LHC* Status and Future Upgrades

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Melbourne

36th International Conference
on High Energy Physics

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Melbourne Convention and Exhibition Centre

Main Topics

- LHC Performance in 2011/2012
  – Improvements & Lessons learned for 2012
  – Achieved and estimated of Performance in 2012
  – Lessons learned for LHC > LS1
- Immediate upgrades: towards 'nominal' and 'ultimate' LHC
  – Long Shutdown 1 (LS1) and LS2
  – Estimated performance in/after 2015
- Future Upgrades: beyond present LHC
  – Luminosity Upgrade (HL-LHC)
  – Energy Upgrade (HE-LHC)
  – LEP3 → Likely will run out of time
  – LheC → will be covered by later talk
  – CLIC & ILC → covered by earlier talks

LHC Performance in 2011/2012
–
A brief review of 2011

In 2011 we ...

- … successfully wrestled with:
  - Total intensity
  - Bunch spacing
  - Bunch intensity
  - Emittance
  - Beta* & aperture

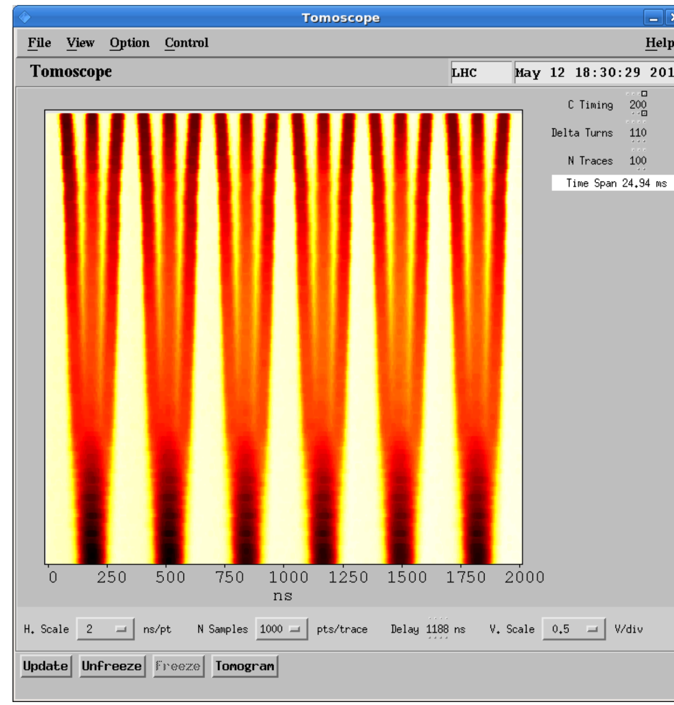
- Good performance from working on all available parameters
- Definitely exploring the effects of high intensity beams:
  - Single-event upsets (SEUs), beam induced heating, vacuum instabilities, etc …
  - Operational efficiency suffering as a result

Of note

- Operational robustness
  - Precycle, injection, ramp & squeeze & collisions are now routine
- Machine protection
  - Unpinned by superb performance of machine protection and associated systems
  - Rigorous machine protection follow-up, qualification and monitoring
- Routine collimation of 110 MJ LHC beams
  without a single quench from stored beams.

2011's “Gold Mine”: Beam from injectors
Twice the Nominal LHC Design Brilliance N_p/ε_n

- Excellent LHC injector performance – years of preparation



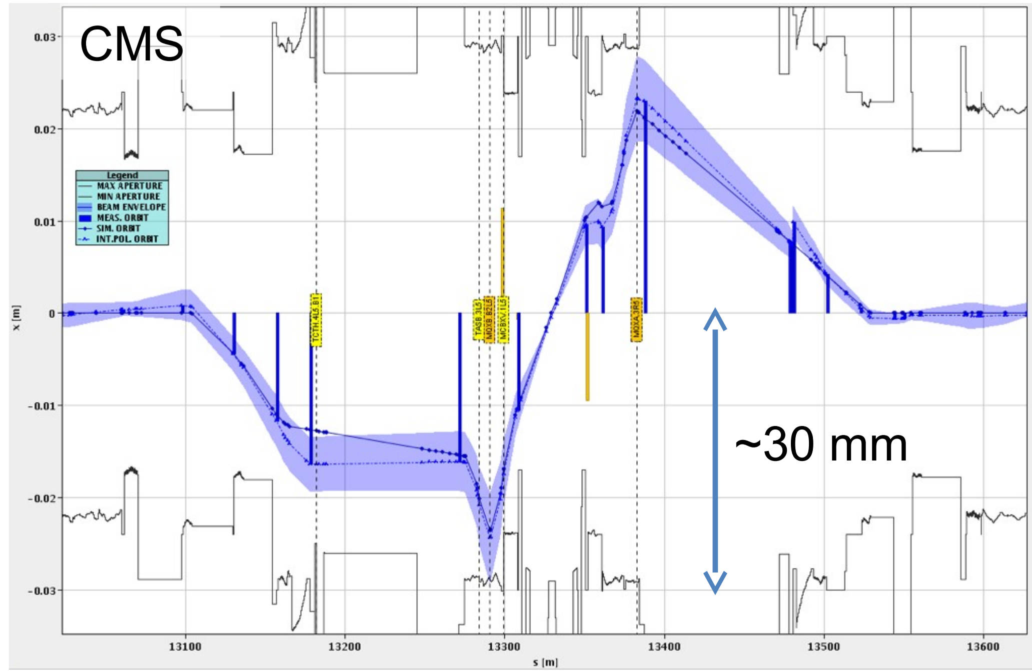
Best in 2011 with 50 ns:
- ~1.45 x 10^{11} ppb
- ~2.3 um into collision

Design with 25 ns:
- **1.15 x 10^{11} ppb**
- **Normalized emittance 3.75 um**

- Measure aperture 4-6 σ larger than the expected 14 σ

IR	Plane	Type of bump in standard optics	Aperture [σ]
1	H	Separation	19.8 – 20.3
1	V	Crossing	18.3 – 18.8
5	H	Crossing	19.8 – 20.3
5	V	Separation	> 20.3

Triplet aperture compatible with a well-aligned machine, a well centred orbit and a ~ design mechanical aperture



Stefano Redaelli

~600 m

Additional margin allowed squeeze to beta* = 60 cm in 2012

- Big success and main ingredient for L_{peak} ~ $0.7 \cdot 10^{34}$ $cm^{-2}s^{-1}$
- Energy 3.5 → 4 TeV: few % Lumi increase due to smaller beam size (also slightly larger cross-section for "some" physics processes)

2011 – 2012 Winter Technical Stop

- Well organized, productive Christmas technical stop
  – Lots of 'radiation-to-electronics' (R2E) related work
  – consolidation and improvements of many systems

- Vacuum consolidation to address successfully diagnosed causes of instabilities in 2011
  – Solenoid windings mitigating e-cloud in critical insertions regions

- Injection collimators issues diagnosed and understood
  – spare in preparation, presently accepting beam-induced heating

- Machine Cool-down exactly on schedule

- Very smooth hardware commissioning including careful quench-less commissioning of main circuits to 4 TeV

- Well-oiled Machine checkout, final tests & preparation for beam

LHC Performance in 2012

2012 Run Configuration

- Energy – 4 TeV
  - Low number of quenches (as in 2011) assumed
  - a bit of extra lumi and increased cross-sections
- Tight collimator settings
  - Now proven operationally
- Atlas and CMS – $\beta^* = 0.60$ m
- Alice and LHCb – $\beta^* = 3$ m
  - Natural satellites versus main bunches in Alice
  - Tilted crossing and offset-luminosity levelling in LHCb
- Bunch spacing – kept 50 ns

25 ns vs. 50 ns Bunch Spacing

- Performance from Injectors:

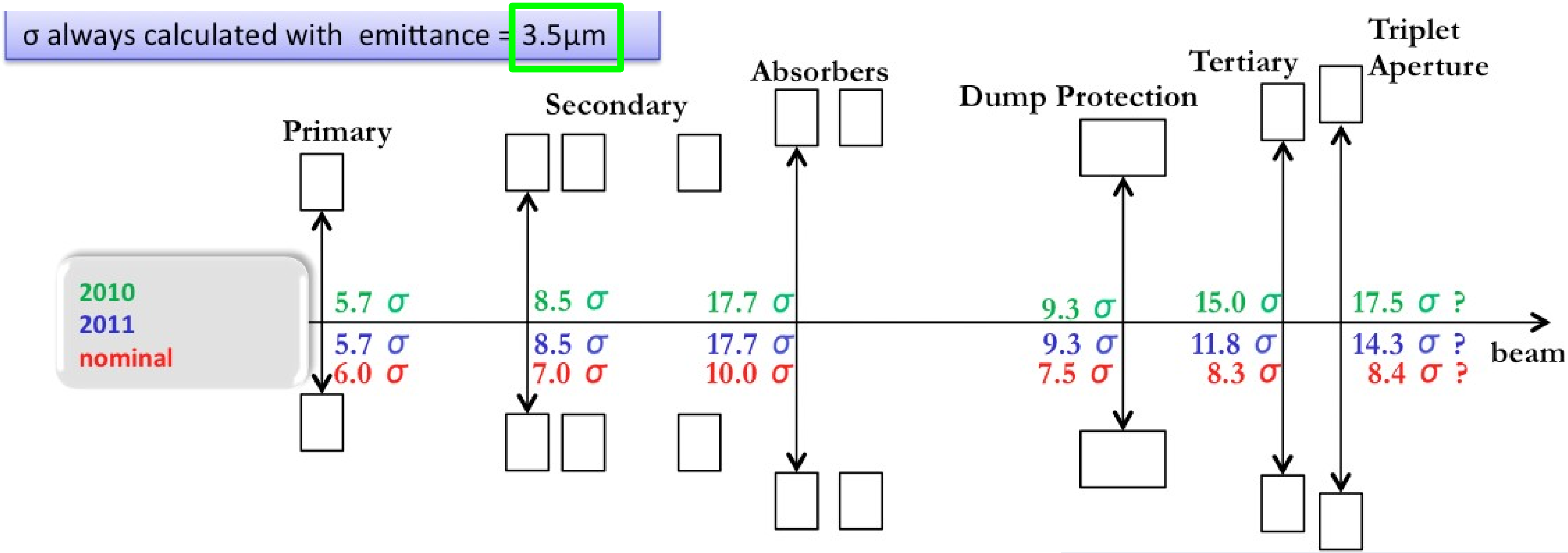
Bunch spacing	From Booster	Protons per bunch (ppb)	Emittance H&V [mm.mrad]
150	Single batch	1.1×10^{11}	1.6
75	Single batch	1.2×10^{11}	2.0
50	Single batch	1.45×10^{11}	3.5
50	Double batch	1.6×10^{11}	2.0
25	Double batch	1.2×10^{11}	2.7

Lumi factor 2.4

$$L_{peak} \approx \frac{f_{rev} k_b \cdot N_b^2}{4\pi\sigma_x\sigma_y} \cdot F = \frac{f_{rev}\gamma k_b \cdot N_b^2}{4\pi\beta^*\epsilon_n} \cdot F$$

Collimator Settings in 2012

- Collimation hierarchy has to be respected to achieve satisfactory protection and cleaning



Aperture plus tight settings
allow us to squeeze to 0.6 m

2012 tight settings:	σ
TCP 7	4.3
TCSG 7	6.3
TCLA 7	8.3
TCSG 6	7.1
TCDQ 6	7.6
TCT	9.0
Aperture	10.5

How tight is 'tight'?

