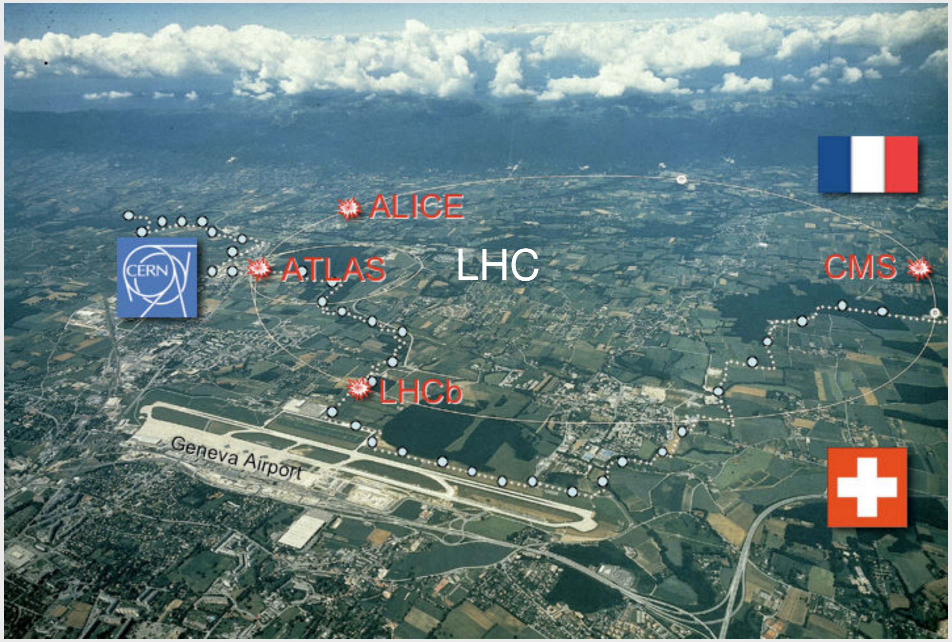
The future of LHC Programme



TWEPP 2009

Paris

September 21, 2009

Sergio Bertolucci
CERN

2009-2013: deciding years

Experimental data will take the floor to drive the field to the next steps:

- LHC and Tevatron results
- θ_{13} (T2K, DChooz, etc..)
- ν masses (Cuore, Gerda, Nemo…)
- Dark Matter searches
- Rare decays
- Astroparticle expts
- …..

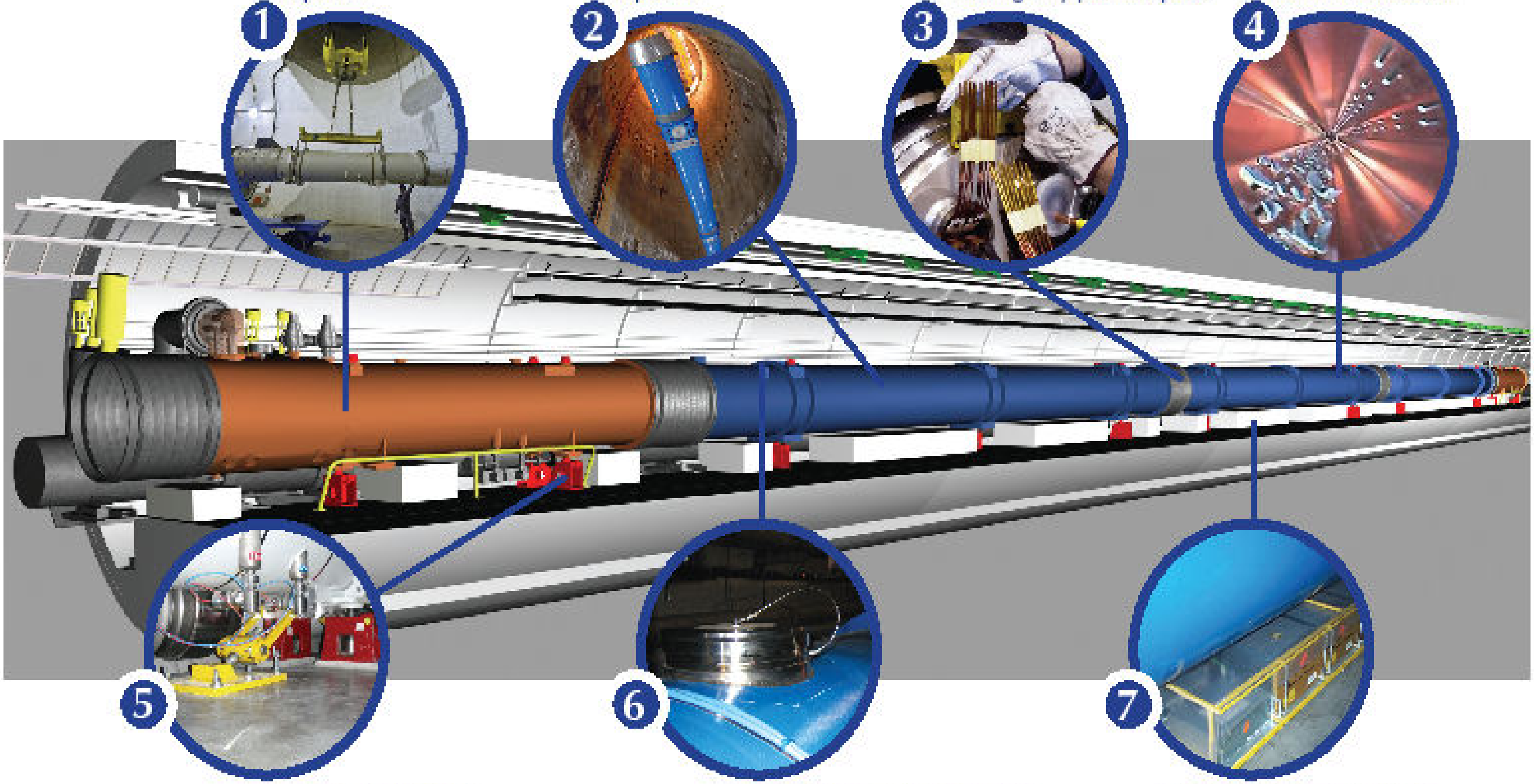
Preparing the next steps

- **More globalization**
- More (coordinated) R&D on accelerators and **detectors**
- More synergies between Particle and Astroparticle Physics
- More space for diversity

Our agony and ecstasy: the LHC

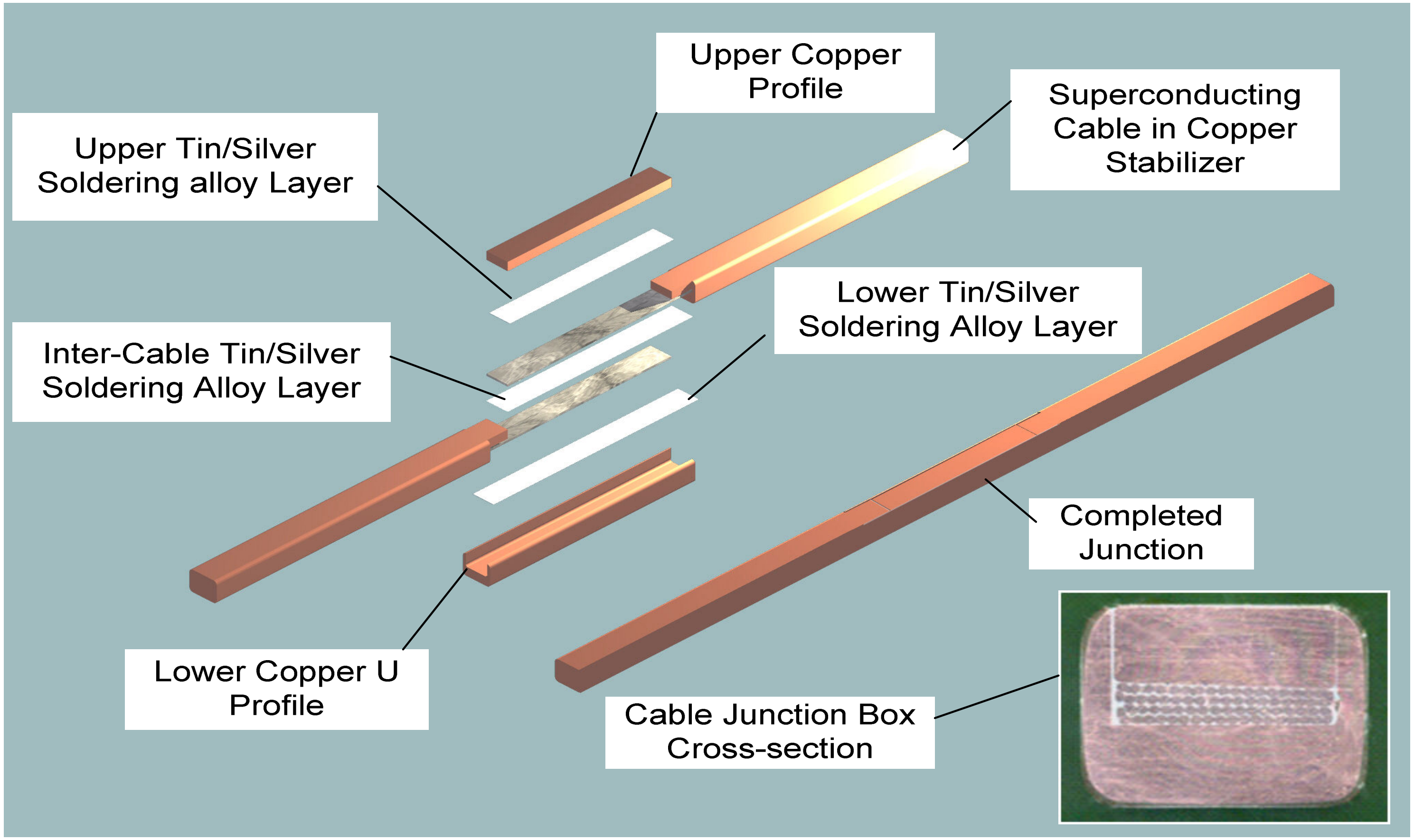
- **Status**
- Schedule
- Commissioning plans
- Early Physics
- **The future**

The LHC repairs in detail



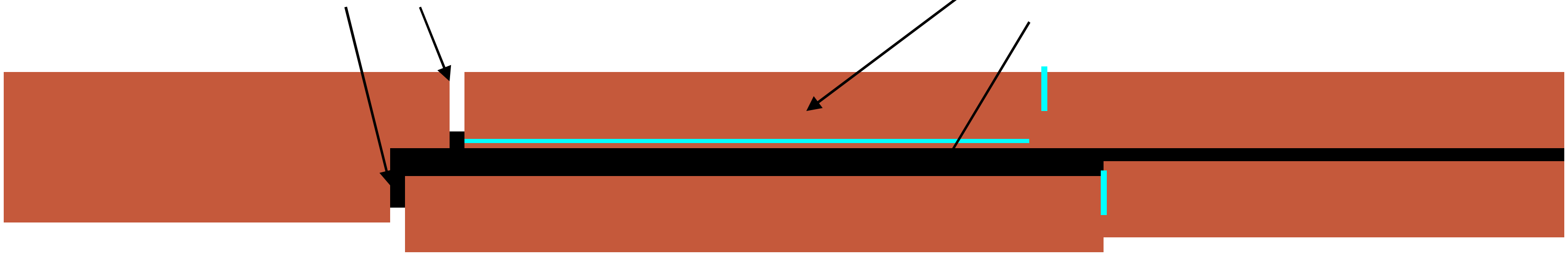
CERN

Show sample



missing electrical contact on at least one side of the connection

lack of solder within the joint



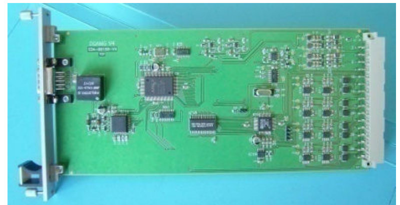
Number of splices in RB, RQ circuits

circuit	splice type	splices per magnet	number of units	total splices
RB	inter pole	2	1232	2464
RB	inter aperture	1	1232	1232
RB	interlayer	4	1232	4928
RB	internal bus	1	1232	1232
RB	interconnect	2	1686	3372
RQ	Inter pole	6	394	2364
RQ	internal bus	4	394	1576
RQ	interconnect	4	1686	6744
total				23912

The nQPS project

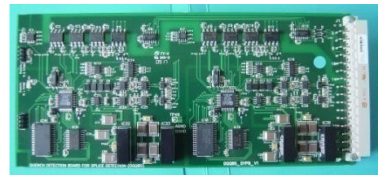
DQQTE board for ground voltage detection

(total 1308 boards, 3 units/crate)



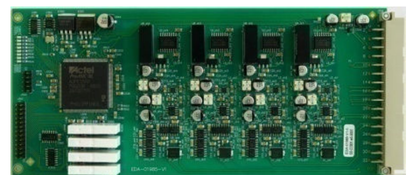
DQAMG-type S controller board

1 unit / crate, total 436 units



DQQBS board for busbar splice detection

5 such boards / crate, total 2180 units



DQQDS board for SymQ detection

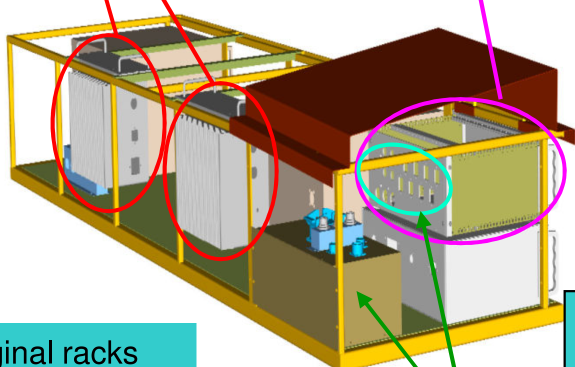
4 boards / crate, total 1744

DQLPUS Power Packs

2 units / rack (total 872 units)

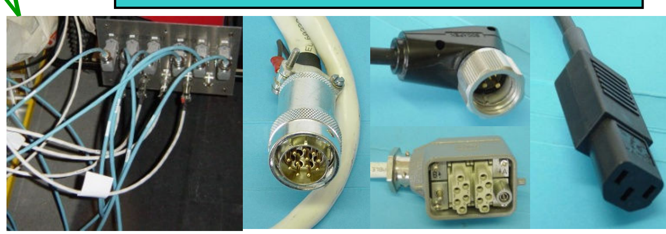
DQLPU-type S crate

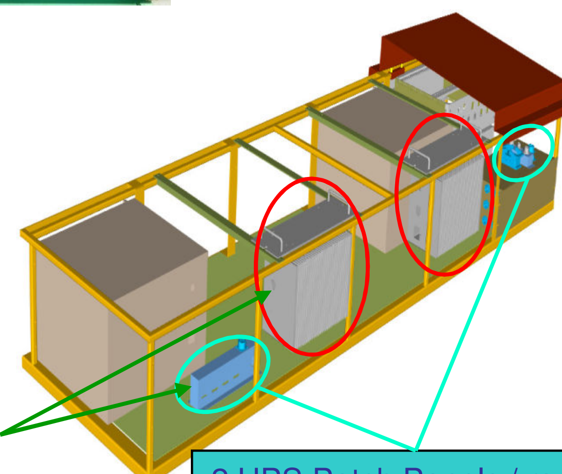
total 436 units



Original racks

'Internal' and 'external' **cables** for sensing, trigger, interlock, UPS power, uFIP   (10'400 + 4'400)



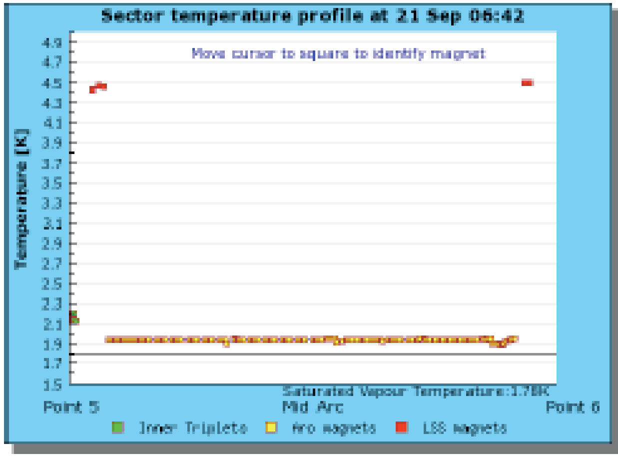


2 UPS Patch Panels / rack &
1 Trigger Patch Panel / rack
total 3456 panel boxes

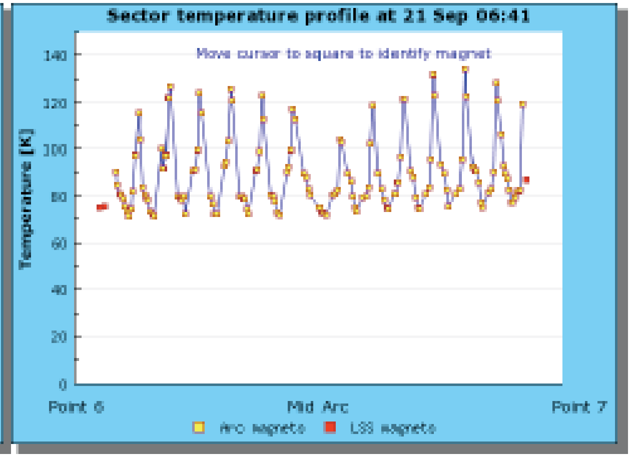
Since August

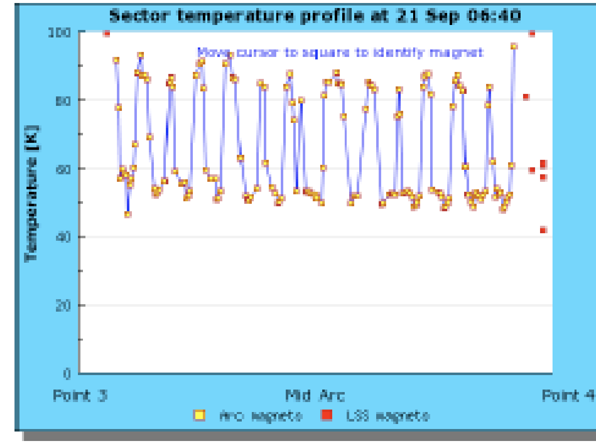
- Start of re-establishment of spares situation as it was before the incident
- Helium leak (flexible in the DFBs) in S45, S23, and S81. All repaired. Same problem 2-3 years ago.
- Magnet/busbar short to earth in S67 (detected and repaired)

Sector 5-6

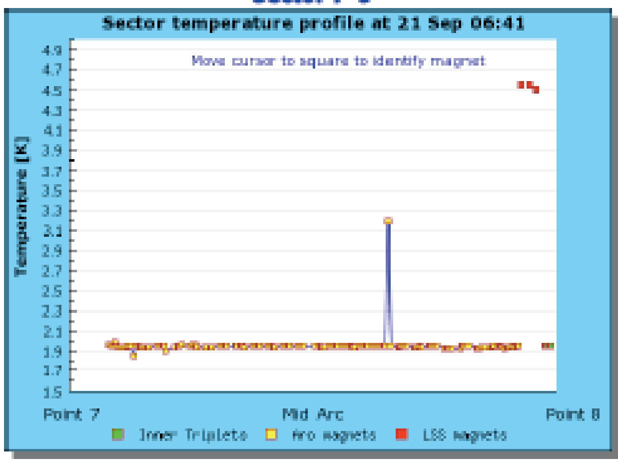


Sector 6-7

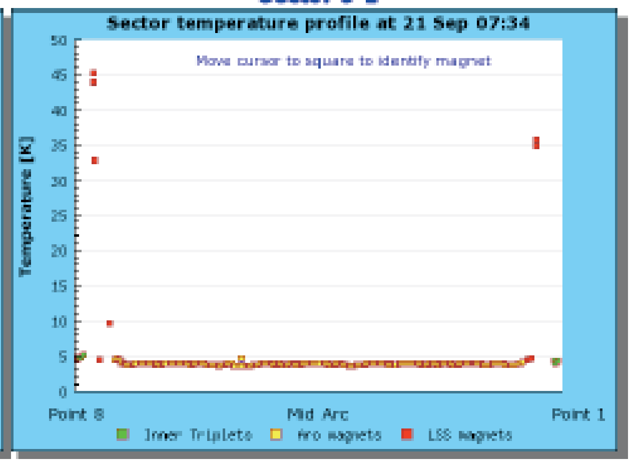


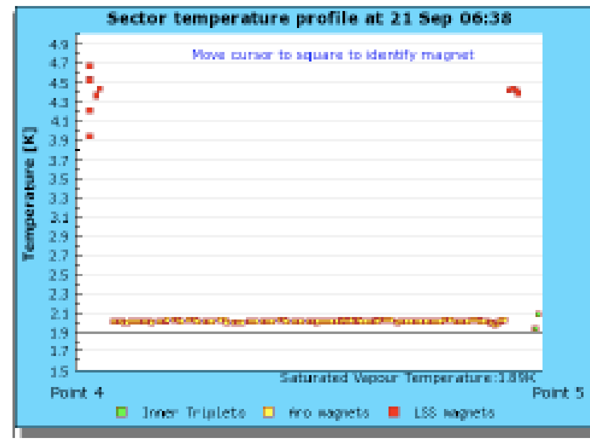


Sector 7-8

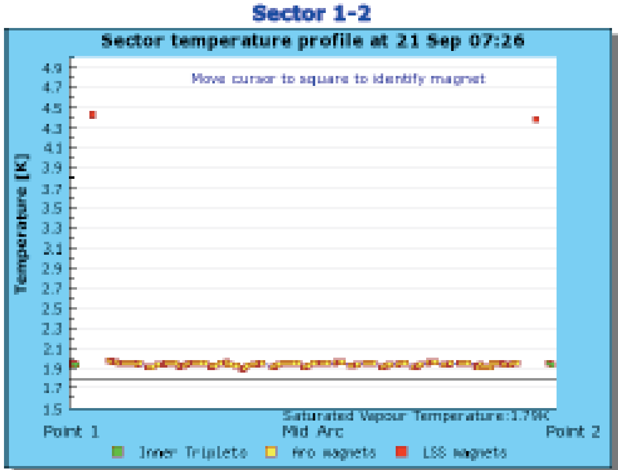


Sector 8-1

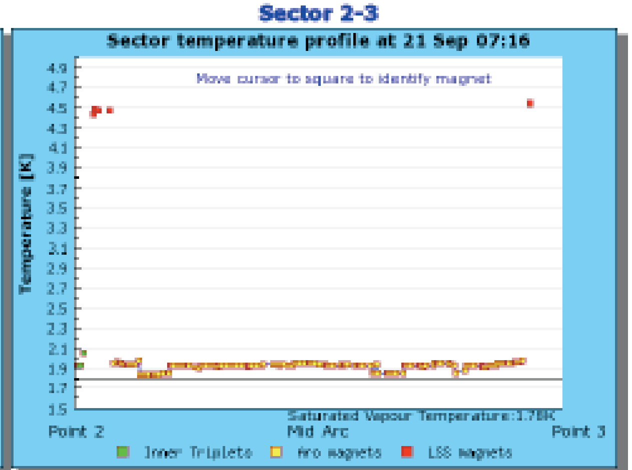




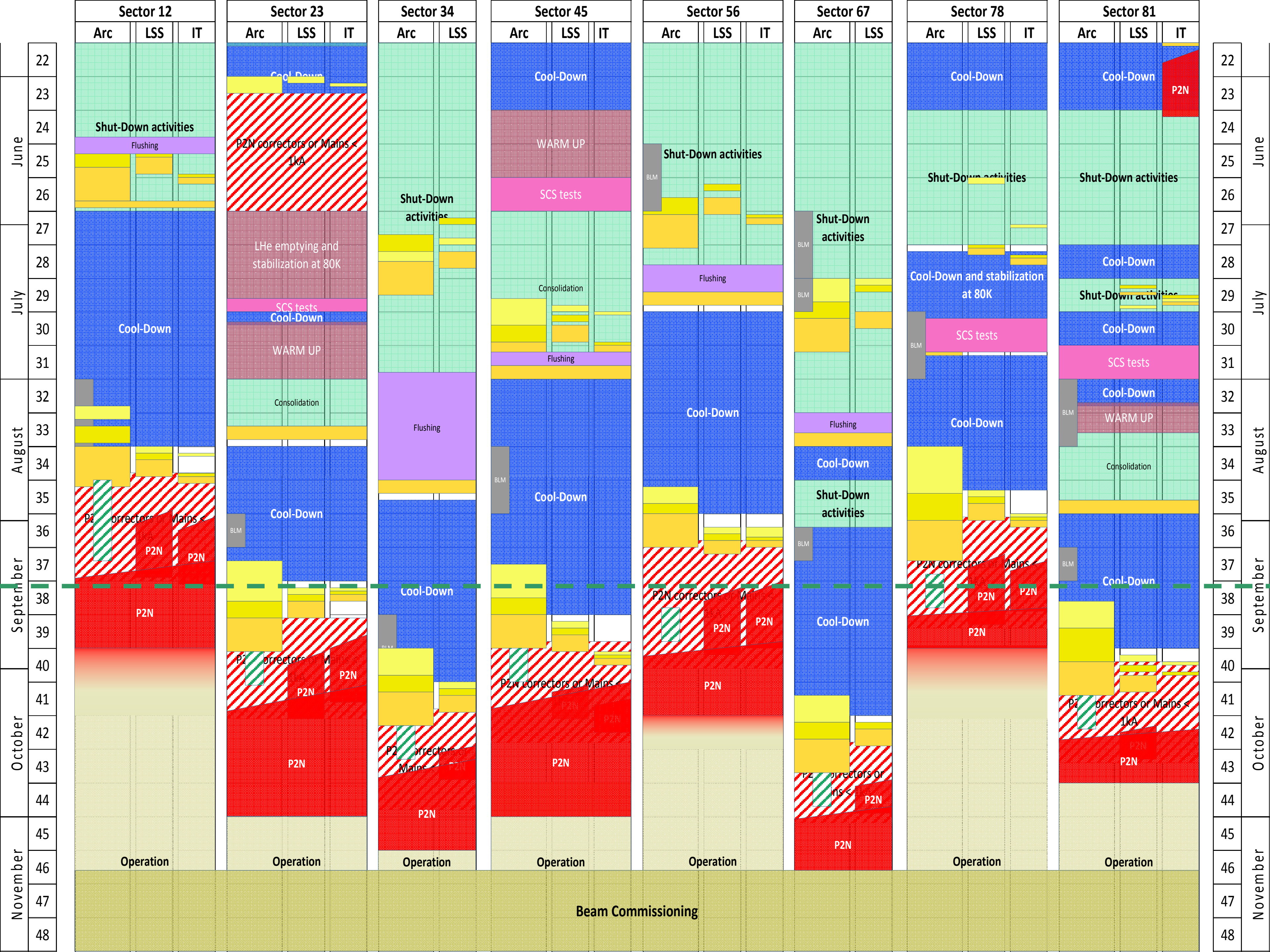
Sector 1-2



Sector 2-3



Cooldown status



Sector 12
Sector 23
Sector 34
Sector 45
Sector 56
Sector 67
Sector 78
Sector 81
Arc
LSS
IT
June
July
August
September
October
November
22
23
24
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28
29
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48
Shut-Down activities
Flushing
Cool-Down
P2N correctors or Mains < 1kA
P2N
Operation
LHe emptying and stabilization at 80K
SCS tests
WARM UP
Consolidation
BLM
Cool-Down and stabilization at 80K
Beam Commissioning

