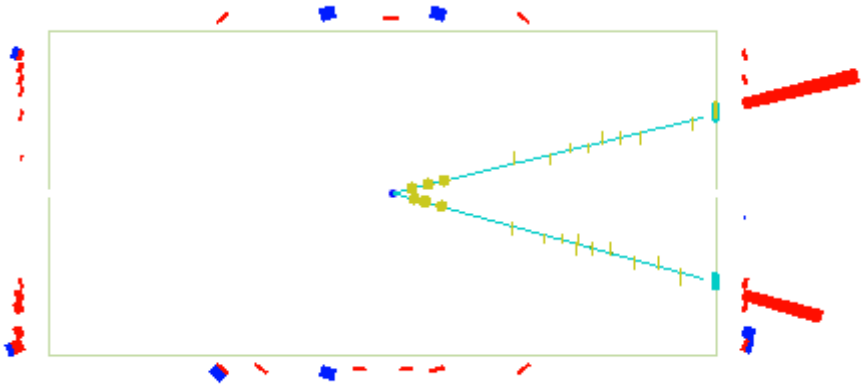

Central Exclusive Production in CMS

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Outline

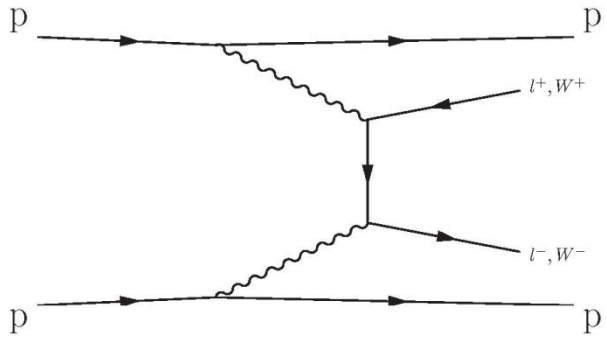
- Introduction
- The CMS Detector
- Exclusive dipohoton and dielectron production
  - Event selection
  - Result
- Exclusive dimuon production
  - Event selection
  - Signal extraction
  - Result
- Summary

Central Exclusive Production

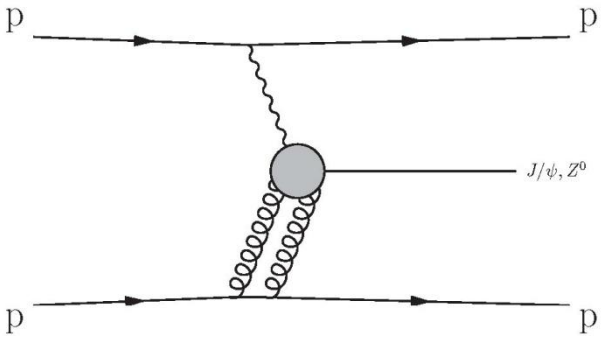
- Central exclusive production:

$$pp \rightarrow p + X + p$$

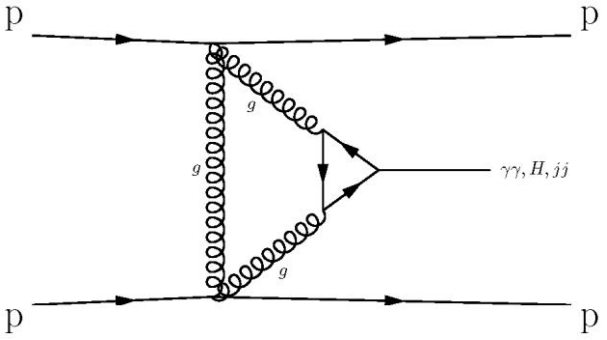
- Both protons stay intact after the interaction
- True rapidity gap and *X* is a simple fully measured system
- Exclusive: no other particles produced
- Cleanest, simplest and "NEW" inelastic pp collision
- Three distinct physics processes involved: γγ, γIP and IPIP interactions



γγ interaction : *X* = e^+e^-, $\mu^+\mu^-$



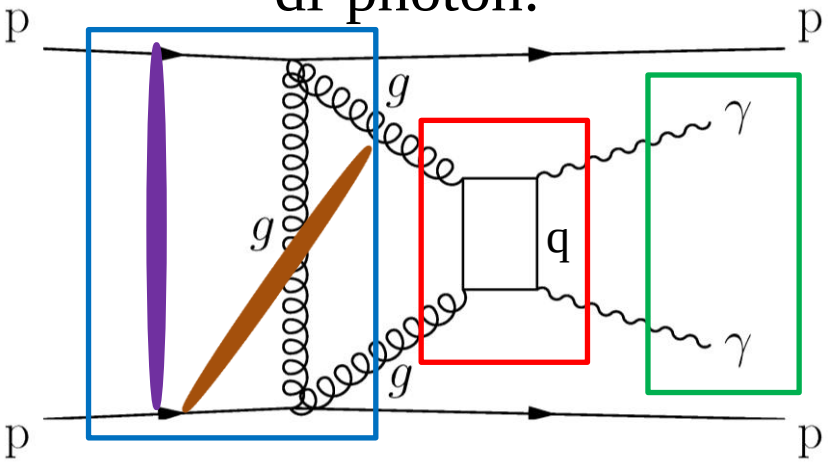
γIP fusion : *X* = Y, Z^0



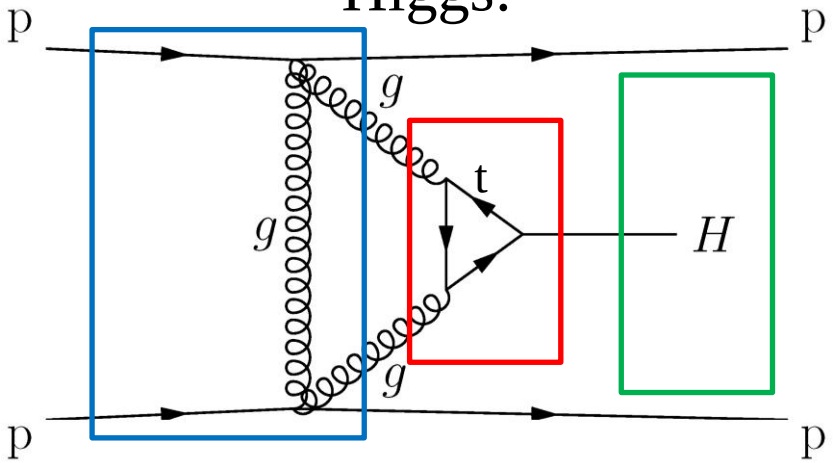
IPIP exchange : *X* = γγ, jj, H

Physics Motivation (IPIP→γγ)

di-photon:



Higgs:

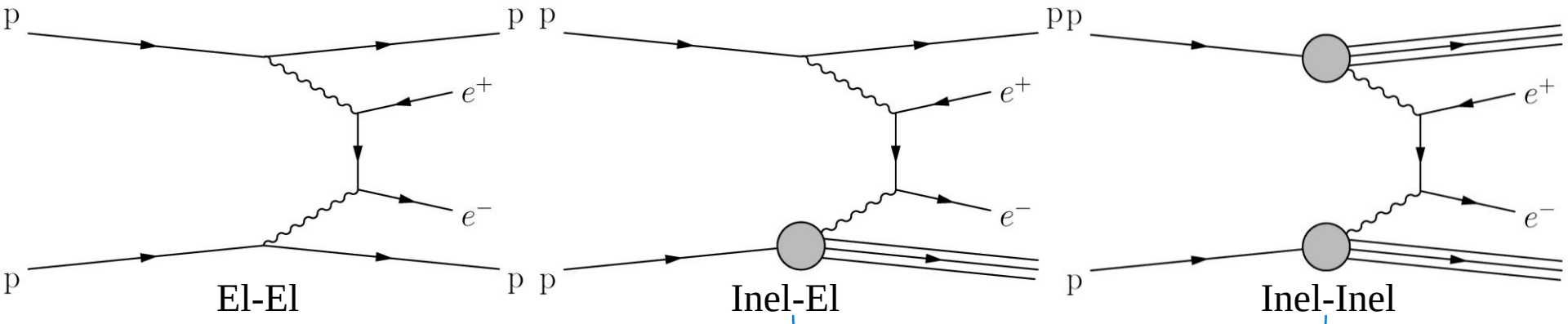


- Double pomeron exchange:
  - *gg* fusion through a quark loop to produce the central system
  - with a soft low-Q^2 screening gluon to cancel the exchanged color
  - Sudakov factor (no partons emitted by the fusing gluons)
  - Soft-survival probability (no additional inelastic pp scattering)

