Energy evolution of the large-t elastic scattering and correlation with multiparticle production

Sergey Troshin
IHEP, Protvino, Russia

In collaboration with N.E. Tyurin, partially based on the two recent papers:

Phys. Lett. B707 (2012) 558-561

Mod. Phys. Lett. A27 (2012) 1250111

Discrimination of hadron scattering mechanisms on the base of the new and future LHC data

TOPICS:

- Functional dependence of large-t elastic scattering: dominance of collective effects
- Correlations with multiparticle production: hints for asymptotic behavior

General facts

- Confinement is a clue to hadron scattering mechanism and the role of elastic scattering is a prominent one in its understanding.
- Super selection rules: colored quarks and gluons live in coherent Hilbert subspaces, those are different from the physical Hilbert subspace too.
- No operator (related to any observable quantity) describing transition between colored and white Hilbert subspaces can exist – so color cannot be observed in principle- it is result of SSR for color degrees of freedom and non-abelian nature of QCD (it is not confinement yet - color should be confined inside hadron).

Superselection Rules from Measurement Theory

Shogo Tanimura arXiv:1112.5701v1 [quant-ph] 24 Dec 2011

- Proof of confinement in QCD is still elusive without known dynamical mechanism. What is known-this mechanism should be based on the collective dynamics of quarks and gluons.

Experimental findings at the LHC

- Collective effects in multiparticle production in pp-collisions, e.g. “Ridge” – coherence in pp-interactions, can be related to confinement

- The collective effects are responsible for the large-t elastic scattering too: power-like dependence provides poorer description of data than Orear exponential dependence does for the available data

Functional dependencies of $\frac{d\sigma}{dt}$ at large values of -t

Common feature: power-like decrease of $\frac{d\sigma}{dt}$

Perturbative QCD: disconnected diagrams (Landshoff) – 3g-exchange

$$\frac{d\sigma}{dt} \propto \frac{i}{\sqrt{stu\mu^2}} F_{qq}^3(\hat{s},\hat{t}) \propto |t|^{-8}$$

