Physics at LHC

13-17 July 2004 . Vienna . Austria

Notes from Physics at LHC

Physics at LHC conference

Vienna, July 2004

The Austrian Academy of Sciences

Founded in 1857, when the Academy was involved in the project of the **"First International Polar Year".** It was responsible for founding the **Central Office for Meteorology and Geomagnetism** in 1851, the establishment of mountain observatories and in 1909 founded the **Institute for Radium Research** in Vienna.

The Academy provided **Mme. Curie** with the raw material from which she first extracted **Radium**. Some famous members: **Christian Doppler**, **Ludwig Boltzmann**, **Victor Hess** (cosmic rays), **Ernst Mach** and **Erwin Schrödinger**.

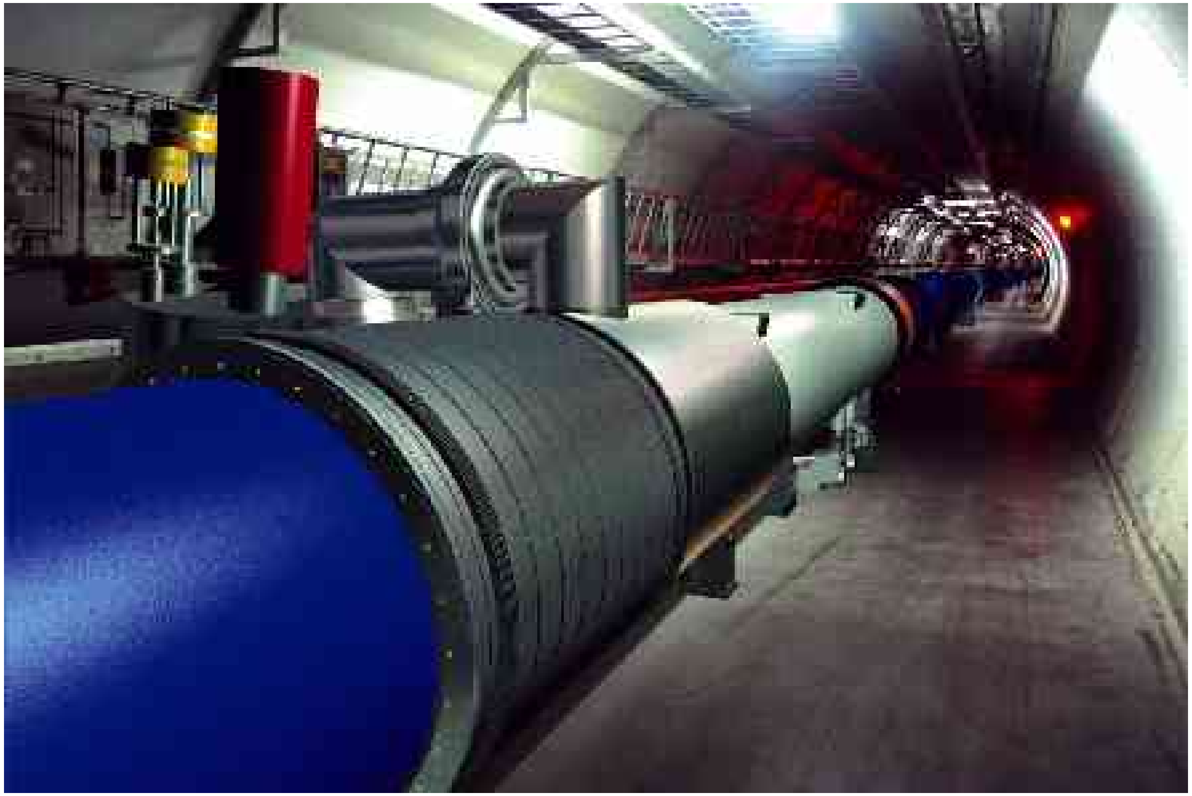
Currently, research on astronomy, materials science, nuclear fusion, atomic physics, **high energy physics**, space research and quantum optics.

The conference was held in the "**Festsaal**" of the academy. Among others, **Beethoven** and **Haydn** played their own pieces there. **Salieri** (Mozart's rival) conducted his own music there.

Outlook

- Many talks, cannot describe all here
- More information and transparencies at:
  http://wwwhephy.oeaw.ac.at/phlhc0
- Points adressed here:
  - LHC status
  - Higgs physics
  - Comissioning

The LHC and the experiments



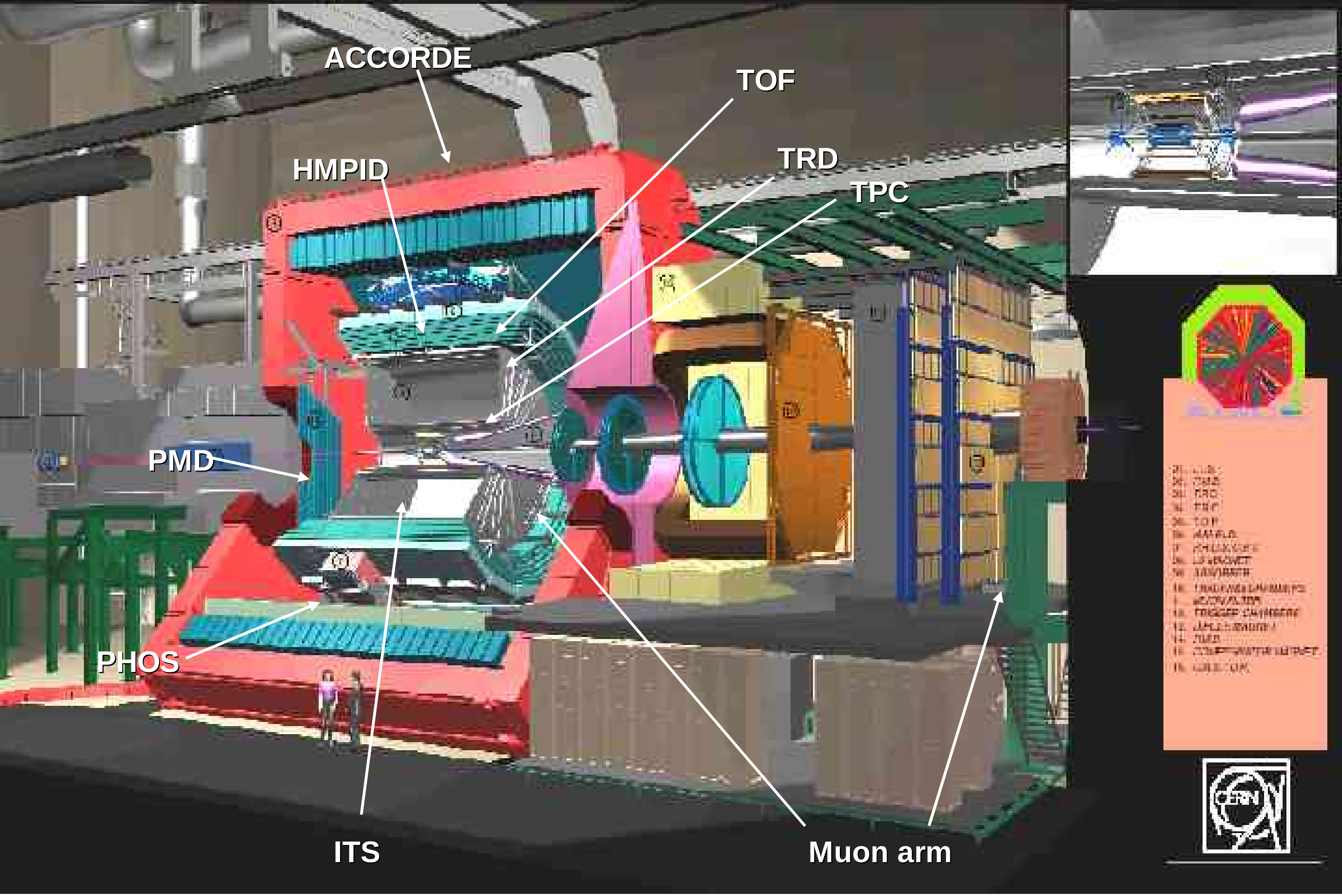
LHC overview

Interesting fact: each dipole stored in the Meyrin site costs as much as a Rolls-Royce

Plans:

- Startup Spring 2007
- First collisions Summer 2007
- Aim to achieve 10^{33} $cm^{-2}s^{-1}$ still in 2007
- Increase luminosity within the following years (potential problems are the “electron cloud” effect and handling enormous 350MJ energy stored in beams)
- Machine limit is 2.5×10^{34} $cm^{-2}s^{-1}$ before beam-beam effects kick in
- Pb-ion programme to start later at $L=10^{27}$ $cm^{-2}s^{-1}$

