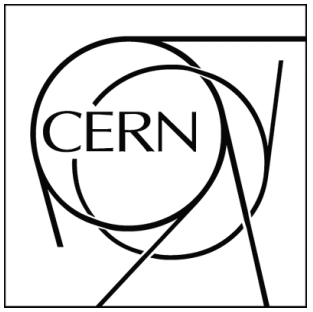
Mini review of Central Exclusive Production at LHC

Grzegorz Brona
(CERN)

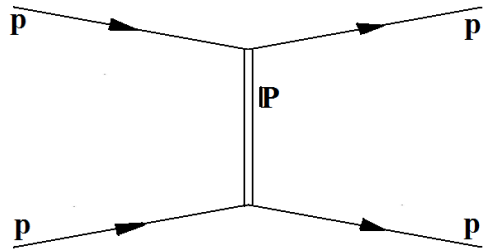
On behalf of CMS and ATLAS

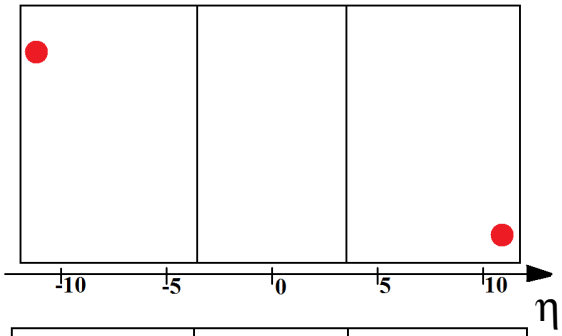


The 2009 Europhysics Conference on High Energy Physics

Kraków, 17.07.2009

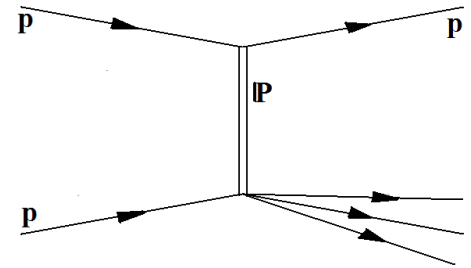
The name of the game

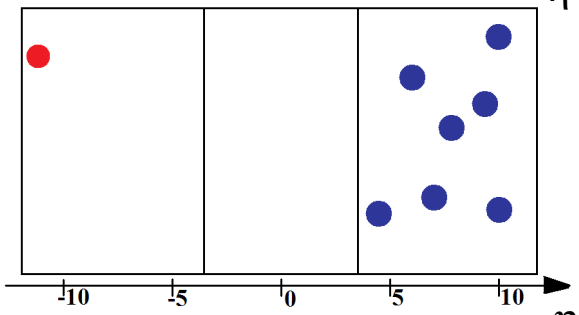




Elastic Scattering (ES)

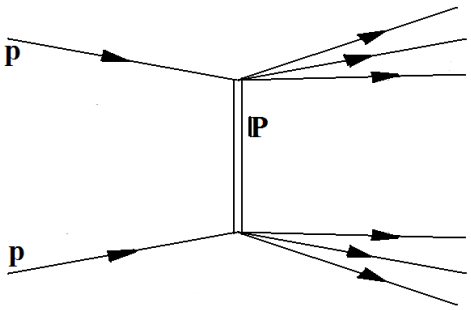
- No activity in central and backward-forward parts
- Protons in very forward detectors

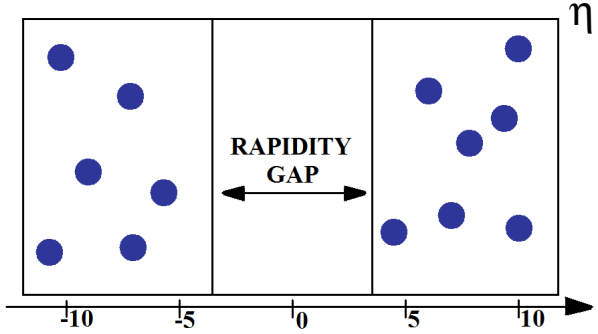




Single Diffraction (SD)

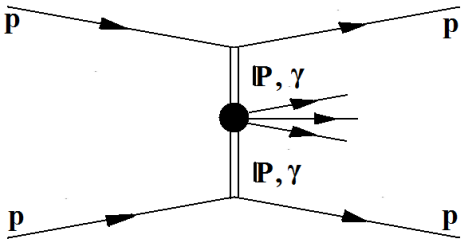
- High activity at one side of detector
- No activity at the other side
- Proton in very forward detector

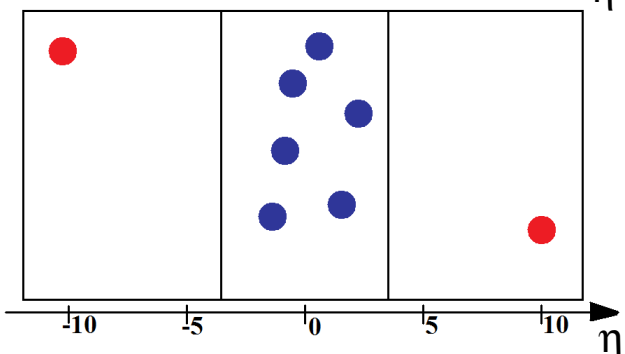




Double Diffraction (DD)

- High activity at both sides
- No activity in the center (rap gap)





Central Production (CP)

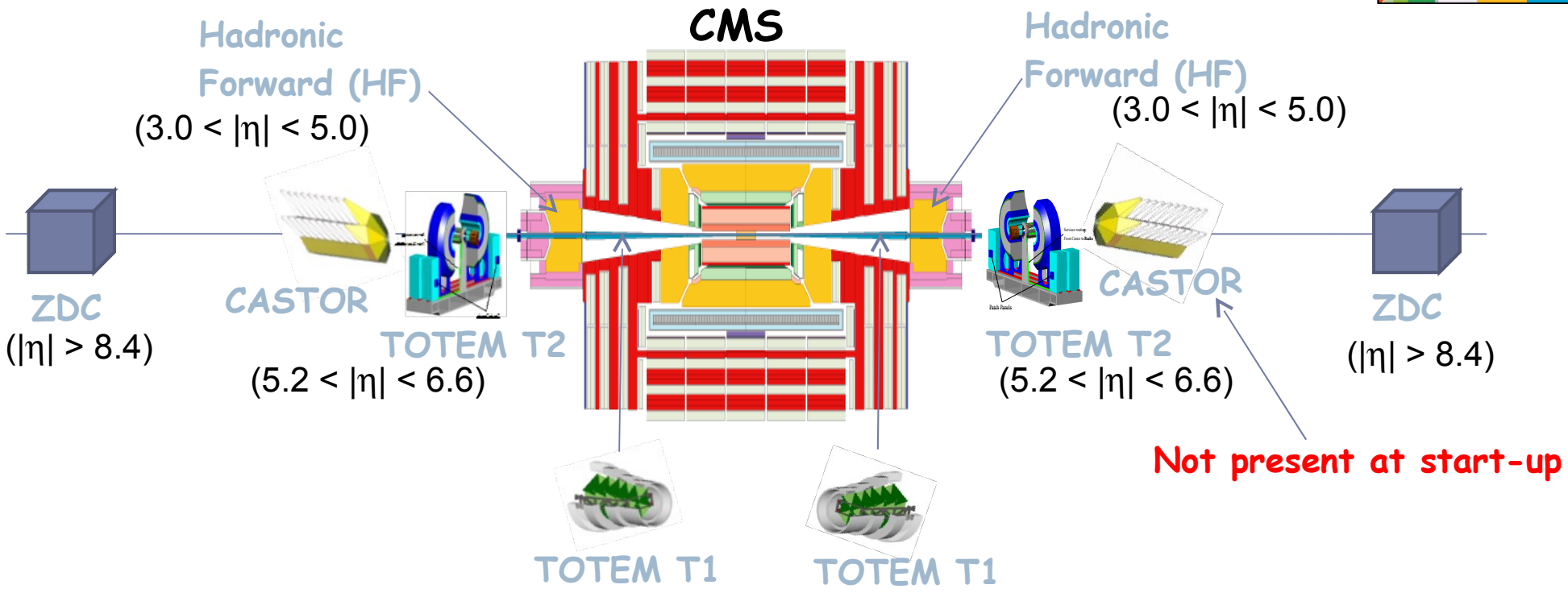
- Activity in the central part
- No activity in forward-backward
- Protons in very forward detectors
- No pomeron remnants

