LHC beyond 2020

Frank Zimmermann

KEK Accelerator Seminar, July 2010

today's menu

contents

- commissioning progress 2009/10
- plan for next decade
- "beyond 2020"
  - High-Luminosity LHC "HL-LHC"
  - Higher-Energy LHC "HE-LHC"
  - Large Hadron electron Collider "LHeC"

commissioning progress 2009/10

LHC – commissioning 2008/09

O. Brüning et al.

- 2008
  - Accelerator complete
  - Ring cold and under vacuum
- September 10th 2008
  - First beams around – made it to Google
- September 19th 2008
  - The incident
- 2008 – 2009
  - 14 months of major repairs and consolidation
  - New Quench Protection System for online monitoring and protection of all inter-magnet joints
  - But: uncertainties about the splice quality (copper stabilizer)
  - Risk of thermal runaway scenarios

    ➔ decision to limit beam energy to 3.5 TeV for first operation

LHC – commissioning 2009

O. Brüning et al.

- November 20th 2009
  - First beams around again
- November 29th 2009
  - Both beams accelerated to 1.18 TeV simultaneously

LHC - highest energy accelerator

- December 8th 2009
  - 2x2 accelerated to 1.18 TeV
  - First collisions seen before beam lost!
- December 14th 2009
  - Stable 2x2 at 1.18 TeV
  - Collisions in all four experiments

Limited to 2 kA in main circuits (1.18 TeV) during deployment and testing of new Quench Protection System

LHC – synchrotron light monitor

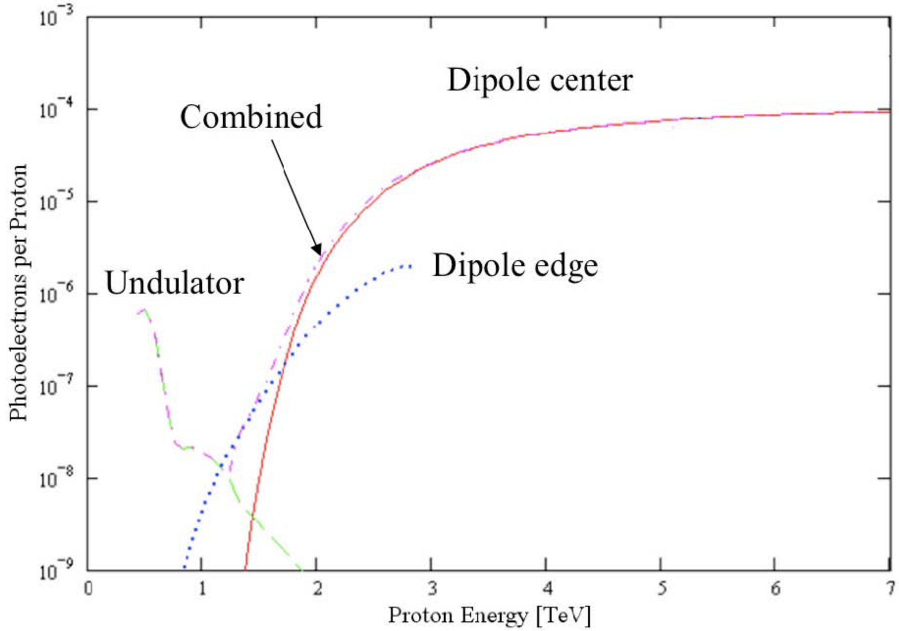


Figure 1: Light intensity as a function of beam energy.

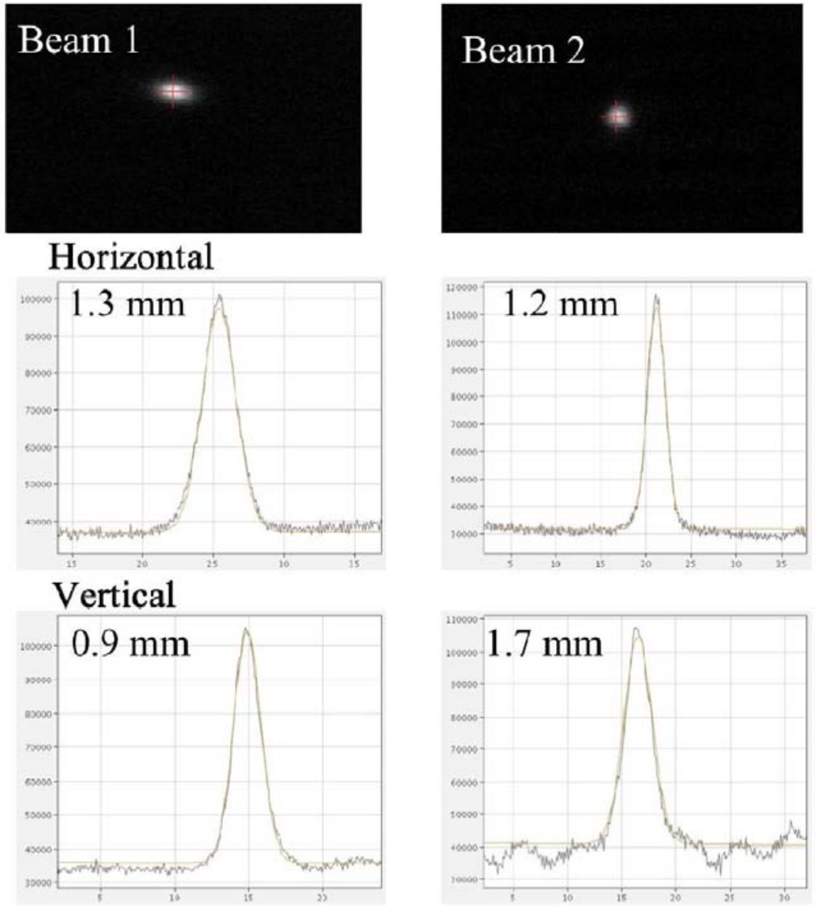


Figure 4: Beam images and profiles at 450GeV

T. Levefre et al.

LHC – commissioning 2010

27th Feb	First injection
28th Feb	Both beams circulating
5th March	Canonical two beam operation: L ~ 10^{27} cm^{-2} sec^{-1}
8th March	Collimation setup at 450 GeV
12th March	Ramp to 1.18 TeV
15th - 18th March	Technical stop – bends good for 6 kA!
19th March	Ramp to 3.5 TeV
30th March	3.5 TeV collision under ‘stable’ beam conditions
19th April	Doubling particles per bunch ➔ 2 10^{10} ppb
23rd April	Squeezed stable beams (**β^* = 2m**): L ~2x10^{28} cm^{-2} sec^{-1}
22nd May	13 bunches @ 2 10^{10} ppb ➔ L ~3x10^{29} cm^{-2} sec^{-1}
9th – 25th June	Setup for operation with nominal bunch intensities
25th June	**3 bunches @ 9 10^{10} ppb ➔ L ~5x10^{29} cm^{-2} sec^{-1}**

LHC – commissioning examples

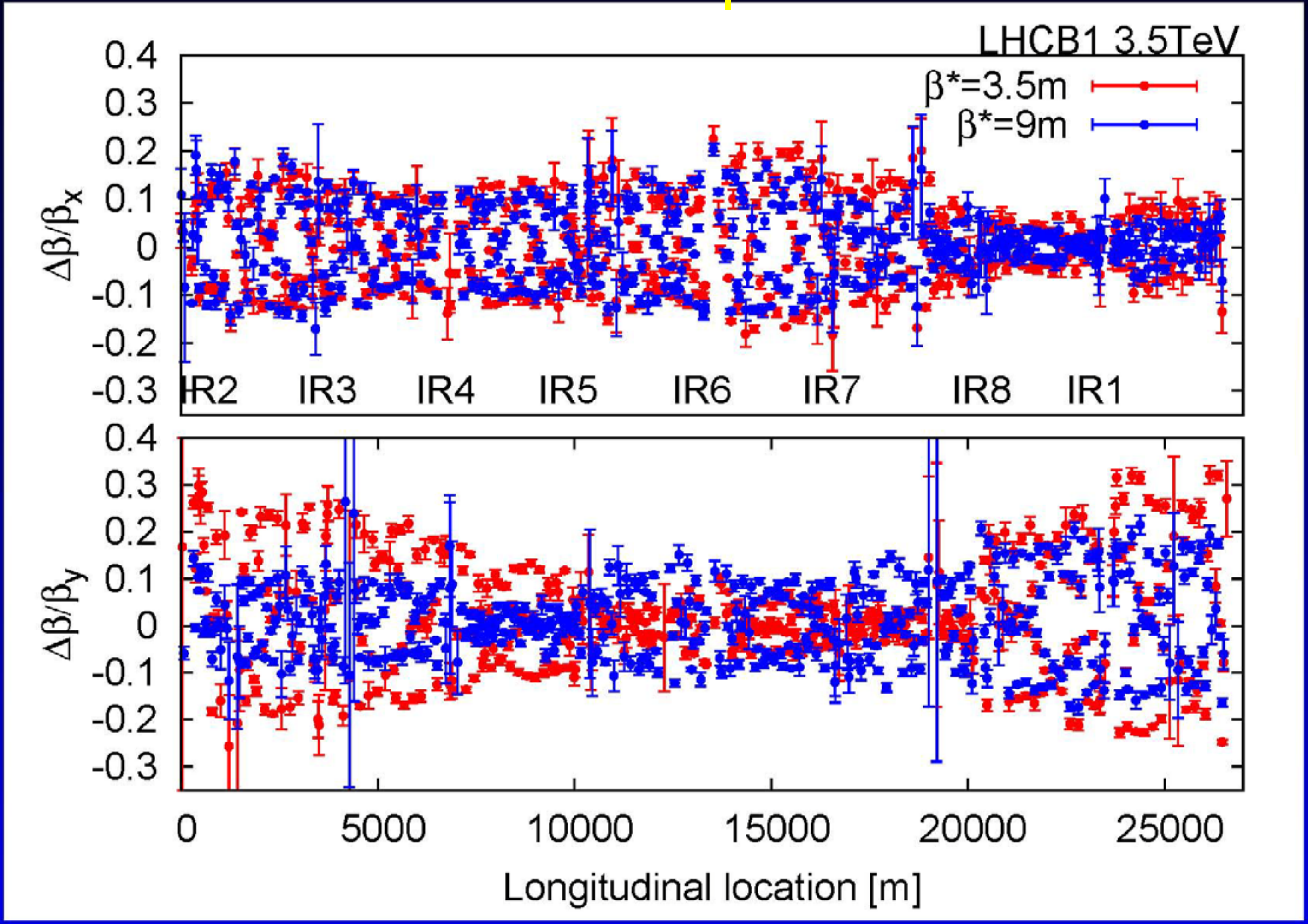
- optics at top energy
- transverse excitation - “hump”
- BPM intensity dependence
- longitudinal beam instability
- vertical beam instability
- luminosity progress
- first sign of beam-beam effects
- machine availability

LHC – beta beating at 3.5 TeV

Beam1 $\beta^* = 9$ and 3.5m

Rogelio Tomas

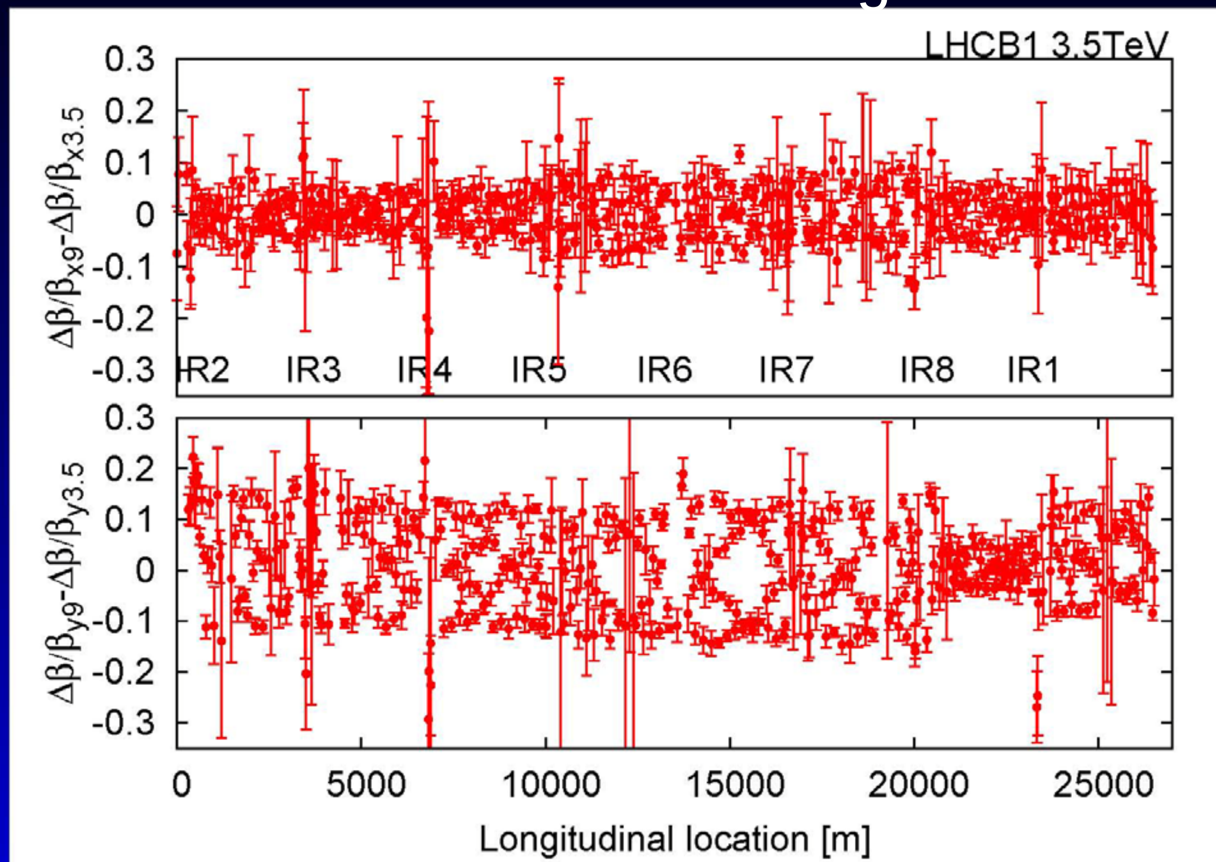
optics measured with ac dipole



LHC – change in β beating

Beam1 $\beta^* = 9$ and 3.5m difference

Rogelio Tomas



During the squeeze β_y changes by $\pm 15\%$

Sources of V beating: IR8, IR1, IR2

LHC – beta functions at IP

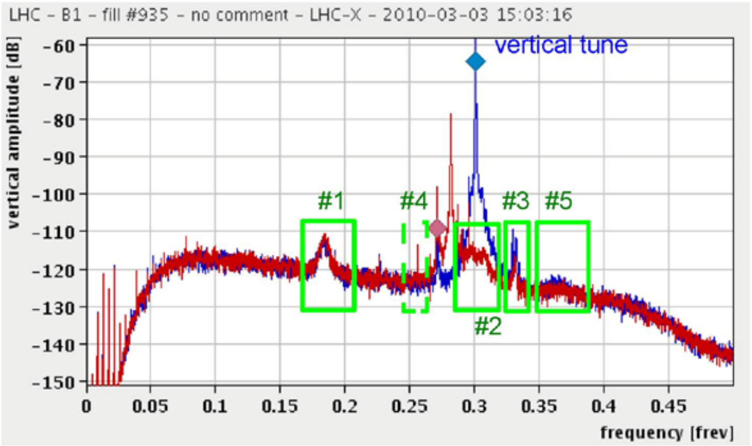
Measured β^*s at 3.5m

	Beam 1		Beam 2	
IP	β^*_x	β^*_y	β^*_x	β^*_y
IP1	3.27 ± 0.01	3.8 ± 0.3	3.5 ± 0.2	3.8 ± 0.4
IP2	3.45 ± 0.09	2.6 ± 0.2	3.3 ± 0.3	4.2 ± 0.1
IP5	3.70 ± 2	3.4 ± 0.3	3.7 ± 0.4	3.9 ± 0.4
IP8	3.42 ± 0.14	3.9 ± 0.7	3.6 ± 0.2	3.1 ± 0.5

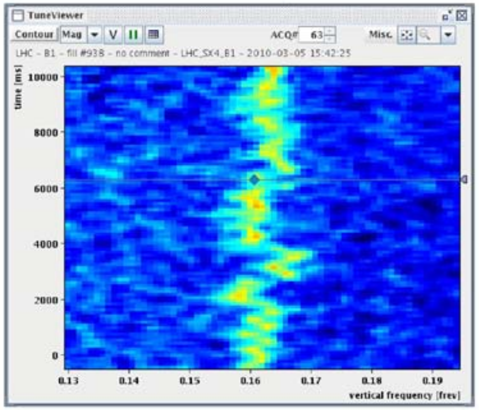
Important mismatch in IP2 β_y

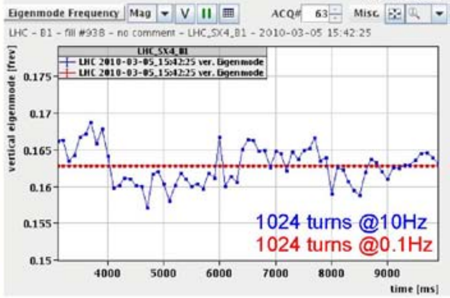
LHC – transverse “hump”

- There are at least three++ 'humps', with approx. base-band frequencies:
  - #1 @ ~ 0.185 f_{rev} , #2 @ ~ 0.302 f_{rev} (vertical tune), #3 @ > 0.333 f_{rev}, and
  - #4 & 5 @ ~0.25 & ~ 0.37 f_{rev} (much smaller and possible harmonic of #)
- Example: Q_v set below 'hump' (red) and after Q_v trim on top of 'hump' #2 (blue):
  - Driving of the tune resonance clearly visible → beam size growth → losses



- Structure of the perturbation depends on the observation time-scale, e.g.
  - 0.1 Hz b→ broad 'hump', or
  - 10 Hz acquisition BW → narrow-bandwidth line with shifting mean frequency
- Here, 'Hump' at 0.16 f_{rev}:





“hump” = Broad-Band Perturbation Source(s) in Vicinity of Nominal Tune Working Points (mainly beam 2 vertical plane)

excluded sources:

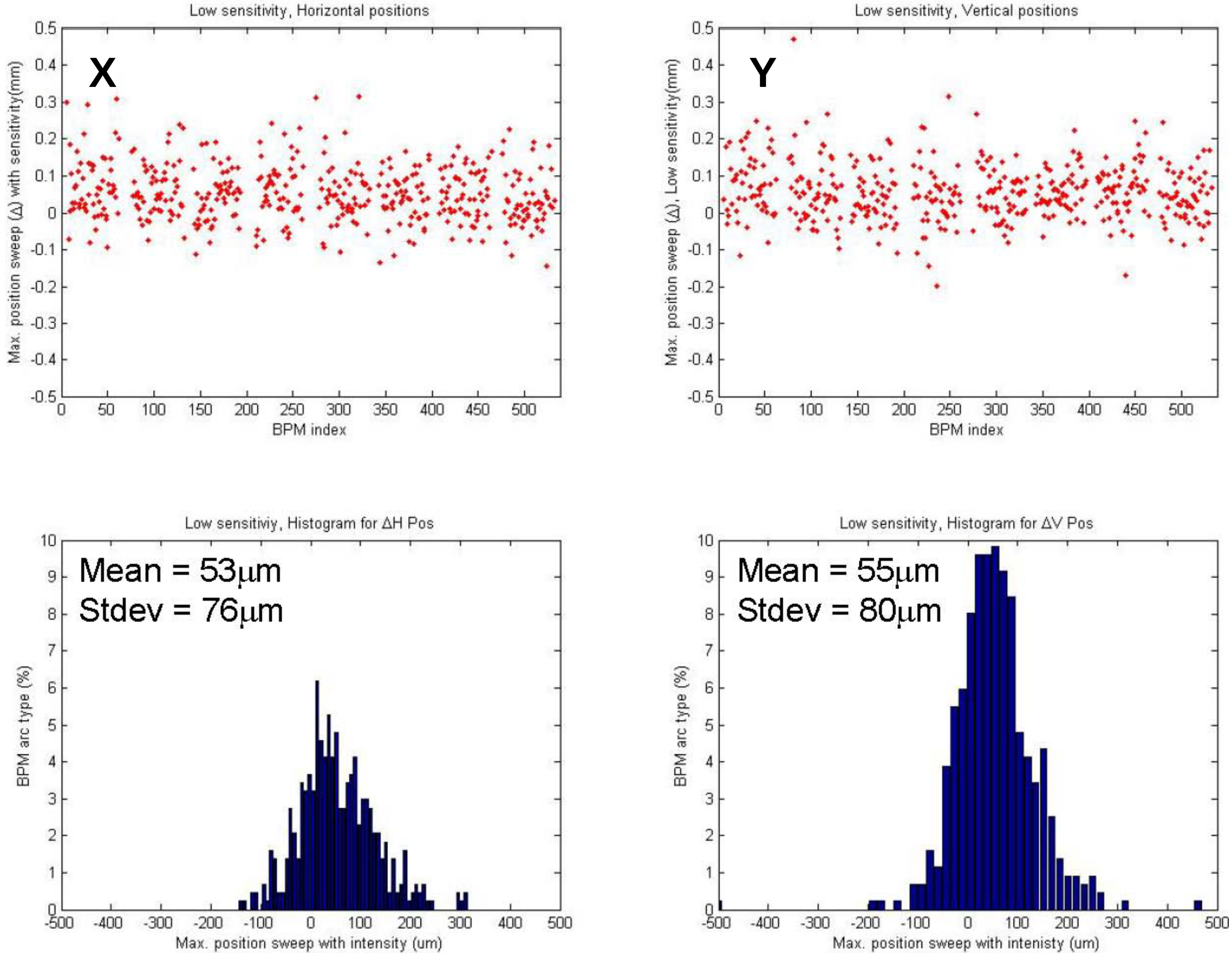
experimental dipoles/compensators
CMS solenoid, TL magnets
60-120-600 A orbit correctors
RCO/RCD/RSS cirxuits
Damper, AC Dipole

further studies:

to cause oscillation of **10 nm: BL=1e-7 Tm**; e.g. current of a few mA over 10 m; **ATLAS solenoid, detector power lines? Vibrations induced by He flow in beam screens? UPS systems?**

