Photon (and W) exchange at the LHC: experimental view

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Outline

- Introduction: LHC as a high energy $\gamma\gamma$ and γp collider
- Tagging photoproduction at the LHC
- Physics menu (and rapidity gap survival)
- Outlook

LHC as a High Energy γγ Collider

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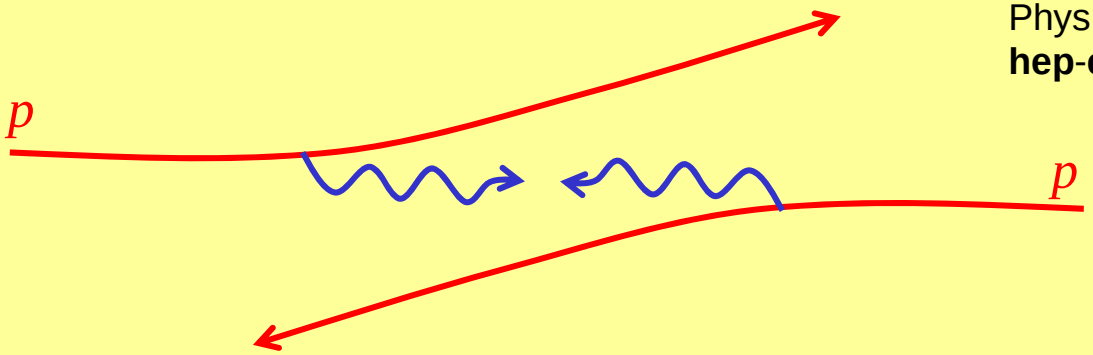
hep-ex/0201027

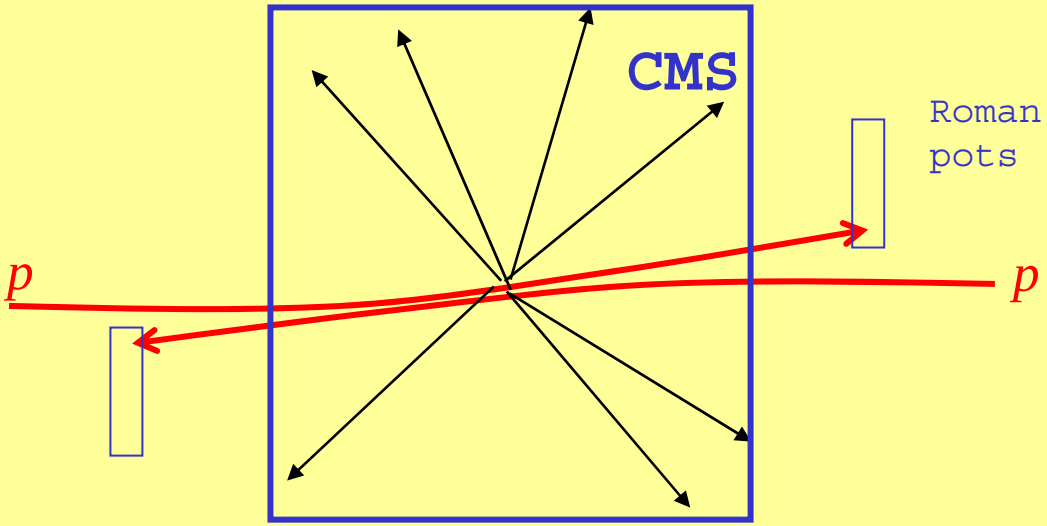


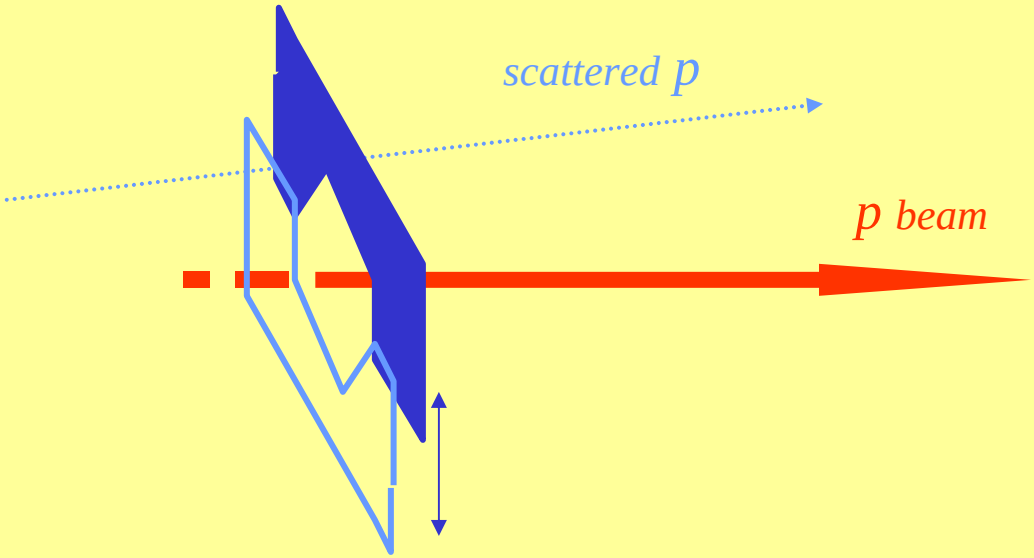
Observation:
Provided efficient measurement of forward-scattered protons one can study high-energy γγ collisions at the LHC

Highlights:
- **γγ CM energy *W* up to/beyond 1 TeV (and under control)**
- **Large photon flux *F* therefore significant γγ luminosity**
- **Complementary (and clean) physics to *pp* interactions, eg studies of *exclusive* production of heavy particles might be possible ➡ opens new field of studying very high energy γγ (and γp) physics**

Exclusive events are really ‘exclusive’!

Measure a centrally produced state in the **CMS** detector and the scattered protons using special detectors..





..i.e. ‘Roman pot’ like detectors put as far (> 100 m) from the IP and as close to the beam (≥ 1 mm) as possible

DISCLAIMER:

This is NOT meant for studying all photon interactions at the LHC but those for which the QCD background is strongly suppressed, as for example in the exclusive production of leptons or gauge bosons.

This IS meant for studying production of *selected* final states in photon interactions at the LHC.

Note: At Tevatron available W too small for EW physics

Kinematics/γγ Luminosity

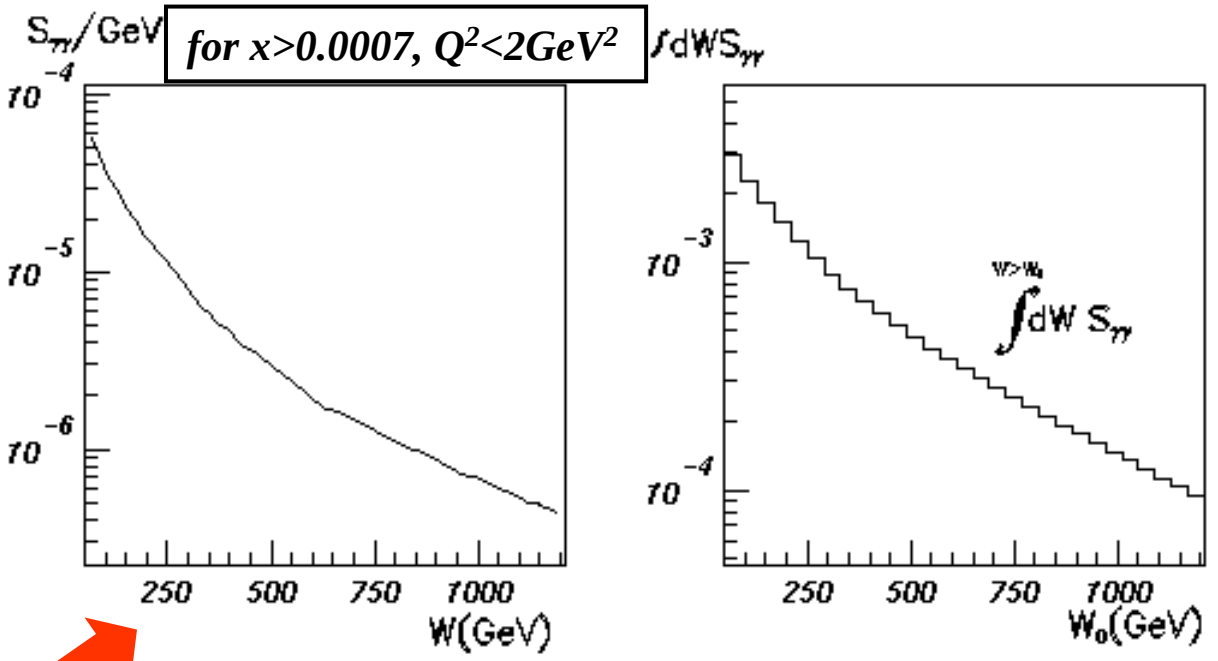
Virtuality Q^2 of colliding photons vary between kinematical minimum = $M_p^2 x^2/(1-x)$ where x is fraction of proton momentum carried by a photon, and $Q^2_{\max} \sim 1/\text{proton radius}^2$

