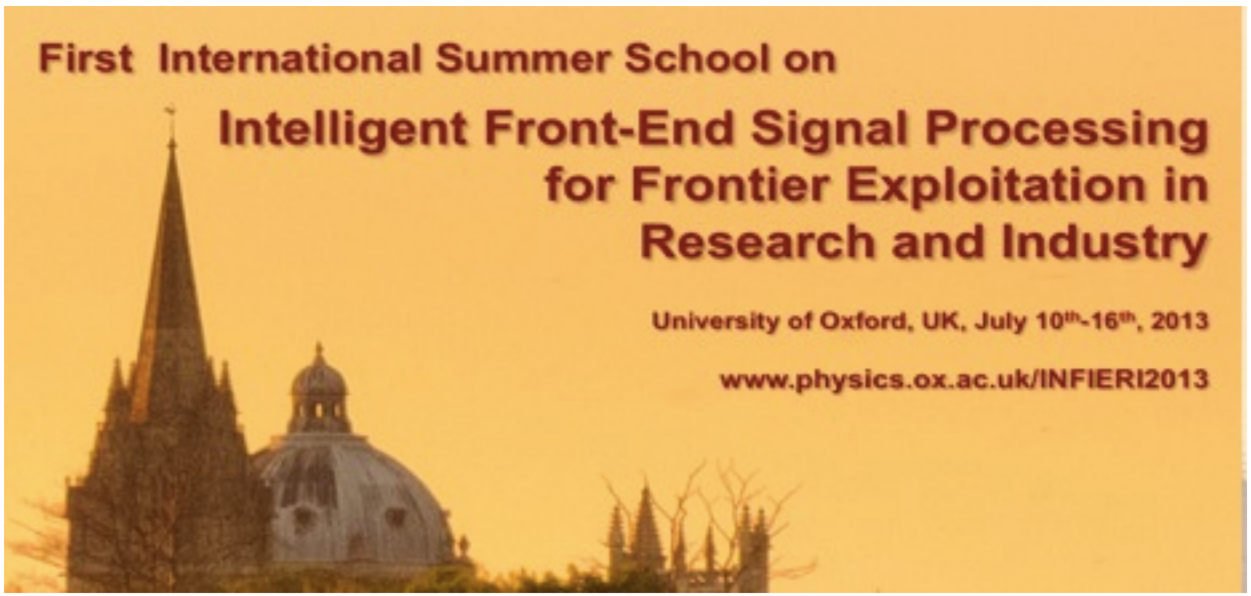
The after-Higgs discovery: vision on the Particle Physics strategy



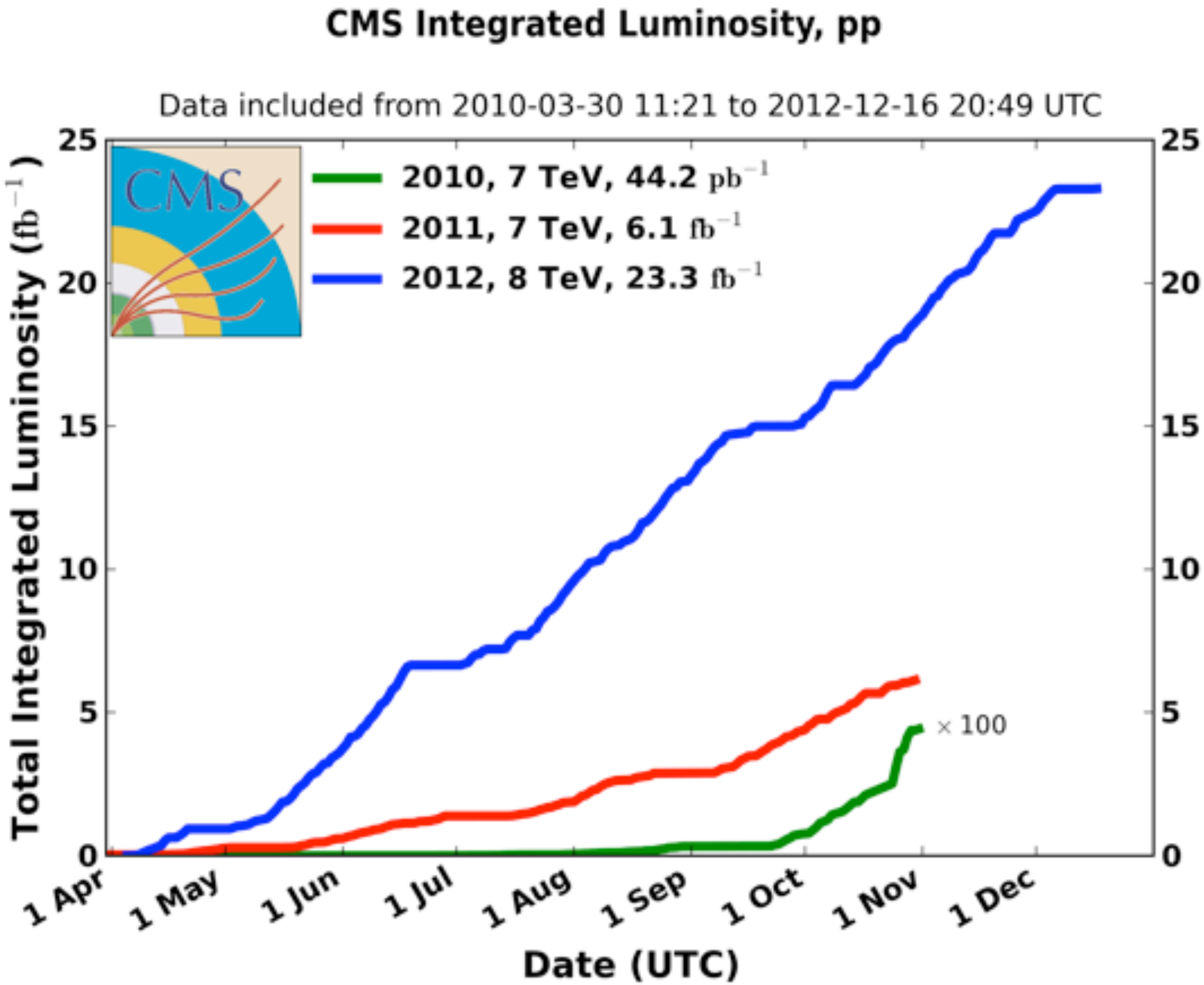
LHC: now and in the future

Gigi Rolandi
CERN & Scuola Normale Superiore

LHC: status

- LHC run 1 ended on February 14, 2013
- A fantastic concurrency of exceptional performances from the accelerators, experiments and computing
- LS1 is now in full swing, while data analysis is proceeding at full speed.
- A very busy and important period in front of us

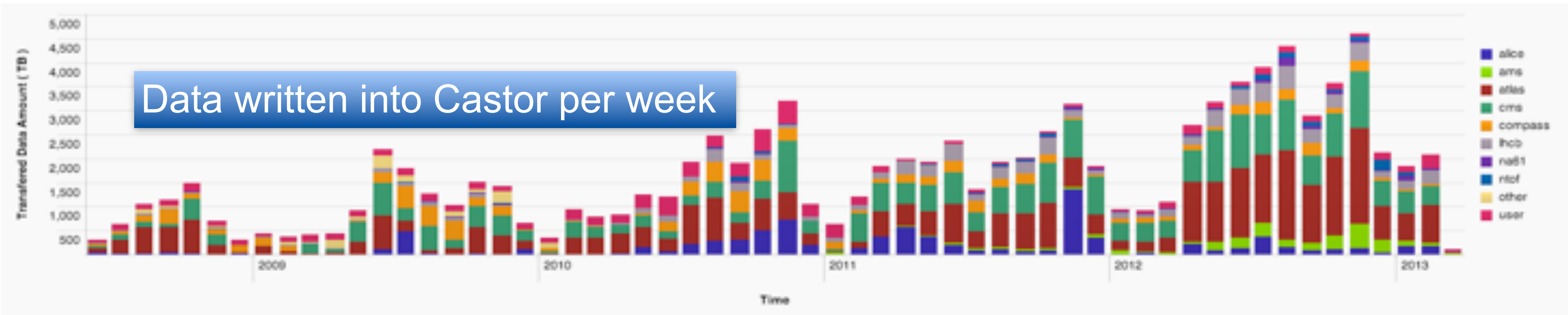
Last 3 years



CMS Integrated Luminosity, pp
Data included from 2010-03-30 11:21 to 2012-12-16 20:49 UTC
2010, 7 TeV, 44.2 pb⁻¹
2011, 7 TeV, 6.1 fb⁻¹
2012, 8 TeV, 23.3 fb⁻¹
× 100
Total Integrated Luminosity (fb⁻¹)
Date (UTC)
1 Apr
1 May
1 Jun
1 Jul
1 Aug
1 Sep
1 Oct
1 Nov
1 Dec
0
5
10
15
20
25
CMS

WLCG Status

Record amounts of data acquired ~30 PB in 2012; CERN archive now ~100 PB
Peaks of >4.6 PB/week in November

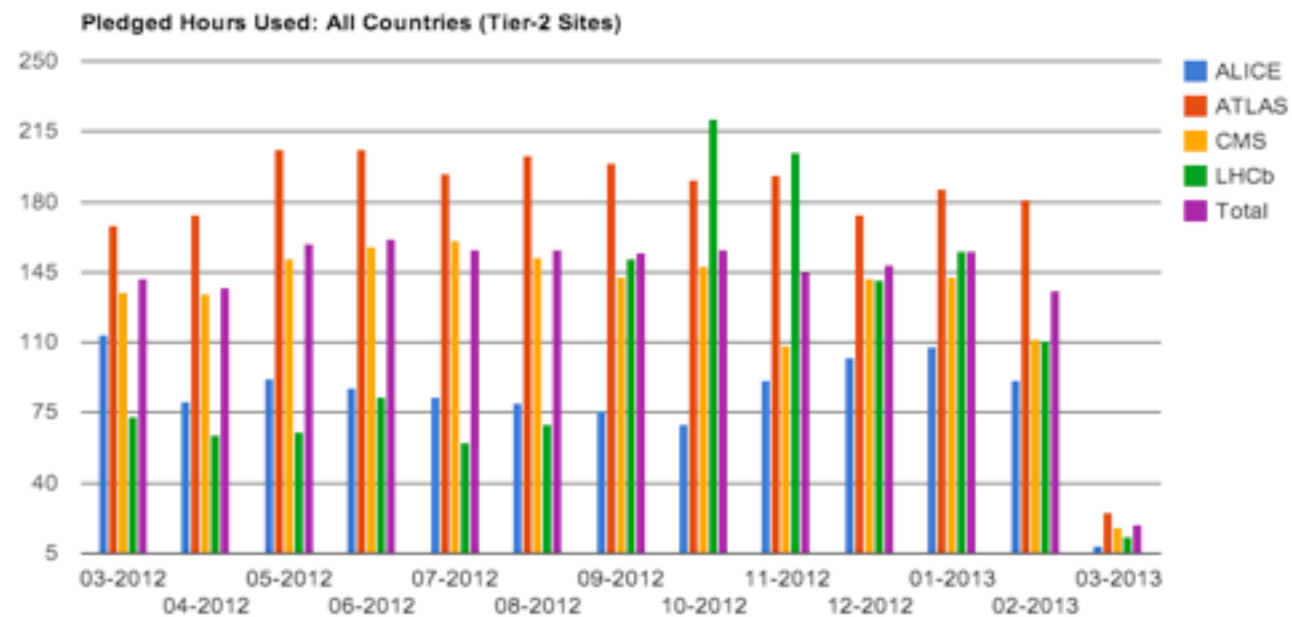


All resources fully used:
~ 2 million jobs/day

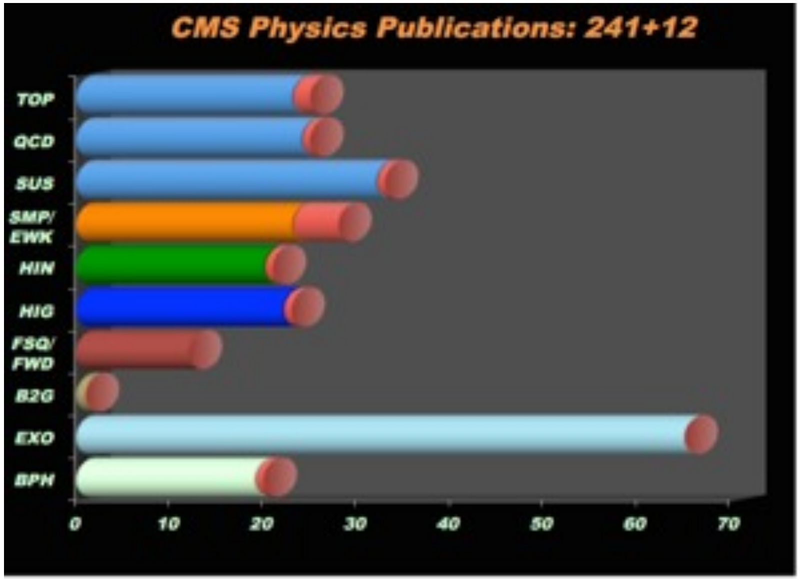
Use of CPU vs pledges
(plot shows Tier 2s)

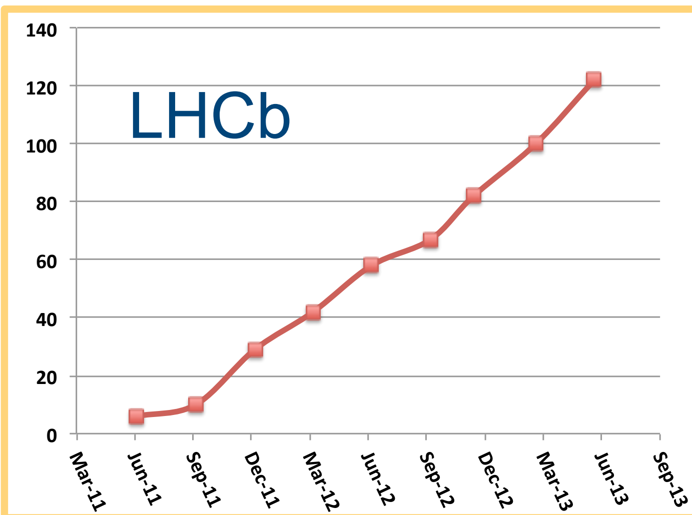
>100% for Tier 1 & 2

Occupation of Tier 0 will
→ 100% during LS1



Published papers



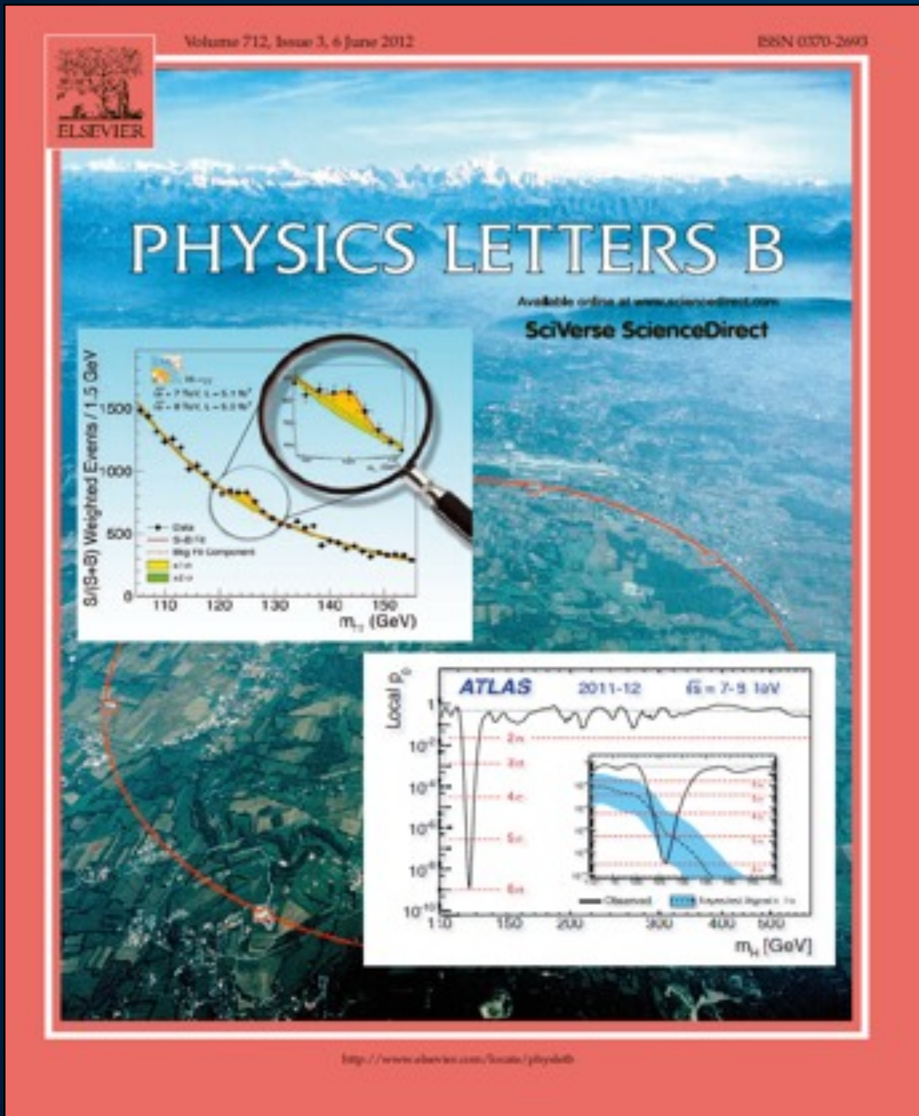


+

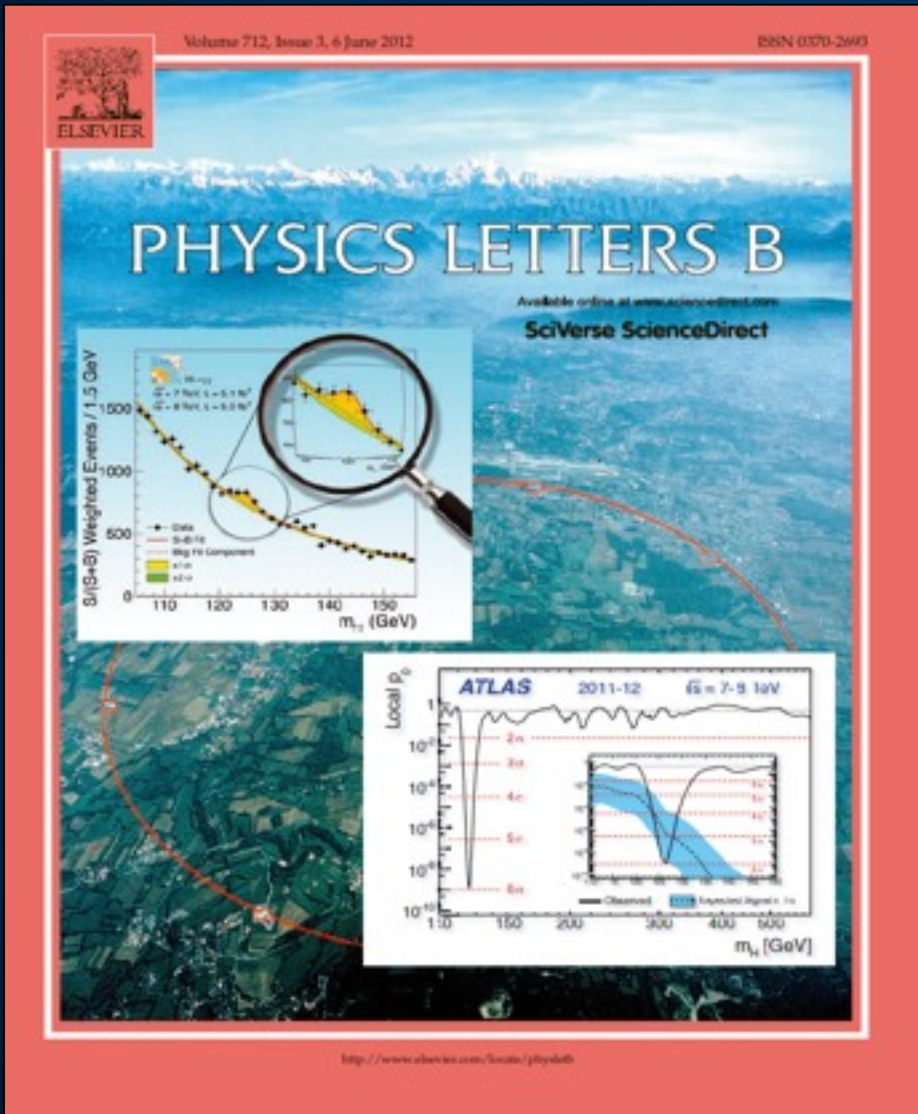
- 66 from ALICE
- 9 from TOTEM
- 9 from LHCf