$$\Delta b \approx 1 Fermi$$

Independent quark scattering at the same angle

Complication: gluon radiation

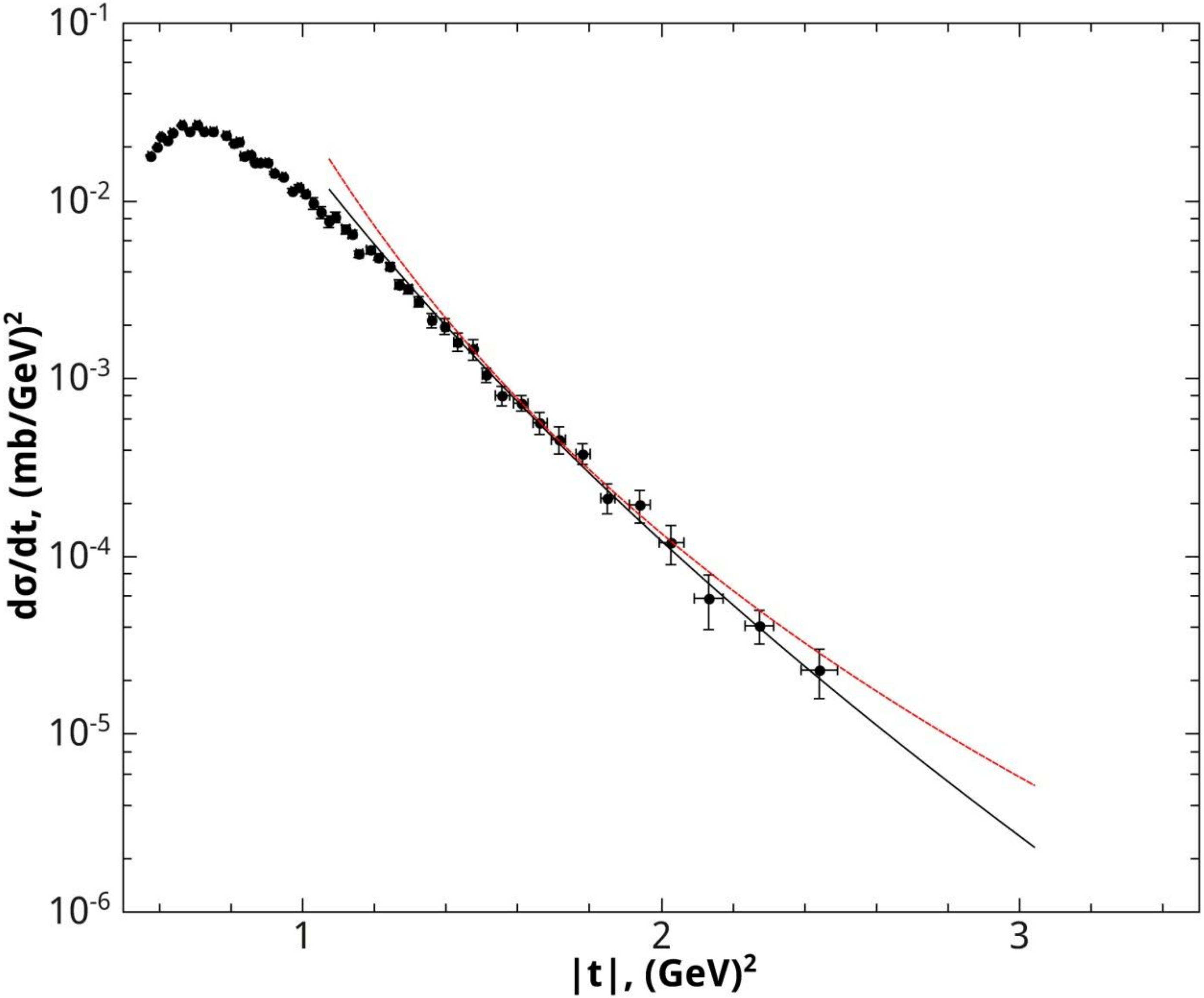
Contribution of connected diagrams for hard proton scattering in QCD

TOTEM data (the experimental parameterization) at

$\sqrt{s=7}$ TeV:

$$\frac{d\sigma}{dt} \propto |t|^{-7.8}$$

Red curve on the Figure next slide



10-1
10-2
10-3
10-4
10-5
10-6
1
2
3
dσ/dt, (mb/GeV)2
|t|, (GeV)2

Orear dependence

- Black curve: $$\frac{d\sigma}{dt} \propto \exp(-c_o\sqrt{-t})$$

$$c_o \cong 12(GeV)^{-1} \qquad c_o(LHC) \cong 2c_o(ISR-)$$

This form describes data in the wider region of –t than power-like form and this form is a result of a coherent scattering. There are many ways to get such dependence. But, all the mechanisms have collective non-perturbative dynamics at their origin.

Coherent dynamics of the large-t elastic scattering

- Moving Regge-like poles in the direct cahannel (tunneling picture of hadronic diffraction)
- Rational form of the unitarization (in case of pure imaginary U-matrix):

$$S(s,b)=\frac{1-U(s,b)}{1+U(s,b)}$$

- Position of poles:

$$1+U(s,b)=0$$

$$b_m(s)=R(s)+i\frac{\pi}{\mu}m$$

Expansion for the amlitude

$$F(s,t) \propto s \sum_{m=1}^{\infty} \tau^m(t) \varphi_m \left[R(s), \alpha(s), \sqrt{-t} \right]$$

$$\boxed{\tau(t) = \exp(-\pi\sqrt{-t} / \mu)}$$

Existence or absence of oscillations beyond the second maximum ?