$W^2 = s\, x_1\, x_2$

Photon flux $\propto 1/Q^2$

$Q^2 - Q^2_{\min} \approx s\theta^2/4$

protons scattered at `zero-degree' angle



Use EPA à la *Budnev et al.**

** error found in the elastic (Q^2 integrated) γ flux for protons!*

$\int dW S_{\gamma\gamma}$ = 'γγ : *pp luminosity'*

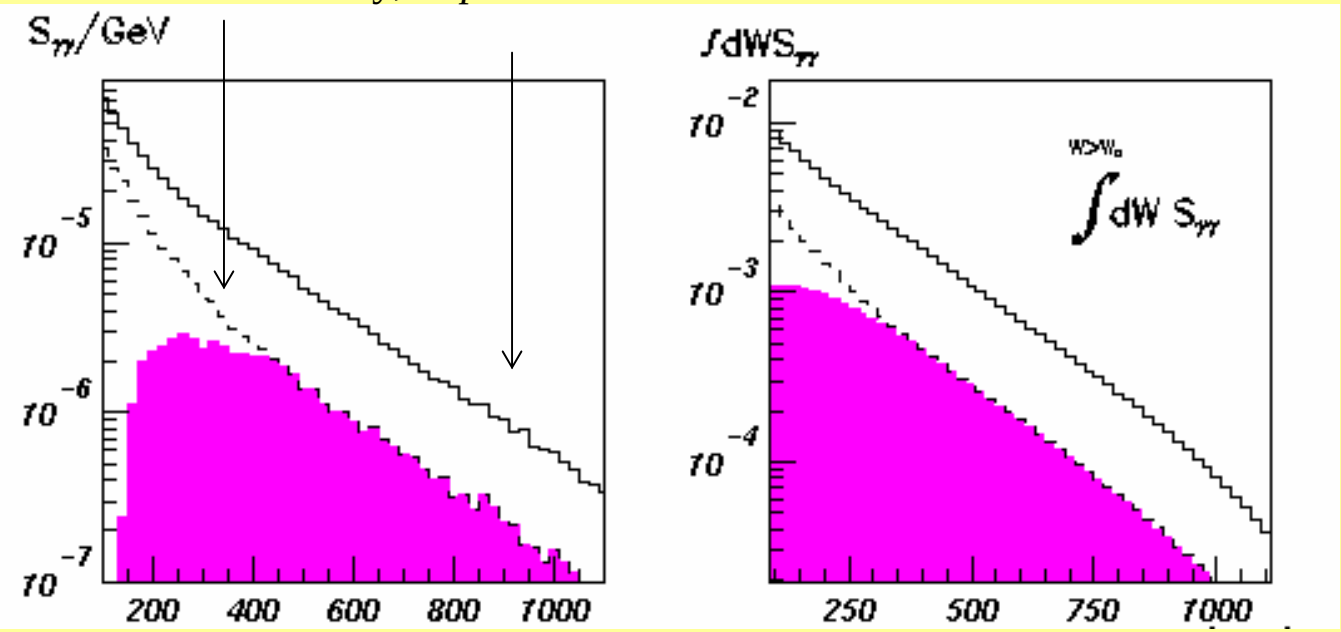
Note: it's few times larger if one of protons is allowed to break up

Tagging two-photon events

Assume detector stations at ~220 m: hence approximately x>0.01 range accessible

Assume 0.1>x>0.01, and Q^2<2 GeV^2 and for dissociative mass M_N < 20 GeV

Single tags:
elastic only, or *p-diss.* incl.

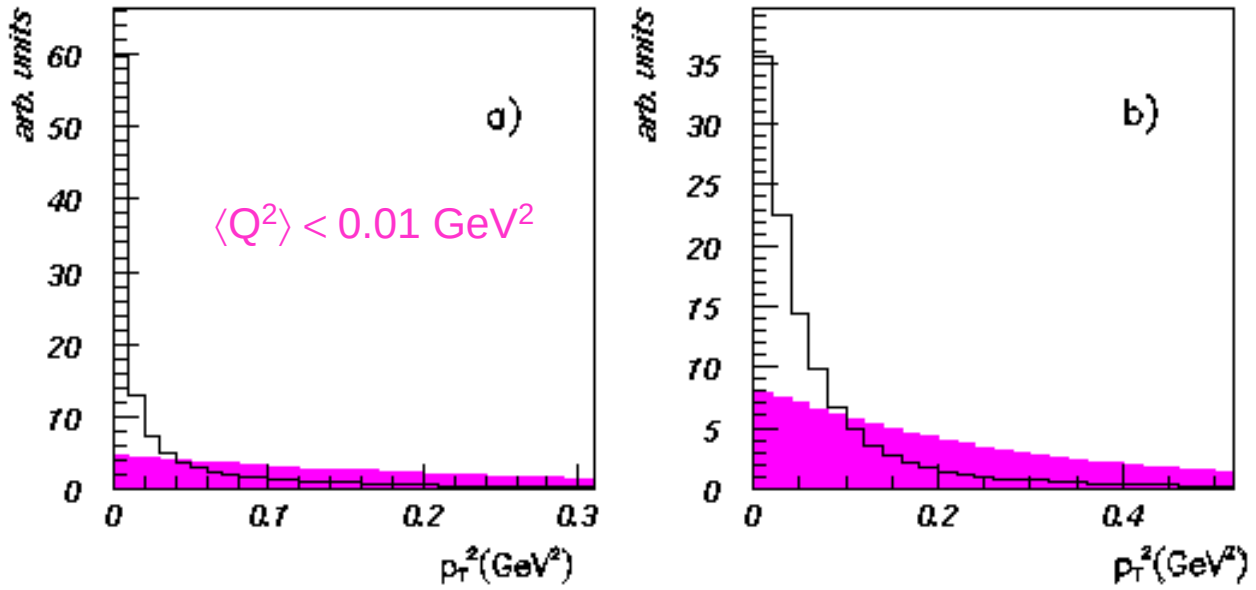


Color: double-tags, hence *elastic* scattering only

Problem: Same signature (one or two very forward protons) has also *central diffraction* (i.e. *pomeron-pomeron* scattering) in strong interactions

Both processes interfere, however the transverse momentum of the scattered protons are in average much softer in two-photon case

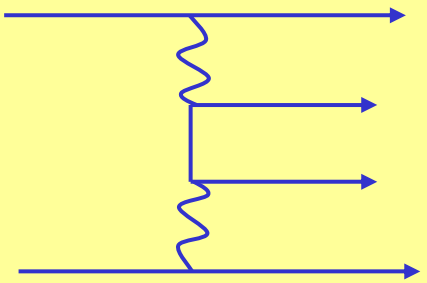
a) `true' distributions; b) distributions smeared due to beam intrinsic p_T; all plots normalized for $p_T^2 < 2\ GeV^2$



