

*Applications of the tensor pomeron model
to exclusive central diffractive meson production*

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1. *Exclusive central diffractive production of scalar and pseudoscalar mesons; tensorial vs. vectorial pomeron*

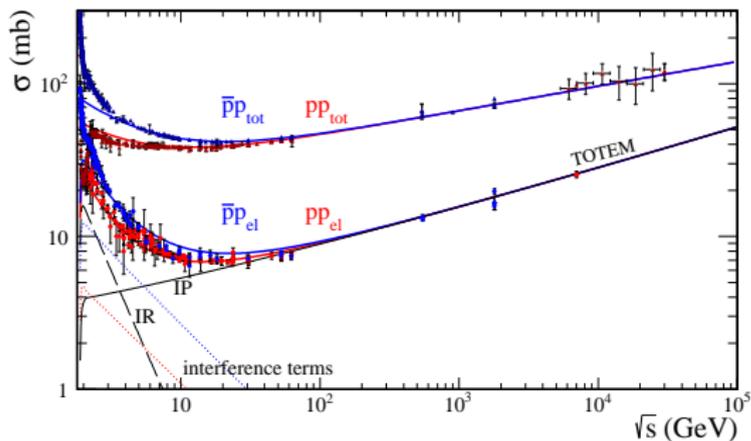
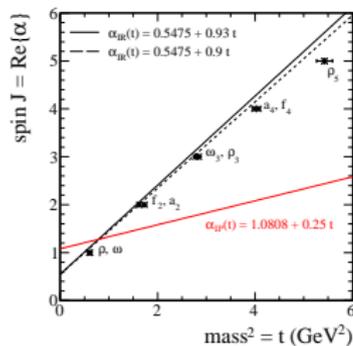
P. Lebiedowicz, O. Nachtmann and A. Szczurek, *Ann. Phys.* 344 (2014) 301

2. *The ρ^0 contribution to exclusive production of $\pi^+\pi^-$ pairs in proton-proton collisions*

P. Lebiedowicz, O. Nachtmann and A. Szczurek, paper in preparation

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How is the nature of soft pomeron?



The Chew-Frautschi plots (the exchanges particles spin J vs its squared mass m_J^2) shows that all possible exchanges form so called Regge trajectories

- In the Regge theory the t -channel Regge exchanges (IR) correspond to a sum of ordinary mesons with the same quantum numbers. $C = +1$ (f_2, a_2) trajectories and $C = -1$ (ω, ρ) trajectories are all degenerate with intercept $\alpha(0) \approx 0.5$ (they contribute terms $\sim 1/\sqrt{s}$). The contributions from the isospin $l = 1$ exchanges ρ_{IR} and a_{2IR} are very much less than that those from $l = 0$ exchanges f_{2IR} and ω_{IR} .
- To generate a non-falling total cross section ($\sqrt{s} \rightarrow \infty, \sqrt{|t|} \lesssim 1 \text{ GeV}$) a new trajectory (Pomeranchuk trajectory) with the leading pole called the pomeron (IP) was postulated. It has $\alpha(0)$ slightly above 1 and the quantum numbers of the vacuum, that is $l = 0$ and $C = +1$. There is belief that the pomeron rather is associated with the exchange of family of glueballs.
- It is possible that there exists also an odderon, a $C = -1$ partner of the pomeron.

Collins, *An introduction to Regge theory and high energy physics*, CUP, 1977,

Donnachie, Dosch, Nachtmann and Landshoff, *Pomeron physics and QCD*, CUP, 2002,

Close, Donnachie, Shaw, *Electromagnetic interactions and hadronic structure*, CUP, 2007

Vector pomeron vs Tensor pomeron

$$i\mathcal{M}_{\hat{\beta}_a \hat{\beta}_b \rightarrow \hat{\beta}_1 \hat{\beta}_2}^{PP \rightarrow PP} |_{IP_V} = \bar{u}(\rho_1, \hat{\beta}_1) i\Gamma_{\mu}^{(IP_V PP)}(\rho_1, \rho_a) u(\rho_a, \hat{\beta}_a) \times i\Delta^{(IP_V) \mu\nu}(s, t) \times \bar{u}(\rho_2, \hat{\beta}_2) i\Gamma_{\nu}^{(IP_V PP)}(\rho_2, \rho_b) u(\rho_b, \hat{\beta}_b)$$

$$i\mathcal{M}_{\hat{\beta}_a \hat{\beta}_b \rightarrow \hat{\beta}_1 \hat{\beta}_2}^{PP \rightarrow PP} |_{IP_T} = \bar{u}(\rho_1, \hat{\beta}_1) i\Gamma_{\mu_1 \nu_1}^{(IP_T PP)}(\rho_1, \rho_a) u(\rho_a, \hat{\beta}_a) \times i\Delta^{(IP_T) \mu_1 \nu_1 \mu_2 \nu_2}(s, t) \times \bar{u}(\rho_2, \hat{\beta}_2) i\Gamma_{\mu_2 \nu_2}^{(IP_T PP)}(\rho_2, \rho_b) u(\rho_b, \hat{\beta}_b)$$

$$i\Gamma_{\mu}^{(IP_V PP)}(\rho', \rho) = -i 3\beta_{IPNN} F_1((\rho' - \rho)^2) M_0 \gamma_{\mu}$$

$$i\Delta_{\mu\nu}^{(IP_V)}(s, t) = \frac{1}{M_0^2} g_{\mu\nu} (-is a'_{IP})^{\alpha_{IP}(t)-1}$$

$$i\Gamma_{\mu\nu}^{(IP_T PP)}(\rho', \rho) = -i 3\beta_{IPNN} F_1((\rho' - \rho)^2)$$

$$\times \left\{ \frac{1}{2} [\gamma_{\mu}(\rho' + \rho)_{\nu} + \gamma_{\nu}(\rho' + \rho)_{\mu}] - \frac{1}{4} g_{\mu\nu} (\rho' + \rho) \right\}$$

$$i\Delta_{\mu\nu, \kappa\hat{\beta}}^{(IP_T)}(s, t) = \frac{1}{4s} \left(g_{\mu\kappa} g_{\nu\hat{\beta}} + g_{\mu\hat{\beta}} g_{\nu\kappa} - \frac{1}{2} g_{\mu\nu} g_{\kappa\hat{\beta}} \right) (-is a'_{IP})^{\alpha_{IP}(t)-1}$$

$$\xrightarrow{s \gg 4m_p^2} i 2s [3\beta_{IPNN} F_1(t)]^2 (-is a'_{IP})^{\alpha_{IP}(t)-1} \delta_{\hat{\beta}_1 \hat{\beta}_a} \delta_{\hat{\beta}_2 \hat{\beta}_b} \leftarrow \text{Donnachie - Landshoff pomeron ansatz}$$

$$\beta_{IPNN} = 1.87 \text{ GeV}^{-1}, \quad M_0 = 1 \text{ GeV}, \quad \alpha_{IP}(t) = \alpha_{IP}(0) + a'_{IP} t, \quad \alpha_{IP}(0) = 1.0808, \quad a'_{IP} = 0.25 \text{ GeV}^{-2}, \quad F_1(t) = \frac{4m_p^2 - 2.79 t}{(4m_p^2 - t)(1 - t/m_D^2)^2}$$

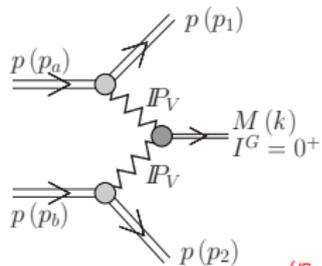
Effective $IP_T pp$ vertex and IP_T propagator compatible with QFT rules !

