Sensitivity to anomalous quartic gauge couplings in $\gamma\gamma$ interactions at LHC

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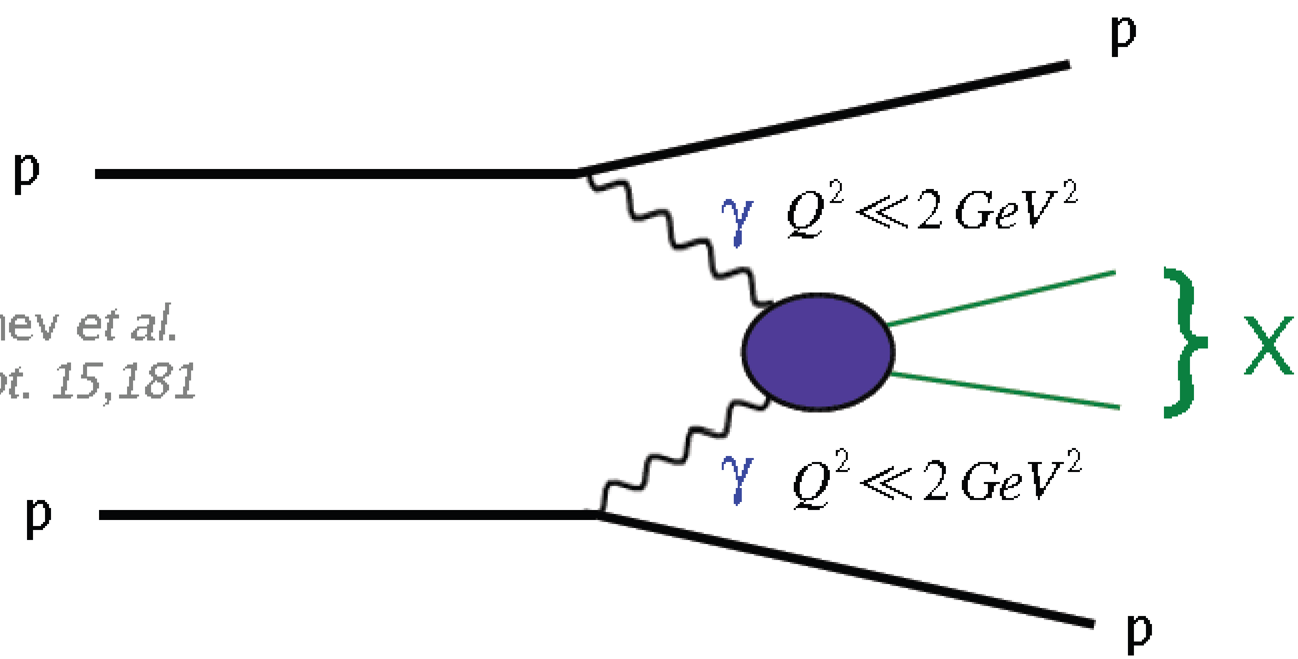
On behalf of the Louvain Photon Group

- Introduction: LHC as a $\gamma\gamma$ collider
- Detection of two-photon exclusive pair production
- Sensitivity to aQGCs: $\gamma\gamma WW$ and $\gamma\gamma ZZ$ case
- Summary/Outlook

Europhysics Conference on High Energy Physics

Kraków, 16-22 July, 2009

LHC as a $\gamma\gamma$ collider



V.M.Budnev *et al.*
Phys.Rept. 15,181

$$\sigma(\,pp \to (\gamma\gamma \to X)\,pp\,)$$

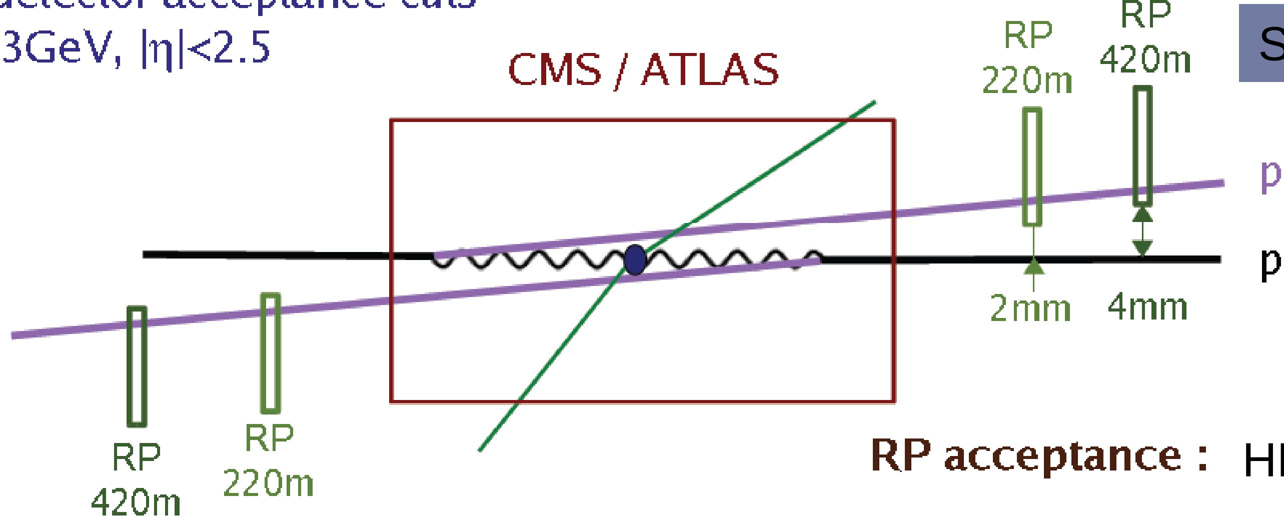
low γ virtuality (typical $Q^2 \sim 0.01\,GeV^2$) $\Rightarrow$

- factorization to
  - long distance photon exchange
  - short distance $\gamma\gamma \to$ X interaction

