Generator study of Diffractive Drell-Yan production of forward lepton pairs at CMS

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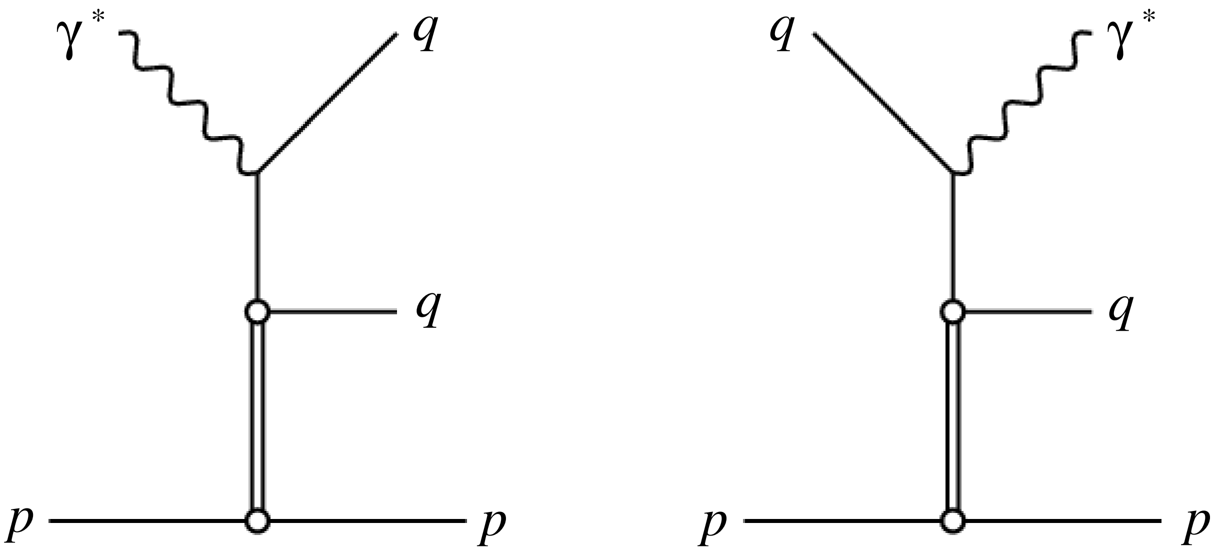
Drell-Yan Production vs. Deep-Inelastic Scattering

Low mass, forward (D)DY and low Bjorken-x (D)DIS are of similar theoretical interest:



→ both processes probe the target at high gluon density

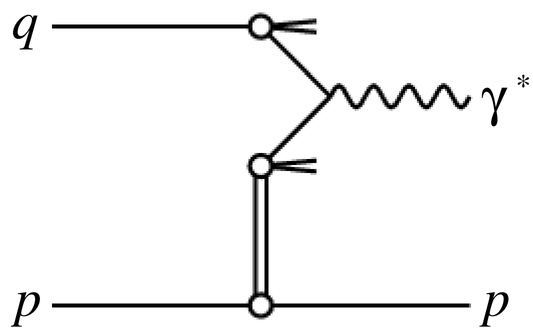
- DY is one of the cleanest processes for the study of QCD phenomena
- DY provides a variety of observables which can be measured (e.g. transverse momentum distribution or angular distributions op the lepton pair)
- Timelike → spacelike photon: this talk focusses on the continuum

Questions:

- Is this a suitable way to continue HERA studies of diffractive structure at the LHC?
- Is there a physics interest in doing this?

Parton model picture

infinite momentum frame



DY kinematics: $M^2 = x_1 x_2 s, \quad x_F = x_1 - x_2$

low M^2, forward DY: $x_2 \ll x_1, \quad x_F \approx x_1$

diffractive DY kinematics: $x_2 = \xi \cdot \beta$

- Parton model cross section:

$$\frac{d^2\sigma_{DY}}{dM^2\,dx_F} = \frac{4\pi\alpha_{em}^2}{9M^2 s}\frac{1}{x_1+x_2}\sum_{f=1}^{N_f} Z_f^2[q_f(x_1)\bar{q}_f^D(x_2) + \bar{q}_f(x_1)q_f^D(x_2)]$$

$$\approx \frac{4\pi\alpha_{em}^2}{9M^4}\frac{F_2(x_1)}{x_1}\cdot x_2\bar{q}^D(x_2)$$

