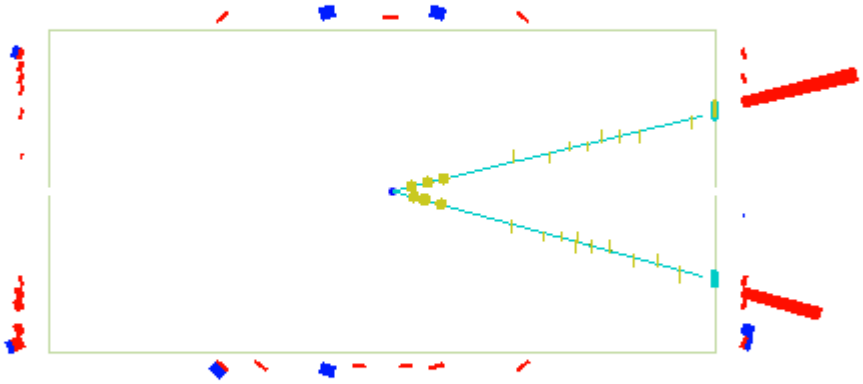

Central Exclusive Production in CMS

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Low-X 2012, June 28, Cyprus

Outline

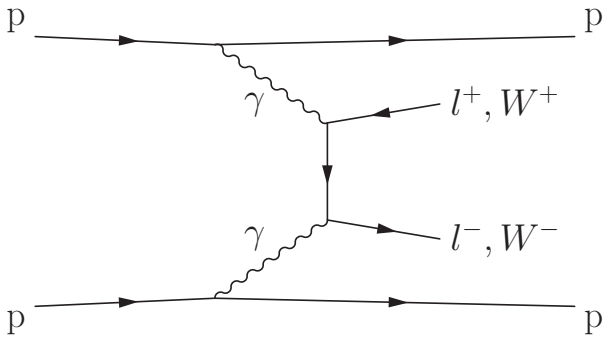
- Introduction
- The CMS Detector
- Exclusive dipohoton and dielectron production
  - Event selection
  - Result
- Exclusive dimuon production
  - Event selection
  - Signal extraction
  - Result
- Summary & Outlook

Central Exclusive Production

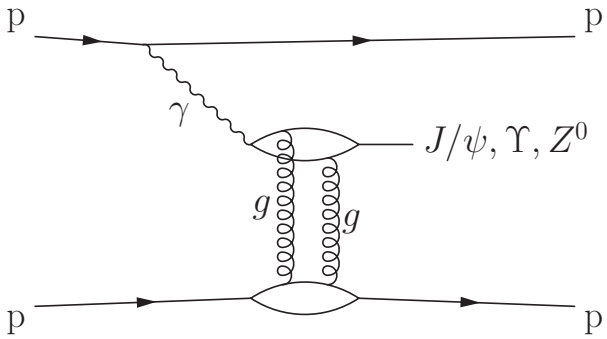
- Central exclusive production:

$$pp \to p + X + p$$

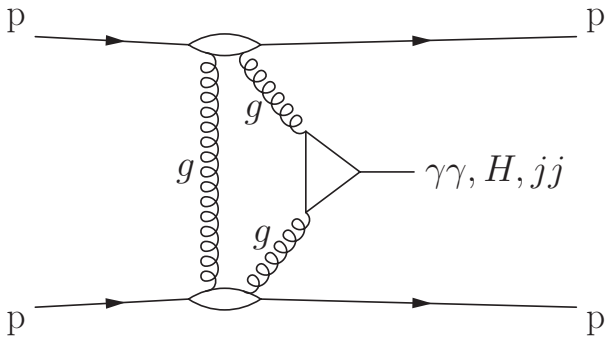
- Both protons emerge intact from the interaction
- X: a simple fully measured system
- Exclusive: no other particles produced & large rapidity gap
- Cleanest and simplest inelastic pp collision
- Physics processes involved: γγ interactions, γIP fusion, and IPIP exchange



γγ interactions

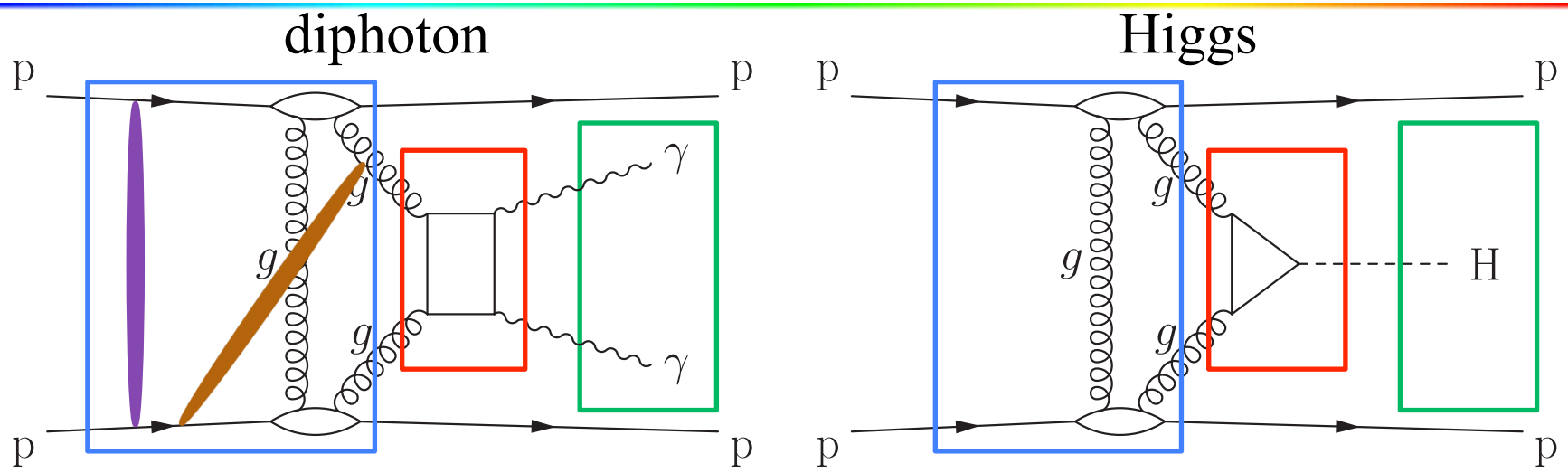


γIP fusion



IPIP exchange

Physics Motivation (IPIP→γγ)