R. Steinhagen, G. Arduini

LHC – BPM orbit vs. intensity



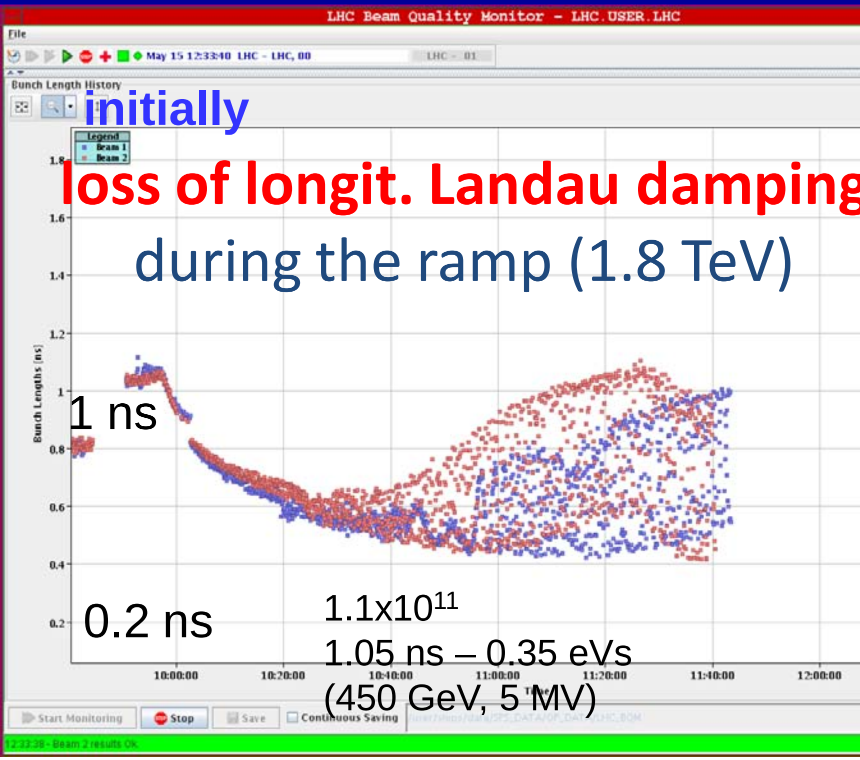
arc BPM reading change between 5x10^{10} and 10^{11} protons per bunch

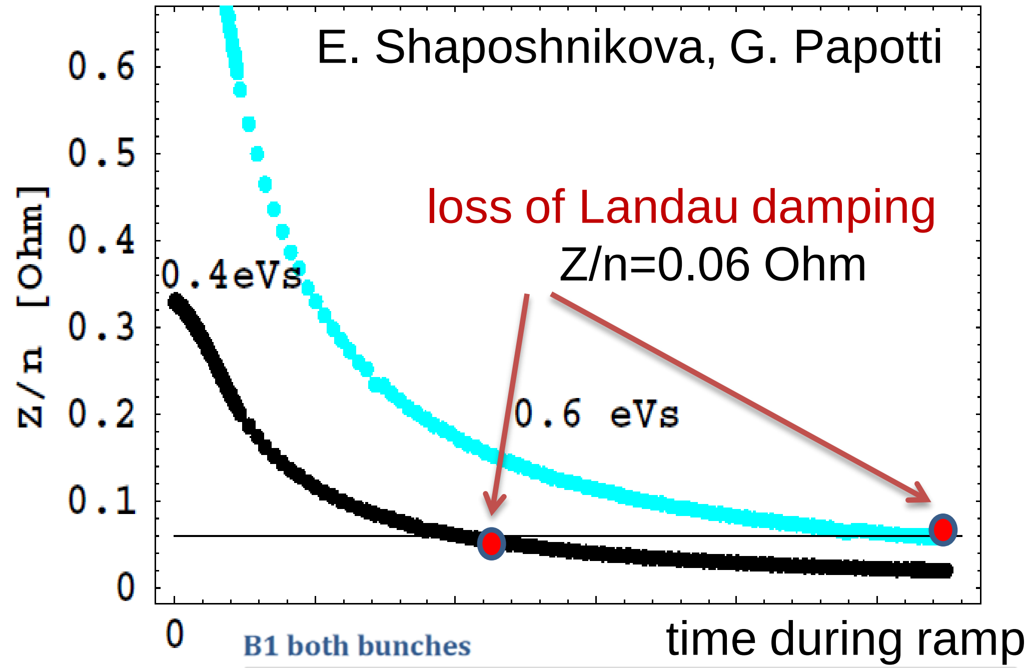
→

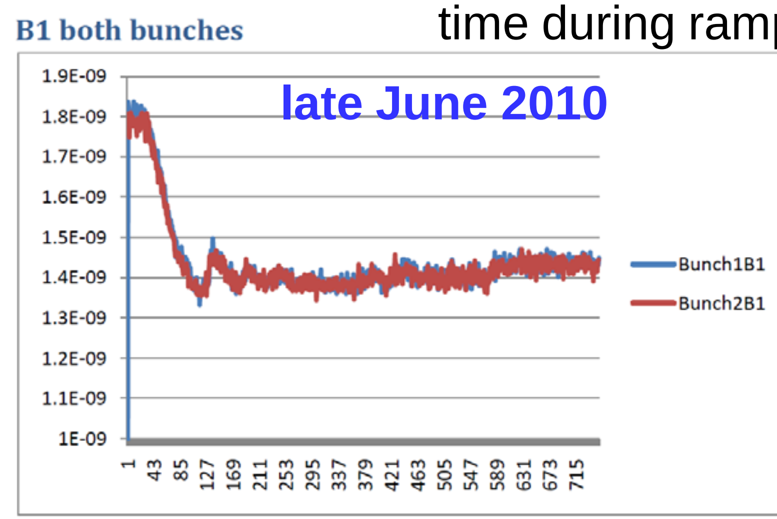
machine protection issue, electronic artifact, impedance effect?

R. Jones

LHC – longitudinal instability





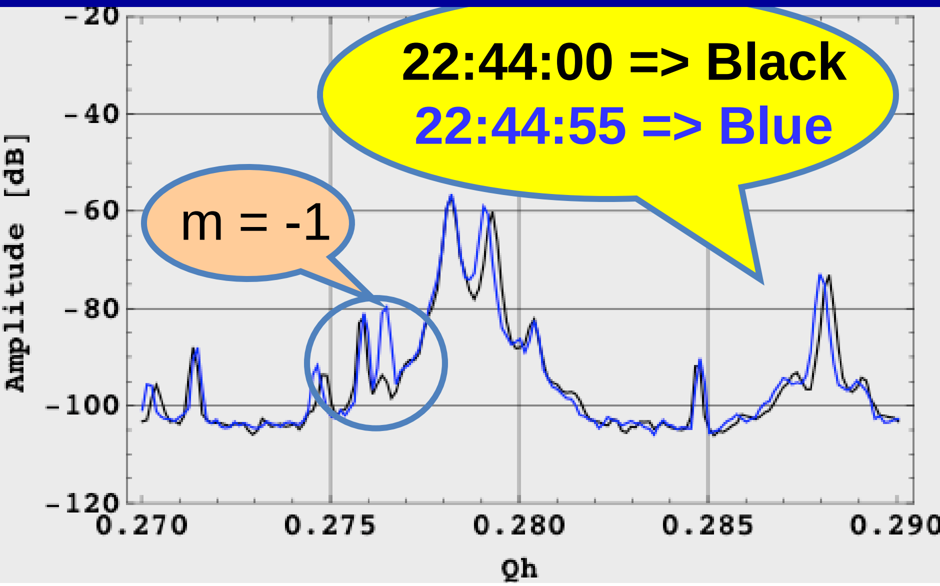


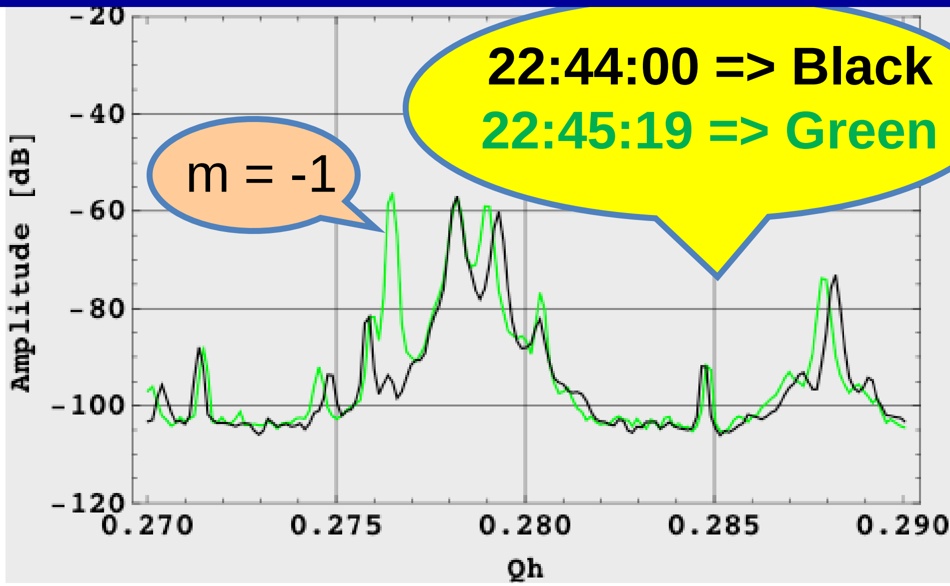
cures:

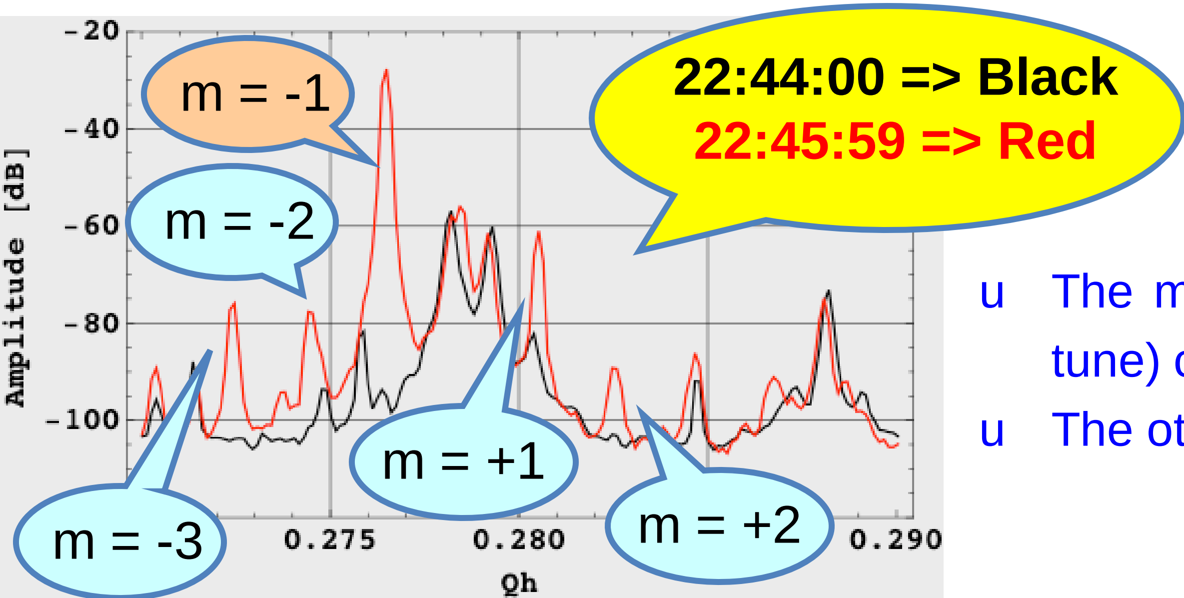
- **increased longitudinal emittance from SPS**
- **change in LHC RF voltage profile**
- **controlled longitudinal blow up on LHC ramp**

feedback on bunch length measurement modulates noise amplitude to control blow-up rate bunch lengths converge correctly to target ~1.5 ns

LHC – transverse instability





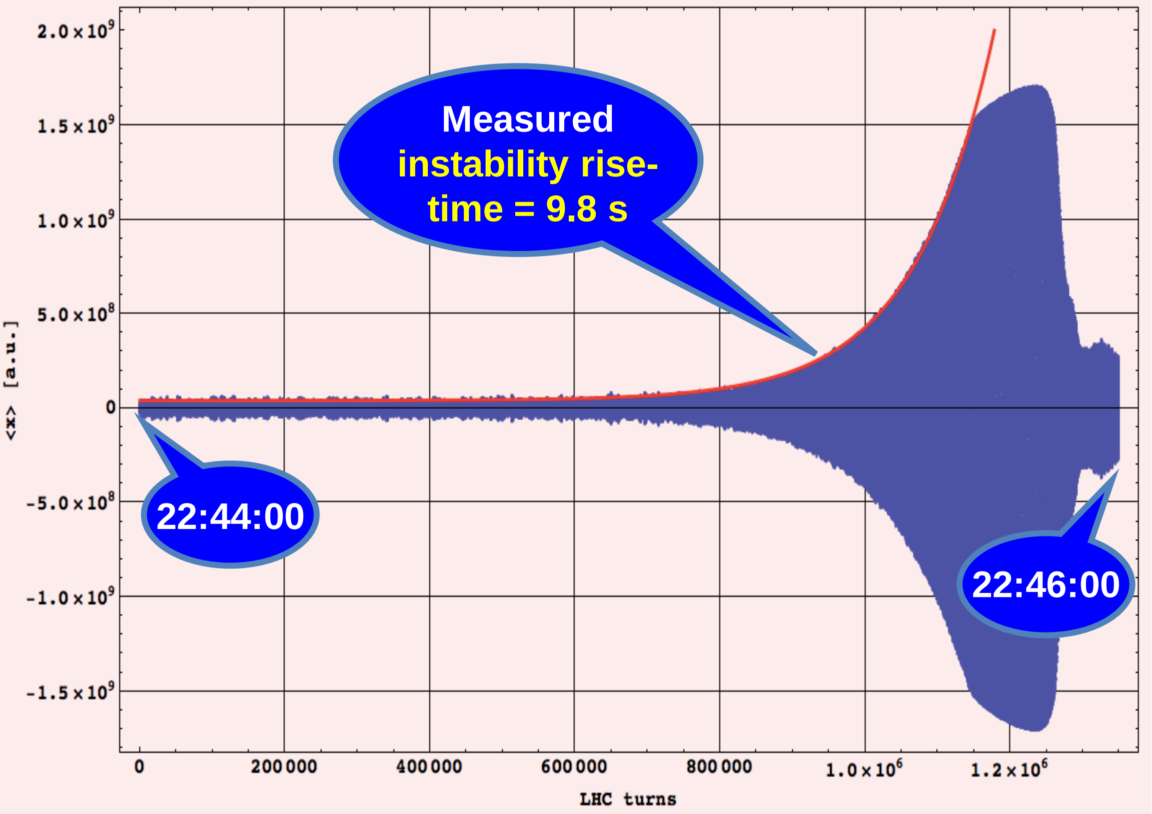


dedicated experiment
17 May 2010

- The mode *m* = -1 (at - Qs from the tune) clearly grows up (Qs ~ 2E-3)
- The other Head-Tail modes follow

E. Metral

LHC – transverse instability



Head-Tail instability of mode *m* = - 1 (for $Q_x' \sim 6$)

measured instability rise-time ~ 9.8 s (with 10 A in the Landau octupoles): simulation predicts ~4.3 s, without octupoles

beam could be stabilized by Landau damping with ~20 A current in octupoles (small fraction of maximum)

cures:

- **better control of chromaticity *Q'*~2**
- **transverse damper**
- **Landau octupoles**

damper and octupoles are normally switched off after bringing beams in collision

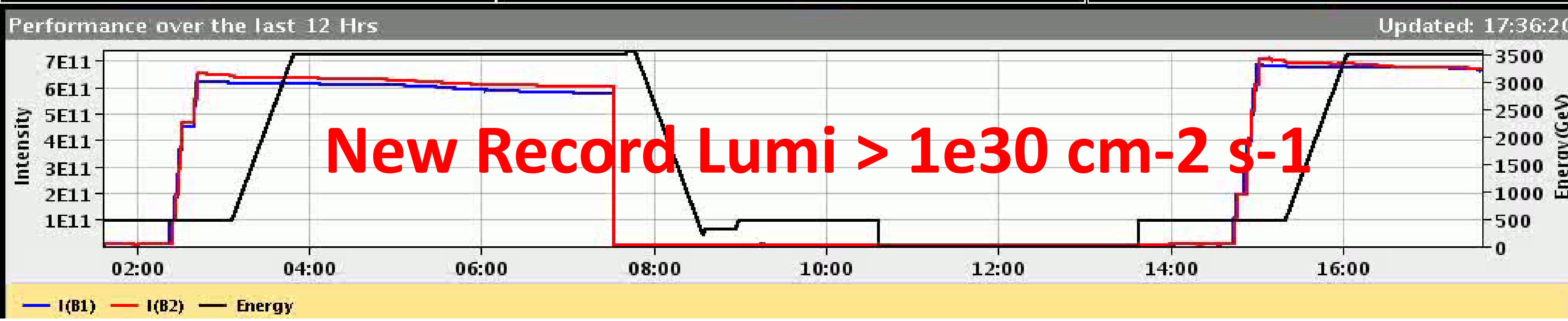
E. Metral

LHC – recent luminosity record

02-Jul-2010 17:36:21 Fill #: 1192 Energy: 3500 GeV I(B1): 6.65e+11 I(B2): 6.70e+11

	ATLAS	ALICE	CMS	LHCb
Experiment Status	PHYSICS	PHYSICS	PHYSICS	PHYSICS
Instantaneous Lumi (ub.s)^-1	1.054	0.004	1.172	1.047
BRAN Count Rate (Hz)	1.098e+04	3.100e+01	1.657e+04	2.124e+04
BKGD 1	0.028	0.016	2.416	0.169
BKGD 2	0.000	0.008	0.002	1.974
BKGD 3	0.000	0.005	0.003	0.060

LHCf MOVING Count(Hz): 0.114 | LHCb VELO Position OUT Gap: 58.0 mm | TOTEM: STANDBY




```
Emittances before ramp :
B1 H: 2.5
B1 V: 2.5
B2 H: 2.5
B2 V: 3.0 (measure not so good)
```

