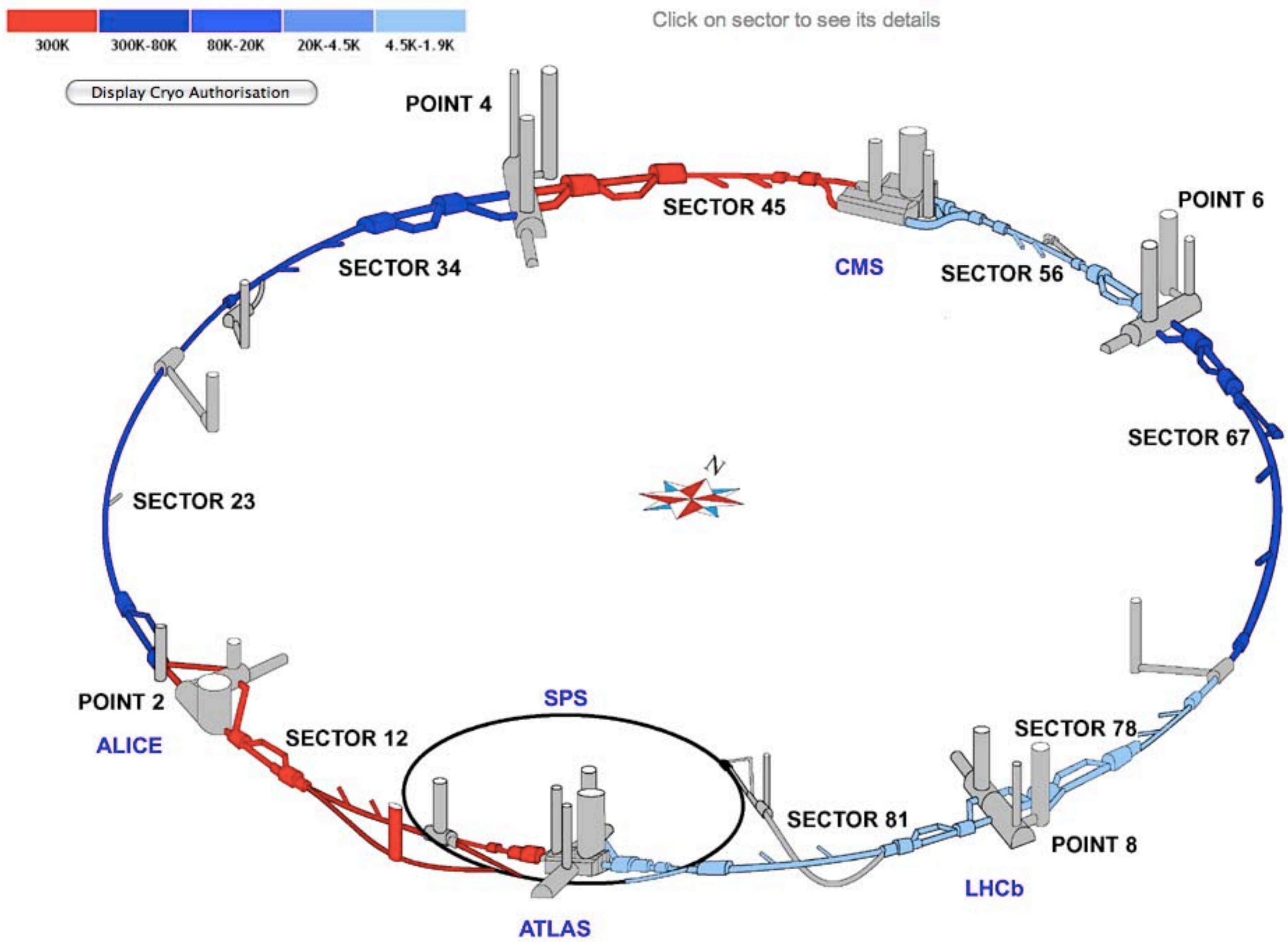
Prospects and Plans for the sLHC Machine and Detectors

Karlheinz Meier – Heidelberg

Outline

- The LHC
- Upgrading the LHC : Why and When ?
- Upgrading the LHC : How ?
- Upgrading the LHC : Consequences for Detectors

The LHC as of Saturday, April 26th 2008



The „No Upgrade LHC“ – „Nominal“ vs „Ultimate“

Parameters	LHC	
	Nominal	Ultimate
Bunch spacing [ns]	25	25
Protons/bunch $N_b[10^{11}]$	1.15	1.7
β^* at ATLAS and CMS [m]	0.55	0.5
Longitudinal bunch profile	Gaussian	Gaussian
r.m.s. bunch length σ_z [cm]	7.55	7.55
Full crossing angle at IP	285 μrad	315 μrad
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1	2.3
Effective luminosity (5h) [10^{34} $cm^{-2}s^{-1}$]	0.56	1.15
Peak events per crossing	19	44

The LHC Upgrade is already on the European Menu

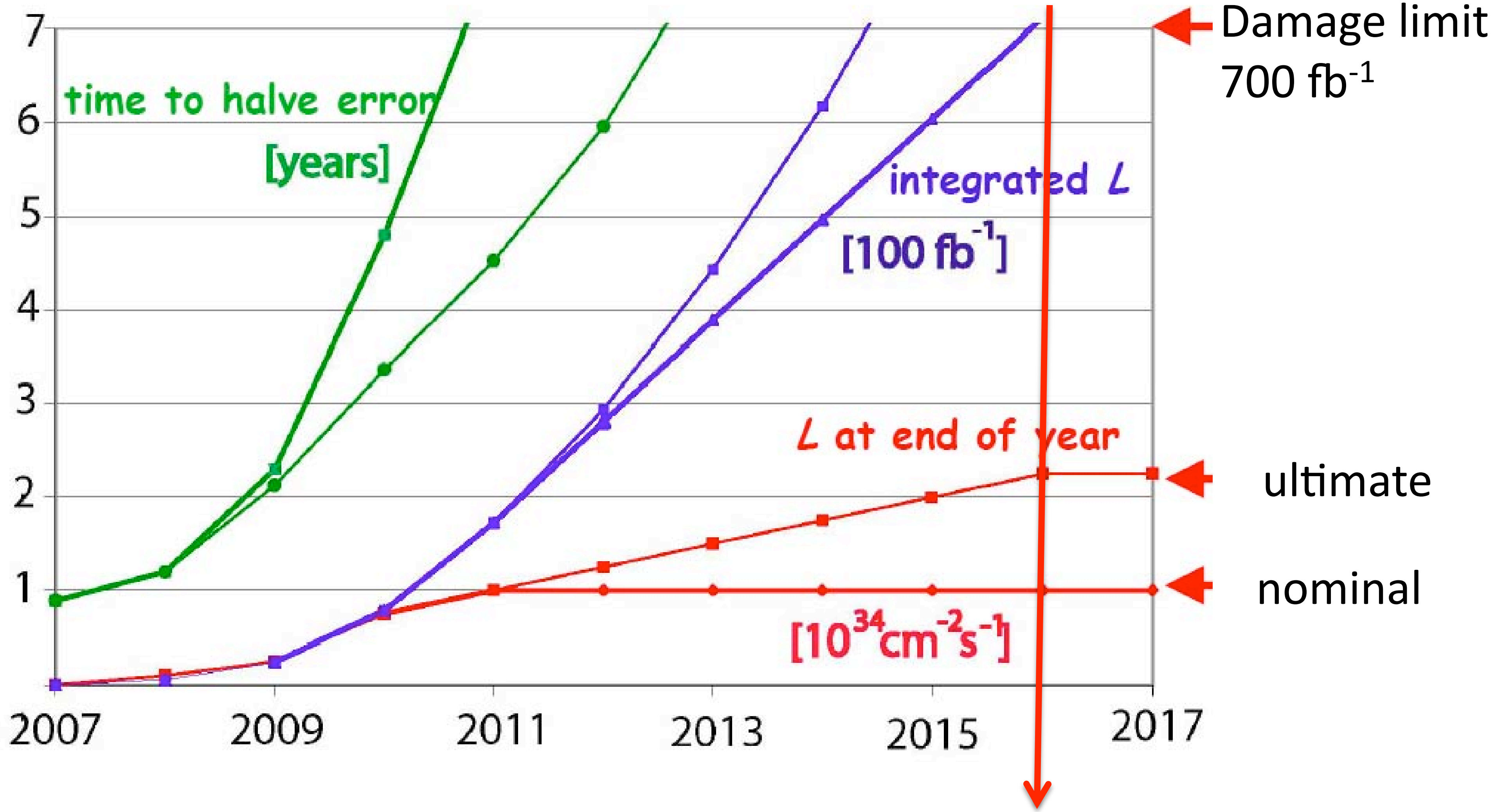
"The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial program have to be secured such that machine and experiments can operate optimally at their design performance. ***A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focused R&D****; to this end, R&D for machine and detectors has to be vigorously pursued now and centrally organized towards a luminosity upgrade by around 2015."*

BUT

SLHC status:

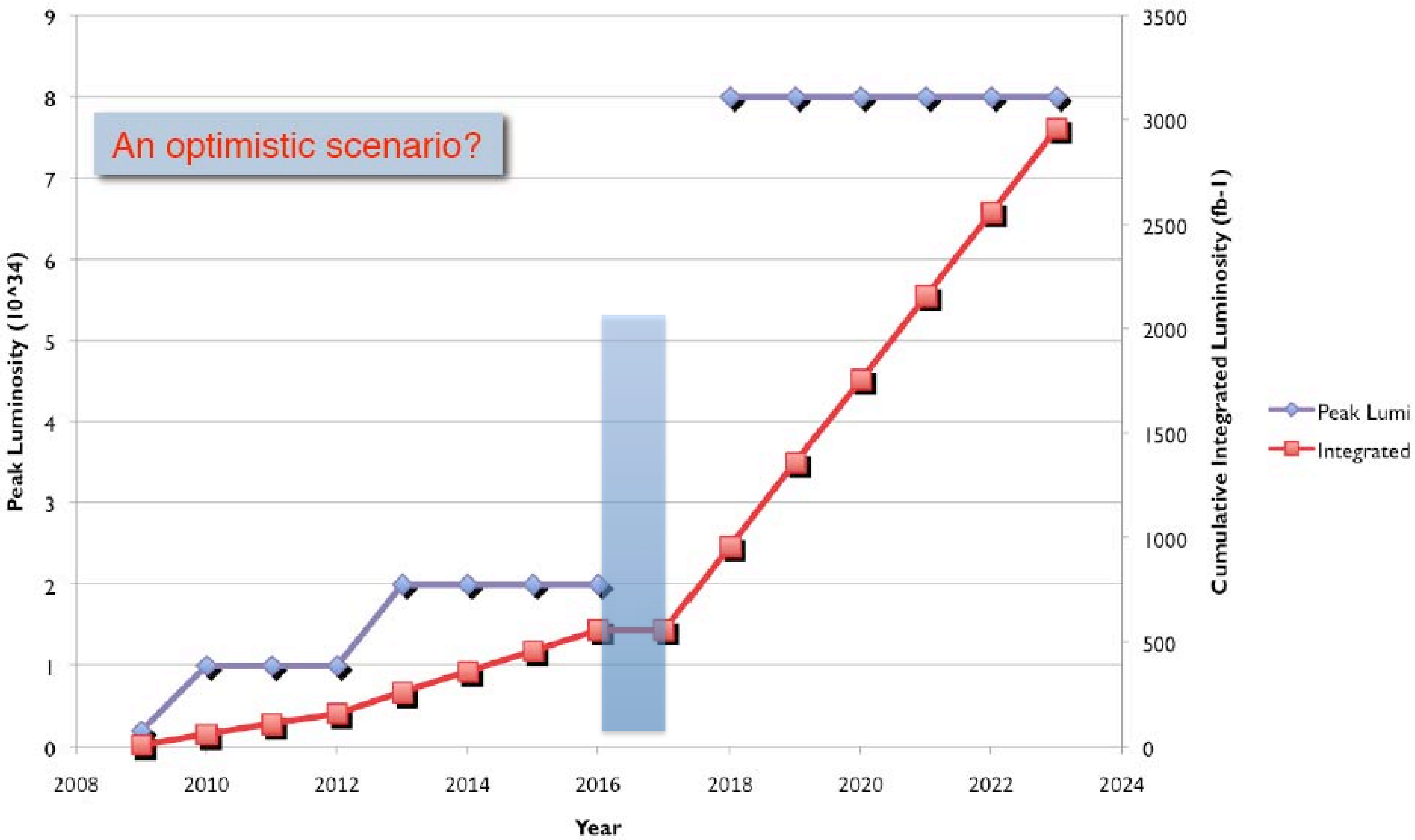
- R&D towards an Upgrade scenario is under way for machine and detectors
- SLHC is not approved yet
- Exact time schedule is not decided and not known
- Machine scenarios exist but are not frozen

L, L_{int}, Radiation damage to IR Quadrupoles and Statistics at the LHC (J.Strait, 2005)

