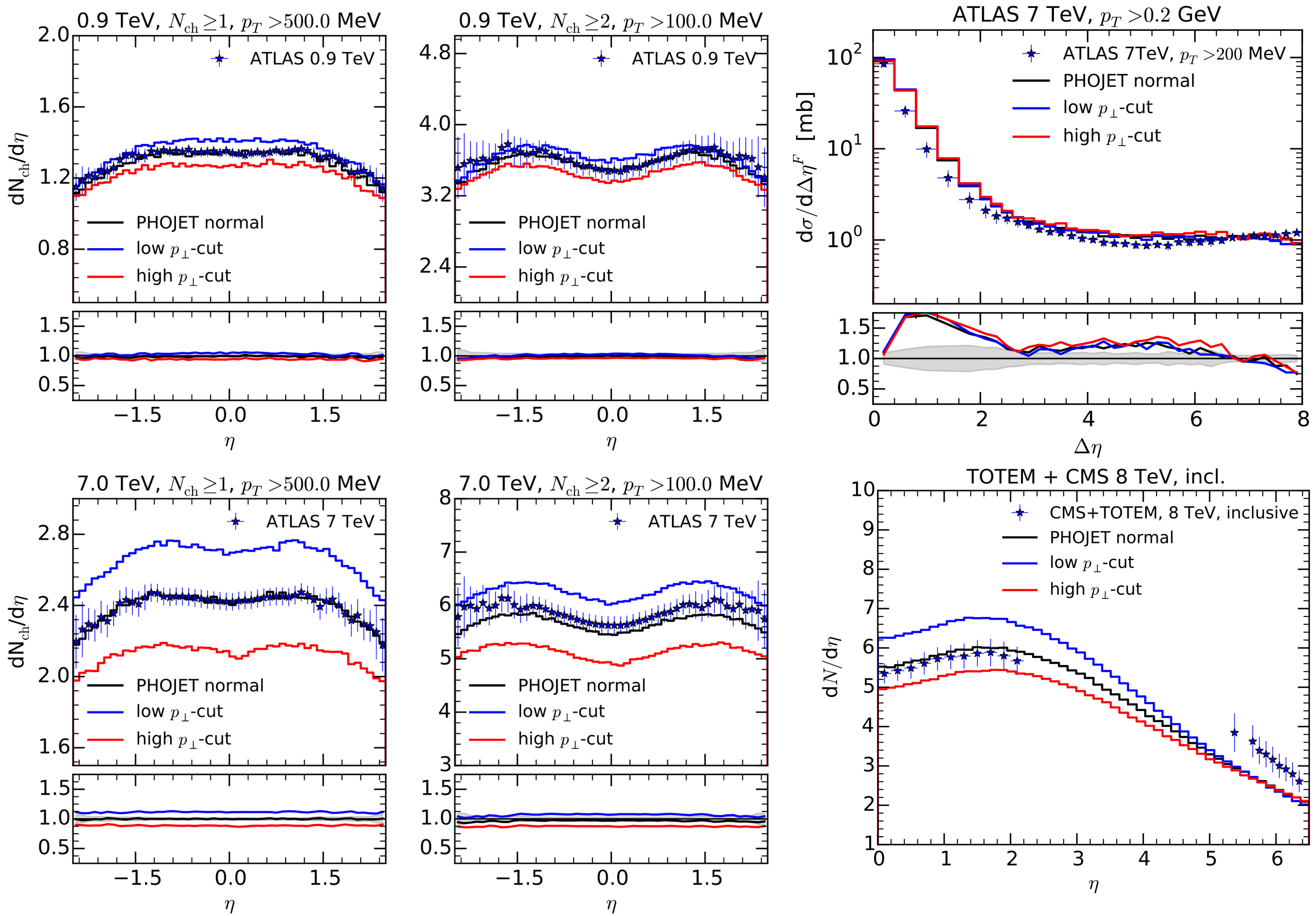
AF and R. Engel, CERN-Proceedings-2015-001

