

Pomeron Odderon interference in production of $\pi^+ - \pi^-$ pairs at LHC

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in collaboration with

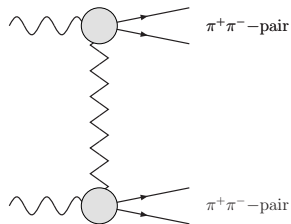
B. Pire (CPHT, Palaiseau), F. Schwennsen (DESY), L. Szymanowski (SINS, Warsaw)

Phys.Rev.D78:094009 (2008) [arXiv:0810.3817 [hep-ph]]

Motivation

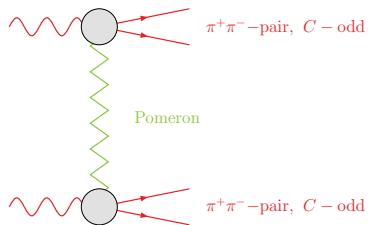
- colorless gluonic exchange
 - $C = +1$: Pomeron, in pQCD described by **BFKL** equation
 - $C = -1$: Odderon, in pQCD described by **BJKP** equation
- best but still weak evidence for \mathbb{O} : pp and $p\bar{p}$ data at **ISR**
- no evidence for perturbative \mathbb{O}
- \mathbb{O} exchange much weaker than $\mathbb{P} \Rightarrow$ two strategies in QCD
 - consider **processes**, where \mathbb{P} vanishes due to C -parity conservation:
 - exclusive $\eta, \eta_c, f_2, a_2, \dots$ in ep ; $\gamma\gamma \rightarrow \eta_c\eta_c \sim |\mathcal{M}_{\mathbb{O}}|^2$
 - exclusive $J/\Psi, \Upsilon$ in pp ($\mathbb{P}\mathbb{O}$ fusion, not $\mathbb{P}\mathbb{P}$)
 - consider **observables** sensitive to the **interference** between \mathbb{P} and \mathbb{O} [first proposed by Brodsky, Rathsman, Merino 1999]
 - $\sim \text{Re} \mathcal{M}_{\mathbb{P}} \mathcal{M}_{\mathbb{O}}^* \Rightarrow$ observable **linear** in $\mathcal{M}_{\mathbb{O}}$
- \mathbb{P}/\mathbb{O} coupling to proton not perturbatively calculable \Rightarrow
 $\gamma^{(*)}\gamma^{(*)}$ collisions: **hard process**

The Process



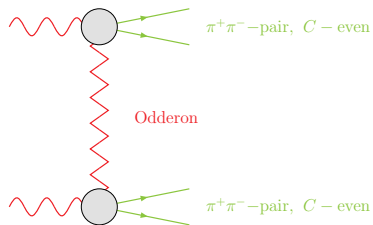
- exclusive production of two $\pi^+\pi^-$ pairs \rightarrow colorless exchange between them
- C-parity of $\pi^+\pi^-$ pair not fixed

The Process



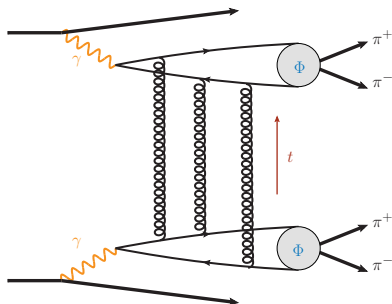
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The Process



- exclusive production of two $\pi^+\pi^-$ pairs \rightarrow colorless exchange between them
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Kinematics, Framework



- Bremsstrahlung: photon virtuality $Q^2 \approx 0$, flux by Weizsäcker-Williams
- perturbative Regge limit: $s_{\gamma\gamma} \gg |t| \gg \Lambda_{\text{QCD}}^2$
- photon Impact Factor known (in contrast to hadron IF)
- model \mathbb{P} (○) by 2 (3) gluons
- collinear approximation: $-t \gg m_{2\pi}^2 \rightarrow 2\pi$ GDA Φ : variables
 - quark momentum fraction z
 - polar angle θ in rest frame of 2π
 - invariant mass $m_{2\pi}$

