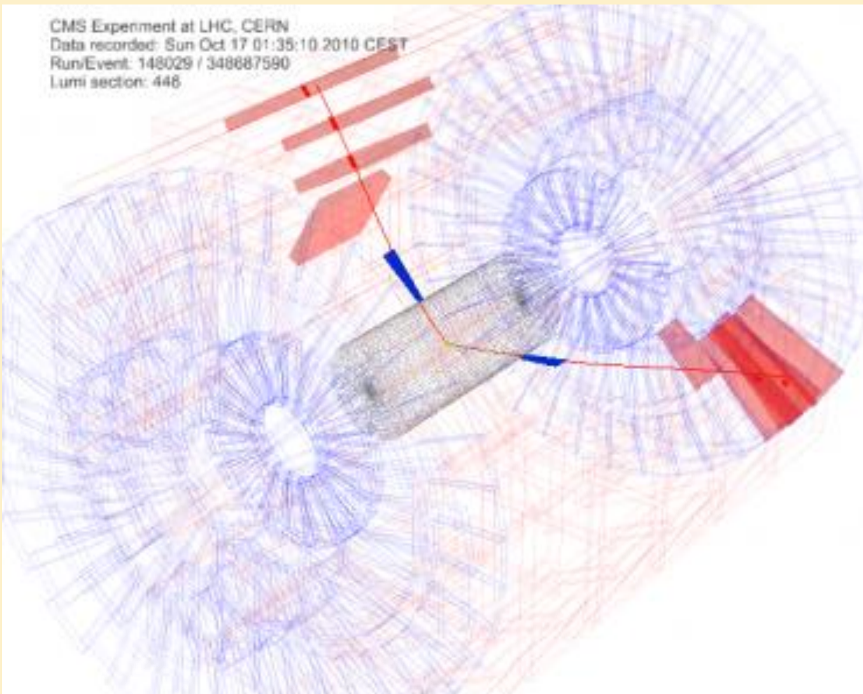
Perspectives for the future studies of high energy $\gamma\gamma$ interactions at the LHC



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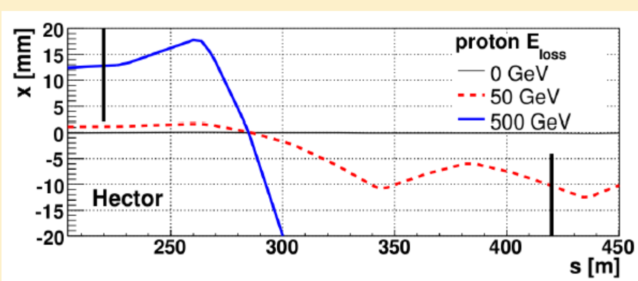
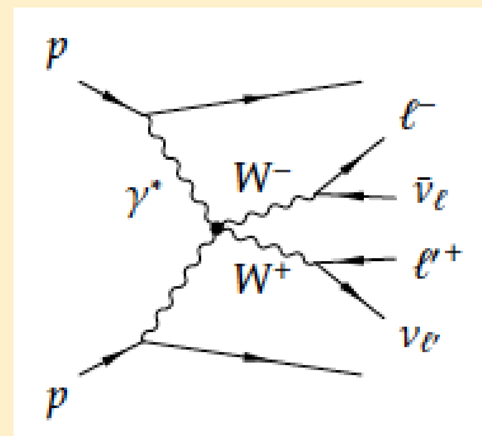




EMMI workshop

Kraków – PAN/PAU

September 5-8, 2017

Outline

Part I: Introduction & motivation

Part II: Perspectives for future studies - the LHC as a high energy photon-photon collider

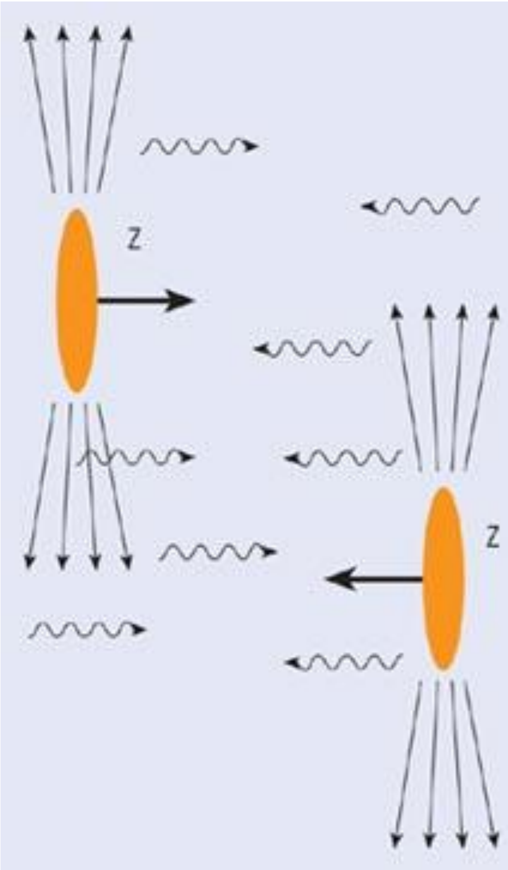
Semiclasical picture: Weizsacker-Williams approximation

Back in 1934, Weizsacker and Williams (independently) considered interactions of fast charged particles in matter by casting these processes into two steps:

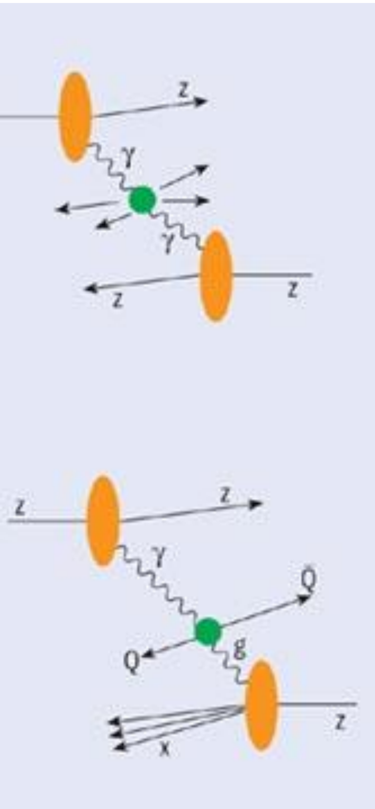
- Representing the particle electromagnetic field by a “cloud” (or flux) of virtual quanta/photons
- Calculating then photon interactions with matter

Following assumptions were made there:

- the charged particle moves uniformly
- its field gets “Lorentz-contracted”, so for a “observer” at some distance b (=impact parameter) it becomes a short pulse of mostly transverse component
- field is Fourier-transformed and finally, its energy can be represented by a appropriate number of quanta (of given frequency)
- there is b_{min}, usually coming from a finite size of charge



Quantum picture: Equivalent Photon Approximation (EPA)



In EPA the photon spectrum is a function of the photon energy ω and its virtuality Q^2 [1]:

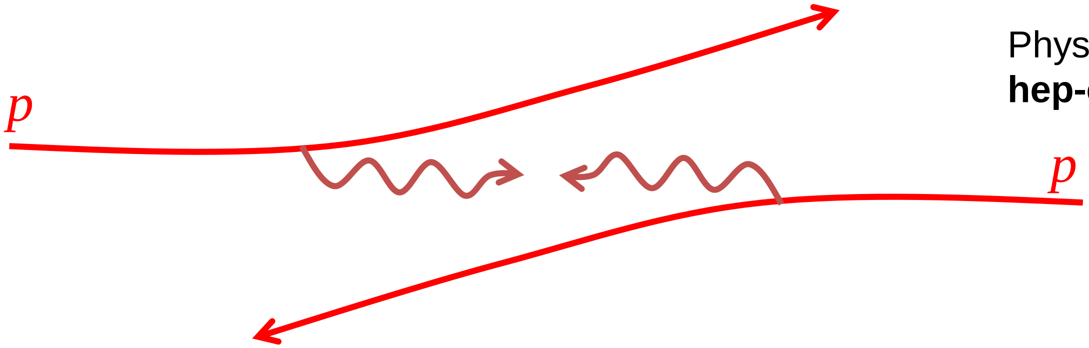
$$\mathrm{d}N = \frac{\alpha}{\pi}\frac{\mathrm{d}\omega}{\omega}\frac{\mathrm{d}Q^2}{Q^2}\left[\left(1-\frac{\omega}{E}\right)\left(1-\frac{Q^2_{min}}{Q^2}\right)F_E + \frac{\omega^2}{2E^2}F_M\right], \tag{1}$$

where α is the fine-structure constant, E is the incoming proton energy and the minimum photon virtuality $Q^2_{min} \simeq [M_N^2 E/(E-\omega) - M_p^2]\omega/E$, where M_p is the proton mass and M_N is the invariant mass of the final state N. For the elastic production, assuming the dipole approximation for proton form factors, $F_M = G_M^2$ and $F_E = (4M_p^2 G_E^2 + Q^2 G_M^2)/(4M_p^2 + Q^2)$, and $G_E^2 = G_M^2/7.78 = (1+Q^2/0.71\mathrm{GeV}^2)^{-4}$. For the inelastic production $F_M = \int \mathrm{d}x F_2/x^3$ and $F_E = \int \mathrm{d}x F_2/x$, where $F_2(x,Q^2)$ is the proton structure function and $x \simeq Q^2/M_N^2$.

Phys. Rev. **D63** (2001) 071502(R)

***Elastic* (or fully exclusive) production + *Inelastic*, when proton dissociates**

LHC as a High Energy γγ Collider



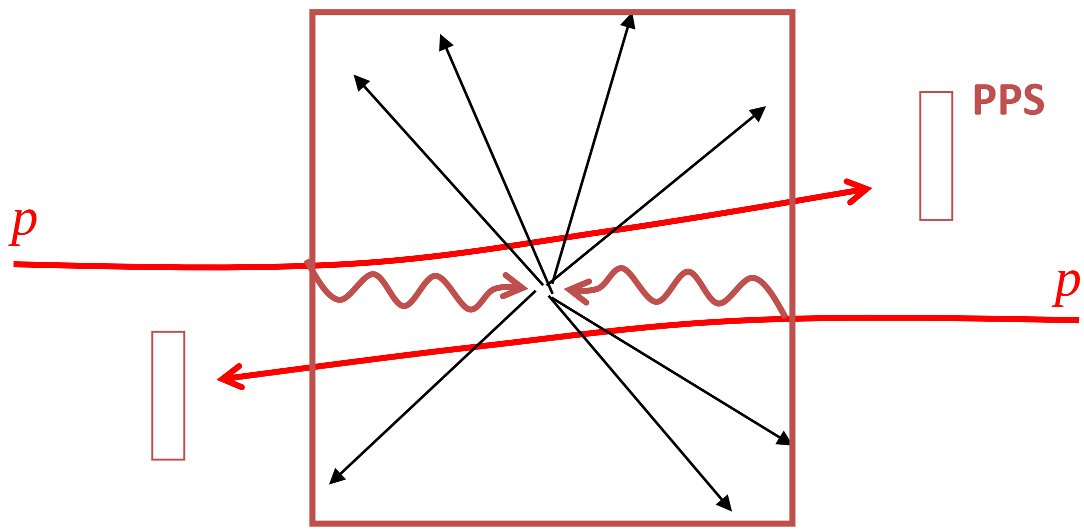
Phys. Rev. **D63** (2001) 071502(R)
hep-ex/0201027

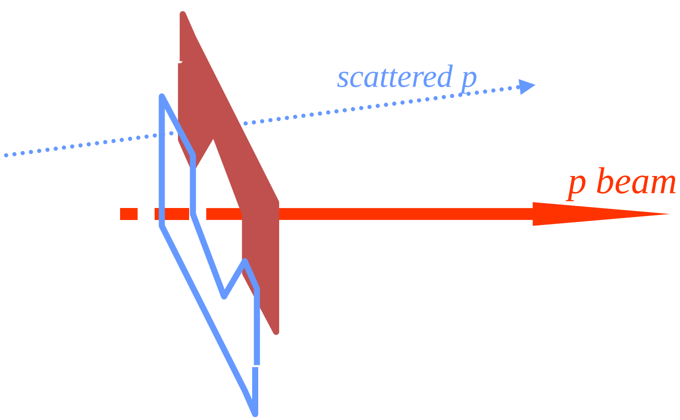
Initial observation:
Provided efficient measurement of very forward-scattered protons one can study high-energy γγ collisions at the LHC

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 high energy γγ (and γp) physics**

How to measure these events?