Fits to cross sections

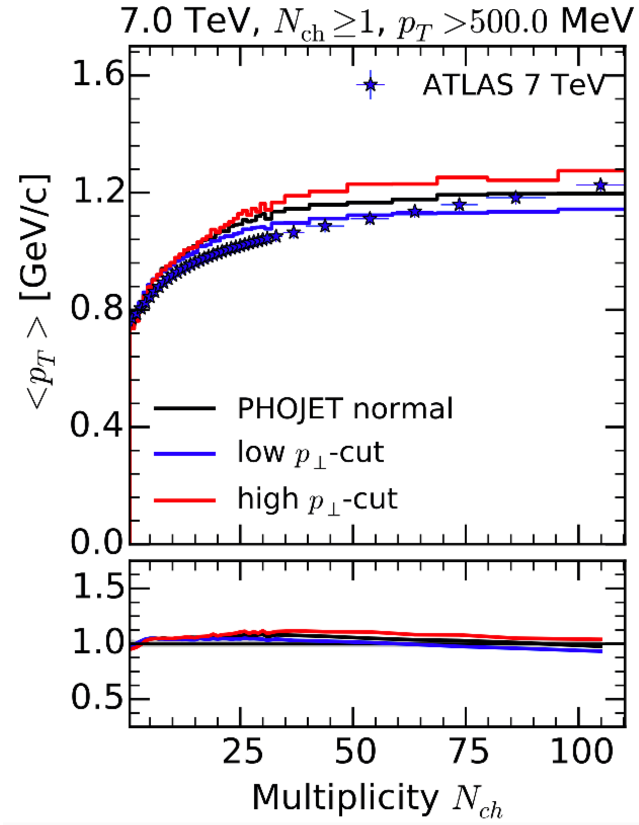
- normal: one good choice of p_T-cut, $\sigma_{tot} \sim s^{\Delta}$
- high: means **low σ_{QCD}**, $\sigma_{tot} \sim s^{\Delta}$
- low: means **high σ_{QCD}**, $\sigma_{tot} \sim \ln^2(s)$ bound by unitarity
- All choices fit these observables "satisfactory"
- Hard and diffractive cross section are related



