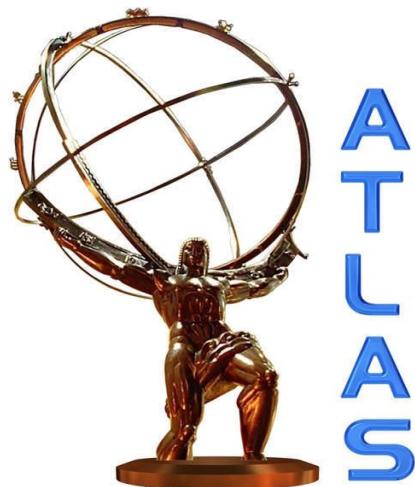


Discovery potential of LHC for extended gauge symmetries



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LMU

Overview

- LHC & ATLAS & CMS
- extended gauge theories
- experimental searches for:
 - W'
 - Z'
 - heavy majorana neutrinos, W_R
 - 2nd generation Leptoquarks
- conclusions

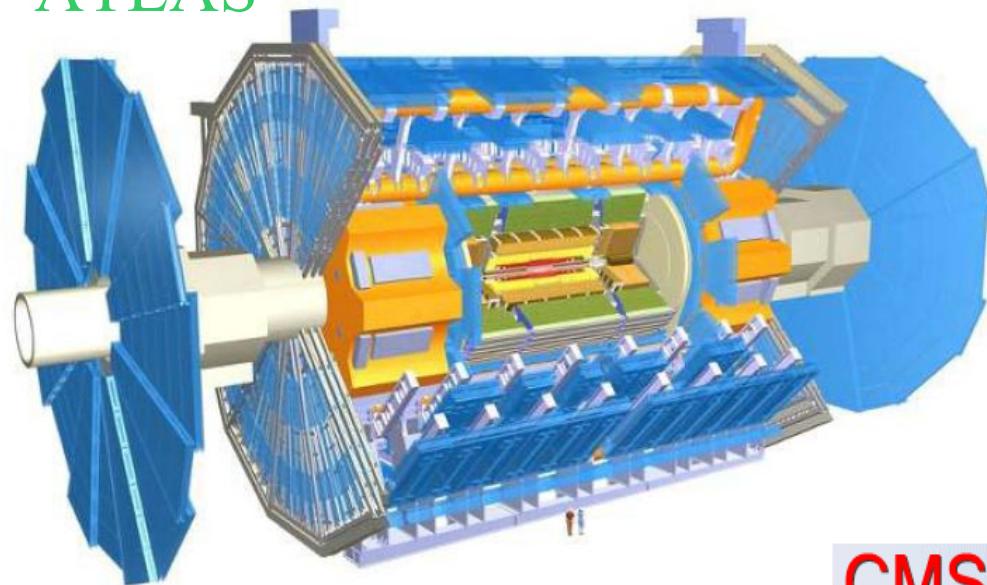
LHC schedule/luminosities



- 1st run at 14 TeV: July 2008
- $\int L dt$ in 1st month (August 2008): a few pb⁻¹
- $\int L dt$ until end of 2008: up to 1fb⁻¹

