σ[pp→ZZ]: cross section measurement & anomalous Triple Gauge Couplings (at CMS experiment)

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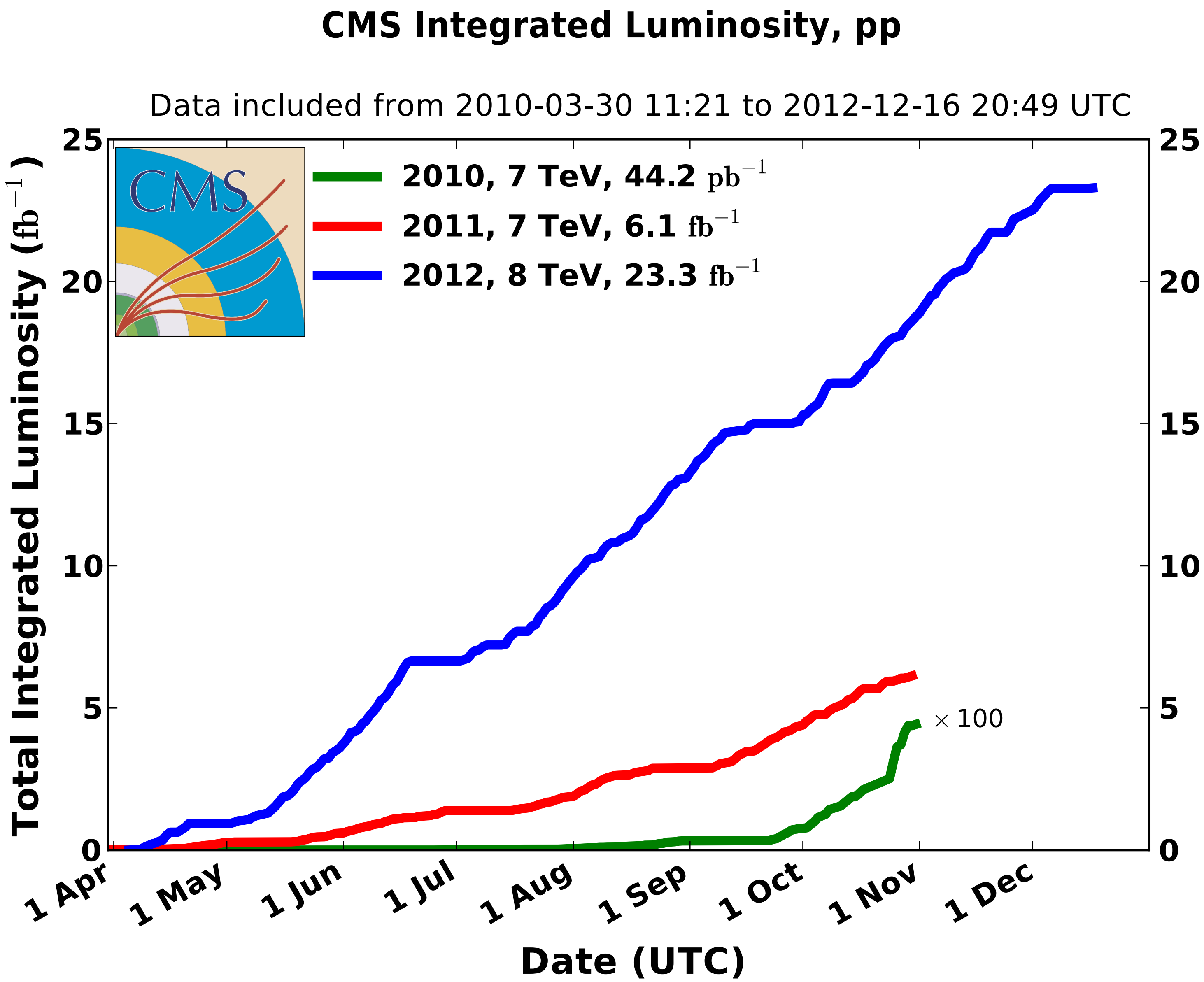
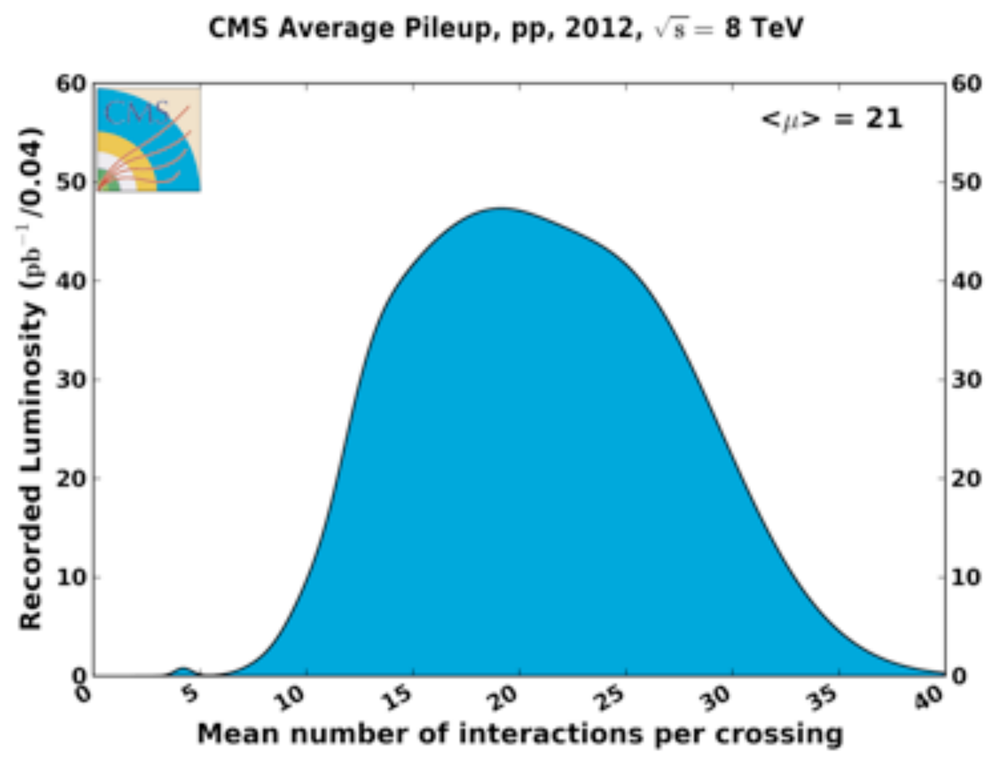
(on behalf of CMS Collaboration)

16th Lomonosov Conference

The Large Hadron Collider

- p-p collision
- Times between bunches: 50 ns
- Center of mass energy: 7 TeV (2011), 8 TeV (2012)
- Instantaneous max. luminosity: $8{\cdot}10^{33}$ $cm^{-2}s^{-1}$



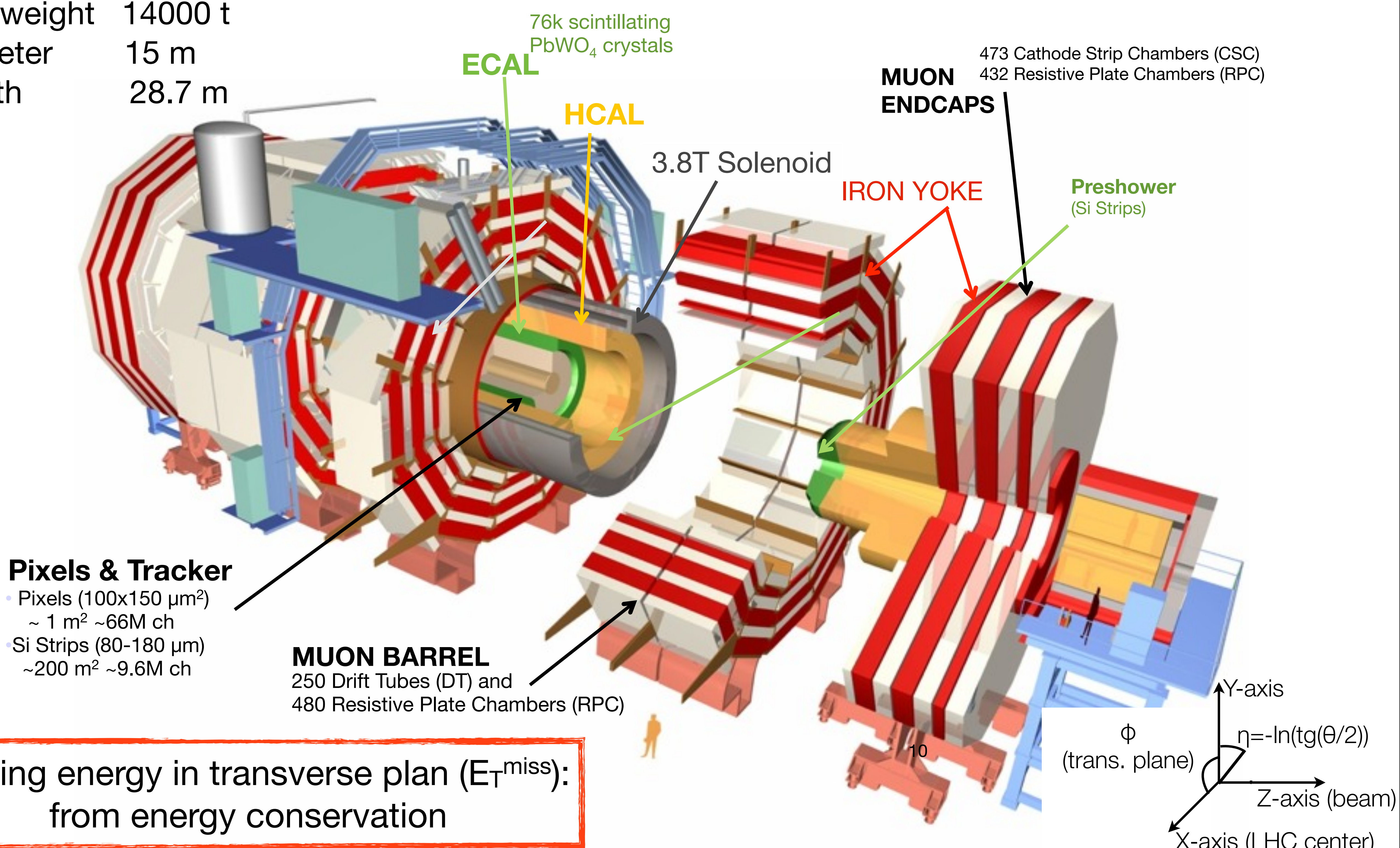


Rate:

$$R_i = \frac{\delta N_i}{\delta t} = \sigma_i \mathcal{L}$$

The Compact Muon Solenoid

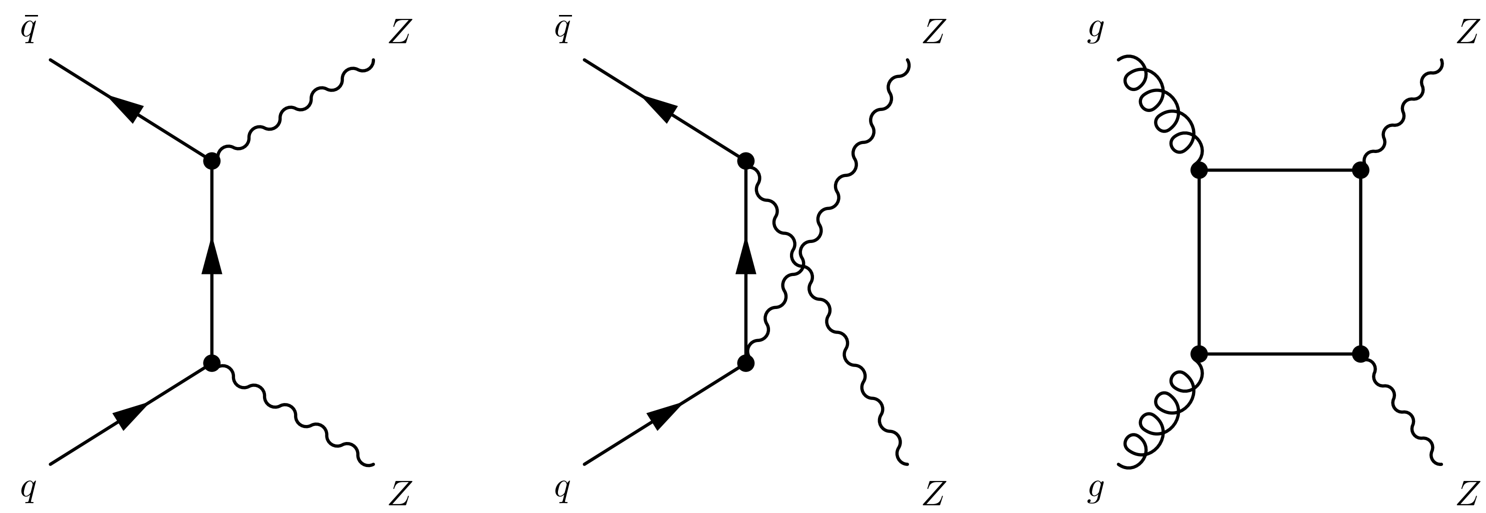
Total weight 14000 t
Diameter 15 m
Length 28.7 m



