Studies of High Energy Photon Interactions at the LHC

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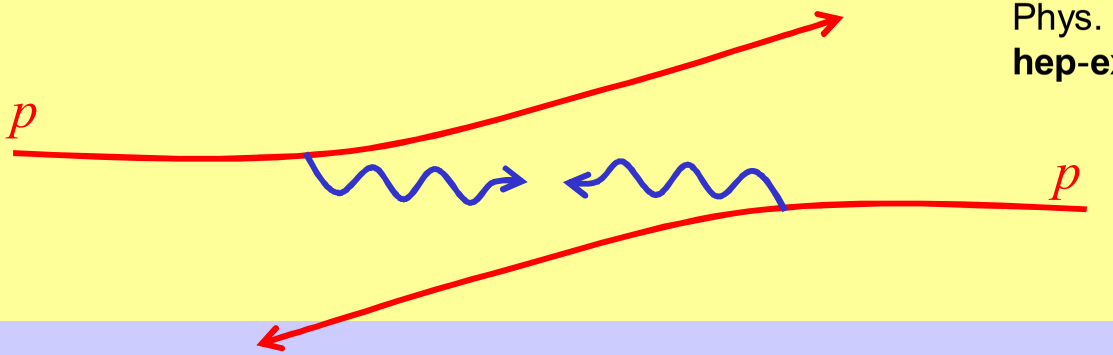
- Introduction: LHC as a high energy $\gamma\gamma$ and γp collider
- Photoproduction of WH (M. vander Donckt)
- Luminosity measurement with exclusive lepton pairs at the LHC (Y. Liu)
- Anomalous quartic couplings and WW and ZZ two-photon production (T. Pierzchała)
- Ion case
- Outlook

LHC as a High Energy γγ Collider

Phys. Rev. **D63** (2001) 071502(R)
hep-ex/0201027



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**

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.

γp interactions at the LHC - super HERA at CERN

Photon-proton interactions at the LHC have significantly higher energy reach and luminosity yield than for the $\gamma\gamma$ events is expected

Example assumptions:

- $0.01 < x_1 < 0.1$, photon tagging range
- $0.005 < x_2 < 0.3$, Bjorken-x range for quarks and gluons

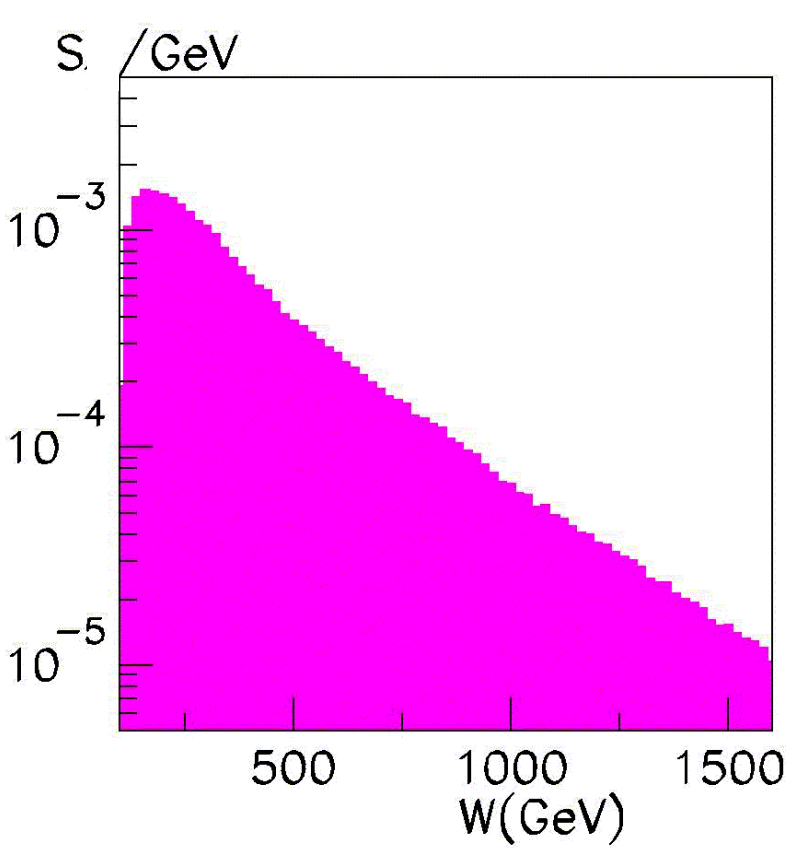
(arbitrary for the moment, could be extended)

