Higgs Hunting 2012
Orsay, July 18-20, 1012

LHC, CMS etc. past, present and some perspectives

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How it all started….
UA1/2, LHC, CMS etc
some present results
what next

How it all started….

- From the W_1, W_2, W_3 and B mass-less gauge vector fields of SU(2) and U(1) through the mechanism of spontaneous symmetry breaking you get the massive W^+, W^- and Z and the mass-less A (γ) φιελdσ related by:

$$Z = W_3 \cos\theta_\omega - B \sin\theta_\omega$$
$$A = W_3 \sin\theta_\omega + B \cos\theta_\omega$$

with three out of the four scalar fields of the theory disappearing in the masses of the W and Z, whilst the fourth survives - the SM Higgs boson!

- First measurements (in 70's) of charged and neutral current neutrino interactions interpreted in this unified electroweak scheme were giving: $\sin^2\theta_w \sim 0.3 - 0.5$

with: $m_W = [\pi\alpha_{em}/(\sqrt{2}G_F)]^{1/2}/\sin\theta_w = 37.4\ \mathrm{GeV}/\sin\theta_w$ $\quad m_Z = m_W/\cos\theta_w$

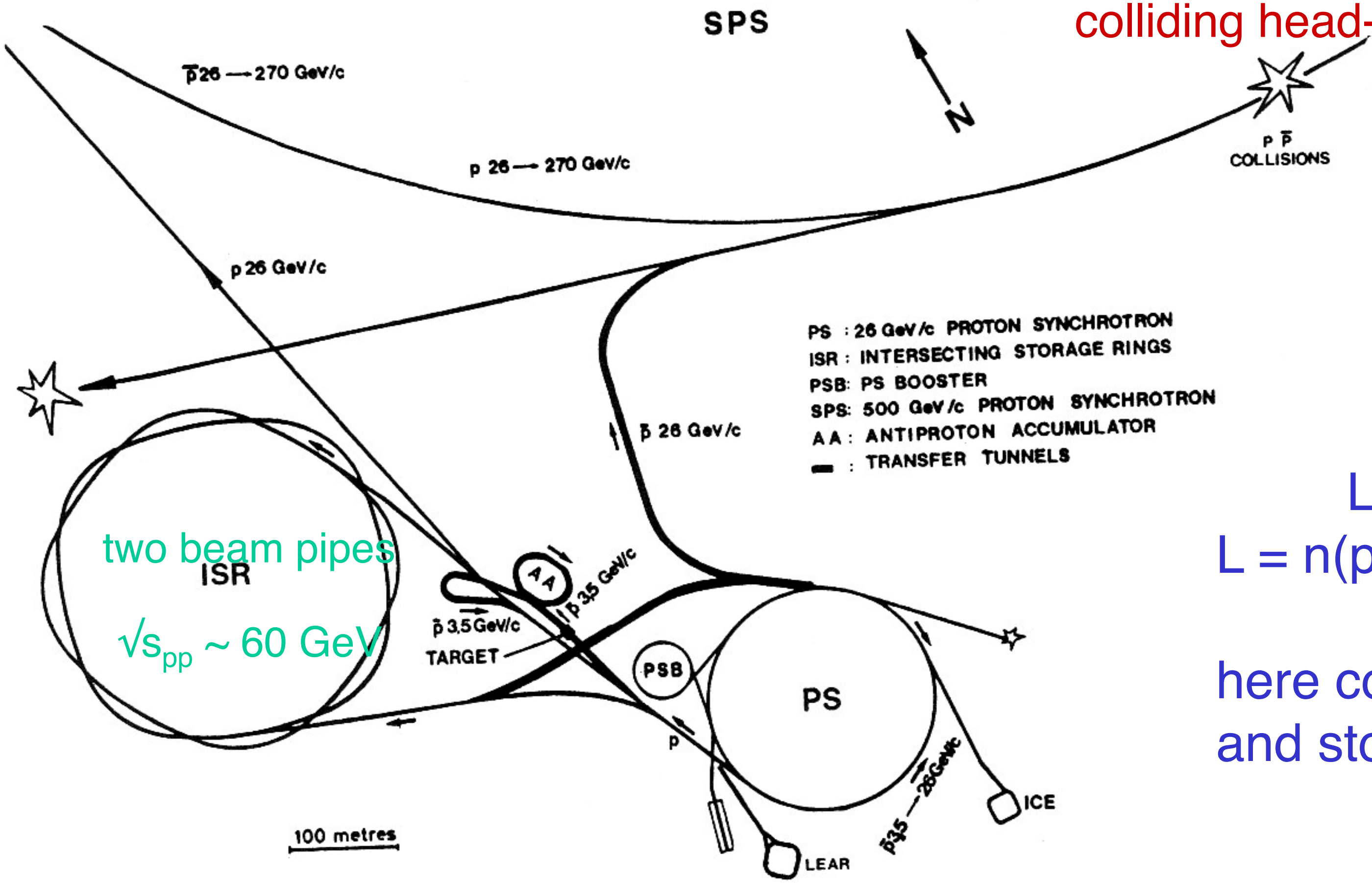
this meant that $m_{W,Z} \sim 50 - 100$ GeV

but existing machines could not give more than $\sqrt{s} \sim 30 - 40$ GeV !! the CERN SPS in a fixed target mode, and the LEP was still far in the future, at least ten years, the ISABELLE proton-proton collider ($\sqrt{s} \sim 200$ GeV) at BNL had difficulties with its magnets…

here came the suggestion of Cline, Mc Intyre, Rubbia to convert an existing proton synchrotron into an antiproton-proton collider!

The CERN antiproton-proton collider complex

protons and antiprotons counter-rotating in same beam pipe - as in an e+e- machine! colliding head-on at $\sqrt{s} \sim 500$ - 600 GeV



colliding head-on at $\sqrt{s} \sim 500$ - 600 GeV is equivalent to ~ 150 TeV beam energy

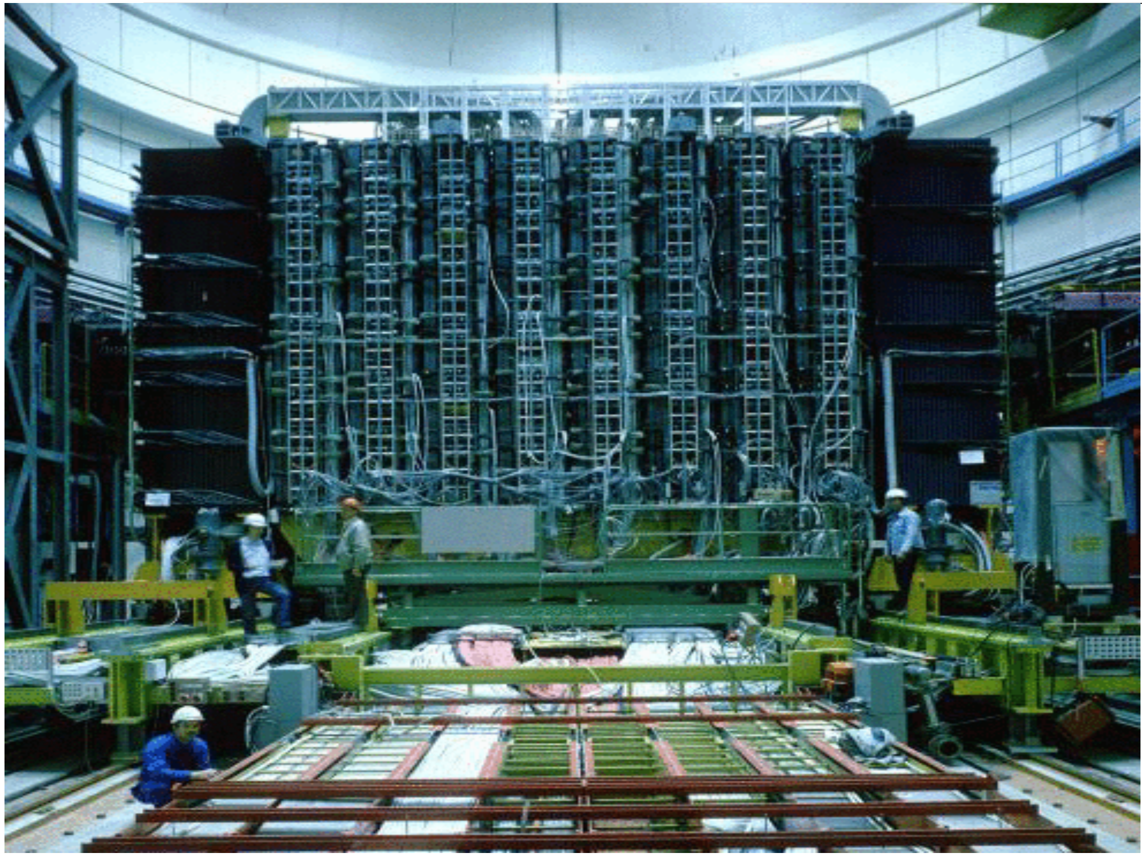
Luminosity:

$L = n(p)n(\text{anti-}p)f/(4\pi\rho^2)$

here comes S. Van der Meer and stochastic cooling….

➡ The transformation of the SPS into a collider at C. Rubbia's initiative was accomplished by the summer of 1981 - in ~ < 3 years

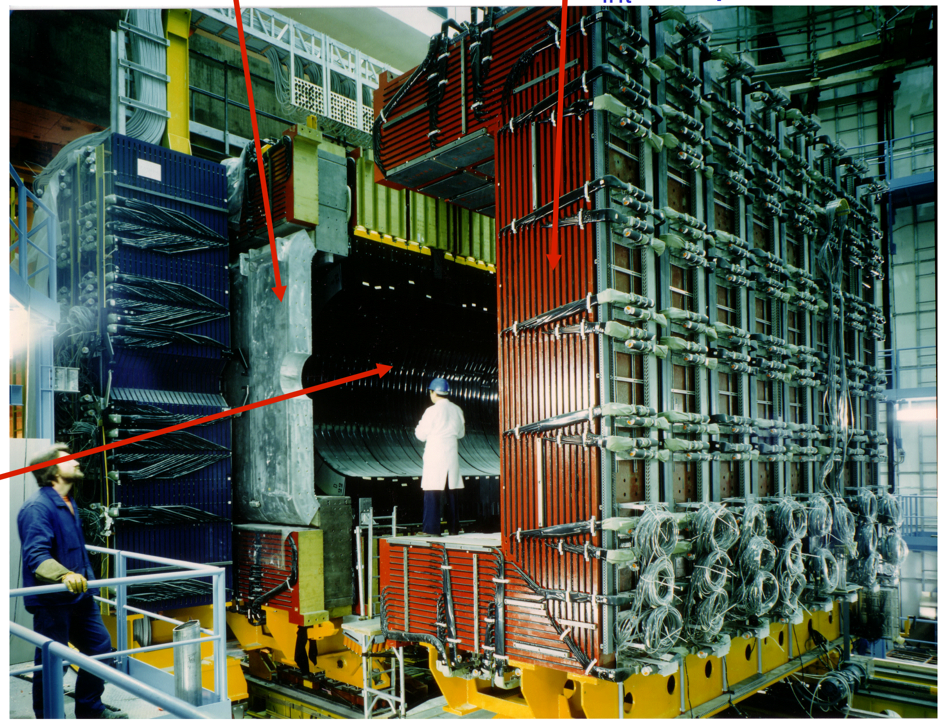
UA1 detector under construction (1979/81!!!)



UA1 detector: ~10 x 6 x 6 m^3,
~ 2000 tons ~130 physicists
calorimetric coverage $|\eta| < 5.0$
tracker coverage $|\eta| < 3.0$
muon system coverage $|\eta| < 2.3$

warm Al coil,
7kG horizontal field,

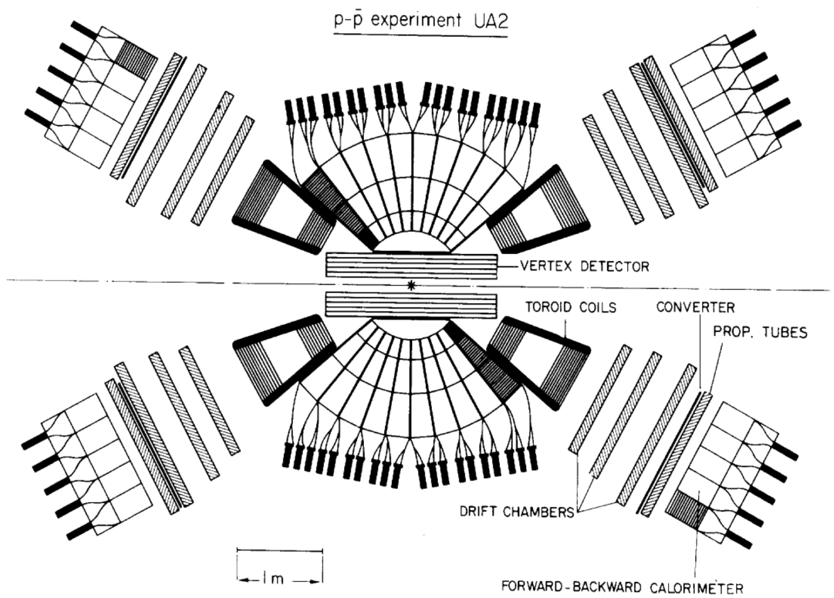
HCAL
5cm iron/1cmScint.
3.5 λ_{int} deep



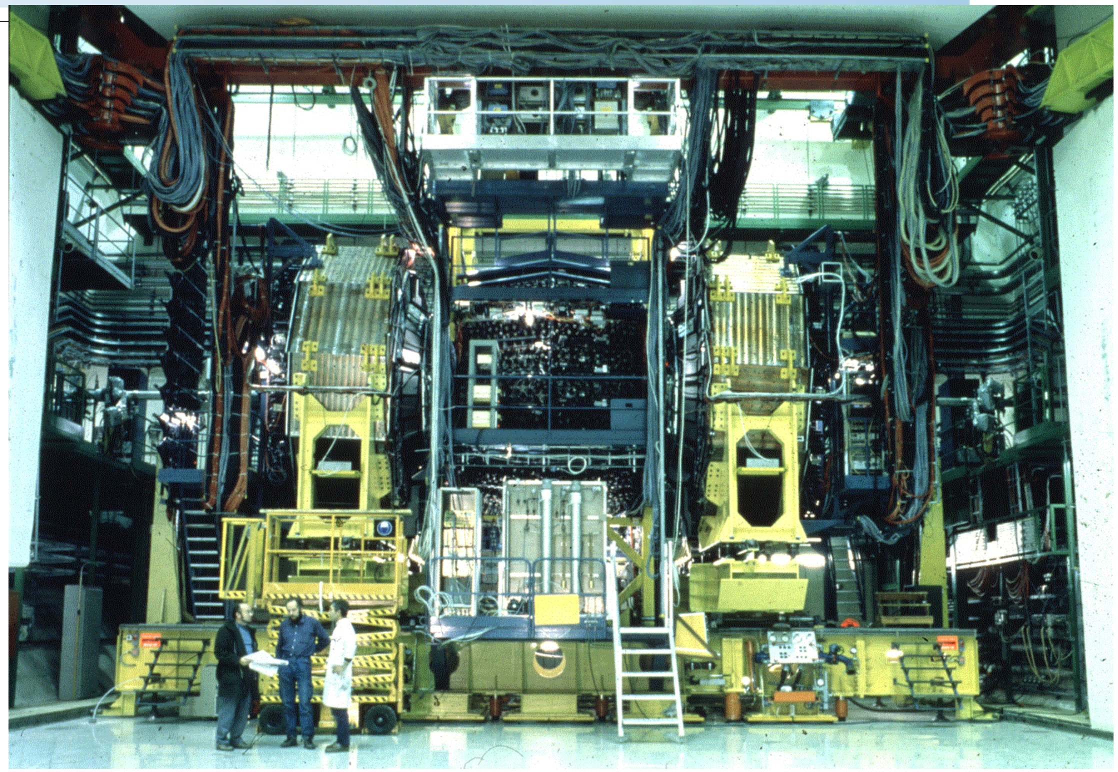
UA1 designed and built in < 3 years!!

ECAL (2x24 gondolas) Scint.-Pb sandwich
1.2 mmPb/1.5 mmSci $\Delta\phi\Delta\eta = 180^o \times 0.14$
$27X_0$ deep, four segments in depth + 2x32 radial sectors in end-caps acceptance $|\eta| < 3.0$

The UA2 detector



The UA2 detector in its initial configuration (1980-85).



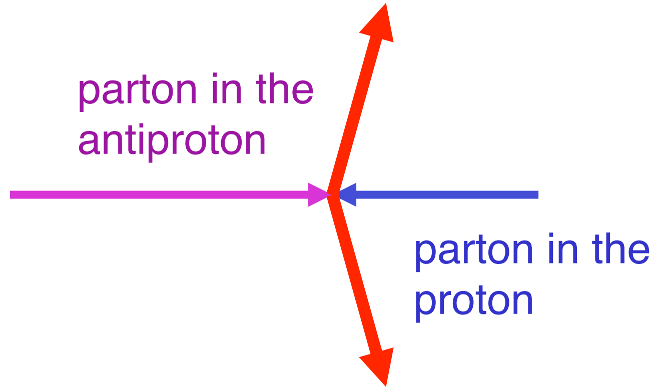
The UA2 experiment in its final configuration for the runs of 1986 to 1990. Full calorimetry down to ~5° thus improved measurement of missing p_T

Central region: tracking detector, "pre-shower" electromag. and hadronic calorimeters;
ECAL: Sci+Pb sandwich, HCAL: Fe+Sci sandwich
$\Delta\theta\ \Delta\phi \sim 10^o x 15^o$,, 4.5 λ_{int} no magnetic field
20° – 40° regions : toroidal magnetic field;
tracking detectors;
"pre-shower" + electromagnetic calo.

The first major success: first observation of hadronic jets at the antiproton-proton collider - summer 1982

Elementary processes :

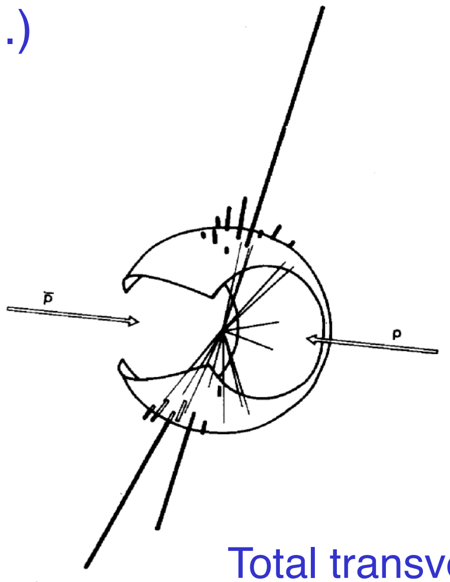
$$\bar{q} + q \to \bar{q} + q$$
$$q + g \to q + g$$
$$g + q \to g + q$$
$$g + g \to g + g$$
$$q + q \to g + g$$
$$g + g \to q + q$$



Not totally sure that jets would be seen in hadron collisions (NA35) …..
- but already seen in e+e- however!

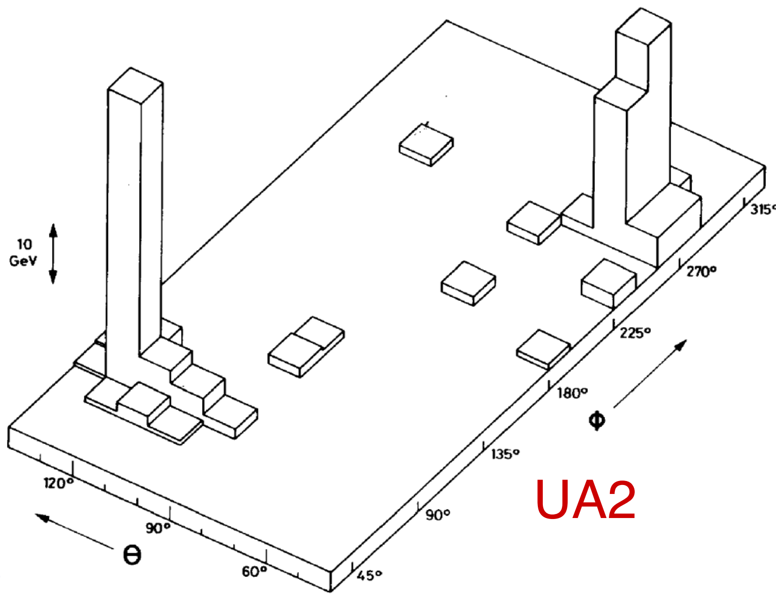
Remember:
NA(35), ISR/AFS
(correlation/trigger bias….)
G. Preparata
(Fire Sousage model….)
Odorico….

First evidence for jets in hadron colliders,
December 1981 run,
spectacular UA2 early jet event in calorimeters,
Paris conf. summer 1982



(a)

Total transverse energy ~ 140 GeV

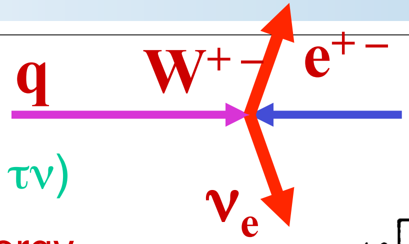


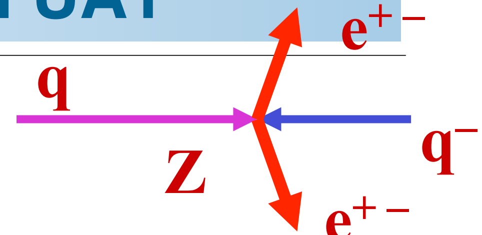
UA2

(b)

Run of winter 1982, W discovery, followed by run of spring 1983 and Z discovery in UA1

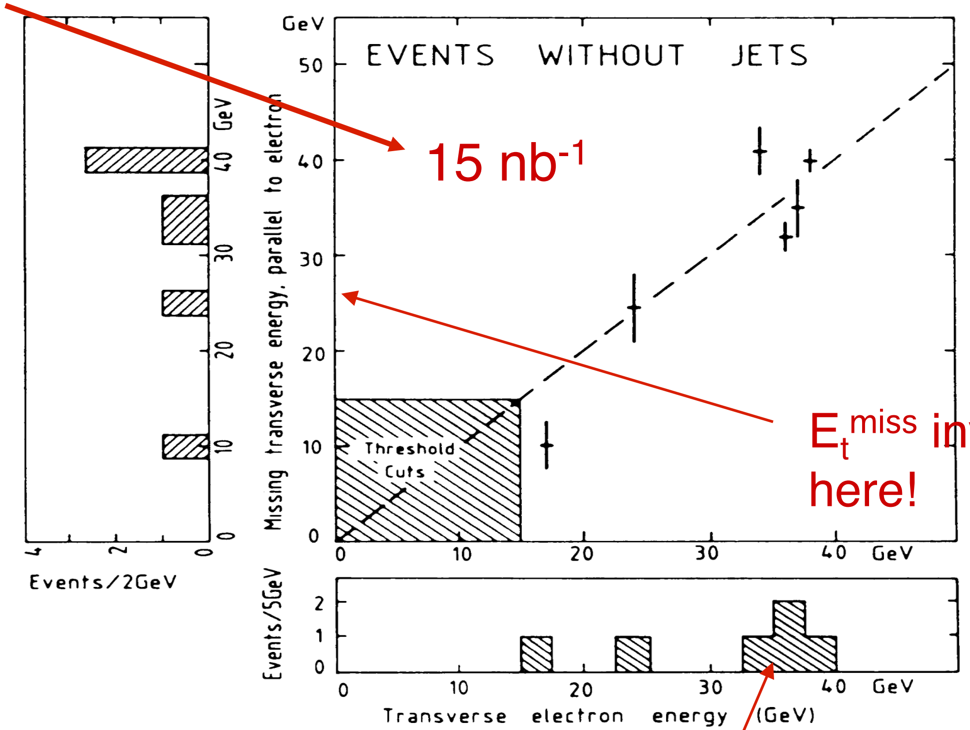
Search for leptonic decays:





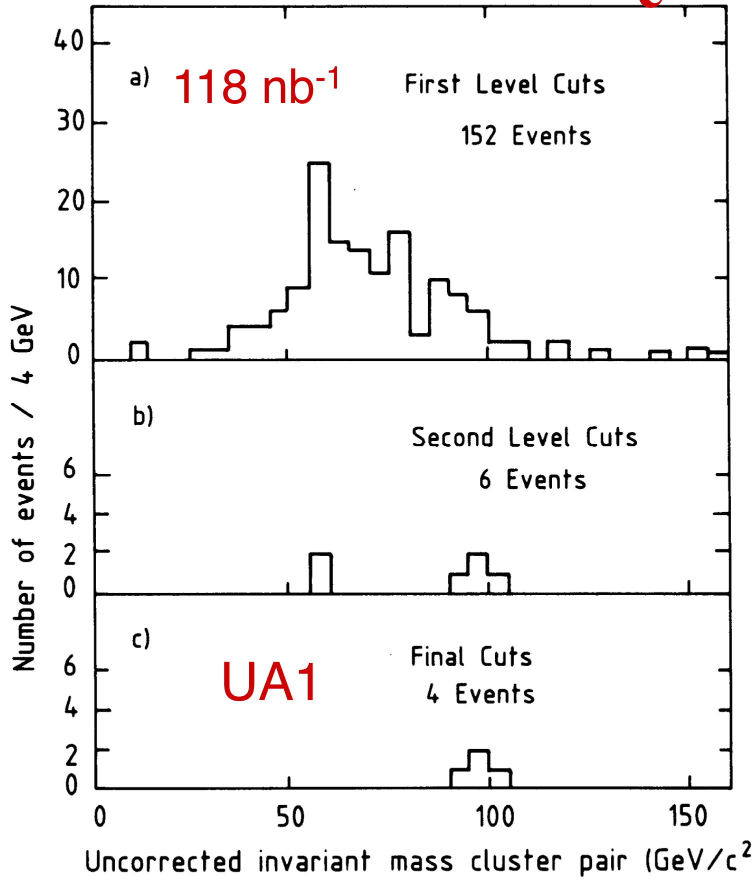
➡ 6 events selected (5 W→ eν + 1 W→ τν)

Correlation between missing transverse energy and e+- transverse energy for the first W events



$15\ nb^{-1}$

E_t^{miss} invented here!



$118\ nb^{-1}$

UA1

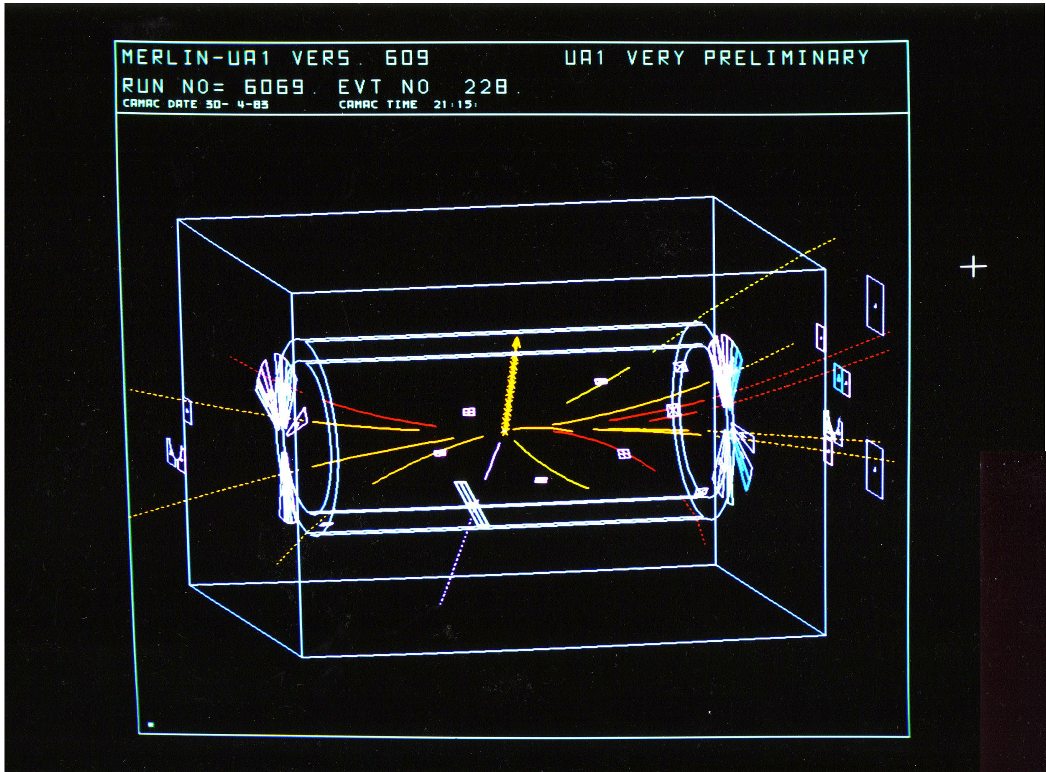
➡ $m_W = 81 \pm 5$ GeV (UA1)

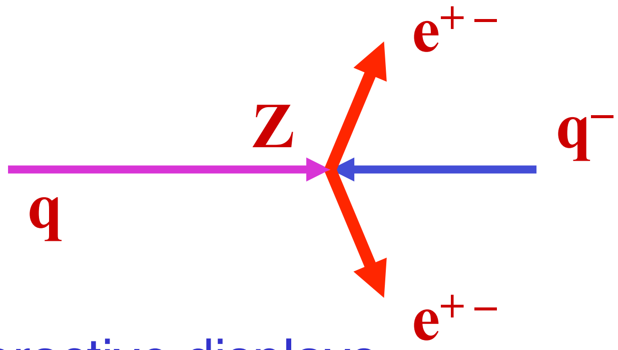
from first "Jacobian peak"

➡ $m_Z = 95.5 \pm 2.5 \pm (3.0)$ GeV (UA1)

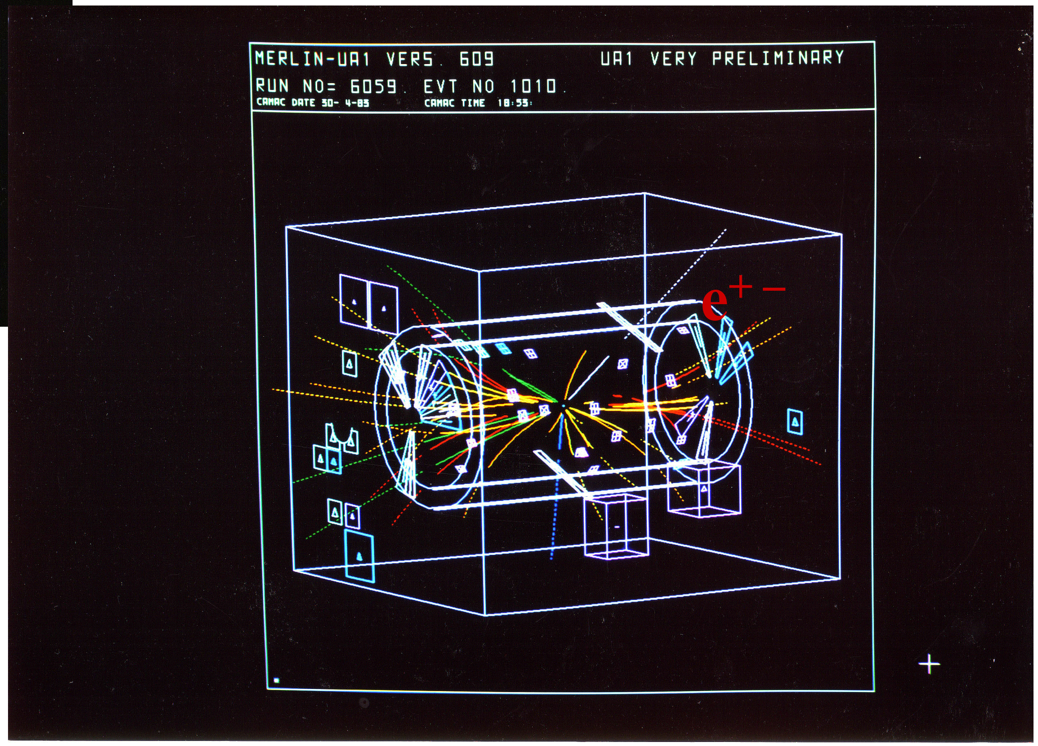
$\sigma_Z BR(Z \rightarrow ll) = 41 \pm 21\ (\pm 7)$ pb

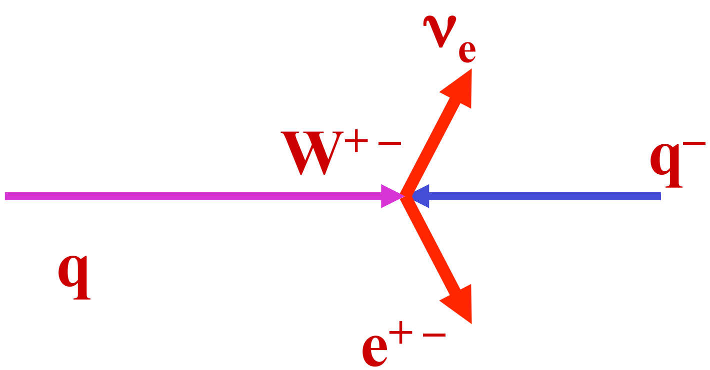
First W → eν events in UA1 (Jan.1983) and first Z → e+e- events in UA1 (May 1983)



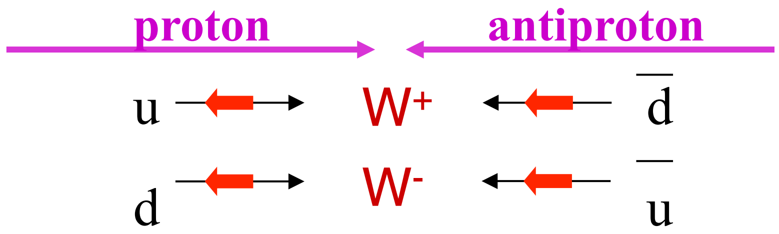


Megatek interactive displays



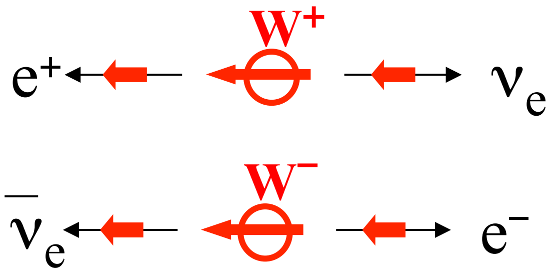


W confirmation, V-A asymmetry in UA1, spring 1983



The almost complete $W^{\pm}$ polarization along antiproton direction was a consequence of V–A coupling - and of the collider cm energy ~ 500 - 600 GeV guarantying valence quark fusion into W (x_q, $x_{anti\text{-}q}$ ~ $m_W / \sqrt{s}$ ~ 0.2), combined with V-A in decay results in leptonic ang. asymmetry!

In the W rest frame:



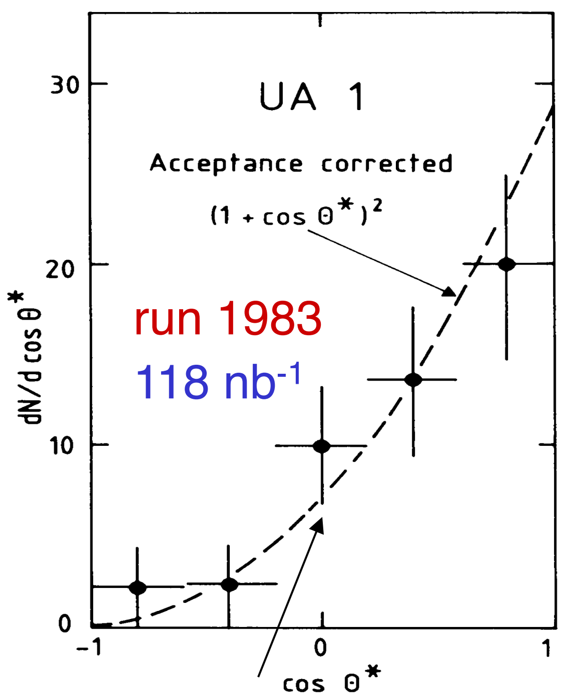
Electron (positron) angular distribution:

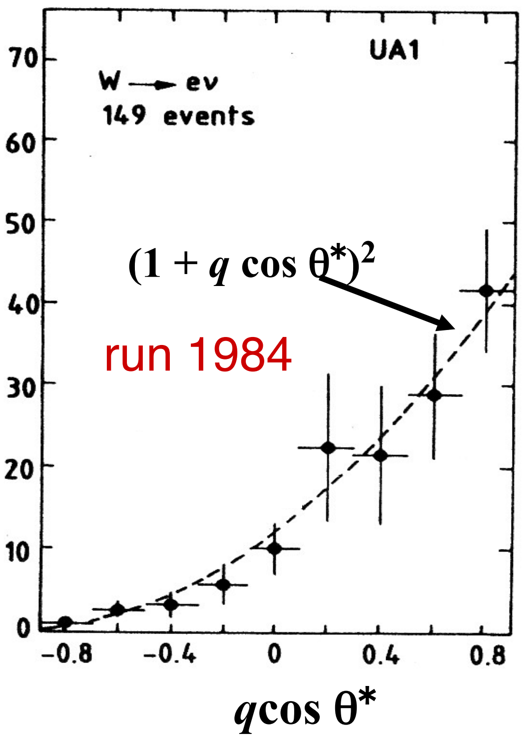
$$\frac{dn}{d\cos\theta^*} \propto \left(1 + q\cos\theta^*\right)^2$$

q = +1 for positrons; q = -1 for electrons

θ^* = 0 along antiproton direction

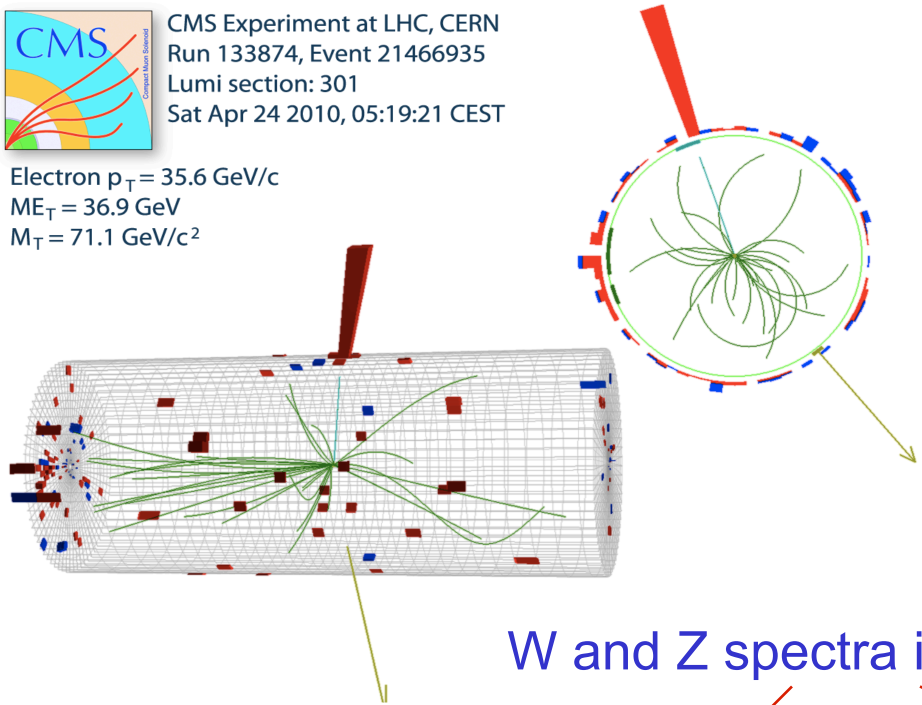
magnetic field of UA1 crucial for this!

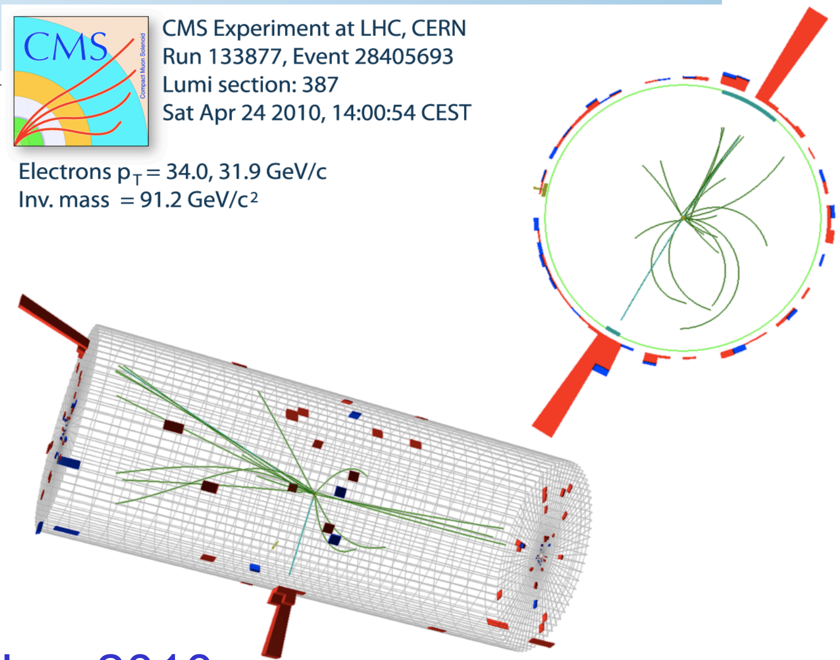




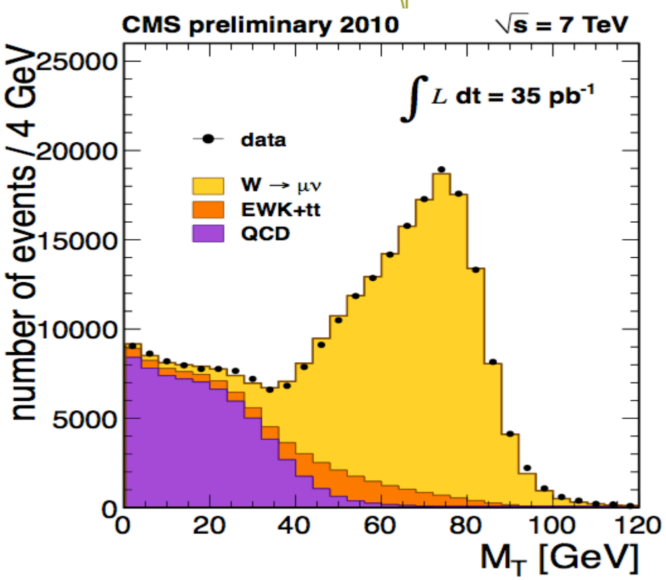
it is really THE W (spin =1, max. parity violation)!

