LHC upgrade scenarios: machine, detectors and physics

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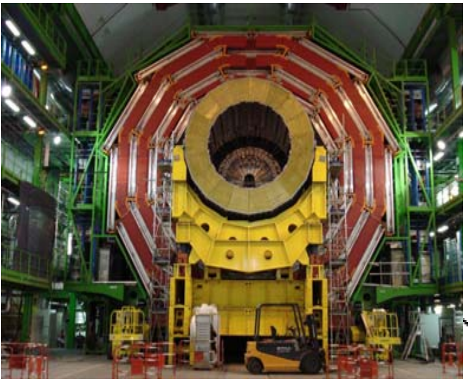
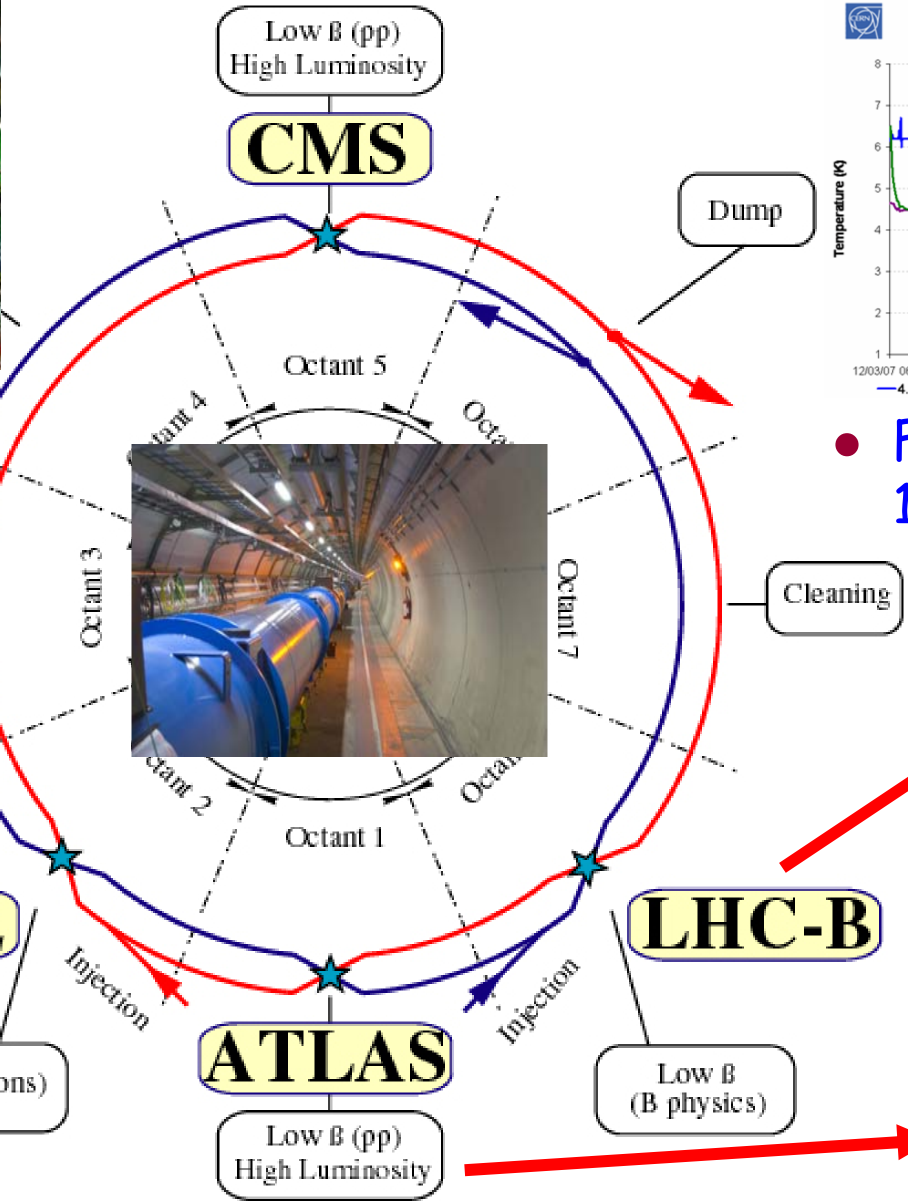
ECFA plenary session

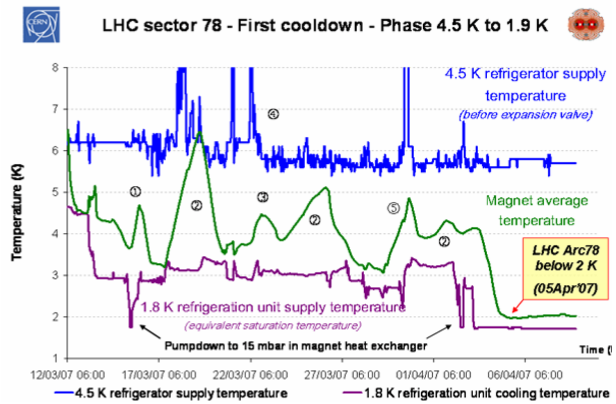
July 21st 2007, Manchester

- Physics motivation
- Machine upgrade
- Detector upgrades

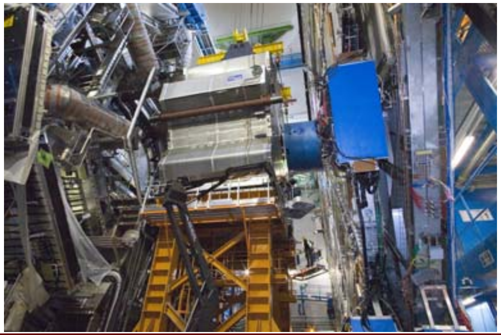
Closing in towards reality …







- First pp collisions at 14 TeV summer 2008



… why going virtual again? *

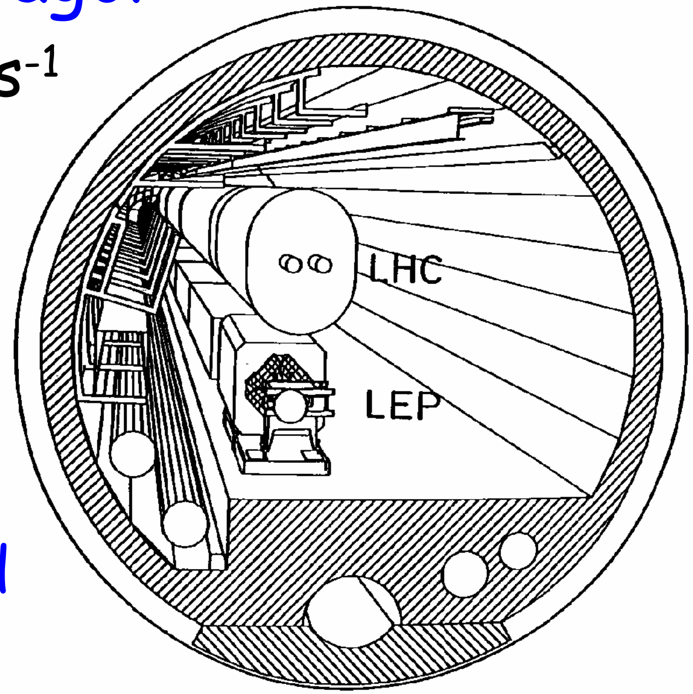
* Completion and exploitation of design LHC has highest priority !!

A short comment on timescales

- LHC: first appeared ~ 23 years ago!
  - → $\sqrt{s}$ = 10-18 TeV, L = 10^{31}-10^{33} $cm^{-2}s^{-1}$
- Construction started in 1998
- First collisions in 2008

1984

ECFA 84/85
CERN 84-10
5 September 1984



LARGE HADRON COLLIDER
IN THE LEP TUNNEL

Vol. I

PROCEEDINGS OF THE ECFA-CERN WORKSHOP

held at Lausanne and Geneva,
21-27 March 1984

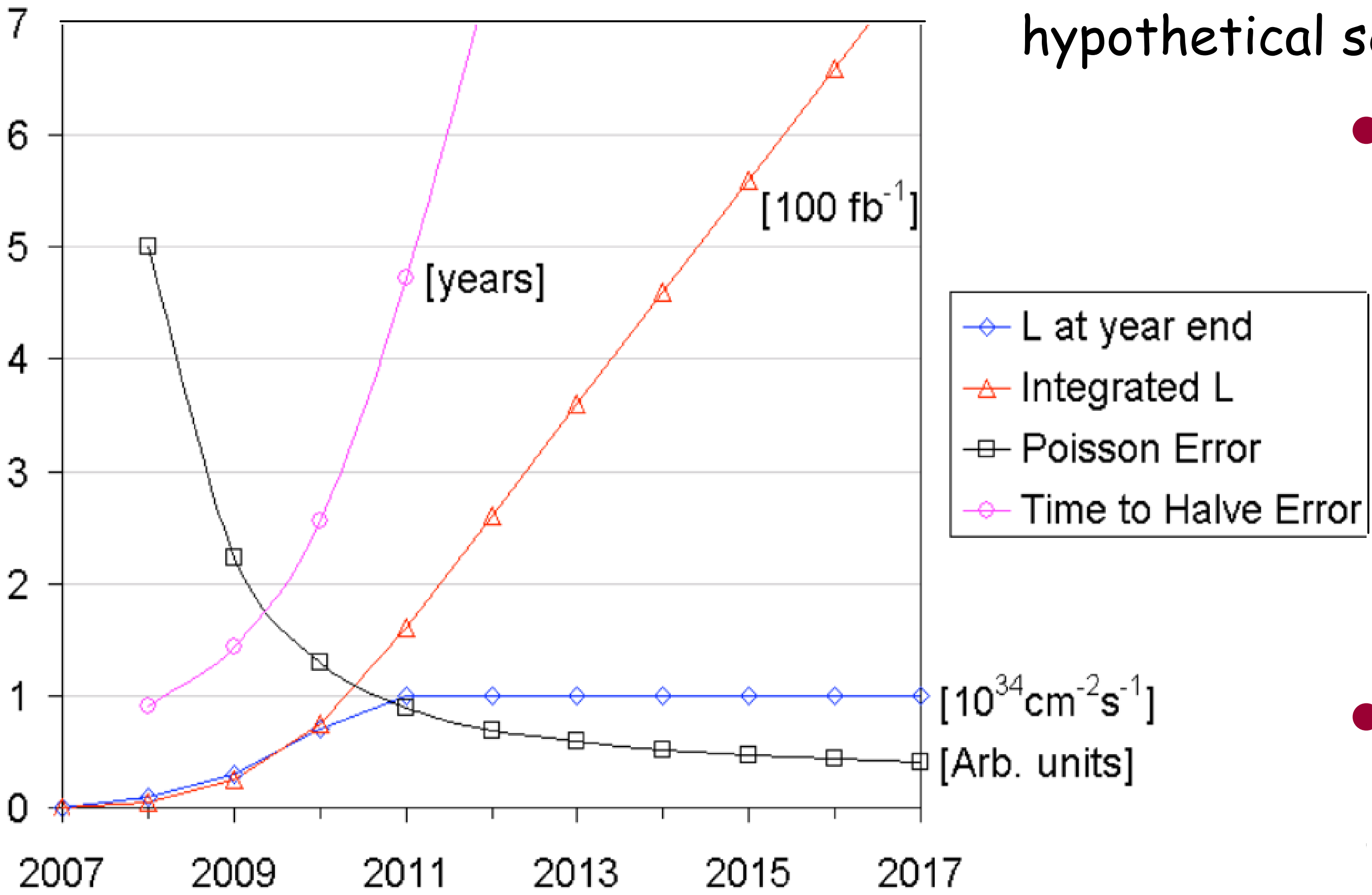
CERN: 50 YEARS AND COUNTING

The life of an experiment

1984	Workshop in Lausanne on installing a Large Hadron Collider (LHC) in the LEP tunnel
1987	CERN's long-range planning committee chaired by Carlo Rubbia recommends LHC as the right choice for lab's future
1989	ECFA Study Week on instrumentation technology for a high-luminosity hadron collider; Barcelona; LEP collider starts operation
1990	ECFA LHC workshop, Aachen
1992	General meeting on LHC physics and detectors, Evian-les-Bains
1993	Letters of intent for LHC detectors submitted
1994	Technical proposals for ATLAS and CMS approved/LHC
1998	Construction begins
2000	CMS assembly begins above ground; LEP collider closes
2003	ATLAS underground cavern completed and assembly started
2004	CMS cavern completed
2007	Experiments ready for beam
2007	First proton–proton collisions
2008	First results
2010	Reach design luminosity
>2014	Upgrade LHC luminosity by factor of 10

- HEP projects have long lead time
  - → R&D phase
  - → construction
  - → installation
  - → commissioning
  - → exploitation

When to upgrade?



hypothetical scenario (J. Strait)

- reduction of stat. errors by simply accumulating luminosity
  → long time – if lumi/year ≈ const.
- radiation limit of about 700 fb^{-1} for quadrupoles

- upgrade around 2015(+n) seems appropriate

Physics motivation

Physics motivation

- LHC has a huge physics potential
  - new physics expected at the TeV scale
  - → find the missing piece of the SM (Higgs boson)
  - → find new forces/particles beyond the SM
  - → improvements/indications via precision measurements
- prepare further extensions of physics program
  - → extend reach for discoveries
    - access to larger mass scales and/or to rare processes
  - → statistically limited precision measurements
- physics aims of upgrade will be a 'moving target'
  - → to be influenced by first LHC results

Physics motivation (cont'd)

- extension of physics reach via
  - → increase in luminosity (for fixed $\sqrt{s}$)
  - → increase in $\sqrt{s}$ (for fixed luminosity)
  - → increase in luminosity and $\sqrt{s}$
- following selected examples use
  - → luminosity: **10^{34}** vs. **10^{35}** $cm^{-2}\ s^{-1}$
  - → $\sqrt{s}$: **14** vs. **28** vs. **42** TeV
- more details to be found in:

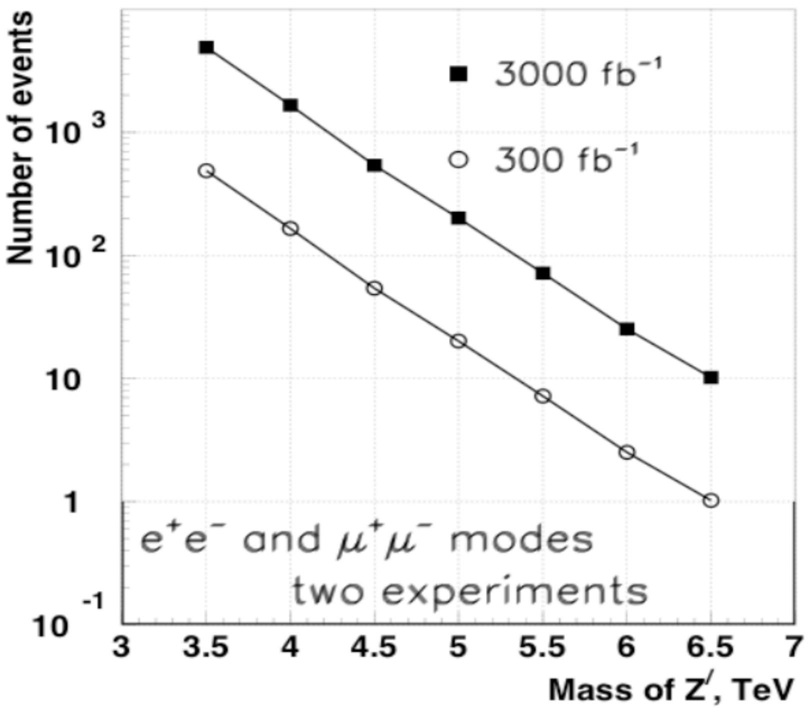
THE EUROPEAN PHYSICAL JOURNAL C

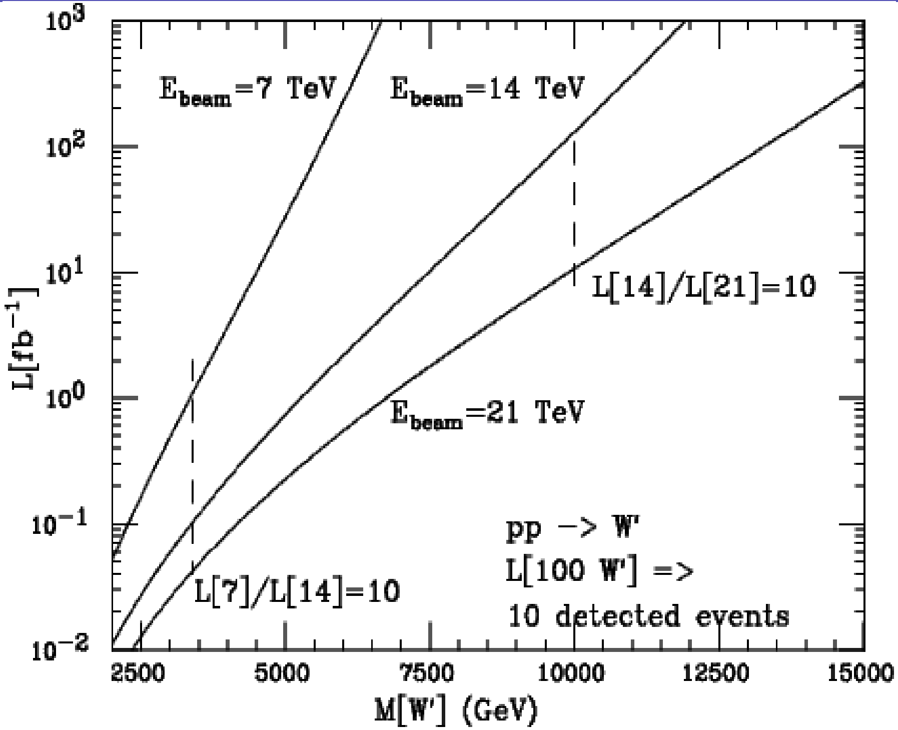
Physics potential and experimental challenges of the LHC luminosity upgrade

Conveners: F. Gianotti[1], M.L. Mangano[2], T. Virdee[1,3]

Eur. Phys. J. C39 (2005), 293

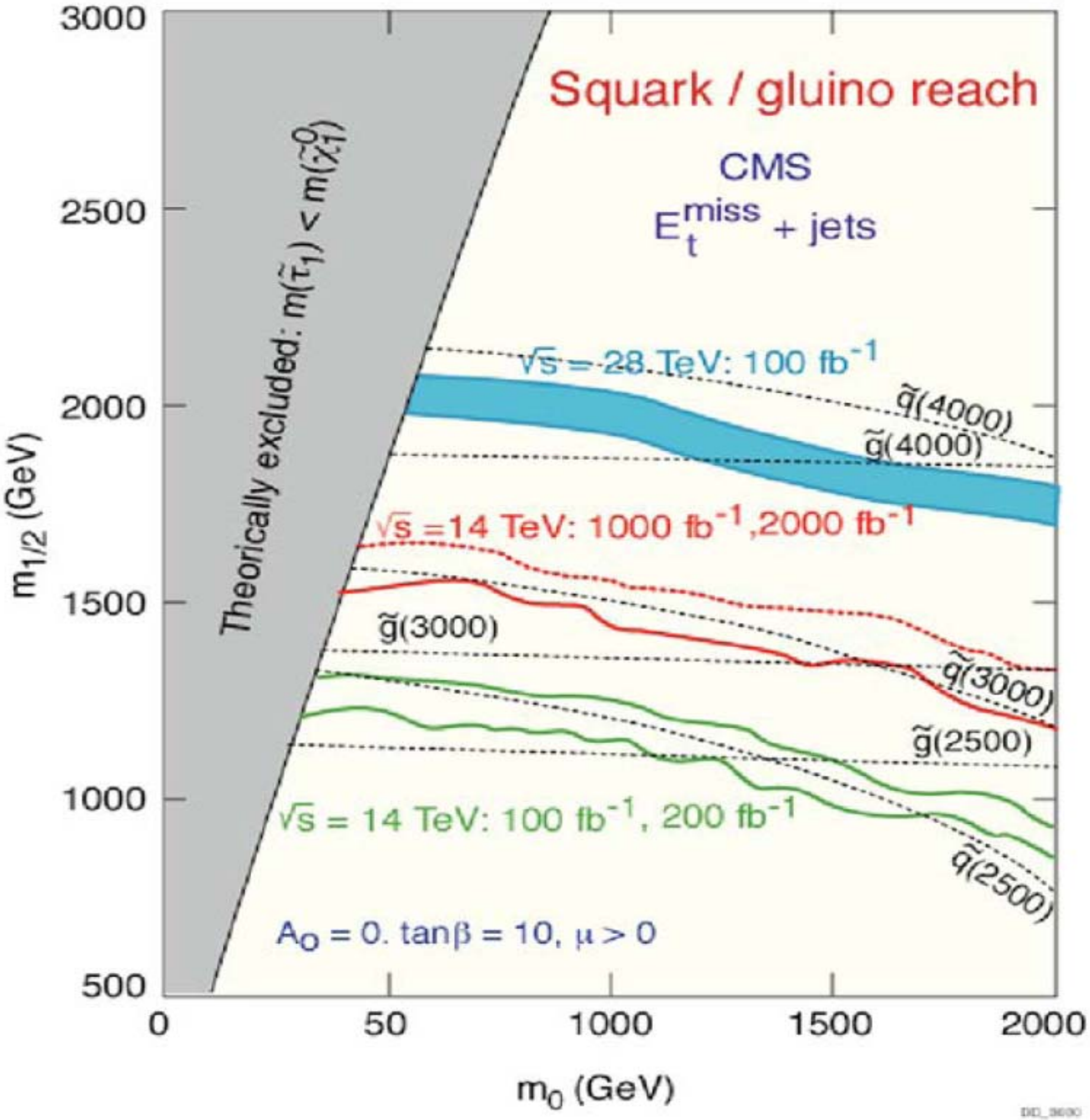
Example: new heavy gauge bosons





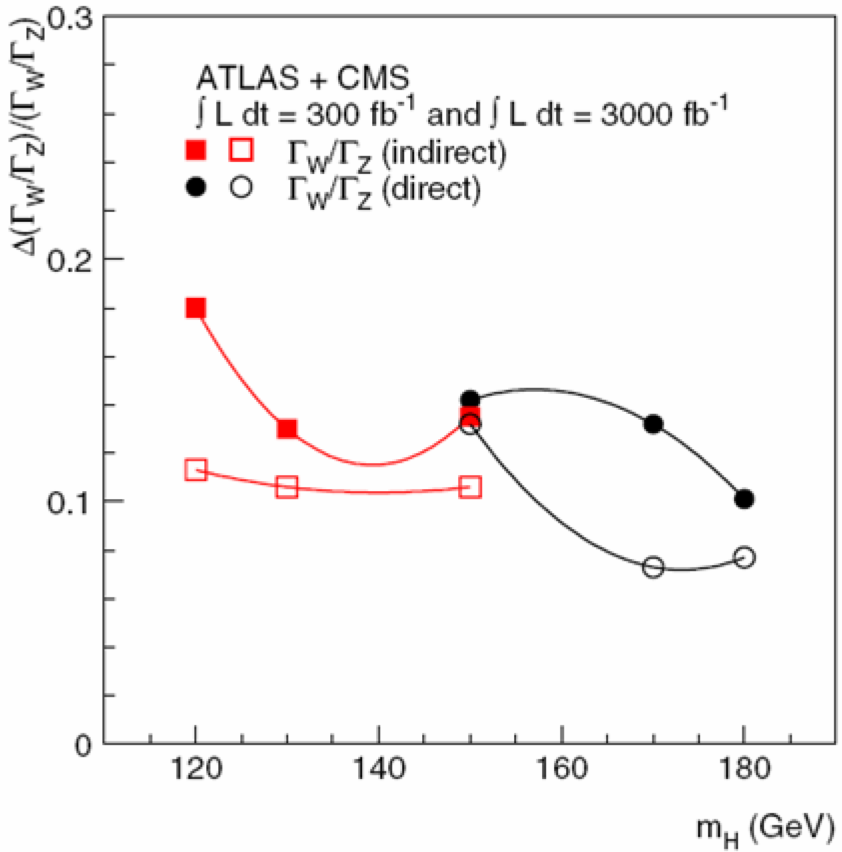
- luminosity increase by factor 10
  - → increase Z' mass reach by ~ 1 TeV
- $\sqrt{s}$ increase gives larger benefit (wrt lumi increase)
  - → increase W' mass reach (while less luminosity needed)

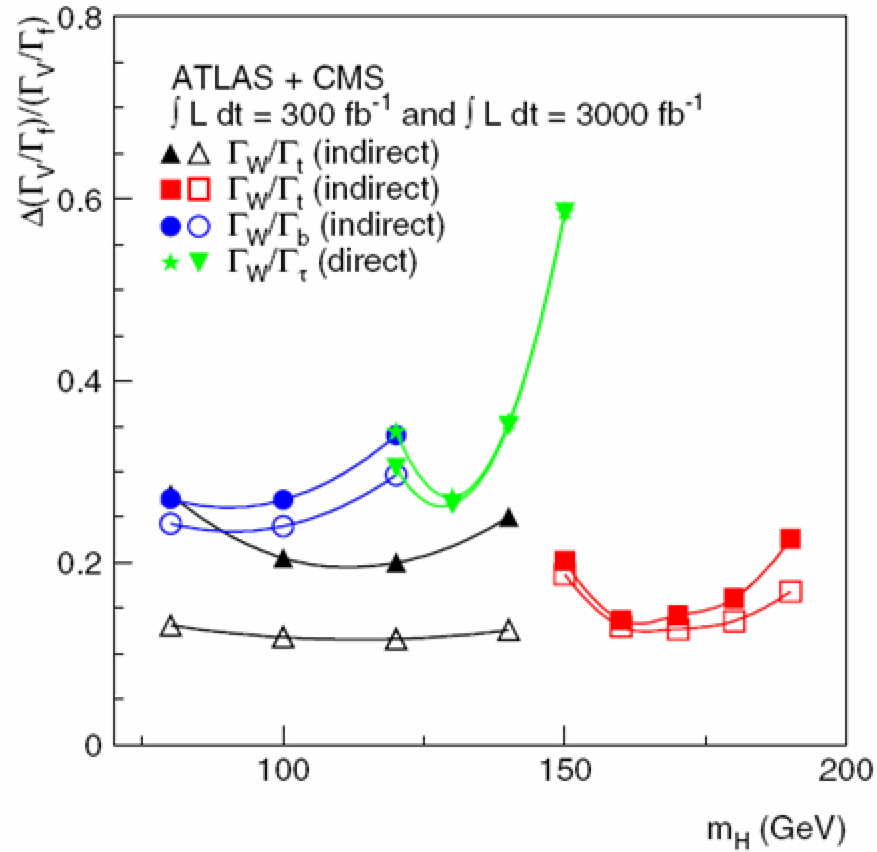
Example: supersymmetry



- within the mSUGRA model
- clear extension of physics reach
  - → as expected, higher √s better then higher L
- to profit from extended reach
  - → need good object ID and reconstruction

