Measurement of Inelastic, Diffractive, and Exclusive processes in CMS

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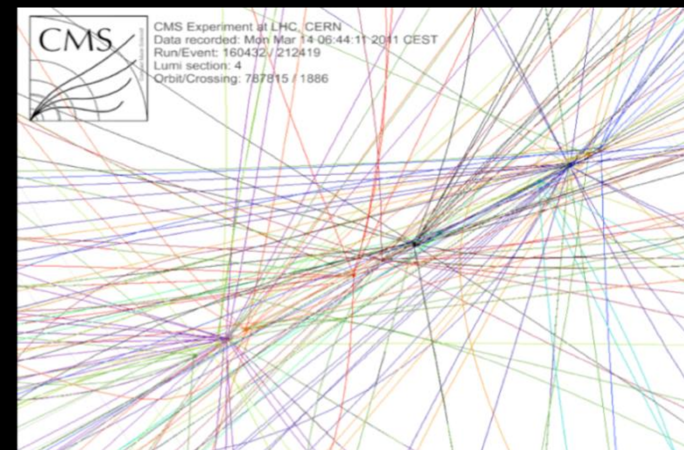
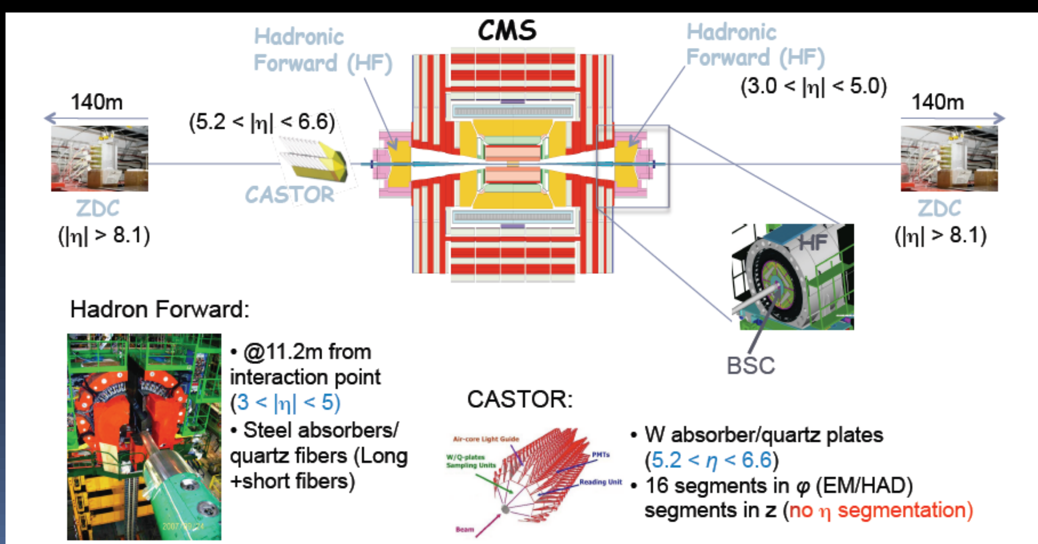
The setting:CMS@LHC

- High energy and high luminosity
  - Allows high statistics precision measurements, and sensitivity to “rare” processes (hard diffraction, exclusive production)
  - But high luminosity comes with high “pileup” – average 2-4 extra interactions/crossing in 2010, 5-8 in 2011





- Good detector coverage
  - Tracking to $|\eta| < 2.4$
  - Hadronic calorimeter (HF) to $|\eta| < 5$
  - Forward calorimeters (cover $-6.6 < \eta < -5.2$ (CASTOR) and $|\eta| > 8.1$ (ZDC)

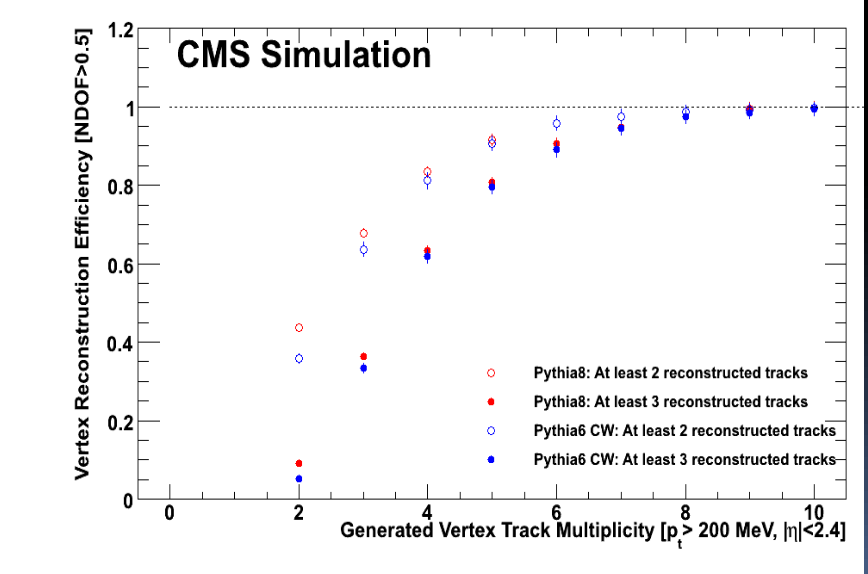
Measurement of the inelastic cross-section using pileup events

CMS PAS FWD 11-001 (in preparation)

