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Cross sections in SMASH

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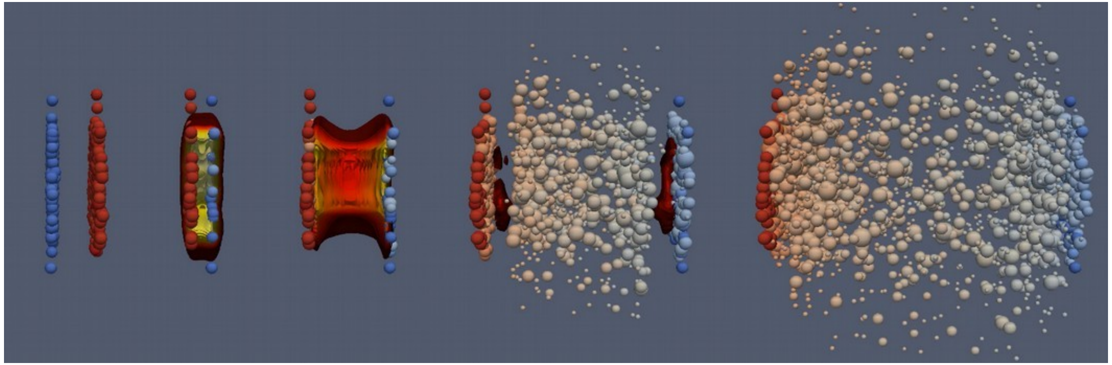
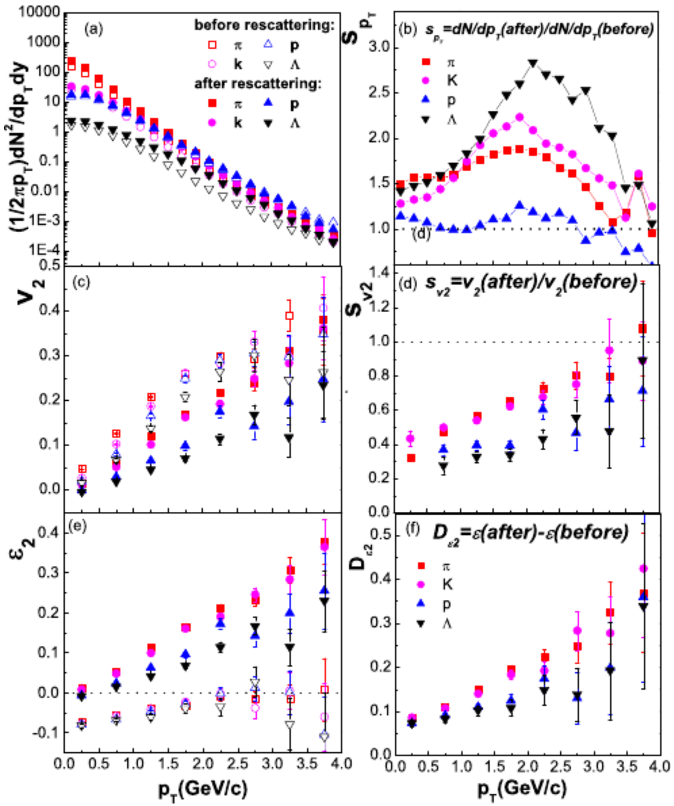
The need for an afterburner



- At some point during a HIC, hydrodynamics stops being applicable. The system is far from equilibrium.
- Rescatterings affect observables: yields increase and flows decrease
- Appropriate description from *Boltzmann transport*



[nucl-th/0505034]

