

# Central exclusive production of axial vector mesons $f_1$ in proton-proton collisions

P. Lebiedowicz, J. Leutgeb, D. Nachtmann, A. Rebhan, A. Szczurek  
(Krakow - Vienna - Heidelberg)

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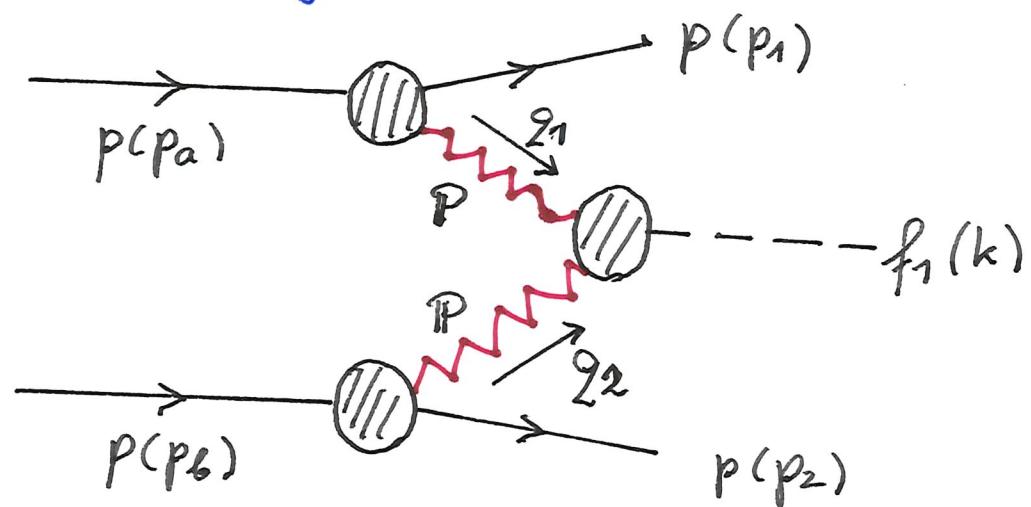
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## 1 Introduction

In this talk we will be concerned with central-exclusive production (CEP) of  $f_1(1285)$  and  $f_1(1420)$  mesons in proton-proton collisions

$$p(p_a) + p(p_b) \rightarrow p(p_1) + f_1(k) + p(p_2)$$

At high energies this should be mainly due to double pomeron exchange.



The relevant kinematic quantities are

$$S = (p_a + p_b)^2 \quad \text{c.m. energy squared}$$

$$q_1 = p_a - p_1, \quad q_2 = p_b - p_2, \quad k = q_1 + q_2,$$

$$t_1 = q_1^2, \quad t_2 = q_2^2, \quad m_{f_1}^2 = k^2$$

$$s_1 = (p_a + q_2)^2, \quad s_2 = (p_b + q_1)^2.$$

We treat our reaction in the tensor-pomeron approach

(Ewerz, Maniatis, O.N., Ann. Phys. 342 (2014) 31). This approach has a good basis from nonperturbative QCD considerations (O.N., Ann. Phys. 209 (1991) 436).

- The pomeron and the charge conjugation  $C = +1$  reggeons are described as effective rank 2 symmetric tensor exchanges
- The odderon and the  $C = -1$  reggeons are described as effective vector exchanges.

A tensor character of the pomeron is also preferred in holographic QCD; see e.g.

Brower, Polchinski, Strassler, Tan, JHEP 12 (2007) 005

Domokos, Harvey, Mann, PRD 80 (2009) 126015

Iatrakis, Ramamurti, Shuryak, PRD 94 (2016) 045005

There are by now many applications of our tensor-pomeron model to diffractive processes:

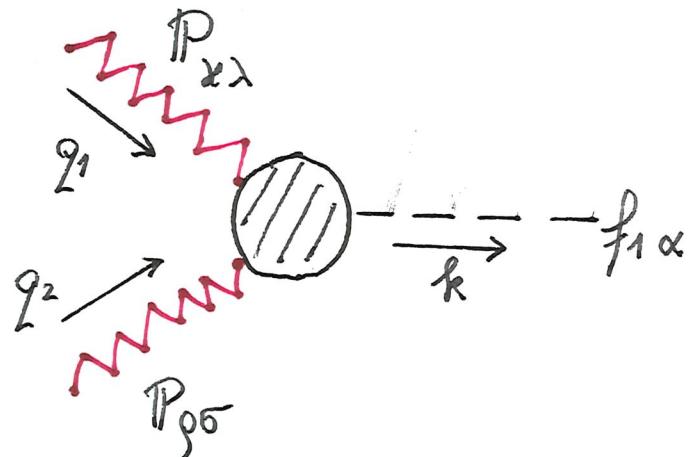
- two body hadronic reactions,
- photo production reactions,
- low  $x$  DIS,

- CEP reactions  $p + p \rightarrow p + X + p$

$$X = \gamma, \gamma', f_0, f_2, p\bar{p}, K\bar{K}, \phi, \phi\phi, 4\pi,$$

From these studies we know the form of the effective  $\mathbb{P}$  propagator and of the  $\mathbb{P}pp$  vertex. New in our present work is the  $\mathbb{P}\mathbb{P}f_1$  vertex.