Motivation & method

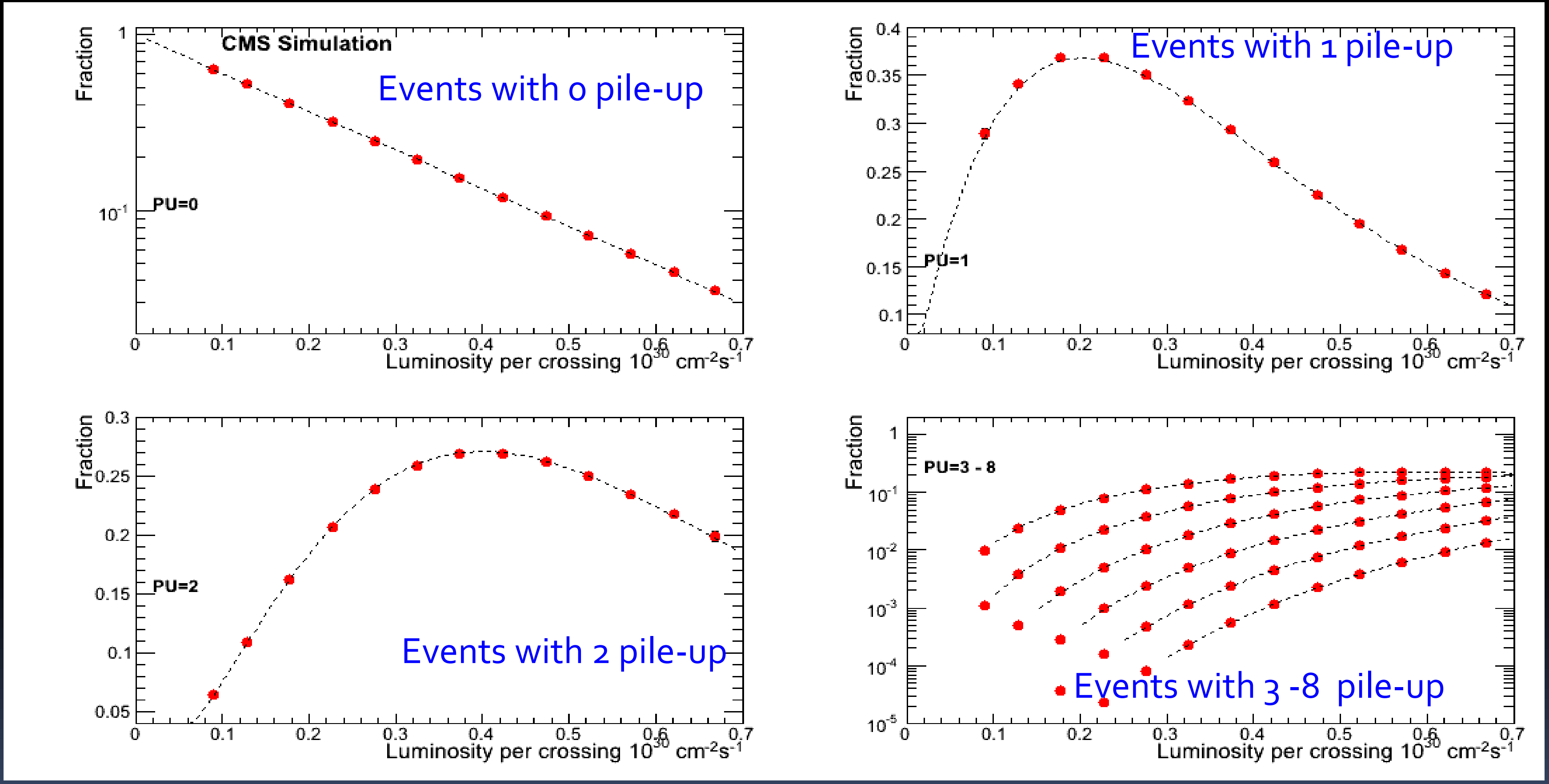
- Probability of a number interactions occurring in a crossing depends on the total *pp* cross-section
  - => Turn pileup into an advantage for measuring σ(*pp*)

$$P(n_{pileup}) = \frac{(L\cdot\sigma)^{n_{pileup}}}{n_{pileup}!}\cdot e^{-(L\cdot\sigma)}$$



- Method based on counting # of vertices as a function of luminosity
  - Samples collected with high-efficiency triggers (e.g. di-electrons)
  - Data is corrected for vertex merging, and inefficiencies in reconstructing vertices with low track multiplicity

Fitting

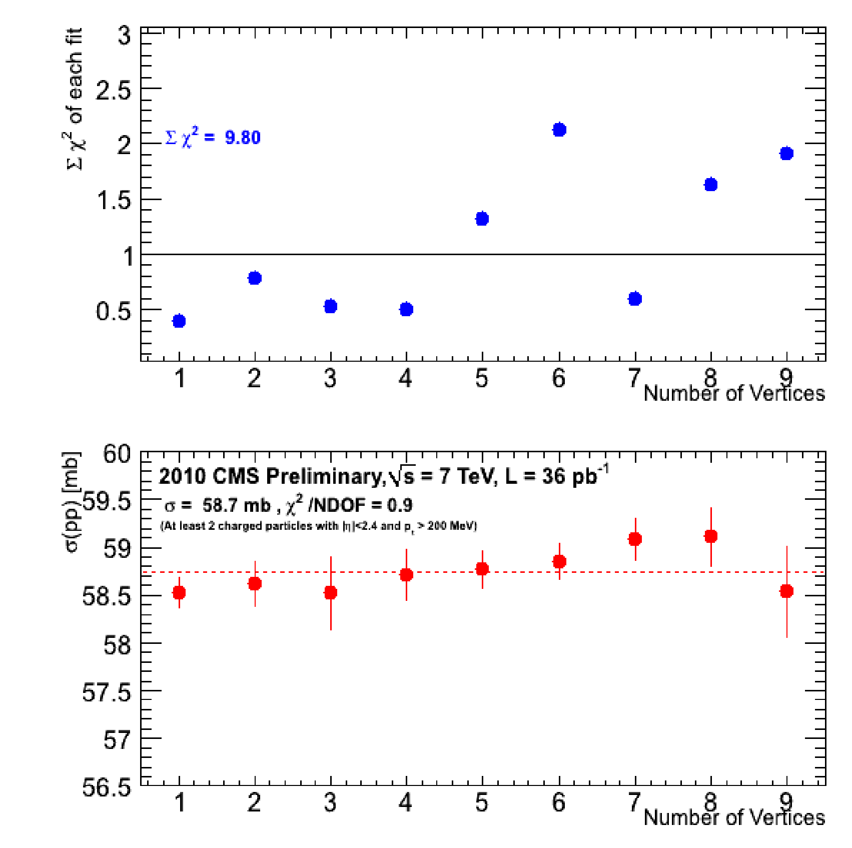


- Unfolded distributions are fit to a Poisson distribution for each value of pileup (=$N_{vertices}$-1) from 0-8

Results (I)

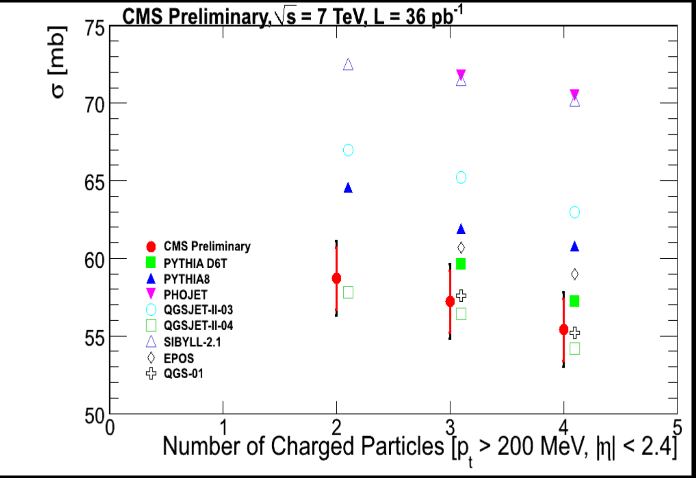
- Nine statistically independent measurements, for each value of the pileup
- Final result from a fit to all nine points
- For 3 tracks with p_T>200MeV, $|\eta| < 2.4$, the resulting cross-section is:

