Higgs Physics and Beyond the Standard Model at CMS/ATLAS

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Rencontres de Moriond EW 2009

7-14 March 2009

La Thuile

Outline

- **Physics motivations**

- Standard Model **Higgs** searches:
  - $H \to WW$, $H \to ZZ$, $H \to \gamma\gamma$, $H \to \tau\tau$

- **Supersymmetry** hints:
  - Multiple jets + leptons, di-jets

- **Beyond** the Standard model:
  - Z', G

- **Conclusions**

P.S. Either CMS or ATLAS results will be shown

Open questions in particle physics

- Is the Higgs mechanism to generate weak boson and fermions masses real ?

- How to solve the problem of the hierarchy between the EWK scale and the GUT or Planck scale ?
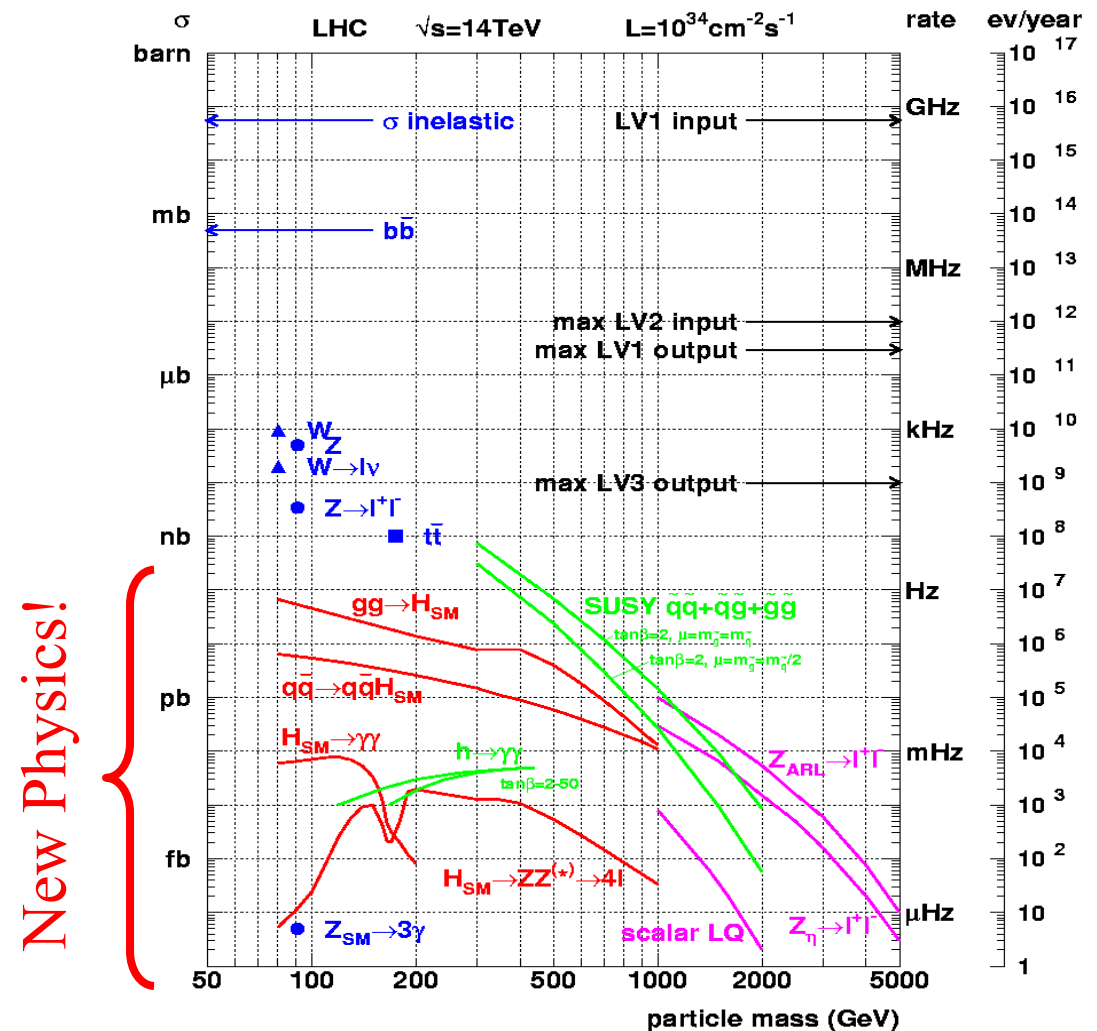
- Are the electroweak and strong forces unified at some GUT scale

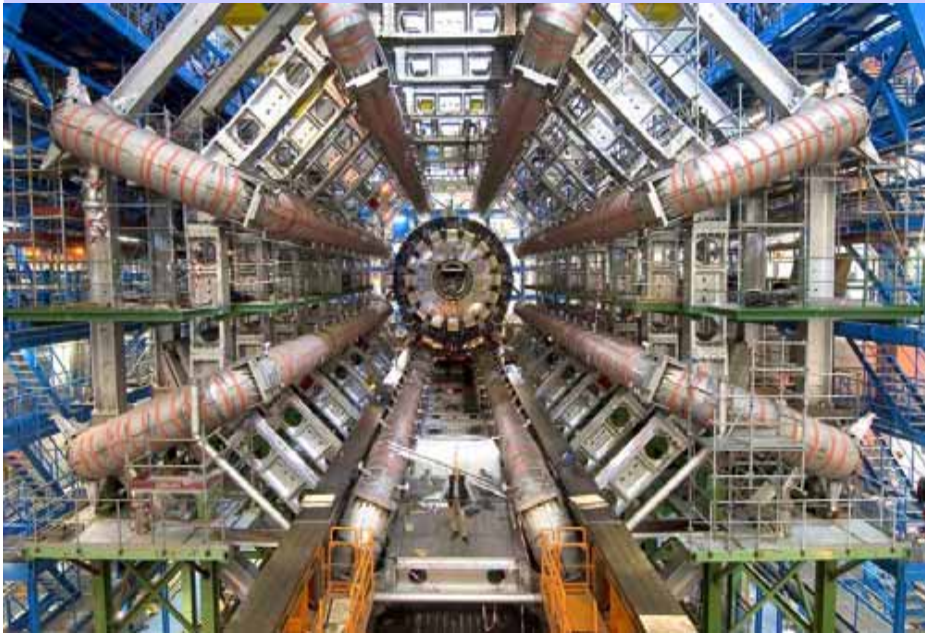- Is the SUSY realized in nature ? Do the SUSY particles exist ? Can they explain the dark matter ?

- Do extra dimensions exist?

- ....etc..

LHC can provide some answers
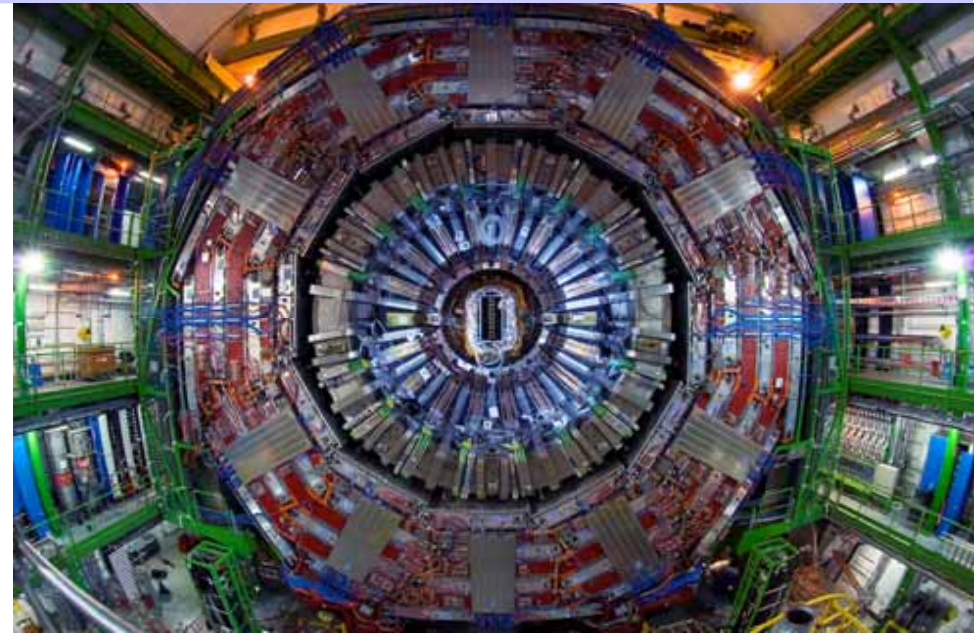
The ATLAS/CMS detectors at LHC

