THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

Central exclusive production of mesons in proton-proton collisions

Piotr Lebiedowicz

Department of the Theory of Strong Interactions
and Many Body Systems (NZ21)

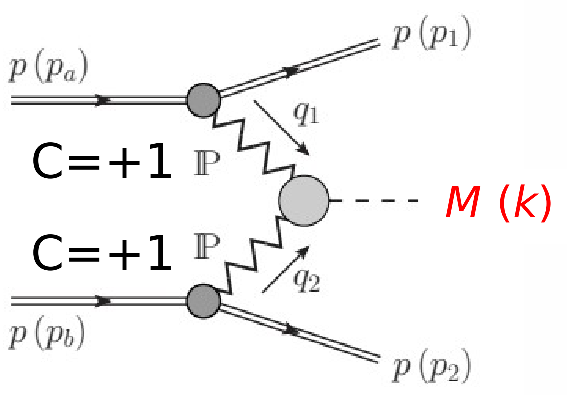
Piotr.Lebiedowicz@ifj.edu.pl

Particle Physics Summer Student (PPSS) Programme 2021

Central exclusive production of mesons in proton-proton collisions

Central Exclusive Production (CEP) of single mesons M

$p\,(p_a) + p\,(p_b) \to p\,(p_1) + M\,(k) + p\,(p_2)$



$$q_1 = p_a - p_1, \quad q_2 = p_b - p_2, \quad k = q_1 + q_2$$
$$t_1 = q_1^2, \quad t_2 = q_2^2, \quad m_M^2 = k^2$$
$$s = (p_a + p_b)^2 = (p_1 + p_2 + k)^2\,, \text{ c.m. energy squared}$$

$$\sqrt{s} \to \infty, \ \sqrt{|t|} \lesssim 1 \text{ GeV}$$

In QCD: neither pure short nor pure long distance regime, difficult to treat.
The physics of exchanges, regge regime: pomeron (IP), reggeons, odderon (?)

At high energies (RHIC, LHC) double pomeron exchange (DPE) is dominant production mechanism.
For IP IP fusion giving M the meson must have $I^G = 0^+$. But varios spin-parity values are possible, e.g. $J^{PC} = 0^{-+}, 0^{++}, 1^{++}, 2^{++}$, ...

We treat our CEP reactions in the tensor-pomeron approach
[Ewerz, Maniatis, Nachtmann, Ann. Phys. 342 (2014) 31]
The pomeron and the charge conjugation C=+1 reggeons are described as effective rank 2 symmetric tensor exchanges.

We know, from the many reactions which we have studied (Lebiedowicz, Nachtmann, Szczurek), the coupling of pomeron to the protons and the IP IP M couplings.

Central exclusive production of mesons in proton-proton collisions

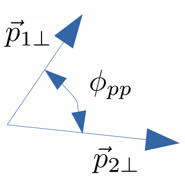
I shall only present you some results for single axial-vector ($J^{PC} = 1^{++}$) meson $f_1(1285)$ production.

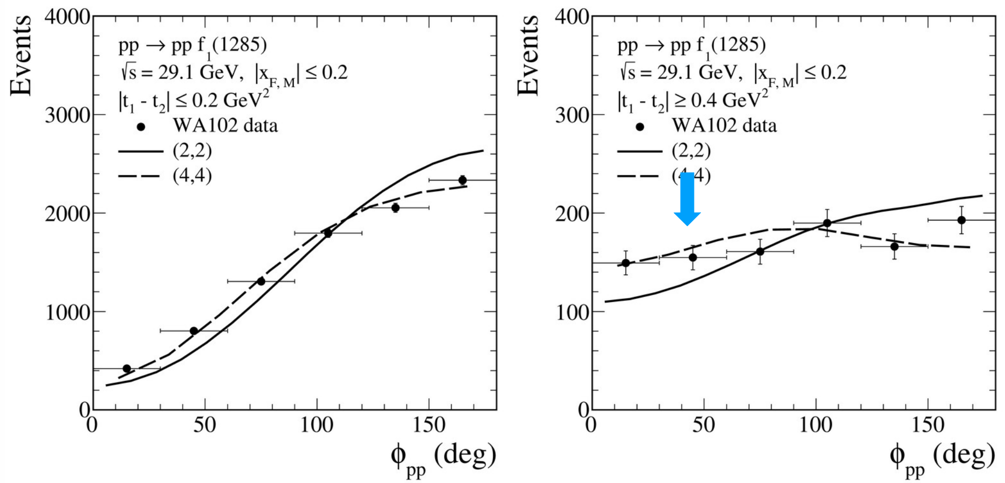
The Born-level amplitude for the *pp* → *pp* f_1 reaction within the tensor-pomeron approach (via IP IP fusion) can be written as