For hard diffraction see Silvia Ochesanu talk

The CMS detector

Requirements:

- Detectors covering forward and backward regions
- Low noise
- Knowledge on the pileup



- **Z**ero **D**egree **C**alorimeter (ZDC)
- **C**entauro **A**nd **ST**range **O**bjects **R**esearch (CASTOR) – calorimeter

- **TOTEM** – separate experiment:
  - T1 – in front of the HF, 7.5 m from IP
  - T2 – in front of CASTOR, 13.6 m from IP
  - RP – 147 & 149 and 216 & 220 m from IP

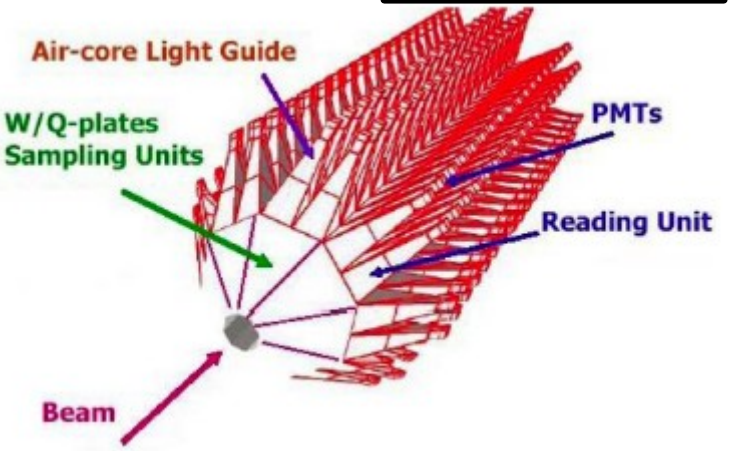
The CMS forward detectors

HF

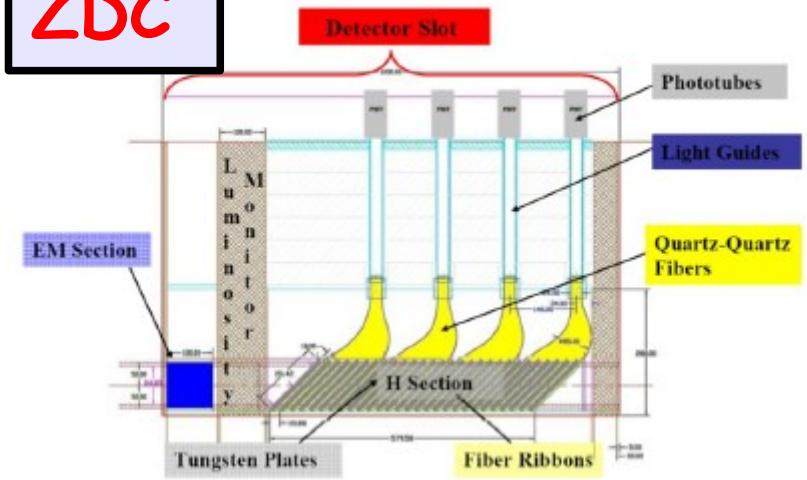
- Located at 11.2 m from IP
- Rapidity coverage: $3 < |\eta| < 5$
- 0.175x0.175 segmentation in η and ϕ
- Steel absorbers and embedded radiation-hard quartz fibers for fast collection of Cherenkov light

CASTOR

- Located at 14.3 m from IP
- Rapidity coverage: $-6.6 < \eta < -5.2$
- Segmentation in ϕ (16 sectors)
- 14 modules (2EM+12HAD)
- Alternate tungsten absorbers and quartz plates



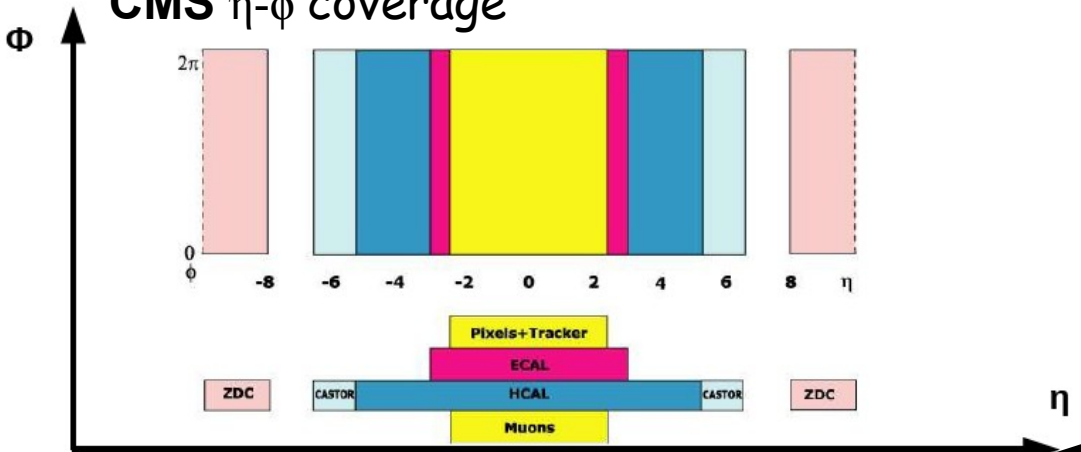
ZDC



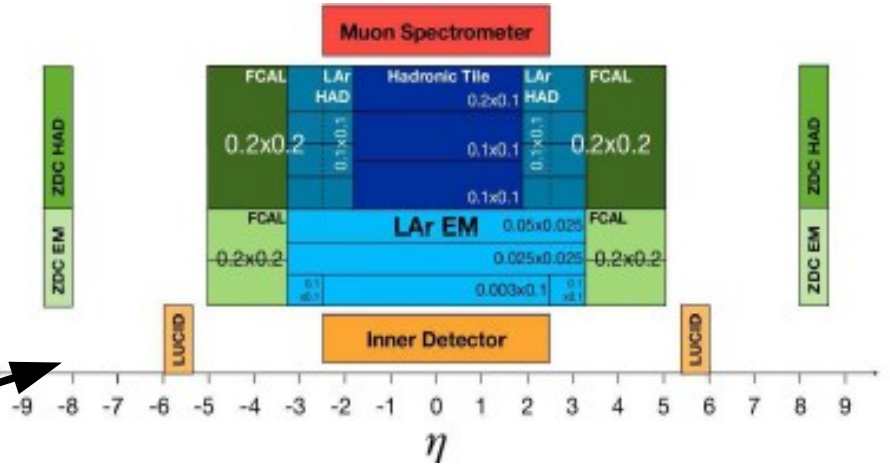
- Located at 140 m from IP
- Rapidity coverage: $|\eta| > 8.1$
- Tungsten/quartz Cherenkov calorimeter with separated EM and HAD sections
- Detection of neutrals (γ, π^0, n)