Jos Engelen

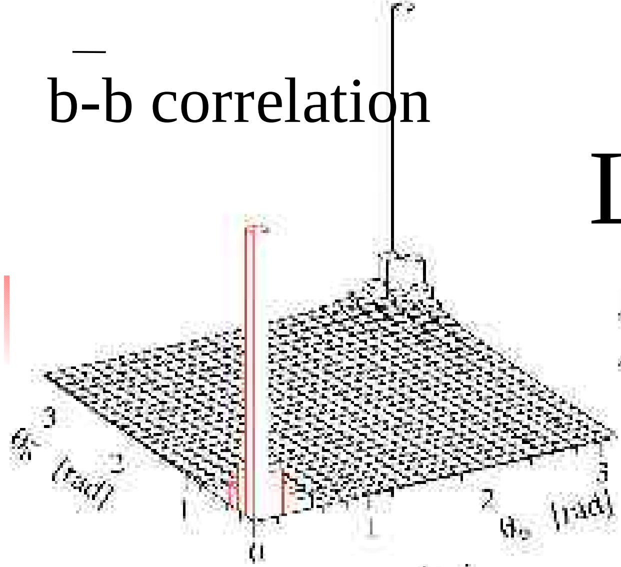


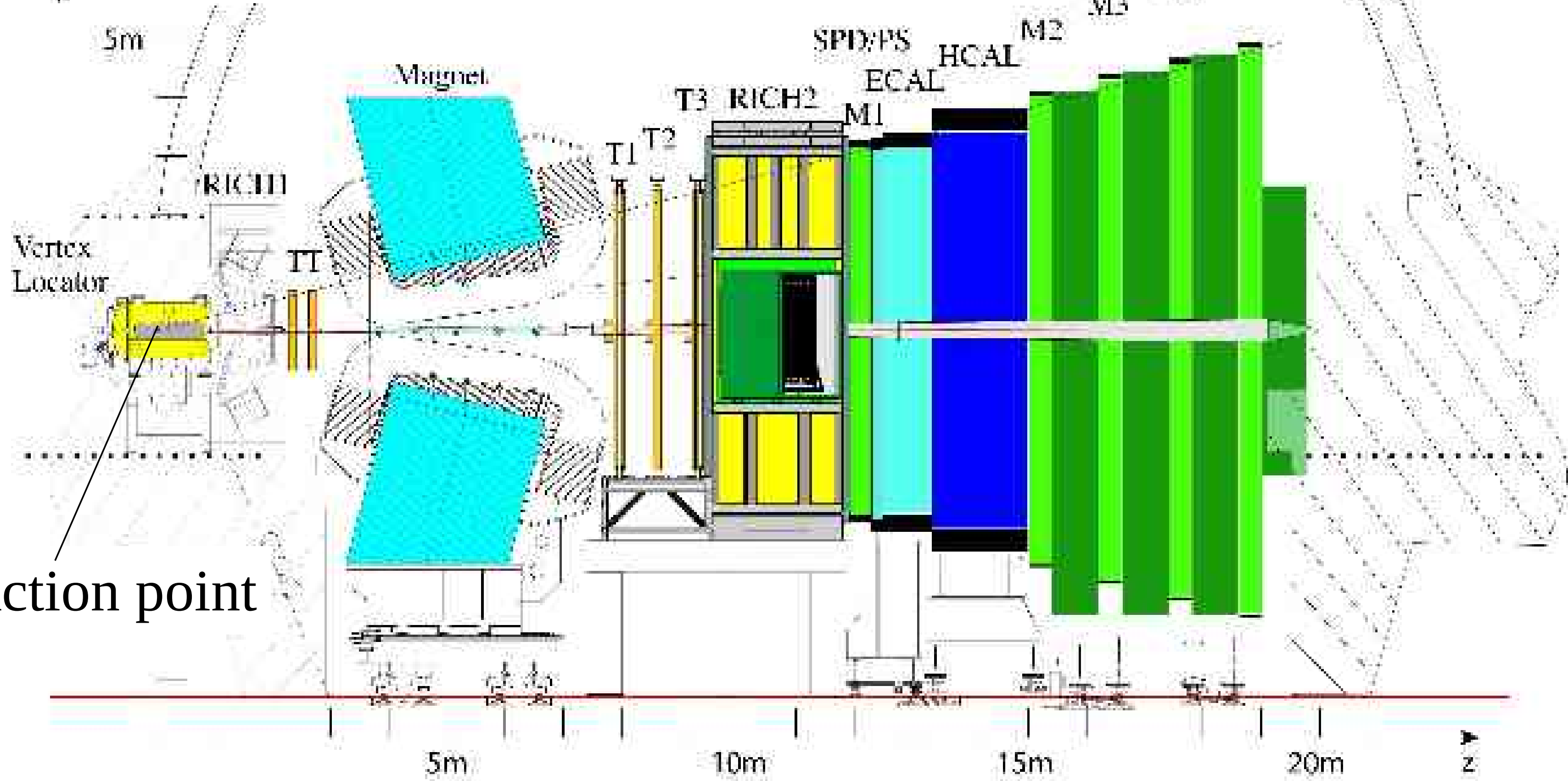
The ALICE Detector

Mounting the TPC Central Electrode

LHCb detector at IP8

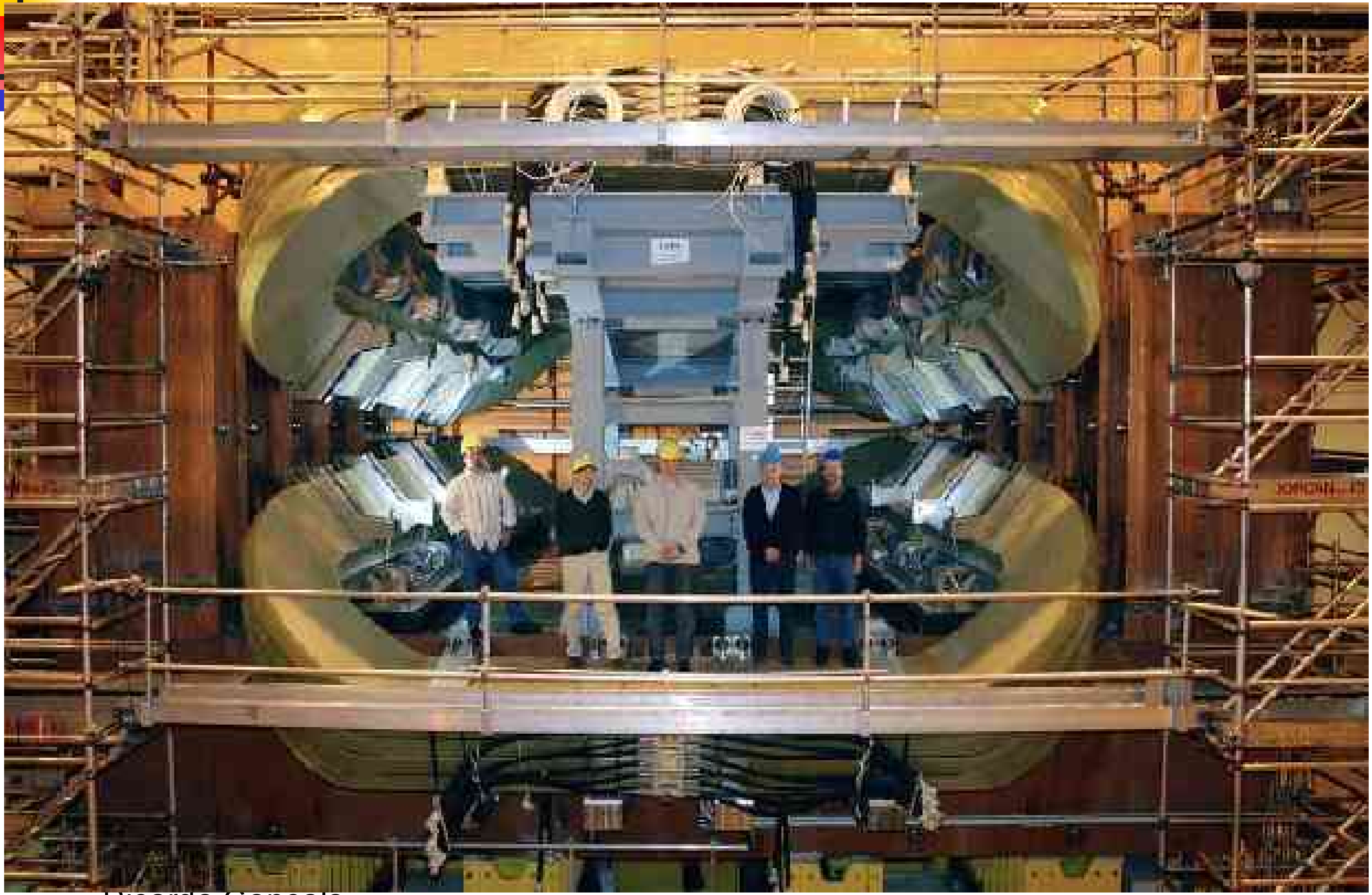
b-$\bar{b}$ correlation



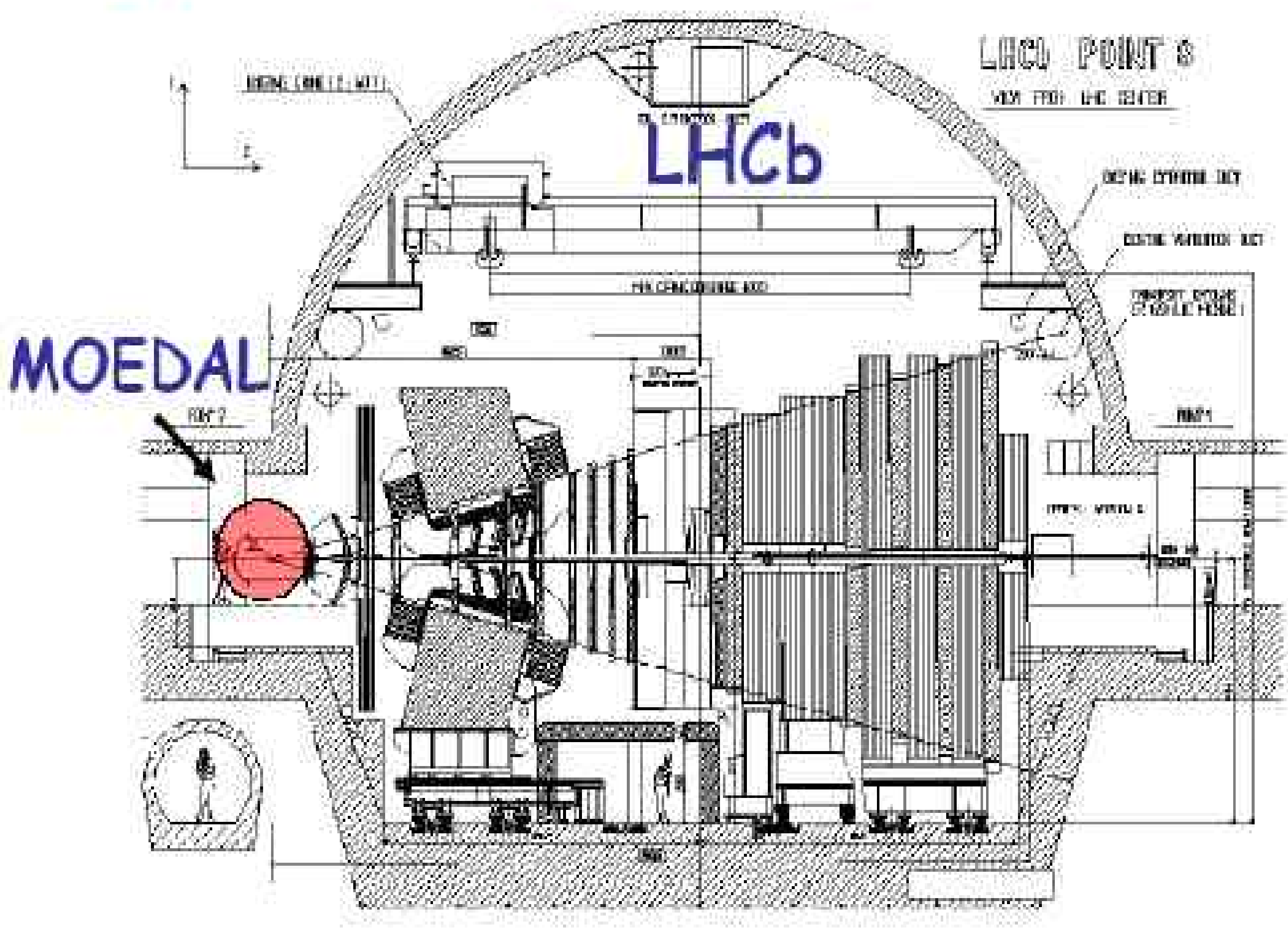


interaction point

LHCb dipole magnet



Magnetic Monopole Search



The Very Forward Region

4 May 2004
Letter of Intent to CERN LHCC [LHCC 2003-057/I-012 rev. 2]

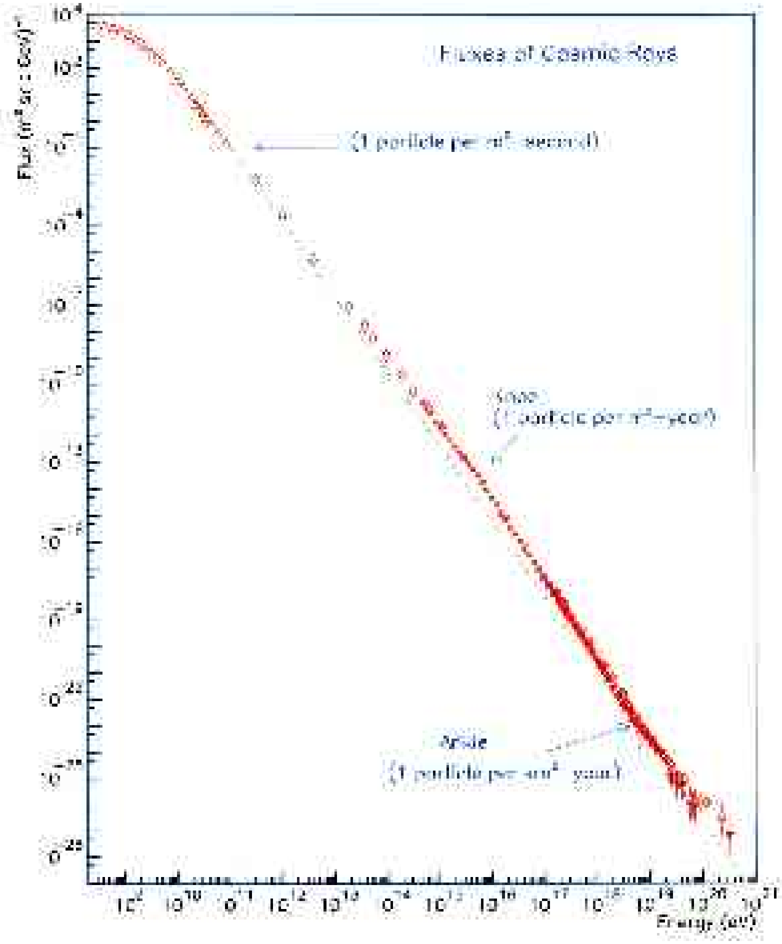
Measurement of Photons and Neutral Pions in the
Very Forward Region of LHC

O. Adriani(1), A. Faus(2), M. Haguenauer(3), K. Kasahara(4), K. Masuda(5), Y. Matsubara(5), Y. Muraki(5), T. Sako(5), T. Tamura(6), S. Torii(6), W.C. Turner(7), J. Velasco(2)

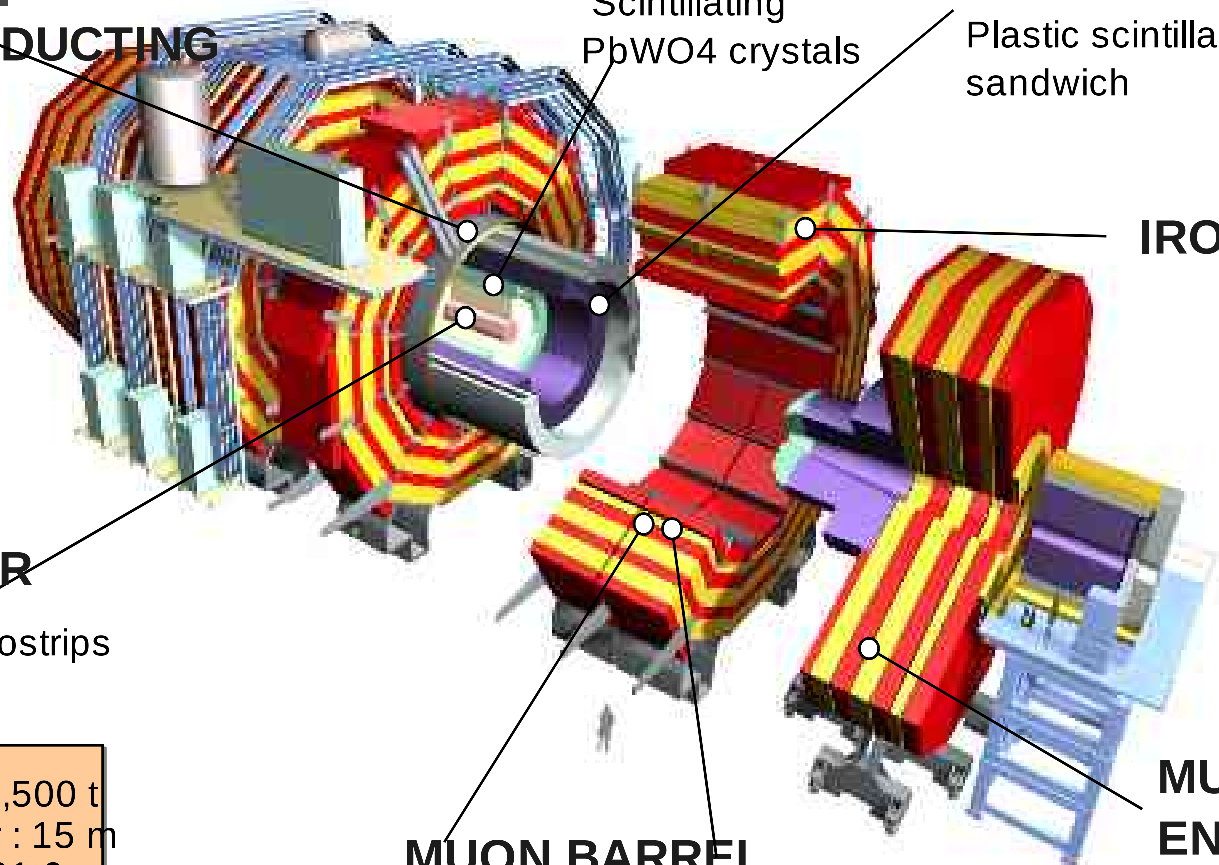
The **LHCf collaboration** (tentative)

Abstract

?? An energy calibration experiment is proposed for ultra high energy cosmic ray experiments in the energy range between 10^{17}eV and 10^{20}eV. Small calorimeters will be located between the two beam pipes in the “Y vacuum chamber” 140m away from the interaction point of the Large Hadron Collider. Within an exposure time of a few hours at luminosity ?10^{29} $cm^{-2}s^{-1}$, very important results will be obtained that will resolve long standing quests by the highest energy cosmic ray physics experiments.



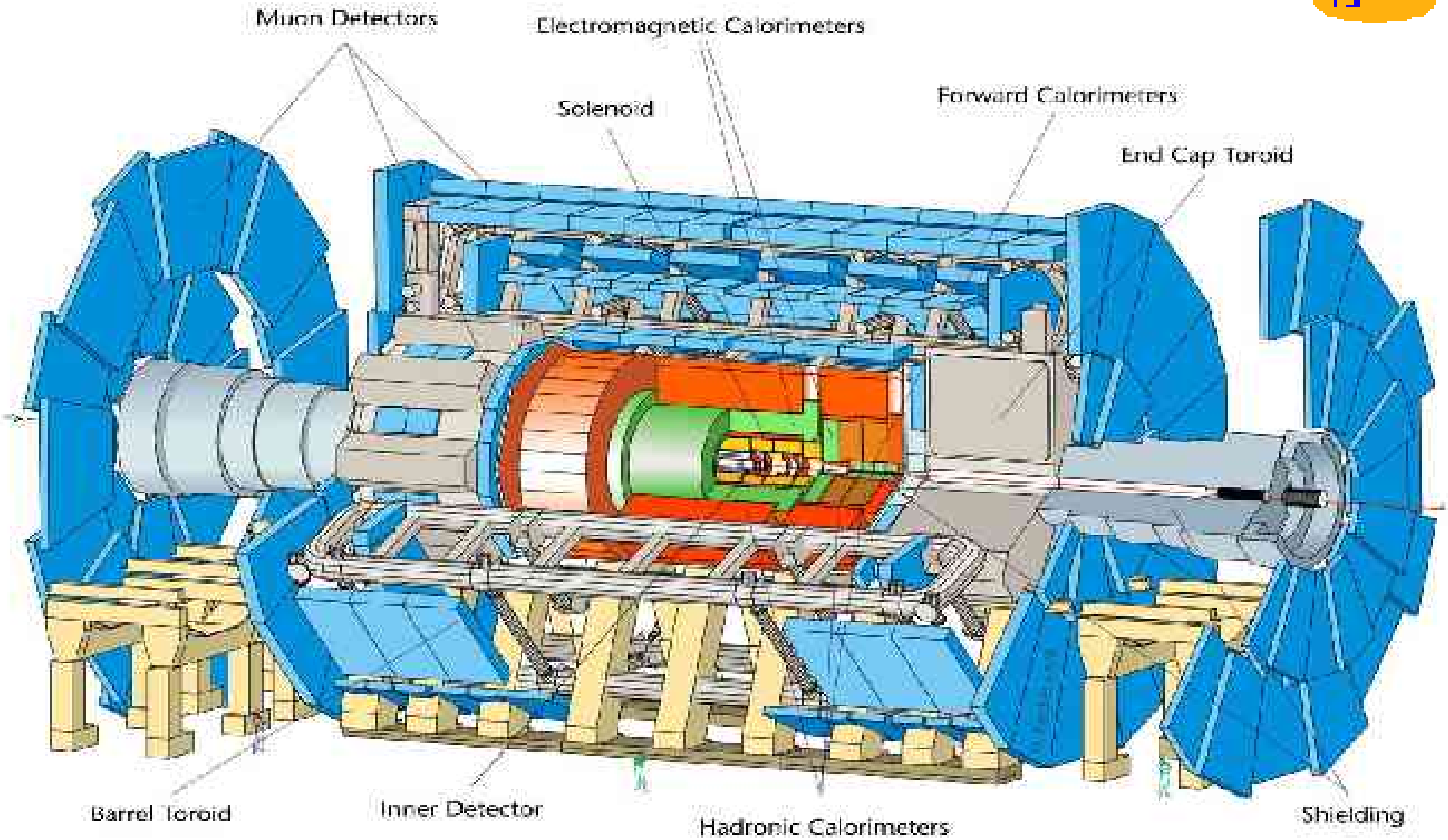
The CMS Detector



Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

ATLAS

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



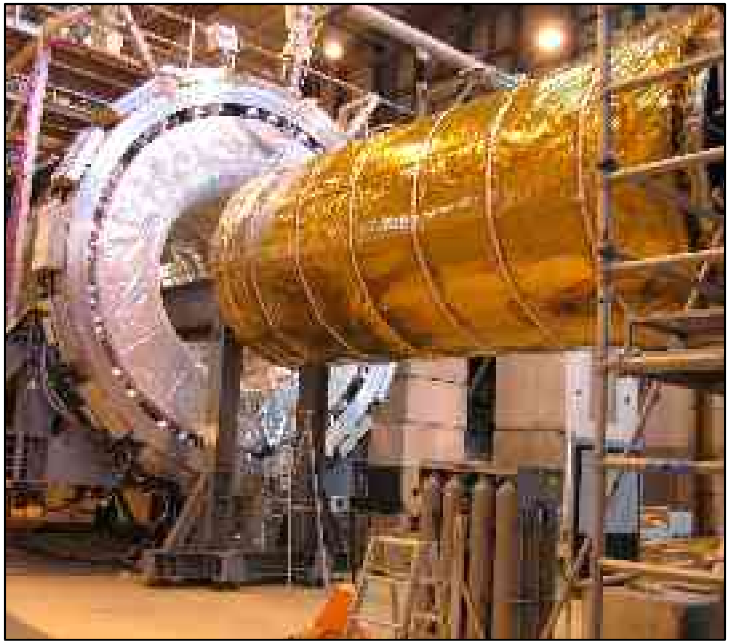
ATLAS Cavern

The barrel EM calorimeter is installed in the cryostat, and after insertion of the solenoid, the cold vessel has been closed and welded

The warm vessel has been closed as well, and the cool down of the whole barrel cryostat has started last week

The tests of the barrel EM (and solenoid) are scheduled until September, followed by installation in the pit in October 2004

LAr barrel EM calorimeter after insertion into the cryostat



Solenoid just before insertion into the cryostat

Barrel Toroid

Most of the component construction in industry is completed, cold mass assembly, cryostating and testing are executed at CERN

The eight *cold masses* have been assembled

- **16 double pancakes of conductor (56 km total)**
- **8 coil casings**
- **all He cooling lines welded (after the long-lasting technical problems were solved) and installed**
- **conductor exits and instrumentation are all done**

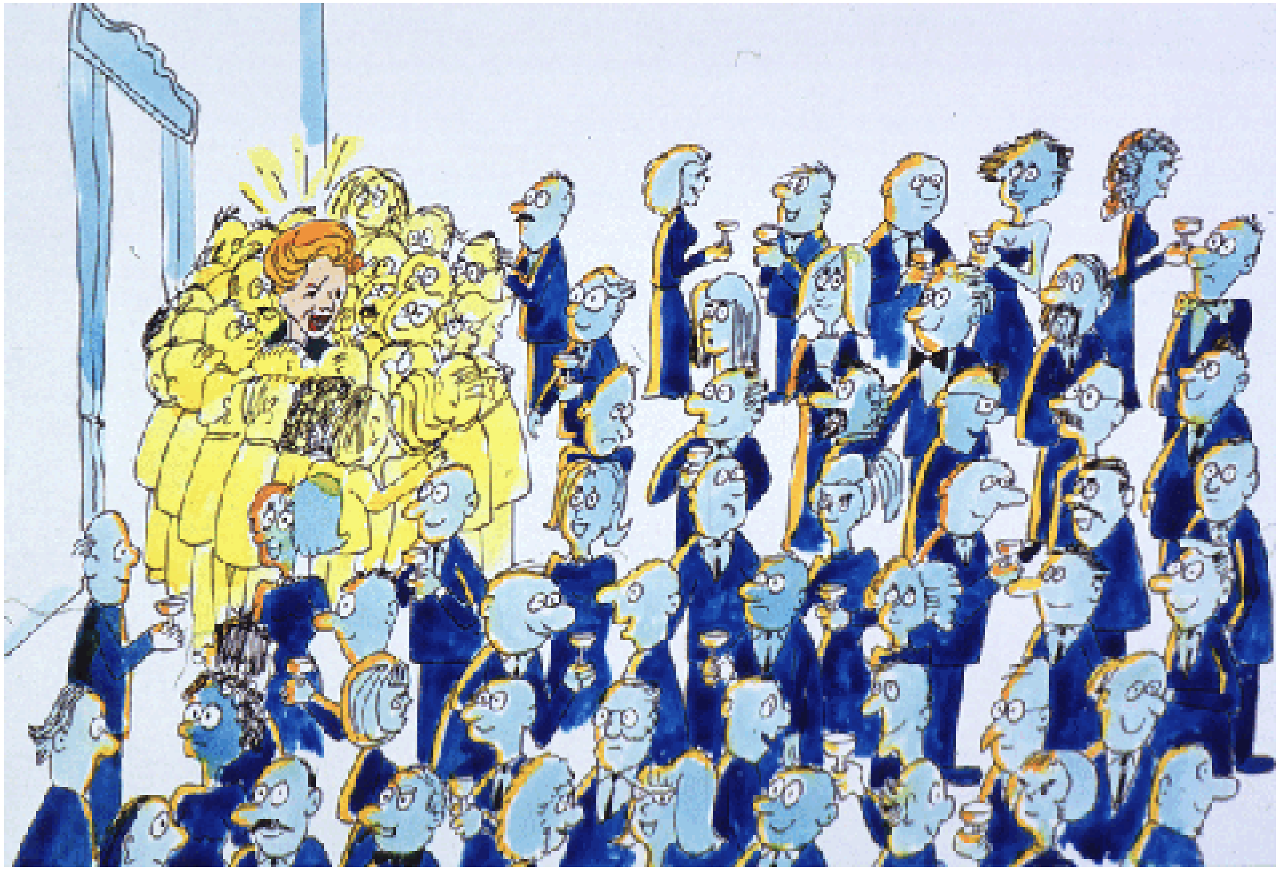

Conductor exit from completed cold mass


Vacuum vessels


Assembled cold masses

The ATLAS cavern yesterday

Higgs physics



SM and SUSY Higgs Phenomenology at the LHC

Standard Model:

One Higgs doublet with weak hypercharge $Y_\Phi=1 \Rightarrow$ 3 degrees of freedom for $W^\pm$, Z, , one left corresponding to H

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

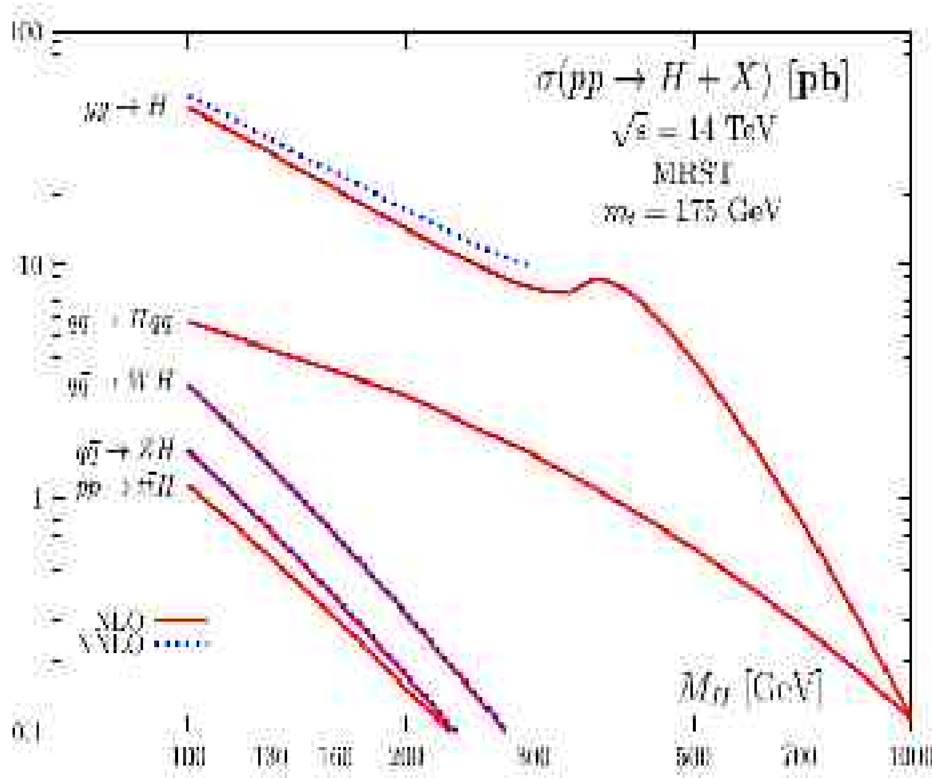
One free parameter: M_H

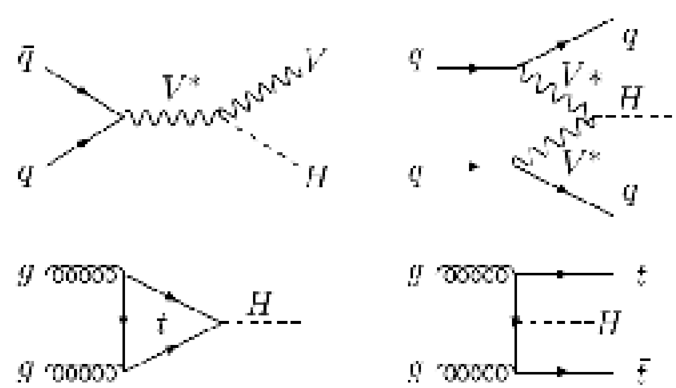
What we know: $M_H \approx$ 114.4 GeV – $\mathcal{O}$(250 GeV)

Hierarchy and unification problems in SM $\Rightarrow$ SUSY?

