ElettroWeak WZ

diboson production at LHC

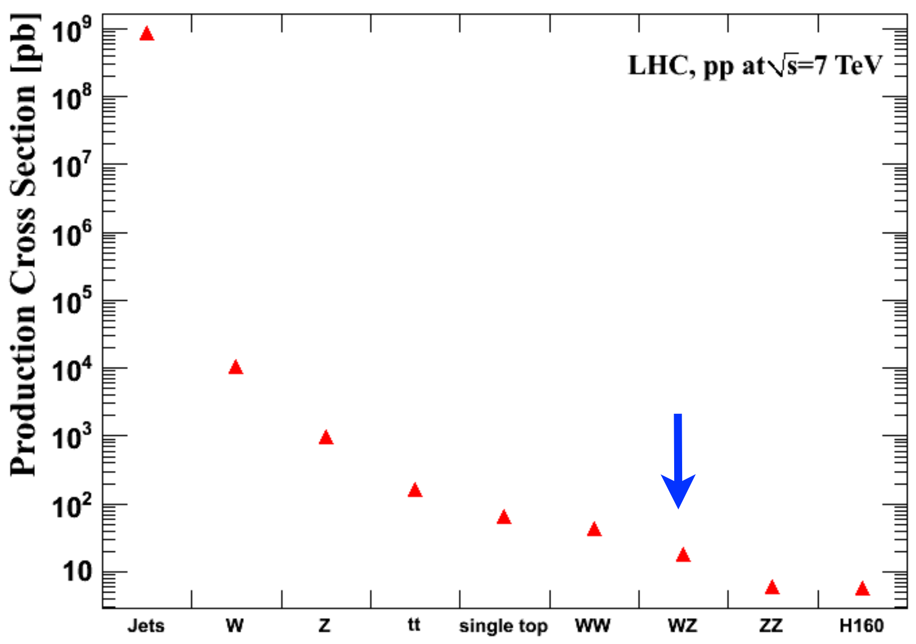
look for in the electron channels at CMS

Outline

- WZ in the Standard Model of Particle Physics
  - SM and EWK gauge group
  - TGC measurements
    - see backup: TGC at LEP and Tevatron
- WZ search at CMS
  - LHC and CMS detector:
    - see backup: the CMS tracker and ECAL
    - electron reconstruction principles
  - WZ channel:
    - production
    - signal topology
    - analysis strategy
    - First results
    - Plans for the future

Motivation

- WZ diboson associated production: allows for a wide physics research program
- SM test through precision measurements (TGC):
  - to compete with previous measurements at LEP and Tevatron
- On the road towards the Higgs search in a multi-lepton final state:
  - background to WW and (H->WW as well)
  - WZ+jets is background to ZZ
  - Z+jets is common background to ZZ->4l (H->ZZ)



- Benchmark for BSM senarios:
  - 3l + MET is a typical and clear signature
  - i.e. W'->WZ->3l+ ME_T early exclusion at 95% C.L. at D0 with $4.1 fb^{-1}$
- In the following: focus on electro-weak measurements

WZ in the Standard Model

- Gauge symmetries are the "natural" requirement to build a theory:
- WZ associated production is predicted by the SM $SU_L(2) \times U_Y(1)$ gauge group:

  - $$\begin{array}{lcl} SU(2)_L & \longrightarrow & W^1_\mu \,,\; W^2_\mu \,,\; W^3_\mu \\ U(1)_Y & \longrightarrow & B_\mu \,. \end{array}$$ + $D_\mu \equiv \partial_\mu - igT^a A^a_\mu$ +

$$W^1_\mu = \frac{1}{\sqrt{2}}(W^+_\mu + W^-_\mu)$$
$$W^2_\mu = \frac{i}{\sqrt{2}}(W^+_\mu - W^-_\mu)$$
$$W^3_\mu = A_\mu \sin\theta_W + Z_\mu \cos\theta_W$$
$$B_\mu = A_\mu \cos\theta_W - Z_\mu \sin\theta_W \,.\,.$$

  - $$\begin{aligned} \mathcal{L}_{YM} \;=\; & -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}Z_{\mu\nu}Z^{\mu\nu} - \frac{1}{2}W^+_{\mu\nu}W^{\mu\nu}_- \\ & +ig\sin\theta_W\,(W^+_{\mu\nu}W^\mu_- A^\nu - W^-_{\mu\nu}W^\mu_+ A^\nu + F_{\mu\nu}W^\mu_+ W^\nu_-) \\ & +ig\cos\theta_W\,(W^+_{\mu\nu}W^\mu_- Z^\nu - W^-_{\mu\nu}W^\mu_+ Z^\nu + Z_{\mu\nu}W^\mu_+ W^\nu_-) \\ & -\frac{g^2}{2}\,(2g^{\mu\nu}g^{\rho\sigma} - g^{\mu\rho}g^{\nu\sigma} - g^{\mu\sigma}g^{\nu\rho}) \\ & \left[W^+_\mu W^-_\nu(A_\rho A_\sigma \sin^2\theta_W + Z_\rho Z_\sigma \cos^2\theta_W + 2A_\rho Z_\sigma \sin\theta_W\cos\theta_W) - \frac{1}{2}W^+_\mu W^+_\nu W^-_\rho W^-_\sigma\right] \end{aligned}$$

  - assuming both C, P conservation -> 6 parameters describe the effective Lagrangian

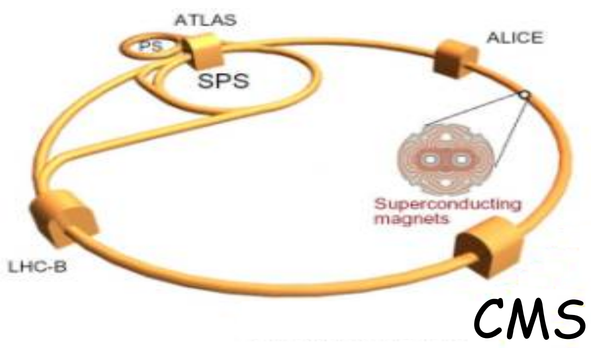
$$L^{WWV}_{eff} = -i\,g_{WWV}\left[g^V_1(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V^\nu W^{\mu\nu}) + k_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{m^2_W}W^\dagger_{\rho\nu}W^\mu_\nu V^{\rho\nu}\right]$$

$$where\;\; V = \gamma, Z \;\;\; g_{WW\gamma} = e,\; g_{WWZ} = e\,cot\theta_W$$

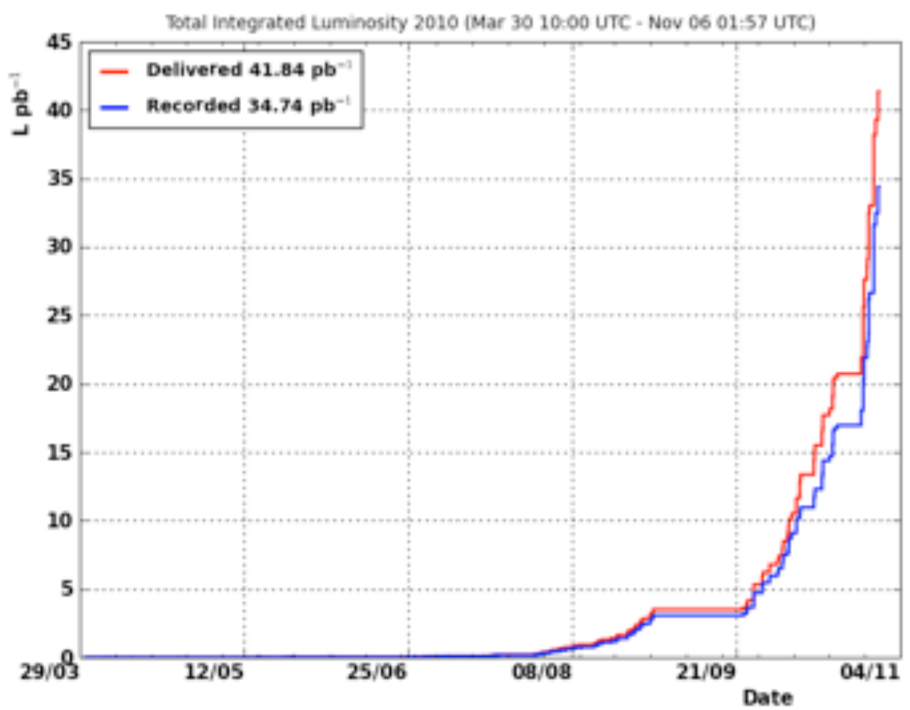
  - with $g^\gamma_1 = 1$ imposed by electromagnetic gauge invariance
  - deviation from SM described by $\Delta g_1^Z \equiv (g_1^Z - 1)$, $\Delta\kappa_\gamma \equiv (\kappa_\gamma - 1)$, $\Delta\kappa_Z \equiv (\kappa_Z - 1)$, λ_γ, λ_Z
    - SM expectation $\Delta\kappa_\gamma = \Delta\kappa_Z = \Delta g_1^Z = \lambda_\gamma = \lambda_Z = 0$

Large Hadron Collider

- p-p collider (√s 7TeV):
  - elucidate EWK symmetry breaking (Higgs)
    - Higgs search up to 1TeV/c2
  - Precision measurements on SM
  - Search for new physics in the TeV energy scale