## 2 The $\bar{P}Pf_1$ coupling



coupling Lagrangian  $\mathcal{L}^{(\bar{P}Pf_1)}$

vertex function

$$i \Gamma^{(\bar{P}Pf_1)}_{\alpha\lambda, \beta\sigma, \gamma} (q_1, q_2)$$

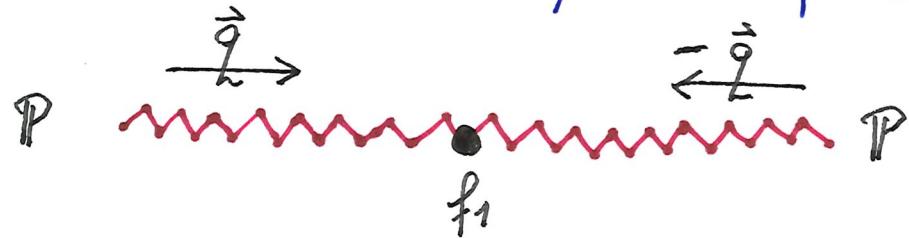
We follow two strategies for constructing  $\mathcal{L}^{(\bar{P}Pf_1)}$

- (1) Phenomenological approach: we consider first a fictitious process, the fusion of two "real spin 2 pomerons" of mass  $m$  (or tensor glueballs) giving an  $f_1$  meson of  $J^{PC} = 1^{++}$ .

$$\mathbb{P}(m, \varepsilon_1) + \mathbb{P}(m, \varepsilon_2) \longrightarrow f_1(m_{f_1}, \varepsilon)$$

$\varepsilon_{1,2}$ : polarisation tensors,  $\varepsilon$  polarisation vector.

We work in the rest system of the  $f_1$ .



The spin of the two "real pomerons" can be combined to a total spin  $S$  ( $0 \leq S \leq 4$ ). This has to be combined with the orbital angular momentum  $l$  to  $J^{PC} = 1^{++}$ , the quantum numbers of  $f_1$ . There are exactly two possibilities:

$$(l, S) = (2, 2) \text{ and } (4, 4).$$

Corresponding couplings  $\text{PP}f_1$  are

$$\mathcal{L}_{\text{PP}f_1}^{(2,2)} = \frac{g'_{\text{PP}f_1}}{32 M_0^2} (P_{x\lambda} \overset{\leftrightarrow}{\partial}_\mu \overset{\leftrightarrow}{\partial}_\nu P_{\rho\sigma}) (\partial_\alpha U_\beta - \partial_\beta U_\alpha) \Gamma^{(8)x\lambda, \rho\sigma, \mu\nu, \alpha\beta}$$

$$\mathcal{L}_{\text{PP}f_1}^{(4,4)} = \frac{g''_{\text{PP}f_1}}{24 \times 32 M_0^4} (P_{x\lambda} \overset{\leftrightarrow}{\partial}_{\mu_1} \overset{\leftrightarrow}{\partial}_{\mu_2} \overset{\leftrightarrow}{\partial}_{\mu_3} \overset{\leftrightarrow}{\partial}_{\mu_4} P_{\rho\sigma}) (\partial_\alpha U_\beta - \partial_\beta U_\alpha) \Gamma^{(10)x\lambda, \rho\sigma, \mu_1..mu_4, \alpha\beta}$$

Here we have  $M_0 \equiv 1 \text{ GeV}$ ,  $g'_{\text{PP}f_1}$ ,  $g''_{\text{PP}f_1}$ : dimensionless coupling parameters,  $P_{x\lambda}$  effective pomeron field,  $U_\alpha$   $f_1$  field,  $\Gamma^{(8)}$ ,  $\Gamma^{(10)}$  known tensor functions. We use these couplings, supplemented by suitable form factors, for the  $f_1$  CEP reactions.

- Holographic QCD approach using the Sakai-Sugimoto model.

