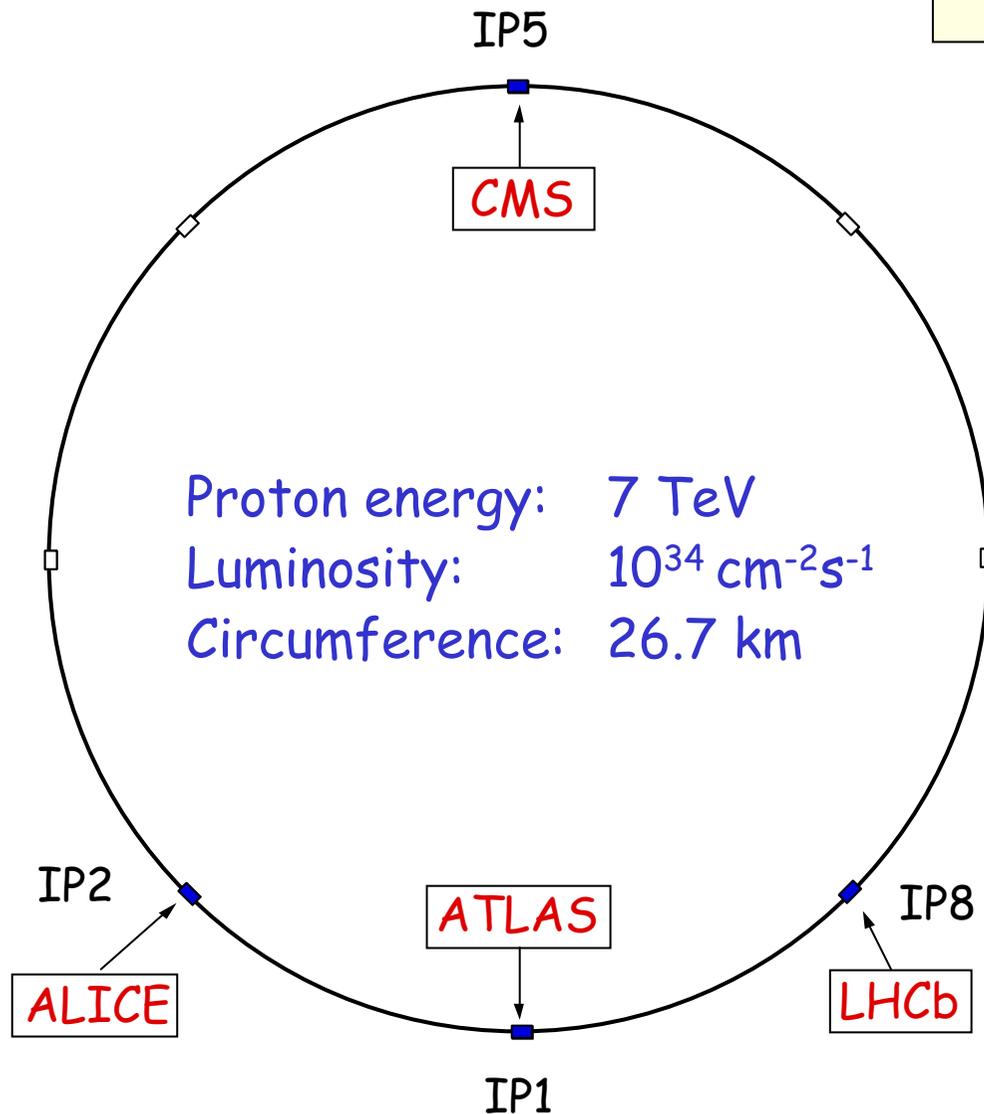


# Present Status of LHC and Prospects with ~~much~~ higher luminosity

Takahiko Kondo (KEK)

Recent Progress in Induction Accelerators (RPIA2003) @ KEK  
Oct. 29-31, 2002

# Design of LHC



Injection energy: 450 GeV  
MR dipoles B: 8.33 Tesla  
length, number: 14.2m, 1232  
MR quads B': 223 T/m  
length, number: 3.1m, 368

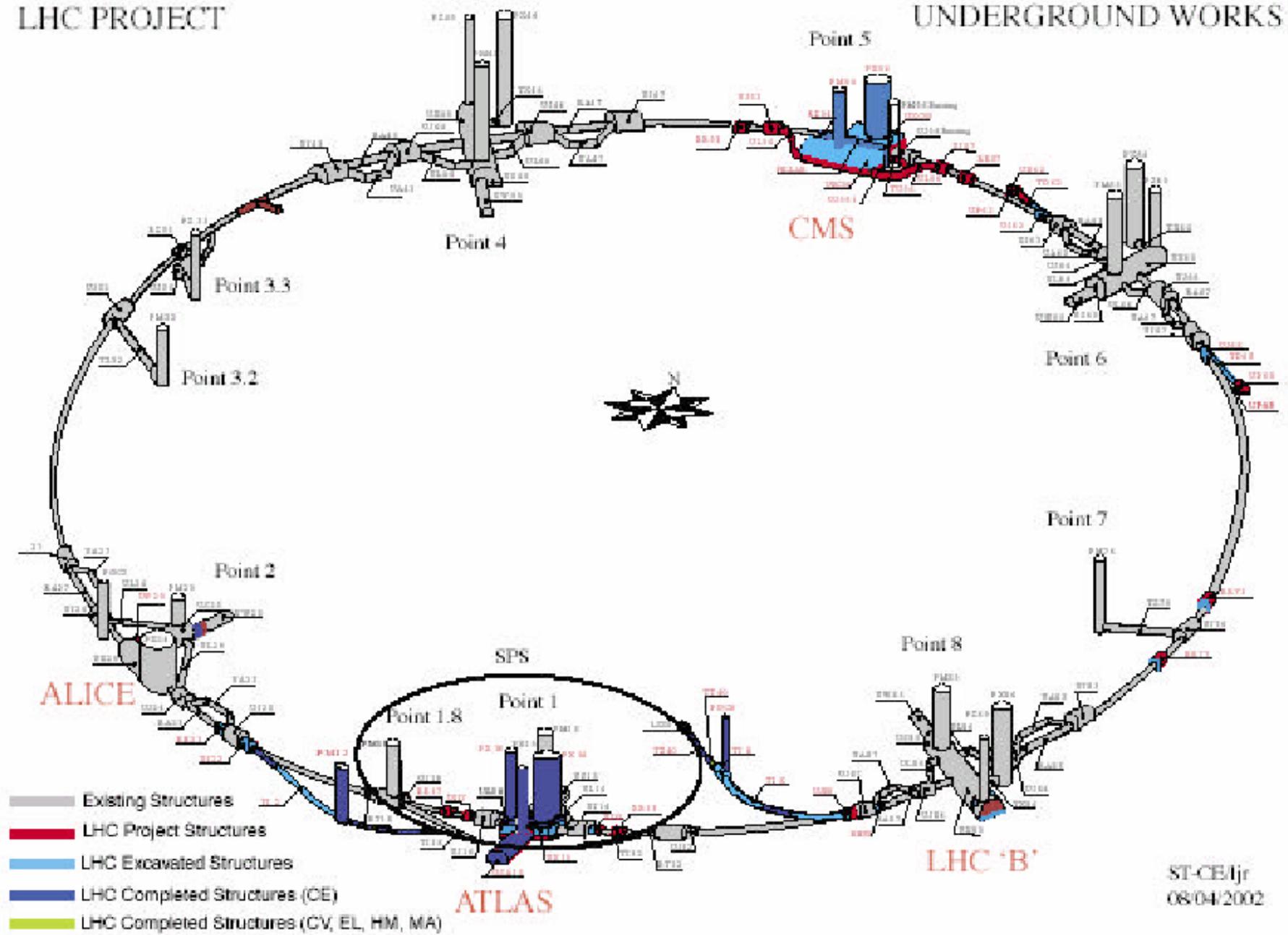
No. of bunches: 2808  
Protons/bunch:  $1.1 \times 10^{11}$   
Beam nor. emittance:  $3.75 \mu\text{m}$   
Beam-beam tune shift: 0.01  
Bunch spacing: **24.95 ns**  
Bunch length: 77 mm  
Beam radius at IP:  $16 \mu\text{m}$   
Half crossing angle:  $160 \mu\text{rad}$   
pp interactions/collision: **19**  
Luminosity lifetime: 15 hours

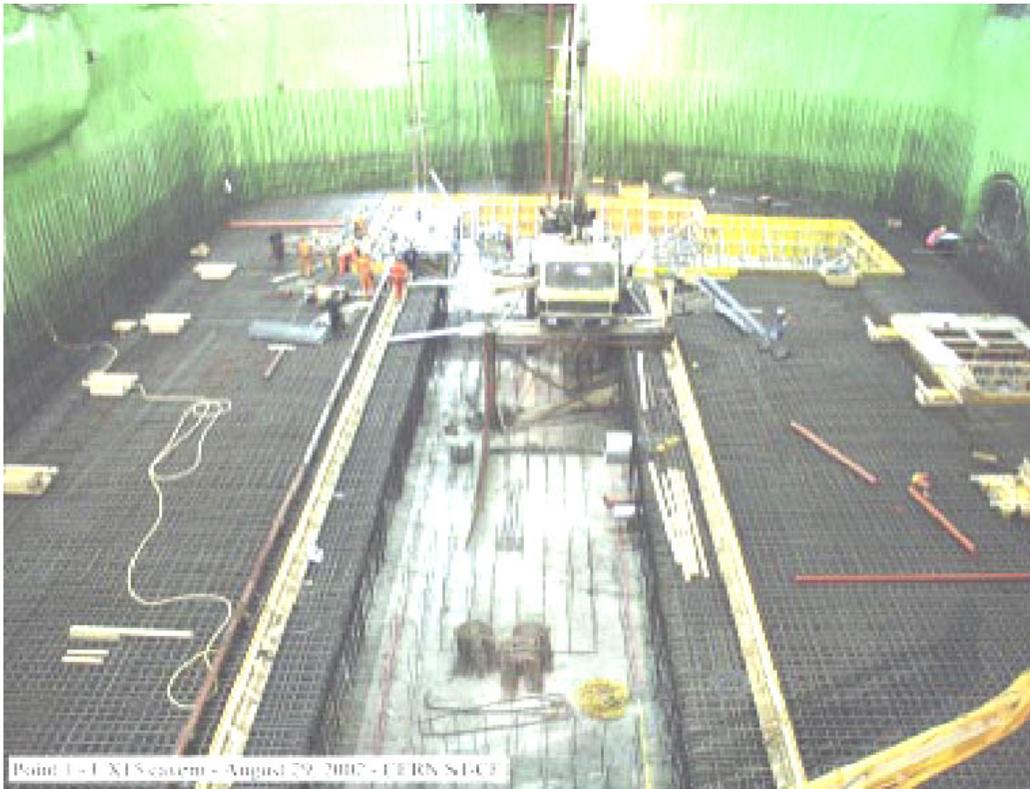
Pb-ion Luminosity:  $2 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1}$

See <http://lhc-new-homepage.web.cern.ch>

# LHC Construction Status

- Civil Engineering in good progress.
- Magnet production started and cold tests of ~20 MR magnets shows good.
- Delay in production of SC cables.
- Components from non-member states.
- Tests on injection beams in good shape:  
Beam emittance, electron cloud.





