SIBYLL

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with

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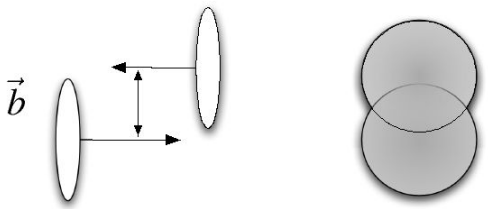
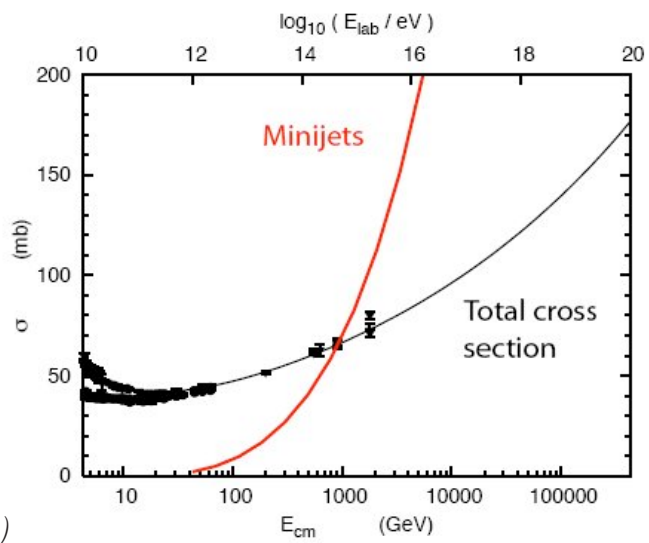
Minijet model



- average number of hard interaction: $\langle n(\mathbf{b}) \rangle = \sigma_{QCD}(s) \cdot A(\mathbf{b})$
- each interaction independent: $P_N = \dfrac{\langle n(\mathbf{b}) \rangle^N}{N!} e^{-\langle n(\mathbf{b}) \rangle}$
- $\sigma_{in,hard} = \displaystyle\int d^2\mathbf{b} \sum_{N=1}^{\infty} P_N$

$$= \int d^2\mathbf{b} \left(1 - e^{-\sigma_{QCD}(s)\, A(\mathbf{b})}\right)$$



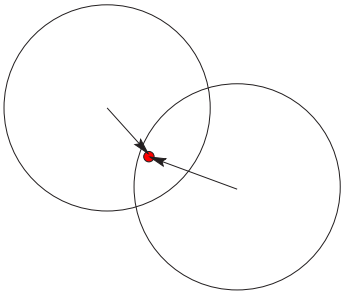
(Figs. by R. Engel)

Hard and soft interaction

$$\sigma_{in} = \int d^2\mathbf{b} \left(1 - e^{-\{\sigma_{QCD}(s)\, A_{hard}(\mathbf{b}) + \sigma_{soft}(s)\, A_{soft}(\mathbf{b})\}}\right)$$

- Hard interaction: point-like $\quad (\Delta p \Delta b \sim 1 \quad \Rightarrow \quad \Delta b \to 0)$

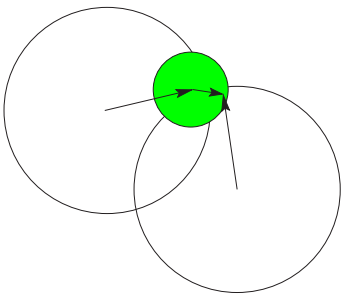
  $A_{hard} \propto$ proton/pion structure functions $\times$
  folding function $(= \delta^{(2)}(\mathbf{b}_1 - \mathbf{b}_2 - \mathbf{b}))$



$p_\perp^{min}(s)$

- Soft interaction: fuzzy $\quad (\Delta p \Delta b \sim 1 \quad \Rightarrow \quad \Delta b \neq 0)$

  $A_{soft} \propto$ proton/pion structure functions $\times$
  folding function $(=$ Gaussian$)$



(Figs. by RE)