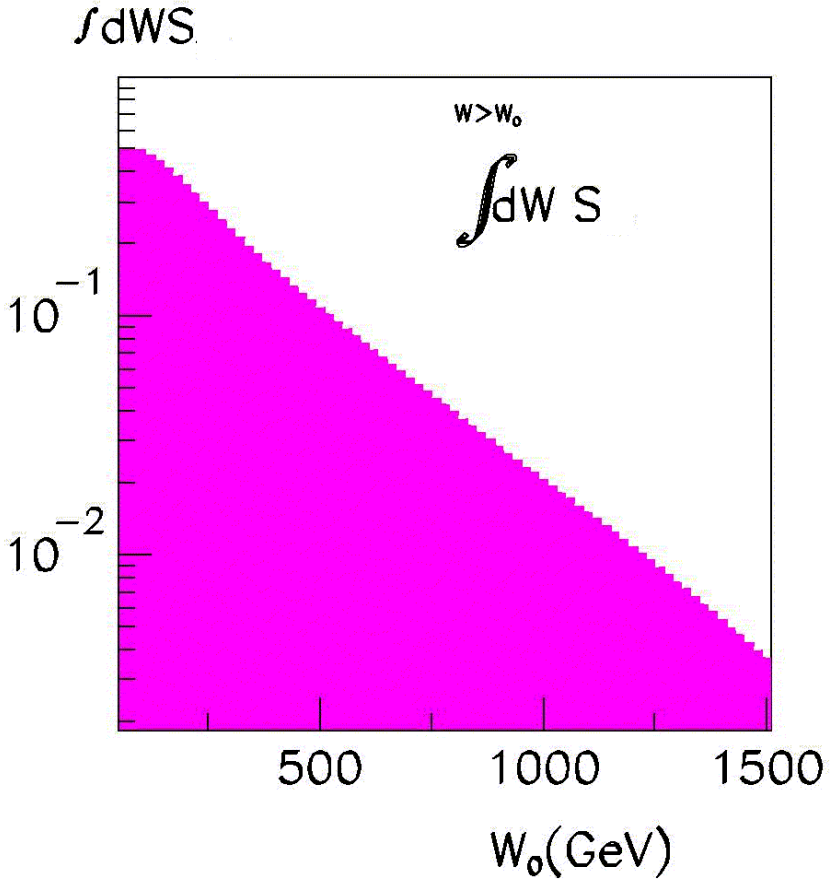
+ use MRST2001 (at $Q^2=10^4$ GeV^2) for partons

$$S(W) = f_\gamma(x_1) \otimes f_p(x_2) \quad , \quad W^2 = 4E_p x_1 x_2$$

$$\sigma_{pp} = \int S \; \sigma_{\gamma p} \; dW$$

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)

$\gamma p \rightarrow WHX$: Introduction

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- For low SM higgs boson mass: $h \rightarrow bb$ is dominant but drowned in QCD background
- In γq interactions, the proton emitting an elastic γ, does not break up $\Rightarrow$ no energy in one HF (+ RP tag) $\Rightarrow$ QCD background reduction.
- BUT : $\sigma_{\gamma\gamma} < \sigma_{\gamma q} < \sigma_{qq}$

- GOAL: assess a possible alternative way to observe a 115-150GeV higgs, in a channel with different systematics from $h \rightarrow \gamma\gamma$.

$\gamma p \rightarrow WHX$: Main features

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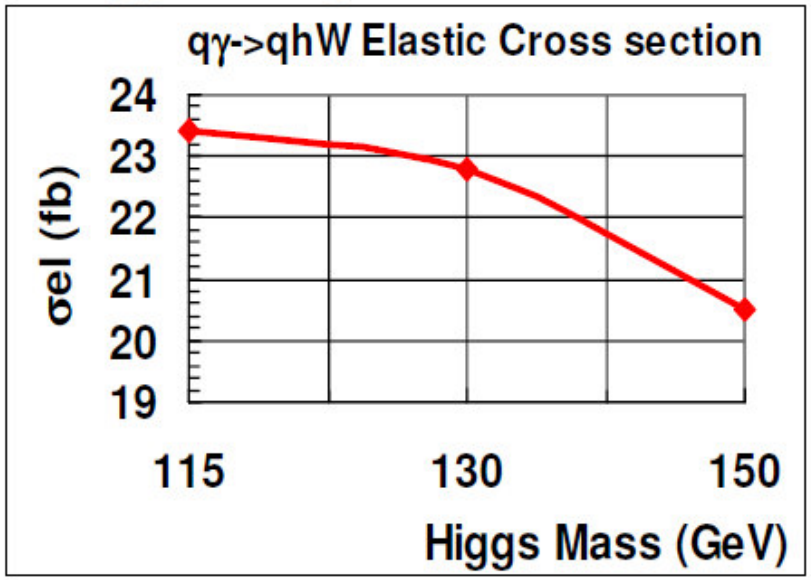
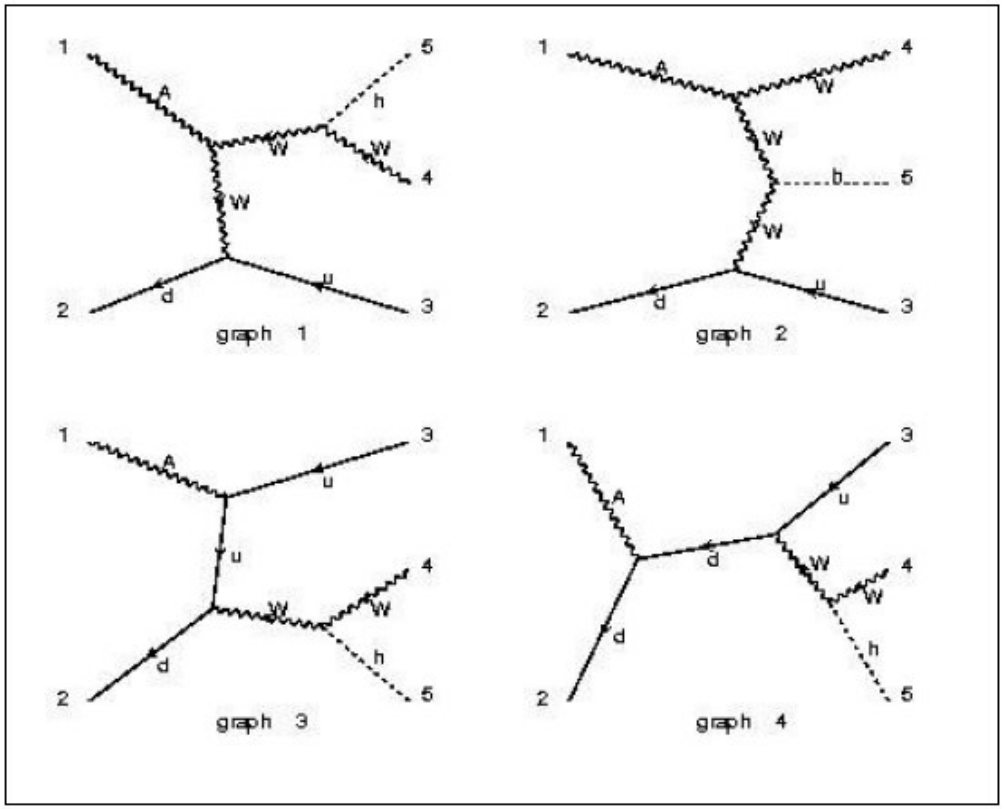
- 1 side of the detector with
  - Little energy in HF
  - Proton tag (only elastic events)
- 1 lepton from $W \rightarrow l\nu$
- 1 extra jet
- Higgs decay: $bb, \tau\tau, WW$