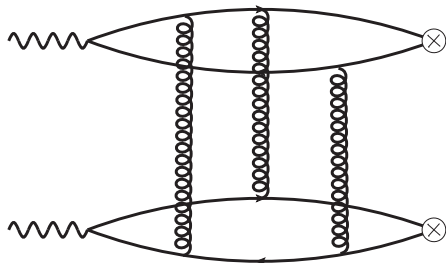
Matrix Element

\mathbb{P} exchange in $\gamma\gamma \rightarrow (\pi^+\pi^-)(\pi^+\pi^-)$:

$$\begin{aligned} \mathcal{M}_{\mathbb{P}} \sim s \int \frac{d^2\vec{k}_1 d^2\vec{k}_2 \delta^{(2)}(\vec{k}_1 + \vec{k}_2 - \vec{p}_{2\pi})}{(2\pi)^2 \vec{k}_1^2 \vec{k}_2^2} \\ \times \left[\int_0^1 dz (z - \bar{z}) \vec{\varepsilon} \cdot \vec{Q}_{\mathbb{P}}(\vec{k}_1, \vec{k}_2) \Phi^{l=1}(z, \theta, m_{2\pi}^2) \right] \\ \times \left[\int_0^1 dz' (z' - \bar{z}') \vec{\varepsilon}' \cdot \vec{Q}'_{\mathbb{P}}(\vec{k}_1, \vec{k}_2) \Phi^{l=1}(z', \theta', m_{2\pi}^2) \right] \end{aligned}$$

Hard Matrix Element

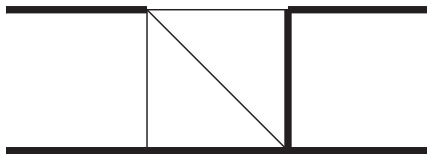
for Odderon: $2 \rightarrow 2$ with four loops



in the high energy limit ($s_{\gamma\gamma} \gg |t|$) ...

Hard Matrix Element

... most complicated diagram corresponds to



where all legs have different off-shellness + two parameter integrations: unknown analytically

(conformal tricks [Broadhurst 93', Pire, Szymanowski, S.W. 05', Pire, Segond, Szymanowski, S.W. 07'] usefull for \mathbb{P} but not applicable for \mathbb{O}
 \Rightarrow use MC integration (CUBA-library [Hahn 2005] provides **Vegas**, Suave, Cuhre, Divonne)

Hard Matrix Element

typical integral for Odderon exchange:

$$\int_0^1 dz \int_0^1 du z(1-z)(1-2z)^2 u(1-u)(1-2u)^2$$

$$\times \int d^2 k_1 \int d^2 k_2 \frac{1}{\vec{k}_1^2 \vec{k}_2^2 \vec{k}_3^2} \frac{\left((\vec{k}_1 - z\vec{p}_{2\pi})\vec{\epsilon}_z \right) \left((\vec{k}_2 - u\vec{p}_{2\pi})\vec{\epsilon}_u \right)}{\left((\vec{k}_1 - z\vec{p}_{2\pi})^2 + \mu_1^2 \right) \left((\vec{k}_2 - u\vec{p}_{2\pi})^2 + \mu_2^2 \right)}$$

[$z(u)$: longitudinal momentum fraction of quark of upper (lower) system, $k_{1,2,3}$: t -channel gluons, $\mu_1^2 = m_q^2 + z(1-z)Q^2$, $\vec{\epsilon}_{z,u}$: photon polarization vector]

Observables

θ dependence of 2π GDA:

