Exclusive and diffractive production of lepton pairs in *pp* collision at high energy

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Plan of the talk

Introduction

- Measuring absolutely normalized cross sections at the LHC is of great importance for high-energy physics community.

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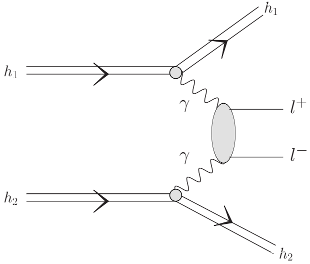
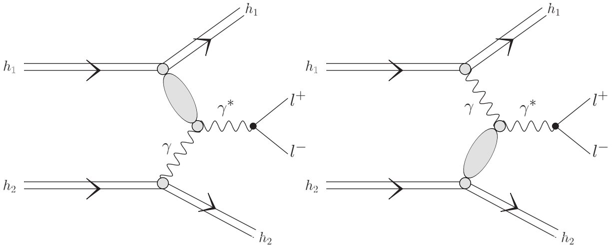
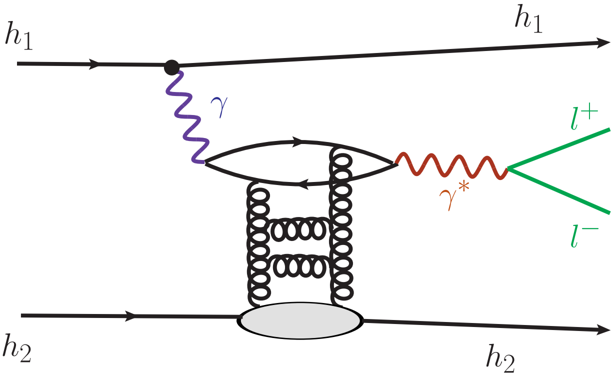


Introduction

- Measuring absolutely normalized cross sections at the LHC is of great importance for high-energy physics community.
- The QED process $pp \to pl^+l^-p$ via $\gamma\gamma$- fusion is often discussed as a process which can be used for measuring the luminosity at the LHC.
- It is therefore important to estimate non-QED contributions to exclusive l^+l^- production.



Amplitude for $\gamma p \to l^+l^-p$



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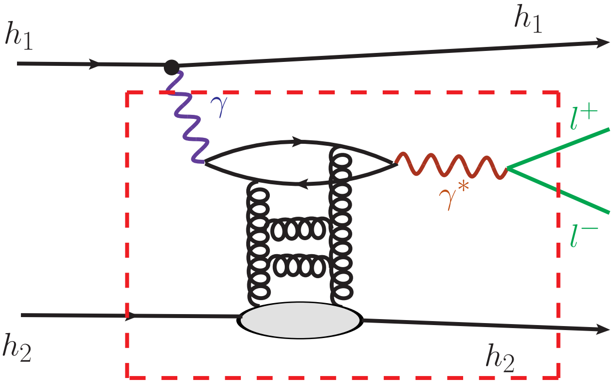

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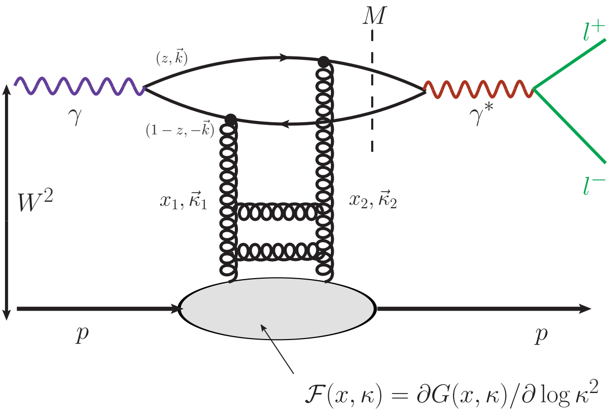

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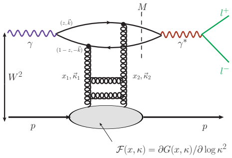

- $\gamma \to \gamma^*$ Time-like Compton Scatering (TCS)
- exchange of off-diagonal QCD gluon ladder
- **W. Schafer,G. Slipek,A. Szczurek**
  Phys. Lett. **B 688** (2010) 185-191

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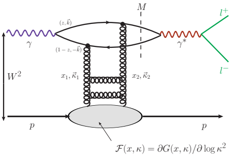

