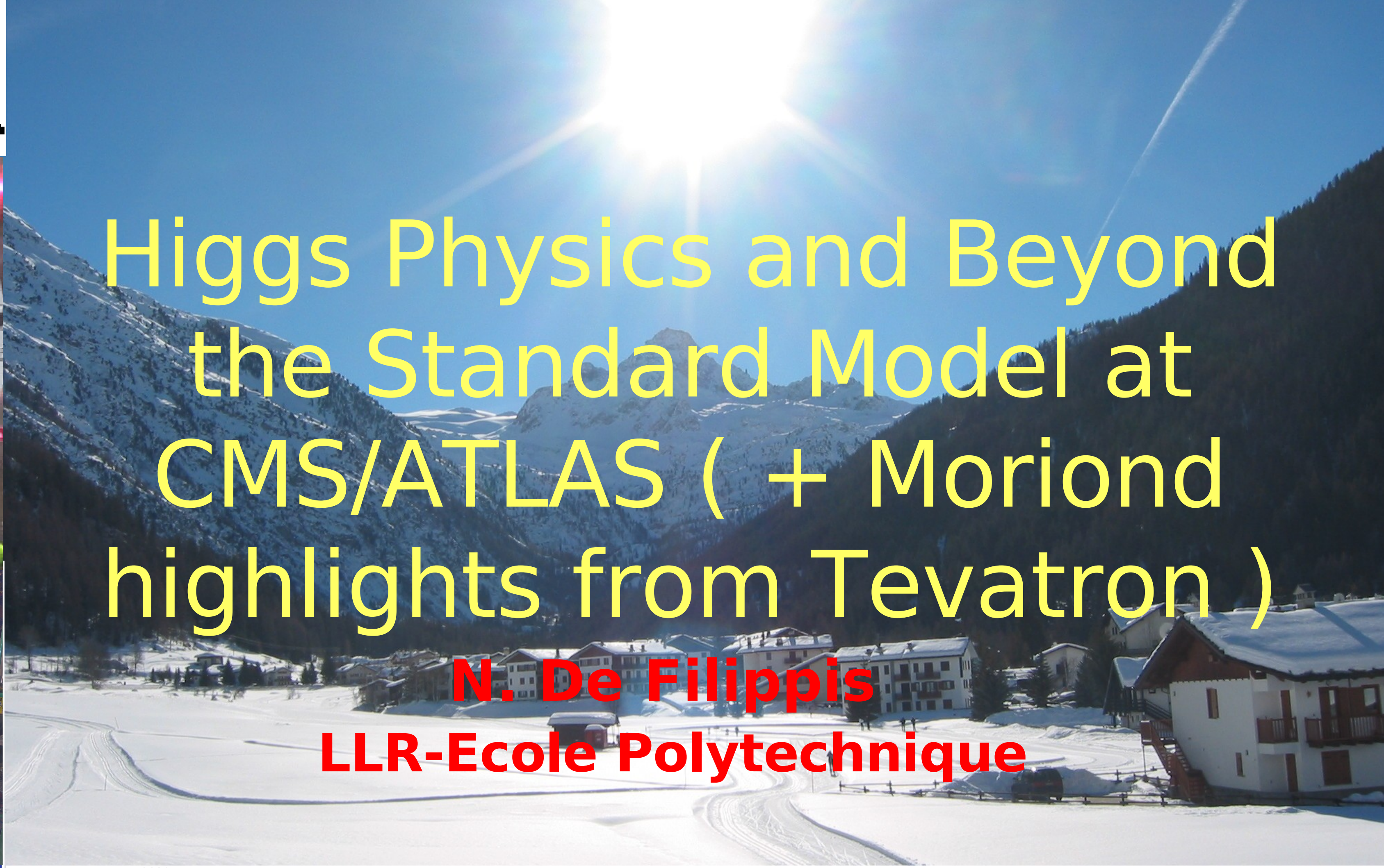
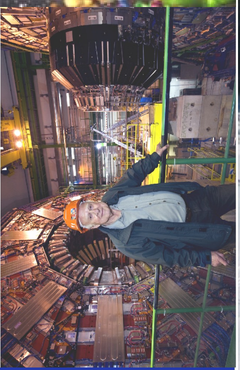
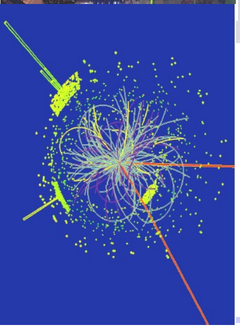


Higgs Physics and Beyond the Standard Model at CMS/ATLAS (+ Moriond highlights from Tevatron)

N. De Filippis

LLR-Ecole Polytechnique





Rencontres de Moriond EW 2009

7-14 March 2009 La Thuile

Outline

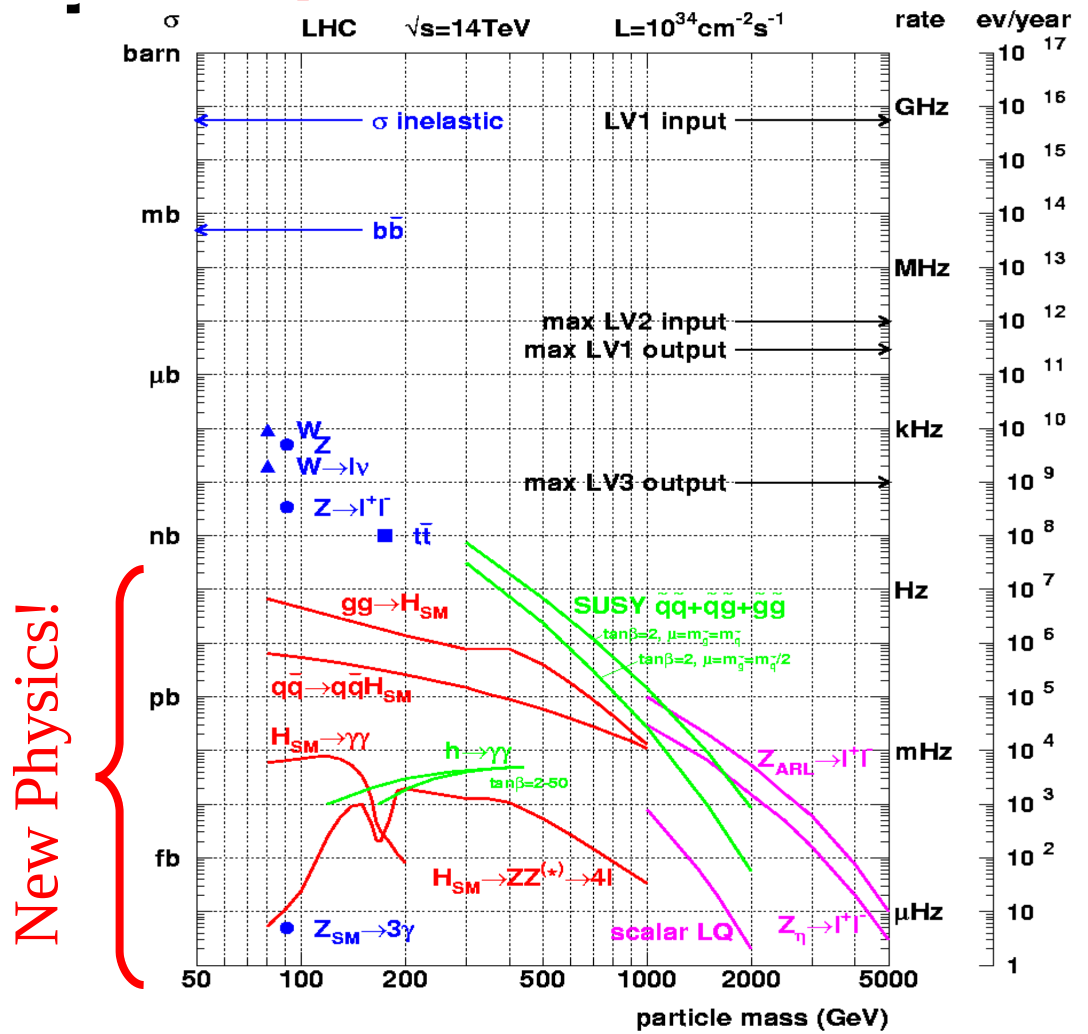
- **Physics motivations**
- **SM Higgs** searches: **H→WW, H→ZZ, H→γγ, H→ττ**
- **Supersymmetry** hints: **Multiple jets + leptons, di-jets**
- **Beyond** the Standard model: **Z', G, HSCP**
- **SM Higgs searches at Tevatron**
- **Conclusions**

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

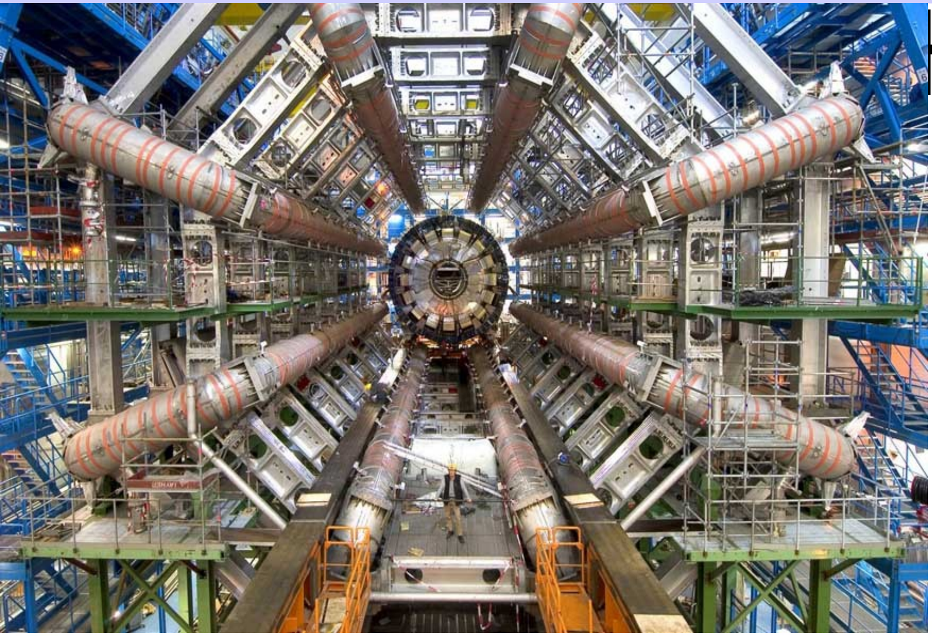
Open questions in particle physics

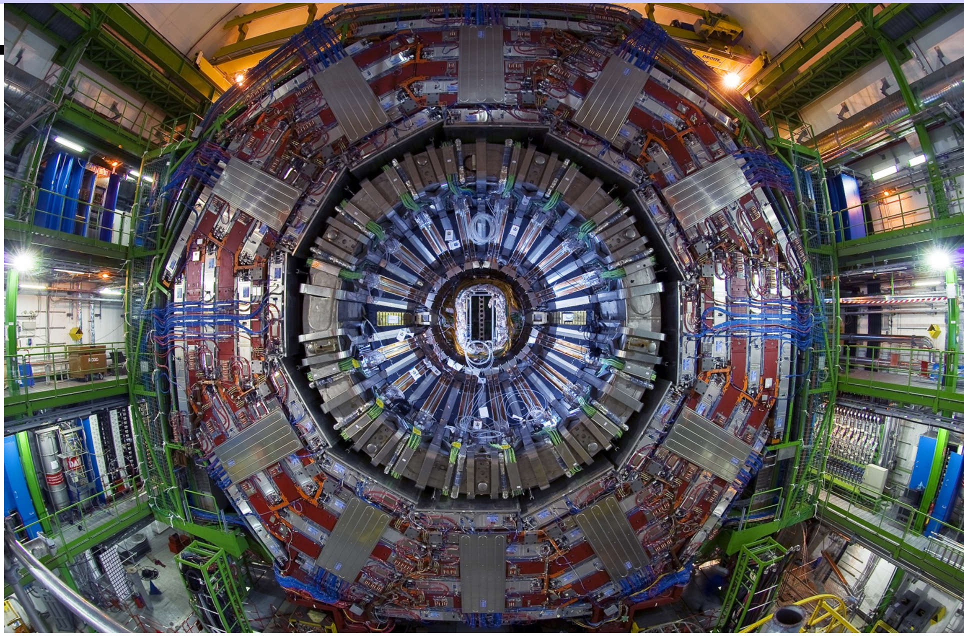
- Is the Higgs mechanism to generate weak boson and fermions masses real ?
- How to solve the problem of the hierarchy between the EWK scale and the GUT or Planck scale ?
- Are the electroweak and strong forces unified at some GUT scale
- Is the SUSY realized in nature ? Do the SUSY particles exist ? Can they explain the dark matter ?
- Do extra dimensions exist?

