CROSS-CHECKING ODDERON SIGNALS

AT SMALL VALUES OF -t

T. Csörgő[1,2] and I. Szanyi [1,3]

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[4] Eötvös University, Budapest, Hungary

Statistically Significant Observations of Odderon

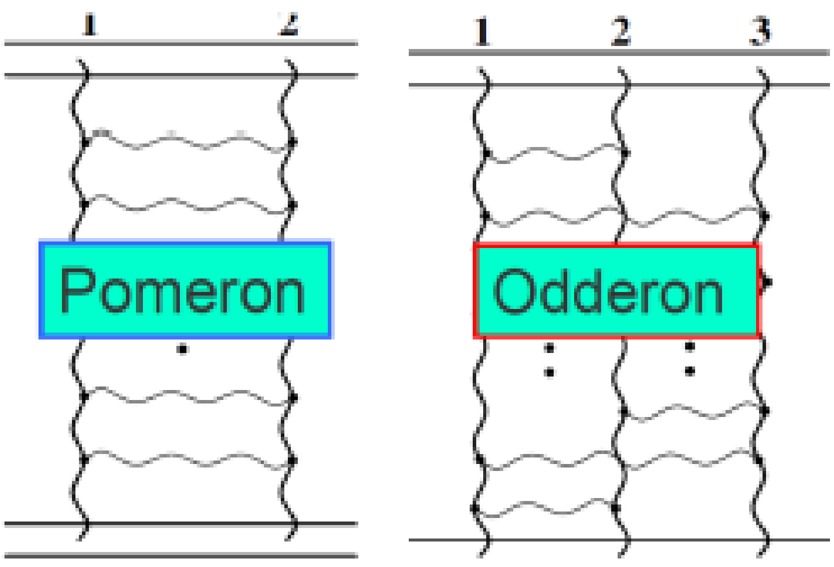
New: Small –t signals,
Model independently
Model dependently
LBB predictions

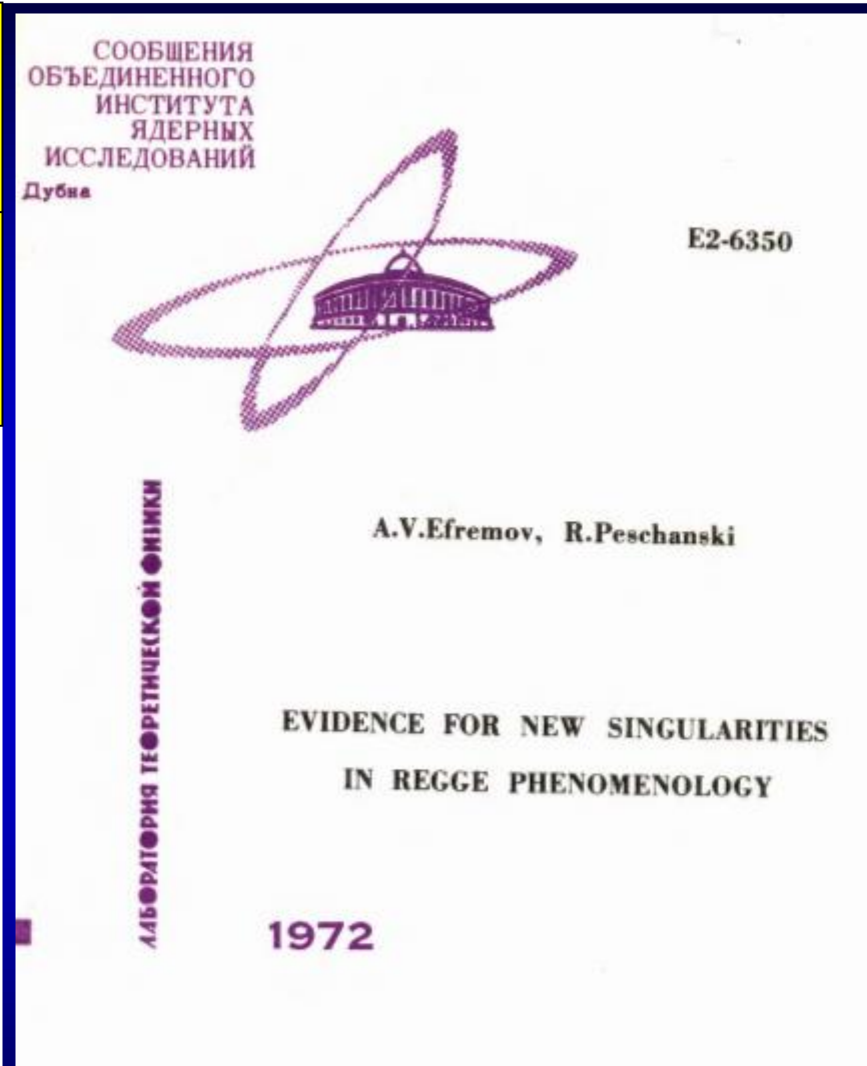
Results on both ρ and R
from data at the dip region

Odderon: 48 years old scientific puzzle

Odderon: L. Lukaszuk, B. Nicolescu,
Lett. Nuovo Cim. 8, 405 (1973)
Received: **31 July 1973**

Odderon is an odd component of elastic scattering:
Changes sign for crossing





Odderon name coined: D. Joynson, E. Leader, B. Nicolescu, C. Lopez,
Nuovo Cim. 30A, 345 (1975) - Well established in QCD by now !
Honorable mention: A. V. Efremov, R. Peschanski, JINR-E2-6350 (1972)

First publications, Odderon with > 5 σ

Evidence of Odderon-exchange from scaling properties of elastic scattering at TeV energies
#5

T. Csörgő (Wigner RCP, Budapest and CERN), T. Novak (Unlisted, HU), R. Pasechnik (Lund U., Dept. Theor. Phys.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest) (Dec 26, 2019)

Published in: *Eur.Phys.J.C* 81 (2021) 2, 180 • e-Print: 1912.11968 [hep-ph]

pdf DOI cite

Eur. Phys. J. C (2021) **81**: 180, Published: 23 February 2021
https://doi.org/10.1140/epjc/s10052-021-08867-6

Observation of Odderon effects at LHC energies: a real extended Bialas–Bzdak model study
#2

T. Csorgo (Wigner RCP, Budapest and EKU KRC, Gyongyos), I. Szanyi (Eotvos U. and Wigner RCP, Budapest) (May 28, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 7, 611 • e-Print: 2005.14319 [hep-ph]

pdf DOI cite

Eur. Phys. J. C (2021) **81**:611 , Published: 13 July 2021
https://doi.org/10.1140/epjc/s10052-021-09381-5

Comparison of pp and $p\bar{p}$ differential elastic cross sections and observation of the exchange of a colorless C-odd gluonic compound
#1

Odderon Exchange from Elastic Scattering Differences between pp and $p\bar{p}$ Data at 1.96 TeV and from pp Forward Scattering Measurements
#1

TOTEM and D0 Collaborations • V.M. Abazov (Dubna, JINR) et al. (Dec 7, 2020)

Published in: *Phys.Rev.Lett.* 127 (2021) 6, 062003 • e-Print: 2012.03981 [hep-ex]

pdf links DOI cite

Phys. Rev. Lett. **127** (2021) 6, 062003, Published: 4 August 2021
https://doi.org/10.1103/PhysRevLett.127.062003

Three Oldest Hungarian Universities

UP Story - 650 years

Home » University » UP Story 650 years

University of Pécs: 1367

The history of higher education in Pécs dates back to 1367, when Louis the Great initiated the establishment of a university in the episcopal city of Pécs. As a result of an integration process of several stages, the University of Pécs was founded, which has become one of the most famous, prestigious institutions having a leading role in regional education. It has ten faculties which cover the full spectrum of high-quality higher education.