Measure $(\gamma\gamma \rightarrow) X$ in the **CMS or ATLAS** detector and scattered protons using **very forward detectors** (thanks to proton energy loss)

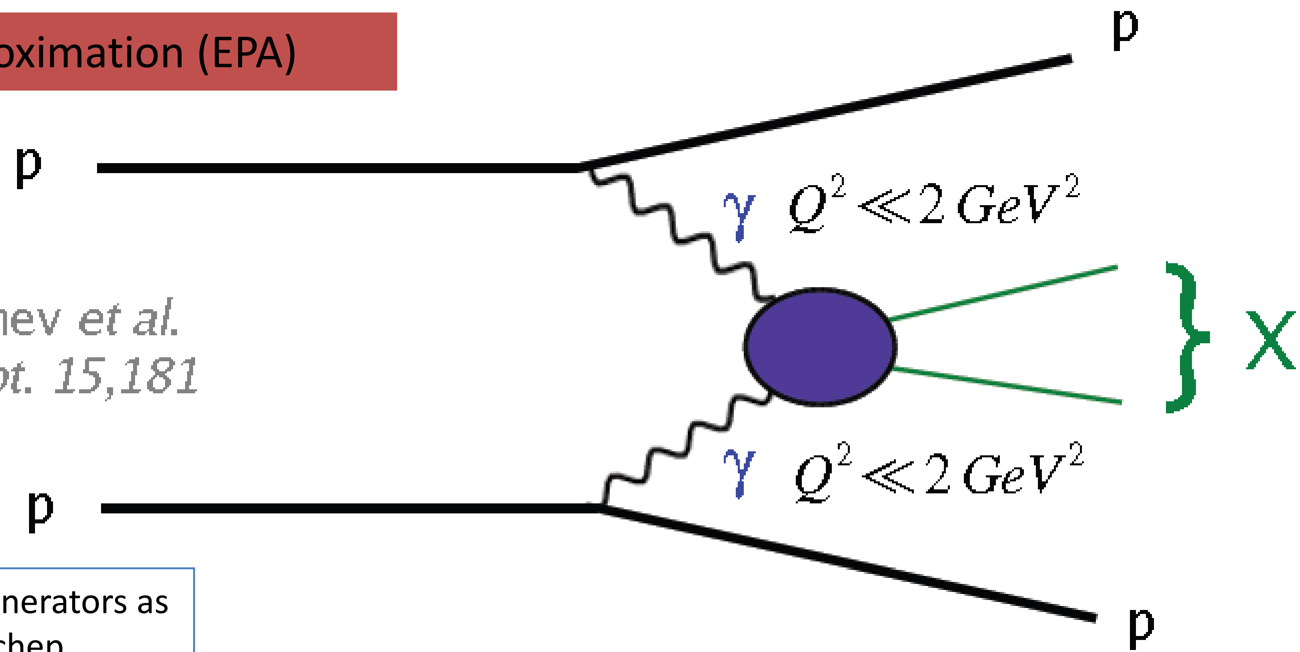




Very forward detectors needed – capable of running at high luminosity, installed as far (> 100 m) from IP and as close to the beam (≥2 mm) as possible – expected photon energy resolution can be of **2–5 GeV !**

LHC as a $\gamma\gamma$ collider

Equivalent photon approximation (EPA)



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

…introduced to major event generators as Madgraph, Pythia, Sherpa, Calchep

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

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

EPA: Kinematics/γγ Luminosity

Virtuality Q^2 of colliding photons vary between kinematical minimum = $M_p^2x^2/(1-x)$ where x is fraction of proton momentum carried by a photon, and Q^2_{max} ~ *1/proton radius²*

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

(*where* $W \equiv M_X$)

Photon flux $\propto 1/Q^2$

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

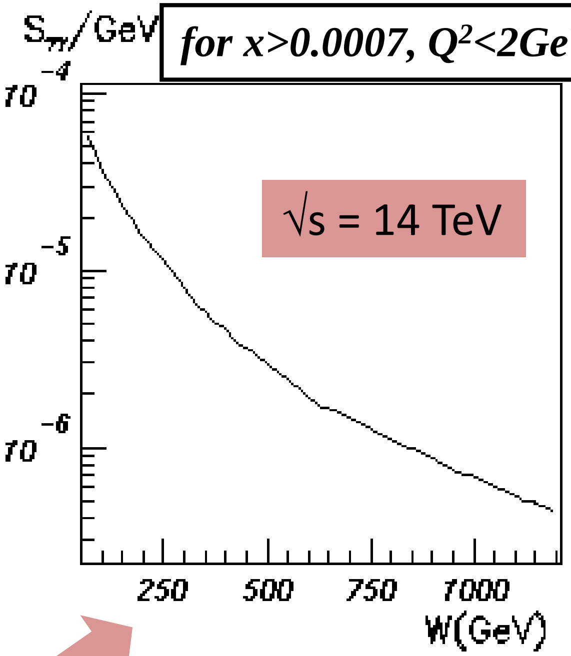
protons scattered at \`zero-degree' angle

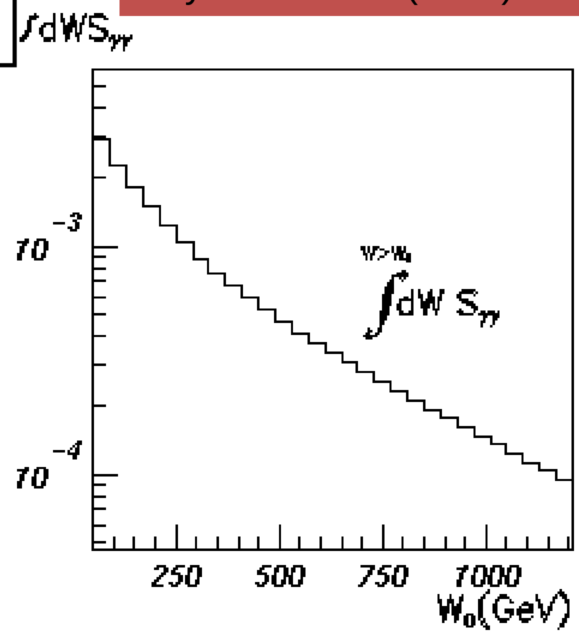
$S_{\gamma\gamma}(W) = N_\gamma(x_1) \otimes N_\gamma(x_2)$

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

Phys. Rev. **D63** (2001) 071502(R)