Strategy for the first LHC physics run

Main strategy in commissioning :
establish circulating beams and good lifetime at the injection energy. ✓ Sept. 2008

Chamonix 2/2009 baseline
1 month commissioning
10 month proton physics
1 month lead ions

August '09 : Detailed discussion of the knowledge from the 5 sectors measured at warm and the 3 sectors measured at 80 K
All put together and discussed in special LMC meeting on 5 Aug. 2009.
Decision by management - 6 Aug. 2009.

Go in three steps
- **collisions at injection energy 2 × 0.45 TeV = 0.9 TeV**
- **physics run at 2 × 3.5 TeV = 7 TeV**
- **physics run at increased energy, max. 2 × 5 TeV = 10 TeV**

Towards the end of 2010 before the winter shutdown : 1st run with heavy ions, lead - lead.

Next steps in commissioning with beam

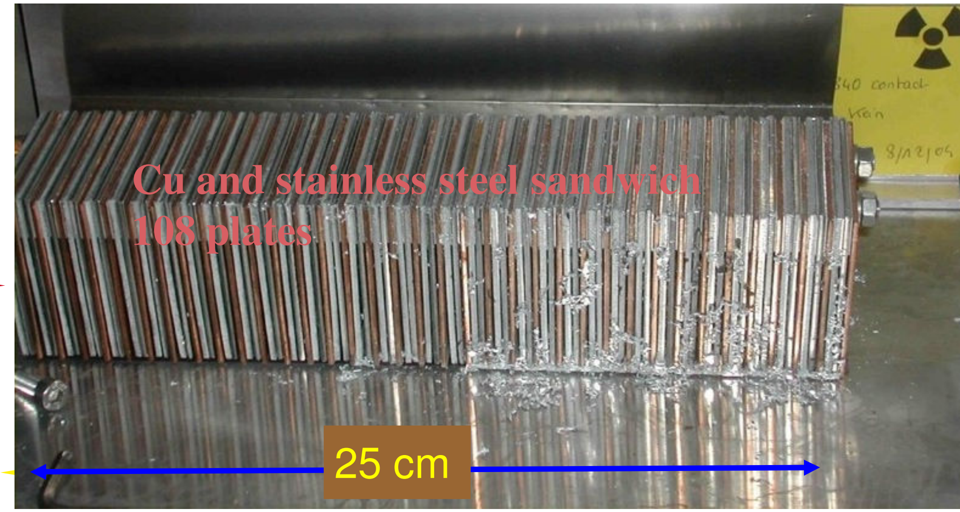
- complete the BPM checks (70%H, 30% V done)
- adjust and capture beam 1
- beam 1 & beam 2 timing
- experiments magnets : turn on solenoids and toroids
- possible to allow for first collisions at 2 × 450 GeV
- turn on IP2 / 8 spectrometers - verify perfect bump closure
- start to use collimators, increase intensity
- check out the beginning of the ramp, ~ 450 GeV to 1 TeV
- QPS commissioning
- beam dump commissioning
- full ramp commissioning to initial physics energy of 3.5 TeV
- first collisions at physics energy of 2 × 3.5 TeV
- increase intensity and partial squeeze

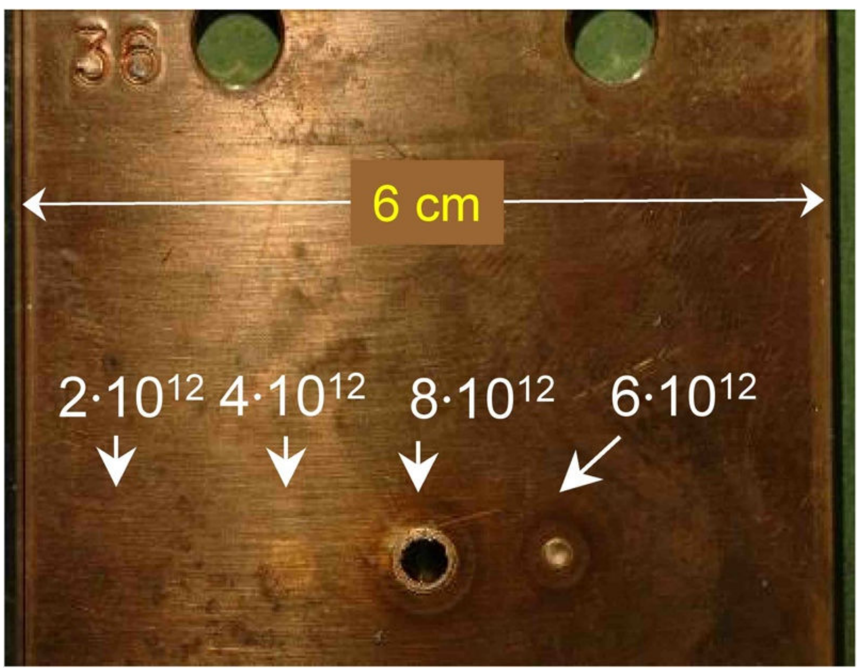
Damage potential : confirmed in controlled SPS experiment

controlled experiment with beam extracted from SPS at 450 GeV in a single turn, with perpendicular impact on Cu + stainless steel target

450 GeV protons

r.m.s. beam sizes $\sigma_{x/y} \approx 1$ mm





SPS results confirmed :

8×10^{12} clear damage 2×10^{12} below damage limit

for details see V. Kain et al., PAC 2005 RPPE018

For comparison, the LHC nominal at 7 TeV :
$2808 \times 1.15\times10^{11} = 3.2\times10^{14}$ p/beam

at $< \sigma_{x/y} > \approx 0.2$ mm

over 3 orders of magnitude above damage level for perpendicular impact

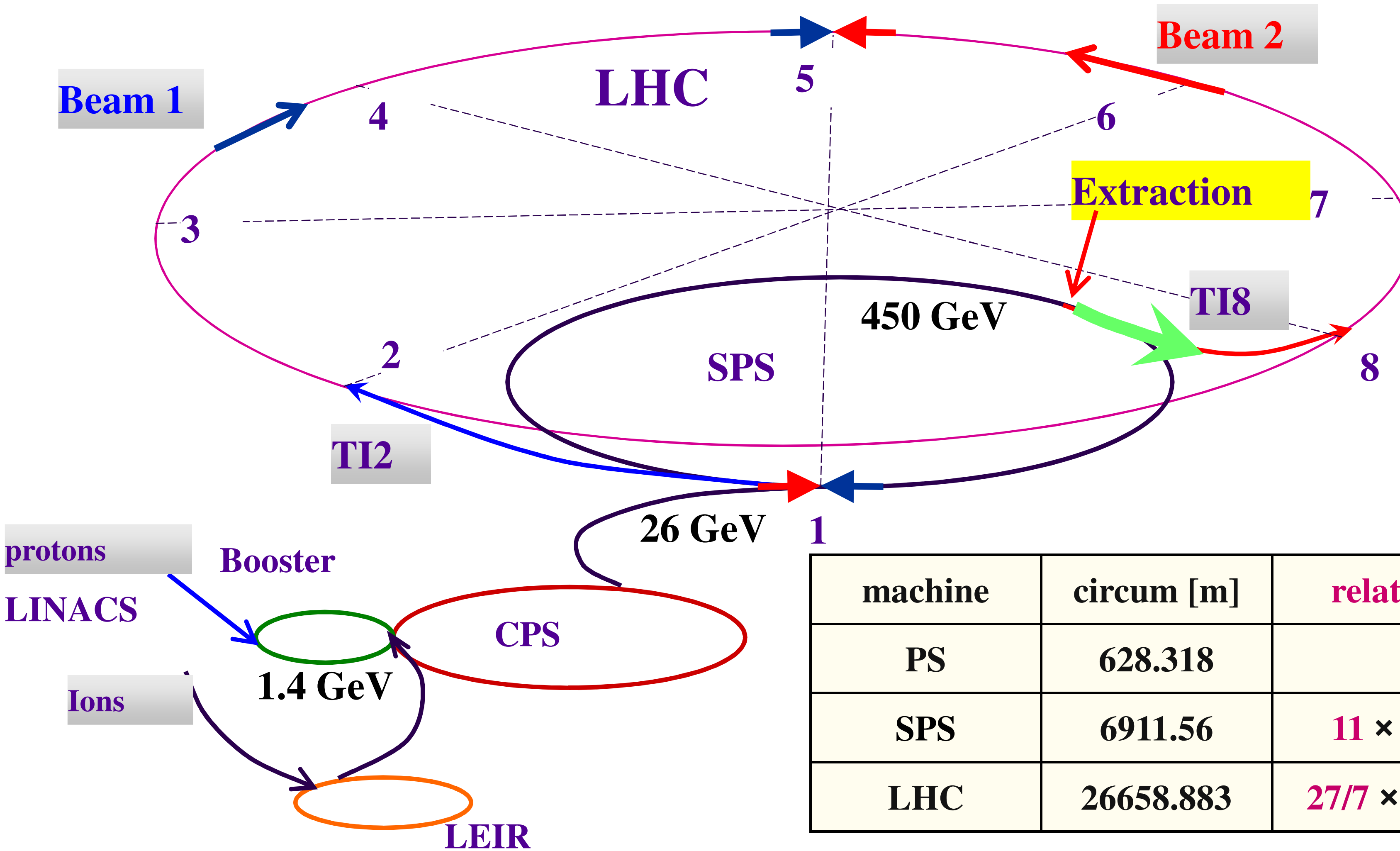
Beam parameters, LHC compared to LEP

	LHC	LEP2
Momentum at collision, TeV/c	7	0.1
Nominal design Luminosity, $cm^{-2}s^{-1}$	1.0E+34	1.0E+32
Dipole field at top energy, T	8.33	0.11
Number of bunches, each beam	2808	4
Particles / bunch	1.15E+11	4.20E+11
Typical beam size in ring, µm	200 – 300	1800/140 (H/V)
Beam size at IP, µm	16	200/3 (H/V)

- **Energy stored in the magnet system: 10 GJoule** Airbus A380, 560 t
- **Energy stored in one (of 8) dipole circuits: 1.1 GJ**
  (sector) at 700 km/h
- **Energy stored in one beam: 362 MJ**
  20 t plane
- **Energy to heat and melt one kg of copper: 0.7 MJ**

the LEP2 total stored beam energy was about 0.03 MJ

The CERN accelerator complex : injectors and transfer



machine	circum [m]	relative
PS	628.318	
SPS	6911.56	11 × PS
LHC	26658.883	27/7 × SPS

simple rational fractions for synchronization
on a single frequency
ator at injection

Beam size of protons decreases with energy : area $\sigma^2 \propto 1 / E$

Beam size largest at injection, using the full aperture

Maximum beam intensity LHC year 1

design LHC intensity : 3.23×10^{14} protons / beam

1st years, limited by magnet quench / collimation

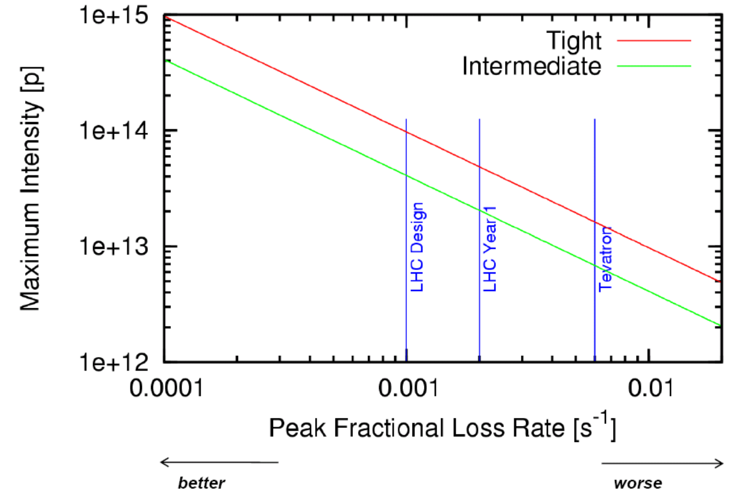
maximum beam loss rate ~ 10^{-3} /s fraction or ~4×10^{11} p/s

Examples for 0.001/s Loss Rate

- It is really the loss rate that matters above a few ms. So what counts is the ratio of loss amount over loss duration (short loss spikes are very dangerous). We get the peak loss rate 0.001/s from:
  - **1% of beam lost in 10 s.**
  - **0.1% of beam lost in 1 s.**
  - **0.01% of beam lost in 100 ms.**
  - **0.001% of beam lost in 10 ms.**
- Stick with the official loss rate 0.001/s from now on, adding some evolution.
- Assume 0.002/s is achieved in the first year of LHC operation at 5 TeV, as shown in following slides.

Ralph Assmann 21

Result: Intensity Limit vs Loss Rate 5 TeV



Ralph Assmann 18

 # bunches : nominal is 2808 bunches, 25 ns spacing

LHC year 1 : Important to go in small steps - minimize beam losses. Max. total intensity at 5 TeV roughly ~ 1/10 nominal.

start of physics run : $I < 2\times10^{13}$ p with intermediate coll. settings

later : $I < 5\times10^{13}$ p with tight coll. settings.

3.5 TeV intensities could be a bit higher - details remain to be worked out

Scaling of beam parameters with energy

Baseline beam parameters for E_b = 5 TeV have been worked out, discussed and agreed, LPC 7/5/09
Details for 3.5 TeV still need to be defined.

		scale factor 3.5 to 5 TeV
intensity	more critical at high E	take 1 ; conservative
emittance	E^{-1}	1.43
β*	$\sim E^{-1}$ triplet aperture	1.43
Luminosity	$\sim E^{-2}$	2
beam-beam tune shift	constant	1

Luminosity estimates : roughly 2× less at 3.5 TeV compared to 5 TeV
this should be conservative and does not take into account that lower energies are less critical for protection, shorter ramp time and faster turnaround.

Beam-beam tune shift parameter ξ
for head-on collisions depends only
on intensity (not energy, β*)

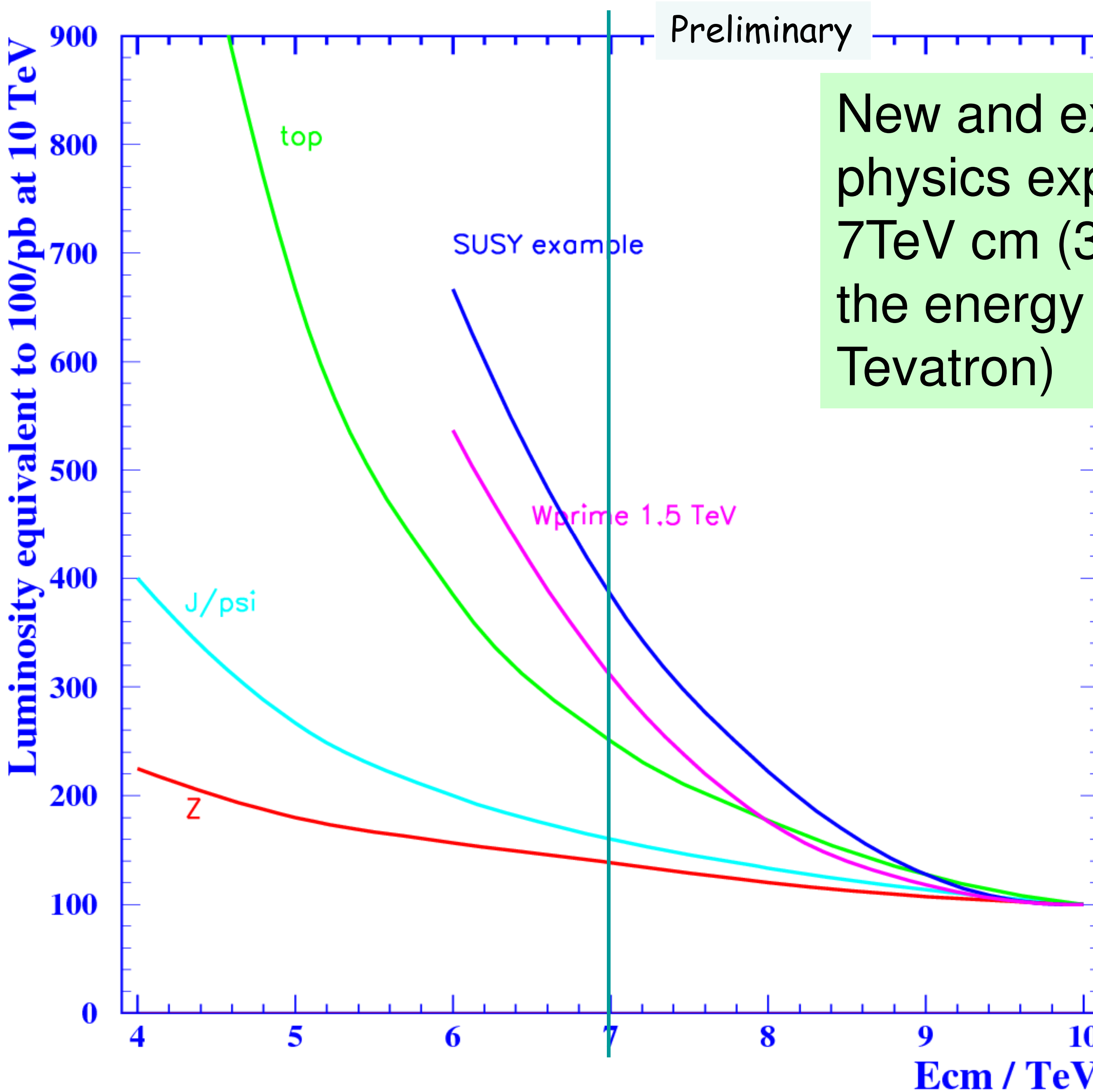
$$\xi = \frac{r_p N}{4\pi \epsilon_N}$$

nominal LHC : round beams and const ε_N

$$\sigma_{x,y} = \sqrt{\beta_{x,y}\,\epsilon_N/\gamma}$$

N	ξ
5×10^9	0.000163
4×10^{10}	0.00130
1.15×10^{11}	0.00374

at the design emittance



New and exciting physics expected at 7TeV cm (3.5 times the energy of the Tevatron)

Integr section

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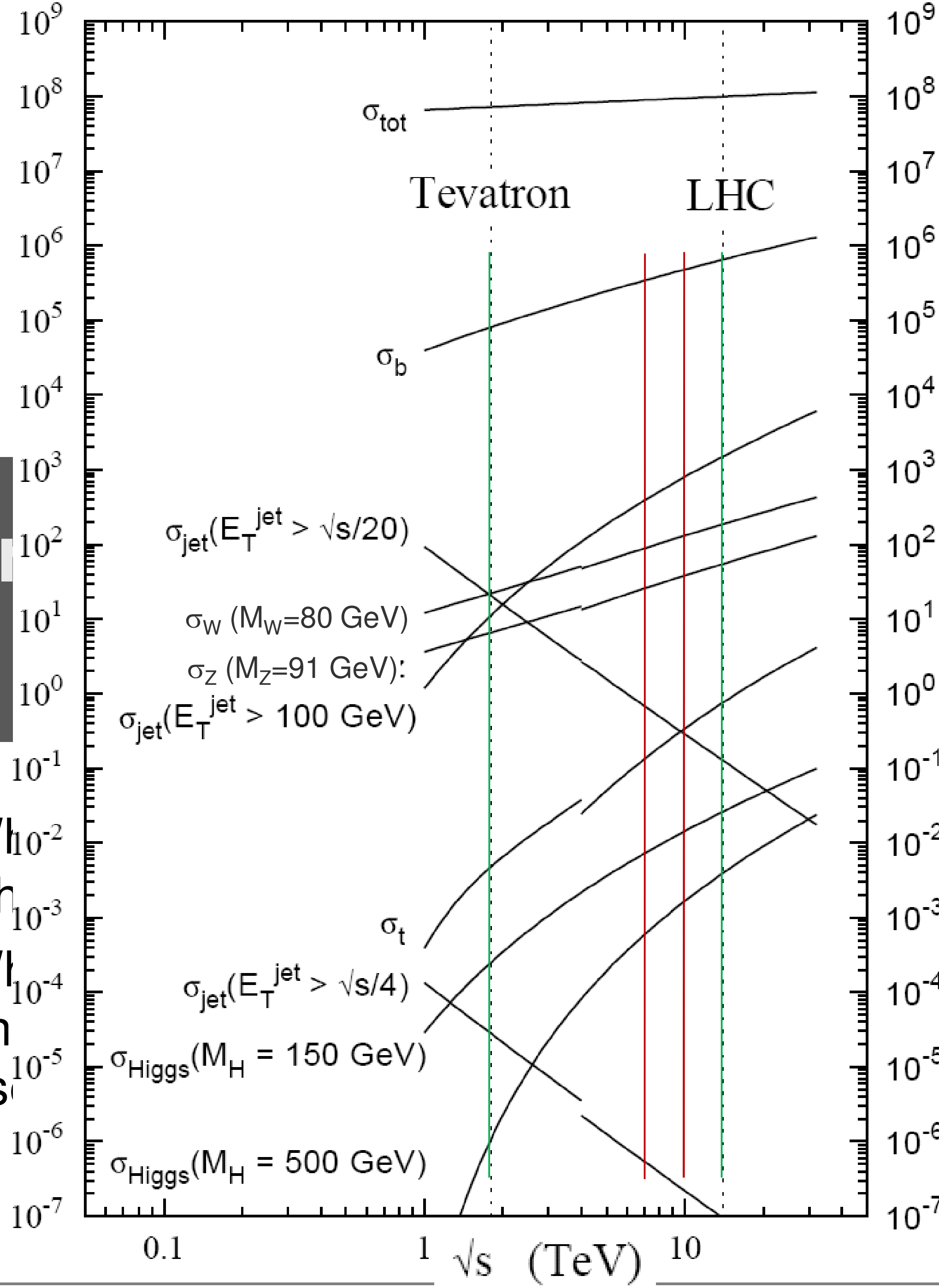
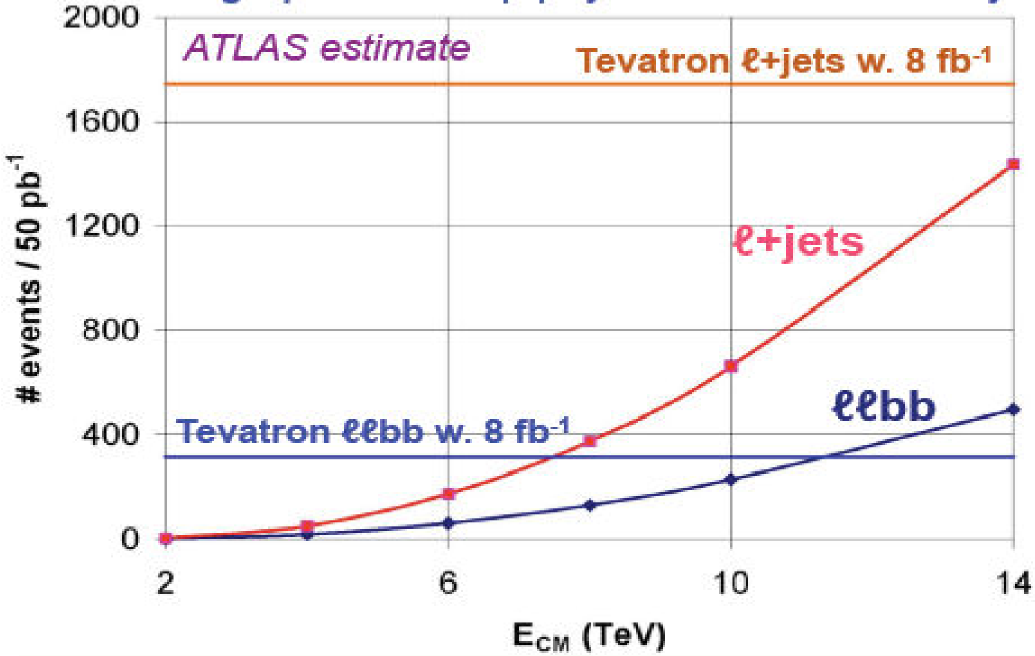


