Model description of proton interactions

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Simple model (6 independent fitting parameters)

E. Nagy et al,
Nucl. Phys. **B150** (1979) 221

$$f(s,t) = i\alpha[A_1 \exp(\frac{1}{2}b_1\alpha t) + A_2 \exp(\frac{1}{2}b_2\alpha t)] - iA_3 \exp(\frac{1}{2}b_3 t),$$

where

$$\alpha(s) = [\sigma_{tot}(s)/\sigma_{tot}(23\,\mathrm{GeV})](1 - i\rho_0(s)).$$

$$\frac{d\sigma}{dt} = |f(s,t)|^2.$$

More complex model – KFK

(K. Kohara, E. Ferreira, and T. Kodama,
Eur.Phys.J. C74 (2014) 3175; arXiv:1408.1599v2)

$$\frac{d\sigma(s,t)}{dt} = (\hbar c)^2 [T_I^2(s,t) + T_R^2(s,t)] \ ,$$

$$\begin{aligned} T_K(s,t) \quad &= \alpha_K(s) \mathrm{e}^{-\beta_K(s)|t|} + \lambda_K(s) \Psi_K(\gamma_K(s), t) \\ &+ \delta_{K,R} R_{ggg}(t) \end{aligned}$$

with $K = R, I$.

The shape functions in $t-$ space

$$\begin{aligned} &\Psi_K(\gamma_K(s), t) \\ = \;\; & 2\, \mathrm{e}^{\gamma_K} \left[\frac{\mathrm{e}^{-\gamma_K \sqrt{1+a_0|t|}}}{\sqrt{1+a_0|t|}} - \mathrm{e}^{\gamma_K}\; \frac{e^{-\gamma_K \sqrt{4+a_0|t|}}}{\sqrt{4+a_0|t|}} \right] , \end{aligned}$$

$$\Psi_K(\gamma_K(s), t=0) = 1 \ , \quad a_0 = 1.39 \text{ GeV}^{-2}$$

$$R_{ggg}(t) \equiv \pm 0.45\ t^{-4}(1 - e^{-0.005|t|^4})(1 - e^{-0.1|t|^2}) \ ,$$

The Coulomb part is neglected as it is important only at extremely small $|t| < 10^{-2}\ \mathrm{GeV}^2$.

Energy dependence of parameters ($\sqrt{s}$ in TeV, and GeV^{-2} in the units of the parameters that are not dimensionless)

$$\alpha_I(s) = 11.0935 + 1.35479 \log \sqrt{s},$$

$$\begin{aligned}\beta_I(s) = \quad & 4.44606586 + 0.3208411 \log\left(\sqrt{s}/30.4469\right) \\ & +0.0613381 \left[\log^2\left(\sqrt{s}/30.4469\right) + 0.5\right]^{1/2},\end{aligned}$$

$$\alpha_R(s) = 0.208528 + 0.0419028 \ \log \sqrt{s} \ ,$$

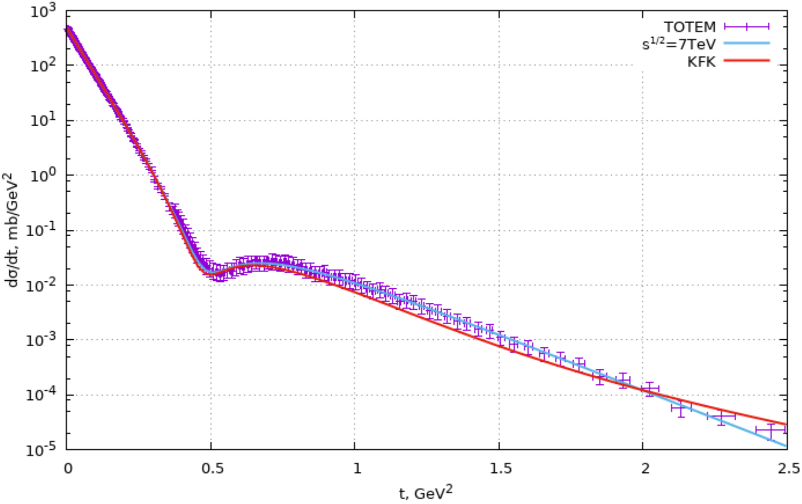
$$\beta_R(s) = 1.1506 + 0.12584 \ \log \sqrt{s} + 0.017002 \ \log^2 \sqrt{s} \ ,$$

$$\gamma_I(s) = 10.025 + 0.79097 \ \log \sqrt{s} + 0.088 \ \log^2 \sqrt{s} \ ,$$

$$\gamma_R(s) = 10.401 + 1.4408 \ \log(\sqrt{s}) + 0.16659 \ \log^2(\sqrt{s}) \ ,$$

$$\lambda_I(s) = 14.02008 + 3.23842 \ \log \sqrt{s} + 0.444594 \ \log^2 \sqrt{s} \ ,$$