First W → eν and Z → e⁺e⁻ events in CMS, April 2010

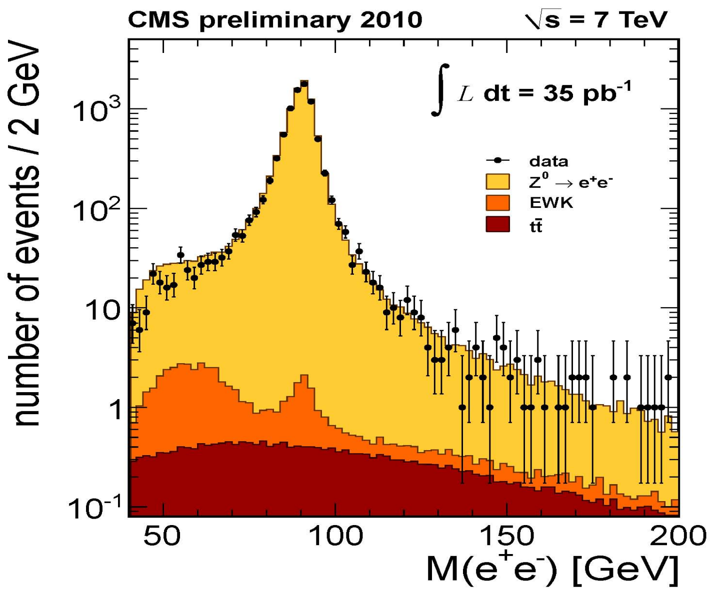




W and Z spectra in CMS, Nov. 2010

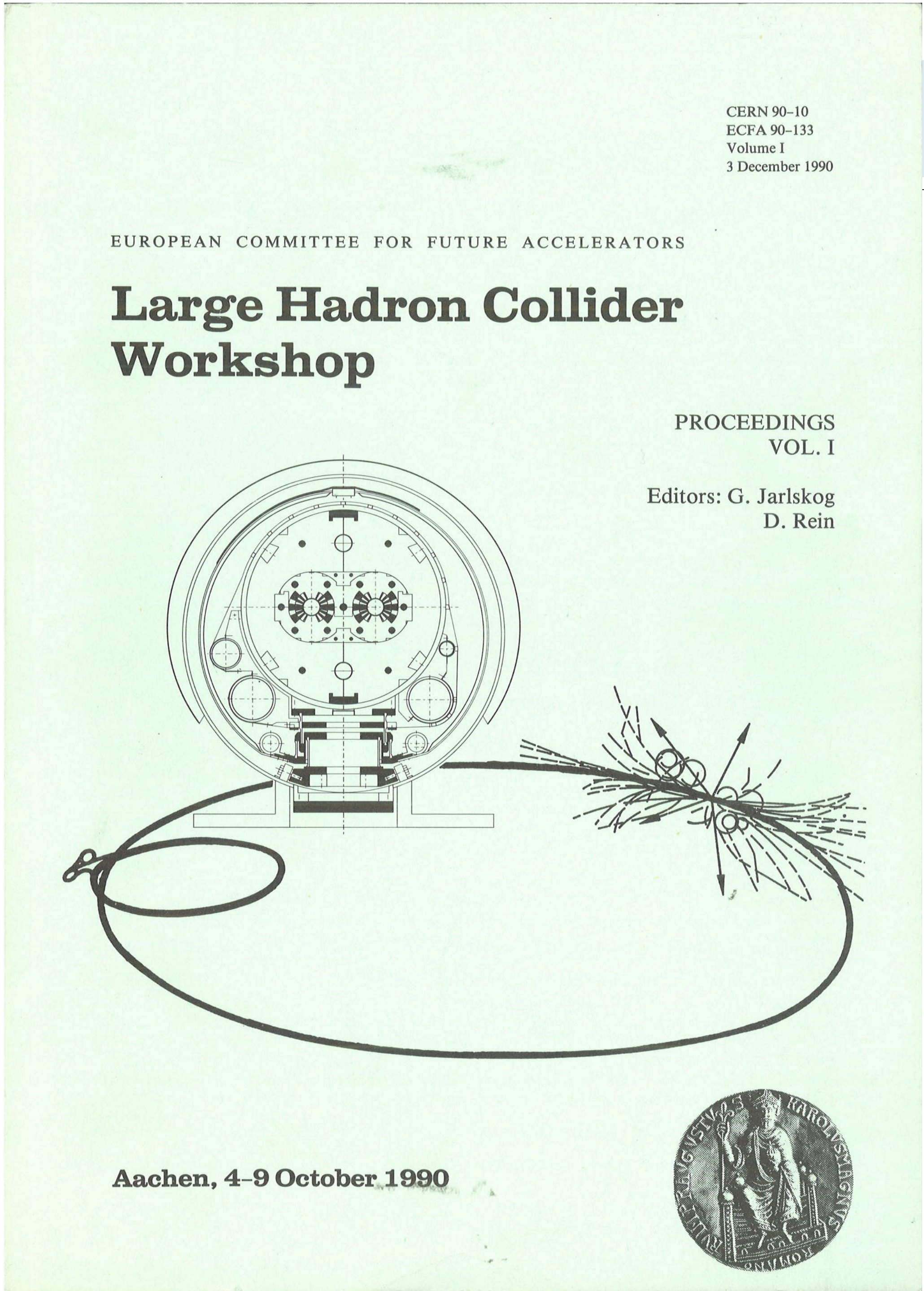


By now, July 2012 we have ~80.000.000 W and ~8.000.000 Z decaying leptonically



Few words about the LHC,
how this adventure began

LHC, how it all started…. 1989-90



Precursor: Lausanne meeting 1984…

In Septembrer 1989 the new DG, C. Rubbia asked (Altarelli, Pauss, D.D.) to organize a year's long study whether and how a 17 TeV pp collider in the existing LEP tunnel could compete with the SSC - then in construction - in the search for the Higgs, top, SUSY etc - assuming 10 Tesla dipoles could be produced.

The outcome was the ECFA Aachen Workshop in October 1990; the main result was that an LHC luminosity ~ ten times larger was required to compensate the factor of ~ 2 inferior energy vs the SSC i.e. $10^{34}cm^{-2}s^{-1}$!!!

The Large Hadron Collider (LHC) - the genesis

The LHC project started at the initiative (and with the daring!!) of C. Rubbia

and the Conference in Aachen, Oct. 90, marked the real start-up, since then work on the collider and magnets, the various detector designs and understanding physics (inspired by the « EHLQ bible »), went on without let-up

Scientifico-diplomatic trips in 1990/91/92 to Japan, India, Russia, USA, Canada etc

LHC vs SSC: Rubbia's arguments: savings!

- existimg LEP tunnel ~1 GCHF
- existing infrastructure at CERN (PS. SPS, etc) ~ 1 GCHF
- "two-in-one" scheme for dipoles saves ~ half the cost of magnet ~ 0.7 to 1 GCHF

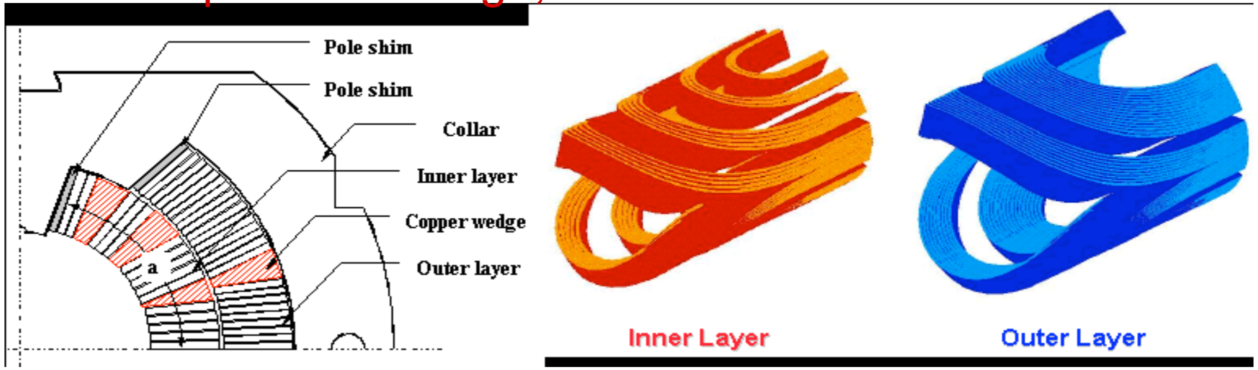
thus overall LHC cost ~ 3 GCHF

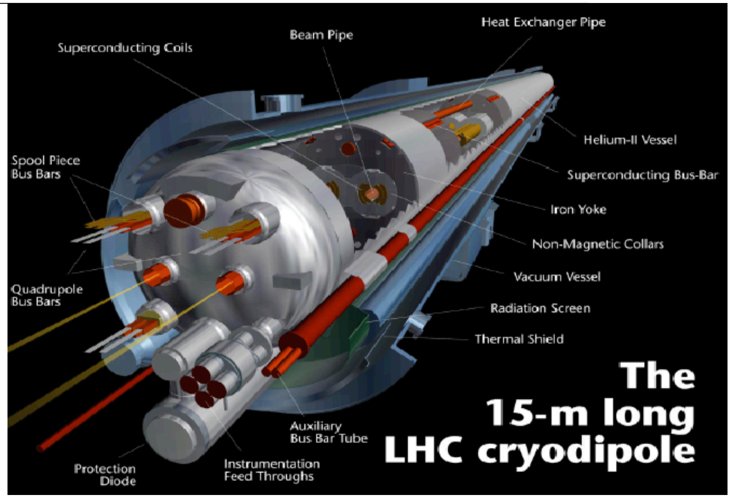
- will be ready by 1998 - 2000 !!

The key elements: LHC dipoles
coil structure for the two-in-one scheme

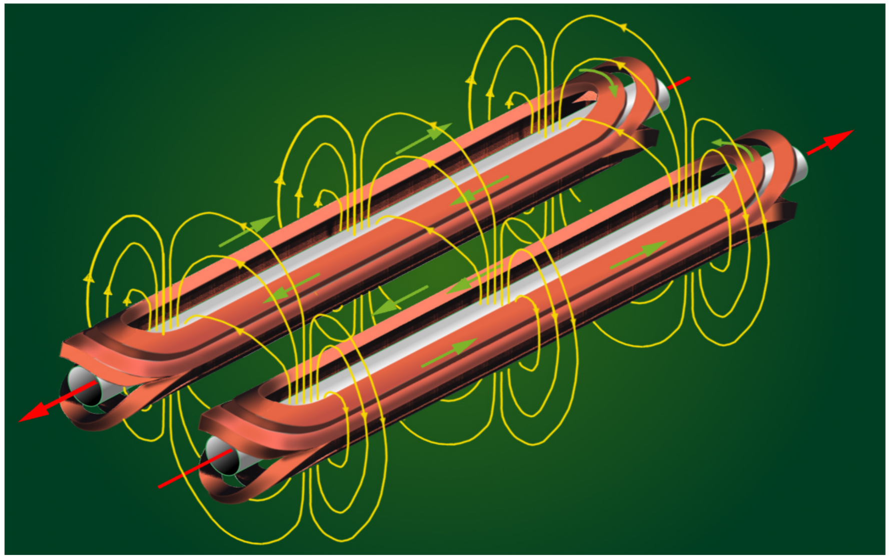
(suggested by R. Palmer in 1984)

LHC dipole coil design, 6-block coil structure

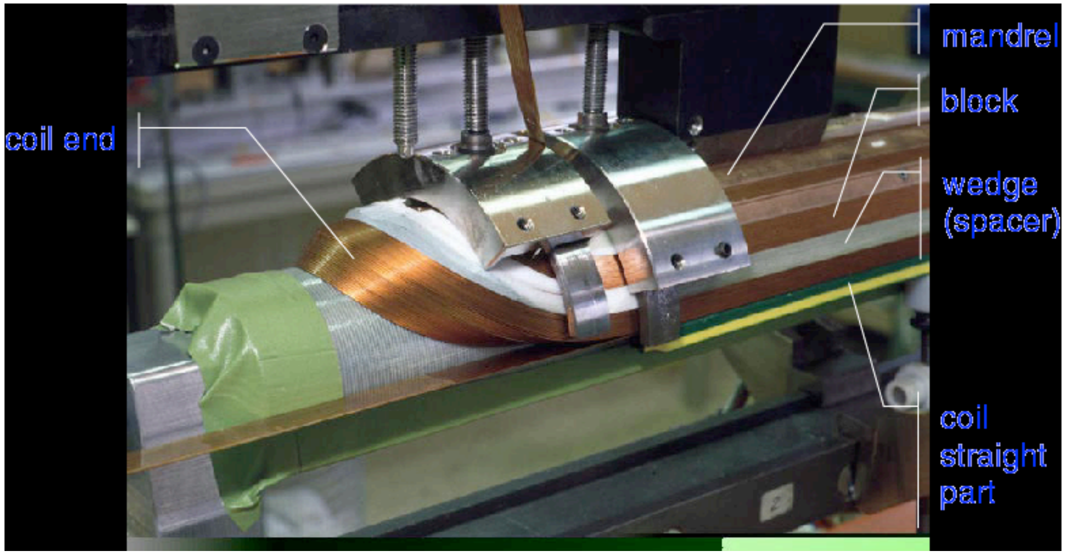




Field lines in the two-in-one dipole
(two beam-lines in a single magnetic enclosure)

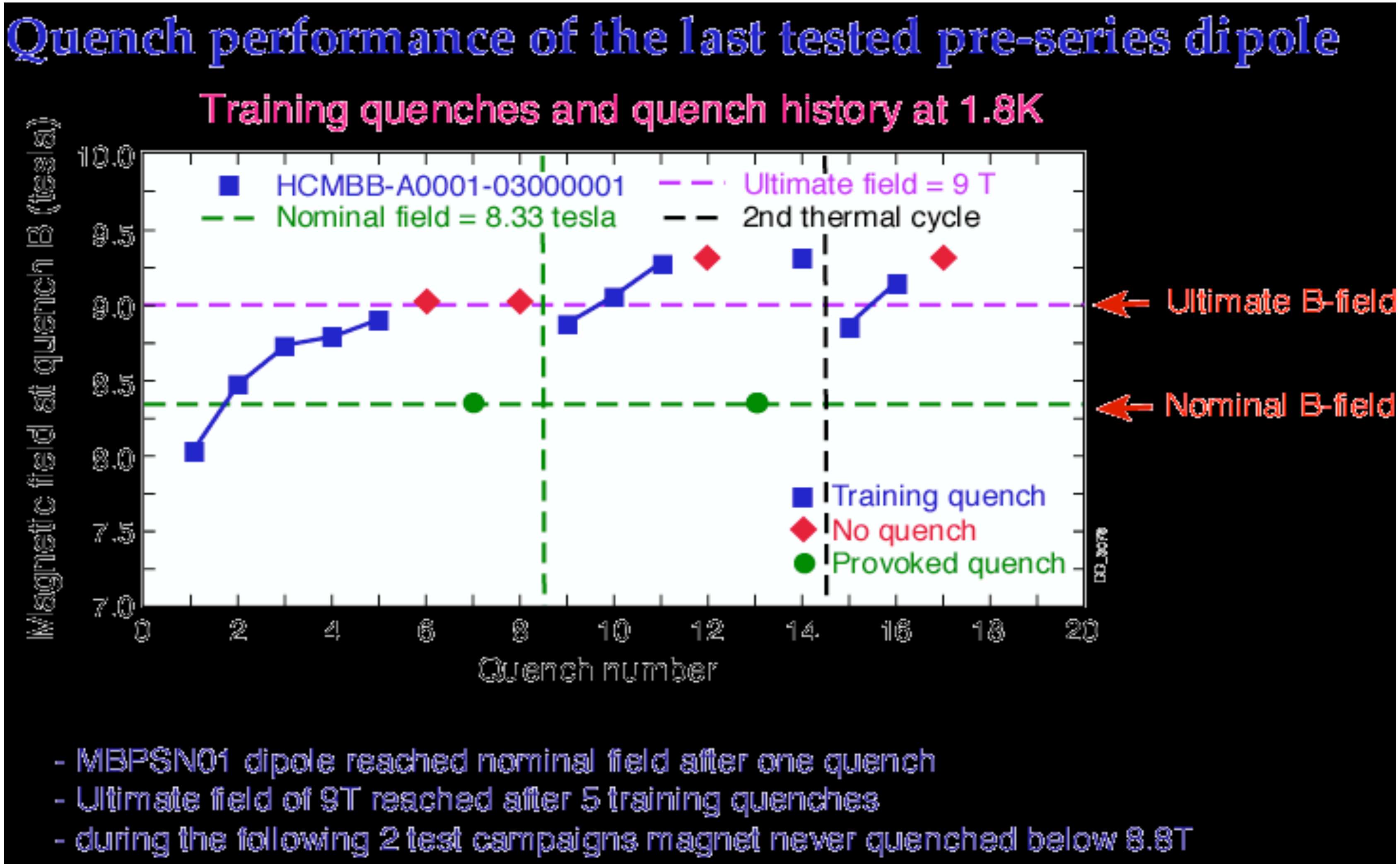


Most delicate is the coil end - this is where most of the quenches occur



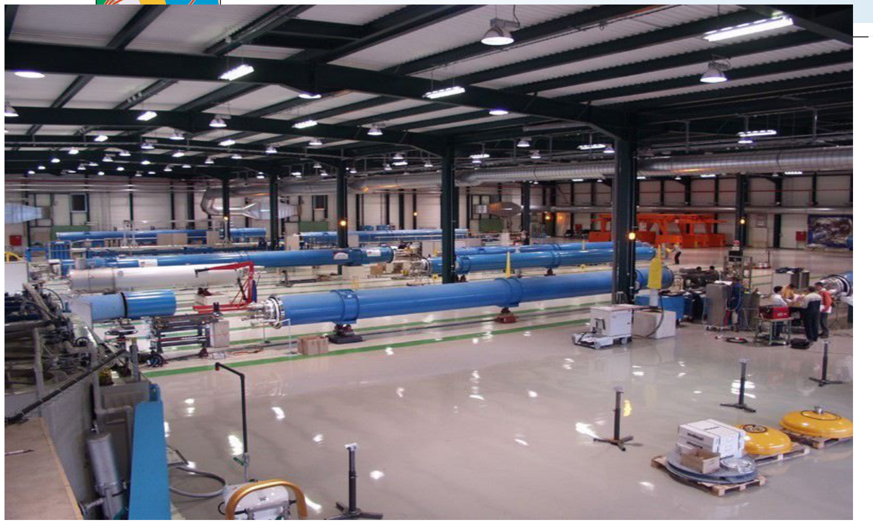
LHC dipoles (pre-series) - training

10 years of R&D were necessary with three generations of prototypes to develope the dipoles

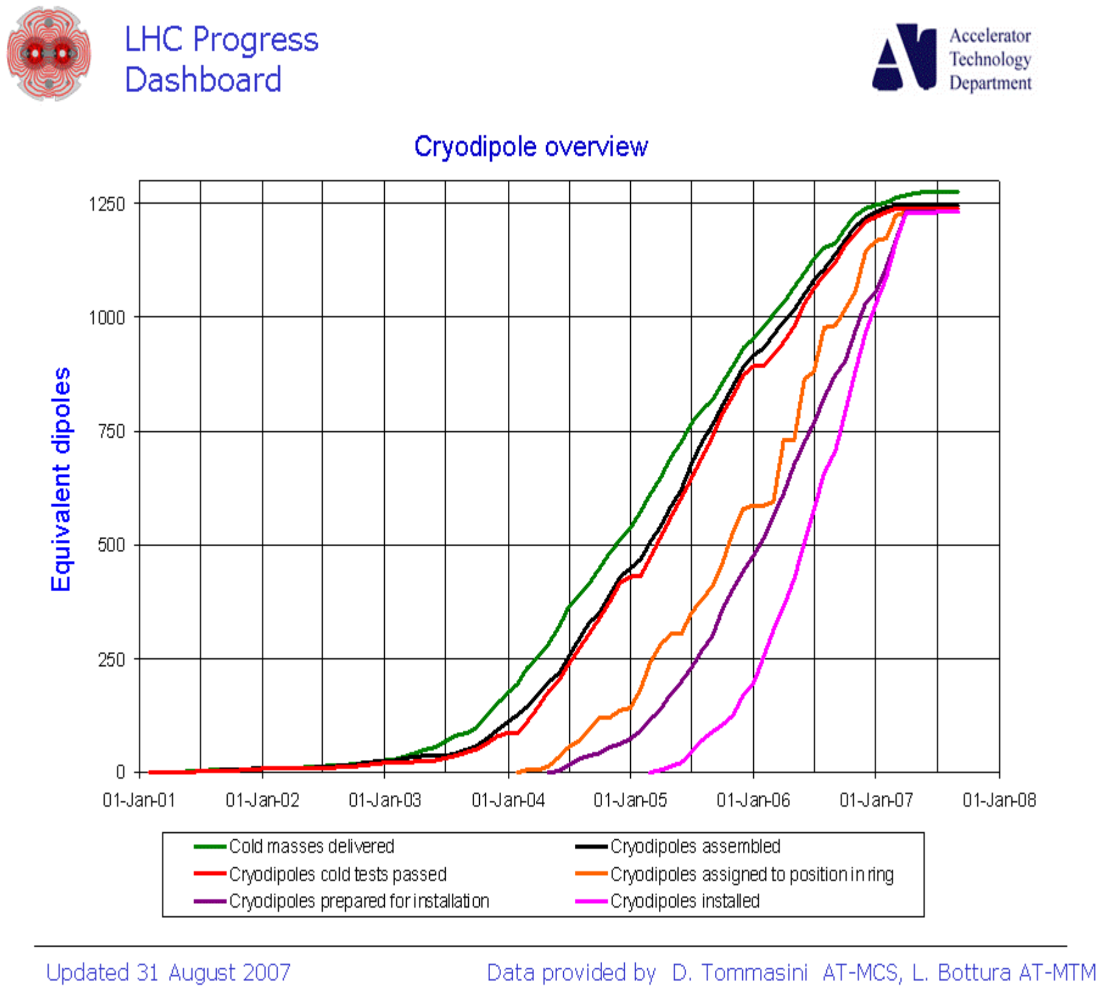


Last modifications to the dipole coil configuration done in 2001

LHC dipoles production, testing, installation, 2002-07



Hall at CERN for final assembly and testing of dipoles -2005/2006

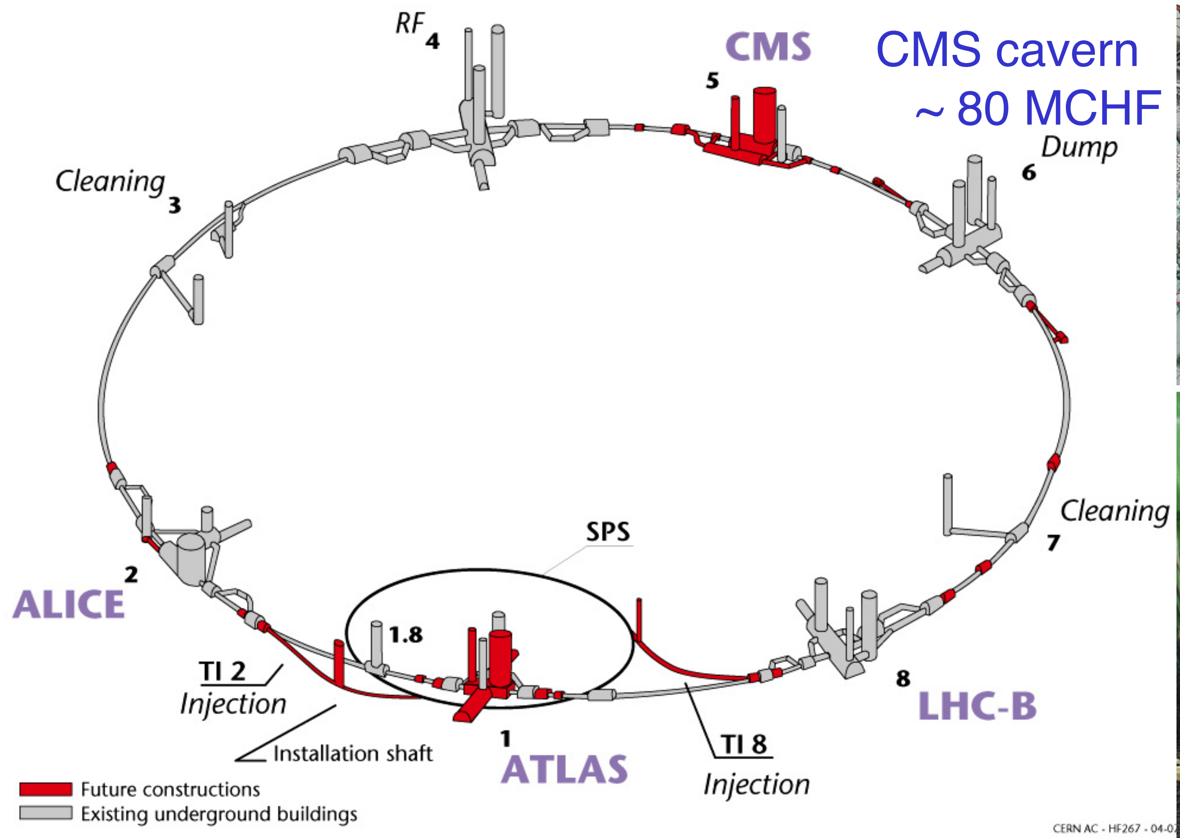


Magnets constructed between 2002 and 2007, by Jan. 2007 ~ 1200 dipoles and ~ 400 quads installed in the tunnel, they have to be aligned with 100μm precision

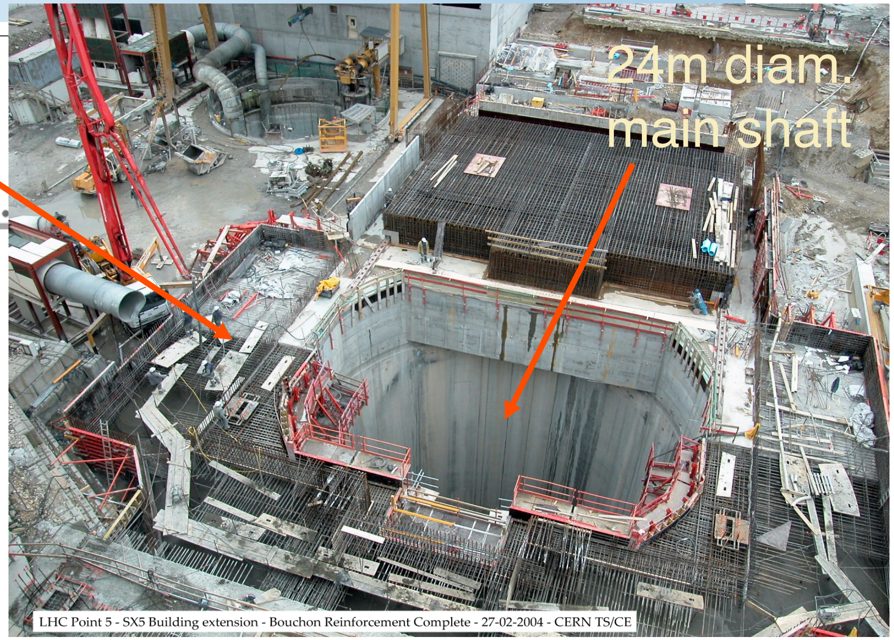
LHC infrastructures - a very major undertaking

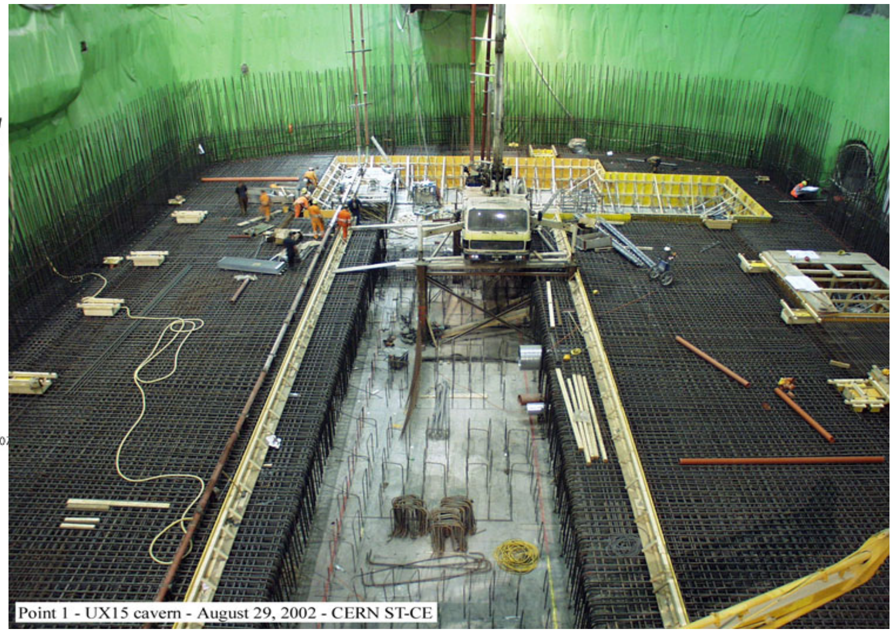
Freeze-out of soil to
-70°C before concreeting

Layout of the LEP tunnel including future LHC infrastructures.



CMS cavern
~ 80 MCHF





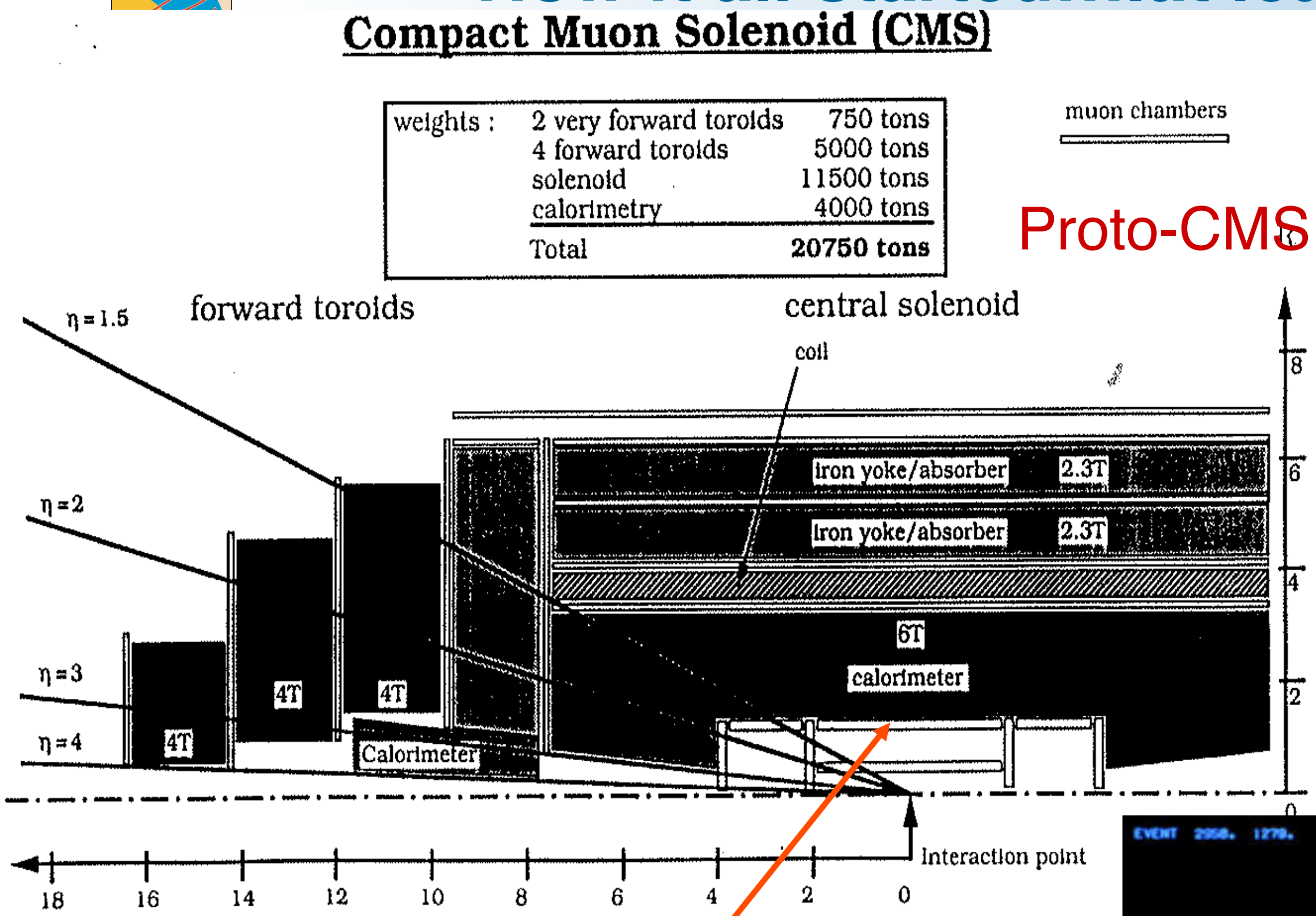
ATLAS cavern finished in May 2003
cost ~ 100 MCHF

Few words about the detectors, the design…..
CMS in particular

- we were just emerging from the p-pbar collider where max. luminosity was $10^{30}cm^{-2}s^{-1}$ - 4 orders of magnitude smaller than needed/desired for LHC   and the Tevatron was just approaching $10^{30}cm^{-2}s^{-1}$

- the backbone of the detector is the magnet (solenoid vs toroid)
  - but what tracking possible/feasible at $10^{34}cm^{-2}s^{-1}$, with ~ 30 pile-ups - a frightening perspective!?
  - what ECAL granularity feasible/acceptable/useful at $10^{34}cm^{-2}s^{-1}$??
  - trigger, DAQ (S. Cittolin!) etc

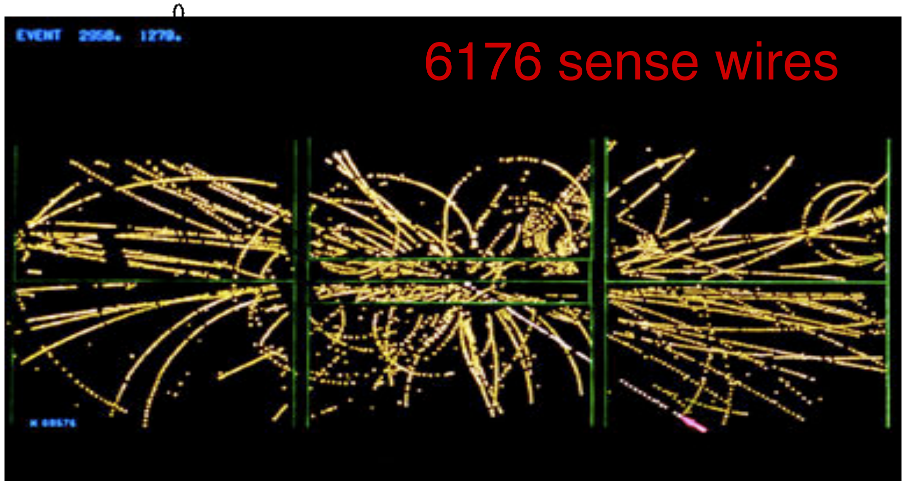
How it all started….at least for CMS!



Proto-CMS in 1990…..

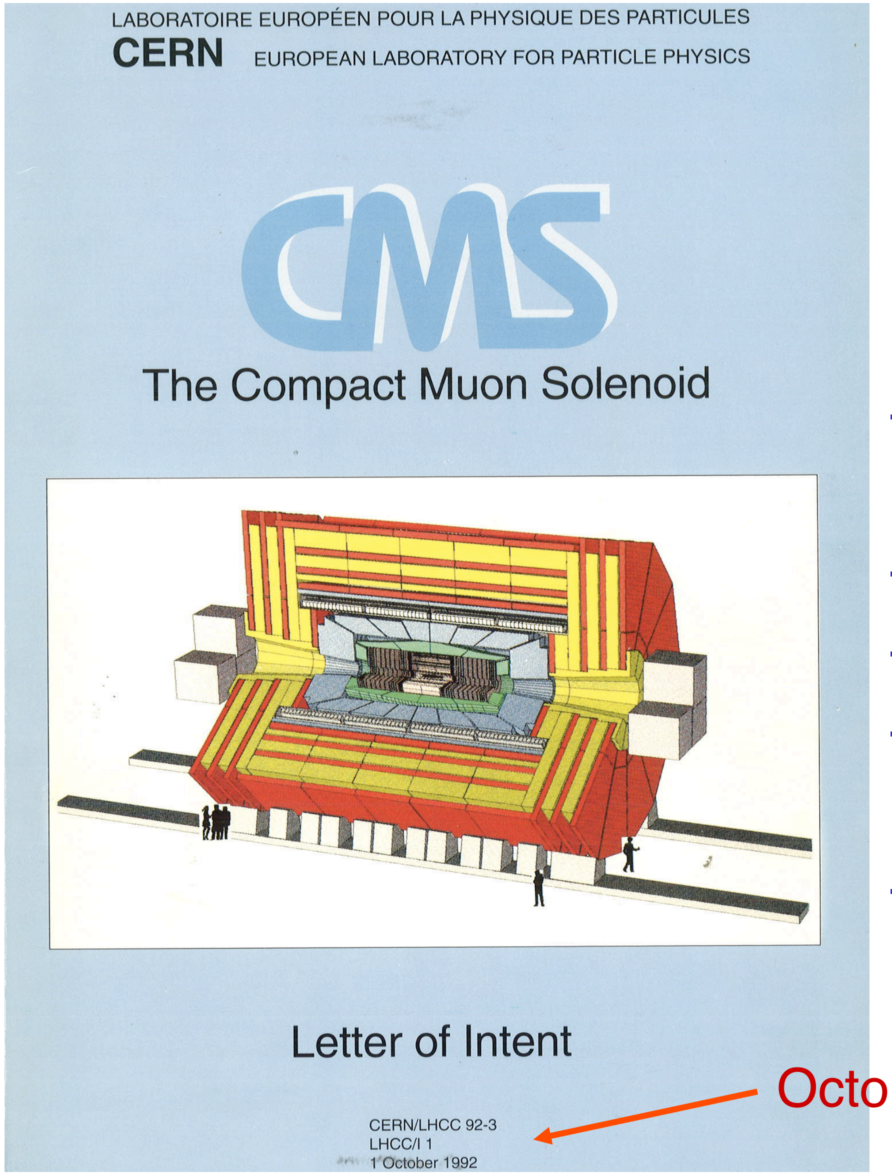
The UA1 tracker was by far the most sophisticated in its days, but the p-pbar collider did not exceed $10^{30}cm^{-2}s^{-1}$ and now for the LHC we need $10^{34}cm^{-2}s^{-1}$!! The answer: granularity and fast response

- Tracking? …maybe in outermost regions…



- Our test beam and MC studies led to rapid progress in the detector design.

