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Odderon and Pomeron from the ReBB model

based on
Eur. Phys. J. C **82**, 827 (19 September 2022) & Eur. Phys. J. C **81**, 611 (13 July 2021)
and other recent results

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Day of Femtoscopy 2022
15 November 2022, Gyöngyös, Hungary

Bialas-Bzdak p=(q,d) model

$$\tilde{\sigma}_{in}(\vec{b}) = \int_{-\infty}^{+\infty} \dots \int_{-\infty}^{+\infty} d^2\vec{s}_q\, d^2\vec{s}\,'_q\, d^2\vec{s}_d\, d^2\vec{s}\,'_d\; D(\vec{s}_q, \vec{s}_d)\; D(\vec{s}\,'_q, \vec{s}\,'_d)\; \sigma(\vec{s}_q, \vec{s}_d; \vec{s}\,'_q, \vec{s}\,'_d; \vec{b})$$

- **quark-diquark distribution inside the proton:**

$$D(\vec{s}_q, \vec{s}_d) = \frac{1+\lambda^2}{R_{qd}^2 \pi} e^{-\frac{s_q^2 + s_d^2}{R_{qd}^2}} \delta^2(\vec{s}_q + \lambda \vec{s}_d)$$

$$\lambda = \frac{m_q}{m_d}$$

$$\vec{s}_d = -\lambda \vec{s}_q$$

$$\vec{s}\,'_d = -\lambda \vec{s}\,'_q$$

- **sum of inelastic interaction probabilities of the constituents:**

$$\sigma(\vec{s}_q, \vec{s}_d; \vec{s}\,'_q, \vec{s}\,'_d; \vec{b}) = 1 - \prod_a \prod_b \left[1 - \sigma_{ab}(\vec{b} + \vec{s}\,'_a - \vec{s}_b)\right]$$

$$\sigma_{ab}(\vec{s}) = A_{ab} e^{-|\vec{s}|^2 / S_{ab}^2}$$

$$S_{ab}^2 = R_a^2 + R_b^2$$

$$a, b \in \{q, d\}$$

- **inelastic cross-sections of quark, diquark scatterings :**

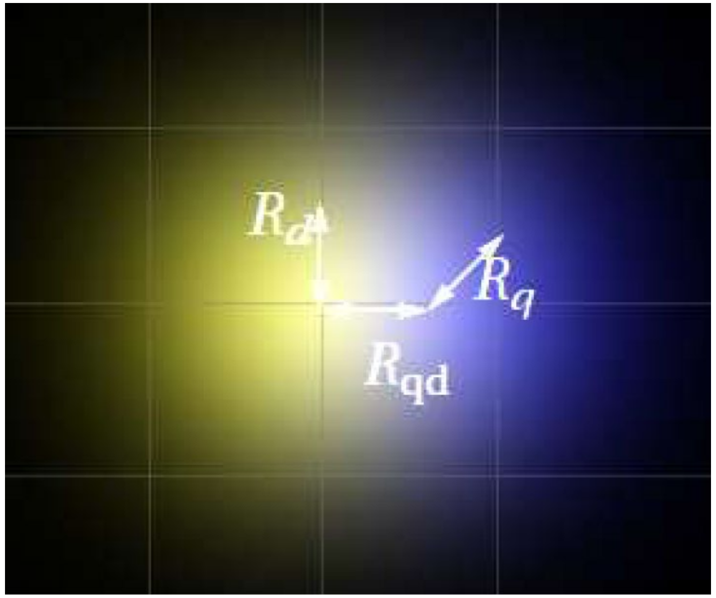
$$\sigma_{ab,in} = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \sigma_{ab}(\vec{s})\, d^2\vec{s}$$

$$\sigma_{qq,in} : \sigma_{qd,in} : \sigma_{dd,in} = 1 : 2 : 4$$

- **free parameters:**

$A_{qq}, \lambda, R_q, R_d, R_{qd}$, $(A_{qq} = 1 \; and \; \lambda = 0.5 \; can \; be \; fixed)$

[A. Bialas, A. Bzdak, Acta Phys.Polon. B 38, 159-168 (2007), Phys.Lett.B 649: 263-268 (2007)]



Proton-(anti)proton scattering in the quark-diquark model (Glauber style calculation).

Unitarily Real Extended Bialas-Bzdak (REBB) model

- **elastic scattering amplitude in the impact parameter space:**

$$t_{el}(s,\vec{b}) = i\left[1 - e^{-\Omega(s,\vec{b})}\right]$$

arXiv:1505.01415

[F. Nemes, T. Csörgő, M. Csanád, Int. J. Mod. Phys. A Vol. 30 (2015) 1550076]

- **the opacity function:**

$$\Omega(s,\vec{b}) = Re\Omega(s,\vec{b}) + i\, Im\Omega(s,\vec{b})$$

$Im\Omega \neq 0$ as the real part of the amplitude is not negligibly small

$$Re\Omega(s,\vec{b}) = -\frac{1}{2} ln[1 - \tilde{\sigma}_{in}(s,\vec{b})]$$

$$Im\Omega(s,\vec{b}) = -\alpha\, \tilde{\sigma}_{in}(s,\vec{b})$$

NEW FREE PARAMETER,
has different values for pp and $\bar{p}p$

- **elastic scattering amplitude in momentum space:**

$$T(s,t) = 2\pi \int_0^\infty t_{el}(s,|\vec{b}|)\, J_0(|\vec{\Delta}||\vec{b}|)|\vec{b}|d|\vec{b}|$$

$$|\vec{\Delta}| \equiv \sqrt{-t} \quad as\ \sqrt{s} \to \infty$$

(t is the squared momentum transfer)

ReBB model analysis of pp and $p\bar{p}$ data

→ fits for pp dσ/dt data at 2.76 TeV and 7 TeV and for $p\bar{p}$ dσ/dt data at 0.546 TeV and 1.96 TeV

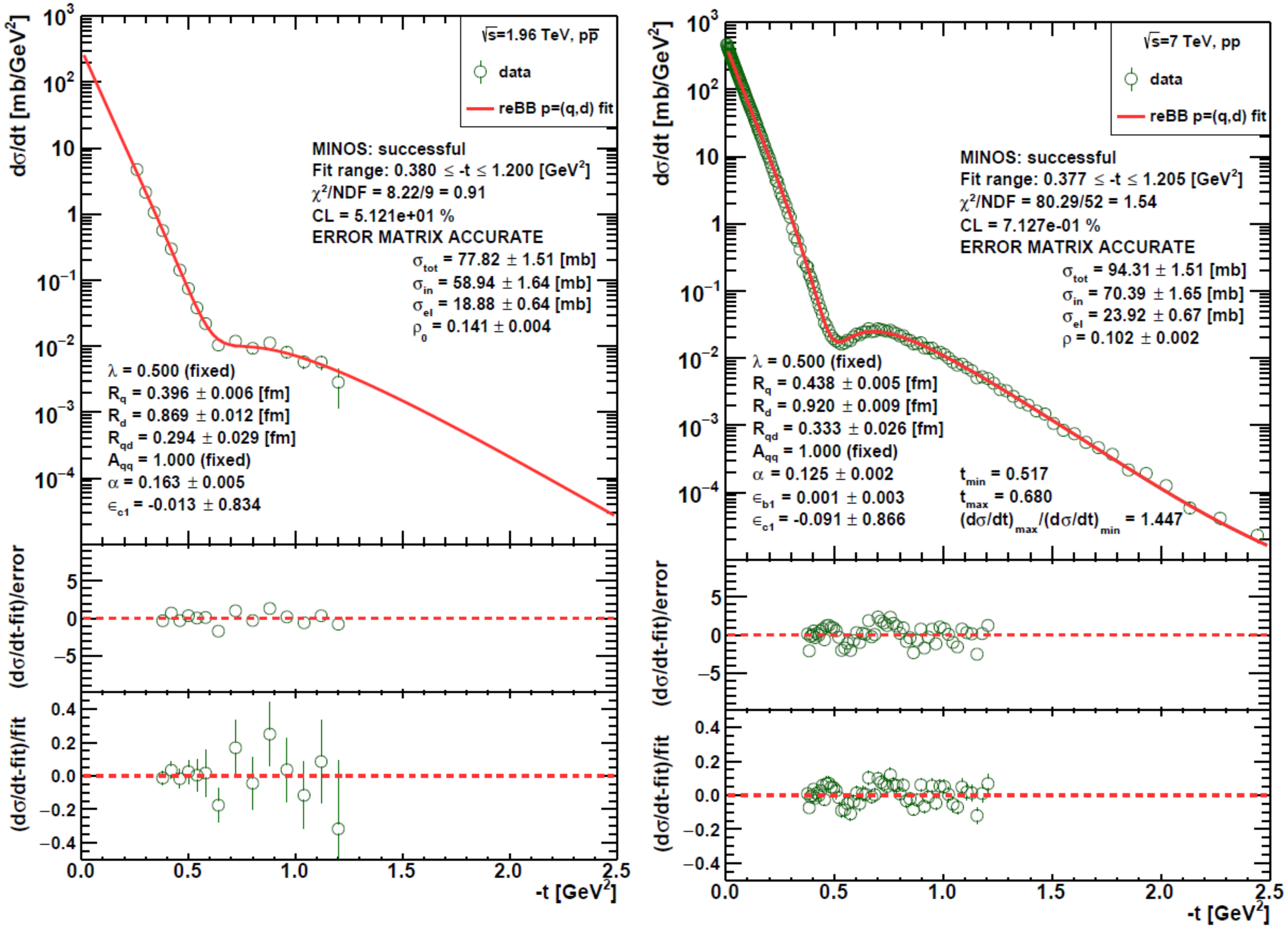
→ use of the χ^2 definition developed by PHENIX

