Exclusive dileptons at CMS
($\gamma\gamma \to l^+l^-$ and $\gamma p \to \Upsilon p \to l^+l^- p$)

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HERA and the LHC Workshop
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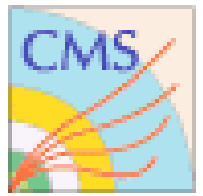
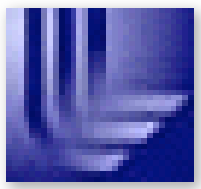
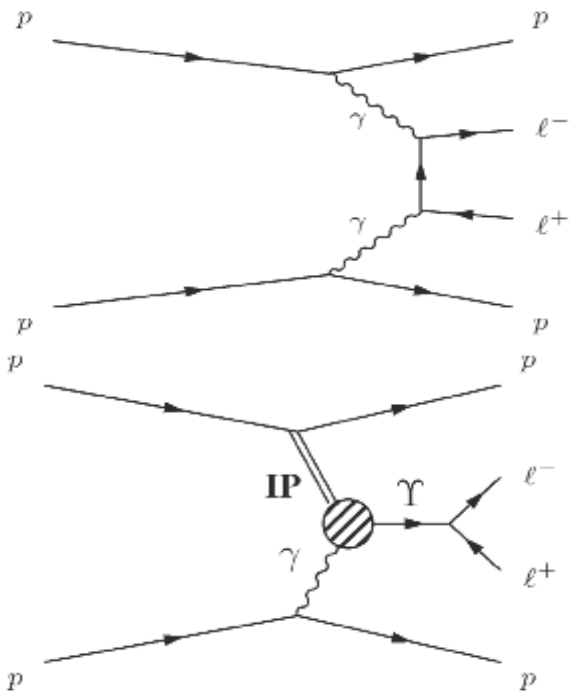




Signal processes

- Excusive dileptons from photon-exchange
  - Two leptons, back to back in ϕ, balanced in p_T
  - "Elastic" interactions: protons remain intact & escape down beamline - no other activity in detector (in limit of zero pileup - assumed here for startup)

- Two processes considered for pp collisions at CMS - identical selection is used for both:
  - Two-photon production - non-resonant lepton pairs from $\gamma\gamma \rightarrow l^+l^-$
    - Studied at LEP, HERA, RHIC, Tevatron, etc.
  - Photoproduction - lepton pairs through Upsilon resonances via $\gamma p \rightarrow \Upsilon p \rightarrow l^+l^- p$
    - Studied at HERA, Tevatron, RHIC...

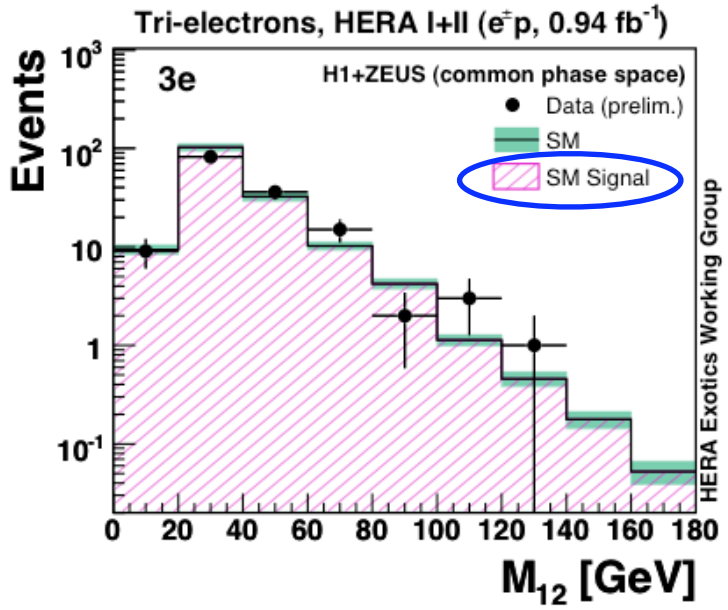


Two-photon physics

- QED process - minimal uncertainties on the cross-section, highly constrained 4-body final state

- Startup/low-luminosity
  - Aboslute luminosity normalization
  - Low p_T lepton ID studies

