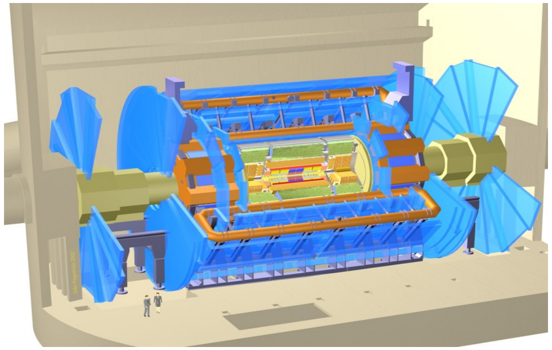
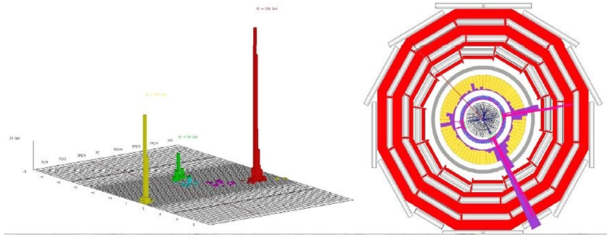
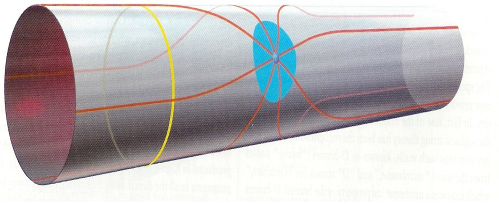




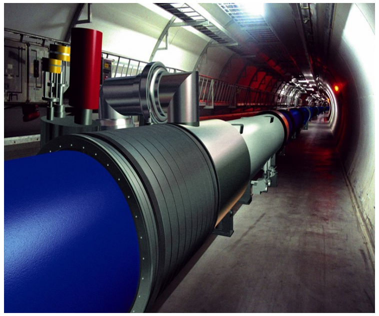


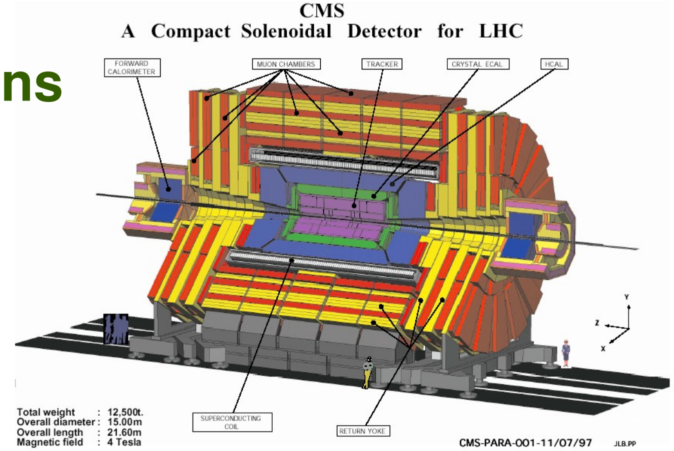
Prospects for Searches for Exotic Phenomena at the LHC

Barbara Clerbaux

ULB, Brussels

For the ATLAS and CMS Collaborations





CMS and ATLAS publications

Recent published results from CMS:

- Physics Analysis Summary (PAS): for early searches (for 10 - 100 pb^{-1})
  http://cms.cern.ch/iCMS/analysisadmin/analysismanagement
- ALSO CMS Physics TDR: Volume II, Physics Performance, Summer 2006
  (10/60 to 100/300 1 fb^{-1})
  http://cmsdoc.cern.ch/cms/cpt/tdr

Recent published results from ATLAS:

- Expected Performance of the ATLAS Experiment Detector, Trigger, Physics, January 2008
  CERN-OPEN-2008-020
  http://cdsweb.cern.ch/record/1125884

Focus on early searches (2009/10 data) – 10,100 pb^{-1} (1 fb^{-1}) :

- Full detector simulation (detailed material description) and trigger simulation
- Low statistics and not ultimate aligned/calibrated detector
- Extract trigger and selection efficiency from data
- Extract background from data
- Estimation of the systematics

→ In this talk: - a selection of some recent results (published >2007)
- focus on final state topologies rather than a particular model

Models ...

GUT theories

Larger group at high scale: SO(10), E6 - particles in supermultiplets
lower energies: symmetry broken via i.e.
$SU(10) \rightarrow SU(3) \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$ $\rightarrow$ RLS models (baryogenesis, small ν_L mass)

heavy boson (Z' and W') production@LHC
leptoquark production@LHC

heavy W_R and right-handed neutrino states N_ℓ production@LHC

Alternative to Higgs mechanism:

Technicolor and Little Higgs
heavy resonance production@LHC

SUSY GMSB - Split SUSY

HSCP production@LHC

PLAN:

1. - **Two high pt same flavor leptons**
   High mass resonance searches
2. - **Two high pt leptons + 2 jets**
   Leptoquark and W_R searches
3. - **HSCP searches**

Models ...

Models with extra-spatial dimensions

If $\sqrt{s} < M_D$: (1) Large flat Extra Dimension (ADD)

Extra dimensions are flat and could be as large as a few μm

SM particles restricted to 3D brane - bulk: only accessible to gravity

→ direct production of KKG → monojet production@LHC

→ virtual effect of KKG

Size of the ED ↑

(2) TeV^{-1} size ED , mUED

if ED small enough R <= TeV^{-1}

SM fields are allowed to propagate in the bulk

→ KK excitation of gauge bosons

→ HCSP production

(3) Randall, Sundrum (RS1 – two branes)

Small extra spatial dimensions

Curved bulk space (AdS5 - slice)

→ narrow resonance of KKG

free parameter: coupling c

In all cases: free parameter: m(1)

If $\sqrt{s} > M_D$: TransPlanckian physics → Black hole production@LHC

PLAN

4. - Monojet and black hole searches

1. Dilepton resonances at high mass

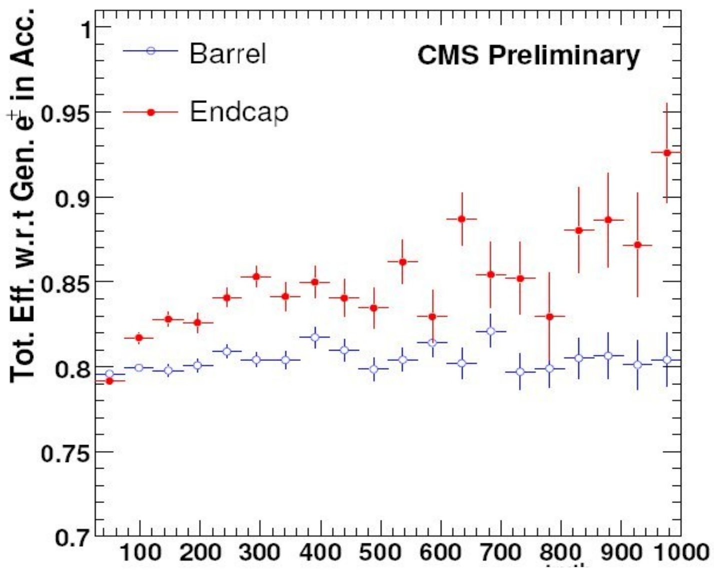
ATLAS Phys TDR
CMS PAS EXO-08-004
CMS PAS EXO-08-001
CMS BSM 07-002

Example: selection for Z' →ee:

- 2 electrons in $|\eta| < 2.5$, pt > 30 GeV
- electron ID (cluster-track matching)
- e isolated in tracker/ECAL/HCAL

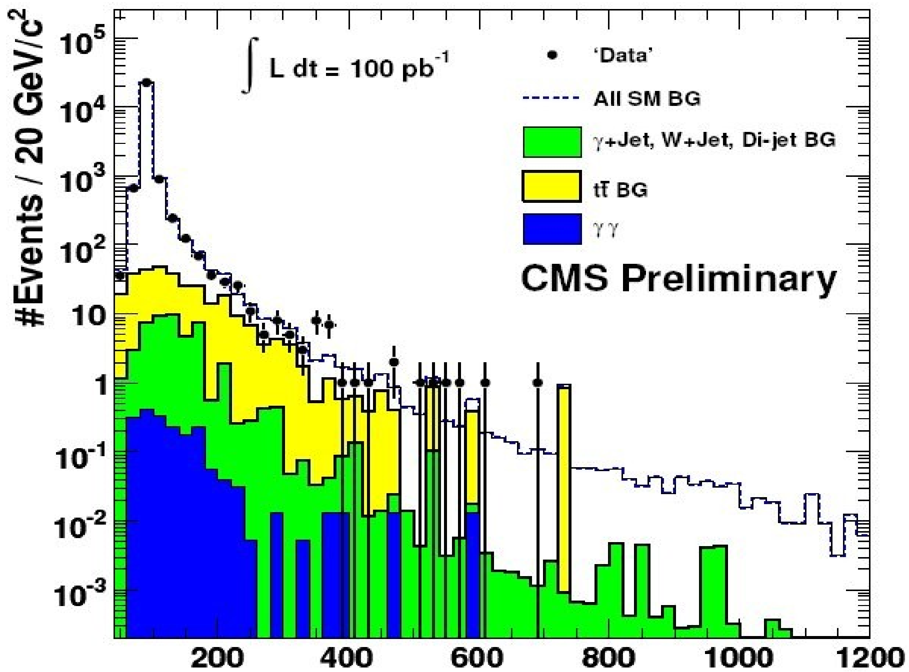
High pt electron reconstruction

Efficiencies relative to acceptance:



→ Pt (GeV)

CMS: after selection



→ Mee (GeV)

Main backgrounds:

Drell-Yan (irreducible)

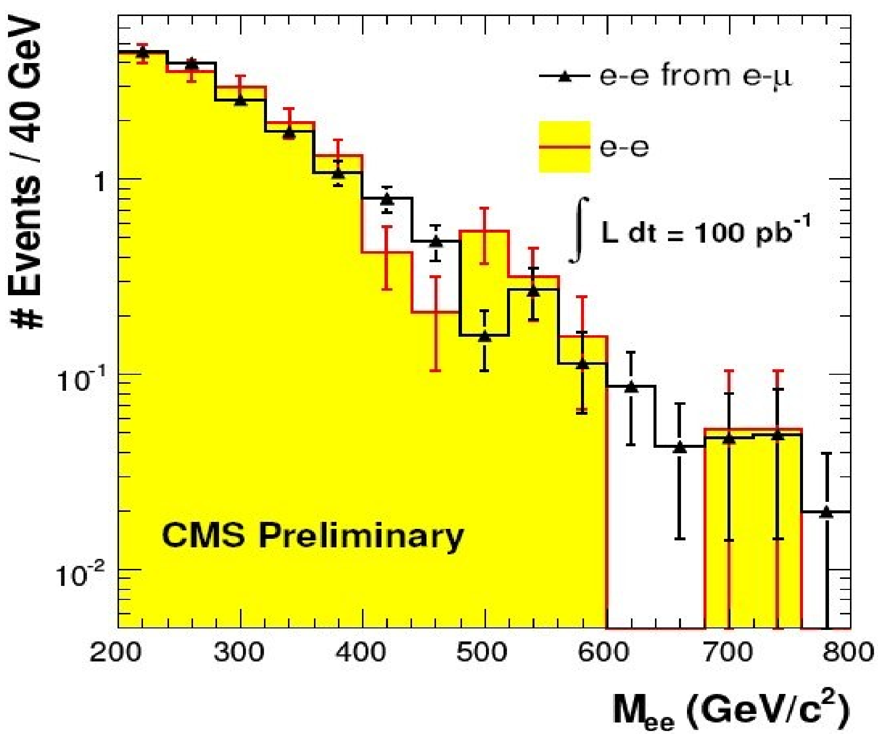
ttbar, W+jets, QCD (reducible)

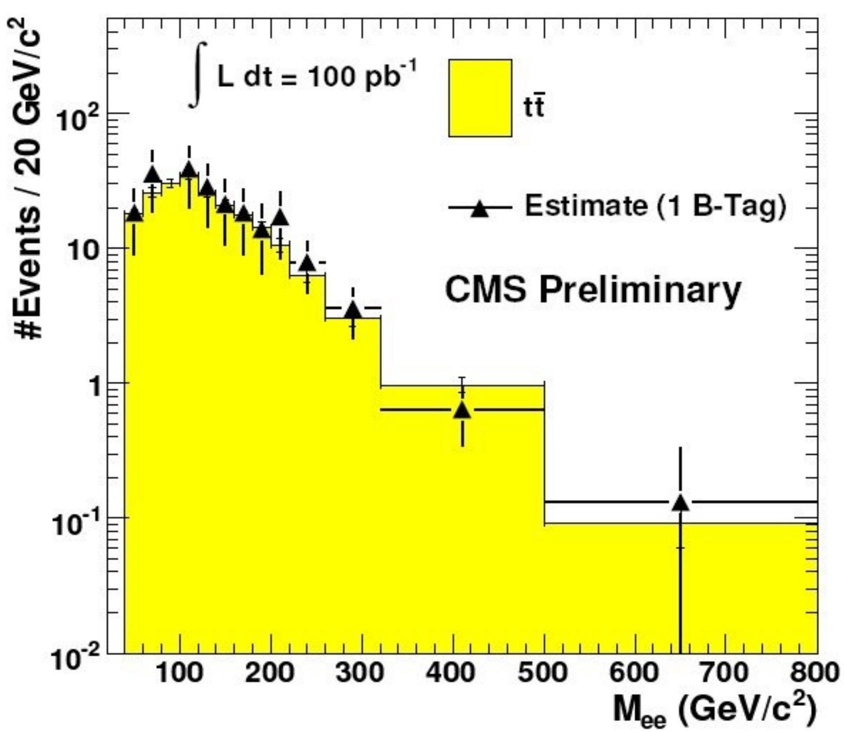
Z' → ee

CMS: Data Driven methods for ttbar background estimation

e-μ method:
Use e-μ events from the 2 W decays
ttbar → e-μ = 2* ttbar → ee
For 100 pb^{-1}: expect 16.1 ttbar bg determined by expected sample of 42.5 e-μ events

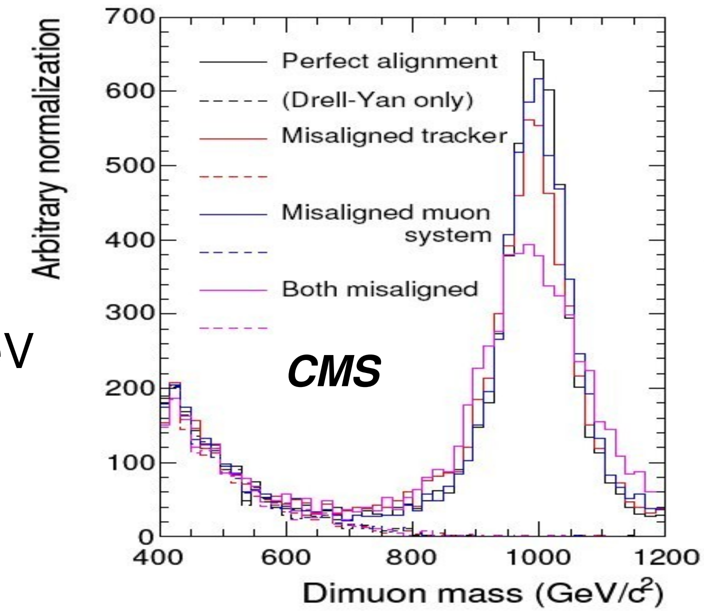
b-tagging method:
Ntt can be extracted from N(1b tag)or N(2b tag) + ε(b)
From n2/n1 + geom acceptance for one or two b-quarks → can extract ε(b) (0.20± 0.09)