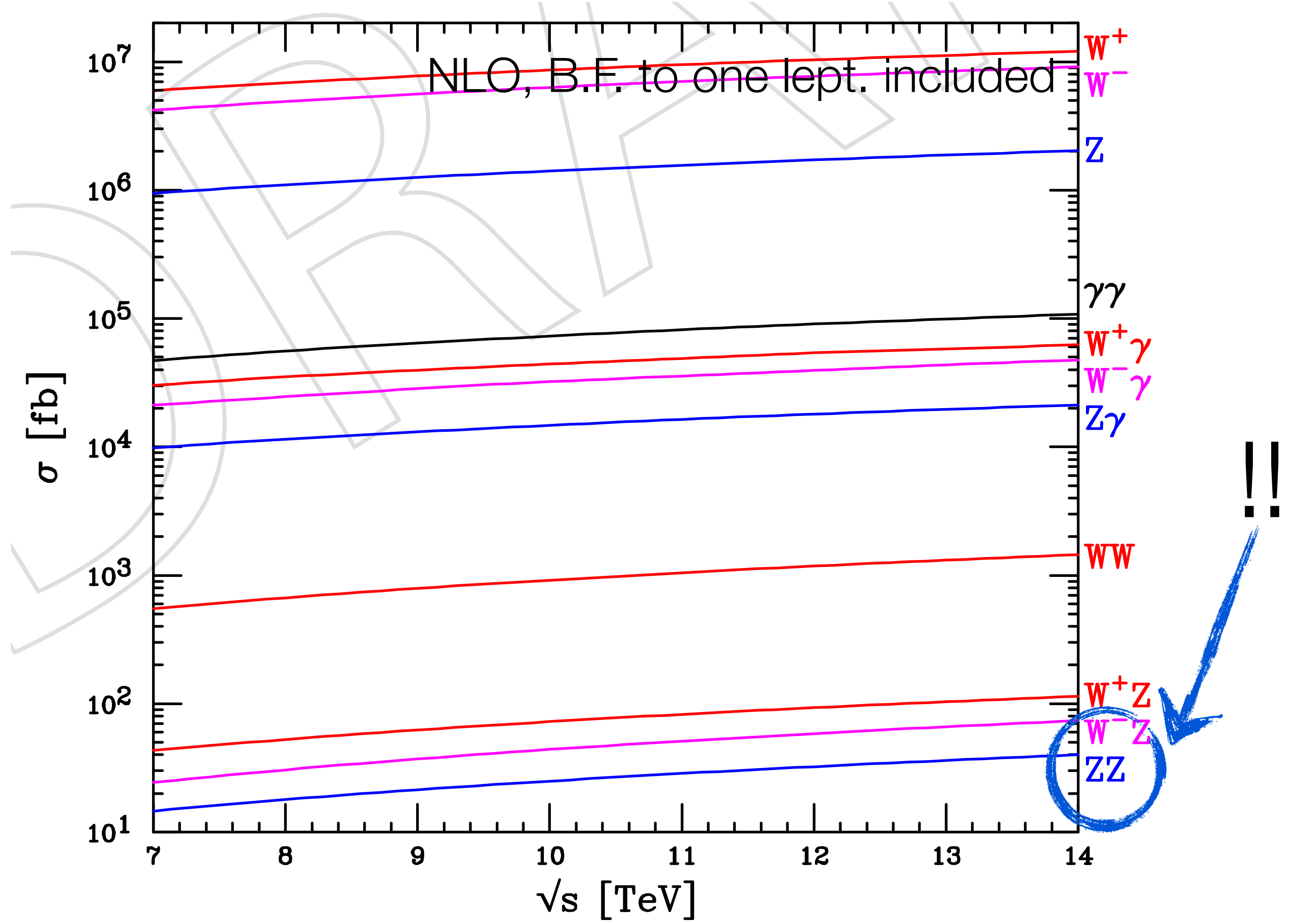
Missing energy in transverse plan (E_T^{miss}):
from energy conservation

Why double Z boson? (1/2)

- Different Feynman diagrams
- Common backgrounds (H→ZZ...)
- Most rare di-boson process



$\sqrt{s}$ [TeV]	$\sigma^{LO}(ZZ)$ [pb]	$\sigma^{NLO}(ZZ)$ [pb]
7	4.17(0)	$6.46(0)^{+4.7\%}_{-3.3\%}$
8	5.06(0)	$7.92(0)^{+4.7\%}_{-3.0\%}$

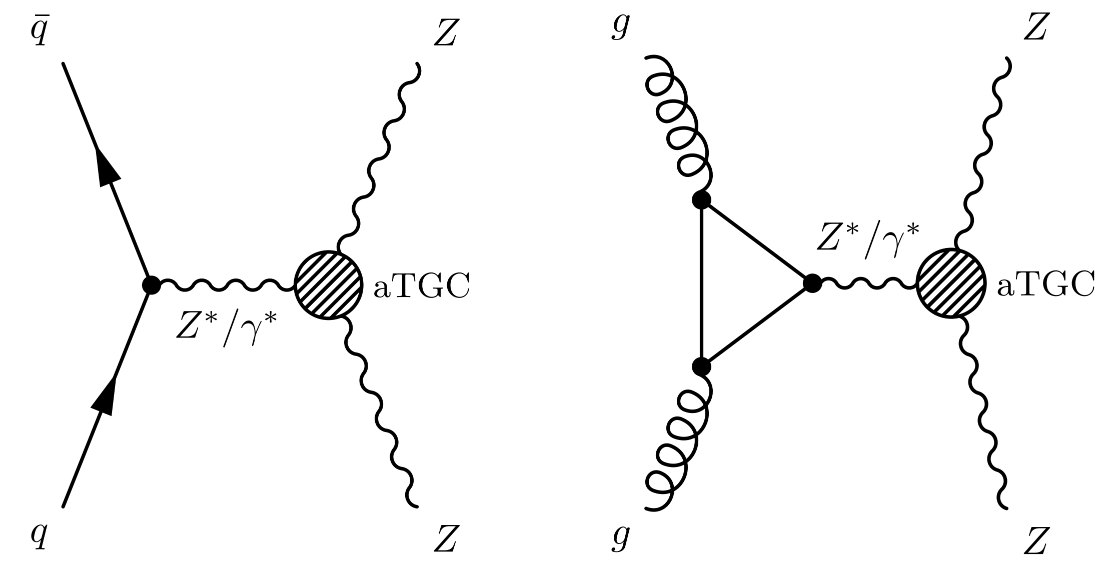


B.F.(ZZ→2l2ν) = 0.0404
B.F.(ZZ→2l2l') = 0.0102
where l=e,μ,τ

Ref: C. W. John M. Campbell, R. Keith Ellis, “Vector boson pair production at the LHC”, JHEP 1107 (2011) 018, doi:10.1007/JHEP07(2011)018, arXiv:1105.0020v

Why double Z boson? (2/2)

- probe of the electro-weak boson self-interactions
- neutral anomalous Triple Gauge Couplings:
  - → γZZ and ZZZ: zero at tree level
- New physics: could be parametrized by aTGC



$P_T(Z)$, $M_{ll'l'}$ distribution: sensitive to aTGC

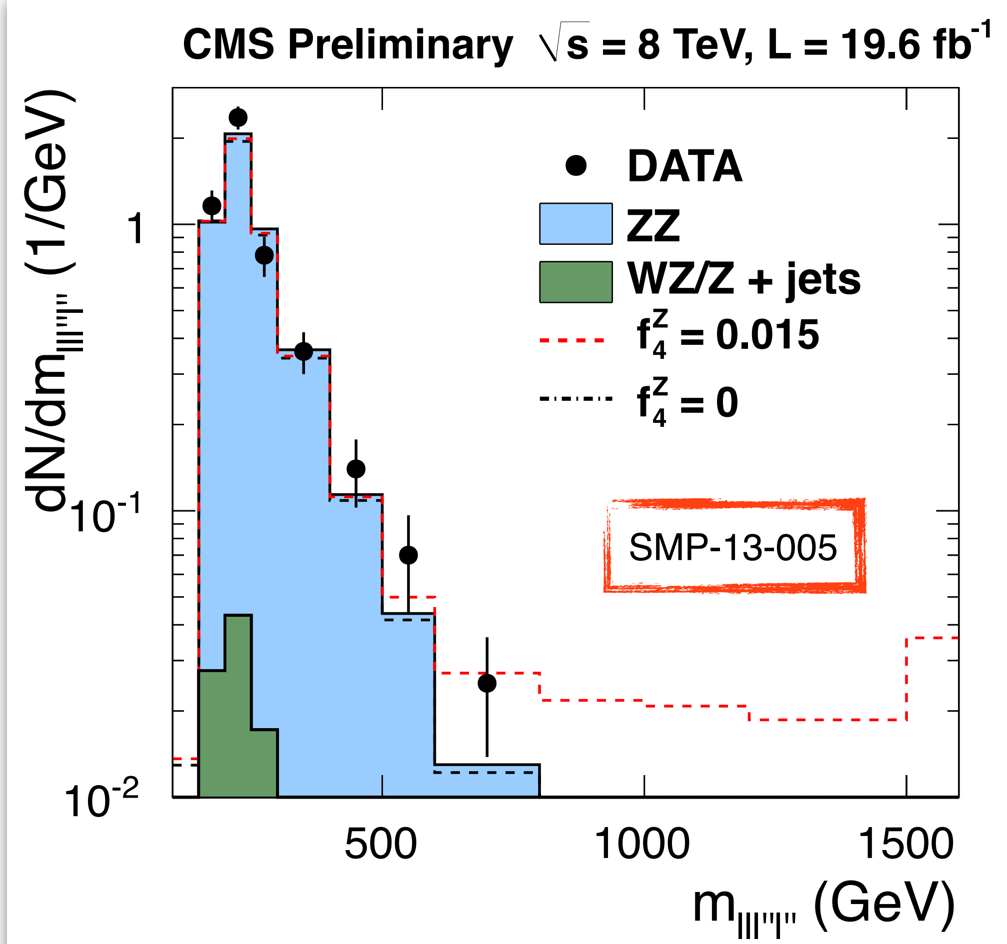
→ Tail is sensitive to aTGC

→ ZZ → 2l2l': clean signature

→ ZZ → 2l2ν: high branching ratio

2 leptons + Missing Energy

Other processes can fake signal



I part

Cross section

Mostly:
data-driven

$$\sigma = \frac{N_{data} - N_{bkg}}{L \cdot A \cdot \epsilon}$$

Integrated
Luminosity

Acceptance
times efficiency!

$ZZ \to 2l2l'$ Signal:

2l2l':

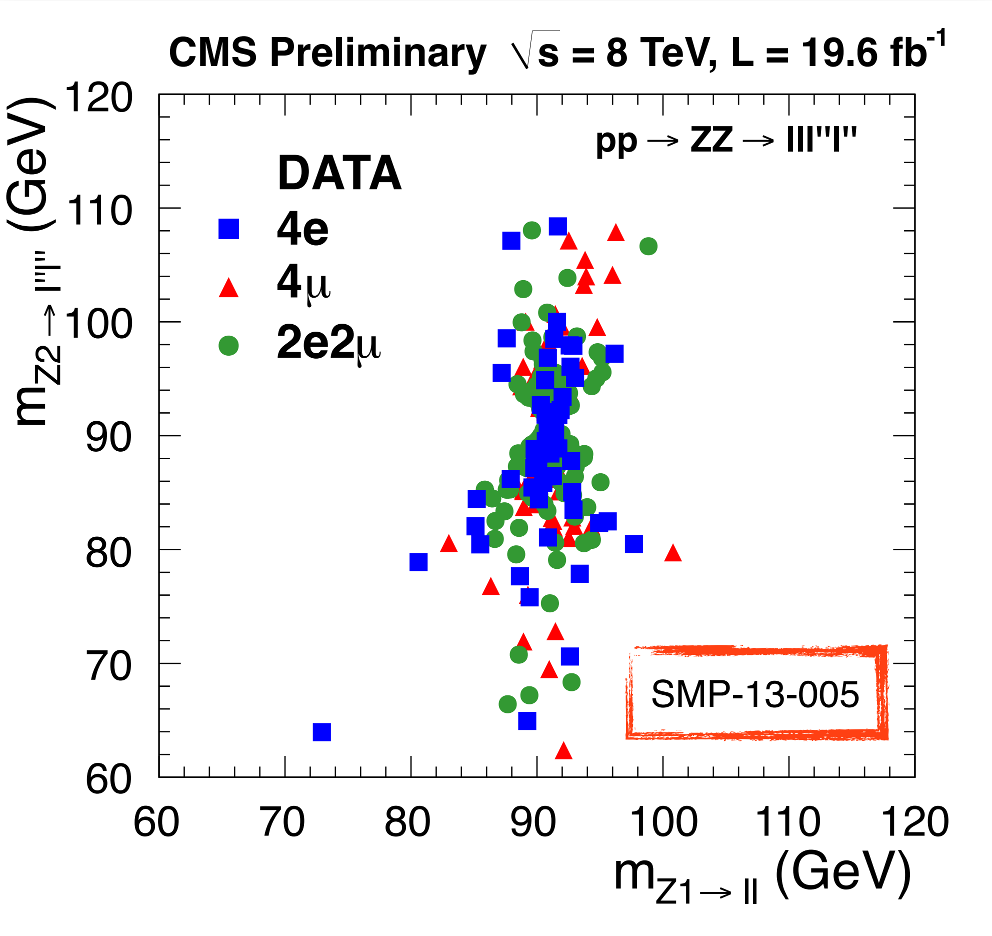
$l^-l^+l'^-l'^+$ where l = e, μ and:

- $M_{ll} \in$ [60,120] GeV and $M_{ll'} > 4$ GeV
- Well identified and isolated, vertex information
- At least one $P_T(l)>20$ GeV and one $P_T(l)>10$ GeV

FSR correction to closest lepton

Z_1: with closer mass to nominal value

Z_2: the other [if more: higher p_T]



2l2τ:

$Z_1 \to l^-l^+$: is defined as before

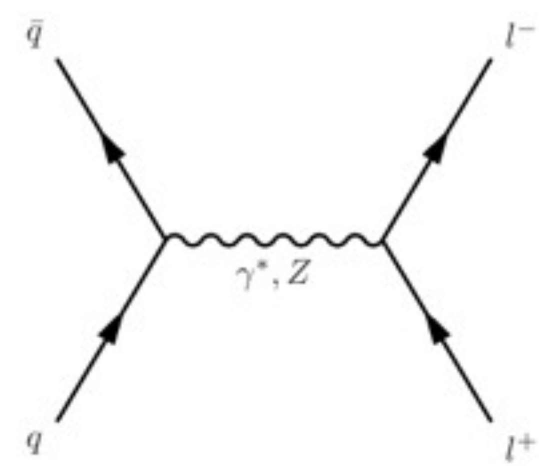
$Z_2 \to \tau^-\tau^+$ (τ_e, τ_μ, τ_h): $P_T(\tau_e)>10$ GeV, $P_T(\tau_h)>20$ GeV

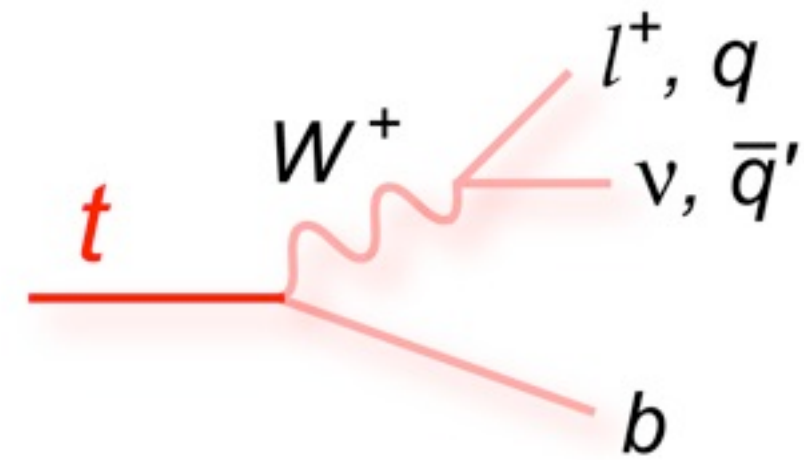
No FSR correction

$M_{min}<m(Z_2)<90$ GeV. M_{min} is 20 (30) GeV for eμ (others) final state

ZZ→2l2l’ backgrounds:

- ❖ Drell Yan
- ❖ Top Bkg (B-veto)
- ❖ WZ (E_t^{miss}< 25 GeV)





Final shape: signal-dominated!

Good signal MC description

Data-driven technique of estimation (more important for 2l2τ).

Ex: DY estimation for 2l2τ final state → Control region Z + X (bb, cc, gluons or light quark):

Z_1: standard selection with relaxed identification and isolation criteria

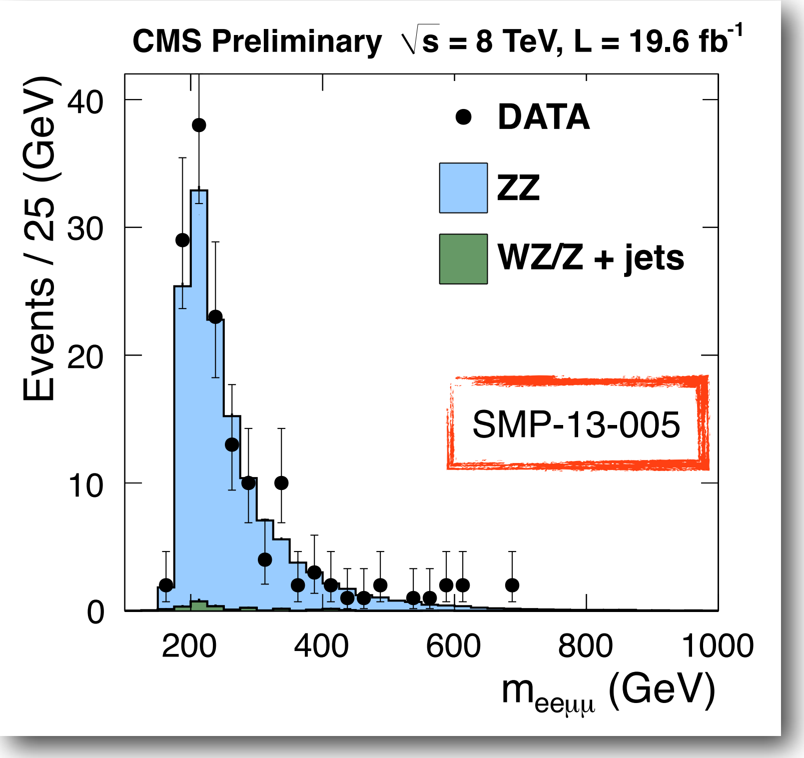
Z_2: ll with same charge/flavour in [60, 120] GeV, M_{4l}>100 GeV.

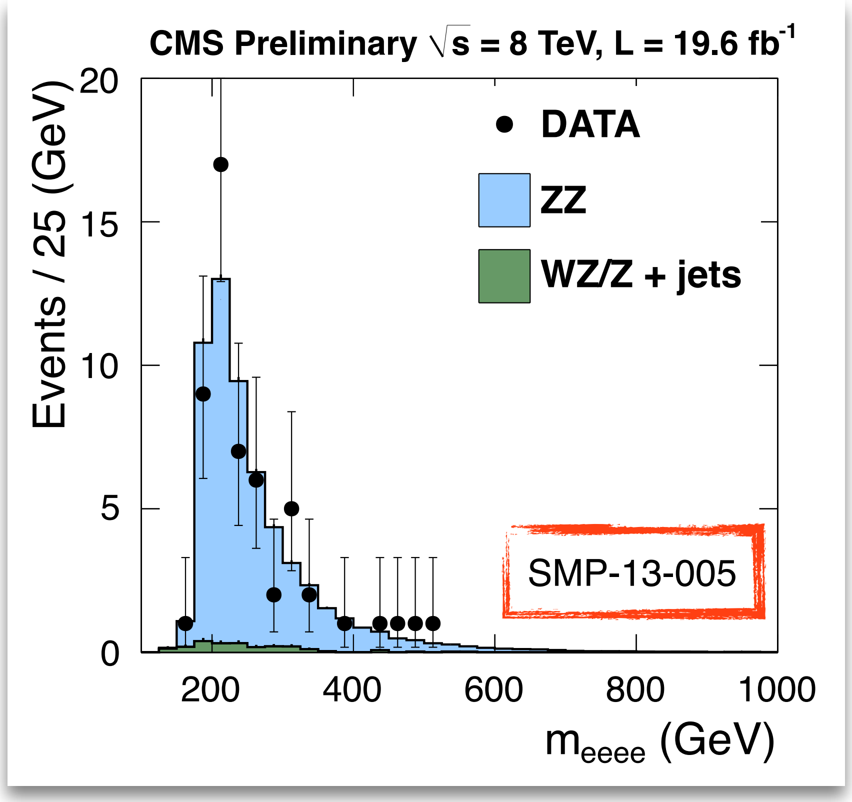
Expected number taken from the lept. misidentification probability from Z_1 + l sample with no id.+iso. on the 3rd lept.

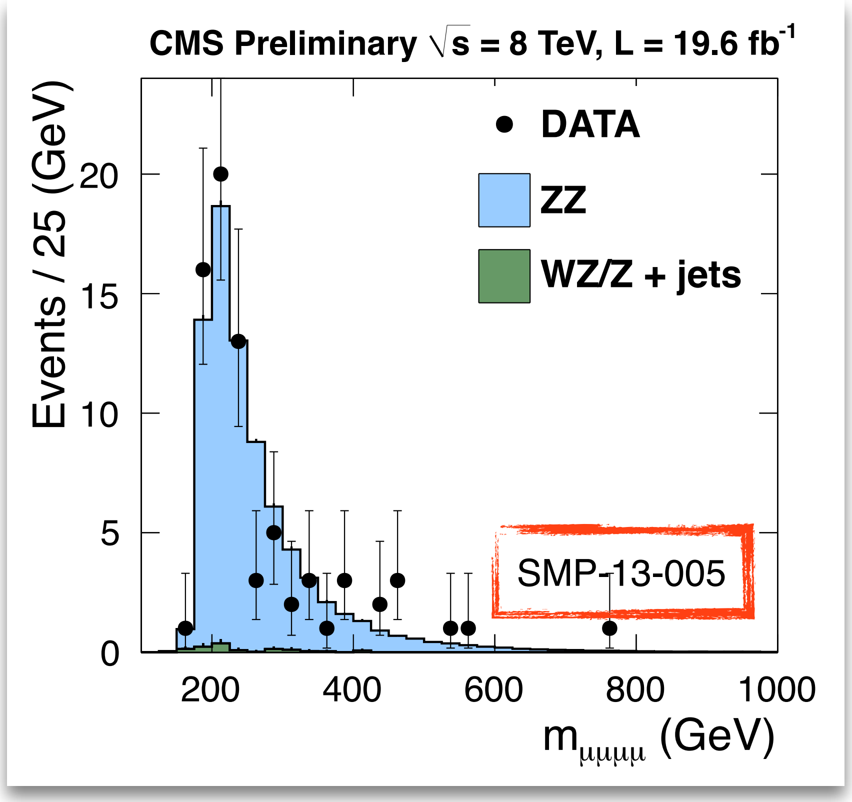
ZZ→2l2l’: Cross section

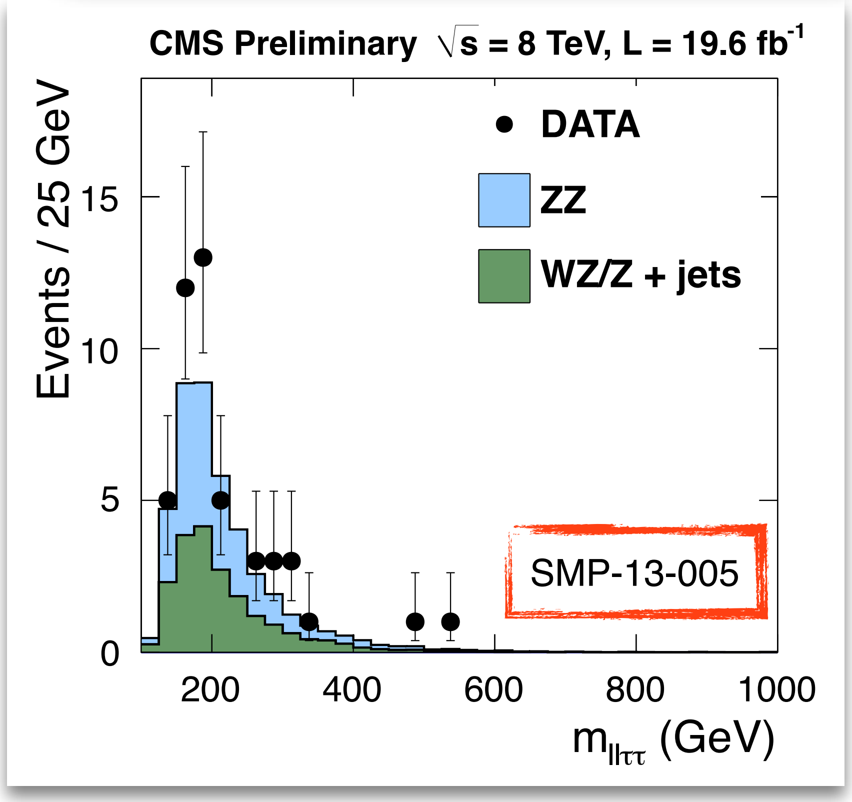
- Final shapes signal-dominated
- Data-driven estimation (see backup)
- Combination of all final states:

simultaneous fit on the observed distribution of the ZZ invariant mass









ZZ→2l2l': Cross section

❖ Acceptance from simulation. Monte Carlo efficiency corrected with Tag&Probe.

❖ Likelihood: written as a combination of individual channel likelihoods for the signal and background hypotheses with the statistical and systematic uncertainties in the form of scaling nuisance parameters.

❖ Each tau decay mode is treated as a separate channel.