The highlight of a remarkable year 2012

The highlight of a remarkable year 2012



The highlight of a remarkable year 2012

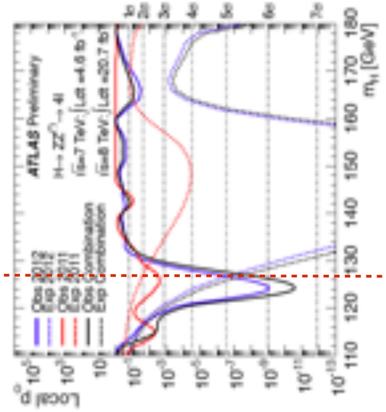


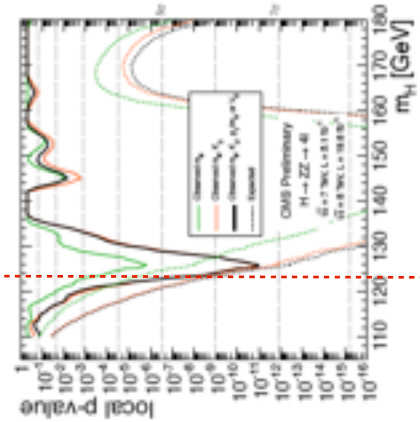
Where we stand

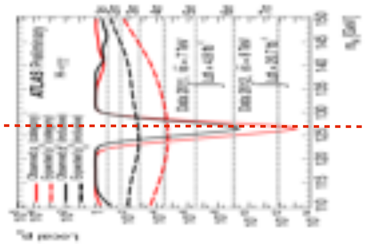
Where we stand

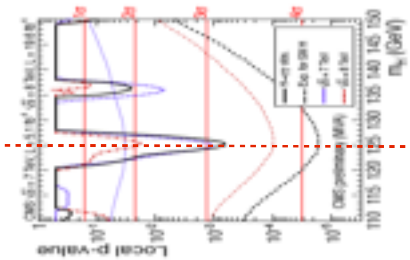
- ✓ **There is a new boson of mass ~125 GeV, with properties consistent with the SM Higgs, within the current uncertainties. More data needed to ascertain the nature of this object.**

A new particle: no doubt that it is there…









>6σ	>6σ	>7σ	>3σ
10^{-11}	10^{-11}	10^{-13}	10^{-3}

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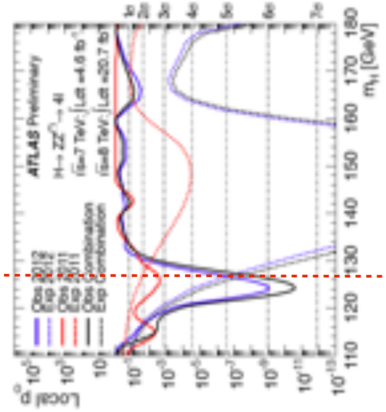
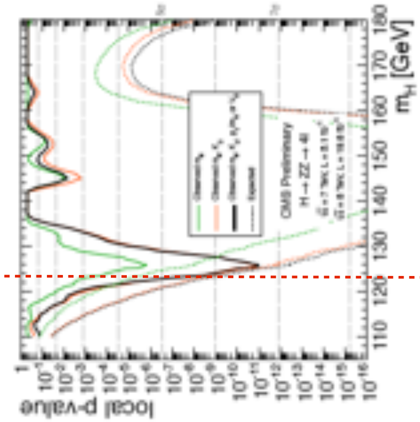
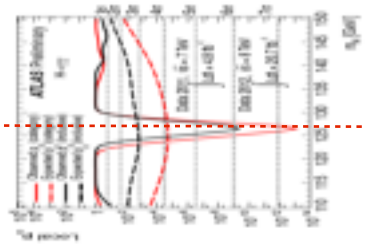
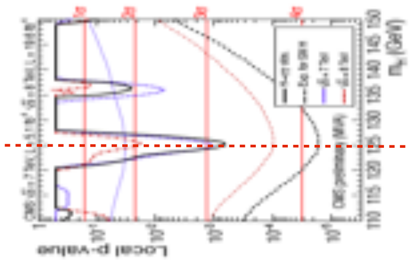






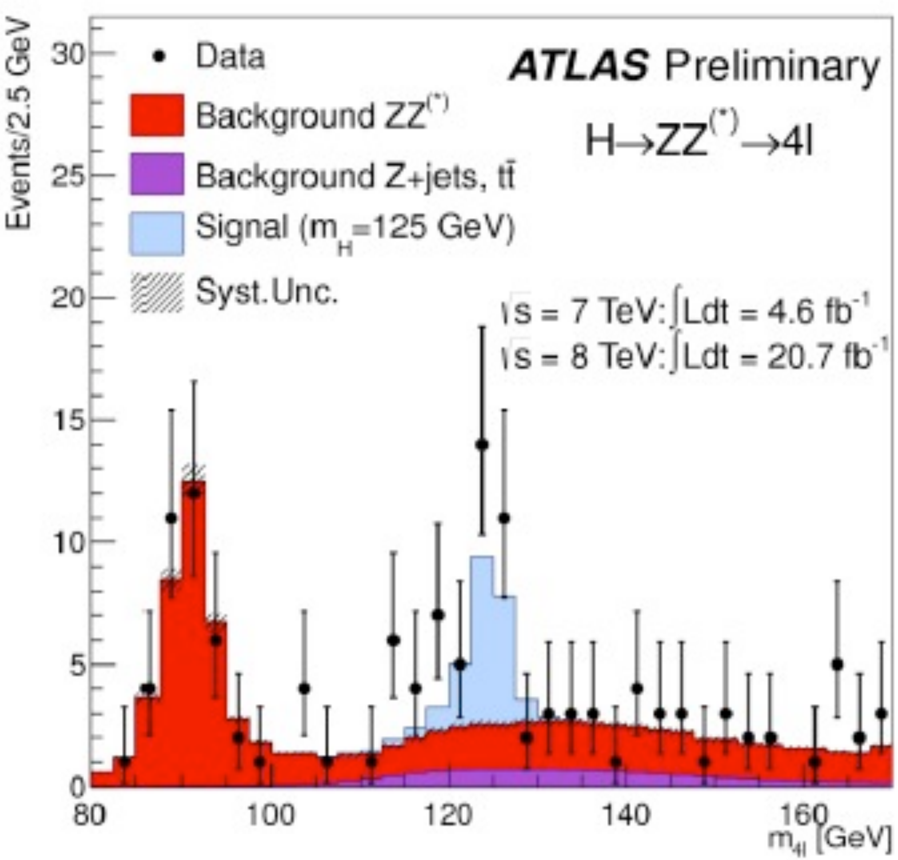


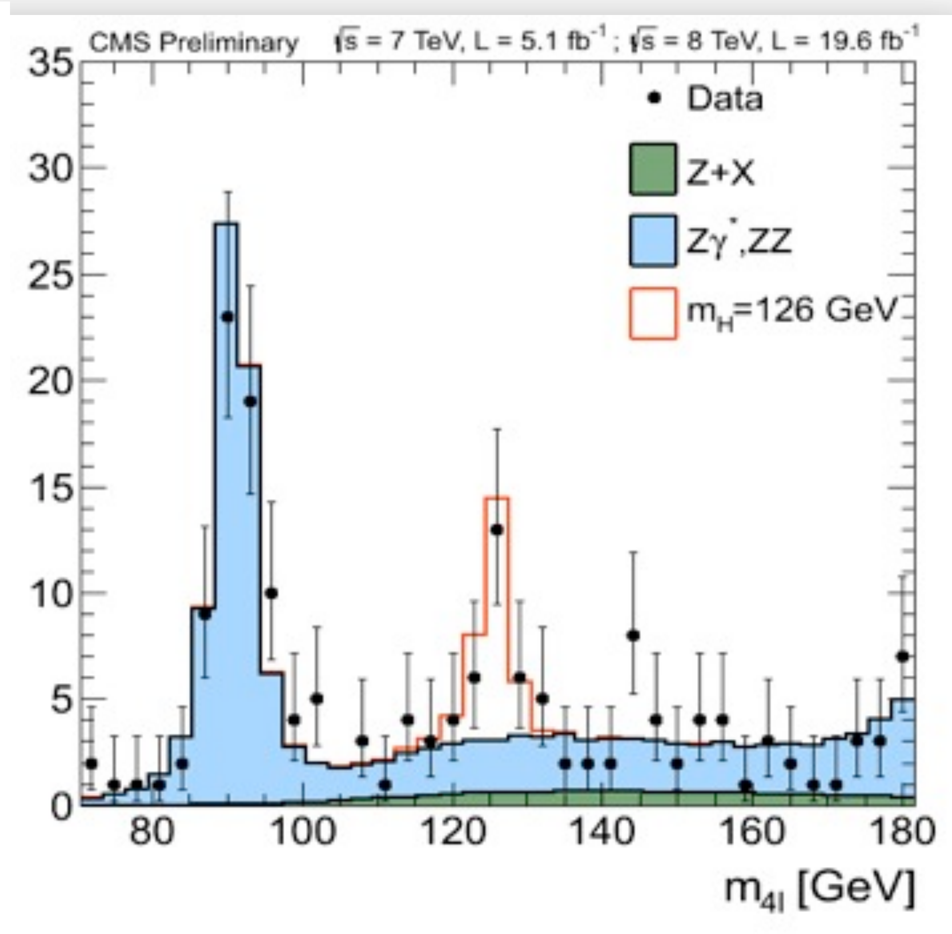
>6σ	>6σ	>7σ	>3σ
10^{-11}	10^{-11}	10^{-13}	10^{-3}

$$10^{-38}$$

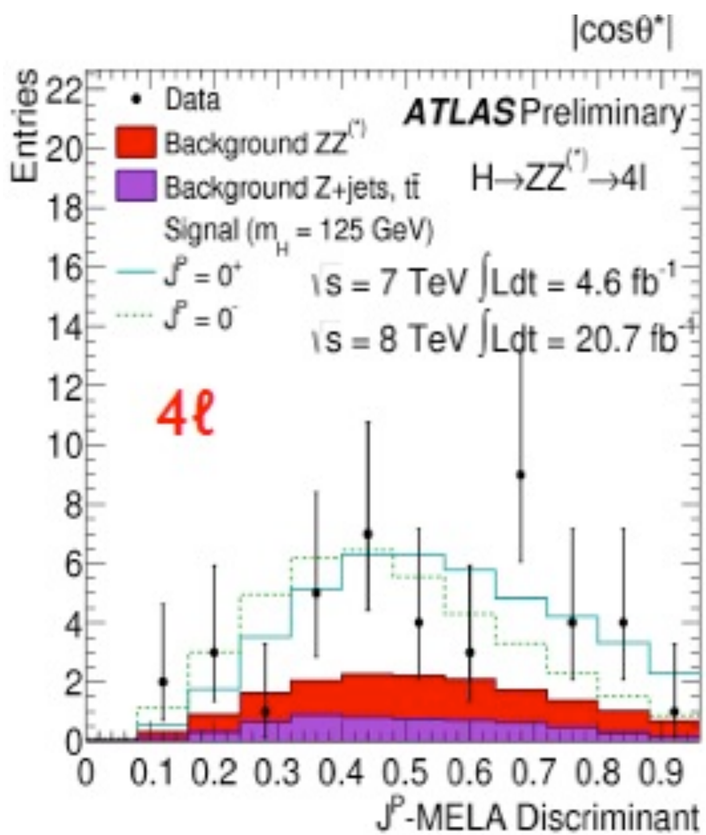
A new particle: no doubt that it is there…

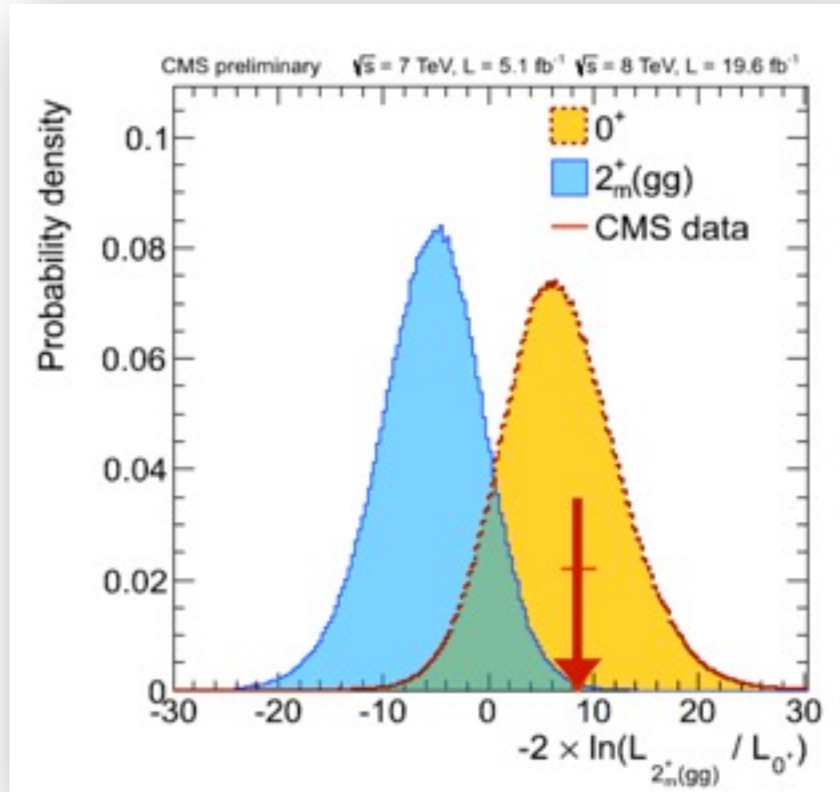
By now we can establish it with a single decay channel!
e.g. $H \rightarrow ZZ \rightarrow 4l$