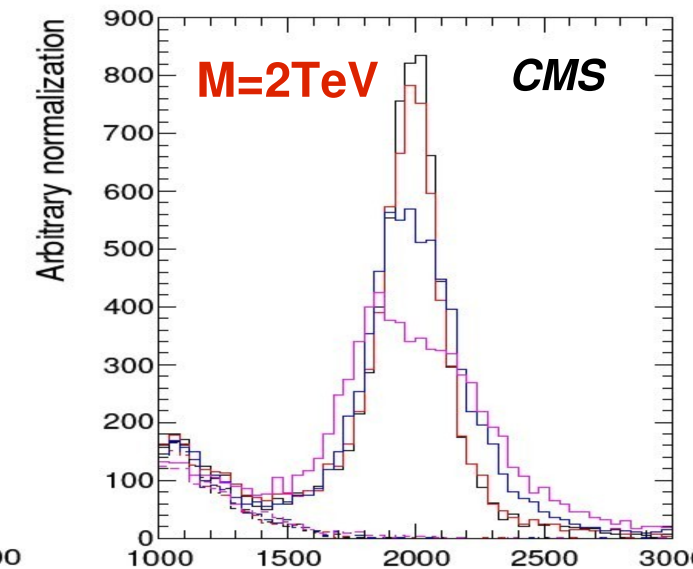




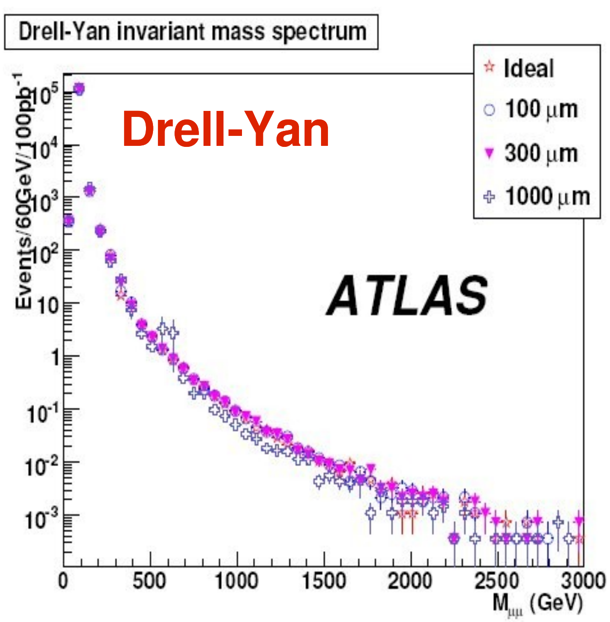
Z' → μμ

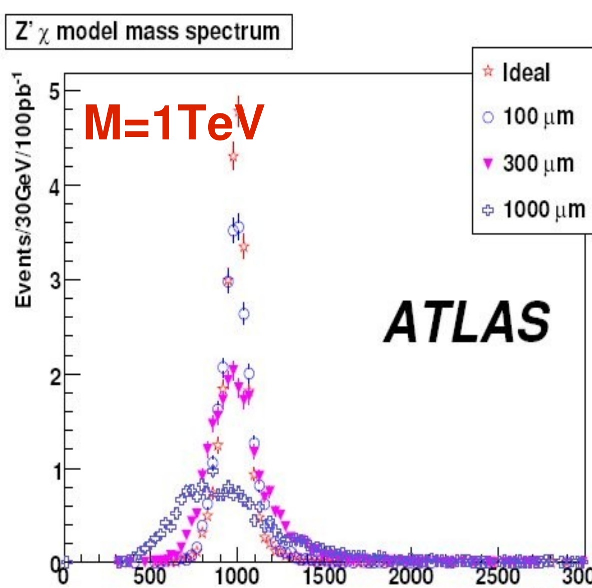
Alignment effect
(startup conditions
100 pb^{-1})
Mass resolution:
7-8 (10) % at 1 (2) TeV





→ Mμμ (GeV)





3

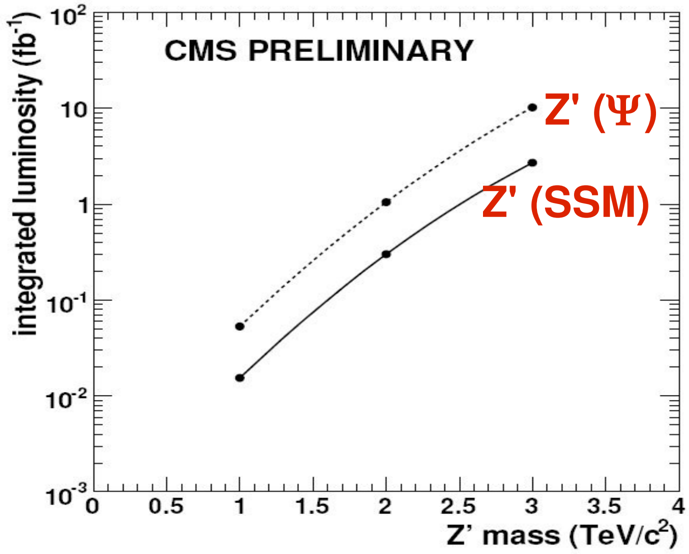
→ Mμμ (GeV)

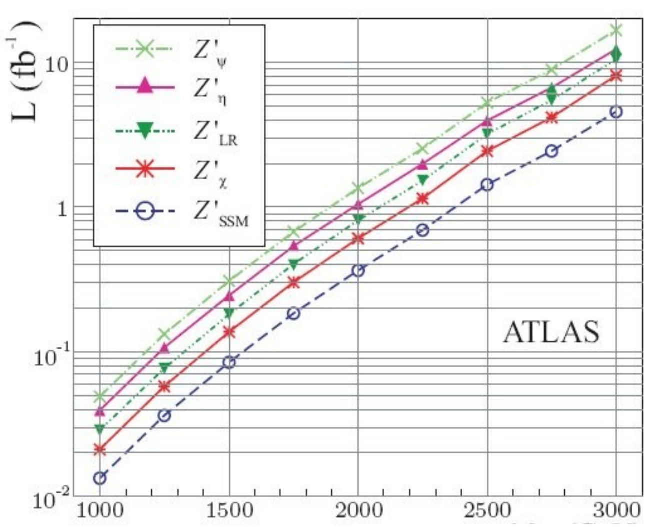
Loss of signal efficiency due to charge mis-ID:

Ideal:	0.98
300 μm:	0.97
1000 μm:	0.88

Z' → ee and Z' → μμ

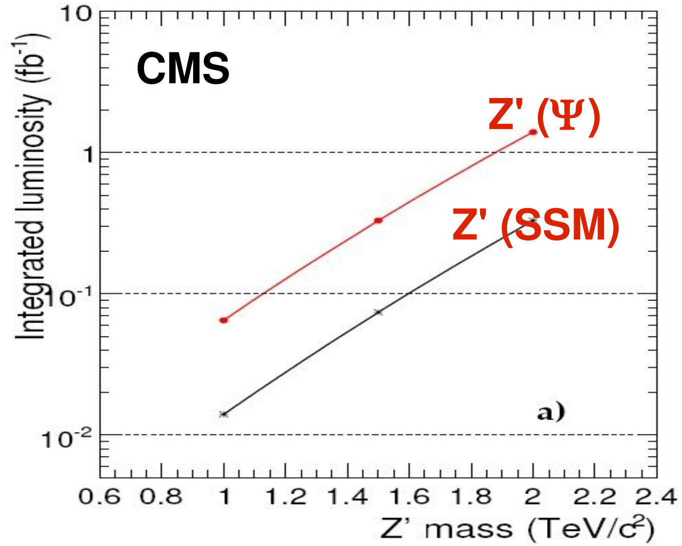
Discovery potential for Z' → ee

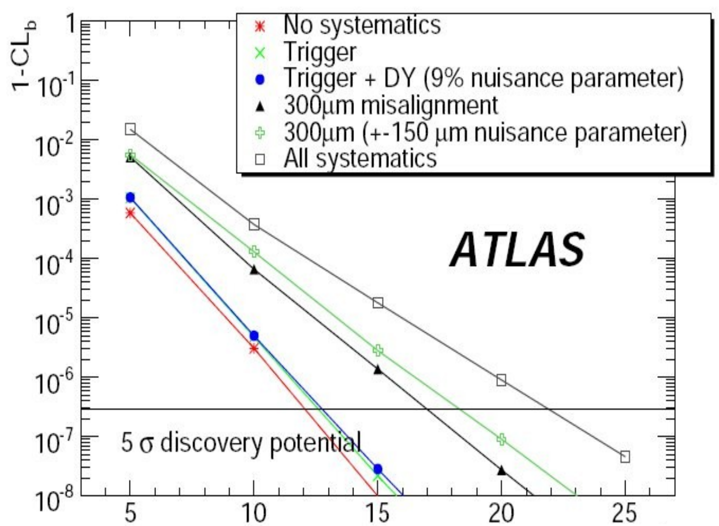




→ **Mee (GeV)**

Discovery potential for Z' → μμ

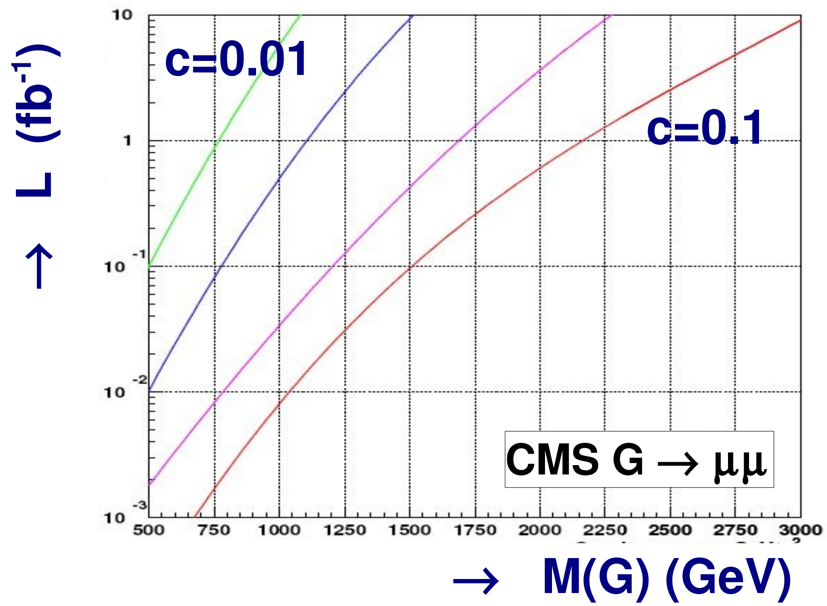


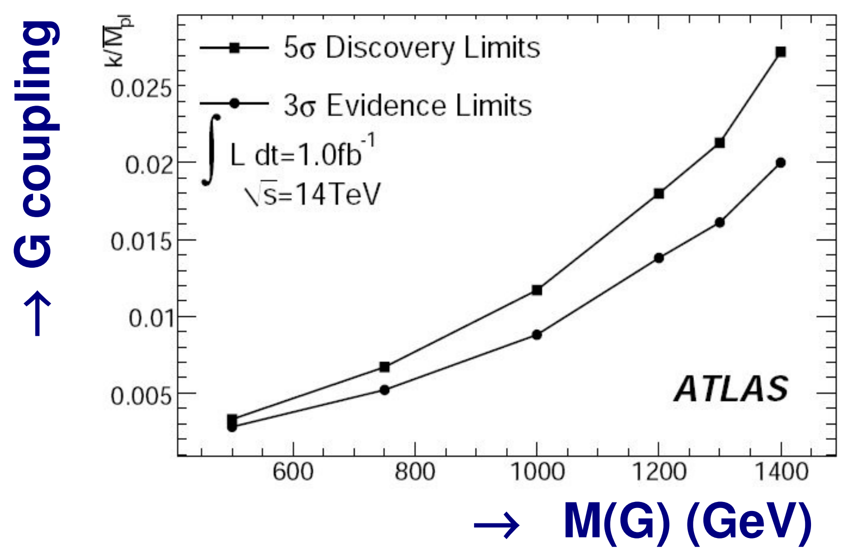


→ **L (pb-1)**

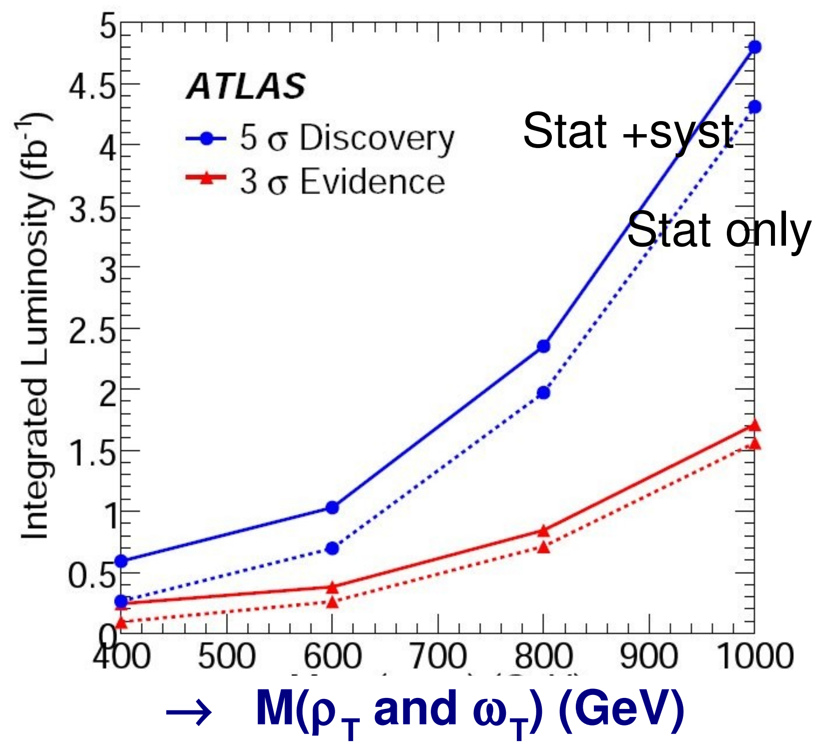
Gravitons and Technicolor mesons

Discovery potential for RS Gravitons:





Discovery potential for Strawman model Technicolor mesons:

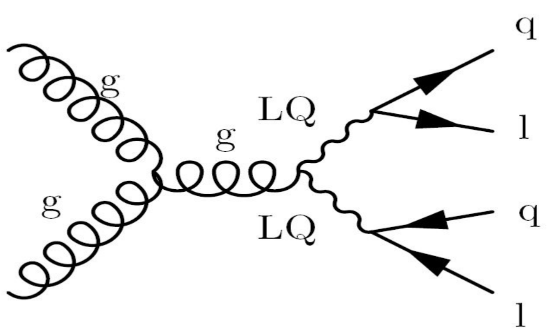


2. leptons and two jets topologies

CMS PAS EXO-08-006
ATLAS Phys TDR

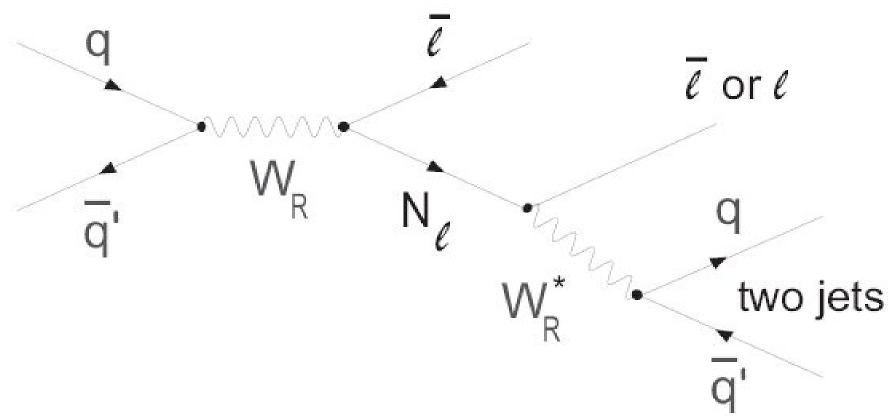
Look for topologies with 2 same flavour leptons and at least 2 jets, and no missing Et
Two models investigated:

1) Leptoquark pair production



M(jl) = M(LQ)

2) Heavy W_R and heavy neutrino production



M_N=M(j1j2 l2), M(W_R)=m(j1j2l1l2)
→ 2 resonance structure

Main background: Drell-Yan and ttbar production

Leptoquark pair production search

ATLAS Phys TDR

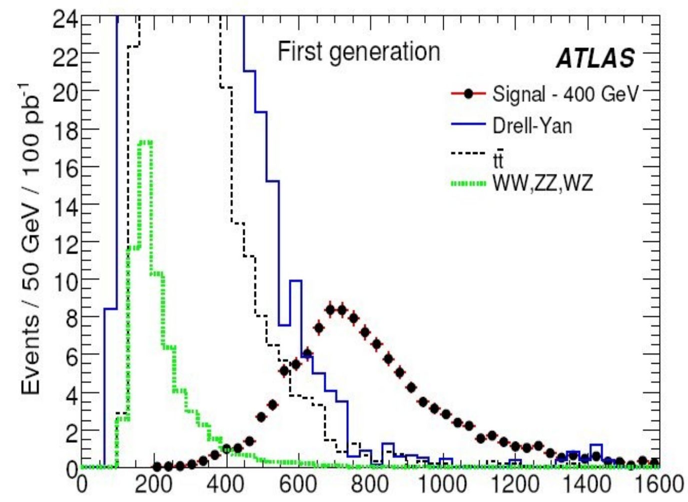
Oppositely charged leptons of same flavour and at least two jets

Example: selection for the first generation LQ:

- e1,e2 with $|\eta| < 2.5$, $P_t > 20$ GeV, electron ID,
- two jets ($\Delta R=0.4$ cone algo), $|\eta| < 4.5$, $P_t > 20$ GeV
- $\Delta R(e\text{-}j) > 0.1$

$$S_T = \sum |\vec{p}_T|_{jet} + \sum |\vec{p}_T|_{lep}$$

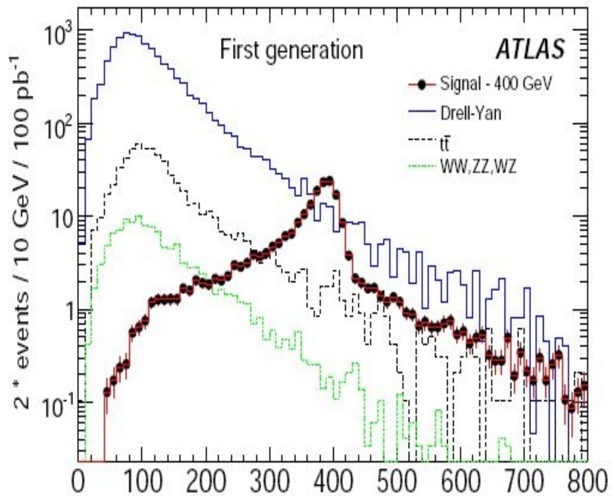
All plots for L=100 pb^{-1}



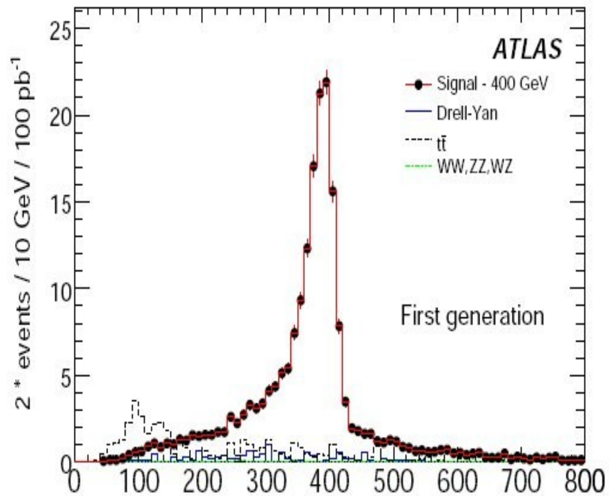
→ S_T (GeV)