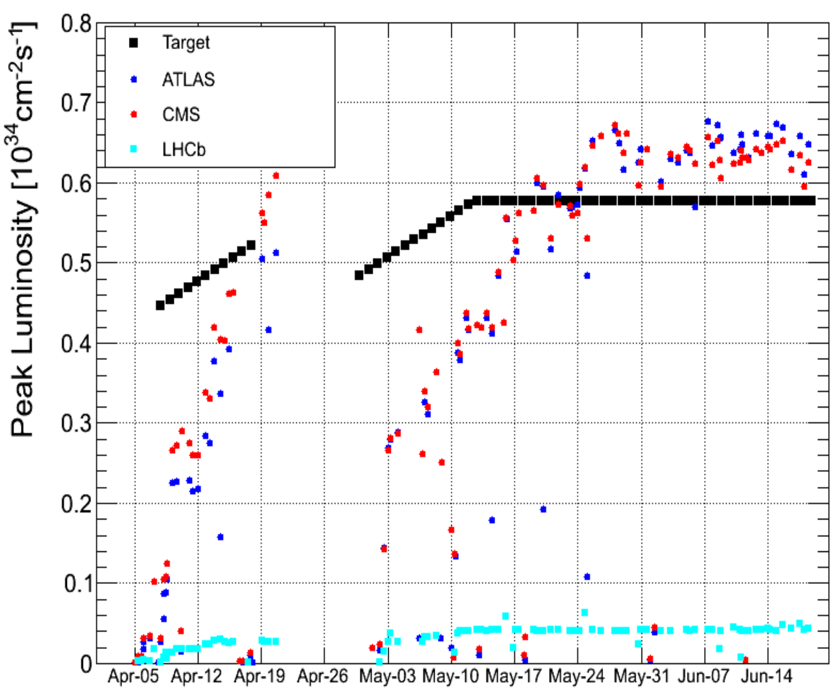
Tight settings (2012):
~2.2 mm gap at primary collimator

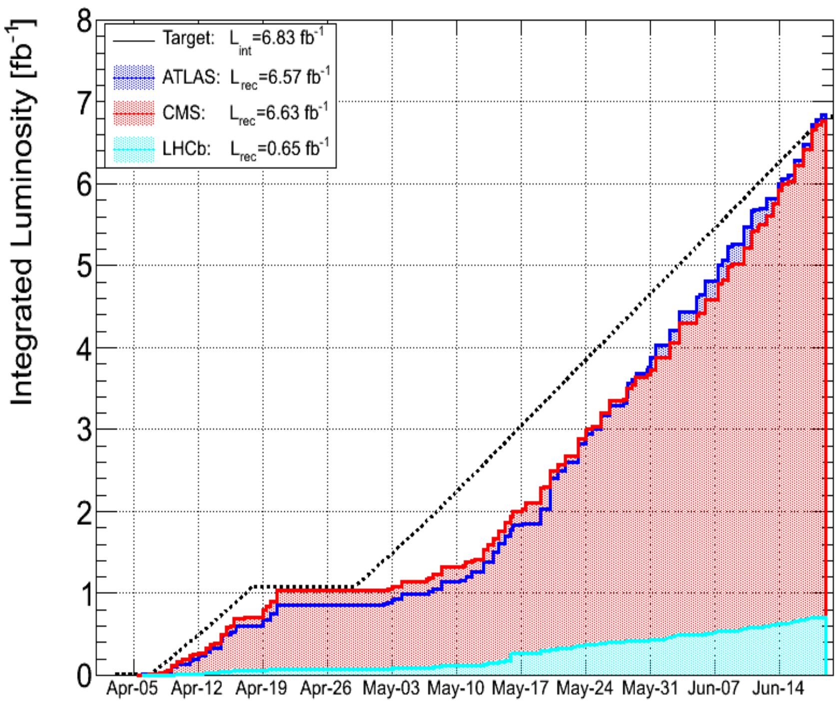
2012 Milestones so far

Date	Milestone
Thu 15.03	Both beams captured, orbit and Q adjusted
Fri 16.03	**Both beams at 4 TeV**
Sun 18.03	**Both beams squeezed to 0.6 m**
Thu 5th April	First stable beams – 3 bunches
Wed 18th April	**1380 bunches/beam - L_{pk} ~$0.55 \cdot 10^{34}$ $cm^{-2}s^{-1}$, L_{int} ~ $1fb^{-1}$**
20-22 April	Machine development
23-27 April	Technical Stop #1
to 10 May	Struggled back up to 1380 ~$4.3 \cdot 10^{33}$ cm-2s-1
Last week before TS2	Back on track: L_{pk}~$0.7 \cdot 10^{34}$ $cm^{-2}s^{-1}$, ΔL_{int} ~ 1 fb^{-1}/week, produced about 7 fb^{-1}/experiment in time for ICHEP'12
18-23 June	Machine development
24-27 June	Technical Stop #2
30 June	Restart, intensity ramp up ongoing

2012 Achieved vs. Target Luminosity Estimates from Moriand (Mike Lamont & Steve Myers)

- Assumptions:
  - 4 TeV, 50 ns, 1380 bunches, 1.6e11, 2.5 um, pile-up ~ 35
  - 150 days of proton physics (assuming similar efficiencies to 2011)

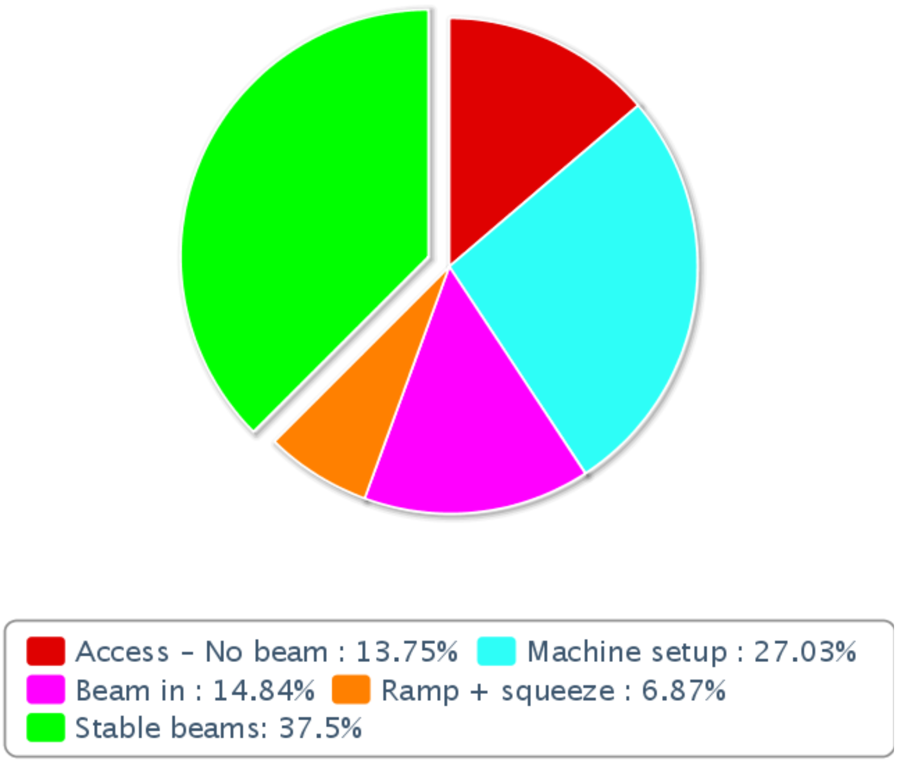




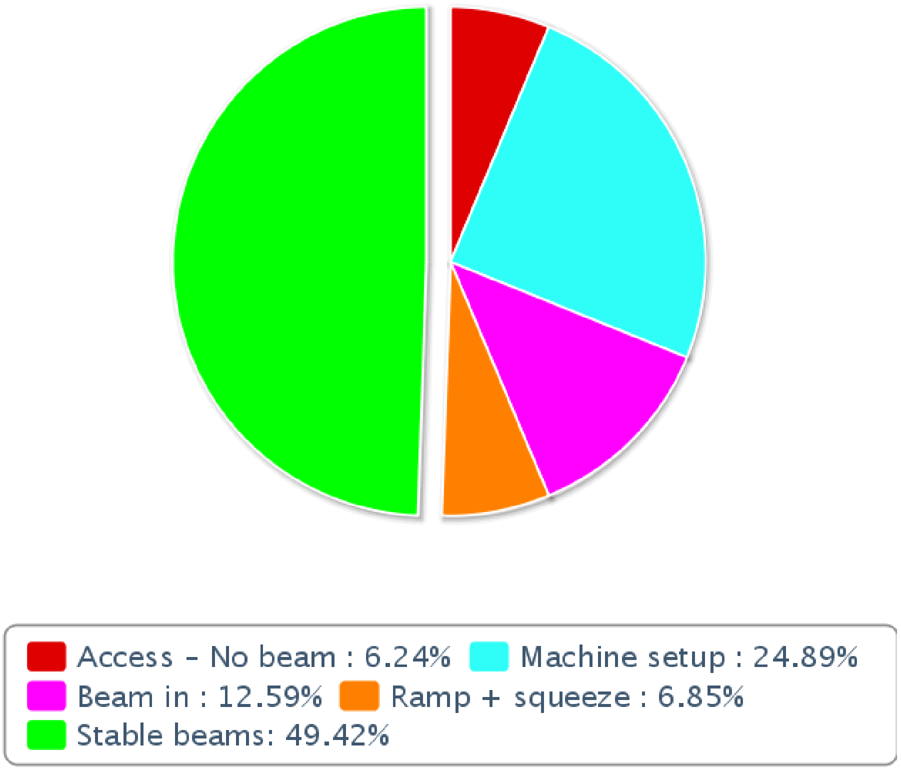
- Initial slow recovery after TS1 but eventually caught up by TS2
- Presently operating with ~1 fb^{-1}/week

LHC Availability for Physics in 2012

Since start of run:



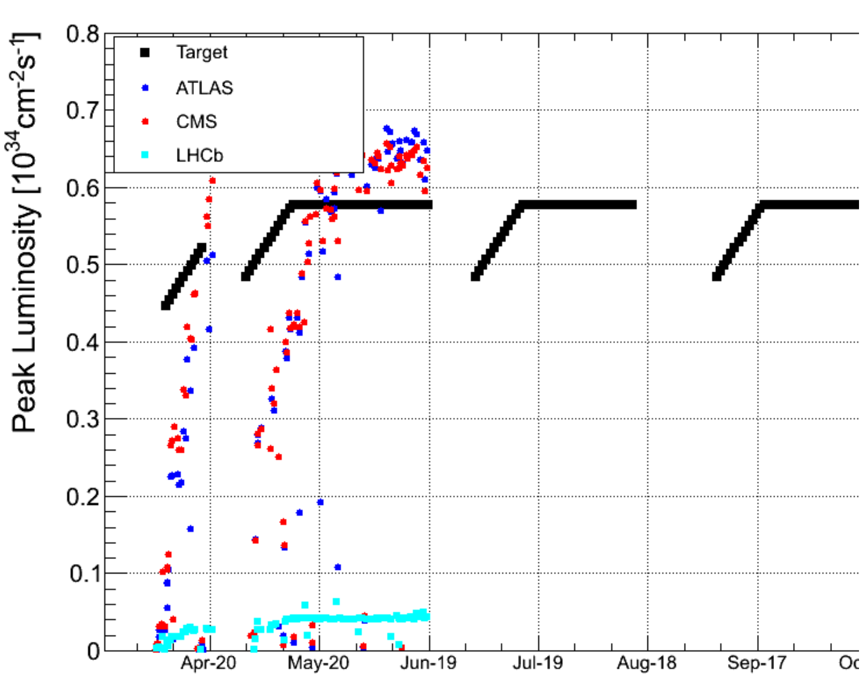
Last week before TS2:

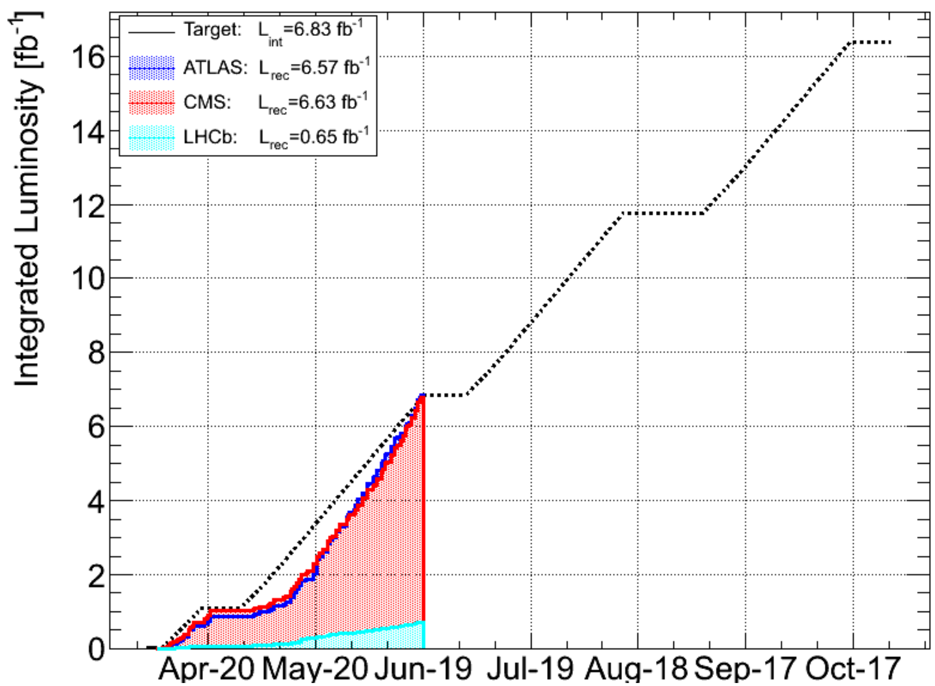


- Clear signs of improvement, close to what can be achieved (~60%)
- Safe assumption is that we continue with a similar performance