Top quark

- Background to new physics searches – must measure cross-section & properties in data
- Expected Tevatron statistics provide a benchmark:
  - Cross-section statistical precision will then be comparable to other uncertainties
  - High-precision top physics will be underway



~50 pb^{-1}@14 TeV would match full Tevatron sample

- lose ~factor 2 in cross-section dropping to 10 TeV
- lose ~another factor 2 dropping to 8 TeV

Below 8 TeV samples will be rather small, with a few tens of pb^{-1}

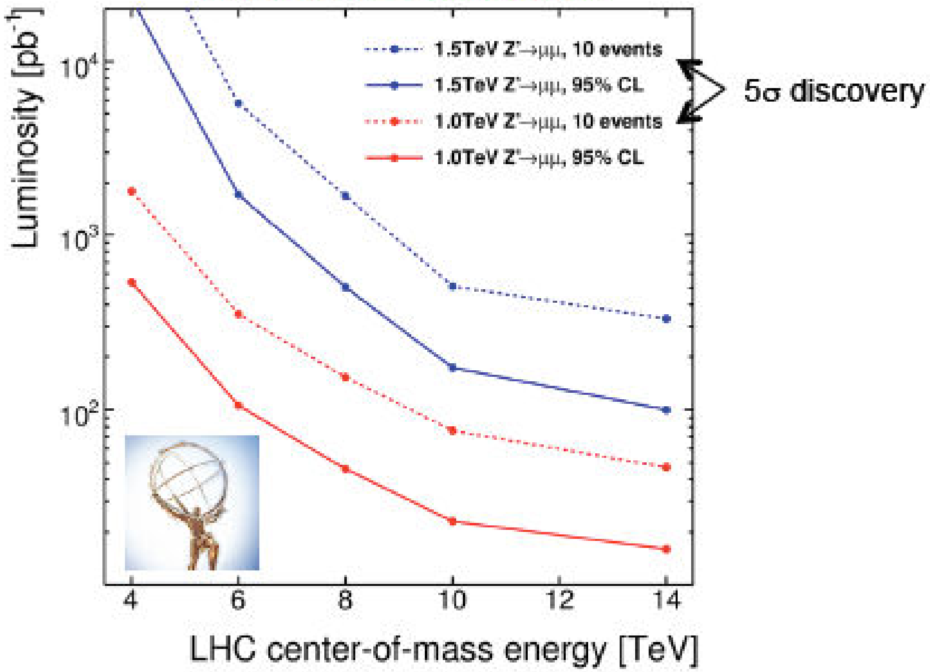
Catch up with Tevatron with $s^{1/2}$ = 8-10 TeV and ~200-100 pb^{-1} g.d.

Z’

Z': Heavy partner of the Z (SSM)

- Very clean experimental signal: $Z' \to \ell\ell$
- Tevatron 95% CL limit at $m_{Z'}$ =1 TeV

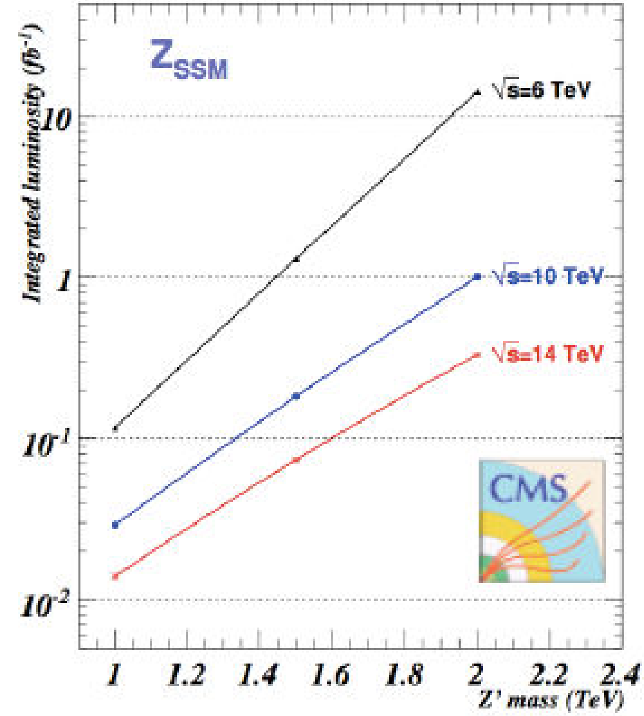
ATLAS fast simulation



Needed luminosity for 95%CL exclusion at $m_{Z'}$ = 1 TeV :

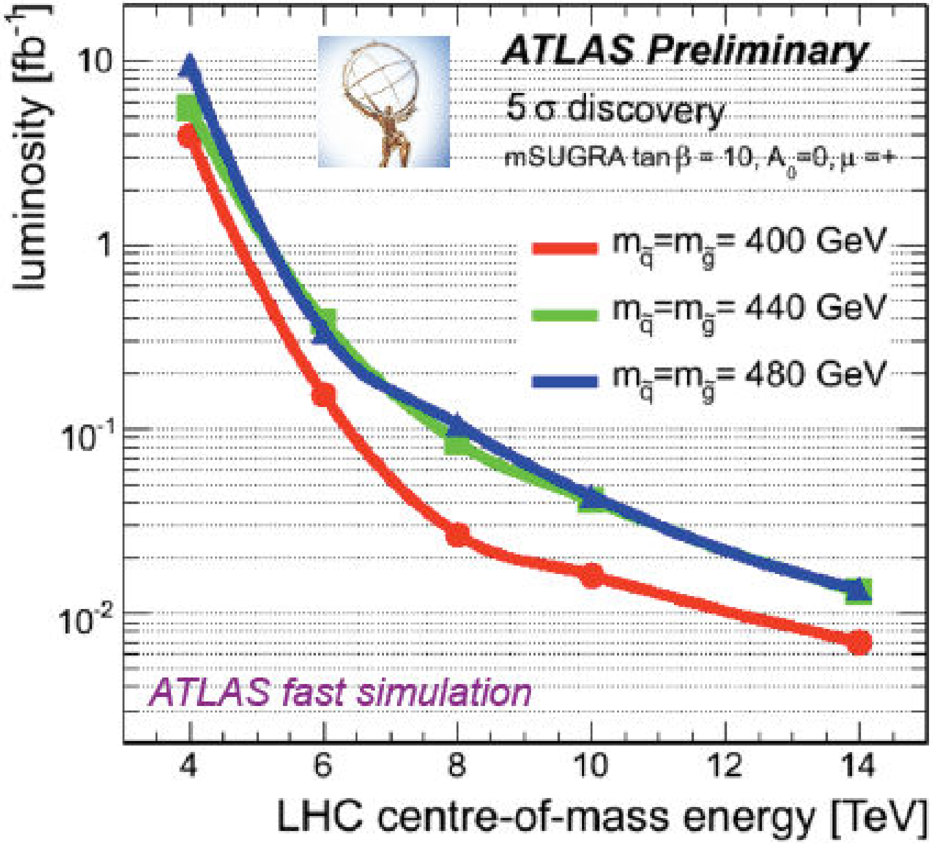
$s^{1/2}$: 14 → 10 → 6 TeV

Lumi: 13 → 30 → 110 pb^{-1}



SUSY, an example

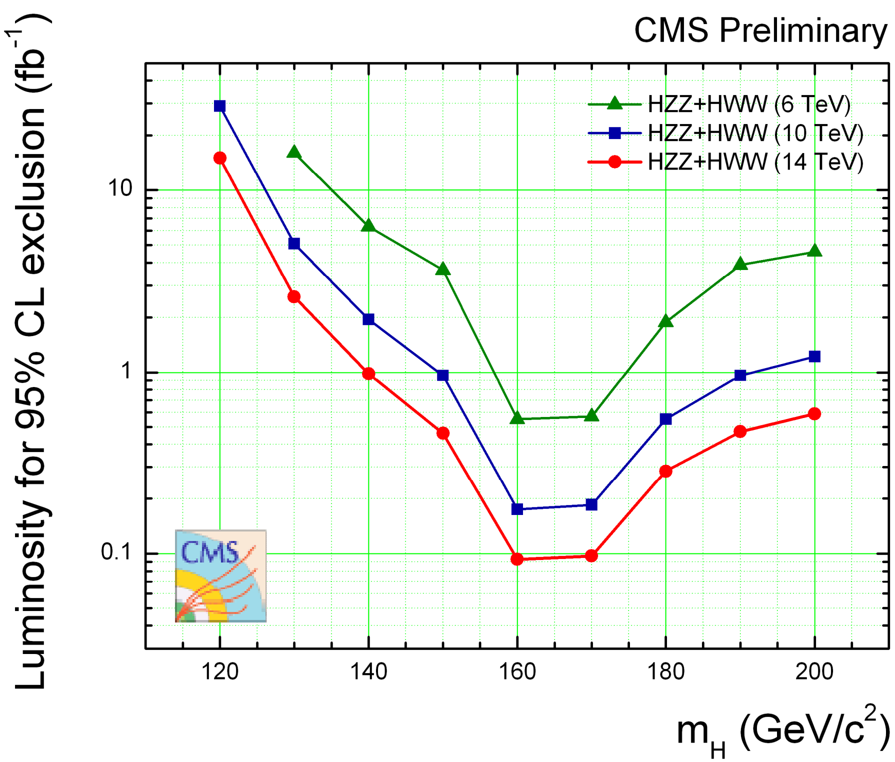
- ℓ+jets+missing-E_T channel
  - Not most sensitive, but will be usable before inclusive jets +missing-E_T analysis
- Tevatron limit currently is 380 GeV in this model ($m_{\tilde{q}} = m_{\tilde{g}}$)
  - plot shows 3 masses above this
- We will be sensitive to a region overlapping with ultimate Tevatron reach
- Below $E_{cm} \approx 8$ TeV, the sensitivity collapses



5σ discovery beyond current Tevatron limits is possible with **$s^{1/2}$ = 8-10 TeV** and ~**30-15 pb^{-1} g.d.**

Higgs 95% CL at LHC GPD , H→ weak bosons, indicative

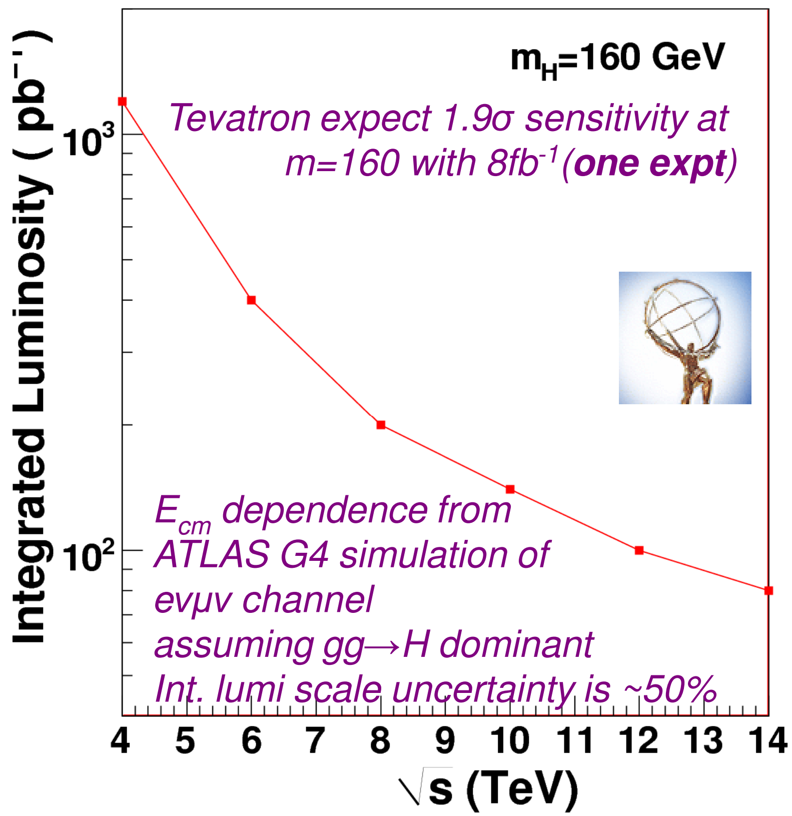
Combined H→WW + H→ZZ: lumi for 95% CL



- Energy $s^{1/2}$ 14 → 10 → 6 TeV
- Lumi needed 0.1 → 0.2 → 0.6 fb^{-1}

Compare sensitivity to Tevatron with 8 fb^{-1}

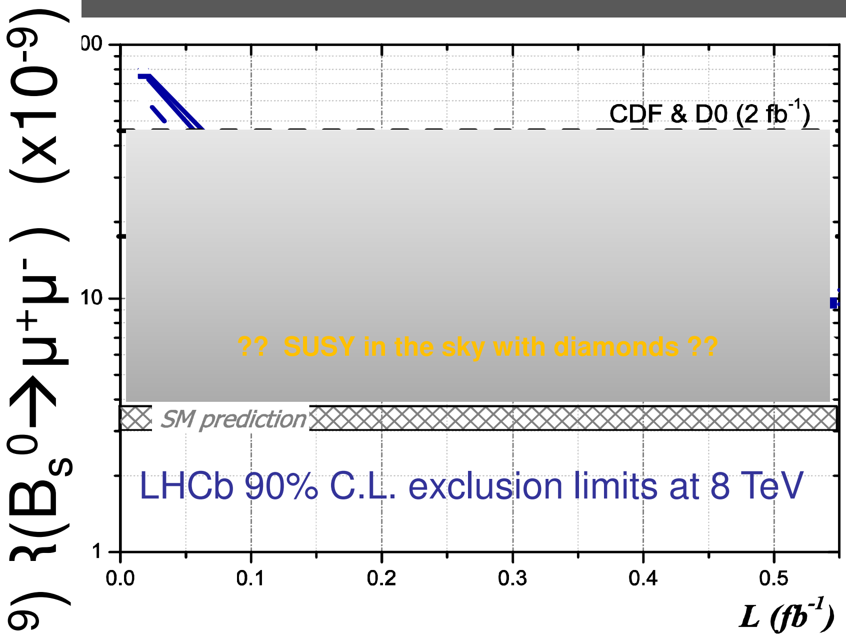
(only H→WW→ $\ell\nu\ell\nu$)

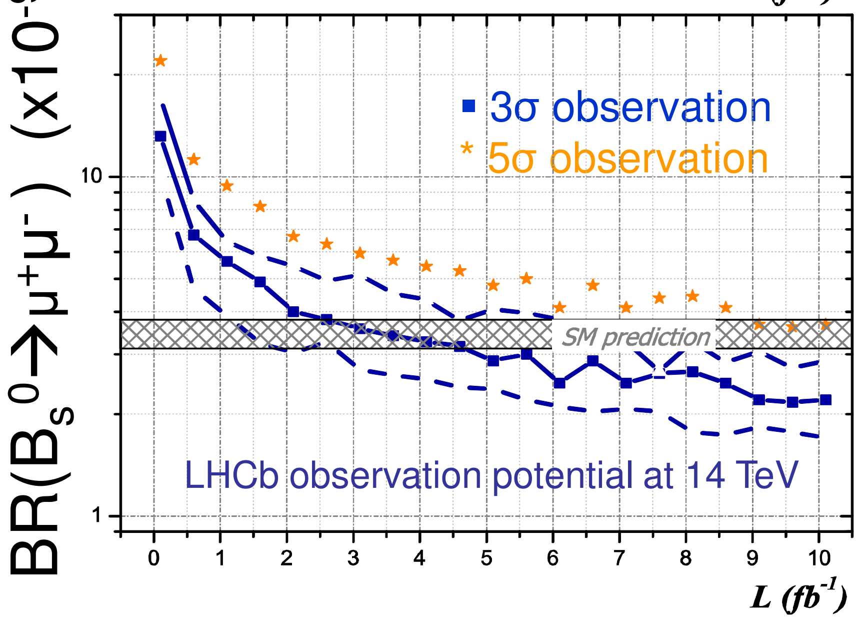


- Massive loss of sensitivity below 6 TeV

To challenge Tevatron with **$s^{1/2}$ = 8-10 TeV**, we need ~**300-200 pb^{-1} g.d.**

Physics reach for BR($B_s^0 \to \mu^+\mu^-$)





- as function of integrated luminosity (and comparison with Tevatron)

At $\mathbf{s^{1/2}}$ **= 8 TeV** , need ~**0.3-0.5 fb^{-1} g.d.** to improve on expected Tevatron limit

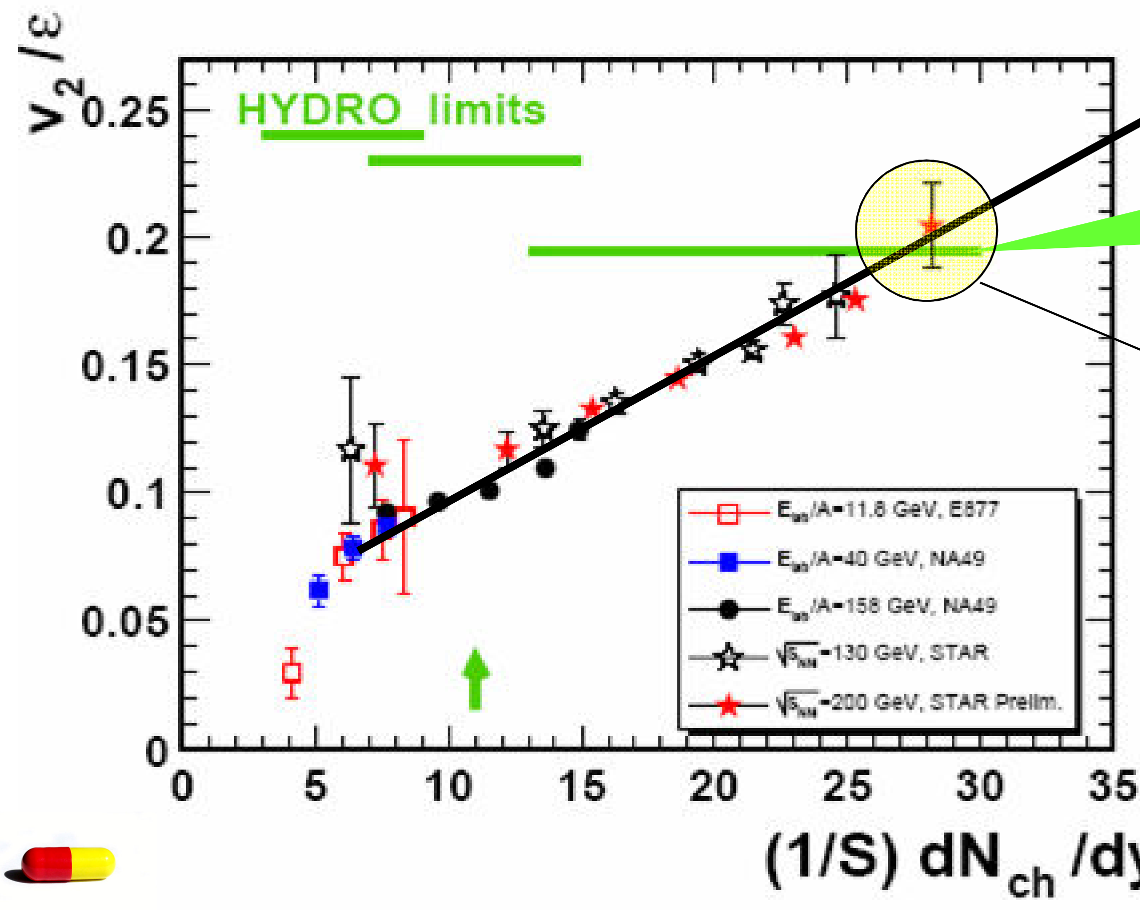
Collect ~3 fb^{-1} for 3σ observation of SM value

Heavy Ions: Flow at LHC

- one of the first and most anticipated answers from LHC
  - 2nd RHIC paper: Aug 24, 22k MB events, **flow surprise** (v_2)
    - Hydrodynamics: modest rise (Depending on EoS, viscosity, speed of sound)

LHC ?

increase of flow



BNL Press release, April 18, 2005:

Data = ideal Hydro

"Perfect" Liquid

New state of matter more remarkable than predicted – raising many new questions

LHC will either

confirm the RHIC interpretation

(and measure parameters of the QGP EoS)

OR

……………………..

