Cross Section Issues in Cosmic Ray Physics

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What this talk will cover

- A summary of collider elastic and total cross section measurements, including a quick and incomplete tour of methods of measuring luminosity-related parameters.
- Mention of shower characteristics of interest to cosmic ray modeling.
- Why we should care about scaling of physical models as particle energies go up.

What we will not cover

- For lack of time, much specific detail about the virtues or failures of various QCD- and QCD-inspired models and fits.
- More than a brief mention of the most important air shower codes and the physics that underlies them.

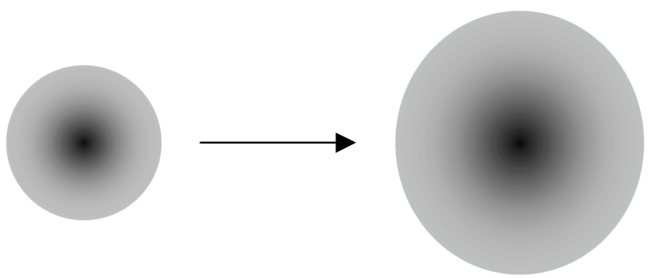
(Goal is to concentrate on what we can do at the Tevatron and LHC, and possibly with direct detection to improve MC models used.)

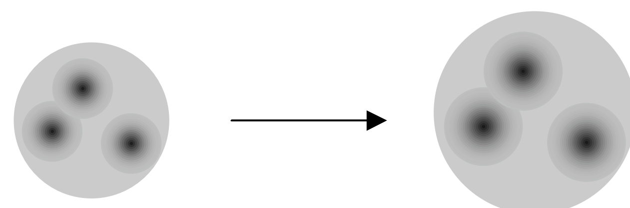
Why we care about total cross sections:

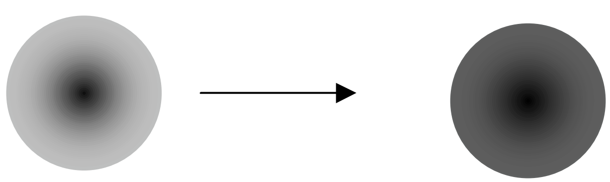
- Of course, at Tevatron, LHC, etc. correct values are needed to calculate total luminosity. (Other techniques possible, see later.)
- Modeling this properly controls parameters of underlying event in collider experiments, and general properties of both events and backgrounds in cosmic ray EAS codes.
- Important for understanding hadron properties.

Basic question for physics at high energies but low x:

Does nucleon get bigger, or **darker** (more opaque), or do the quarks within it themselves get darker or larger (either individually or through their interaction with the nearby color field) as overall energy of the interaction increases?