The coverage

CMS η-ϕ coverage



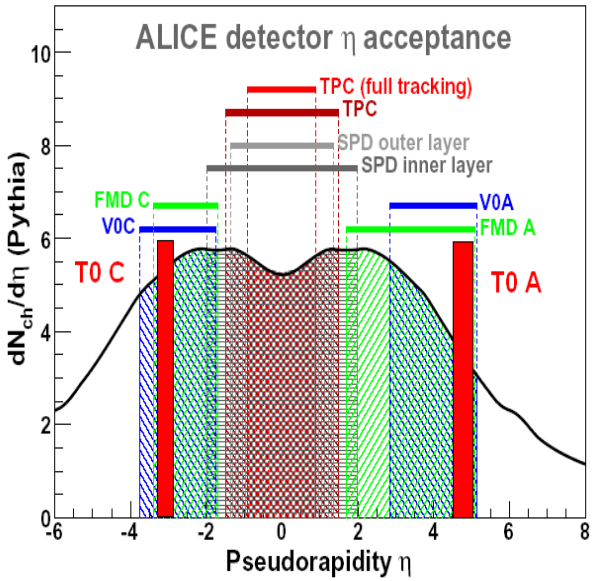
ATLAS η coverage



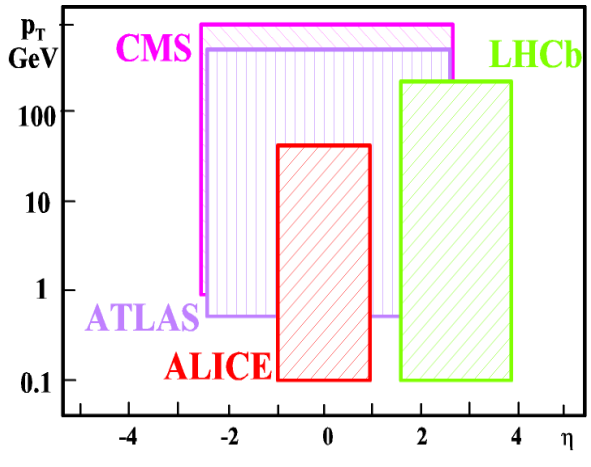
Similar coverage in **ATLAS**:

- FCAL
- LUCID - $5.6 < |\eta| < 5.9$ → pointing Cherenkov counters (lumi monitor+gap)
- ZDC - $|\eta| > 8.3$

Future: FP220 and 420

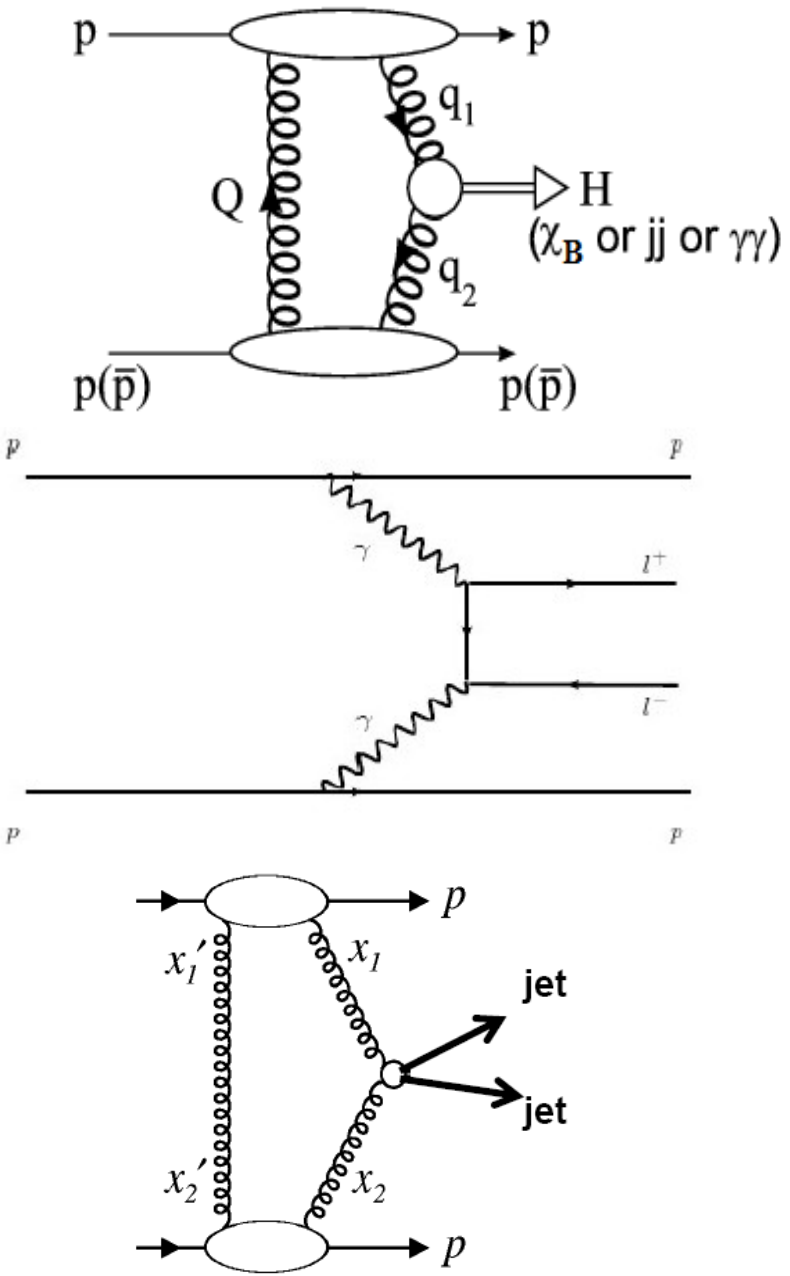


Central barrel coverage:



Low p_T covered by ALICE central barrel:
acces to ϕ, J/Ψ, ϒ **CEP** via ee channel

