Exclusive production of π^0 and neutral technipion

Antoni Szczurek
Institute of Nuclear Physics (PAN), Cracow, Poland
Rzeszów University, Rzeszów, Poland

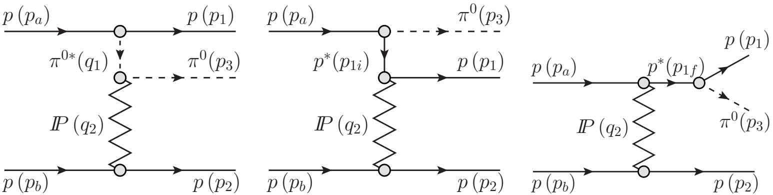
III Workshop on QCD and Diffraction at the LHC
joint with LHC Forward Physics and Diffraction WG meeting

Kraków, November 18-20

$pp \longrightarrow pp\pi^0$

Lebiedowicz-Szczurek,
Phys. Rev. **D87** (2013) 074037

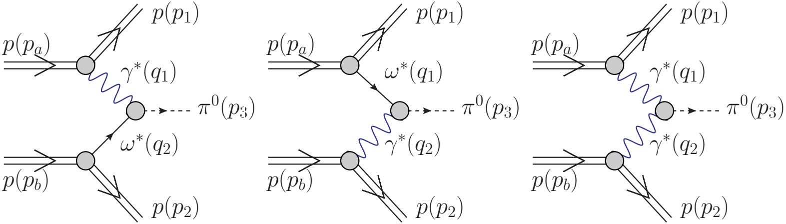
$pp \to pp\pi^0$, mechanisms



$pp \to pn\pi^+$ studied at low energies

3 diagrams: Drell-Hiida-Deck model

$pp \to pp\pi^0$, new mechanisms

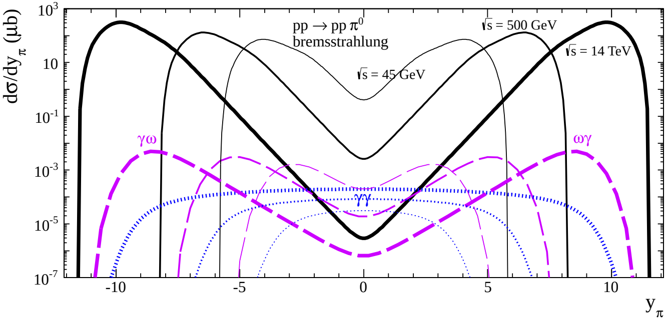


strong coupling of omega to nucleon

$\gamma^* \gamma^* \pi^0$ anomalous coupling

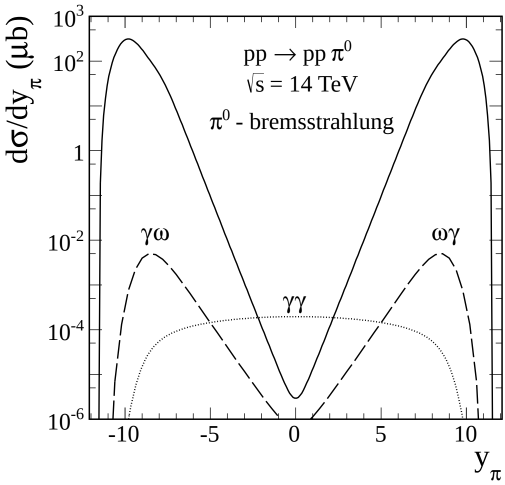
The strenght fixed from $\pi^0 \to \gamma\gamma$.

$pp \rightarrow pp\pi^0$, rapidity distributions



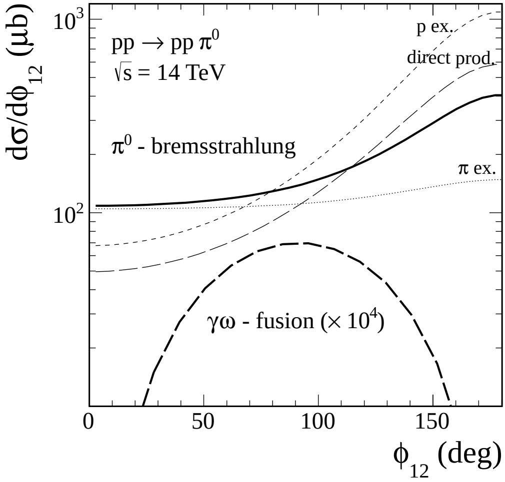
A shift of peaks with cm-energy.