- \mathbb{P} exchange \rightarrow C odd 2π system $\rightarrow \Phi^{I=1} \sim \cos\theta + \dots$
- \mathbb{O} exchange \rightarrow C even 2π system \rightarrow
 $\Phi^{I=0} \sim c_0 + c_2 \cos(2\theta) + \dots$

$$\int d\sigma(s, t, m_{2\pi}, m'_{2\pi}, \theta, \theta') \sim |\mathcal{M}_{\mathbb{P}}|^2 + |\mathcal{M}_{\mathbb{O}}|^2$$

Observables

θ dependence of 2π GDA:

- \mathbb{P} exchange $\rightarrow C$ odd 2π system $\rightarrow \Phi^{l=1} \sim \cos\theta + \dots$
- \mathbb{O} exchange $\rightarrow C$ even 2π system $\rightarrow \Phi^{l=0} \sim c_0 + c_2 \cos(2\theta) + \dots$

\Rightarrow consider double asymmetry:

$$\frac{\int \cos\theta \cos\theta' d\sigma(s, t, m_{2\pi}, m'_{2\pi}, \theta, \theta')}{\int d\sigma(s, t, m_{2\pi}, m'_{2\pi}, \theta, \theta')} \sim \frac{|\mathcal{M}_{\mathbb{O}} \mathcal{M}_{\mathbb{P}}|}{|\mathcal{M}_{\mathbb{P}}|^2 + |\mathcal{M}_{\mathbb{O}}|^2}$$

2π Distribution Amplitude

no experimental data on 2π GDA

starting point:

- expand GDA in Gegenbauer polynomials $C_n^{3/2}(2z - 1)$
(diagonalize QCD ERBL evolution kernel)

and Legendre polynomials $P_l(\beta \cos \theta)$, where $\beta = \sqrt{1 - \frac{4m_\pi^2}{m_{2\pi}^2}}$

$\zeta = \frac{1 + \beta \cos \theta}{2}$ = fraction of long. momenta $p_{2\pi}$ carried by π^+

- keep dominant contributions

2π Distribution Amplitude - isovector

Isovector case given by electromagnetic pion form factor

$$\Phi^{I=1}(z, \theta, m_{2\pi}) = 6z(1-z)\beta \cos\theta F_{\pi}(m_{2\pi}^2),$$

- modulus of F_{π} well measured in $e^+e^- \rightarrow \pi^+\pi^-$

2π Distribution Amplitude - isoscalar - ansatz I

For isoscalar case we use three ansätze - ansatz I:

- use phase shifts from elastic $\pi\pi$ scattering, moduli given by f_0 and f_2 resonance

[Hägler, Pire, Szymanowski, Teryaev 2002]

$$\Phi^{I=0}(z, \theta, m_{2\pi}) = 5z(1-z)(2z-1) \times \left(-\frac{3-\beta^2}{2} e^{i\delta_0(m_{2\pi})} |BW_{f_0}(m_{2\pi}^2)| + \beta^2 e^{i\delta_2(m_{2\pi})} |BW_{f_2}(m_{2\pi}^2)| P_2(\cos\theta) \right)$$

[BW : Breit-Wigner amplitude, P_2 : Legendre polynomial, δ_I phase shifts from elastic $\pi\pi$ scattering (experiment)]

2π Distribution Amplitude - isoscalar - ansatz II

For isoscalar case we use three ansätze - ansatz II:

- use phase shifts from elastic $\pi\pi$ scattering, moduli given by **Omnès** function

$$\Phi^{I=0}(z, \theta, m_{2\pi}) = 5z(1-z)(2z-1) \times \left(-\frac{3-\beta^2}{2} e^{i\delta_0(m_{2\pi})} f_0(m_{2\pi}^2) + \beta^2 e^{i\delta_2(m_{2\pi})} f_2(m_{2\pi}^2) P_2(\cos\theta) \right)$$

where

$$f_l(m_{2\pi}^2) = \exp \left(\pi l_l + \frac{m_{2\pi}^2}{\pi} \int_{4m_\pi^2}^{s_{\max}} ds \frac{\delta_l(s)}{s^2(s - m_{2\pi}^2 - i\epsilon)} \right)$$