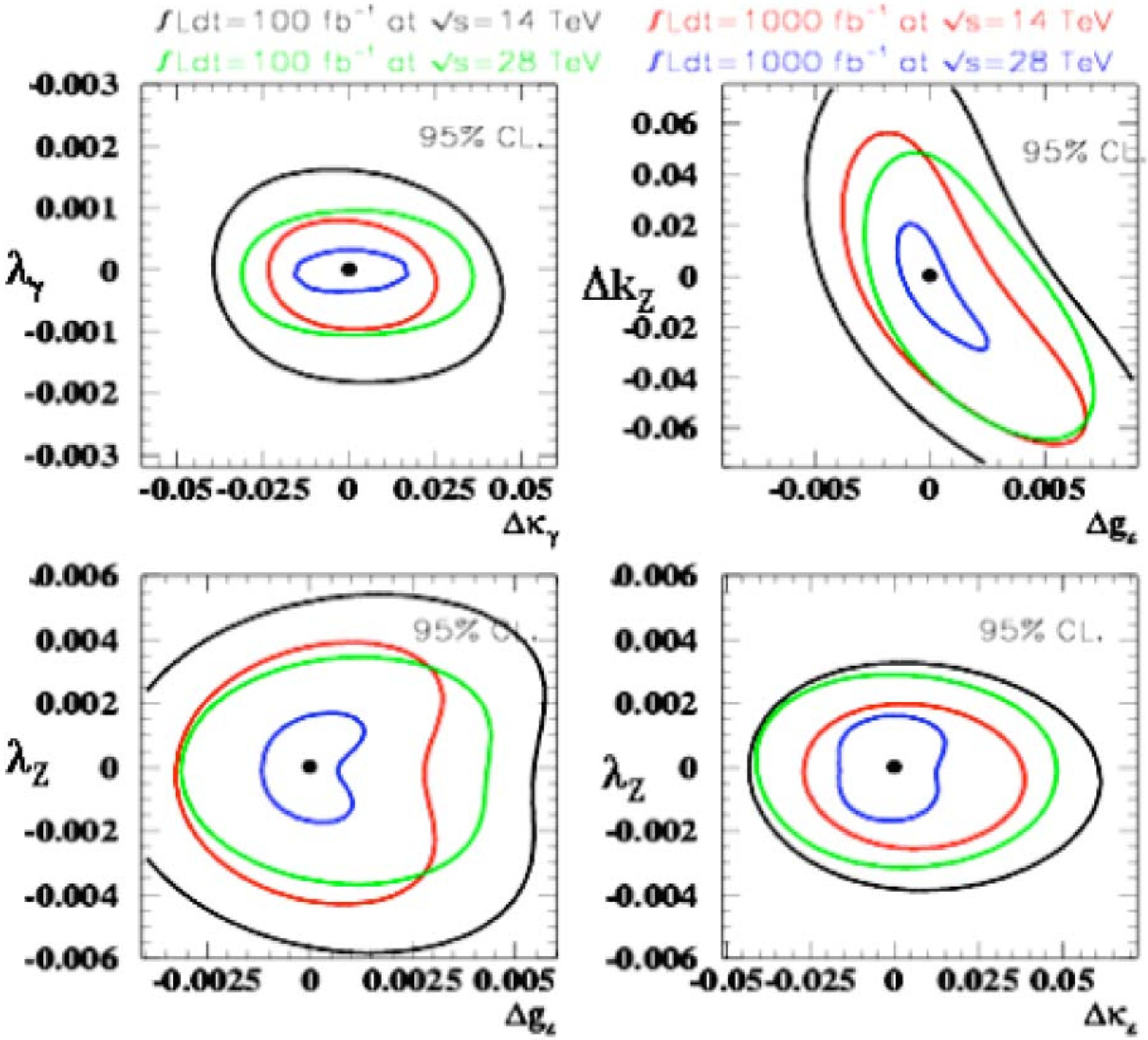
Example: (SM) Higgs boson properties





- improvement on coupling to fermions and bosons
- access to rare decay modes: $H \rightarrow \mu\mu$, $H \rightarrow Z\gamma$
- access to Higgs self-coupling ?

Example: triple gauge boson couplings



- sensitivity to anomalous couplings improves with
  - → higher √s
  - → higher L
  - → higher √s and L
- **SLHC reaches level of ew radiative corrections**

Comparison of extension in reach

Process	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	DLHC 28 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks (TeV)	2.5	3	4	0.4	2.5
$W_L W_L$ (σ)	2	4	4.5	6	90
Z′ (TeV)	5	6	8	$8^{\perp}$	$30^{\perp}$
Extra-dimens. scale (TeV)	9	12	15	$5–8.5^{\perp}$	$30–55^{\perp}$
q^* (TeV)	6.5	7.5	9.5	0.8	5
Compositeness scale (TeV)	30	40	40	100	400
TGC, λ_γ (95%CL)	0.0014	0.0006	0.0008	0.0004	0.00008

$^{\perp}$*Indirect reach from precision measurements*

Summary on physics potential

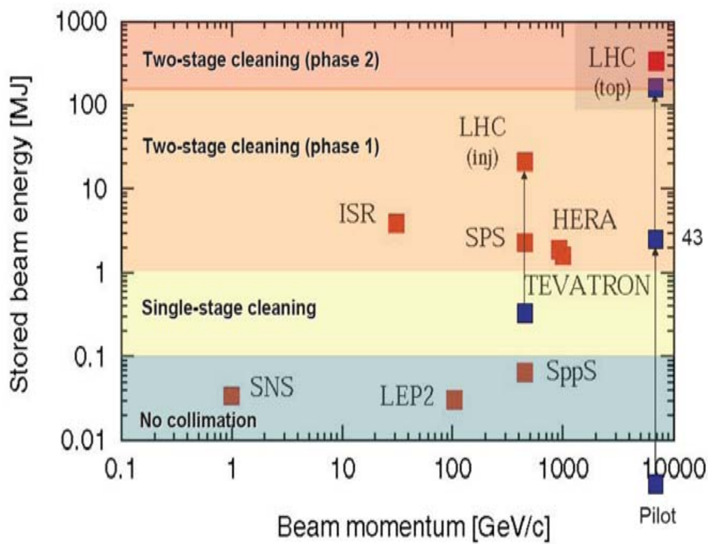
- largest benefits due to increase in $\sqrt{s}$
  - → experimental conditions possibly less challenging
- luminosity increase provides good extension
  - → increased reach in mass scale by 20-30 %
  - → strong requirements on detector performance
    - for (some) discoveries reduced performance tolerable
    - for (precision) measurements, similar performance in high p_T signatures as for present detectors needed
- upgrades of LHCb and ALICE to extend their physics potential being studied as well
  - → see later (time permitting)

Machine upgrade

- Talk in parallel session at EPS
  - O. Brüning, LHC challenges and upgrade options, July 20^{th} 16:00 – ID232

Nominal design LHC parameters

collision energy	E_{cm}	2x7	TeV
dipole peak field	B	8.3	T
injection energy	E_{inj}	450	GeV
protons per bunch	N_b	1.15	10^{11}
bunch spacing	Δt	25	ns
average beam current	I	0.58	A
stored energy per beam		362	MJ
radiated power per beam		3.7	kW
normalized emittance	ε_n	3.75	µm
rms bunch length	σ_z	7.55	cm
beam size at IP1&IP5	σ^*	16.6	µm
beta function at IP1&IP5	β^*	0.55	m
full crossing angle	θ_c	285	µrad
luminosity lifetime	τ_L	15.5	h
peak luminosity	L	10^{34}	$cm^{-2}s^{-1}$
events per bunch crossing		19.2	
integrated luminosity	$\int L\,dt$	66.2	fb^{-1}/year



- unprecedented challenges @ LHC
  - → stored beam energy
  - → synchrotron radiation
  - → large number of superconducting magnets

Upgrade phases

- three phases envisaged
  - → phase 0: stretch performance to the maximum possible ('ultimate')
    - number of protons per bunch to beam-beam limit
      - upgraded injectors
    - collisions at two IP's only
    - (dipole field to 9 T → $\sqrt{s}$ = 15 TeV)
  - → phase 1: sizeable luminosity increase, keep LHC arcs unchanged
    - will concentrate on this phase here
  - → phase 2: major hardware changes
    - upgrade injectors, superconducting SPS (1 TeV)
    - new superconducting dipoles

Large Hadron Collider Project

LHC Project Report 626

(2002)

LHC Luminosity and Energy Upgrade: A Feasibility Study

O. Brüning[§], R. Cappi[‡], R. Garoby[‡], O. Gröbner[†], W. Herr[§], T. Linnecar[§], R. Ostojic[†], K. Potter[*], L. Rossi[†], F. Ruggiero[§] (editor), K. Schindl[‡], G. Stevenson[¶], L. Tavian[†], T. Taylor[†], E. Tsesmelis[*], E. Weisse[§], and F. Zimmermann[§]

LHC parameters: nominal & ultimate

parameter	symbol	nominal	ultimate	12.5 ns, short
transverse emittance	ε [μm]	3.75	3.75	3.75
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7
bunch spacing	Δt [ns]	25	25	12.5
beam current	I [A]	0.58	0.86	1.72
longitudinal profile		Gauss	Gauss	Gauss
rms bunch length	σ_z [cm]	7.55	7.55	3.78
beta* at IP1&5	β* [m]	0.55	0.5	0.25
full crossing angle	θ_c [μrad]	285	315	445
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0.64	0.75	0.75
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1	2.3	9.2
peak events per crossing		19	44	88
initial lumi lifetime	τ_L [h]	22	14	7.2
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.7
	$T_{run,opt}$ [h]	21.2	17.0	12.0
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	0.56	1.15	3.6
	$T_{run,opt}$ [h]	15.0	12.0	8.5
e-c heat SEY=1.4(1.3)	P [W/m]	1.07 (0.44)	1.04 (0.59)	13.34 (7.85)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.17	0.25	0.5
image current heat	P_{IC} [W/m]	0.15	0.33	1.87
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.04 (0.38)	0.06 (0.56)	0.113 (1.13)
extent luminous region	σ_l [cm]	4.5	4.3	2.1
comment				partial wire c.

baseline upgrade parameters 2001-2005

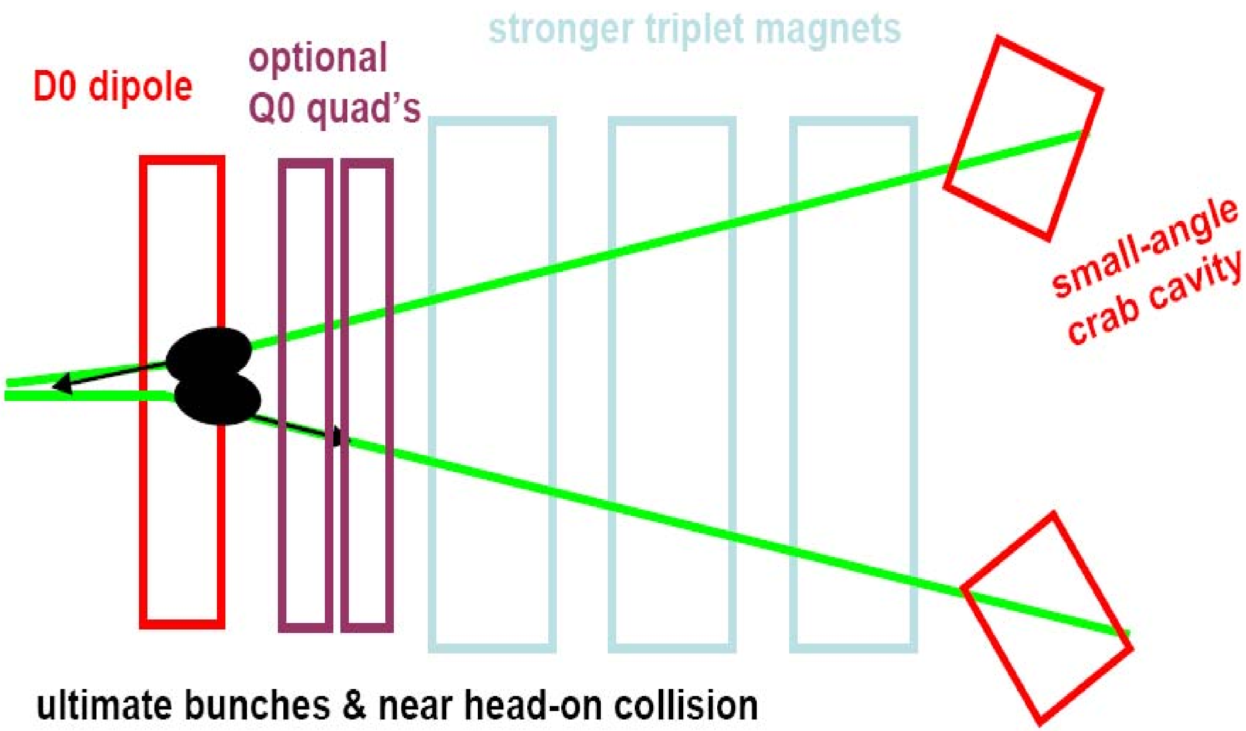
abandoned at LUMI'06

(SR and image current heat load well known)

Frank Zimmermann, PAC07, TUZAKI02

total heat far exceeds max. local cooling capacity of 2.4 W/m

Early separation scenario (ES)

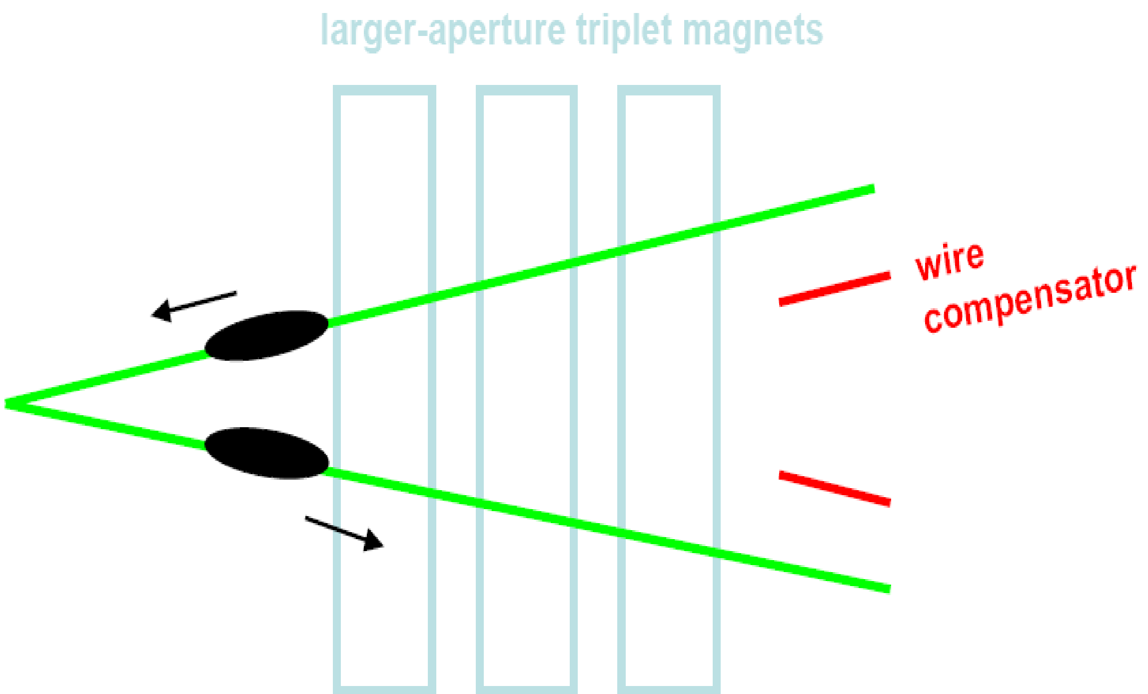


- ultimate beam
- stronger focusing
- early separation dipoles
- crab cavities

- challenges
  → new machine elements (deep) inside the detectors
  → crab cavities for hadron beams
  → poor beam and luminosity lifetime

