Aspettando l'LHC

Vittorio Del Duca
INFN Torino

Alessandria 29 Novembre 2006

the Standard Model of Particle Physics

$\mathcal{L}_{SM} = \quad -\frac{1}{4}F^{a}_{\mu\nu}F^{a\mu\nu} + i\bar{\psi}D\psi$	gauge sector
$+\ \psi_i\lambda_{ij}\psi_j H + h.c.$	flavour sector
$+\ \lvert D_\mu H\rvert^2 - V(H)$	EWSB sector
$+\ N_i M_{ij} N_j$	(Majorana) ν-mass sector

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☛ are there elementary scalars in the SM ? Higgs boson ???

the Standard Model of Particle Physics

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☛ do they cause spontaneous symmetry breaking ?

→ fermion and gauge boson masses

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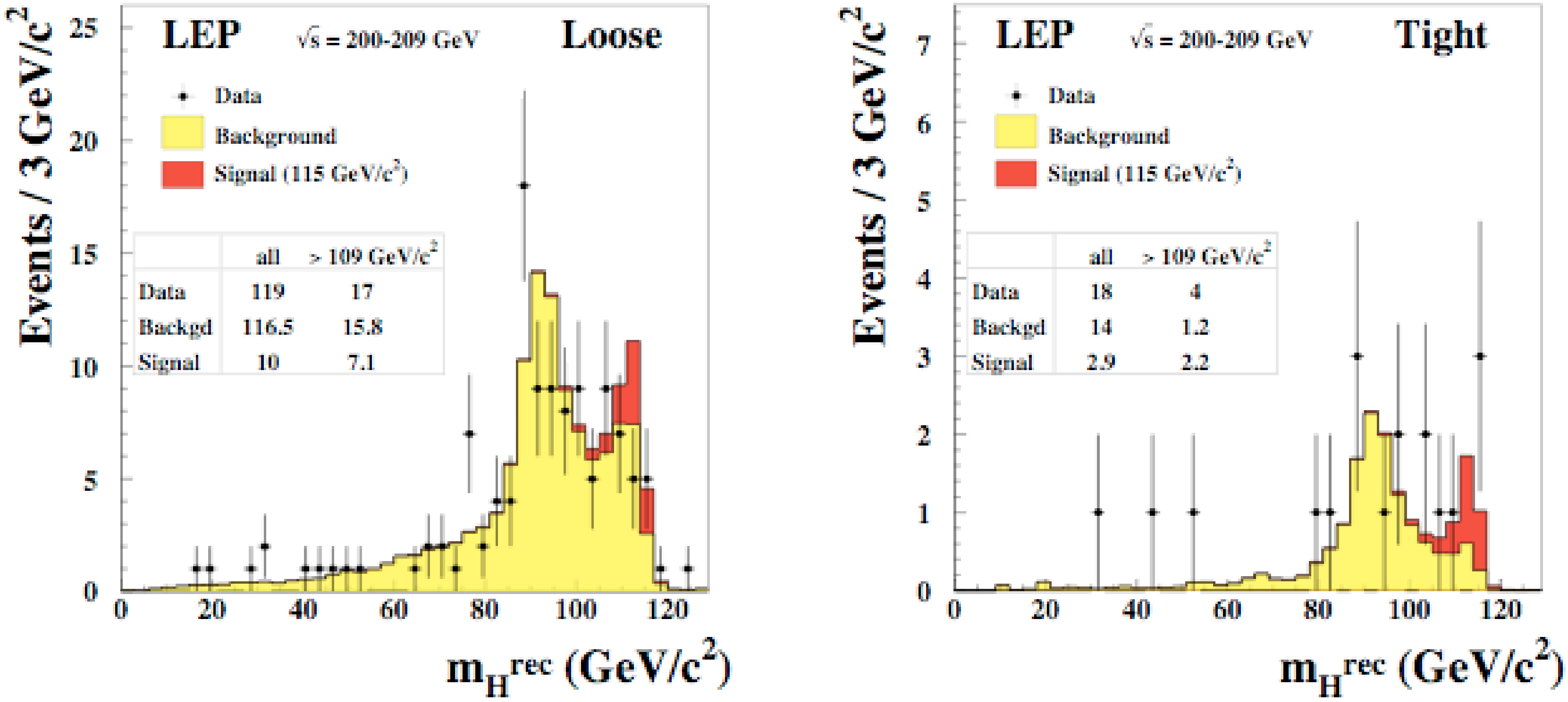
☛ do they cause spontaneous symmetry breaking ?
→ fermion and gauge boson masses

- foremost task of the LHC is to find the Higgs boson

Search for the Standard Model Higgs Boson at LEP

ALEPH, DELPHI, L3 and OPAL Collaborations
The LEP Working Group for Higgs Boson Searches[1]



	all	> 109 GeV/c²
Data	119	17
Backgd	116.5	15.8
Signal	10	7.1

	all	> 109 GeV/c²
Data	18	4
Backgd	14	1.2
Signal	2.9	2.2

histograms are MC predictions; in loose and tight selections, cuts are adjusted so as to obtain, for m_H = 115 GeV, approximately 0.5 and 2 times more expected signal than background events

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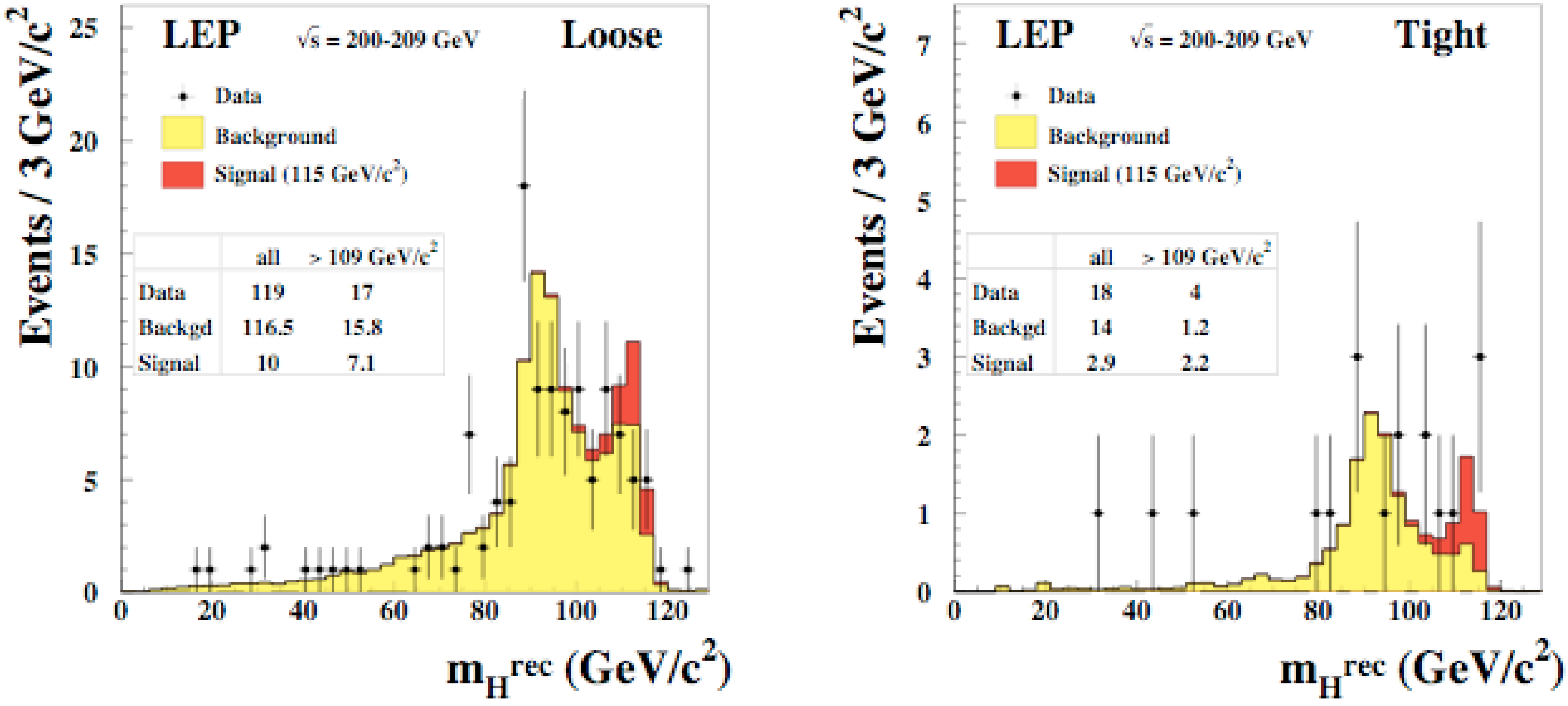

Loose:

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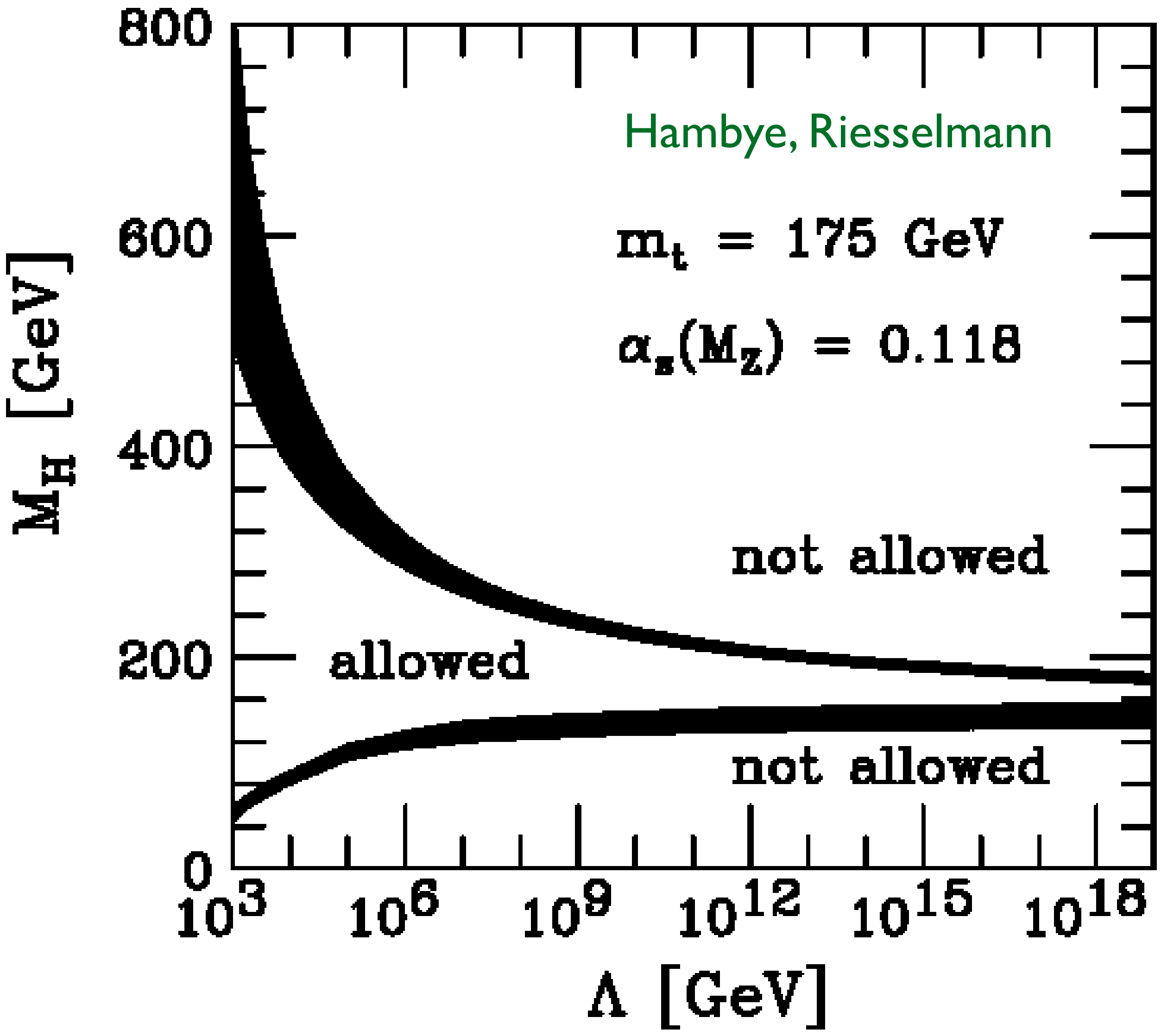
Lower bound: m_H = 114.4 GeV at 95% *CL*

Theoretical bounds on the SM Higgs mass

Λ : scale of new physics beyond the SM

Lower bound:
vacuum (meta)stability
Upper bound:
No Landau pole up to Λ



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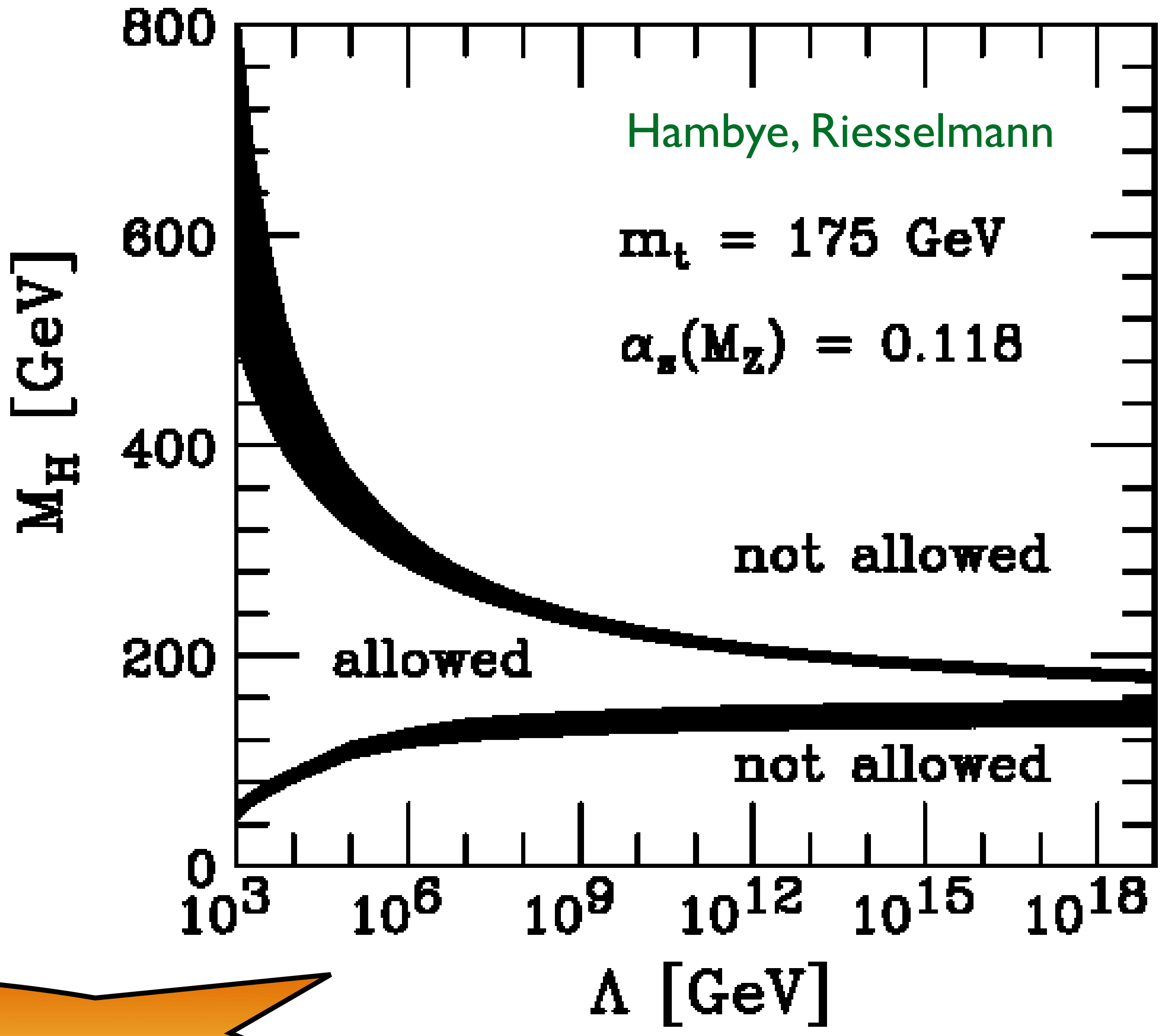
Hambye, Riesselmann

were the SM valid up to M_{Pl}, then
M_H would be limited to a small range

Higgs potential (lower bound on m_H)

classic $V[\phi] = -\mu^2\phi^2 + \lambda\,\phi^4$ $\mu^2 > 0, \quad \lambda > 0$

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renormalization group improved PT

quantum corr. $\lambda\phi^4 \to \lambda\phi^4 \left(1 + \gamma \ln \dfrac{\phi^2}{\Lambda^2} + \ldots\right) \xRightarrow{\text{RG}} \lambda(\Lambda)\,\phi'^4(\Lambda)$

$$\phi' = \left(\exp \int dt\gamma(t)\right)\phi \qquad t = \frac{\ln(\Lambda)}{\mathrm{v}}$$

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Running coupling

$$\frac{d\lambda(t)}{dt} = \beta_\lambda(t) \propto \left(\lambda^2 + 3\lambda\,h_t^2 - 9h_t^4 + \ldots\right)$$

h_t top Yukawa coupling

initial conditions (at Λ = v) $\quad \lambda_0 = \dfrac{m_H^2}{4\mathrm{v}^2} \quad h_{0t} = \dfrac{m_t}{v}$

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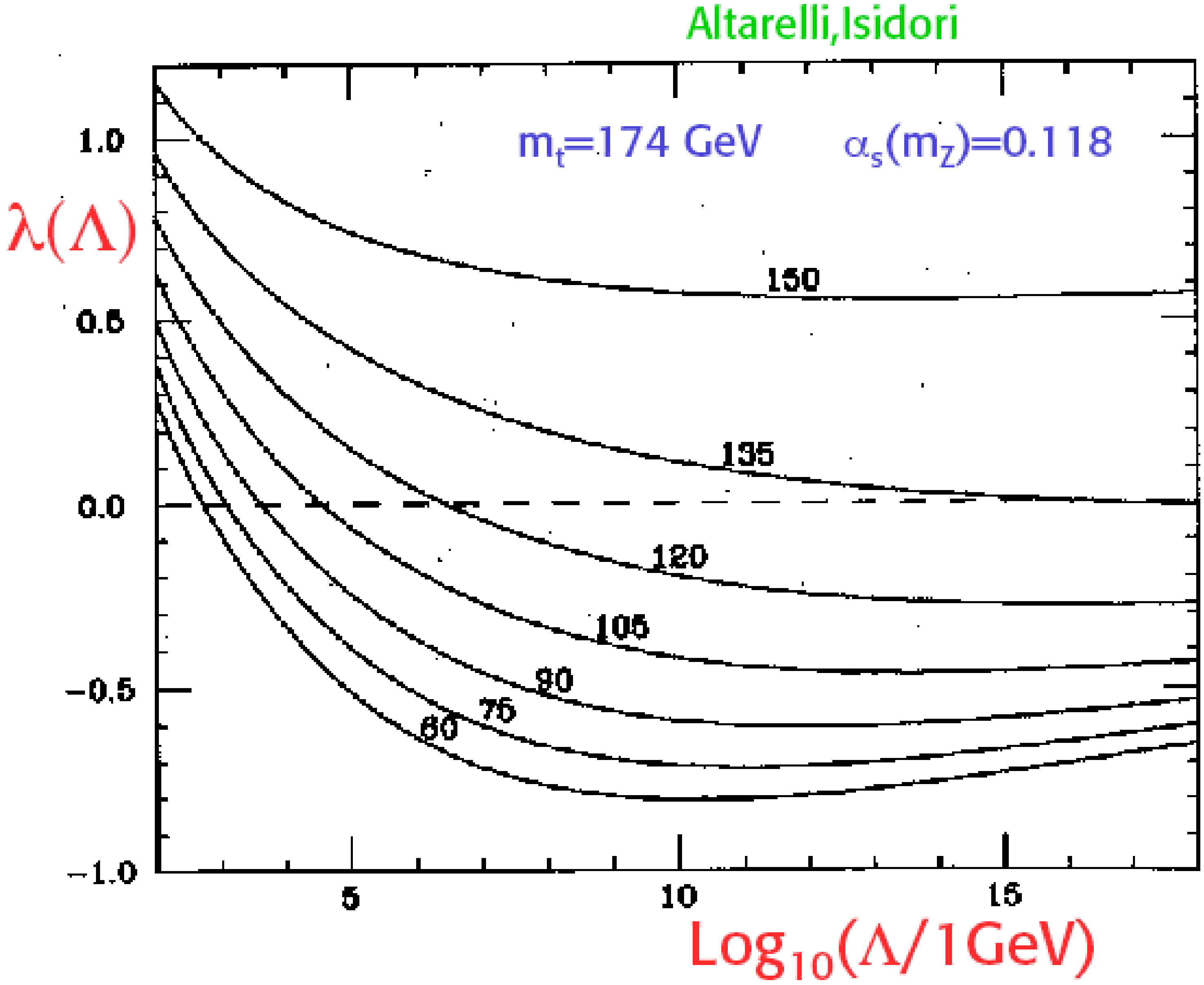
if m_H is too small, h_t dominates → $\lambda(t)$ decreases

