Exclusive dimuon production at CMS

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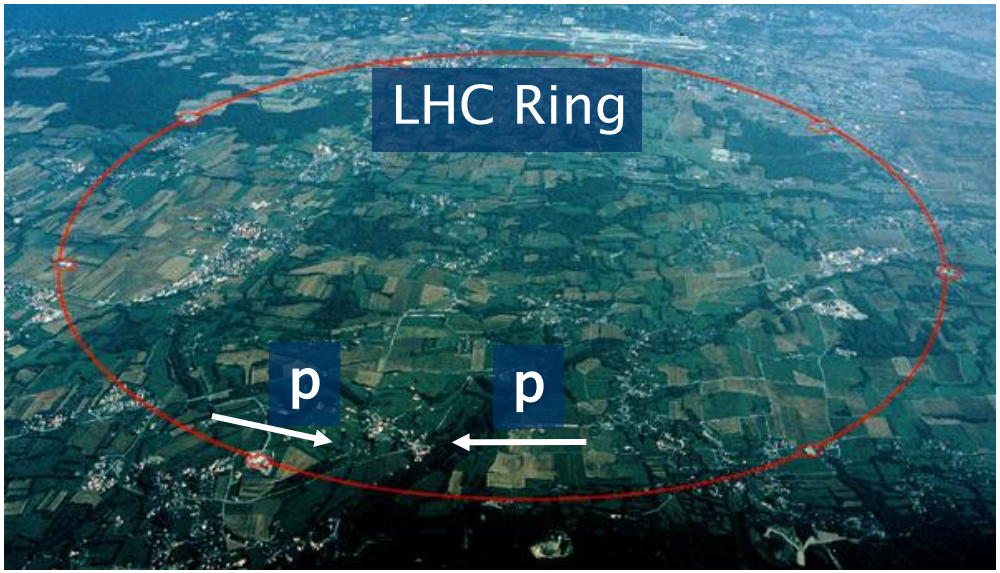
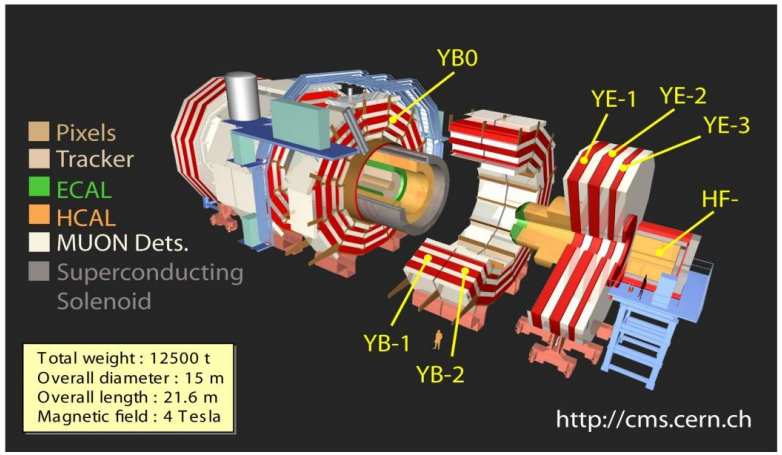
The Large Hadron Collider

- 27km ring, located at CERN, Geneva, Switzerland
- At design, will produce proton-proton collisions up to 7x the energy of any existing collider



Phase	CM Energy	Peak Instantaneous Luminosity ($cm^{-1}\ s^{-1}$)
Startup	0.9 TeV	Low
2010/first year run	7/10 TeV	10^{29} – 10^{32}
Design	14 TeV	10^{34}

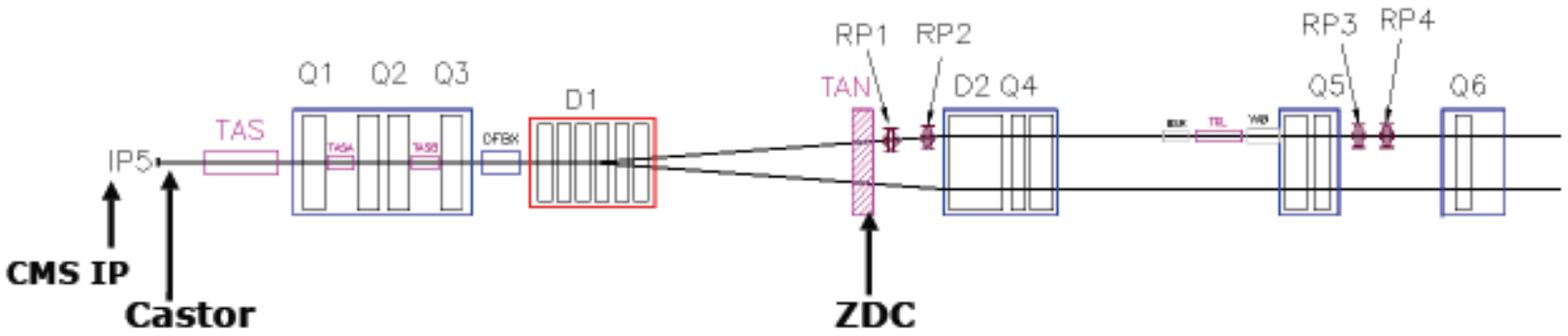
CMS



- The "Compact Muon Solenoid"
  - 4T solenoidal magnet
  - Hadronic and electromagnetic calorimeters
  - Muon system: Cathode-Strip chambers, Resistive-Plate Chambers, Drift Tubes
  - Silicon strip tracker and pixel detector
- Last major central detector systems were lowered in December 2007

CMS Forward

- Coverage of the central CMS hadronic calorimeter extends to $|\eta| < 5.0$, tracking extends to $|\eta| < 2.4$

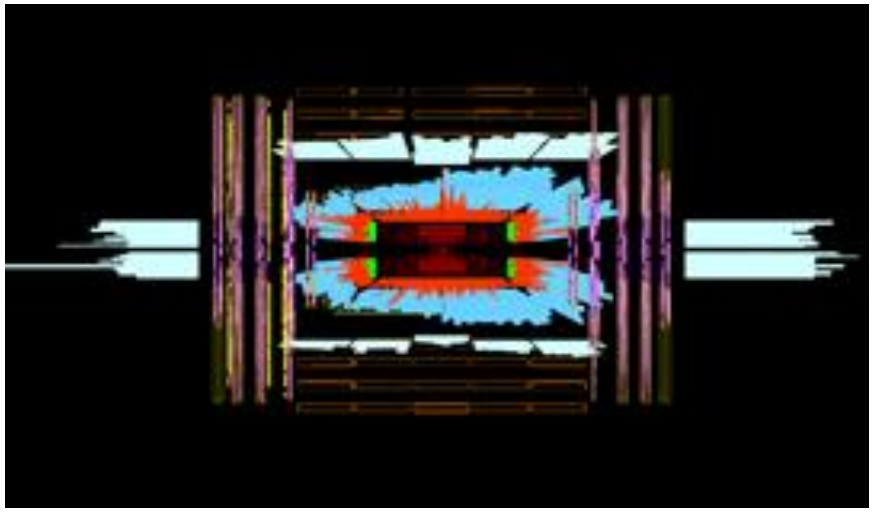


- Recent additions – far forward calorimeters
  - CASTOR: $-5.2 < \eta < -6.6$ (one side only)
  - Zero-Degree Calorimeter (ZDC): located 140m from the interaction point, covering $|\eta| > 8.2$
  - Both detectors installed and will be operational at startup