Evolution of CMS, LOI in October 1992, organization of proto-collaborations 1991-1994



October 1992

By mid-1992 the design of CMS has much evolved and "stabilized", stayed remarkably the same since the LOI (October 1992), only changes in subdetector technology

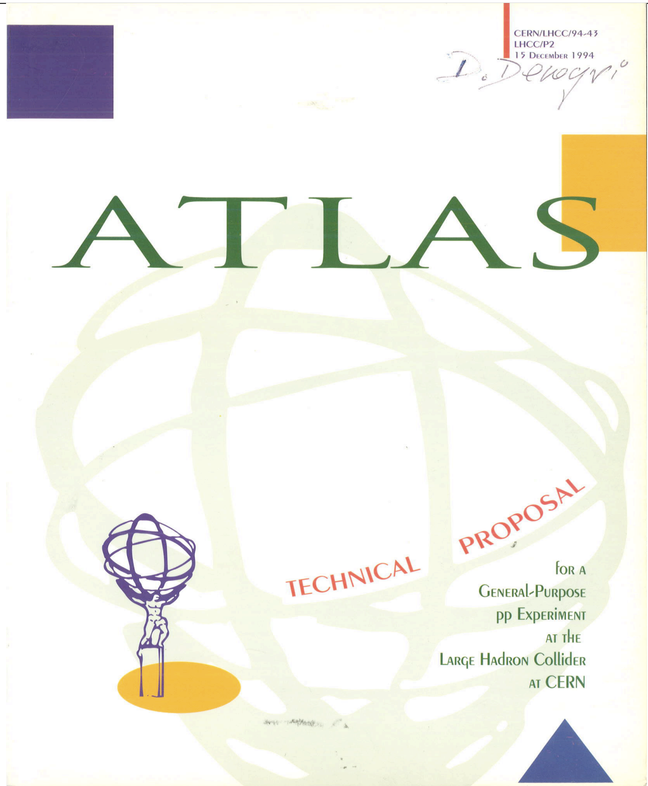
For CMS, the key points in the design were:

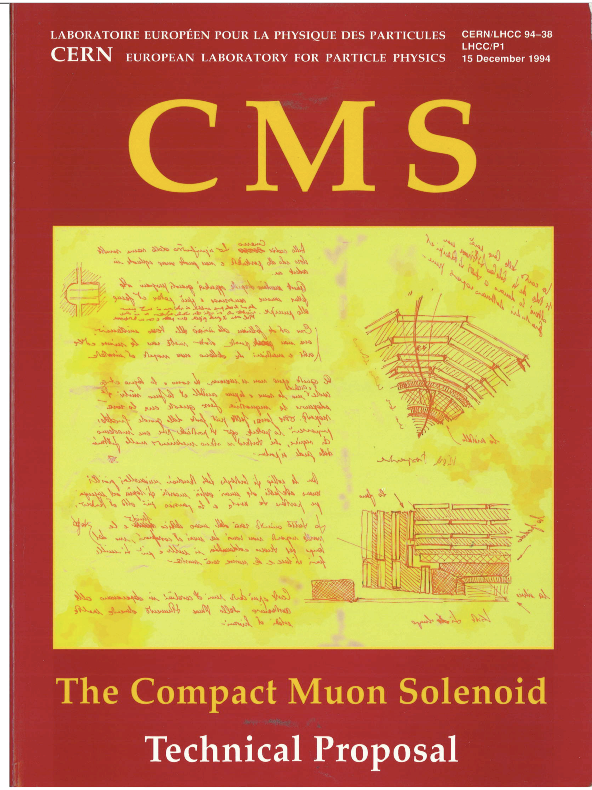
- robust large-acceptance muon system with a strong solenoidal field - driven by H → 4 muons
- excellent electromagnetic calo. - driven by H → γγ
- excellent tracking, of highest granularity affordable
- overall calorimetry hermetic - driven by SUSY (E_t^{miss})
- of reasonable overall cost:

  initial ceiling imposed by LHCC: 450 MCHF

Marriages in 1992/93:
ASCOT + EAGLE into ATLAS
CMS + L3P into CMS

Technical proposals of ATLAS and CMS, Dec. 1994



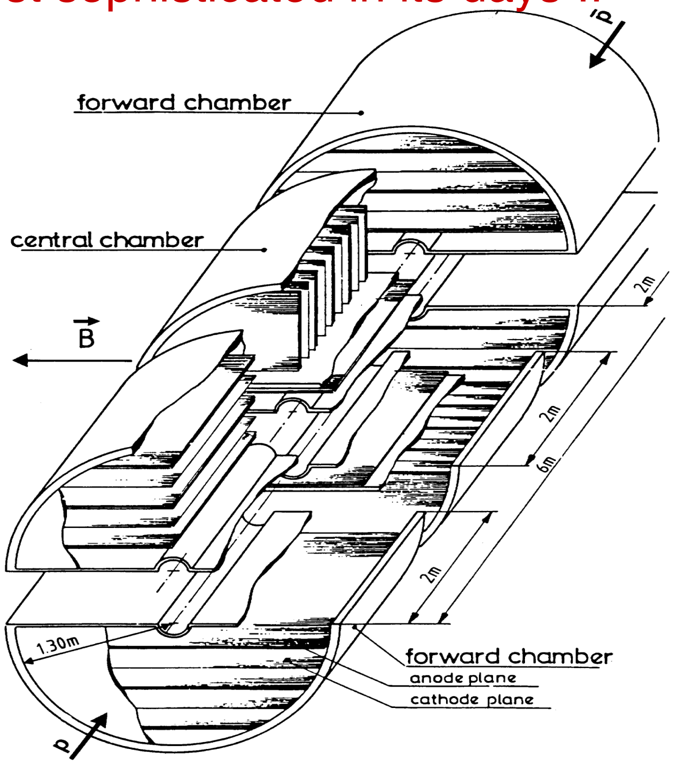


CMS changes in subdetector technology since LOI:

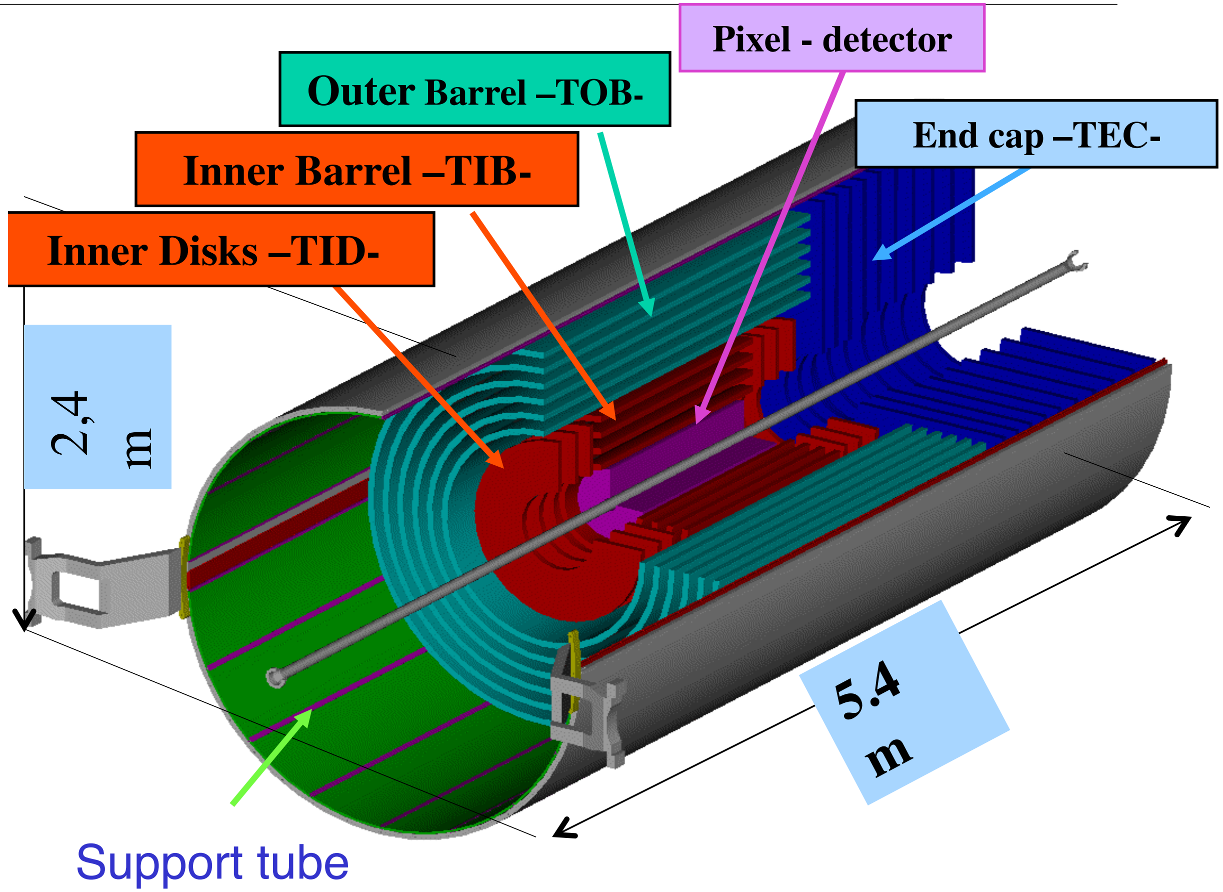
- for the ECAL: shashlik (Pb+Sci sandwich)/CeF_3 to $PbWO_4$ crystals in Sept. 94 - for reasons of resolution and space (L_{rad}, R_{Mol})
- for the tracker: MSGC to Si microstrips in 1994/95 - as Si became affordable
- in 1994/95 adjunction of a Si-pixel microvertex detector to the tracker design

The UA1 tracker and the all-Silicon CMS tracker

The UA1 tracker was by far the most sophisticated in its days !!



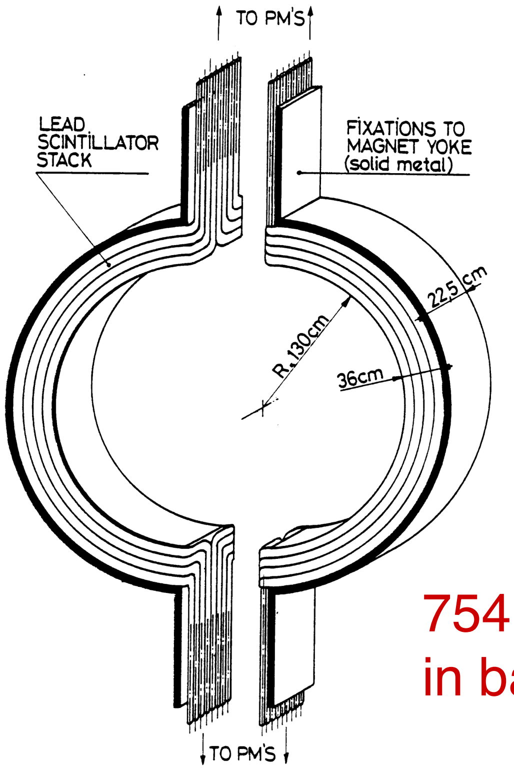
UA1 tracker: Imaging drift chamber, 6m long, 2.3m in diameter, 6176 sense wires, up to 180 hits per track, maximum drift distance 18cm
i.e. 4μsec drift time,
Acceptance $|\eta| < 3.0$



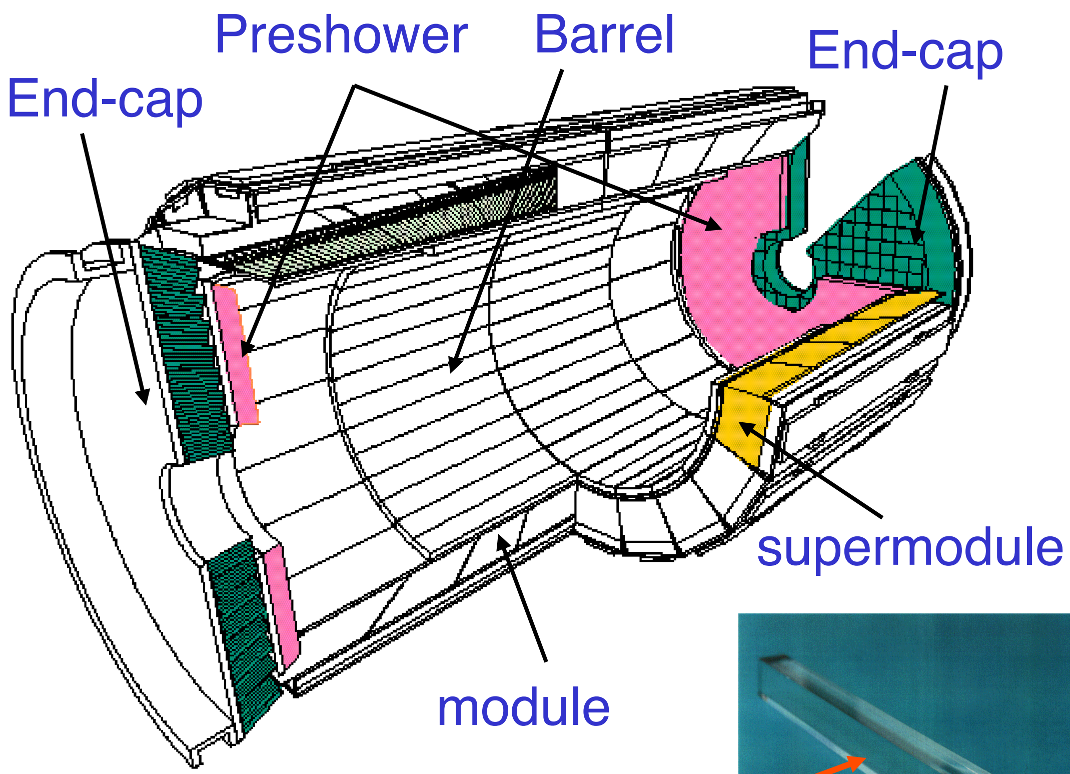
Factor ~10^4 in granularity!

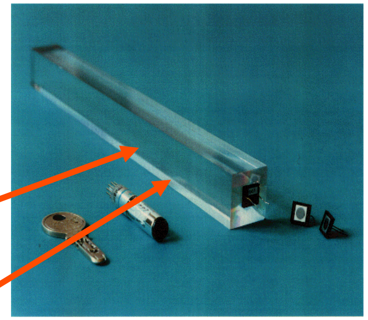
210 m^2 of silicon sensors
~ 6,000 thin detectors (1 sensor)
~ 9,000 thick detectors (2 sensors)
10 million microstrips and
70 Million pixels

From the UA1 electromagnetic calorimeter to the crystal ($PbWO_4$) calorimeter of CMS



754 PM's
in barrel





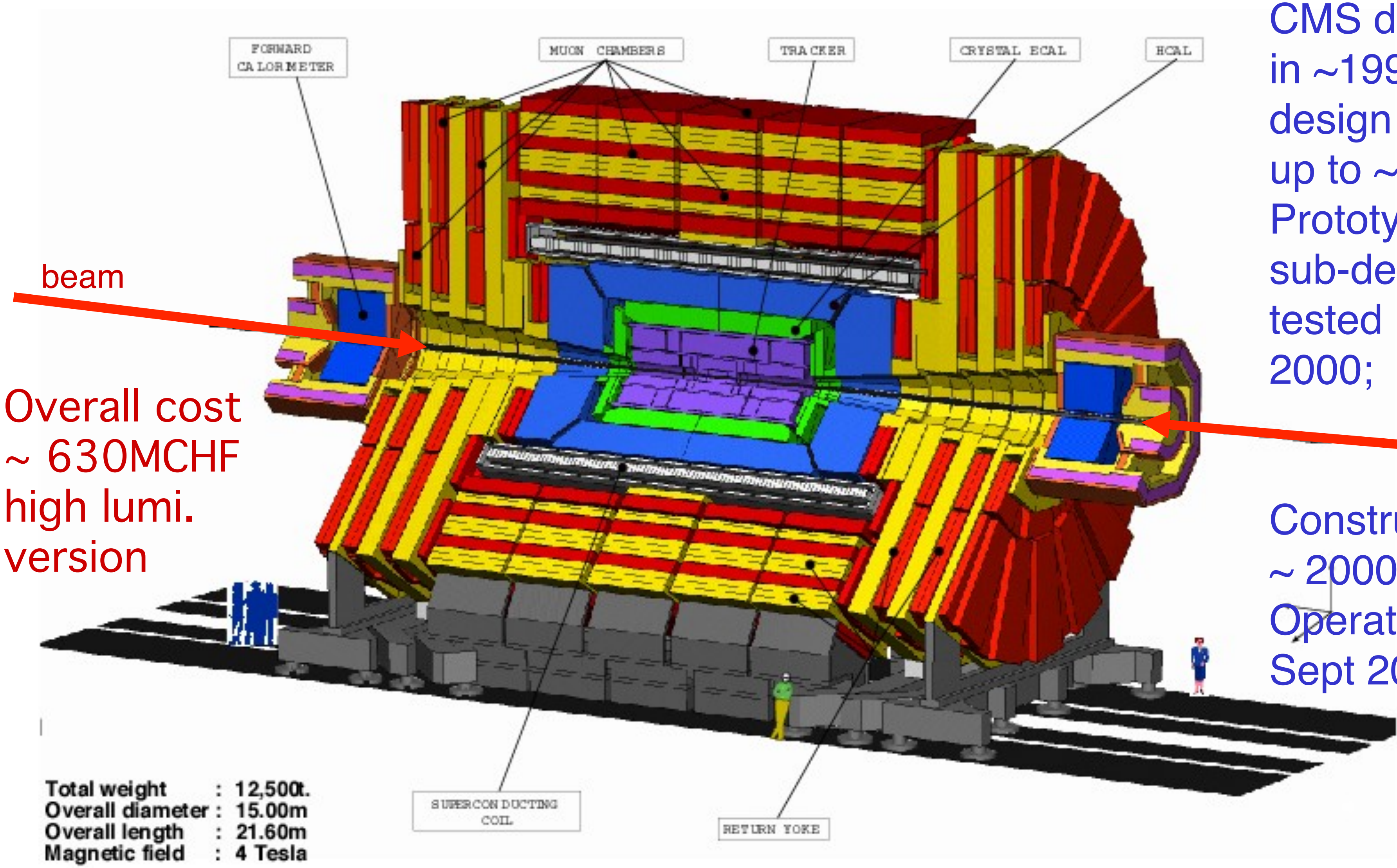
ECAL (2x24 gondolas)
Scint.-Pb sandwich, 1.2mmPb/1.5mmSci
$\Delta\phi\Delta\eta$= 180° x 0.14; 27X_0 deep, four segments in depth + 2x32 radial sectors in end-caps
ECAL acceptance: $|\eta| < 3.0$
Resolution for electrons/photons:
$\Delta E/E \approx 14\%/\sqrt{E} + 3\%$(sust)

A TeV em shower contained in a crystal of 24x2x2cm^3

Factor ~10^2 in granularity!

74.000 crystals
L_{rad} = 9mm, R_{mol} = 2cm ($\Delta\eta$ = 0.014)
read out with avalanche photo-diodes in barrel and VPT's in the end-caps

The CMS (Compact Muon Solenoid) detector

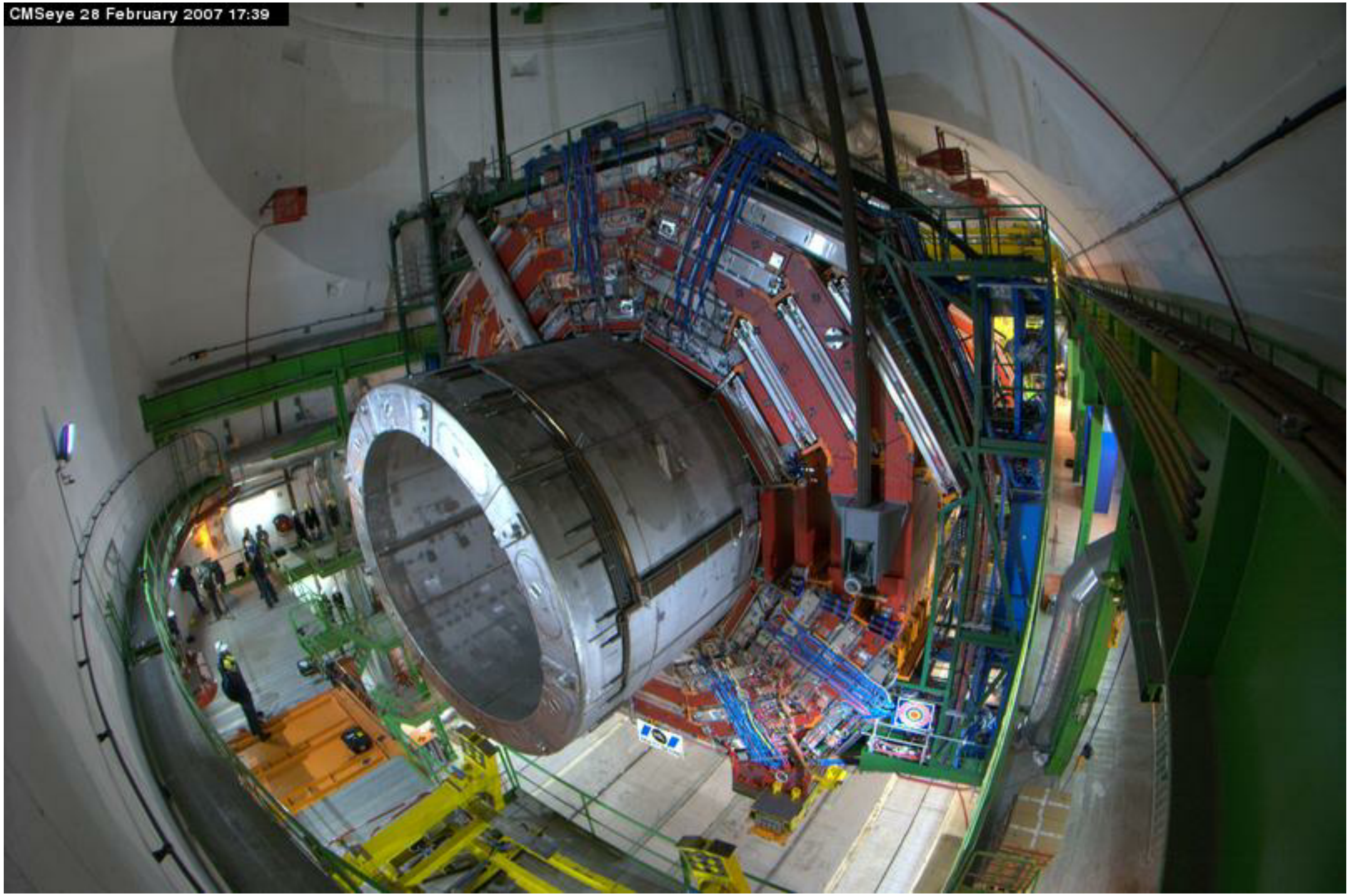


Overall cost ~ 630MCHF high lumi. version

CMS designed in ~1991/92, design optimized up to ~1995; Prototypes for sub-detectors tested up to ~ 2000;

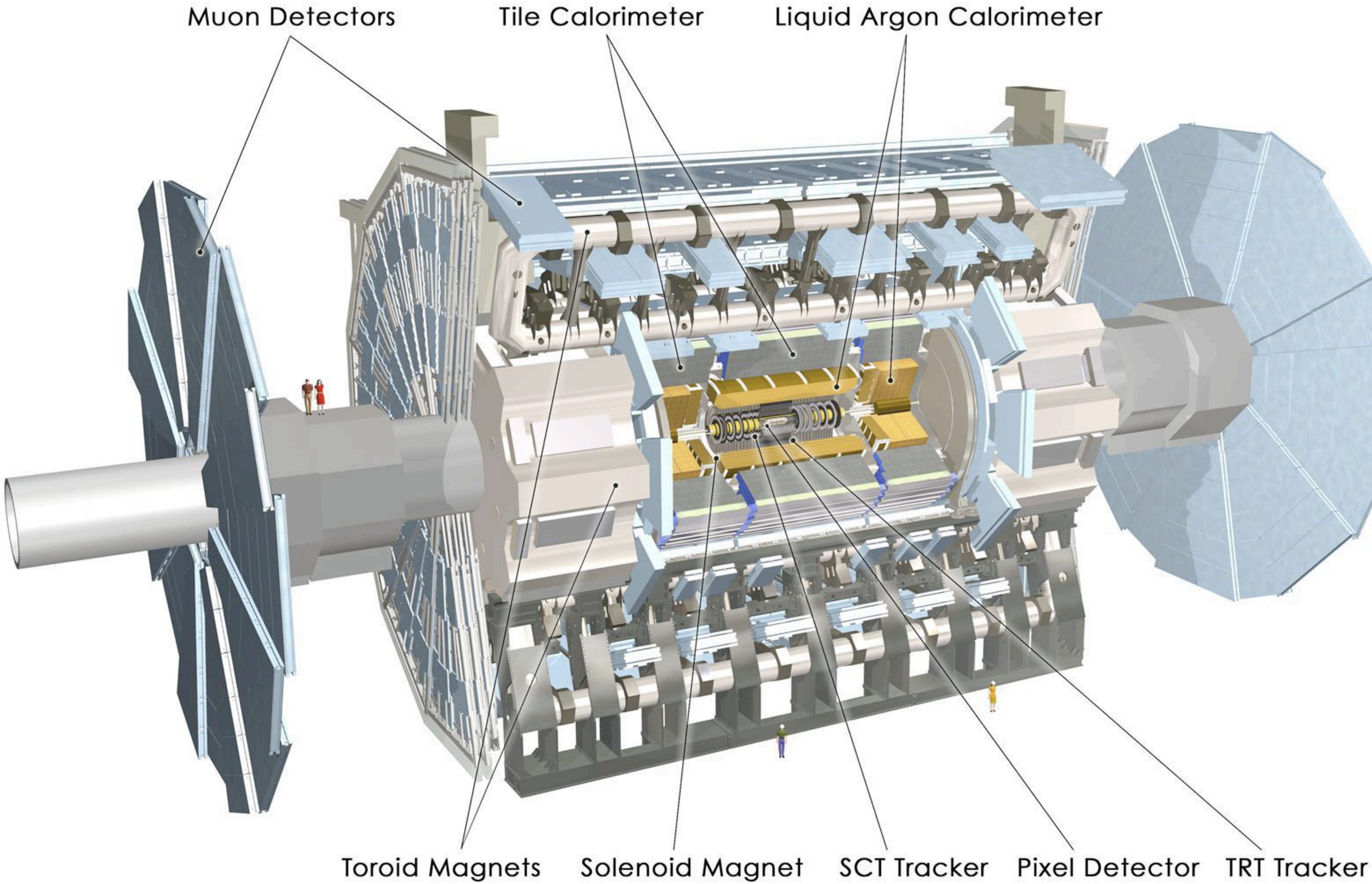
Construction from ~ 2000 till 2008 Operational in Sept 2008

From the construction phase of CMS: a delicate operation, YB0 emerging from the shaft into the underground experimental cavern, Feb. 28-th 2007



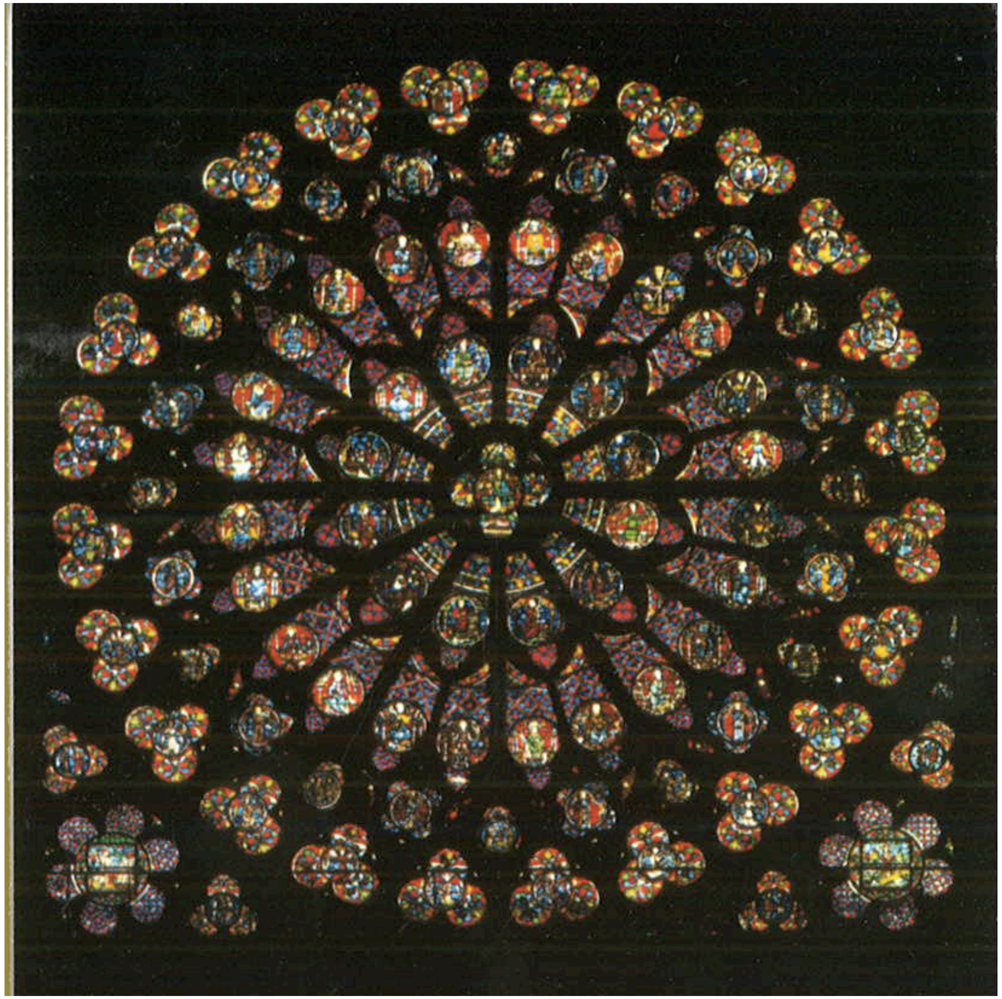
The central piece of CMS, of 2500 tons on four cables after a trip of 100 meters in 10 hours! Clearance of ~20 cm in the shaft!

ATLAS



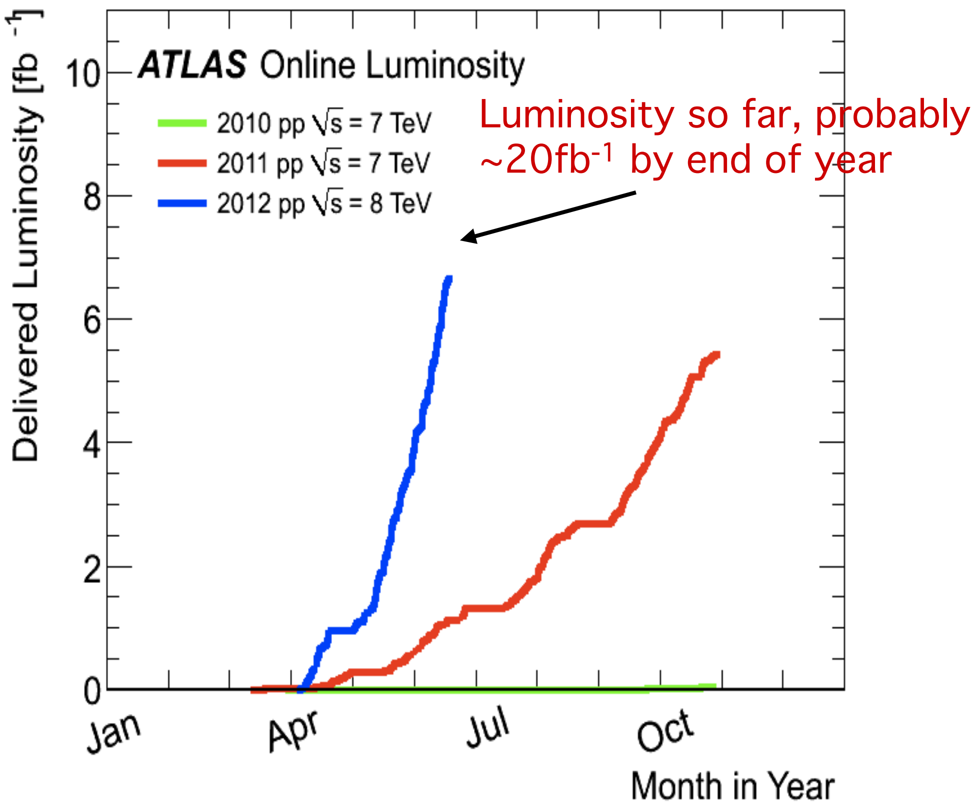
Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

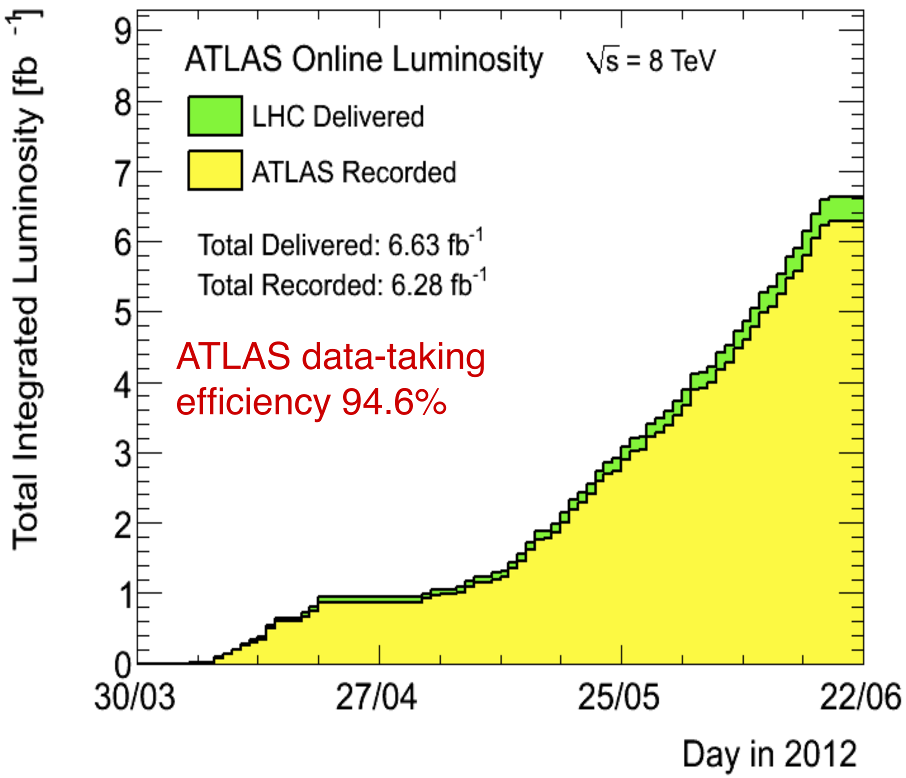
CMS - of quasi-celestial harmony and perfection!



enough of history and the past,
what is going on now?

Luminosity delivered to ATLAS last three years, √s = 7, 8 TeV, data taking efficiency in 2012,



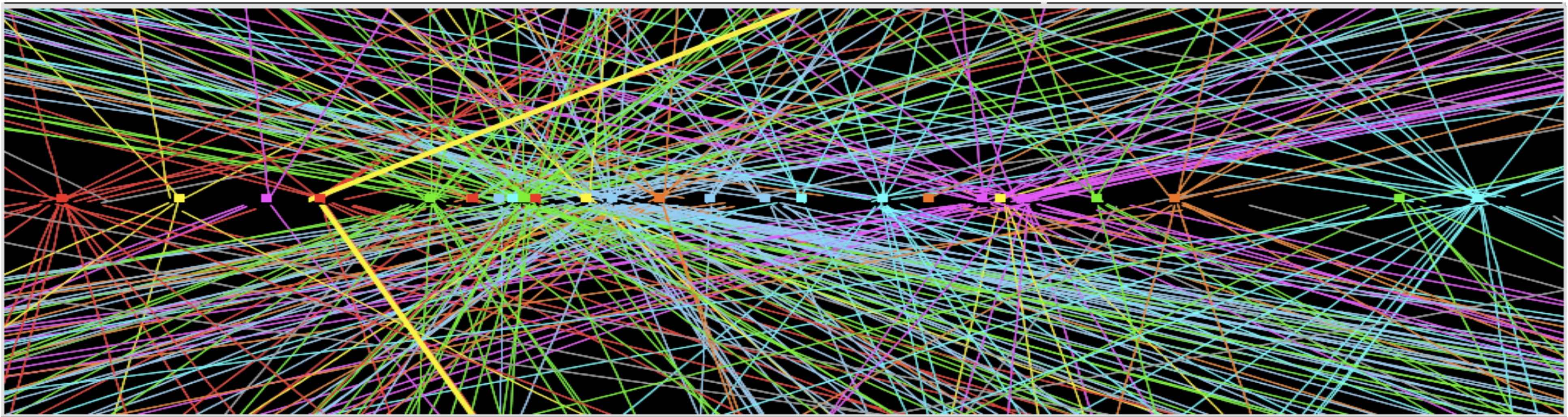


Peak luminosity in 2012 ~ 6.8 $x10^{33}$ $cm^{-2}s^{-1}$, up to 200 pb^{-1}/day and up to $1fb^{-1}$/week has been achieved, and down to 2.1 hours turn-around time!

ATLAS and CMS working at >~ 95% efficiency, remarkable after 3 years of running

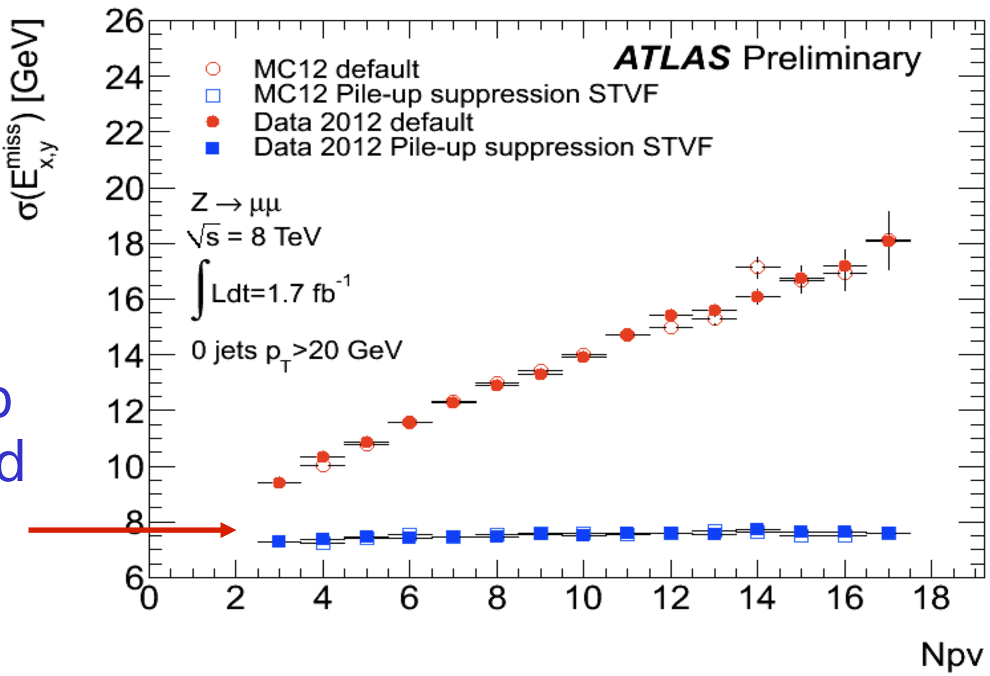
➡ The start of Long Shutdown-1 postponed by 2 months!
p-p running up to Dec.17th, proton-Pb running Jan.14 - Feb.11th.

LHC operation in 2012: pile-up, up to ~ 30 (50 nsec bunch spacing) - a major challenge for the trackers



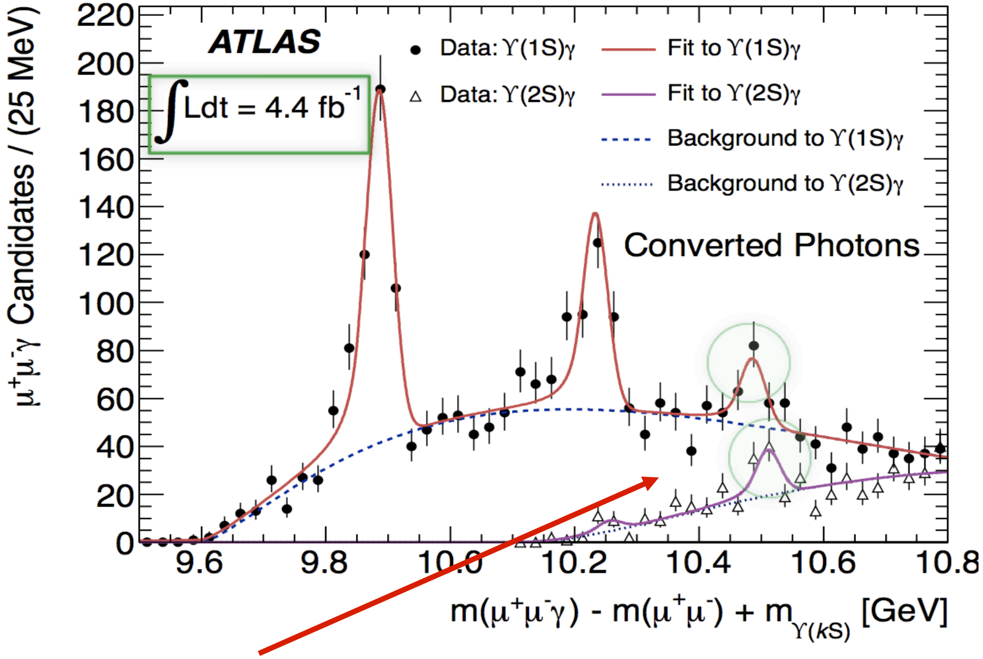
Z → μμ event from 2012 data in ATLAS with 25 reconstructed vertices

E_{T}-miss resolution vs pile-up In Z → μμ events before and after pile-up suppression using tracking information

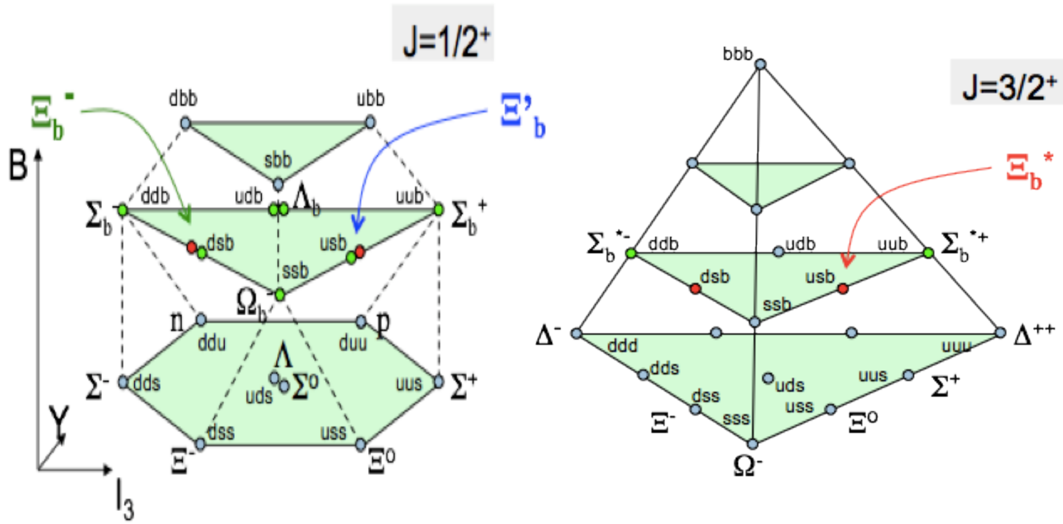


D. Denegri; Higgs Hunting, Orsay, July 2012

Some new particles have already been found at the LHC…..