For the vacuum to be stable, $\lambda(t)$ must be > 0 below Λ → lower bound on m_H

$$m_H > 129.5 + 2.1\,(m_t - 171.4) - 4.5\frac{\alpha_s(m_Z) - 0.118}{0.006}$$

m_H ≥ 130 GeV at $\Lambda = M_{GUT}$

Higgs potential



Upper bound on m_H

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Landau pole (signals PT breakdown)

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Landau pole (signals PT breakdown)

The upper bound on m_H is obtained
by requiring that no Landau pole occurs below Λ

m_H ≤ 180 GeV if Λ ~ M_{GUT}

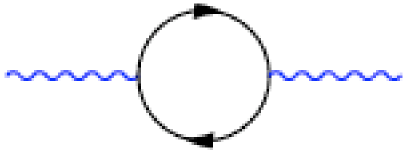
600 ÷ 800 GeV if Λ ~ O(TeV)

Hierarchy problem in the SM

Symmetry principles protect against power-like divergences

Hierarchy problem in the SM

Symmetry principles protect against power-like divergences



photon self-energy

$$\delta m_\gamma^2 \propto \xcancel{\Lambda^2} + m_\gamma^2 \ln \Lambda$$

gauge symmetry protects against quadratic divergence

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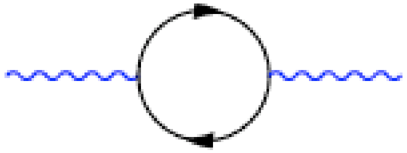

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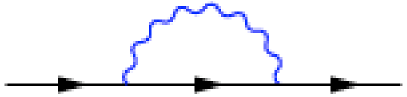

electron self-energy $\delta m_e \propto \cancel{\Lambda} + m_e \ln \Lambda$

chiral symmetry protects against linear divergence

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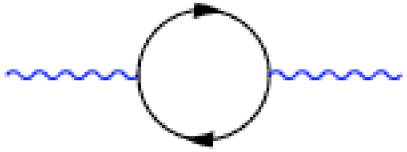

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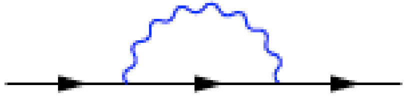

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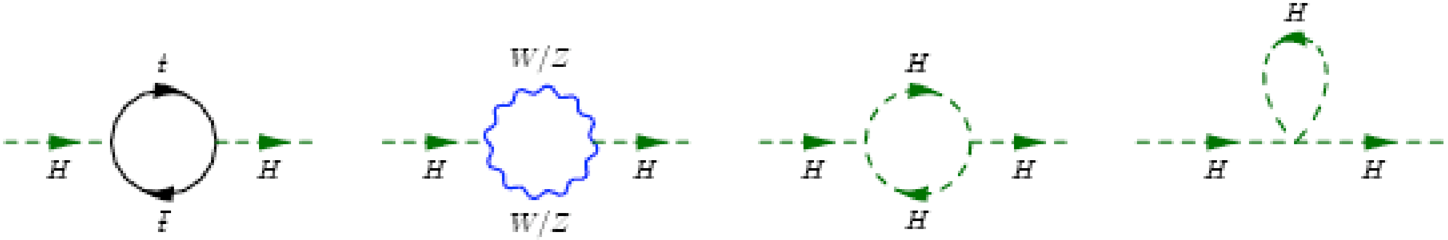

Higgs self-energy

$$\delta m_H^2 = \frac{3G_F}{4\sqrt{2}\pi^2}\left(2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2\right)\Lambda^2$$

no symmetry protects against quadratic divergences

Fine tuning and unnaturalness

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A *natural* solution to hierarchy: supersymmetry

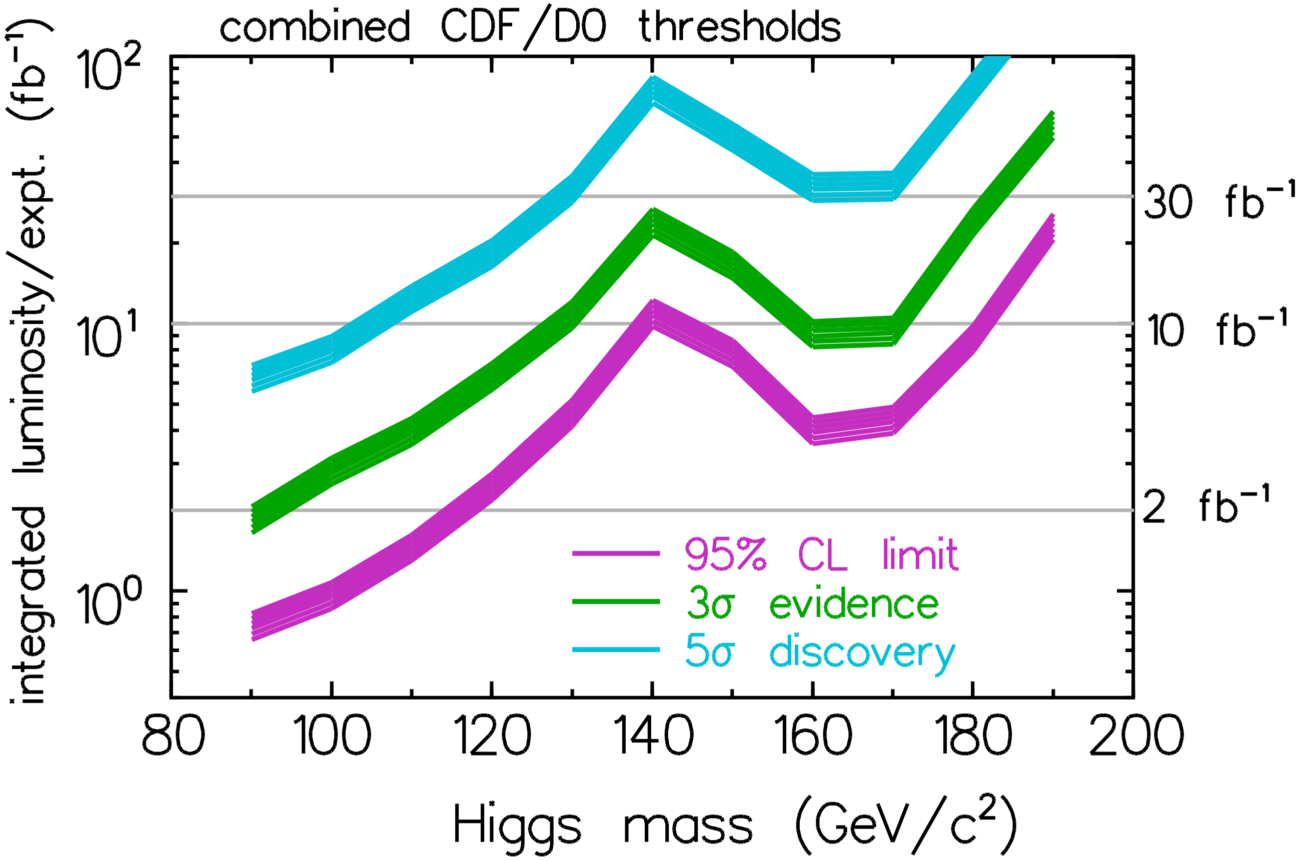
postulate a new symmetry principle, which yields new particles that cancel the quadratic divergences of the Higgs self-energy, such that

$$\delta m_H^2 \sim \mathcal{O}(m_H^2)\ln\Lambda$$

Higgs search - Tevatron reach

Tevatron has collected so far about 2 fb^{-1}

Although it cannot collect enough integrated luminosity to claim discovery above the LEP exclusion limit (114.4 GeV), it could collect enough to hint at some evidence for a signal



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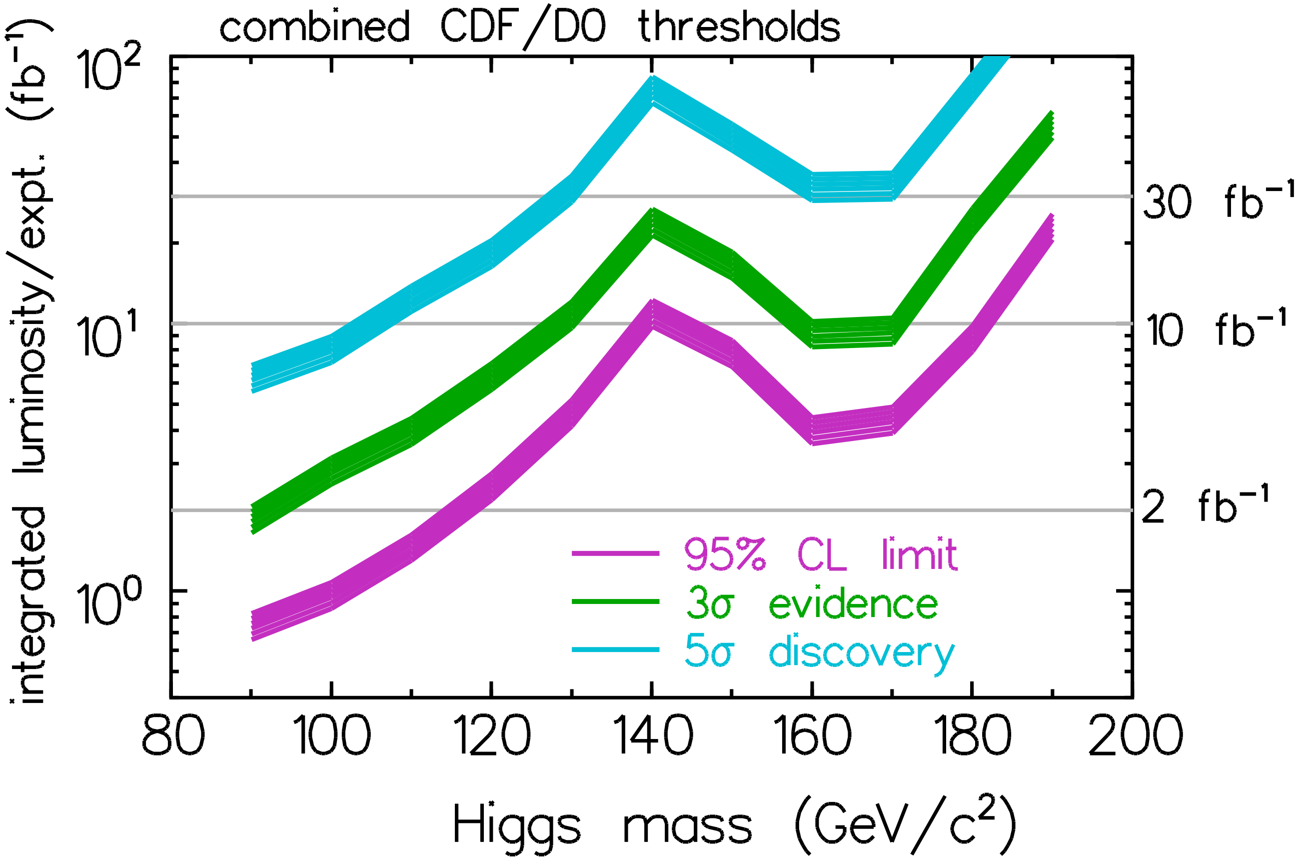
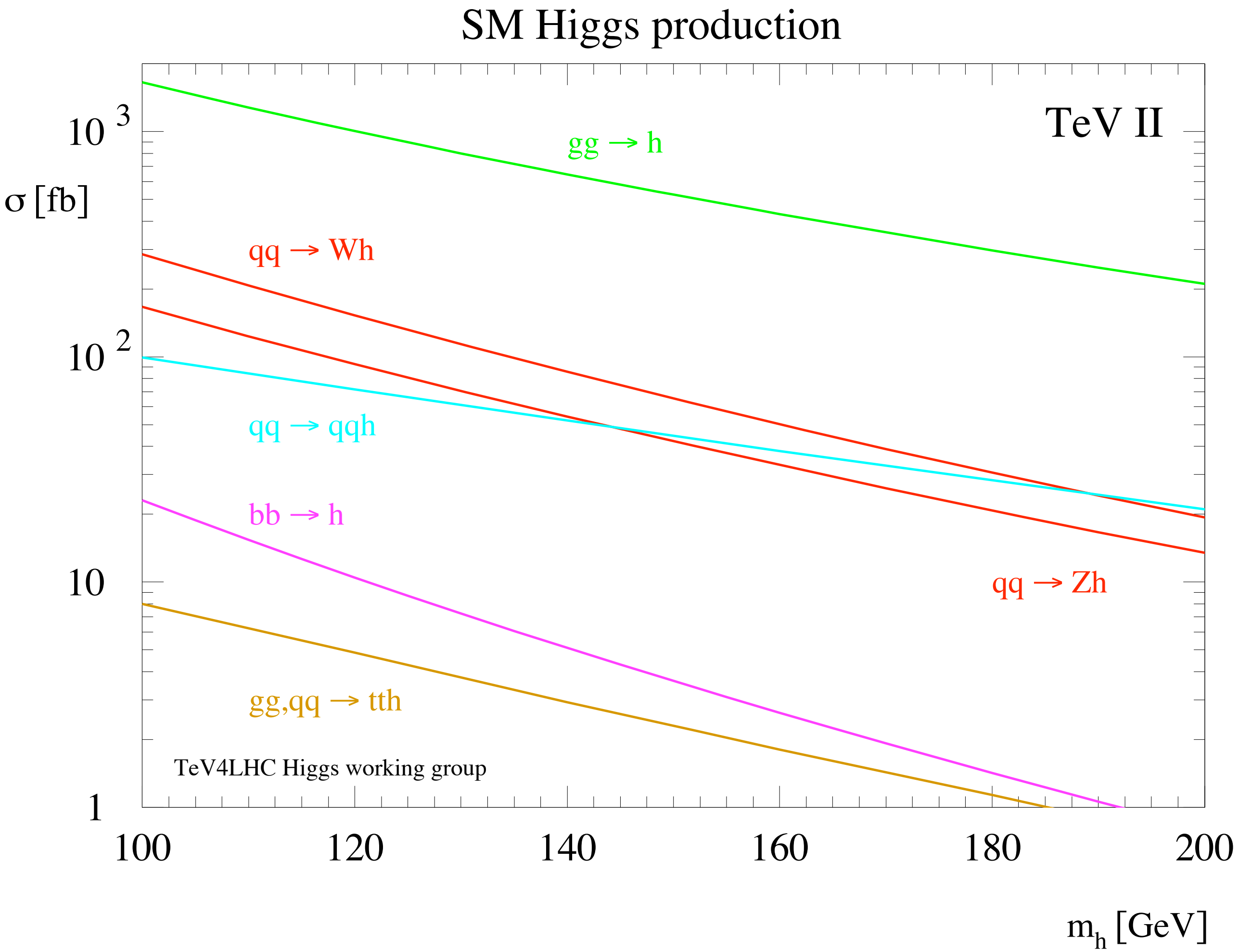


Sensitivity in the mass region above LEP limit (114 GeV) starts at ~2 fb^{-1}

With 8 fb^{-1}: exclusion 115-135 GeV & 145-180 GeV,

5 - 3 sigma discovery/evidence @ 115 – 130 GeV

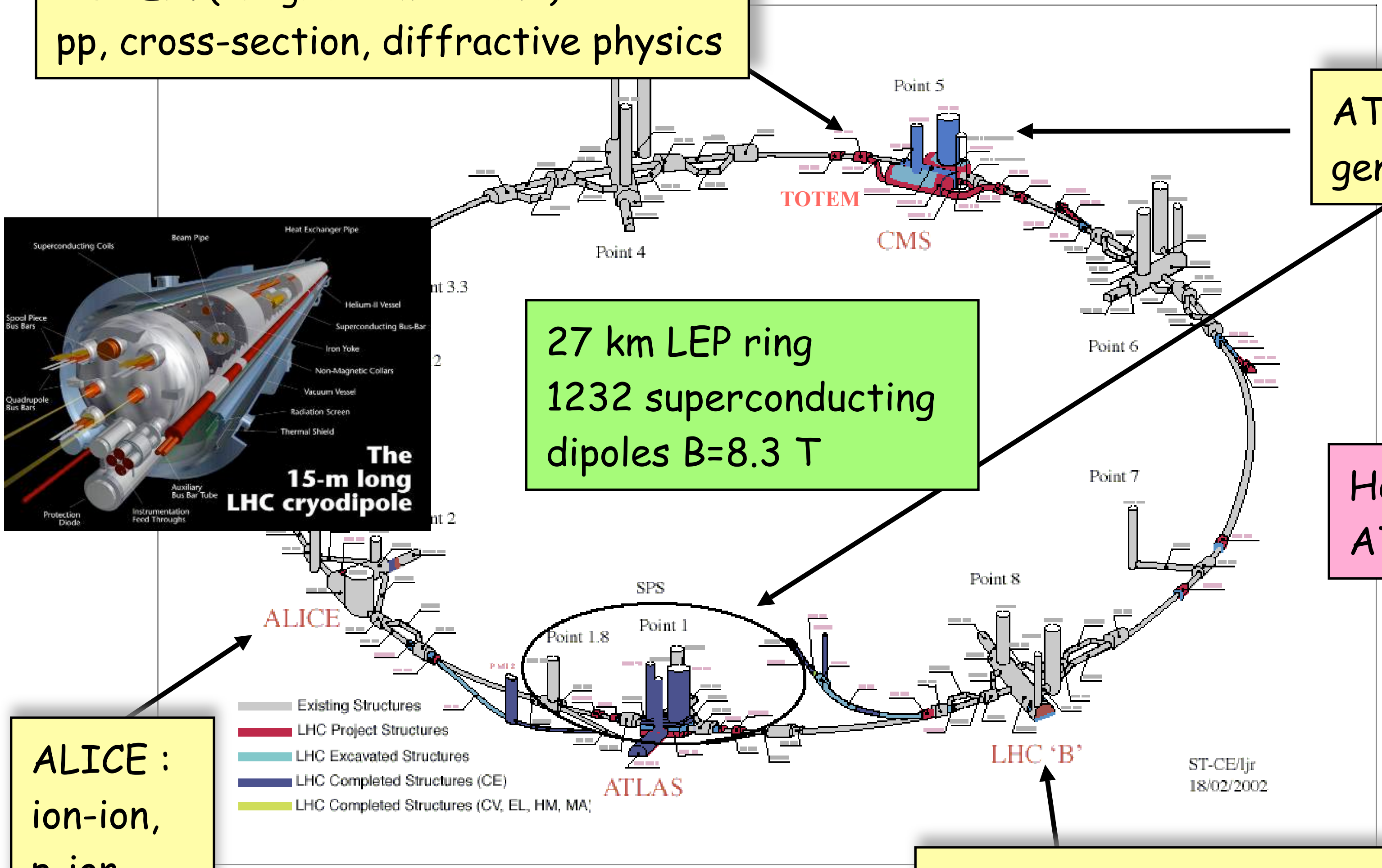
Higgs production at Tevatron Run-II



- in the intermediate Higgs mass range $M_H \sim 100 - 200$ GeV
  - gluon fusion cross section is ~ 0.2 – 2 pb
  - *WH, ZH* yield cross sections of ~ 10 – 300 fb
  - WBF cross section is ~ 20 - 100 fb

LHC

- pp $\sqrt{s}$ = 14 TeV $L_{design} = 10^{34}$ cm^{-2} s^{-1} (after 2009)
  $L_{initial} \leq$ few x 10^{33} cm^{-2} s^{-1} (until 2009)
- Heavy ions (e.g. Pb-Pb at $\sqrt{s}$ ~ 1000 TeV)