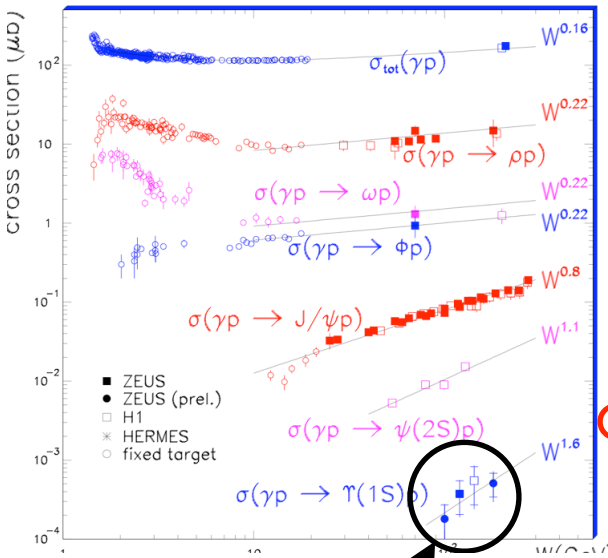
- High-luminosity
  - Alignment sample for forward proton taggers
  - "Standard candle" for BSM physics in high energy $\gamma\gamma$ interactions: $\gamma\gamma \to \tilde{l}^+\tilde{l}^-$, $\gamma\gamma \to H^{++}H^{--}$, $\gamma\gamma \to \gamma\gamma$, $\gamma\gamma \to W^+W^-$ couplings, etc.



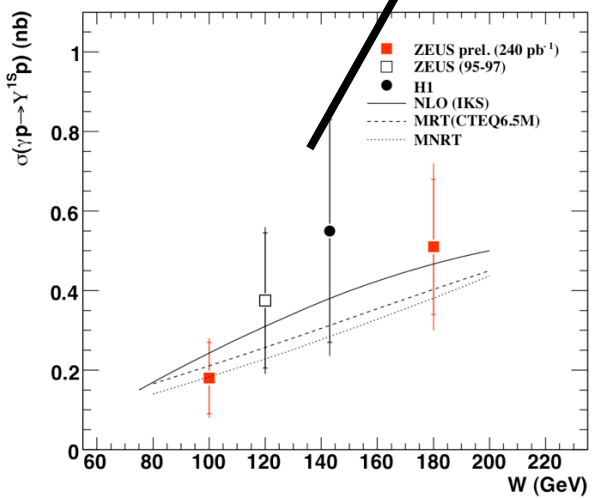
HERA: $\gamma\gamma \to l^+l^-$ ("Bethe-Heitler") studied as dominant background in dilepton/trilepton searches

Upsilon photoproduction

- Cross-check low p_T muon reconstruction
- QCD/diffractive physics measurements
  - cross-section (sensitive to generalized parton distributions)
  - t-dependence (momentum transfer at p-vertex)
- W-dependence of the cross-section is well measured for light-quark mesons
  - Heavy flavor ($b\bar{b}$) meson photoproduction measured at HERA
  - LHC extends energy by ~1 order of magnitude



X CMS



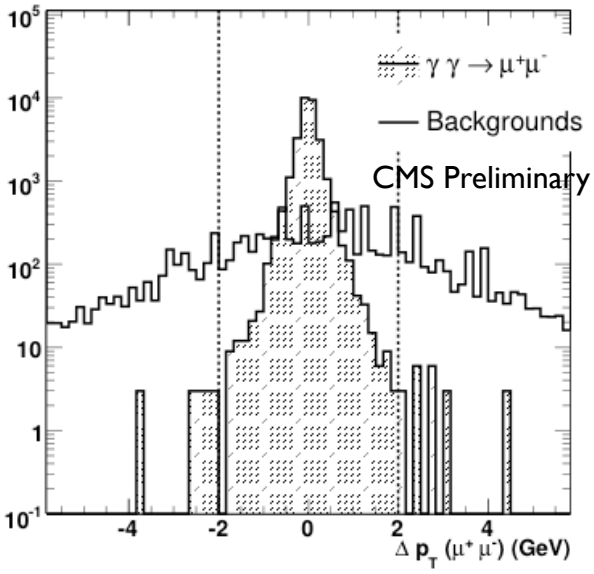
W (γp CM energy)