Tracker: |η| < 2.5
SI pixels, SI strips, straw-tubes
$\sigma/p_T \approx 0.05\% \, p_T \oplus 1\%$

Tracker: |η| < 2.5
SI pixels, SI strips
$\sigma/p_T \approx 0.015\% \, p_T \oplus 0.5\%$

Muon spectrometer: |η| < 2.7
Drift tubes (barrel), CSC (endcap), RPCs
$\sigma/p_T \approx 10\%$ (1 TeV muons)

Muon spectrometer: |η| < 2.6
Drift tubes (barrel), CSC (endcap), RPCs
σ/p_T = 4.5-7 % (1 TeV μ), if comb. with TK

EM Calorimeter: |η| < 3.2
Lead/LAr
$\sigma/E \approx 10\% / \sqrt{E} \oplus 0.7\%$

EM Calorimeter: |η| < 3.0
Lead tungstate (PbWO4) crystals
σ/E = 2.8 %/$\sqrt{E} \oplus$ 0.3 % (barrel)

...in preparation for real data

- **CMS** and **ATLAS** communities are improving analyses, focusing on perspective searches with **low** luminosity ($< 1 \text{ fb}^{-1}$).

- **Full simulation/**closer to the real experimental set-up → start-up conditions (miscalibration/misalignment of the detectors) used

- Focus on **data driven methods** to estimate background and efficiency from data → evaluation of systematics

- Improved **signal & backgrounds understanding** (more complex MCs, NLO QCD/EW corrections)

SM Higgs production at LHC
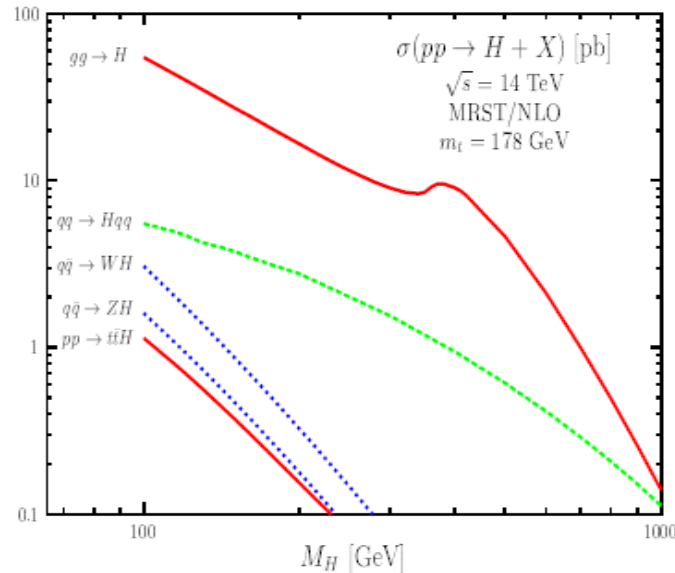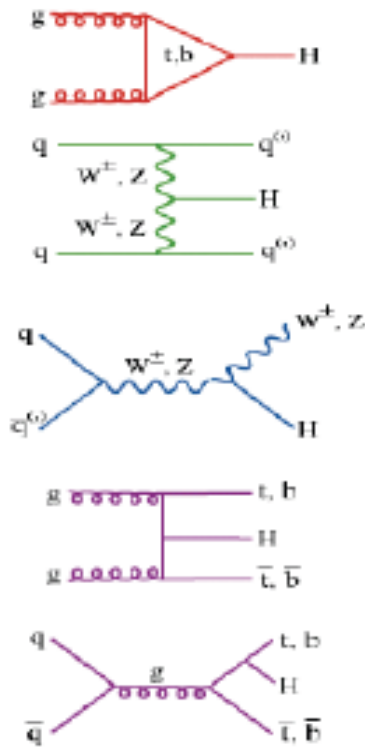
- Higgs production cross-section (NLO): 0.1-50 pb
- gluon fusion dominates at LHC especially at low m_H

A.Djouadi, **Phys.Rept.457:1-216,2008**

- 'Low mass range', $M_H \lesssim 130$ GeV:
  - $H \to b\bar{b}$ dominant, BR = 60–90%
  - $H \to \tau^+\tau^-, c\bar{c}, gg$ BR= a few %
  - $H \to \gamma\gamma, \gamma Z$, BR = a few permille.

- 'High mass range', $M_H \gtrsim 130$ GeV:
  - $H \to WW^*, ZZ^*$ up to $\gtrsim 2M_W$
  - $H \to WW, ZZ$ above (BR $\to \frac{2}{3}, \frac{1}{3}$)
  - $H \to t\bar{t}$ for high M_H; BR $\lesssim 20\%$.
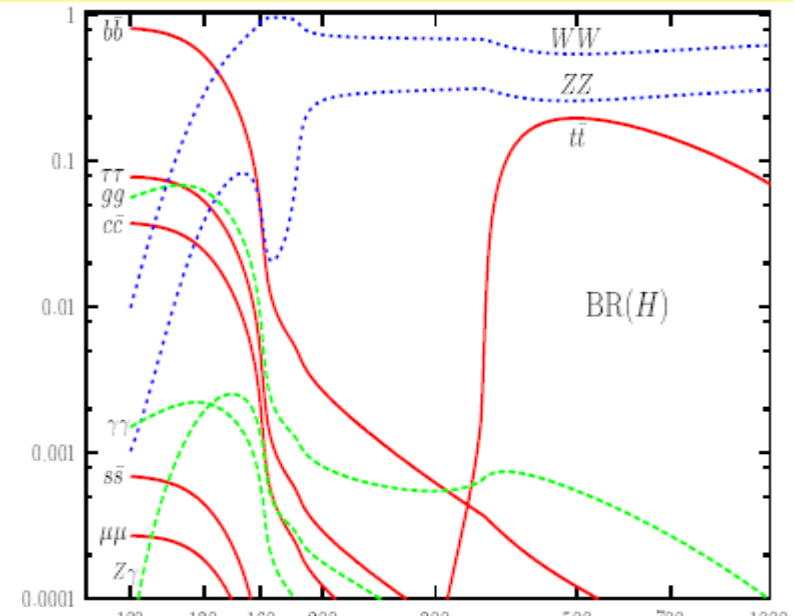
H→WW and H→ZZ are important channels at low lumi