sLHC : luminosity upgrade

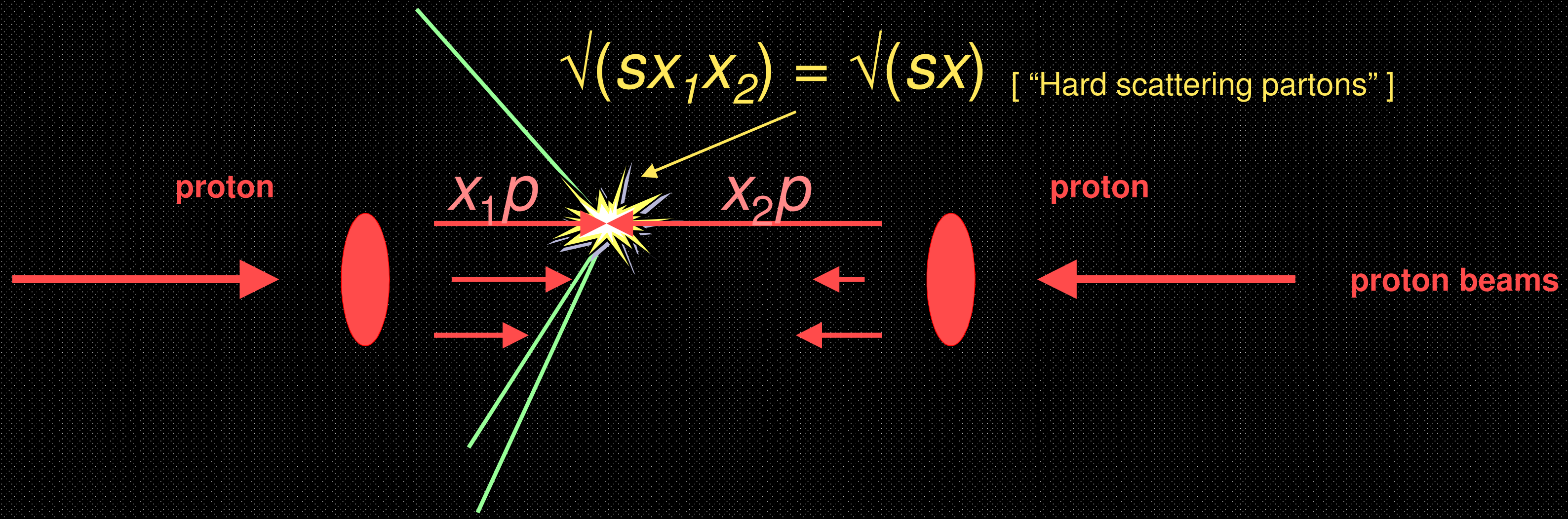
Marzio Nessi

Lepton Photon, 20th August 2009

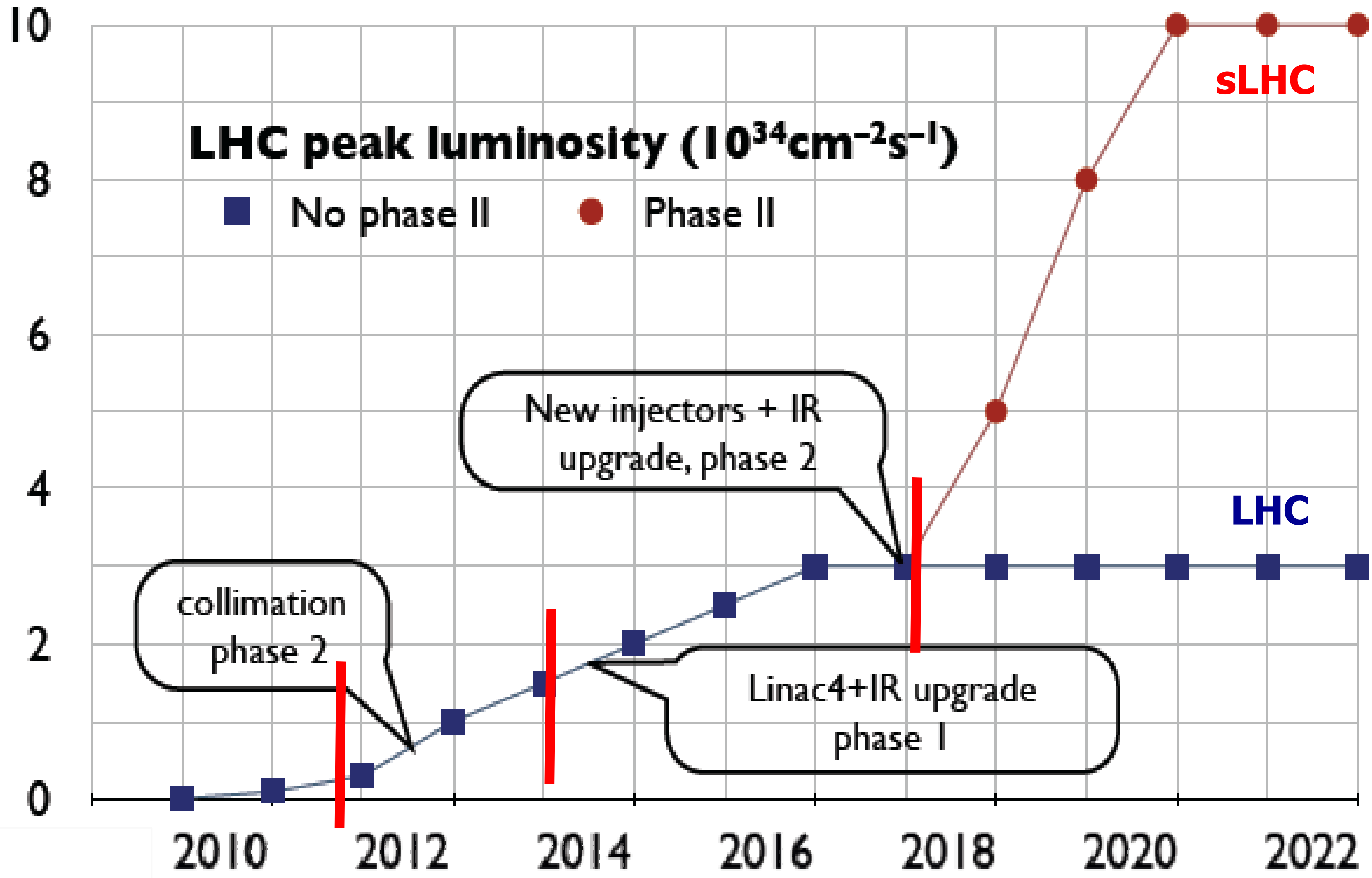
What is the sLHC ?

The sLHC will represent a Luminosity upgrade of the present 14 (7 + 7) TeV LHC accelerator facility

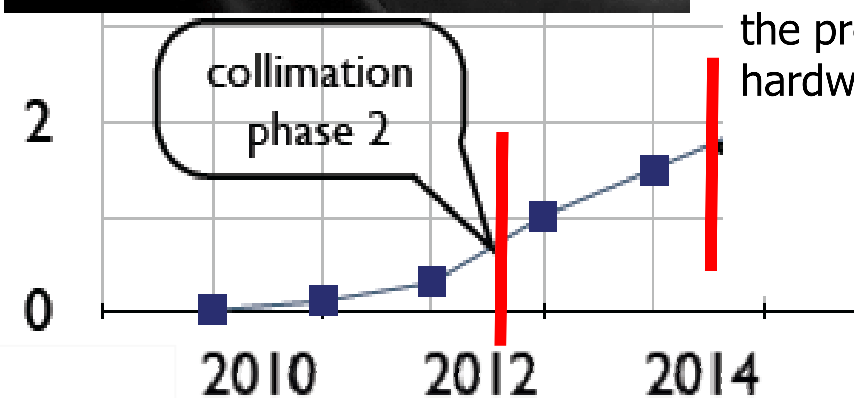
…. with expected collision rates ~ 20-40 MHz for a peak Luminosity ~ 10^{35} cm^{-2} s^{-1} or a delivered Integrated Luminosity of ~3000 fb^{-1} or more



Luminosity road map in 2 phases



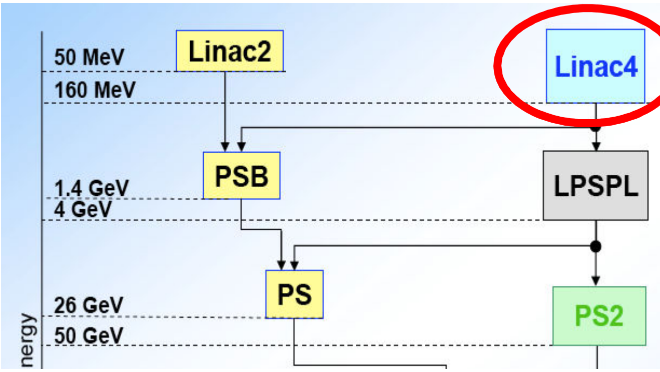
How will the next few years develop ?



- ✓ Through a sequence of long runs alternated to relative long shutdowns
- ✓ Initial runs to tune and get to know machine and experiments (7 TeV -> 10 TeV -> 14 TeV)
- ✓ Shutdowns to upgrade the energy to 7 TeV (probably in steps, fix known problems, re-train magnets,…), but also to increase luminosity and machine protection (collimation upgrade)
- ✓ 200-300 fb^{-1} is the integrated Luminosity level where the pp experiments expect some aging of the present pixel innermost layer and when new hardware might become necessary

New discoveries will eventually influence this path

Phase I upgrade brings us to end of the LHC mandate

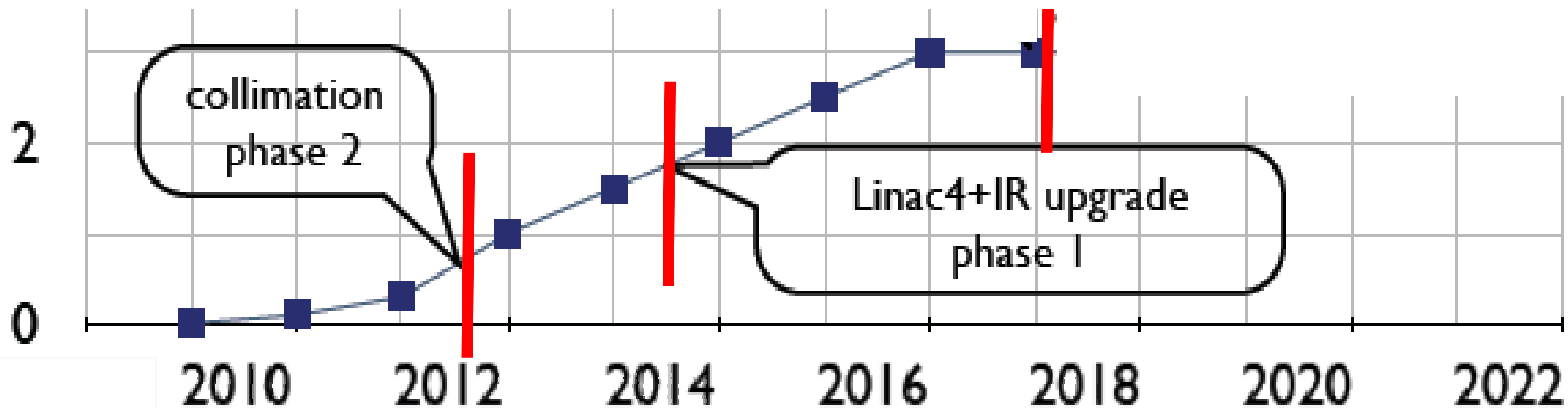


Linac4 higher performance:

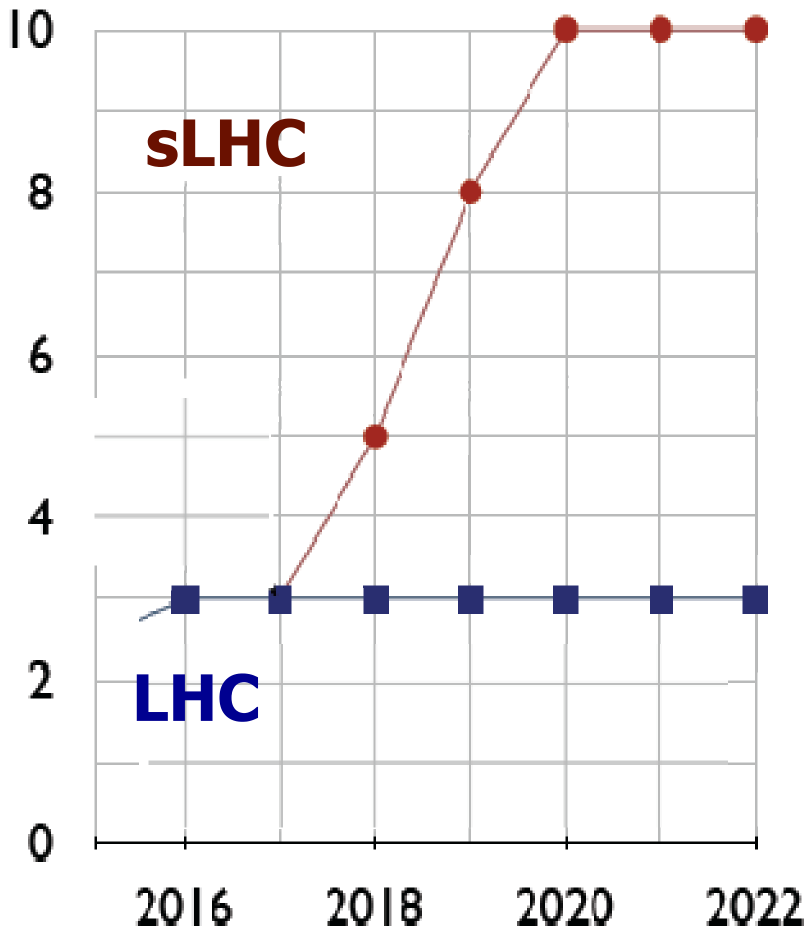
Space charge decreased by a factor of 2 in the PSB, factor 2 gain in $\beta\gamma^2$

$\Rightarrow$ potential to double the beam brightness at constant tune shift and fill the PS with the LHC beam in a single pulse

- ✓ *Linac-4 approved and construction work has started*
- ✓ *Allows to increase the LHC current to "ultimate" which is 2.3 times the nominal*
- ✓ *New Inner Triplet focusing magnets. Larger aperture, allows β^* of 0.25 m, L x 2 !*
- ✓ ***The expectation is that these two improvements will allow a ramp-up to 3 x nominal Luminosity, 120-180 fb^{-1} /year***



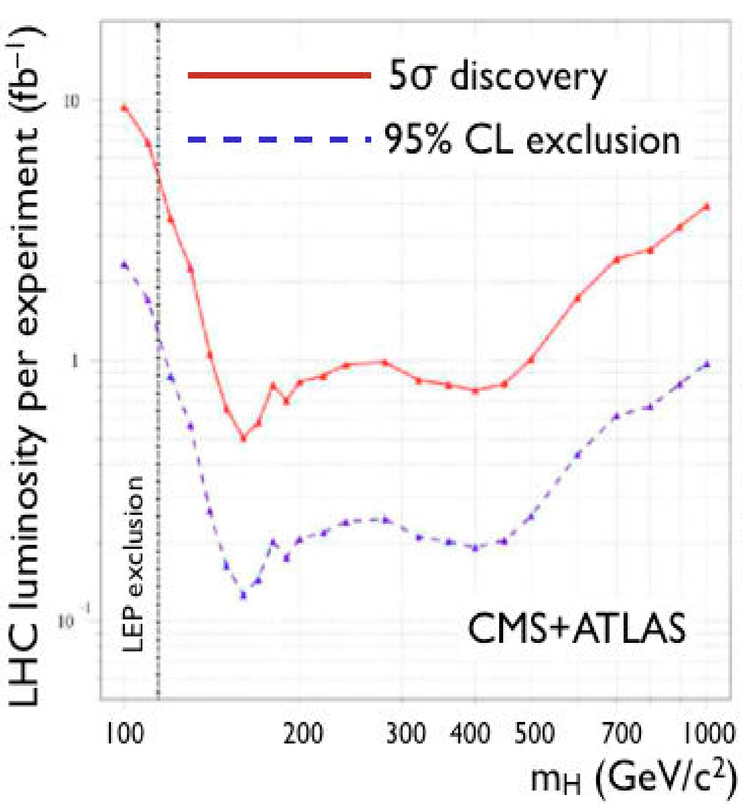
Why should we go beyond 600 fb^{-1}: sLHC ?

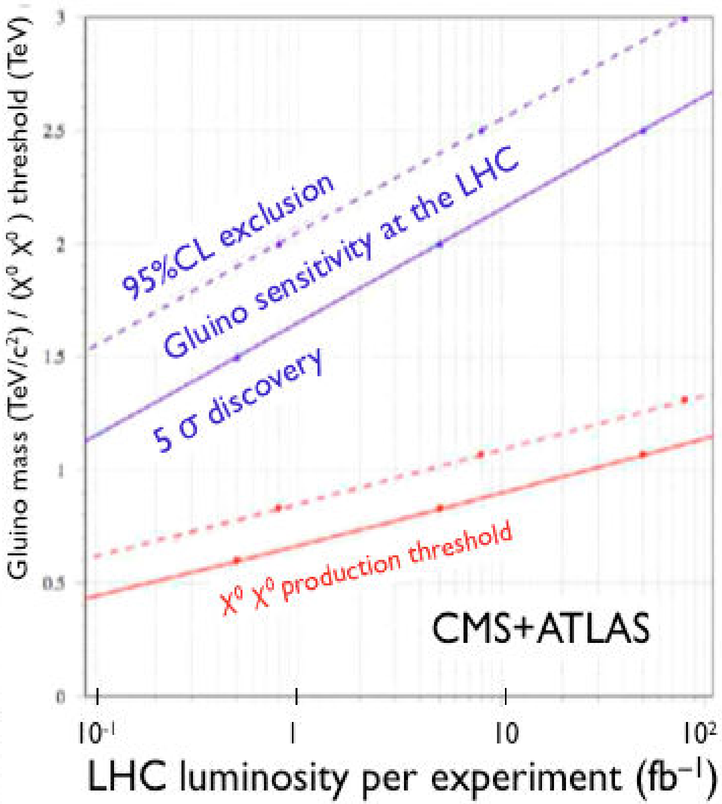


10 times more statistics, is there a physics motivation for 3000 or more fb^{-1}?

Whatever the decision will be, in 8-9 years from now the pp detectors will need a major upgrade; some components like the Inner Detectors will be suffering from aging and radiation damage

Why should we go beyond 600 fb^{-1} ?

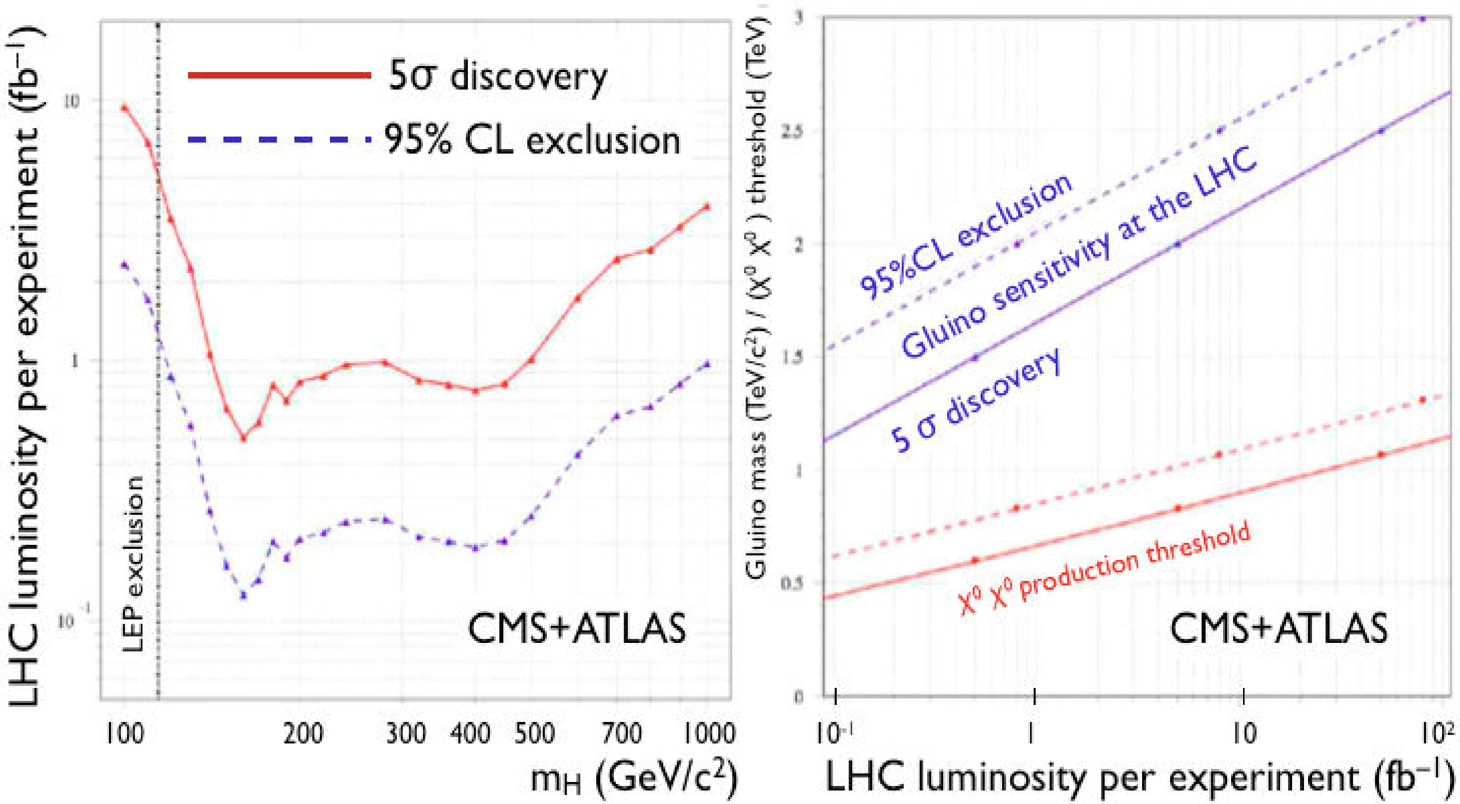




With 10fb^{-1} the LHC will either discover or exclude the SM Higgs and Gluinos up to 1.8-2 TeV. This probably after 2 years of running at 14 TeV and at 10^{33} cm^{-2}sec^{-1}

Whatever the results will be, we will be left with a lot of new questions and problems to solve. There will be no limit to the need of accuracy after that!

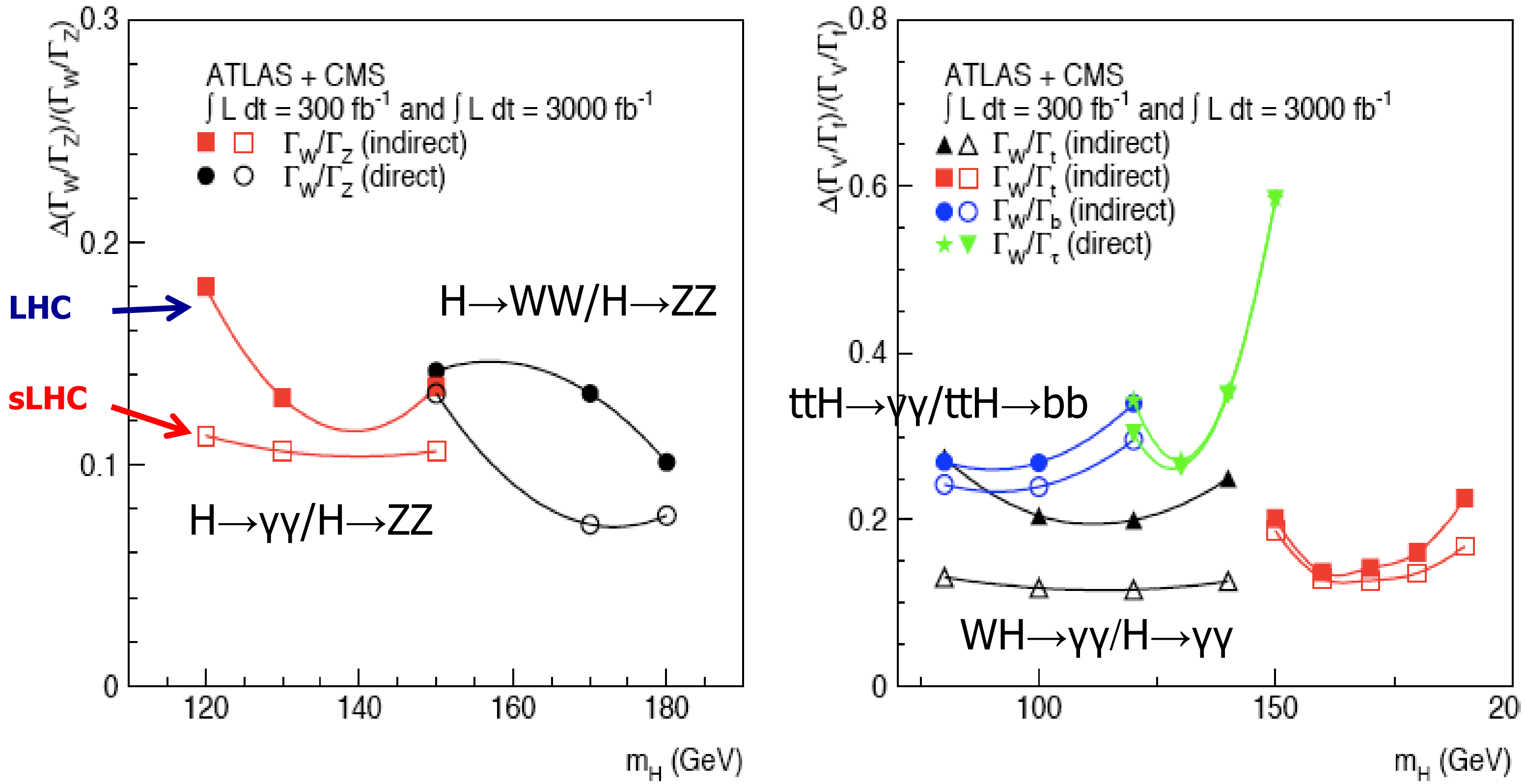
Why should we go beyond 600 fb^{-1} ?