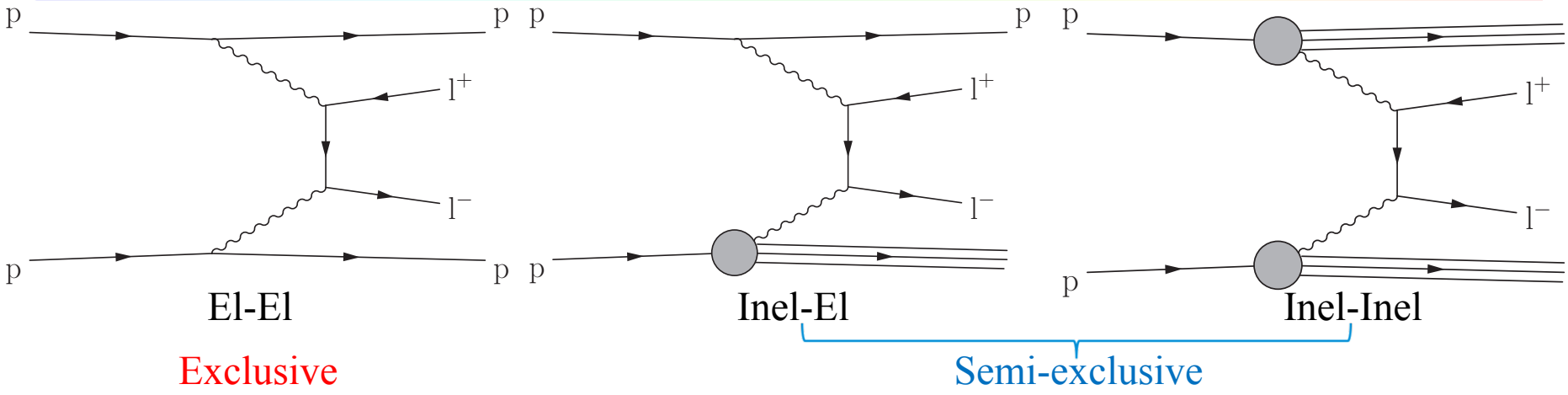


- Double pomeron exchange:
  - *gg* fusion through a quark loop to produce the central system
  - with a soft low-Q^2 screening gluon to cancel the color flow
  - Sudakov factor (no partons emitted by the fusing gluons)
  - Rapidity-gap survival probability (no additional inelastic pp scattering)

- Shed light on diffraction and double pomeron exchange
  - Low-*x* gluon density ($\sigma \sim (xg)^4$)
  - Rapidity-gap survival probability

- Provide excellent test of theoretical predictions of exclusive Higgs production
  - QCD calculation (blue box) is same, where most uncertainties come from
  - Only the calculable matrix elements (red box) are different for H and γγ cases
  - $\frac{\mathrm{d}\sigma(M_{\gamma\gamma})}{\mathrm{d}M_{\gamma\gamma}} : \sigma_H$ should be well determined theoretically

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



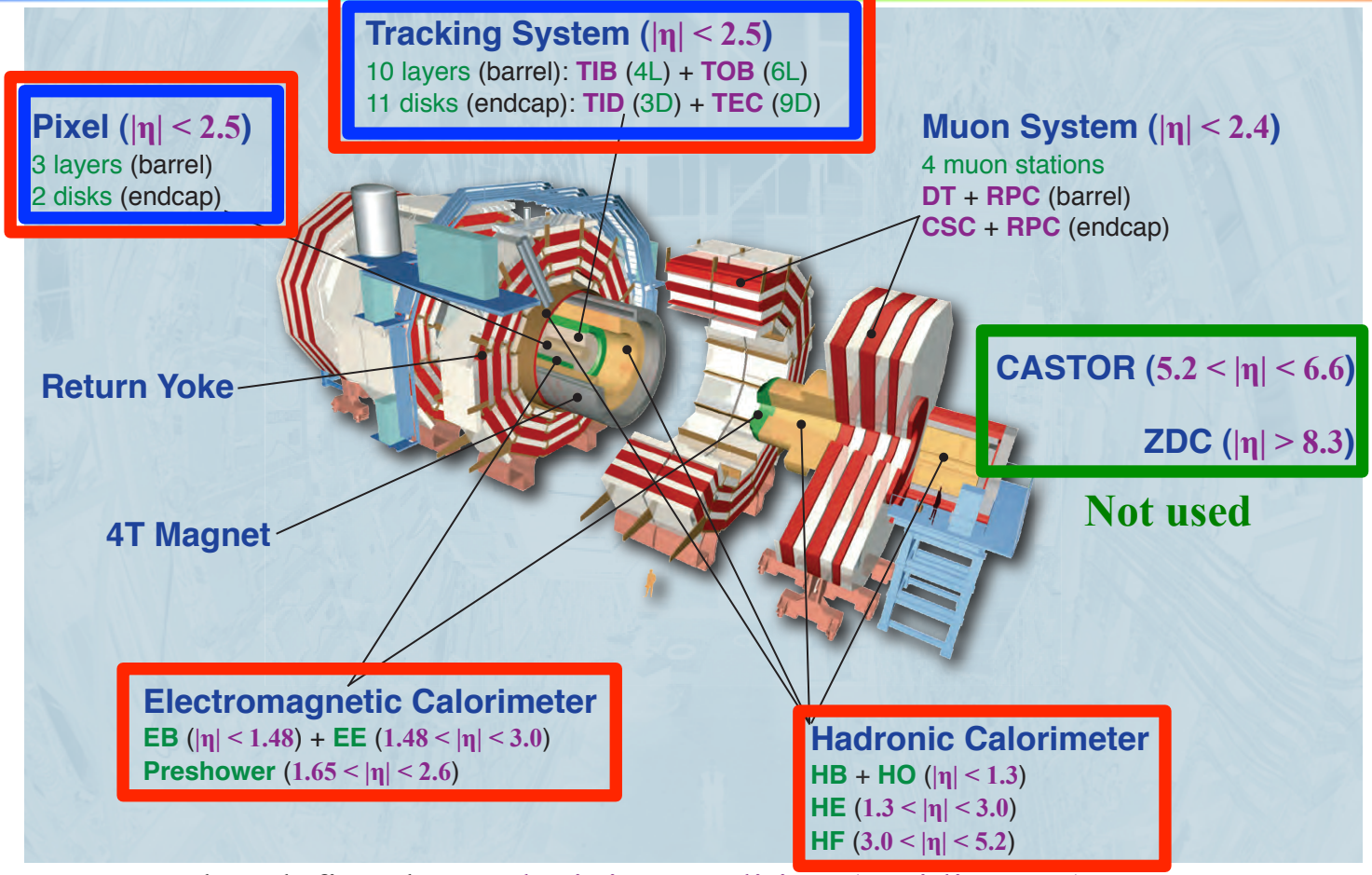
Exclusive production:

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

Semi-exclusive production:

- Either or both protons excited and diffractively dissociated.
- Much less theoretically determined
- Suppression of semi-exclusive events depends on performance of the forward detectors (In CMS, this process contributes more than half of the candidates)

The CMS Detector



Subdetectors used to define the exclusivity condition (rapidity gap):

- Diphoton and dielectron analyses: Tracker (blue box) + Calo (red box) ($|\eta_{max}|$=**5.2**)
- Dimuon analysis: Tracker only (blue box) ($|\eta_{max}|$=**2.5**)

Exclusivity condition: no other particles detected besides the two photons/electrons/muons

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

FWD-11-004

Event Selection

- Any other inelastic interaction overlapping with an exclusive interaction would spoil the exclusivity condition and make the exclusive interaction unobservable
- Only 2010 data sample used (low pileup) ($36pb^{-1}$)

- Trigger: 2 EM showers with $E_T > 5GeV$
- Photon (electron) selection:
  - Exactly two identified photons (electrons) with $E_T > 5.5GeV$ and $|\eta| < 2.5$
- 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 track segments in the DTs and CSCs
- 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 (fraction of events with single interaction): 14.5%

Result

Number of events remaining after each selection:

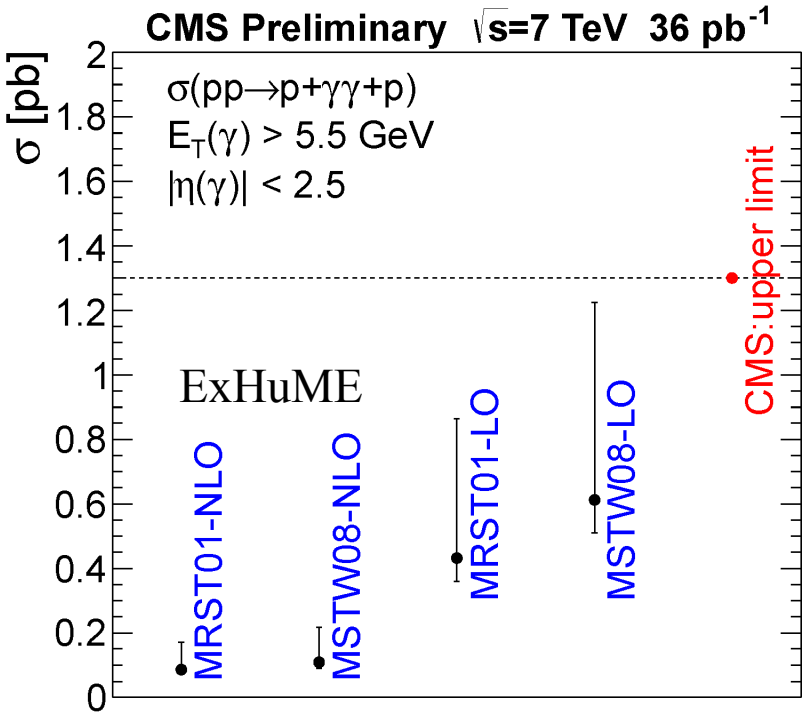
exclusive diphoton analysis		exclusive dielectron analysis	
selection criterion	events remaining	selection criterion	events remaining
Trigger	3 023 496	Trigger	3 023 496
Photon reconstruction	1 683 526	Electron reconstruction	132 271
Photon identification	40 692	Electron identification	2 648
Cosmic ray 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 $|\eta| < 5.2$. (difficult to calculate its contribution precisely) (but is expected to be of similar magnitude)



- Predictions: exclusive (el-el) only
- LO vs NLO: different low-x gluon distribution

	MRST01		MSTW08	
	LO	NLO	LO	NLO
ExHuME	0.624	0.124	0.885	0.157
SuperCHIC		0.103	0.472	
New①		0.039	0.18	

①: see the talk from Valery

Result (e^+e^-)

Number of candidates expected:

S^2 not included in σ

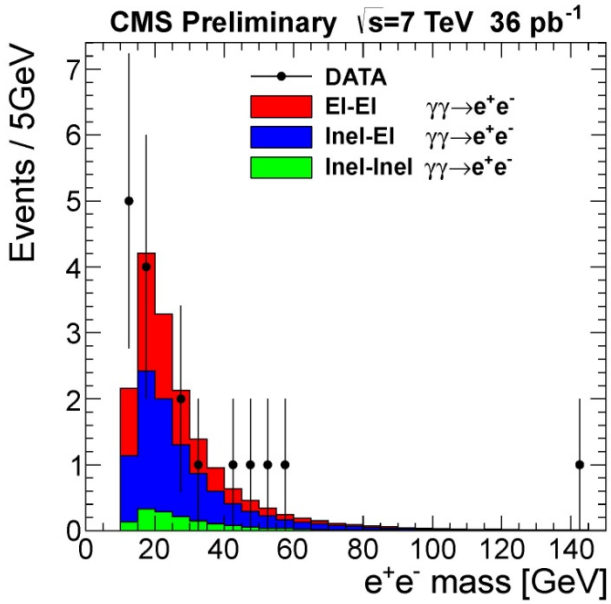
Process	$\mathcal{L}$	σ	ε	nEvents
el-el	$36\pm1.4\,pb^{-1}$	3.74 ± 0.04 pb	0.0488 ± 0.0056	6.57 ± 0.07 (theo.)±0.80 (syst.)
inel-el	$36\pm1.4\,pb^{-1}$	3.34 ± 0.67 pb $\times2$	0.0348 ± 0.0035	8.37 ± 1.68 (theo.)±0.90 (syst.)
inel-inel	$36\pm1.4\,pb^{-1}$	3.52 ± 0.70 pb	0.0119 ± 0.0011	1.51 ± 0.30 (theo.)±0.15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

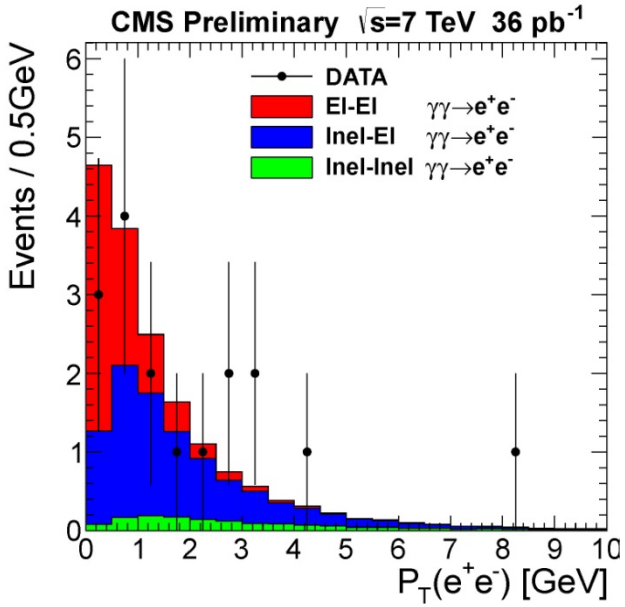
- 17 exclusive e^+e^- events on a background of 0.84 ± 0.28 events are observed.
- The theoretical prediction is 16.5 ± 2.1 events.
- Observation in good agreement with QED prediction (LPAIR generator).

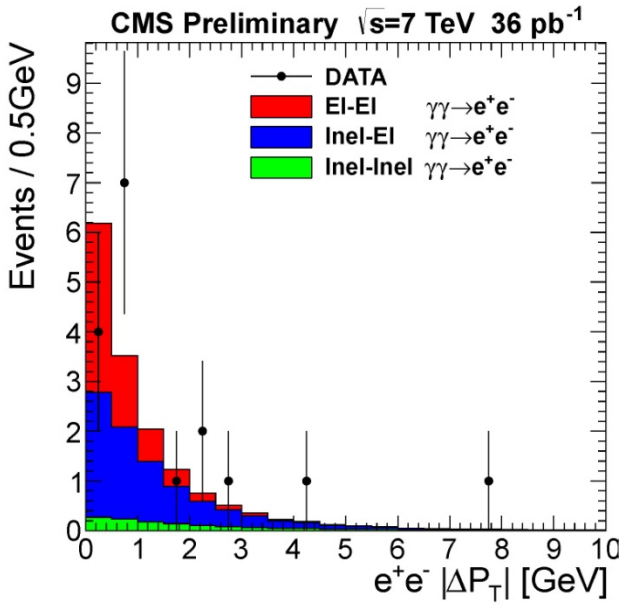
- Rapidity-gap survival probability is not included in LPAIR.
- From Valery:

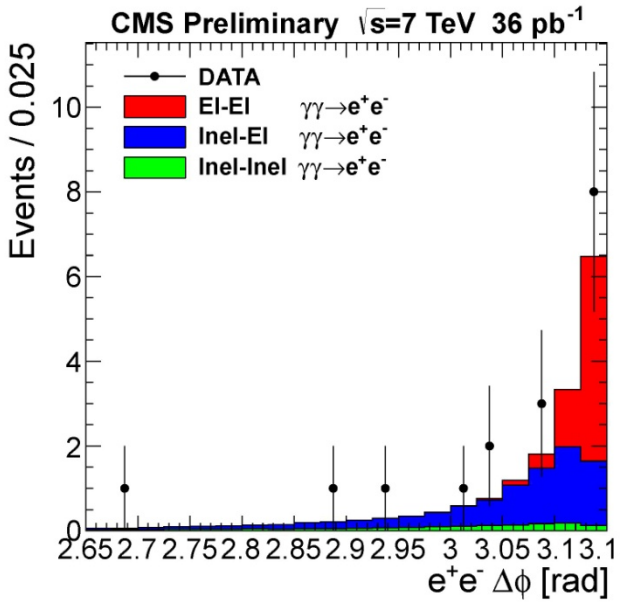
Process	State	S^2
el-el		1
inel-el	low mass ($M_X < 2$–2.5 GeV)	0.86 ± 0.03
	high mass	0.81 ± 0.03
inel-inel	low mass + low mass	0.3–0.45
	low mass + high mass	0.2–0.28
	high mass + high mass	0.08–0.16

Result (e^+e^-)

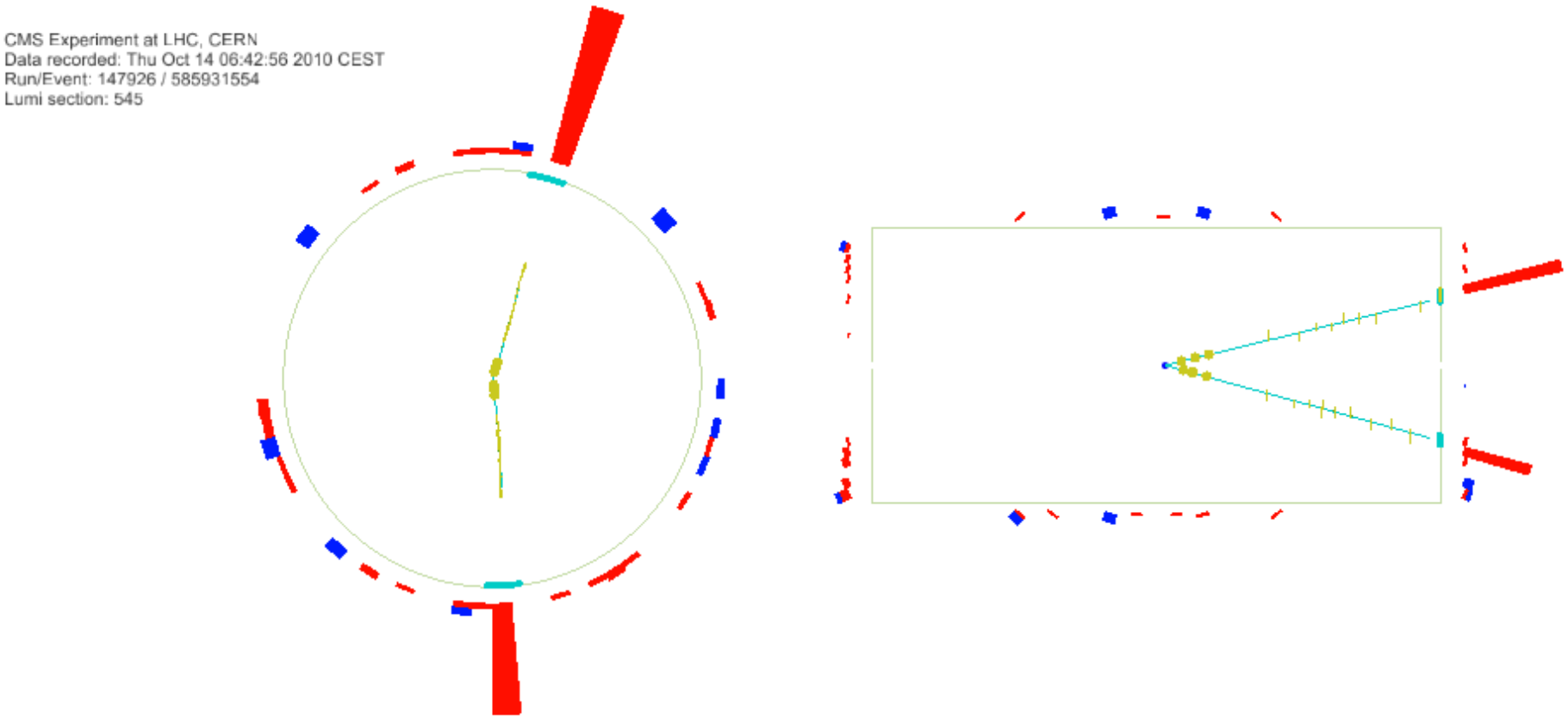

CMS Preliminary √s=7 TeV 36 pb-1
DATA
EI-EI γγ→e+e-
Inel-EI γγ→e+e-
Inel-Inel γγ→e+e-
Events / 5GeV
e+e- mass [GeV]


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

JHEP 01 (2012) 052

Event Selection

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

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

- 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)

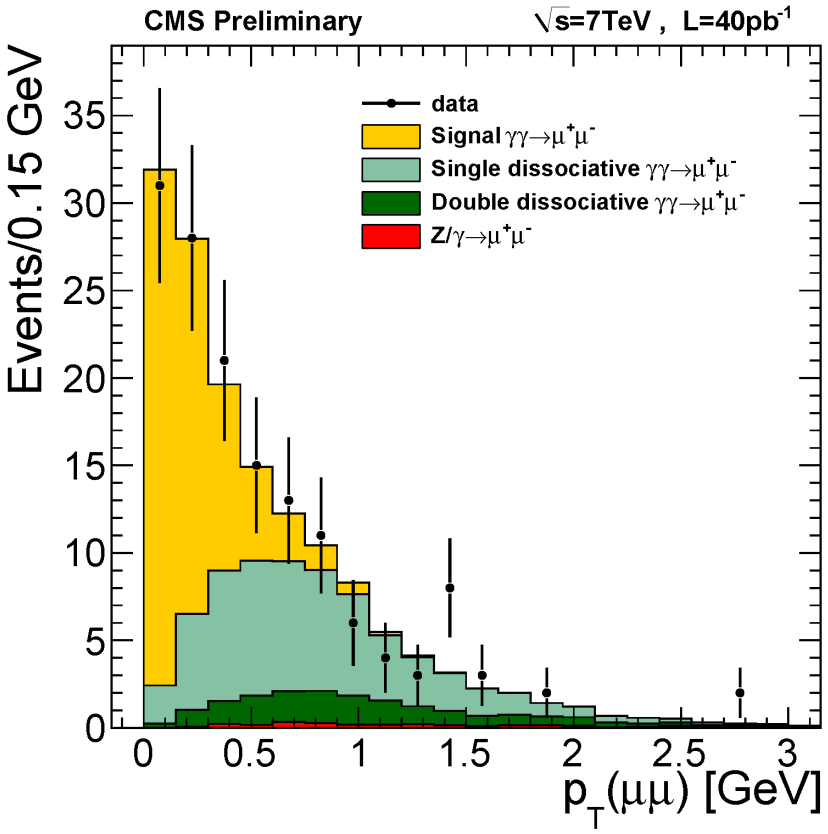
  } Suppress non-exclusive and semi-exclusive background