Diffraction dissociation

- Non-inelastic
- particle excited and decays
- conserve quantum numbers

Projectile and **T**arget

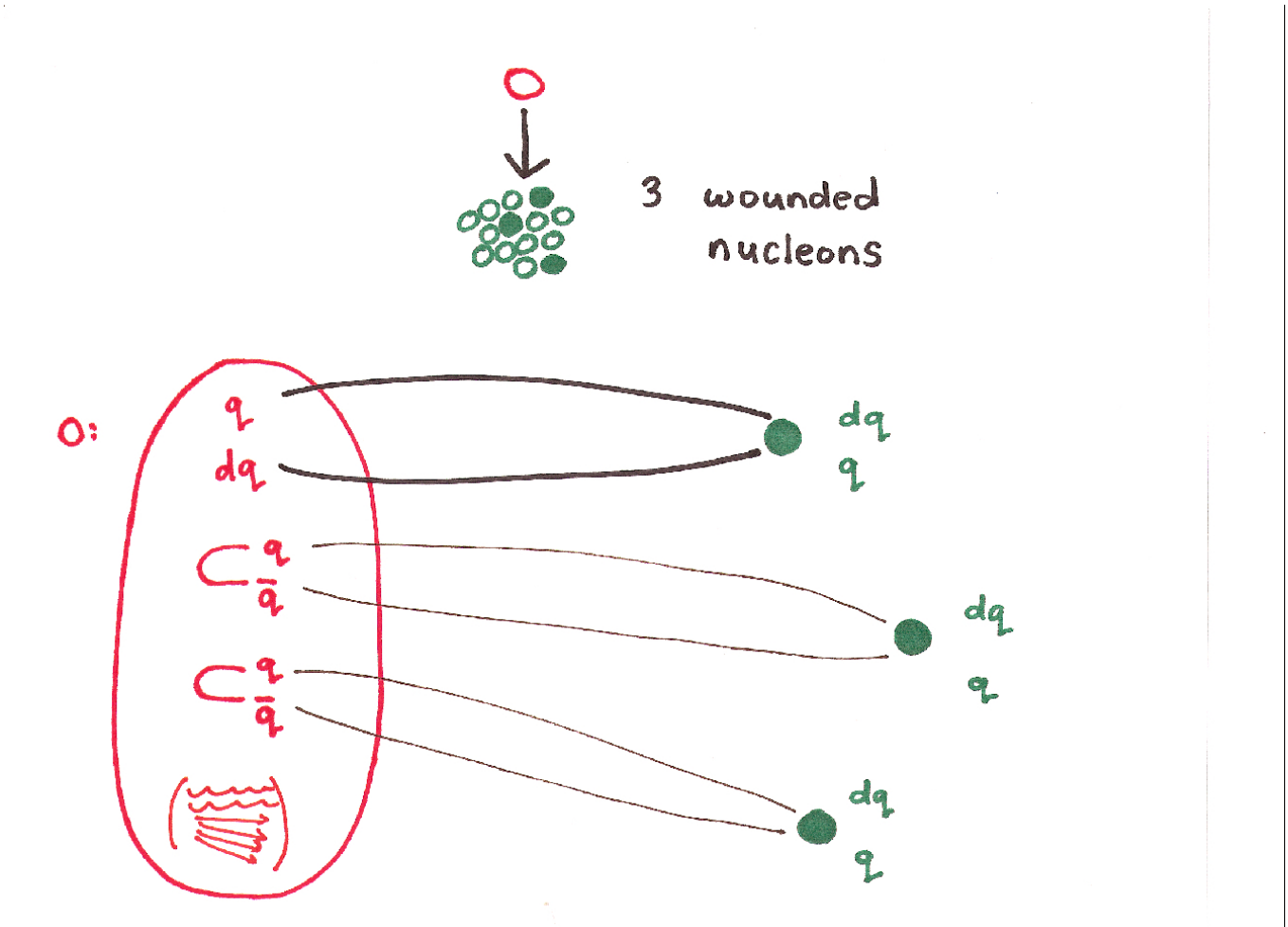
elastic scattering $P\ T \longrightarrow P\ T$