- e.g. F. Zimmermann, talk at PAC07

Large Piwinski angle scenario (LPA)



- double bunch spacing
- more intense bunches
- wire compensation
  - → of long range beam-beam interactions
- challenges
  - → high bunch charge, larger beam current
  - → operate with large Piwinski parameter (unproven)
  - → wire compensation (almost established)

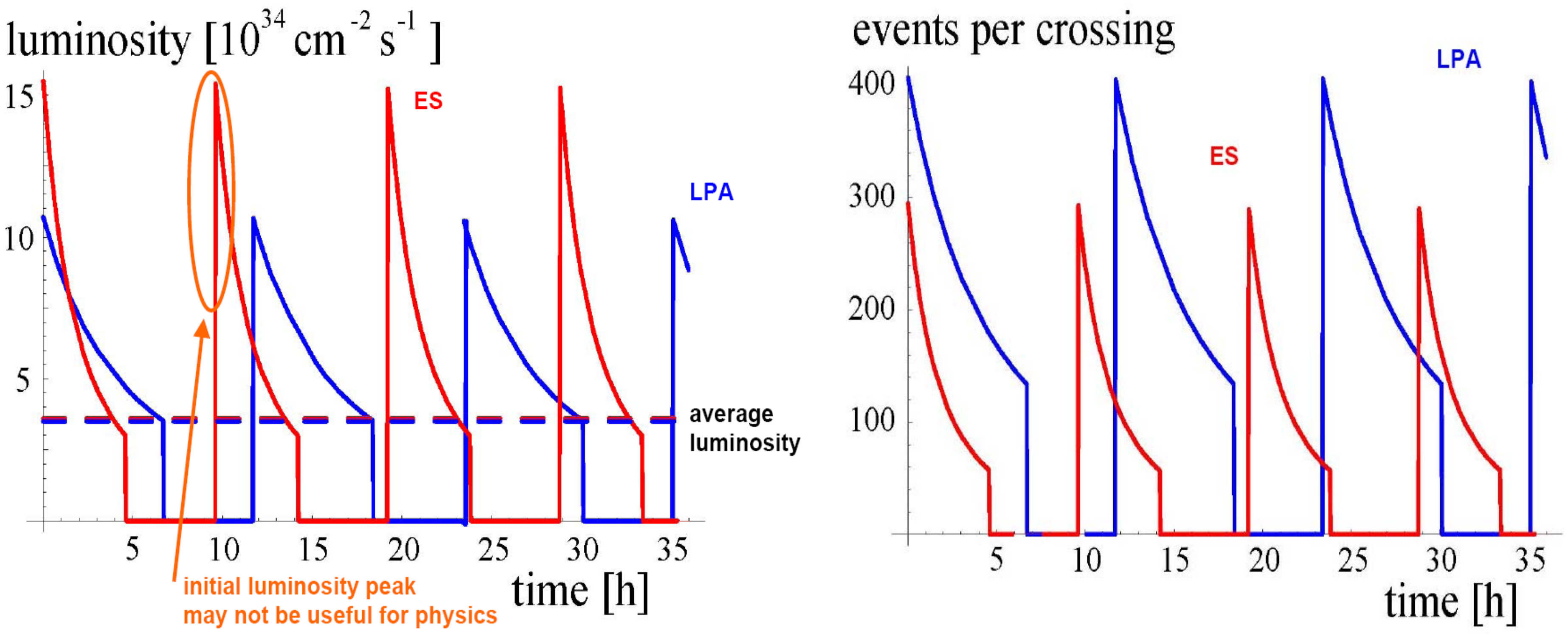
- e.g. F. Zimmermann, talk at PAC07

LHC upgrade parameters

Table 1 ES LPA

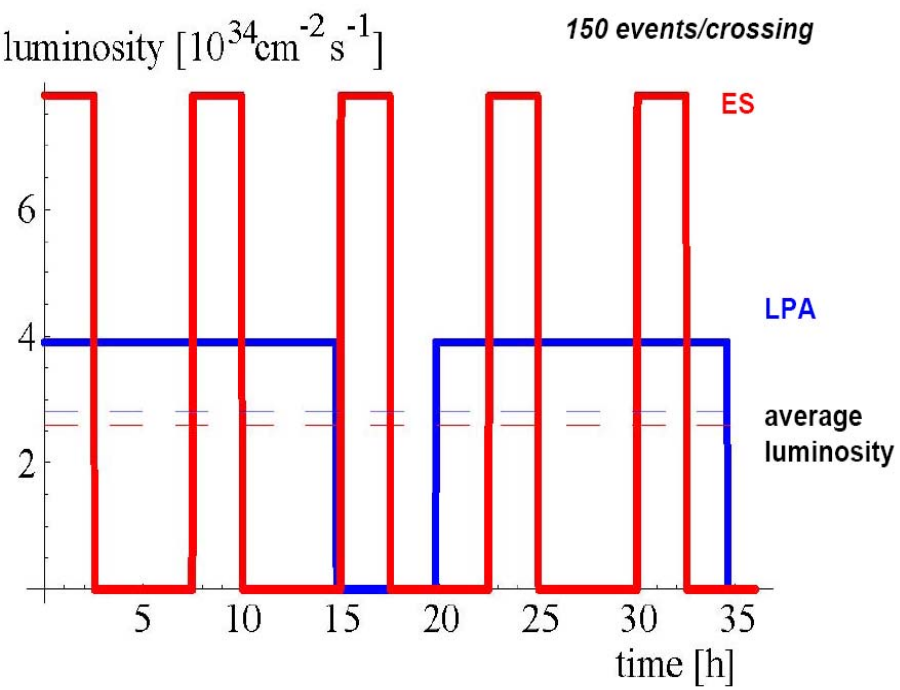
parameter	symbol	nominal	ultimate	25 ns, low beta*	50 ns, long bunches
number of bunches	n_b	2808	2808	5616	1404
protons/bunch	N_b [10^{11}]	1.15	1.7	1.7	4.9
bunch spacing	Δt_{sep} [ns]	25	25	25	50
average current	I [A]	0.58	0.86	0.86	1.22
longitudinal profile		Gaussian	Gaussian	Gaussian	uniform
rms bunch length	σ_z [cm]	7.55	7.55	7.55	11.8
beta at IP1 & IP5	β^* [m]	0.55	0.5	0.08	0.25
crossing angle	θ_c [μrad]	285	315	0	381
Piwinski parameter	$\theta_c\sigma_z/(\sigma^* 2)$	0.64	0.75	0.60	2.5
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	1.0	2.3	15.5	10.7
optimum average luminosity for 10h turnaround time	$\langle L \rangle$ [10^{34} cm^{-2}s^{-1}]	0.46	0.91	2.4	2.5
optimum run length with 10h turnaround time	τ_{opt} [h]	21.2	17.0	6.6	9.5
total heat load on beam screen (max SEY=1.4)	dP/ds [W/m]	1.39	1.62	1.62	1.50
peak number of events/crossing		19	44	294	403

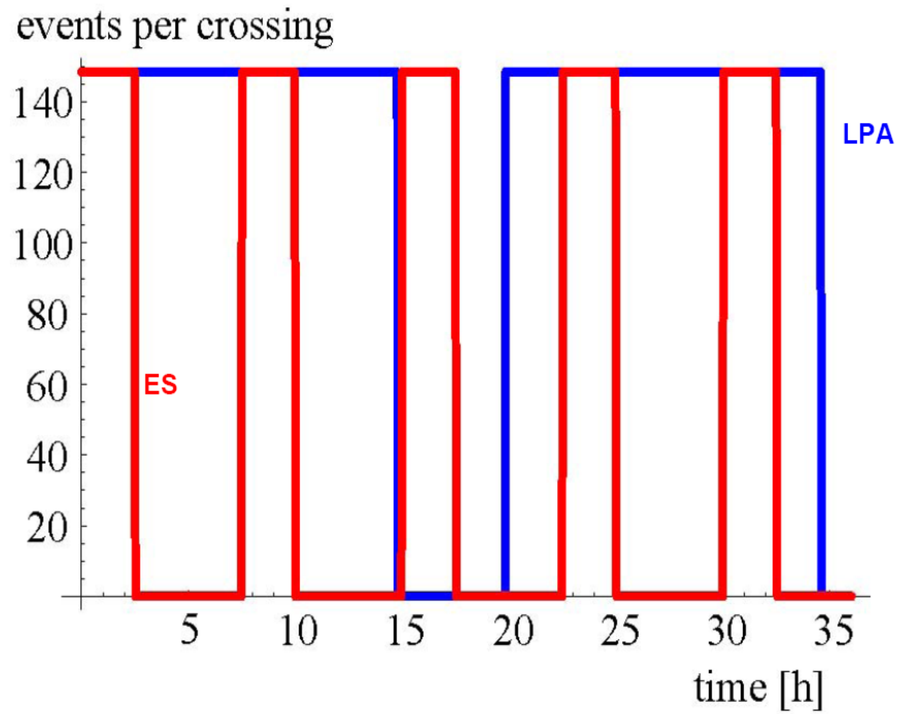
Time evolution: luminosity



- shorter beam life time of ES scenario
  → usefulness of initial peak luminosity?
- larger number of events per crossing (LPA)
  → up to 400 simultaneous inelastic pp interactions

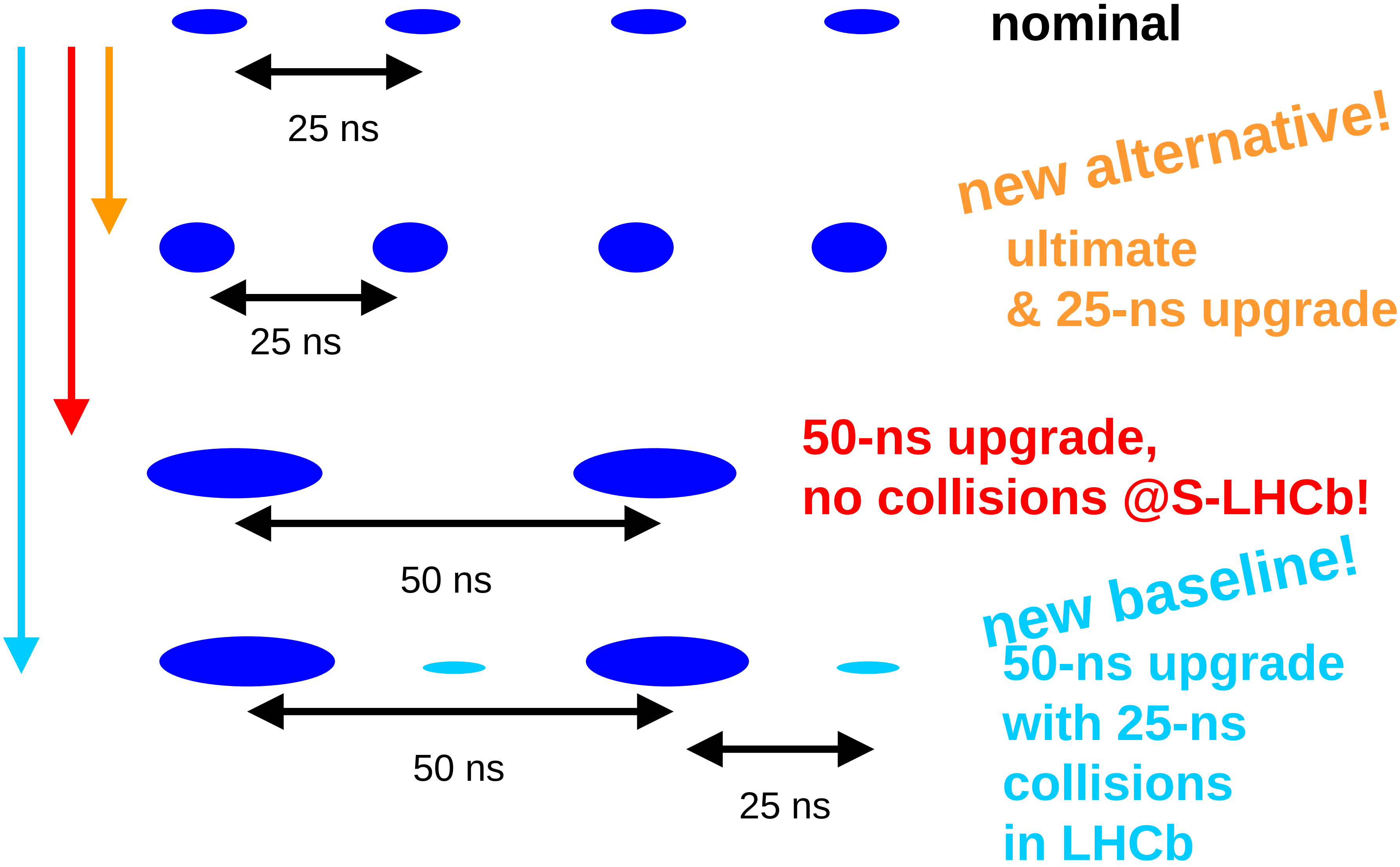
Under study: luminosity leveling





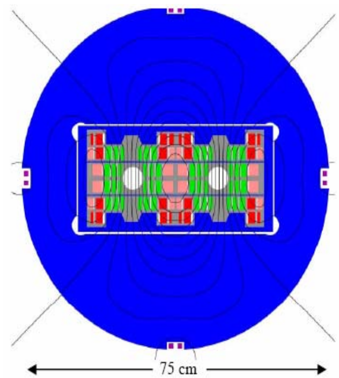
- perform dynamic β* squeeze during a store
  - → alternative for LPA scenario: dynamic bunch length reduction
- favourable for experiments
  - → less 'pile-up' events at beginning of store

Bunch structure: LHC & upgrades



Increasing the beam energy?