LHC as a $\gamma\gamma$ collider

main detector acceptance cuts
$p_t(\mu)>3$GeV, $|\eta|<2.5$

See FP420 talk



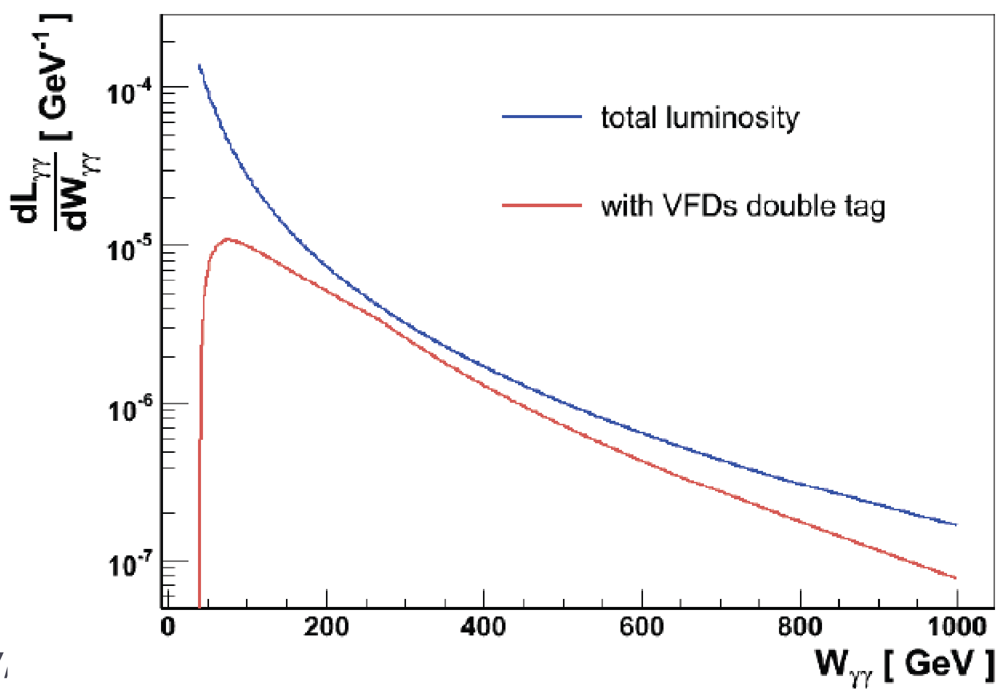
RP acceptance : HECTOR

120GeV < tagged E_γ < 900GeV

RP 220m

20GeV < tagged E_γ < 120GeV

RP 420m



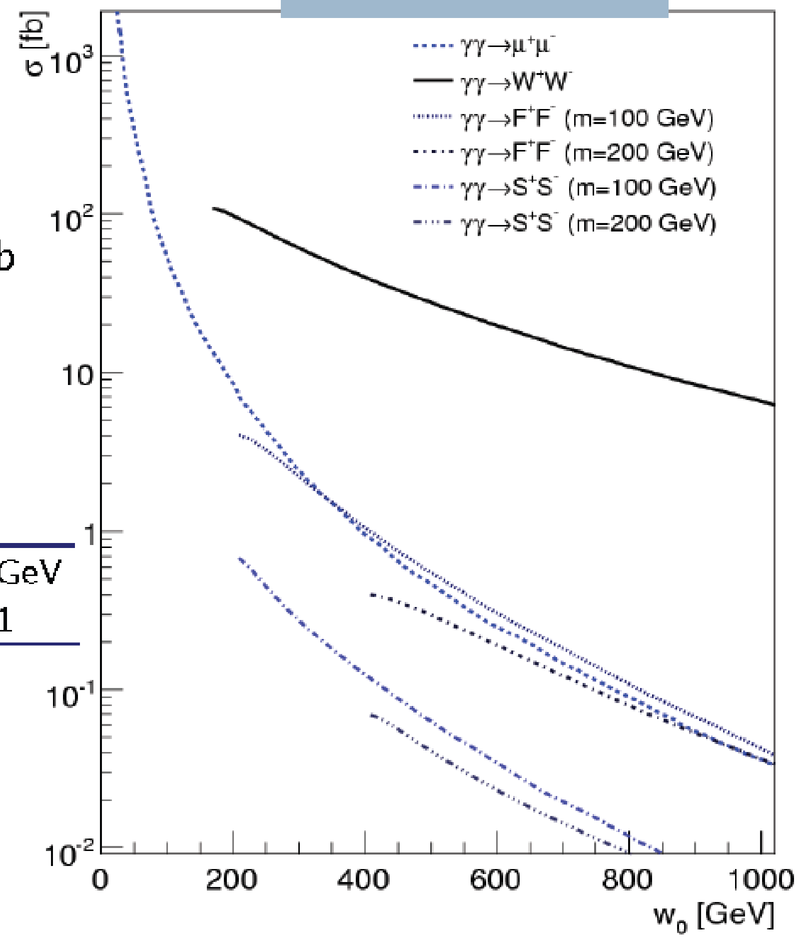
$$\sigma_{pp} = \int \sigma(W_{\gamma\gamma}) \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} dW_{\gamma\gamma}$$

LHC as a $\gamma\gamma$ collider

arXiv:0807.1121

- $\gamma\gamma \to \mu\mu$ first $\gamma\gamma$ process to be seen
- $\gamma\gamma \to W^+W^-$ very interesting SM process 108fb
- New physics !

Processes		[fb]	Generator
$\gamma\gamma \to \mu\mu$		72 500	LPAIR pt > 2 GeV $\lvert\eta\rvert < 3.1$
$\gamma\gamma \to$ WW		108	
$\to$ FF	(m=100GeV)	4.06	MadGraph
$\to$ FF	(m=200GeV)	0.40	/
$\to$ SS	(m=100GeV)	0.68	MadEvent
$\to$ SS	(m=200GeV)	0.07	



Cross sections for $\gamma\gamma$ processes as a function of the minimal $\gamma\gamma$ cms energy W_0

moreover :

lepton final states

clear signature – background suppression

Lagrangian for aQGCs

we use Lagrangian for genuine anomalous quartic vector boson couplings which conserves C, P as well as local U(1)em and SU(2)$_C$

$$L_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W^-_\alpha - \frac{e^2}{16\cos^2\Theta_W}\frac{a_0^Z}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} Z^\alpha Z_\alpha$$

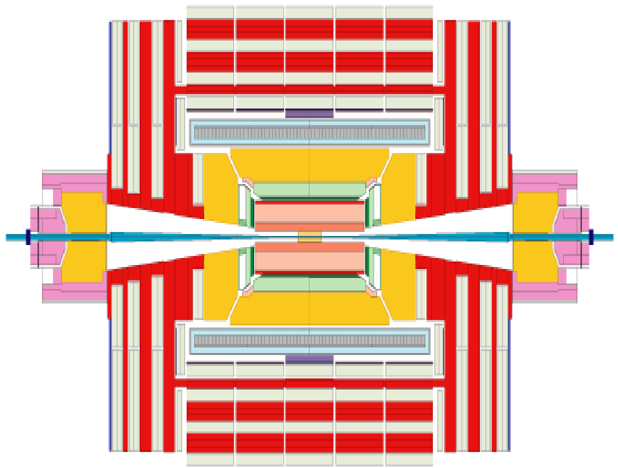
$$L_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta}(W^{+\alpha} W^-_\beta + W^{-\alpha} W^+_\beta) - \frac{e^2}{16\cos^2\Theta_W}\frac{a_C^Z}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} Z^\alpha Z_\beta$$

This gives a general auxiliary formula for a cross section (total or differential, with or without cuts) as a function of the anomalous parameters:

$$\sigma = \sigma_{SM} + \sigma_0 a_0 + \sigma_{00} a_0^2 + \sigma_C a_C + \sigma_{CC} a_C^2 + \sigma_{0C} a_0 a_C$$

Detector acceptance

Simple event counting in the main detector
with a two leptons (e or μ) signature within the acceptance cuts :



$$|\eta| < 2.5$$

$$p_T > 10\,GeV$$

- WW : $\gamma\gamma \to W^+W^- \to l^+l^-\nu_l\bar{\nu}_l$
- ZZ : $\gamma\gamma \to ZZ \to l^+l^- jj$

(no cuts on jets)

for a background we assume :

- WW : only SM $\gamma\gamma \to$ WW
- ZZ : no background – as no tree level SM $\gamma\gamma \to$ ZZ

Note: CEP of WW is < 1 fb

Setting limits on aQGCs

if $N_{obs} = \sigma_{cuts}^{SM} \cdot L$, $CL=95\%$

$$\sum_{k=0}^{N_{obs}} P_{Poisson}\left(\lambda^{up} = \sigma^{up} \cdot L;\ k\right) = 1 - CL$$

The calculated cross section CL=95% upper limits are :

σ^{up} [fb]	$\gamma\gamma \to WW$ $\sigma_{cuts}^{SM} = 4.081$ fb	$\gamma\gamma \to ZZ$ $N_{obs} = 0$, $\lambda^{up} = 2.996$
$L = 1\ fb^{-1}$	9.2	3.0
$L = 10\ fb^{-1}$	5.3	0.3

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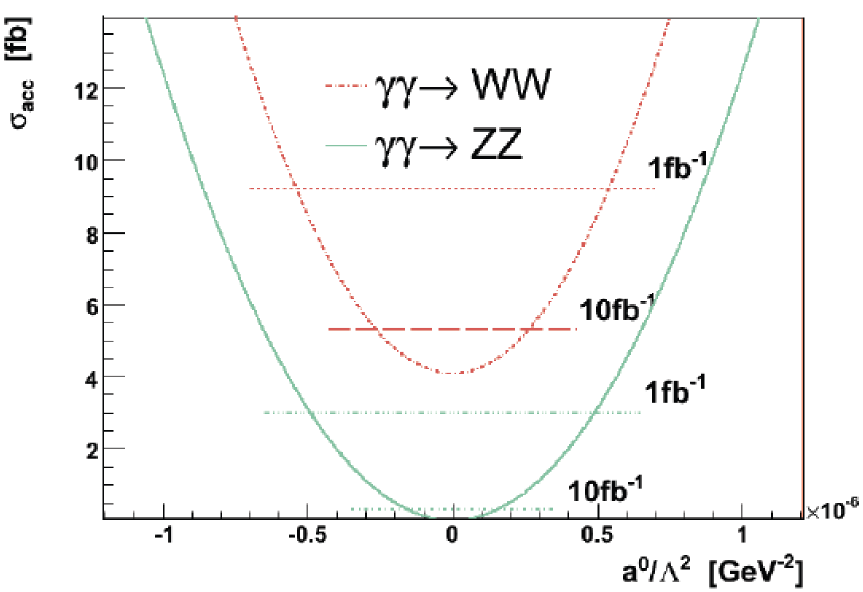
can be easily converted to the limit on the anomalous quartic couplings



Coupling	Limits $[GeV^{-2}]$ L=1fb^{-1}	L=10fb^{-1}
$\lvert a_0^Z / \Lambda^2 \rvert$	$0.49 \cdot 10^{-6}$	$0.16 \cdot 10^{-6}$
$\lvert a_0^W / \Lambda^2 \rvert$	$0.54 \cdot 10^{-6}$	$0.27 \cdot 10^{-6}$