CompHep takes into account
Interferences between the 4 diagrams



$\gamma p \rightarrow WHX$: Forward tagging

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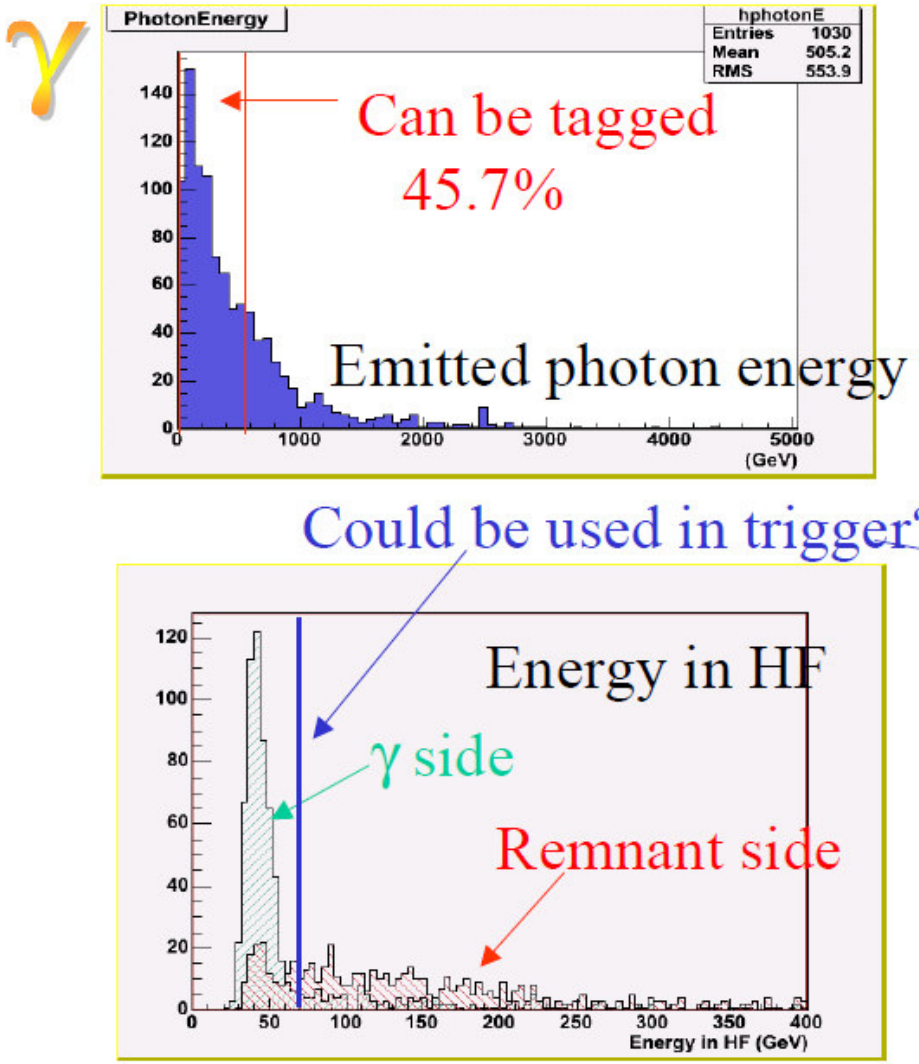