→ extract diffractive DY structure function: $F_{DY}^D(x=\xi\beta) = xq^D(x)$
(cfr. $F_{jj}^D(x)$ from CDF)

- NLO QCD corrections are needed to describe absolute cross section and shape of the dilepton transverse momentum distribution (no large transverse momenta at LO)

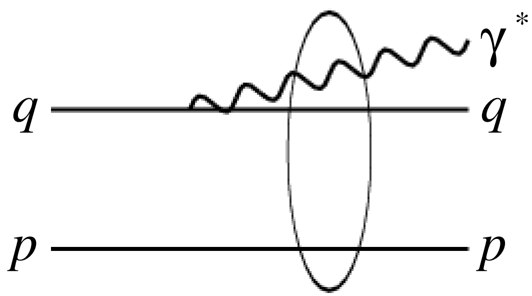
→ especially for forward and diffractive DY, gluon-driven QCD-Compton processes are expected to contribute a lot!

note: more complicated procedures are needed to avoid the divergence of the differential cross section at zero transverse momentum

Dipole model picture

In the target rest frame, DY dilepton production should be treated as bremsstrahlung, rather than parton annihilation!

target
rest frame



expansion in interaction eigenstates:

$$|q\rangle = \sqrt{Z_2}|q_{bare}\rangle + \Psi^{T,L}_{\gamma^* q}|q\gamma^*\rangle + \dots$$

ρ = quark-photon transverse separation
α = light-cone momentum fraction of the initial quark taken by the photon

- Dipole model non-diffractive DY cross section:

Brodsky, Hebecker, Quack
hep-ph/9609384

$$\frac{d\sigma(qp \to \gamma^* X)}{d\ln\alpha} = \int d^2\rho\,|\Psi^{T,L}_{\gamma^* q}(\alpha,\rho)|^2\,\sigma_{q\bar{q}}(x_2,\alpha\rho)$$

➔ the same dipole cross section can be used in DIS and DY because the target colour field is probed at different impact parameters in both cases

- Dipole cross section combines colour transparency at low separations with saturation at large separations
  ➔ dipole model very well suited to describe diffraction
  ➔ as for diffractive and non-diffractive DIS, diffractive DY will be more sensitive to large separations than non-diffractive DY

Cross section and invariant mass distribution

- Interplay of hard and soft fluctuations:

Kopeliovich
hep-ph/9806283

$$\langle \rho^2 \rangle \propto \frac{1}{(1-\alpha)M^2}$$

rare, asymmetric fluctuations with $1 - \alpha \sim \mu^2/M^2$ will have large ρ and will interact with a large cross section

→ soft contribution is not small! (cfr. aligned jet model)

- Dependence on M^2:

	$\Psi_{\gamma^* q}$	$\sigma_{q\bar{q}}$	$\Psi_{\gamma^* q}\sigma_{q\bar{q}}$	$\Psi_{\gamma^* q}\sigma^2_{q\bar{q}}$
hard	~ 1	$\sim 1/M^2$	$\sim 1/M^2$	$\sim 1/M^4$
soft	$\sim \mu^2/M^2$	$\sim 1/\mu^2$	$\sim 1/M^2$	$\sim 1/\mu^2 M^2$

→ invariant mass distribution in DDY will be affected differently by soft and hard contributions

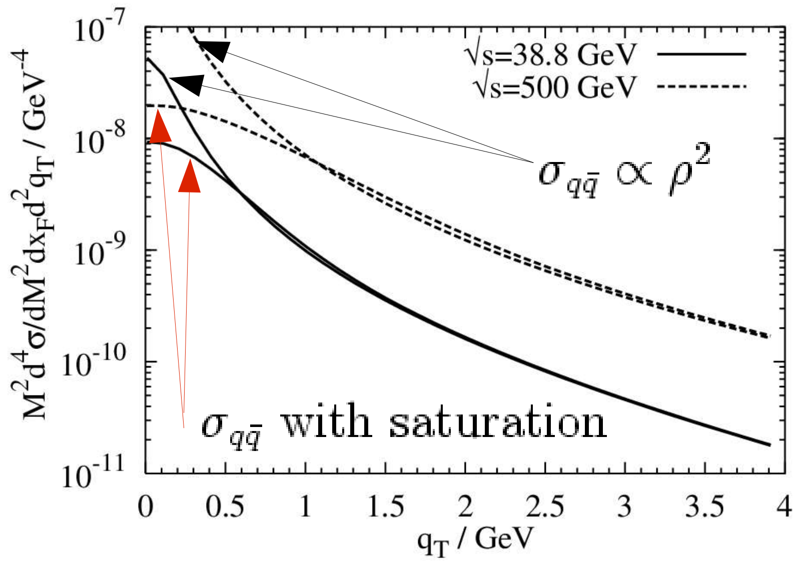
- Additional hadron form factor introduces an extra suppression (beyond the usual survival probability):

$$\left(\frac{\sigma^D}{\sigma^{tot}}\right)_{DY} \approx \frac{1}{2}\left(\frac{\sigma^D}{\sigma^{tot}}\right)_{DIS}$$