There, the  $\bar{P}Pf_1$  coupling can be derived from the bulk Chern-Simons term requiring consistency of supergravity and the gravitational anomaly.

$$\mathcal{L}^{CS} = \alpha' U_\alpha \varepsilon^{\alpha\beta\gamma\delta} P^\kappa_\beta \partial_\delta P_{\gamma\mu} + \alpha'' U_\alpha \varepsilon^{\alpha\beta\gamma\delta} (\partial_\gamma P^\kappa_\beta) (\partial_\delta \partial_\mu P^\nu_\gamma - \partial_\delta \partial_\gamma P^\nu_\mu)$$

$\alpha'$ : dimensionless,  $\alpha''$ : dimension  $\text{GeV}^{-2}$ .

Sakai, Sugimoto, Progr.Theor.Phys. 113 (2005) 8432; 114 (2005) 1083,  
Leutgeb, Rebhan, PRD 101 (2020) 114015.

For our fictitious reaction with real pomerons there is strict equivalence

$$\mathcal{L}^{\text{CS}} \triangleq \mathcal{L}^{(2,2)} + \mathcal{L}^{(4,4)}$$

if the couplings satisfy

$$g'_{\text{PPPf}_1} = -x' \frac{M_0^2}{k^2} - x'' \frac{M_0^2 (k^2 - 2m^2)}{2k^2},$$

$$g''_{\text{PPPf}_1} = x'' \frac{2M_0^4}{k^2}.$$

For the CEP reaction the pomerons have masses squared  $t_1, t_2 < 0$  instead of  $m^2$ . Replacing above  $2m^2 \rightarrow t_1 + t_2$  we expect still approximate equivalence to hold. This is confirmed by explicit numerical studies.

### 3 Preliminary results

- Comparison with experimental results from WA102:

p p collisions,  $\sqrt{s} = 29.1$  GeV. They worked at the omega spectrometer at CERN in 1997 - 2000.

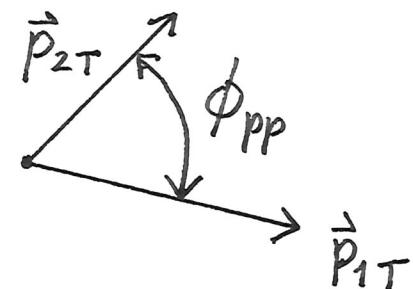
They could measure the complete final state, cross section,