Standard Model

- gg→H: dominant production channel at LHC
- qq →qqH: promising for measurement of couplings to gauge bosons
- qq/gg→ttH: useful for ttH coupling measurement
- qq→HW/HZ: dominant at the Tevatron; low rates at LHC



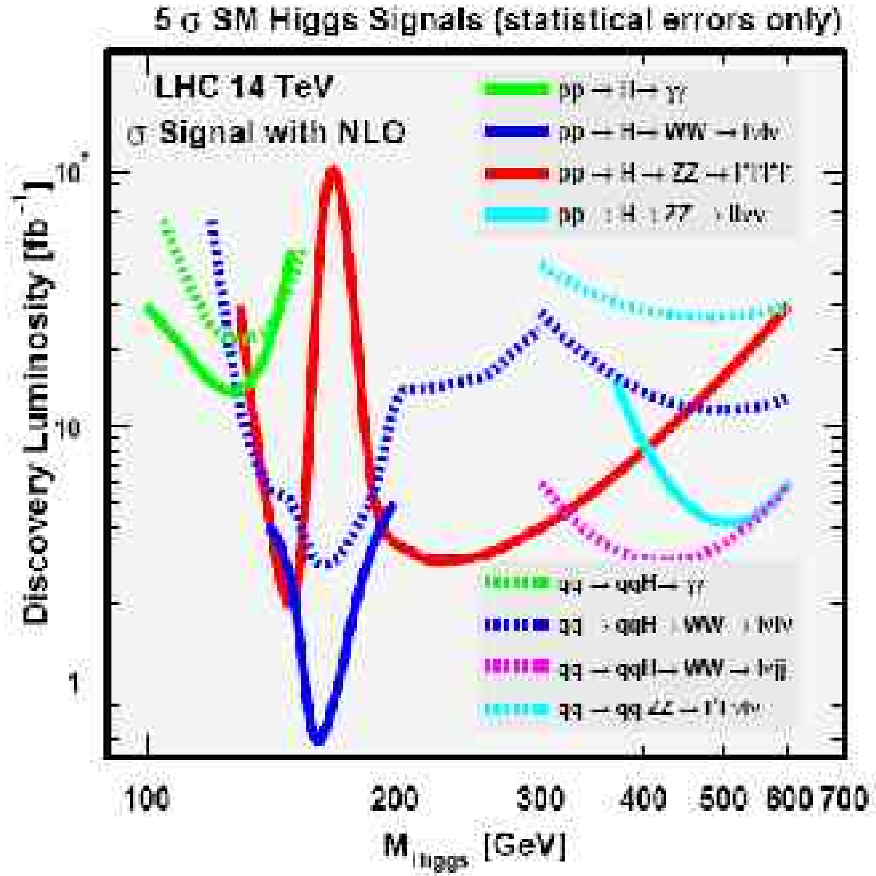


Standard Model

Production	Cross section calculations	Decay channels
$gg \to H$	known at NLO for arbitrary m_t and approximately NNLO; large corrections but nicely convergent in perturbative order	$H \to \gamma\gamma$ (M_H < 130 GeV) $H \to WW^{(*)}/ZZ^{(*)}$ (M_H > 130 GeV)
$qq \to qqH$	known at NLO; small scale dependency (measure of higher order corrections)	Rates: O(pb) for M_H < 130 GeV Topology: forward jets and central H decay $H \to WW^{(*)}$ / $\gamma\gamma$ / $\tau^+\tau^-$ feasible $H \to$ ZZ / $b\underline{b}$ / $\mu^+\mu^-$ need high $\mathcal{L}$ and more study
$qq/gg \to t\underline{t}H$	complicated; NLO available only recently	Not mentioned
$q\underline{q} \to HW/HZ$	theoretically very clean; available at NNLO; known EW corrections (5%); small PDF uncertainties (normalize to Drell-Yan)	Dominant at Tevatron, but only marginal role at LHC $H \to b\underline{b}$ (M_H < 130 GeV) $H \to WW^{(*)}$ (M_H > 130 GeV)

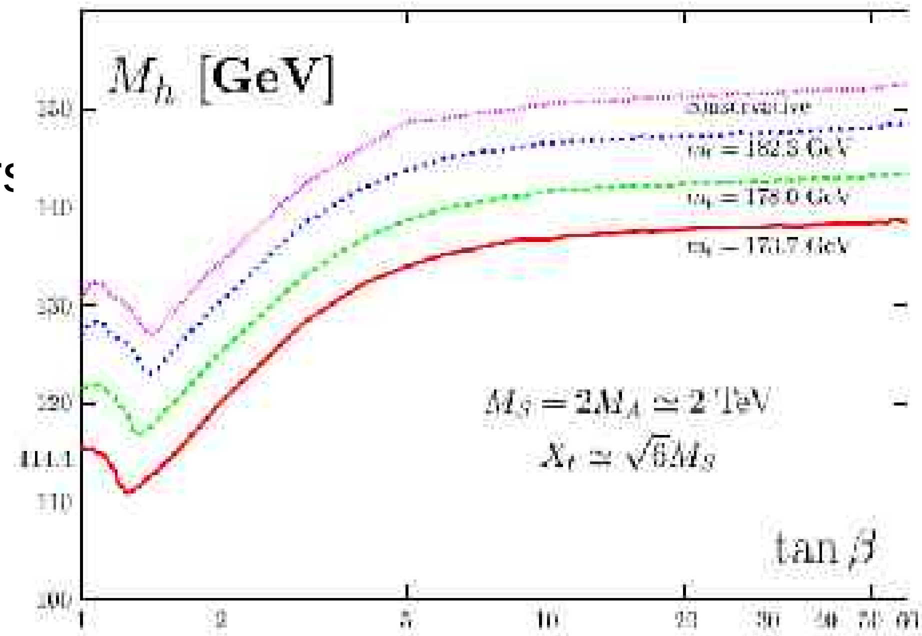
Standard Model

- Higgs detection in principle guaranteed in the SM
- Many redundant channels
- 5σ discovery for low $\mathcal{L}$ once all channels combined
- Then measure:
  - Higgs mass and total width
  - Couplings to fermions and gauge bosons
  - Higgs self coupling? (seems hopeless)
  - Spin and parity quantum numbers (challenging!)



SUSY: the Higgs bosons of the MSSM

- Two doublets of complex scalar fields with opposite Y= ±1 ⇒ 5 Higgs particles: h, H, A, $H^{\pm}$
- 4 masses and 2 extra parameters needed: tan β= v_2/v_1 and α BUT constrains from SUSY:
  - Only 2 independent parameters: tan β and M_A usual
  - Hierarchy in spectrum:
    - $M_h < M_A < M_H$
    - $M_{H\pm} > M_W$
    - $M_h < M_Z$
- Above relations are broken by radiative corrections for large m_t
- Consequences: M_h^{max} ~150 GeV; tan β^{min} ~1



$$M_h^{max} \sim M_Z |\cos 2\beta| \left[1 - \mathcal{O}\left(\frac{M_Z^2}{M_A^2}\right)\right] + \frac{3 m_t^4}{2\pi^2 v^2}\left(\ln \frac{M_S^2}{m_t^2} + \frac{X_t^2}{2 M_S^2} - \frac{X_t^4}{12 M_S^4}\right)$$

MSSM: cross sections

Neutral Higgs example for tan β >> 1 and M_A > 150 GeV:

- b loops dominant in $gg \to H/A$ (coupling $g\Phi bb$ proportional to tan β)
- $b\underline{b}$ final states dominant in $pp \to q\underline{q}+H/A$ (σ proportional to $\tan^2\beta$)
- No vector-boson fusion or associated production of Higgs and vector bosons for A (CP) or H (suppressed)

A,H,h:

Generally same channels as in SM but cross sections enhanced or suppressed by different couplings to fermions and gauge bosons

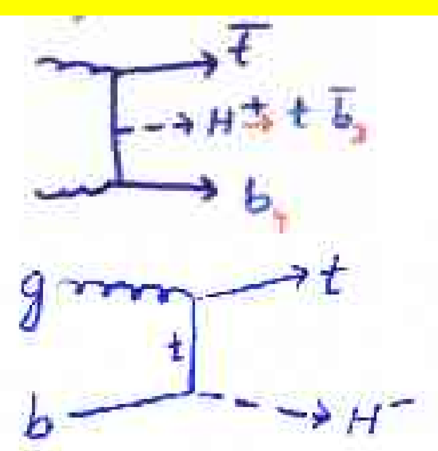
H^+,H^-:

($M_{H\pm}$ < $\sim m_t$)

$gg/q\underline{q} \to t\underline{t} \to H^\pm+X \to \tau^\pm\nu+X$

($M_{H\pm}$ > $\sim m_t$)

$gb \to H^-t$ and $gg/q\underline{q} \to H^-t \to \tau\nu/\ \tau b$



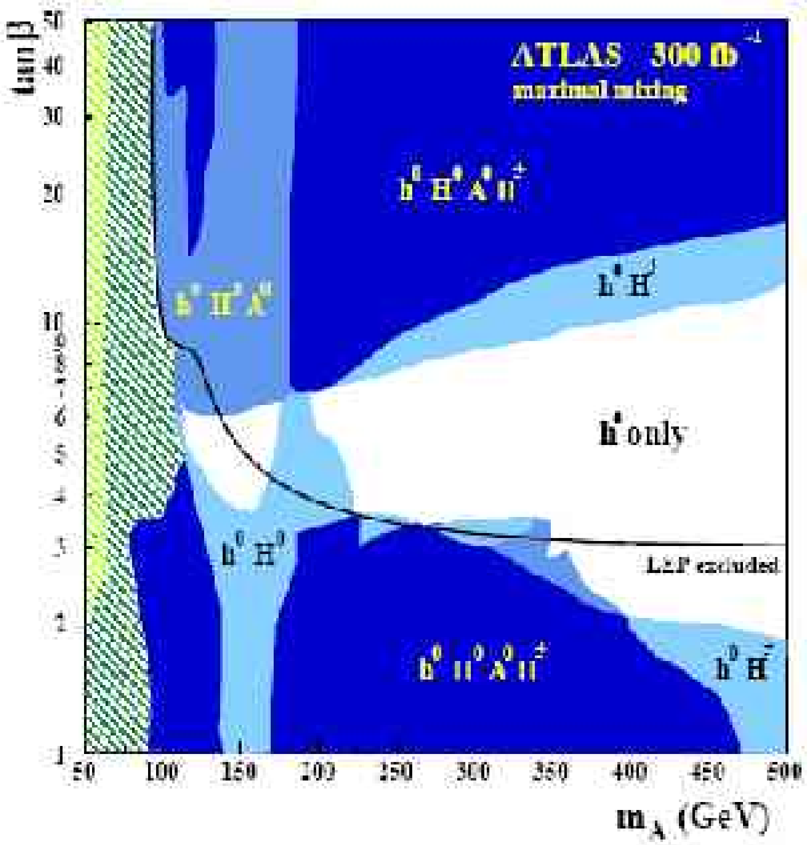
MSSM: regions of parameter space

The decoupling regime:

- $M_A >> M_Z$ and tan $\beta >> 1$
- SM-like h with 115 GeV < M_h < 150 GeV
- Heavy H,A,H±

The intermediate regime:

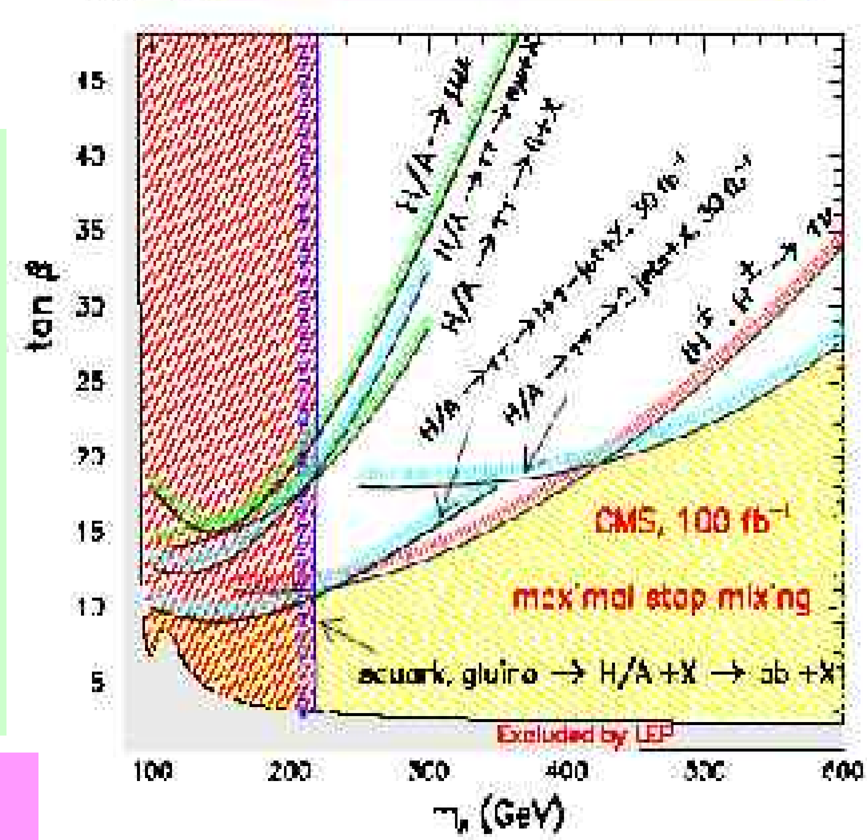
- MA < 500 GeV and tan β < 5~10
- h not yet SM-like; more difficult than SM
- All production cross sections smaller than SM
- Couplings to WW,ZZ,tt suppressed and couplings to bb, $\tau\tau$ enhanced
- Decays to WW,ZZ,$\gamma\gamma$ suppressed
- Small cross sections for H,A,H± production



MSSM & etc

Intense coupling regime:

- MA< 120~150 GeV and tan β >> 1
- New and interesting features
- H,h,A light and of similar masses
- Large production cross sections for many channels
- Also some problems:
  - H,A,h masses too close to each other and with large width
  - Interesting BRs suppressed wrt SM for both h and H



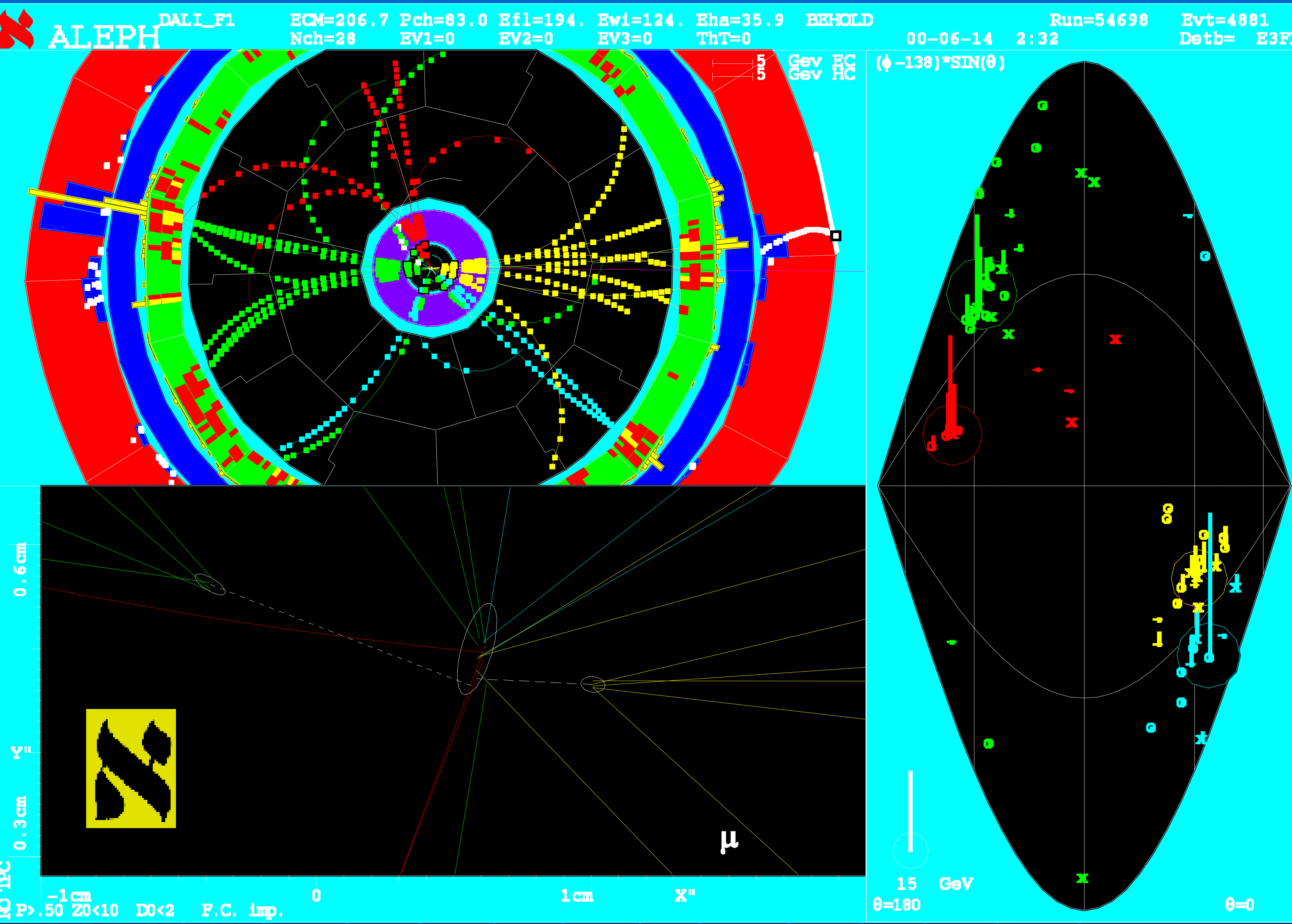
SUSY regime:

- Not too heavy SUSY particles
- SUSY loops may play important role in production/decay (e.g. light stop coupling to h)
- $\sigma(gg \rightarrow h) x BR(H \rightarrow \gamma\gamma)$ may be small (must rely on gg/qq→h stop stop)

Extended regime: SUSY extensions such as NMSSM (2 H doublets + singlet) with less fine-tuning than MSSM. But … more tricky!…

Higgs results from LEP

Nikos Konstantinidis


ALEPH
DALI_F1
ECM=206.7 Pch=83.0 Efl=194. Ewi=124. Eha=35.9 BEHOLD
Nch=28 EV1=0 EV2=0 EV3=0 ThT=0
Run=54698 Evt=4881
00-06-14 2:32
Detb= E3F
5 Gev EC
5 Gev HC
(ϕ-138)*SIN(θ)
0.6cm
Y"
0.3cm
-1cm
0
1cm
X"
P>.50 Z0<10 D0<2 F.C. imp.
μ
15 GeV
θ=180
θ=0

ALEPH Candidate 54698/4881

(recorded on 14/06/2000)

Properties

- Two clear b-jets (dec. length, inv. mass of tracks in vertex)
- Event well-measured: P_{mis} in direction of jet with μ from vertex
- Planar event, as in threshold production of two heavy particles
- b-jets: 55GeV & 59GeV, like in a decay almost at rest
- Non-b jets: 43GeV & 49GeV, like in a Z decay almost at rest
- Raw invariant mass of non-b jets 92.3GeV
- non-b jets: leading parton effect, low multiplicity (q vs. gluon)

Impossible to be a WW, almost impossible to be bbgg, very unlikely a ZZ*?qqbb and if it is…

One candidate is not a discovery, but if m_H~116GeV this was the first Higgs ever observed!