SU4 20-plets



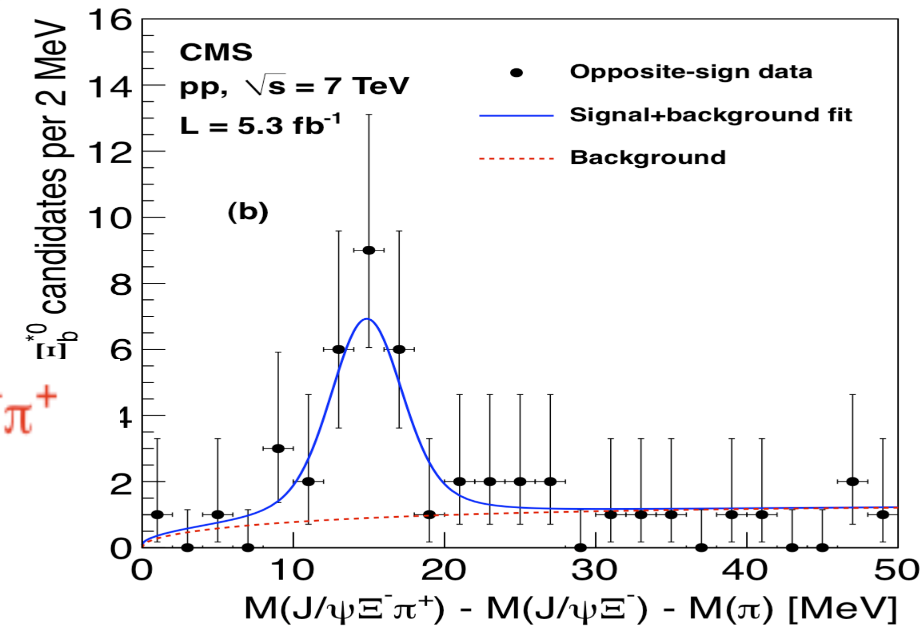
χ_b(3P) by ATLAS

Ξ^{*0}_b by CMS

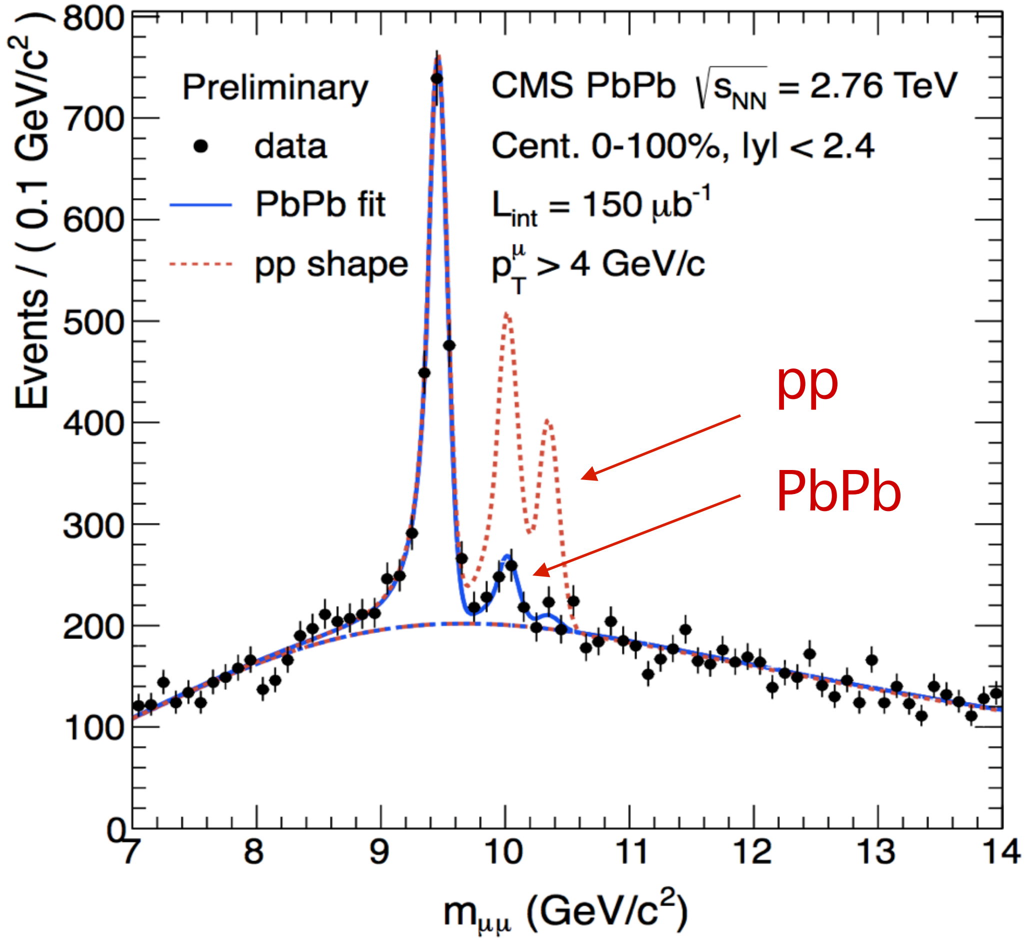
Charm sector cousin: $\Xi_c(2645)^0 \rightarrow \Xi_c^+ \pi^-$

$\Xi_b^{*0} \rightarrow \Xi_b^- \pi^+ \rightarrow \Xi^- J/\psi\, \pi^+ \rightarrow \Lambda \pi^- \mu^+ \mu^- \pi^+ \rightarrow p^+ \pi^- \pi^- \mu^+ \mu^- \pi^+$

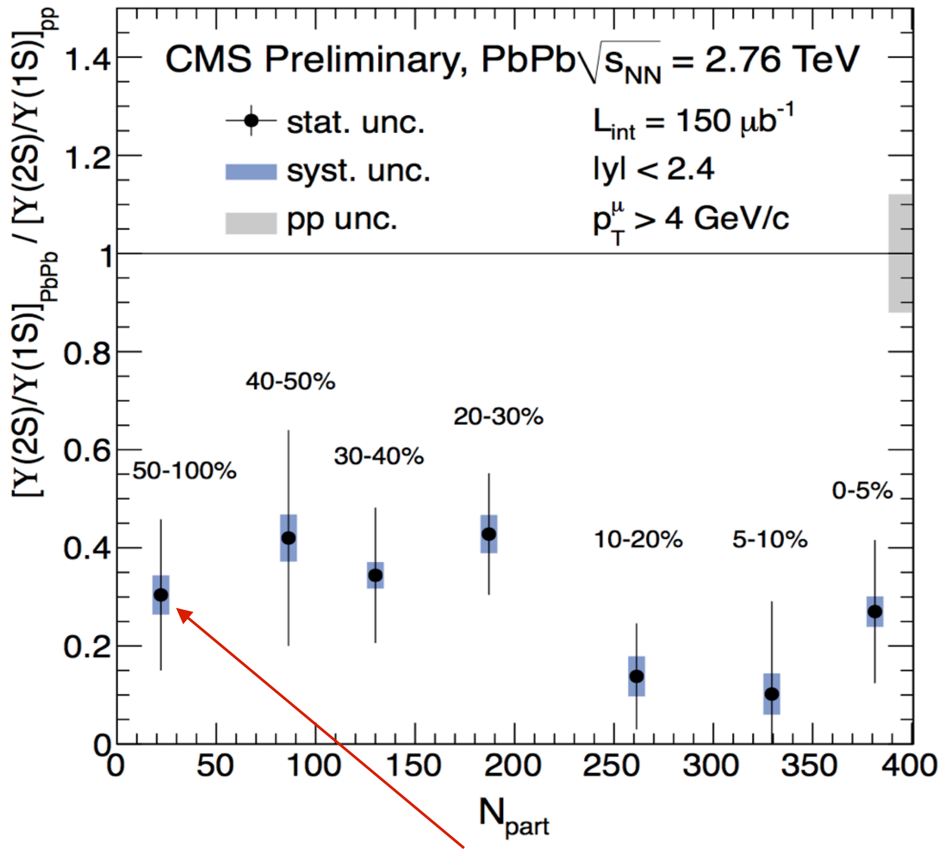
Expected $Q(\Xi_b^{*0}) = M(\Xi_b^{*0}) - M(\Xi_b^-) - M(\pi^+)$ ~ 11-29 MeV



and some are melting away……
Ypsilons suppression in Pb-Pb collisions, CMS



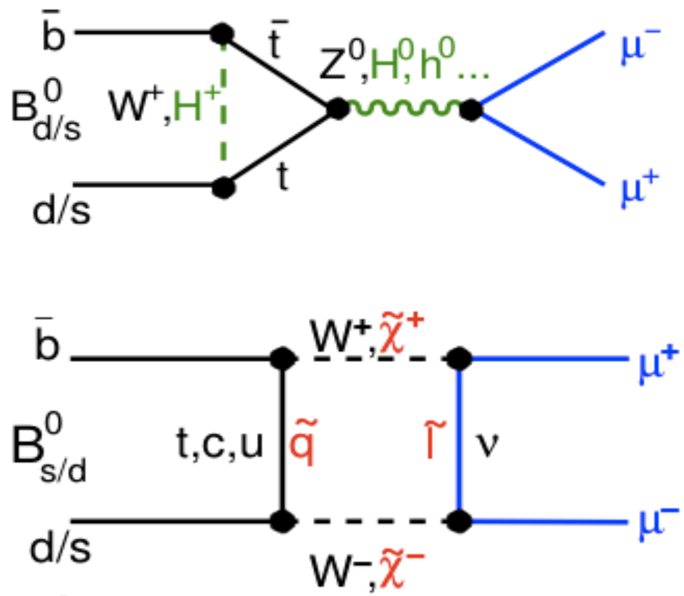
Sequential suppression of Y states
In Pb-Pb



To study onset of suppression of Y states either much more statistics needed or collisions with lighter nuclei…..

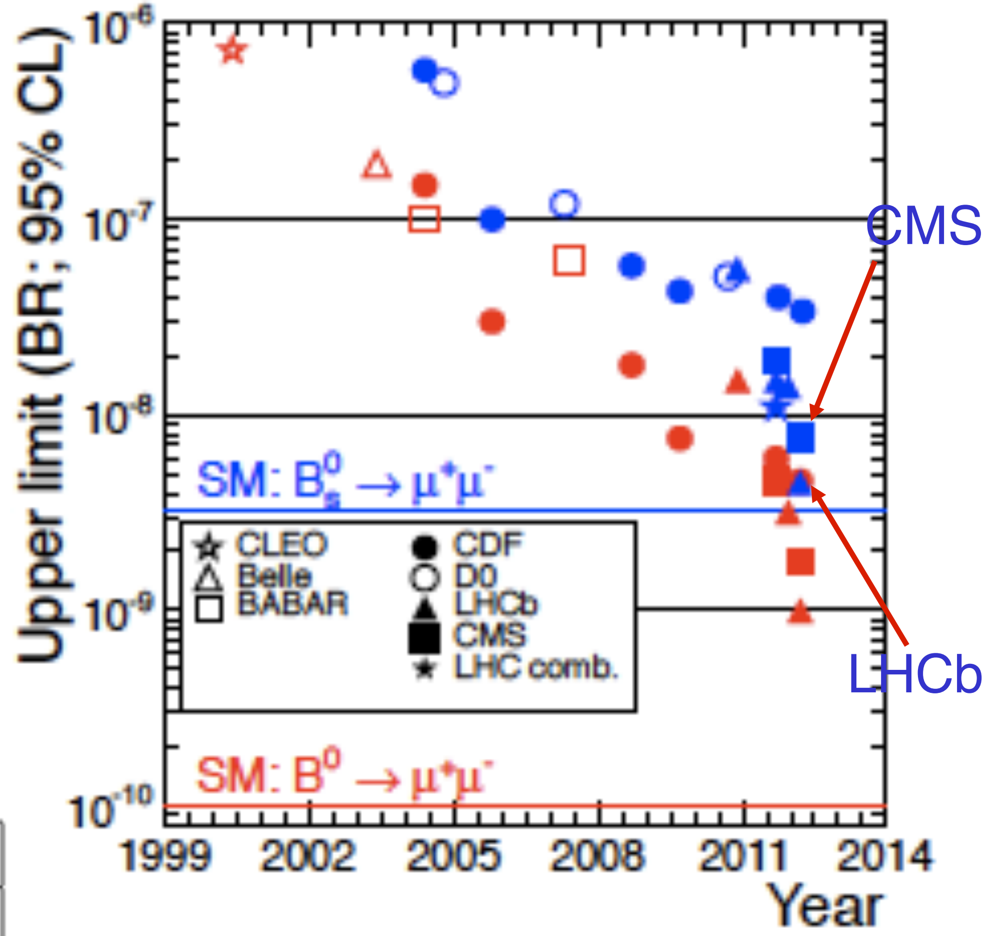
Some should appear soon…
Search for rare decays $B^0_{d,s} \to \mu^+\mu^-$

Indirect search for new physics via rare decays, $B_s \to \mu^+\mu^-$



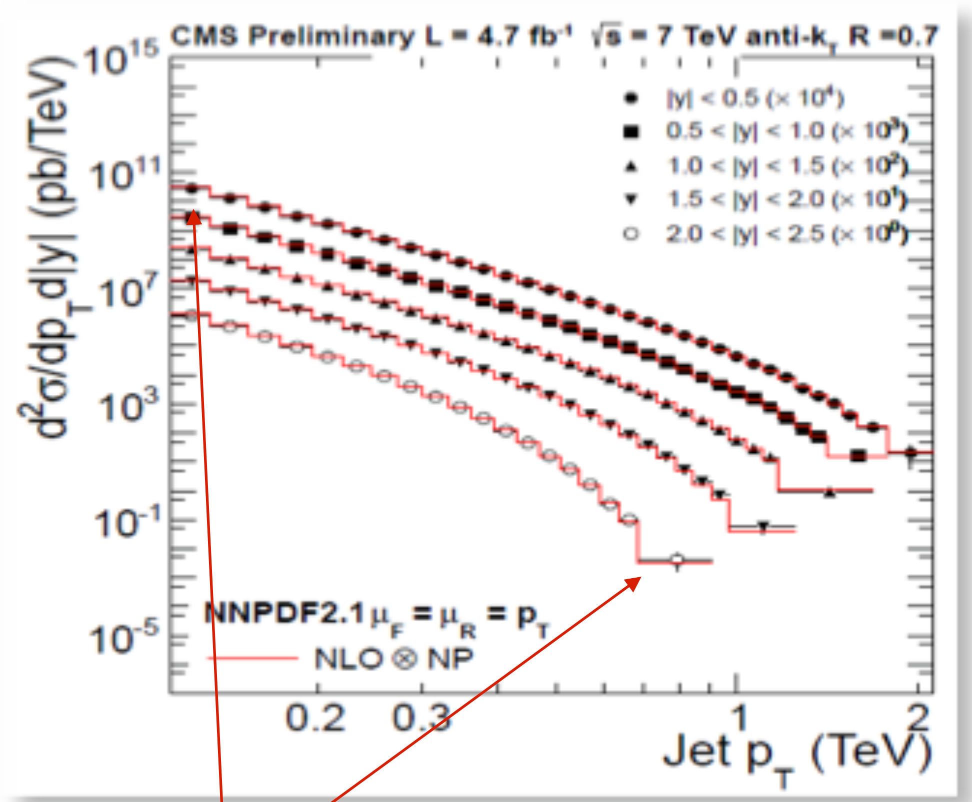
CMS values 2011 data, cut based analysis:

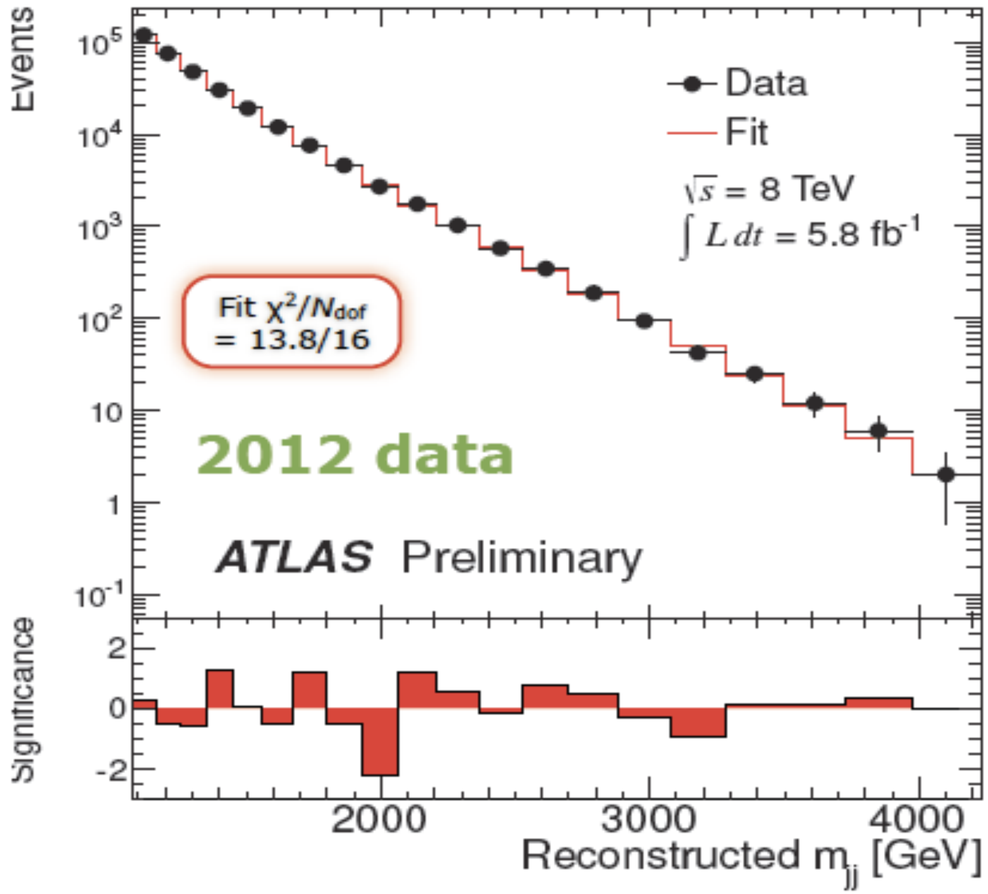
upper limit (95%CL)	observed	expected
$\mathcal{B}(B^0_s \to \mu^+\mu^-)$	7.7×10^{-9}	8.4×10^{-9}
$\mathcal{B}(B^0 \to \mu^+\mu^-)$	1.8×10^{-9}	1.6×10^{-9}



MVA-based analysis should bring improvement by~25%

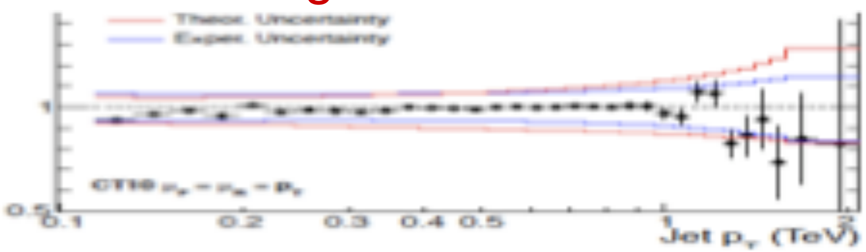
QCD, inclusive jets and dijets





18 < p_T < 1900 GeV; |η| < 2.5

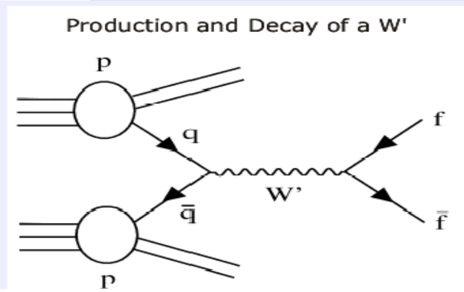
13 orders of magnitude variation in cross section!!



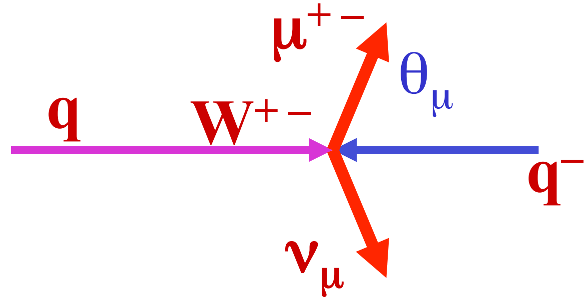
Limits: m(q*) > 3.66 TeV;
L (contact interaction) > 7.6 TeV

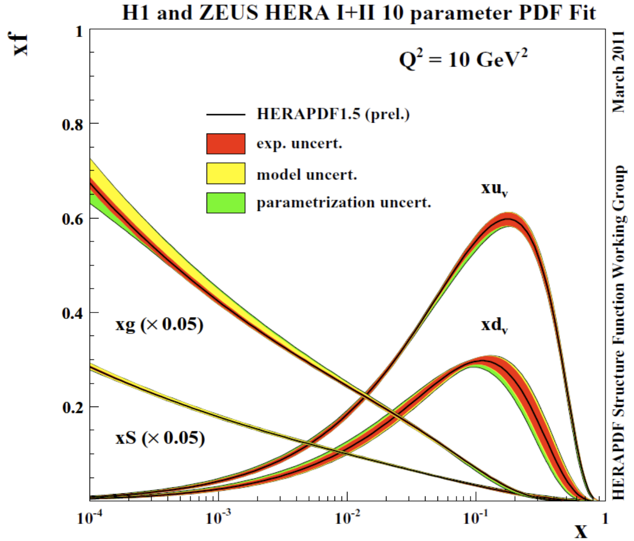
Inclusive jet and dijets. 2-4% JES.
Constrains gluon PDF up to x = 0.6

EWK physics, W and Z at forward rapidities, LHCb complementary to ATLAS and CMS



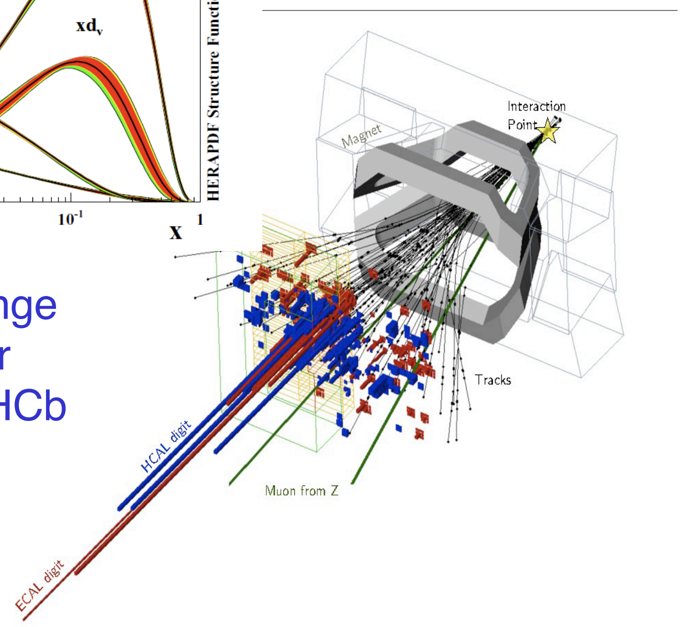
W rapidity cannot be measured but $W^{+-} \rightarrow$ lepton$^{+-}\nu$ charge asymmetry vs. η can, and is highly constraining for structure functions

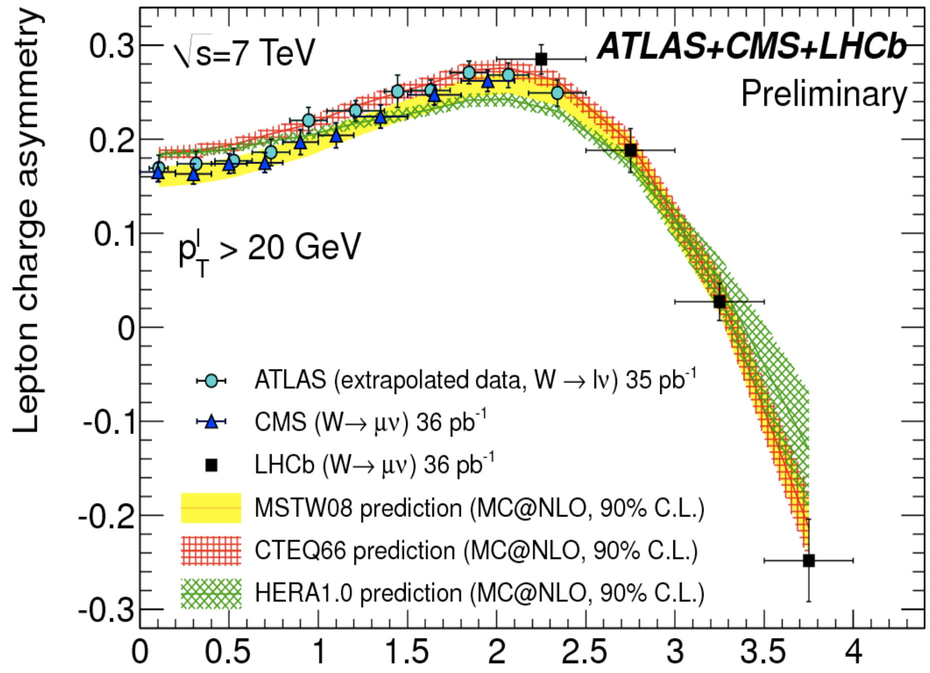




$$A_W = \frac{d\sigma/d\eta(\ell^+) - d\sigma/d\eta(\ell^-)}{d\sigma/d\eta(\ell^+) + d\sigma/d\eta(\ell^-)}$$

charge asymmetry vs. η

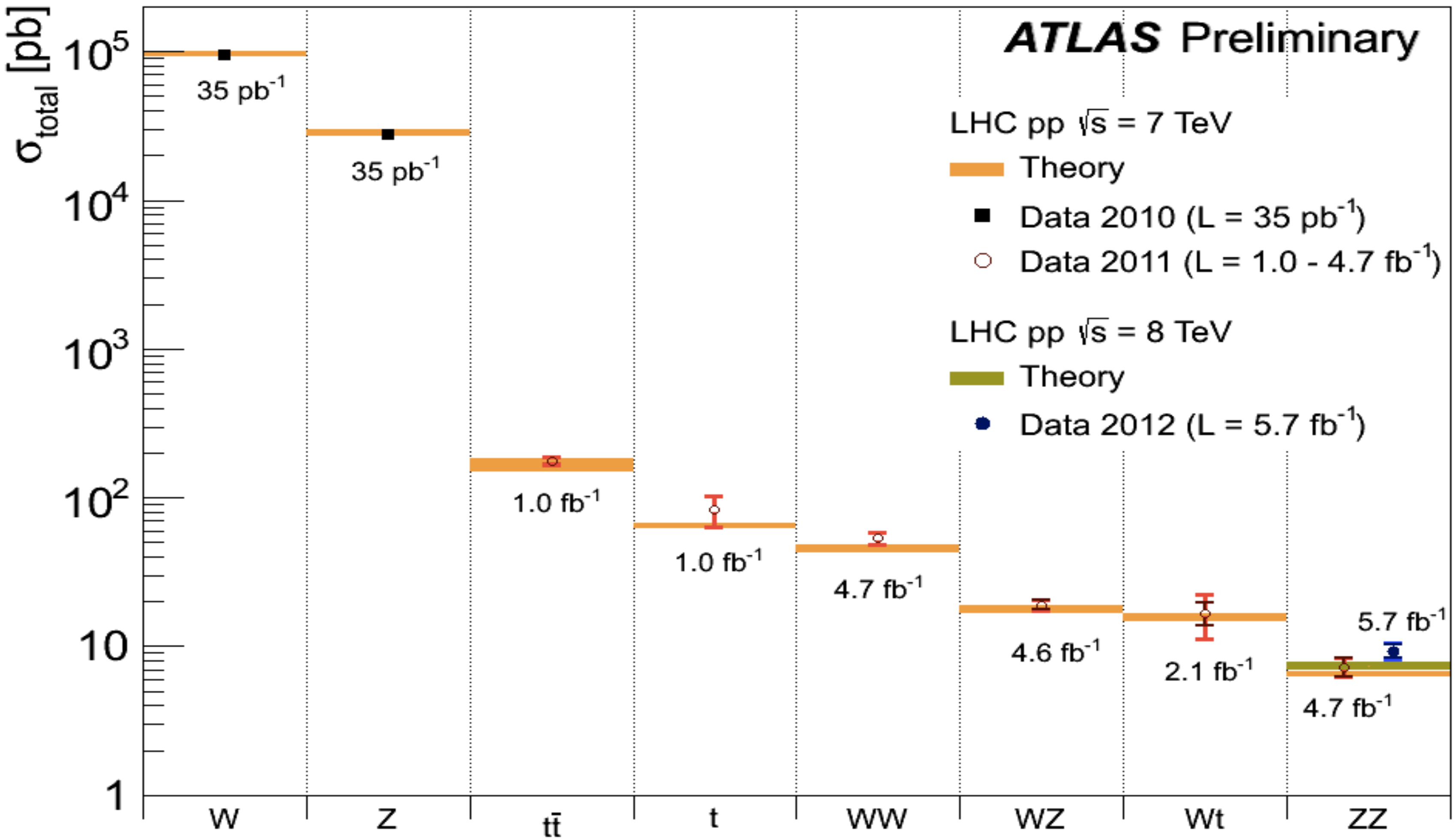




$\eta_\mu = -\ln tg(\theta_\mu/2)$

Unique kinematic range down to $x = 8\ 10^{-6}$ for W/Z production at LHCb

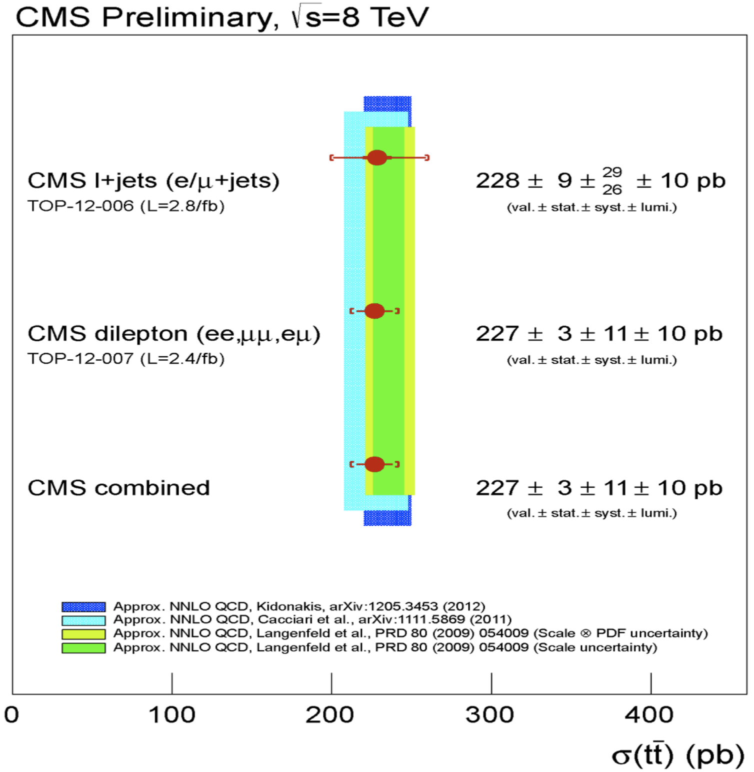
Overview of EWK and top physics

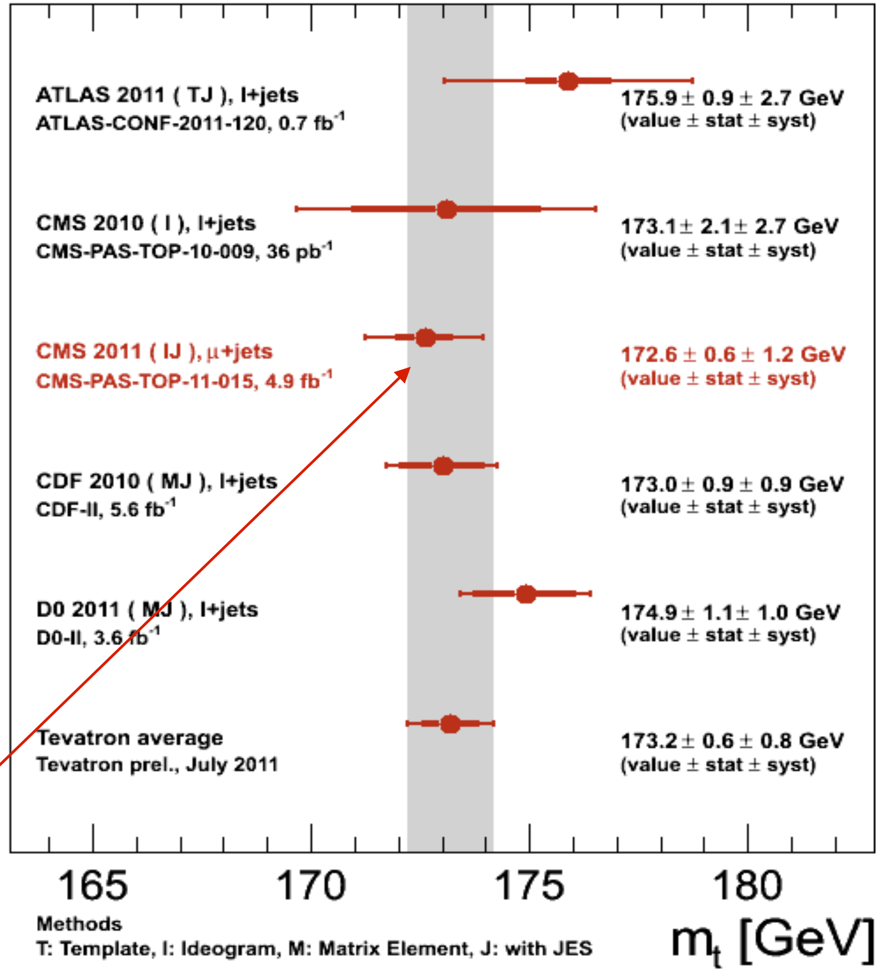


These channels are important on their own right and must be well understood as most of these processes are backgrounds to Higgs searches

Top at the LHC, cross section and mass, an important issue….

