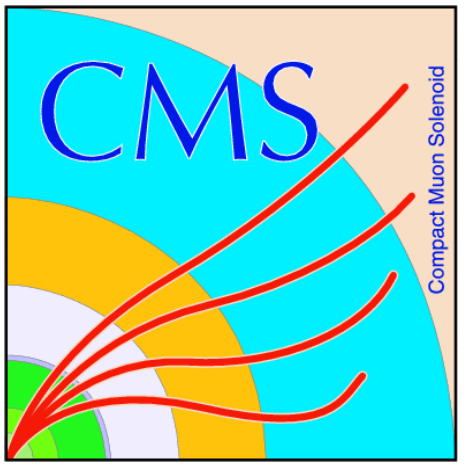
Discovery potential of LHC for extended gauge symmetries

SUSY 07
Karlsruhe
27.7.2007



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LMU

Overview

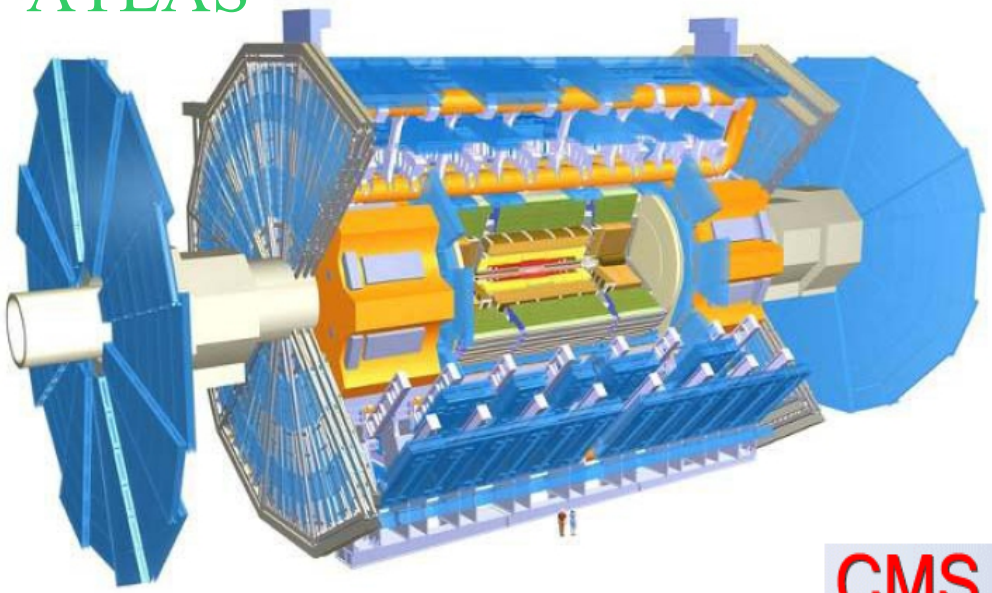
- LHC & ATLAS & CMS
- extended gauge theories
- experimental searches for:
  - W'
  - Z'
  - heavy majorana neutrinos, W_R
  - 2^{nd} generation Leptoquarks
- conclusions