- doubling the energy (DLHC) $\sqrt{s}$ = 28 TeV
  - → nominal B field of 16.8 T (design for 18.5 - 19.3 T)
    - use Nb_3Sn superconductor
    - several 1m models exists (with 10 - 13 T fields)
  - → timescales
    - detailed R&D program: at least 10 years
    - production in industry: ~ 8 - 10 years
    - high cost
- tripling the energy (TLHC): $\sqrt{s}$ = 42 TeV
  - → nominal B field of 25 T (design for 28 - 29 T)
    - HTS-BSCCO supercond., to be fully demonstrated
    - large aperture needed (efficient beam screen)
  - → timescales
    - R&D program: at least 20 years
    - extremely high costs



- P. McIntyre, PAC05

Summary on machine upgrade

- scenarios for luminosity upgrade have evolved
  - → shorter bunch spacing (12.5 ns) now excluded
- two new scenarios developed
  - → LPA (50 ns spacing): baseline, less risks and uncertainties
  - → ES (25 ns spacing): leave as backup solution
    - both need further refinement in studies
- luminosity leveling to be seriously considered
- significant energy upgrade: much more ambitious and expensive
- keep in mind: what counts in the end is accumulated integrated luminosity!
  - → stable running at somewhat lower peak luminosity preferable to unstable running at higher peak luminosities

Detector upgrade

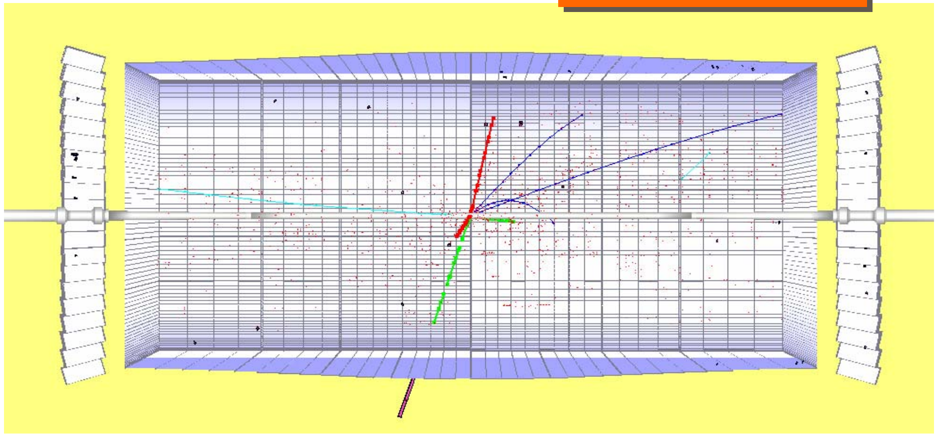
- Talks in parallel session at EPS
  - I. Dawson, The SLHC prospects for ATLAS and CMS, July 21st 12:15 – ID459
  - C. Parkes, Ideas for the LHCb upgrade, July 21st 12:00 – ID458

The challenges

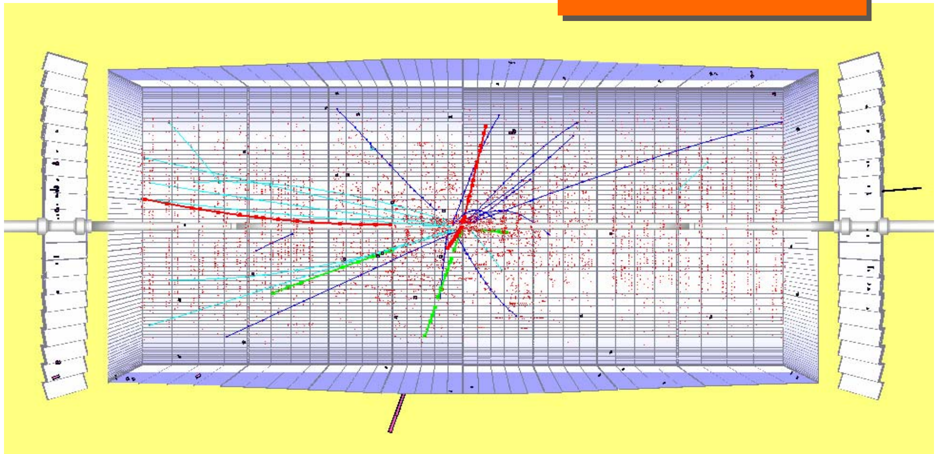
- Requirement to fully exploit physics potential
  - → similar detector performance as 'today'
- However much more demanding environment
  - → increased backgrounds
  - → larger particle fluxes (radiation damage)
  - → higher rates
- What to upgrade/adapt?
  - → reasonable approach: can not build a new detector!
  - → replacement of tracking detectors
    - 10 y lifetime expectation @ 10^{34} – sensor/electronics damage
  - → forward region
    - new machine elements closer to interaction point?
  - → check on calorimeter and muon systems
  - → trigger and data acquisition: evolution?

