High Energy pp Elastic Scattering in Condensate Enclosed Chiral Bag Model and TOTEM Elastic Measurements at LHC at 7 TeV

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1. The first collider to appear was the CERN pp ISR Collider in the early seventies at energy ~ 50 GeV.

2. This was followed by the CERN $\bar{p}p$ SPS Collider in the mid-eighties at energy ~0.5 TeV.

3. Soon after came the Fermilab $\bar{p}p$ Tevatron Collider in the early nineties at c.m. energy 1.8 TeV.

4. Finally, we now have the CERN Large Hadron Collider (LHC) where elastic scattering has been recently measured at c.m. energy 7 TeV by the TOTEM Collaboration.

One aspect is to build an effective field theory model of the proton[1, 2)] based on:

a) Gell-Mann-Levy Linear σ-Model and spontaneous breakdown of chiral symmetry.

b) A hidden gauge symmetry that introduces vector mesons ρ and ω as gauge bosons.

c) A path integral formalism that leads to Wess-Zumino-Witten action and introduces topological (or, geometric) baryonic charge.

d) A scalar field $\zeta(r)$ that leads to a nucleon core, which contains three massless valence quarks. Also, the scalar field $\zeta(r)$ makes quarks and antiquarks in the Dirac sea (which surrounds the proton baryonic charge) massive and leads to a condensed ground state. The latter forms an outer cloud of the proton (and the antiproton).

The other aspect of our study is the phenomenological investigation of pp and $\bar{p}p$ elastic scattering in the TeV region. The goals are:

i) identify the main processes underlying elastic scattering based on our field theory model of the proton;

ii) describe quantitatively the measured elastic differential cross sections at 7.0 TeV (pp), 1.96 TeV ($\bar{p}p$), and 0.630 TeV ($\bar{p}p$);

iii) predict pp elastic $d\sigma/dt$ at LHC at 14 TeV—which is planned to be measured by the TOTEM Collaboration.

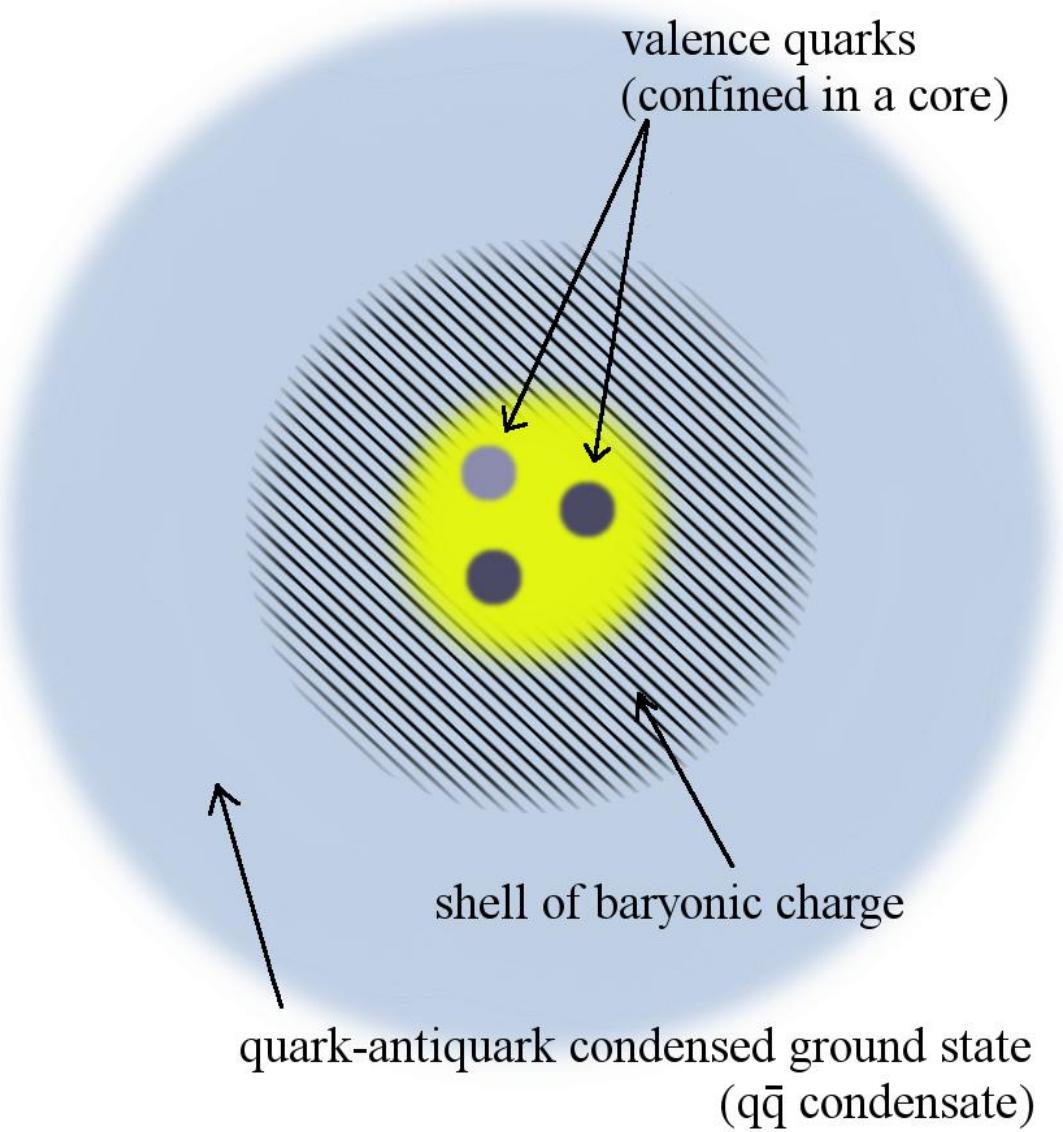
Sizes
valence quarks
(confined in a core)
~0.2 fm
shell of baryonic charge
~0.44 fm
quark-antiquark condensed ground state
(qq̄ condensate)
~0.86 fm