single diffraction $P\ T \longrightarrow P^\star\ T$

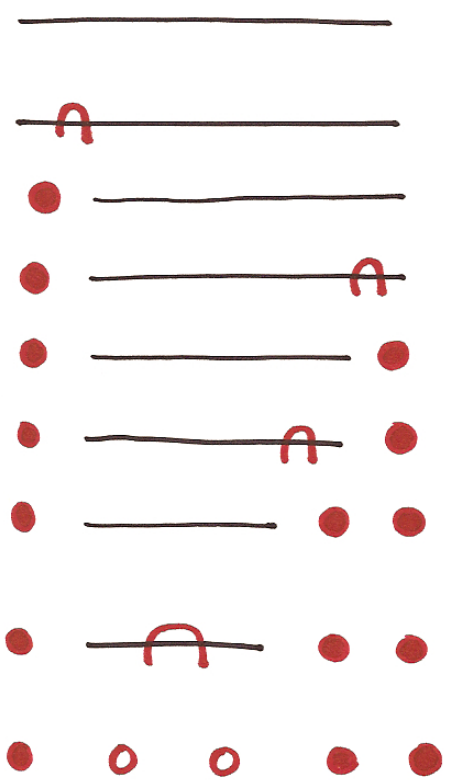
$P\ T \longrightarrow P\ T^\star$

double diffraction $P\ T \longrightarrow P^\star\ T^\star$

Proton-air collision

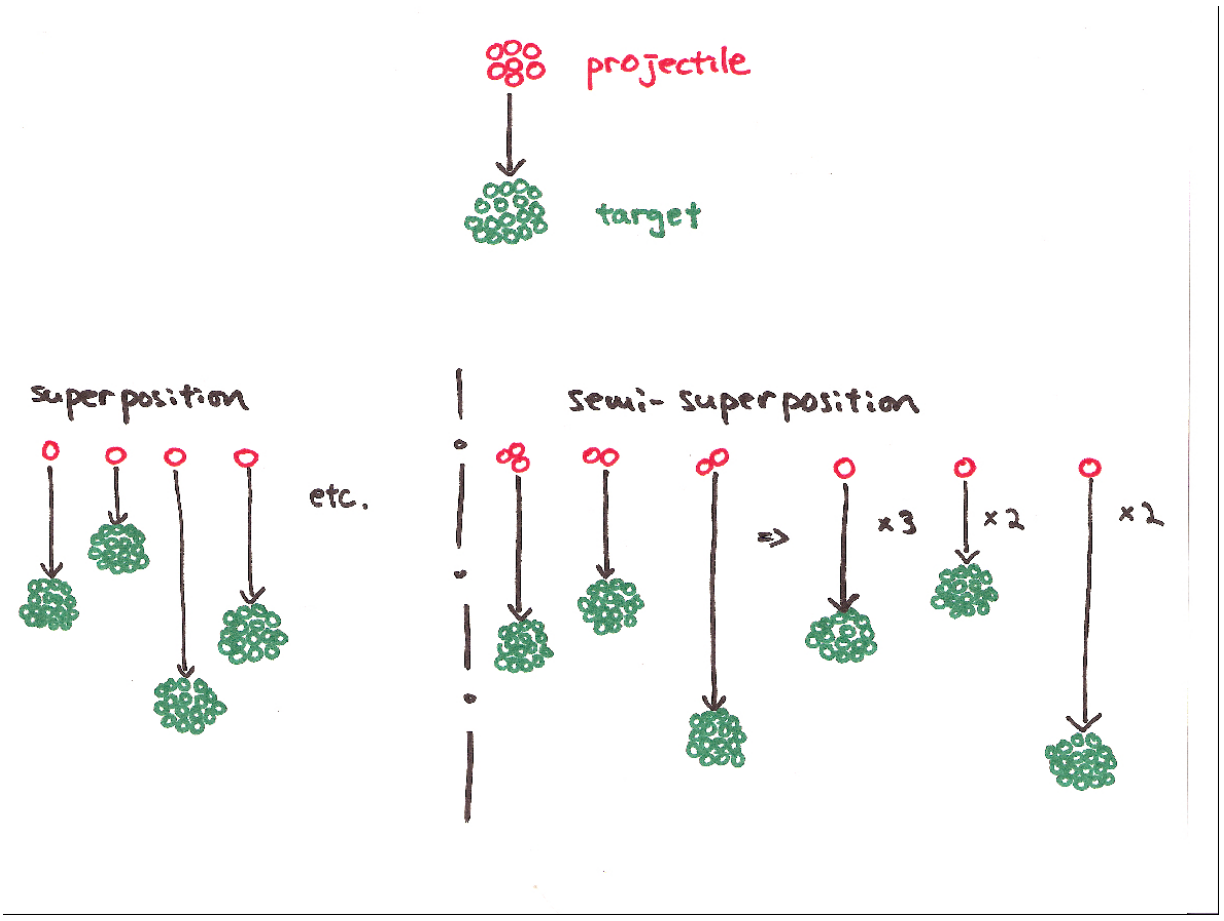