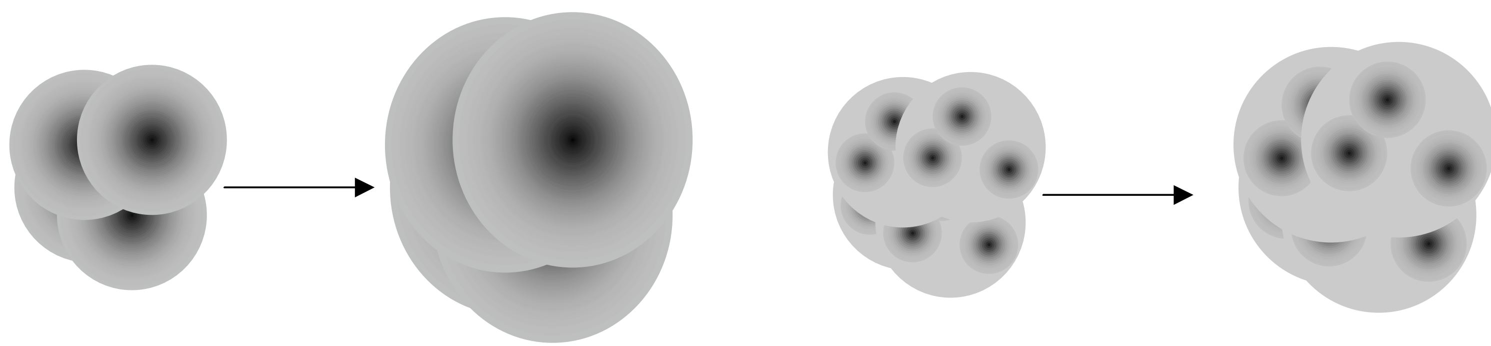


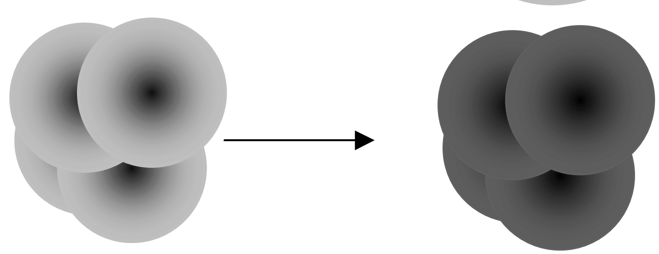


Or some combination of these effects??

Scaling from hadron-nucleon to nucleus-nucleus events:

Evolution of conversion relation between p-p and p-air cross sections, for example, as a function of energy depends on details of the assumed model for nucleon internal behavior, and many internal details of QCD.





Shadowing, diffraction, etc. for multiple nucleons produce different effects in different QCD models.

Basic experimental situation:

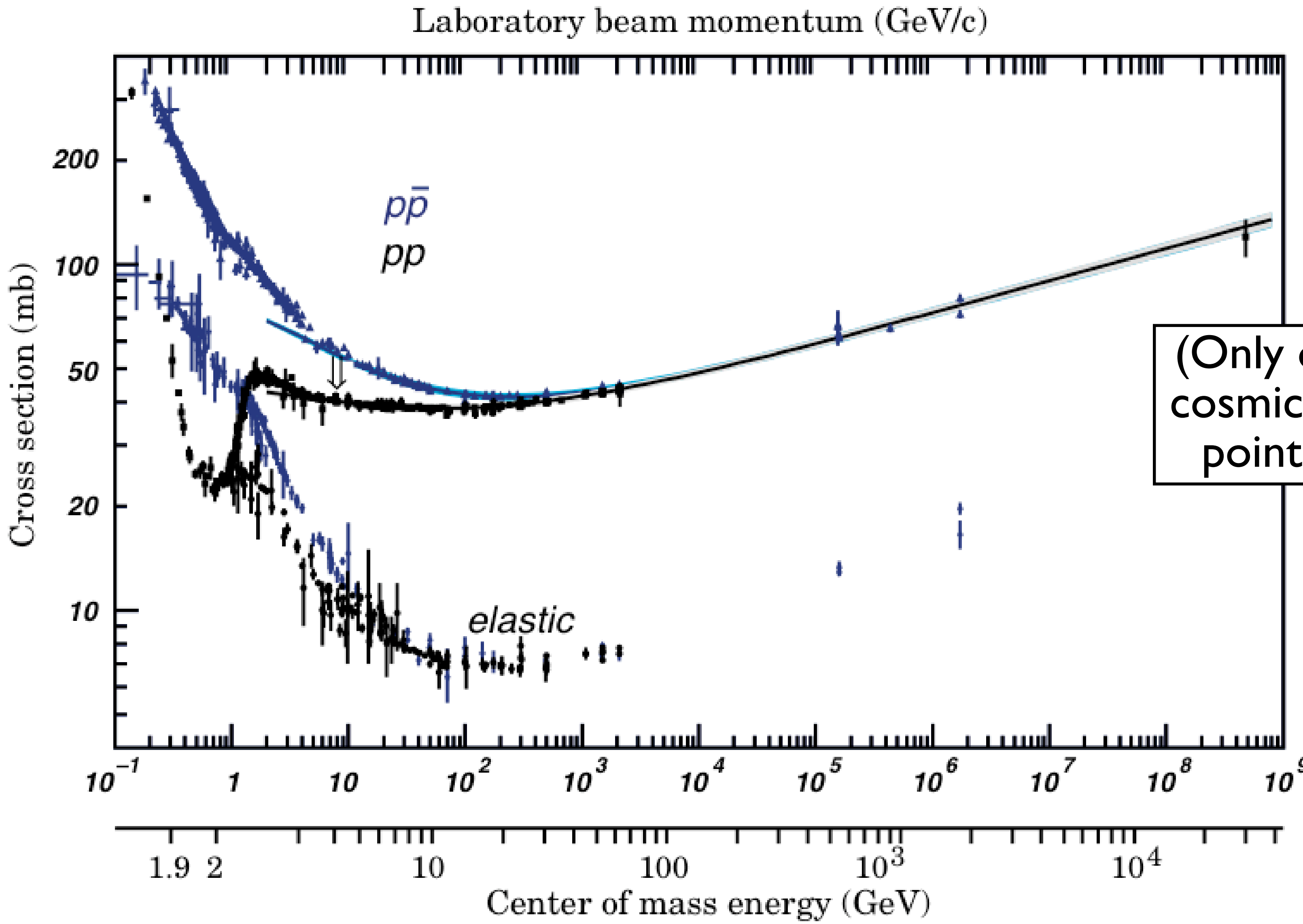
Accelerator data:

- Elastic pp, ppbar scattering and inelastic cross section measured at a variety of machines up to the ISR, and by CDF, E710 and E811 at the Tevatron.
- Pion-nucleon and a variety of other elastic, quasielastic and resonance production experiments also relevant.
- Data on nucleon-nucleus and nucleus-nucleus interactions limited to relatively low CM energies.

Cosmic ray data:

- Air shower data for xmax, shower product particle distribution used to extract composition, energy and initial hadronic interaction probability simultaneously => hard to sort out all of the effects.

Particle Data Group (2000)



(Only one cosmic ray point!!)

In more detail:

Regge / S-matrix-inspired fit form (PDG):

$$\sigma^{ab} = Z^{ab} + B \log^2(s/s_0) + Y_1^{ab}(s_1/s)^{\eta 1} - Y_2^{ab}(s_1/s)^{\eta 2},$$

$$\sigma^{\bar{a}b} = Z^{ab} + B \log^2(s/s_0) + Y_1^{ab}(s_1/s)^{\eta 1} + Y_2^{ab}(s_1/s)^{\eta 2},$$

Z, B, Y_i are universal xsec components that come in at universal scales indicated.

- Fits a wide variety of data
- Why log squared? Why universal scales?
- QCD hints at some answers: $\log^2$ = saturation of Froissart bound, Pomeron/Odderon interpretation for exponents in diffraction, etc.)

We're not done yet!

- Having a fit, or even a fit form, for the total cross section is not sufficient to do more than guide the models used in air shower Monte Carlo production.
- Still need to scale from hadron-hadron to proton-air and/or nucleus-air interactions (nucleus-nucleus in the case of balloon and/or satellite experiments, neutrino showers, etc.) Depends on the details of the inner components of the nucleon and their arrangement.
- Cross-check with observable kinematic distributions.
- Need to reproduce both cross section and kinematic distributions within a single picture!

Problems

- Total p-p and p-pbar cross sections are not measured directly above the ISR (see plot). Instead, collider experiments such as CDF, E710 and E811 at Fermilab, UA4 at CERN SPS measure only the slope of the elastic cross-section near t=0 and then project using Gribov-Regge theory to infer the total cross section.
- Results of this method are sensitive to diffraction, shadowing/ screening, details of the optical theorem, backgrounds, etc.
- Detailed comparison among the Tevatron experiments failed to resolve this problem: 10% uncertainties remained. These project to be more than proportionately higher at high E.
- For this reason, have to read cross section results for other processes carefully to make sure of assumptions used in any individual paper about the total cross section used in that result.

