The nonperturbative Odderon in exclusive Pion-Photoproduction at e^+e^- colliders

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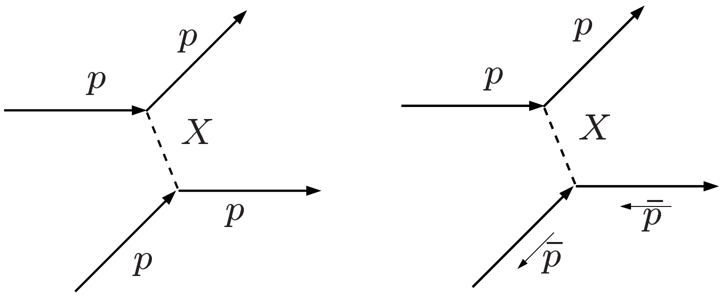
Odderon from Regge theory

- Odderon is the P=C=-1 partner of the Pomeron trajectory; couples differently to particles and antiparticles (in contrast to Pomeron)
- first postulated in 1973 by Nicolescu et al to explain differences between pp and $p\bar{p}$ total cross sections
- So far, only seen in differences between $\frac{d\sigma}{dt}$ for pp and $p\bar{p}$ elastic scattering (Donnachie et al 1973)
- expected (Berger et al 1999/ 2000), but not measured (H1 collaboration 2001) in pion-photoproduction at H1
- in pQCD described by 3-gluon-exchange (Bartels 1980, Kwiecinski et al 1980)

$\Rightarrow$ new option: investigation of processes with Odderon as dominant contribution

Model for the Odderon

- Odderon propagator
  consider pp and $p\bar{p}$ scattering:



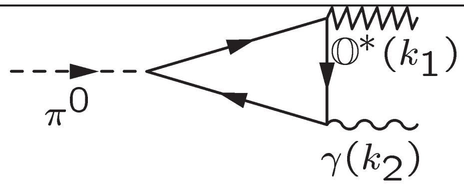
ansatz: decompose $\mathcal{M}^{(pp)}$, $\mathcal{M}^{(p\bar{p})}$ into helicity amplitudes, assume helicity conservation
$\Longrightarrow$ effective Regge Ansatz for Pomeron and Odderon propagators
(Donnachie, Landshoff 1984, Kilian et al 1997)

$$\boxed{-i\,\eta_{\mathbb{O}}\left[(-is/s_0)^{(\alpha_{\mathbb{O}}(t)-1)}\right]}$$

$\eta_{\mathbb{O}} = \pm 1$ is yet undetermined phase

$$\boxed{\begin{array}{ll} s_0 = 1\text{GeV}^2; & \alpha_{\mathbb{O}}(t) = \alpha_{\mathbb{O}}(0) + \alpha'_{\mathbb{O}}(t) \\ \alpha_{\mathbb{O}}(0) = 1.0; & \alpha'_{\mathbb{O}} = 0.25\text{GeV}^{-2} \end{array}}$$

- $\gamma\mathbb{O}^*\pi^0$ coupling



(a) from triangle-anomaly $\pi^0 \longrightarrow \gamma\gamma$:

$$\Gamma^{\gamma\gamma\pi^0}_{\mu\nu} = \frac{\alpha}{\pi\, f_{\pi^0}}\,\varepsilon_{\mu\nu\rho\sigma}\, k_1^{\rho} k_2^{\sigma};\ \ f_\pi = 93\,\mathrm{MeV}$$

(b) $\gamma\mathbb{O}\pi^0$ coupling
$\Psi_{\pi^0} \sim u\bar{u} - d\bar{d}$, coupling of Odderon charge-blind (Kilian et al 1997):

$$\frac{\Gamma^{\gamma\gamma\pi^0}}{\Gamma^{\gamma\mathbb{O}\pi^0}} = 3\,\frac{\beta_{\mathbb{O}}}{e}$$

$\beta_{\mathbb{O}}$ Odderon coupling constant.