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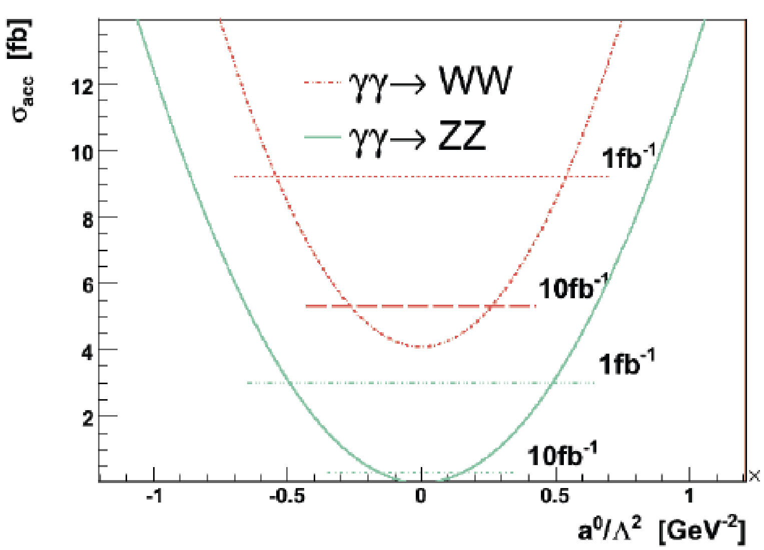
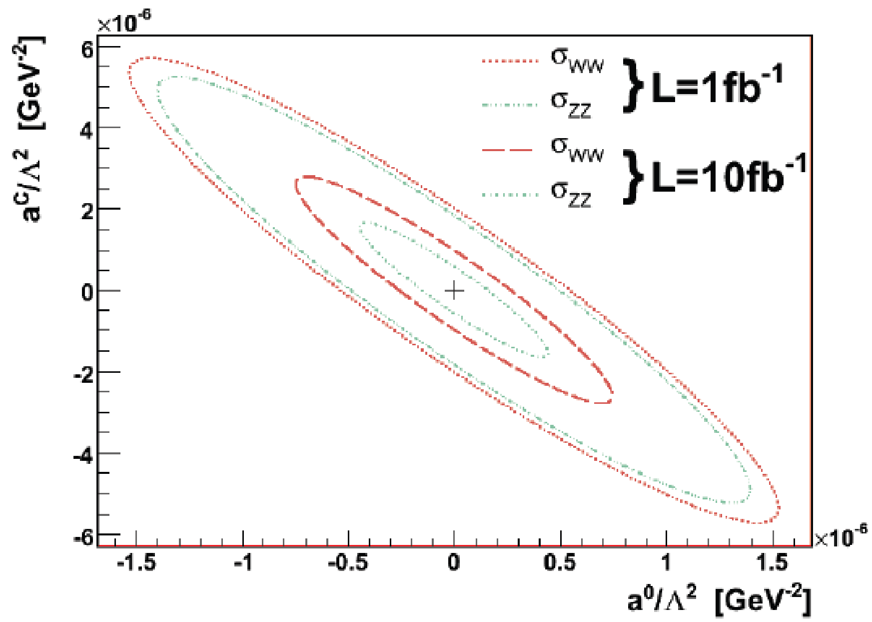
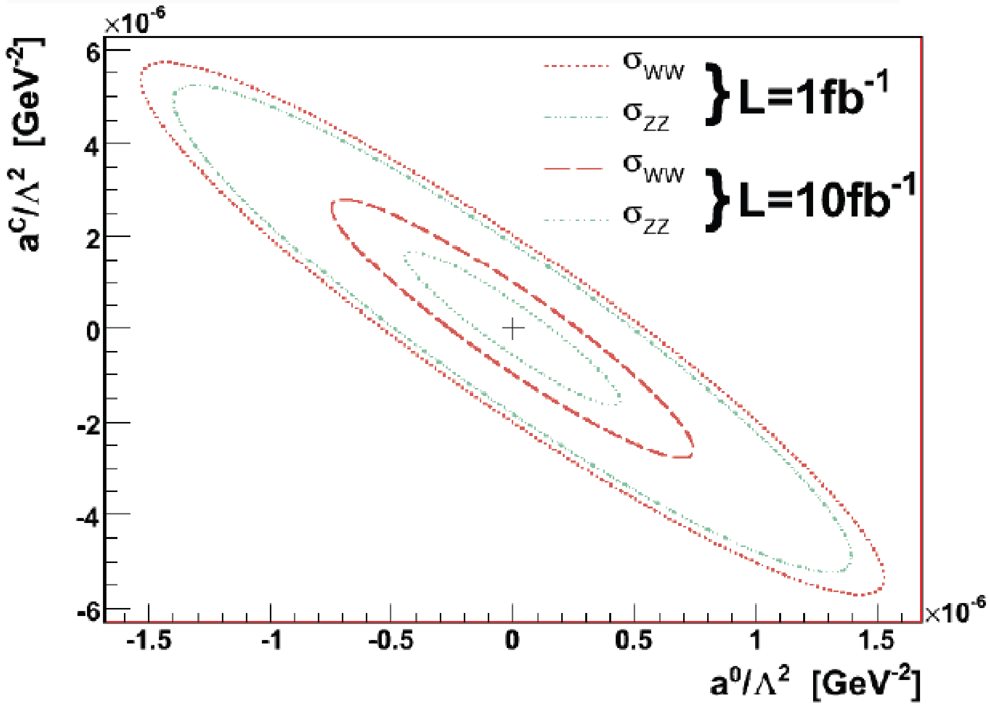


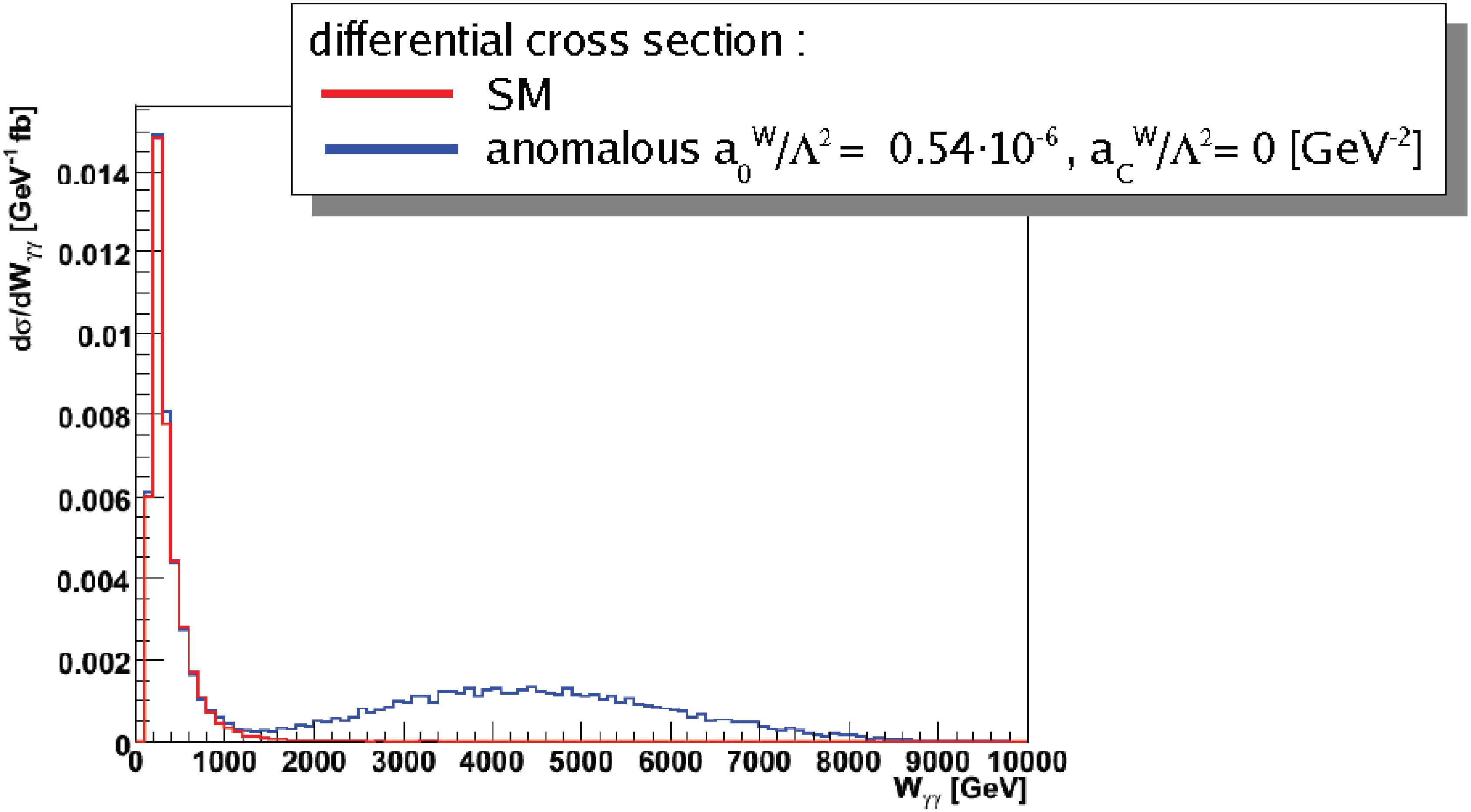


Setting limits on aQGCs



Coupling	Limits [GeV^{-2}] L=1fb^{-1}	L=10fb^{-1}
$\lvert a_0^Z/\Lambda^2\rvert$	$0.49\cdot10^{-6}$	$0.16\cdot10^{-6}$
$\lvert a_0^W/\Lambda^2\rvert$	$0.54\cdot10^{-6}$	$0.27\cdot10^{-6}$
$\lvert a_C^Z/\Lambda^2\rvert$	$1.84\cdot10^{-6}$	$0.58\cdot10^{-6}$
$\lvert a_C^W/\Lambda^2\rvert$	$2.02\cdot10^{-6}$	$0.99\cdot10^{-6}$

Unitarity bounds



Anomalous enhancement mostly at high $W_{\gamma\gamma}$ mass

So far no constrains on W were applied → need to watch unitarity bounds!