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 $1fb^{-1}$

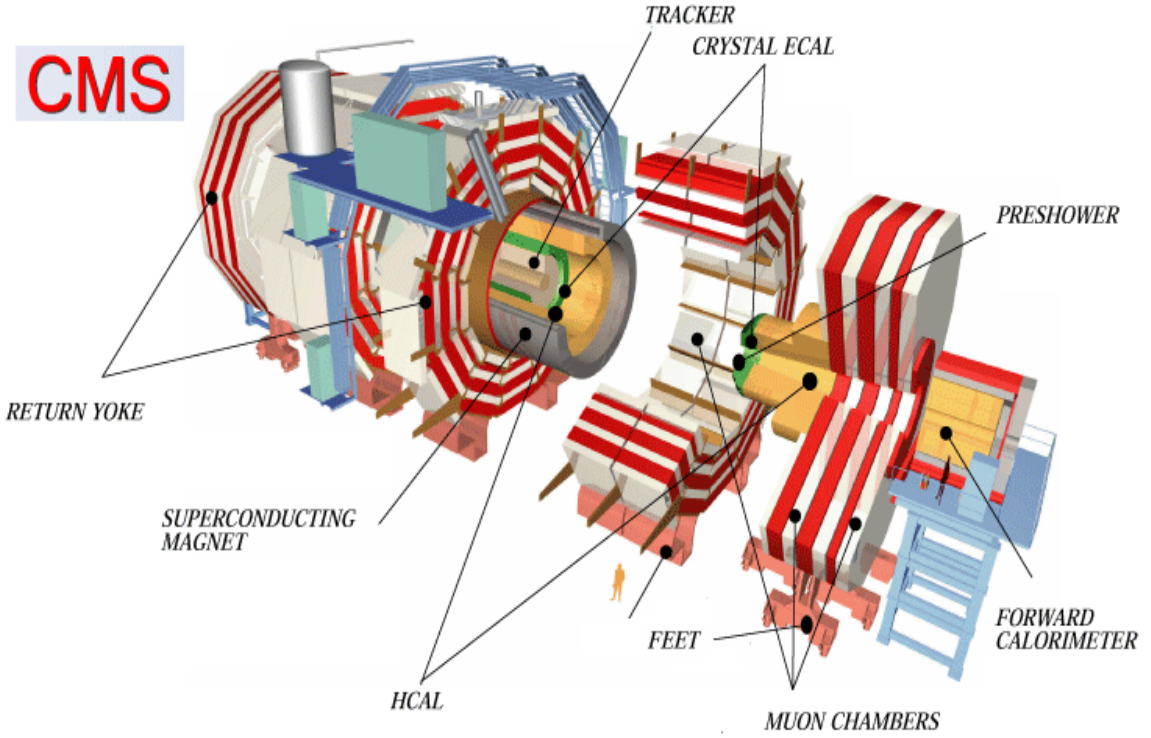
The Detectors

ATLAS



Diameter	*25 m*
Barrel toroid length	*26 m*
End-cap end-wall chamber span	*46 m*
Overall weight	*7000 Tons*

CMS



Diameter	15 m
Length	21.5 m
Magnetic field	4 T
Overall weight	12500 t

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.

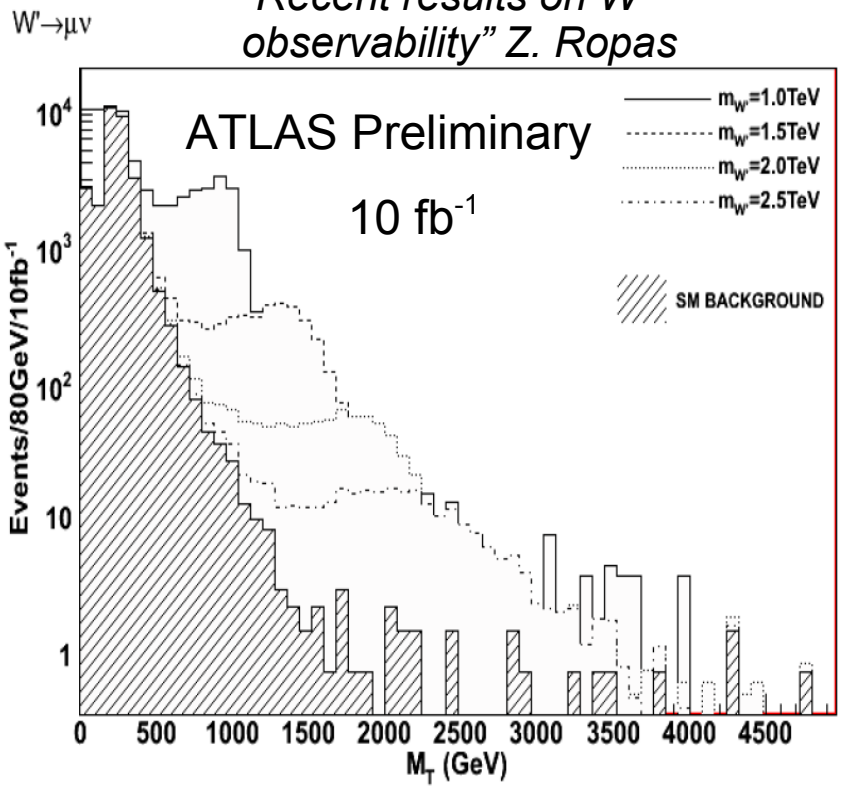
W' (ATLAS)

- 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)