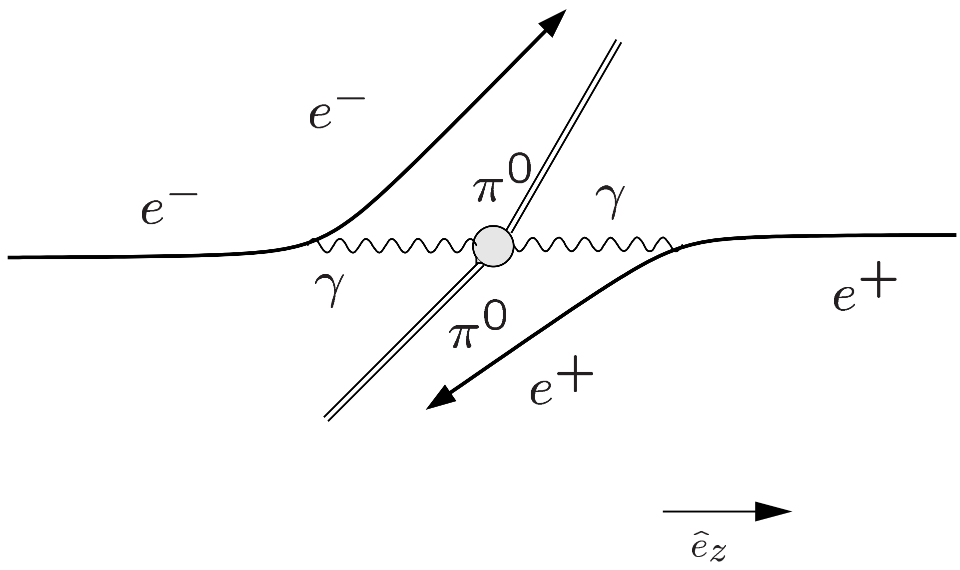
(c) virtuality of exchange particle: (Brodsky et al 1979,1980, 1981)

$$\frac{\alpha}{\pi\, f_\pi} \longrightarrow \frac{\alpha}{\pi\, f_\pi}\,\frac{1}{1+Q^2/8\pi^2 f_\pi^2}$$

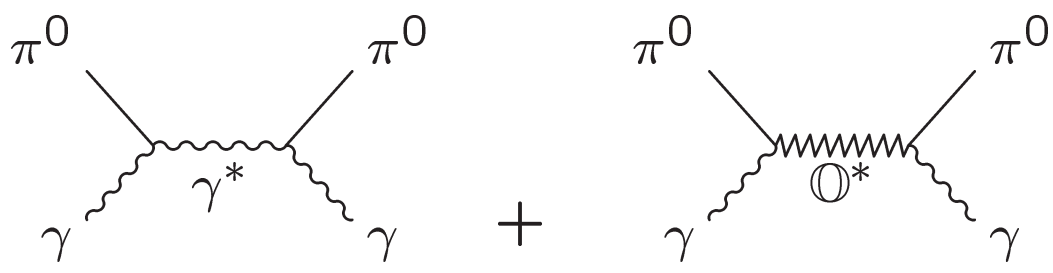
$$\boxed{\Gamma^{\gamma\,\mathbb{O}^*\,\pi^0}_{\mu\nu} = \underbrace{\frac{\alpha}{\pi\, f_{\pi^0}}\,\varepsilon_{\mu\nu\rho\sigma}\, k_1^{\rho} k_2^{\sigma}}_{(a)}\;\underbrace{\frac{1}{1-k_1^2/8\pi^2 f_{\pi^0}}}_{(b)}\;\underbrace{\frac{\beta_{\mathbb{O}}}{e}\, r_{\pi^0}}_{(c)}}$$

Investigated reaction: $\gamma\gamma \longrightarrow \pi^0\pi^0$

Direct test for the Odderon



Feynman diagrams of inner reaction:



(+ crossed diagrams).

Detector cuts

- angular cuts: $|\cos\theta| \leq \cos\theta_{\text{max}}$ (scattering angle),
  energy cuts: $E_{\pi^0} \geq E_{min}$ (min. detector energy).