Point 1 - LXS cavern - August 29, 2002 - CERN ST-CE

## Point 1 for ATLAS



Beneficial occupancy  
on April 15, 2003

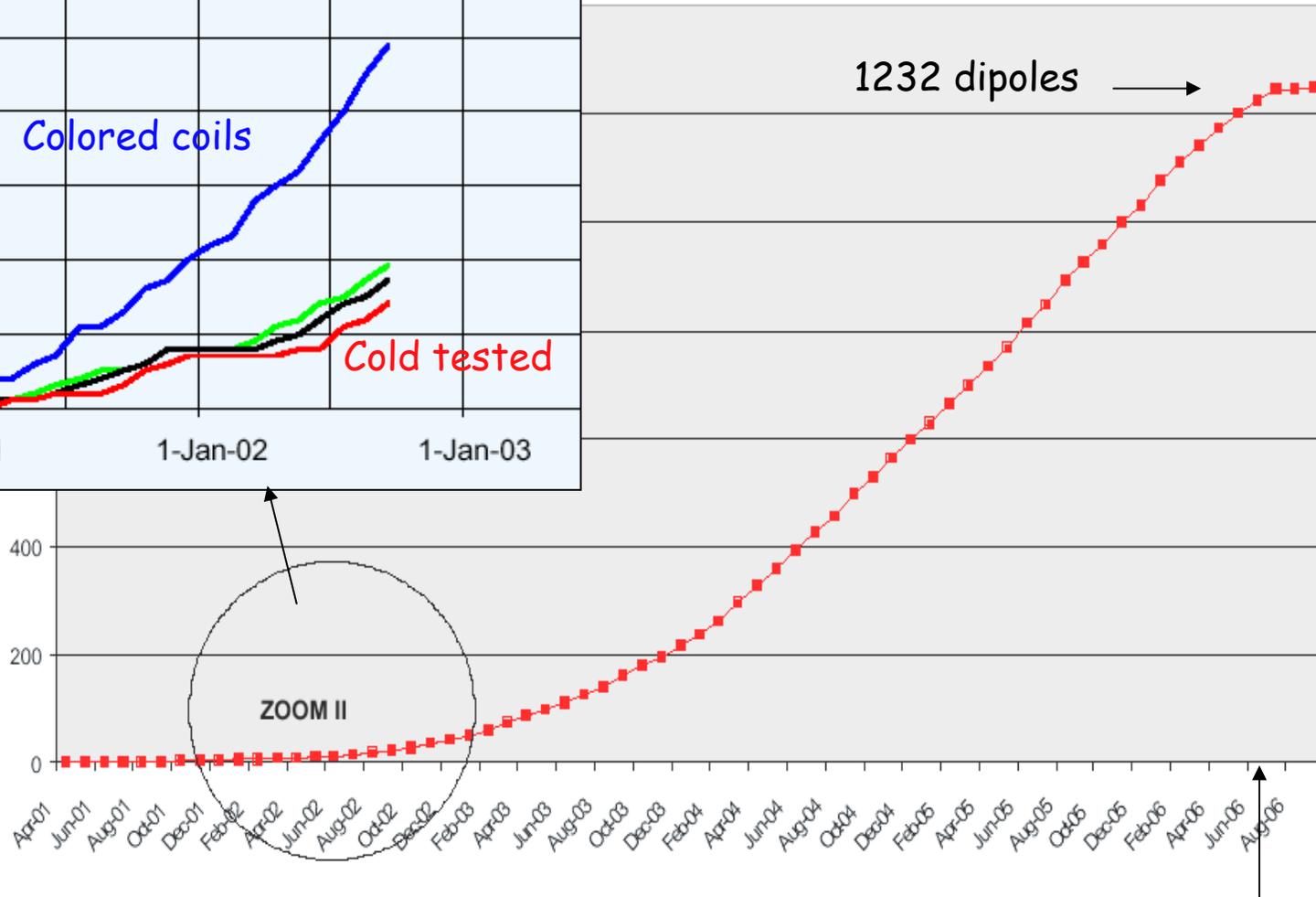
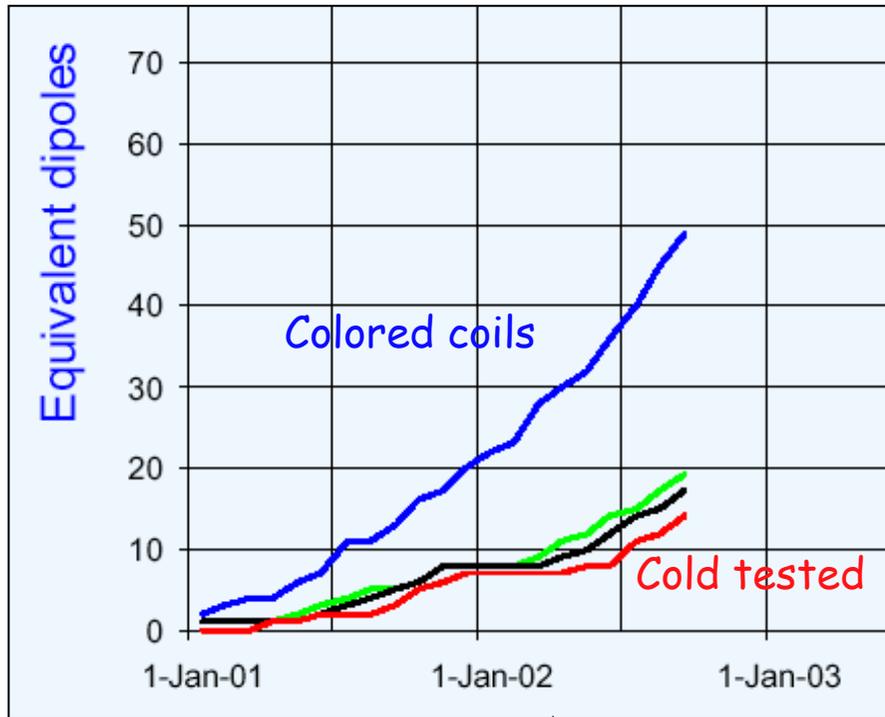


Point 5 - general view of USC55 cavern (looking towards point 4) - August 30, 2002 - CERN ST-CE