$\sigma(t\bar{t})$





The LHC cought-up with the Tevatron:

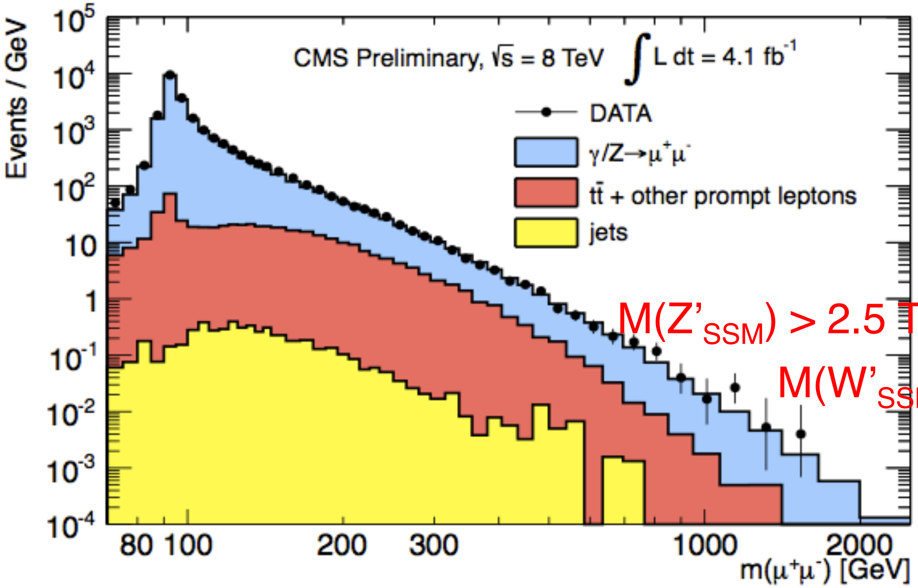
CMS average : 172.6 ± 0.4 ± 1.2 GeV

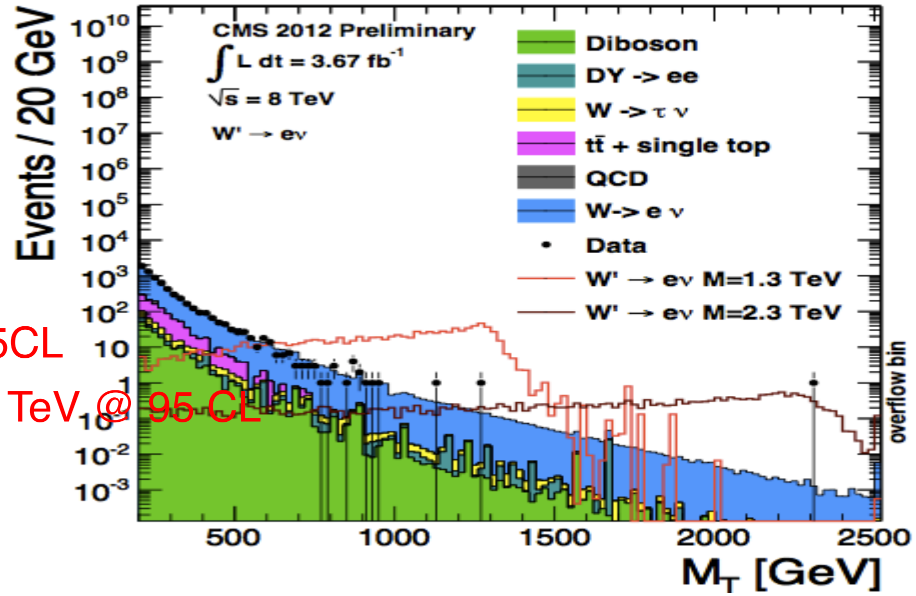
Tevatron average: 173.2 ± 0.6 ± 0.8 GeV

➡ A significant improvement expected with the channel $tt \to bWbW \to bl\nu bqq$ with $b \to \psi + X$ with $\psi \to \mu^+\mu^-$ but this requires >~ 100 - 300 fb^{-1}

vacuum stability questions depend sensitively on Δm_{top} and Δm_H

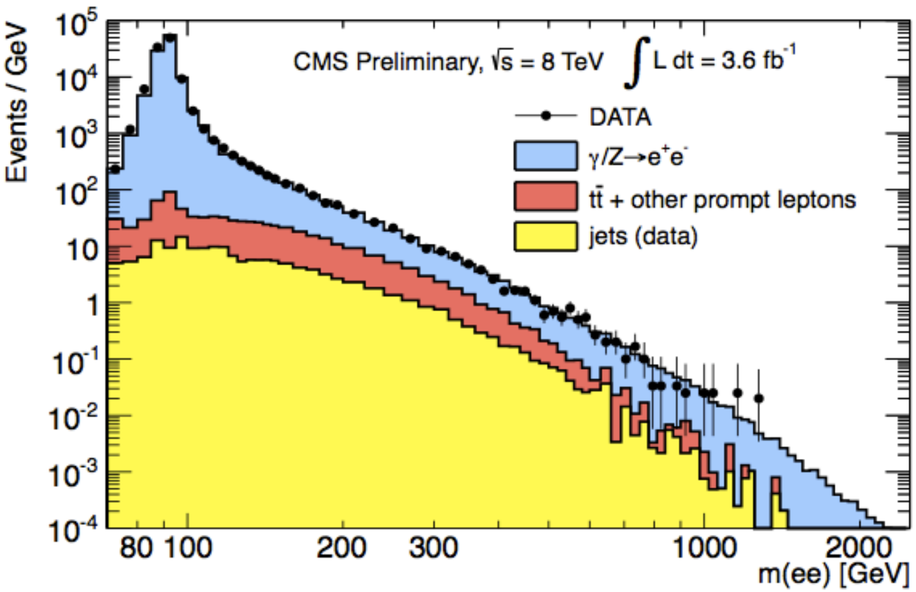
Z'→ l^+l^-, W'→ l+ν searches, √s = 8 TeV, G_{RS} → γγ

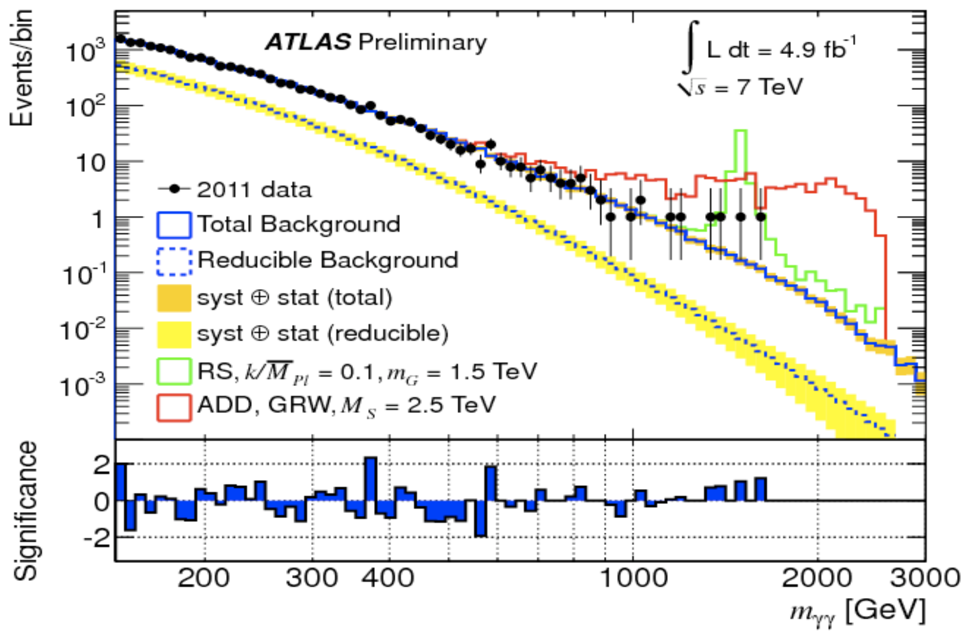




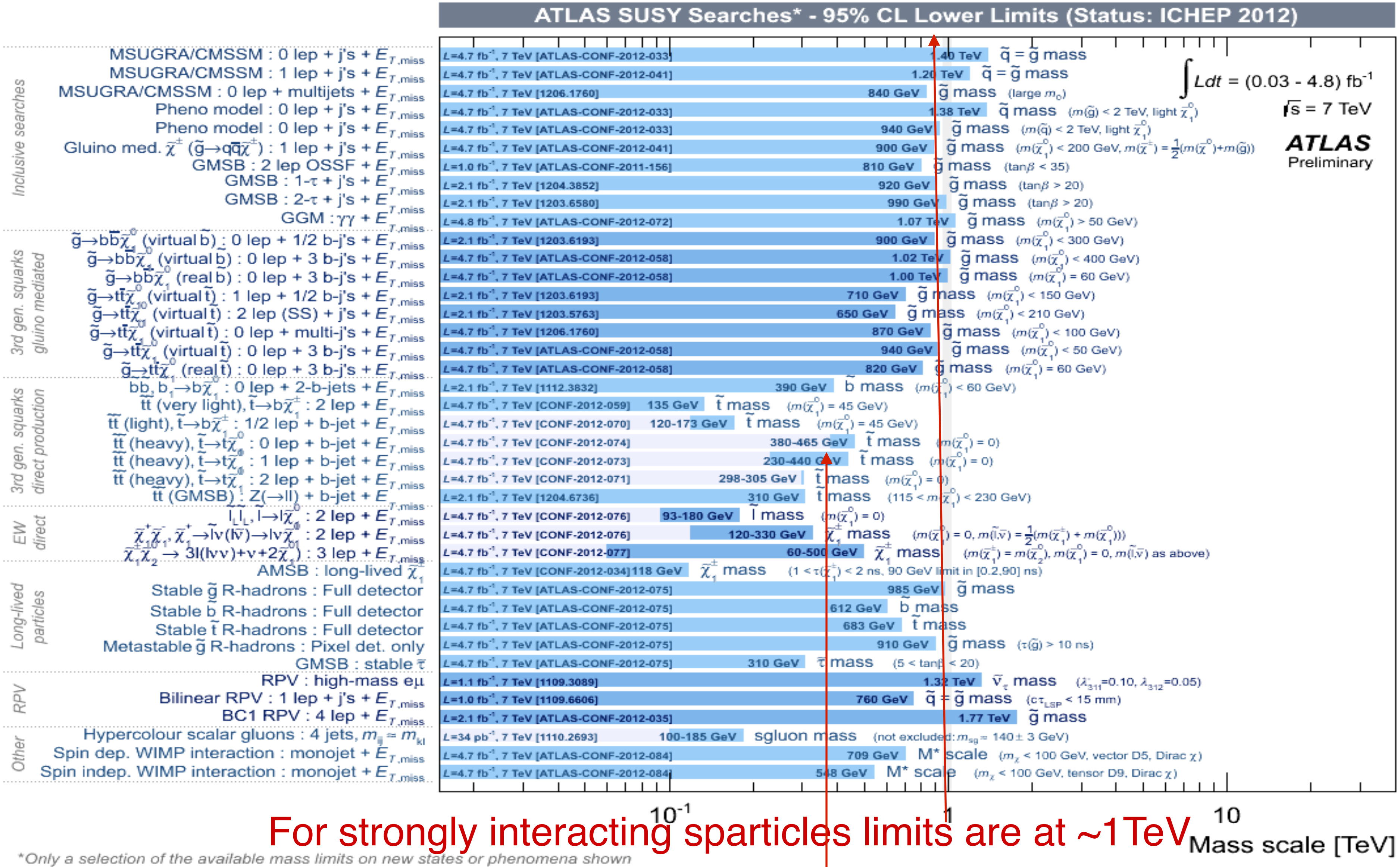
M(Z'$_{SSM}$) > 2.5 TeV @95CL

M(W'$_{SSM}$) > 2.8 TeV @ 95 CL





Large variety of SUSY searches, for ex. status in ATLAS. June 2012. ~ 5 fb^{-1}

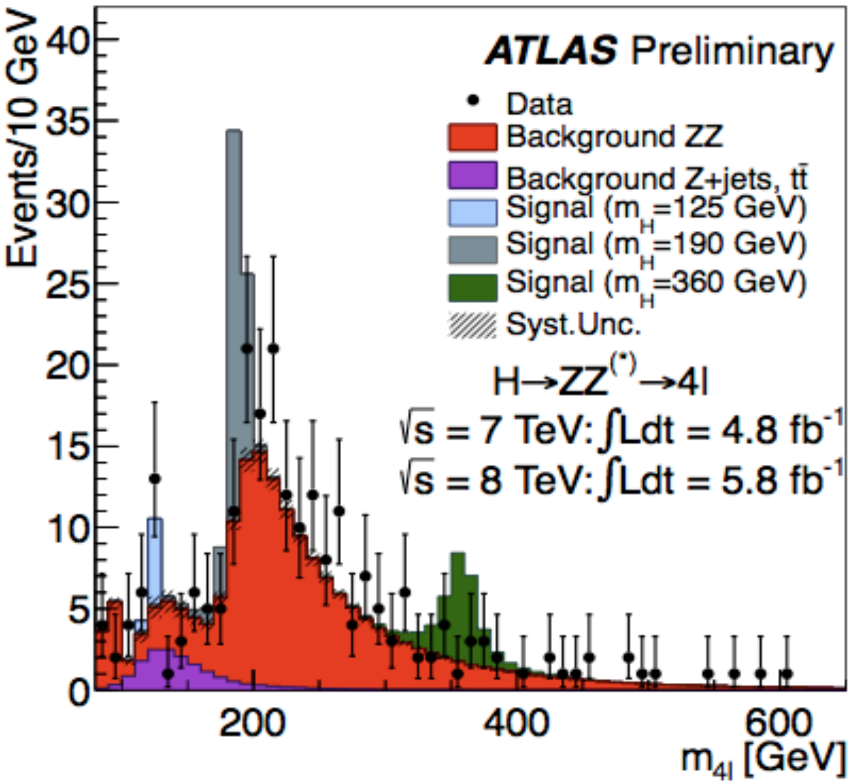


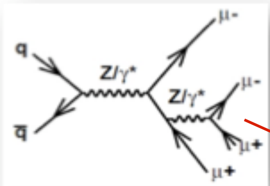
For strongly interacting sparticles limits are at ~1TeV

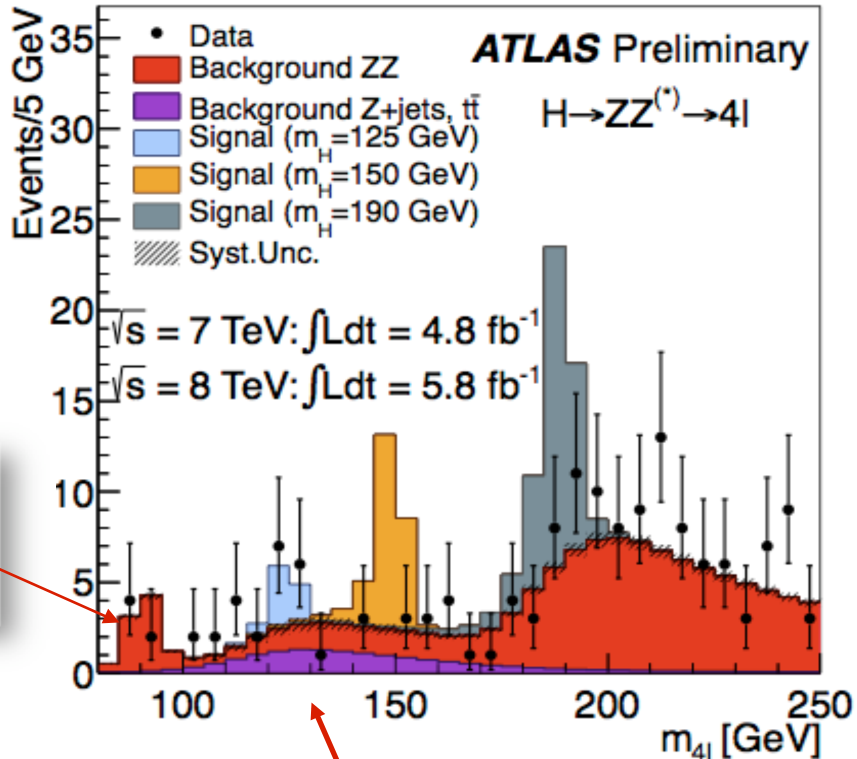
For stops it is ~300-400GeV

the Higgs…..

H → ZZ, ZZ*→ 4 leptons search in ATLAS, final selection, 2011 + 2012 data ~ 10.6 fb^{-1}







m(4l) > 160 GeV (largely ZZ bkgd):

147 ± 11 events expected

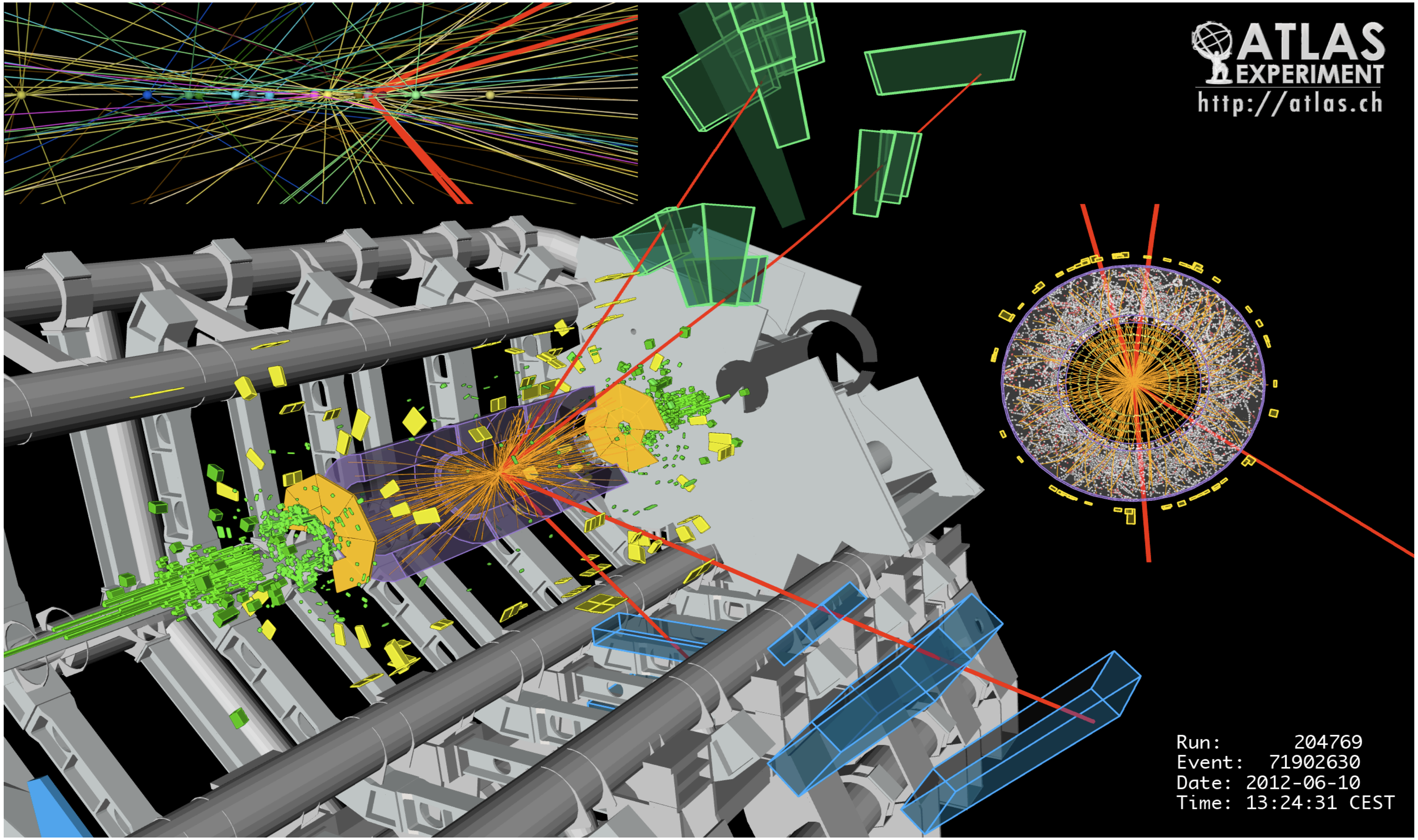
191 observed

~ 1.3 times more ZZ data than the SM prediction

measured σ(ZZ) = 9.3 ± 1.2 pb

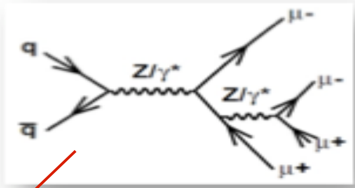
SM (NLO) σ(ZZ) = 7.4± 0.4 pb

$H \rightarrow \mu\mu\mu\mu$ candidate in ATLAS, $\sqrt{s}$ = 8TeV, with $m(4\mu)$ = 125.1GeV

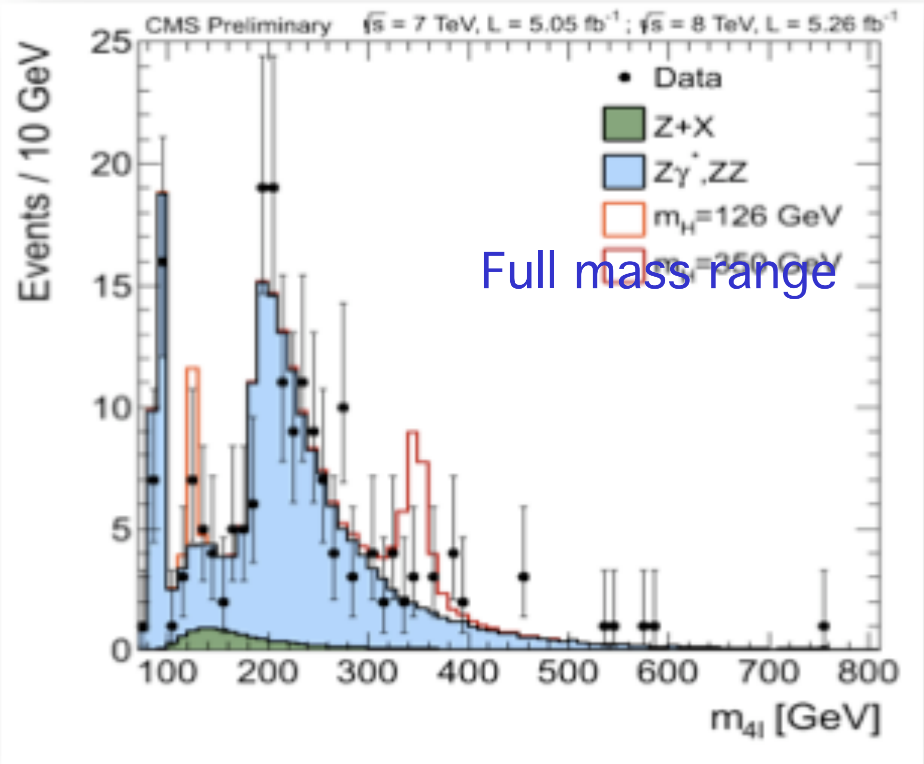


p_T (muons)= 36.1, 47.5, 26.4, 71 .7 GeV, m_{12}= 86.3 GeV, m_{34}= 31.6 GeV
15 reconstructed vertices

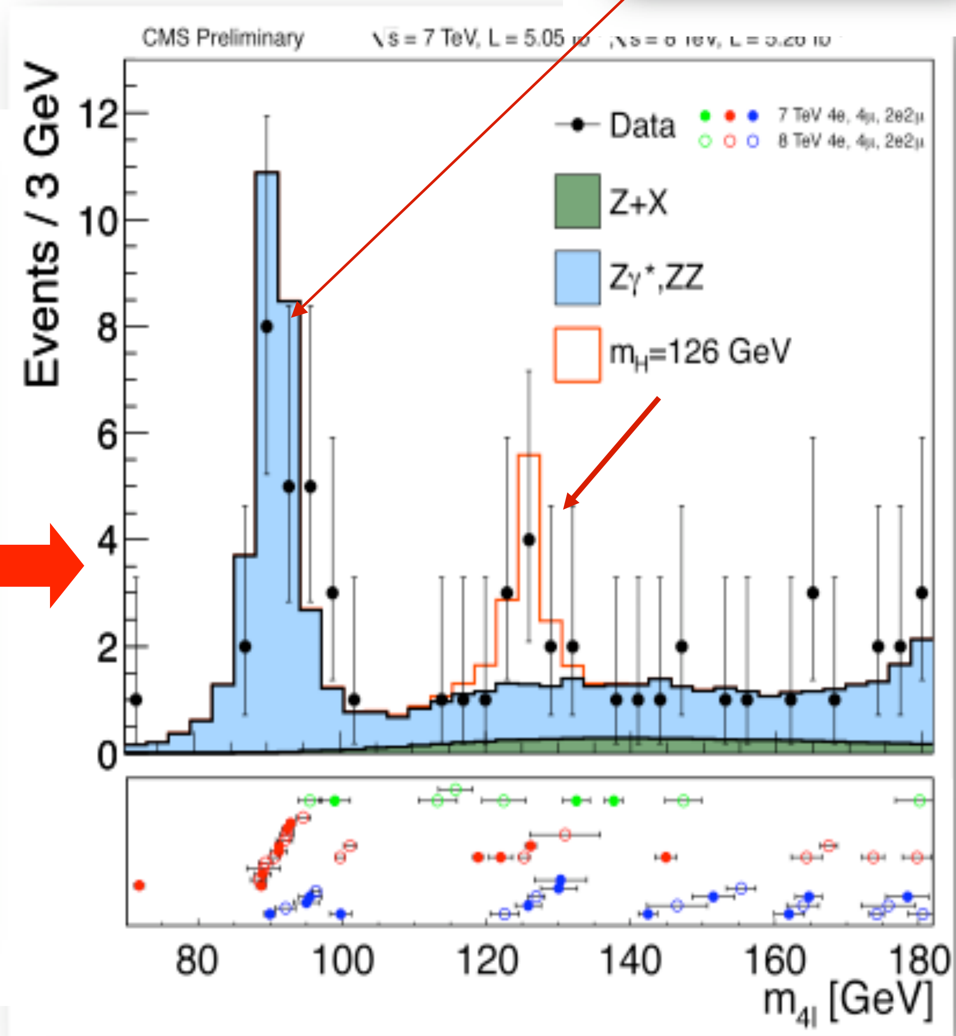
H → ZZ, ZZ*→ 4 leptons search in CMS, 2011 + 2012 data, ~ 10.3 fb^{-1}



164 events expected in 100-800 GeV
172 events observed in 100-800 GeV

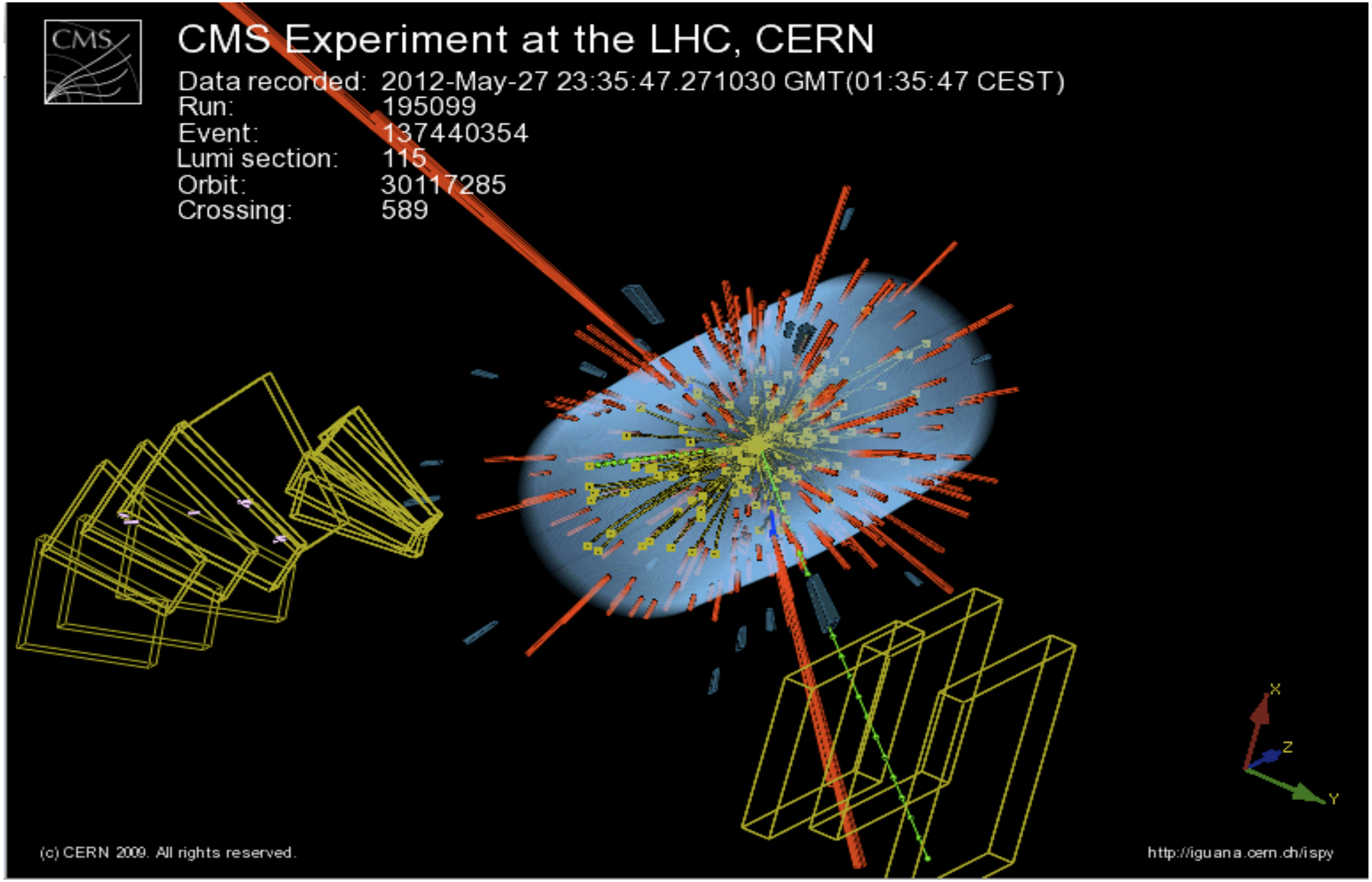


Full mass range

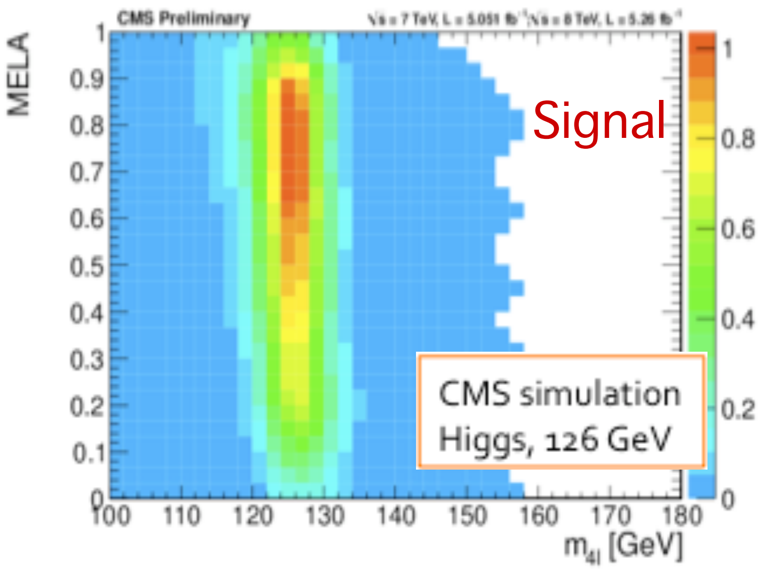


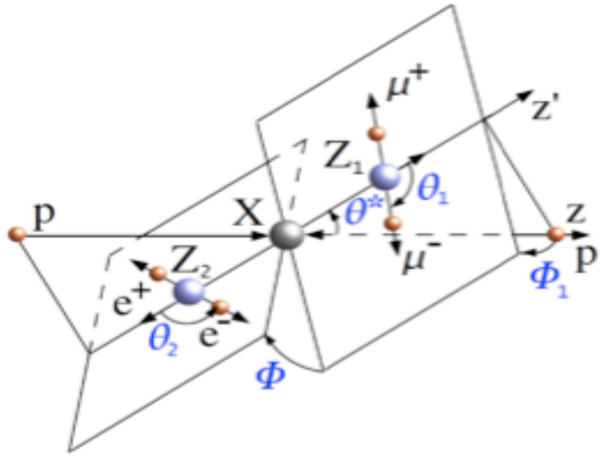
event by event error on mass

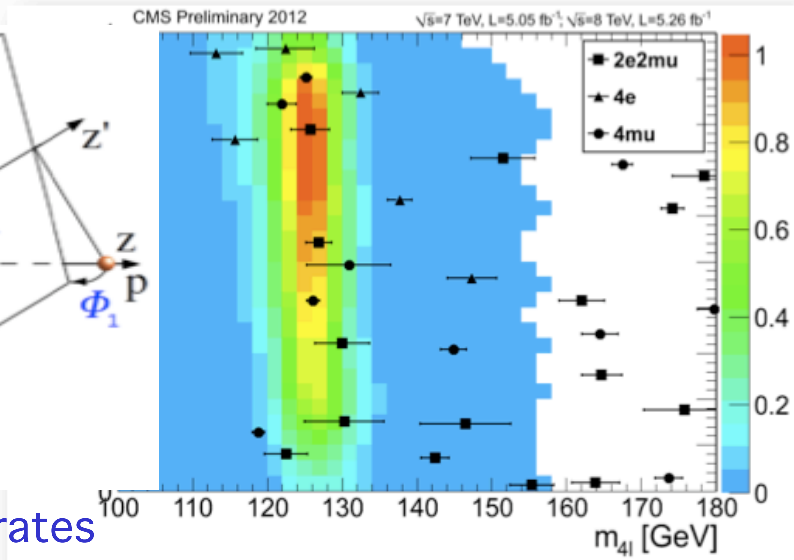
H → ZZ → eeμμ candidate event in CMS, √s = 8 TeV, data of June 2012



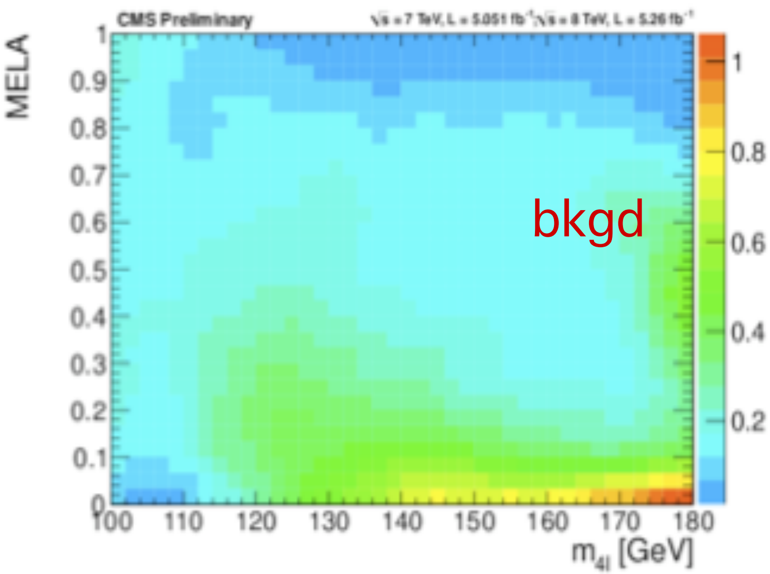
H → ZZ, ZZ*→ 4 leptons search in CMS, 2011 + 2012 data, ~10.3 fb^{-1}, angular analysis, MELA

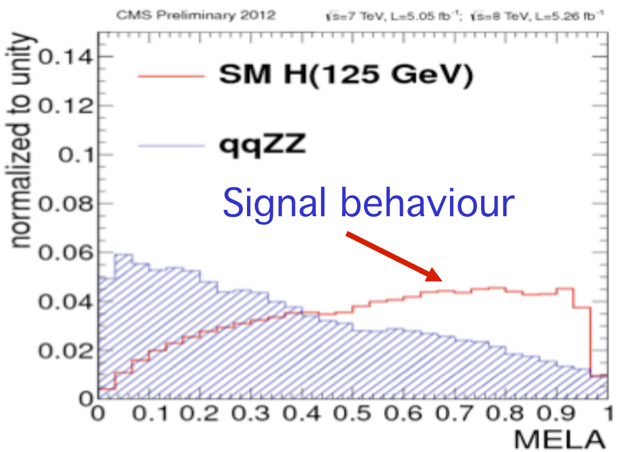


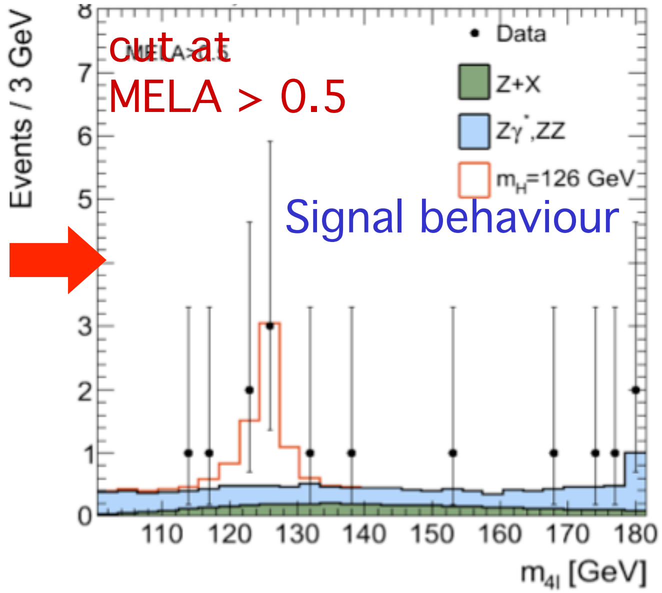




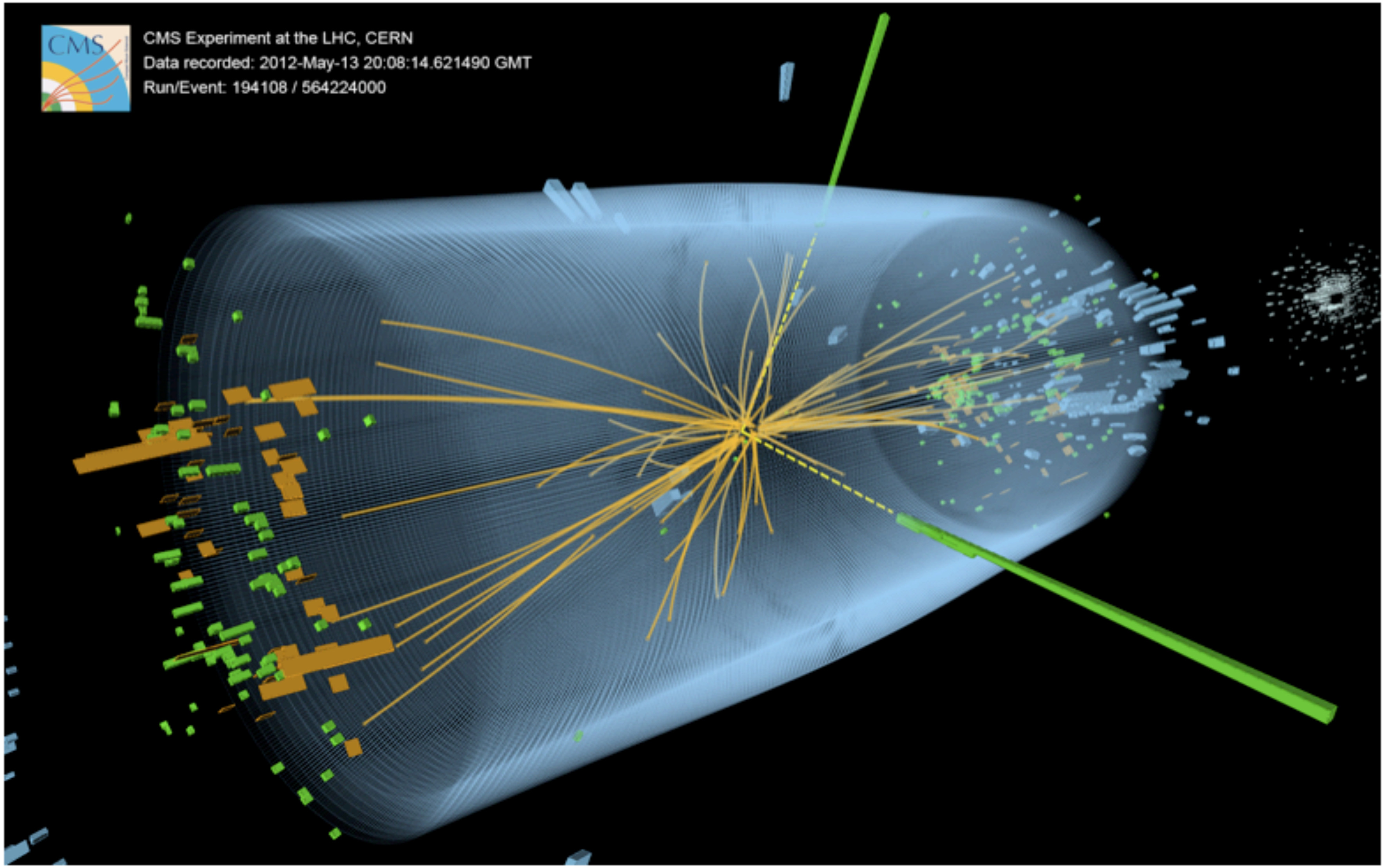
MELA variable incorporates information on the two masses Z$_1$ and Z$_2$ and 5 angles





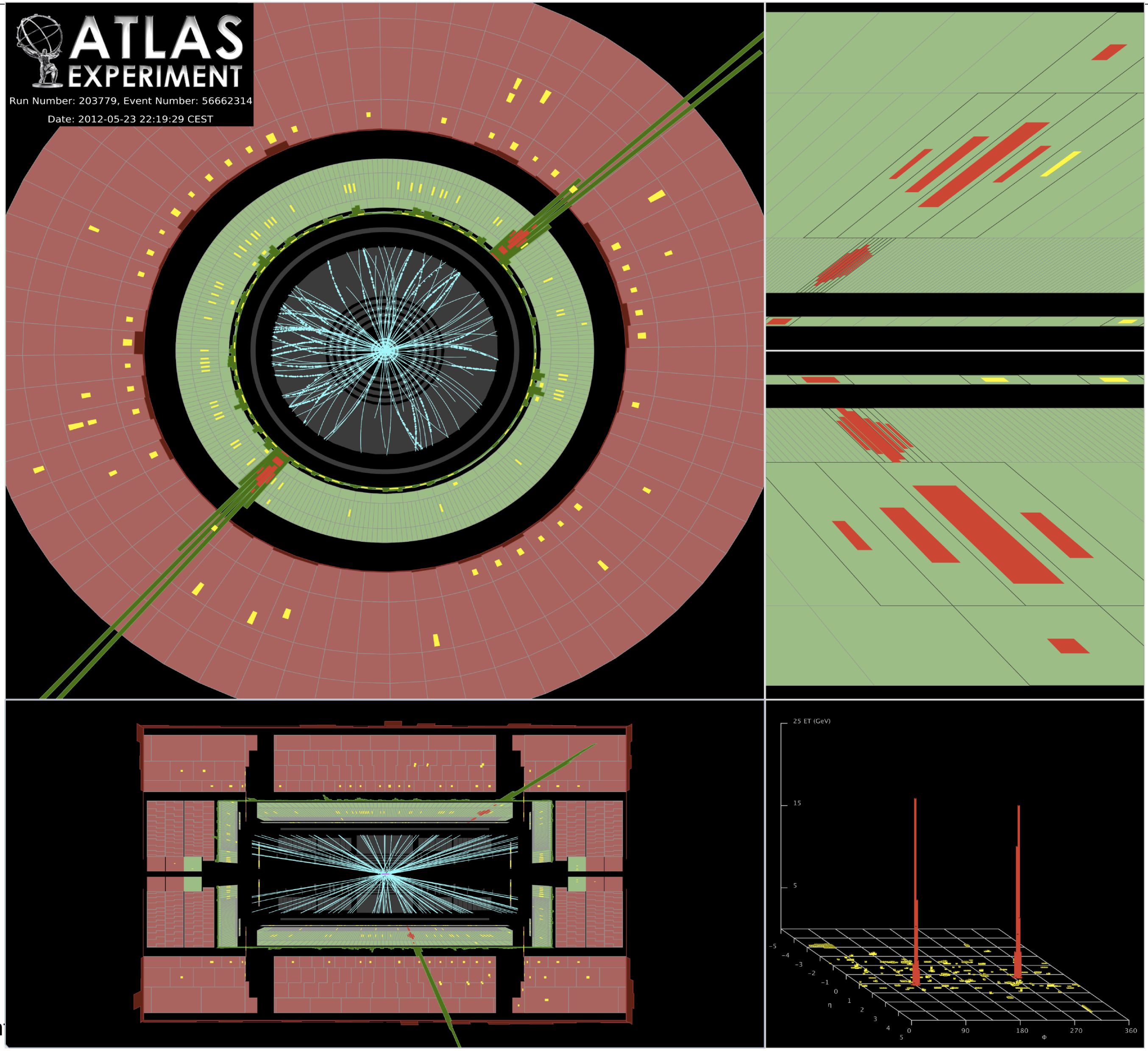


$H \rightarrow \gamma\gamma$ candidate in CMS

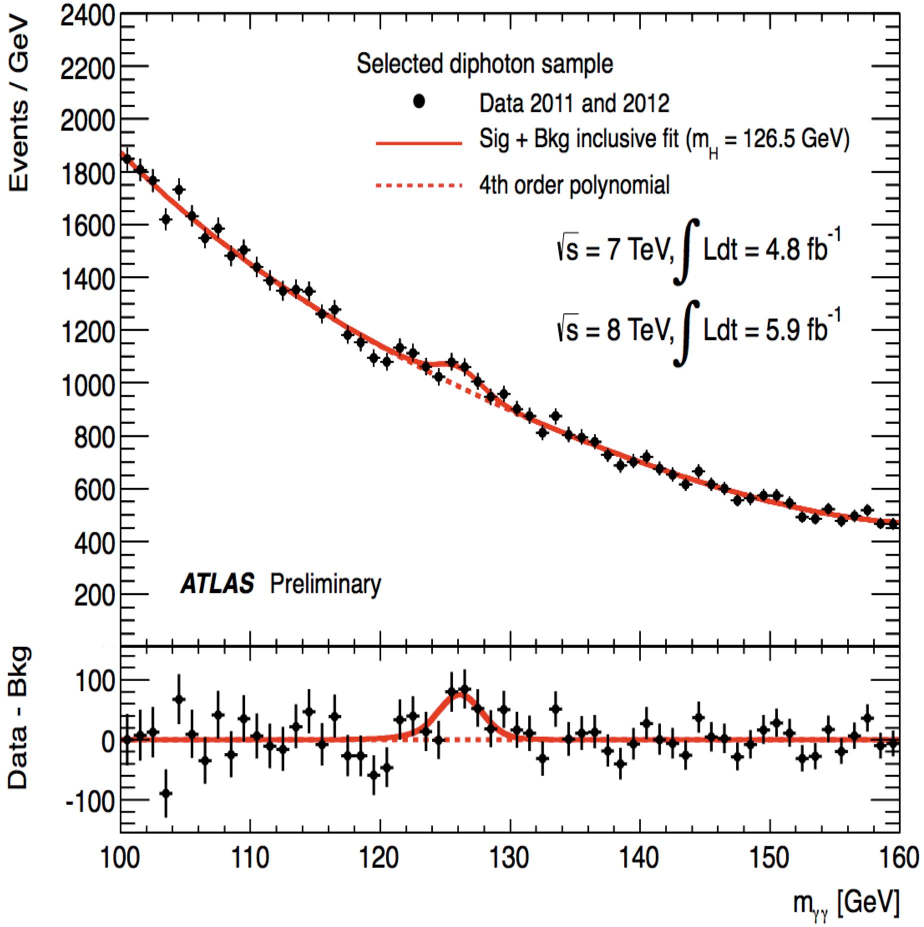


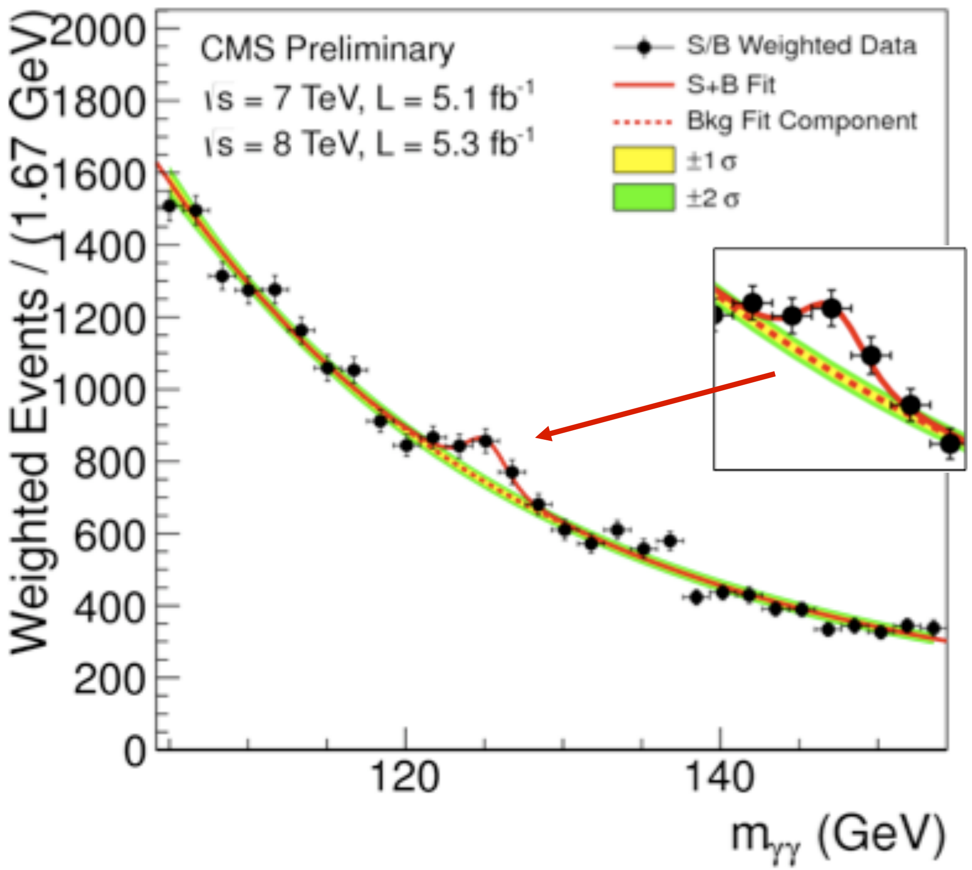
$$m^2_{\gamma\gamma} = 2\,E_1E_2\,(1 - \cos\theta_{12})$$

$H \rightarrow \gamma\gamma$ candidate in ATLAS, $\sqrt{s}$ = 8TeV, May 2012



H → γγ in ATLAS and CMS





Expected: 110-139.5 GeV
Excluded (95% CL):
112-122.5 GeV, 132-143 GeV

Minimum local p-value at 125 GeV with a local significance of 4.1 σ

prospects, near future at least

by the end of 2012 we should have ~ 25 - 30 fb^{-1}

…….medium term prospects

after LTS-1 (2013/14) we should be getting >~ 50fb^{-1}/year,

after LTS-2 (2017/18) >~100fb^{-1}/year

The obvious questions now: is the object seen the Higgs?