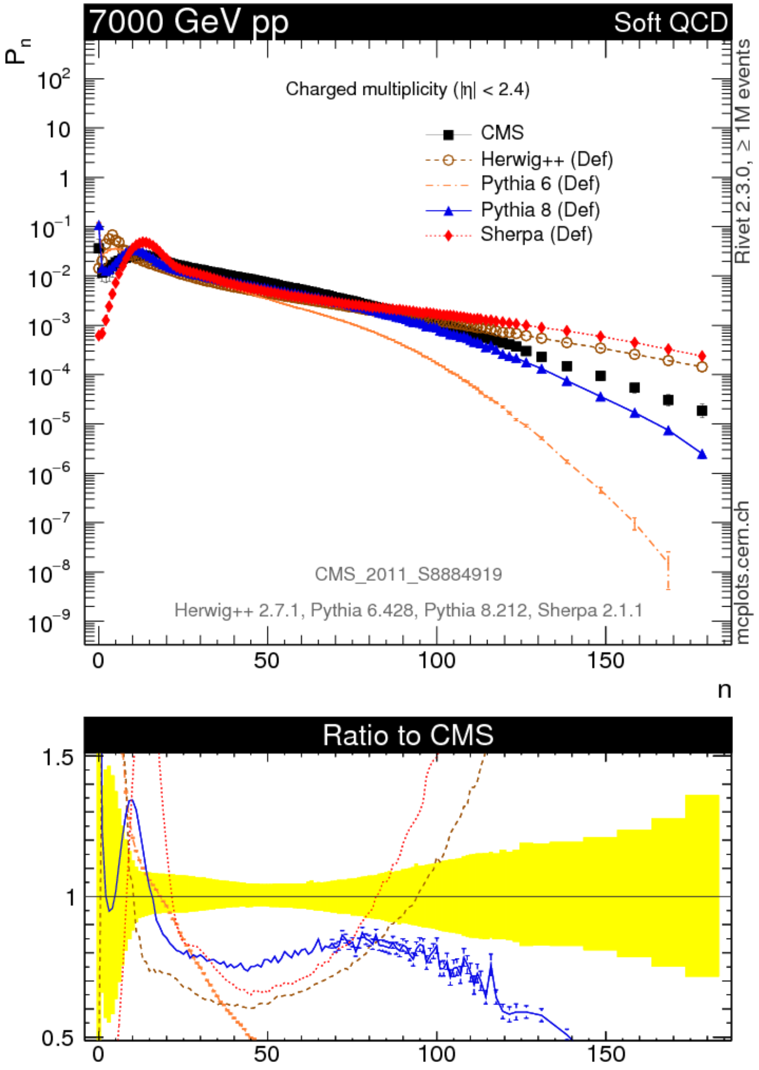
Tuned to minimum-bias

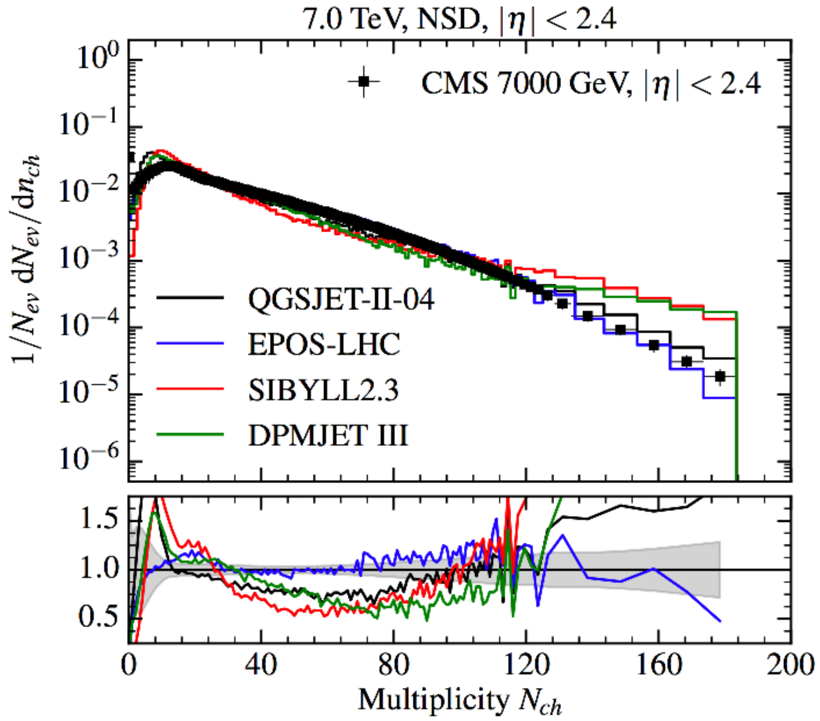