## Point 5 for CMS

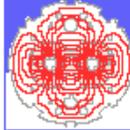
Beneficial occupancy  
on July 1, 2004





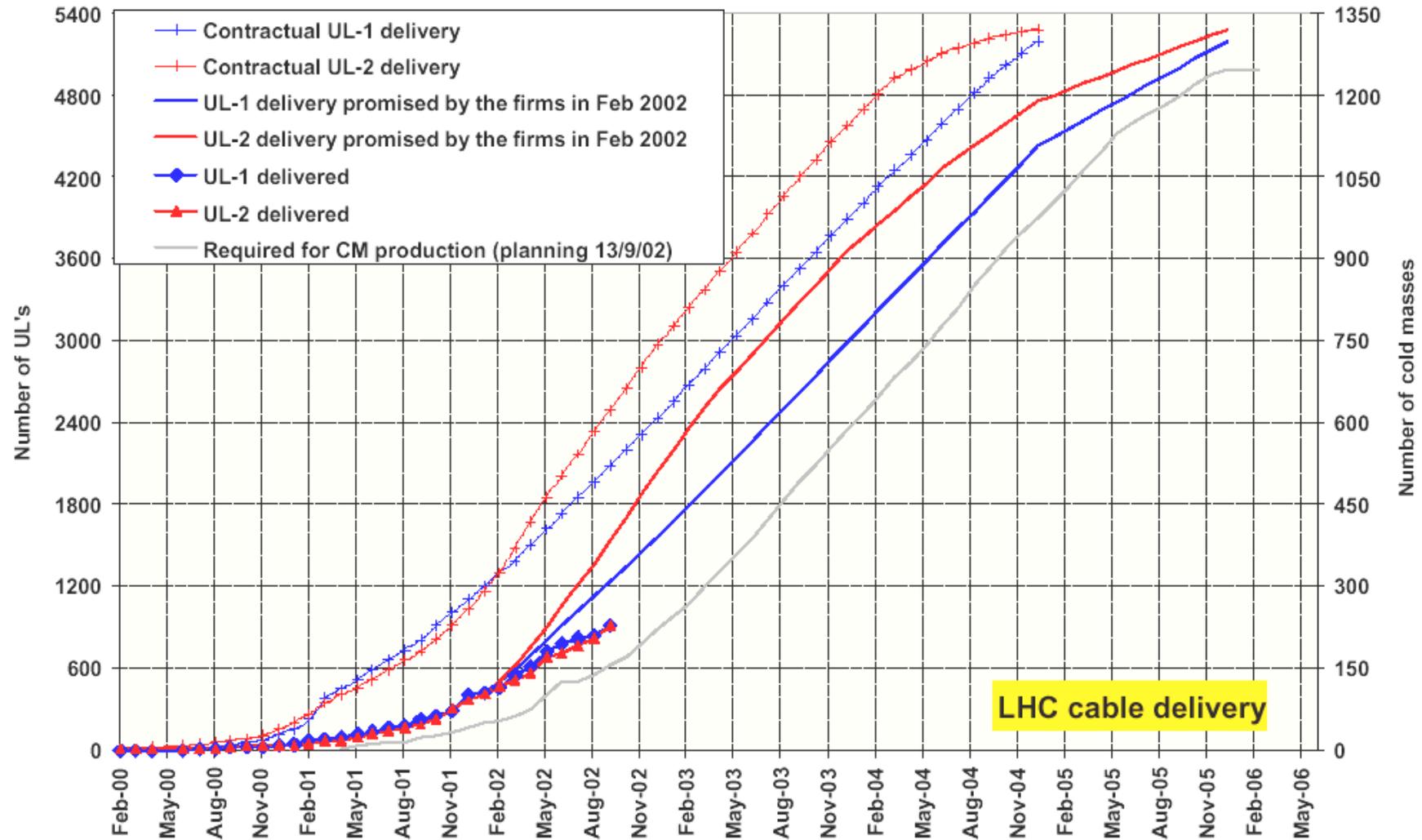
# Production of the MR Dipoles

Aug. 2006



# the Large Hadron Collider accelerator

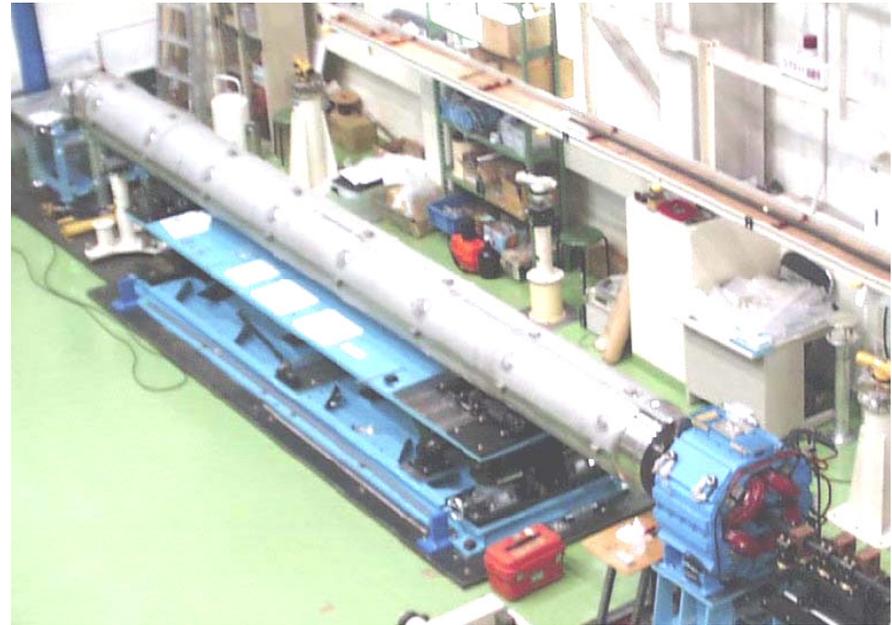
## Cable delivery



# LHC Accelerator Components from non-member states (1)



from USA



from Japan

# LHC Accelerator Components from non-member states (2)

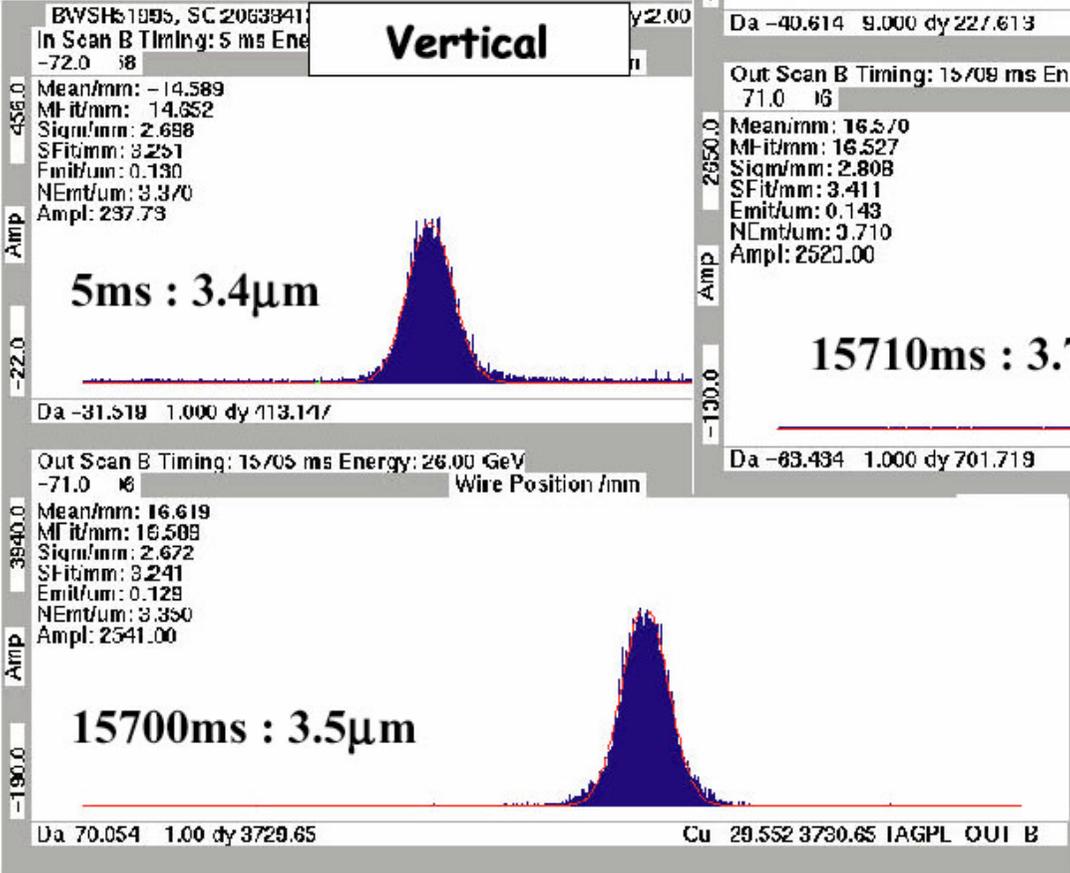
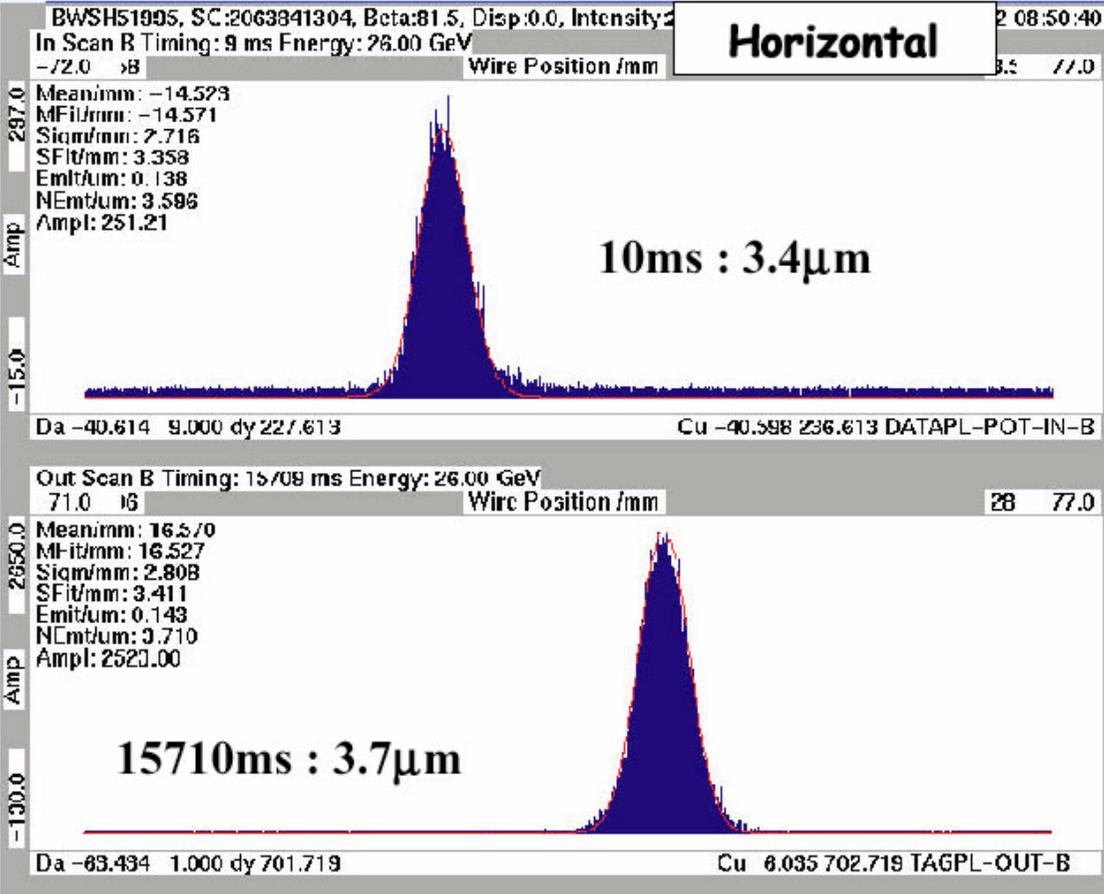