Predicted Luminosities until end of 2012

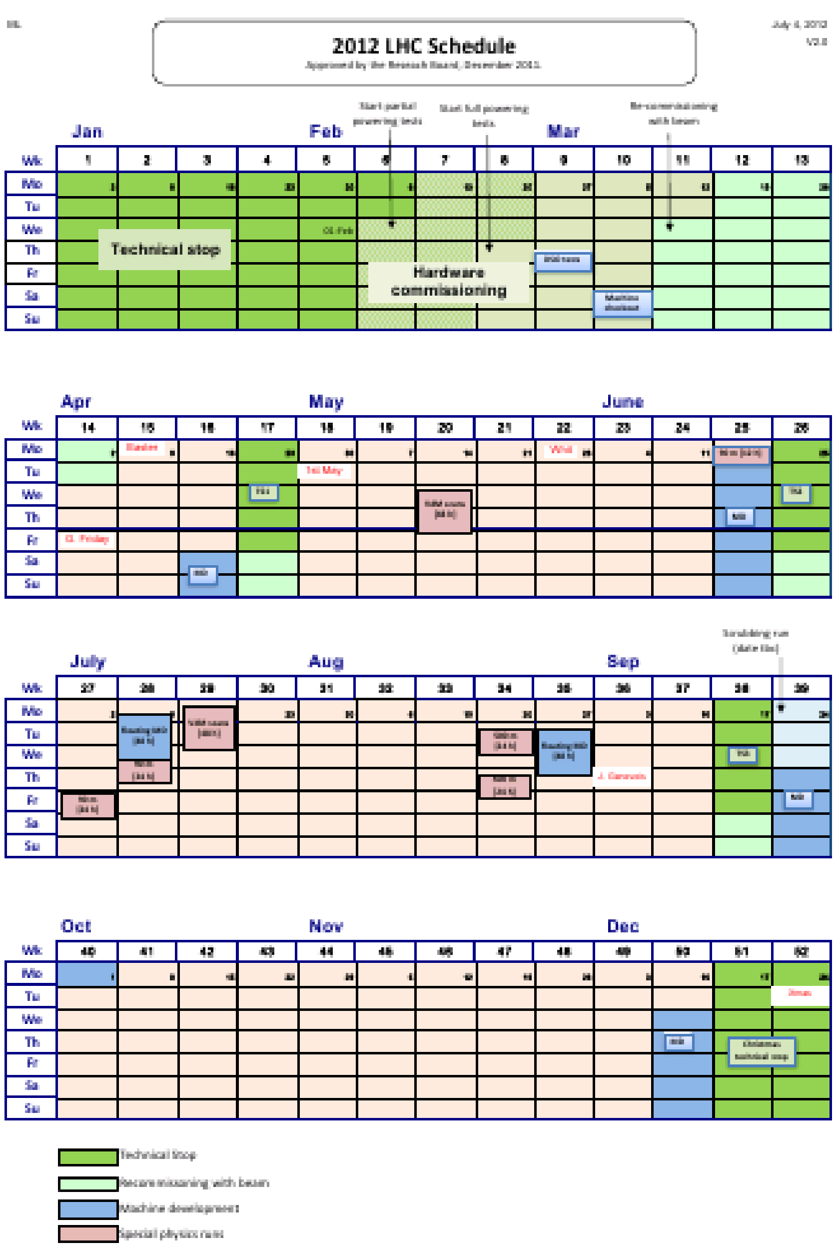
- Assuming we continue with the status quo...





- 15 fb^{-1} seems to be reasonable safe assumption by the end of 2012
  - N.B. assumption: no “surprises” and modulo low-lumi operation (dedicated high-β* fills for ALFA & TOTEM, etc.)

DG's Extension of 2012 Run by 3 Month



+ three months
~15 → ~20 fb^{-1}

2012 Lessons for the Future

- Head-on beam-beam is not a limitation

- Long range beam-beam has to be taken seriously
  - Need separation (otherwise bad lifetime and beam loss)
  - Small as possible emittances are good
  - Established 10 -12 σ separation and thus the crossing angle (important because our F is going to bite at lower beta)

- Established β* reach (aperture, collimation, optics)

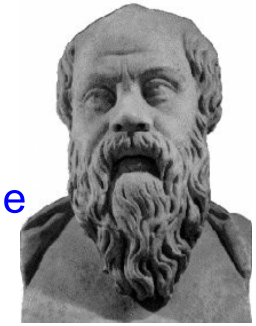
- *Lumi*-leveling via offset tested – works fine in LHCb!
  - N.B. β*-leveling for IR1&5 tested during last MD (not operational yet)

- High-intensity operation close to beam instability limits
  - Instabilities for small IP beam offsets while going into collisions, impedances (kicker, collimator heating), collective effects, ...
    → controlled but (too?) strong octupoles needed!?!

- Availability issues (SEUs, vacuum, UFOs, cryogenics, …) – vigorous follow-up and consolidation

Immediate and Future LHC upgrades

LHC Upgrade – Disclaimer



- Based on Socrates path to 'wisdom':
  "[We] know one thing, that [we] know nothing"
  … well, since Wednesday: “some harder indication” of a new boson-like particle
  – Need to better understand the physics and existing data before concluding and moving to any major upgrades
  – Implies that we need to accumulate as much data/luminosity to make this assessment possible

→ Reflected in 2012 guideline and CERN's 10 year plan

- In parallel, maintain necessary level of R&D (HL-LHC, HE-LHC, LHeC, LEP3, CLIC, ILC, …) to be prepared when we need to move on to a new regime:
  – Significant lead times of new accelerators: ~10++ years (or more)
  – maintain accelerators & detectors know-how/expertise to be ready when it's needed and specific parameters are confirmed

Parameters to Maximise Luminosity

$$L_{peak} \approx \frac{f_{rev} k_b \cdot N_b^2}{4\pi\sigma_x\sigma_y} \cdot F = \frac{f_{rev}\, \gamma\, k_b \cdot N_b^2}{4\pi\beta^* \epsilon_n} \cdot F$$

- Maximise beam brightness 'N_b/ε'
  - Limited by injectors: $L \sim \sqrt{N_b} \rightarrow$ LINAC4 (LS2), e-cloud, ...
- Maximise number of bunches/stored beam '$k_b N_b$'
  - Limits; collective effects, beam power, collimation and MP
- Minimise final focus β* – ultimate limit: hour-glass effect

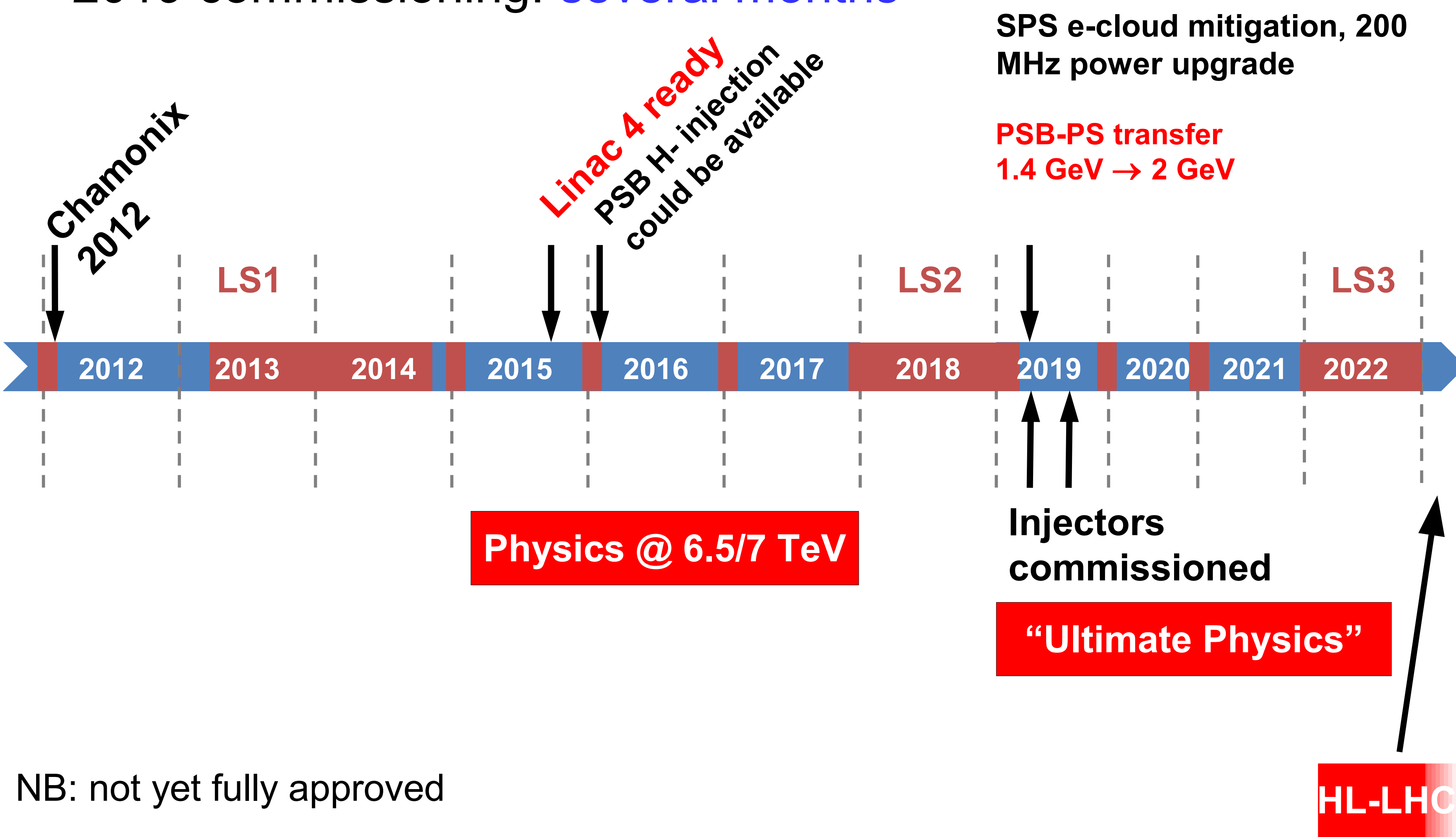
- Provide "useful" integrated luminosity
  - trade-off between: 'Low μ ↔ low $\int L_{pk}dt$' vs. 'high $\int L_{pk}dt$ ↔ high μ'
  - Need to keep an eye on overall efficiency and avoid luminosity optimisations that unnecessarily cause instabilities or down-times.
  - Very good collaboration between experiments and accelerator to find and facilitates improvements and trade-offs on either side!

Immediate LHC upgrades:

...targeted at exploiting LHC towards its 'nominal' and 'ultimate' parameter sets, distributed over three Long-Shutdowns

LHC and LHC Injector Upgrade Reflected in 10 Year Plan

- Length of LS2: minimum 12months
- 2019 commissioning: several months



NB: not yet fully approved

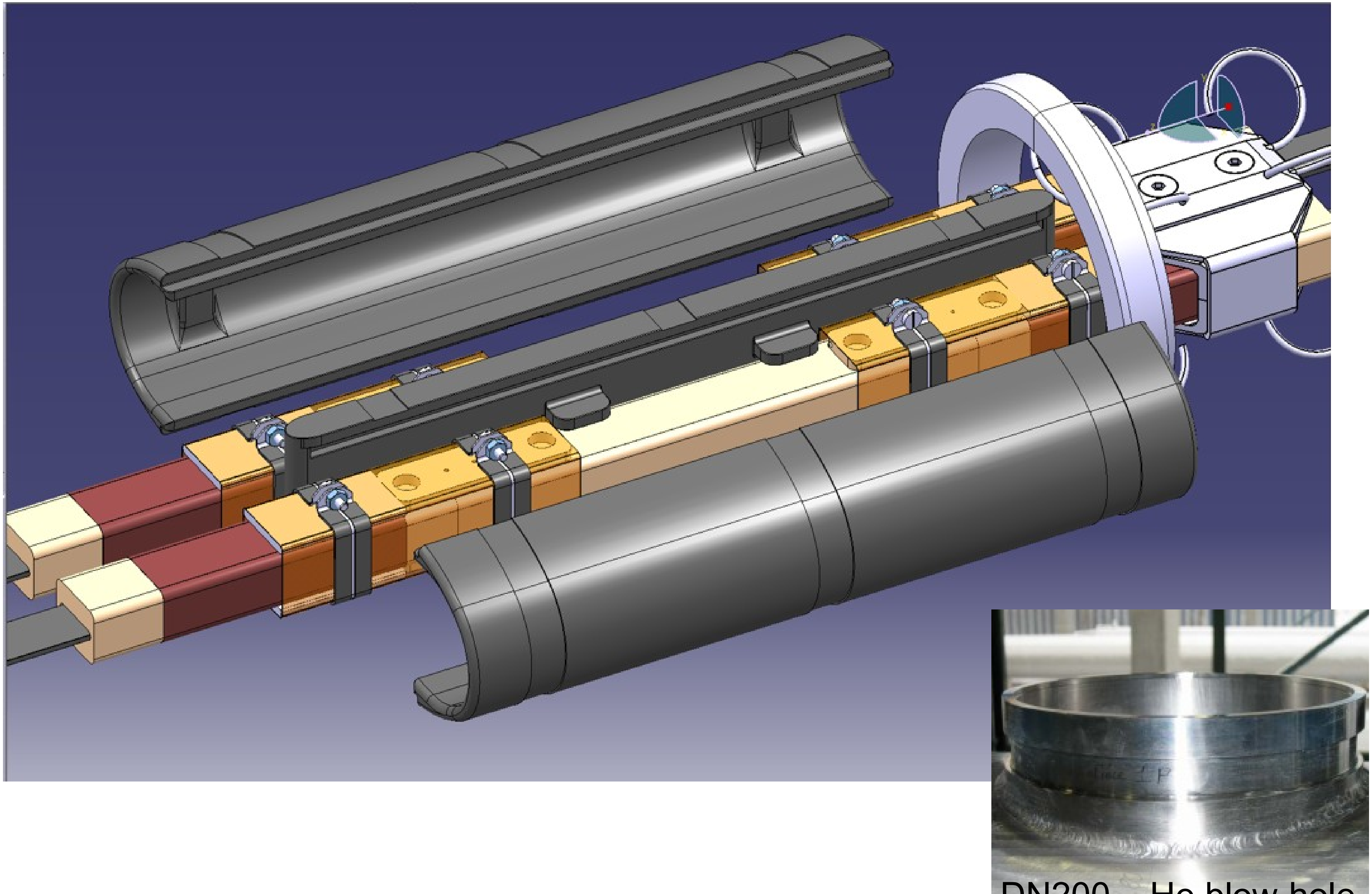
Immediate LHC Upgrades – Long Shutdowns (LS)