Unitarity bounds

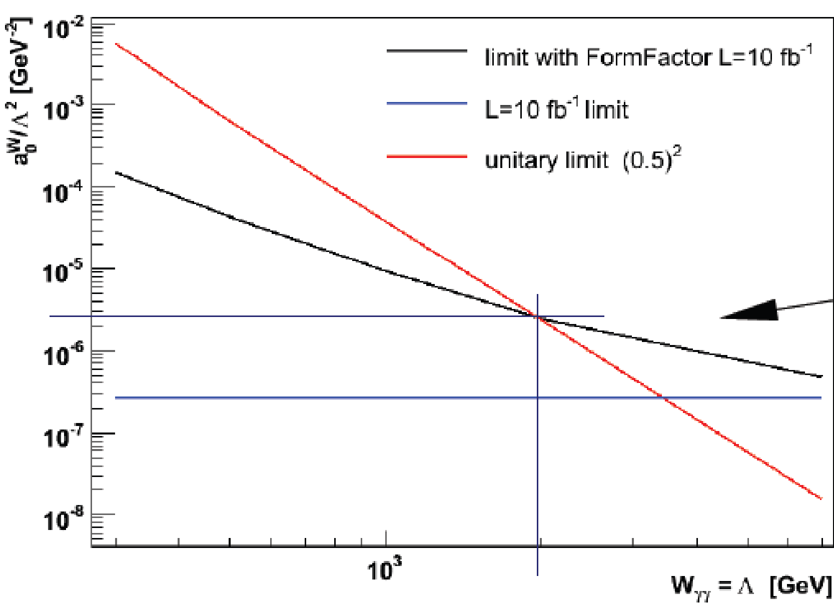
In non elastic scattering partial wave function a_L :

$$a_L = \frac{1}{32\pi} \int_{-1}^{1} M(\sqrt{s}, \cos\Theta, a_0, a_C) \cdot P_L(\cos\Theta) d\cos\Theta$$

must satisfy :

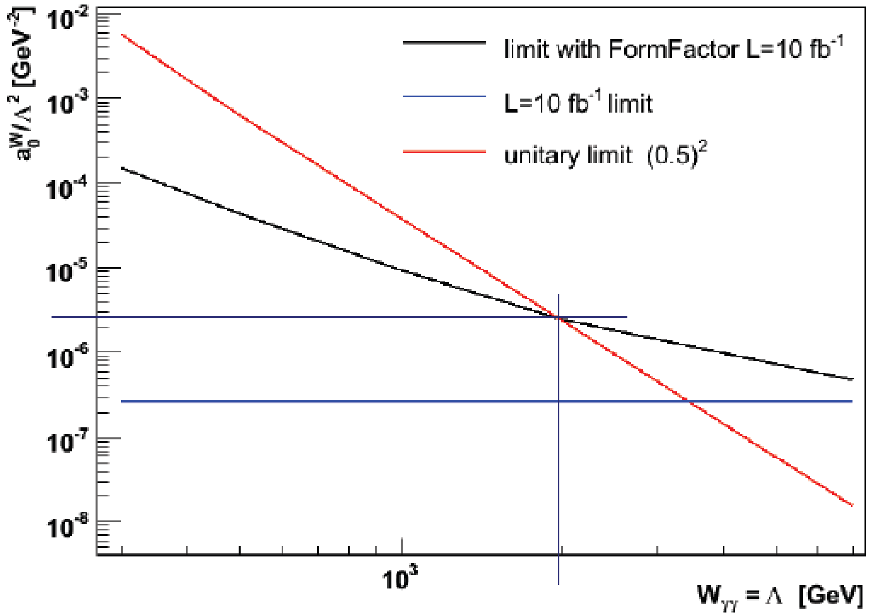
$$\beta \sum_{pol} |a_L(\sqrt{s}, a_0, a_C)|^2 < (1/2)^2$$

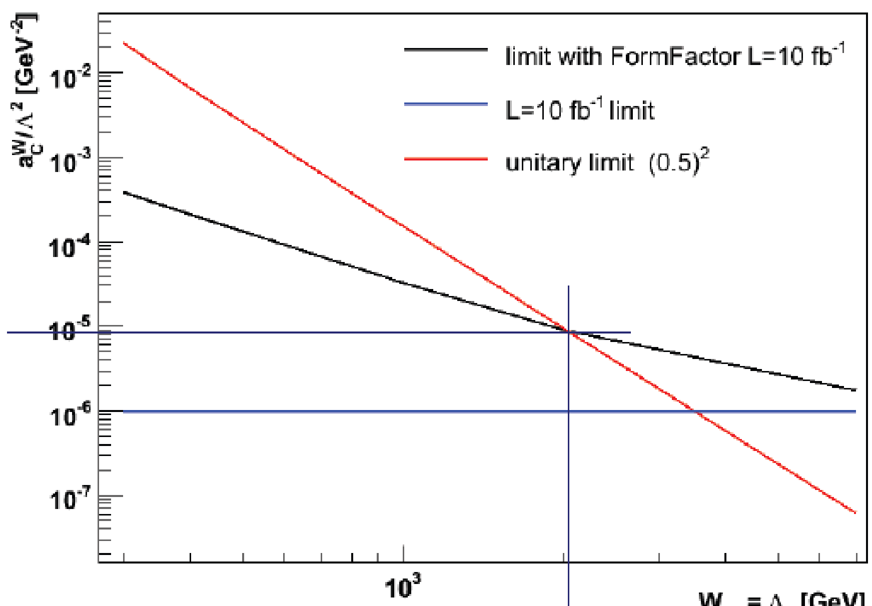
$$a \to \frac{a}{\left(1 + \frac{W_{\gamma\gamma}^2}{\Lambda^2}\right)^X}$$



we used X=2

Unitarity bounds





dipole form-factor

$$a \rightarrow \frac{a}{\left(1+\frac{W_{\gamma\gamma}^2}{\Lambda^2}\right)^2}$$

Limits including form-factor :

$a_0^W/\Lambda^2 < 2.5 \cdot 10^{-6}\ \mathrm{GeV}^{-2}$

$a_Z^W/\Lambda^2 < 9 \cdot 10^{-6}\ \mathrm{GeV}^{-2}$

whilst LEP :