The Detectors

ATLAS



Diameter

25 m

Barrel toroid length

26 m

End-cap end-wall chamber span

46 m

Overall weight

7000 Tons

Diameter

15 m

Length

21.5 m

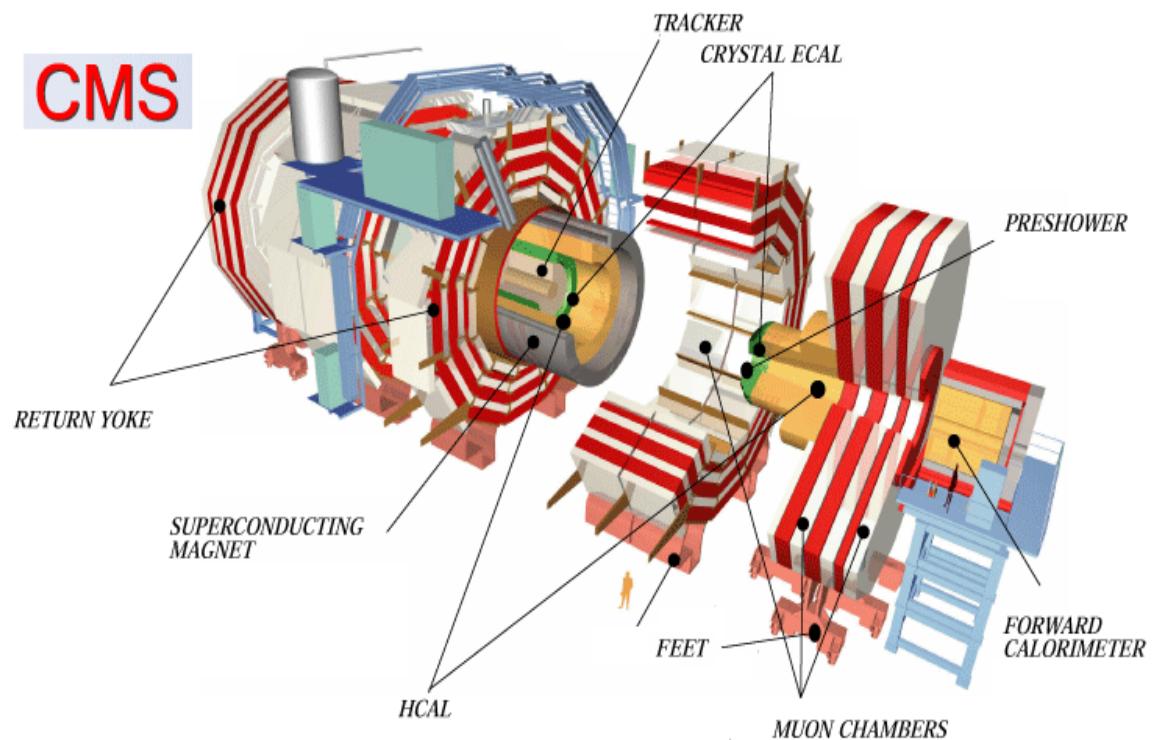
Magnetic field

4 T

Overall weight

12500 t

CMS



Extended Gauge Symmetries

- Many extensions of the Standard Model rely on larger symmetry groups
 - Extended Gauge Symmetries:
 - Left-right-symmetric models (LRSM)
 - Z' , W_R , heavy majorana neutrinos etc.
 - Sequential standard model
 - Z' , W' etc.
 - Superstring inspired E_6 -models
 - Z' , Leptoquarks etc.
 - Grand-Unifying-Theories (GUTs)
 - Leptoquarks etc.
 - Little Higgs Model
 - Z' etc.

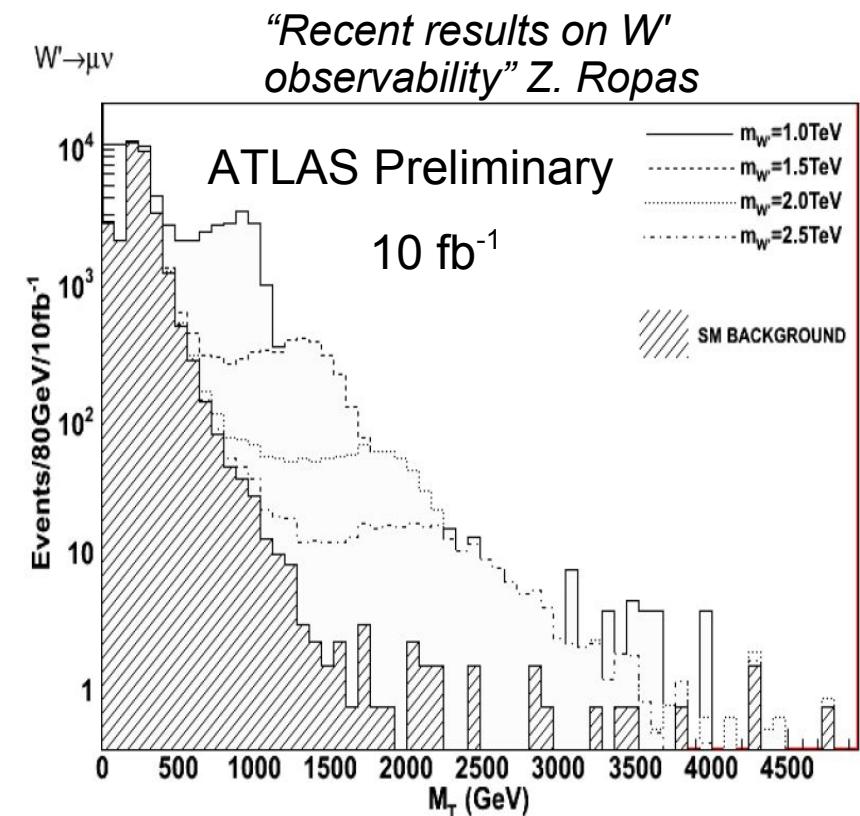
W' (ATLAS)