$$\begin{aligned}\mathcal{M}^{\rm Born}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\lambda_{f_1}} = \; & (-i)\,(\epsilon^{\mu}(\lambda_{f_1}))^{*}\,\bar{u}(p_1,\lambda_1) i\Gamma^{(\mathbb{P}pp)}_{\mu_1\nu_1}(p_1,p_a) u(p_a,\lambda_a) \\ & \times i\Delta^{(\mathbb{P})\,\mu_1\nu_1,\alpha_1\beta_1}(s_1,t_1)\, i\Gamma^{(\mathbb{P}\mathbb{P}f_1)}_{\alpha_1\beta_1,\alpha_2\beta_2,\mu}(q_1,q_2)\, i\Delta^{(\mathbb{P})\,\alpha_2\beta_2,\mu_2\nu_2}(s_2,t_2) \\ & \times \bar{u}(p_2,\lambda_2) i\Gamma^{(\mathbb{P}pp)}_{\mu_2\nu_2}(p_2,p_b) u(p_b,\lambda_b)\end{aligned}$$

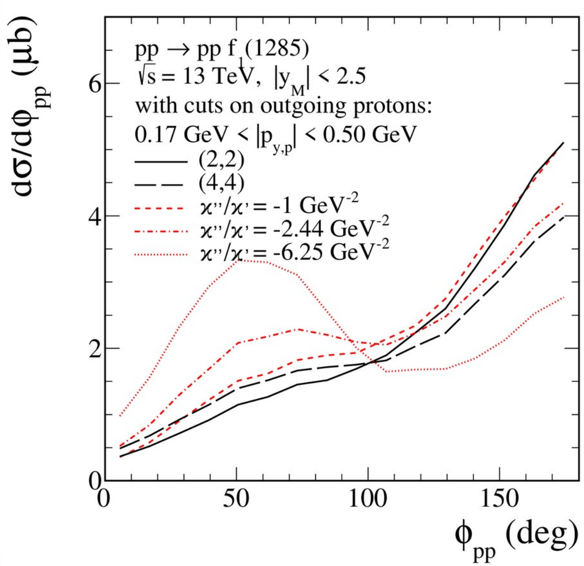
To give the full physical amplitude we should include absorptive corrections (pp-rescattering corr.)

Comparison with data from A. Kirk (WA102 Collaboration), Nucl. Phys. A 663 (2000) 608