$$\sigma = 58.7 \pm 2.0\ (\mathrm{Sys}) \pm 2.4\ (\mathrm{Lumi})\ \mathrm{mb}$$

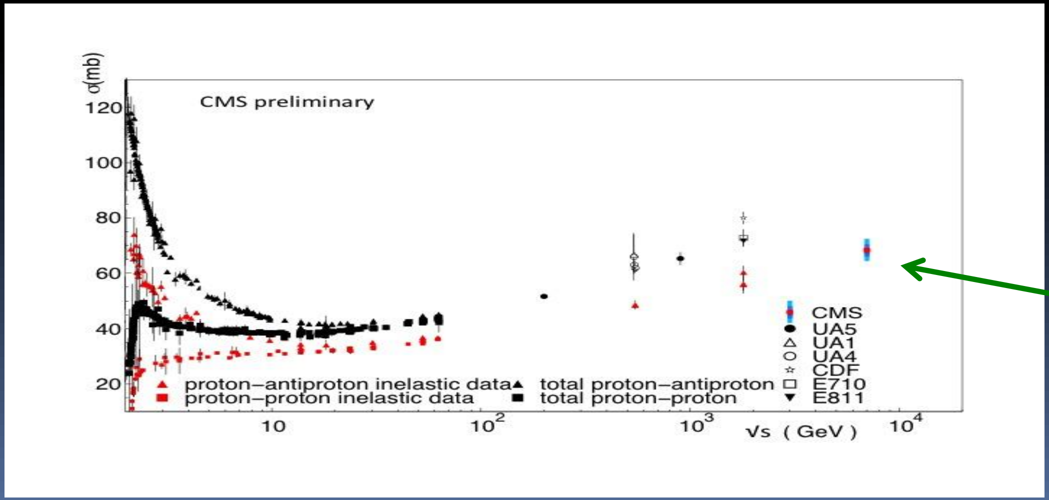


Results (II)

- Measurement is compared to predictions of several models
  - Gives a range of extrapolation factors that can be used to bound the total inelastic cross-section:



o(pp) = 68.0 ± 2.0 (Sys) ± 2.4 (Lumi) ± 4.0 (Extr.) mb



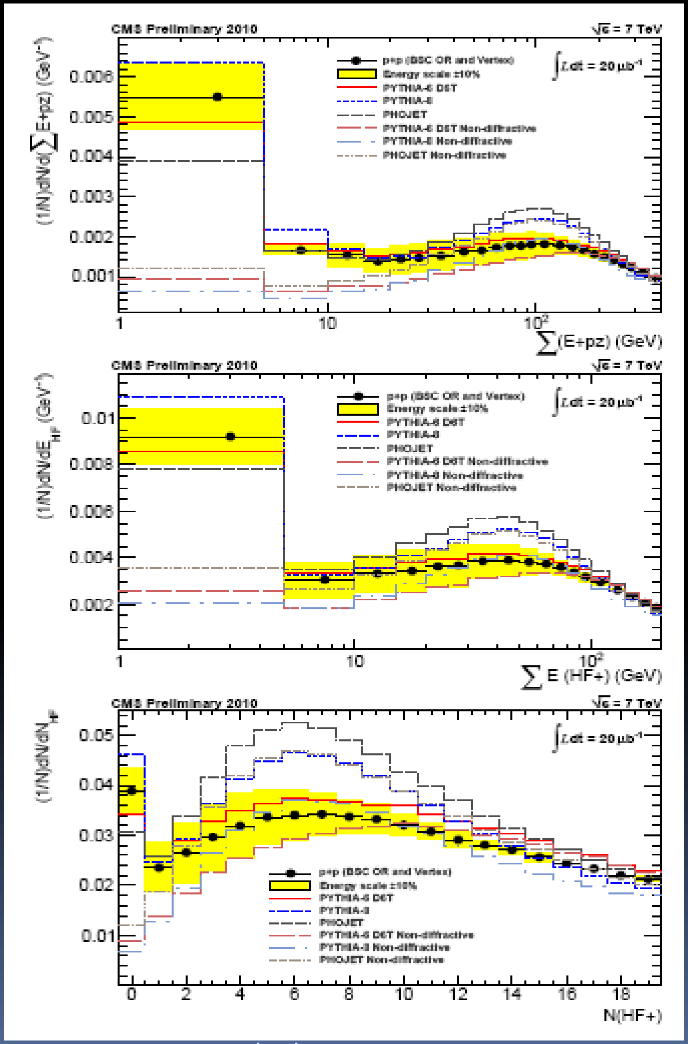
CMS model-dependent extrapolation

Diffraction @ 7TeV

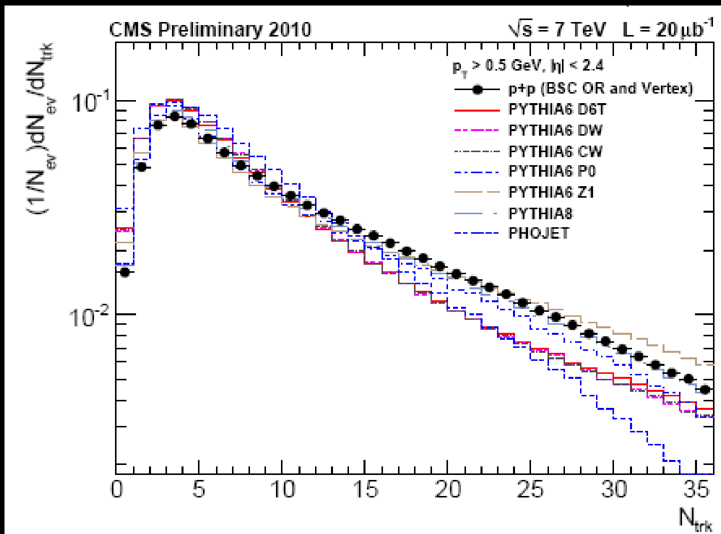
CMS PAS FWD 10-007

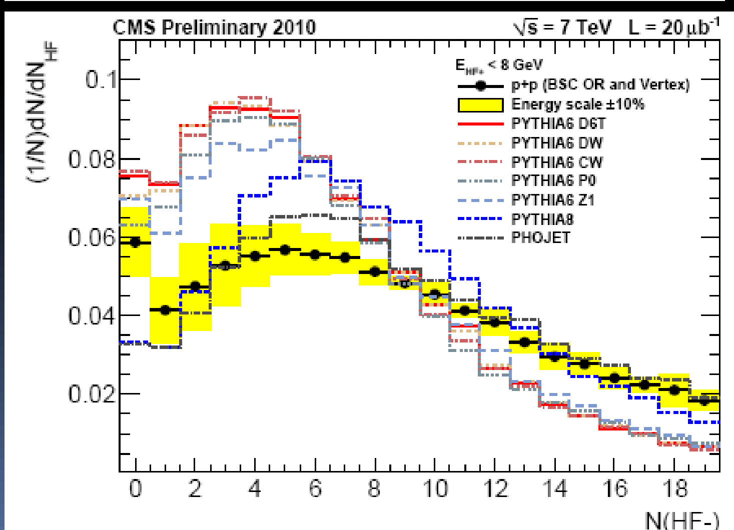
Inclusive Diffration

- Analysis based on 20μb^{-1} of low-pileup 7TeV data
    - Extends previous CMS results on diffraction at 900GeV and 2.36TeV
    - Trigger with scintillator counters (BSC) and require a vertex consistent with collisions
- Diffractive signal appears as an enhancement near zero in several sensitive variables
    - N(HF towers over threshold)
    - ΣE(HF)
    - ΣE-p_Z (~ξ), summed over all calorimeter towers



Event distributions





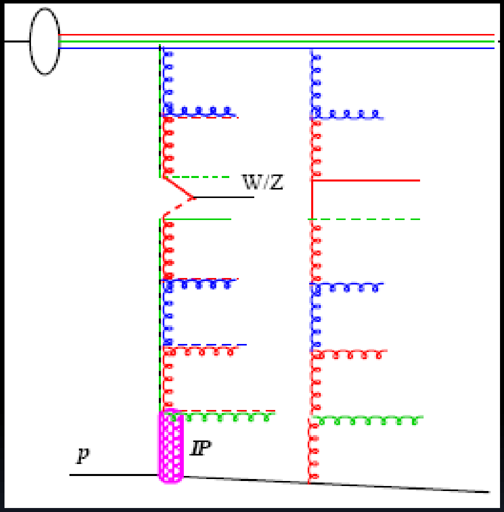
- Select a diffractively enhanced sample by requiring <8GeV in HF+
- Track multiplicities, track p_T distributions, and energy deposits opposite the gap side compared a range of models
  - Pythia 8 and Phojet better describe the diffractive component, while Pythia 8 and several Pythia 6 tunes perform better for inclusive distributions
- None of the models describe all features of the data

Diffractive W/Z

CMS PAS FWD 10-008

Introduction and selection

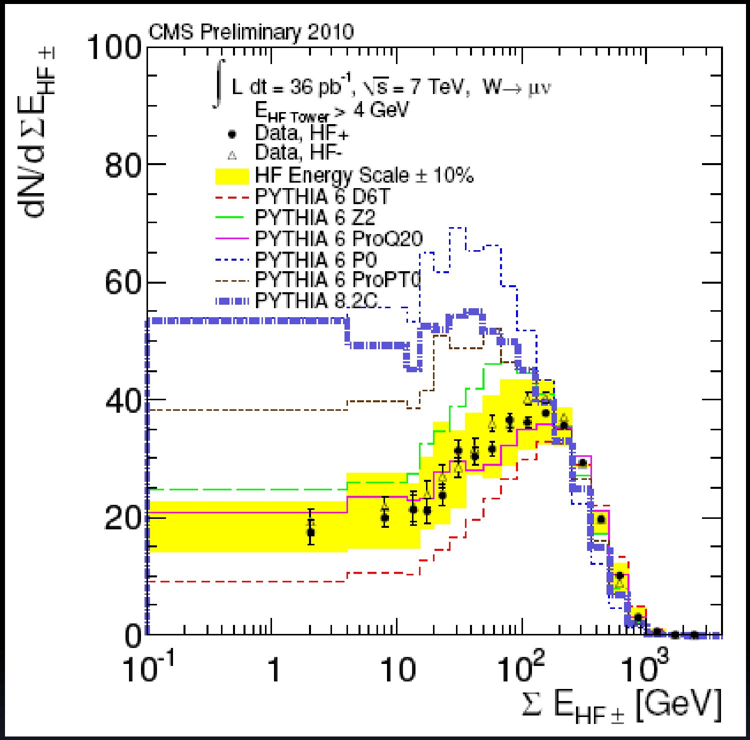
- Part of a larger systematic study of track multiplicity and forward energy flow in W/Z events
- Search for a diffractive component in *W/Z* events
- Sensitive to multi-parton interactions (MPI), gap-survival probabilities
  - Additional interactions may "fill the gap" in diffractive interactions



- Select *W/Z* events with a single-vertex to suppress pileup
  - Residual contamination from soft pileup events studied in MC, and in data as a function of average instantaneous luminosity

W/Z with gaps

- Search for a diffractive component in W/Z events
- Define Large Rapidity Gap selection using sum of calorimeter towers in HF ($3 < |\eta| < 5$) above 4 GeV
- Excess of events with zero energy compared to Pythia 6 D6T tune
  - But – deficit compared to Pythia 6 Z2, Pythia 8