A hadronic transport approach

Simulating Many Strongly-interacting Hadrons

smash

Hadrons are evolved with the Boltzmann equation

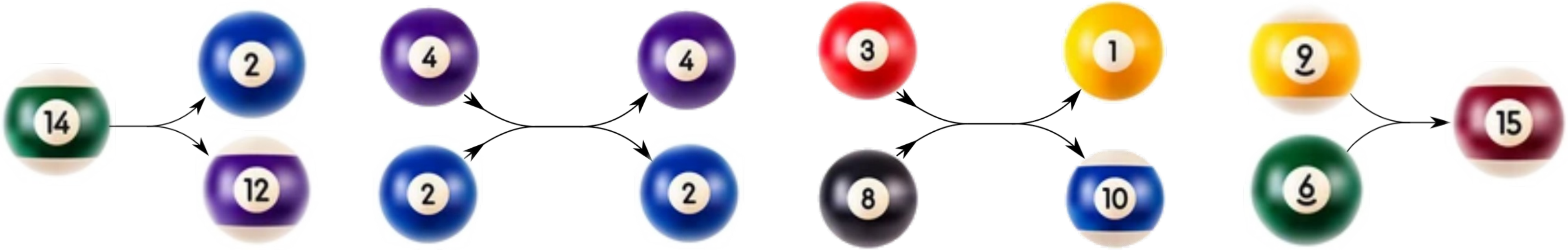
$$p^\mu \partial_\mu f_i(x,p) + \cancel{m_i F^\alpha \partial^p_\alpha f_i(x,p)} = C^i_{\text{coll}}$$

Disregard potentials in the afterburner

with a *geometric* criterion for collisions

$$d^2_{\text{trans}} = (\vec{r_a} - \vec{r_b})^2 - \frac{((\vec{r_a} - \vec{r_b}) \cdot (\vec{p_a} - \vec{p_b}))^2}{(\vec{p_a} - \vec{p_b})^2} \qquad d_{\text{trans}} < d_{\text{int}} = \sqrt{\frac{\sigma_{\text{tot}}}{\pi}}$$

Then only binary interactions are possible



The cross sections

SMASH follows a bottom-up approach:

$$\sigma_{\text{tot}}^{A+B}(s) \Leftarrow \sum_R \sigma_{AB\to R}(s) + \sum_{X,Y} \sigma_{AB\to XY}(s) + \sigma_{\text{string}}(s)$$

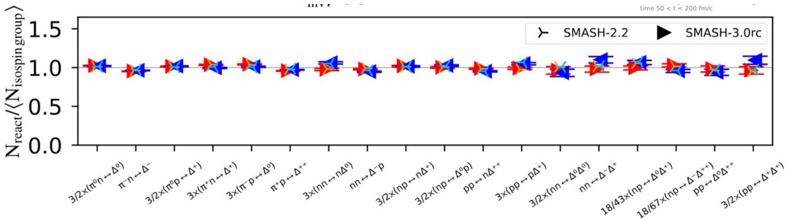
Since only binary scatterings are permitted, 1→N and 2→N processes happen via decay chains.

$$\omega \to \rho\pi \to 3\pi \qquad N + \bar{N} \to \rho^0 + h_1(1170) \to \pi\pi + \pi\rho \to 5\pi$$

Time-reversal symmetry → detailed balanced is assumed

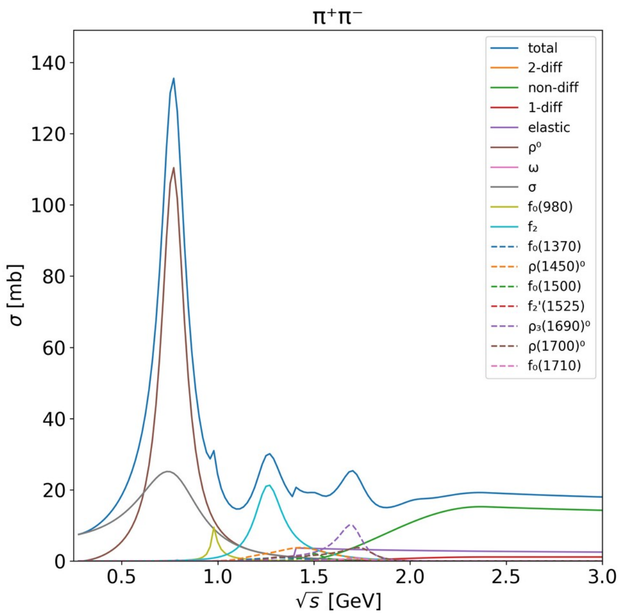
$$\sigma_{cd\to ab}(s) = (2J_a+1)(2J_b+1)\frac{S_{cd}}{S_{ab}}\left|\frac{\vec{p}_f}{\vec{p}_i}\right|\frac{1}{s}\sum_I \left(C_{ab}^I C_{cd}^I\right)^2 \frac{|\mathcal{M}|^2_{ab\leftrightarrow cd}(s,I)}{16\pi}$$