  - $m(\mu\mu) > 11.5$ GeV (Reject Y(1S,2S,3S) photoproduction)
  - 3D opening angle $> 0.95\pi$ (Reject cosmic ray events)
- Exclusivity selection criteria (vertex exclusivity only):
  - no additional 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



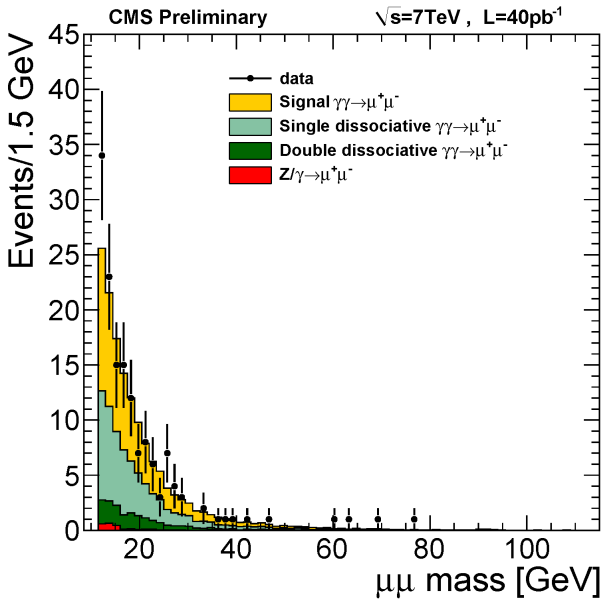
- After all selections, 148 events remain (~50% expected to be from proton dissociation)
- Signal (el-el) is extracted with a binned maximum likelihood fit to the $p_T(\mu\mu)$ distribution with 3 free parameters:
  - Signal yield
  - Single proton dissociation (inel-el) yield
  - Correction factor to the shape of single proton dissociation events
- Shape and yield of double proton dissociation (inel-inel) and Drell-Yan production are fixed from simulation (Varied as systematic uncertainties)

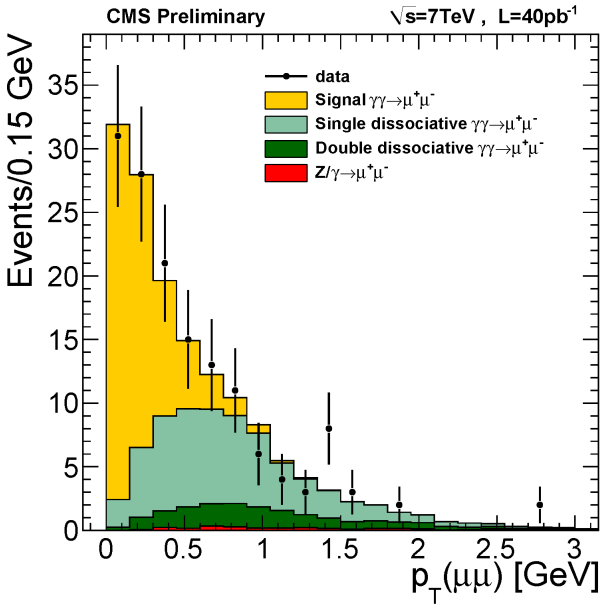
For $p_T(\mu) > 4$ GeV, $|\eta(\mu)| < 2.1$ and $m(\mu\mu) > 11.5$ GeV, the measured cross section and the ratio to the LPAIR prediction are:

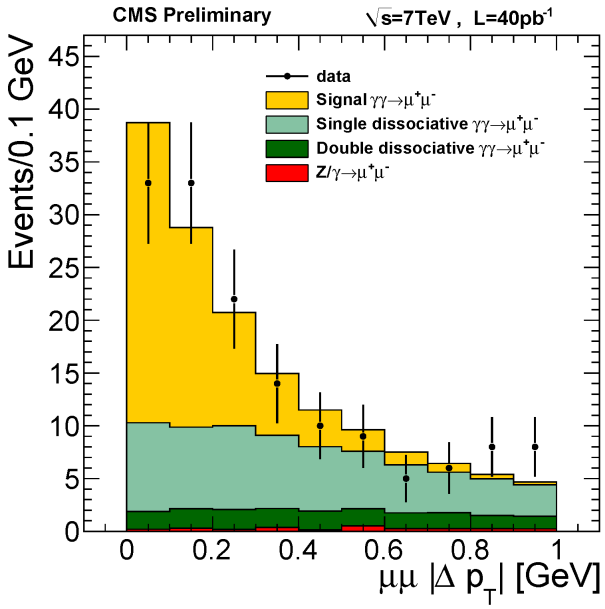
$$\sigma = 3.38^{+0.58}_{-0.55}\,(\text{stat.}) \pm 0.16\,(\text{syst.}) \pm 0.14\,(\text{lumi.})\ \text{pb}$$

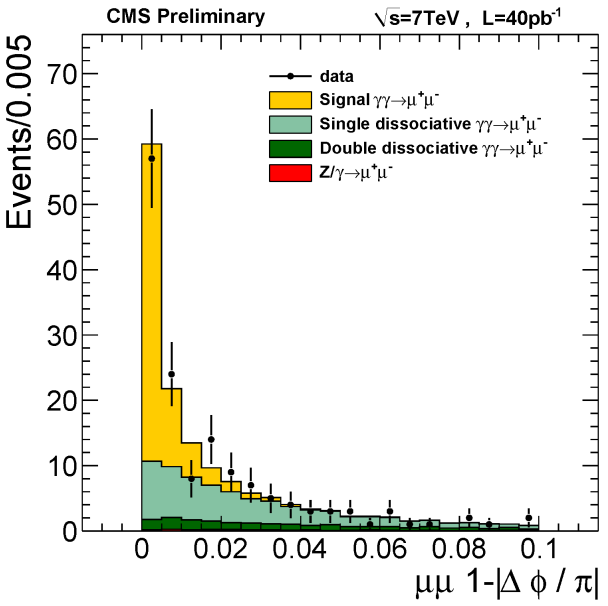
$$R = 0.83^{+0.14}_{-0.13}\,(\text{stat.}) \pm 0.04\,(\text{syst.})$$

Kinematic distributions









Conclusion

- 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.

- 17 dielectron candidates on top of a background of 0.84 events are observed from both exclusive and semi-exclusive 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 with LPAIR generator.