$a_0^W/\Lambda^2 < 2.0 \cdot 10^{-2}\ GeV^{-2}$

$a_Z^W/\Lambda^2 < 3.7 \cdot 10^{-2}\ GeV^{-2}$

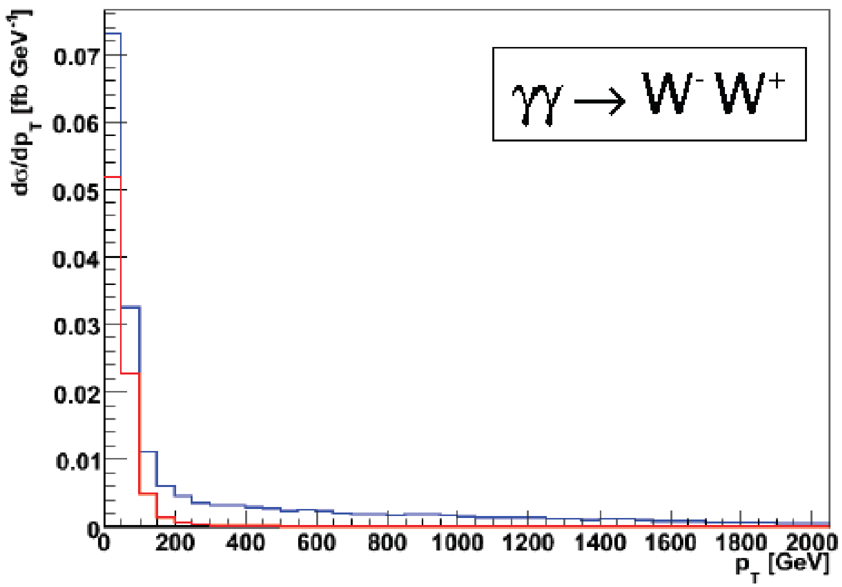
for L = 10 fb^{-1}

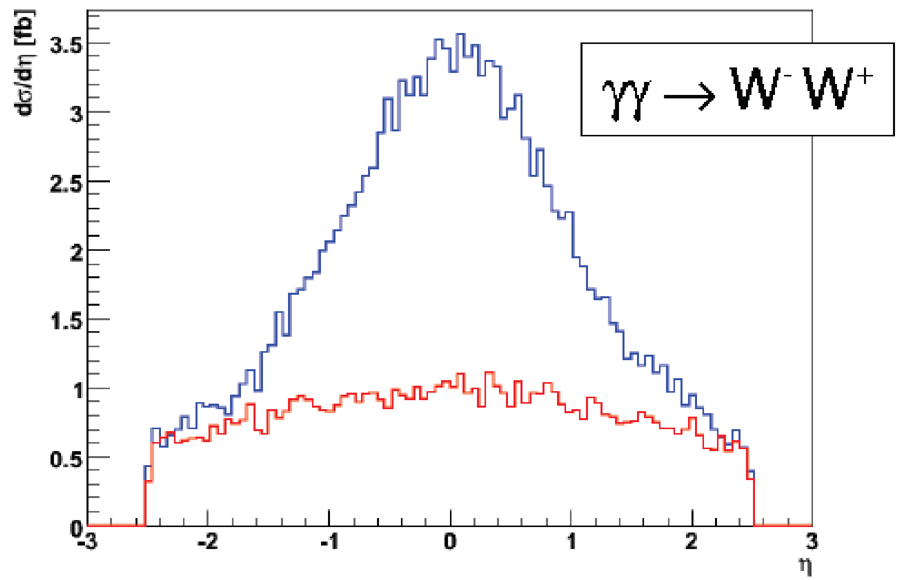
Improvement of ~4000

Differential distributions

- use of leptons p_T and/or η distributions – discriminating power

differential cross section :
SM
anomalous $a_0^W/\Lambda^2 = 0.54 \cdot 10^{-6}$, $a_C^W/\Lambda^2 = 0$ [GeV^{-2}]





Definitely a lot of space for improvements,
but can it be done at very high luminosity?

Event pileup

In preceding discussion no event pileup was assumed so full exclusivity condition could be applied: Apart from two leptons, no activity in central detectors (including calorimeters)

Very powerful condition, leaves no non-exclusive backgrounds (beautifully applied at Tevatron: see 5 papers by CDF) BUT cannot be used if two events occur in the same bunch crossing $\rightarrow$ large loss of luminosity by requesting single event BX…

Solution 1:

Use track-based exclusivity, allow only two leptons and NO more tracks from the vertex (Note: only charged particlers and ± 2.5 rapidity units vs ± 5 for calorimeters)
Works well for medium luminosities, up to 2.10^{33} $cm^{-2}s^{-1}$

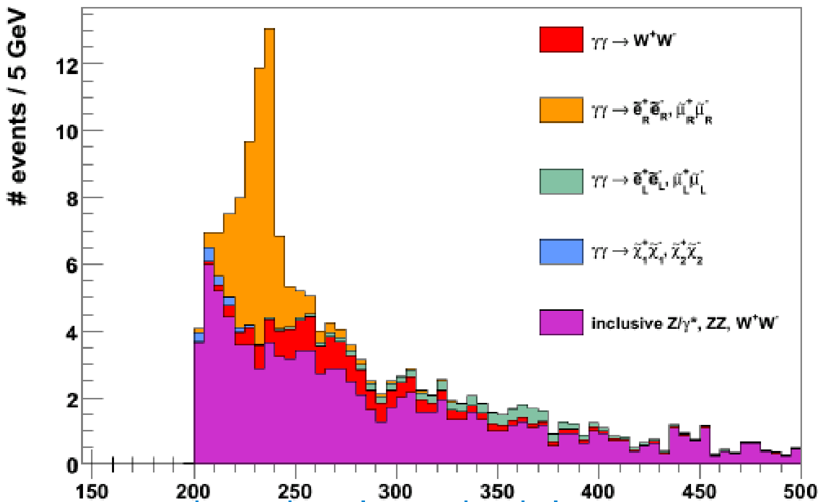
Solution 1+2:

Apply track exclusivity and require detection in the forward detectors + z-vertex matching from time difference measurements in ToF detectors (GasToF)

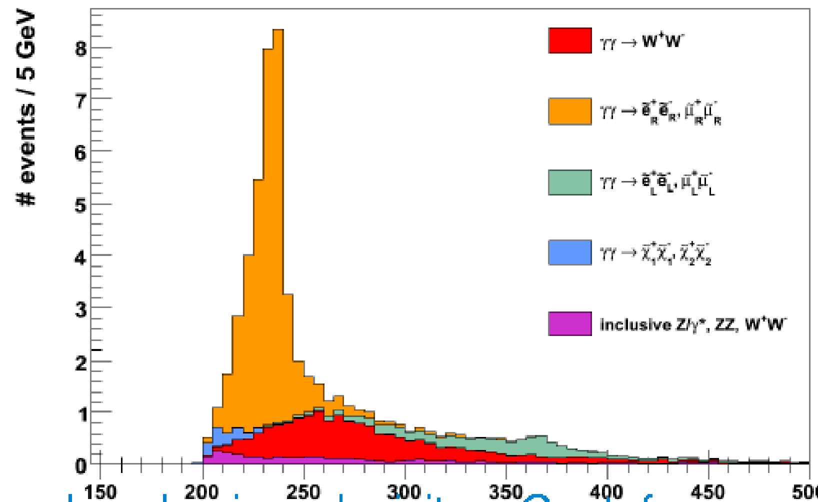
See FP420 talk for details

Exclusive dileptons at high $\mathcal{L}$

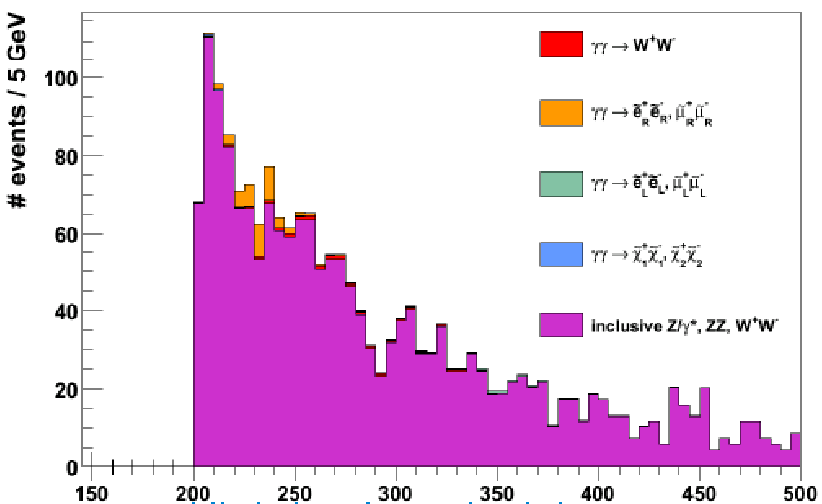
N. Schul at SUSY'09: Assume 10 ps ToF resolution



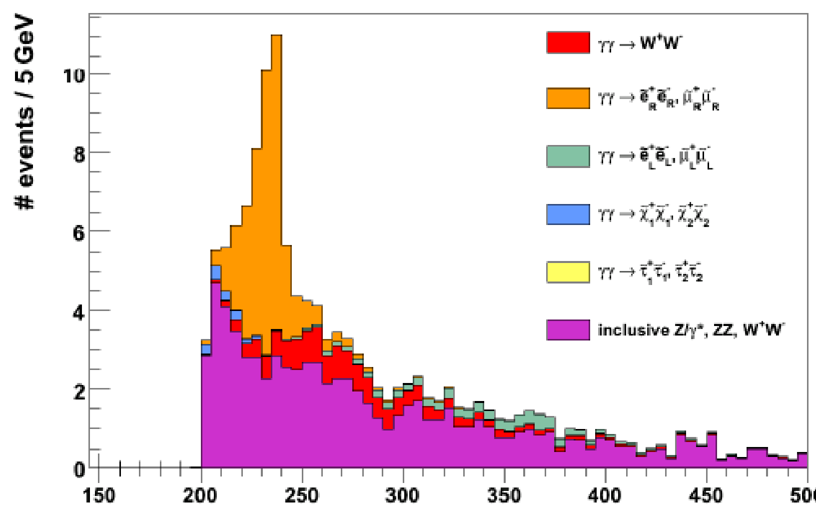
Low lumi, exclusivity



Low lumi, exclusivity + Gastof



High lumi, exclusivity



High lumi, exclusivity + Gastof

Summary/Outlook

- LHC is a powerful photon-photon collider (1% pp luminosity available for $\gamma\gamma$ collisions at energies above 200 GeV)

- Exclusive two-photon WW and ZZ production provides stringent tests if SM

- Exclusive dilepton events from leptonic W and Z decays will allow to improve LEP quartic gauge couplings limits by orders of magnitudes already with small integrated LHC luminosity

- To be able to study the exclusive production at nominal LHC luminosity novel, very forward proton detectors are mandatory!

- Wide set of other models will be studied (SU(2) gauge symmetric, Higgsless scenarios, etc.)