More particles in the Higgs sector? Is the Higgs boson elementary or composite? Origin of fermion masses ?

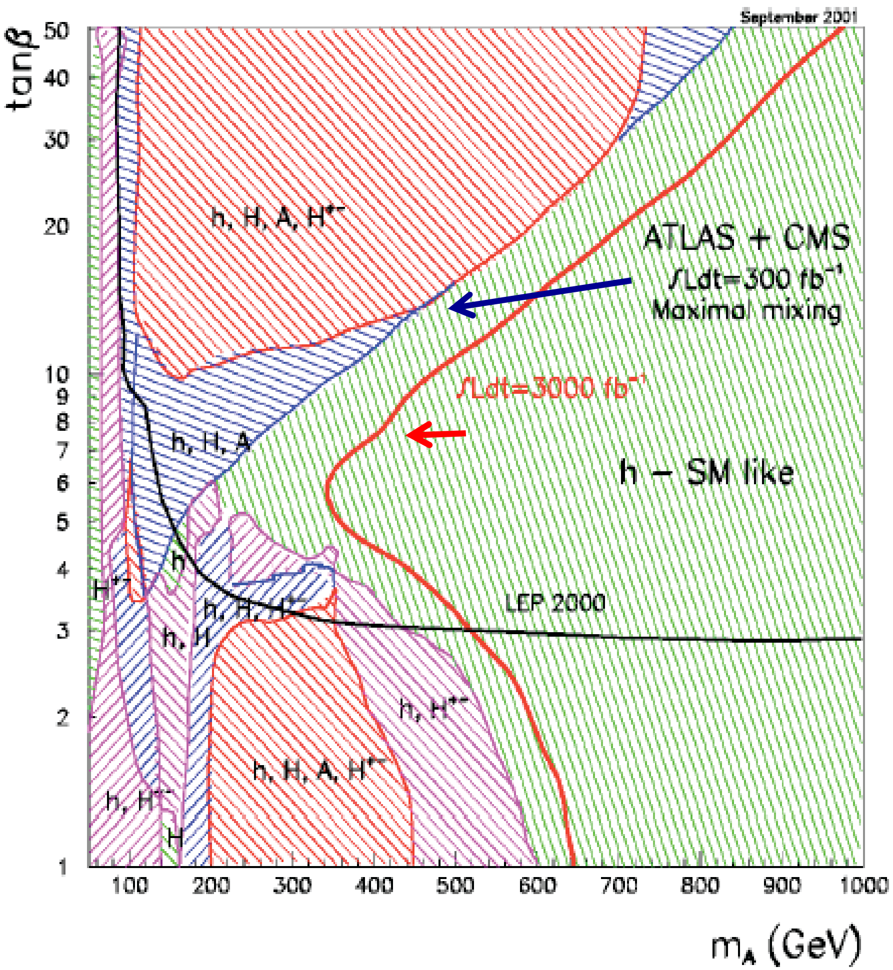
Extend the mass reach of new particles ! Determination of SUSY masses and parameters !

Precision measurements of the SM Higgs sector



- Higgs couplings to fermions, gauge bosons
- Rare decay modes : H-> Zγ (~10^{-3} BR), H-> $\mu\mu$ (10^{-4} BR)
- Self couplings λ : H -> HH -> WWWW -> lνlνjjj (sLHC 20-30%)
- ....

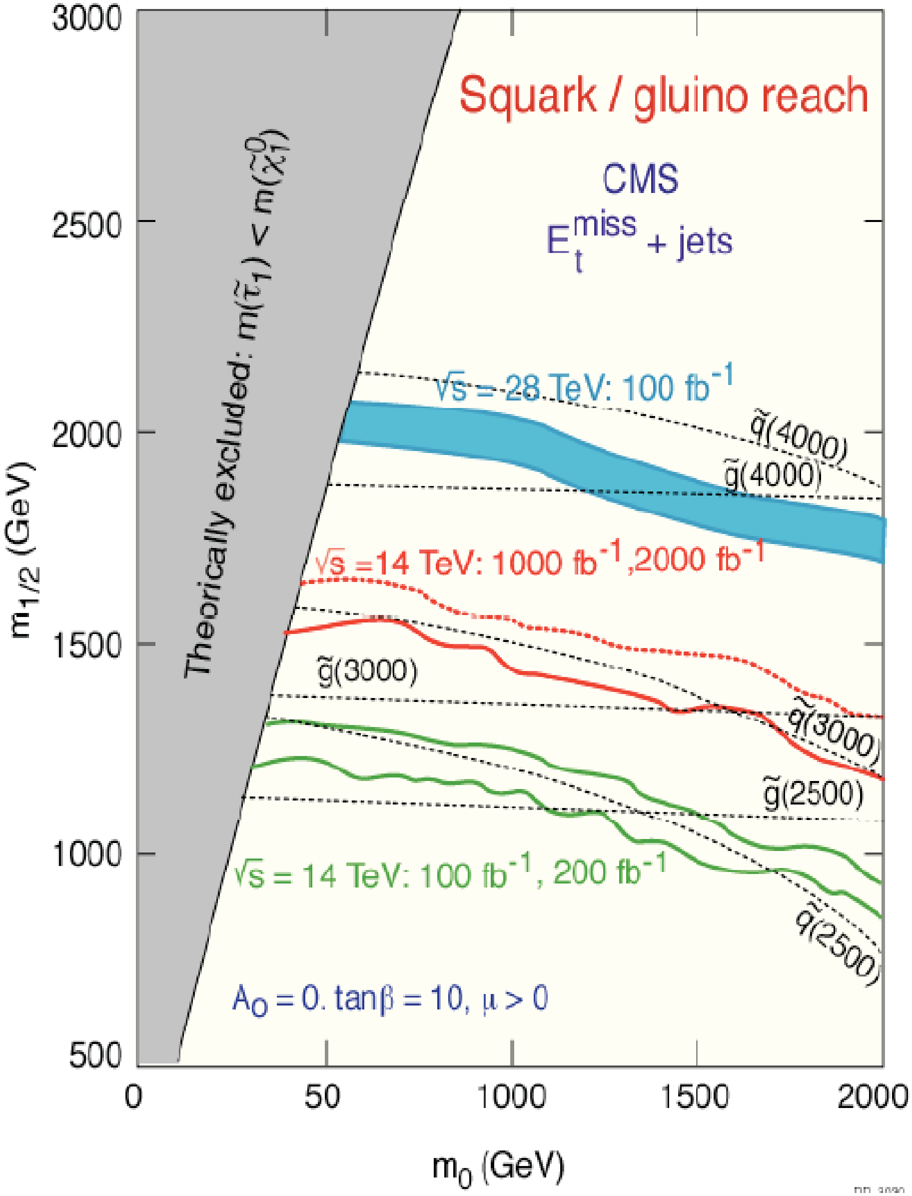
MSSM Higgs (h, H, A, H^{+-})?



Over part of the parameter space the LHC should be able to discover two or more SUSY Higgs bosons

The sLHC should extend significantly the region over which only the lightest Higgs boson h can be observed

SUSY mass reach !



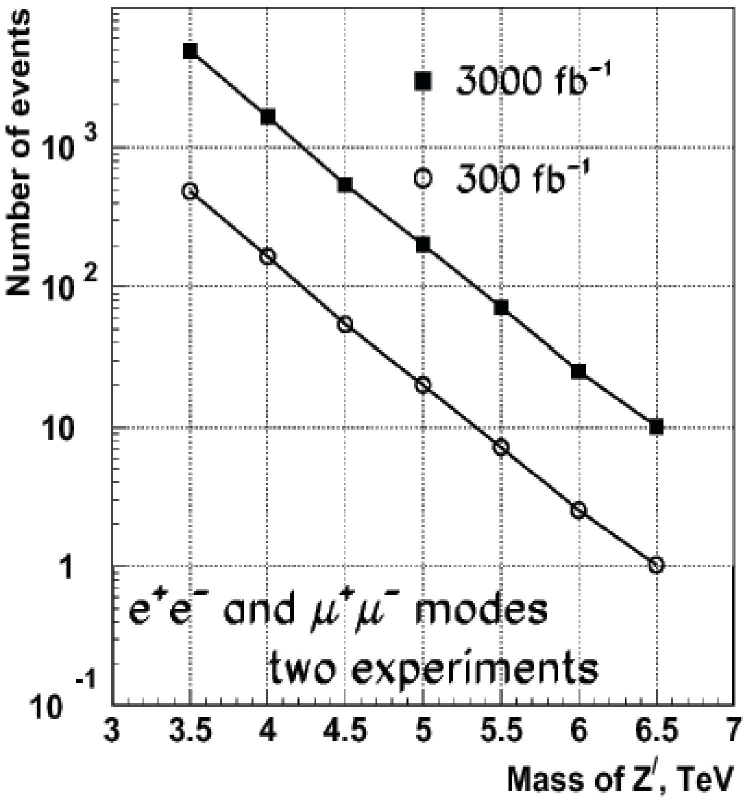
The mass sensitivity grows logarithmically with the statistics

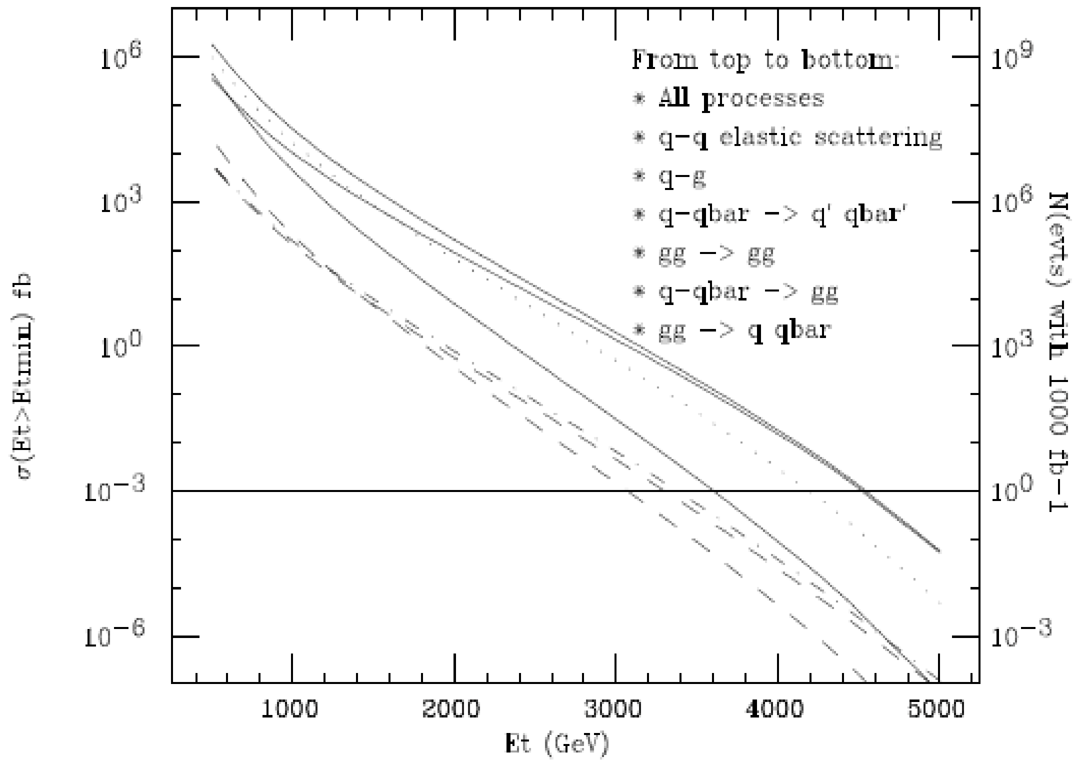
A factor 10 in Luminosity -> 500 GeV

This will increase the mass reach around 3.0-3.3 TeV at sLHC

M reach ~ 500 GeV more than LHC

New forces (Z′, W′) ? , Compositeness ?



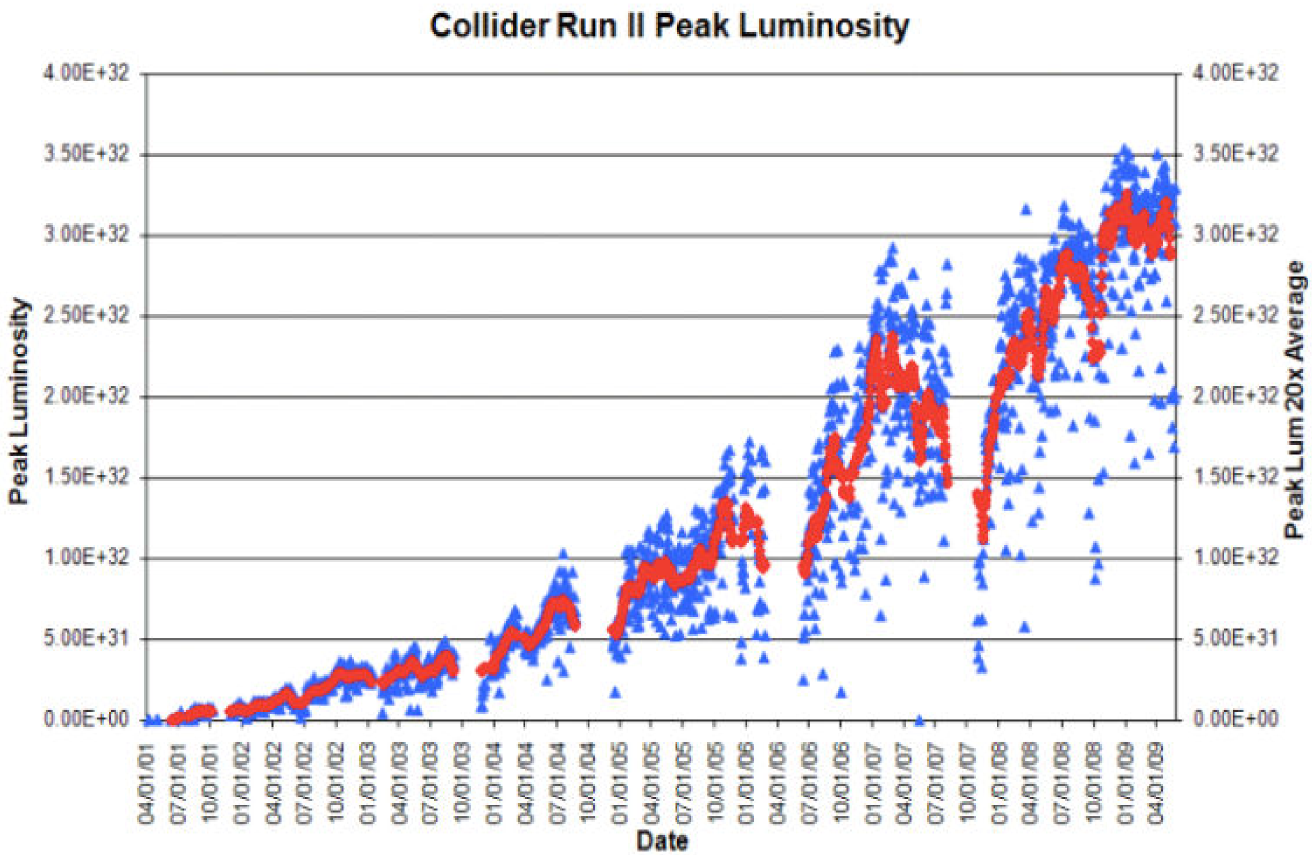


The mass reach can be pushed by ~ 1.1TeV to **6.5 TeV**

$\Lambda >$ 40 TeV limit at LHC

$\Lambda >$ **60 TeV** limit at sLHC

Lesson from the Tevatron

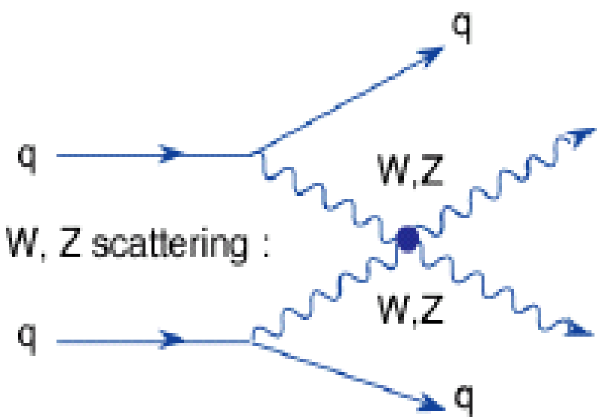


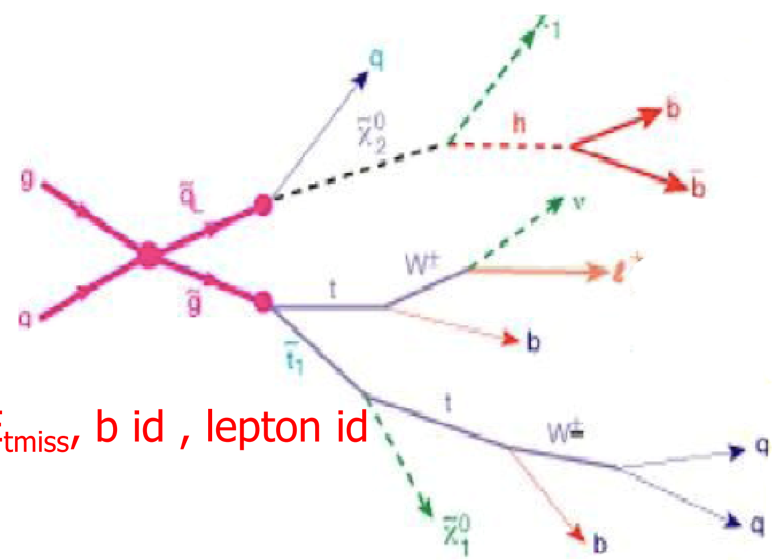
The lesson from the Tevatron is that once data are available, the experimental ingenuity can deliver the "impossible" (M.Mangano)

..but it also says that it takes time

Detector requirements @ sLHC

Detector performance needs to be maintained despite the new environment we will find at sLHC (pile-up, radiation, ...) ...... in particular now when we don't know anything about the new energy domain





E_{tmiss}, b id , lepton id

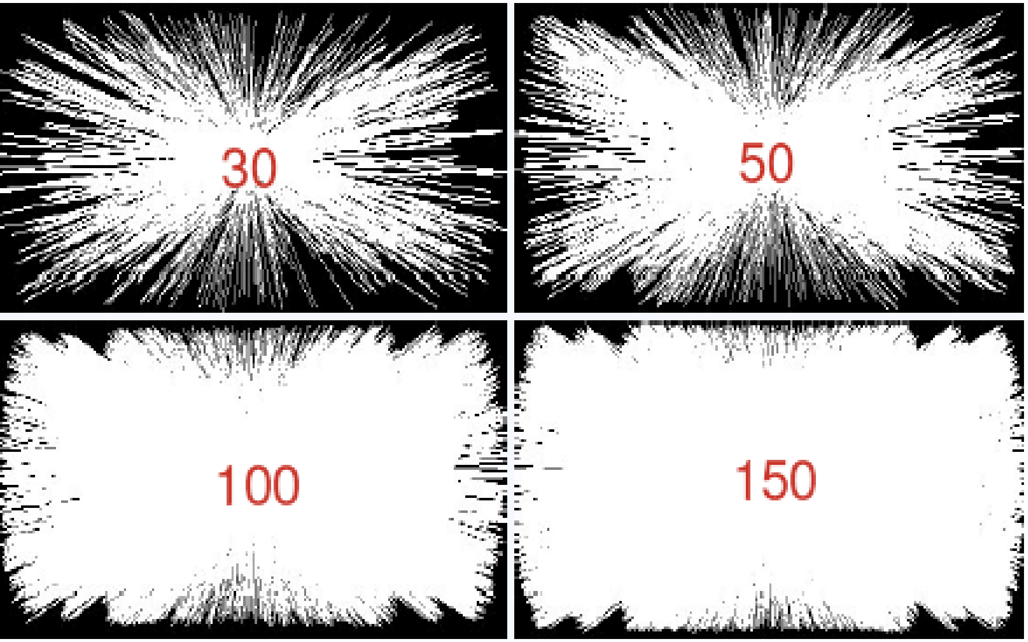
High-mass (~TeV Z',W',..) can tolerate some degradation; backgrounds are low

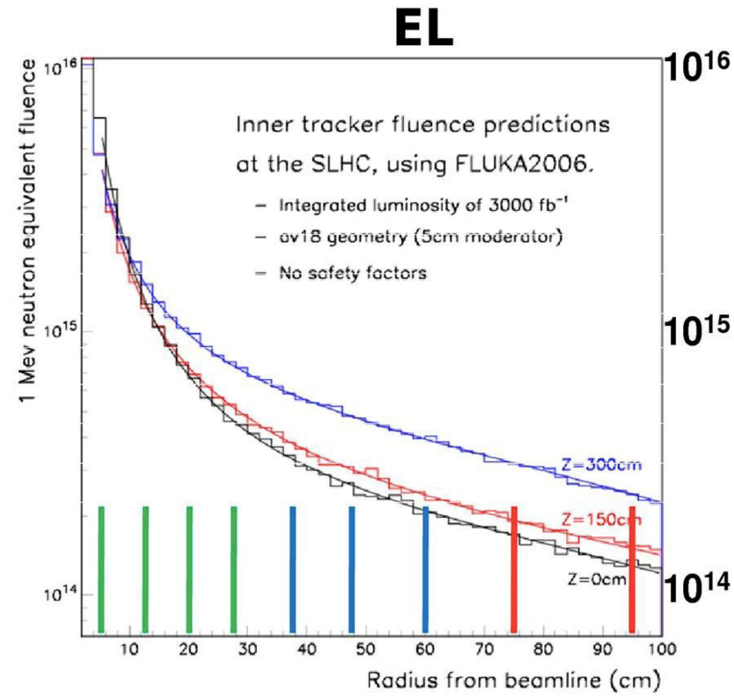
WW scattering (Higgs couplings or vector boson fusion) needs forward jet reconstruction and central jet veto

Vertex, missing E_T, p_T resolution and efficiencies remain important, for many channels of interest

Electron and muon identification fundamental for W/Z, W'/Z', and SUSY

Detector environment and requirements





Minimum bias events ***pile-up*** *dominated by the peak Luminosity. Different sLHC scenarios define the value we have to assume in our design (today's worst case* ***300 to 400 pile-up events / bunch crossing****). Detector granularity, detector transparency and trigger strategy will need to be tuned to it*

Detector ***radiation*** *resistance requirement dominated by the delivered integrated Luminosity. Here the detector radius and pseudo rapidity location (η) are the scaling factors. $10^{17}/cm^2$ neutrons will be the fluence at the front face of the forward calorimeters*