→ determination of the energy dependences of the model parameters

→ satisfactory description in the kinematical range: $0.546 \leq \sqrt{s} \leq 8$ TeV & $0.37 \leq -t \leq 1.2$ GeV^2

I. Szanyi, T. Csörgő, Eur. Phys. J. C 82, 827 (2022)

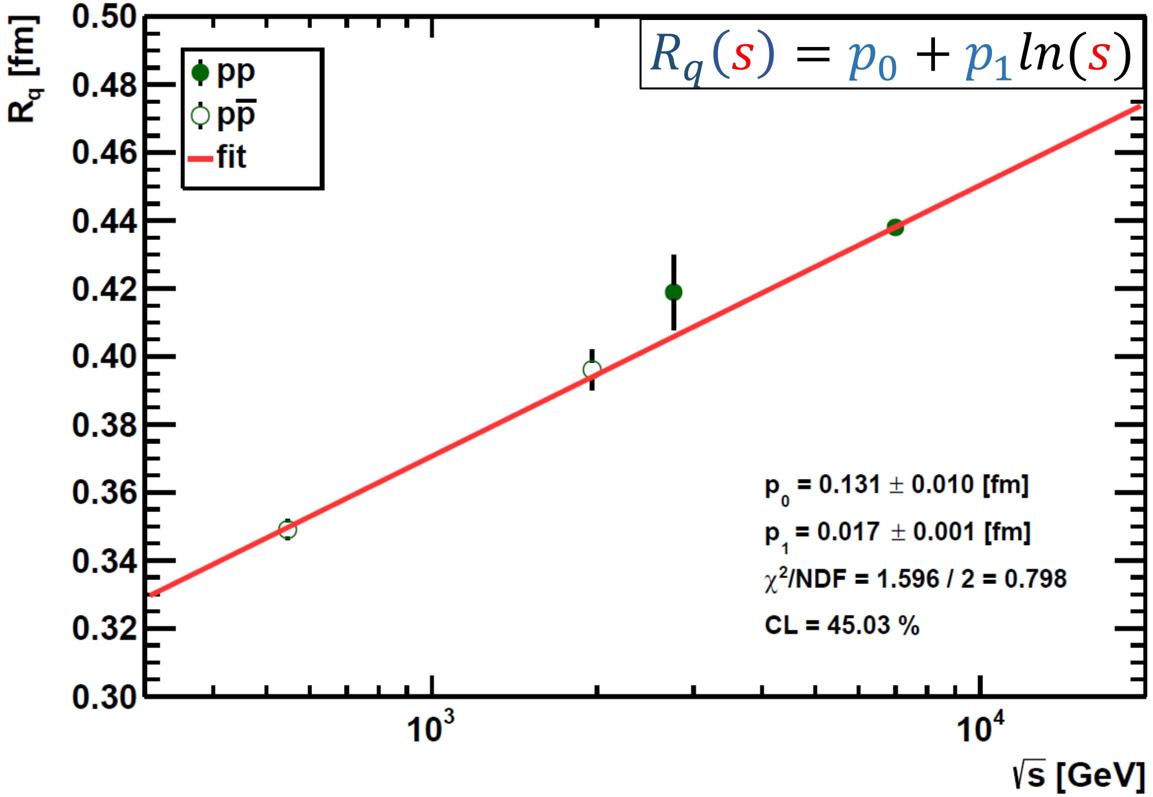
T. Csörgő, I. Szanyi, *Eur. Phys. J. C* 81, 611 (2021)

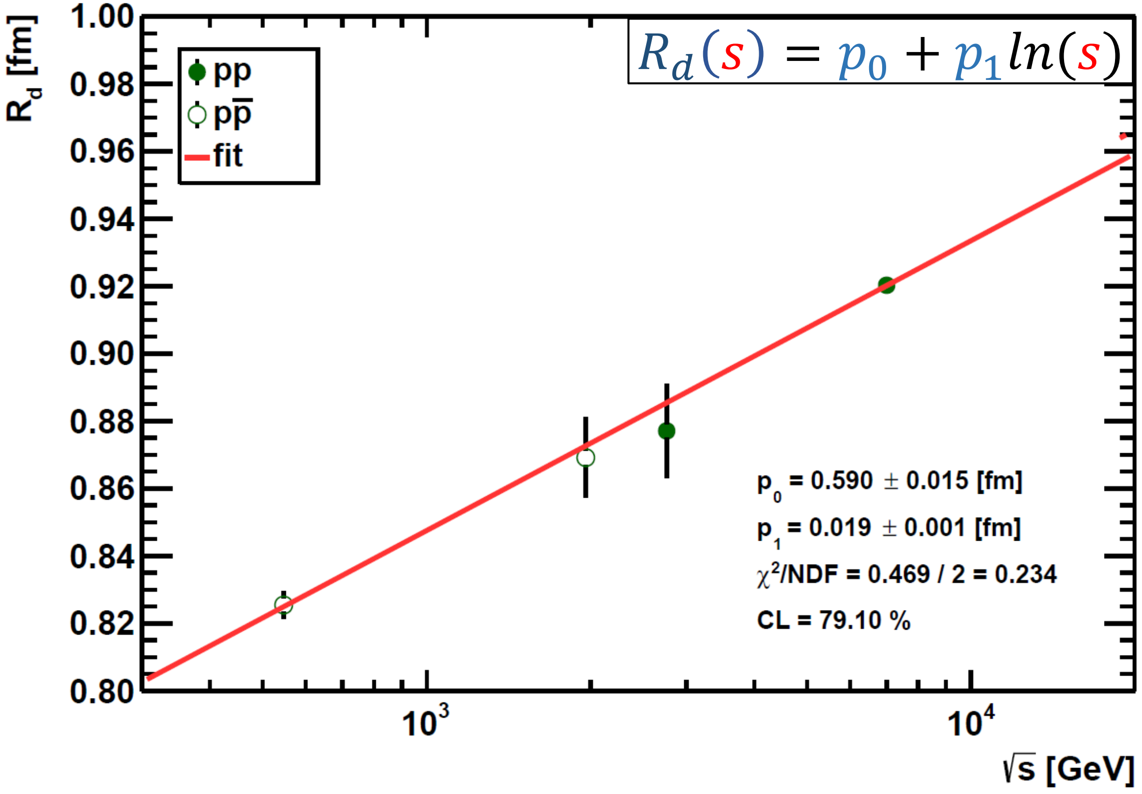


Examples of ReBB model fits for pp and $p\bar{p}$ differential cross section data.

