WZ di-boson production at CMS

Outline

- Physics motivations
- Existing results (Tevatron $\sqrt{s}$ = 1.96TeV)
- Existing prospects for CMS at $\sqrt{s}$ = 14TeV
- Preliminary prospects for CMS at $\sqrt{s}$ = 7TeV

WZ Physics motivation

- WZ: complementary signature to allow for SM EWK test (at LHC with un-preceding $\sqrt{s}$)
  - WWZ TGC + boson longitudinal polarization + SM σ prediction (see later)

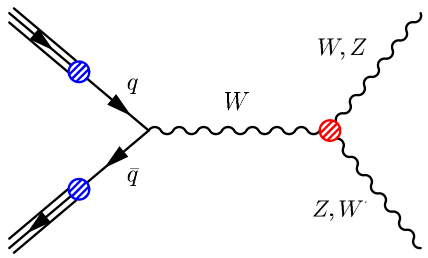
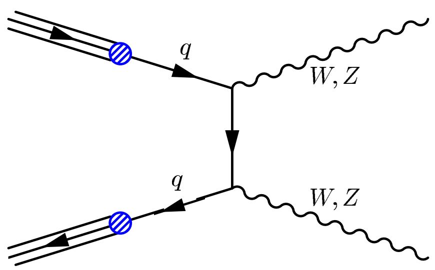
- WZ is a background for the 2main Higgs channels ->WW and ->ZZ:
  - WZ bg to WW (and H->WW) and WZ+jets among backgrounds for ZZ
  - Z+jets background is the main one for WZ and contributes to ZZ->4l bg as well
  - to exploit 3l + (1SCluster || 1 Track) -> higher statistic in ZZ (and higher bg)

to be looked at!!

- BSM signals providing 3leptons + ME_T:
  - SM contribution is expected to be reduced (constraints on signature)
  - BSM models (R-parity, SUSY, Little Higgs) allow for multi-lepton final states
  - i.e. W'->WZ->3l+ ME_T early exclusion at 95% C.L. at D0 with $4.1 fb^{-1}$:
    - $188 < M_{W'} < 520$GeV (SSM) and $208 < \rho_T < 408$GeV (low scale technicolor)

- Focus here on EWK processes and σ observation measurements

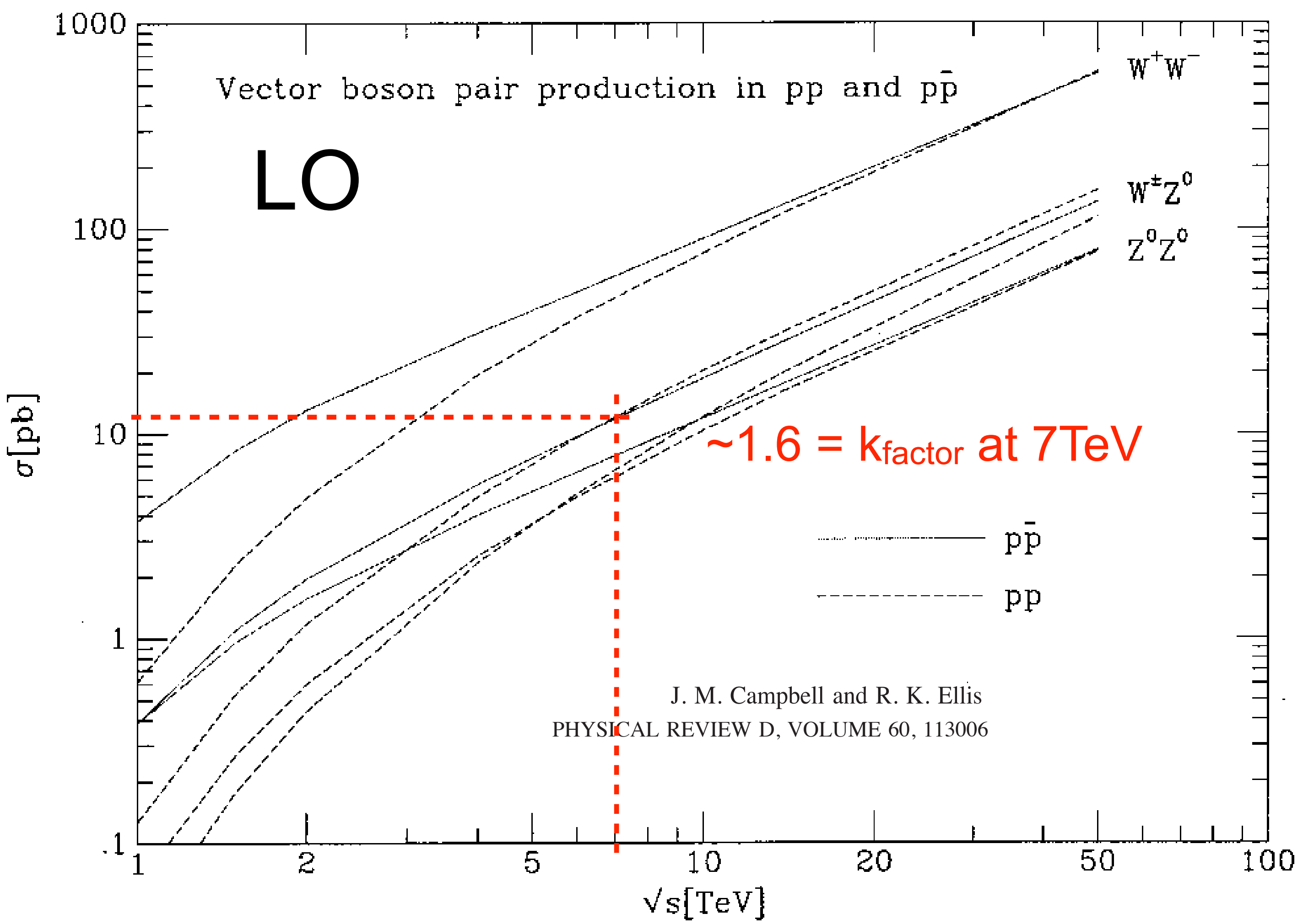
WZ at hadron collider

- s-channel  t-channel  and interference

  - at Tevatron (p - pbar): q-qbar channel enhanced, $\sigma(W^+Z) = \sigma(W^-Z)$
  - at LHC: no gg quark loop involved (*gg->ZWq-qbar gives small contribution*)