$$l_l = \frac{1}{\pi} \int_{4m_\pi^2}^{s_{\max}} ds \frac{\delta_l(s)}{s^2}$$

2π Distribution Amplitude - isoscalar - ansatz III

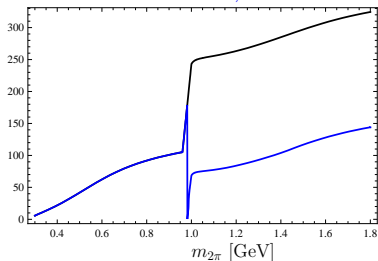
For isoscalar case we use three ansätze - ansatz III:

- like ansatz II but phase shift $\delta_{T,I}$ from \mathcal{T} -matrix

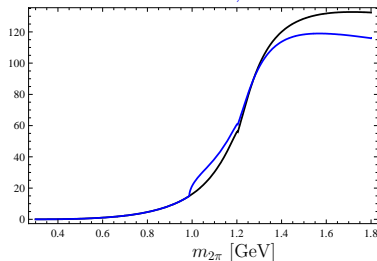
$$\frac{\eta_I e^{2i\delta_I} - 1}{2i} \quad [\text{Warkentin, Diehl, Ivanov, Schäfer 2007}]$$

- motivation: phase of form factor $\Gamma(s) = \langle \pi\pi | m_u \bar{u}u + m_d \bar{d}d | 0 \rangle$ follows above $K\bar{K}$ threshold rather $\delta_{T,I}$ than δ_I
[Ananthanarayan et.al. 2004]

δ_0 and $\delta_{T,0}$



δ_2 and $\delta_{T,2}$



2π Distribution Amplitude - isoscalar - ansatz III

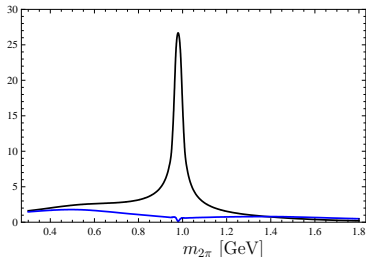
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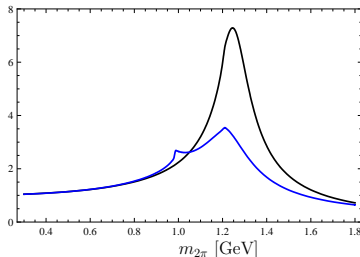
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$|f_0|$ from δ_0 and $\delta_{T,0}$



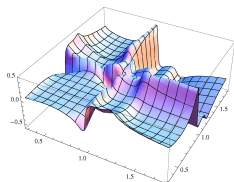
$|f_2|$ from δ_2 and $\delta_{T,2}$



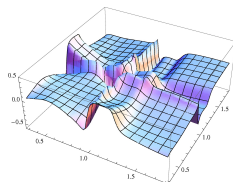
Double Differential

at given t asymmetry depends on $m_{2\pi}$ of both 2π systems

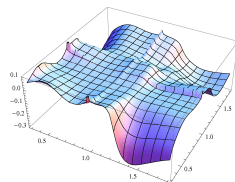
ansatz I



ansatz II



ansatz III



double differential cross section hard to measure . . .