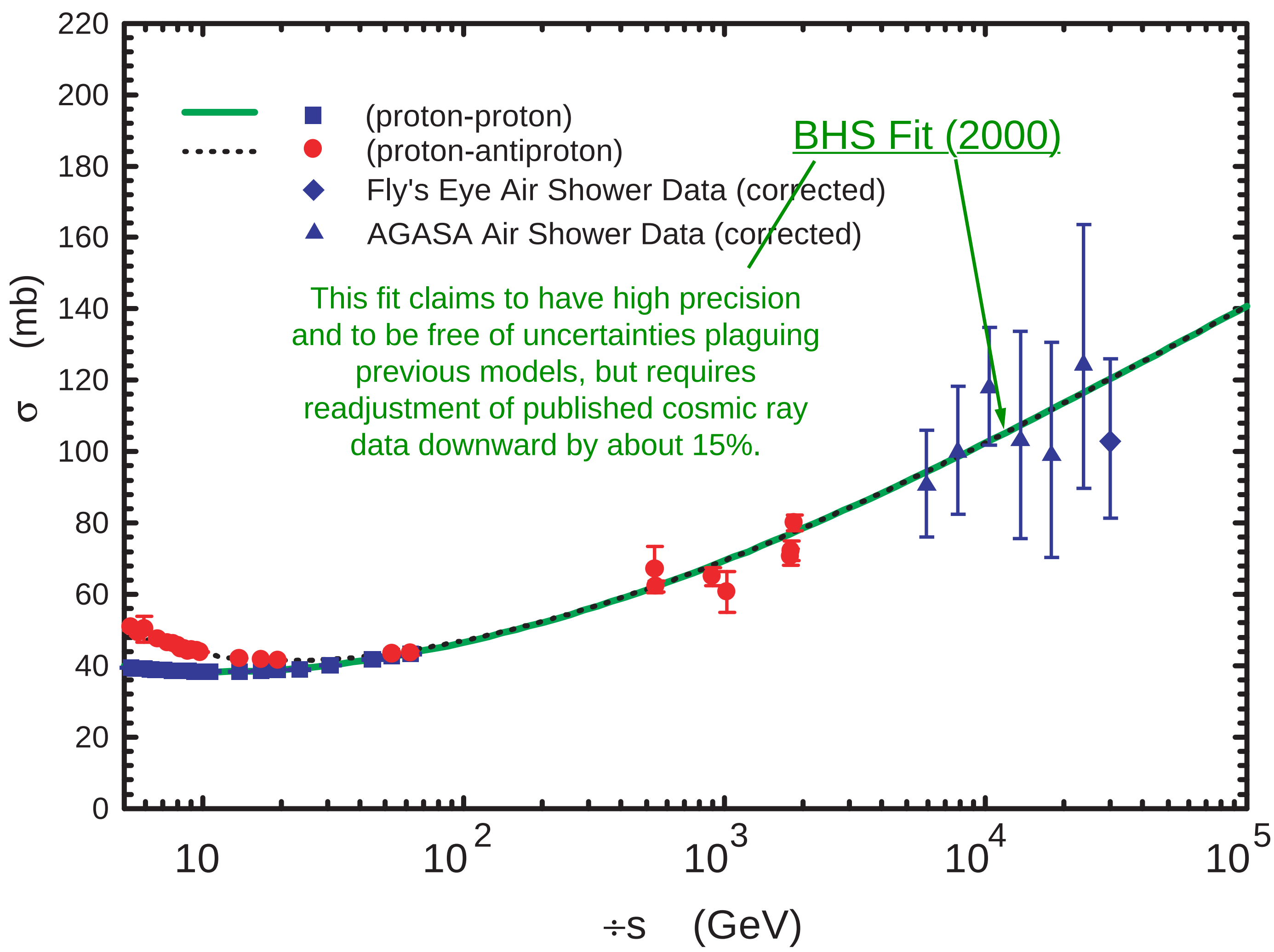
Recent Progress

- Tevatron experiments (D0, CDF) agreed to use a single consistent average value (60.7 +/- 2.4 mb) for inelastic cross section to present Run II results.
- Eliminates historical discrepancy between experiments, makes it easier to compare results.
- Opens door to use higher-precision central electroweak processes to calibrate luminosity for all high-pT central collider results.
- Leaves open question of connecting forward production needed for cosmic-ray physics to central electroweak results. (What's new? Much more statistics on central EW processes.)