from Canada



from Russia

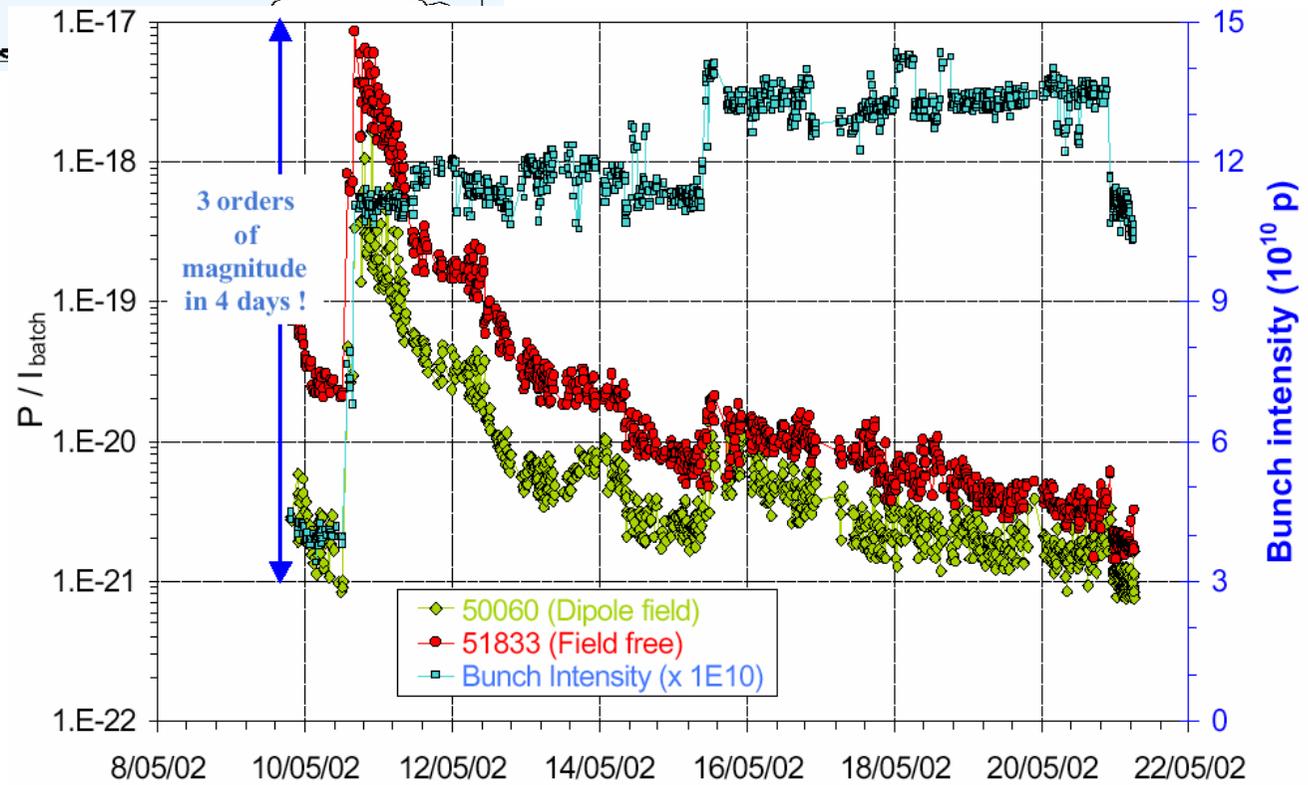
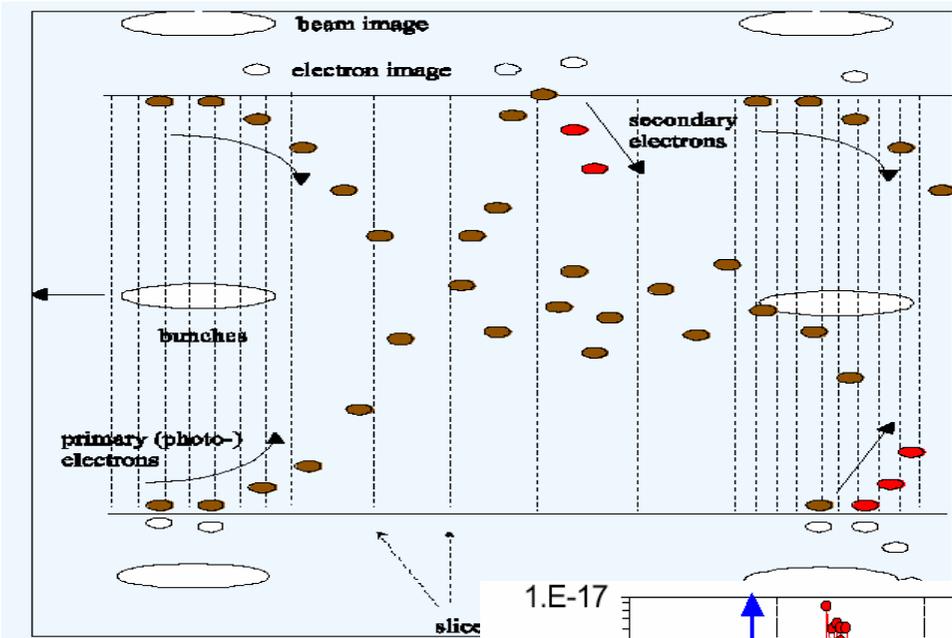
**Emittance Preservation (Almost)**



**2 Batches of 72 bunches with  $1.3 \times 10^{11}$  protons/bunch**

**PS Emittance :  $\sim 3.2 \mu\text{m}$**

# Electron Cloud Study at SPS



# LHC upgrade scenarios (1)

See web site <http://cern.ch/lhc-proj-IR-upgrade>

## Phase 0: without hardware changes to LHC

- Collide beams only in IP1 and IP5.
- Increase bunch population:  $1.1 \rightarrow 1.7 \times 10^{11}$
- Increase dipole B to 9 Tesla

resulting  $L = 2.3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ ,  $E_p = 7.54 \text{ TeV}$

## Phase 1: Changes in insertions and/or injector complex

- Modify  $\beta^*$  at IR :  $0.5 \text{ m} \rightarrow 0.25 \text{ m}$
- Increase x-ing angle:  $300 \mu\text{rad} \rightarrow 424 \mu\text{rad}$ .
- Increase Nb up to ultimate intensity.
- Halving  $\sigma_z$  with a higher harmonic.
- Doubling number of bunches:  $\rightarrow 12.5 \text{ ns}$  bunch interval

resulting  $L = 9.4 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$  time scale  $\geq 2012$  ?

# LHC upgrade scenarios (2)

For details, see F. Zimmermann' talk on the 3<sup>rd</sup> day

## Phase 1' : Introduce 300m long super-bunch

- Modify  $\beta^*$  at IR : 0.5 m  $\rightarrow$  0.25 m
- Increase x-ing angle to several mrad.
- Inject a bunched beam of 1 A.
- Use barrier buckets to form a single long super-bunch.
- Halving bunch length with a higher harmonic RF

resulting  $L = 9 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

It may avoid electron cloud effects and minimize the cryogenic heat load.

But the detectors need major changes.

## LHC upgrade scenarios (3)

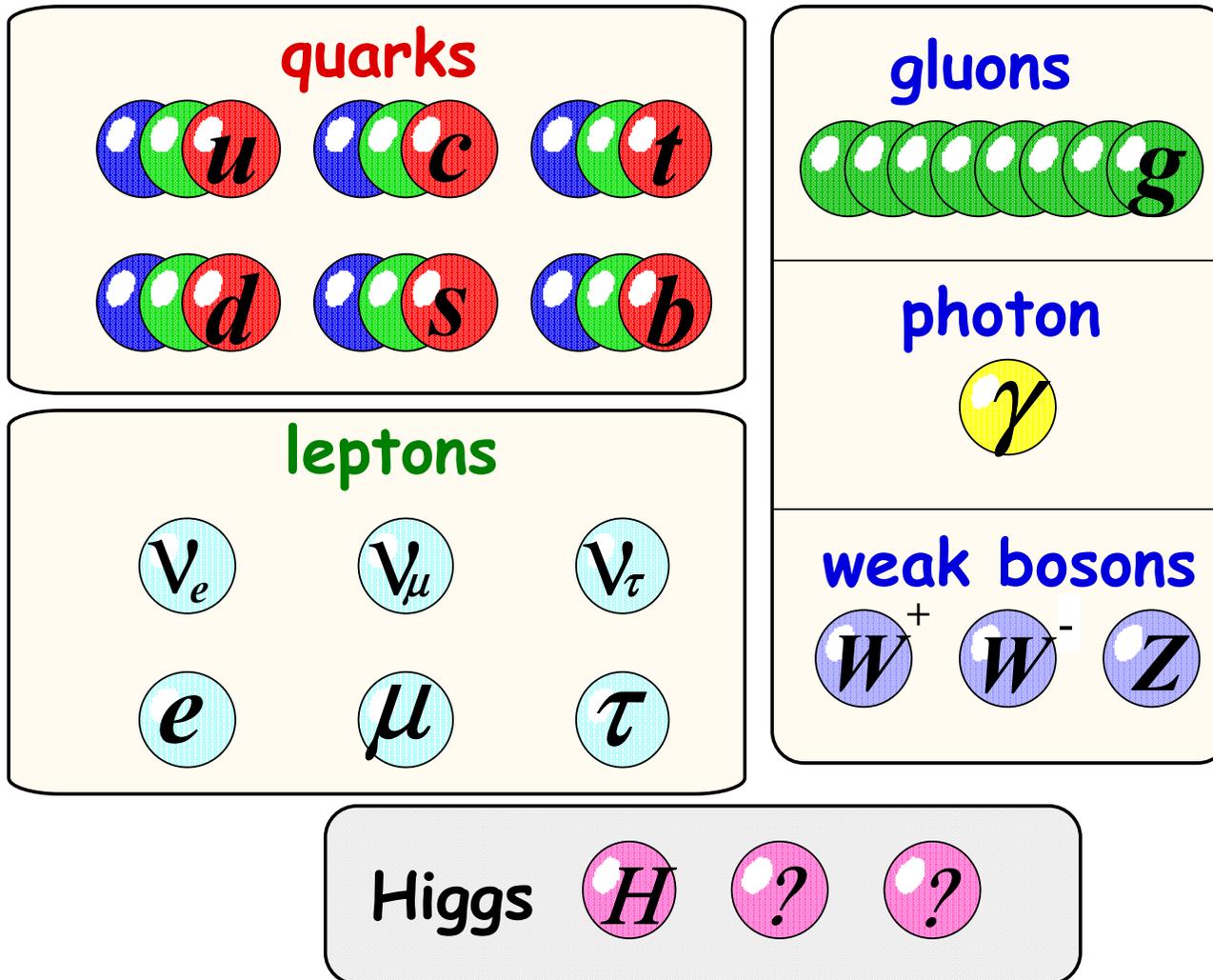
### Phase 2 : Major hardware changes in the arcs