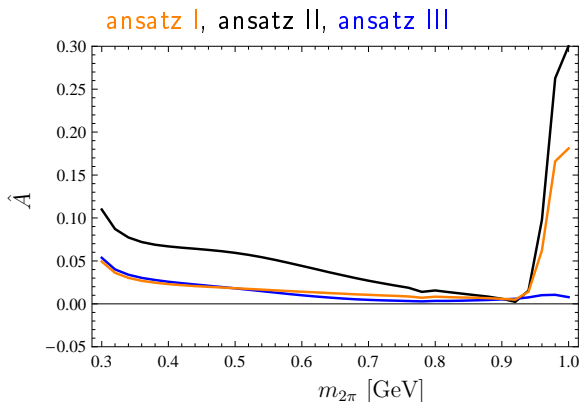
Definition Single Differential

... integrate asymmetry for one $\pi^+\pi^-$ pair

$$\hat{A}(m_{2\pi}, t) \equiv \frac{\int_{m_{\min}^2}^{m_{\max}^2} dm'_{2\pi} \int d\cos\theta d\cos\theta' |\mathcal{M}|^2 \cos\theta \cos\theta'}{\int_{m_{\min}^2}^{m_{\max}^2} dm'_{2\pi} \int d\cos\theta d\cos\theta' |\mathcal{M}|^2}$$

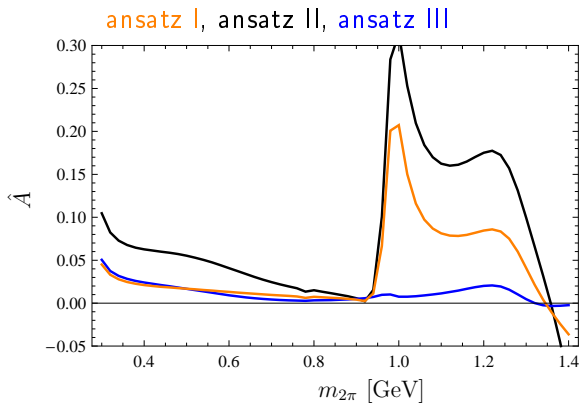
Single Differential at $t = -1\text{GeV}^2$

To get single differential observable: integrate asymmetry for one $\pi^+\pi^-$ pair from .3 GeV to $m_\rho=776$ MeV



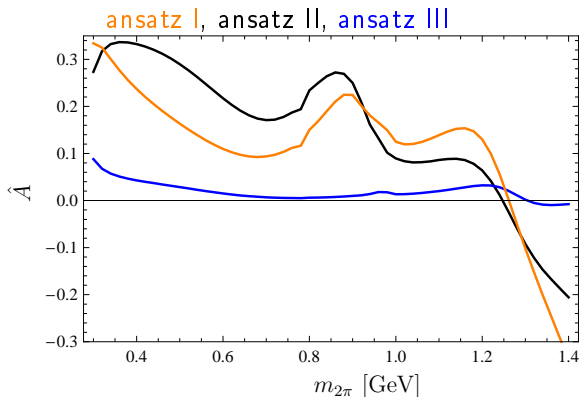
Single Differential at $t = -2\text{GeV}^2$

Integrate asymmetry for one $\pi^+\pi^-$ pair from .3 GeV to $m_\rho=776$ MeV



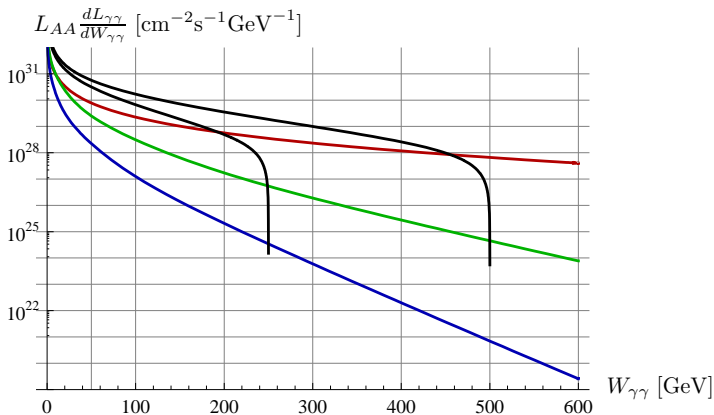
Single Differential at $t = -2\text{GeV}^2$