- typical values:

$Experiment$	$\lvert\cos\theta\rvert_{max}$	E_{min} [GeV]
$TESLA(e^+e^-/\gamma\gamma)$	0.98	0.5
$OPAL(e^+e^-)$	0.81	0.4
$BaBar(e^+e^-)$	0.96; 0.77	0.08

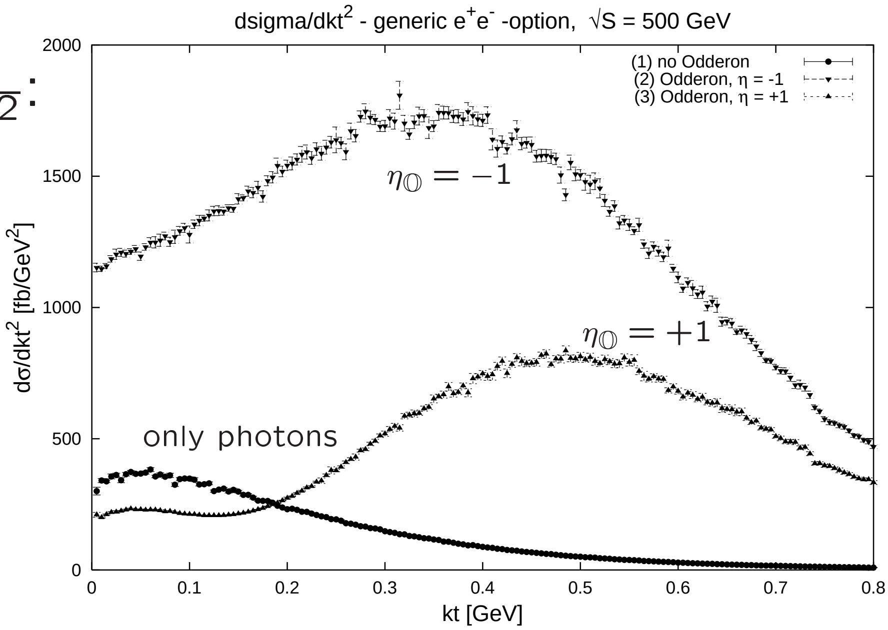
- angular cuts very strongly limit magnitude of total cross sections

$(cos\theta)_{max}$	σ/σ_{nocut}
0.98	0.6 – 0.7
0.9	0.3 – 0.4

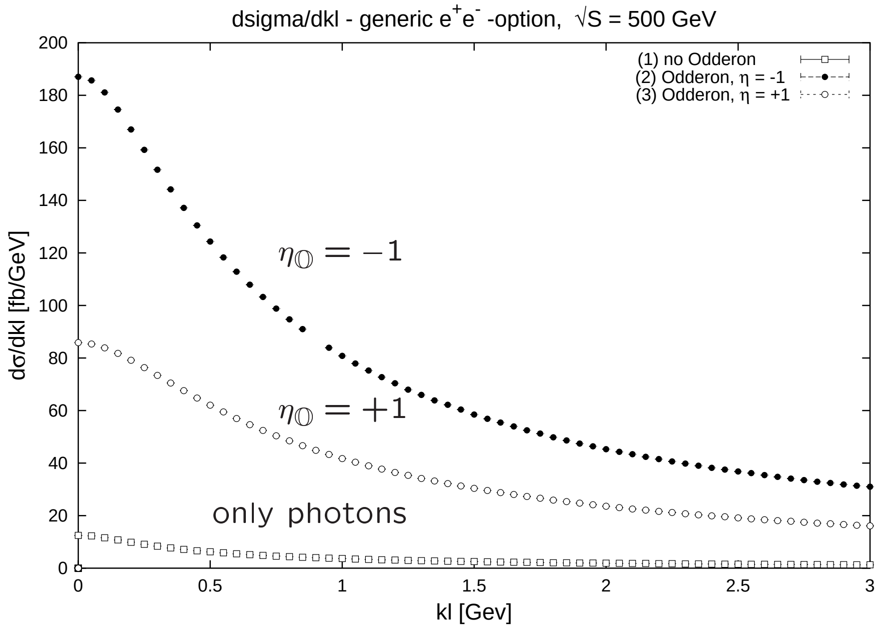
- energy cuts determine shape of differential cross sections; “interesting physics”, i.e. parameter determination and phase distinction, only possible for $E_{min} \leq 0.5$ GeV

Generic results; $\sqrt{S} = 500\,\text{GeV}$

- $\frac{d\sigma}{d|k_t|^2}$:



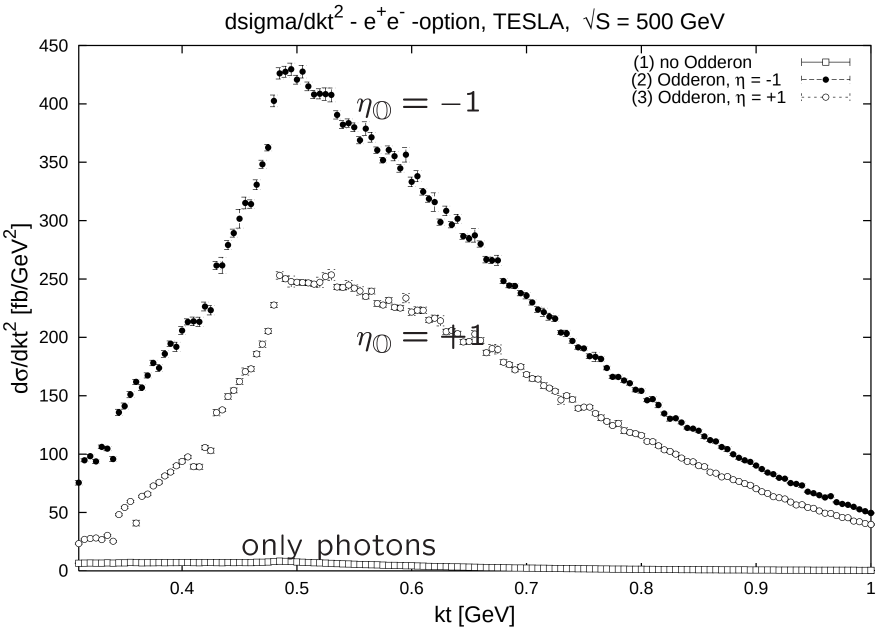
- $\frac{d\sigma}{dk_l}$:



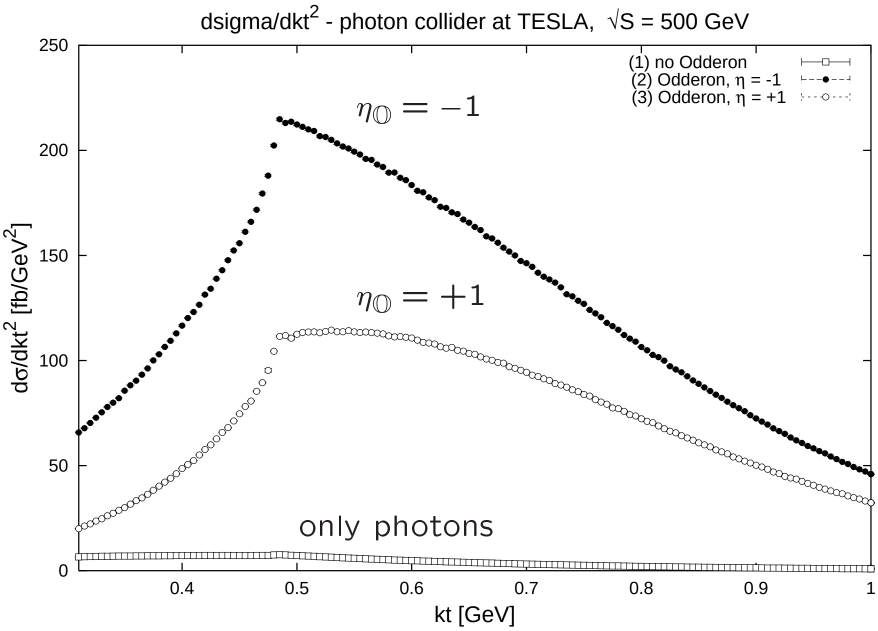
$\Longrightarrow$ $\boxed{\text{results for } \frac{d\sigma}{d|k_t|^2} \text{ more significant !!}}$

Results for TESLA; $\sqrt{S}$ = 500 GeV

TESLA (e^+e^-)