1367

The University of Debrecen, the oldest institution of higher education in the country operated continuously in the same city, is one of the research universities of national excellence in Hungary offering the widest spectrum of educational programs in 14 faculties and 24 doctoral schools.

University of Debrecen: 1538

ts of higher education in the city reach all the way back to the 16^{th} century and the foundation Reformed College of Debrecen in 1538. The College played a central role in Hungarian education and culture for centuries. This is the date featured on the symbol of the university as well, the *gerundium*, a tool originally used by the students of the Reformed College to put out fires, showing respect for ancestors and traditions.

(S,C) structure evident,
S: statement, valid if
C: condition is satisfied
See talk of R. Dardashti at ISMD21

Eötvös Loránd University: 1635

The predecessor of Eötvös Loránd University (ELTE) was founded in Nagyszombat in 1635 (sixteen thirty-five) by Archbishop of Esztergom, Péter Pázmány, and it is the oldest Hungarian university where the teaching has continued uninterrupted since its inception. More than sixty years

Formalism: elastic scattering

$$\frac{d\sigma(s)}{dt} = \frac{1}{4\pi}|T_{el}(s,\Delta)|^2, \qquad \Delta = \sqrt{|t|}.$$

$$\sigma_{el}(s) = \int_0^\infty d|t|\frac{d\sigma(s)}{dt}$$

$$A(s) = \lim_{t\to 0}\frac{d\sigma}{dt}(s,t)$$

$$A(s) = \frac{1}{16\pi}(1+\rho_0^2(s))\sigma_{tot}^2(s)$$

$$B(s,t) = \frac{d}{dt}\ln\frac{d\sigma(s)}{dt}$$

$$\rho(s,t) \equiv \frac{\mathrm{Re}\,T_{el}(s,\Delta)}{\mathrm{Im}\,T_{el}(s,\Delta)}$$

$$B(s) \equiv B_0(s) = \lim_{t\to 0} B(s,t),$$

$$\rho(s) \equiv \rho_0(s) = \lim_{t\to 0}\rho(s,t)$$

$$\sigma_{\rm tot}(s) \equiv 2\,\mathrm{Im}\,T_{el}(\Delta=0,s)$$

Basic problem: dσ/dt measures an amplitude, *modulus squared*.
If Odderon exists: signals in elastic scattering at t = 0 and at –t > 0.

Formalism: Elastic scattering at small -t

$$\frac{d\sigma}{dt}(s,t) \simeq A(s)\exp(tB(s))$$

$$\sigma_{el}(s) = \int_0^\infty d|t| \frac{d\sigma(s)}{dt}$$

$$A(s) = \frac{1}{16\pi}(1+\rho_0^2(s))\sigma_{tot}^2(s)$$

$$\sigma_{\mathbf{el}}(s) = \frac{1}{16\pi}(1+\rho_0^2(s))\frac{\sigma_{tot}^2(s)}{B_0(s)}$$

If Odderon exists: signals in elastic scattering at t = 0 and at –t > 0.
Where from the significance of the signal is coming ?

Odderon Search at small –t

$$T_{\text{el}}^{O}(s,t) = \frac{1}{2}\left(T_{\text{el}}^{p\bar{p}}(s,t) - T_{\text{el}}^{pp}(s,t)\right)$$

valid for $\sqrt{s} \geq 1\ \text{TeV},$

Some simple consequences at small –t, Gaussian sources:

$$\frac{d\sigma}{dt}(s,t) \simeq A(s)\exp(tB(s))$$

If any of

$$\begin{aligned} A^{pp}(s) &\neq A^{p\bar{p}}(s), \\ B^{pp}(s) &\neq B^{p\bar{p}}(s). \end{aligned}$$

$$\begin{aligned} \rho_0^{pp}(s) &\neq \rho_0^{p\bar{p}}(s), \\ \sigma_{el}^{pp}(s) &\neq \sigma_{el}^{p\bar{p}}(s), \\ \sigma_{tot}^{pp}(s) &\neq \sigma_{tot}^{p\bar{p}}(s). \end{aligned}$$

is statistically significant

$$\text{for } \sqrt{s} \geq 1\,\text{TeV} \implies T_{el}^{O}(s,0) \neq 0$$

Odderon Search at small -t

$$T_{\text{el}}^{O}(s,t) = \frac{1}{2}\left(T_{\text{el}}^{p\overline{p}}(s,t) - T_{\text{el}}^{pp}(s,t)\right)$$ **valid for** $$\sqrt{s} \geq 1 \text{ TeV},$$

Some simple consequences at small –t, Levy sources:

$$\frac{d\sigma}{dt}(s,t) \simeq a(s)\exp\left[-(tb(s))^{\alpha_L/2}\right]$$

If any of

$$\begin{aligned} a^{pp}(s) &\neq a^{p\bar{p}}(s), \\ b^{pp}(s) &\neq b^{p\bar{p}}(s), \\ \alpha_L^{pp} &\neq \alpha_L^{p\bar{p}}, \end{aligned}$$

$$\begin{aligned} \rho_0^{pp}(s) &\neq \rho_0^{p\bar{p}}(s), \\ \sigma_{el}^{pp}(s) &\neq \sigma_{el}^{p\bar{p}}(s), \\ \sigma_{tot}^{pp}(s) &\neq \sigma_{tot}^{p\bar{p}}(s). \end{aligned}$$

is statistically significant

$$\text{for } \sqrt{s} \geq 1\,\text{TeV} \implies T_{el}^{O}(s,0) \neq 0$$

Levy generalized Bialas-Bzdak Model

Simple results at small -t:

$$a(s) = \frac{81}{16}\pi\left(2R_q^{\alpha_L(s)}(s)\right)^{4/\alpha_L}\left(1+4\alpha_R^2(s)\right)$$

$$b(s) = \frac{1}{36}\left(\frac{4}{3}\right)^{2/\alpha_L(s)}\left(\left(2+2^{\alpha_L(s)}\right)R_{qd}^{\alpha_L(s)}(s)+3^{\alpha_L(s)}\left(2R_d^{\alpha_L(s)}(s)+R_q^{\alpha_L(s)}(s)\right)\right)^{2/\alpha_L(s)}$$

$$\rho_0(s) = 2\alpha_R(s)$$

$$\sigma_{tot}(s) = 9\pi\left(2R_q^{\alpha_L(s)}(s)\right)^{2/\alpha_L(s)}$$

$$\sigma_{el}(s) = \frac{a(s)}{b(s)}\Gamma\left(\frac{2+\alpha_L(s)}{\alpha_L(s)}\right)$$

From data fits: R_q, R_d, R_{qd}, α_L is same in pp and pbarb

But!