Integrate asymmetry for one $\pi^+\pi^-$ pair from m_{f_0} to $m_{\text{max}}=1400$ MeV



Effective Luminosities

ee at ILC (250 & 500 GeV), pp at LHC, ArAr at LHC, PbPb at LHC



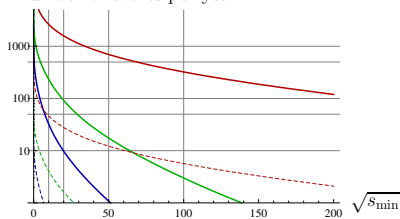
Rates at LHC

Rates at LHC per year: **PbPb** (1 month), **ArAr** (1 month), **pp** (6 months) after $\int_{s_{\min}} ds_{\gamma\gamma} \int^{t_{\min}} dt$

$t = -1 \text{ GeV}$

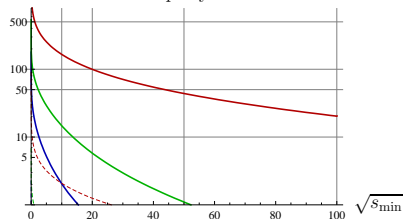
$t = -2 \text{ GeV}$

number of events per year



dotted: just Odderon exchange

number of events per year

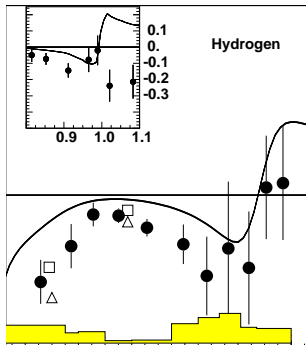


Summary and Outlook

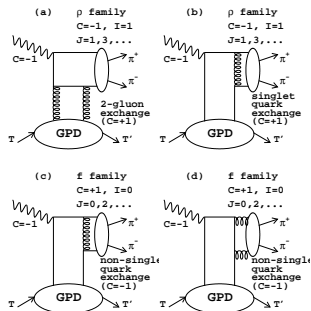
- asymmetry in $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$: a promising candidate to find perturbative Odderon in **ultraperipheral** events
- only soft input: need for 2π -GDA from experiment
very recent results from **CLAS @ JLab**: $f_0(980)$ **seen** \Rightarrow scenarii I or II favored, and thus high asymmetry expected
- **background**: $\mathbb{P} - \gamma$ and $\mathbb{P} - \mathbb{P}$ **peripheral** events
 - selection easier in heavy ion mode (detection of neutrons produced by giant dipole resonance), but low cross-section
 - Coulomb pole at $t = 0$ for $\gamma - \gamma$ mode \rightarrow cut in p_t of $\pi^+\pi^-$ pairs to separate peripheral and ultraperipheral events (but smearing due to beam size +initial running condition: see **Piotrkowski**)
- questions for **LHC**:
 - pile-up in the high luminosity mode
 - tagging on π^\pm of low $p_t \sim 1 - 2\text{GeV}$ very difficult

f_0

asymmetry in $\pi^+\pi^-$ production in ep scattering [HERMES 2004]



- big: calculation without f_0 [Lehmann-Dronke et.al. 2000,2001]
- inset: calculation with f_0 [Hägler et.al. 2002]



Operator Definition of GDA

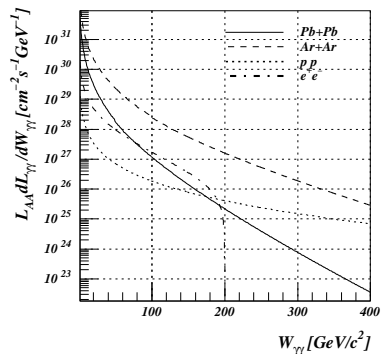
$$\Phi(z, \zeta, m_{2\pi}^2) = \int \frac{d\lambda}{2\pi} e^{-iz\lambda(q'n)} \langle \pi^+(k) \pi^-(k') | \bar{q}(\lambda n) \not{n} q(0) | 0 \rangle$$

with $2\zeta - 1 = \beta \cos \theta$, n : lightlike auxiliary vector, $q' = k + k'$

effective photon flux in the literature

Most recent report on UPC: K. Hencken *et al.*, Phys. Rept. **458** (2008) 1: pp with $L = 10^7 \text{ mb}^{-1}\text{s}^{-1}$ and $\sqrt{s} = 14000 \text{ GeV}$