for $x>0.0007$, $Q^2<2GeV^2$





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

From the TESLA photon collider TDR

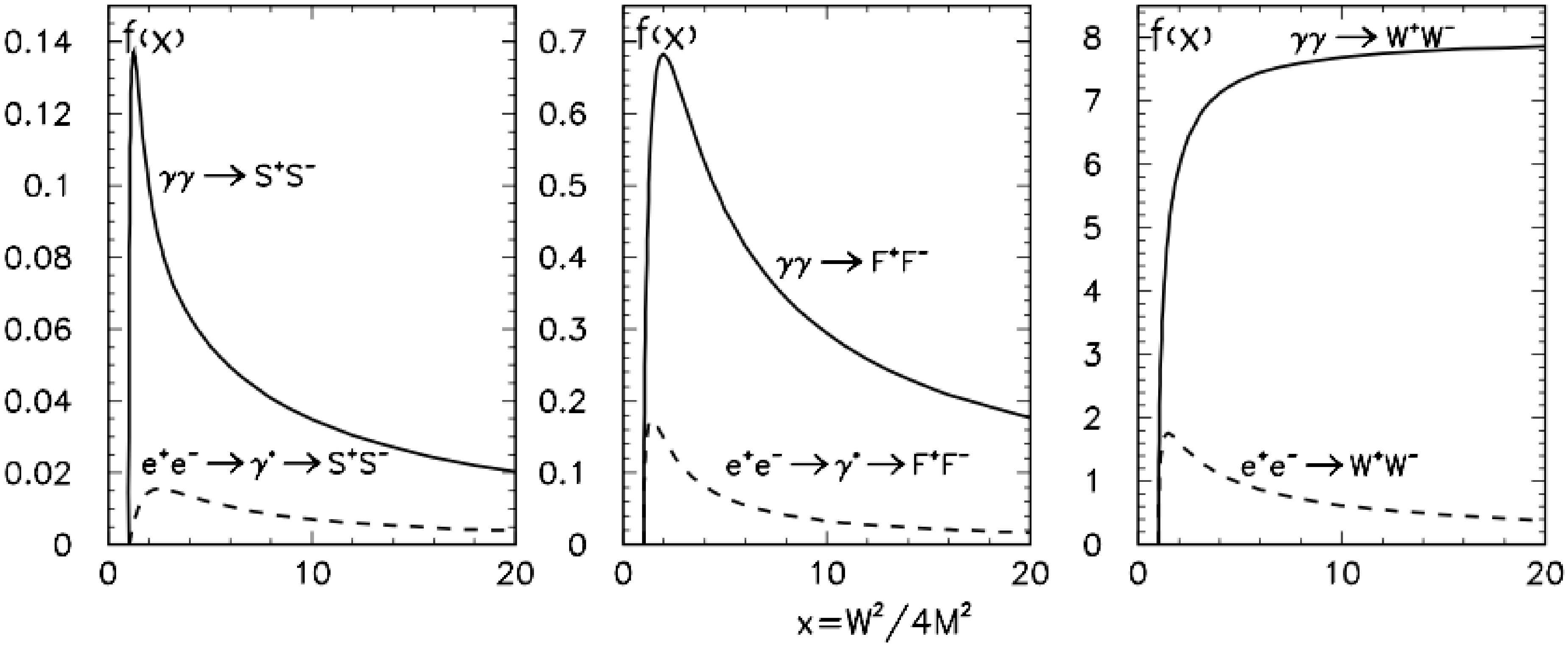


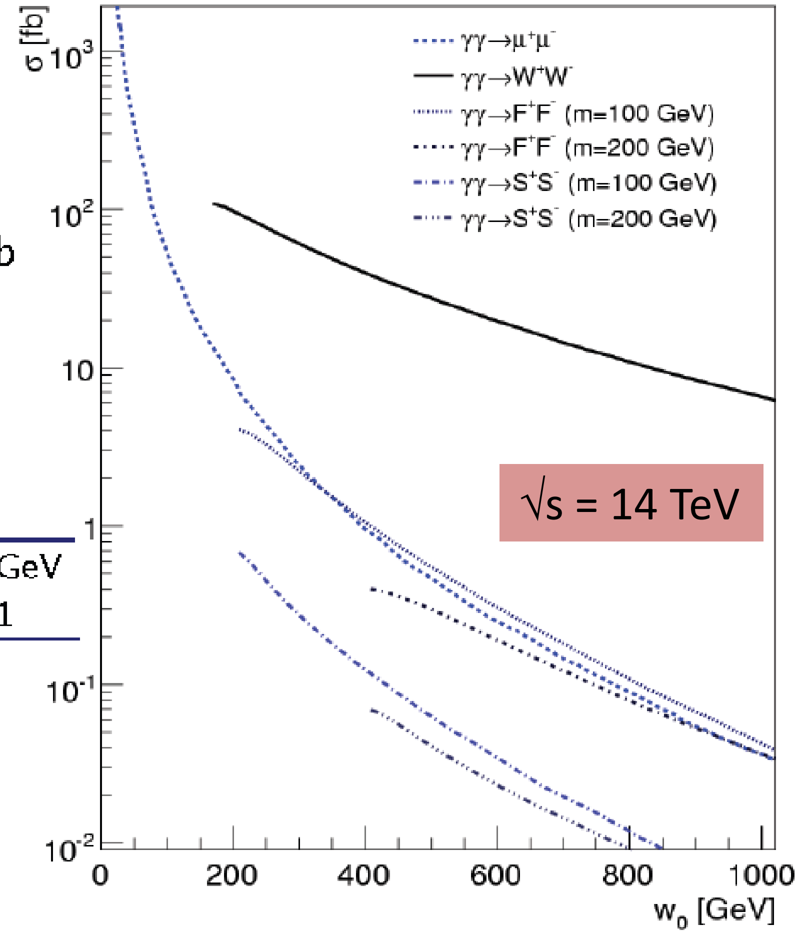
Figure 1.1.3: *Comparison between cross sections for charged pair production in unpolarised e^+e^- and $\gamma\gamma$ collisions. S (scalars), F (fermions), W (W bosons); $\sigma = (\pi\alpha^2/M^2)f(x)$, M is the particle mass, W is the invariant mass (c.m.s. energy of colliding beams), $f(x)$ are shown. Contribution of Z boson for production of S and F in e^+e^- collisions was not taken into account, it is less than 10%*

LHC as a $\gamma\gamma$ collider

arXiv:0908.2020

- $\gamma\gamma \to \mu\mu$ 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

LHC as a $\gamma\gamma$ collider

Two-photon exclusive pair production cross-section is given just by:

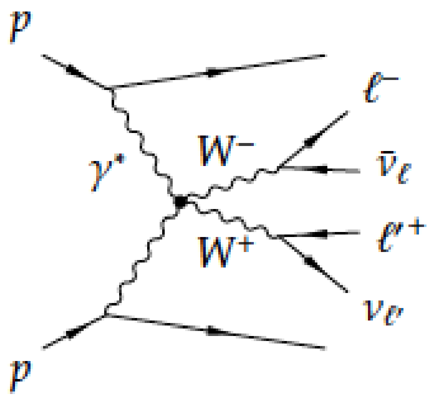
- particle charge, mass and spin

for a given mass and charge it is largest for vector particles , then for fermions

$\gamma\gamma \rightarrow$ WW pair production has very sizable cross-section at the LHC of $\sim$100 fb (and x 4 if inelastic production included)!

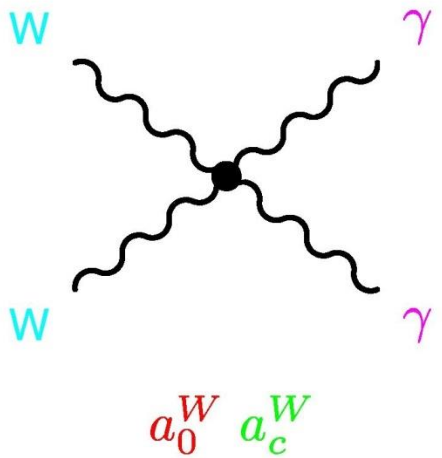
Massive fermions have sizable $\gamma\gamma$ cross-sections up to about 200 GeV masses, for scalars cross-sections are about 5 times smaller (but there is H^{++} case, for example)

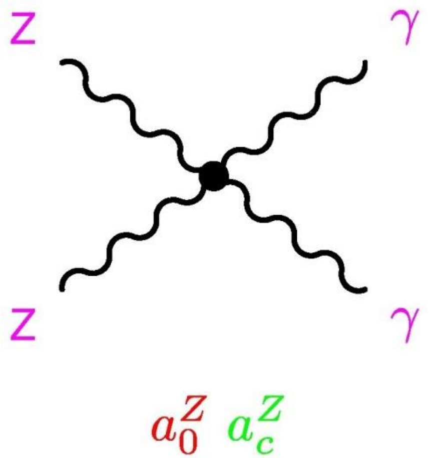
Physics with $\gamma\gamma \to$ WW (and ZZ)

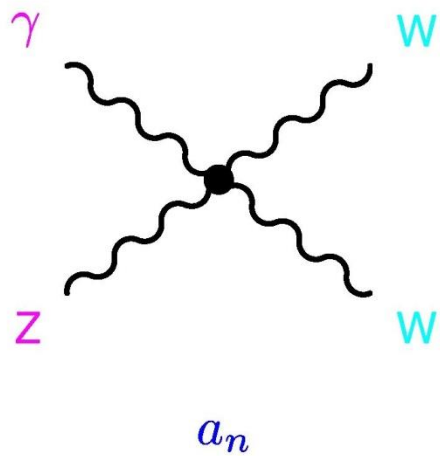


$\gamma\gamma \to$ WW and ZZ (=0 at tree level in SM) pairs as a powerful test bench for the gauge boson sector at the LHC

Search for anomalous quartic couplings







$$\gamma\gamma \rightarrow WW \rightarrow \mu e \nu\nu$$

Hot news in 2013…

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERNCOURIER
VOLUME 53 NUMBER 6 JULY/AUGUST 2013

LHC PHYSICS

CMS sees first direct evidence for $\gamma\gamma \to WW$

In a small fraction of proton collisions at the LHC, the two colliding protons interact only electromagnetically, radiating high-energy photons that subsequently interact or "fuse" to produce a pair of heavy charged particles. Fully exclusive production of such pairs takes place when quasi-real photons are emitted coherently by the protons rather than by their quarks, which survive the interaction. The ability to select such events opens up the exciting possibility of transforming the LHC into a high-energy photon–photon collider and of performing complementary or unique studies of the Standard Model and its possible extensions.

The CMS collaboration has made use of this opportunity by employing a novel method to select "exclusive" events based only on tracking information. The selection is made by requesting that two – and only two – tracks originate from a candidate vertex for the exclusive two-photon production. The power of this method, which was first developed for the pioneering measurement of exclusive production of muon and electron pairs, lies in its effectiveness even in difficult high-luminosity conditions with large event pile-up at the LHC.

The collaboration has recently used this approach to analyse the full data sample collected at $\sqrt{s}$=7 TeV and to obtain the first direct evidence of the $\gamma\gamma \to WW$ process. Fully leptonic W-boson decays have been measured in final states characterized by opposite-sign and opposite-flavour lepton pairs where one W decays into an electron and a neutrino, the other into a muon and a neutrino (both neutrinos leave undetected). The leptons were required to have: transverse momenta p_T>20 GeV/c and pseudorapidity $|\eta|$<2.1; no extra track associated with their vertex; and for the pair, a total p_T>30 GeV/c. After applying all selection criteria, only two events remained – compared with an expectation of 3.2 events: 2.2 from $\gamma\gamma \to WW$ and 1 from background (figure 2).

The lack of events observed at large values of transverse momentum for the pair, which would be expected within the Standard Model, allows stringent limits on anomalous quartic $\gamma\gamma WW$ couplings to be derived. These surpass the previous best limits, set at the Large Electron–Positron collider and at the Tevatron, by up to two orders of magnitude (figure 3).

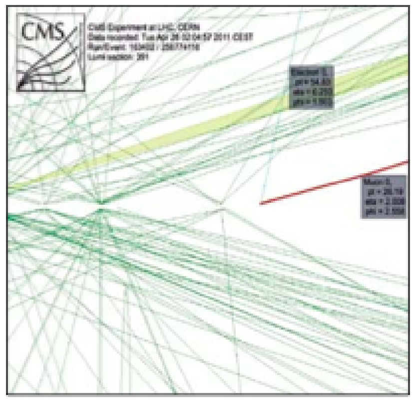


Fig. 1. Above: Proton–proton collisions recorded by CMS at $\sqrt{s}$=7 TeV, featuring candidates for the exclusive two-photon production of a W^+W^- pair, where one W boson has decayed into an electron and a neutrino, the other into a muon and a neutrino.

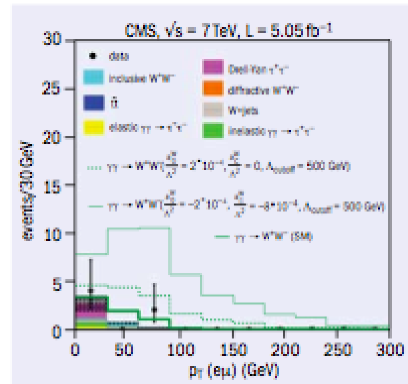


Fig. 2. Top right: The p_T distribution of eμ pairs in events with no extra tracks compared with the Standard Model expectation (thick green line) and predictions for anomalous quartic gauge couplings (dashed green histograms).

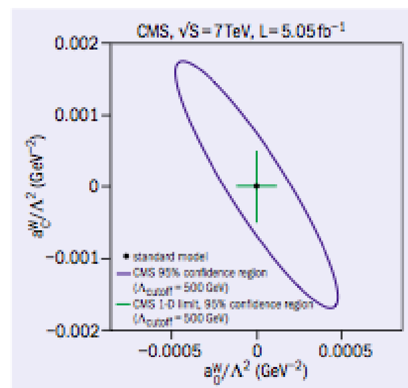


Fig. 3. Right: Limits on anomalous quartic $\gamma\gamma WW$ couplings.