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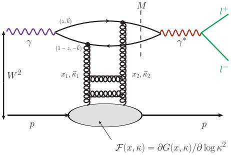
- the imaginary part of the forward TCS amplitude

$$\Im m \mathcal{M}_f(\gamma p \to \gamma^*(q^2)p) = W^2\, 16\pi^2 \alpha_{\rm em} e_f^2$$

$$\cdot \left\{ \Theta(4m_f^2 - q^2) \int_{4m_f^2}^{\infty} dM^2 \frac{\Im m\, a_f(W^2, M^2)}{M^2 - q^2} \right.$$

$$\left. + \Theta(q^2 - 4m_f^2) \left(\mathrm{PV} \int_{4m_f^2}^{\infty} dM^2 \frac{\Im m\, a_f(W^2, M^2)}{M^2 - q^2} + \pi\, \Re e\, a_f(W^2, q^2) \right) \right\}$$

Amplitude for $\gamma p \to l^+ l^- p$



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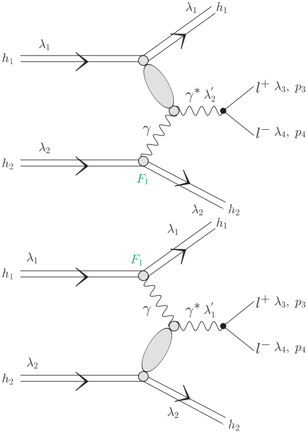
- spectral density $\Rightarrow a_f(W^2, M^2) = \int_0^{\frac{1}{4}M^2 - m_f^2} \frac{dk^2}{J_f} \mathcal{A}_f(M^2, k^2, W^2)$,
- $\mathcal{A}_f(M^2, k^2, W^2) \Rightarrow$ a convolution of $\mathcal{F}(x, \kappa^2)$ and some functions
- The Gluone exchange ladder is modelled by $\mathcal{F}(x, \kappa^2)$

Amplitude for $pp \to pl^+l^-p$ ($\gamma\mathbf{P}$ exchange)



$$\mathcal{M}^{\lambda_3\lambda_4}_{pp\to ppl^+l^-}$$

$$= eF_1(q_1{}^2)(\bar{u}_1\gamma^\mu u_a)\left(\frac{-ig_{\mu\nu}}{t_1}\right)\sum_{\lambda_1\ \lambda_1'}\epsilon^\nu(\lambda_1)\mathcal{M}^{\lambda_1\lambda_1{}'}_{\gamma p\to\gamma^* p}(W_2, M_{34})$$

$$\epsilon^{\alpha^*}(\lambda_1{}')\left(\frac{-ig_{\alpha\beta}}{s_{34}}\right)ee_f(\bar{u}(\lambda_3,p_3)\gamma^\beta v(\lambda_4,p_4))$$

$$+eF_1(q_2{}^2)(\bar{u}_2\gamma^\mu u_b)\left(\frac{-ig_{\mu\nu}}{t_2}\right)\sum_{\lambda_2\ \lambda_2'}\epsilon^\nu(\lambda_2)\mathcal{M}^{\lambda_2\lambda_2{}'}_{\gamma p\to\gamma^* p}(W_2, M_{34})$$

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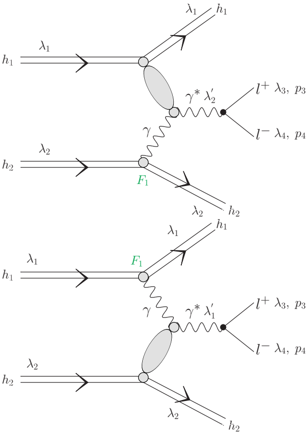

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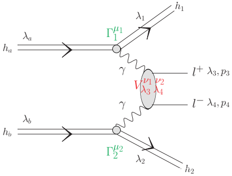
- $\mathcal{M} \Rightarrow \sigma$
- four-body phase-space numerically $\Rightarrow$ (long formula see **P.Lebiedowicz,A. Szczurek** Phys. Rev. **D 81** (2010) 036003)