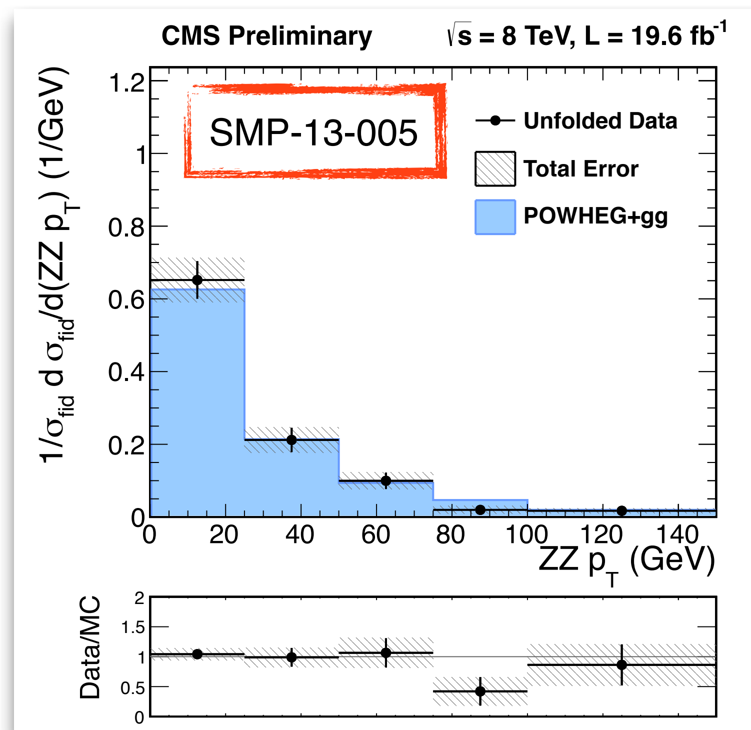
Decay	Cross sections
$\mu\mu\mu\mu$	$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 7.3^{+0.8}_{-0.8}\,(\mathrm{stat.})^{+0.6}_{-0.5}\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{theo.}) \pm 0.3\,(\mathrm{lum.})\,\mathrm{pb}$
eeee	$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 7.2^{+1.0}_{-0.9}\,(\mathrm{stat.})^{+0.6}_{-0.5}\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{theo.}) \pm 0.3\,(\mathrm{lum.})\,\mathrm{pb}$
$\mu\mu$ee	$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 8.1^{+0.7}_{-0.6}\,(\mathrm{stat.})^{+0.6}_{-0.5}\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{theo.}) \pm 0.4\,(\mathrm{lum.})\,\mathrm{pb}$
$\ell\ell\tau\tau$	$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 7.7^{+2.1}_{-1.9}\,(\mathrm{stat.})^{+2.0}_{-1.8}\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{theo.}) \pm 0.3\,(\mathrm{lum.})\,\mathrm{pb}$
Total	$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 7.7^{+0.5}_{-0.5}\,(\mathrm{stat.})^{+0.5}_{-0.4}\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{theo.}) \pm 0.3\,(\mathrm{lum.})\,\mathrm{pb}$

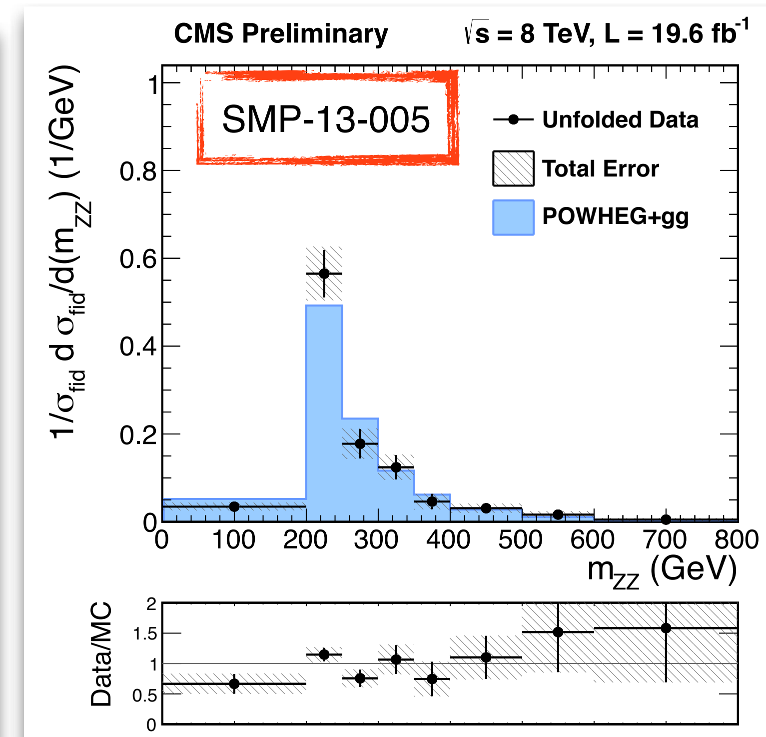
Theoretical cross section with MCFM: 7.7 ± 0.6 pb at NLO

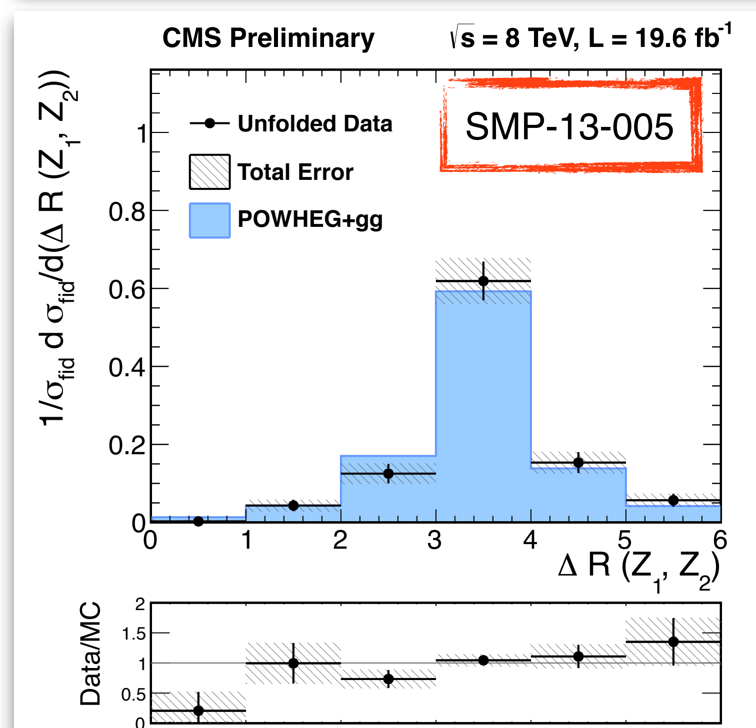
ZZ→2l2l’: Differential cross section

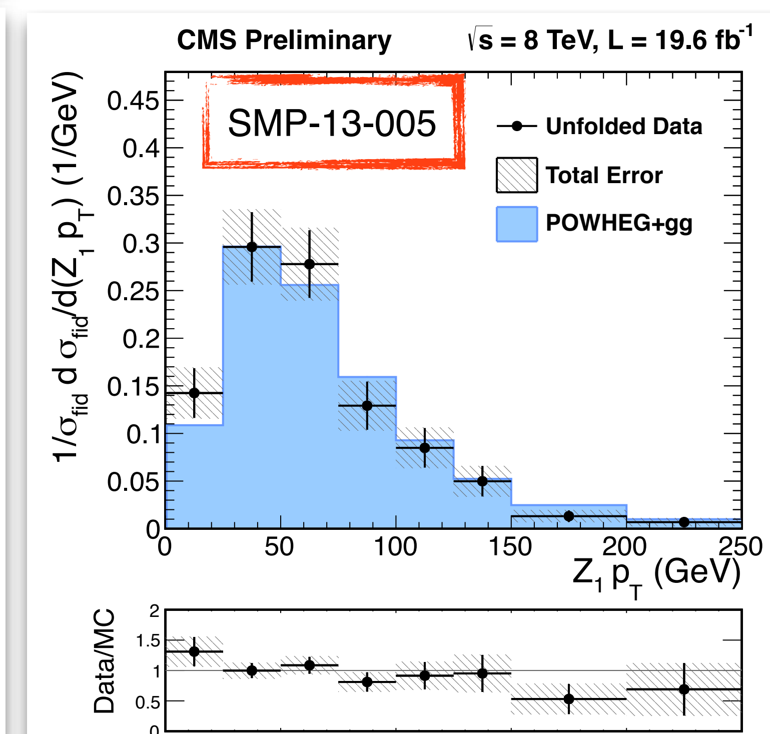
- Further constrains Standard Model
- Good agreement on all variables
- Needs more statistics to see small variations

Pt-related observable







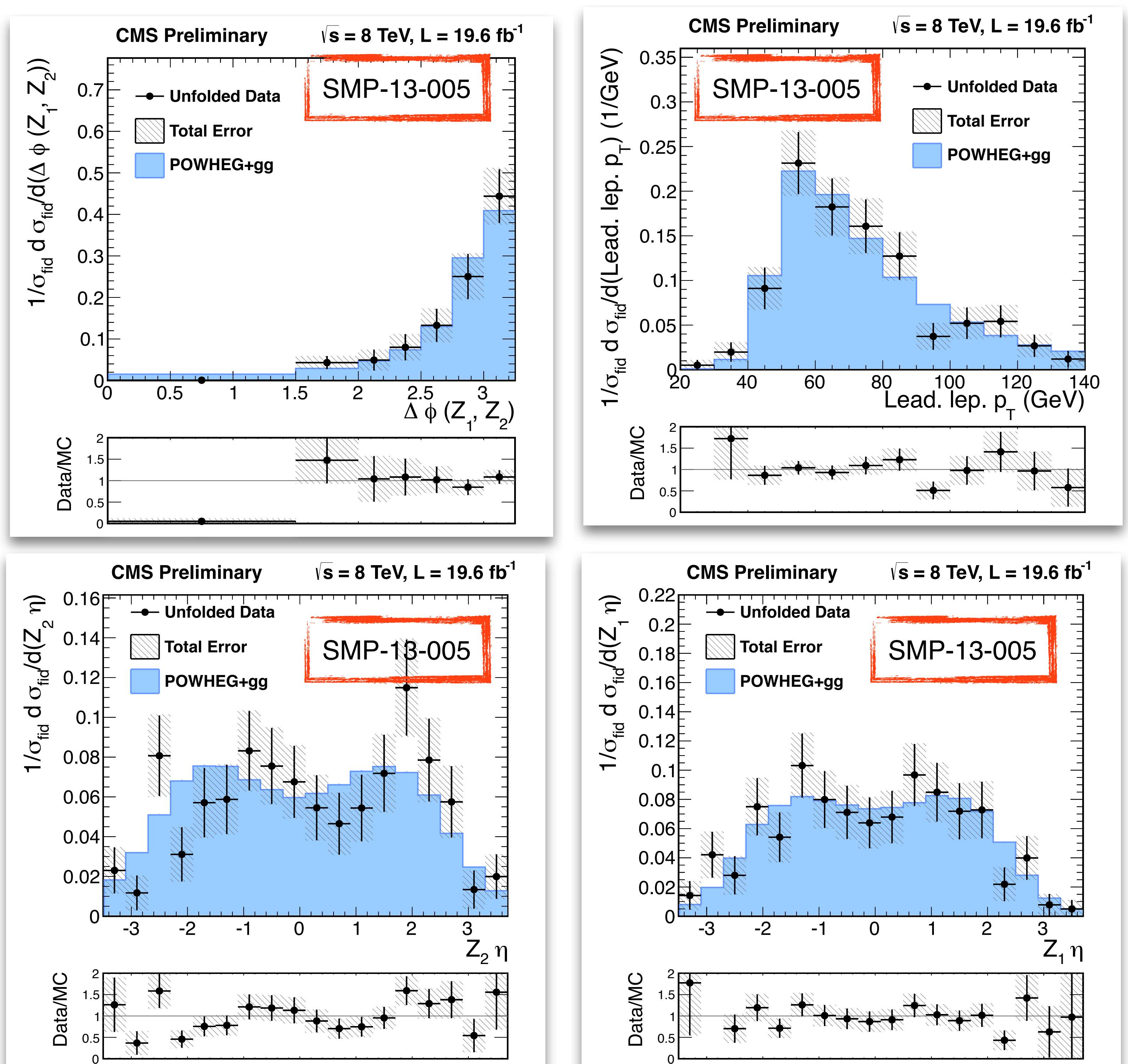


Ref: Measurement of the ZZ production cross section and anomalous trilinear gauge couplings in lll’l’ decays at sqrt(s) = 8 TeV at the LHC (SMP-13-005)

ZZ→2l2l’: Differential cross section

- Further constrains Standard Model
- Good agreement on all variables
- Needs more statistics to see small variations

Angular observable



Ref: Measurement of the ZZ production cross section and anomalous trilinear gauge couplings in lll’l’ decays at sqrt(s) = 8 TeV at the LHC (SMP-13-005)

II part

And now...

aTGC

aTGC generation:

- Effective Lagrangian:

$$\mathcal{L}_{\mathrm{VZZ}} = -\frac{e}{M_Z^2}\left\{\left[f_4^\gamma\left(\partial_\mu F^{\mu\alpha}\right)+f_4^Z\left(\partial_\mu Z^{\mu\alpha}\right)\right]Z_\beta\left(\partial^\beta Z_\alpha\right)-\left[f_5^\gamma\left(\partial^\mu F_{\mu\alpha}\right)+f_5^Z\left(\partial^\mu Z_{\mu\alpha}\right)\right]\tilde{Z}^{\alpha\beta}Z_\beta\right\}$$