Central Production

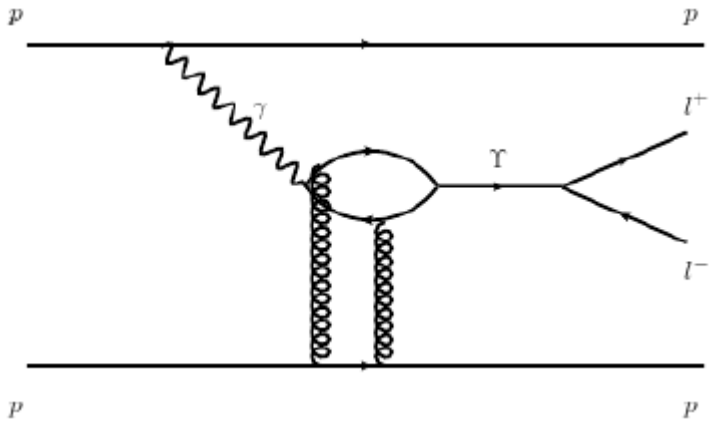


pp → p + gap + X + gap + p

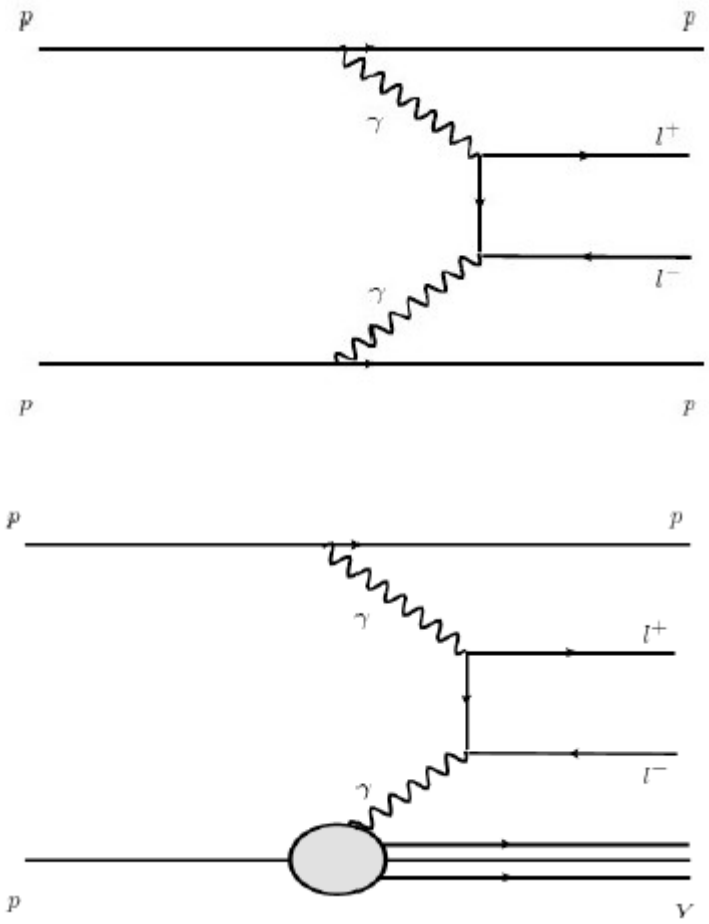
- X is a central system (ϒ, di-jet, di-lepton, di-photon, WW , Higgs, SUSY etc.)
- X is produced exclusively (protons stay intact)
- With pile-up studies much more difficult
- Protons scattered at very low angles – not in acceptance of existing forward detectors
- Protons detection – *very forward detectors*:
  FP220 and FP420
  both in CMS and ATLAS
  kinematics **fully** reconstructed
  access to quantum numbers
  Higgs but also SUSY particles

CEP of Υ and di-leptons

Υ photo-production



+



Elastic two photon di-lepton production

Inelastic two photon di-lepton production

Production Mechanism:

- **Quasi real photon fluctuates into a qq pair**
- **The pair interacts diffractively with the other proton**

***lepton* = e, μ**

Also $\gamma\gamma \rightarrow \tau\tau$

The analysis presented here → CMS, 14 TeV, CMS PAS DIF-07-001

Exclusive di-leptons

MC samples:

- **LPAIR** for elastic and inelastic two photon di-lepton production
- **STARLIGHT** for Υ production (σ x BR(Υ(1S) → μμ = 39.0 pb)
- **PHITI** used for comparison

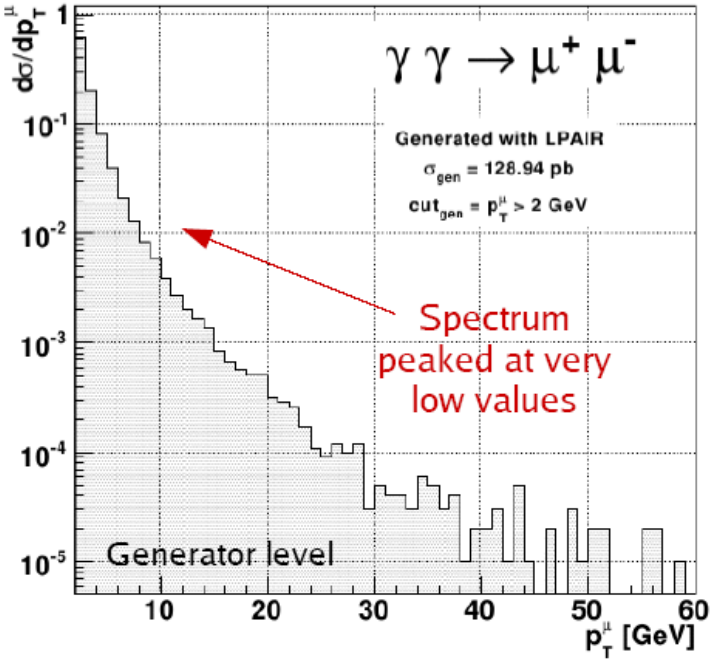
Thanks to J. Nystrand, J. de Favreau

- **Full Simulation** of the CMS detector
- Reconstruction based on the **official** algorithms
- **Trigger emulation** applied to all samples

Triggers:

- Two very soft leptons – use lowest possible p_T treshold at trigger level

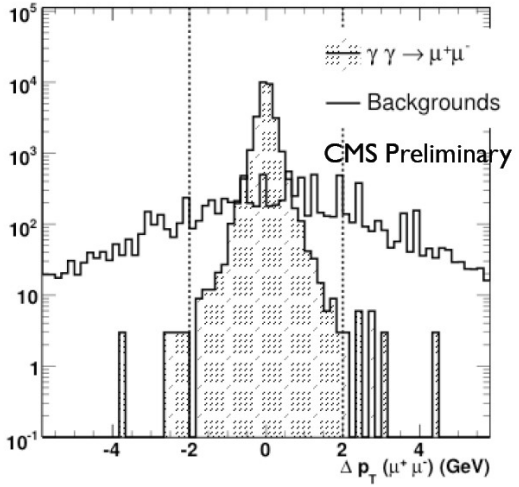
- μμ: standard CMS trigger p_T>3 GeV
- ee: dedicated trigger proposed:
  - At least 2 e/γ candidates with p_T > 6 GeV
  - With E_T imbalance smaller than 10 GeV
  - And high acoplanarity

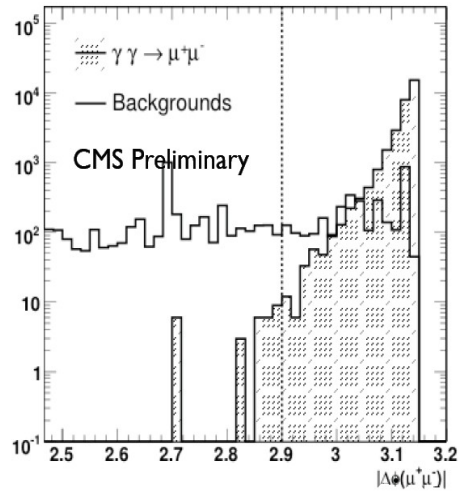


Exclusive di-leptons

Di-lepton selection:

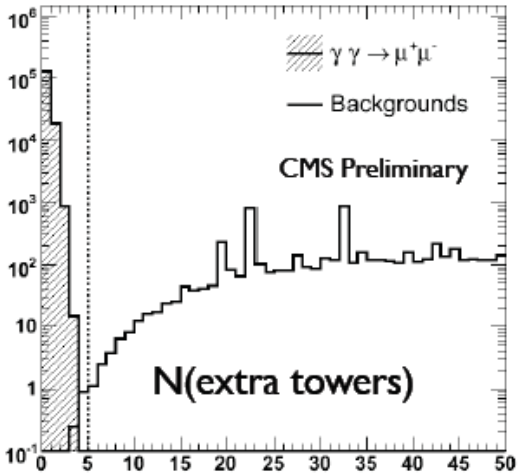
- 2 reconstructed opposite sign leptons
- For di-muons:
  - $\Delta p_T < 2.0$ GeV
  - $|\Delta\phi| > 2.9$
- For di-electrons:
  - $\Delta p_T < 5.0$ GeV
  - $|\Delta\phi| > 2.7$