$$\sigma_{ab\to R}(s) = \frac{2J_R+1}{(2J_a+1)(2J_b+1)} S_{ab}\frac{2\pi^2}{\vec{p}_i^{\,2}}\Gamma_{ab\to R}(s)\mathcal{A}_R(\sqrt{s})$$

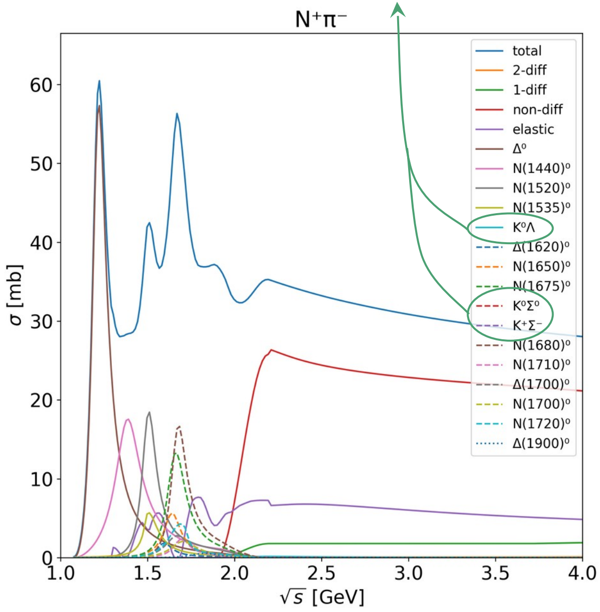


Low energy interactions

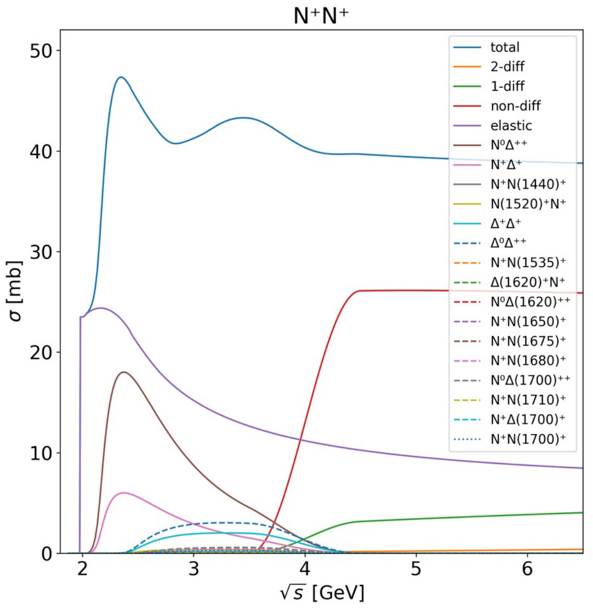
MM: only via resonances, elastic cross sections are automatic