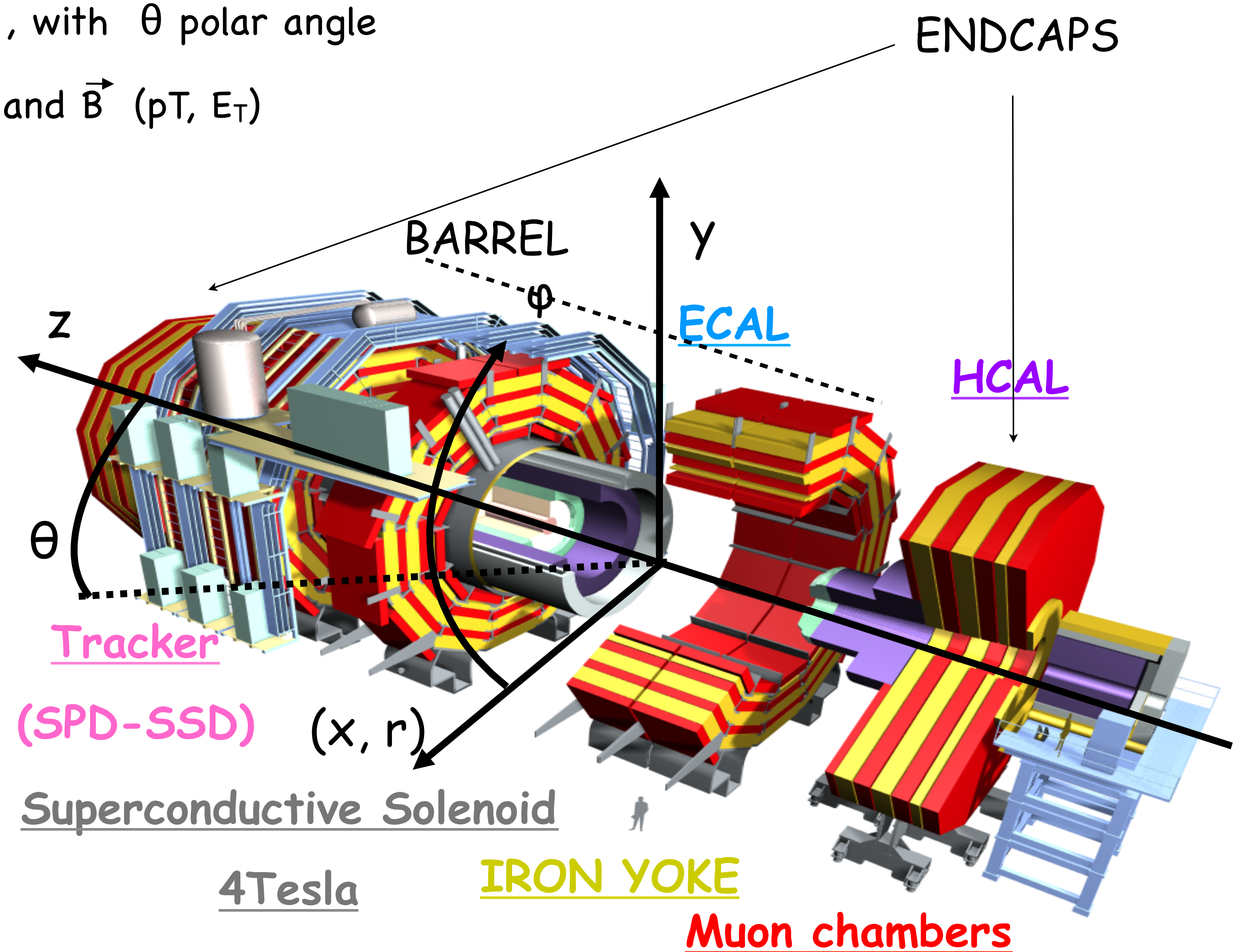
$n_{events} = L \cdot \sigma$



- Collision designed rate 40MHz:
  - ~20collisions/event -> ~ 1000 charged particles/25ns
- Detectors designed:
  - high granularity detectors with good time resolution
  - radiation hard materials

the CompactMuonSolenoid

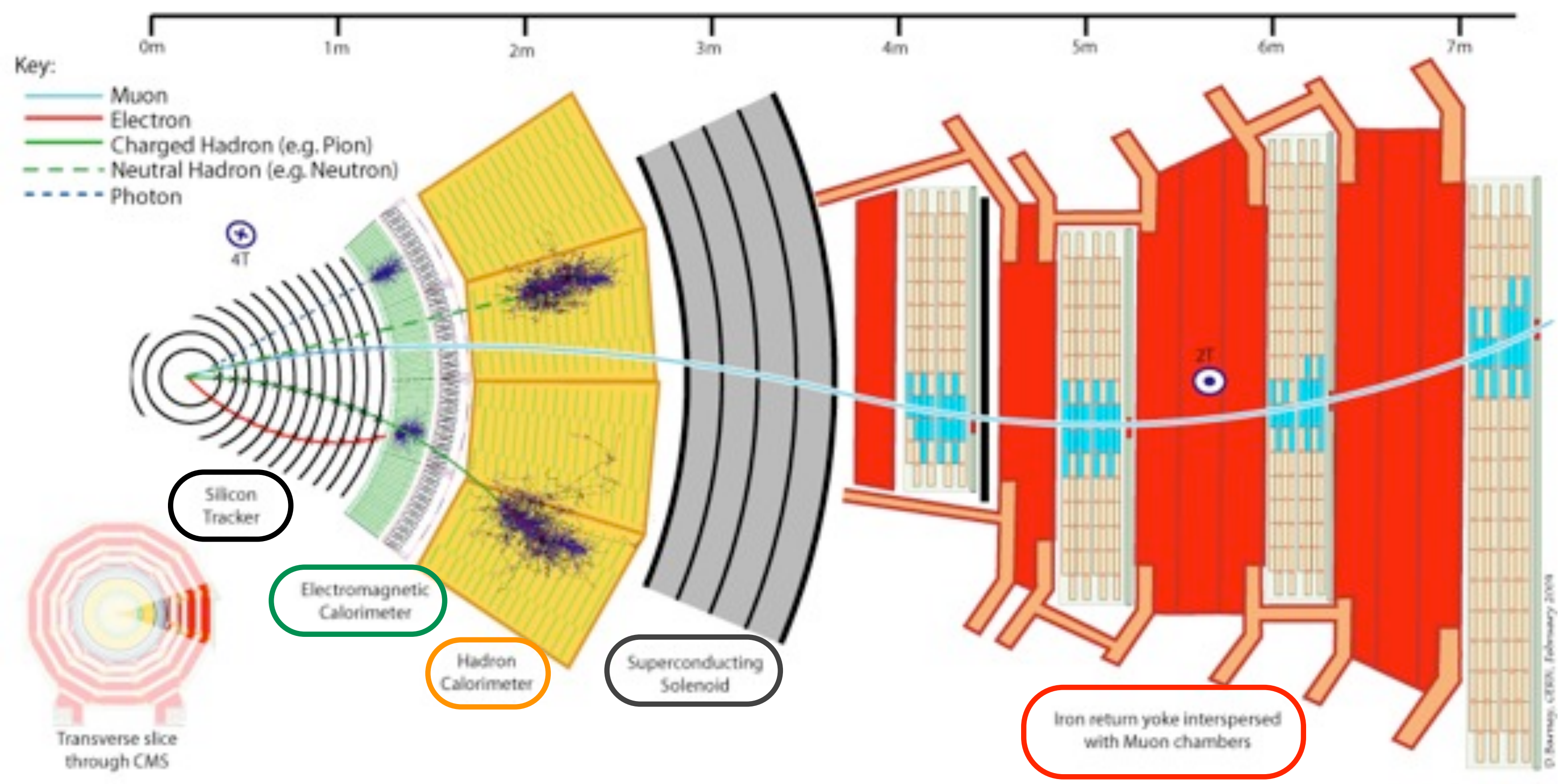
- CMS reference frame (r,η,φ):
  - pseudorapidity $\eta = -\ln(\tan(\theta/2))$, with θ polar angle
  - (x,y) transverse plane wrt beam and $\vec{B}$ (pT, E_T)



- At hadron colliders:
  - physics in the transverse plane is "under control"
- in the transverse plane
  - event pT = 0 (maximum event boost O(1GeV) = proton rest mass)

the CMS detector

- It's a Compact muon solenoid since it's "small" with respect to its weight
- Choice of the magnet field drives the detector design



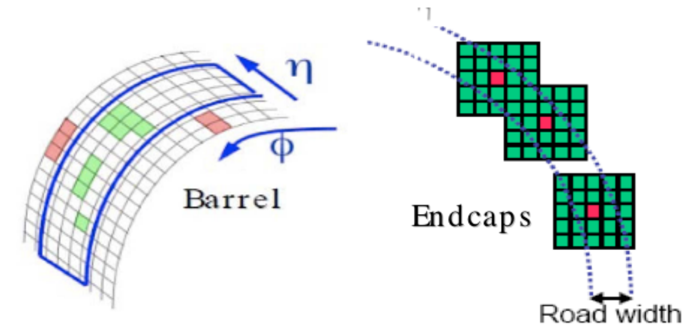
- Detector requirements to meet

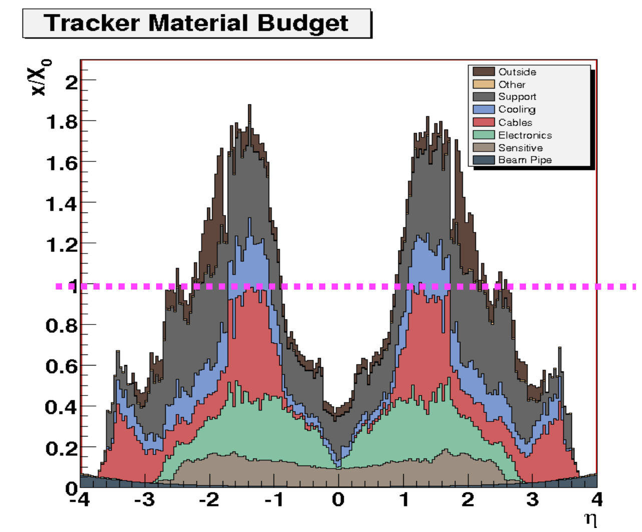
  the LHC physics goals:
  - good μ identification
  - excellent energy resolution
  - charge measurement
  - ...