LHC can provide some answers



The ATLAS/CMS detectors at





Tracker: $\|\eta\| < 2.5$ SI pixels, SI strips, straw-tubes $\sigma/p_T \approx 0.05\%\ p_T \oplus 1\%$	**Tracker: $\|\eta\| < 2.5$** SI pixels, SI strips $\sigma/p_T \approx 0.015\%\ p_T \oplus 0.5\%$
Muon spectrometer: $\|\eta\| < 2.7$ Drift tubes (barrel), CSC (endcap), RPCs $\sigma/p_T \approx 10\%$ (1 TeV muons)	**Muon spectrometer: $\|\eta\| < 2.6$** Drift tubes (barrel), CSC (endcap), RPCs $\sigma/p_T = 10\ \%$ (1 TeV μ)
EM Calorimeter: $\|\eta\| < 3.2$ Lead/LAr $\sigma/E \approx 10\% / \sqrt{E} \oplus 0.7\%$	**EM Calorimeter: $\|\eta\| < 3.0$** Lead tungstate (PbWO4) crystals $\sigma/E = 2.8\ \%/\sqrt{E} \oplus 0.3\ \%$ (barrel)

...in preparation for real data

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

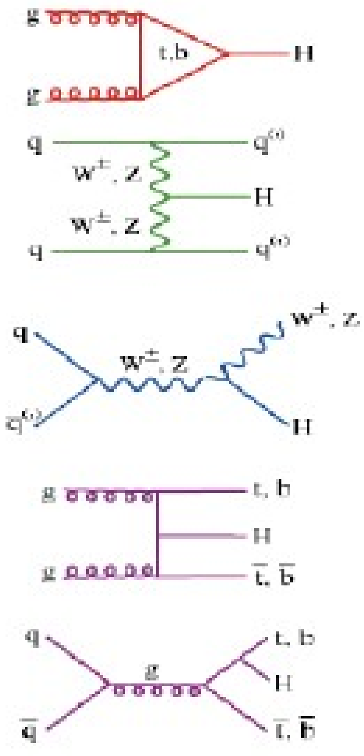
- **Full simulation**/closer to the real experimental set-up → start-up conditions (miscalibration/misalignment of the detectors) used

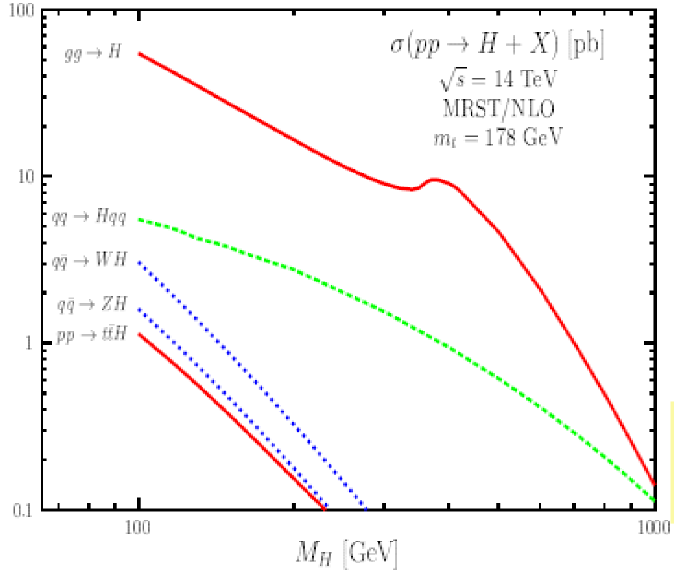
- Focus on **data driven methods** to estimate background and efficiency from data → evaluation of systematics

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

SM Higgs searches

SM Higgs production at LHC

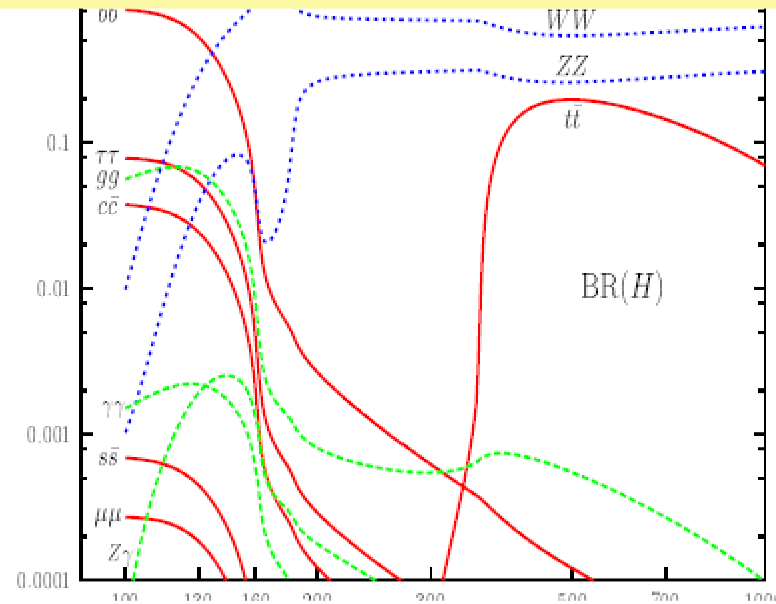




- Higgs production cross-section (NLO): 0.1-50 pb
- gluon fusion dominates at LHC especially at low m_H

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

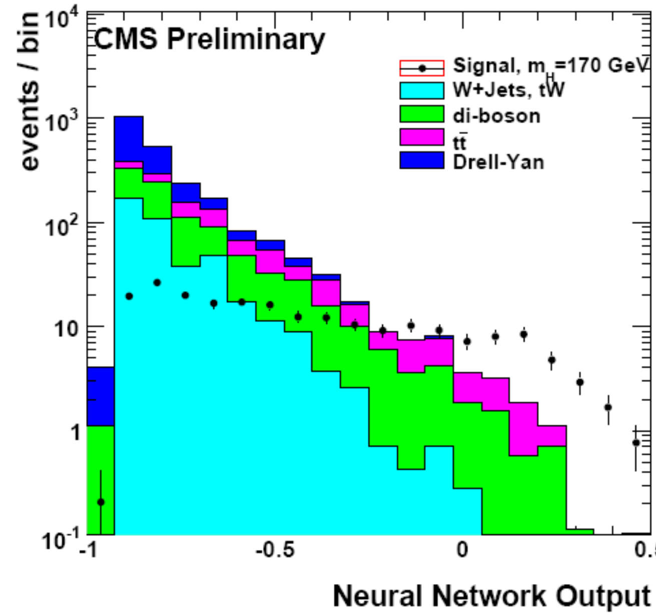
H → WW → llνν analysis

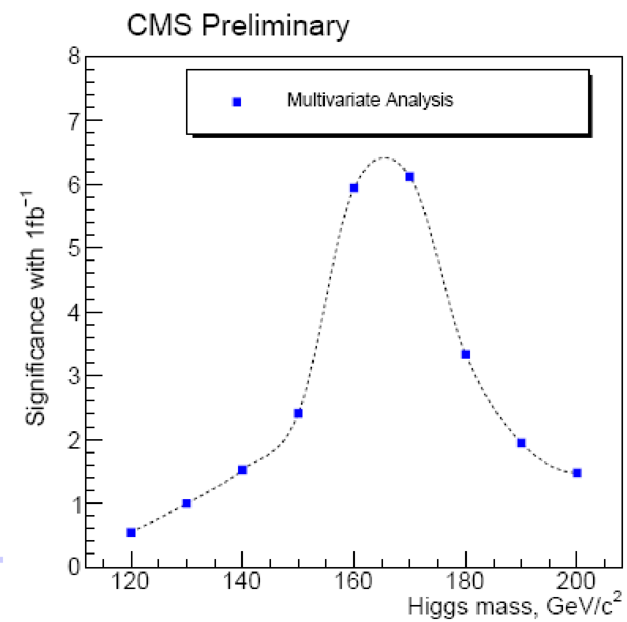
- Signatures: 2 isolated high p_T leptons + MET, no hard jet in the central region, no H mass peak
- Backgrounds: tt, DY, di-boson, tW, W +jets

Preselection strategy:
- Single lepton triggers
  - 2 isolated leptons opp. charge
  - p_T 1,2>10 GeV or at least one p_T>20 GeV

- 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 tt and WW bkg rates and jet faking leptons rate

6,

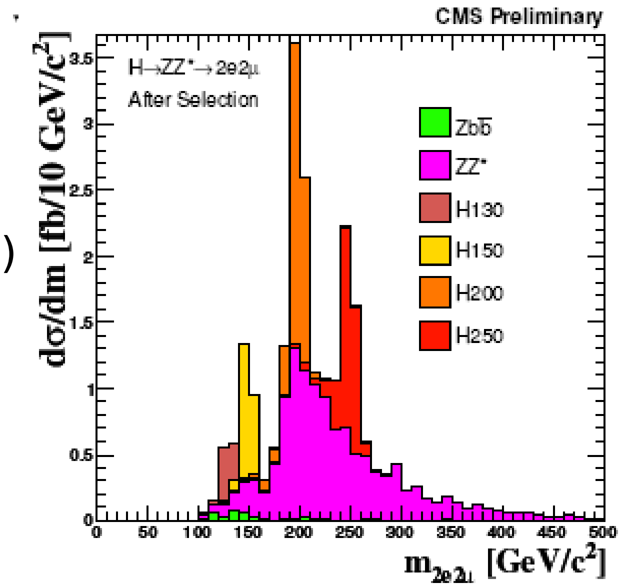


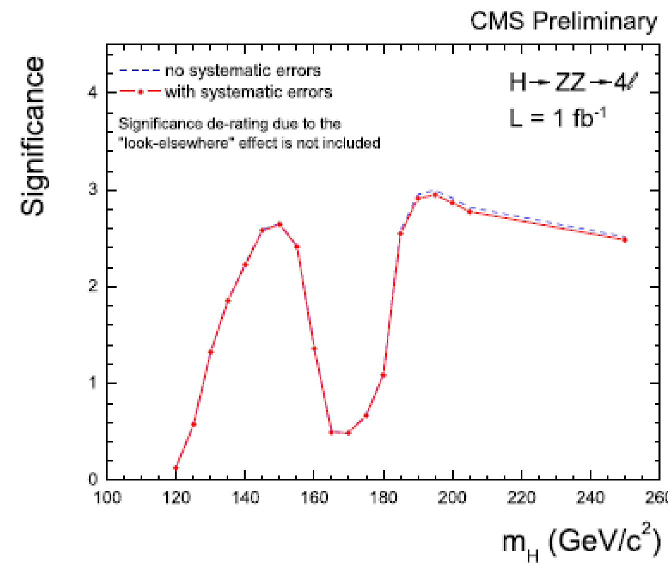


H → ZZ → 4l analysis

- 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
- control from real data of
  - the efficiencies (lepton and jet reconstruction)
  - the estimation of ZZ and Zbb bkg rates

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

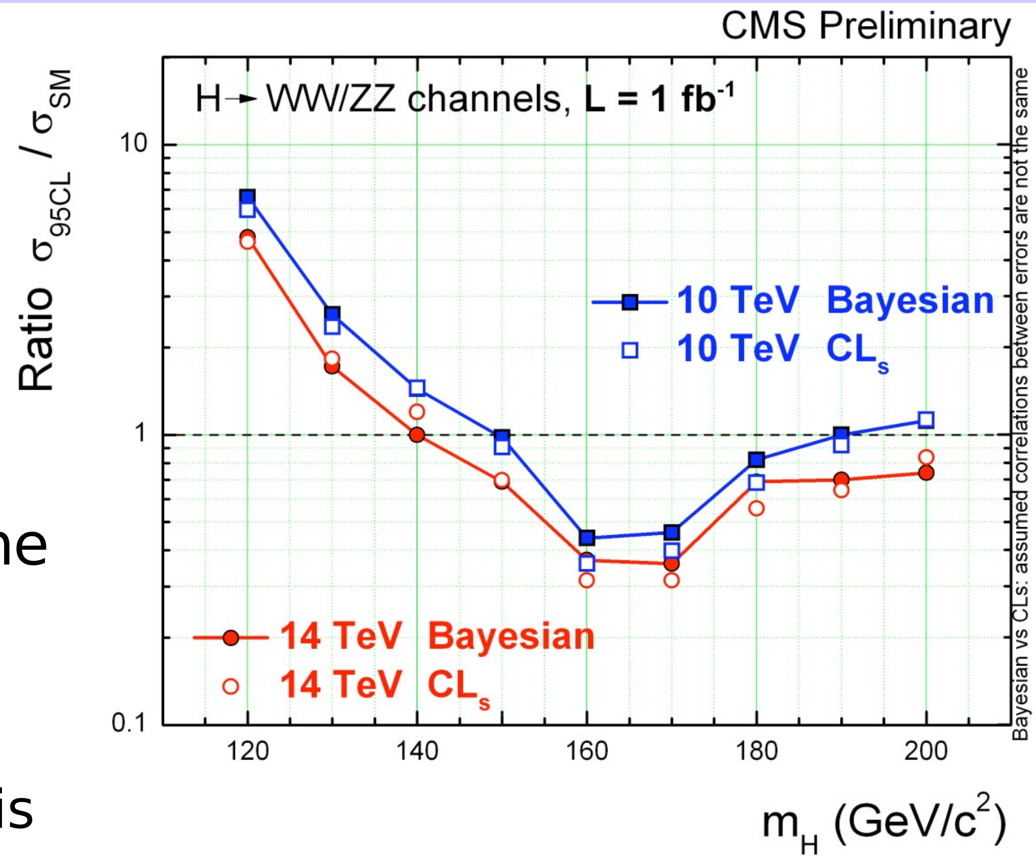




$H \to ZZ$ and $H \to WW$ com

In absence of a signal
→ UL on σ

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



Projection at 10 TeV:

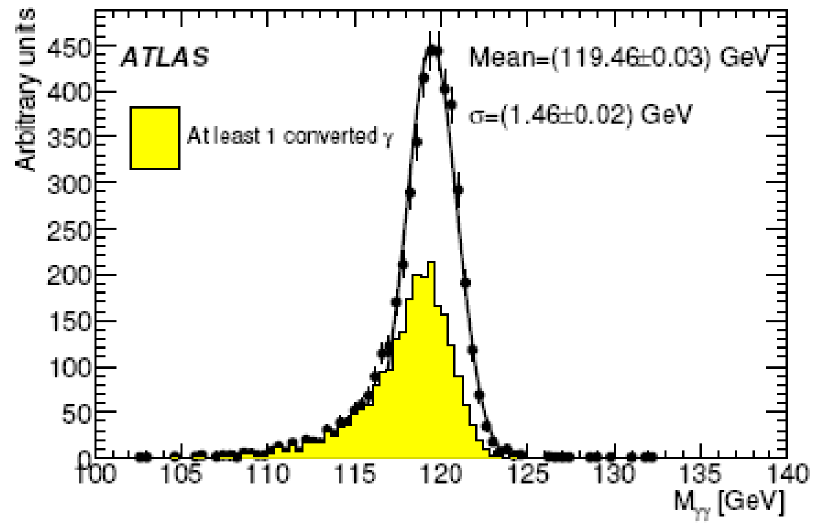
- Most important effect is the change in **σ**
  - -- gg→H: 10 TeV/14 TeV is ~0.54
  - -- WW/ZZ: 10 TeV/14 TeV is ~0.65
- Rescaling of signal and main backgrounds yields from the 14 TeV analyses

→ 14→**10 TeV** is approximately equivalent to a loss of a factor 1.5 in sensitivity

$H \rightarrow \gamma\gamma$

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

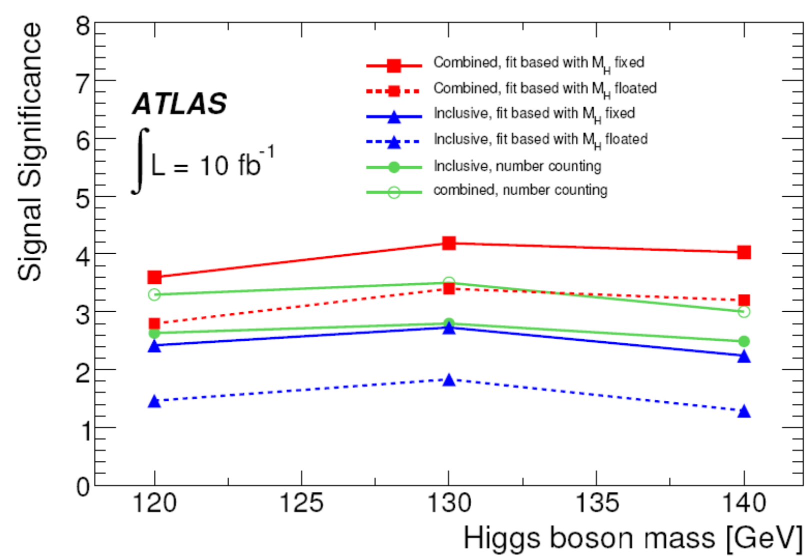
Backgrounds: *irreducible* (gg→γγ, qqbar, qg→γγ, pp→γ+jets (2 prompt γ); *reducible* (pp→γ+jets (1 prompt γ + 1 fake γ), pp→jets (2 fake γ), fake γ from $\pi^0 \rightarrow \gamma\gamma$



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.,

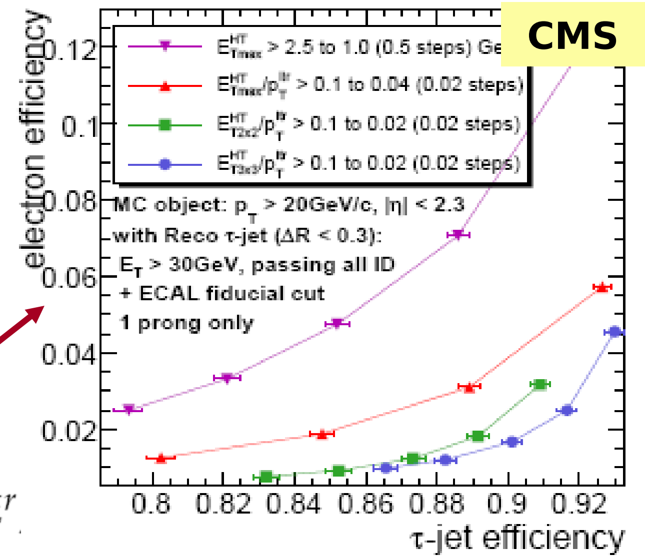


→ significance based on event counting of **2.6** with **10 fb⁻¹** for m_H = **120 GeV** in the case of **inclusive analysis**

VBF qqH, H → ττ → l+jets

Important channel for Higgs discovery in 115 < m_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

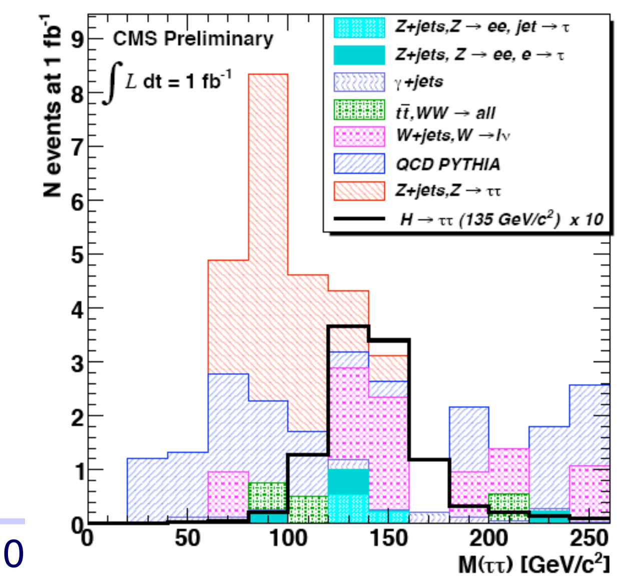


- **Problematic issue: electrons faking τ jets**

$E^{HT}_{T\,max}$ and $E^{HT}_{T\,max}/p^{ltr}_T$

- **Offline analysis:** arate e/τ:

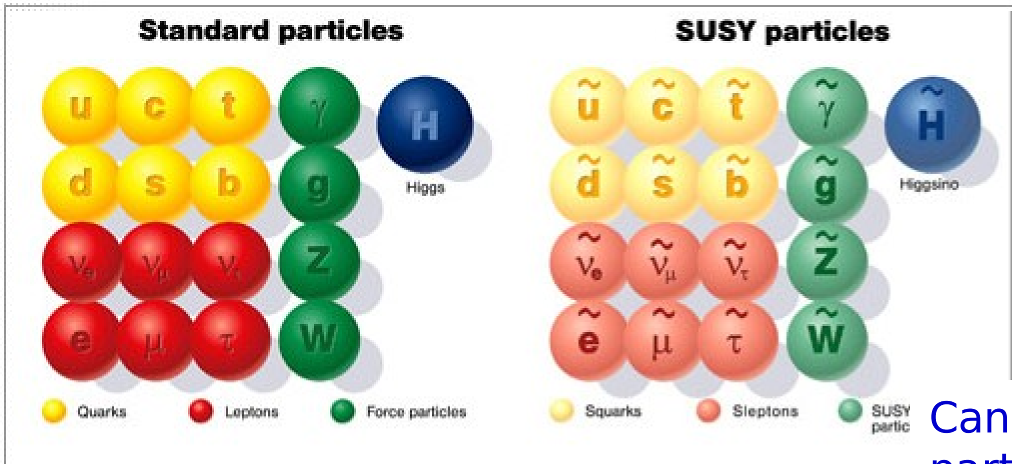
Lepton Counting	VBF Event Selection
Lepton Selection	Mass Reconstruction
Vertex Selection	Central Jet Veto
τ -jet Selection	Background Rejection
Selection of VBF Jets	Lepton-MET system



- No signal evidence is expected at **1 fb^{-1}** but it is a discovery channel at 30 fb^{-1}.

Searches for SUSY

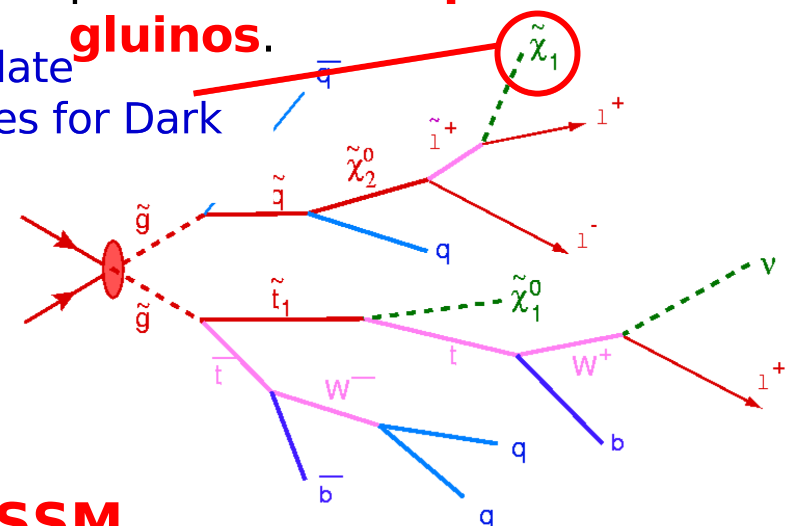
Searches for SUSY



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:

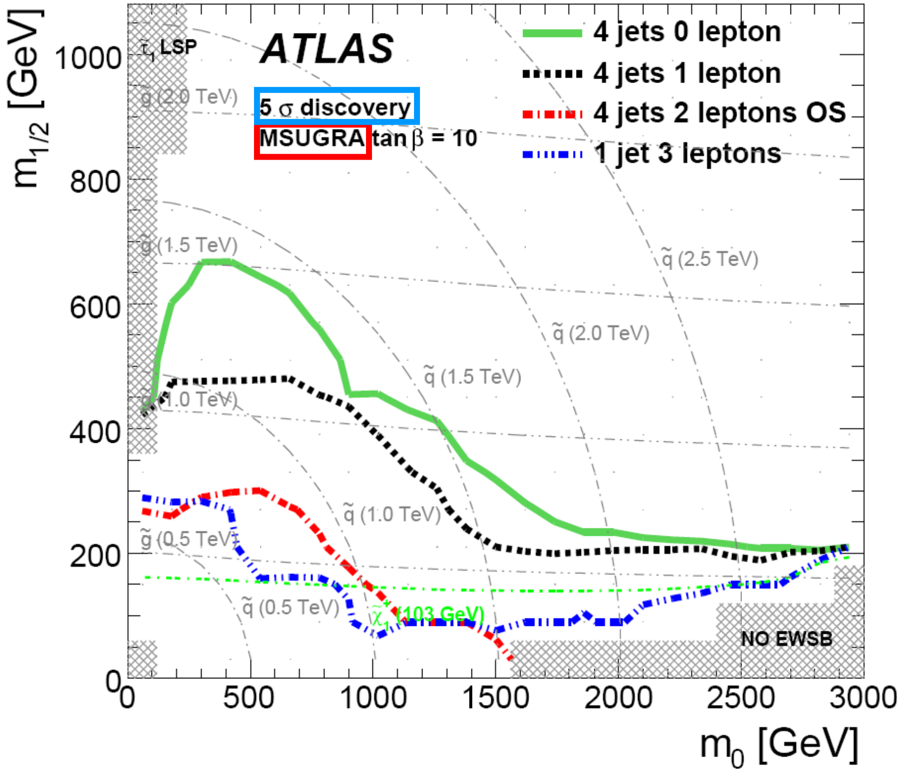
- multiple jets, often energetic
- + possibly some lepton,
- + missing E_T
- multileptons + missing ET