see C. Ewerz, M. Maniatis and O. Nachtmann, *Ann. Phys.* 342 (2014) 31,

O. Nachtmann, a talk *High-energy soft reactions: A model with tensor pomeron and vector odderon*,

WE-Heraeus-Summerschool, Heidelberg, 2013

Exclusive production of resonances via $IP_V IP_V$ fusion



$$\langle \rho(p_1, \hat{n}_1), \rho(p_2, \hat{n}_2), M(k) | \mathcal{T} | \rho(p_a, \hat{n}_a), \rho(p_b, \hat{n}_b) \rangle |_{IP_V} \equiv$$

$$\mathcal{M}_{\hat{n}_a \hat{n}_b \rightarrow \hat{n}_1 \hat{n}_2 M}^{2 \rightarrow 3} |_{IP_V} = (-i) \bar{u}(p_1, \hat{n}_1) i \Gamma_{\mu_1}^{(IP_V \rho \rho)}(p_1, p_a) u(p_a, \hat{n}_a)$$

$$\times i \Delta^{(IP_V)} \mu_1 \nu_1 (s_{13}, t_1) i \Gamma_{\nu_1 \nu_2}^{(IP_V IP_V \rightarrow M)}(q_1, q_2) i \Delta^{(IP_V)} \mu_2 \nu_2 (s_{23}, t_2)$$

$$\times \bar{u}(p_2, \hat{n}_2) i \Gamma_{\mu_2}^{(IP_V \rho \rho)}(p_2, p_b) u(p_b, \hat{n}_b)$$

$$i \Gamma_{\mu\nu}^{(IP_V IP_V \rightarrow M)}(q_1, q_2) = \left(i \Gamma_{\mu\nu}^{\prime (IP_V IP_V \rightarrow M)} |_{bare} + i \Gamma_{\mu\nu}^{\prime\prime (IP_V IP_V \rightarrow M)}(q_1, q_2) |_{bare} \right) F_{IPVM}(q_1^2, q_2^2)$$

$$J^{PC} = 0^{++} : \quad i \Gamma_{\mu\nu}^{\prime (IP_V IP_V \rightarrow M)} |_{bare} = i g'_{IP_V IP_V M} M_0 2g_{\mu\nu} \quad \leftarrow (I, S) = (0, 0) \text{ term}$$

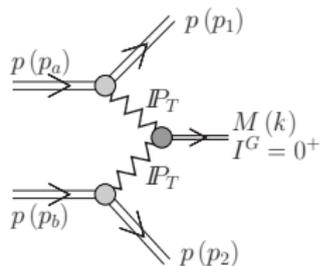
$$i \Gamma_{\mu\nu}^{\prime\prime (IP_V IP_V \rightarrow M)}(q_1, q_2) |_{bare} = \frac{2i g''_{IP_V IP_V M}}{M_0} [q_{2\mu} q_{1\nu} - (q_1 q_2) g_{\mu\nu}] \quad \leftarrow (I, S) = (2, 2) \text{ term}$$

$$J^{PC} = 0^{-+} : \quad i \Gamma_{\mu\nu}^{\prime (IP_V IP_V \rightarrow \tilde{M})}(q_1, q_2) |_{bare} = i \frac{g'_{IP_V IP_V \tilde{M}}}{2M_0} \varepsilon_{\mu\nu\rho\sigma} q_1^\rho q_2^\sigma \quad \leftarrow (I, S) = (1, 1) \text{ term}$$

The dimensionless coupling constants for scalar mesons $g'_{IP_V IP_V M}$, $g''_{IP_V IP_V M}$ and for pseudoscalar mesons $g'_{IP_V IP_V \tilde{M}}$ can be fixed from the meson production data.

$$F_{IPVM}^M(t_1, t_2) = F_M(t_1) F_M(t_2), \quad F_M(t) = F_\pi(t) = \frac{1}{1 - t/\Lambda_0^2}, \quad \Lambda_0^2 = 0.5 \text{ GeV}^2$$

Exclusive production of resonances via $IP_T IP_T$ fusion



$$\langle p(\rho_1, \bar{\rho}_1), p(\rho_2, \bar{\rho}_2), M(k) | \mathcal{T} | p(\rho_a, \bar{\rho}_a), p(\rho_b, \bar{\rho}_b) \rangle |_{IP_T} \equiv$$

$$\mathcal{M}_{\bar{\rho}_a \bar{\rho}_b \rightarrow \bar{\rho}_1 \bar{\rho}_2 M}^{2 \rightarrow 3} |_{IP_T} = (-i) \bar{u}(\rho_1, \bar{\rho}_1) i \Gamma_{\mu_1 \nu_1}^{(IP_T PP)}(\rho_1, \rho_a) u(\rho_a, \bar{\rho}_a)$$

$$\times i \Delta^{(IP_T)} \mu_1 \nu_1 \cdot \kappa_1 \bar{\rho}_1 (s_{13}, t_1) i \Gamma_{\kappa_1 \bar{\rho}_1 \cdot \kappa_2 \bar{\rho}_2}^{(IP_T IP_T \rightarrow M)}(q_1, q_2) i \Delta^{(IP_T)} \kappa_2 \bar{\rho}_2 \cdot \mu_2 \nu_2 (s_{23}, t_2)$$

$$\times \bar{u}(\rho_2, \bar{\rho}_2) i \Gamma_{\mu_2 \nu_2}^{(IP_T PP)}(\rho_2, \rho_b) u(\rho_b, \bar{\rho}_b)$$

$$i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow M)}(q_1, q_2) = \left(i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow M)} |_{bare} + i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow M)}(q_1, q_2) |_{bare} \right) F_{IP_T PM}(q_1^2, q_2^2)$$

$J^{PC} = 0^{++}$:

$$i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow M)} |_{bare} = i g'_{IP_T IP_T M} M_0 \left(g_{\mu\kappa} g_{\nu\bar{\rho}} + g_{\mu\bar{\rho}} g_{\nu\kappa} - \frac{1}{2} g_{\mu\nu} g_{\kappa\bar{\rho}} \right) \leftarrow (l, S) = (0, 0) \text{ term}$$

$$i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow M)}(q_1, q_2) |_{bare} = \frac{i g''_{IP_T IP_T M}}{2M_0} [q_{1\kappa} q_{2\mu} g_{\nu\bar{\rho}} + q_{1\kappa} q_{2\nu} g_{\mu\bar{\rho}} + q_{1\bar{\rho}} q_{2\mu} g_{\nu\kappa} + q_{1\bar{\rho}} q_{2\nu} g_{\mu\kappa} - 2(q_1 q_2)(g_{\mu\kappa} g_{\nu\bar{\rho}} + g_{\nu\kappa} g_{\mu\bar{\rho}})] \quad (2.2)$$

$$J^{PC} = 0^{-+} : i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow \bar{M})}(q_1, q_2) |_{bare} = i \frac{g'_{IP_T IP_T \bar{M}}}{2M_0} (g_{\mu\kappa} \varepsilon_{\nu\bar{\rho}\rho\sigma} + g_{\nu\kappa} \varepsilon_{\mu\bar{\rho}\rho\sigma} + g_{\mu\bar{\rho}} \varepsilon_{\nu\kappa\rho\sigma} + g_{\nu\bar{\rho}} \varepsilon_{\mu\kappa\rho\sigma}) (q_1 - q_2)^\rho k^\sigma \leftarrow (1, 1)$$

$$i \Gamma_{\mu\nu, \kappa\bar{\rho}}^{(IP_T IP_T \rightarrow \bar{M})}(q_1, q_2) |_{bare} = i \frac{g''_{IP_T IP_T \bar{M}}}{M_0^3} \{ \varepsilon_{\nu\bar{\rho}\rho\sigma} [q_{1\kappa} q_{2\mu} - (q_1 q_2) g_{\mu\kappa}] + \varepsilon_{\mu\bar{\rho}\rho\sigma} [q_{1\kappa} q_{2\nu} - (q_1 q_2) g_{\nu\kappa}]$$