H → WW → llνν analysis

■ **Signatures:** 2 isolated high p_T leptons + MET, no higgs mass peak

■ **Backgrounds:** tt, DY, di-boson, tW, W+jets

■ Preselection strategy:
- Single lepton triggers
- 2 isolated leptons opp. charge
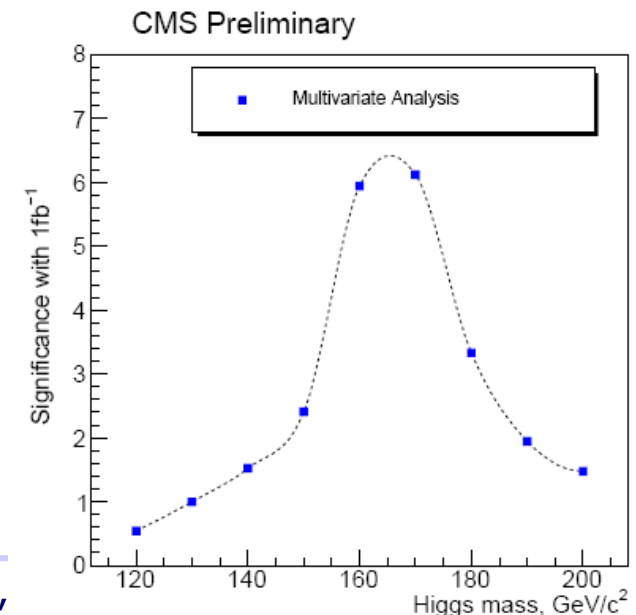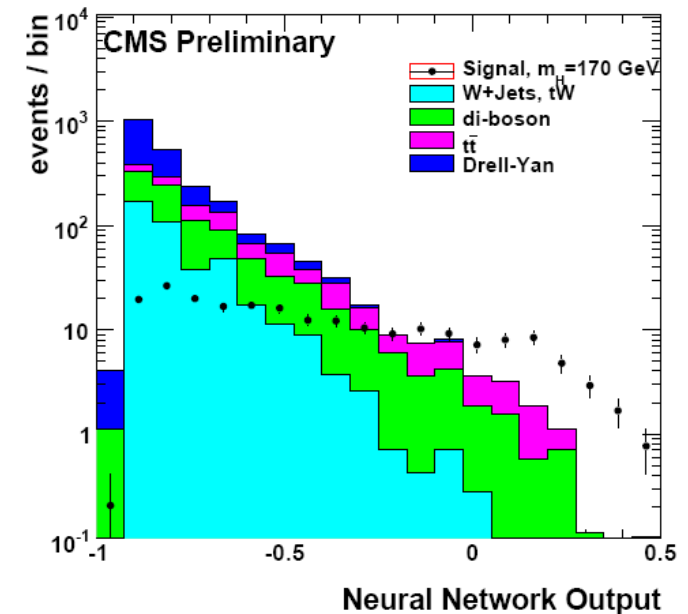- p_T 1,2>10 GeV or at least one p_T>20 GeV
- MET > 30 GeV, m_{ll}>12 GeV

■ Main selection observables:
- Central jet veto
- Angular correlations btw leptons
- Di-lepton mass, MET, leptons p_T

■ cut based and NN approaches

■ control from real data of
- the efficiencies (lepton and jet reconstruction)
- of the systematics on the MET measur.
- the estimation of bkg rates and fake rate

H → ZZ → 4l analysis

- **Signatures:** 4e,4mu and 2e2mu final state
- **Backgrounds:**
  - *irreducible* ZZ (each virtual or real Z in $\mu^+\mu^-$)
  - *reducible* Zbb (Z in $\mu^+\mu^-$ and semilept. decay of b)
  - *reducible* tt (each t in bW and semilept. decay of b)
 - and tt+jets, Z+jets, W+jets, QCD

- **Preselection strategy:** (to get rid of QCD bkg with fake leptons)
  - Single & double lepton triggers
  - 4 loose isolated leptons opp. charge and eleId
  - $m_{ll} > 12$ GeV, $m_{4l} > 100$ GeV

- **Main selection observables:**
  - tight isolation (against tt, Zbb)
  - impact parameter (against Zbb and tt)
  - $50 < m_Z < 100$ GeV, $20 < m_{Z*} < 100$ GeV

→ **Baseline cut-based analysis, m_H-independent, able to get rid of main bkg → first observation with reasonable lumi**
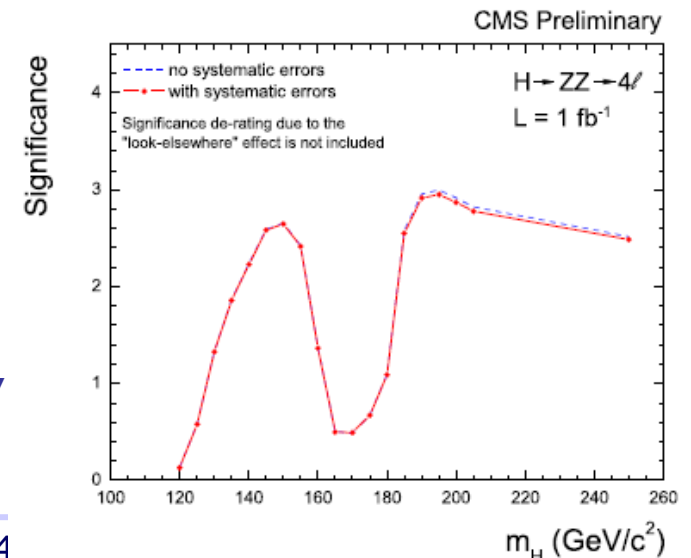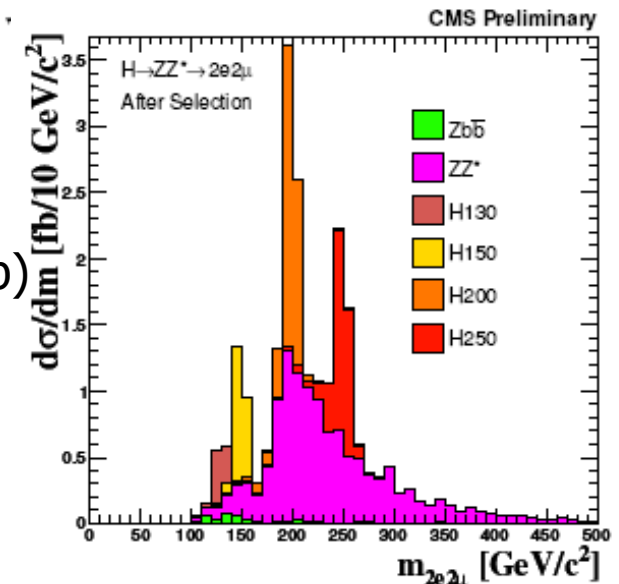
H → ZZ and H → WW combination

**In absence of a signal →
UL on σ**

→ SM-like Higgs could be
excluded for $m_H > 140$ GeV at
√s = **14 TeV** with 1 fb^{-1}

Projection at 10 TeV:
■ Most important effect is the
change in σ
    -- gg→H: 10 TeV/14 TeV is
    ~0.54
    -- WW/ZZ: 10 TeV/14 TeV is
    ~0.65
■ Rescaling of signal and main
backgrounds yields from the 14
TeV analyses   → 14→**10 TeV** is approximately equivalent
to a loss of a factor 1.5 in sensitivity

CMS Preliminary

H→WW/ZZ channels, L = 1 fb^{-1}

Ratio $\sigma_{95CL} / \sigma_{SM}$

m$_H$ (GeV/c^2)

10 TeV Bayesian
10 TeV CL$_s$
14 TeV Bayesian
14 TeV CL$_s$

Bayesian vs CL$_s$: assumed correlations between errors are not the same

H → γγ
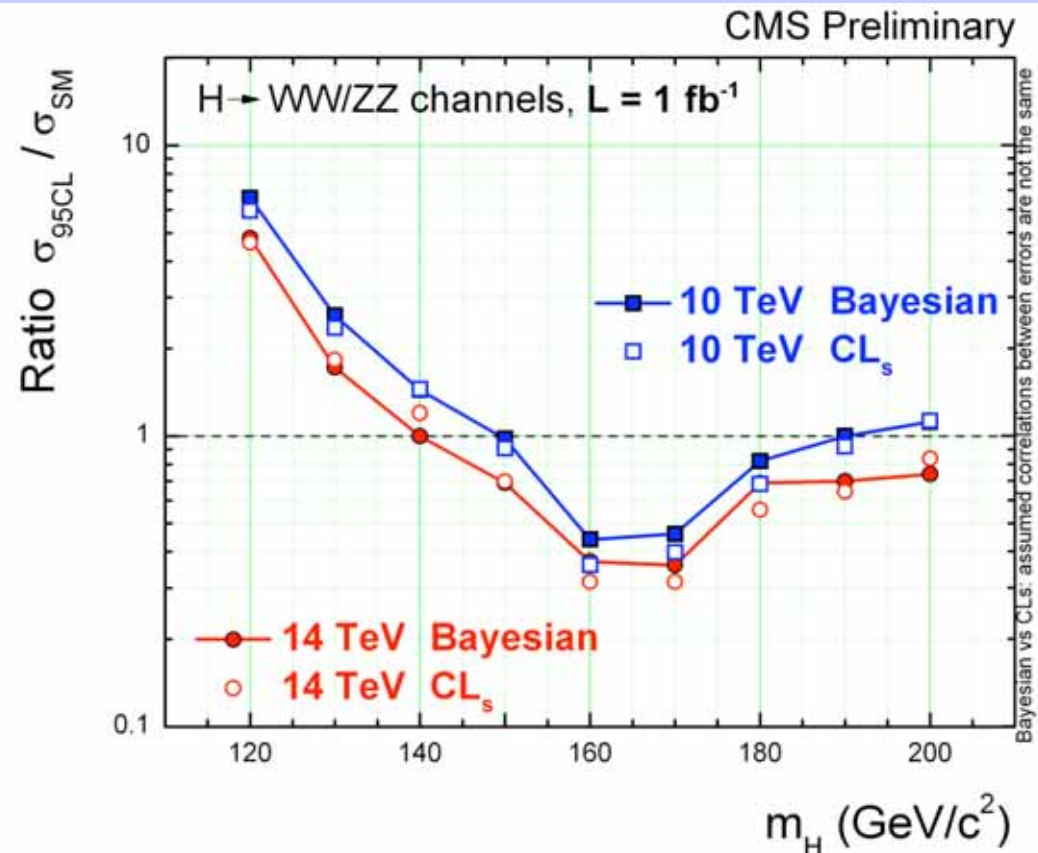
Important channel for Higgs with 110< m_H <140 GeV because **clear signature** but small B.R. (0.2%)