$\gamma p \rightarrow WHX$: $H \rightarrow bb$ event rates

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2 samples:

- Elastic and quasi-elastic events without pile-up: $10 fb^{-1}$
- Elastic events with pile-up and Roman Pot tag : $100\ fb^{-1}$ at $2x10^{33}$

el+QE M_h	115
$10\ fb^{-1}$ full decay	585
$+ W \rightarrow l\nu$	185
$+ h \rightarrow bb$	135
$\|\eta_l\| < 2.5$	113
E_{HF}<70 GeV or RP	112

Elastic M_h	115
$100\ fb^{-1}$ full decay	2340
$+ W \rightarrow l\nu$	741
$+ h \rightarrow bb$	543
$\|\eta_l\| < 2.5$	462
RP tag (45.7%)	211

γ flux: Cross check

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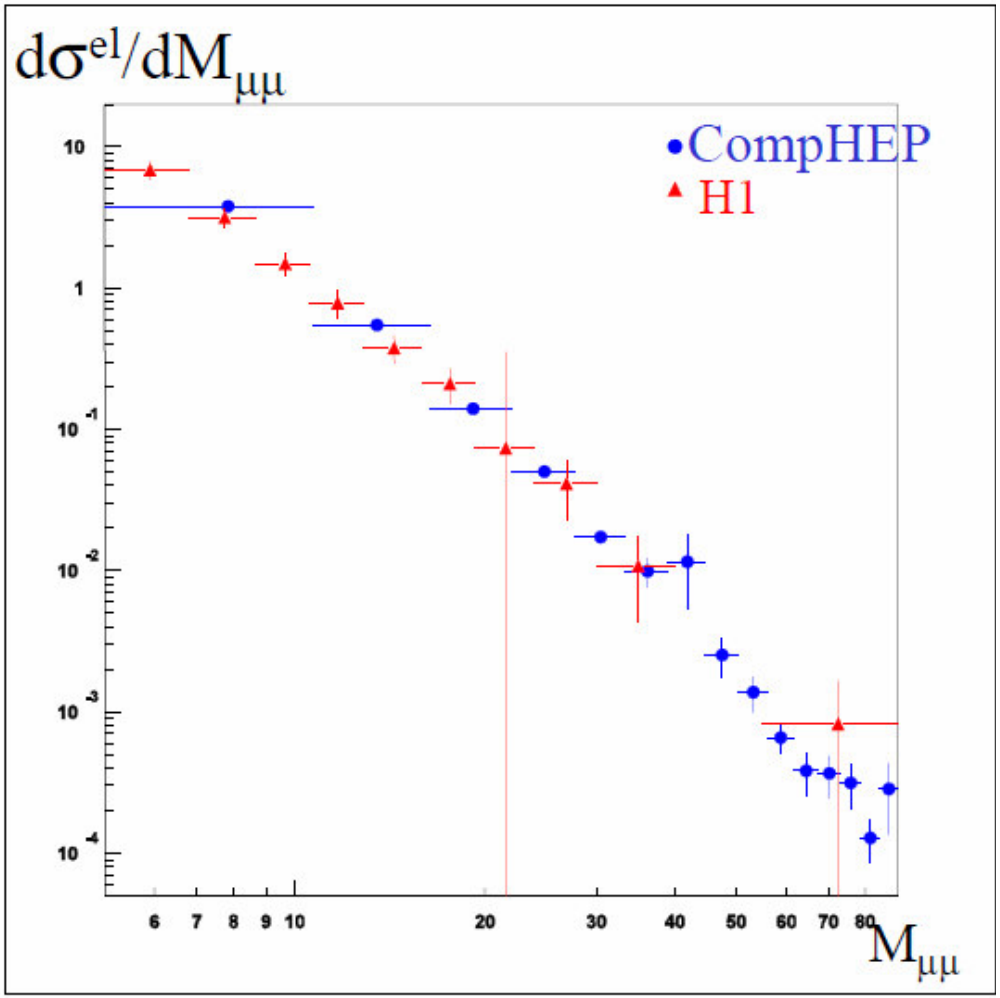
- γ pdfs: Equivalent Photon Approximation

  Budnev et al, Phys. Lett. C15 (1975), 181.

- Added and tested in CompHEP for elastic γ emission ($Q^2<1 GeV^2$)

$\sigma_{H1}=25.3\pm1.0\pm3.5$ pb

$\sigma_{compHEP}=25.8$ pb

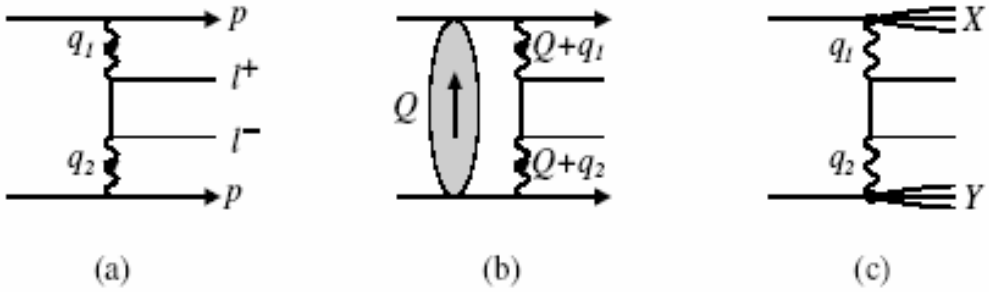


Aktas et al, Phys Rev Lett B583 (2004), 28-40

Introduction : $pp \longrightarrow pe^+e^-p$

- QED process (a) production σ precisely known.

event generator LPAIR based on ME by Vermaseren



- Hadronic corrections [(b) (c)] small. Can suppress with experimental cuts and subtract by fitting final state kinematics.