- W' in the sequential Standard Model:

- W' is an additional heavy gauge boson
- W' has same couplings with left-handed fermions like W; no interaction with other heavy gauge bosons (W, Z, Z')
- lower bound on W' mass (direct searches): ~ 1 TeV

- studied channel at ATLAS: $W' \rightarrow \mu + \nu_\mu$
- Standard model backgrounds considered:

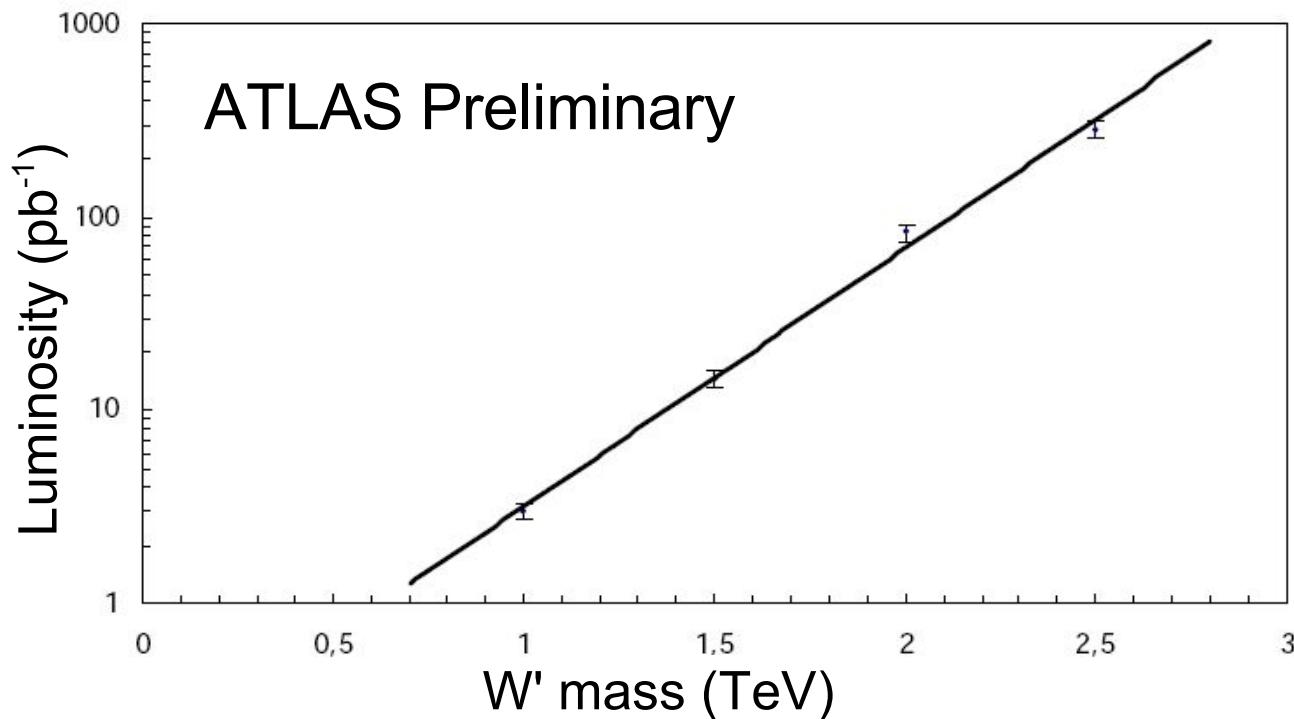
- $W \rightarrow \mu\nu_\mu + X$
- $Z \rightarrow \mu\mu + X$
- QCD (dijet processes)



- **W' signature:** high energy muon accompanied by missing energy allows easy separation of signal and background reactions

W' (ATLAS)

Expected luminosity needed for a 5σ discovery (likelihood ratio method)