- Offers an ideal way to study diffractive and double pomeron exchange
  - Low-*x* gluon density ($\sigma \sim (xg)^4$)
  - Constraints on calculation of Sudakov factor and soft-survival probability

- Provide excellent test of the theoretical predictions of exclusive Higgs production
  - Theoretical predictions for *H* production: cover a range of over 2 orders of magnitude
  - Only the calculable matrix elements (red box) are different for H and γγ cases
  - $\frac{\mathrm{d}\sigma(M)}{\mathrm{d}M_{\gamma\gamma}} : \sigma_H(M)$ should be well determined theoretically

Physics Motivation ($\gamma\gamma \rightarrow l^+l^-$)



exclusive

semi-exclusive

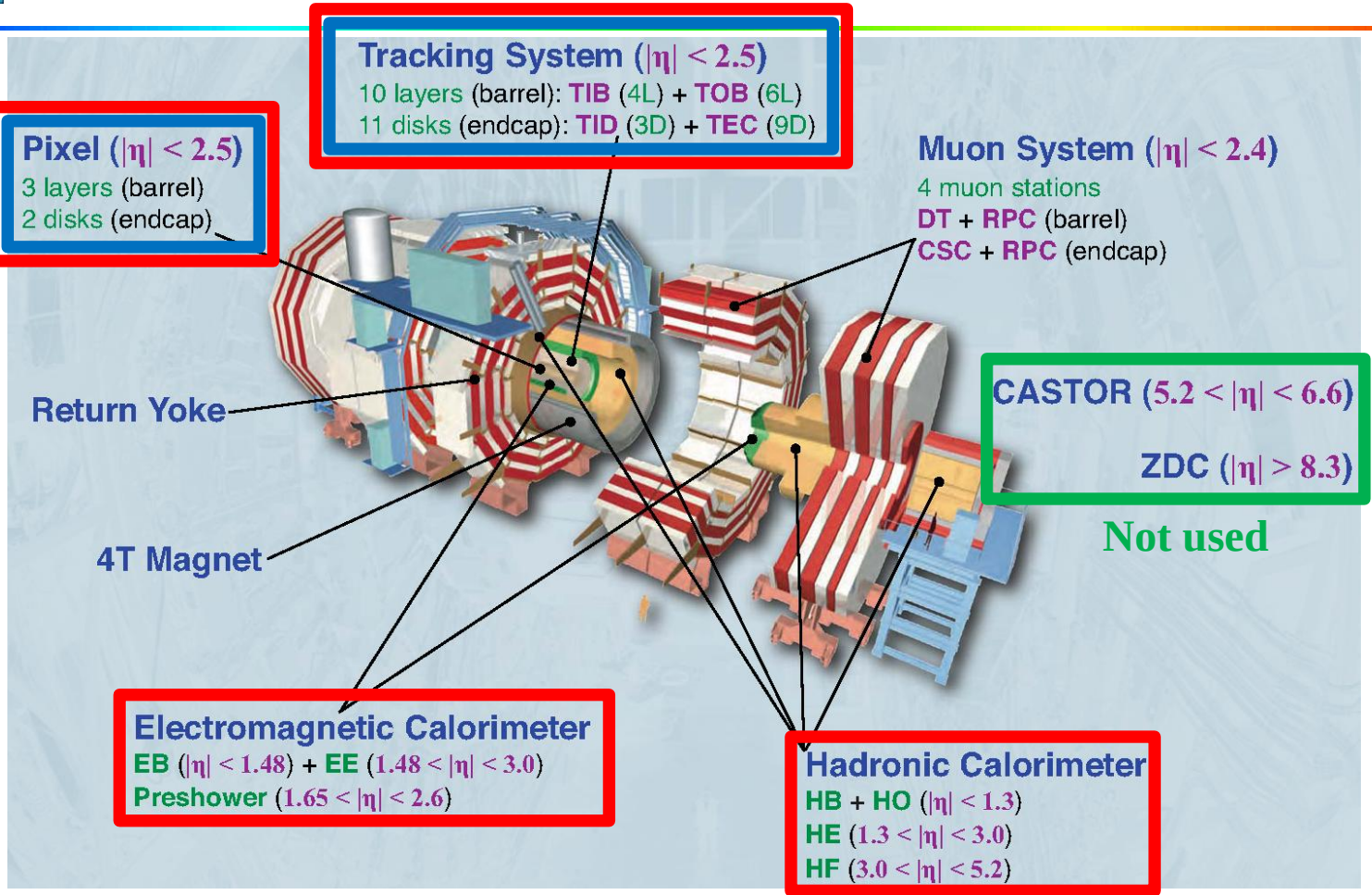
Exclusive production:

- Basically a QED process, cross section known with high accuracy at theoretical level (<1%).
- Provides a control sample for other exclusive processes
- Potentially interesting for future integrated luminosity measurement (provided that semi-exclusive production is well understood or well suppressed)

Semi-exclusive production:

- One or two protons are excited and diffractively dissociated.
- Much less theoretically determined
- Suppression of semi-exclusive events depends on the performance of the forward detectors (in CMS, this production will contribute more than half of the candidates)

The CMS Detector



Sub-detectors used to define exclusivity condition:

- Diphoton and dielectron analyses: Tracker + Calo (red box) (|η|<5.2)
- Dimuon analysis: Tracker only (blue box) (|η|<2.5)

Exclusivity condition: no other particles detected besides the two central particles

Exclusive $\gamma\gamma$ production
&
Exclusive e^+e^- production

FWD-11-004

Event Selection

- Any other non-exclusive interaction would spoil the exclusivity condition
- Only 2010 data sample used (low pile-up) ($36pb^{-1}$)

- Trigger: 2 EM showers with $E_T > 5GeV$
- Photon (electron) selection:
  - exactly two photons (electrons) with $E_T > 5.5GeV$ and $|\eta| < 2.5$
  - both pass identification cuts (dedicated for this analysis)
- Cosmic ray rejection criteria:
  - EM timing of the two photons (electrons)
    - $|t_1| < 2ns$ and $|t_2| < 2ns$
    - $|t_1 - t_2| < 2ns$
  - $\Delta\varphi > 2.5$ rad
  - No segments in the DT and CSC
- Exclusivity selection criteria (overriding part):
  - No additional tracks ($|\eta| < 2.5$)
  - No additional towers above noise thresholds in EB, EE, HB, HE and HF ($|\eta| < 5.2$)

Additional: not associated to the two central photons (electrons)
Noise threshold: determined using unpaired events and zerobias events
Exclusivity efficiency: 14.5%

Result

Number of events remaining after each selection:

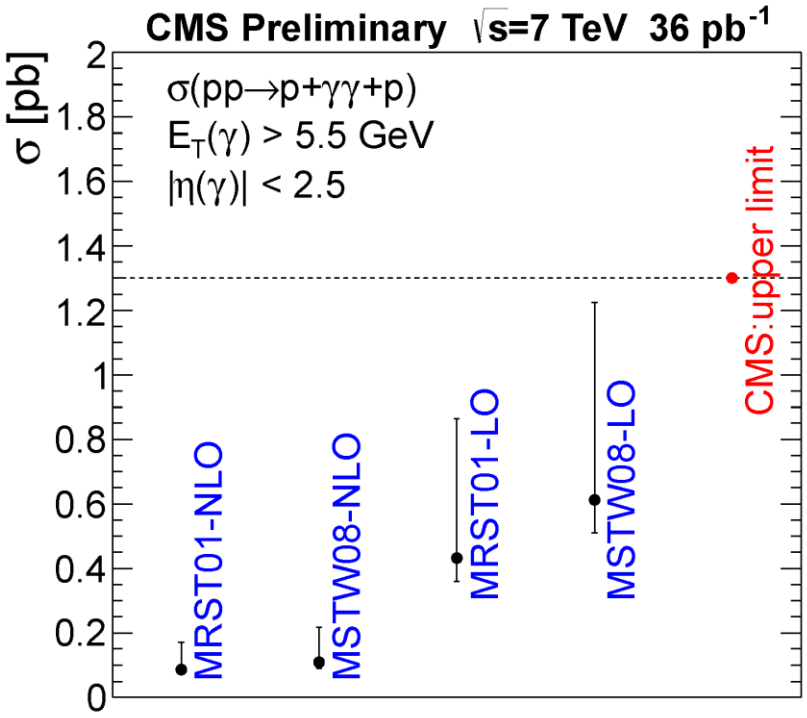
exclusive diphoton analysis		exclusive dielectron analysis	
selection criterion	events remaining	selection criterion	events remaining
Trigger	3 023 496	Trigger	3 023 496
Photon reconstruction	1 683 526	Electron reconstruction	132 271
Photon identification	40 692	Electron identification	2 648
Cosmic ray rejection	32 775	Cosmic ray rejection	2 023
Exclusivity requirement	0	Exclusivity requirement	17