Amplitude for $pp \to pl^+l^-p$ ($\gamma\gamma$ fusion)



$$\mathcal{M}^{pp\to ppl^+l^-}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\lambda_3\lambda_4} = \bar{u}(p_1,\lambda_1)\Gamma_1^{\mu_1}(q_1)u(p_a,\lambda_a)\left(\frac{-ig_{\mu_1\nu_1}}{t_1}\right) V^{\nu_1\nu_2}_{\lambda_3\lambda_4}(q_1,q_2,p_3,p_4)\left(\frac{-ig_{\mu_2\nu_2}}{t_2}\right)\bar{u}(p_2,\lambda_2)\Gamma_2^{\mu_2}(q_2)u(p_b,\lambda_b)$$

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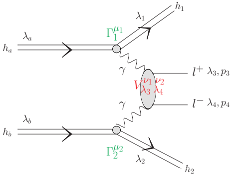

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- the production amplitude of lepton pair

$$V^{\nu_1\nu_2}_{\lambda_3\lambda_4}(q_1,q_2,p_3,p_4) = e^2\bar{u}(p_3,\lambda_3)\left[\gamma^{\nu_1}\frac{\hat{q}_1-\hat{p}_3-m}{(q_1-p_3)^2-m^2}\gamma^{\nu_2} - \gamma^{\nu_2}\frac{\hat{q}_1-\hat{p}_4+m}{(q_1-p_4)^2-m^2}\gamma^{\nu_1}\right]v(p_4,\lambda_4)$$

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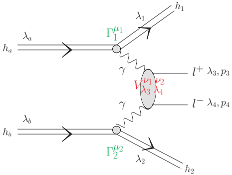

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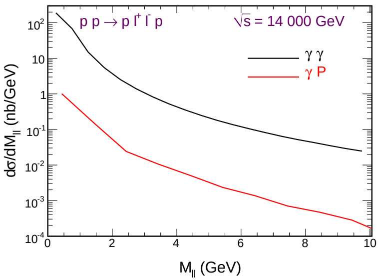
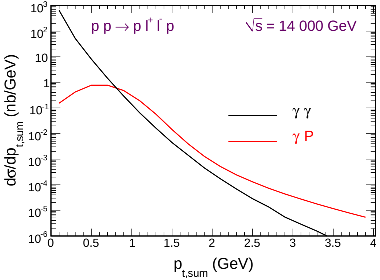
- $\Gamma_1^{\mu_1}(q_1) = \gamma^{\mu_1}F_1(q_1) + \frac{i\kappa_p}{2M_p}\sigma^{\mu_1\nu_1}q_{\nu_1}F_2(q_1)$
  $\Gamma_2^{\mu_2}(q_2) = \gamma^{\mu_2}F_1(q_2) + \frac{i\kappa_p}{2M_p}\sigma^{\mu_2\nu_2}q_{\nu_2}F_2(q_2)$

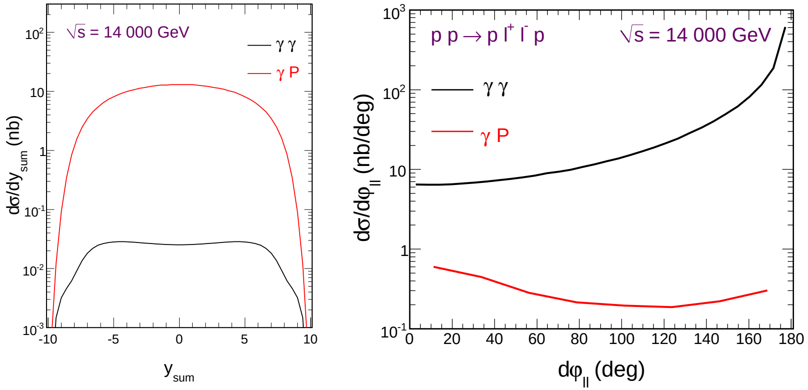
Dependence on dilepton invariant mass and $p_{t,sum}$