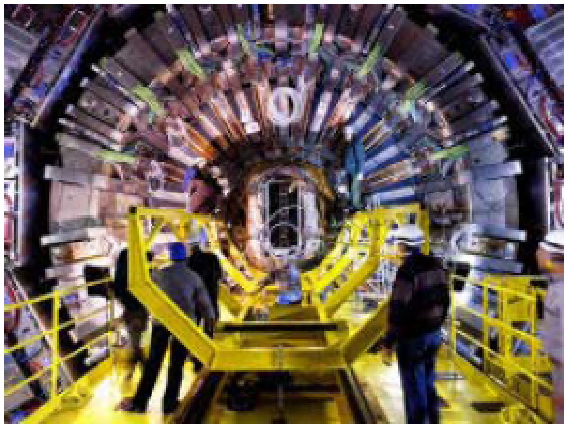
Stay Tuned!

Phys. Rev. Lett. **102**, 242001
(issue of 19 June 2009)
Title and Authors

24 June 2009

A Higgs Boson without the Mess

Particle physicists at CERN's Large Hadron Collider (LHC) hope to discover the Higgs boson amid the froth of particles born from proton-proton collisions. Results in the 19 June *Physical Review Letters* show that there may be a way to cut through some of that froth. An experiment at Fermilab's proton-antiproton collider in Illinois has identified a rare process that produces matter from the intense field of the strong nuclear force but leaves the proton and antiproton intact. There's a chance the same basic interaction could give LHC physicists a cleaner look at the Higgs.



CERN

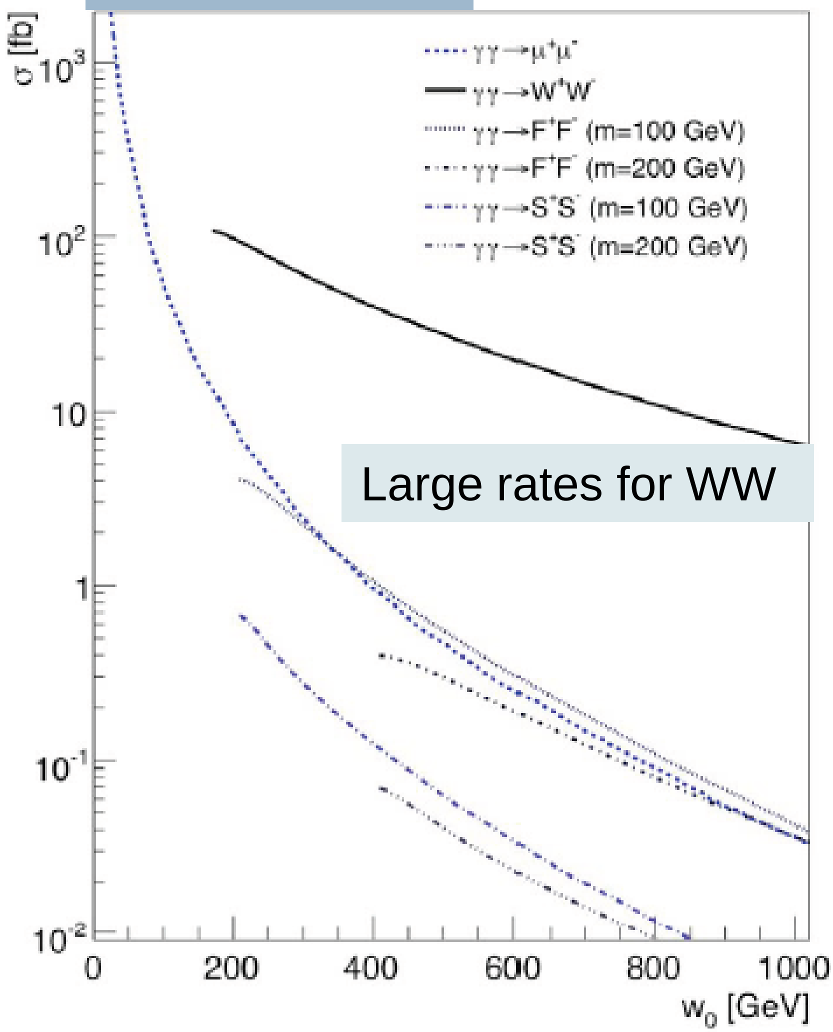
Higgs machine. If CERN's Large Hadron Collider (LHC) can create Higgs bosons, a handful may appear in rare "exclusive" reactions that don't destroy the colliding protons--similar to a reaction now observed at Fermilab. CERN's ATLAS and CMS teams are considering adding equipment to their detectors (CMS shown here) to look for such events (click image to enlarge)

A proton is always surrounded by a swarm of ghostly virtual photons and gluons associated with the fields of the electromagnetic and strong nuclear forces. Researchers have predicted that when two protons (or a proton and an antiproton) fly past one another at close range, within

Backup slides

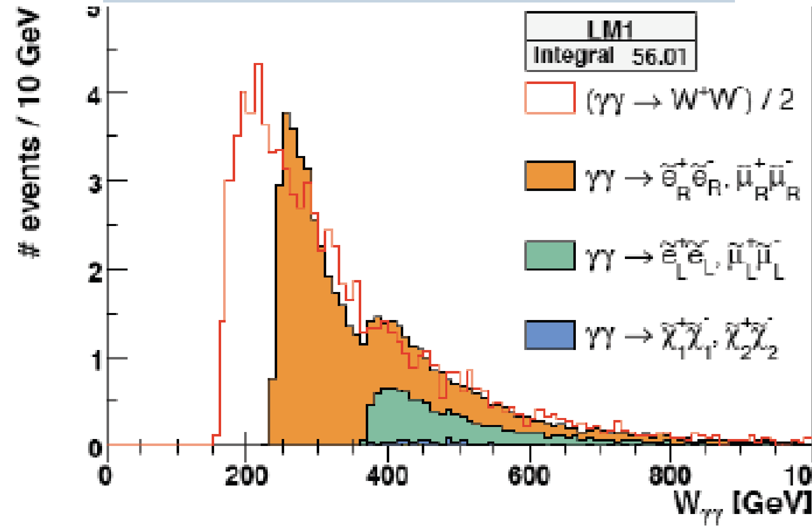
Two-photon physics

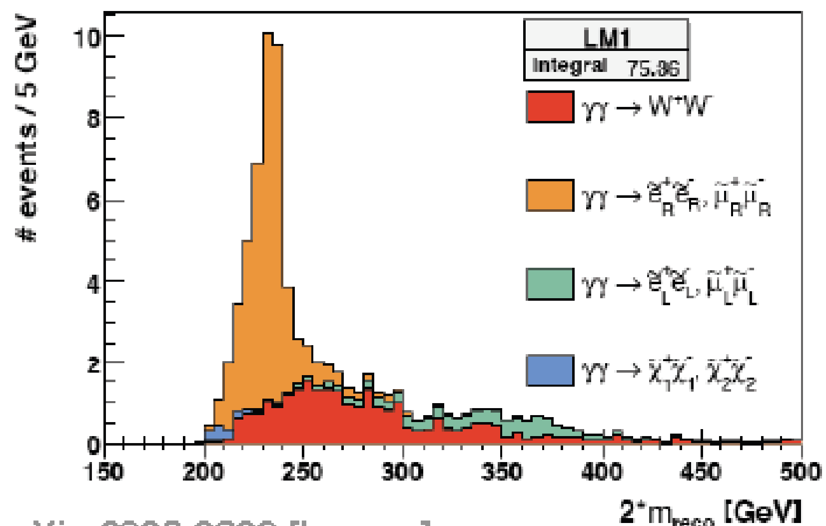
arXiv:0807.1121



Large rates for WW

MSSM: 100 fb-1 (no pileup)





:iv:0808.0322 [hep-ph],arXiv:0806.1097 [hep-ph], arXiv:0806.0302 [hep-ex]