Number of background events:

exclusive $\gamma\gamma$ production		exclusive e^+e^- production	
Background	Events	Background	Events
exclusive e^+e^-	0.11 ± 0.03	exclusive $\Upsilon(1S,2S,3S) \to e^+e^-$	negligible
cosmic ray	negligible	cosmic ray	0.04 ± 0.01
non-exclusive	1.68 ± 0.40	non-exclusive	0.80 ± 0.28
exclusive $\pi^0\pi^0$ and $\eta\eta$	negligible	exclusive $\pi^+\pi^-$	negligible
Total	1.79 ± 0.40	Total	0.84 ± 0.28

Result ($\gamma\gamma$)

- 95% confidence level upper limit: $\sigma^{E_T(\gamma)>5.5\,\mathrm{GeV},\,|\eta(\gamma)|<2.5}_{\text{exclusive }\gamma\gamma\text{ production}} < 1.30\ \mathrm{pb}$
- This upper limit is actually on the cross section for the sum of
  - exclusive (el-el) production
  - semi-exclusive (inel-el and inel-inel) production with no particles from the proton dissociation having $|\eta| < 5.2$. (less controlled theoretically) (difficult to calculate its contribution precisely) (but is expected to be of similar magnitude)



Theoretical predictions: exclusive (el-el) only

Difference between LO and NLO results reflect mostly the difference of low-*x* gluon density.

Error bar shows the uncertainties coming from:
cross section of $gg\to\gamma\gamma$
Sudakov factor
Soft-survival probability

Predictions would be higher by a factor of ~2 if contribution from semi-exclusive included.

Result (e^+e^-)

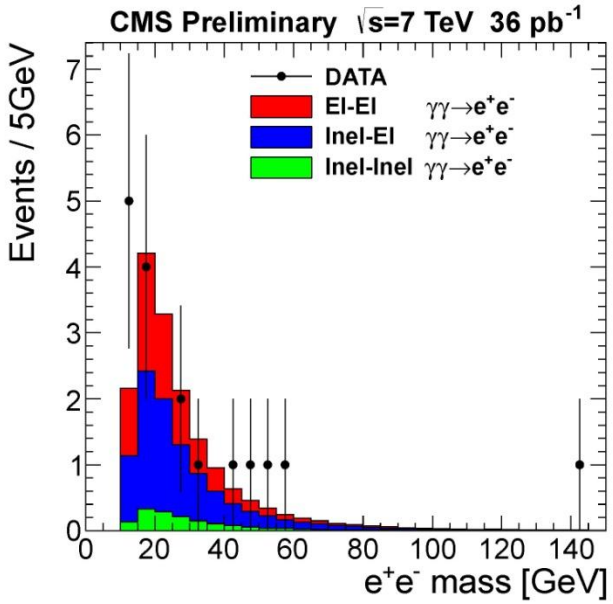
Number of candidates expected:

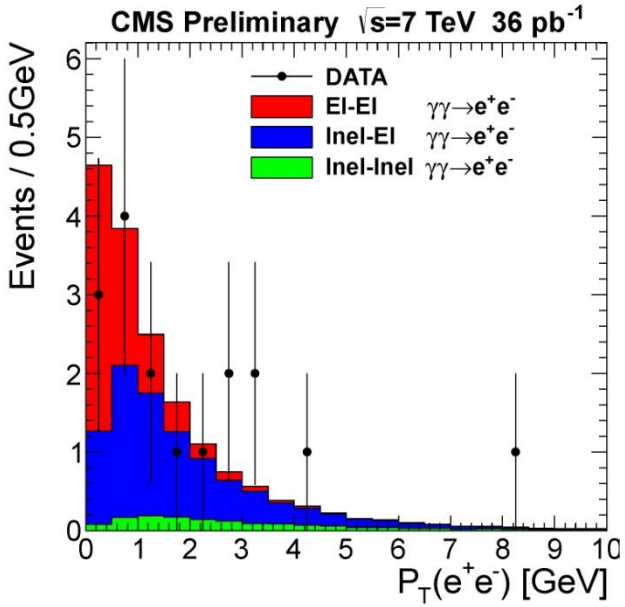
Process	$\mathcal{L}$	σ	ε	nEvents
el-el	$36\pm1.4\,\mathrm{pb}^{-1}$	3.74 ± 0.04 pb	0.0488 ± 0.0056	6.57 ± 0.07 (theo.)±0.80 (syst.)
inel-el	$36\pm1.4\,\mathrm{pb}^{-1}$	3.34 ± 0.67 pb $\times2$	0.0348 ± 0.0035	8.37 ± 1.68 (theo.)±0.90 (syst.)
inel-inel	$36\pm1.4\,\mathrm{pb}^{-1}$	3.52 ± 0.70 pb	0.0119 ± 0.0011	1.51 ± 0.30 (theo.)±0.15 (syst.)
Total				16.5 ± 1.7 (theo.)±1.2 (syst.)

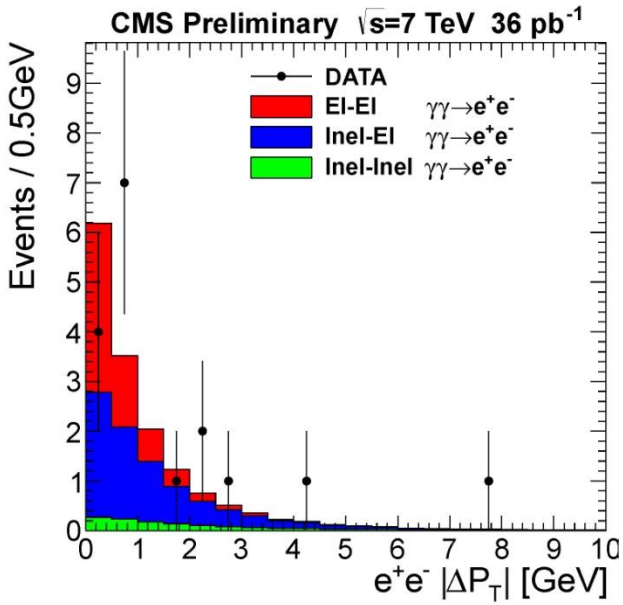
- 17 exclusive e^+e^- events on a background of 0.84 ± 0.28 events are observed.
- The theoretical prediction is 16.5 ± 2.1 events.
- Observation in good agreement with QED prediction (LPAIR generator).
- The kinematic distributions are in good agreement with simulation (next slide)

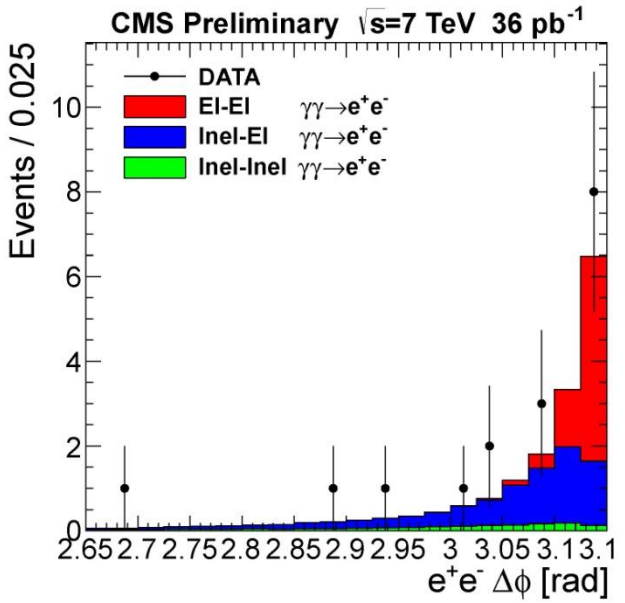
- Validate the technique used in this analysis, especially the exclusivity selection.
- Give confidence to the exclusive $\gamma\gamma$ result.