- SM cross-section production: LO and NLO

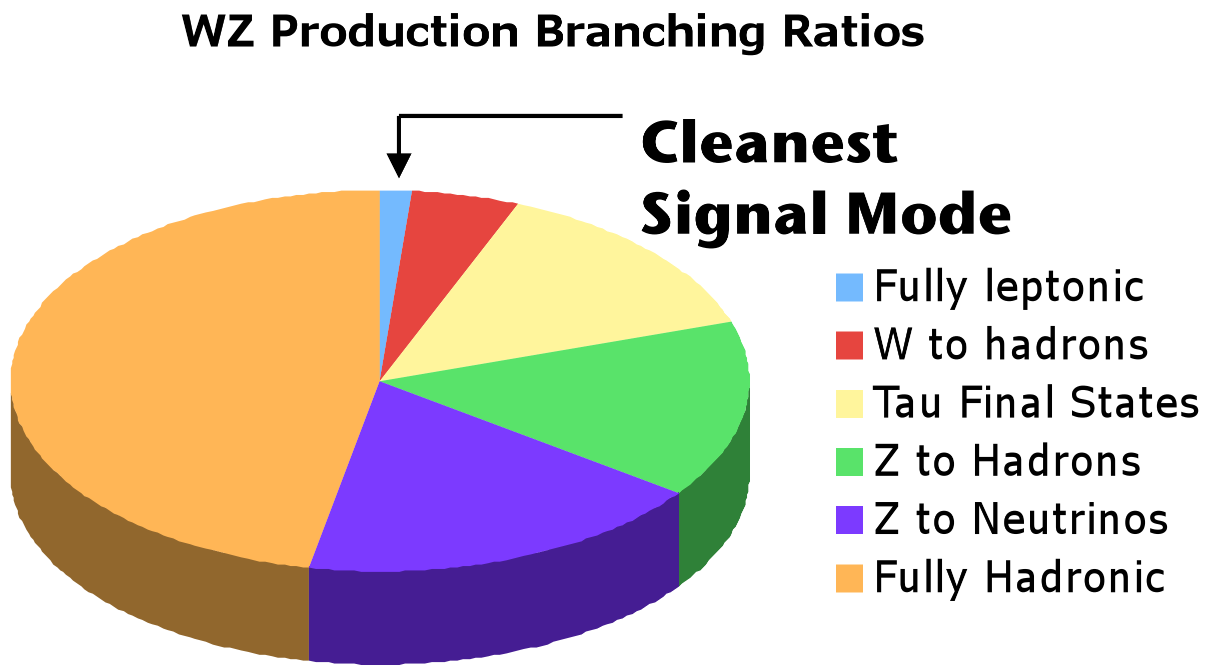
Tevatron:	1.96TeV	3.7±0.3 pb
LHC:		
14 TeV (pb)	10TeV (pb)	7TeV (pb)
51.05±0.09	31.40±0.05	18.27±0.03



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

WZ at collider

- Decay modes:



- 3lepton choice (l = e, μ):
  - reduced BR ~ 1.5%
  - clear signature and background reduction in hadronic environment
  - lepton charge disentangles W charge: allows for EWK precision tests (polarization)

- Focus on the pure leptonic final states

Physics motivation: TGC

- TGC: direct consequence of the non-Abelian SU(2) x U(1) gauge group in the SM:
  - assuming both C, P conservation -> 6 parameters describe the effective Lagrangian

$$L_{eff}^{WWV} = -i\, g_{WWV}\left[g_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V^\nu W^{\mu\nu}) + k_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} W^\dagger_{\rho\nu} W^\mu_\nu V^{\rho\nu}\right]$$

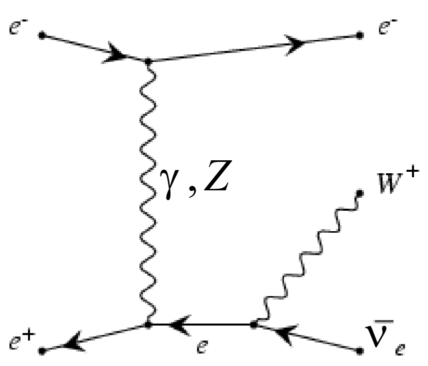
$$where\;\; V = \gamma, Z \;\; g_{WW\gamma} = e,\; g_{WWZ} = e\, cot\theta_W$$

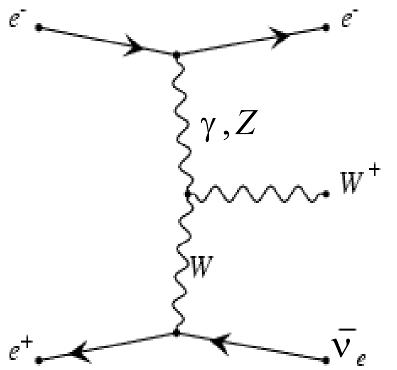
  - with $g^\gamma{}_1 = 1$ imposed by electromagnetic gauge invariance
  - deviation from SM described by $\Delta g_1^Z \equiv (g_1^Z - 1)$, $\Delta\kappa_\gamma \equiv (\kappa_\gamma - 1)$, $\Delta\kappa_Z \equiv (\kappa_Z - 1)$, λ_γ, λ_Z with $\Delta\kappa_\gamma = -\cot(2\theta_W)\cdot(\Delta\kappa^Z - \Delta g_1^Z)$, $\lambda_\gamma = \lambda_Z$
    - SM expectation $\Delta\kappa_\gamma = \Delta\kappa_Z = \Delta g_1^Z = \lambda_\gamma = \lambda_Z = 0$
    - $(\Delta g^0{}_1, \Delta k^0, \lambda^0, M^2{}_{WZ}, \Lambda)$ due to tree level unitarity requirement at high energy
  - ref. Nuclear Physics B282 (1987) 253-307 (K. HAGIWARA et al.)