- 2013 – 2014: LS1 consolidate LHC for 6.5 / 7TeV:
  - Measure all splices and repair the defective
  - Consolidate interconnects with new design (clamp, shunt)
  - Finish installation of pressure release valves (DN200)
  - Magnet consolidation
  - Electronics relocation, redesign, etc. to further reduce SEE (R2E)
  - Install collimators with integrated button BPMs (tertiary collimators and a few secondary collimators)

- 2018: LS2 to prepare for 'ultimate LHC' parameter set:
  - Phase II collimation upgrade
  - Major injectors upgrade (LINAC4, 2GeV PS Booster, SPS coating, …)
  - Prepare for crab cavities and LR-BBC (for HL-LHC)

(Not discussed: extensive parallel consolidation/upgrades of experiments → discussed in other sessions)

LHC MB Circuit Splice Consolidation Proposal Clamping and Shielding



DN200 – He blow-hole

Integral Part of LHC are the Injector and their Upgrade
Motivation:

- Aim of HL-LHC is to provide 250-300 fb^{-1} per year

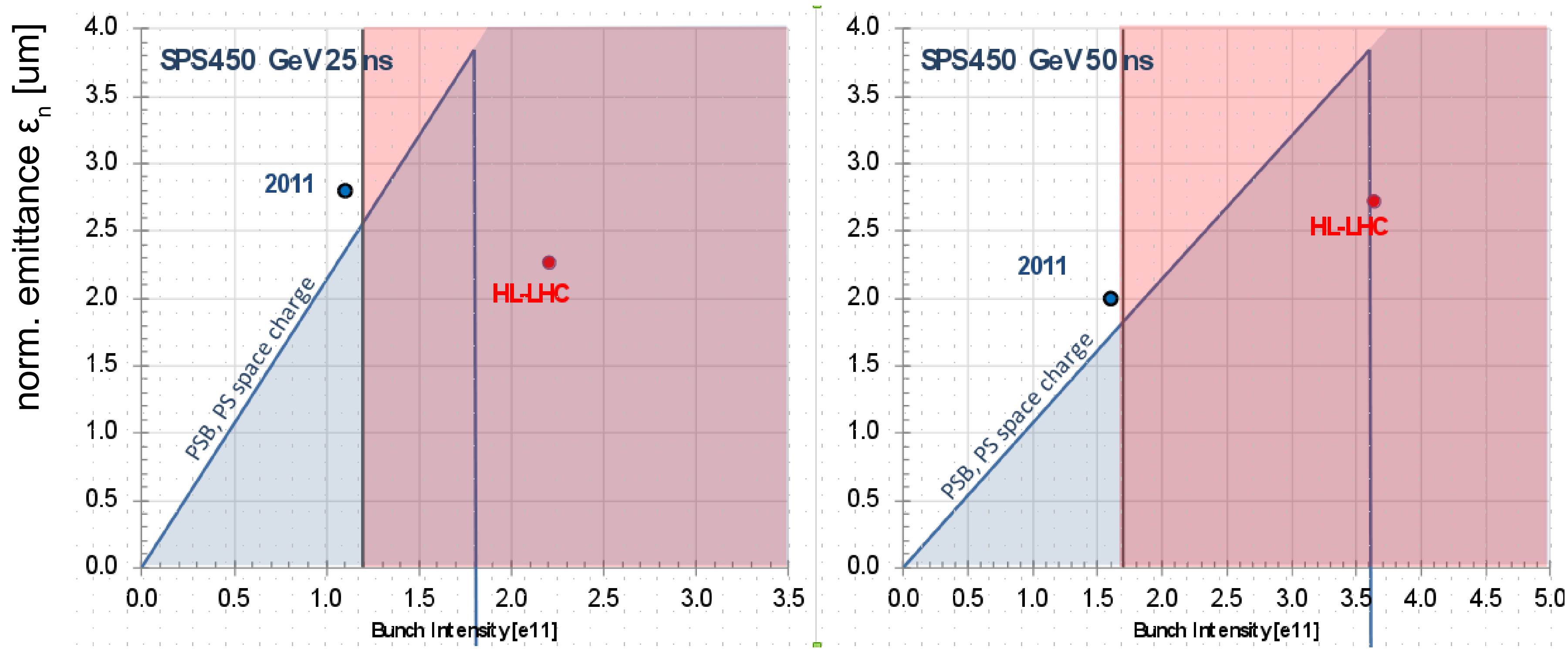
Parameter	nominal	minimum β* 25ns	minimum β* 50ns
N	1.15E+11	**2.0E+11**	**3.3E+11**
n_b	2808	2808	1404
beam current [A]	0.58	**1.02**	**0.84**
x-ing angle [μrad]	300	475	520
beam separation [σ]	10	10	10
β* [m]	0.55	**0.15**	**0.15**
ε_n [μm]	3.75	2.5	3.0
ε_L [eVs]	2.51	2.5	2.5
energy spread	1.00E-04	1.00E-04	1.00E-04
bunch length [m]	7.50E-02	7.50E-02	7.50E-02
IBS horizontal [h]	80 -> 106	**25**	**17**
IBS longitudinal [h]	61 -> 60	**21**	**16**
Piwinski parameter	0.68	**2.5**	**2.5**
geom. reduction	0.83	**0.37**	**0.37**
beam-beam / IP	3.10E-03	**3.9E-03**	**5.0E-03**
Peak Luminosity	$1\ 10^{34}$	**$7.4\ 10^{34}$**	**$8.4\ 10^{34}$**
Events / crossing	19	**141**	**257**

at LHC collision

- … beyond intensities and brightness of the present injectors

O.Brüning, HI-LUMI event 16-18 November 2011

2011 to post-LS2



- Excellent in 2011/2012:
  - 50 ns: $1.5\cdot10^{11}$ p/bunch with 2.5 um (at LHC flat-top)
  - 25 ns: around $1.1\cdot10^{11}$p/bunch with 2.8 um, extracted from SPS
- Still large improvement is required for either 25 or 50 ns beam!

LHC Performance after LS1

- What can the injectors deliver?
- What can the LHC take?
  - RF, cryo, MP, e-cloud…
- What can the LHC do with it?
  - Squeeze, pile-up…
- … folded with scheduled time, machine availability & operational robustness

Beam from Injectors I/II

Operational production scheme		nominal 25 ns	50 ns (CBI-limit)
PS injection	Bunch intensity, $\times 10^{11}$ p/b	**16**	12
	Emittance, $\beta\gamma\varepsilon$	2.4 µm	1.8 µm
	Vert. tune spread, ΔQy	-0.26	-0.25
PS ejection	Bunch intensity, $\times 10^{11}$ p/b	1.27	1.90
	Emittance, $\beta\gamma\varepsilon$	2.5 µm	1.9 µm
	Bunches per batch	**72**	36
Brightness limit PSB		X	X
Space charge limit PS		X	X
Coupled-bunch limit PS			X
SPS ejection: expected (achieved)	Bunch intensity, $\times 10^{11}$ p/b	**1.15**	**1.7**
	Emittance, $\beta\gamma\varepsilon$	**2.8 µm**	**2.1 µm**
Relative beam quality factor, *qib*		1.2	→ 40 % → **1.7**

Potential for nominal luminosity in LHC…

H. Damerau – Chamonix2012

Beam from Injectors II/II

First PS studies in 2012		25 ns – low $\varepsilon_x/\varepsilon_y$	25 ns ultra-bright
PS injection	Bunch intensity $\times 10^{11}$ p/b	**8**	0.65
	Emittance, $\beta\gamma\varepsilon$	1.2 μm	1.0 μm
	Vert. tune spread, ΔQy	-0.24/-0.26	-0.26
PS ejection	Bunch intensity x 10^{11} p/b	1.27	1.54
	Emittance, $\beta\gamma\varepsilon$	1.3 μm	1.1 μm
	Bunches per batch	36/**48**	32
Brightness limit PSB		**X/-**	**X**
Space charge limit PS		**-/X**	**X**
Coupled-bunch limit PS			
SPS ejection	Bunch intensity $\times 10^{11}$ p/b	**1.15**	**Beyond SPS reach**
	Emittance, $\beta\gamma\varepsilon$	**1.4 μm**	
Relative beam quality factor, *qib*		**2.2**	

Potential for ~twice the nominal luminosity in LHC…

H. Damerau – Chamonix2012

25 ns vs. 50 ns Bunch Spacing Pro's and Con's

- 50-ns beam: smaller emittance from the PS
  - less splittings in the PS; i.e. less charge in the PSB
  - ε_n ~2 vs ~3.5 um at LHC injection
- 25-ns beam: ε-growth due to e-cloud in the SPS and LHC
  - to be improved by scrubbing in the LHC, and a-C coating in the SPS
- 25-ns has more long-range beam-beam interactions
  - Larger crossing angle → smaller aperture margin → limit on β*
- Total current limit (by vacuum; RF) → limit # bunches
- Bunch train current limits in SPS & LHC → limit # bunches
- UFO rate seems to greatly increase for 25-ns spacing
- Factor ~2 lower pile-up for 25 ns vs. 50 ns (assuming const. Lumi)
  → Ultimately we will (try to) transit to 25-ns spacing because of pile-up
  - Alternative: lumi-leveled 50-ns operation (worked upon)

Folding in Assumption on LHC Operation after LS1

- Energy 6.5 TeV (in 2015)
- Aperture not worse than now
- Bunch spacing 25 ns or 50 ns
- Understand (and control) emittance increase
- Pile-up – assume acceptable mean mu of ~40
  - This will constrain the utility of 50 ns
- Beta* ~0.5 m
  - of limited utility to squeeze further

- Some additional options:
  - Beta* lumi-leveling to mitigate the initial large pile-up
  - Faster ramp + partial squeeze

Potential Performance

	β^* [m]	I_b SPS [10^{11} p/b]	Emit SPS [um]	Peak Lumi [$10^{34}cm^{-2}s^{-1}$]	~Pile-up μ	Int. Lumi [fb^{-1}]
25 ns	.5	1.2	2.8	1.2	28	32
25 ns low emit	.5	1.2	1.4	2.2	46	57
50 ns level	.5	1.7	2.1	1.7 level 0.9	76 level 40	40 – 50*

- 150 days proton physics
- 5% beam loss, 10% emittance blow-up in LHC
- 10 sigma separation
- 70 mb visible cross-section
- * different operational model - caveat

All numbers approximate!

Mike Lamont

Disclaimer: Potential Limitations – Caveats

- Performance could be impacted by:
  - Radiation to electronics – SEU's
  - UFOs at higher energy & with 25 ns
  - Electron cloud & high energy & at 25 ns
  - Long-range beam-beam & smaller crossing angle & at 25 ns
  - Emittance growth in physics
  - Single- and bunch-by-bunch beam instabilities (imepdances...)