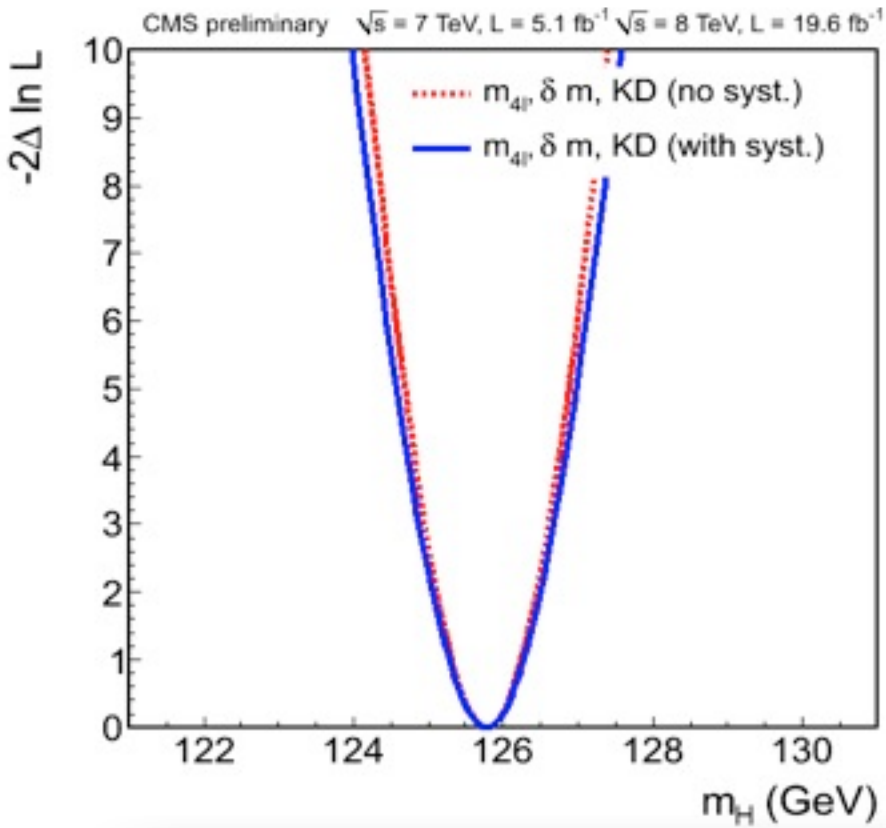


…it prefers 0+ quantum numbers

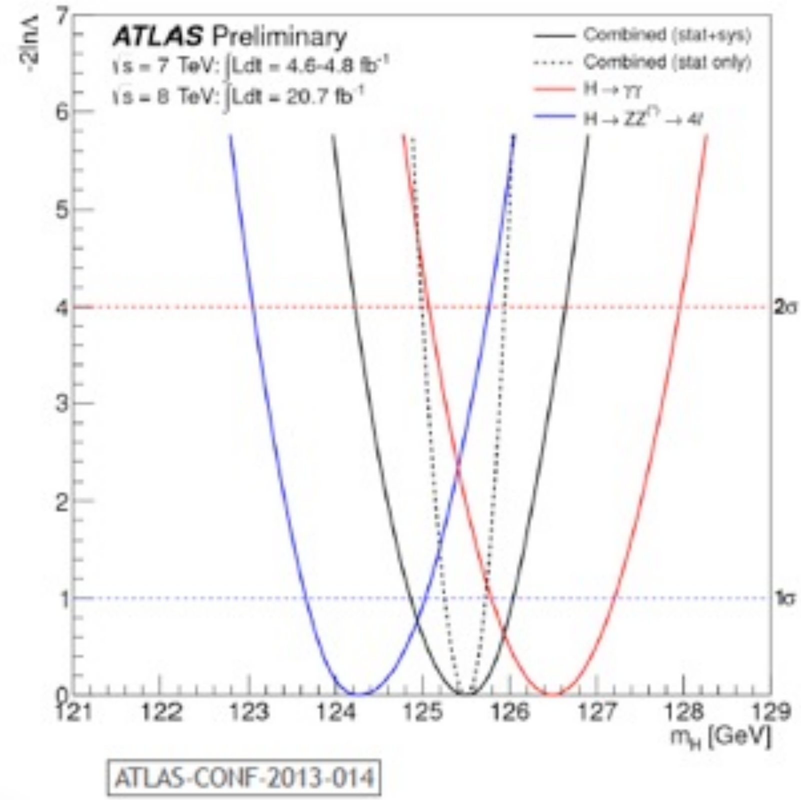




…its mass is measured to .5%

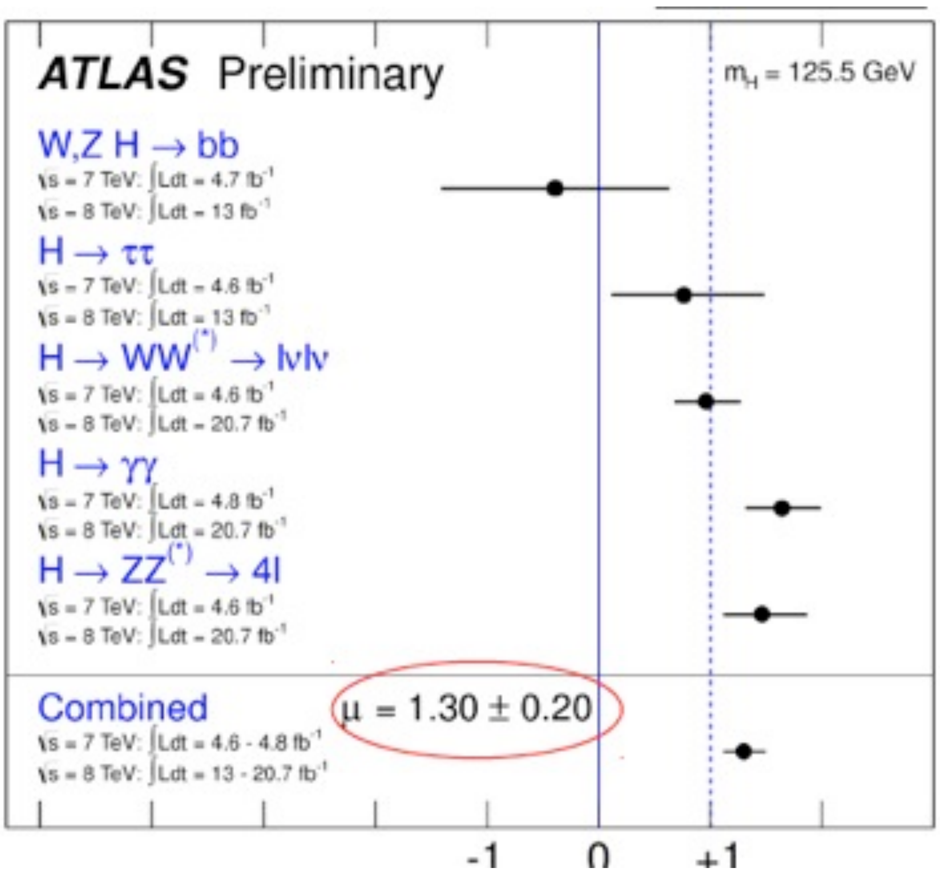


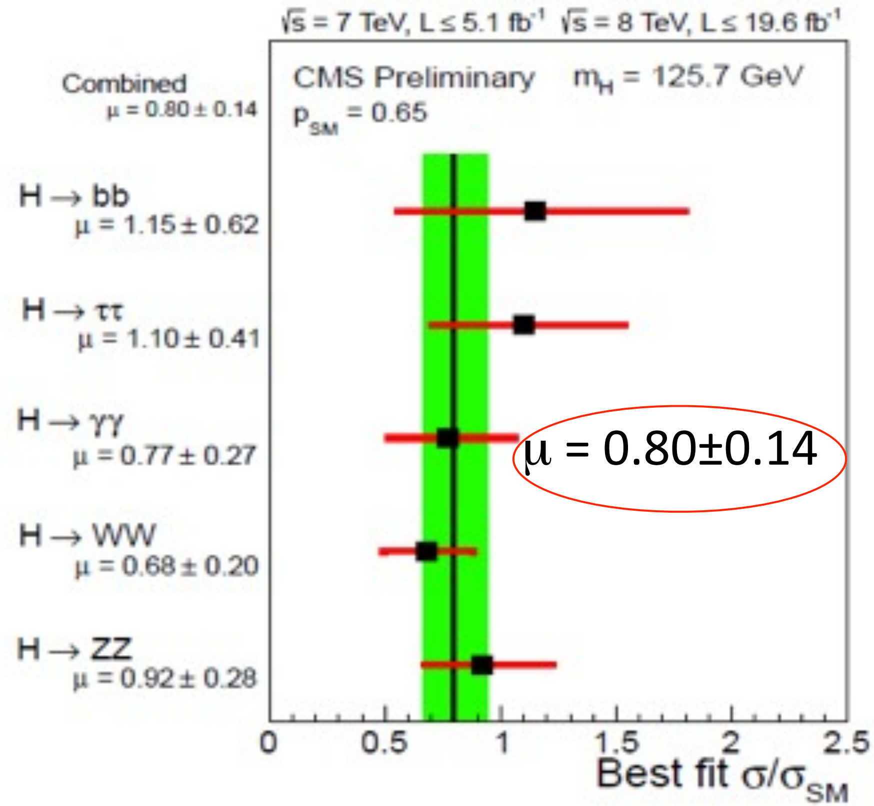
$125.8 \pm 0.5(stat.) \pm 0.2(syst.)$



$m_H = 125.5 \pm 0.2 \pm ^{0.5}_{0.6}$ GeV

…and the signal strength is compatible with a SM Higgs





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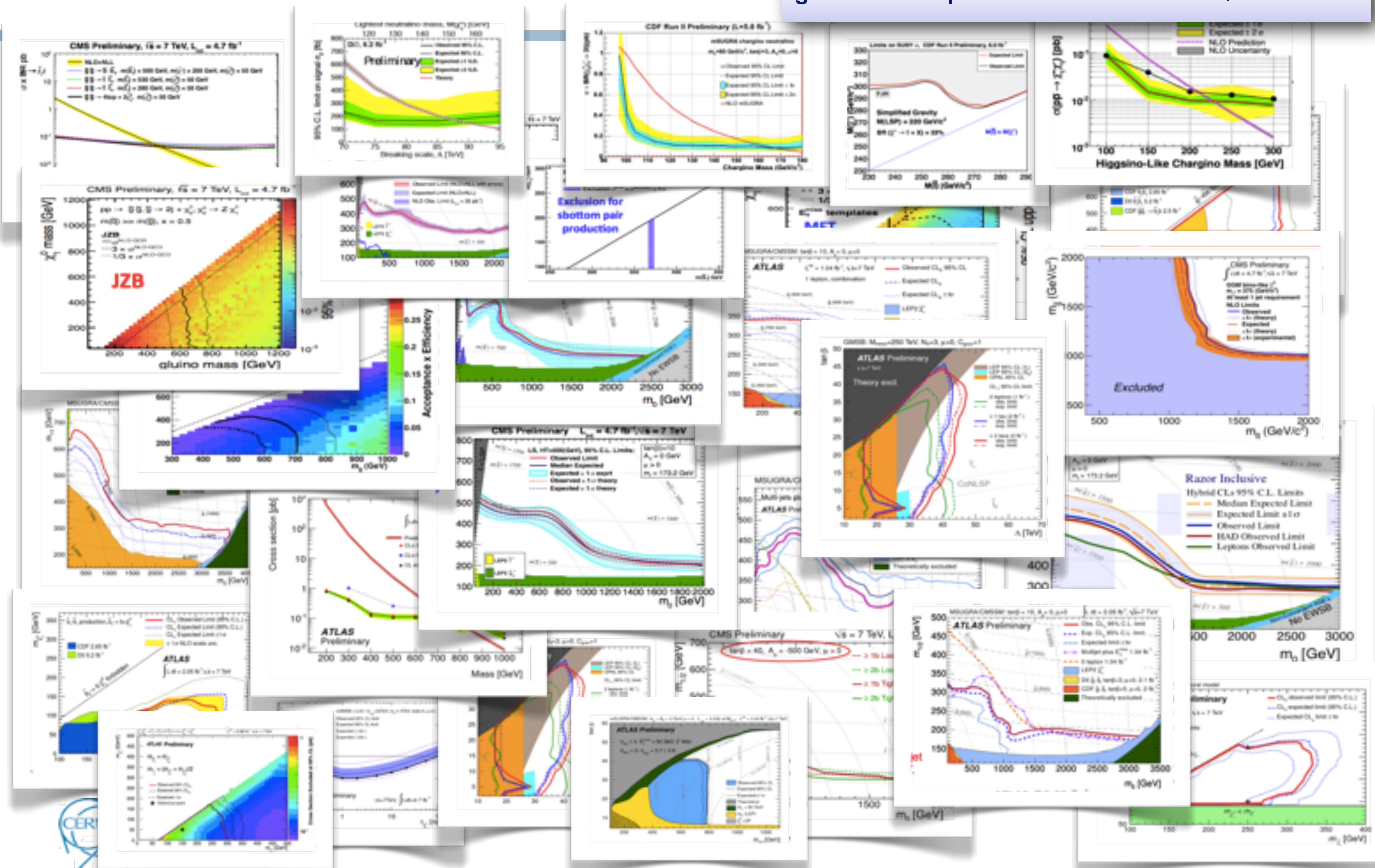
  - exotica: heavy objects probed up to masses of 2-3 TeV;
  - a lot of room still to be explored, **14 TeV will be essential**!

BSM: we have searched....

eg. exclusions plots shown at Moriond QCD 2012....



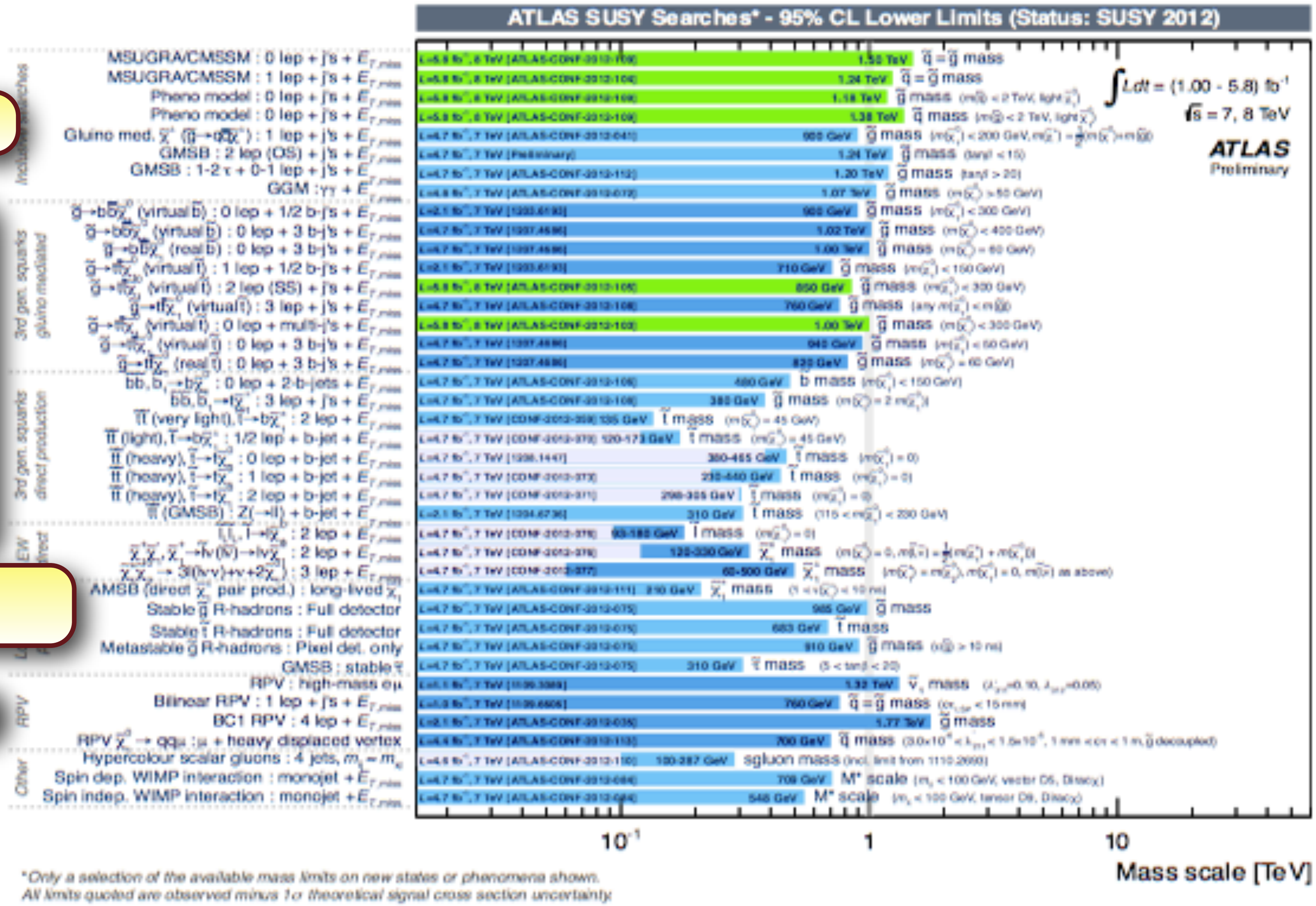
The big picture

inclusive searches

Natural SUSY

long-lived particles,
eg. split SUSY

RPV



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CombinedSummaryPlots

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LHCb rare decay $B_s \rightarrow \mu\mu$

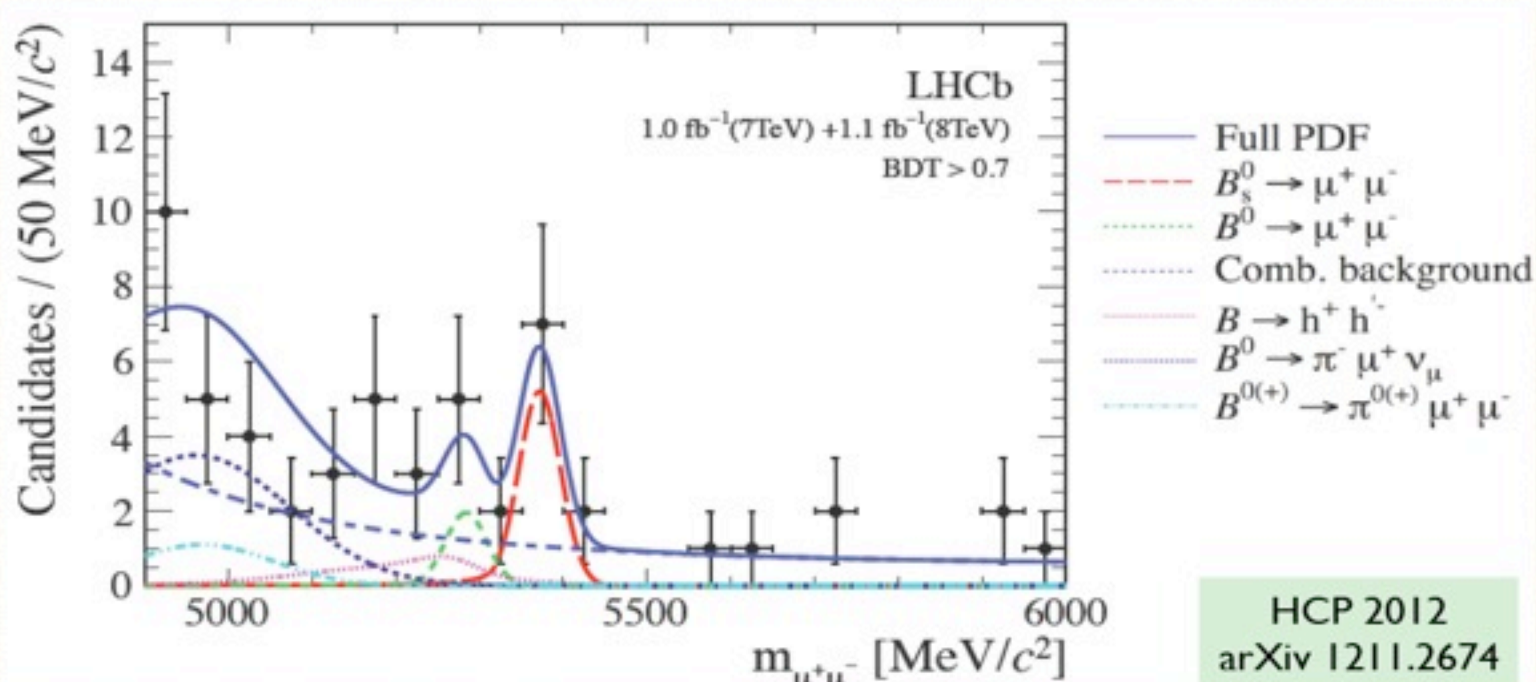
LHCb

The search for $B_{s\,(d)} \rightarrow \mu\,\mu$

Branching fractions extracted from unbinned maximum likelihood fit to the mass spectra in 8 (7 TeV) and 7 (8 TeV) bins in BDT

$\mathcal{B}(B^0_s \rightarrow \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$

SM: $BR(B_s \rightarrow \mu\,\mu) = 3.5 \pm 0.2\ 10^{-9}$



HCP 2012
arXiv 1211.2674

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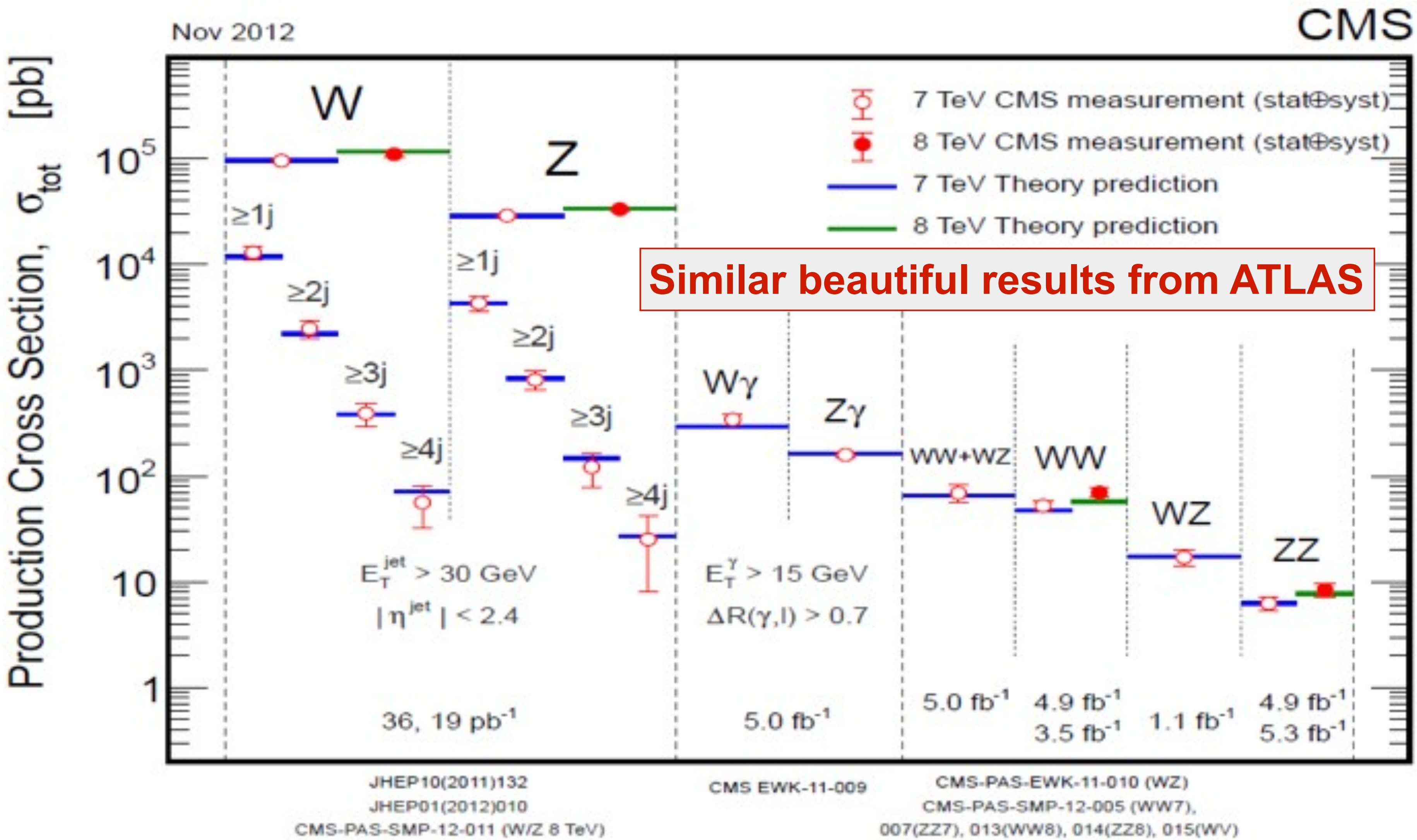
- **The SM (in terms of its QCD and EWK parts) works perfectly well, up to the % level, at the highest energies probed so far (7 and 8 TeV)**.

- **We have very advanced theory tools at hand, but we will need even better ones!**

A summary of Standard Model measurements



Similar beautiful results from ATLAS

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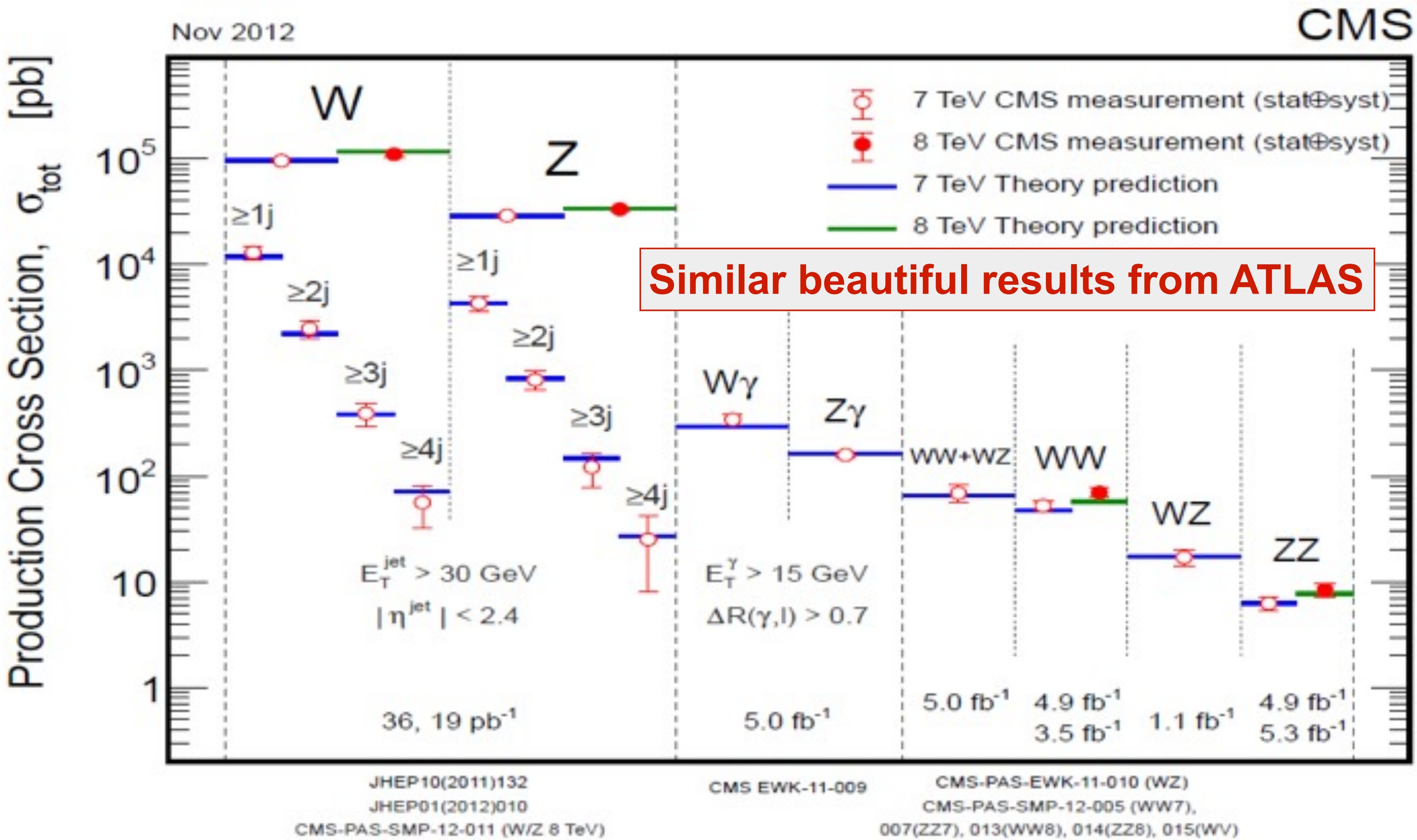
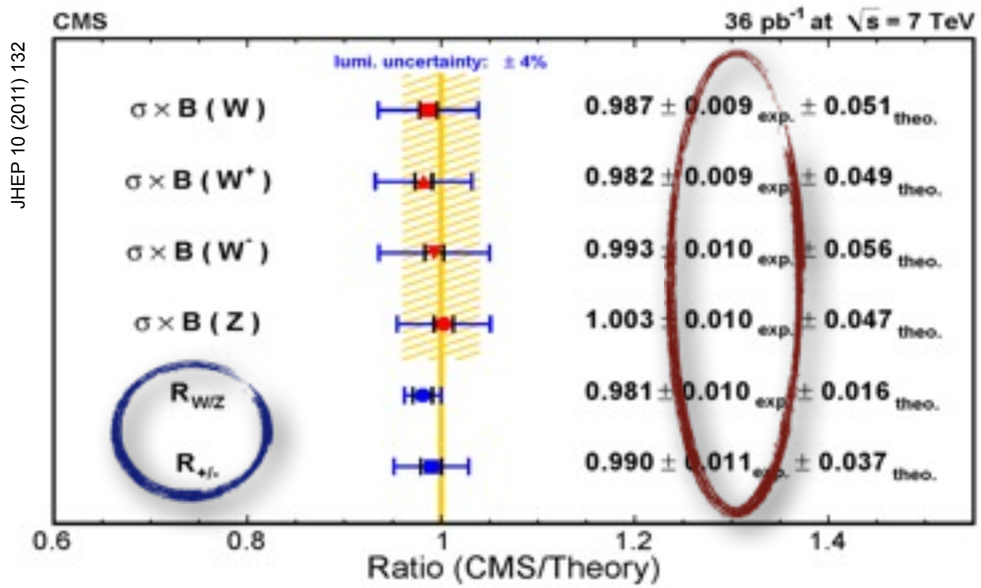