$$\rho_0^{pp}(s) \neq \rho_0^{p\bar{p}}(s),$$

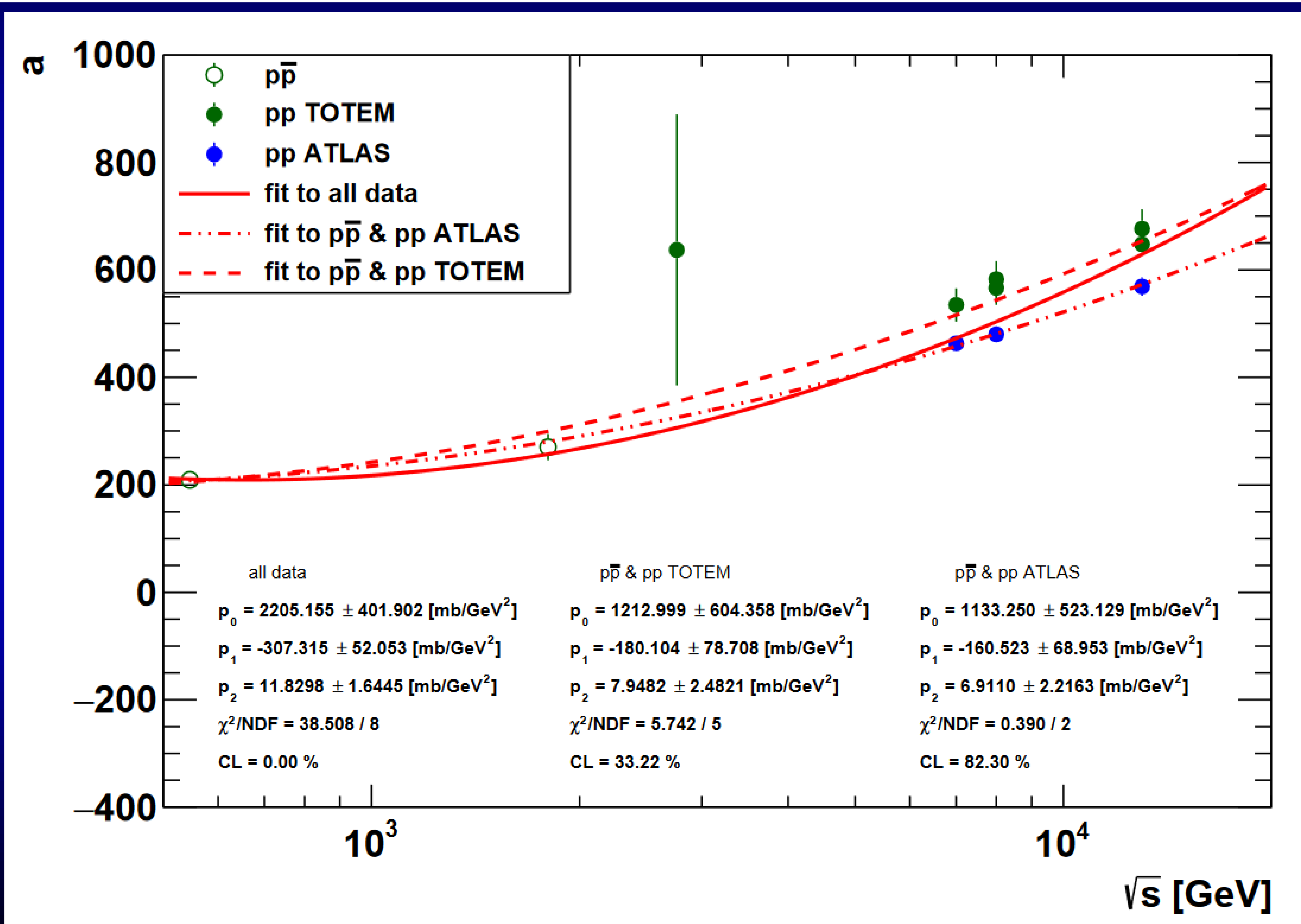
Click a bar to select papers. Click the bar again to reset your selection.

Lévy α-stable model for the non-exponential low-$|t|$ proton-proton differential cross section

#1

T. Csörgő (Karoly Robert U. Coll. and Budapest, RMKI), S. Hegyi, I. Szanyi (Karoly Robert U. Coll. and Budapest, RMKI and Eotvos U., Dept. Atomic Phys.) (Aug 9, 2023)

Published in: *Universe* 9 (2023) 361 • e-Print: 2308.05000 [hep-ph]



Lévy α-stable model for the non-exponential low-$|t|$ proton-proton differential cross section #1

Click a bar to select papers. Click the bar again to reset your selection.

T. Csörgő (Karoly Robert U. Coll. and Budapest, RMKI), S. Hegyi, I. Szanyi (Karoly Robert U. Coll. and Budapest, RMKI and Eotvos U., Dept. Atomic Phys.) (Aug 9, 2023)