Fig. 1

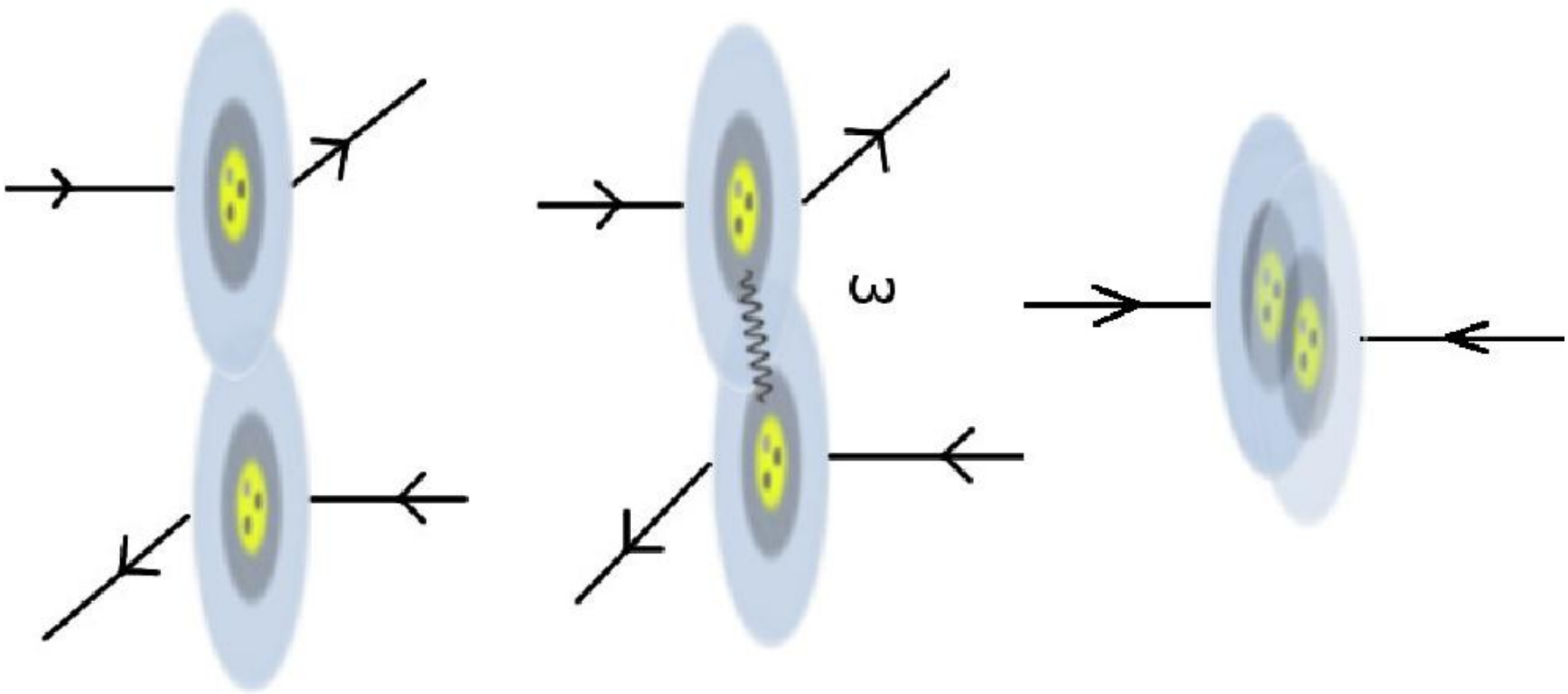

Fig. 2

The first process occurs in the small $|t|$ region, i.e. in the near forward direction, when the outer cloud of $q\bar{q}$ condensate of one proton interacts with that of the other. It gives rise to diffraction scattering, which underlies:

(i) the observed increase of the pp total cross section with energy as $(\ln s)^2$,

(ii) the equality of pp and $\bar{p}p$ total cross sections at high energy, and

(iii) the saturation of the Froissart-Martin bound, $\sigma_{tot} = const.(\ln s)^2$. By itself, the diffraction process would lead to diffraction oscillations (as in optics).

The second process comes into play at $|t| \gtrsim 0.5$ GeV^2, when the topological baryonic charge of one proton probes that of the other via vector meson ω-exchange.