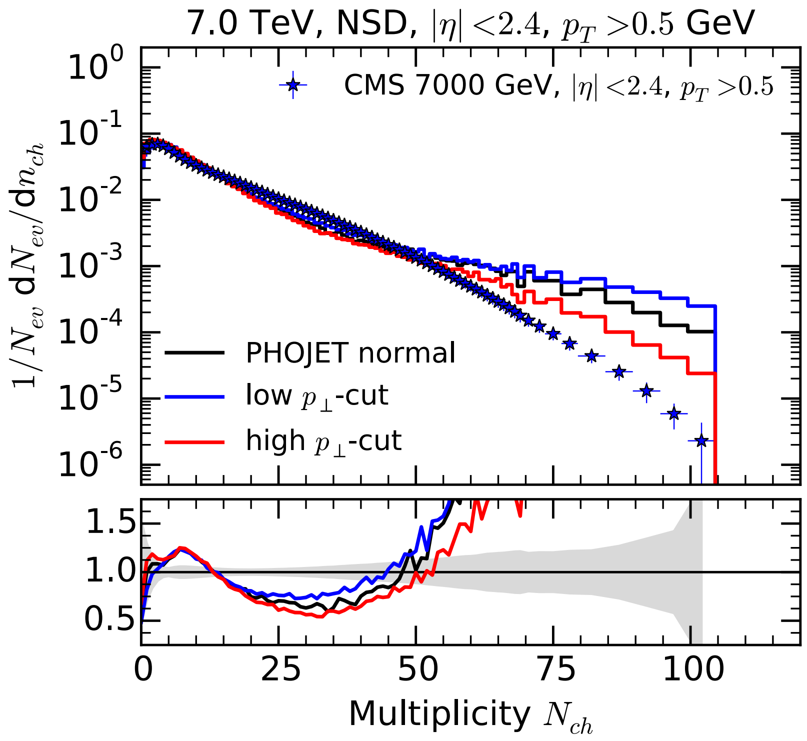
Fragmentation parameters are universal for hard and soft strings

