Studies of High Energy Photon Interactions at the LHC

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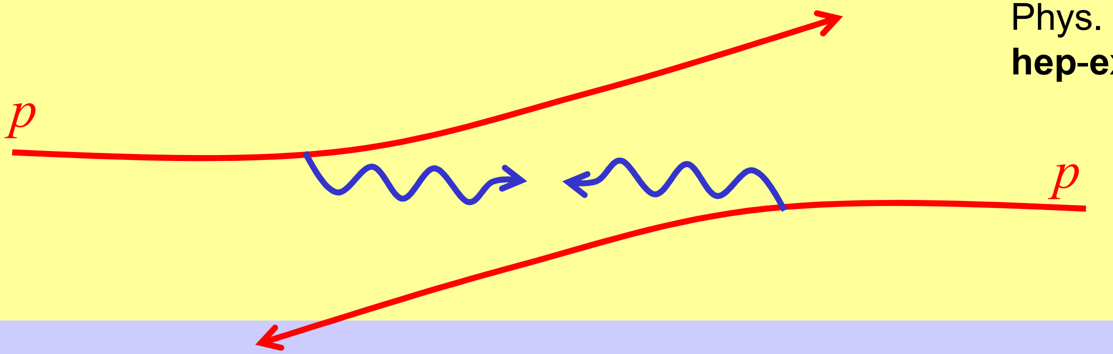
- Introduction: *LHC as a high energy $\gamma\gamma$ and γp collider*
- Photoproduction of WH (M. vander Donckt)
- *Anomalous quartic couplings and WW and ZZ two-photon production (T. Pierzchała)*
- Luminosity measurement with exclusive lepton pairs at the LHC (Y. Liu)
- Outlook

LHC as a High Energy $\gamma\gamma$ Collider

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



Highlights:

- $\gamma\gamma$ CM energy W up to/beyond 1 TeV (and under control)
- Large photon flux F therefore significant $\gamma\gamma$ 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 $\gamma\gamma$ (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.

Kinematics/γγ Luminosity

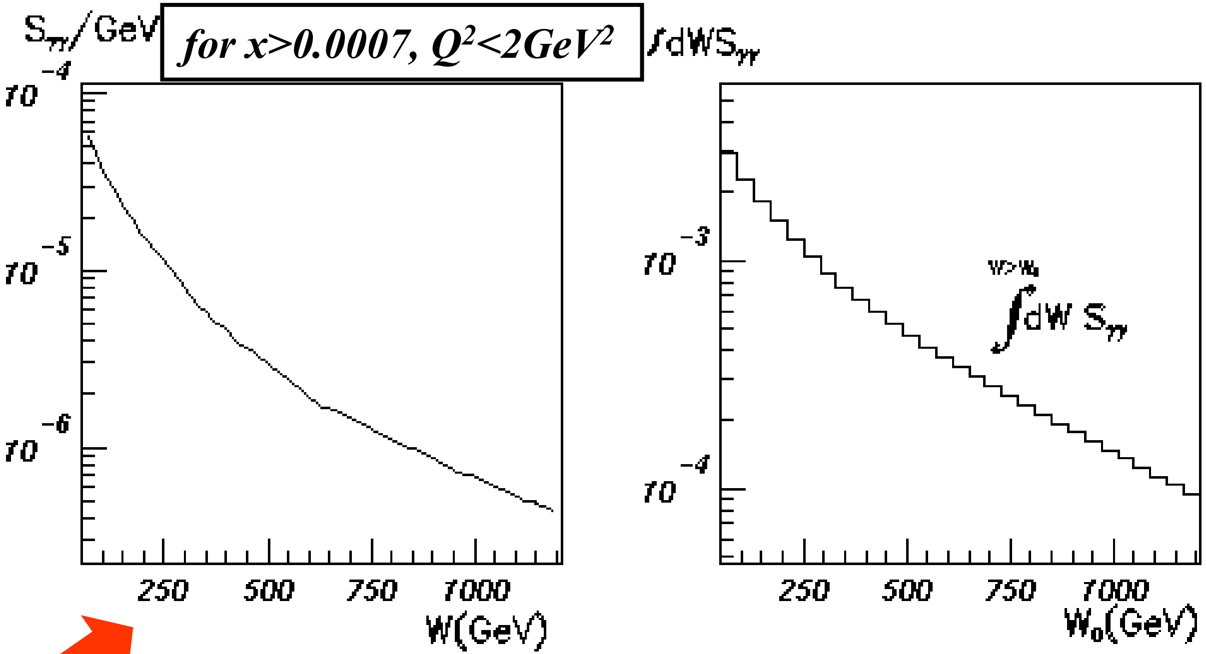
Virtuality Q^2 of colliding photons vary between kinematical minimum = $M_p^2 x^2/(1-x)$ where x is fraction of proton momentum carried by a photon, and $Q^2_{\text{max}} \sim 1/\text{proton radius}^2$

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

Photon flux $\propto 1/Q^2$

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

protons scattered at `zero-degree' angle



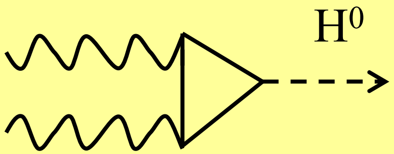
Use EPA à la *Budnev et al.**

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

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

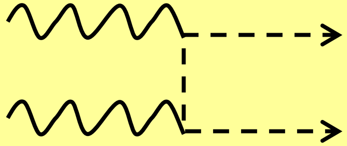
Note: it's few times larger if one of protons is allowed to break up

$\gamma\gamma$ Physics Menu - Highlights

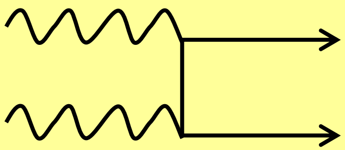


$\sigma \sim 10$ pb (at $W=M_H=200$ GeV)

$\sigma \sim 80$ pb



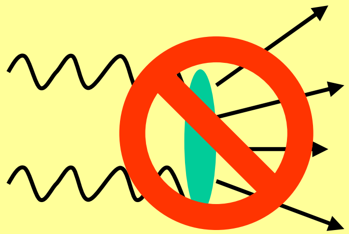
W^+W^-



tt

$\sigma \sim 1$ pb

+ ***SUSY processes***



All ?