$pp \to pp\pi^0$, contributions



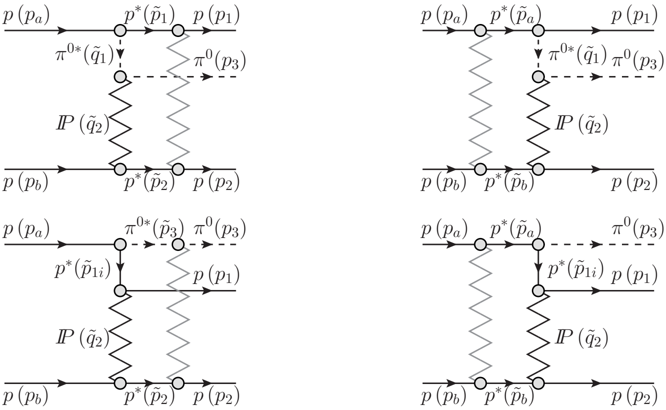
Pion bremsstrahlung at large rapidities

$pp \to pp\pi^0$, contributions

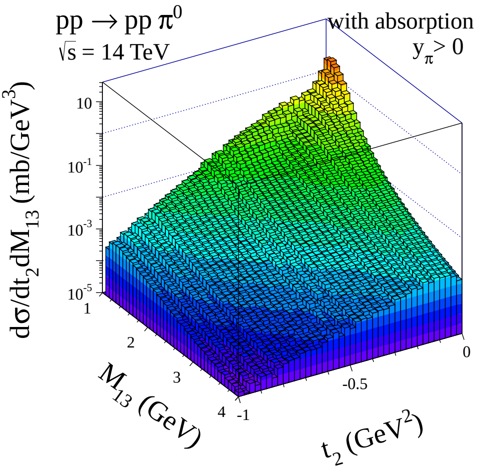


Convenient way to fix relative contribution of different diagrams

$pp \to pp\pi^0$, absorption effects



$pp \to pp\pi^0$, with absorption



mass-dependent slope

A comment on single diffractive cross section

At the LHC single diffraction (SD) and double diffraction (DD) processes constitute a large contribution to the inelastic cross section (about a half).

Low excitations are not well understood (!)

Jenkovszky, Kuprash, Orava and Salii, arXiv:1211.5841 (hep-ph)

use dual Regge model with nonlinear proton trajectories

In their model the low mass excitation is dominated by the excitation of the proton resonances:

$N^*(1440)$ with $J^P = \frac{1}{2}^+$ (not so obvious)

$N^*(1680)$ with $J^P = \frac{5}{2}^+$ (OK).

This is the region where the absorbed Drell-Hiida-Deck mechanism predicts an huge enhancement.

Our DHD mechanism contributes to the single diffraction cross section as

$$\sigma_{SD}^{DHD} = 3\,\sigma_{pp \to pp\pi^0}^{DHD} \,. \quad (1)$$

Our estimate of the DHD contribution is 1-5 mb.

Low energy excitation in single diffraction

How large is this contribution?

But elastic contribution could (in principle) be contaminated (at high energies) by other processes:

- photon bremsstrahlung
- $pp \to ppe^+e^-$
- photoproduction of Δ isobar excitation
- diffractive excitation of low-excited resonances
- DHD contribution