- Object reconstruction
  - response from different subdetectors:
  - quality cuts applied to select objects
    - isolation,
- def. MET = Missing transverse energy
  - MET = - [Σ(E+H) - Muons]$_T$
- neutrinos leave undetected

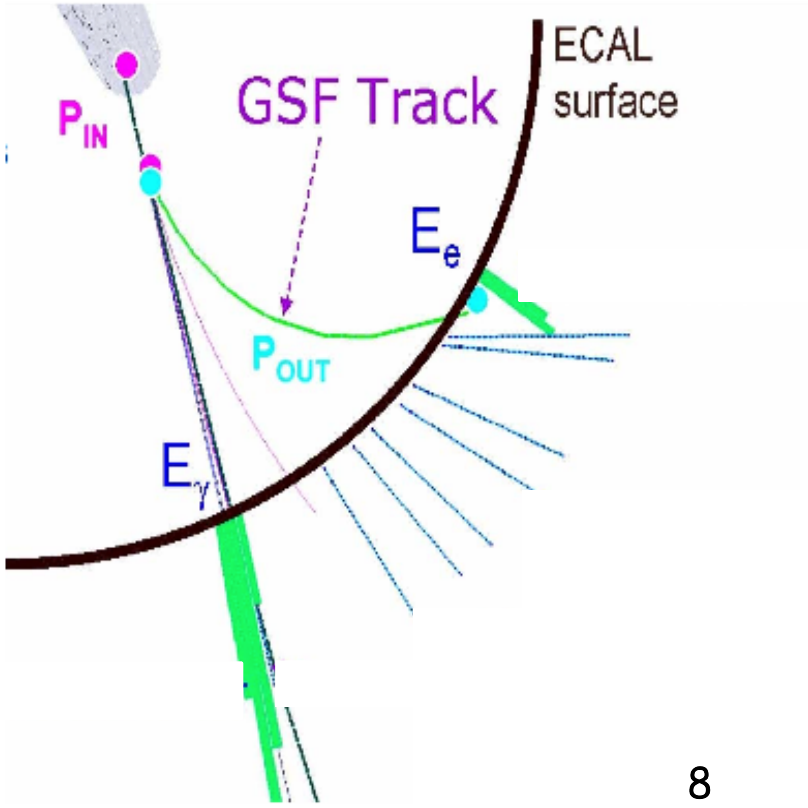
The electron reconstruction

- Electron = track + superCluster in ECAL
  - Energy is clusterized in a large φ window to account for
    - unconverted energy containment: ~97% into a matrix of 5x5 around the impact crystal
    - material budget in front of the ECAL: electron bremsstrahlung and photon conversions are enhanced (70% electron energy radiated by brehm. + 50% probability γ->e)
    - B field further spreads along φ the energy deposited in ECAL





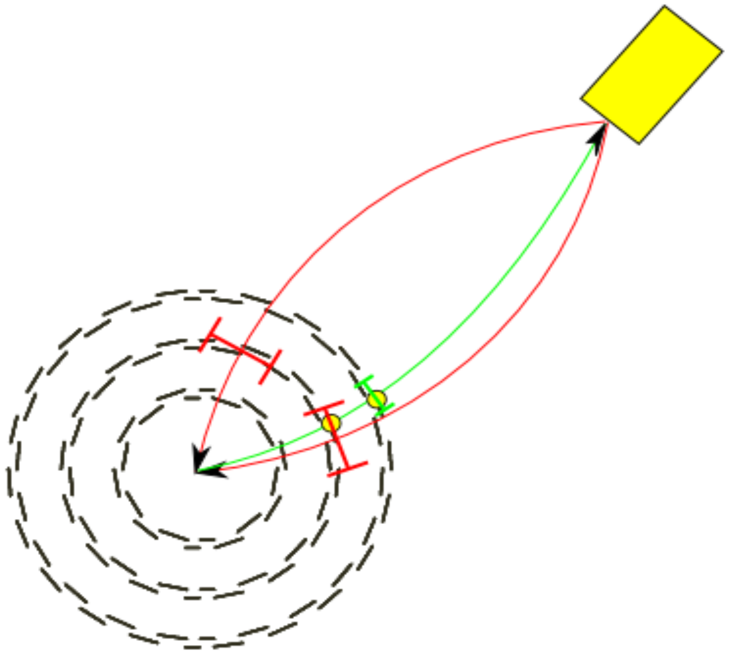
  - Seed finding (see next slide)
  - Electron tracking relies on the Gaussian Sum Filter algorithm: to deal with high material budget in a high magnetic field contest
    - Allows for a tracker estimate of the energy lost by bremsstrahlung $f_{brem} = (p_{in}-p_{out})/p_{in}$
    - Accounts for non gaussian energy loss due to bremsstrahlung
    - Allows for an unbiased estimate of the track at each point



  - Electron preselection (association Tk-Scl)

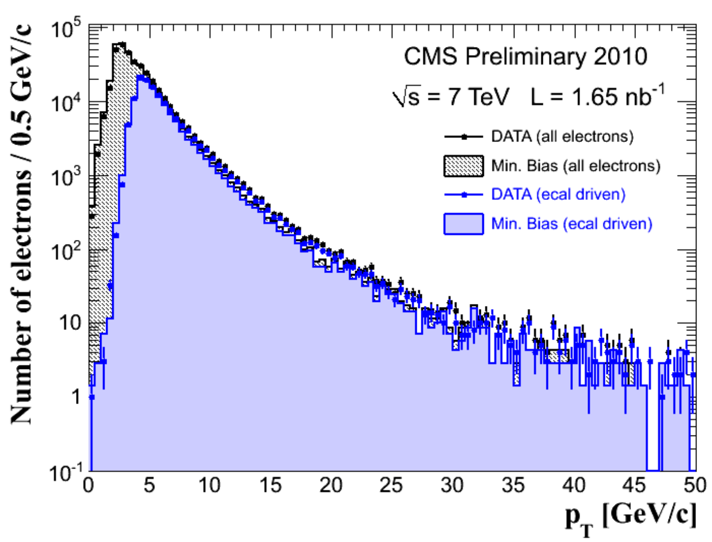
The electron reconstruction

- 2 different algorithms for electron reconstruction in CMS
- The starting point for the "ECAL driven" electron reconstruction is the seeding
  - Seed finding: matching strategy -> ECAL driven electrons
    - from SCluster, for both charge hypothesis
    - seeds are selected, if both the hits are found within reasonable windows around the expected position
    - the beam spot position is the constraint for the 1st hit search
    - vertex z is computed wrt 1st hit to look for the 2nd one



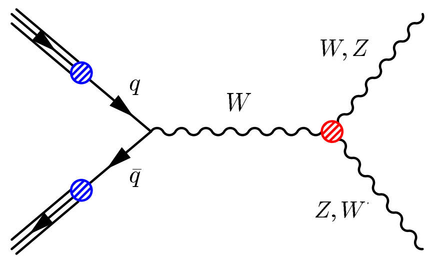
	1st windows		2nd windows			
	δz or δr_T	$\delta\phi$	δz	δr_T (PXF)	δr_T (TEC)	$\delta\phi$
10 GeV/c	$\pm 5\sigma_z$	[-0.14;0.08] rad	$\pm$0.09 cm	$\pm$0.15 cm	$\pm$0.2 cm	$\pm$4 mrad
35 GeV/c	$\pm 5\sigma_z$	[-0.05;0.03] rad	$\pm$0.09 cm	$\pm$0.15 cm	$\pm$0.2 cm	$\pm$4 mrad

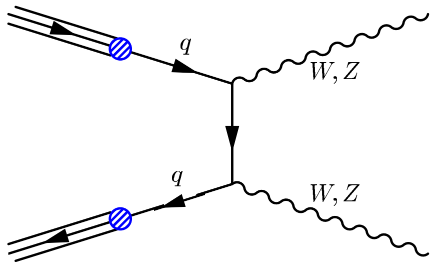
- "TRACKER driven" electrons completely rely on high quality tracks extrapolation
  - particularly efficient for low p_T and converted photons