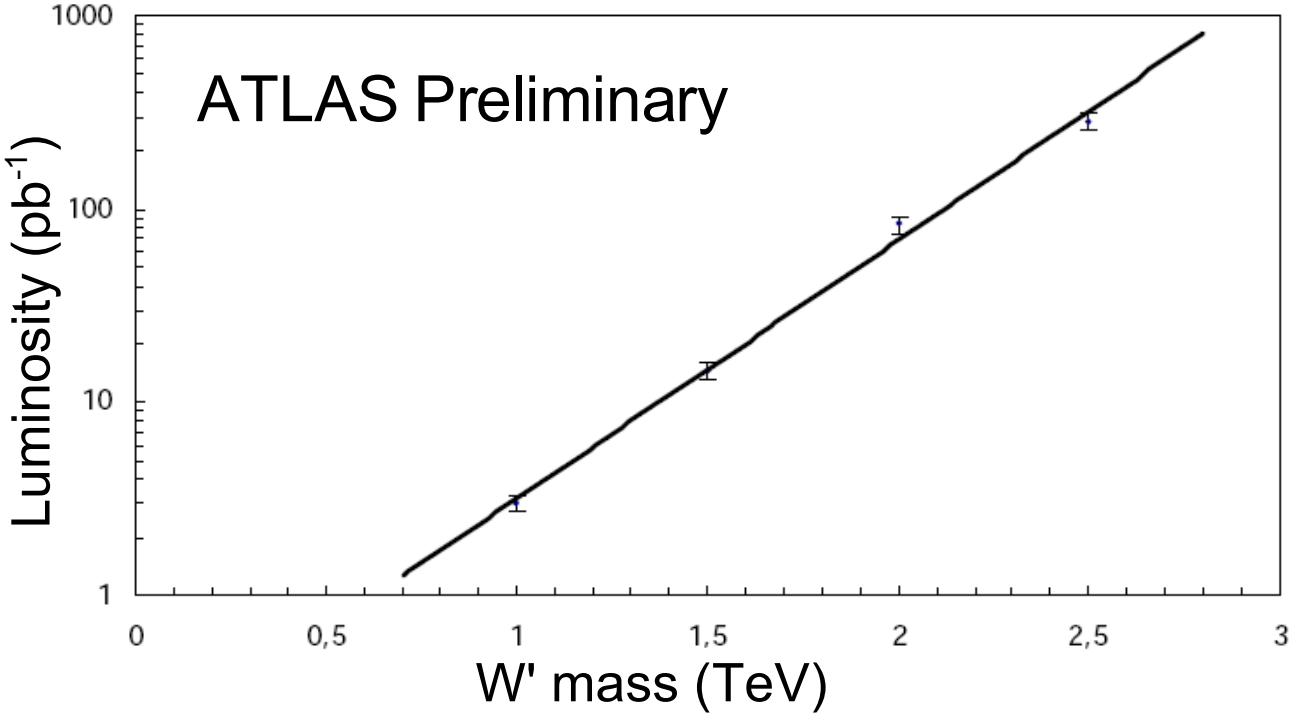
"Recent results on W' observability" Z. Ropas



- **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%

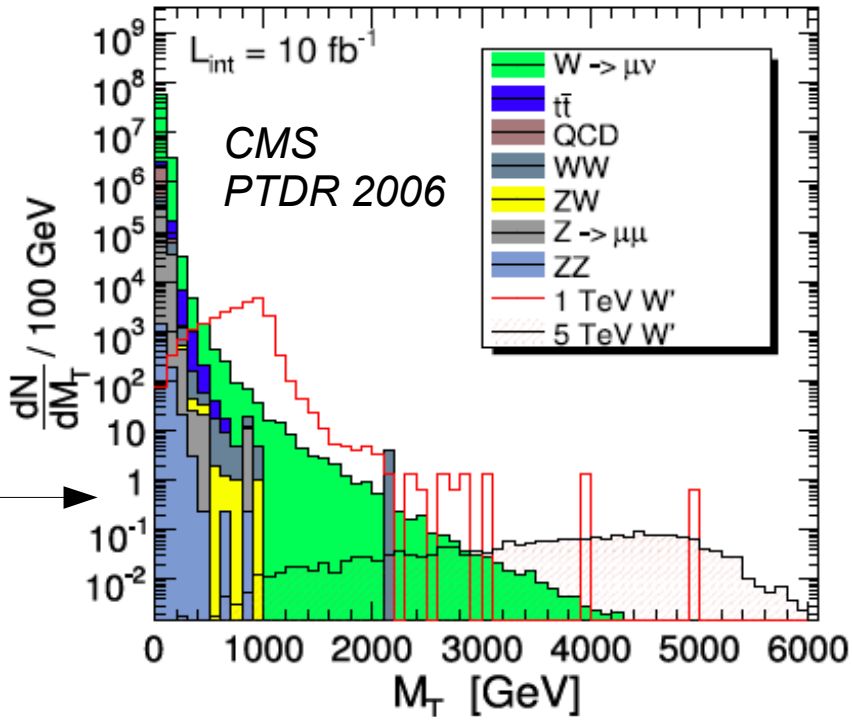
W' (CMS)