Backgrounds: *irreducible* (gg→γγ, qqbar, qg→γγ, pp→γ+jets (2 prompt γ); *reducible* (pp→γ+jets (1 prompt γ + 1 fake γ), pp→jets (2 fake γ), fake γ from π^0→γγ

Important issues:
• γ reconstruction and calibration
• γ identification to reject bkg from jets faking γ
• separation of converted and unconverted γ
• excellent energy and angular resolution obtained to achieve ~1.2% resolution in Higgs mass reconstruction degrading slightly when pileup added.

Many topologies: Inclusive, H+1jet, H+2jet, H+MET+ lept. Iso., H+MET

→ significance based on event counting of **2.6** with **10 fb⁻¹** for m_H = **120 GeV** in the case of **inclusive analysis**
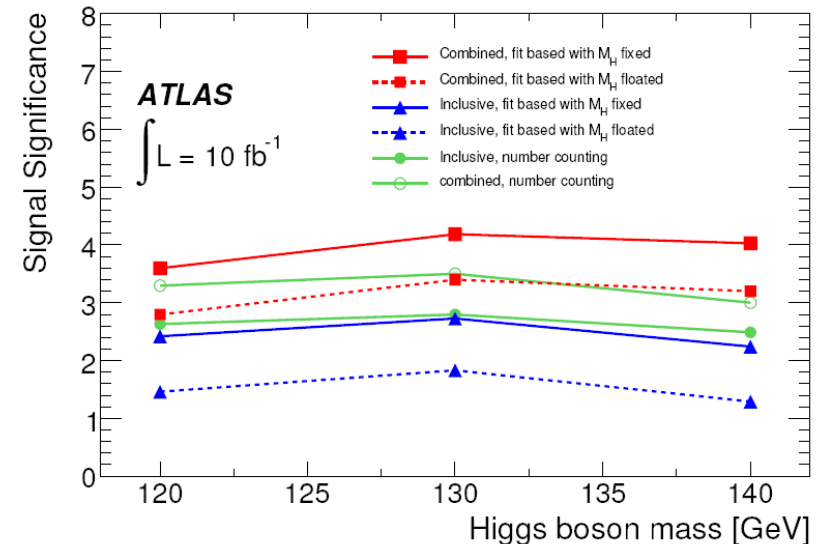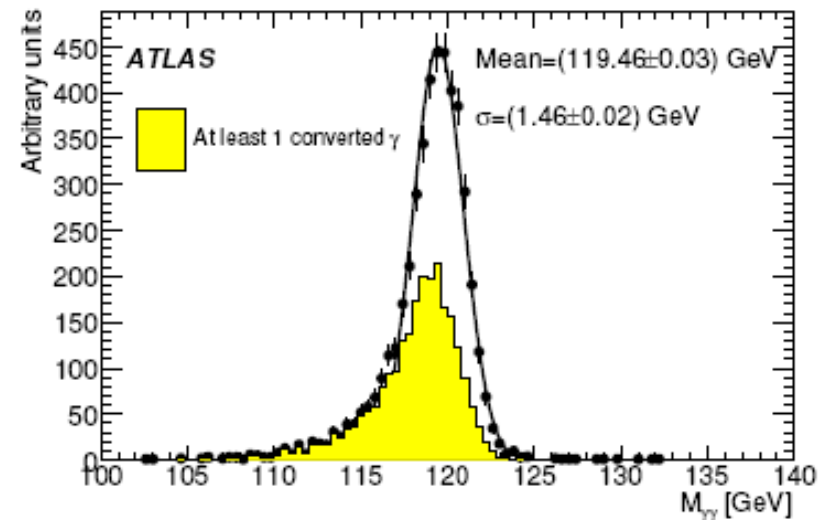
Searches for SUSY
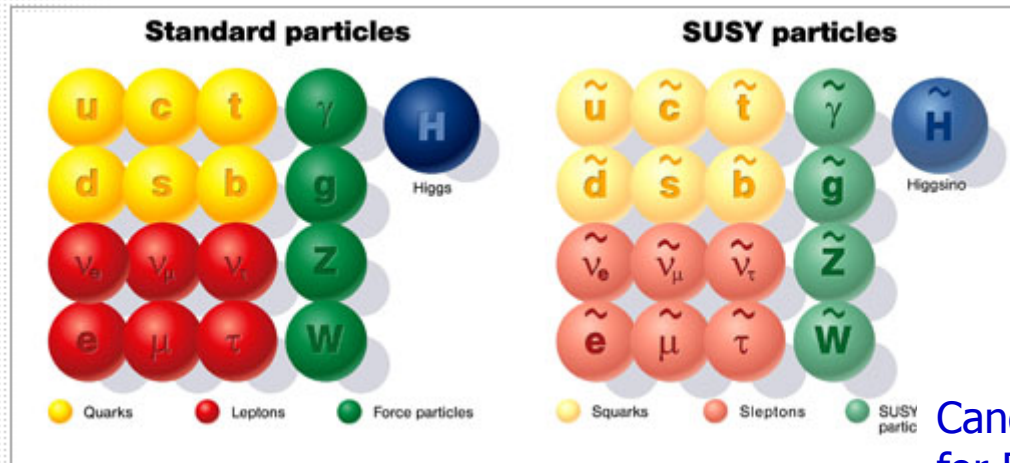
Spectrum of new particles, partner of SM particles

A SUSY signal at LHC is typically dominated by the production of **squarks and gluinos**.

Candidate particles for Dark Matter

Event topologies of SUSY:
- multiple jets, often energetic
- + possibly some lepton,
- + missing E_T
- multileptons + missing ET
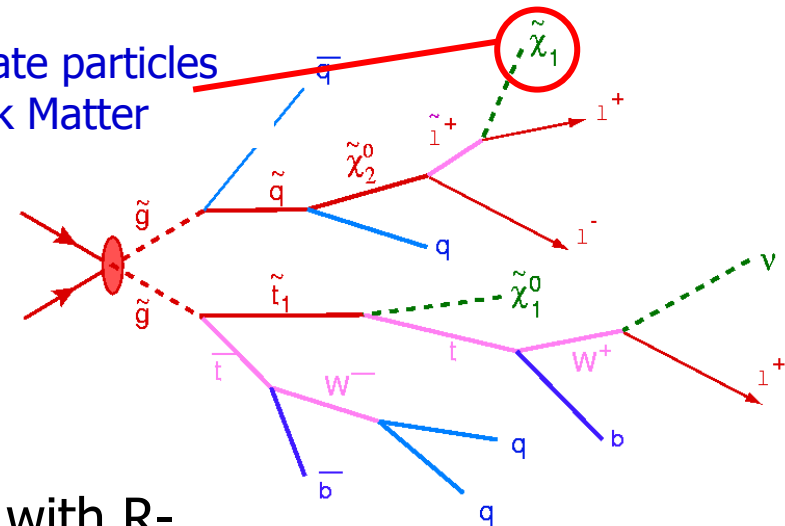
Most studies done in the context of **MSSM** with R-parity conservation, squarks and gluinos heavy
-- SUSY breaking scenarios considered:
- **mSUGRA - minimal SuperGravity**
- GMSB - Gauge Mediated SUSY Breaking
- AMSB - Anomaly Mediated SUSY Breaking