(Light) SUSY case

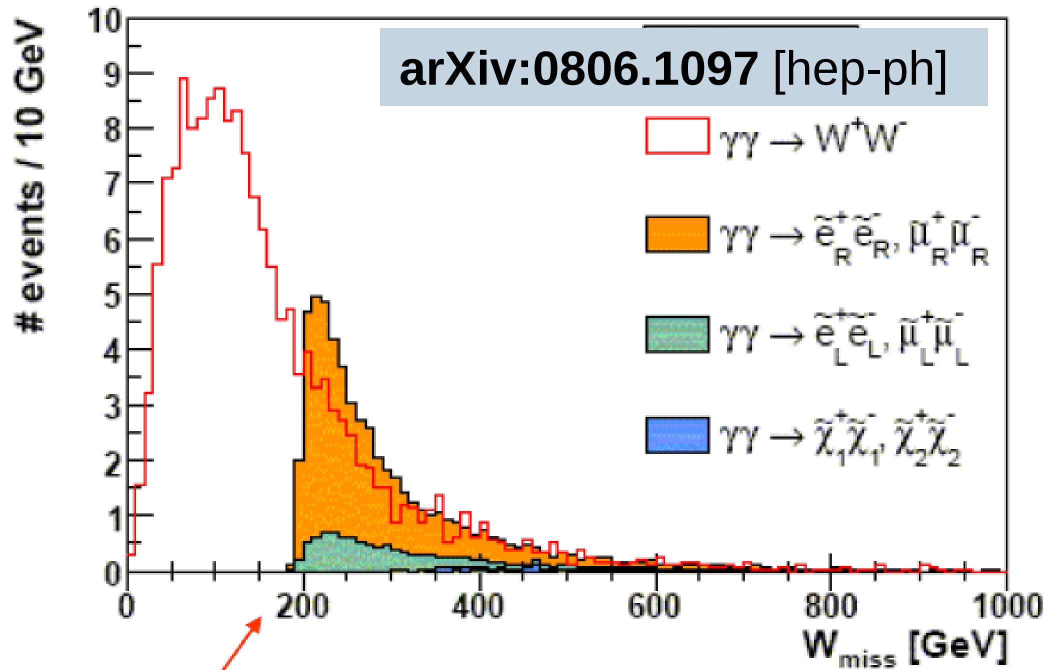


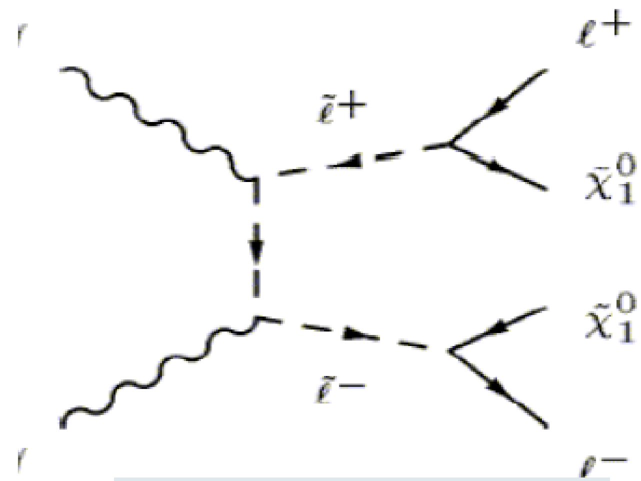
Figure 3. Distribution of missing invariant mass W_{miss} for the LM1 MSSM benchmark for the integrated luminosity L = 100 fb^{-1}. It starts at about $\boxed{2\, m_{LSP}}$ for SUSY, at zero for the WW background.

$$\boxed{W_{miss} = \sqrt{E^2_{miss} - P^2_{miss}}}$$

Brief history:

Ohnemus & Zerwas '93

Piotrzkowski '00, '01



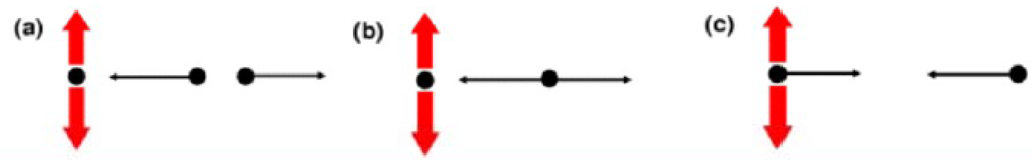
Forward detectors crucial for kinematics reconstruction (charged dilepton states only!):

Unique contribution!

Accidental overlays

Additional background arises from **accidental coincidence** where the detected system X in the central detector and the forward protons in VFD do not come from the same vertex :

arXiv:0806.0302



At the LHC, **$\langle N_{\text{pile-up}} \rangle$** is	~5 events	for $\mathcal{L} = 2{*}10^{33}$ cm^{-2} s^{-1}	*Poisson* distributed
	~25 events	for $\mathcal{L} = 1{*}10^{34}$ cm^{-2} s^{-1}	

* Single diffraction (pp->Xp)

σ = 14.30 mb

ε_{FP220} = 15%

ε_{FP420} = 12% --> σ_{VFD} = 3.8 mb

* Double diffraction (pp->X)

σ = 10.21 mb

ε_{FP220} = 1.3%

ε_{FP420} = 0.02% --> σ_{VFD} = 0.13 mb

* Non-Diffractive inelastic (pp->X)