Non-SM Higgs searches

Fermiophobic Higgs

- $h^0 \to \gamma\gamma$

Invisible Higgs

- e.g. $h^0 \to$ neutralinos

Flavour independent Higgs

- $h^0 \to$ qqbar

Charged Higgs

- $H^+ \to$ csbar or $\tau^+\nu_\tau$

Neutral Higgs bosons of the MSSM

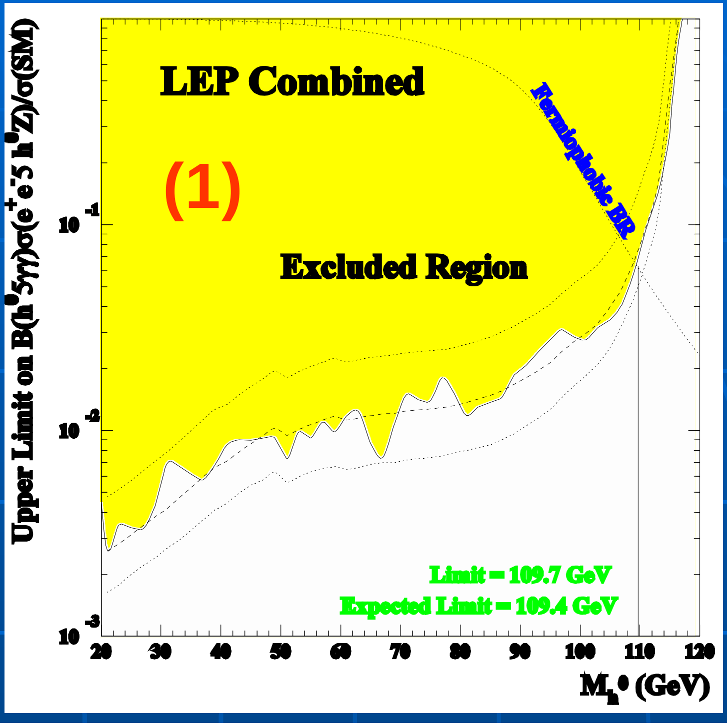
- $e^+e^- \to$ hZ/hA h/A –>bbbar

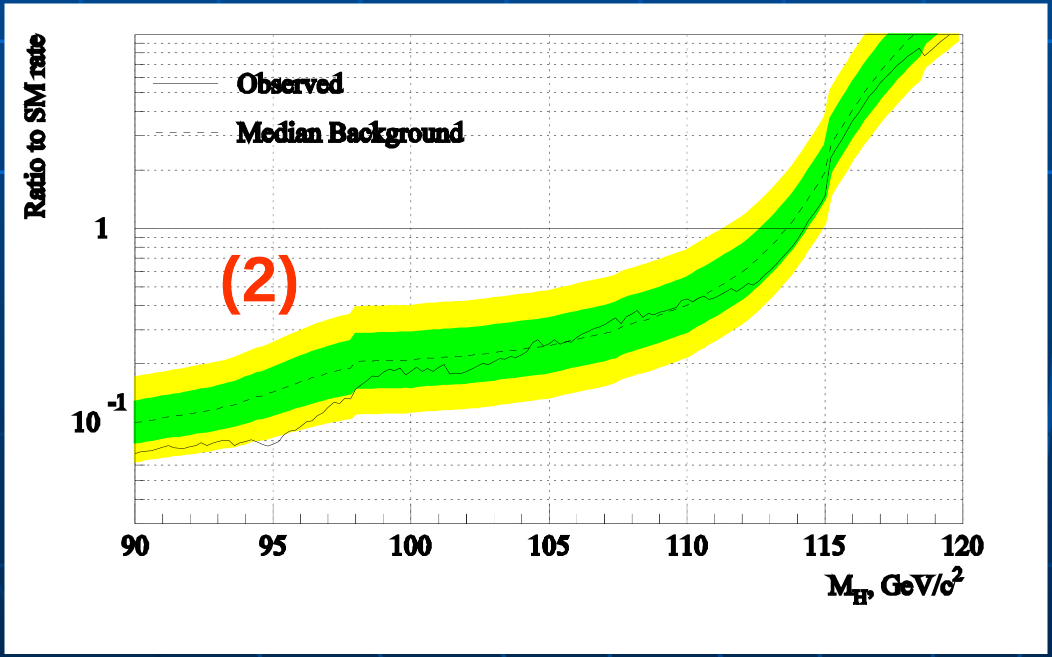
Non-SM Higgs results

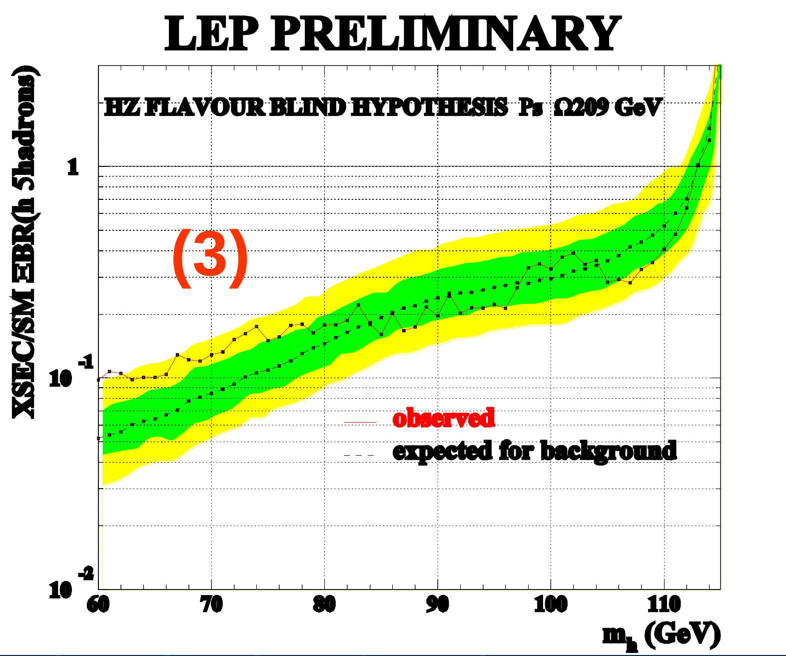
For SM cross-section

1. Fermiophobic $m_h > 117.2$GeV
2. Invisible $m_h > 114.2$GeV
3. Flavour Indep. $m_h > 112.9$GeV

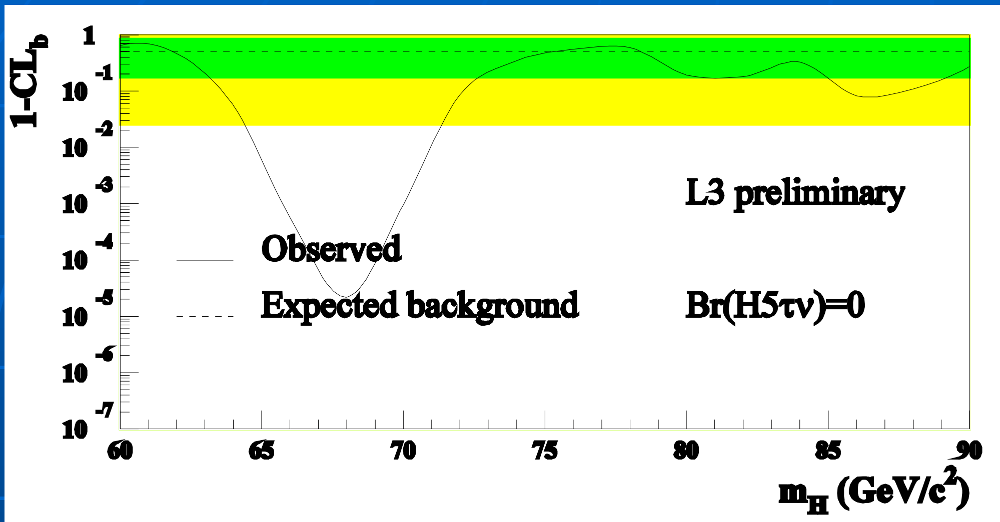
[LEPHWG '01]







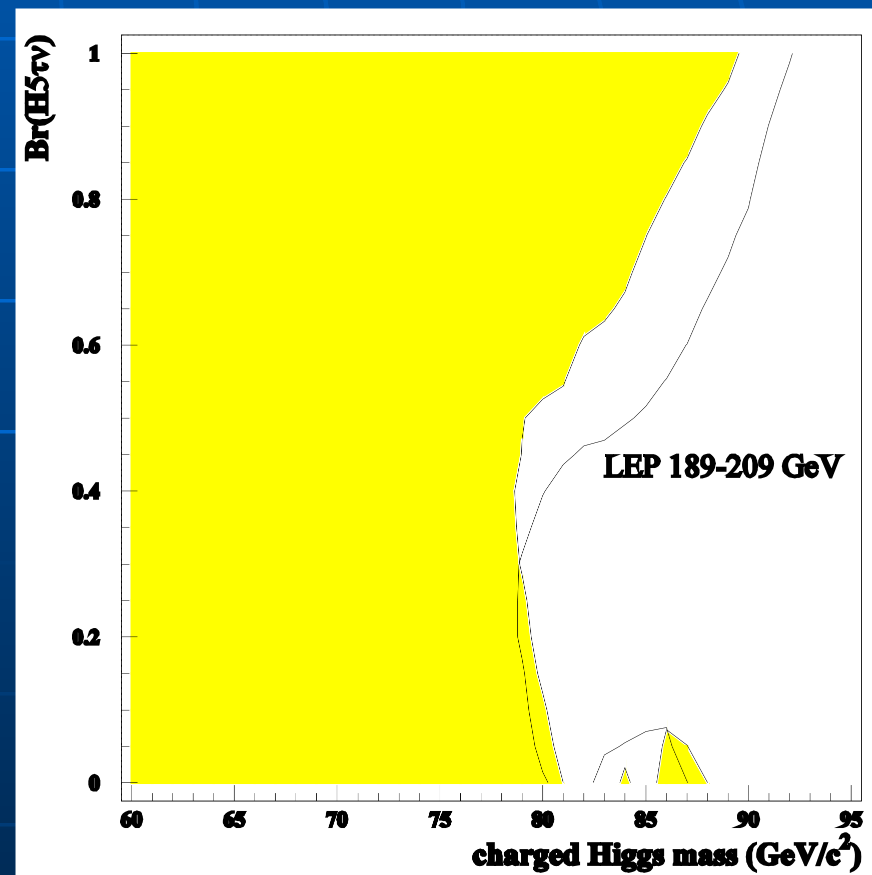
Charged Higgs results



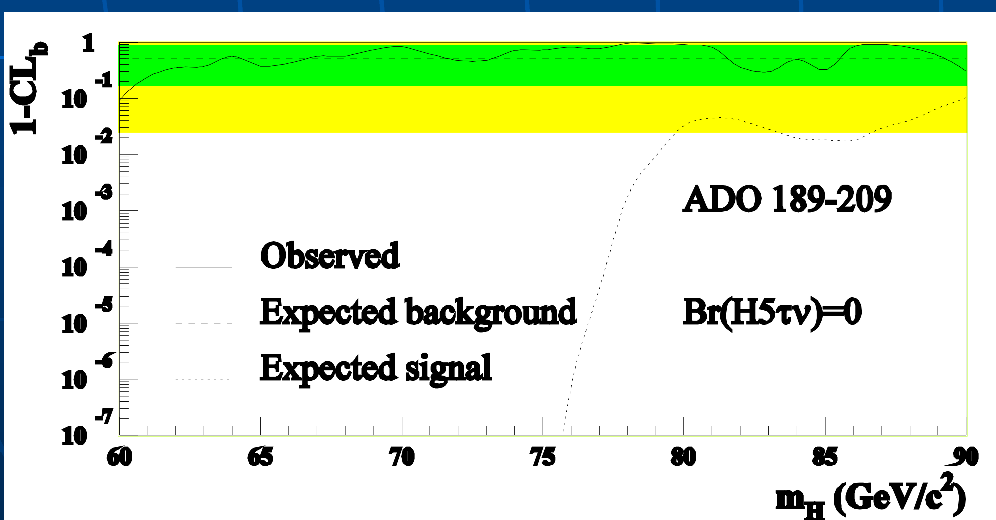
Independent of Br(H–>τν)

m_H > 78.6GeV

[LEPHWG '01]

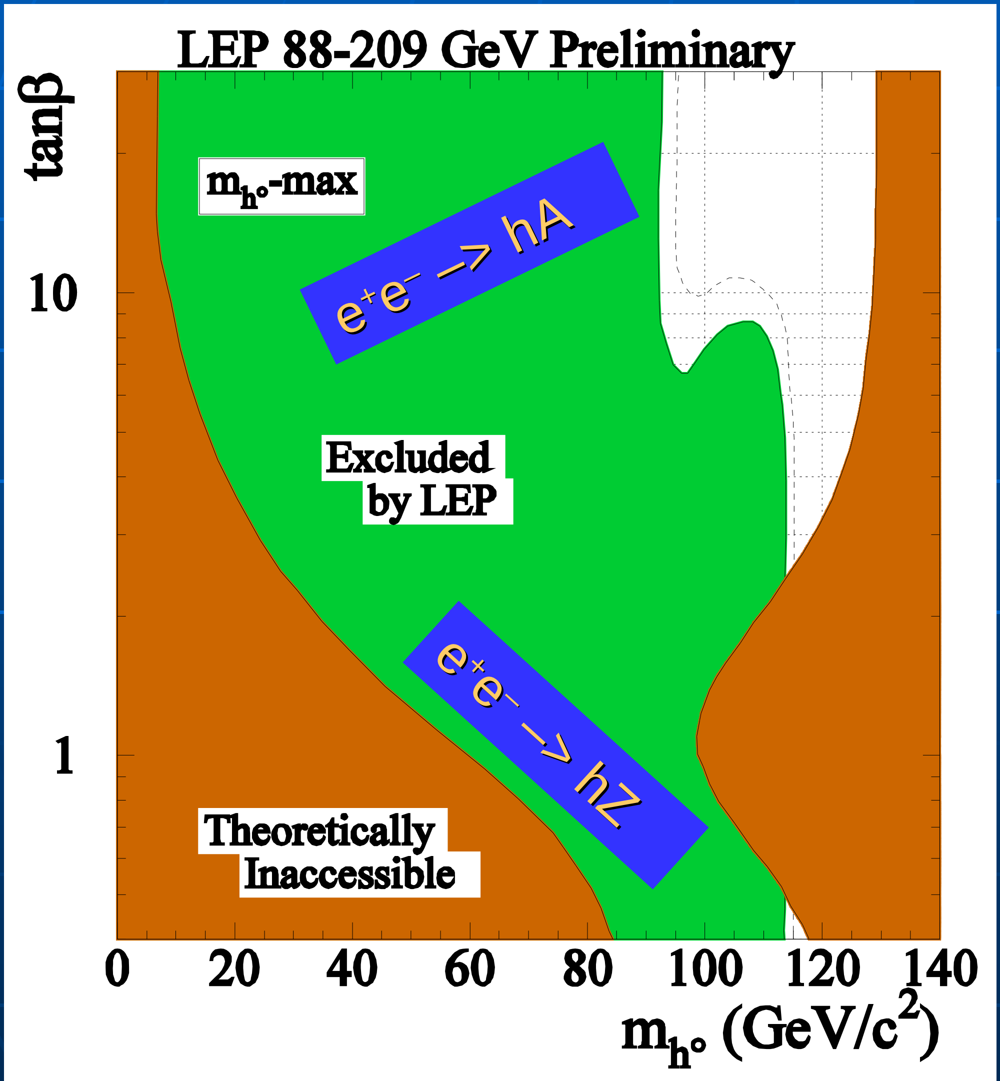


L3 excess at ~68GeV, mainly in cscs channel, not seen by ADO



MSSM neutral Higgs results

[LEPHWG '01]



Excluded for all tanβ

- $m_h > 91.0$ GeV
- $m_A > 91.9$ GeV

The range of tanβ that is fully covered depends on the theoretical upper bound on m_h

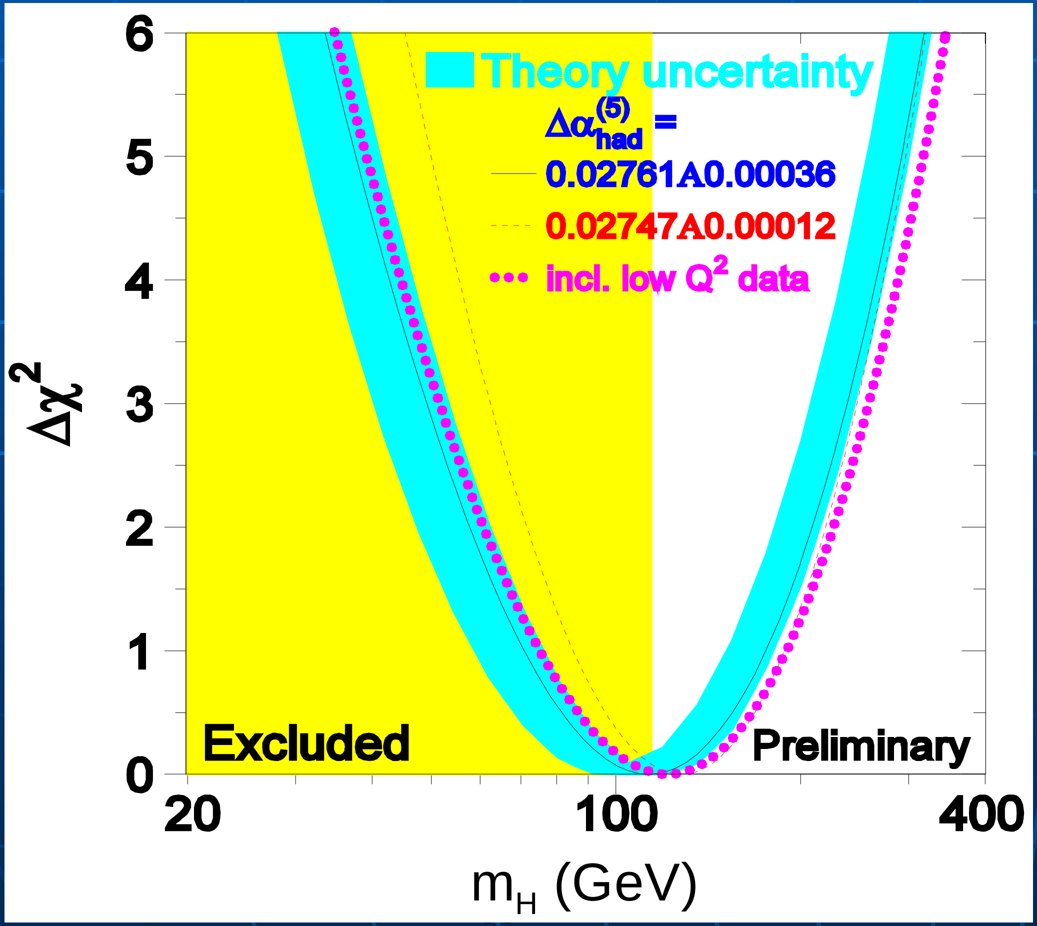
E/weak data and the Higgs

$\log_{10} M_H = 2.05 \pm 0.20$

A 10% measurement!