TOTEM (integrated with CMS):
pp, cross-section, diffractive physics

ATLAS and CMS :
general purpose

27 km LEP ring
1232 superconducting
dipoles B=8.3 T

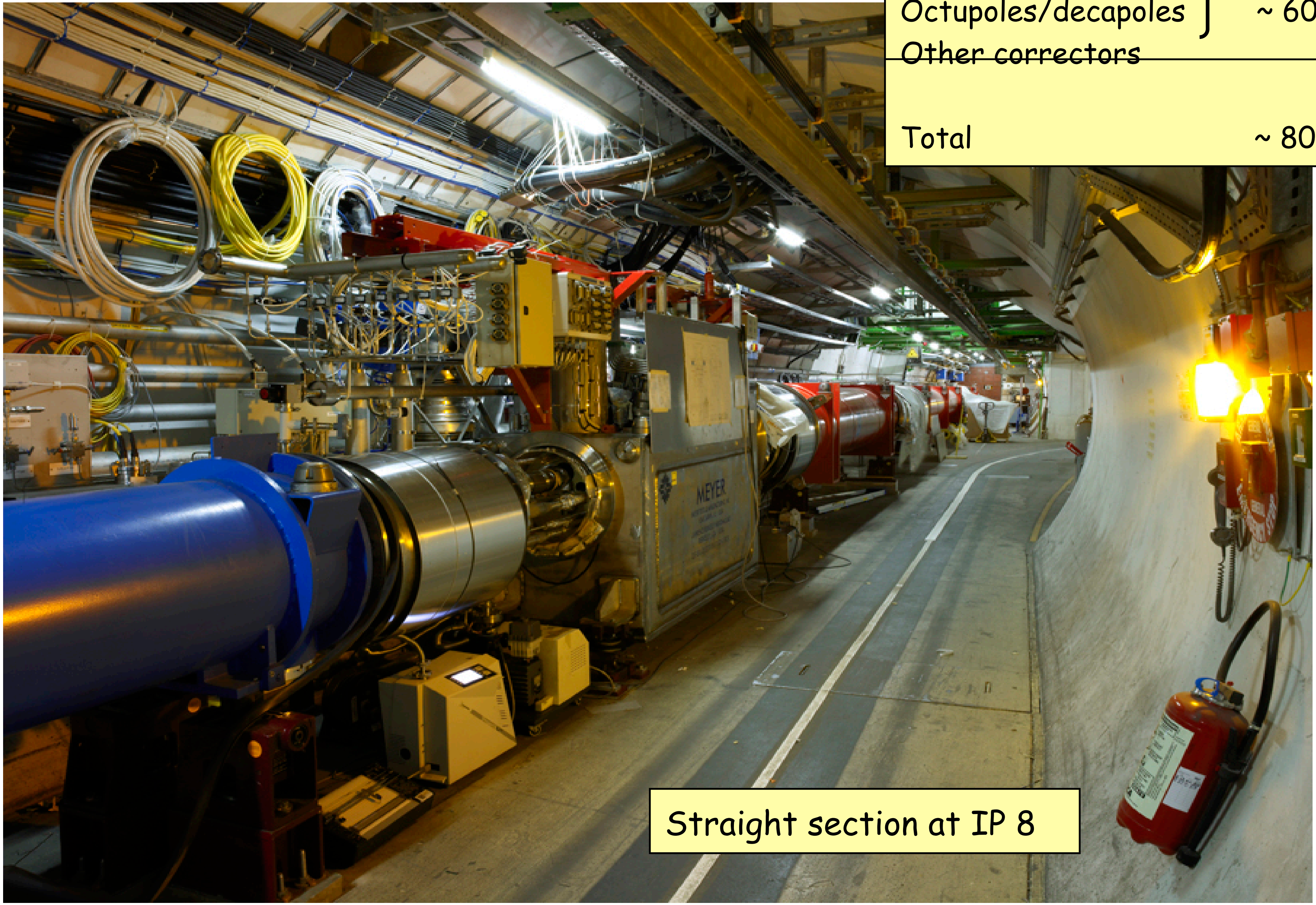
Here:
ATLAS and CMS

ALICE :
ion-ion,
p-ion

LHCb :
pp, B-physics, CP-violation

dipoles & more

Main dipoles	1232
Quadrupoles	~ 400
Sextupoles	~ 6000
Octupoles/decapoles	
Other correctors	
Total	~ 8000



Straight section at IP 8

LHC schedule

"nominal luminosity" **(reached gradually !)** :
2808 bunches (25 ns spacing), N=1.15 x 10^{11}/ bunch,
full *squeeze* at I.P. ($\Rightarrow L \sim 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$)

~15 pb^{-1}

Stage 1

Initial commissioning
43x43 to 156x156, N=3x10^{10}
Zero to partial squeeze

$L = 3\times10^{28} - 2\times10^{31}$

Stage 2

75 ns operation
936x936, N=3-4x10^{10}
partial squeeze

$L = 10^{32} - 4\times10^{32}$

~1 fb^{-1}

Stage 3

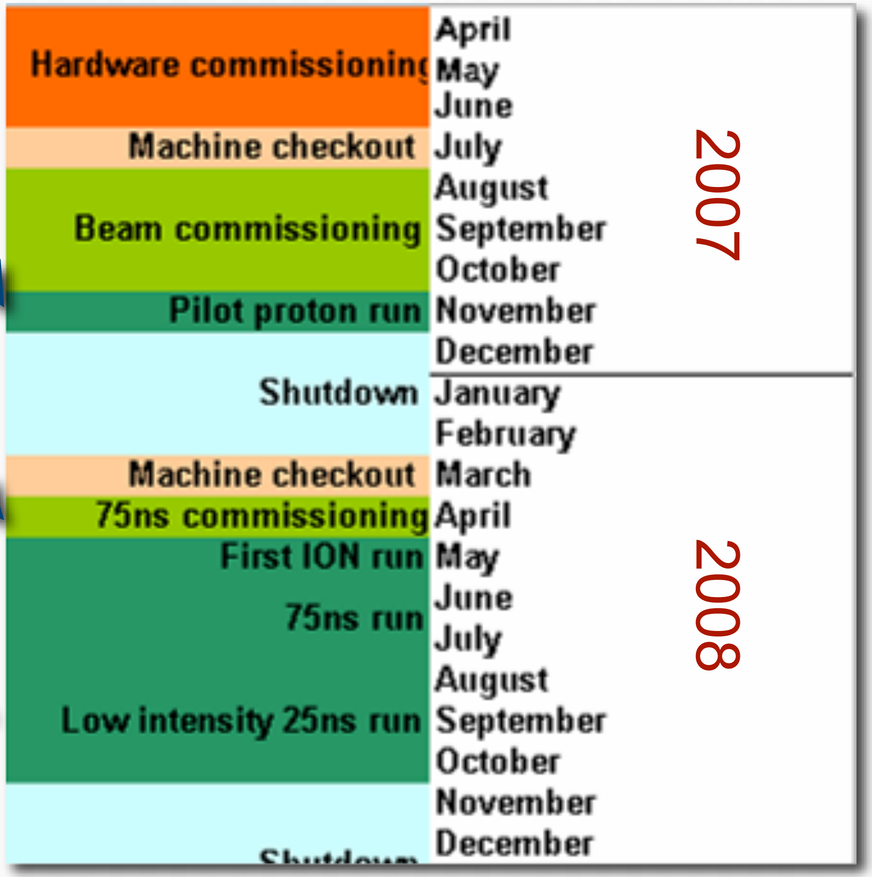
25 ns operation
2808x2808, N=3-5x10^{10}
partial to near full squeeze

$L = 7\times10^{32} - 2\times10^{33}$

Stage 4

25 ns operation
Push to nominal per bunch
partial to full squeeze

$L = 10^{34}$



Hardware commissioning	April	2007
	May	
	June	
Machine checkout	July	
Beam commissioning	August	
	September	
	October	
Pilot proton run	November	
Shutdown	December	
	January	2008
	February	
Machine checkout	March	
75ns commissioning	April	
First ION run	May	
75ns run	June	
	July	
Low intensity 25ns run	August	
	September	
	October	
Shutdown	November	
	December	

(Revised) LHC schedule

as presented to CERN Council on 23 June 2006

- Last magnet installed : March 2007
  Machine and experiments closed : 31 August 2007

- First collisions ($\sqrt{s}$ = 900 GeV, L~10^{29} cm^{-2} s^{-1}) : November 2007
  Commissioning run at injection energy until end 2007, then shutdown (3 months ?)

- First collisions at $\sqrt{s}$=14 TeV (followed by first physics run): Spring 2008

L. Evans,
CERN Council,
23/6/2006

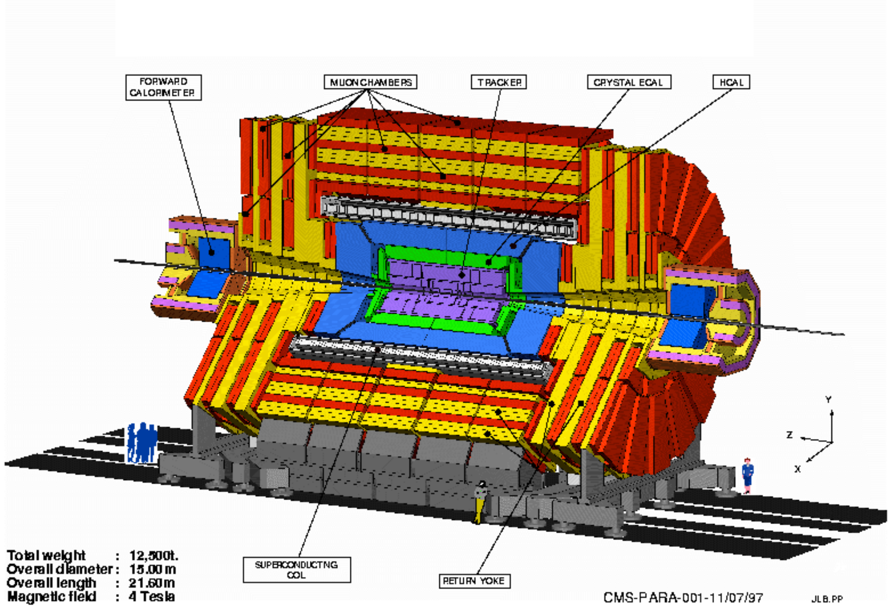
- Sectors 7-8 and 8-1 will be fully commissioned up to 7 TeV in 2006-2007.
  If we continue to commission the other sectors up to 7 TeV,
  we will not get circulating beam in 2007.

- The other sectors will be commissioned up to the field needed for de-Gaussing.

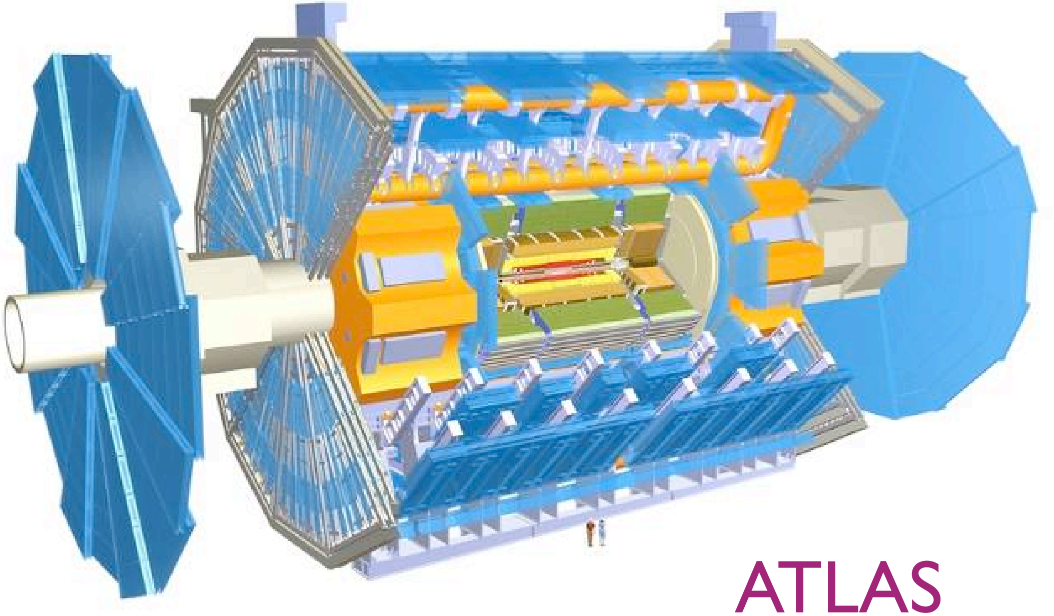
- Initial operation will be at 900 GeV (CM) with a static machine (no ramp, no squeeze)
  to debug machine and detectors.

- Full commissioning up to 7 TeV will be done in the winter 2008 shutdown

ATLAS & CMS



CMS

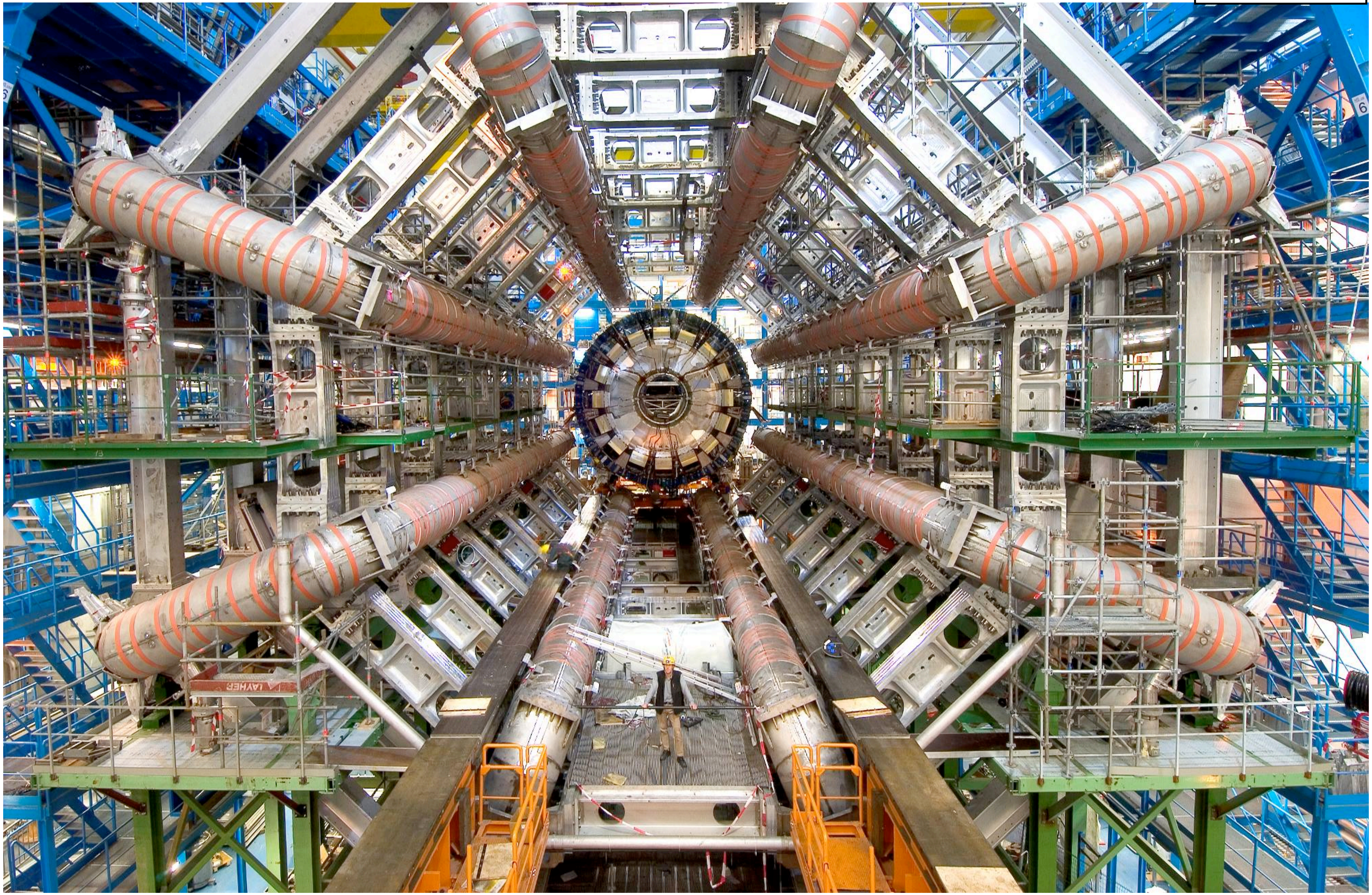


ATLAS

	ATLAS	***CMS***
Overall weight (tons)	***7000***	***12500***
Diameter	***22 m***	***15 m***
Length	***46 m***	***22 m***
Solenoid field	***2 T***	***4 T***

ATLAS

Oct. 2006



Barrel toroid: cool down started (November 06, T~120 K), first tests of full field in Sept 07. End-cap toroids: will be installed in the pit end 2006-beg 2007

from the CERN news

Just before midnight on 9 November the largest superconducting magnet ever built was successfully powered up to the magnetic field of about 4 tesla. An electrical current of more than 21 000 amperes passed through the eight gigantic coils of the magnet.

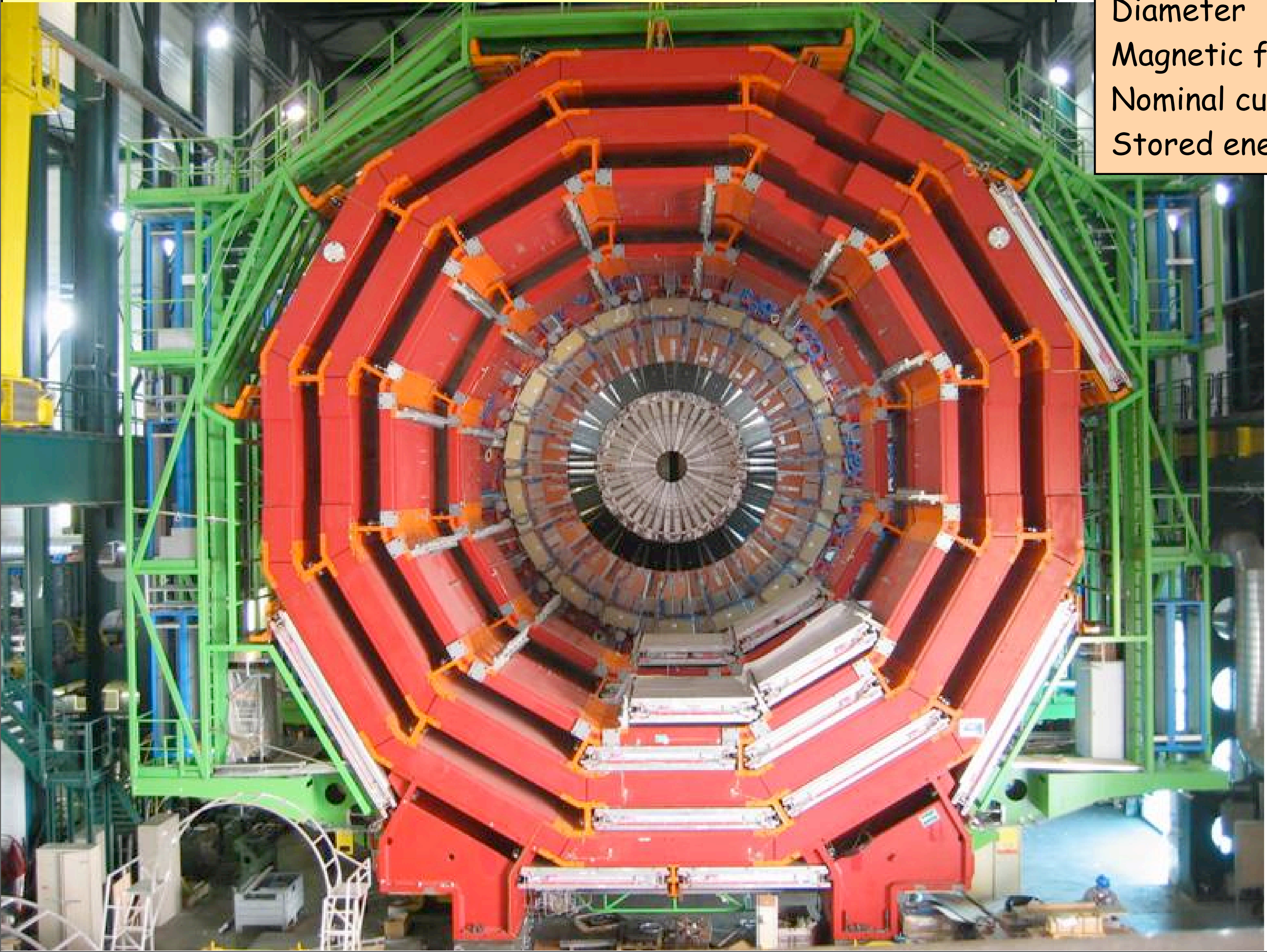
This magnet is a main part of the ATLAS detector, one of the four big experiments on the Large Hadron Collider (LHC) due to be commissioned next year. The ATLAS Barrel Toroid magnet consists of eight superconducting coils, each in the shape of a round-cornered rectangle, 5 metres wide, 25 metres long and weighing 100 tonnes. It provides a powerful magnetic field for the ATLAS detector and will work with other magnets in the ATLAS experiment to bend the paths of charged particles in collisions.