MB: resonances + parametrized (remaining) elastic + tuned rare 2→2



BB: elastic parametrized + one-boson exchange 2→2 inelastic



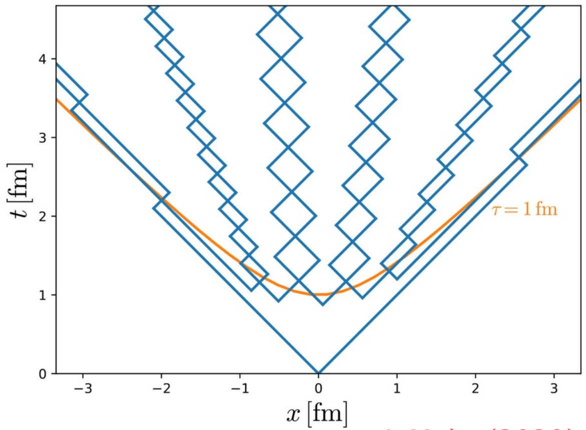
Strings

color flux tubes

As partons fly apart, the energy in the color field between them increases, until *fragmentation*

Types:

- Single diffractive [AB→AX or AB→XB]: one hadron is excited into a string
- Double diffractive [AB→XX]: both hadrons become strings
- Non-diffractive [AB→XX]: the hadrons exchange valence quarks, and a string forms inbetween them
- Hard [AB→XX]: Not actually a string, interactions at parton level (pQCD)



J. Mohs (2020)

PYTHIA 8 only accepts pions and nucleons → Use the additive quark model (AQM)

$$\sigma_{AB} = \frac{n_{q1}}{3}\frac{n_{q2}}{3}\left(1 - 0.4x_1^s\right)\left(1 - 0.4x_2^s\right)\sigma_{\text{known}}$$

Intermediate energies

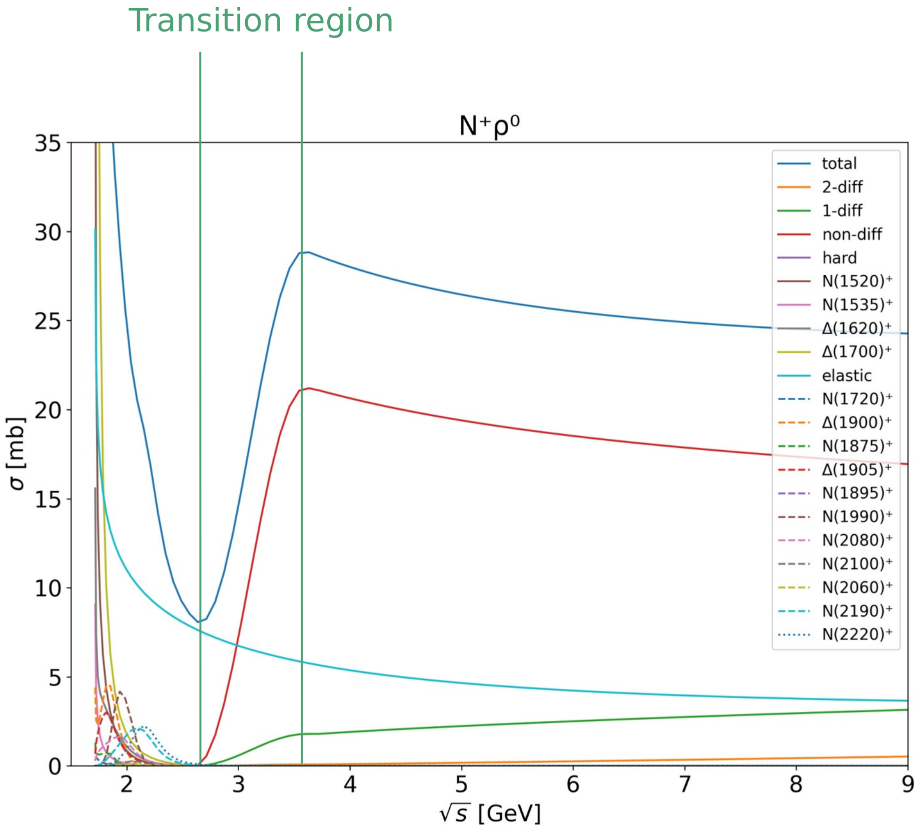
Smooth linear interpolation between regimes

$$\sigma_{\mathrm{mid}}(s) = \lambda\sigma_{\mathrm{high}}(s) + (1-\lambda)\sigma_{\mathrm{low}}(s)$$