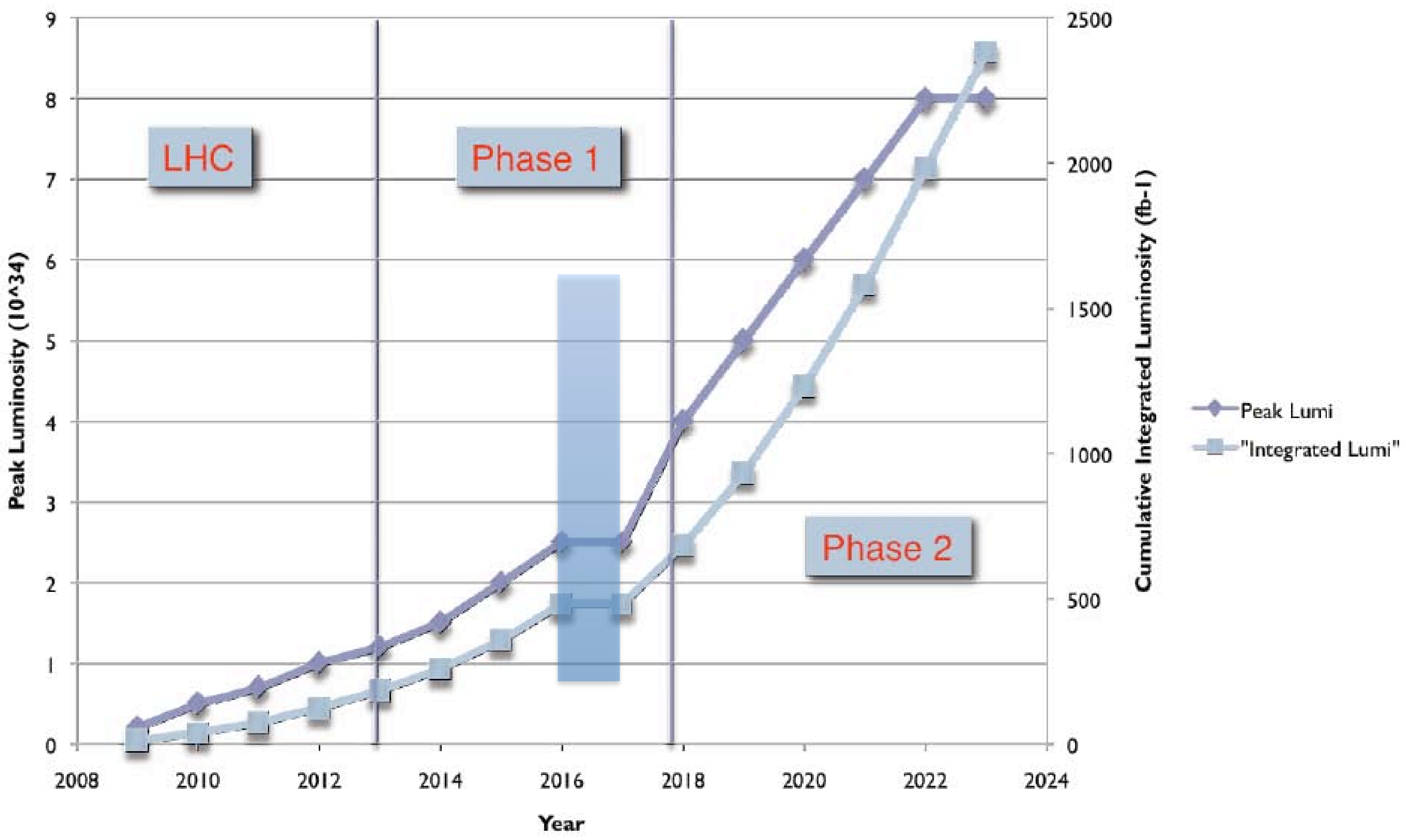


Reasons to plan a LHC luminosity upgrade after about 2015

A probably unrealistic LHC upgrade scenario (J. Nash, CMS Upgrade Meeting)



A possibly realistic LHC upgrade scenario (J. Nash, CMS Upgrade Meeting)



Pushing the LHC - in Phases .....

PHASE 1 : Expand luminosity to the (beam-beam) limit („ultimate“)

1.7×10^{11} protons per bunch, improved injector chain
$L = 2.3 \times 10^{34} cm^{-2} s^{-1}$

Work on interaction points (experimental areas)
leave arcs untouched („sLHC“)

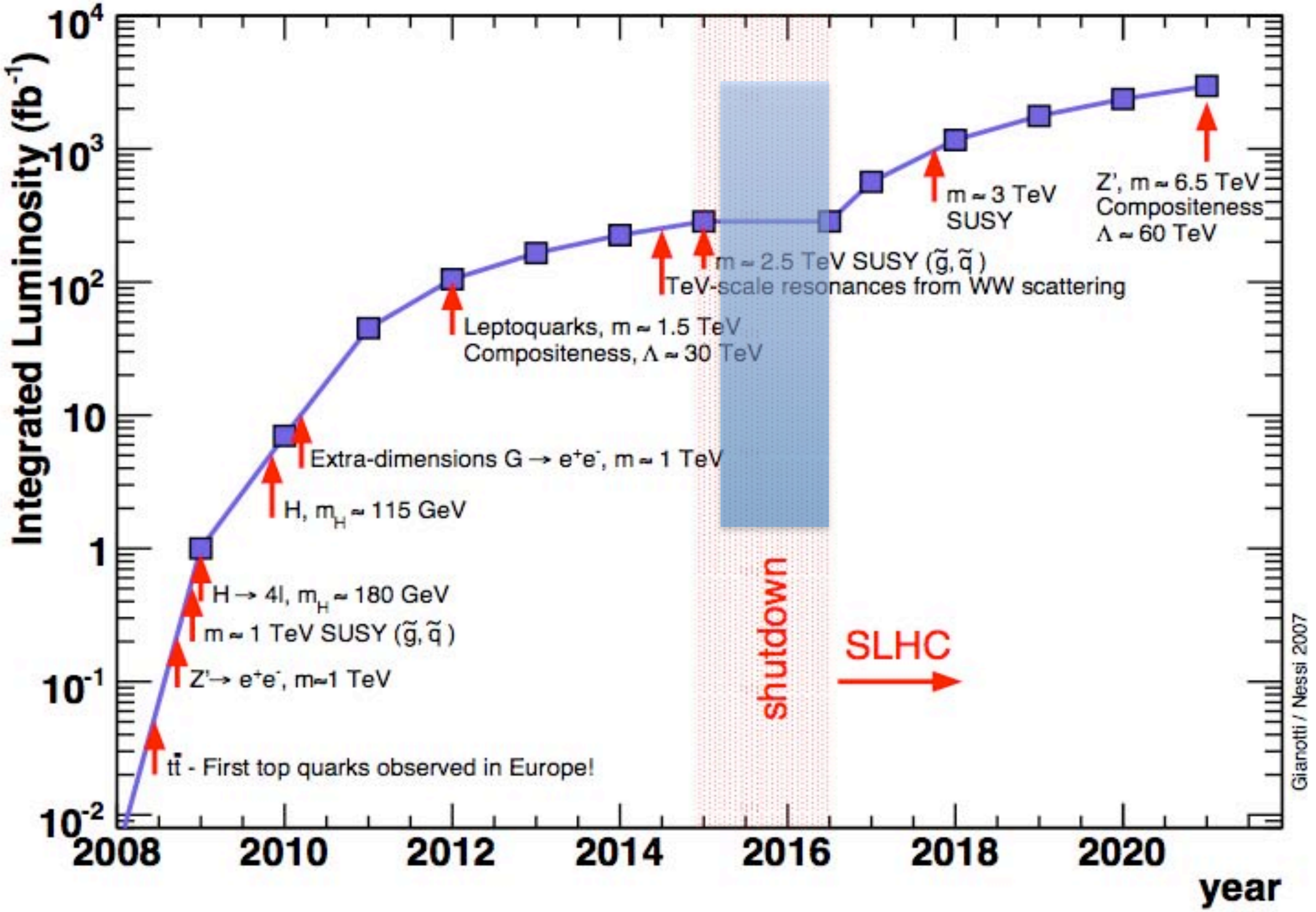
$L = 10.7 \times 10^{34} cm^{-2} s^{-1}$ to $15.5 \times 10^{34} cm^{-2} s^{-1}$
2 scenarios under discussion
THIS IS WHAT WE CALL THE sLHC

Phase 2 : Run the sLHC to accumulate 2.5 – 3 ab^{-1}

Later : Major replacements of machine components

New dipole magnets
D(ouble)LHC : 2x14 = 28 TeV, T(riple)LHC : 3x14 = 42 TeV
New 1 TeV SPS Injector

Integrated Luminosity Growth and Physics Reach



Physics Motivations for a Luminosity Upgrade

Increased mass reach

Production of new particles
Compositeness (Quark constituents)
Vector-boson scattering
uncritical, need to understand high Et response of detectors

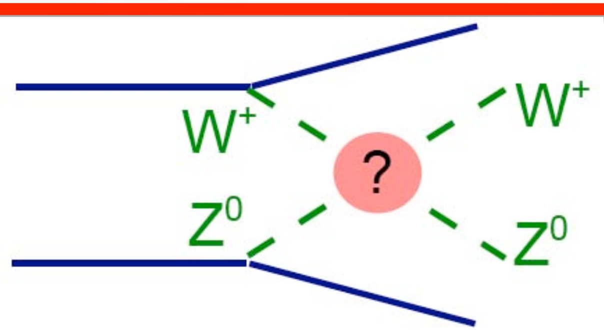
Statistics limited physics or systematics limited by statistics

Higgs couplings, Higgs self-coupling
SUSY properties
good understanding (improvement) of detector performance critical

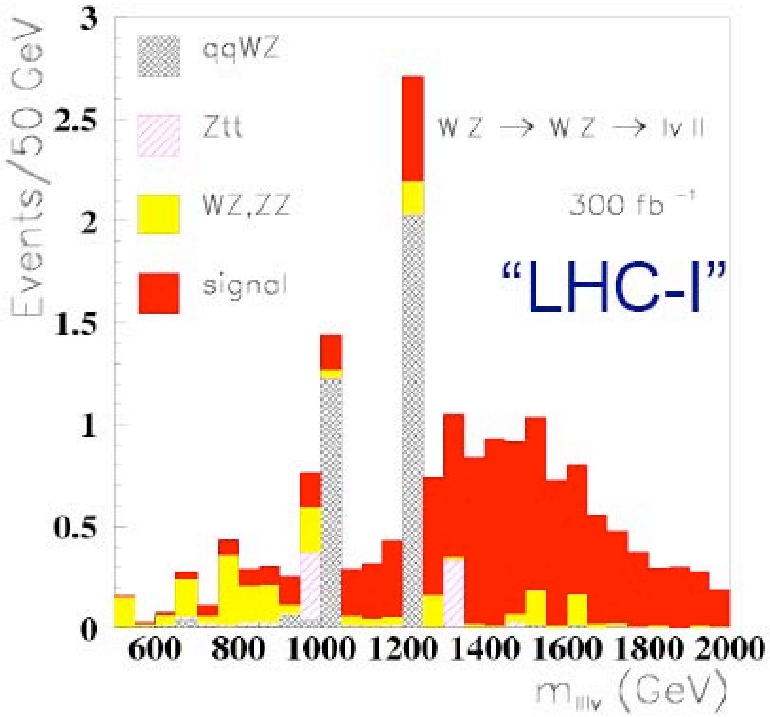
Rare and very rare phenomena

H -> μμ, H-> ZY, t-> cϒ
good understanding (improvement) of detector performance critical

