Photon physics with roman pots

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Introduction + benchmark processes:

- Calibration candle: Muon pairs two-photon production (Y.Liu)
- WW (and ZZ) case (J. de Favereau + T. Pierzchala)
- Single W photoproduction (J. de Favereau)
- WH photoproduction (M. vander Donckt et al.)
- (SUSY)

Louvain group

J. de Favereau, V. Lemaître, Y. Liu, S. Ovyn, T. Pierzchała, K. Piotrzkowski, X.Rouby

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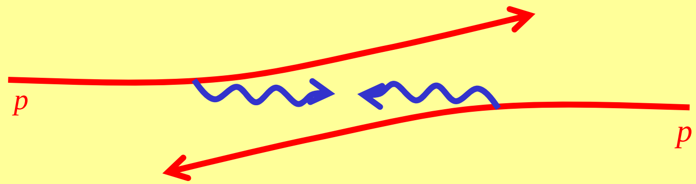
Investigate potential of studying in CMS high-energy photon interactions

Three main areas:

- SM tests in γγ interactions
- SM tests in γp (γA) interactions
- Luminosity with lepton pairs (+ diffractive meson photoproduction)



Note: Significant fraction of *pp* collisions involves high-energy photon exchanges; e.g. at LHC effective luminosity of γγ collisions is about 1% (of *pp* luminosity) for γγ cms energies above 100 GeV, and for γq and γg collisions is about 10% for γq and γg cms energies above 1 TeV!

Tagging photon interactions is needed to suppress *pp* backgrounds – in low pileup conditions can be done using rapidity gap (or exclusivity) signature, at high luminosity forward proton detector are obligatory (see Phys. Rev. **D63** (2001) 071502(R) and **hep-ex**/0201027)

Complementary physics to inclusive *pp* interactions becomes accessible, as *exclusive* production of heavy particles in γγ and γp interactions

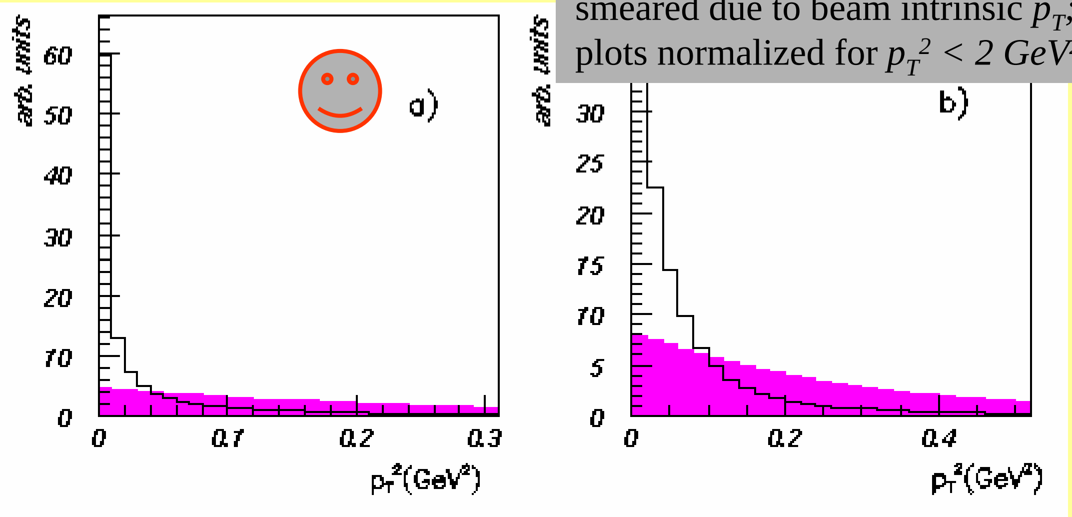
Q1: Can one select photon-induced events among very many *pp* interactions?

Inclusive- (*pp*) vs. photo-production: Examples

Process/σ[pb]	*pp*	$\gamma\gamma$ or γp
WW	~ 70	0.2
$t\bar{t}$	~ 600	1.5
WH	~ 1.2	0.03

pp needs large suppression, more difficult at high luminosities

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



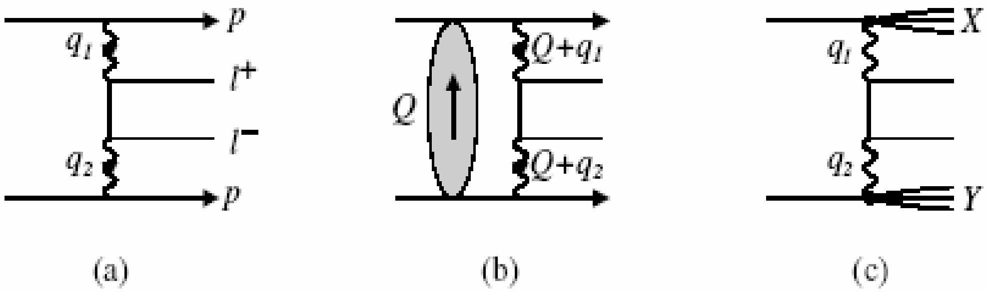
Q2: What about diffractive irreducible backgrounds?

A: For above, only important for top photo-production (similar size for exclusive DPE)

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

- 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)*

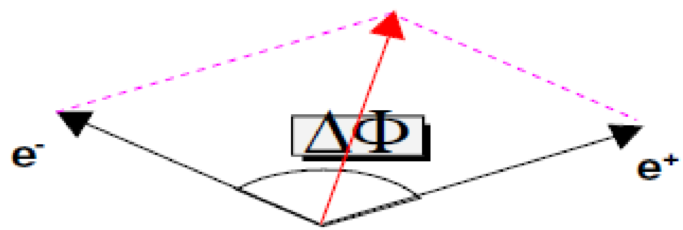
- Production rate considerable,

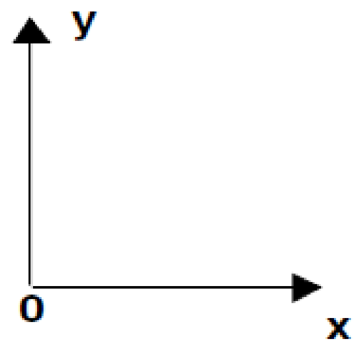
e.g. $\sigma_{(P_T>2\ \mathrm{GeV})} = 0.129\ \mathrm{nb} \pm 0.234\ \mathrm{pb}.$

CMS week,March 18,20

Final state kinematics

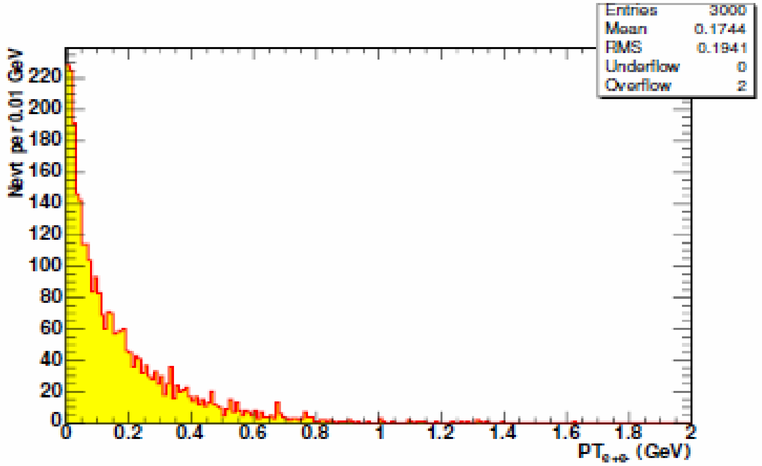
- $l^- l^+$ and pp in final state.
- Scattered protons with small transverse momenta.
- The momenta of $l^+ l^-$ well balanced in $x - y$ plane:
  - Transverse momentum $l^+ l^-$ system very small.
  - $l^+ l^-$ are back-to-back : $\Delta\Phi \approx \pi$



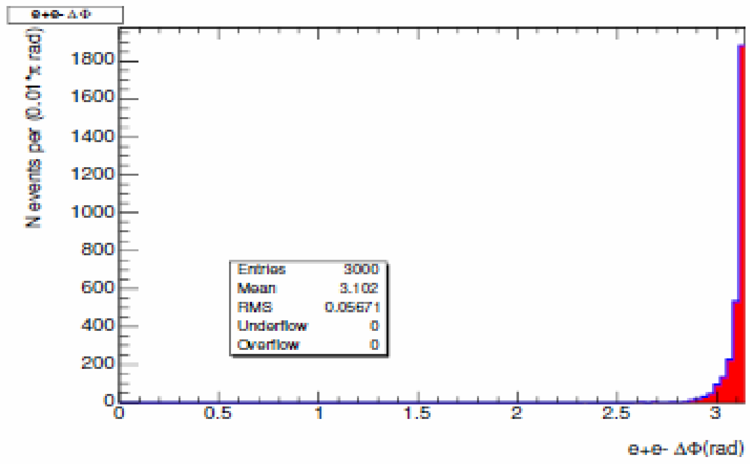


Lpair:3K $pp \rightarrow pe^+e^-p$ (P_T>2GeV)

