

Hard Pomeron-Odderon effects in the production of $\pi^+\pi^-$ pairs in ultraperipheral collisions

[Phys.Rev.D78:094009]

Florian Schwennsen

LPT, Université Paris-Sud 11 and CPhT, École Polytechnique



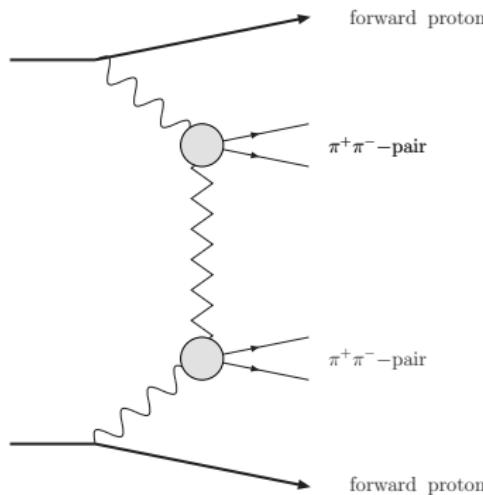
in collaboration with B. Pire, L. Szymanowski, S. Wallon

DIS 2009, Madrid, 26-30 April

Motivation

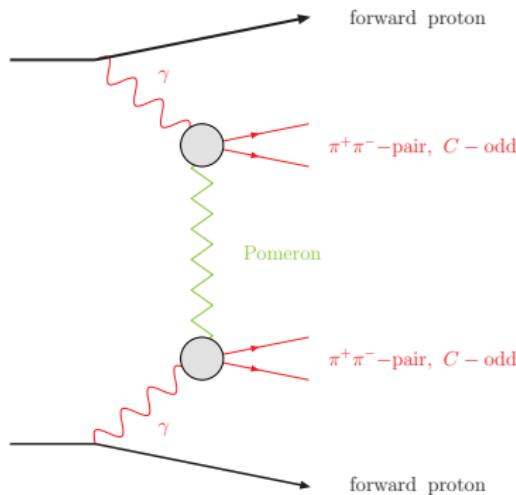
- colorless gluonic exchange
 - $C = +1$: Pomeron, in pQCD described by BFKL equation
 - $C = -1$: Odderon, in pQCD described by BKP equation
- best but still weak evidence for \textcircled{O} : $p p$ and $p \bar{p}$ data at ISR
- no evidence for perturbative \textcircled{O}
- \textcircled{O} exchange much weaker than \mathbb{P} \Rightarrow two strategies in QCD
 - consider observables, where \mathbb{P} vanishes due to C -parity conservation $\sim |\mathcal{M}_{\textcircled{O}}|^2$
 - consider observables sensitive to the interference between \mathbb{P} and $\textcircled{O} \sim \text{Re } \mathcal{M}_{\mathbb{P}} \mathcal{M}_{\textcircled{O}}^*$
- $\mathbb{P}/\textcircled{O}$ coupling to proton not perturbatively calculable \Rightarrow photon collisions

The Process



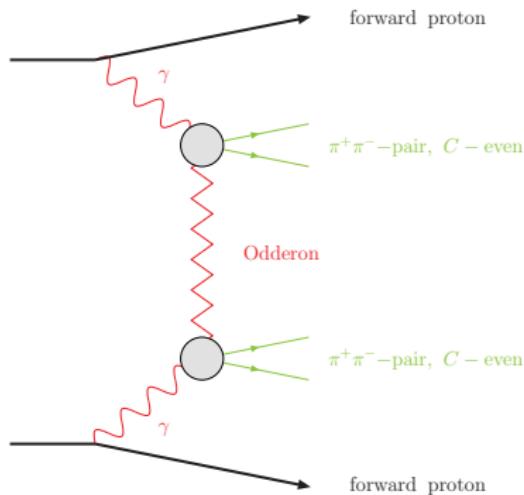
- in ultra-peripheral collisions at the LHC: hadrons as a source of almost real photons
- exclusive production of two $\pi^+\pi^-$ pairs → colorless exchange between them
- C-parity of $\pi^+\pi^-$ pair not fixed