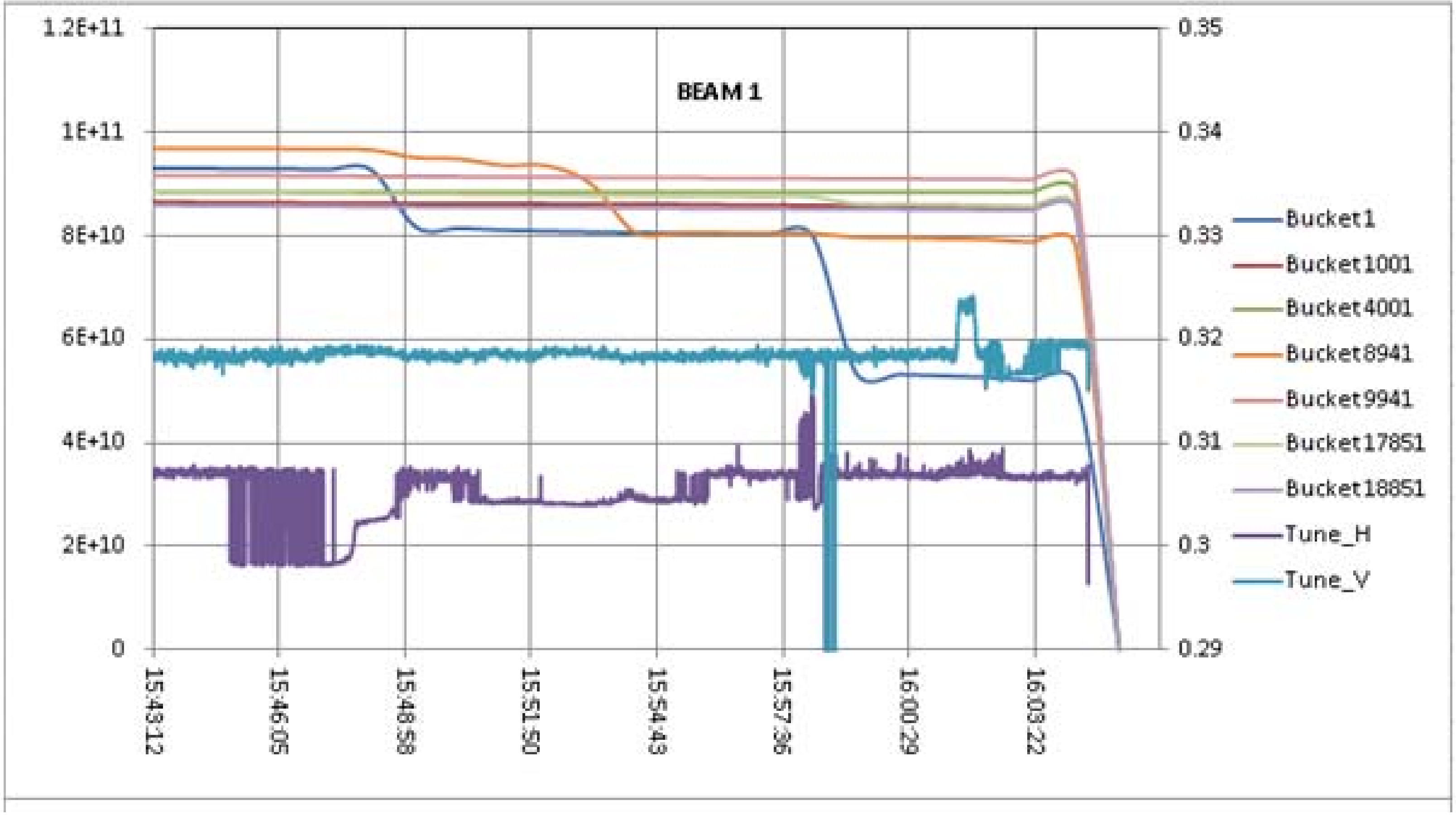
```
Emittances meas during the ramp
B1 H:4.2
B1 V:5.1

B2 H:2.3
B2 V:2.9
```

7x7 bunches

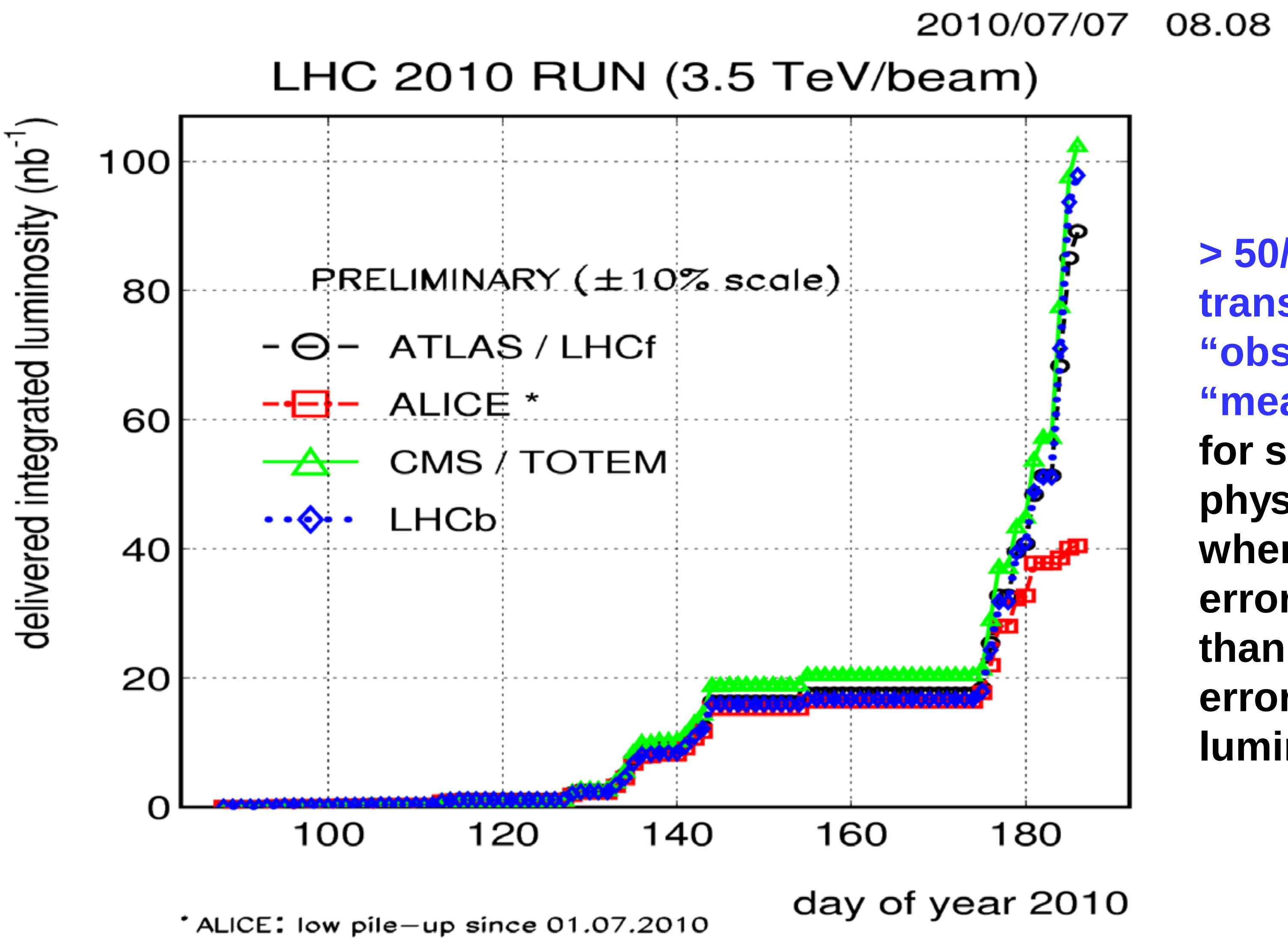
LHC – loss due to beam-beam?

Bunch Intensity versus Time



different bunches lose differently ➔ beam-beam effects

LHC – integrated luminosity

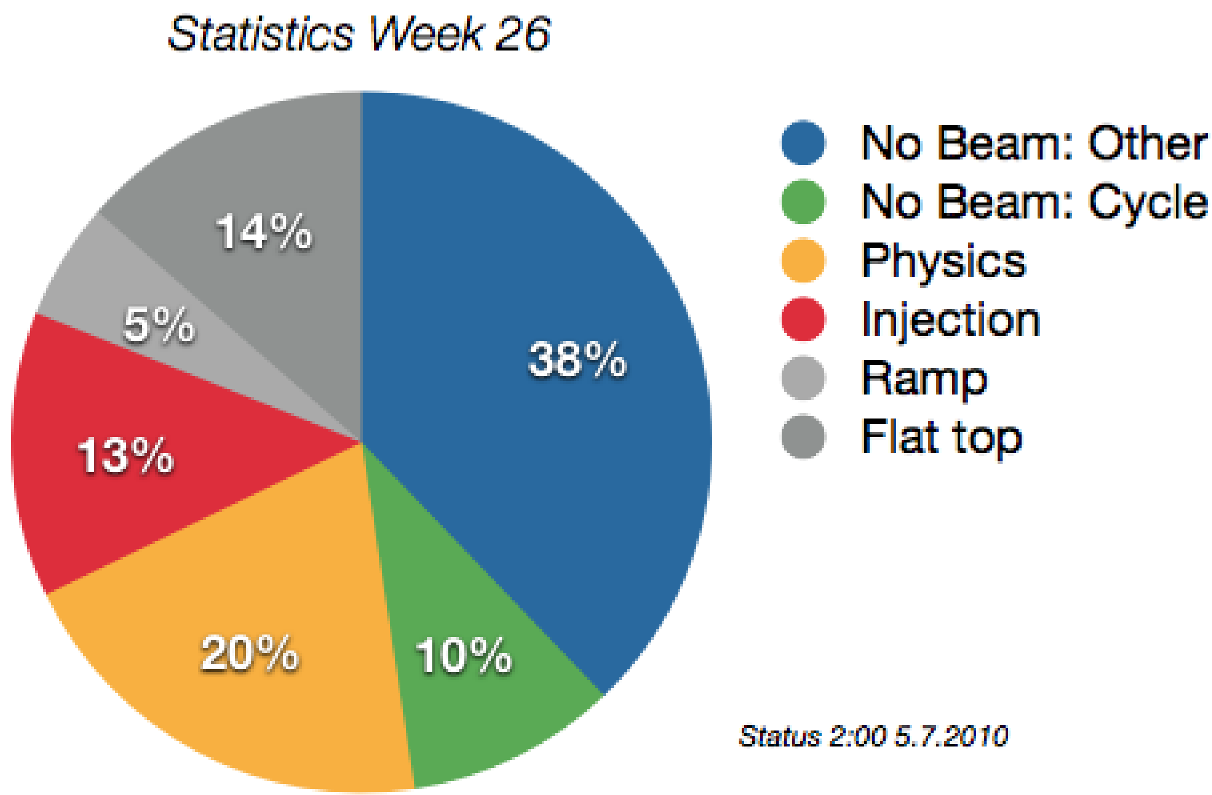


> 50/nb: transit from "observation" to "measurement" for some of the physics channels, where the statistical error now is smaller than the systematic error of the luminosity value

Courtesy M. Ferro-Luzzi

LHC – statistics week 26, 2010

	No Beam: Other	No Beam: Cycle	Physics	Injection	Ramp	Flat top
Fraction	38.3%	9.9%	20.5%	13.3%	5.5%	13.7%
Time [h]	*64:19*	*16:34*	*34:28*	*22:23*	*9:12*	*23:04*



R. Assmann

LHC plan for next decade

LHC – plan for 2010

Main goal for 2010:

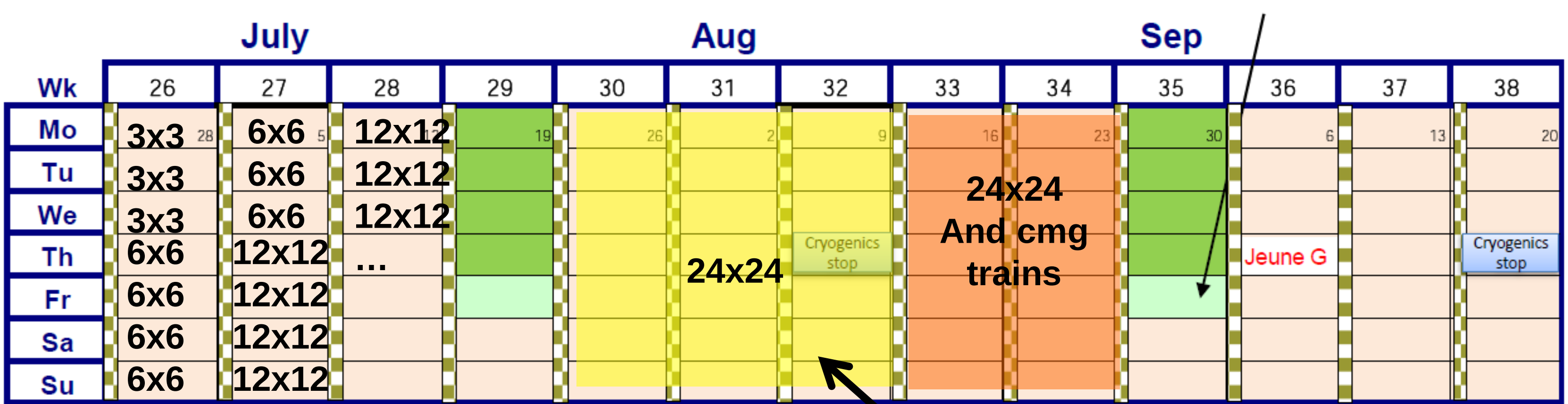
Commissioning of peak luminosity of 10^{32} cm^{-2} sec^{-1}

➔ requires ca. 800 bunches with $N_b > 8\ 10^{10}$ ppb and $\beta^* = 3.5$ m

or ca. 400 bunches with $N_b > 8\ 10^{10}$ ppb and $\beta^* = 2$ m

➔ implies operation with stored beam energies above 30 MJ

compared to operation with ca. 2 MJ in Tevatron

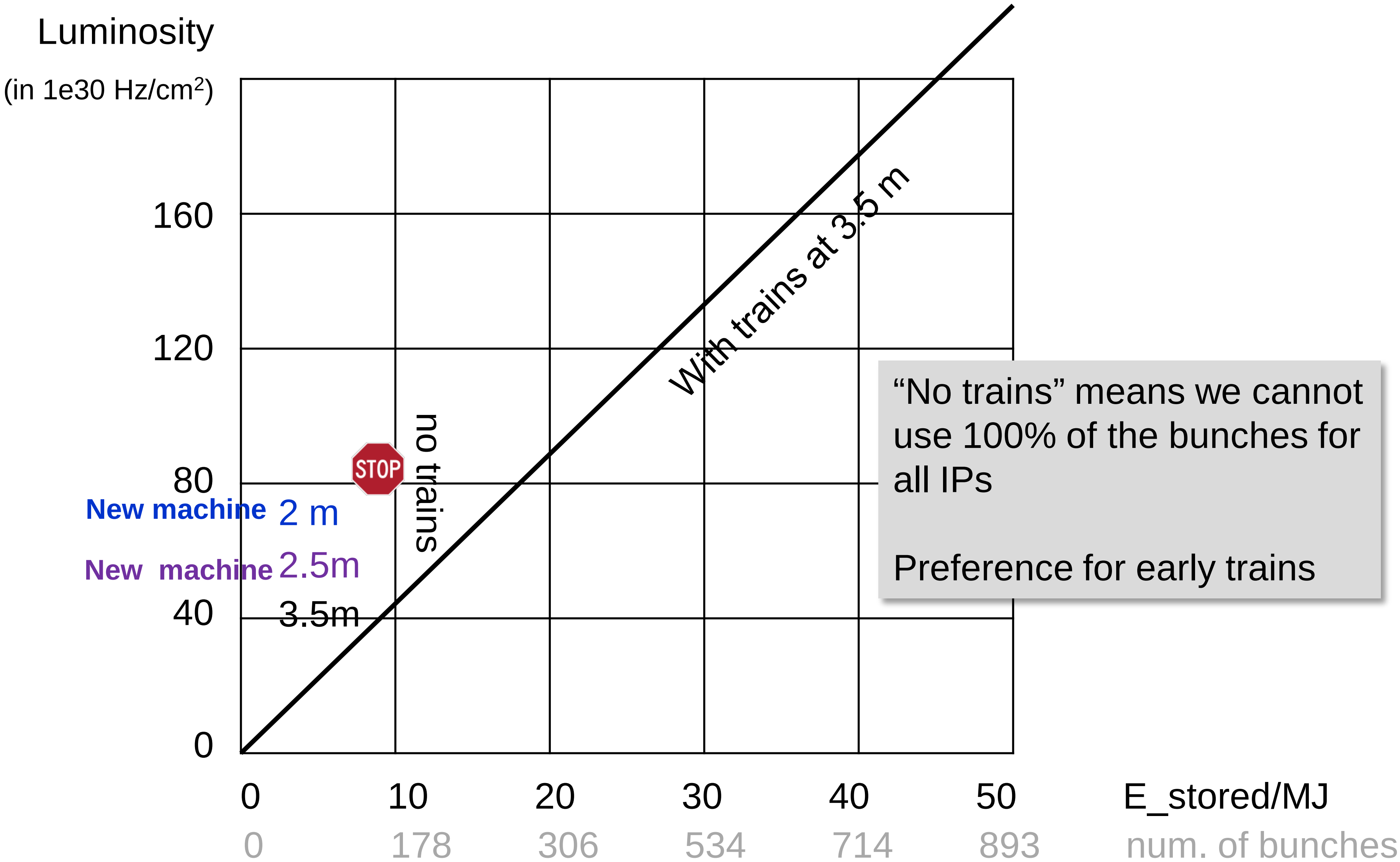


(6x6 became 7x7)

4×10^{30} cm^{-2} sec^{-1}

O. Bruning, M. Ferro-Luzzi

LHC – case for bunch trains



“No trains” means we cannot use 100% of the bunches for all IPs

Preference for early trains

M. Ferro-Luzzi

LHC – plan for 2011

3.5 TeV: run flat out at ~100 pb^{-1} per month

	# bunches	Particles per bunch	Total # protons/ beam	Beam energy [MJ]	beta* [m]	Peak Luminosity [$1/cm^2/s$]	Integrated Luminosity per month [pb^{-1}]
baseline	432	7 e10	3 e13	17	2.5	7.4 e31	~63 (34)
pushing limit	796	7 e10	5.1 e13	31	2.5	1.4 e32	~116 (63)

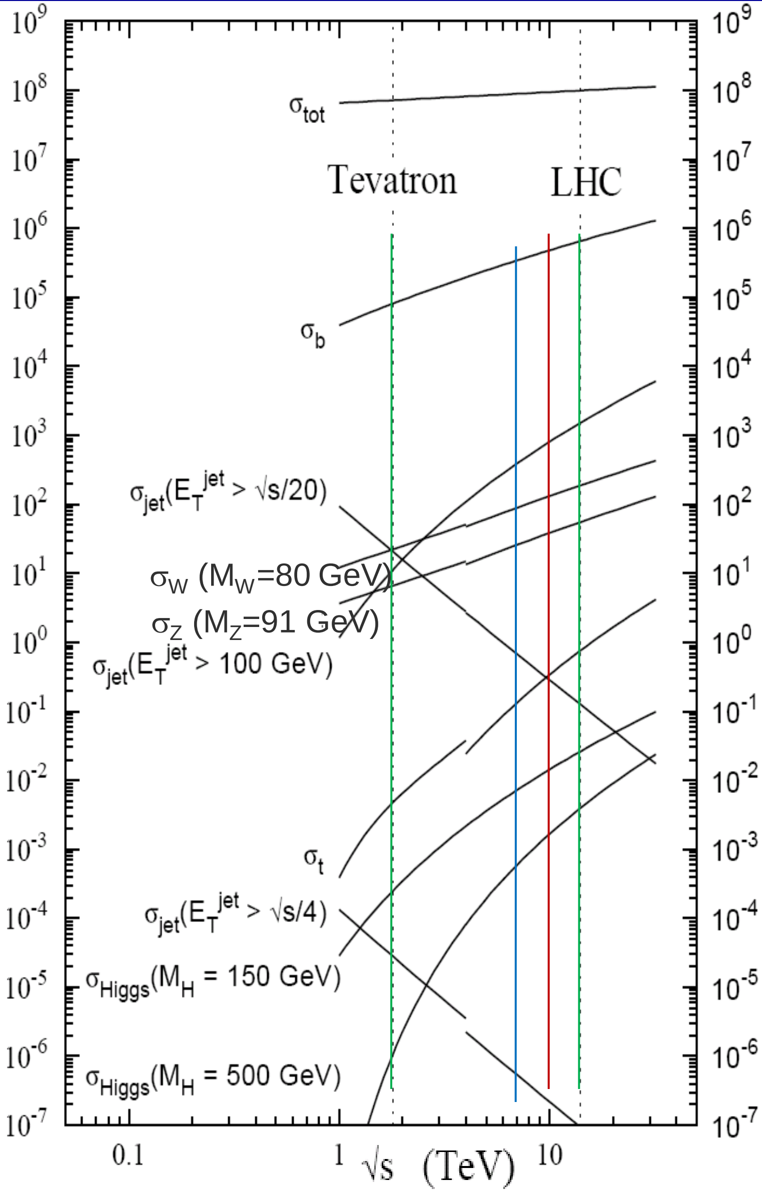
16% of nominal

should be able to **deliver around 1 fb^{-1} by the end of 2011**

M. Lamont

LHC – why 1/fb by 2011?

master plot cross section vs. energy



with1/fb at 7 TeV c.m. LHC will compete with or surpass Tevatron in virtually all physics
(Higgs searches, Z' resonances, B physics,…)