Result (e^+e^-)

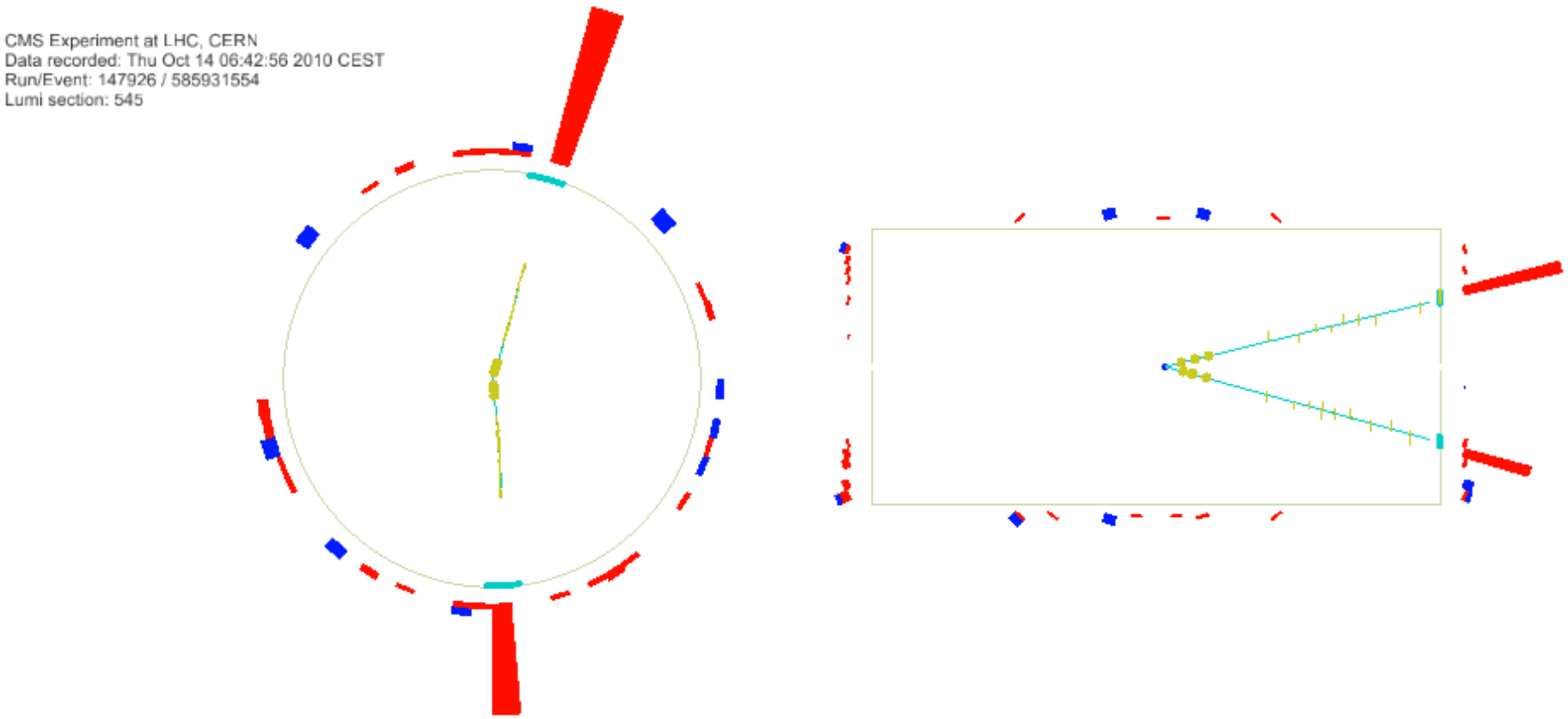

CMS Preliminary √s=7 TeV 36 pb-1
DATA
EI-EI γγ→e+e-
Inel-EI γγ→e+e-
Inel-Inel γγ→e+e-
Events / 5GeV
e+e- mass [GeV]


CMS Preliminary √s=7 TeV 36 pb-1
DATA
EI-EI γγ→e+e-
Inel-EI γγ→e+e-
Inel-Inel γγ→e+e-
Events / 0.5GeV
PT(e+e-) [GeV]


CMS Preliminary √s=7 TeV 36 pb-1
DATA
EI-EI γγ→e+e-
Inel-EI γγ→e+e-
Inel-Inel γγ→e+e-
Events / 0.5GeV
e+e- |ΔPT| [GeV]


CMS Preliminary √s=7 TeV 36 pb-1
DATA
EI-EI γγ→e+e-
Inel-EI γγ→e+e-
Inel-Inel γγ→e+e-
Events / 0.025
e+e- Δϕ [rad]

Display of one exclusive event



Exclusive $\mu^+\mu^-$ production

FWD-10-005

Event Selection

- Full 2010 data sample used (low pile-up) ($40pb^{-1}$)
- Both events with and without pileup are used (exclusivity in tracker only)

- Unlike dielectron analysis, only exclusive (el-el) events are considered as signal

- Trigger: 2 muons with $p_T > 3GeV$
- Muon selection:
  - Two muons with $p_T > 4GeV$ and $|\eta| < 2.1$
  - Both pass tight identification cuts
  - Coming from the same primary vertex
- Muon pair kenimatics:
  - $\Delta p_T(\mu\mu) < 1.0$ (balanced in p_T)
  - $1-|\Delta\phi(\mu\mu)| < 0.1$ (back to back in ϕ)

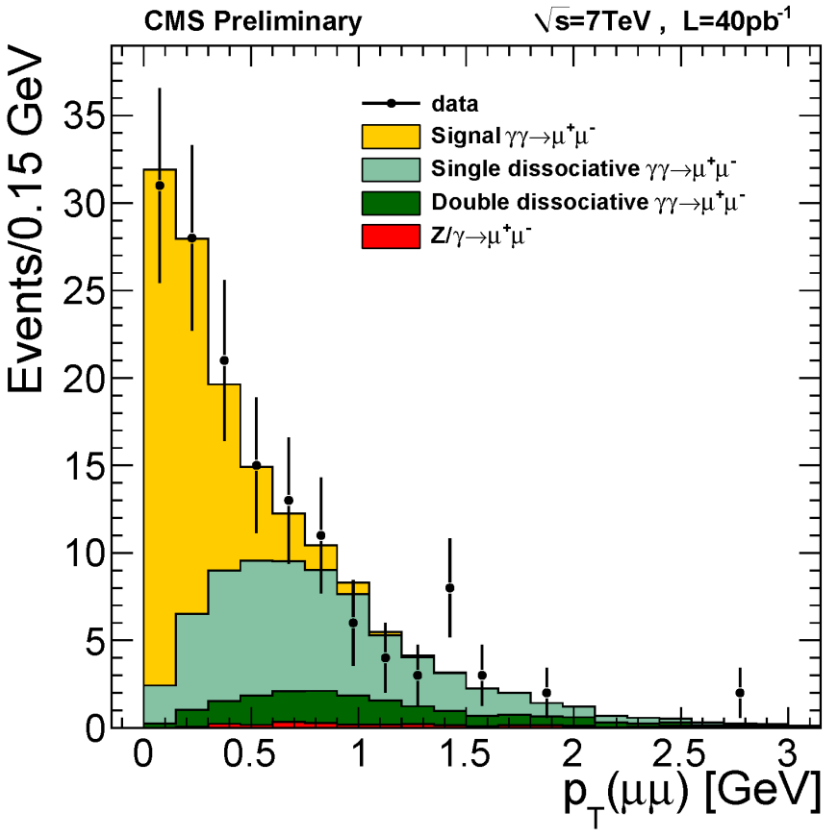
  } Suppress contributions from non-exclusive and semi-exclusive production