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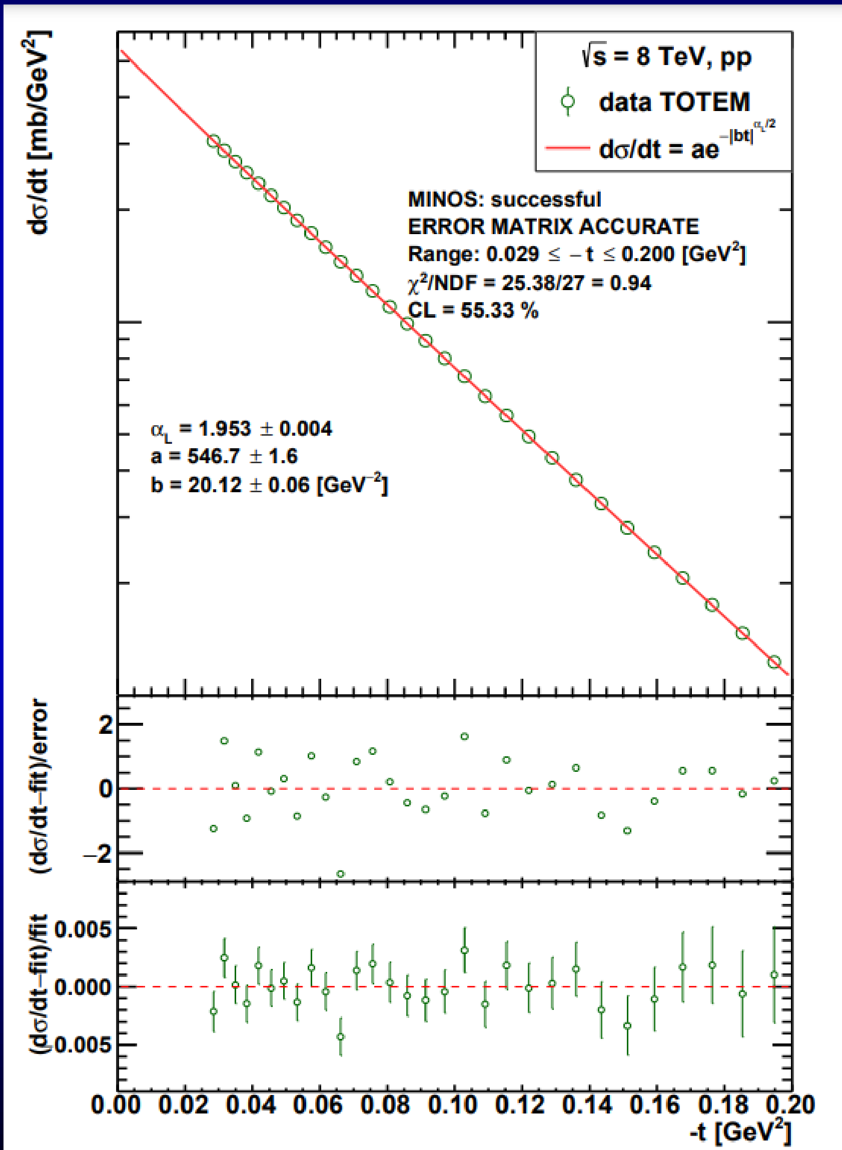
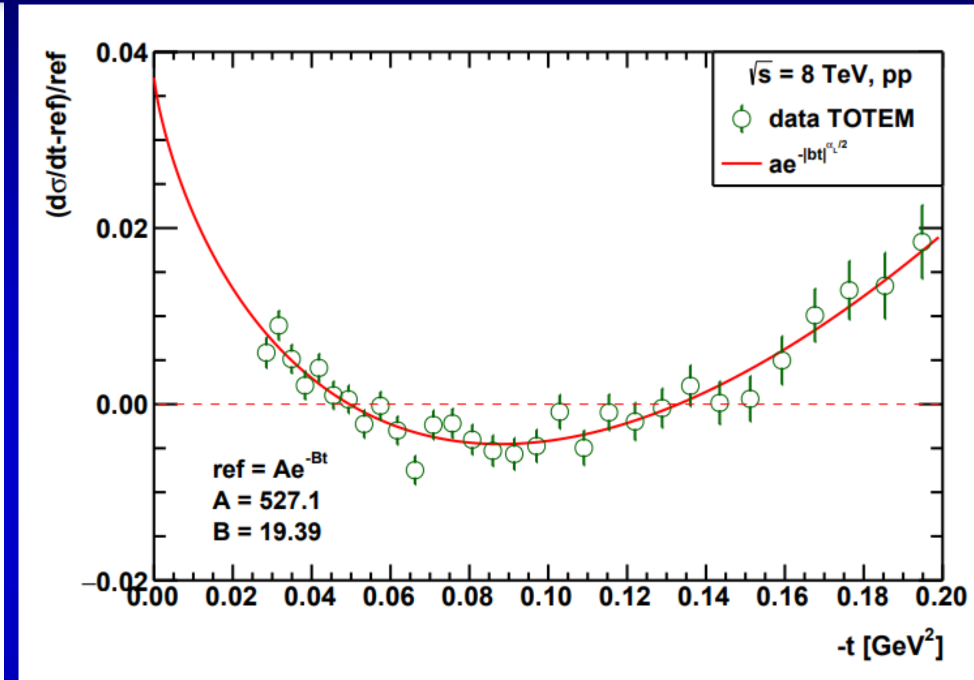
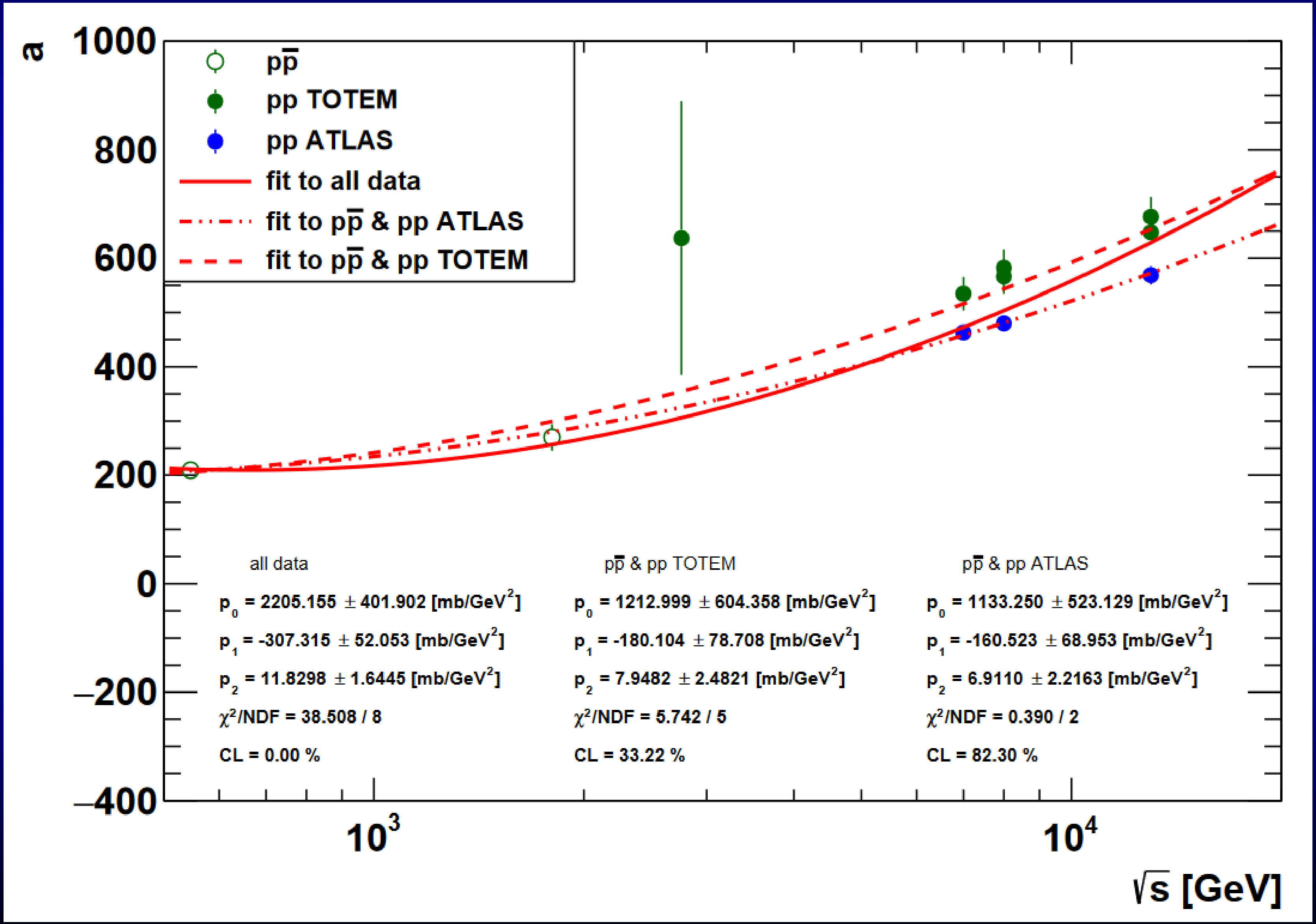