The Process



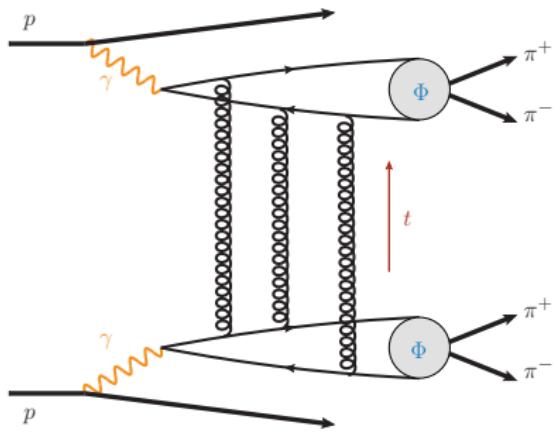
- in ultraperipheral collisions at the LHC: hadrons as a source of almost real photons
- exclusive production of two $\pi^+\pi^-$ pairs \rightarrow colorless exchange between them
- C-parity of $\pi^+\pi^-$ pair not fixed

The Process



- in ultraperipheral collisions at the LHC: hadrons as a source of almost real photons
- exclusive production of two $\pi^+\pi^-$ pairs \rightarrow colorless exchange between them
- C -parity of $\pi^+\pi^-$ pair not fixed

Kinematics, Framework



- Bremsstrahlung: photon virtuality $Q^2 \approx 0$, flux by Weizsäcker-Williams
- high energy limit $s_{\gamma\gamma} \gg |t| \gg \Lambda_{\text{QCD}}^2$
- photon impact factor known (in contrast to hadron IF)
- model $\mathbb{P} (\mathbb{O})$ by 2 (3) gluons
- collinear approximation $\rightarrow 2\pi$ 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 $\gamma\gamma \rightarrow (\pi^+\pi^-)(\pi^+\pi^-)$:

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

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 $\rightarrow \Phi^{I=0} \sim c_0 + c_2 \cos(2\theta) + \dots$

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

Observables

θ dependence of 2π GDA:

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

\Rightarrow consider double asymmetry:

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

2π Distribution Amplitude

no experimental data on 2π GDA

starting point:

- expand GDA in Gegenbauer polynomials $C_n^{3/2}(2z - 1)$ and Legendre polynomials $P_l(\beta \cos \theta)$, where $\beta = \sqrt{1 - \frac{4m_\pi^2}{m_{2\pi}^2}}$
- 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

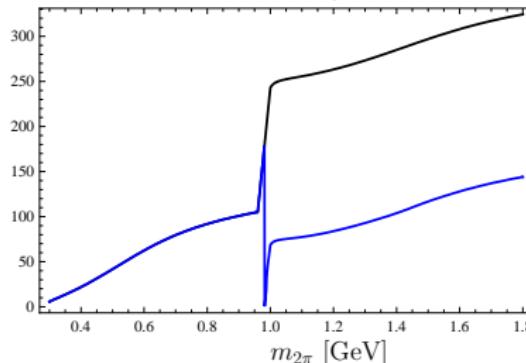
$$f_I(m_{2\pi}^2) = \exp \left(\pi I_I + \frac{m_{2\pi}^2}{\pi} \int_{4m_\pi^2}^{s_{\max}} ds \frac{\delta_I(s)}{s^2(s - m_{2\pi}^2 - i\epsilon)} \right)$$
$$I_I = \frac{1}{\pi} \int_{4m_\pi^2}^{s_{\max}} ds \frac{\delta_I(s)}{s^2}$$

2π Distribution Amplitude - isoscalar - ansatz III

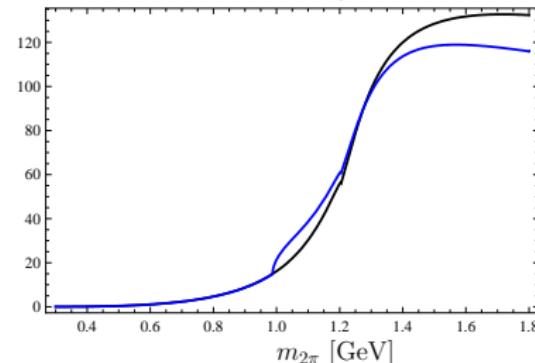
For isoscalar case we use three ansätze - ansatz III:

- like ansatz II but phase shift $\delta_{T,I}$ from \mathcal{T} -matrix
 $\frac{\eta_I e^{2i\delta_I} - 1}{2i}$ [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 $\delta_{T,2}$