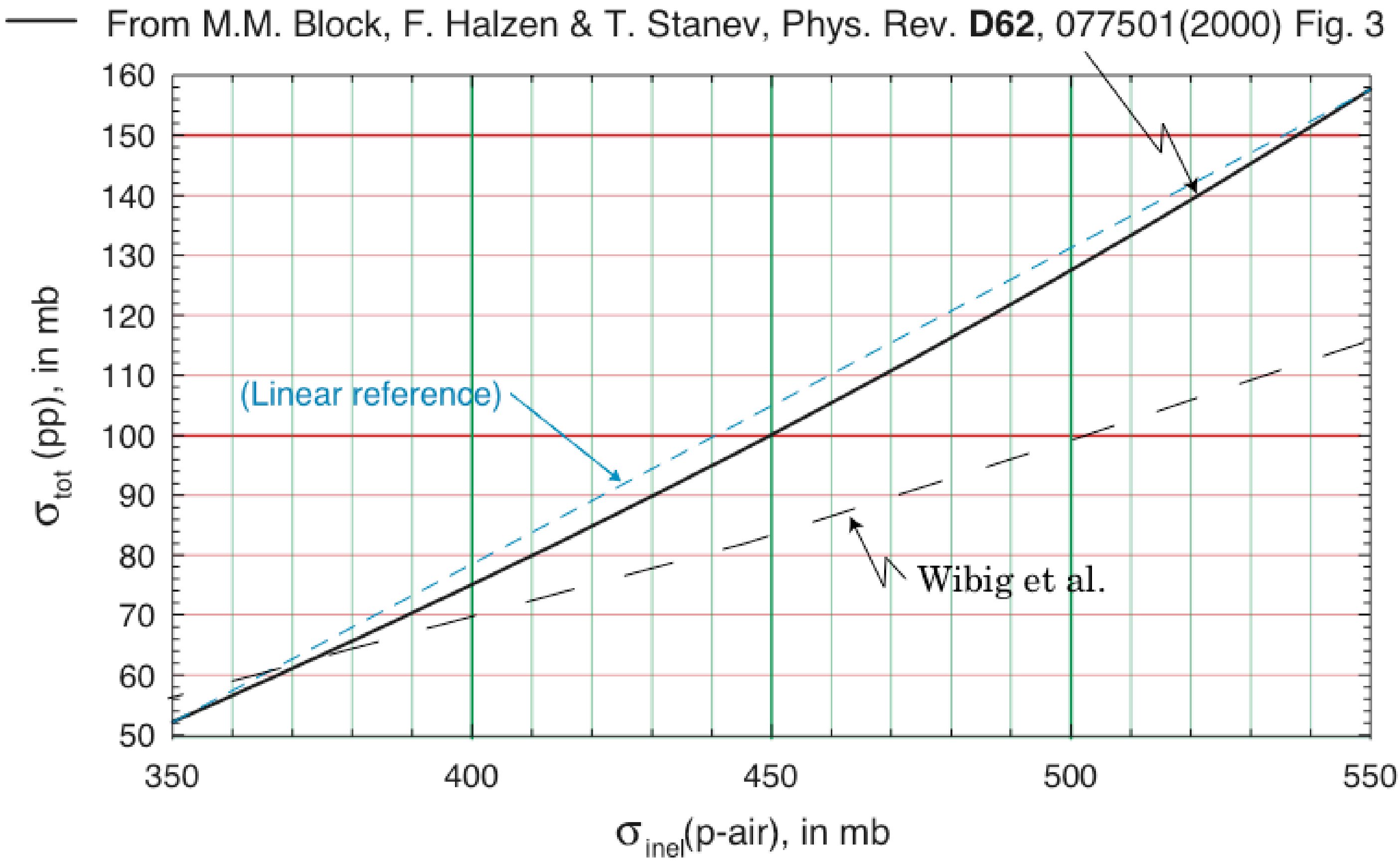
Recent scaling and normalization efforts

- Block, Halzen and Stanev (2000): rescale high-enegy cosmic ray results based on extrapolation model from simultaneous fit. Recent work consistent with these ideas.
- Hi-Res: new p-air cross section result based on fit including explicit deconvolution of interaction length from shower profile. Gives value consistent w/ above fit.
- Still leaves open question of detailed QCD model for scaling between p-p and p-air - this question is less well settled than assumed now in the literature.