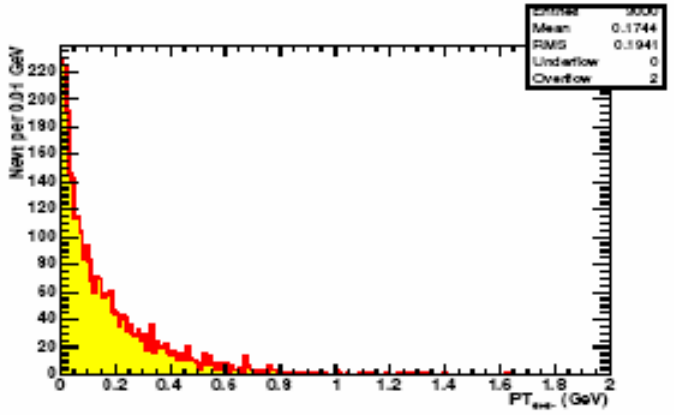
V. A. Khoze et al Eur. Phys. J **C19**, *313-322 (2001)*

- Production rate considerable,

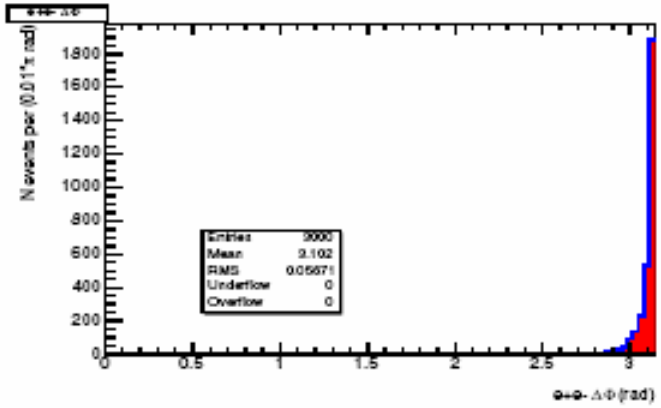
e.g. $\sigma_{(P_T>2\ \mathrm{GeV})} = 0.129\ \mathrm{nb} \pm 0.234\ \mathrm{pb}.$

Lpair:3K $pp \to pe^+e^-p$ (P_T>2GeV)

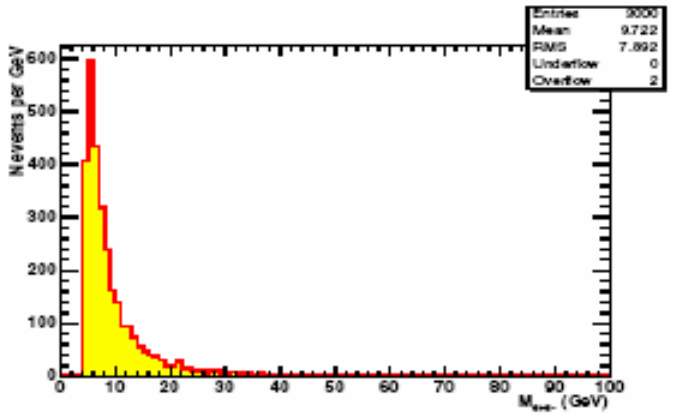
e^+e^- two body system P_T



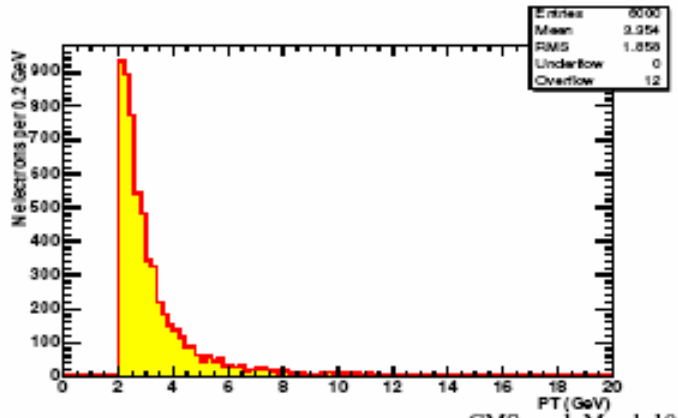
$\Delta\Phi$



Invariant mass of e^+e^-



PT of the leptons



CMS week, March 18, 2005 –

Infer E_γ at initial state.