* $\eta = -\ln(\tan(\theta/2))$

Status of the LHC

- Restarted injection tests within the past month
- First “beam splash” events of 2009 were recorded in CMS ~two weeks ago
- Circulating beams planned for this weekend!

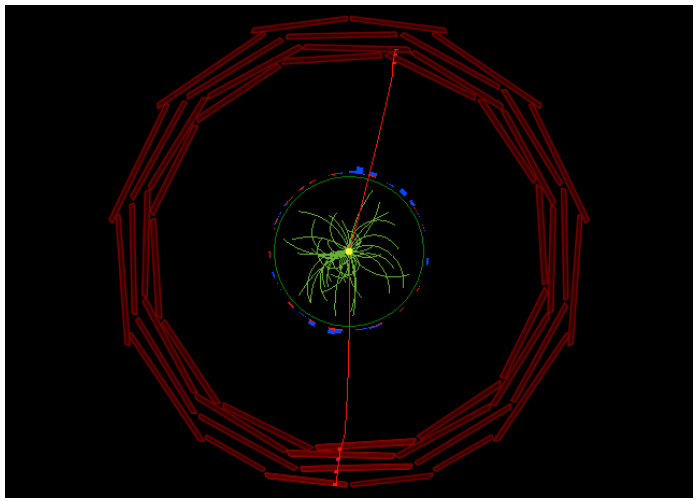


- Then plan to deliver first 900 GeV (and possibly 2.2 TeV) collisions before the end of the year, before shutdown and restart at 7 TeV in February

The physics

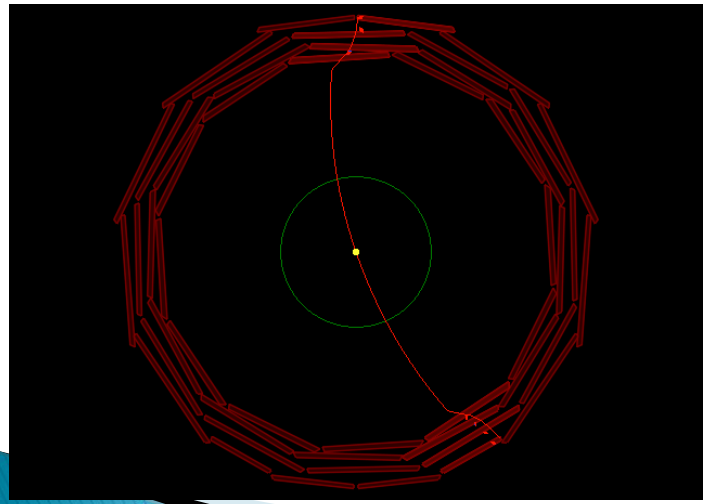
Exclusive dimuons

Drell-Yan MC



- In *pp* collisions, muon pairs are normally produced in association with additional "underlying event" activity
  - e.g. Drell-Yan ($q\bar{q}\rightarrow\mu\mu$)

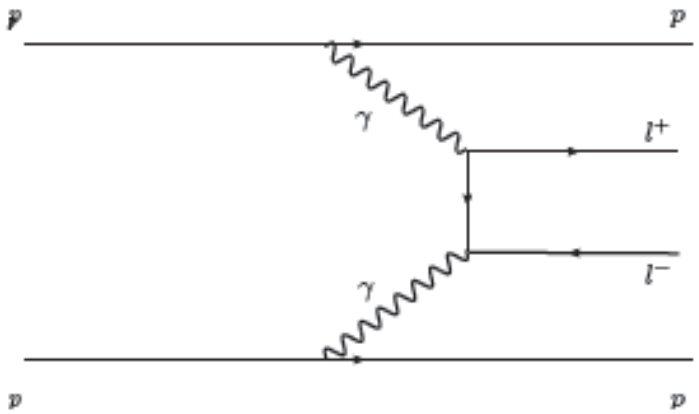
Exclusive MC



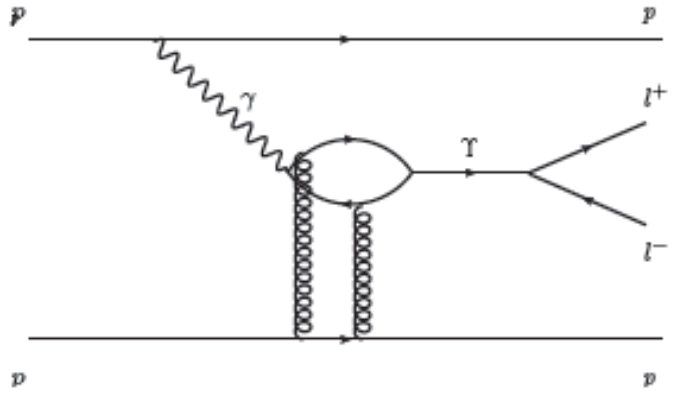
- In exclusive production ($pp\rightarrow p\mu\mu p$), the initial state protons remain intact and escape down the beamline
  - Final state is two muons back-to-back in ϕ and with equal p_T, and "nothing else"

Exclusive signal processes

- Two distinct sub-processes contribute
  - The same selection can be used for both!