This process is analogous to one electric charge probing another via photon exchange. The spin-1 ω acts like a photon, because of its coupling with the topological baryonic charge.

The third process also occurs at $|t| \gtrsim 0.5$ GeV^2 (transverse distance $b \lesssim 0.3$ fm, $b \sim \frac{1}{q}$), when elastic scattering originates from the hard collision of a valence quark of one proton with that of the other.

This process can be better visualized in momentum space (Fig. 3).

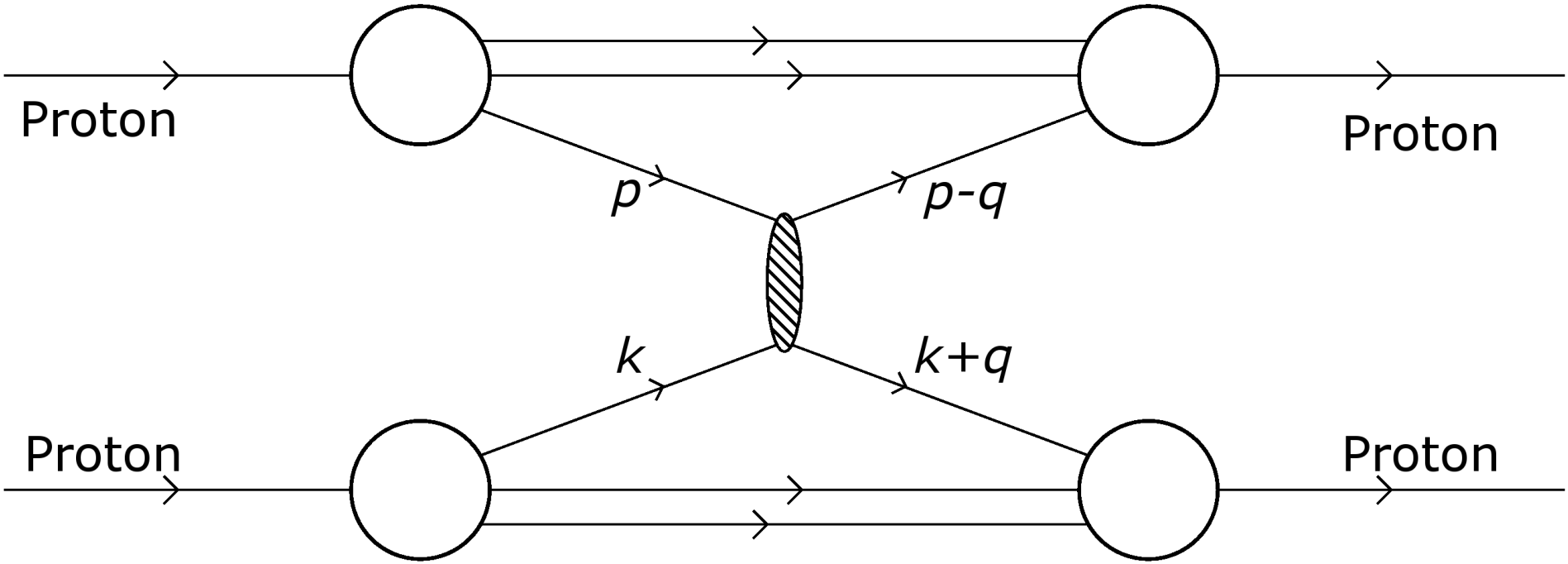

Fig. 3

Our original prediction of pp elastic scattering at 7.0 TeV agreed reasonably well with 2011 TOTEM $d\sigma/dt$ measurements in the momentum transfer regions:

$|t| = 0.02 - 0.33$ and $0.36 - 0.47$ GeV^2.