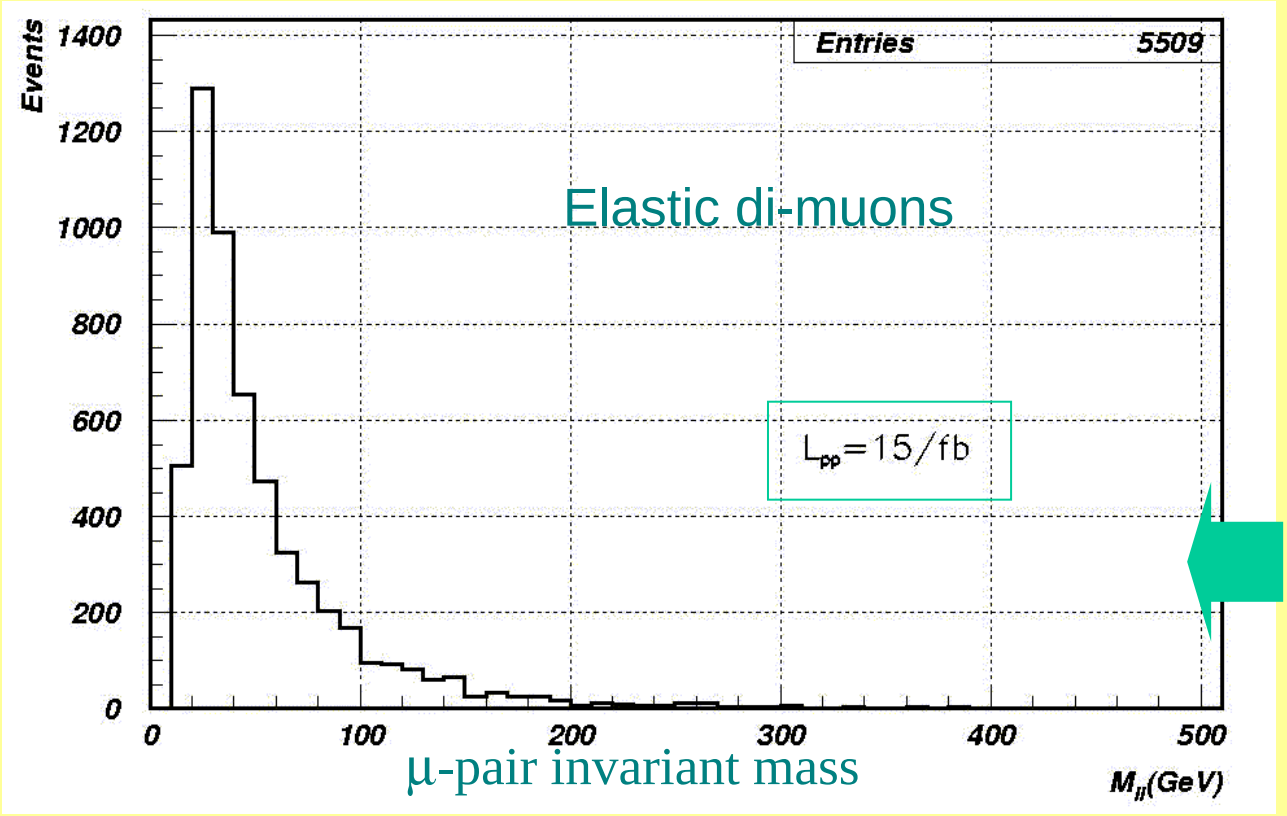
p_T gives powerful separation handle provided that size of $\gamma\gamma$ and pomeron-pomeron cross-sections are not too different

Assuming ultimate p_T resolution ≈ 100 MeV; i.e. neglecting detector effects

Calibration & monitoring tool: two-photon ee/μμ production



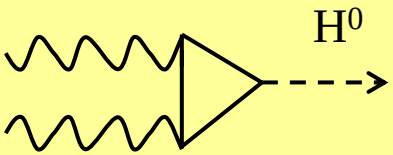
Setting *W* scale + background control + elastic/inelastic separation, and luminosity measurement (Shamov&Telnov)



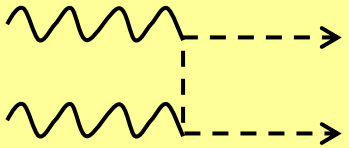
Single *p* tags (ie. x>0.01) + $p_T(\mu)$>5 GeV $|\eta(\mu)|$<2.5

Note: It does not assume proton trigger!

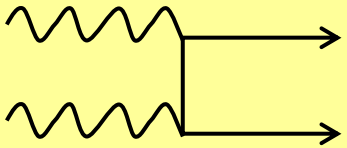
γγ Physics Menu – Highlights



Note: Sets ultimate limit for excl. H production, survival~0.86 *(Khoze et al.)*

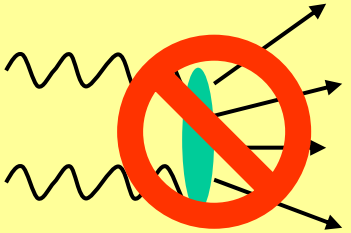


σ ~ 80 pb, study WWγ coupling



σ ~ 1 pb

+ SUSY processes

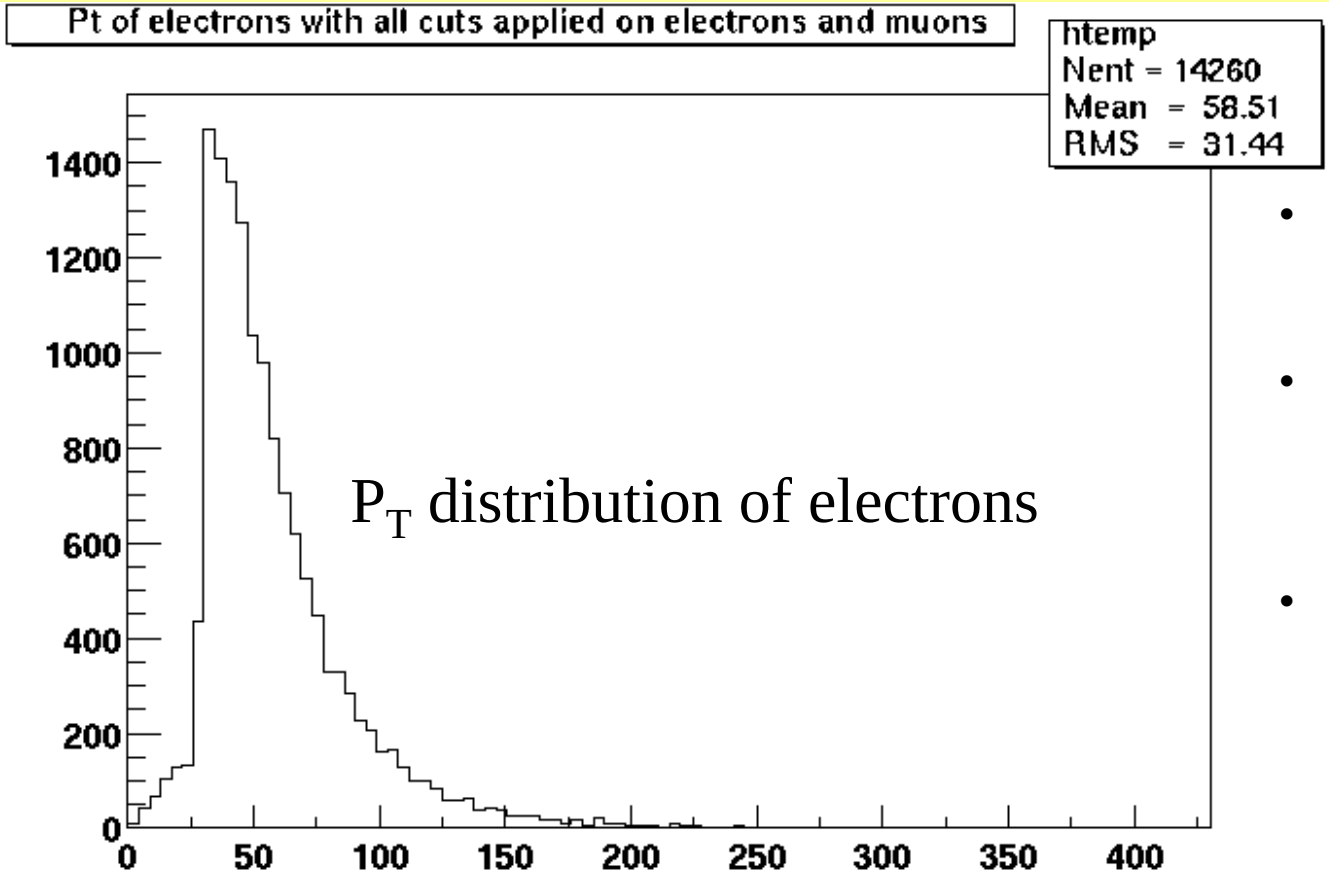


All ?