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

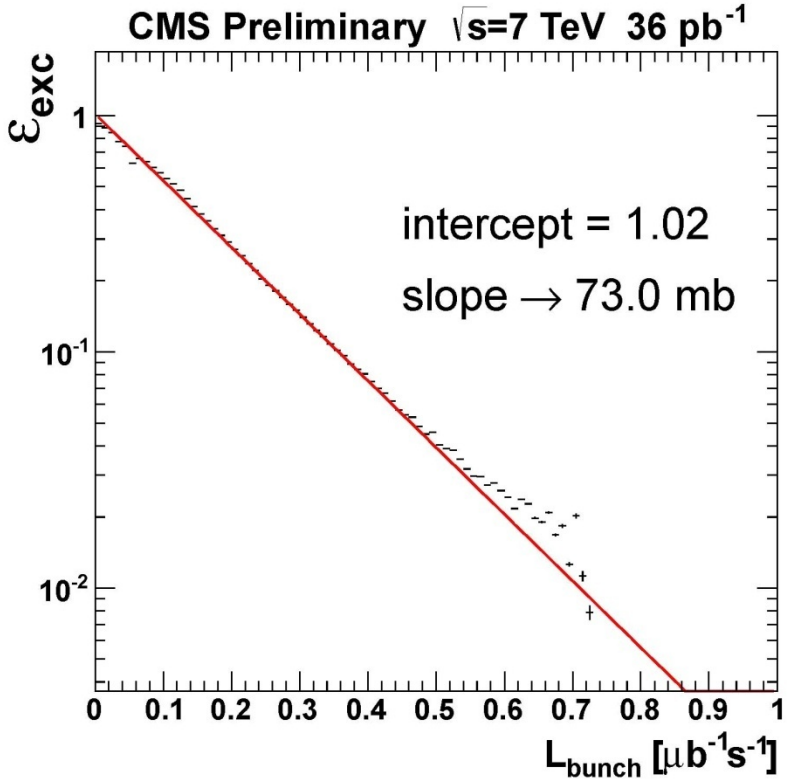
$$\sigma = 3.38^{+0.58}_{-0.55}\,(\text{stat.}) \pm 0.16\,(\text{syst.}) \pm 0.14\,(\text{lumi.})\ \text{pb}$$

Outlook:

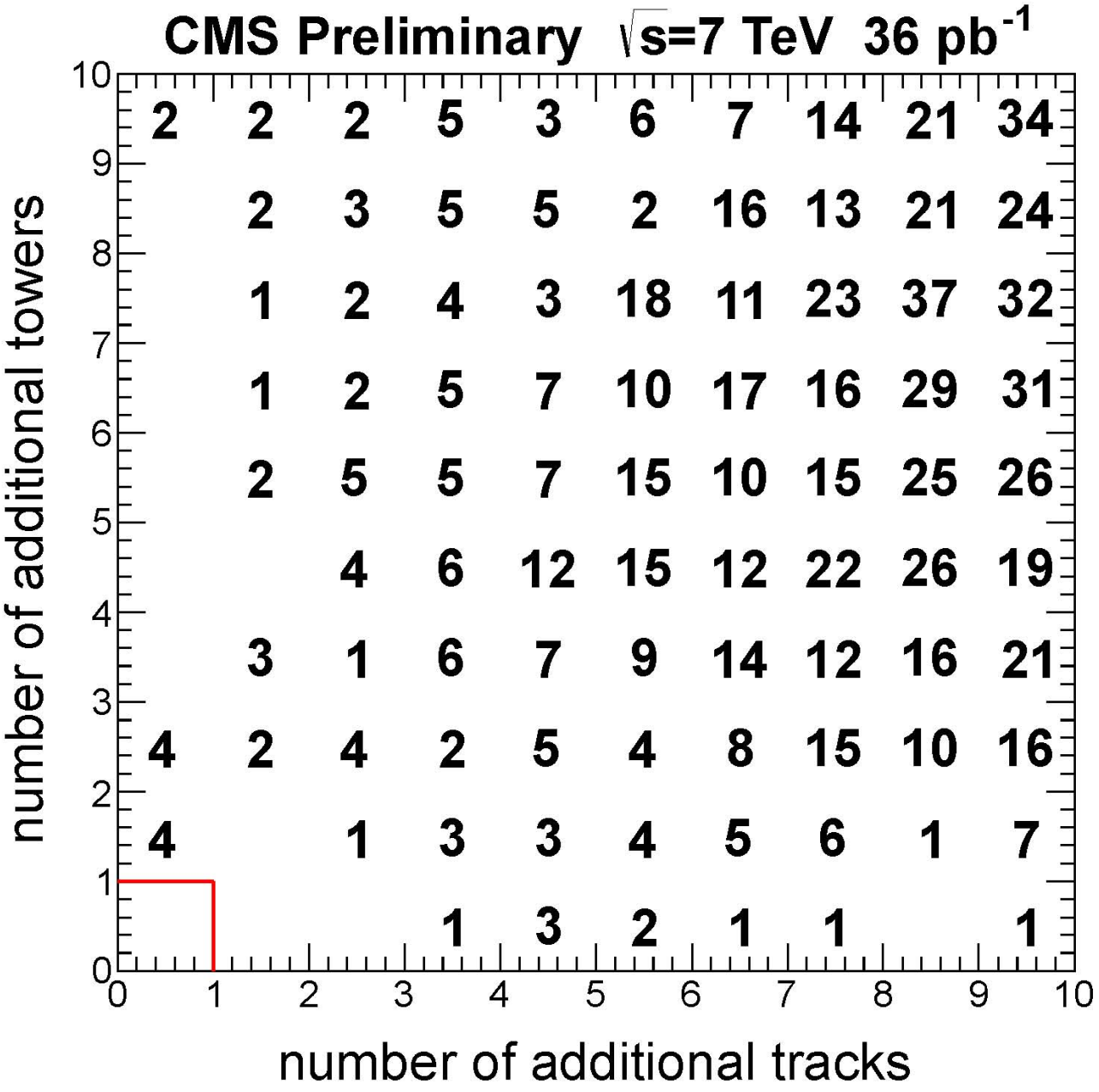
- Exclusive W^+W^- production via $\gamma\gamma$ interactions
- Exclusive Z production via γIP fusion
- Exclusive $\pi^+\pi^-$ production

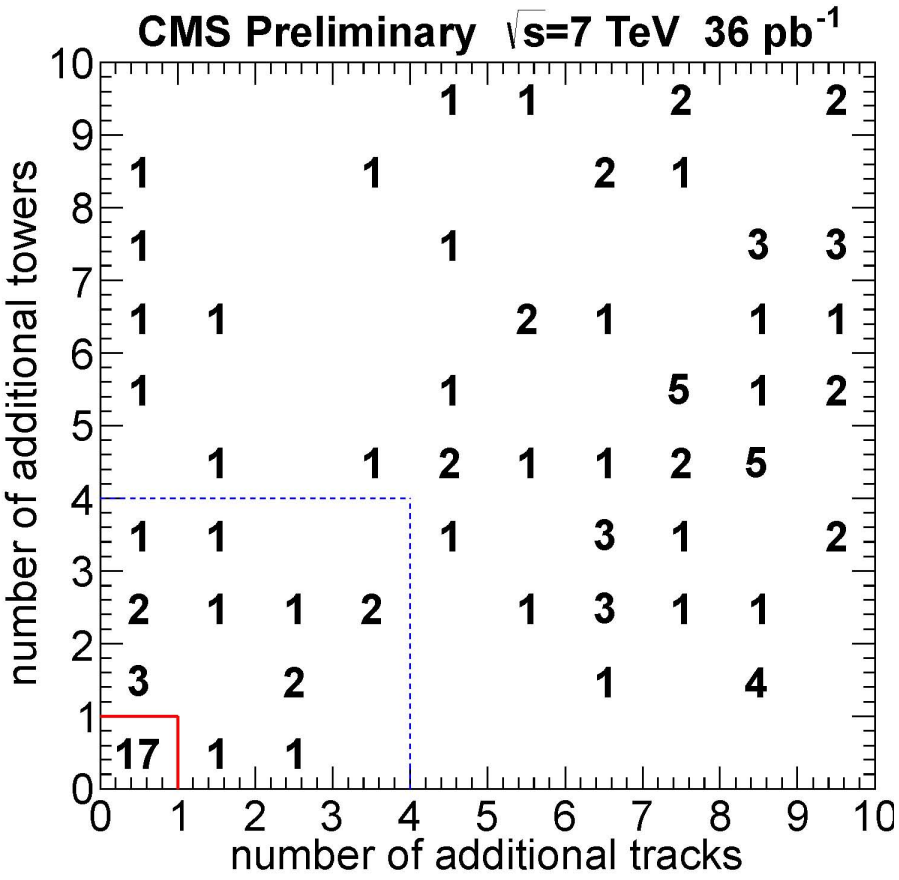
Thank you !