$$\lambda_R(s) = 3.31949 + 0.743706 \ \log \sqrt{s} \ .$$



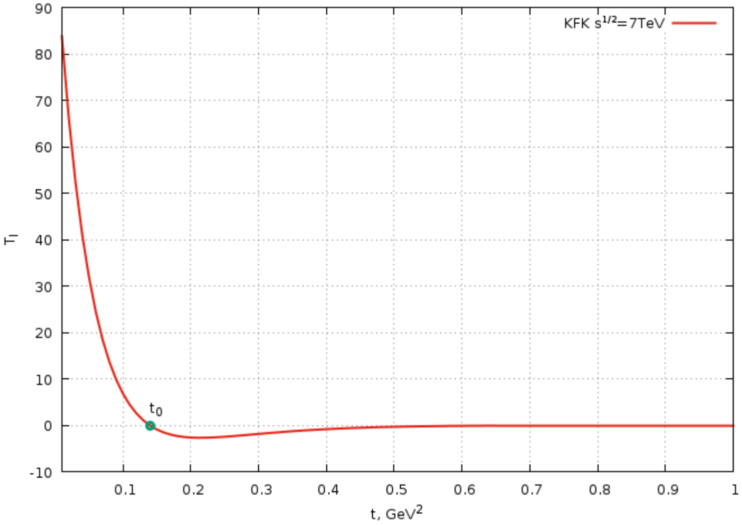
TOTEM
s^1/2=7TeV
KFK
dσ/dt, mb/GeV^2
t, GeV^2
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
0
0.5
1
1.5
2
2.5

First model: better fit but no $\sqrt{s}$ dependence of parameters (recalculate fit at each $\sqrt{s}$).

Second model: in fact each parameter has "internal" fitted parameters to reproduce $\frac{d\sigma(s,t)}{dt}$ in wide range of $\sqrt{s}$ (from 20 GeV to 7 TeV) still having sufficiently good fit at each $\sqrt{s}$.

Advantage: can try to extend fit to larger $\sqrt{s}$ and calculate $\sqrt{s}$ dependence of values like slope B and t_0 – zero of imaginary part of amplitude ($T_I(s,t)$).

t_0 – zero of imaginary part of amplitude



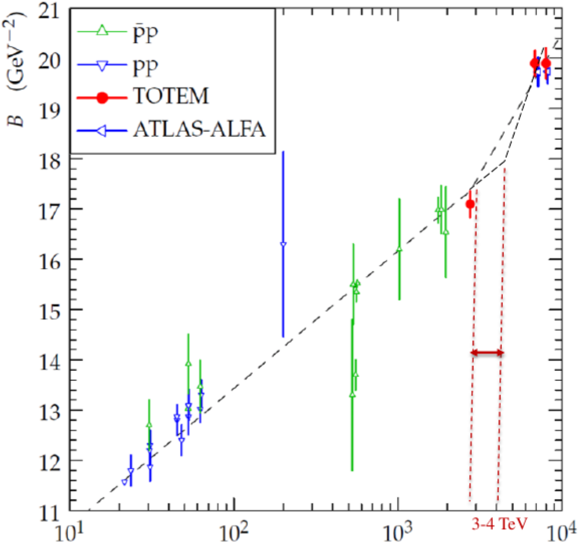
$$\sigma(s) = 4\sqrt{\pi}\,(\hbar c)^2 \;\; [\alpha_I(s) + \lambda_I(s)] \ ,$$

$$\rho(s) = \frac{T_R^N(s, t=0)}{T_I^N(s, t=0)} = \frac{\alpha_R(s) + \lambda_R(s)}{\alpha_I(s) + \lambda_I(s)} \ ,$$

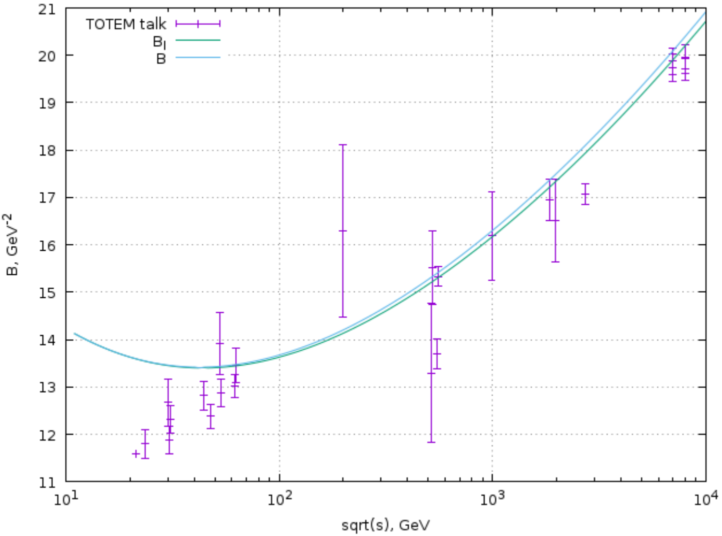
$$B_K(s) \qquad = \frac{2}{T_K^N(s,t)} \frac{dT_K^N(s,t)}{dt}\Big|_{t=0} = \ \frac{2}{\alpha_K(s) + \lambda_K(s)} \times$$
$$\Big[\alpha_K(s)\beta_K(s) + \frac{1}{8}\lambda_K(s) a_0 \Big(6\gamma_K(s) + 7\Big)\Big] \ .$$