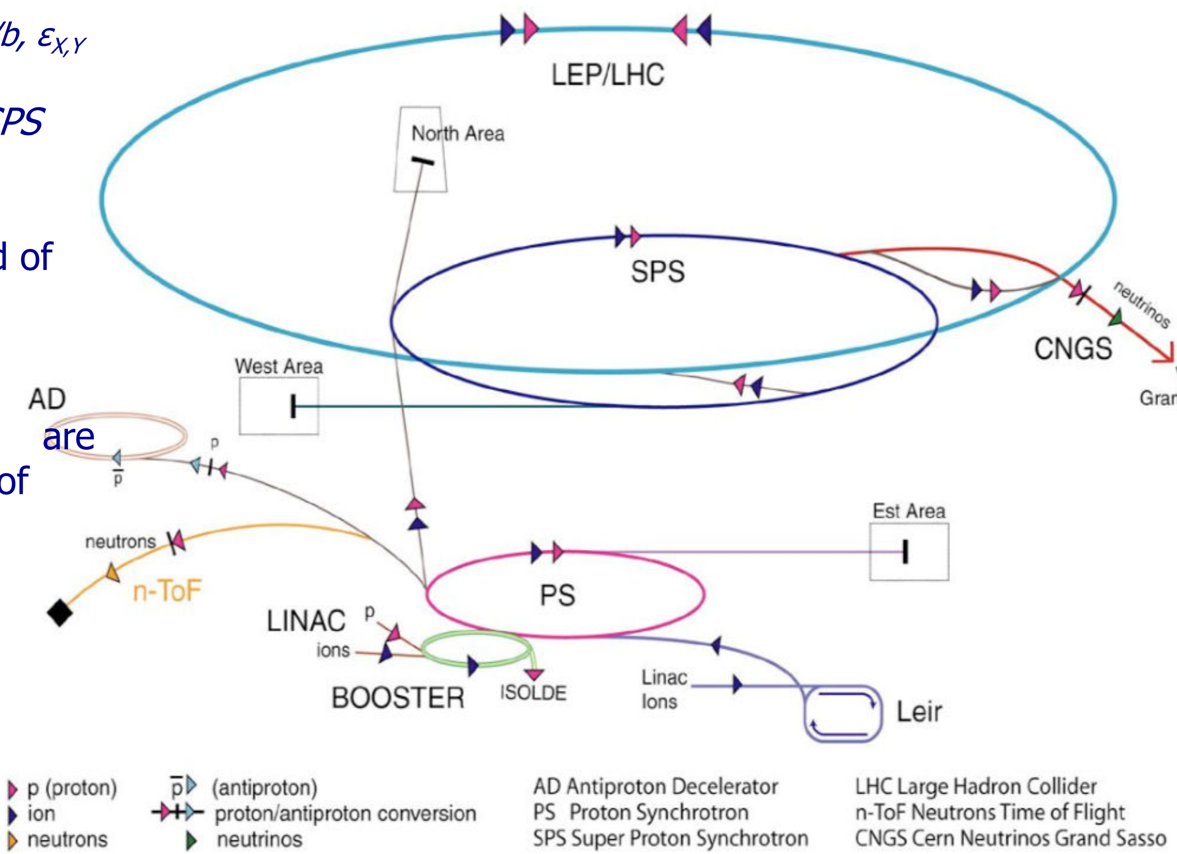
The CERN accelerators complex upgrade

✓ *The LHC-imposed beam brightness ($N_b / \varepsilon_{x,y}$) must be present from the lowest energy on (Liouville's theorem)*

- Beam loss is higher than foreseen: ultimate beam characteristics ($N_b = 1.7\ 10^{11}$ p/b, $\varepsilon_{X,Y} = 3.5$ mm.mrad) *cannot be obtained.* *Nominal* $N_b = 1.15\ 10^{11}$ *p/b achieved in the SPS*

- Operation is complicated and involves the control of many RF systems: risk of drift and of long duration of repair/re-adjustment

- Reliability is uncertain: many equipments are old (e.g. PS magnets) and used at the limit of their capability

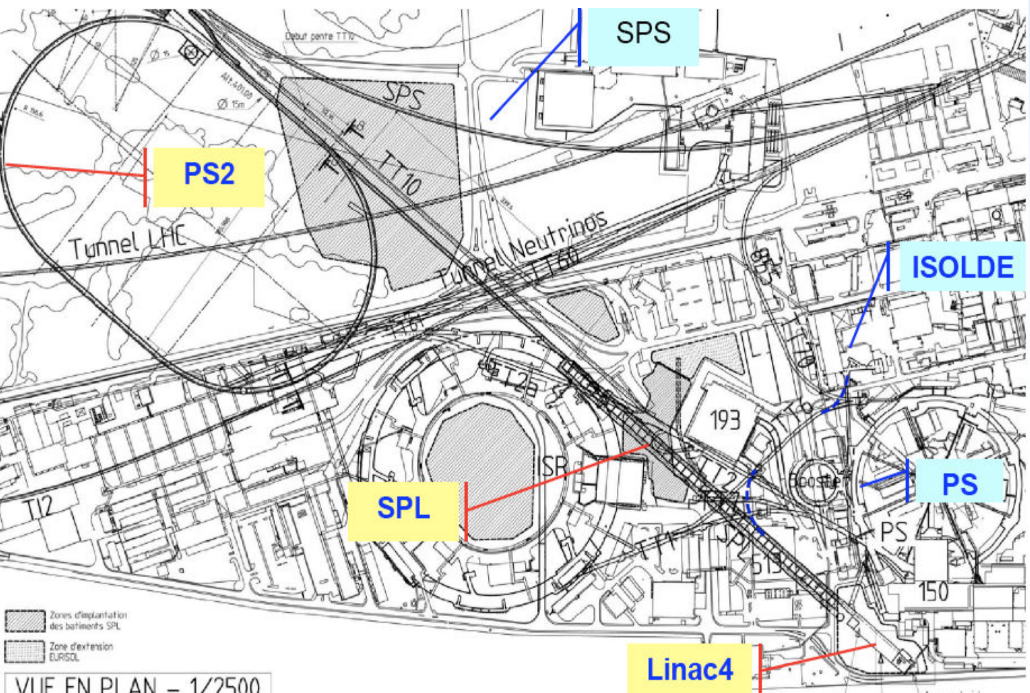


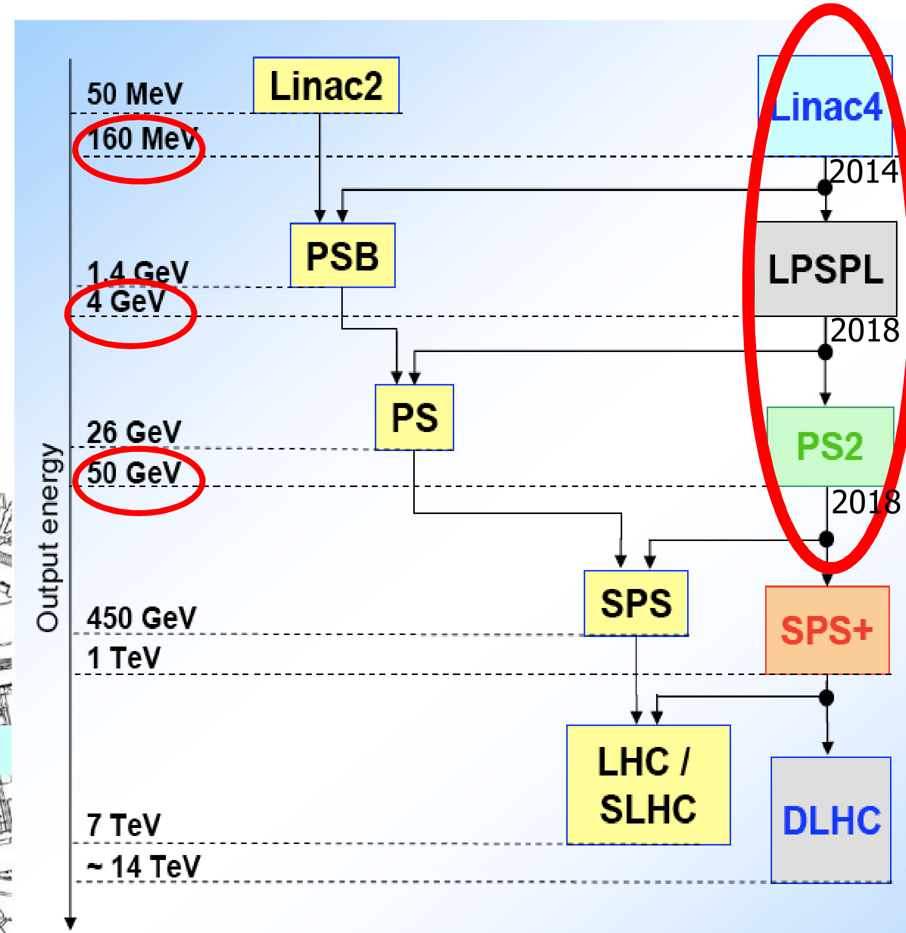
The CERN injectors complex upgrade

✓ Beam at sLHC injection shall have up to twice the ultimate brightness

(N_b =3.4$10^{11}$ p/b, $\varepsilon_{X,Y}$ =3.7 mm.mrad)

- ⇒ *Simple operating mode*
- ⇒ *Margin in beam performance*
- ⇒ *Margin in equipment ratings*
- ⇒ *Advantage of shorter LHC filling time*





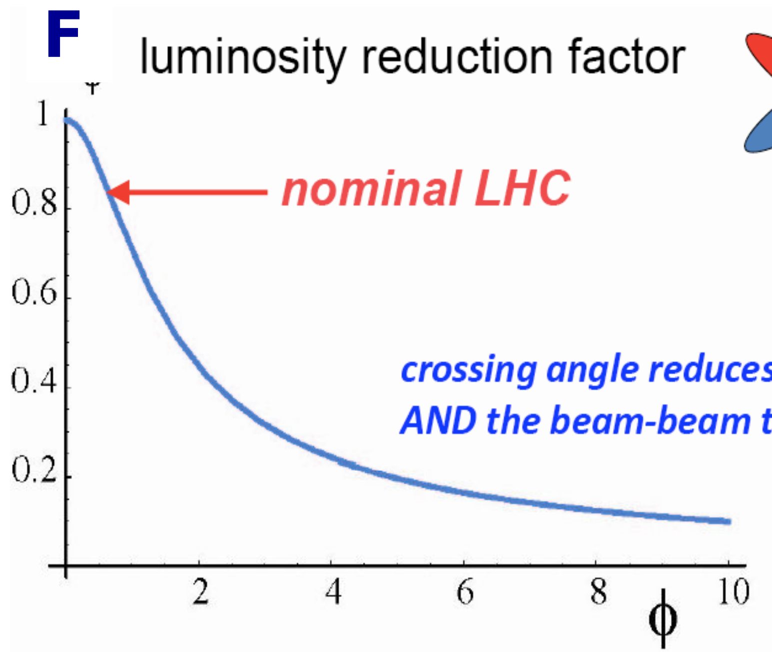
✓ Linac4 project has started, ready in 2014 for phase I

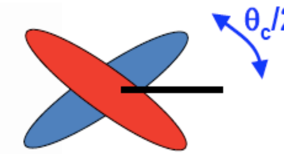
Peak Luminosity also depends on the IR properties

$$L = \frac{N_b^2 n_b f_r \gamma}{4\pi \varepsilon_n \beta^*} F$$

N_b	number of particles per bunch
n_b	number of bunches
f_r	revolution frequency
ε_n	normalised emittance
β^*	beta value at Ip
F	reduction factor due to crossing angle

N_b, ε_n	→	injector chain
β^*	→	LHC insertion
F	→	beam separation schemes
n_b	→	electron cloud effect





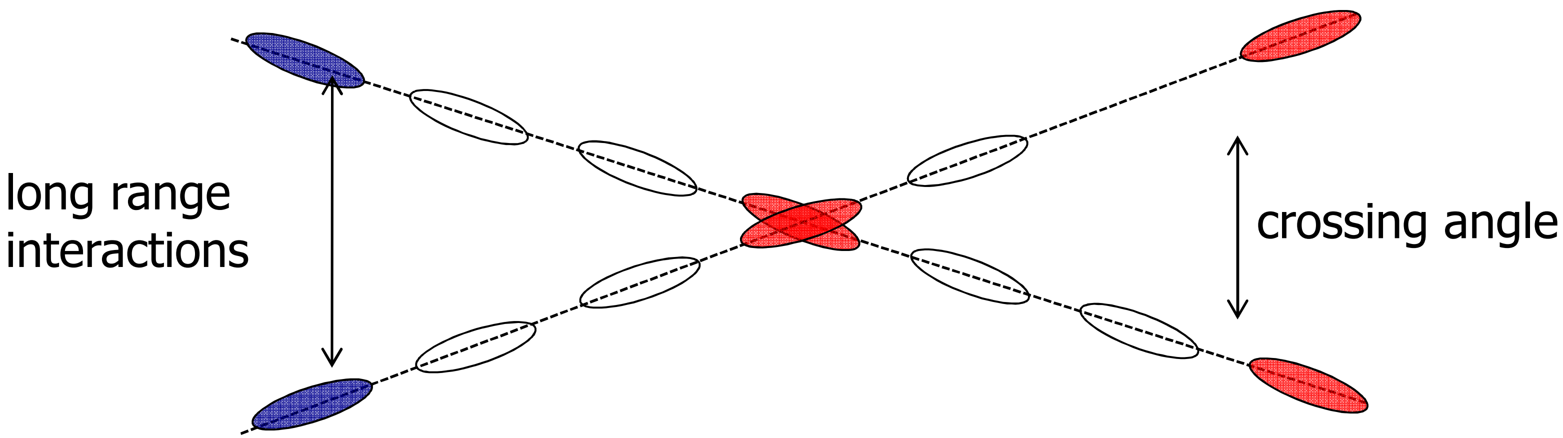
effective beam size $\sigma \rightarrow \sigma/F$

crossing angle reduces the luminosity AND the beam-beam tune shift

$$F = \frac{1}{\sqrt{1+\phi^2}}; \quad \phi \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$ “Piwinski angle”

beam-beam tune (ΔQ) shift proportional to **F** *and beam brightness (beam stability)*

Crossing angle : the LHC solution !



~30 long range beam beam interaction per IP

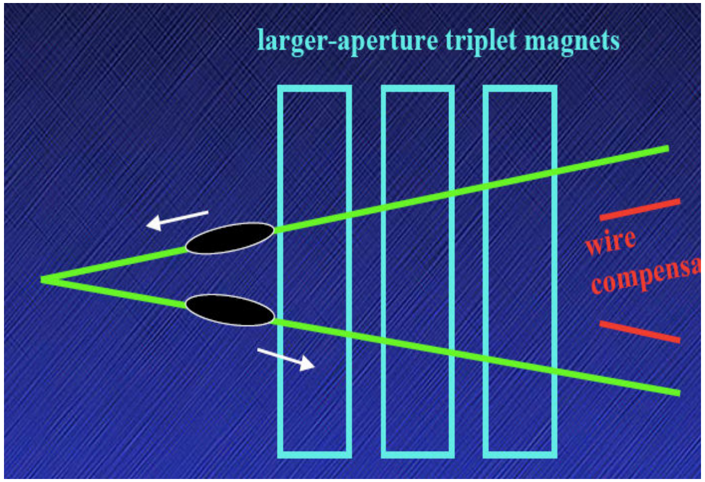
tune shift would increase 30 times without crossing angles

To increase Luminosity choose between head-on collisions, large beam brightness, minimize transverse emittance …. or a combination of them …

… but minimize beam beam tune shift ΔQ_{bb}

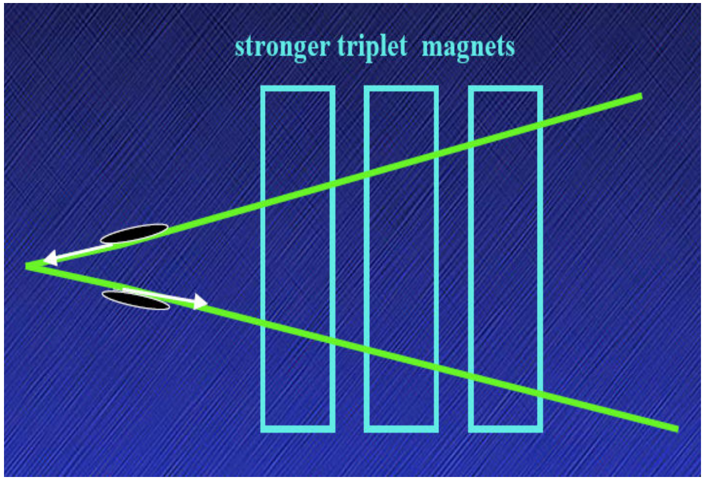
Several solutions still possible !!

Large Piwinski angle (LPA)



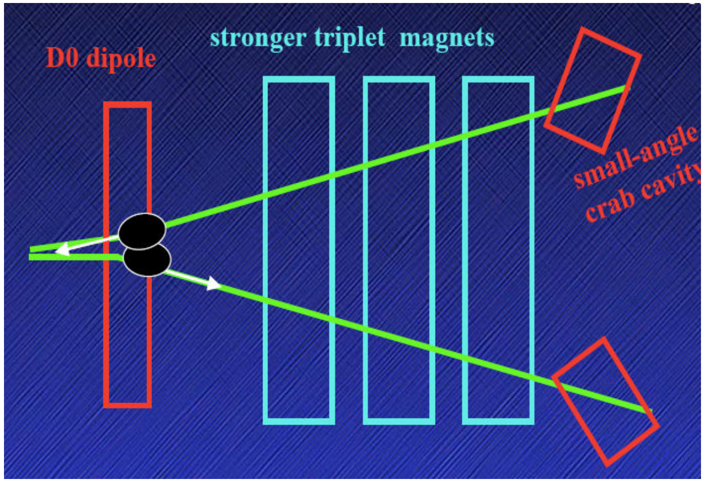
50ns, flat intense bunches, $\theta_c \sigma_z >> 2 \sigma_x$

Low transverse emittance (LE)



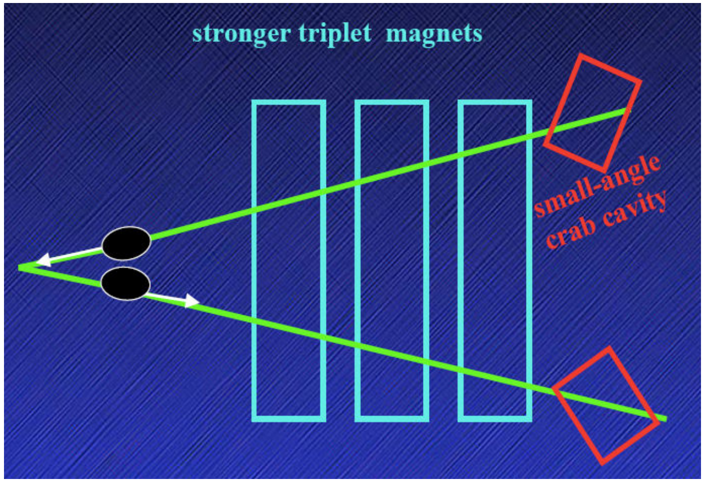
Constraint on new injectors, $\gamma\varepsilon \sim 1\text{-}2\ \mu m$

Early separation + crab cavities (ES)



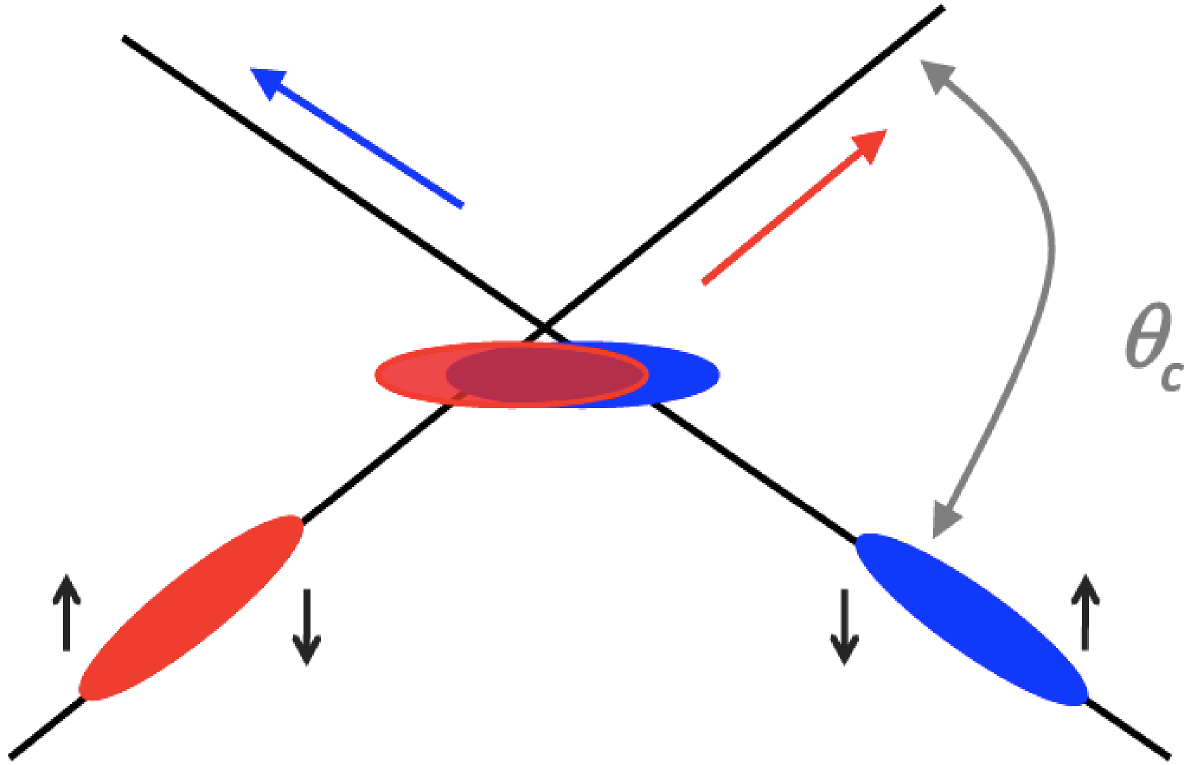
Dipoles inside the experiments

Full crab crossing (FCC)



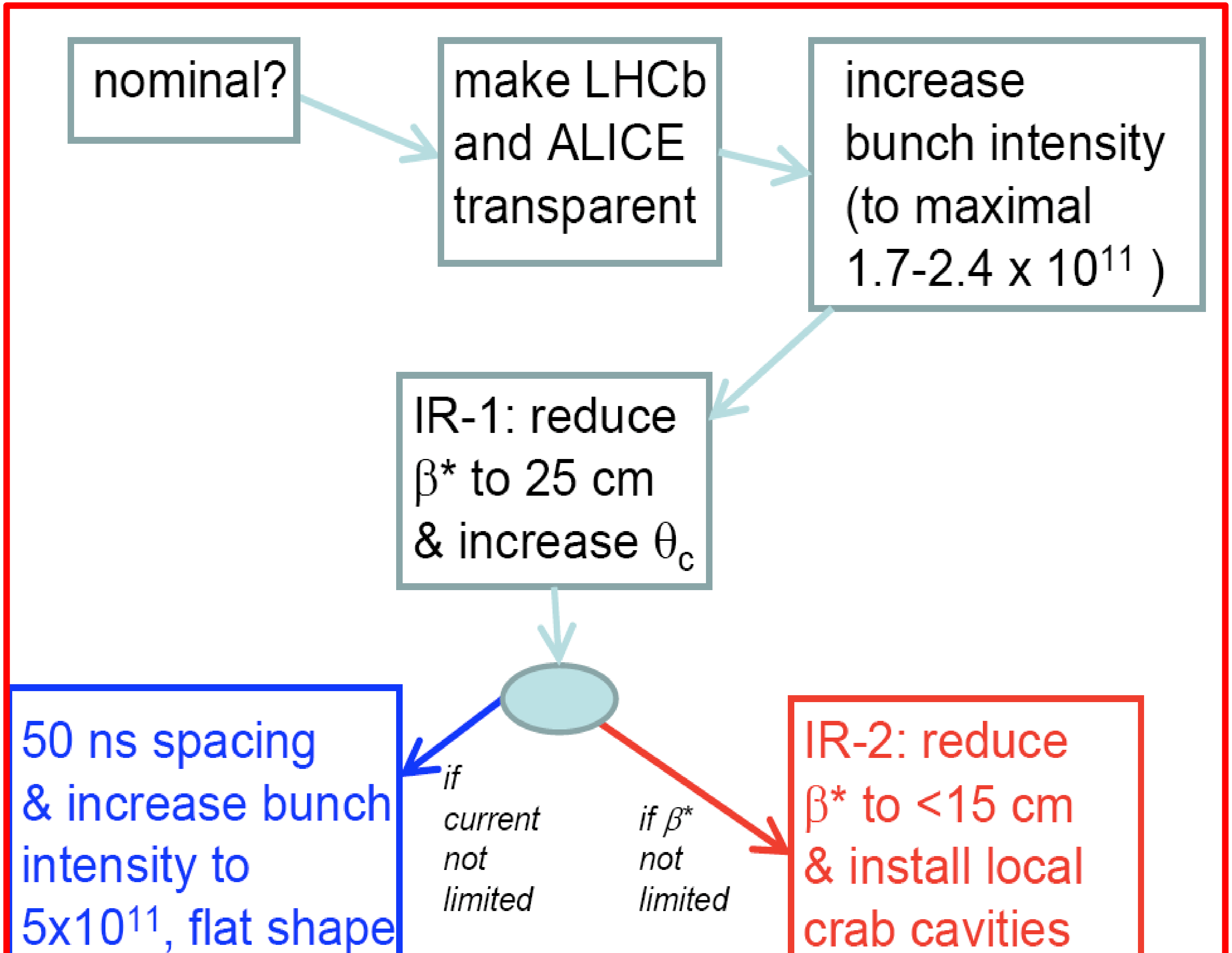
Crab cavities with 60% higher voltage

Full crab cavities : a very elegant solution !