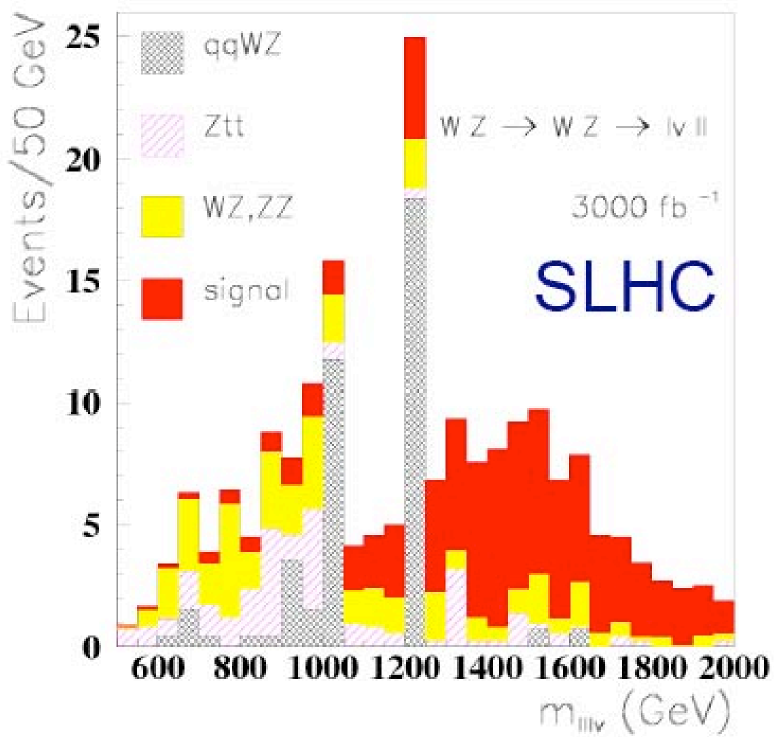
sLHC Case : The „no-Higgs Scenario“



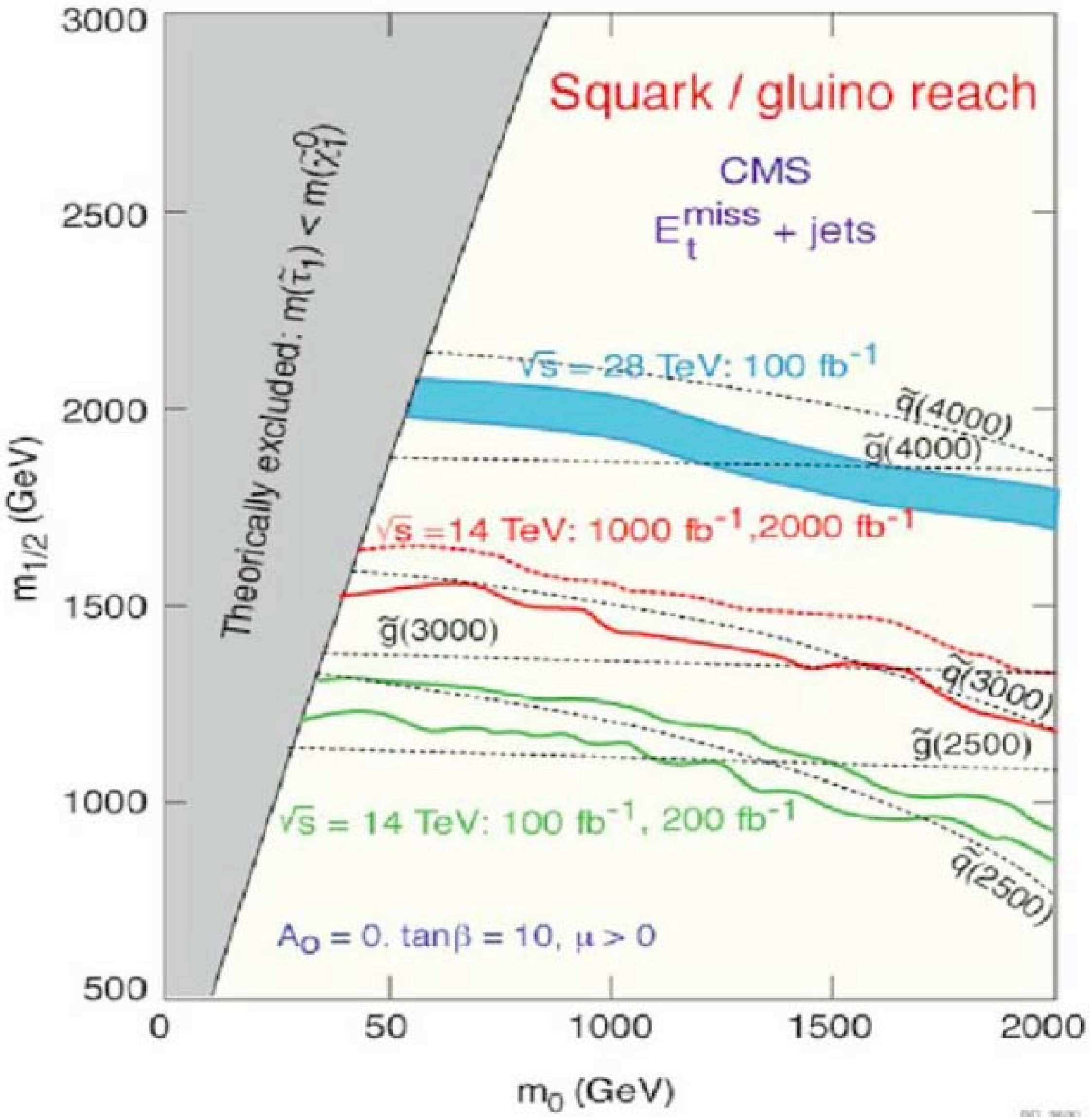
300 fb^{-1}



3000 fb^{-1}



sLHC Case : The „high mass squark / gluino Scenario“

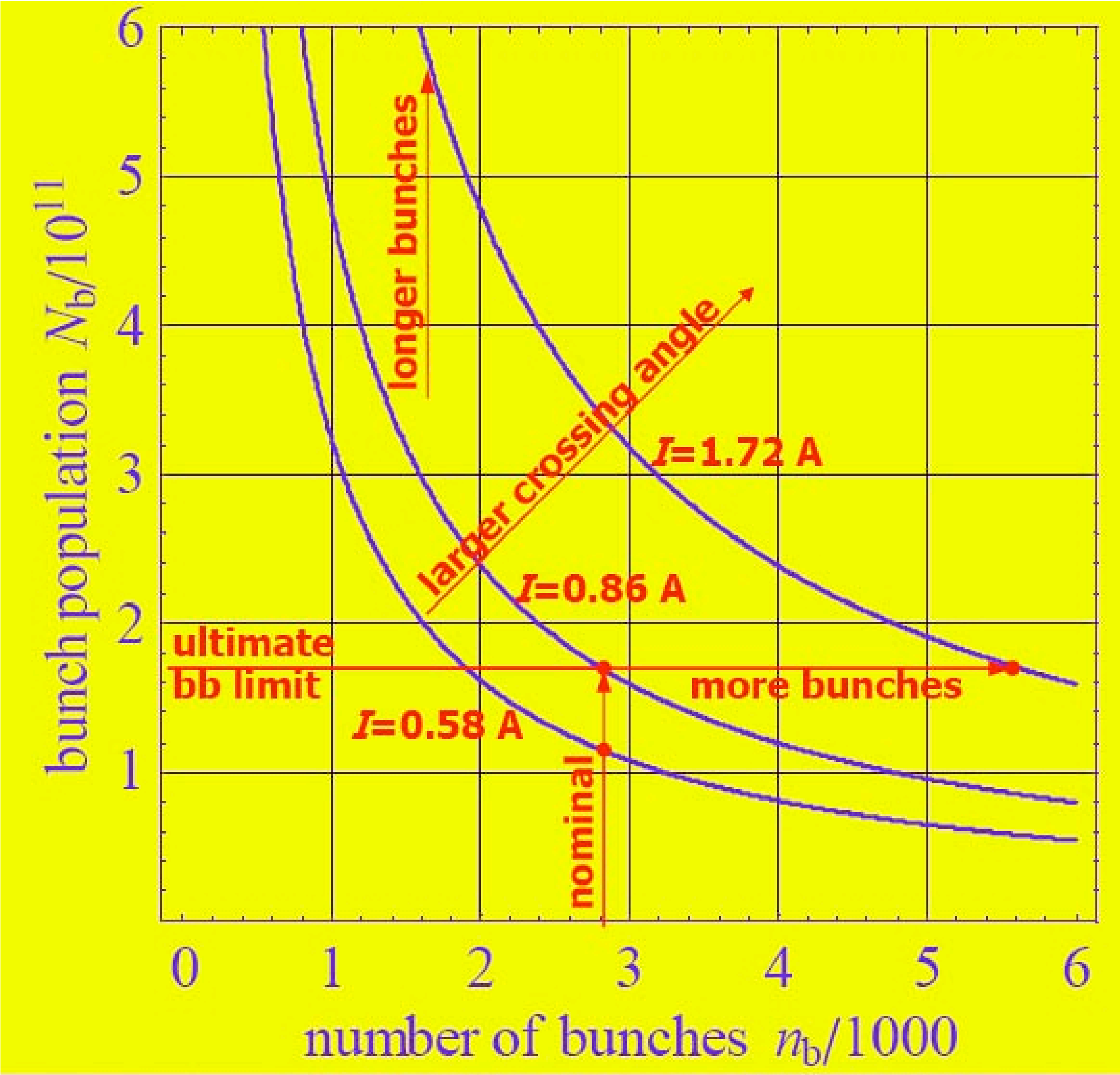


Within mSUGRA

From 100/200 fb-1 to 1000/2000 fb-1 :

Go from 2.5 TeV mass scale to 3 TeV mass scale

N_b and n_b – Easy ways to increase the Luminosity ?

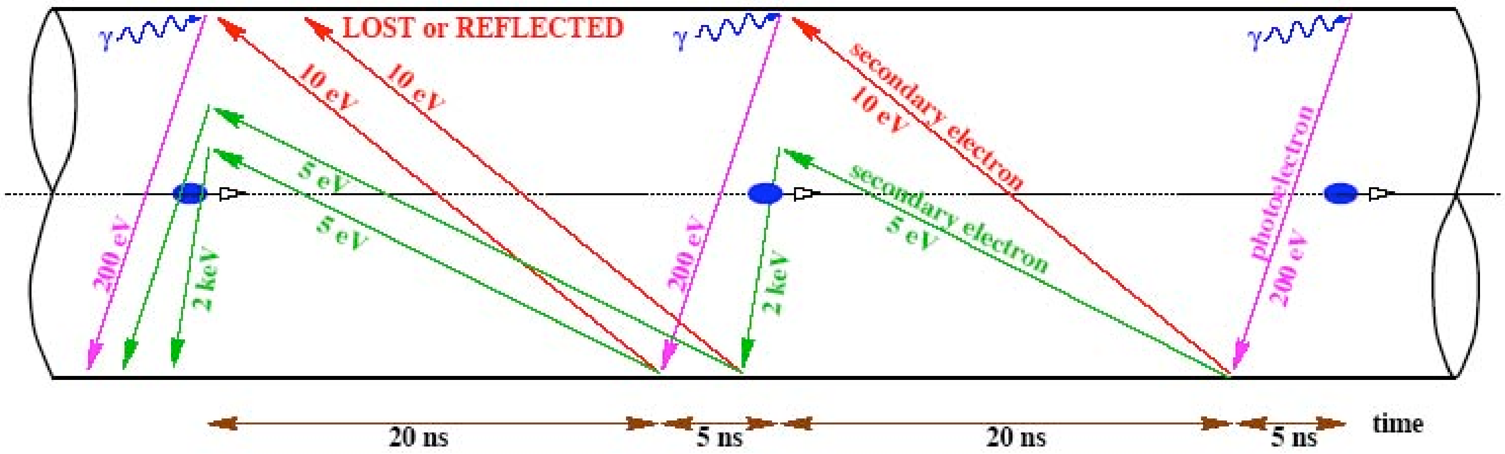


$$L \propto f_{rev} n_b N_b \frac{1}{\beta^*}$$

-More bunches ?
-More protons / bunch ?
-More both ?
-Less bunches and a lot more protons per bunch ?

F. Ruggiero, 2005

The Electron Cloud Effect



Photoelectrons are accelerated by p-bunches to O(100 eV) leaving the pipe in 5 ns

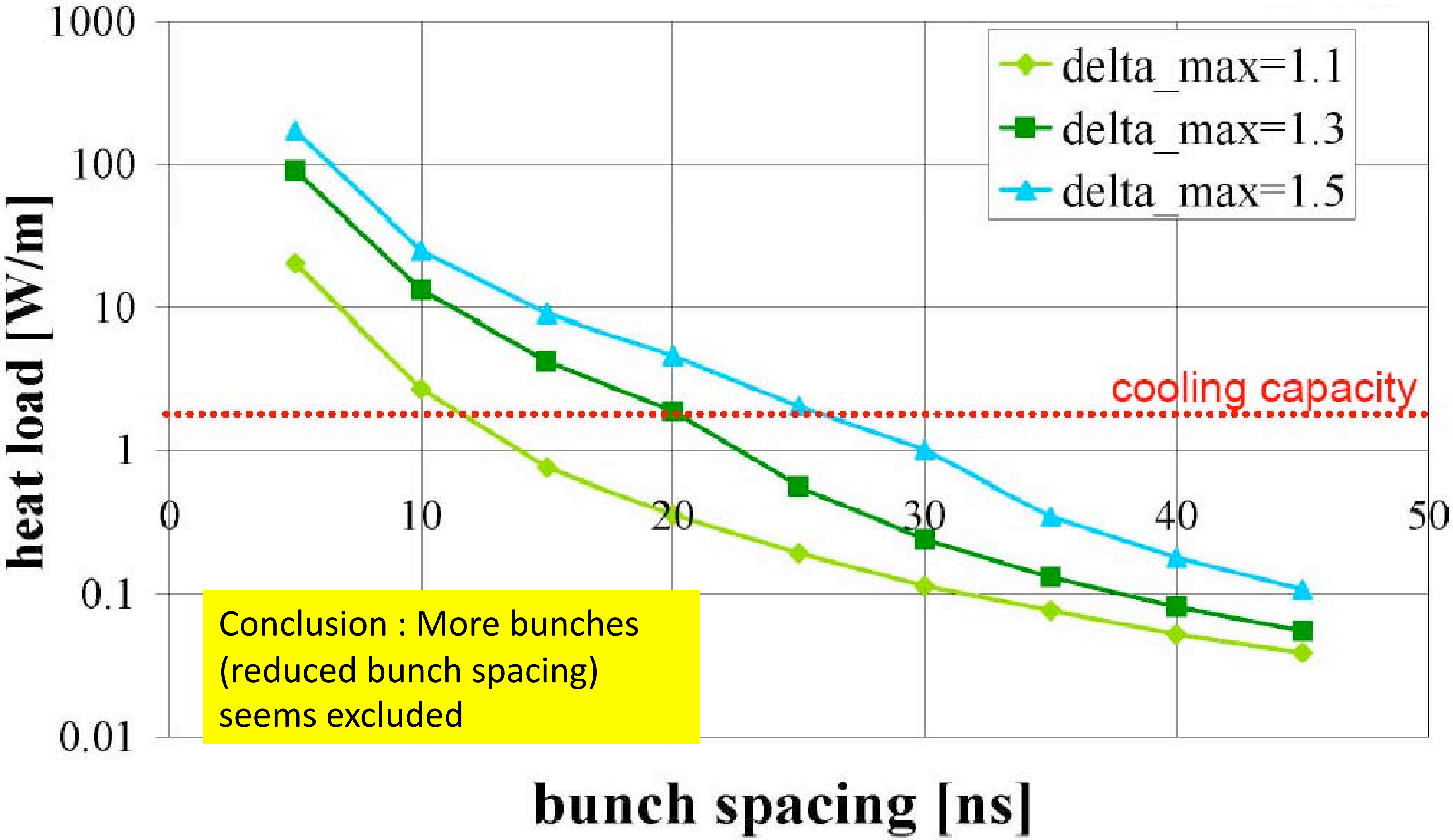
Slow and reflected secondary electrons stay in the pipe for longer periods (e-CLOUD)

