Elastic Scattering at the TOTEM experiment.

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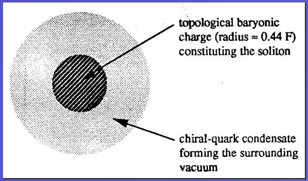
Models for elastic scattering

- QCD cannot directly describe elastic scattering at the moment $\Rightarrow$ phenomenological models must be used

- models
  - inspired by QCD, Regge and other theories
  - approximate but try to hit key features of original theories
  - concrete predictions (that agree with existing experimental data)
  - contain a lot ($\approx$ 10) free parameters
  - sample models: Islam, Bourrely–Soffer–Wu, Petrov–Predazzi–Prokudin, Block–Halzen (Ref. [1])

Islam model

- Idea of nucleon structure (supported by nonlinear sigma model), Refs. [2], [3], [4], [5]



- 3 mechanisms of scattering $\quad T = T_D + T_C + T_Q, \quad \frac{\mathrm{d}\sigma}{\mathrm{d}t} \sim |T(s,t)|^2$
  - diffraction – outer clouds overlap

$$T_D(s,t) \sim \int_0^\infty b\mathrm{d}b\, J_0(b\sqrt{-t})\, A_D(s,b), \qquad A_D(s,b) \sim \left[\frac{1}{1+e^{\frac{b-R}{a}}} + \frac{1}{1+e^{-\frac{b+R}{a}}} - 1\right]$$

  - core scattering – inner cores scatter one off the other via ω exchange

$$T_C(s,t) \sim \frac{s\,F^2(t)}{m_\omega^2 - t}$$

  - quark scattering – high $|t| \gtrsim 5$ GeV^2, transition to perturbation region (BFKL theory)

$$T_Q(s,t) \sim \frac{s\,\mathcal{F}(q_\perp)}{|t| + r_0^{-2}}$$

Eikonal models

- Fourier–Bessel transform

$$T(s,t) \sim \int_0^\infty b\mathrm{d}b\, J_0(b\sqrt{-t})\,(e^{2i\delta(s,b)} - 1)$$

- **Petrov–Prokudin–Predazzi** (Ref. [6])
  - simple model with 5 or 6 Regge particles

$$\delta(s,b) = \sum \delta_j(s,b), \qquad \delta_j(s,b) \sim c_j(-is)^{\alpha_j(0)-1}\,\frac{e^{-b^2/\varrho_j^2}}{4\pi\,\varrho_j^2}, \qquad \varrho_j^2 = 4\alpha_j'(0)\ln s + r_j^2$$

- **Bourrely–Soffer–Wu** (Ref. [7])
  - factorized dependency on s and b: $\delta \sim S(s)\,F(b)$
  - s-dependence deduced form behavior of Feynman diagrams for a QCD-like QFT model

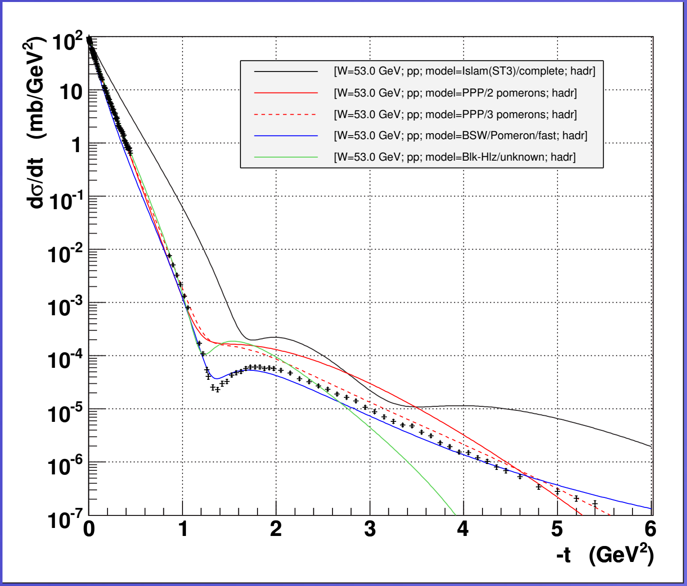
$$S(s) = \frac{s^c}{(\ln s)^{c'}} + \frac{u^c}{(\ln u)^{c'}}$$

  - t-dependence given by assumption of equal electric and hadronic charge distributions, rough approximation

$$F(b) = \int_0^\infty b\,\mathrm{d}b\, J_0(b\sqrt{-t})\,\tilde{F}(t), \qquad \tilde{F}(t) = f(t)^2\,\frac{a^2+t}{a^2-t}, \qquad f(t) = \left(1 - \frac{t}{m^2}\right)^{-2}$$