Searches for jets + lepts (e,μ) + MET
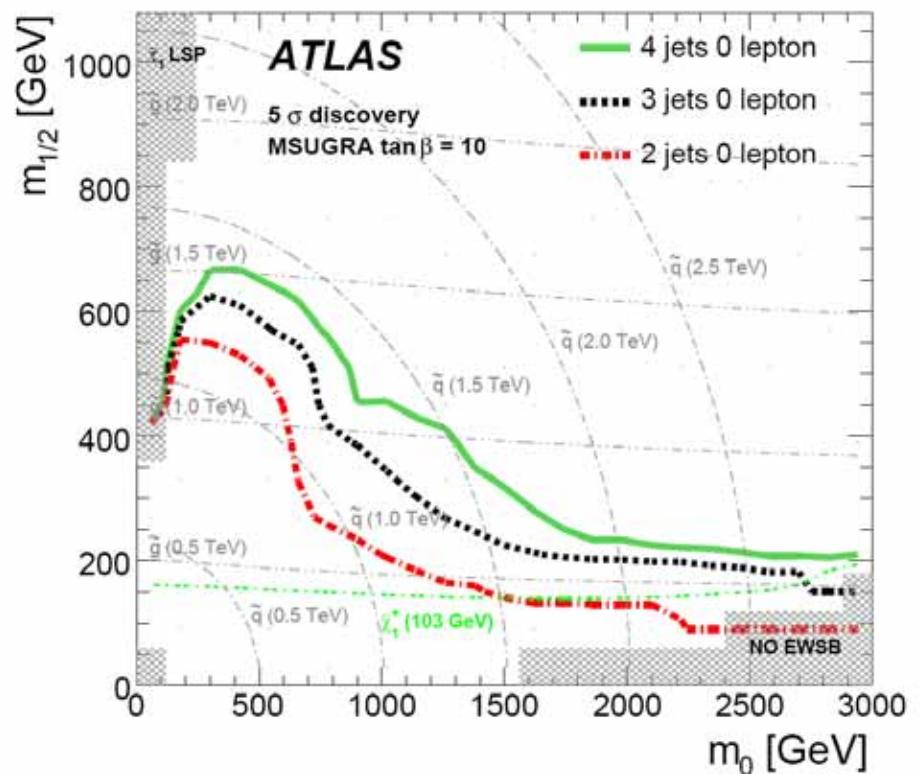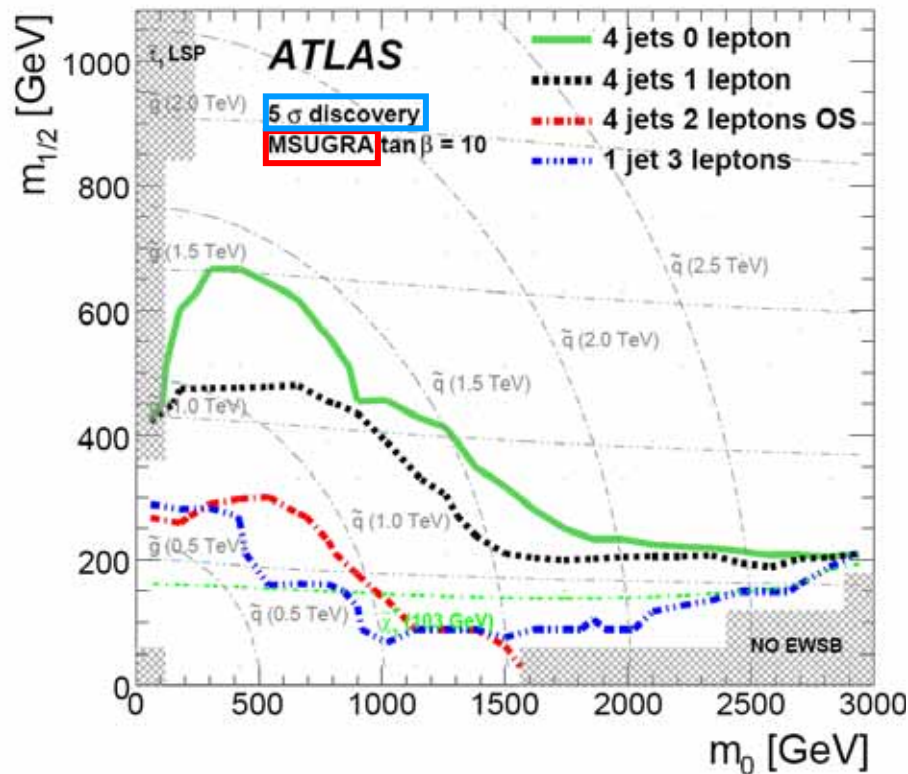
- **0-lepton** mode can probe close to min[m($\tilde{q}$), m($\tilde{g}$)] = **1.5 TeV** with 1 fb^{-1}; reach is roughly independent of tanβ for 0- and 1 lepton modes
- 4-jet requirement seems best in 0-lepton mode

→ ATLAS should discover signals for R-parity conserving SUSY with gluino and squark masses less than O(1TeV) after having accumulated and understood an integrated luminosity of about 1fb^{-1}.

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SUSY searches with di-jet

$$pp \to \widetilde{q}\overline{\widetilde{q}}, \quad \widetilde{q} \to q\,\widetilde{\chi}_1^0 (\text{LSP})$$: di-jet + missing E_T signature

CMS

Main background: QCD
di-jet, Z+jet (Z→νν)

Sample	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0	$\tan\beta$	$\text{sign}(\mu)$	σ NLO (pb)	(LO) (pb)	lightest $\tilde{q}$ (GeV)	χ_1^0 (GeV)
LM1	60	250	0	10	+	54.86	(43.28)	410 ($\tilde{t}_1$)	97
LM2	185	350	0	35	+	9.41	(7.27)	582 ($\tilde{t}_1$)	141
LM3	330	240	0	20	+	45.47	(34.20)	446 ($\tilde{t}_1$)	94
LM4	210	285	0	10	+	25.11	(19.43)	483 ($\tilde{t}_1$)	112

Kinematical variables used to
suppress the QCD bkg like:

$$\alpha = E_T^{j2} / M_{\text{inv}}^{j1,j2}$$

Data driven techniques for:

Selection cut	QCD	$t\bar{t}$,W,Z	$Z \to \nu\bar{\nu}$	LM1
Trigger	1.1×10^8	147892	1807	25772
Preselection	3.4×10^7	9820	878	2408
HT > 500 GeV	3.2×10^6	2404	243	1784
$\alpha > 0.55$	0	7.2	19.7	227.6
$\alpha_T > 0.55$	0	19.9	58.2	439.6
$\Delta\phi_{j1,j2} < 2\pi/3$	0	18.7	57.2	432.4

▮ bkg estimation via matrix
method

▮ Z+jets (Z→νν) bkg from W+jets

Several SUSY benchmark points can be discovered with S/B up to 6
with a data sample smaller than 1fb^{-1}

Beyond SM: Z′ → e⁺e⁻

Massive gauge bosons expected in several models; **Z′** in SSM (sequential standard model), **G** in Randall-Sundrum

Main bkg: DY, tt (2 real ele), QCD, W+jets, γ+jets, $\gamma\gamma$ (with one jet faking electron)