$\sigma \sim 100$–500 nb

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

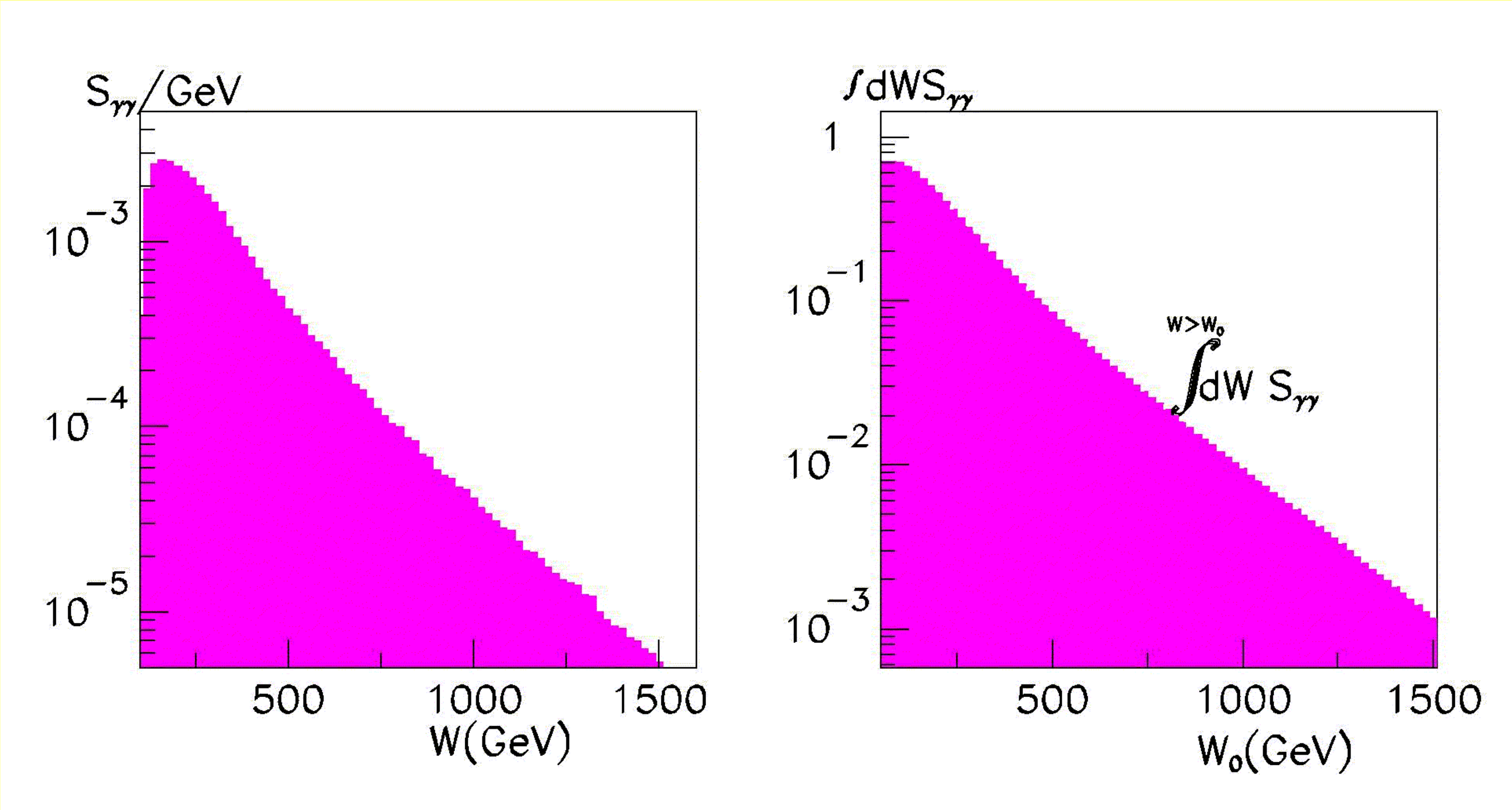
(arbitrary for the moment, could be extended)

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

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

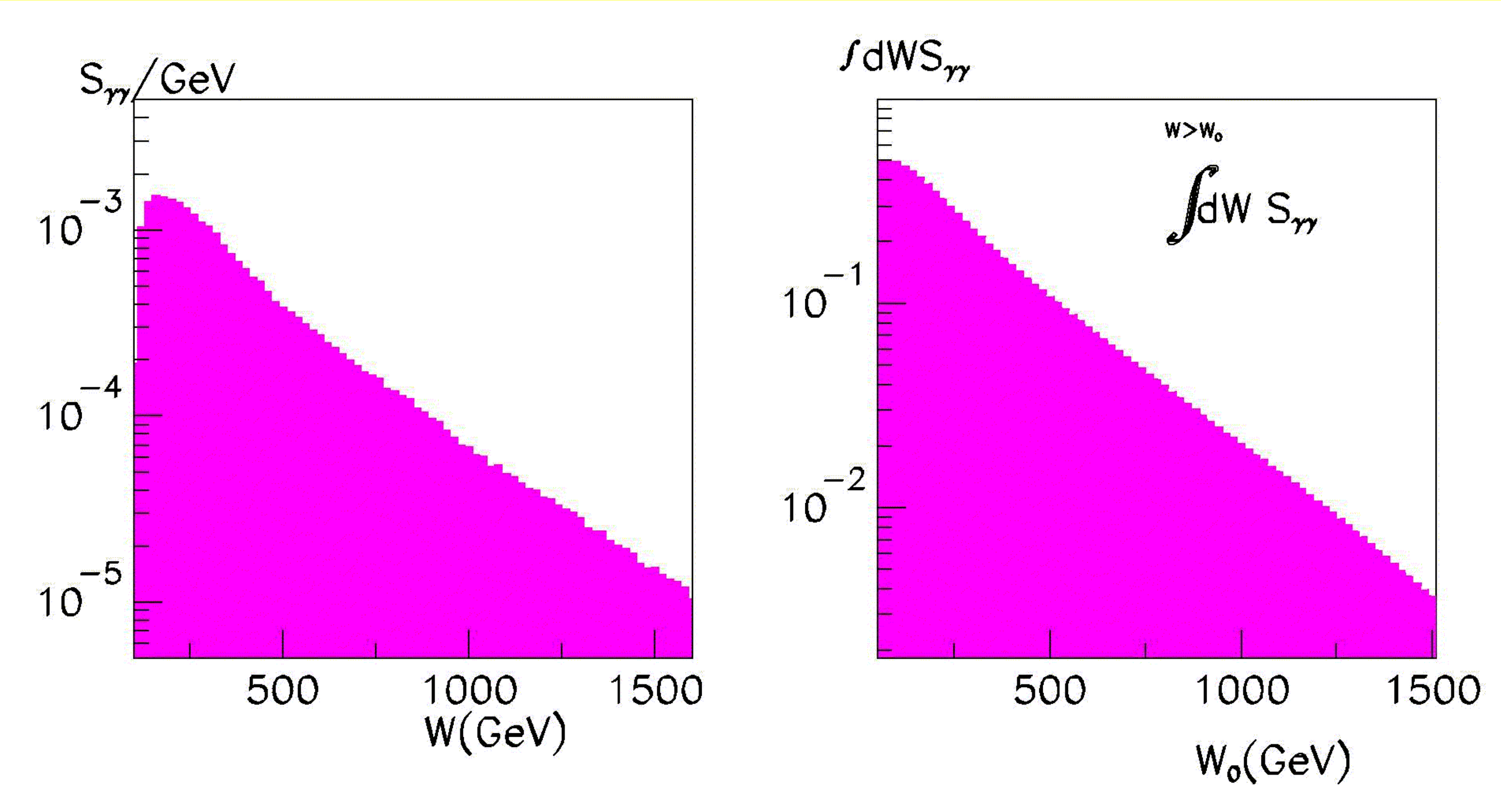
$$\sigma_{pp} = \int S \, \sigma_{\gamma p} \, dW$$

Photon-gluon luminosity spectra



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

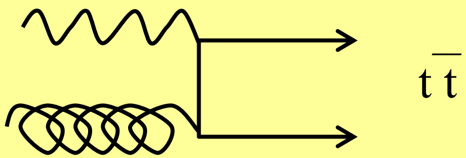
Photon-quark luminosity spectra



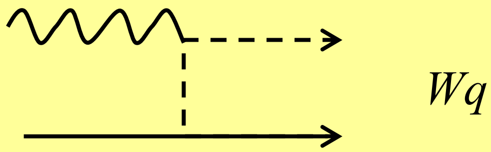
Note: at $W_{\gamma q}$ > 300 GeV photon-quark luminosity is about one third of the nominal *pp* (and still significant beyond 1 TeV)

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
- SM BEH – for example, $\gamma\, b \rightarrow H\, b$, $\gamma\, q \rightarrow H\, W\, q$
- SUSY studies (complementary to the nominal ones) - $H^{+}t$ production (and H^{++}), b and t spairs, $\tilde{t}\chi$ pair, ...
- Exotics: compositness, excited quarks, ...