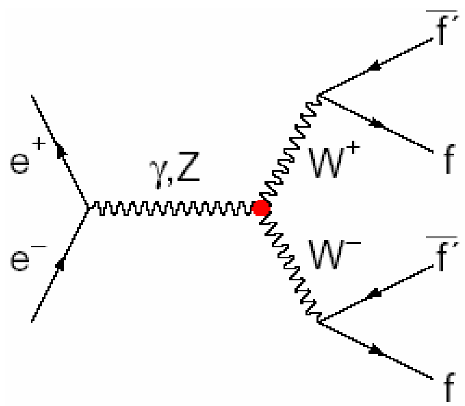
- WWγ and WWZ : only allowed in the SM
  - model dependent access to TGC through σ measurement and kinematic variables:
    - expectation from MC generators with anomalous TGC
    - t-channel and s-channel contribution from theory
  - some constraints from LEP2 and Tevatron

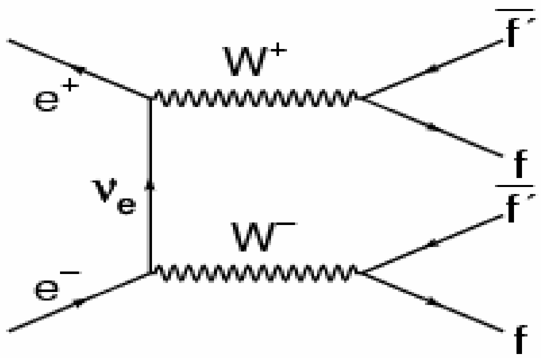
TGC at LEP2 ($\sqrt{s}$ = 198GeV)

- Main processes in the direct WWV measurement:
  - single W (WWγ, mainly Δk_γ):
    - only t-channel to disentangle WWZ from WWγ
    - σ has large sensitivity on WWγ coupling
  - WW (both WWγ and WWZ)
    - s channel
    - t channel









- Final combined result:
  - in agreement with SM expectation
  - best sensitivity up to now
    - clean environment: no pdf uncertainties
    - better defined background

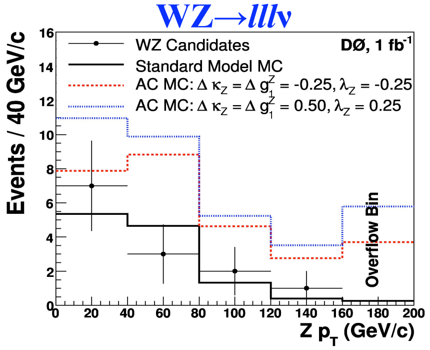
Parameter	95% C.L.
Δg^Z_1	[-0.051, 0.034]
Δk_γ	[-0.105, 0.069]
λ_γ	[-0.059, 0.026]

TGC at Tevatron (1.96TeV)

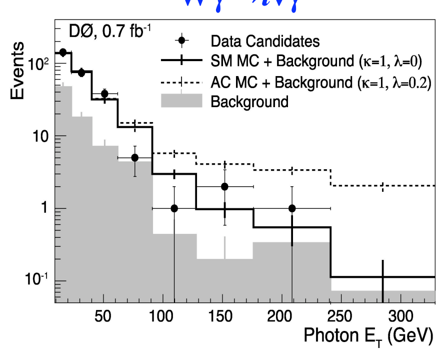
- Multiple topologies taken into account
- **WZ first observation** (unavailable at LEP2): direct meas. to decouple WWγ WWZ
- current result in the **full leptonic final state** (Moriond, March 2010)
  - CDF 1.9fb^{-1}: $\sigma(WZ)_{meas} = 4.3^{+1.3}_{1.0}(stat) \pm 0.4(syst+lumi)pb$
  - D0 1.1 fb^{-1} $\sigma(WZ)_{meas} = 2.7^{+1.7}_{1.3}pb$

Combination of four DØ analyses to probe TGCs and W magnetic dipole (μ_W) and electric quadrupole (q_W) moments.

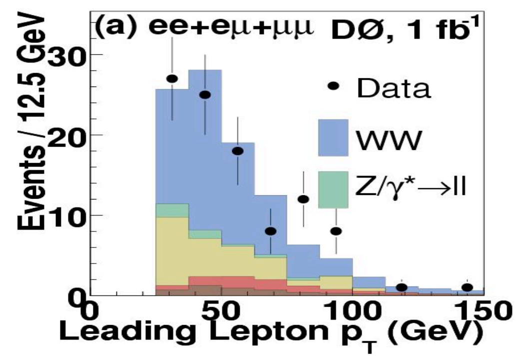
WZ→lllν



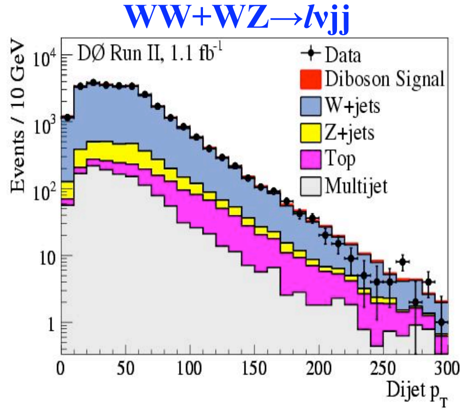
Wγ→lνγ



WW→llνν



WW+WZ→lνjj



95% C.L. limits (Λ=2 TeV)

Imposing SU(2)$_L$×U(1)$_Y$

- $-0.29 < \Delta\kappa_\gamma < 0.38$
- $-0.08 < \lambda < 0.08$
- $-0.07 < \Delta g_1^Z < 0.16$
- $1.86 < \mu_W < 2.16$
- $-1.16 < q_W < -0.84$

Assuming equal couplings

- $-0.11 < \Delta\kappa < 0.18$
- $-0.08 < \lambda < 0.08$
- $1.86 < \mu_W < 2.15$
- $-1.16 < q_W < -0.87$

