Searches for vector glueball $J^{PC} = 1^{-1}$



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on behalf of **TOTEM collaboration**

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Outline

- Motivation
- TOTEM experiment at LHC
- · Elastic scattering
- $\cdot ~\sigma_{tot}\, \& \, \rho$ measurement at 13 TeV
- $3g J^{PC} = 1^{--} t$ -exchange
- Other possible 3g t-exchange manifestations
- · 3g s-channel production



3g J^{PC} = 1⁻⁻ search motivation

- Originally predicted as Odderon in Regge-like Axiomatic field theory frameworks
 L. Lukaszuk and B. Nicolescu. Lett. Nuovo Cim. 8 (1973) 405.
- Confirmed in QCD: Colorless 3-gluon bound state with stronger internal coupling than external J. Bartels, Nucl. Phys. B175 (1980) 365; J. Kwiecinski and M. Praszalowicz, Phys. Lett. B94 (1980) 413; T. Jaroszewicz and J. Kwiecinski, Z. Phys. C12 (1982) 167; L.N. Lipatov, Sov. Phys. JETP 63 (1986) 904; E. Levin and M. Ryskin, Phys. Rep. 189 (1990) 268
- Vector glueball in lattice calculations with a mass of 3-4 GeV e.g. C.J. Morningstar and M. Peardon, Phys. Rev. D 60 (1999) 034509
- s-channel:
 - pair and/or single production of vector glueball state $J^{PC} = 1^{-1}$ e.g. in central exclusive processes
- t-channel:
 - modification of central exclusive vector meson production (vs γ)
 - modification of elastic scattering (vs Pomeron & γ) \Rightarrow TOTEM sensitive in t-channel (full |t|-range elastic scattering)





Experimental setup @ IP5



Roman Pots: diffractive protons (di-proton trigger)

TOTEM





Reconstruction of proton kinematics = inversion of transport equation Transport matrix elements depend on $\xi \rightarrow$ non-linear problem (except in elastic case!)

Excellent optics understanding needed.





A. Donnachie and P. V. Landshoff, Z. Phys. C 2 (1979) 55. 9



3g J^{PC} = 1⁻ in elastic pp scattering

Theory: 3g J^{PC}=1⁻⁻⁻ existence would imply for pp elastic scattering :

- Persistence of diffractive dip at LHC energies
- Faster increase of σ_{tot} with \sqrt{s}
- Non-constant hadronic phase & low-t deviation from pure exponential
- faster decrease of $\rho \equiv \Re A^{\text{had}} \Im A^{\text{had}}|_{t=0}$ with \sqrt{s} : @ 14 TeV $\rho \approx 0.14$ (without 3g J^{PC} = 1⁻⁻) vs $\rho \approx 0.10$ (with 3g J^{PC} = 1⁻⁻)

$\Rightarrow \sigma_{tot}$ & ρ not consistent with models without 3g t-exchange

- pQCD (without oscillatory effects) at large |t|
- \Rightarrow TOTEM measurements consistent with existence of 3g J^PC = 1-

$3g J^{PC} = 1^{-}$ in elastic pp scattering

TOTEM









$\beta^* = 90 \text{ m dN}_{el}/\text{dt} @ \sqrt{s} = 13 \text{ TeV}$

diffractive slope B: $d\sigma/dt \approx ae^{-Bt}|_{t=0}$













Later will make full exploration of phases, hadronic amplitudes & inteference formulas (as @ 8 TeV)

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- Coulomb-hadronic interference:
- Kundrát-Lokajícek formula
- Modulus of hadronic amplitude: $\sum^{N_b} b_n t^n$ a exp at low |t|
- Phase of hadronic amplitude: slow variation with |t| ("central", same as pre-LHC measurements)

Fit results:

t -ranges used:		$ t _{\rm max} = 0.07 {\rm GeV^2}$		$ t _{\rm max} = 0.15 {\rm GeV^2}$	
UA4 range equivalent	N_b	χ^2/ndf	ρ	χ^2/ndf	ρ
$- t < 0.15 \text{ GeV}^2$:	1	0.7	0.09 ± 0.01	2.6	-
maximal (without	2	0.6	0.10 ± 0.01	1.0	0.09 ± 0.01
effects due to dip)	3	0.6	0.09 ± 0.01	0.9	0.10 ± 0.01