$\gamma q \rightarrow W q$ is being studied at HERA!

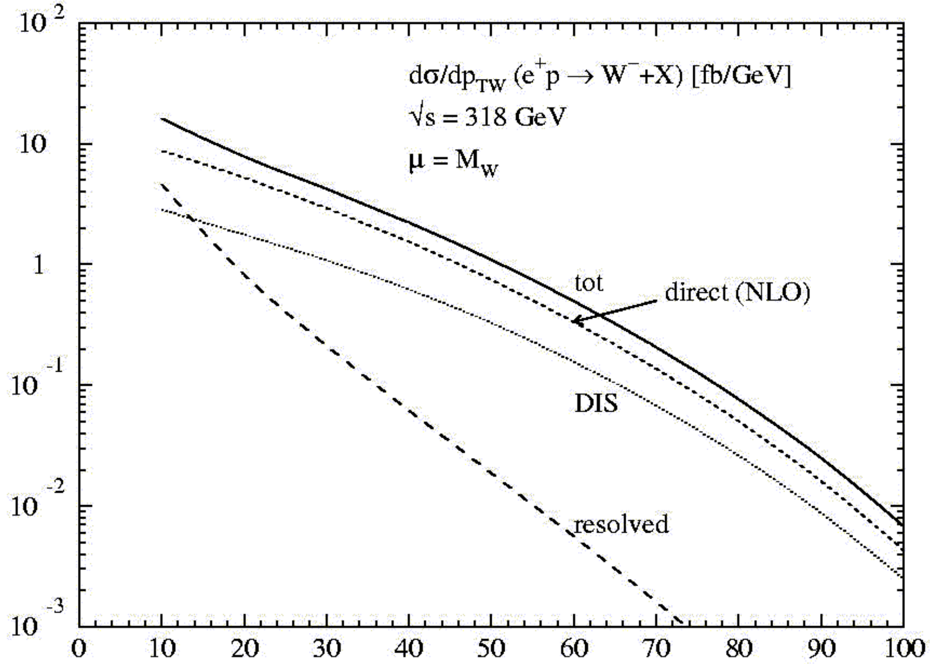


Figure 8: *Transverse momentum distributions of W bosons at HERA. The full curves show the total p_{TW} distributions, while the broken lines exhibit the individual LO DIS, NLO direct and LO resolved contributions. The upper plot is for W^+ production and the lower for W^- bosons.*

Diener et al.

Introduction

Muriel vander Donckt

- 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 $h \rightarrow \gamma\gamma$.

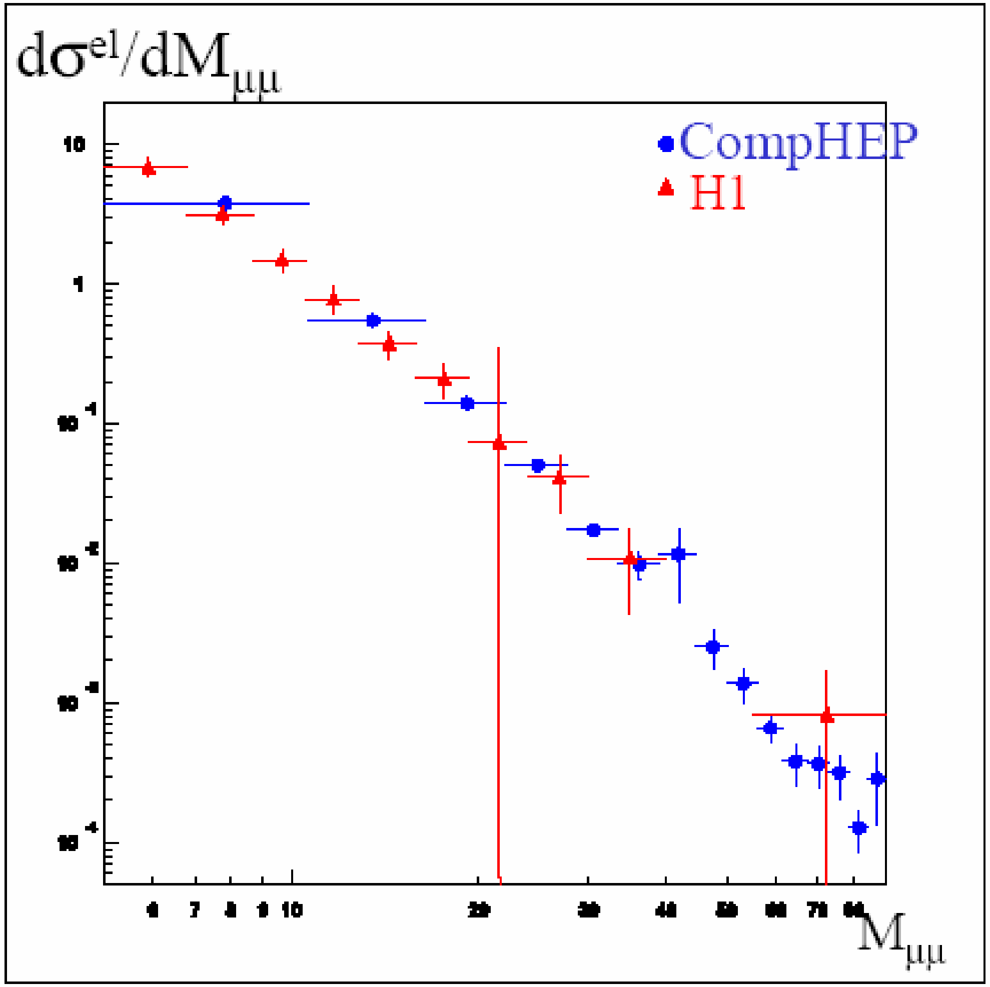
- γ pdfs: Equivalent Photon Approximation

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

- Added and tested in CompHEP for elastic γ emission ($Q^2<1\,\mathrm{GeV}^2$)