Mjl=M(LQ) choose combination such M_1 closest to M_2

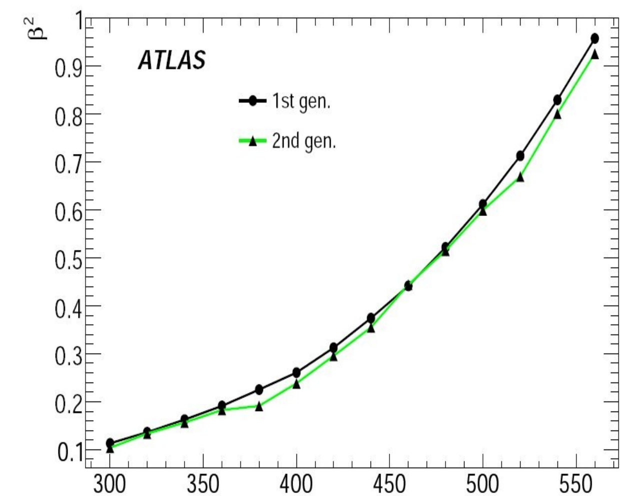
+ M(ee) > 120 GeV
+ S > 490 GeV



→ M(lj) (GeV)



→ M(lj) (GeV)



→ M(LQ) (GeV)

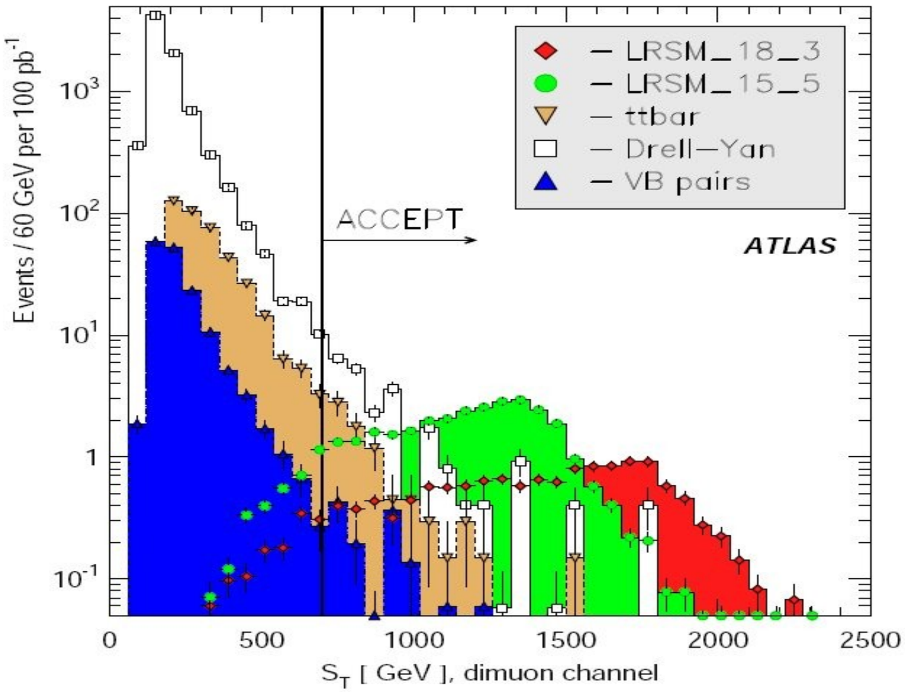
Heavy W and Neutrinos in L-R symmetric model

CMS PAS EXO–08–006
ATLAS Phys TDR

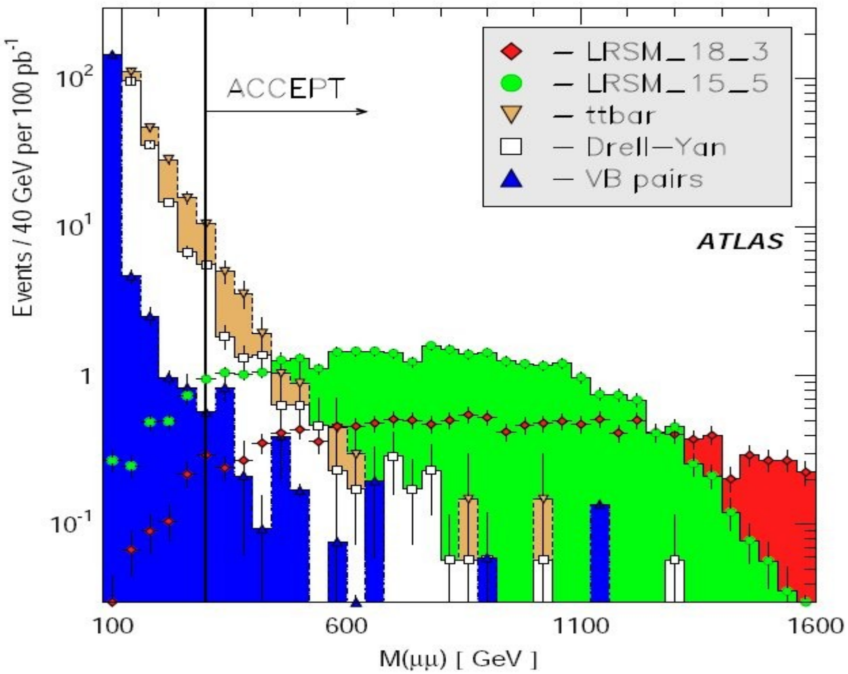
M_N=M(j1j2 l2) and $M(W_R)$=M(j1j2l1l2)
if $M(W_R) >> M_N \rightarrow$ jjl2 system boosted

$$S_T = \sum |\vec{p}_T|_{jet} + \sum |\vec{p}_T|_{lep}$$

Example: selection for the dimuon channel
same as for Leptoquark
$M(\mu\mu) > 300$ GeV and $S > 700$ GeV
Special care in the di-electron channel to recover jet-e merging tologogy



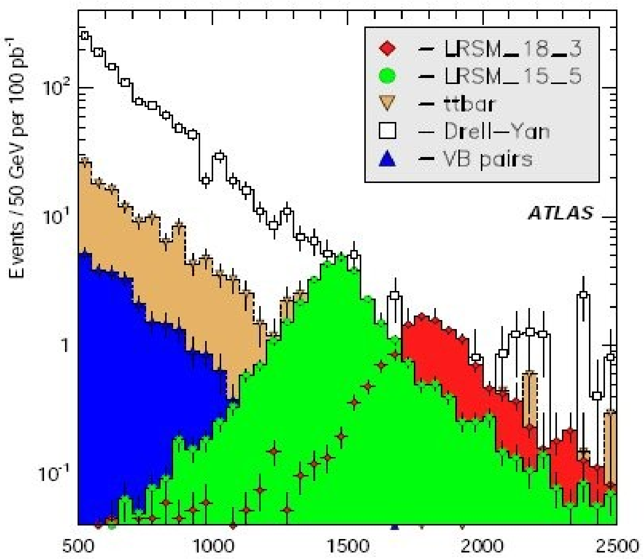
→ S_T (GeV)



→ $M(\mu\mu)$ (GeV)

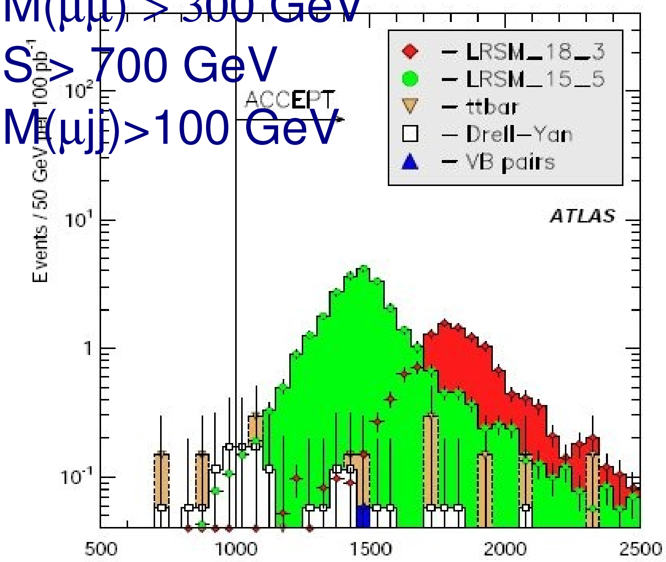
All plots for $L=100\ pb^{-1}$

Heavy Neutrinos and W in L-R symmetric model



→ M(μμjj) (GeV)

+ M(μμ) > 300 GeV
+ S > 700 GeV
+ M(μjj)>100 GeV



→ M(μμjj) (GeV)

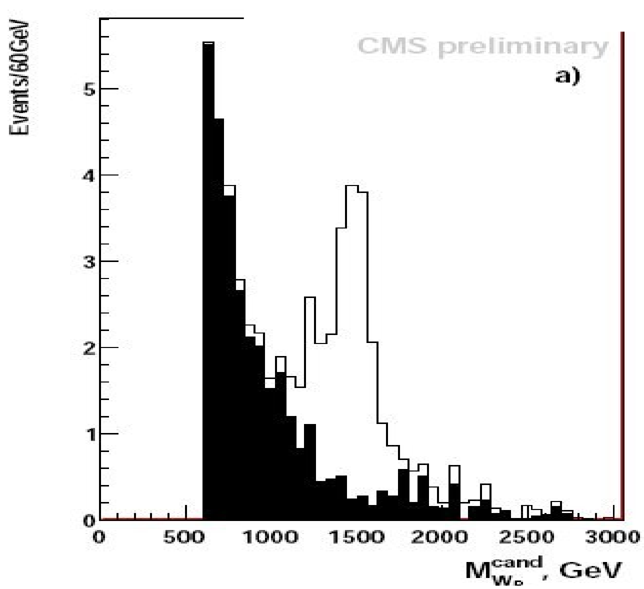
ATLAS muon channel

Mass resolution:

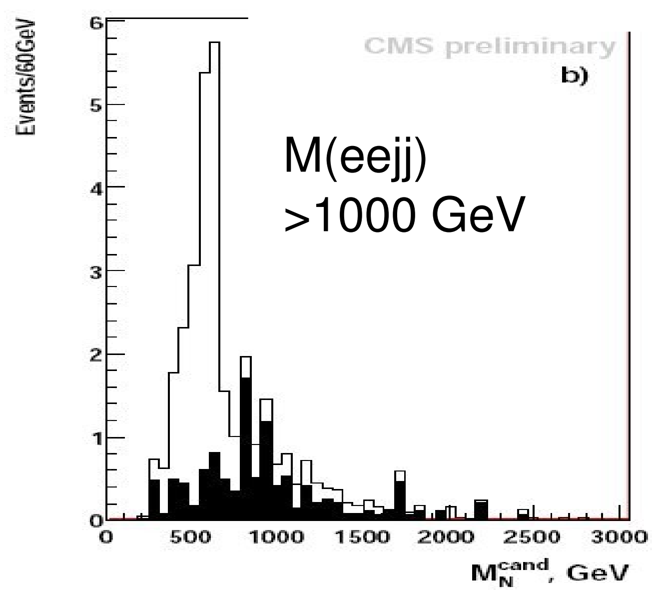
M_N : 6 %

$M(W_R)$: 5-8 %

All plots for L=100 pb^{-1}



→ M(eejj) (GeV)



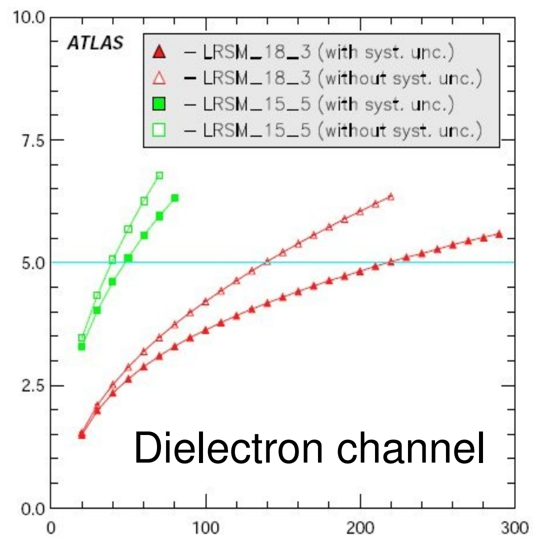
→ M(eej) (GeV)

CMS electron channel:

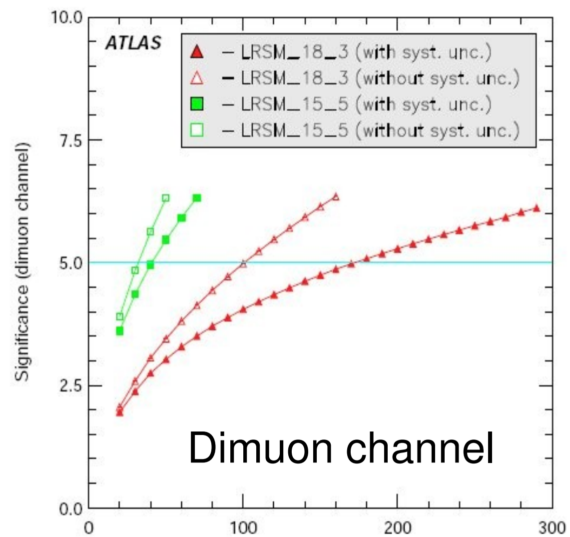
- Signal efficiency measurement from data (tag and probe method)
- Background : normalise to signal-free region: $M(W_R) < 800$ GeV
- Check bg from data: e-μ method (ttbar bg)

Heavy Neutrinos and W in L-R symmetric model

→ Significacne



→ L (pb^{-1})



→ L (pb^{-1})

ATLAS syst: 45%(e)-40%(μ) assumed from bg contribution

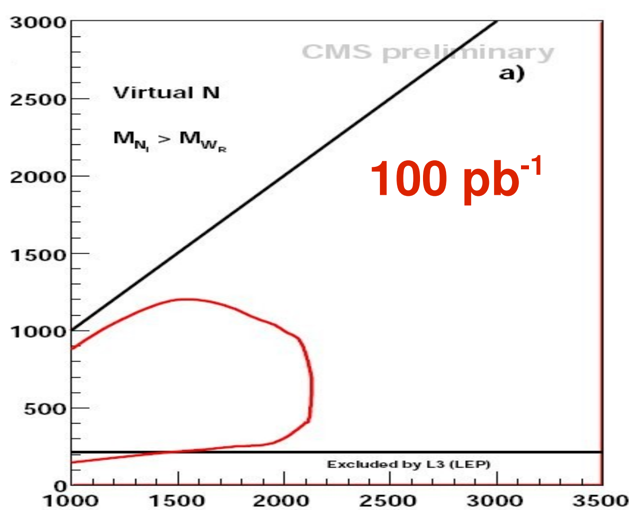
Expected sensitivity:

ATLAS: 2 mass points: M(W_R), M_N

[1500, 500] needs 40-60 pb^{-1}

[1800, 300] needs 100-200 pb^{-1}

→ M(N)



→ M (W_R) (GeV)

muon channel has a bit better sensibility compared to electron

CMS Expected sensitivity for 100 pb^{-1}:

M(W_R) = 2100 GeV

M_N = 1200 GeV

3. Search for heavy stable charged particles

CMS PAS EXO-08-003

HSCP arise from various models with new state and new (almost) conserved global quantum number, i.e. SUSY with R-parity or ED with KK-parity
Exist a LSP and possibly also heavier state (meta)stable
HSCP as NLSP

Models here:

a) **SUSY GMSB** long lived Stau NLSP, LSP = gravitino
dominant production: from decay chain of squark/gluino

b) **mUED** – long-lived KK states
direct pair production of KK tau

c) **Split SUSY** (all scalar particles have high mass)
long-lived gluino (R-hadron)

d) **MSSM** with light stop as NLSP and small $\Delta M = M(st-\chi^0)$

Heavy: mass > 100 GeV (non relativistic)
Semi-stable: c tau > few m (escape the detector)

After production, $\tilde{g}$ and $\tilde{t}$ hadronise to metastable particle by combining with light quarks and gluons generically called **R-hadon**

Data Sample	Cross section (pb)	HSCP in $\lvert\eta\rvert < 2.4$ (%)
$\tilde{\tau}_1$ (156 GeV)	1.19	97.6
$\tilde{\tau}_1$ (247 GeV)	0.097	97.5
KK tau (300 GeV)	0.020	84.7
$\tilde{g}$ (200 GeV)	2.2×10^3	89.7
$\tilde{g}$ (300 GeV)	100	91.7
$\tilde{g}$ (600 GeV)	5.00	93.7
$\tilde{g}$ (900 GeV)	0.46	92.6
$\tilde{g}$ (1200 GeV)	61×10^{-3}	91.4
$\tilde{g}$ (1500 GeV)	10×10^{-3}	90.4
$\tilde{t}_1$ (130 GeV)	1.11×10^3	87.8
$\tilde{t}_1$ (200 GeV)	1.77×10^2	90.9
$\tilde{t}_1$ (300 GeV)	27.4	92.8
$\tilde{t}_1$ (500 GeV)	1.27	95.3
$\tilde{t}_1$ (800 GeV)	7.81×10^{-2}	96.9

Search for heavy stable charged particles

Key element: measurement of velocity β

Two techniques:

- time of flight measurement by muon DT
- using specific ionisation in tracker

calculate particle mass $m = p/(\beta\gamma c)$

Lepton-like HSCP

- Can penetrate the whole detector
- High ionization energy loss
- Delayed with respect to lightspeed particles

R-Hadron-like HSCP

- Heavy parton behaves as a spectator
- Does not shower in the calorimeters
- The charge can change in hadronic interactions with matter while crossing the detector

HSCP triggering:

- Timing issue important:
  L1/HLT not prepared for slow particle which can be reco in different BX

- Two main trigger paths:

- Muon HLT path: trigger by HSCP or SM muon
- MET HLT path: MET present in many models (from cascade) – indep of timing problems

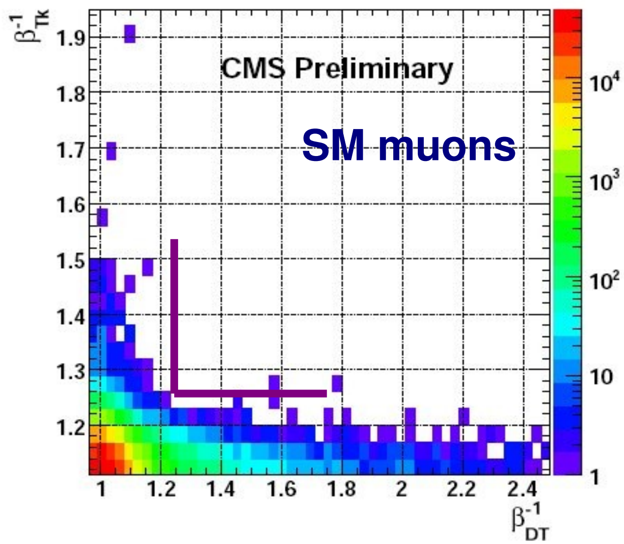
Final trigger efficiency:

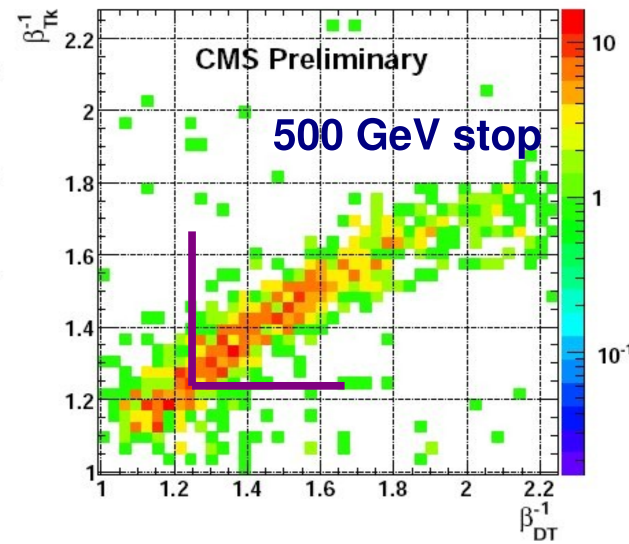
~70% for lepton-like HSCP

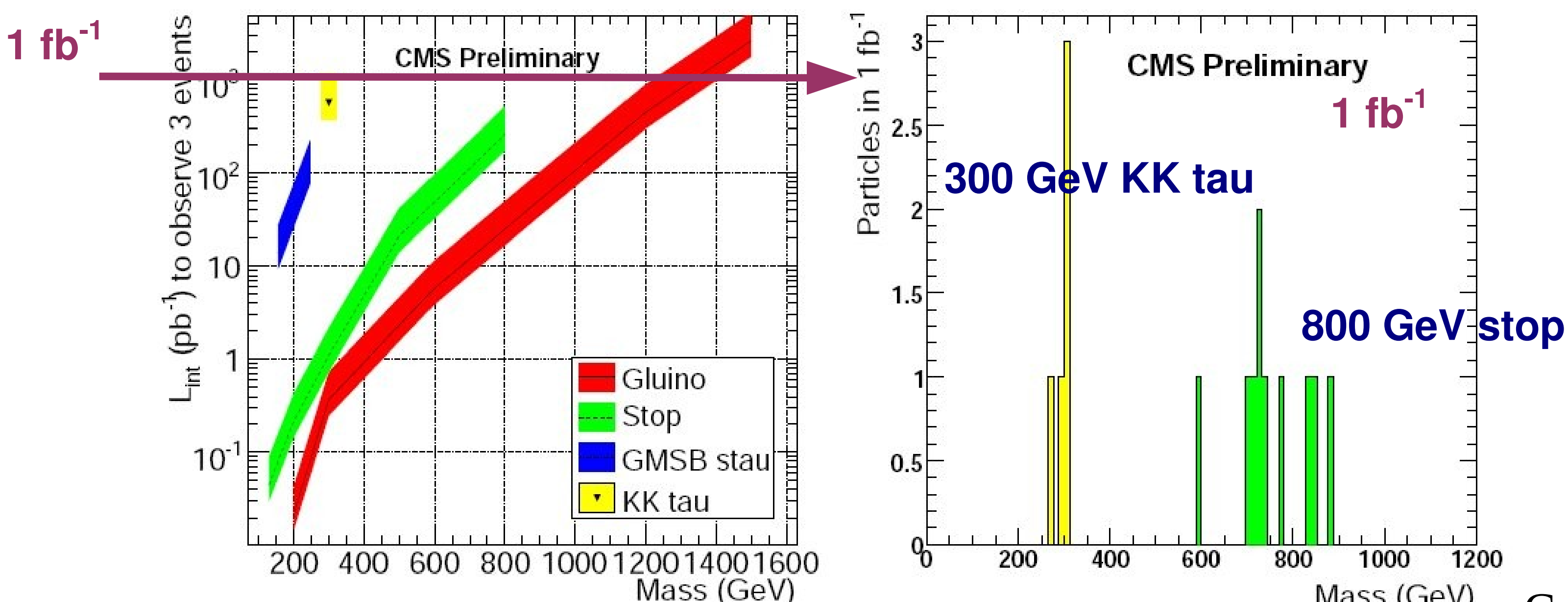
~40-95 % for R-Hadrons

Search for heavy stable charged particles

- $\beta_{DT} < 0.80$ and $\sigma_{\beta^{-1}} < 0.1$
- $\beta_{Tk} < 0.80$
- $m_{avg} > 100$ GeV







Error bar: 50% syst on trigger efficiency - background free analysis

Goal: <1 bg event for L=1fb^{-1}

4. Search for monojet

Graviton Production

- Gravitons propagate in the bulk as Kaluza-Klein towers. In the brane they appear as massive spin-2 particles
- They gravitationally couples to SM matter
- In collider experiments, they "appear" as *Missing Tranverse Energy (MET)*
- The cross section is:

$$\sigma \sim \frac{1}{M_D^2}\left(\frac{\sqrt{s}}{M_D}\right)^{\delta}$$

CMS PAS EXO-08-011

Selection:

MET > 400 GeV

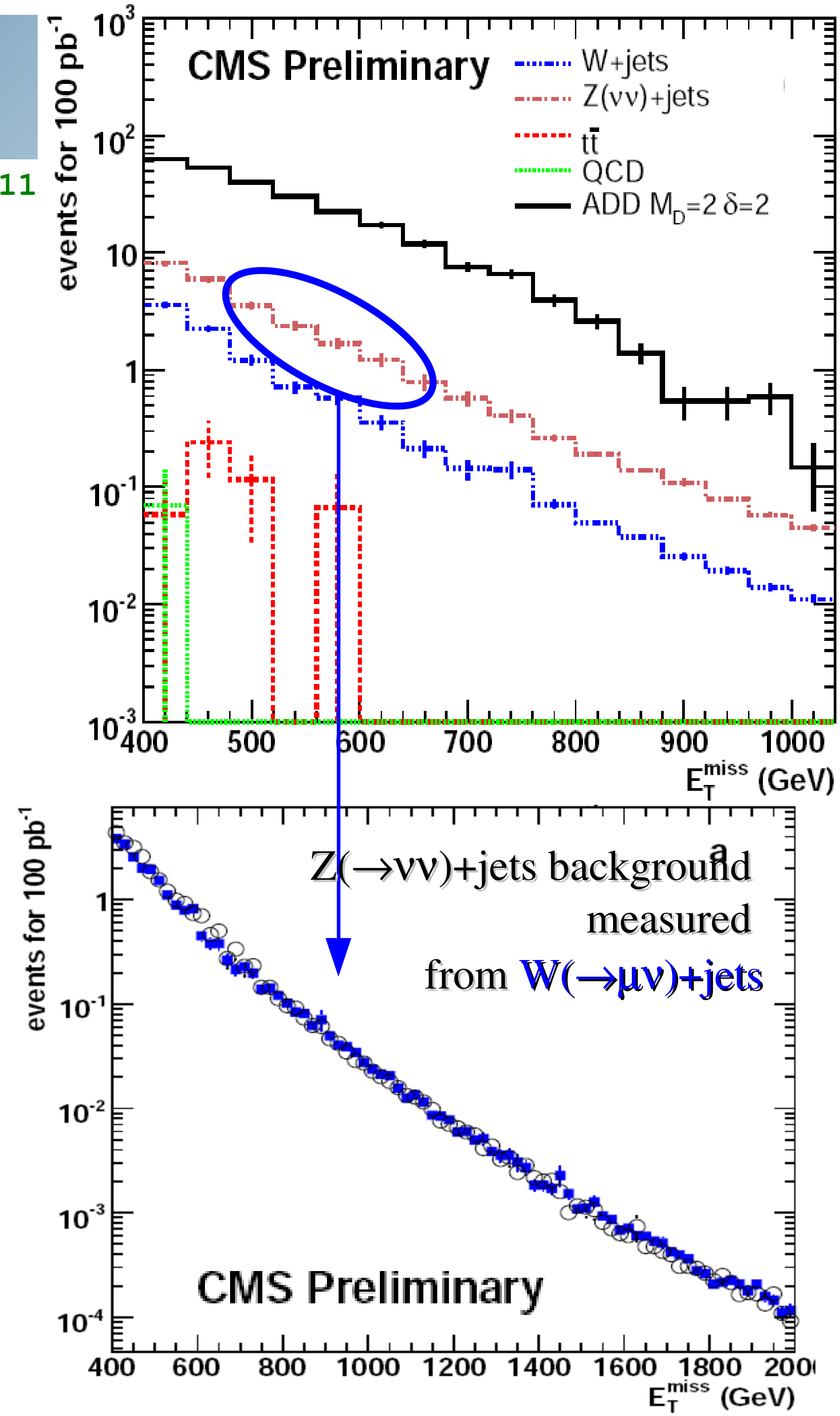
1 high-p_T jet

$\Delta\phi$(MET-jet)