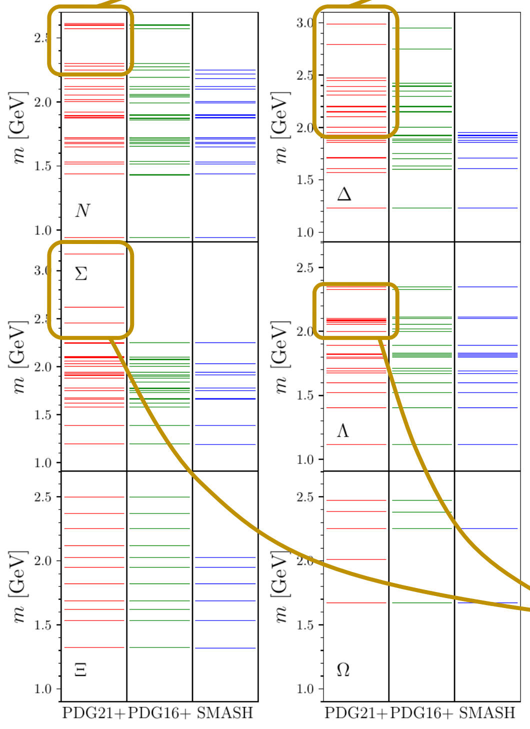
This works well for established processes, but creates an unphysical gap where there are little to no inelastic interactions.

Possible solutions:

- Reduce lower end of transition (PHSD): angular distribution becomes more forward-backward
- Continuous spectrum of fake resonance (UrQMD): increases momentum distribution of decay products

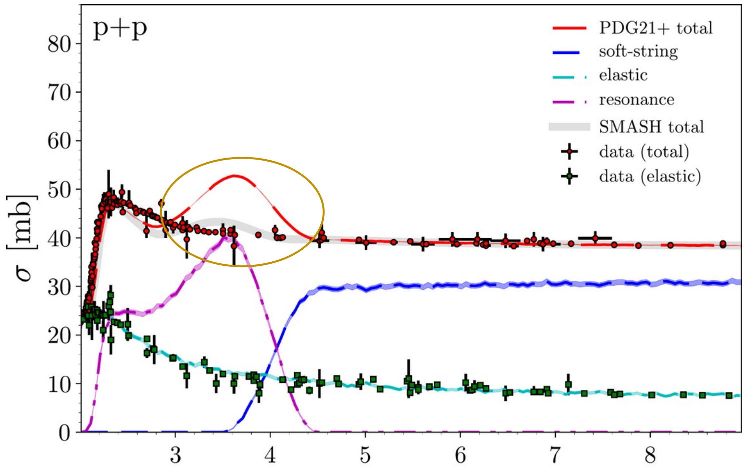


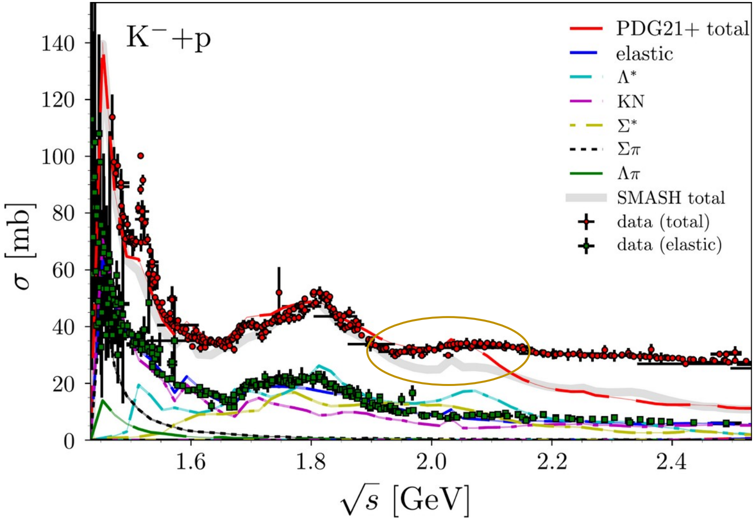
Addition of PDG21+ resonances



Inelastic 2→2 for BB is <u>tuned</u>, so new resonances break agreement with data