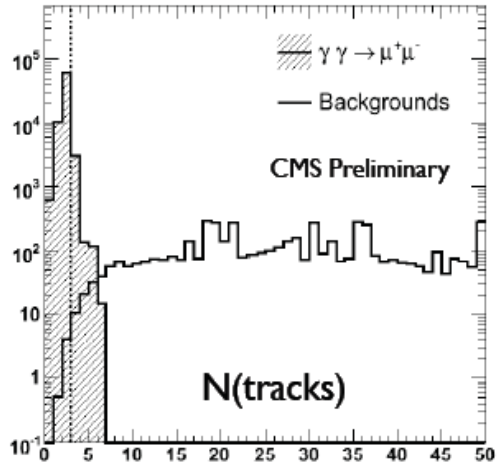




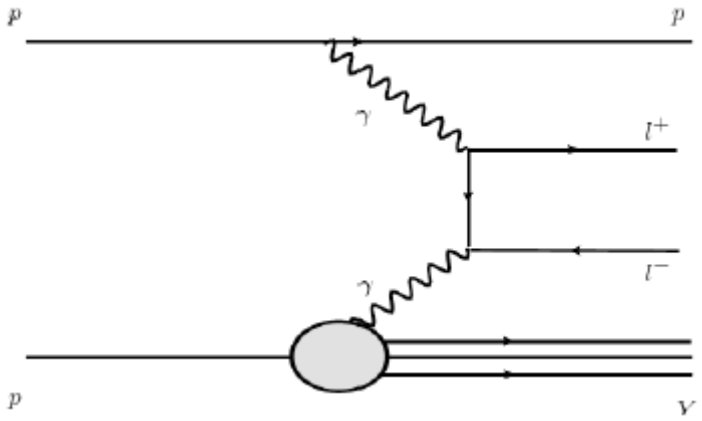
Exclusivity cuts:

- Number of extra calorimeter towers < 5
  extra tower = E > 5 GeV, isolated from lepton candidates (R>0.3 in the ϕ-η plane)
- Number of tracks in central region (η<2.5) < 3





Exclusive di-leptons



Dominant background:

Inelastic two photon di-lepton production other processes (Drell-Yann, quarkonium decays, heavy flavor jets) mostly rejected with cuts

x-section similar to elastic

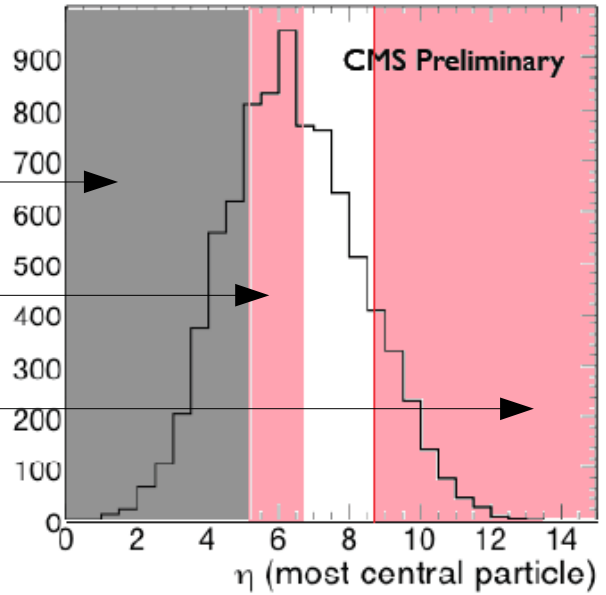
In 75% of these events no activity in central (up to HF) CMS expected

Veto on ZDC (|η|>8.4) and CASTOR (5.2<|η|<6.6, one side) reduces inelastic bg by 60%

Central

Castor

ZDC

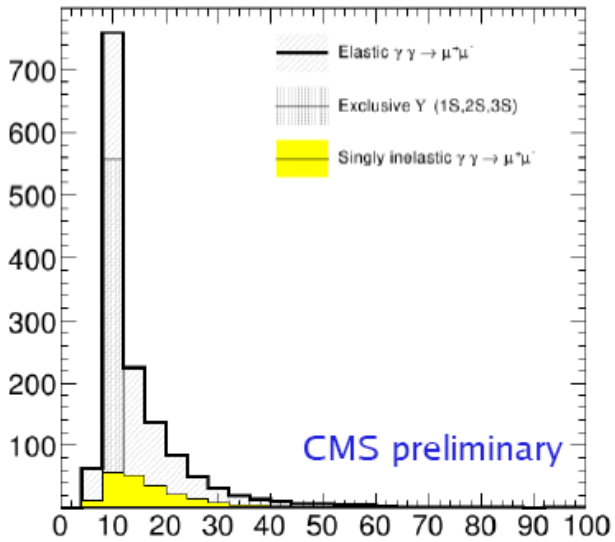


The usage of this veto will change with time

Exclusive di-leptons

Statistics in 100 pb^{-1} ← Integrated no-pileup luminosity after first LHC year (according to a'la Chamonix predictions)

Muon pairs



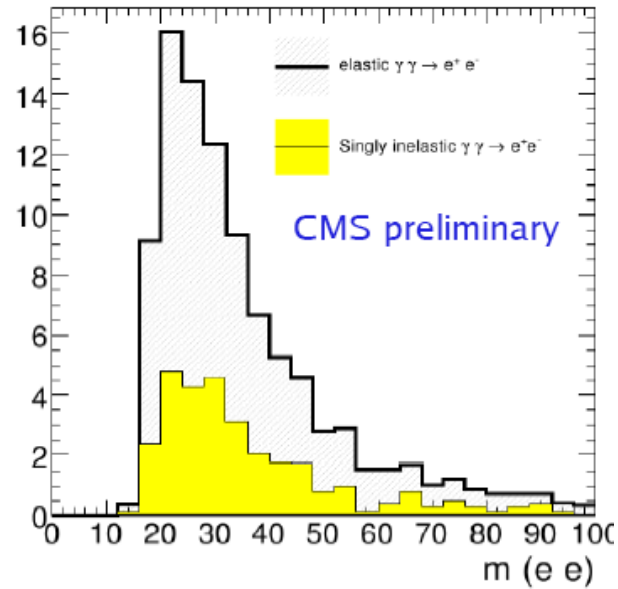
Elastic events: 709 +/- 27 (stat)

Single inelastic events: 223 +/- 15 (stat) +/- 42 (model)

Without ZDC and CASTOR Vetos:

Single inelastic events: 636 +/- 25 (stat) +/- 121 (model)

Electron pairs



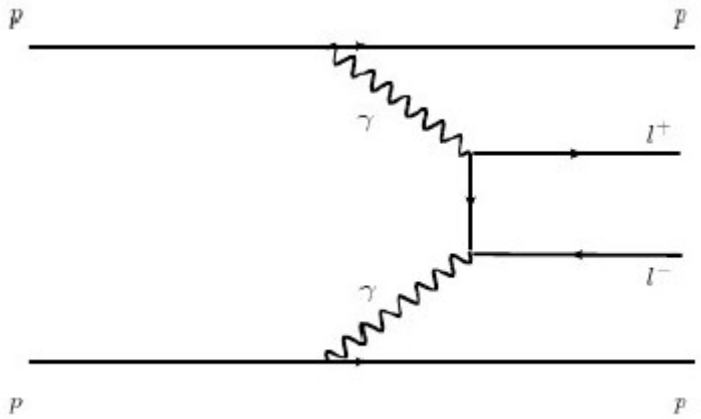
Elastic events: 67 +/- 8 (stat)

Single inelastic events: 31 +/- 6 (stat) +/- 6 (model)

Without ZDC and CASTOR Vetos:

Single inelastic events: 82 +/- 9 (stat) +/- 15 (model)

Elastic exclusive di-leptons production



Interesting process by itself

LHC as a photon collider

Pure QED process → very well known x-section

Low luminosity phase:

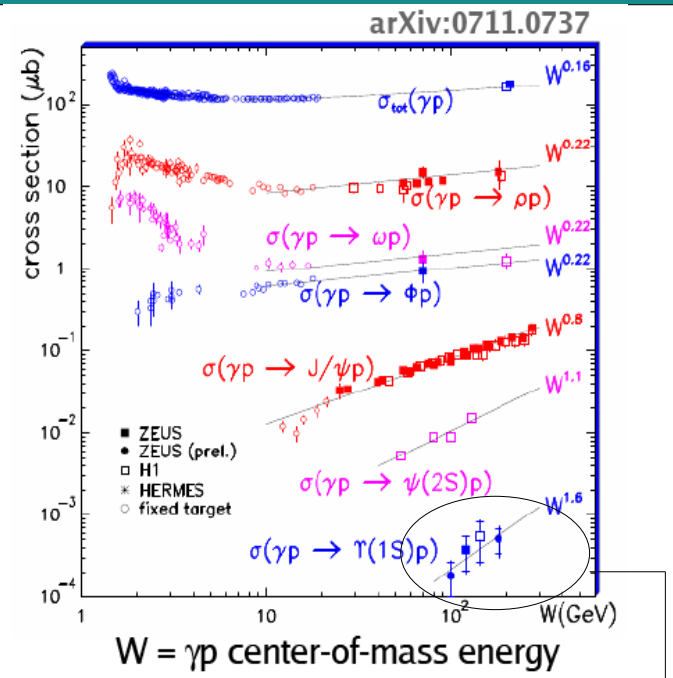
- Luminosity monitor
- Lepton identification studies

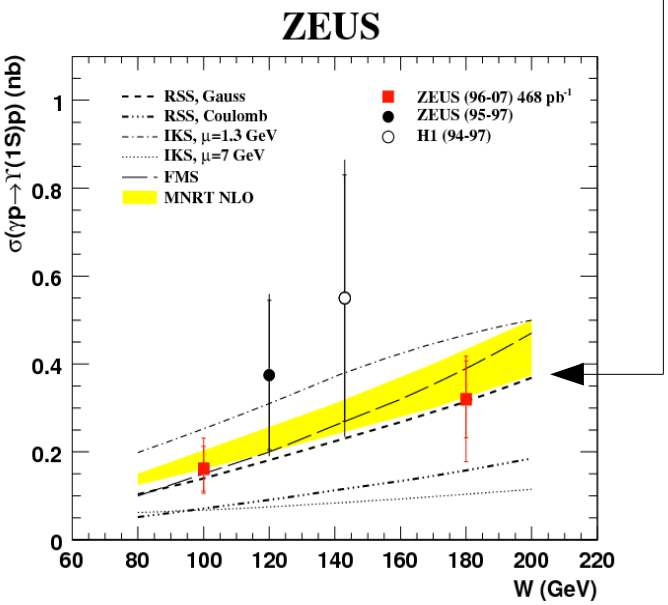
High luminosity phase:

- Calibration of the forward detectors
- Control sample for BSM physics (e.g. $\gamma\gamma$ -> SUSY)

Integrated luminosity measurement with precision ~4%

CEP of Υ





arXiv:0903.4205

Motivation:

- Studies of the low p_T muon reconstruction
- Alignment of forward proton detectors

- Sensitivity to the generalised gluon distribution
- Can be used to constrain QCD models
- LHC extends W coverage by a factor of 3-4

For the studies x-section taken from STARLIGHT:

$$pp(\gamma P \to \Upsilon \to \mu\mu)pp$$

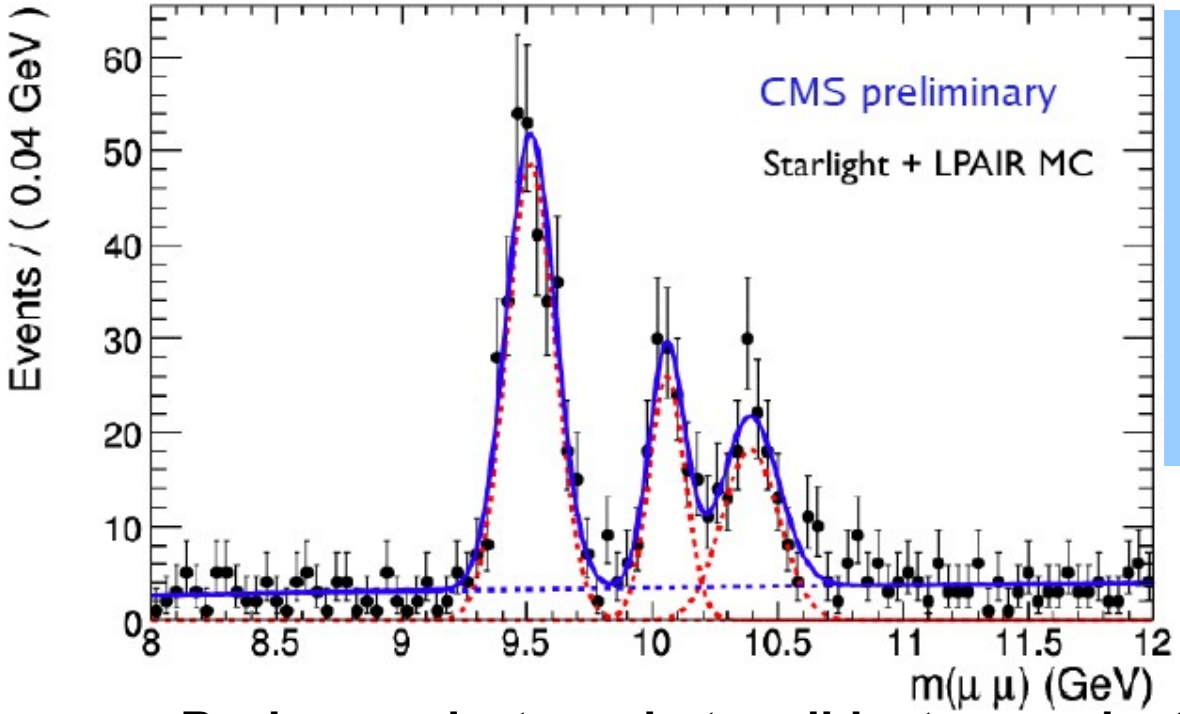
- 39 pb (1S)
- 13 pb (2S)
- 10 pb (3S)

Studies only for μμ decay channel – trigger in ee channel kills masses in Υ range

CEP of Υ

Υ selection using inv. mass distribution:

Triggers efficiency: 8.7% +/- 0.5%



- Proton 4-momentum transfer (t variable) highly corelated with Υ p_T^2
- p_T^2 distribution fitted to find b parameter
- Can be compared with true value obtained with MC-truth t

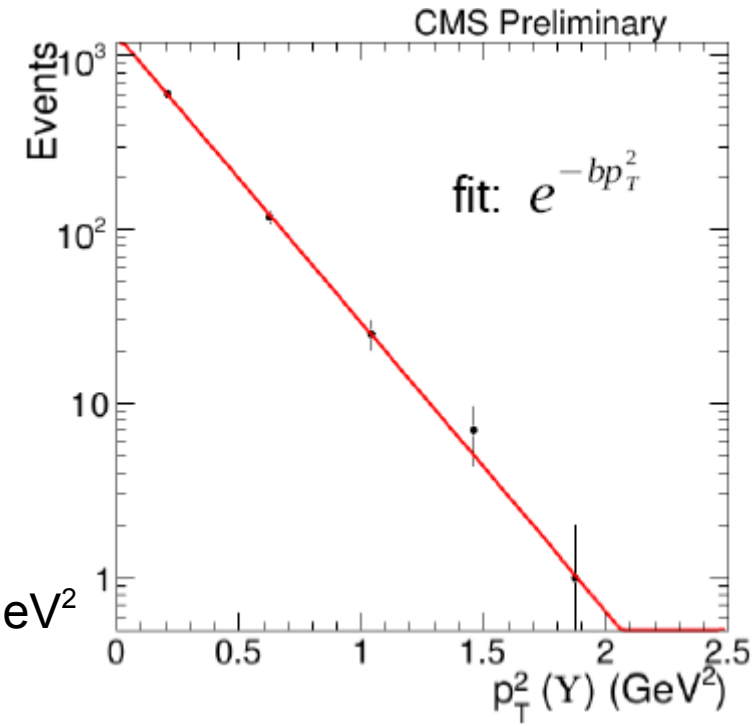
Background – two-photon di-lepton production