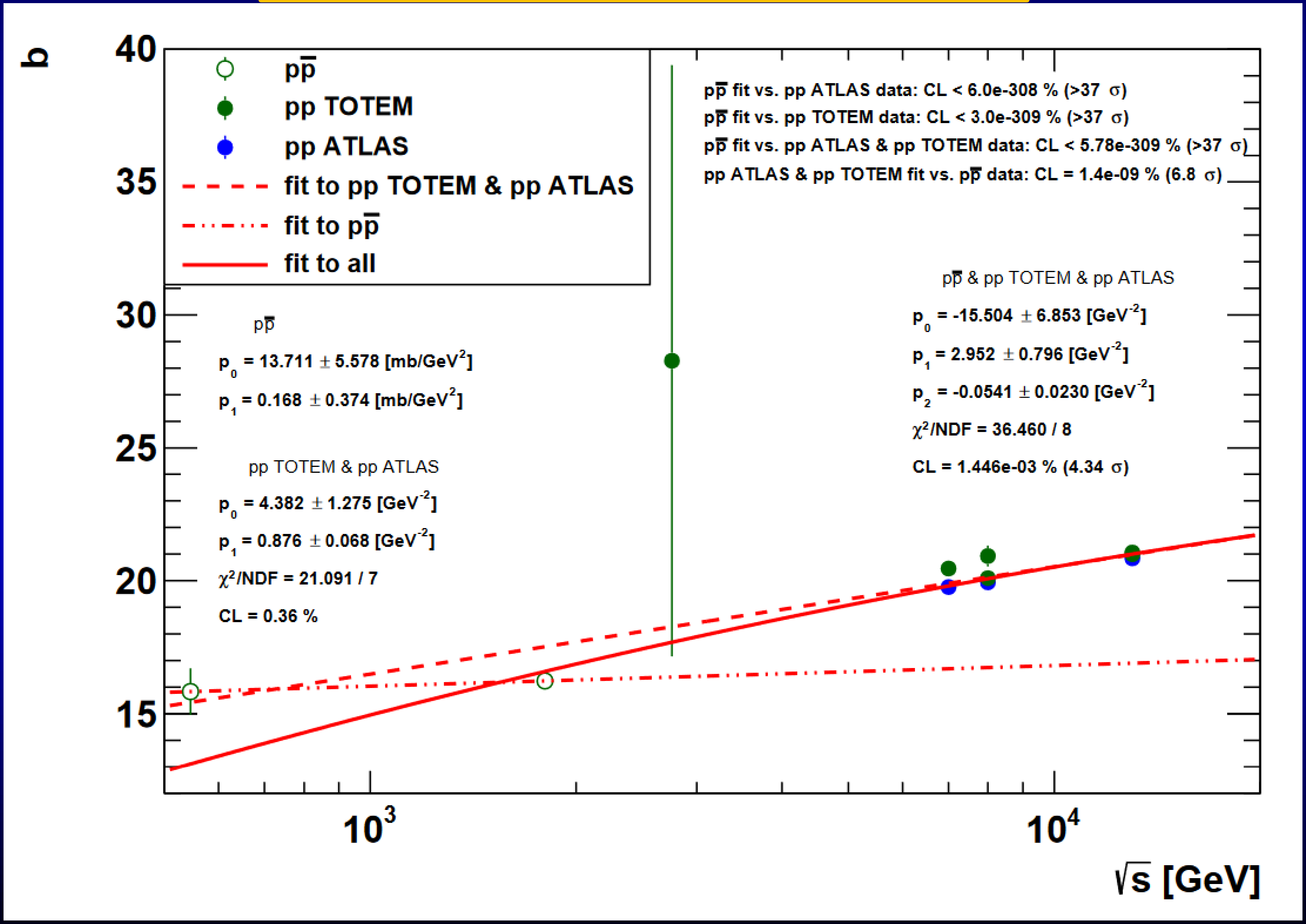
$$\frac{d\sigma}{dt}(s,t) \simeq a(s)\exp\left[-(tb(s))^{\alpha_L/2}\right]$$

From Glauber's theory, p=(q,d)
Good quality fits at 8 TeV and also
at every low –t dataset for pp, pbarp

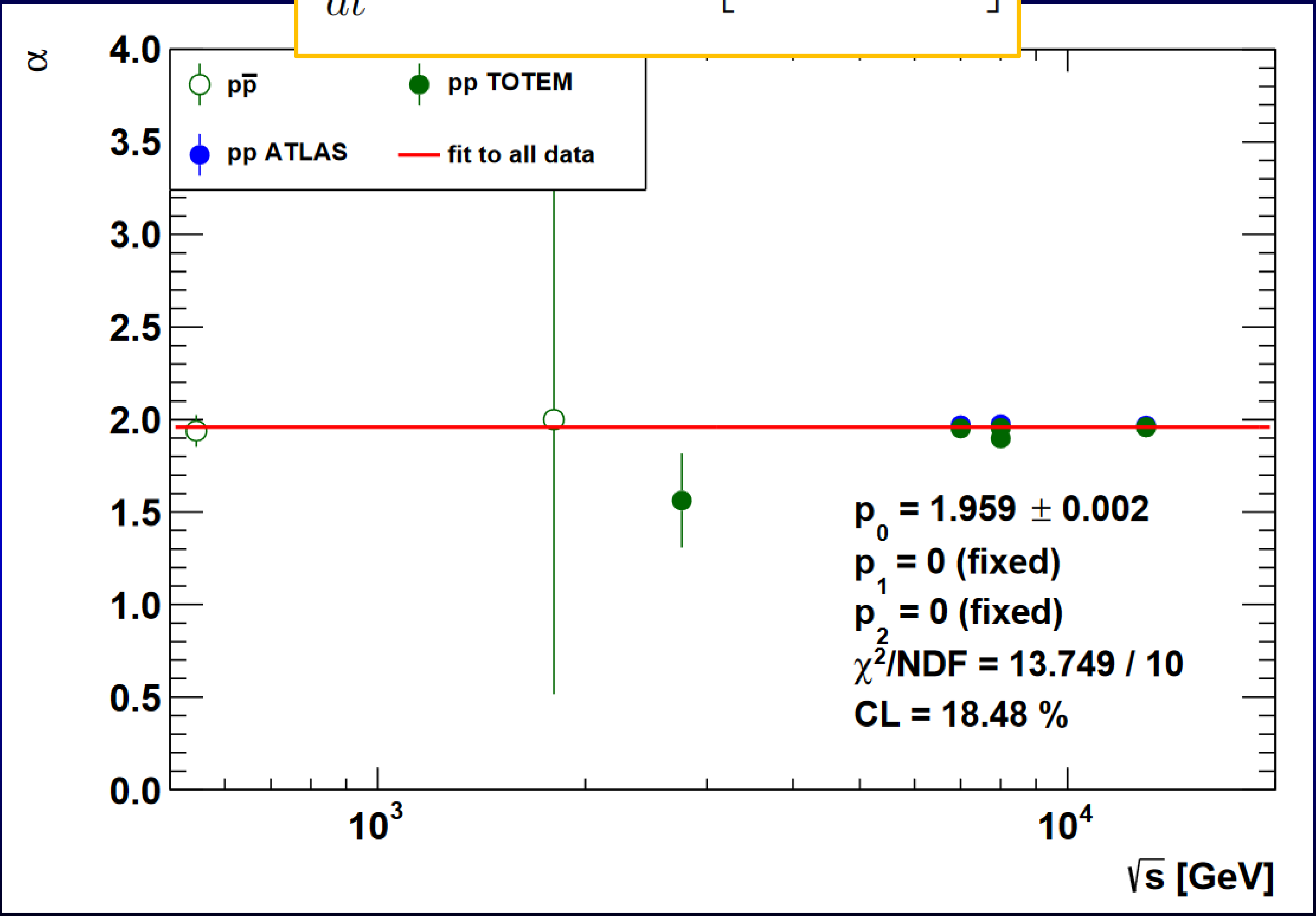
$$\frac{d\sigma}{dt}(s,t) \simeq a(s)\exp\left[-(tb(s))^{\alpha_L/2}\right]$$