Energy dependences of the ReBB model parameters

T. Csörgő, I. Szanyi, *Eur. Phys. J. C* 81, 611 (2021)



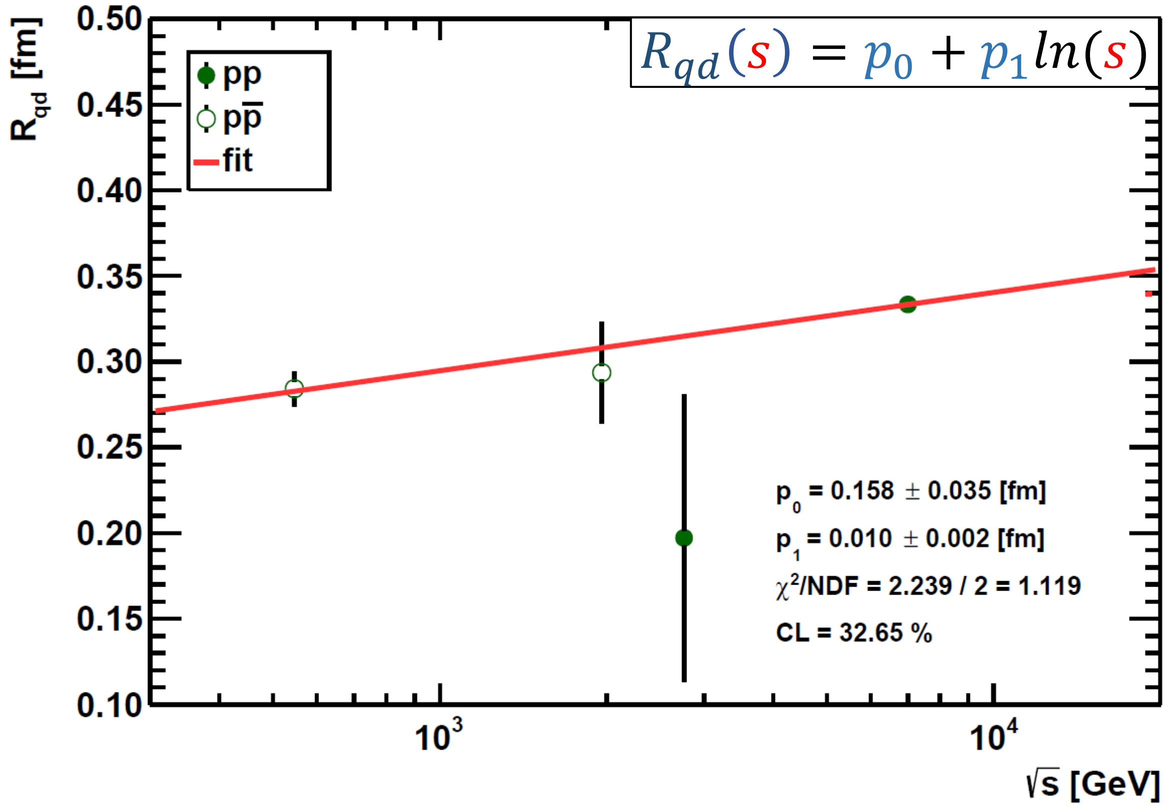


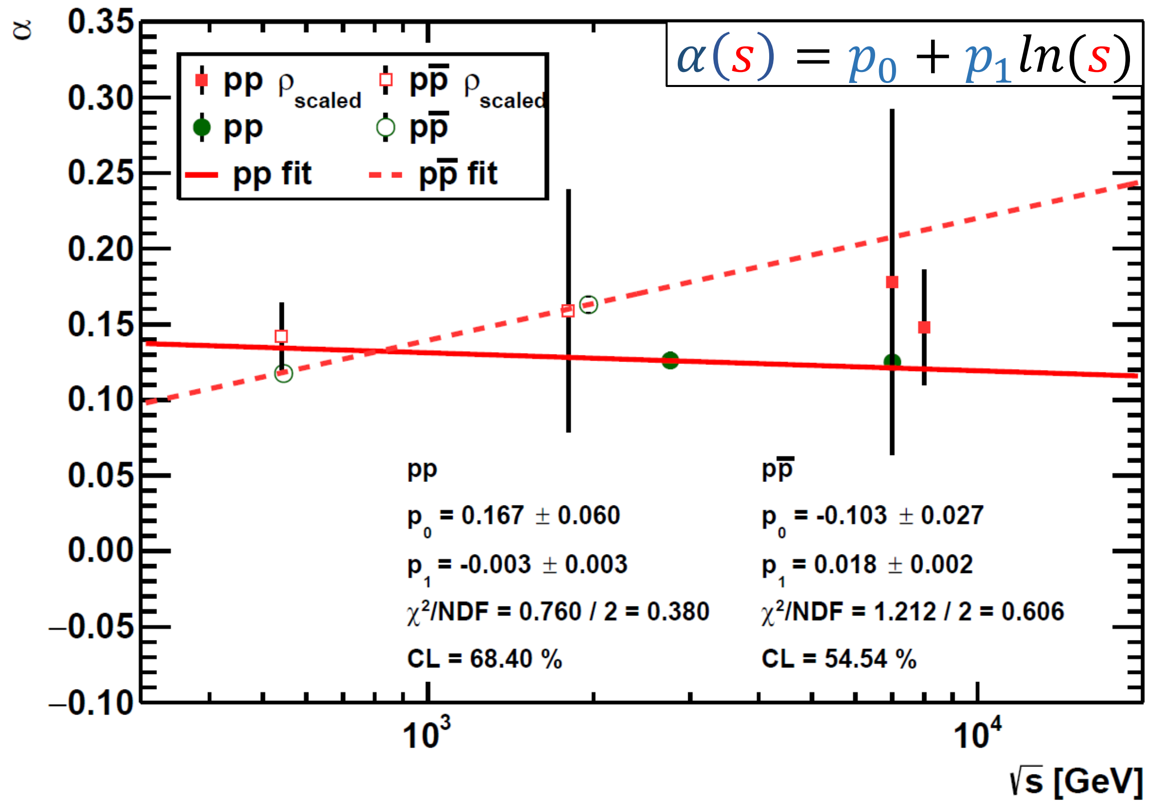
The energy dependences of the scale parameters, $R_q(s)$, $R_d(s)$, and $R_{qd}(s)$ are linear logarithmic and the same for pp and p$\bar{p}$ processes!

The energy dependence of the α parameter, $\alpha(s)$ is linear logarithmic too, but not the same for pp and p$\bar{p}$ processes!

Energy dependences of the ReBB model parameters

T. Csörgő, I. Szanyi, *Eur. Phys. J. C* 81, 611 (2021)





The energy dependences of the scale parameters, $R_q(s)$, $R_d(s)$, and $R_{qd}(s)$ are linear logarithmic and the same for pp and $p\bar{p}$ processes!

The energy dependence of the α parameter, $\alpha(s)$ is linear logarithmic too, but not the same for pp and $p\bar{p}$ processes!

Pomeron & odderon from pp & p$\bar{\text{p}}$ elastic scattering amplitudes

- **according to the Regge formalism the strong scattering amplitude for pp and $p\bar{p}$ scattering is written in terms of $C=+1$ and $C=-1$ exchange components**

$$\boxed{T^{pp}(s,t)=T^{+}(s,t)-T^{-}(s,t)} \qquad \boxed{T^{p\bar{p}}(s,t)=T^{+}(s,t)+T^{-}(s,t)}$$

- **for $\sqrt{s}\gtrsim 1\,\mathrm{TeV}$ the mesonic reggeon exchanges are negligible and essentially only the gluonic Pomeron and Odderon exchanges are present implying that**

$$\boxed{T^{+}(s,t)\equiv T^{P}(s,t)} \qquad \boxed{T^{-}(s,t)\equiv T^{O}(s,t)}$$

$$\Rightarrow$$

$$\boxed{T^{P}(s,t)=\frac{1}{2}\left(T^{pp}(s,t)+T^{p\bar{p}}(s,t)\right)}$$

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

- **In the ReBB model the pp and $p\bar{p}$ scattering amplitudes are defined and fitted to the data; the odderon and pomeron amplitudes are expressed in terms of those**

Pomeron & odderon from the ReBB model

- **In the ReBB model the pp and $p\bar{p}$ scattering amplitudes depend on energy through four energy dependent parameters:**

$$\boxed{T_{el}^{pp}(s,t) = F(R_q^{pp}(s), R_d^{pp}(s), R_{qd}^{pp}(s), \alpha^{pp}(s); t)}$$

$$\boxed{T_{el}^{p\bar{p}}(s,t) = F(R_q^{p\bar{p}}(s), R_d^{p\bar{p}}(s), R_{qd}^{p\bar{p}}(s), \alpha^{p\bar{p}}(s); t)}$$

- **It is found that:**

$$\boxed{\begin{aligned} R_q(s) \equiv R_q^{pp}(s) &= R_q^{p\bar{p}}(s) \\ R_d(s) \equiv R_d^{pp}(s) &= R_d^{p\bar{p}}(s) \\ R_{qd}(s) \equiv R_{qd}^{pp}(s) &= R_{qd}^{p\bar{p}}(s) \\ \alpha^{pp}(s) &\neq \alpha^{p\bar{p}}(s) \end{aligned}}$$

thus

$$\boxed{T_{el}^{\mathbb{P}}(s,t) = G(R_q^{pp}(s), R_d^{pp}(s), R_{qd}^{pp}(s), \alpha^{pp}(s), \alpha^{p\bar{p}}(s); t)}$$

$$\boxed{T_{el}^{\mathbb{O}}(s,t) = H(R_q^{pp}(s), R_d^{pp}(s), R_{qd}^{pp}(s), \alpha^{pp}(s), \alpha^{p\bar{p}}(s); t)}$$

Pomeron & odderon from the ReBB model in b space

- **the ReBB model b-dependent pp and $p\bar{p}$ scattering amplitudes are:**

$$t_{el}^{pp}(s,b) = i\left(1 - e^{i\,\alpha^{pp}(s)\,\tilde{\sigma}_{in}(s,b)}\sqrt{1-\tilde{\sigma}_{in}(s,b)}\right)$$

$$t_{el}^{p\bar{p}}(s,b) = i\left(1 - e^{i\,\alpha^{p\bar{p}}(s)\,\tilde{\sigma}_{in}(s,b)}\sqrt{1-\tilde{\sigma}_{in}(s,b)}\right)$$