- same channel studied as in ATLAS:

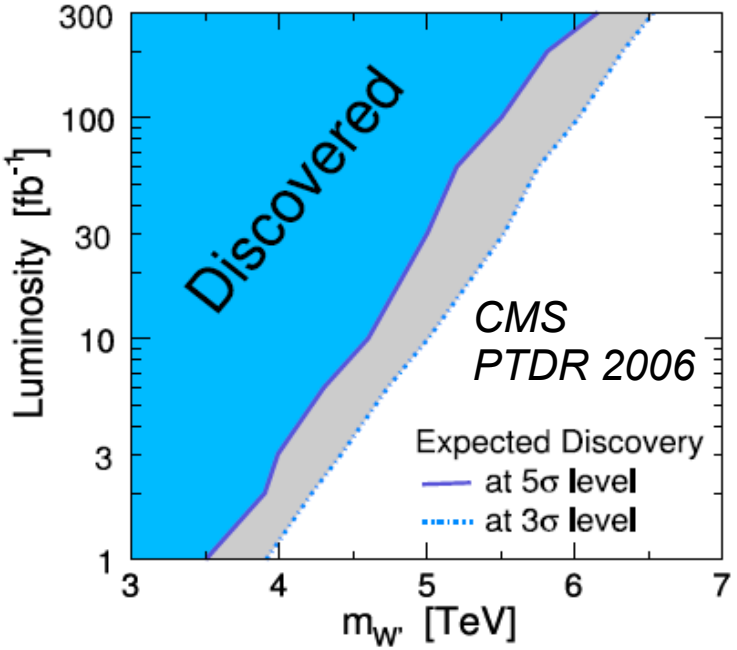
$$W' \rightarrow \mu + \nu_{\mu}$$

→ 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)

- expected properties of studied models

CMS PTDR 2006

Model	Γ/M %	$Z' \to \mu^+\mu^-$ BR in %	$\sigma^{LO} \cdot$ Br, full interference, fb (PYTHIA)		
			1 TeV/c^2	3 TeV/c^2	5 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)

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
  - $Z' \rightarrow$ hadrons instrumental background from QCD

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

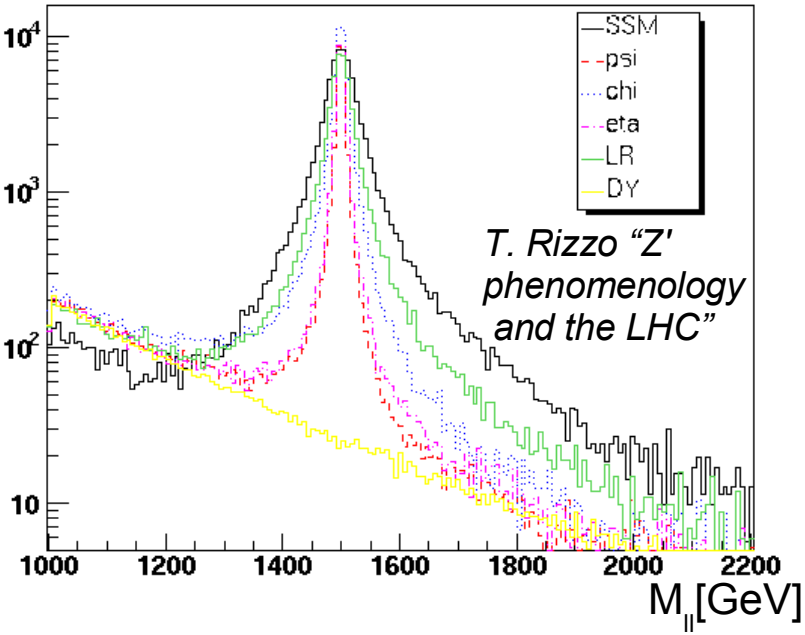
- studied channel (ATLAS):

$$Z' \rightarrow e^+e^-$$

- dominant and irreducible background:

$$pp \rightarrow \gamma/Z^0 \rightarrow e^+e^-$$

Z' 1.5 TeV (theoretical expectations)