Similar beautiful results from ATLAS

The excellent performance in measuring Standard Model physics gives confidence for the readiness of the two experiments to search for New Physics

W/Z (+Jet) Production

Inclusive



- incl. cross sections:
- experimental precision at the 1% level, especially for ratio-observables
- excellent agreement with NNLO QCD, both at 7 and 8 TeV
- many diff. distributions measured

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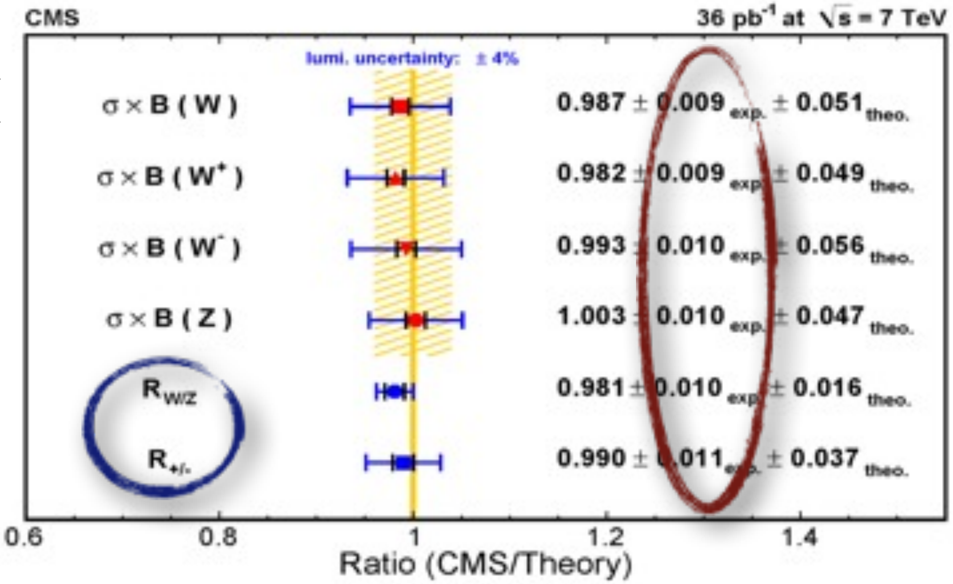
Inclusive

JHEP 10 (2011) 132



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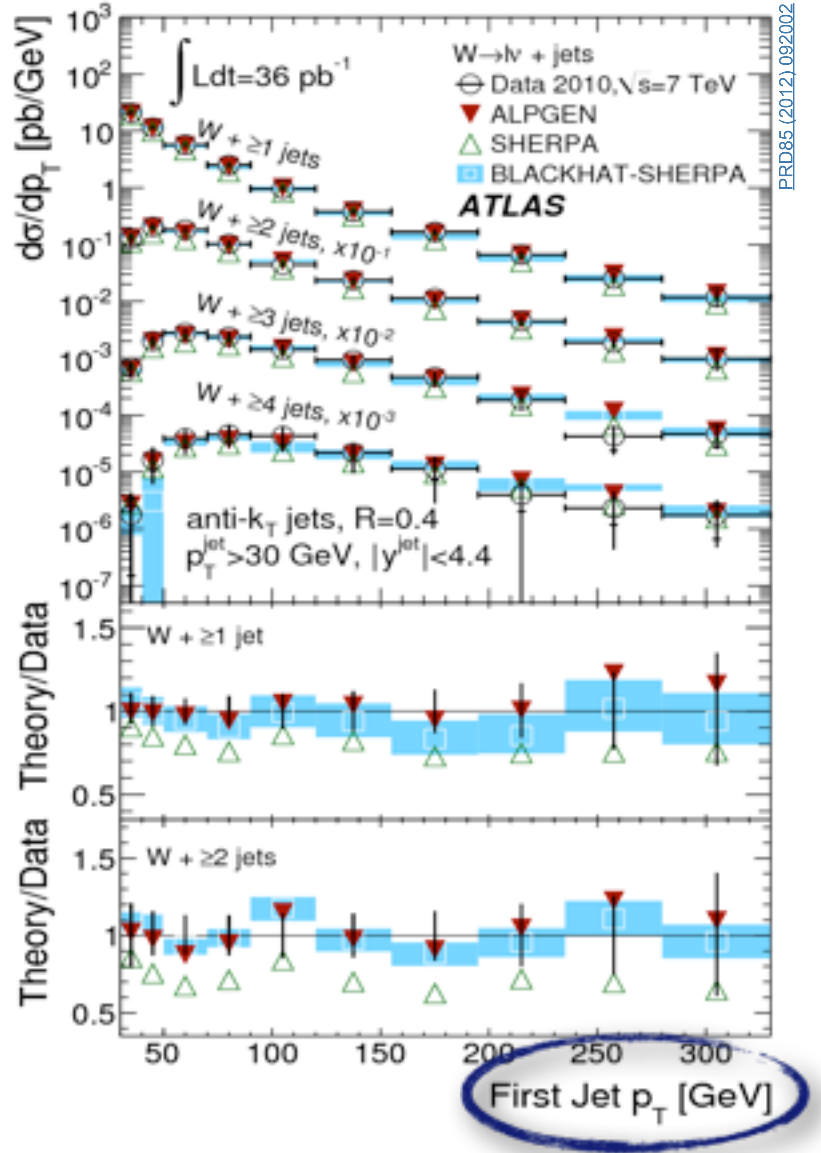
- V+jets:
- “triumph” for MCs with matched matrix elements and parton showers
- also multi-leg NLO calculations available by now
- confidence in background predictions for many searches

+jets



PRD85 (2012) 092002

But, despite its success…

…. we know that the Standard Model is not complete because:

- It doesn’t solve the hierarchy problem
- It has no explanation for dark matter/dark energy
- Its mechanisms of CPV are too small to explain matter/antimatter imbalance
- It cannot provide a QFT of gravitation
- ….etc

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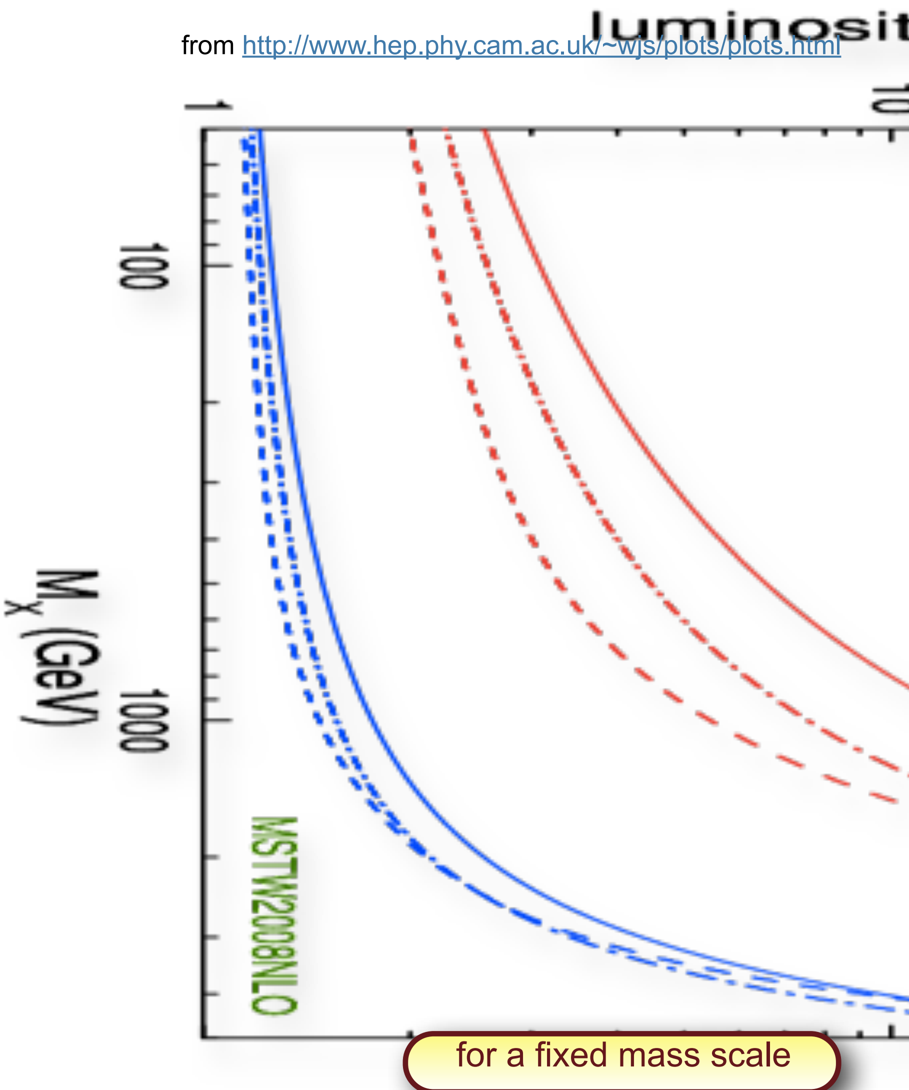
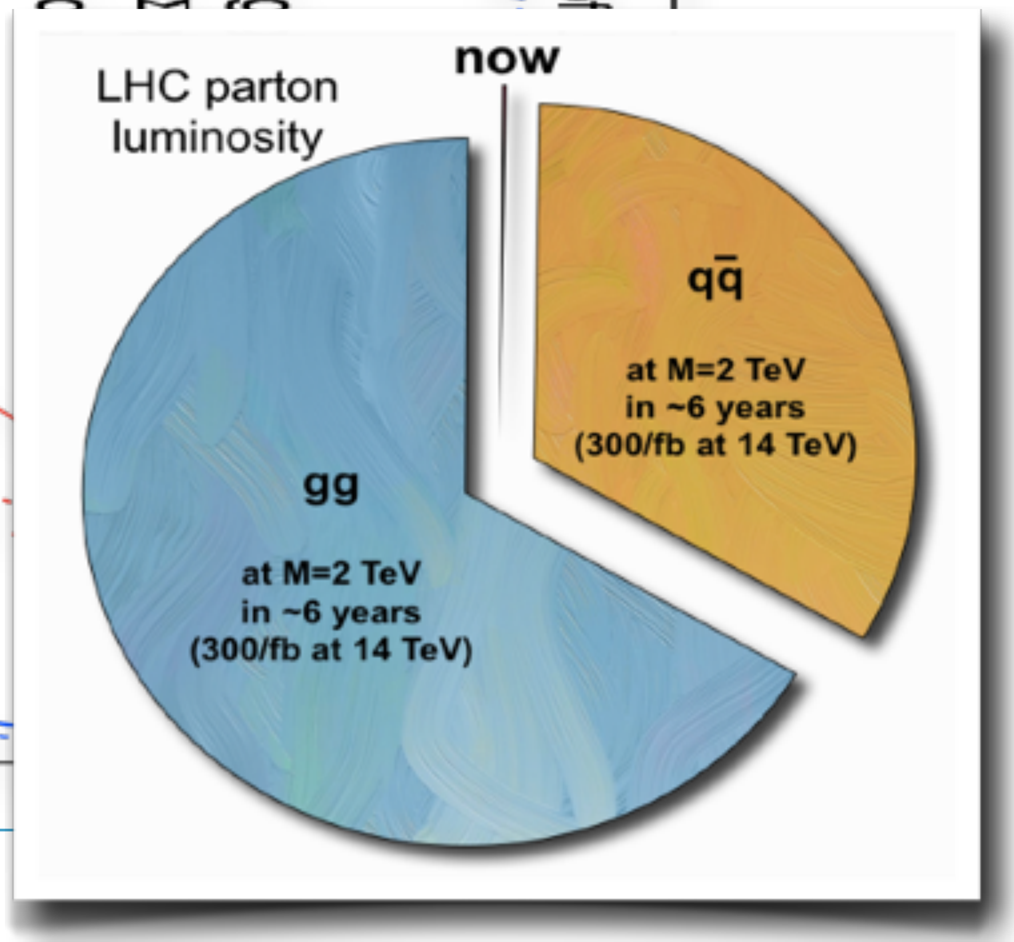
- **We have very advanced theory tools at hand, but we will need even better ones!**

- **Most important: at the LHC, we are JUST AT THE BEGINNING of the HEF exploration!**

Parton luminosities

from http://www.hep.phy.cam.ac.uk/~wjs/plots/plots.html





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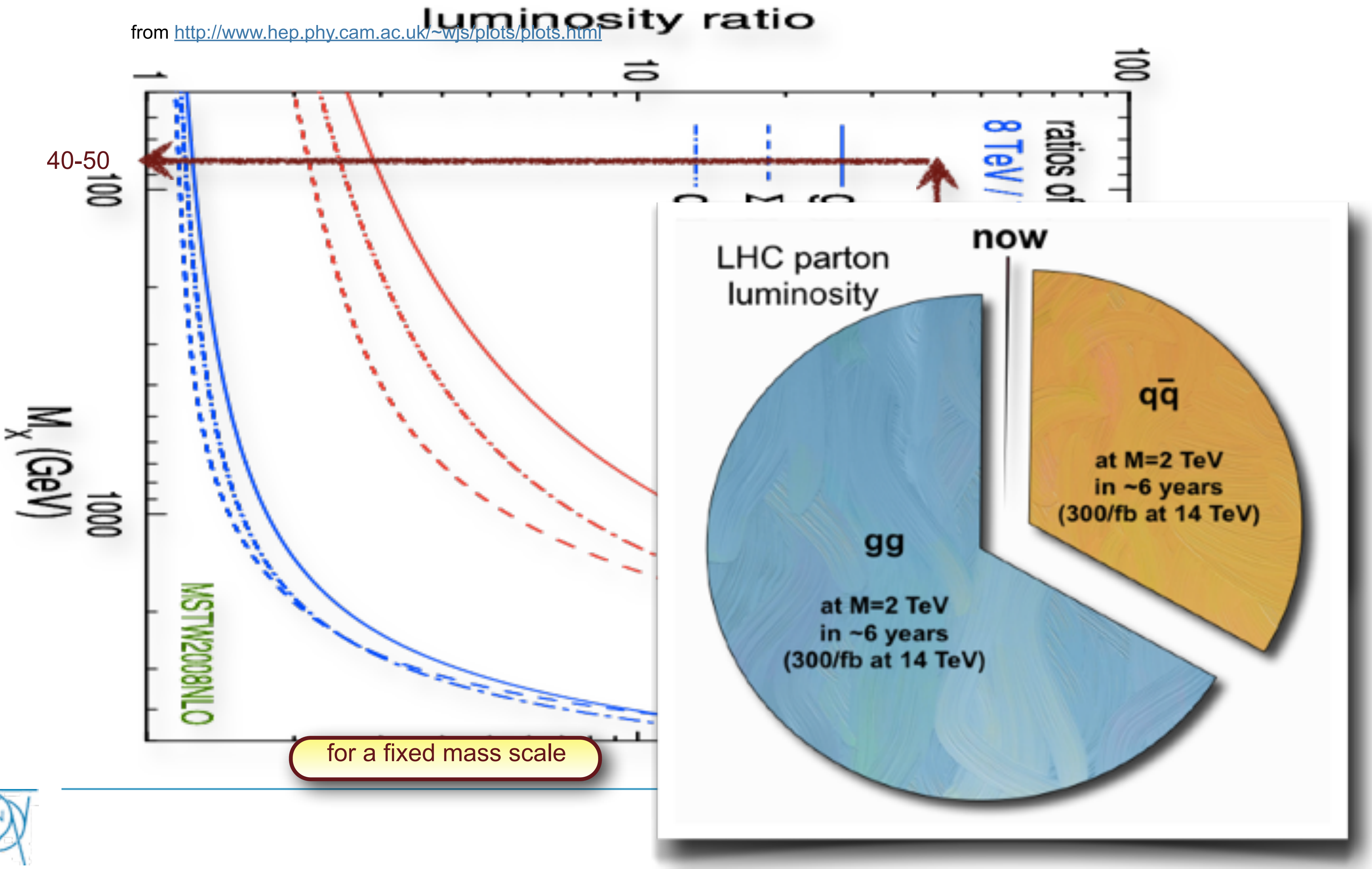
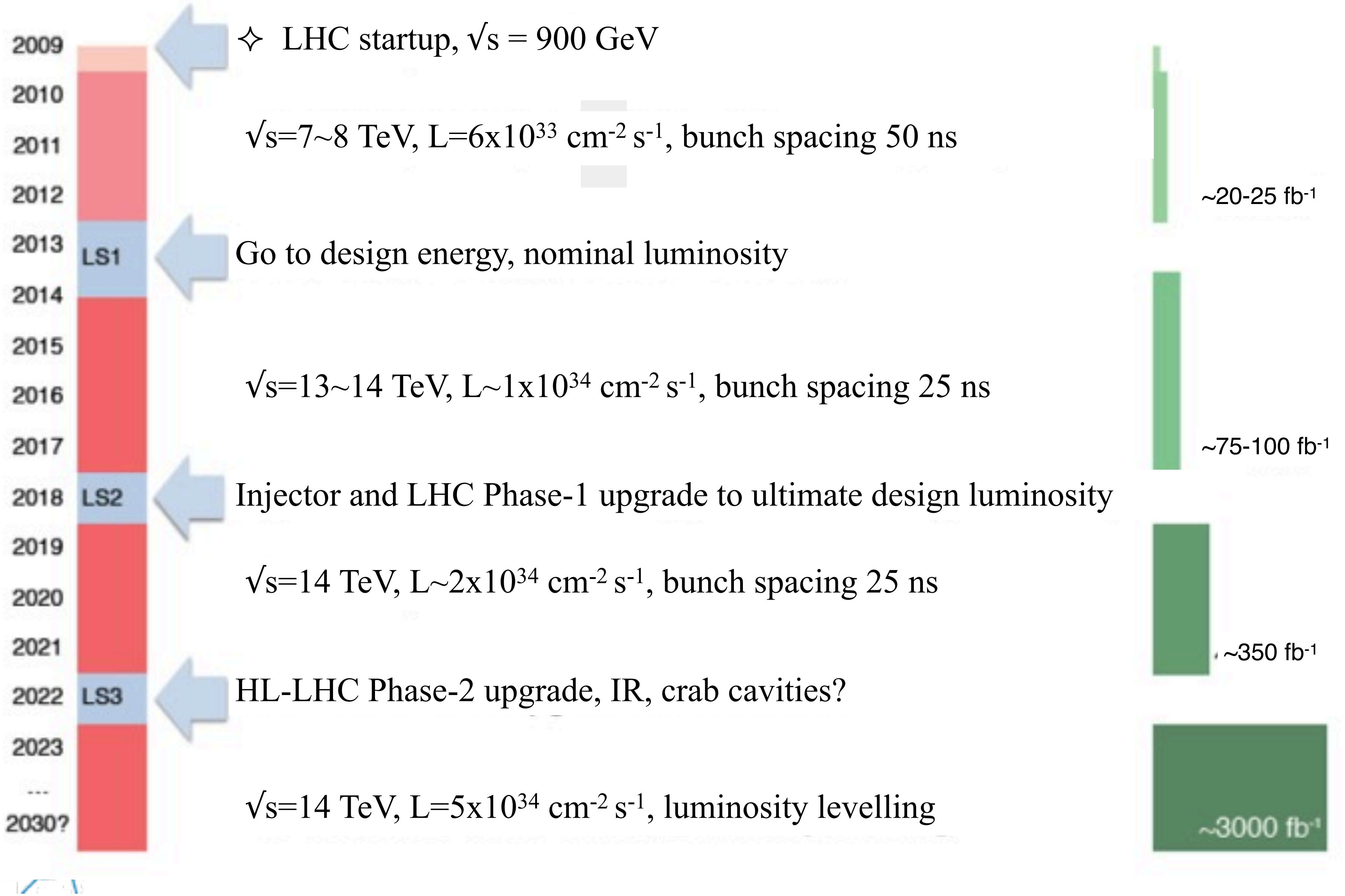