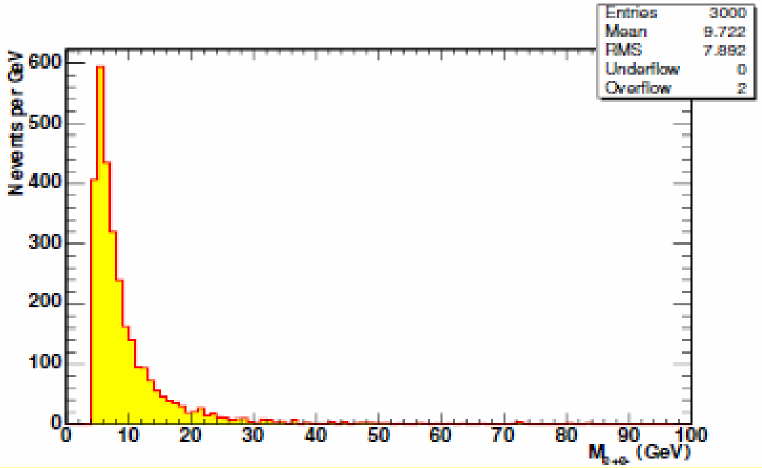
e^+e^- two body system P_T



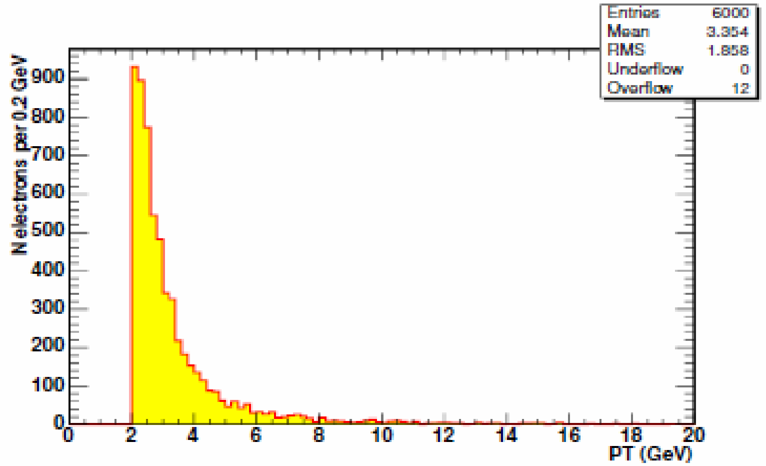
$\Delta\Phi$



Invariant mass of e^+e^-



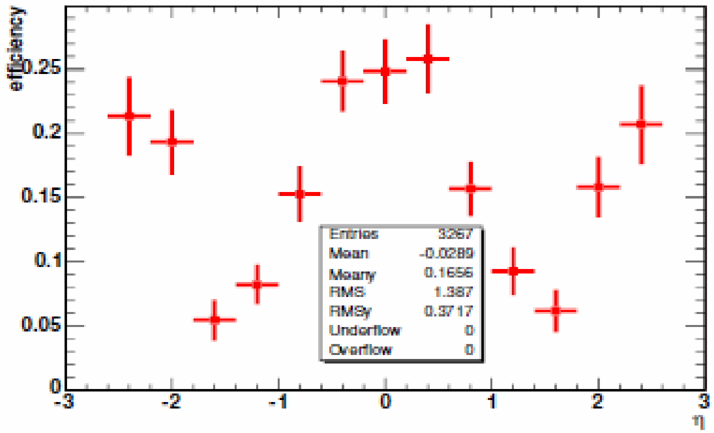
PT of the leptons



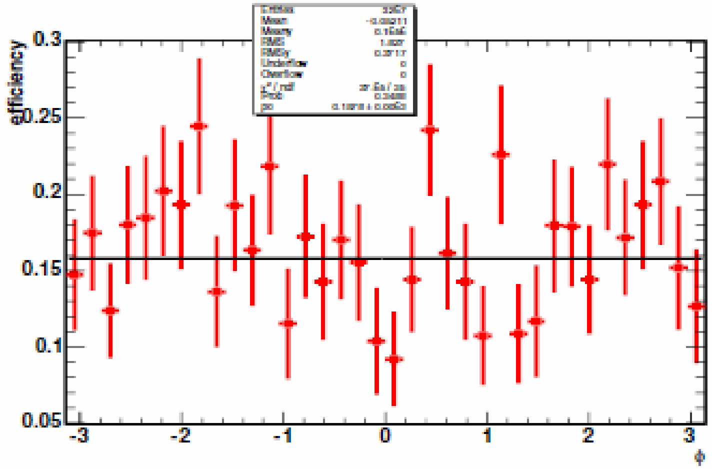
EG Electron: efficiency

$$\frac{\text{Reconstructed leptons } (0.8<E/P<1.2, H/E<0.5)}{\text{Generated leptons heading to fiducial volume}}$$

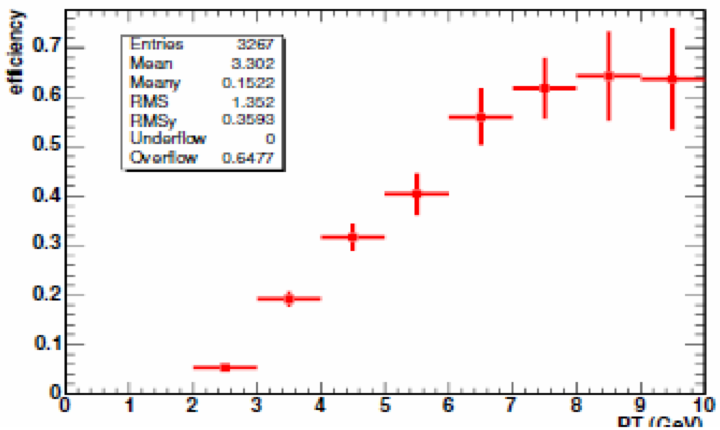
eff vs. η (per lepton)



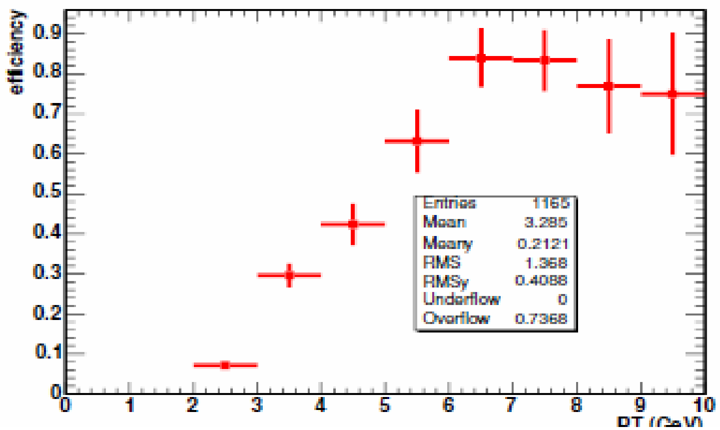
eff vs. ϕ (per lepton)



eff vs. P_T (per lepton)

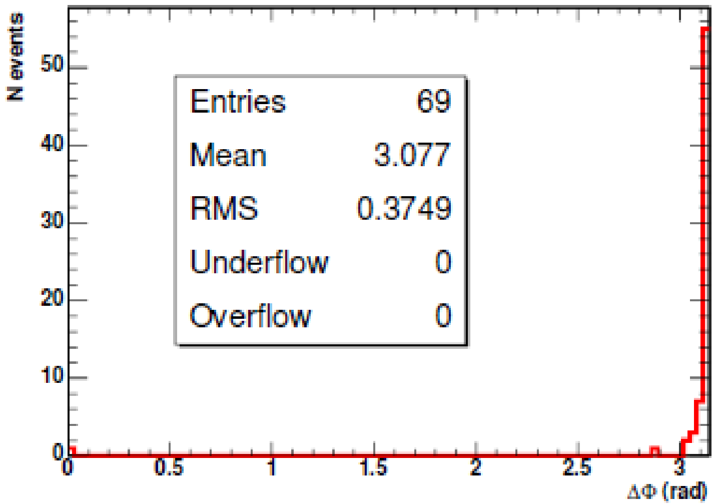


eff vs. P_T (per lepton with $|\eta| < 0.8$)

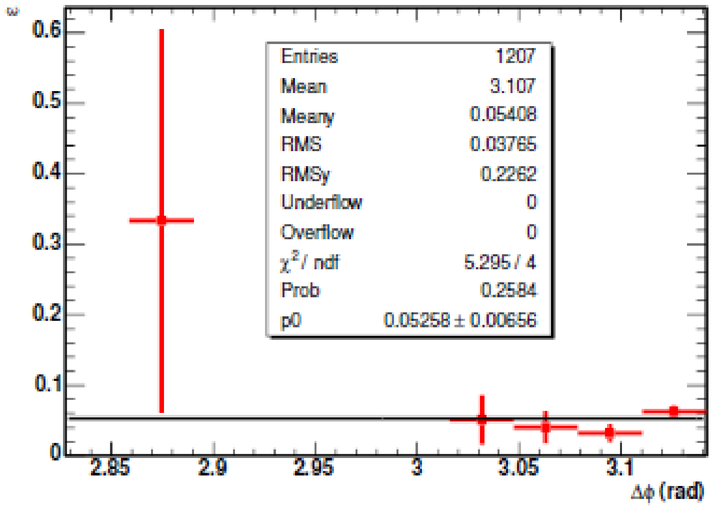


events with both e^+e^- reconstructed

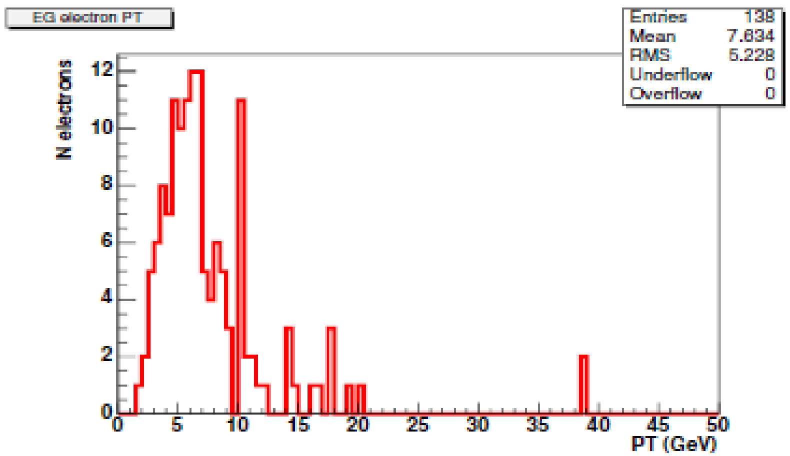
$\Delta\Phi$ distribution



Reco eff vs. $\Delta\Phi$



P_T of the electrons



Tricky

Requires a dedicated trigger

Only at low luminosity?