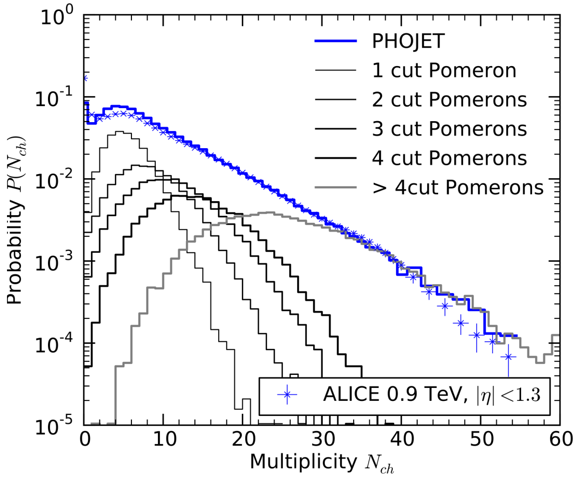


But…



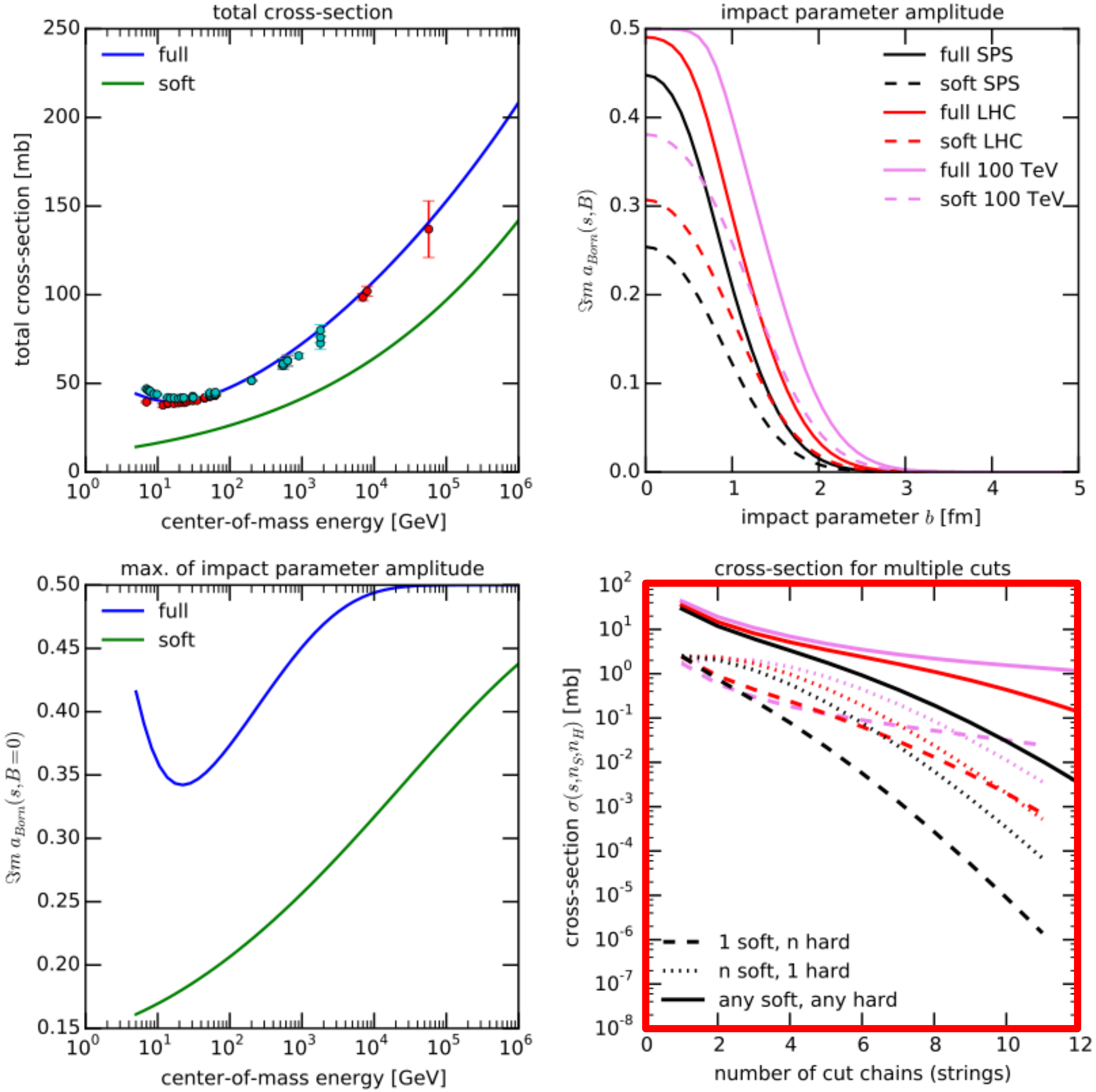






Some models show characteristic flattening of the high N_{ch} tail

Deformation of multiplicity distribution from approaching the black disk limit

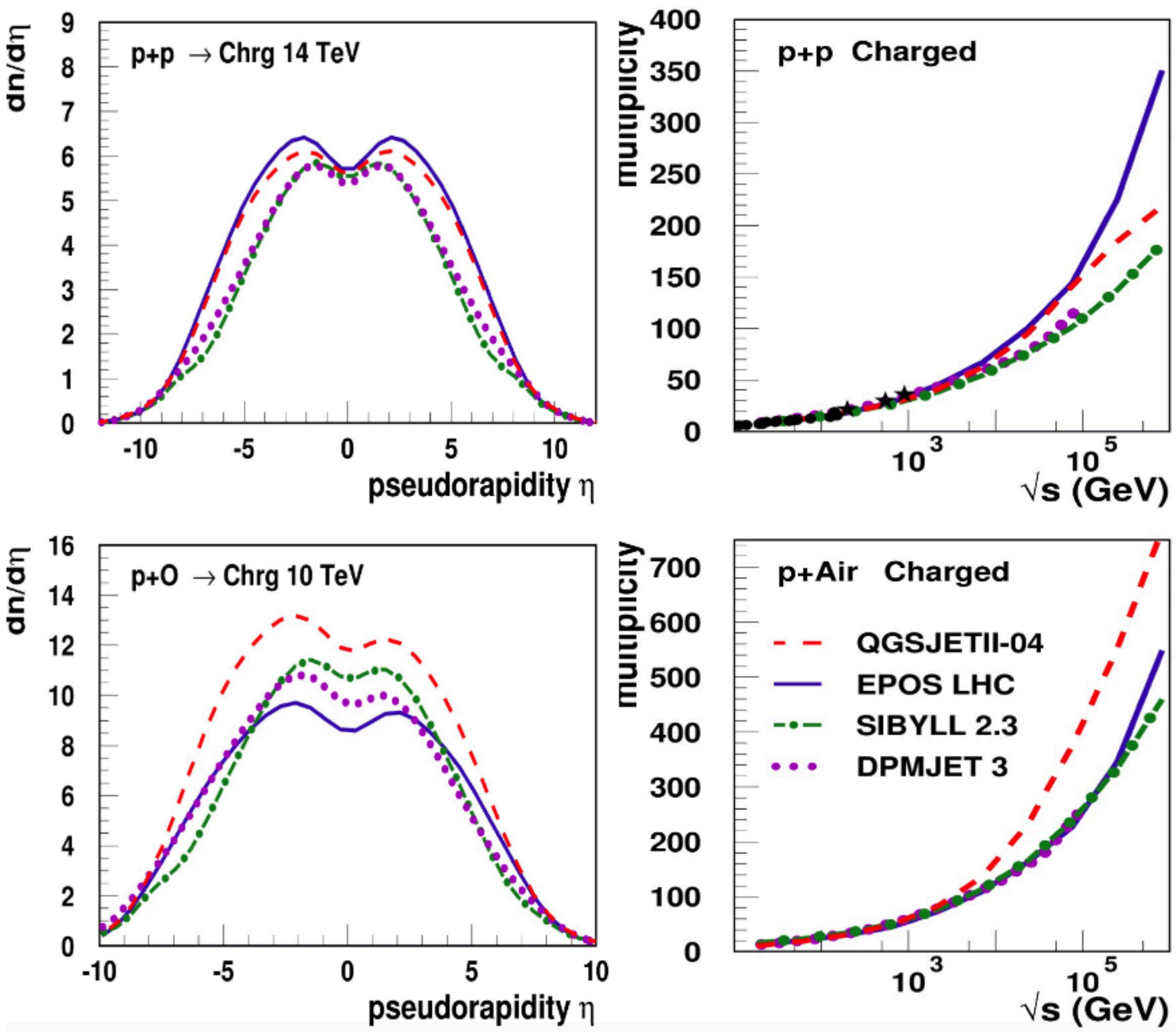


- Simplified model:
  - Only one pomeron graph with soft and hard part
  - Eikonal is only

$$\chi_{\text{soft}} + \chi_{\text{hard}} + \chi_{\text{reggeon}}$$

  - Impact parameter shape is gaussian
- Width of b-shape scales with ln(s) for soft (constant for hard part)
- Hard intercept fitted to minijet cross section ~0.2
- Without some mechanism to suppress n_{hard}, the shape of multiplicty distribution will flatten at some point