- QED: non-resonant production from $\gamma\gamma \rightarrow \mu\mu$



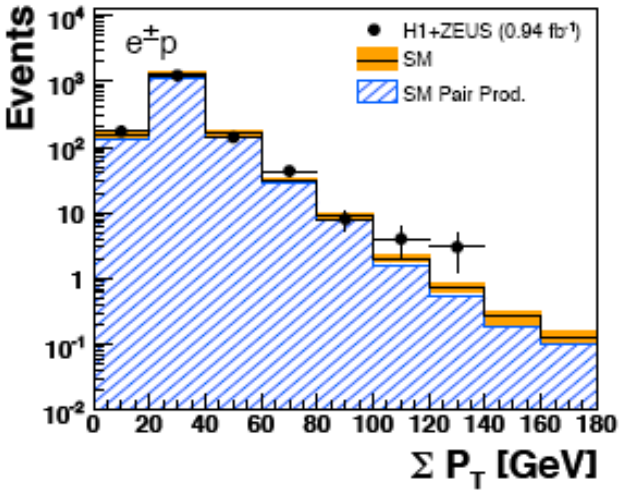
- Vector-meson photoproduction: resonant production through $\gamma p \rightarrow Yp \rightarrow \mu\mu p$

$\gamma\gamma \to \mu\mu$ Physics

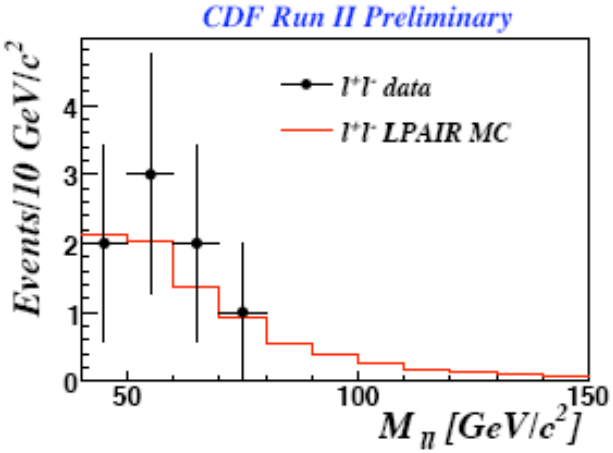
- Early data
  - One of the largest systematic uncertainties in many early cross-section measurements will be the integrated luminosity
    - Goal of ~10% uncertainty from machine scans, or from Z/W yields measured in CMS (dominated by PDF uncertainties)
  - Theoretical uncertainties on the elastic $\gamma\gamma \to \mu\mu$ cross-section are $\leq 1\%$
  - As a luminosity measurement, limited only by statistical and experimental systematic errors

- Longer term
  - Plans to search for Beyond Standard Model physics in very high energy $\gamma\gamma$ and γp interactions using forward proton spectrometers
  - $\gamma\gamma \to \mu\mu$ can be used as a "Standard Candle" for high-energy photon interactions, and an alignment sample for forward detectors

The competition

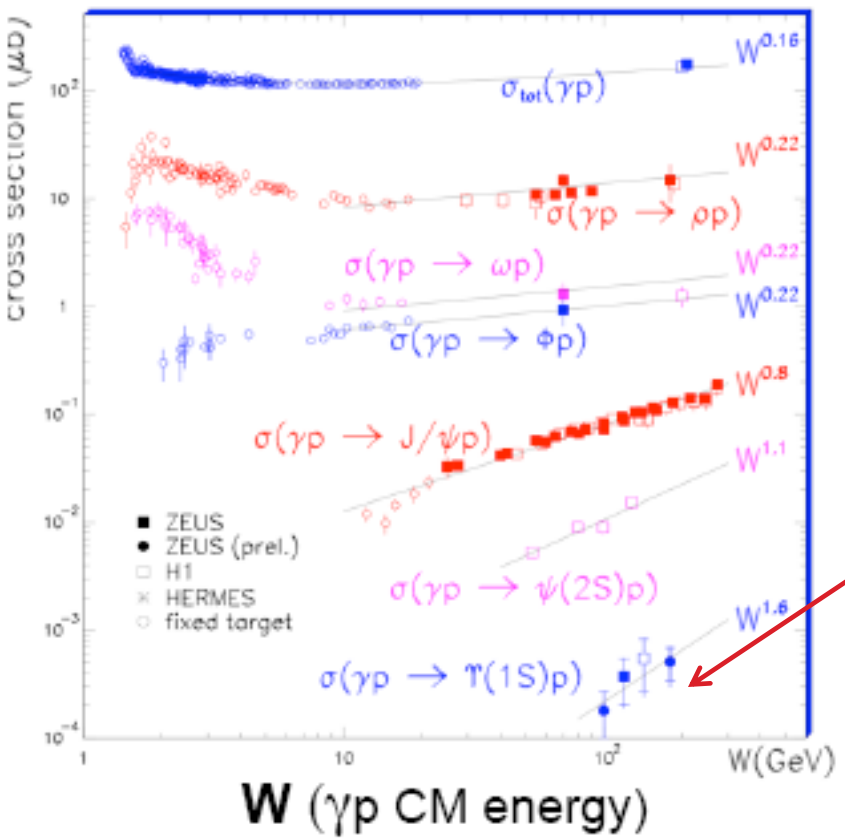


- Low-mass cross-sections for $\gamma\gamma \to ll$ have been measured in pp, ep, e^+e^-, and heavy-ion collisions, all in agreement with QED



- Tevatron (1.96 TeV $p\bar{p}$ collisions) and HERA (ep collisions) have observed events up to ~100 GeV
  - Limits on Beyond Standard Model processes for m $\geq$ m(Z)

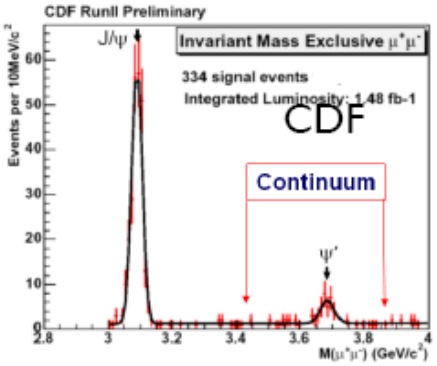
$\gamma p \rightarrow Yp$ Physics

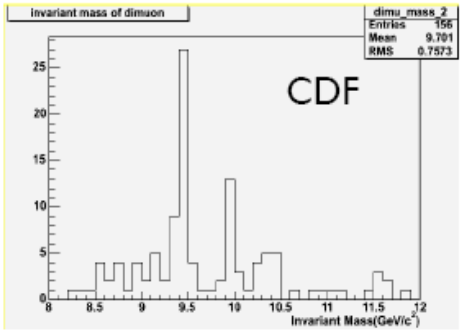


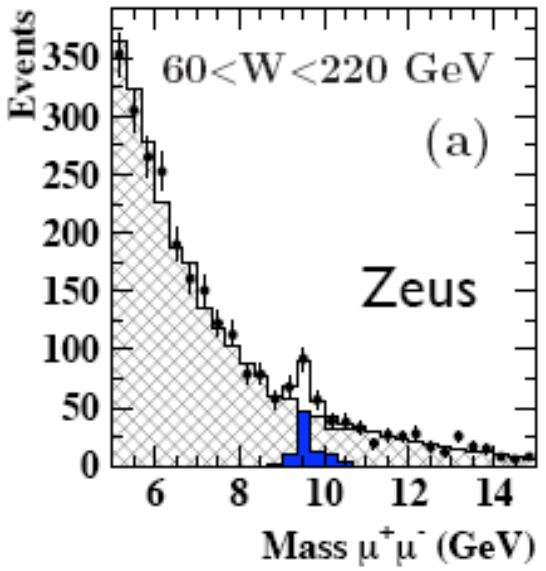
- When hard scales (heavy-flavors) are involved, expect perturbative QCD applies
  - Leading order pQCD predicts a steep rise in the cross-section with energy ($\sigma \sim W^{1.7}$)
- Light meson photoproduction has been well studied, limited data on the Υ cross-section
  - Theoretical predictions for LHC energies vary by a factor of 3 or more
- CMS will probe W values 2-5 times higher than the existing HERA measurements