$$\sigma_{el}^{meas} = \sigma_{el} + \Delta\sigma \qquad (2)$$

Then

$$\sigma_{in}^{meas} = \sigma_{tot} - \sigma_{el}^{meas}$$

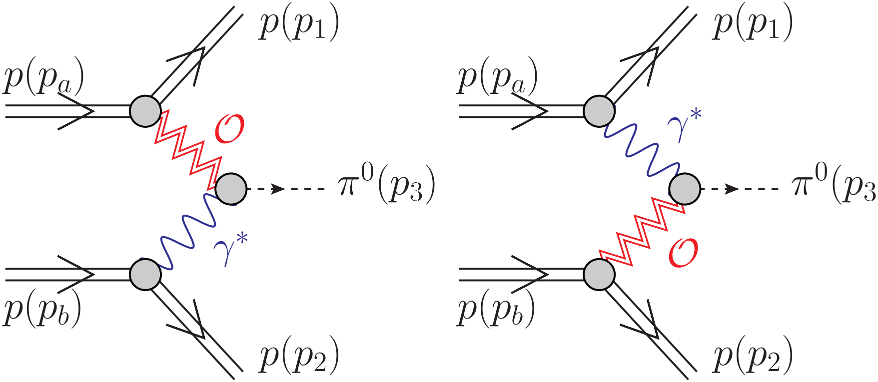
$$\sigma_{in}(M < M_0) = \sigma_{in} - \sigma_{in}^{vis}$$

This is instead

$$\sigma_{in}^{meas} - \sigma_{in}^{vis} < \sigma_{in}(M < M_0)$$

$pp \to pp\pi^0$, odderon exchanges

At midrapidity dominance of $\gamma\gamma \to \pi^0$



$pp \to pp\pi^0$, odderon exchanges

- Berger, Donnachie, Dosch, Kilian, Nachtmann, Reuter (1999) predicted cross section of 341 nb at the HERA energy.
- HERA search was negative and found only an upper limit for this process $\sigma_{\gamma p \to \pi^0 p} < 49$ nb.
- Ewerz and Nachtmann (2007) found an explanation within a nonperturbative approach using chiral symmetry and PCAC. In the chiral limit $m_\pi \to 0$ the corresponding amplitude vanishes. The amplitude is proportional to m_π^2, i.e. rather small. They have estimated that the cross section damped by a factor of 50 compared to the early estimate of BDDKNR1999.

$pp \to pp\pi^0$, odderon exchanges

The cross section for photon-odderon and odderon-photon exchanges can be estimated in the parton model.

$$\frac{d\sigma}{dy dp_\perp^2} = z_1 f(z_1) \frac{d\sigma_{\gamma p \to \pi^0 p}}{dt_2}\left(s_{23}, t_2 \approx -p_\perp^2\right) + z_2 f(z_2) \frac{d\sigma_{\gamma p \to \pi^0 p}}{dt_1}\left(s_{13}, t_1 \approx -p_\perp^2\right) , \quad (3)$$

where $f(z)$ is an elastic photon flux in the proton.

$z_{1/2} = \frac{m_t}{\sqrt{s}} \exp(\pm y)$ with $m_t = \sqrt{m_\pi^2 + p_t^2}$.

The differential cross section $\gamma p \to \pi^0 p$ is parametrized as:

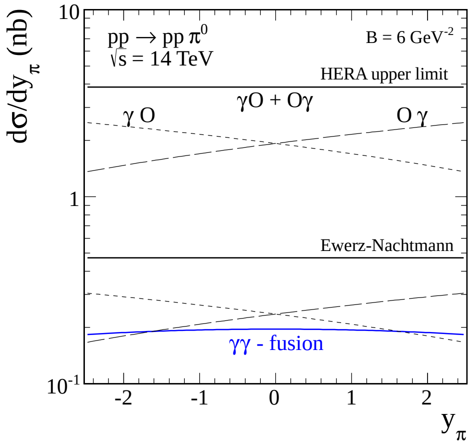
$$\frac{d\sigma}{dt} = B^2(-t) \exp(Bt) \sigma_{\gamma p \to \pi^0 p} \ . \quad (4)$$

The differential cross section vanishes at t = 0 which is due to helicity flip.

The slope parameter as for other soft processes i.e. $B \sim$ 4 - 8 GeV^{-2}.