"Recent results on W' observability" Z. Ropas

W' mass (TeV)	Luminosity (pb^{-1})
1	3.0 ± 0.3
1.5	14.6 ± 1.4
2	84 ± 9
2.5	283 ± 31

assumed sys. uncertainties:
signal 5%
background 20%

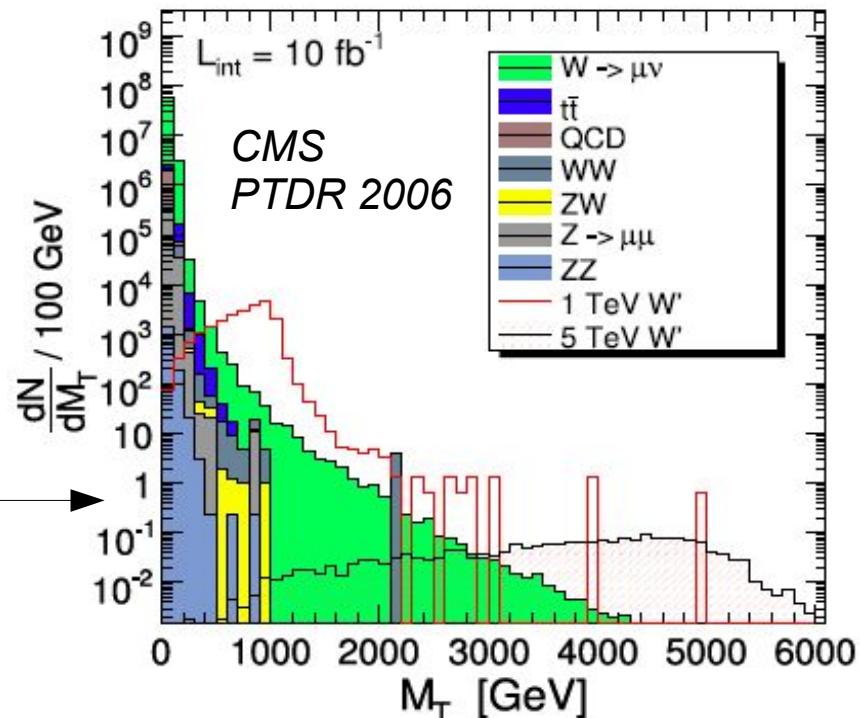
W' (CMS)

- same channel studied as in ATLAS:

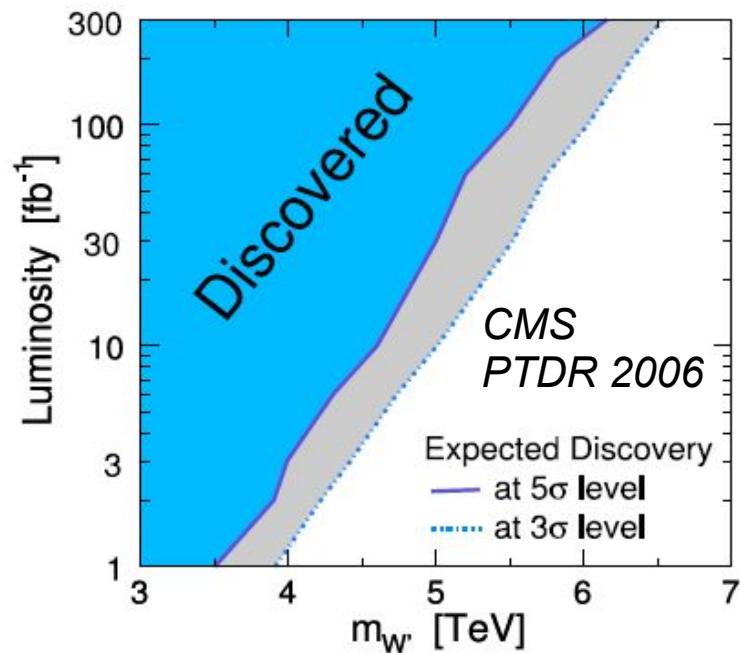
$$W' \rightarrow \mu + \nu_\mu$$

→ same background channels and same W' signature as in ATLAS

- number of events for signal and background after selection cuts



discovery limits for W'



Z'

- Z' is an additional heavy gauge boson, predicted in many extended gauge theories, excluded mass: ~ 1 TeV (direct searches)

CMS
PTDR 2006

Model	Γ/M %	$Z' \rightarrow \mu^+ \mu^-$ BR in %	$\sigma^{\text{LO}} \cdot \text{Br, full interference, fb}$ (PYTHIA)		
			$1 \text{ TeV}/c^2$	$3 \text{ TeV}/c^2$	$5 \text{ TeV}/c^2$
Z_{SSM}	3.1	3.0	610	2.8	0.050
Z_ψ	0.6	4.0	340	1.7	0.032
Z_η	0.7	3.4	370	1.8	0.035
Z_χ	1.3	5.7	500	2.2	0.038
Z_{LRM}	2.2	2.3	500	2.3	0.040
Z_{ALRM}	1.6	8.6	740	3.7	0.077