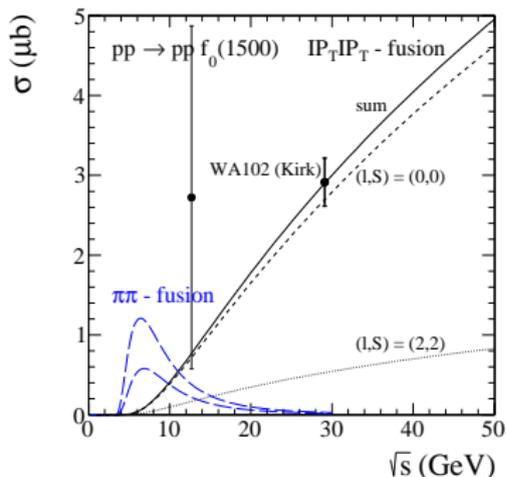
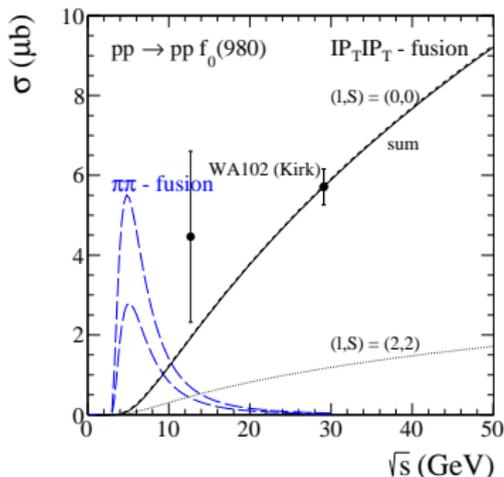
$$+ \varepsilon_{\nu\kappa\rho\sigma} [q_{1\bar{\rho}} q_{2\mu} - (q_1 q_2) g_{\mu\bar{\rho}}] + \varepsilon_{\mu\kappa\rho\sigma} [q_{1\bar{\rho}} q_{2\nu} - (q_1 q_2) g_{\nu\bar{\rho}}] \} (q_1 - q_2)^\rho k^\sigma \leftarrow (3, 3)$$

Scalar mesons ($J^{PC} = 0^{++}$)

Experimental results for total cross sections of scalar mesons in pp collisions at $\sqrt{s} = 29.1$ GeV (WA102)

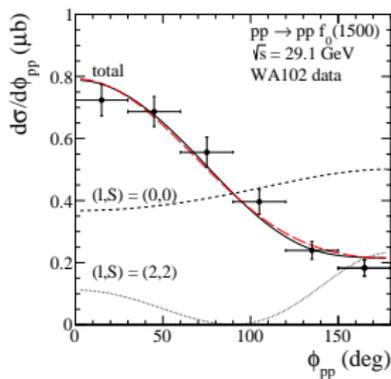
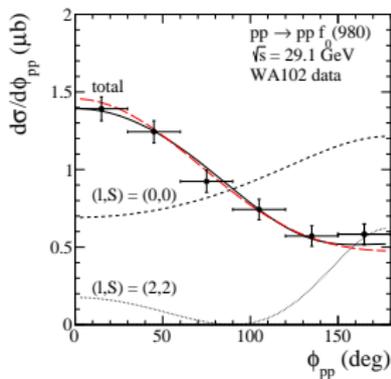
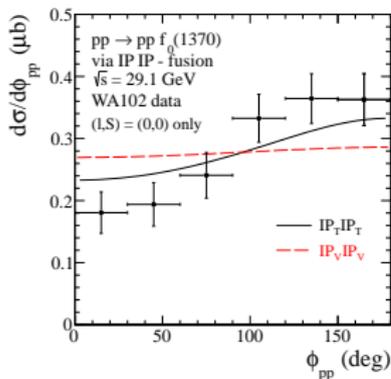
A. Kirk, Phys. Lett. B489 (2000) 29

	$f_0(980)$	$f_0(1370)$	$f_0(1500)$	$f_0(1710)$	$f_0(2000)$
$\sigma(\mu\text{b})$	5.71 ± 0.45	1.75 ± 0.58	2.91 ± 0.30	0.25 ± 0.07	3.14 ± 0.48

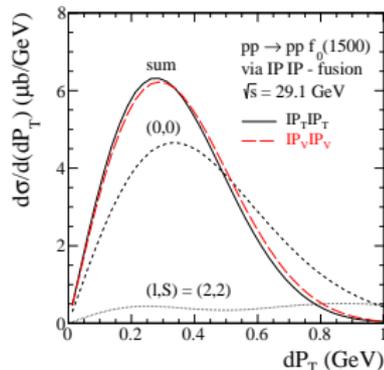
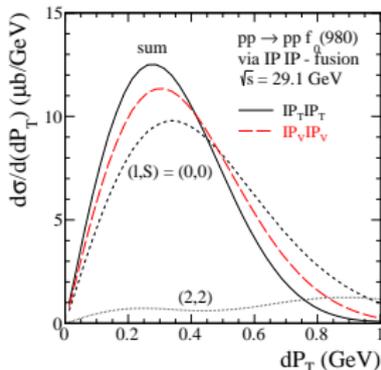
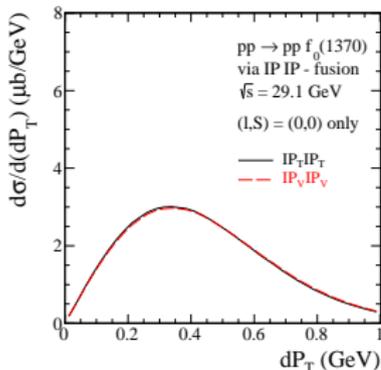


0^{++} , ϕ_{pp} and dP_{\perp} distributions

Our results and the WA102 exp. distributions have been normalized to the value of total cross sections given by Kirk.

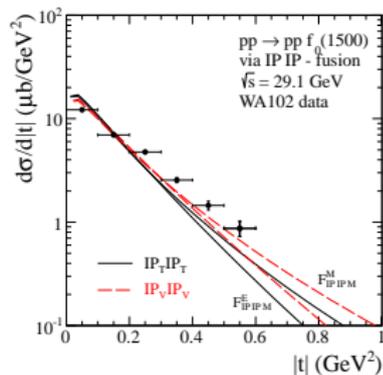
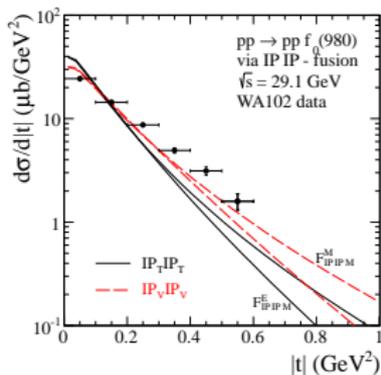
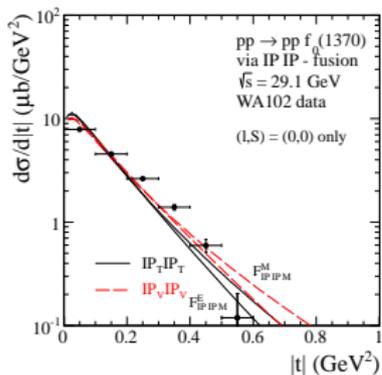


For $f_0(1370)$ the tensorial pomeron with the $(l, S) = (0, 0)$ coupling alone already describes data. The vectorial pomeron term is disfavoured here.



$$dP_{\perp} = |d\vec{p}_{\perp}| = |\vec{q}_{1\perp} - \vec{q}_{2\perp}| = |\vec{p}_{2\perp} - \vec{p}_{1\perp}| \text{ see F.E. Close and A. Kirk, Phys. Lett. B397 (1997) 333}$$

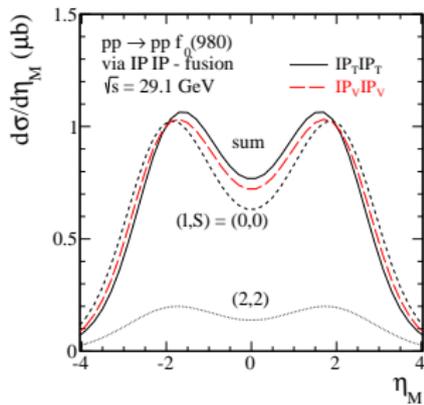
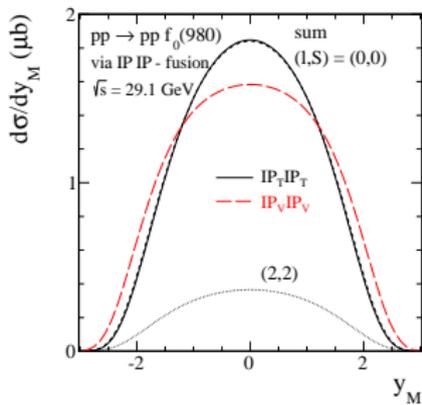
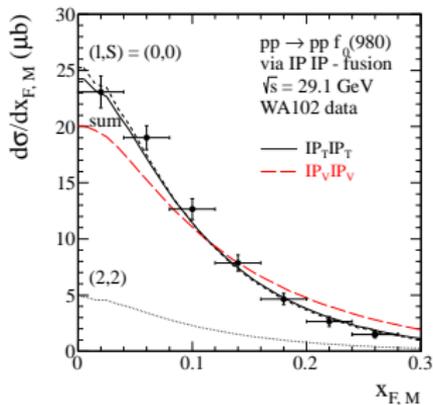
0^{++} , t distribution



$$F_{IPIP}^M(t_1, t_2) = F_M(t_1)F_M(t_2), \quad F_M(t) = F_\pi(t) = \frac{1}{1 - t/\Lambda_0^2}, \quad \Lambda_0^2 = 0.5 \text{ GeV}^2$$

$$F_{IPIP}^E(t_1, t_2) = \exp\left(\frac{t_1 + t_2}{\Lambda_E^2}\right), \quad \Lambda_E^2 = 0.64 \text{ GeV}^2$$