Cosmic ray applications



T. Pierog, UHECR 2016

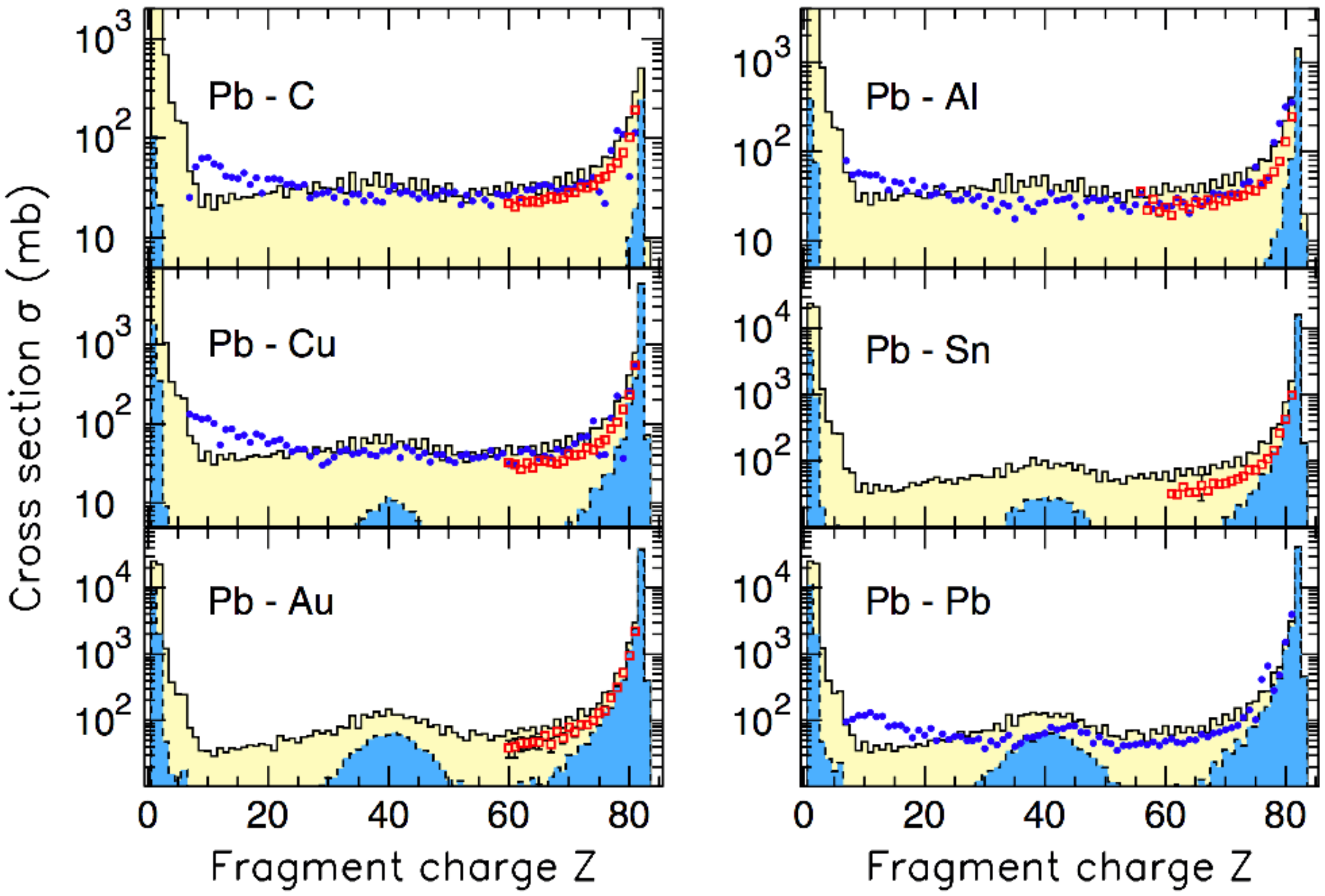
- For cosmic ray applications extrapolation to very high energies and p-Air interactions are crucial
- Listed models are adjusted using only 7 TeV data
- Model predictions diverge stronger for p+O ➡ input from LHC needed

Summary and conclusion

- DPMJET III 2016 is an improved general purpose and cosmic ray Monte Carlo
- Re-tuned using minimum-bias data from all LHC experiments at 7 TeV
- Air-shower cascade/cosmic ray extension: Ultra high energies, hadron-nucleon/nucleus cross sections
- Problems with multiplicity distributions remain (as in many models) ➡ new phenomenology needed or impact parameter dependent cross sections
- Next steps:
  - Finalize public versions (clean up, small technical things..)
  - Connect with LHC MC tools (Rivet/Professor, CRMC,..)
  - Air-shower simulations
  - Look at 13 TeV results!

Where nuclear remnants matter

NA49 @ 158 A GeV



- Radiation protection!
- Machine design
  - LHC accelerator elements
  - Magnets
  - Future accelerators
  - …
- Beam halo
- Main application fields of FLUKA

Braun et al., Accelerators and Beams 17, 021006 (2014)