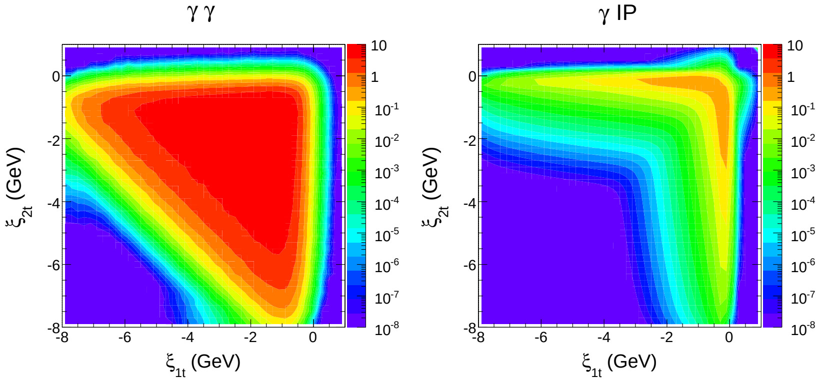


- M_{ll} invariant mass of outgoing leptons
- $\overrightarrow{p_{t,sum}} = \overrightarrow{p_{1t}} + \overrightarrow{p_{2t}}$

Azimuthal angle and rapidity distributions

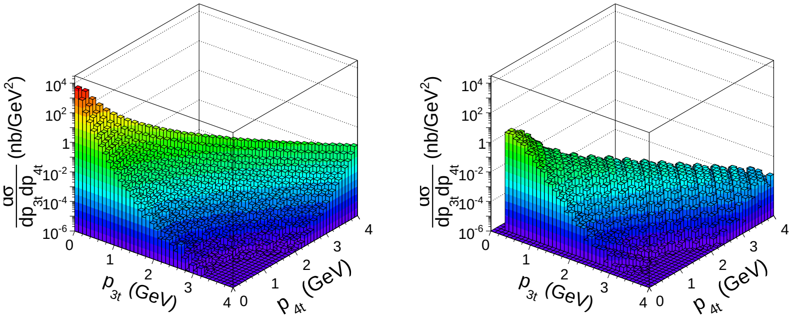


Transverse momentum correlations of outgoing protons

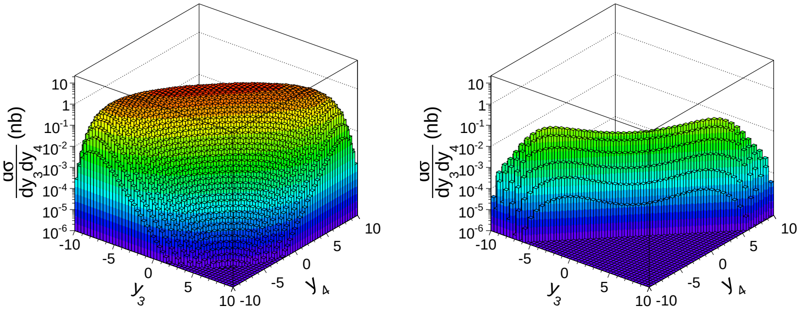


- $\xi_1 = \log_{10}[p_{1t}/1GeV]$ $\qquad$ $\xi_2 = \log_{10}[p_{1t}/1GeV]$
- expect $\Rightarrow$ difficult to measure

Transverse momentum correlations of outgoing leptons



Rapidity correlations of leptons



Introduction

- more complicated processes ⇒ inclusive diffractive processes. They are discussed in terms of Pomeron exchanges.

Introduction

- **G. Ingelman and P. E. Schlein,** Phys. Lett. **B 152** (1985) 256

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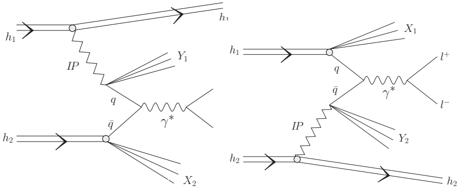
- the hard process take place in
  - pomeron-proton or proton-pomeron → single diffraction



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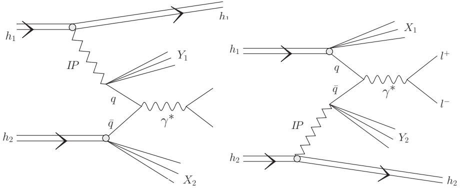
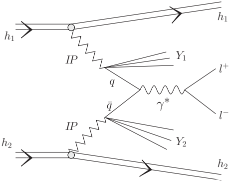
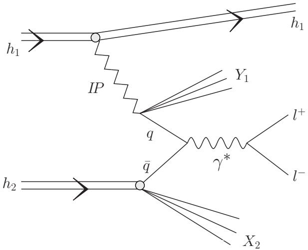