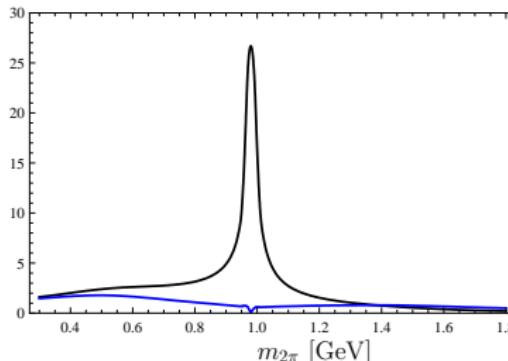


2π Distribution Amplitude - isoscalar - ansatz III

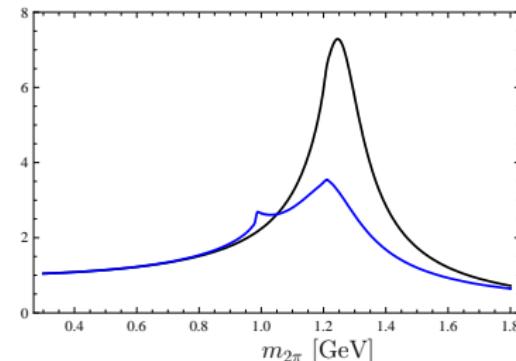
For isoscalar case we use three ansätze - ansatz III:

- like ansatz II but phase shift $\delta_{T,I}$ from \mathcal{T} -matrix
 $\frac{\eta_I e^{2i\delta_I} - 1}{2i}$ [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]

$|f_0|$ from δ_0 and $\delta_{T,0}$



$|f_2|$ from δ_2 and $\delta_{T,2}$



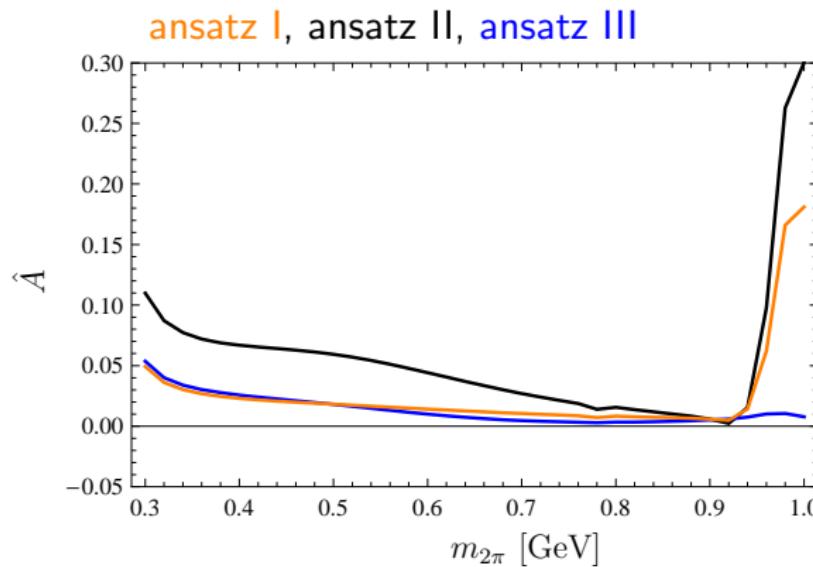
Definition Single Differential

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

$$\hat{A}(m_{2\pi,1}, t) \equiv \frac{\int_{m_{\min}^2}^{m_{\max}^2} dm_{2\pi,2}^2 \int d \cos \theta_1 d \cos \theta_2 |\mathcal{M}|^2 \cos \theta_1 \cos \theta_2}{\int_{m_{\min}^2}^{m_{\max}^2} dm_{2\pi,2}^2 \int d \cos \theta_1 d \cos \theta_2 |\mathcal{M}|^2}$$