Approaching sensitivity of individual LEP experiments

12

Probing TGCs: Non-SM WWZ coupling enhances cross section at high values of Z p_T

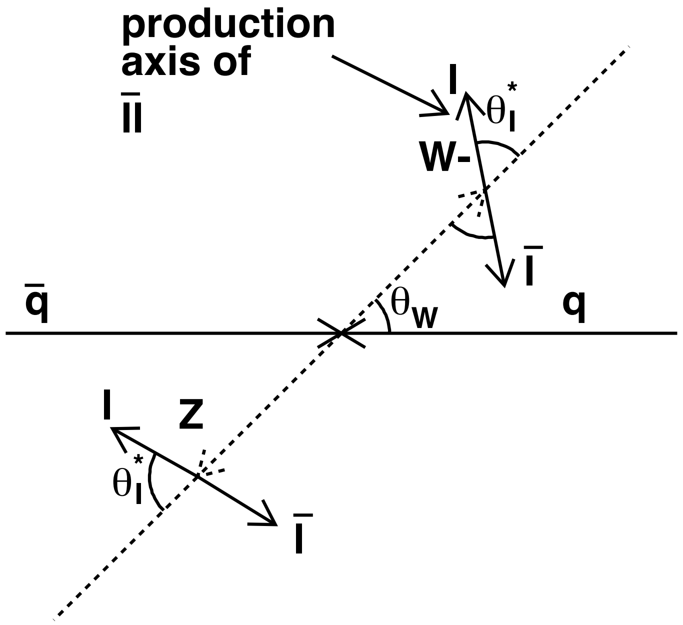
95% C.L. limits for Λ=2 TeV

DØ published, 1 fb^{-1}	CDF preliminary, 1.9 fb^{-1}
$-0.17 < \lambda_Z < 0.21$	$-0.13 < \lambda_Z < 0.14$
$-0.14 < \Delta g_Z < 0.34$	$-0.13 < \Delta g_Z < 0.23$
$-0.12 < \Delta\kappa_Z = \Delta g_Z < 0.29$	$-0.76 < \Delta\kappa_Z < 1.18$

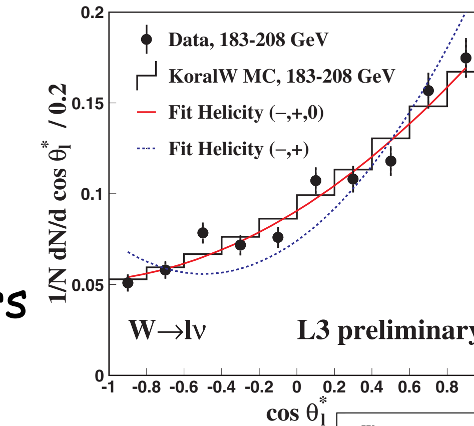
- poor statistic

Physics motivation: Bosons polarization

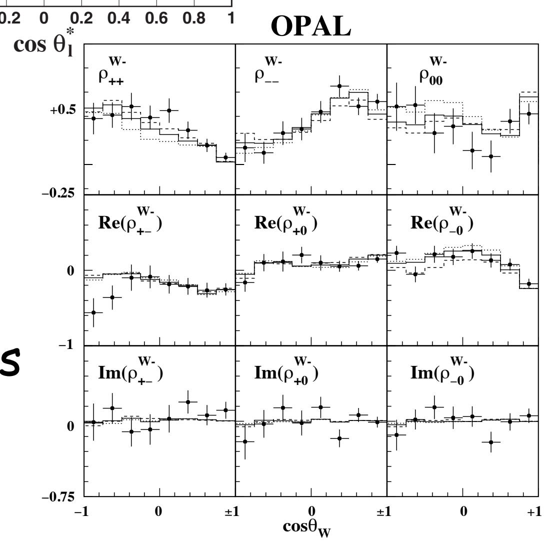
- W and Z longitudinal polarization: direct consequence of Higgs mechanism
- H->VV decay: access to Higgs spin and separation from di-boson continuum
- W->l nu decay: test on the SM V-A current
- Longitudinal polarization accessible in the only di-boson production:
- Boson decay angle θ^*_l : the kinematic observable sensitive to the boson polarization
  - being ρ_{--} ρ_{++} ρ_{00} the transverse left/right handed and longitudinal polarization of the boson
- i.e. in the WZ process, wrt the V rest frame (with $A = 2\, g_V g_A / [g^2_V + g^2_A]$)
  - Z: $$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*_\ell} = \rho_{--}\frac{3}{8}(1+2A\cos\theta^*_\ell+\cos^2\theta^*_\ell)+\rho_{++}\frac{3}{8}(1-2A\cos\theta^*_\ell+\cos^2\theta^*_\ell)+\rho_{00}\frac{3}{4}\sin^2\theta^*_\ell$$
  - W: $$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*_\ell} = \rho_{--}\frac{3}{8}(1+\cos\theta^*_\ell)^2+\rho_{++}\frac{3}{8}(1-\cos\theta^*_\ell)^2+\rho_{00}\frac{3}{4}\sin^2\theta^*_\ell$$
  - caveat: ME_T + p_{lepton} constrained on M_W to reconstruct $\cos(\theta^*_l)$