Smooth functions when phase of U is different from $\pi / 2$ and oscillating ones when phase $\alpha(s) = \pi / 2$

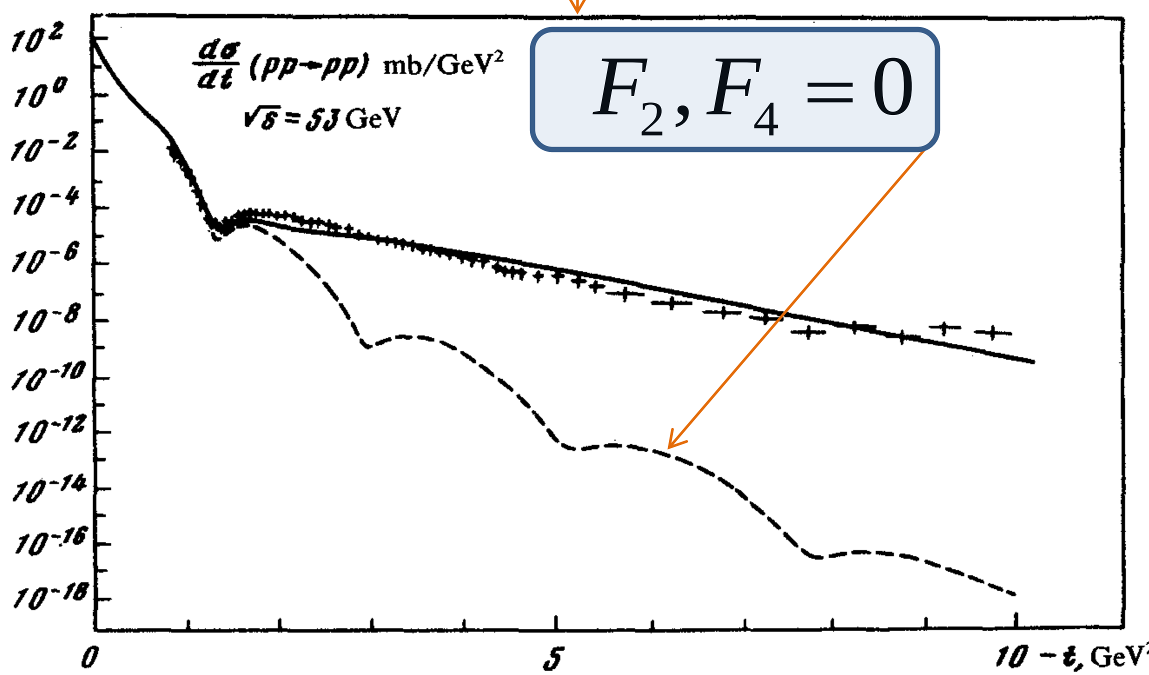
Spin and large-t oscillations

Account for the spin (i.e. helicity-flip amplitudes contributions) can explain absence of oscillations at lower energies:

Spin effects in elastic scattering in the region of large momentum transfer

V. F. Edneral, S. M. Troshin, and N. E. Tyurin
Institute of High Pressure Physics

(Submitted 25 June 1979)
Pis'ma Zh. Eksp. Teor. Fiz. **30**, No. 6, 356–360 (20 September 1979)



Helicity amplitudes

$$F_i(s,t) = \phi_i(s,t)\cos[R_i(s)\sqrt{-t} + \omega_i(s)]$$

Exponentially decreasing with $\sqrt{-t}$

F_2, F_4 - double helicity-flip amplitudes; (5 independent helicity-flip amplitudes for pp elastic scattering process)

It is difficult to expect that any helicity-flip amplitude would survive at the LHC energies. Then oscillations should be expected provided spin mechanism is responsible for their absence at lower energies