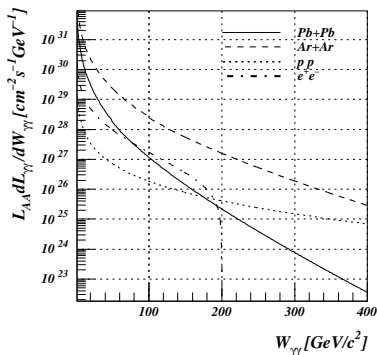
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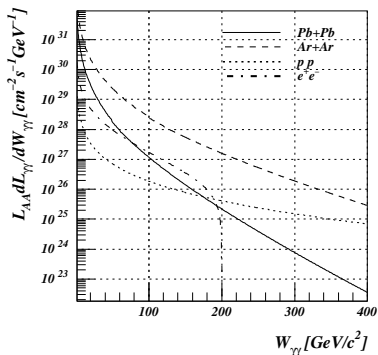
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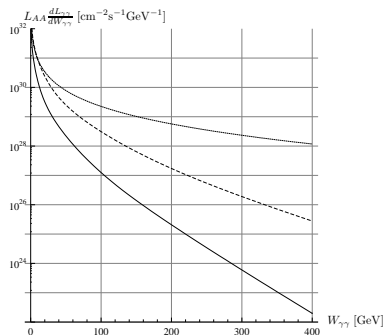
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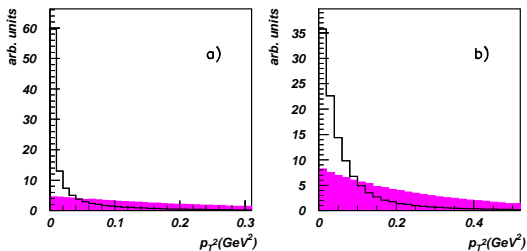


with design Lumi for all

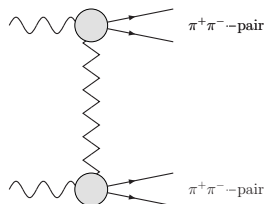


Tagging the two photon production

[Piotrkowski: Phys. Rev. D (2001) 63, 071502]



The Process



- exclusive production of two $\pi^+\pi^-$ pairs \rightarrow colorless exchange between them
- C-parity of $\pi^+\pi^-$ pair not fixed
 - $\pi^+\pi^-$ pair C odd $\Rightarrow \mathbb{P}$ omeron
 - $\pi^+\pi^-$ pair C even $\Rightarrow \mathbb{O}$ dderon
- 2π GDA depends on polar angle θ in rest frame of 2π

$$\frac{\int \cos \theta_1 \cos \theta_2 d\sigma(s, t, m_{2\pi,1}, m_{2\pi,1}, \theta_1, \theta_2)}{\int d\sigma(s, t, m_{2\pi,1}, m_{2\pi,1}, \theta_1, \theta_2)} \sim \frac{|\mathcal{M}_{\mathbb{O}}\mathcal{M}_{\mathbb{P}}|}{|\mathcal{M}_{\mathbb{P}}|^2 + |\mathcal{M}_{\mathbb{O}}|^2}$$

Single Differential at $t = -2\text{GeV}^2$

Integrate asymmetry for one $\pi^+\pi^-$ pair from $.3\text{GeV}$ to $m_\rho=776\text{MeV}$

ansatz I, ansatz II, ansatz III for isoscalar GDA