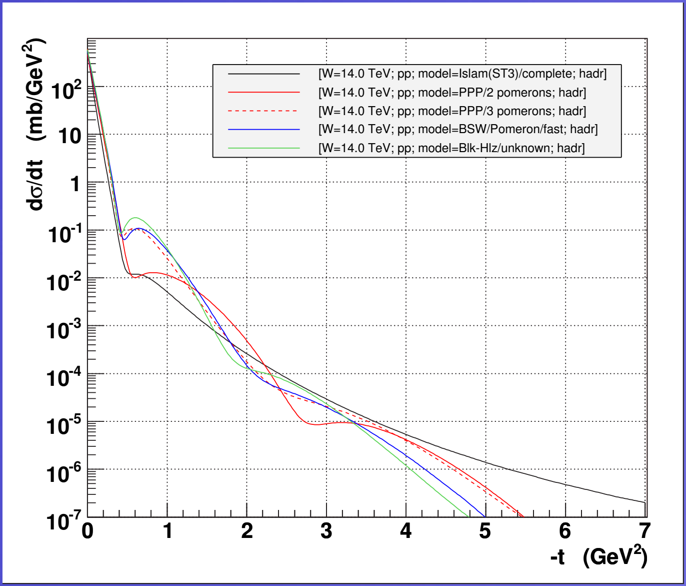
Models – comparison with measurement

pp scattering at energy of 53 GeV, data taken from Ref. [8]
plotted with the same parameters as for 14 TeV prediction