Z_{SSM} within the sequential standard model

Z_η , Z_ψ , Z_χ arising in E_6 (and SO(10)) GUT groups

Z_{LRM} and Z_{ALRM} arising in the framework of the so-called “left-right” and “alternative left-right” models ($g_R = g_L$ chosen)

k-factor used: 1.35 (mass-independent)

- expected properties of studied models

Z'

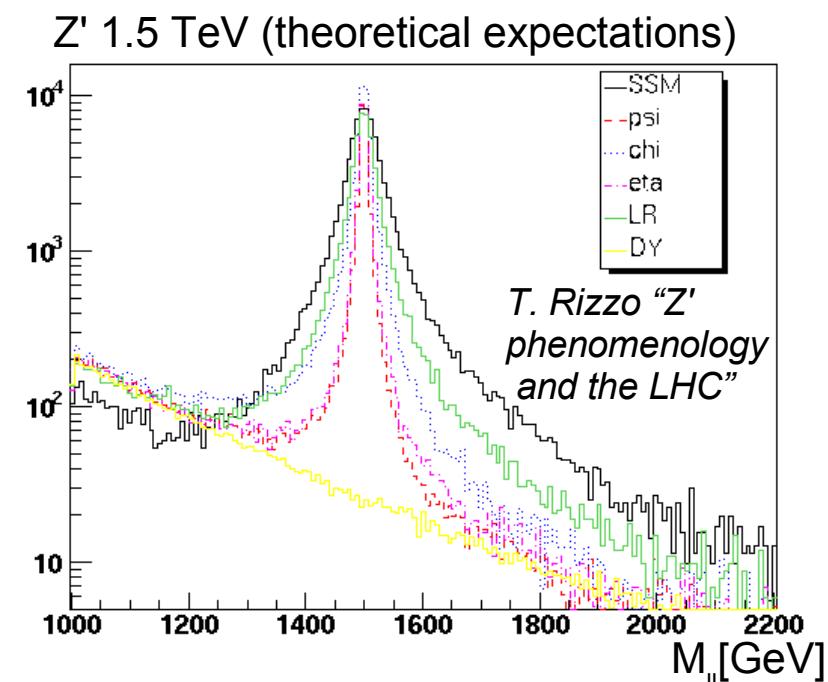
- Decay channels (assumption: no exotics channels opened):

• $Z' \rightarrow \mu^+ \mu^-$	promising
• $Z' \rightarrow e^+ e^-$	promising
• $Z' \rightarrow \tau^+ \tau^-$	instrumental background from QCD
• $Z' \rightarrow \text{hadrons}$	instrumental background from QCD

- **Z' signal:** high invariant mass peak above Drell-Yan line shape

- studied channel (ATLAS):
 $Z' \rightarrow e^+ e^-$

- dominant and irreducible background:
 $\text{pp} \rightarrow \gamma/Z^0 \rightarrow e^+ e^-$



studied channel: $Z' \rightarrow \mu^+ \mu^-$ (CMS)(assumption: no exotic channels opened)