- MC signal sample: from SHERPA LO generator JHEP 0902 (2009) 007, doi:10.1088/1126-6708/2009/02/007, arXiv:0811.4622
- 4 Parameters: f_4^Z, f_4^γ → violate CP
  f_5^Z, f_5^γ → conserve CP
- aTGC simulation inside a grid: finer binning using the quadratic dependence of the cross section on $f_{4/5}^{Z/\gamma}$
- Previous limits:

At 5fb[-1] →

Experiment	f_4^Z	f_4^γ	f_5^Z	f_5^γ	Ref.	Comments
LEP	[-0.30; 0.30]	[-0.17; 0.19]	[-0.34; 0.38]	[-0.32; 0.36]	[51]	LEP combination No form factors, 1D
CDF	[-0.12; 0.12]	[-0.10; 0.10]	[-0.13; 0.12]	[-0.11; 0.11]	[52]	Λ = 1.2 TeV
DØ	[-0.28; 0.28]	[-0.26; 0.26]	[-0.31; 0.29]	[-0.20; 0.28]	[53]	1 fb^{-1}, Λ = 1.2 TeV
CMS	[-0.011; 0.012]	[-0.013; 0.015]	[-0.012; 0.012]	[-0.014; 0.014]	[6]	No form factors
ATLAS	[-0.013; 0.013]	[-0.015; 0.015]	[-0.013; 0.013]	[-0.016; 0.015]	[54]	No form factors
ATLAS	[-0.019; 0.019]	[-0.022; 0.023]	[-0.020; 0.019]	[-0.023; 0.023]	[54]	Λ = 3 TeV

- Actual limits (L^{8TeV} ~19 fb^{-1}):

$-0.004 < f_4^Z < 0.004$ $\quad -0.005 < f_5^Z < 0.005$

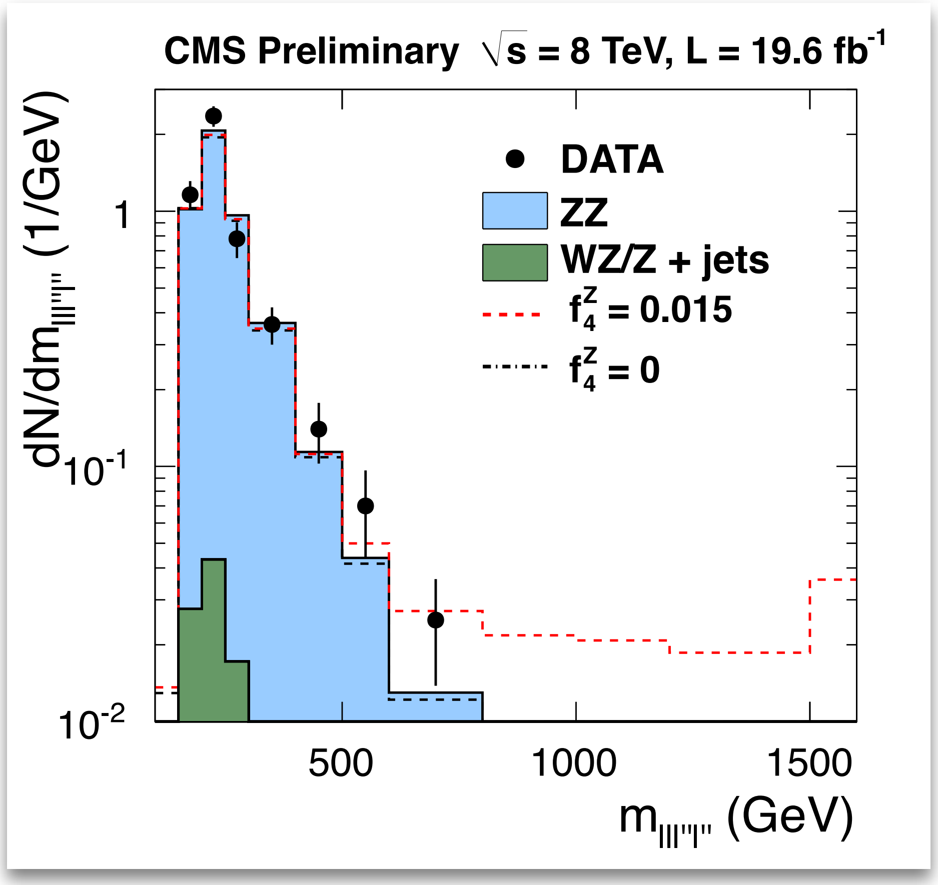
$-0.004 < f_4^\gamma < 0.004$ $\quad -0.005 < f_5^\gamma < 0.005$

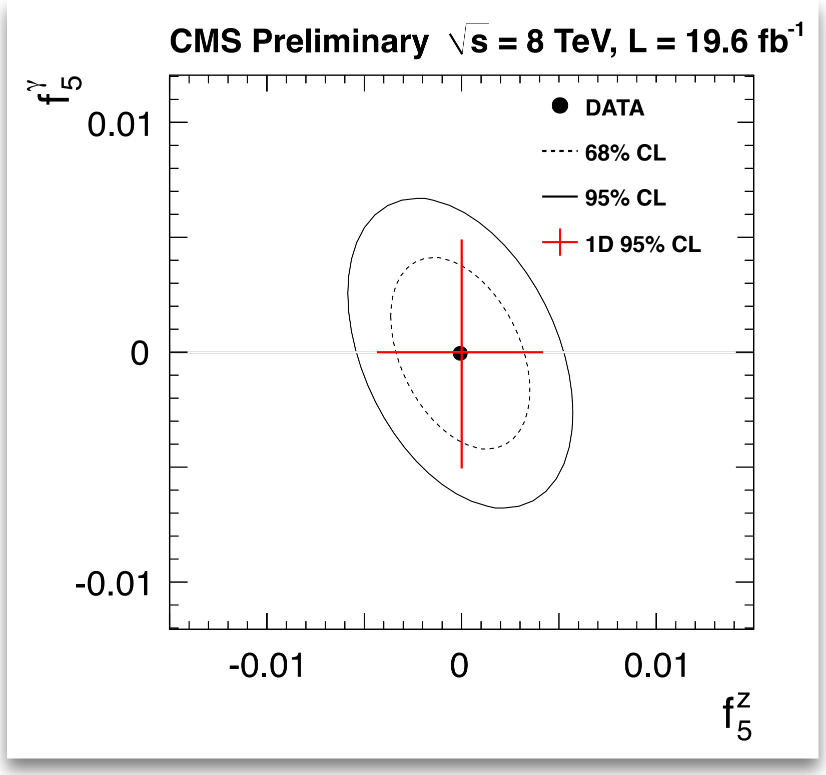
(at 95% CL.)

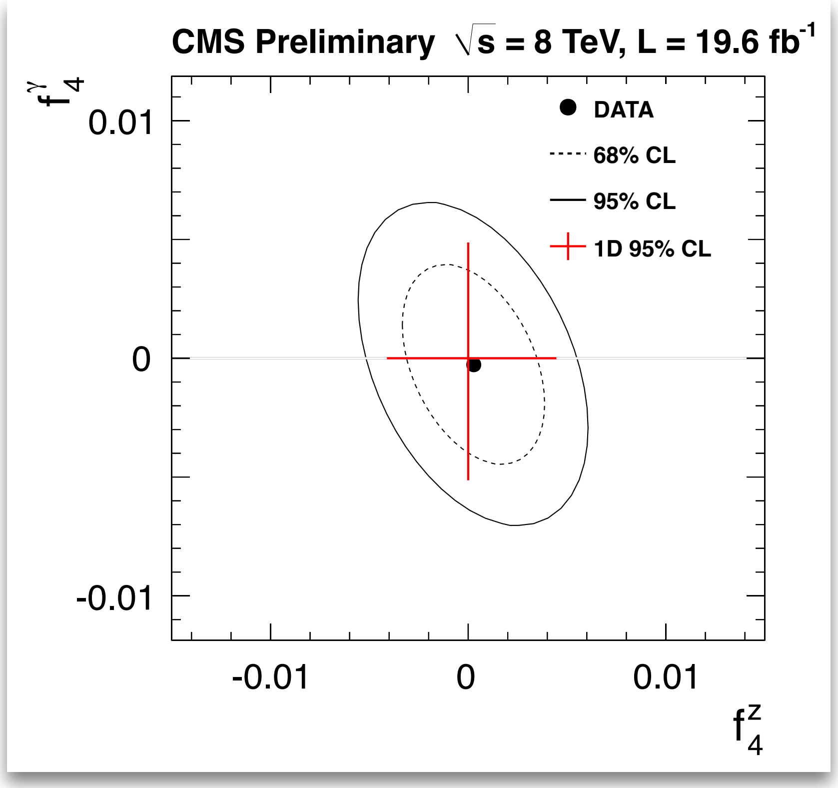
Ref: Measurement of the ZZ production cross section and anomalous trilinear gauge couplings in lll'l' decays at sqrt(s) = 8 TeV at the LHC (SMP-13-005)

aTGC limits:

- 2l2l’ final state has $m_{lll'l'}$ as most sensitive variable
- Same selection that for cross section



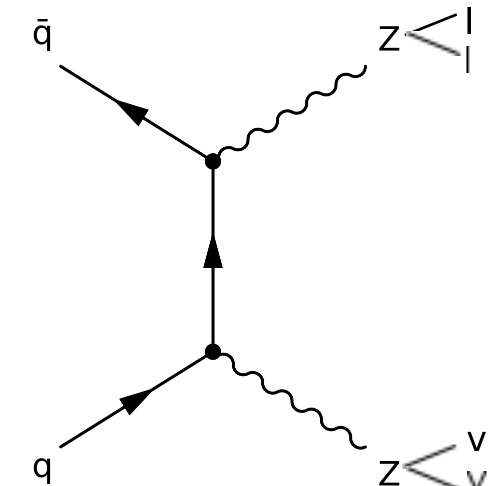




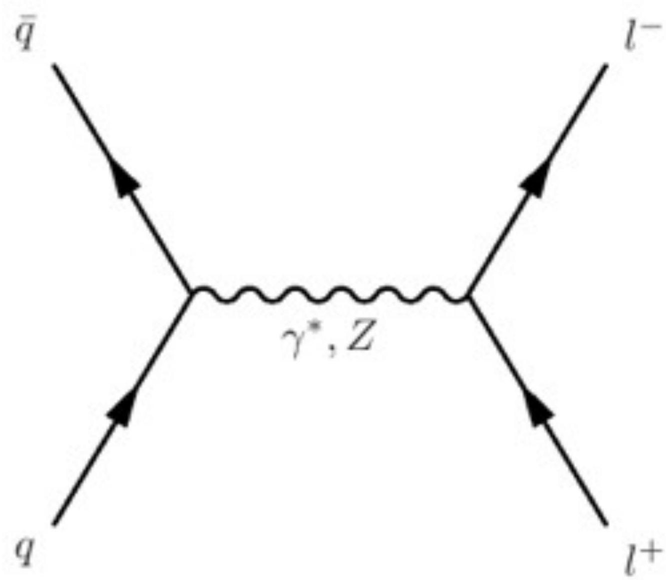
- Signal: aTGC - Standard Model contribution
- Fit on the shape to derive limits

2l2v: backgrounds:

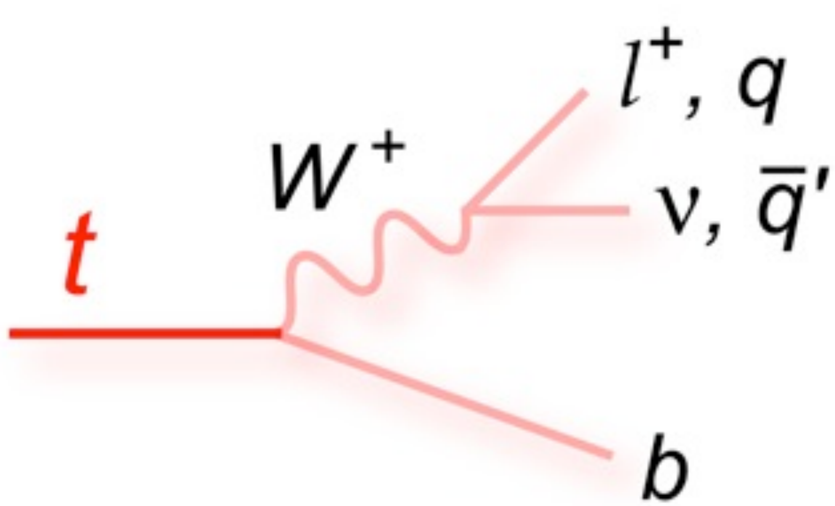
- Competitive and independent channel for aTGC limits.
  - DY: Z+jets. High rate. E_t^{miss} helps us to discriminate it.
  - Top Bkg: since t→Wb, a B-veto avoid the top contribution.
  - WZ: (Z→ll, W→qq,lv). 3rd Lep Veto and E_t^{miss} avoid part of that.
  - WW: Request of M_Z can remove part of that contribution.