Critical :

- Effect on beam stability
- Emittance growth
- Heat load to the beam pipe

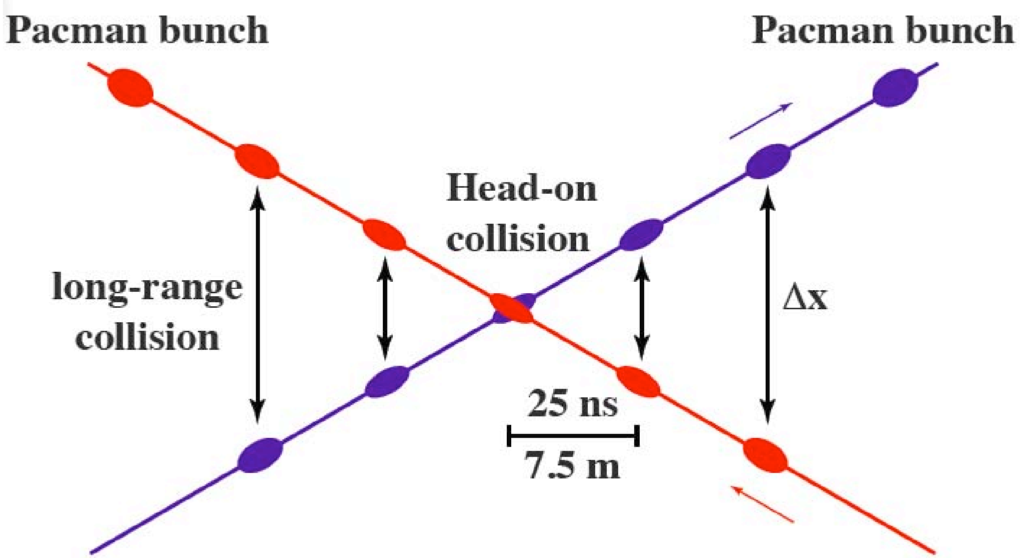
Heat Load to LHC Beampipe, $N_b = 1.15 \times 10^{11}$

Frank Zimmermann, LTC 2005



Conclusion : More bunches (reduced bunch spacing) seems excluded

Crossing Angle and Luminosity



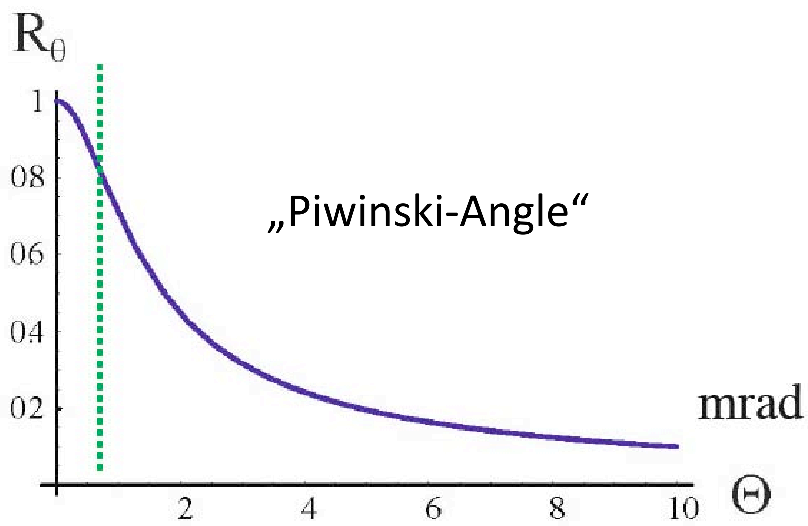
Crossing Angle is needed to avoid encounters closer than about 6 σ

For nominal LHC luminosity the crossing angle will be ± 142.5 μrad

Effect : Geometrical loss in luminosity

$$R_\theta = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

$R_\theta = 0.84$ or 20 % loss for nominal θ



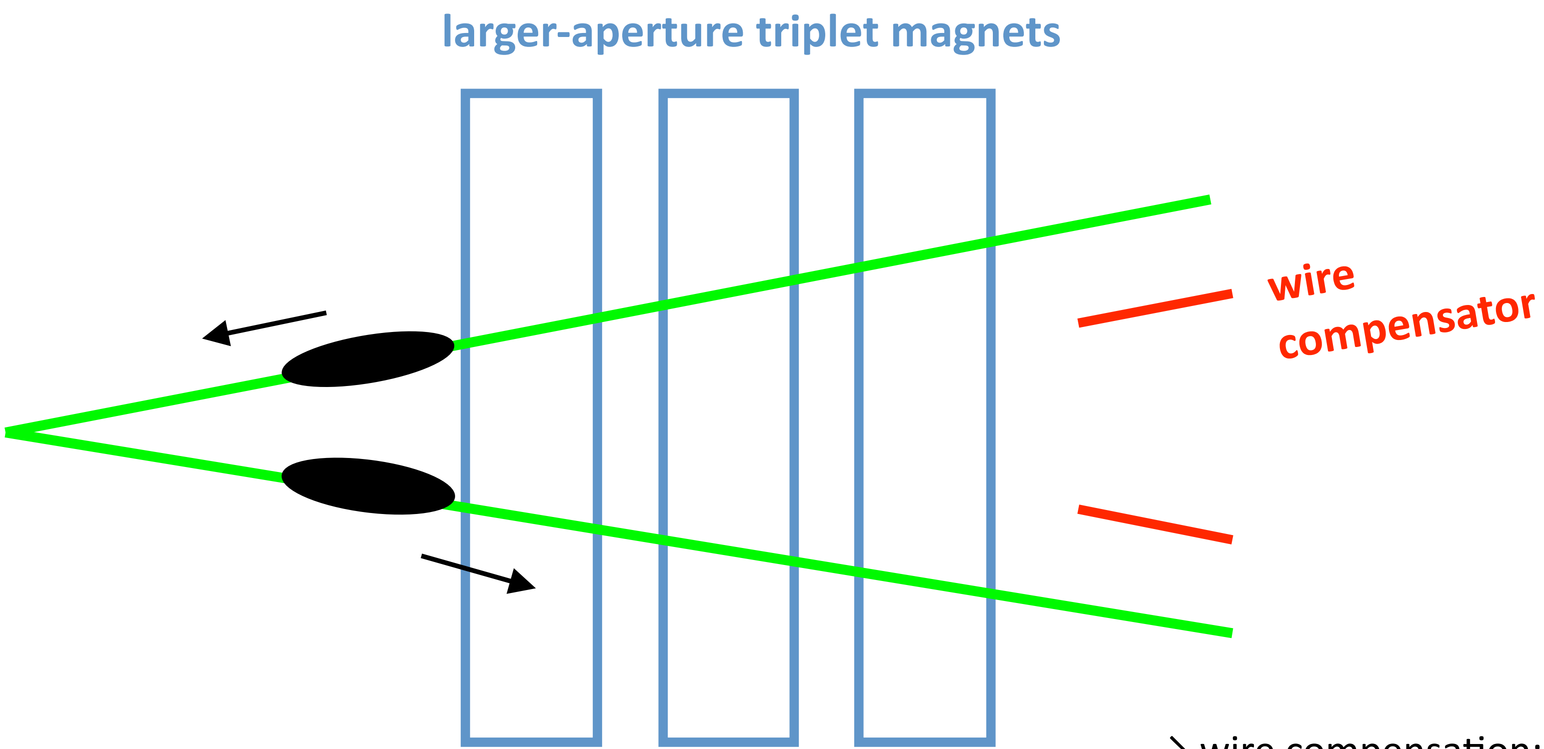
Large Piwinski Angle (LPA) Scenario

- double bunch spacing (50 ns)
- longer & more intense bunches 4.9×10^{11} protons/bunch with large crossing angle
- Go for b*~25 cm (achieved by larger-aperture low-β quads)
- no additional any elements inside detectors
- long-range beam-beam interaction : charged wire compensation

→ novel operating regime for hadron colliders

$$L \propto f_{rev} n_b N_b \frac{1}{\beta^*}$$

Interaction Region Layout for the LPA Option



→ wire compensation:
TUPAN091, U. Dorda et al
TUPAS095, W. Fischer et al

long bunches & nonzero crossing angle & wire compensation

The Early Separation (ES) Scenario

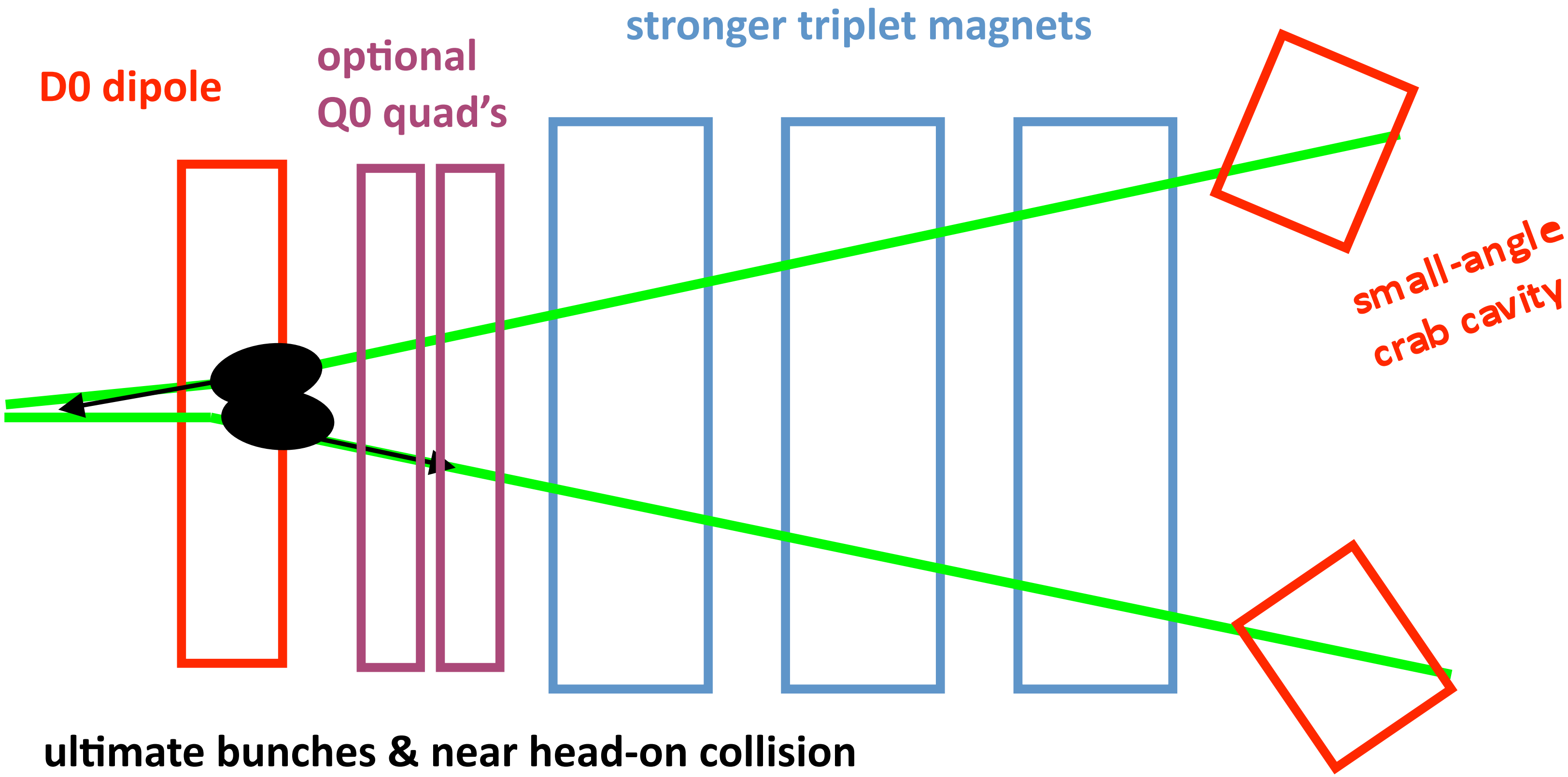
- Keep "ultimate" LHC beam : 1.7×10^{11} protons/bunch, 25 ns spacing
- Squeeze β^* to ~ 8 cm in ATLAS & CMS
- add early-separation dipoles in detectors starting at ~ 3 m from interaction point
- possibly also add quadrupole-doublet inside detector at ~13 m from interaction point
- add "crab cavities" for 0 crossing angle