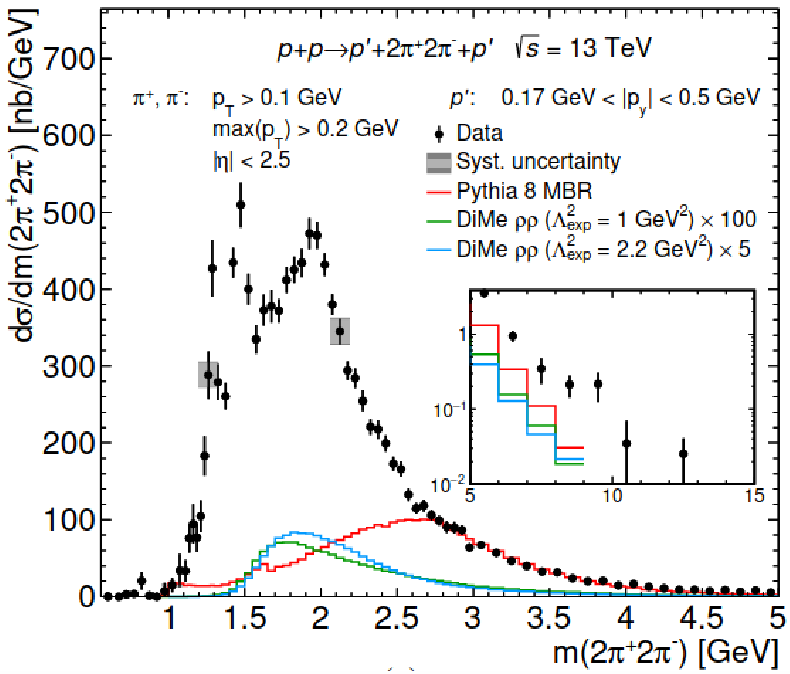




Our predictions for LHC, PRD102 (2020) 114003



Central exclusive production of mesons in proton-proton collisions



← ATLAS preliminary results
R.Sikora, CERN-THESIS-2020-235

Differential cross section for CEP of $2\pi+2\pi-$ state as a function of the invariant mass measured at ATLAS. Predictions from two MC models, MBR and DiMe, are shown → not reproduces low-mass data

Above 1 GeV the cross section rises rapidly, and a narrow peak is visible around 1.25 - 1.3 GeV. Small width of the peak suggests, that narrow f1(1285) resonance is responsible for this structure.

Between 1.3 – 1.6 GeV another structure is visible: a peak with maximum around 1.45 GeV, followed by a dip around 1.55 GeV. These structures can possibly be attributed to the production of the f0(1500) resonance. The enhancement and suppresion of the cross section, below and above the resonance mass, might result from interference terms.
Around M ~ 1.95 GeV another peak is visible, whose nature is not obvious. Potential resonance which could be produced in DPE is f2(1950). However, it is also possible that lower mass resonances interfere with four-pion continuum leading to the observed structure.

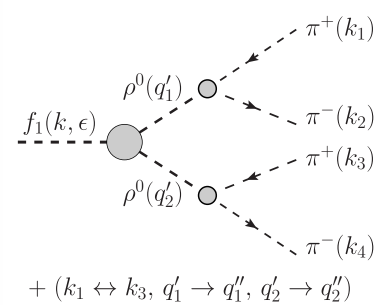
The f0(1500) and f2(1950) states are candidates to be scalar and tensor glueball, respectively. However, identification of possible glueball-like states in this channel requires calculation/ estimation both of resonant and continuum processes.

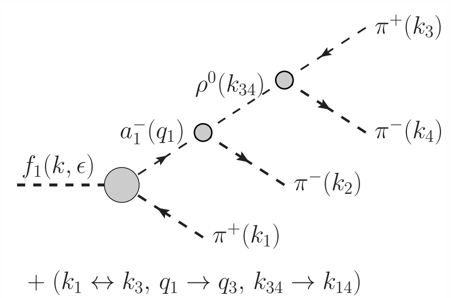
Central exclusive production of mesons in proton-proton collisions

CEP of 2*π*+2*π*- can proceed in several ways:

- continuum (triple Pomeron exchange)
  Kycia, Lebiedowicz, Szczurek, Turnau, PRD 95 (2017) 094020
- production of two resonances (*via the intermediate σσ* and *ρρ state*), each decaying to *π*+*π*-
  Lebiedowicz, Nachtmann, Szczurek, PRD 94 (2016) 034017
- production of a single resonance (e.g. f_1(1285)) that decays to *π*+*π*-*π*+*π*-

Theoretical/phenomenological studies of the 2 → 6 reaction (*pp* → *pp* *π*+*π*-*π*+*π*-) including both the resonances and continuum contributions in consistent model are chellenging task. This requires, for example, an analysis of decay processes (1 → 4):





Possible to do using GenEx MC generator for exclusive reactions:
Kycia, Chwastowski, Staszewski, Turnau, Commun. Comput. Phys. 24 (2018) 860;
the adaptive Monte Carlo toolbox for phase space integration and generation:
Kycia, Turnau, Chwastowski, Staszewski, Trzebiński, Commun. Comput. Phys. 25 (2019) 5;
and DECAY MC library for the decay of a particle with ROOT compatibility:
Kycia, Lebiedowicz, Szczurek, arXiv: 2011.14750 [hep-ph], in print Commun. Comput. Phys.