WZ at hadron collider

- s-channel   t-channel   and interference



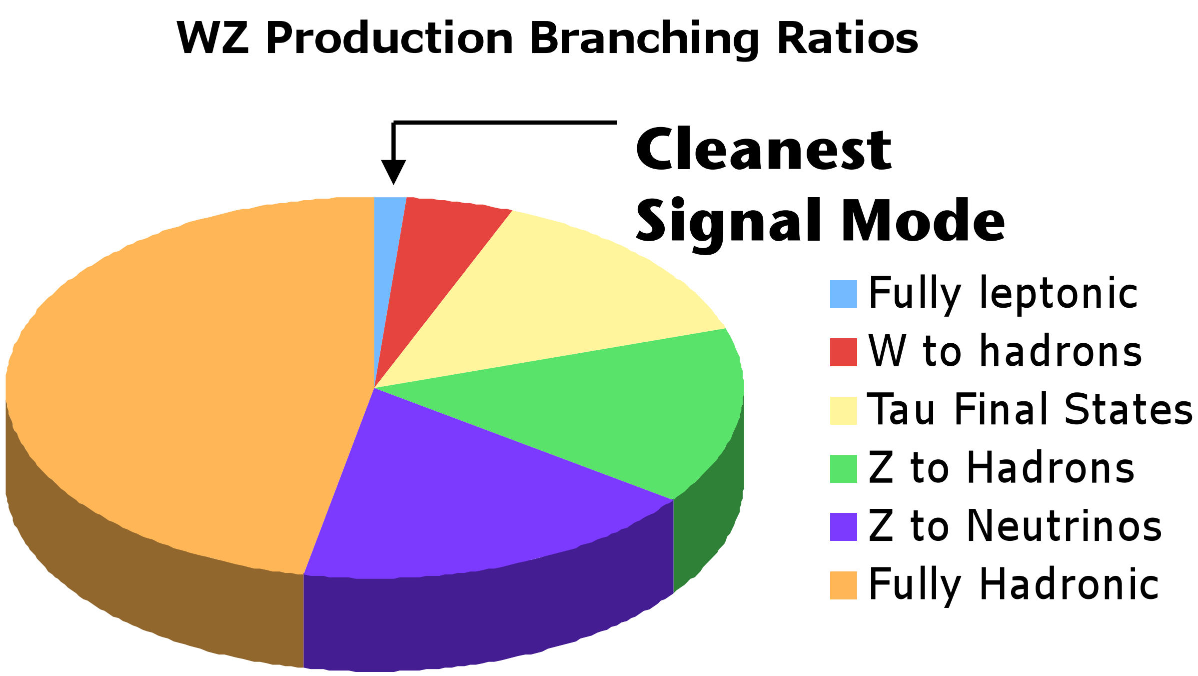


  - (q, $\overline{q}'$ required) at LHC: $\sigma(W^+Z) > \sigma(W^-Z)$, at Tevatron ($p-\overline{p}$) $\sigma(W^+Z) = \sigma(W^-Z)$

- Inclusive NLO cross-sections:

Tevatron:	1.96TeV	3.7±0.3 pb
LHC:		
14 TeV (pb)	10TeV (pb)	7TeV (pb)
51.05±0.09	31.40±0.05	18.27±0.03

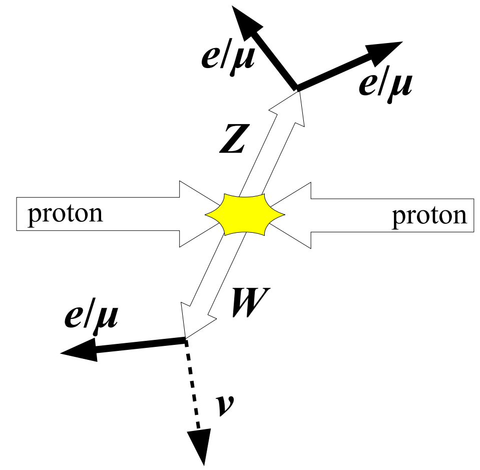
higher c.m.s energy
$\sigma_{LHC} \sim 5\ \sigma_{Tevatron}$

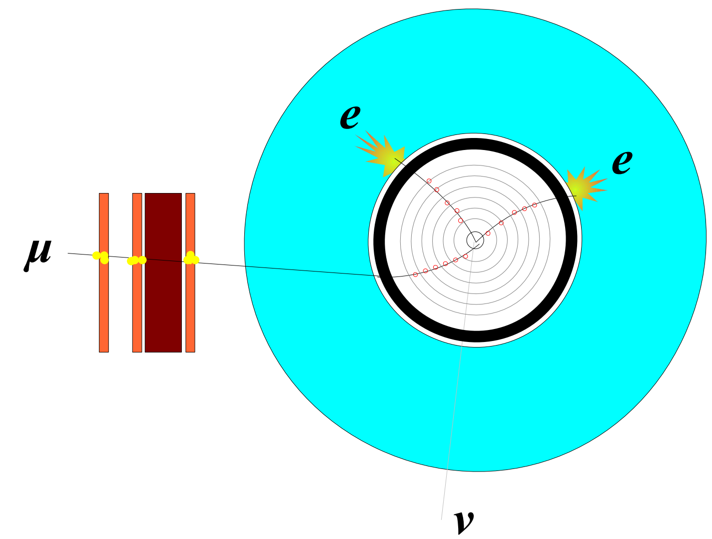


- Fully leptonic final state:
  - clear signature in hadronic environment
  - reduced BR (1.5% if lepton = e,μ)
  - (here: focuse on leptonic channel, l = e, μ)

WZ signature

- Signal topology:
  - 3 isolated, high energy leptons
  - neutrino -> large MET



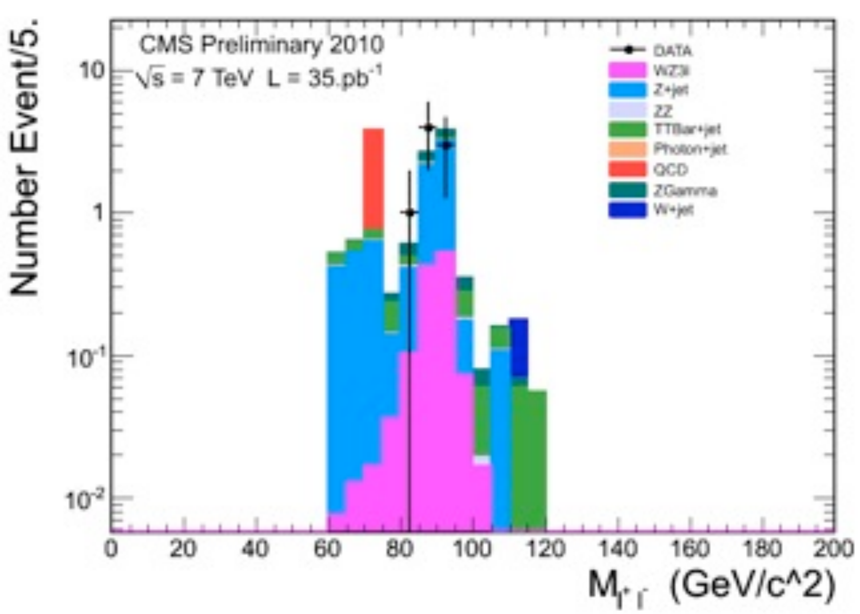


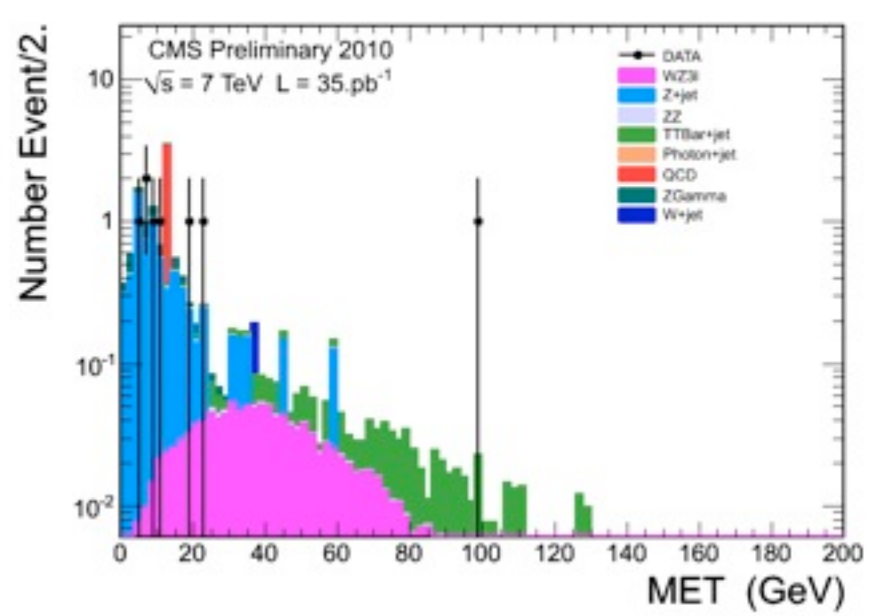
- What to look for/ benchmark kinematic variables
- Z (M = 91.1876±0.0021 GeV/c²)
  - M: l^+l^- pair with reasonable invariant mass (60GeV/c2 < MZ < 120GeV/c2, pT >15GeV/c)
- W (M = 80.398±0.023 GeV/c²)
  - neutrino being undetected, large MET (MET > 25GeV)
  - 3rd high pT (>20GeV) lepton (e, μ) looked for to have the final state topologies (eee, eeμ, μμe)
  - M estimated in the transverse plane: $$M_T(W) = \sqrt{2 \cdot MET \cdot E_\ell (1 - cos\Delta\phi_{MET,\ell})}$$
    - E_l = energy of the 3rd lepton
    - Δϕ(MET,l) = azimuthal separation between MET direction and 3rd lepton
    - p_υ = (MET, METx, METy, p_υz)

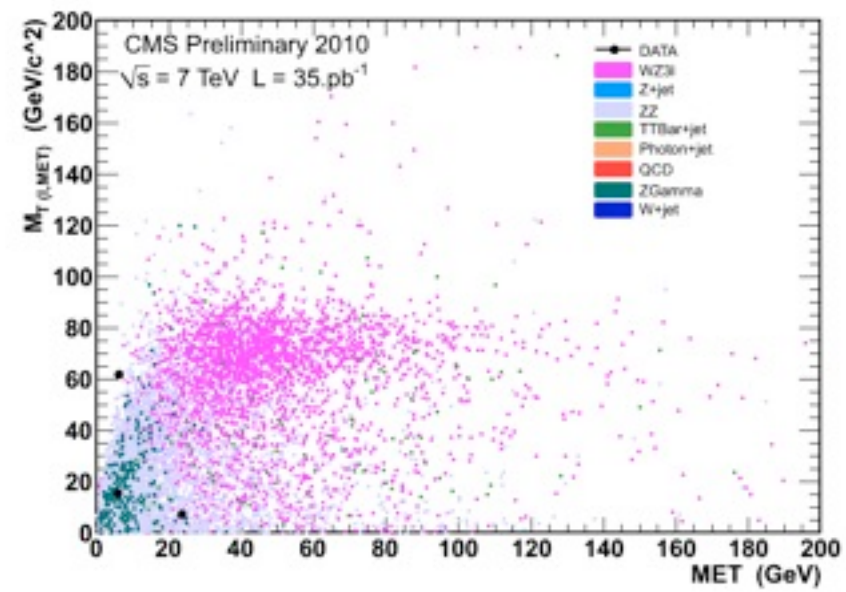
the analysis...