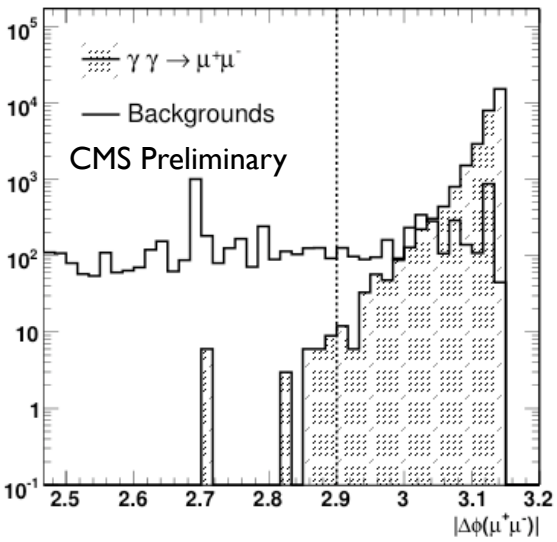
MC and trigger

- Full simulation, reconstruction, & trigger emulation applied to all samples
  - Two-photon (elastic + inelastic): LPAIR
  - STARLIGHT for Upsilon photoproduction
    - $\sigma \times B(\Upsilon(1S) \rightarrow \mu\mu) = 39.0$ pb
    - Also compared to PHITI - σ lower by a factor of 3
  - Pythia for backgrounds (Drell-Yan, quarkonium, heavy flavor, etc.)

- Signal is mostly very soft leptons
  - Need lowest possible trigger thresholds required to retain signal
- Standard CMS startup dimuon trigger ($p_T > 3$ GeV)
- Dedicated dielectron trigger ($E_T > 6$ GeV)
  - Require no additional jet activity, plus E_T balance and $\Delta\phi$ cuts

Dilepton selections





Arbitrary normalization

- Offline analysis selection: require exactly 2 reconstructed opposite-sign muons or electrons
- Signal is sharply peaked at $|\Delta\phi| = \pi$ and $\Delta p_T = 0$

Select events with:
Δp_T (μμ) < 2.0 GeV
$|\Delta\phi(\mu\mu)| > 2.9$

ΔE_T (ee) < 5.0 GeV
$|\Delta\phi(ee)| > 2.7$

Exclusivity

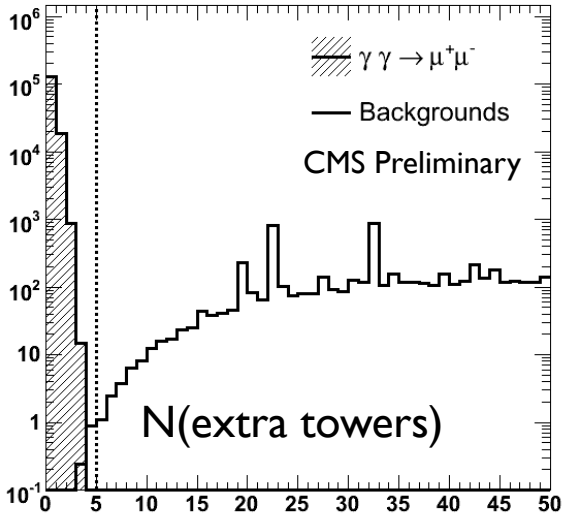
- Calorimeter exclusivity: backgrounds contain "extra" calorimeter towers
  - "Extra" towers: E > 5 GeV, isolated from either of the lepton candidates by R > 0.3 in the η-ϕ plane
- Tracker exclusivity: coverage in central region (|η| < 2.5)
  - Reject events with extra tracks above 900 MeV

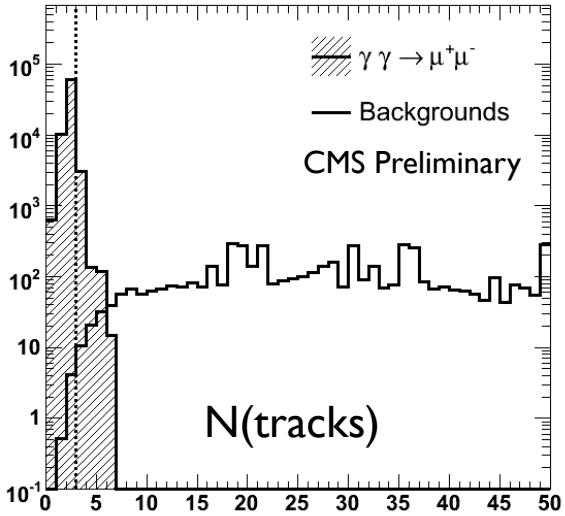
Select events with:

N(extra towers) < 5

N(tracks) < 3

(same for electrons & muons)

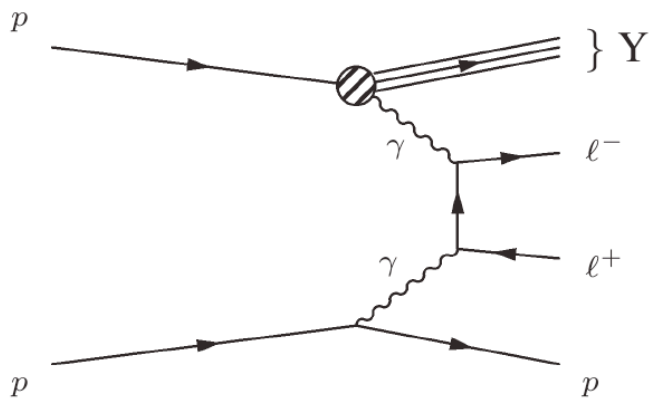


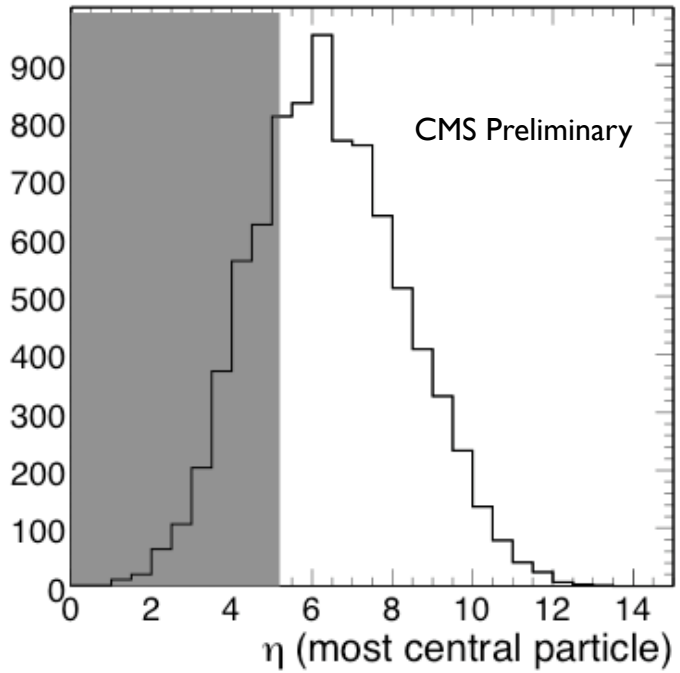


Arbitrary normalization

Inelastic backgrounds

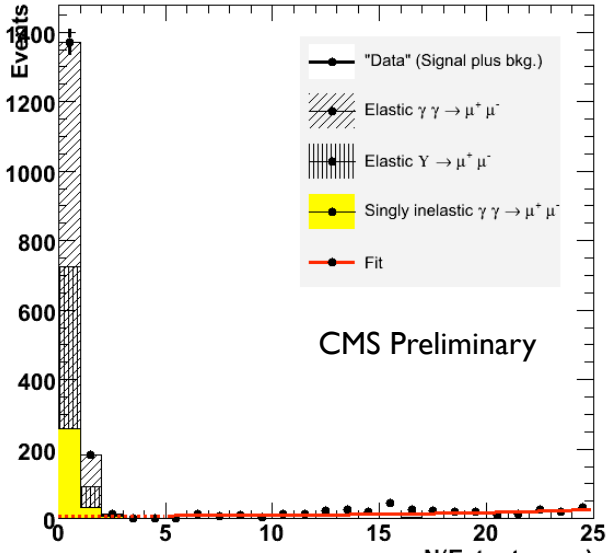
- Irreducible background from inelastic (proton-dissociation) photon-exchange events
  - Cross-section similar to elastic signal, theoretically less clean - in 75% of these events, expect no activity within CMS forward hadron calorimeter (HF) acceptance
- Veto with far-forward calorimeters
  - ZDC (Zero Degree Calorimeter): Detection of neutrals in the range $|\eta| > 8.6$
  - Castor: Detection of charged/neutral activity in the range $5.2 < |\eta| < 6.6$
  - Based on acceptance, 2/3 of remaining inelastic events can be rejected using ZDC (2 directions) + Castor (1 direction)