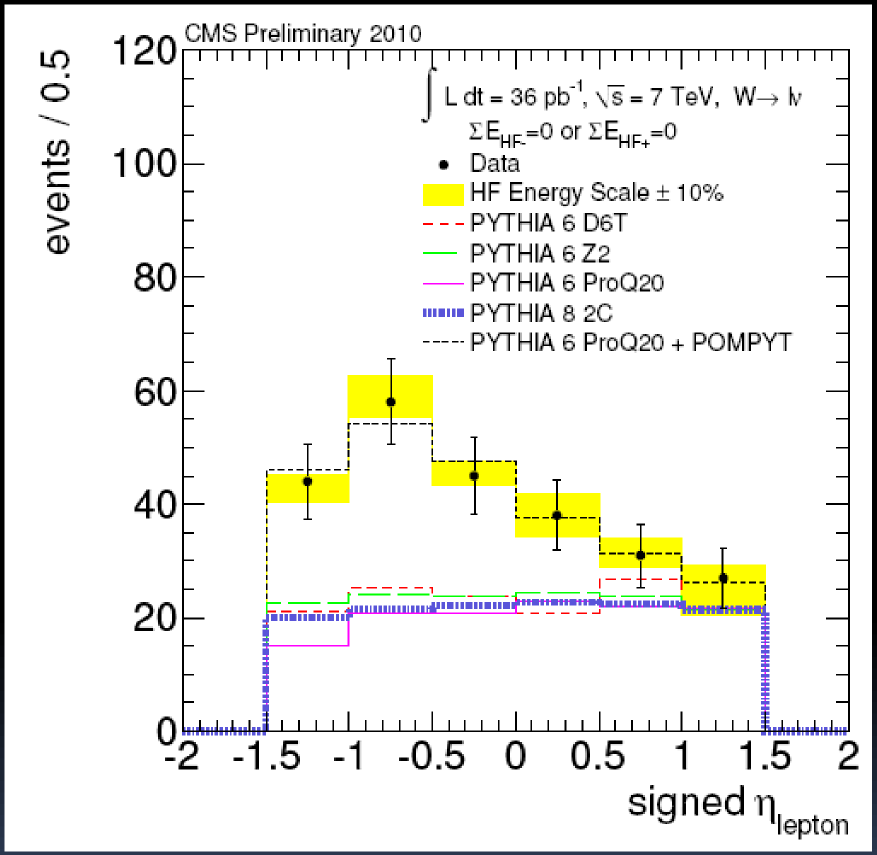
$W \rightarrow \mu \nu X$

Fraction of LRG events

$W \rightarrow l\nu$ = 1.46 ± 0.09 (stat.) ± 0.38 (syst.) %

$Z \rightarrow ll$ = 1.60 ± 0.25 (stat.) ± 0.42 (syst.) %

Lepton asymmetry



$W \to l\nu X$

- Additional sensitivity to diffraction from the charged lepton asymmetry η_{Lepton}
  - POMPYT MC predicts leptons from diffractive *W/Z* are preferentially produced opposite the LRG (small-x diffractive PDF's)
  - All Pythia tunes predict a flat distribution
- Large asymmetry observed in the LRG sample in data, with best-fit fraction for the diffractive component:

50.0 ± 9.3 (stat.) ± 4.2 (syst.) %

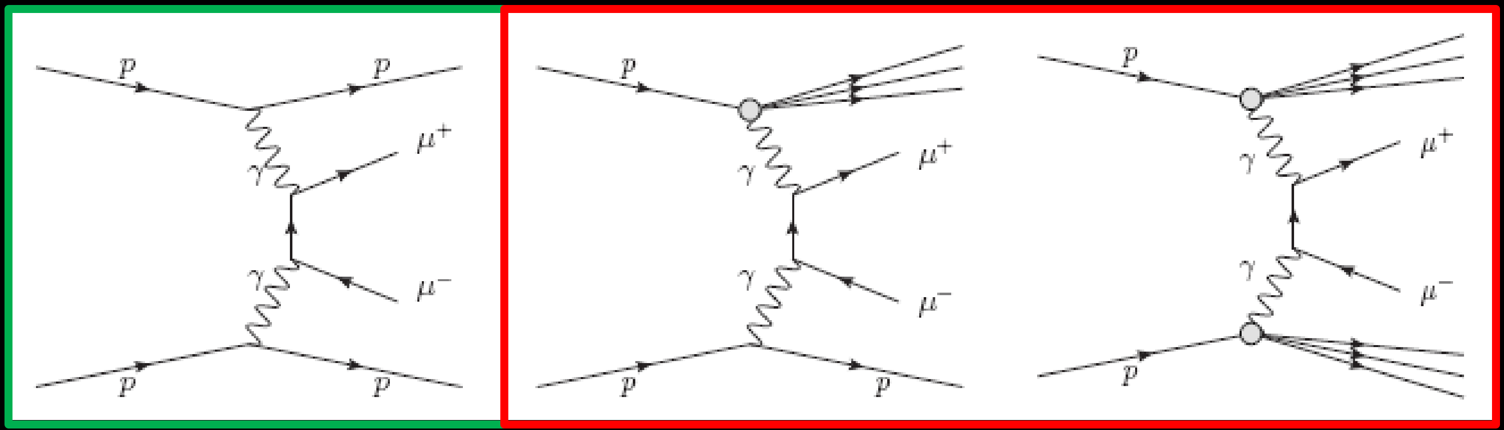
Exclusive $\gamma\gamma \rightarrow \mu\mu$

CMS PAS FWD 10-005

$\gamma\gamma \rightarrow \mu\mu$

Exclusive production

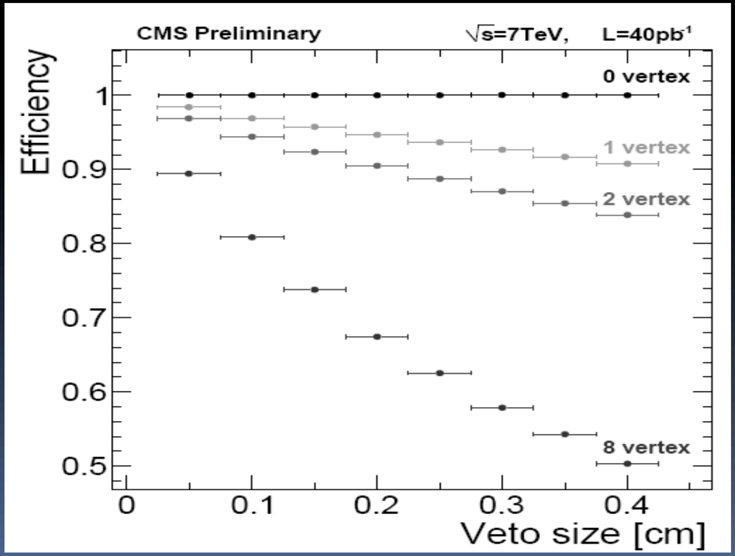
Proton dissociation



- Exclusive production $pp \rightarrow p\mu\mu p$
  - QED like "Standard Candle", proposed as a possible future luminosity measurement
- Largest "background" from $\gamma\gamma \rightarrow \mu\mu$ with proton dissociation
  - $pp \rightarrow p\mu\mu Y$, or $pp \rightarrow X\mu\mu Y$ with proton remnants undetected

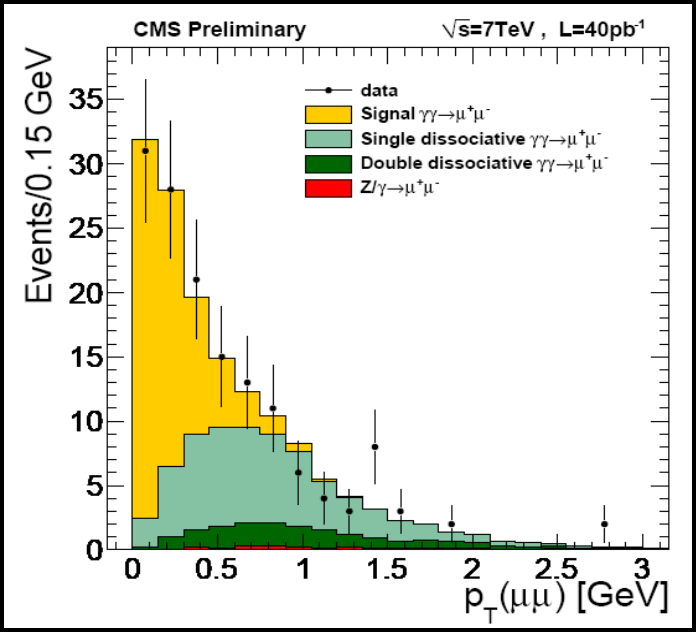
Exclusive dimuons

- Selection based on tracking only, to keep high efficiency with pileup
- Require a $\mu\mu$ vertex, with no other tracks associated
  - Measurement in a restricted phase space $p_T(\mu) > 4$ GeV, $|\eta(\mu)| < 2.1$, $m(\mu\mu) > 11.5$ GeV , to minimize systematic errors and remove Υ photoproduction