- **the C-even part is:**

$$\mathcal{R}e\, t_{el}^{\mathbb{P}}(s,b) = \sqrt{1-\tilde{\sigma}_{in}}\,\sin\left(\frac{\alpha^{pp}+\alpha^{p\bar{p}}}{2}\tilde{\sigma}_{in}\right)\cos\left(\frac{\alpha^{p\bar{p}}-\alpha^{pp}}{2}\tilde{\sigma}_{in}\right)$$

$$\mathcal{I}m\, t_{el}^{\mathbb{P}}(s,b) = 1-\sqrt{1-\tilde{\sigma}_{in}}\cos\left(\frac{\alpha^{pp}+\alpha^{p\bar{p}}}{2}\tilde{\sigma}_{in}\right)\cos\left(\frac{\alpha^{p\bar{p}}-\alpha^{pp}}{2}\tilde{\sigma}_{in}\right)$$

- **the C-odd part is:**

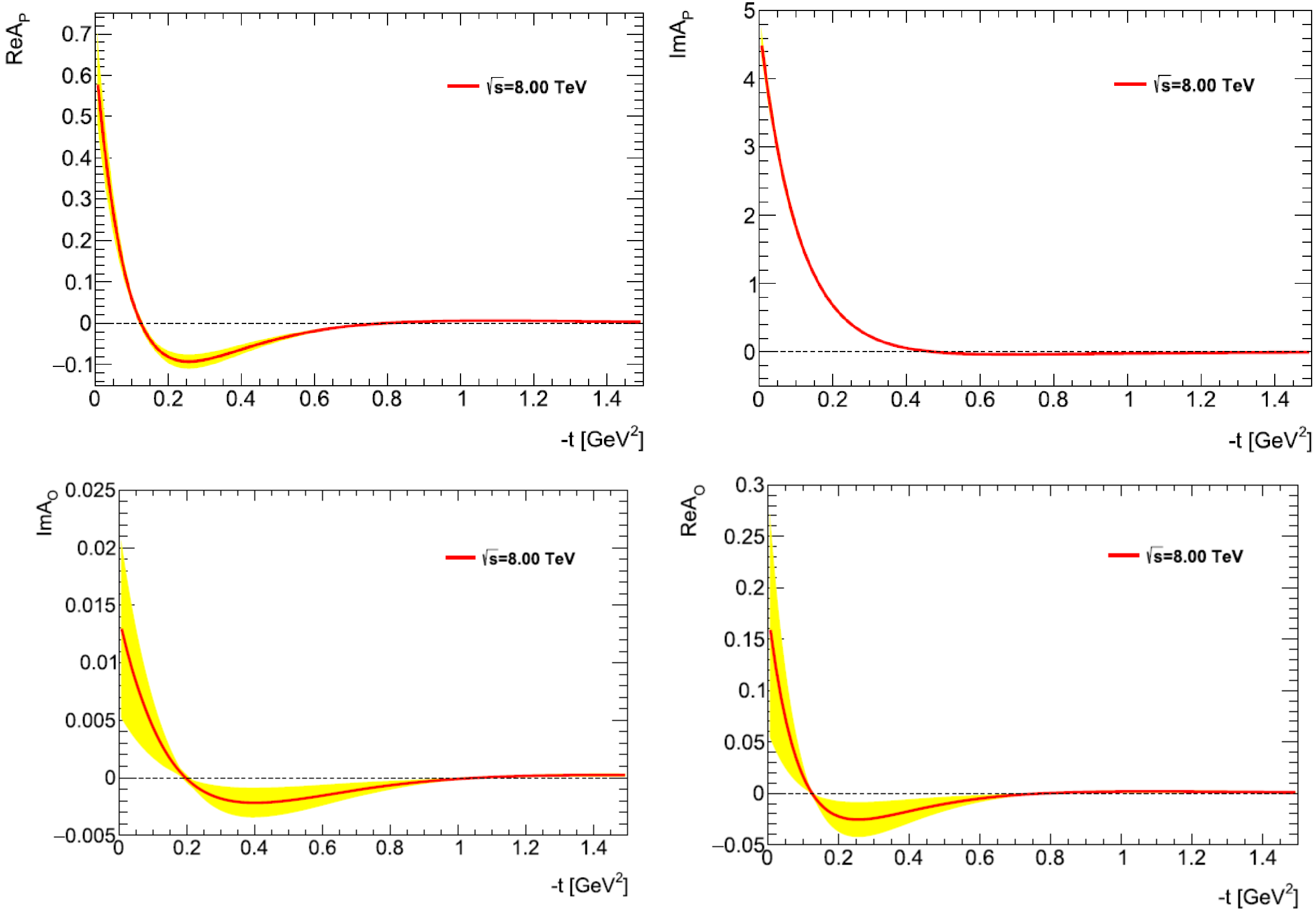
$$\mathcal{R}e\, t_{el}^{\mathbb{O}}(s,b) = \sqrt{1-\tilde{\sigma}_{in}}\,\sin\left(\frac{\alpha^{p\bar{p}}-\alpha^{pp}}{2}\tilde{\sigma}_{in}\right)\cos\left(\frac{\alpha^{p\bar{p}}+\alpha^{pp}}{2}\tilde{\sigma}_{in}\right)$$

$$\mathcal{I}m\, t_{el}^{\mathbb{O}}(s,b) = \sqrt{1-\tilde{\sigma}_{in}}\,\sin\left(\frac{\alpha^{p\bar{p}}-\alpha^{pp}}{2}\tilde{\sigma}_{in}\right)\sin\left(\frac{\alpha^{pp}+\alpha^{p\bar{p}}}{2}\tilde{\sigma}_{in}\right)$$

- **the C-odd part vanishes if, and only if** $\alpha^{pp}(s) \equiv \alpha^{p\bar{p}}(s)$

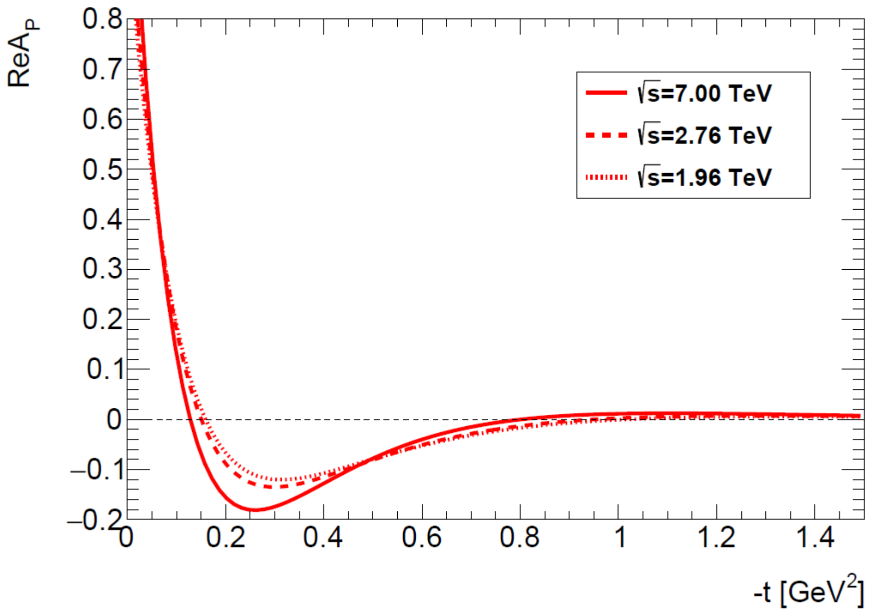
ReBB pomeron & odderon amplitudes @ 8 TeV

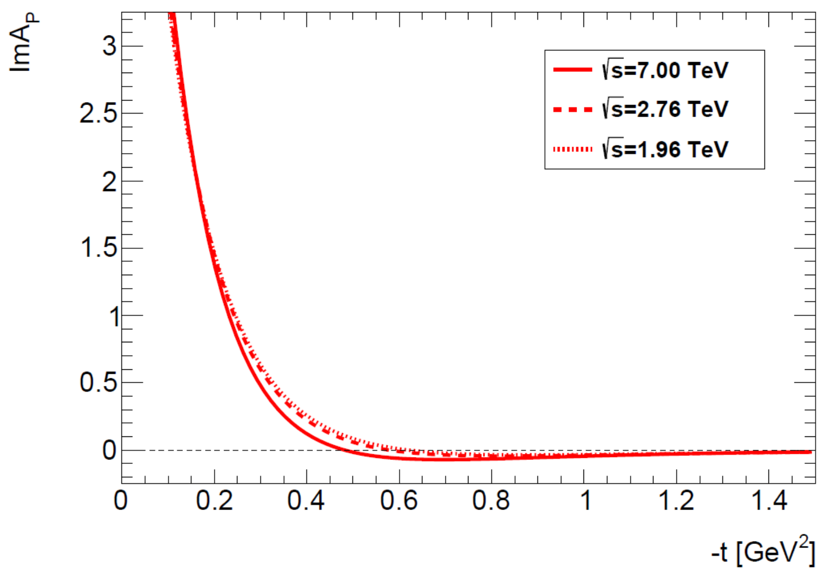
- both the real and the imaginary parts are dominated by the Pomeron at low-t
- the real part of the Odderon is about an order of magnitude larger, than its imaginary part; the opposite is true for the Pomeron
- however, the ReBB model is not calibrated at low-t (Levy generalization & Coulomb corrections are needed)