However, our prediction disagreed significantly with TOTEM results in the region $|t| \simeq 0.5 - 2.5$ GeV^2

(shown later in Fig. 6).

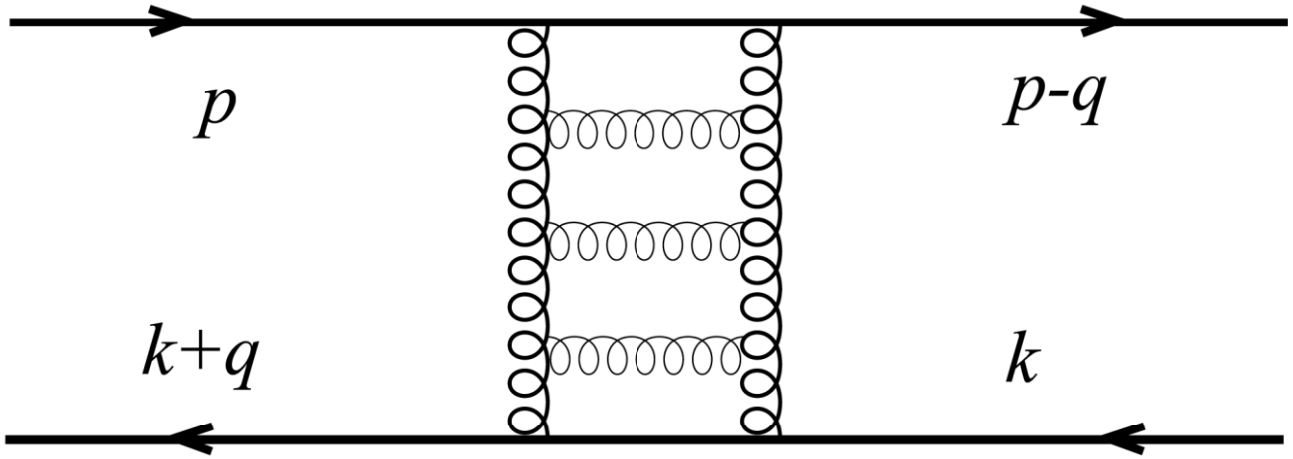

Fig. 4a. Valence quark-quark scattering by exchange of gluons in the form of ladders (BFKL ladders).