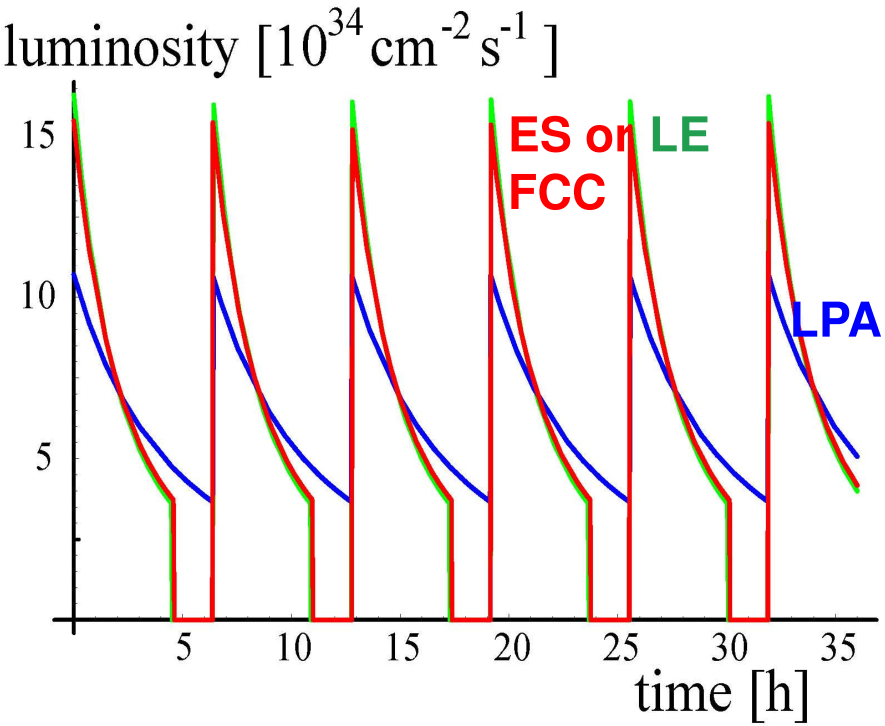
- ✓ RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" for luminosity and tune shift
- ✓ bunch centroids still cross at an angle (easy separation)
- ✓ 1st proposed in 1988, in operation at KEKB since 2007

Possible Luminosity Upgrade road map

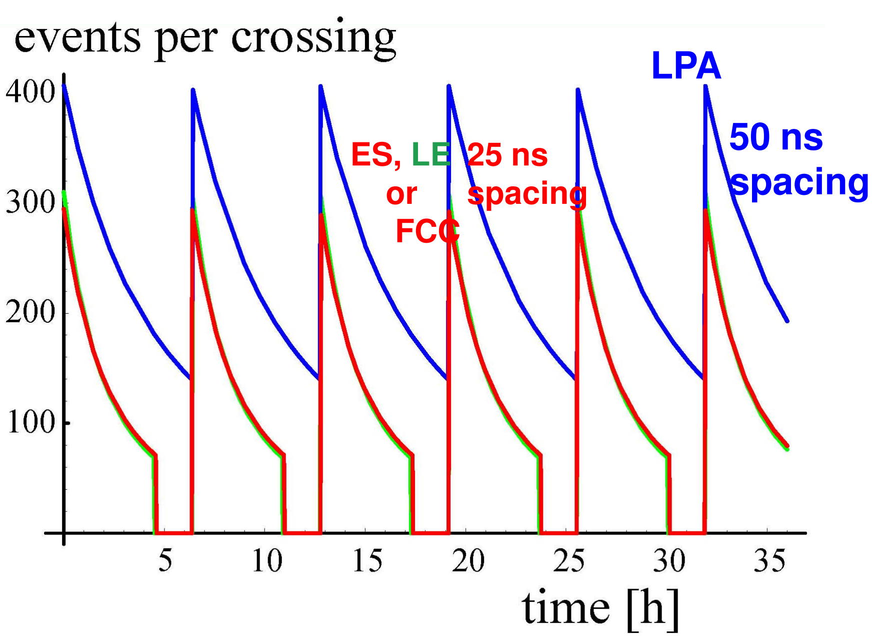


F. Zimmerman 2009

Luminosity life time



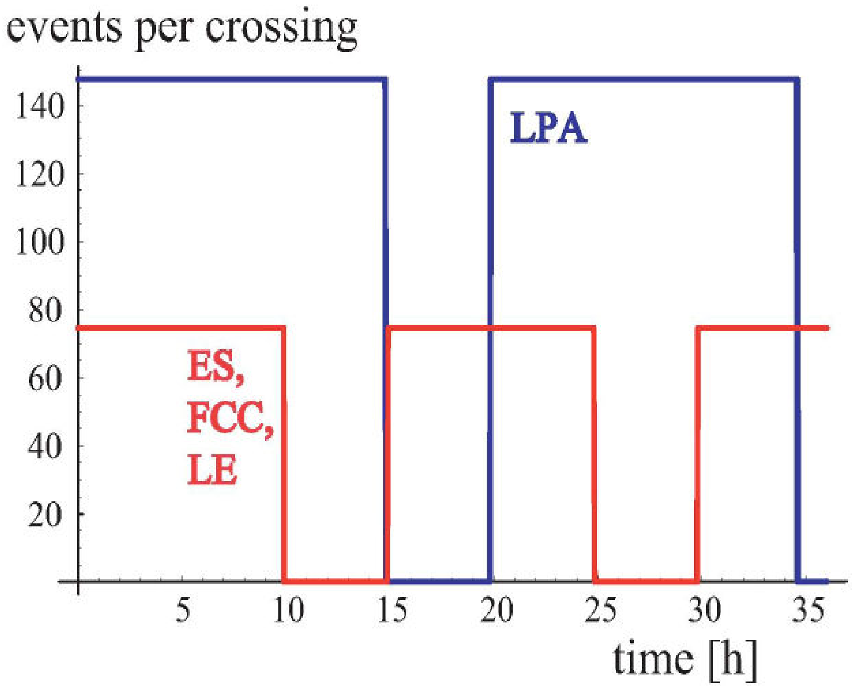
Very inefficient way to use the beam, very difficult experimental environment at the very beginning of the fill, short cycles (5-6 hours)



expected very fast decay of luminosity (few hours) dominated by proton burn-off in collisions

$$\boxed{\tau_{eff} = \frac{N_b n_b}{n_{IP} \hat{L} \sigma_{tot}}}$$

The solution : Luminosity Leveling



Flat luminosity profile (~80 events per crossing, ~10 h fill lifetime for leveling with crossing angle

Optimize Integrated Luminosity vs. Peak Luminosity

Luminosity leveling** **(changing dynamically θ_c , β^* or σ_z in store to keep luminosity constant) becomes a powerful strategy to reduce event pile up in the detector & peak power deposited in IR magnets

Leveling with crossing angle has distinct advantages:

- increased average luminosity if beam current not limited
- operational simplicity

Natural option for early separation or crab cavities

p-p experiments plans/strategies for sLHC

- Assess and understand which components of the existing detectors can still be used at very high Luminosity
- Improve detector and background modeling, based on the real LHC environment experience
- Fully rebuild the inner detectors (tracking), mostly using silicon technology
- Improve the trigger capabilities to cope with ~ factor 5-10 higher amount of hard collisions, in particular at level 1 (μseconds scale)
- Minimize cavern background (new TAS, forward shielding)

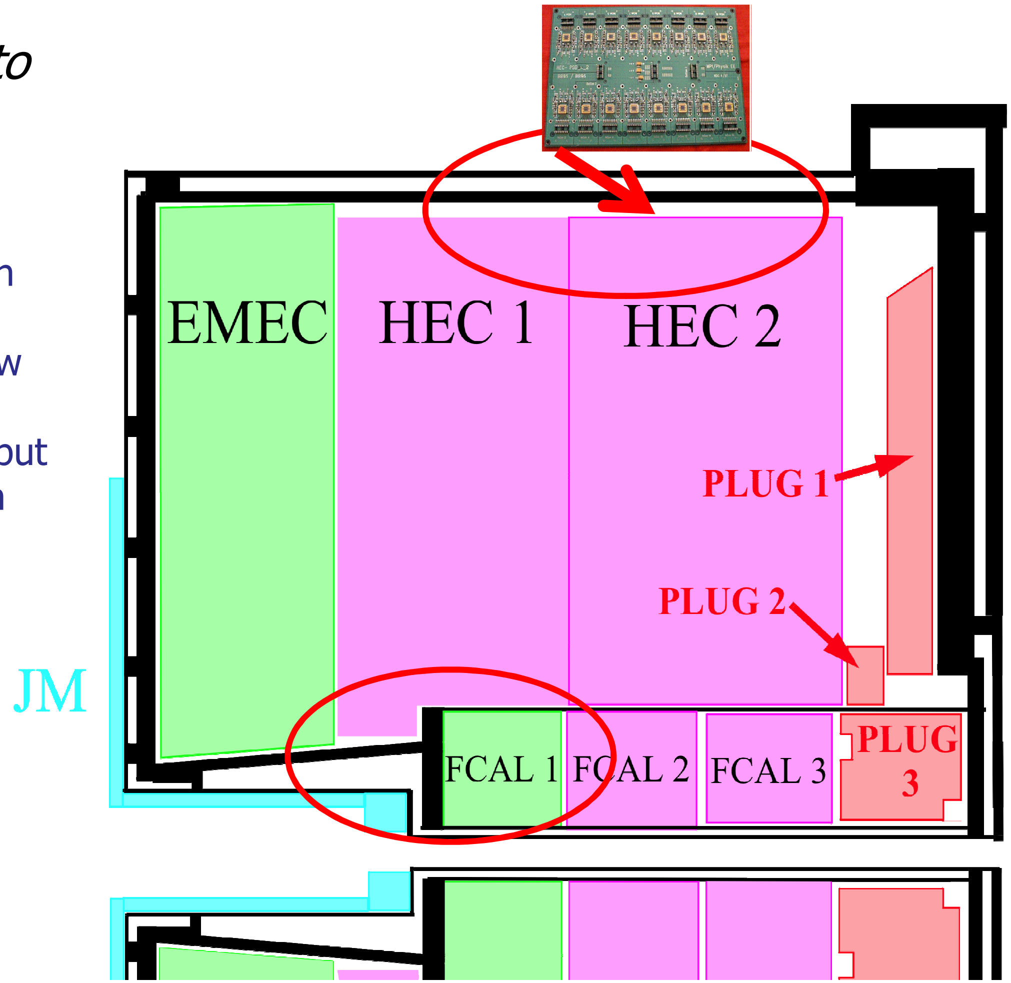
Example: ATLAS LAr Calorimeters problems at sLHC

2 types of problems (mainly related to dose and dose rate):

✓ Hadronic end cap cold electronics: radiation hardness at the limit. Need to measure radiation levels in situ after LHC turn on to clarify safety factors!! The related electronics boards with new preamplifier and summing amplifier IC's can be replaced without taking the HEC wheels apart, but requires cryostat opening in situ. More radiation tests are ongoing!

✓ FCAL : various problems (dose :10^{17-18} neq/cm^2)

- *-Boiling of LAr*
- *-Ion build up between electrodes*
- *-Voltage drop over HV resistor*



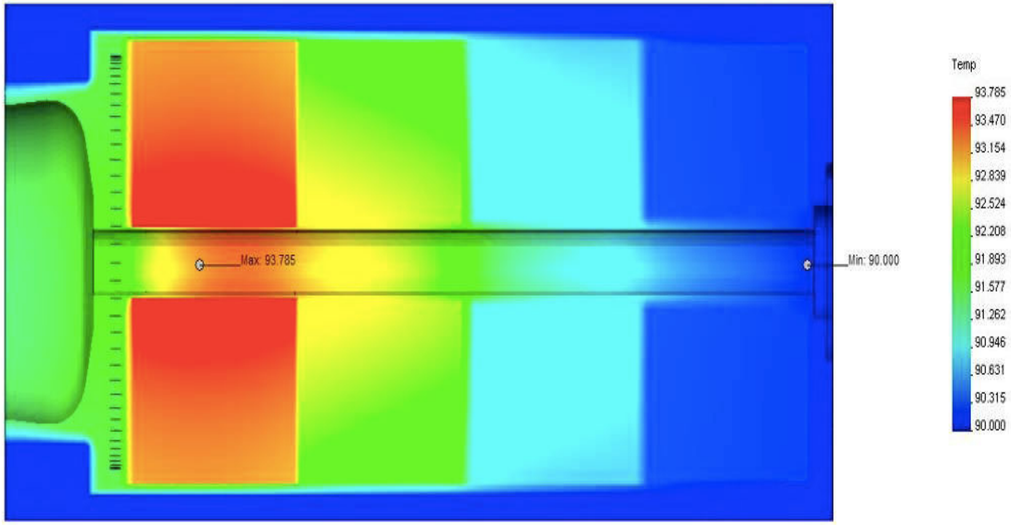
The Lar Calorimeters (forward) will need a major rework

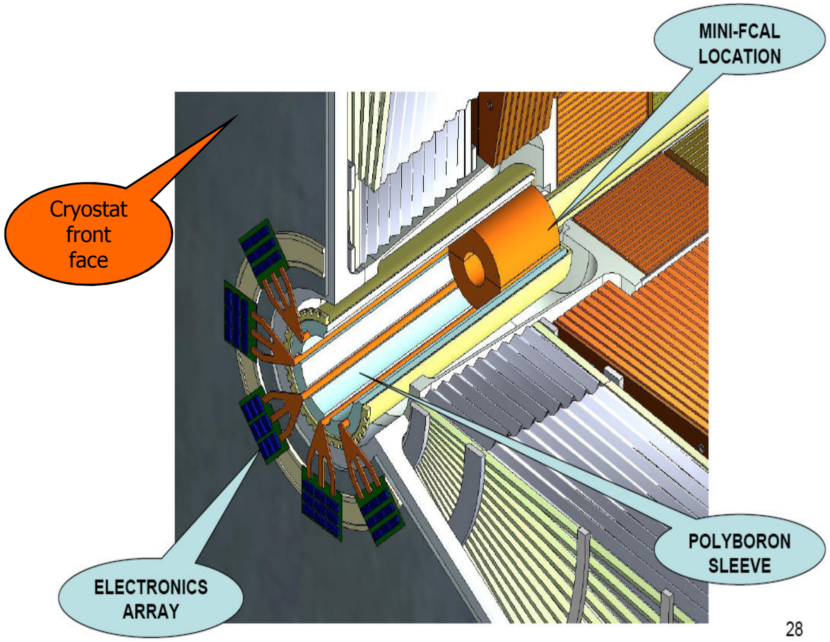
Studies and tests under way; if these show that action is needed, two solutions are considered:

- Warm calorimeter in front of current calorimeter (diamond technology?)

-Open cryostat, insert complete new FCAL with smaller gaps and more cooling power

All this will require a major shutdown of about 15 months to operate in the experimental cavern

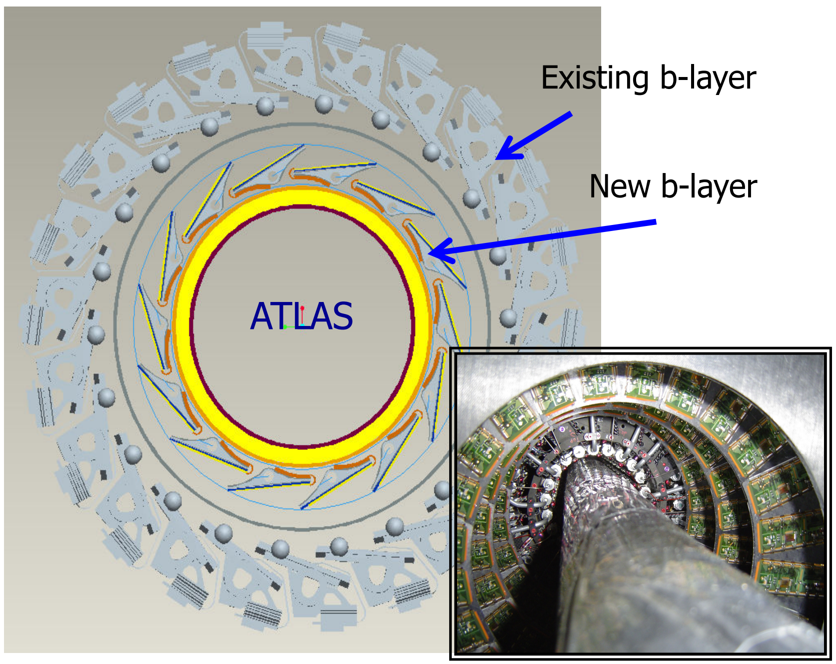




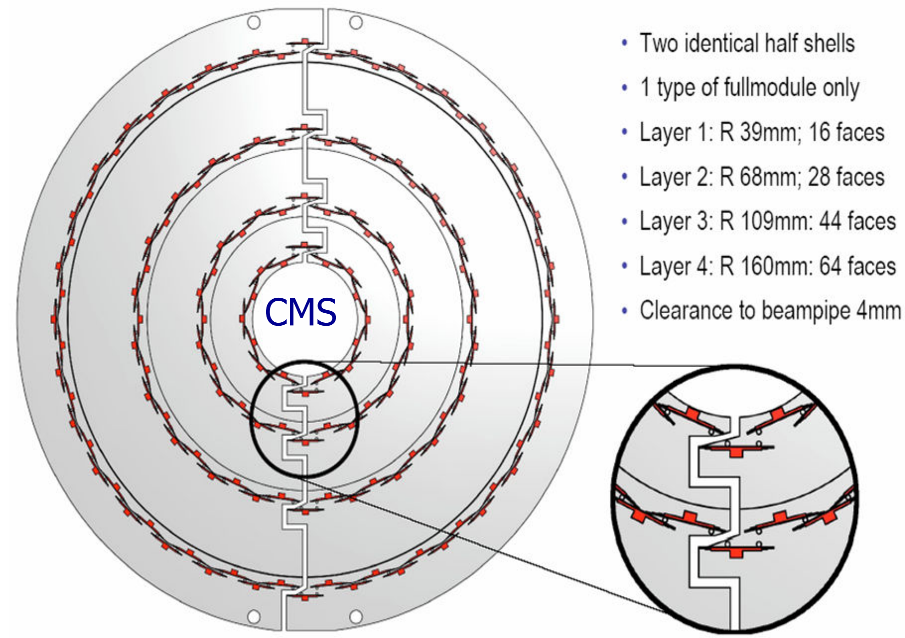
Inner Tracking Detectors

Phase 1 : > 300 fb^{-1}, L ~2-3 10^{34} cm^{-2} s^{-1}, ~ 2014

- ✓ Present Pixel detector, in particular b-layer will become inefficient
- ✓ Both ATLAS and CMS plan a major upgrade



Add new b-layer around a smaller beam pipe, stave structure, 160 MHz readout, CO_2 cooling



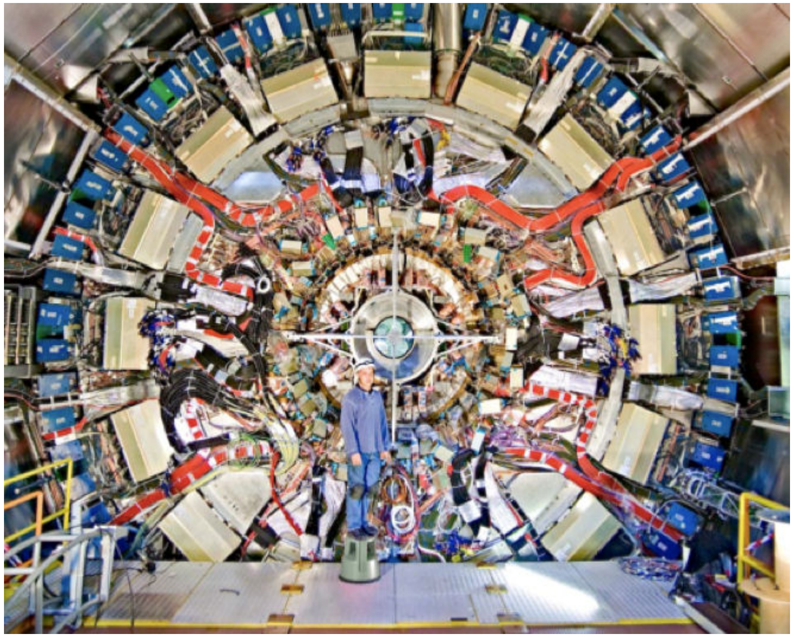
Full substitution : 4 barrel layers + 3 disks per side, weight a fact 3 down, 160 MHz readout, CO_2 cooling

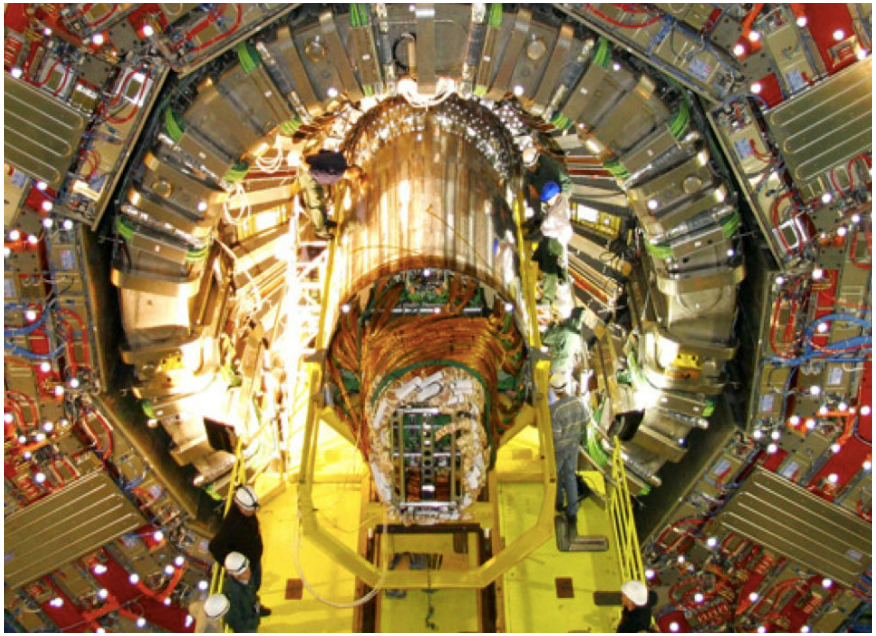
Inner Tracking Detectors

Phase 2 : > 600-700 fb^{-1}, $L \sim 10^{35}$ cm^{-2} s^{-1}, ~ 2018

✓ The present silicon and straw tracker will definitely not survive and will need to be replaced

✓ Both ATLAS and CMS plan a major upgrade, needing a substantial shutdown (ATLAS ~18 months) for in situ installation/integration