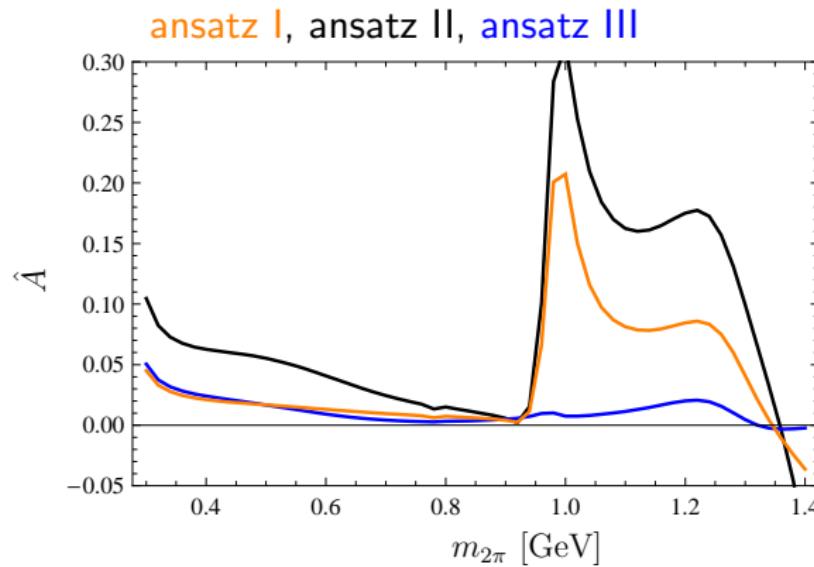
Single Differential at $t = -1\text{GeV}^2$

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



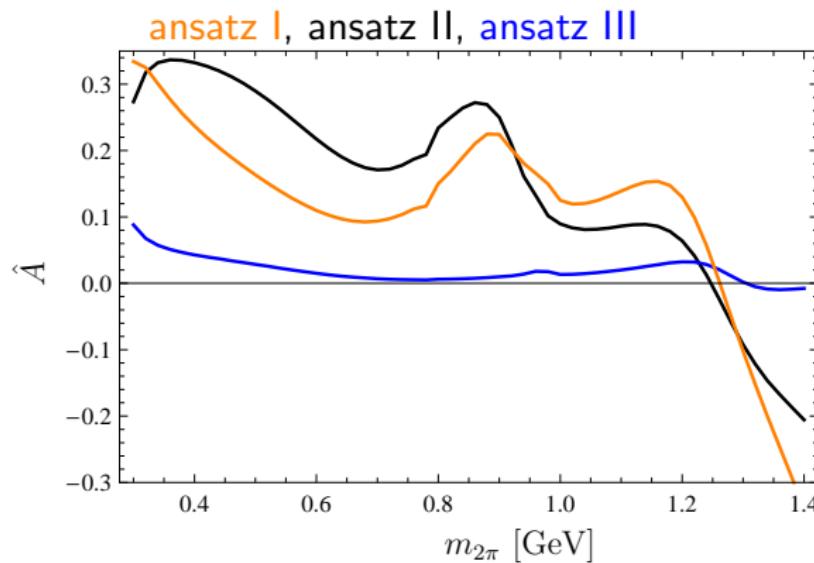
Single Differential at $t = -2\text{GeV}^2$

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



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

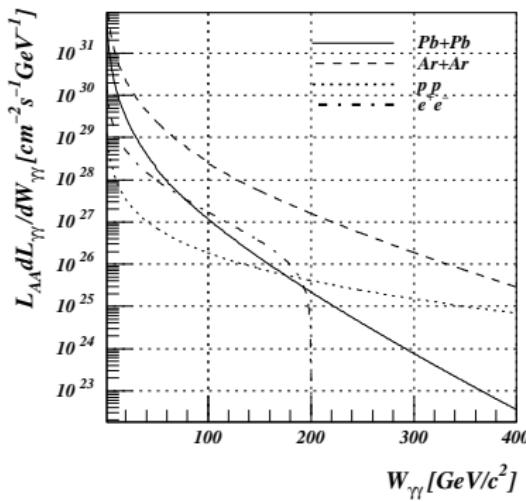
Integrate asymmetry for one $\pi^+\pi^-$ pair from m_{f_0} to $m_{\max}=1400\text{MeV}$



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 $\sqrt{s} = 14000 \text{ GeV}$

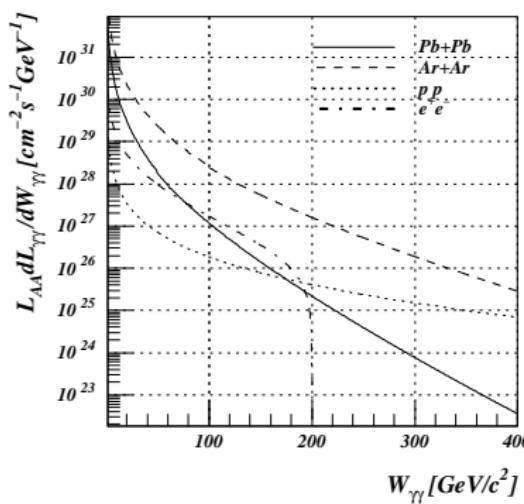
Hencken et.al.