σ ~ 100–500 nb

$\gamma\gamma \to WW$ events

J. de Favereau

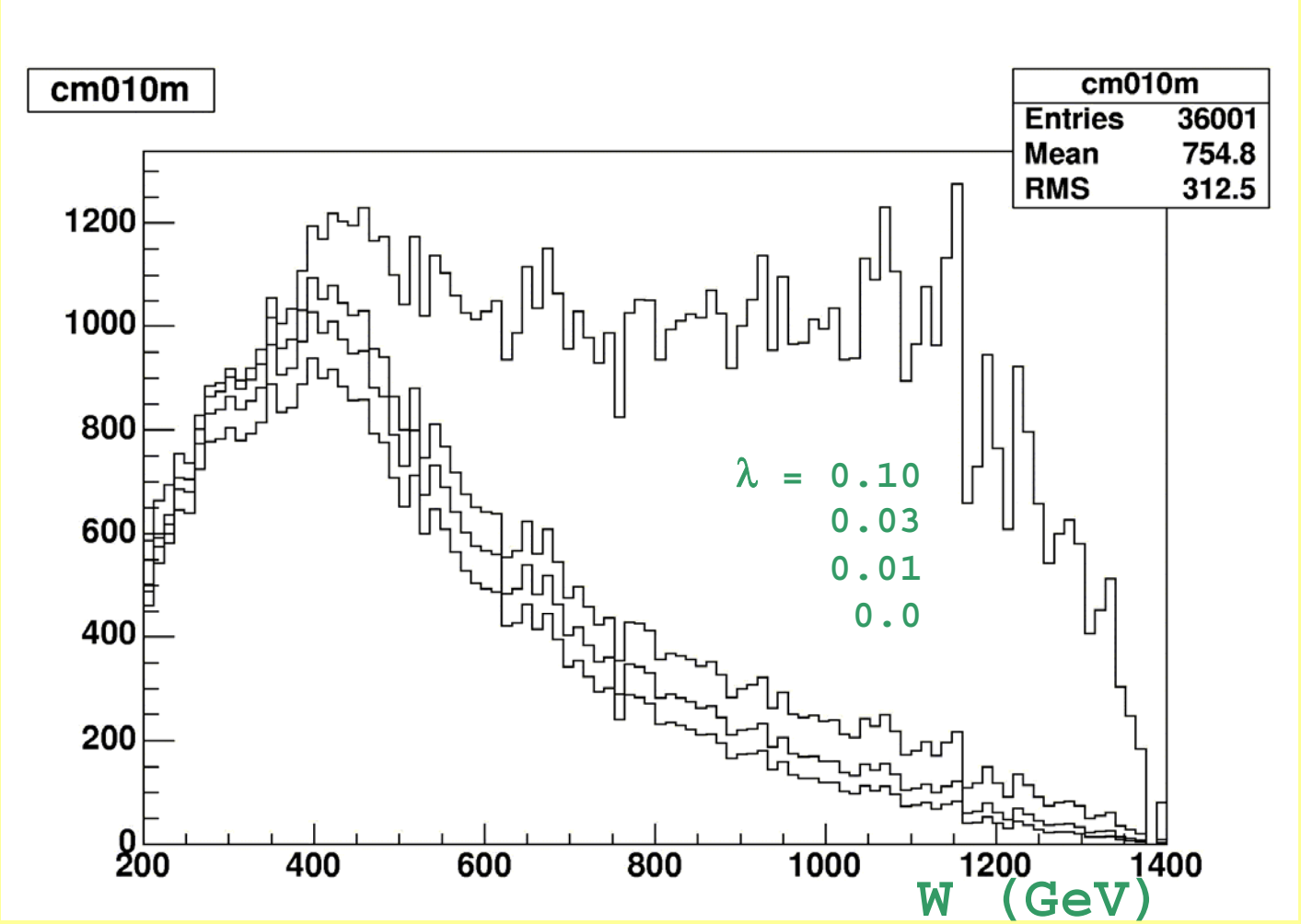


- Events with at least one leptonic *W* decay (electron or muon in final state)
- Require <u>single</u> tagging, i.e. registration of at least one proton with energy loss above 1% (and $p_T < 1$ GeV)
- Apply cuts: (electron $p_T >$ 29 GeV or muon $p_T > 14$ GeV)* |eta|<2.5 to simulate ‘ geometrical ’ + trigger acceptance

High p_T reach expected – the distribution corresponds to integ. luminosity of about 100 fb^{-1}

First very preliminary results for anomalous (and exclusive) production of ***WW*** pairs in two-photon interactions

J. de Favereau



Assumed 30 fb^{-1}

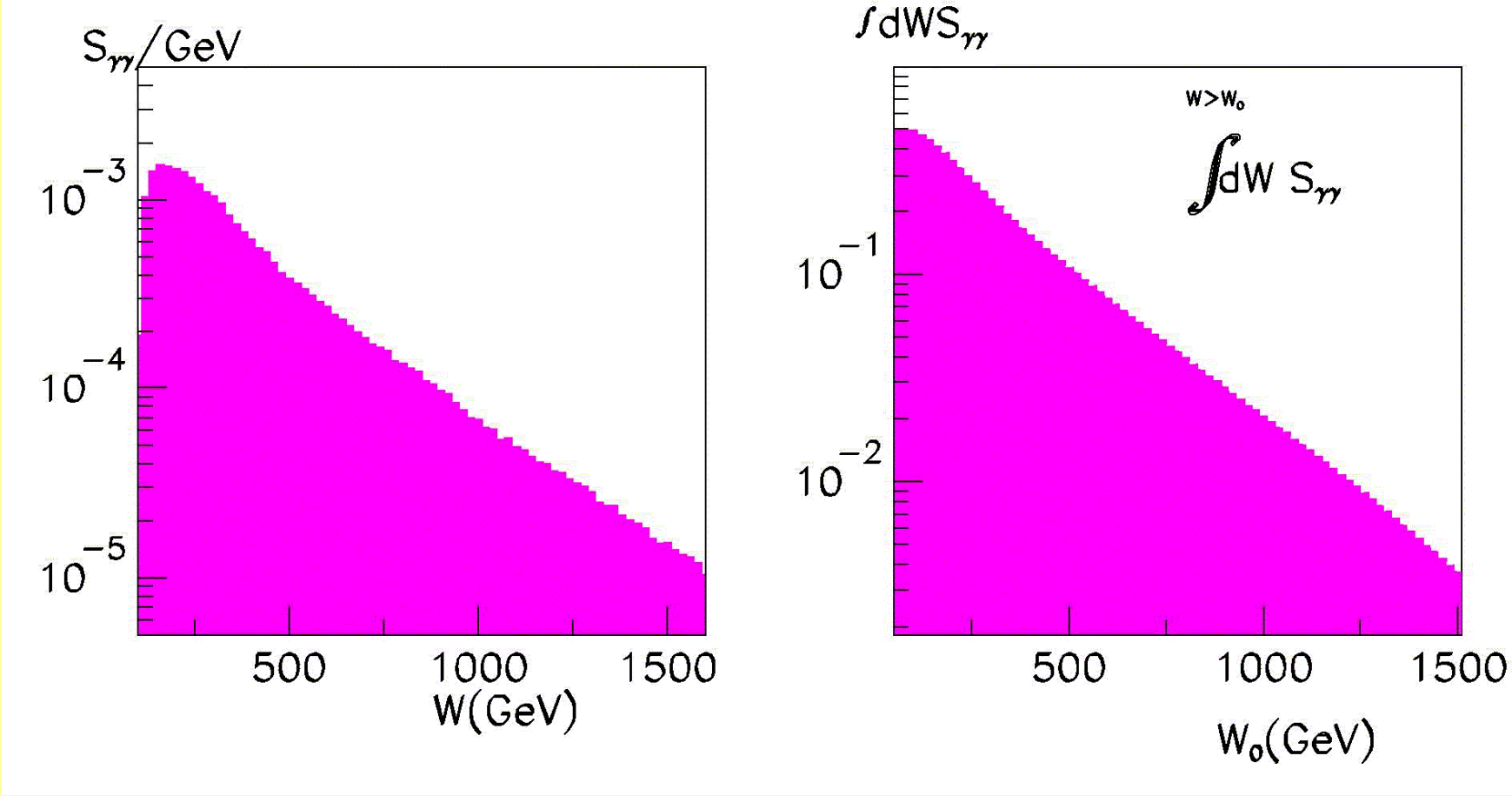
Tagging γp interactions – super HERA @ CERN

Given the tagging capability – an exciting possibility of measuring photon-proton interactions at the LHC opens up:
- significantly higher energy reach and luminosity yield than for $\gamma\gamma$ events is expected

Assumptions:
- $0.01 < x < 0.1$, photon tagging range
- $0.005 < x < 0.3$, Bjorken-x range for quarks and gluons
  (arbitrary for the moment, could be extended)

+ use MRST2001 (at $Q^2=10^4$ GeV^2)

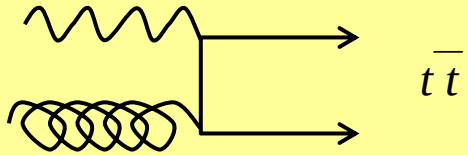
Photon-quark luminosity spectra



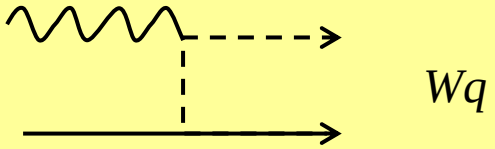
Note: at $W_{\gamma q}$ > 300 GeV photon-quark luminosity is about one third of the nominal *pp* (and still significant beyond 1 TeV)