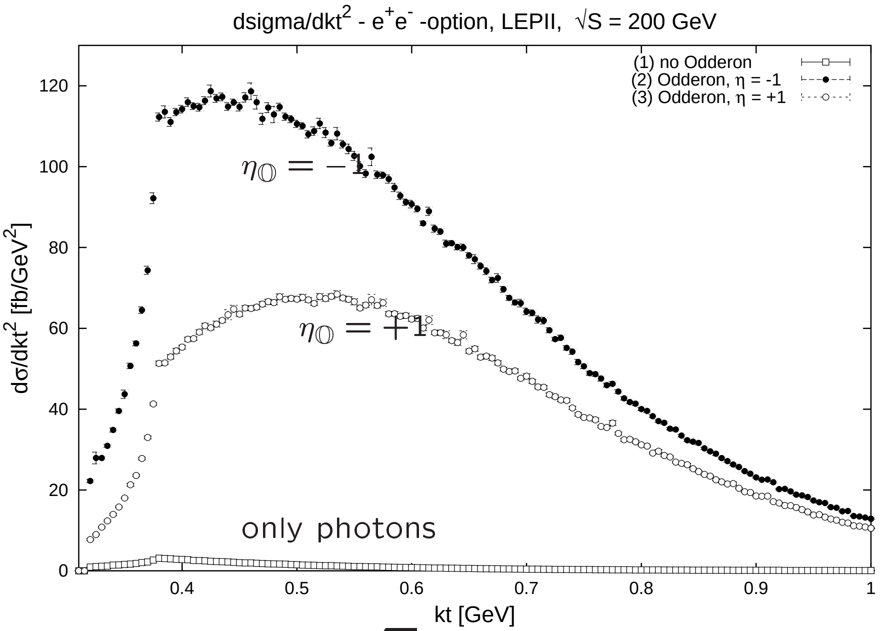


TESLA ($\gamma\gamma$)

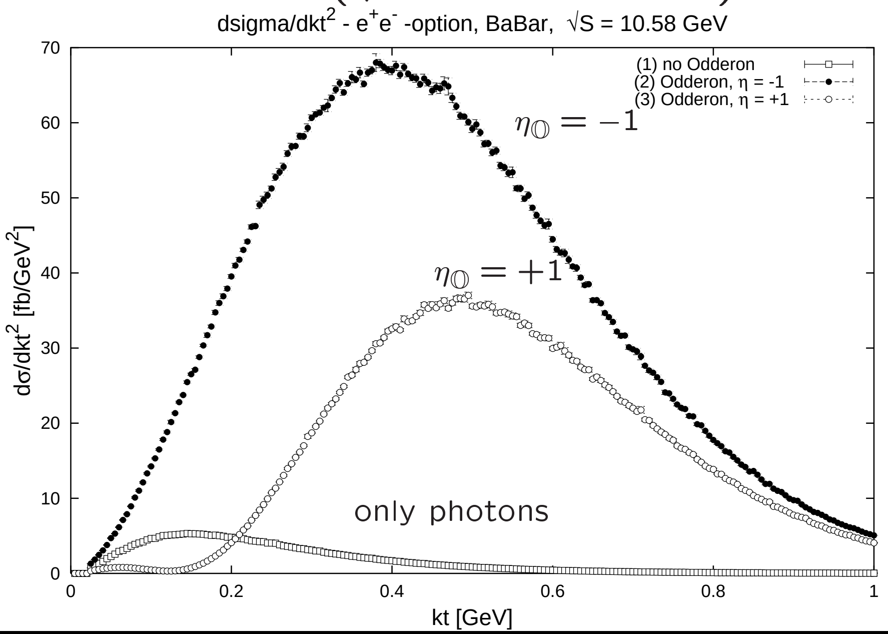


Results for OPAL and BaBar

OPAL (LEP II, $\sqrt{S} = 200\,\mathrm{GeV}$)



BaBar ($\sqrt{S} = 10.58\,\mathrm{GeV}$)