The challenge: visually

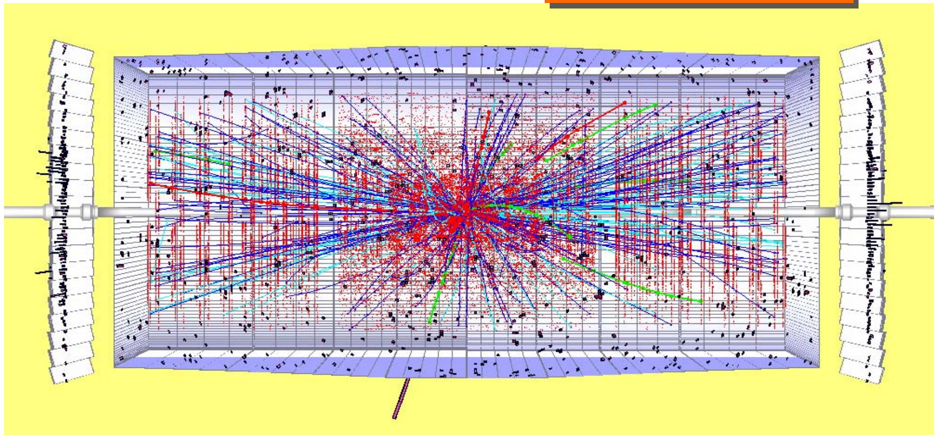
10^{32} cm^{-2} s^{-1}



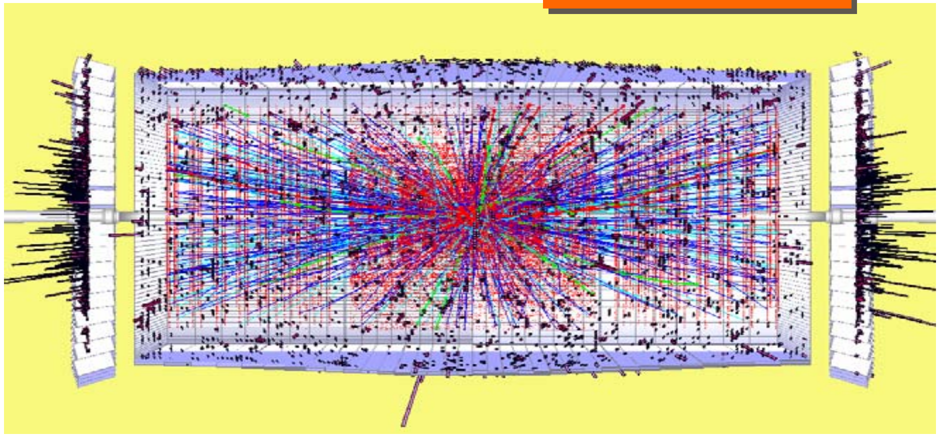
10^{33} cm^{-2} s^{-1}



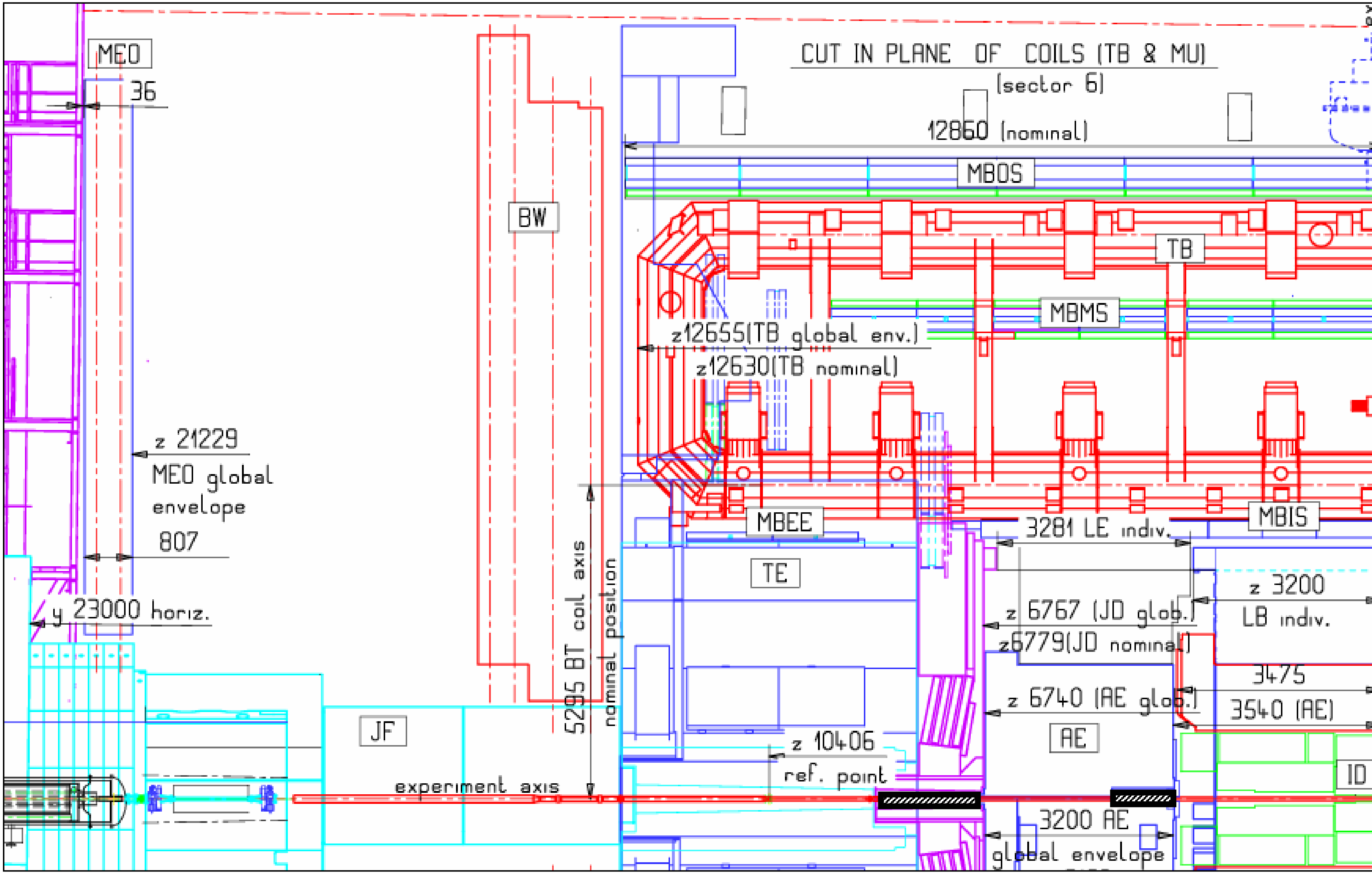
10^{34} cm^{-2} s^{-1}



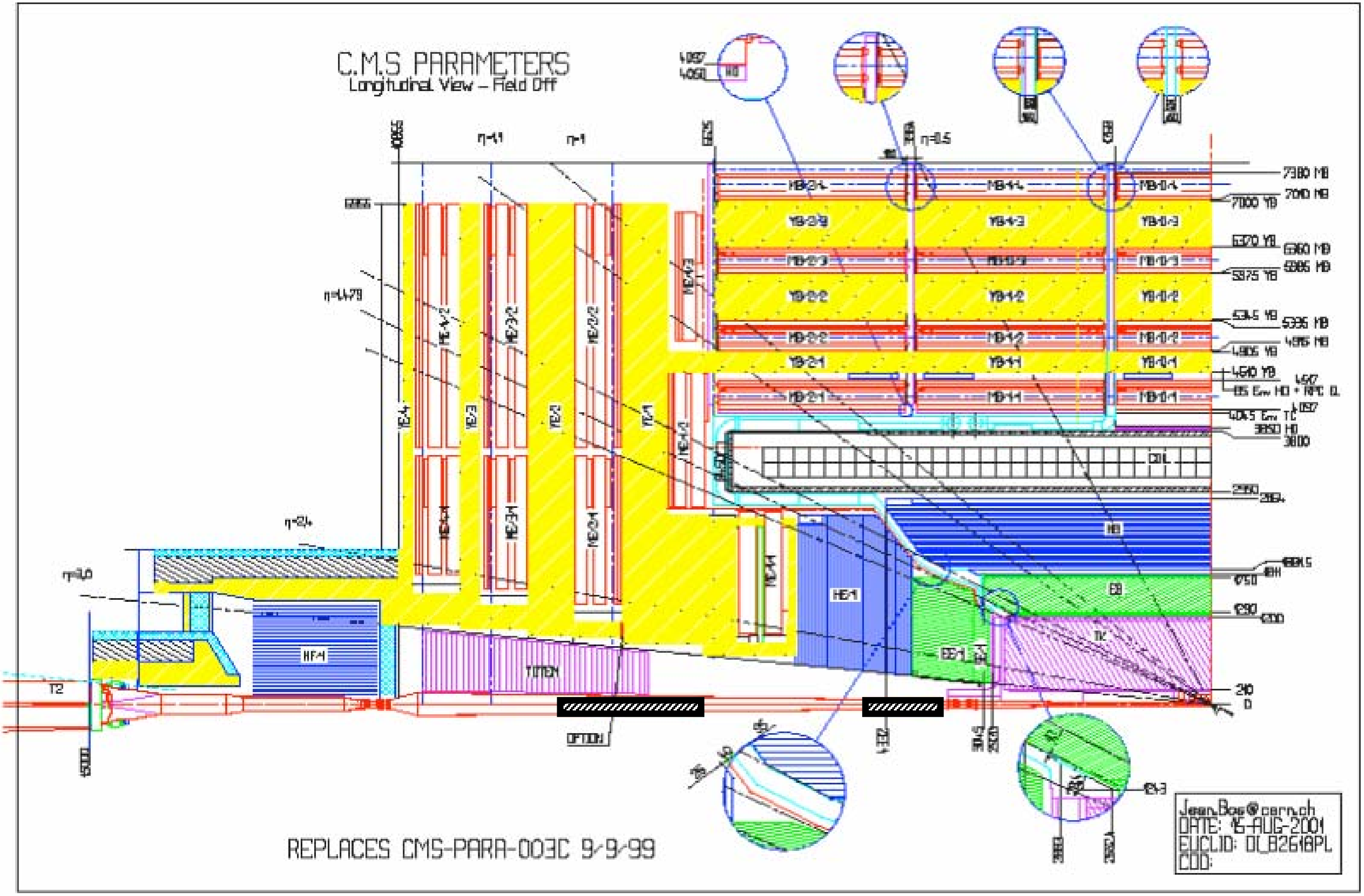
10^{35} cm^{-2} s^{-1}



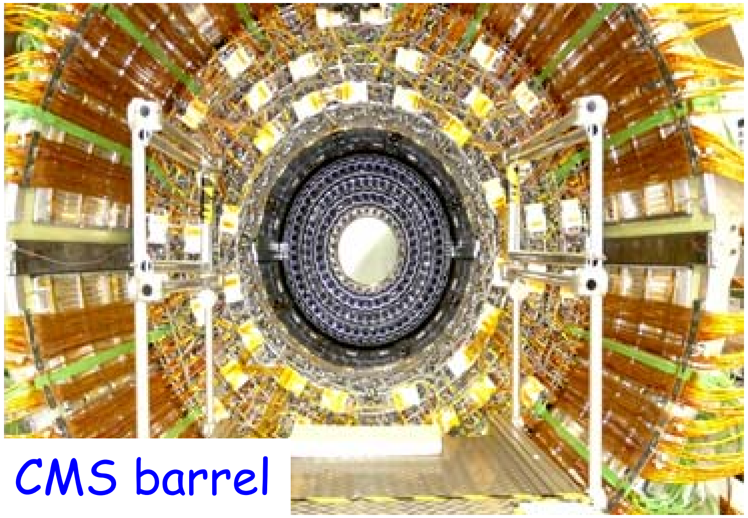
Machine elements inside ATLAS



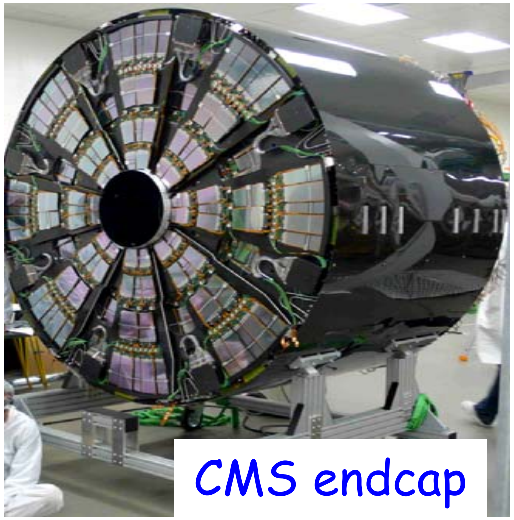
Machine elements inside CMS



Inner tracking: present and future

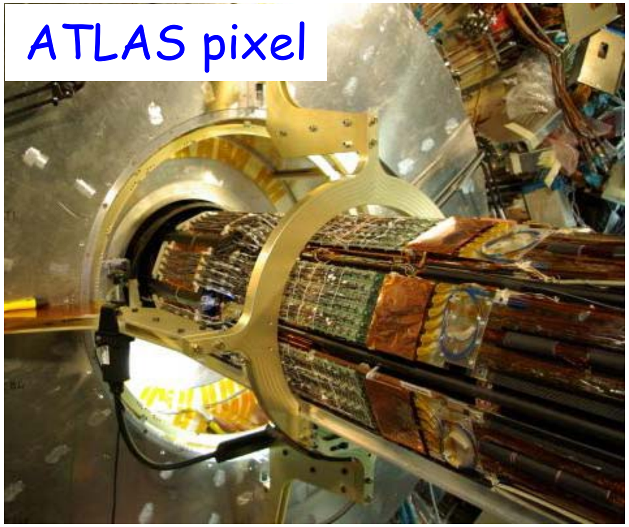


CMS barrel

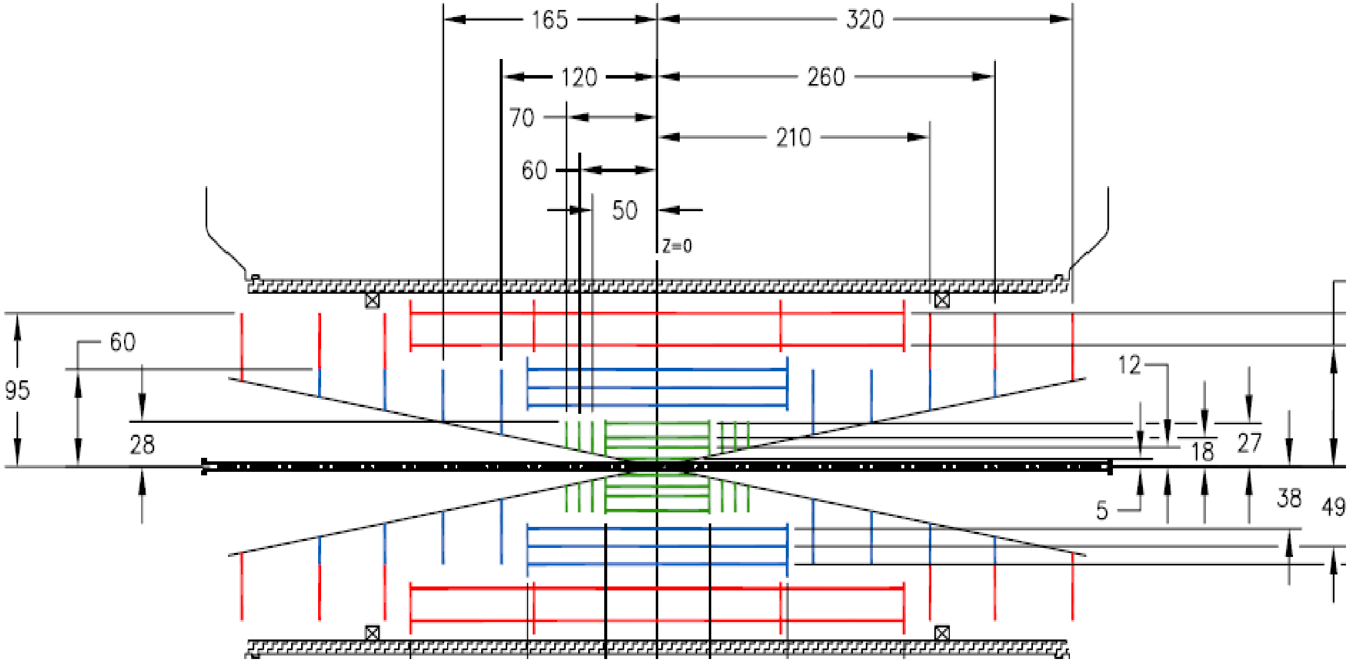


CMS endcap

ATLAS pixel



- strawman layout of full Si tracker upgrade (ATLAS)
  - → pixels
  - → short strips
  - → long strips



Radiation levels

- radiation :

—— 500 fb^{-1} = ~ 10 years at LHC

—— 3000 fb^{-1} = ~ 3 years at SLHC

CMS tracker

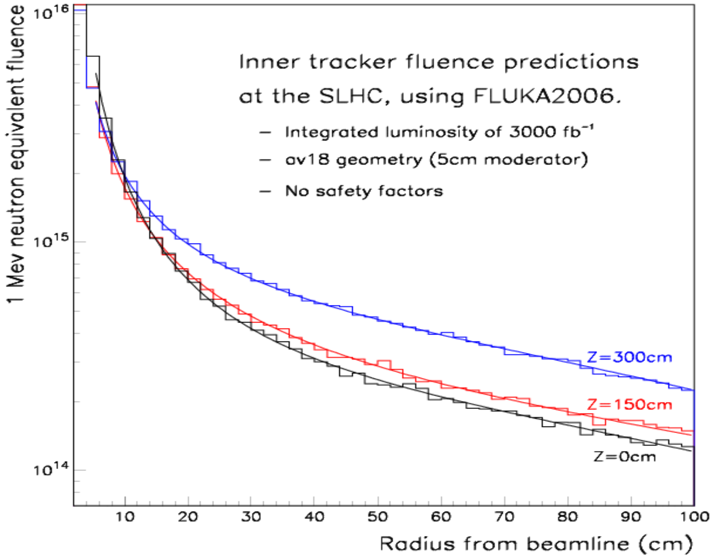
R (cm)	hadron fluence 10^{14} cm^{-2}	Dose (kGy)
4	30/190	840/5000
11	5/28	190/1130
22	1.5/10	70/420
75	0.3/2	7/40
115	0.2/1	2/11

CMS calorimeters

1 Gy = 1 Joule/Kg

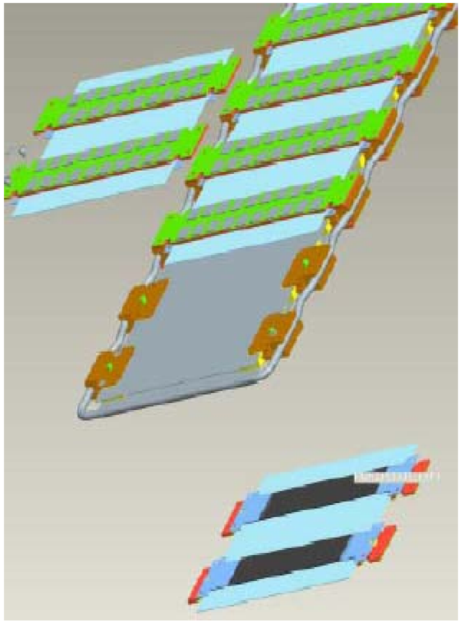
η	ECAL dose (kGy)	HCAL dose (kGy)
0-1.5	3/18	0.2/1
2.0	20/120	4/25
2.9	200/1200	40/250
3.5		100/600
5		1000/6000

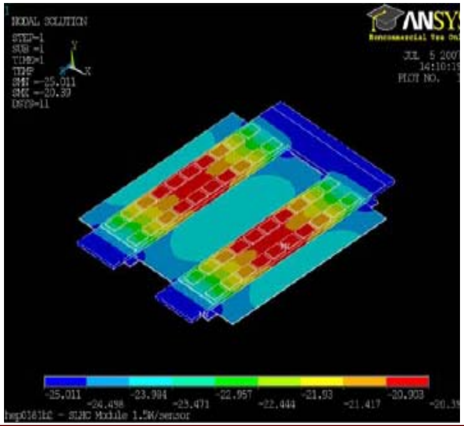
- important issues
  - → validation with first real LHC data of present background models absolutely mandatory!
  - → need operational experience



Issues for tracker upgrades

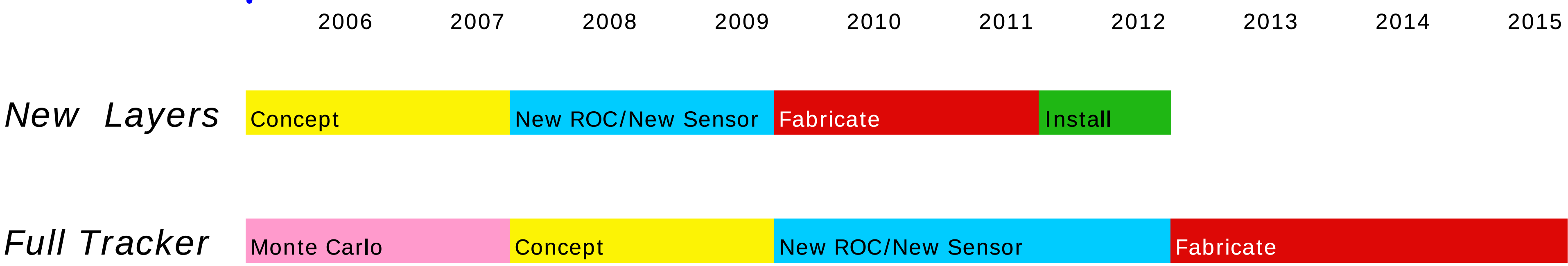
- performance optimization
  - → occupancies, material budget, tracking performance
- radiation hard sensors
  - → use n-in-p or n-in-n sensors
    - can operate underdepleted
  - → innermost (b-)layer: new technology needed
    - 3d silicon, CVD diamond, …
- readout electronics
- optoelectronics / control links
- structures: modules, staves, …
- services
  - → cables
  - → cooling
  - → power: demands and distribution
    - serial powering, DC-DC converter, …
- activation





Possible timescale for tracker upgrade

- example from CMS



- new layers: approx. 5 years after LHC start
- full tracker: ~ 8 - 10 years after LHC start

- to achieve these timescales, focused R&D efforts are needed
  - → need to take into account the service aspects from the very beginning

Comments on other systems

- calorimeters
  - → most parts will be kept (partially new electronics)
  - → ATLAS: forward calorimeter subject to most radiation
  - → CMS: impact of machine elements on HF, radiation damage of scintillator (HCAL) for $|\eta|>2$
- muon systems
  - → need running experience, some electronics might be replaced, background uncertainties (data needed)
  - → ATLAS: reduction of background (factor 2) by Be beampipe
- trigger and data acquisition
  - → has to cope with higher rates, occupancies, …
  - → CMS: need for track trigger at first level

Upgrade organization

- ATLAS and CMS
  - → upgrade steering groups
    - coordination of activities
    - assessment and recommendation of R&D proposals
    - upgrade workshops
      - → inreach to the collaboration, outreach to interested groups
      - → CMS: 4 general workshops, 2 workshops on tracker
      - → ATLAS: 2 general workshops, 2 workshops for trackers
        - and additional smaller workshops
- common R&D efforts envisaged
  - → ATLAS CMS electronics workshop (March 07)
    - http://indico.cern.ch/conferenceTimeTable.py?confId=10010

LHCb upgrade plans

- plan to operate 5 years at $2*10^{33}$ cm^{-2} s^{-1}
  - → accumulate 100 fb^{-1}
- some of the physics goals
  - B_s physics 'unique' to LHCb
  - → weak mixing phase ϕ_s (from $B_s \to J/\psi\ \phi$)
  - → b→s transition using $B_s \to \phi\phi$
  - → CKM angle γ from $B \to DK$, $B_s \to D_s K$
- experimental upgrade independent of LHC upgrade
  - → replace VELO with more radiation hard variant
  - → add first level trigger on detached vertices
  - → further components under study

ALICE upgrade plans

- present physics program extends until 2017
  - → Pb Pb, p p and p ion running
  - → later low mass ions and lower energies
- present plans for further installation
  - → 2010 electromagnetic calorimeter
  - → 2012-2015 thinner beam pipe, new pixel detector, improved high p_T particle ID, improved forward instrumentation
- request for accelerator R&D to increase PbPb luminosity to $5*10^{27}$ cm^{-2} s^{-1}
  - → need modification to TPC, TPC electronics and DAQ

Outlook

Outlook

- **completion and exploitation of design LHC machine and detectors has the highest priority!**

- strong physics case for upgraded LHC
  → 'moving target', will evolve with first LHC results
- new baseline scenario for luminosity upgrade
  → further details to be worked out
- detectors will develop with increasing luminosity
  → minimize changes necessary
  → complete replacement of tracking (inner) detectors needed
  → costs are not negligible

acknowledgement: results presented based on work from many colleagues from machine groups, ATLAS and CMS!