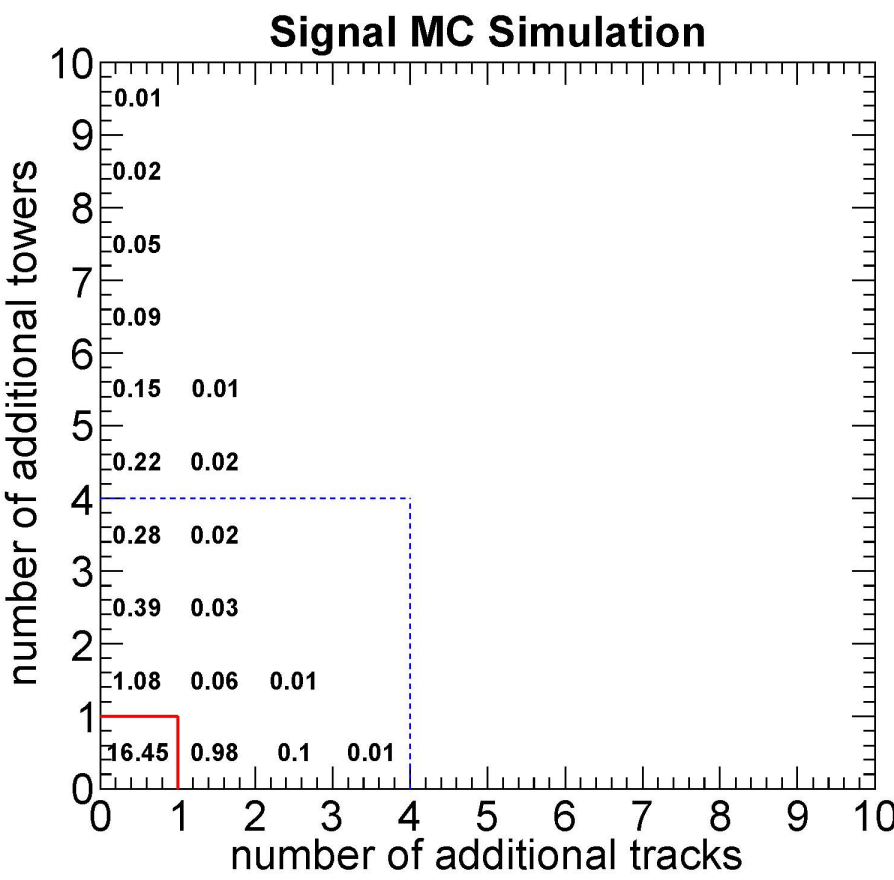
$$\varepsilon_{\text{exc}}(\mathcal{L}_{\text{bunch}}) = \frac{N^{\text{exc}}_{\text{zerobias}}(\mathcal{L}_{\text{bunch}})}{N_{\text{zerobias}}(\mathcal{L}_{\text{bunch}})} \approx e^{-\overline{n}} = e^{-\mathcal{L}_{\text{bunch}} \cdot \sigma_{\text{inelastic}} / f}$$