String fragmentation

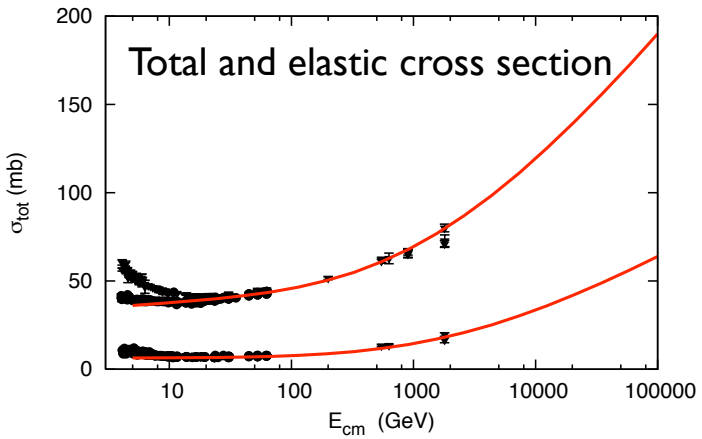


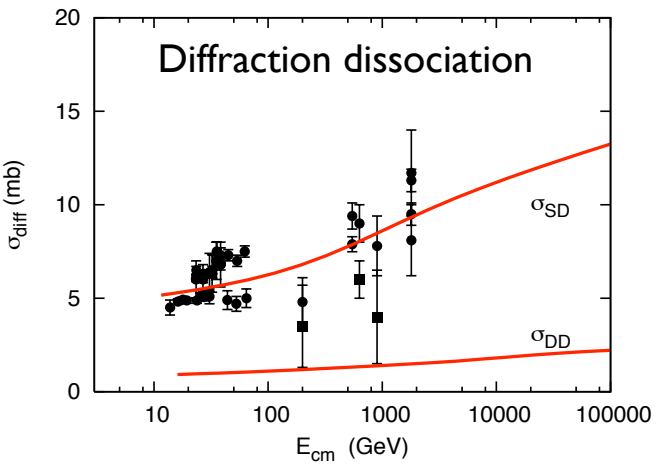
Nucleus-nucleus scattering

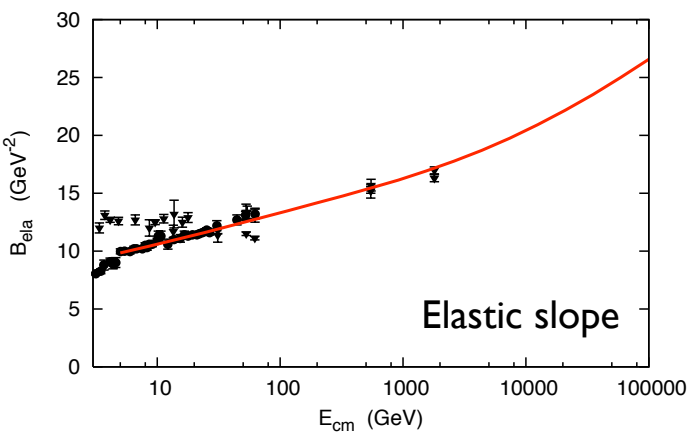
Semi-superposition model



SIBYLL cross section fits