- Efficiency of the track veto is measured in beam-crossing triggered data
  - 92% for full 2010 sample
  - ~70% for events with 8 vertices and 2mm veto size

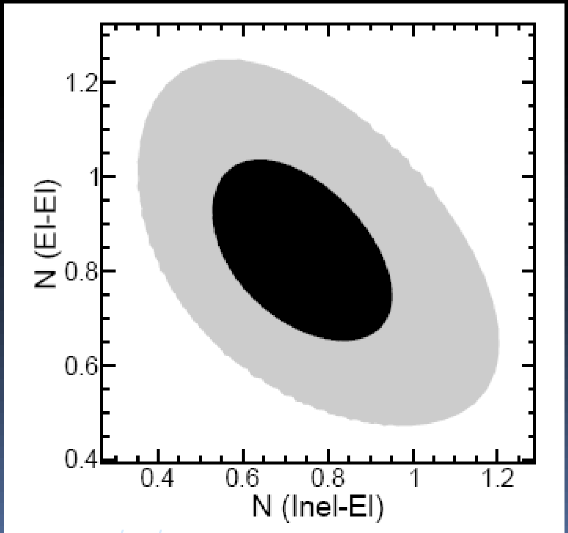
Exclusive dimuons



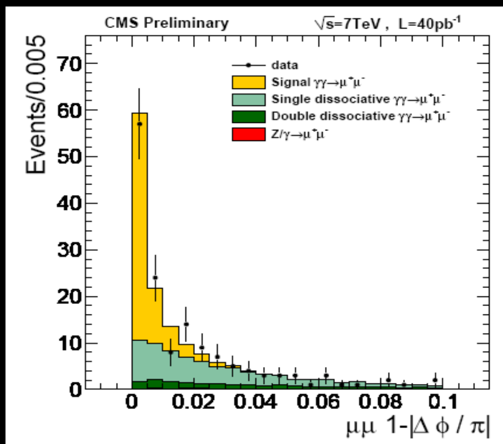
- Signal yield and ratio to the prediction obtained from a fit to the $p_T(\mu\mu)$ distribution
  - Signal yield, single *p*-dissociation yield, and a correction to the slope of the *p*-dissociation are free parameters
  - Signal and p-dissociation yields are highly anti-correlated

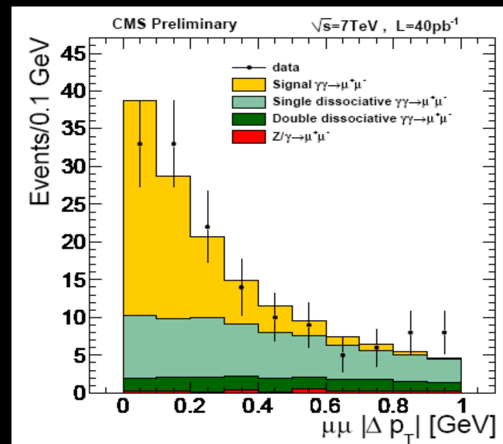
For $p_T(\mu) > 4$ GeV, $|\eta| < 2.1$, $m(\mu\mu) > 11.5$ GeV:

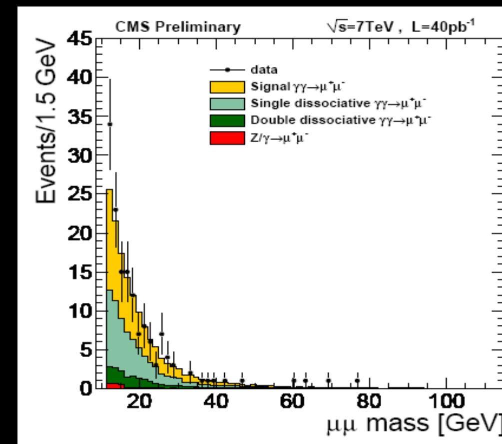
$\sigma = 3.38^{+0.58}_{-0.55}$ (stat.) $\pm$ 0.16 (syst.) $\pm$ 0.14 (lum.) pb
Ratio = $0.83^{+0.14}_{-0.13}$ (stat.) $\pm$ 0.04 (syst.)



Kinematic distributions







- Kinematic distributions compared to LPAIR MC with best fit normalization
- Good agreement with expectations for exclusive $\gamma\gamma\rightarrow\mu\mu$ plus proton dissociation
  - $|1-\Delta\phi(\mu\mu)/\pi|$, $\Delta p_T(\mu\mu)$ peak at ~0, consistent with exclusive production
  - $m(\mu\mu)$ spectrum extends to 76 GeV, no events consistent with $Z\rightarrow\mu\mu$ (consistent with suppression of spin-1 resonance production $\gamma\gamma$ interactions)

Conclusions

- Inelastic cross-section
  - New measurement based on counting vertices in pileup events
- Inclusive diffraction at 7 TeV
  - No models completely describe calorimeter and charged track distributions
- *W/Z*
  - No models completely describe energy flow and charged track distributions
  - Study of LRG events, and measurement of diffractive component from η_{lepton}
- Exclusive production
  - Observation of $\gamma\gamma\rightarrow\mu\mu$ standard candle, data well-described by LPAIR MC
- Inelastic cross-section, diffractive *W/Z*, exclusive $\gamma\gamma\rightarrow\mu\mu$ analyses based on the full 2010 sample (36-40 pb^{-1}), including data collected with pileup
  - Stay tuned for new results