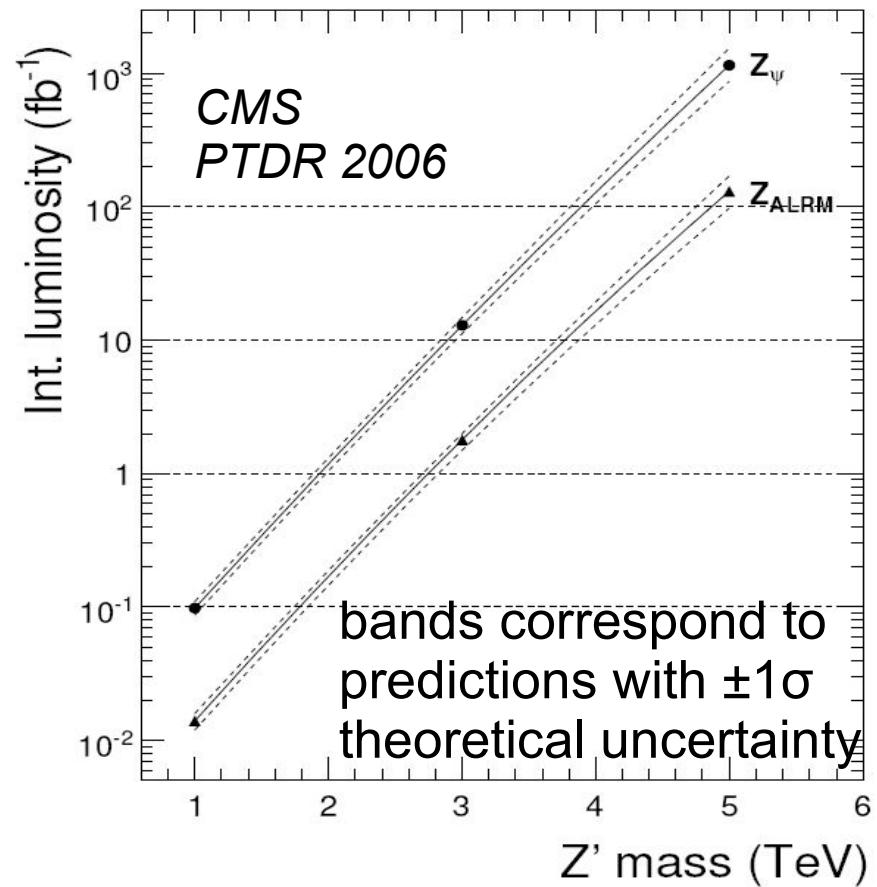
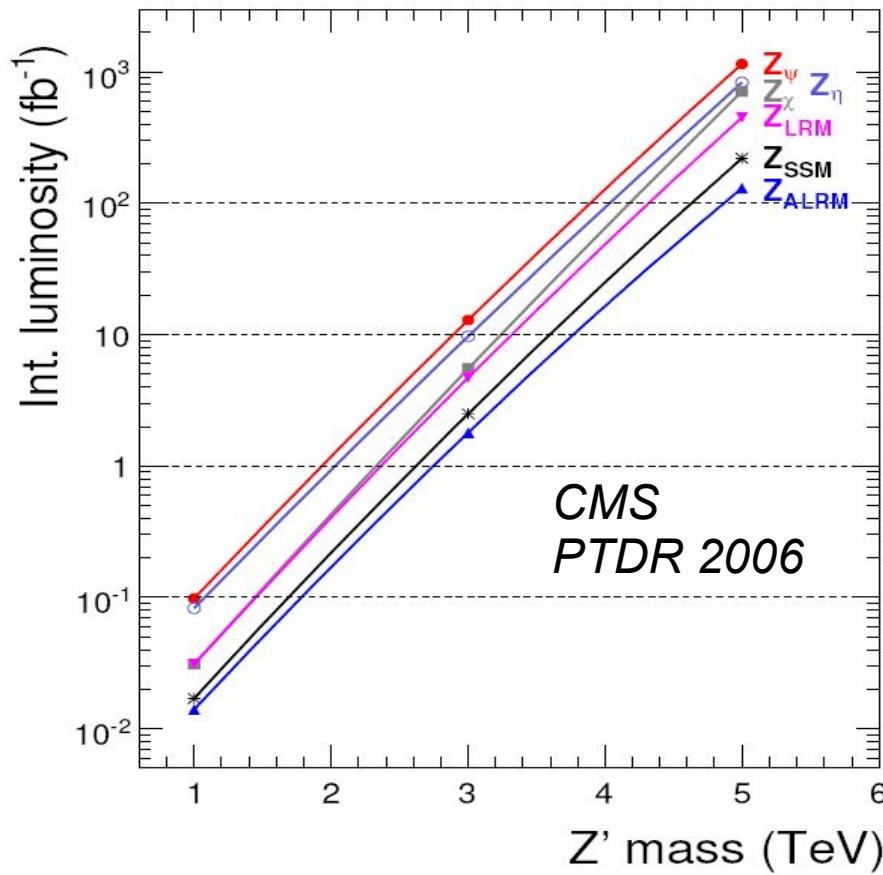
- overall efficiency (incl. acceptance, trigger, reconstruction) for $Z' \rightarrow \mu^+ \mu^-$ events at CMS:

75%-85%

Z' (CMS)

- dominant and irreducible background: $\text{pp} \rightarrow \gamma/Z^0 \rightarrow \mu^+\mu^-$
- other backgrounds negligible (after signal-selection criteria)