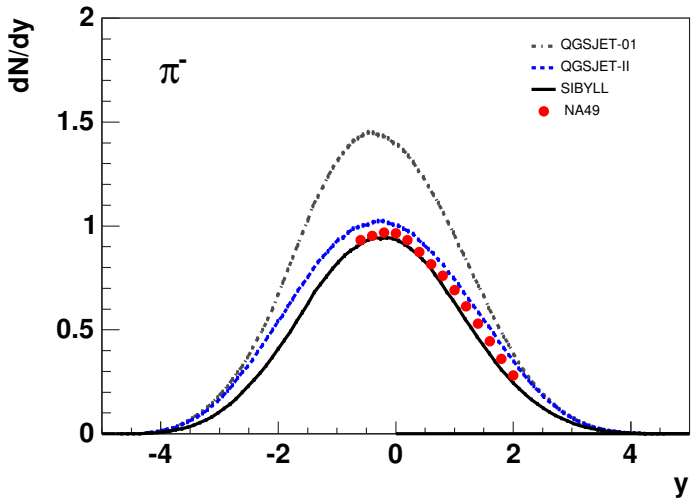


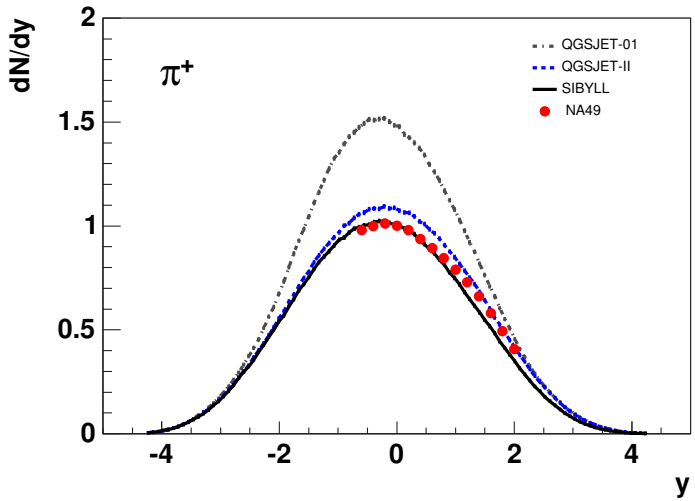


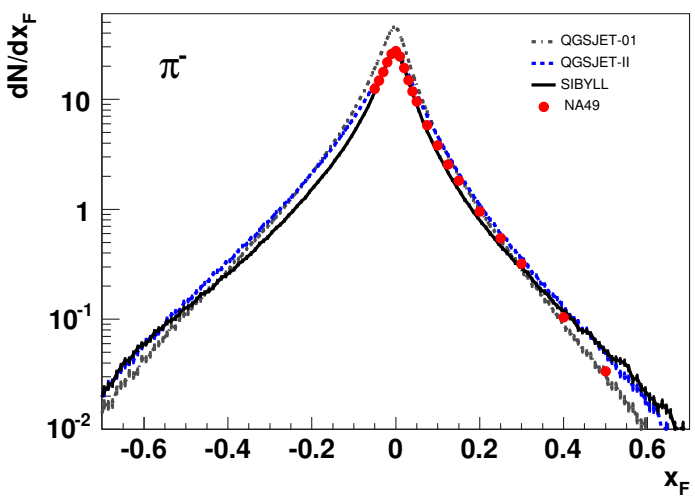


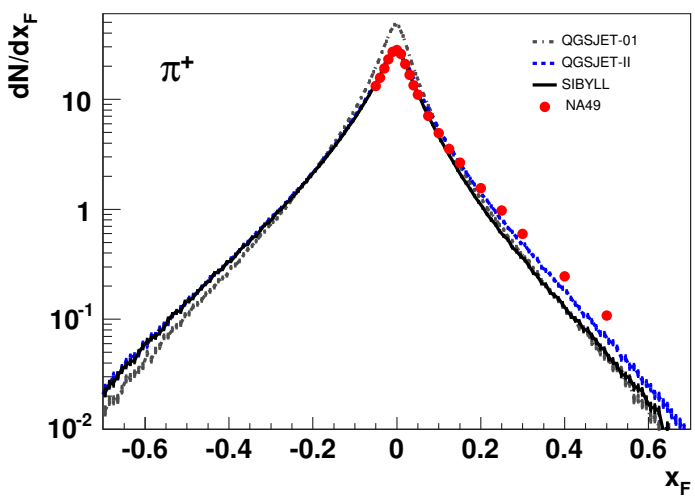
Low energy:
parametrizations
of data are used

(from RE)