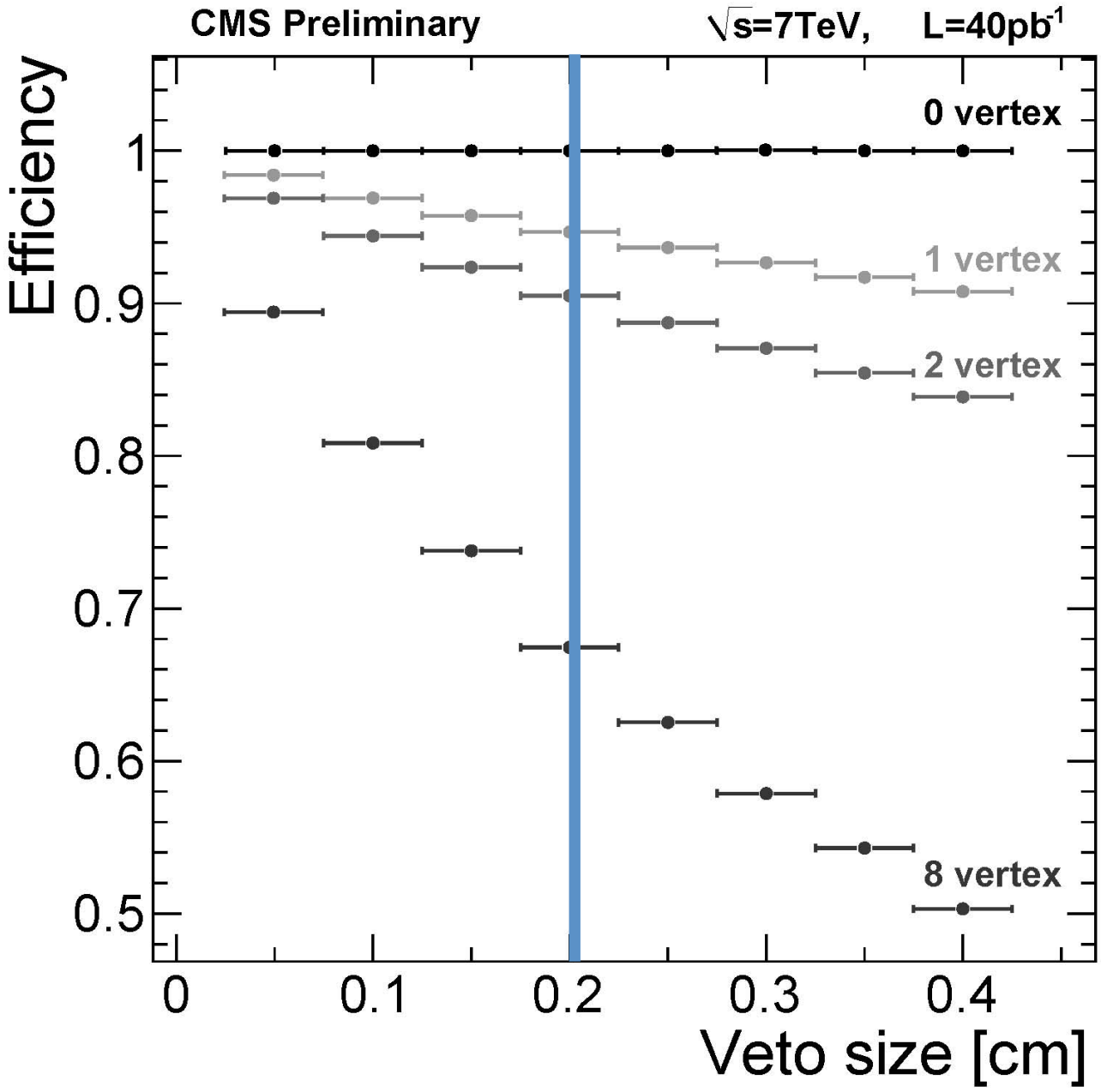


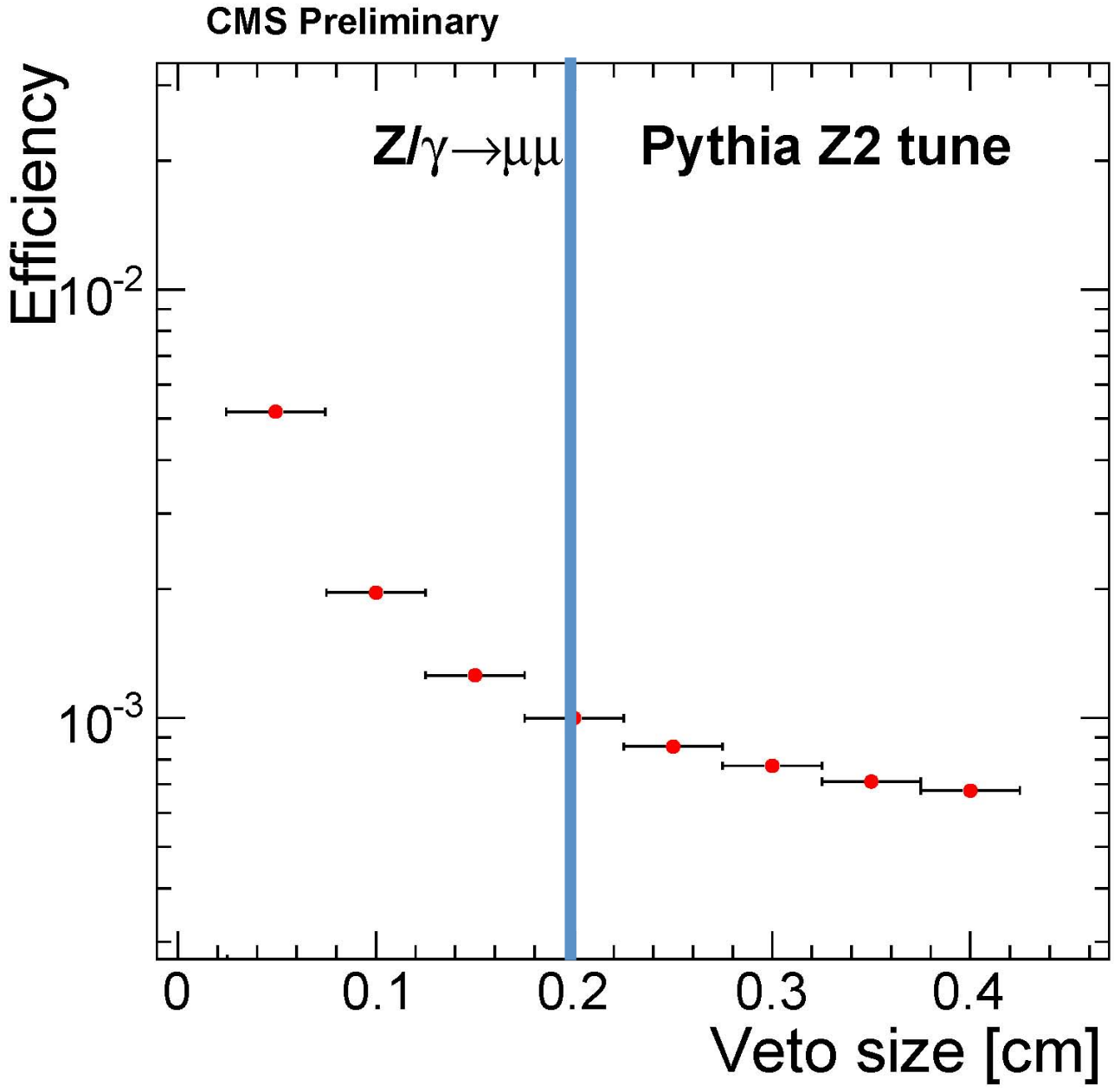
$$\varepsilon_{\text{exc}} = \frac{\int \frac{\mathrm{d}N_{\text{zerobias}}}{\mathrm{d}\mathcal{L}_{\text{bunch}}} \cdot \mathcal{L}_{\text{bunch}} \cdot \varepsilon_{\text{exc}}(\mathcal{L}_{\text{bunch}}) \cdot \mathrm{d}\mathcal{L}_{\text{bunch}}}{\int \frac{\mathrm{d}N_{\text{zerobias}}}{\mathrm{d}\mathcal{L}_{\text{bunch}}}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


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 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]

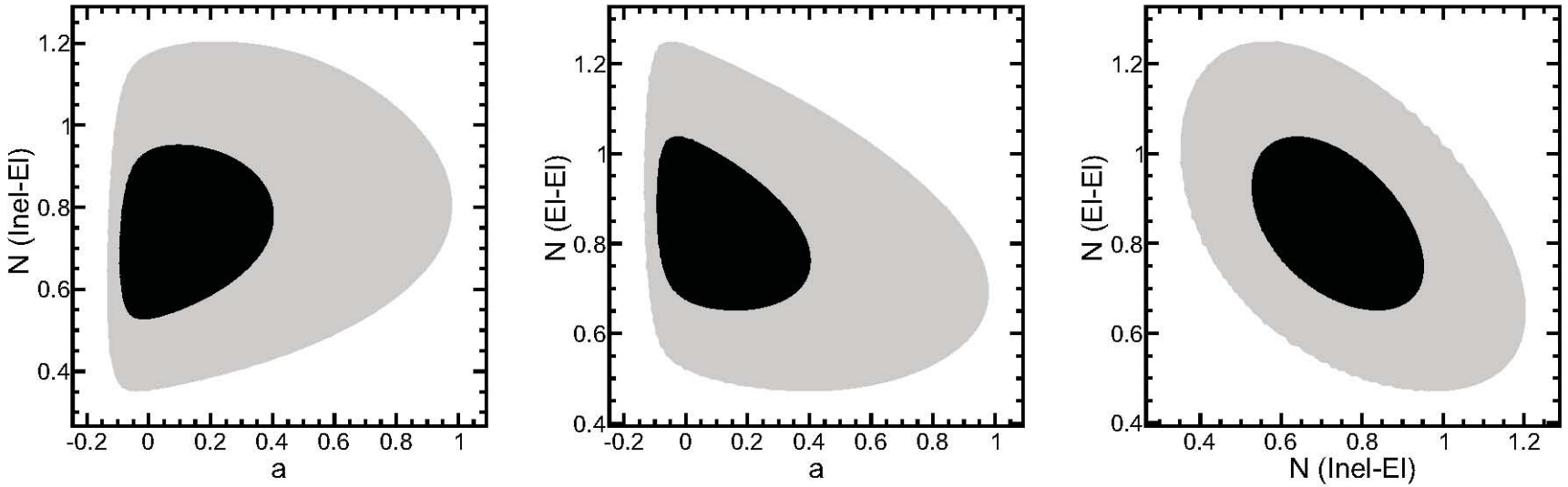


Figure 6: 1 and 2 sigma contours in the plane of fitted parameters for the p dissociation yield vs slope (left), slope vs. signal yield ratio (center), and signal yield ratio vs. p dissociation yield ratio (right).

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.