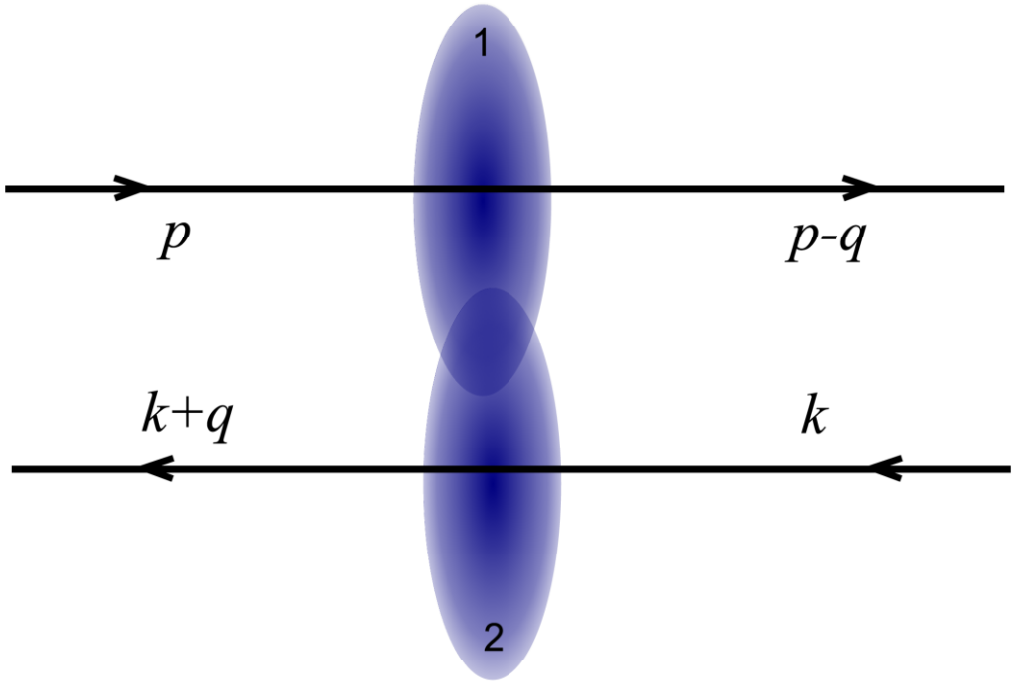

Fig. 4b. Valence quark-quark scattering where the low-x gluon cloud of one quark interacts with that of the other.

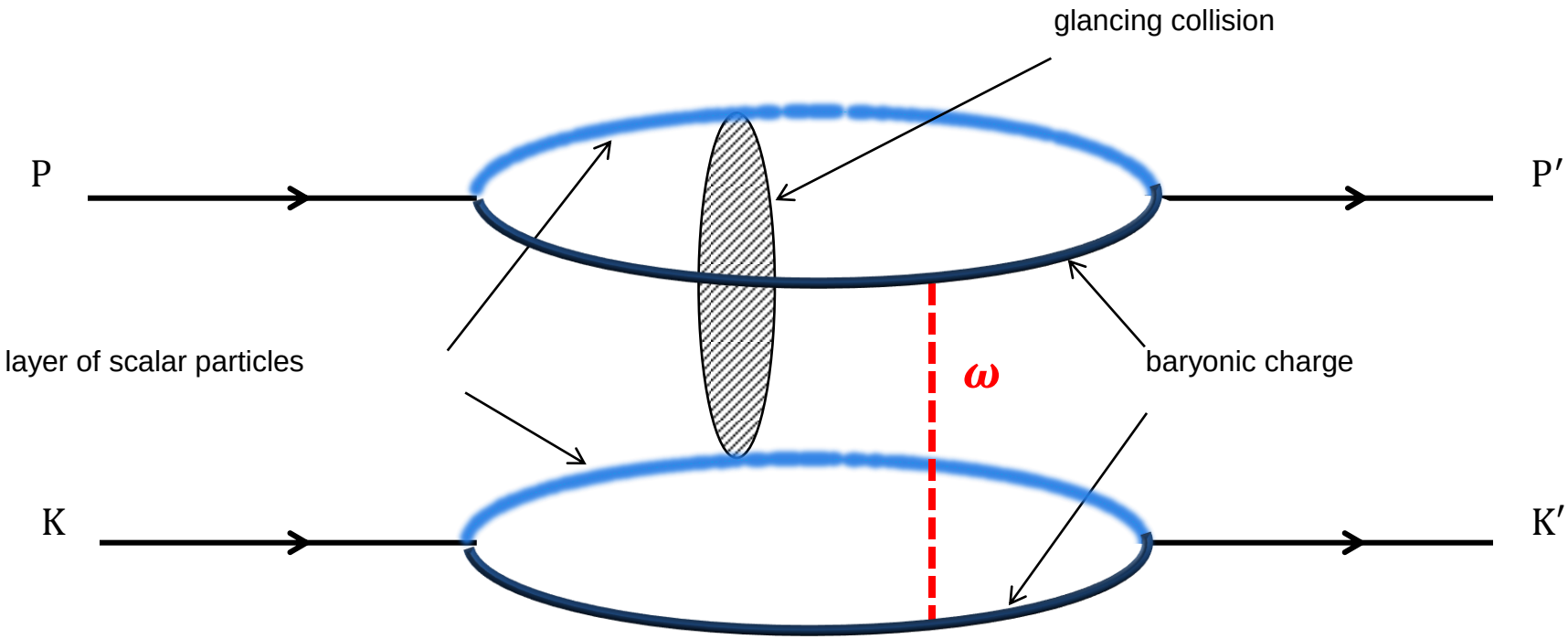
glancing collision
P
P′
layer of scalar particles
ω
baryonic charge
K
K′

Fig. 5

With the above phenomenological features taken into account, we are able to describe quantitatively:

i) pp elastic scattering at LHC at 7.0 TeV measured by the TOTEM Collaboration[7, 8];

ii) $\bar{p}p$ elastic scattering at the Tevatron at 1.96 TeV measured by the D0 Collaboration[9];

iii) the earlier $\bar{p}p$ elastic scattering at the SPS Collider at 0.630 TeV measured by the UA4 Collaboration[10].