Use CASTOR?

Muon case

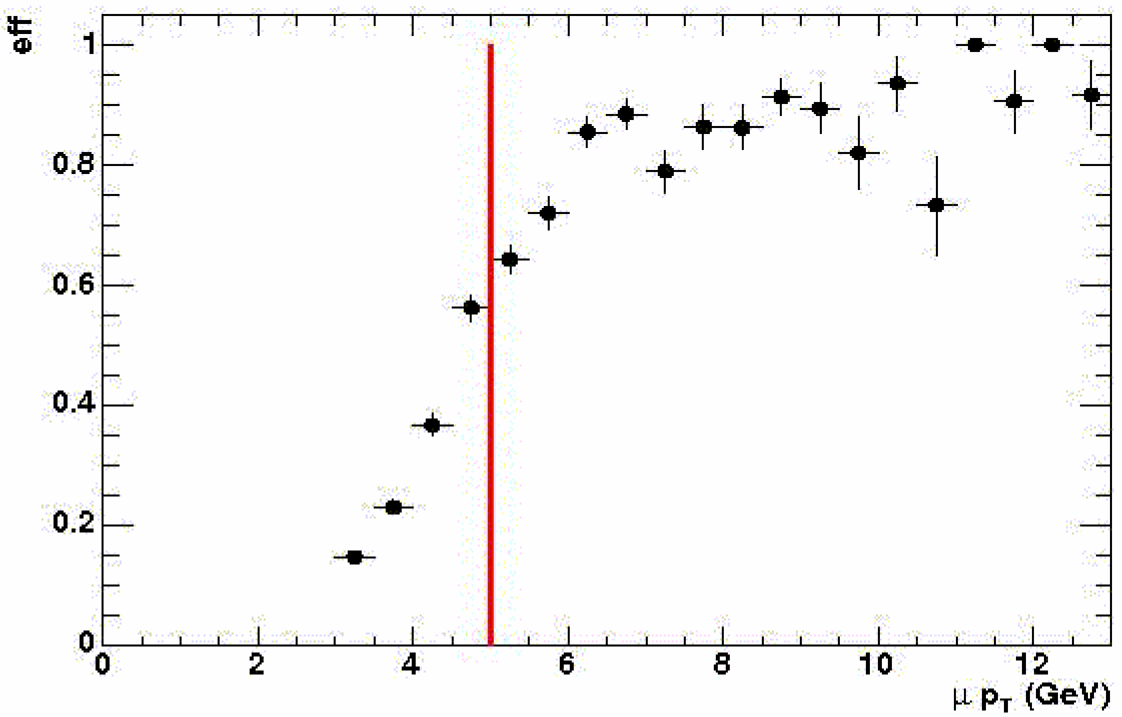
Reconstruction & trigger efficiencies:

- Sample of 5000 μμ pairs at p_T > 3 GeV generated with LPAIR ($\sigma \approx 50$ pb)

- Reconstructed with ORCA - efficiency for muons reaches plateau of 90% at p_T = 7GeV (at p_T=5 GeV it is 60%)

- Cross-section for reconstructed pairs is 6 pb, L1 efficiency is high but high p_T cuts at HLT results in 40% global trigger efficiency

Note: Roman Pots are NOT used for trigger!



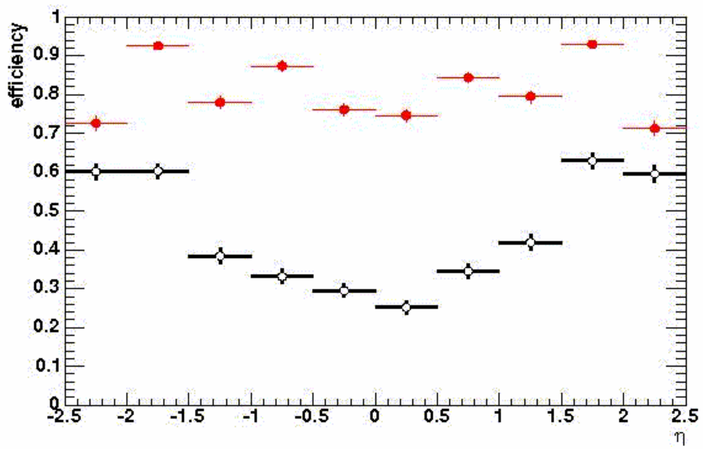
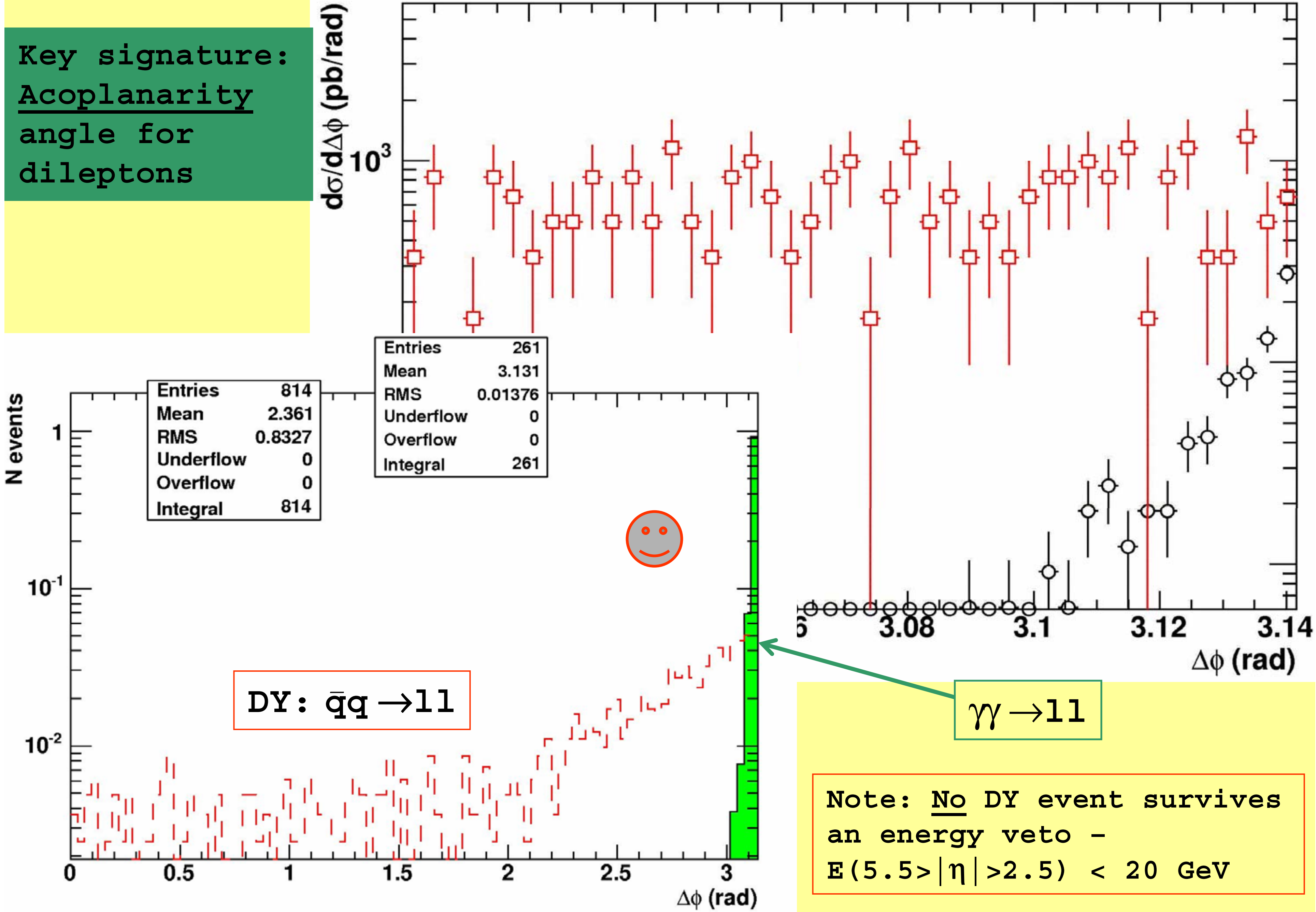


Figure 8: The muon reconstruction efficiency vs. the muon η. The open dots are from muons with p_T above 3 GeV, and the solid dots are from muons with p_T above 5 GeV.