→ new hardware inside ATLAS & CMS detectors, first hadron-beam crab cavities

$$L \propto f_{rev} n_b N_b \frac{1}{\beta^*}$$

Interaction Region Layout for the ES Option

→ ES scheme: THPAN072,
E. Todesco, J.-P. Koutchouk et al



ultimate bunches & near head-on collision

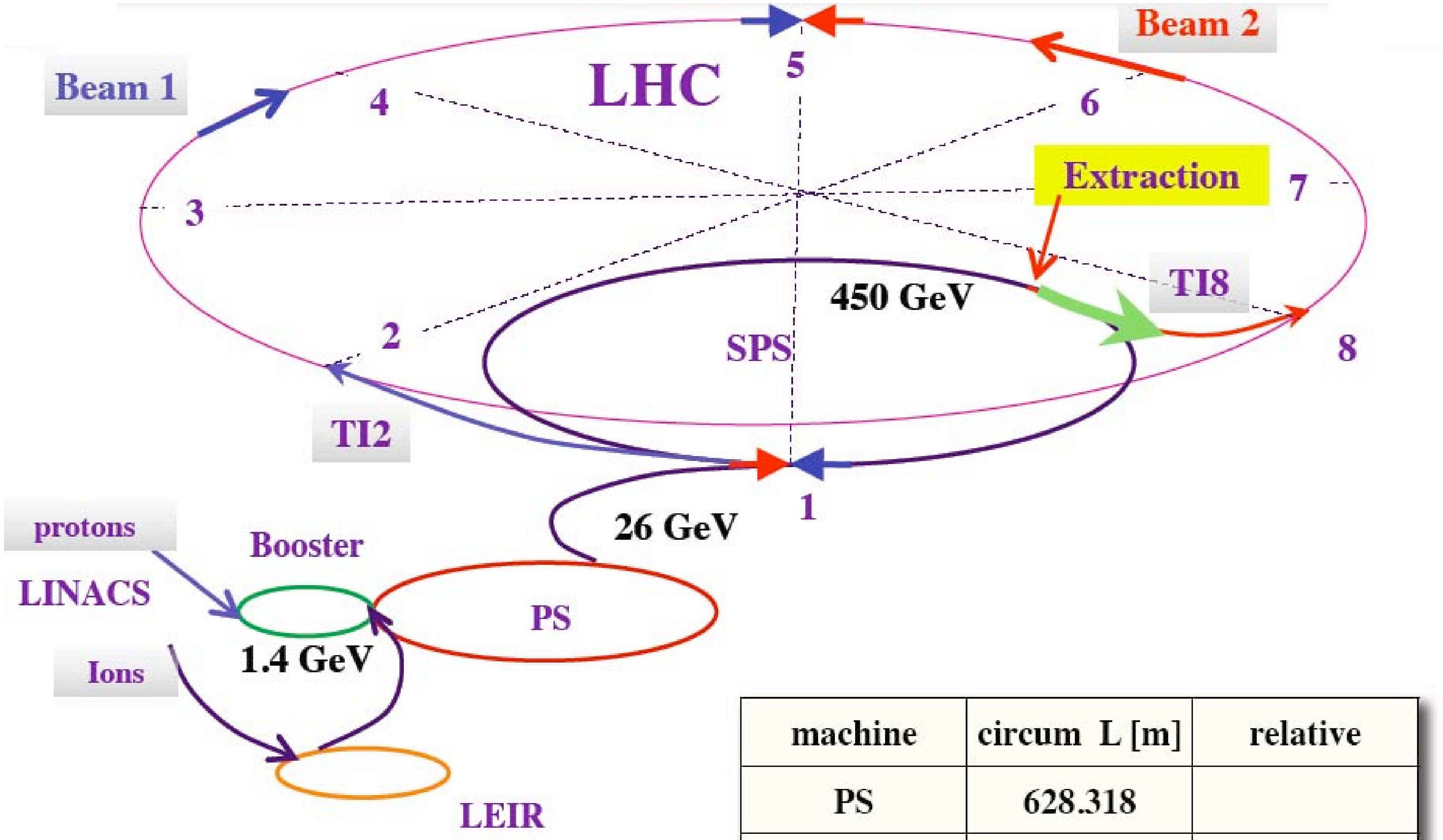
sLHC Upgrade Scenarios – Summary and Comparison

Parameters	LHC		SLHC	
	Nominal	Ultimate	LPA	ES
Bunch spacing [ns]	25	25	50	25
Proton/bunch Nb[10^{11}]	1.15	1.7	4.9	1.7
β* at IP1&5 [m]	0.55	0.5	0.25	0.08
Longitudinal profile	Gaussian	Gaussian	Flat	Gaussian
rms bunch length σ_z[cm]	7.55	7.55	11.8	7.55
Full crossing Angle at IP	285 µrad	315 µrad	381 µrad	0
Peak luminosity [10^{34} $cm^{-2}s^{-1}$]	1	2.3	10.7	15.5
Effective luminosity (5h) [10^{34} $cm^{-2}s^{-1}$]	0.56	1.15	3.5	3.6
Peak events per crossing	19	44	403	294
New Technology			Wire comp.	Crab + D0 (+ Q0)

LPA : less demanding, less obstrusive to detectors

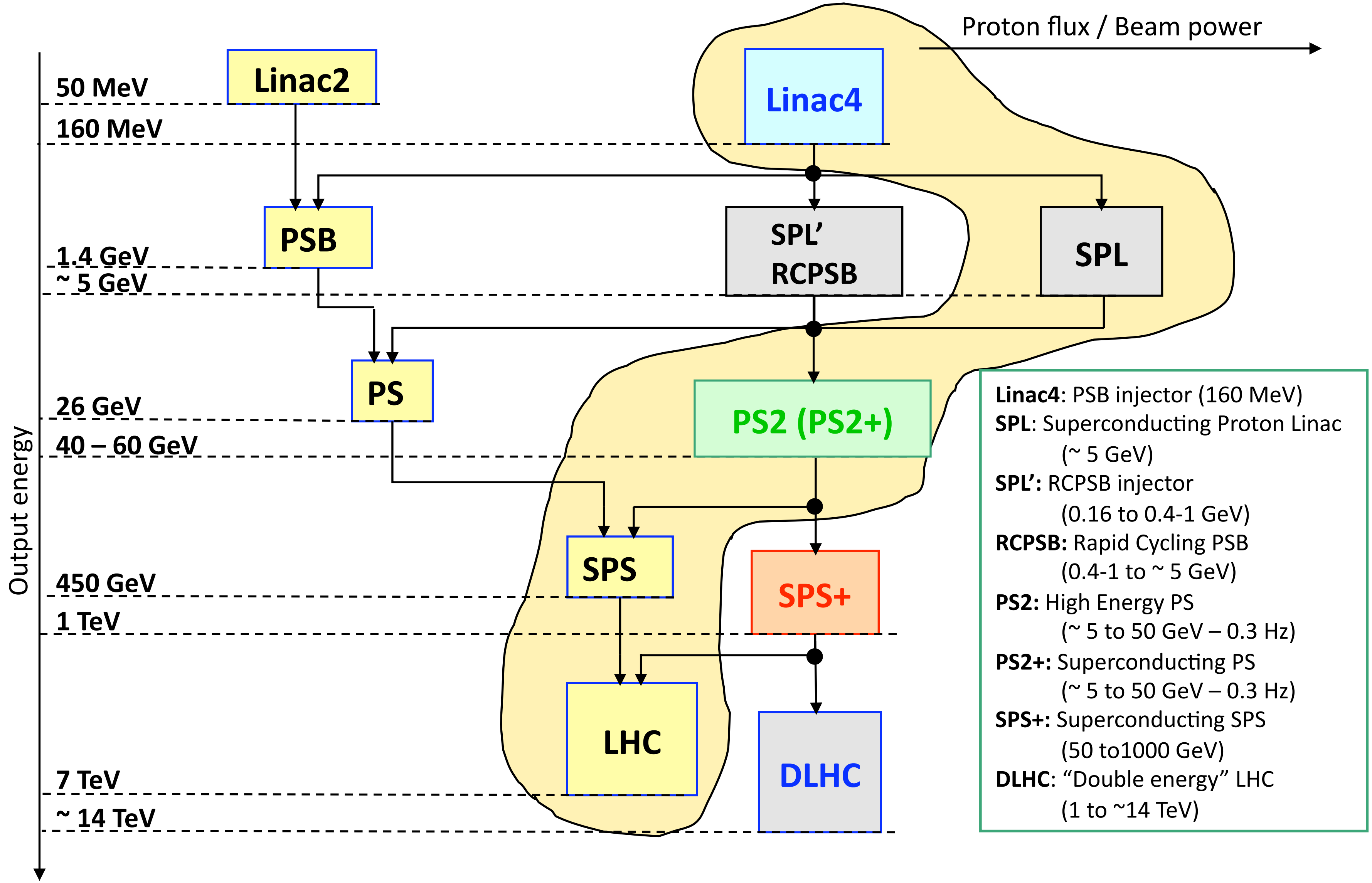
ES : new technology (crab cavities at hadron collider), obstrusive to detectors

Todays LHC Injector Chain



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

Injector Chain Upgrade Scenarios

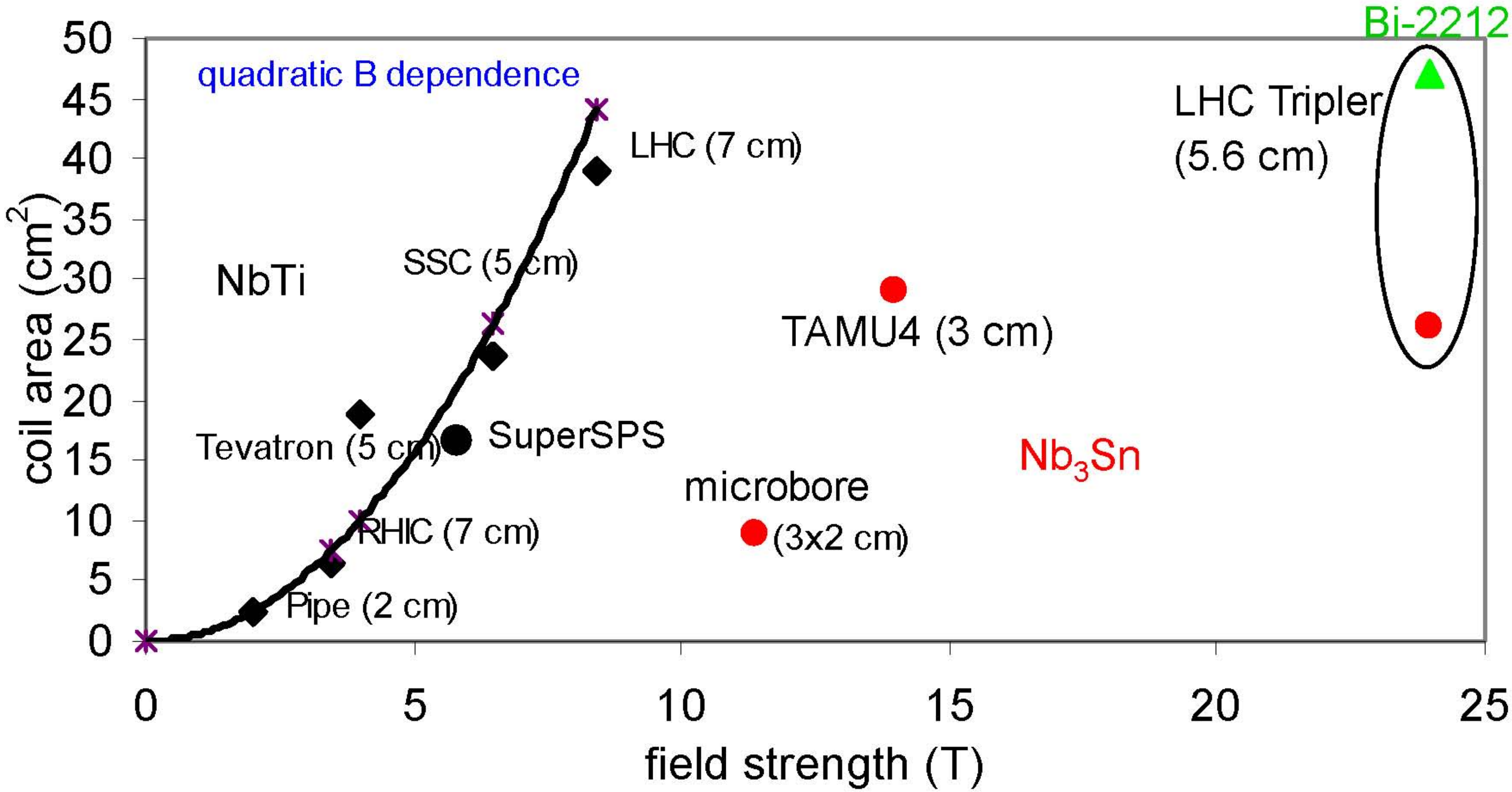


M. Benedikt, R. Garoby, CERN DG

dLHC with 100 fb^{-1} – Worth the Effort ?