Partial K+N→X processes are via resonances, so an updated hadron list improves agreement





from Jordi's talk

Strategy

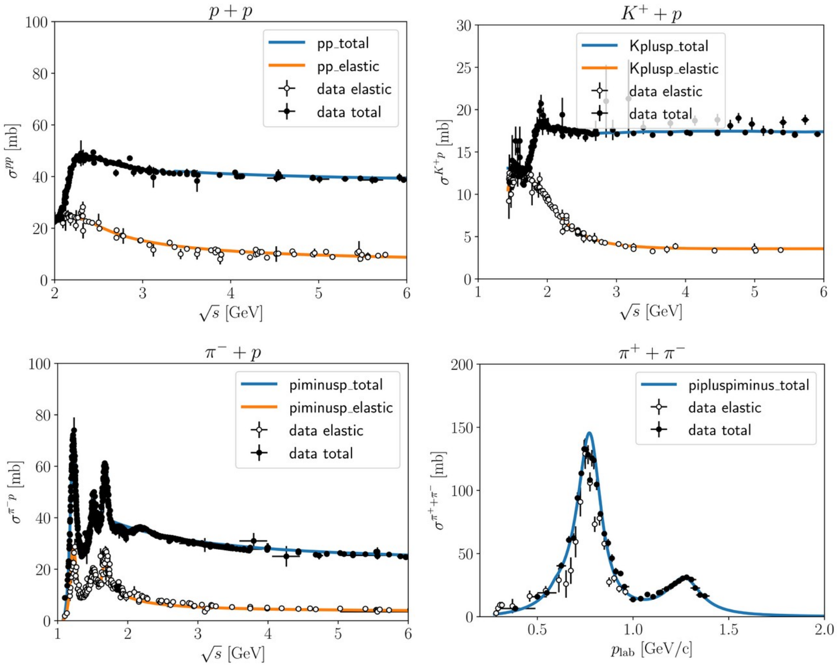
- Elementary cross sections: rescale to fits/parametrizations

$$\lambda = \frac{\sigma_{\mathrm{tot}}^{\mathrm{goal}}}{\sigma_{\mathrm{tot}}^{\mathrm{SMASH}}}, \quad \sigma_i^{\mathrm{SMASH}} \to \lambda \sigma_i^{\mathrm{SMASH}}$$

- New resonances: use AQM scaling

$$\sigma_{ab}^{\mathrm{goal}} = \frac{\sigma_{\pi N}^{\mathrm{goal}}}{\sigma_{\pi N}^{AQM}} \sigma_{ab}^{AQM}, \quad \sigma_{ab}^{AQM} = 40 \left(\frac{2}{3}\right)^{n_M} (1 - x_a^s)(1 - x_b^s)$$

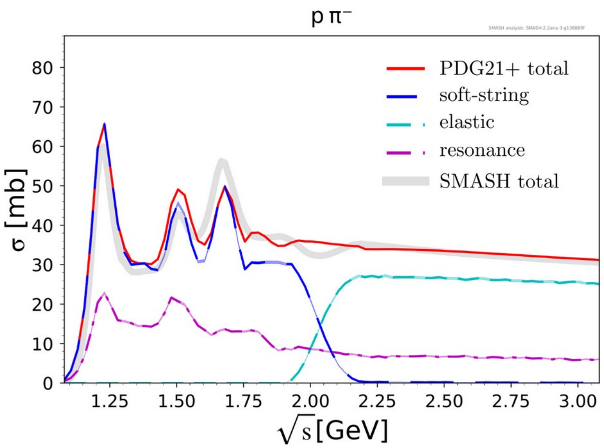
Parametrizations of total cross sections