Extra

cross-section systematics

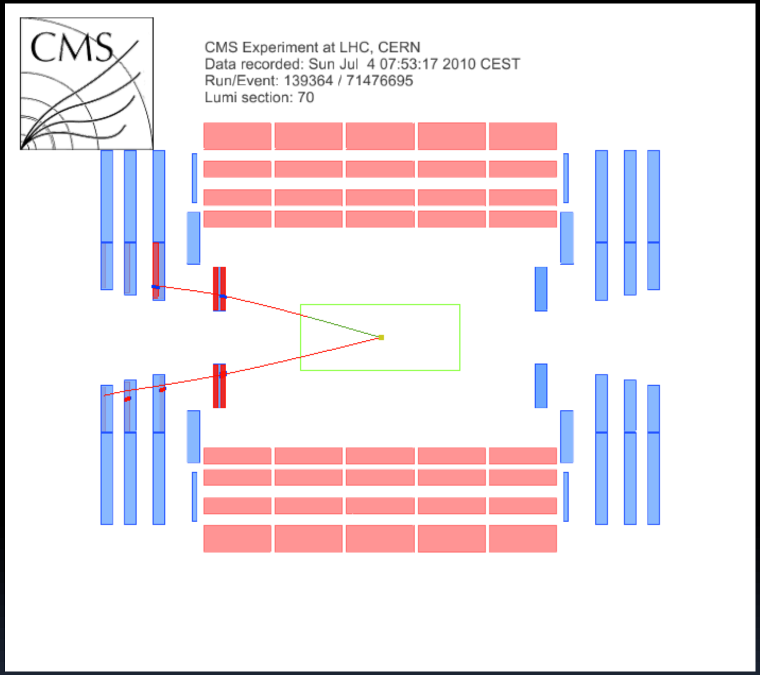
Luminosity	$\Delta\sigma_{vtx}$
Scale the luminosity by +4%	-2.3
Scale the luminosity by -4%	+2.4

Analysis parameters	$\Delta\sigma_{vtx}$
Perform Analysis on a different dataset	+0.9
Change the fit upper limit from 0.6 to 0.5 $\cdot 10^{30} cm^{-2} s^{-1}$	0.3
Change the fit lower limit from 0.05 to 0.15 $\cdot 10^{30} cm^{-2} s^{-1}$: $\Delta\sigma_{vtx} = -0.3$	-0.3
Reduce the z-vertex range from 20 to 10 cm	-0.1
Change the ε correction by 2%	-0.4
Change the ε correction by -2%	0.3
Impose the minimum distance of ±1mm between two vertices	0.1