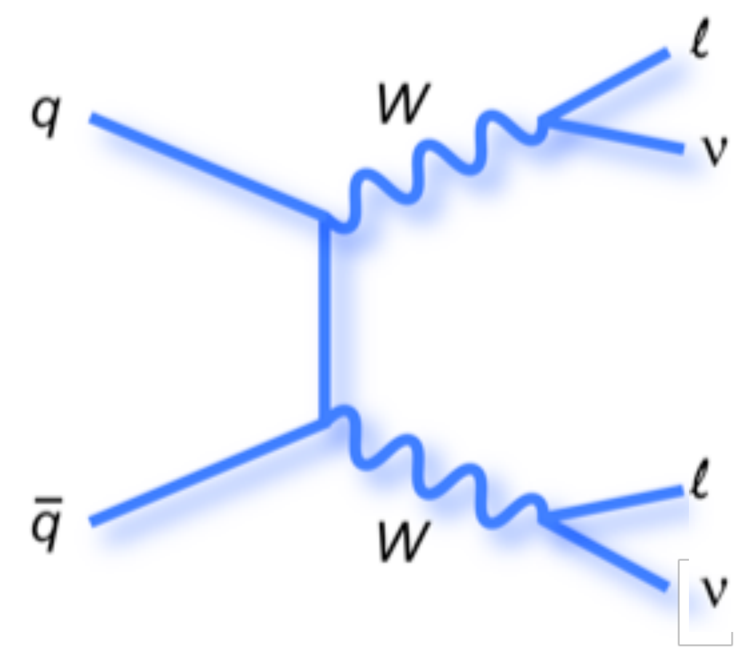
Signal:
σ_{8TeV} = 7.7 pb



DY: σ_{8TeV} = 35041 pb



tt: σ_{8TeV} = 225 pb

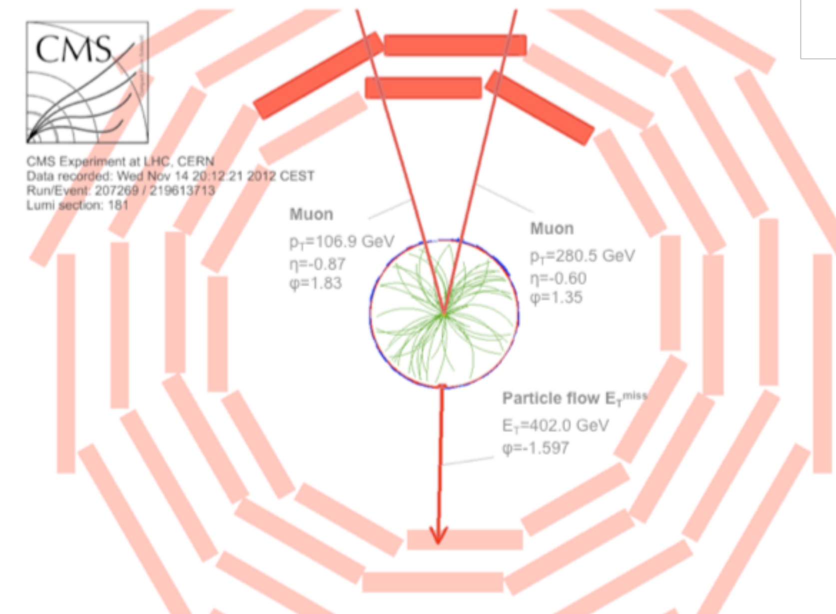


WW: σ_{8TeV} = 69.9 pb

Where l=e,μ

2l2v: Reduced Met:

- Need to master E_T^{miss}
- We need: efficiency, stability under Pile Up, jet resolution

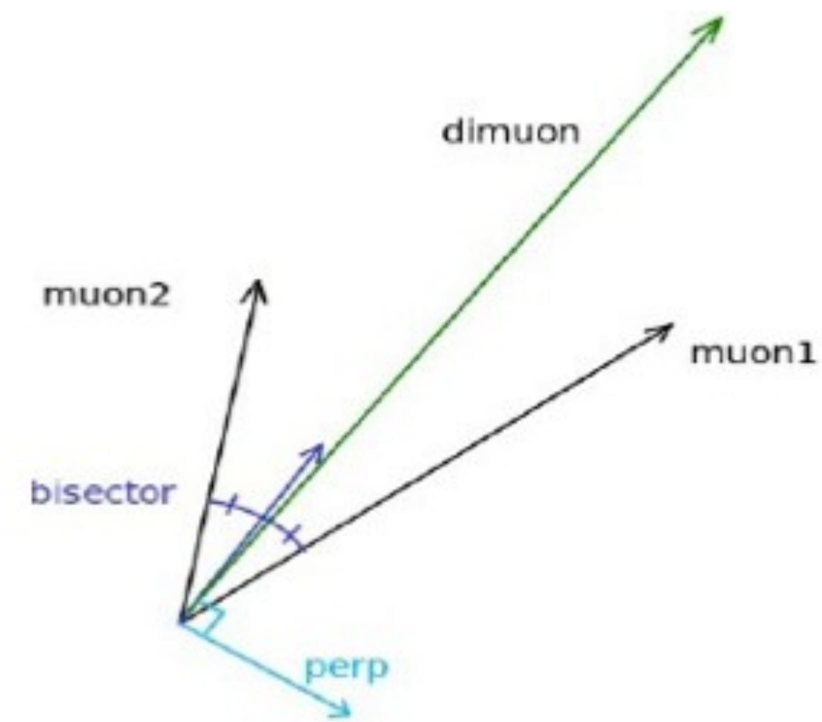


- Define a reference frame in the transverse plane:

  $\vec{d}=\vec{l}_1+\vec{l}_2$ as reference

- On each axis we define:

  Recoil term: Min(| E_T^{miss} + $q_T(l_1 l_2)$ | , | $\sum_i \vec{P}_T(Jets_i)$ |)



On each direction (i = Long., Perp.) define:

$$redMET_i = q_{T\,i} + recoilTerm_i$$

$$redMET = sqrt(redMET_L^2 + redMET_T^2)$$

2l2v: boosted Z region

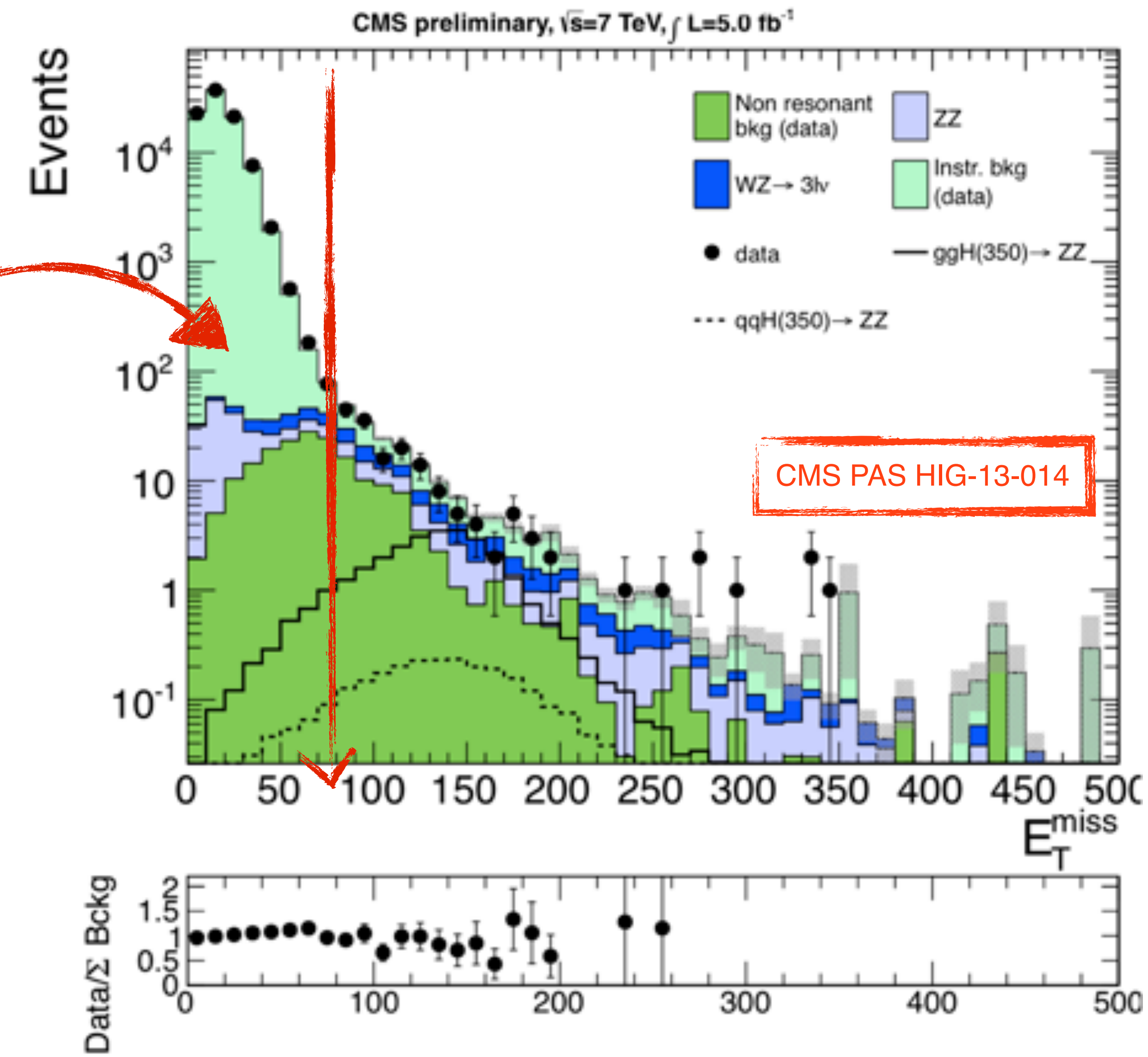
Pre-selection:
→ At least 2 leptons
→ Loose selection on: p_T, η, lept. identification and isolation

Selection:

1) $|M_{ll}-M_Z| < 7.5$ GeV
2) $P_t(ll) > 45$ GeV
3) B-veto & JetVeto
4) RedMet > 65 GeV
5) $0.4 < Met/qt < 1.8$
6) $\Delta\Phi$ (Jet-Met) > 0.5
7) 3^{lept}Veto

Data-driven estimation done for DY!!

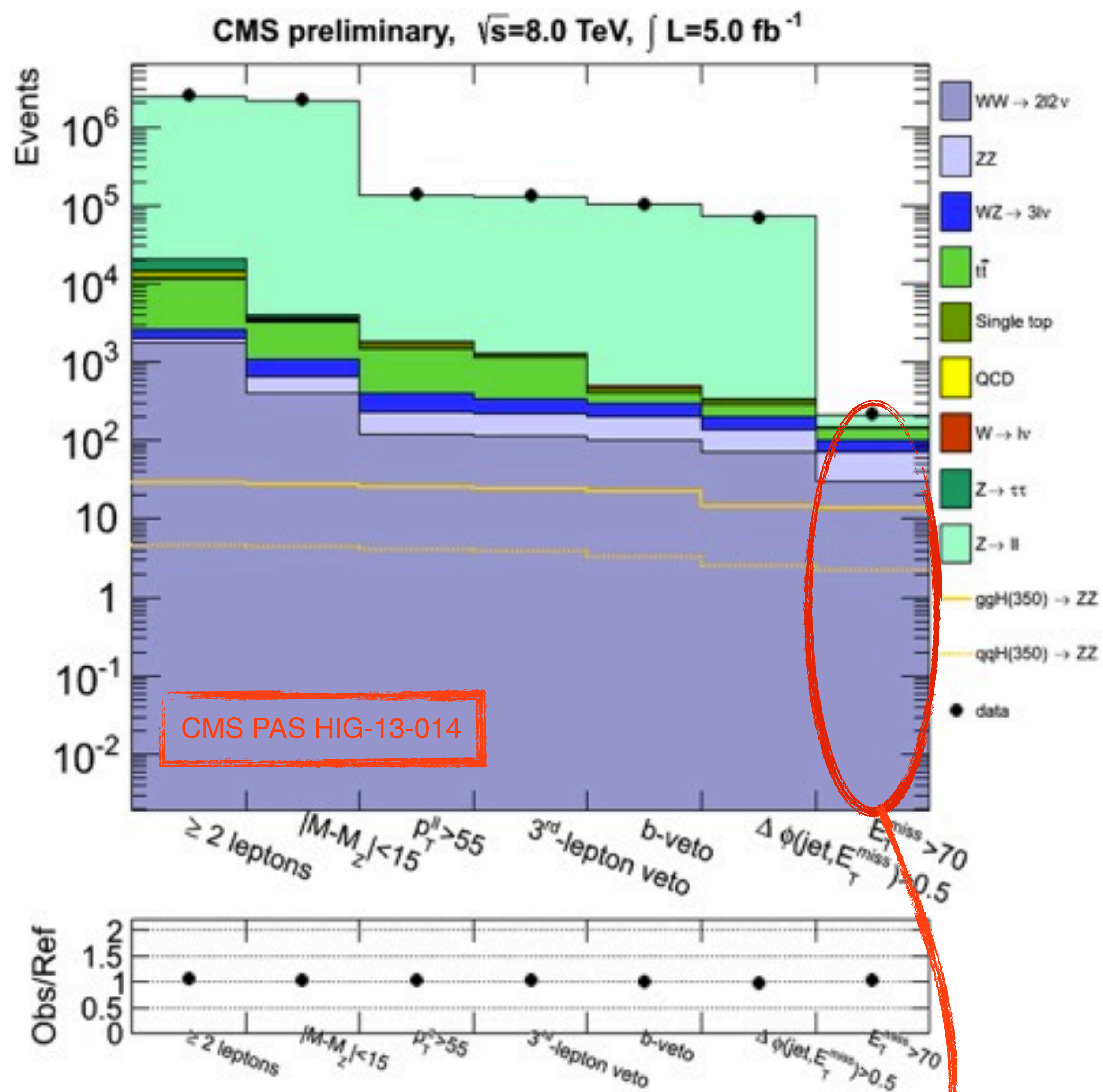
DY



2l2ν: Cross section

- Drell Yan estimated from γ+Jets data
- Non resonant background estimated from sidebands
- After whole selection large ZZ contribution
- Selection efficiency shows cuts efficiency
- Same sensitivity to aTGC of 2l2l' final state