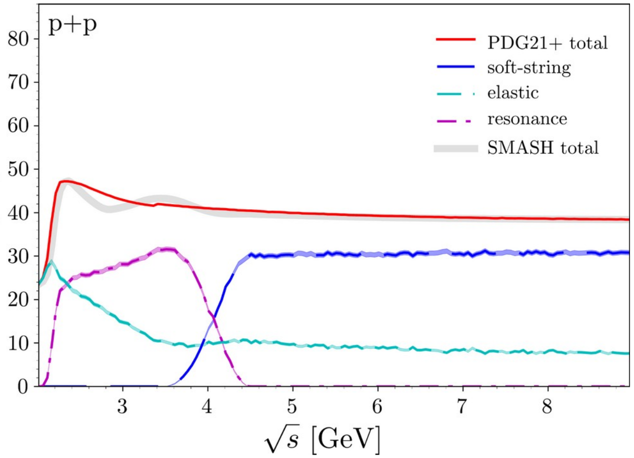


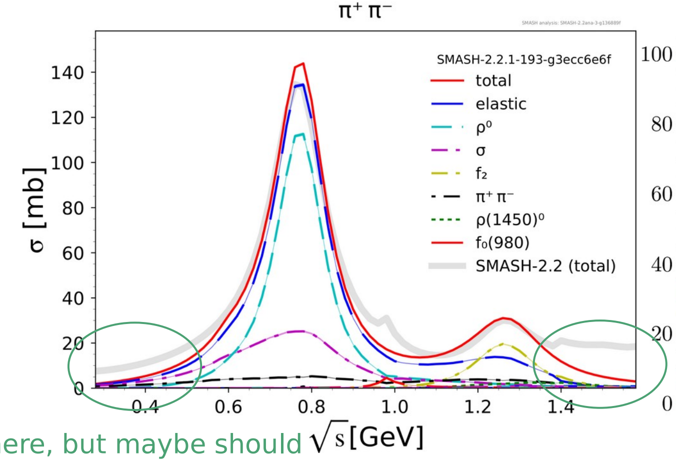
- pp (= nn)
- $p\bar{p}$ (= $n\bar{n}$, ≈$n\bar{p}$)
- np
- π^+p (= π^-n…)
- π^-p (= π^+n…)
- $\pi^+\pi^-$
- K^+p
- K^+n
- K^-p
- K^-n

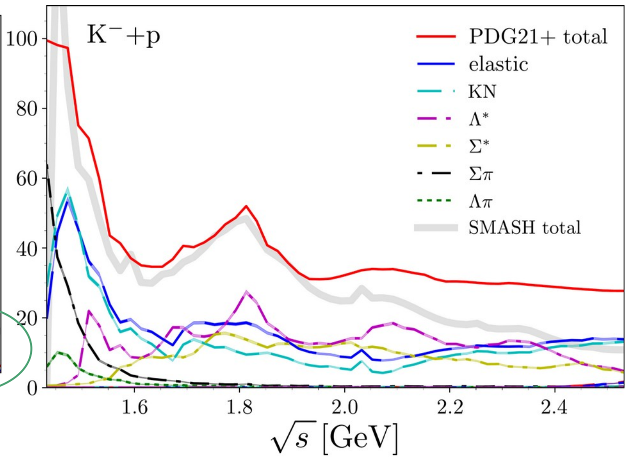
Results

Total cross sections match by construction









No data exists here, but maybe should have non-zero cross section

Conclusions

- Gap in intermediate region suggests (yet) missing resonances
- Because some tuned cross sections are used, changing the hadron list would require retuning
- This rescaling provides a (quick and dirty) way of accommodating different degrees of freedom without losing experimental agreement

Outlook

- Rescaling the *total* cross section does *not* eliminate the problem with an inelastic gap
- Parametrizations can be improved with new data or first-principle calculations

Thanks for the attention!