- In my analysis: 3l + MET (l = e, μ) 1 electron explicitly required => eee, eeμ, $\mu\mu$e
  - MC reference:
    - signal WZ->3l (l = e, μ, τ)
    - Main backgrounds: Z+Jets, ZZ, TTBar, ZGamma, PhotonJet (final state topology as the signal one)
  - DATA: 35pb^{-1} collected so far

- Z->ee selection survived events

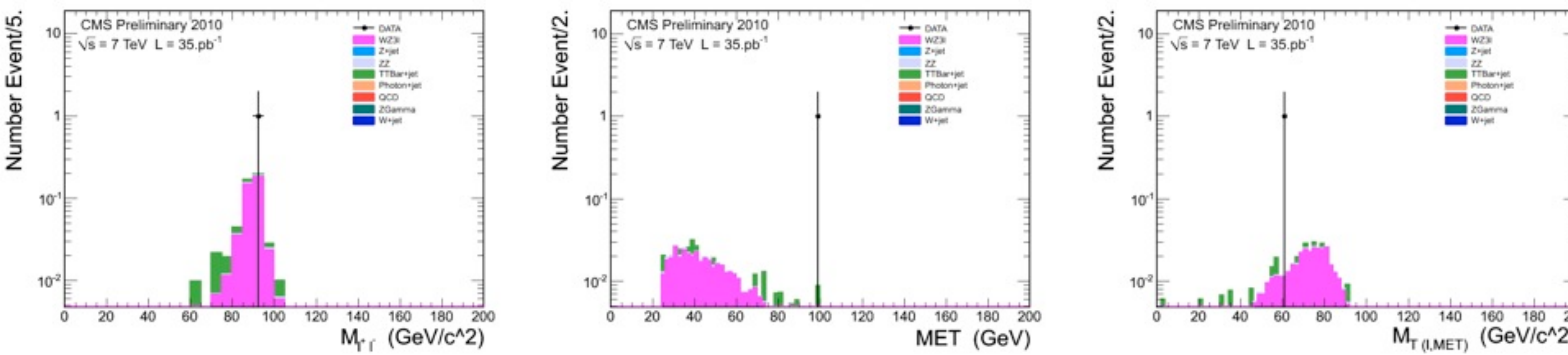




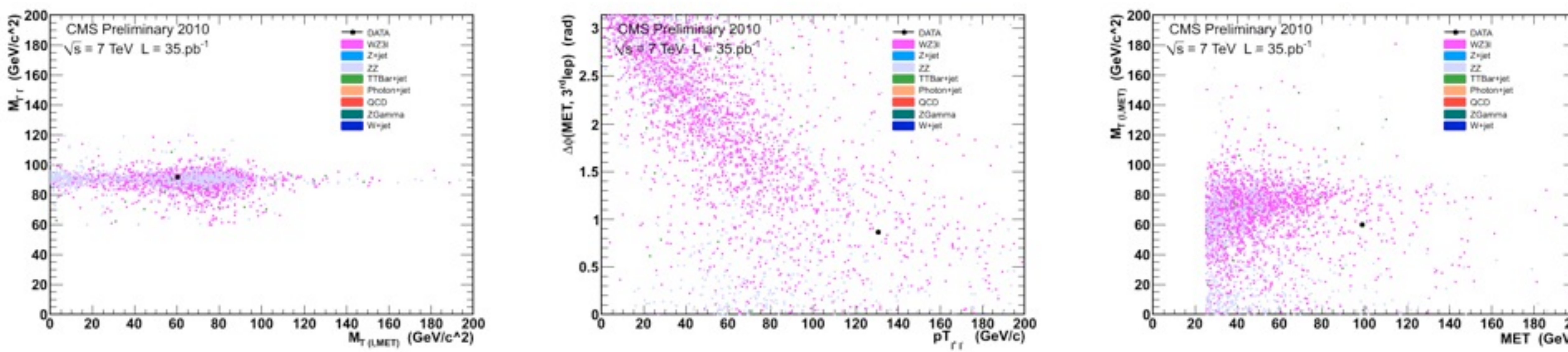


…the analysis: eeμ channel

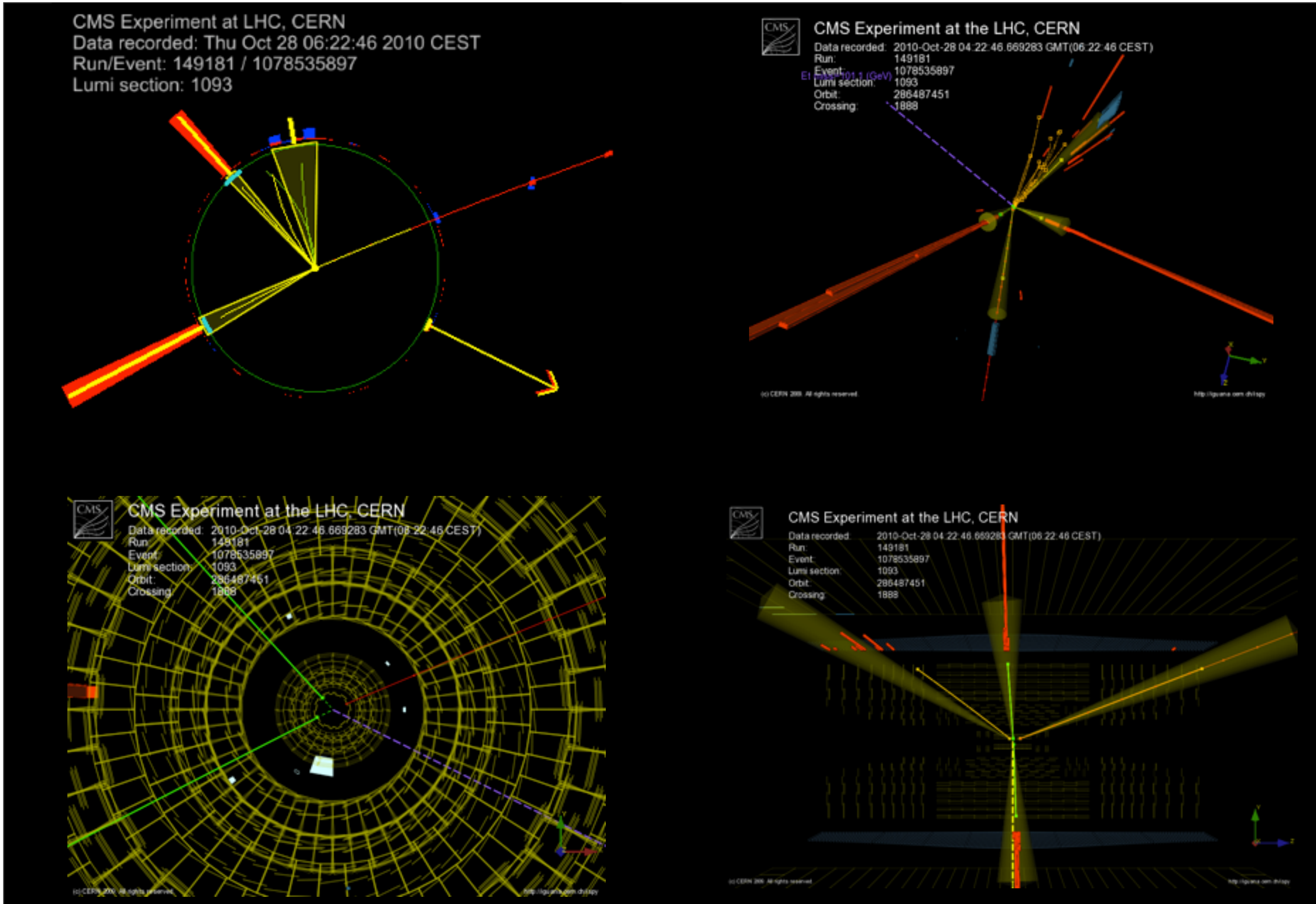
- 2electron 1muon final state:



- M(e+ e-) vs M_T DPhi(MET-μ) vs pT(e+e-) M_T vs MET

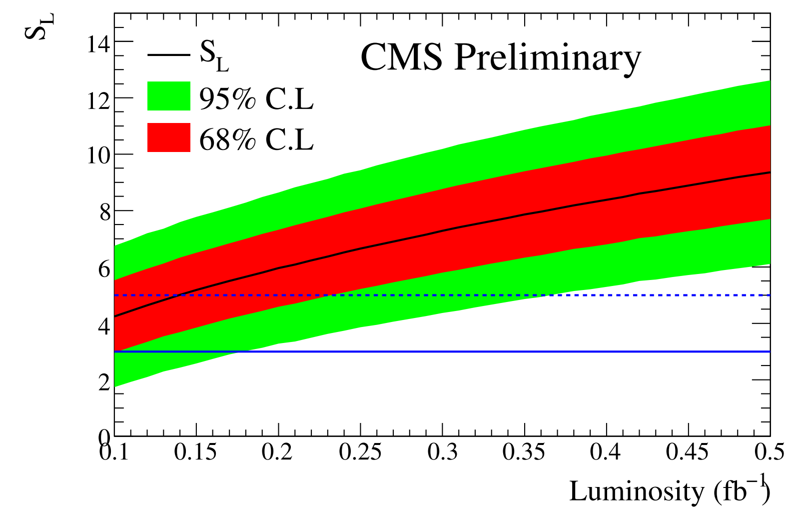


$ee\mu$ event display



WZ search at CMS

- Prospective results (**√s 14TeV**)
  - 5σ significance on observation with < 350pb-1 at 95%CL:



- Preliminary results for **√s 7TeV**
  - Significance Scl = √(2[(S + B) ln(1 + S/B)] − S)

	Normalized to DATA Lumi			Normalized to $500pb^{-1}$		
	Signal	**Tot Bkg**	**Scl**	**Signal**	**Tot Bkg**	**Scl**
eee	0,37	0,05	0,65	5,25	0,68	2,43
eeμ	0,42	0,09	0,58	2,66	1,30	1,08
μμe	0,42	0,66	0,20	1,19	9,38	

observation possible within 2011

Next steps

- Systematics understanding, to extrapolate a significance for observation
  - Efficiencies of selection
  - Background estimate from DATA:
    - lack in statistic in the generated samples
    - simulated conditions different from DATA or not reliable

      Zgamma: measure gamma->electron conversion rate in DATA with a T&P selection of Zgamma($\mu\mu\gamma$), use Z->$\mu\mu\gamma$ MC sample for normalization

      ZJets: measure jet->electron fake rate in a Di-jet triggerred sample, use a control region to estimate normalization

- About TGC measurements...
  - approach the "physics aspect of the measurement" (TGC)

Conclusions

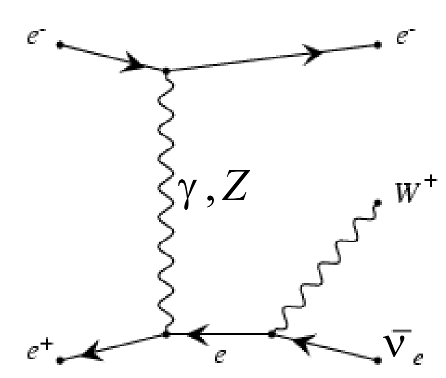
- WZ production is a EWK process, consequence of the SU(2)xU(1) gauge group
  - WWZ TG vertex measurement through WZ final state
- WZ search at the CMS:
  - Leptonic final state (electron or muon)
  - At least 1 electron
- WZ analysis strategy was designed and a first look at 2010 DATA was given: first results
  - ~2.5σ Scl significance estimated for $500pb^{-1}$ in eee channel
    - Z+jets, TTBar most important backgrounds
  - look at DATA -> first WZ event in μvee

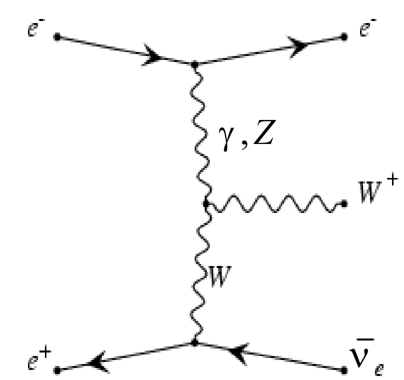
BACKUP

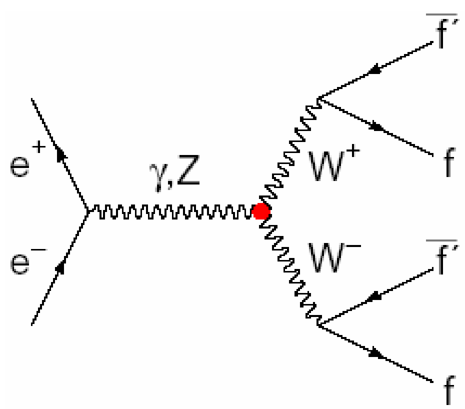
backup: TGC (and WZ)

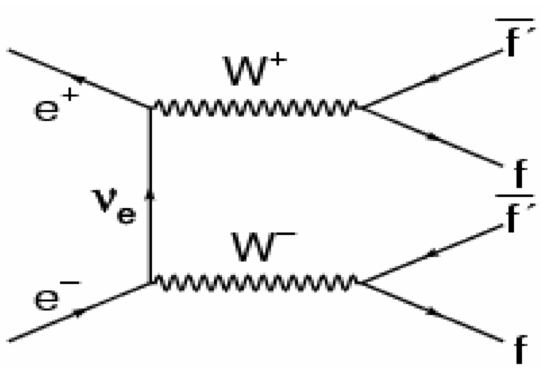
- Anomalous TGC effect the event kinematic: high pT_{Boson} is particularly sensitive

- TGC first measurements at LEP2 ($\sqrt{s}$ = 198GeV, e+ e-):
  - through
    - single W production, access to WWγ vertex
    - WW production, access to WWZ and WWγ
  - in agreement with SM expectation
  - best sensitivity up to now
    - clean environment: no pdf uncertainties
    - better defined background





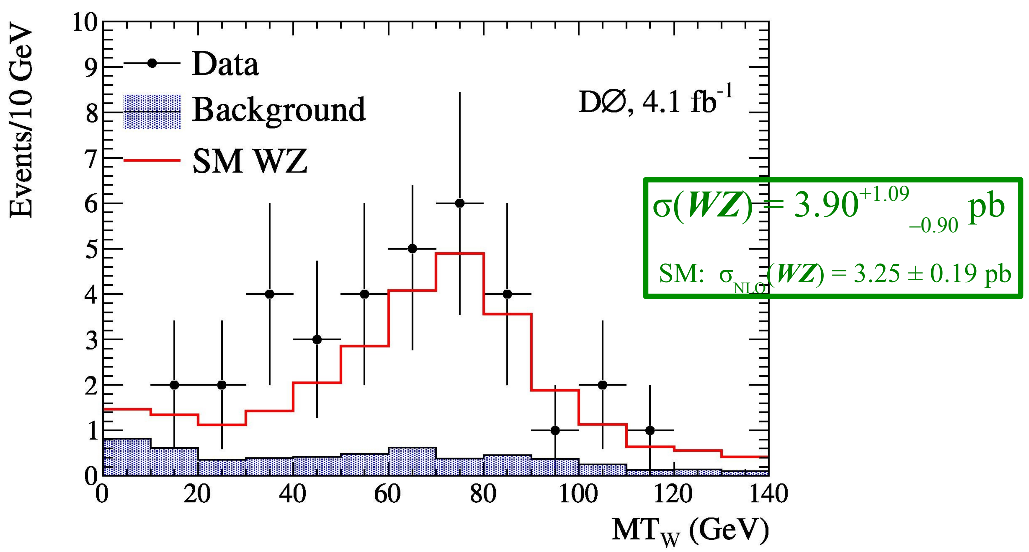


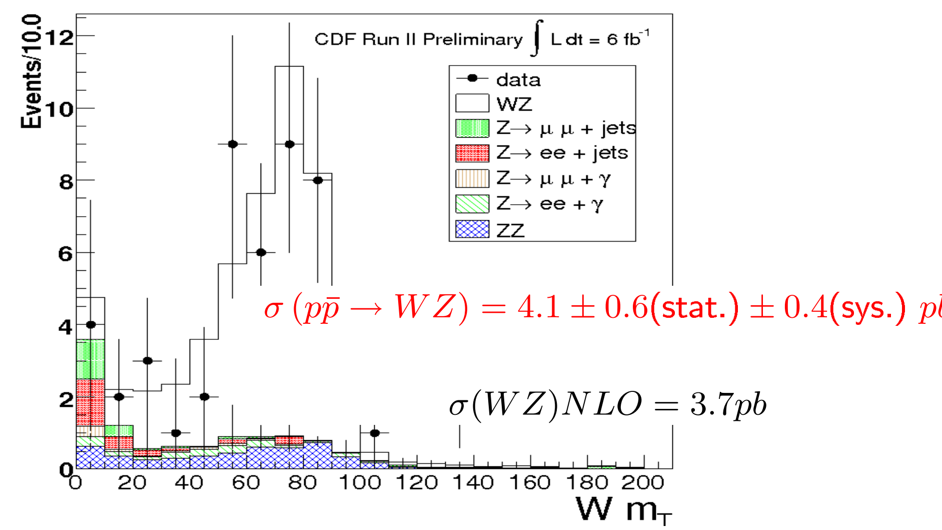


Parameter	95% C.L.
Δg^Z_1	[-0.051, 0.034]
Δk_γ	[-0.105, 0.069]
λ_γ	[-0.059, 0.026]