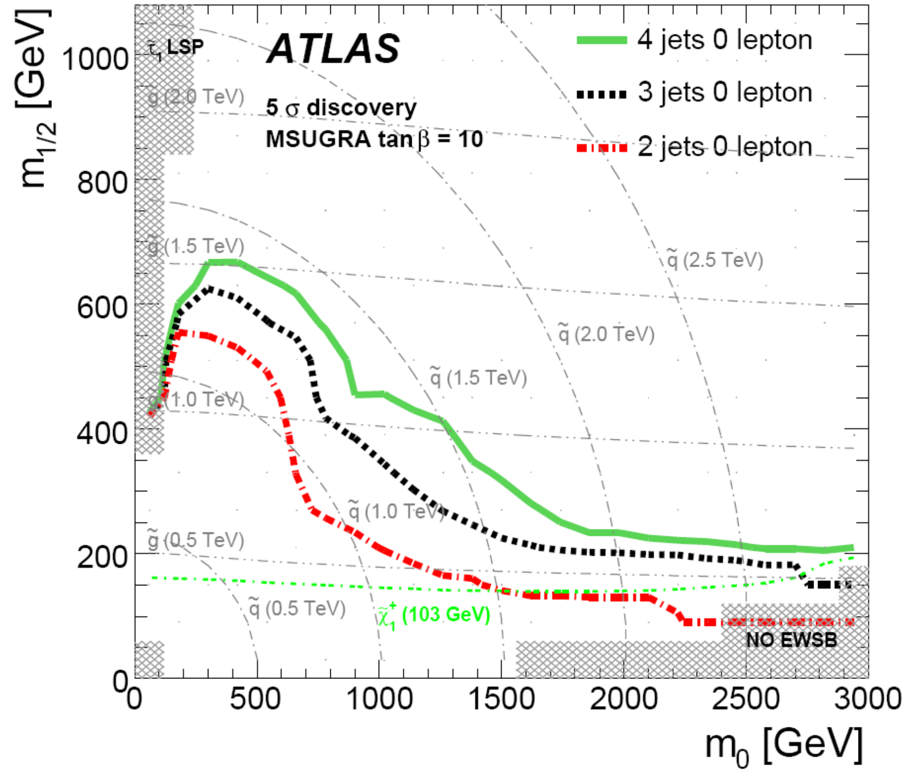
Most studies done in the context of **MSSM** with R-parity conservation, squarks and gluinos heavy

-- SUSY breaking scenarios considered:

- **mSUGRA - minimal SuperGravity**
- GMSB - Gauge Mediated SUSY Breaking

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

SUSY searches with di-jet

$$pp \rightarrow \tilde{q}\tilde{\bar{q}}, \quad \tilde{q} \rightarrow q\,\tilde{\chi}_1^0 (\text{LSP})$$: 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	$\tan\beta$	sign(μ)	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 lil

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

Selection cut	QCD	$t\bar{t}$,W,Z	$Z \rightarrow \nu\bar{\nu}$	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

Data driven techniques for:

α bkg estimation via matrix method

α 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}

BSM searches

Beyond SM: Z' → e^+e^-

Massive gauge bosons expected in several models; **Z'** in SSM (sequential standard model), **G** in Randall-Sunc Phys. Rev. Lett. **83** (1999) 3370–3373

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

Model mass (GeV/c^2)	$M = 1000$	$M = 1500$	$M = 2000$	$M = 2500$
SSM Z'				
$\sigma \cdot$ 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 ($c = 0.1$)				
$\sigma \cdot$ 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

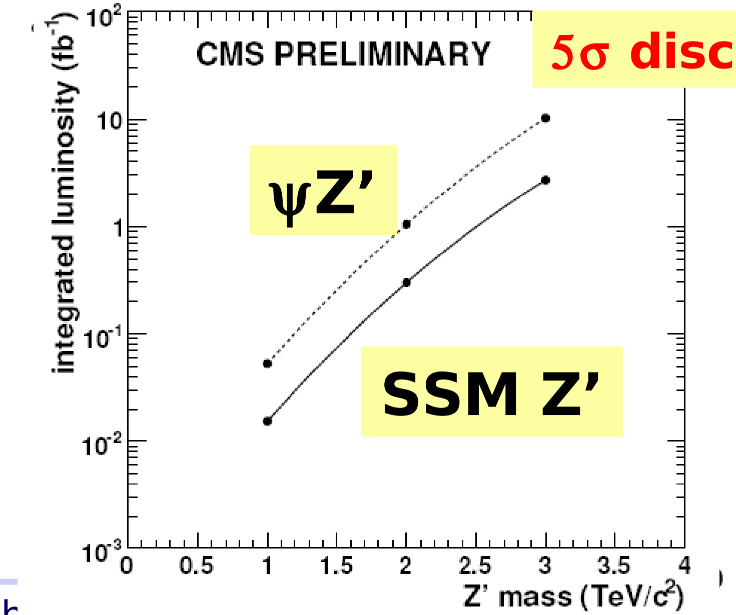
Important features:

-- High threshold trigger: E_T> 80 and loose isolation OR E_T>200 GeV in ECAL

-- saturation in ECAL electronics for very high energy deposition in ecal crystals

-- efficiency checked using Tag & Probe with data (Extr. from Z or DY)

tt measured with data



Beyond SM: Z’ $\longrightarrow \mu^+\mu^-$

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.

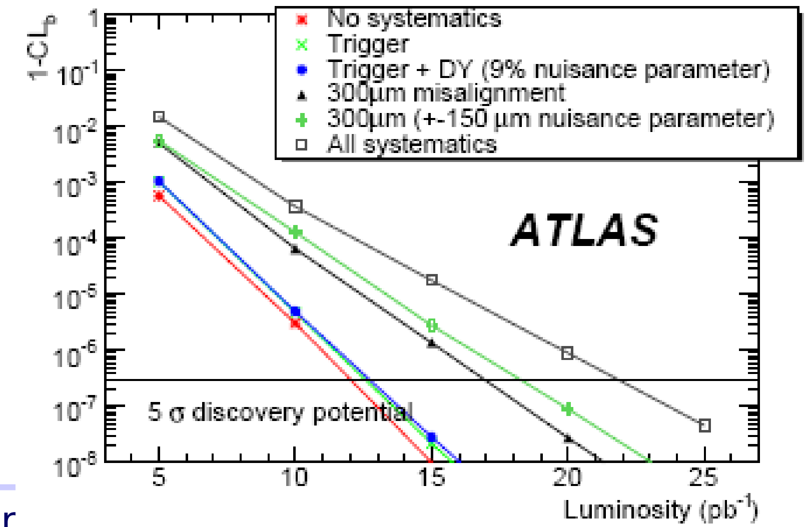
Background sources: DY (irreducible), inclusive jets, W+jets, Z +jets.

Xsec in fb

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
$p_T \geq 30$ 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 (difficulty to determine the charge of muon)
- Luminosity needed for a **5σ discovery** ranges from **20 to 40 pb⁻¹**, which is competitive with the di-electron channel.



Beyond SM: Heavy stable charged particles

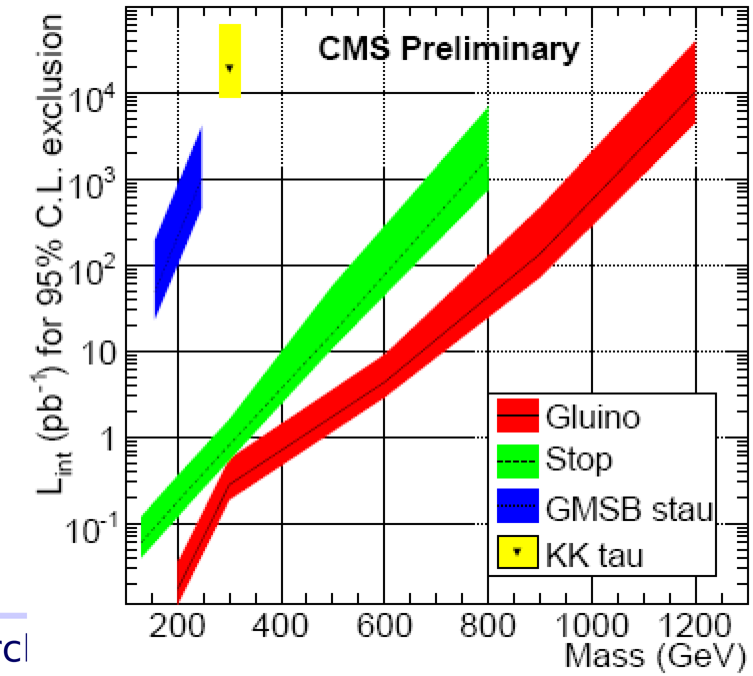
Several models predicting HSCP: susy with R-parity and extra dimension with KK-parity:

- **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

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

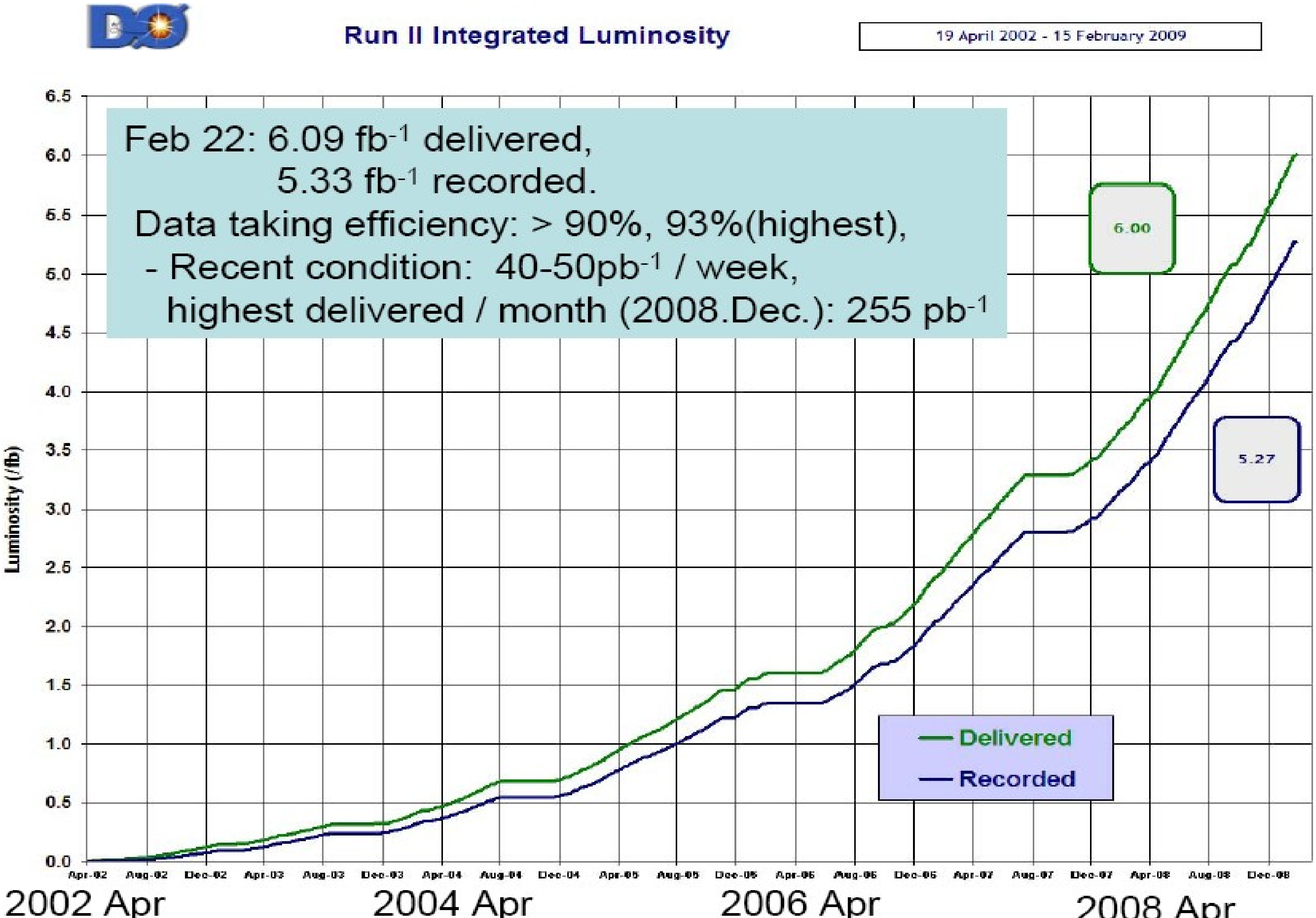
- measuring TOF with the Barrel Muon Drift Tube
- measuring dE/dx with the Silicon tracker