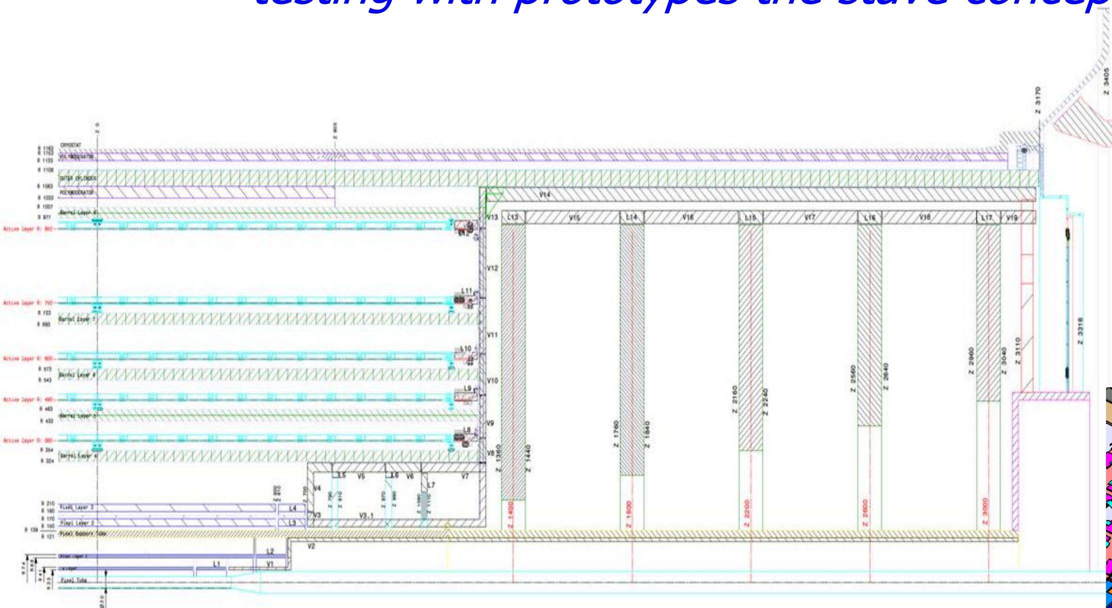


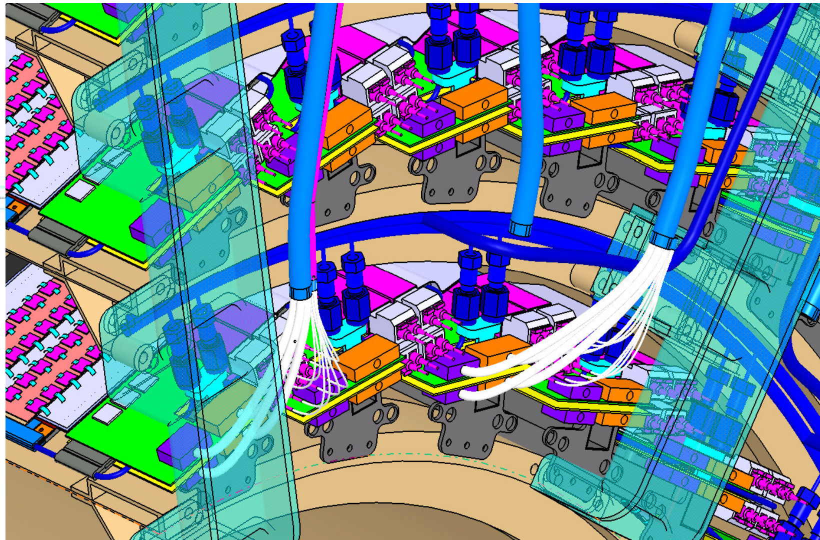


Bringing more realism in the layout
(services and supports)

Key issues are:

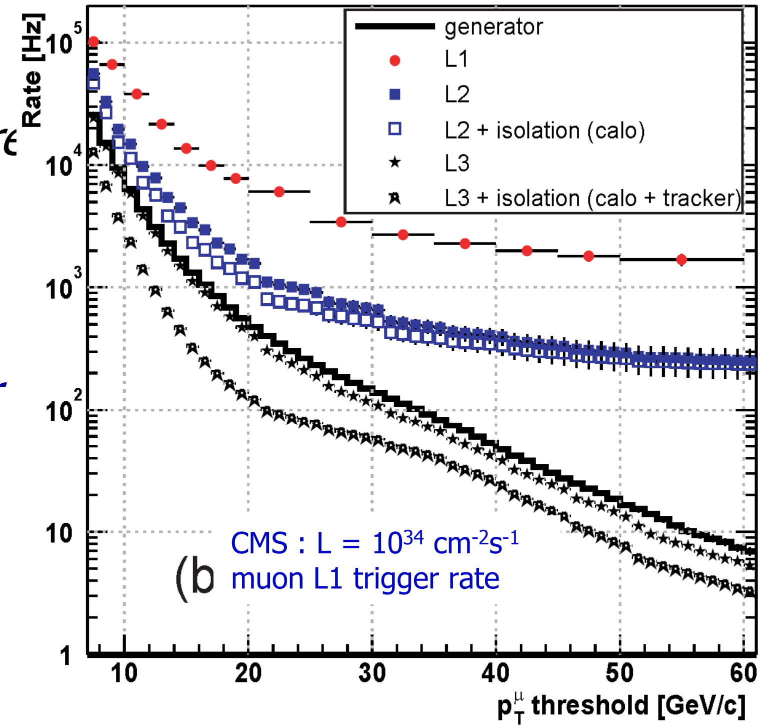
- ✓ *an effective cooling system (~-30 C, CO_2 .... smaller diameter pipes)*
- ✓ *an effective power distribution (serial/parallel power, less copper needed !)*
- ✓ *testing with prototypes the stave concept (prototyping phase just starting)*





Trigger upgrade

- *The goal is to maintain the trigger rates. At 10^{35} $cm^{-2}s^{-1}$ the single e and μ trigger rate will easily exceed 100 kHz. Increasing the p_T thresholds (and using isolation from calorimeters) will not help much*



- *Still challenging! We have to reject 10 times more events at LVL1 and process much more data at (pile-up → bigger events)*

- *For sure there will be a continuous process over years of replacing and increasing the processor to get more efficiency and rejection power the HLT level*

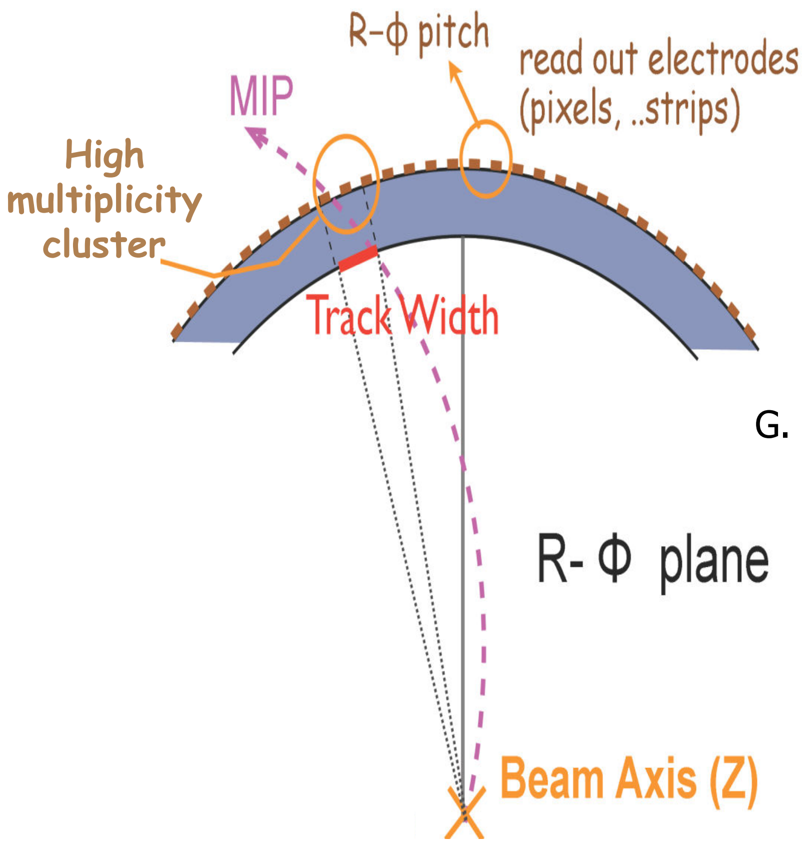
- *One could consider increasing the LVL1 latency (from ~2.5μs to 5-6μs) to allow more complexity at the early stage*

- *Bringing in the tracker information at LVL1 is an interesting solution (CMS is very active on this!)*

High P_T track trigger

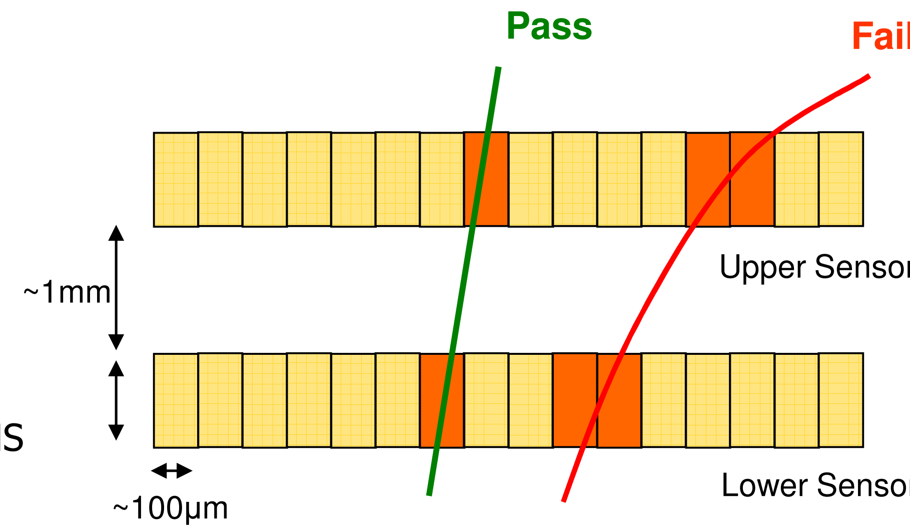
Cluster width

select hits with low strip multiplicity



Stacked layers

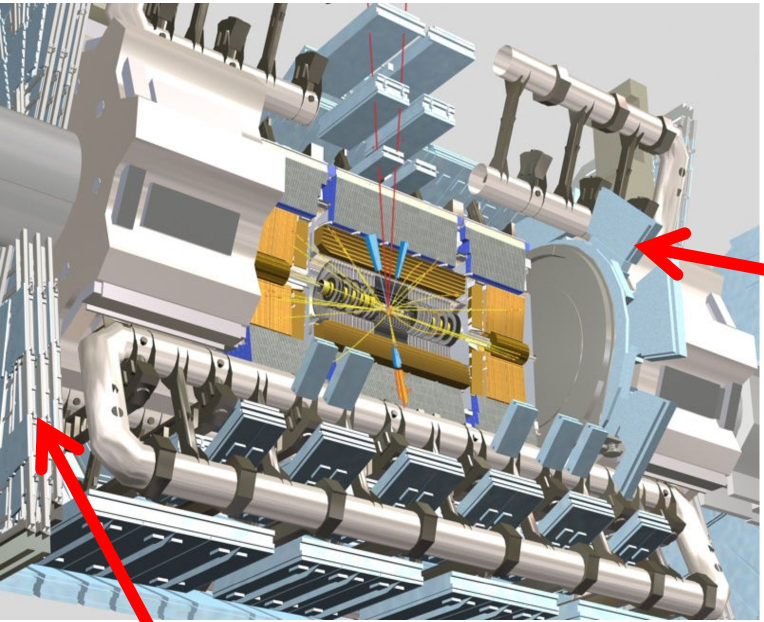
Correlate hit positions in closely spaced (~mm) layers

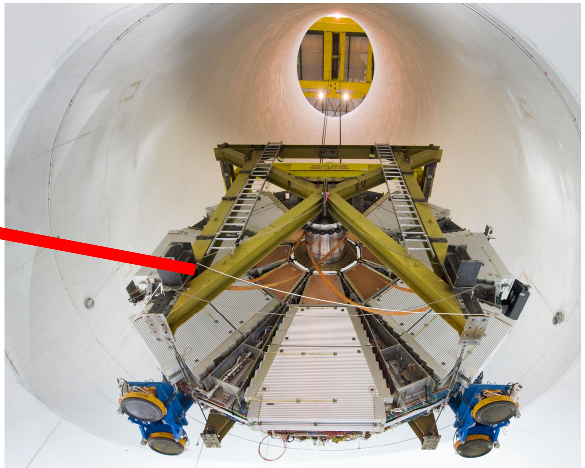


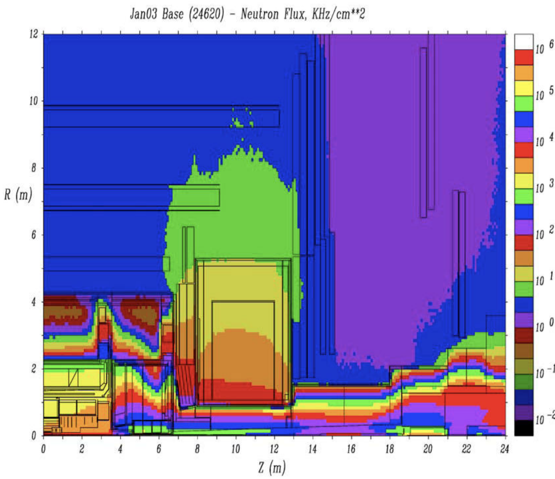
G. Parrini, CMS

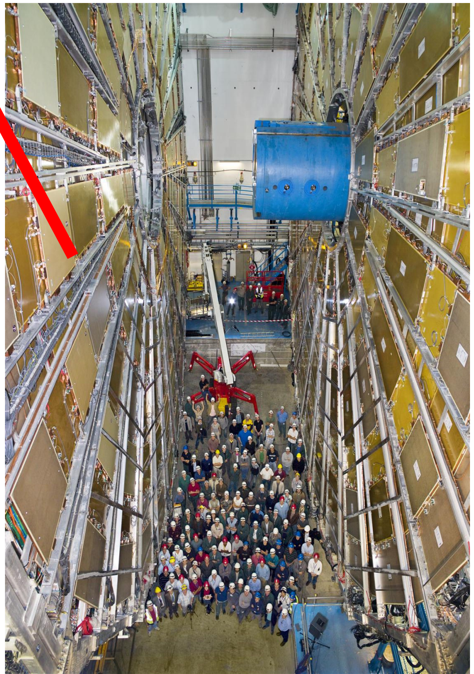
First simulation results show a very good potential : at R=25, 2mm separation rejects almost 100% below p_T=3 GeV/c

Forward muon spectrometer





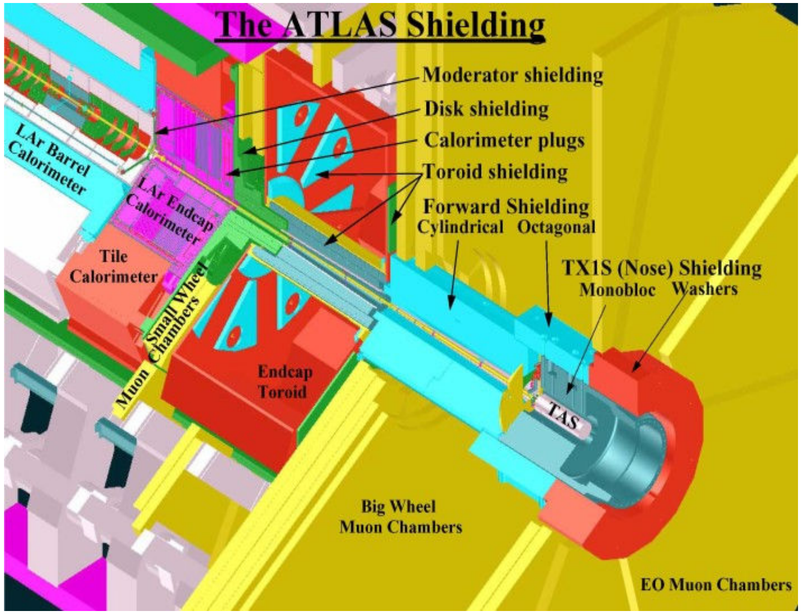




By its nature the muon spectrometers (trigger and precision chambers) sit in large neutron clouds. Neutrons will be captured, will convert to photons and electrons, contributing substantially to the overall signal/trigger background

This problem is particularly acute for ATLAS with the Toroid air core concept

Forward radiation shielding



Radiation shielding optimization in an air core toroid is a really difficult problem

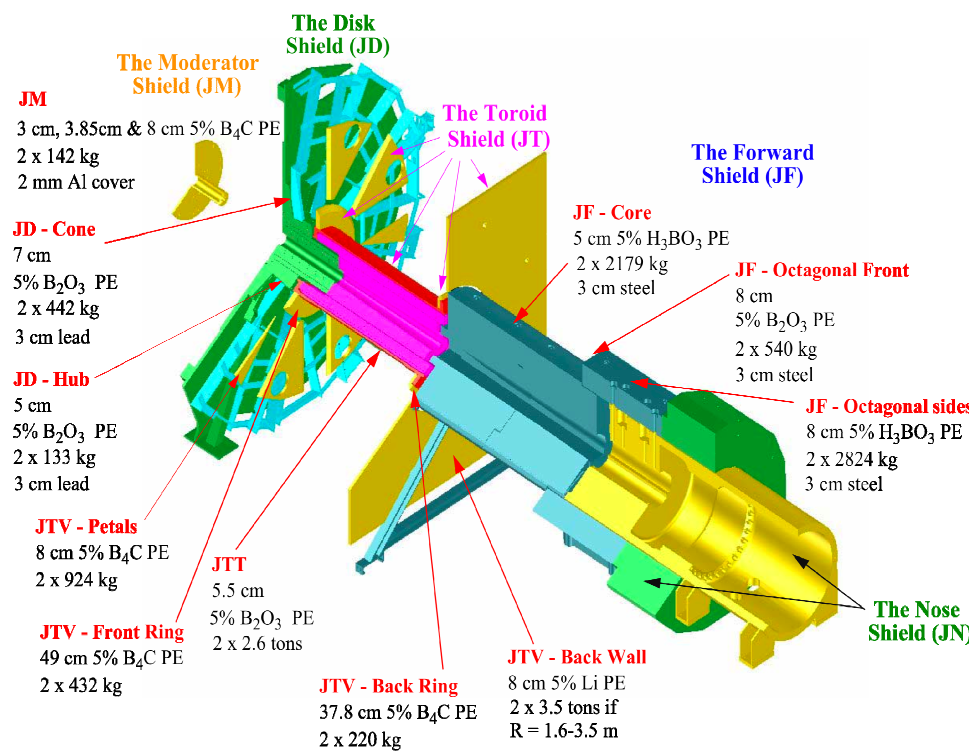
The muon spectrometer occupancy and its LVL1 trigger depend on it severely

New additional layers of trigger chambers migth become necessary

Years of optimization have been spent

Most of the available space is used. The new large aperture triplets will require a new painful optimization of the forward region

We will need for sure transparent Be beam pipe everywhere (factor 2)!



Detectors Upgrade Strategy

- **Major R&D and construction work needed**. Even if we learned the lesson with the first LHC detectors, it will take a many years of construction work and few years to integrate it and getting it operational (ID in particular).

- Designing today also means that we assume the technical feasibility of sLHC and we integrate in the design the **worst pile-up and radiation/activation environmen**t

- While the financial green light for this new enterprise will probably take a few years and will be tuned to the first LHC discoveries, **the detector community has to act now**, preparing technology, making choices, testing prototypes and going deeply in the engineering design.

Summary

- ✓ Both accelerator and experiments are vigorously planning the LHC Luminosity upgrade

- ✓ The accelerator will have to consolidate its injection chain. A series of new machines are in preparation. The LINAC4 is already an active project, ready for 2014. Several solutions exist for phase 2 upgrade, but need now to mature in a proper R&D environment. The experiments look with great interest to the Luminosity leveling concept

- ✓ The experimental challenge for the detectors is in the tracking and in the trigger, which will need to be fully rebuilt around 2018

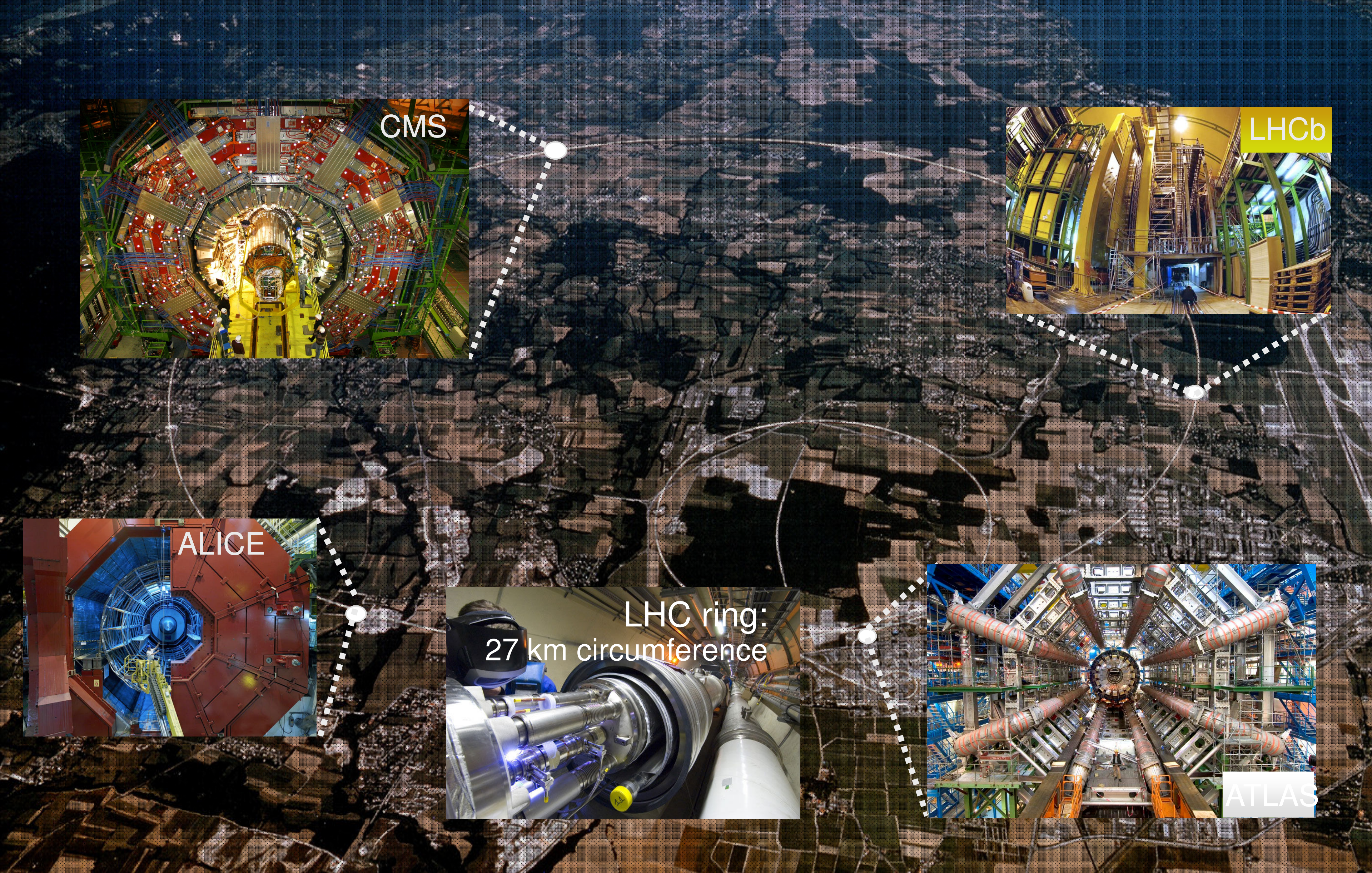
- ✓ The detector upgrade projects have started and will now enter the usual phase of proposal and approval (LOI, TP, TDRs, MOU, ...). The project organization is slowly taking shape!

- ✓ I am sure, once the first LHC discoveries will be evident, this luminosity upgrade strategy will become a natural and necessary road map of the LHC program and of the HEP community at large

To conclude

- By year 2013, **experimental results** will be dictating the agenda of the field.
- Early discoveries will greatly accelerate the case for the construction of the next facilities (sLHC, Linear Collider, ν-factory …)
- No time to idle: a lot of work has to be done in the meantime

Very exciting years are ahead of us



Thank you!

Recent CERN Academic Training Lectures (June 2009):
http://indico.cern.ch/conferenceDisplay.py?confId=55041

... and special thanks to : M. Nessi, M. Ferro Luzzi, F.Gianotti, M.Mangano, F.Zimmerman, …