During a six-week period in July-August, the ATLAS Barrel Toroid was cooled down to -269°C, just four degrees above the absolute zero, the temperature needed to create and maintain a superconducting state. Once the magnet reached full power, the current was gradually switched off and magnetic energy of 1.1 Gigajoules, the equivalent of about 10 000 car traveling at 70 km/h, has been safely dissipated, raising the magnet temperature to -218°C.

CMS

At the surface, solenoid inserted on 14 Sept. 2005;
cooled down to 4.5 K in February 2006;
ramping up the current, now at 12.5 kA (2.5 T)
→ magnetic test/field map starting Aug./Sept. 2006 (MTCC)

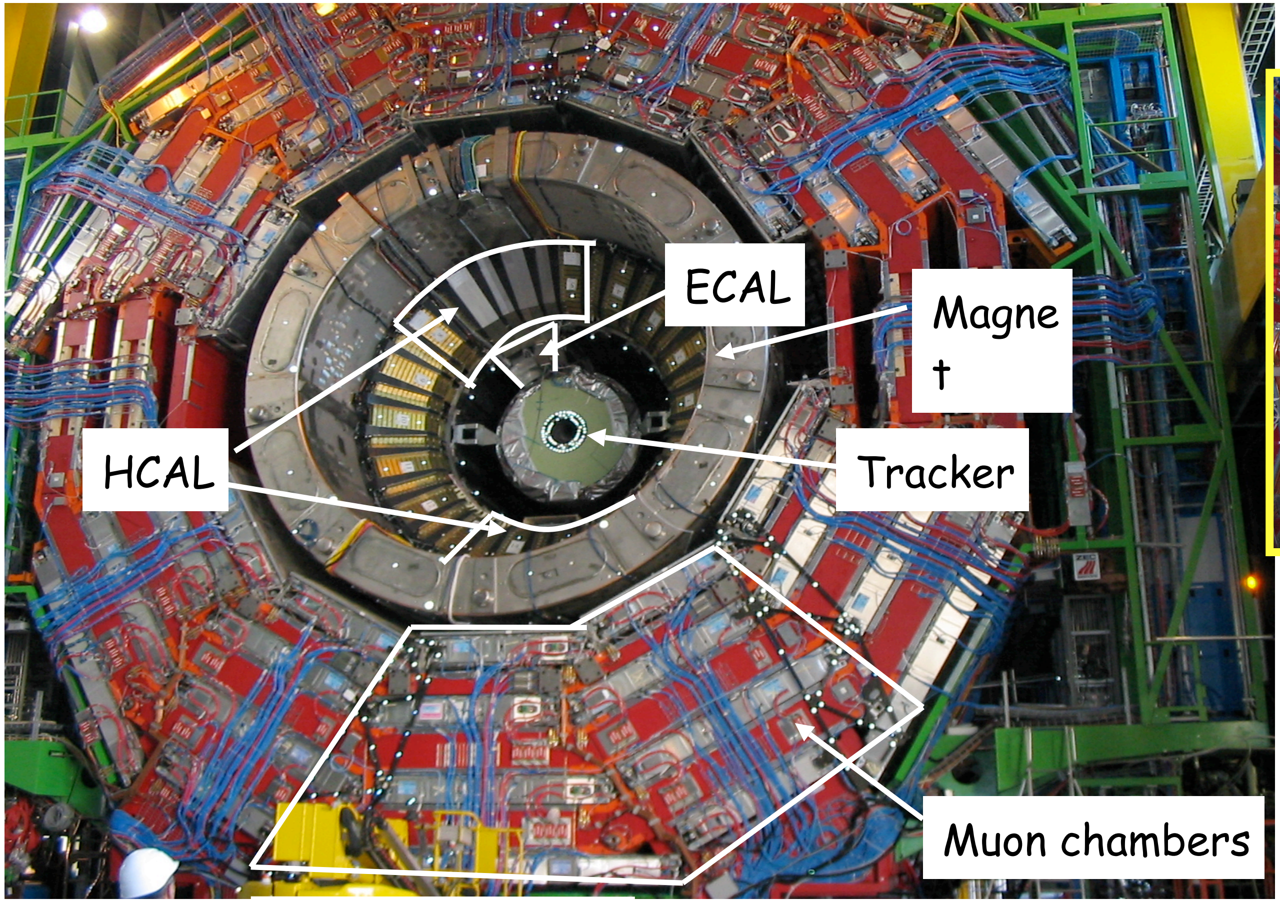
Magnetic length	12.5 m
Diameter	6 m
Magnetic field	4 T
Nominal current	20 kA
Stored energy	2.7 GJ

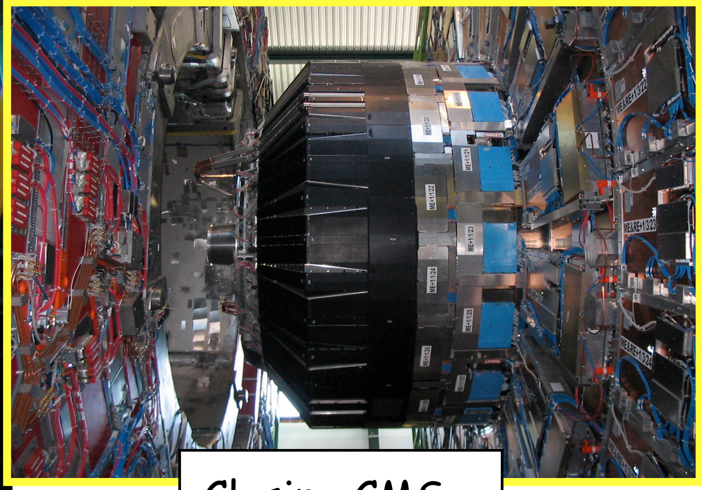


Towards Physics: the CMS Magnet Test and Cosmic Challenge (MTCC)

Cosmics run of a ~full detector slice (few percent of CMS coverage) inside 4T field.
Magnet being energized, detector closed, data taking started …

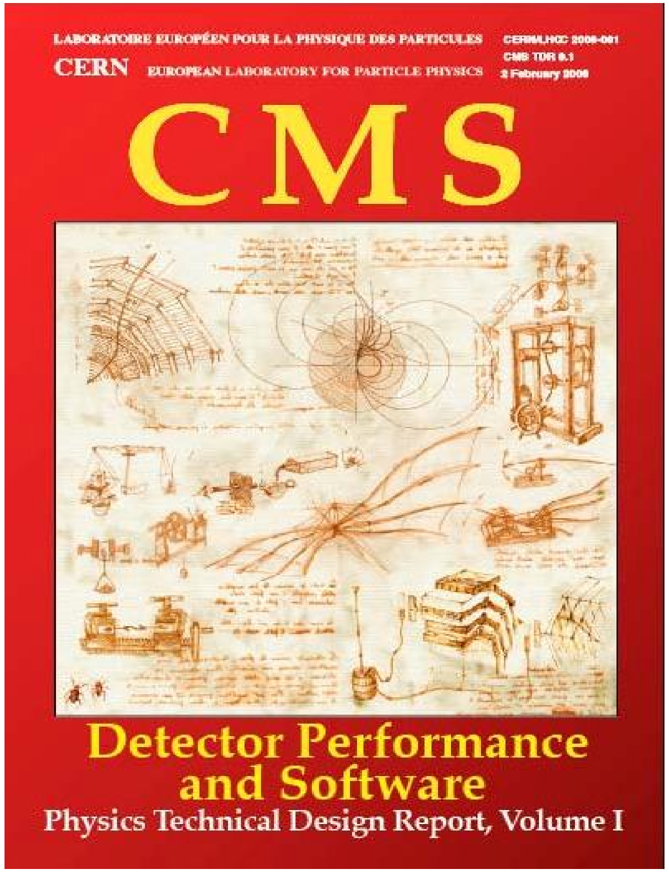
Test: detector installation and closing; magnet commissioning and field map;
combined operation of full chain detector-electronics-DAQ-trigger-DCS-software
identical to final experiment; timing, calibration, alignment procedures





Closing CMS …

CMS Physics Technical Design Reports



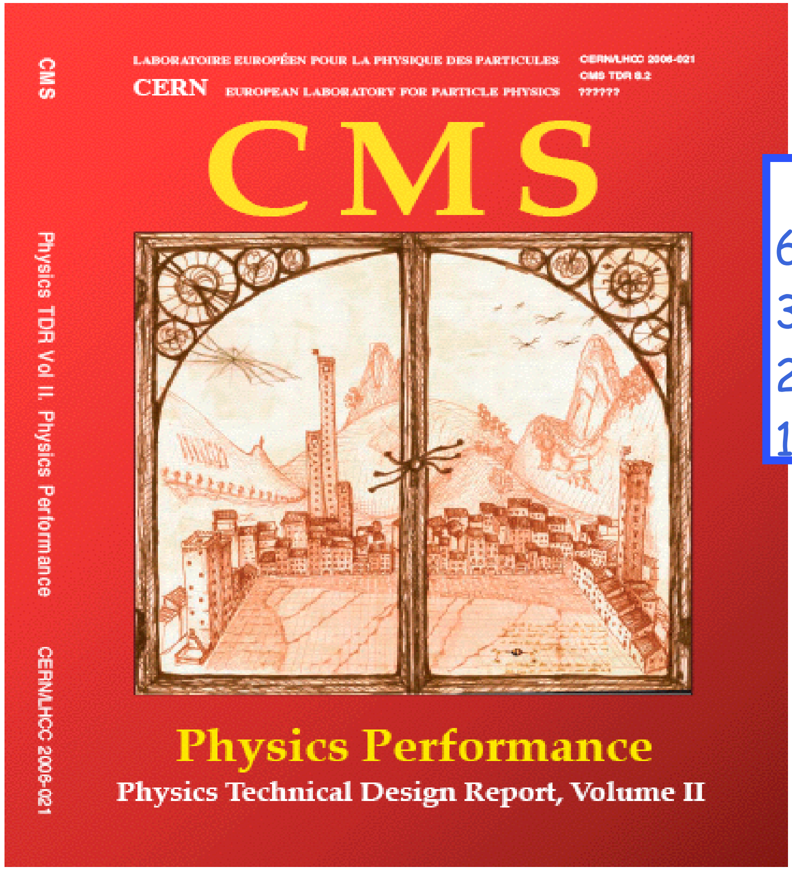
LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN/LHCC 2006-001
CMS TDR 8.1
2 February 2006

CMS

Detector Performance and Software

Physics Technical Design Report, Volume I



CMS Physics TDR Vol II. Physics Performance CERN/LHCC 2006-021

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CERN/LHCC 2006-021
CMS TDR 8.2
??????

CMS

Physics Performance

Physics Technical Design Report, Volume II

650 pages
308 figures
207 tables
1.50 Kg

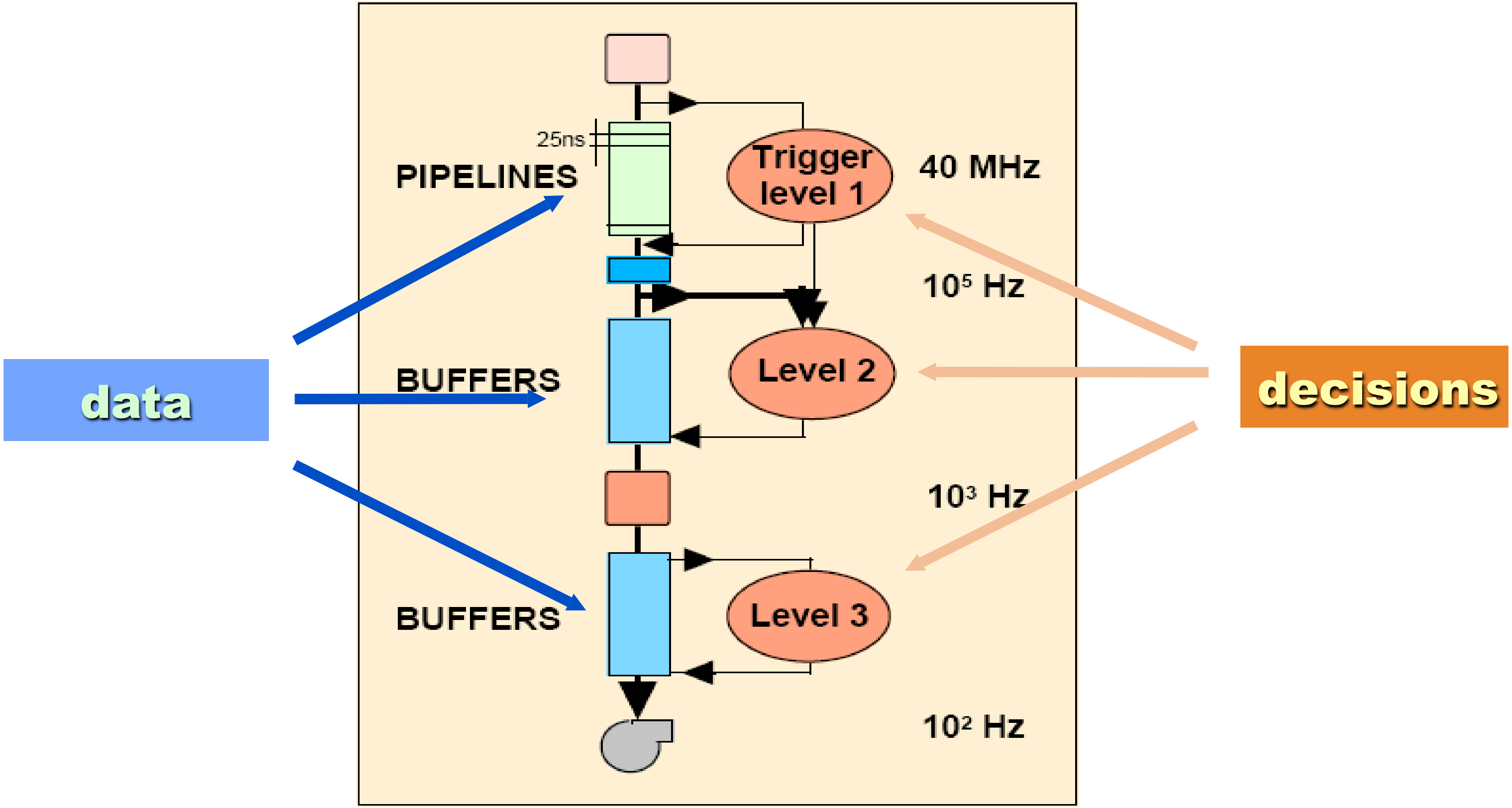
http://cmsdoc.cern.ch/cms/cpt/tdr/

CERN/LHCC 2006-001
February 2006

CERN/LHCC 2006-021
June 2006

The data analysis challenge

The full picture of the data flow



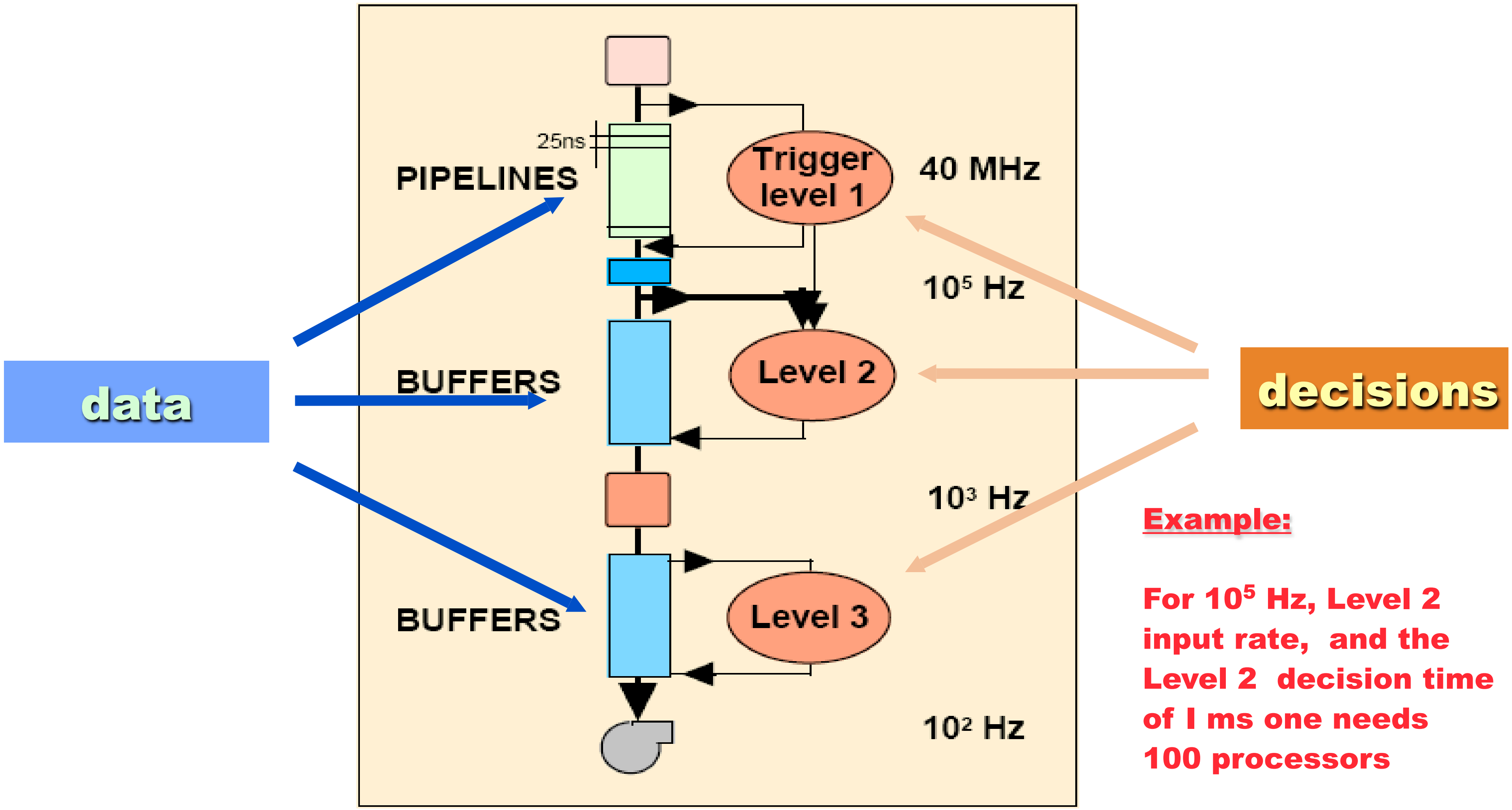
data

decisions

W. Krasny

The data analysis challenge

The full picture of the data flow



Example:

For 10^5 Hz, Level 2 input rate, and the Level 2 decision time of I ms one needs 100 processors

W. Krasny

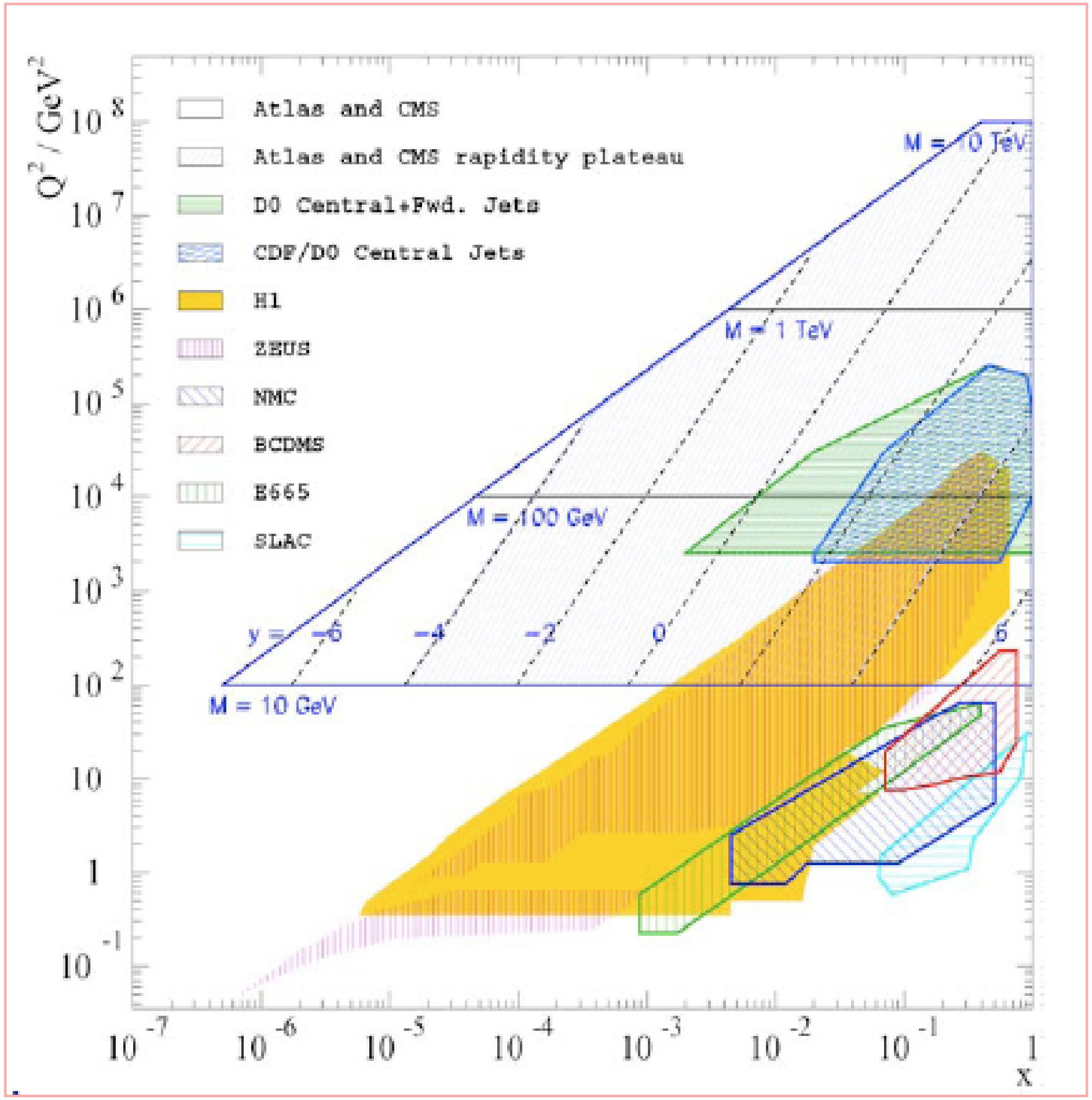
An example (LVL1) of the trigger menu table