Process	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	DLHC 28 TeV 100 fb^{-1}
Squarks (TeV)	2.5	3	4
$W_L W_L$ (σ)	2	4	4.5
Z′ (TeV)	5	6	8
Extra-dimens. scale (TeV)	9	12	15
q^* (TeV)	6.5	7.5	9.5
Compositeness scale (TeV)	30	40	40
TGC, λ_γ (95%CL)	0.0014	0.0006	0.0008

Most ambitious – The "LHC Tripler"



Outline

- The LHC
- Upgrading the LHC : Why and When ?
- Upgrading the LHC : How ?
- Upgrading the LHC : Consequences for Detectors

Changes arising from the LHC Upgrade

- Cope with direct consequences of machine upgrade (magnets in IR, new bunch structure)

- Cope with radiation related consequences (tracker survival, forward calorimeters)

- Cope with physics related consequences (multiple interactions, trigger, data volume)

- Improve aspects which may not have been perfect in the first place (e.g. material budget)

Subdetector Activitities (generic overview)

Trackers

Performance optimisation : occupancies, tracking performance, material budget
Radiation issues . use n-in-n or n-in-p sensors, new technologies for inner layers : 3D silicon or Diamond
Readout electronics
Link technologies . optical, control concept
Support structures . modules, staves
Technicalities . cables, cooling, powering

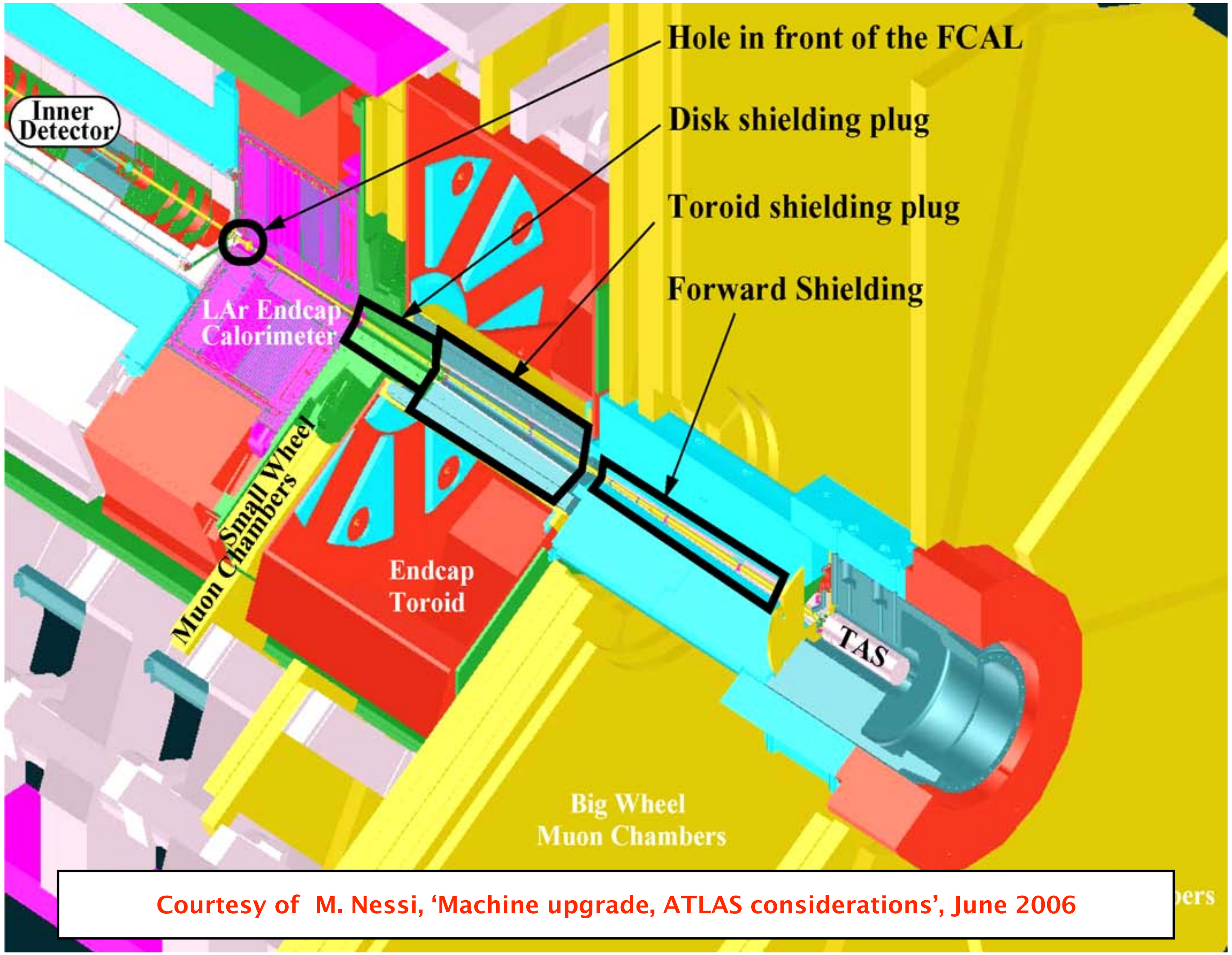
Calorimeters

Major central components to be kept, mostly electronics upgrade, integration with trigger, replacement of forward calorimeters

Muon Spectrometers

Physics muon rates are small, punch through and sneak trough rates to be studied with real data

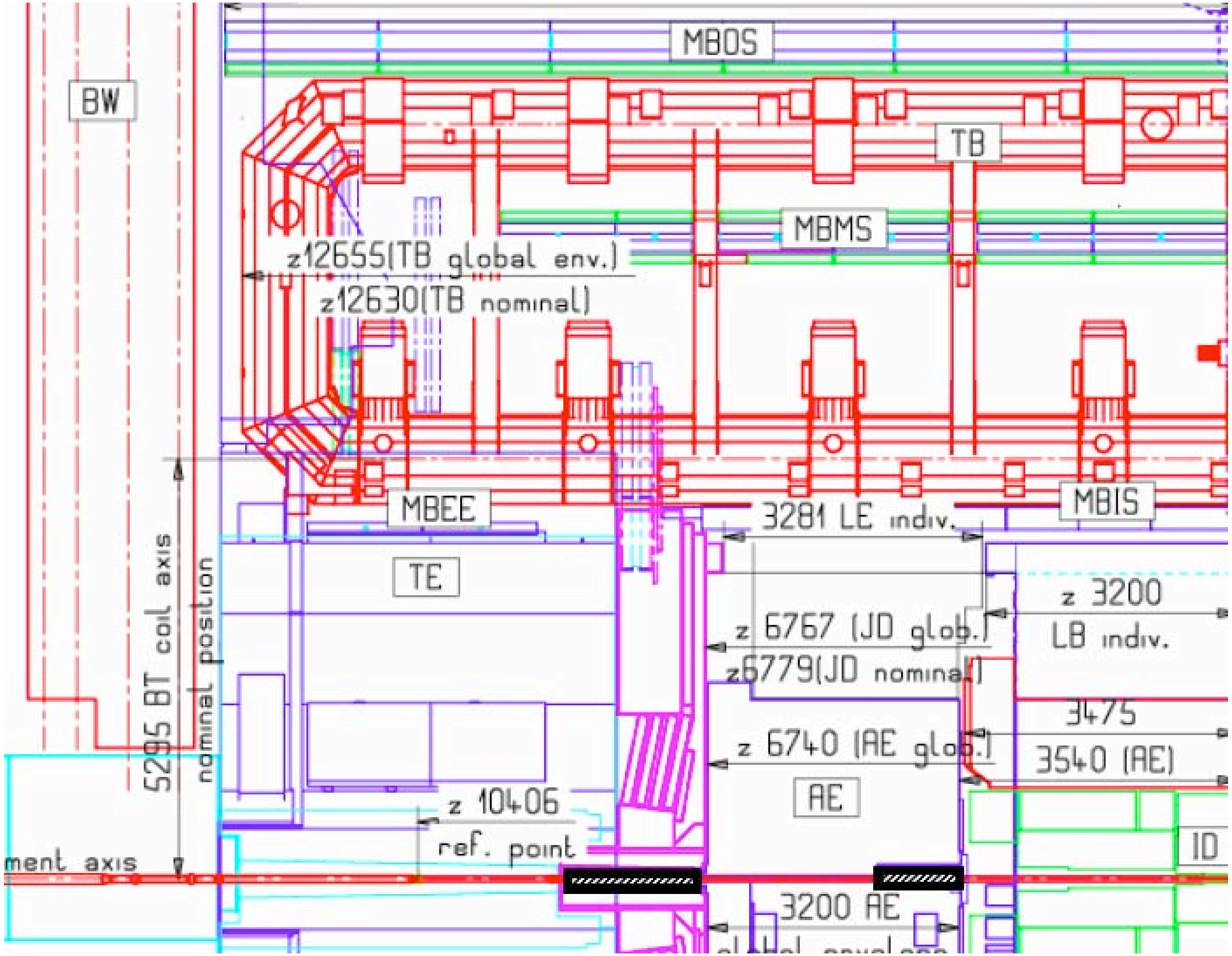
ES Scenario Consequences for ATLAS



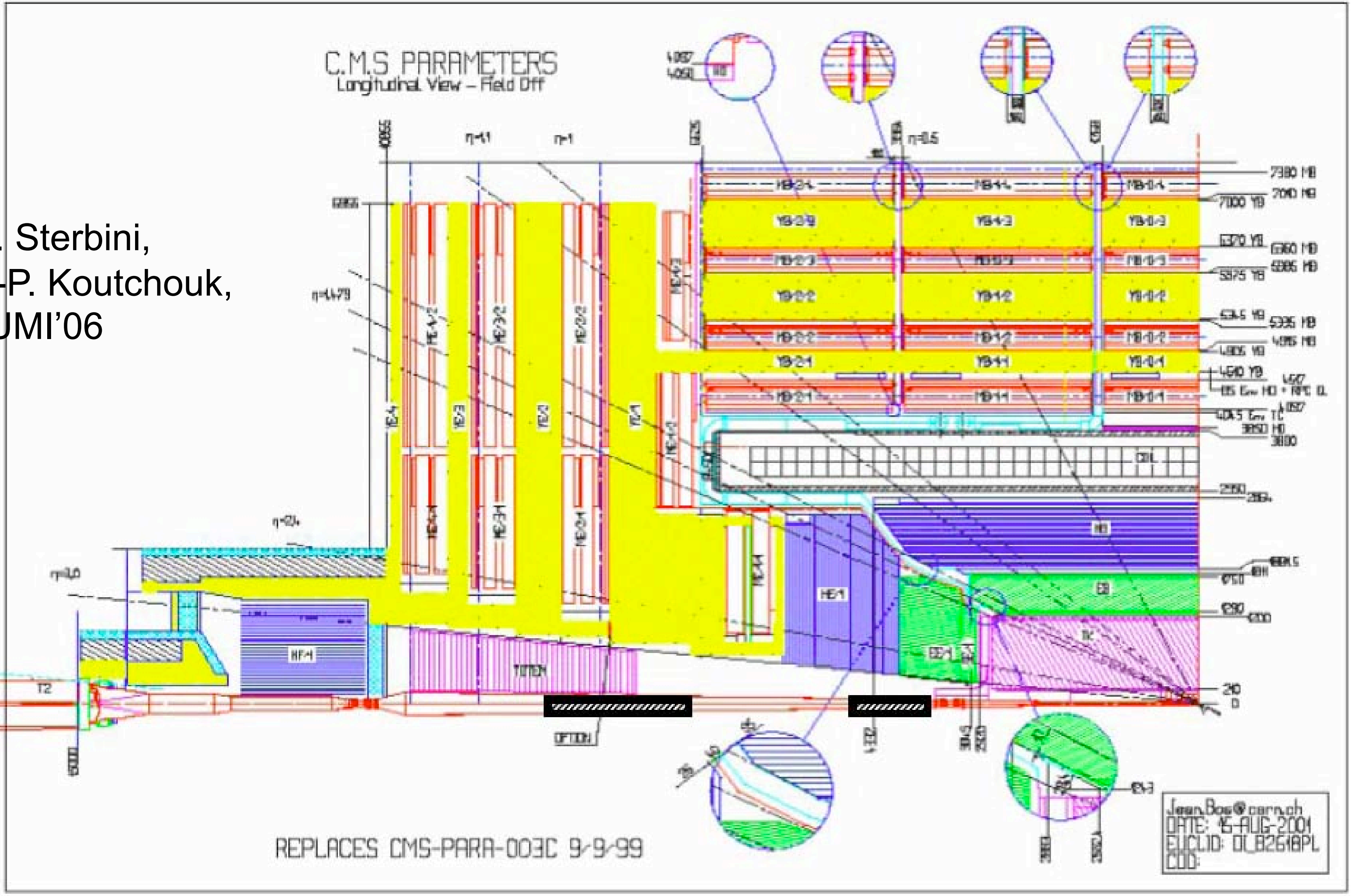
Courtesy of M. Nessi, 'Machine upgrade, ATLAS considerations', June 2006