- Equip SPS with superconducting magnets for 1 TeV injection to LHC.
- New arc dipoles with  $B=16-16.5$  T
- Upgrade the injectors.
- Super-bunch (?).

resulting  $E = 14$  TeV,  $L = 9 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$

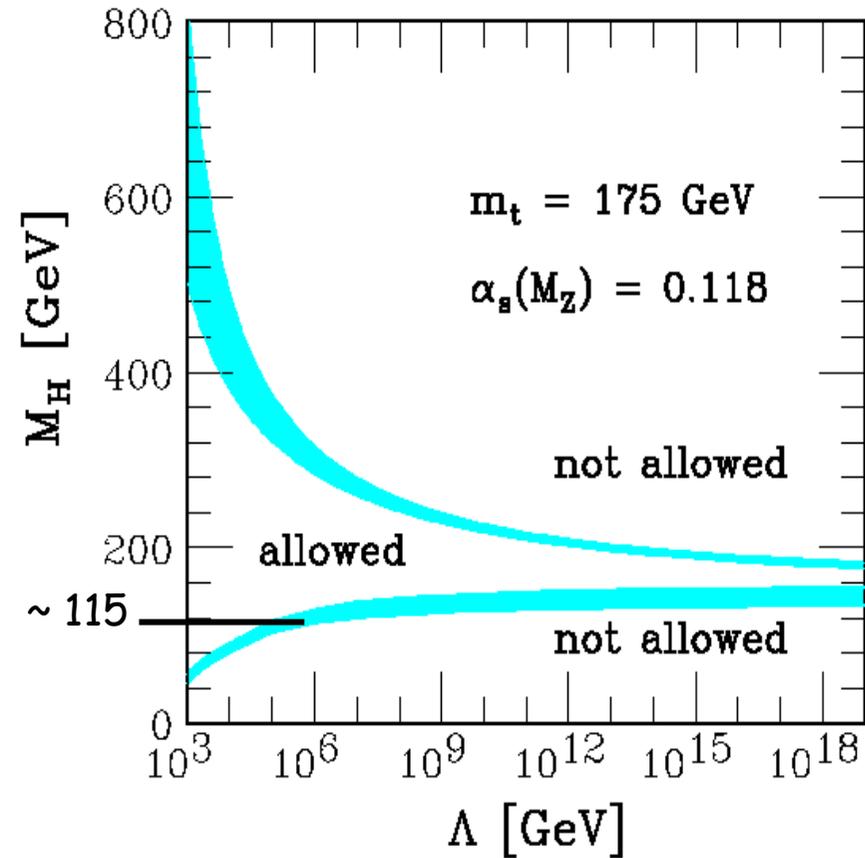
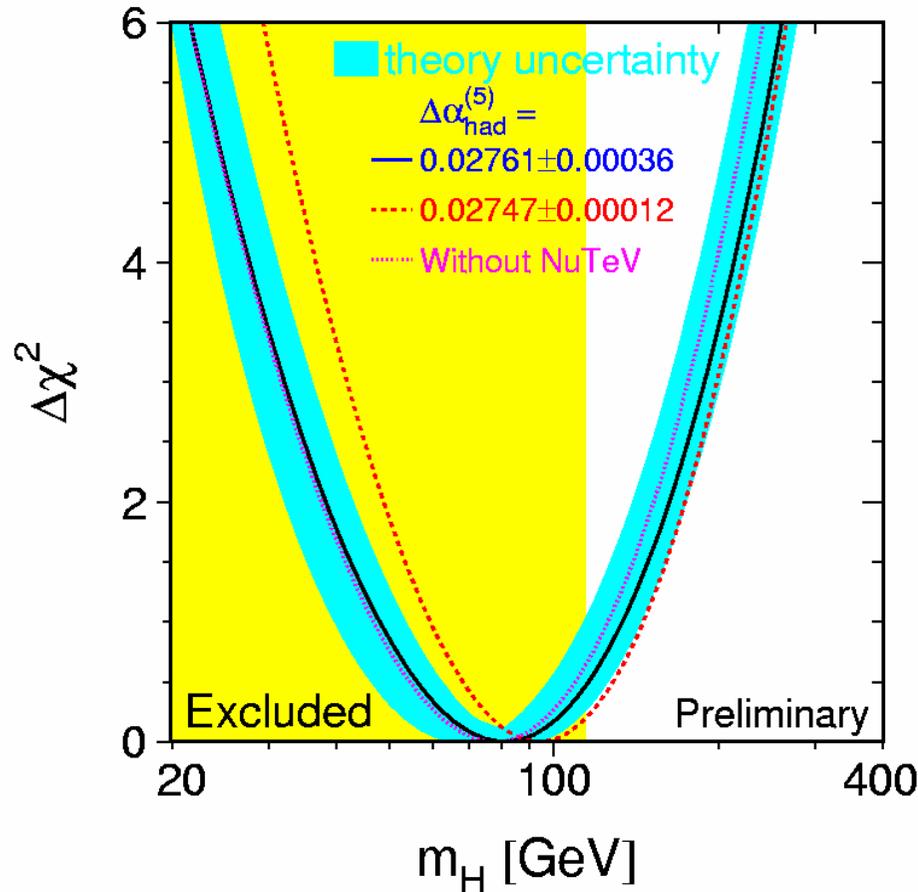
time scale  $\geq 2015$  ?

# Standard Model:



Only Higgs particles are to be discovered !!

# Where are Higgs Particles ?

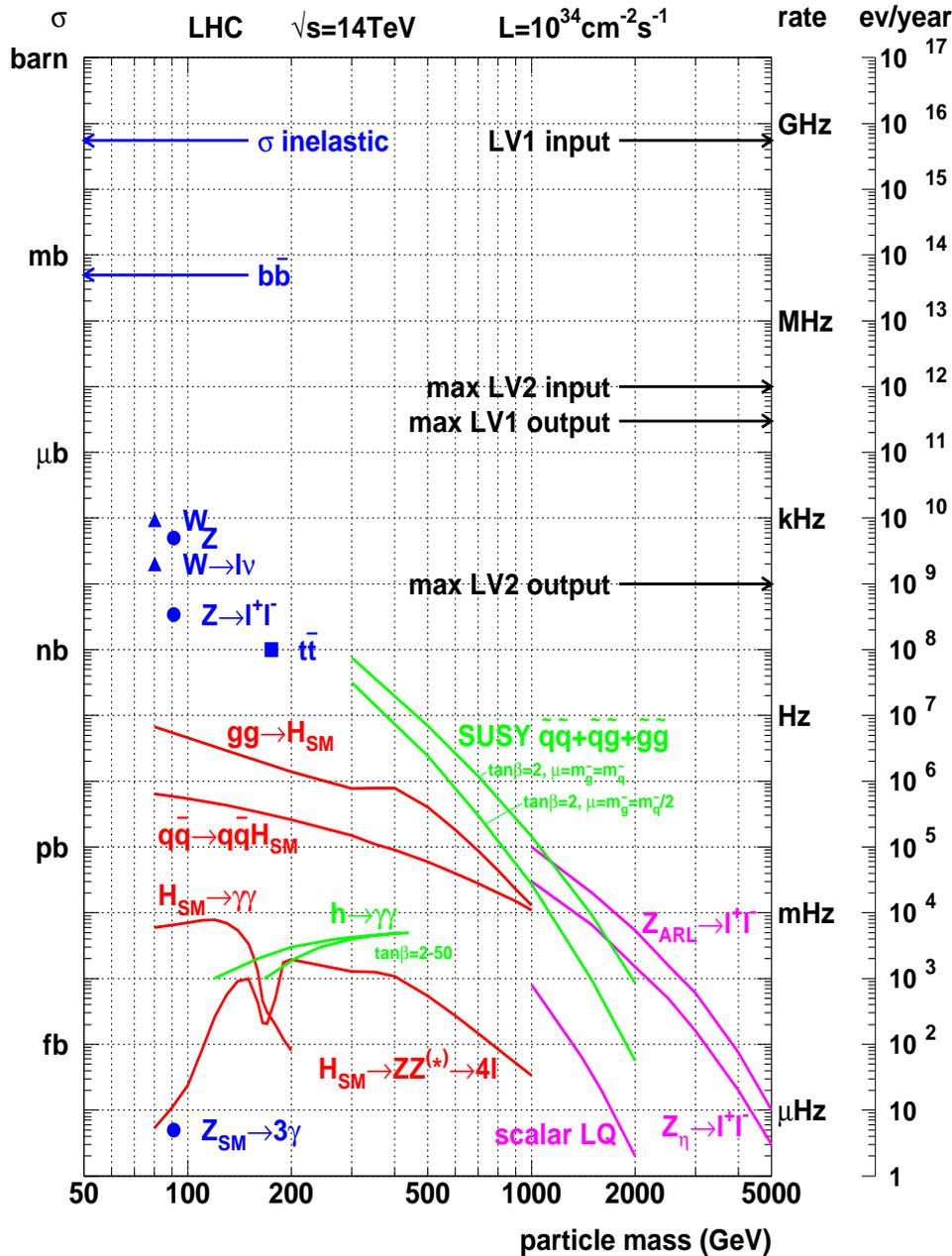


$\Lambda$ =energy scale of next new physics

Theories suggest small  $m_{SMH}$

LEP data excluded  $m_{SMH} < 114$  GeV/c<sup>2</sup>,  
 But strong indication for  $m_{SMH} < 300$  GeV/c<sup>2</sup>.