- Total beam intensity limits in the LHC:
  Ralph Assmann (Chamonix'12):"Beam current limit for HL-LHC"
  - Ultimate total intensity seems a reasonable assumption
    → $1.7 \cdot 10^{11}$ p/bunch x 2808 bunches

Long-Term Upgrades after LS3

- More data needed to understand the discovered and other possible new physics signatures.
  Until these physics cases are fully established, HL-LHC is probably the “safest bet” and base-line from 2022++ until probably at least 2032 (tbc.).

- Provided the absence/existence of new physics within LHC's range:
  - Open-up to the energy frontier: HE-LHC
  - Open-up to the precision frontier: LEP3, LHeC, ...

Very Long-Term Objectives: High-Energy LHC I/II

- Very preliminary HE-LHC parameter (large error bars)

	nominal LHC	HE-LHC
beam energy [TeV]	7	16.5
dipole field [T]	8.33	20
dipole coil aperture [mm]	56	40-45
#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

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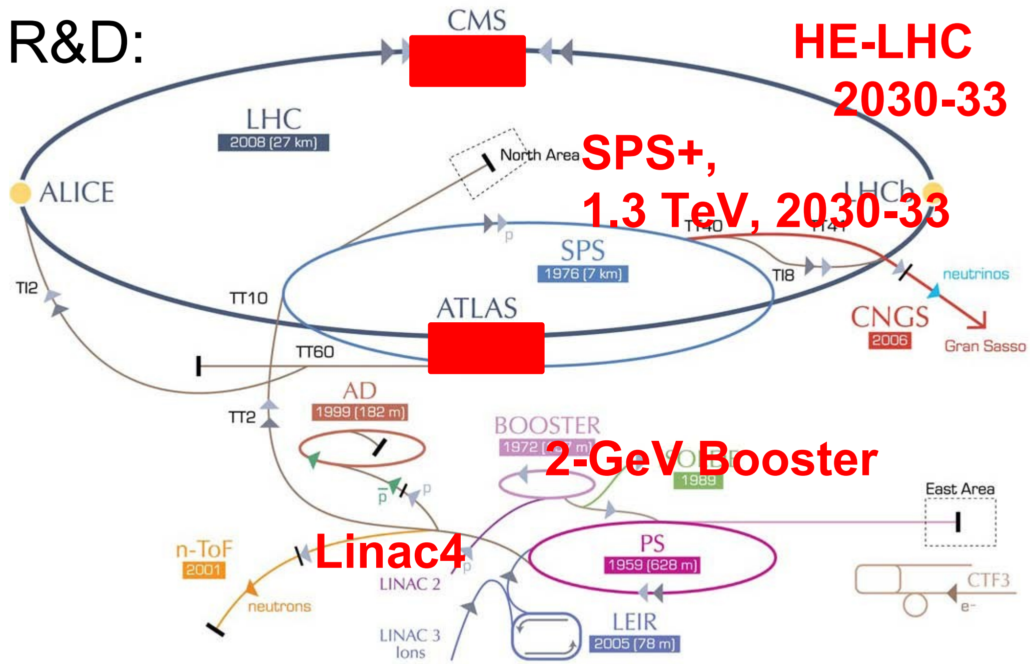
Very Long-Term Objectives: High-Energy LHC II/II

HE-LHC – main Issues and R&D:



- High-field 20T dipole magnets based on Nb_3Sn, Nb_3Al, and HTS
- High-gradient quadrupole magnets for arc and IR
- Fast cycling SC magnets for ~1.3 TeV injector
- Emittance control in regime of strong SR damping and IBS
- Cryogenic handling of SR heat load (first analysis; looks manageable)
- Dynamic vacuum

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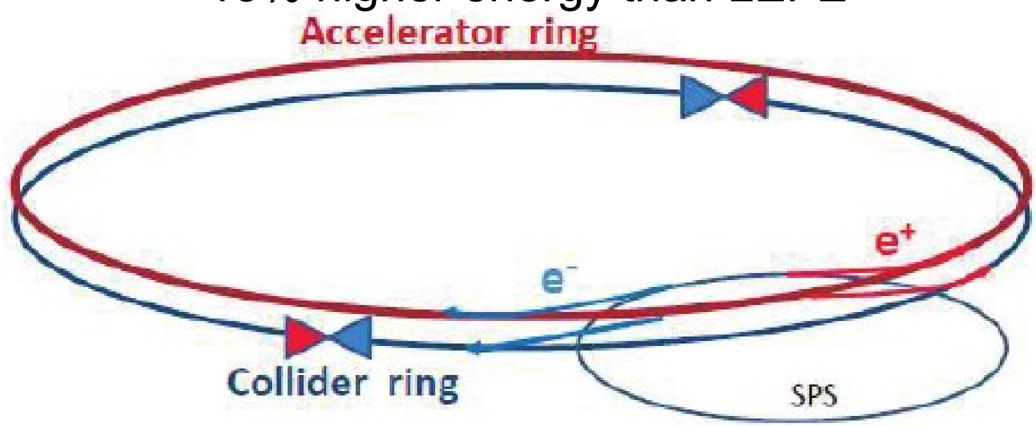
Very Long-Term Objectives: LEP3 circular Higgs factory ($e^+e^- \rightarrow Z^* \rightarrow Z+H$) I/II

- Initial thoughts – <u>very</u> preliminary:
  EuCARD: http://indico.cern.ch/conferenceDisplay.py?confId=193791
  - ~ 15% higher energy than LEP2



- Installation in the LHC tunnel "LEP3"
  - + inexpensive (<0.1xLC)
  - + tunnel exists
  - + reusing ATLAS and CMS detectors
  - + reusing LHC cryoplants
  - - interference with LHC and HL-LHC

Alain Blondel, Frank Zimmermann et al.

	LEP2	LHeC	LEP3
b. energy E_b [GeV]	104.5	60	120
circumf. [km]	26.7	26.7	26.7
beam current [mA]	4	100	7.2
#bunches/beam	4	2808	4
$\#e^-$/beam [10^{12}]	2.3	56	4.0
horiz. emit. [nm]	48	5	25
vert. emit. [nm]	0.25	2.5	0.10
bending rad. [km]	3.1	2.6	2.6
part. number J_ϵ	1.1	1.5	1.5
mom. c. α_c [10^{-5}]	18.5	8.1	8.1
SR p./beam [MW]	11	44	50
β^*_x [m]	1.5	0.18	0.2
β^*_y [cm]	5	10	0.1
σ^*_x [μm]	270	30	71
σ^*_y [μm]	3.5	16	0.32
hourglass F_{hg}	0.98	0.99	0.67
E^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99
$V_{RF,tot}$ [GV]	3.64	0.5	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	4.2
ξ_x/IP	0.025	N/A	0.09
ξ_y/IP	0.065	N/A	0.08
f_s [kHz]	1.6	0.65	3.91
E_{acc} [MV/m]	7.5	11.9	20
eff. RF length [m]	485	42	606
f_{RF} [MHz]	352	721	1300
δ^{SR}_{rms} [%]	0.22	0.12	0.23
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.69	0.23
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	N/A	107
number of IPs	4	1	2
beam lifetime [min]	360	N/A	16
Υ_{BS} [10^{-4}]	0.2	0.05	10
n_γ/collision	0.08	0.16	0.60
ΔE^{BS}/col. [MeV]	0.1	0.02	33
ΔE^{BS}_{rms}/col. [MeV]	0.3	0.07	48

Conclusions

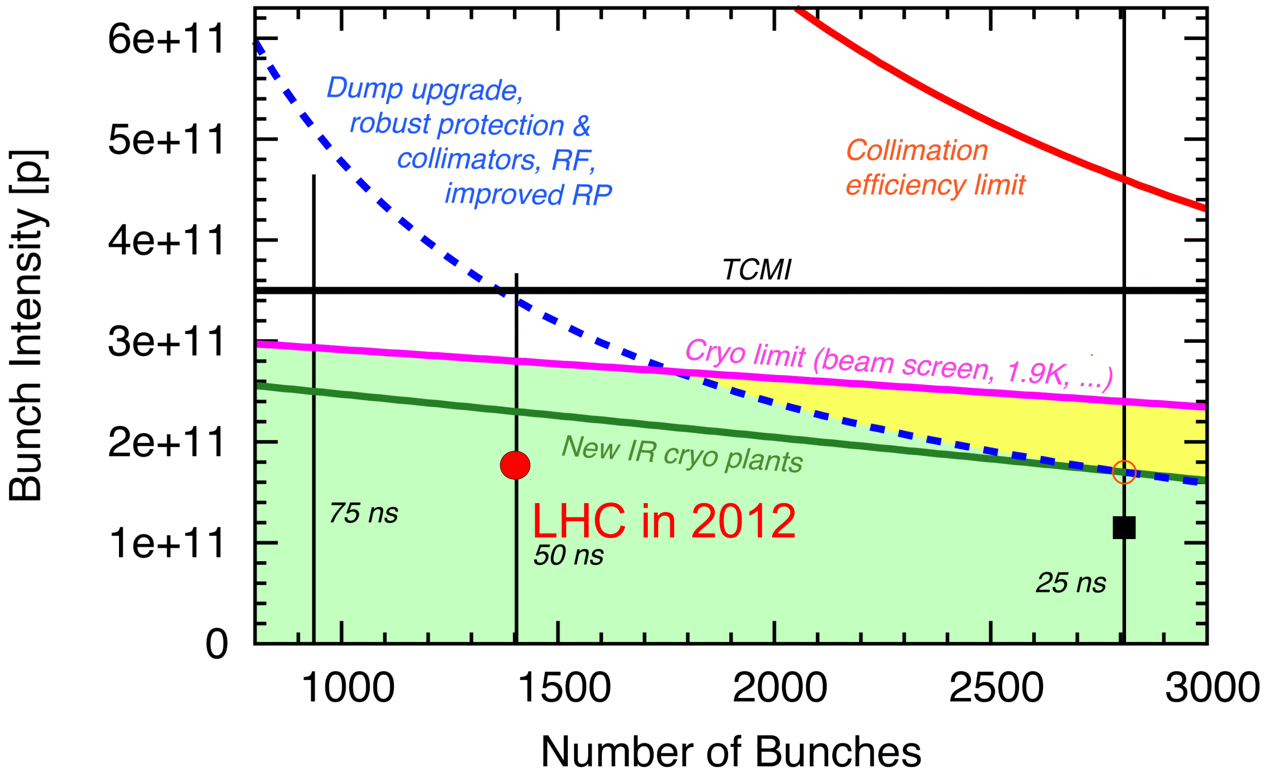
- 2012 performance – after some more experience – is looking encouraging, goals for year and > LS1 credible
- Immediate Upgrade targets 7 TeV & Luminosity: LIU & HL-LHC
  - Need more data to study aspects of the Higgs in detail
- 25 ns is baseline with potential to reach ultimate luminosity certainly after – possibly before – LS1
- Levelled 50 ns is an interesting option, particularly if there are total intensity limitations – certainly not yet operational
- Provided the absence/existence of new physics within LHC's range:
  - Open-up to the energy frontier: HE-LHC (under study)
  - Open-up to the precision frontier: LEP3, LHeC (under study)

} Probably ~ HL-LHC

Spare Slides

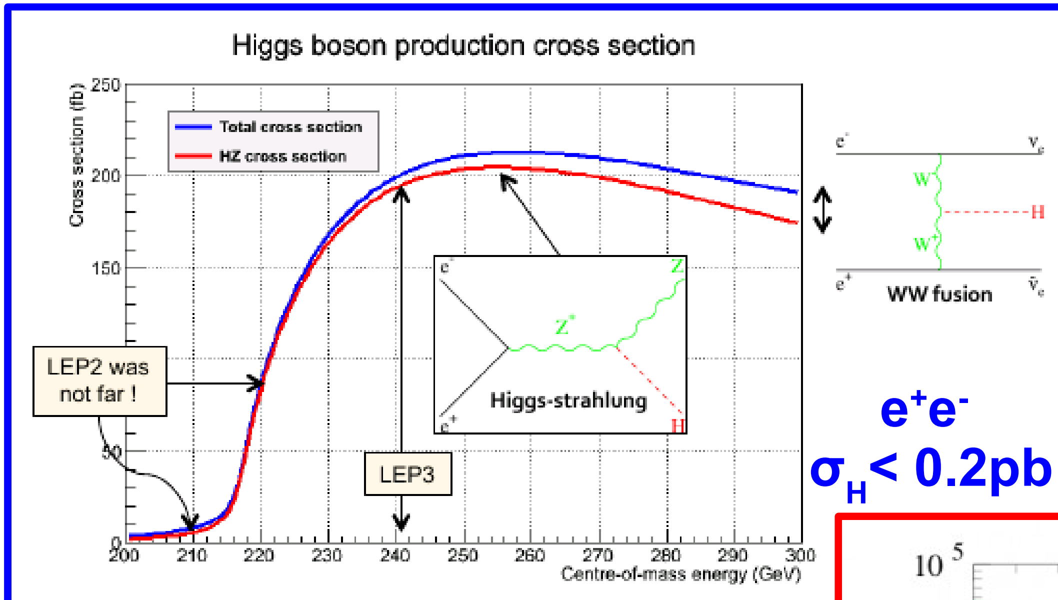
LHC Limits

- Encyclopedic run through by Ralph Assmann at Chamonix'12
  - Google: "Beam current limit for HL-LHC"