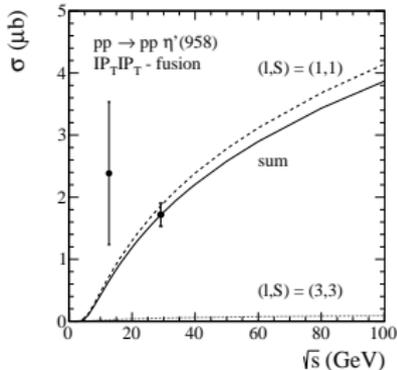
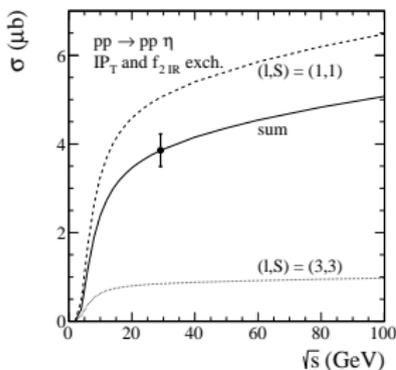
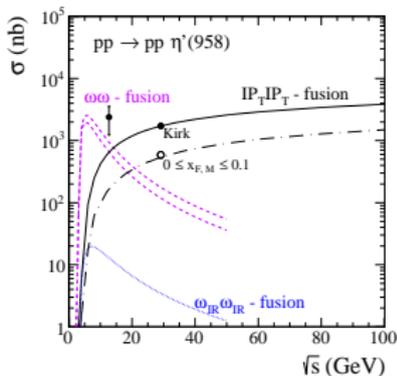
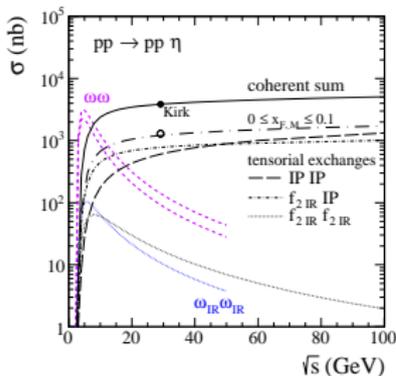
0^{++} , $x_{F,M}$, y_M , and η_M distributions



- The meson distribution peaks at $x_{F,M} = 0$ and the protons at $x_{F,p} \rightarrow \pm 1$, $x_F = 2p_z/\sqrt{s}$

Pseudoscalar mesons ($J^{PC} = 0^{-+}$)

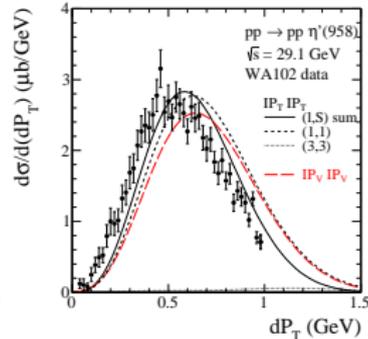
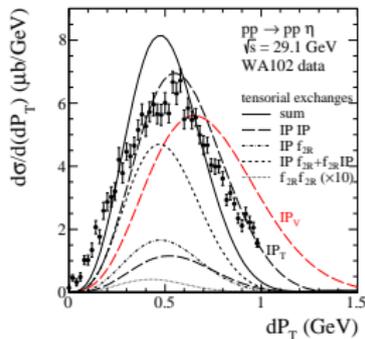
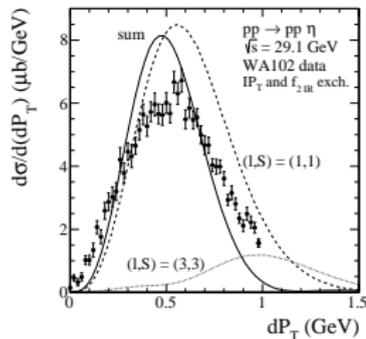
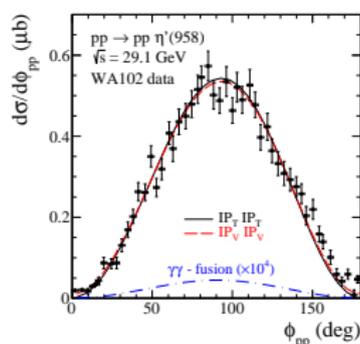
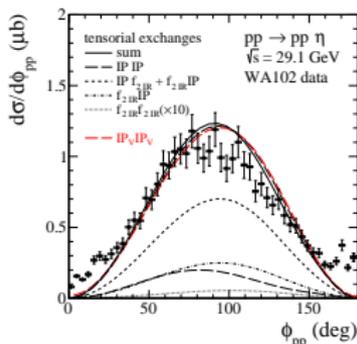
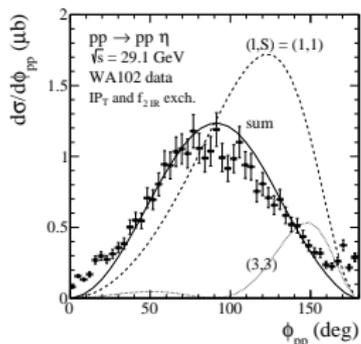
For η production we included subleading exchanges (reggeon-pomeron, pomeron-reggeon, and reggeon-reggeon) which improve the agreement with experimental data.



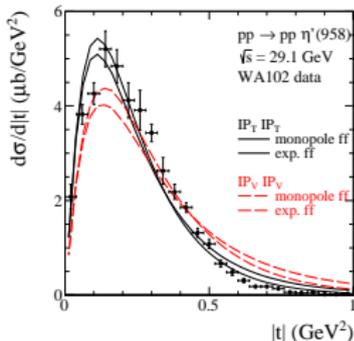
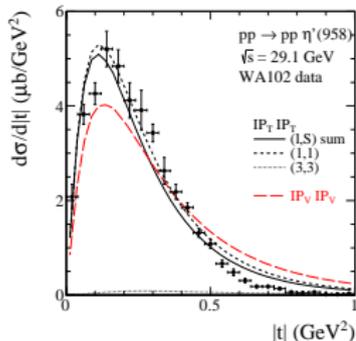
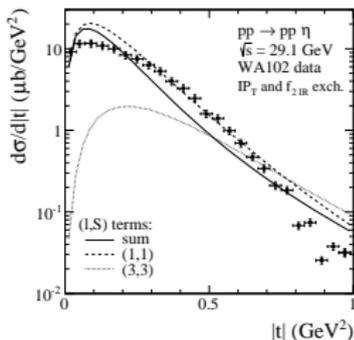
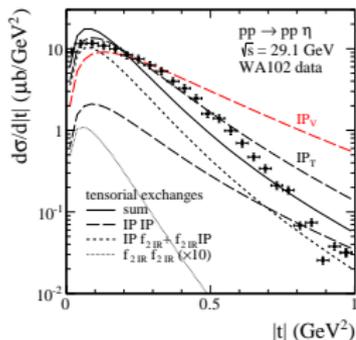
$\sigma(\eta) = 3.86 \pm 0.37 \mu\text{b}$, $\sigma(\eta') = 1.72 \pm 0.18 \mu\text{b}$ from A. Kirk, Phys. Lett. B489 (2000) 29

0^{-+} , ϕ_{pp} and dP_{\perp} distributions

Our results and the WA102 exp. distributions have been normalized to the value of total cross sections given by Kirk.