$\Longrightarrow$ BaBar offers best environment due to low energy cuts

Parameter variation

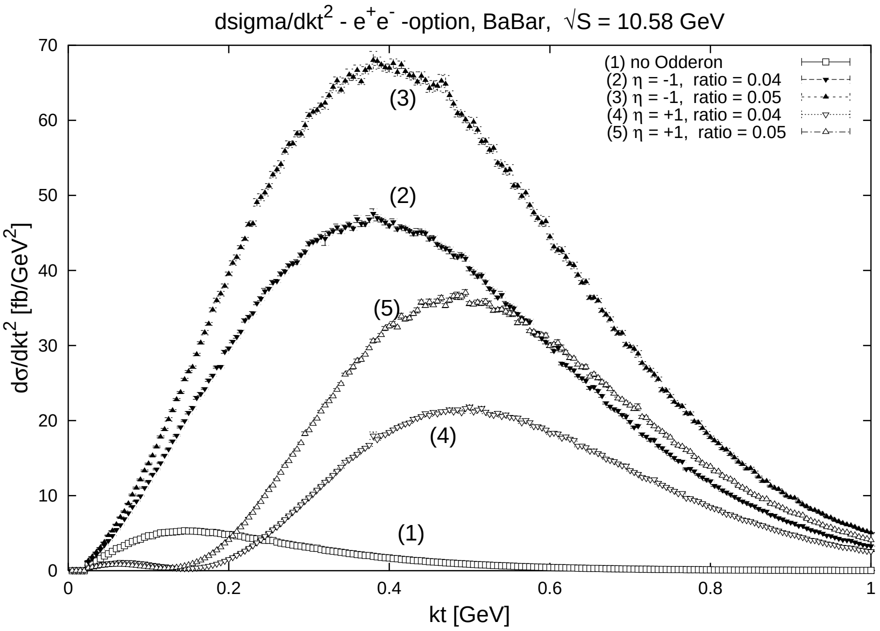
- 3 unknown parameters:
  1) $\alpha_{\mathbb{O}}(0)$, $\alpha'_{\mathbb{O}}$ (Regge trajectory of Odderon)
  2) $\beta_{\mathbb{O}}$ (Odderon coupling)
- restriction due to dispersion relations: (Covolan et al 1993)

$$|\rho^{(pp)}(s) - \rho^{(\bar{p}p)}(s)| \lesssim 0.05$$

for $\sqrt{s} \geq 100\,\text{GeV}$ and with $\rho = \frac{Re\mathcal{M}}{Im\mathcal{M}}$.

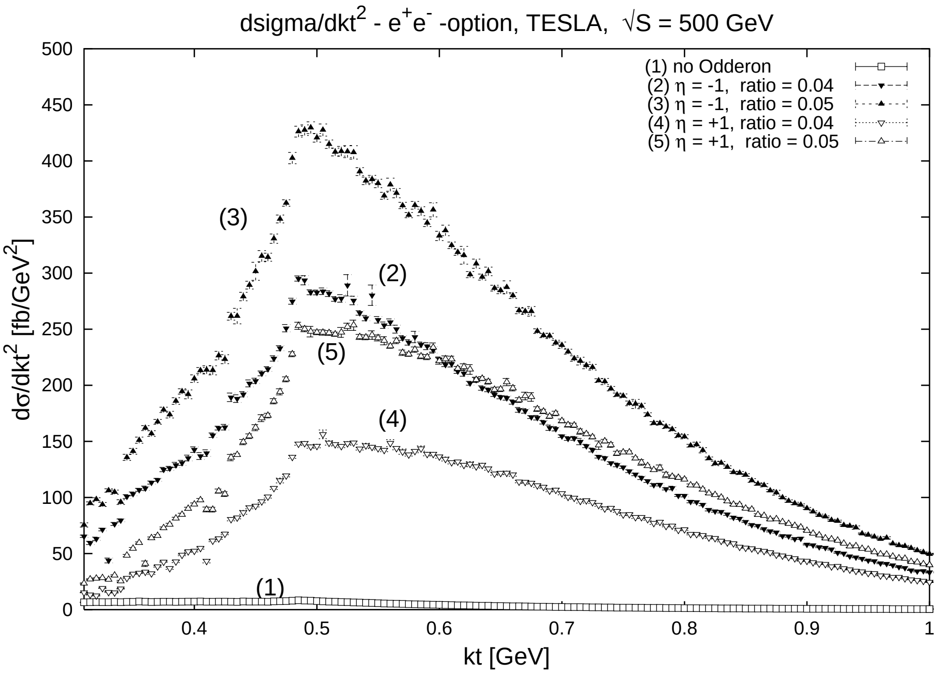
Variation of $\beta_{\mathbb{O}}$

$$\sigma \propto (\beta_{\mathbb{O}})^4; \Longrightarrow \text{strong effects !!}$$