γp Physics Menu – Highlights

$\sigma \sim 25$ pb at W=400 GeV



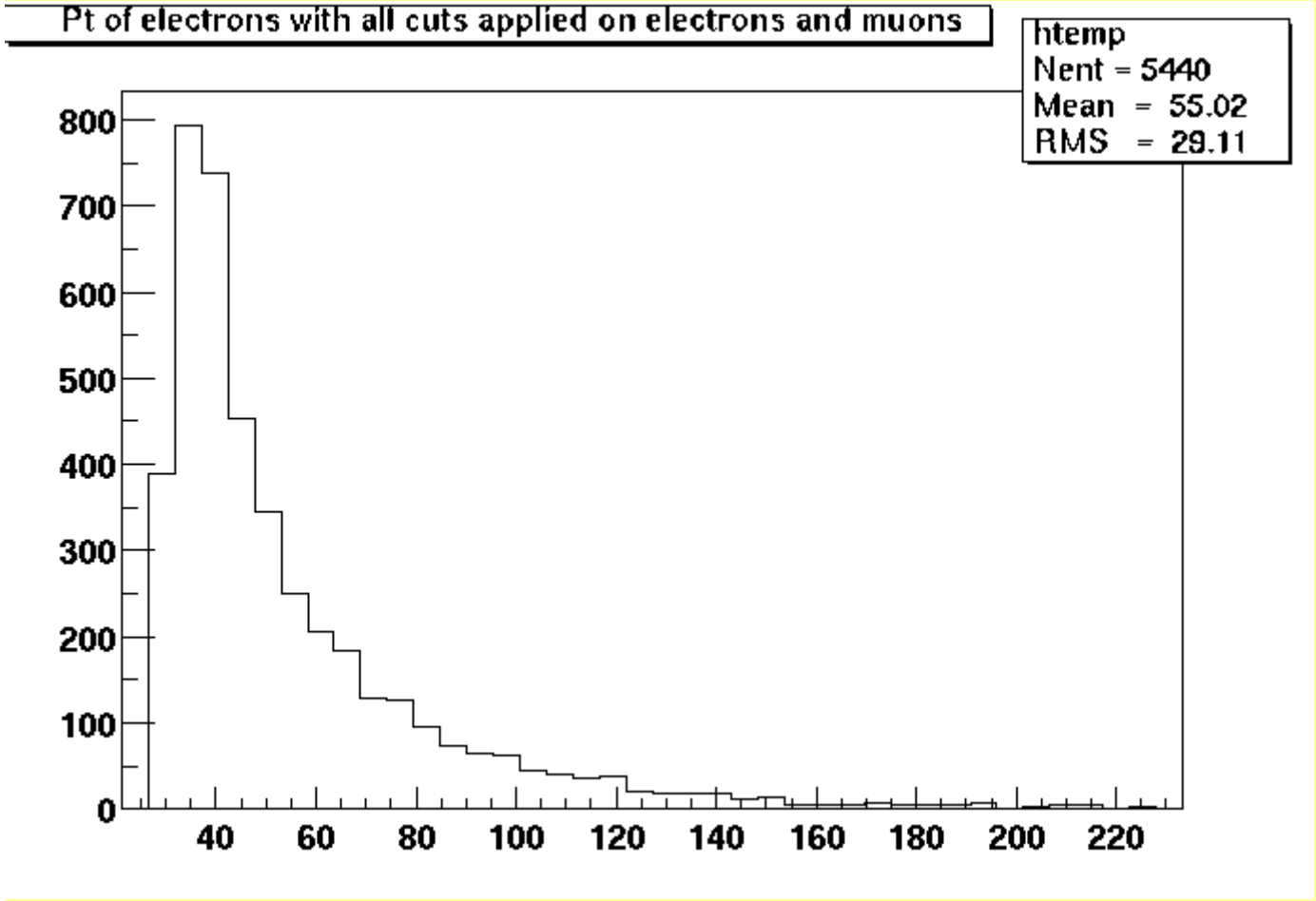
$\sigma \sim 40$ pb for $\gamma q \rightarrow Wq$ at W > 200 GeV



- anomalous W and Z production at $W_{\gamma q} \geq 1$ TeV
- top pair production – top charge (+ mass?) determination
- single top production and anomalous Wtb vertex

Single W production in γp – first results

P_T distribution of electrons



Large event samples expected - the distributions correspond to integ. luminosity of about $1 fb^{-1}$

Already studied at HERA

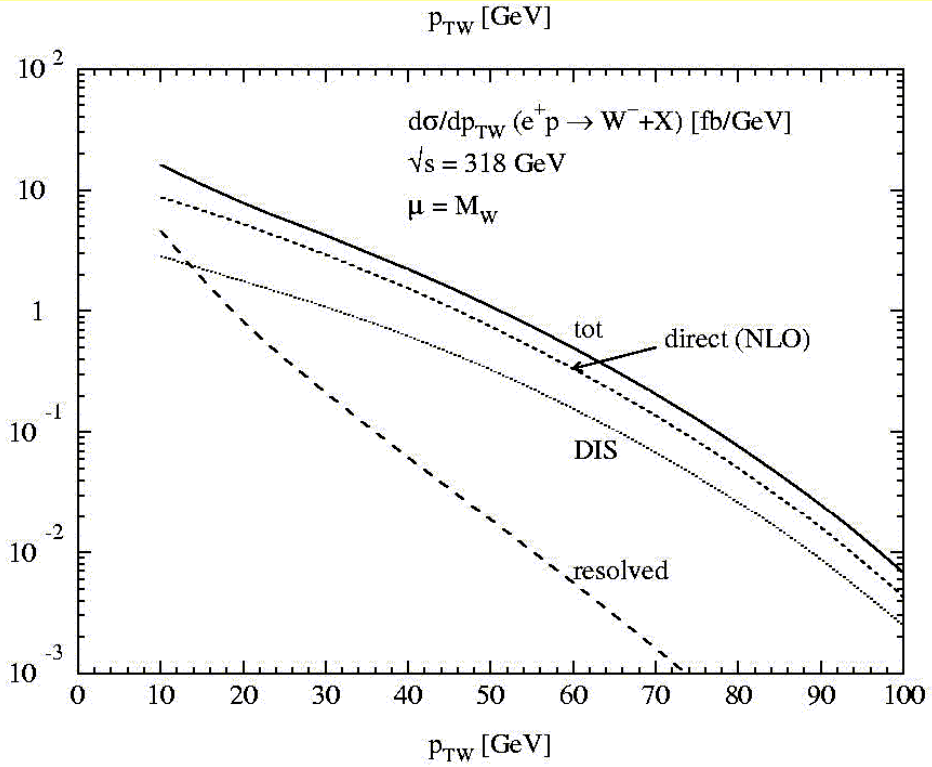
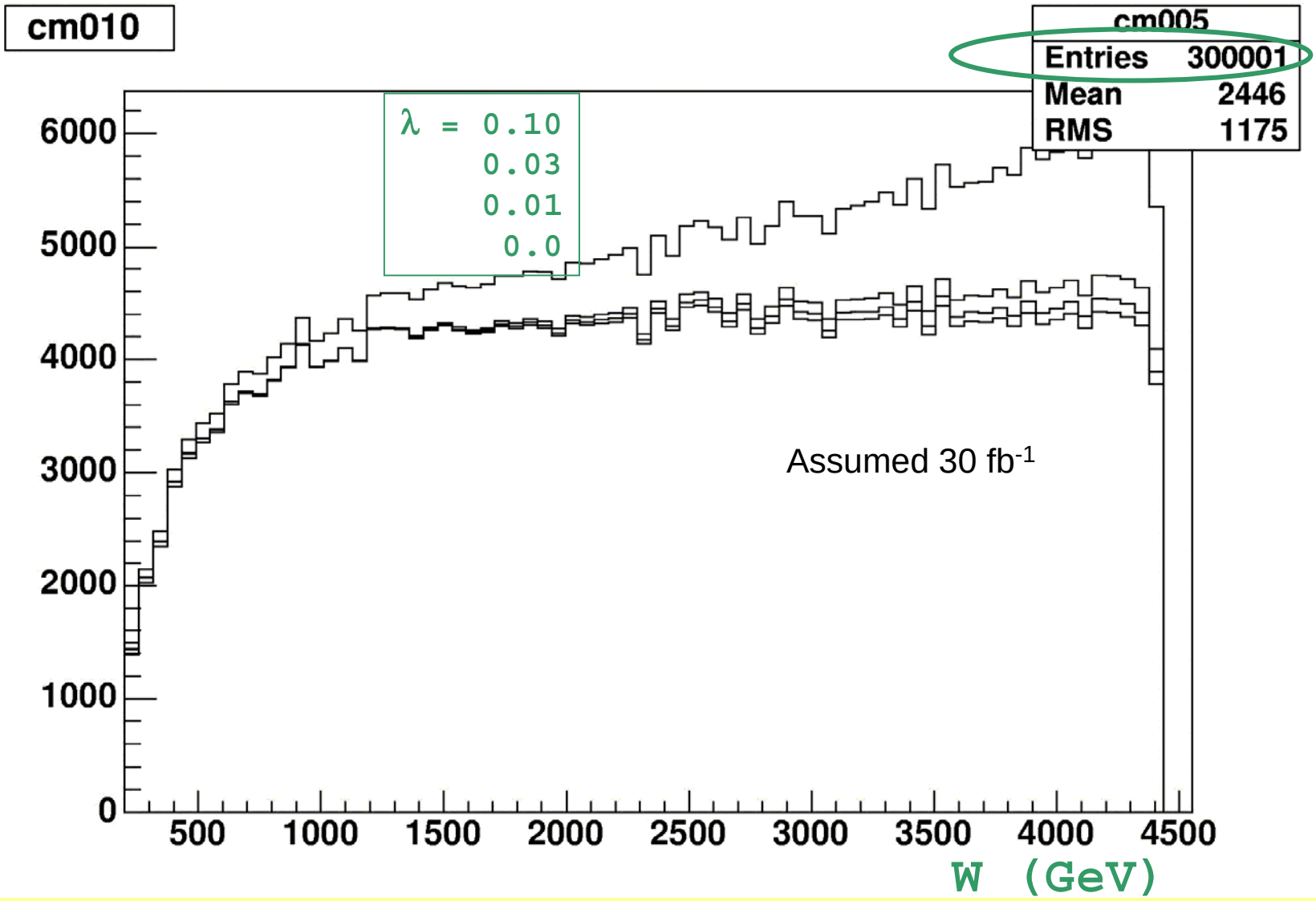