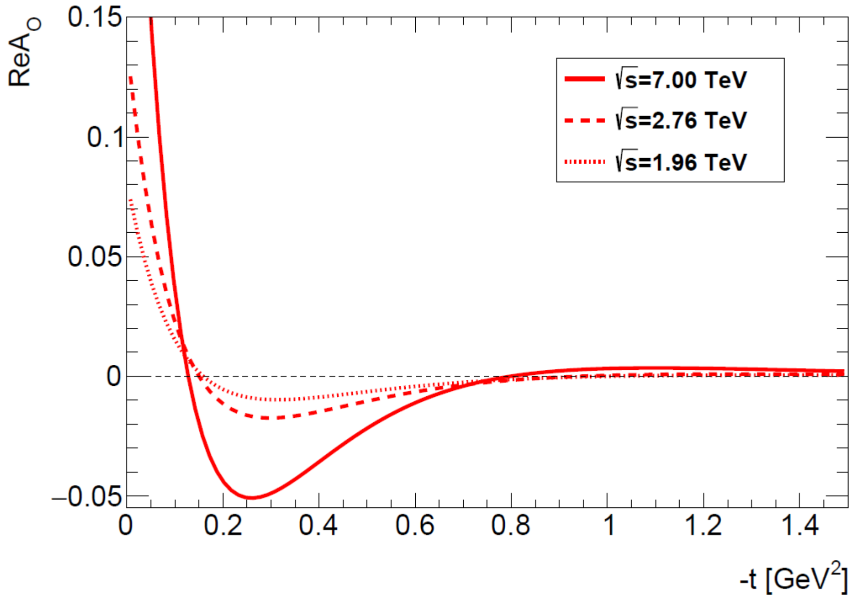


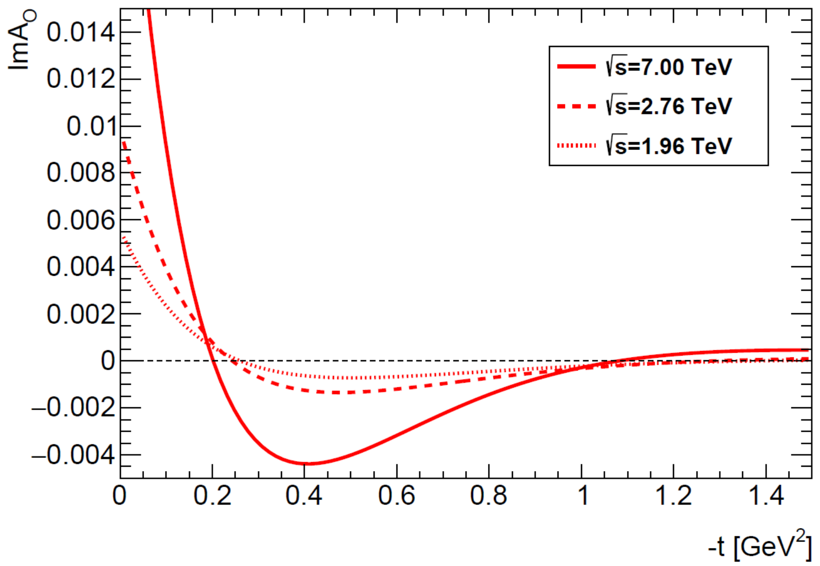
ReBB pomeron & odderon amplitudes @ TeV energies

- the real and imaginary parts of both pomeron and odderon amplitudes have fixed points
- The real part of the pomeron and the real and imaginary parts of the odderon have two zeros
- however, the ReBB model is not calibrated at low-t (Levy generalization & Coulomb corrections are needed)