The competition

- Selected recent photoproduction results
- Tevatron: Measurements of exclusive J/ψ and ψ(2S) cross-sections
  - Observation of exclusive Υ (preliminary)
- Final HERA results: Significant Υ signal, not able to resolve the three Upsilon resonances



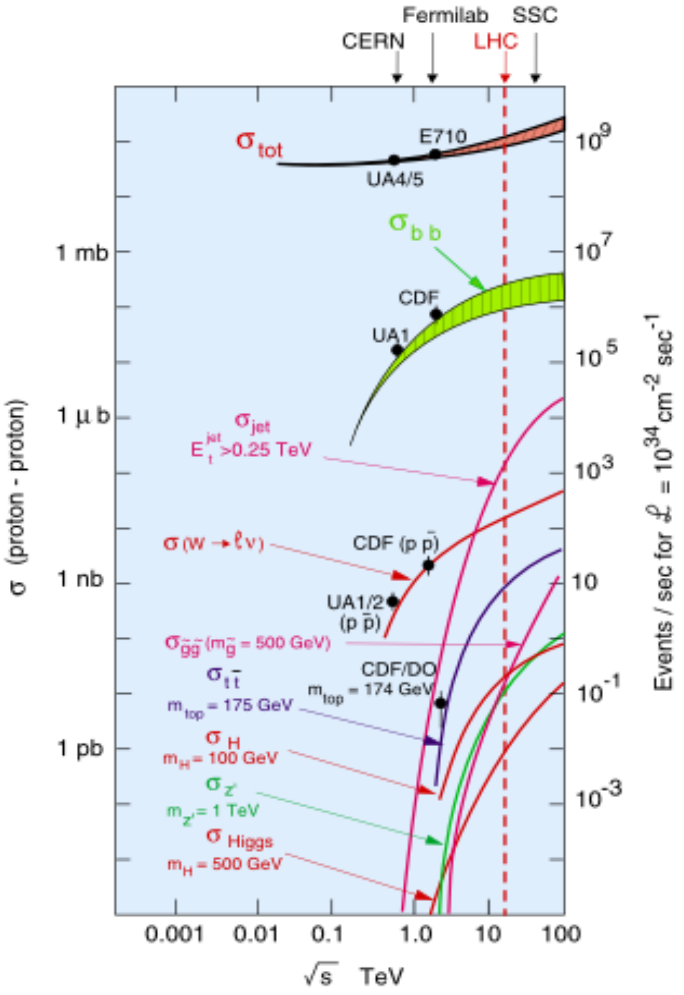




Exclusive dimuons in CMS

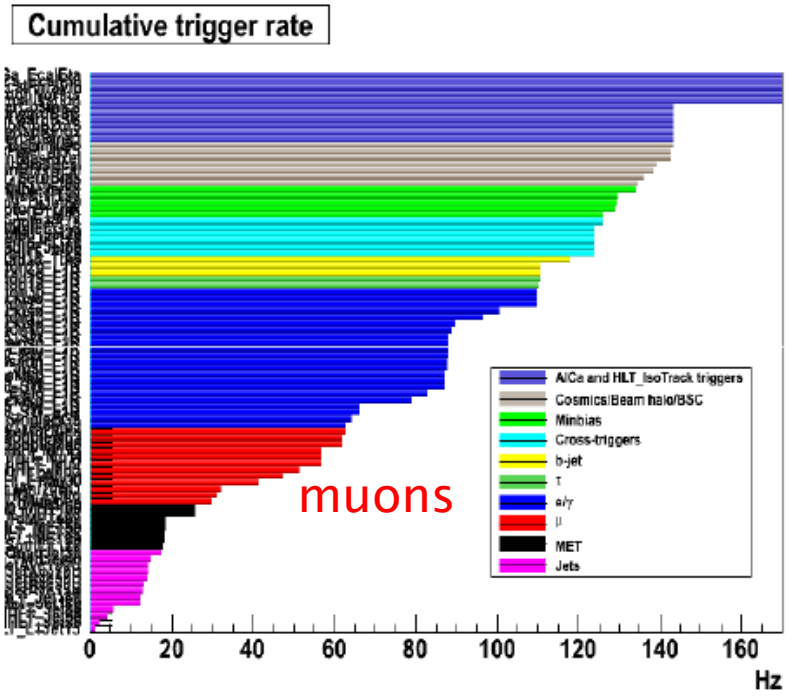
Trigger

- At 7 TeV and an instantaneous luminosity of 10^{31}, the predicted interaction rate is already O(1) MHz
- CMS uses a two-level trigger system to reduce the rate to tape of physics events to ~150 Hz
  - Level 1 hardware trigger (calorimeters and muon chambers only) with a maximum rate of 100kHz
  - Software High Level Trigger (including limited tracking & vertexing) further reduces this to ~150 Hz



Muon triggers

- The muon spectrum of the exclusive signal is peaked at very low p_T
  - Keeping the lowest possible trigger thresholds is necessary to retain signal
- CMS has early trigger menus with a range of complementary and backup muon triggers