LHC, the next 20 years



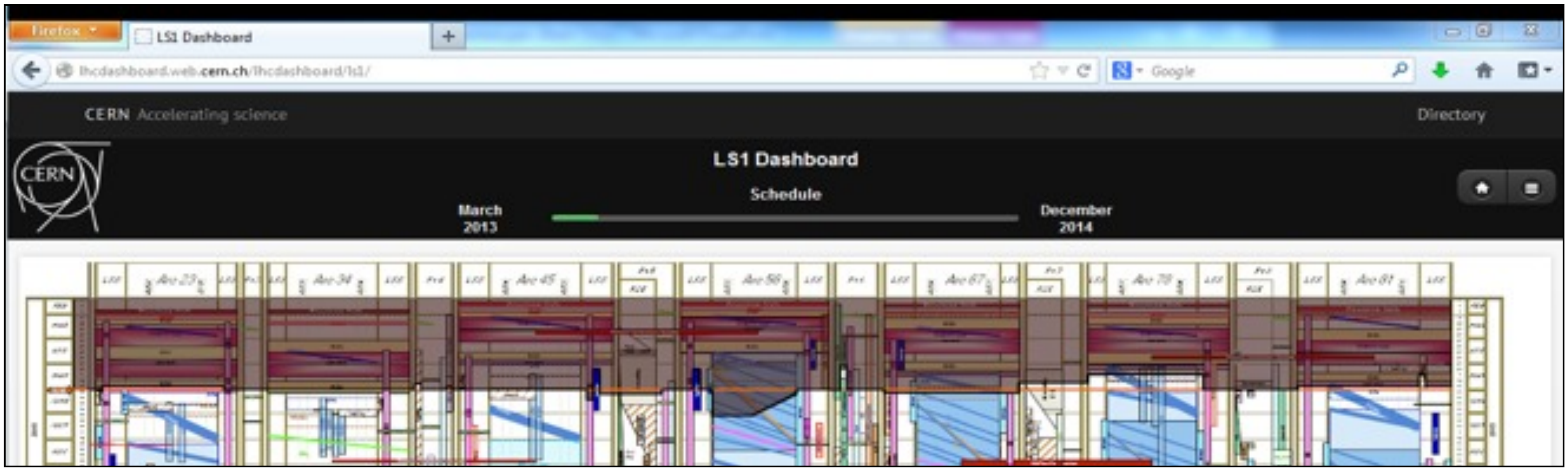
The machine – LS1

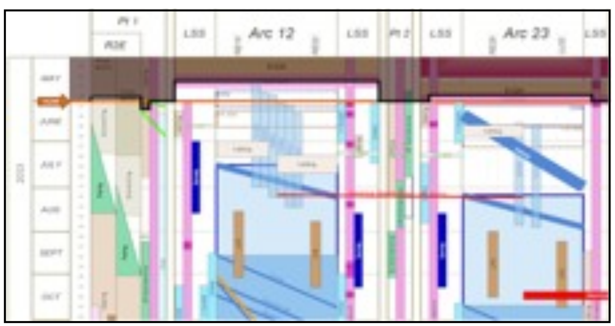
- Repair defective interconnects
- Consolidate all interconnects with new design
- Finish off pressure release valves (DN200)
- Bring all necessary equipment up to the level needed for 7 TeV/beam

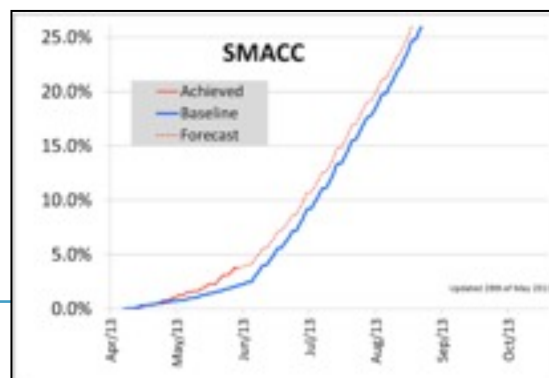
Dashboards

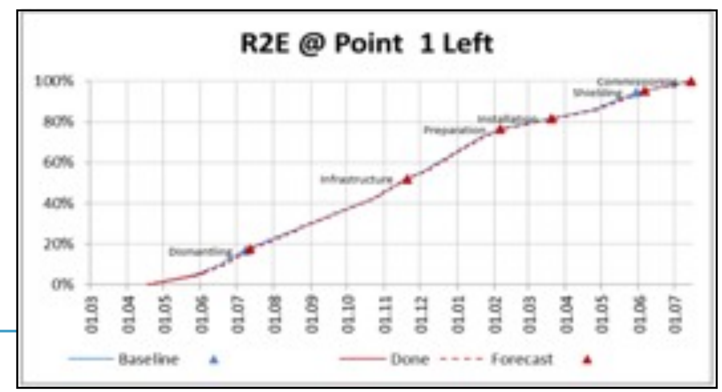
- General and detailed progress

  http://lhcdashboard.web.cern.ch/lhcdashboard/ls1/









Then…

- E=6.5TeV
- β^* = 0.5m (maybe 0.4)
- All other conditions as in 2012 i.e. LHC availability same, etc..

Potential performance

	Number of bunches	Ib LHC FT[1e11]	Collimator scenario	Emit LHC (SPS) [um]	Peak Lumi [cm-^{2}s^{-1}]	~Pile-up	Int. Lumi [fb^{-1}]
25 ns	2760	1.15	S1	3.5 (2.8)	9.2e33	21	24
25 ns low emit	2320	1.15	S4	1.9 (1.4)	1.6e34	43	42
50 ns	1380	1.6	S1	2.3 (1.7)	1.7e34 level	76 level	~45*
50 ns low emit	1260	1.6	S4	1.6 (1.2)	2.2e34	108	…

- 6.5 TeV
- 1.1 ns bunch length
- 150 days proton physics, HF = 0.2
- 70 mb visible cross-section
- * different operational model – caveat - unproven

All numbers approximate

In words

- Nominal 25 ns
  - gives more-or-less nominal luminosity
- BCMS 25 ns
  - gives a healthy 1.6e34
  - peak <mu> around 40
  - 83% nominal intensity
- Nominal 50 ns
  - gives a virtual luminosity of 1.7e34 with a pile-up of over 70
  - levelling mandatory
- BCM 50 ns
  - gives a virtual luminosity of 2.2e34 with a pile-up of over 100
  - levelling even more mandatory

The experiments

A new mode of operations!

- All busy in repairs, consolidations, first upgrades
- Massive amount of work, with a very tight schedule…
- …while keeping looking at the data, prepare for the next energy
- …and proceed to a very substantial progress in their computing models.

It will need a massive recommissioning, if they want to be at the same readiness level as in 2010

The experiments, upgrades

- Fully engaged in the LS2 upgrades, which is particularly demanding for LHCb and ALICE
- Active R&D programs on the BIG upgrades in 2022
- Need to use the coming run to better focus the program

Extending the reach…

- Weak boson scattering
- Higgs properties
- Supersymmetry searches and measurements
- Exotics
- t properties
- Rare decays
- CPV
- ..etc

Experiments are planning a workshop in October 2013 to assess their physics reach and the implications on the detector upgrades and associated R&D

Couplings fit at LHC

CMS

Coupling	Uncertainty (%)			
	300 fb^{-1}		3000 fb^{-1}	
	Scenario 1	Scenario 2	Scenario 1	Scenario 2
κ_γ	6.5	5.1	5.4	1.5
κ_V	5.7	2.7	4.5	1.0
κ_g	11	5.7	7.5	2.7
κ_b	15	6.9	11	2.7
κ_t	14	8.7	8.0	3.9
κ_τ	8.5	5.1	5.4	2.0

CMS Projection

Assumption NO invisible/undetectable contribution to Γ_H:

- Scenario 1: system./Theory err. unchanged w.r.t. current analysis
- Scenario 2: systematics scaled by 1/sqrt(L), theory errors scaled by ½

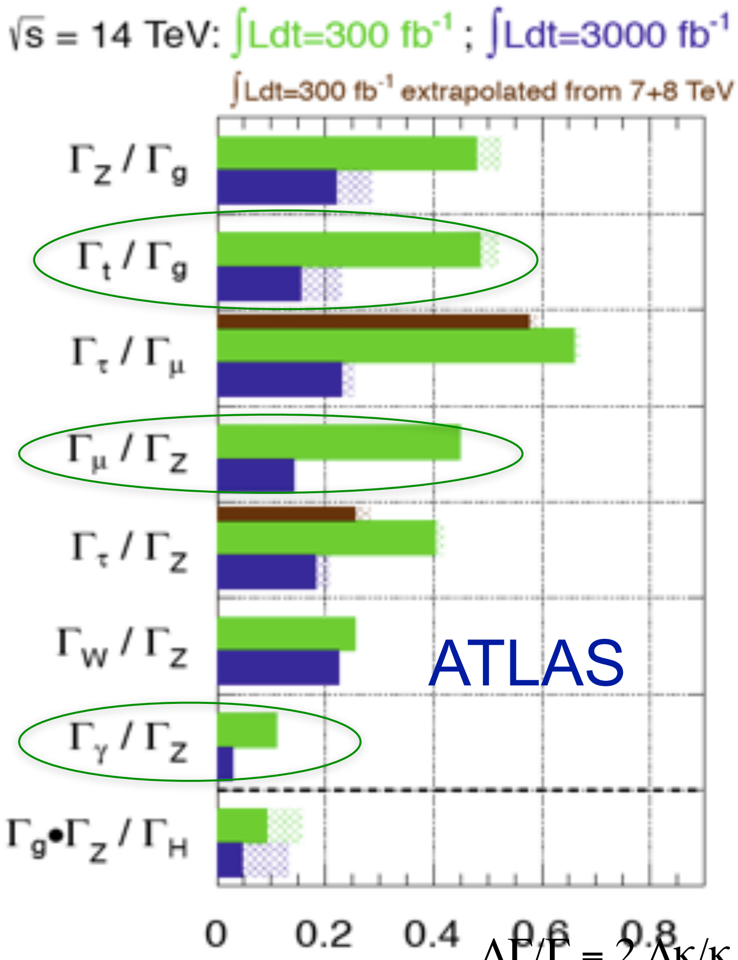
✓ γγ loop at 2-5% level

✓ down-type fermion couplings at 2-10% level

✓ direct top coupling at 4-8% level

✓ gg loop at 3-8% level

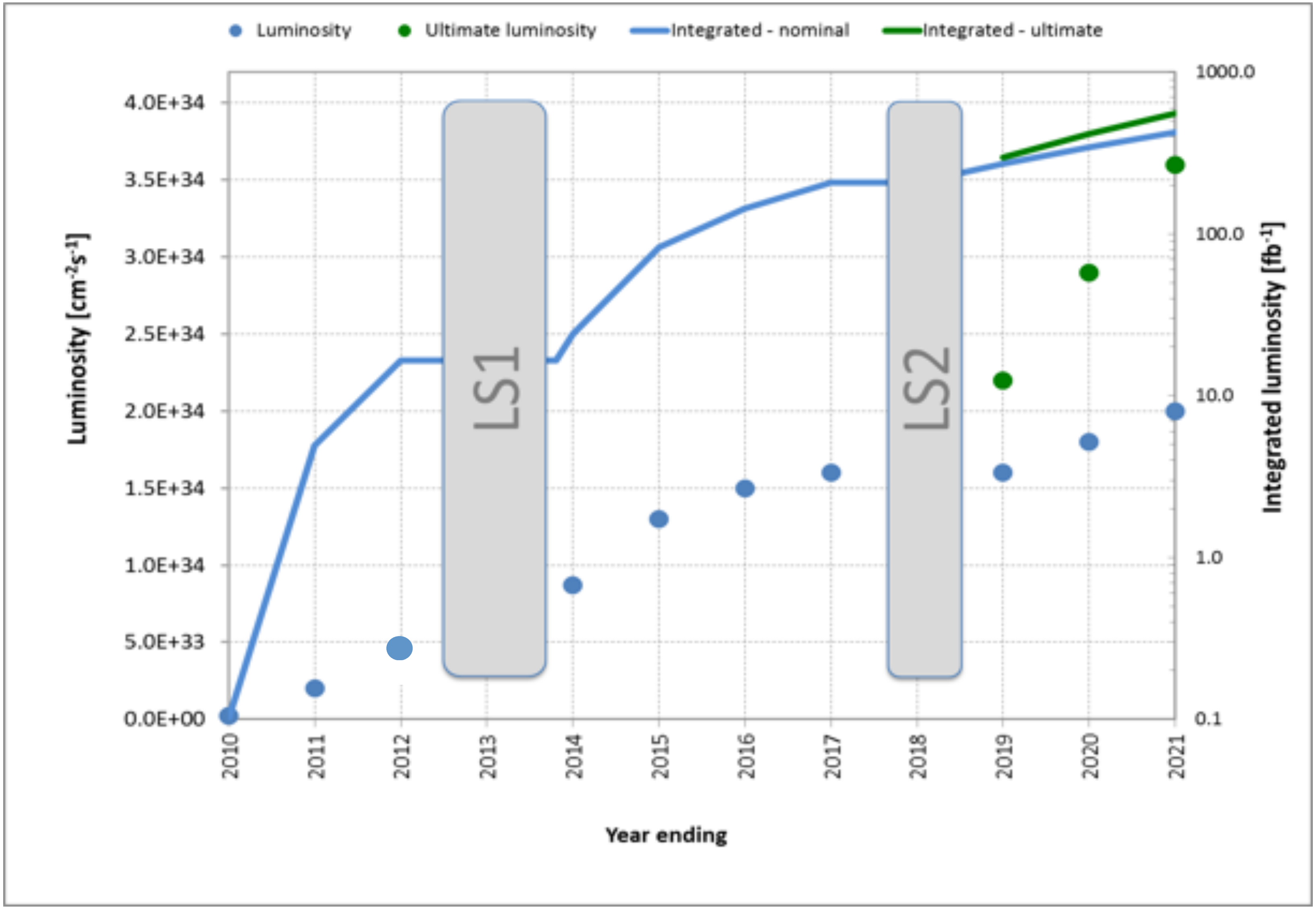
Coupling Ratios Fit at LHC



$\Delta\Gamma/\Gamma = 2\,\Delta\kappa/\kappa$

- Fit to coupling ratios:
  - No assumption BSM contributions to Γ_H
  - Some theory systematics cancels in the ratios
- Loop-induced Couplings $\gamma\gamma$ and gg treated as independent parameter
  - κ_γ/κ_Z tested at 2%
  - gg loop (BSM) κ_t/κ_g at 7-12%

Luminosity: Best Guess for the next 10 years



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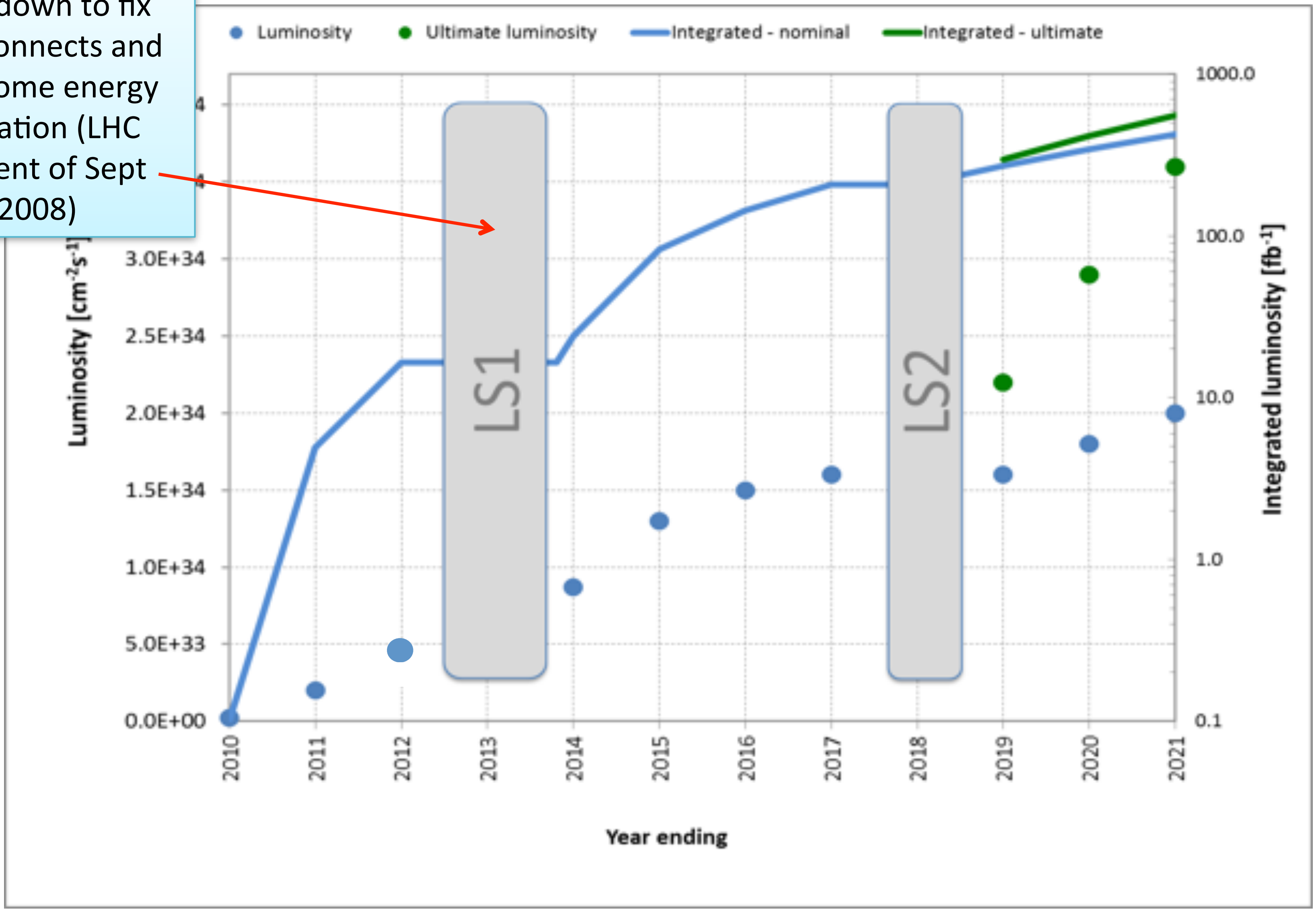
Shut down to fix interconnects and overcome energy limitation (LHC incident of Sept 2008)