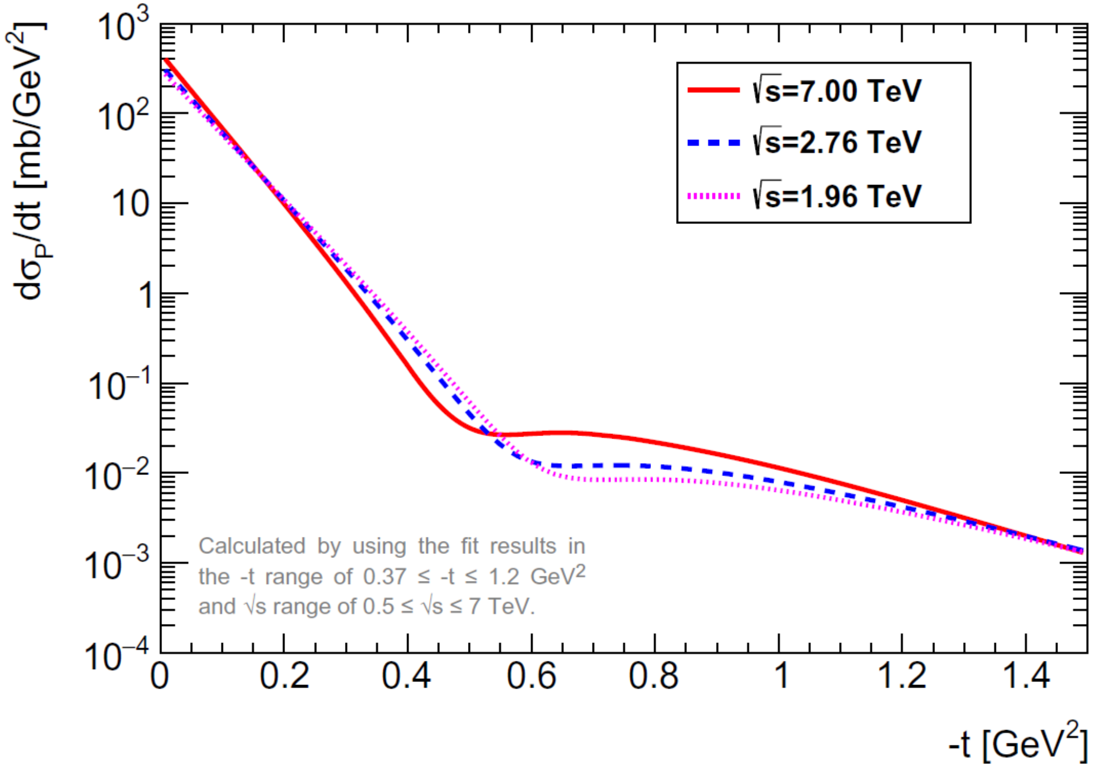


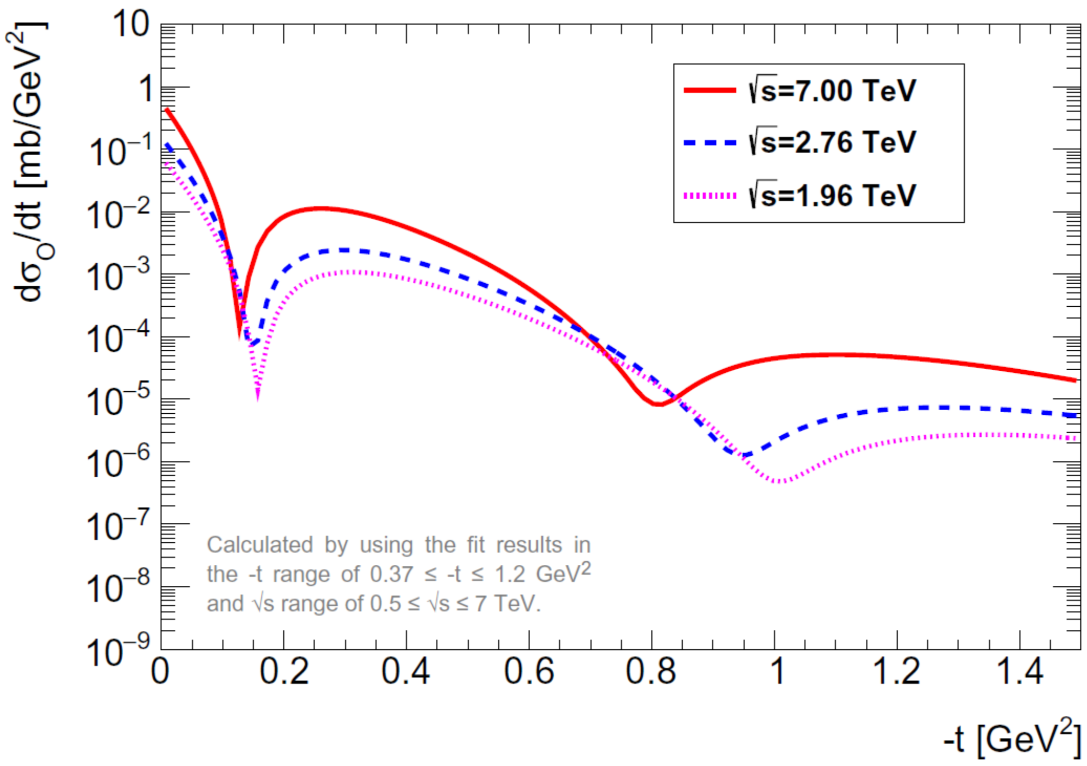




ReBB pomeron & odderon dσ/dt @ TeV energies

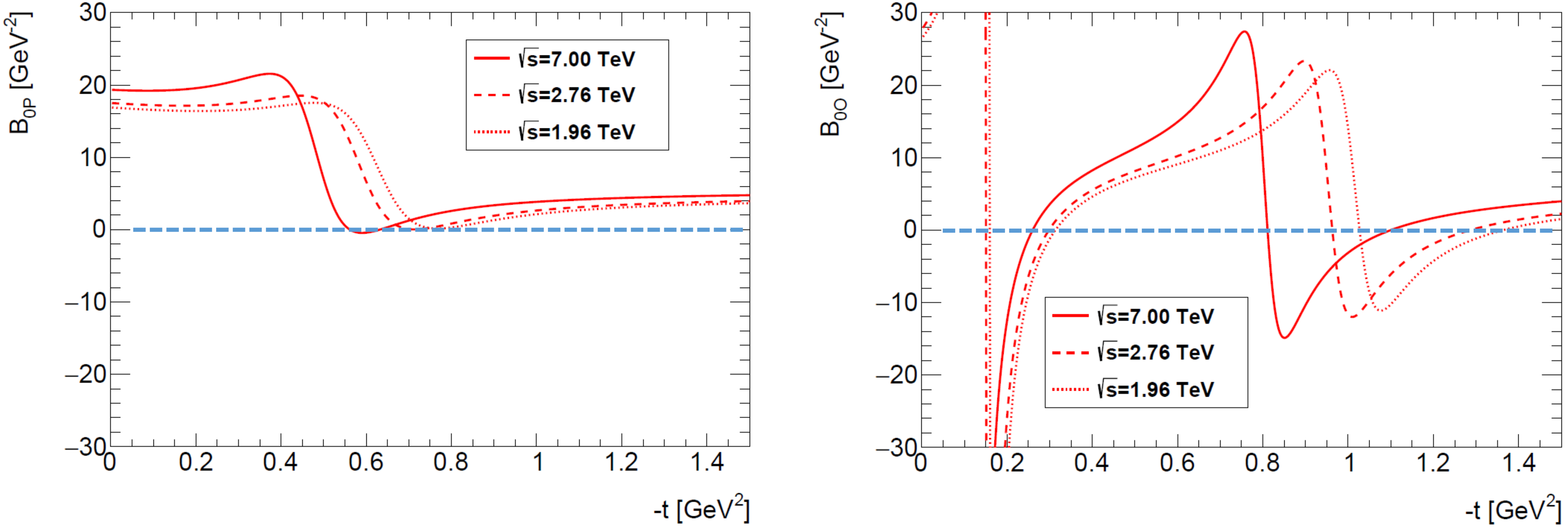
- the pomeron exchange does not lead to a pronounced diffractive minimum structure
- the odderon exchange may lead even to two pronounced diffractive minima
- however, the interference between the pomeron and the odderon exchange leads to a single diffractive minimum in elastic pp collisions at the TeV scale





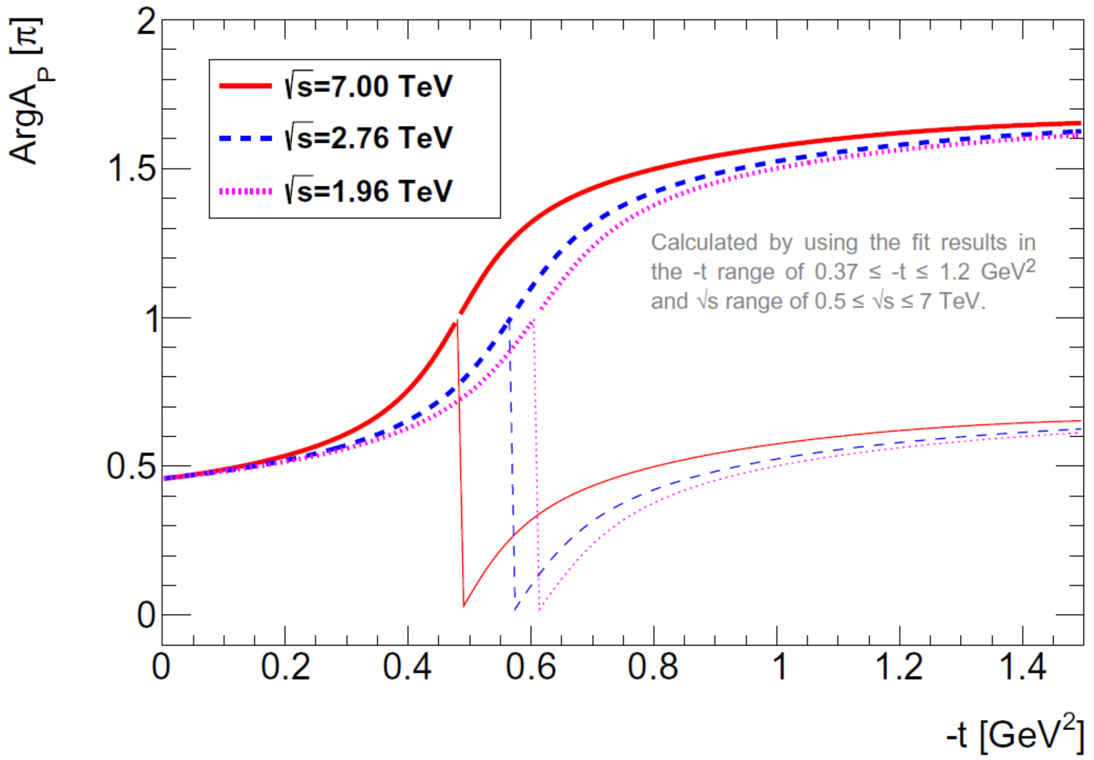
ReBB pomeron & odderon local slope @ TeV energies

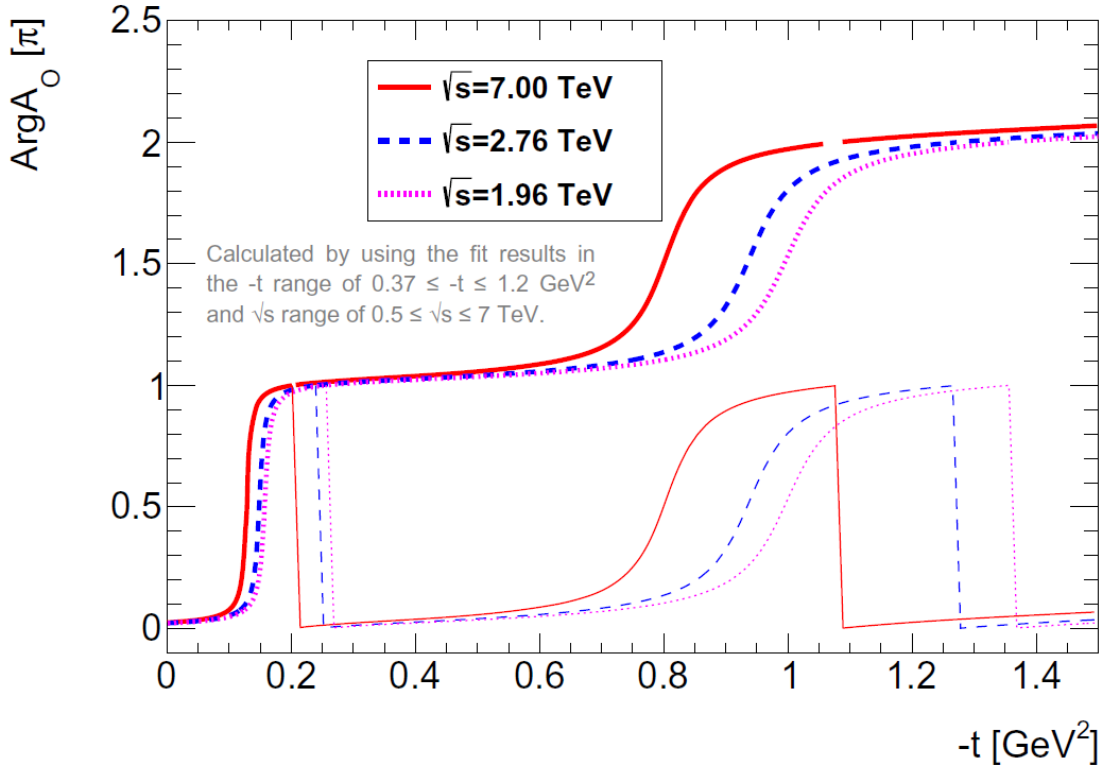
- Near the diffractive minimum of the pomeron and odderon components of the differential cross section the local slopes reach or even cross zero