Key signature: <u>Acoplanarity</u> angle for dileptons



Note: <u>No</u> DY event survives an energy veto – $E(5.5>|\eta|>2.5) < 20$ GeV

Invariant mass distribution driven by p_T acceptance.

Still significant around upsilon mass!

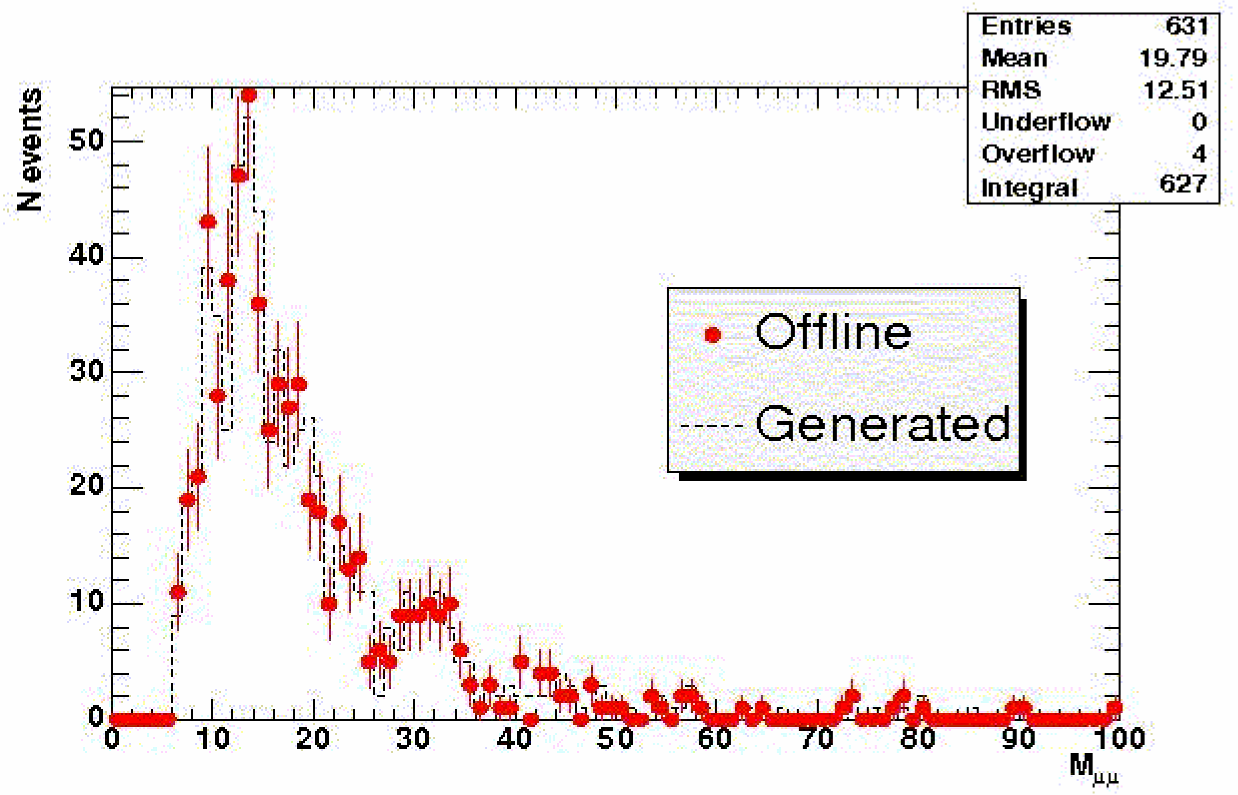


Figure 11: The reconstructed and generated di-muon mass.

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

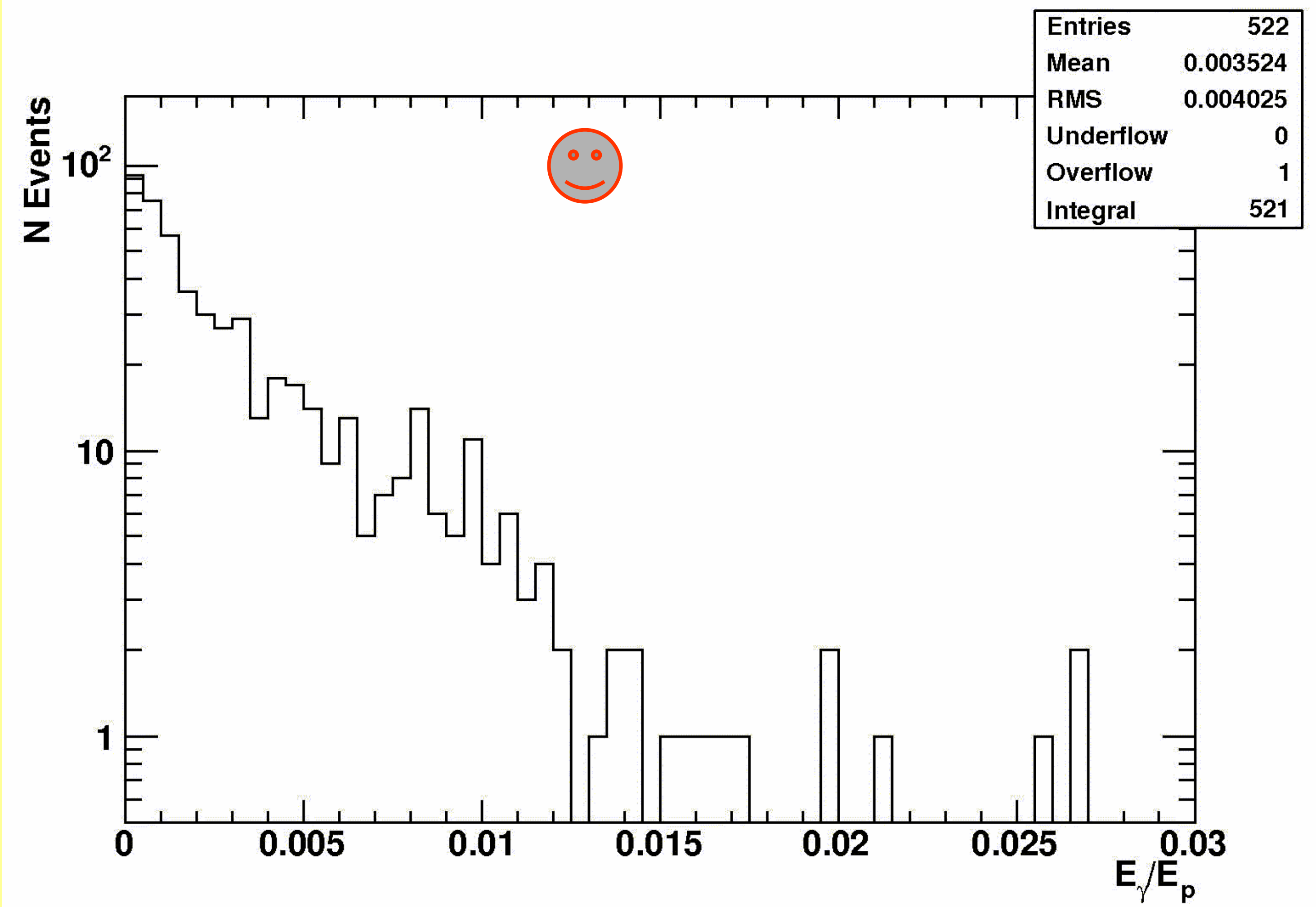
(1) $$M_{l+l-} = 4E_{\gamma 1}E_{\gamma 2};$$