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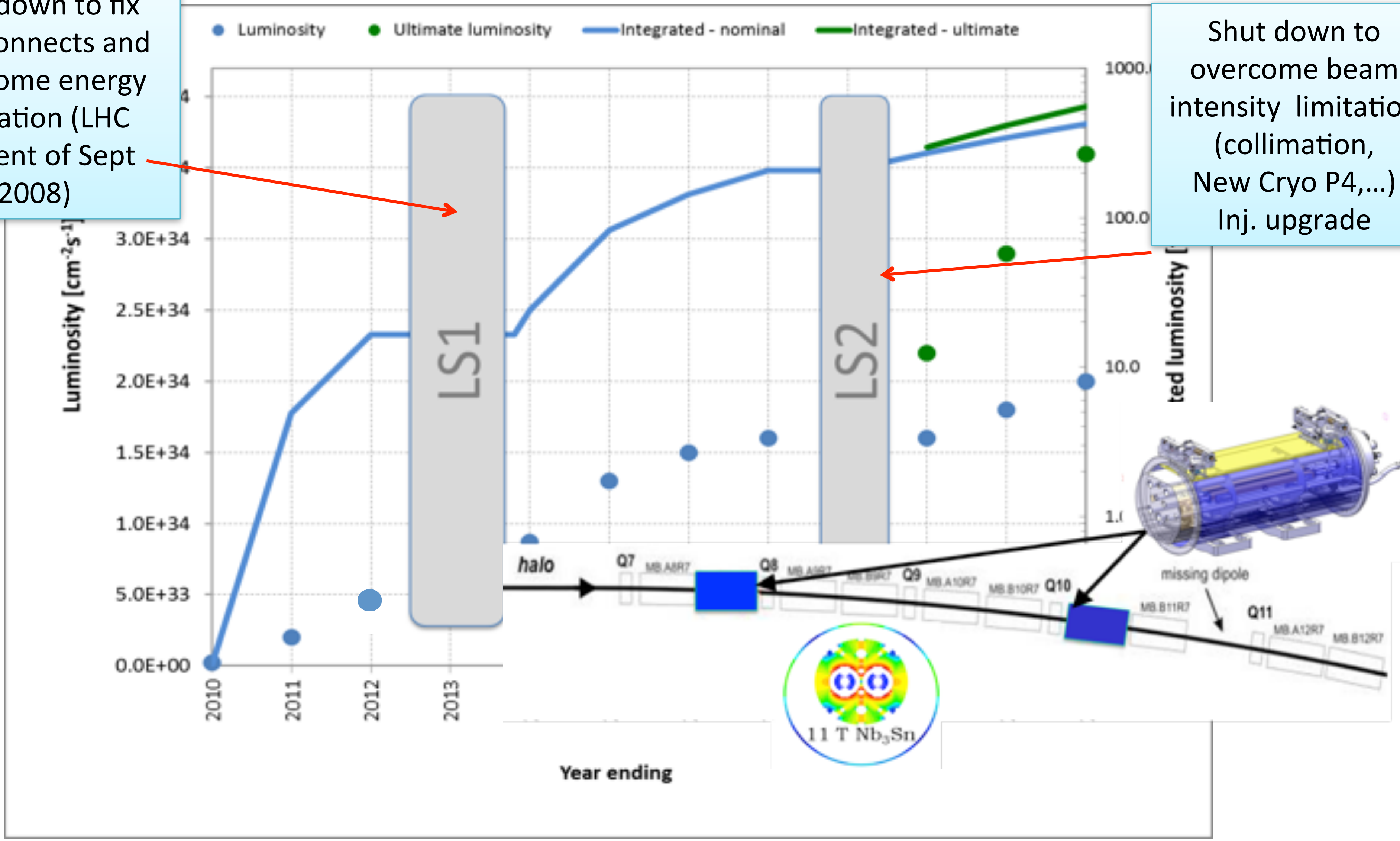
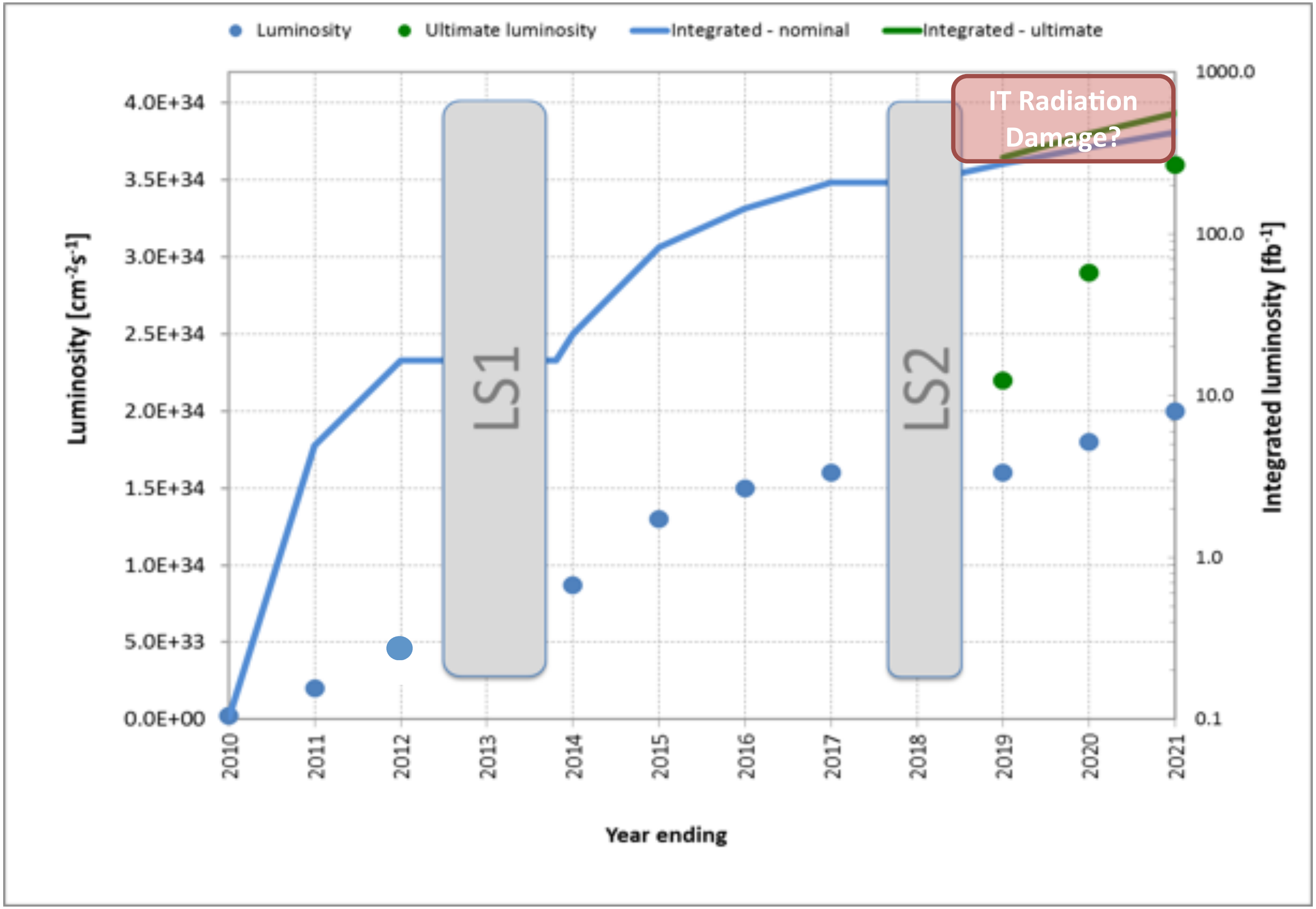
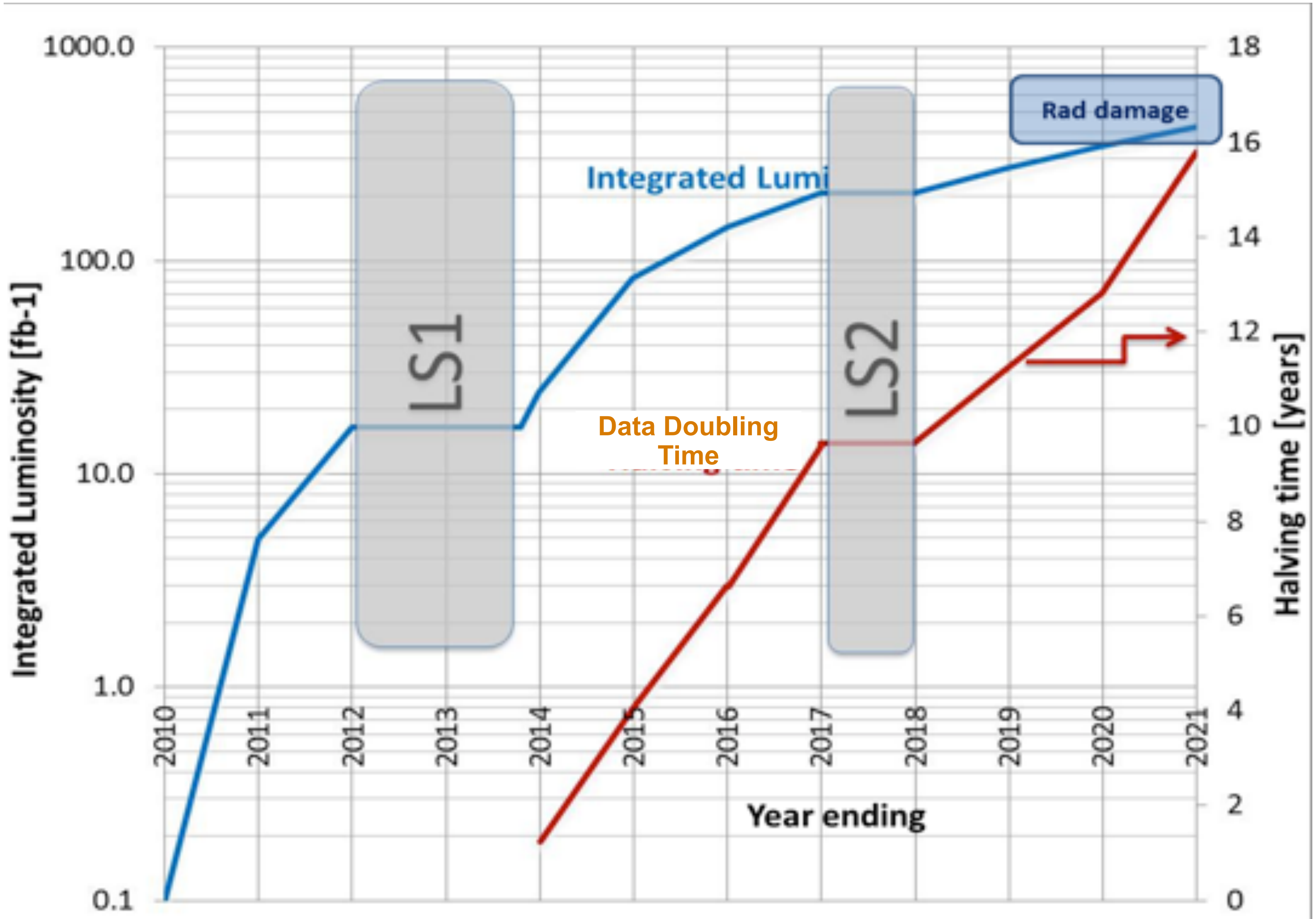
Shut down to overcome beam intensity limitation (collimation, New Cryo P4,…) Inj. upgrade



Luminosity: Best Guess for the next 10 years



HL-LHC: The need for an Upgrade



Around 2022 the Present Triplet magnets reach the end of their useful life (due to radiation damage)
…and will anyway need replacing.

In addition the Luminosity of the LHC will saturate by then

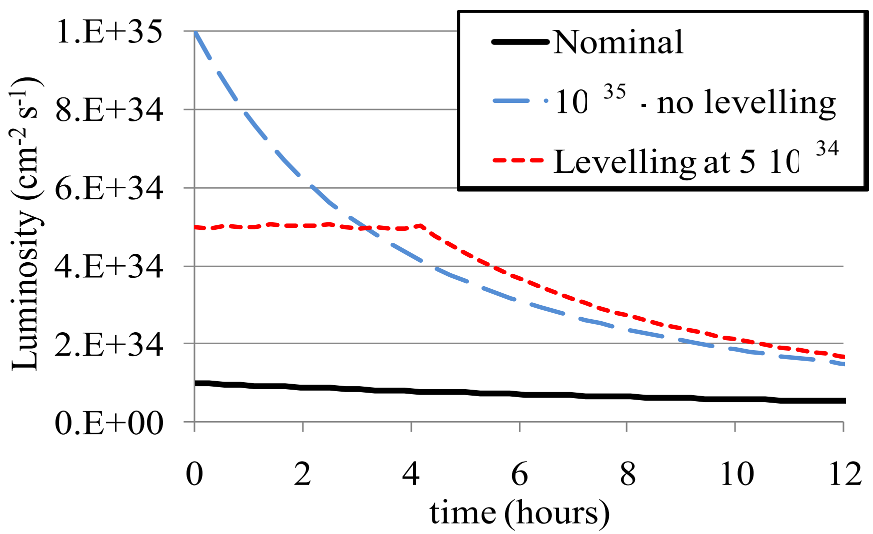
Time for an upgrade!

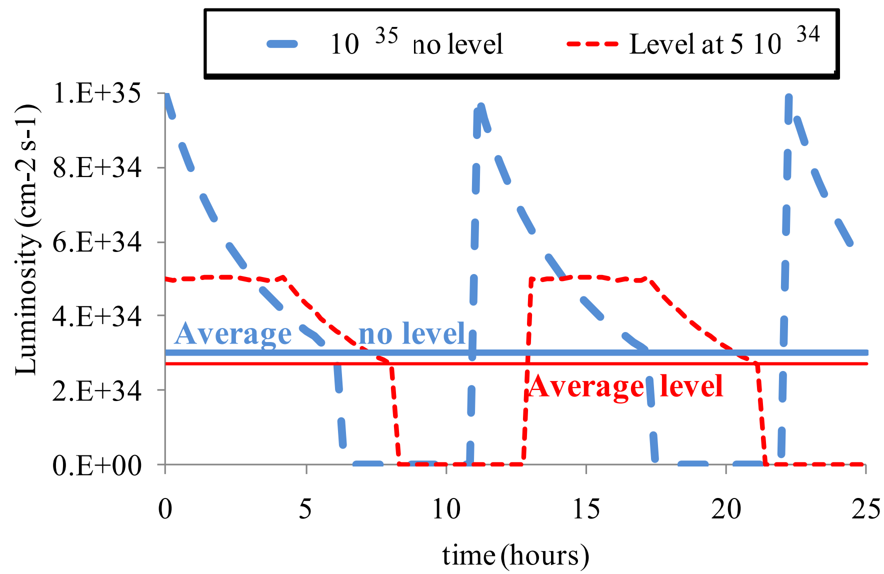
HL-LHC The Goal

The main objective of HL-LHC is to implement a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

- A luminosity of **5×10^{34} $cm^{-2}s^{-1}$ with leveling**
- Implies a “Virtual” peak luminosity of $>10^{+35}$ $cm^{-2}s^{-1}$
- An integrated luminosity of **250 fb^{-1}** per year, enabling the goal of **3000 fb^{-1}** twelve years after the upgrade.

Why Level?





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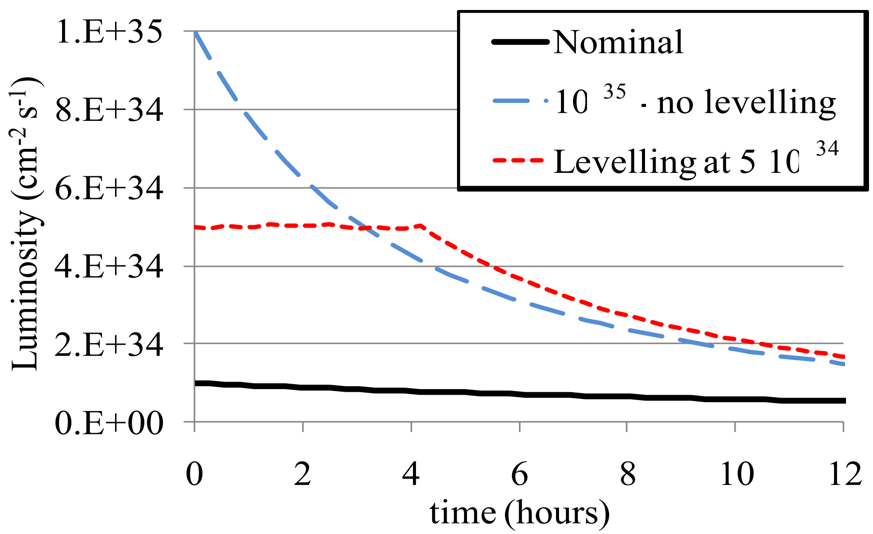
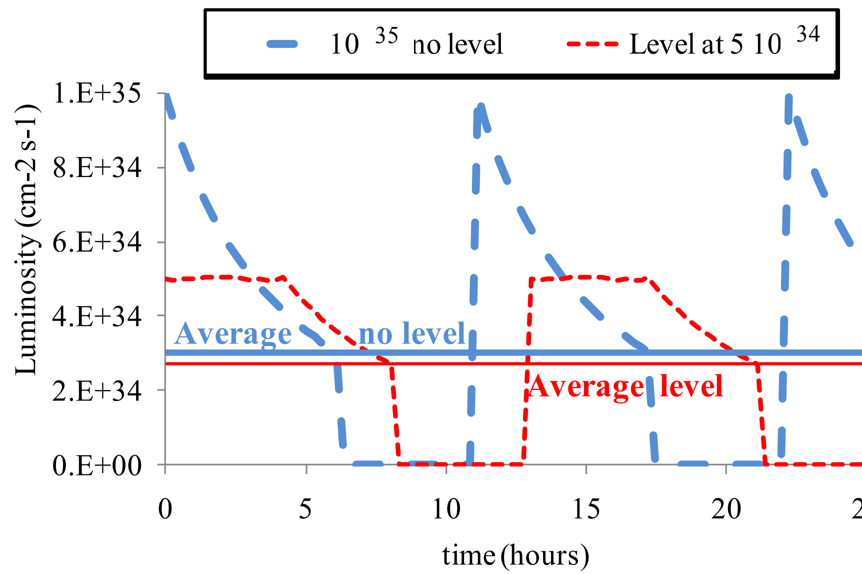




- ✓ Allow design integrated Luminosity for a lower peak L, and less pile up for the experiments
- ✓ Lower peak heat deposition in the magnets

Target parameters for

Efficiency is defined as the ratio between the annual luminosity target of 250 fb^{-1} over the potential luminosity that can be reached with an ideal cycle run time with no stop for 150 days: $t_{run} = t_{lev} + t_{dec} + t_{turn}$. The turnaround time after a beam dump is taken as 5 hours, t_{decay} is 3 h while t_{lev} depends on the total beam current

Parameter	Nom. 25 ns	Target 25 ns	Target 50 ns	LIU 25 ns	LIU 50 ns
N_b [10^{11}]	1.15	2.0	**3.3**	1.7	2.5
n_b	2808	2808	1404	2808	1404
I [A]	0.56	**1.02**	0.84	0.86	0.64
θc [μrad]	300	475	445	480	430
β* [m]	0.55	**0.15**	**0.15**	**0.15**	**0.15**
ε_n [μm]	3.75	**2.5**	**2.0**	**2.5**	**2.0**
ε_s [eV s]	2.5	2.5	2.5	2.5	2.5
IBS h [h]	111	25	**17**	25	**10**
IBS l[h]	65	21	**16**	21	**13**
Piwinski	0.68	2.5	2.5	2.56	2.56
F red.fact.	0.81	0.37	0.37	0.37	0.36
b-b/IP[10^{-3}]	3.1	3.9	**5**	3	**5.6**
L_{peak}	1	7.4	8.4	5.3	**7.2**
Crabbing	no	yes	yes	yes	yes
$L_{peak\ virtual}$	1	20	22.7	14.3	19.5
Pileup L_{lev}=5L_0	19	95	190	95	190
Eff.† 150 days	=	0.62	0.61	0.66	0.67

baseline

HL-LHC: the detector upgrades

- Both ATLAS and CMS detectors are planning **important upgrades** to stand the harsher running conditions at HL-LHC: pile-up, rates, radiation damage
  - Pile-up ~ 4-5 times more pile-up then today
- Plan: keep detector performance for main physics objects at the same level as we have today
  - Improved trigger system
  - New tracking systems
  - Improved forward detectors
  - ….


and beyond LHC ?