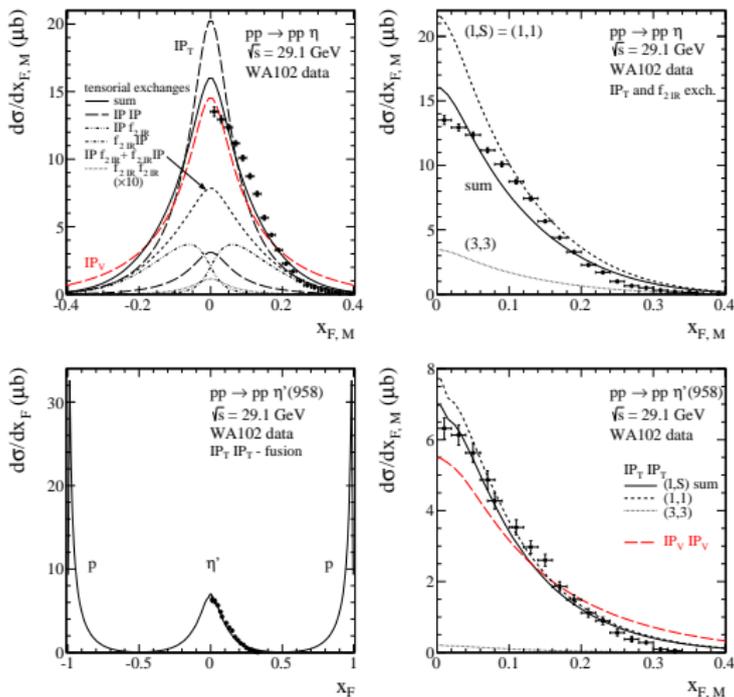
0^{-+} , t distribution



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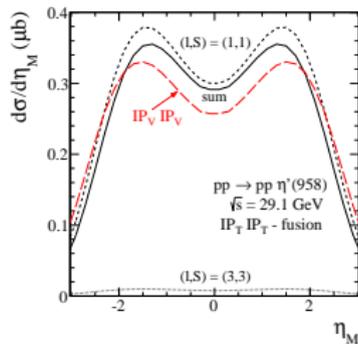
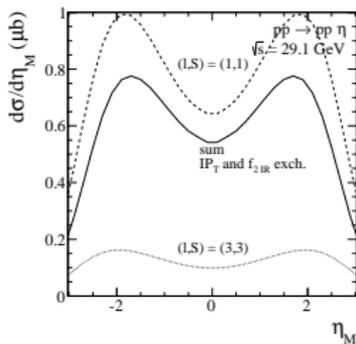
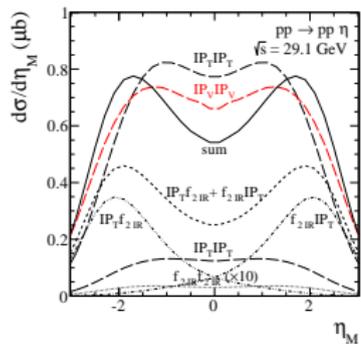
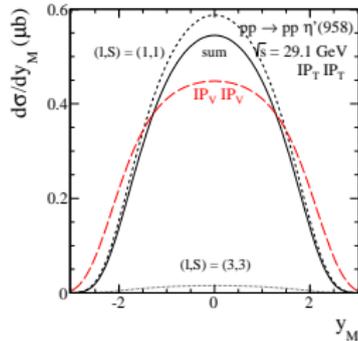
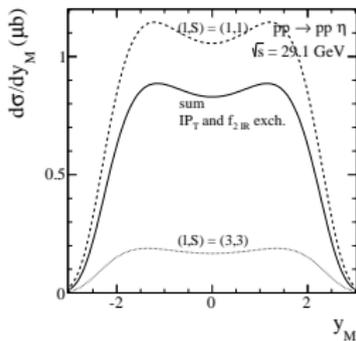
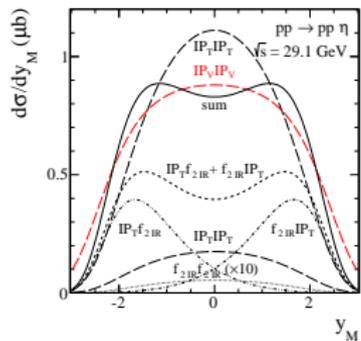
$$F_{IPIP}^E(t_1, t_2) = \exp\left(\frac{t_1 + t_2}{\Lambda_E^2}\right), \quad \Lambda_E^2 = 0.64 \text{ GeV}^2$$

0^{-+} , x_F distribution

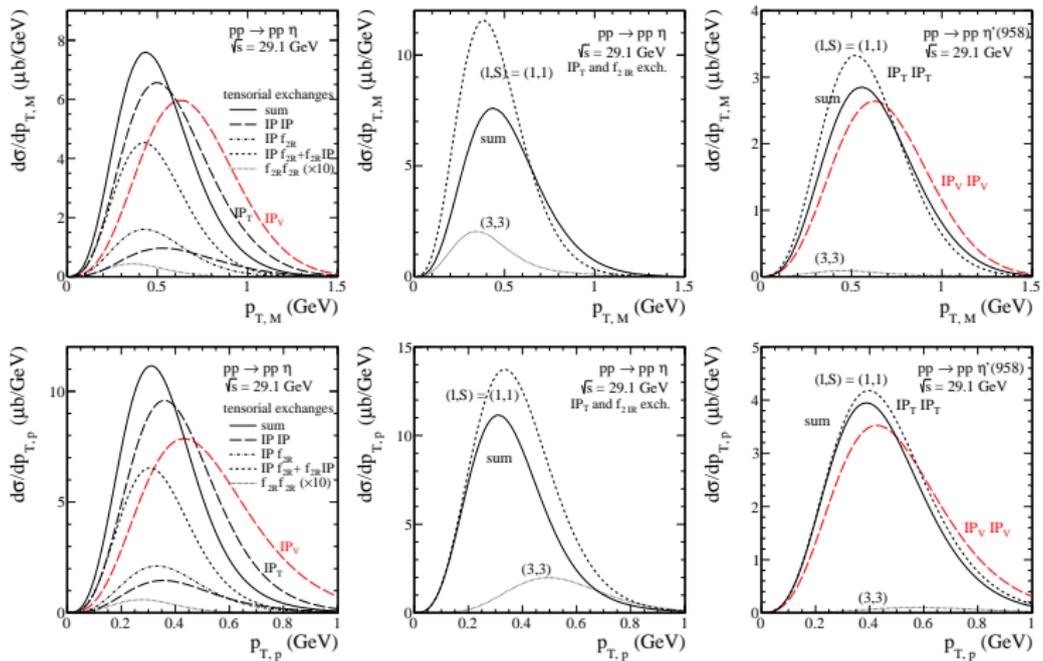


- The enhancement of the η distribution at larger values of $x_{F,M}$ can be explained by the $f_{2IR}IP$ and IPf_{2IR} exchanges
- Production of η' seems to be less affected by contributions from subleading exchanges

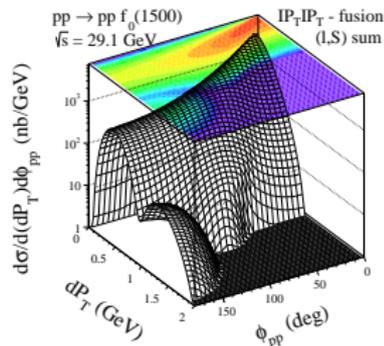
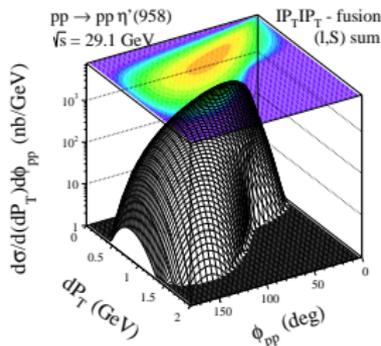
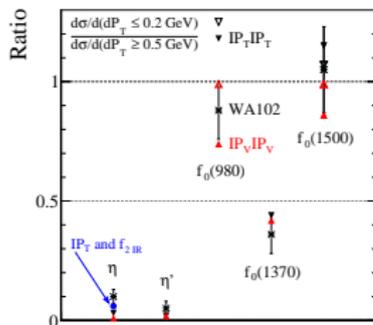
0^{-+} , γ_M and η_M distributions



0^{-+} , $p_{\perp,M}$ and $p_{\perp,p}$ distributions



0^{-+} and 0^{++} , (dP_{\perp}, ϕ_{pp}) distribution



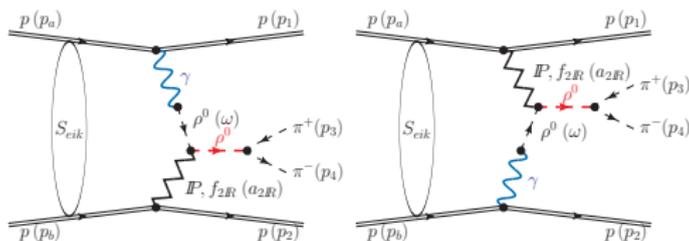
The ratio of mesons production at small dP_{\perp} to large dP_{\perp} for two models has been compared with the experimental results from [A. Kirk, Phys. Lett. B489 \(2000\) 29](#).