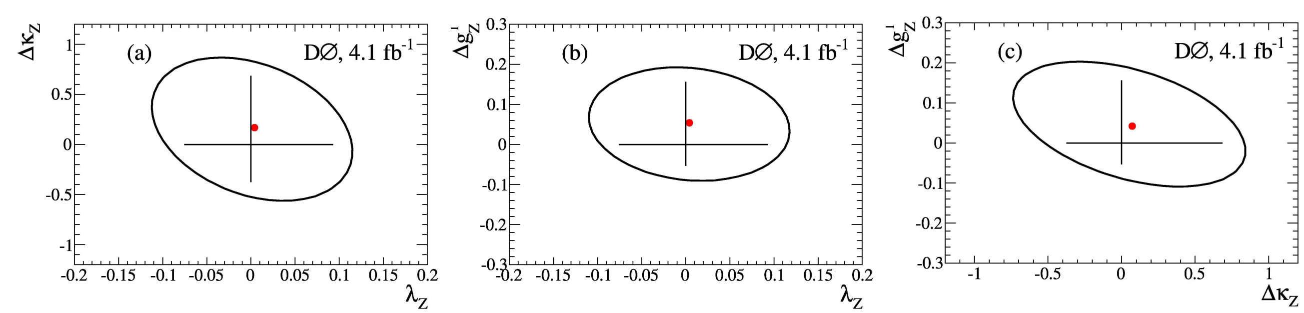
backup: TGC and WZ

- At Tevatron (√s = 1.96TeV, p-pbar) multiple diBoson topologies are exploited
- WZ for instance: first observation at CDF with $1.1 fb^{-1}$ arXiv:hep-ex/0702027v1
  - current results (ICHEP 2010)



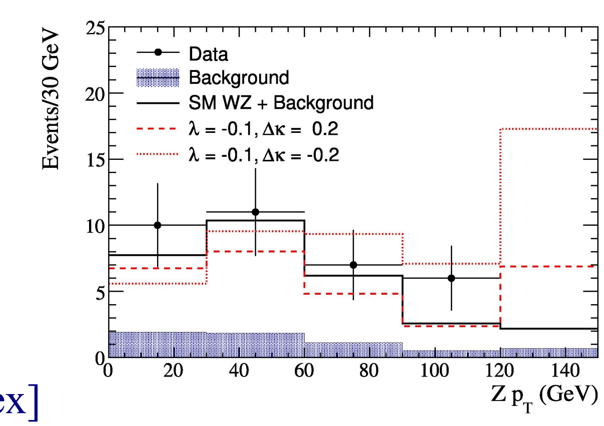


- D0 TGC limits from WZ-> lnu ll:
  - 2-D 95% confidence contours (ellipses)
    - Two couplings are varies while the third fixed at the SM value
  - 1-D 95% confidence intervals (lines)
    - One coupling is varied while the other two fixed at the SM values



$$-0.075 < \lambda_Z < 0.093$$
$$-0.053 < \Delta g_1^Z < 0.156$$
$$-0.376 < \Delta\kappa_Z < 0.686$$

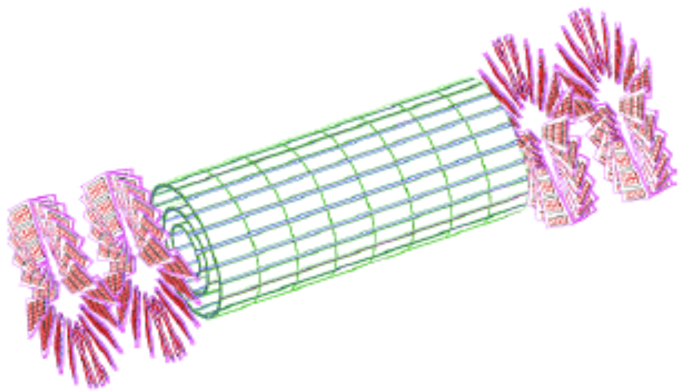
Best limits from the direct measurement of WWZ vertex

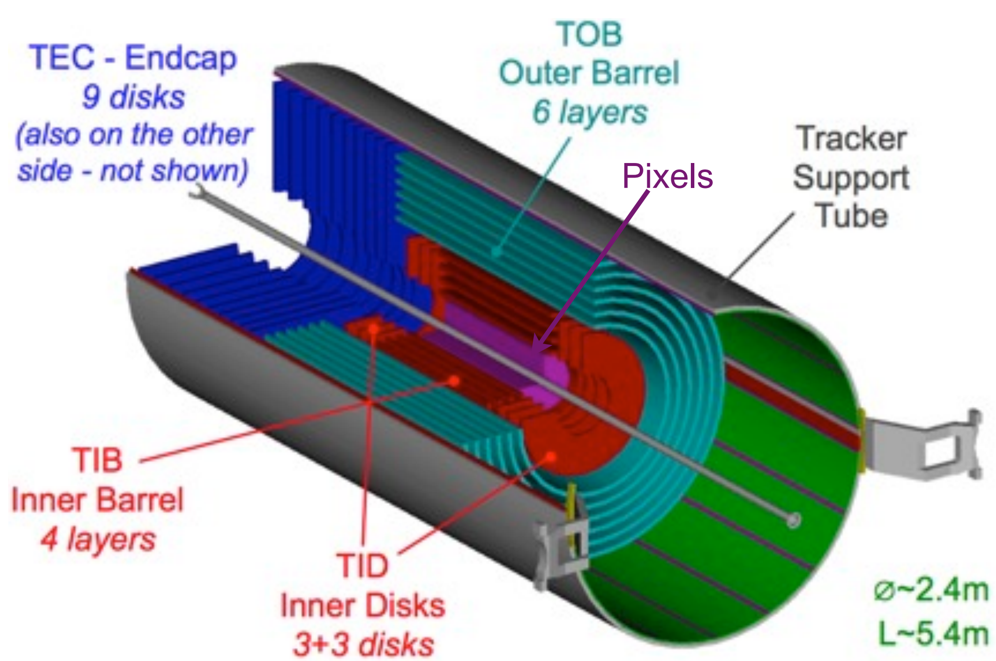


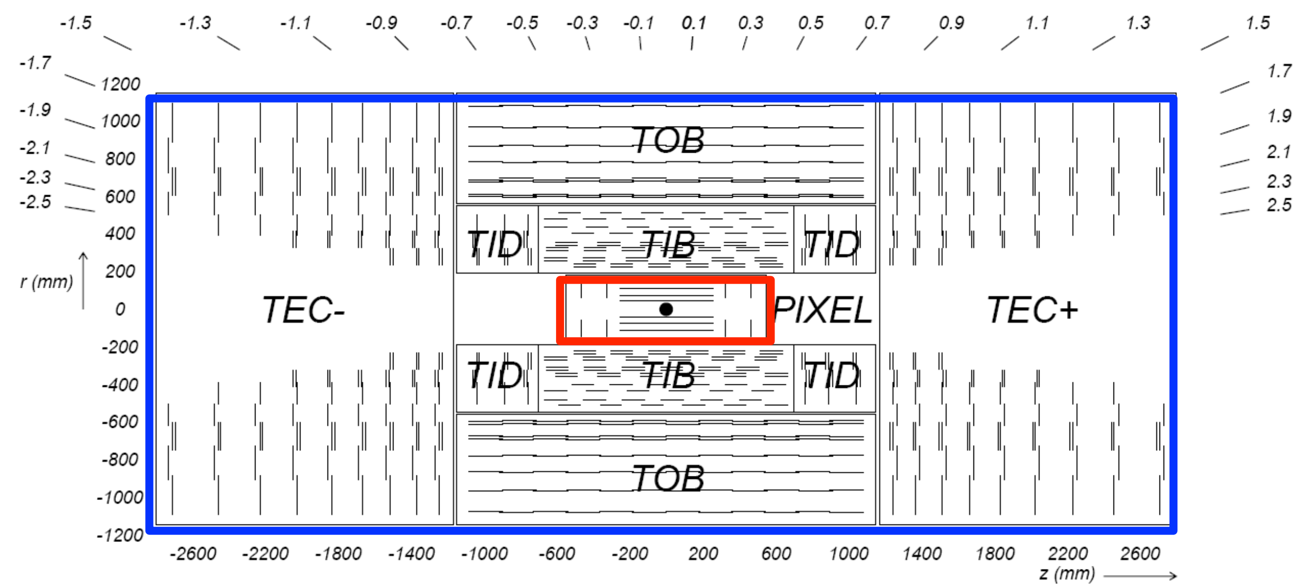
arXiv:1006.0761 [hep-ex]

backup: CMS detector - the Tracker

- Silicon tracker device:
  - pixel around the beam line
  - strips all around
  - provides 10% resolution on 1TeV/c muon







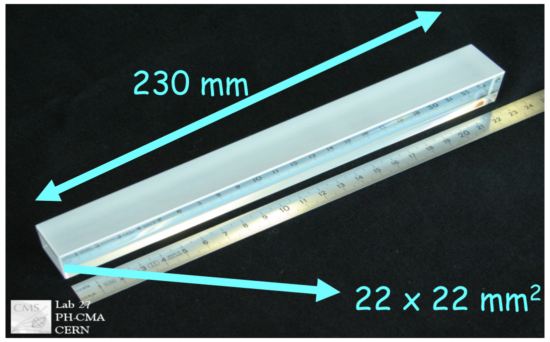
- Tracking efficiency: ε >99% (μ), ~90% hadrons
- Resolution: Δpt/pt ~ 1-2% (η<1.6)

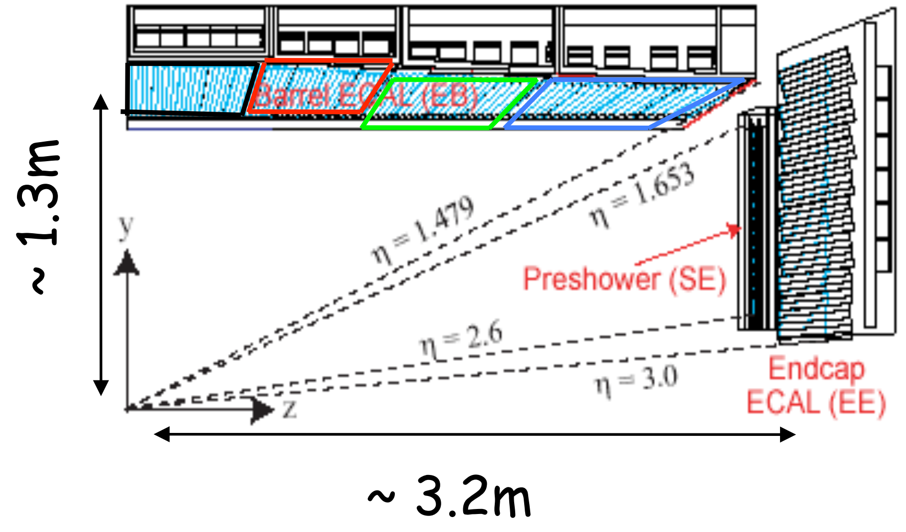
Pixel barrel layers and forward disks:
~1 m^2 of Si sensors, 65 M channels, 1440 modules
r = 4, 7, 11cm;   L = 53cm