BHS cross section rescaling (2000)

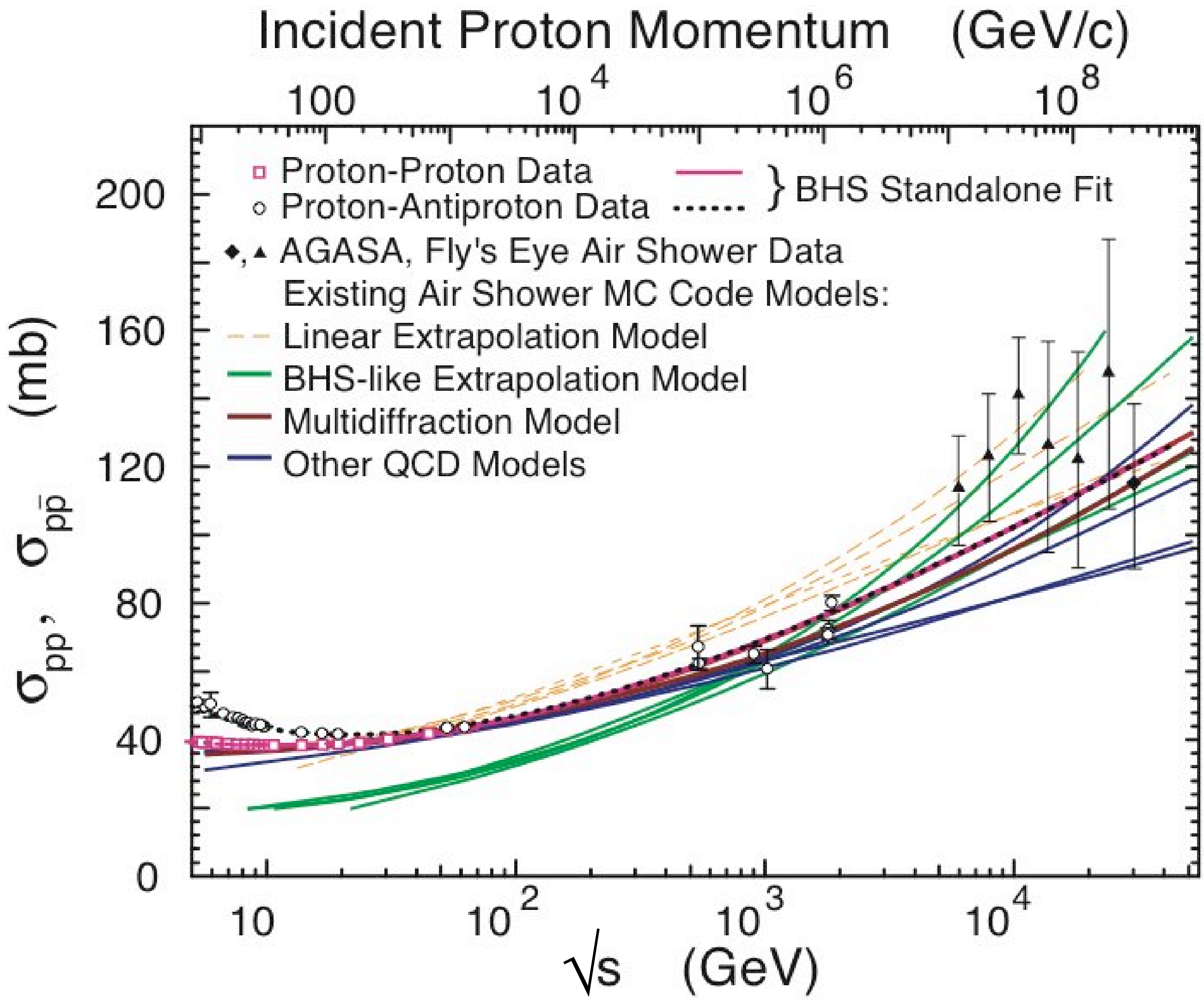


Translation issues for cross section from pp to p-air:



QCD models vary, are not unique

Effects of different scaling models on p-p to p-air translation:

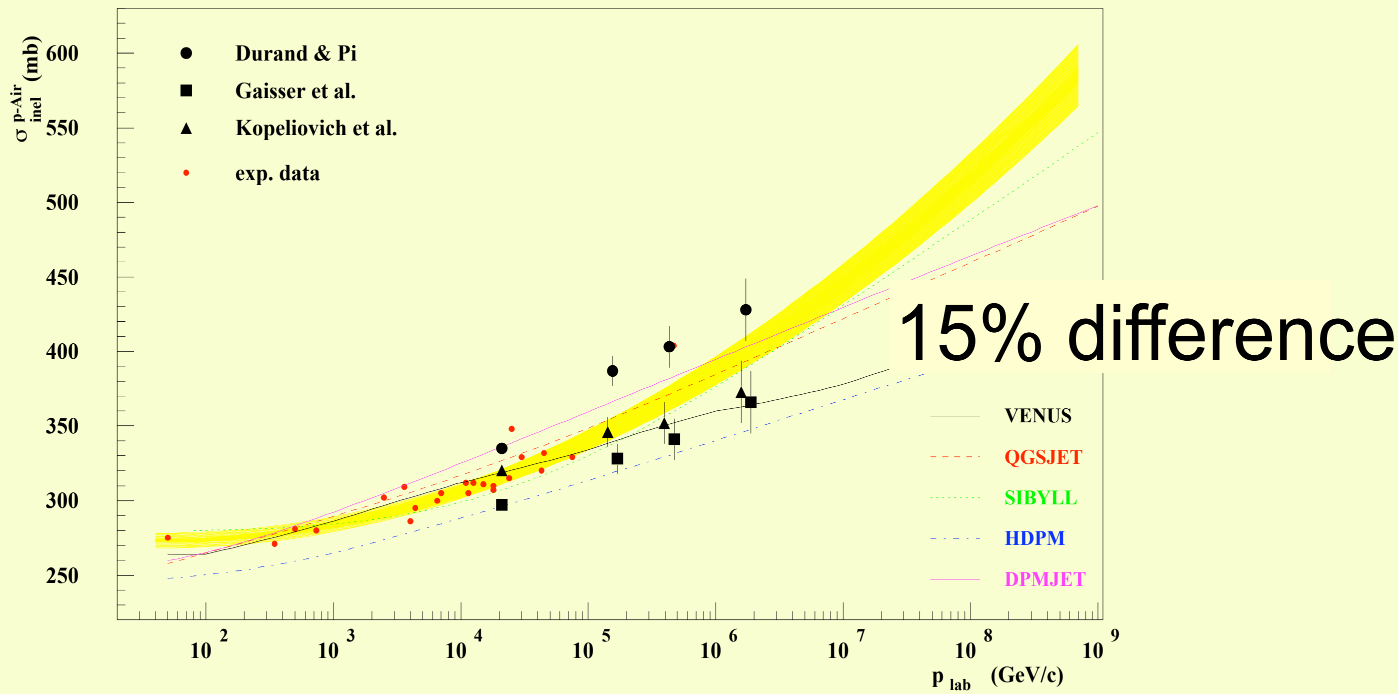


Projection of MC air shower models back onto σ_{pp} plot

(Example fits and extrapolation models, others possible...)

From J. Knapp - Corsika school, May 2005:

Conversion from p-p to p-Air cross sections (Glauber Theory)