- Total Rate: 50 kHz. Factor 3 safety, allocate 16 kHz

Trigger	Threshold (ε=90-95%) (GeV)	Indiv. Rate (kHz)	Cumul rate (kHz)
1e/γ, 2e/γ	29, 17	4.3	4.3
1μ, 2μ	14, 3	3.6	7.9
1τ, 2τ	86, 59	3.2	10.9
1-jet	177	1.0	11.4
3-jets, 4-jets	86, 70	2.0	12.5
Jet * Miss-E_T	88 * 46	2.3	14.3
e * jet	21 * 45	0.8	15.1
Min-bias		0.9	16.0

P. Spicas

LHC kinematic reach

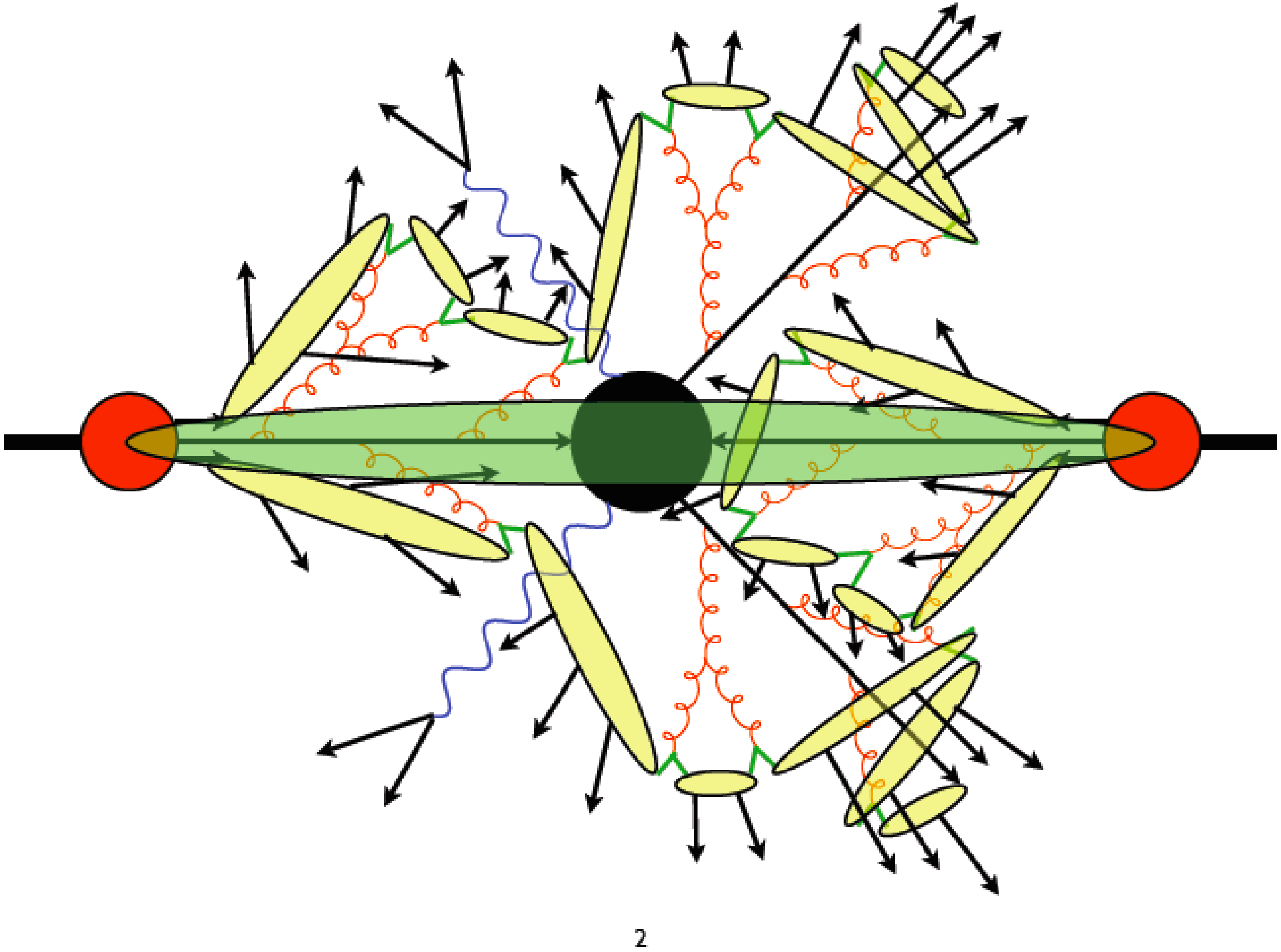


LHC opens up a new kinematic range

Feynman x's for the production of a particle of mass M

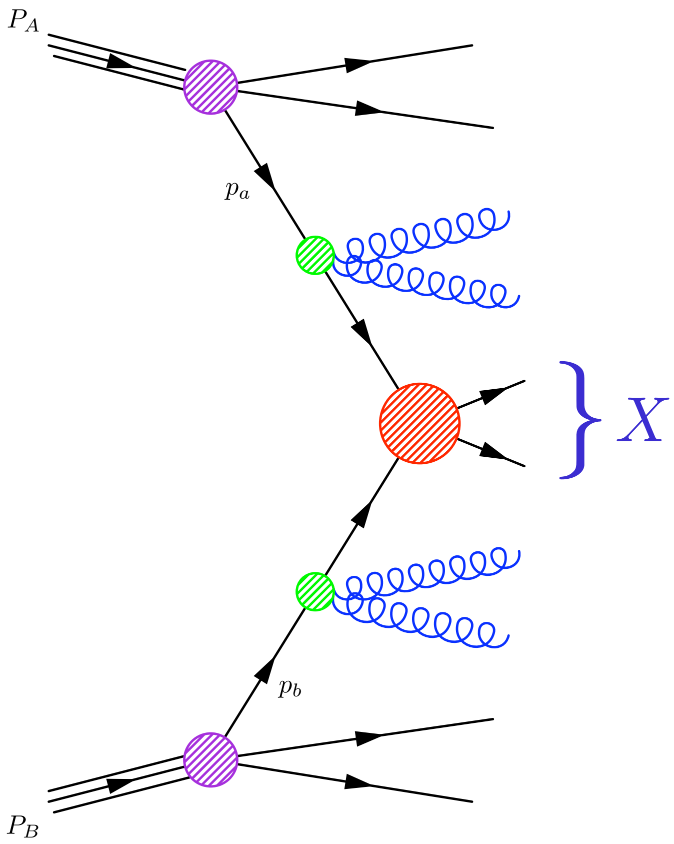
$$x_{1,2} = \frac{M}{14\,\mathrm{TeV}}\, e^{\pm y}$$

LHC Event Simulation



Parton showering and hadronisation are modelled through shower **Monte Carlos** (**HERWIG** o **PYTHIA**)

Cross sections at high Q^2



separate the short- and the long-range interactions through factorisation

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_{a/A}(x_1,\mu_F^2)\, f_{b/B}(x_2,\mu_F^2)$$
$$\times\ \hat{\sigma}_{ab\to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_F^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$

$$X = W, Z, H, Q\bar{Q}, \text{high-}E_T\text{jets}, \ldots$$

$\hat{\sigma}$ is known as a fixed-order expansion in α_S

$$\hat{\sigma} = C\alpha_S^n(1 + c_1\alpha_S + c_2\alpha_S^2 + \ldots)$$

$c_1 =$ NLO $\qquad$ $c_2 =$ NNLO

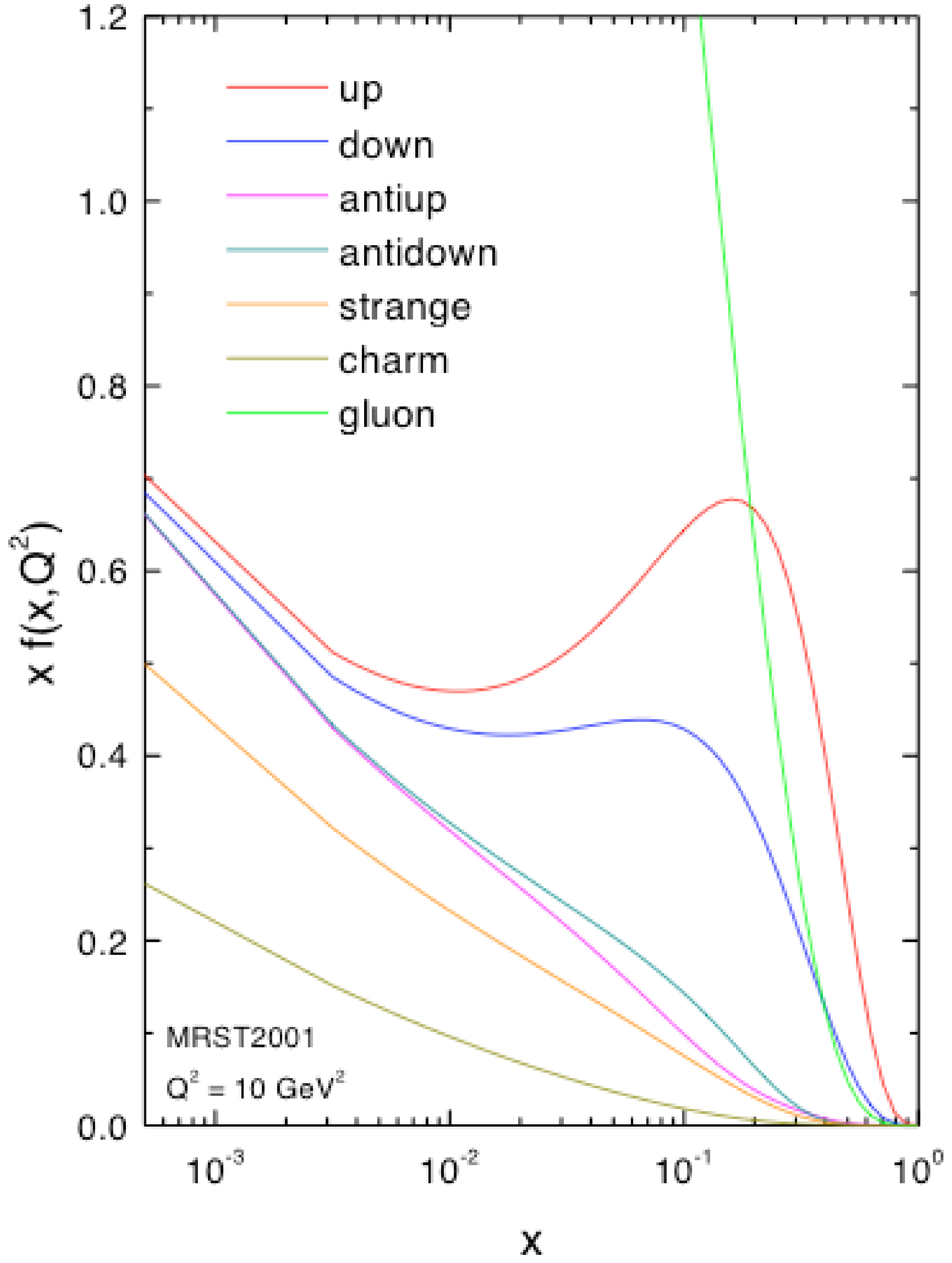
or as an all-order resummation

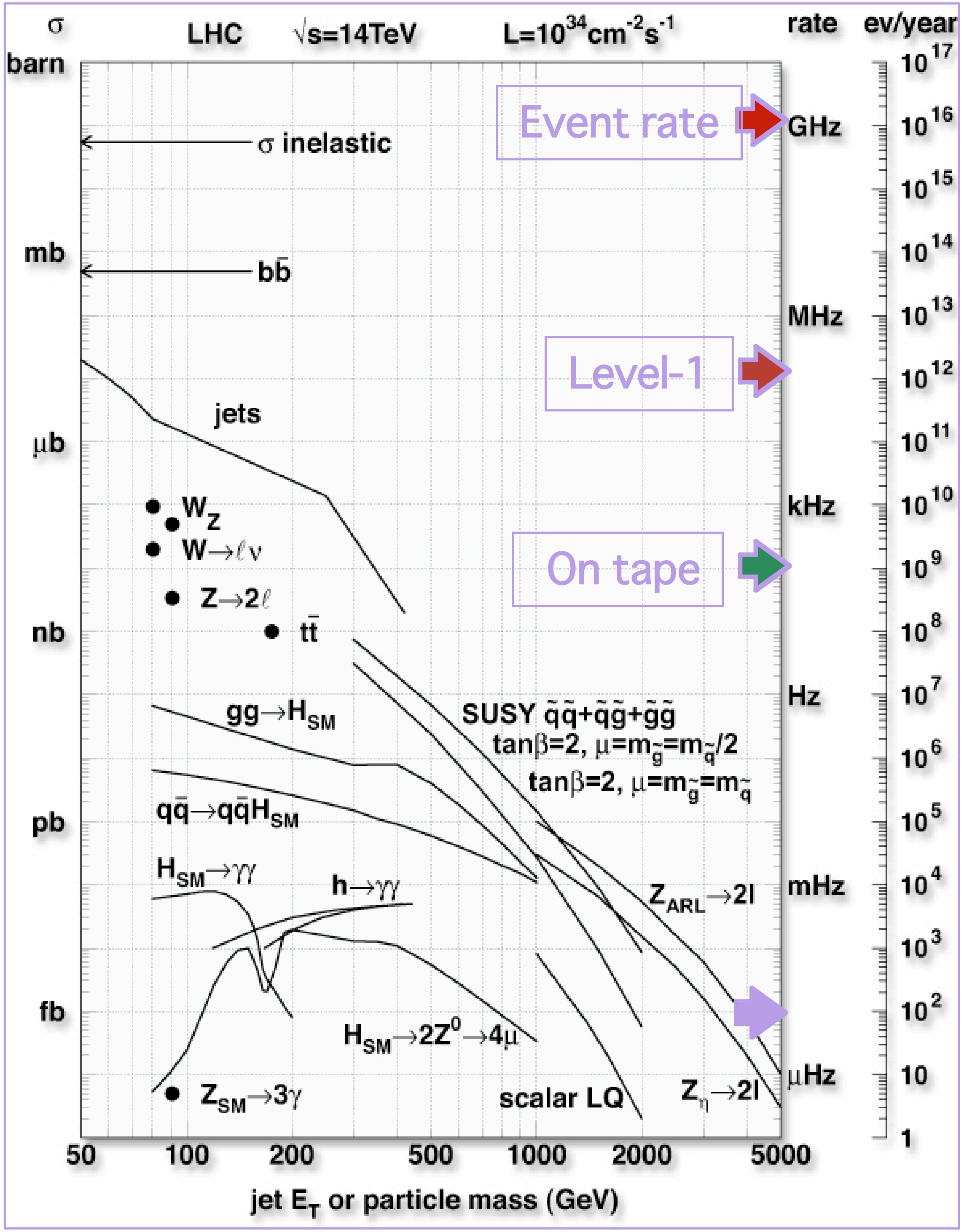
$$\hat{\sigma} = C\alpha_S^n[1 + (c_{11}L + c_{10})\alpha_S + (c_{22}L^2 + c_{21}L + c_{20})\alpha_S^2 + \ldots]$$

where $L = \ln(M/q_T), \ln(1-x), \ln(1/x), \ln(1-T), \ldots$

$c_{11}, c_{22} =$ LL $\qquad$ $c_{10}, c_{21} =$ NLL $\qquad$ $c_{20} =$ NNLL

MRST 2001 PDF's





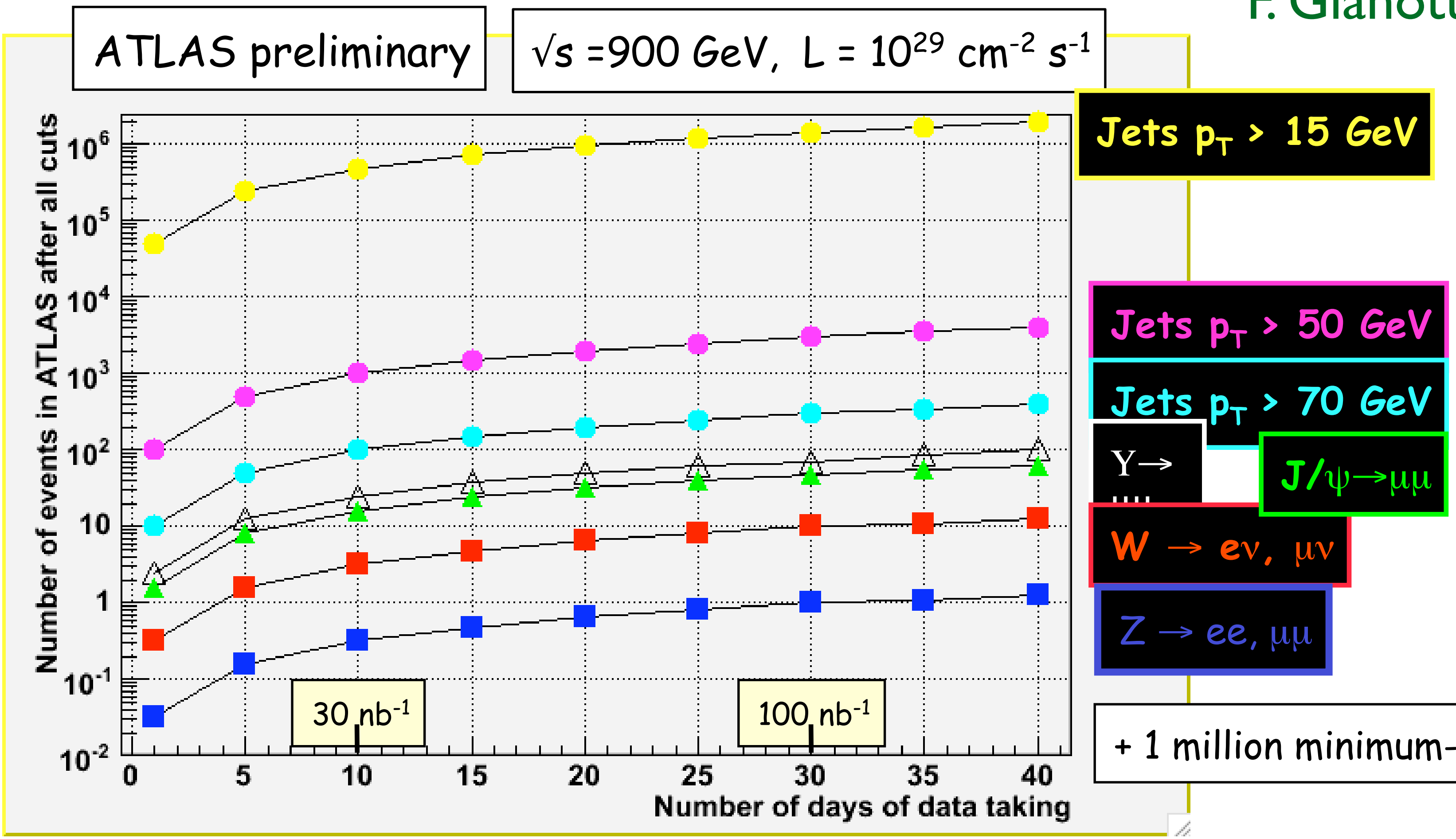
LHC is a QCD machine

processi di SM sono background a segnali di Nuova Fisica

1 fb^{-1} (per exp)	Events on tape
W → μ ν	7×10^6
Z → μ μ	1.1×10^6
$t\bar{t}$ → W b W b → μ ν + X	8×10^4
QCD jets p_T>150	~ 10^6
Minimum bias	~ 10^6

What data samples in 2007 ?