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 $\sqrt{s} = 14000 \text{ GeV}$
infact copied from G. Baur *et.al.*, Phys. Rept. **364** (2002) 359: pp with $L = 14000 \text{ mb}^{-1}\text{s}^{-1}$ (?) and $\sqrt{s} = 14000 \text{ GeV}$

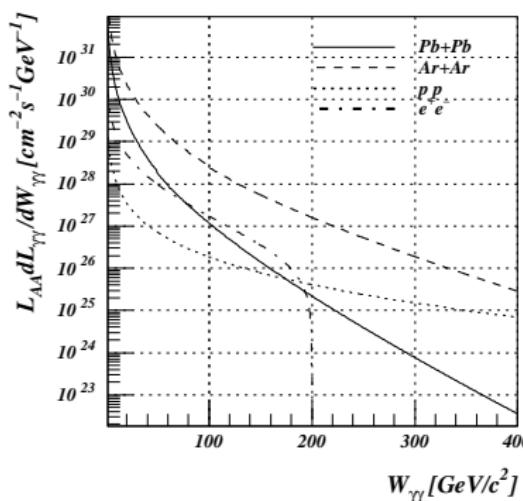
Baur et.al.



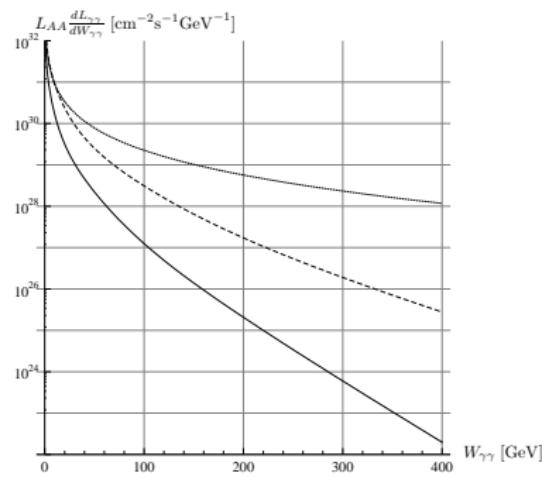
effective photon flux in the literature

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 $\sqrt{s} = 14000 \text{ GeV}$
infact copied from G. Baur *et.al.*, Phys. Rept. **364** (2002) 359: pp with $L = 14000 \text{ mb}^{-1}\text{s}^{-1}$ (?) and $\sqrt{s} = 14000 \text{ GeV}$

Baur et.al.



with design Lumi for all



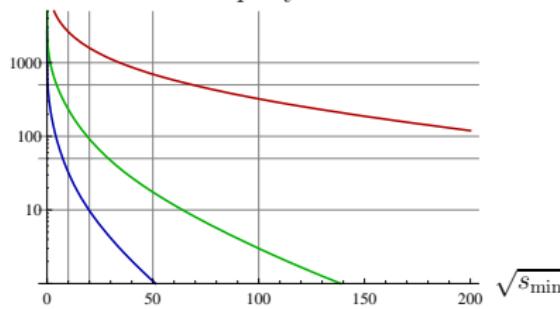
Rates at LHC

Rates at LHC per year: PbPb (1 month), ArAr (1 month), pp (6 months)