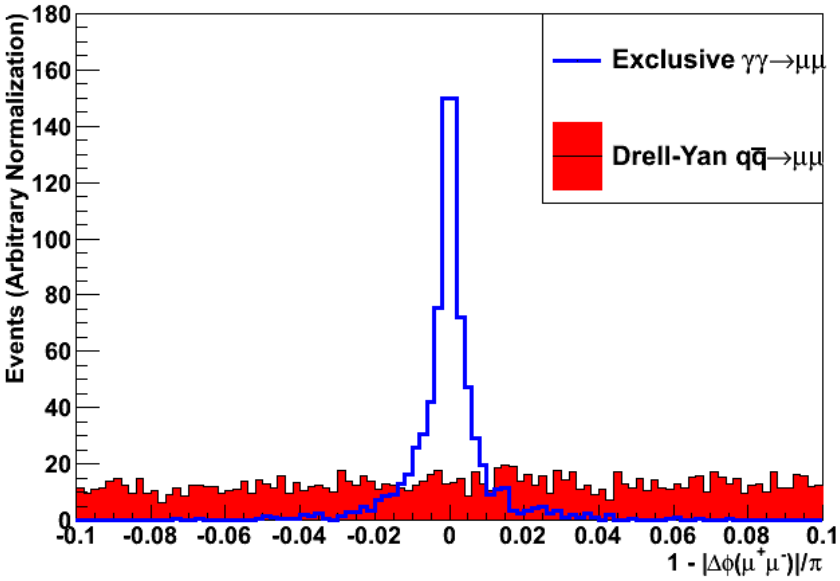
- Projections are that all dimuon events with $p_T(\mu) > 3$ GeV will be triggered up to luminosities above 10^{31}

Muon selection

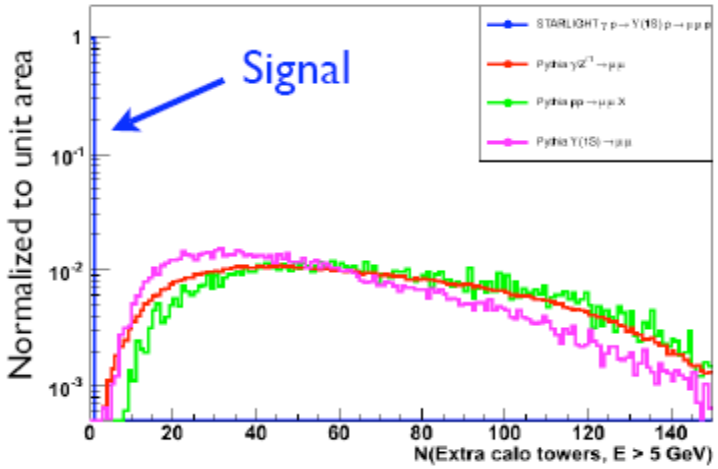
- Select events with opposite-sign muons, with a minimum number of segments hit in the muon chambers
  - 2 in the central region, 1 in the forward for low p_T muons

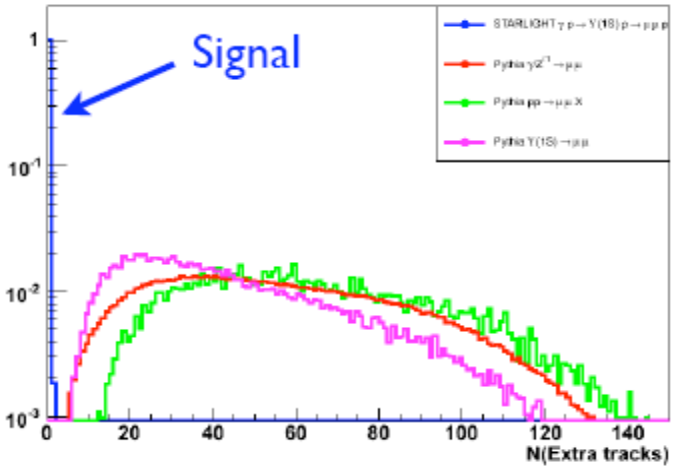
- Further requirements on the muon-pair kinematics
  - $|1 - \Delta\phi(\mu\mu)/\pi| < 0.08$
  - $|\Delta p_T(\mu\mu)| < 1.5$ GeV

- Signal appears as a narrow peak in $|1 - \Delta\phi(\mu\mu)|/\pi$



Exclusivity selection



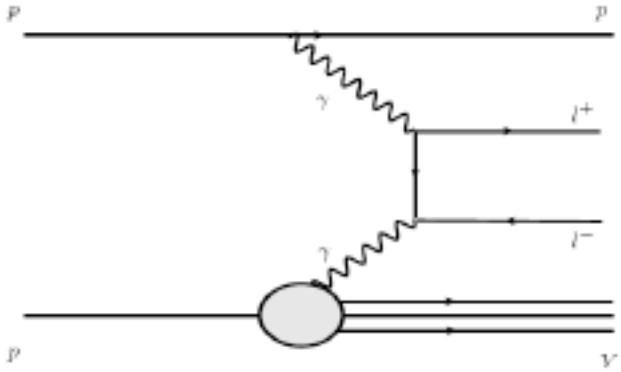


- Select events with
  - Zero charged tracks, except for the two muons
  - Less than 5 calorimeter towers above 5 GeV
- Signal gives a sharp peak at zero in both variables
- Inclusive backgrounds (Drell-Yan, QCD, inclusive quarkonium production) are expected to have significantly more activity

Efficiencies and backgrounds

Process	Efficiency (%)
$\gamma\gamma \to \mu\mu$	99.1±0.3
$\gamma p \to Y(1S)p$	99.4±0.6
$\gamma p \to Y(2S)p$	98.6±0.8
$\gamma p \to Y(3S)p$	99.1±0.6

- The efficiency for both the QED and Upsilon signals is expected to be >98%, relative to the triggered sample

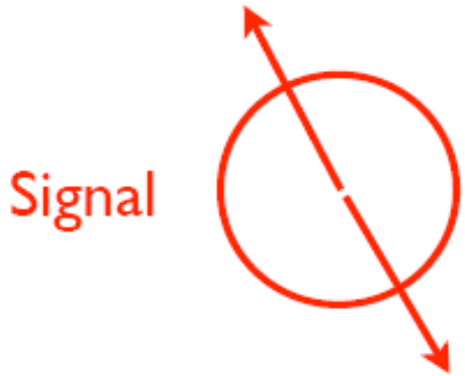


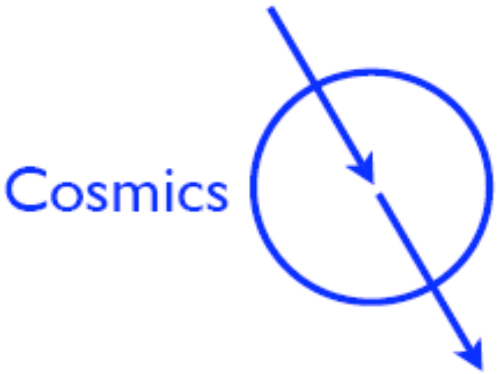
- After all selections, the largest remaining "background" in MC is inelastic photon exhange
  - Mimics the elastic signal when remnants of the dissociating proton escape undetected