Figure 8: *Transverse momentum distributions of W bosons at HERA. The full curves show the total p_{TW} distributions, while the broken lines exhibit the individual LO DIS, NLO direct and LO resolved contributions. The upper plot is for W^+ production and the lower for W bosons.*

Diener et al.

First very preliminary results obtained for anomalous W production



Survival probability/rescattering

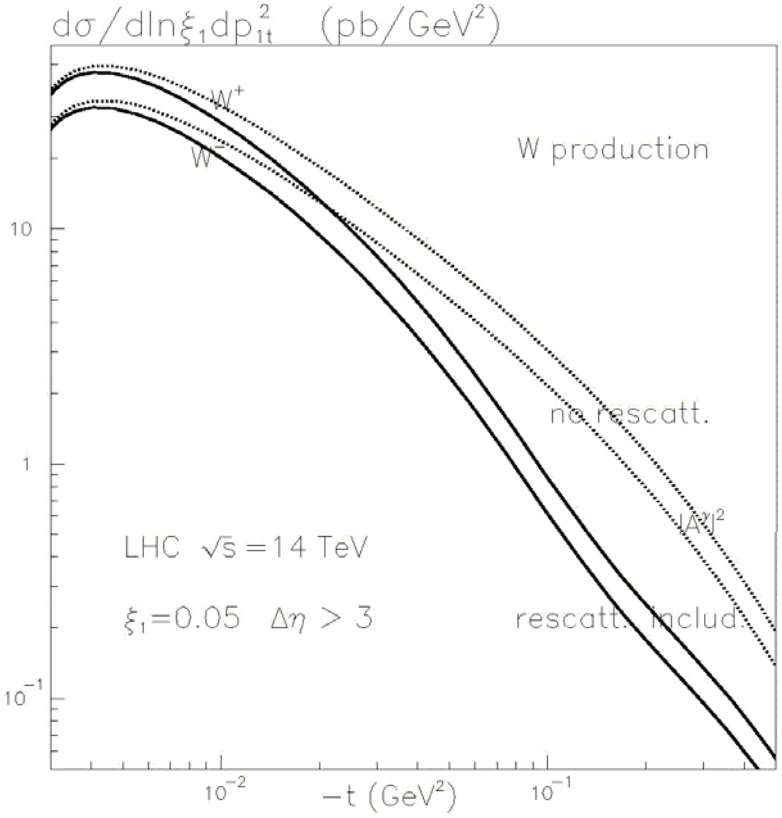


Fig. 9. The differential cross section for $pp \to p + W^{\pm} + X$ at the LHC. The dotted and continuous curves correspond, respectively, to the predictions without and with the rescattering effects of Figs. 8b,c. In each case W^+ production corresponds to the upper one of the pair of curves. The rapidity gap between the quark recoil jet and the W boson is taken to satisfy $\Delta\eta > 3$

V. Khoze et al. EPJC (2002)

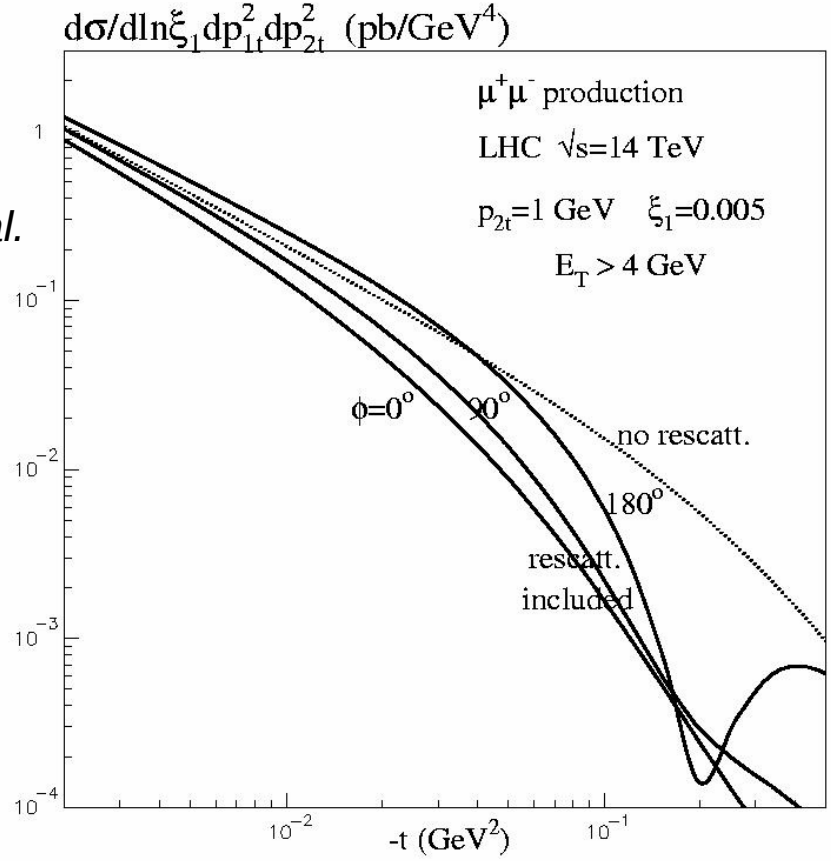
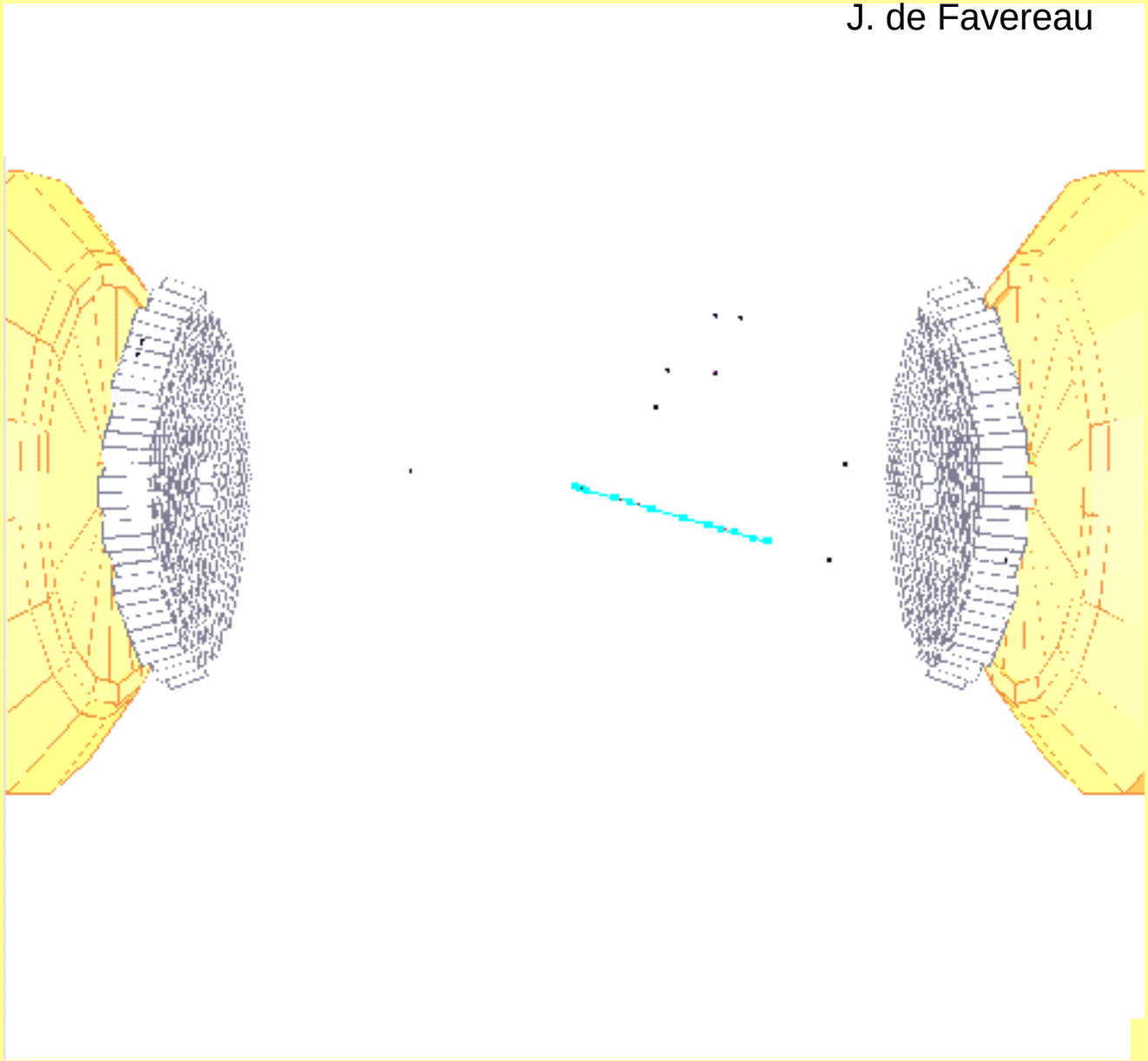