F. Gianotti



+ 1 million minimum-bias/day

- Start to commission triggers and detectors with collision data (minimum bias, jets, ..) in real LHC environment
- Maybe first physics measurements (minimum-bias, underlying event, QCD jets, …) ?
- Observe a few W→ lν, Υ → μμ, J/ψ → μμ ?

With the first physics run in 2008 ($\sqrt{s}$ = 14 TeV) ….

F. Gianotti

1 fb^{-1} (100 pb^{-1}) ≡ 6 months (few days) at L= 10^{32} $cm^{-2}s^{-1}$
with 50% data-taking efficiency
→ may collect a few fb^{-1} per experiment by end 2008

Channels (examples …)	Events to tape for 100 pb^{-1} (per expt: ATLAS, CMS)	Total statistics from some of previous Colliders
$W \to \mu \nu$	~ 10^6	~ 10^4 LEP, ~ 10^6 Tevatron
$Z \to \mu \mu$	~ 10^5	~ 10^6 LEP, ~ 10^5 Tevatron
$tt \to W b W b \to \mu \nu + X$	~ 10^4	~ 10^4 Tevatron
QCD jets p_T > 1 TeV	> 10^3	---
$\tilde{g}\tilde{g}$ m = 1 TeV	~ 50	---

With these data:

- Understand and calibrate detectors in situ using well-known physics samples
  e.g. - $Z \to ee, \mu\mu$ tracker, ECAL, Muon chambers calibration and alignment, etc.
  - $tt \to bl\nu\ bjj$ jet scale from $W \to jj$, b-tag performance, etc.

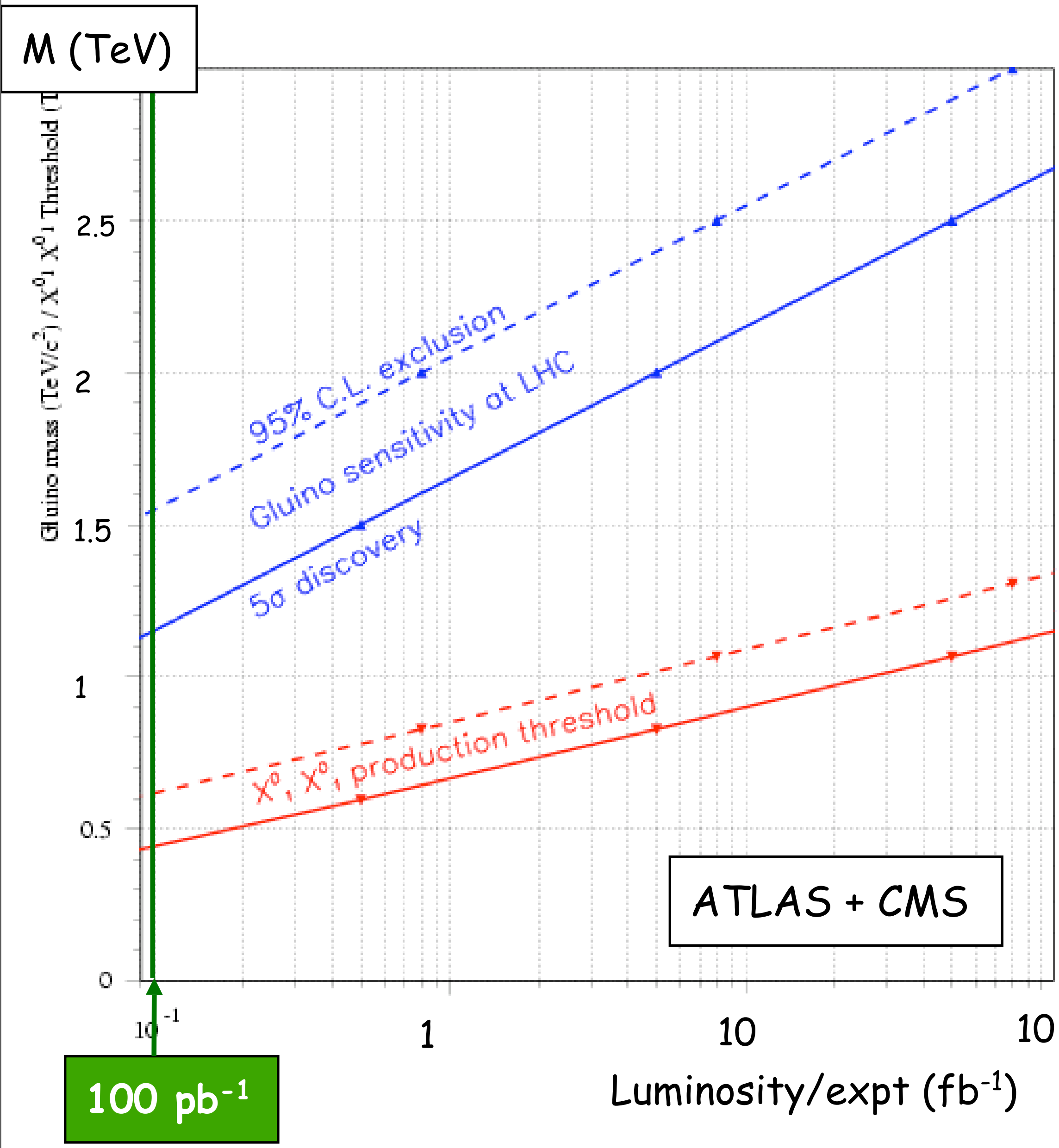
- Measure SM physics at $\sqrt{s}$ = 14 TeV : W, Z, tt, QCD jets …
  (also because omnipresent backgrounds to New Physics)

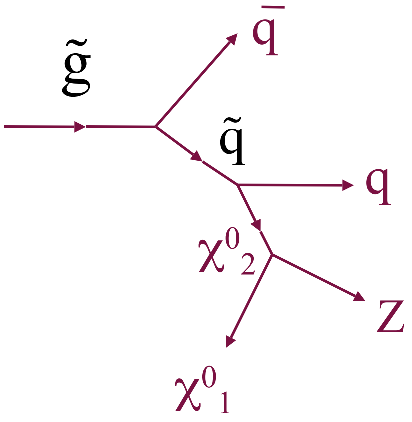
Example of "early" discovery: Supersymmetry ?

F. Gianotti

If SUSY at TeV scale → could be found "quickly" …. thanks to:

- large $\tilde{q},\tilde{g}$ cross-section → ≈ 10 events/day at 10^{32} for m ($\tilde{q},\tilde{g}$) ~ 1 TeV
- spectacular signatures (many jets, leptons, missing E_T)





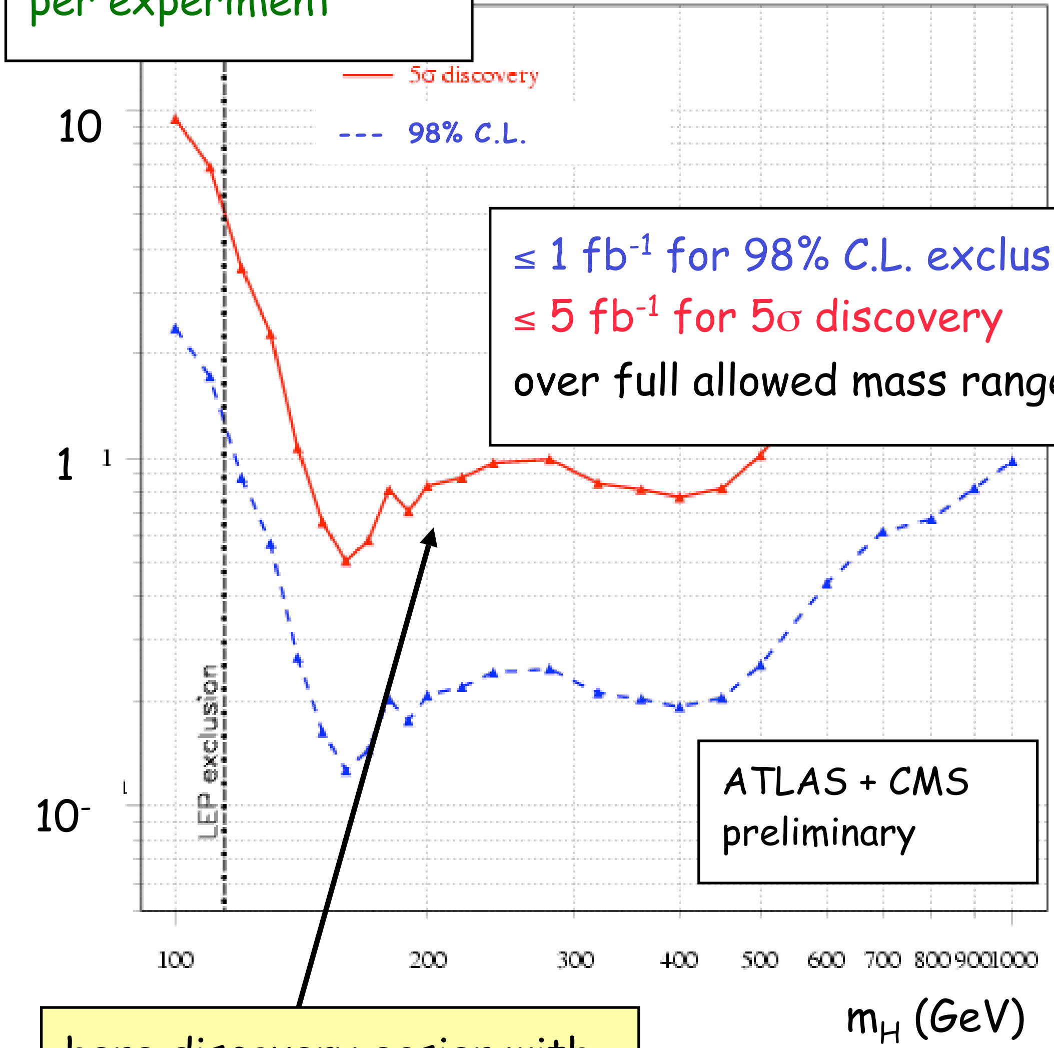
Our field, and planning for future facilities, will benefit a lot from quick determination of scale of New Physics. E.g. with 100 (good) pb^{-1} LHC could say if SUSY accessible to a ≤1 TeV ILC

BUT: understanding E_T^{miss} spectrum (and tails from instrumental effects) is one of the most crucial and difficult experimental issue for SUSY searches at hadron colliders.

What about the SM Higgs boson ?

F. GIANOTTI. ICHEP 06

Needed ∫Ldt (fb^{-1}) per experiment



≤ 1 fb^{-1} for 98% C.L. exclusion

≤ 5 fb^{-1} for 5σ discovery

over full allowed mass range

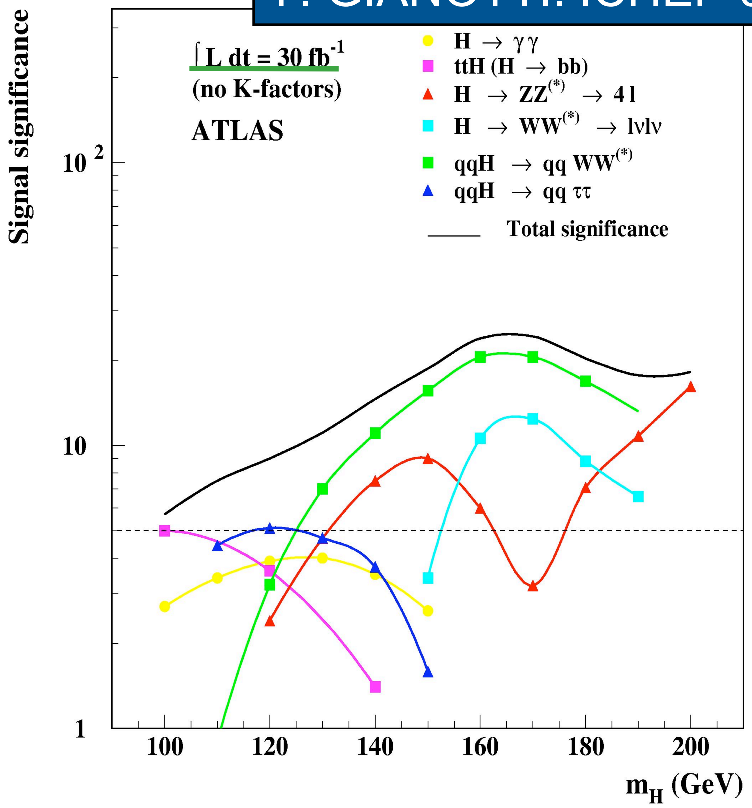
ATLAS + CMS preliminary

here discovery easier with gold-plated H → ZZ → 4l

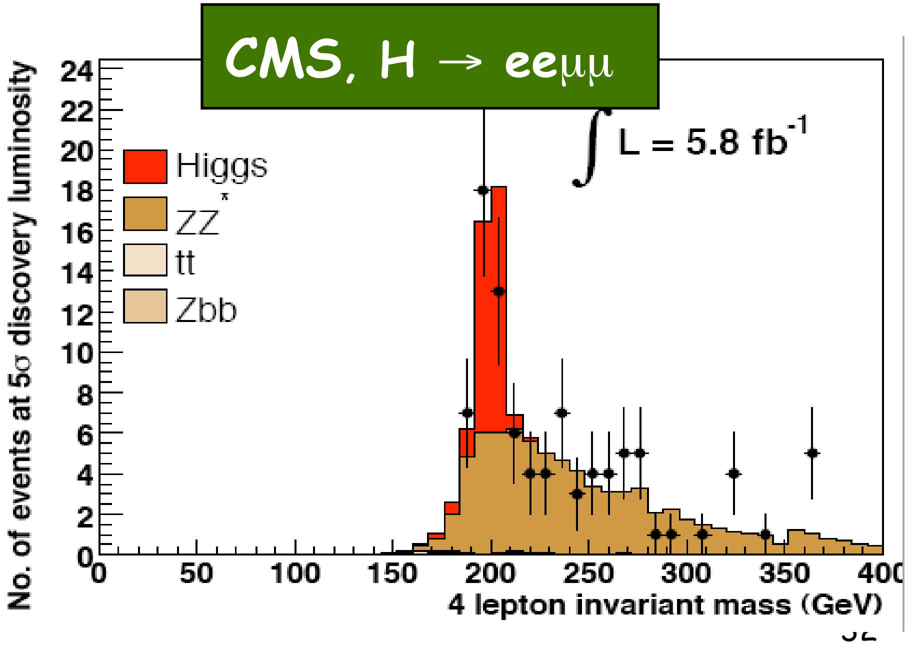
→ by end 2008 ?

H → 4l : narrow mass peak, small background

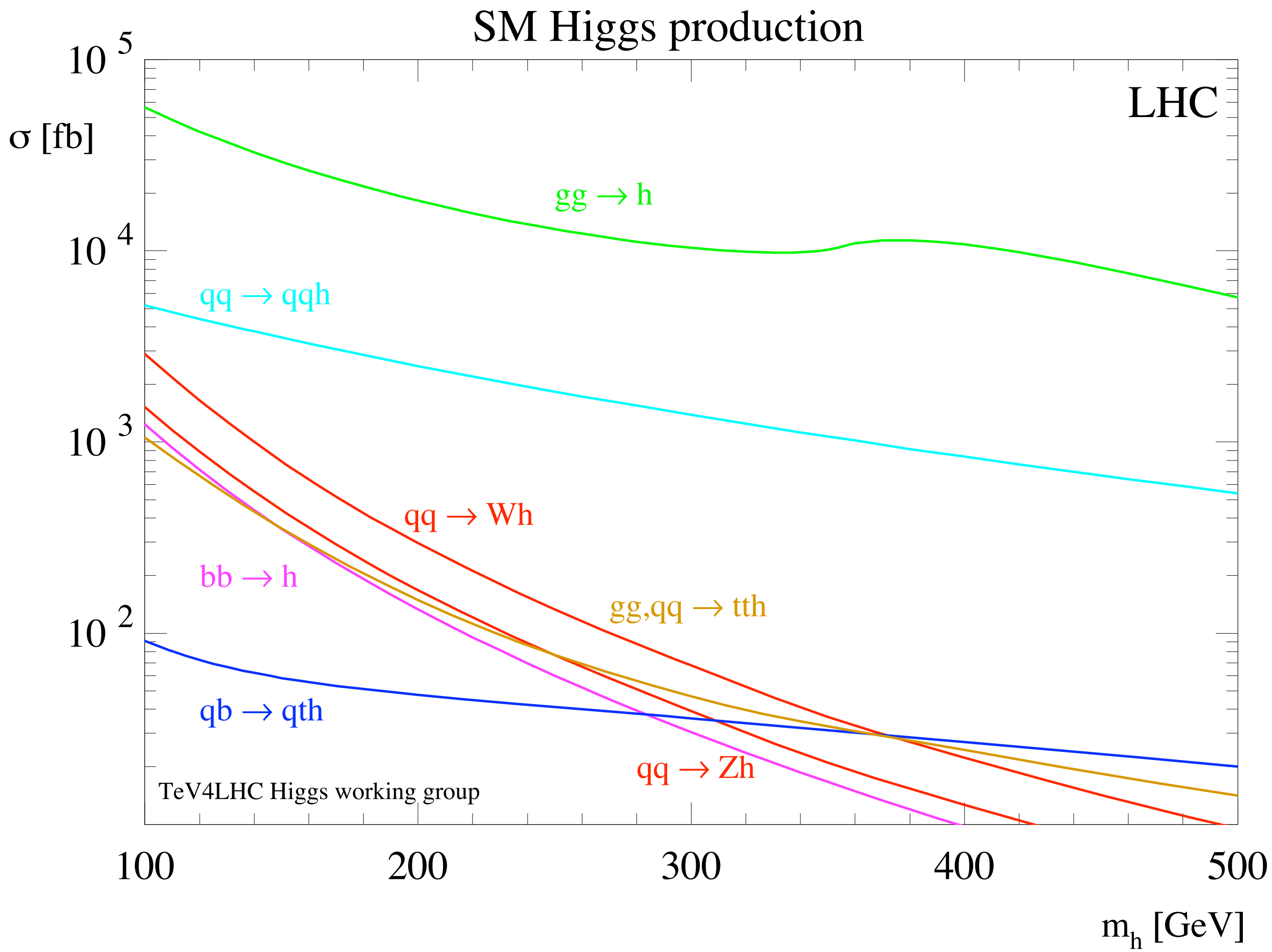
H → WW → lνlν (dominant at the Tevatron): counting channel (no mass peak)



CMS, H → eeμμ



HIGGS PRODUCTION AT LHC

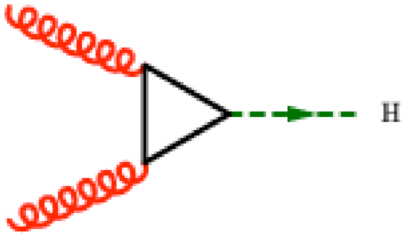


- in the intermediate Higgs mass range $M_H \sim 100 - 200 \text{ GeV}$
  - gluon fusion cross section is $\sim 20 - 60 \text{ pb}$
  - WBF cross section is $\sim 3 - 5 \text{ pb}$
  - $WH, ZH, t\bar{t}H$ yield cross sections of $\sim 0.2 - 3 \text{ pb}$

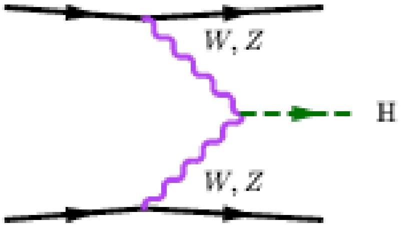
HIGGS PRODUCTION MODES AT LHC

In proton collisions at 14 TeV, and for $M_H > 100\ \mathrm{GeV}$ the Higgs is produced mostly via

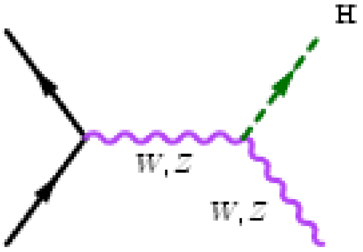
- gluon fusion $gg \to H$
    - largest rate for all M_H
    - proportional to the top Yukawa coupling y_t



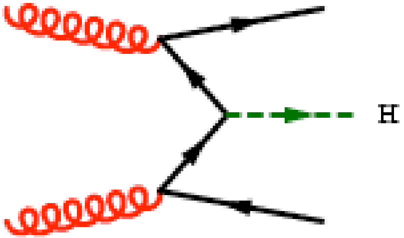
- weak-boson fusion (WBF) $qq \to qqH$
    - second largest rate (mostly $u\,d$ initial state)
    - proportional to the WWH coupling