Our calculated $d\sigma/dt$ for these energies are shown in Fig. 7.

Finally, we show in the same figure our prediction of pp elastic scattering at LHC at 14 TeV.

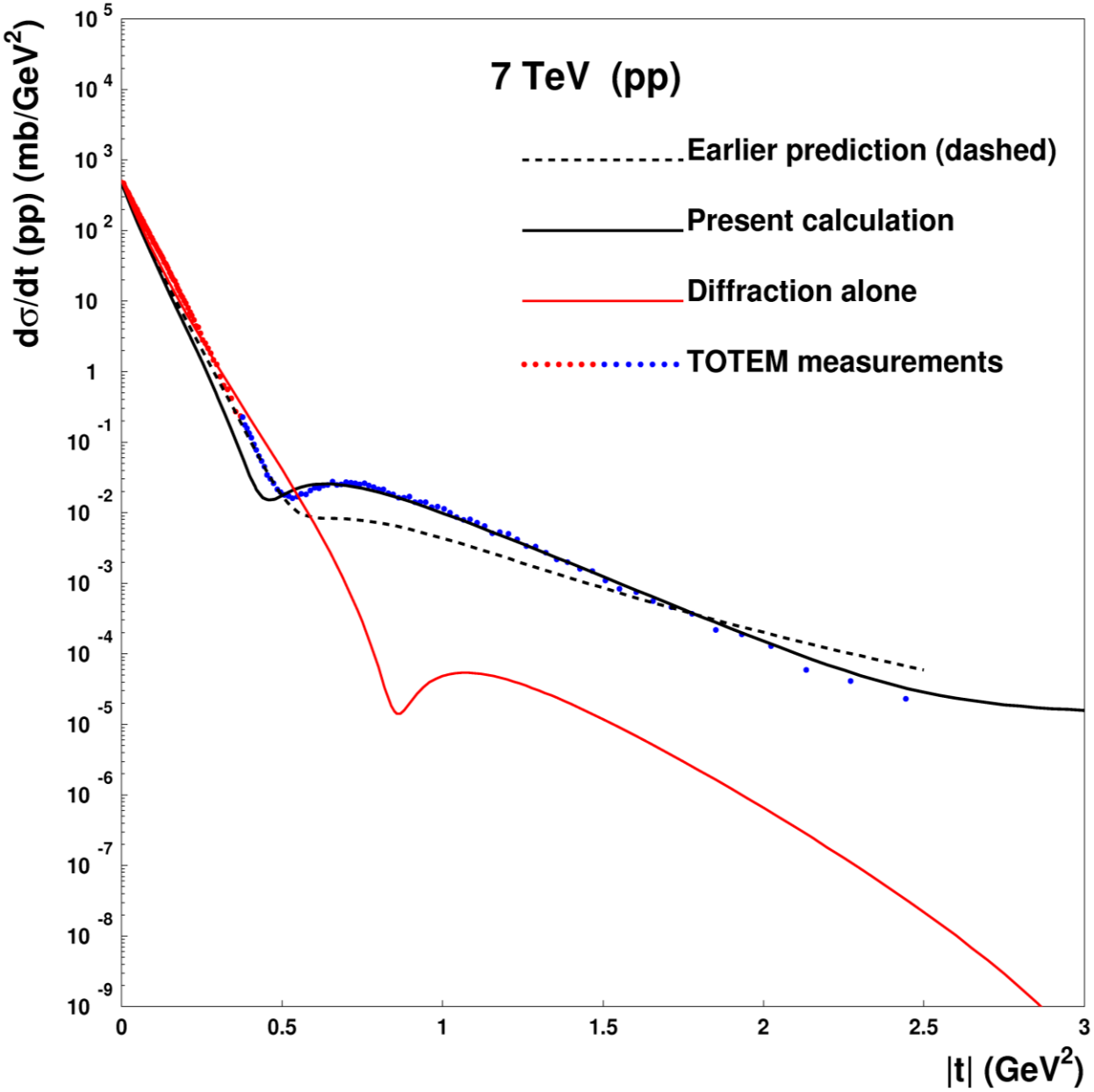
7 TeV (pp)
Earlier prediction (dashed)
Present calculation
Diffraction alone
TOTEM measurements
dσ/dt (pp) (mb/GeV²)
|t| (GeV²)
10 5
10 4
10 3
10 2
10
1
10 -1
10 -2
10 -3
10 -4
10 -5
10 -6
10 -7
10 -8
10 -9
0
0.5
1
1.5
2
2.5
3