$$\frac{d\sigma}{dt}(s,t) \simeq a(s)\exp\left[-(tb(s))^{\alpha_L/2}\right]$$



$$\frac{d\sigma}{dt}(s,t) \simeq a(s)\exp\left[-(tb(s))^{\alpha_L/2}\right]$$

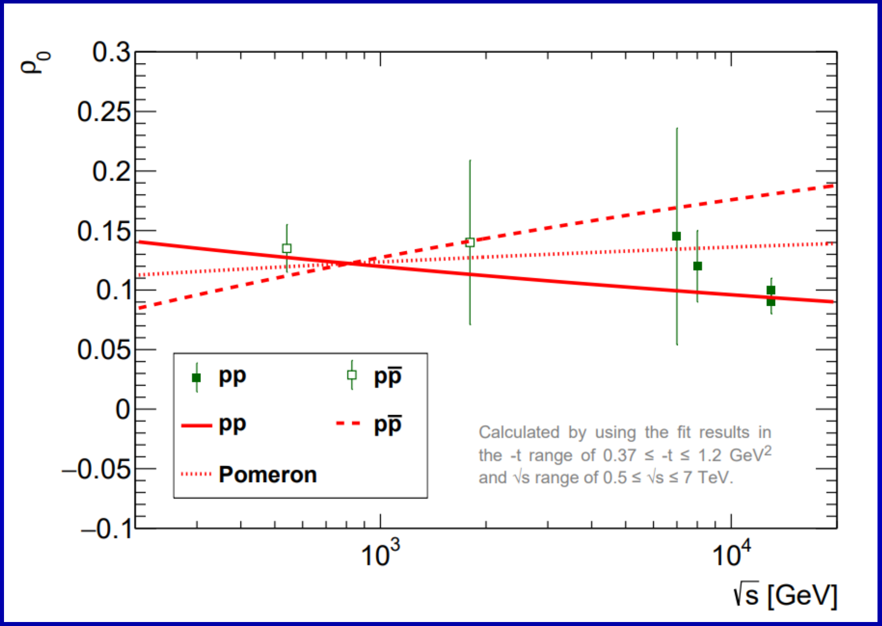


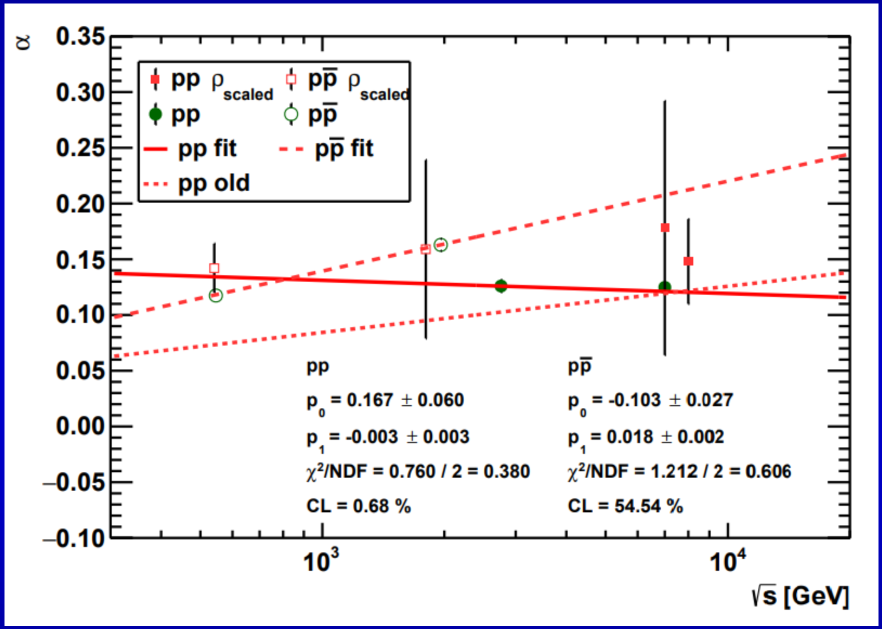
ρ_0 from fits to data

Observation of Odderon effects at LHC energies: a real extended Bialas–Bzdak model study

T. Csorgo (Wigner RCP, Budapest and EKU KRC, Gyongyos), I. Szanyi (Eotvos U. and Wigner RCP, Budapest) (May 28, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 7, 611 • e-Print: 2005.14319 [hep-ph]





From data fits: R_q, R_d, R_{qd} is the same, but $\alpha \sim \rho$ (opacity) is not the same in pp and pbarb

$$\rho_0^{pp}(s) \neq \rho_0^{p\bar{p}}(s),$$

Levy + Bialas-Bzdak at small t

$$\frac{d\sigma}{dt}(s,t) \simeq a(s) \exp\left[-(tb(s))^{\alpha_L/2}\right]$$

Easy to fit model, with dramatic consequences

$$\begin{aligned} b^{pp}(s) &= b^{p\bar{p}}(s), \\ \sigma_{tot}^{pp}(s) &= \sigma_{tot}^{p\bar{p}}(s). \end{aligned}$$

Strong form of Pomeranchuk theorem, but Signal of odderon exchange in optical point, ρ and elastic cross-section!

$$\begin{aligned} a^{pp}(s) &\neq a^{p\bar{p}}(s), \\ \rho_0^{pp}(s) &\neq \rho_0^{p\bar{p}}(s), \\ \sigma_{el}^{pp}(s) &\neq \sigma_{el}^{p\bar{p}}(s), \end{aligned}$$

OBSERVATION OF ODDERON

2020 → 2O2O

THANK YOU FOR YOUR ATTENTION

ODE TO ODDERON → OBERON

Ode to Odderon

Let's be truly happy,
for what we've come upon:
We have just discovered
the elusive odderon!

For forty-eight years,
forging a ring of colors white:
Odd number of gluons
has been hiding in plain sight!

``Discovery consists of seeing what everybody has seen,
and thinking what nobody has thought."
Albert Szent-Györgyi