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

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

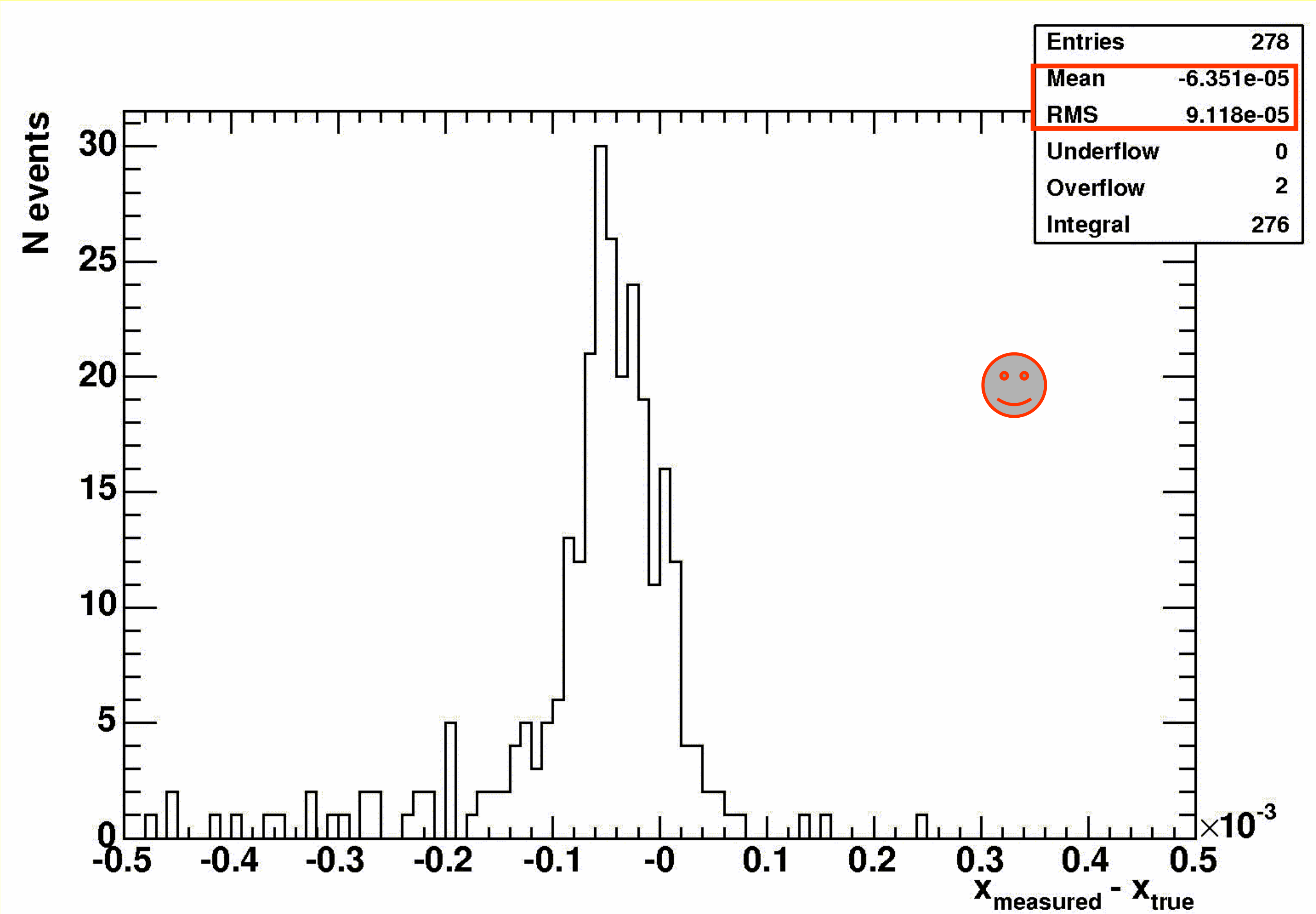
- This can be used to calibrate forward detectors.

Distribution of the proton energy loss for the reconstructed (and triggered) dimuon pairs:



Perfectly suited for FP420 calibration, but still some efficiency for TOTEM pots (-> high lumi)

Resolution of the proton energy loss for the reconstructed dimuon pairs:



Conclusions for lepton pairs:

Two-photon (exclusive) lepton pairs are excellent candidate for *in situ*, data-driven calibration of the proton energy scale AND acceptance (+ *pp* luminosity!)

Even using standard CMS di-muon trigger, good statistics can be collected; e.g. already for 100 pb^{-1} one will have about 300 calibration events

Resolution in energy loss is excellent, better than the beam energy smearing of 10^{-4}

Backgrounds at low lumi, when forward energy veto can be applied, should be negligible – best calibration data will be collected in 'no-pileup' conditions

Providing low p_T dedicated trigger and inclusion of upsilon photoproduction will improve that further!

Note: For precise lumi, control triggers necessary, i.e. SINGLE low-pT lepton + exclusivity conditions?

Photia development

J. de Favereau

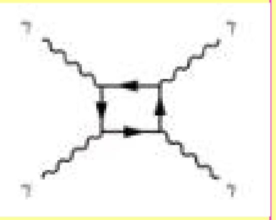
- Use Pythia 6.152 to simulate $\gamma\gamma$ and γp interactions
- Introduce photon spectra for proton beams (for $\gamma\gamma$ and γp case) with proper normalization (*pp* cross-section calculations)
- Elastic and inelastic production possible (but no *p* dissociation simulation so far)
- Direct photo-production

- *Photia* interfaced to Oscar/Orca

Gauge boson photoproduction

- Sensitivity to TGCs and QGCs (WW anomalous production for LED and strong W sector)

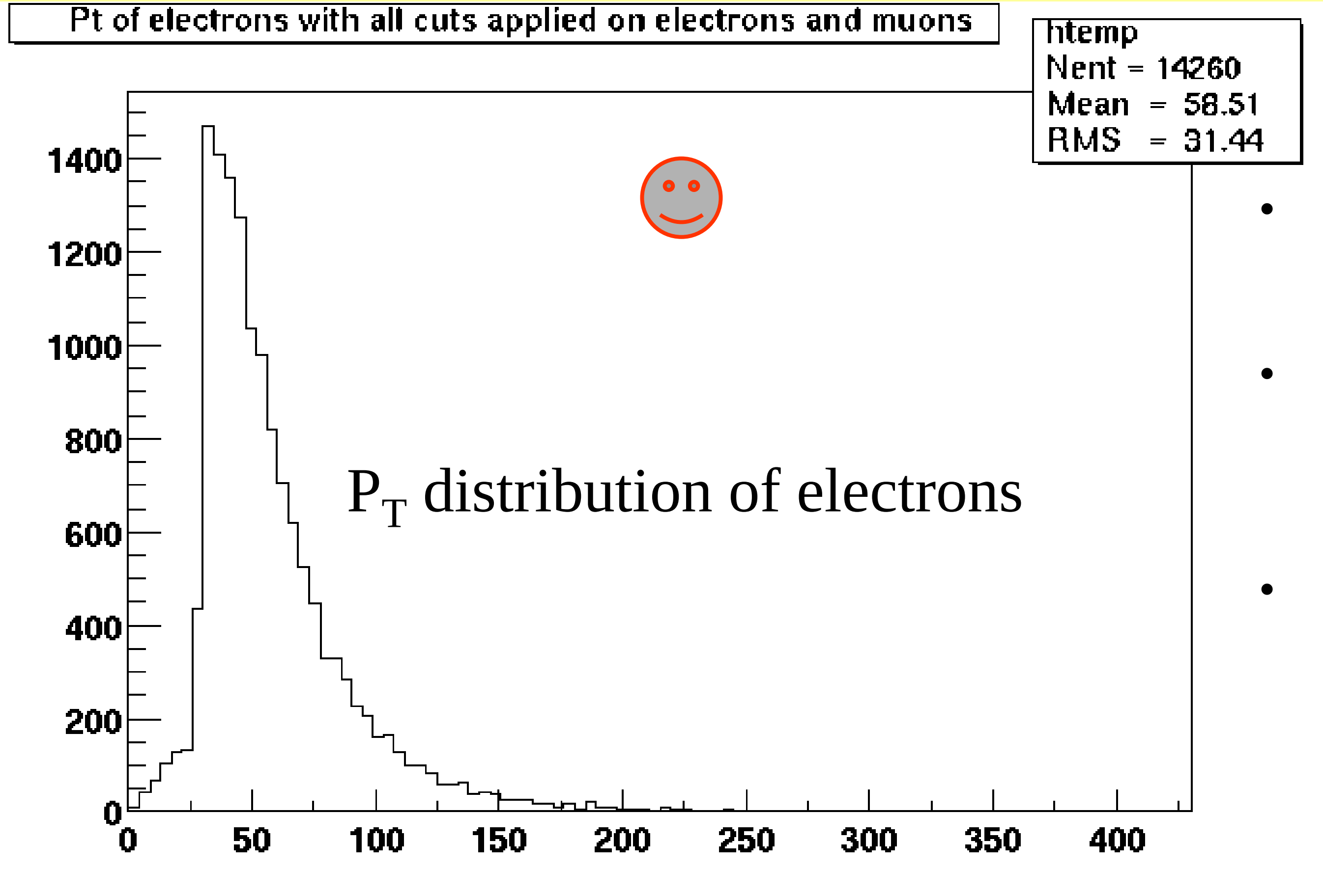
$\gamma\gamma \rightarrow \gamma\gamma$ (not possible at tree level), eg. sensitivity to massive monopole contributions (large p_T physics)



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

$\gamma\gamma \rightarrow WW$ events

J. de Favereau



- Events with at least one leptonic *W* decay (electron or muon in final state)
- Require single tagging, i.e. registration of at least one proton with energy loss above 1% (and $p_T < 1$ GeV)
- Selection cuts: (electron p_T > 29 GeV or muon p_T > 14 GeV)* |eta|<2.5

Good efficiency due to high lepton p_T expected distribution corresponds to integ. luminosity of about 1000 fb^{-1}

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)