$$\sigma_{\text{exp}} (\text{nb}), |x_F| \leq 0.2$$

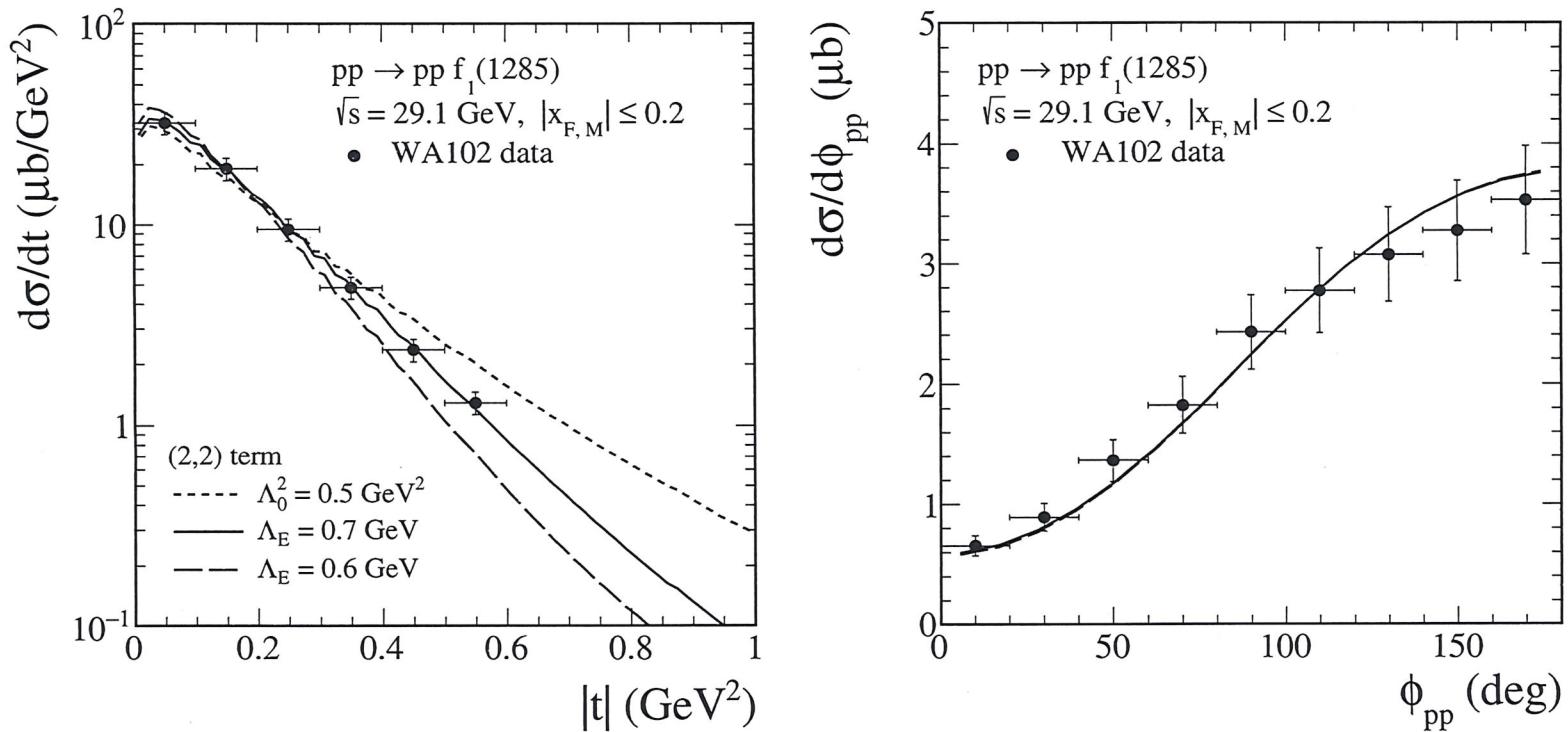
$t$  and  $\phi_{pp}$  distributions

$$f_1(1285) \quad 6919 \pm 886$$

$$f_1(1420) \quad 1584 \pm 145$$

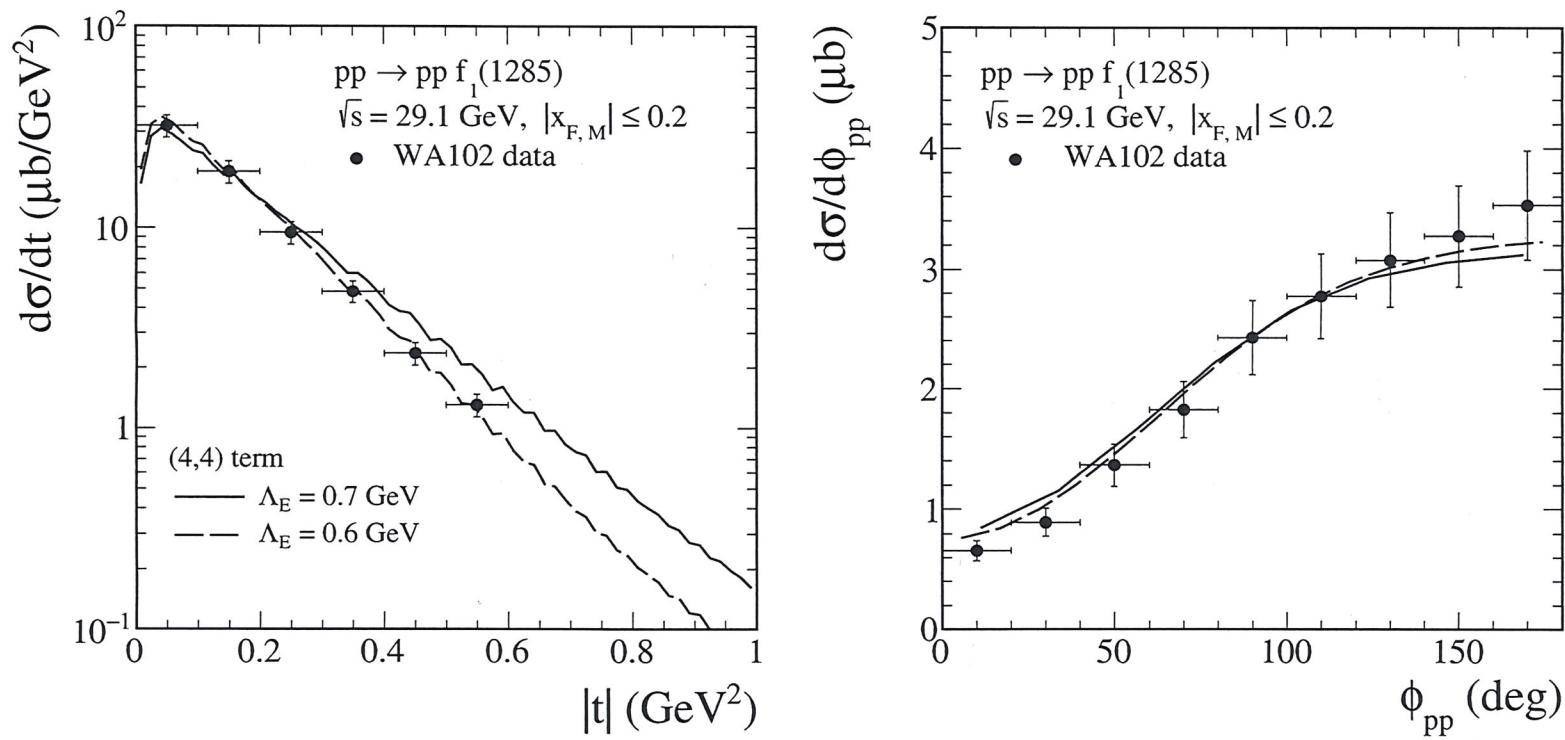


$$0 \leq \phi_{pp} \leq \pi$$



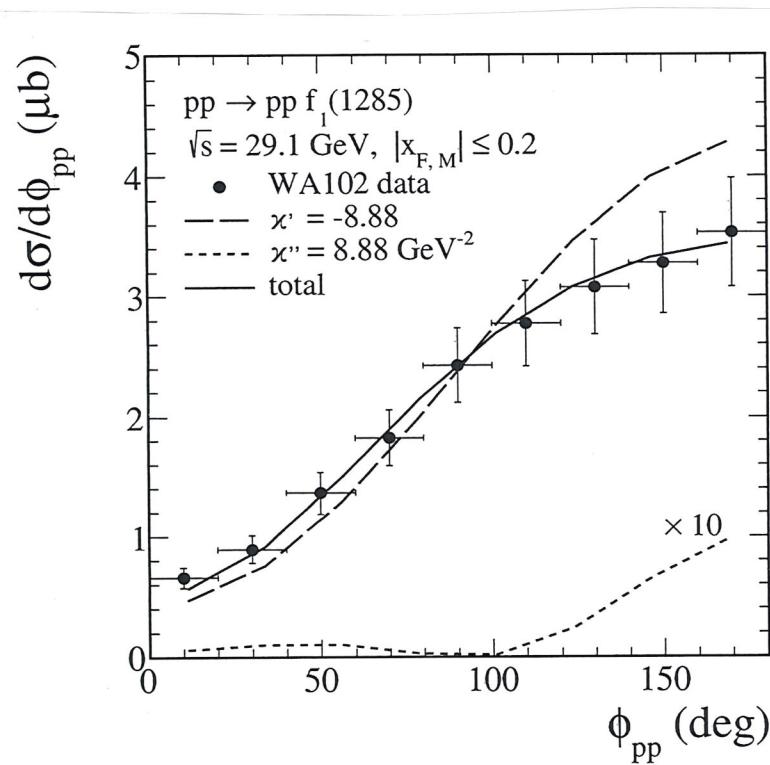
$(2,2)$  term only,  $|g'_{PPf_1}| = 4.89$

Absorption effects are included.



$(4,4)$  term only,  $|g''_{PPf_1}| = 10.31$

Absorption effects are included



The relation between the  $(l,S)$  and CS forms of the couplings can now be checked.

With  $m_{f_1}^2 = (1.2819)^2 \text{ GeV}^2$ ,  $t_1 = t_2 = -0.2 \text{ GeV}^2$  we get

$$g'_{PPf_1} = 0.12,$$

$$g''_{PPf_1} = -10.81.$$

Chern-Simons coupling

$$\chi' = -8.88, \quad \chi''/\chi' = -1.0 \text{ GeV}^{-2}$$

Absorption effects included.

This CS coupling corresponds practically to a pure  $(l,S) = (4,4)$  coupling.

## Conclusions

We have discussed in detail the forms of the  $\bar{P}Pf_1$  coupling.

We obtain a good description of the WA102 data at  $\sqrt{s} = 29.1 \text{ GeV}$ .

Our preliminary results for LHC energies indicate similar distributions as at the lower energy and cross sections of  $\sigma = 2 - 35 \mu\text{b}$  depending on cuts, e.g., on the  $f_1$  rapidity.

Detailed tests of the Sakai - Sugimoto model are possible.

Experimental studies of single meson CEP reactions will give many  $\bar{P}P$  meson coupling parameters. Their theoretical calculation is a challenging problem of non perturbative QCD.