  - $m(\mu\mu) > 11.5$ GeV (be safe from Y(1S,2S,3S) photoproduction)
  - 3D opening angle $> 0.95\pi$ (reject cosmic ray events)
- Exclusivity selection criteria (vertex exclusivity only):
  - no extra tracks from the dimuon primary vertex
  - no other tracks within 2mm of the dimuon vertex

- Exclusivity efficiency: 92.3%

much higher than the case using ideal exclusivity requirements (Tracker + Calo) (15%)

Signal Extraction



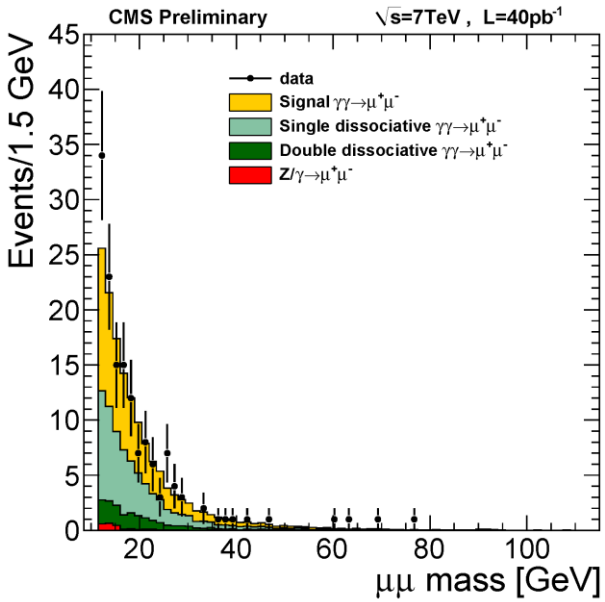
- After all selections, 148 events remain (~50% expected to be from proton dissociation)
- Signal (el-el) is extracted with a binned maximum likelihood fit to the $p_T(\mu\mu)$ distribution with 3 free parameters:
  - Signal yield
  - Single proton dissociation yield
  - Correction to the exponential slope of single proton dissociation
- Double proton dissociation and Drell-Yan normalization are fixed from MC, and varied as systematic uncertainties

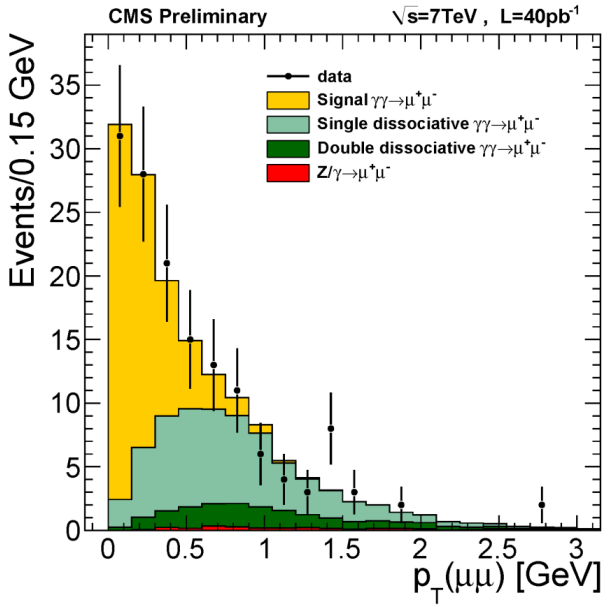
For $p_T(\mu) > 4$ GeV, $|\eta(\mu)| < 2.1$ and $m(\mu\mu) > 11.5$ GeV, the measured cross section and the ratio to the LPAIR prediction are:

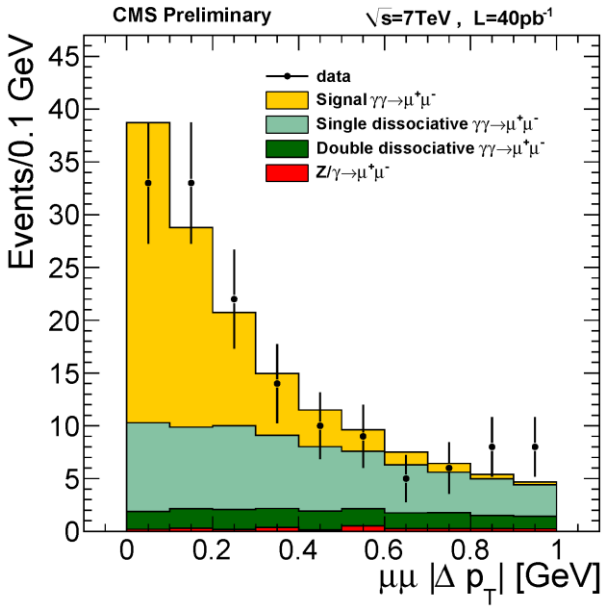
$$\sigma = 3.38^{+0.58}_{-0.55}\,(\text{stat.}) \pm 0.16\,(\text{syst.}) \pm 0.14\,(\text{lumi.})\ \text{pb}$$

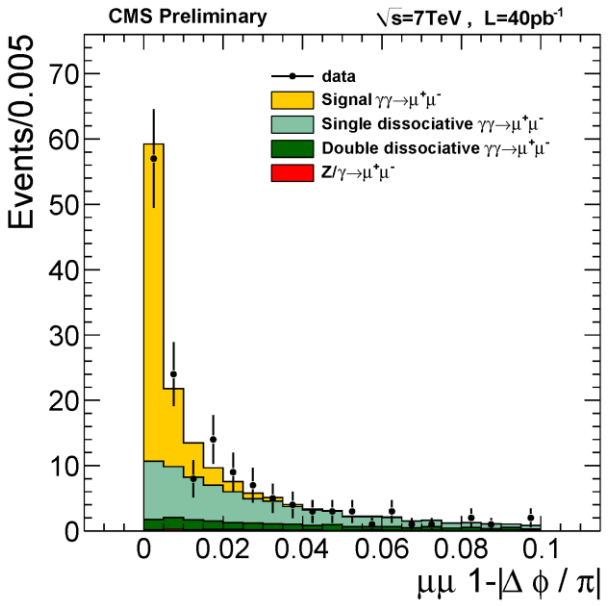
$$R = 0.83^{+0.14}_{-0.13}\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$

Kinematic distributions









Conclusion

- First search for exclusive diphoton production at 7TeV pp collisions is performed.
- No diphoton candidate survived all the selection criteria.
- An upper limit on the cross section is set at 1.30 pb with 95% confidence level.
- Provides some constraint on the theoretical calculation.

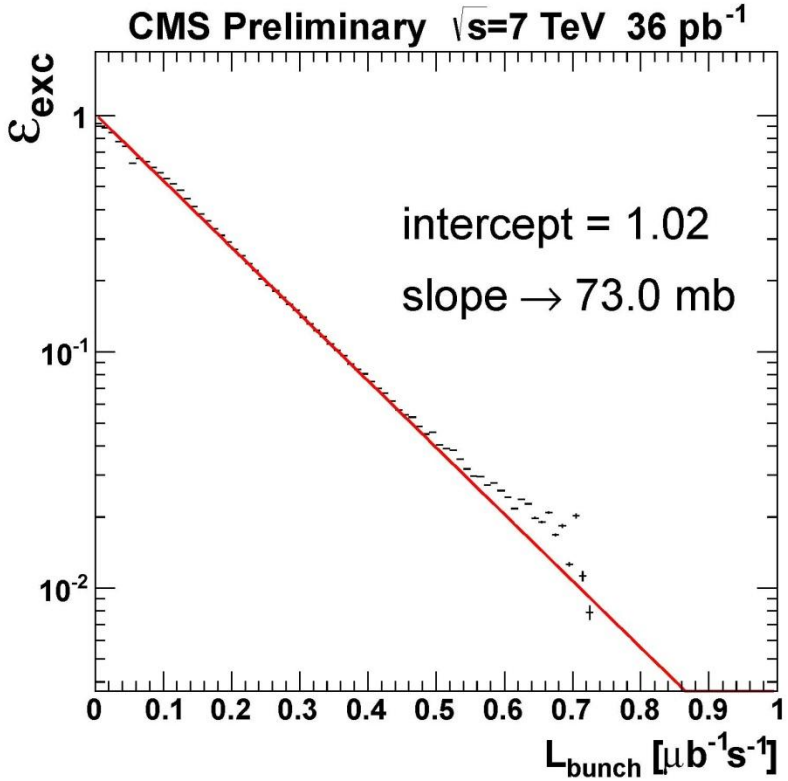
- 17 dielectron candidates on top of a background of 0.84 events are observed from both exclusive and semi-exclusive dielectron production while the predicted number is 16.5 ± 2.1.
- Both the number of candidates and the kinematic distributions are in good agreement with QED predictions evaluated from LPAIR generator.