Towards real data

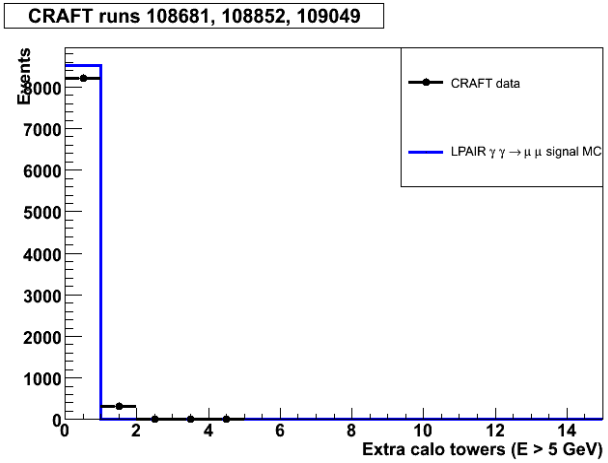
Cosmics and noise studies

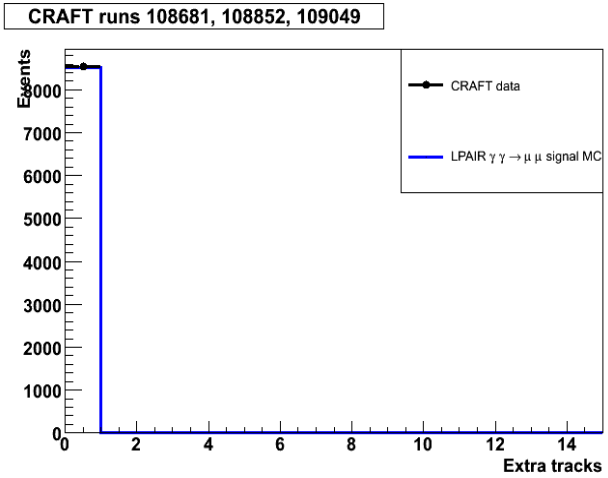
- CMS has logged several hundred million cosmic ray events in 2009
- These are real “exclusive muon” events!
- Can use these to study noise thresholds and effects on the signal efficiency without relying on Monte Carlo simulations





Cosmics results

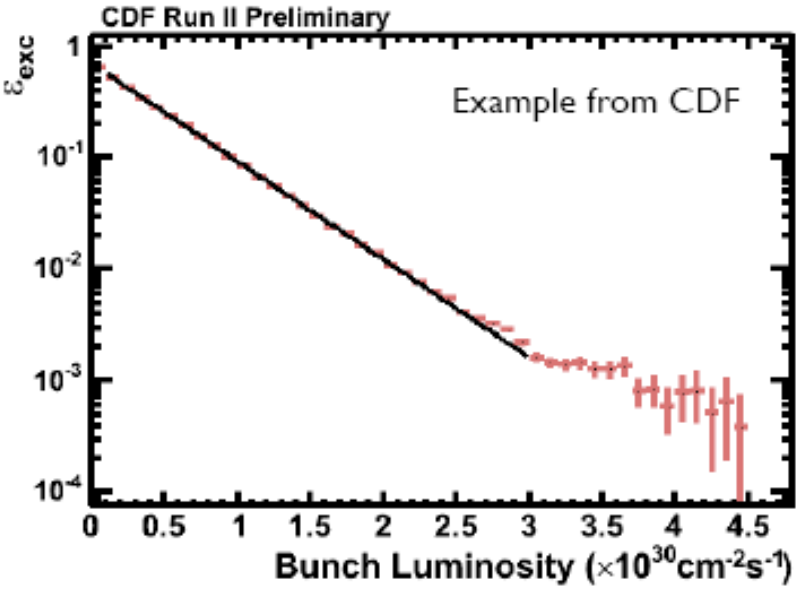




- ~16000 events of field-on data from 2009
- Select events with muons passing through the tracker acceptance
  - With two legs reconstructed in both top and bottom halves of CMS
- 100% of events pass the calo tower and track vetos, in agreement with the simulation

Pileup

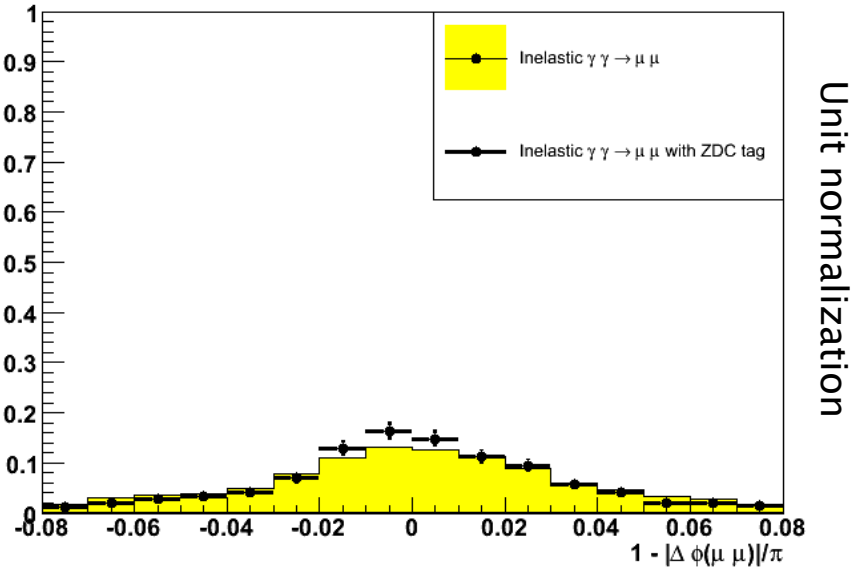
- The rate of multiple interactions per crossing ("pileup") will increase with luminosity
  - Leads to a decrease in the signal efficiency
- With real data, can be monitored using "Zero-Bias" triggers on beam-crossings



- From simulations, pileup of ~2 interactions/crossing leads to a 50% decrease in the signal efficiency
  - Corresponds to the largest pileup forseen for the first high-energy LHC run