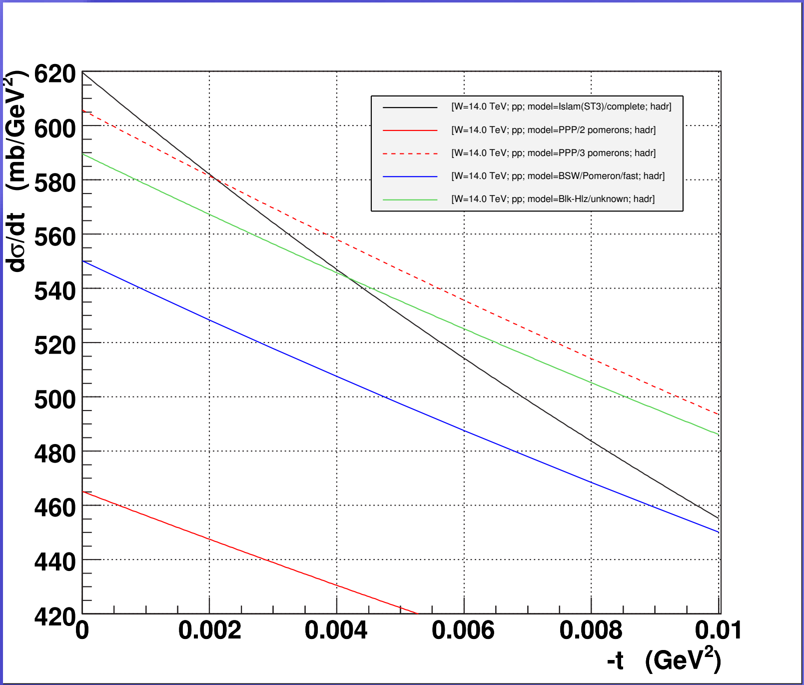
Models – TOTEM prediction, large $|t|$

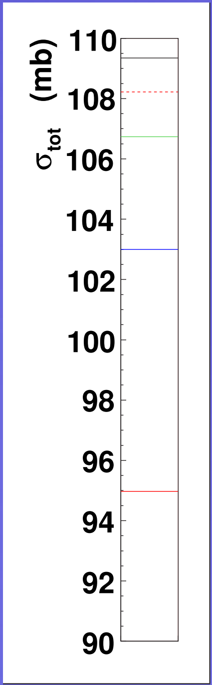
pp scattering at energy of 14 TeV



- huge differences – TOTEM will be able to exclude some models

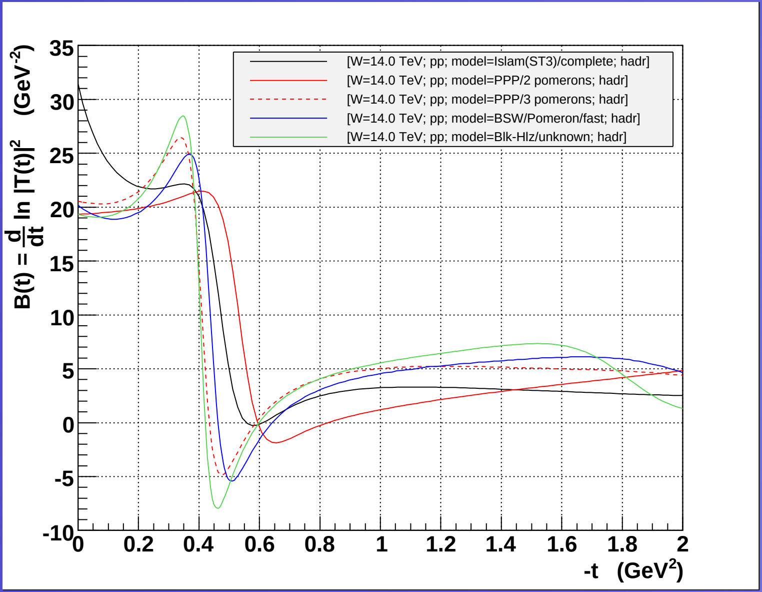
Models – TOTEM prediction, low $|t|$





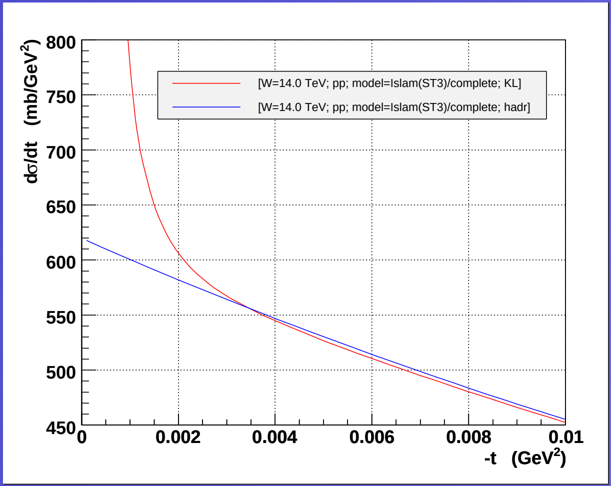
Models – TOTEM prediction, elastic slope

$$B(t) = \frac{\mathrm{d}}{\mathrm{d}t} \ln \frac{\mathrm{d}\sigma}{\mathrm{d}t}$$



Coulomb interference

- for small $|t|$ electromagnetic interaction is significant too



- need of amplitude for combined coulomb–hadronic force
- standard analysis with assumption $T^{C+H} = T^C + T^H e^{i\varphi}$
  - i.e. simple addition up to phase shift
  - there is no reason why it should be so

Coulomb interference – theory

- 2 basic theoretical approaches – eikonal and QFT, none is perfect

- QFT (e.g. West and Yennie, e.g. Ref. [9])
  - summing relevant class of Feynman diagrams ⇒ general formula
  - crucial approximation $T^H(s,t) \sim e^{Bt}$ in whole kinematical region (it made sense at that times, but it is excluded by experiments now) ⇒ simplified formula

$$T^{C+H} = T^C + T^H e^{i\varphi(t)}, \qquad \varphi = \pm\left(\gamma + \ln\frac{-Bt}{2}\right)$$

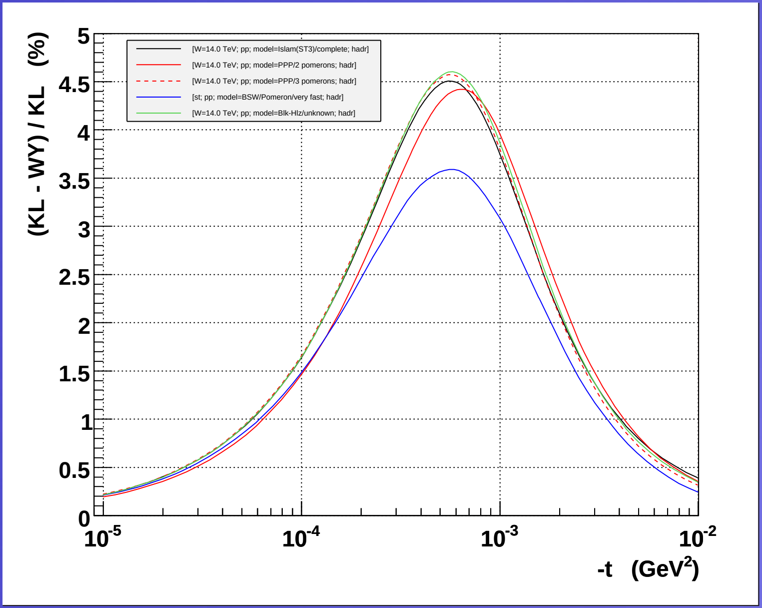
- eikonal
  - based on eikonal (high energy) approximation in QM
  - Cahn (Ref. [10]) showed equivalence with general formula of West and Yennie
  - Kundrát and Lokajíček took up Cahn's work (removed some approximations) and obtained general formula involving form factors (Ref. [11])