ReBB pomeron & odderon phase @ TeV energies

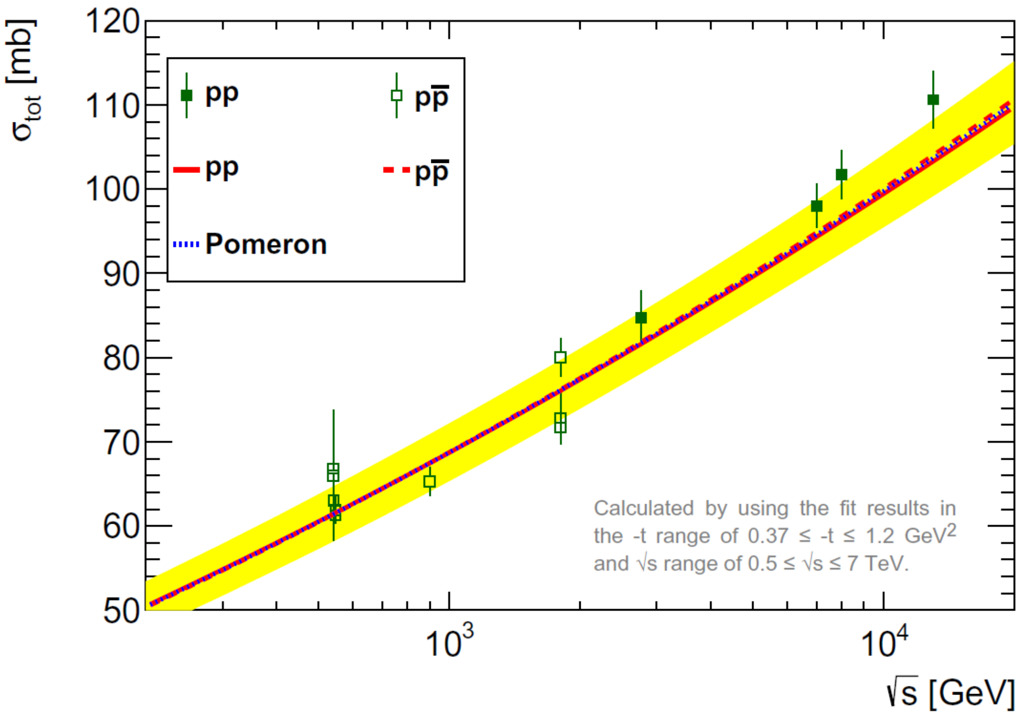
- at low-t, the Pomeron contribution is predominantly imaginary; near the diffractive minimum the real part is starting to be important
- at very low-t and near the diffractive minimum, the Odderon contribution is predominantly real