It was observed that all undisputed $q\bar{q}$ states (η , η' , $f_1(1285)$ etc.) are suppressed as $dP_{\perp} \rightarrow 0$, whereas the glueball candidates (e.g. $f_0(1500)$, $f_2(1950)$) are prominent.

The dP_{\perp} and ϕ_{pp} effects \rightarrow in general more than one coupling structure $IPIM$ is possible.

Challenge for theory to predict these coupling structure from calculations in the framework of QCD.

ρ^0 contribution to central exclusive production of $\pi^+\pi^-$ pairs



$$\mathcal{M}^{(P\text{-wave})} = \mathcal{M}^{YIP} + \mathcal{M}^{IPY} + \mathcal{M}^{Yf_{2IR}} + \mathcal{M}^{f_{2IR}Y}$$

$$\begin{aligned} \mathcal{M}_{\hat{n}_a \hat{n}_b \rightarrow \hat{n}_1 \hat{n}_2}^{YIP} &= \bar{u}(p_1, \hat{n}_1) i \Gamma_{\mu}^{(YPP)}(p_1, p_a) u(p_a, \hat{n}_a) \\ &\times i \Delta^{(Y)} \mu \sigma(q_1) i \Gamma_{\sigma\nu}^{(Y \rightarrow \rho)}(q_1) i \Delta^{(\rho)} \nu \rho_1(q_1) i \Delta^{(\rho)} \rho_2 \kappa(p_{34}) i \Gamma_{\kappa}^{(\rho\pi\pi)}(p_3, p_4) \\ &\times i \Gamma_{\rho_1 \rho_2 \alpha \beta}^{(IP\rho\rho)}(-q_1, p_{34}) i \Delta^{(IP)} \alpha \beta \delta \eta(s_2, t_2) \bar{u}(p_2, \hat{n}_2) i \Gamma_{\delta \eta}^{(IPPP)}(p_2, p_b) u(p_b, \hat{n}_b) \end{aligned}$$

$$\begin{aligned} \mathcal{M}_{\hat{n}_a \hat{n}_b \rightarrow \hat{n}_1 \hat{n}_2}^{Yf_{2IR}} &\cong \pm e(p_1 + p_a)^\mu F_1(t_1) \delta_{\hat{n}_1 \hat{n}_a} \\ &\times e \frac{m_\rho^2}{\gamma_\rho} \frac{1}{t_1} \Delta_{\mu\rho_1}^{(\rho)}(q_1) \Delta_{\rho_2 \kappa}^{(\rho)}(p_{34}) \frac{g_{\rho\pi\pi}}{2} (p_3 - p_4)^\kappa F_{\rho\pi\pi}(s_{34}) F_{\rho\pi\pi}(s_{34}) \\ &\times V^{\rho_1 \rho_2 \alpha \beta}(s_2, t_2) 2(p_2 + p_b)_\alpha (p_2 + p_b)_\beta F_M(t_2) F_1(t_2) \delta_{\hat{n}_2 \hat{n}_b} \end{aligned}$$

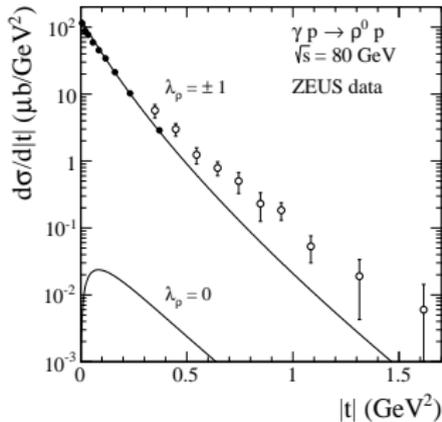
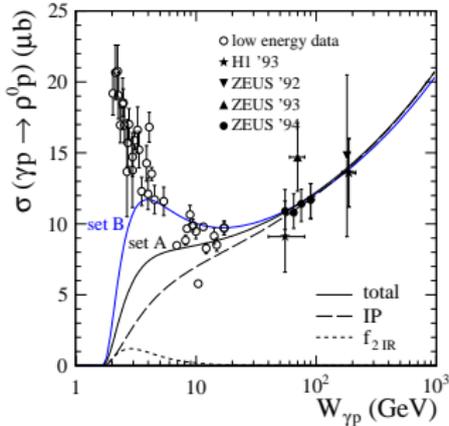
Photoproduction of ρ^0 meson

$$\mathcal{M}_{\beta_Y \beta_b \rightarrow \beta_\rho \beta_2}(s, t) \cong c^{(Y \rightarrow \rho)} (\Delta_T^{(\rho)})^{-1} \epsilon_Y^\mu (\epsilon_\rho^\nu)^* V_{\mu\nu\kappa\lambda}(s, t) (p_2 + p_b)^\kappa (p_2 + p_b)^\lambda 2\delta_{\beta_2 \beta_b} F_1(t) F_M(t)$$

where $c^{(Y \rightarrow \rho)} = -iem_\rho^2/\gamma_\rho$, $4\pi/\gamma_\rho^2 = 0.496$, $\Delta_T^{(\rho)} = -m_\rho^2 + im_\rho\Gamma_{\rho, tot}$

$$V_{\mu\nu\kappa\lambda}(s, t) = \frac{1}{4s} \left\{ \Gamma_{\mu\nu\kappa\lambda}^{(0)}(-p_Y, p_\rho) \left[6\beta_{IPNN} a_{IP\rho\rho} (-is'_a)_{IP}^{\alpha_{IP}(t)-1} + 2M_0^{-1} g_{f_{2IR\rho\rho}} \alpha_{f_{2IR\rho\rho}} (-is'_a)_{IR+}^{\alpha_{IR+}(t)-1} \right] \right. \\ \left. - \Gamma_{\mu\nu\kappa\lambda}^{(2)}(-p_Y, p_\rho) \left[3\beta_{IPNN} b_{IP\rho\rho} (-is'_a)_{IP}^{\alpha_{IP}(t)-1} + M_0^{-1} g_{f_{2IR\rho\rho}} b_{f_{2IR\rho\rho}} (-is'_a)_{IR+}^{\alpha_{IR+}(t)-1} \right] \right\}$$

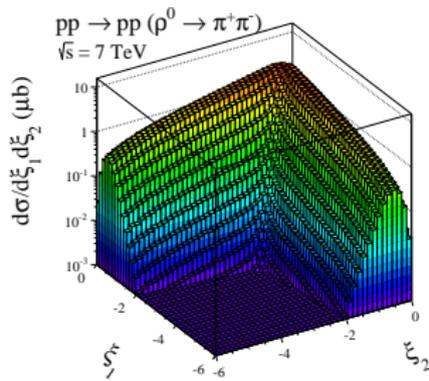
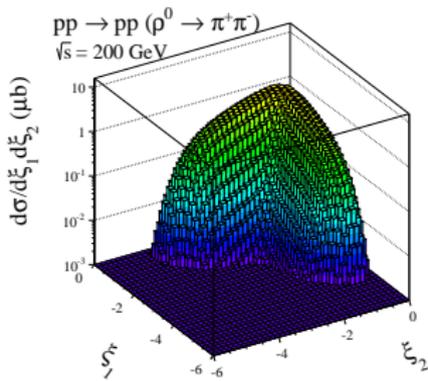
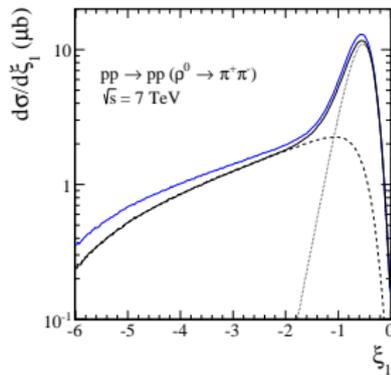
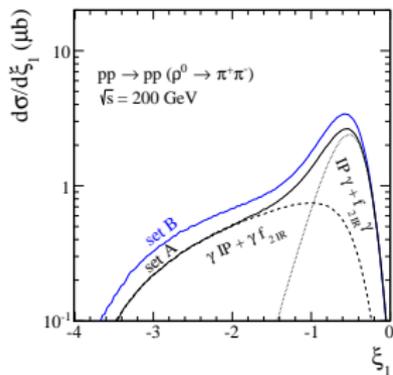
two rank-four tensor functions \rightarrow C. Ewerz, M. Maniatis and O. Nachtmann, *Ann. Phys.* 342 (2014) 31