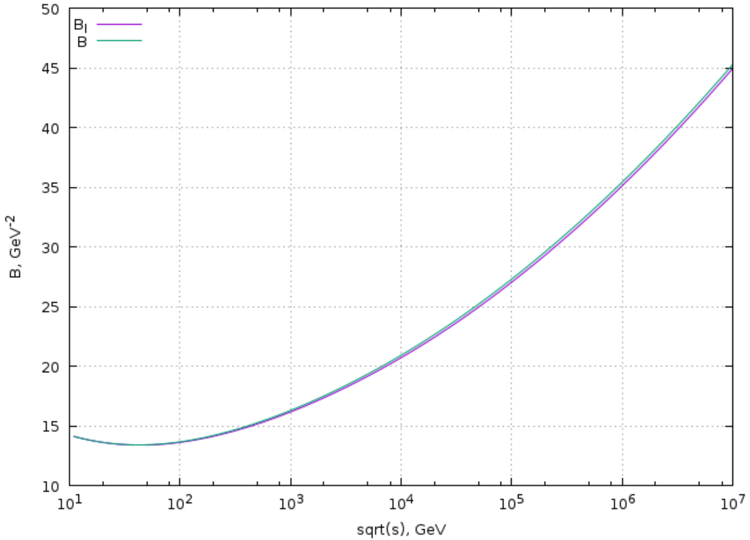
$$B = \frac{B_I + \rho^2 B_R}{1 + \rho^2}$$

B-slope (taken from TOTEM presentation)

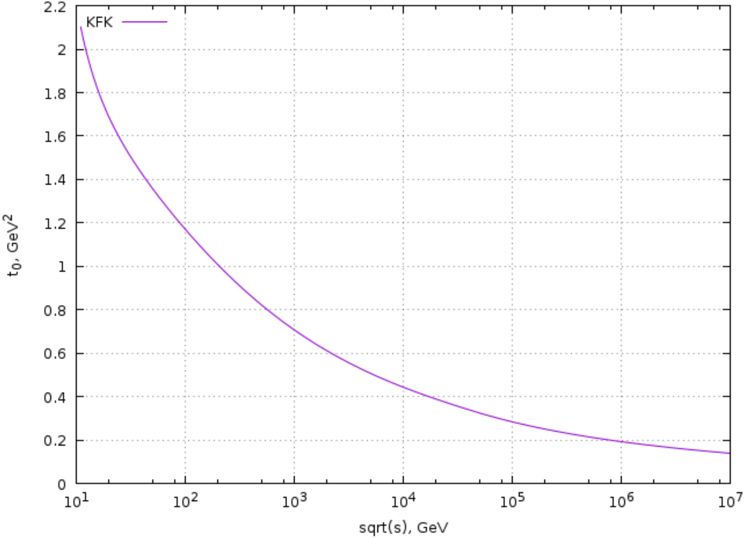


B-slope calculated in KFK model

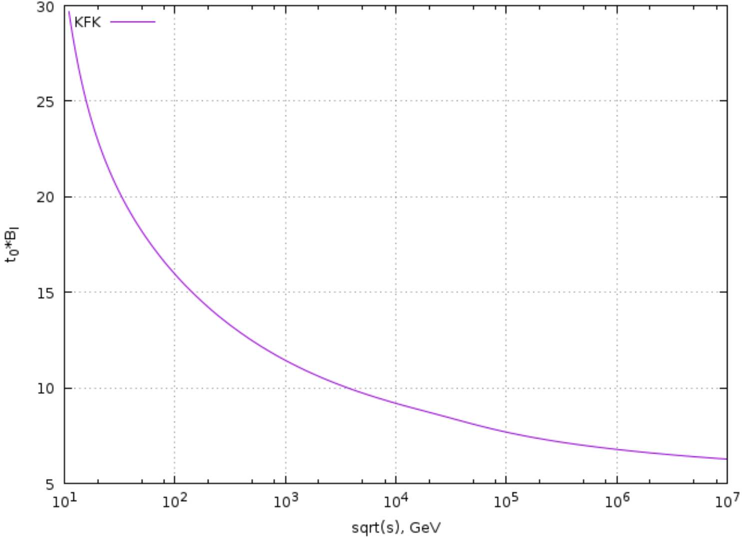




B, GeV^-2
sqrt(s), GeV
B_l
B
50
45
40
35
30
25
20
15
10
10^1
10^2
10^3
10^4
10^5
10^6
10^7



KFK
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
t_0, GeV^2
10^1
10^2
10^3
10^4
10^5
10^6
10^7
sqrt(s), GeV



30
25
20
15
10
5
t_0*B_I
KFK
10^1
10^2
10^3
10^4
10^5
10^6
10^7
sqrt(s), GeV

Conclusions

- Models allow unified view on experimental data
- we can look at values which are not measured directly
- we can make predictions to the energy range which is still not available experimentally