Dilepton transverse momentum distribution

- Parton model has problems in describing low transverse momenta of the dilepton
  → need to resum large logarithms log(q_T/M) from soft gluon radiation to avoid divergence at $q_T = 0$
  → or introduce intrinsic p_T of the partons in the colliding protons

- Dipole model naturally predicts a finite cross section at $q_T = 0$ thanks to saturation at large ρ



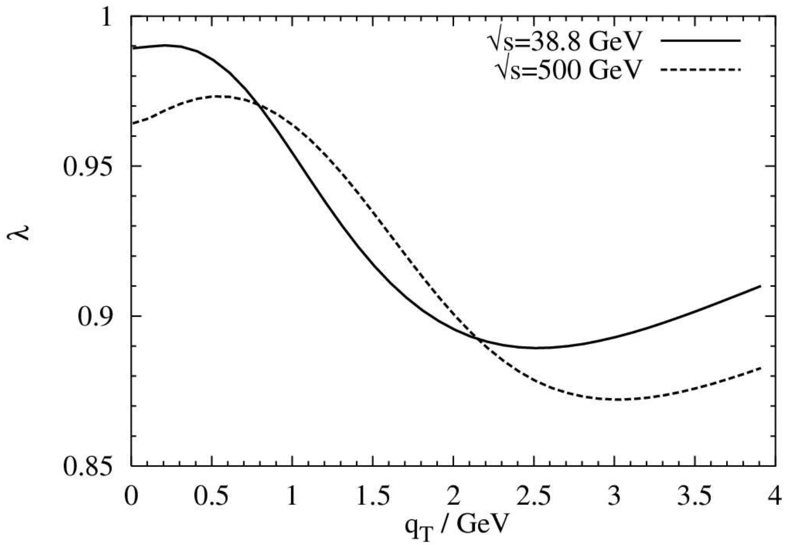
Kopeliovich, Raufeisen, Tarasov
hep-ph/0012035

- Diffraction probes large ρ → saturation effects at low q_T should be more pronounced

- Look for difference in M^2 distribution at low and high q_T to disentangle hard and soft contributions
  → expectation: same slope in DY, different slope in DDY

Angular distributions

The measurement of polar and azimuthal angles of the decay leptons allows to investigate longitudinal and transverse photons!



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- Dependence on polar angle θ:

$$\frac{d\sigma}{d\cos\theta} \propto 1 + \lambda \cos^2\theta$$

$$\lambda = \frac{\sigma_T - \sigma_L}{\sigma_T + \sigma_L}$$

parton model predicts: $\lambda(q_T = 0) = 1$ (Lam-Tung relation)
dipole model predicts: $\lambda(q_T = 0) < 1$ due to saturation
→ as before, DDY probes large ρ and therefore stronger saturation effects are expected

- Dependence on azimuthal angle ϕ:

$$\frac{d\sigma}{d\Omega} \propto 1 + \lambda \cos^2\theta + \mu \sin 2\theta \cos\phi + \frac{\nu}{2} \sin^2\theta \cos 2\phi$$