- For $p_T(\mu) > 4\text{GeV}$, $|\eta(\mu)| < 2.1$ and $m(\mu\mu) > 11.5\text{GeV}$, a cross section of exclusive dimuon production is measured:

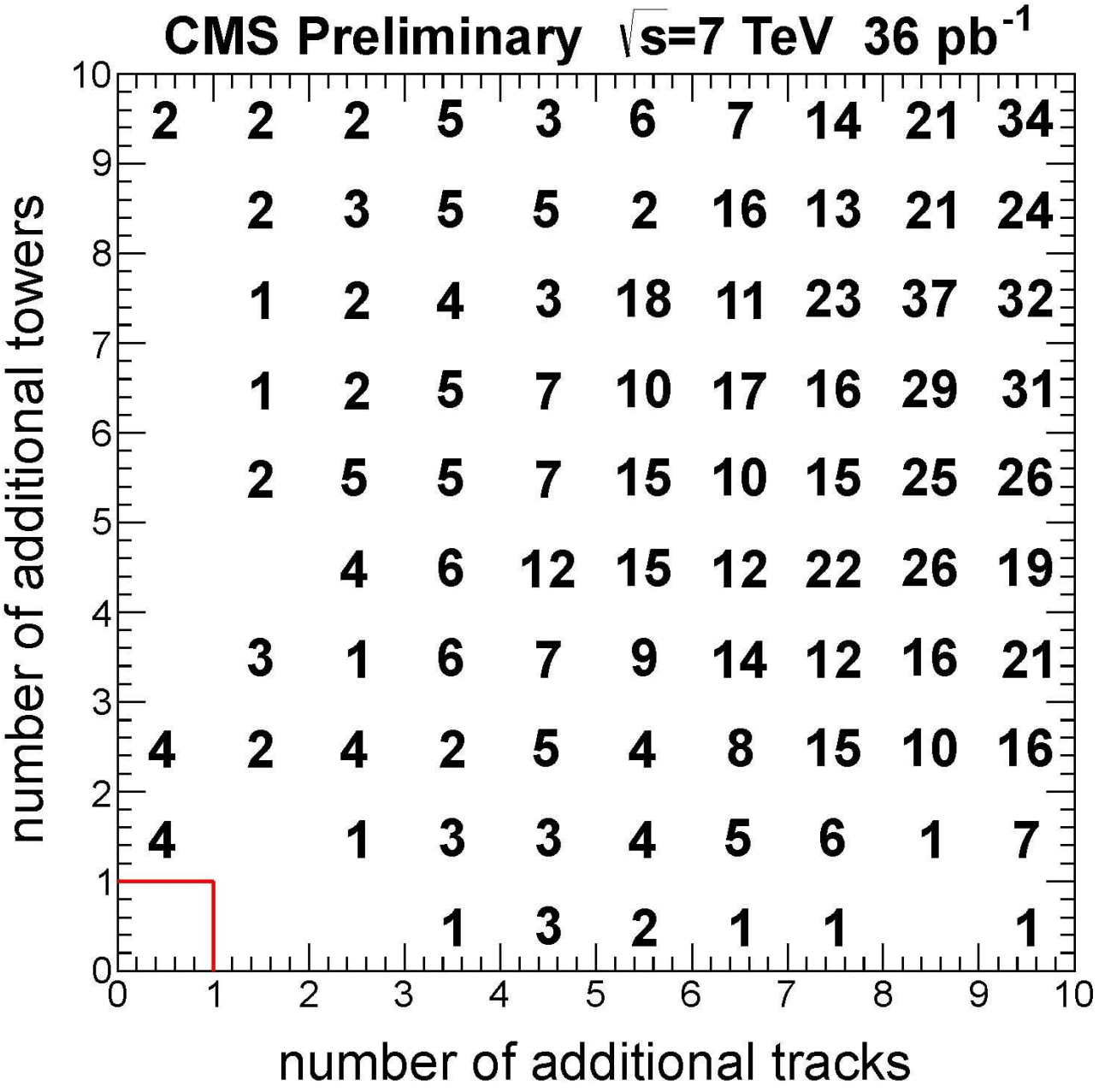
$$\sigma = 3.38^{+0.58}_{-0.55}\,(\text{stat.}) \pm 0.16\,(\text{syst.}) \pm 0.14\,(\text{lumi.})\ \text{pb}$$

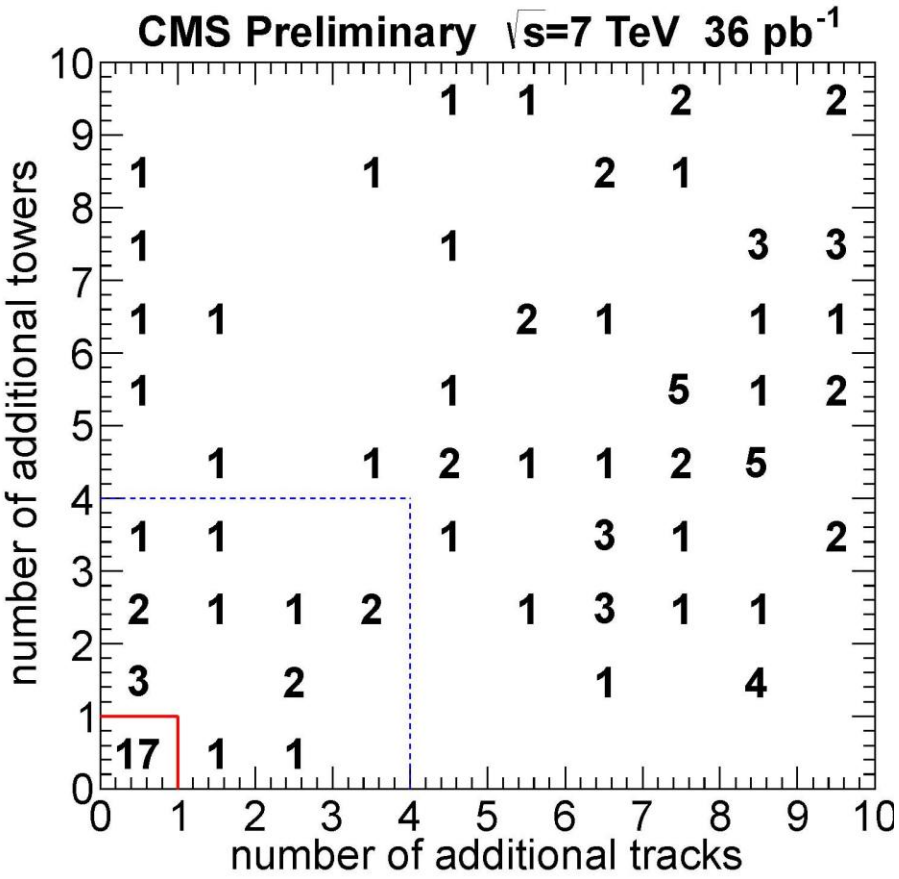
Thank you !