  - pomeron-pomeron → double diffraction



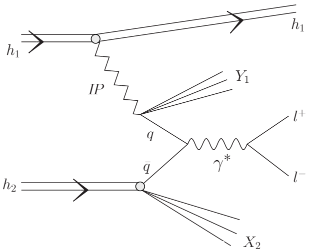
Single diffraction



- $$\frac{d\sigma_{SD}}{dy_1\, dy_2\, dp_t^2} = K \frac{|M|^2}{16\pi^2 \hat{s}^2} \left(x_1 q_f^D(x_1, \mu^2)\, x_2 \bar{q}_f(x_2, \mu^2)\right) + \left(x_1 \bar{q}_f^D(x_1, \mu^2)\, x_2 q_f(x_2, \mu^2)\right).$$

- $|M|^2$ - matrix element (text book formula)
  $$|M(q\bar{q} \to l^+l^-)|^2 = 32\pi^2 a_{em}^2 \frac{(m_l^2 - \hat{t})^2 + (m_l^2 - \hat{u})^2 + 2m_l^2 \hat{s}}{\hat{s}^2}.$$

Single diffraction



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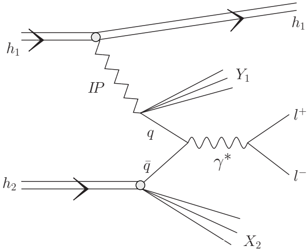
- $$x_1 = \frac{m_t}{\sqrt{s}}(\exp(y_1)+\exp(y_2)),$$
  $$x_2 = \frac{m_t}{\sqrt{s}}(\exp(-y_1)+\exp(-y_2)),\qquad \text{where } m_t = \sqrt{p_t^2+m_l^2}.$$

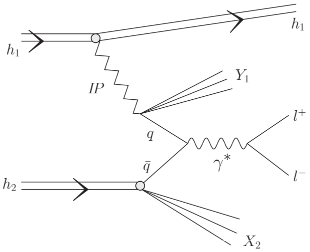
Single diffraction



- $$\frac{d\sigma_{SD}}{dy_1\,dy_2\,dp_t^2} = K\frac{|M|^2}{16\pi^2\hat{s}^2}\left(x_1\,q_f^D(x_1,\mu^2)\,x_2\bar{q}_f(x_2,\mu^2)\right. \left. + (x_1\,\bar{q}_f^D(x_1,\mu^2)\,x_2 q_f(x_2,\mu^2)\right).$$

- K - factor $\Rightarrow$ effectively higher order Drell-Yan contributions $K = 1 + \frac{\alpha_s}{2\pi}\frac{4}{3}\left(1 + \frac{4}{3}\pi^2\right)$.
  V. Barger and R. Phillips"Collider Physics"

Single diffraction



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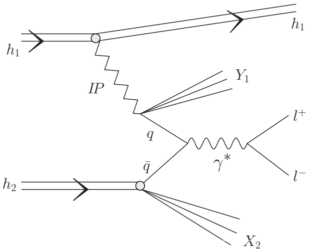
- diffractive quark distribution
  $q_f^D(x,\mu^2) = \int dx_P d\beta\, \delta(x - x_P\beta) q_{f/P}(\beta,\mu^2)\, f_P(x_P) = \int_x^1 \frac{dx_P}{x_P} f_P(x_P) q_{f/P}(\frac{x}{x_P},\mu^2)$
  $q_{f/P}(\frac{x}{x_P},\mu^2) \longrightarrow$ the parton distribution in the Pomeron
  $f_P(x_P) \longrightarrow$ the flux of Pomeron
- $f_P(x_P)$ and $q_{f/P}(\frac{x}{x_P},\mu^2)$
  $\Rightarrow$ **A.Aktas et. al (H1 Collaboration)** Eur. Phys. J. **C 48** (2006) 715

Single diffraction



- $$\frac{d\sigma_{SD}}{dy_1 dy_2 dp_t^2} = K \frac{|M|^2}{16\pi^2 \hat{s}^2} \left(x_1 q_f^D(x_1,\mu^2)\, x_2 \bar{q}_f(x_2,\mu^2)) + (x_1 \bar{q}_f^D(x_1,\mu^2)\, x_2 q_f(x_2,\mu^2)\right).$$