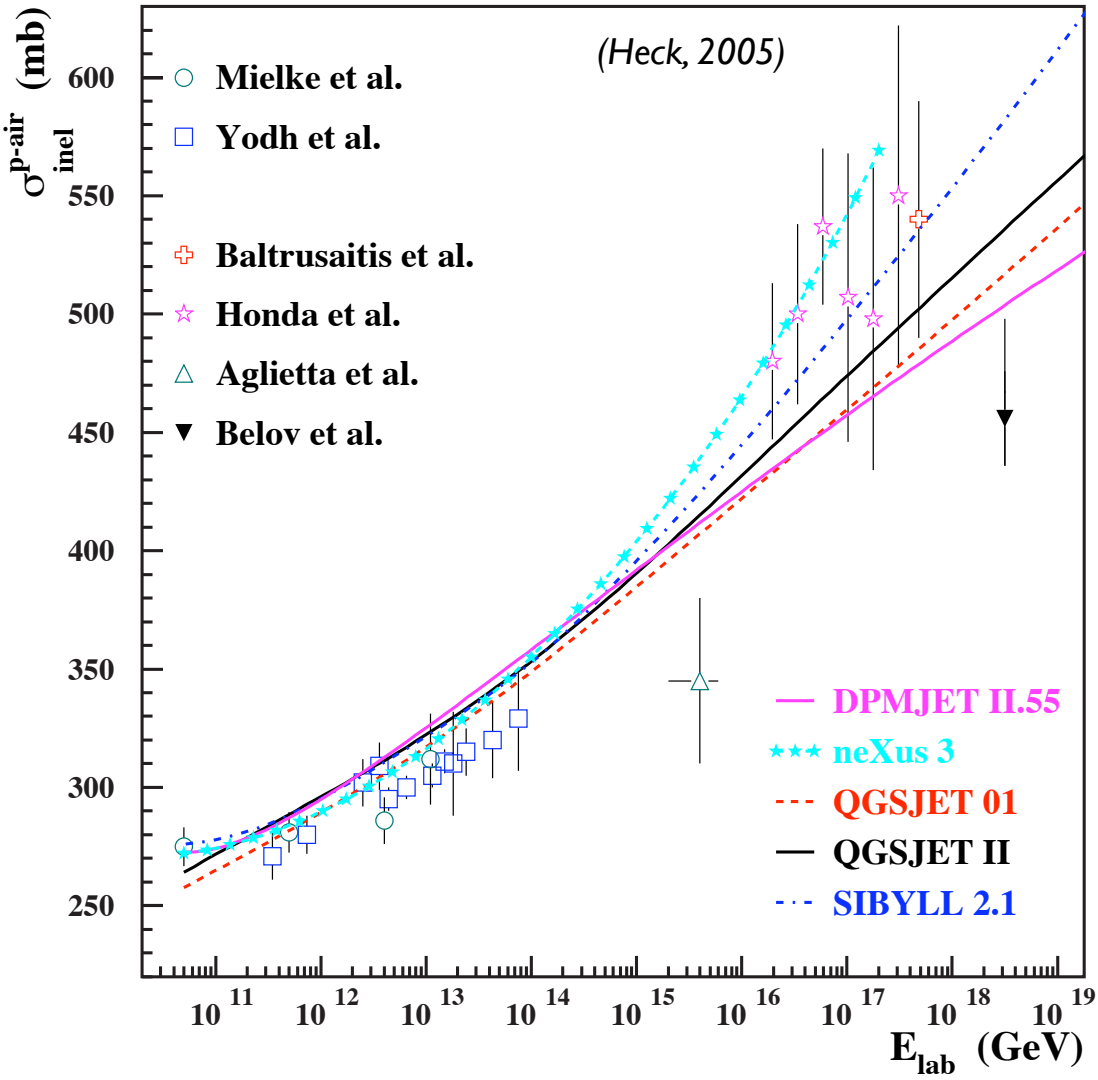






NA49 (p-C collision, $E_{lab} = 158$ GeV)