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

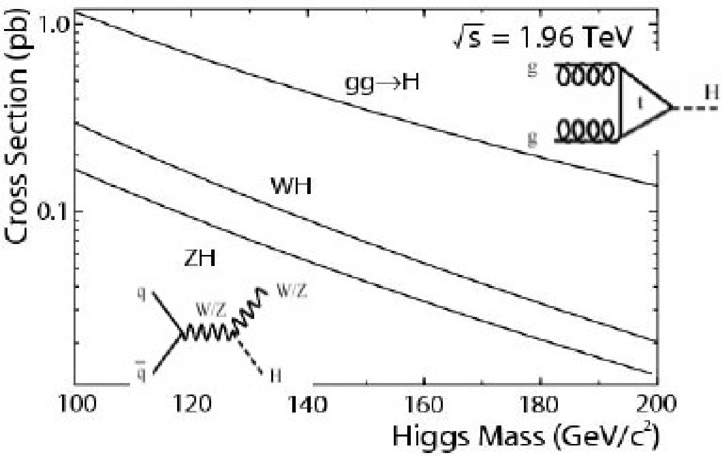


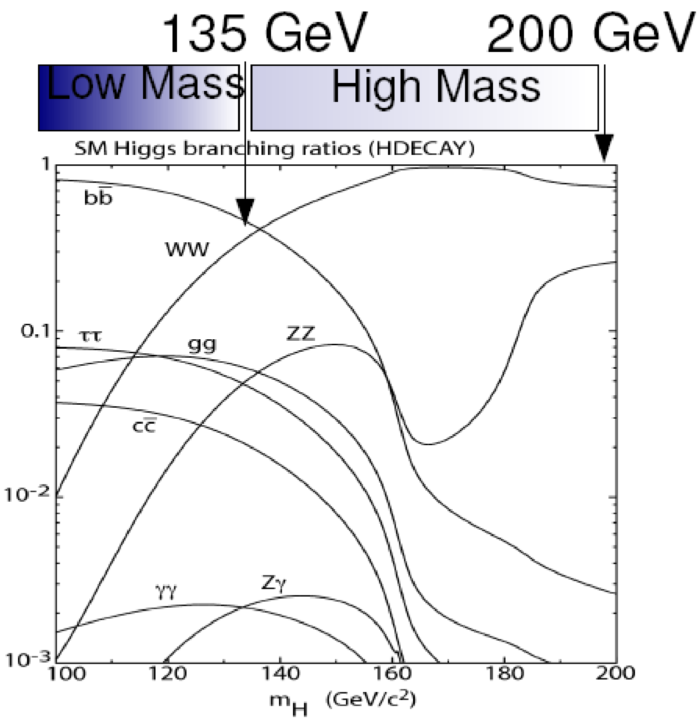
SM Higgs searches at Tevatron

Run II integrated lumi. at Tevatron



SM Higgs search at Tevatron



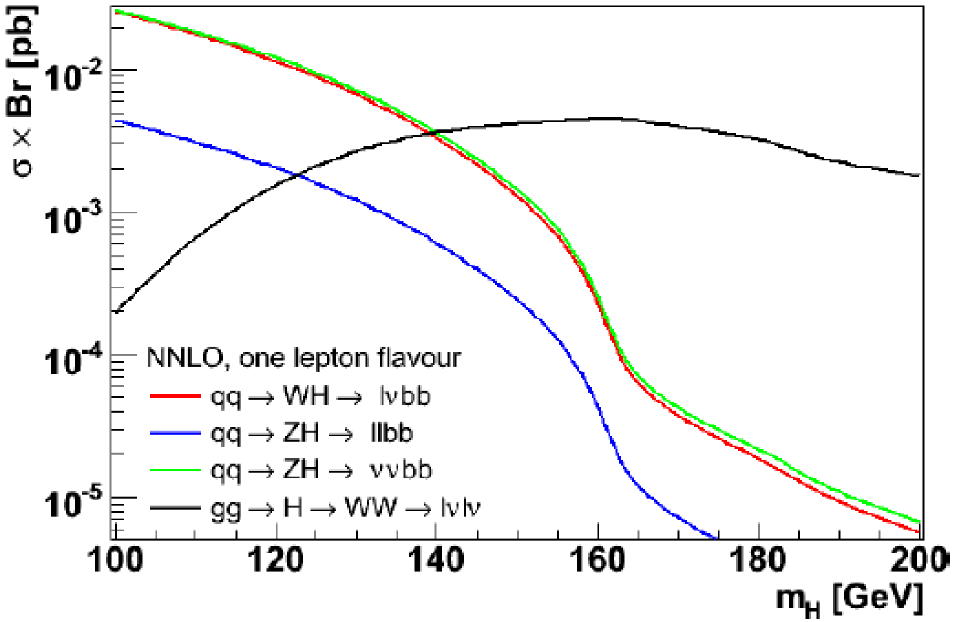


- **Production**
  1. **Gluon fusion** (0.8 ~ 0.2 pb)
  2. **WH associated production** (0.2~0.03pb)
  3. **ZH associated production** (0.1~0.01pb)
- **Decay**
  - **m_H < 135 GeV** **H → bb is dominant**
  - **m_H > 135 GeV** **H→ WW**

Analysis Strategy	**Background**
m_H < 135 GeV **WH/ZH + H→ bb**	top, Wbb, Zbb
m_H > 135 GeV **Gluon fusion + H→WW**	WW, WZ Drell-Yann

+

SM Higgs search at low mass



ZH→νν bb	WH→lν bb	ZH→ll bb
MET+bb	l+MET+bb	2l(e/μ)+bb
Rich signal	Rich signal	less signal
0-lepton	1-lepton	2-lepton

Multi-Jet (MJ) BG:

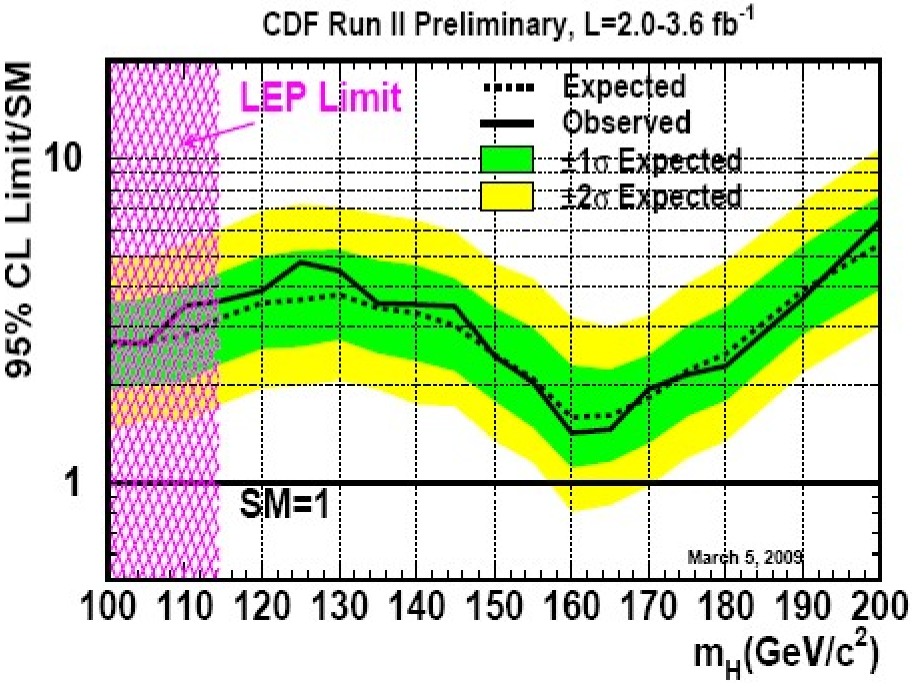
HIGH → LOW

Extension:

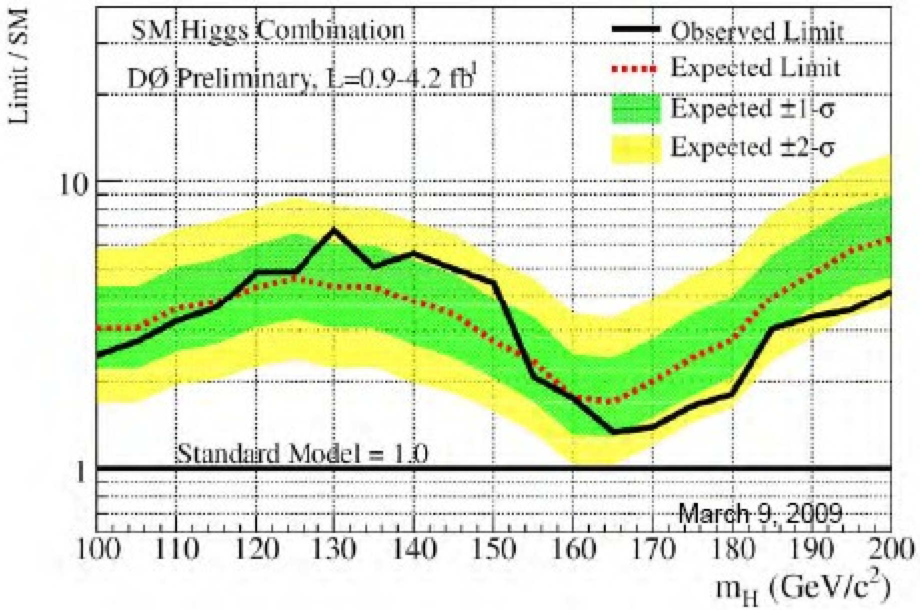
- H→ γγ
- VH→τ + jets
- ttH→ttbb
- Signal from gg->H, VH, VBF

CDF and D0 limits at low mass

<u>CDF Combination</u> (2009 Mar)



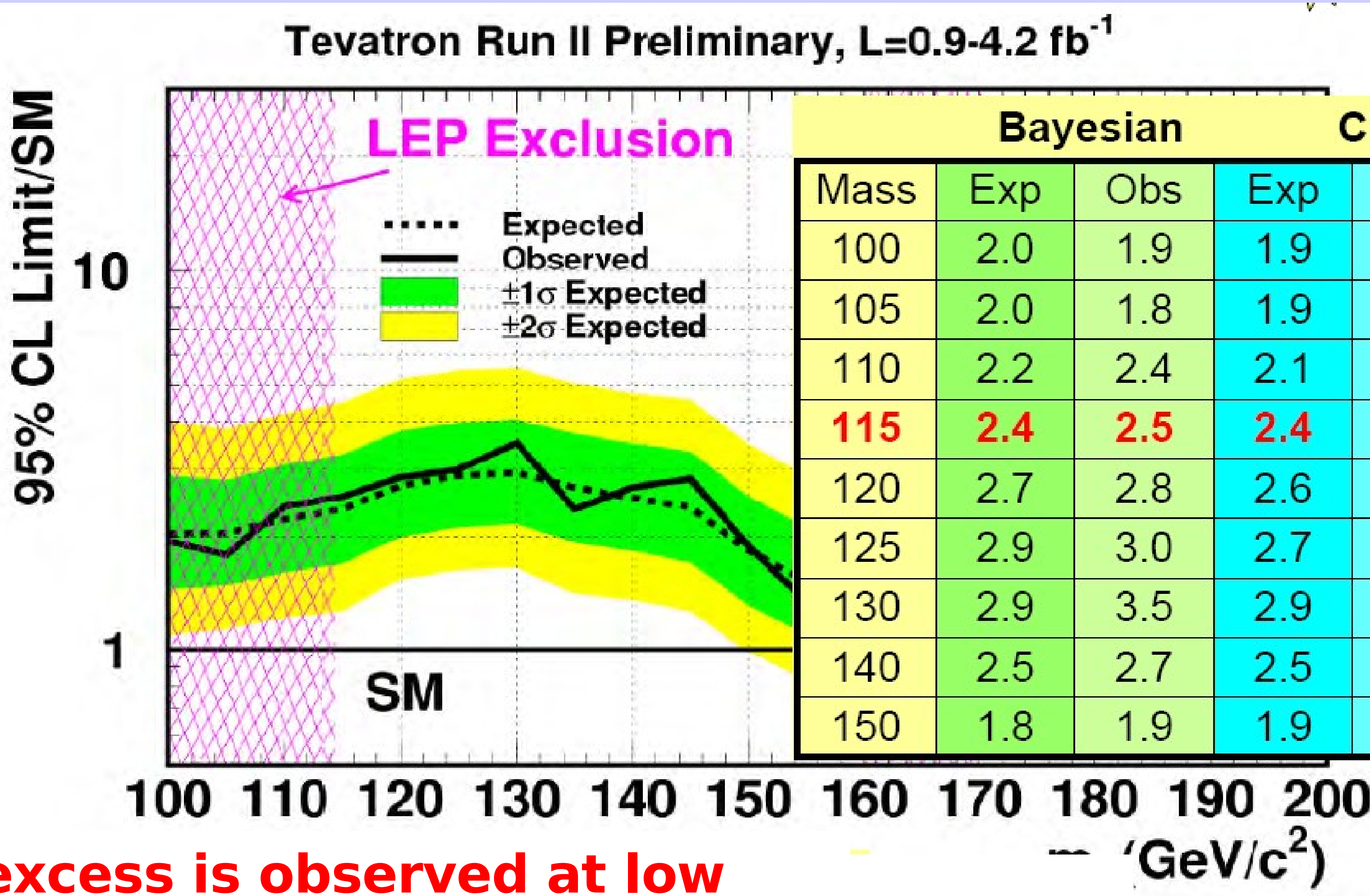
<u>DØ Combination</u> (2009 Mar)