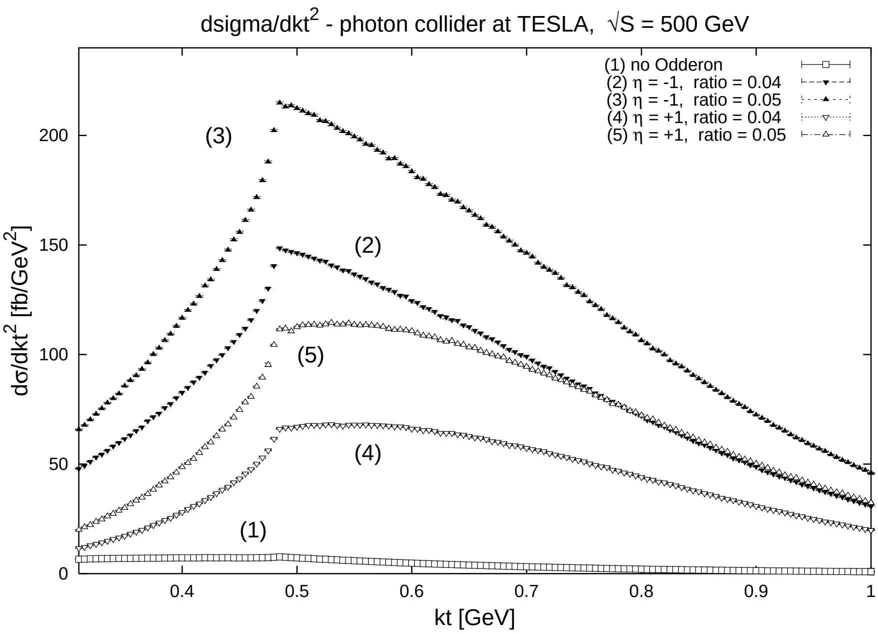


Results for TESLA

- e^+e^-

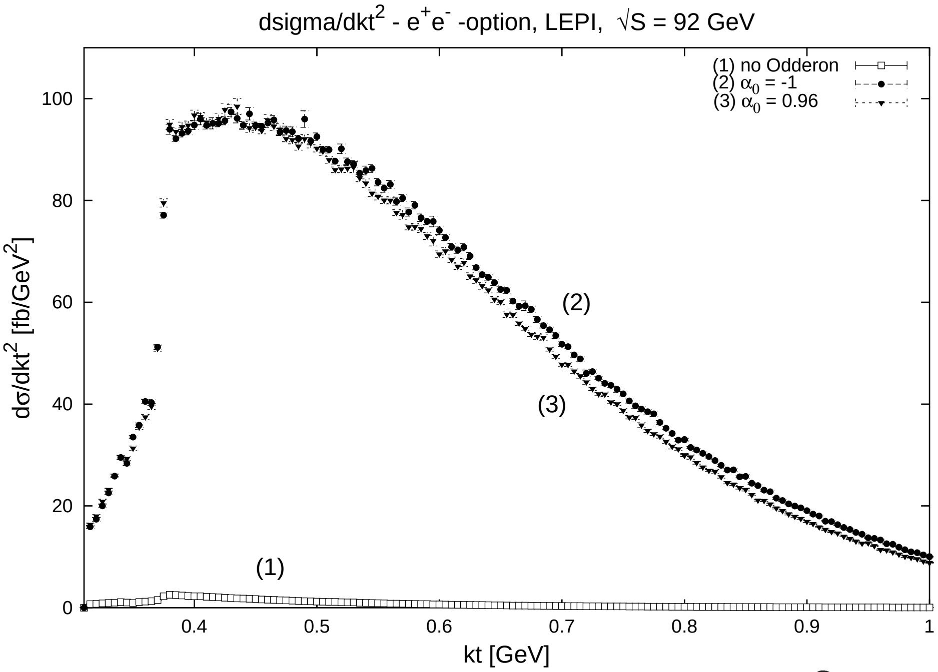


- $\gamma\gamma$

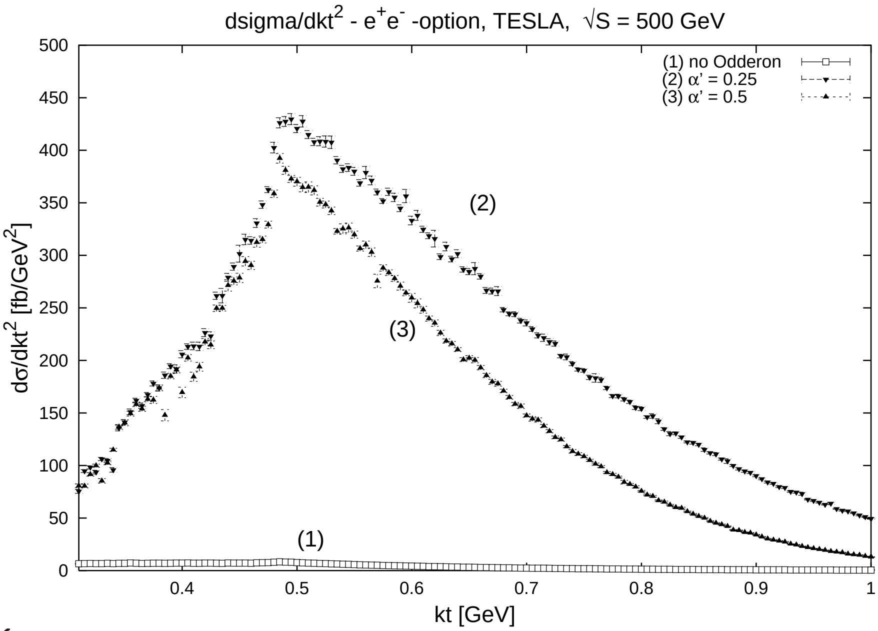


Variation of $\alpha_{\mathbb{O}}(0)$ and $\alpha'_{\mathbb{O}}$

- $\alpha_{\mathbb{O}} = 0.96$ leads to little to no effects.



- Variation of $\alpha'_{\mathbb{O}}$: $\alpha'_{\mathbb{O}} = 0.5\,\mathrm{GeV}^{-2}$



(expected variation much smaller)

Total cross sections

Experiment	$\sqrt{S}$	γ	$\mathbb{O}_{-1}$	$\mathbb{O}_{+1}$
$OPAL$	200	0.32	31.9	21.72
$TESLA(e^+e^-)$	500	1.44	97.40	62.34
$TESLA(\gamma\gamma)$	500	1.6	81.86	53.00
$BaBar$	10.58	0.41	16.06	9.43

(results in fb)

Counting rates:

Experiment	$\sqrt{S}$	γ	$\mathbb{O}_{-1}$	$\mathbb{O}_{+1}$
$OPAL(LEPII)$ $[y^{-1}]$	200	0.081	8.071	5.495
$TESLA_{(e^+e^-)}$ $[h^{-1}]$	500	0.176	11.922	7.630
$TESLA_{(\gamma\gamma)}$ $[h^{-1}]$	500	0.143	10.020	6.483
$BaBar$ $[(1.5\,y)^{-1}]$	10.58	28.7	1124.2	660.1

(Different units depending on different luminosities used.)

$\Rightarrow$ significant modification of σ_{tot};