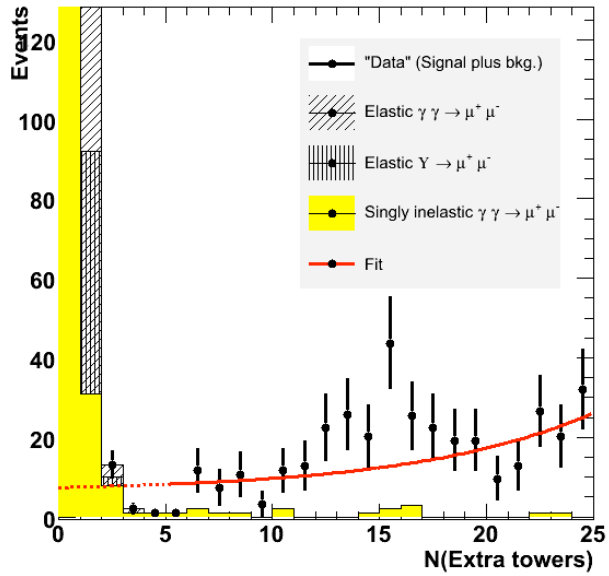




Backgrounds/systematics

- Remaining non-inelastic backgrounds can be estimated from data by fitting sidebands of calorimeter tower multiplicity distribution
  - In MC, this contribution is smaller than the inelastic background by a factor of 5
- Systematics
  - Inelastic background: assume 19% relative uncertainty based on CDF study
  - Calo noise: Studied, small effect after cleanup of hot/dead channels





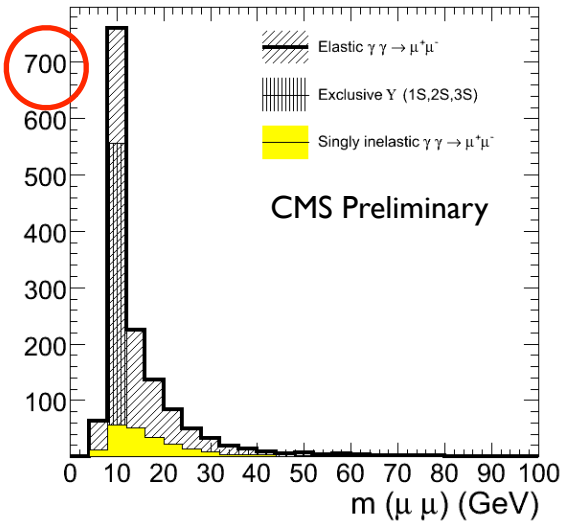
Magnified sideband region

Final samples (100 pb^{-1})

- In MC, several hundred two-photon and Upsilon events pass the final selection in the dimuon channel

709 ± 27 (stat) elastic events
223 ± 15 (stat) ± 42 (model) singly inelastic events

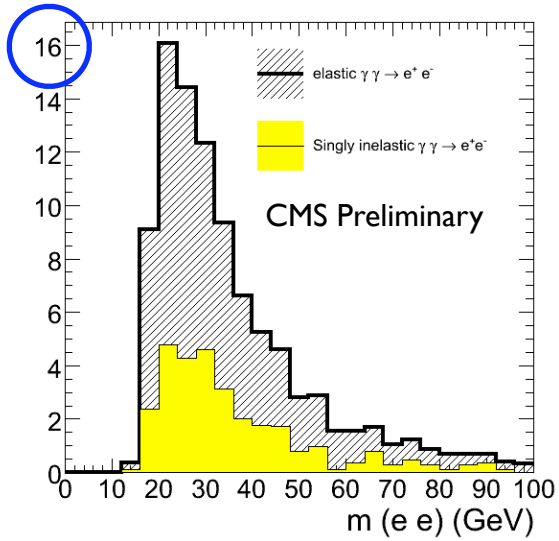
636 ± 25 (stat) ± 121 (model) singly inelastic events, no ZDC/Castor