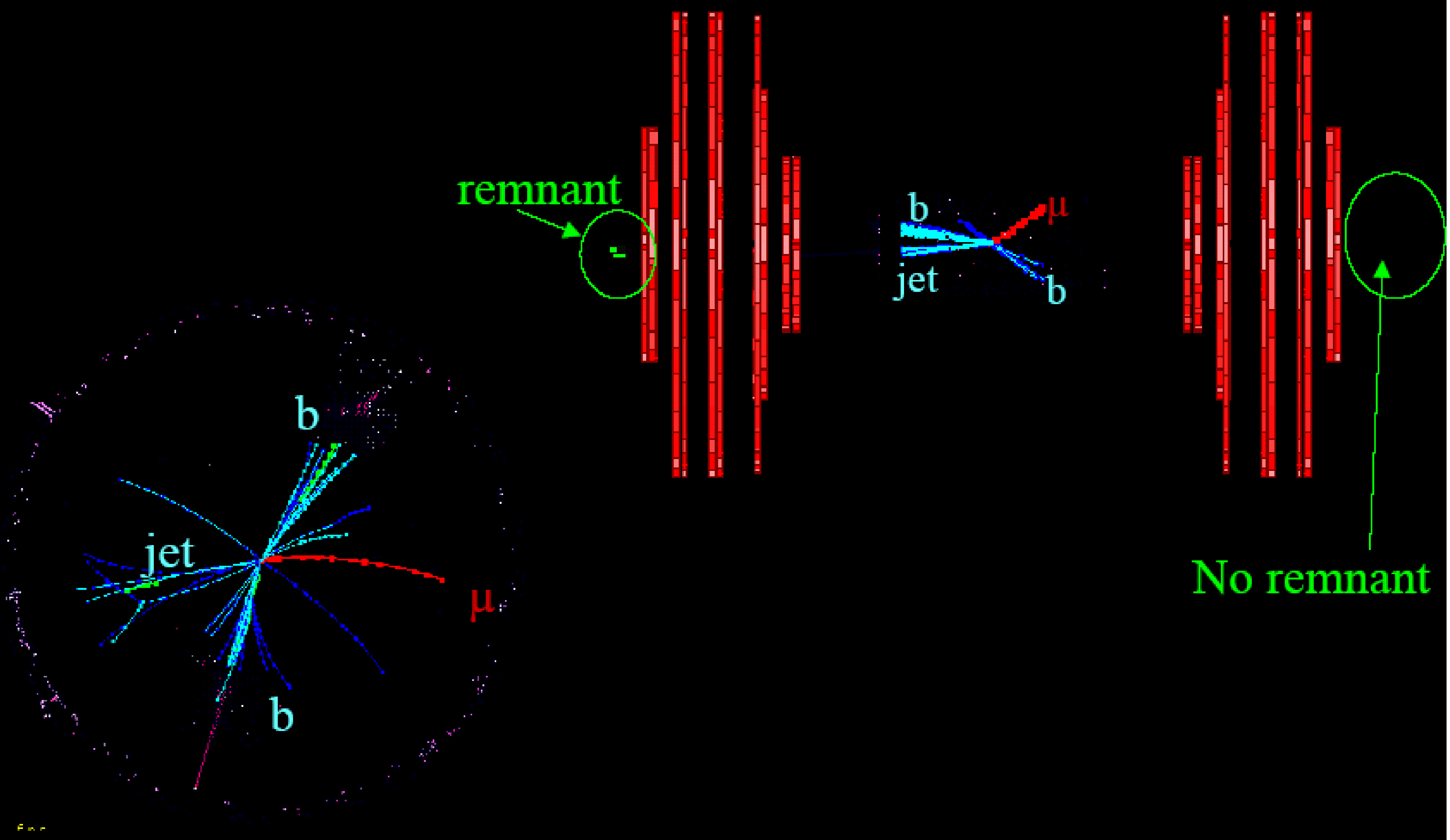
σ_{H1}=25.3±1.0 ±3.5 pb

$\sigma_{compHEP}$=25.8 pb



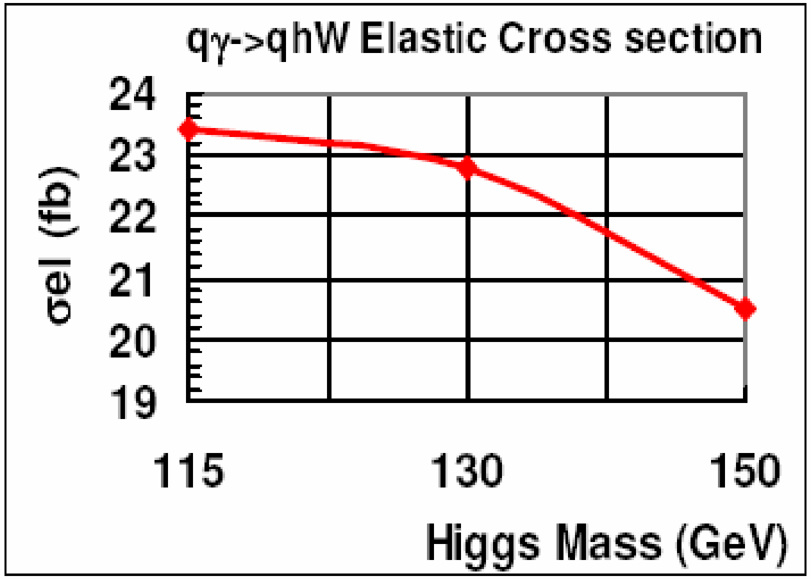
Aktas et al, Phys Rev Lett B583 (2004), 28-40

$\gamma q \rightarrow q'hW \rightarrow q'bbl\nu$ (iguana)