$b(\text{reco } p_T^2) = 3.82 \pm 0.16$ **GeV²**

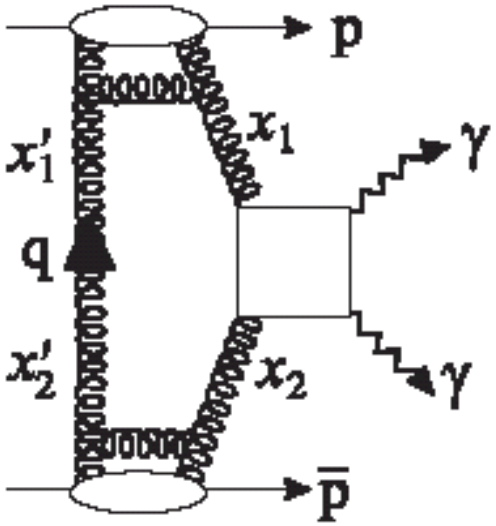
$b(\text{true } t) = 4.03 \pm 0.04$ **GeV²**

$\langle W_{\gamma p} \rangle \cong$ **537** GeV → After selection

$\langle q^2 \rangle = 0.046$ GeV² → Max 1.2 GeV²



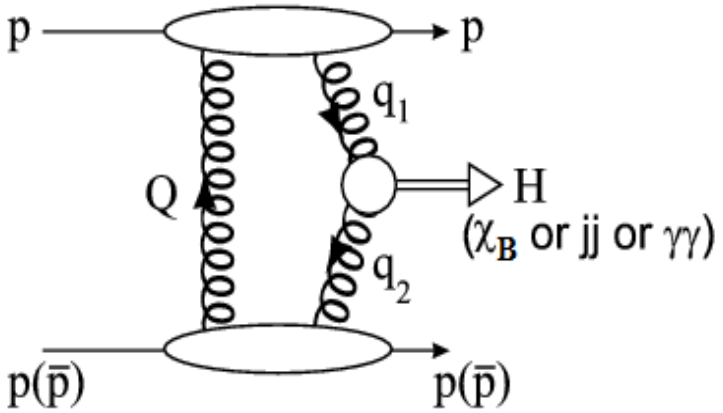
γγ exclusive production



Central production of γγ is very similar to **H** CEP:

- Test different ingredients for exclusive H search: $g(x_1,x_2)$, Sudakhov form factor, rapidity gap survival prob.
- Two outgoing photons – no strong interactions
- Two q-γ couplings → small x-section

Complementary reaction: **$pp(PP \rightarrow \chi_{b0} \rightarrow \gamma\Upsilon \rightarrow \gamma\mu\mu)pp$**



Predictions:

- **p_T (γ) > 5 GeV (existing trigger)**
- **σ (-2<y<2) = 600 fb**
- **Non-pileup integrated luminosity for the first LHC year: 100 pb^{-1}**

Not taking into account CMS acceptance and efficiency:

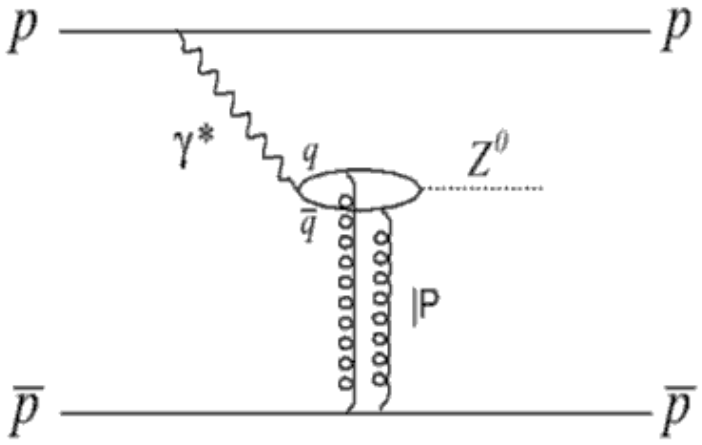
50 events in the first year

γγ exclusive production

- The exclusive γγ measured cross section will tell what number of exclusive H events to expect.
- When exclusive H is measured, the ratio #H/#γγ (corrected for kinematic dependencies) will measure **ggH** coupling.
- If H is not found – this measurement can place the best exclusion

---

Other possible study:

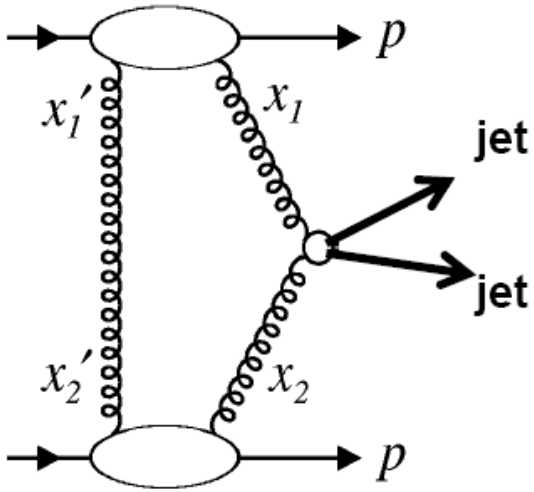


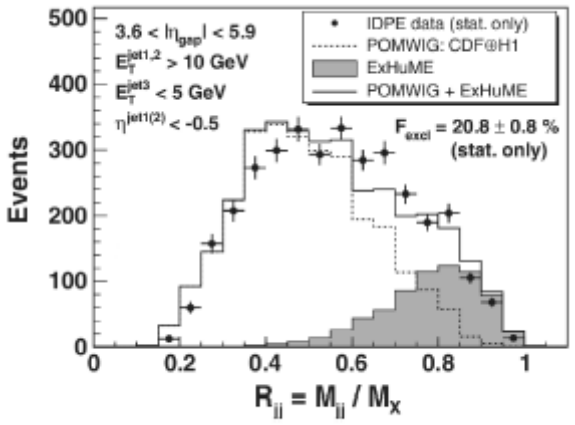
$$\gamma \rightarrow \sum qq \rightarrow Z$$

In SM x-section is negligible (0.3 fb – Motyka, Watt)

Observation - indication of physics beyond SM

Di-jets exclusive production



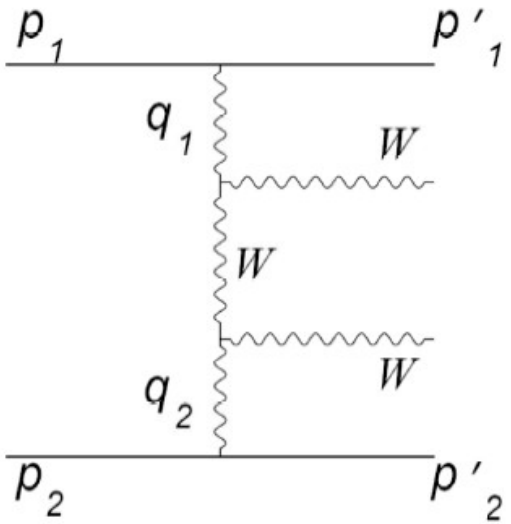


Exclusive di-jets as observed by CDF collaboration
Phys. Rev D 77, 05, 2004

- Two jets produced exclusively
- $R_{jj} = M_{jj}/M_X$ variable (for CEP close to ~1)
- Observation at Tevatron (Phys. Rev. D77, 05, 2004)
- Good agreement with KMR calculations
- $\sigma \sim O(10)$ pb at LHC energies (large sample)
- Dedicated triggers
- Central two – three jets production can be used to constrain Sudakov factor
- Studies in both CMS and ATLAS