Indirect lepton veto

Reach: after 100 pb^{-1}:

M_D reach (TeV)	L=100 pb^{-1} $\delta = 2$	$\delta = 4$
5σ limit	3.07	2.15
3σ limit	3.69	2.72
95% C.L.	4.82	3.67



Search for Black Holes

ATLAS Phys TDR

BH Production

- The Schwarzschild radius in Extradimensional theories is smaller than its 4-d version:

$$r_{S(4+\delta)} = \frac{1}{\sqrt{\pi} M_D} \left[\frac{M_{BH}}{M_D} \left(\frac{8\Gamma((\delta+3)/2)}{\delta+2} \right) \right]^{\frac{1}{\delta+1}}$$

- Parton level cross sections for e.g. $M_D \sim 2$ TeV are in the pb range:

$$\sigma(BH) = \pi r_{S(4+\delta)}$$

- Due to Hawking radiations, BH has short lifetime ($\sim 10^{-27}$ s) and decays "democratically" in all SM particles

Selection:

Object = e,μ,γ or jet

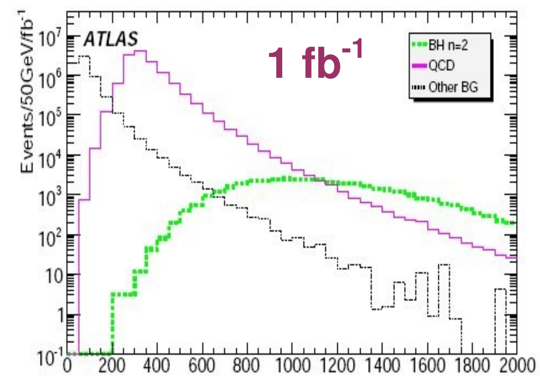
Pt>15 GeV + ID+isolation (lepton/γ)

Pt>20 GeV (jet)

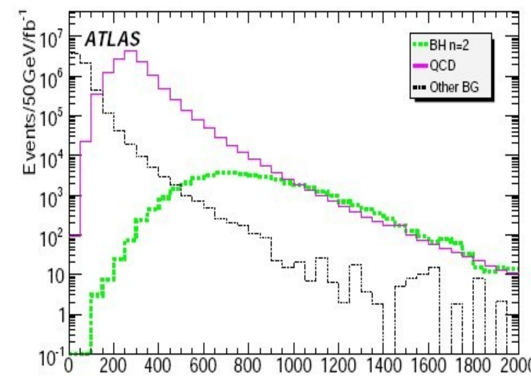
Signal MC: Charybdis, M_{pl} = 1 TeV

δ=2,4,7 and M_{BH}= from 5 to 14 TeV

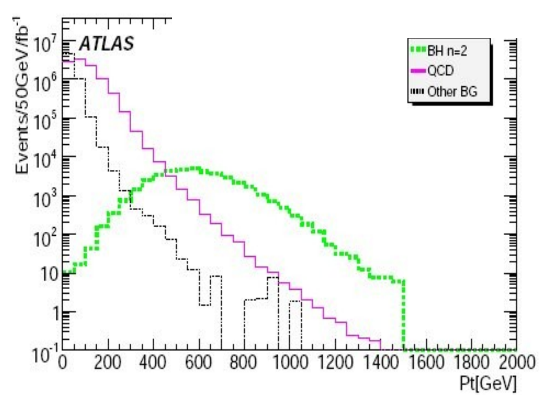
Robust discovery reach potential for BH is difficult because of the semi-classical assumption used, only valid well above M_{Pl} → M_{BH} > 5 TeV



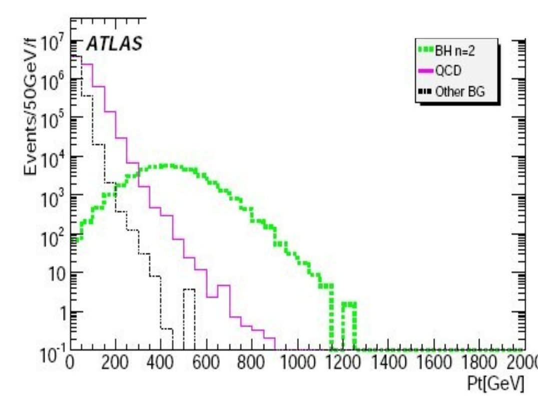
→ Pt(1) (GeV)



→ Pt(2) (GeV)

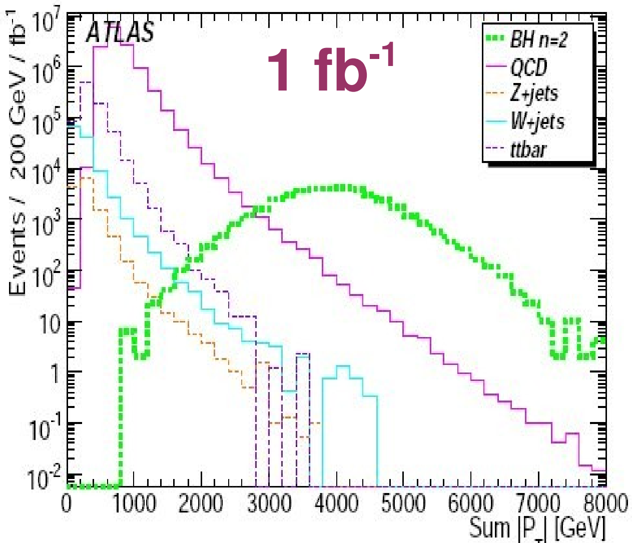


→ Pt(3) (GeV)



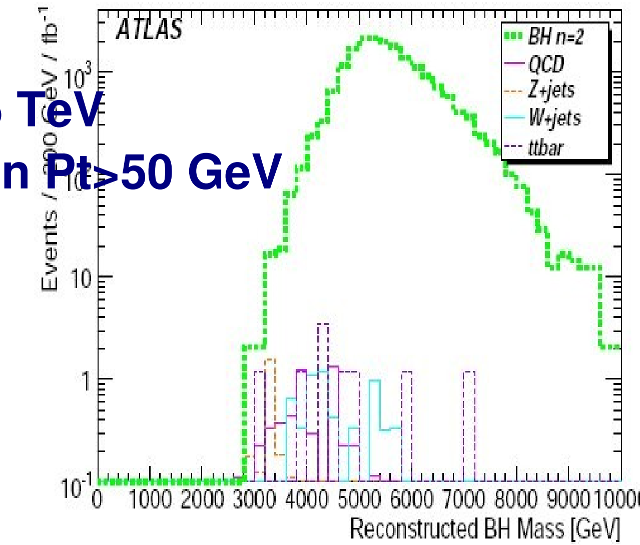
→ Pt(4) (GeV)

Search for Black Holes



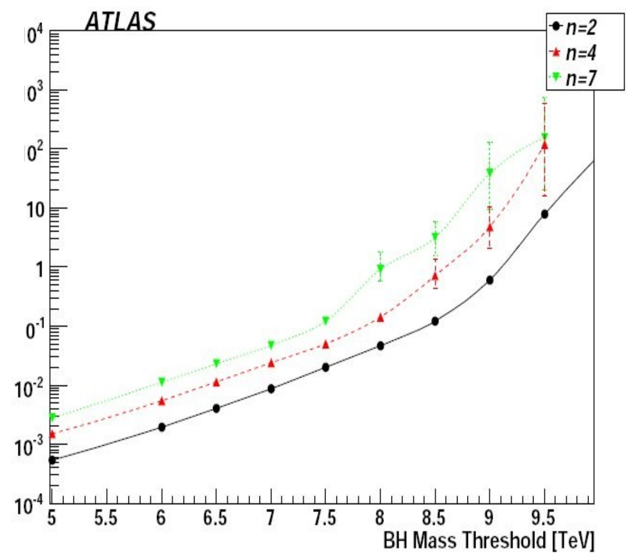
$\rightarrow$ Σ |Pt| (GeV)

Σ| Pt|>2.5 TeV
and lepton Pt>50 GeV



$\rightarrow$ M_{BH} (GeV)

$\rightarrow$ L (fb^{-1})



$\rightarrow$ M_{BH} (TeV)

BH signature should be very clear at LHC if it exists

LHC can discover BH up to kinematical limit assuming the signal is correctly modelled

(Huge BH cross section - small QCD background after cuts)

Conclusions

Many analyses performed:

Many different topologies - predicted by many models

Focus on early searches (2009/10 data) – 10,100 pb^{-1}

- Full detector simulation
- Low statistics and not ultimate aligned/calibrated detector
- Extract efficiency and bg from data themselves

Already discovery potentials with few tens of pb^{-1}
for a large spectrum of exotica models
CMS/ATLAS EXOTICA are ready for data
Looking forward to the first data from LHC

More results to come:

on 10 TeV run

more experimental challenging topologies ...

Try to cover all possible final state topologies to catch new physics