Brodsky, Hebecker, Quack
hep-ph/9609384

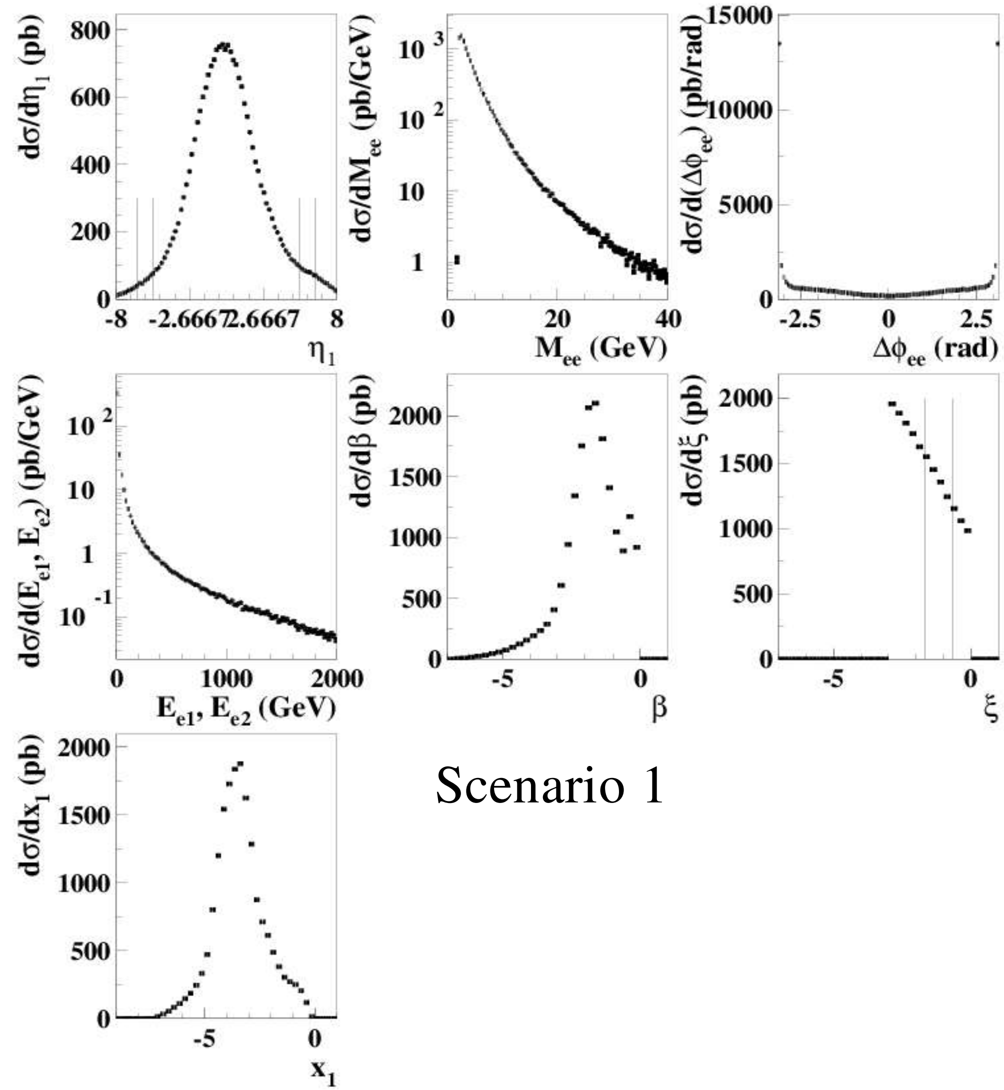
allows to disentangle T, L, TT and LT interference terms
σ_T: most senstive to large rho → leading twist in diffraction
σ_L, σ_{TT}, and σ_{LT}: dominated by small ρ → only higher twist in diffraction

POMWIG study of DDY at TOTEM/CMS (K. Sedlak)

- Subdetectors:
  - Roman Pots at 147, 180 and 220m
    → $0.02 < \xi < 0.20$
  - CASTOR calorimeter
    → $5.30 < |\eta| < 6.46$
  - T2 tracker → $5.3 < |\eta| < 6.6$

- POMWIG:
  - $q\bar{q} \to Z^0/\gamma \to e^+e^-$ (IPROC = 11351)
  - $M_{ee} > 2$ GeV, $10^{-6} < t < 4$ GeV^2

- LHC start-up luminosity:
  - single interaction bunch-crossings
    → assume 22% of 1-10 fb^{-1}/year



Scenario 1

	TOTEM	CASTOR	σ^D_{DY}	number of events
Scenario 1	not required	not required	$\sim$ 4500 pb	900 000 - 9 000 000
Scenario 2	$0.02 < \xi < 0.2$	$5.30 < \|\eta\| < 6.46$	$\sim$ 10.7 pb	2 100 - 21 000
Scenario 3	$0.02 < \xi < 0.2$	$5.30 < \eta < 6.46$	$\sim$ 4.6 pb	900 - 9 000