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

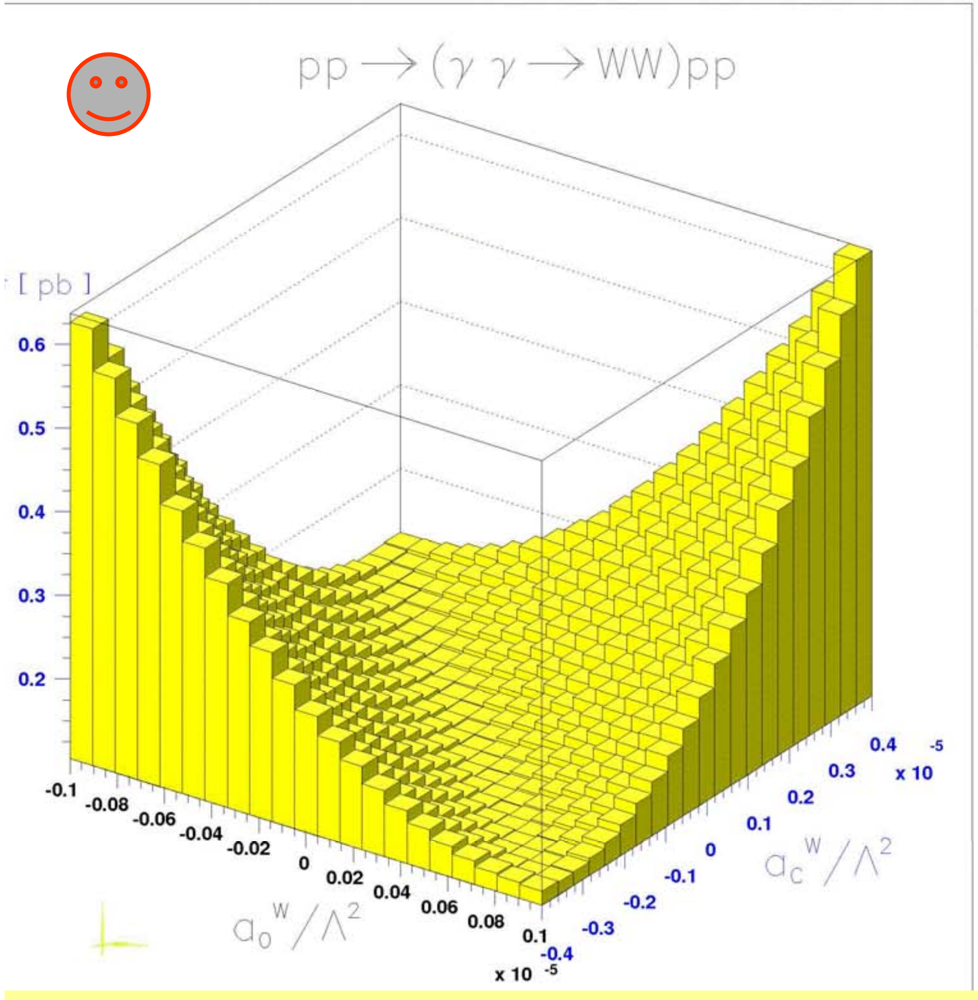
$$-0.029\ \mathrm{GeV}^{-2} < \quad a_{\mathrm{c}}^{\mathrm{Z}}/\Lambda^2 \quad < 0.029\ \mathrm{GeV}^{-2},$$

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

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

T.Pierzchala

Anomalous quartic vector boson couplings



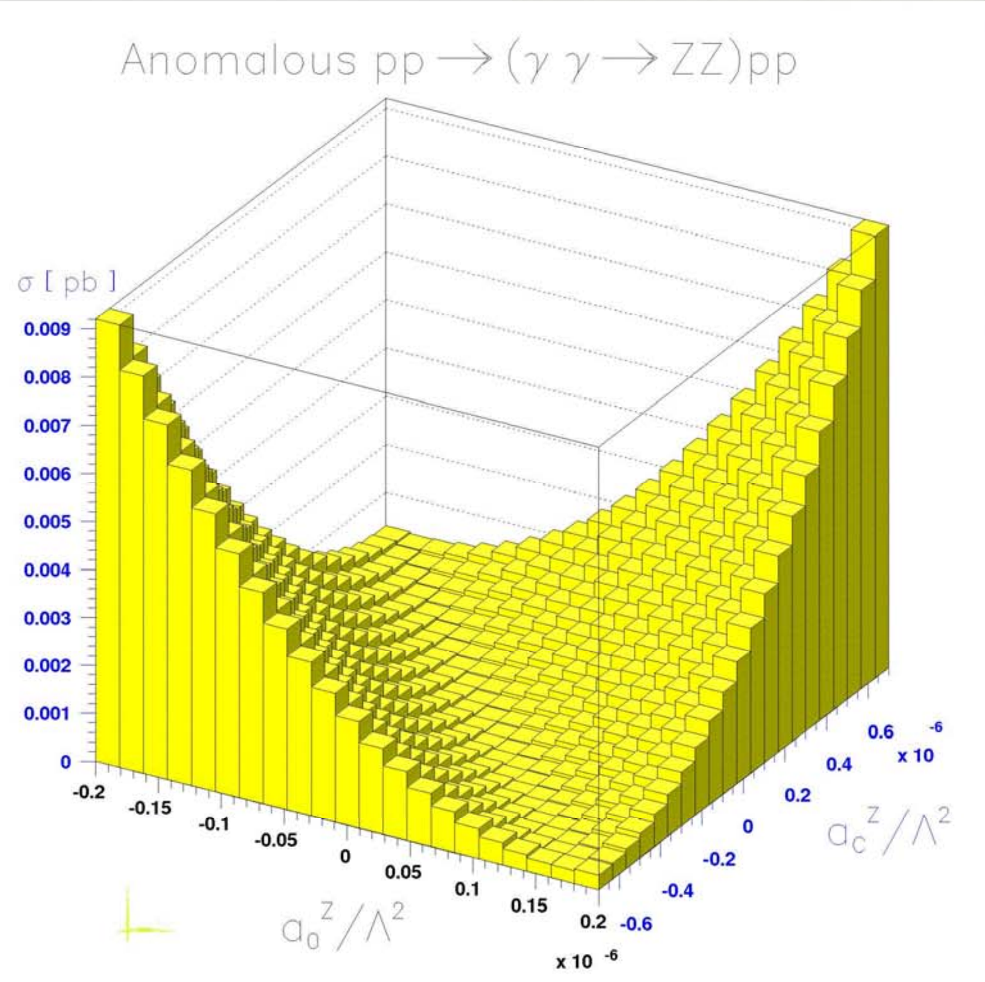
- SM $\gamma\gamma \to WW$ for $\int L_{pp}\, dt$=30fb^{-1} ⇒ about 3000 W pairs will be produced
- we expect at least 10 000 × stronger limits:

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

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

T.Pierzchala

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



- In SM $\gamma\gamma \rightarrow ZZ$ quantum effect

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

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

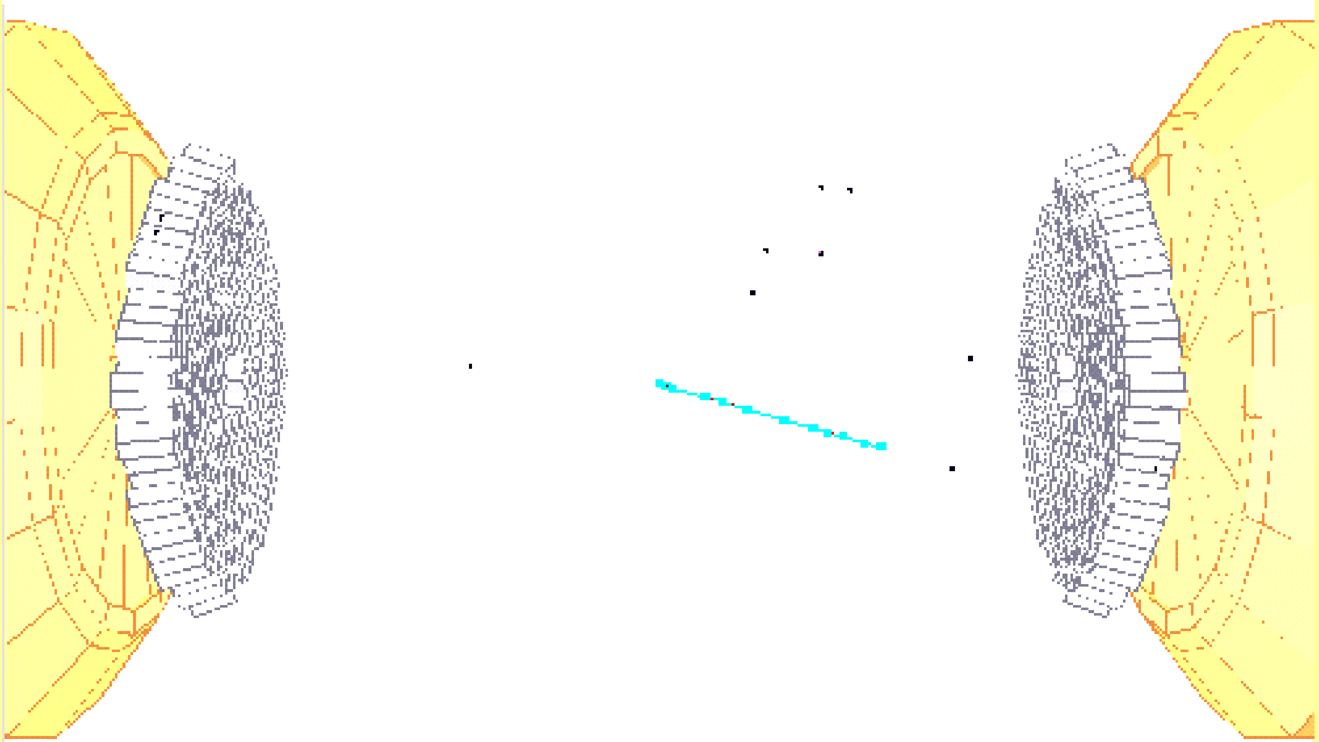
$$-0.2{\cdot}10^{-6}\ \mathrm{GeV}^{-2} < a_0^Z/\Lambda^2 < 0.2{\cdot}10^{-6}\ \mathrm{GeV}^{-2}$$