after $\int_{s_{\min}} ds_{\gamma\gamma} \int^{t_{\min}} dt$

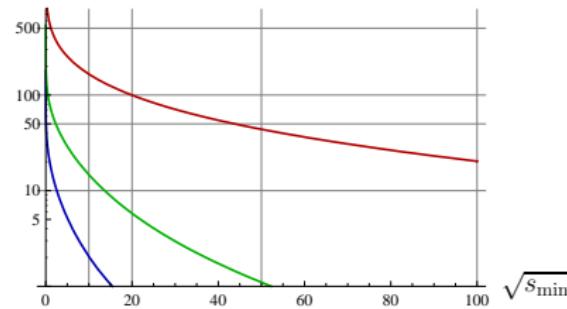
$$t_{\min} = -1 \text{ GeV}$$

number of events per year



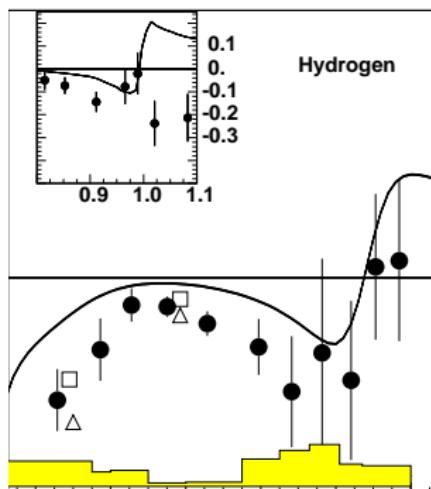
$$t_{\min} = -2 \text{ GeV}$$

number of events per year

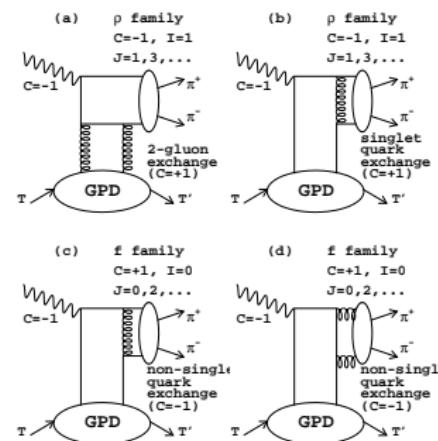


Summary and Outlook

- asymmetry in $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$: a promising candidate to find perturbative Odderon
- only soft input: need for 2π -GDA from experiment

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]



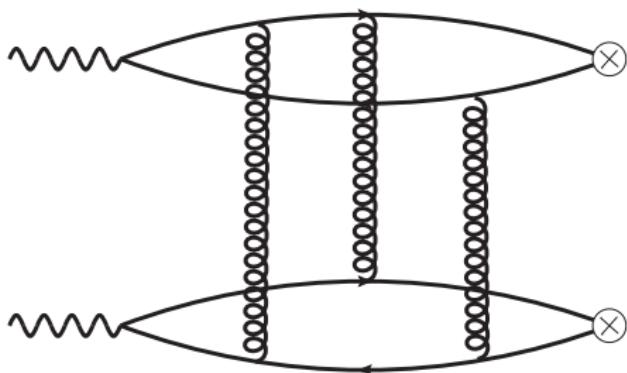
Operator Definition of GDA

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

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

Hard Matrix Element

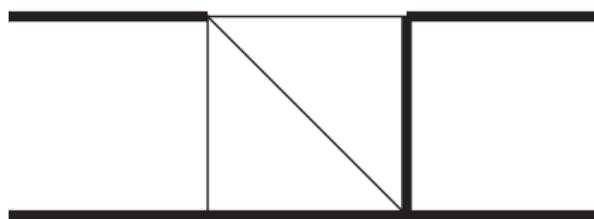
for Odderon: $2 \rightarrow 2$ with four loops



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

⇒ use MC integration (CUBA-library [[Hahn 2005](#)] provides **Vegas**, **Suave**, **Cuhre**, **Divonne**)