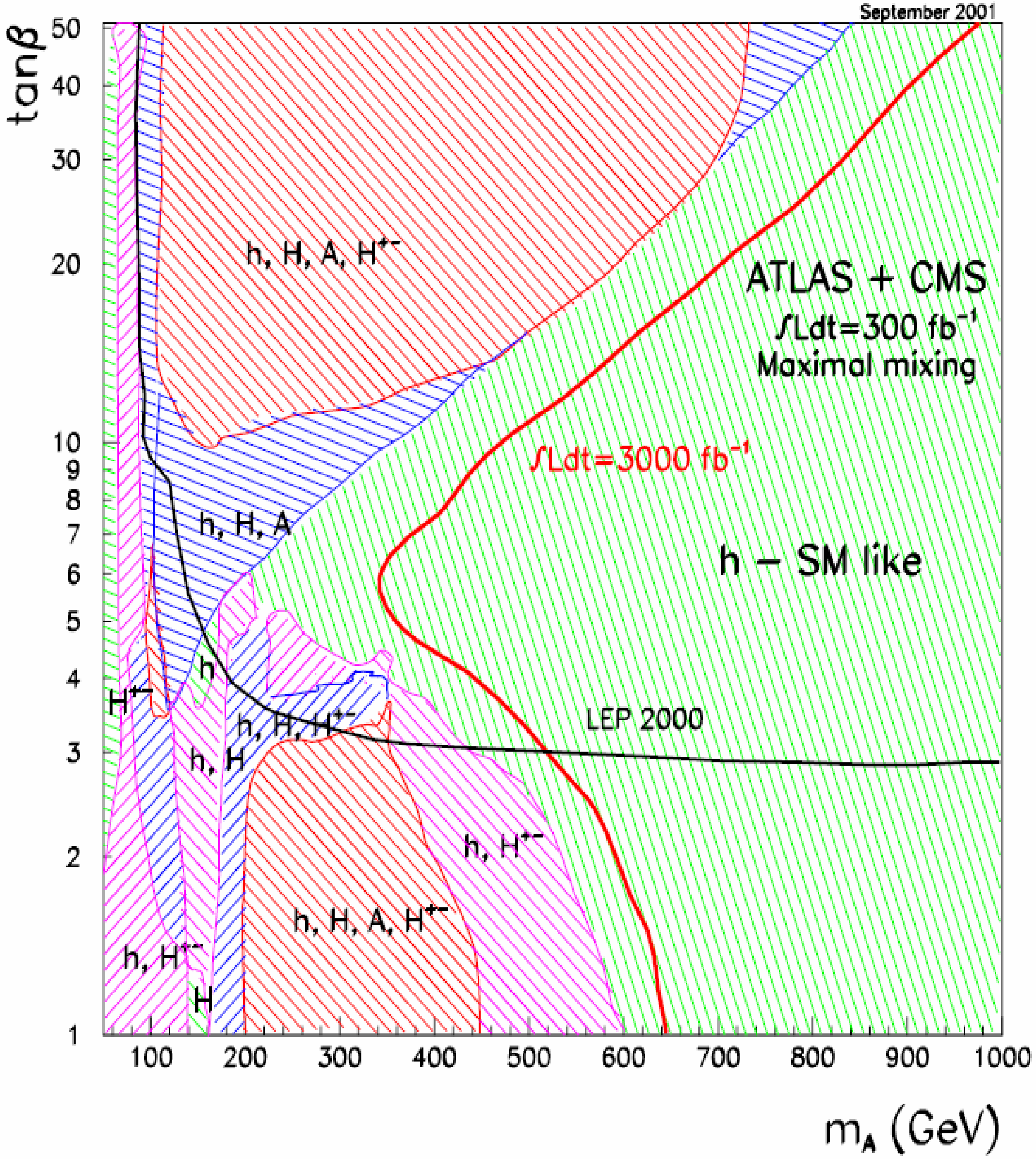
Resources for more information

- CERN
  - → POFPA (Physics Opportunities for Future Proton Accelerators)
    - http://pofpa.web.cern.ch/pofpa/
  - → PAF (Proton Accelerators for the Future)
    - http://paf.web.cern.ch/paf/
- Machine upgrade
  - → CARE-HHH network
    - High energy High intensity Hadron beams
    - http://care-hhh.web.cern.ch/care-hhh
  - → CARE-NED joint activity
    - Next European Dipole
    - http://lt.tnw.utwente.nl/research/HCS/Projects/CARE-NED/
  - → US.LARP
    - Large hadron collider Accelerator Research Program
    - http://uslarp.org/
- Detector upgrades
  - → ATLAS
    - http://atlas.web.cern.ch/Atlas/GROUPS/UPGRADES/
  - → CMS:
    - Expression of Interest CERN/LHCC 2007-014

CERN council strategy group

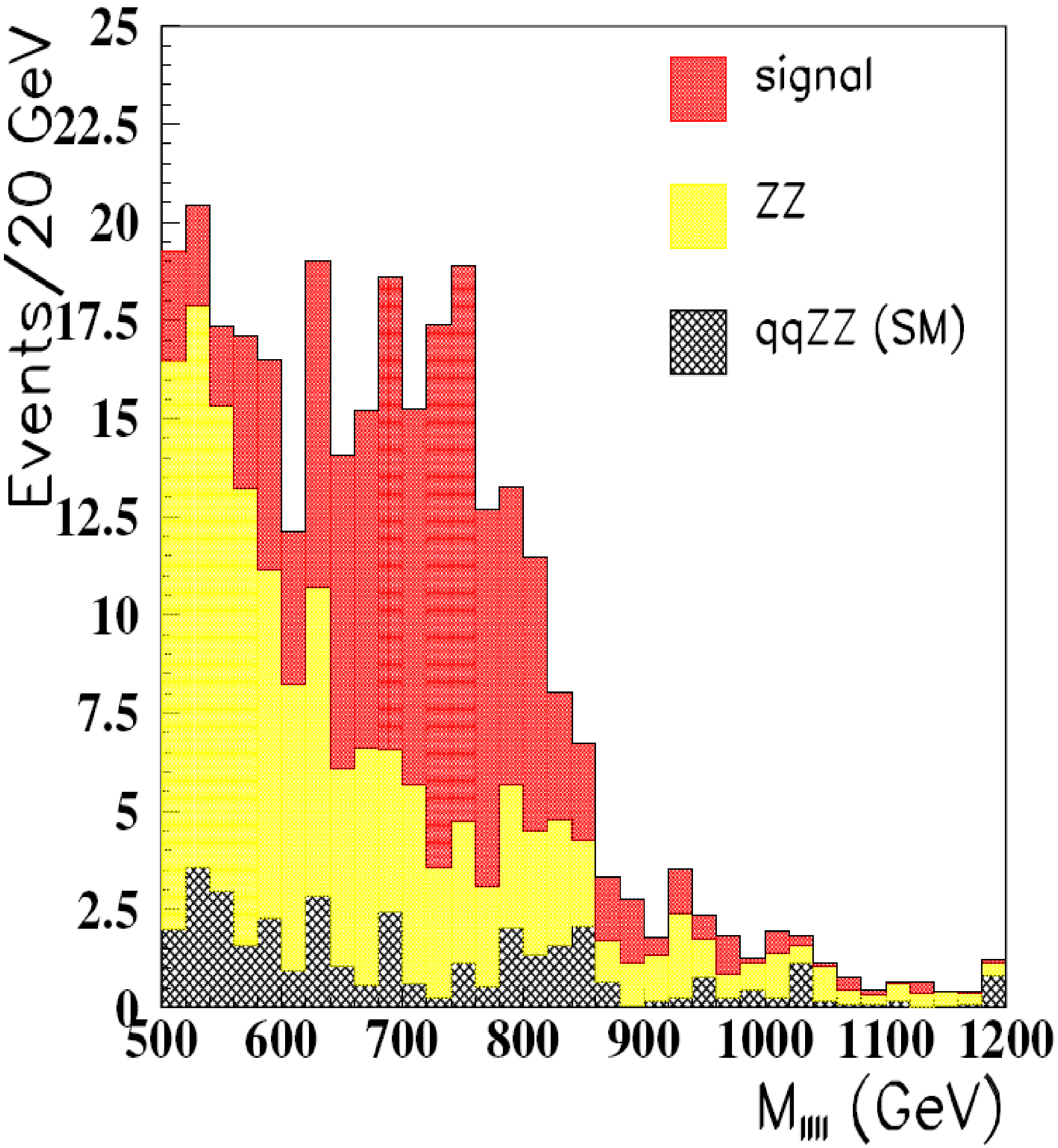
3. The LHC will be the energy frontier machine for the foreseeable future, maintaining European leadership in the field; *the highest priority is to fully exploit the physics potential of the LHC, resources for completion of the initial programme have to be secured such that machine and experiments can operate optimally at their design performance.* A subsequent major luminosity upgrade (SLHC), motivated by physics results and operation experience, will be enabled by focussed 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.*

Example: MSSM Higgs bosons



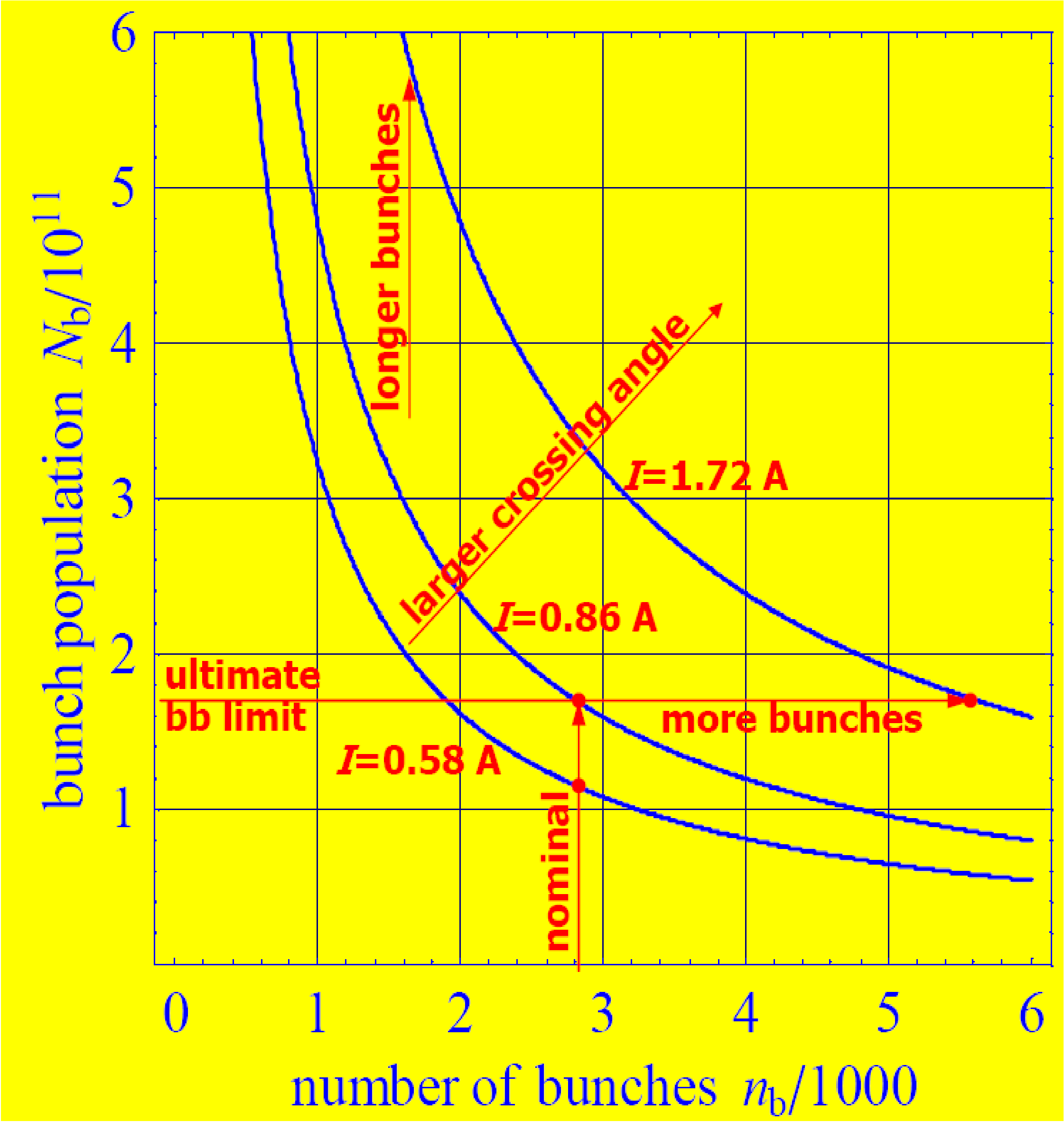
- difficult region:
  - → large m_A values
  - → only one SM like Higgs boson observable
- increased SLHC luminosity
  - → coverage in m_A extended by about 100 GeV
    - especially around $\tan\beta \approx 5$