M. Ferro-Luzzi

LHC – ult. performance limits

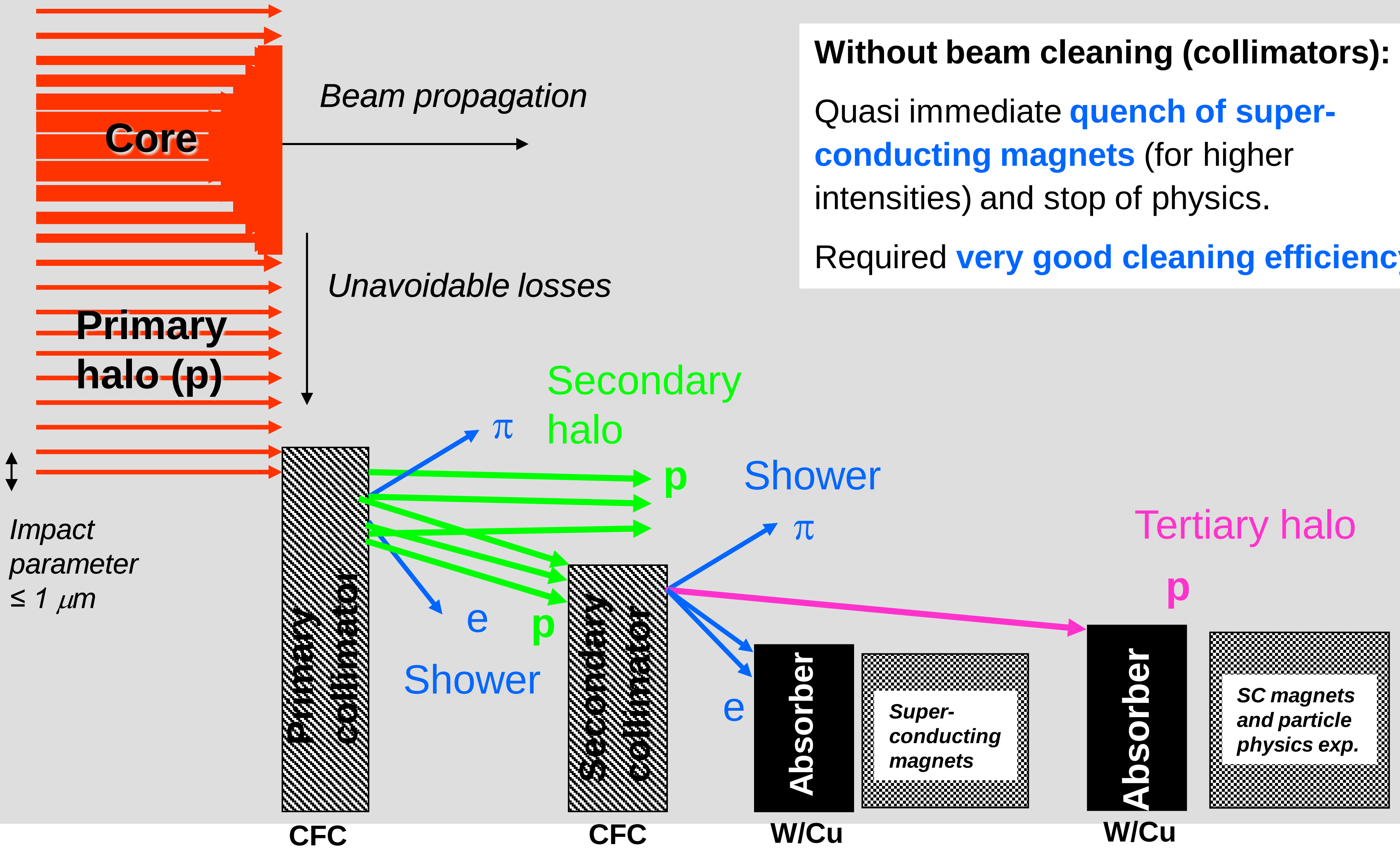
- **machine protection**
- **collimation** cleaning efficiency
- head-on & long-range **beam-beam** interaction
- **electron cloud**
- collimator impedance
- **hardware** limits for intensities above nominal
- **injector** limits
- **triplet aperture & chromatic correction**
- **radiation effects** (electronics, magnets)
- …

LHC – multistage cleaning

Without beam cleaning (collimators):

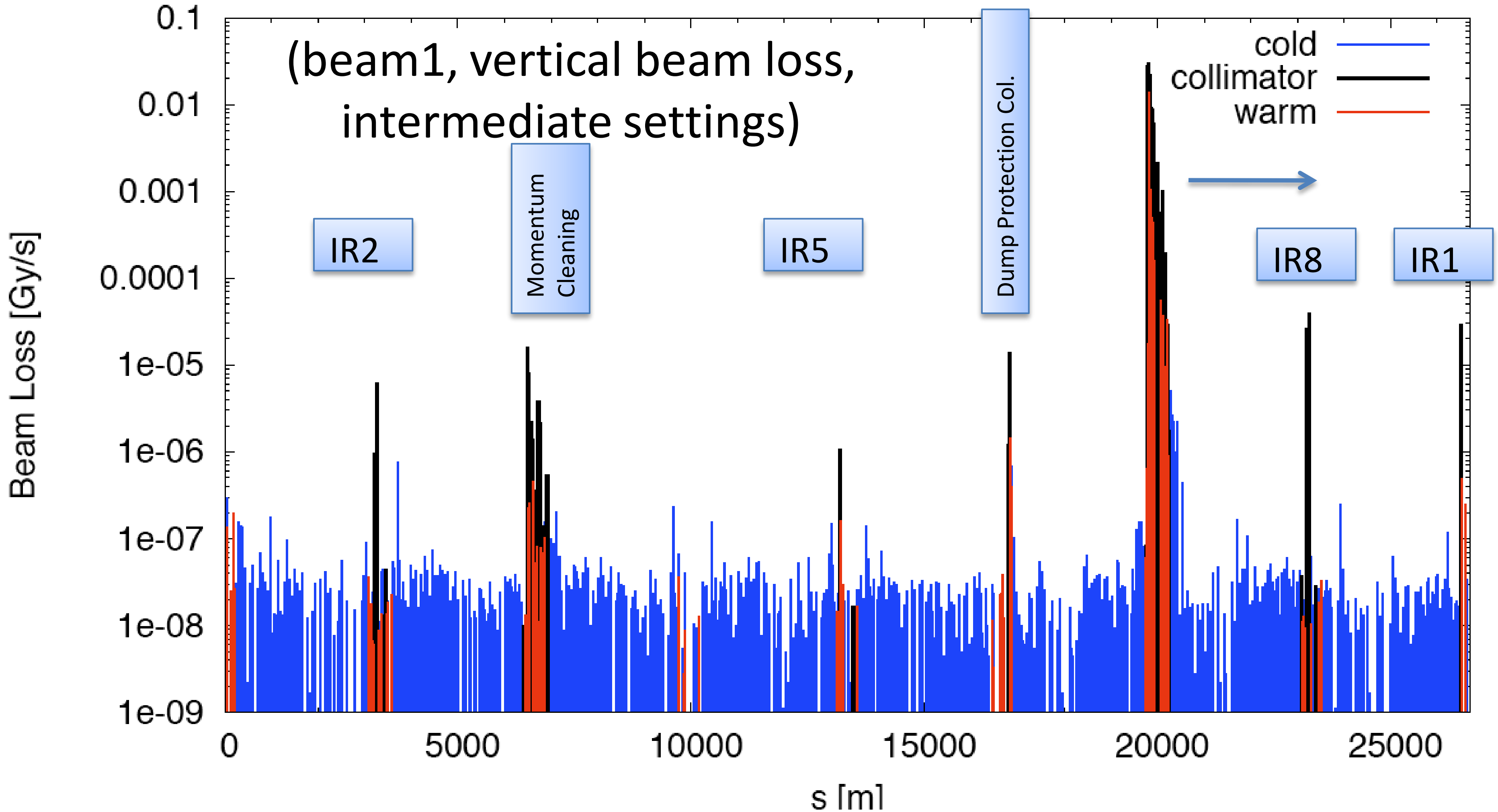
Quasi immediate **quench of super-conducting magnets** (for higher intensities) and stop of physics.

Required **very good cleaning efficiency**



R. Assmann

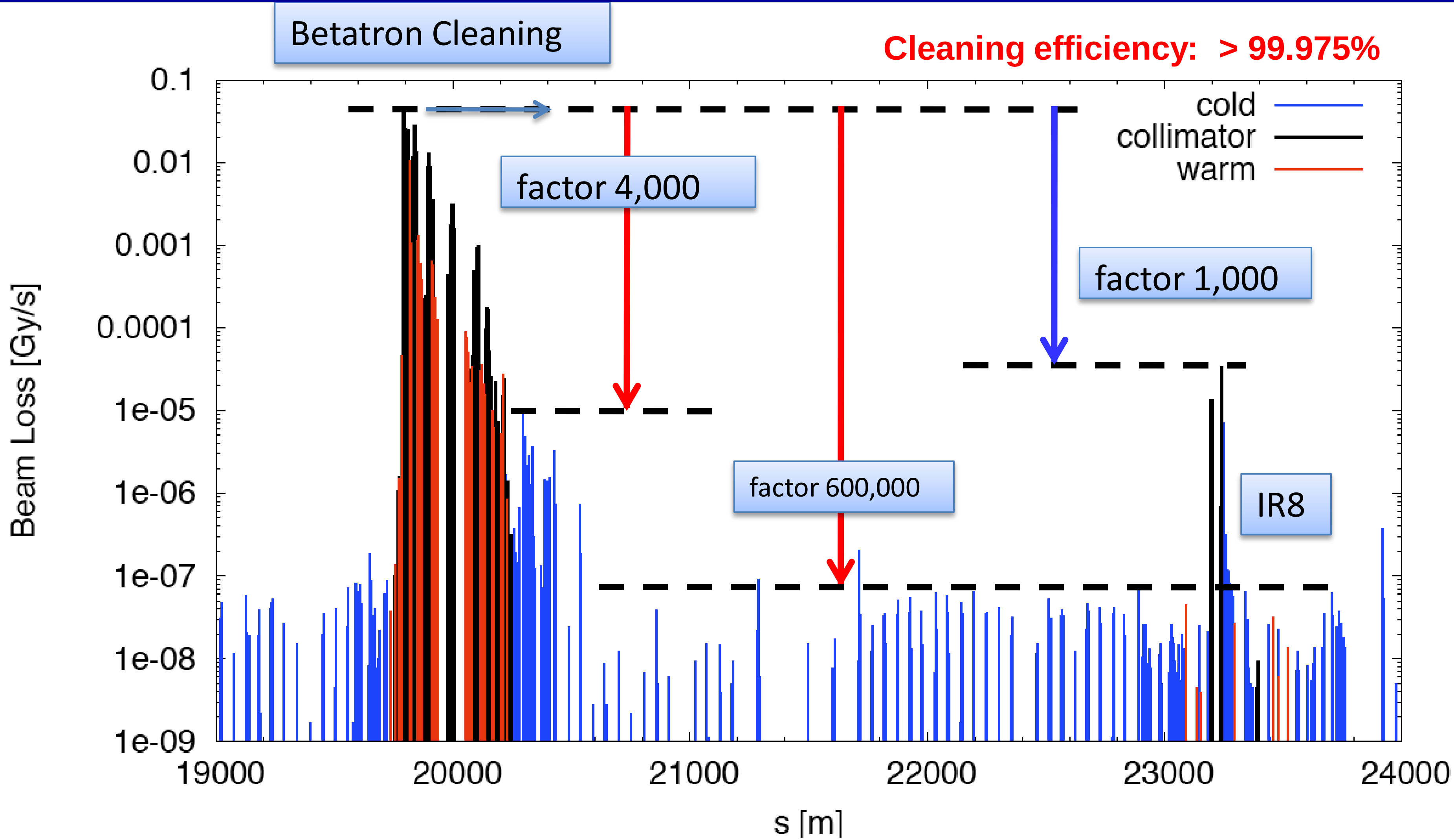
LHC – measured cleaning at 3.5 TeV



2m beta* optics exposes IR's as expected! Protected by tertiary collimators.

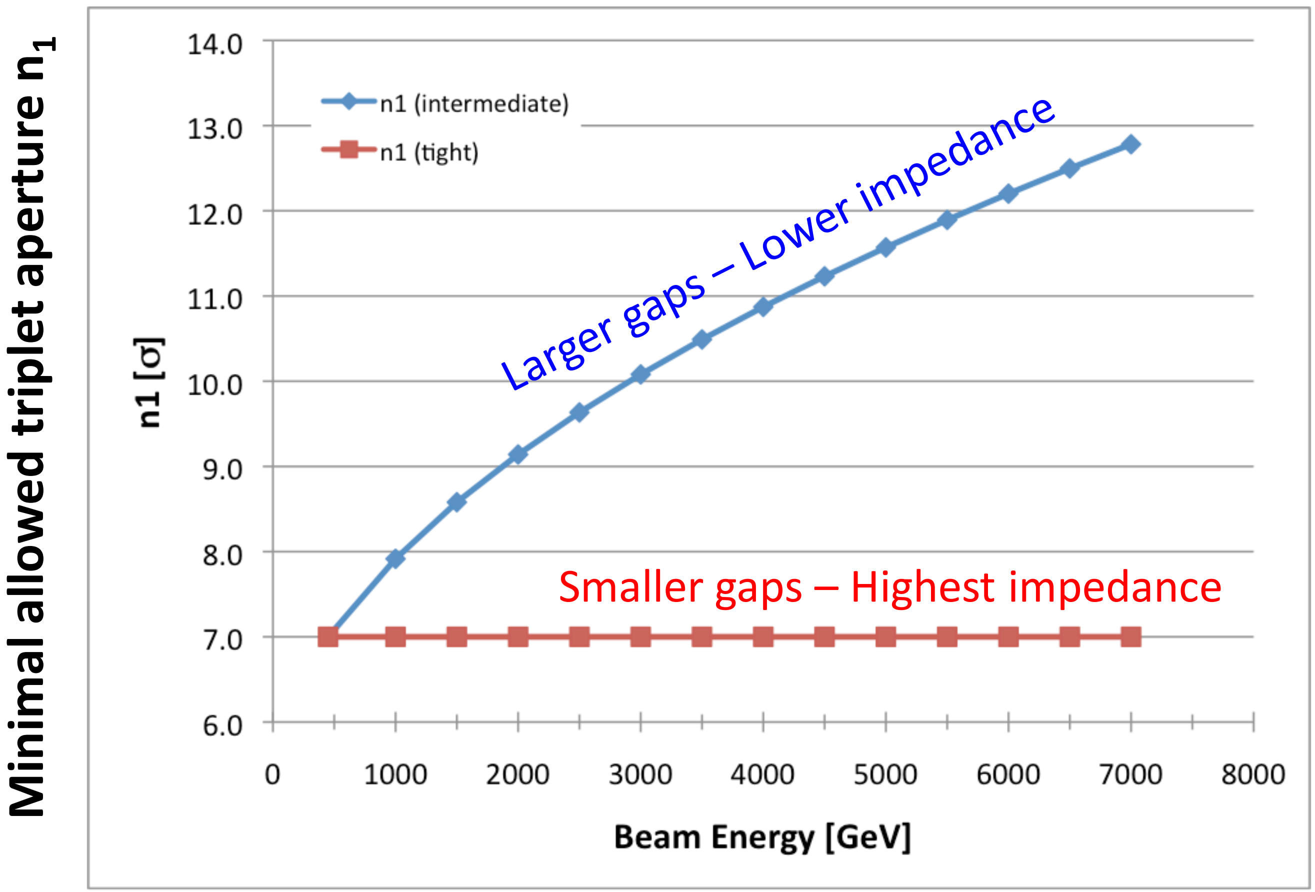
R. Assmann

LHC – measured cleaning at 3.5 TeV



R. Assmann

LHC – collimator gap size vs β^*



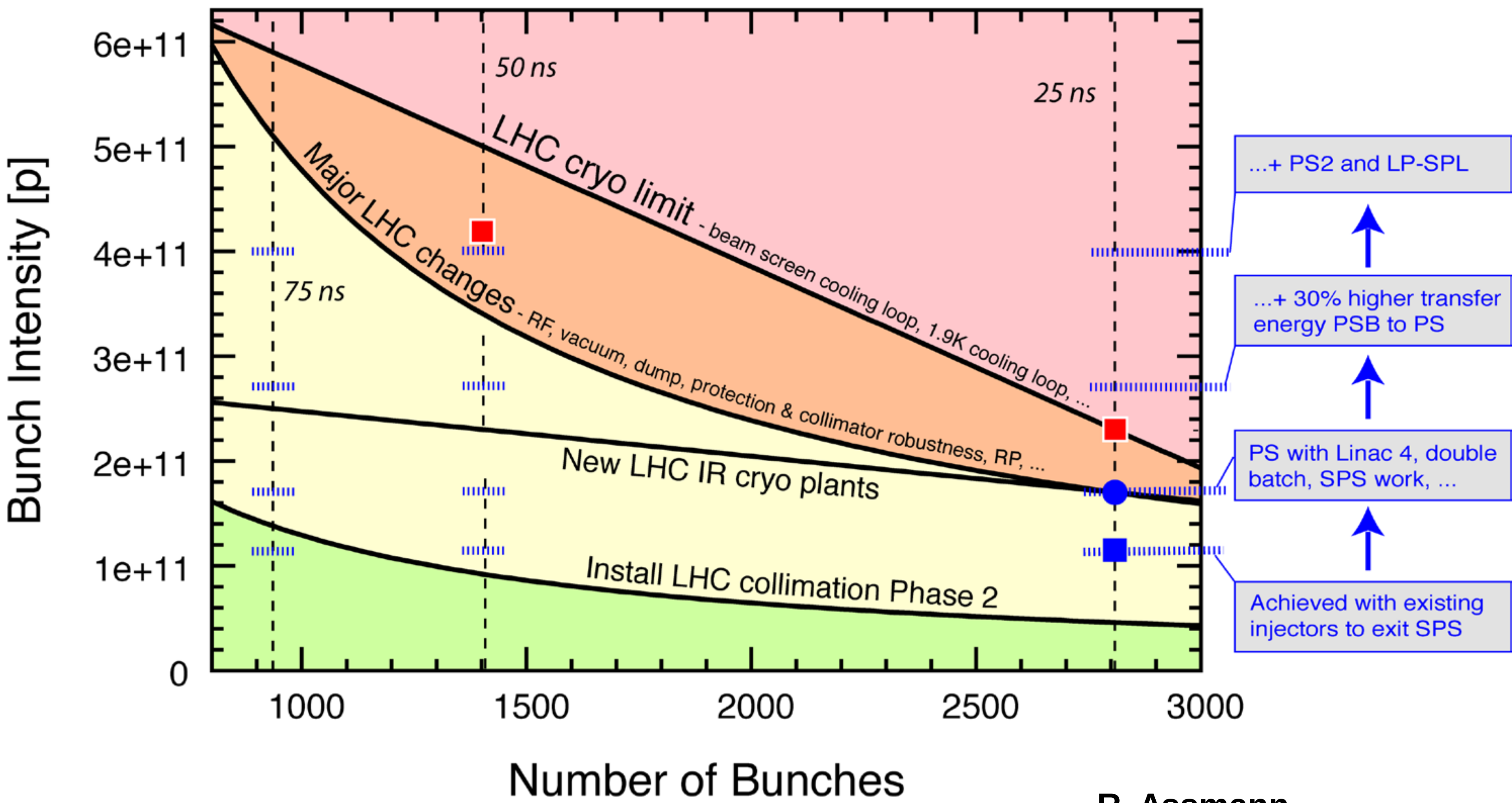
- Larger beta*
- Lower peak lumi
+ Larger tolerances

+ Lower beta*
+ Higher peak lumi
- Lower tolerances

At 3.5 TeV: “n_1” ≥ 10.5 for intermediate collimation settings

R. Assmann, C. Bracco

LHC –LHC intensity limits

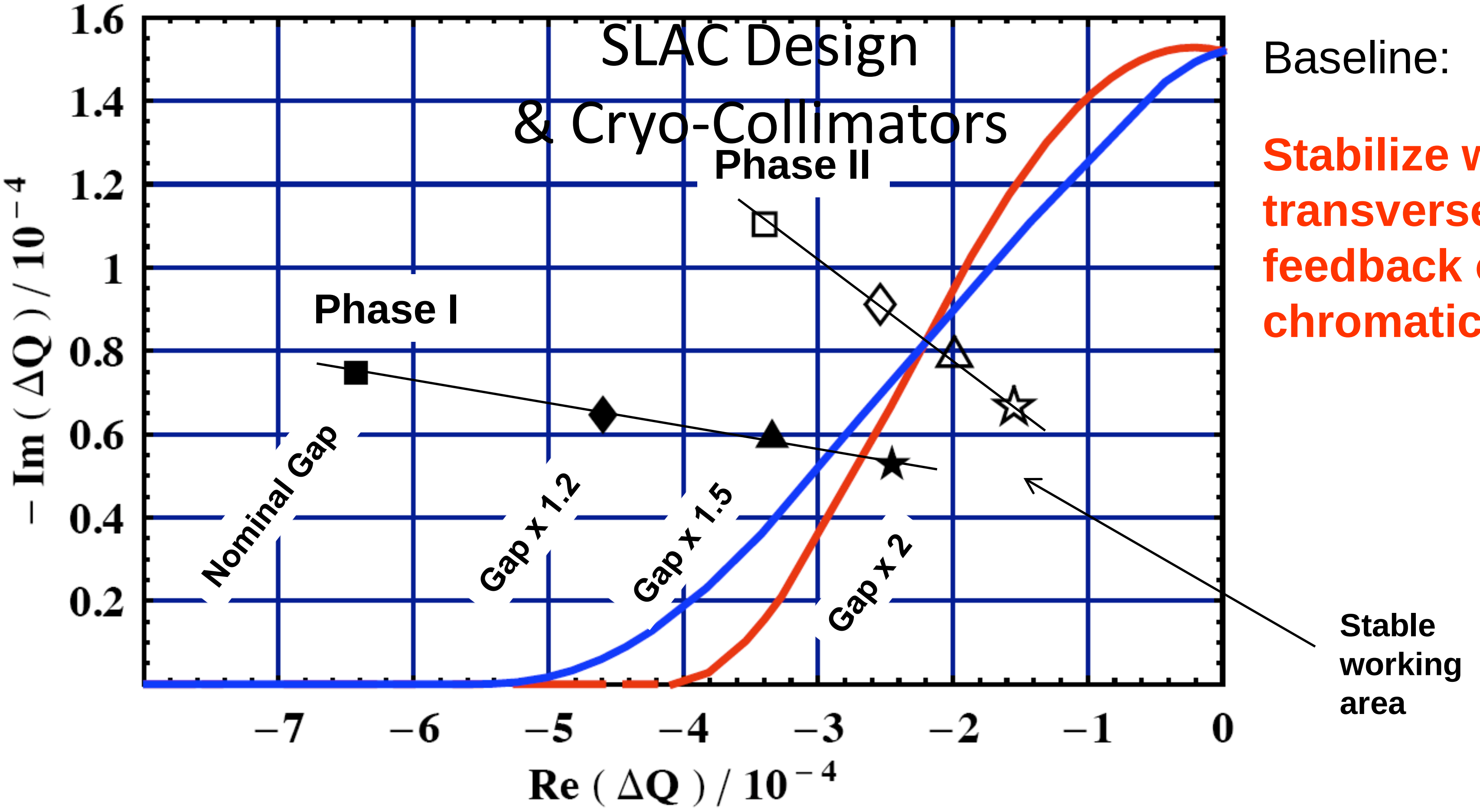


R. Assmann

Ideal scenario: no imperfections included!