$0.20 \approx 0.13 \oplus 0.13 \oplus 0.08$

exp. ΔM_t $\Delta\alpha(M_Z^2)$



~30% improvement wrt 4 years ago:

$0.28 \approx 0.14 \oplus 0.15 \oplus 0.19$

[LEPEWWG ’04]

Future Prospects

Assuming no discovery before 2007, emphasis will be on electroweak fits

In "Physics at LHC – 2007" expect:

- Uncertainty from α negligible
- $\Delta m_t \sim 3\text{GeV}$ ← Main improvement needed
- $\Delta m_W \sim 25\text{MeV}$

This will give

$$\Delta(\log_{10} M_H) \approx 0.10(\text{exp}) \oplus 0.09(\text{top}) \oplus 0.04(\alpha) \approx 0.14$$

Higgs results from the Tevatron

Boris Tuchming

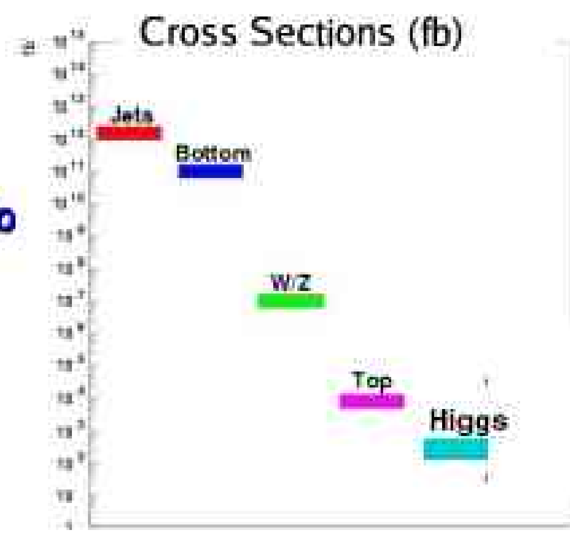
Experimental status

Still early stage of the data taking :

- Understand detector performance
- Test and improve reconstruction algorithms
- Study instrumental background:
  - jets faking leptons, photons
  - missing E_T induced by mismeasured jets
  - jets faking b-quarks
- Study physics background
  - Comparison with LO Matrix Element Monte Carlo
  - (W+jets, Z+jets, bbj, bbjj)
    - Comphep + Herwig showering
    - ALPGEN + Pythia showering

→

- Jet energy scale
- Jet energy resolution
- b-tagging
- Missing E_T

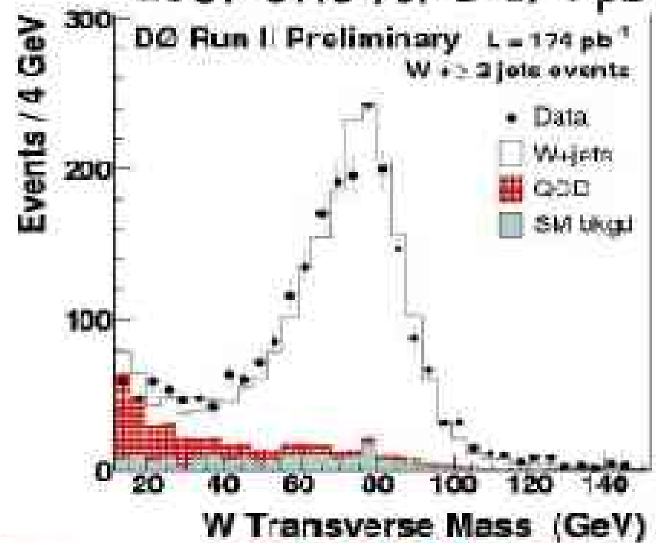


All these will be important issues at ATLAS!

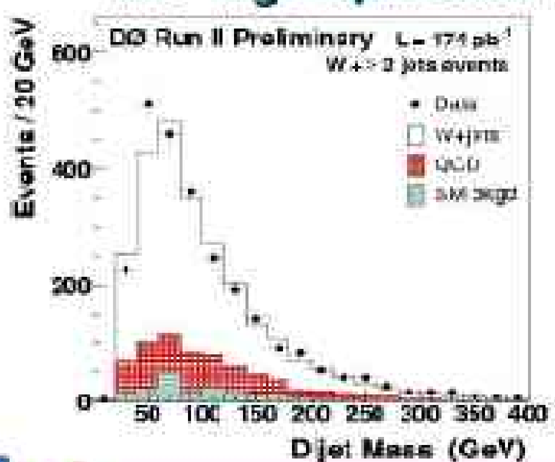
DØ: WH->Wbb electron channel only

- First preselection
  - Central isolated e, p_T>20 GeV
  - Missing E_T > 25 GeV
  - ≥2 jets: E_T>20, Gev $|\eta|$<2.5
- Background
  - W+jets production
  - QCD faking isolated electron
  - top pair production

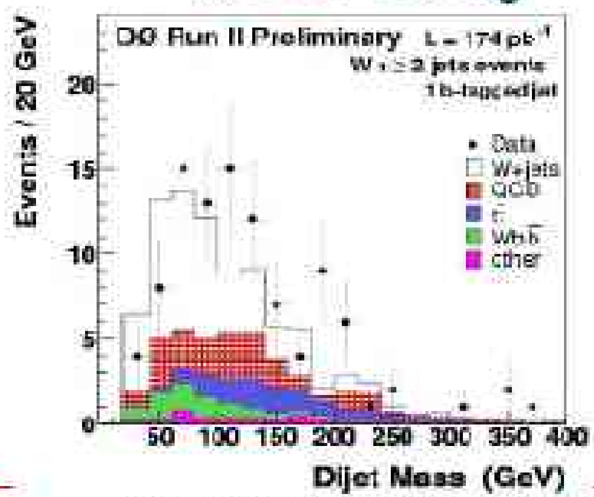
2587 evts for L=174 pb^{-1}



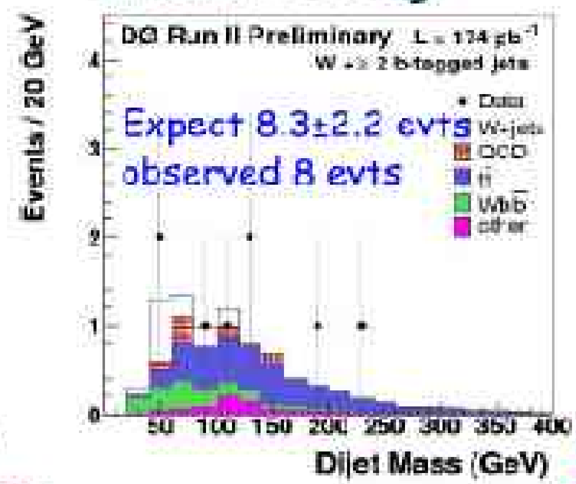
no b-tag requirement



at least 1 b-tag

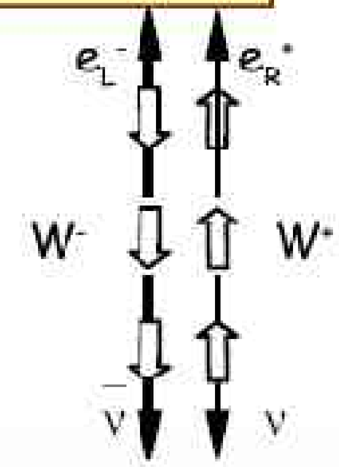


at least 2 b-tag



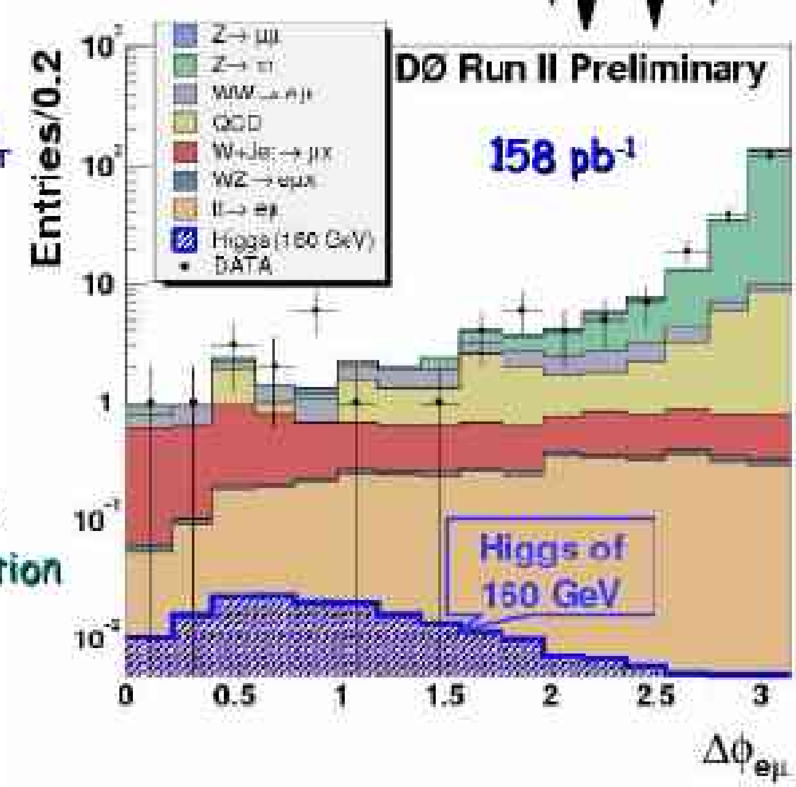
Physics at LHC, Vienna — Beate Heinemann - Higgs results from Tevatron — 13

H->WW* Production



- Signature :
  - 2 isolated, high Pt leptons
  - large missing E_T
  - spin correlation : The charged leptons tend to be collinear
    - low di-leptons mass
    - small $\Delta\phi(l^+l^-)$
- Backgrounds
  - electroweak WW production
  - Drell Yann Z/γ +jets faking missing E_T
  - W+ jets faking electrons
  - diboson production : ZZ, WZ

DØ eμ channel:
after preselection



Final sample:

	DØ ee	DØ eμ	DØ μμ	CDF ll
Observed	2	2	5	3
Expected	2,7 ± 0,4	3,1 ± 0,8	5,3 ± 0,6	4,7 ± 0,5

Higgs prospects vs luminosity prospects

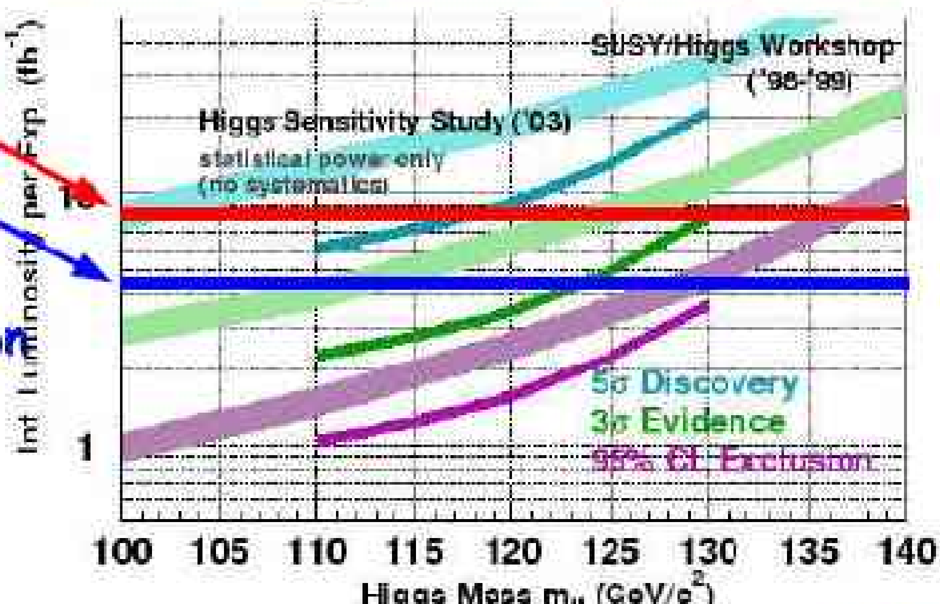
- Design projection = challenging
  - 8.5 fb^{-1} by end of 2009
- Base projection= conservative
  - schedule slippage
  - under-performance

  4.4 fb^{-1} by end of 2009

Tevatron Higgs Sensitivity Study 2003

2009 8.5 fb^{-1}

2009 4.4 fb^{-1}



- Base projection

  Range 115-130 covered for exclusion

  3σ evidence up to ~125 GeV.
- Design projection

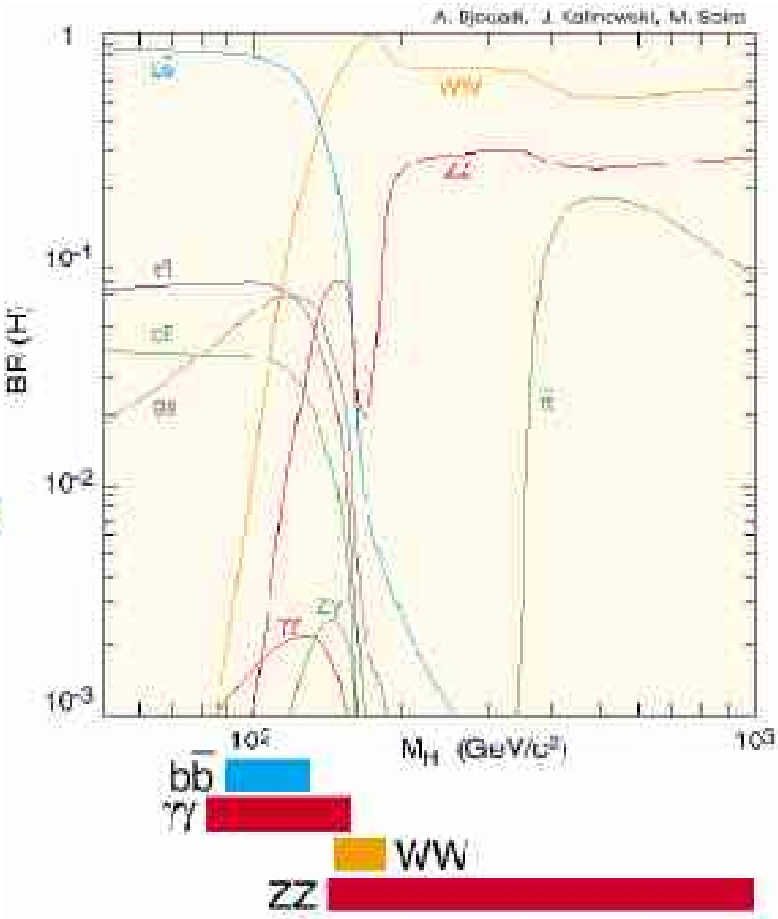
  3σ evidence up to 130 GeV

  5σ discovery up to 120 GeV

Back to the LHC

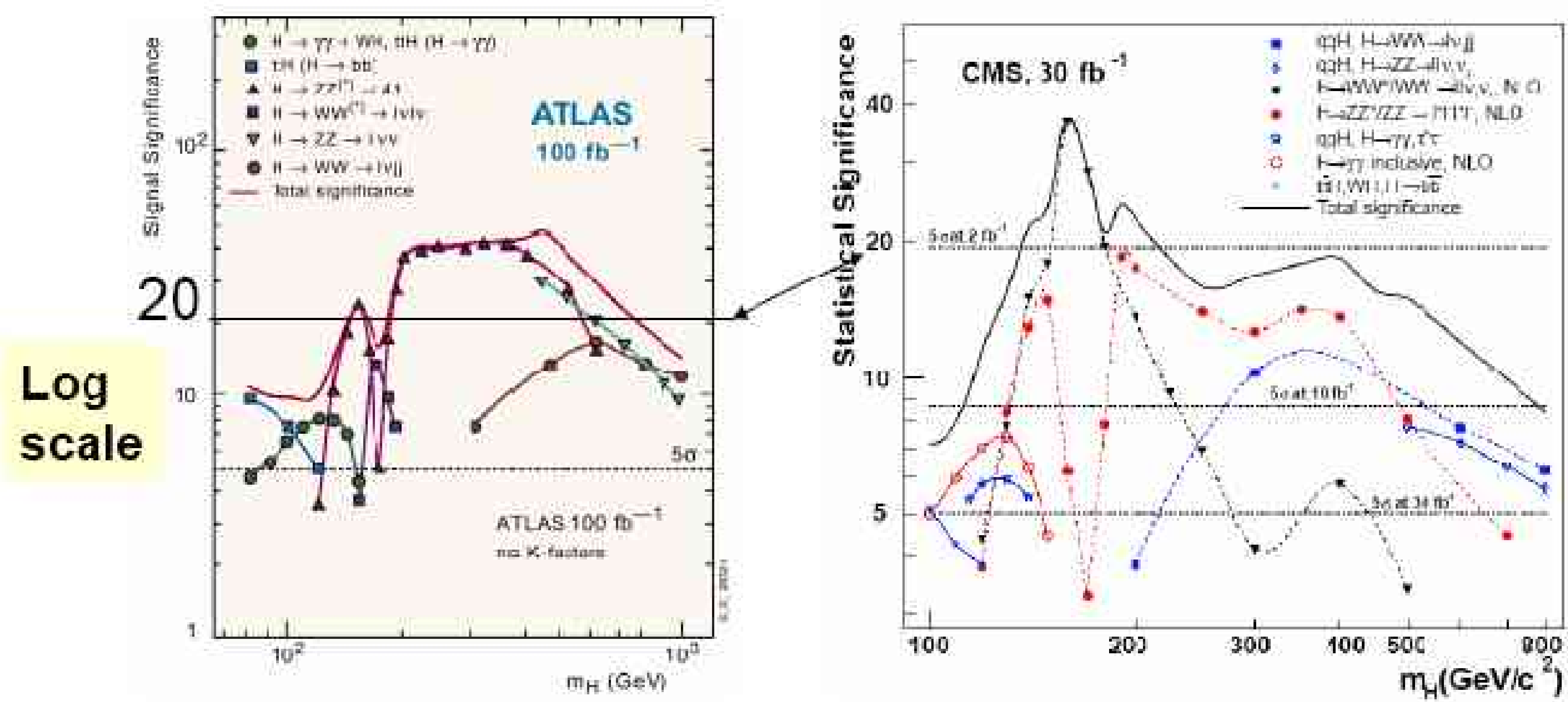
SM Higgs (II)