G. Sterbini,
J.-P. Koutchouk,
LUMI'06

ES Scenario Consequences for ATLAS (cont'd)

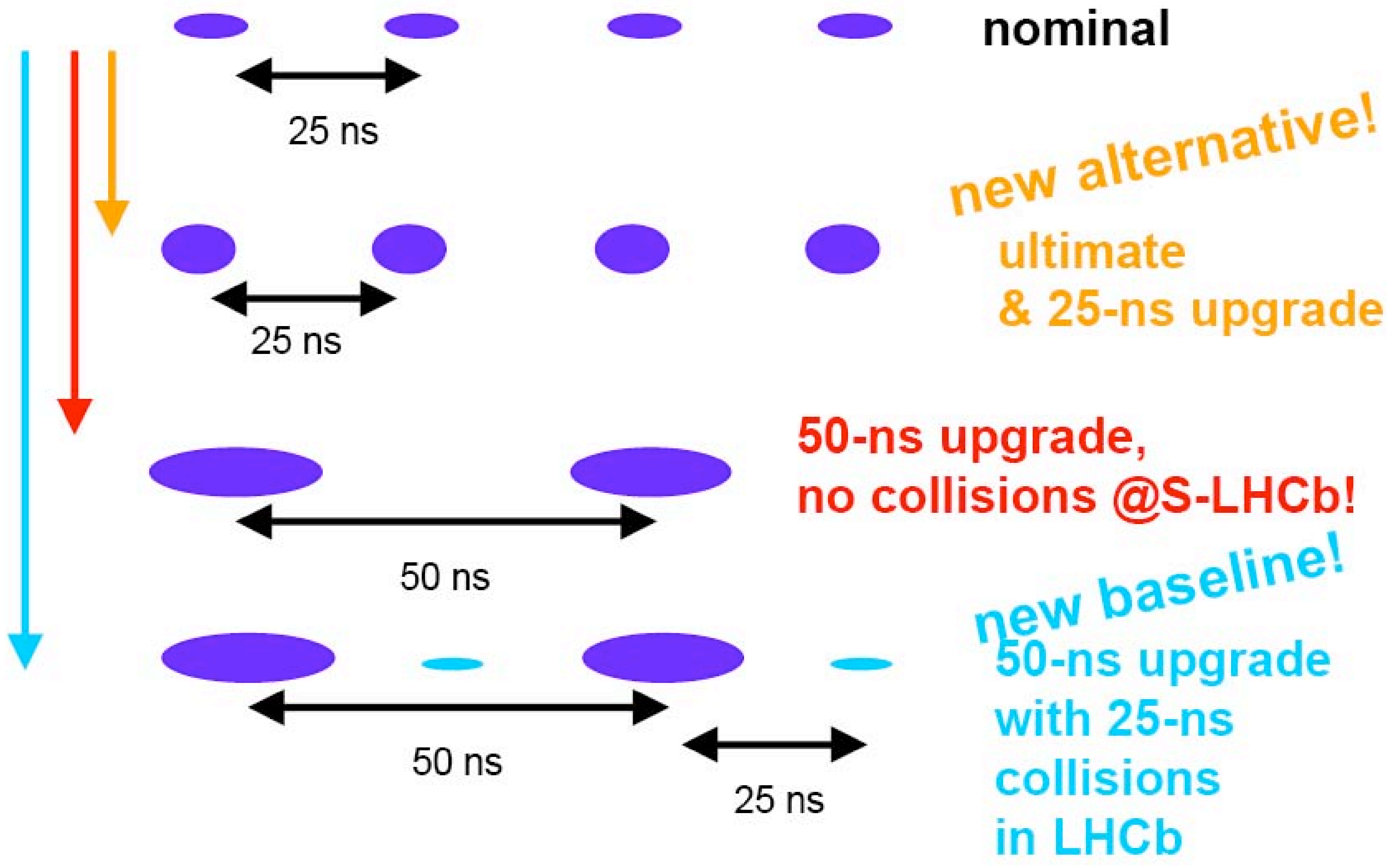


ES Scenario Consequences for CMS

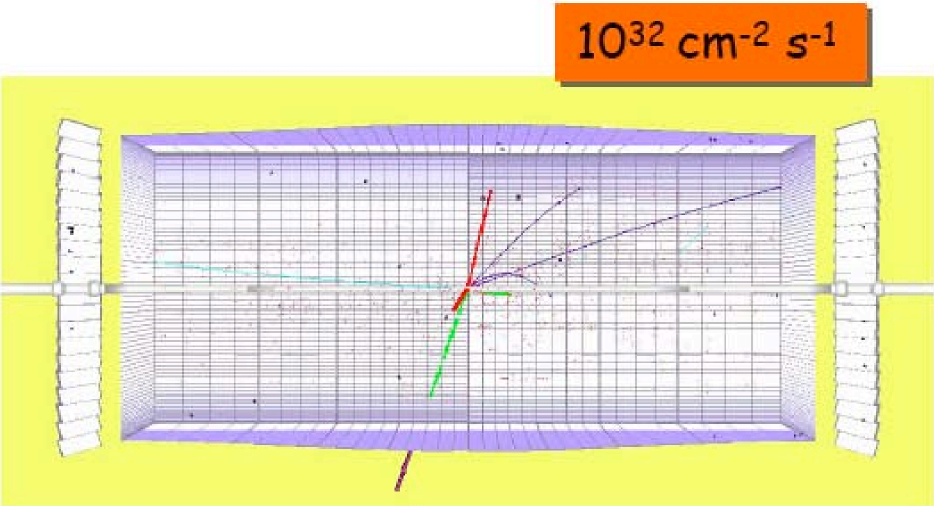


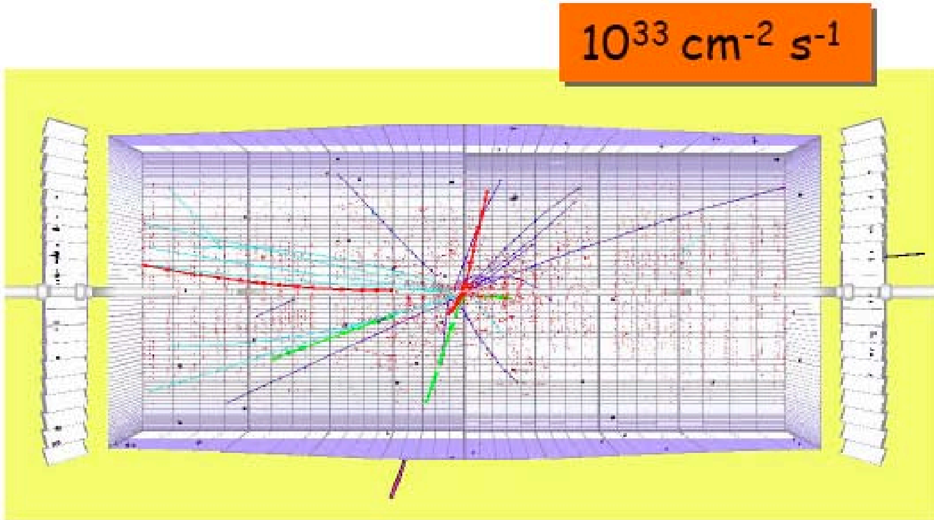
G. Sterbini,
J.-P. Koutchouk,
LUMI'06

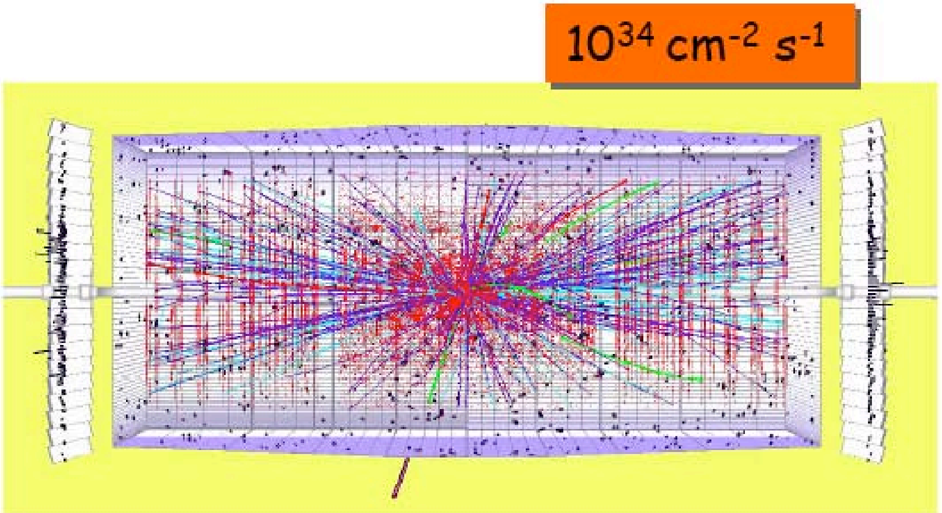
Bunch Structure for the 2 Scenarios – LHC-b Operation

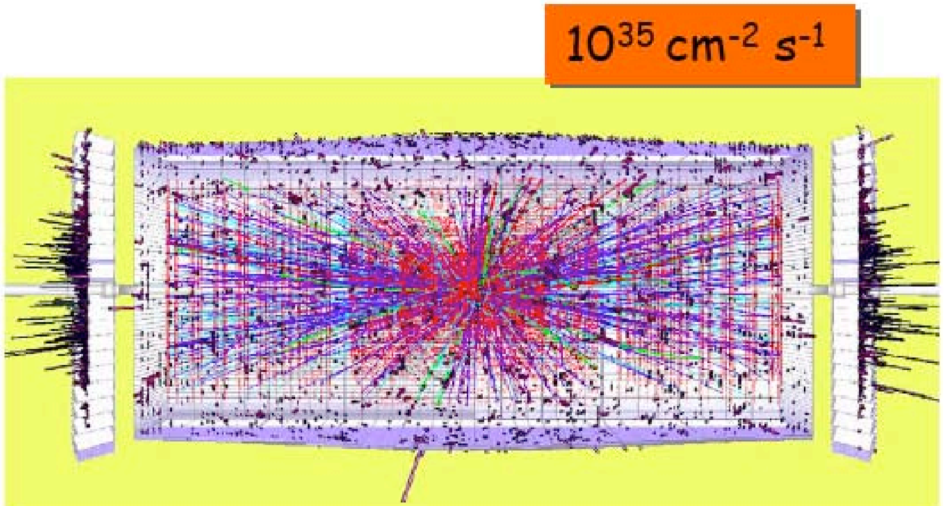


Multiple Inelastic pp-Collisions (CMS Example)