- When both leptons are observed, the energy of the $\gamma\gamma$ at initial state can be infered -assumption : their transverse momenta are small

$$M_{l+l-} = 4E_{\gamma 1}E_{\gamma 2}; \quad (1)$$

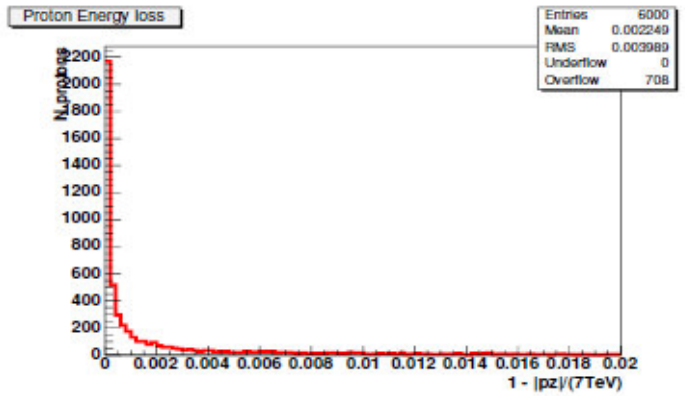
$$Y_{l+l-} = \frac{1}{2}\log\frac{E_{\gamma 1}}{E_{\gamma 2}} \quad (\text{take } P_{z\gamma 2} < 0) \quad (2)$$

where, M_{l+l-}, Y_{l+l-} are the invariant mass, rapidity of the l^+l^- two body system respectively.

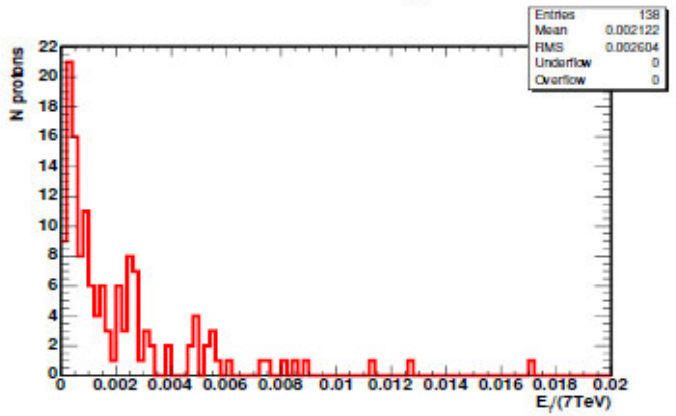
- This can be used to calibrate forward detectors.

$x \equiv E_\gamma / E_p$

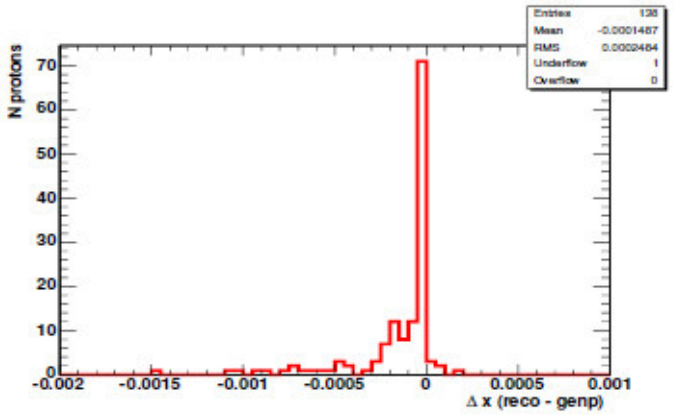
Generator level



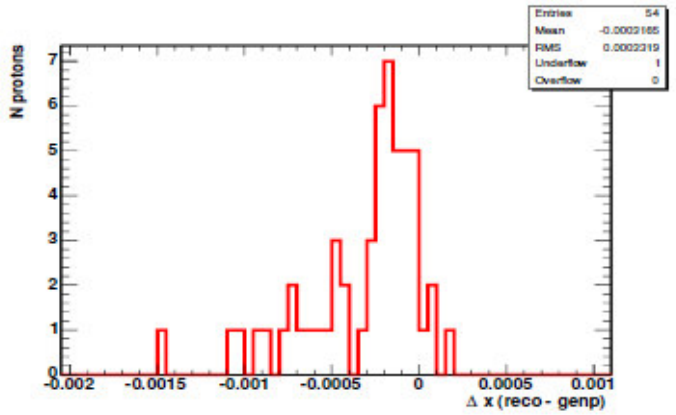
reconstructed using e^+e^-



The difference



Difference ($x_{true} > 0.002$)



For 420m detectors ($x > 0.002$), resolution comparable with beam spread. 10^{-4}

Summary & Outlook

- $\sigma * 69/3000 \approx 3\text{pb}$, i.e, possible to measure the luminosity to $2-3\%$ with 1 fb^{-1}
- It is a good tool to calibrate forward detectors.
- Need to think about triggering low P_T lepton pair + "exculsivity" .
- Need to consider backgroud, such as DY.
- This trigger (to propose) will collect $\Upsilon \rightarrow l^+l^-$: useful for detector calibration.
- Including $\mu^+\mu^-$ will be helpful.Currently in to-do's.
- Need to understand the (in)efficiency and fake rate for low P_T leptons. Source of systematics.