Limit / SM @ m_H = 115 GeV
CDF : exp 3.2 obs 3.8

Limit / SM @ m_H = 115 GeV
DØ : exp 3.8 obs 3.6

CDF and D0 combination at low



	Bayesian		CLs	
Mass	Exp	Obs	Exp	Obs
100	2.0	1.9	1.9	1.7
105	2.0	1.8	1.9	1.7
110	2.2	2.4	2.1	2.2
115	**2.4**	**2.5**	**2.4**	**2.6**
120	2.7	2.8	2.6	2.8
125	2.9	3.0	2.7	2.9
130	2.9	3.5	2.9	4.0
140	2.5	2.7	2.5	3.1
150	1.8	1.9	1.9	2.0

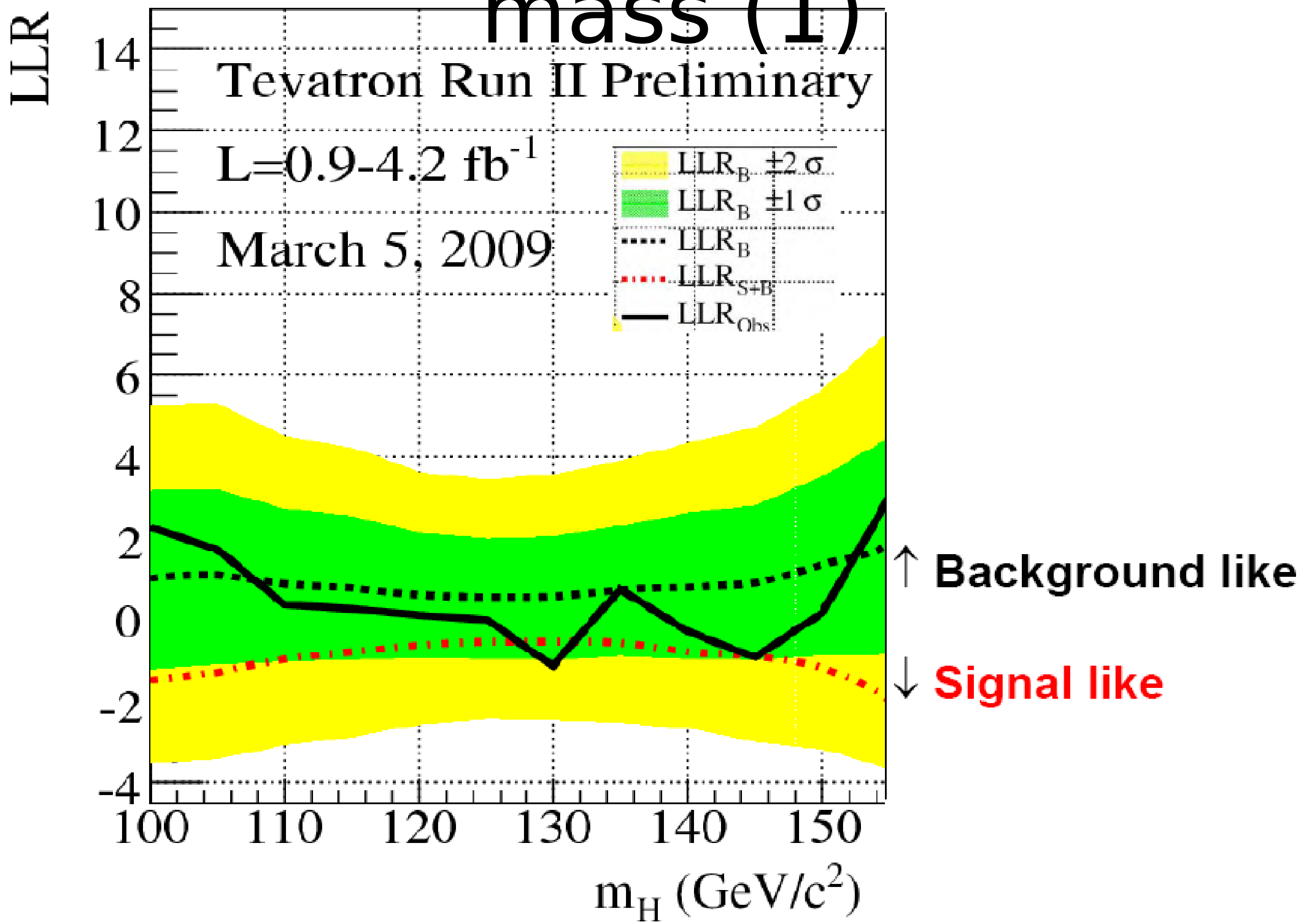
No excess is observed at low mass

15GeV

m_H<150 GeV: expected limit always below 3xSM!

→ Analyses are based on average ~ 2.5 fb^{-1}.

CDF and D0 combination at low mass (1)

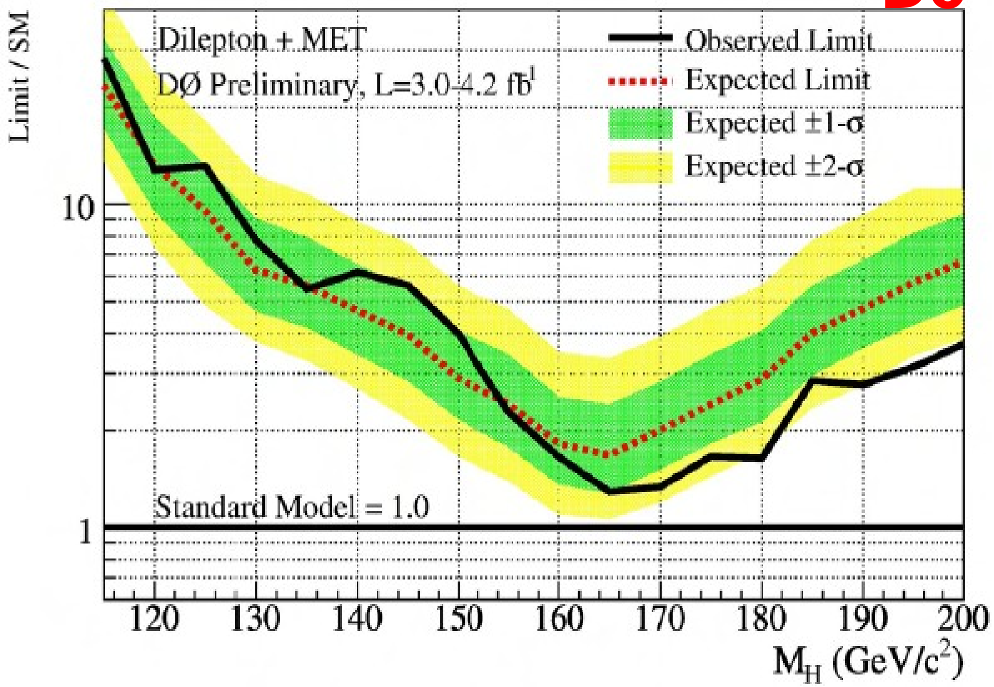


Both experiments will present results with more than **5 fb^{-1} this Summer**!