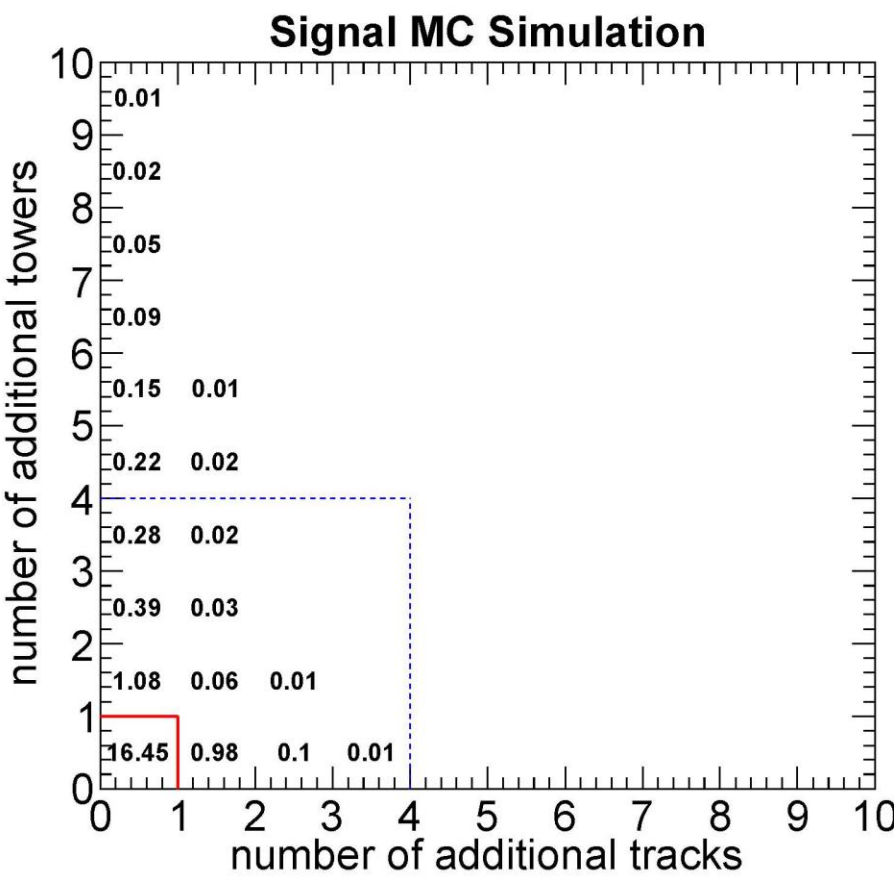
$$\varepsilon_{\text{exc}}(\mathcal{L}_{\text{bunch}}) = \frac{N^{\text{exc}}_{\text{zerobias}}(\mathcal{L}_{\text{bunch}})}{N_{\text{zerobias}}(\mathcal{L}_{\text{bunch}})} \approx e^{-\overline{n}} = e^{-\mathcal{L}_{\text{bunch}} \cdot \sigma_{\text{inelastic}} / f}$$