Inelastic backgrounds from data

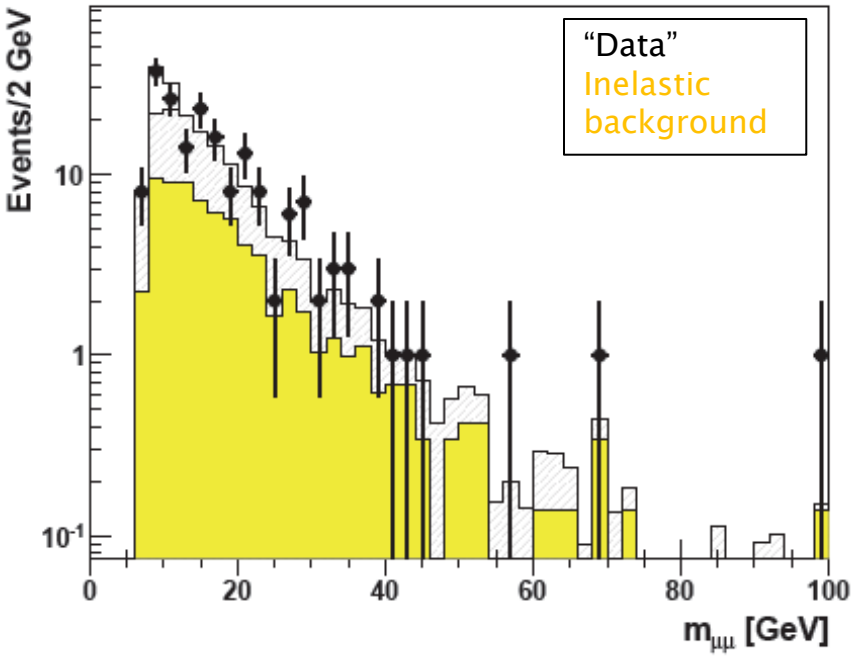
- The dominant inelastic backgrounds tend to produce high energy forward γ's and neutrons
- Can use the Zero Degree Calorimeter to veto or "tag" a control sample of these events



- Use the tagged sample to check the Monte-Carlo modeling of the inelastic background shape

Prospects for 20pb^{-1}at 7 TeV

(Possible) results



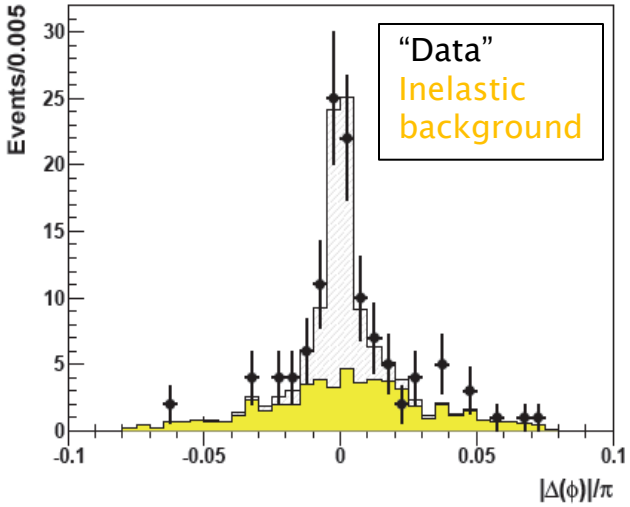
- For the final analysis, divide the sample into an "Υ region" (8–12 GeV) and a "QED region" (everything else)

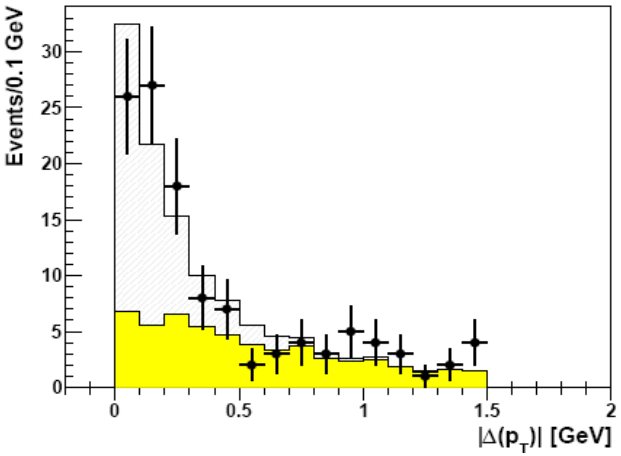
- Expect ~200 events passing all selections
- We should see
  - A continuum with events to 50–100 GeV
  - Some excess near 10 GeV
- We should not see
  - J/ψ (removed by trigger thresholds)
  - Z (spin-1 resonance production in $\gamma\gamma$ interactions is suppressed)
  - Any same sign dimuon pairs

The QED region

- In 20pb^{-1}, expect ~65 signal events with an equal number of inelastic background events
  - The two components can't be separated event-by-event
  - Can be done statistically by fitting the peak of the $|1 - \Delta\phi(\mu\mu)|/\pi$ distribution

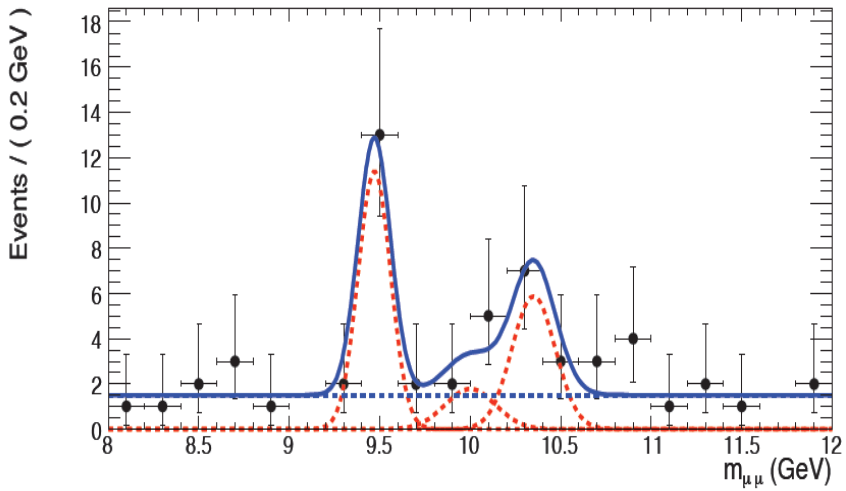
- Expected statistical error of 12-15% with 20pb^{-1}