To higher values of -t

From typical values of the impact parameters

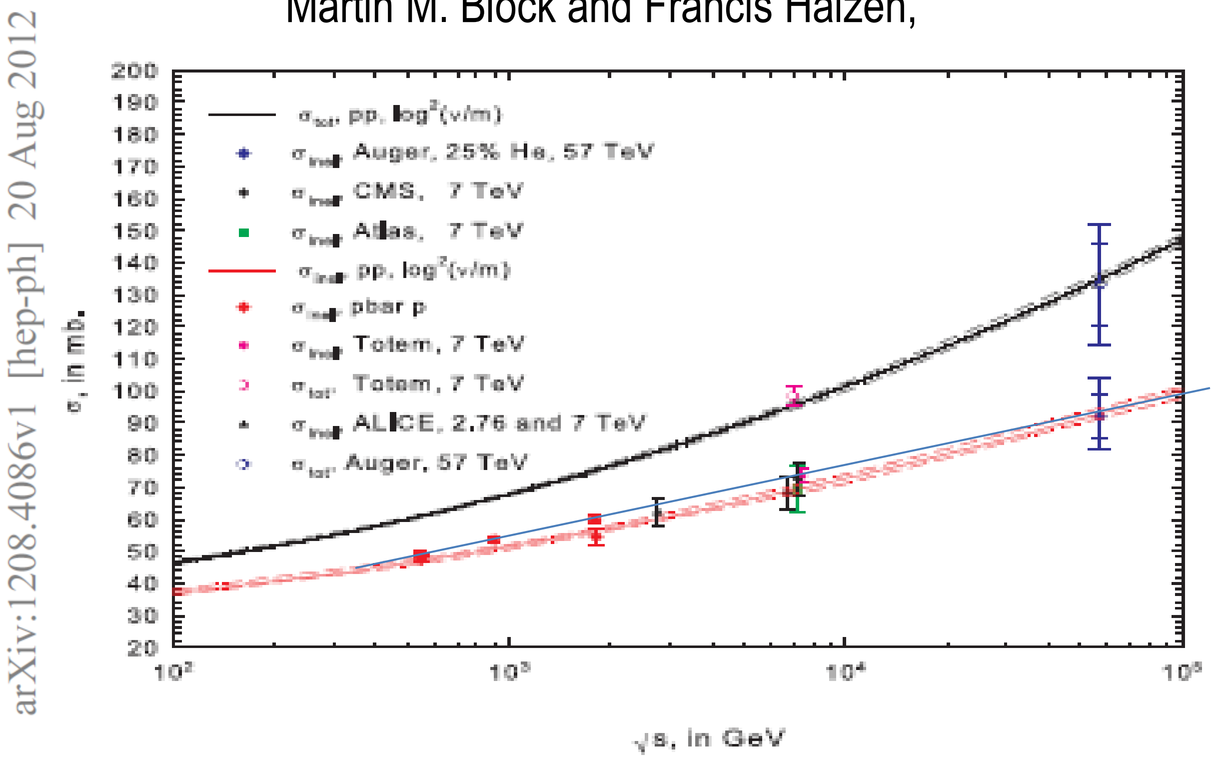
$$b \propto R(s)$$

$$b \approx 0$$

Asymptotic regime in hadron scattering

"New experimental evidence that the proton develops asymptotically into a black disk"

Martin M. Block and Francis Halzen,



$$\sigma_{inel}(s) \propto \ln s$$

Simple logarithmic dependence of the total inelastic cross-section cannot be exluded as wel as the limit

$$\boxed{\sigma_{inel}(s)/\sigma_{tot}(s) \to 0 \; at \; s \to \infty}$$

Role of the large-t elastic scattering

- Current experimental data cannot indicate the true asymptotic behavior.
- Large-t region (in elastic process) is sensitive to small values of impact parameters (FB transform)

$$H_{el,inel}(s,t)=\frac{s}{\pi^2}\int_0^\infty bdbh_{el,inel}(s,b)J_0(b\sqrt{-t})$$