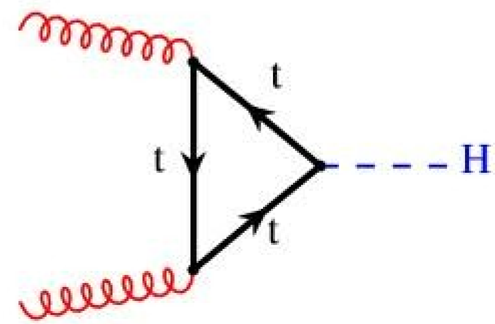


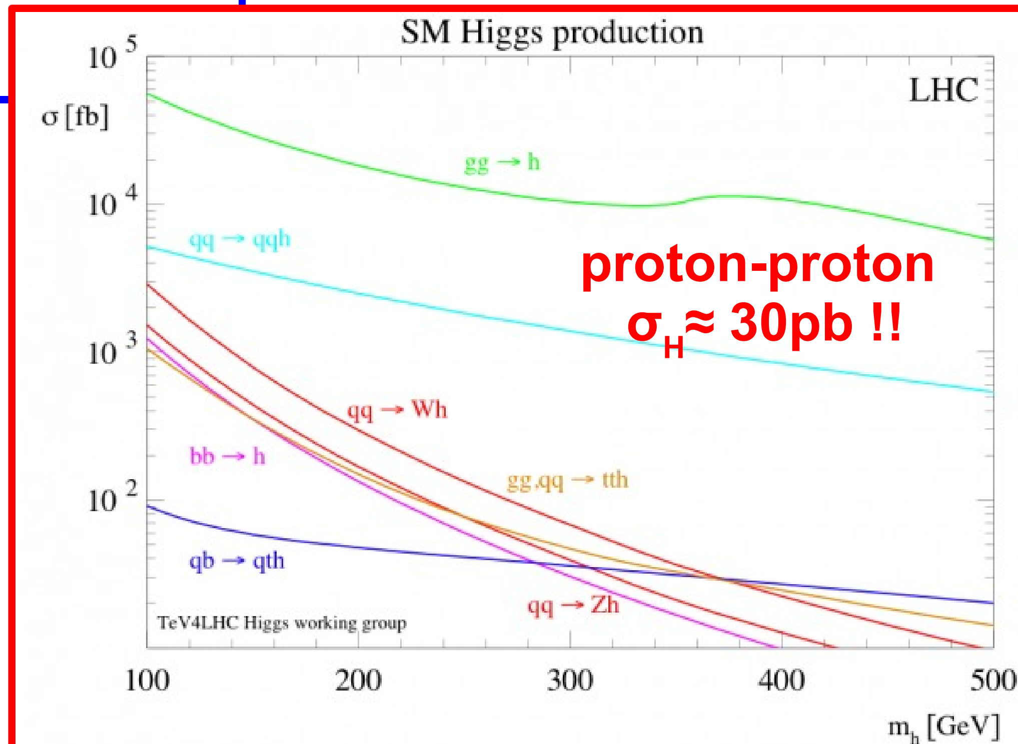
- Potential limits from: RF, Vacuum, e-cloud, Cryo, Magnets, Injection and Protection, Collimation, SEUs, Radiation Protection, …
- Ultimate intensity seems a reasonable assumption
  → $1.7 \cdot 10^{11}$ p/bunch x 2808 bunches

Higgs Cross-Sections e^+e^- vs. pp Collider
N.B. Working Assumption m_h=124 GeV



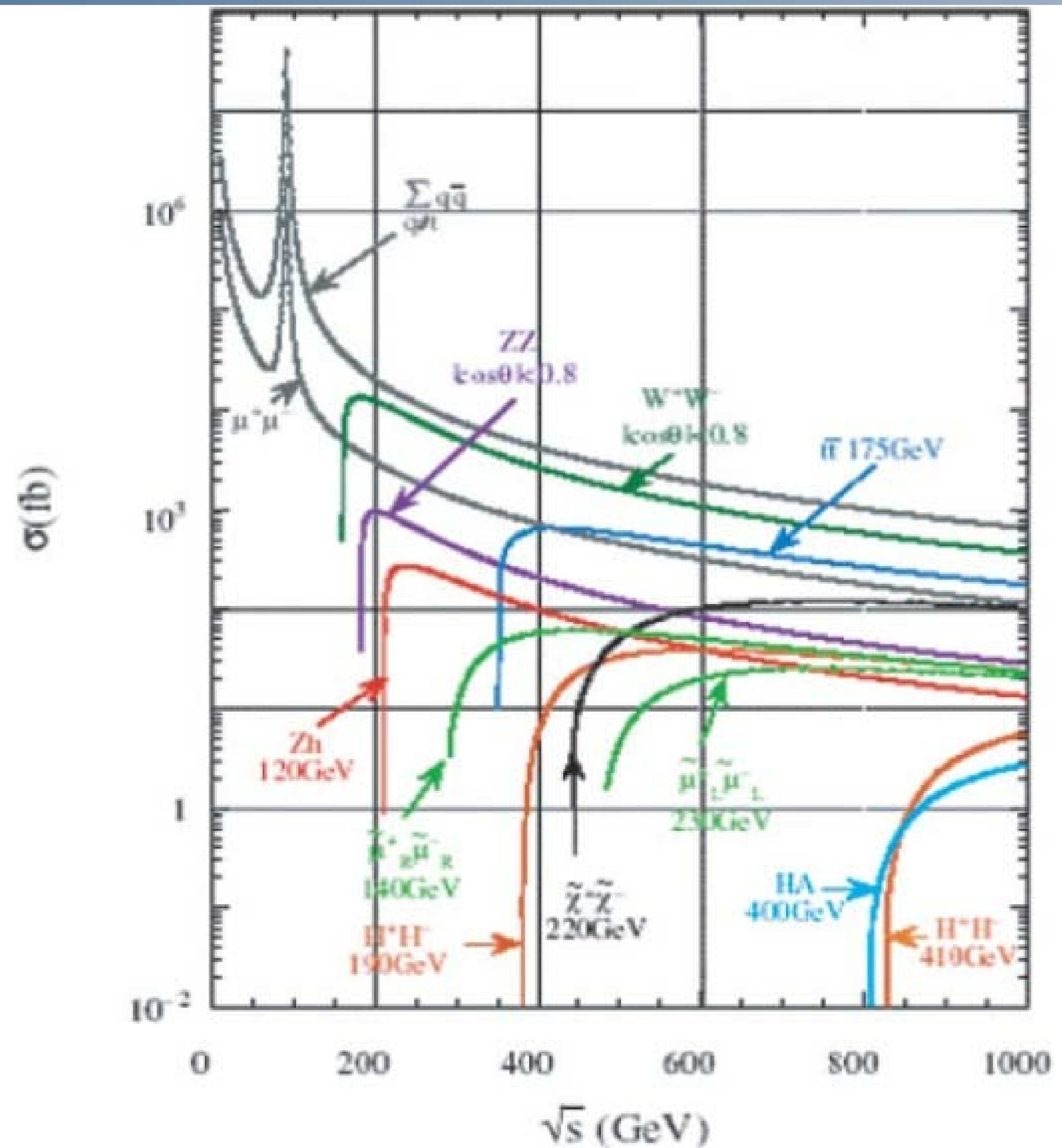
e^+e^-
σ_H< 0.2pb





proton-proton
σ_H≈ 30pb !!

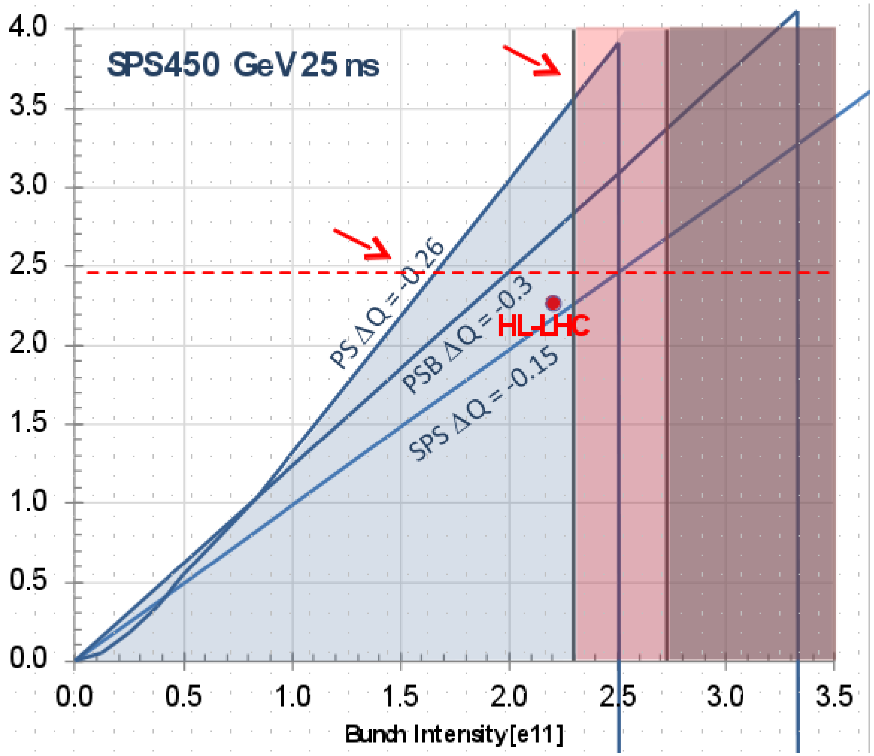
e⁺e⁻ vs. background



After LS1 & LS2 LIU Upgrade: 25 ns vs. 50 ns

25 ns:

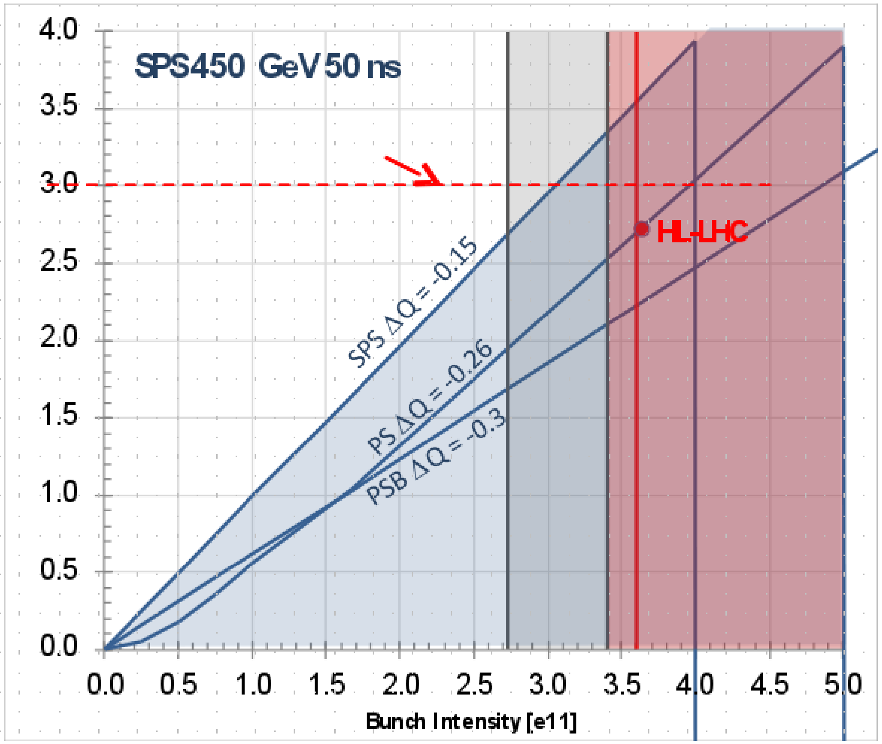
- Limit is 2.3e11 p+/b in 3.6 um at SPS extraction (1.6e11 in 2.3 um)



- Fundamental limit: space charge in PS

50 ns:

- Limit is 2.7e11 p+/b in 2.7 um at SPS extraction (closer to HL-LHC requ.)