# Why high luminosities for Higgs search ?



For  $m_H = 150 \text{ GeV}$ ,

$$\sigma(pp \rightarrow H) \sim 10 \text{ pb} = 10^{-35} \text{ cm}^2$$

$$\text{BR}(H \rightarrow Z^*Z \rightarrow e^+e^-e^+e^-) \sim 10^{-4}$$

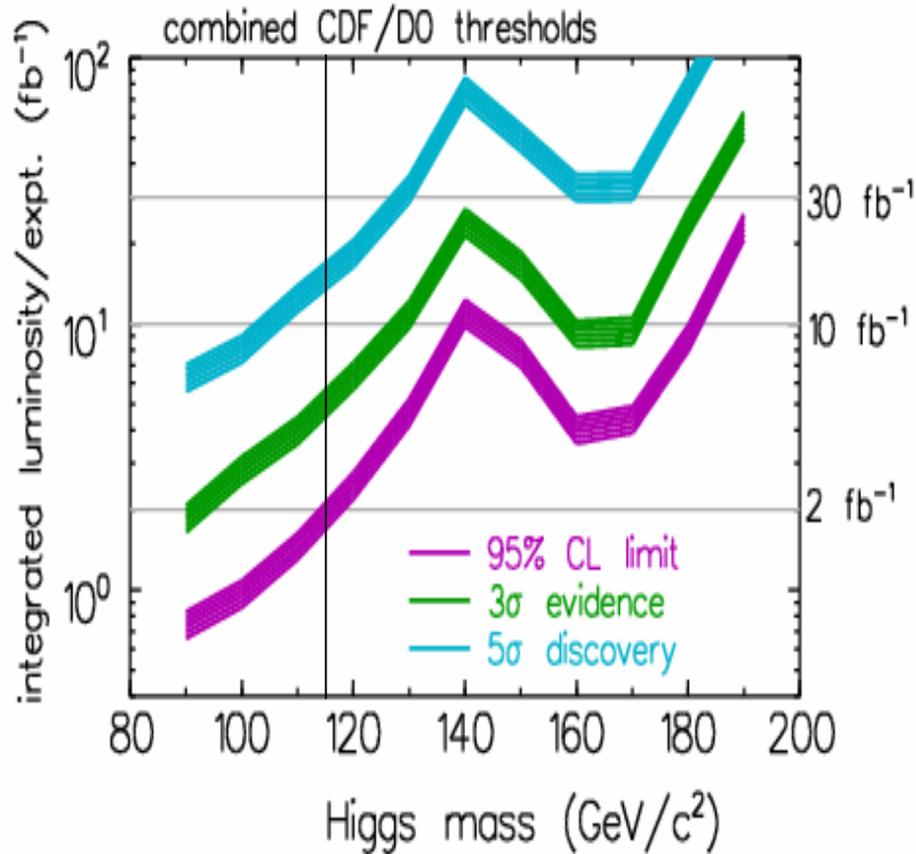
Detection efficiency  $\sim 0.1$

$$N_H \sim 10^{-35} \times 10^{-4} \times 0.1 \times 10^{34}$$

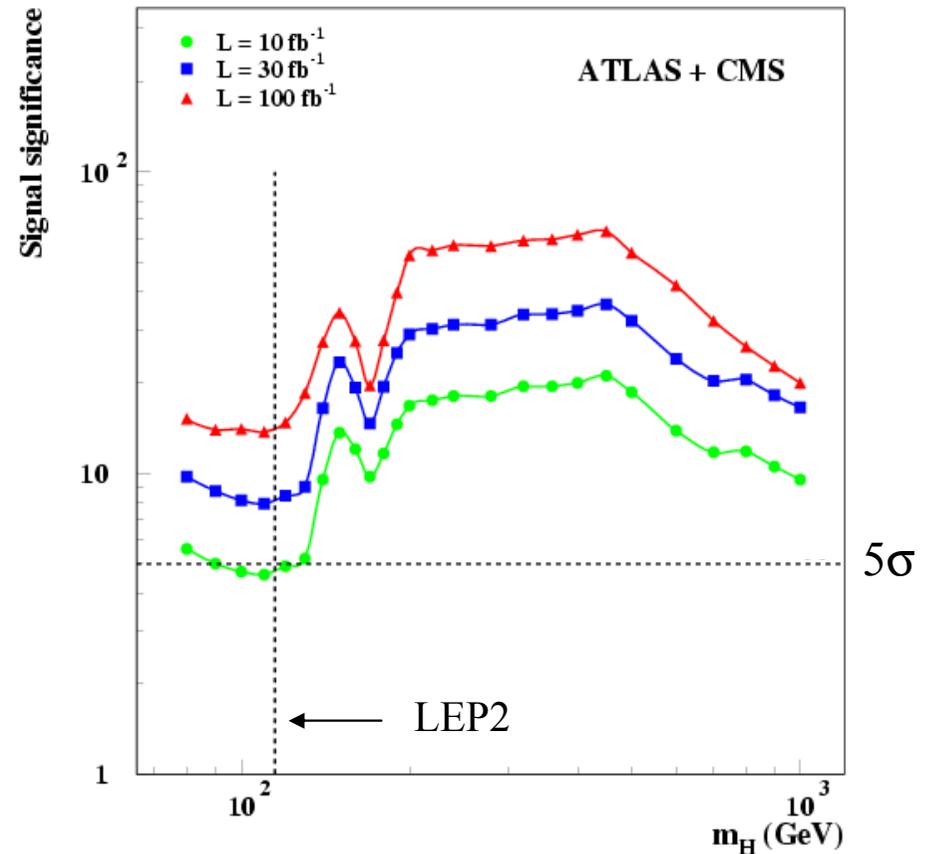
$$\sim 10^{-6} / \text{sec}$$

$$\sim 10 / \text{year}$$

# Tevatron or LHC will discover Higgs



SM Higgs may be discovered at Tevatron if its integrated L exceeds 10~30/fb



LHC covers the entire mass range of the SM Higgs

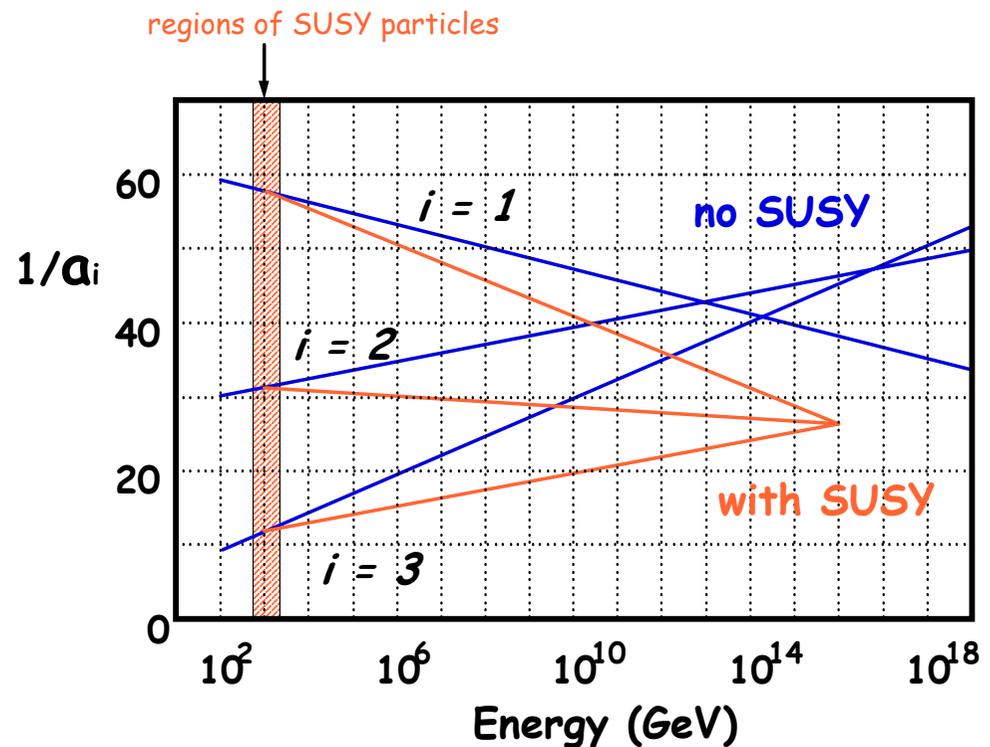
# Many SUSY particles may be discovered at LHC

**Hierarchy problem:** If GUTS is right, mass corrections of Higgs are too big. SUSY particles cancel out the mass corrections.

If SUSY particle exists at  $\sim 1$  TeV, all three forces can unify at one point at  $\sim 10^{16}$  GeV.