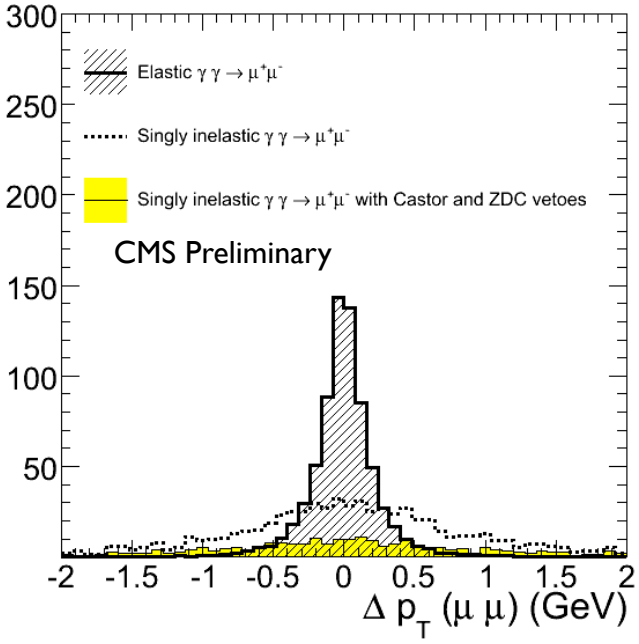
- Electron sample a factor of ~10 smaller due to higher trigger threshold, efficiency for low E_T electron reconstruction
  - No sensitivity to Upsilon region

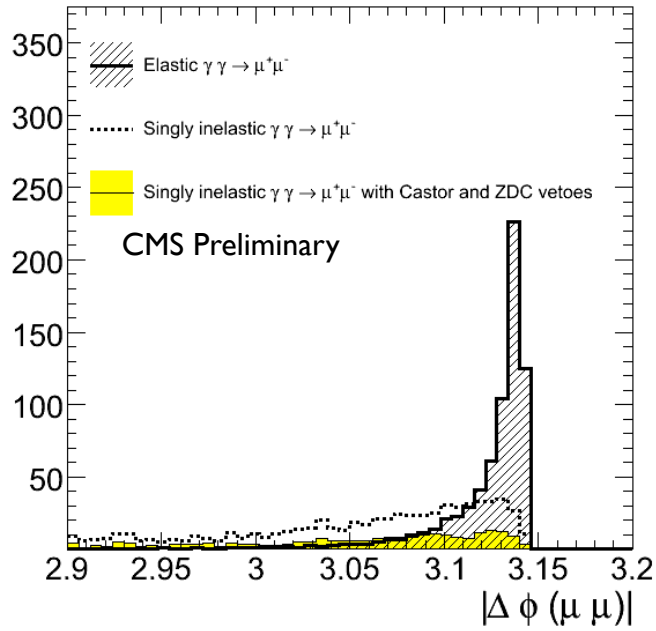
67 ± 8 (stat) elastic events
31 ± 6 (stat) ± 6 (model) singly inelastic events

82 ± 9 (stat) ± 15 (model) singly inelastic events, no ZDC/Castor



Luminosity prospects





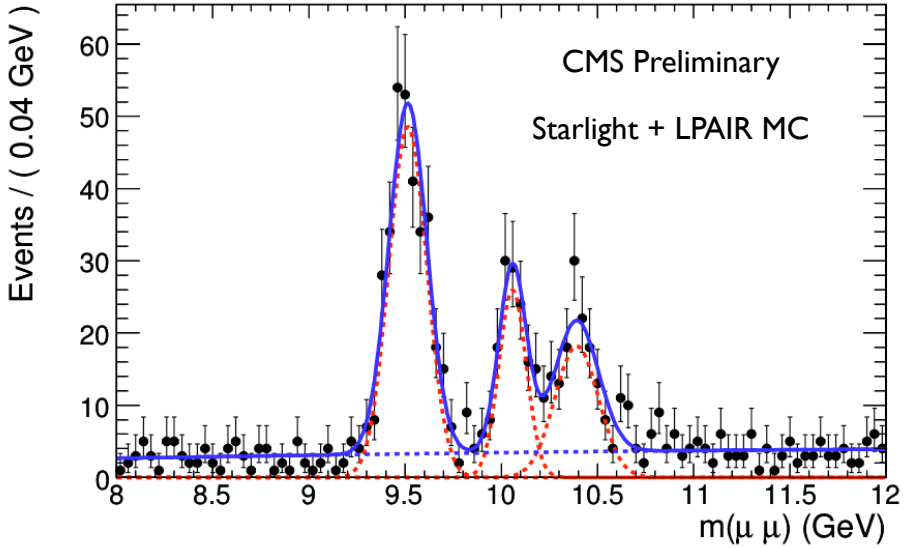
- $\sqrt{N}$ (elastic) ≈ 4%, but elastic events can't be separated event-by-event due to inelastic background
- Can be done statistically using differences in shapes of $\Delta\phi$ and Δp_T distributions within signal region
  - Improved precision with forward Castor/ZDC vetos