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

Photia Events in CMS

J. de Favereau

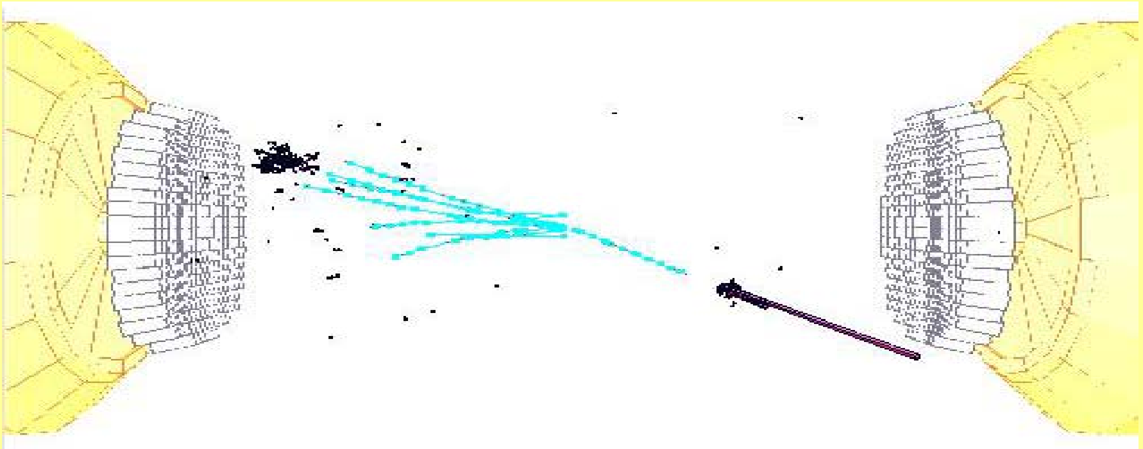
- $\gamma\gamma \rightarrow WW \rightarrow jje\nu$
- $\gamma q \rightarrow Wq \rightarrow jjj$
- $\gamma q \rightarrow Wq \rightarrow e\nu j$
- $\gamma q \rightarrow Wq \rightarrow \mu\nu j$

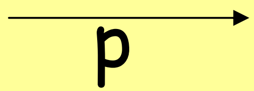


CMS efficiency

J. de Favereau

First look at leptonic Final states : $\gamma p \to XW \to l\nu$





Efficiency at L1 and HLT (ORCA 8_1_2)

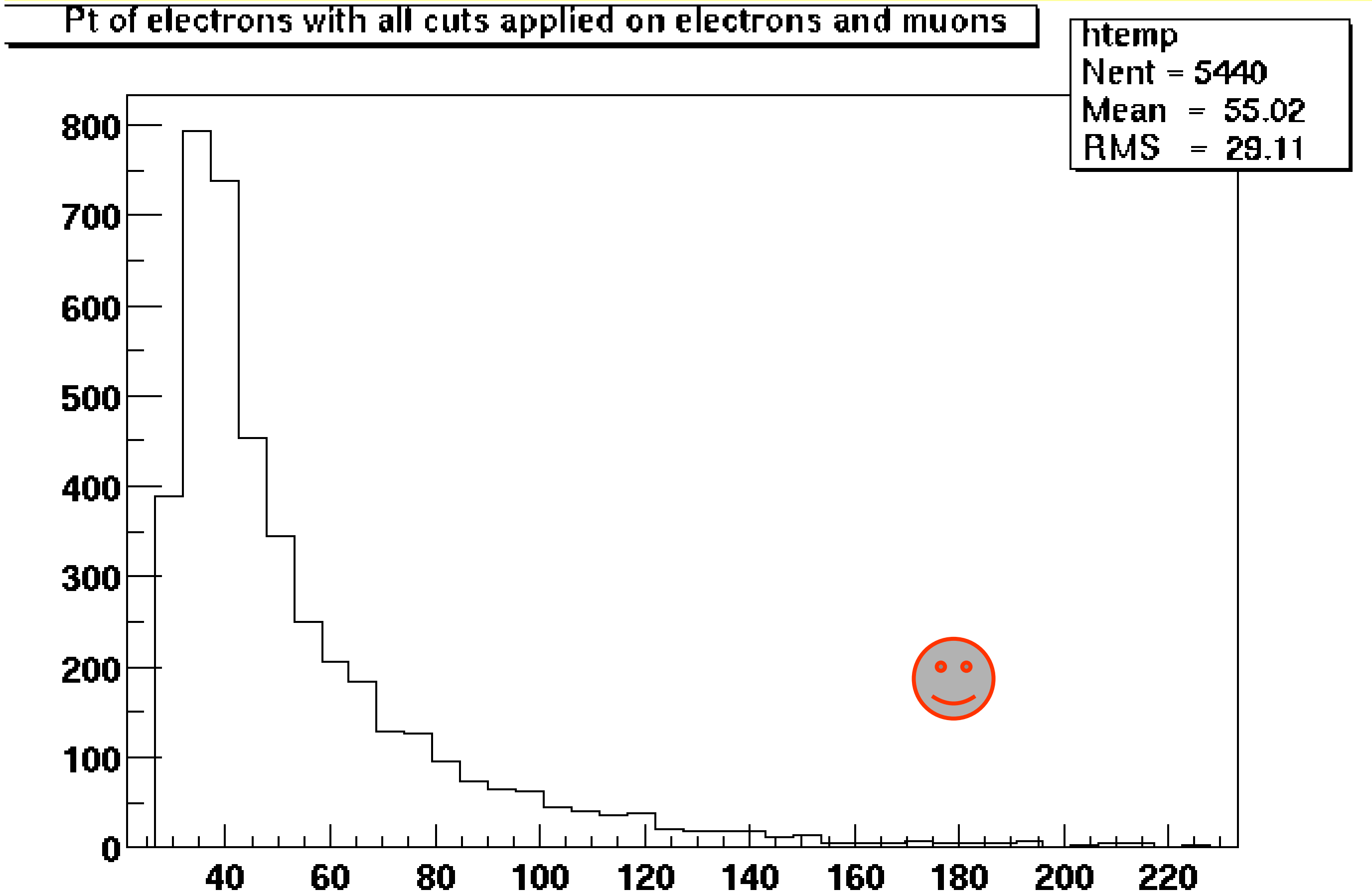
L1 : 48 %

HLT : 29 %

! No endcap muons in orca : HLT efficiency is underestimated !

Single *W* production in γp – first results

P_T distribution of electrons



Large event samples expected - the distributions correspond to integ. luminosity of about 10 fb^{-1}

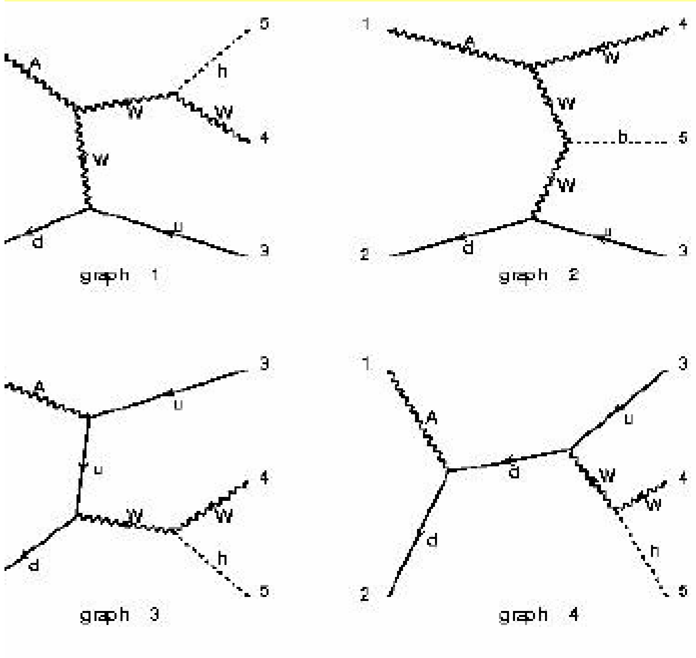
More Photoproduction

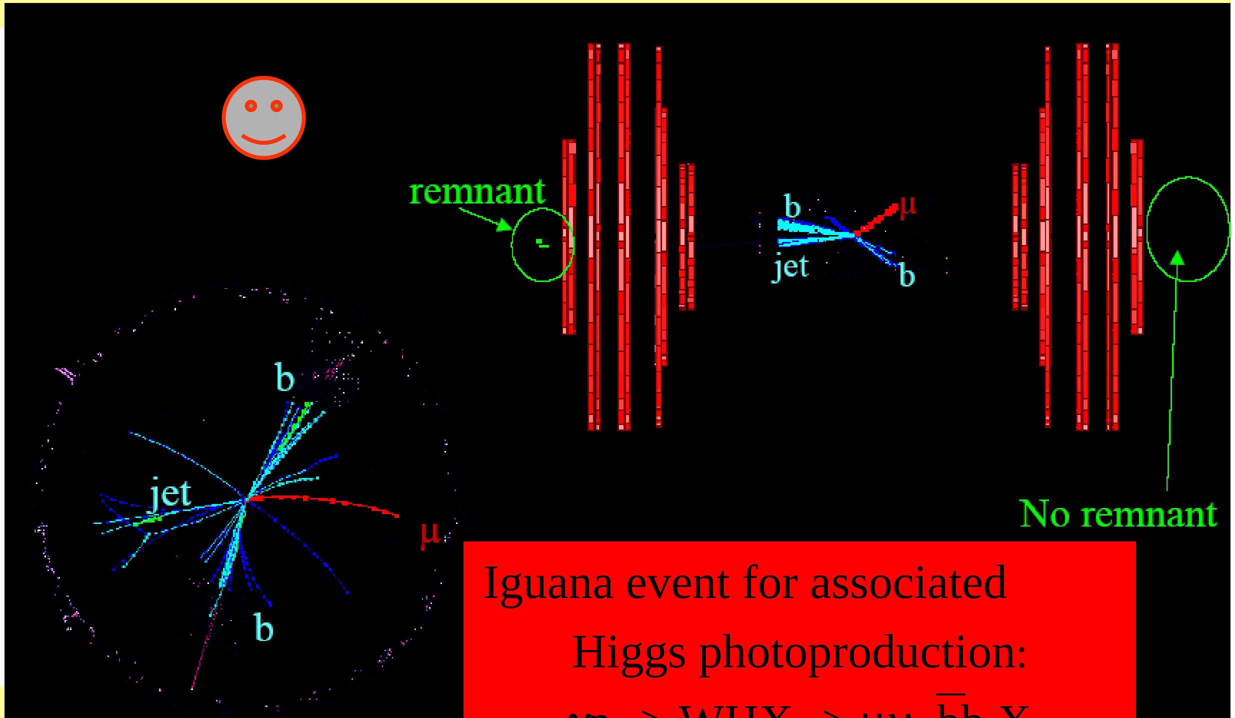
More tools have been developed for γγ and γp physics at LHC:

• Assuming equivalent photon approximation photon fluxes were introduced for *pp* interactions in CALCHEP/COMPHEP, SHERPA and recently in MadGraph

• After generation, photon events are fed to Pythia for decays and hadronization

• For some analyses full CMS simulation and reconstruction have been already performed



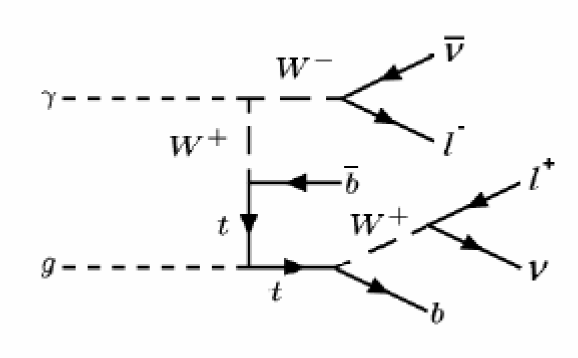


Iguana event for associated Higgs photoproduction:
$\gamma p \to WHX \to \mu\nu\, \bar{b}b\, X$

Higgs photoproduction

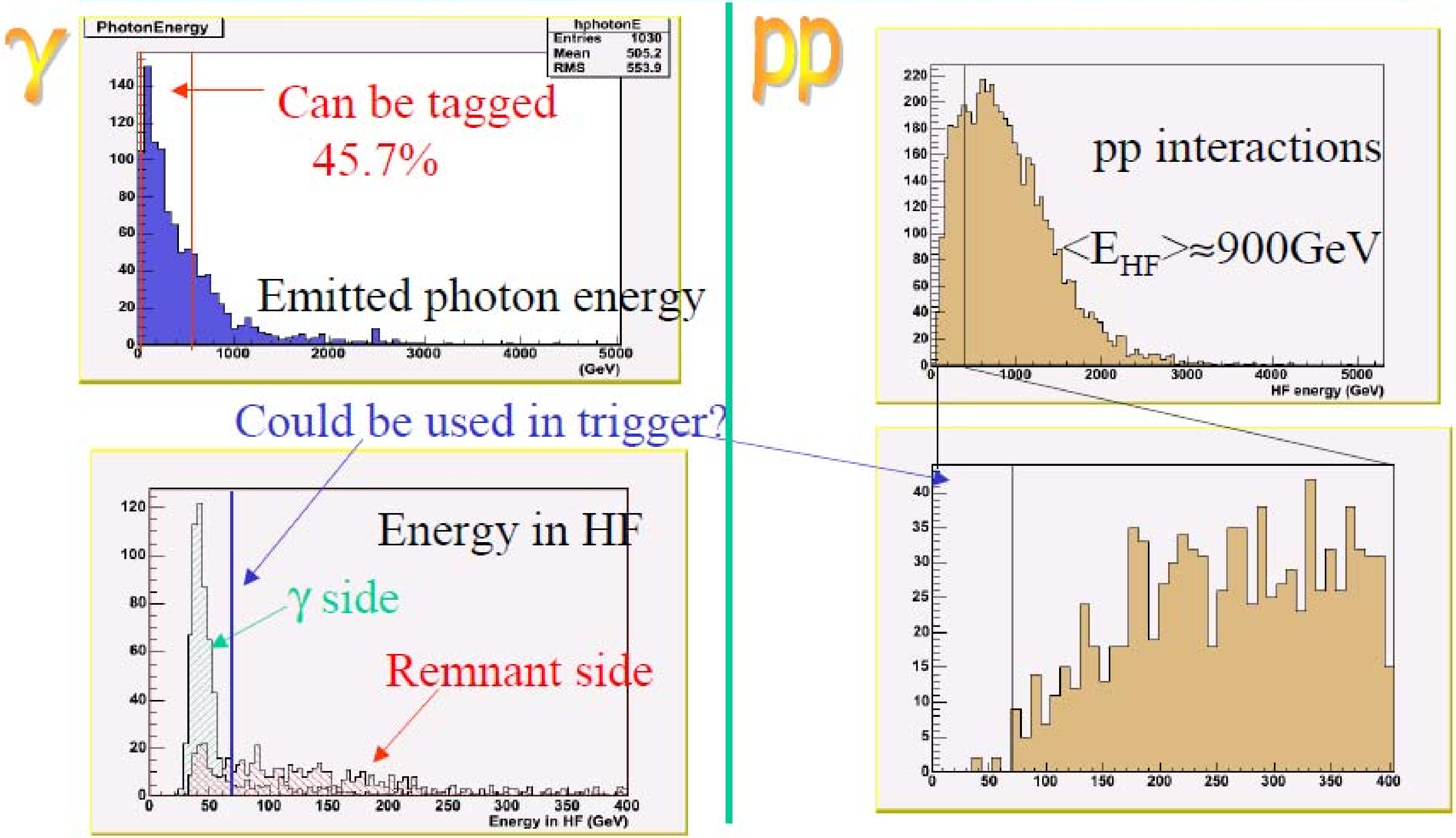
Associated photoproduction of WH has significant cross-section at LHC and much better signal-to-background ratio; we study low mass region with Higgs decaying to bb, ττ and WW.

We generated all relevant backgrounds, which deserve their own studies, as photo-production of top pairs, WZ, or single top (as at HERA!):



- Full CMS simulation available for bb signal and its irreducible background (including trigger efficiency); other backgrounds at the generator level
- Should propose dedicated trigger (eg. 1 RP * leptonic W)

γq vs pp interactions (no pile-up)



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

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

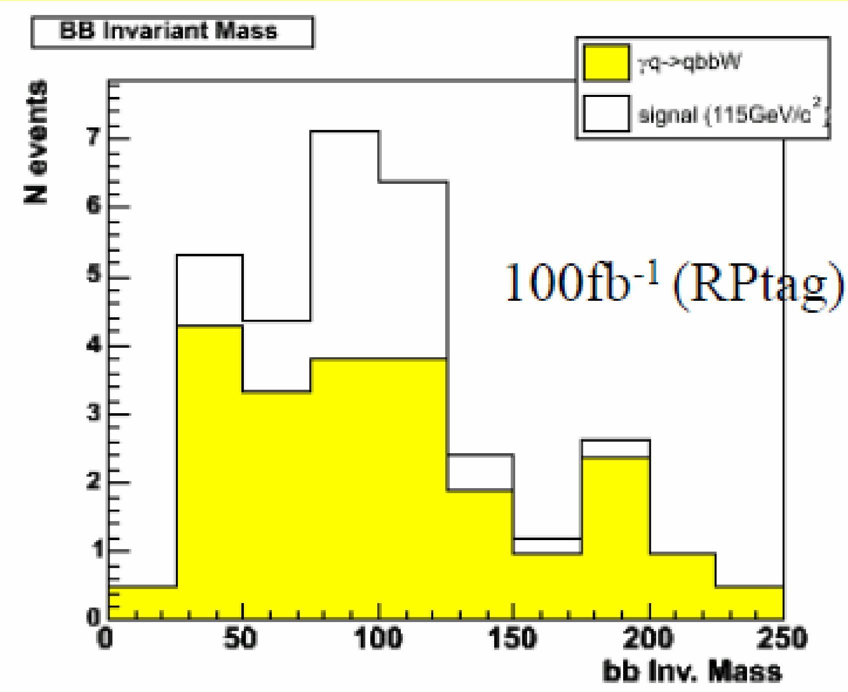
ORCA 8.2.0: trigger & reconstruction

	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?

WH case: which plots to show?



Only bb inv. mass to indicate potential?

Or, also forward proton energy distribution?

What about tables?

General: Should we give a short summary what statistics/studies might be possible for each integrated luminosity 100 pb^{-1}, 1fb^{-1} and 100 fb^{-1} ?

General trigger issues

In general all interesting processes have good CMS efficiency with nominal triggers (thanks to leptonic W decays considered so far) but one would gain significantly in statistics and in control of systematics (backgrounds) if dedicated triggers are available, for example:

Low-pT threshold for an electron or a muon

AND

Forward p tag = 220m RP trigger OR rapgap (using HF?)/exclusivity signature