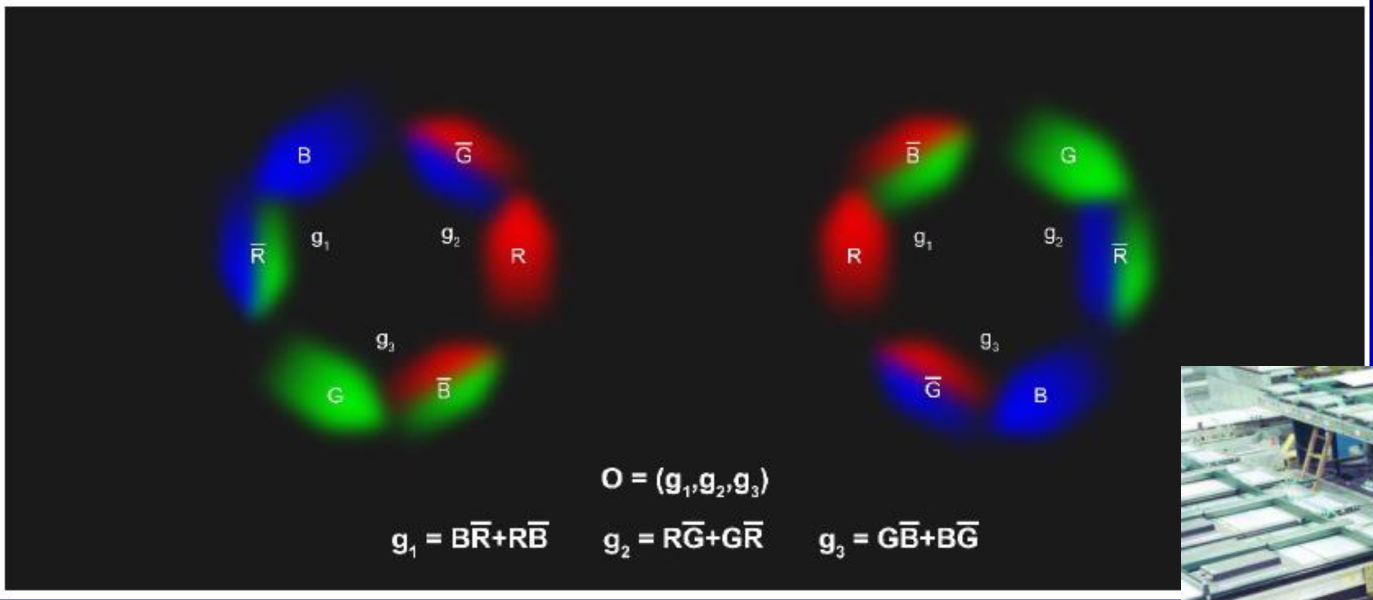
OBERON POETRY MAGAZINE

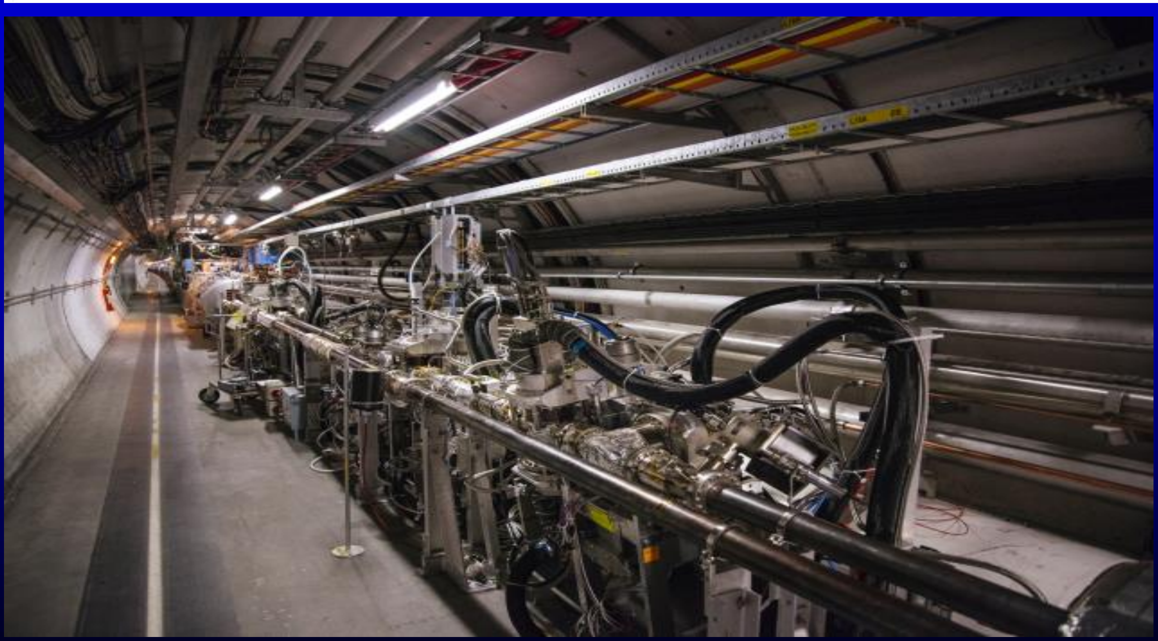
So happy together,
with love for science and research:
Happiness and pleasure
must not slow down the search!

Let's live in harmony,
and in equanimity:
Let's make light of the fight,
gloom is our true enemy!

© by Tamás Csörgő
Gyöngyös, Hungary, March 11 – April 11, 2021

BACKUP SLIDES





BACKUP SLIDES

cordis.europa.eu/article/id/429667-particle-physics-milestone-achieved-at-cern

Alkalmazások CERN ET Wigner Conf Stabil-Invest Kft. Szanyi István

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European | CORDIS

English EN

For most of us, physics terms such as odderon are – and will always remain – firmly lodged in the science fiction realm. Not so for the scientific community, whose determined members spent nearly half a century searching (without much success) for this mythical particle.

Now, a research team including physicists from Hungary and Sweden has discovered the odderon by analysing experimental data from the Large Hadron Collider (LHC) at Switzerland's European Organization for Nuclear Research, better known as CERN. Supported by the EU-funded MorePheno project, the physicists have published a paper describing their findings in the 'The European Physical Journal C'.

DE

Particle physics milestone achieved at CERN

After 50 years of research, physicists have found evidence that the elusive subatomic quasiparticle called odderon actually exists.

BACKUP SLIDES

Nature Reviews Physics | https://doi.org/10.1038/s42254-021-00375-6 | Published online: 02 September 2021

IN RETROSPECT

Discovery of the odderon

In the 1950s, experimental data on the total cross-section for proton–proton collisions (σ_{pp}) suggested that σ_{pp} was initially decreasing as the collision energy increased and then flattening out to a constant value. Isaak Pomeranchuk hypothesized a 'crossing even' mechanism to explain this behaviour, which involved an equal contribution to the cross-section for proton–antiproton collisions ($\sigma_{p\bar{p}}$). This became known as pomeron exchange. Since beams of antiprotons are very difficult to produce, data on $\sigma_{p\bar{p}}$ were scarce, but did seem to fit the idea of pomeron exchange.

In the 1970s, pp collisions at the much higher total centre of mass energy (E_{CM} = 53 GeV) at the Intersecting Storage Rings (ISR) collider at CERN showed that σ_{pp} was actually growing as the energy increased, begging the question of what is the theoretical maximal permitted rate of growth. Marcel Froissart answered that it should be $\sigma_{pp} \sim [\log(E_{CM})]^2$. Like the pomeron exchange, this mechanism was crossing even, so that at sufficiently high energies one would find similar growth with the same factor for pp and $p\bar{p}$ cross-sections and thus, eventually, at high enough energies the difference between σ_{pp} and $\sigma_{p\bar{p}}$ would go to zero.

In 1973, Leszek Łukaszuk and Basarab Nicolescu argued that there could, in principle, also exist a 'crossing odd' mechanism: one that contributes to σ_{pp} and $\sigma_{p\bar{p}}$ with opposite signs, and which could also grow like $[\log(E_{CM})]^2$, a mechanism known as odderon exchange.

The main implication of odderon exchange was that σ_{pp} and $\sigma_{p\bar{p}}$ would not become equal as the energy increased. It also implied that the real parts of the pp and $p\bar{p}$ elastic scattering amplitudes would not become equal and the shapes of their differential cross-sections would differ.