Hard Matrix Element

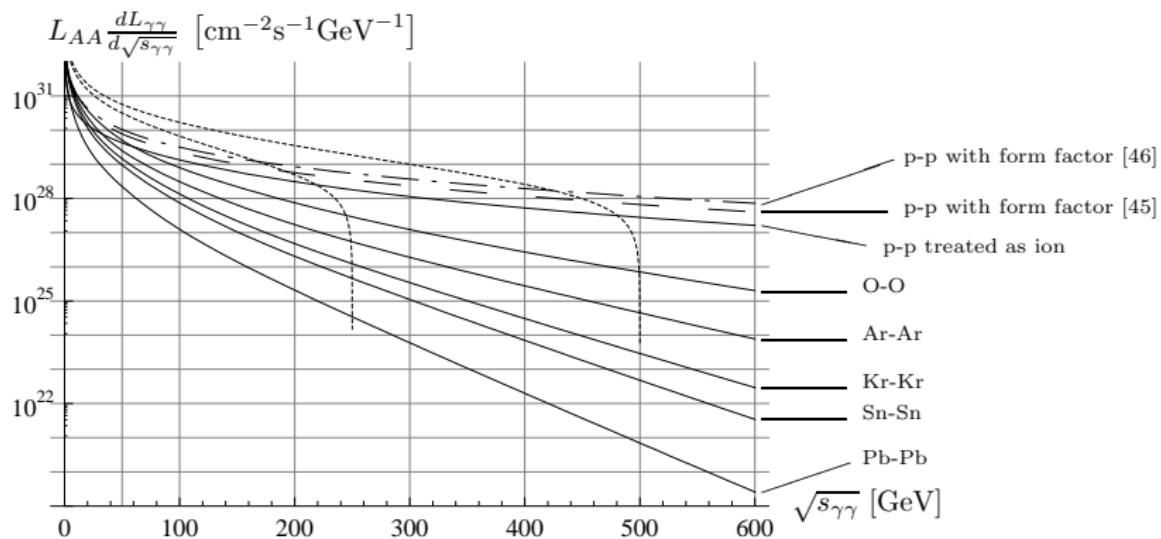
typical integral for Odderon exchange:

$$\int_0^1 dz \int_0^1 du z(1-z)(1-2z)^2 u(1-u)(1-2u)^2 \\ \times \int d^2 k_1 \int d^2 k_2 \frac{1}{\vec{k}_1^2 \vec{k}_2^2 \vec{k}_3^2} \frac{\left((\vec{k}_1 - z\vec{p}_{2\pi})\vec{\epsilon}_z\right) \left((\vec{k}_2 - u\vec{p}_{2\pi})\vec{\epsilon}_u\right)}{\left((\vec{k}_1 - z\vec{p}_{2\pi})^2 + \mu_1^2\right) \left((\vec{k}_2 - u\vec{p}_{2\pi})^2 + \mu_2^2\right)}$$

[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]

Effective Luminosities

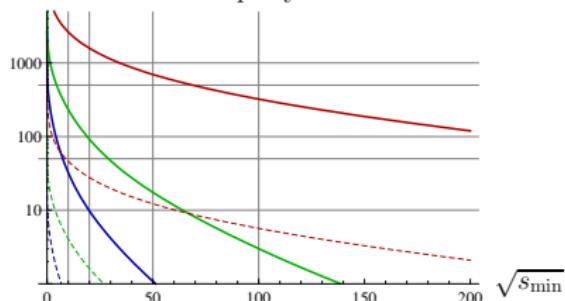


Rates at LHC

Rates at LHC per year: PbPb (1 month), ArAr (1 month), pp (6 months)

$$t = -1 \text{ GeV}$$

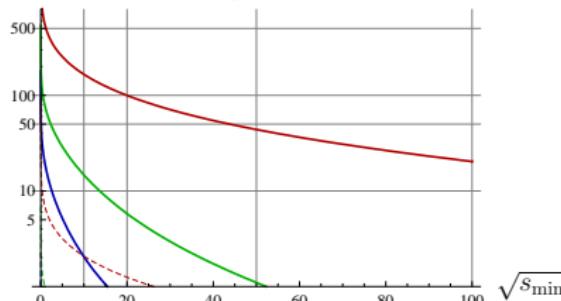
number of events per year



dotted: just Odderon exchange

$$t = -2 \text{ GeV}$$

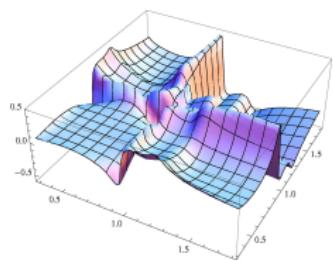
number of events per year



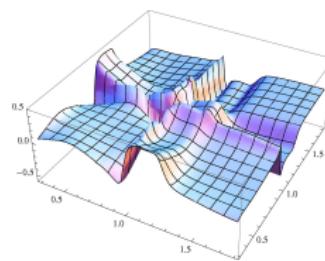
Double Differential

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

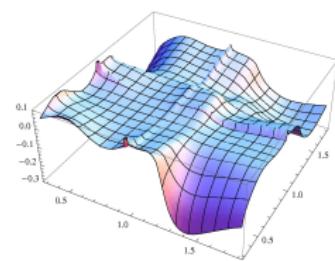
ansatz I



ansatz II



ansatz III



double differential cross section hard to measure ...