Fig. 10. The cross section for $pp \to p + (\mu^+\mu^-) + p$ at the LHC energy, with (continuous curves) and without (dotted curve) rescattering effects included. The rescattering effects are shown for three values of the azimuthal angle ϕ between the transverse momenta, $\vec{p}_{1t}$ and $\vec{p}_{2t}$, of the outgoing protons

Use photoproduction to scan/verify rescattering models ($p_T^2 \sim Q^2 \sim -t$ controls impact parameter involved): proton detection essential!

(Custom-made) Pythia Events in CMS

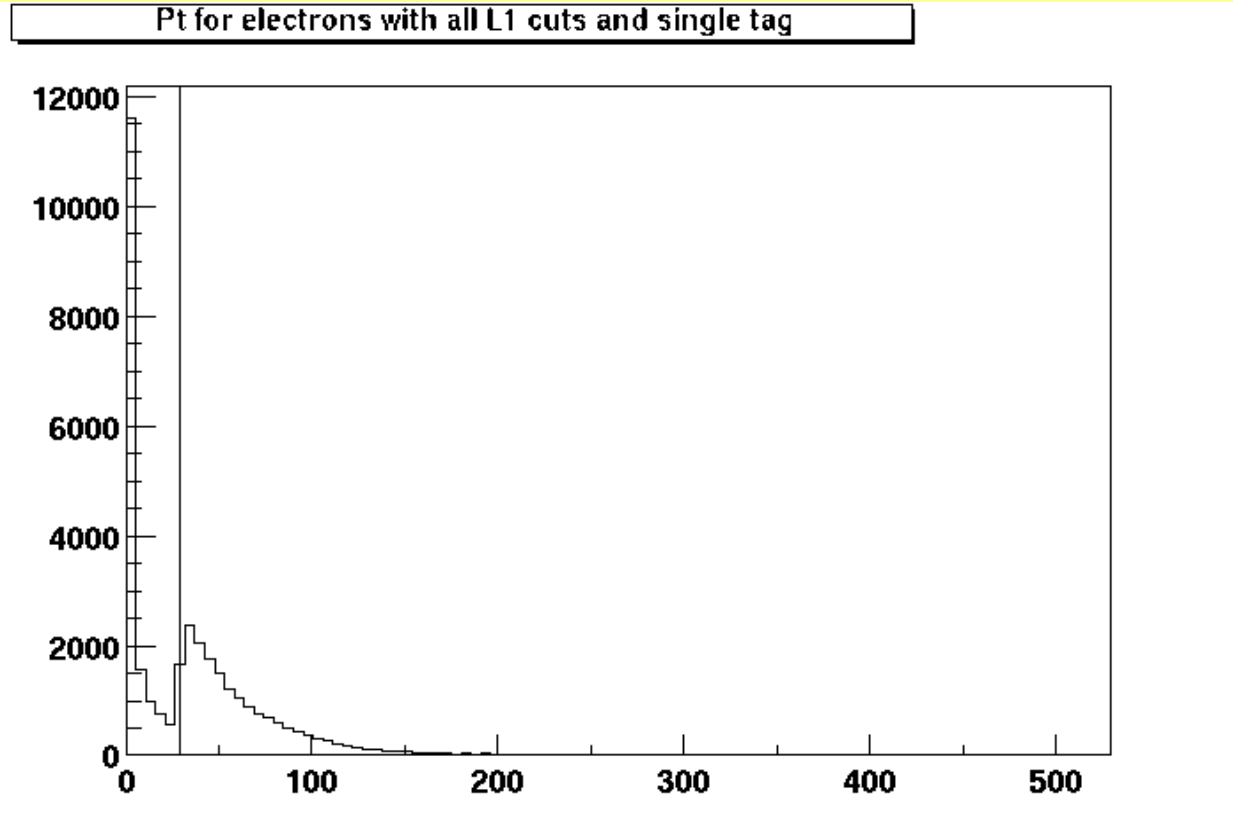
- $\gamma\gamma \rightarrow WW \rightarrow jje\nu$
- $\gamma q \rightarrow Wq \rightarrow jjj$
- $\gamma q \rightarrow Wq \rightarrow e\nu j$
- $\gamma q \rightarrow Wq \rightarrow \mu\nu j$



$\overline{t}\,t$ – first look

J. de Favereau

P_T distribution of electrons



Large event samples expected - the distributions correspond to integ. luminosity of about 20 fb^{-1}

Sensitivity to top charge!

Can contribute to top mass determination?
– One more degree of freedom known (γ energy), and large statistics too...

Summary/Outlook

Tagging photon interactions at the LHC opens up new possibilities:

- testing SM in EW sector
- searches for new physics in $\gamma\gamma$ and γp interactions
- testing ground for models of long-range interactions in *pp* collisions

Detection of forward protons essential

Full simulations underway to demonstrate feasibility: exclusivity signatures (eg. rap gaps), forward jets (W exchange), irreducible backgrounds (eg. W production via IP exchange), ...