High Energy-LHC (HE-LHC)

	Turns	%
Nb-Ti	40	28%
Nb_3Sn	58	41%
HTS	45	31%

CERN working group since April 2010

EuCARD AccNet workshop HE-LHC'10 ,

14-16 October 2010, Proc. CERN-2011-003

<u>key topics</u>

beam energy 16.5 TeV; 20-T magnets

cryogenics: **synchrotron-radiation heat**

radiation damping & emittance control

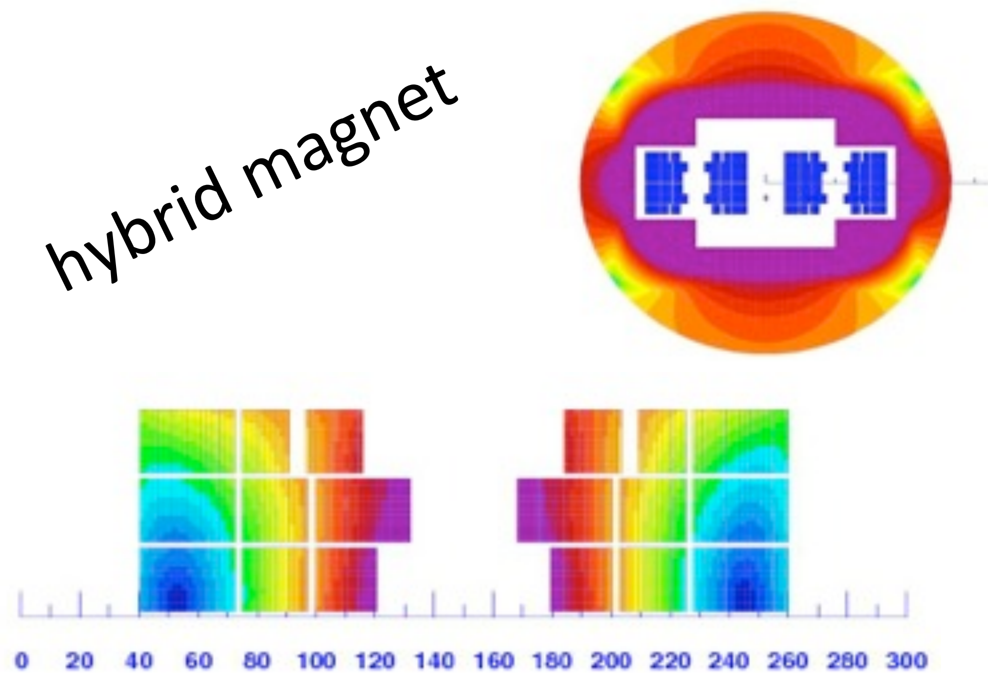
vacuum system: synchrotron radiation

new injector: energy > 1 TeV

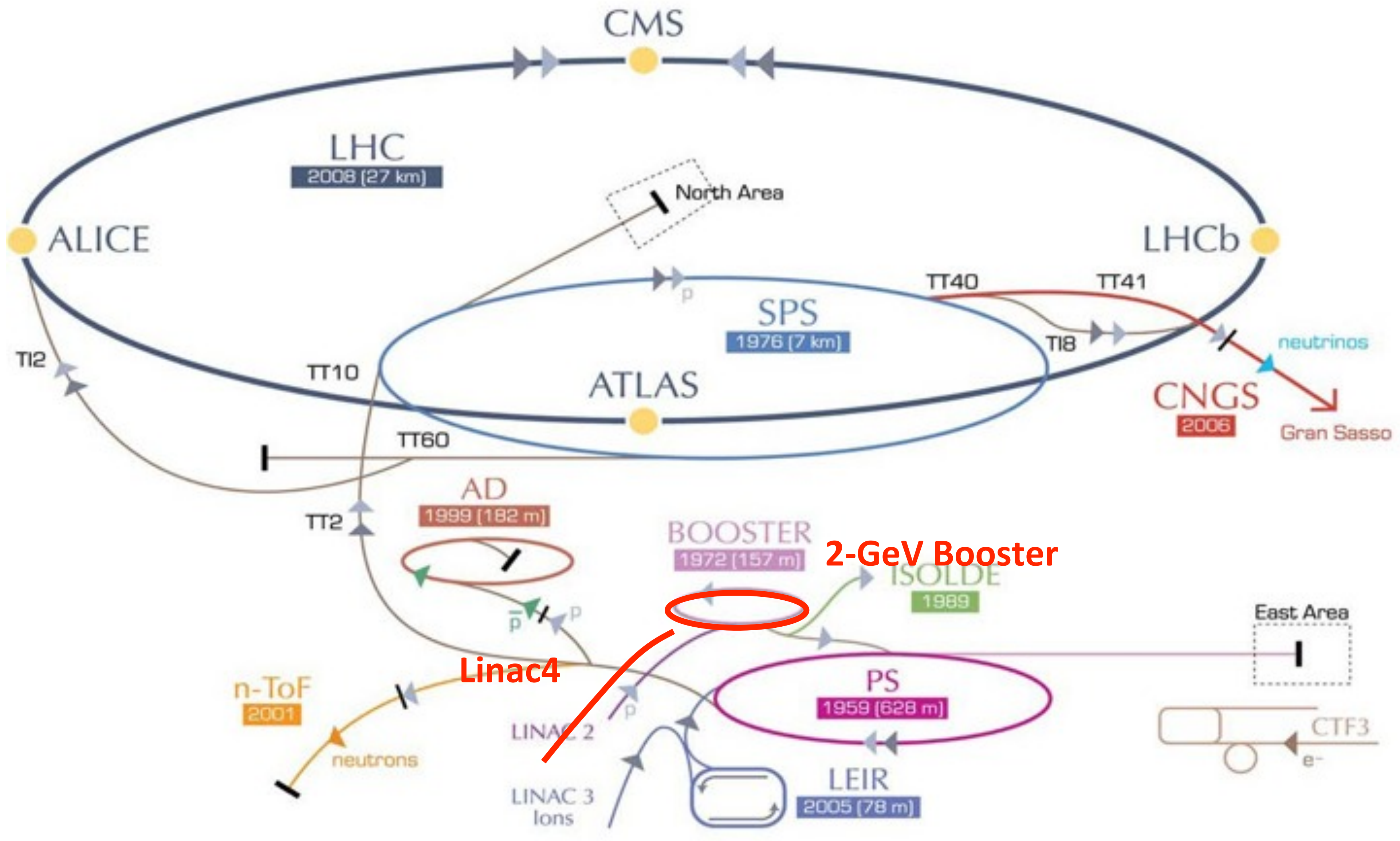
parameters

	LHC	HE-LHC
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40
#bunches	2808	1404
IP beta function [m]	0.55	1 (x), 0.43 (y)
number of IPs	3	2
beam current [A]	0.584	0.328
SR power per ring [kW]	3.6	65.7
arc SR heat load dW/ds [W/m/ap]	0.21	2.8
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1.0	2.0
events per crossing	19	76

E. Todesco



HE-LHC – LHC modifications



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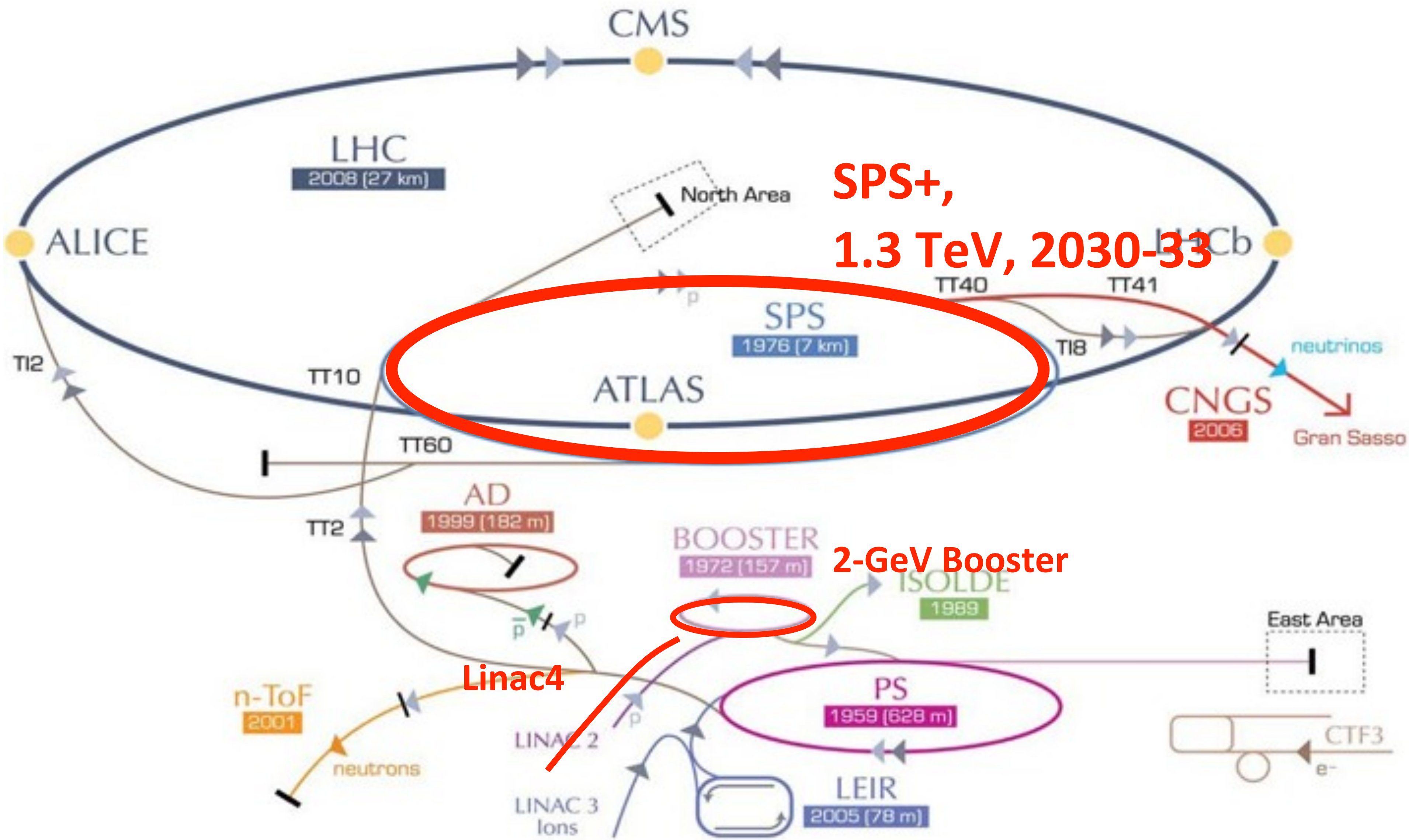

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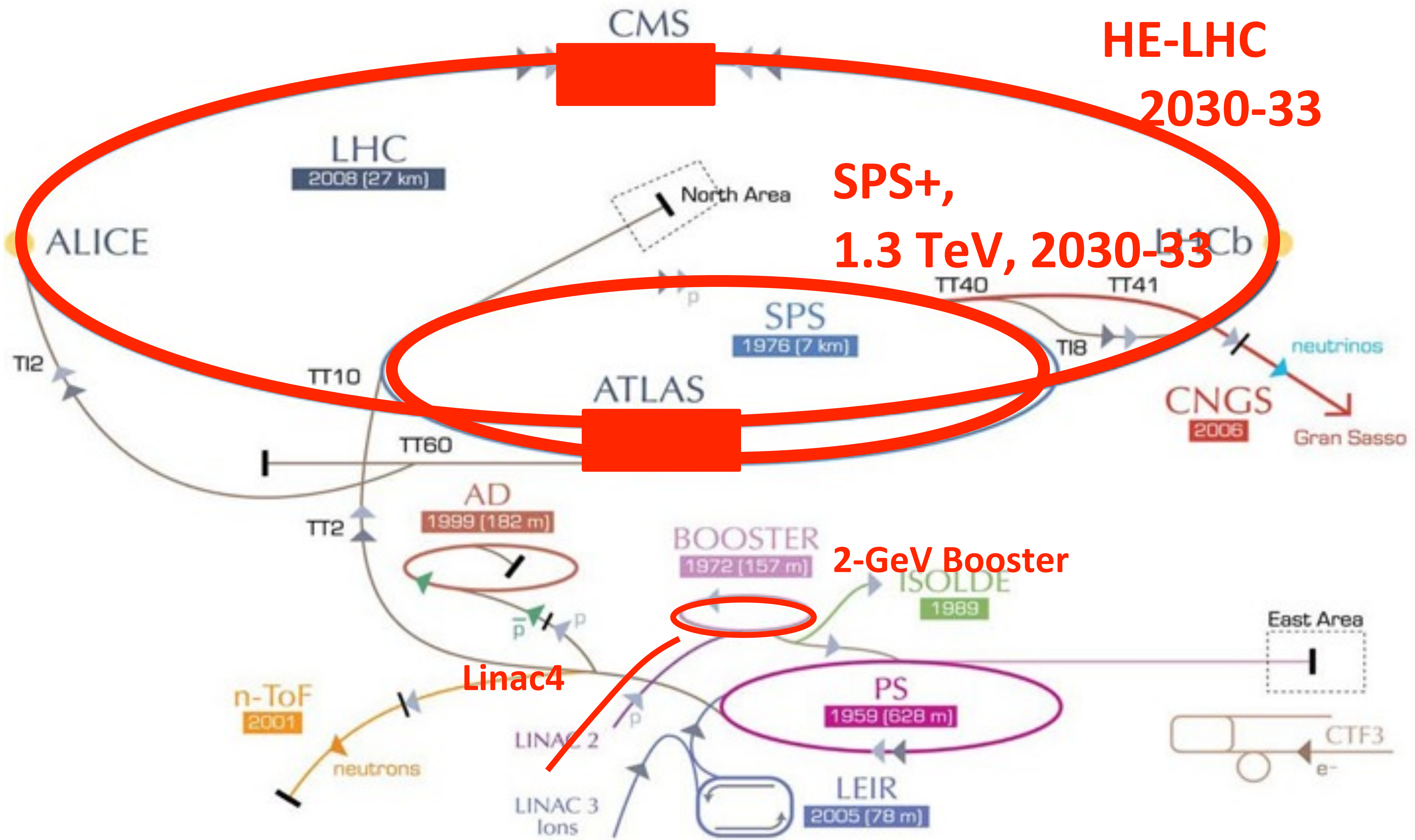
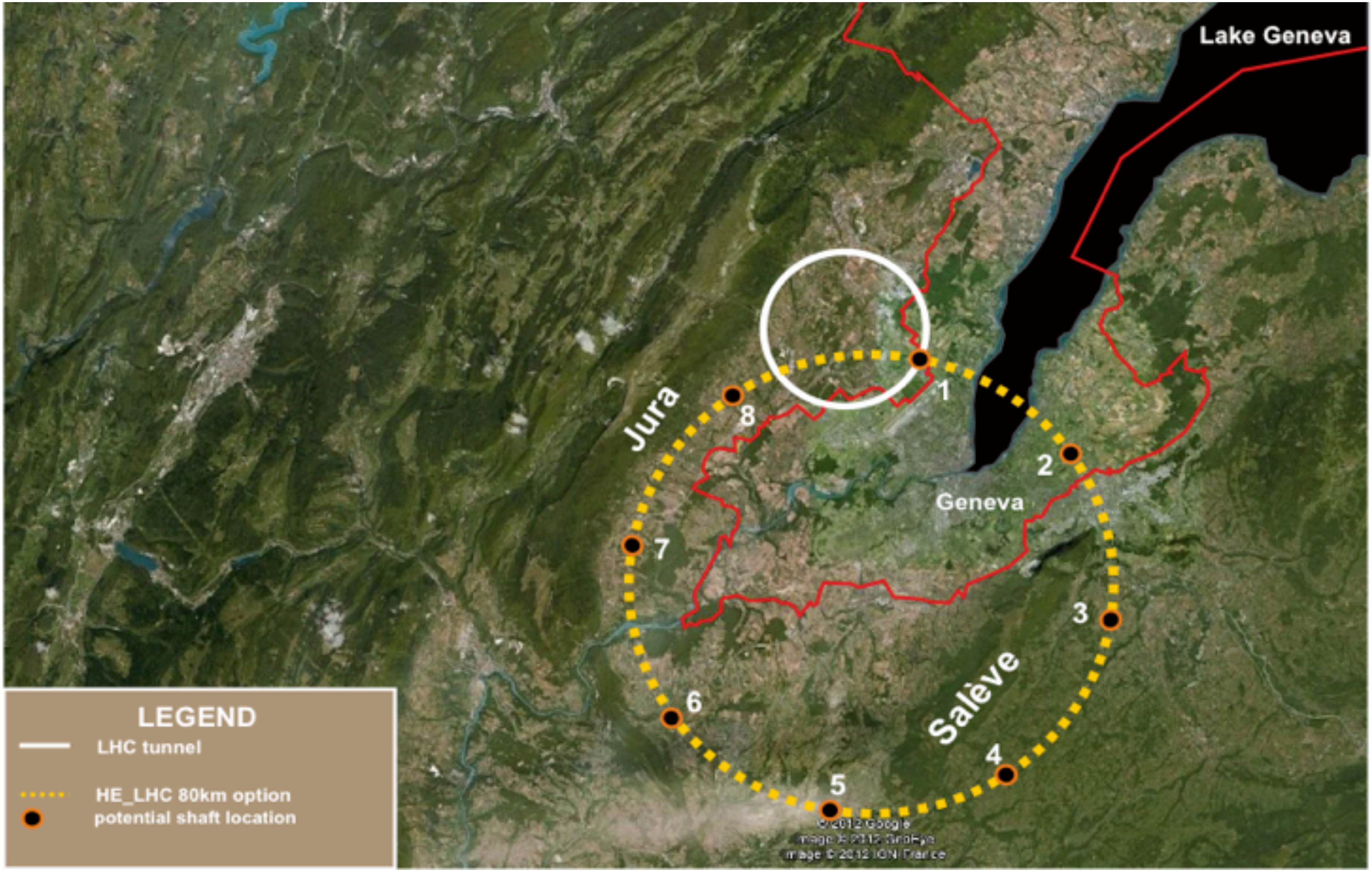
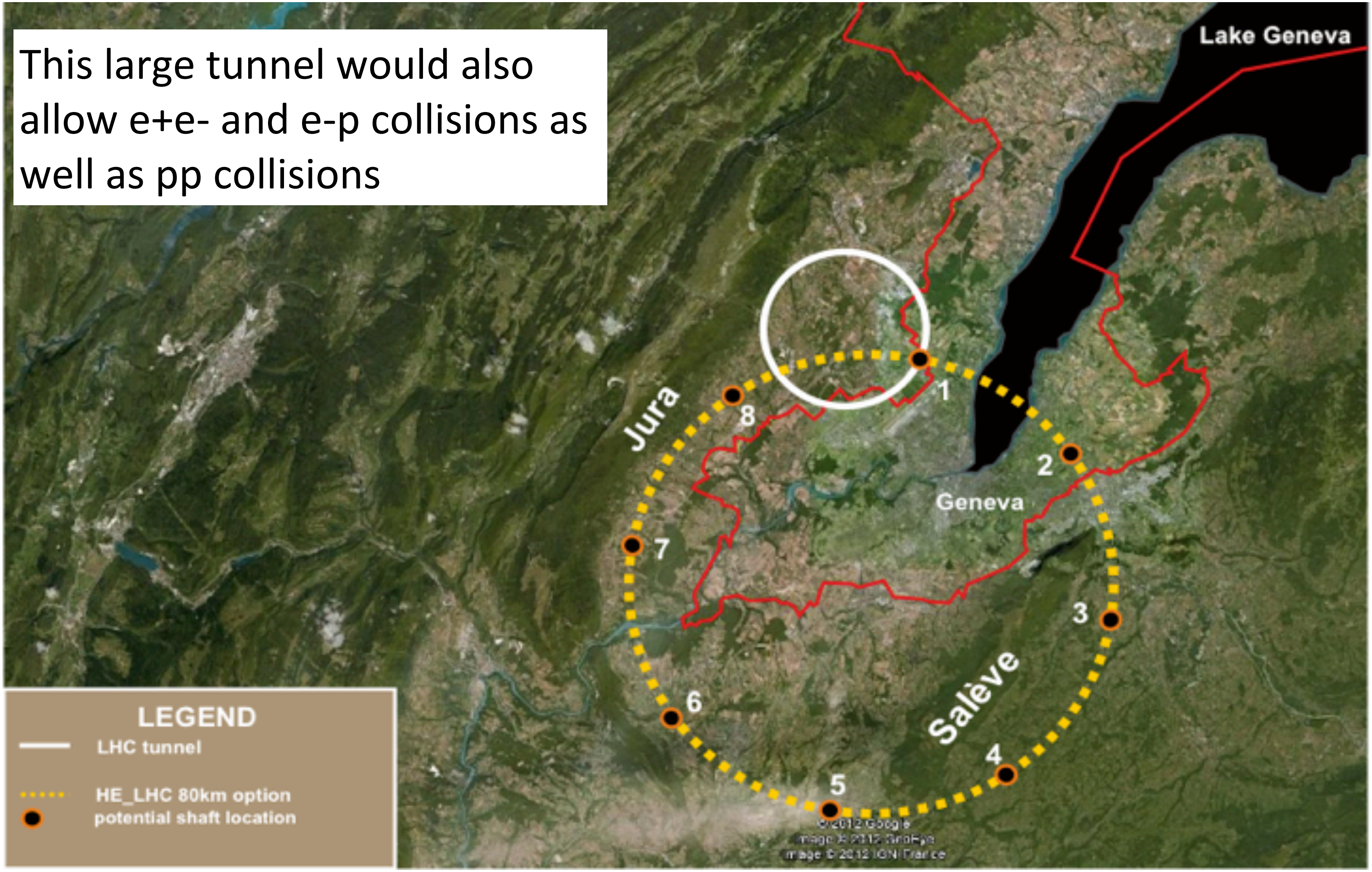


Thinking BIG



Thinking BIG

This large tunnel would also allow e+e- and e-p collisions as well as pp collisions



In summary

- 2010-2012: extraordinary years!
- But we are just at the beginning of a long journey.
- By now, **experimental results** are dictating the agenda of the field.
- We need to accelerate the reflection on **next steps**
- No time to idle: a lot of work has to be done

Thank you !

CERN today….into the future

- CLIC conceptual design report published
- Participation in all LC activities
- LHeC conceptual design report published
- R&D for high-field magnets (towards HE-LHC)
- Accelerator R&D (TLEP, Plasma Acc)
- Participation in Neutrino-Projects studied

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Position CERN as Laboratory at the energy frontier


and elsewhere?