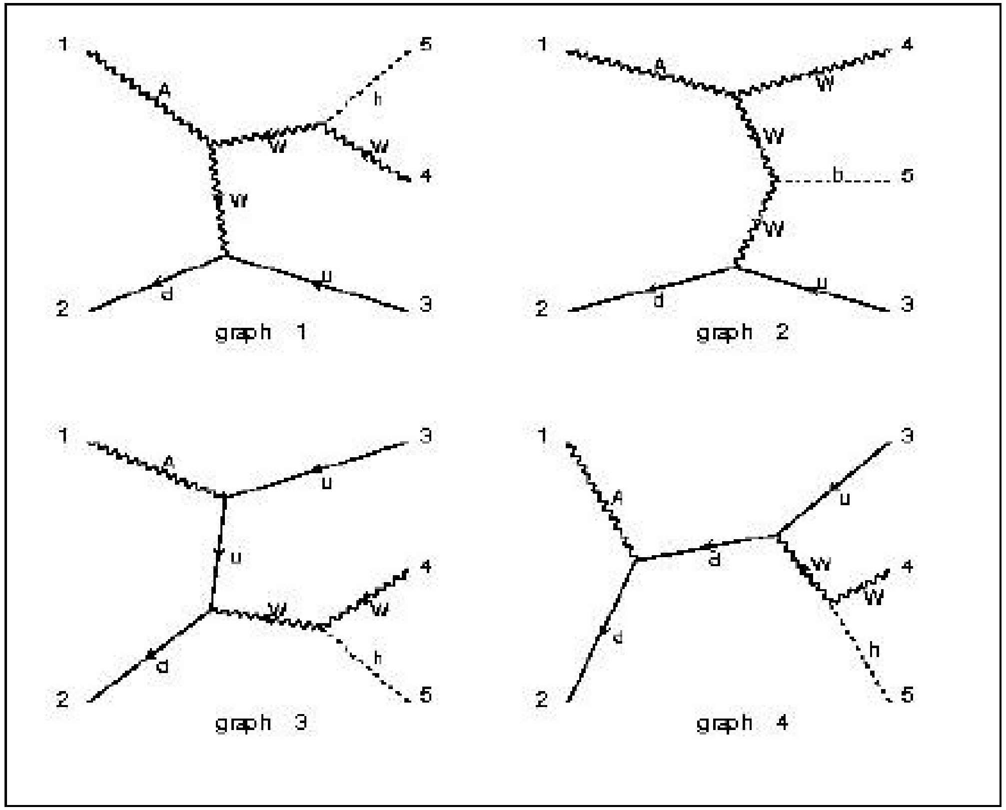


$\gamma q \rightarrow q' hW$

- 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



Expected signal events

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

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

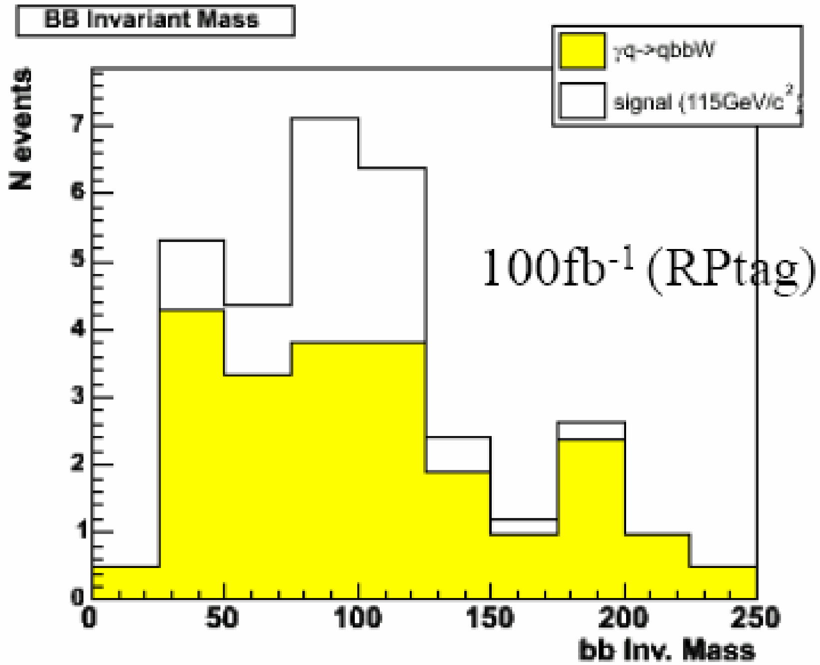
ORCA 8.2.0: trigger & reconstruction

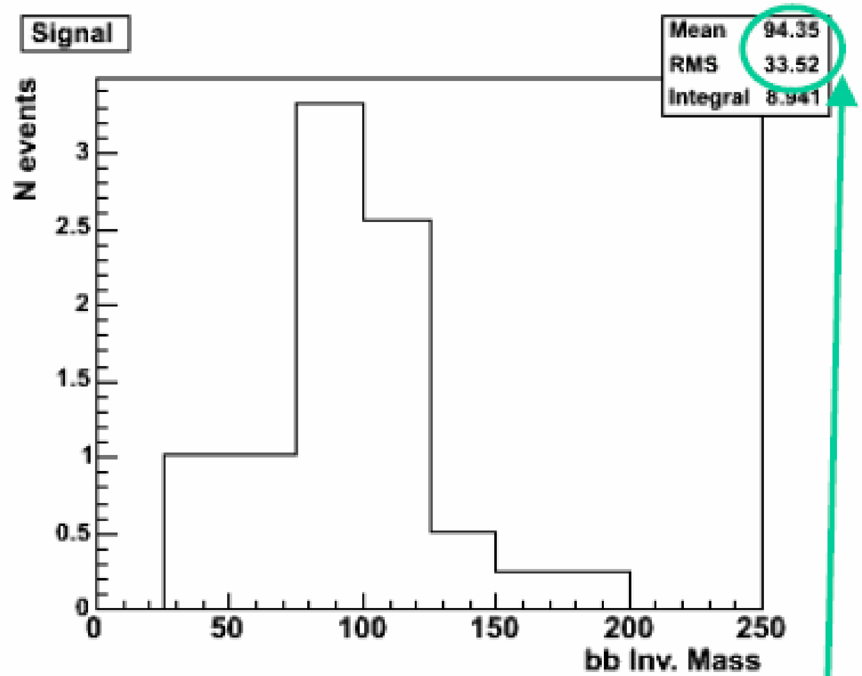
	efficiency	#evts ($10fb^{-1}$)	#evts ($100fb^{-1}$)
L1	0.75	84	158
HLT	0.60	50	95
$\lvert\eta_b\rvert<2.5$	0.77	39	73
2 b-tags	0.125	5	9

W/o pile-up:
Design L1 & HLT:
HF<70 + soft lepton + jet
Under study

Assess best parameters & method.
Lepton tag?

Discriminant variable: M_{bb}





Need :
- more background statistics
- All backgrounds
- Energy flow + calibration

Need better calibration
(CMS-IN-2001/01) + $Z \to bb$

Calibration from data: $ZZ \to l^+l^-bb$

T.Pierzchala

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)

$$-0.007\ \mathrm{GeV}^{-2} < \quad a_0^{\mathrm{Z}}/\Lambda^2 \quad < 0.023\ \mathrm{GeV}^{-2},$$

$$-0.029\ \mathrm{GeV}^{-2} < \quad a_{\mathrm{c}}^{\mathrm{Z}}/\Lambda^2 \quad < 0.029\ \mathrm{GeV}^{-2},$$

$$-0.020\ \mathrm{GeV}^{-2} < \quad a_0^{\mathrm{W}}/\Lambda^2 \quad < 0.020\ \mathrm{GeV}^{-2},$$

$$-0.052\ \mathrm{GeV}^{-2} < \quad a_{\mathrm{c}}^{\mathrm{W}}/\Lambda^2 \quad < 0.037\ \mathrm{GeV}^{-2},$$

Anomalous WW

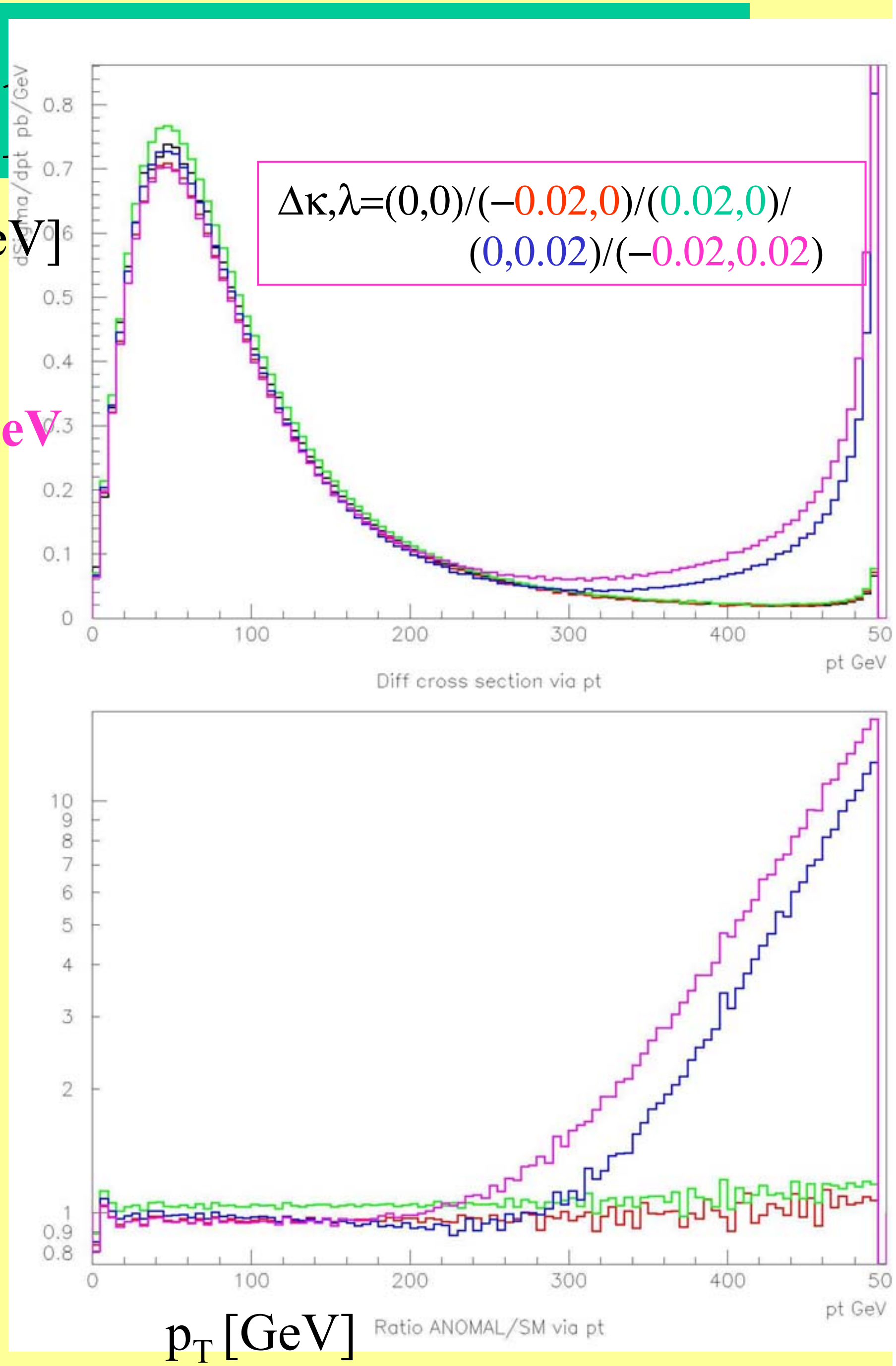
At a generator level so far:

- κ changes mostly normalization, λ also affects the p_T shape
- From statistical point of view better than LEP2 limits seems feasible
- Looking also into a single W photoproduction

$d\sigma/dp_T$ [pb/GeV]

Ex.: $\gamma\gamma$ at 1 TeV

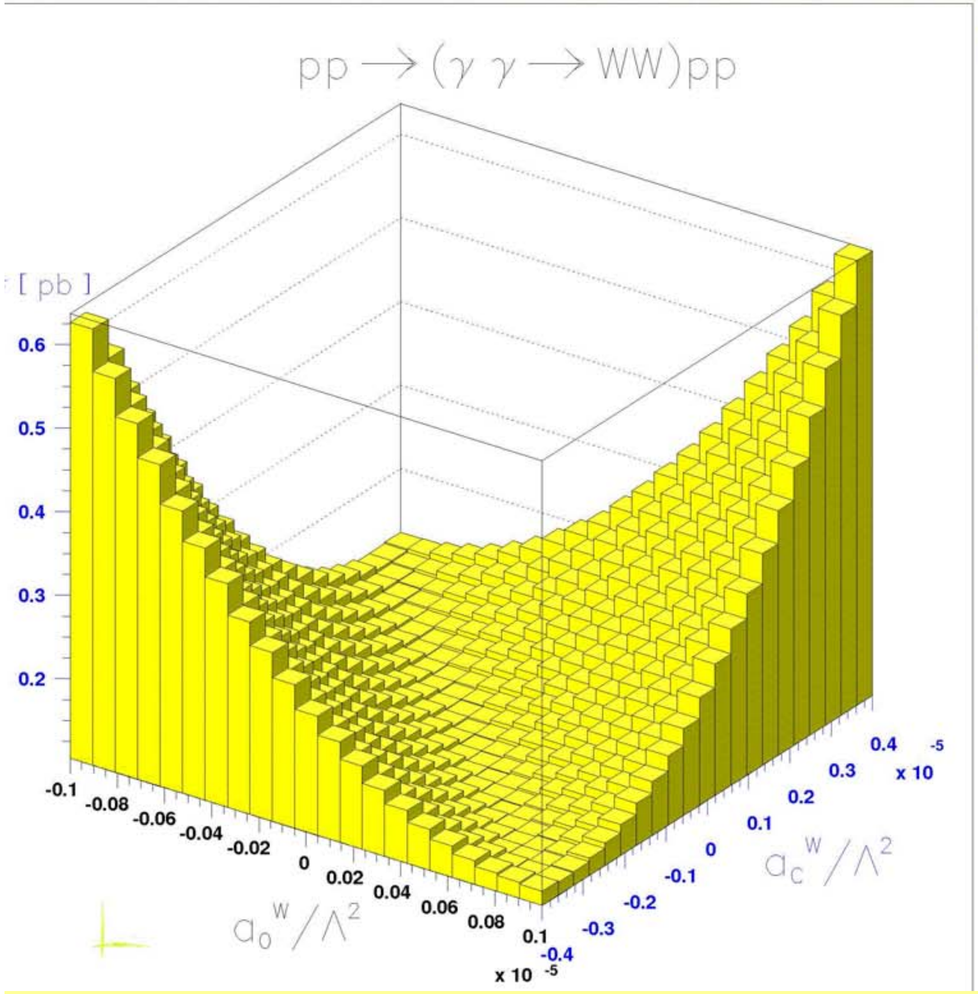
Anom/SM



p_T [GeV]