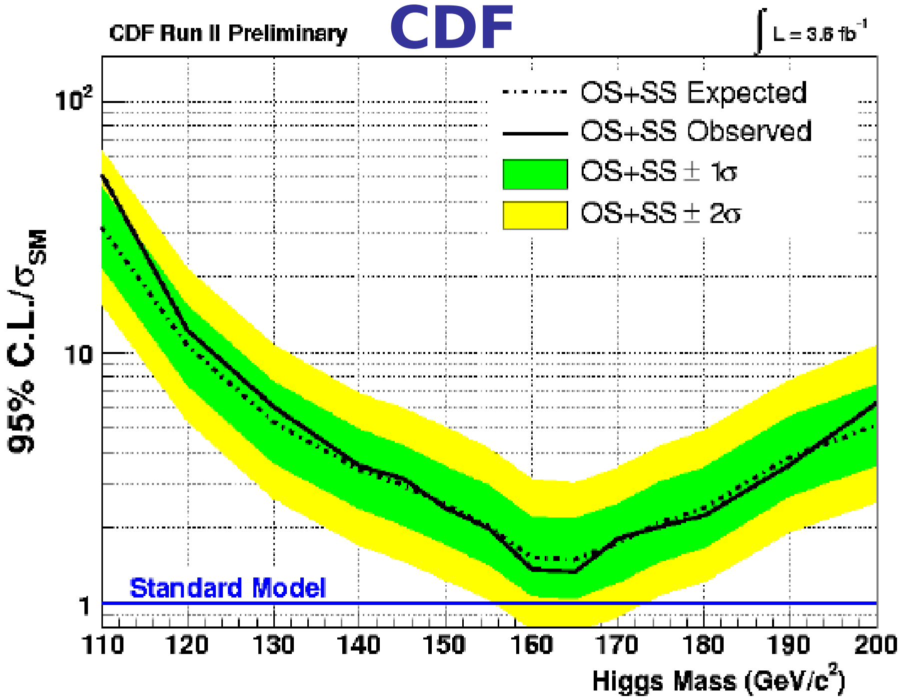
CDF and D0 limits at high mass

$H \rightarrow WW^* \rightarrow l \nu l \nu$ Limits

D0



CDF



For $M_H = 165$

Exp limit 1.7 x σ_{SM}

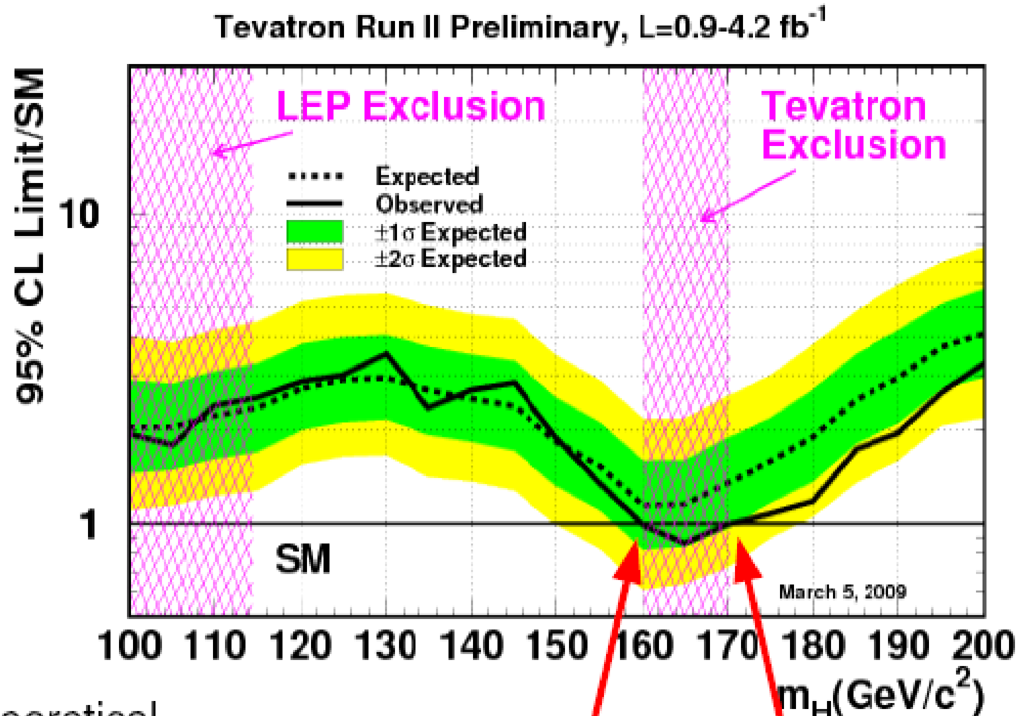
Obs limit 1.3 x σ_{SM}

At $M_H = 165$,

Exp limit - $1.5x\sigma_{SM}$

Obs limit- $1.3x\sigma_{SM}$

CDF and D0 combination at high

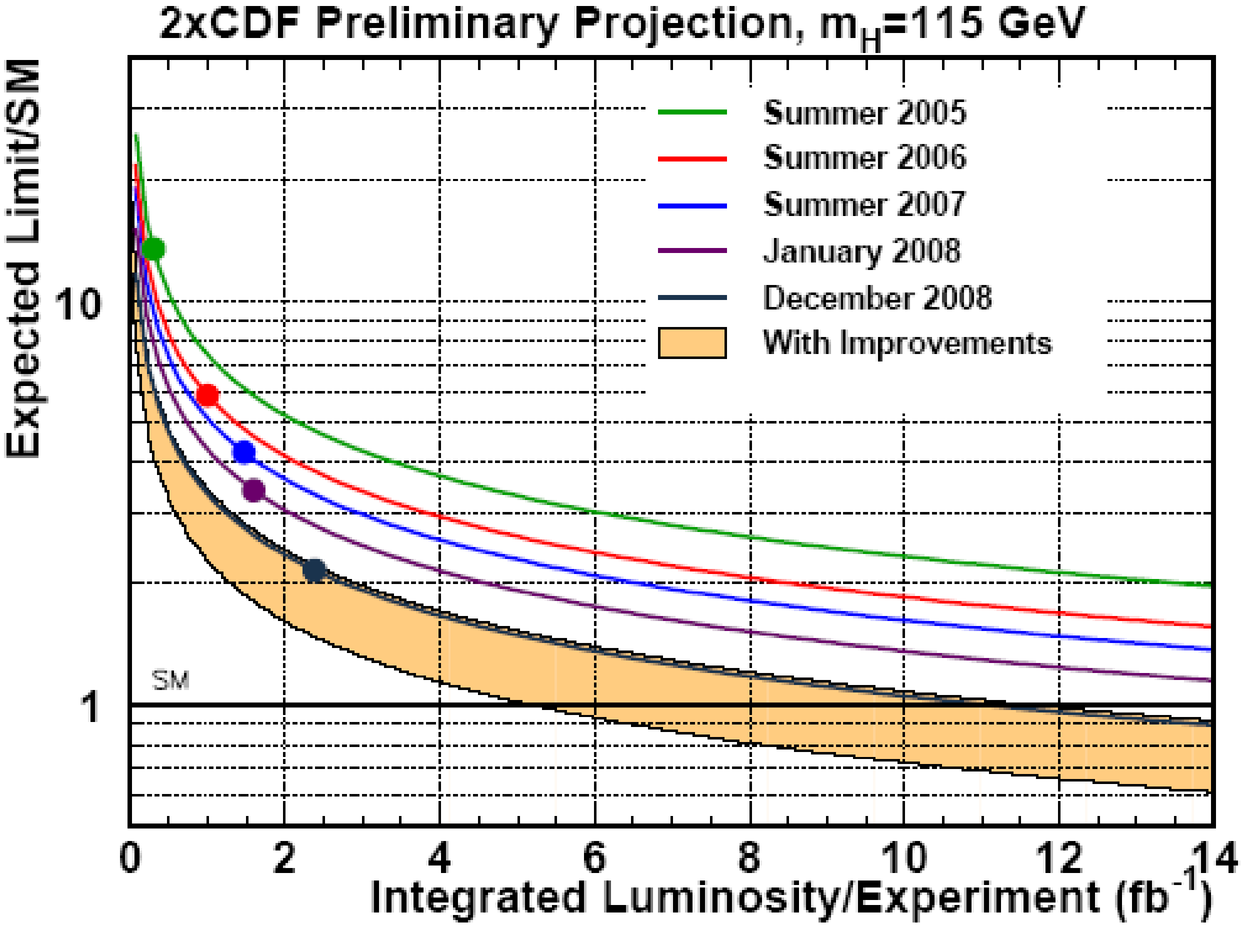


Use latest theoretical inputs including: $\sigma(gg \to H)$ by de Florian & Grazzini w/ MSTW 2008 NNLO PDF set

Bayesian	155	160	165	170	175	180	185	190	195	200
Expected	1.5	1.1	1.1	1.4	1.6	1.9	2.2	2.7	3.5	4.2
Observed	1.4	0.99	0.86	0.99	1.1	1.2	1.7	2.0	2.6	3.3
CIs	155	160	165	170	175	180	185	190	195	200
Expected	1.5	1.1	1.1	1.3	1.6	1.8	2.5	3.0	3.5	3.9
Observed	1.3	0.95	0.81	0.92	1.1	1.3	1.9	2.0	2.8	3.3

SM Higgs is excluded with the mass range 160 – 170 GeV/c² @ 95% CL

Scaling of limits with the int. lumi



Result improves almost linearly with $\int \mathcal{L}\, dt$, not $\sqrt{\int \mathcal{L}\, dt}$.

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 **$\sqrt{s}$=10 TeV with 200 pb^{-1}** detector conditions.

- **Tevatron** results:

  → **SM Higgs is excluded in the mass range 160–170 $GeVc^2$ @ 95% CL**

Backup slides

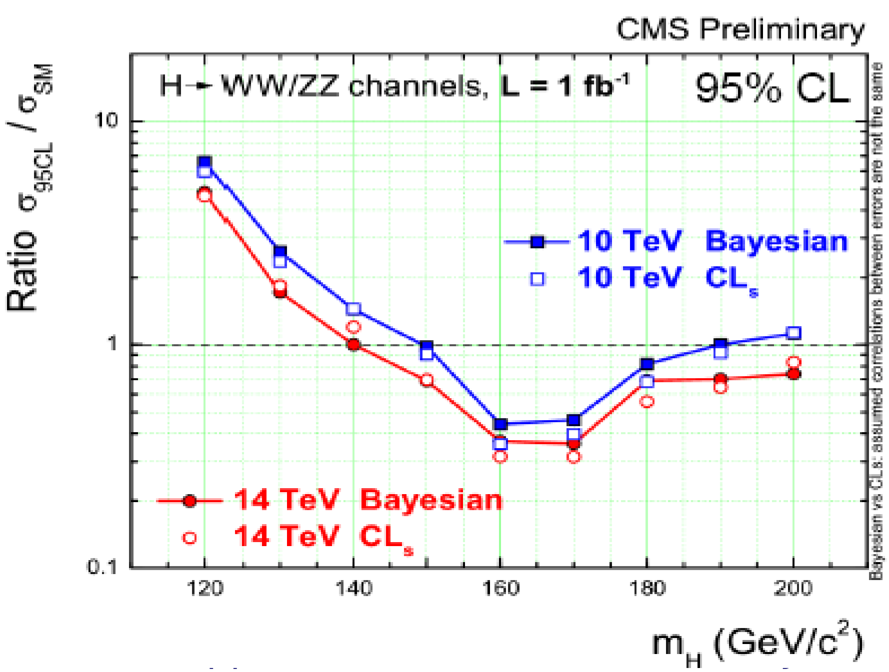
Bayesian vs frequentist

CMS Higgs combination upper limits (preliminary)

- Likelihood based on event counts in the $H \rightarrow WW$ and ZZ analyses
- Two approaches:
  - Bayesian based with flat prior for $r = \sigma_H / \sigma_{H,SM} > 0$ and integration of systematics in the likelihood function:

$$\mathcal{L}(r) = \frac{1}{A} \int \prod p(n_i^{obs} | b_i + r\, s_i)\, g_T(x)\, dx$$

  - conservative frequentist CLs (using RooStatsCms software)



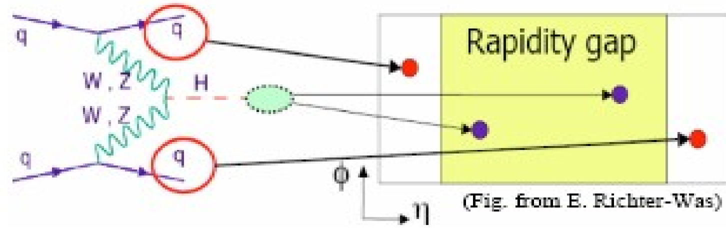
- Both give close expected upper limits at O(10%), although differences:
  - in the assumption on correlations
  - in the statistical methods

  → in agreements to the differences seen in the Tevatron combinations

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



(Fig. from E. Richter-Was)

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)

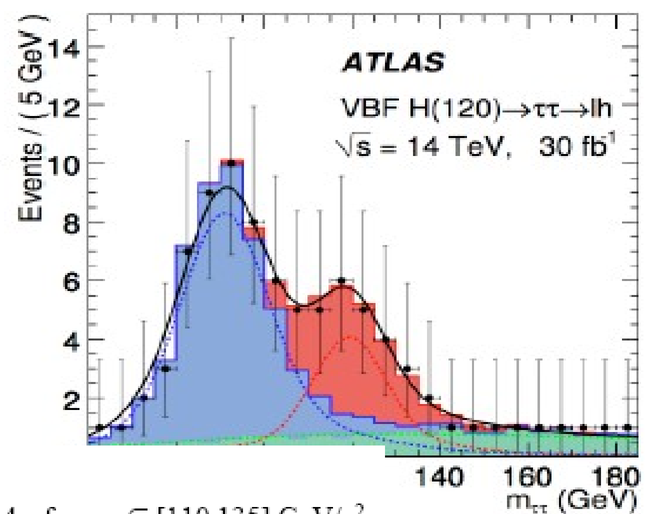
→ Large impact of the underlying event (UE) and pile-up events (E_T^{mis} resolution, CJV)

⇒Very difficult experimentally, but also very promising

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 $m_H \pm$ 15 GeV/c^2 : S/B ~ 3

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



⇒ 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

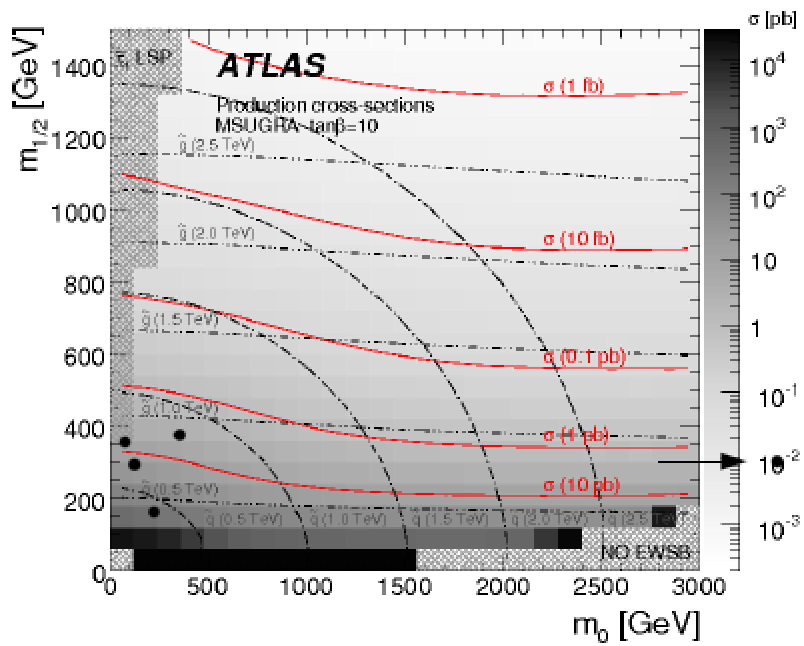
The hadron-hadron channel is considered as well but needs further studies (QCD background)

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
-- $\mu > 0$
-- $m(\tilde{g}) < 1$ TeV
-- Comparable $\tilde{g}$ and $\tilde{q}$ masses
-- $m(\tilde{g})/m(\tilde{\chi}_1^0) \approx 6\text{-}8$
-- NLO xsec used