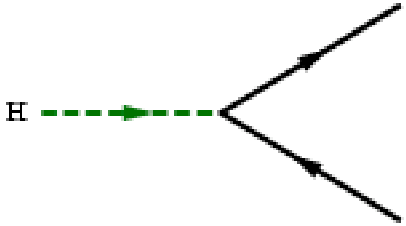
- Higgs-strahlung $q\bar{q} \to W(Z)H$
    - third largest rate
    - same coupling as in WBF



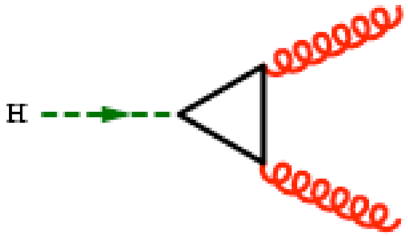
- $t\bar{t}(b\bar{b})H$ associated production
    - same initial state as in gluon fusion, but higher x range
    - proportional to the heavy-quark Yukawa coupling y_Q



HIGGS DECAY MODES AT LHC

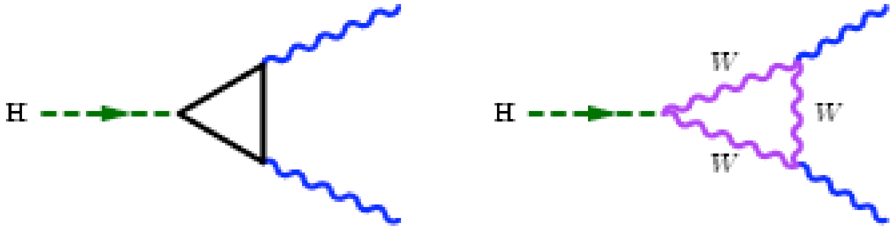


proportional to the Yukawa coupling squared, and thus to m_f^2

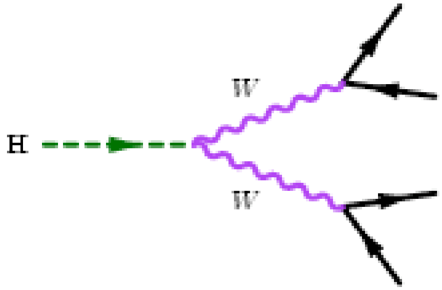


proportional to m_f^4/m_H^4

but dominated by top quark Yukawa coupling



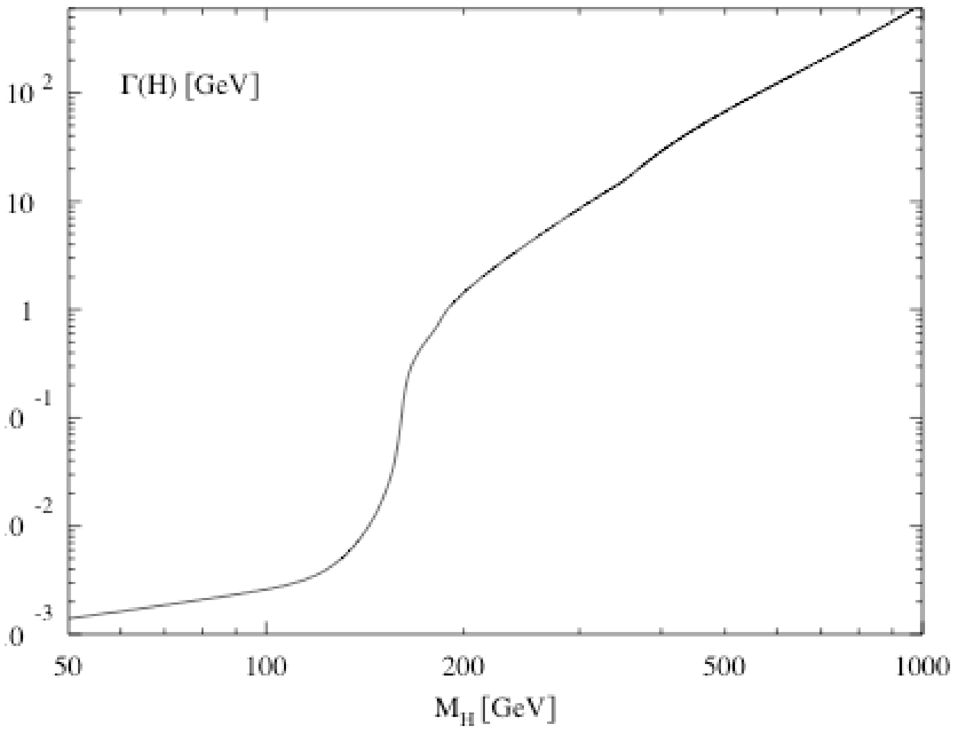
dominated by EW coupling



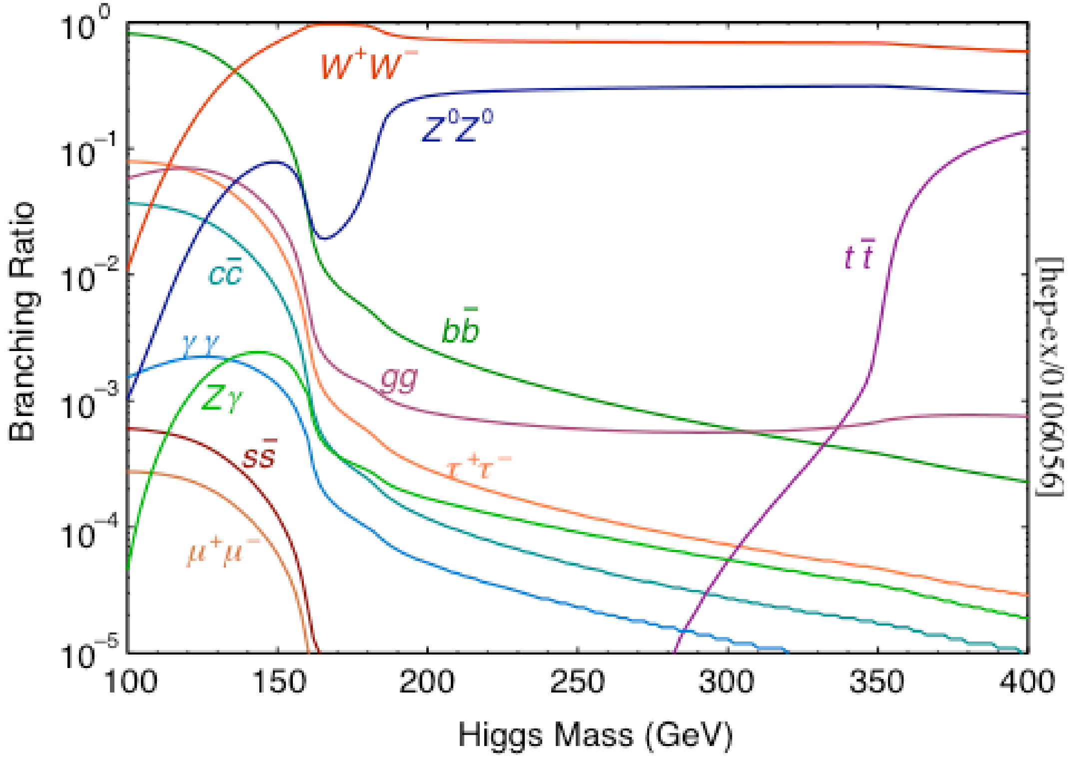
proportional to α_W

Decay width into W^*W^* plays a significant role

HIGGS DECAY AT LHC

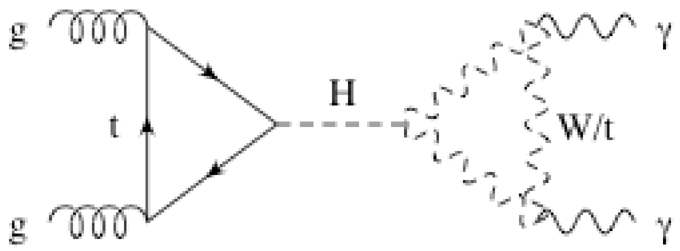


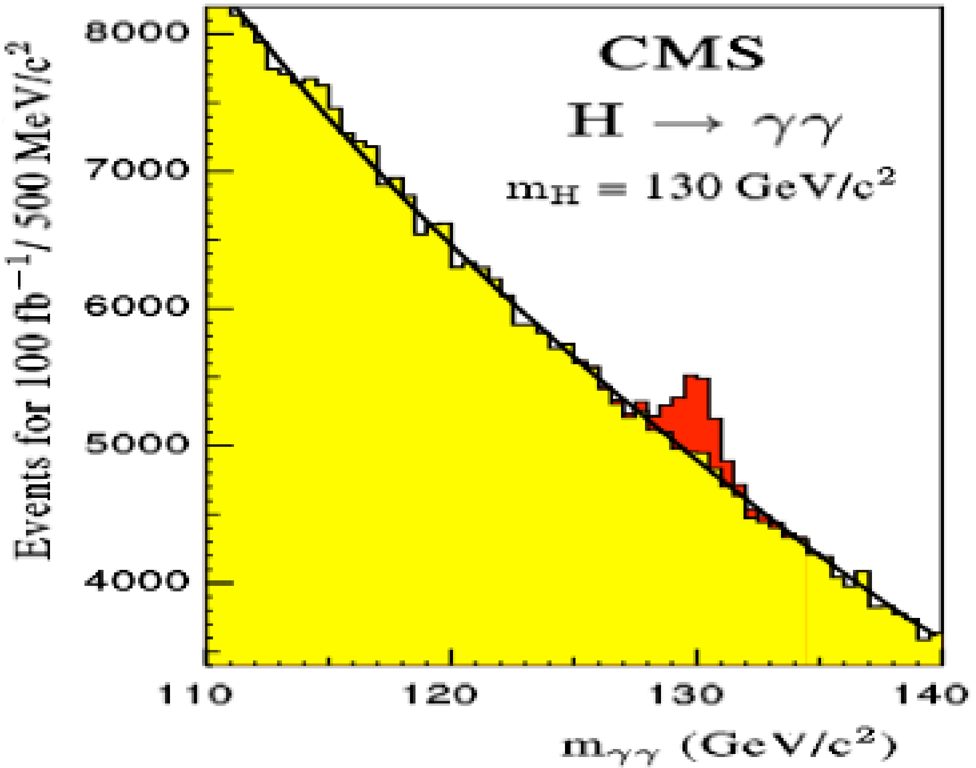
total width



branching fractions

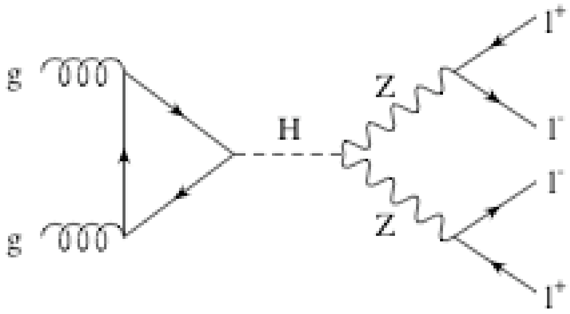
INCLUSIVE SEARCHES: $H \to \gamma\gamma$

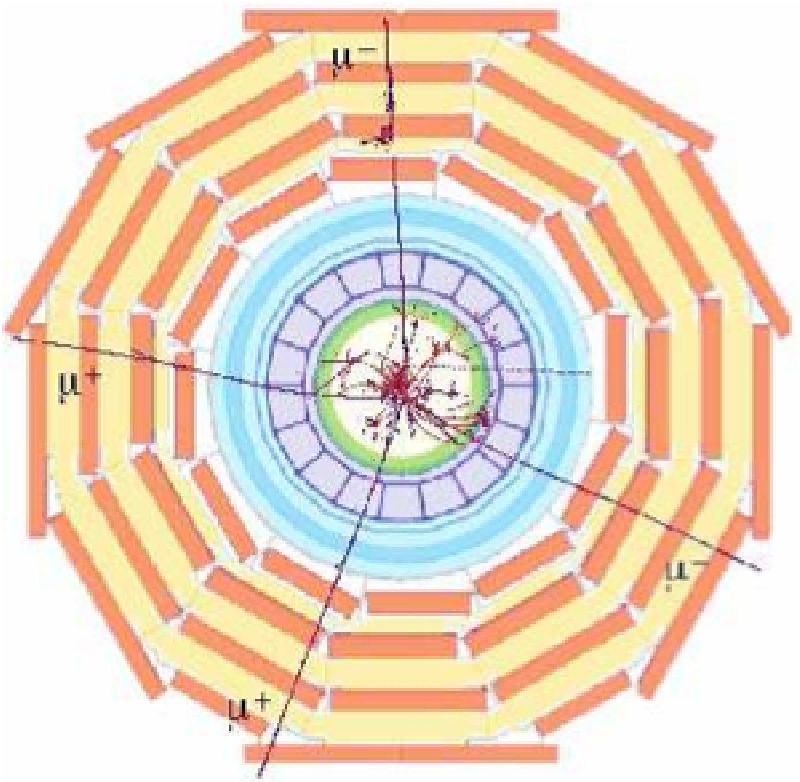




- Small BR: $\approx 10^{-3}$
- Large backgrounds from $pp \to \gamma\gamma$
- CMS and ATLAS have very good photon-energy resolution: $\mathcal{O}(1\%)$
- Search for a narrow $\gamma\gamma$ invariant mass peak, with $m_H < 150$ GeV
- Background is smooth: extrapolate it into the signal region from the sidebands

INCLUSIVE SEARCHES: $H \rightarrow ZZ \rightarrow l^+l^-l^+l^-$

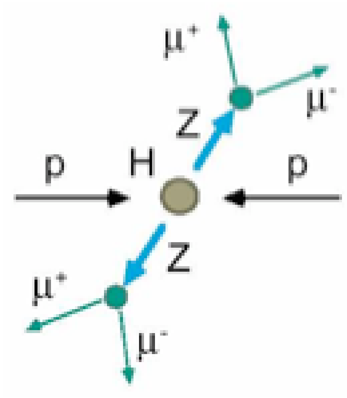


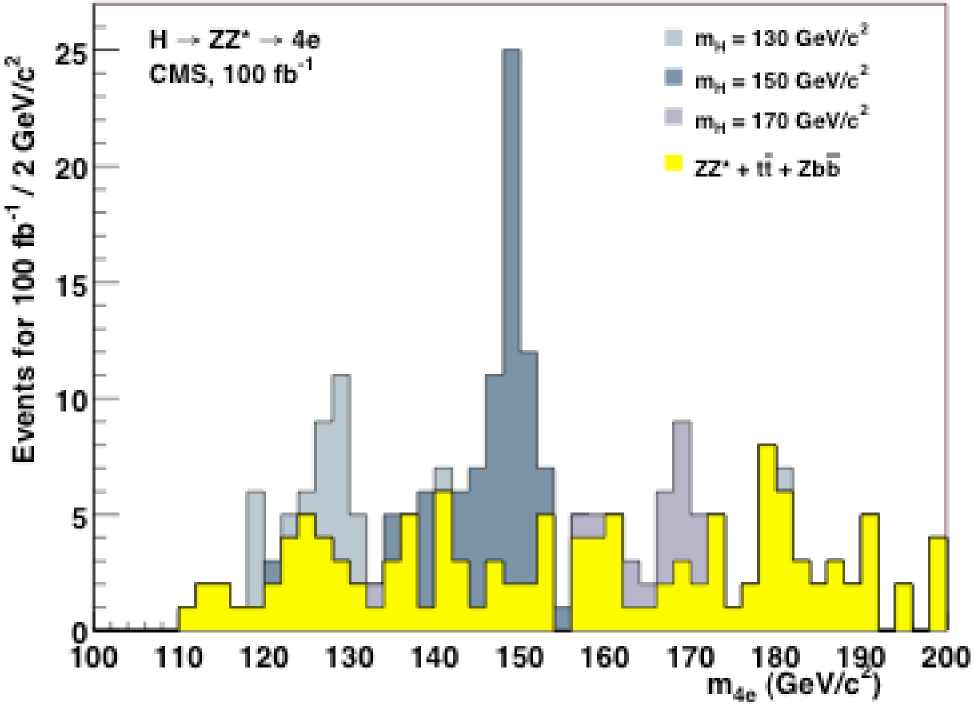


- Gold-plated mode: cleanest mode for $2m_Z < m_H < 600$ GeV
- Smooth, irreducible background from $pp \rightarrow ZZ$
- Small BR: $\mathrm{BR}(H \rightarrow ZZ)$ is a few $\%$ at threshold

INCLUSIVE SEARCHES: $H \rightarrow ZZ \rightarrow l^+l^-l^+l^-$

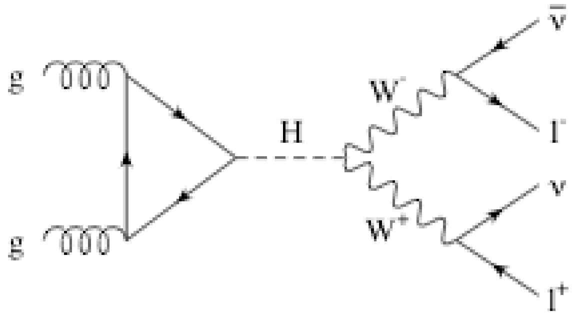
- Fully reconstructed invariant mass of the leptons





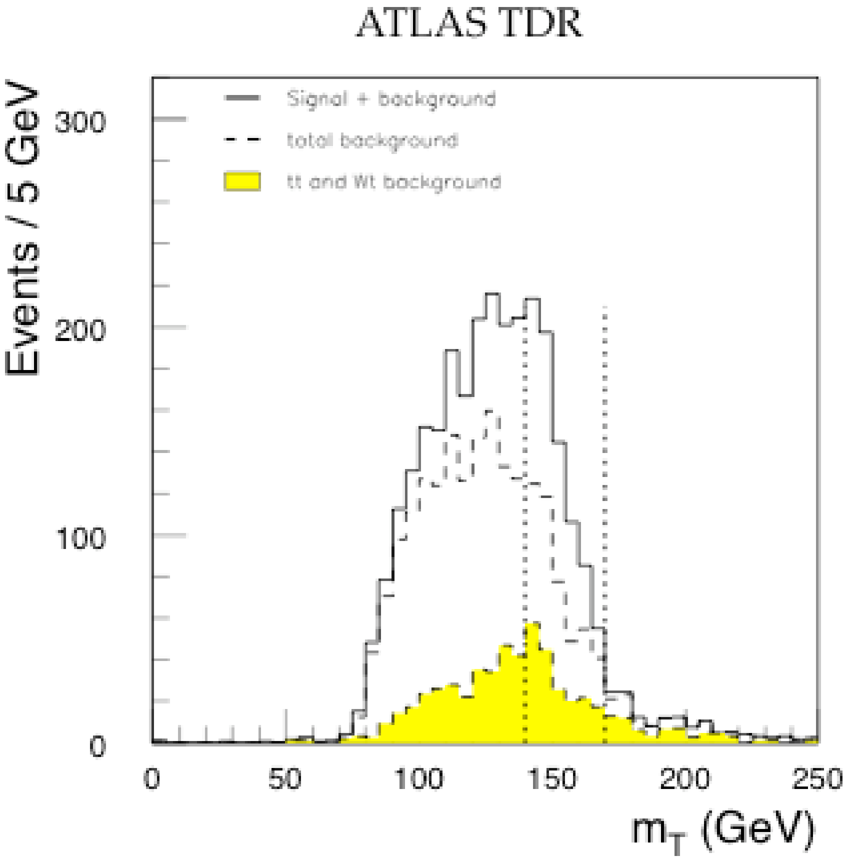
- Silver-plated mode $H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$ useful for $m_H \approx 0.8 - 1$ TeV

INCLUSIVE SEARCHES: $H \rightarrow WW \rightarrow l^+\nu l^-\bar{\nu}$



- Exploit l^+l^- angular correlations

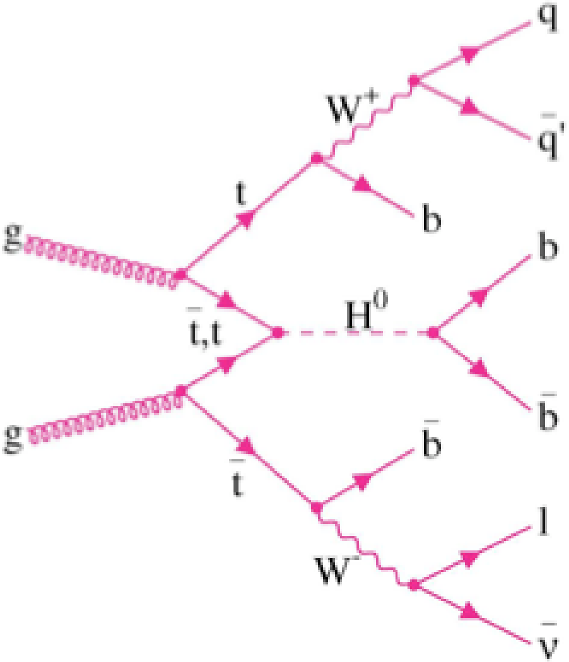
- Signal and background have similar shapes: must know background normalisation well