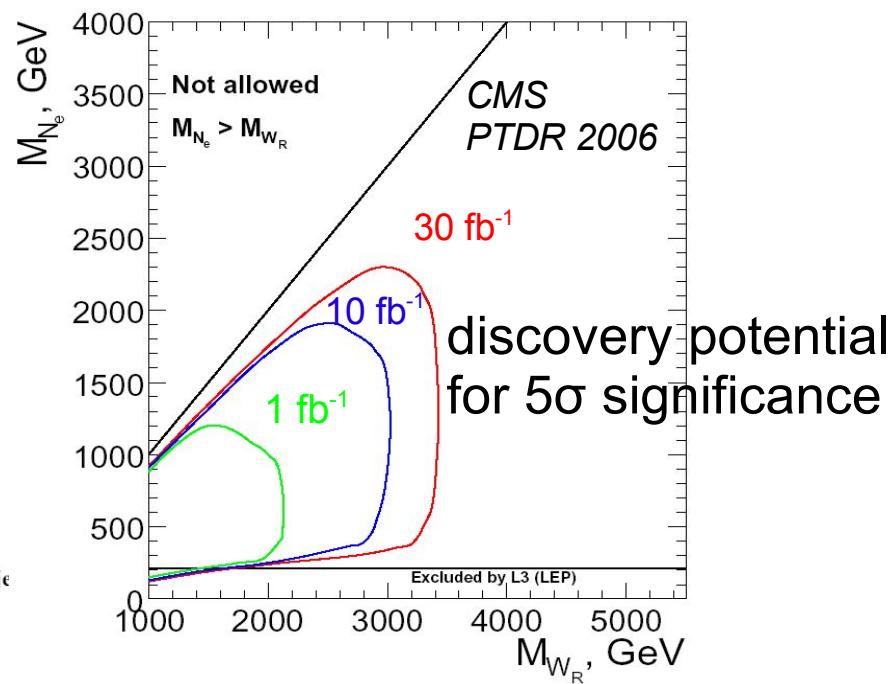
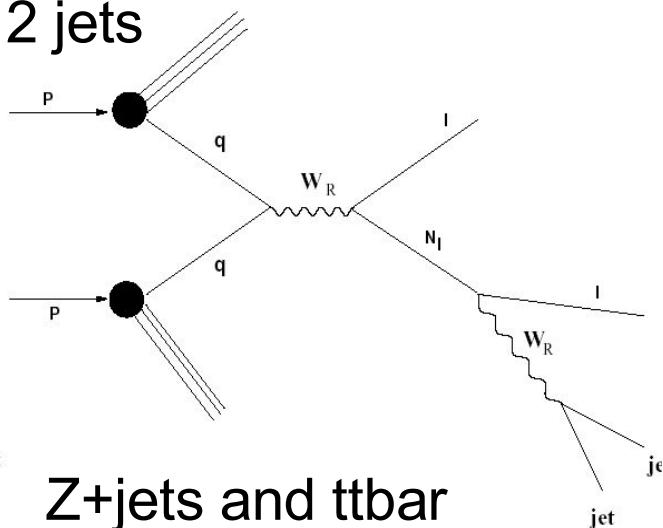
luminosity needed to discover Z' in $Z' \rightarrow \mu^+\mu^-$
channel with 5σ significance



- discovery potential with 1 fb^{-1} :
- Z_{SSM} (2.6 TeV), Z_η (2 TeV), Z_ψ (1.95 TeV), Z_χ (2.5 TeV), Z_{LRM} (2.5 TeV) and Z_{ALRM} (2.7 TeV)

Heavy Majorana neutrinos, W_R (CMS)

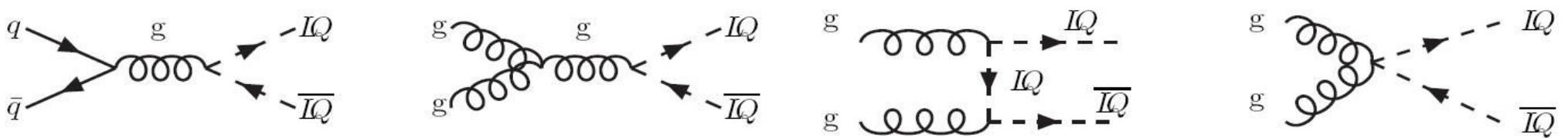
- LRSM model ($SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$) incorporates three additional heavy gauge bosons W_R , Z' and the heavy right-handed Majorana neutrino states N .
- The N s can be partner of light neutrino states and can provide their non-zero masses through the see-saw mechanism.
- assumption: $g_R = g_L$
- studied channel: $pp \rightarrow W_R \rightarrow e N_e$
(cross-section for this channel is 10 times higher than for $pp \rightarrow Z' \rightarrow N_e N_e$)
- **W_R signal:** 2 leptons + 2 jets
- **N signal:** lepton + 2 jets