A lepton collider: a decisive asset…

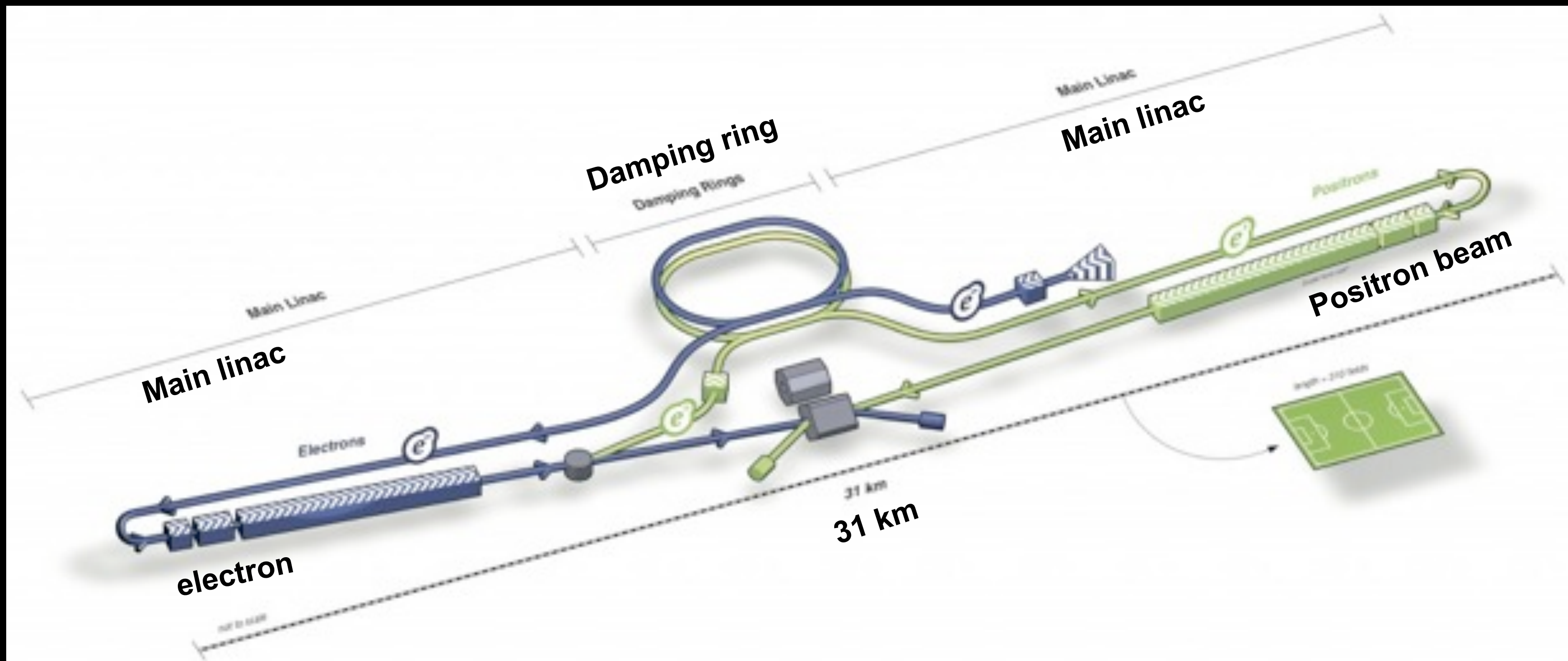
..if

- Can be decided/built soon
- It might start at 250 Gev, but it should be upgradable at 500 GeV, with a possible extension to 1 TeV c.m.

Best candidate: the International Linear Collider:

- Mature design
- TDR delivered
- Japanese community has submitted to the government a request to host it.

ILC (International Linear Collider)



- 500 GeV CM with 31 km → upgrade later to ~ 1TeV CM with 50 km
- Luminosity 1.8 x 10^{34} /cm^2s (@500 GeV CM)

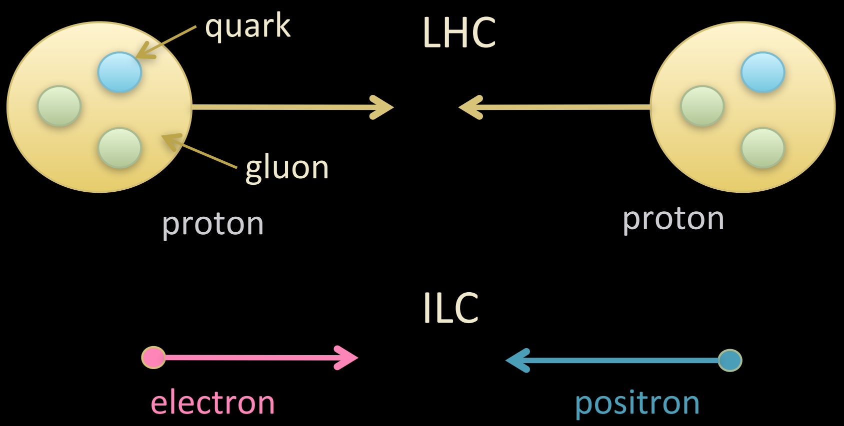
ILC features : cleanliness

- Collision of two elementary particles
  - proton + proton at LHC
    - Proton = 3 quarks + gluons
  - electron + positron at ILC

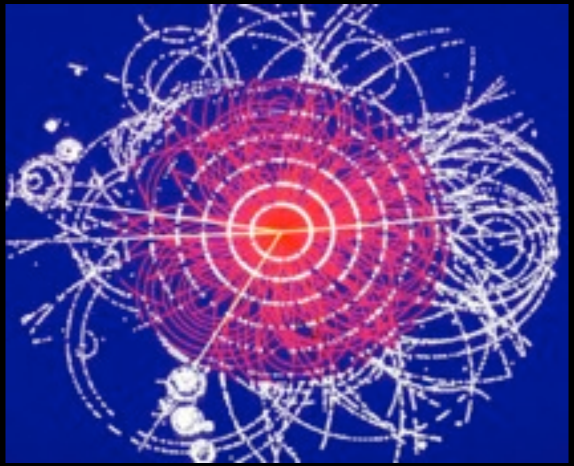
→ Signal is clearly seen without much noises

→ Trigger-less data taking

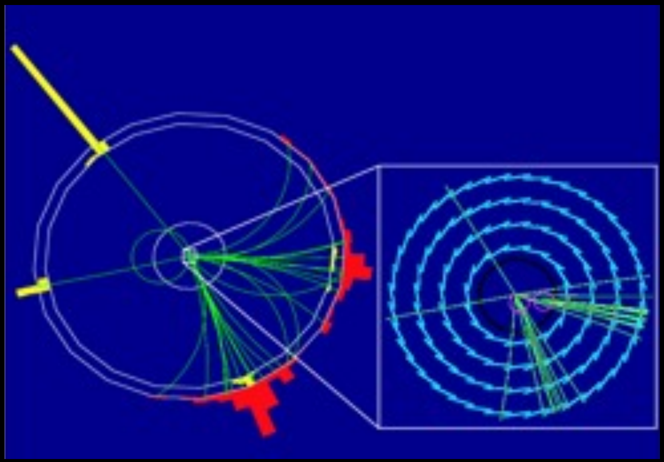
→ Theoretically clean
(less theoretical uncertainties)



LHC



ILC



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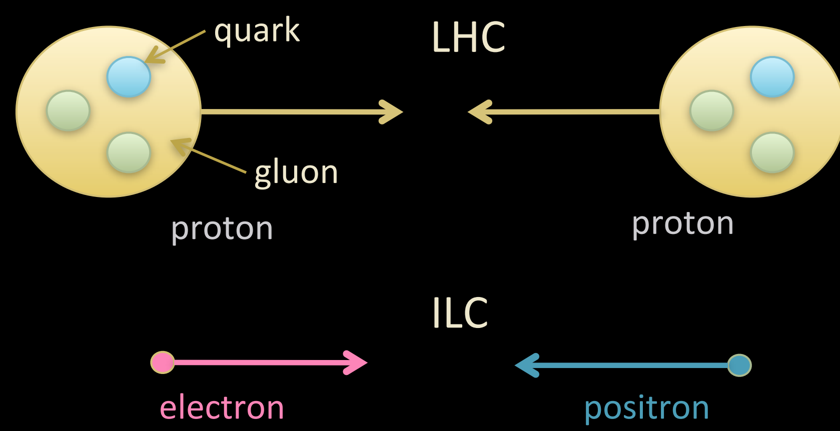
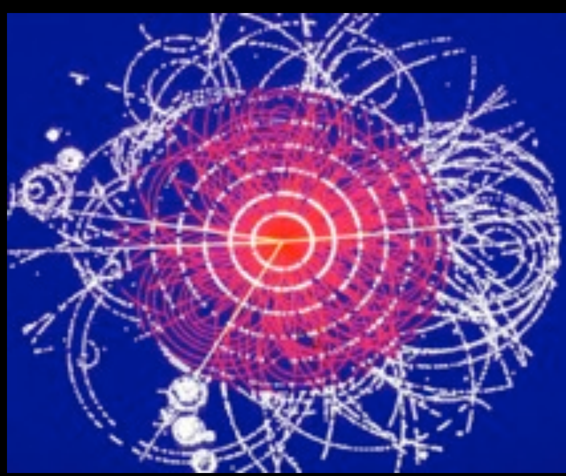


LHC



ILC

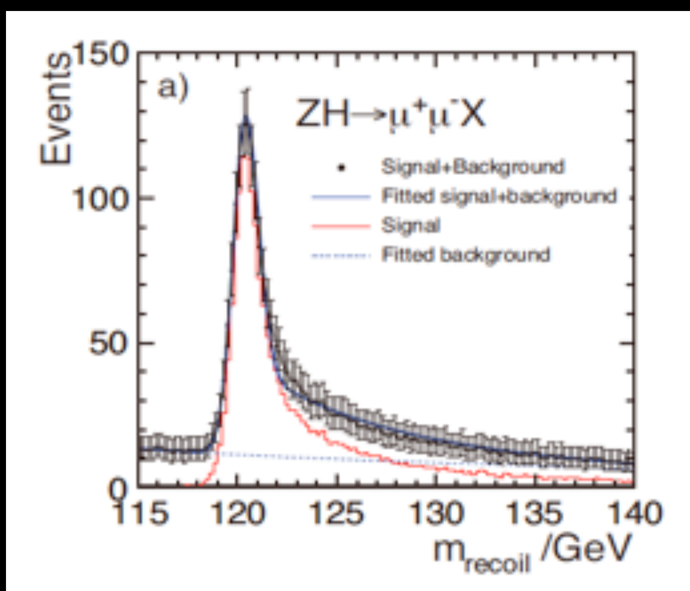
ILC features : control

- Initial state of electron-positron interaction :
  - Energy-momentum 4-vector is specified
  - Electron polarization (80%~90%) is specified
    - Positron polarization (60%) is optional (30% comes for free)

Energy-momentum 4-vector

→ e.g. recoil mass analysis: tagged Higgs

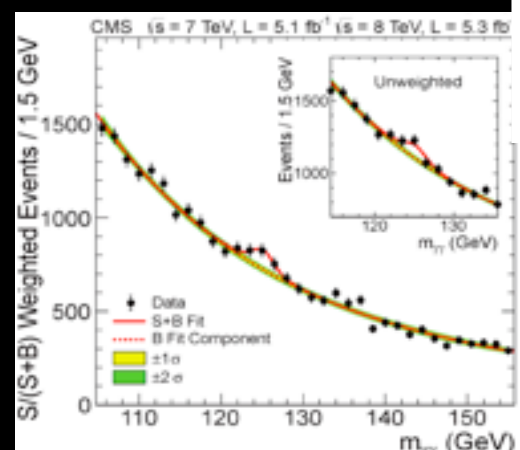
Higgs to ALL (including invisible final state)

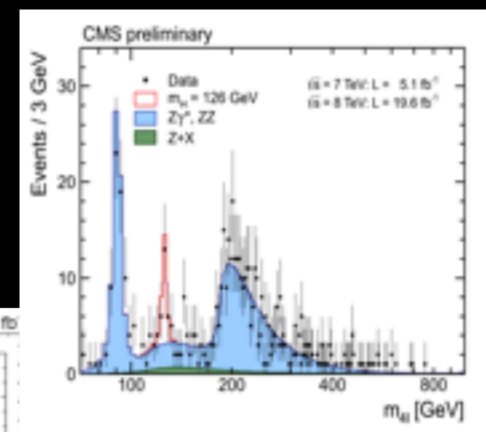


ILC

LHC

H→γγ



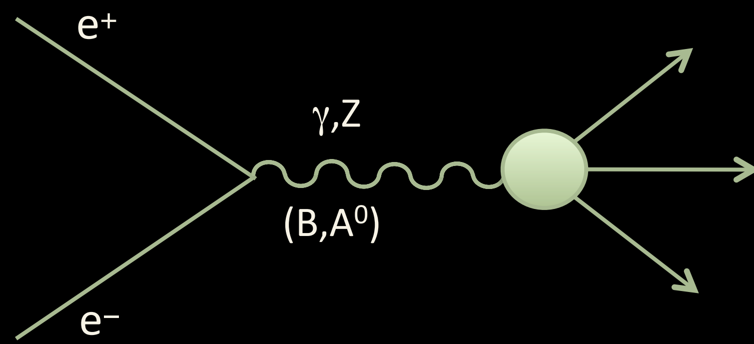


H→ZZ

Electron polarization

Specify the intermediate state

- Right-handed e- turns off A^0
  - Information on the gauge structure of the final state

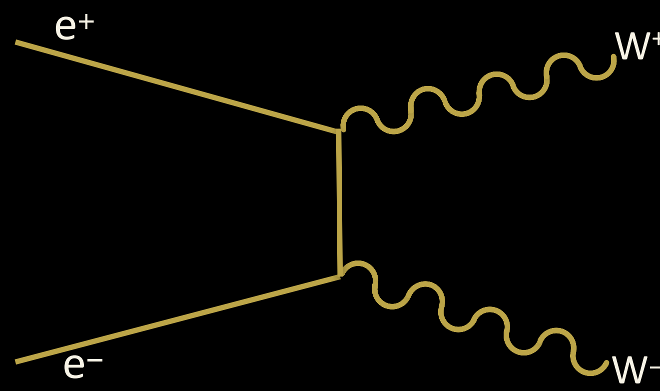


Increase rates

- e.g. $P^-/P^+ = -0.8/0.3$:

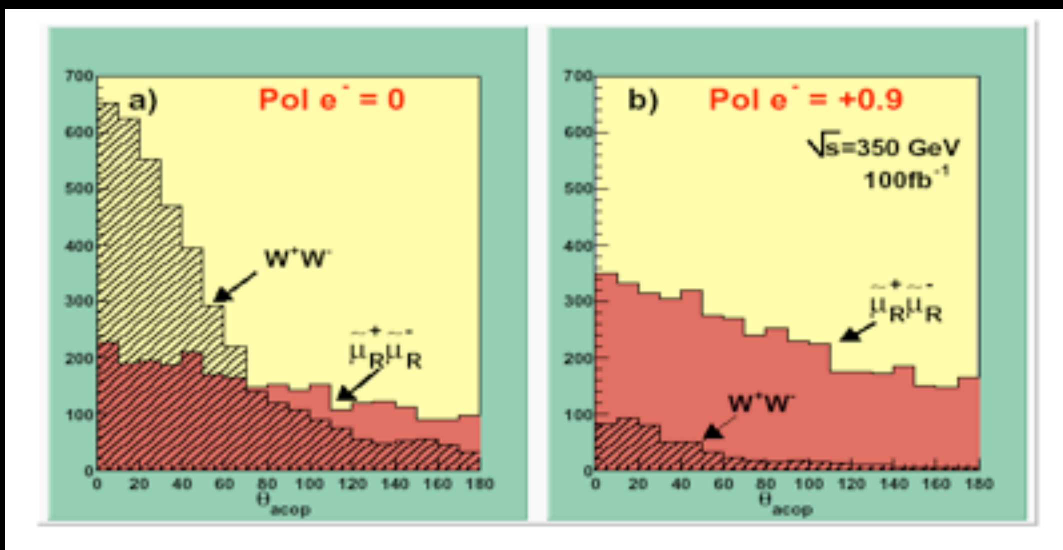
  Increases the H production mode

  $\sigma(\nu\nu H)$ by X 2.34 (=1.8 x1.3)



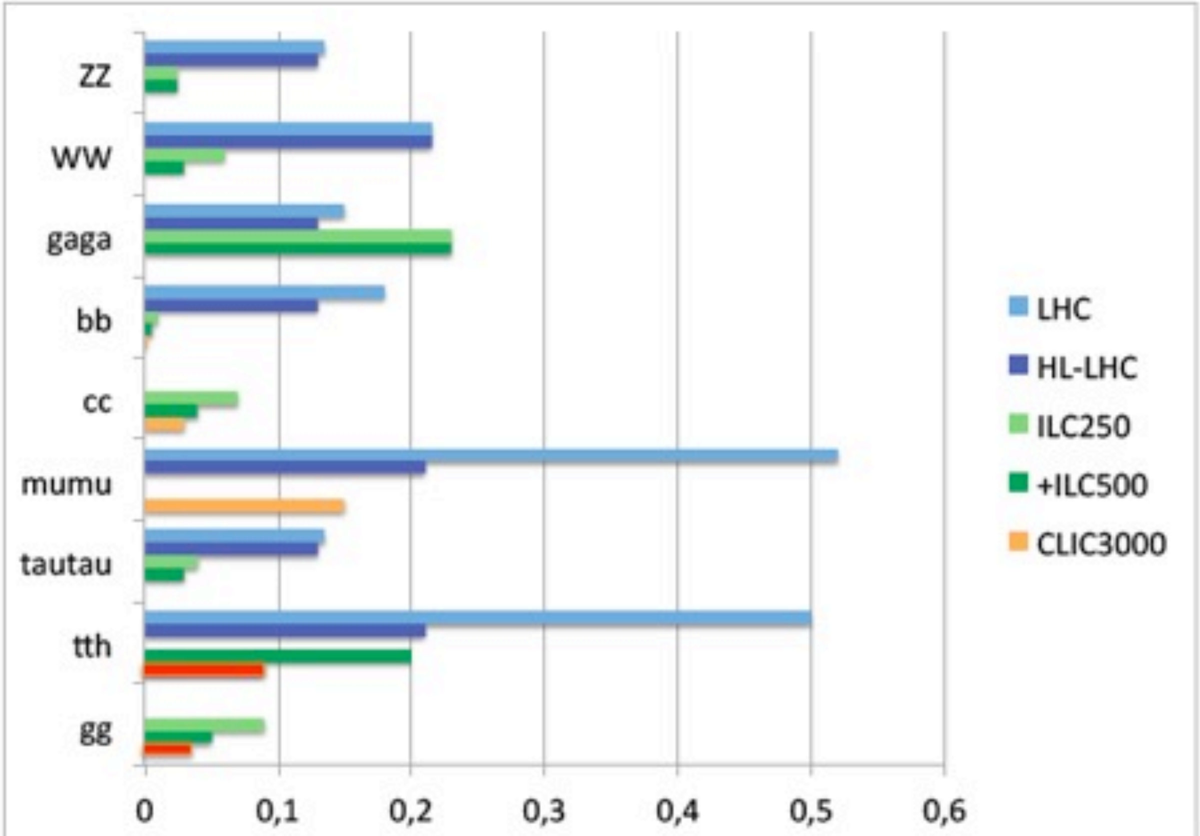
Background rejection

- Right-handed e- turns off W



e.g. acoplanar muon pair produciton
such as smuon pair production

LHC vs LC: „signal strength“



KD attempt to compile available experimental studies.
(best estimates)

HANDLE WITH CARE

fineprint:

ATLAS/CMS from Krakow notes
(= preliminary!)

LHC = (ATLAS+CMS)/2 (300 fb^{-1})
HL-LHC = ATLAS (3000 fb^{-1})
ILC250 = 250 fb^{-1} at 250 GeV
+ILC500 = 500 fb^{-1} at 500 GeV + 250 fb^{-1} at 250 GeV
ILC1000 + CLIC3000 are only examples

1) prec. on σ_{HZ}(total)
2) prec. on $\sigma_{WW\text{-}Fusion}$(total)

LHC – mostly syst. limited
LC – mostly stat. limited

ILC1000/CLIC1400 further improves precision

ILC: not only a precision machine

- Great impact in exploring the EWK part of Supersimmetry, in a region which might be not accessible at the LHC, because the unfavorable S/B.
- A fundamental contribution in the precision studies of the W and Z bosons and the top quark.

The joint information coming from LHC and ILC will be a “conditio sine qua non” to enable the next particle accelerator at the energy frontier

CERN going global….

- Membership for Non-European countries
- New Associate Membership defined
- CERN participation in global projects independent of location

From Choices *to* Choice

- Roadmap (Japan) just published
- Roadmap discussion (US) in progress, completes next year
- Update of the European Strategy for Particle Physics completed ≡ Strategy of Europe in a global context

  - Several Meetings with **international participation**

  Open meeting September 2012, Cracow, then drafting session in January 2013 **in Erice**

  - Official approval in Bruxelles, 29-30 May 2013

(http://council.web.cern.ch/council/en/EuropeanStrategy/esc-e-106.pdf)

- Use as 1st step to harmonize globally Particle Physics Strategy

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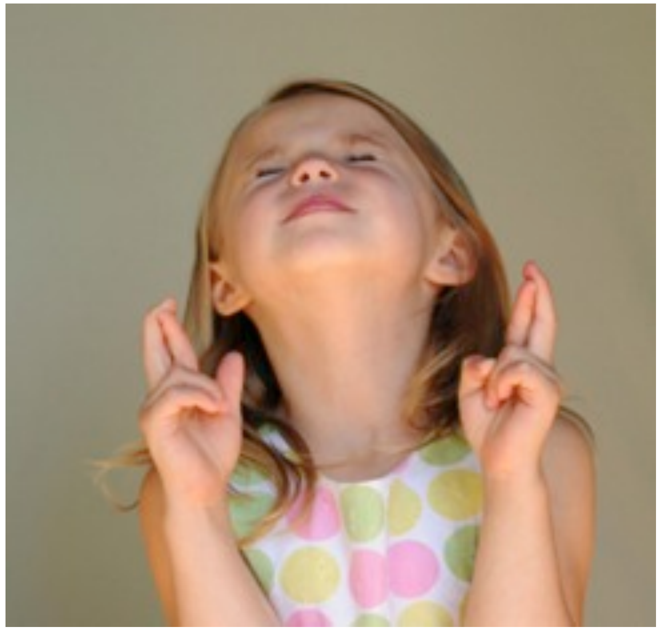
We will need

- Flexibility
- Preparedness
- Visionary global policies

- ...and a bit of luck!



Thank you!