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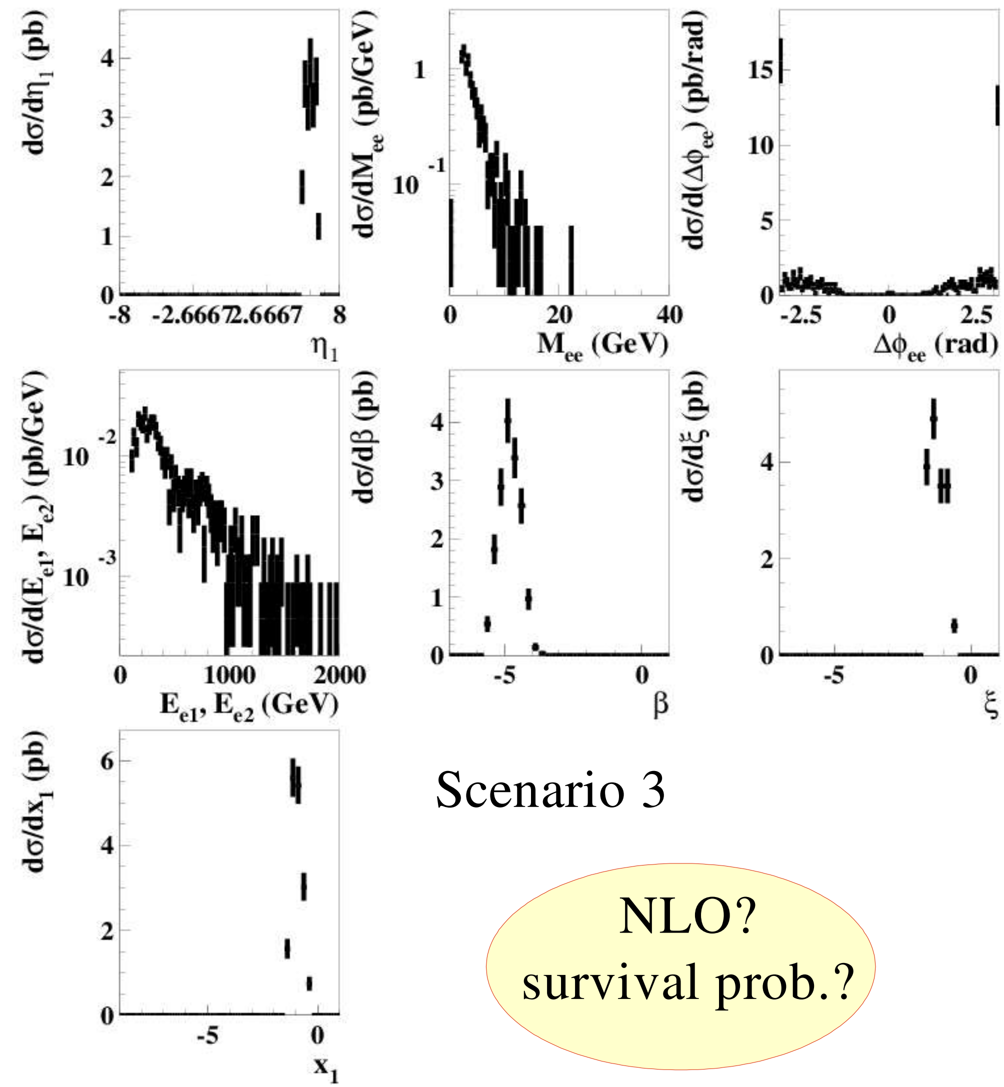
→ $\beta \simeq 10^{-5}$



Scenario 3

NLO?
survival prob.?

	TOTEM	CASTOR	σ^D_{DY}	number of events
Scenario 1	not required	not required	~ 4500 pb	900 000 - 9 000 000
Scenario 2	$0.02 < \xi < 0.2$	$5.30 < \lvert\eta\rvert < 6.46$	~ 10.7 pb	2 100 - 21 000
Scenario 3	$0.02 < \xi < 0.2$	$5.30 < \eta < 6.46$	~ 4.6 pb	900 - 9 000

Conclusion

- Low mass Drell-Yan production of forward lepton pairs and deep-inelastic scattering are very similar processes
- Drell-Yan production at the LHC provides an opportunity to continue low-x and diffractive studies from HERA
- Several observables are particularly sensitive to saturation effects
- Diffractive Drell-Yan production probes larger radii and is therefore even more sensitive to saturation effects
- A preliminary generator study based on POMWIG shows that diffractive Drell-Yan can be measured at CMS/TOTEM