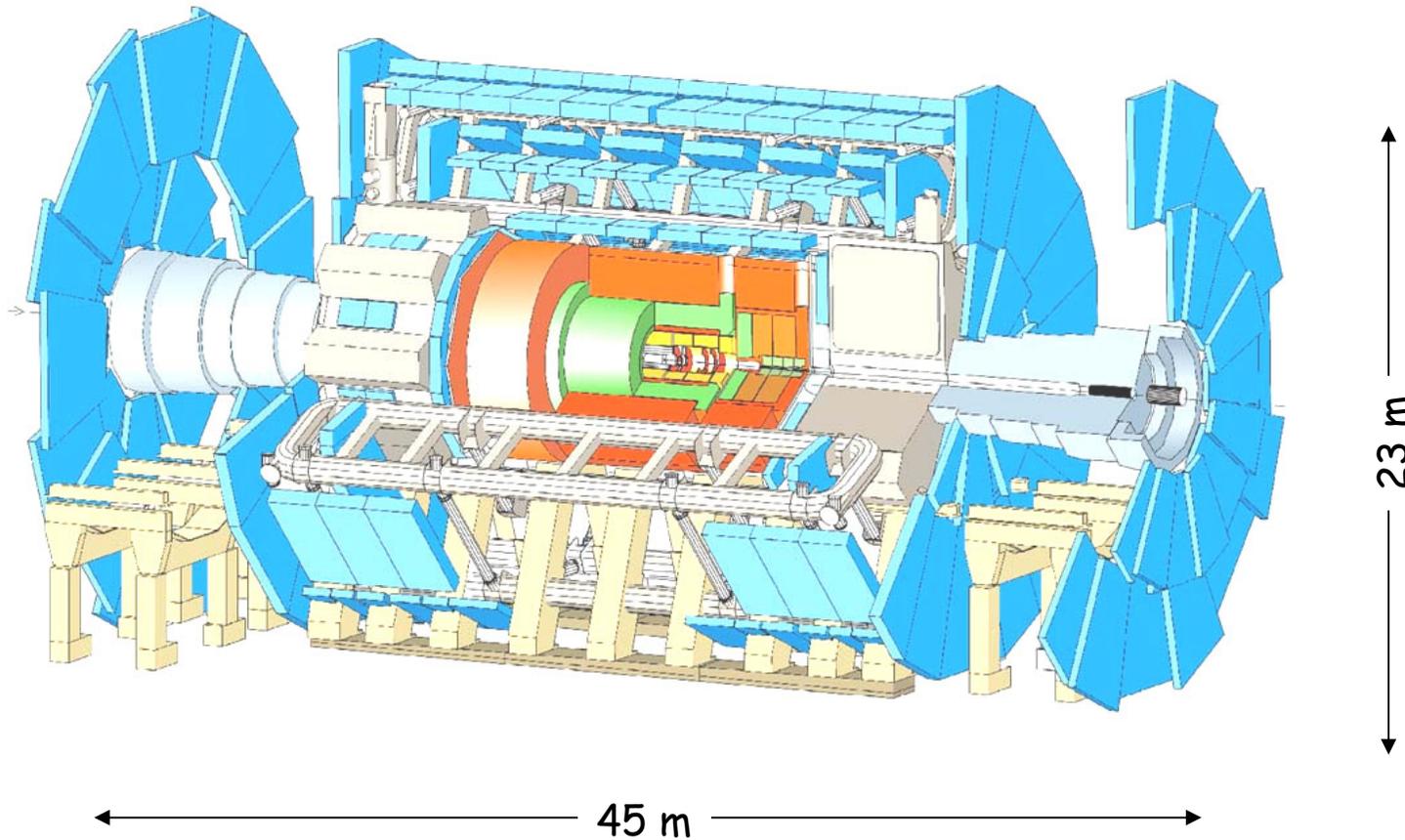
Excellent agreement on  $\sin^2\theta_W$   
0.2315 (LEP experiments)  
0.2309 (SUSY GUTS theory)

→ Many SUSY particles to be found at LHC !!



# ATLAS Detector

35 countries  
150 institutes  
1500 physicists  
475 + 68 MCHF  
for construction



Major issues : Complexity, Cost, Scale, **Radiation Damage**, Data amount

# ATLAS Construction by Japan

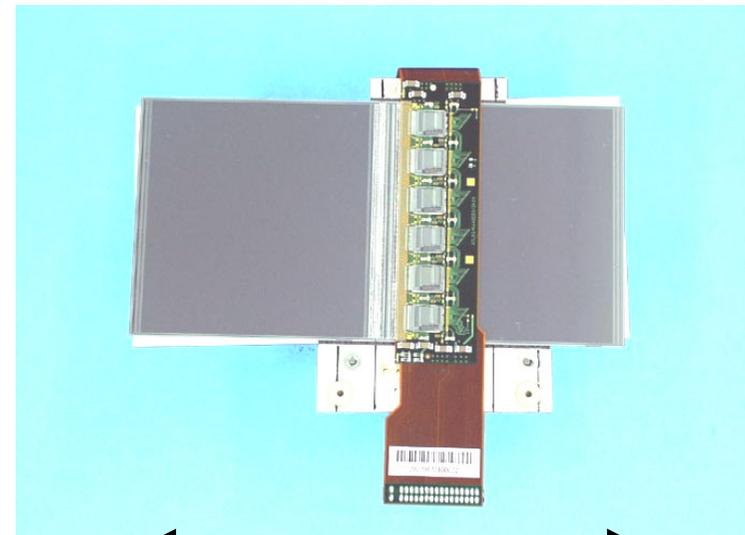


ATLAS solenoid arrived  
at CERN in Sep. 2002



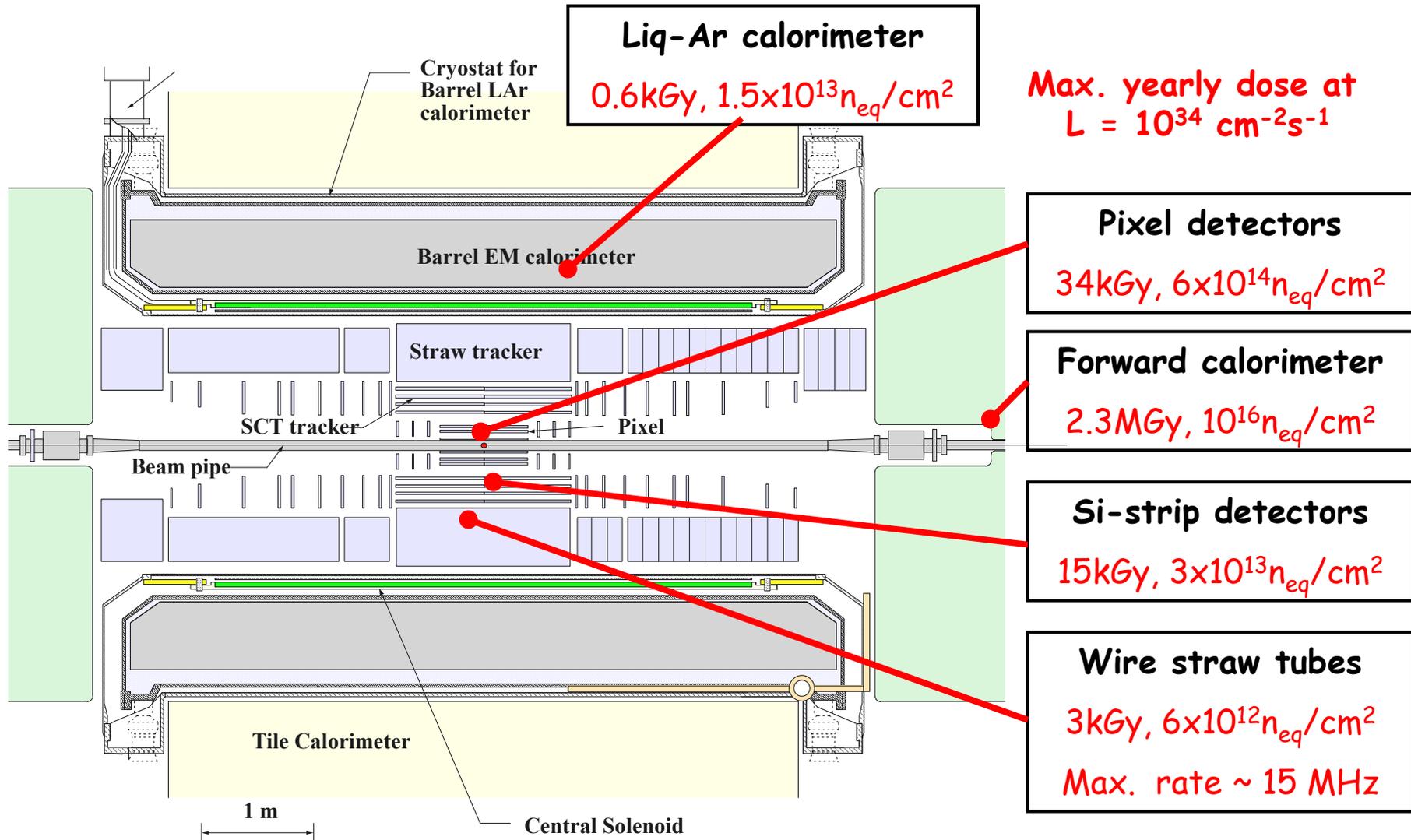
1100 TGC  
chambers  
in production

700 Silicon  
modules  
in production



12 cm

# Radiation Levels

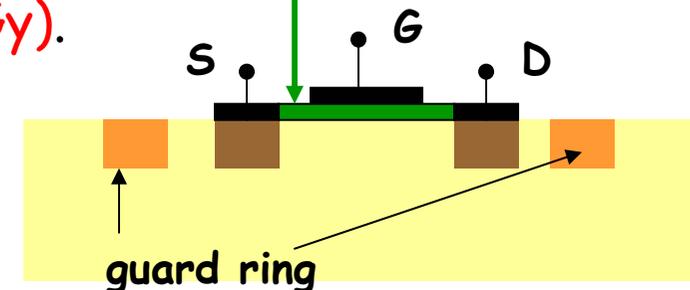


# Radiation-hard detector technologies

- Silicon detectors work to  $10^{15} n_{eq} / \text{cm}^2$ 
  - n  $\rightarrow$  p type inversion, anti-annealing effects etc.
  - Need to be cooled down to  $-10^\circ \text{C}$  all the time.
  - Still progressing :  $\text{O}_2$  diffused Silicon, Cryogenic temperature operation, 3D detectors.....