● **Further reading**

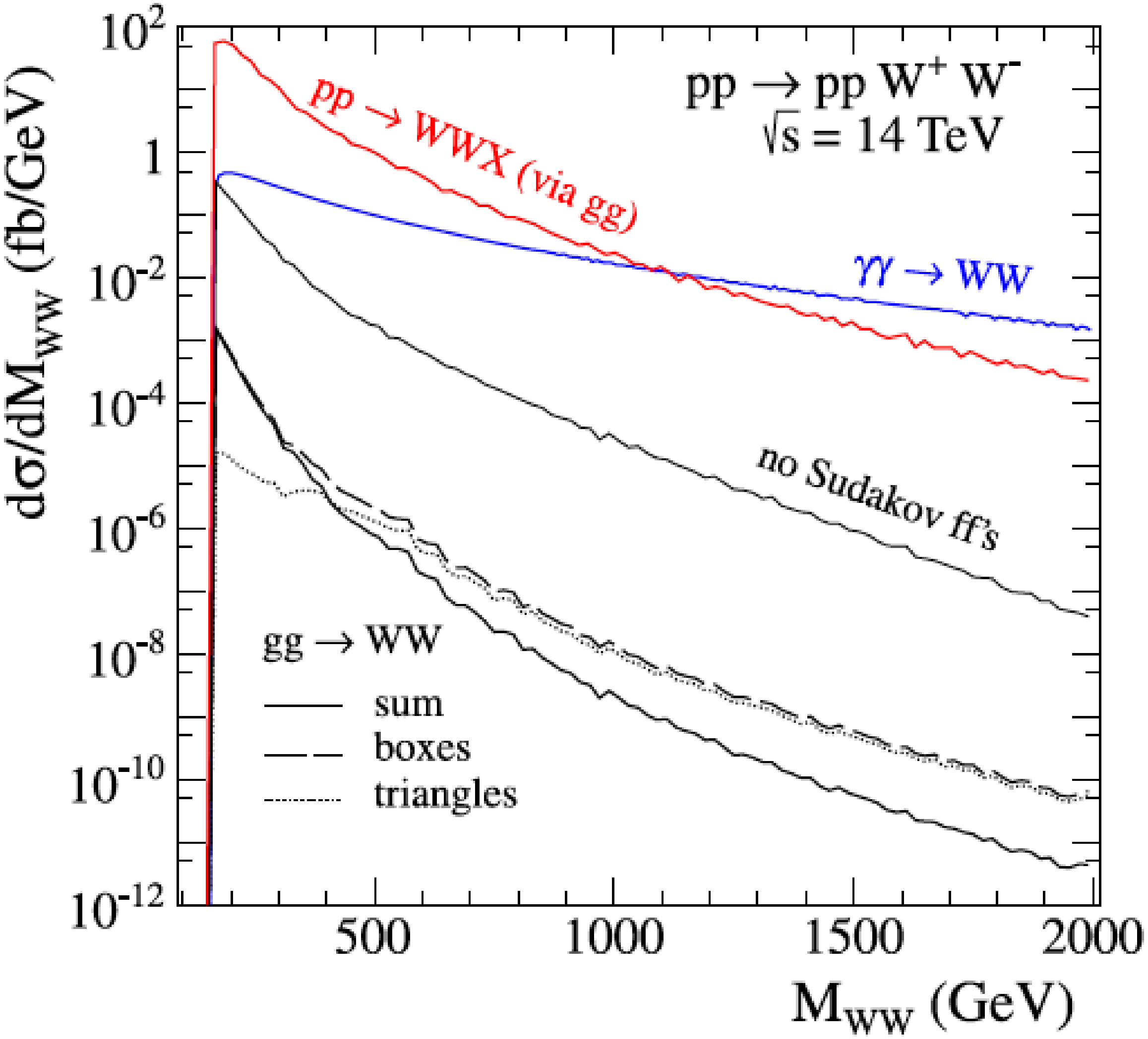
CMS collaboration 2013 arXiv:1305.5596 [hep-ex], submitted to *JHEP*.

Part II

What are new avenues in the near future?

(Thanks to “photon-tagging”, i.e. detection of forward-scattered protons)

WW pair production @ LHC



At very high energy γγ wins over 'inclusive' production !!

Nucl. Phys. B ***867*** *(2013) 61*

Untagged data vs rescattering

- The *untagged* photon-photon interactions (+ studies of new interesting channels as $\gamma\gamma \to ZZ$) can be studied at yet higher energies

- The major systematic error comes from estimation of (**inevitable** at highest $\gamma\gamma$ energies) *rescattering* (absorptive) corrections – there are **no models available**, even for the calibration candle: $\gamma\gamma \to \mu\mu$
  (another issue is modelling proper $2 \to 4$ kinematics)

- Adding roman pot detectors allow not only *tagging* photon interactions and measurement of $\gamma\gamma$ energy W but also **direct** measurement of the single-dissociation $pp \to p\, l^+ l^- N$ where the dissociative mass M_N is **reconstructed**:

will $d\sigma/dM_N$ be measured?

Untagged lepton pairs

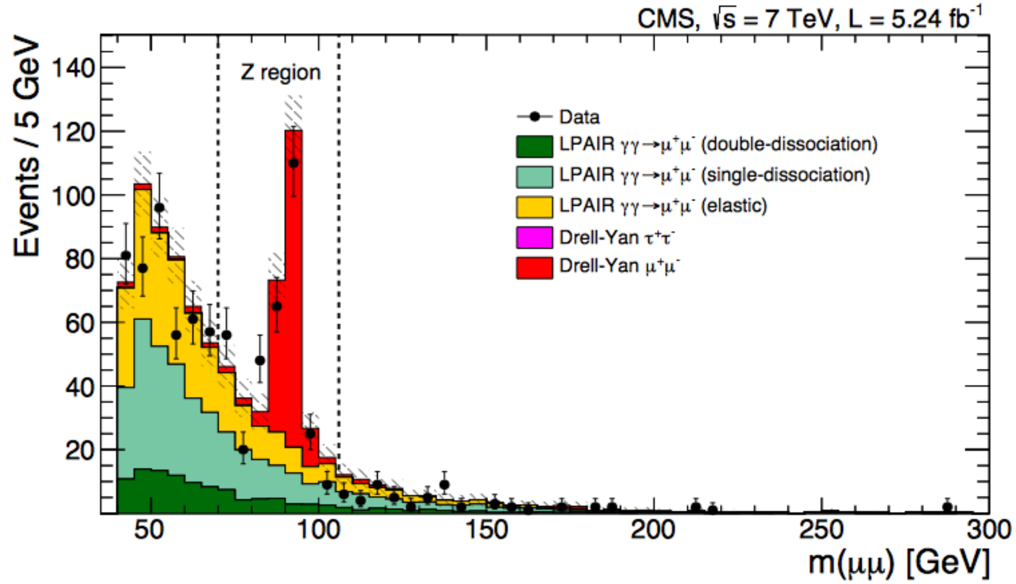
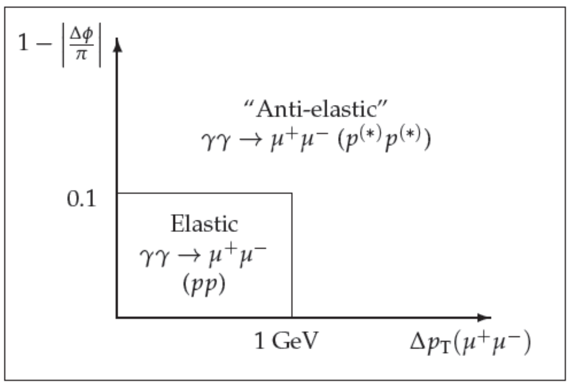


Figure 3: Invariant mass distribution of the muon pairs for the elastic selection with no additional track on the dimuon vertex. The dashed lines indicate the Z-peak region. The hatched bands indicate the statistical uncertainty in the simulation.



Still lack **ANY** MC model describing rescattering !!

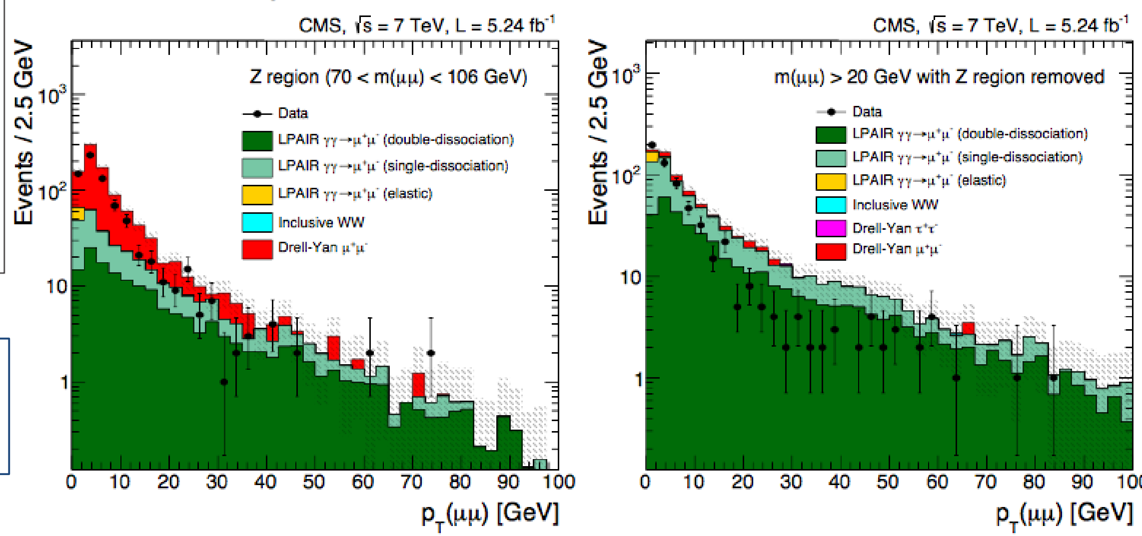
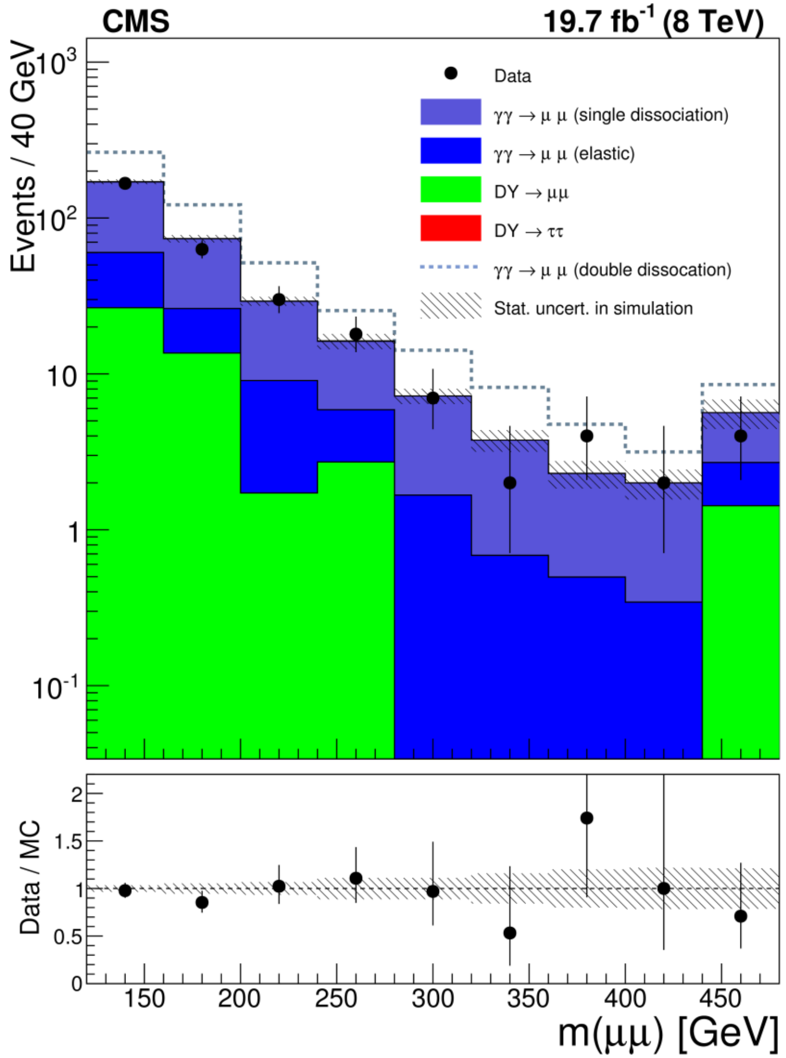
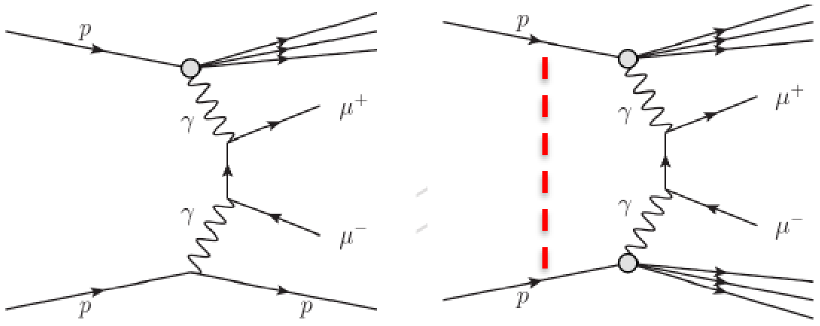