Fig. 6

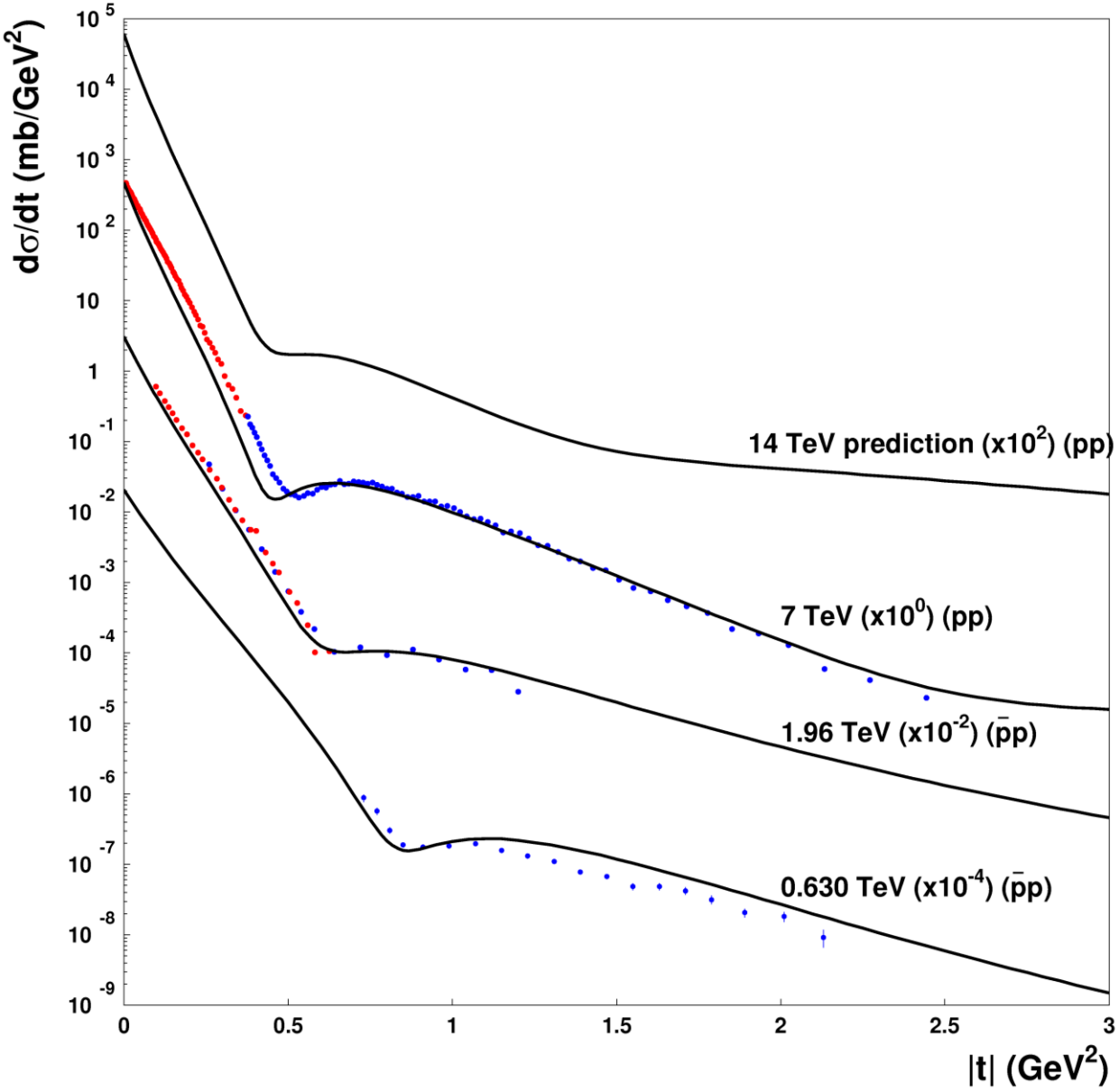
dσ/dt (mb/GeV²)
|t| (GeV²)
14 TeV prediction (x10²) (pp)
7 TeV (x10⁰) (pp)
1.96 TeV (x10⁻²) (p̄p)
0.630 TeV (x10⁻⁴) (p̄p)

Fig. 7

Let me end my talk with an optimistic tone.