- Deep sub-micron MOS Technology

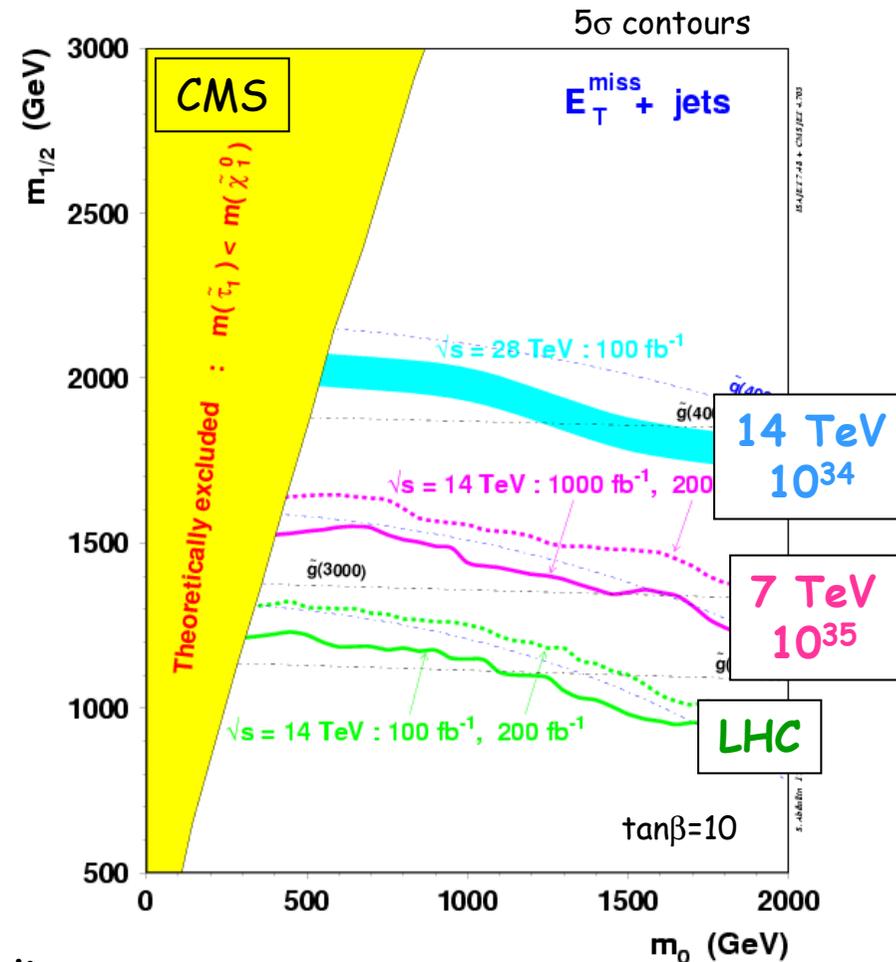
- Smaller process size (eg  $0.25 \mu\text{m}$ ) has better radiation hardness due to tunneling in very thin  $\text{SiO}_2$  layers.
- CERN successfully developed rad-hard DSM technology.
- Can survive at  $> 30 \text{ Mrad}$  ( $300 \text{ kGy}$ ).



# Operations of ATLAS/CMS detectors at $10^{35} \text{cm}^{-2} \text{s}^{-1}$

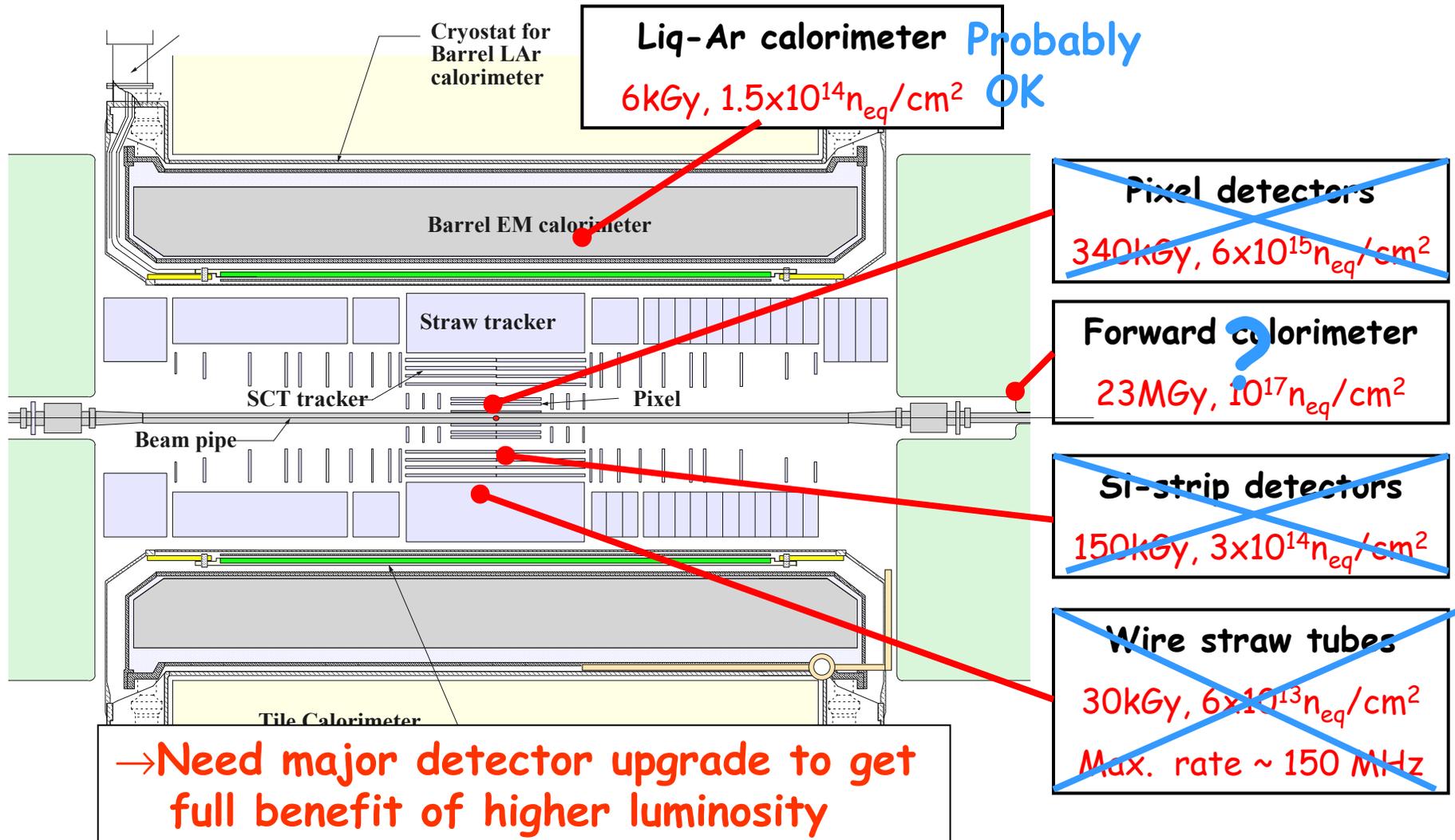
Without major detector upgrades

- ✧ 20% improvement in mass reach using only high  $p_T$  jets,  $\gamma$  and  $\mu$ .
- ✧ Failure of Inner Detector  $\rightarrow$  much worse e-ID, b tagging.
- ✧ Event pile-up  $\rightarrow$  worse forward jet tagging.



See hep-ph/0204087 for more detail studies

# Need major detector upgrades for full benefit of higher $10^{35} \text{cm}^{-2} \text{s}^{-1}$



# Physics reaches by future machines

Copied from F. Gianotti's talk at ICFA 2002 Seminar at CERN  
 (<http://dsu.web.cern.ch/dsu/of/icfasource.html>)

Unit=TeV

PROCESS	LHC 14 TeV 100 fb <sup>-1</sup>	SLHC 14 TeV 1000 fb <sup>-1</sup>	28 TeV 100 fb <sup>-1</sup>	VLHC 40 TeV 100 fb <sup>-1</sup>	VLHC 200 TeV 100 fb <sup>-1</sup>	LC 0.8 TeV 500 fb <sup>-1</sup>	LC 5 TeV 1000 fb <sup>-1</sup>
Squarks	2.5	3	4	5	20	0.4	2.5
W <sub>L</sub> W <sub>L</sub>	2σ	4σ	4.5σ	7σ	18σ		90σ
Z'	5	6	8	11	35	8 <sup>†</sup>	30 <sup>†</sup>
Extra-dim (δ=2)	9	12	15	25	65	5-8.5 <sup>†</sup>	30-55 <sup>†</sup>
q*	6.5	7.5	9.5	13	75	0.8	5
Δ compositeness	30	40	40	50	100	100	400

Approximate mass reach of pp machines:

- $\sqrt{s} = 14 \text{ TeV}, L=10^{34} \text{ (LHC)}$  : up to  $\approx 6.5 \text{ TeV}$
- $\sqrt{s} = 14 \text{ TeV}, L=10^{35} \text{ (SLHC)}$  : up to  $\approx 8 \text{ TeV}$
- $\sqrt{s} = 28 \text{ TeV}, L=10^{34}$  : up to  $\approx 10 \text{ TeV}$
- $\sqrt{s} = 40 \text{ TeV}, L=10^{34}$  : up to  $\approx 13 \text{ TeV}$
- $\sqrt{s} = 200 \text{ TeV}, L=10^{34} \text{ (VLHC)}$  : up to  $\approx 75 \text{ TeV}$

probes directly  
up to  $\sim 100 \text{ TeV}$   
with ultimate  
luminosity

probes indirectly  
up to  $\sim 1000 \text{ TeV}$   
with ultimate  
luminosity

## Personal Summary

- ATLAS and CMS are designed for  $10^{34}\text{cm}^{-2}\text{s}^{-1}$ , but not for higher luminosities.
- Need major detector upgrades for the full benefit of operation at  $10^{35}$ .
- Energy frontier physicists always welcomes higher luminosities, but wants higher energies more favorably in general.
- But if high luminosity is the only way to explore the energy frontier physics, experimentalists will surely challenge and encounter any difficulties anyway.