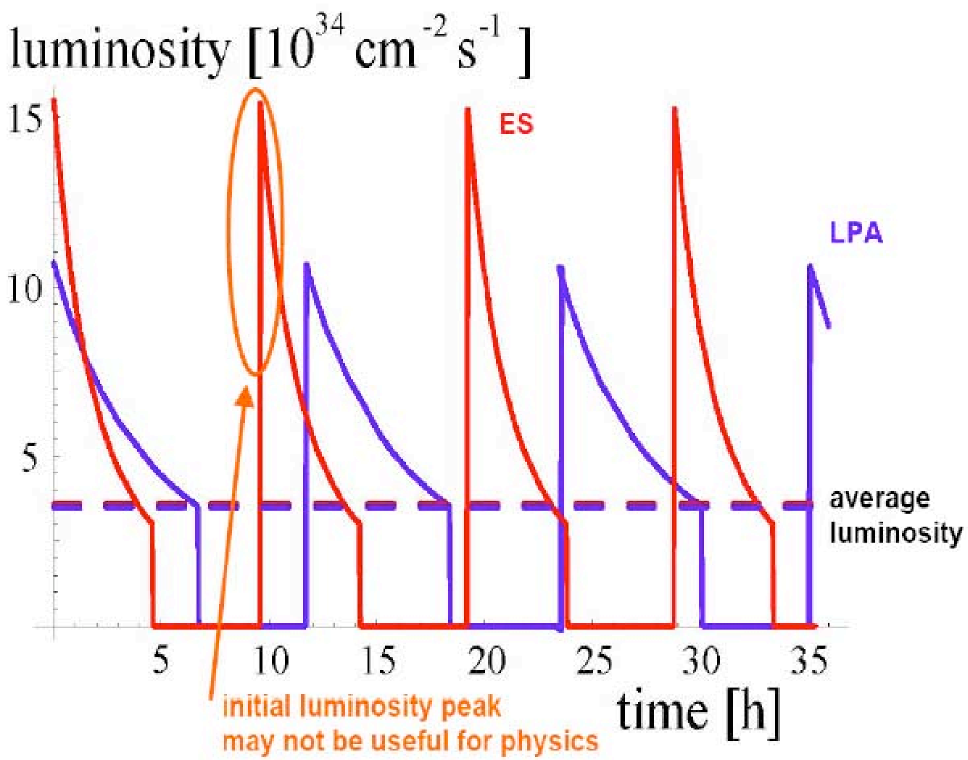


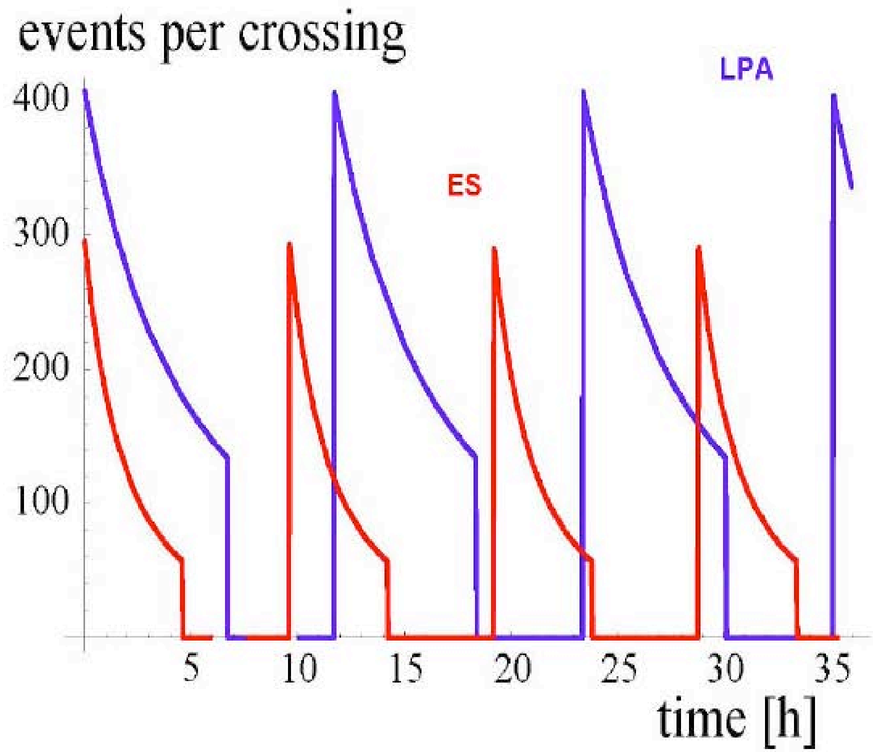






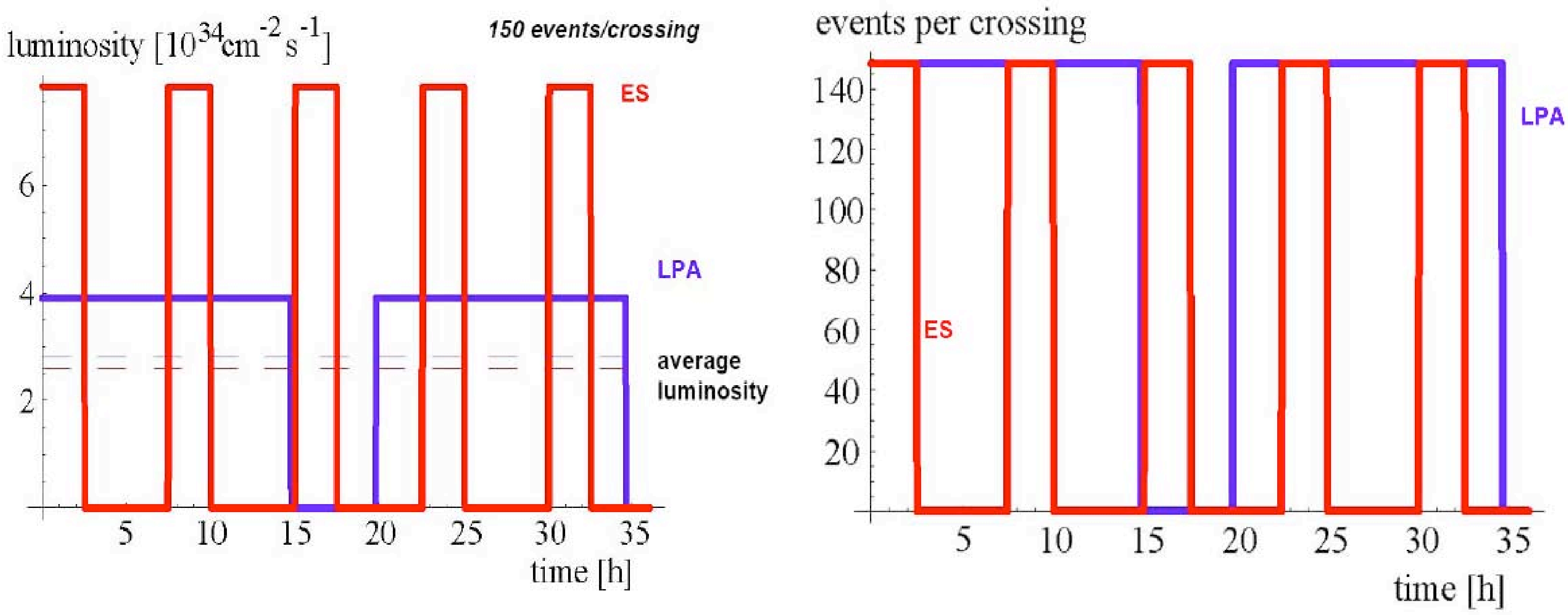
Running the sLHC – L(t) and Multiple Collisions





$$\frac{events}{x-ing} = \frac{L}{n_b}\frac{\sigma_{bb}}{f_{rev}}$$

New Idea – Luminosity Levelling



dynamic machine parameters, e.g. $\beta^* = \beta^*(t)$

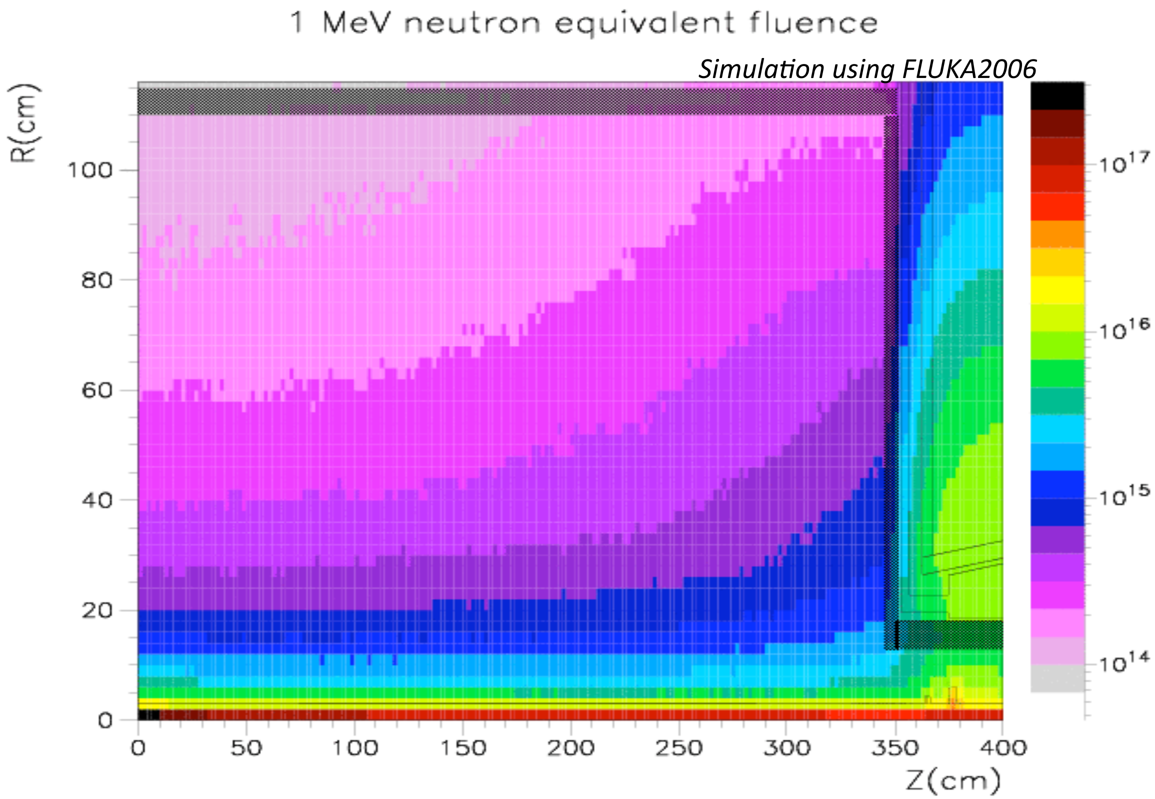
Radiation Background in ATLAS at SLHC (Ferrere (U Geneva))

- With safety factor of two, design short microstrip layers to withstand $10^{15} n_{eq}/cm^2$ (50% neutrons)
- Outer layers up to $4 \times 10^{14} n_{eq}/cm^2$ (and mostly neutrons)

Thermal management and shot noise. Silicon looks to need to be at ~ -25°C (Thermal runaway).

Si power: 1W @ -20°C
4W @ -10°C
10W @ 0°C

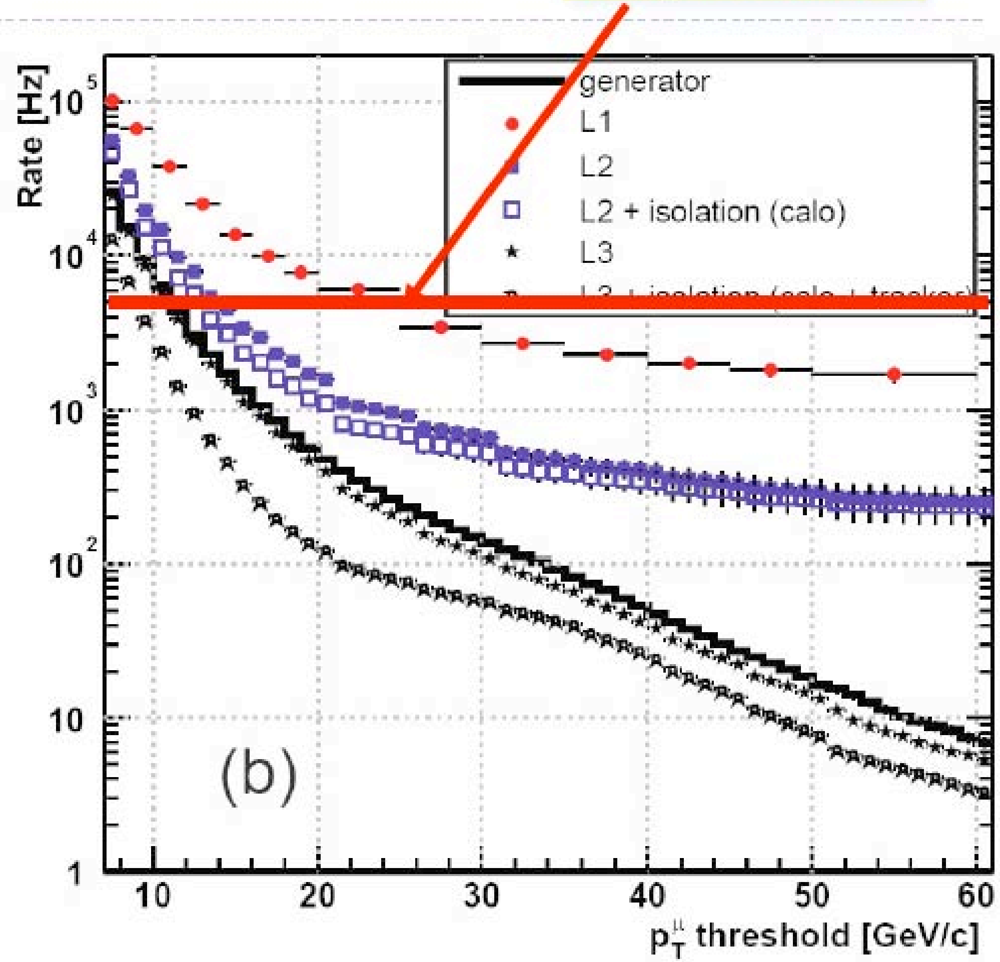
→ High levels of activation will require careful consideration for access and maintenance.



1 MeV equivalent neutron fluences assuming an integrated luminosity of 3000 fb^{-1} and 5 cm of moderator lining the calorimeters (reduces fluences by ~25%)

The case for more intelligent Triggers (CMS Example)

Level 1 Trigger has no discrimination for $P_T > \sim 20$ GeV/c



Level-1 Trigger looses selectivity for high transverse moemntum electrons (> 20 GeV),

Challenge : Involve tracker in the 2 µs Level-1 decision

J. Nash, CMS Trigger Upgrade Meeting 2008

Conclusions

Finish the LHC

then **Study the LHC**

then **Take Decisions**

BUT : Prepare yourself well by serious R+D NOW because building accelerators and detectors and making them operational takes a lot of time !