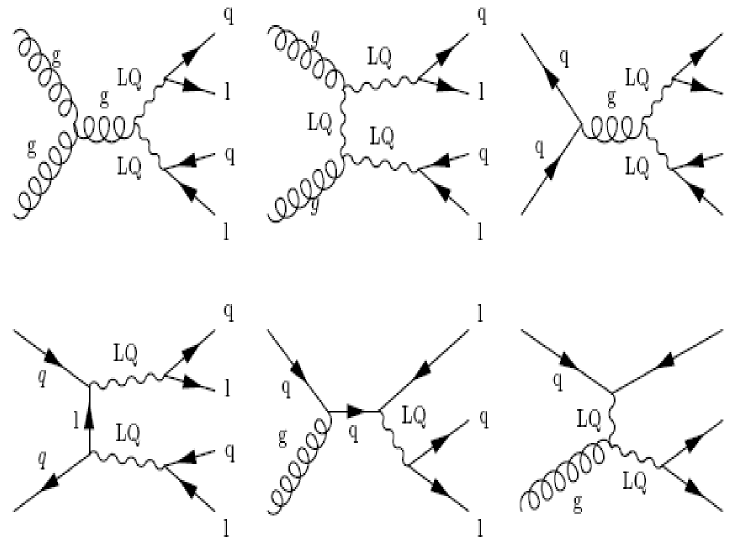
Beyond SM: Leptoquarks

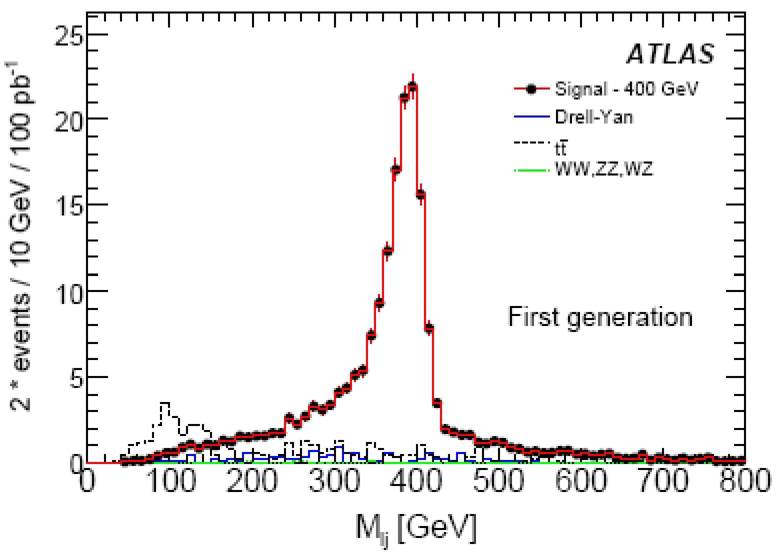
Leptoquarks (LQ) = hypothetical bosons

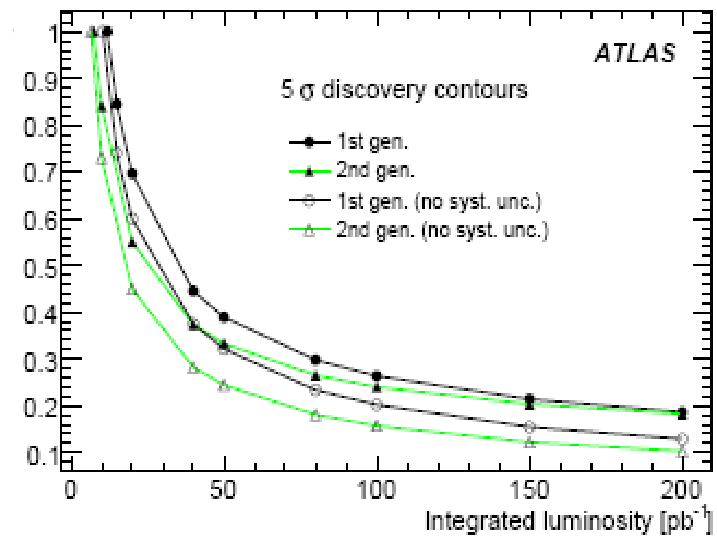
- with both quark and lepton quantum numbers
- decay in any combination of a lepton and a quark
- three generations of leptoquarks, each coupled to a lepton and a quark from the same SM generation.
- produced in pairs by the strong interaction or in association with a lepton via the leptoquark-quark-lepton coupling
- decay final

energetic le

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







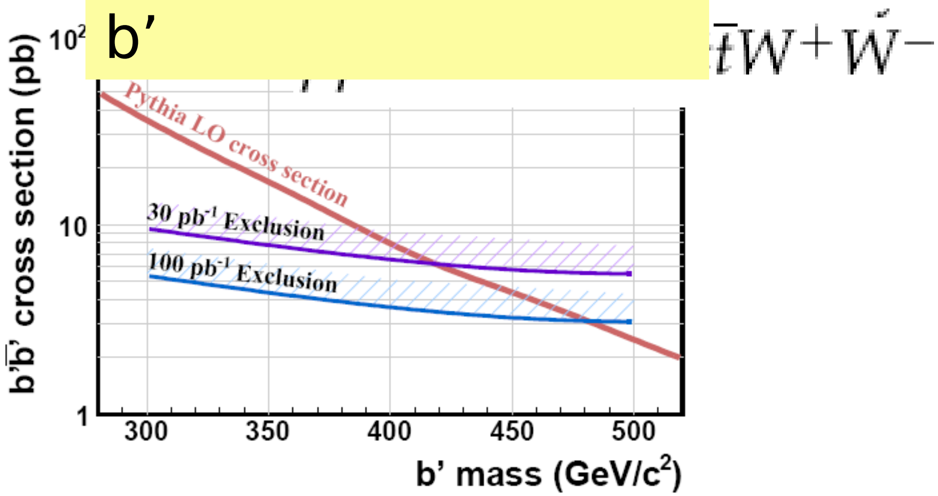
Beyond SM: 4th lepton generation

- 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

- Tevatron and ATLAS evaluated the impact of the 4th lepton gen. on the Higg

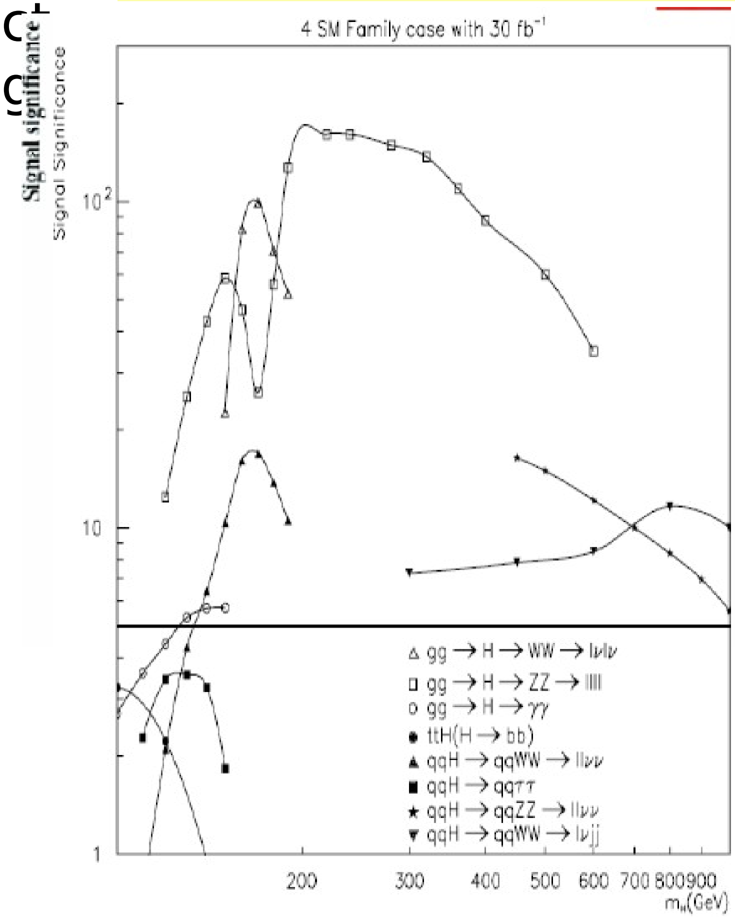
CMS searches for b'



- Significance of 7.5 for m(b') ~ 300 GeV with 100 pb-

- If no signal → m(b')<480 excluded at 95% CL

ATLAS searches



Combination of searches at low

- In total, 23 inputs from CDF, 52 inputs from DØ

Limits are at m_H=115GeV

Production	Decay	CDF		DØ	
		Lumi	Limit/SM exp (obs)	Lumi	Limit/SM exp (obs)
WH	$l\nu$ bb	2.7	4.8 (5.6)	2.7	6.4 (6.7)
WH	$\tau\nu$ bb	----	-----	1.0	42 (34)
ZH	ll bb	2.7	9.9 (7.1)	3.6	8.0 (9.1) *
VH	$\nu\nu$ bb	2.1	5.6 (6.9)	2.1	8.4 (7.5)
VH	jjbb	2.0	37 (38)	-----	-----
All	τ + jets	2.0	30 (24)	1.0	42 (44)
All	$\gamma\gamma$	-----	-----	4.2	18 (13)
ttH	ttbb	-----	-----	2.1	45 (64)

Tevatron: method for combination (1)

At Tevatron: **High background (BG) and sizable systematic uncertainties**
→ Test **BG(b)** only and **BG+signal (s+b)** hypotheses
using **Poisson statistics accounting for systematic uncertainties.**

- We use two methods
  - Bayesian method (CDF) : Bayesian integration over likelihoods

$$\mathcal{L}(R,\vec{s},\vec{b}|\vec{n},\vec{\theta}) \times \pi(\vec{\theta}) = \prod_{i=1}^{N_C} \prod_{j=1}^{Nbins} \mu_{ij}^{n_{ij}} e^{-\mu_{ij}} / n_{ij}! \times \prod_{k=1}^{n_{np}} e^{-\theta_k^2/2}$$

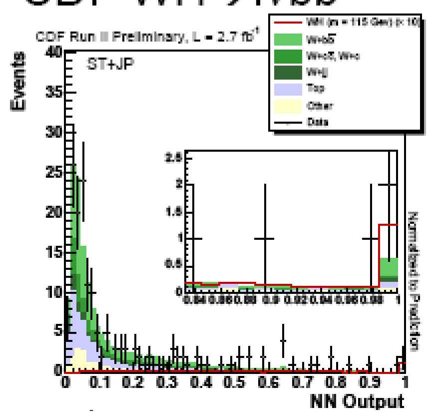
  - Modified Frequentist method, CLs (DØ)

$$LLR = -2\ln\frac{p(\mathrm{data}|H_1)}{p(\mathrm{data}|H_0)}; \quad CL_b = p(LLR \geq LLR_{obs}|H_0) \quad CL_{s+b} = p(LLR \geq LLR_{obs}|H_1) \quad CL_s = \frac{CL_{s+b}}{CL_b}$$

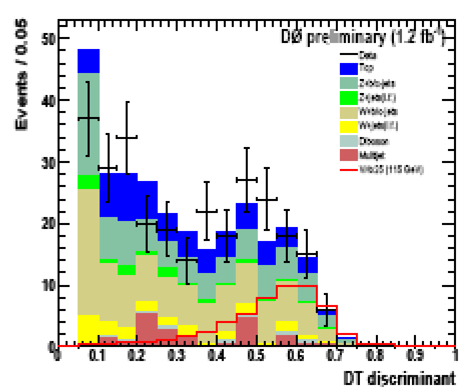
- Both methods use differential distributions, not only integrated yields.

There are 23 inputs from CDF and 52 inputs from DØ, they are orthogonal inputs.

CDF WH→lνbb



DØ VH→ννbb



Tevatron: method for combination (2)

- Treatment of systematic uncertainties
  - Systematics are included via Gaussian smearing of expected number of events.
  - Correlations of systematic uncertainties are included across all input channels.
  - CLs method fits uncertainty parameter values for each hypothesis
  - Bayesian method integrates over uncertainty parameters.

- Correlated uncertainties between CDF and DZero analyses
  - Luminosity (4%),
  - Cross section: Higgs(6%,12%), top(10%), single top(10%), diboson(6%).
- Correlated uncertainties in CDF
  - b-tagging(5-12%), JES(3-10%), gluon radiation (3-4%).
- Correlated uncertainties in Dzero
  - b-tagging(4-15%), JES(3-5%), JetID/resolution(3-5%)