Figure 6: Transverse momentum distribution for $\mu^+\mu^-$ pairs with zero extra tracks passing the dissociation selection, for the Z region only (left), and with the Z region removed (right). The hatched bands indicate the statistical uncertainty in the simulation.

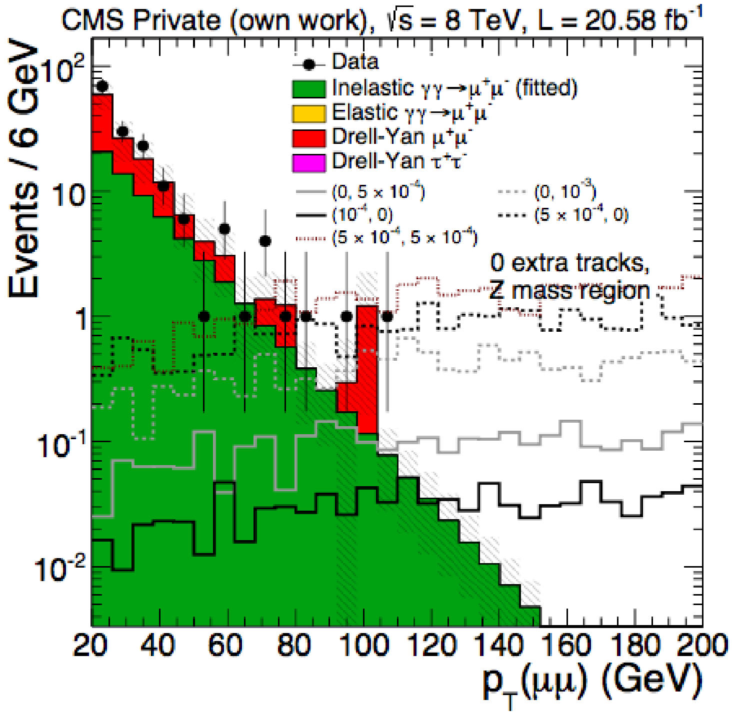
γγ lepton pairs @ 8 TeV

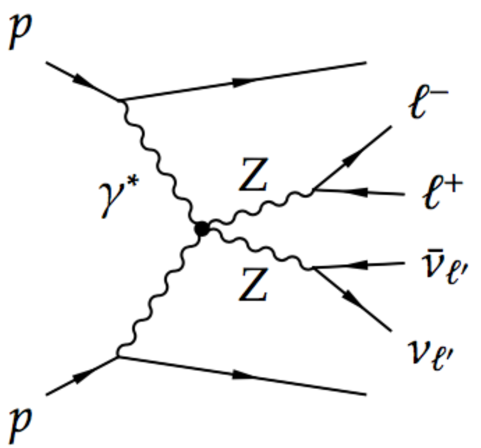




Untagged data showed **a very strong suppression of double dissociative events** and not (yet) visible rescattering effects for single dissociation

γγZZ studies @ 8 TeV





L. Forthomme
UCLouvain thesis Feb 2016

Figure 3.25: Dilepton transverse momentum distribution inside the Z mass region. The main background sources are given by the stacked histograms, with the dissociative $\gamma\gamma \rightarrow \ell^+\ell^-$ contribution as extracted from the sideband fits described in the text.

Tagging two-photon production

- *Double tagging* (= both protons detected) gives very clean, pure elastic only sample but at (large) cost of statistics due to much lower photon fluxes and tagging inefficiencies:

  - one needs to include also semi-leptonic WW decays where one gains not only statistics (thanks to BF) but also over-constrained kinematics reconstruction allowing fully differential studies (as discussed by O. Nachtmann *et al*.)

- At not too high event pileup ***single tagging*** of semi-leptonic events WW $\rightarrow$ e/μ + ν + jj should be possible, allowing to recover back full photon fluxes and higher efficiencies, but better MC simulation is then compulsory:

  - one needs full 2 $\rightarrow$ 4 kinematics in WW MC (as in LPAIR for $\mu\mu$)

Side remark: high energy $\gamma\gamma$ physics in ion collisions at the LHC

To profit from Z^4 enhancement in two-photon interactions one has to fulfill *coherence condition*: $xM < 1/(2R)$, where M and R are the ion mass and radius, respectively.

• Using empirical parameterization of R = 1.25 fm $A^{1/3}$ one gets $1/(2R)$ equal to 48 and 20 MeV for oxygen (A=16) and lead (A=208) respectively; this leads to the following coherence conditions:

$x < 0.0032$ for **oxygen** ions (56 TeV beams, $E_\gamma < 180$ GeV)

$x < 0.0001$ for **lead** ions (574 TeV beams, $E_\gamma < 57$ GeV)

Note:
Proton-ion collisions lead to (much) higher energy $\gamma\gamma$ collisions + possibility to tag "proton-photons" (not possible for "ion-photons")

Summary

- Recent 13 TeV data will extend sensitivities for the *untagged* photon-photon interactions + studies of new interesting channels as $\gamma\gamma \rightarrow$ ZZ

- Adding roman pot detectors to allow *tagging* photon interaction greatly enhance physics programme (apart from allowing to do this physics at very high LHC luminosity with enormous event pileup):

  - *Selection of fully exclusive (=elastic) events*

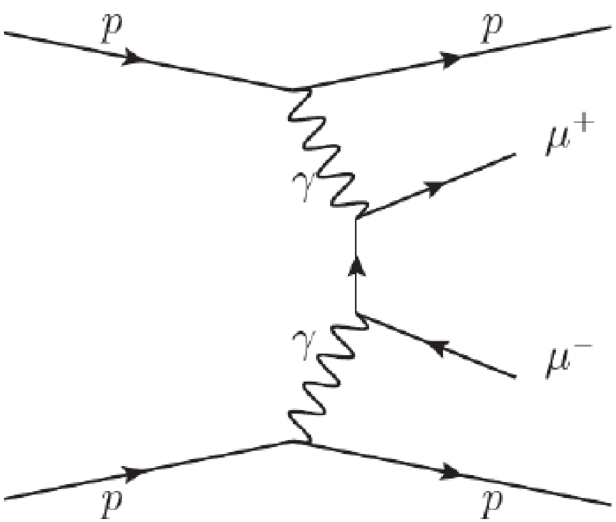
  - *Studies of semi-leptonic WW events (large p_T $e/\mu + jj$)*

  - *Direct separation of fully-elastic and semi-elastic $\gamma\gamma \rightarrow ll$*

Extra slides

Exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$

The first measurement focus on the dimuon channel – standard candle:



* ***Pure QED process:***

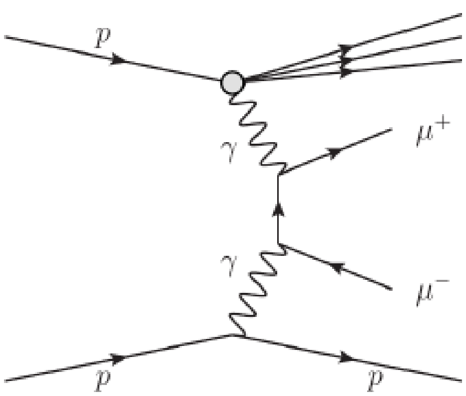
- No PDF to account for
- Small theoretical uncertainties

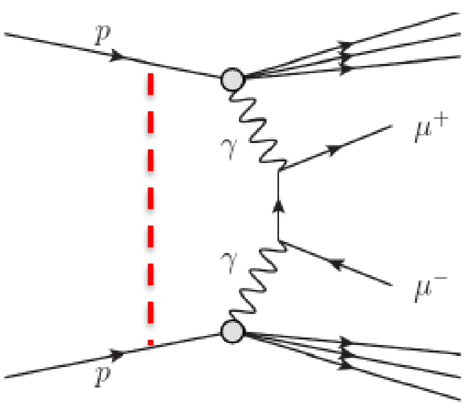
* ***Striking kinematic distributions:***

- due to very small virtuality of the exchanged photons

* measured in previous experiments to be in agreement with the ME ***LPAIR generator***

• Largest background arises from *semi-exclusive* **two-photon** production due to single and double proton dissociative (or inelastic) photon exchange:





Tagging two-photon events

Assume detector stations at ~220 m where approximately $x > 0.01$ range accessible

Note: If only one forward p detected – single tag, but then non-elastic, p dissociative photon emission is possible