Data incompatible with purely exponential (confirmation of 8 TeV result !) ρ @ 13 TeV significantly lower than expected (0.09-0.10 vs 0.14)



UA4-like fit in corresponding in equivalent |t|-range

Large freedom for fit (in maximal |t|-range w/o any dip interference) ⇒ purely exponential incompatible with data (confirming 8 TeV result)





TOTEM @ 13 TeV: ρ = 0.10 \pm 0.01 & 0.09 \pm 0.01





Comparison models without 3g exchange

Comparison with COMPETE model predictions: J.R. Cudell et al., PRL 89 (2002) 201801.





Comparison models with 3g t-exchange

Nicolescu: Axiomatic field theory-based with Odderon-component

R. Avila, P. Gauron and B. Nicolescu, Eur. Phys. J. C49 (2007) 581; E. Martynov and B. Nicolescu, arXiv:1711.03288

Durham model: QCD based model without/with 3g-component V.A. Khoze, A.D. Martin, M.G. Ryskin, Int. J. Mod. Phys. A30 (2015) 1542004; V.A. Khoze, A.D. Martin and M.G. Ryskin, arXiv:1712.00325



Compatibility measured by P-value: Durham without 3g t-exchange: 0.02 (ρ) Adding Odderon/3g t-exchange improves model descriptions of TOTEM $\sigma_{tot} \& \rho$ measurements



Other 3g t-channel manifestations

More pronounced "dip" in |t|-distribution in pp than in pp



Fig. 1. pp and $\bar{p}p \ d\sigma/dt$ predictions for the case without the odderon, together with the experimental points, at $\sqrt{s} = 52.8 \text{ GeV}$

A. Breakstone et al., Phys. Rev. Lett. 54 (1985) 2180



D0 Collaboration, V.M. Abazov et al., Phys. Rev. D 86 (2012) 012009.

Clear indications of effect !



Other 3g t-channel manifestations

Contribution to (large p_{τ}) exclusive meson production (vs γ)



H1 Collaboration, C. Adloff et al., Phys. Lett. B 544 (2002) 35.

Odderon-10 $1/\sigma * d\sigma / dp_T^2 [1/GeV^2]$ γ -Pomeron Pomeron **Exclusive vector** $\boldsymbol{\phi}_{1}^{\lambda_{1}\lambda_{2}\lambda_{3}}$ Φ_p^Y meson production 0.1 at hadron colliders b) 0 (in competation 0.01 with γ & Pomeron 0.2 0.4 0.6 0.8 1 0 $\boldsymbol{\Phi}_{p}^{\kappa_{1}\kappa_{2}}$ $\boldsymbol{\Phi}_{D}^{\kappa_{1}\kappa_{2}}$ + p dissociation) L. Motyka, arXiv:0808.2216

Pomeron with proton dissociation contributes here

1.2 1.4

J/ψ odderon

 p_T^2 [GeV²]

J/w (photon) -

No convincing evidence of effect !



3g s-channel manifestations

- Production vector glueball: pair (single) production through Pomeron-Pomeron (Odderon-Pomeron) in central exclusive processes
- Mass predicted from lattice to be 3-4 GeV (latest predictions more closer to 4 GeV than 3 GeV) e.g. 3.8 GeV *Y. Chen et al., Phys. Rev. D* 73, 014516 (2006)
- Decays to two pseudoscalar mesons and one vector mesons e.g. $\omega\pi\pi$ and K*K π expected to be dominant; also decays one vector meson and one pseudoscalar meson expected to large e.g. $\rho\pi$ and K*K
- F. Giacosa, J. Sammet and S. Janowski, Phys. Rev. D 95, 114004 (2017)



Summary

- ✓ Conventional models (COMPETE) not able to describe simultaneously TOTEM $\sigma_{tot} \& \rho$ measurements ⇒ data most compatible with t-channel exchange of a colourless QCD 3 gluon JPC = 1⁻⁻ bound state
- ✓ To be able to confirm 3g t-exchange: ρ measurements at lower √s, comparison of pp vs pp (dip etc...), observation of 3g t-exchange in exclusive vector meson production
- Search for 3g s-channel production