σ extraction through maximum likelihood fit to the reduced E_T^{miss}



Fit to the reduced E_T^{miss} in this bin

Conclusions:

- pp→ZZ cross section at 7 and 8 TeV of center of mass energy has been presented
- Two very different final states have been investigated
- Background estimation needed
- Differential cross section verifies Standard Model
- Strongest limits on aTGCs parameters

Backup

2l2v: Dataset:

Signal samples

Dataset	$\int \mathcal{L}$ [pb^{-1}]	Run range
7 TeV		
/PD/Run2011A-HZZ-08Nov2011-v1/AOD	2312	160431-173692
/PD/Run2011B-HZZ-19Nov2011-v1/AOD	2739	175860-180252
Total for the 2011 dataset	5051	
8 TeV		
/PD/Run2012A-PromptReco-v1/AOD	890	190459-193621
/PD/Run2012B-PromptReco-v1/AOD	4430	193834-195947
/PD/Run2012C-PromptReco-v1/AOD	490	197774-198913
/PD/Run2012C-PromptReco-v2/AOD	6390	198913-200601
Total for the 2012 dataset	12200	

PD: DoubleElectron
DoubleMu
SingleMu

2012 D data already available
(not in PAS yet) → + 7.4 fb^{-1}

Background control samples

Top/WW Estimation	/MuEG/Run2011A-HZZ-08Nov2011-v1/AOD
	/MuEG/Run2011B-HZZ-19Nov2011-v1/AOD
	/MuEG/Run2012A-PromptReco-v1/AOD
	/MuEG/Run2012B-PromptReco-v1/AOD
	/MuEG/Run2012C-PromptReco-v1/AOD
	/MuEG/Run2012C-PromptReco-v2/AOD
DY Estimation	/Photon/Run2011A-16Jan2012-v1/AOD
	/Photon/Run2011B-16Jan2012-v1/AOD
	/Photon/Run2012B-PromptReco-v1/AOD
	/Photon/Run2012B-PromptReco-v1/AOD
	/Photon/Run2012C-PromptReco-v1/AOD
	/Photon/Run2012C-PromptReco-v2/AOD

Triggers

Channel	2011 p_T thresholds [GeV/c, GeV/c]	2012 p_T thresholds [GeV/c, GeV/c]
ee	17, 8	17, 8
$\mu\mu$	7, 7 13, 8 17, 8	17, 8
$e\mu$	17 (μ), 8 (e) 17 (e), 8 (μ)	17 (μ), 8 (e) 17 (e), 8 (μ)
γ	20,30,50,75,90 125,135,200	22,36,50,75,90 (EB only) 135,150,160,250,300

2l2v: Dataset:

Most cross sections from https://twiki.cern.ch/twiki/bin/viewauth/CMS/StandardModelCrossSections
https://twiki.cern.ch/twiki/bin/viewauth/CMS/StandardModelCrossSectionsat8TeV

Process	Dataset	σ
	7 TeV	
$W \rightarrow \ell\nu$	/WJetsToLNu_TuneZ2_7TeV-madgraph-tauola/F11-S6-v1	31314 ± 1558
$Z \rightarrow \ell\ell$	/DYJetsToLL_TuneZ2_M-50_7TeV-madgraph-tauola/F11-S4-v1	3048 ± 132
$t\bar{t}$	/TTJets_TuneZ2_7TeV-madgraph-tauola/F11-S4-v1	165^{+8}_{-11}
Single top	/T_TuneZ2_tW-channel-DR_7TeV-powheg-tauola/F11-S6-v1	7.87 ± 0.59
	/Tbar_TuneZ2_tW-channel-DR_7TeV-powheg-tauola/F11-S6-v1	7.87 ± 0.59
	/T_TuneZ2_t-channel_7TeV-powheg-tauola/F11-S6-v1	$41.92^{+1.8}_{-0.9}$
	/Tbar_TuneZ2_t-channel_7TeV-powheg-tauola/F11-S6-v1	$22.6^{+0.84}_{-1.04}$
	/T_TuneZ2_s-channel_7TeV-powheg-tauola/F11-S6-v1	$3.19^{+0.14}_{-0.12}$
	/Tbar_TuneZ2_s-channel_7TeV-powheg-tauola/F11-S6-v1	$1.44^{+0.06}_{-0.07}$
Di-bosons	/ZZJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola/F11-v1	$6.83^{+0.30}_{-0.21} \times 0.0386$
	/WWJetsTo2l2Nu_TuneZ2_7TeV-madgraph-tauola/F11-S6-v1	$52.4 \pm 2.0_{stat} \pm 4.7_{syst} \times 0.105$
	/WZJetsTo3LNu_TuneZ2_7TeV-madgraph-tauola/F11-S6-v1	$18.5^{+1.0}_{-0.8} \times 0.033$
	8 TeV	
$W \rightarrow \ell\nu$	/WToENu_TuneZ2star_8TeV_pythia6/S12-S50-v1	12085
	/WToMuNu_TuneZ2star_8TeV_pythia6/S12-S50-v1	
	/WToTauNu_TuneZ2star_8TeV_pythia6_tauola_cff/S12-S50-v1	
$Z \rightarrow \ell\ell$	/DYJetsToLL_M-50_TuneZ2Star_8TeV-madgraph-tarball/S12-S52-v2	35041
$t\bar{t}$	/TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola/S12-v1	225
Single top	/Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/S12-S52 ($\bar{t}$)	11.2
	/T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/S12-S52 (t)	11.2
	/Tbar_t-channel_TuneZ2star_8TeV-powheg-tauola/S12-S52 ($\bar{t}$)	55.5
	/T_t-channel_TuneZ2star_8TeV-powheg-tauola/S12-S52 (t)	30.0
	/Tbar_s-channel_TuneZ2star_8TeV-powheg-tauola/S12-S52 ($\bar{t}$)	3.9
	(t)	1.76
Dibosons	/ZZJetsTo2L2Nu_TuneZ2star_8TeV-madgraph-tauola/S12-S52-v3	$8.384^{+0.37}_{-0.24} \times 0.0386$
	/WWJetsTo2L2Nu_TuneZ2star_8TeV-madgraph-tauola/S12-S52-v1	$69.9 \pm 2.8_{stat} \pm 6.4_{syst} \times 0.105$
	/WZTo3LNu_TuneZ2star_8TeV_pythia6_tauola/S12-S52-v1	$22.9^{+1.2}_{-0.9} \times 0.033$

- All cross sections at NLO or NNLO when available
- ZZ, WZ cross sections from MCFM
  - NLO + gg contribution
- WW from CMS analyses

- Diboson, DY, tt: MADGRAPH
- W+jets: PYTHIA/MADGRAPH
- Single top: POWHEG

2l2v: Object definition:

Muons:

- $|\eta| < 2.4$
- $P_T > 20$ GeV
- Iso. < 0.2
- Global & tracker
- Plus: IP, Hits, χ^2, $\sigma(p_T)/p_T$

Electrons:

- $|\eta| < 2.5$
- $P_T > 20$ GeV
- Iso. < 0.15
- Track-ECAL: ϕ,η, $|1/E - 1/P|$
- Plus: IP, Hits, H/E

Jets:

- PF jets, PU subtraction
- Anti-K_T, ΔR=0.5
- $|\eta| < 5.0$
- $P_T > 15$ GeV
- ΔR(lept,jet)=0.4

2l2v: Preliminary corrections:

- Cross section from MCFM (generator cut M_{ll}>40 GeV)

σ_{incl}(7TeV) = (6.829 ± 0.025) pb

σ_{excl}(7TeV) = (87.98 ± 0.32) fb

σ_{incl}(8TeV) = (8.384 ± 0.030) pb

σ_{excl}(8TeV) = (108.16 ± 0.39) fb

$BR(ZZ \to 2\ell 2\nu) = 0.0387$

- Standard PU re-weighting
- Events re-weighted for Trigger efficiency (only 2011)
- Events re-weighted for Data/MC scale factor for ID+iso
- Jet pt: correction according JER measured in Data

2l2v: Non res. bkg. estimation:

- tt, single t, WW: no Z peak
- Estimated from emu final state
- Scaling factor between ee/μμ and eμ for sideband

$$N_{ee}^{sign} = \alpha_{ee} \cdot N_{e\mu}^{sign}, \qquad \alpha_{ee} = N_{ee}^{SB} / N_{e\mu}^{SB}$$
$$N_{\mu\mu}^{sign} = \alpha_{\mu\mu} \cdot N_{e\mu}^{sign}, \qquad \alpha_{\mu\mu} = N_{\mu\mu}^{SB} / N_{e\mu}^{SB}$$

- Statistical error on α: systematic uncertainty
- Optimized errors trying different selection

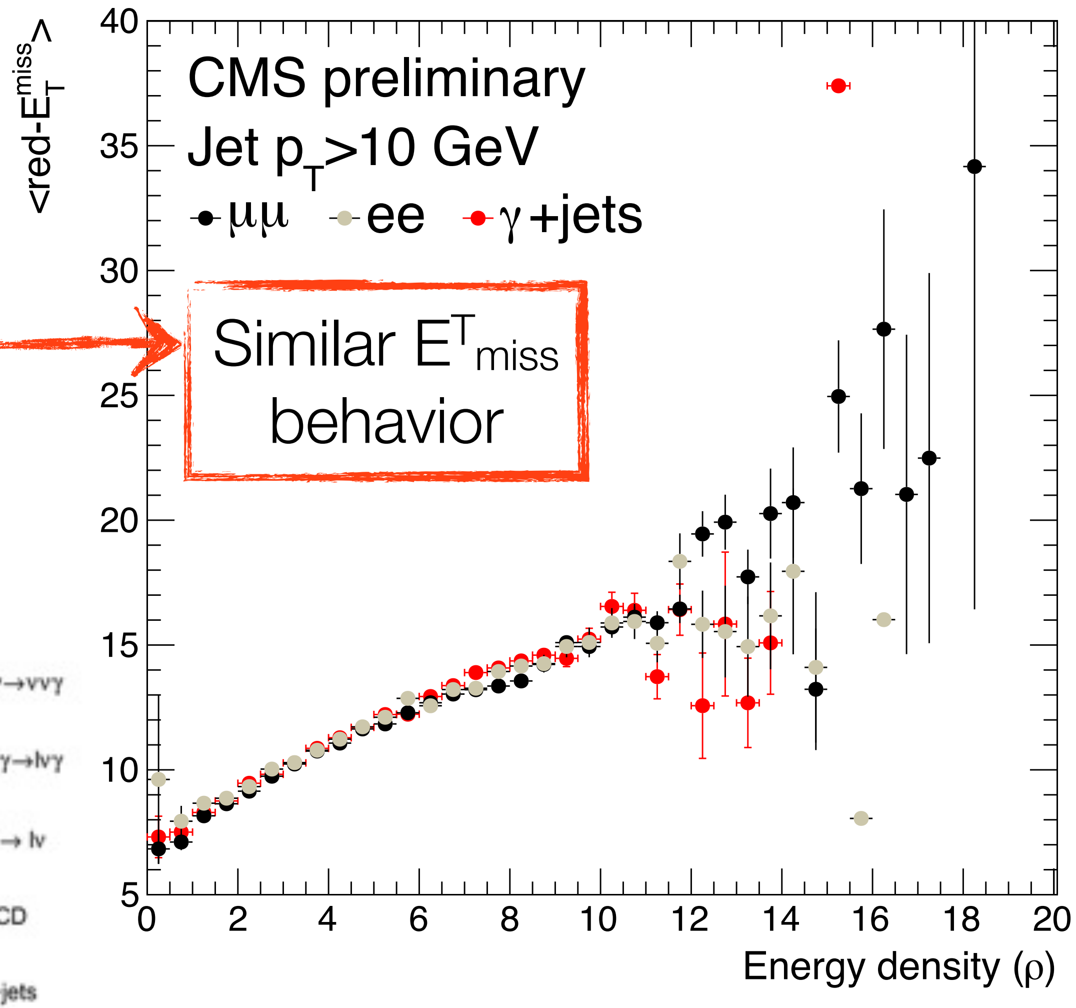
2l2v: DY estimation:

Since DY is not well modeled: Data-driven estimation

DY contribution because of: fake E^T_{miss}

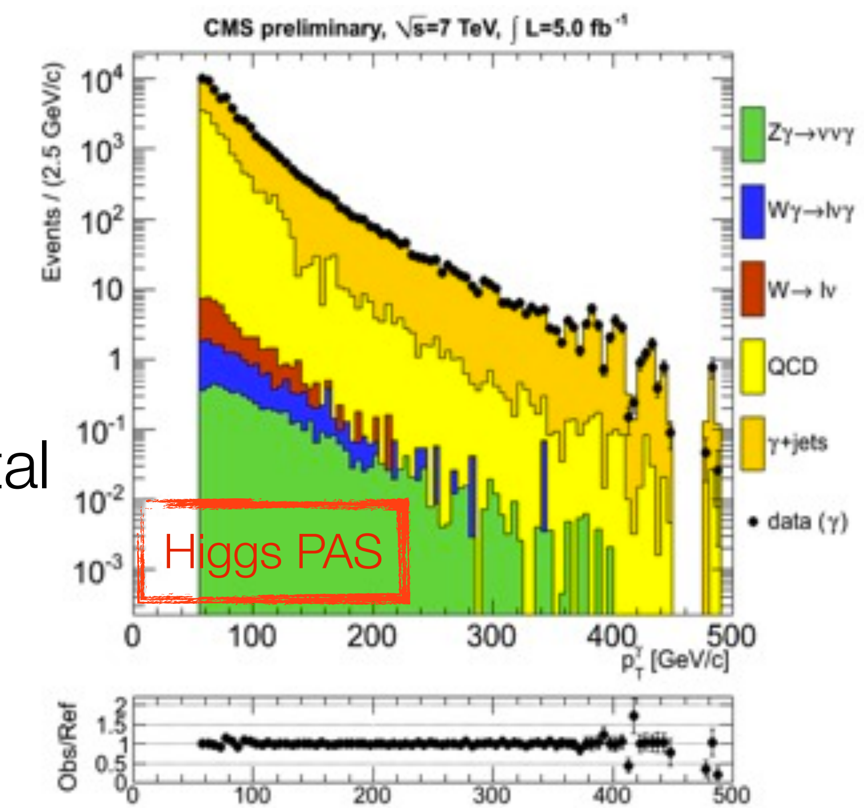
(Noise, Pile Up, mis-measured jets....)