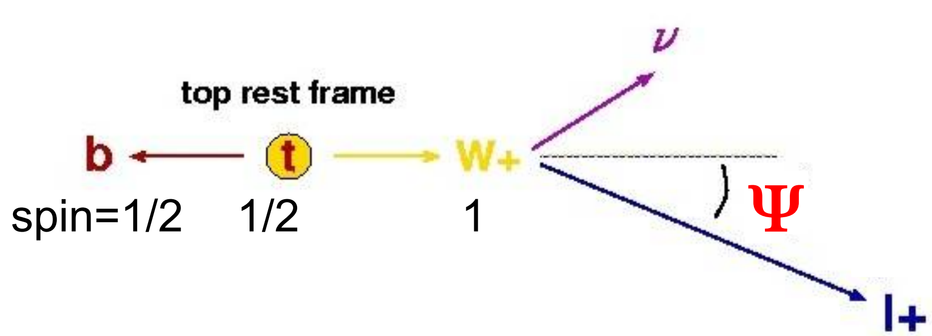
W polarization measurements

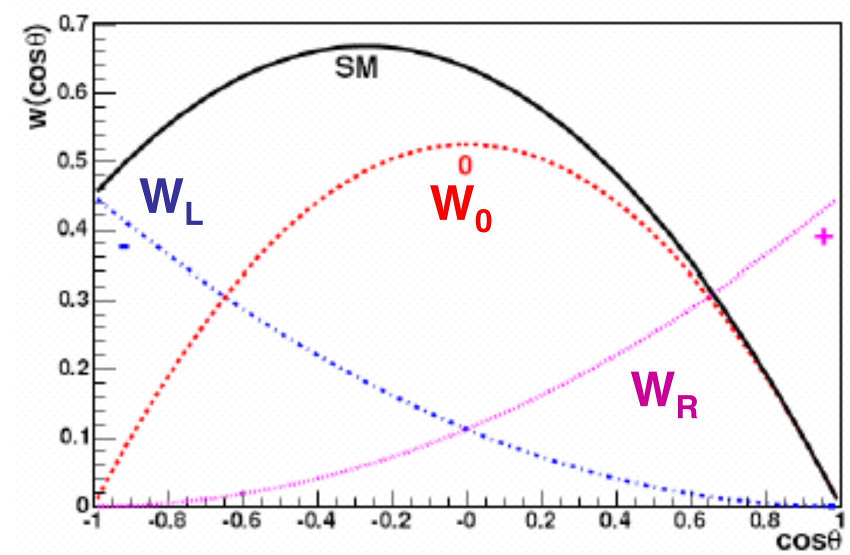


- at LEP2 in the WW production:
  - polarization described by a complex 3x3 Spin-Density-Matrix
    - imaginary SDM elements are sensitive to CP violating TGC parameters
  - focusing on single W->l nu allows for unambiguously W tagging
  - Results by combining WW correlations:
    - measurements are consistent with helicity distribution from SM
    - no evidence for CP-violating couplings: constraints for new possible contributions



- at Tevatron in the top decay:
  - SM expectation: $$\frac{1}{N}\frac{dN}{d\cos\Psi}=\frac{3}{2}\left[F_0\cdot\left(\frac{\sin\Psi}{\sqrt{2}}\right)^2+F_L\cdot\left(\frac{1-\cos\Psi}{2}\right)^2+F_R\cdot\left(\frac{1+\cos\Psi}{2}\right)^2\right]$$
    - F_0~ 70%, F_L~30%, F_R~0%
  - Result with big errors, within SM expectation





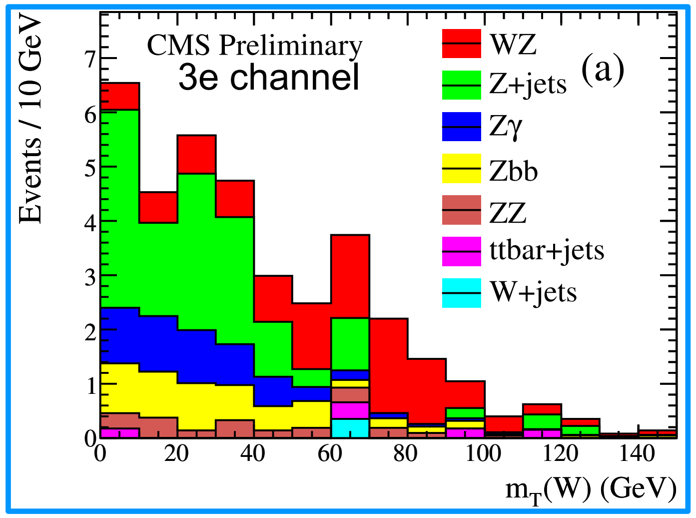
LHC potentialities

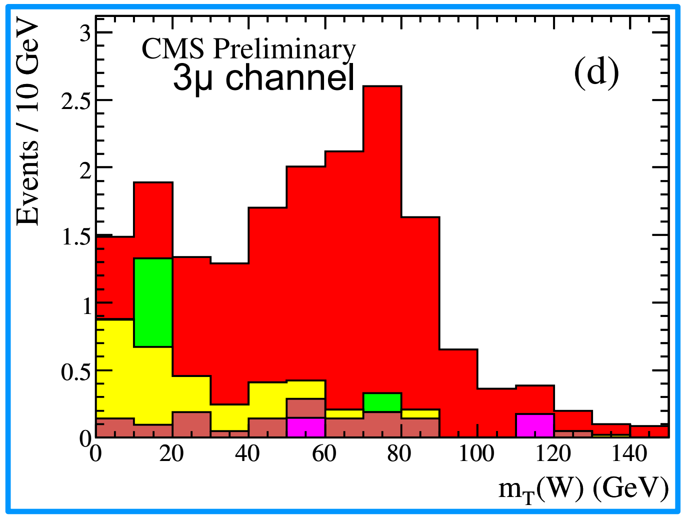
CMS studies (LHC 14TeV)

CMS PAS EWK-08-003

AN2010/050

- Signal topology: WZ -> lnu ll (l = e, μ) channel
- Main backgrounds: Z+jets, ZZ, Zγ, t-tbar, W+jets
- Selections:
  - trigger: total eff. > 98%
    - Z->ee single or double electron trigger + Z->$\mu\mu$ single muon trigger
  - lepton selection:
    - isolation
    - 3 charged leptons (l = e, μ): pT>15GeV (10GeV), $|\eta_e| < 2.5$ (2.4), $|\eta_\mu| < 2.4$ + 1l: pT > 20GeV
  - kinematical selection:
    - only 1 Z: 50GeV(70GeV) < M_Z < 120GeV (110GeV), if other Z: |M_Z - 20GeV| event rejected
    - W: pT>20GeV + M^W_T > 50GeV (15GeV) + ME_T > 15GeV
    - isolation between W_l and each Z_l: $\Delta R > 0.1$





CMS studies (14TeV)

- Expected numbers of selected events for $300 pb^{-1}$: $S/B \sim 2.5$ $S/\sqrt{B} \sim 9.5$

		all	$3e$	$2e1\mu$	$2\mu 1e$	3μ
WZ^0		34.9±0.5	7.9±0.3	8.0±0.3	8.9±0.3	10.1±0.3
$Z^0 + jets$	50%	3.9±1.0	1.9±0.8	< 0.1	1.8±0.7	0.1±0.1
bbll		2.9±0.3	1.2±0.2	0.1±0.1	1.3±0.2	0.3±0.1
$t\bar{t} + jets$	20%	2.2±0.6	0.6±0.3	0.6±0.3	0.6±0.3	0.3±0.2
$W + jets$		0.4±0.4	0.4±0.4	< 0.1	< 0.1	< 0.1
Z^0Z^0	30%	2.8±0.3	0.8±0.1	0.6±0.1	0.7±0.1	0.7±0.1
$Z^0 + \gamma$		1.4±0.1	0.7±0.1	< 0.1	0.7±0.1	< 0.1
B total	100%	13.6				

  - WZ selection efficiency ~ 15%

- Systematic uncertainties:

Source	Relative Uncertainty (%) WZ	ZZ	WW+tX+$DY \to \ell\ell$+W + jets	$V(W/Z) + \gamma$
Luminosity	10	10	—	10
Lepton & trigger efficiencies	6	6	—	4
Lepton miscalibration and misalignment	3	3	—	3
E_T^{miss} modeling	2	9	—	29
Jet reconstruction	—	—	—	—
PDF uncertainties	2	4	—	4
NLO effects	6	9	—	9
Fakes	—	—	30	—
Conversions	—	—	—	30
MC statistics	4	11	—	35

AN2010/050

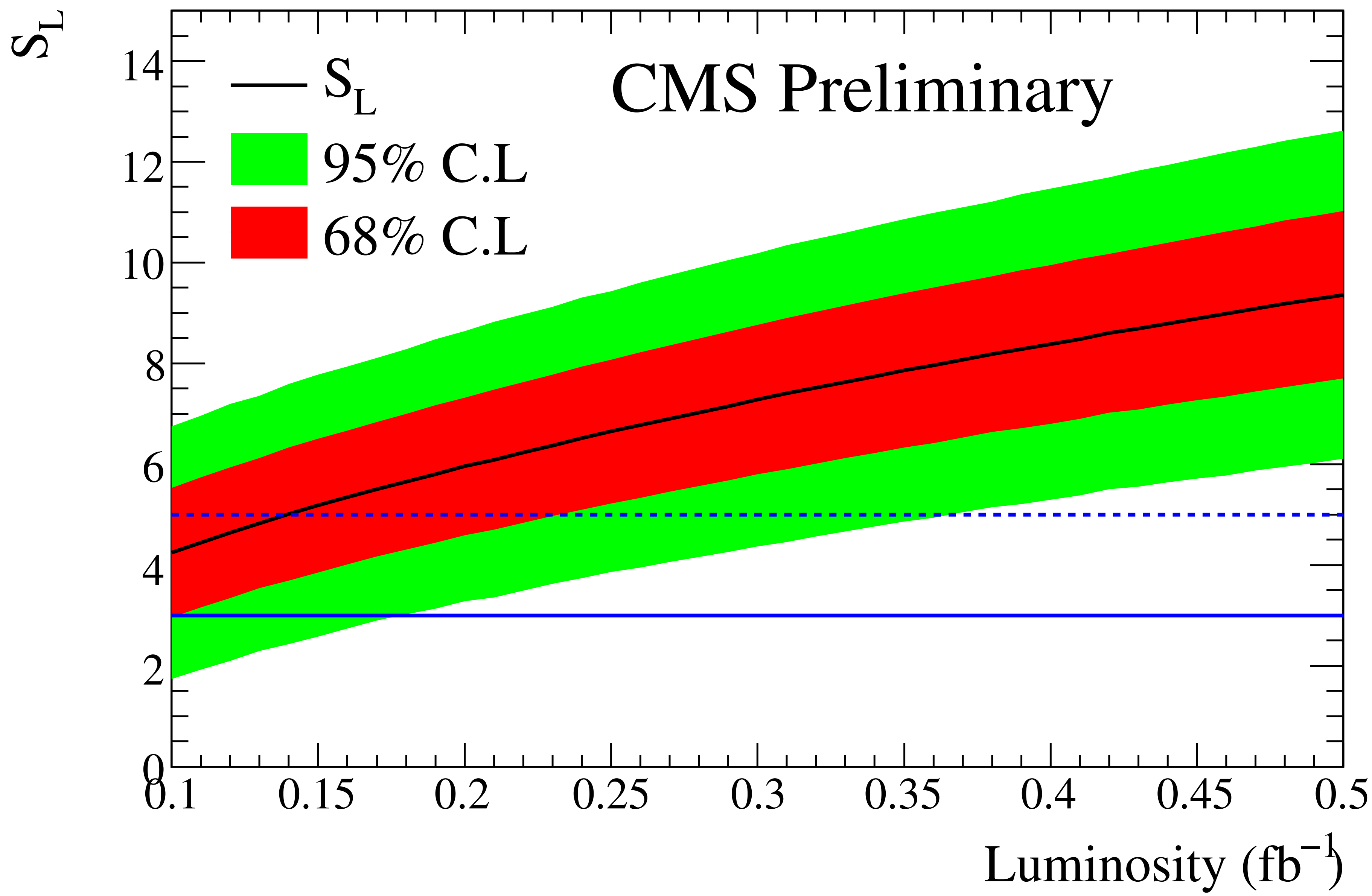
Source	Systematic uncertainty,%
Luminosity	10.0
Trigger	1.0
Lepton reconstruction	2.0
Electron charge determination	2.0
Muon charge determination	1.0
Lepton energy scale	1.0
Electron identification	4.0
Muon identification	2.0
PDF uncertainties	4.0
$M_T(W)$ requirement	10.0

CMS PAS EWK-08-003

CMS studies (14TeV)

- 5σ significance on WZ observation with less then 350pb-1 at 95%CL:
  - frequentist approach to estimate variation of expected signal and background events