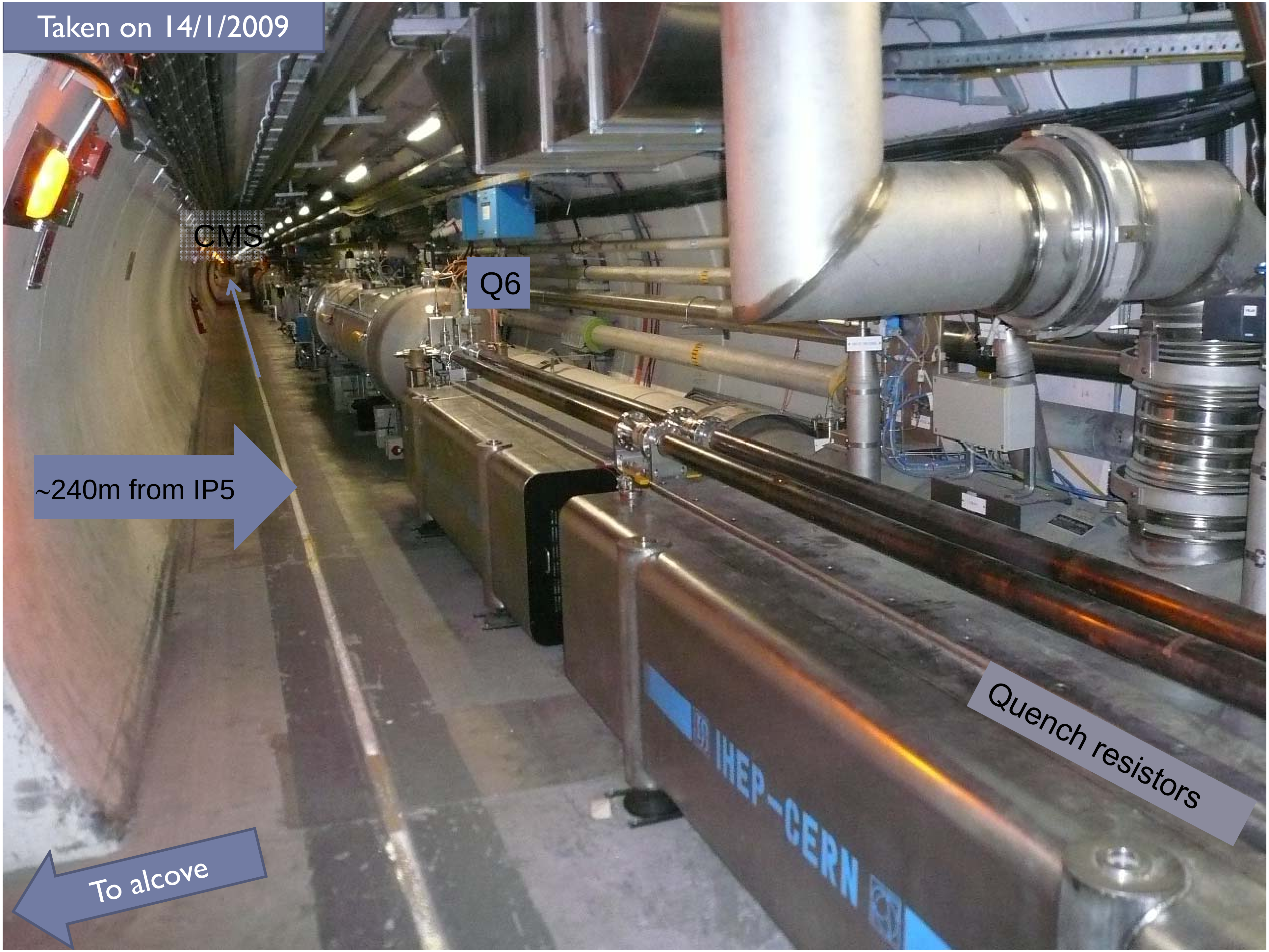
σ = 54.71 mb

ε_{FP220} = 0.33%

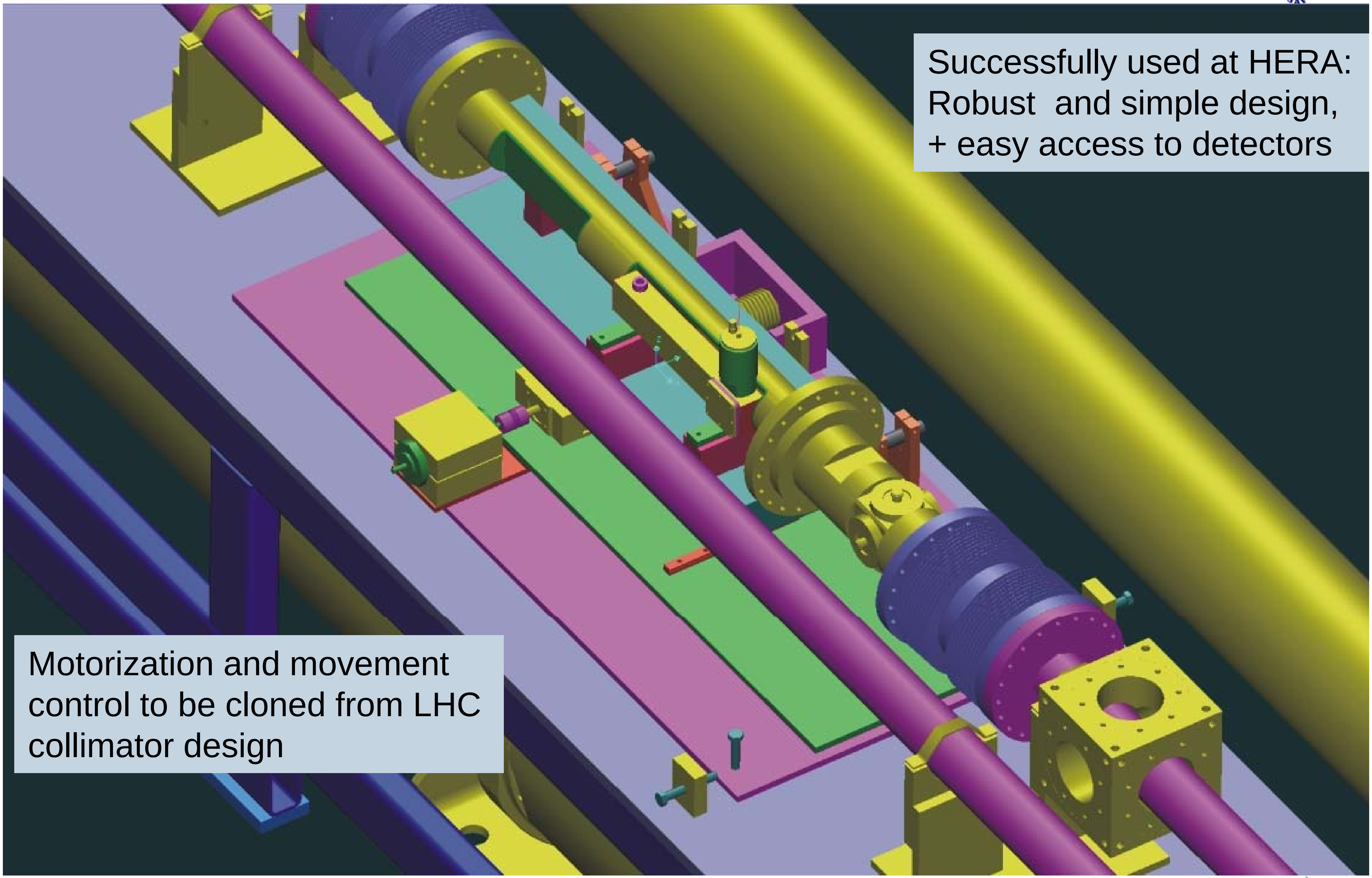
ε_{FP420} < 0.01% --> σ_{VFD} = 0.18 mb

==> Global: $\langle\varepsilon_{FP240}\rangle$= 2.165% $\langle\varepsilon_{FP420}\rangle$= 3.015% --> $\sigma_{VFD,TOT}$ = 4.10 mb

Use timing for background suppression

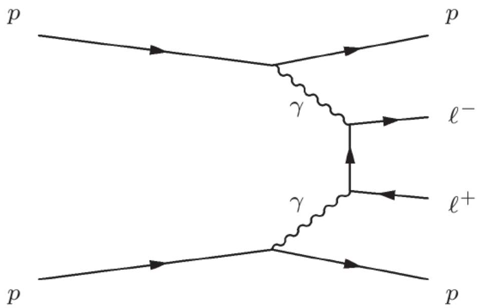

Taken on 14/1/2009
CMS
Q6
~240m from IP5
Quench resistors
To alcove
IHEP-CERN

Moving Hamburg pipe concept



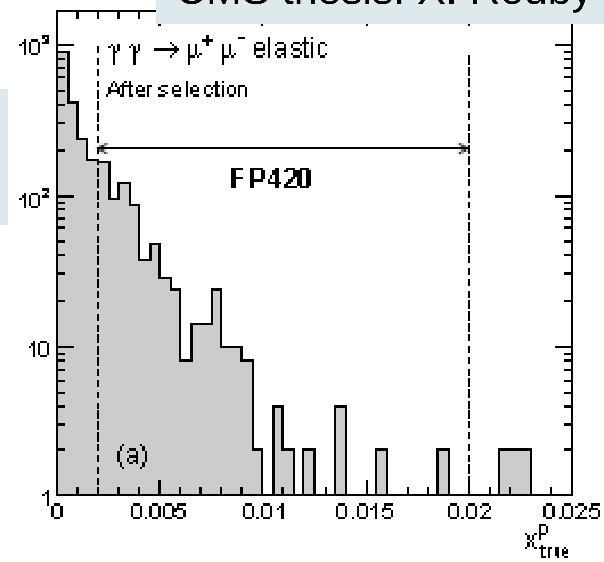
Calibration with exclusive di-muons

pp → pp l^+l^-



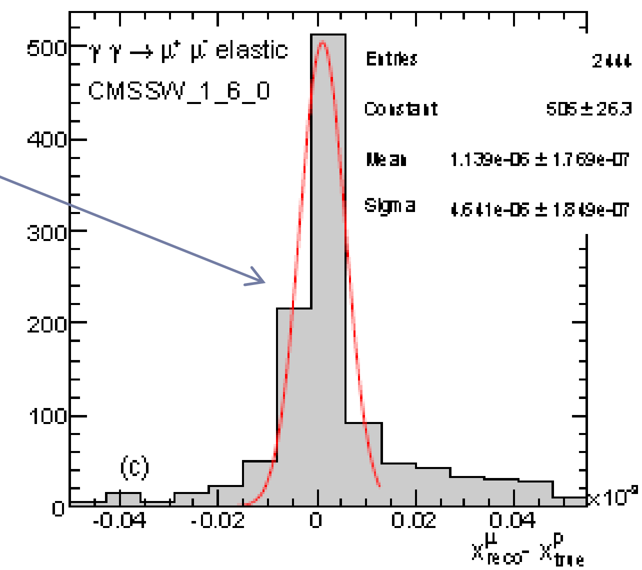
CMS thesis: X. Rouby

~ 700 μμ events in 100 pb^{-1}
(single-interaction data @ 14TeV)



- Nearly pure QED process
- Calibration/alignment of FP420 detectors (about 40% protons detected!):

Expected resolution of x=Eγ/E is ~5.10-6 !



Calibration procedure itself can be very well controlled using Upsilon signal!

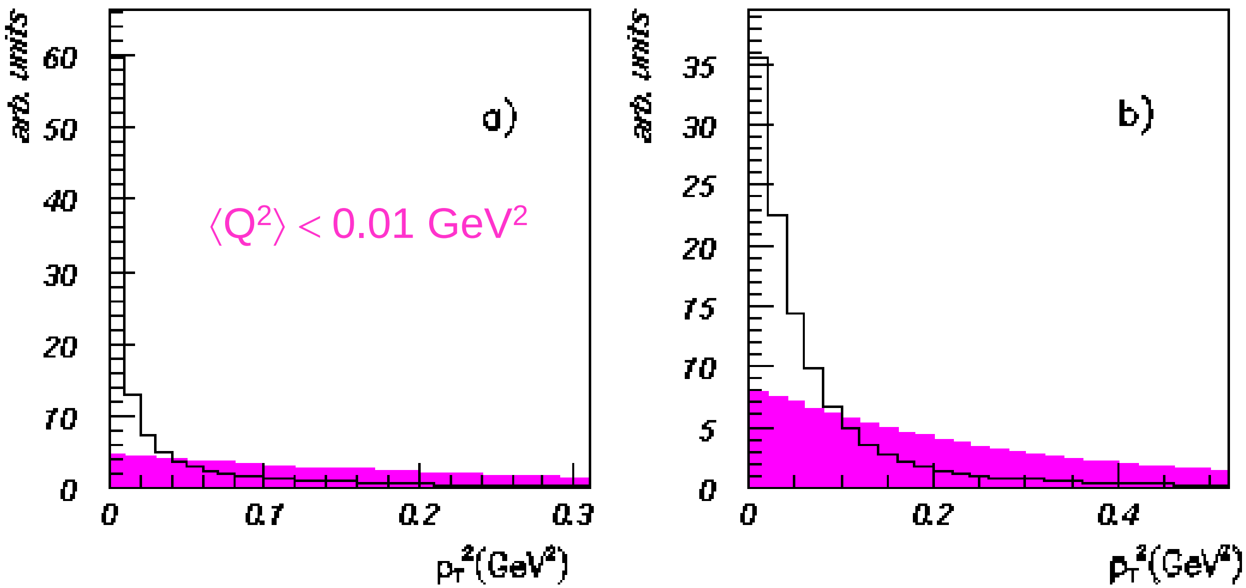
BOTTOMLINE:

Exclusive low-mass dimuons crucial for FP420

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

Both processes weakly interfere, and 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