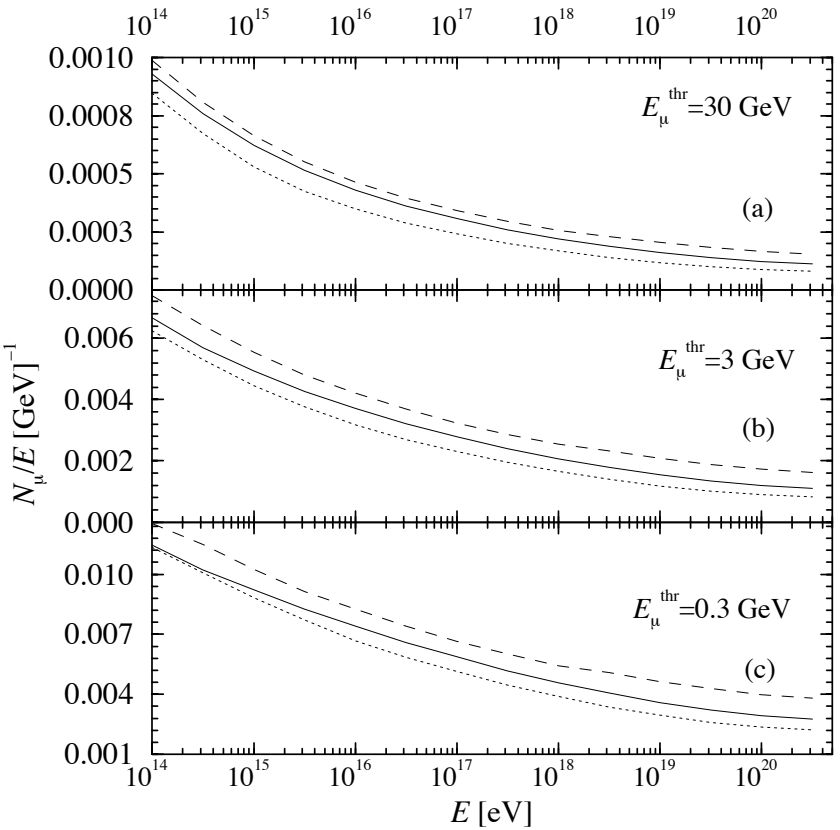
(Figs. from RE)


(Heck, 2005)
Mielke et al.
Yodh et al.
Baltrusaitis et al.
Honda et al.
Aglietta et al.
Belov et al.
DPMJET II.55
neXus 3
QGSJET 01
QGSJET II
SIBYLL 2.1
$\sigma^{p\text{-}air}_{inel}$ (mb)
600
550
500
450
400
350
300
250
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
E_{lab} (GeV)

Difference between 1.7 and 2.1

- Energy dependence in determining hard and soft interaction ($p_\perp^{min}(s)$);
- soft interaction: $\sigma_{soft}(s)$ is new, $A_{soft}(\mathbf{b})$ is better;
- multiple soft interactions possible;
- diffraction included;
- parton distribution functions updated from pre-HERA to post-HERA;
- updated parameterisations of fragmentation and cross sections.

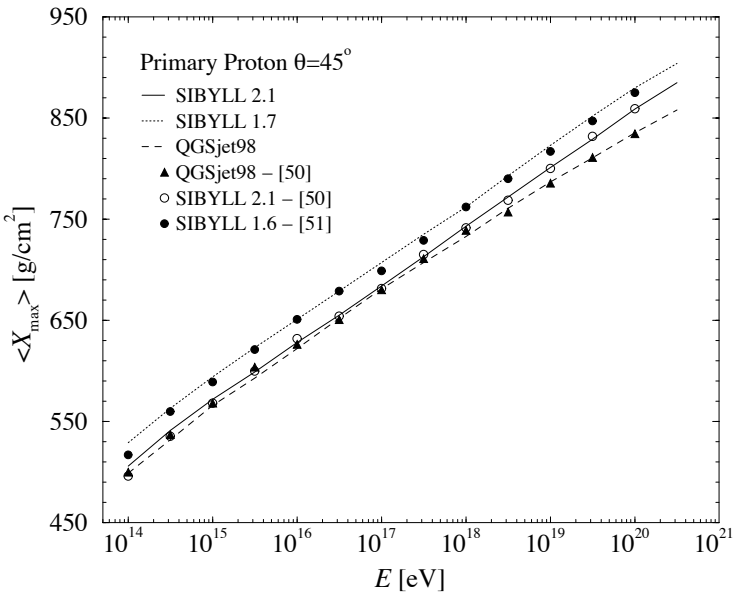
Muon numbers



QGSJet 98: dashed

SIBYLL 2.1: solid

SIBYLL 1.7: dotted



(Alvarez-Muniz et al 2002)

Limitations and improvements to make

- Too few $K^{\pm}$ multiplicity in p-p ;
- not enough anti-baryons produced.

- Full Glauber implementation for nucleus-nucleus interaction ;
- add $\mathbf{b}$ dependence to $p_{\perp}^{min}(s)$;
- add energy dependence to $A_{hard}(\mathbf{b})$;
- retune parameters with updated experiments.

Conclusions

- SIBYLL is minijet model based with other models added.
- SIBYLL 2.1 gives good agreement with collider and air shower data.
- Further improvements planned for next version.