$$T^{C+H}(s,t) = \mp\frac{\alpha s}{t}\, F_C^2(t) \,+\, T^H(s,t)\left[1 \pm i\alpha \int\limits_{t_{min}}^{0} \mathrm{d}t' \,\left(\ln\frac{t'}{t}\,\frac{\mathrm{d}F_C^2(t')}{\mathrm{d}t} - \left(\frac{T^H(s,t')}{T^H(s,t)} - 1\right)\, I(t,t')\right)\right]$$

$$I(t,t') = \frac{1}{2\pi}\int\limits_0^{2\pi} \mathrm{d}\varphi\,\frac{F_C^2(t'')}{t''}$$

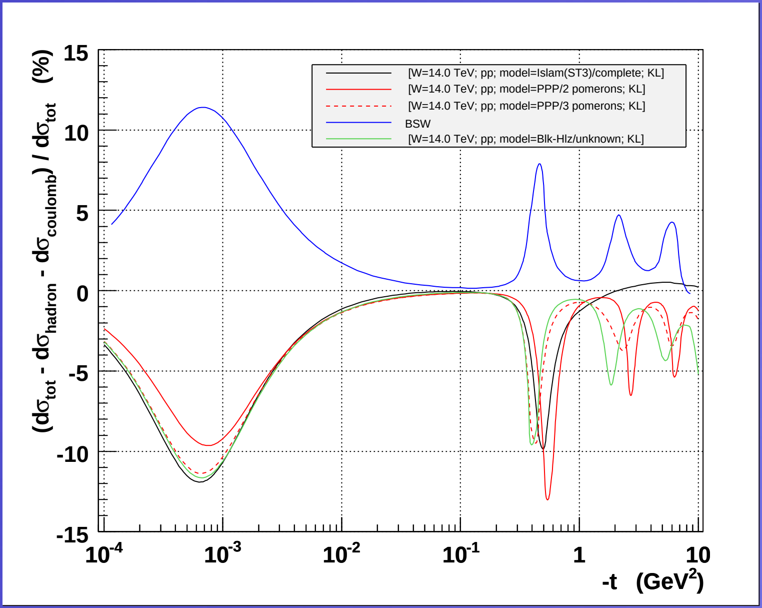
Difference between CKL and WY formulae

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}t}\Big|_{\mathrm{CKL}} - \frac{\mathrm{d}\sigma}{\mathrm{d}t}\Big|_{\mathrm{WY}}\right) / \frac{\mathrm{d}\sigma}{\mathrm{d}t}\Big|_{\mathrm{CKL}}$$



Importance of interference

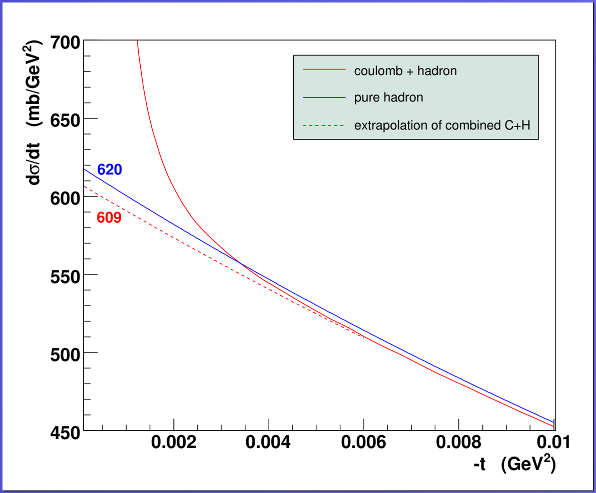
$$\left(\frac{d\sigma}{dt}\Big|_{\mathrm{full}} - \frac{d\sigma}{dt}\Big|_{\mathrm{coulomb}} - \frac{d\sigma}{dt}\Big|_{\mathrm{hadron}} \right) \Big/ \frac{d\sigma}{dt}\Big|_{\mathrm{full}}$$



Extrapolation to $t = 0\ \mathrm{GeV}^2$

- measurement of σ_{tot} is important part of physical program of the TOTEM experiment (Ref. [12])
- luminosity independent method

$$\sigma_{\mathrm{tot}} = \frac{16\pi}{(1+\varrho^2)} \frac{(\mathrm{d}N_{\mathrm{el}}/\mathrm{d}t)_{t=0}}{N_{\mathrm{el}} + N_{\mathrm{inel}}}$$



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