- **Decays & discovery channels**
  - Higgs couples to m_f^2
    - Heaviest available fermion (b quark) always dominates
    - Until WW, ZZ thresholds open
  - Low mass: b quarks→ jets; resolution ~ 15%
    - Only chance is EM energy (use $\gamma\gamma$ decay mode)
  - Intermediate mass: WW, ZZ*
    - Useful at M_H>125 GeV already
  - Once M_H>$2M_Z$, use this
    - W decays to jets or lepton+neutrino (E_T^{miss})



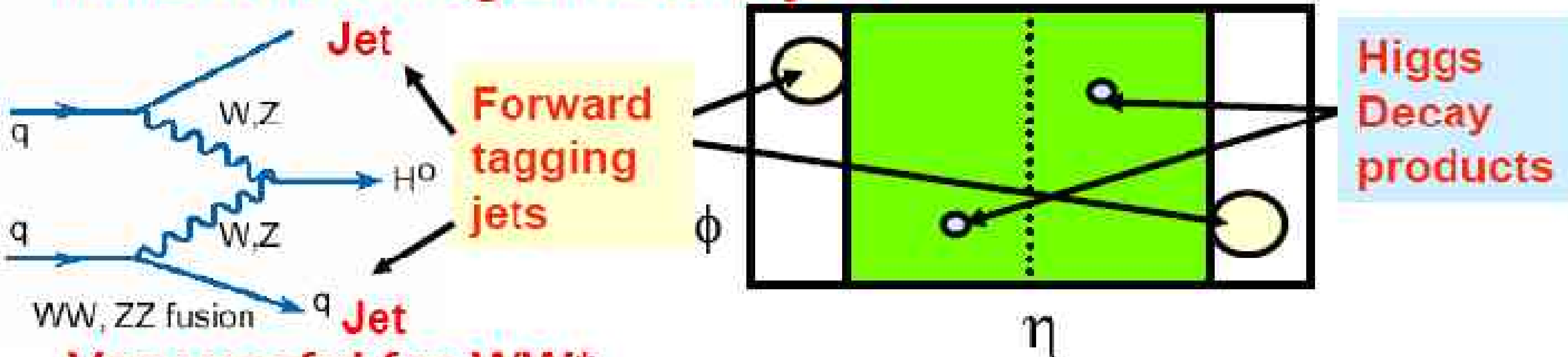
Higgs discovery prospects @ LHC

- **The LHC can probe the entire set of "allowed" Higgs mass values;**
  - in most cases a few months at $2\times10^{33}cm^{-2}s^{-1}$ are adequate for a 5σ observation

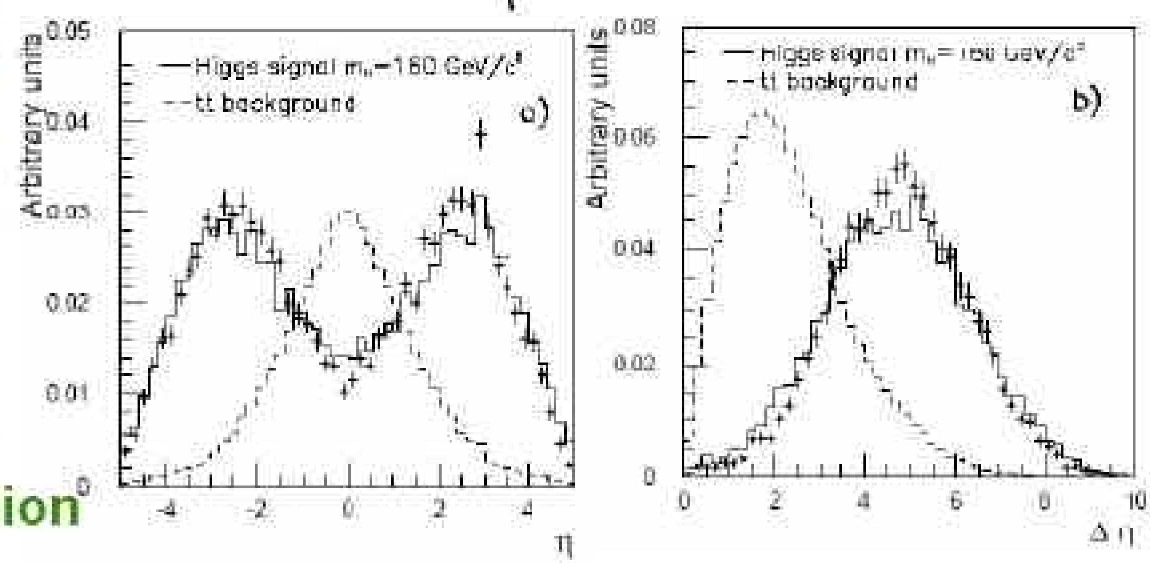


New Higgs channels: VBF-based

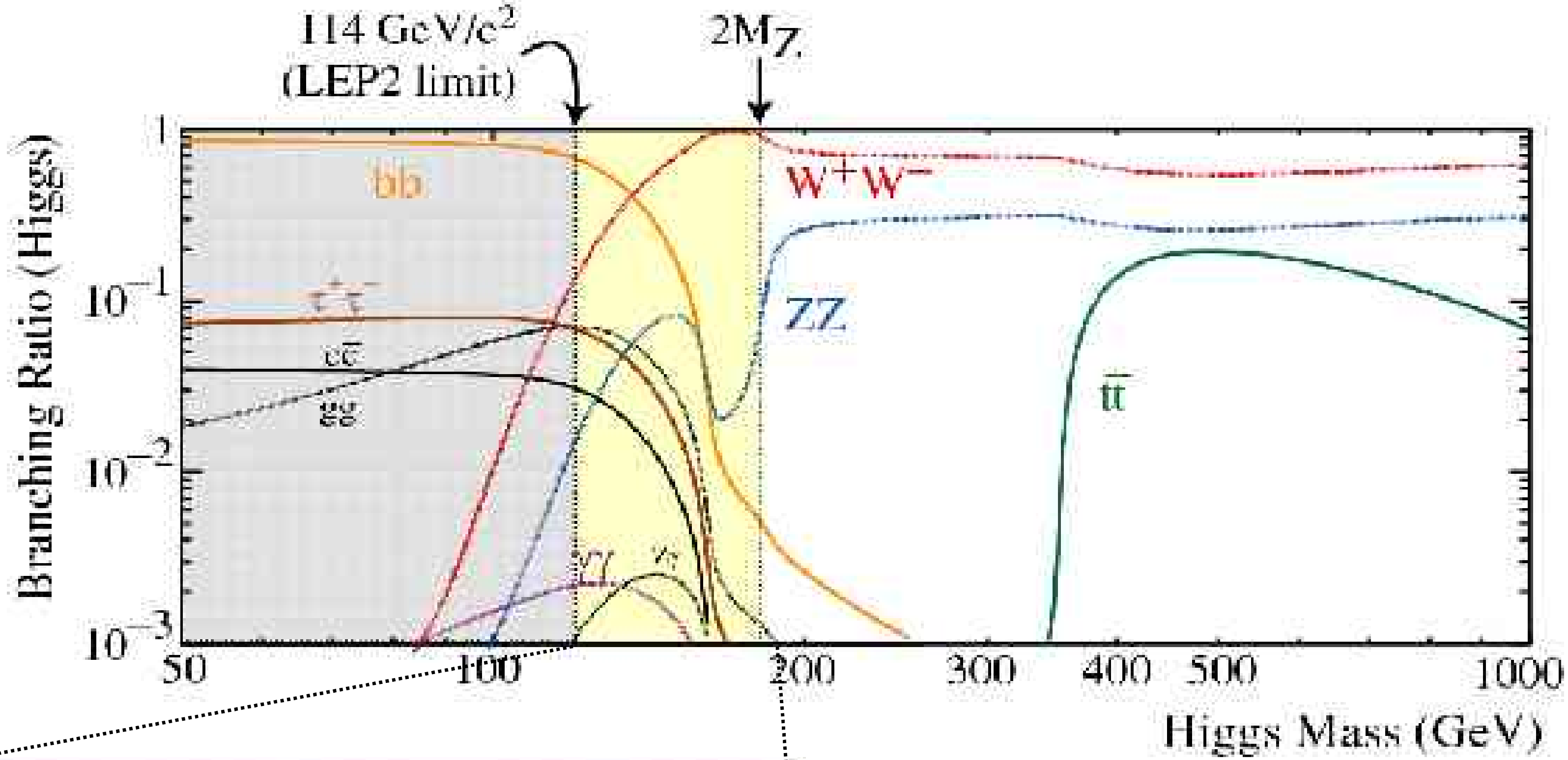
- Cross section varies from 10%(low-mass) to total (high-mass): advantage: forward jets



- Very useful for WW*
  - Rainwater&Zepenfeld
  - $\sigma(M_H=120\text{-}140)\sim 4$ pb
  - compare to tt bkg:
    - FWD jets
    - Large η difference
    - "Quiet" central region



STANDARD MODEL HIGGS DECAY



"Low" Mass Range
(i.e., LEP2 limit to ~2 M_Z)

$H \to \gamma\gamma$: smallest BR but best resolution

$H \to b\bar{b}$: good BR but poor resolution

$H \to \tau\tau$: via VBF

$H \to WW^* \to \ell^+\nu\ell^-\nu$ or $\ell^+\nu qq$: via VBF

$H \to ZZ^* \to 4\ell^\pm$

VBF production mode enhances low mass Higgs sensitivity

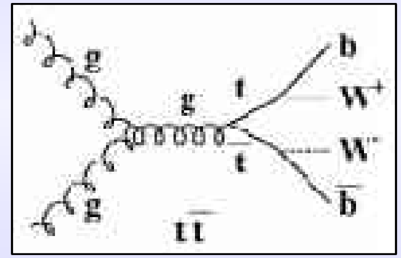
- **Rainwater & Zeppenfeld (1997)**
- **Beyond SM:Invisible Higgs decays (Eboli and Zeppenfeld, 2000)**
- **Improves Higgs parameters measurements (couplings)**

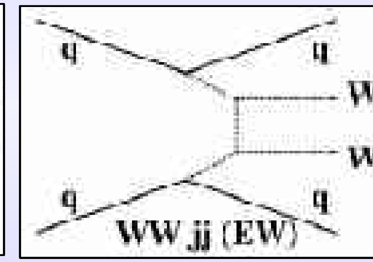
LOW MASS VBF FINAL STATES

$H \to WW^* \to$?ν?ν or ?νqq'

Main Background

- Strongest channel: $125 < M_H < 190$ GeV/c^2
- Higgs mass from transverse mass (M_T)

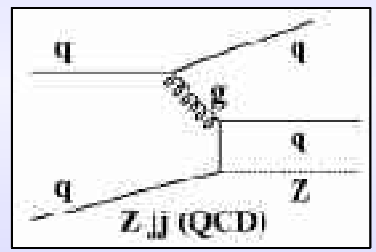


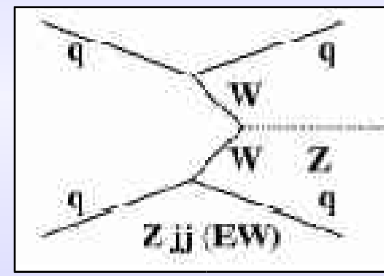


$H \to \tau^+\tau^- \to$?νν?ν or ?νν had.ν

Main Background

- Strong near LEP limit $M_H \sim 115$ GeV/c^2
- Higgs mass from collinear approximation $M_{\tau\tau}$ with $\Delta M_H/M_H \sim 10\%$



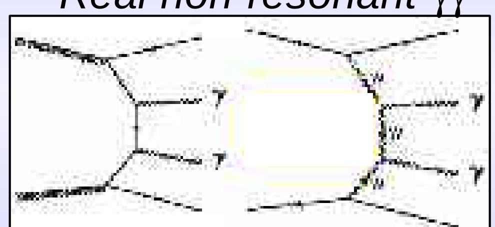


$H \to \gamma\gamma$ *(2 jets VBF-style)*

Main Background

- Sensitive: $115 < M_H < 150$ GeV/c^2
- Excellent Higgs mass from $M_{\gamma\gamma}$ with $\Delta M_H/M_H \sim 1.4\%$

Real non-resonant γγ



Fake non-resonant γγ

$H \to WW^{(*)} \to ?\nu\ ?\nu$

HIGGS MASS RECONSTRUCTION

- For $M_H < 2M_W$: W's at rest in Higgs center-of-mass: $M_{??} ? M_{\nu\nu}$

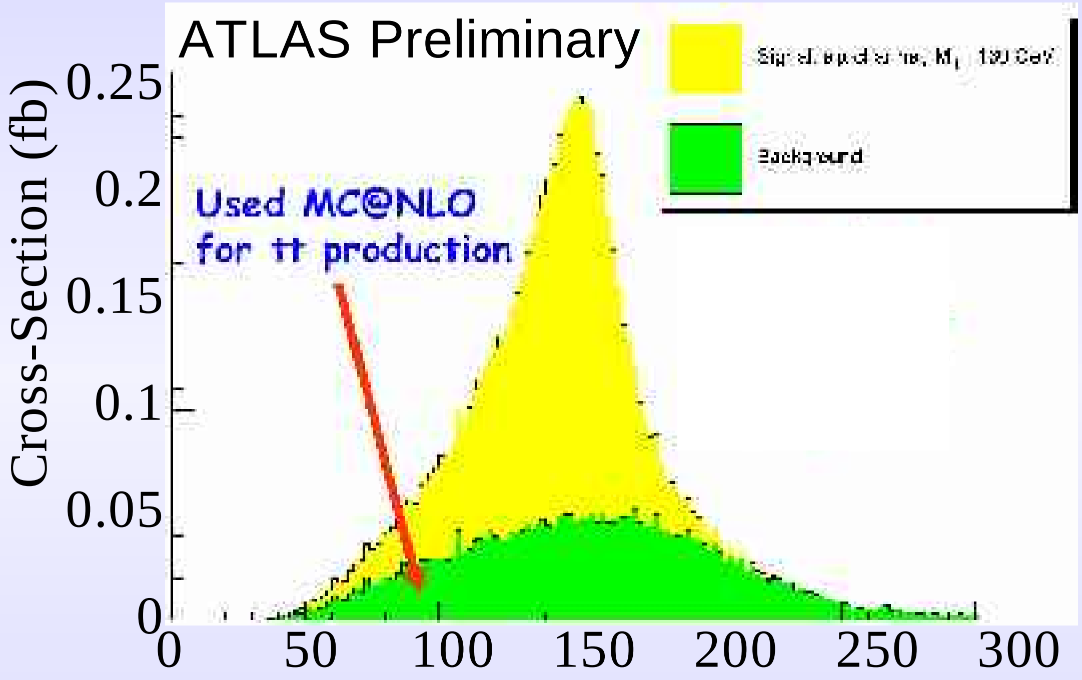
$$E_T^{\ell\ell} = \sqrt{(P_T^{\ell\ell})^2 + m_{\ell\ell}^2}$$

$$E_T^{\nu\nu} = \sqrt{(P_T^{miss})^2 + m_{\ell\ell}^2}$$

$$M_T = \sqrt{(E_T^{\ell\ell} + E_T^{\nu\nu})^2 - (\mathbf{p}_T^{\ell\ell} + \mathbf{p}_T^{miss})^2}.$$

ANALYSIS STRATEGY

- Leption identification
- p_T cuts on leptons
- Two energetic and well rapidity-separation for tag jets
- Leptons between tag jets
- Lepton criteria (angular, invariant mass, p_T)
- Tau veto
- Invariant mass of two tag jets
- Transverse momentum balance
- Jet veto

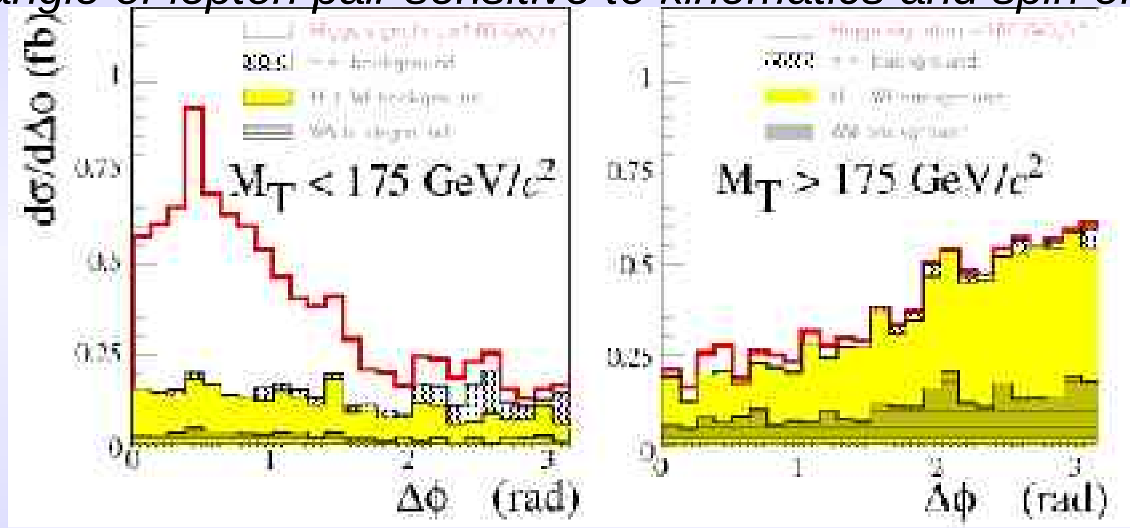


Multivariate (NN) analyses are also being developed with promising ~45% improvement

SELECTED $H \rightarrow WW^{(*)} \rightarrow$?ν ?ν ANALYSIS DETAILS

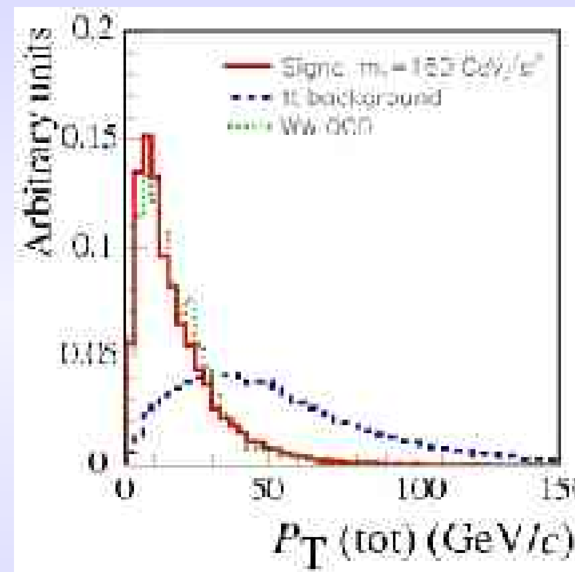
Azimuthal opening angle of lepton pair sensitive to kinematics and spin of Higgs boson

LEPTON KINEMATIC/SPIN-0 CONSISTENCY



TRANSVERSE MOMENTUM BALANCE

- If no hard initial- or final-state gluons, p_T of Higgs balanced by p_T of tag jets
- $P_T^{tot} = P_T^{\ell,1} + P_T^{\ell,2} + P_T^{miss} + P_T^{j,1} + P_T^{j,2}$
- At high luminosity, only broadening of p_T distribution; largely insensitive to jets from pile-up



INVISIBLE HIGGS DECAYS VIA VBF

In a variety of models and scenarios beyond the SM, Higgs could decay to new weakly interacting particles (i.e., invisible decay products)