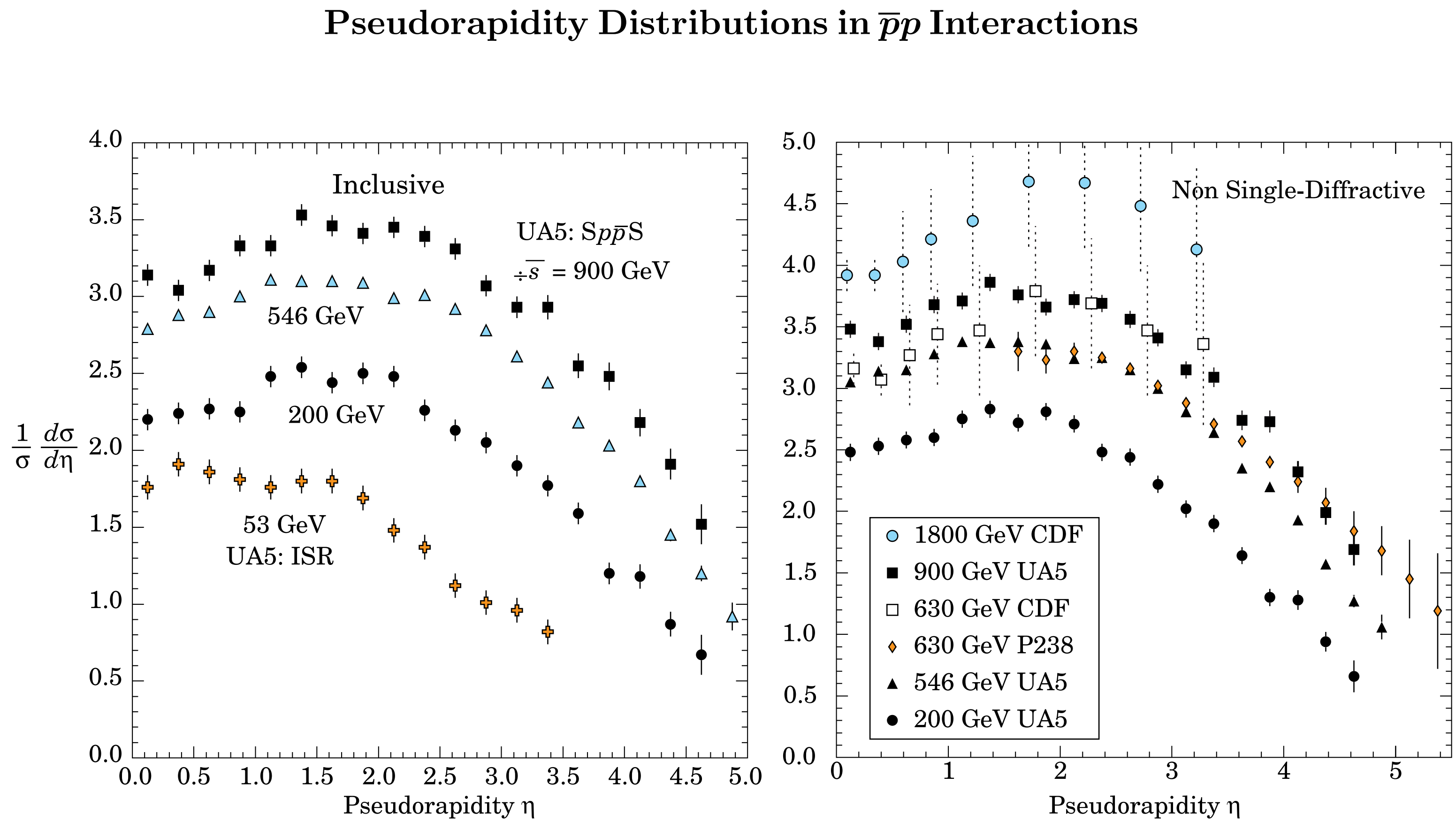
3 groups applied Glauber theory to deduce
the proton-Air inelastic cross-section from
the measured p-p cross-sections (SppS, Tevatron)

origin of difference? what exactly is the nucleon distribution of a nucleus?

What can we do to help at the Tevatron and LHC?

- Run II measurements on central electroweak cross sections (W - e nu, mu nu, Z - e+e-, mu+mu-) are now available and of more than sufficient quality to be used for normalization of Tevatron luminosity.   (IMPORTANT!)
- Re-measure multiplicities (<N>, $dN/d\eta$) with higher statistics, rates in especially forward detectors; and look for other quantities that can be compared directly to results from EAS-related interaction models.
- Do energy scan at Tevatron while measuring above quantities. Same at LHC when we get there.
- Dedicated experiments (TOTEM, CASTOR) at LHC.

Related collider measurements:



Note: Tevatron hasn't published multiplicity distributions since beginning of Run 0 (1989)!

Other ways of normalizing luminosity measurements

- Beam waist (profile vs. z) using inclusive triggers to measure β^* (easy, in progress)
- Look for pp - $\gamma\gamma$ - e+e- in forward detectors during low-luminosity runs
- Elastic scattering using better detectors (columnar silicon, etc.): prototype use of LHC detectors at Tevatron?

Conclusions

- Historical problems with disagreements between and among both collider and air shower cross section results are slowly being addressed by a combination of new approaches, more standardized averaging, improved code and new measurements.
- Recent measurement of HiRes consistent with ideas from BHS fits and $\ln^2(s)$ scaling.
- Much work still remains to be done in understanding relation between p-p and p-air (nucleus-air) cross sections and how these are modeled at high energies in the cosmic ray MC codes.
- New areas for cross-comparison between collider measurements and MC codes are possible.