- main backgrounds: $Z + \text{jets}$ and $t\bar{t}$

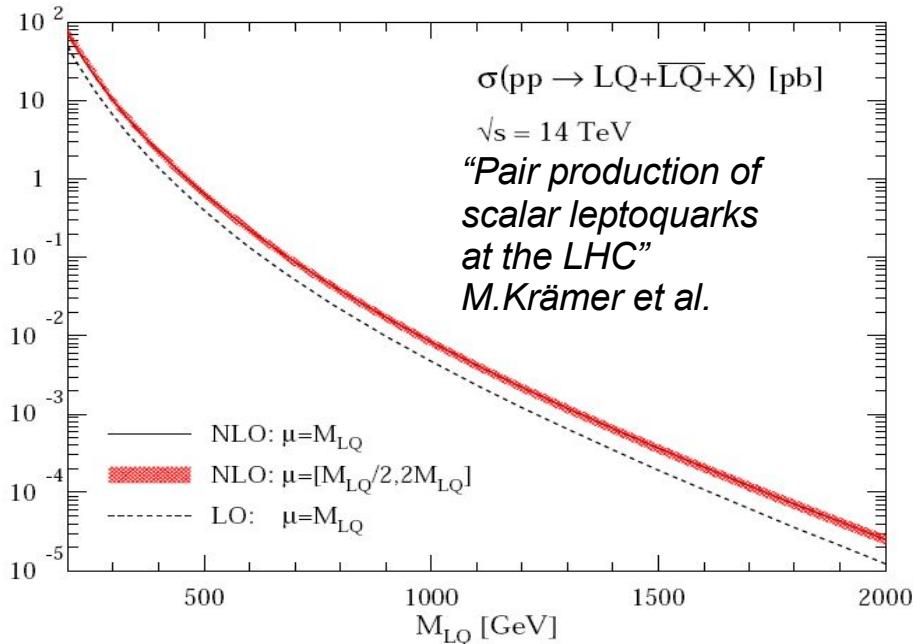
Scalar Leptoquarks (ATLAS)

- Leptoquarks (LQ) are particles which carry both lepton- and baryon-numbers. LQ interactions conserve the lepton- and baryon-numbers separately.
- 1st Assumption: LQ couple only to one generation of quarks and to one generation of leptons of the standard model → 3 generations of LQ
- 2nd assumption: LQ interactions are chiral
- With these assumptions there are 14 kinds (mBRW model) of LQ
- only pair production of scalar LQ considered here → single production depends on the unknown Yukawa ($q\text{-}\ell\text{-LQ}$) coupling



Scalar Leptoquarks

- 2nd generation LQ



- main background channels:

process	$\sigma \times \text{BR} (\text{in pb})$
Z / $\gamma^*(\mu\mu) + \text{jets}$ $p_T^{\text{jet}} > 20 \text{ GeV}$	313
t̄t ($\mu\nu j \mu\nu j$)	9.5
ZZ ($\mu\mu jj$)	1.2
ZW ($\mu\mu jj$)	1.2
WW ($\mu\nu \mu\nu$)	1.1

- 2nd generation Leptoquark decay channels: $LQ \rightarrow q + \mu$ or $LQ \rightarrow q + \nu_\mu$
- assumed: 100% of 2nd generation LQ decays: $LQ \rightarrow q + \mu$

- excluded mass for 2nd generation LQ (so far): $\sim 250 \text{ GeV}$
- signal: 2 high energetic jets,
2 high energetic muons

Leptoquark mass	ATLAS Preliminary Expected Luminosity for exclusion with 95% C.L.
300 GeV	2.8 pb^{-1}
400 GeV	6.6 pb^{-1}
600 GeV	40 pb^{-1}
800 GeV	220 pb^{-1}

Conclusions

- presented a selection of analyses on particles predicted by extended gauge theories
- LHC with ATLAS and CMS provides a powerful tool to discover or exclude many particles predicted by extended gauge theories
- many particles can be discovered or excluded already in the early phase of the LHC
- exciting years ahead