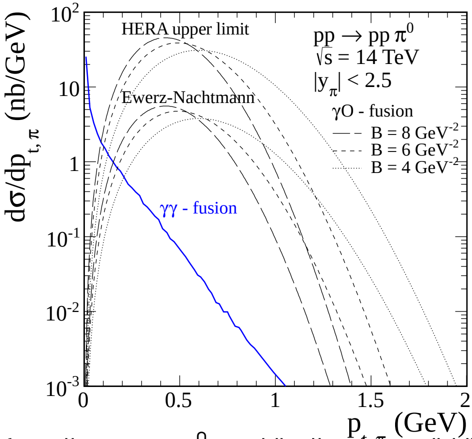
At the LHC, at midrapidities typical energies are similar as at HERA !

odderon exchanges, first results



HERA upper limit ($\sigma_{\gamma p \to \pi^0 p}$ = 49 nb) and
Ewerz-Nachtmann estimate ($\sigma_{\gamma p \to \pi^0 p}$ = 6 nb).

odderon exchanges, first results



Any deviation from the $\gamma\gamma \to \pi^0$ contribution to p_t distribution of π^0 at midrapidity would be a potential signal of photon-odderon (odderon-photon) contributions. One can expect potential deviations from the $\gamma\gamma$ contribution at $p_t \sim 0.5$ GeV.

$pp \to pp\pi^0$ (technipion)

Let us repeat the calculation for more exotic objects like technipions (neutral)

Lebiedowicz-Pasechnik-Szczurek, arXiv:1309.7300 (hep-ph)

$pp \longrightarrow pp\pi^0$ (technipion), introduction

- Recently a new technicolor phenomenological model has been proposed by Pasechnik-Beylin-Kuksa-Vereshkov, arXiv:1304.2081
- The model is called Chiral-Symmetric Technicolor Model or Vector-like Technicolor Model
- In this model techniquarks (U and D) may form technipion and technisigma particles, analogues of usual pion and sigma mesons in hadronic physics.
- The techniquarks couple to usual matter via exchange of weak gauge bosons $(\gamma, Z, W^{\pm})$. So the cross sections should be smaller than in typical QCD processes where gluons are exchanged.
- The model has some parameters: m_{π^0} (technipion mass), m_Q (techniquark mass) and g_{tc} (coupling of quarks to technipions).

A specific technipion model

- Two techni-flavours (U and D) and three techni-colors N_{TC} = 3.
- We assume $m_U = m_D = m_Q$.
- Quark charges: q_U = 2/3 and q_D = -1/3.
- A simple Lagrangian for $\bar{\tilde{Q}}\tilde{Q}V$ coupling, where $V = \gamma, Z^0, W^\pm$ (vector-like interactions of techniquarks and gauge bosons).
- Composed technisigma (scalar) and triplet of technipions (pseudoscalars).
- Effective interaction of constituent techniquarks with technipions

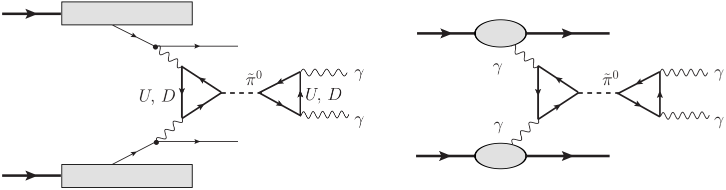
$$L_{\bar{\tilde{Q}}\tilde{Q}\tilde{\pi}} = -i\sqrt{2}g_{\rm TC}\,\tilde{\pi}^+\bar{U}\gamma_5 D - i\sqrt{2}g_{\rm TC}\,\tilde{\pi}^-\bar{D}\gamma_5 U - ig_{\rm TC}\,\tilde{\pi}^0(\bar{U}\gamma_5 U - \bar{D}\gamma_5 D)\,.$$

  Universal coupling constant g_{TC}.
- There exists also coupling of technipions with vector bosons.