If the planned measurement of elastic $d\sigma/dt$ at LHC at 14 TeV by the TOTEM Collaboration shows satisfactory quantitative agreement with our prediction for 14 TeV, then —

the underlying picture of the proton shown in Fig. 1 as a Condensate Enclosed Chiral Bag will be confirmed.

This will be a tribute to:

i) four generations of pp and $\bar{p}p$ colliders;

ii) decades of effort by theorists to build nonperturbative models of the nucleon; and

iii) dedicated work by collaborations like TOTEM, D0 and UA4 to measure elastic $d\sigma/dt$ with high precision.

References

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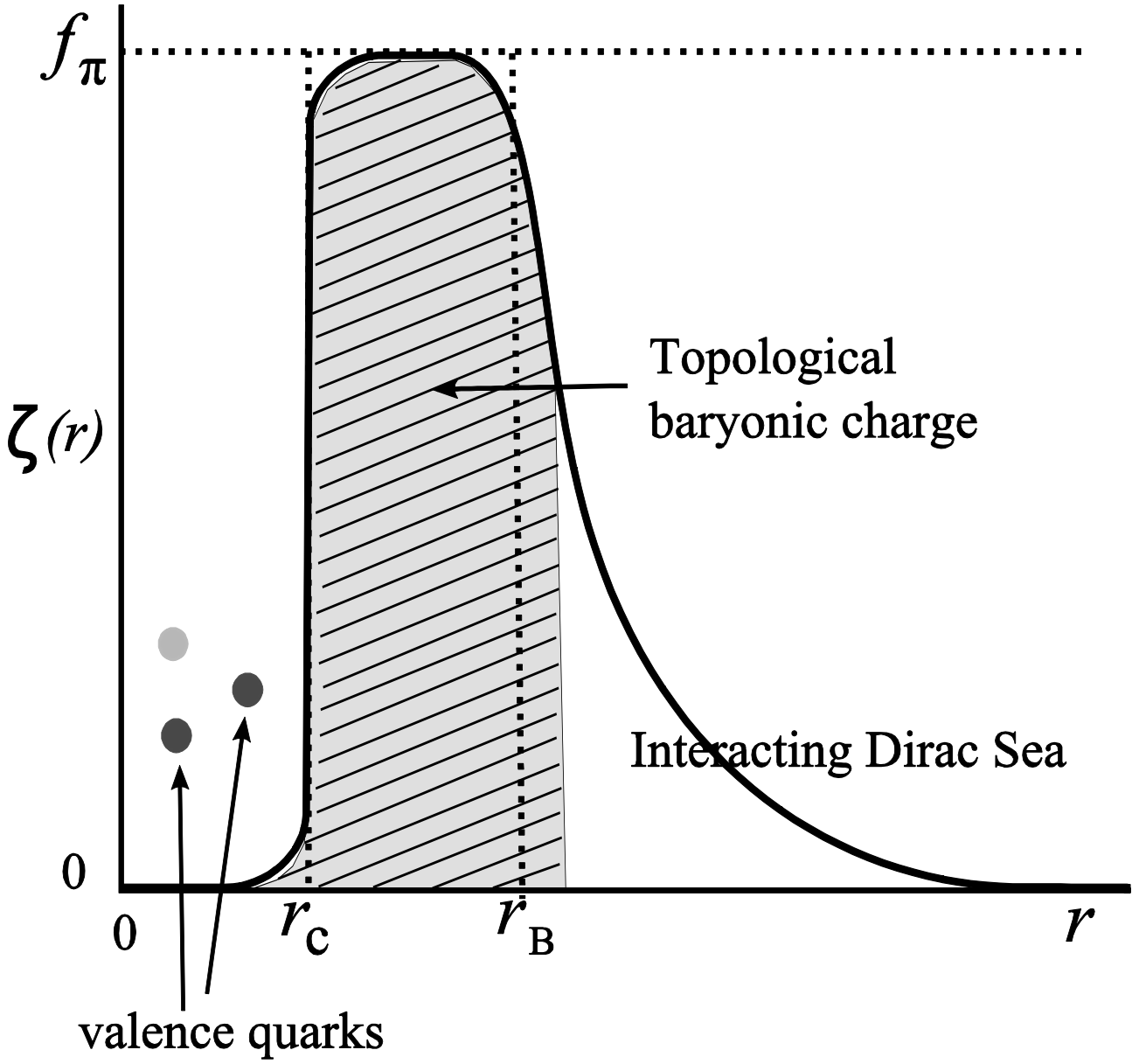

Fig. (Extra). Scalar field $\zeta(r)$ as a function of r.