Note: Some assumptions and conditions apply…

LHC – collimator impedance



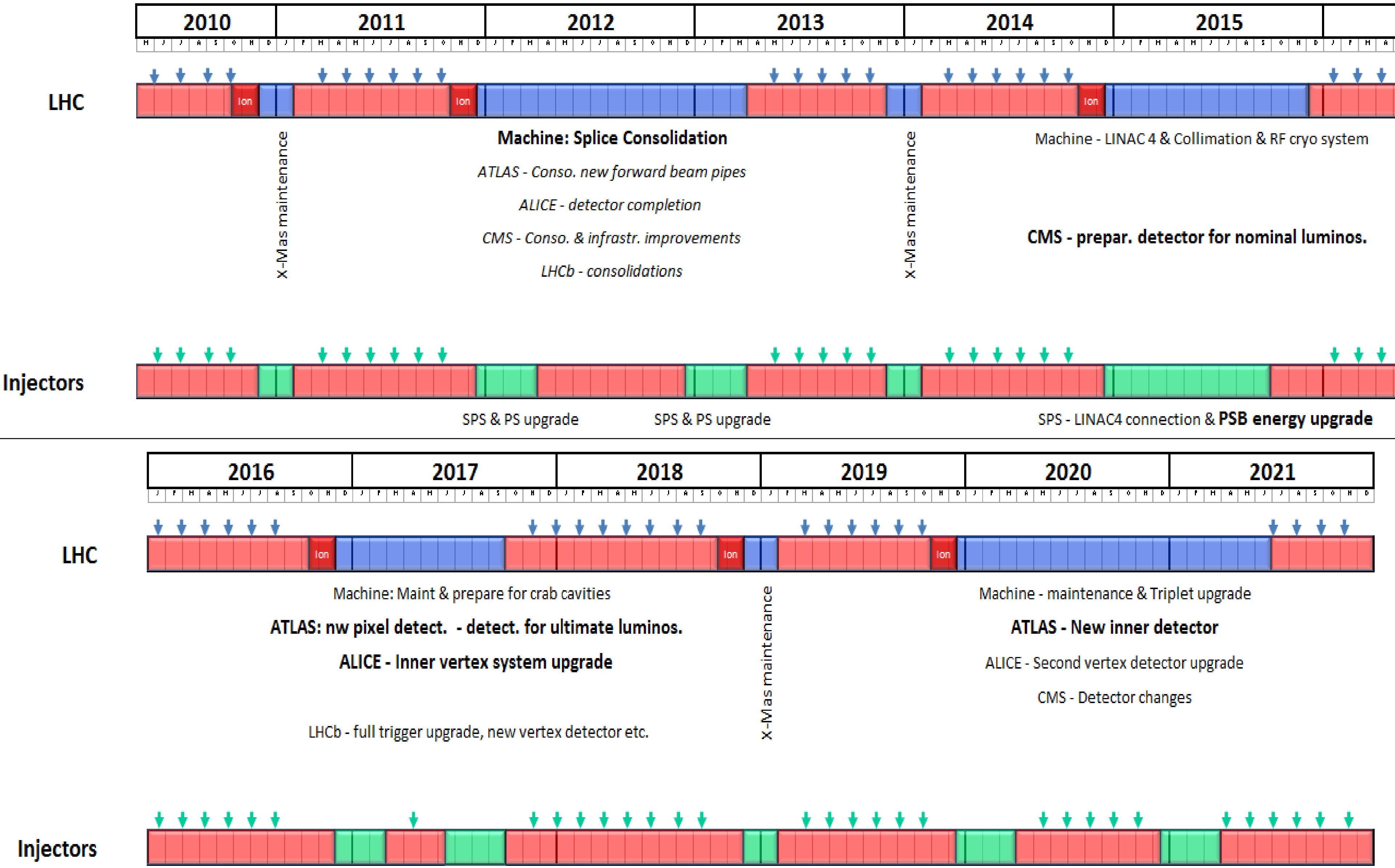
Baseline:

Stabilize with transverse feedback or chromaticity!

Metallic Cu secondary collimators (phase II) require less gap opening for stability ➔ illustrates lower impedance compared to phase I!

R. Assmann, E. Metral

LHC – preliminary plan 2012-20



High-Luminosity LHC

"HL-LHC"

HL-LHC - motivation & status

motivation:

- reducing **statistical errors** by factor 3
- **radiation damage** limit of IR quadrupoles ~400/fb
- extending **physics potential**; boost **discovery mass reach** from about 6.5 to 8 TeV

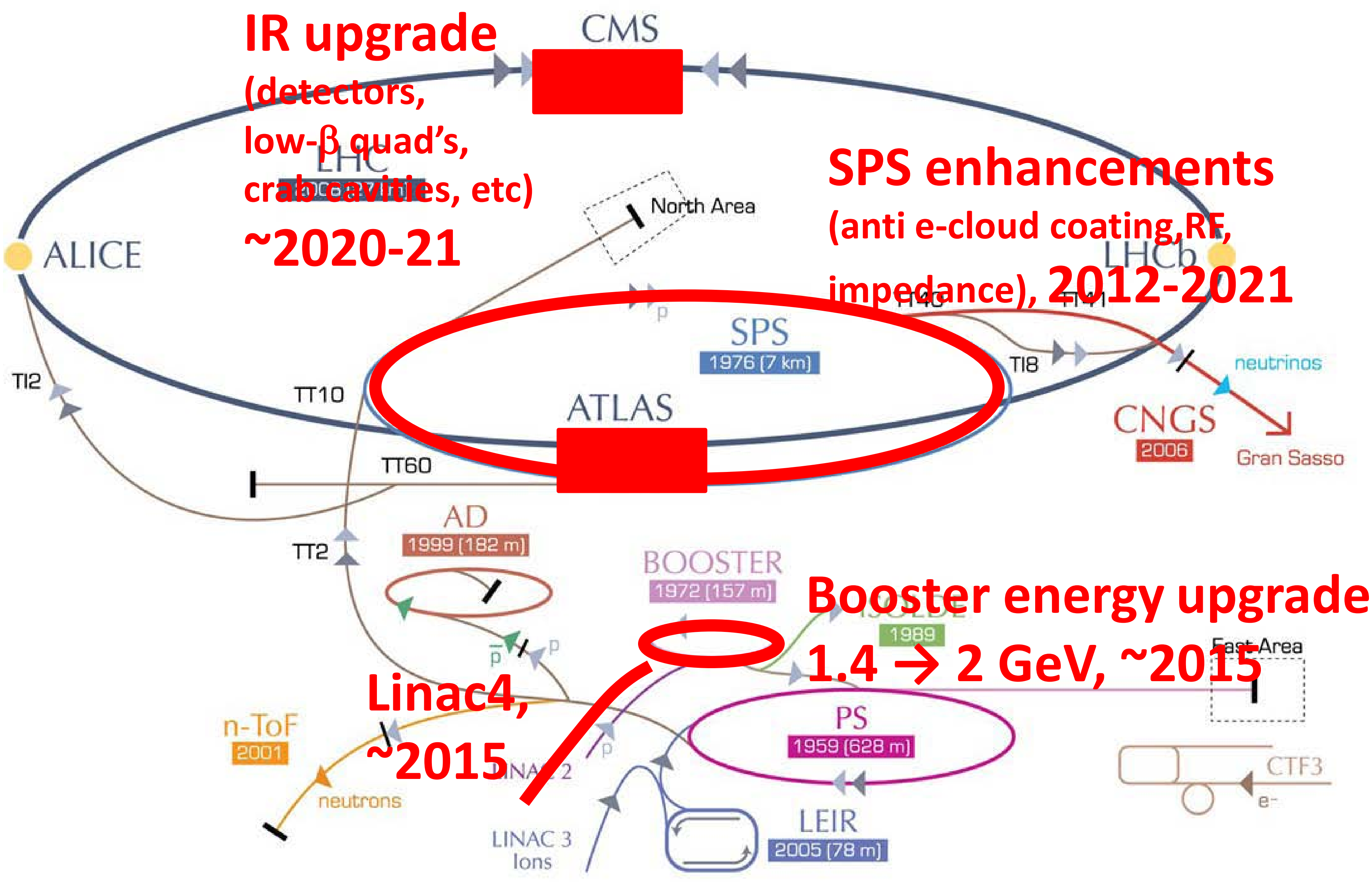
status:

- **major revision** of LHC upgrade plan & schedule at and after Chamonix2010 workshop
- **LINAC4** under construction; **collimation "phase II"** defined; **Nb-Ti and Nb_3Sn low-β quadrupole prototypes** under development; **crab-cavity R&D** ongoing ; **PS booster energy upgrade** preparation
- embedded in European & international **collaborations**

HL-LHC – example parameters

parameter	symbol	**nom.**	nom.*	**HL-LHC**	LPA – 25	LPA – 50
protons per bunch	N_b [10^{11}]	**1.15**	1.7	**1.6**	**2.6**	**4.2**
bunch spacing	Δt [ns]	**25**	50	**25**	**25**	**50**
beam current	I [A]	**0.58**	0.43	**0.81**	**1.32**	**1.06**
longitudinal profile		**Gauss**	Gauss	**Gauss**	**Flat**	**Flat**
rms bunch length	σ_z [cm]	**7.55**	7.55	**7.55**	**11.8**	**11.8**
beta* at IP1&5	$\beta*$ [m]	**0.55**	0.55	**0.14**	**0.50**	**0.25**
full crossing angle	θ_c [μrad]	**285**	285	**(509)**	**339**	**381**
Piwinski parameter	$\phi=\theta_c\sigma_z/(2*\sigma_x*)$	**0.65**	0.65	**0.0**	**2.0**	**2.0**
tune shift	ΔQ_{tot}	**0.009**	0.0136	**0.01**	**0.01**	**0.01**
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	**1**	1.1	**7.9**	**4.0**	**7.4**
peak events per #ing		**19**	40	**150**	**75**	**280**
initial lumi lifetime	τ_L [h]	**23**	16	**4.0**	**12.4**	**5.3**
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	**0.55**	0.56	**1.5**	**1.9**	**2.6**
	$T_{run,opt}$ [h]	**15.2**	12.2	**9.3**	**11.3**	**7.5**
e-c heat SEY=1.3	P [W/m]	**0.4**	0.1	**0.7**	**1.4**	**0.8**
SR+IC heat 4.6-20 K	P_{SR+IC} [W/m]	**0.32**	0.30	**0.53**	**0.77**	**0.82**
annual luminosity	L_{int}[fb^{-1}]	**57**	58	**158**	**198**	**274**

HL-LHC – LHC modifications



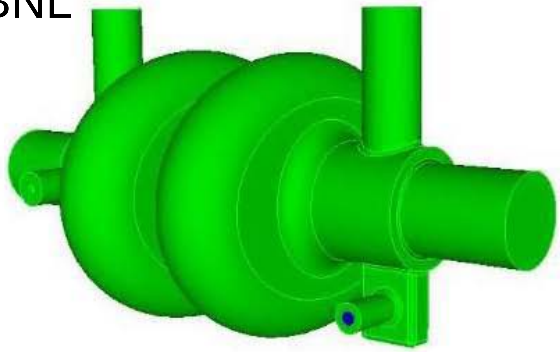
HL-LHC – main issues and R&D

- ***low-β quadrupoles*** *(technology choice)*
- ***chromatic correction*** *and minimum β**
- *modification of matching sections (aperture, strengths)*
- *collimation (cleaning efficiency, impedance, robustness)*
- *machine protection*
- ***crab cavities*** *(novel compact cavity design, compatibility with machine protection)*
- ***beam intensity limits***
- ***detector upgrades***

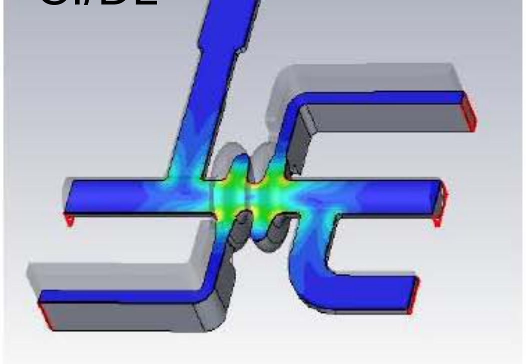
HL-LHC – crab cavity R&D

conventional, elliptical, “global” crab cavities

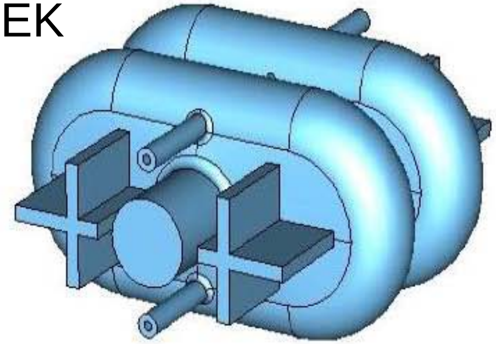
BNL



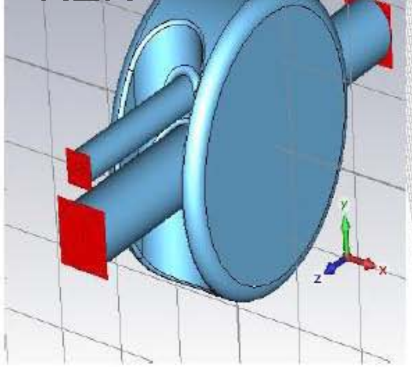
CI/DL



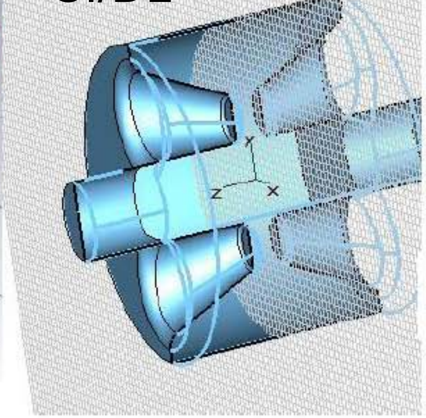
KEK



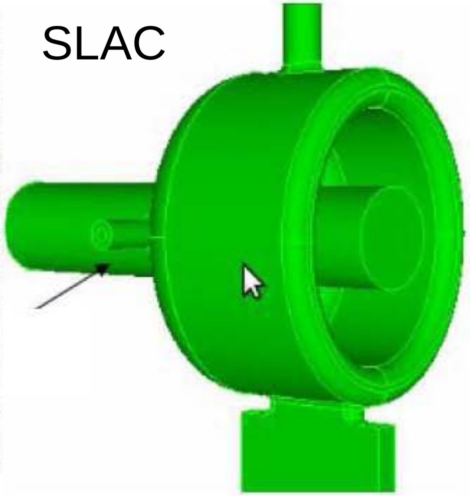
KEK



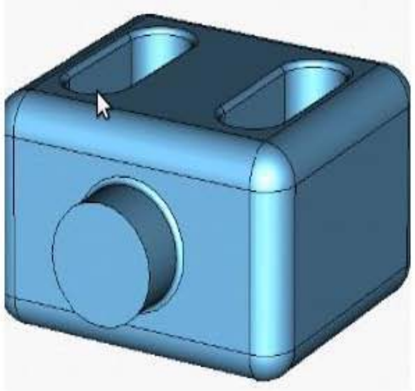
CI/DL



SLAC



JLAB



compact, “local” crab cavities

HL-LHC – present schedule

2010-11: LHC running at 3.5 TeV beam energy; 1/fb

2012-13: >1.0 years of stop to prepare LHC for 7 TeV and high beam intensity

2013-2014: LHC running; decisions for 2020 IR upgrade

~2016: LINAC4 connection, PSB energy upgrade, CMS & ATLAS upgrades, SPS enhancements

2015-20: high-luminosity operation delivering a total of 300-400/fb (lifetime limit of low-β quadrupoles)

2020-21: HL-LHC, IR upgrade: new low-β quadrupoles & crab cavities, major detector upgrades

2021-30: operation at $5 \times 10^{34}/cm^2/s$ w. leveling; 3000/fb

High-Energy LHC

“HE-LHC”

HE-LHC - motivation & status

motivation:

- **lifetime limit of LHC** reached after ~3000/fb
- **boost discovery mass reach to >11 TeV**

status:

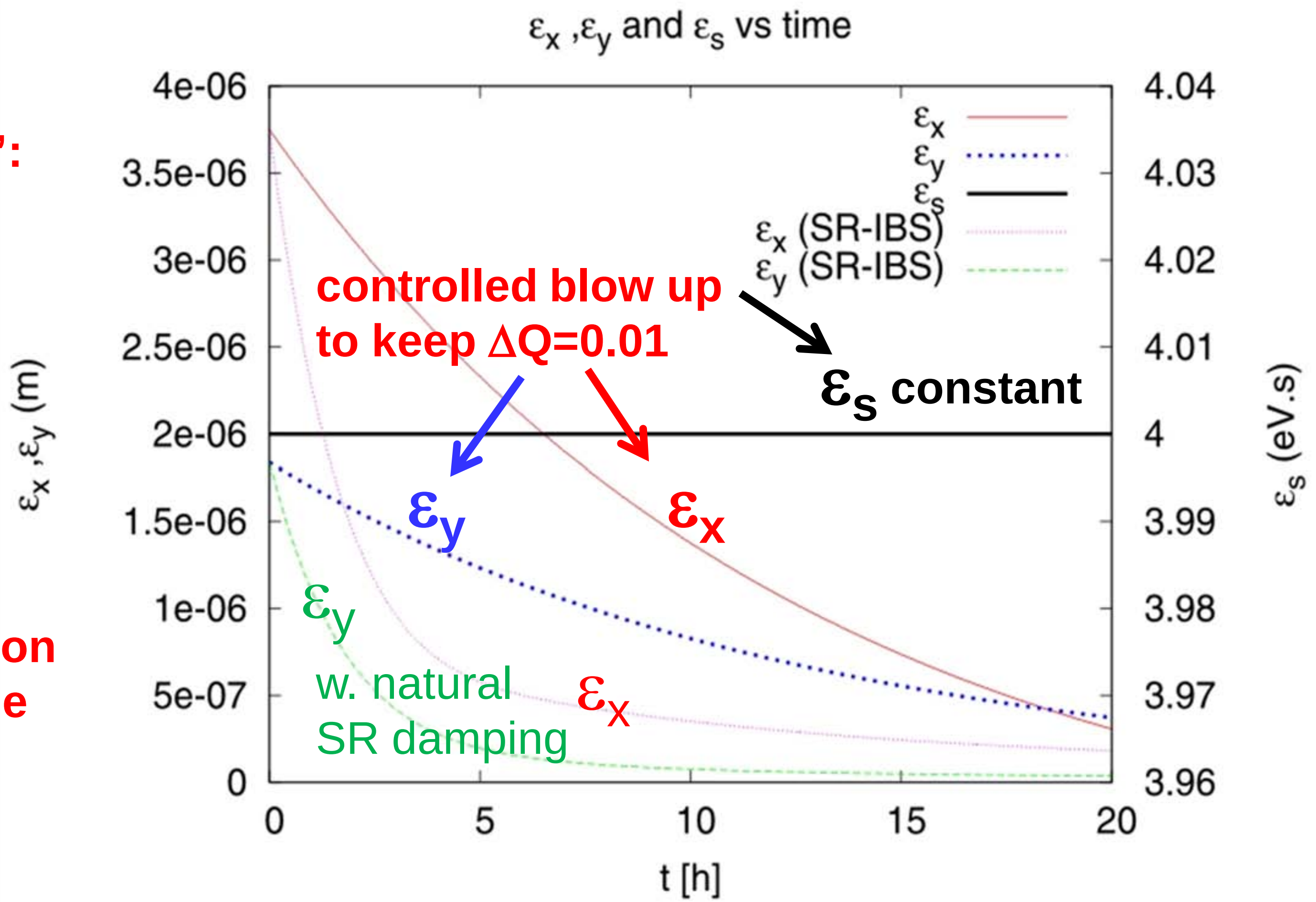
- preliminary considerations **since ~2000**
- **LBNL 16-T Nb_3Sn dipole magnet in 2003**
- **CERN task force** launched in April 2010
- **EuCARD HFM** programme aims at developing 13-T Nb_3Sn dipole with 6-T insert by 2014
- **US-LARP progress** on Nb_3Sn quadrupole magnets development