$pp \to pp\pi^0$ (technipion), introduction

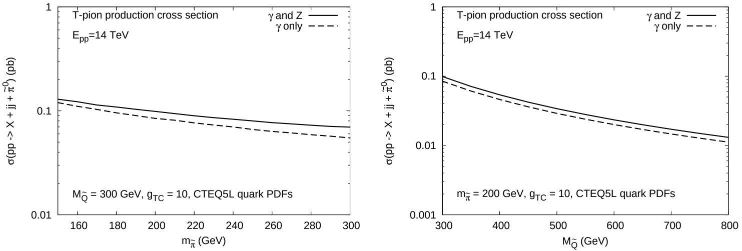
- In inclusive processes technipions are produced in $2 \to 3$ $q_1 q_2 \to q_1, q_2 \tilde{\pi}^0$ (both quarks and antiquarks). The standard $2 \to 1$ $\gamma\gamma \to \pi^0(tc)$ approach in collinear approximation (photons being partons in the proton) gives incorrect cross section, as the main contribution comes from transverse transferred four-momenta.
- The mechanism of exclusive production of technipion is similar as the one discussed for the central exclusive production of π^0 meson. The differences are in parameters (masses and coupling constants).
- In general, there are several different combinations of exchanges: $\gamma\gamma, \gamma Z, Z\gamma, ZZ$, etc.
- At small four-momentum squared transfers the photon-photon exchanges dominate. In addition, the coupling of photons to protons is well known experimentally.

Production of technipions



- $\gamma\gamma$, WW, ZZ and mixed terms in the intermediate state in inlusive processes.
- $\gamma\gamma$, (γZ, $Z\gamma$ and ZZ not included) in exclusive process.

Inclusive production of technipion



calculation done by R. Pasechnik

$qq' \to qq'\pi^0(tc)$ subprocesses

rather weak dependence on masses

dominance of $\gamma\gamma$ fusion

$pp \to pp\pi^0$ (technipion)

The corresponding matrix element for the $2 \to 3$ process can be written as:

$$\mathcal{M}^{pp\to pp\pi^0}_{\lambda_a\lambda_b\to\lambda_1\lambda_2} = V^{\mu_1}(\lambda_a \to \lambda_1)\frac{(-ig_{\mu_1\nu_1})}{t_1} \mathcal{F}_{\gamma\gamma\to\pi^0}(M_Q, M_\pi)\epsilon^{\nu_1\nu_2\alpha\beta}q_{1,\alpha}q_{2,\beta} \frac{(-ig_{\mu_2\nu_2})}{t_2}V^{\mu_2}(\lambda_b \to \lambda_2)\,. \quad (6)$$

The 6-fold sum above can be easily reduced to a 4-fold sum using properties of the metric tensor.
The vertex functions can be approximated as (spin conserving only):

$$\begin{aligned} V^{\mu_1}(\lambda_a \to \lambda_1) &\approx F_1(t_1)\bar{u}(\lambda_1)i\gamma^{\mu_1}u(\lambda_a) \\ V^{\mu_2}(\lambda_b \to \lambda_2) &\approx F_1(t_2)\bar{u}(\lambda_2)i\gamma^{\mu_2}u(\lambda_b) \end{aligned} \quad (7)$$

$pp \longrightarrow pp\pi^0$ (technipion)

The triangle function reads:

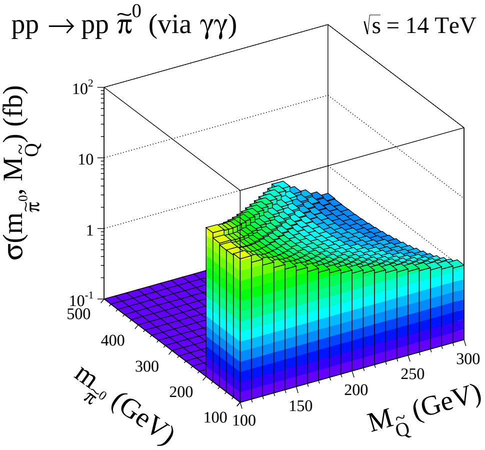
$$\mathcal{F}_{\gamma\gamma\to\pi^0}(M_Q, M_\pi) = \frac{4g_{tc}\alpha_{em}}{\pi}\frac{M_Q}{M_\pi^2}arcsin^2\left(\frac{M_\pi}{2M_Q}\right) . \quad (8)$$

The natural limitation is:

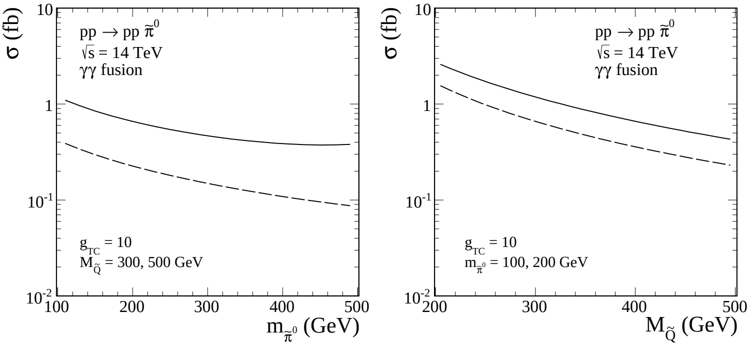
$$\frac{M_\pi}{2M_Q} < 1 . \quad (9)$$

First results

Dependence of the cross section on model parameters:

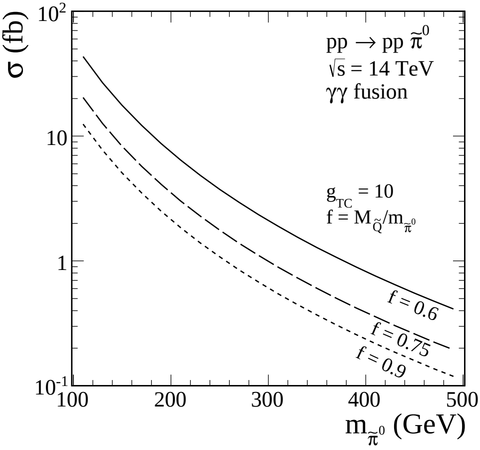


Dependence of the cross section on model parameters:

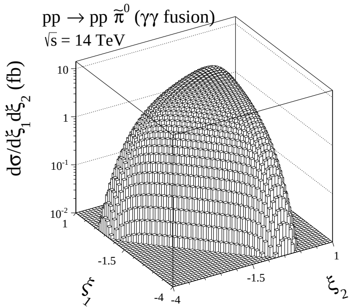


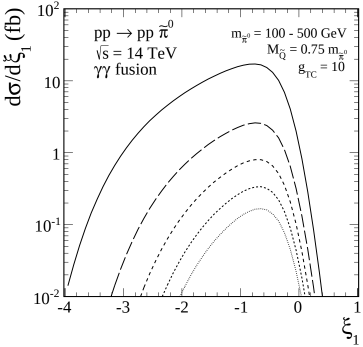
First results

Dependence of the cross section on model parameters:



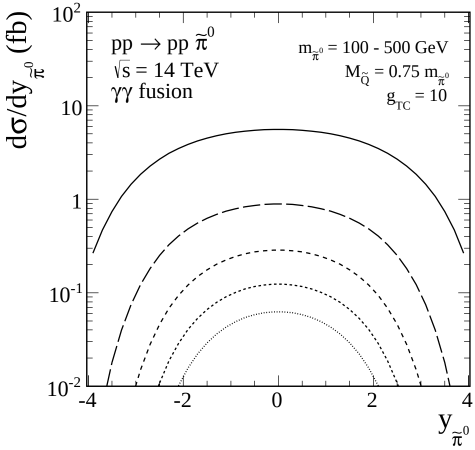
Some technical details





$$\xi_1 = log_{10}(p_{1,t}/1GeV)$$
$$\xi_2 = log_{10}(p_{2,t}/1GeV)$$

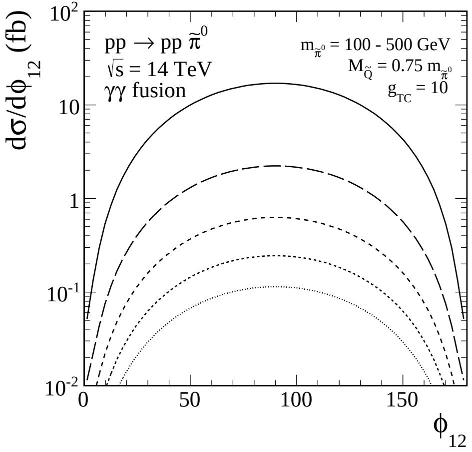
Some differential distributions



technipion centrally produced

Could be measured in central detectors ?