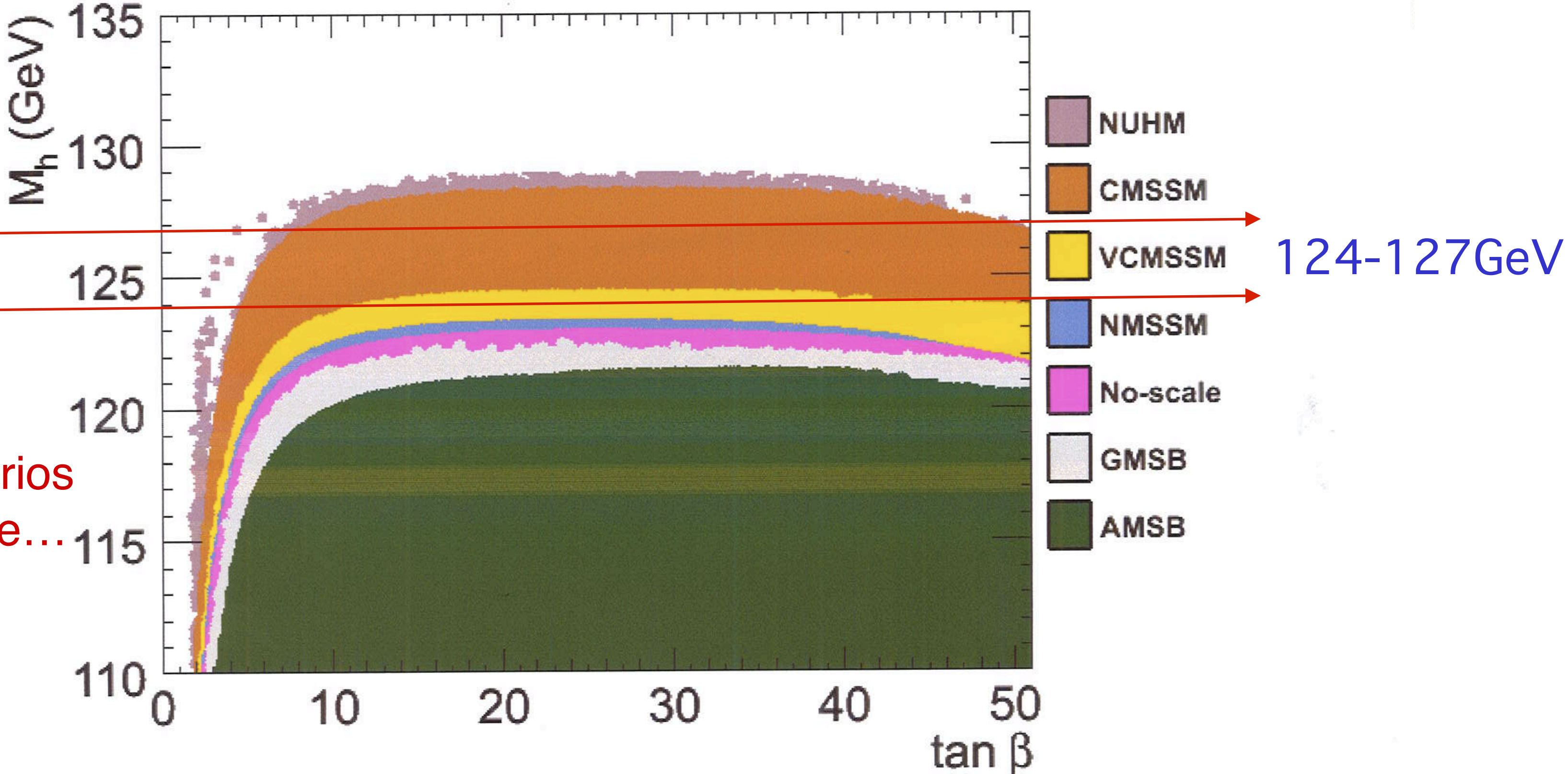
- mass, J^P, more BR's, more precisely
- is it the SM, the SUSY lightest, a composite etc??

with > ~` 300 - 500 fb^{-1} look for new modes

($H_{SM} \rightarrow Z\gamma$, $H_{SM} \rightarrow \mu^+\mu^-$ at known Higgs mass)

with > ~1000 fb^{-1} look for HHH couplings…..

Implications for MSSM of a 125 GeV Higgs - the mass really matters, filters out possible models…

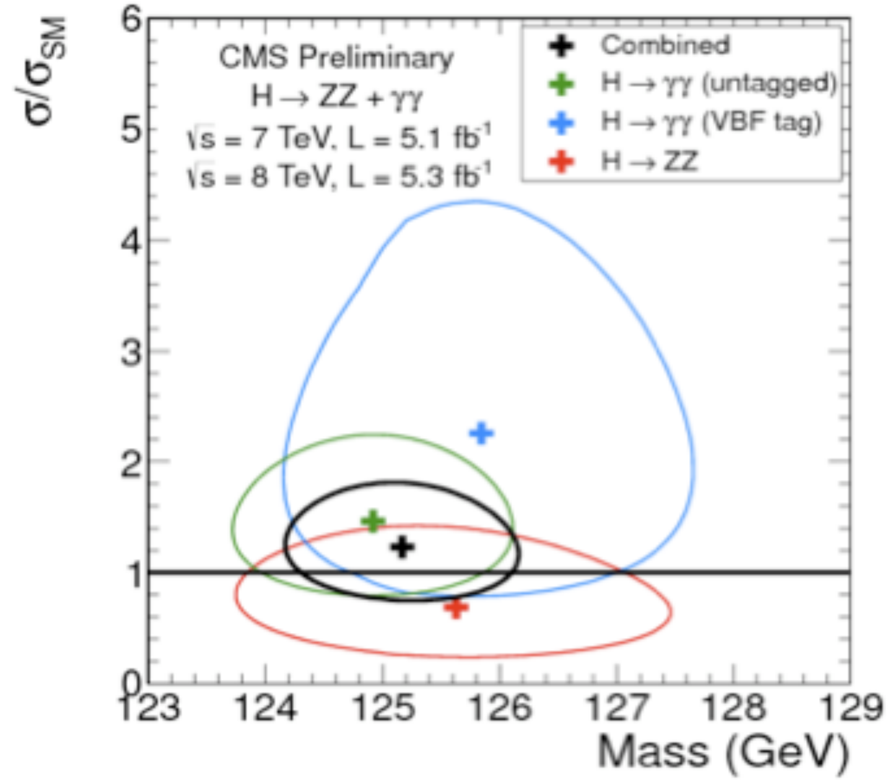


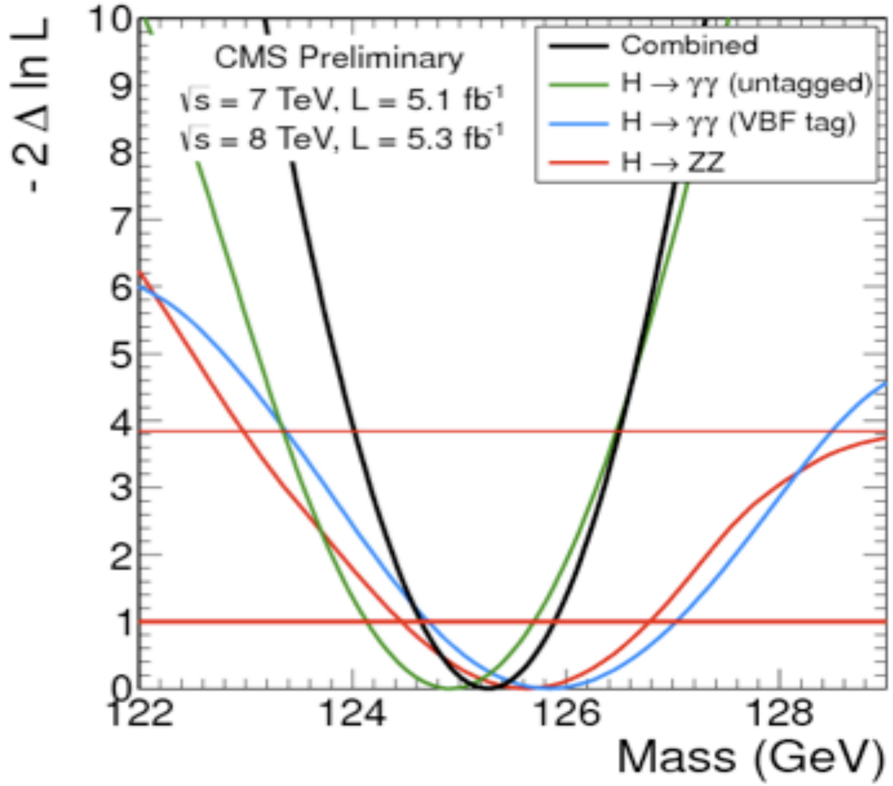
Some SUSY scenarios are clearly in trouble…

model	amsb	gmsb	sugra	noscale	cnmssm	vcmssm	nuhm
M_h^{max}	120	121	128	123	123	126	128

CERN 27/03/2012 Implications of a 125 GeV Higgs – A. Djouadi – p.17/2(

The mass, and the mass matters!

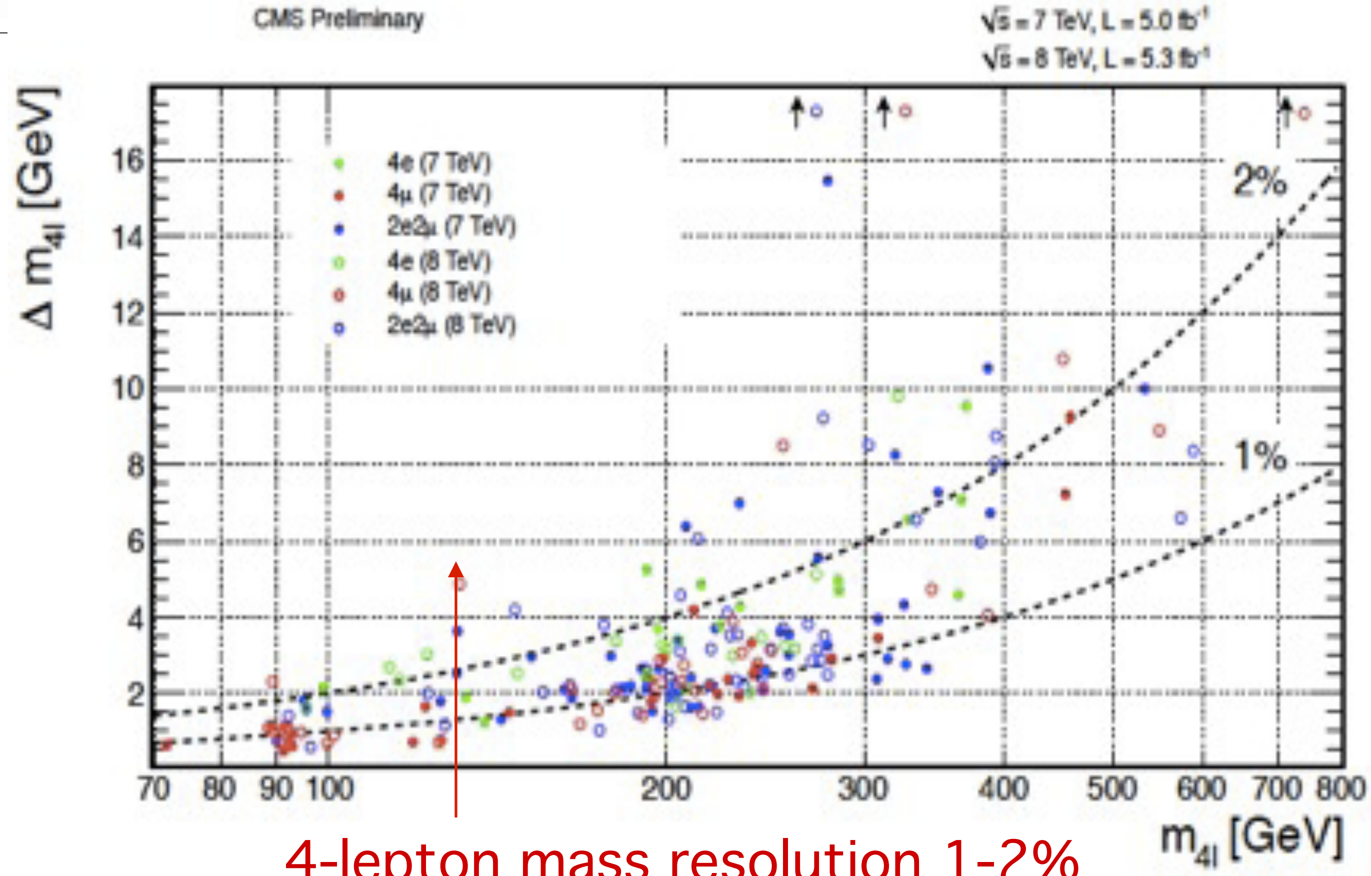




Fit for the common mass in the three channels: $m_X = 125.3 \pm 0.4 \pm 0.5$ GeV

H → γγ should give the best result. We are limited by our capability to reach the ultimate performance in the calibration of the ECAL Improvements: use of di-jet tagged channels and VH production (VBF and VH - better S/B, but needs large stat....). Accuracy on the mass possibly down to ~ 400 MeV with 30fb^{-1}

The mass, H → ZZ*→ 4 leptons channel



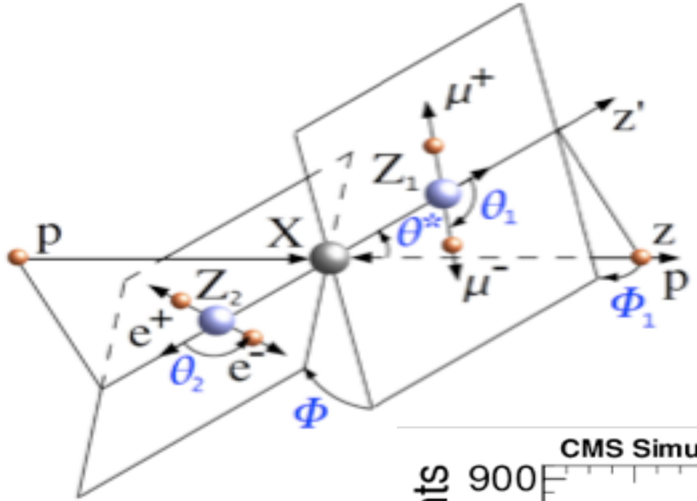
4-lepton mass resolution 1-2%

At present totally statistics limited, even with ~25fb^{-1}. For electron component limited by our capability to reach the ultimate performance of the ECAL

Muon component will have a totally independent/different systematics.

➡ This channel is of primary importance for the spin-parity determination!

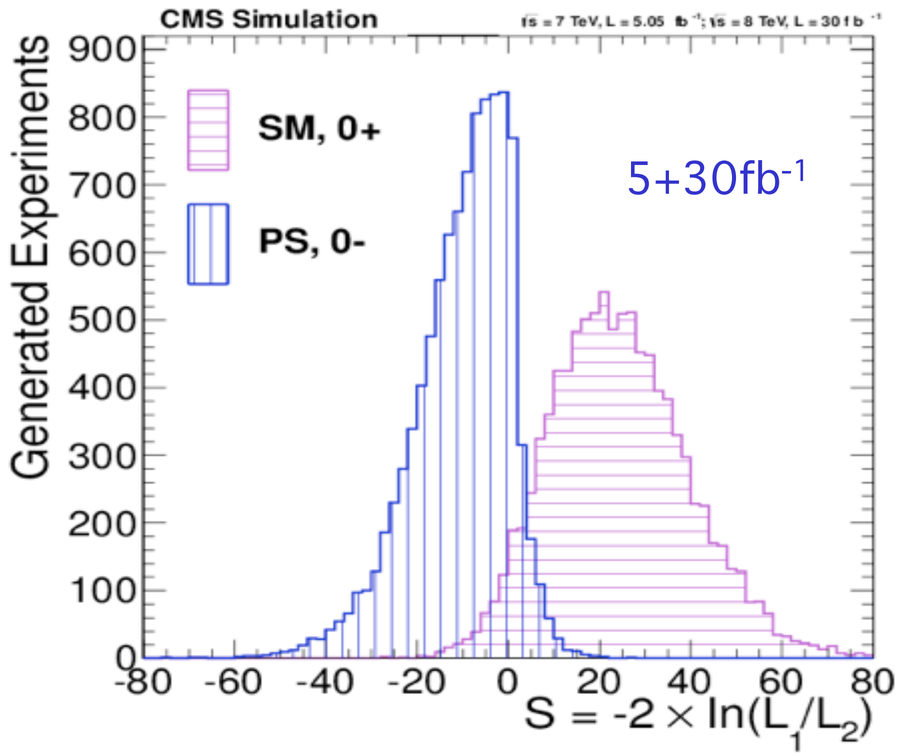
H → ZZ, ZZ*→ 4 leptons, possible scalar vs pseudoscalar separation with 35 fb^{-1}



$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

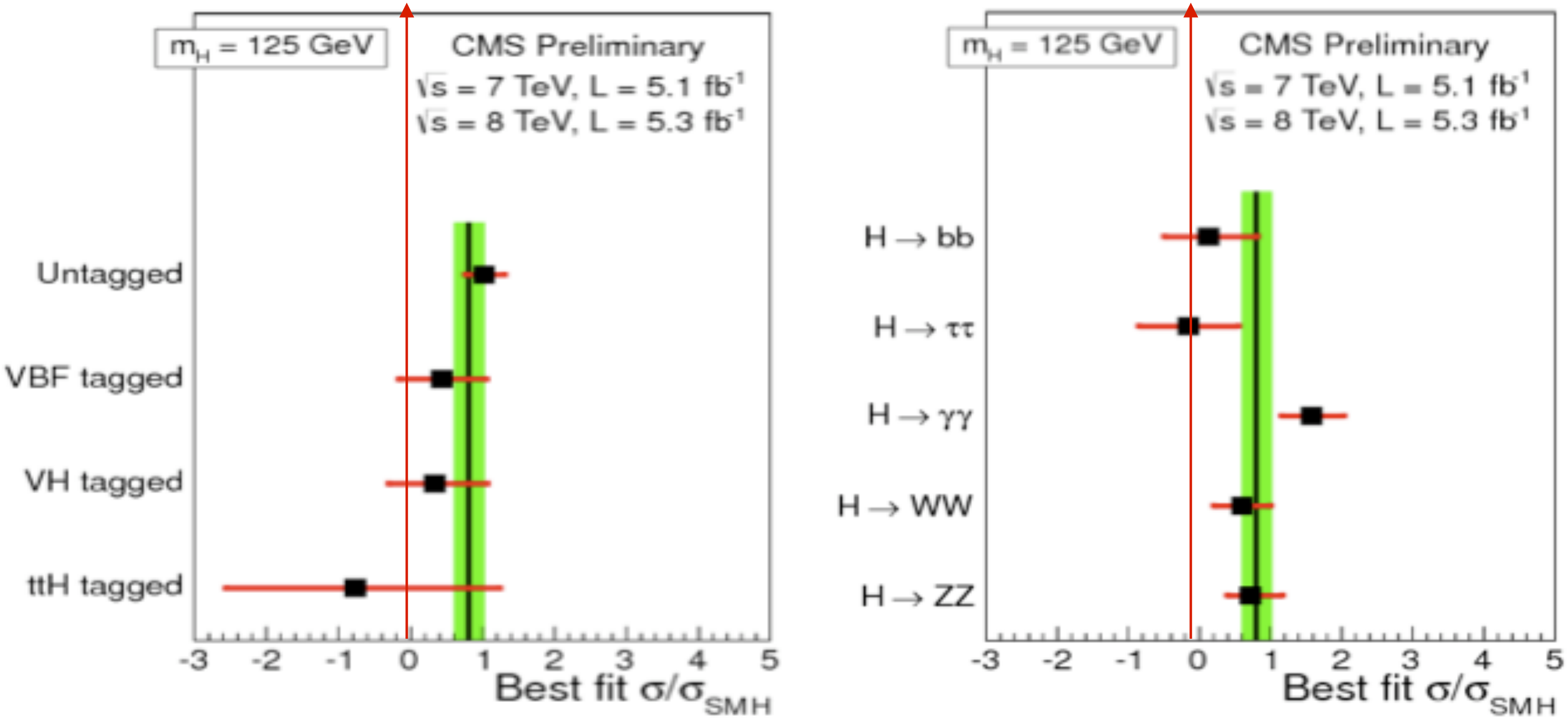
MELA variable incorporates information on the two masses Z_1 and Z_2 and 5 angles allowing a strong discrimination against background

PRD81, 075022(2010)



We shall probably have a ~3σ separation 0^+ vs 0- by the LS-1 - end 2012

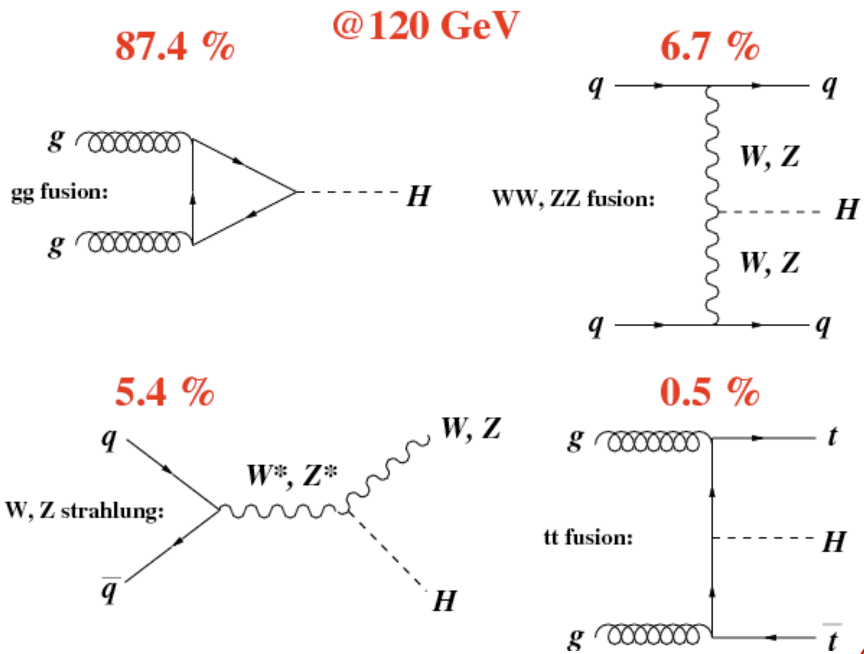
Checking for compatibility with SM Higgs: signal strengths in various production channels and decay modes

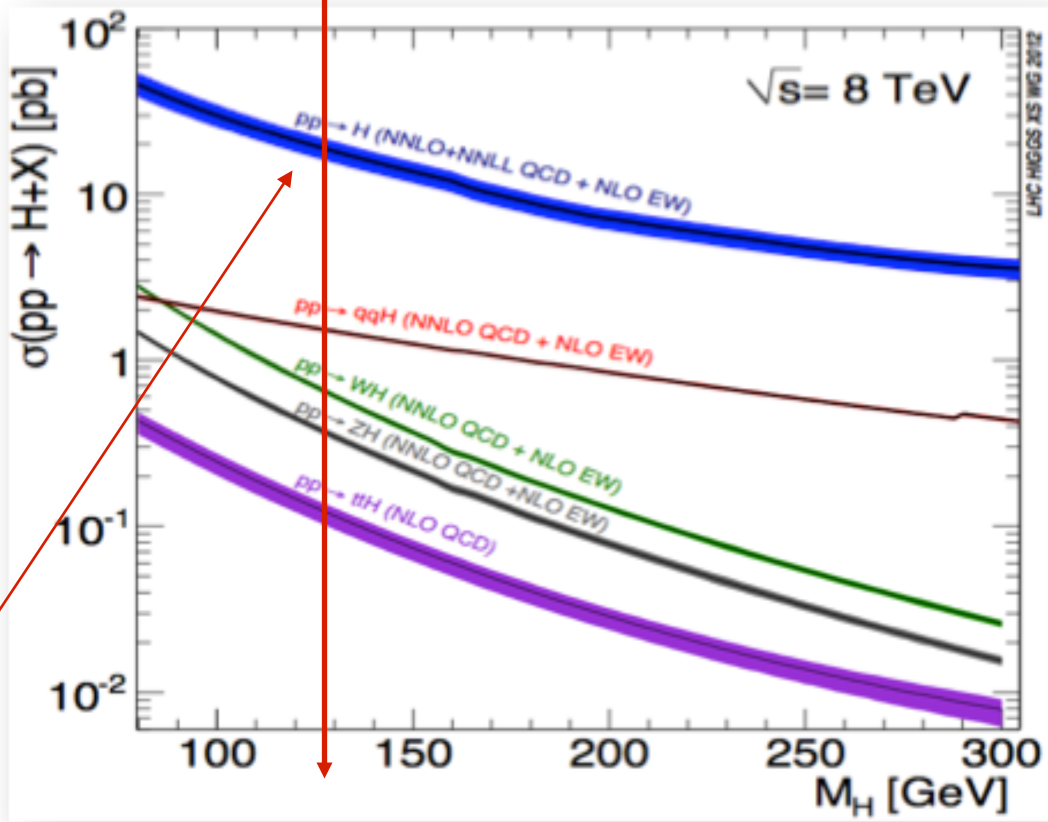


For several modes we have not yet even reached sensitivity to distinguish SM from background!

This is just the beginning, we should strive to get (ratios of) BR's to ~5 - 10% accuracy with ~300 - 1000 fb^{-1}

Higgs production and theoretical uncertainties





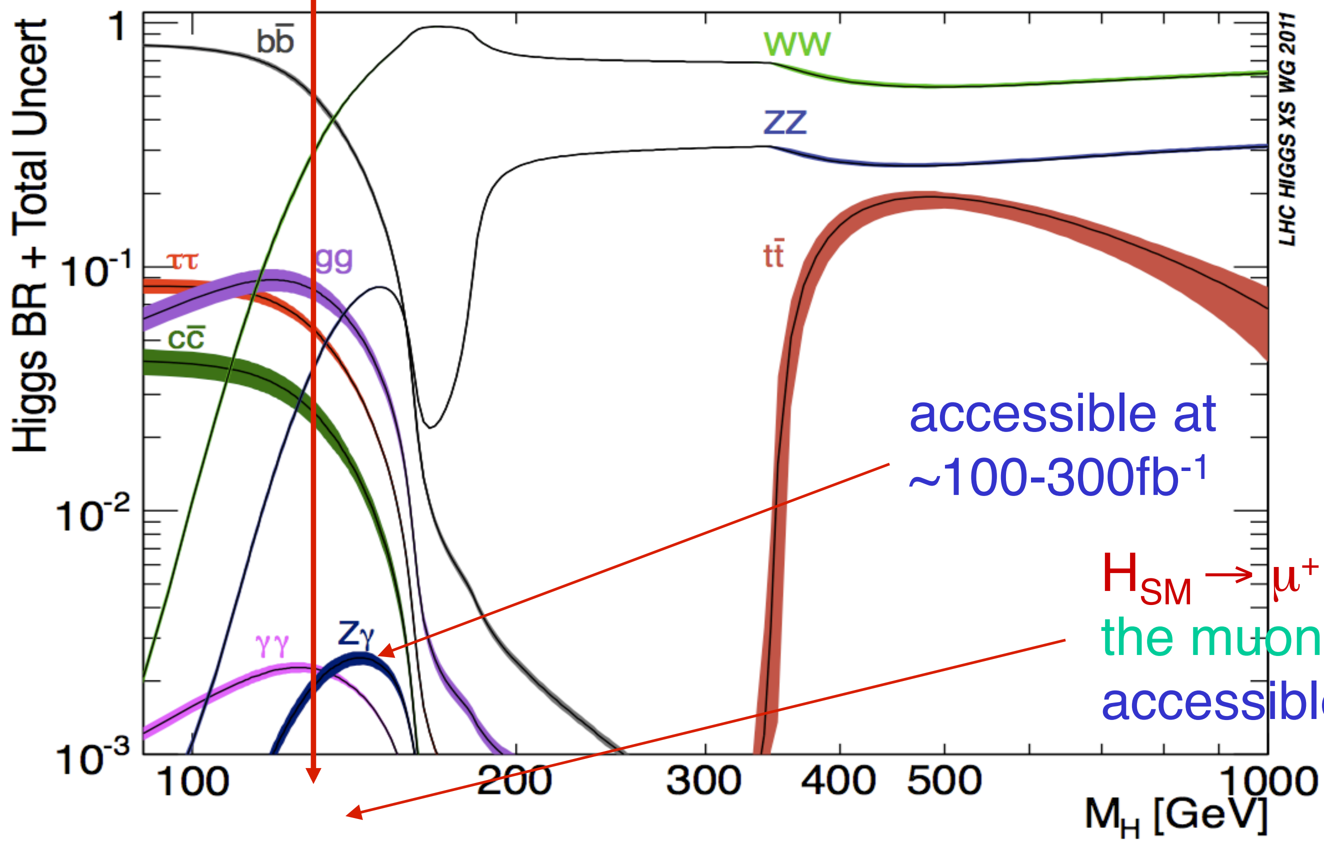
Gluon-gluon fusion, the dominant production mechanism at LHC, is still affected by a significant uncertainty and knowing as precisely as possible what is the production cross section will be very important in the (near) future to understand the exact nature of the object seen....

Typical size of the th uncertainty

	ggF	VBF	WH/ZH	$t\bar{t}H$
QCD scale:	$^{+12\%}_{-8\%}$	$\pm 1\%$	$\pm 1\%$	$^{+3\%}_{-9\%}$
PDF + α_s:	$\pm 8\%$	$\pm 4\%$	$\pm 4\%$	$\pm 8\%$
Mass line shape:	$(150\%) \times \left(\frac{M_H}{TeV}\right)^3$			

A 125 GeV Higgs is a particularly favorable case

A Higgs boson with a mass of 125 GeV is “well located” i.e. in a mass range in which a number of decay modes is accessible, bosonic and fermionic.



accessible at ~100-300fb^{-1}

$H_{SM} \to \mu^+\mu^-$ (BR ~ 10^{-4})
the muon collider mode
accessible at ~ 300fb^{-1}

The main task in the coming years will be to determine branching ratios - from production cross sections and decays in the various modes - to clarify the nature of the object seen…..SM, SUSY, composite….

Looking at the future

- We are doing much better than expected!, not only ~20 years ago when the LHC adventure started, but even few years ago (Physics TDRs)!

- With half the energy (7-8 TeV) and almost the design inst. luminosity at twice the pile-up (50 vs 25 nsec), but ~1/3 the integrated luminosity thought to be needed, we most likely have the Higgs!

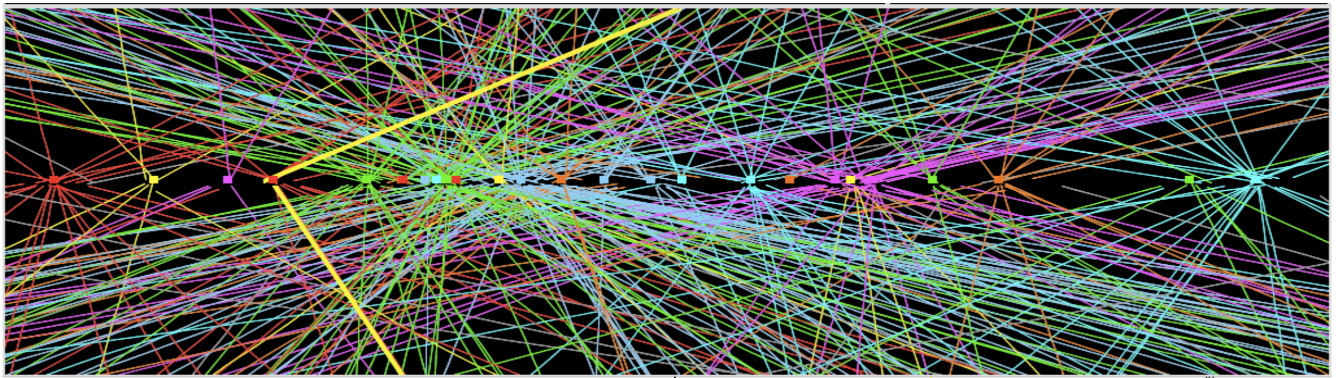
Performances on physics objects (eff., purity, isolation - for electrons, taus, b-jets etc resolution on Etmiss, taus ...) as well as full physics channel analyses are much better - due to Tevatron-induced more sophisticated software/analysis tools (BDT, MVA etc) - than we thought they will be,

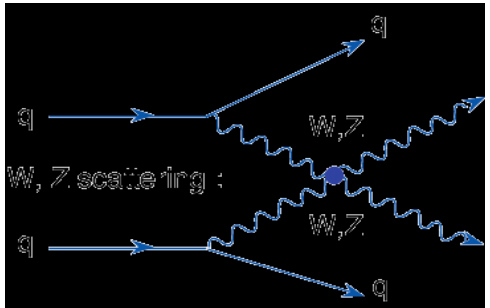
- and we are coping much better with pile-up than initially feard.

Thus we can look with confidence at $\sqrt{s}$ = 13-14 TeV, 2 - 4 x$10^{34}cm^{-2}s^{-1}$ (25 ns) and getting ~50 -100 fb^{-1}/year looks very promising!

Importance of forward jet tagging with ~10^{34} and increasing towards 10^{35} cm^{-2} s^{-1} as cross sections are small!

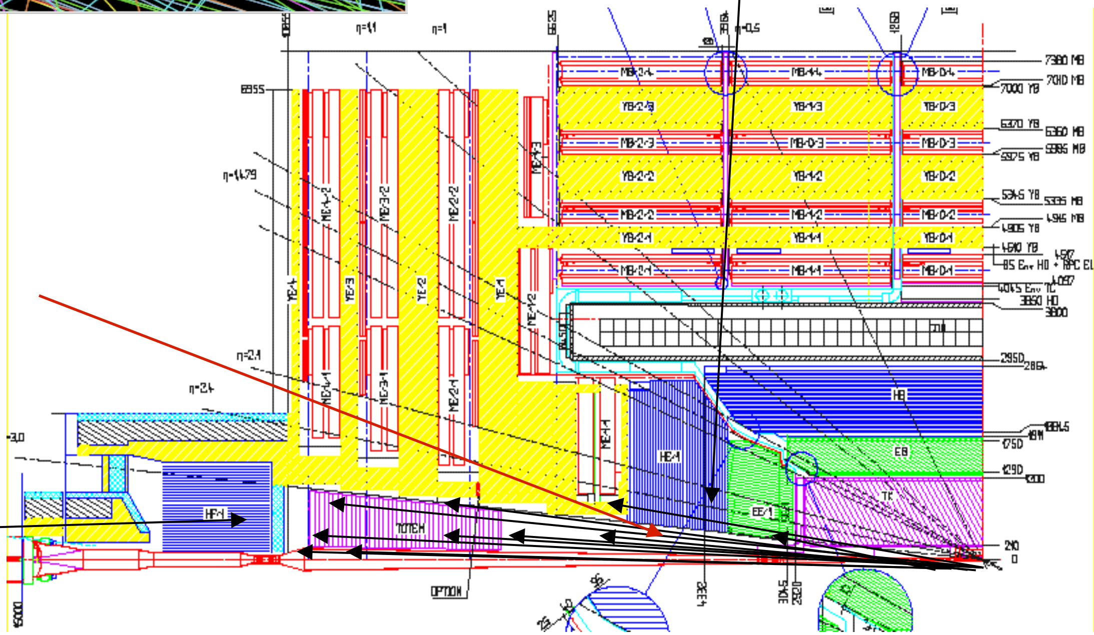
A key instrumental issue in ~ 5 - 8 years, needed to improve S/B in VB fusion/scattering processes pp → qqH, qqVV …., investigating unitarity constraint, if elementary H or not….? The problem is pile-up!