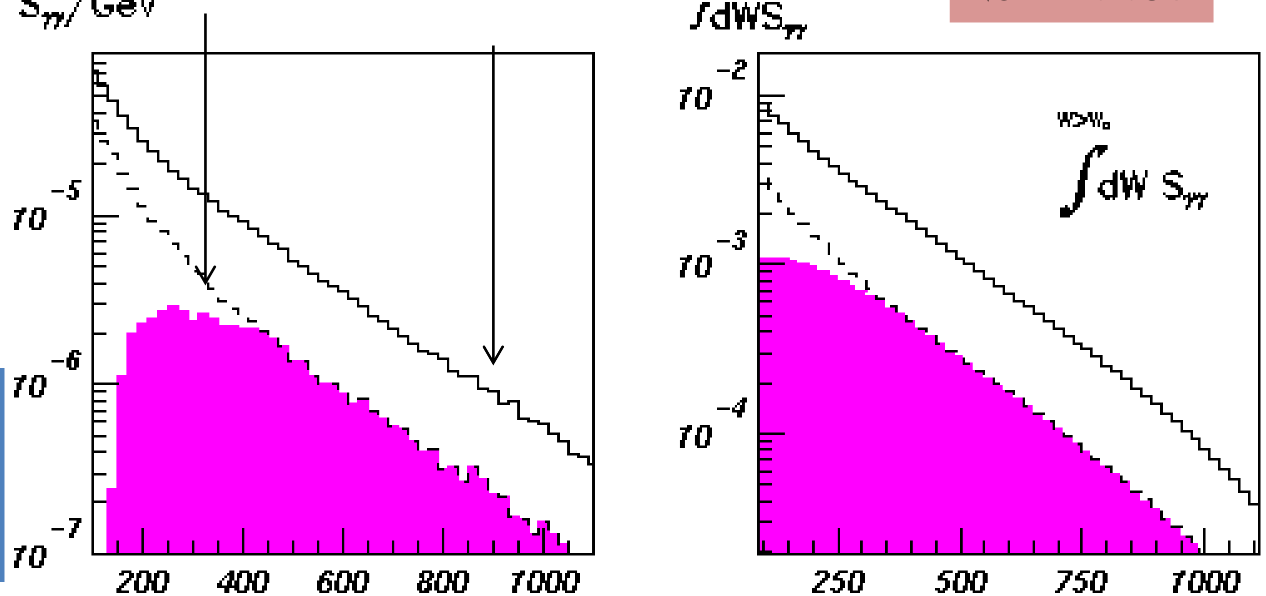
Assume 0.1>x>0.01, and Q²<2 GeV² and for dissociative mass M_N < 20 GeV

$$S_{\gamma\gamma}(W) = N_\gamma(x_1) \otimes N_\gamma(x_2)$$

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

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

√s = 14 TeV

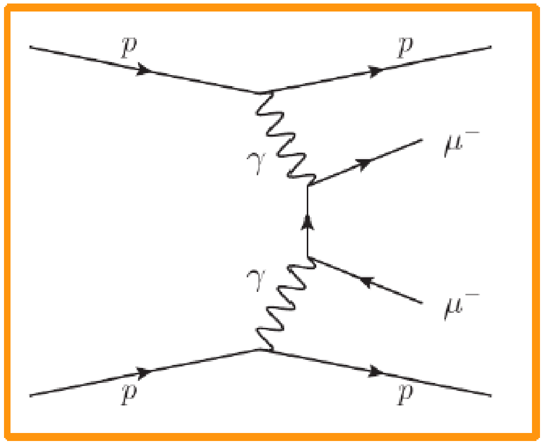


GeV

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

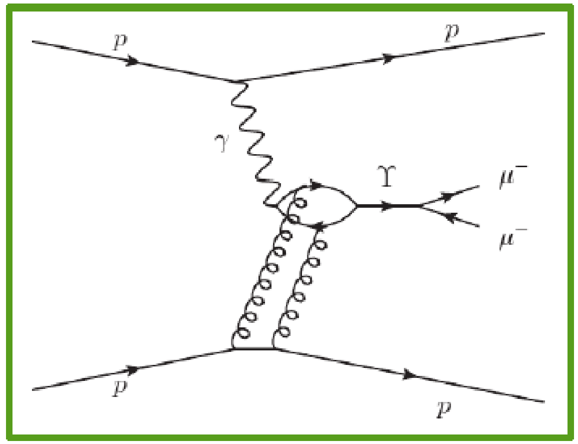
Exclusive physics @ LHC

Two-photon production



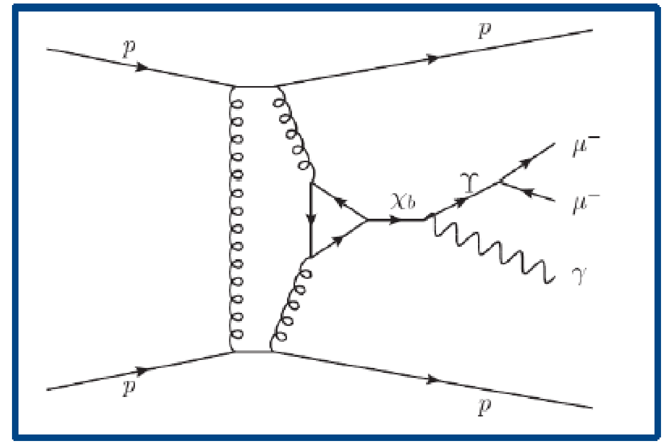
$\mu^+\mu^-$, e^+e^-, $\pi^+\pi^-$
W^+W^-, H^+H^-, $\tilde{l}^+\tilde{l}^-$, ...

Photo-production



ρ, J/Ψ, Υ, Z, ...

Central Exclusive Production

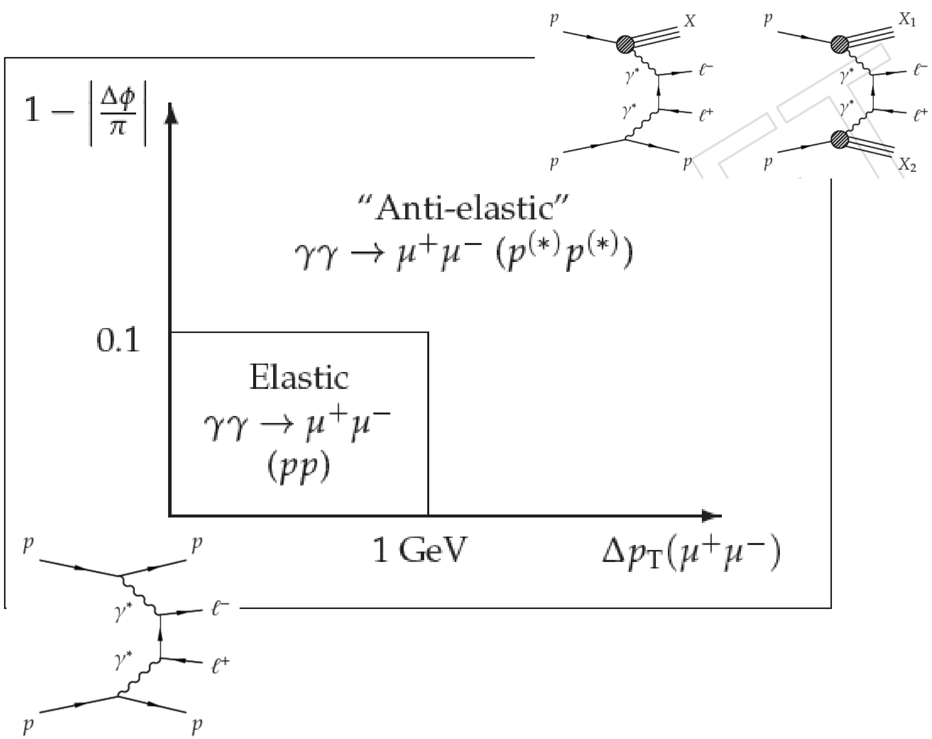


χ_c, χ_b, $\pi^+\pi^-$, dijets, γγ,
Higgs, ...

→ Early analysis: studying SM physics by imposing exclusivity conditions on the central system of CMS

→ Near Future: SM/BSM physics by detecting (both) forward scattered protons with the proposed ’Proton Precision Spectrometer' (PPS) detectors

$\mu\mu$ calibration candle

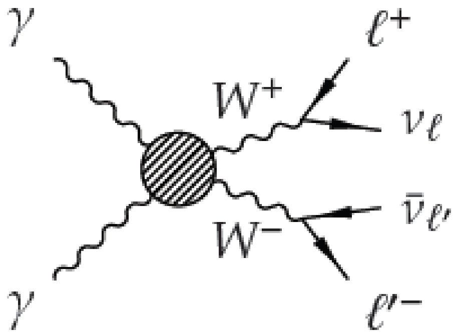


- Use Δp_T and $|1-\Delta\phi/\pi|$ to select regions enriched in elastic or inelastic events
  - Same cuts as used for 2010 $\gamma\gamma\to\mu\mu$ cross-section paper

- Also separate *Z* peak region (76-105GeV) to check modeling of Drell-Yan
  - $\gamma\gamma\to Z$ is suppressed at tree-level , exclusive Z is expected to be <1fb including branching fraction

Notation

- Fully exclusive (or "elastic"): events in which both protons stay intact
  - Theoretically clean QED-like production
- Quasi-exclusive (or "inelastic" or "proton dissociation"): events in which one or both protons fragment into an undetected low-mass system $p^{(*)}$
  - Larger uncertainties, possible rescattering corrections
- Cannot separate the two contributions in a counting experiment, therefore signal is defined to include both:



$$pp \to p^{(*)}W^+W^-p^{(*)}$$

Lagrangian for aQGCs

arXiv:0908.2020

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

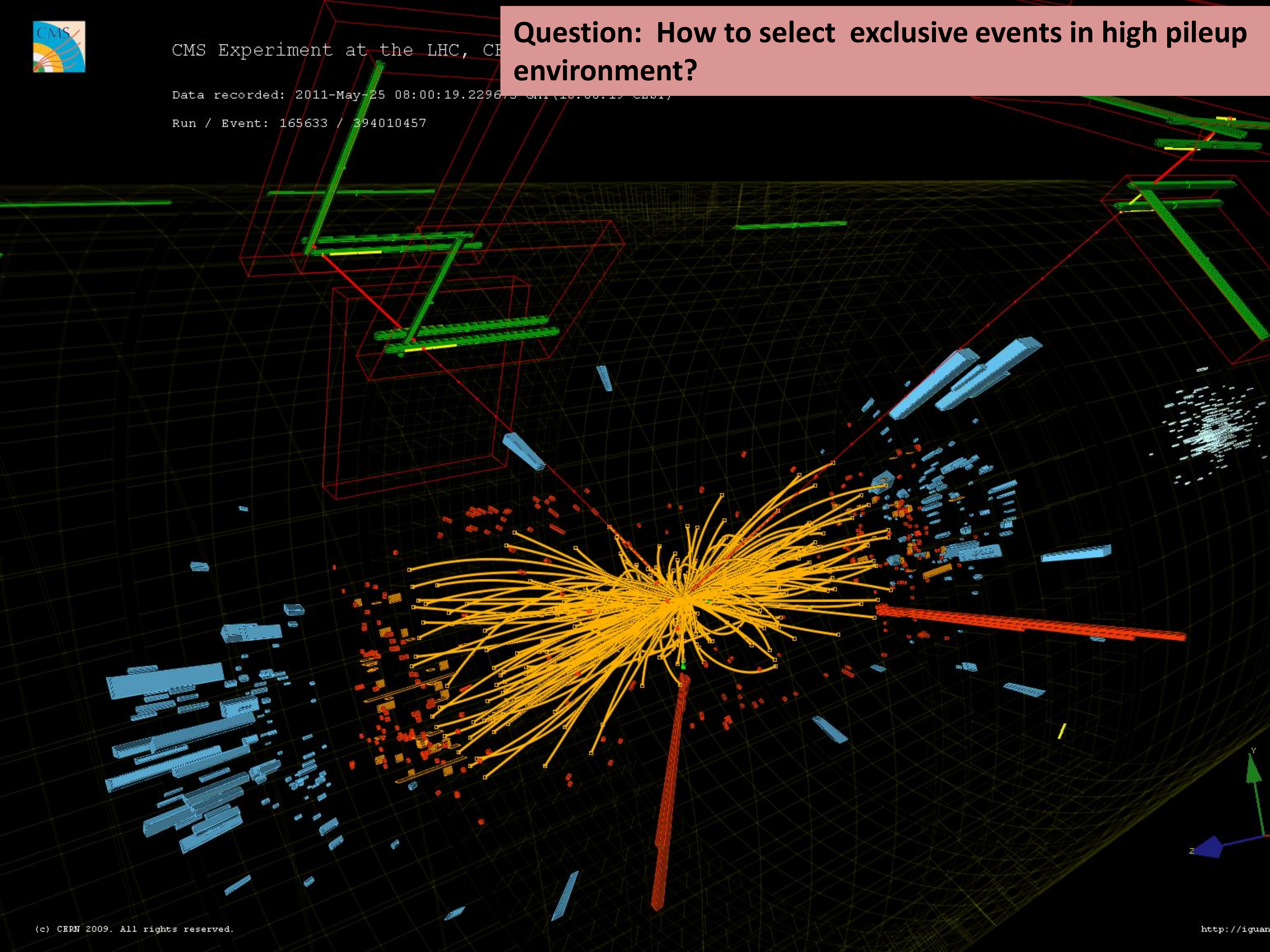
$$L_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha - \frac{e^2}{16\cos^2\Theta_W}\frac{a_0^Z}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}Z^\alpha Z_\alpha$$