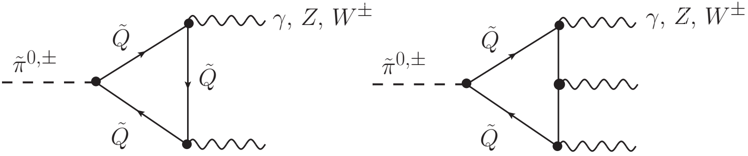
Azimuthal correlations between protons



Select in ϕ_{12} arround 90^o to reduce background?

Protons must be measured.

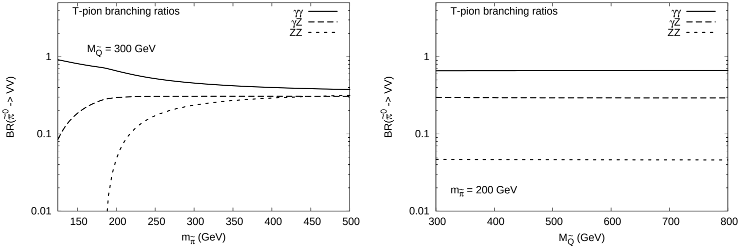
Observation channel?



At low masses of neutral technipion $\gamma\gamma$ seems to be preferable.

Branching fractions

Branching fractions for $\pi(tc)$ decay



$\gamma\gamma$ channel the best option

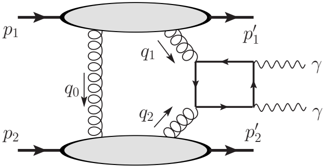
However, big background for inclusive reactions.

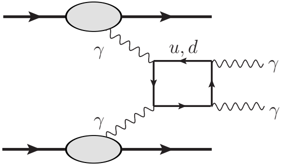
In exclusive reaction:

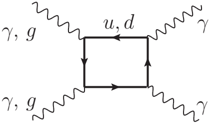
impose lower cut on transverse momentum of photons to get rid of soft backgrounds

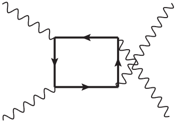
KMR pQCD mechanism is the biggest background at large transverse momenta for exclusive process.

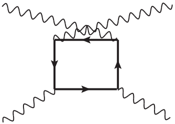
Backgrounds in the $\gamma\gamma$ channel



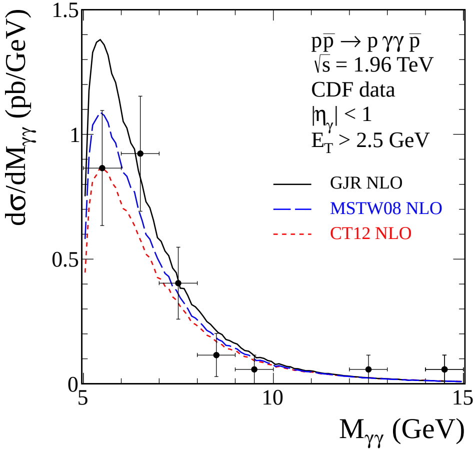








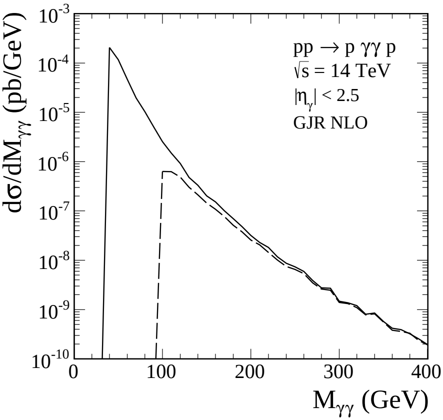
Two-photon exclusive production at low invariant masses



Lebiedowicz, Pasechnik, Szczurek

Nucl. Phys. **B867** (2013) 61.

Two-photon background (KMR mechanism)



calculation done by P. Lebiedowicz

Cross section drops quickly with $\gamma\gamma$ invariant mass.