WW and SUSY

See K. Piotrzkowski talk

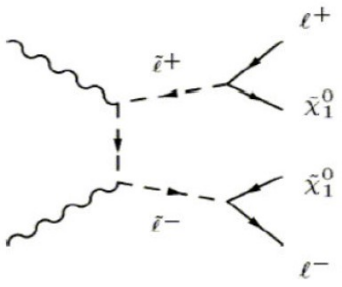


$\gamma\gamma \rightarrow W^+W^-$

- Exclusive W pair production via photon exchange
- Cross section ~100 fb
- Exclusivity demand + high p_T leptons
- For 200 pb^{-1} 6 CEP WW events expected with background of 0.4
- Studies of anomalous coupling (improvment in comparison with OPAL limits – factor 1000-10000)

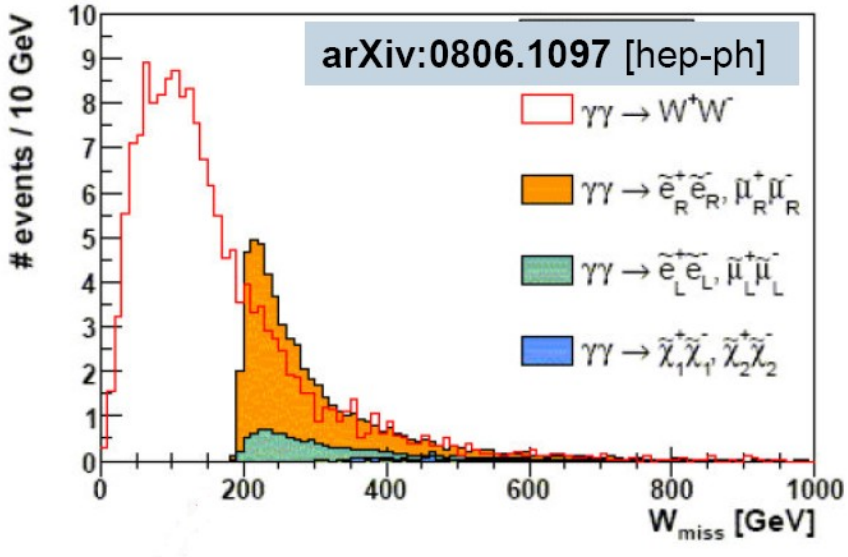
SUSY CEP

- High luminosity phase (100 fb^{-1})
- Very forward detectors crucial – missing mass determination

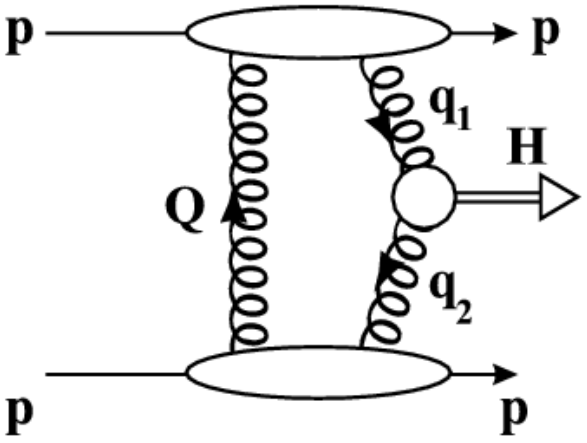


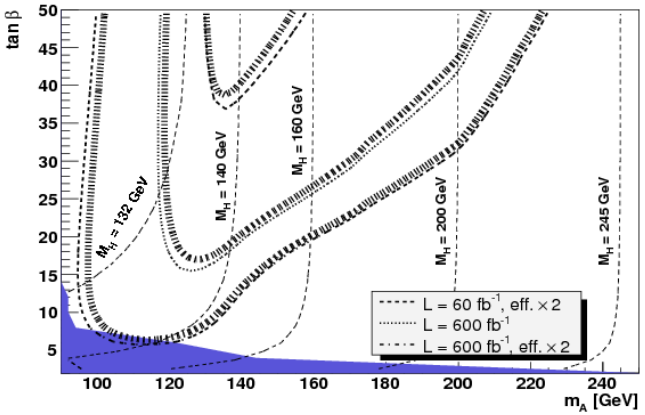
$$W_{miss} = \sqrt{E^2_{miss} - P^2_{miss}}$$

+ timing for bg suppresion



Higgs





5 σ discovery contours for H-> bb

arXiv:0708.3052

Assets of central exclusive production:

- Central system is $J^{PC} = 0^{++}$ (to good approx). A particle produced with proton tags has known quantum numbers.
- Excellent mass resolution from protons, independent of decay products of H in central detector.
- CP quantum numbers and CP violation in Higgs sector directly measurable from azimuthal asymmetry of the protons.
- S/B largely improved:

  i.e. b jets **channel**:

  M_H = 120 GeV; σ = 2 fb (uncertainty factor ~ 2.5)

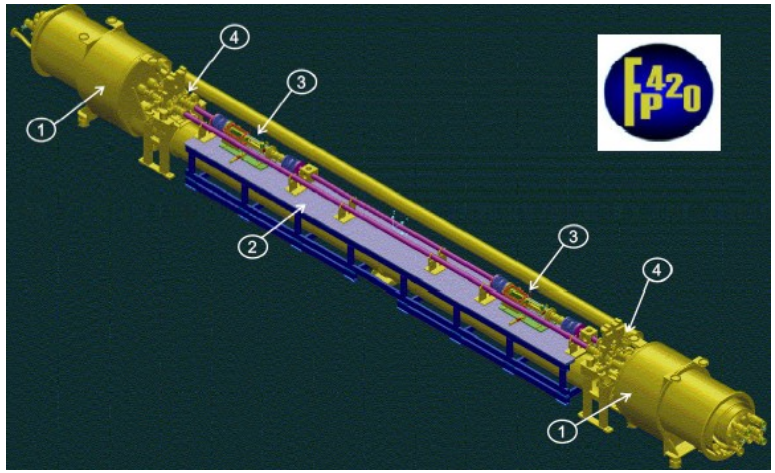
  11 signal / O(10) background in 30 fb^{-1} generator studies with detector cuts

  This H decay cannot be measure in LHC in nonCEP
- CEP may be discovery channel in certain regions in MSSM where the Xsection can be much larger than in SM
- Very forward detectors needed (FP220(40) + FP420)

Status of the Very Forward Detectors

See K. Piotrzkowski talk

- FP420
  - Instalation of SI detectors in cryogenic region of LHC (cryostat redesign)
  - Space limitation – movabel beam pipe (no roman pots)
  - Radiation hardness (~SLHC)
  - Fast timing detectors (resolution 10 ps)



- FP220(40)
  - Instalation in warm part of LHC
  - Space available (in CMS FP240 - TOTEM)
  - H → bb can be triggered by FP220(40)
  - Complementary to FP420 – together 0.1-10% proton energy loss covered

- The FP420 R&D report published, is basis of the CMS (and ATLAS) FP420 proposal
- The R&D (first) phase ends with a complete cryostat design and a preprototyped, tested concept for high precision near-beam detectors at LHC

Summary

- CEP studies will be done with early LHC data → 10-100 pb^{-1} :
  - Upsilon photoproduction
  - Di-leptons
  - Exclusive di-jets
- CEP studies will be done with first (+second) year LHC data:
  - Di-photons
  - WW
- CEP studies will be done with high-luminosity:
  - Higgs
  - Susy
- Both CMS and ATLAS are ready for the first phase – low luminosity (low pile-up)
- For high luminosity new forward detectors needed (FP220(40)-420) studies ongoing

Thank you!

Physical Review Focus

Focus Archive | PNU Index | Image Index | Focus Search

Previous Story / Volume 23 archive

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.

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

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