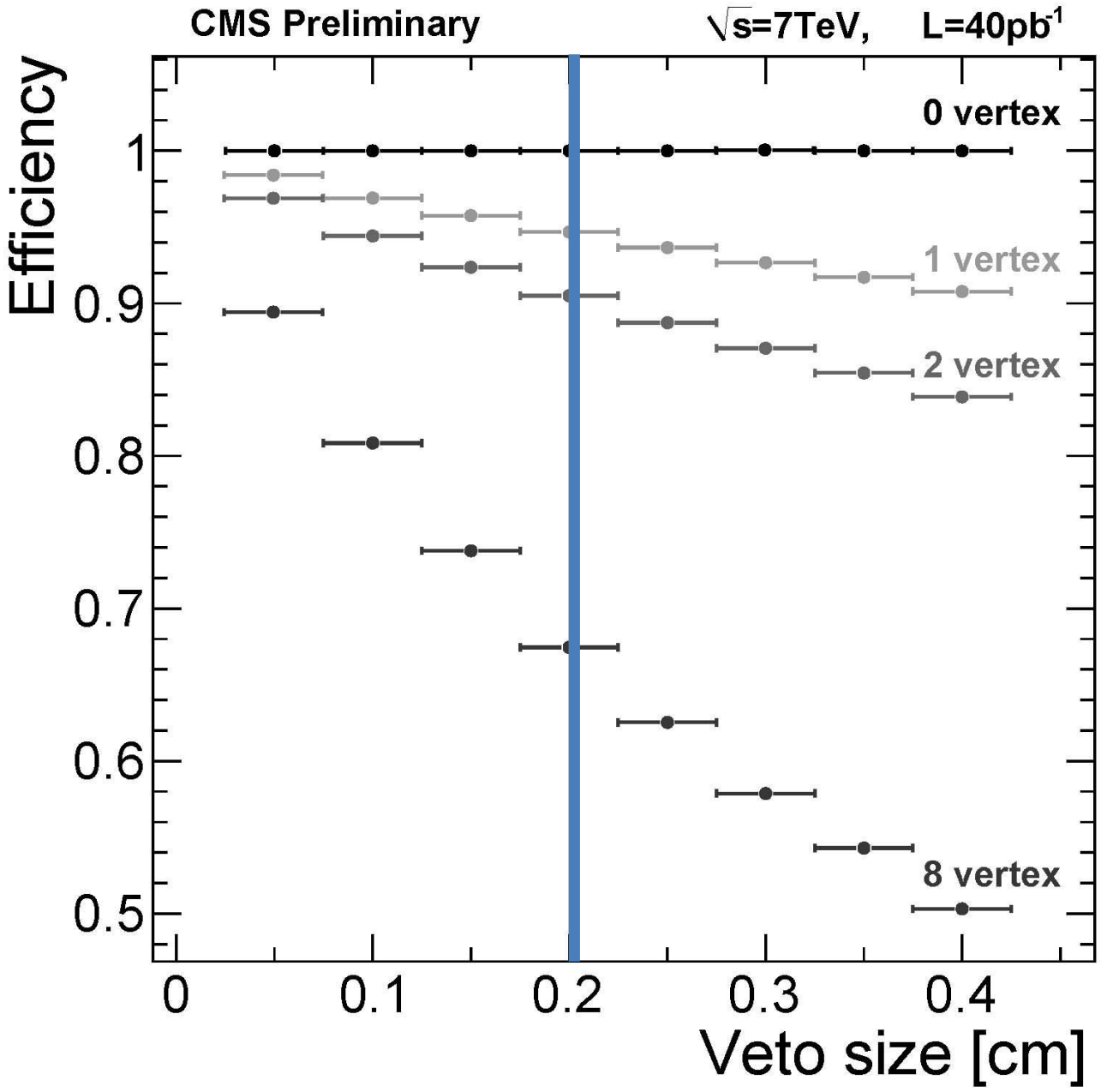


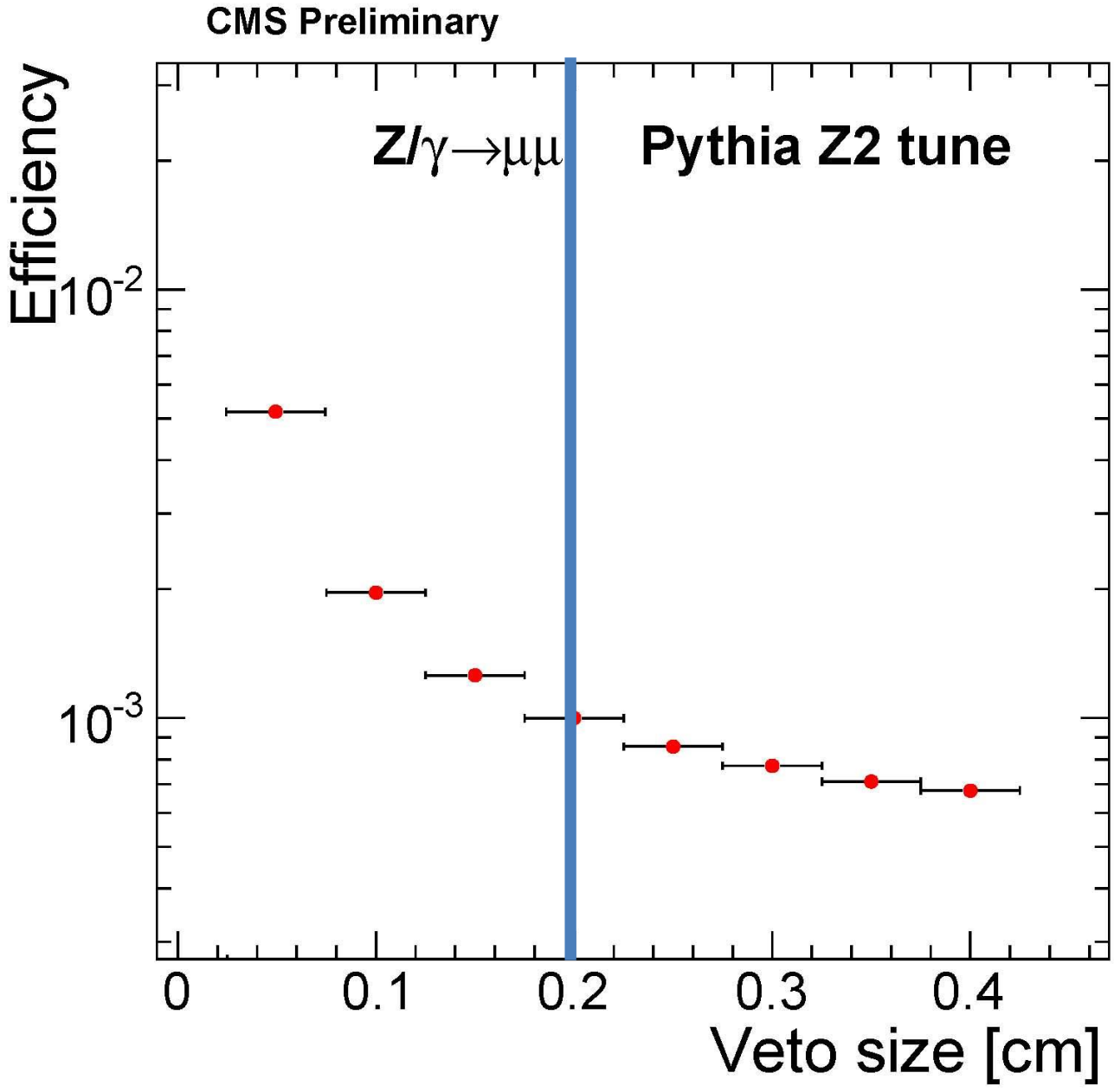
$$\varepsilon_{\text{exc}} = \frac{\int \frac{\mathrm{d}N_{\text{zerobias}}}{\mathrm{d}\mathcal{L}_{\text{bunch}}} \cdot \mathcal{L}_{\text{bunch}} \cdot \varepsilon_{\text{exc}}(\mathcal{L}_{\text{bunch}}) \cdot \mathrm{d}\mathcal{L}_{\text{bunch}}}{\int \frac{\mathrm{d}N_{\text{zerobias}}}{\mathrm{d}\mathcal{L}_{\text{bunch}}} \cdot \mathcal{L}_{\text{bunch}} \cdot \mathrm{d}\mathcal{L}_{\text{bunch}}} = 0.145 \pm 0.008$$


CMS Preliminary √s=7 TeV 36 pb-1
number of additional towers
number of additional tracks
0 1 2 3 4 5 6 7 8 9 10
2 2 2 5 3 6 7 14 21 34
2 3 5 5 2 16 13 21 24
1 2 4 3 18 11 23 37 32
1 2 5 7 10 17 16 29 31
2 5 5 7 15 10 15 25 26
4 6 12 15 12 22 26 19
3 1 6 7 9 14 12 16 21
4 2 4 2 5 4 8 15 10 16
4 1 3 3 4 5 6 1 7
1 3 2 1 1 1


CMS Preliminary √s=7 TeV 36 pb-1
number of additional towers
number of additional tracks
0 1 2 3 4 5 6 7 8 9 10
1 1 2 2
1 1 2 1
1 1 3 3
1 1 2 1 1 1
1 1 5 1 2
1 1 2 1 1 2 5
1 1 1 3 1 2
2 1 1 2 1 3 1 1
3 2 1 4
17 1 1


Signal MC Simulation
number of additional towers
number of additional tracks
0 1 2 3 4 5 6 7 8 9 10
0.01
0.02
0.05
0.09
0.15 0.01
0.22 0.02
0.28 0.02
0.39 0.03
1.08 0.06 0.01
16.45 0.98 0.1 0.01


CMS Preliminary
√s=7TeV, L=40pb-1
Efficiency
1
0.9
0.8
0.7
0.6
0.5
0 vertex
1 vertex
2 vertex
8 vertex
0
0.1
0.2
0.3
0.4
Veto size [cm]


CMS Preliminary
Efficiency
10^{-2}
10^{-3}
$Z/\gamma \rightarrow \mu\mu$
Pythia Z2 tune
0
0.1
0.2
0.3
0.4
Veto size [cm]

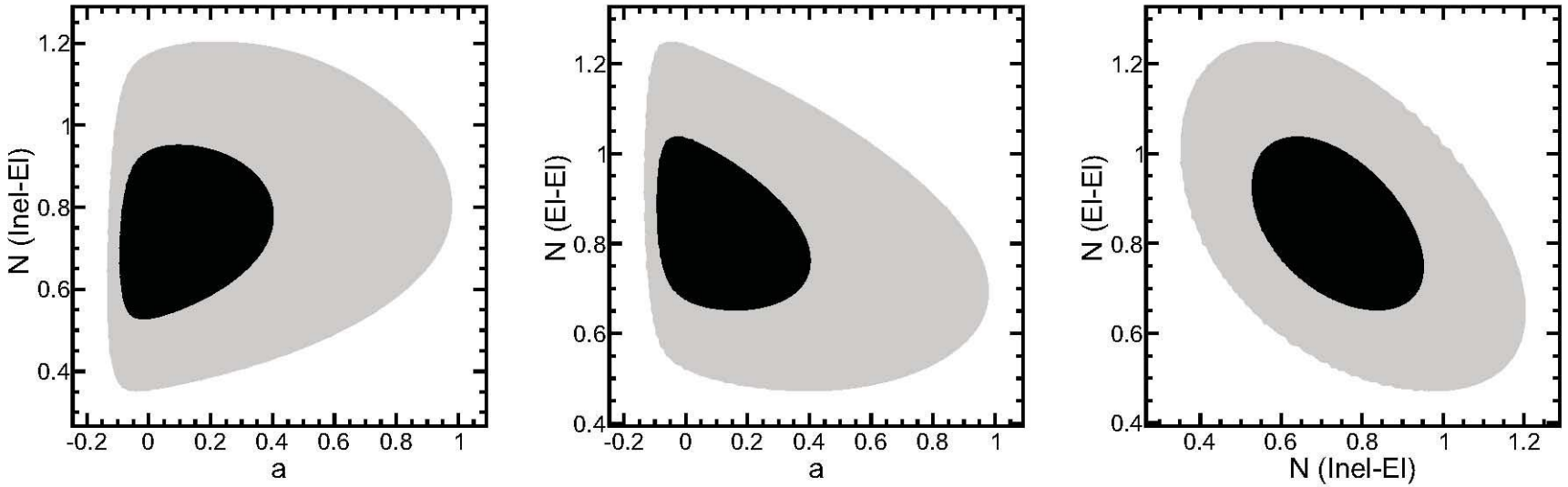


Figure 6: 1 and 2 sigma contours in the plane of fitted parameters for the p dissociation yield vs slope (left), slope vs. signal yield ratio (center), and signal yield ratio vs. p dissociation yield ratio (right).

Selection	N_{El-El}	$N_{Inel-El}$
All selection criteria applied	$0.83^{+0.14}_{-0.13}$	$0.73^{+0.16}_{-0.14}$
No $\lvert\Delta p_T\rvert$	$0.82^{+0.13}_{-0.13}$	$0.63^{+0.11}_{-0.10}$
No $\lvert\Delta p_T\rvert$ or $1-\lvert\Delta\phi/\pi\rvert$	$0.81^{+0.13}_{-0.13}$	$0.45^{+0.08}_{-0.07}$

Table 2: Best fit values of N_{El-El} and $N_{Inel-El}$ for the nominal selection, and with the requirements on $\lvert\Delta p_T\rvert$ and $1-\lvert\Delta\phi/\pi\rvert$ removed.

Selection	Variation from nominal yield
track veto size	3.6%
track quality	2.5%
Drell-Yan background	0.4%
double $p-$dissociation background	0.9%
Crossing-angle	1.0%
Tracking efficiency	0.1%
Vertexing efficiency	0.1%
Momentum scale	0.1%
Efficiency correlations in J/ψ control sample	0.7%
Muon and trigger efficiency statistical error	0.8%
Total	4.8%

Table 3: Relative systematic uncertainties.