$\gamma\gamma \to$ WW production at the LHC

Anomalous quartic vector boson couplings

- imposing C,P conservation, local $U(1)_{em}$, global $SU(2)_c \Rightarrow \ \rho = 1$

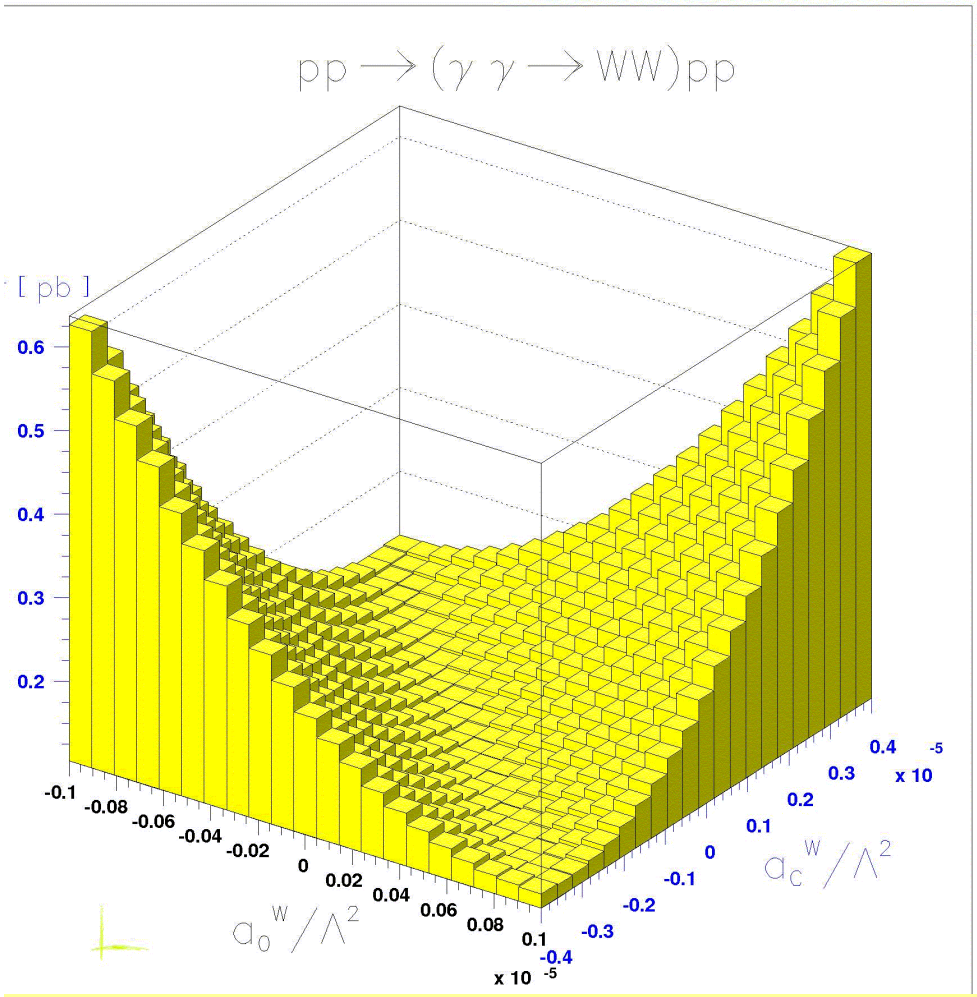
$$\mathcal{L}_6^0 = -\frac{e^2}{8}\frac{a_0^{\mathrm{W}}}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_{\alpha} - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^{\mathrm{Z}}}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}Z^{\alpha}Z_{\alpha},$$

$$\mathcal{L}_6^{\mathrm{c}} = -\frac{e^2}{16}\frac{a_{\mathrm{c}}^{\mathrm{W}}}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_{\beta} + W^{-\alpha}W^+_{\beta}) - \frac{e^2}{16\cos^2\theta_W}\frac{a_{\mathrm{c}}^{\mathrm{Z}}}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}Z^{\alpha}Z_{\beta}.$$

- current limits form OPAL (hep-ex/0402021)

$$\begin{aligned}
-0.007\ \mathrm{GeV}^{-2} < \ & a_0^{\mathrm{Z}}/\Lambda^2 \ < 0.023\ \mathrm{GeV}^{-2},\\
-0.029\ \mathrm{GeV}^{-2} < \ & a_{\mathrm{c}}^{\mathrm{Z}}/\Lambda^2 \ < 0.029\ \mathrm{GeV}^{-2},\\
-0.020\ \mathrm{GeV}^{-2} < \ & a_0^{\mathrm{W}}/\Lambda^2 \ < 0.020\ \mathrm{GeV}^{-2},\\
-0.052\ \mathrm{GeV}^{-2} < \ & a_{\mathrm{c}}^{\mathrm{W}}/\Lambda^2 \ < 0.037\ \mathrm{GeV}^{-2},
\end{aligned}$$

Anomalous quartic vector boson couplings



- SM $\gamma\gamma \to WW$ for $\int L_{pp}\, dt$=30fb^{-1} $\Rightarrow$ about 3000 W pairs will be produced
- we expect at least 10 000 $\times$ stronger limits:

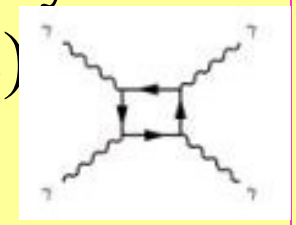
$$-0.1{\cdot}10^{-5}\ \mathrm{GeV}^{-2} < a_0^W/\Lambda^2 < 0.1{\cdot}10^{-5}\ \mathrm{GeV}^{-2}$$

$$-0.4{\cdot}10^{-5}\ \mathrm{GeV}^{-2} < a_c^W/\Lambda^2 < 0.4{\cdot}10^{-5}\ \mathrm{GeV}^{-2}$$

Gauge boson photoproduction

- Hope for large sensitivity in QGC, will study WW anomalous production for LED and strong W sector

$\gamma\gamma \to \gamma\gamma$ (also not possible at tree level), eg. sensitivity to massive monopole contributions (large p_T physics)



$\gamma\gamma \to ZZ$ suppressed in SM (~10^{-3}), good place to look for BSM

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 $0.1>x>0.01$

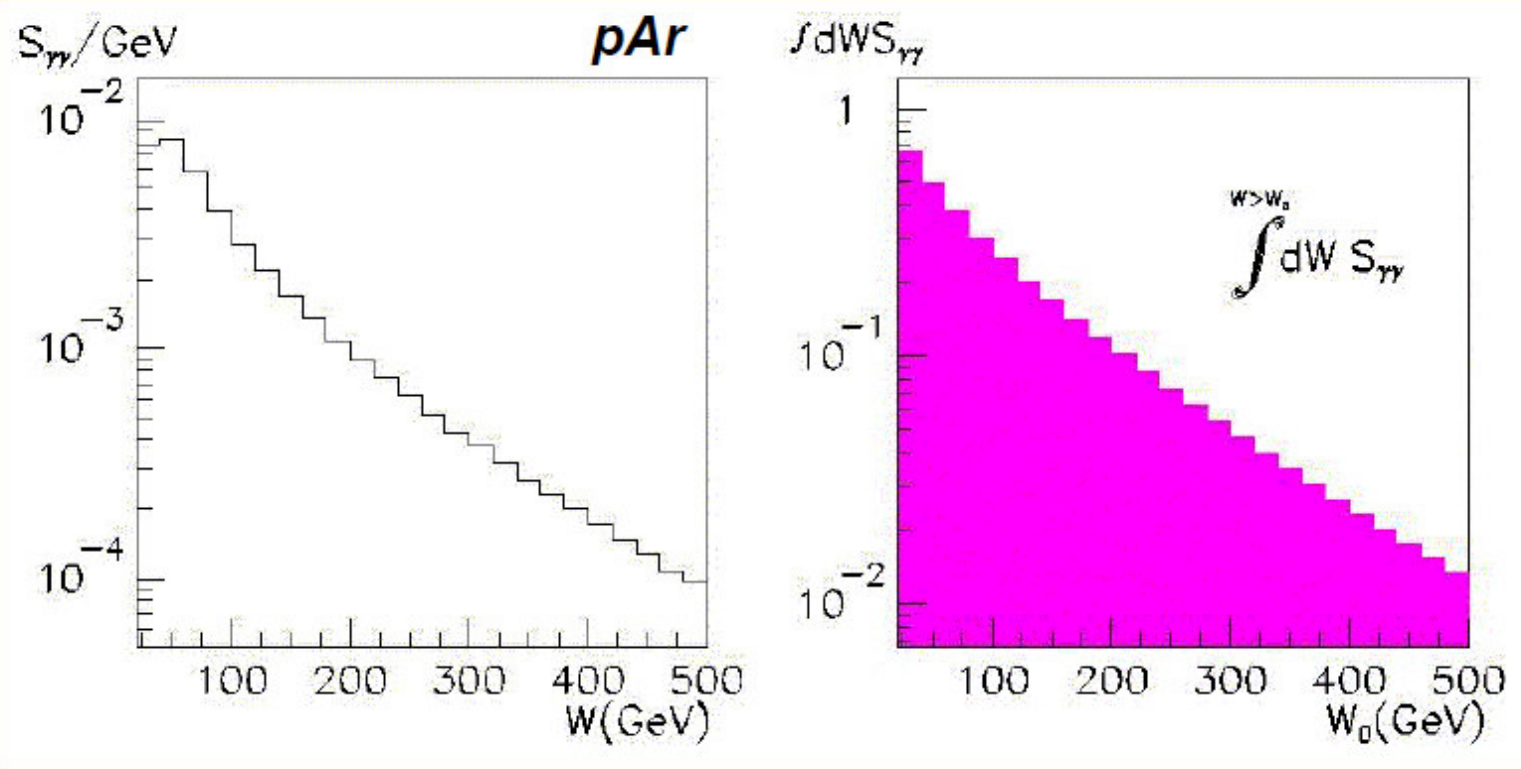
This has two consequences:

- 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

FP420 changes the situation – tagging of a couple of per mille energy losses makes the coherent zone accessible (for not too heavy ions as Ar or Ca), i.e. (single-)tagged photon-photon collisions in ArAr case.

- Forward proton detectors at the LHC opens up new, exciting physics domain

- Tagging photon interactions at high energy will allow for new contributions to the electroweak sector

- Photon induced events are of experimental interest for calibration of forward detectors

- Tagging photon interactions in ion collisions should also be considered

Stay Tuned !