Methods: - increase forward calo granularity, reduce jet reconstruction cone 0.4 to ~ 0.2, optimise jet algorithms to minimize false jets;

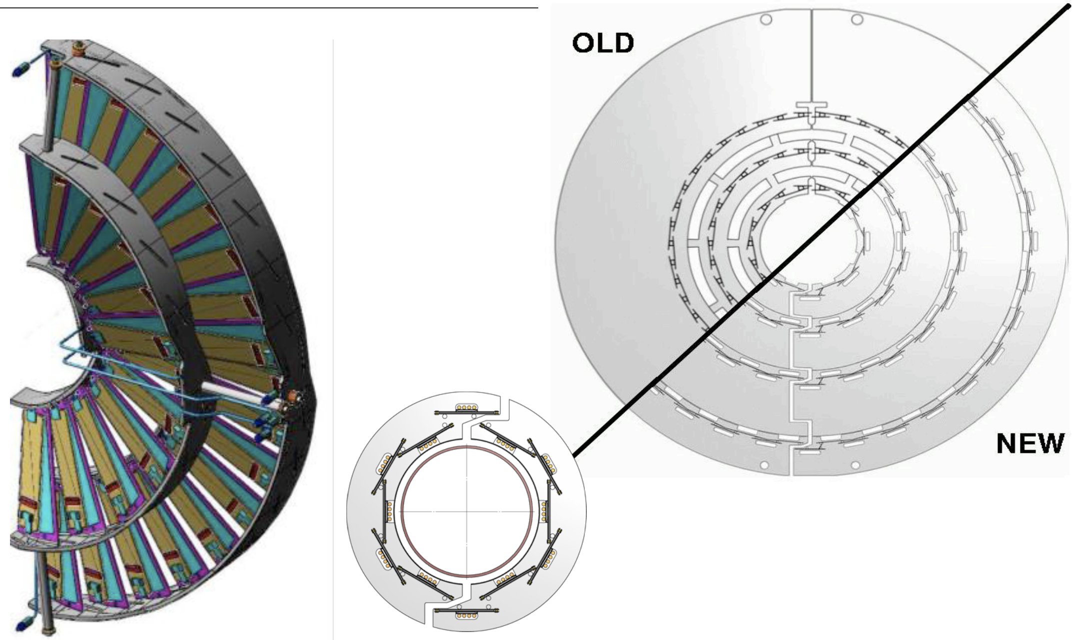
introduce some tracking beyond 2.5 in rapidity with resolution δz ~ 2-3mm, or δt ~ 20-40 psec, and/or a device to count impacts/density on front face of VFCAL



CMS: Pixels and HCAL upgrades 2013 - 1016

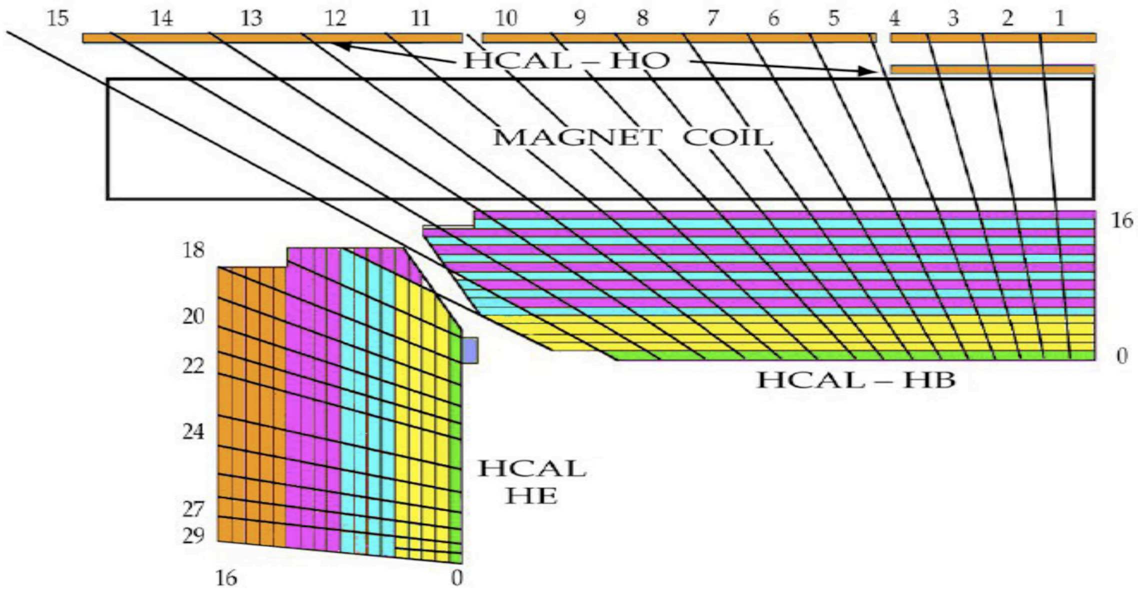
- New Pixels Design
– 4 barrel layers and
  3 endcap disks at each end.
  smaller inner radius
–– Reduced mass

- Installation date
– Ready by late-2016,

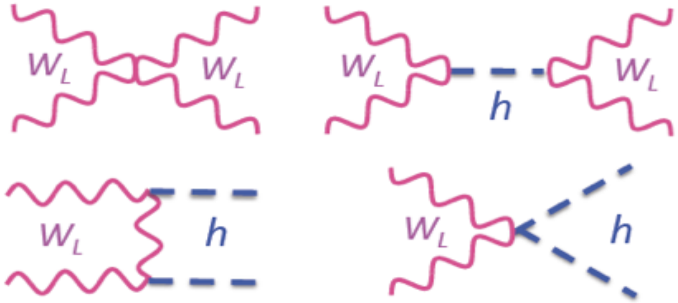


- New HCAL Design
– HF new PMT
– Replace HPDs with SiPMs in HB and HE
- longitudinal segmentation

- Installation date
- HF full PMT in LS1
- HBHE slice after LS1
- HB and HE in LS2



Future ~ 300 - 1000 - 3000fb^{-1} (EWK sector) WW scattering, new Higgs modes, QGC's, HHH?

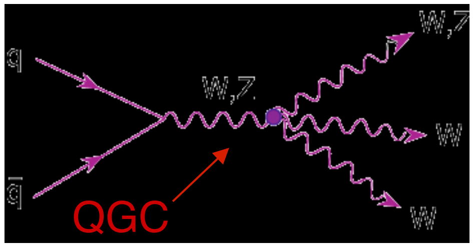


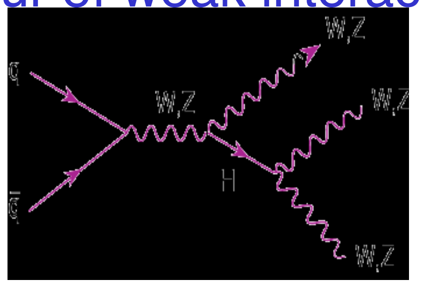
we must look how the Higgs boson Standard controls the cross-section growth for the scattering of longitudinal W's at ~1TeV.

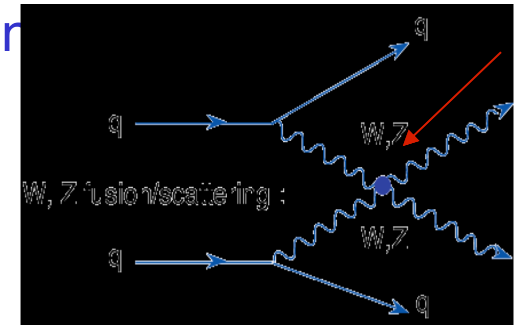
- Increased statistics 3-600 fb^{-1} will allow to look for additional modes, for example:
  $H_{SM} \to \mu^+\mu^-$ (BR ~ 10^{-4}) - the muon collider mode!
  $H_{SM} \to Z\gamma \to l^+l^-\gamma$ (BR ~ 10^{-3}); $H^\pm \to \mu\nu$

- extend significantly coverage of the MSSM parameter space, for example in:
  $A/H \to \mu^+\mu^-$, $A/H \to \tau^+\tau^- \to \mu\varepsilon$, $A/H \to \tau^+\tau^- \to \mu/\varepsilon + \tau\text{-}\varphi\varepsilon\tau$, $A/H \to \tau^+\tau^- \to \tau\text{-}\varphi\varepsilon\tau+\tau\text{-}\varphi\varepsilon\tau$, $H^\pm \to \tau\nu$

- Test of high energy behaviour of weak interaction







QGC

+......

Conclusions

The LHC is an incredible technological and scientific endeavor - on a world-wide scale

The LHC started operation in 2010, in 2012 LHC restarted at 8 TeV with a luminosity approaching 7 x 10^{33} cm^{-2} s^{-1} - almost at the design value! - and delivering up to 1fb^{-1} per week to ATLAS and CMS.

All experiments ATLAS, CMS, ALICE and LHCb have taken in 2011 and 2012 quality data, operating with very high efficiencies. ATLAS and CMS are experiments of unprecedented complexity. The analysis of ~10 fb^{-1} of data gives sign in both experiments and in two distinct channels of the production of a Higgs-like object at ~125 GeV at the expected level of sensitivity for a SM Higgs.

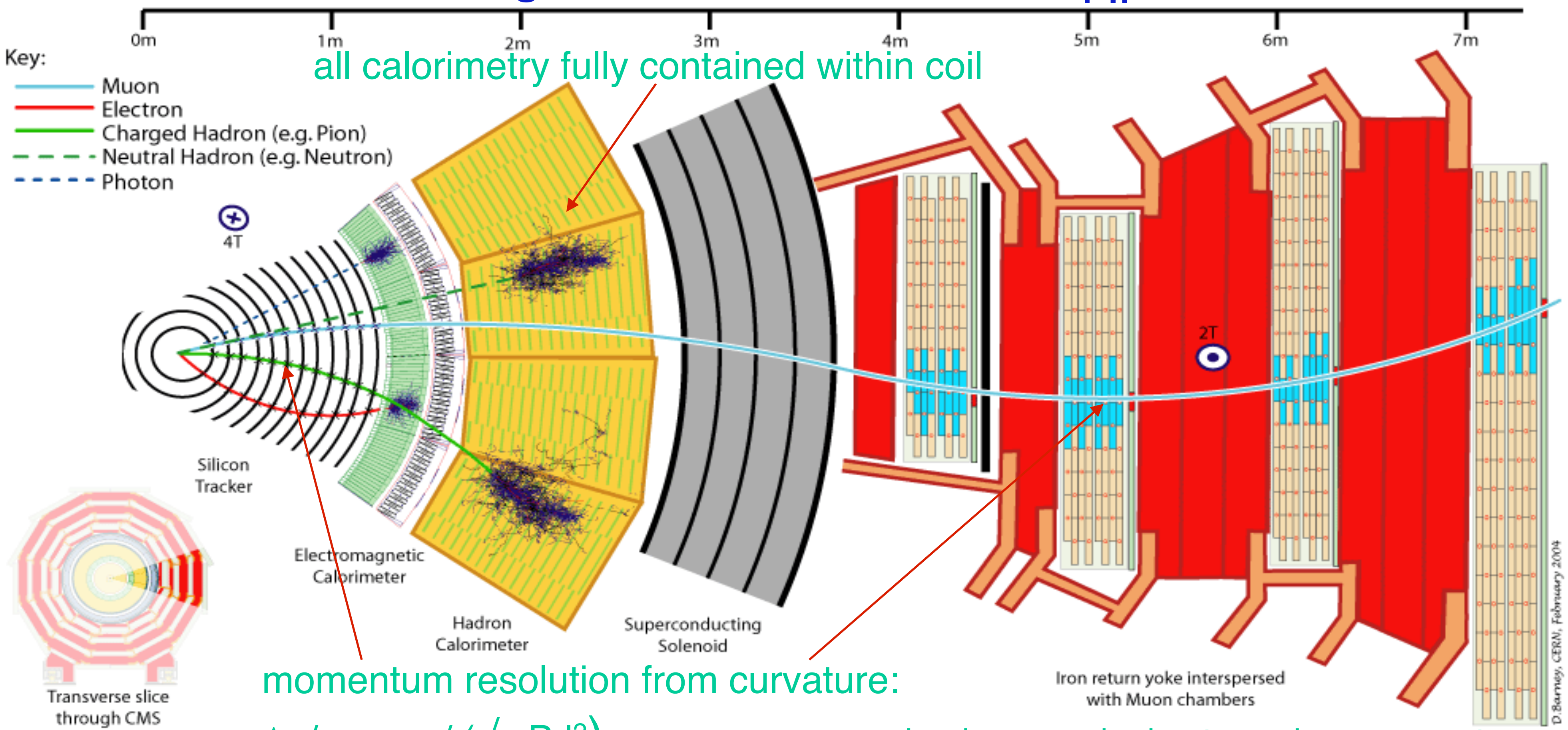
The second half of year 2012 will be exciting, with ~ 20 - 25 fb^{-1} by the end of 2012, much progress will be made towards clarifying the exact nature of the object seen! And watch out for SUSY!

The LHC will go to ~13 TeV in 2014/15 and feed the world particle physics community for the next ~ 10 - 20 years

spares

Central region of CMS; detector functions

Tracking + Ecal + Hcal + Muons for $|\eta|<2.4$



$\Delta p/p \sim \varepsilon\, p \,/\, (\sqrt{n}\, B\, l^2)$

redundancy and robustness in muon system

Si TRACKER

Silicon Microstrips and Pixels

CALORIMETERS

ECAL
Scintillating $PbWO_4$ crystals

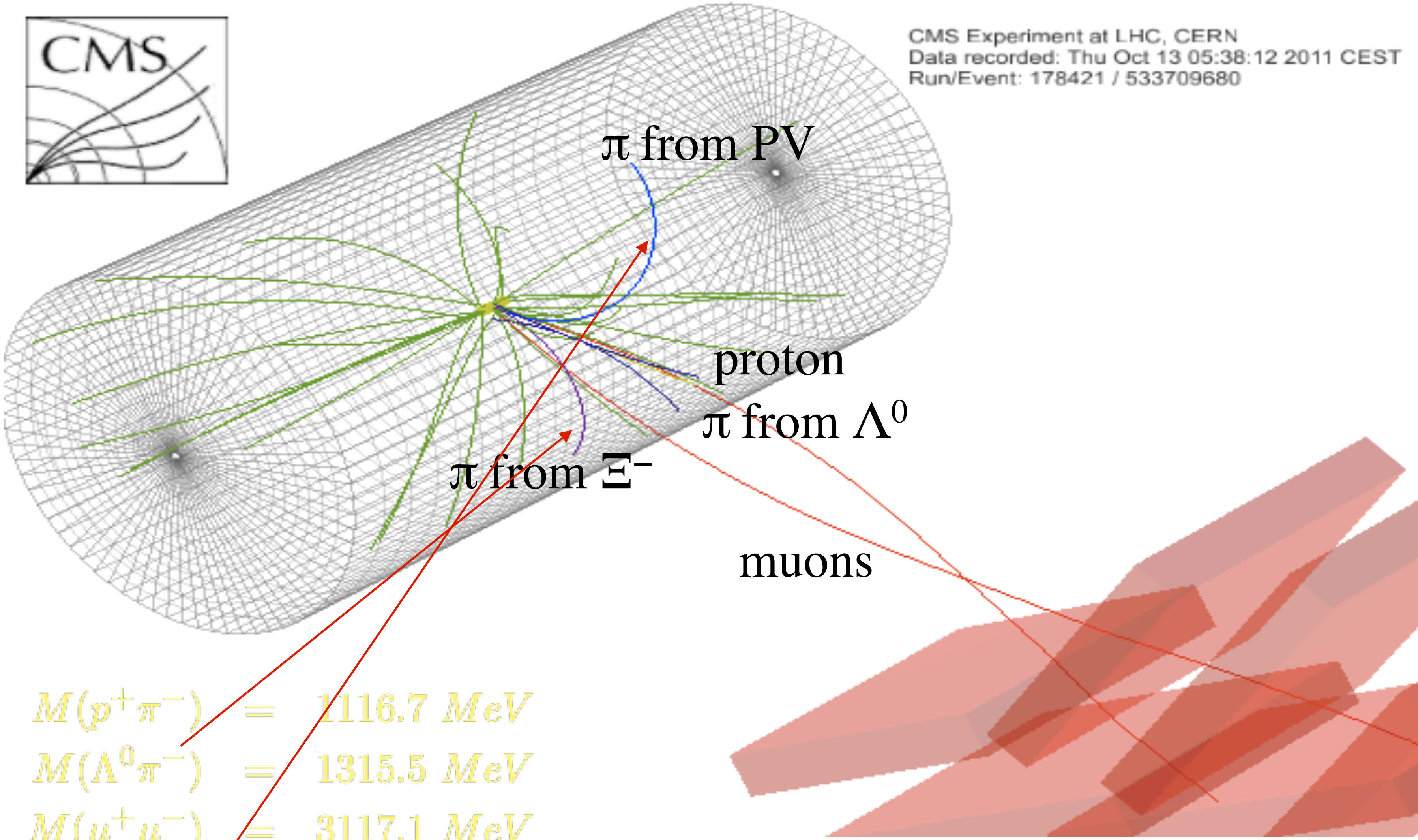
HCAL
Plastic scintillator/brass sandwich

MUON BARREL

Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

Ξ^{*0}_b event in CMS



$$M(p^+\pi^-) = 1116.7\ MeV$$
$$M(\Lambda^0\pi^-) = 1315.5\ MeV$$
$$M(\mu^+\mu^-) = 3117.1\ MeV$$
$$M(J/\psi\Xi^-) = 5787.8\ MeV$$
$$Q(J/\psi\Xi^-\pi^+) = 15.7\ MeV$$

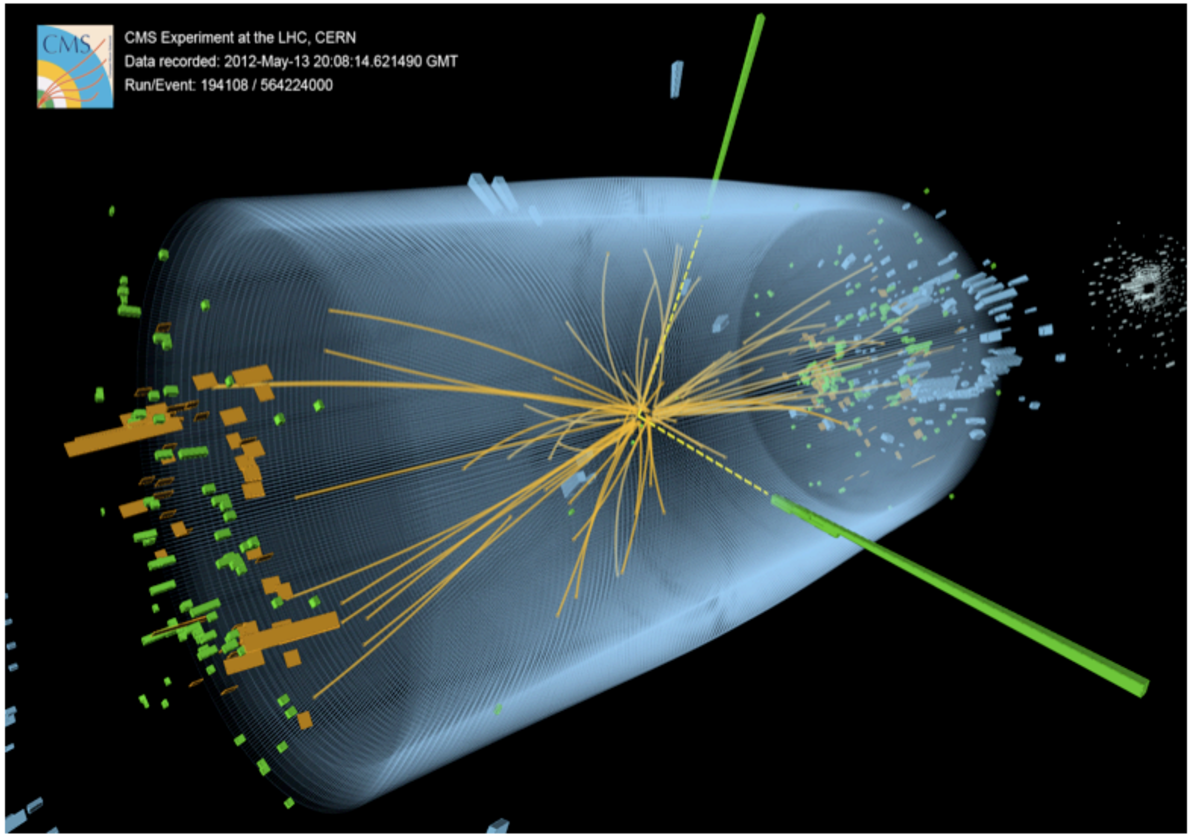
$\Xi_b^{*0} \rightarrow \Xi_b^- \pi^+ \rightarrow \Xi^- J/\psi\, \pi^+ \rightarrow \Lambda \pi^- \mu^+ \mu^- \pi^+ \rightarrow p^+ \pi^- \pi^- \mu^+ \mu^- \pi^+$

$H \rightarrow \gamma\gamma$ search in CMS, search for a mass peak in two isolated high-pt photons spectrum, 2011 + 2012 data

Essential requirements:
excellent photon ID (against, π^0, jets)
excellent $\gamma\gamma$ mass resolution of ~1%

$$m^2_{\gamma\gamma} = 2\, E_1 E_2\, (1 - \cos\theta_{12})$$

Selection criteria:
$E_T(\gamma_1) > m\gamma\gamma/3$,
$E_T(\gamma_2) > m\gamma\gamma/4$
photons are isolated: PF isolation
photon id is based on MVA output

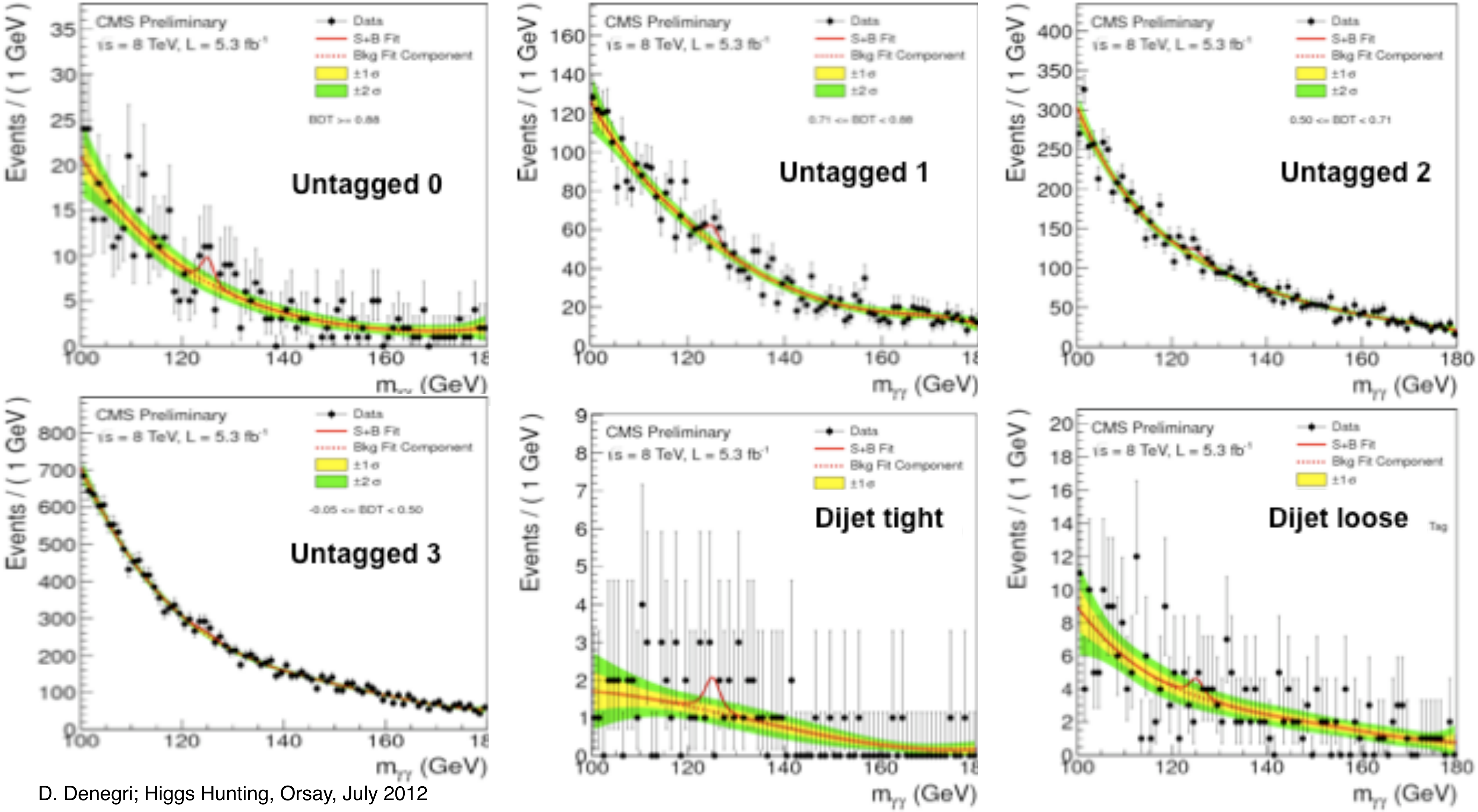


- Blind analysis in 2012
- Background MC only used for analysis optimization,
- $Z \rightarrow ee$ also used to measure photon efficiencies and resolution with data

After full selection, we expect for 10.3 fb^{-1}
~ 150 signal events
~ 6000 bkgd events in 2σ mass window at 125 GeV
i.e. S/B ~ 4% inclusive (~ 20% VBF-2jet category)
Irreducible $\gamma\gamma$ bkgd dominant ~70%

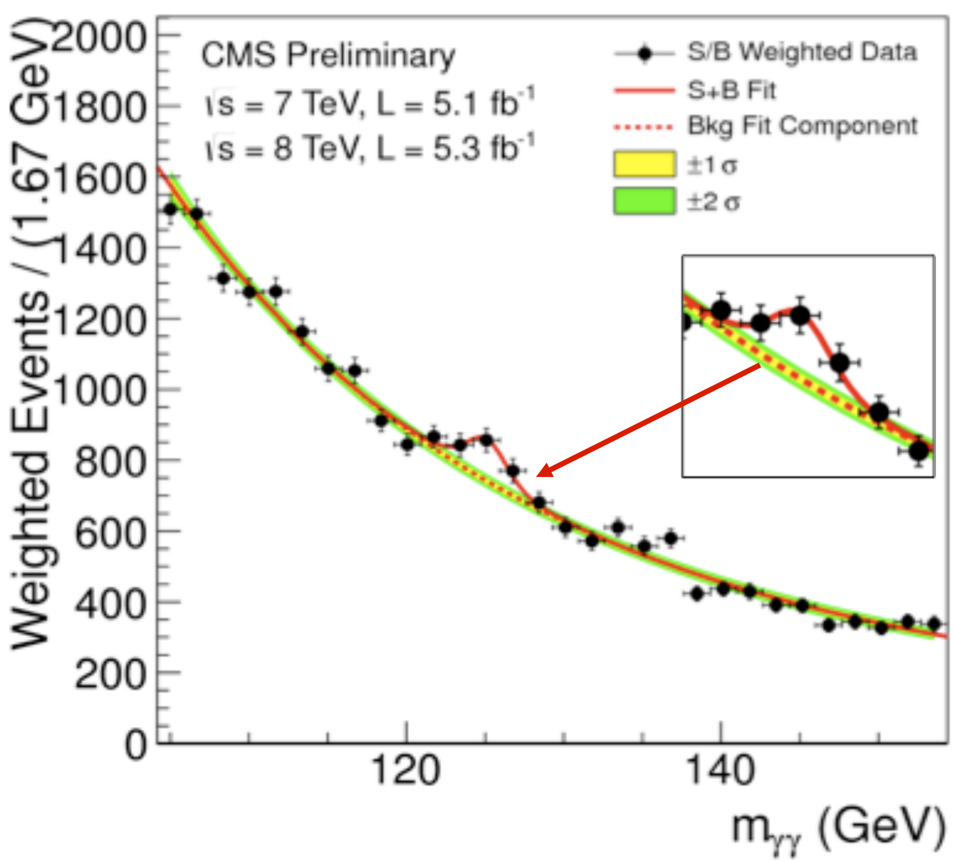
$H \rightarrow \gamma\gamma$ search in CMS, 2012 data, $\sqrt{s}$ = 8TeV, event classes

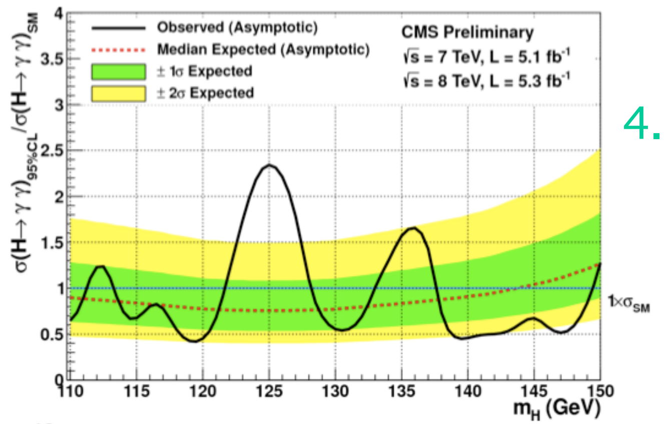
To increase sensitivity events subdivided in 6 classes (depending on γ rapidity, $P_t^{\gamma\gamma}$, cluster size, jets….); mass distributions for each event class:



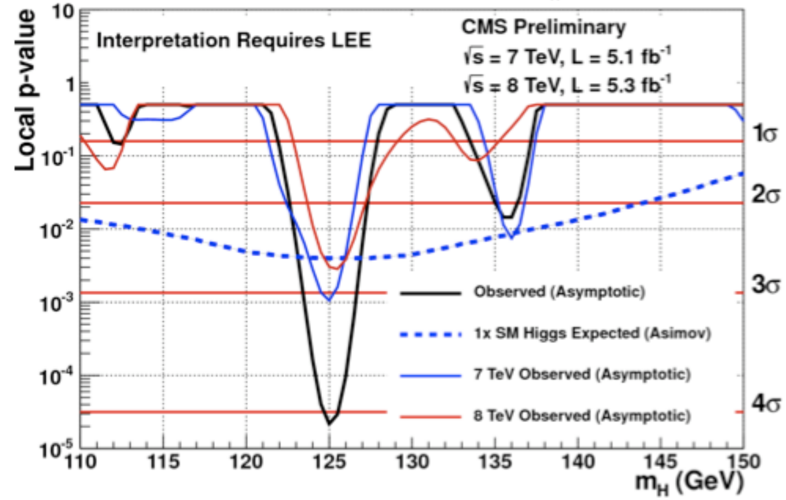
$H \rightarrow \gamma\gamma$ search in CMS, 2011 + 2012 data

Sum of mass distributions for each event class, weighted by S/B, B is integral of background model over a constant signal fraction interval





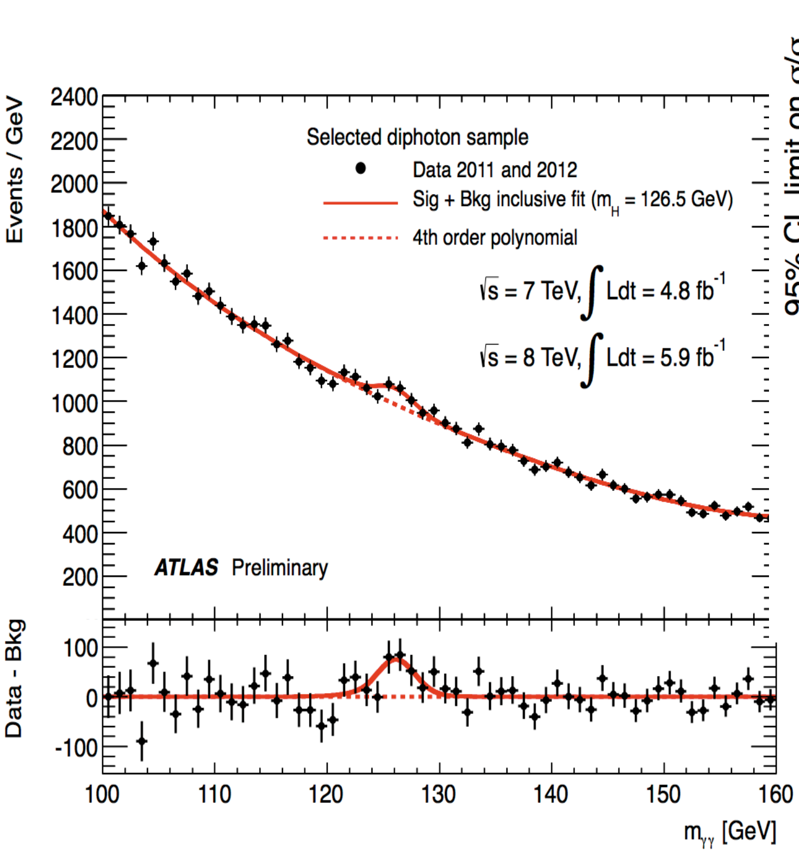
4.1 σ excess

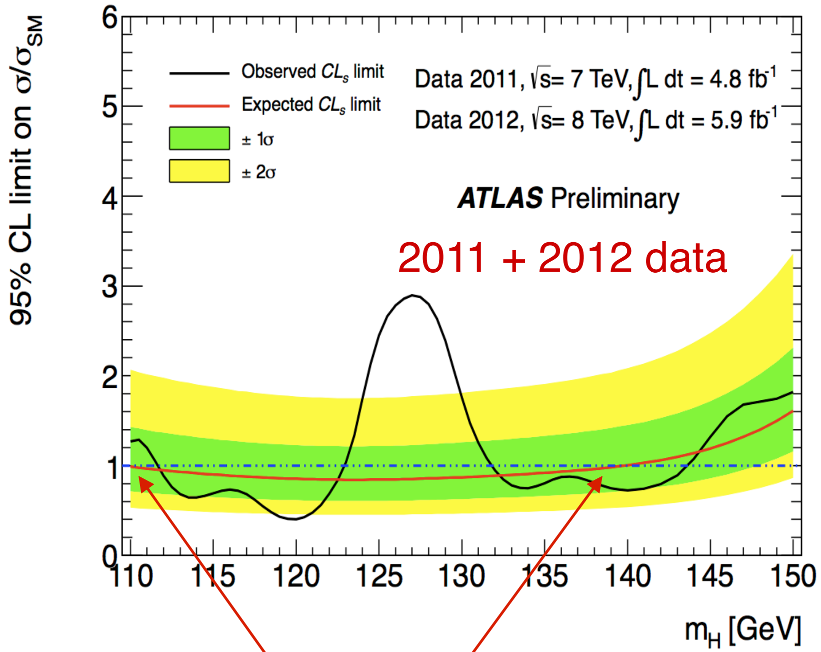


- Minimum local p-value at 125 GeV with a local significance of 4.1 σ
- Global significance (with LEE) in the full search range (110-150 GeV): 3.2 σ

Combined best fit signal strength σ/σ_{SM} = 1.56 ± 0.43 x SM,

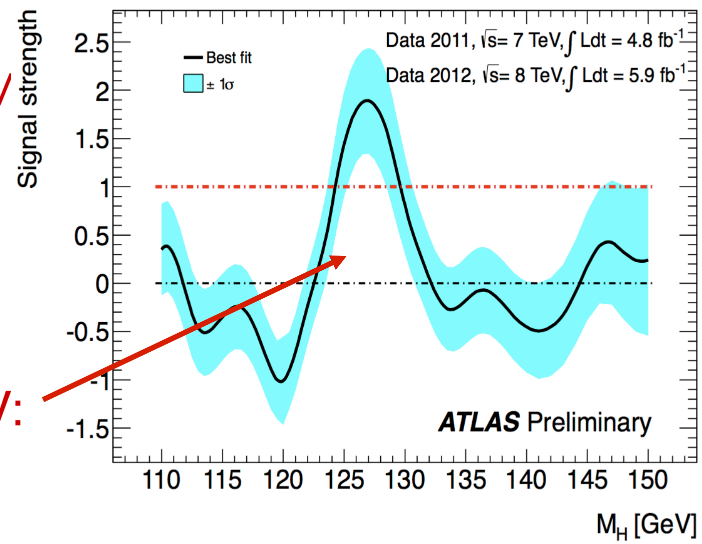
H → γγ in ATLAS, search for a peak, signal strength





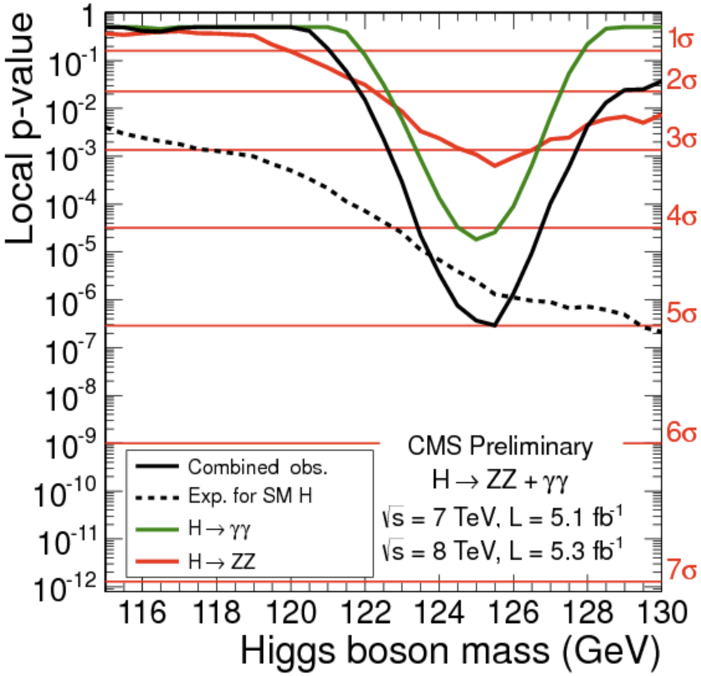
Normalized to SM Higgs expectation at given $m_H(\mu)$

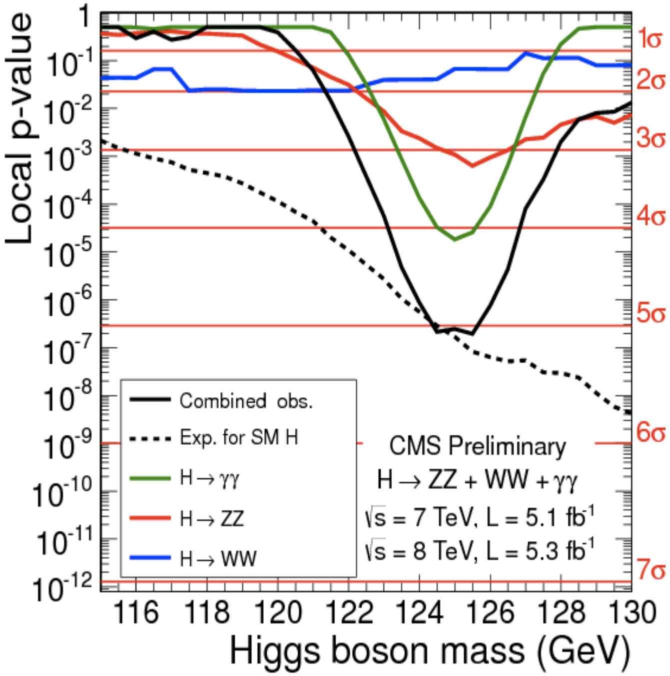
Expected: 110-139.5 GeV
Excluded (95% CL):
112-122.5 GeV, 132-143

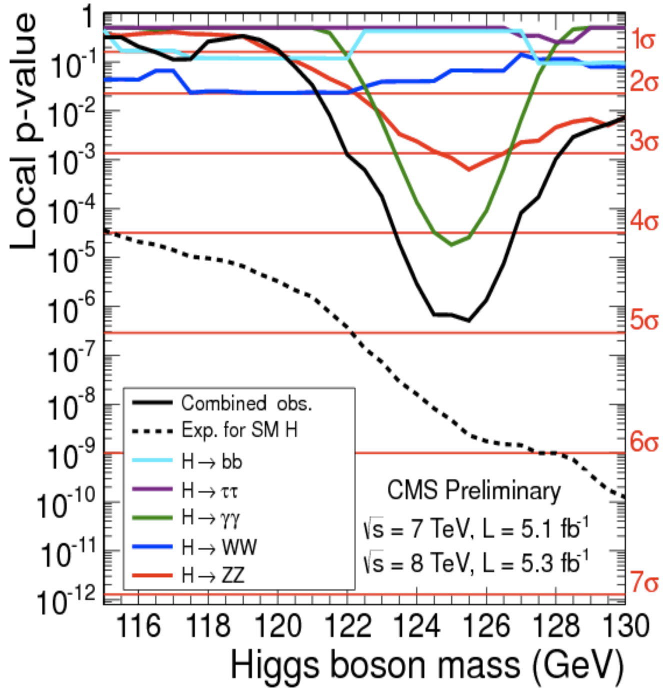


Best-fit value at 126.5 GeV:
μ = 1.9 ± 0.5

Observed signal strength, analysis per channel







high sensitivity, high mass resolution channels: **γγ + 4l**

combined significance: 5.0 σ

expected significance for SM Higgs: 4.7 σ

add high sensitivity low mass resolution WW:

combined significance: 5.1 σ

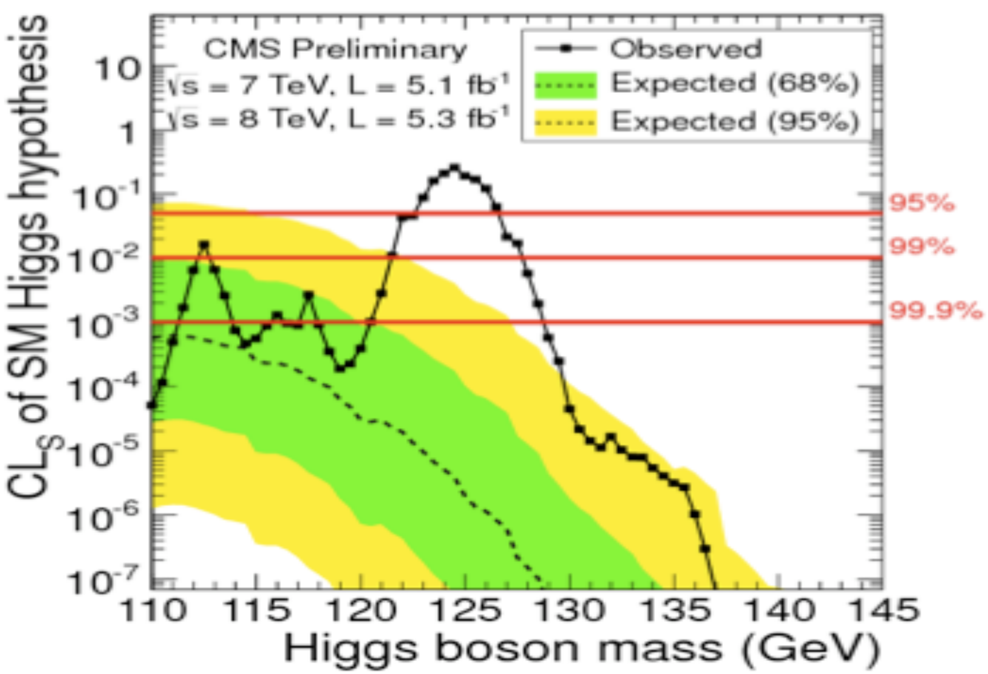
expected significance for SM Higgs: 5.2 σ