Tagging two-photon interactions in HI collisions

Effective luminosity of $\gamma\gamma$ collisions is high, especially for *ArAr* case at LHC (comparable to *pp)*, and two-photon production is enhanced ($\sim Z^4$), due to coherence, with respect to pomeron-pomeron case

$\Rightarrow$ LHC optics in Heavy Ion mode similar to the *pp* one, hence assume same tagging range $0.1>x>0.01$

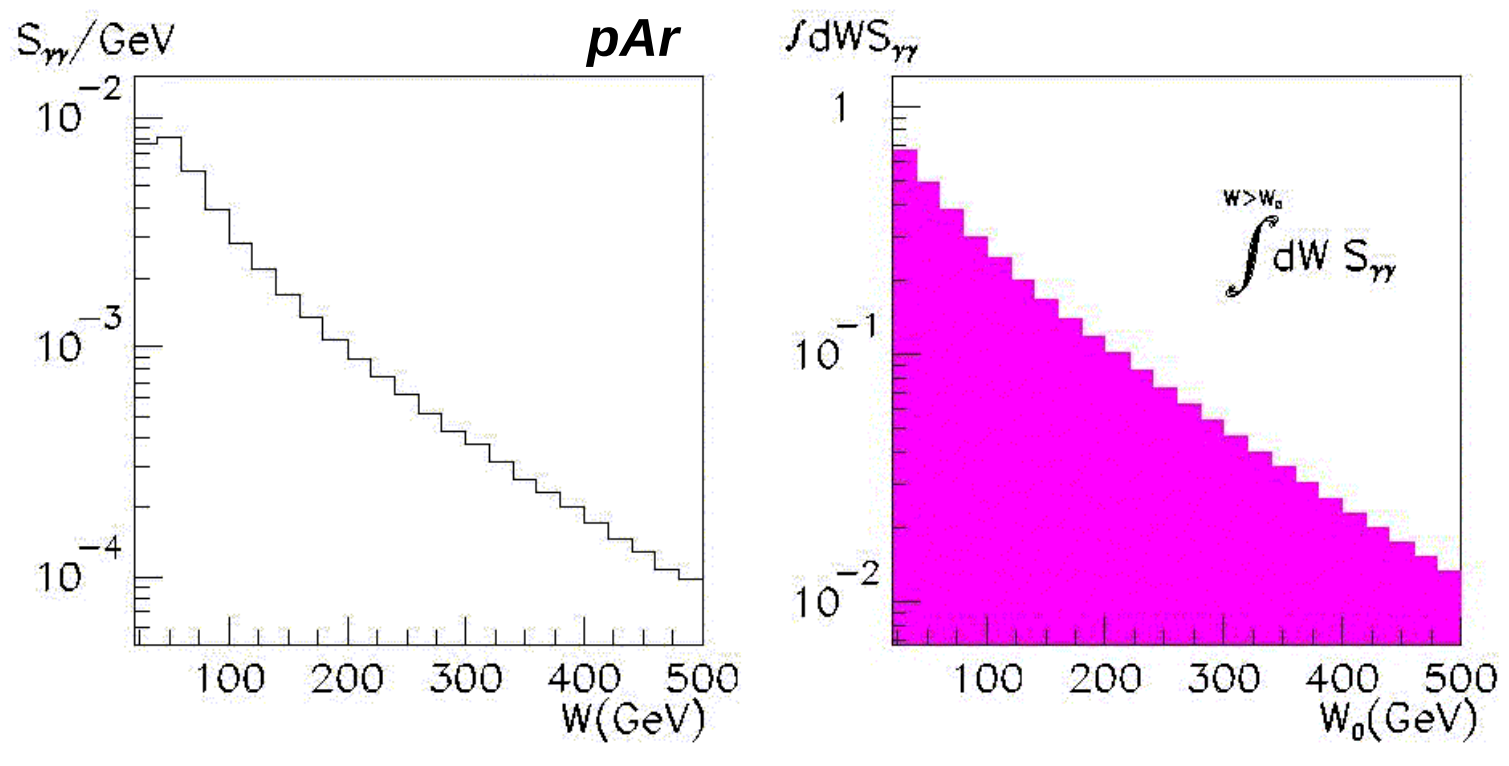
This has two consequences:

- Tagged *W* values are very large and corresponding luminosity is small (coherence loss), e.g. for 140 TeV beams *W* range is approximately 4-25 (0.5-25) TeV for double (single) tagging

- Intrinsic HI beam divergence results in large p_T smearing, much bigger than typical values for two-photon events

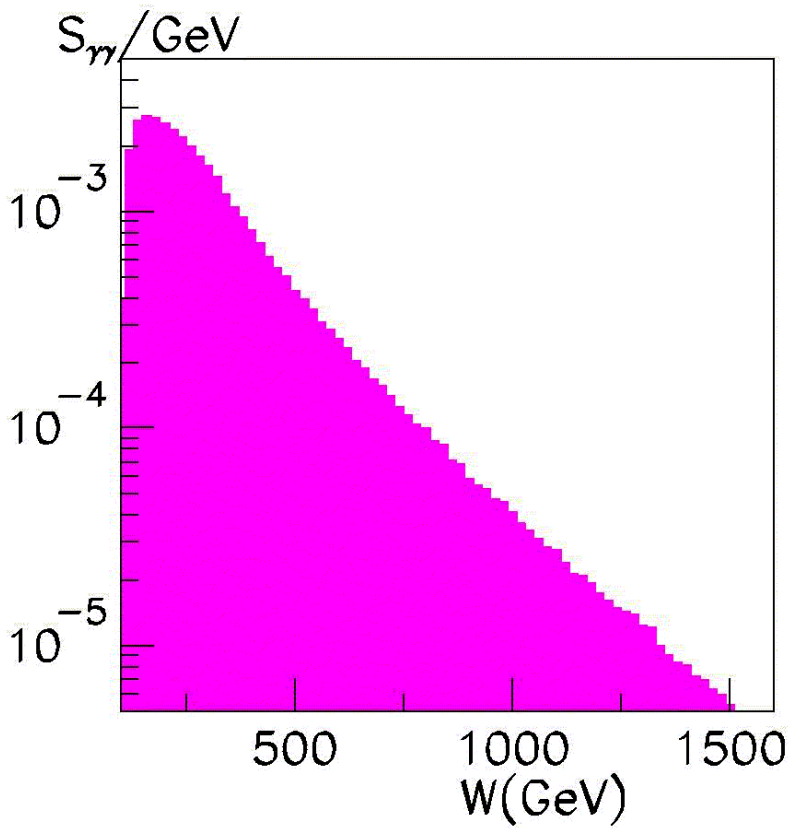
Tagging $\gamma\gamma$ interactions in HI collisions II

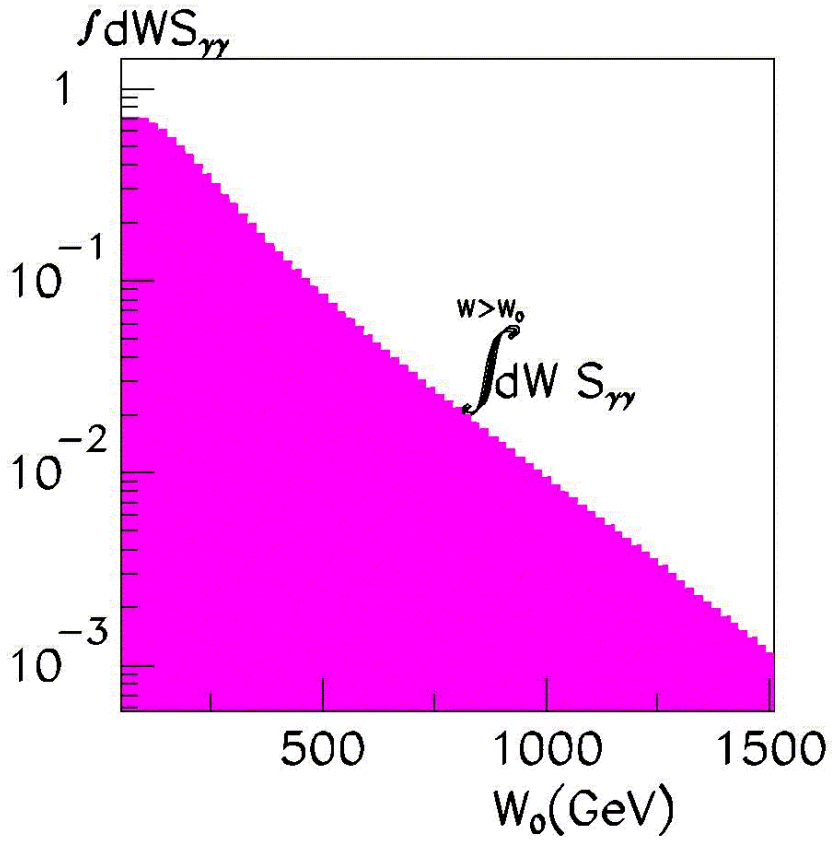
More exciting is possibility of measuring very forward protons in *pA* collisions - in such a case full signature of $\gamma\gamma$ events is recovered (for single tags)



At W = 100 GeV $S_{\gamma\gamma}$ is almost 100 bigger than for *pp* case, i.e. one needs 'only' 300 pb^{-1} *pAr* sample to achieve similar $\gamma\gamma$ statistics

Photon-gluon luminosity spectra





Note: at $W_{\gamma g} > 400$ GeV photon-gluon luminosity is about 10% of the nominal *pp*