T.Pierzchala

Anomalous quartic vector boson couplings



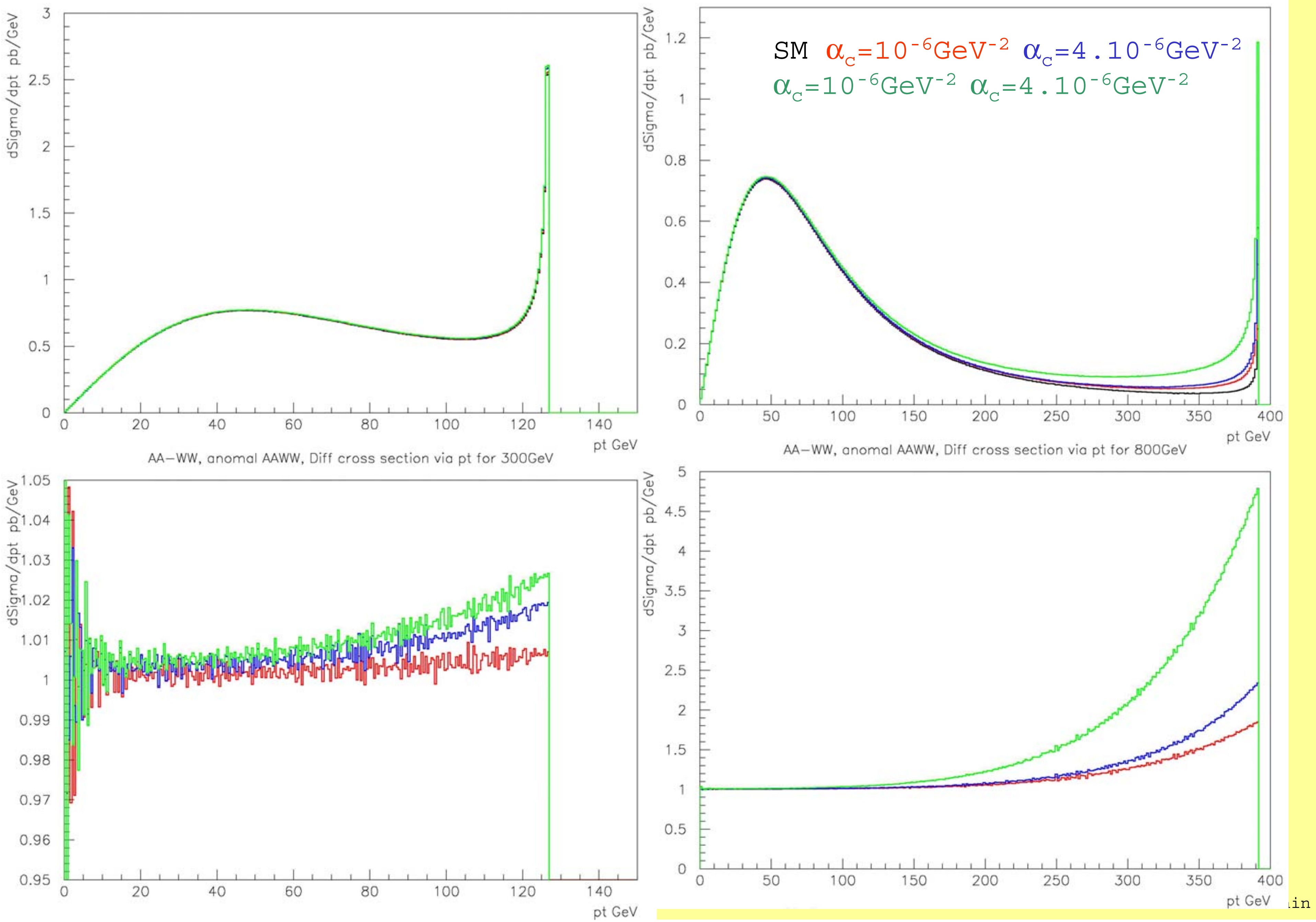
- SM $\gamma\gamma \rightarrow WW$ for $\int L_{pp}\, dt$=30fb^{-1} ⇒ about 3000 W pairs will be produced
- we expect at least 10 000 × stronger limits:

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

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

$d\sigma/dp_T$ at W=300 and 800 GeV

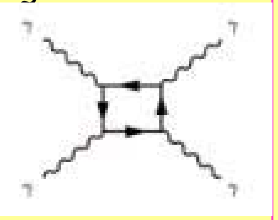
T.Pierzchala



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 ($\sim 10^{-3}$), good place to look for BSM

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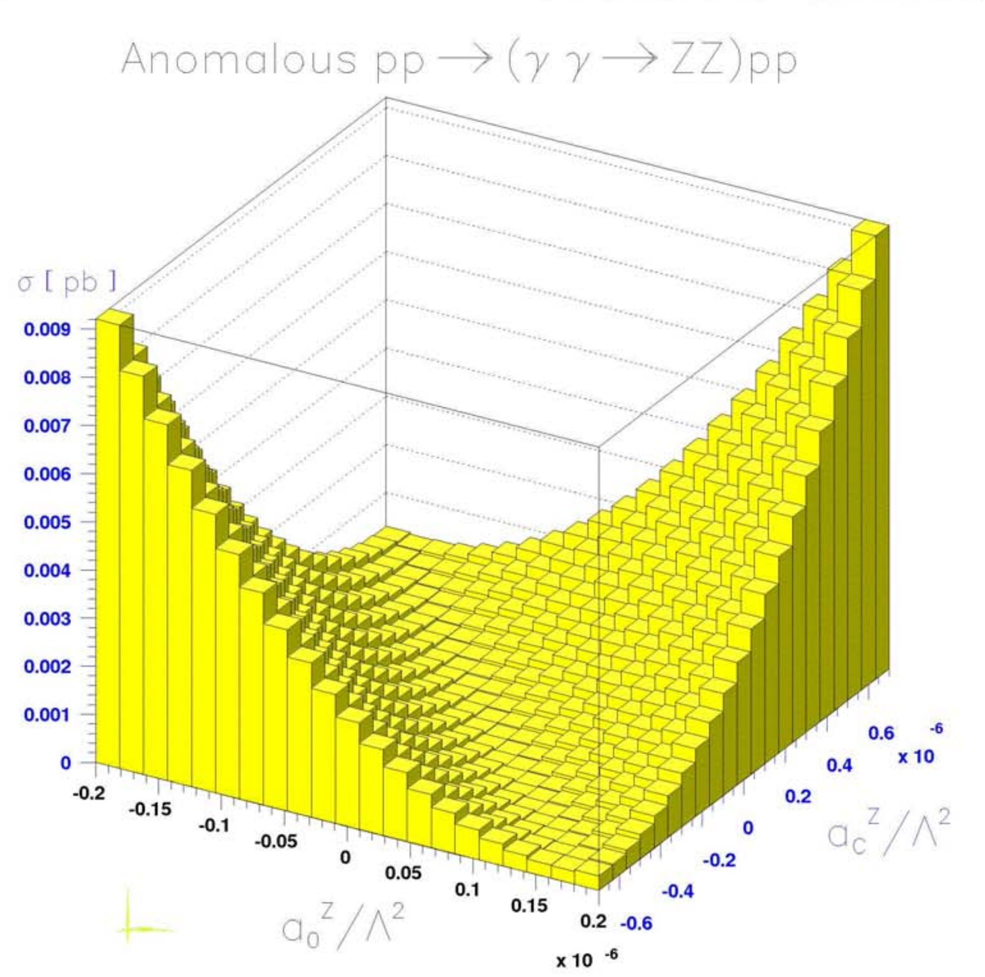
Anomalous $\gamma\gamma \rightarrow$ZZ quartic couplings



- In SM $\gamma\gamma \rightarrow ZZ$ quantum effect
  for $\int L_{pp}\, dt$=30 $fb^{-1} \Rightarrow$ about 5 SM Z pairs will be produced

- our limits estimations (more 10 000 $\times$):

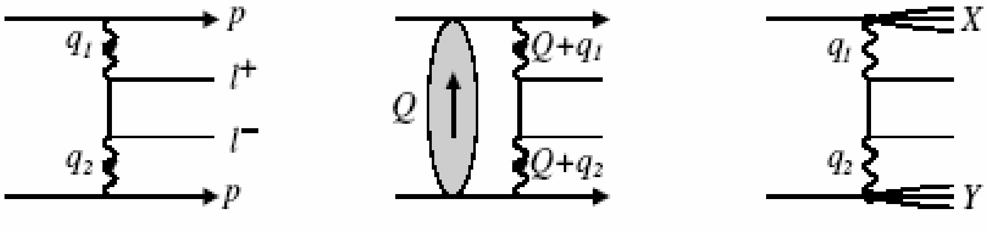
$$-0.2{\cdot}10^{-6}\ \mathrm{GeV}^{-2} < a_0^Z/\Lambda^2 < 0.2{\cdot}10^{-6}\ \mathrm{GeV}^{-2}$$

$$-0.7{\cdot}10^{-6}\ \mathrm{GeV}^{-2} < a_c^Z/\Lambda^2 < 0.7{\cdot}10^{-6}\ \mathrm{GeV}^{-2}$$

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

- QED process (a) production σ precisely known.

event generator LPAIR based on ME by Vermaseren



(a) (b) (c)