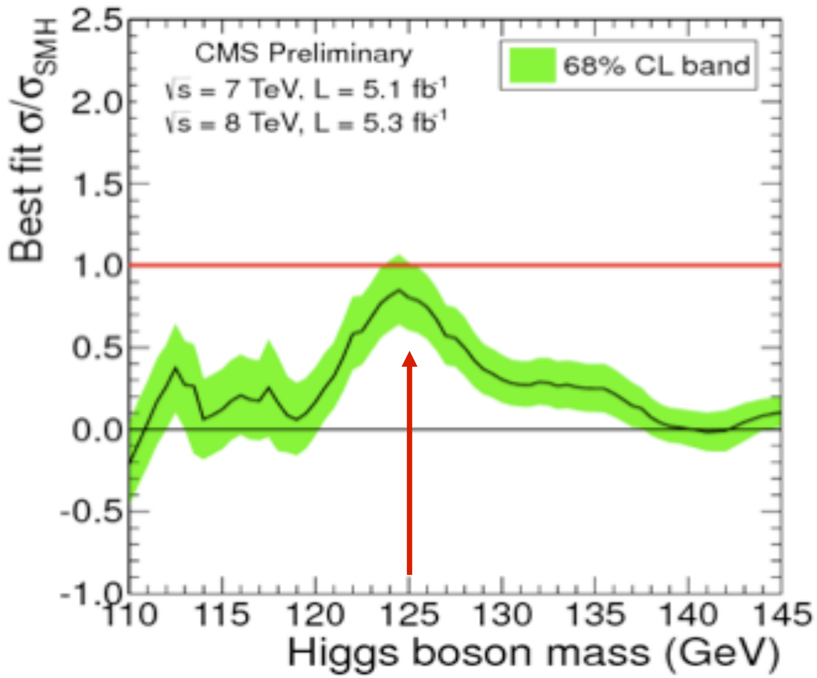
all channels together:

combined significance: 4.9 σ

expected significance for SM Higgs: 5.9 σ

CMS combination, SM Higgs exclusion level, all channels investigated in 2011 and 2012, signal strength





Expected exclusion:

110 - 600 GeV at 95% CL

110 - 580 GeV at 99% CL

Observed exclusion:

110 - 122.5 and 127 - 600 GeV at 95% CL

110 - 121 and 128 - 600GeV at 99% CL

Overall best-fit signal strength in the overall combination:

$\sigma/\sigma_{SM} = 0.80 \pm 0.22$

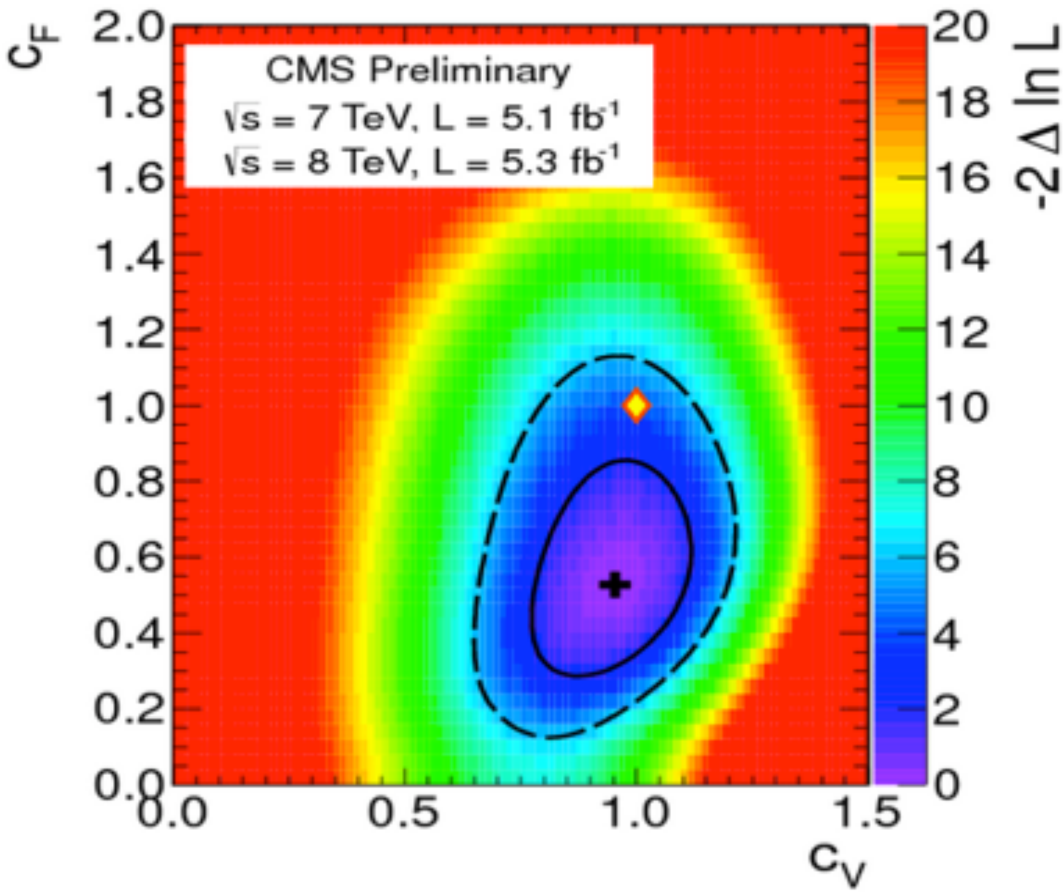
Checking for compatibility with the SM Higgs:
C_V and C_F couplings - prototype of future activities

Higgs couplings regrouped into “Vectorial” and “Fermionic” sets.

Attach a modifier to the SM prediction to each of those (CV and CF).

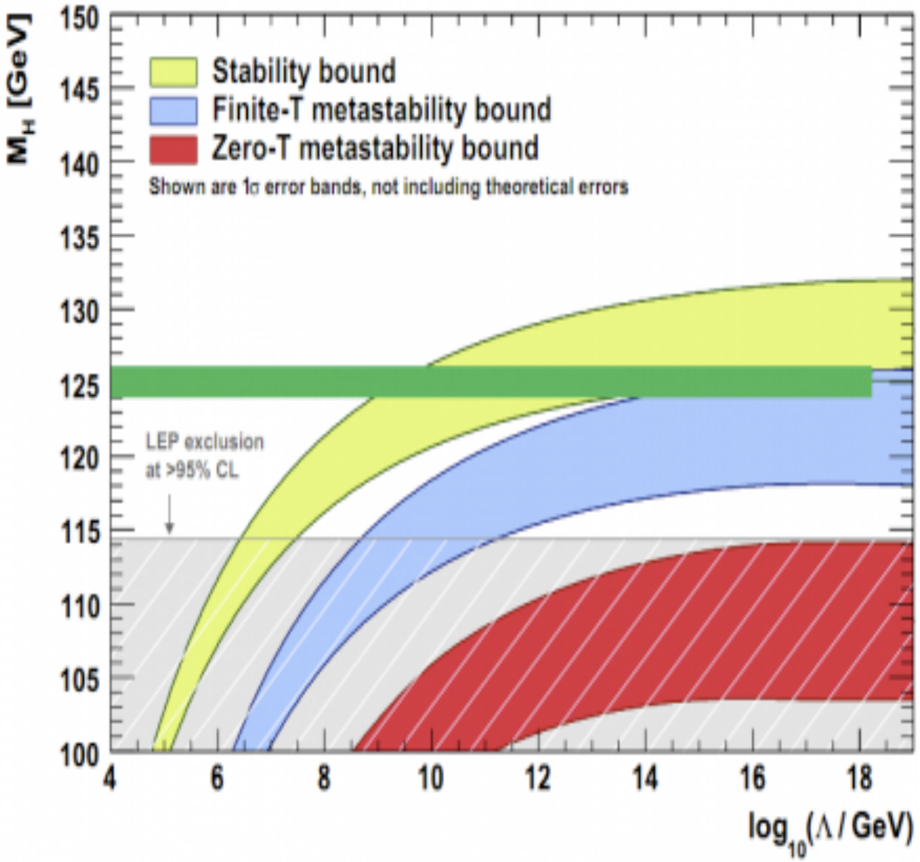
Use LO theoretical prediction for loop-induced H → γγ, H → gg couplings.

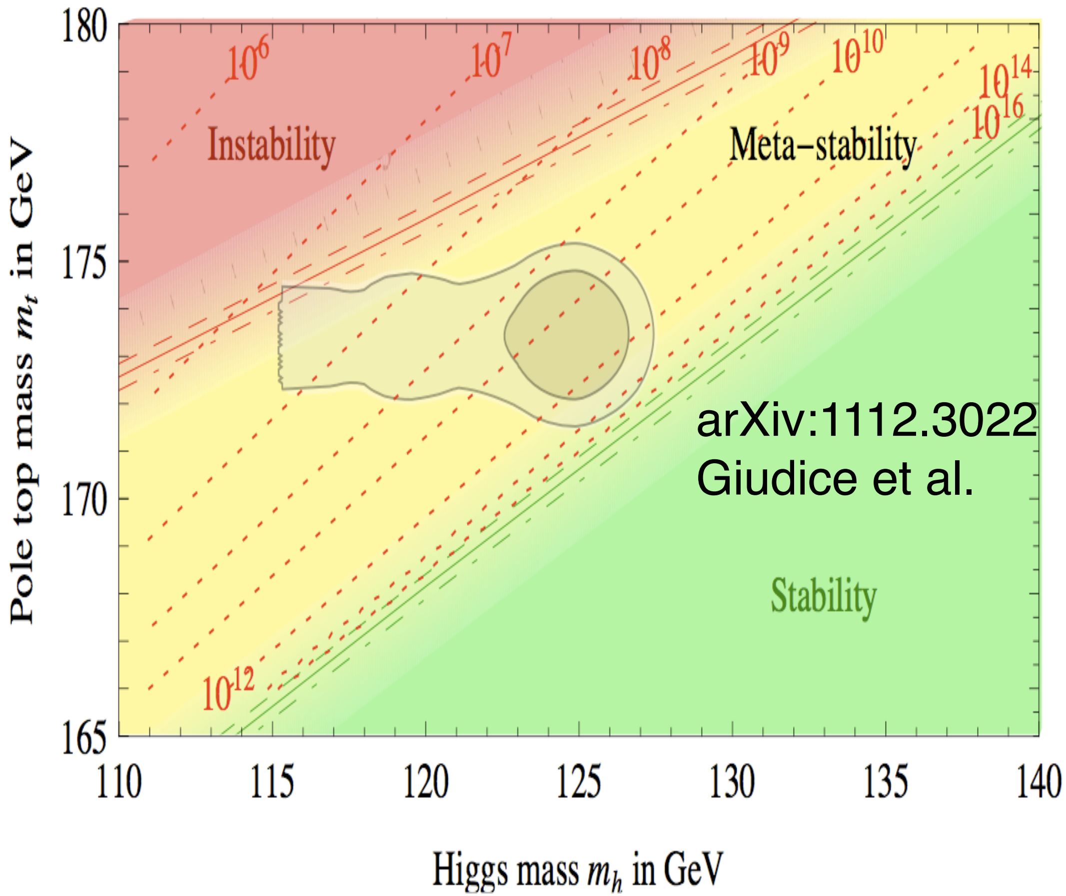
Result:
In agreement with the SM within the 95% CL
we need more data!



solid contour: 68% CL
dashed contour: 95% CL

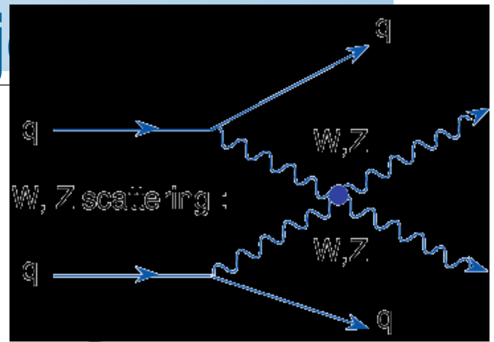
A Higgs at 125 GeV, exact mass indeed matters…





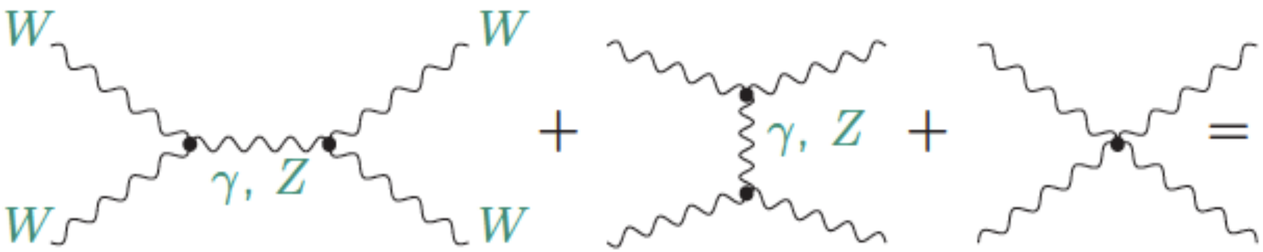
Apparently we are not far from the edge! For a Higgs mass 124–126 GeV, and for the current central values of the top mass, the Higgs potential develops an instability around 10^{11} GeV, with a lifetime still much longer than the age of the Universe. Taking into account theoretical and experimental errors, stability up to the Planck scale cannot be excluded.

H and the unitarity constraint , need to detect and select on forward j



Scattering of longitudinal W's: $W_L W_L \rightarrow W_L W_L$

$\mathcal{M}_V =$

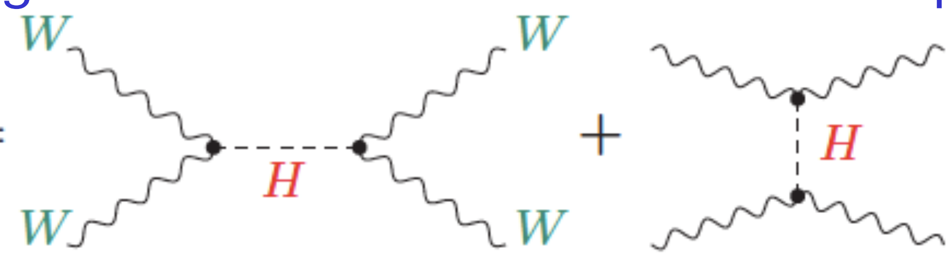


$= -g^2 \frac{E^2}{M_W^2} + \mathcal{O}(1)$ for $E \rightarrow \infty$

violation of unitarity

Adding a contribution of a scalar with coupling proportional to mass:

$\mathcal{M}_S =$



$= g_{WWH}^2 \frac{E^2}{M_W^4} + \mathcal{O}(1)$ for $E \rightarrow \infty$

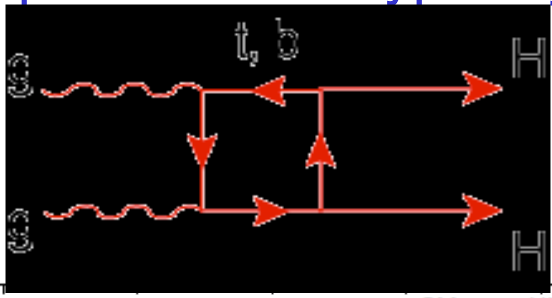
$$\mathcal{M}_{\rm tot} = \mathcal{M}_V + \mathcal{M}_S = \frac{E^2}{M_W^4}\left(g_{WWH}^2 - g^2 M_W^2\right) + \ldots$$

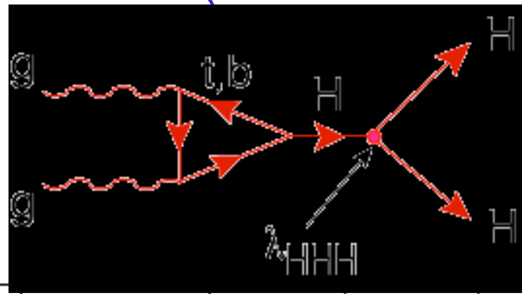
Compensation of terms with bad energy behavior provided:

$$g_{WWH} = g\, M_W$$

Higgs pairs, composite Higgs/SM Higgs at 125 GeV

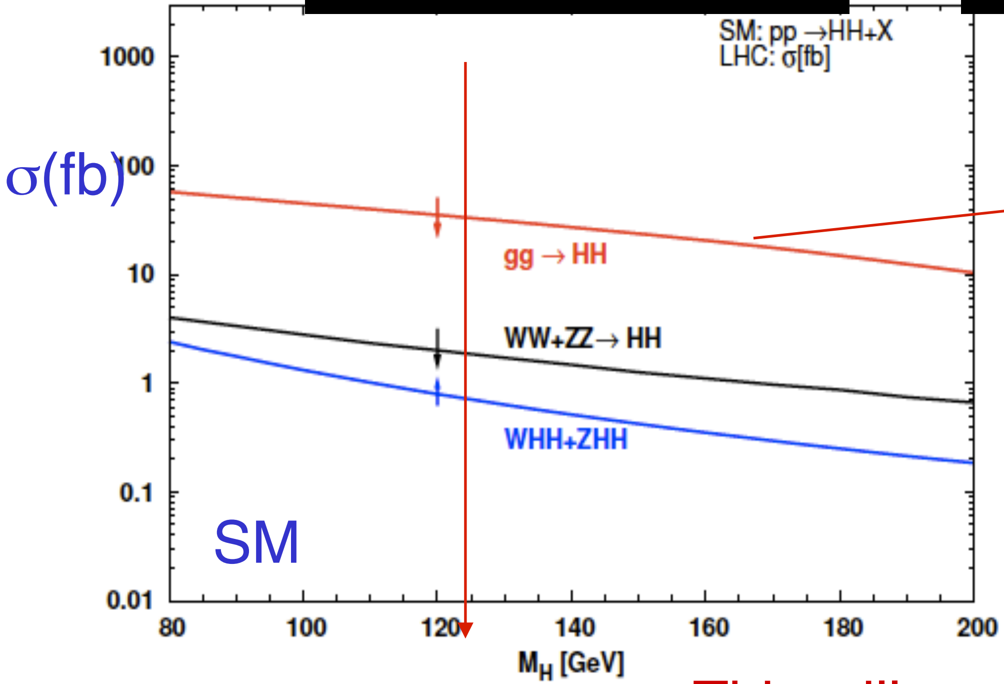
Higgs pair production is typically enhanced(non-standard Higgs self-coupling)

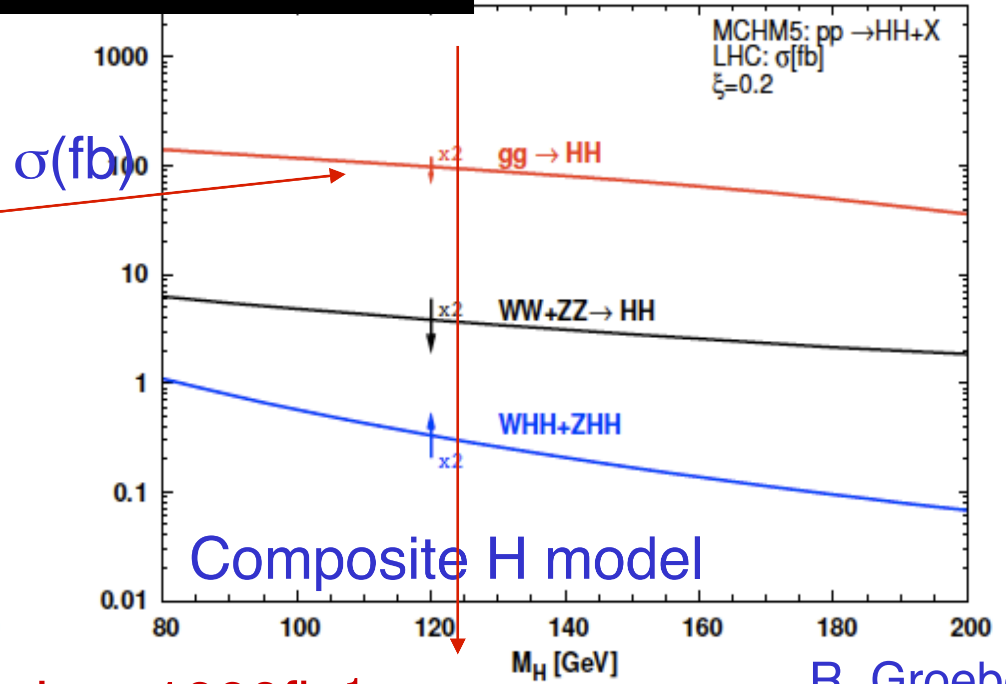




+….

triple H coupling:
$\lambda_{HHH}^{SM} = 3m_H^2/v$





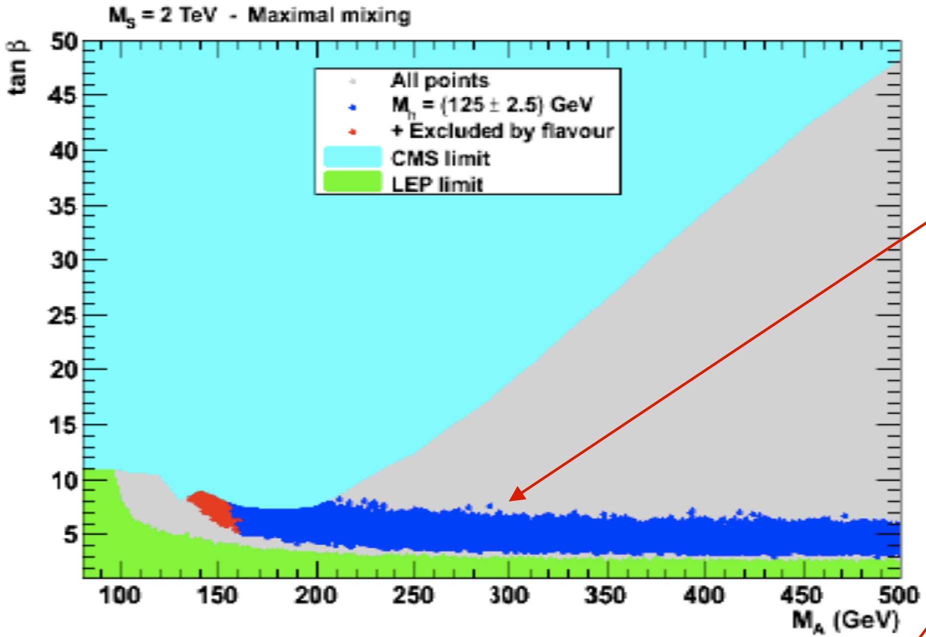
R. Groeber

This will require ~1000fb^{-1}

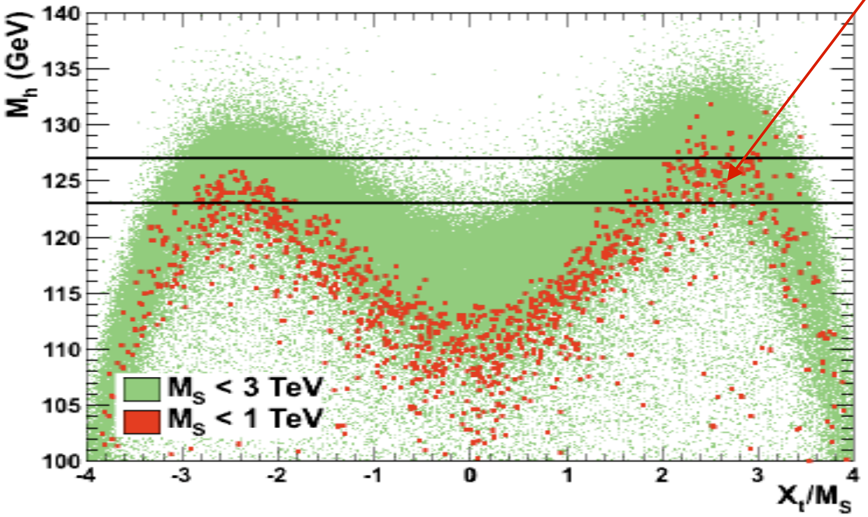
A more recent preliminary study shows that with HH → bbττ there is some hope…

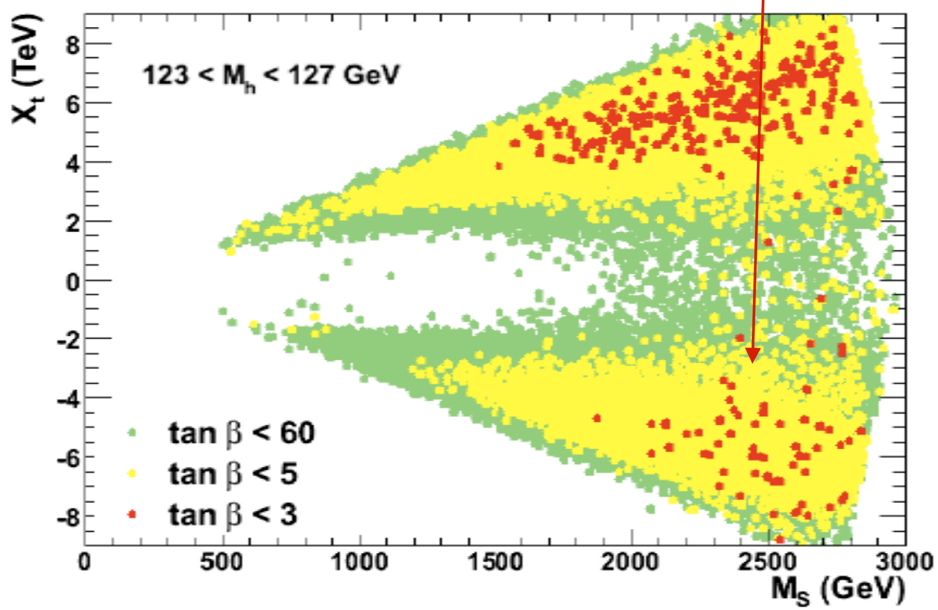
Higgs Self-Coupling Measurements at the LHC, Matthew Dolan

Implications for MSSM of a 125 GeV Higgs



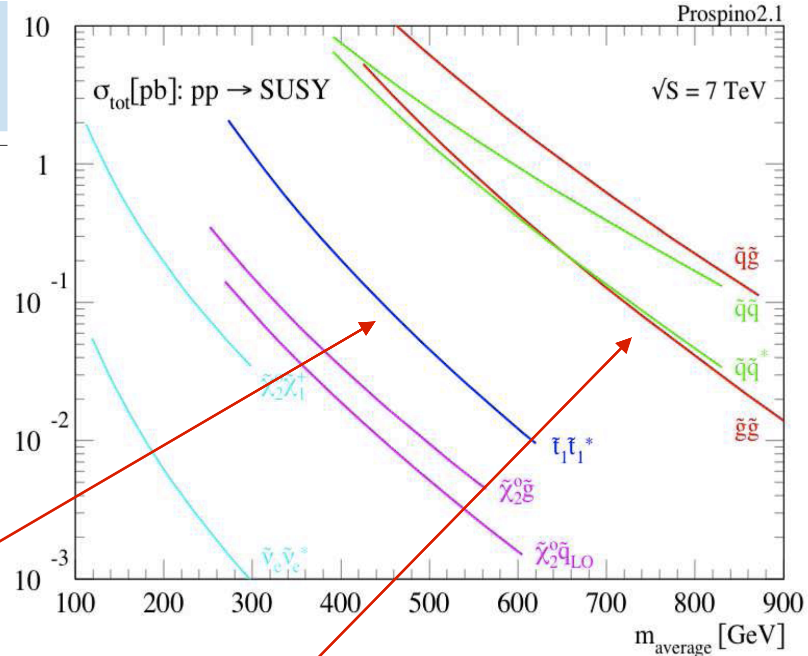
M_h at ~125 GeV possible,
seems to favor tgβ ~5-<10
Requires large mixing and stop at >~500 GeV,
but could also be much heavier……
……….could thus require HL-SLHC

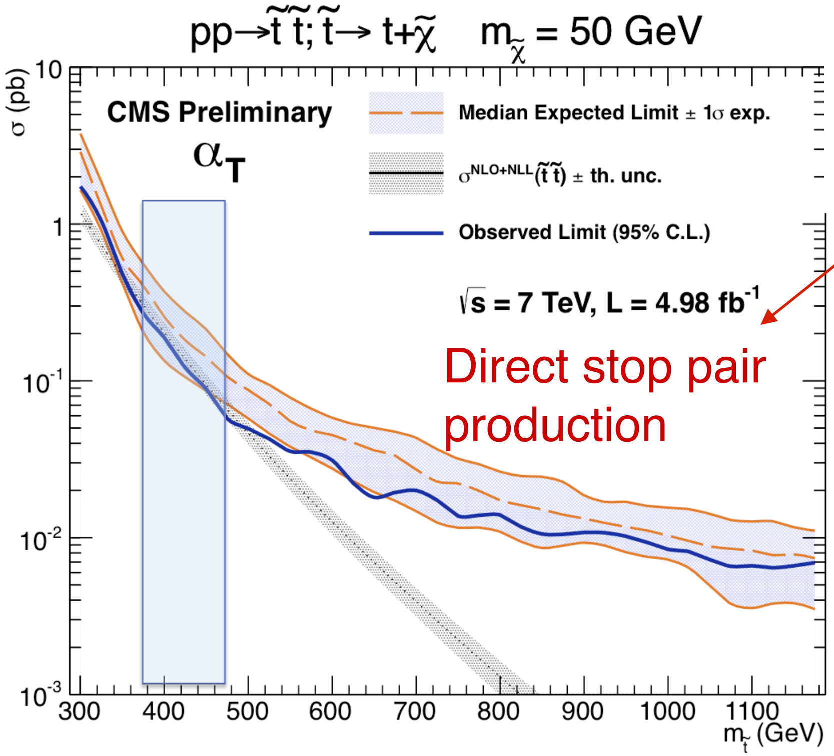




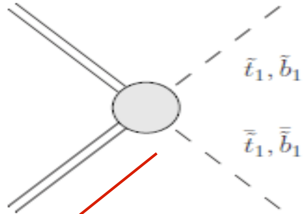
Examples of stop searches

SUSY with a light 3rd generation is well motivated
- the recent indication of a Higgs makes a light stop is an attractive candidate ("Natural SUSY")
- Searches include for stops, sbottoms, experimental signatures involve tops, b's and taus

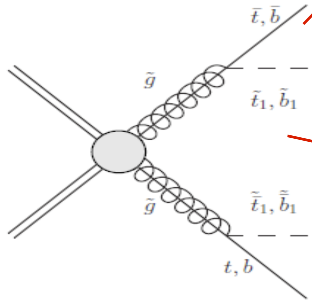


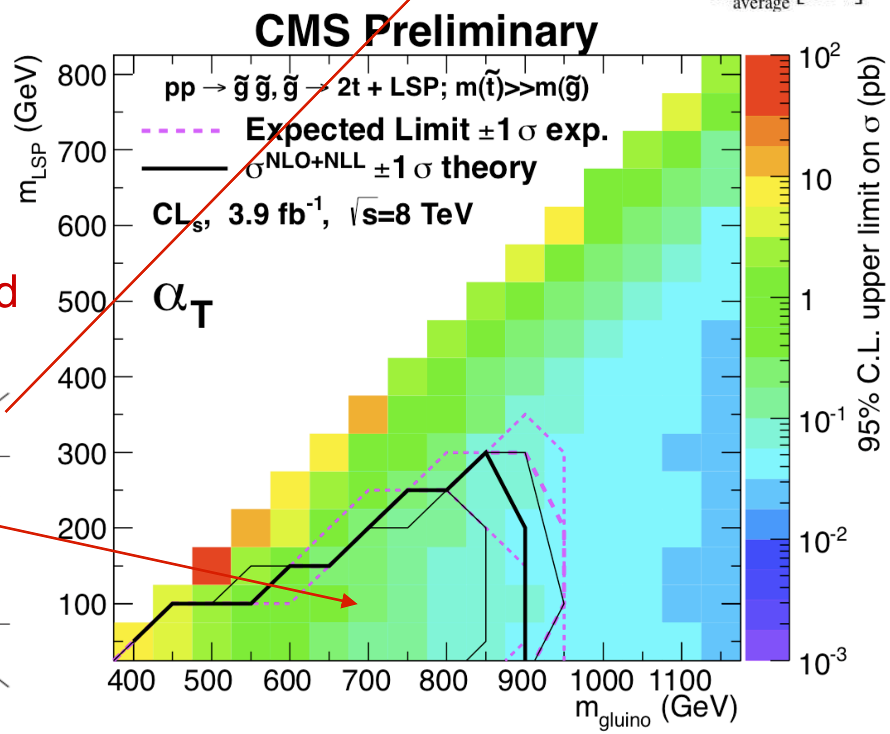


Direct stop pair production



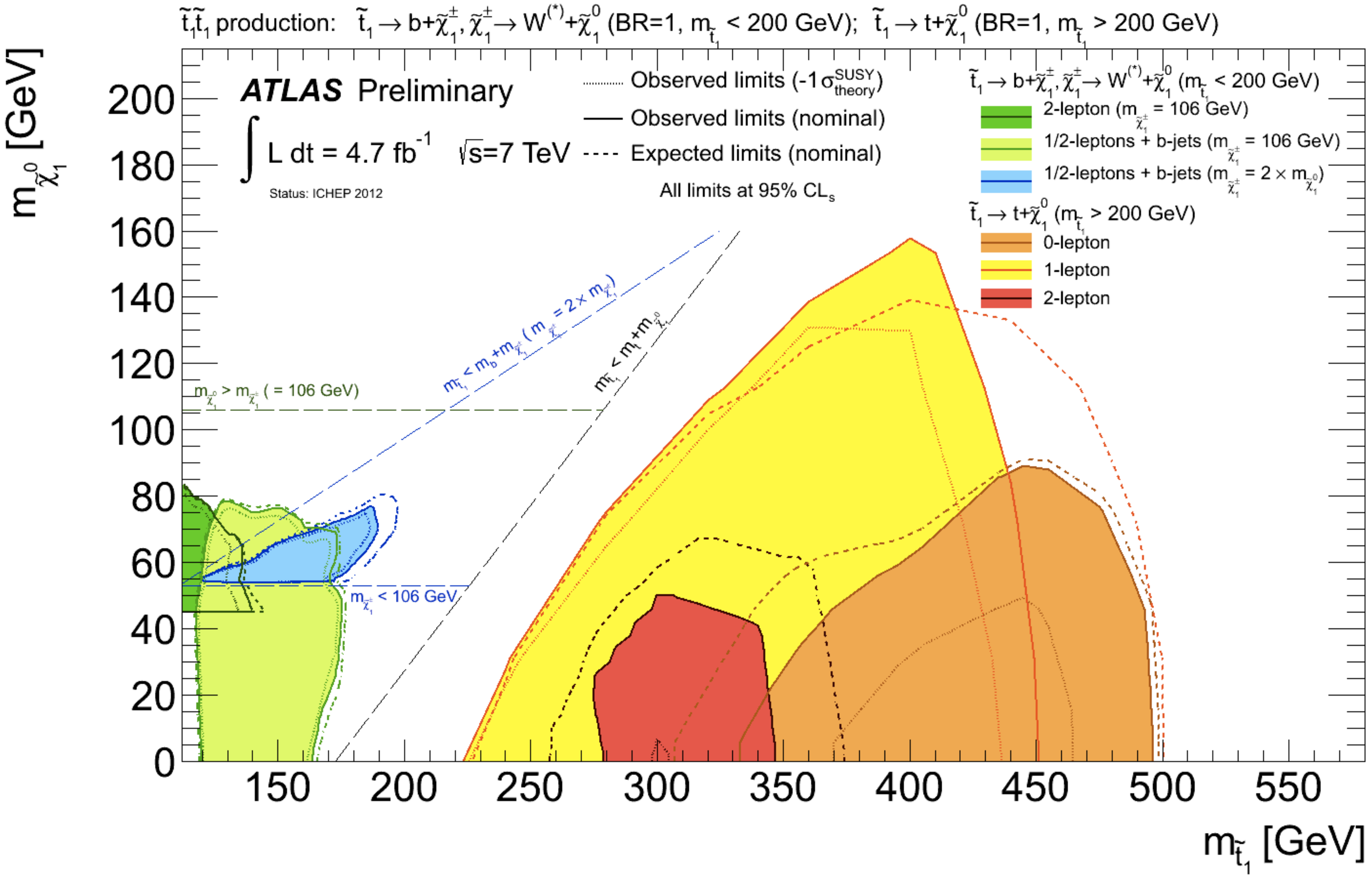
Gluino mediated stop production





Stop searches - summary from ATLAS

Variety of methods and strategies used; absence of significant excess gives these 95%CL's.



D.

Upgrades - LHC - CMS

Potential LHC performance:

After Long Shutdown-1 (2013-14)

: $\sqrt{s}$ = 13-14 TeV, 2.1 x 10^{34} - peak (25 ns, 46 pile-ups, ~ 55 fb^{-1})

After Long Shutdown-2 (~2018)

: 2.8 x 10^{34} - peak (25 ns, 1.6 x 10^{11}p/b, 56 pile-ups, ~65 fb^{-1})

Longer term : collect ~300 fb^{-1} per experiment

HL-LHC go to ~> 5 x 10^{34} , new injectors? Ultimately aim at collecting ~ 3000 fb^{-1}

For CMS

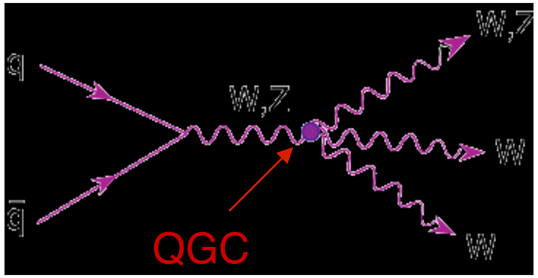
- Prepare for significant peak luminosity and pile-up before LS3,
- – Ready to install Pixels end-2016
- – Prepared to upgrade HF before LS2, and HBHE during LS2
- – Prepare to grow new L1-Trigger in parallel, de-coupled from LS2

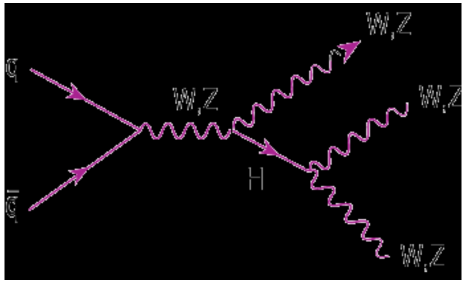
Longer term upgrades:

HF, tracking in $2.5 < |\eta| < 4.5$?

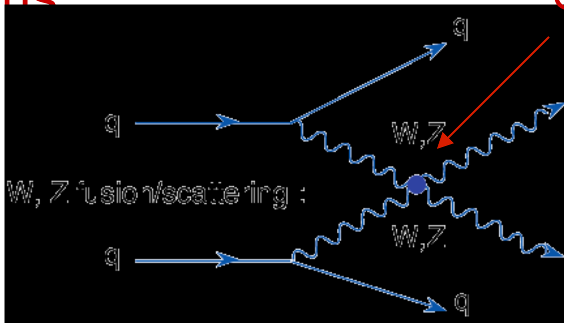
EW physics: multiple gauge boson production at HL-LHC/SLHC, quartic couplings (QGC) in WWW, WWZ…

Test of high energy behaviour of weak interactions





QGC



+……

W,Z ® leptons cleanest, but rate limited at LHC, obvious topic for HL-LHC and full SLHC!

Expected numbers of events in purely leptonic final states, 3 and 4 VB production, 6000 fb^{-1}

lepton cuts: $p_t > 20$ GeV, $|\eta| < 2.5$, assumed reconstruction efficiency 90%

(LO rates, CTEQ5M, k ~ 1.5 expected for these final states)						
Process	*WWW*	*WWZ*	*ZZW*	*ZZZ*	*WWWW*	*WWWZ*
$N(m_H = 120$ GeV)	2600	1100	36	7	5	0.8
$N(m_H = 200$GeV)	7100	2000	130	33	20	1.6

On-shell decays

WWW → 3 leptons, WWZ → 4 leptons accessible at HL-LHC: several hundred of purely leptonic events!

WZZ → 5 leptons, ZZZ → 6 leptons accessible at full SLHC
(barely so at HL-LHC with ~ 600 fb-1 i.e. 2-3 years at 200 fb-1 /year)