- Limited by long. instabilities in PS/SPS + brightness in SPS

Brennan Goddard

Performance Estimates after LS2

- Assumption:
  - 7 TeV, 150 days of proton physics
  - Hübner Factor = 0.2 for 25 ns
  - Different operations model for 50 ns levelled

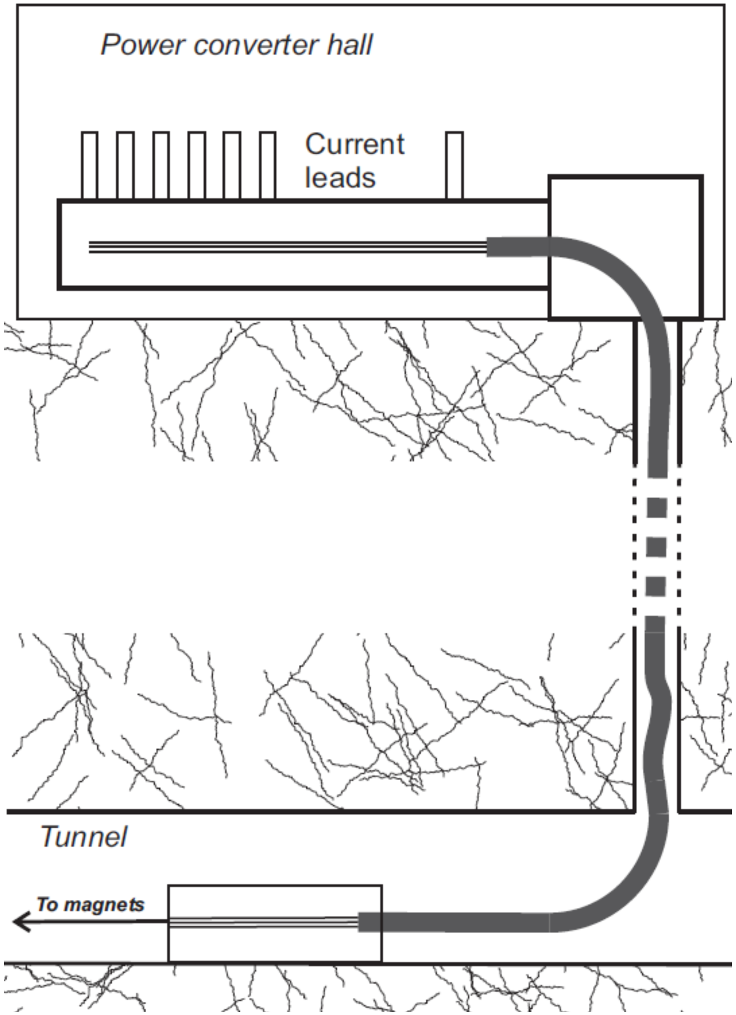
	β* [m]	Ib (SPS) [10^{11}p/b]	Emit (SPS) um	Peak Lumi [10^{34}cm-2s-1]	Pile-up	Int. Lumi [fb^{-1}]
25 ns	.5	1.6	2.3	2.5	56	~65
50 ns	.5	2.7e11	2.7	2.8 level 0.9	125 level 40	~50

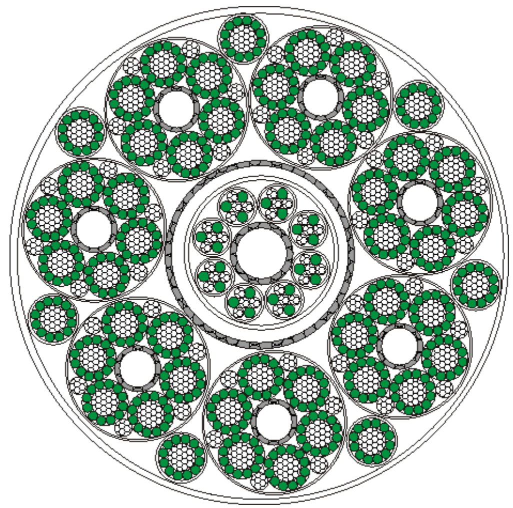
Neglecting low emittance option
All numbers approximate!

Mike Lamont

R&D Superconducting Links

Motivated by the need to remove the power converters out of the tunnel. avoiding radiation effects





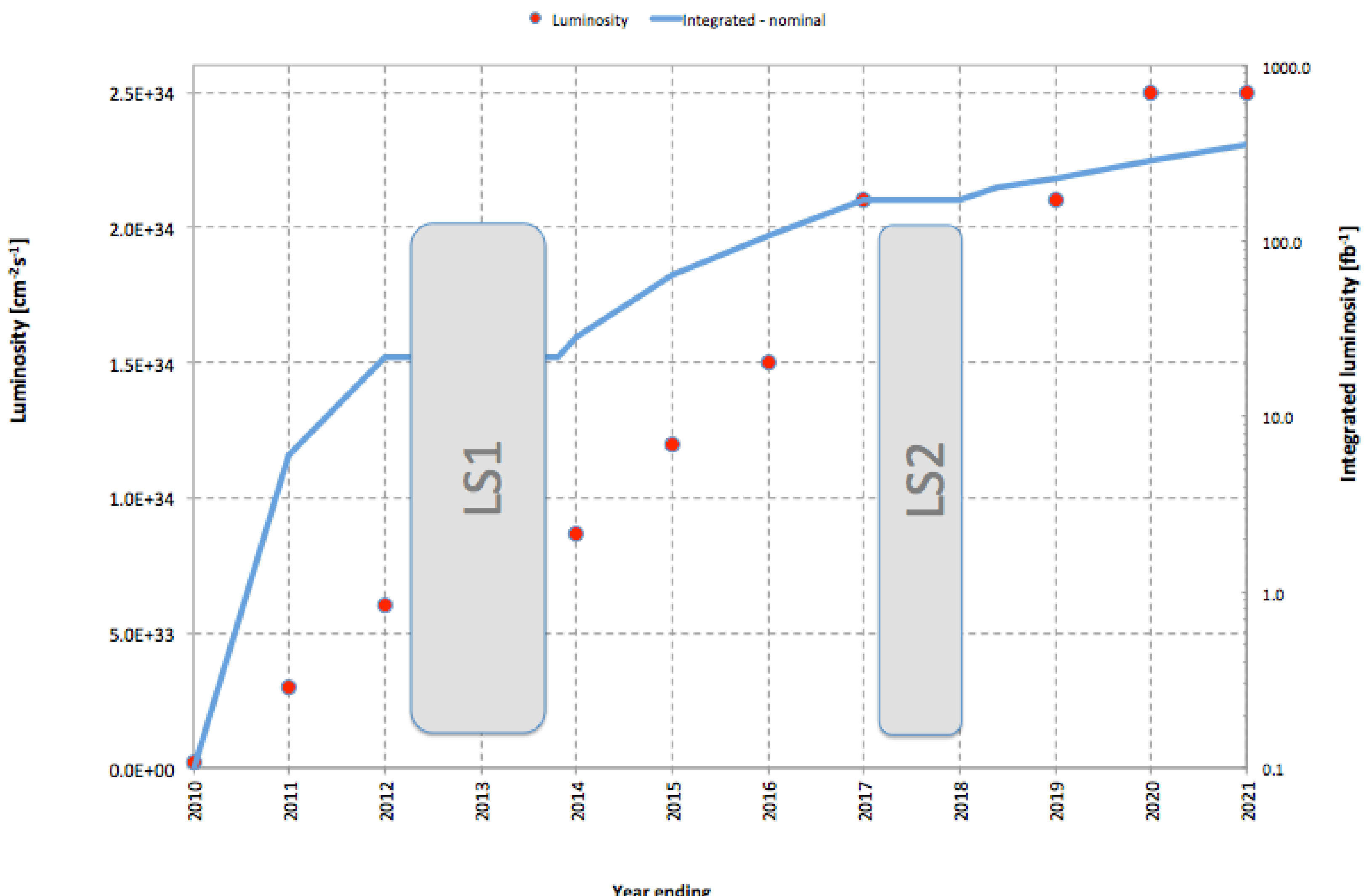
Φ = 62 mm

MgB2
(or other
HTS)

7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables I tot~120 kA @ 30 K

Also DFs with current leads removed to surface
Definitive solution to R2E problem
Make room for shielding unmovable electronics
Make much easier maintnance and application
ALARA

Projections



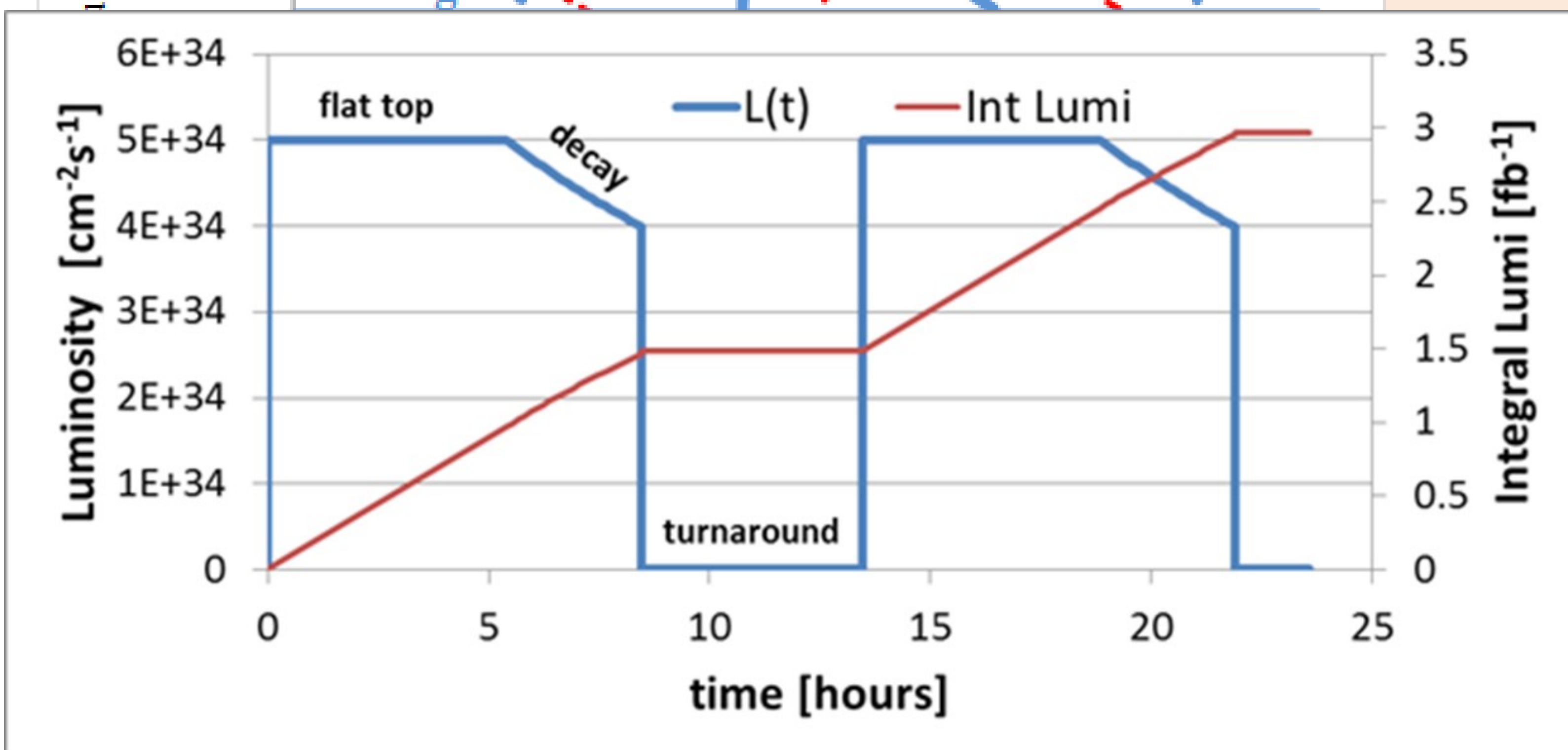
- 25 ns
- Low emittance option viable between LS1 & LS2
- Usual warnings apply