HE-LHC - parameters

	nominal LHC	HE-LHC
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40
#bunches / beam	2808	1404
bunch population [10^{11}]	1.15	1.29
initial transverse normalized emittance [μm]	3.75	3.75 (x), 1.84 (y)
number of IPs contributing to tune shift	3	2
maximum total beam-beam tune shift	0.01	0.01
IP beta function [m]	0.55	1.0 (x), 0.43 (y)
full crossing angle [μrad]	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})
stored beam energy [MJ]	362	479
SR power per ring [kW]	3.6	62.3
longitudinal SR emittance damping time [h]	12.9	0.98
events per crossing	19	76
peak luminosity [10^{34} cm^{-2}s^{-1}]	1.0	2.0
beam lifetime [h]	46	13
integrated luminosity over 10 h [fb^{-1}]	0.3	0.5

HE-LHC – emittance control

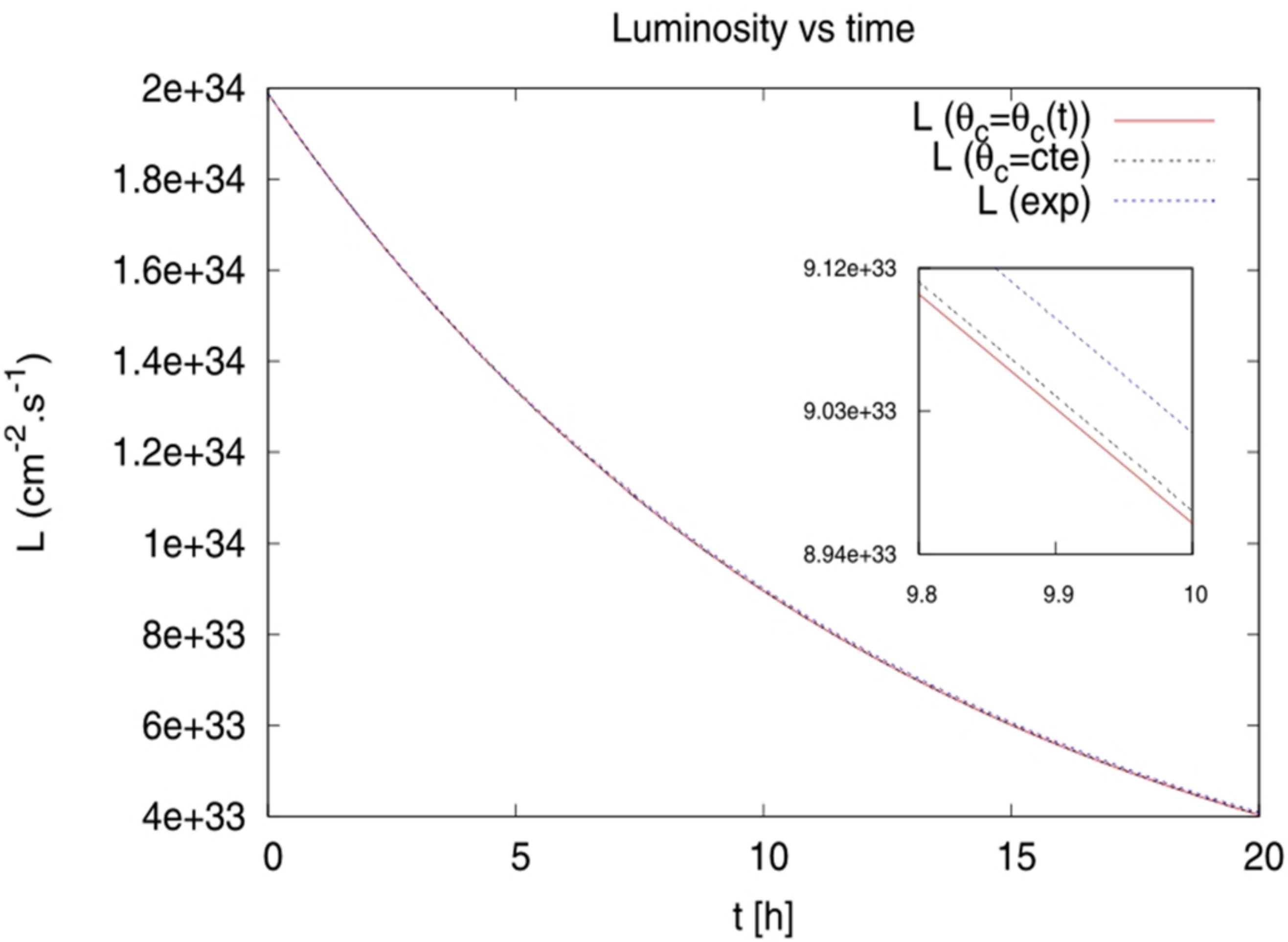
SR damping is "too strong": emittance Shrinks too much and beam-beam tune shift "explodes" → noise injection to control the emittance



Evolution of **HE-LHC emittances during physics store** with controlled transverse blow up & constant longitudinal emittance (three thicker lines on top), and natural transverse emittance evolution due to radiation damping and IBS only (two thinner lines at bottom) – still for constant longitudinal emittance –, which would lead to an excessive tune shift.

HE-LHC – luminosity evolution

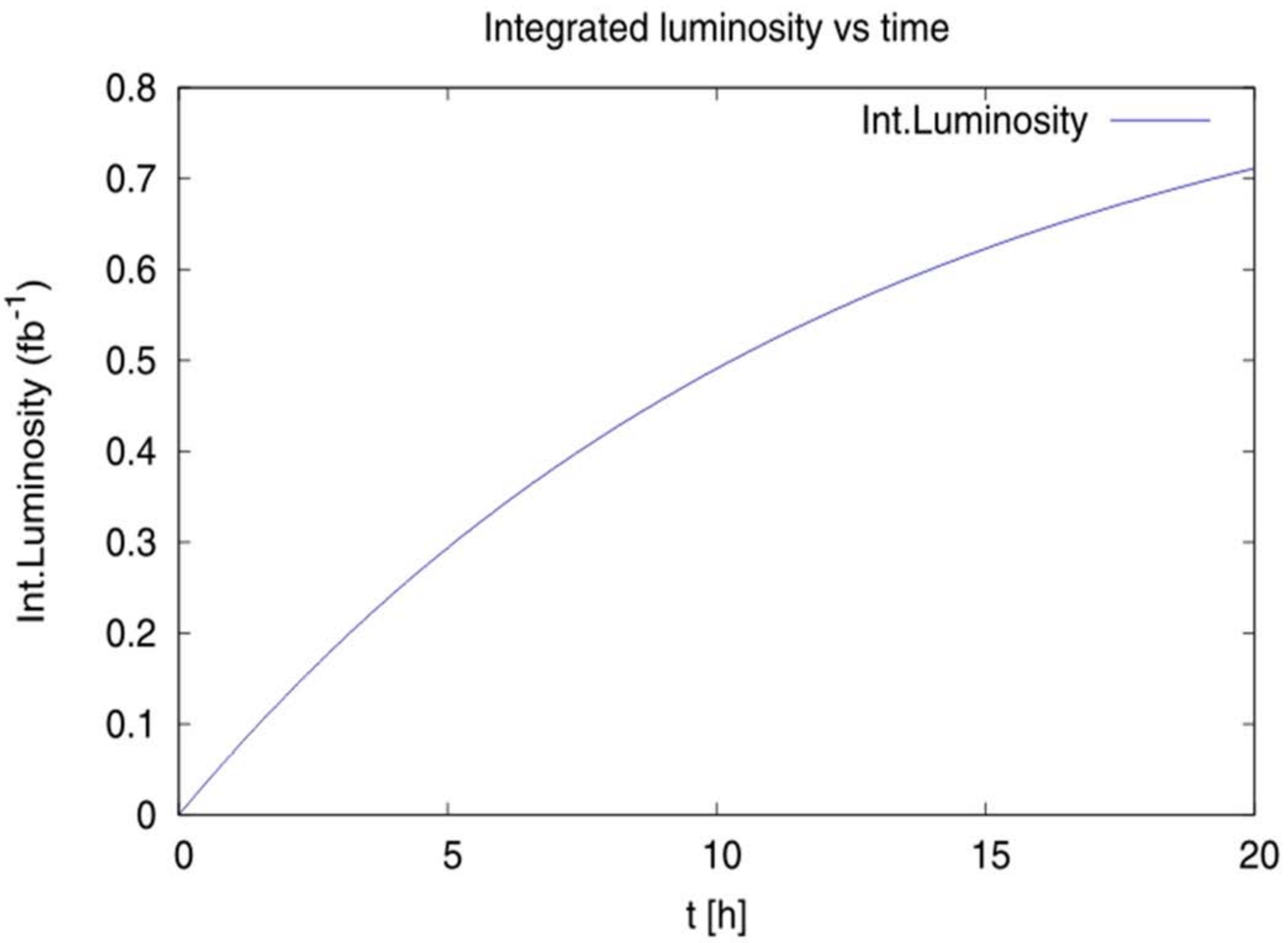
peak luminosity 2x nominal LHC (similar to KEKB) with luminosity lifetime ~12 h



Time **evolution of the HE-LHC luminosity** including emittance variation **with controlled transverse & longitudinal blow up and proton burn off.**

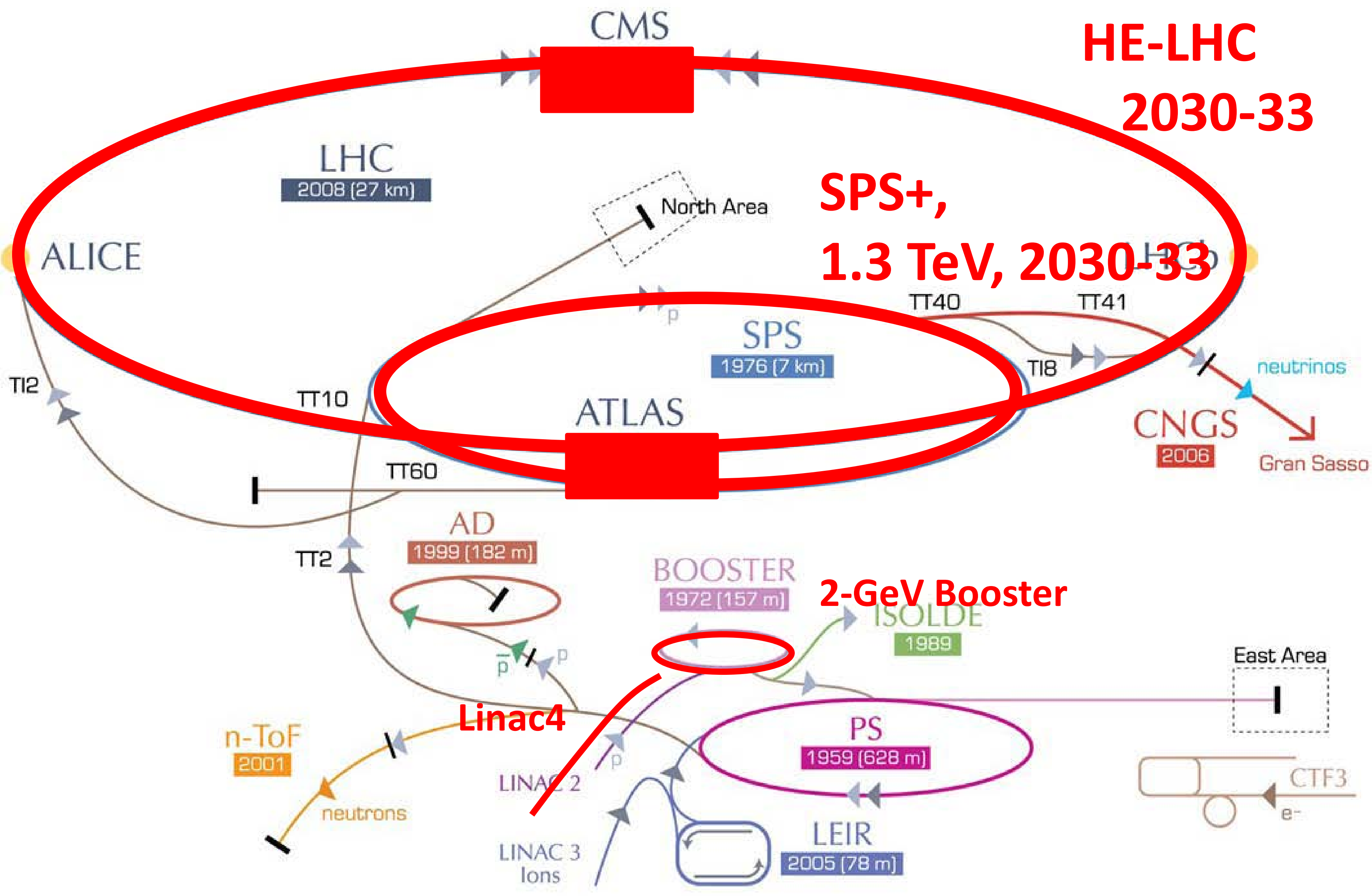
HE-LHC – integrated luminosity

integrated luminosity ~1/fb per day



Time evolution of the **HE-LHC integrated luminosity during a physics store** including emittance variation with controlled blow up and proton burn off.

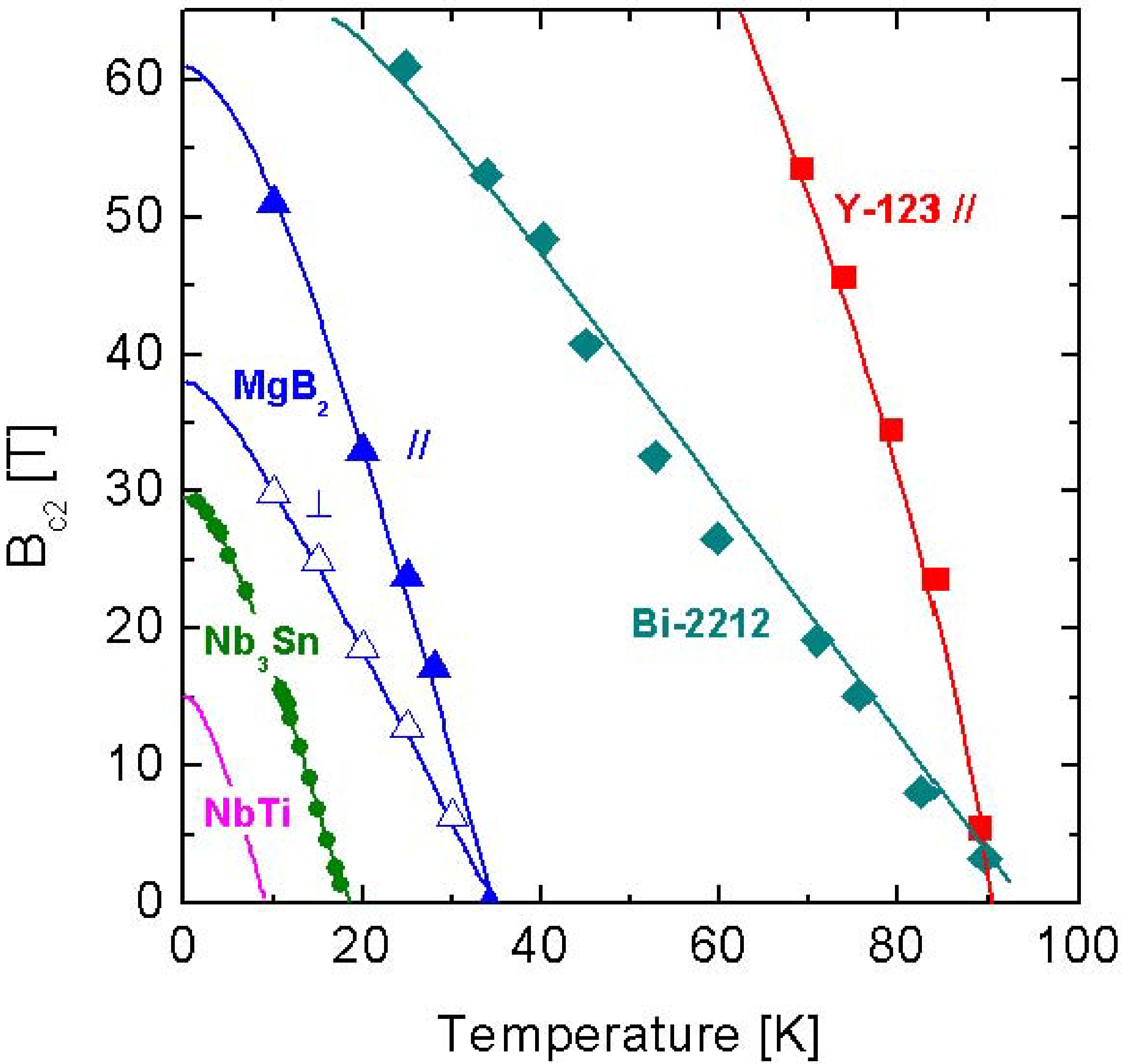
HE-LHC – LHC modifications



HE-LHC – main issues and R&D

- ***high-field 20-T dipole*** *magnets based on Nb_3Sn, Nb_3Al, and HTS*
- ***high-gradient quadrupole magnets*** *for arc and IR*
- ***fast cycling SC magnets*** *for 1-TeV injector*
- ***emittance control*** *in regime of strong SR damping and IBS*
- *cryogenic handling of* ***SR heat load*** *(this looks manageable)*
- *dynamic* ***vacuum***

HE-LHC – high-field magnets

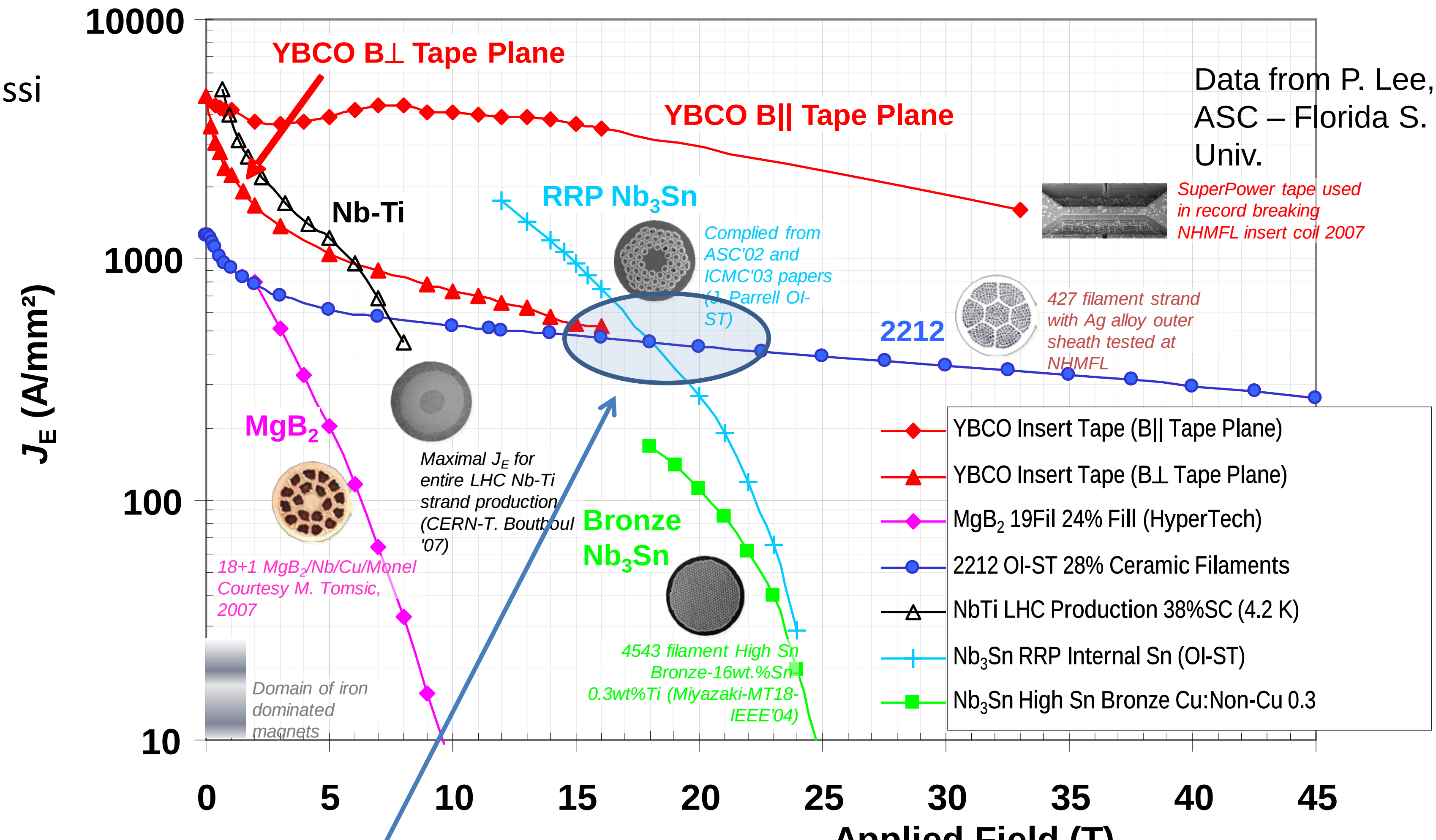


"today," fraction of usable B_{c2}:
80% for NbTi
70% for Nb_3Sn
10-15% for HTS & MgB_2