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

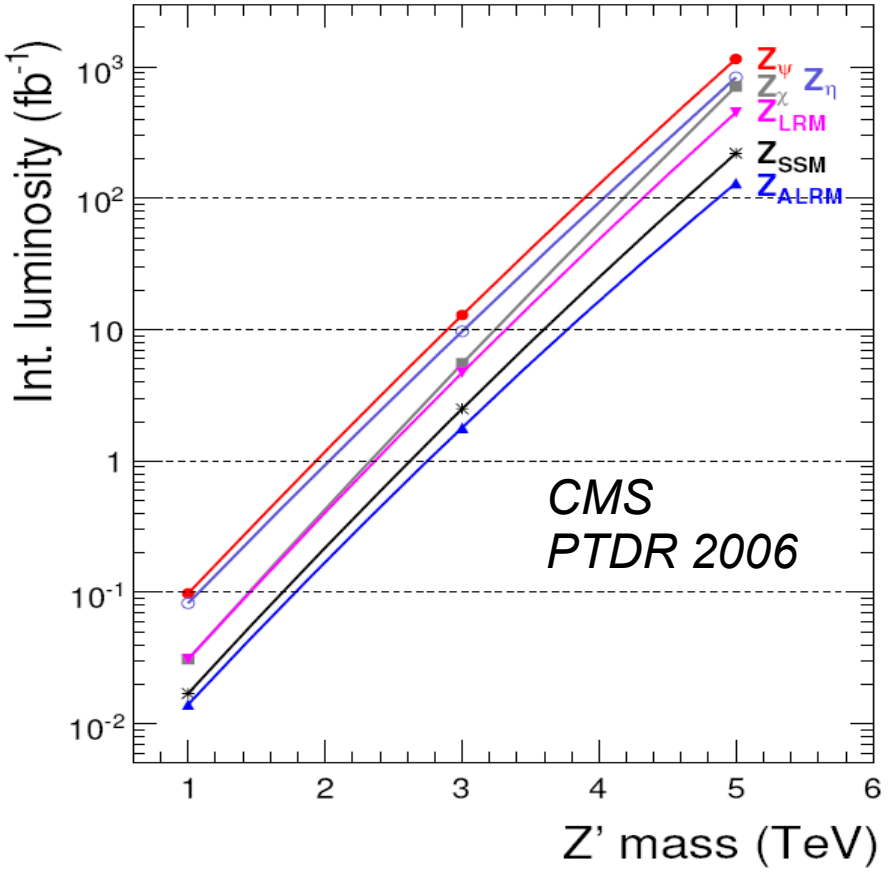
- overall efficiency (incl. acceptance, trigger, reconstruction) for $Z' \rightarrow \mu^+\mu^-$ events at CMS:

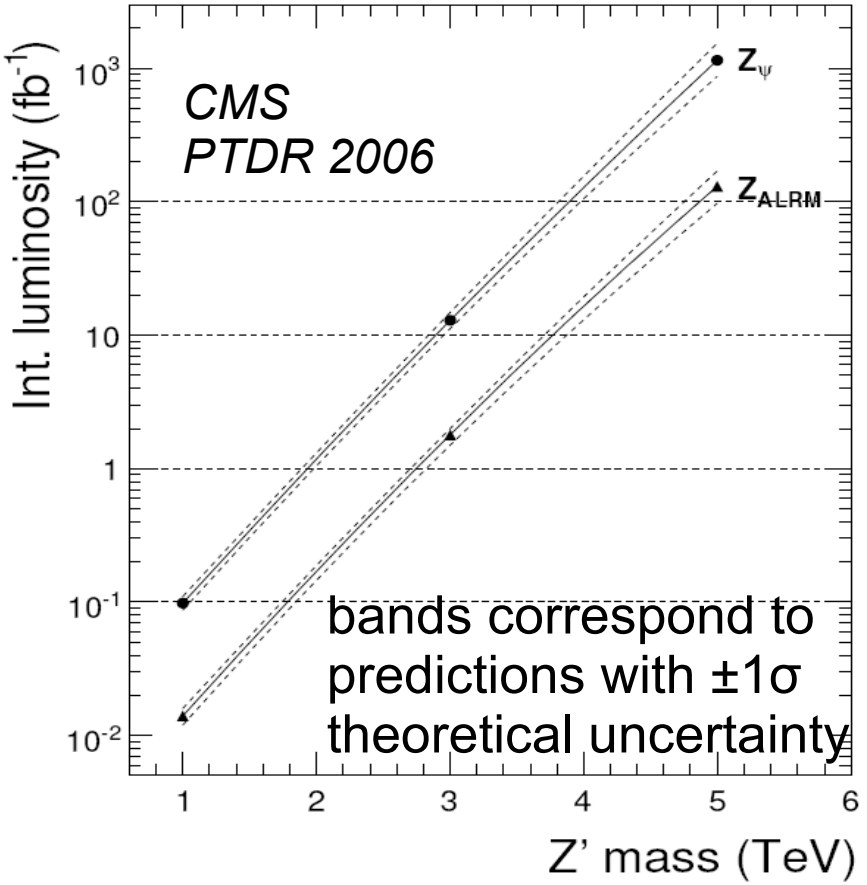
75%-85%

Z' (CMS)

- dominant and irreducible background: $pp \rightarrow \gamma/Z^0 \rightarrow \mu^+\mu^-$
- 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)

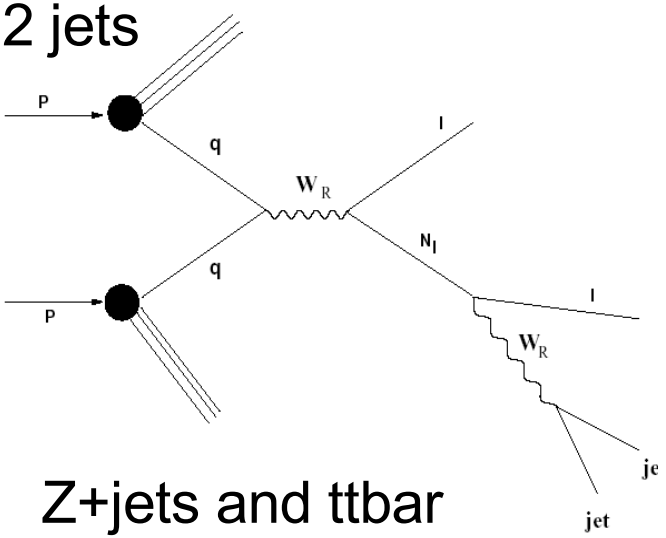
Heavy Majorana neutrinos, W_R (CMS)

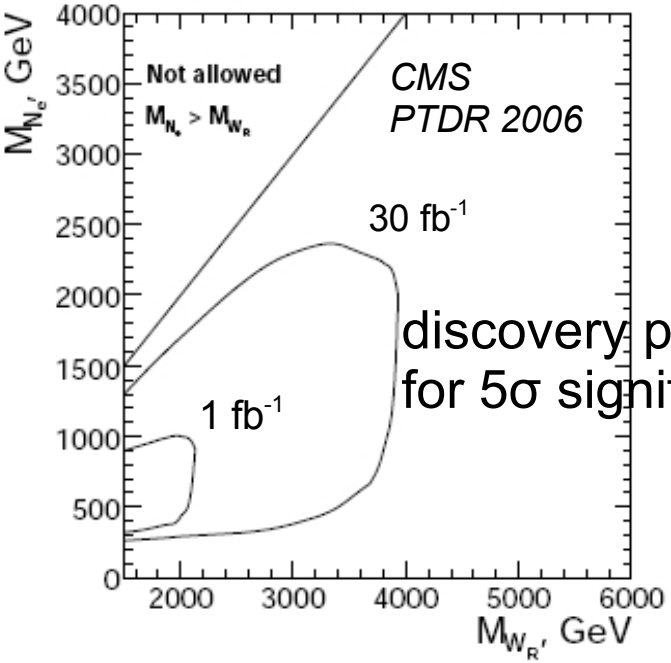
- LRSM model ($SU_C(3) \otimes SU_L(2) \otimes SU_R(2) \otimes U(1)$) incorporates three additional heavy gauge bosons W_R, Z' and the heavy right-handed Majorana neutrino states N.