Model mass (GeV/c^2)	$M = 1000$	$M = 1500$	$M = 2000$	$M = 2500$
SSM Z'				
$\sigma \cdot \mathrm{BR}$ (fb)	458	80	20	5.8
nb. ev. for 100 pb^{-1} and 2 el. with $\lvert\eta\rvert < 2.5$	38	7.2	1.8	0.54
RS G ($c = 0.1$)				
$\sigma \cdot \mathrm{BR}$ (fb)	660	76	14	3.5
nb. ev. for 100 pb^{-1} and 2 el. with $\lvert\eta\rvert < 2.5$	62	7.2	1.3	0.32
DY bg. (GeV/c^2)	$M > 600$	$M > 1100$	$M > 1600$	$M > 2100$
cross section (fb)	50	4.4	0.76	0.18
nb. ev. for 100 pb^{-1} and 2 el. with $\lvert\eta\rvert < 2.5$	4.0	0.4	0.07	0.02

Important features:

-- High threshold trigger: $E_T >$ 80 and loose isolation OR $E_T >$ 200 GeV
-- saturation in ECAL electronics for very high energy deposition in ecal crystals
-- efficiency checked using Tag & Probe with data
-- tt measured with data
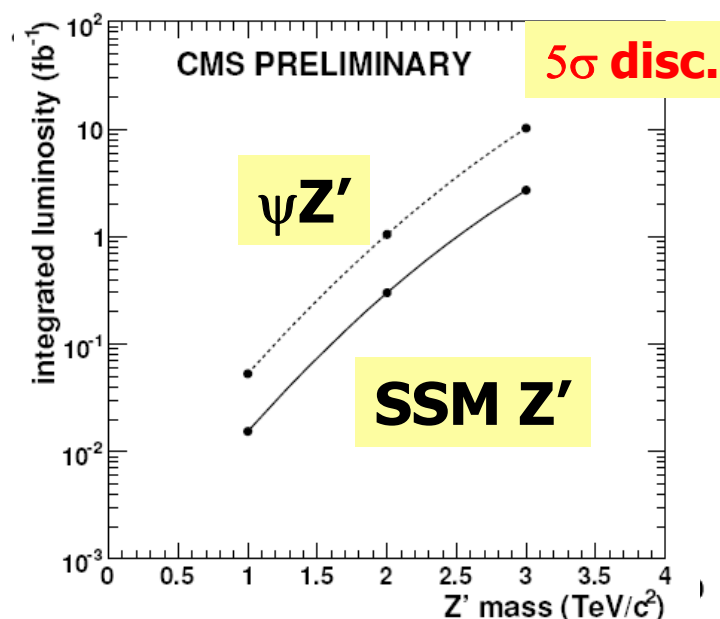
Beyond SM: Z′ → μ⁺μ⁻

Muons in the 1 TeV Z′ sample have a most probable p_T of about 500 GeV → p_T resolution of approximately 5% is found.

Background sources: DY (irreducible), inclusive jets, W+jets, Z+jets.

Sample	Z'_{SSM} (1 TeV)	Z'_{χ} (1 TeV)	Drell-Yan
Generated	508.6	380.6	13.5
$|\eta| \leq 2.5$	366.8	271.5	10.8
$p_T \geq 30\,\text{GeV}$	364.0	270.1	10.7
Muon identification	342.3	256.0	10.0
Trigger	325.2	243.2	9.5
Opposite charge	324.8	243.0	9.5

SSM Z′

➤ **Muon chamber misalignment** has an important effect → loss of Z′ mass resolution

➤ Luminosity needed for a **5σ discovery** ranges from **20 to 40 pb⁻¹**, which is competitive with the di-electron channel.

N. De Filippis   Rencontres de Moriond EW, Marc
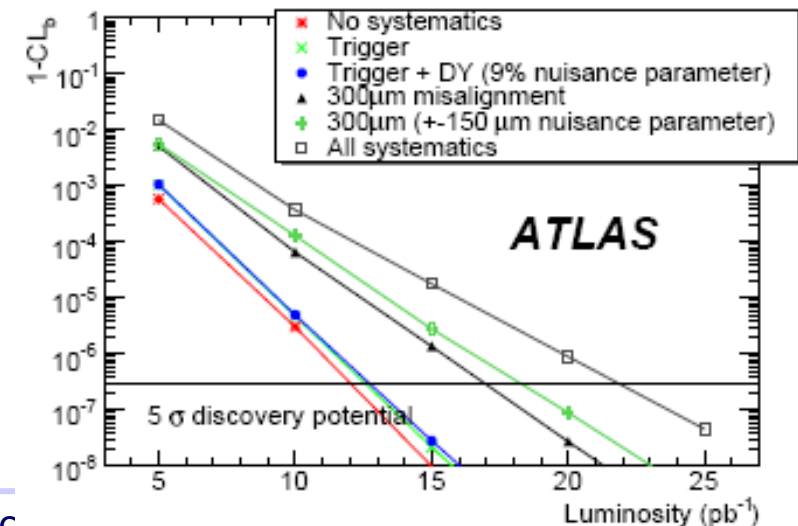
Summary and conclusions

➤ **CMS and ATLAS are ready for real data** analyses making use of most advanced knowledge of the detectors and designed to use real data to control background and estimate systematics

➤ CMS/ATLAS should be able to observe **an excess or put new constraints on several scenario for new physics with 100 pb^{-1} - 1 fb^{-1}** of integrated luminosity

➤ the **discovery** of SUSY and BSM/Extra dimension is possible with relatively small data samples and even with roughly calibrated detectors

→ Looking forward with analyses at **√s=10 TeV with 200 pb^{-1}** detector conditions.

Backup slides

VBF qqH, H $\to \tau\tau \to$ l+jets

Important channel for Higgs discovery in 115 < m$_\text{H}$ < 145 GeV

■ Improved s/b ratio, **thanks to forward jets and no had. activity in the central region**

■ Main backgrounds:
Z + jets, W + jets, tt and QCD multi-jet →
detailed study done in CMS about
background estimate from data

■ **Problematic issue: electrons faking τ jets**

Variables proposed to separate e/τ: $E^{HT}_{T\ max}$ and $E^{HT}_{T\ max} / p^{ltr}_T$

CMS

■ **Offline analysis:**

■ Lepton Counting	■ VBF Event Selection
■ Lepton Selection	■ Mass Reconstruction
■ Vertex Selection	■ **Central Jet Veto**
■ τ-jet Selection	■ Background Rejection
■ **Selection of VBF Jets**	■ Lepton-MET system

■ No signal evidence is expected at **1 fb^{-1}** but it
is a discovery channel at 30 fb^{-1}.
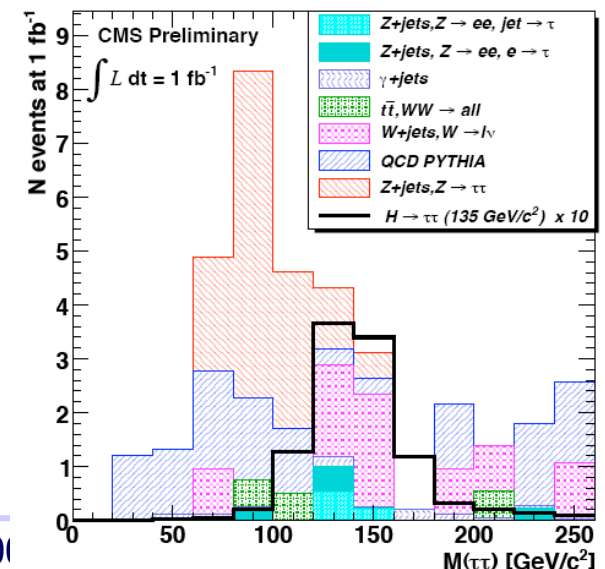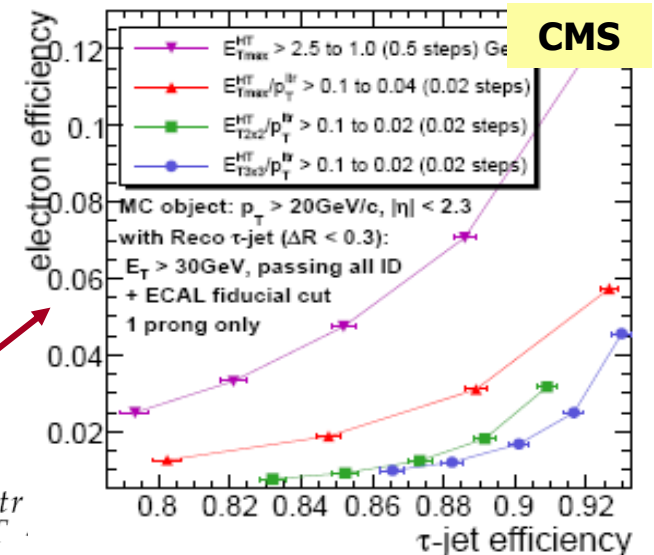
VBF qqH, H → ττ → l+jets (ATLAS)