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

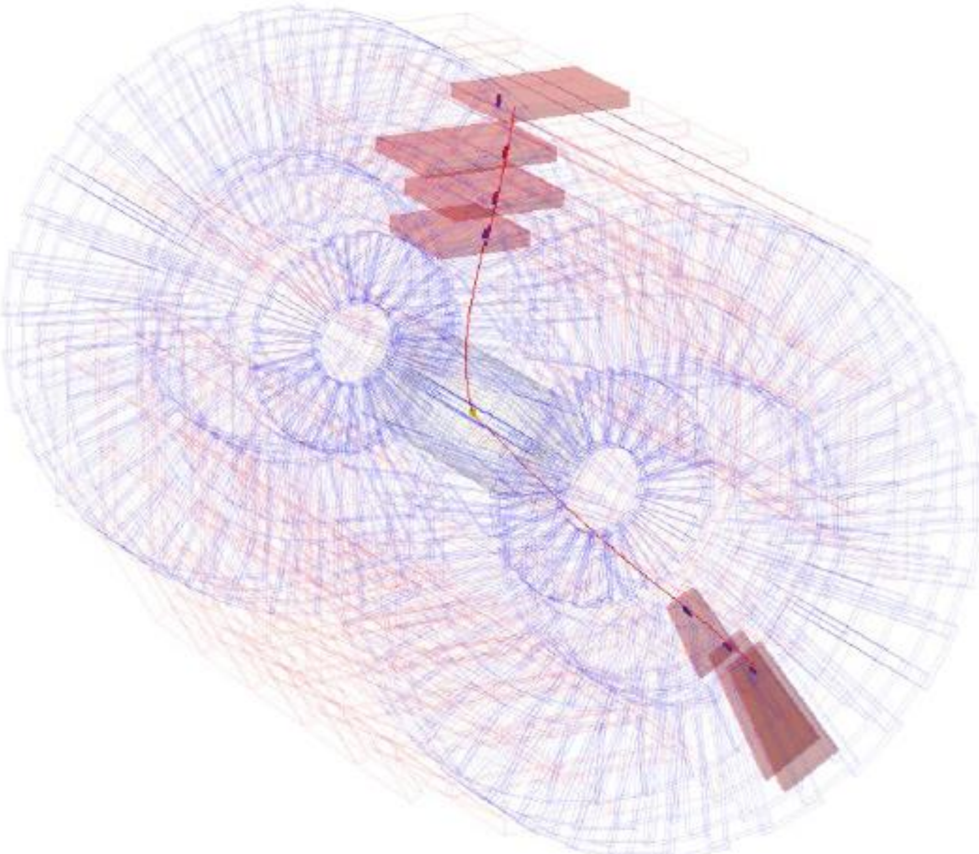
This gives a general auxiliary formula for a cross section (total or differential, with or without cuts) as a function of the anomalous parameters:

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

Question: How to select exclusive events in high pileup environment?



Exclusivity conditions



In initial (very) low luminosity era:
2 muons and "nothing else"
in the tracker **and** calorimeters

In 2010, each event of interest was accompanied by extra "PileUp" events within the same bunch crossing:
~ 2-3 pileup interactions

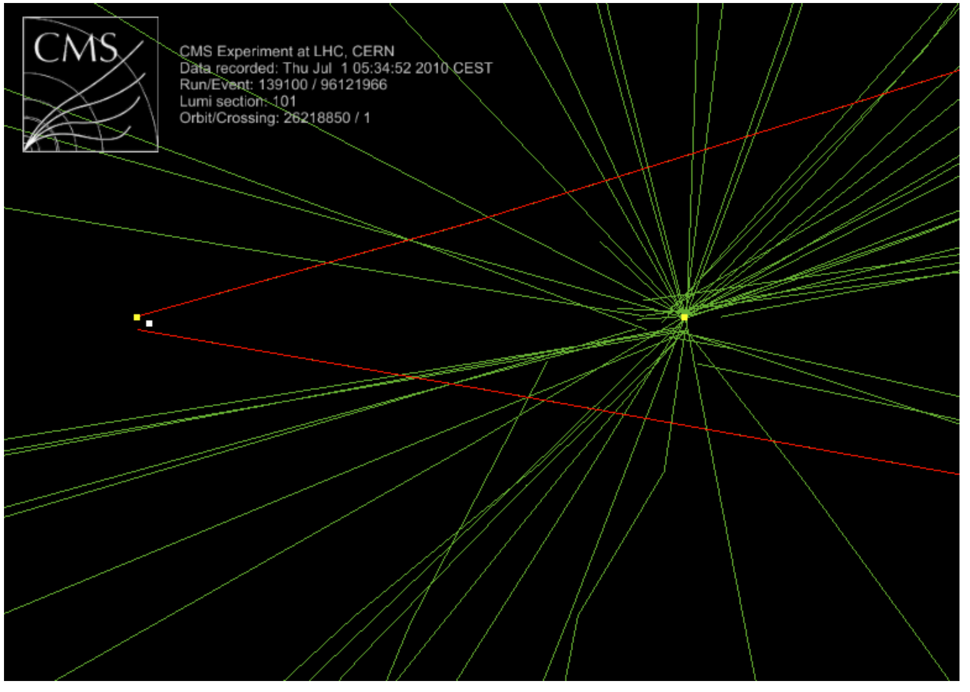
In 2011, roughly 7-10 PU per crossing

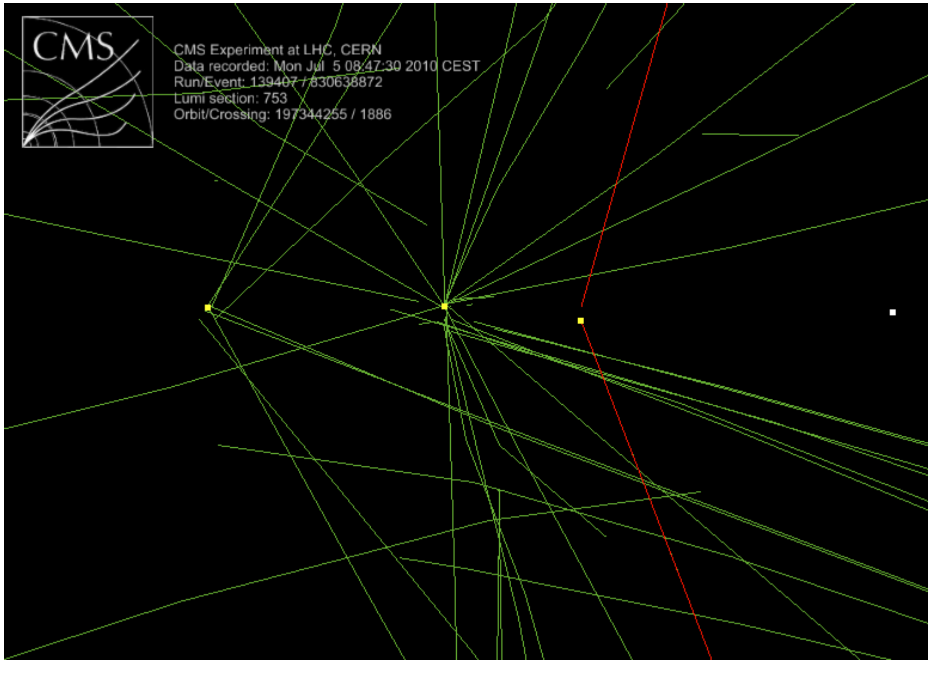
In 2012, PU =25 put the method to a very limit…

Restricting the analysis to single interactions only would have reduced the data sample a very small fraction of the total → **impose exclusivity using tracking only**

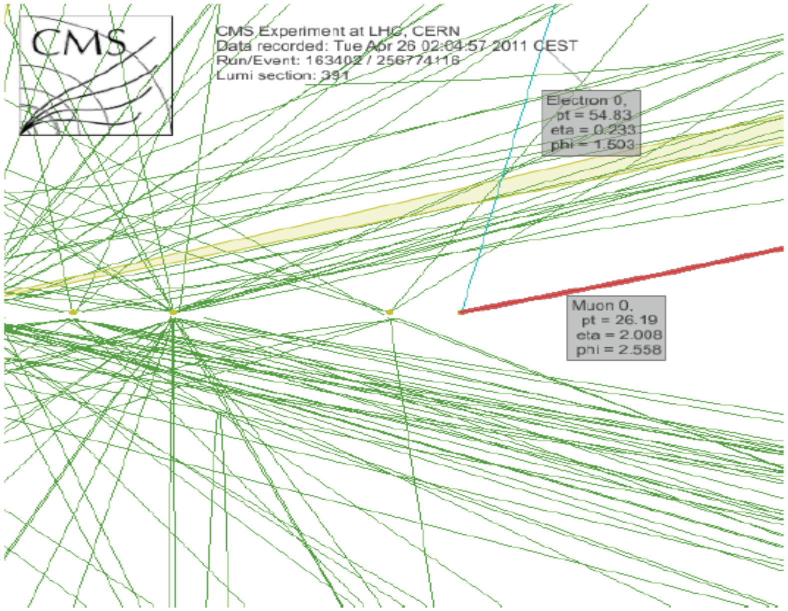
Question: How to select exclusive events in high pileup environment?