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  $q_{f/P}(\frac{x}{x_P},\mu^2) \rightarrow$ the parton distribution in the Pomeron
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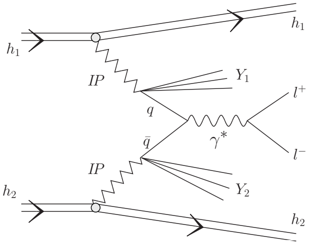
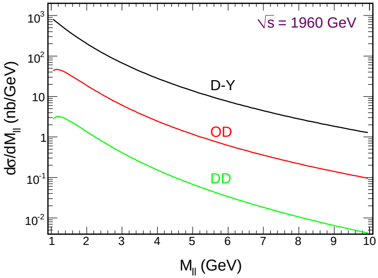
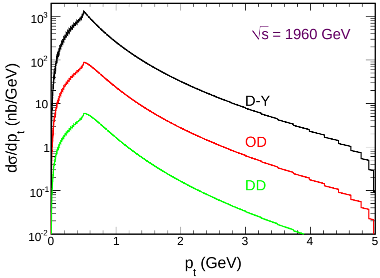
Double diffraction



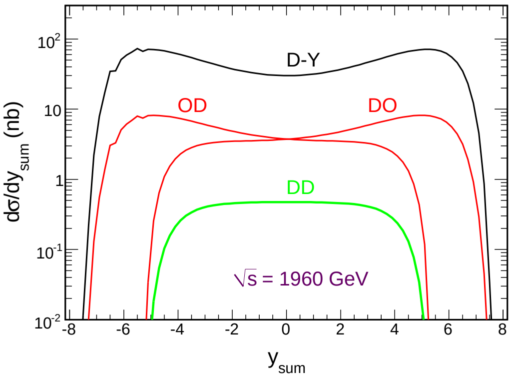
$$\frac{d\sigma_{DD}}{dy_1\, dy_2\, dp_t^2} = K \frac{|M|^2}{16\pi^2 \hat{s}^2} \left(x_1 q_f^D(x_1, \mu^2)\, x_2 \bar{q}_f^D(x_2, \mu^2) \right) + \left(x_1 \bar{q}_f^D(x_1, \mu^2)\, x_2 q_f^D(x_2, \mu^2) \right).$$

Dependence on dilepton invariant mass and p_t

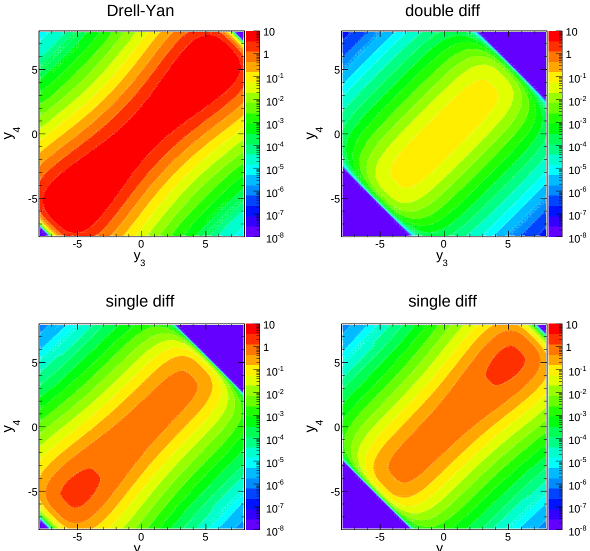




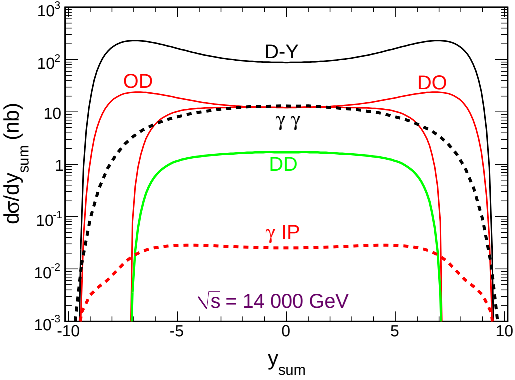
Dependence on dilepton rapidity



Rapidity correlations of leptons



EXCLUSIVE Vs DIFFRACTIVE



- I have presented results for exclusive and diffractive production of lepton pairs.

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- We find that non-QCD contribution to exclusive production dominant in large p_{tsum}

Future:

- to include absorptive corrections (the 'elastic rescattering')
- to include Pauli form factor

Thank You for attention!