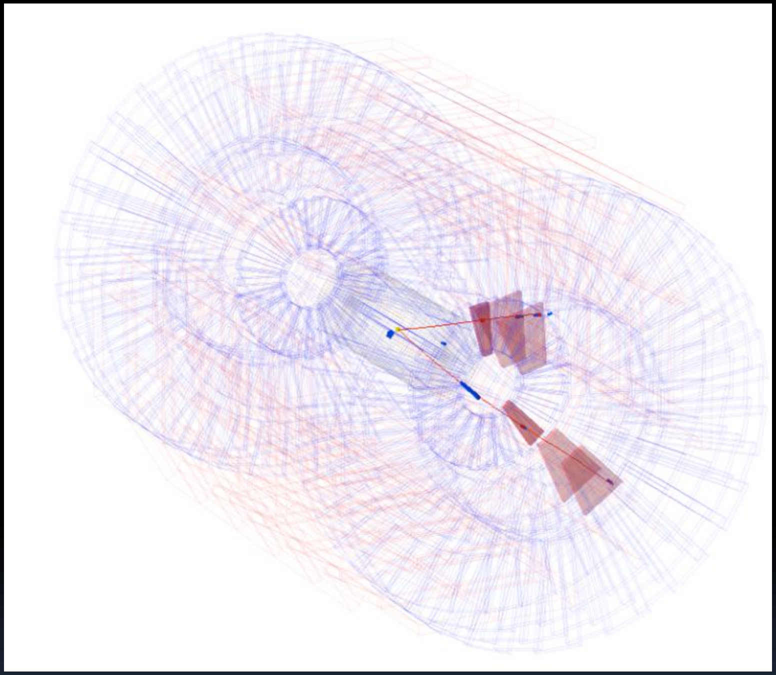
$\gamma\gamma \to \mu\mu$ systematics

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%

Exclusive quarkonia candidates

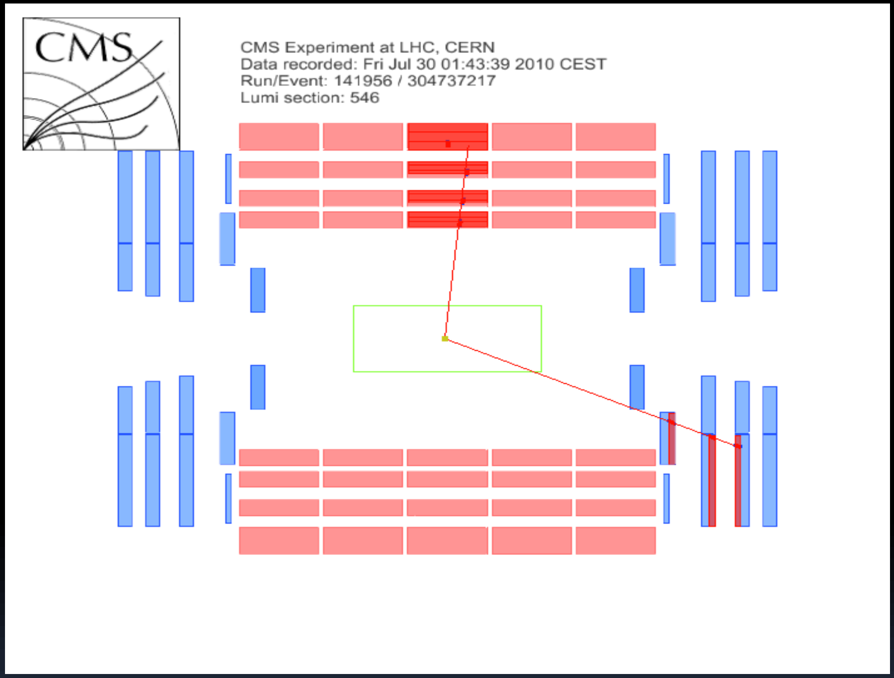


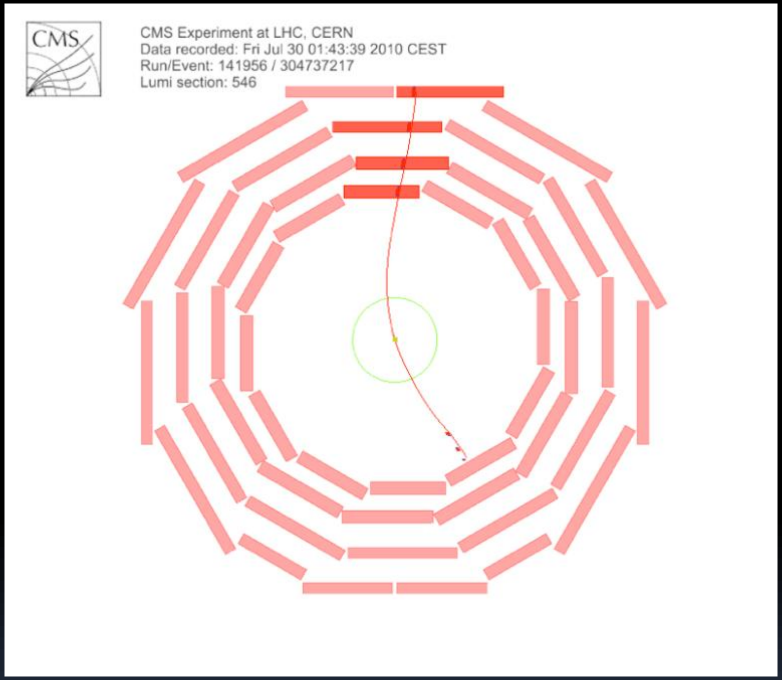
$$\begin{aligned} m &= 3.05 \pm 0.03 \text{ GeV} \\ \frac{\Delta\phi}{\pi} &= 0.98 \\ \Delta p_T &= 0.05\text{GeV} \end{aligned}$$



$$\begin{aligned} m &= 9.44 \pm 0.08 \text{ GeV} \\ \frac{\Delta\phi}{\pi} &= 0.99 \\ \Delta p_T &= 0.20\text{GeV} \end{aligned}$$

Exclusive $\gamma\gamma \rightarrow \mu\mu$ candidates

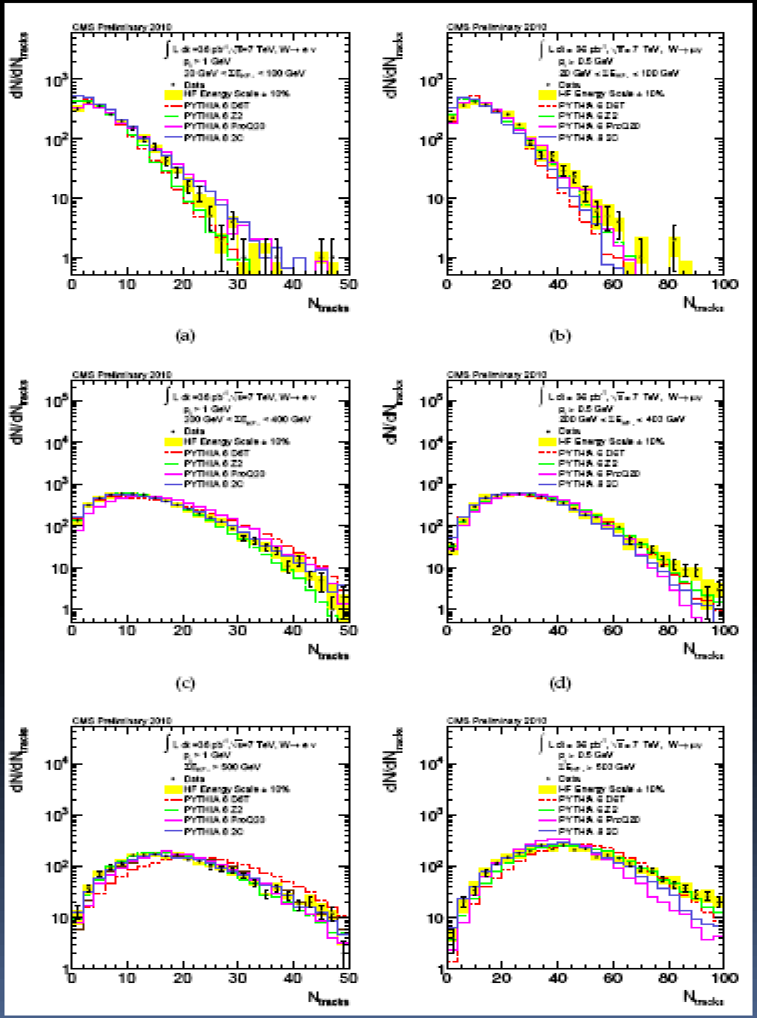




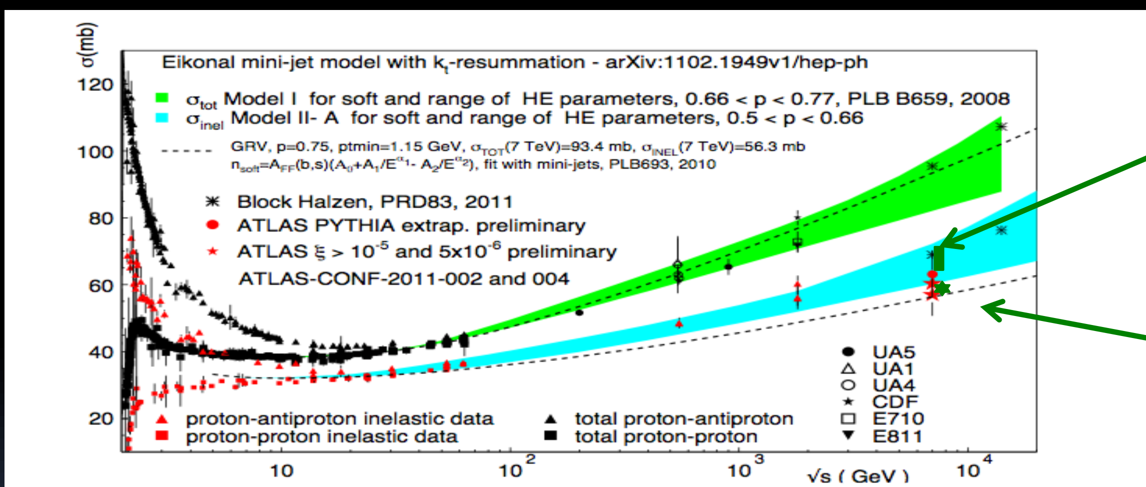
$$\begin{aligned} m &= 20.51 \pm 0.2 \text{ GeV} \\ \frac{\Delta\phi}{\pi} &= 0.98 \\ \Delta p_T &= 0.48 \end{aligned}$$

W/Z Distributions

- Measurements of
  - Energy flow in HF ($3 < |\eta| < 4.9$), summing calorimeter towes above4GeV
  - Track multiplicites ($|\eta| < 2.4$), for p_T>0.5 GeV and p_T>1.0 GeV
  - Correlations – track multiplicites in bins of energy flow, energy deposits in HF+ vs. HF-
- Comparison to a range of Pythia6 and Pythia8 tunes
  - No tune simultaneously describes all multiplicity and energy flow distributions in data



Total cross-section



CMS Model dependent extrapolation

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