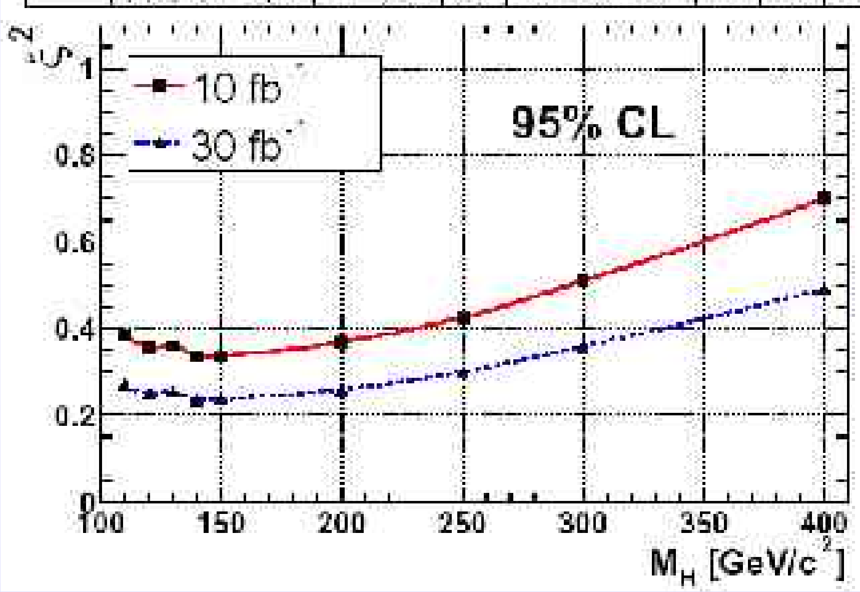
SIGNAL

- Two high $|\eta|$ tagging jets
- considerable $\not{p}_T$ in central region
- need to augment LVL1 $\not{E}_T$ trigger with 2 jets, if not x2.5 less sensitive

BACKGROUND

- Zjj with $Z\to\nu\nu$
- Wjj with W→?ν, ?undetected
- QCD multi-jet with semileptonic decays and/or undetected particles

	m_H (GeV/c^2)	110	120	130	140	150	200	250	300	400
L (fb^{-1}) 10	σ [illegible] (fb)	35.1	[illegible]	59.1	[illegible]	[illegible]	57.8	[illegible]	41.8	30.5
	ξ^2(%) (stat)	39.4	18.0	26.3	[illegible]	17.1	18.7	21.5	25.8	35.4
	ξ^2(%) (stat+syst)	38.5	35.6	36.1	[illegible]	[illegible]	[illegible]	42.0	51.0	70.0
30	ξ^2(%) (stat)	11.2	10.4	9.5	9.8	9.9	10.8	12.1	14.9	20.4
	ξ^2(%) (stat+syst)	27.	25.0	25.4	[illegible]	[illegible]	26.0	[illegible]	35.9	49.2



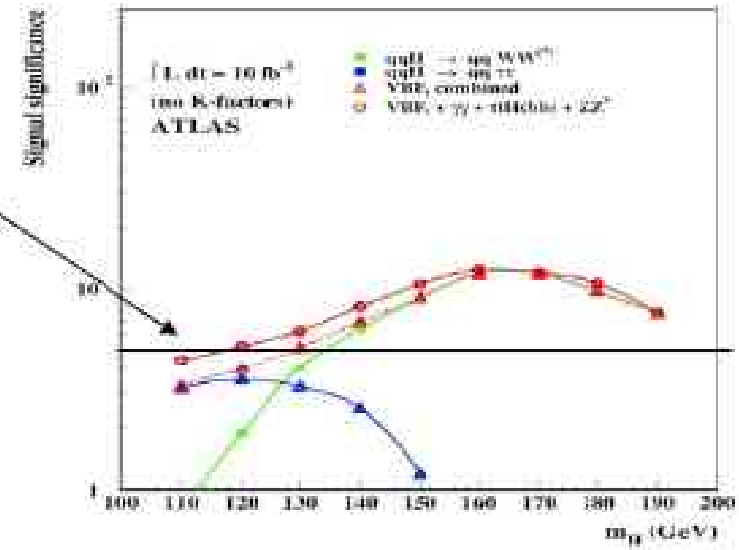
Model-dependent parameter

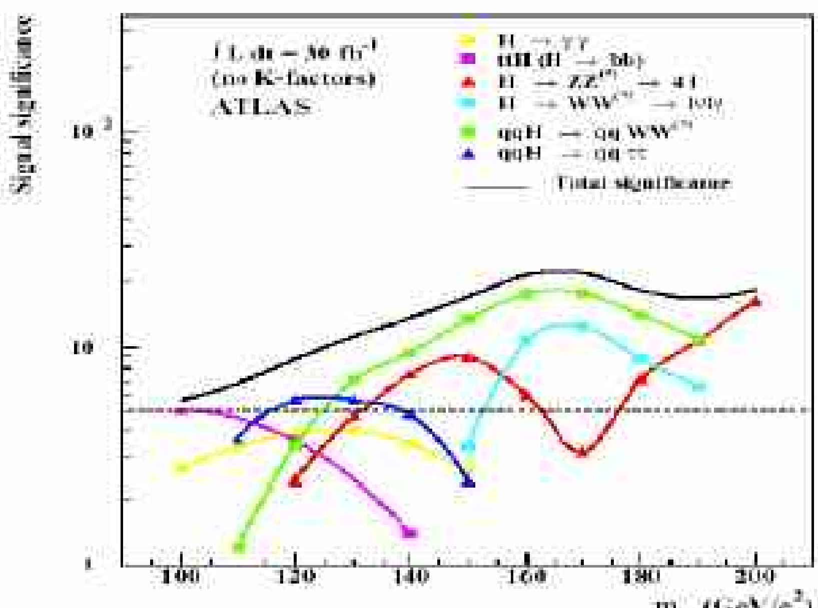
$$\xi^2 = BR(H\to Inv.) \times \frac{\sigma(qq\to qqH)}{\sigma(qq\to qqH)_{SM}}$$

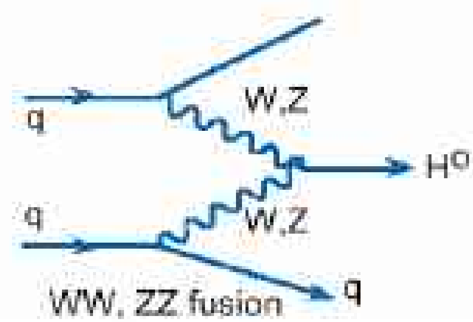
Via VBF, possible to probe ξ^2 values down to 35% for m_H = 140 GeV/c^2 and down to 70% for 400 GeV/c^2

VBF: increased reach

- **VBF: increased discovery reach for low-mass H**
  - $10 fb^{-1}$: actual discovery mode
    - Mainly WW*, ττ also helps
  - Bonus: several channels observable
    - Higgs-couplings determination

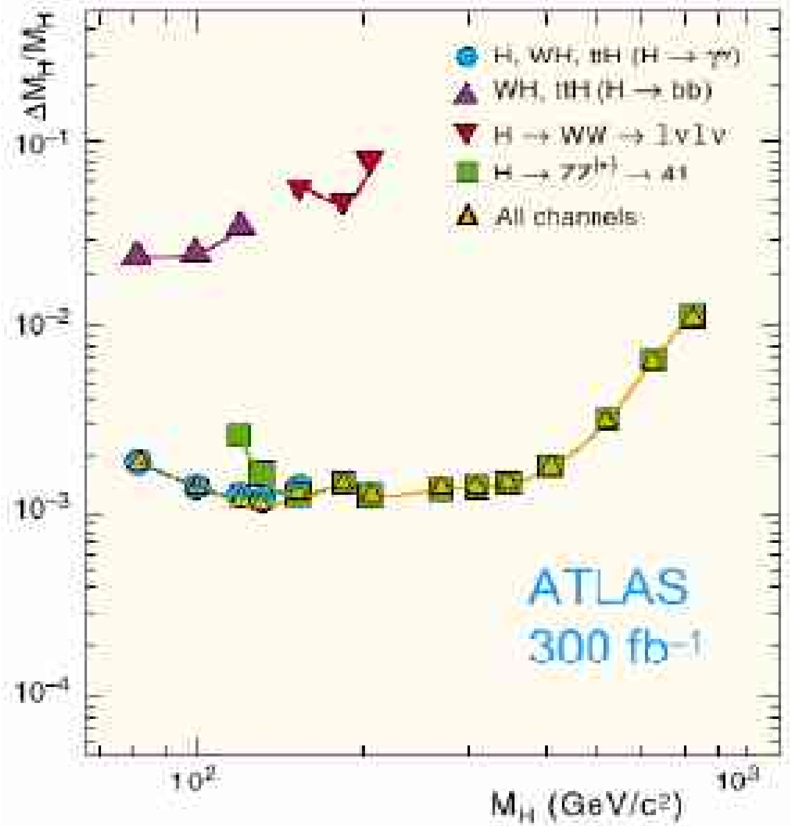






SM Higgs properties (I): mass

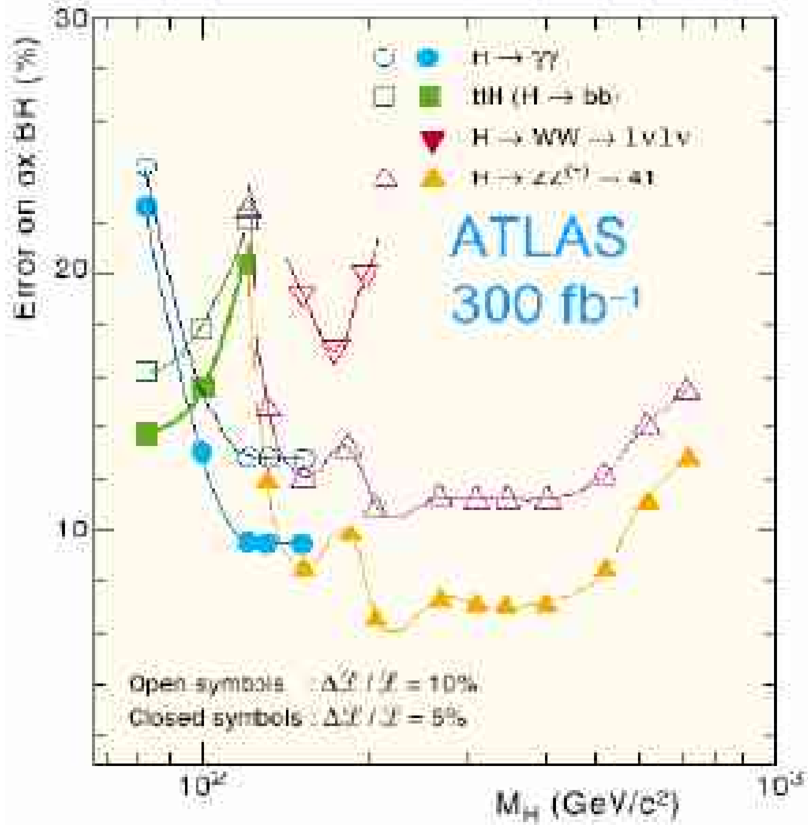
- **Mass measurement**
  - Limited by absolute energy scale
    - leptons & photons: 0.1% (with Z calibration)
    - Jets: 1%
  - Resolutions:
    - For $\gamma\gamma$ & $4\ell \approx 1.5$ GeV/c^2
    - For bb ≈ 15 GeV/c^2
  - At large masses: decreasing precision due to large Γ_H
  - CMS ≈ ATLAS



SM Higgs properties (II): BRs

- Biggest uncertainty (5-10%): Luminosity
  - Relative couplings statistically limited
    - Small overlap regions

Measure	Error	M_H range
$\frac{B(H\to\gamma\gamma)}{B(H\to b\bar{b})}$	30%	80–120
$\frac{B(H\to\gamma\gamma)}{B(H\to ZZ^*)}$	15%	125–155
$\frac{\sigma(t\bar{t}H)}{\sigma(WH)}$	25%	80–130
$\frac{B(H\to WW^{(*)})}{B(H\to ZZ^{(*)})}$	30%	160–180



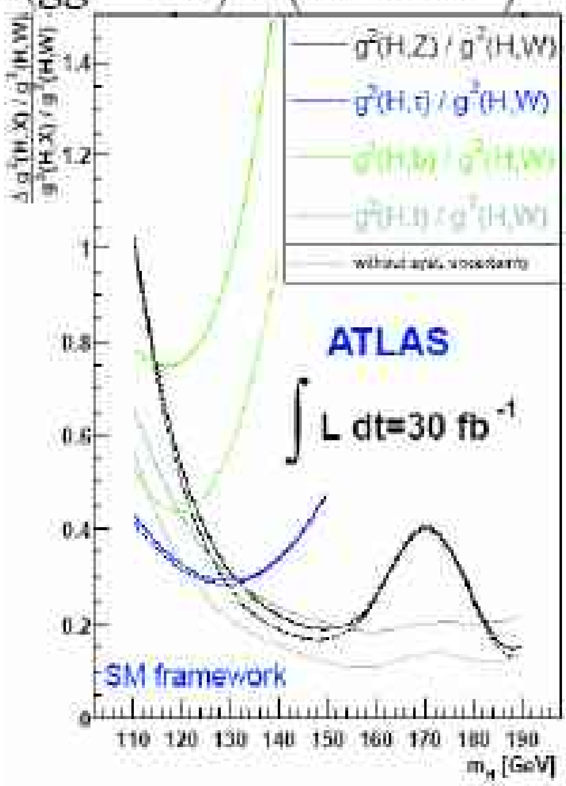
Higgs properties (II): couplings

$$\frac{\sigma(gg\to H)\cdot \mathrm{B}(H\to WW)}{\sigma(gg\to H)\cdot \mathrm{B}(H\to ZZ)} = \frac{\Gamma_W}{\Gamma_Z}$$

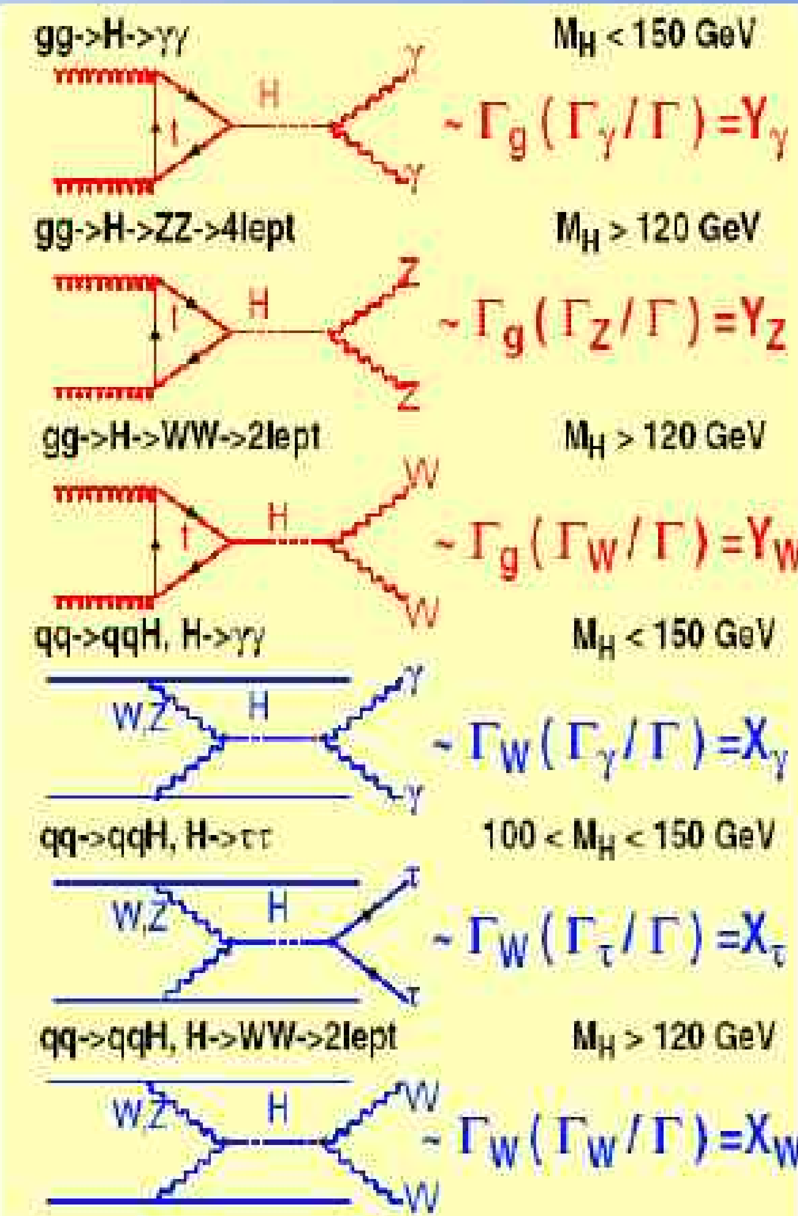
Th-err: ~4%

$$\frac{\sigma(gg\to H)\cdot \mathrm{B}(H\to \gamma\gamma)}{\sigma(gg\to H)\cdot \mathrm{B}(H\to ZZ)} = \frac{\Gamma_\gamma}{\Gamma_Z} \propto \frac{\Gamma_W}{\Gamma_Z}$$

$$\frac{\sigma(qq\to qqH)\cdot \mathrm{B}(H\to WW^*)}{\sigma(gg\to H)\cdot \mathrm{B}(H\to ZZ^*)} = \mathrm{F}_{\mathrm{QCD}}\frac{\Gamma_W}{\Gamma_Z}$$



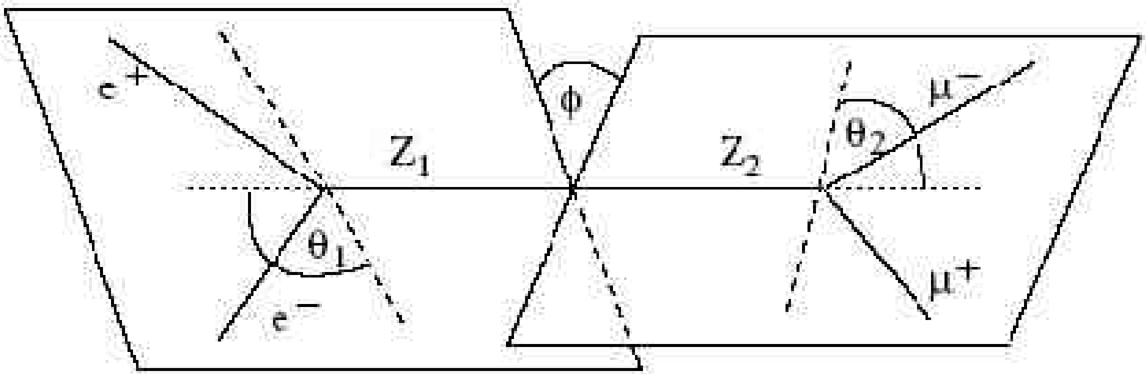
Th-err: ~20%



Determination of Spin / CP

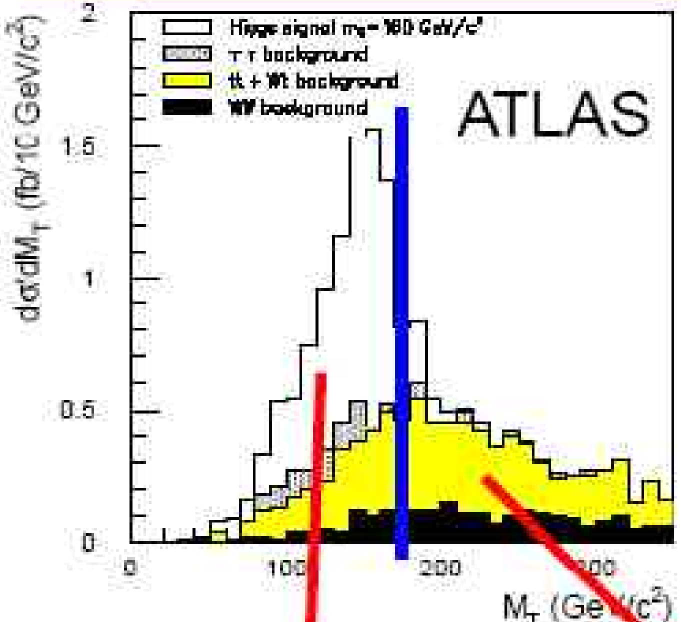
Possible observables:

- Spin 1: no decays H $\longrightarrow \gamma\gamma$ or GF-Production (gg $\longrightarrow$ H)
- Discrimination of Spin 0 / Spin 1 in WBF H $\longrightarrow$ WW $\longrightarrow l\nu\, l\nu$
- H $\longrightarrow$ ZZ $\longrightarrow$ 4l : polarisation correlations of decay products



- Still under study: angular correlations in WBF and $t\bar{t}$ H / $t\bar{t}$ A

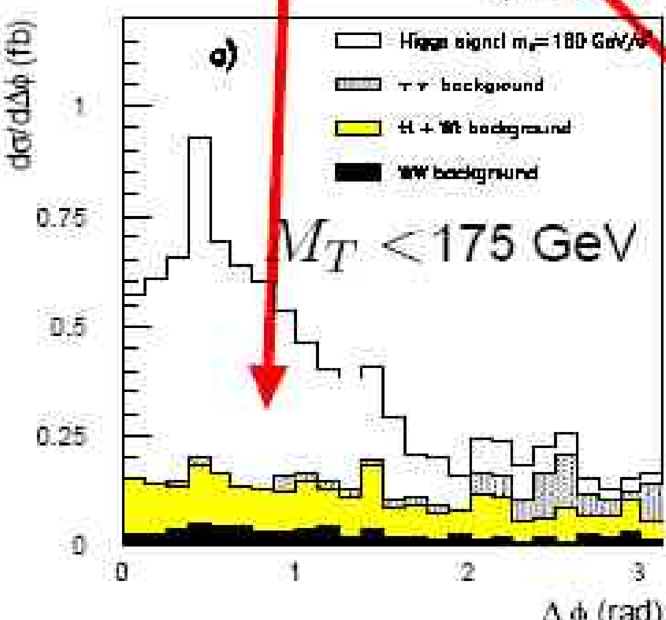
Determination of Spin in WBF $H \rightarrow WW \rightarrow l\nu\, l\nu$

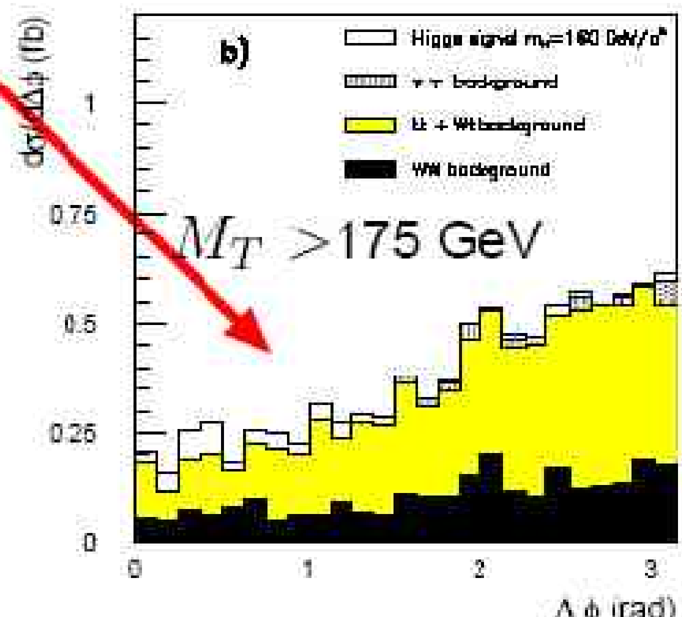


Spin correlation of W-Bosons:

→ For a Spin 0 Higgs Boson leptons tend to go in the same direction.

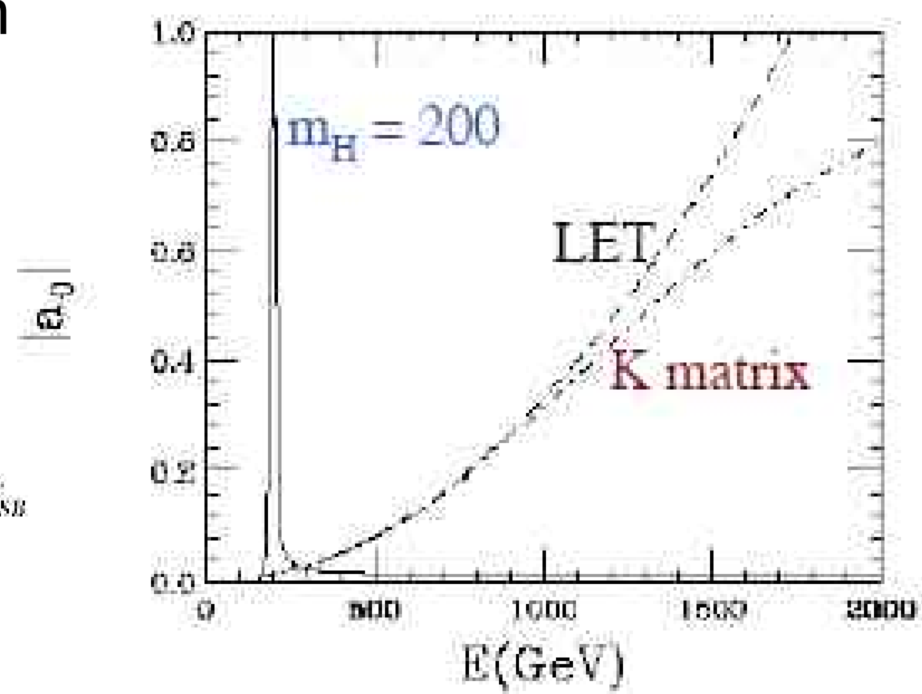
→ Evidence in distribution of transverse opening angle $\Delta\phi$ for signal and background.

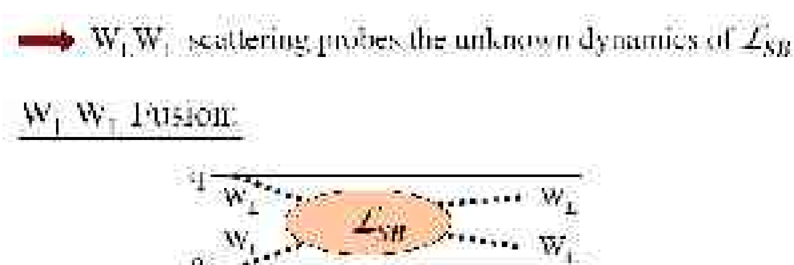




What if the Higgs isn't found directly? WW scattering

- In the SM, the Higgs boson is necessary to keep the WW scattering cross section finite.
- Otherwise, it becomes > 1 for √s > 1~2 TeV





Both the observation of WW scattering and its absence can give us information on EWSB

M.Chanowitz

LHC startup

Allegory for LHC: Huge mess; lots of collisions per bunch crossing; a few particles emerging at high p_T; spectator quarks in beam remnants do nothing very useful

Which detectors the first year ?

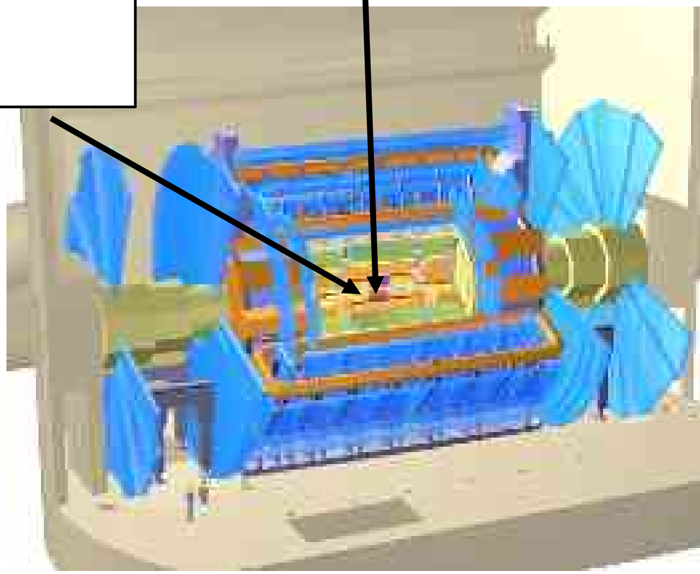
Scenarios for 1st year at LHC

RPC over $|\eta|<1.6$ (instead of $|\eta|<2.1$)

4th layer of end-cap chambers missing

2 pixel layers/disks instead of 3

TRT acceptance over $|\eta|<2$ (instead of $|\eta|<2.4$)



Both experiments: deferrals of high-level Trigger/DAQ processors

LVL1 output rate limited to

50 kHz CMS (instead of 100 kHz)

~ 25 kHz ATLAS (instead of 75 kHz)

Impact on physics visible but acceptable

Main loss : B-physics strongly reduced (single μ threshold p_T> 14-20 GeV)

Fabiola Gianotti

❶ Machine start-up scenario

(from Chamonix XII Workshop, January 2003)

~ 300 dipoles delivered
~ 200 cold-tested

~ **January 2007 - March 2007: machine cool-down**

~ **April 2007 : start machine commissioning (mainly single beam)**

~ **Summer 2007 : two beams in the machine → first collisions**

-- 43 + 43 bunches, $L = 6 \times 10^{31}$ cm^{-2} s^{-1}
(possible scenario: tuning of machine parameters)

-- 936+936 bunches (bunch spacing 75 ns, no electron cloud), $L > 5 \times 10^{32}$

} ~ 4 months

-- 2-3 month shut-down ?

-- **2808 + 2808 bunches (bunch spacing 25 ns), L up to ~2×10^{33} (first year goal)**

→ ~ 7 months of physics run

A lot of uncertainties in this plan → here assume 1 - 10 fb^{-1} /expt on tape after the first year of operation

Case study: impact of LAr calibration on H->γγ

④ First collisions : calibration with $Z \rightarrow ee$ events ← rate ~ 1 Hz at 10^{33}, ~ no background, allows ECAL standalone calibration

$c_{tot} = c_L \oplus c_{LR}$

$c_L \approx 0.5\%$ demonstrated at the test-beam over units $\Delta\eta \times \Delta\varphi = 0.2 \times 0.4$
c_{LR} = long-range response non-uniformities from unit to unit (400 total)
(module-to-module variations, different upstream material, etc.)

↓

Use $Z \rightarrow ee$ events and Z-mass constraint to correct long-range non-uniformities.

From full simulation : ~ 250 $e^{\pm}$ / unit needed to achieve $c_{LR} \le 0.4\%$ → $c_{tot} = 0.5\% \oplus 0.4\% \le 0.7\%$

↑ ~ 10^5 $Z \rightarrow ee$ events (few days of data taking at 10^{33})

Nevertheless, let's consider the worst (unrealistic ?) scenario : no corrections applied

- c_L = 1.3 % measured "on-line" non-uniformity of individual modules
- c_{LR} = 1.5 % no calibration with $Z \rightarrow ee$

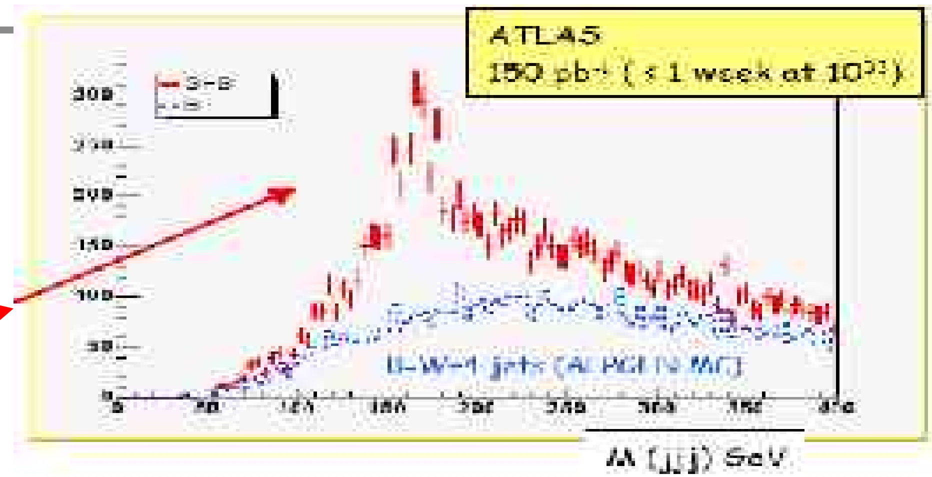
} → $c_{tot} \approx 2\%$

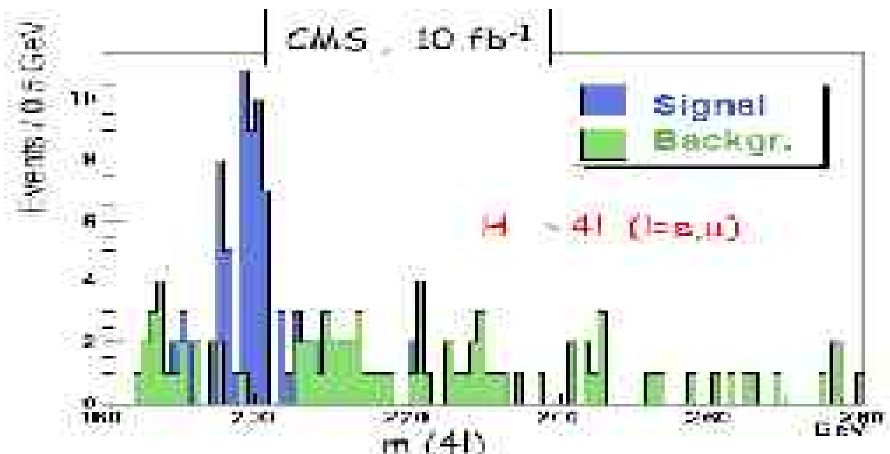
conservative : implies very poor knowledge of upstream material (to factor ~2)

$H \rightarrow \gamma\gamma$ significance m_H~ 115 GeV degraded by ~ 25%
→ need 50% more L for discovery

What measurements?

- Experiments will start with reduced detectors: impact visible but “acceptable”
- Main loss in b-physics capabilities
- LHC will be a top factory (1 top/s): should be able to get mass peak even without b tagging
- Use top as an instrument: peak in wrong place will indicate wrong CAL calibration during startup
- During 1st year may get clear Higgs signal **IF** Higgs is reasonably heavy



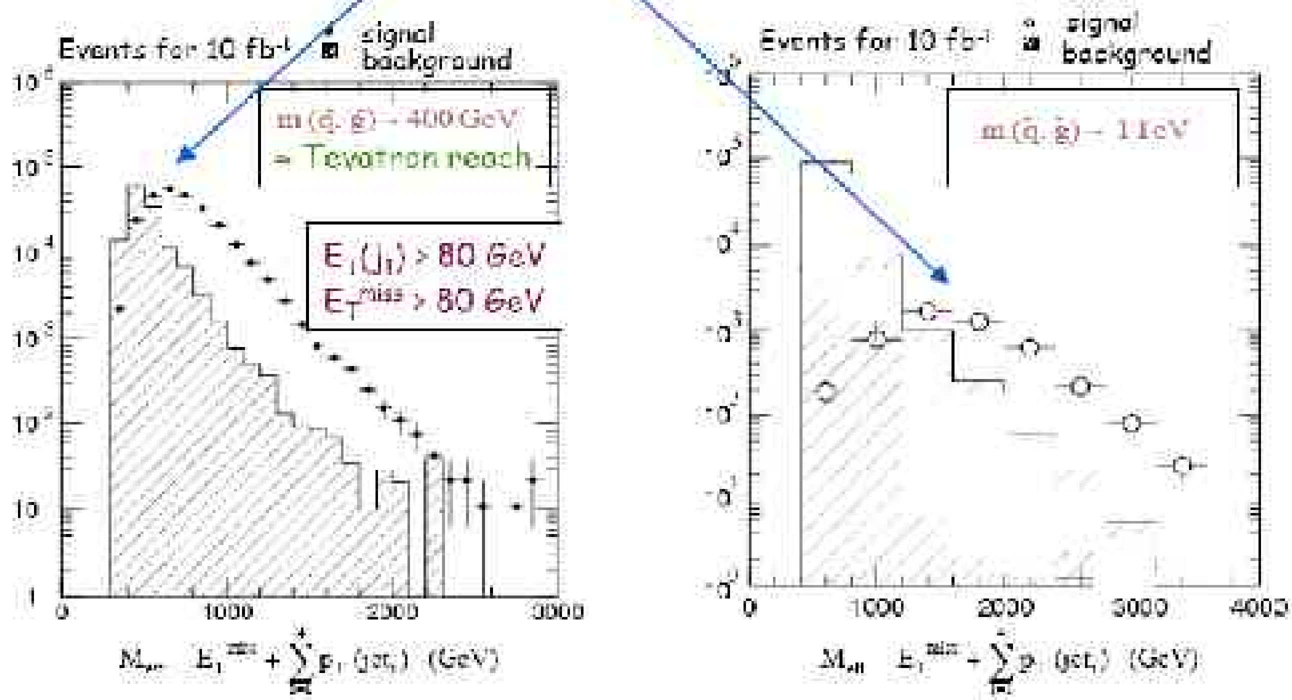


m_H > 180 GeV

SUSY mass scale may be found quickly

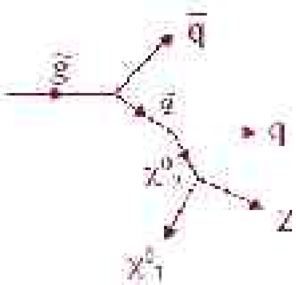
Using multijet + E_T^{miss} (most powerful and model-independent signature if R-parity conserved)

Peak position correlated to M_{SUSY} = min (m($\tilde{q}$), m($\tilde{g}$))



ATLAS

(But measurement of sparticle masses will take > 1 year)



From M_{eff} peak → first/fast measurement of SUSY mass scale to ≈ 20% (10 fb-1, mSUGRA)

Detector/performance requirements:

-- quality of E_T^{miss} measurement (calorimeter inter-calibration, cracks)

→ use control samples (e.g. Z → ll +jets)

-- "low" Jet / E_T^{miss} trigger thresholds for low masses at overlap with Tevatron region (~400 GeV)

To finish…

If electroweak symmetry were not hidden . . .

- ▷ Quarks and leptons would remain massless
- ▷ QCD would confine them into color-singlet hadrons
- ▷ *Nucleon mass would be little changed*, but proton outweighs neutron
- ▷ QCD breaks EW symmetry, gives ($1/2500\times$observed) masses to W, Z, so weak-isospin force doesn't confine
- ▷ Rapid! β-decay $\rightarrow$ lightest nucleus is one neutron; no hydrogen atom
- ▷ Probably some light elements in BBN, but ∞ Bohr radius
- ▷ No atoms (as we know them) means no chemistry, no stable composite structures like the solids and liquids we know

Chris Quigg

A Decade of Discovery Ahead . . .

- ▷ Higgs search and study: EWSB / 1-TeV scale [$p^{\pm}p$ colliders; e^+e^- LC]
- ▷ CP violation (B); Rare decays (K, D, . . .) [e^+e^-, $p^{\mp}p$, fixed-target]
- ▷ Neutrino oscillations [$\nu_{\odot}$, ν_{atm}, reactors, ν beams]
- ▷ Top as a tool [$p^{\pm}p$ colliders; e^+e^- LC]
- ▷ New phases of matter; hadronic physics [heavy ions, ep, fixed-target]
- ▷ Exploration! [colliders, precision measurements, tabletop, . . .]
  Extra dimensions / new dynamics / SUSY / new forces & constituents
- ▷ Proton decay [underground]
- ▷ Composition of the universe [SN Ia, CMB, LSS, underground, colliders]