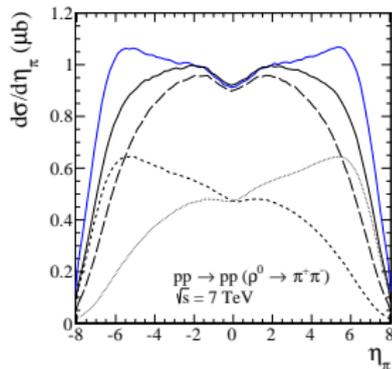
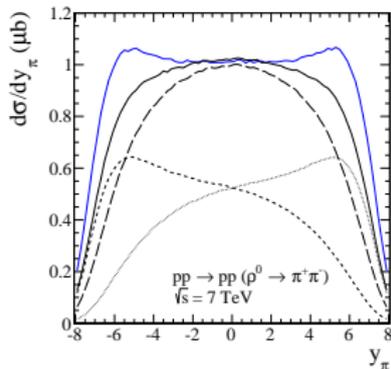
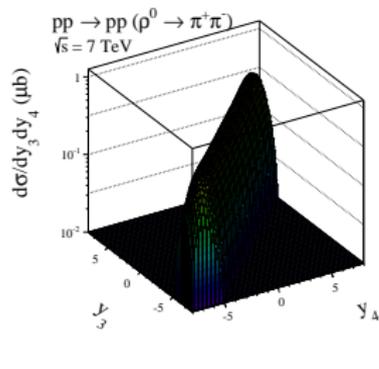
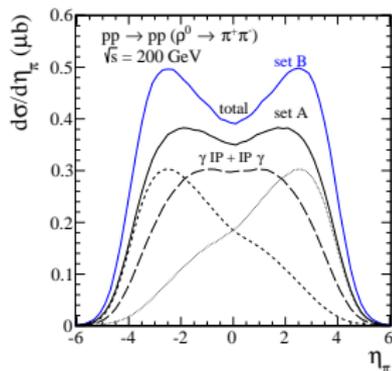
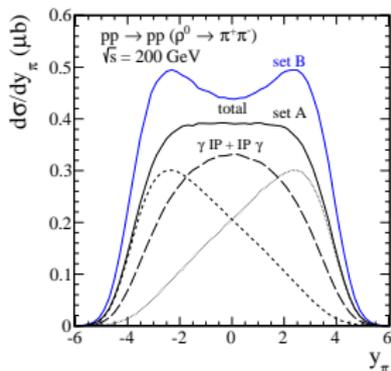
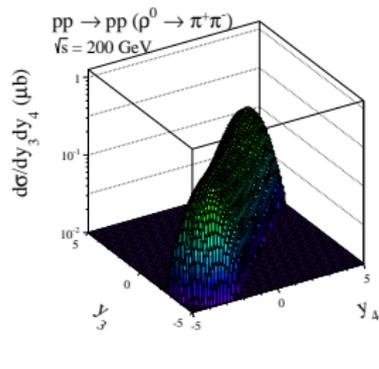
set A : $a_{IP\rho\rho} = 0.45 \text{ GeV}^{-3}$, $\alpha_{f_{2IR\rho\rho}} = 2.91 \text{ GeV}^{-3}$, $b_{IP\rho\rho} = 6.50 \text{ GeV}^{-1}$, $b_{f_{2IR\rho\rho}} = 5.80 \text{ GeV}^{-1}$

set B : $a_{IP\rho\rho} = \alpha_{f_{2IR\rho\rho}} = 0 \text{ GeV}^{-3}$, $b_{IP\rho\rho} = 6.70 \text{ GeV}^{-1}$, $b_{f_{2IR\rho\rho}} = 14.50 \text{ GeV}^{-1}$

$\xi_1 = \log_{10}(p_{1\perp}/1 \text{ GeV})$ distribution



Y_{π^+} and η_{π^+} distributions

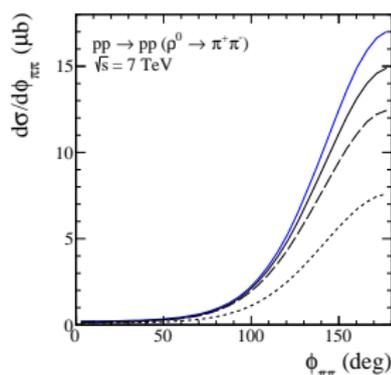
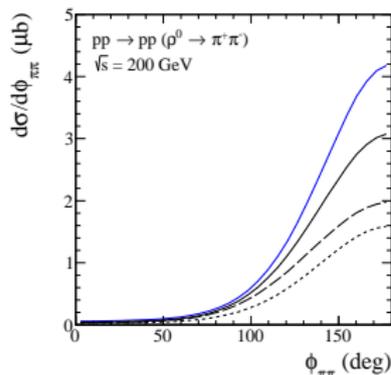
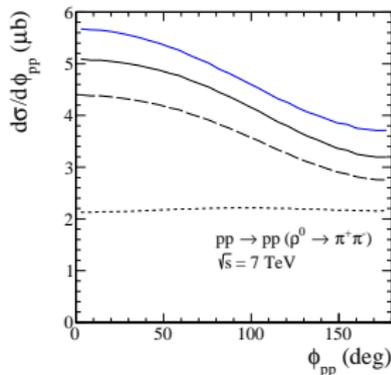
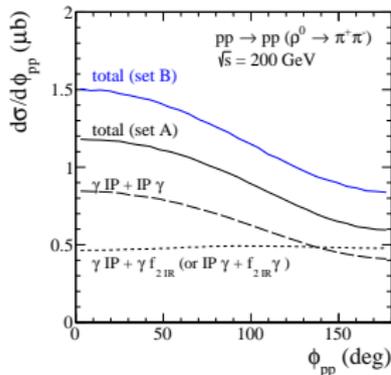


- The rapidities of the two pions are strongly correlated and $y_{\pi^+} \approx y_{\pi^-}$.

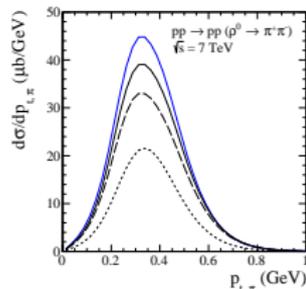
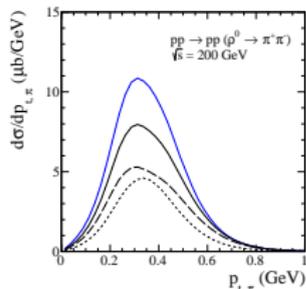
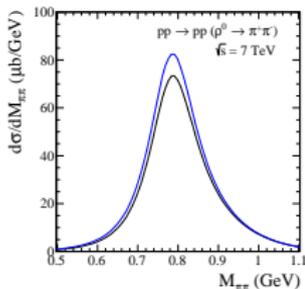
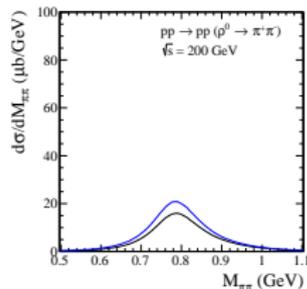
This is similar characteristic as for the double pomeron/reggeon exchanges in the fully diffractive mechanism see P. L. and A. Szczurek, *Phys. Rev. D* **81** (2010) 036003.