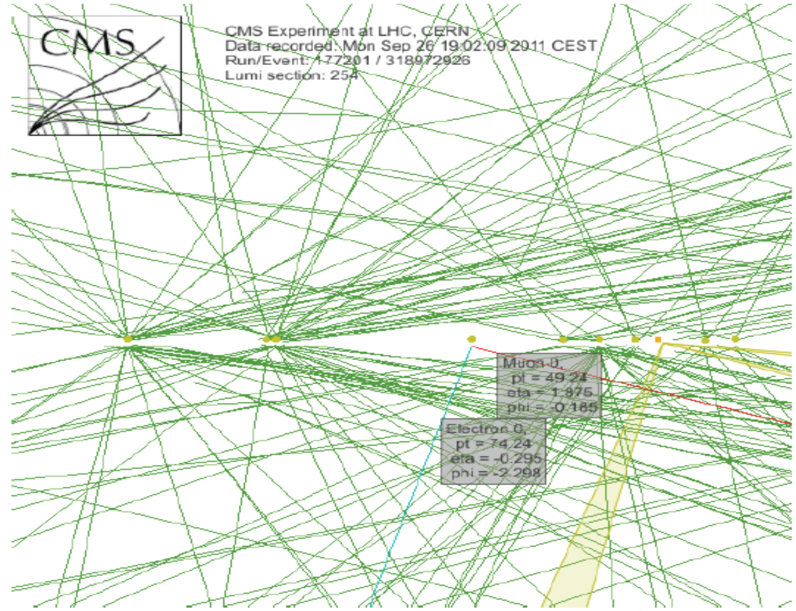
Answer: Use tracking only and zoom in onto the vertices!





SM Signal candidates





Variable	Event 1	Event 2
Run	163402	177201
LumiSection	391	254
Event number	256774116	318972926
$m(\mu^{\pm}e^{\mp})$ [GeV]	85.5	190.3
$1 - \lvert\Delta\phi(\mu^{\pm}e^{\mp})/\pi\rvert$	0.66	0.33
$p_{\mathrm{T}}(\mu^{\pm})$ [GeV]	26.2	49.2
$E_{\mathrm{T}}(e^{\pm})$ [GeV]	54.8	74.2
$\eta(\mu^{\pm})$	2.01	1.88
$\eta(e^{\pm})$	0.23	-0.30

- Event displays and single/double lepton information for the two selected events

Photon physics with « roman » pots…

Compact Muon Solenoid experiment at CERN's LHC

PUBLIC WEBSITE

CMS People | Detector | Physics | Education and Outreach

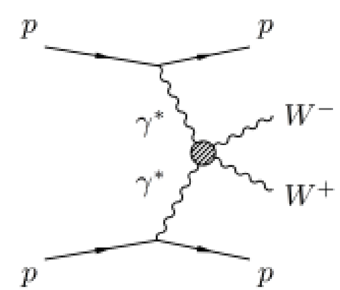
CERN › CMS Experiment › The LHC as a photon collider

The LHC as a photon collider

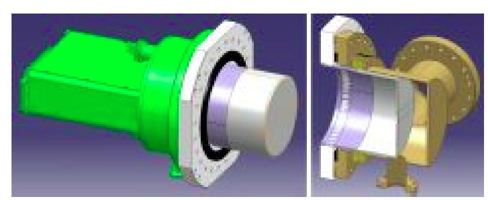
Yes, that's correct: *photon* collider.

The Large Hadron Collider is known for smashing together protons. The energy from these collisions gets converted into matter, producing new particles that allow us to explore the nature of our Universe. The protons are not fired at one another individually; instead, they are circulated in bunches inside the LHC, each bunch containing some 100 billion (100,000,000,000) particles. When two bunches cross each other in the centre of CMS, a few of the protons — around 25 or so — will collide with one another. The rest of the protons continue flying through the LHC unimpeded until the next time two bunches cross.

Sometimes, something very different happens. As they fly through the LHC, the accelerating protons radiate photons, the quanta of light. If two protons going in opposite directions fly very close to one another within CMS, photons radiated from each can collide together and produce new particles, just as in proton collisions. The two parent protons remain completely intact but recoil as a result of this photon-photon interaction: they get slightly deflected from their original paths but continue circulating in the LHC. We can determine whether the photon interactions took place by identifying these deflected protons, thus effectively treating the LHC as a photon collider and adding a new probe to our toolkit for exploring fundamental physics.



Quartic gauge coupling: A Feynman diagram showing how protons radiate photons that then interact and produce W bosons.



Drawings of the cylindrical detector housing for the new Roman Pots designed to accommodate timing detectors

AQGCs

- The anomalous couplings in the $\gamma\gamma \to W^+W^-$, can be introduced with the following effective Lagrangians
- Local $U(1)_{em}$ and global $SU(2)_c$ invariance imposed; these are genuine quartic couplings <u>independent</u> of the gauge ones (a la LEP):

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

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

- Where Λ is the scale for new physics, which is set in this analysis to 500 GeV

EPA and absorption corrections

EPA assumes **full** factorization of the long range (-> photon fluxes) and short range (-> $\gamma\gamma$ fusion) physics; values of the impact parameter b are the best check of a regime one works with – they are different for the proton elastic and dissociative cases, though the flux **b** dependence is similar, $dn \propto bdb$.

If one takes the 8 TeV beam and x=0.01 (corresponding to W=160 GeV) than:

Elastic: $b_{max} \approx 20$ fm and $b_{min} \approx 0.6$ fm

Inelastic (dissociative): typ. $b_{max} \approx 0.1$ fm and $b_{min} \approx 0.01$ fm

For two-photon exchange one deals with two impact parameters, so one can approximate $b \approx b_1 + b_2$

EPA and absorption corrections

For two-photon exchange one deals with two impact parameters, hence one can approximate $b \approx b_1 + b_2$

Therefore, relatively small absorption are expected both for fully exclusive (elastic-elastic) as well as single dissociative SD (2x elastic-inelastic) and **BIG** one for DD case (inelastic-inelastic)

Three important comments regarding two-photon lepton pair production:

- Lepton acoplanarity is a good measure of the relevant impact parameters involved; if there is significant absorption it must distort the acoplanarity
- Absorption should increase with increase of W (since b_{max} decreases)
- Fully exclusive pairs die fast with increasing pair pT; so above 1 GeV/c one is left with SD+DD only

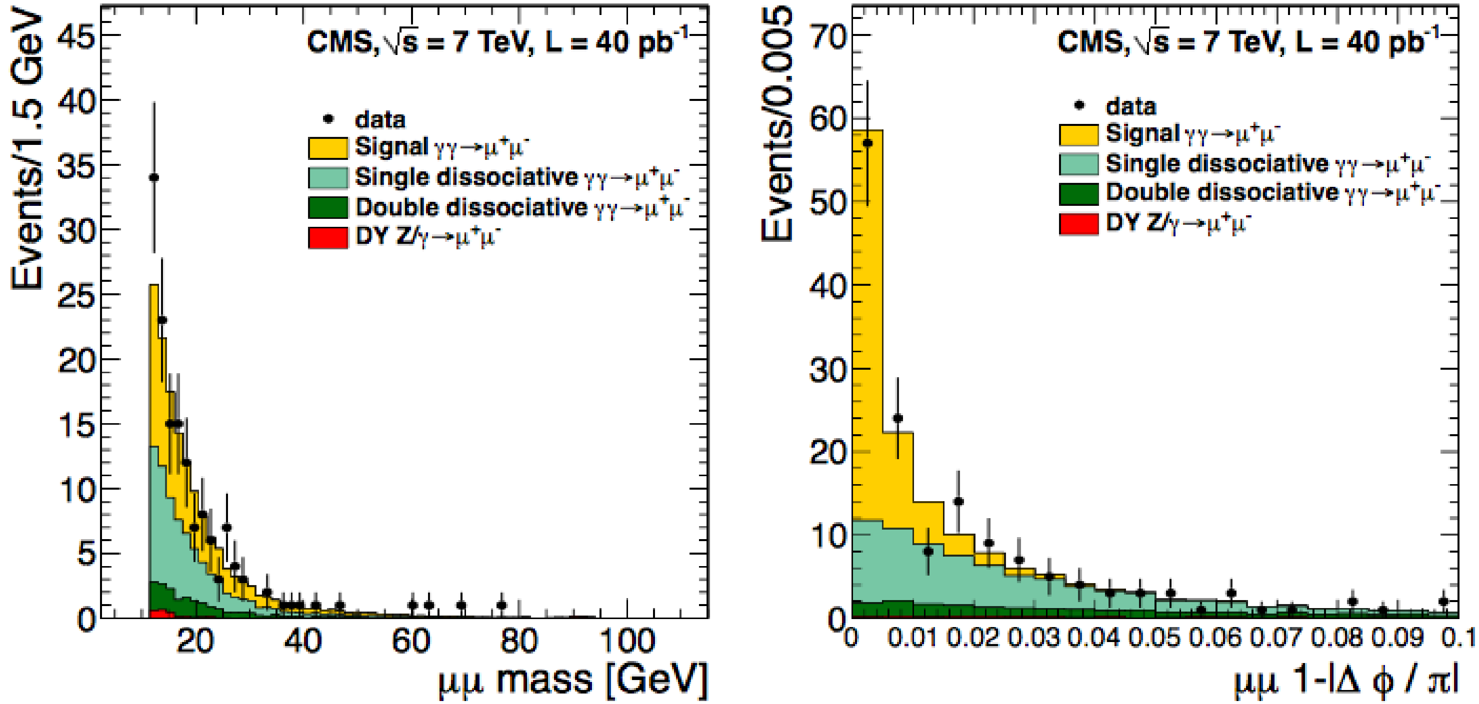


Figure 7: Muon pair invariant mass spectrum (left) and acoplanarity (right), with all selection criteria applied and the simulation normalized to the best-fit value. Data are shown as points with statistical error bars, while the histograms represent the simulated signal (yellow), single (light green) and double (dark green) proton dissociative backgrounds, and DY (red).

data-theory signal ratio: $R_{El-El} = 0.83^{+0.14}_{-0.13}$;

single-proton dissociation yield ratio: $R_{diss-El} = 0.73^{+0.16}_{-0.14}$;

Observe some deficiency but within stat.+syst. errors, without clear hint for absorptive effects in fully exclusive case

EPA and $\gamma\gamma$ -> WW

Summary for the dilepton (semi-)exclusive production:

No evidence for strong absorption in elastic-elastic production; also above 160 GeV

- LPAIR, which is "mirrored" by EPA calculations, describes well both acoplanarity and invariant mass (W) distributions
- DD seems to be almost completely suppressed! Proper modeling of the DD is essential for further detailed studies of the absorptive corrections.

S O L U T I O N for getting a proper $\gamma\gamma$-> WW from pp –> pWWp(*) as proposed and applied by CMS (and followed recently by ATLAS):

This is a data-driven F factor (in 2011) which "automatically" takes into account the absorptive effects:

$$F = \left. \frac{N_{\mu\mu \text{ data}} - N_{\text{DY}}}{N_{\text{elastic}}} \right|_{m(\mu^+\mu^-)>160\,\text{GeV}}.$$

$$F = 3.23 \pm 0.53.$$

The basic assumption there (backed by the data) is that the absorptive corrections are NOT strongly changing with W

EPA and $\gamma\gamma$ -> WW

The basic assumption there (backed by the data) is that the absorptive effects are NOT changing fast; in practice, it was tested by calculating F factor for increased threshold values, above 160 GeV – up to about 400 GeV we see no clear trend, just (rather small) statistical fluctuations which have been included into systematic errors

BOTTOM LINE:

The $\gamma\gamma$ -> WW cross-sections measured (correctly) by CMS have no bias due to (not well known) absorption and the corresponding uncertainties of our data-driven procedure of extracting the proper $\gamma\gamma$ -> WW are included in syst. errors.