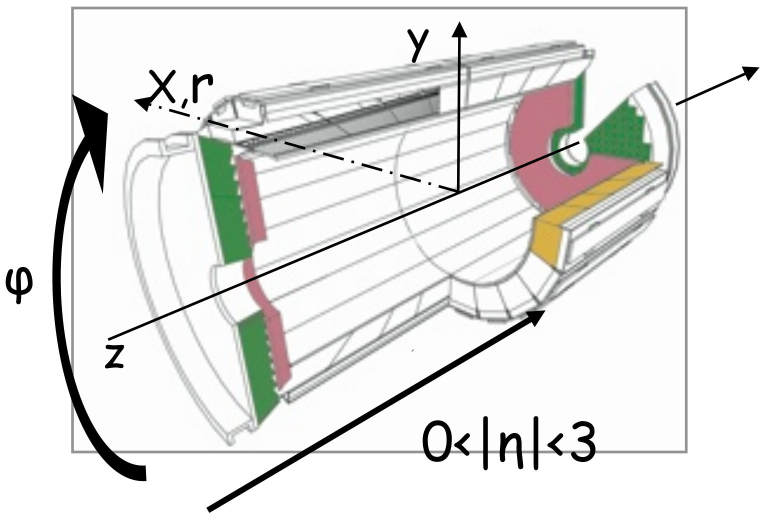
Strips all around:
~198 m^2 of Si sensors, ~9.6 M channels, 15148 modules
10 barrel layers, 9 End-Cap Wheels per side

backup: the Electromagnetic CALorimeter

- The homogeneous $PbWO_4$ crystals of the Electromagnetic CALorimeter:
  - **BARREL** 61200 crystals in 36 super-modules
  - **ENDCAP** 3662 crystals x 4 D

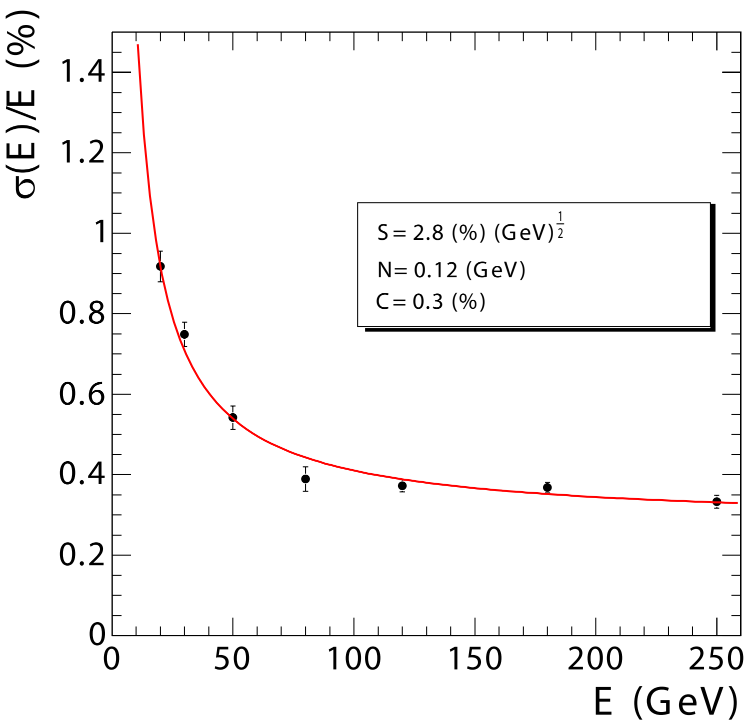






compact & **high granularity** for an **excellent energy containment**:
- Molière radius 22mm
- Radiation length X_0 8.9mm

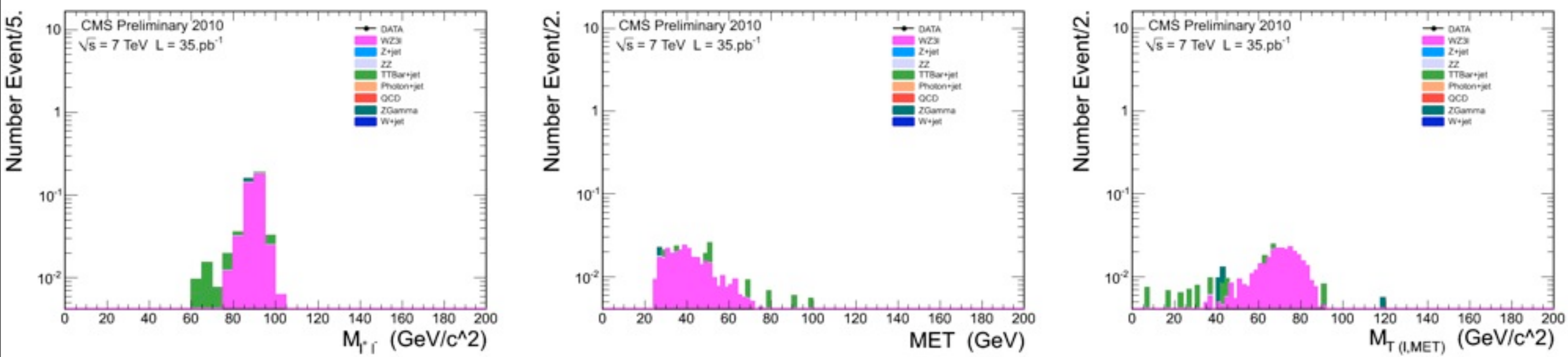
- ECAL global energy scale fixed with a 120GeV electron beam
  - confirmed with DATA within 1% (3%) forEB (EE)
- inter-calibration precision ~0.6% for |eta| < 0.8
- time synchronizations better than 1ns
- excellent energy resolution



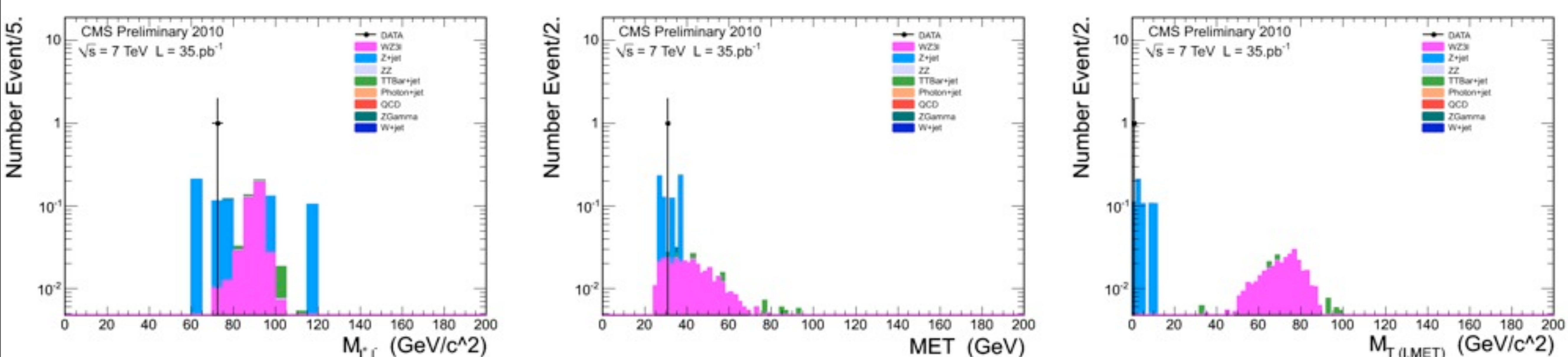
$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2$$

backup: …the analysis: eee, eμμ channels…

- 3electron final state:



- 1electron 2muon final state:



backup: Selections Z

- Identify a Z candidate, than looking for a 3rd lepton
- Z-> ee
  - electron selections:
    - ID + Iso + NoConversion: VBTF with WP(95%)
    - ele pT: both ele pT > 15GeV
    - $|\eta| < 2.5$ + crack region excluded
    - electron opposite charge invariant mass: 60GeV < MZ < 120 GeV
- Z-> mumu:
  - muon selections:
    - globalMuons & trackerMuon, VBTF ID
    - Iso: tkIsoR03 < 3
    - pT: both muons pT > 20GeV
    - $|\eta| < 2.4$
  - muon opposite charge invariant mass: 60GeV < MZ < 120GeV

backup: Selections W

- MET > 25GeV

- 3rd lepton required: electron for Z-> ee || Z-> mumu, muon for Z->ee
- 3rd = electron
  - selections:
    - ID + Iso + NoConversion: VBTF with WP(80%)
    - ele pT > 20GeV
    - |eta| < 2.5 + crack region excluded

- 3rd = muon
  - selections:
    - globalMuons & trackerMuon, VBTF ID
    - Iso: (tkIsoR03 + emIsoR03 + hadIsoR03)/Pt < 0.15
    - pT: both muons pT > 20GeV
    - |eta| < 2.1