$\Rightarrow$ better statistics for TESLA and BaBar;

$\Rightarrow$ for OPAL (LEPI/ LEPII), counting rates very low.

Summary and Outlook

- $\Rightarrow$ Effective description of Odderon introduced by Kilian et al significantly influences total and differential cross section of $\gamma\gamma \longrightarrow \pi^0\pi^0$ at e^+e^- colliders
- $\Rightarrow$ Cross sections very sensitive to coupling strenght of the Odderon $\beta_{\mathbb{O}}$; $\sigma \propto (\beta_{\mathbb{O}})^4$
- $\Rightarrow$ Regge trajectory parameters $\alpha_{\mathbb{O}}(0)$, $\alpha'_{\mathbb{O}}$ harder to determine
- $\Rightarrow$ Total and differential cross sections are very sensitive to detector cuts; need $E_{min} \lesssim 0.5\,\mathrm{GeV}$ for parameter determination
- $\Rightarrow$ Extension to different pseudoskalar mesons (η, η') or vectormesons (f_2) possible
- $\Rightarrow$ Need measurements for further statments
- $\Rightarrow$ Use of improved photoncollider spectrum desireable
- $\Rightarrow$ Diploma thesis available at hep-ph/0302048

. ☺☺ !!! Thanks for listening !!! ☺☺