- 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)*

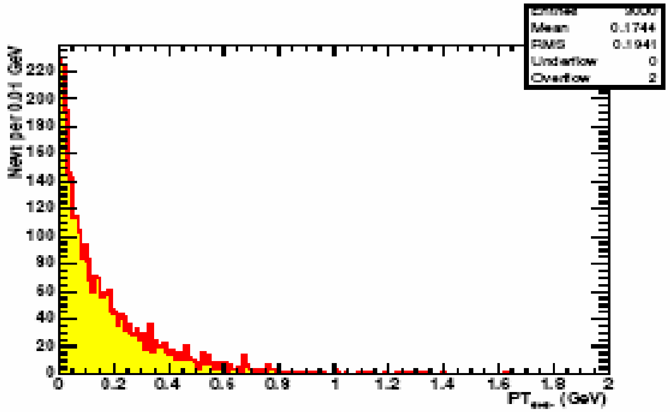
- Production rate considerable,

CMS week, March 18,20

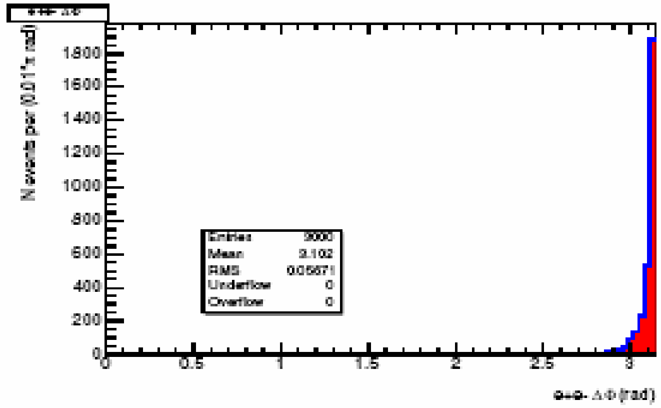
e.g. $\sigma_{(P_T>2\ \mathrm{GeV})} = 0.129\ \mathrm{nb} \pm 0.234\ \mathrm{pb}$.

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

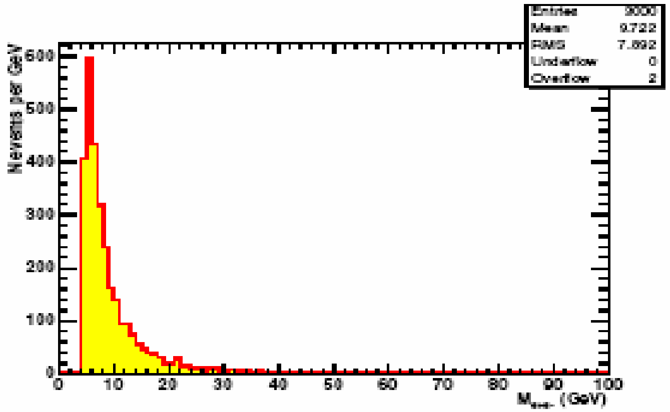
e^+e^- two body system P_T



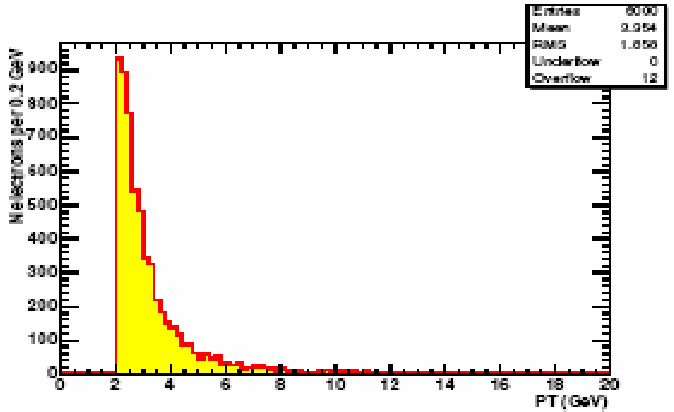
$\Delta\Phi$



Invariant mass of e^+e^-



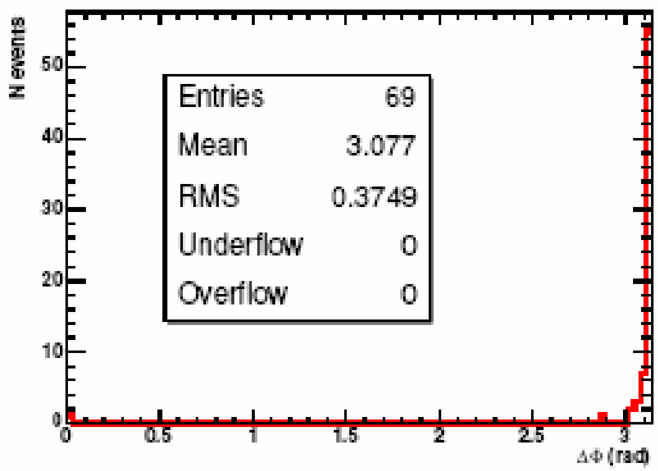
PT of the leptons



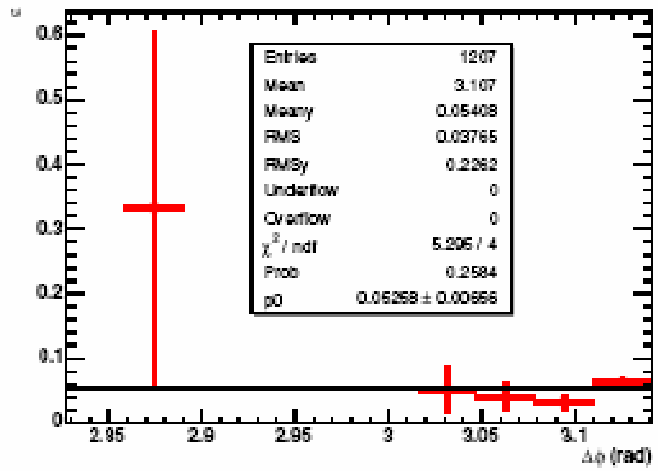
CMS week, March 18, 2005 –

events with both e^+e^- reconstructed

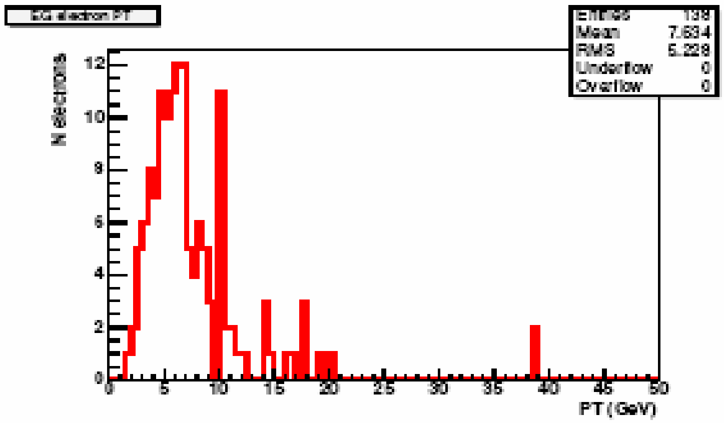
$\Delta\Phi$ distribution



Reco eff vs. $\Delta\Phi$



P_T of the electrons



CMS week, March 18, 2005

Summary & Outlook

- $\sigma * 69/3000 \approx 3$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.