VBF H → ττ : more intricate but more fun

~ 1600 events produced @ 10 fb^{-1}, for m_H = 120 GeV/c^2
in the lepton-hadron (lh) and di-lepton (ll) final states,
but large and difficult backgrounds, small efficiencies

All detector capabilities needed :
- soft leptons, hadronic taus
- E_T^{mis} (mass reconstruction)
- b-tagging (veto against tt)
- forward jets and soft central jets (central jet veto CJV)

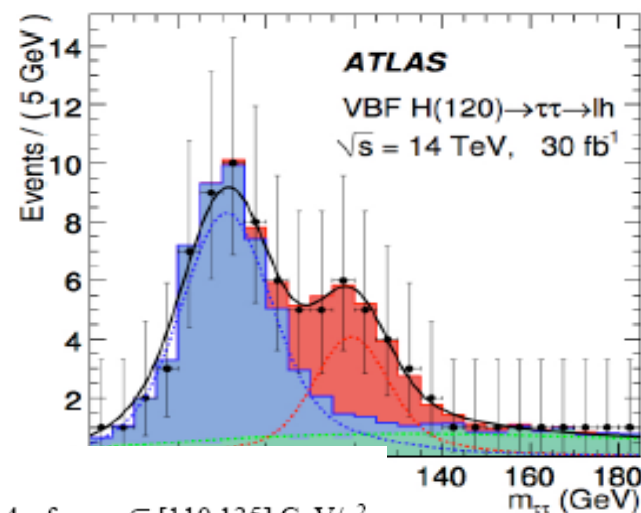→ Large impact of the underlying event (UE) and pile-up events (E_T^{mis} resolution, CJV)

⇒ Very difficult experimentally, but also very promising

Rapidity gap

(Fig. from E. Richter-Was)
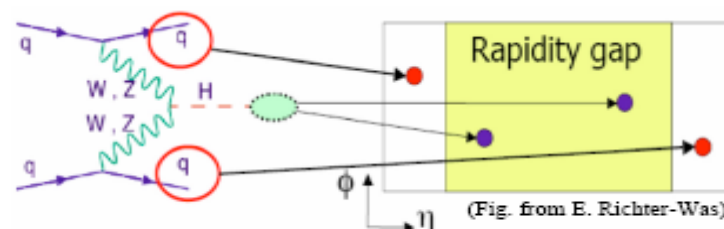
Example of mass spectrum for
m_H = 120 GeV/c^2 and 30 fb^{-1} in the lh final state
B ~ 2.5 fb / S = 0.72 fb

Within m_H ± 15 GeV/c^2 : S/B ~ 3

$\sigma(m_{\tau\tau})$ ~ 10 GeV/c^2

ATLAS

VBF H(120)→ττ→lh

$\sqrt{s}$ = 14 TeV, 30 fb^{-1}

Events / (5 GeV)

$m_{\tau\tau}$ (GeV)

⇒ Combining the lh and ll channels,
5σ discovery with 30 fb^{-1} for m_H = 115 GeV/c^2, and above ~ 4σ for $m_H \in$ [110,135] GeV/c^2

The hadron-hadron channel is considered as well but needs further studies (QCD background)

mSugra benchmark points
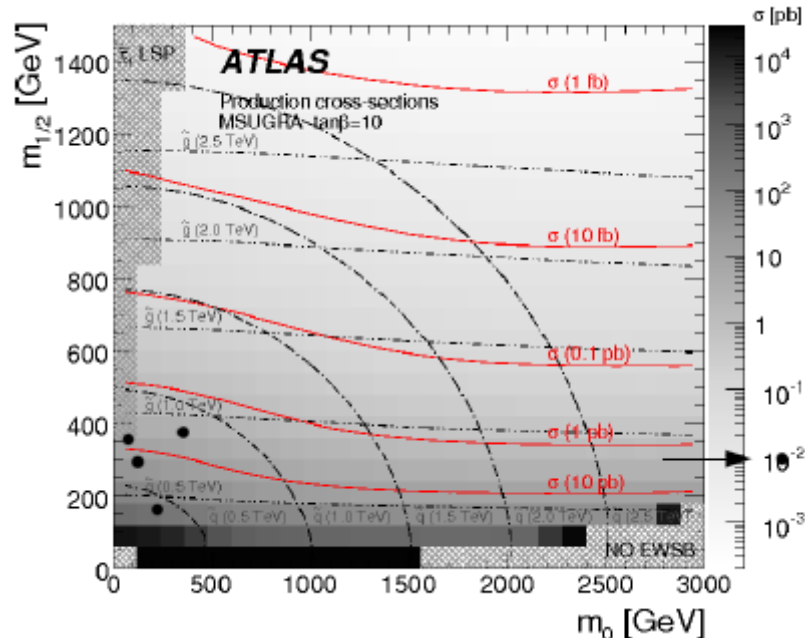
m$_0$, m$_{1/2}$

universal spin 0
& 1/2 particle
masses at the
GUT scale

mSugra benchmark points

|	m_0 (GeV)	m_1/2 (GeV)	A0 (GeV)	tan(beta)	σ(NLO) (pb)	Comment
SU1	70	350	0	10	10.9	Soft leptons, taus
SU2	3550	300	0	10	7.2	gluino/gaugino production, heavy flavor decays
SU3	100	300	-300	6	27.7	Generic point
SU4	200	160	-400	10	402.2	Low mass point near Tevatron bound
SU6	320	375	0	50	6.1	Tau rich

Common features for all points
-- μ > 0
-- m($\tilde{g}$) < 1 TeV
-- Comparable $\tilde{g}$ and $\tilde{q}$ masses
-- m($\tilde{g}$)/m($\tilde{\chi}_1^0$) ≈ 6-8
-- NLO xsec used

Beyond SM: Leptoquarks

Leptoquarks (LQ) = hypothetical bosons
- with both quark and lepton quantum numbers
- decay in any combination of a lepton and a quark
- three generations of leptoquarks, each coupled to a lepton and a quark from the same SM generation.
- produced in pairs by the strong interaction or in association with a lepton via the leptoquark-quark-lepton coupling.
- decay final states with **two highly energetic leptons + two jets and no MET**
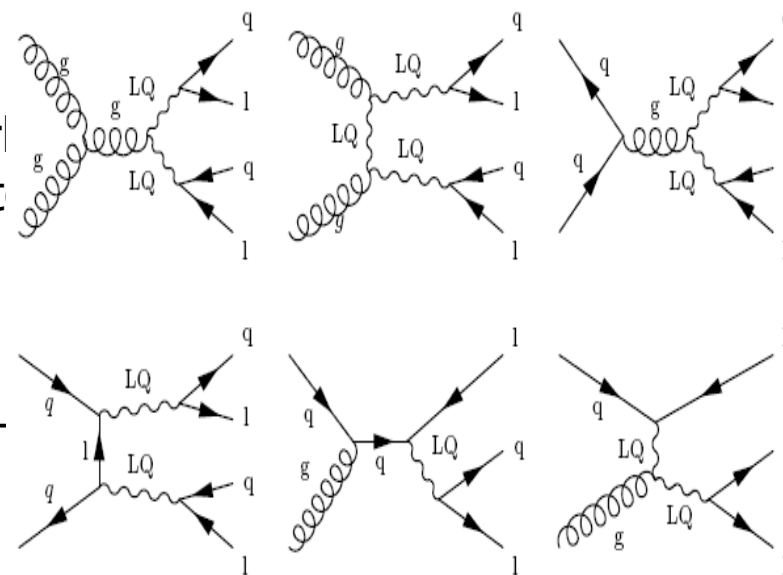