CMS PAS EWK-08-003

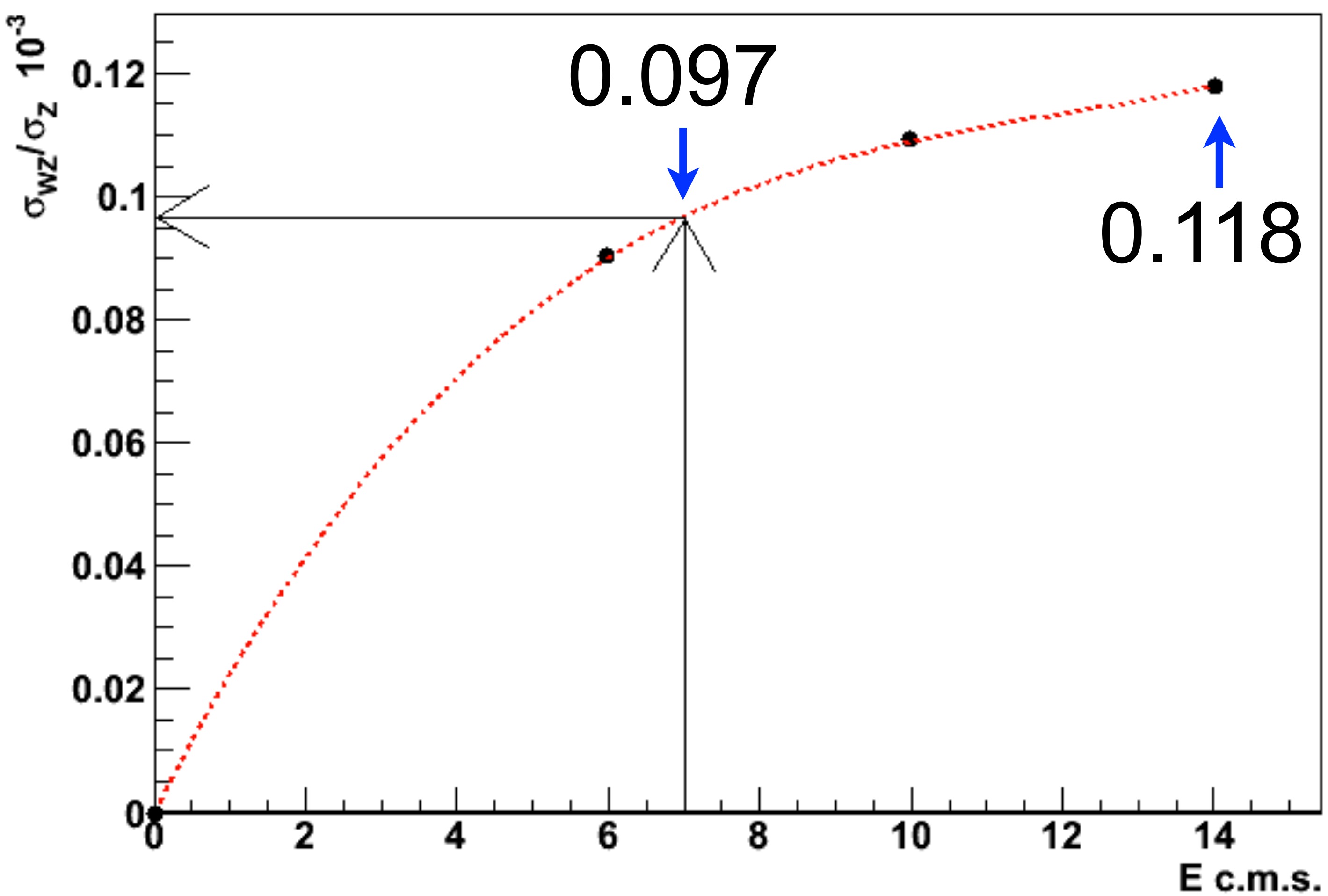


7TeV reach

c.m.s. - LHC 7 TeV

- Signal: $\sigma_{14TeV} \sim 3\ \sigma_{7TeV}$
- Main backgrounds: σ rescaling assumed as the one for Z
- $\frac{\sigma(WZ)}{\sigma(Z)}$ NLO computed at 14TeV, 10TeV, 6TeV (from theory)
  - J.M. Campbell et al. "Normalizing Weak Boson Pair Production at the Large Hadron Collider" arXiv:0906.2500v2
  - negligible dependence on generator cuts
- S/B rough extrapolation at 7TeV: -18% from 14TeV -> 7TeV
  - Z+jet dominating bg
  - σ(Z+jet) rescales as σ(Z) with c.m.s. energy

important effect expected



acceptance and kinematic

- 20 000 events in W->l nu Z->ll (l = e, μ) were generated with PYTHIA
  - both at 7TeV and 14TeV

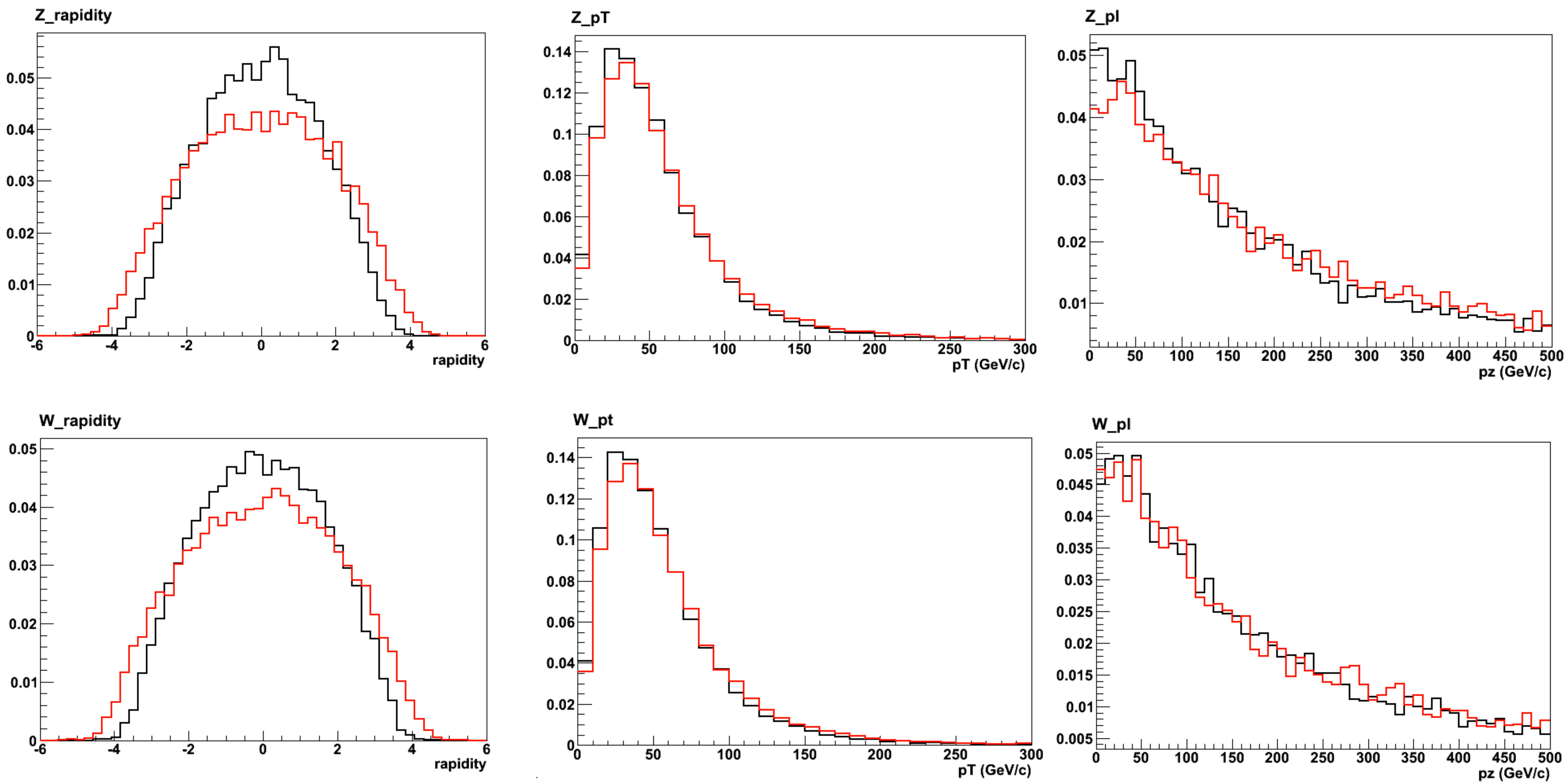
- Selections from CMS-PAS applied to both samples:

Selection	% events - 14 TeV	% events - 7 TeV
$pT_{lepton} > 15$ GeV/c	78,02	77,67
$\lvert \eta_e \rvert < 2.5$ && $\lvert \eta_\mu \rvert < 2.4$	23,9	30,17
50GeV < M_Z < 120GeV	97,53	96,77
Combined	19,53	24,69

new tuning needed

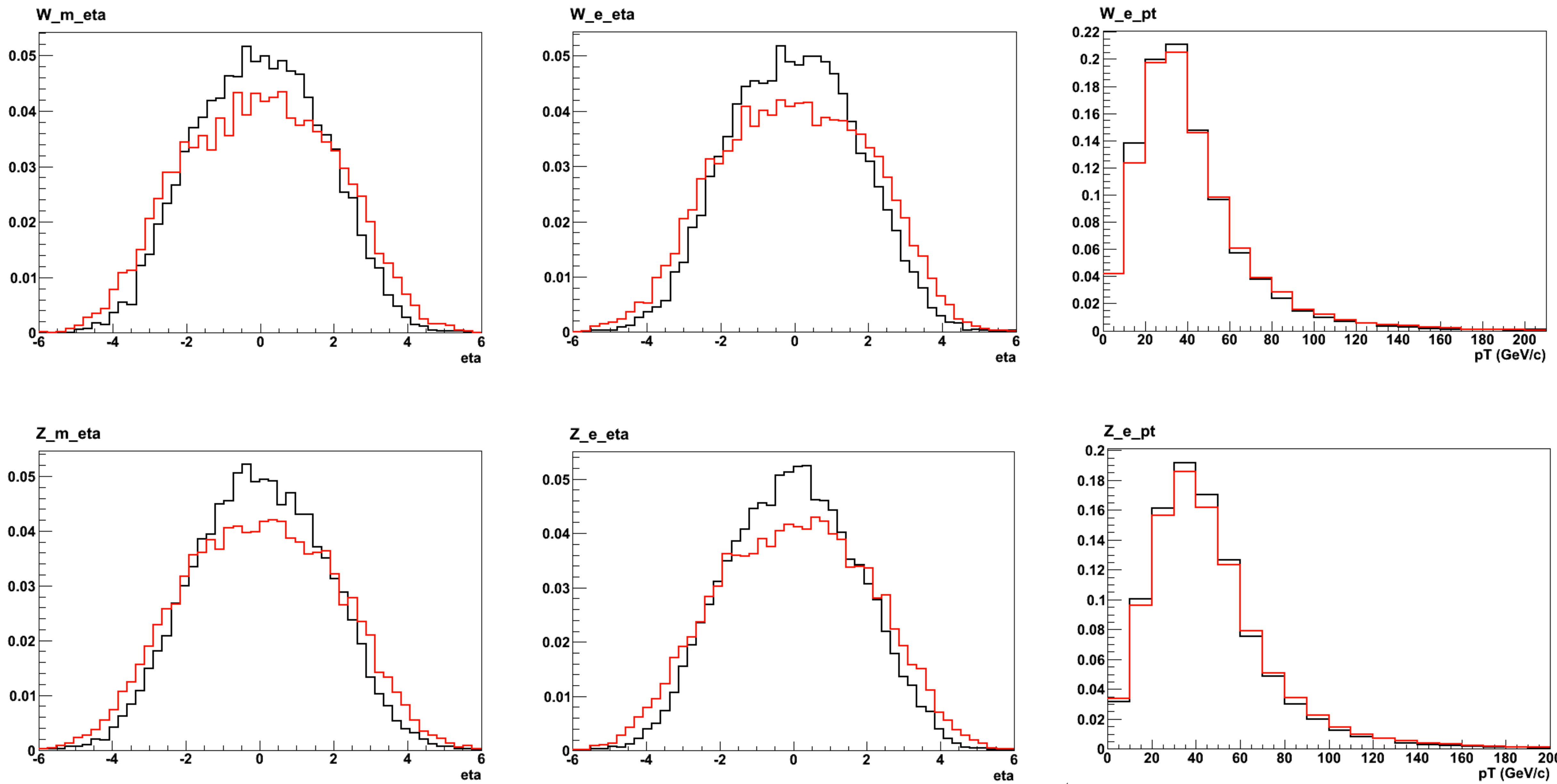
kinematic comparison

- Shape comparison: 14TeV 7TeV
- 7TeV: distributions are more central



lepton selections

- Shape comparison: 14TeV 7TeV



- Rough estimate: 35 WZ events (300pb^{-1} - 14TeV) -> ~ 5 events (100pb^{-1} - 7TeV)
- Detailed study needed with backgrounds included

Conclusions

- The Standard Model WZ channel was presented:
  - physics motivation
- Existing CMS prospects were looked at
  - 2008 public analysis at 14TeV
  - 2010 internal note at 7TeV
- Next steps
  - Rely on NLO generator samples at 7TeV (signal + backgrounds)
  - Optimize event selections wrt different acceptance and kinematic distribution
  - Update analysis for new electron reco and ID developments
  - Estimate observation sensitivity wrt integrated lumi
  - Second order study: estimate integrated lumi. needed for EWK SM tests