L. Rossi, 2009

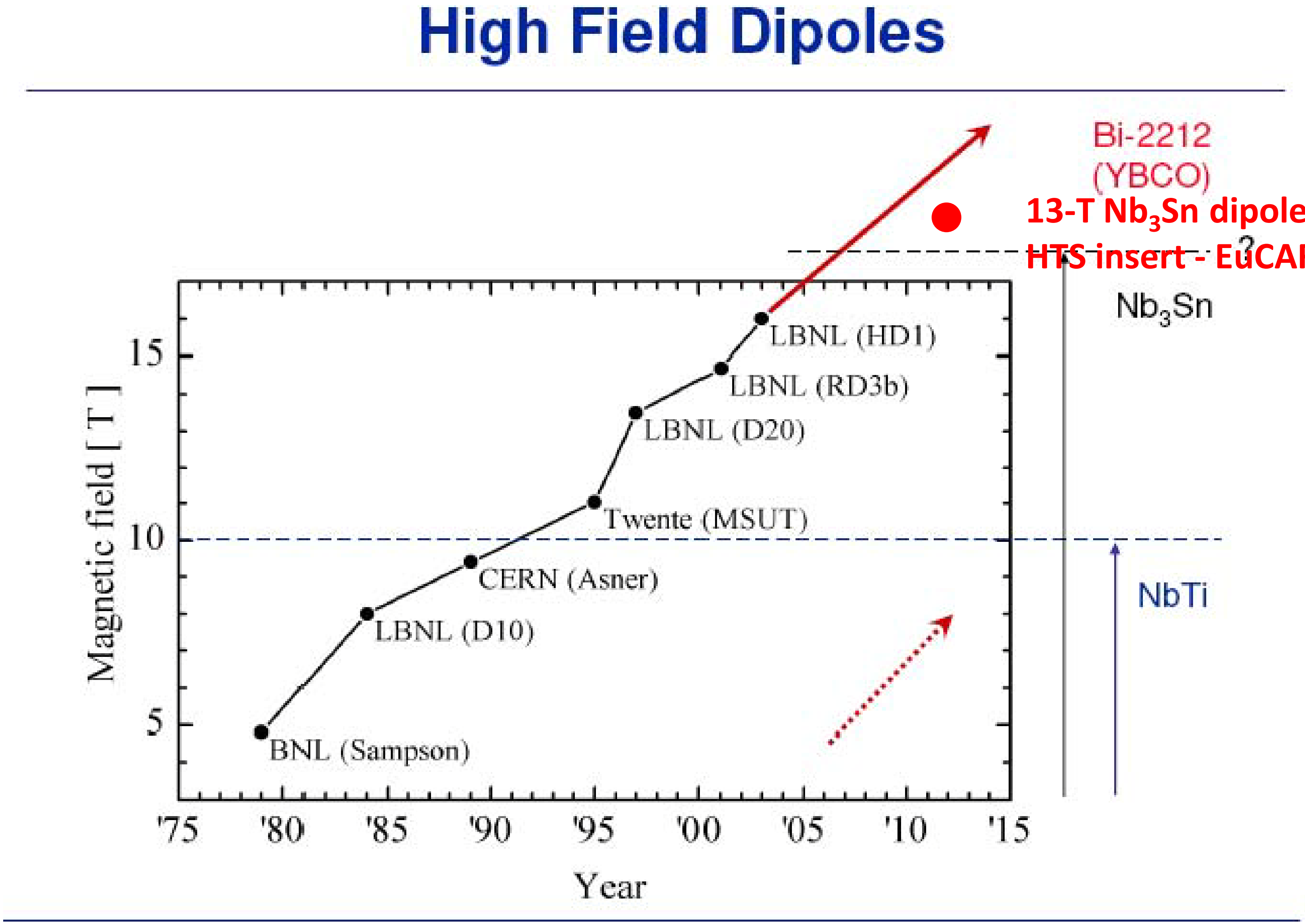
HE-LHC – SC critical current

L. Rossi



Interesting zone : 15-24 T ; Possible Superconductors:
Nb_3Sn up to 17-18 T (existing, needs improvement)
HTS : either Bi-2212 (existing, **needs a lot of improvement**) or YBCO existing only in small tapes (**needs a lot of of R&D**, however there is some synergy with R&D for energy application at 80 K)

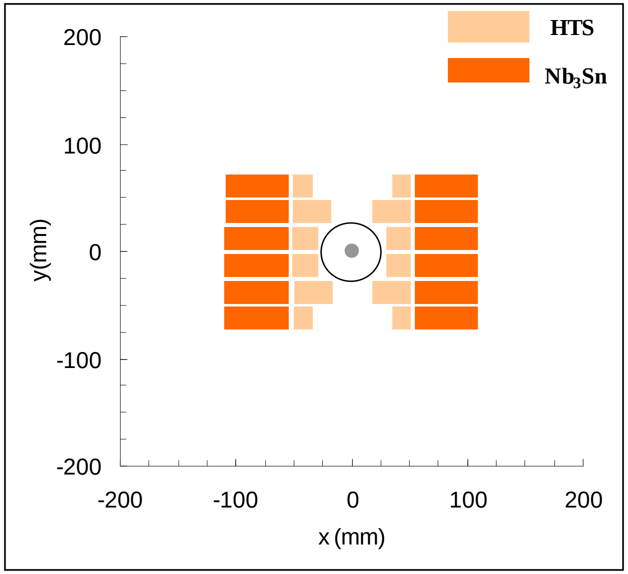
HE-LHC – record field evolution

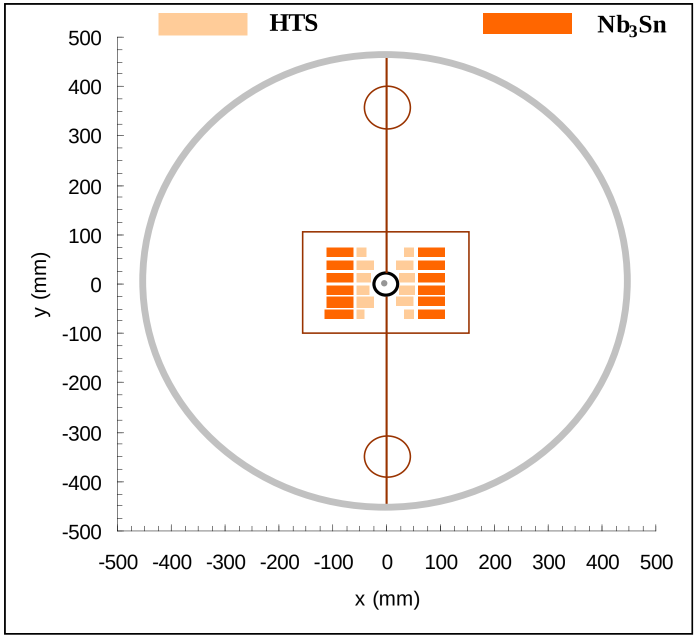


HE-LHC – A 20-T dipole

- 50 mm aperture
- 20 Tesla operational field
  - Inner layers: High Tc superconductor
  - Outer layers: Nb_3Sn
- To be explored for cost reduction: outer layer in Nb-Ti and Nb_3Sn

- Operational current: 18 KA
- Operational current density: 400 A/mm^2 (optimist but possible: only 30-50% increase need wrt today performance)
- **20% operational margin (more than LHC)**
- Next step: Twin dipole + yoke reduction



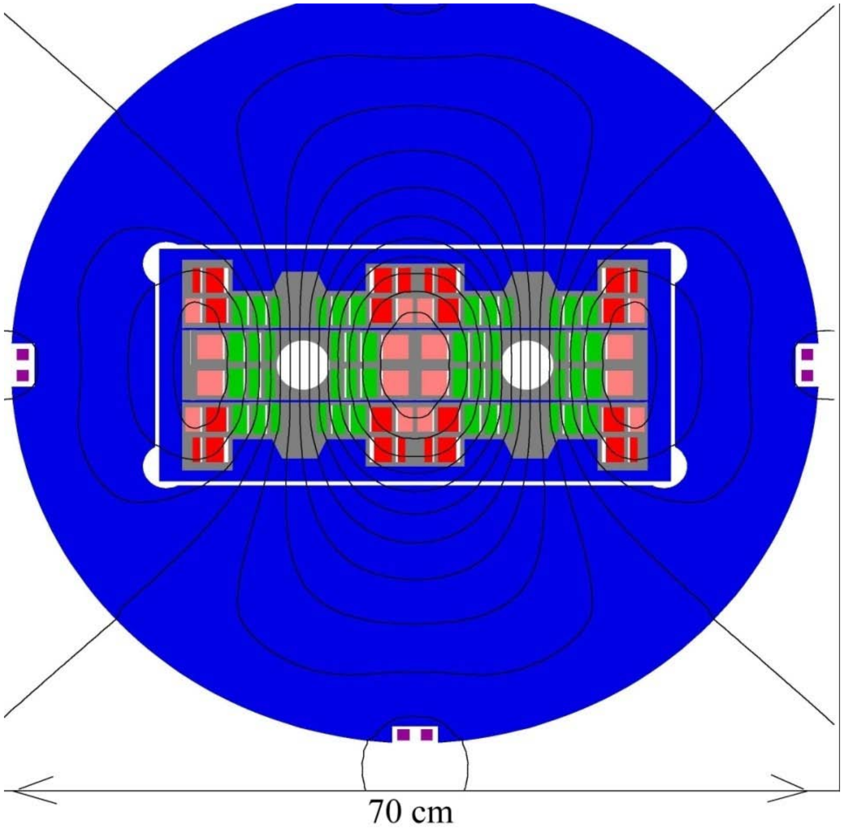


Lay-out by E. Todesco (CERN)

L. Rossi (CERN), P. McIntyre (Texas A&M)

HE-LHC – field limits

Tripler 24 T by P. McIntyre (Texas A&M), PAC 2005

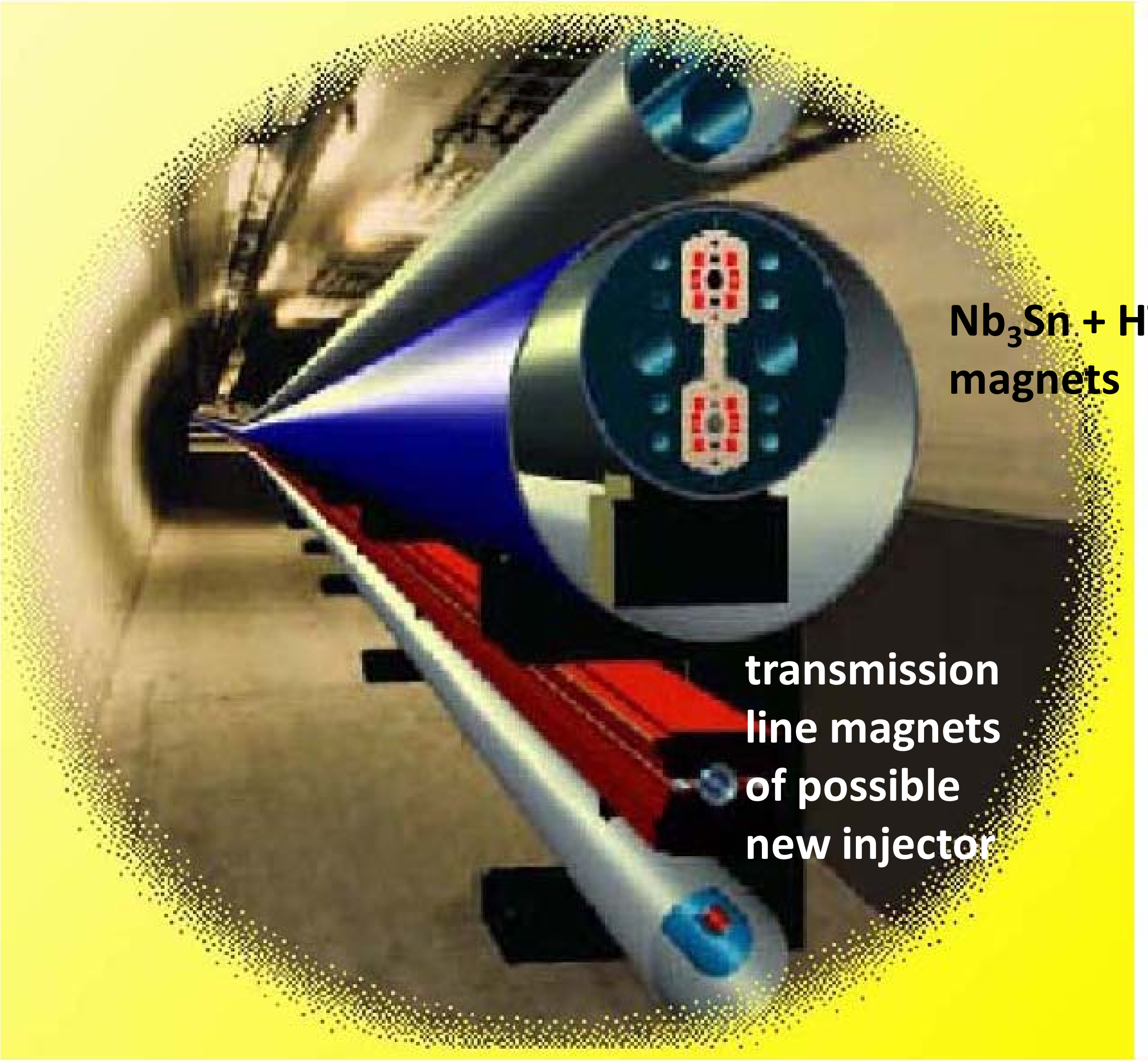


Use of Nb-Ti (pink), Nb3Sn (red) and HTS (green). But what are the issues?

- **Stress management** is certainly one issue: today we know how to do up to 13-15 T…
- The **uniformity of the SC**, especially for HTS, will be a problem
- The **cost : 4-4.5 G$** for the HE-LHC magnet system (L. Rossi, CERN edms n. 745391)
- The handling of the synchrotron radiation power. VLHC solutions (cold fingers are envisaged but no R&D or conceptual design done so far…)

L. Rossi

HE-LHC – possible arc layout



L. Rossi, 2009

HE-LHC – possible schedule

2022: start of 20-T magnet procurement

2022-30: building/preparing new 1.3-TeV injector

2030-33: installation of HE-LHC ring in LHC tunnel

Large Hadron electron Collider

"LHeC"

LHeC - motivation & status

motivation:

- rich physics program: e-q physics at TeV energies
- ❑ precision QCD & electroweak physics
- ❑ boosting precision and range of LHC physics results
- ❑ beyond the Standard Model
- ❑ high density matter: low x and eA

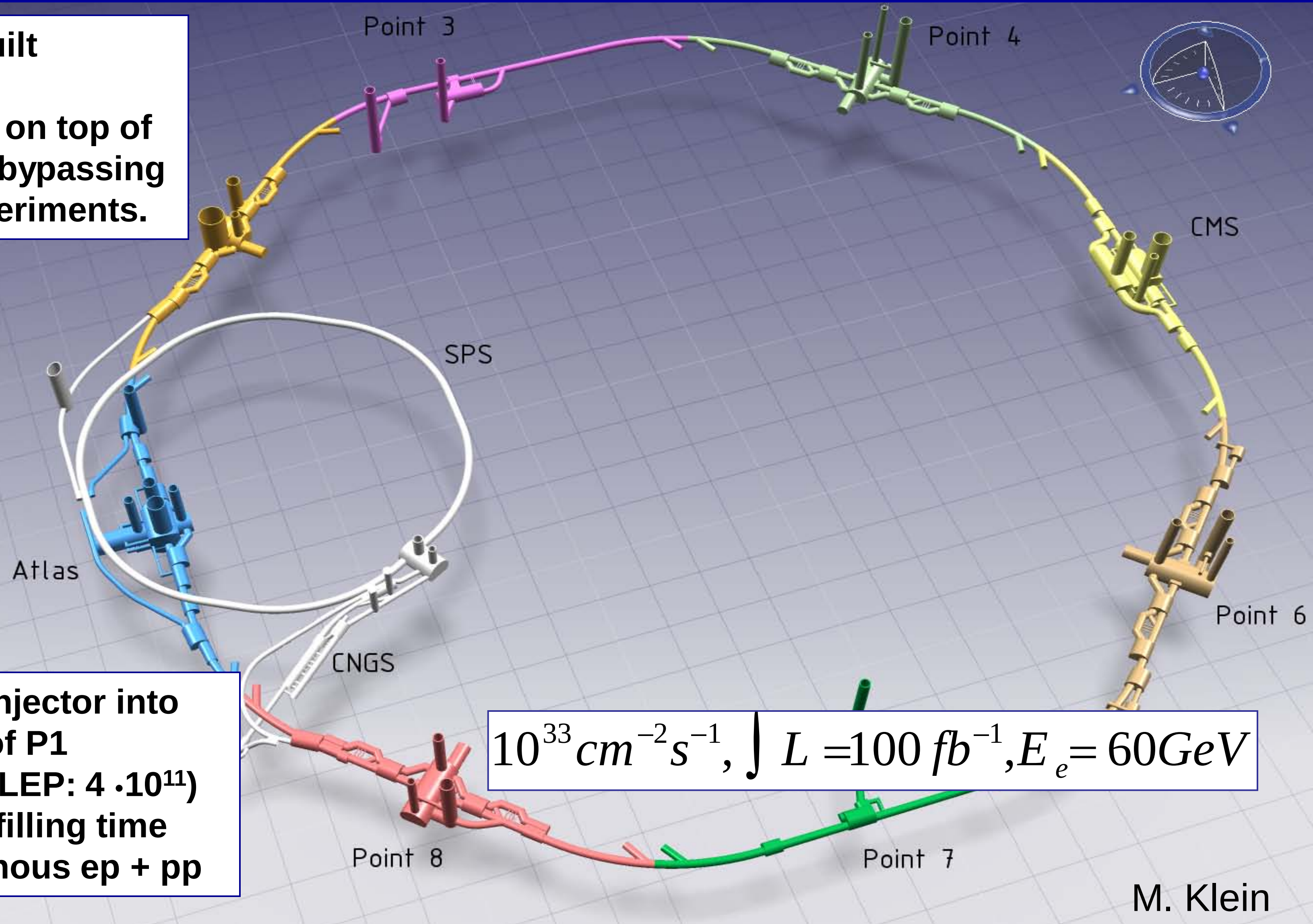
Tevatron/LEP/HERA (Fermiscale) → LHC/LC/LHeC (Terascale)
100 fold increase in luminosity, in Q^2 and $1/x$ w.r.t. HERA

status:

- CERN-ECFA-NuPECC workshops (2008, 2009, 2010: 28.-30.October)
- Conceptual Design Report in print by spring 2011

LHeC – Ring-Ring configuration

Newly built magnets installed on top of the LHC bypassing LHC experiments.