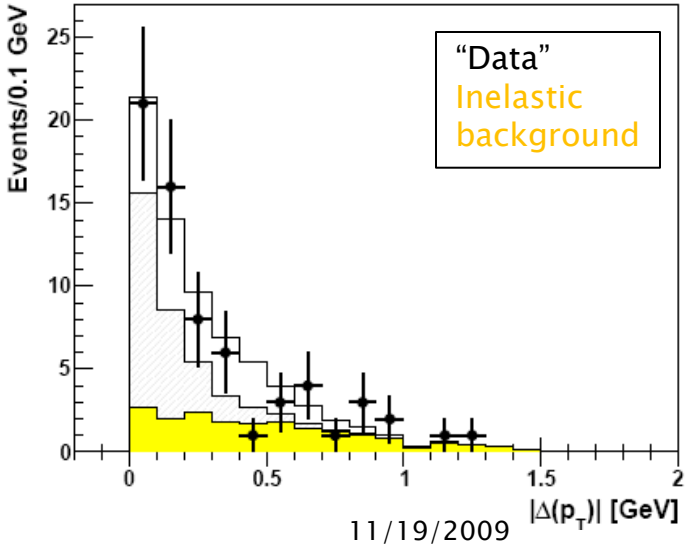




The Υ region

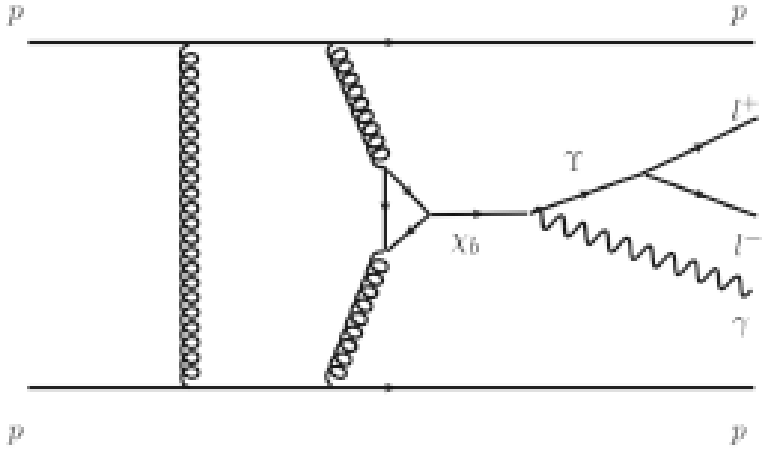
- Fit the mass spectrum in the 8–12 GeV region with 3 Gaussians and a flat QED background to extract the Upsilon yield
- For the upper range of cross-section predictions, expect ~20 events over the QED continuum
  - Alternatively, seeing no signal would already exclude a range of models
- The $|\Delta p_T|$ and $|1 - \Delta\phi(\mu\mu)|/\pi$ variables should also show a broader distribution than expected for pure QED

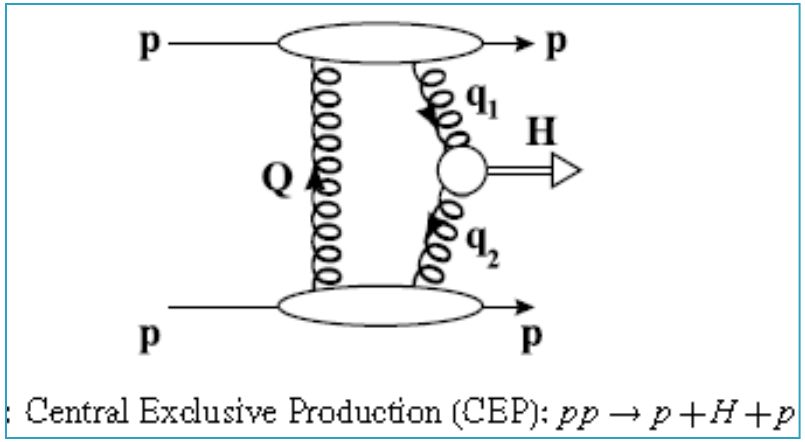




Beyond 20pb^{-1}: Exclusive χ_b

- Some fraction of the Υ(1S) signal will come from exclusive pseudo-scalar χ_b production
  - Difficult to distinguish the extra soft photon (< 400 MeV) when $\chi_b \rightarrow \Upsilon(1S)\gamma \rightarrow \mu\mu\gamma$





: Central Exclusive Production (CEP): $pp \rightarrow p + H + p$

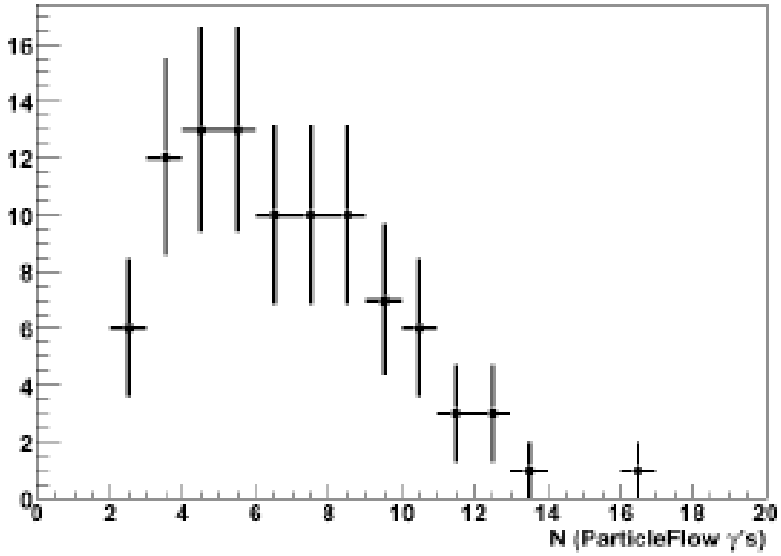
- Besides affecting interpretation of the Υ(1S) yield, this is closely related to exclusive Higgs production
  - χ_c measured at Tevatron, no previous results on exclusive χ_b

Prospects for χ_b in CMS?

- Efficiency for reconstructing the soft photon is approximately 21%
- Would give ~10 signal events in 100pb^{-1} (with very large theoretical uncertainties)

- Main challenge is purity of the low-energy photon selection

- For every real ~300 MeV photon, expect to find 5-10 "fakes"
  - Still to be determined if this can be improved enough for a viable analysis



Conclusions

- With 20pb^{-1} collected at 7 TeV, CMS expects to trigger on and reconstruct a significant number of exclusive dimuon events
- These events can be cleanly separated from the backgrounds using calorimeter/tracker exclusivity and the dimuon kinematics
  - Early data (with low-pileup) is favorable for doing this while keeping high signal efficiency
- Statistical+theoretical uncertainties on the QED sample could be below 15% already
  - Use for luminosity measurements will depend on controlling systematics with real data
- Should observe/limit Υ photoproduction at energies above any previous measurements

- Stay tuned for results with real data (hopefully soon)

Extras

Muon efficiencies

- Cross-section depends on the trigger, tracking, and muon reconstruction efficiencies
- Use the "Tag-&-Probe" method with inclusively produced J/ψ, Υ, Z
- Identify one leg of a resonance decay as a muon ("tag"), use the other leg as an unbiased sample to measure the efficiency ("probe")
- Preliminary tests show the efficiencies measured with inclusive Υ can be used to correct the QED signal without a significant bias