ϕ_{pp} and $\phi_{\pi\pi}$ distributions

- The effect of ϕ_{pp} deviation from a constant is due to interference of γ - IP and IP - γ amplitudes. Similar effect was discussed first in [W. Schafer and A. Szczurek, Phys. Rev. D76 \(2007\) 094014](#) for the exclusive production of J/ψ meson; see [A. Cisek talk](#)



$M_{\pi\pi}$ and $p_{\perp,\pi}$ distributions



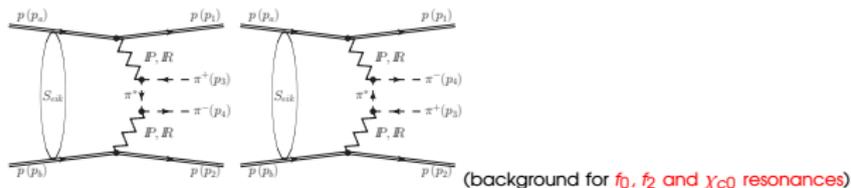
$\sigma_{pp \rightarrow pp(\rho^0 \rightarrow \pi^+\pi^-)}$ in μb (Born approximation)

\sqrt{s} , TeV	cuts	IP and f_{2IR} set A (set B)	IP set A
0.2	—	2.88 (3.73)	2.03
0.5	—	4.67 (5.79)	3.52
1.96	—	8.48 (9.97)	6.88
7	—	13.28 (14.85)	11.45
0.2 (STAR I)	$ \eta_{\pi^\pm} < 1, p_{\perp,\pi^\pm} > 0.15$ GeV, $0.003 < -t_{1,2} < 0.035$ GeV ²	0.032 (0.038)	0.026
0.5 (STAR II)	$ \eta_{\pi^\pm} < 1, p_{\perp,\pi^\pm} > 0.15$ GeV, $0.1 < -t_{1,2} < 1.5$ GeV ²	0.004 (0.004)	0.004
7 (CMS)	$ \eta_{\pi^\pm} < 2.5, p_{\perp,\pi^\pm} > 0.1$ GeV	4.14 (4.11)	4.02
7 (ALICE)	$ \eta_{\pi^\pm} < 0.9, p_{\perp,\pi^\pm} > 0.1$ GeV	0.91 (0.89)	0.89

- The tensorial pomeron IP_T can equally well describe existing experimental data on the exclusive meson production as the less theoretically justified vectorial pomeron IP_V frequently used in the literature.
- In most cases ($J^{PC} = 0^{++}, 0^{-+}$) one has to add coherently amplitudes for two lowest (I, S) couplings. The corresponding coupling constants are not known and have been fitted to existing experimental data.
- Our study certainly shows the potential of $pp \rightarrow pMp$ reactions for testing the nature of the soft pomeron. Pseudoscalar meson production could be of particular interest in this respect since there the distribution in ϕ_{pp} may contain, for the IP_T , a term which is not possible for the IP_V .
- We have made estimates of the central exclusive ρ^0 meson production to the $pp \rightarrow pp\pi^+\pi^-$ reaction. The ρ^0 contribution constitutes 10-20% of the double pomeron/reggeon exchange contribution calculated in a simple Regge-like model. Similar characteristic of rapidity and $p_{\perp, \pi}$ distributions, but different dependence on $p_{\perp, p}$ and ϕ_{pp} . This could be used to separate the ρ^0 contribution (should be strongly enhanced at $\phi_{pp} < 90^\circ$).
- Future experimental data on exclusive meson production at high energies should thus provide good information on the spin structure of the soft pomeron and on its couplings to the nucleon and the mesons.
- To-do list
 - To extend the studies of central meson production in diffractive processes to higher energies, where the dominance of the IP exchange can be better justified. A consistent model of the resonances decaying into the $\pi\pi$ channel (other mesons like $f_2(1270)$) and the non-resonant background. The interference of the resonance signals with the $\pi\pi$ continuum.
 - Absorption effects may also change the shapes of $t_1/t_2, \phi_{pp}$, etc. distributions. The deviation from "bare" distributions probably is more significant at high energies where the absorptive corrections should be more important.

Backup, other mechanisms to $pp \rightarrow pp\pi^+\pi^-$ reaction

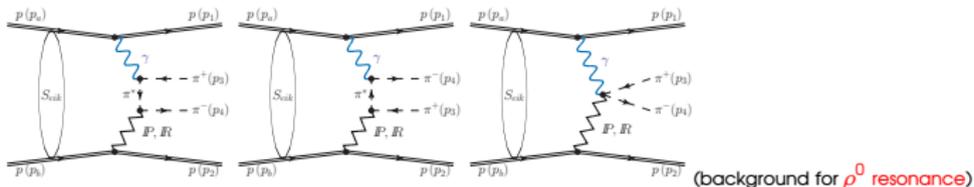
The measurement of forward/backward protons is crucial in better understanding of the mechanism of $pp \rightarrow pp\pi^+\pi^-$ reaction:
 R. Staszewski, P. L., M. Trzebiński, J. Chwastowski, A. Szczurek, *Acta Phys. Polon. B42 (2011) 1861* (ATLAS + ALFA); (CMS + TOTEM)



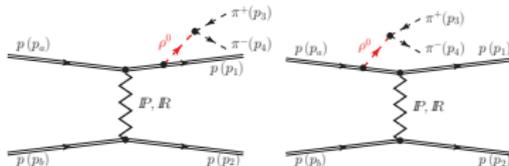
P. L. and A. Szczurek, *Phys. Rev. D81 (2010) 036003* ($pp \rightarrow pp\pi^+\pi^-$)

P. L., R. Pasechnik and A. Szczurek, *Phys. Lett. B701 (2011) 434* ($pp \rightarrow pp(\chi_{c0} \rightarrow \pi^+\pi^-)$)

P. L. and A. Szczurek, *Phys. Rev. D85 (2012) 014026* ($pp \rightarrow ppK^+K^-$)



At smaller \sqrt{s} are important the non-central (bremsstrahlung) mechanisms while at higher \sqrt{s} contribute at very forward/backward rapidities



Similar processes was discussed in pp and/or $p\bar{p}$ collisions at high energies:

A. Cisek, P. L., W. Schafer and A. Szczurek, *Phys. Rev. D83 (2011) 114004* ($pp \rightarrow pp\pi^0$)

P. L. and A. Szczurek, *Phys. Rev. D87 (2013) 074037* ($pp \rightarrow pp\omega$)

P. L. and A. Szczurek, *Phys. Rev. D87 (2013) 114004* ($pp \rightarrow pp\eta$)

What are the possible values of spin J and parity P for meson?

The values of l , S , and J , P of orbital angular momentum, total spin of the two "vector-pomeron particles", and total angular momentum, parity of the state, respectively, possible in the annihilation reaction $IP_V IP_V \rightarrow M$.

l	S	J	P
0	0	0	+
	2	2	
1	1	0, 1, 2	-
2	0	2	+
	2	0, 1, 2, 3, 4	
3	1	2, 3, 4	-
4	0	4	+
	2	2, 3, 4, 5, 6	

The values of l , S , J , and P possible in the annihilation of two "spin 2 pomeron particles" ($IP_T IP_T \rightarrow M$):

$$IP(2, m_1) \overset{\vec{k}}{\curvearrowright} M \overset{-\vec{k}}{\curvearrowleft} IP(2, m_2)$$

l	S	J	P
0	0	0	+
	2	2	
	4	4	
1	1	0, 1, 2	-
	3	2, 3, 4	
2	0	2	+
	2	0, 1, 2, 3, 4	
	4	2, 3, 4, 5, 6	
3	1	2, 3, 4	-
	3	0, 1, 2, 3, 4, 5, 6	
4	0	4	+
	2	2, 3, 4, 5, 6	
	4	0, 1, 2, 3, 4, 5, 6, 7, 8	

J^{PC}	meson M	IP_V		IP_T	
		l	S	l	S
0^{-+}	η	1	1	1	1
	$\eta'(958)$			3	3
0^{++}	$f_0(980)$	0	0	0	0
	$f_0(1370)$	2	2	2	2
	$f_0(1500)$			4	4
1^{++}	$f_1(1285)$	2	2	2	2
	$f_1(1420)$			4	4
2^{++}	$f_2'(1270)$	0	2	0	2
	$f_2'(1525)$	2	0	2	0
		2	2	2	2
		4	2	2	4
				4	2
				4	4
4^{++}	$f_4(2050)$	2	2	0	4
		4	0	2	2
		4	2	2	4
				4	0
				4	2
				4	4

$$P = (-1)^l, |l - S| \leq J \leq l + S$$

The continuation of the table for $l > 4$ is straightforward.

In general, different couplings with different l and S of two "pomeron particles" are possible.