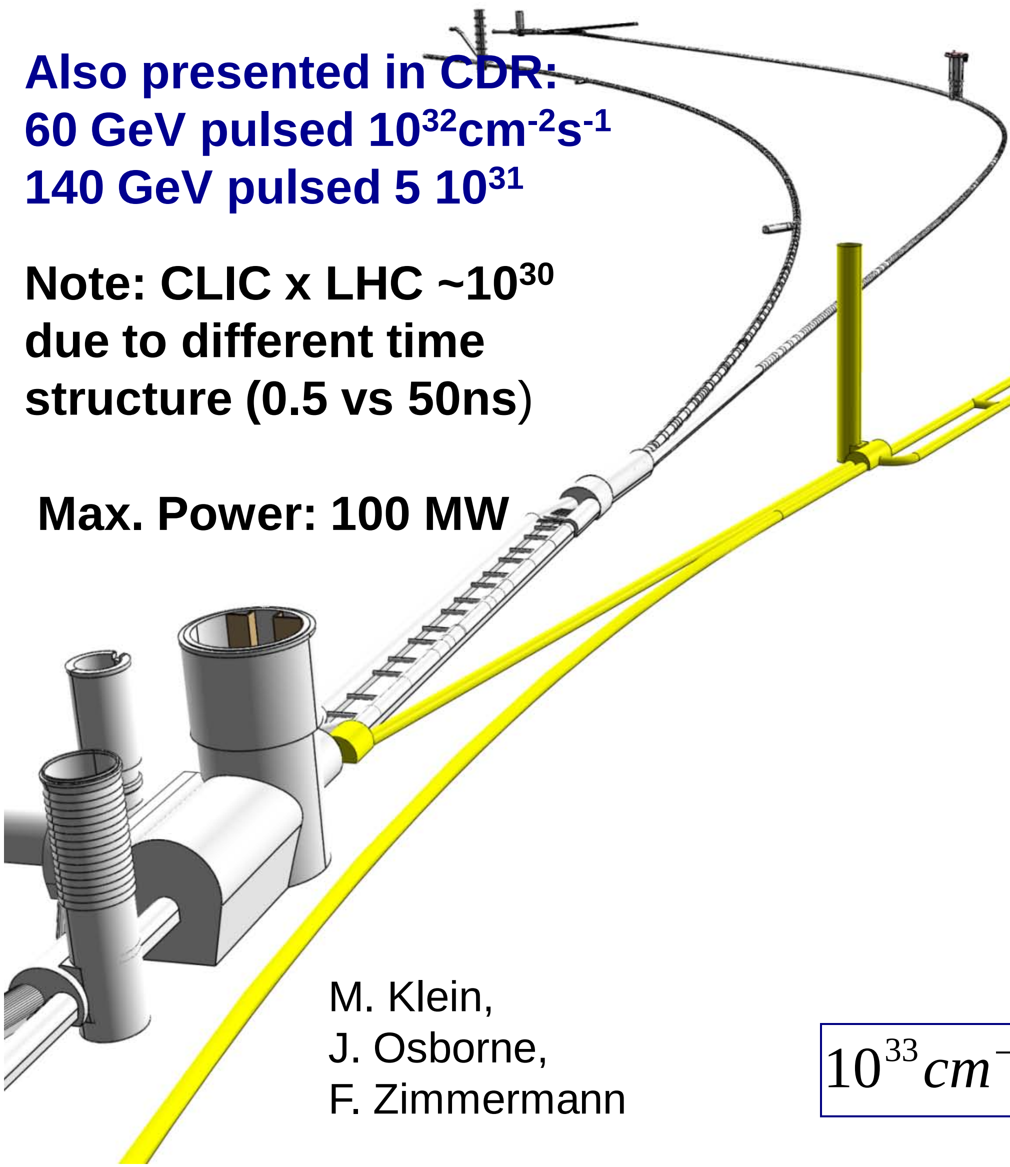


10 GeV injector into bypass of P1
2 ·10^{10}e (LEP: 4 ·10^{11})
~10 min filling time
synchronous ep + pp

$$10^{33} cm^{-2} s^{-1}, \int L = 100\, fb^{-1}, E_e = 60 GeV$$

M. Klein

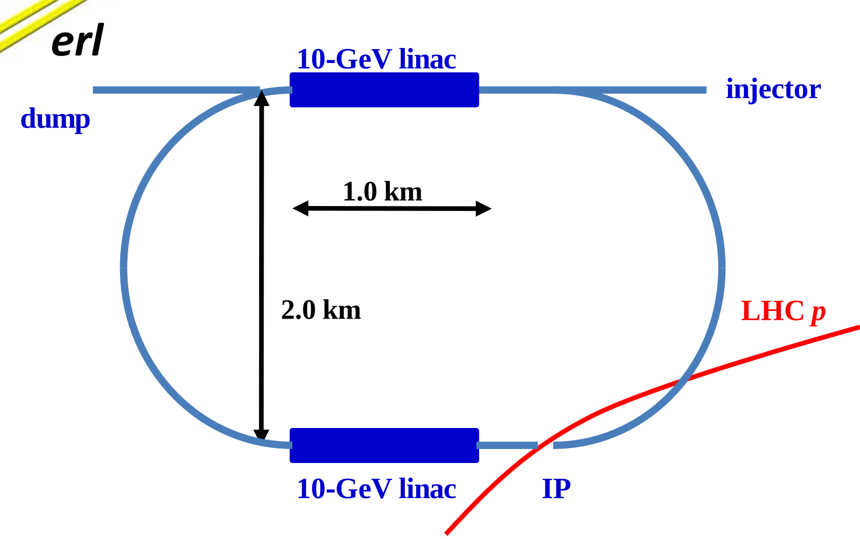
LHeC – Linac-Ring "erl" baseline



Also presented in CDR:
60 GeV pulsed $10^{32} cm^{-2}s^{-1}$
140 GeV pulsed $5\ 10^{31}$

Note: CLIC x LHC ~10^{30} due to different time structure (0.5 vs 50ns)

Max. Power: 100 MW

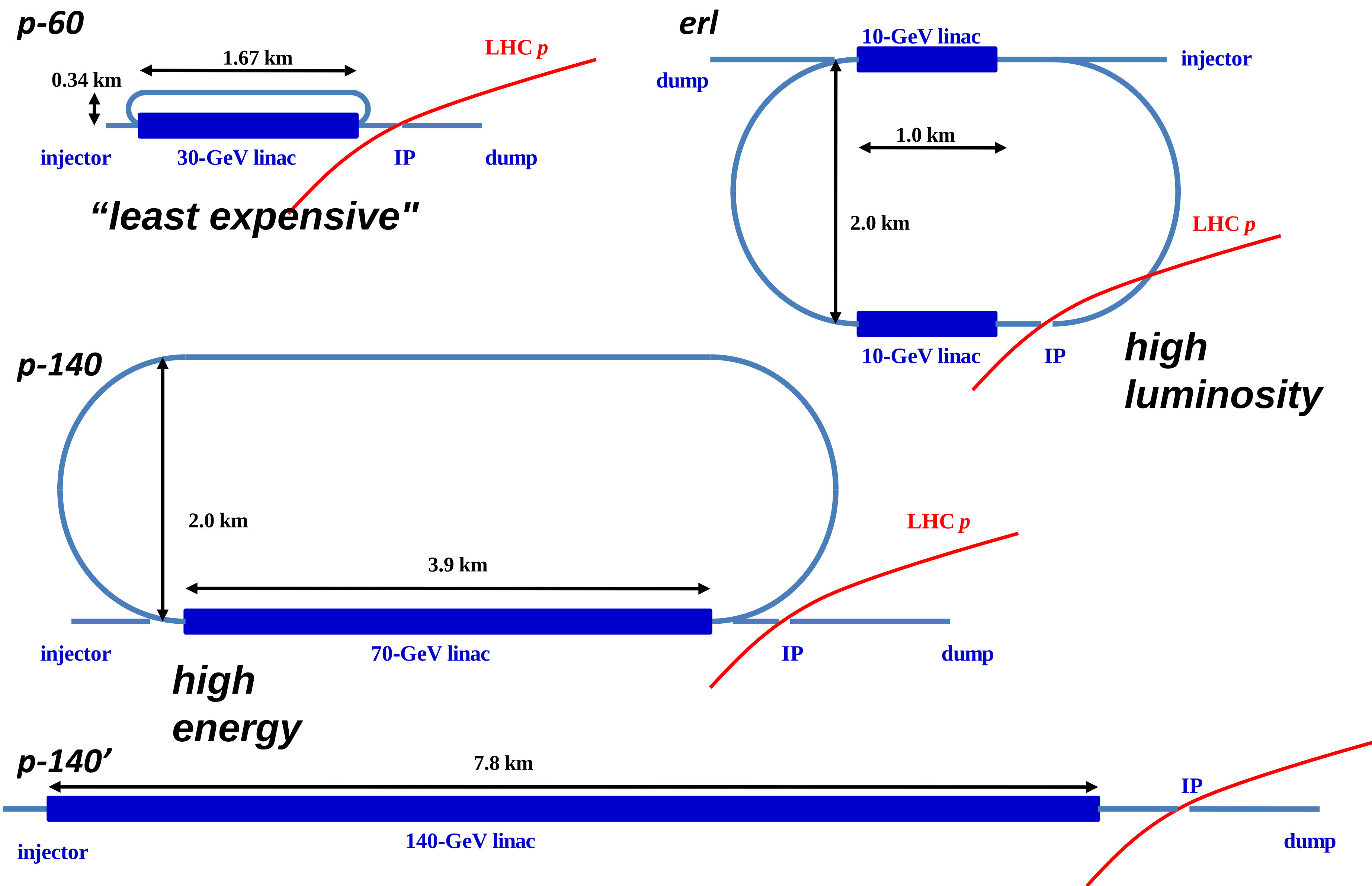


Energy recovery (94%),
β^*=10cm

$$10^{33} cm^{-2}s^{-1}, \int L = 100\ fb^{-1}, E_e = 60 GeV$$

M. Klein,
J. Osborne,
F. Zimmermann

LHeC –Linac-Ring configurations



LHeC - parameters

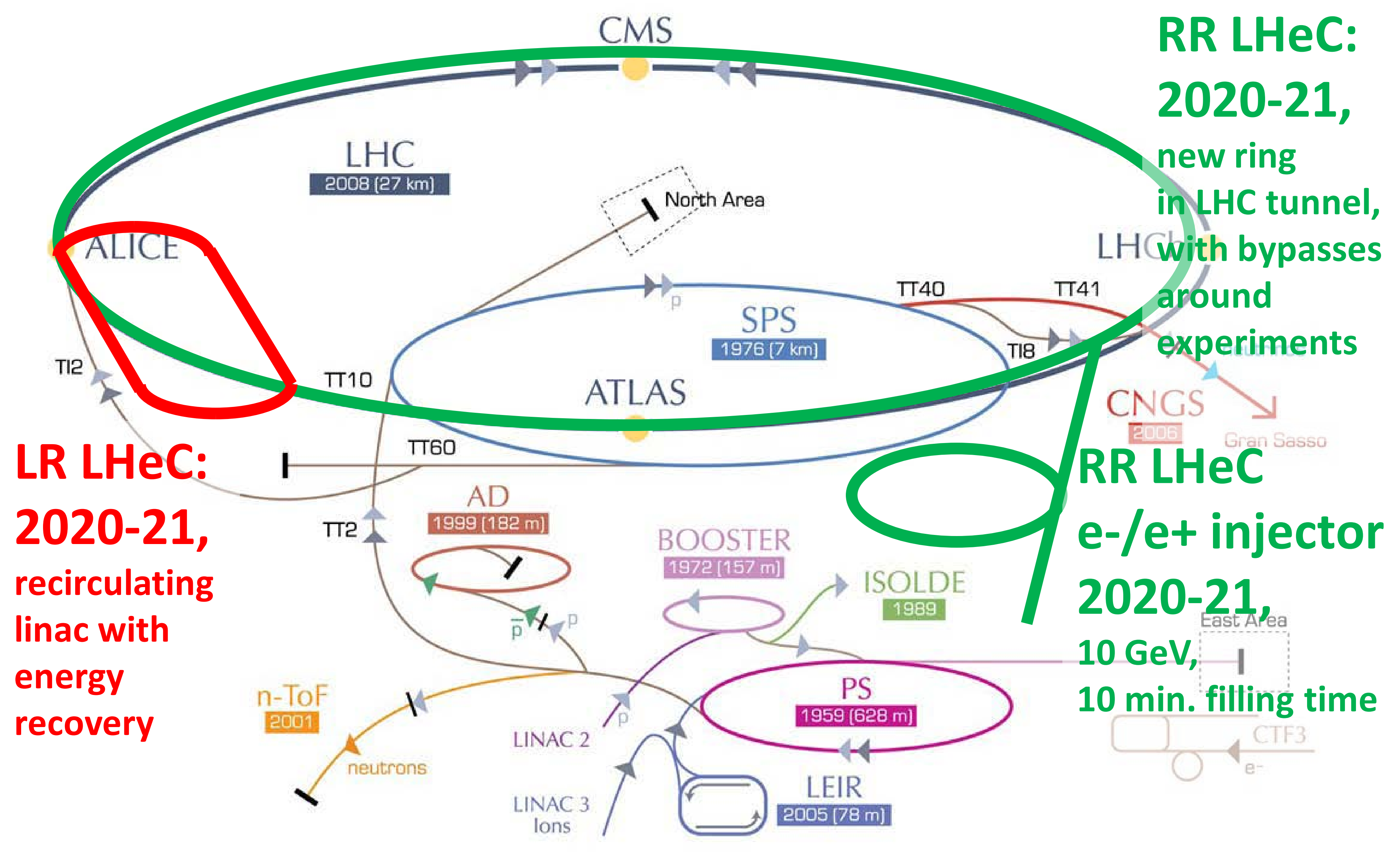
e- beam	RR	LR ERL	LR "p-140"
e- energy at IP[GeV]	60	60	140
luminosity [10^{32} $cm^{-2}s^{-1}$]	17.1	10.1	0.44
polarization [%]	5 - 40	90	90
bunch population [10^9]	26	2.0	1.6
e- bunch length [μm]	10000	300	300
bunch interval [ns]	25	50	50
transv. emit. $\gamma\varepsilon_{x,y}$ [mm]	0.58, 0.29	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	30, 16	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.18, 0.10	0.12	0.14
full crossing angle [mrad]	0.93	0	0
geometric reduction H_{hg}	0.77	0.91	0.94
repetition rate [Hz]	N/A	N/A	10
beam pulse length [ms]	N/A	N/A	5
ER efficiency	N/A	94%	N/A
average current [mA]	131	6.6	5.4
tot. wall plug power[MW]	100	100	100

p- beam	RR	LR
bunch pop. [10^{11}]	1.7	1.7
tr.emit.$\gamma\varepsilon_{x,y}$ [μm]	3.75	3.75
spot size $\sigma_{x,y}$ [μm]	30, 16	7
$\beta^*_{x,y}$ [m]	1.8,0.5	0.1$
bunch spacing [ns]	25	25

$ smaller LR *p*-β* value than for nominal LHC (0.55 m):
- reduced *l** (23 → 10 m)
- only one *p* beam squeezed
- new IR quads as for HL-LHC

B. Holzer,
M. Klein,
F. Zimmermann

LHeC – LHC modifications



LHeC – major issues and R&D

Linac-Ring

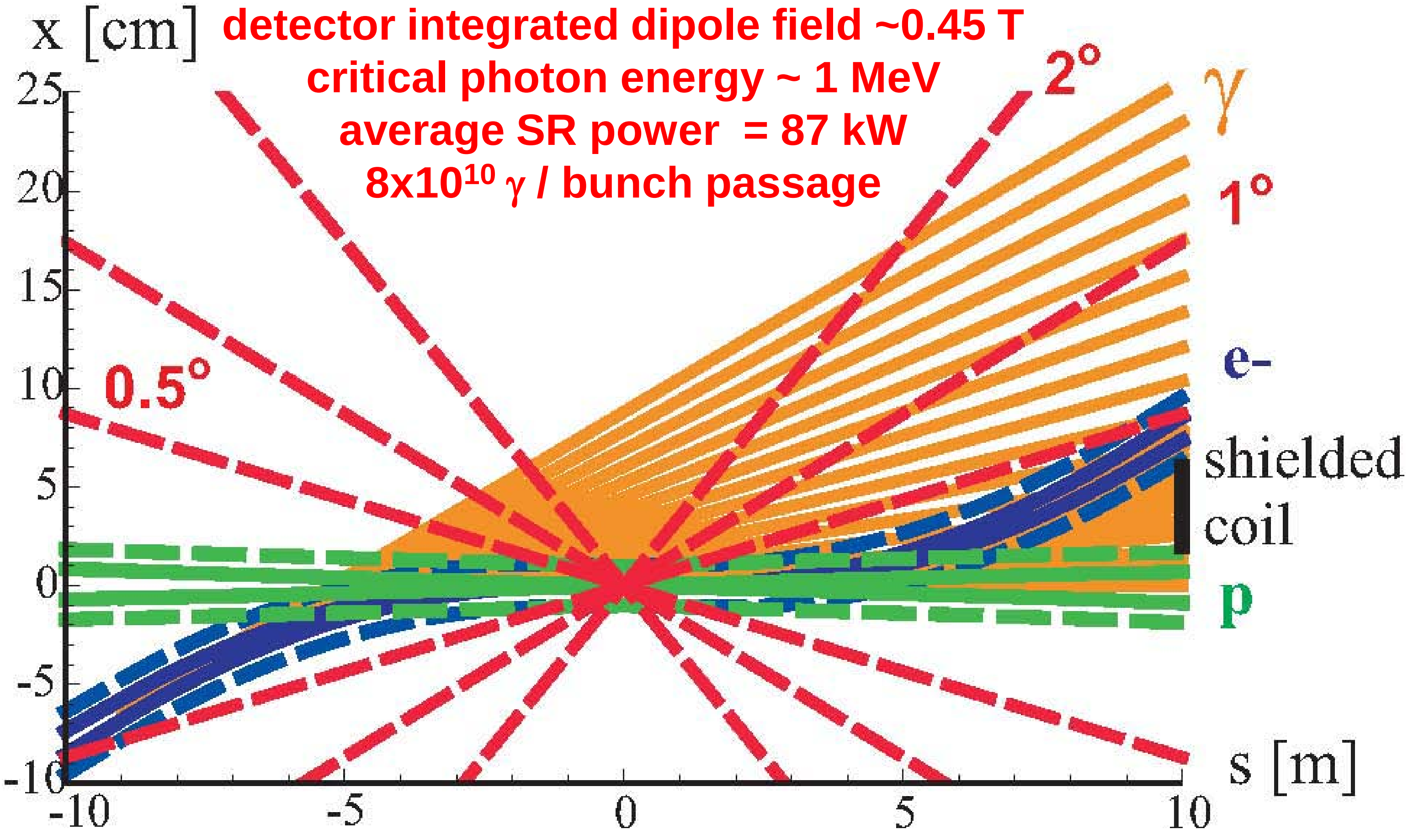
- ***IR: layout & synchrotron radiation and magnets***

  (detector-integrated dipole, and p quadrupole with e- exit hole)
- ***e^+ source*** *& e^+ recovery*
- ***SC linac design, ERL*** *design & ER efficiency*

Ring-Ring

- ***compatibility with LHC*** *tunnel infrastructure (bypasses) & operation*
- ***new dipoles: prototypes at Novosibirsk and at CERN***
- ***polarization; beam-beam effects & circumference match***
- ***IR layout & IR magnet design***
- *crab cavities (5-10 x HL-LHC voltage)*

LHeC – Linac-Ring IR layout

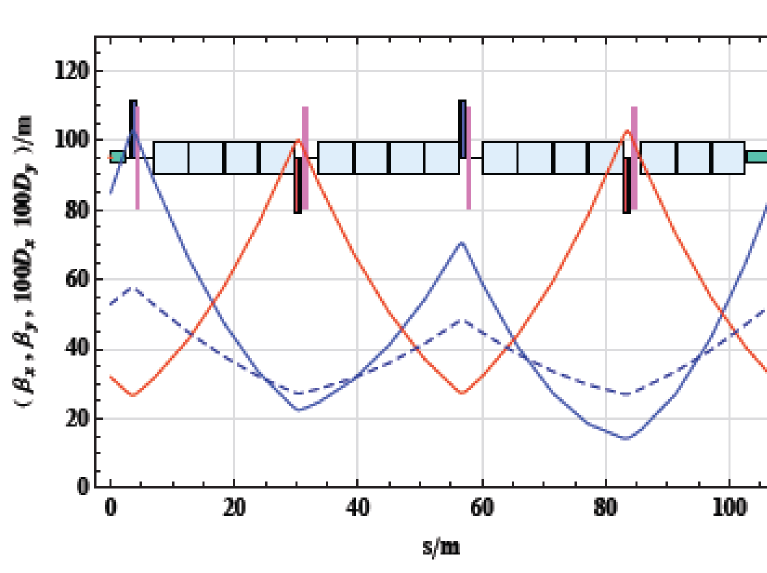


Beam envelopes of 10σ (electrons) [solid blue] or 11σ (protons) [solid green], the same envelopes with an additional constant margin of 10 mm [dashed], the synchrotron-radiation fan [orange], and the approximate location of the magnet coil between incoming protons and outgoing electron beam [black]

LHeC – e Ring Design

H. Burkhardt,
B. Holzer,
J. Jowett

ARC cell design:



LHC Cryo jumpers accounted for in asymmetric FODO.

Further interferences mapped and being studied.

Experiments bypassed in new tunnels which houses rf.

Meets spatial LHC constraints
Synchrotron radiation < 50MW
Two types of quadrupoles
Reasonable sextupole parameters
Dipoles: 4 times lighter than LEP
Prototypes: Novosibirsk and CERN

LHeC – possible schedule

2020-21: installation of (ring or linac) LHeC,
during HL-LHC upgrade shutdown

2021-30: ~10 years of operation with LHC [p/A]
colliding with $E_e \approx 60$ GeV [e^-/e^+]: ~100 fb^{-1}

after 2030: possible extension to high E_e LHeC,
during HE-LHC upgrade shutdown
and long term operation with 16.5 TeV p
colliding with e.g. $E_e = 140$ GeV [e^-/e^+]

conclusions

LHC **beam commissioning so far smoother than expected** (beam-beam fairly benign with few bunches, no dynamic aperture issue, high availability)

LHC and its upgrades/extensions will **push the energy frontier of particle physics for next 30-40 years**

HE-LHC potential is **particularly attractive**, for both particle physics and accelerator design

a final quotation

“The energy frontier does not stop at 14 TeV.

…

Let’s focus on the exploration of Nature at its most fundamental level, and set ourselves the most ambitious targets!”

Michelangelo Mangano,
CARE-HHH LUMI’05 workshop, Arcidosso 2005


お仕舞い
ご清聴ありがとう
ございました
Thanks to many people: Ralph Assmann, Roger Bailey, Oliver Brüning, Yoshihiro Funakoshi, Naoko Iida, Kimiyo Ikeda, Yoshiko Nagashio, Kota Nakanishi, Kazuhito Ohmi, Katsunobu Oide, Fumihiko Takasaki, Demin Zhou, etc. etc.

appendix

HE-LHC – mini-workshop

EuCARD-AccNet mini-workshop on a higher-energy LHC "HE-LHC'10" – 14-16 October '10

Goals:

- Investigate critical questions for HE-LHC and propose solutions or follow-up
- Document the HE-LHC concepts for future reference
- Initiate collaborative work around HE-LHC challenges amongst CERN, EuCARD partners, US, and KEK
- Generate and/or identify synergies with FAIR and past VLHC studies

Topics:

Parameters, magnets for arcs and IR's, synchrotron radiation, & beam dynamics, new injector and other infrastructure

Malta, Villa Bighi, Headquarters of the Malta Council for Science and Technology, 14-16 October '10