Needs for data sample with same E^T_{miss} topology: γ+Jets



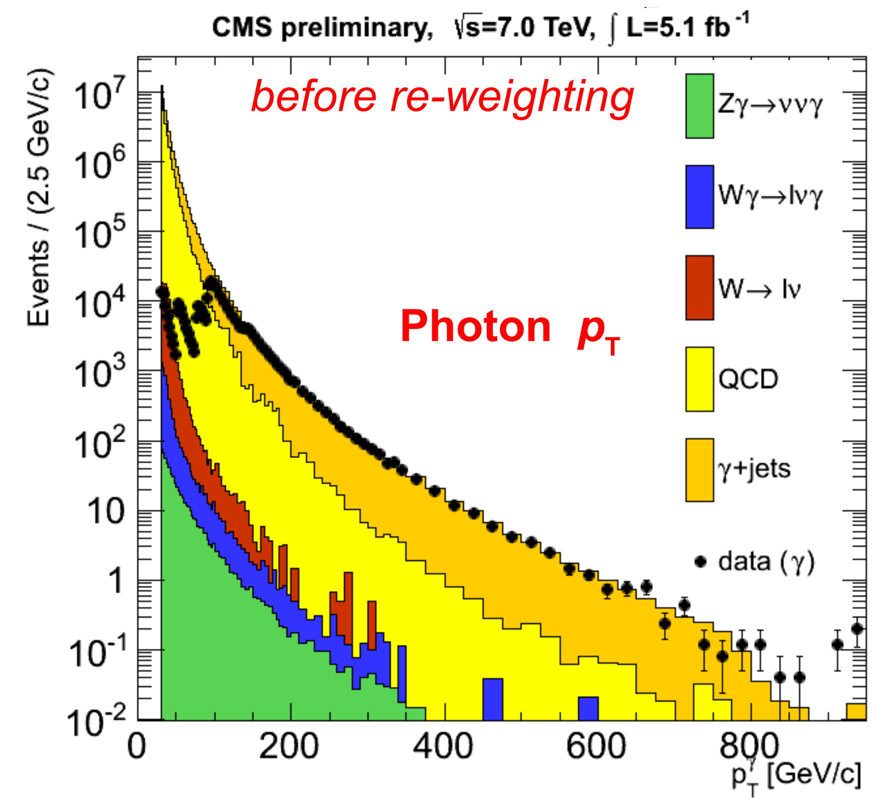
Reweighing the γ+Jets spectrum in P_T:

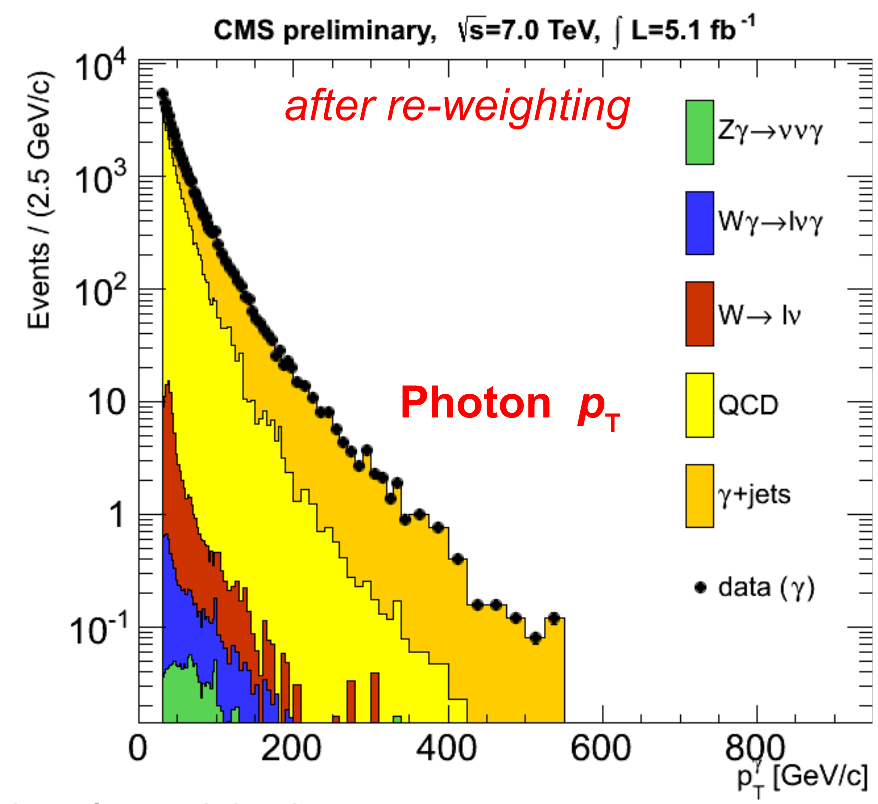
γ+Jets captures the behavior of the instrumental background



2l2ν: γ+jets selection:

- Z + jets modeled using γ + jets events
  - exactly 1 γ in the barrel (|η| < 1.4442), p_T > 30 GeV
  - no jets with p_T > 30 GeV/c, no leptons, conversion veto
  - re-weight γ p_T to match Z spectrum in data
    → this also accounts for different photon trigger prescales vs p_T
  - final normalization to Z yield in region red-MET < 40 GeV
- Processes with real MET from neutrinos contribute to the photon sample
  - Wγ, Zγ, W+jets with fake photon
  - therefore, the estimation from the γ template (N^0_{DY}) is an upper limit on the actual DY contribution
    - let the DY prediction float between 0 and N^0_{DY}
      → 100% uncertainty
    - the best normalization is found by the maximum-likelihood fit to the redMET spectrum during the cross section measurement





D. Trocino – ZZ → 2ℓ2ν Pre-Approval I

2l2l' Backgrounds estimation: (1/2)

→ Control region Z + X (bb, cc, gluons or light quark):

Z_1 selection but relaxed criteria for additional ll (same charge/flavour).

Z_2 in [60, 120] GeV, M_{4l}>100 GeV.

Expected number taken from the lept. misidentification probability

from Z_1 + l sample with no id.+iso. on the 3rd lept.

→ Prob. to misidentify a jet as a τ_h:

Using $l^- l^+ \tau_h \tau_h$ sample: Z_1 all selection + no iso. for the τ (only Z+jets events)

$$\tau_h \text{ misidentification rate: } \frac{\#\tau_h \text{ passing loose or medium working point}}{\#\tau_h \text{ initial}}$$

→ Misidentify rate for τ_e:

Using $\mu^- \mu^+ \tau_\mu \tau_e$ sample: Z_1 all selection + 1lepton and a τ not isolated

$$\tau_e \text{ misidentification rate: } \frac{\#\tau_e \text{ passing loose or medium working point}}{\#\tau_e \text{ initial}}$$

$2l2l'$ Backgrounds estimation: (2/2)

N_{Bi} is the # background in the Signal region.

N_i the events passing fill selection except isolation on 1-2 leptons.

$F(l_i)$ misidentification rate

→ Category 0: both object from Z_2 do not pass isolation

Mostly Z+Jets

$$N_{B0}: \frac{N_0 \, F(l_1)F(l_2)}{1-F(l_1)F(l_2)}$$

→ Category 1: one object from Z_2 do not pass isolation

Mostly Z+Jets, WZ+jets

$$N_{B1}: \frac{N_1 \, F(l_1)}{1-F(l_1)}$$

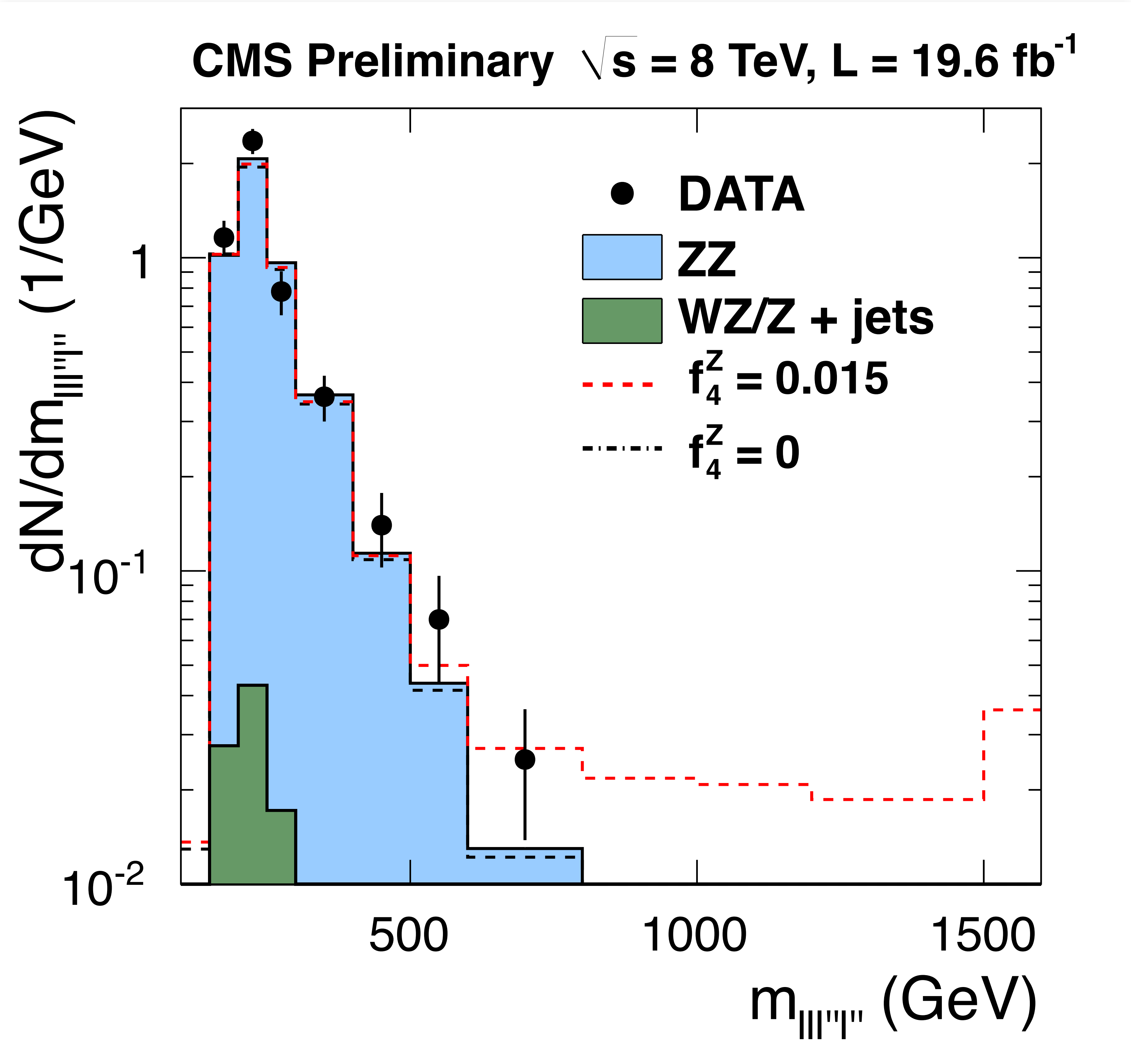
→ Category 2: 1st object pass isolation, 2nd fail

Mostly Z+Jets, WZ+jets

$$N_{B2}: \frac{N_2 \, F(l_2)}{1-F(l_2)}$$

At the end: $N^{est}_{bkg} = N_1F_1 + N_2F_2 - N_0F_1F_2$

(N.B. category 0 contribute to 1 and 2)


CMS Preliminary √s = 8 TeV, L = 19.6 fb-1
DATA
ZZ
WZ/Z + jets
f4Z = 0.015
f4Z = 0
dN/dm_llll (1/GeV)
1
10-1
10-2
500
1000
1500
m_llll (GeV)