Bkg: tt, inclusive Z/g processes, multijet events with two jets are misidentified as leptons


N. De Filippis
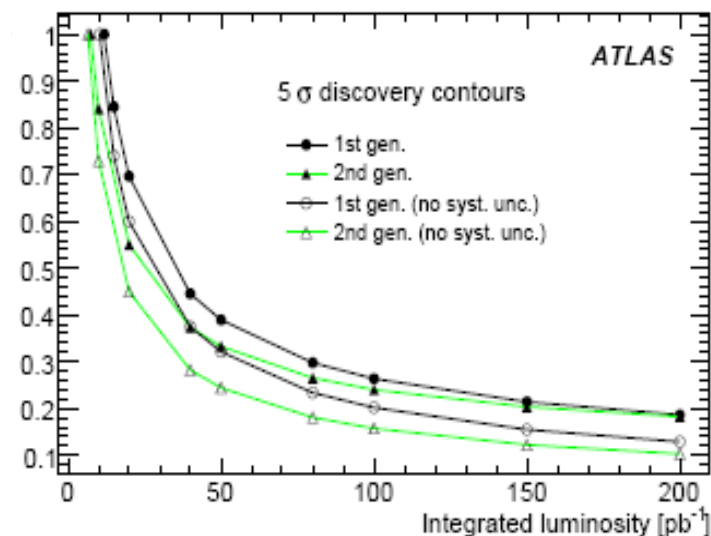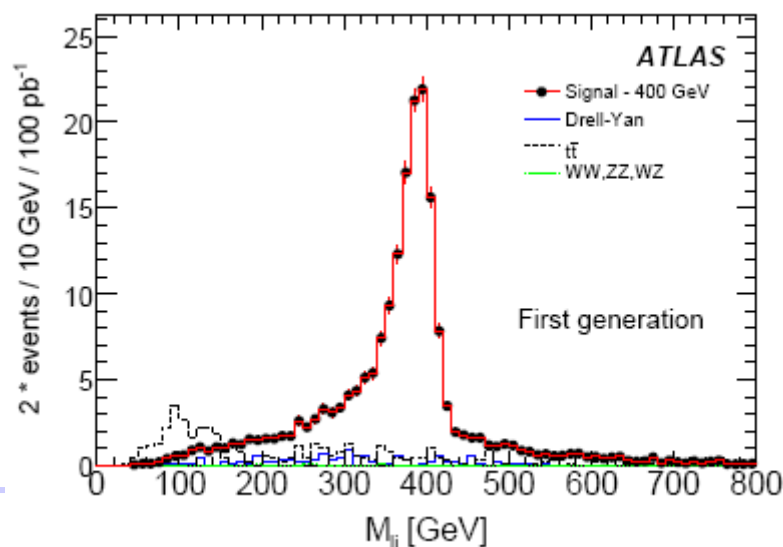
Beyond SM: 4th lepton generation

■ Phase in CKM can give CP violation but is too small to cope with the asymmetry between matter to antimatter → 4th lepton generation (b', t')

■ Searches at Tevatron gave m(b') > 268 GeV at 95 % C.L.

■ Tevatron and ATLAS evaluated the impact of the 4th lepton gen. on the Higgs observability

ATLAS searches

CMS searches for b'

$$pp \rightarrow b'\bar{b}' \rightarrow t\bar{t}W^+W^-$$
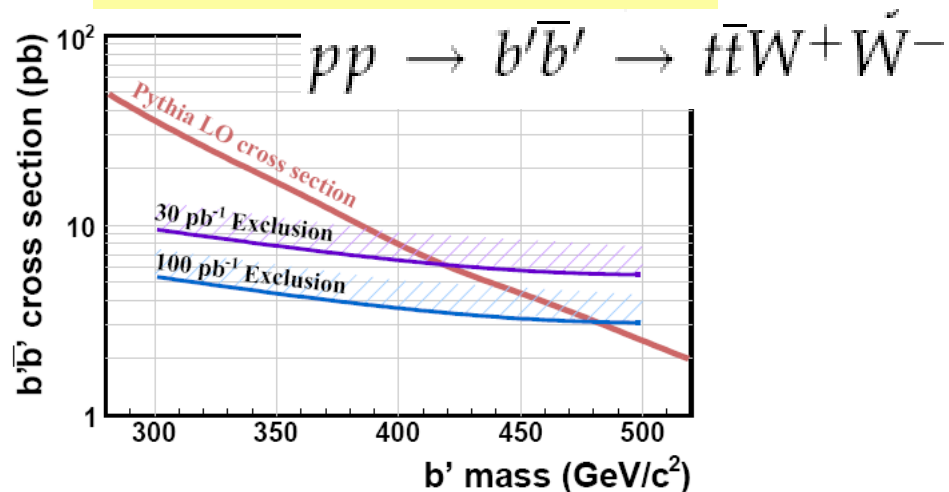
■ Significance of 7.5 for m(b') ~ 300 GeV with 100 pb⁻

■ If no signal → m(b')<480 excluded at 95% CL
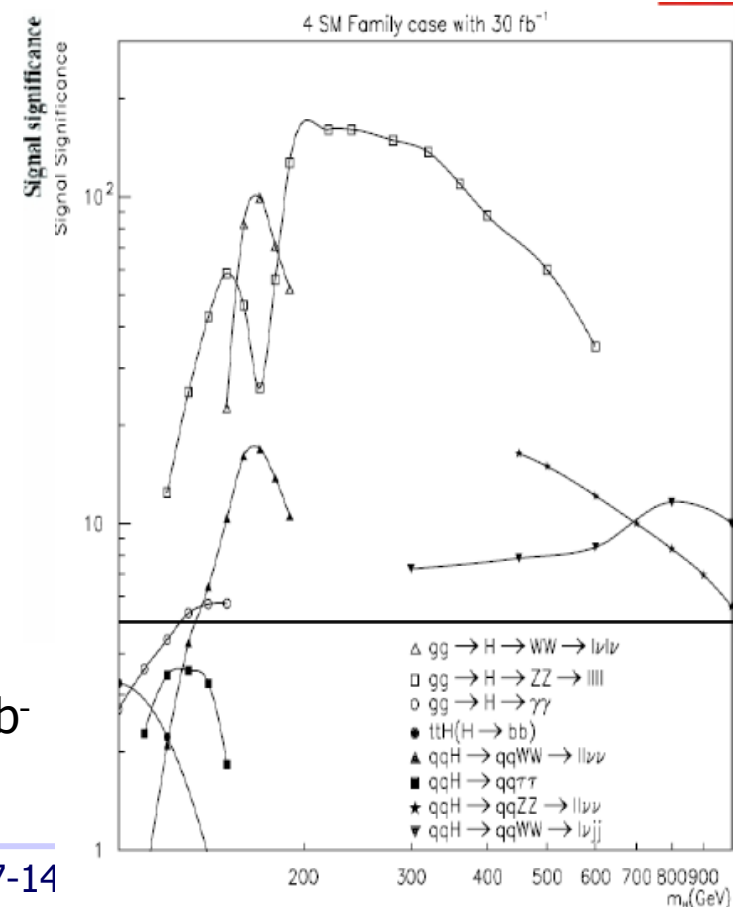
Beyond SM: Heavy stable charged particles

Several models predicting HSCP: susy with R-parity and extra dimension with KK-parity:

> **Leptons-like** HSCPS (sleptons and stau in SUSY models with GMSB

> HSCPs with **strong** charge will hadronize in **R-hadrons (R-hadrons, R-mesons, R-gluonball)** → hadronic interaction with the matter

Signature: a low velocity particle associated with a high momentum of few hundred GeV; two techniques to measure β by:

> measuring TOF with the Barrel Muon Drift Tube

> measuring dE/dx with the Silicon tracker

HSCPs can be discovered with early data for different models and mass region

CMS Preliminary

L_{int} (pb^{-1}) for 95% C. L. exclusion

Gluino
Stop
GMSB stau
KK tau

Mass (GeV)