QED background

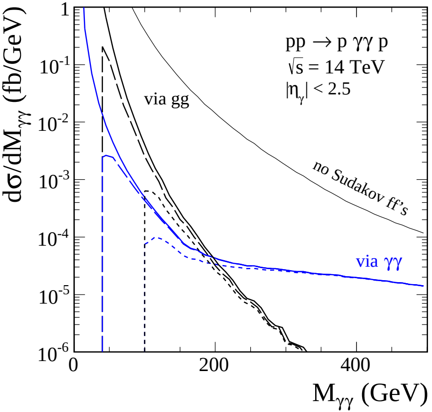
Approximate calculation as in the parton model:

$$\frac{d\sigma}{dy_3 dy_4 d^2p_{\gamma\perp}} = \frac{1}{16\pi^2 \hat{s}^2} x_1 \gamma_{el}(x_1) x_2 \gamma_{el}(x_2) \overline{|\mathcal{M}_{\gamma\gamma\to\gamma\gamma}(\lambda_1,\lambda_2,\lambda_3,\lambda_4)|^2} \,. \tag{10}$$

$\gamma_{el}(x_1)$ and $\gamma_{el}(x_2)$ are equivalent photon fluxes. They can be calculated easily assuming simple form of electromagnetic form factors.

A more involved and precise four-body calculation for the $pp \to pp\gamma\gamma$ is expected to give a very similar result.

Two-photon background



photon-photon rescattering dominates at large invariant masses

Signal of New Physics

Table: The cross sections (in fb) for $\gamma\gamma$ central exclusive production at $\sqrt{s} = 14$ TeV in $|\eta_\gamma| < 2.5$ and with cuts in $p_{\perp,\gamma} > 50$ GeV on both outgoing photons.

$M_{\gamma\gamma}$	σ (fb) at $\sqrt{s} = 14$ TeV and $\|\eta_\gamma\| <$			
	$\gamma\gamma \to \gamma\gamma$		$gg \to \gamma\gamma$, GJR08VFNS NLO	
	no cuts $p_{\perp,\gamma}$	$p_{\perp,\gamma} > 50$ GeV	no cuts $p_{\perp,\gamma}$	$p_{\perp,\gamma} > 50$ GeV
50 -- 100	97.01×10^{-3}	--	3.048	--
100 -- 150	11.62×10^{-3}	4.10×10^{-3}	62.72×10^{-3}	22.55×10^{-3}
150 -- 200	2.96×10^{-3}	2.01×10^{-3}	5.90×10^{-3}	4.21×10^{-3}
200 -- 250	1.78×10^{-3}	1.51×10^{-3}	0.95×10^{-3}	0.79×10^{-3}
250 -- 300	1.44×10^{-3}	1.34×10^{-3}	0.23×10^{-3}	0.21×10^{-3}
300 -- 350	1.23×10^{-3}	1.19×10^{-3}	0.06×10^{-3}	0.05×10^{-3}
350 -- 400	1.06×10^{-3}	1.05×10^{-3}	0.02×10^{-3}	0.02×10^{-3}

Conclusions, π^0

- Different mechanisms have been identified:
  Deck mechanism (forgotten), $\gamma\omega$ fusion, $\gamma\gamma$ fusion, $\gamma odderonfusion$.
- Pion produced dominantly in the forward direction and could be measured with the help of Zero Degree Calorimeters.
- The Deck mechanism contributes sizeable amount to inelastic cross section with low-energy excitations $M_X < 5$ GeV.
- The Deck mechanism leaves less room for Roper resonance discussed recently in the literature.
- Searches for odderon possible in exclusive π^0 meson production via photon-odderon mechanism.
  Who can measure low transverse momentum π^0 ?

Conclusions, technipion

- Technipions could be produced via fusion of vector bosons.
- Results for inclusive and exclusive proceses have been shown.
- Technipions could be identified in the $\gamma\gamma$ channel. For not too large technipion masses the biggest branching fraction.
- In inclusive process large background from $q\bar{q} \to \gamma\gamma$ subprocess.
- Exclusive process much smaller background (diffractive and photon-photon rescattering).
- First evaluation of the cross section for different values of the model parameters.
- Examples of differential distributions have been presented. One has to measure protons.
- $\phi_{12} \sim 90^o$ suggested to reduce background.
- $\gamma\gamma$ background at large invariant masses interesting by itself as it tests $\gamma\gamma \to \gamma\gamma$ scattering. A possible search for physics beyond Standard Model.