Example: strong V_L-V_L scattering



- if no Higgs
- $Z_L Z_L$ resonance at mass of 750 GeV
  - → decay to 4 leptons
  - → L_{int} = 3000 fb^{-1}
  - → not detectable at LHC
- requirement of forward jet tagging

Optimization phase space



- parameters
  - → number of bunches
    - bunch spacing
  - → number of protons per bunch
    - limits on total intensity due to electron cloud, collimation, injectors
  - → crossing angle at interaction point
    - limitations due to triplet aperture

Maximizing Luminosity

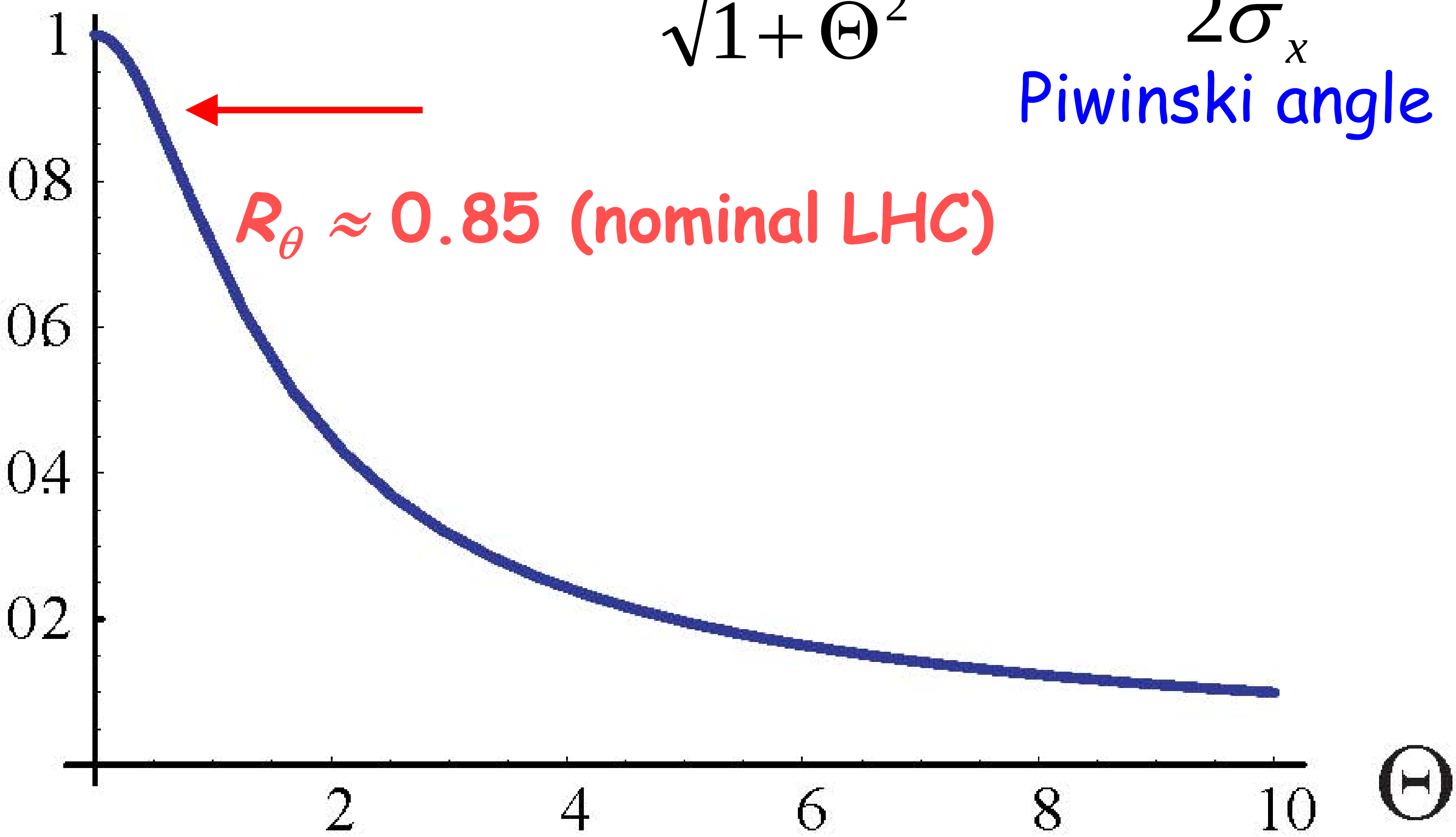
$$L = \frac{f_{rev}\gamma}{2r_p} n_b \frac{1}{\beta^*} N_b (\Delta Q_{bb}) F_{profile} F_{hg}$$

- luminosity for alternating crossings at two IP's
  - at beam-beam limit
- parameters for optimization
  - → n_b: number of bunches
  - → N_b: number of protons per bunch
  - → β^* : final focusing
  - → ϕ : Piwinski parameter $\phi=(\theta_c \sigma_z)/(2\sigma_x)$
  - → $F_{profile}$: longitudinal profile function
    - → =1 (Gaussian) resp. = $\sqrt{2}$ (uniform)
  - → ΔQ_{bb} : total beam-beam tune shift

Luminosity reduction: Piwinski parameter

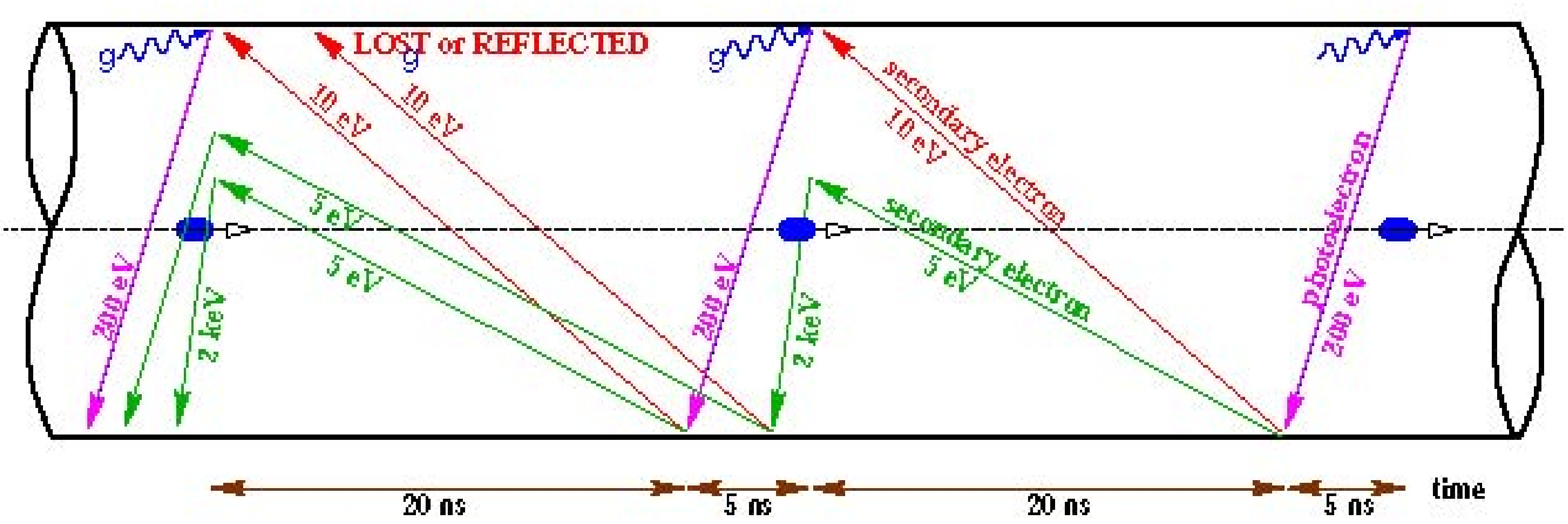
$$R_\theta = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$

Piwinski angle



Exclusion of shorter bunch spacing

- heat load into LHC beam screen for (12.5 ns) would exceed maximum cooling capacity due to
  → synchrotron radiation and image currents alone!
    - not even considering contribution from electron cloud effect



schematic of e- cloud build up in the arc beam pipe, due to **photoemission** and **secondary emission**

LHC upgrade parameters (detailed)

parameter	symbol	Early Separation	Large Piwinski Angle
transverse emittance	ε [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	β* [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	2.4	2.5
	$T_{run,opt}$ [h]	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff}[10^{34} cm^{-2}s^{-1}]	3.6	3.5
	$T_{run,opt}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

early separation (ES)

large Piwinski angle (LPA)

two new upgrade scenarios

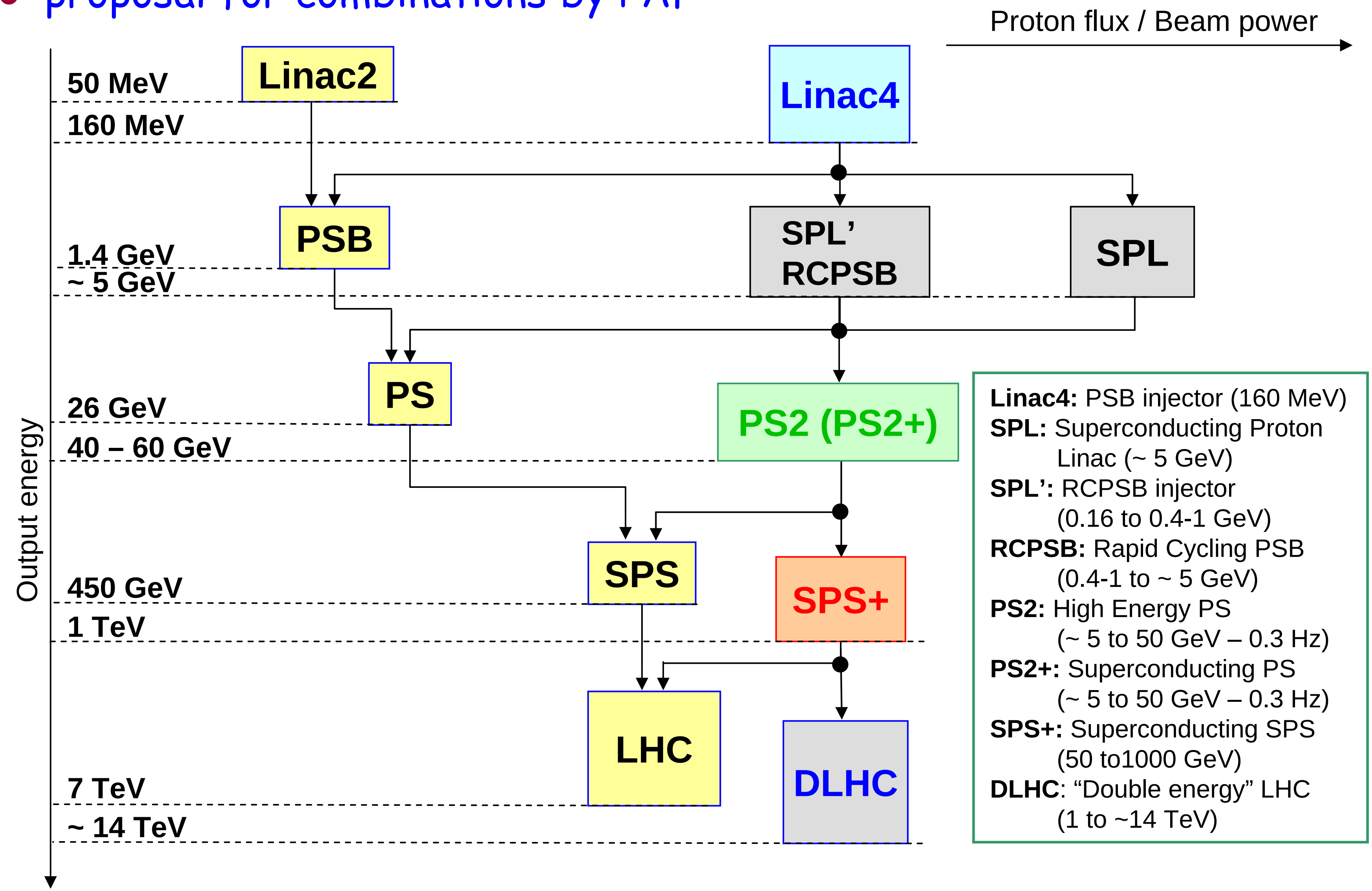
compromises between heat load and # pile up events

Upgrade: LHCb collision parameters

parameter	symbol	25 ns, offset	25 ns, late collision	50 ns, satellites
collision spacing	T_{coll}	25 ns	25 ns	25 ns
protons per bunch	N_b [10^{11}]	1.7	1.7	4.9 & 0.3
longitudinal profile		Gaussian	Gaussian	flat
rms bunch length	σ_z [cm]	7.55	7.55	11.8
beta* at LHCb	β* [m]	0.08	3	3
rms beam size	$\sigma_{x,y}$* [μm]	6	40	40
rms divergence	$\sigma_{x',y'}$* [μrad]	80	13	13
full crossing angle	θ_c [urad]	550	180	180
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	3.3	0.18	0.28
peak luminosity	L [10^{33} cm^{-2}s^{-1}]	1.13	2.1	2.4
initial lumi lifetime	τ_L [h]	1.8	2.8	9
length of lum. region	σ_l [cm]	1.6	5.3	8.0

Evolution of CERN accelerator complex

- *proposal for combinations by PAF*



Linac4: PSB injector (160 MeV)
SPL: Superconducting Proton Linac (~ 5 GeV)
SPL': RCPSB injector (0.16 to 0.4-1 GeV)
RCPSB: Rapid Cycling PSB (0.4-1 to ~ 5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
PS2+: Superconducting PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
DLHC: "Double energy" LHC (1 to ~14 TeV)