- The Ns 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: $pp \rightarrow W_R \rightarrow eN_e$

(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





discovery potential for 5σ significance

- main backgrounds: Z+jets and ttbar

Scalar Leptoquarks (ATLAS)

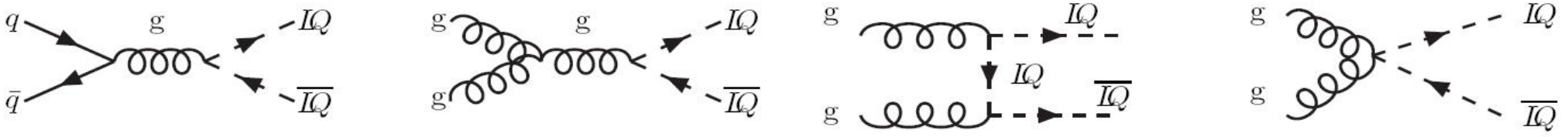
- Leptoquarks (LQ) are particles which carry both lepton- and baryon-numbers. LQ interactions conserve the lepton- and baryon-numbers separately.

- 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

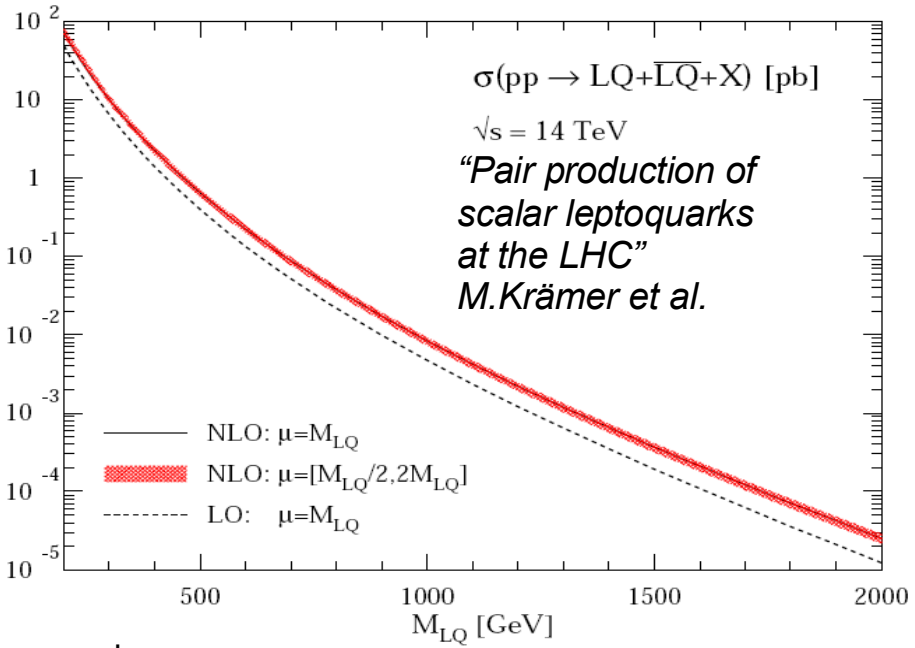
- With these assumptions there are 14 kinds (mBRW model) of LQ

- only pair production of scalar LQ considered here →
  single production depends on the unknown Yukawa (q-ℓ-LQ) coupling



Scalar Leptoquarks

- 2nd generation LQ



- main background channels:

process	σ x BR (in pb)
Z/γ^*(μμ)+jets p_T^{jet}>20GeV	313
$t\bar{t}$ (μνj μνj)	9.5
ZZ (μμ jj)	1.2
ZW (μμ jj)	1.2
WW (μν μν)	1.1

- 2nd generation Leptoquark decay channels: **LQ → q + μ** or LQ → q + ν_μ
- assumed: 100% of 2nd generation LQ decays: **LQ → q + μ**

- excluded mass for 2nd generation LQ (so far): ~ 250 GeV

- signal: 2 high energetic jets, 2 high energetic muons

ATLAS Preliminary

Leptoquark mass	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