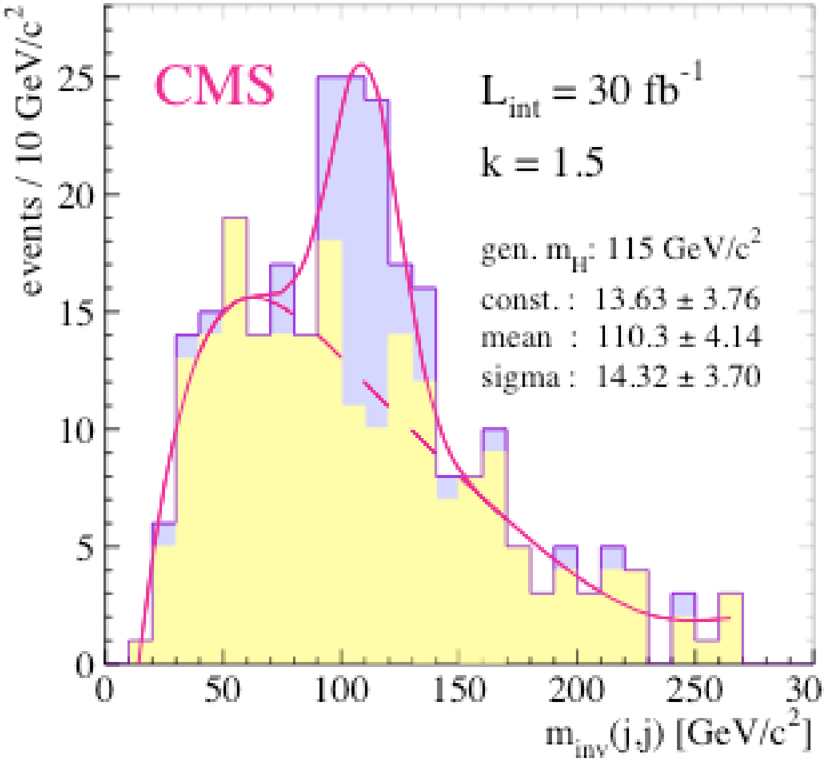


$m_H = 170\ \text{GeV}$

integrated luminosity: $20\ \text{fb}^{-1}$

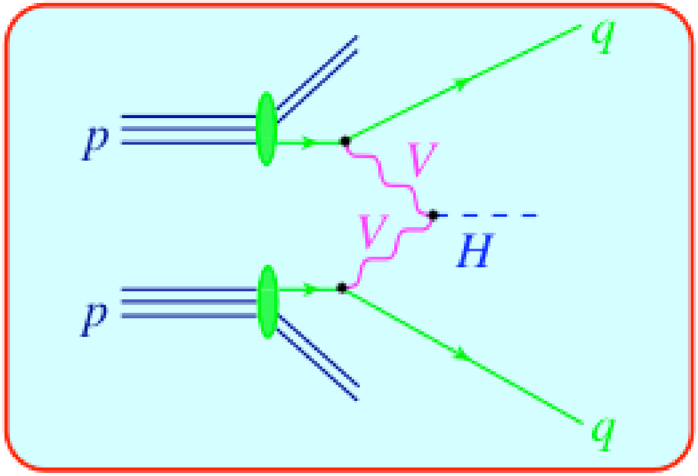
ASSOCIATED PRODUCTION: $Ht\bar{t} \longrightarrow t\bar{t}b\bar{b}$

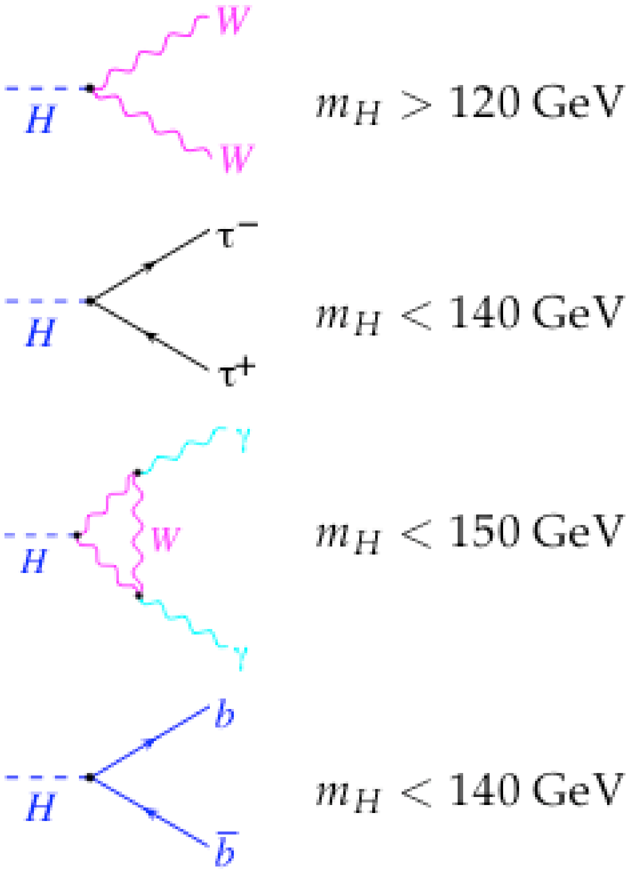




- Search channel for $m_H = 120 - 130\ \mathrm{GeV}$
- Measure $h_t^2\ \mathrm{BR}(H \to b\bar{b})$ with $h_t = Ht\bar{t}$ Yukawa coupling
- must know background normalisation well

WEAK BOSON FUSION: $qq \longrightarrow qqH$

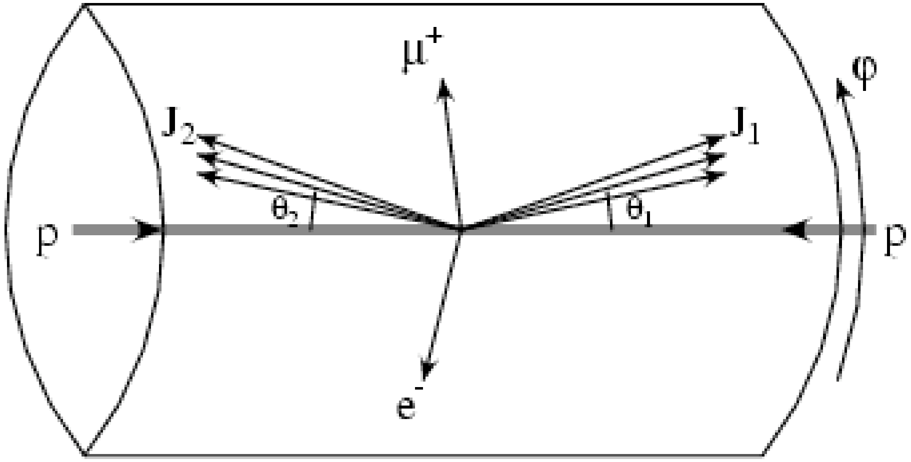




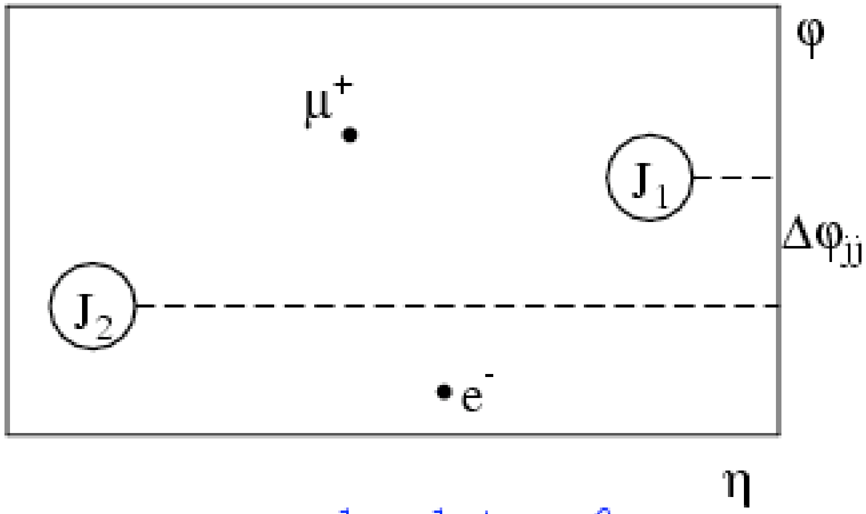
- WBF can be measured with good statistical accuracy: $\sigma \times \mathrm{BR} \approx \mathcal{O}(10\%)$

WEAK BOSON FUSION

A WBF event



Lego plot

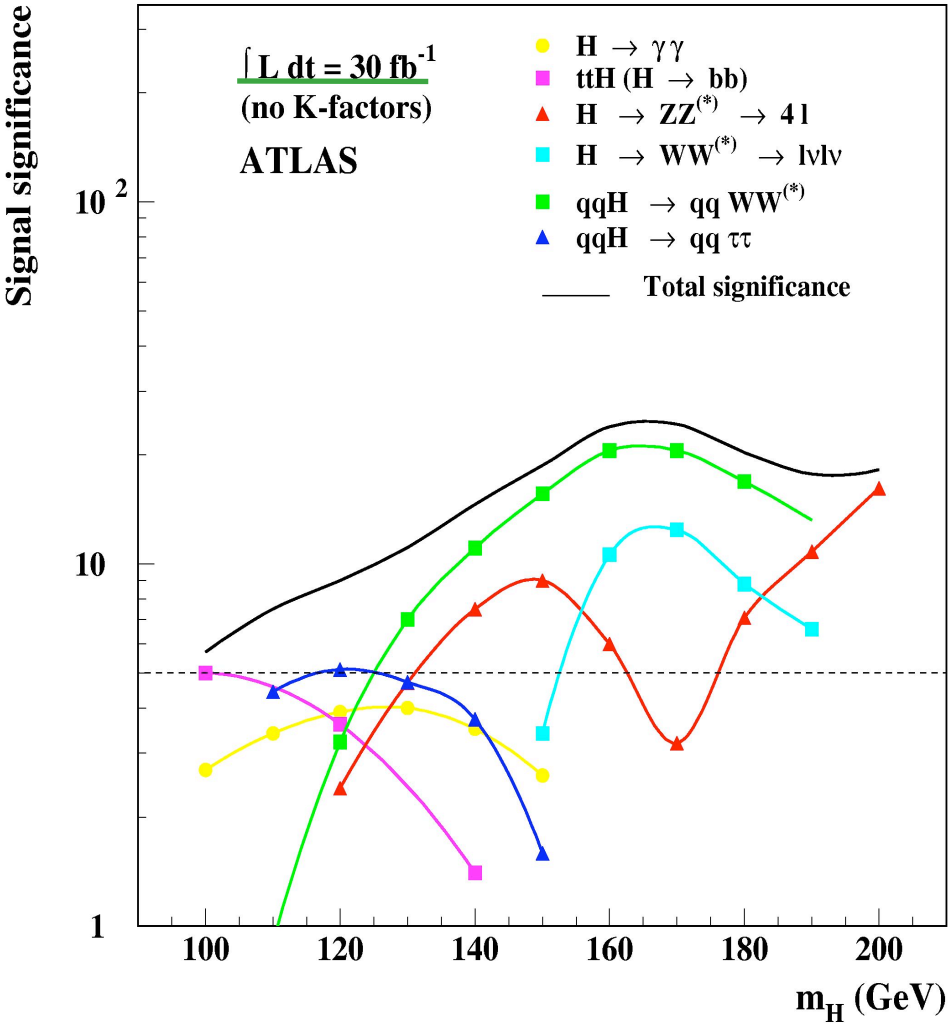


$$\eta = \frac{1}{2}\ln\frac{1+\cos\theta}{1-\cos\theta}$$

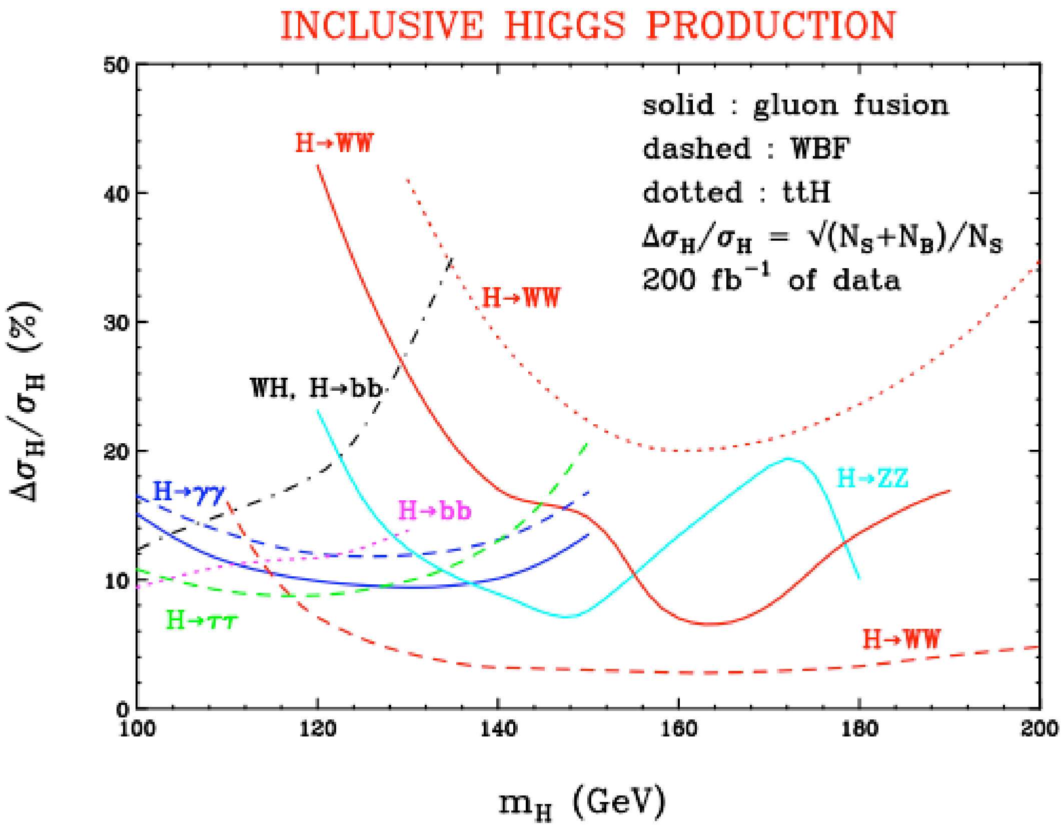
- WBF features
  - energetic jets in the forward and backward directions
  - Higgs decay products between the tagging jets
  - sparse gluon radiation in the central-rapidity region, due to colourless W/Z exchange
  - NLO corrections increase the WBF production rate by about $10\,\%$, and thus are small and under control

Campbell, Ellis; Figy, Oleari, Zeppenfeld 2003

SIGNAL SIGNIFICANCE AND (STAT + SYST) ERROR



Statistical significance: $\frac{N_S}{\sqrt{N_S + N_B}}$



hep-ph/0203187

QCD/p.d.f. uncertainties:

$\mathcal{O}(5\%)$ for WBF

$\mathcal{O}(20\%)$ for gluon fusion

luminosity uncertainties: $\mathcal{O}(5\%)$

HIGGS COUPLINGS AND QUANTUM NUMBERS

The properties of the Higgs-like resonance are its

- couplings: gauge, Yukawa, self-couplings
- quantum numbers: charge, colour, spin, CP

Duehrssen et al.'s analysis hep-ph/0406323

- use narrow-width approx for Γ (fine for $m_H < 200$ GeV)
- production rate with H decaying to final state xx is

$$\sigma(H) \times \mathrm{BR}(H \to xx) = \frac{\sigma(H)^{\mathrm{SM}}}{\Gamma_p^{\mathrm{SM}}} \frac{\Gamma_p \Gamma_x}{\Gamma}$$

branching ratio for the decay is $\mathrm{BR}(H \to xx) = \dfrac{\Gamma_x}{\Gamma}$

observed rate determines $\dfrac{\Gamma_p \Gamma_x}{\Gamma}$

- WBF and gluon-fusion rates yield measurements of combinations of partial widths

$\frac{\Gamma_W \Gamma_\gamma}{\Gamma}$ from $qq \to qqH,\ H \to \gamma\gamma$

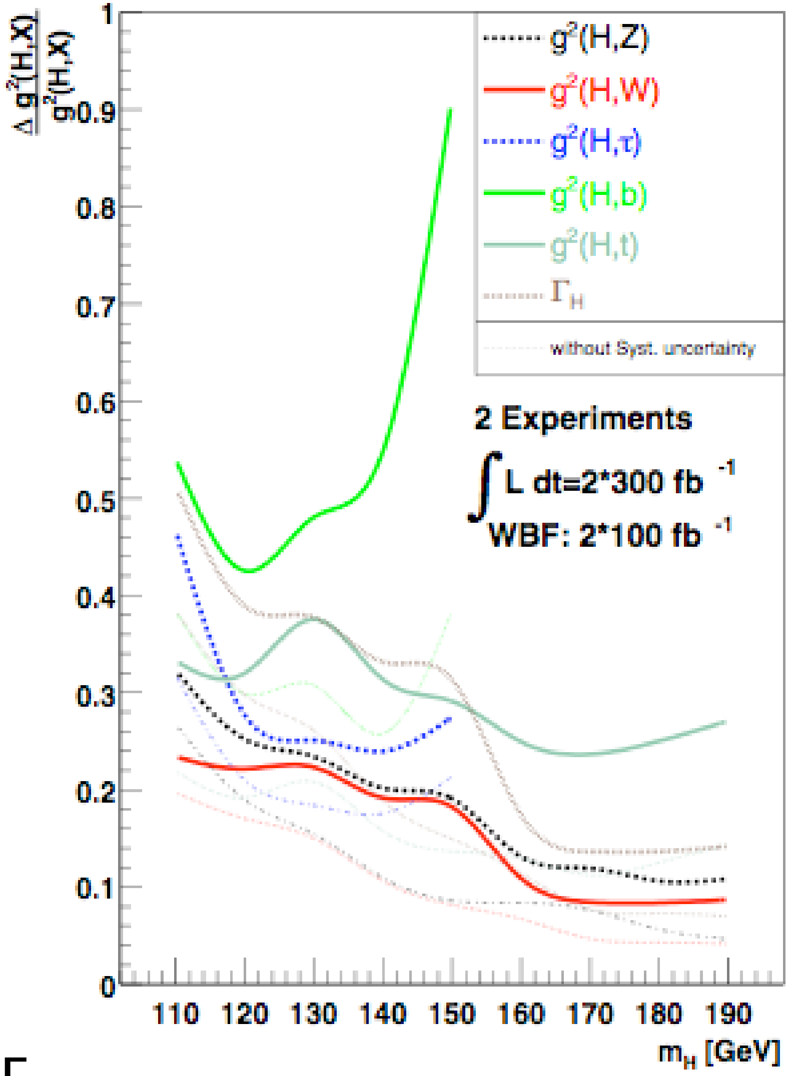
$\frac{\Gamma_W \Gamma_\tau}{\Gamma}$ from $qq \to qqH,\ H \to \tau\tau$

$\frac{\Gamma_W^2}{\Gamma}$ from $qq \to qqH,\ H \to WW^*$

$\frac{\Gamma_g \Gamma_\gamma}{\Gamma}$ from $gg \to H \to \gamma\gamma$

$\frac{\Gamma_g \Gamma_Z}{\Gamma}$ from $gg \to H \to ZZ^*$

$\frac{\Gamma_g \Gamma_W}{\Gamma}$ from $gg \to H \to WW^*$



- Note that Γ can be estimated:

  direct observation of *H* yields lower bound on Γ

  assume $\Gamma_V \leq \Gamma_V^{\rm SM} \qquad V = W, Z$

  (true in any model with arbitrary # of Higgs doublets ⇒ true in MSSM)

  combine $\Gamma_V \leq \Gamma_V^{\rm SM}$ with measure of Γ_V^2/Γ from $H \to VV$

  obtain upper bound on Γ

HIGGS COUPLINGS AND QUANTUM NUMBERS

The gauge coupling has also CP properties and a tensor structure. Info on that can be obtained by analysing the final-state topology of Higgs + 2 jet events

CONCLUSIONS

- LHC will begin operations in about a year
- It is going to be the most complex scientific undertaking ever
- If a Standard Model Higgs is there, LHC will see it with 5 fb^{-1}
- Once the Higgs is found, we shall want to study its couplings and quantum numbers