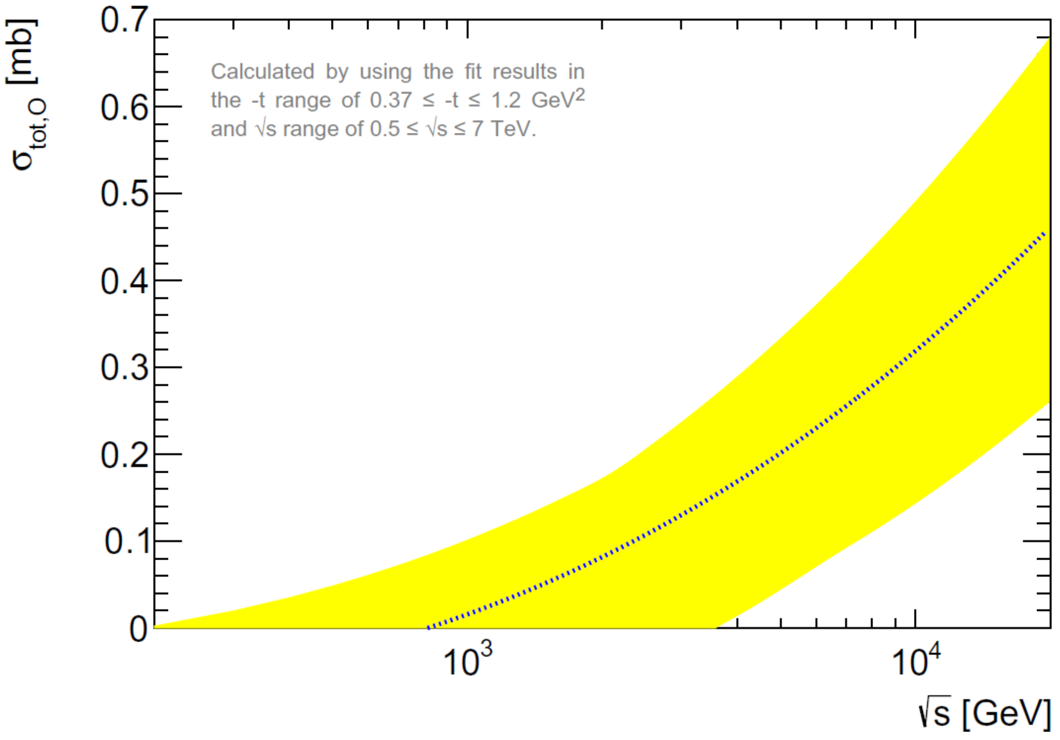




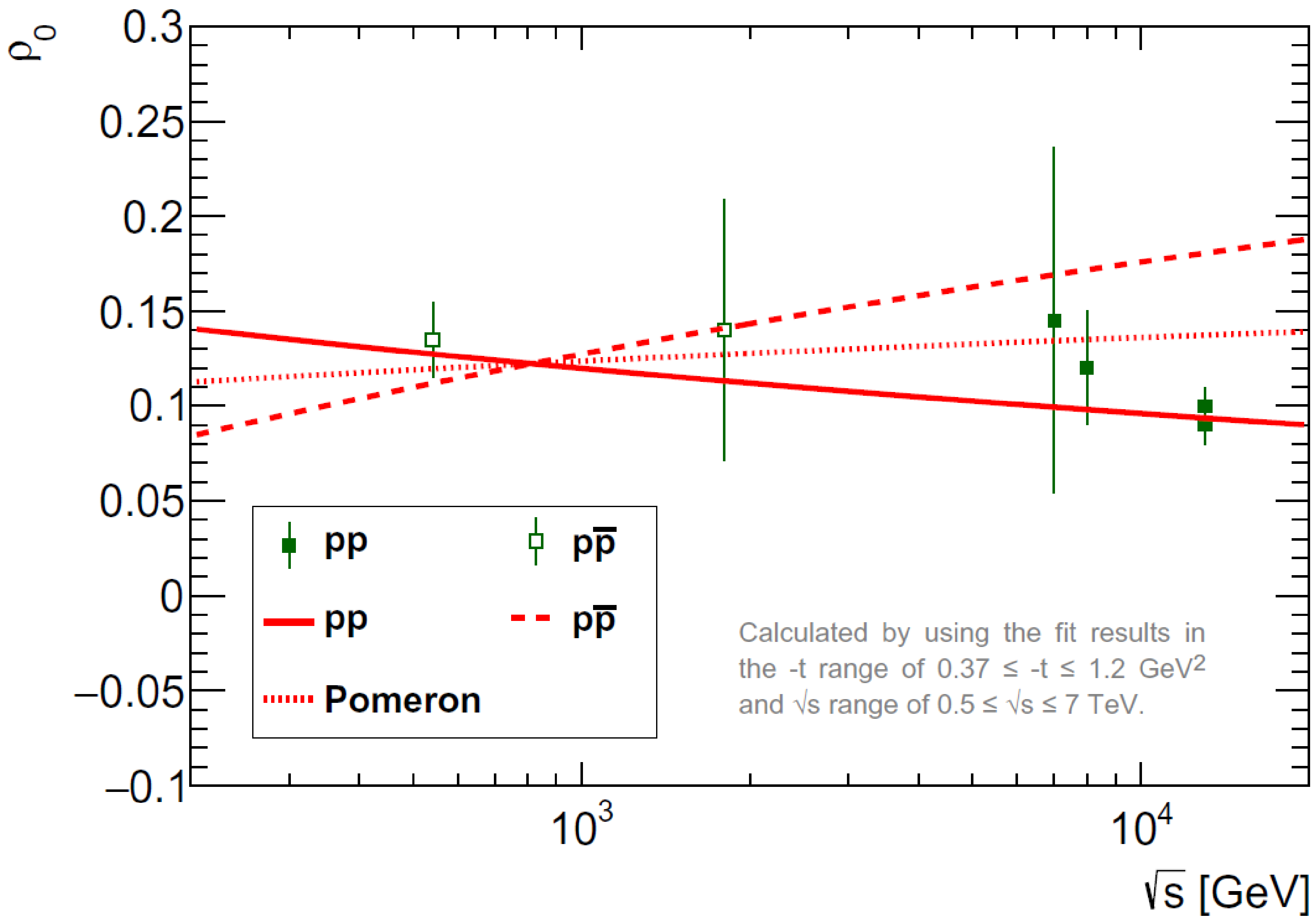
ReBB pomeron & odderon σ_{tot}

- within experimental uncertainties the effect of the odderon is negligible if one considers only σ_{tot} data
- the odderon starts to be present from about 1 TeV
- the pomeron is about two orders of magnitude grater than the odderon at LHC energies





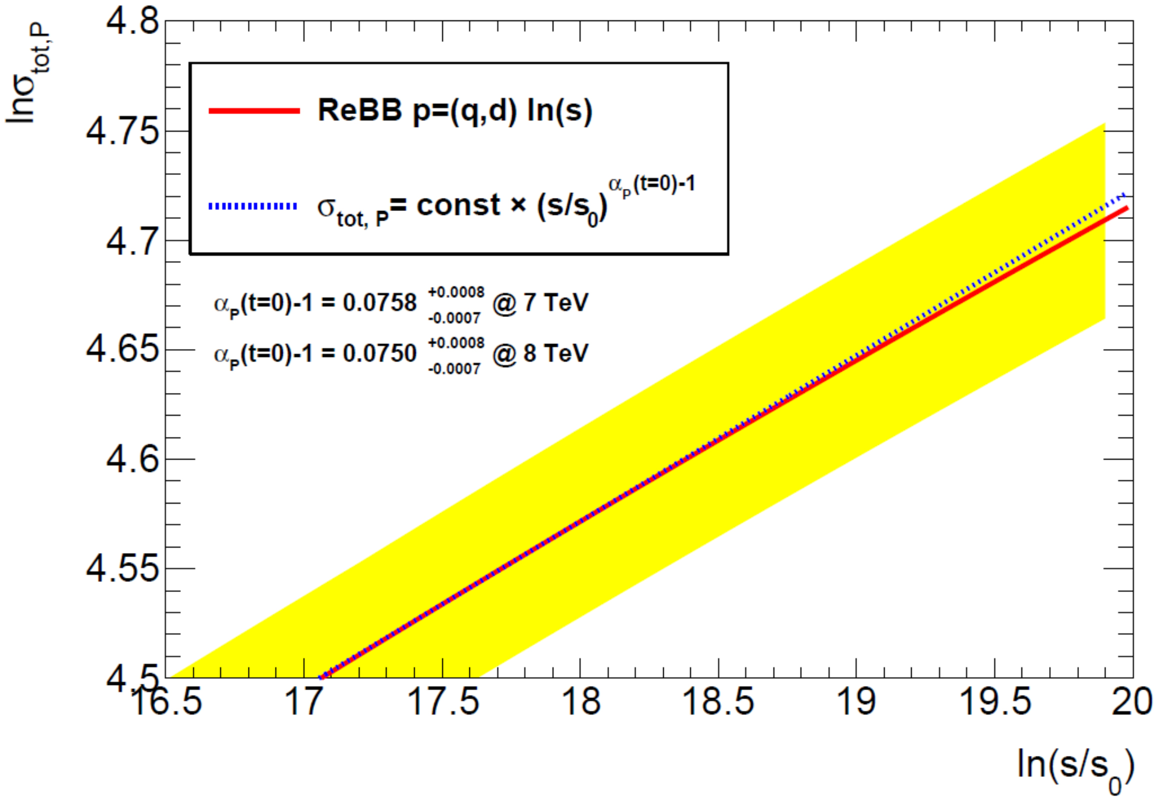
ReBB rho parameter with and without odderon

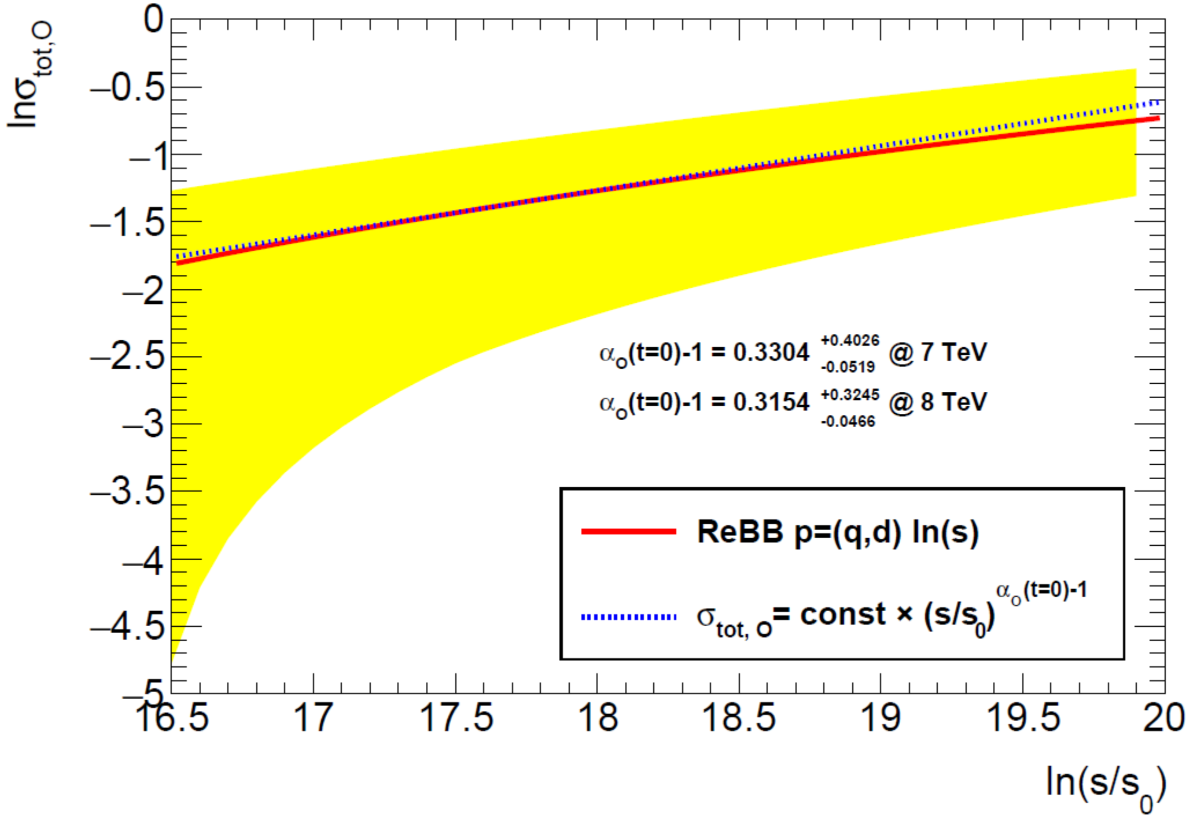


- **Lévy generalization and Coulomb corrections are need to get a decisive result**
- **A. Donnachiea, P. V. Landshoff, Phys. Lett. B 831 (2022): weak odderon signal from ρ at 13 TeV**

Pomeron & odderon intercepts

- the pomeron intercept is normal
- the odderon intercept is quite large





Summary & conclusions

- **the ReBB model represents all available pp and $\mathrm{p\bar{p}}$ $d\sigma/dt$ data in the kinematical ranges $0.546 \leq \sqrt{s} \leq 8$ TeV and $0.37 \leq -t \leq 1.2$ GeV^2 in a statistically acceptable manner**

- **from the pp and $\mathrm{p\bar{p}}$ ReBB model amplitudes the ReBB model Pomeron and Odderon amplitudes are calculated**

- **from the ReBB model Pomeron and Odderon amplitudes the corresponding components of the measurable quantities are calculated**

- **there is a need for Lévy generalization and Coulomb corrections in order to get statistically acceptable and hence decisive results**

Thank you for your attention!