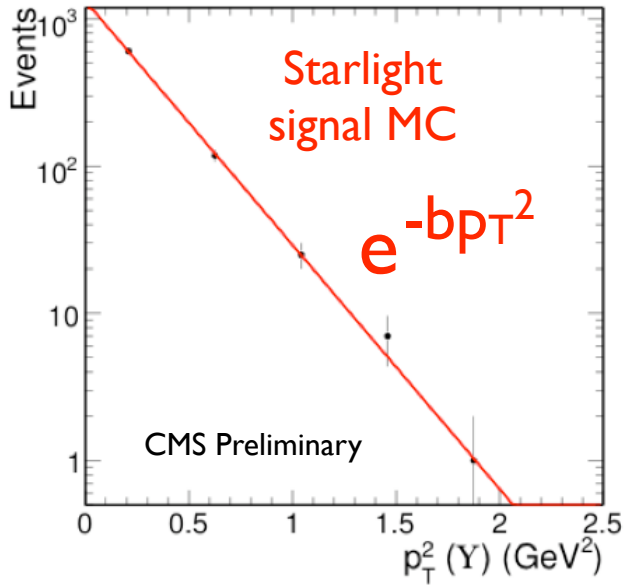
Upsilon region

- First 3 Upsilon resonances can be observed over two-photon continuum with 100 pb^{-1} of single-interaction data
- proton 4-momentum transfer "t" highly correlated with Upsilon p_T^2
  - Fit p_T^2 distribution to find the slope parameter b
  - Consistent with true value of "t" up to a small bias

$b(\text{reco } p_T^2) = 3.82 \pm 0.17 \text{ GeV}^2$
$b(\text{true t}) = 4.03 \pm 0.04 \text{ GeV}^2$

$\langle W \rangle = 2398 \text{ GeV}$
$\langle q^2 \rangle = 0.05 \text{ GeV}^2$





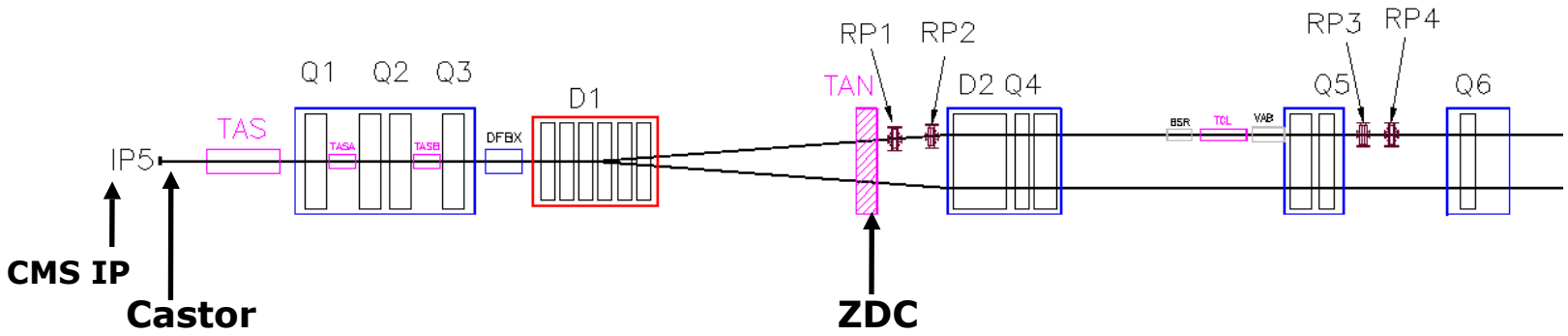
Conclusions

- A significant sample of exclusive dimuons from $\gamma\gamma \rightarrow \mu^+\mu^-$ and $\gamma p \rightarrow \Upsilon p \rightarrow \mu^+\mu^- p$ can be triggered on and reconstructed in CMS, with 100 pb^{-1} and minimal pileup
  - Plus a smaller sample of dielectrons from $\gamma\gamma \rightarrow e^+e^-$
- Other backgrounds should be small compared to inelastics and signal
- This sample can be used for several photon-physics and calibration studies with early data from the LHC:
  - High-energy Upsilon photoproduction
  - Absolute luminosity normalization
  - Lepton ID studies
- For further details, see:

  http://cms-physics.web.cern.ch/cms-physics/public/DIF-07-001-pas-v4.pdf

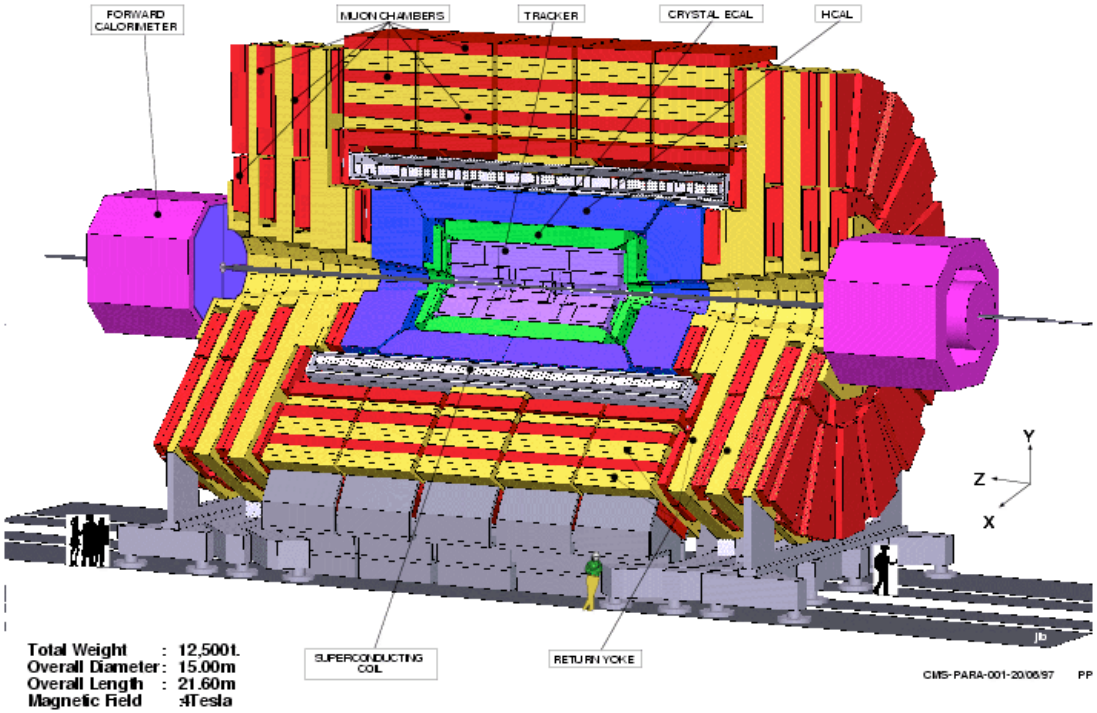
Extra slides

CMS forward calorimeters



- "Baseline" CMS forward hadronic calorimeter (HF) extends to $|\eta| < 5$
- Castor: quartz-tungsten sampling calorimeter
  - ~14 m from IP, covers $5.2 < |\eta| < 6.6$
- ZDC: quartz-tungsten sampling calorimeter
  - ~140 m from IP, covers $|\eta| > 8.6$

CMS



Silicon tracker
- micro strips (10M ch)
- pixel (40M ch)

(5.4m long, 2.4m Φ: $|\eta| < 2.4$)

Central calorimeter
- ECAL: PbWO4 crystal
- HCAL: brass+scinti.

($|\eta| < 3.0$)

in 4 Tesla solenoid

(12.5m long, 6m Φ in)

muon system
- DT+RPC (barrel)
- CSC+RPC (endcap)

(in iron yoke: $|\eta| < 2.4$)

Fast cerenkov forward calorimeter
- quartz fiber

($3 < |\eta| < 5$)

Toal weight	12500 t
Overall diameter	15 m
Overall length	21.6 m