Literally during the last week of operation of the ISR in 1985, data were obtained showing that the shapes of the differential cross-sections for pp and $p\bar{p}$ at E_{CM} = 53 GeV were indeed different, but the general feeling in the community was that this was not sufficient to confirm the existence of the odderon.

On the theoretical side, many later papers based on quantum chromodynamics showed that abstract mechanisms such as the pomeron and odderon exchange could emerge in reality as a result of the forces produced by the exchange of an even or an odd number of gluons in the scattering process.

The most direct way to demonstrate the existence of the odderon is to compare σ_{pp} and $\sigma_{p\bar{p}}$ at equal and sufficiently high energies, where it is safe to ignore contributions from the known mechanisms that contribute at lower energies. Data from the Tevatron $p\bar{p}$ collider at Fermilab, and from the Relativistic Heavy Ion Collider pp collider at Brookhaven National Laboratory, were in agreement regarding a $\sim[\log(E_{CM})]^2$ growth, and this was confirmed for the pp case at the high energies (between 2.76 TeV and 13 TeV) reached at the Large Hadron Collider (LHC) at CERN. Unfortunately, the highest energy reached for the $p\bar{p}$ case, at the Tevatron, was E_{CM} = 1.96 TeV, slightly below the minimum energy at which the LHC operates, so an absolute direct comparison of σ_{pp} and $\sigma_{p\bar{p}}$ at identical ultra-high energies was not possible. To make matters worse, two different measurements at Fermilab disagreed with each other significantly. Nonetheless, in a recent article in *Physical Review Letters* the CERN TOTEM and the Fermilab D0 collaborations reported the discovery of the odderon. This result is based mainly on an almost model-independent extrapolation down in the energy of the pp differential cross-sections measured at the LHC and a comparison with the $p\bar{p}$ differential cross-section measured at the Tevatron. The significant difference in the shape of differential cross-sections (pictured) at this ultra-high energy is at last convincing evidence for the existence of the odderon.

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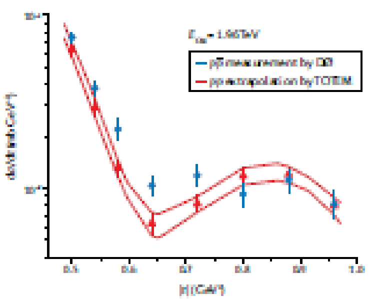
Competing interests
The author declares no competing interests.



Three Odderon Proceedings with > 5 σ

Scaling of high-energy elastic scattering and the observation of Odderon #1

T. Csörgő (Wigner RCP, Budapest and Eszterhazy Karoly U., Eger), T. Novák (EKU KRC, Gyongyos), R. Pasechnik (Lund U., Dept. Theor. Phys.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest and Eotvos U.) (Apr 15, 2020)

Published in: Gribov-90 Memorial Volume, pp. 69-80 (2021) (World Scientific, Singapore, ed. Yu. Dokshitzer, P. L\'evai, \'A. Luk\'acs and J. Nyiri) • e-Print: 2004.07318 [hep-ph]

pdf DOI cite

Gribov'90 Memorial Volume, pp. 69-80 (2021)
https://doi.org/10.1142/9789811238406_0012

Proton Holography -- Discovering Odderon from Scaling Properties of Elastic Scattering #2

T. Csorgo (Wigner RCP, Budapest and Eszterhazy Karoly U., Eger), T. Novak (EKU KRC, Gyongyos), R. Pasechnik (Lund U. and Rez, Nucl. Phys. Inst.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest and Eotvos U.) (Apr 15, 2020)

Published in: *EPJ Web Conf.* 235 (2020) 06002 • Contribution to: ISMD 2019 • e-Print: 2004.07095 [hep-ph]

pdf DOI cite

EPJ Web Conf. 235 (2020) 06002, proc. **ISMD 2019**
https://doi.org/10.1051/epjconf/202023506002

Comparison of differential elastic cross sections in pp and $p\bar{p}$ collisions as evidence of the existence of the colourless C-odd three-gluon state #1

D0 and Totem Collaborations • Christophe Royon (Kansas U.) for the collaborations. (Dec 5, 2020)

Published in: *PoS* ICHEP2020 (2021) 496 • Contribution to: ICHEP2020, 496 • e-Print: 2012.03150 [hep-ex]

pdf DOI cite

PoS **ICHEP 2020** (2021)
https://doi.org/10.22323/1.390.0496

Looking for Crossing-Odd(eron) effects

$$T_{\rm el}^{pp}(s,t) = T_{\rm el}^{+}(s,t) - T_{\rm el}^{-}(s,t),$$
$$T_{\rm el}^{p\overline{p}}(s,t) = T_{\rm el}^{+}(s,t) + T_{\rm el}^{-}(s,t),$$
$$T_{\rm el}^{+}(s,t) = T_{\rm el}^{P}(s,t) + T_{\rm el}^{f}(s,t),$$
$$T_{\rm el}^{-}(s,t) = T_{\rm el}^{O}(s,t) + T_{\rm el}^{\omega}(s,t).$$

$$T_{\rm el}^{P}(s,t) = \frac{1}{2}\left(T_{\rm el}^{pp}(s,t) + T_{\rm el}^{p\overline{p}}(s,t)\right)$$
$$T_{\rm el}^{O}(s,t) = \frac{1}{2}\left(T_{\rm el}^{p\overline{p}}(s,t) - T_{\rm el}^{pp}(s,t)\right)$$

for $\sqrt{s} \geq 1$ TeV,

Three simple consequences:

$$T_{el}^{O}(s,t) = 0 \implies \frac{d\sigma^{pp}}{dt} = \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV}$$

$$\frac{d\sigma^{pp}}{dt} = \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \;\not\Longrightarrow\; T_{el}^{O}(s,t) = 0.$$

$$\frac{d\sigma^{pp}}{dt} \neq \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \implies T_{el}^{O}(s,t) \neq 0$$

Odderon differential cross-section from pp and ppbar collisions, Reggeized Philips-Barger:
A. Ster, L. Jenkovszky, T. Cs., **arxiv:1501.03860,** *Phys.Rev.D* **91** (2015) 7, 074018

Odderon search: strategy with scaling

Known trivial s-dependences in
$\sigma_{tot}(s)$, $\sigma_{el}(s)$, $B(s)$, $\rho(s)$

Try to scale this out
Look for data collapsing (scaling)

Look for scaling violations

In the TeV energy range:
Odderon is equivalent with
a crossing-odd component
Look for violations of C-symmetry

Close the energy gap with scaling

Honorable mentions: Odderon, qualitatively

Proposal for LHC to hunt down the Odderon:

Extracting the Odderon from pp and $\bar{p}p$ scattering data #1

Andras Ster (Budapest, RMKI), Laszlo ... Budapest, RMKI) (Jan 15, 2015)

Published in: *Phys.Rev.D* 91 (2015) 7, ...

Searching for the odderon in $pp \to ppK^+K^-$ and $pp \to pp\mu^+\mu^-$ reactions in the $\phi(1020)$ resonance region at the LHC #2

Piotr Lebiedowicz (Cracow, INP), Otto Nachtmann (U. Heidelberg, ITP and Rzeszow U.), Antoni Szczurek (Cracow, INP) (Nov 5, 2019)

Published in: *Phys.Rev.D* 101 (2020) 9, 094012 • e-Print: 1911.01909 [hep-ph]

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