- It can probe form of the inelastic oferlap function:

$$\operatorname{Im} F(s,t)=H_{el}(s,t)+H_{inel}(s,t)$$

$$\operatorname{Im} f(s,b)=|f(s,b)|^2+h_{inel}(s,b)$$

Reflection and elastic scattering at large values of -t

$$S(s,b)=\pm\sqrt{1-4h_{inel}(s,b)}$$

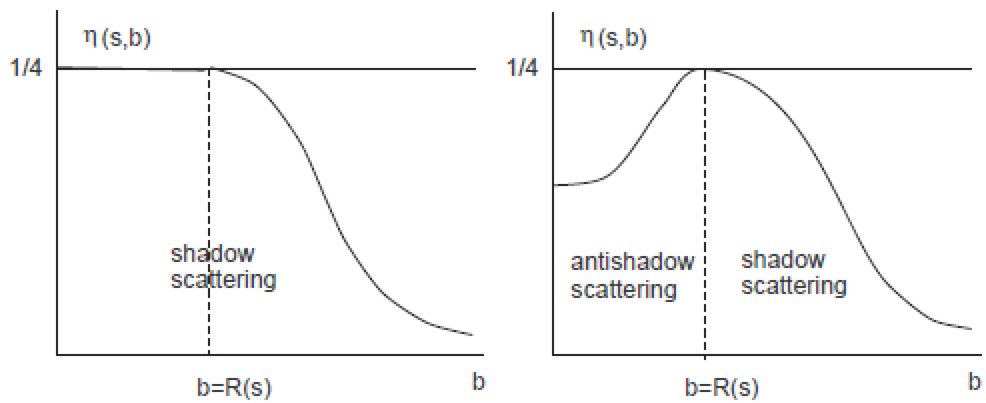
Survival amplitude of the prompt elastic channel

$$1-S^2(s,b)=4h_{inel}(s,b)$$

Probability of absorptive (destructive) collisions

$$\eta(s,b)\equiv h_{inel}(s,b)$$

Sign of survival amplitude depends on form of the inelastic overlap function



Two regimes: black or reflective disks?

- In the black disk regime survival amplitude S(s,b) vanishes at b=0 in the limit of very high s values
- Reflective disk regime - this amplitude is -1 in this limit
- How to discriminate those regimes?
- Large-t elastic scattering which is sensitive to small impact parameters

Unitarity saturation

- It is the limit where $|f(s,b=0)| \to 1$ at $s \to \infty$

- Elastic scattering at large -t dominates then over multiparticle production, no associated multiparticle production.

- Inelastic overlap function has a minimum at b=0:

$$h_{inel}(s,b) = |f(s,b)|(1-|f(s,b)|)$$

- Vanishing probability of absorption:

$$1 - S^2(s,b=0) \to 0$$

Reflective mechanism

- This mechanism asymptotically decouples deep-elastic scattering and multiparticle production
- At finite energies it corresponds to decreasing correlations of deep elastic scattering and multiparticle production
- Respective asymptotic cross-section (deep-elastic) of the black disk is four times lower than the reflective disk one

Conclusion

- ***Recent data of the LHC are consistent with coherent collective dynamics of hadron interactions***

- ***Studies of elastic scattering at higher values of –t can help to discriminate the possible asymptotic behavior: decreasing (with s and t increase) correlations of elastic scattering with multiparticle production.***

- ***Asymptotically, at very large s and –t, the elastic scattering would completely decouple from multiparticle production in case of reflective disk mechanism.***

- ***The picture would be opposite if the black disk mechanism was responsible for asymptotic behavior.***

Back-up slide

Superselection Rules from Measurement Theory

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- A superselection rule is stated as follows. There is an operator J, which is called the superselection charge. If a self-adjoint operator A represents a measurable quantity, it must satisfy the commutativity [J,A] = 0.
- This is a superselection rule, which is a necessary condition for measurability of A.