Preliminary HL-LHC Performance Estimates

aseline

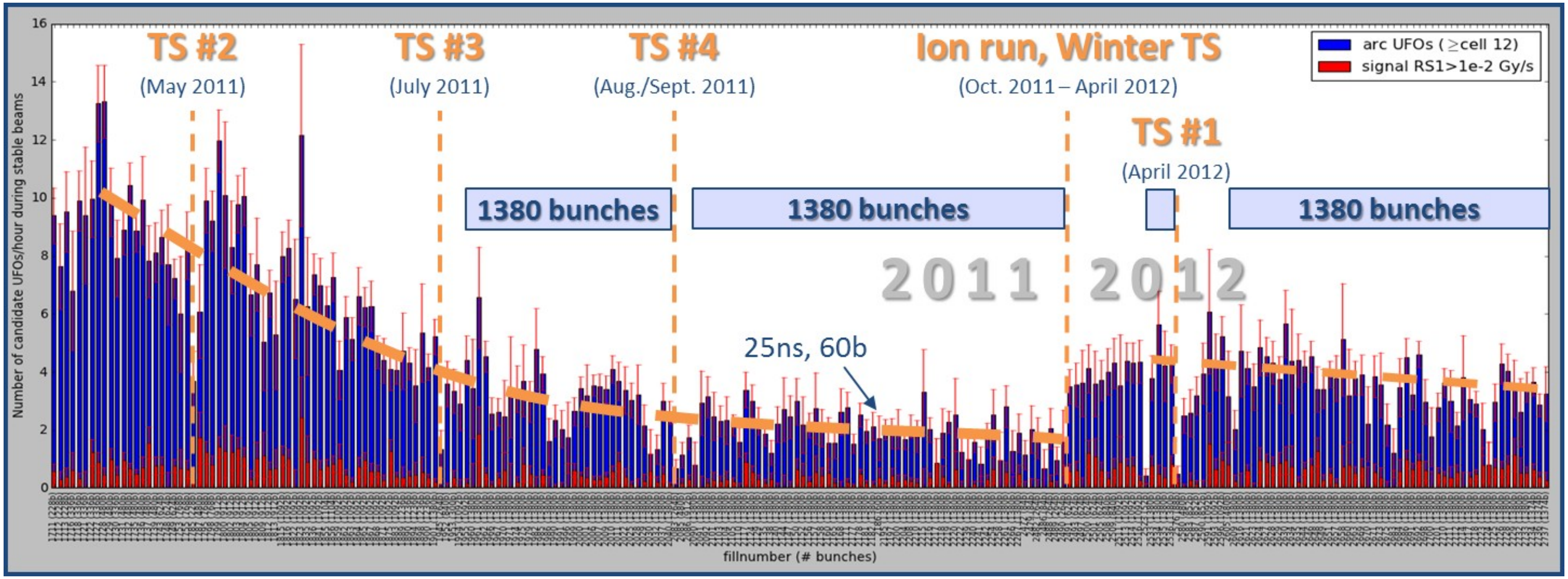
) ns

.5



UFO's@LHC: Beam Dumps due to (Un)identified Falling Objects

- 35 beam dumps between July 2010 and Aug. 2011
  - ~10 turns loss duration with often unconventional loss locations (e.g. arc)
  - UFOs occur all around the LHC. Particularly many UFOs around MKIs
- Throughout 2011: Mitigation by increase of BLM thresholds

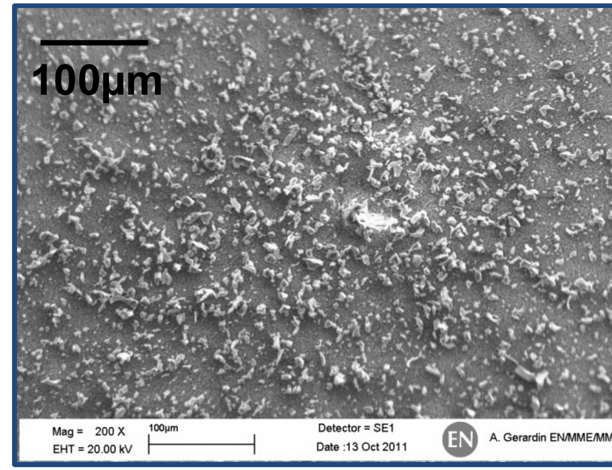


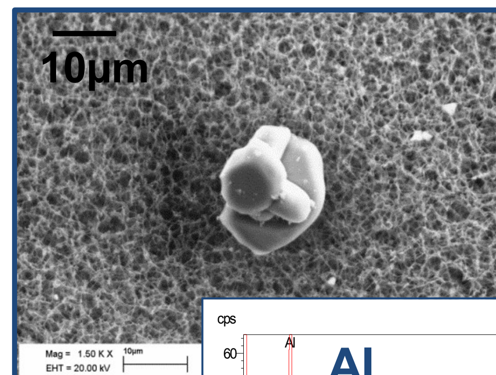
- UFO rate scales with intensity and even stronger with energy → to be closely monitored after LS1

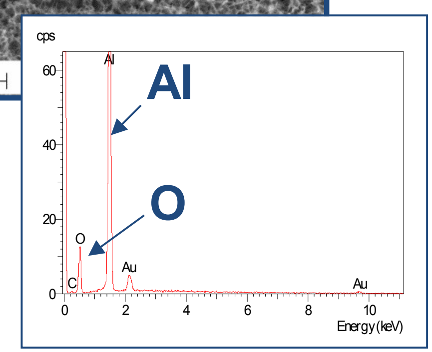
UFO Sources: Macro Particles in MKIs

- Operational tank removed and inspected.
- Energy-dispersive X-ray spectroscopy showed particles mainly consist of Al and O, probably pieces of the Al2O3 ceramic tube.
- Reference measurements:

  clean room air: 100 particles on filter
  new ceramic tube: 10‘000 particles on filter
- **5‘000‘000 particles on filter** found during inspection of removed MKI.
- Improved cleaning can reduce this by an order of magnitude
- Typical macro particle diameter: **1-100µm.**





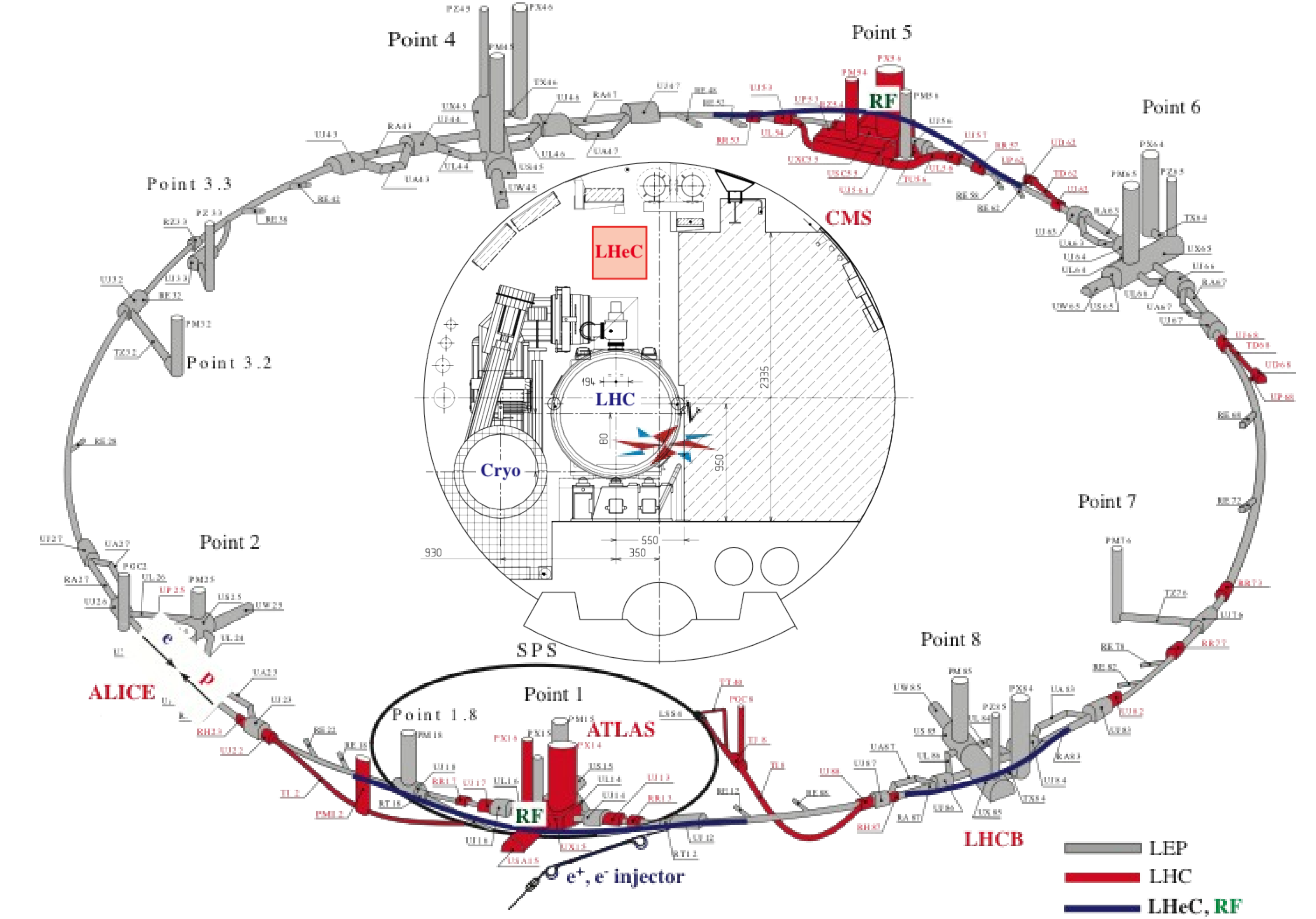


50 ns Performance Estimates

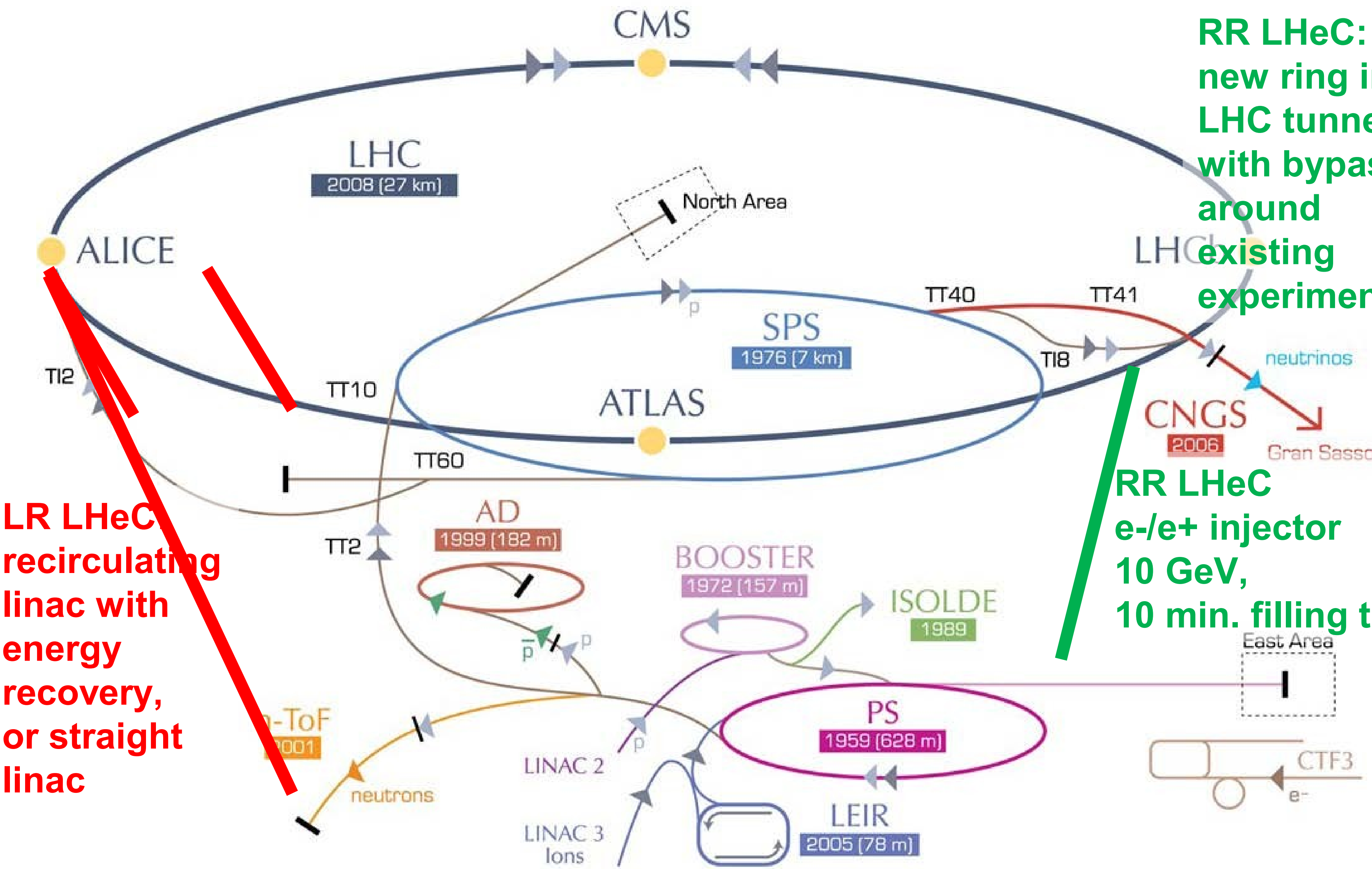
- From Moriond (Mike Lamont):
  - 4 TeV, 50 ns, 1380 bunches, 1.6e11, 2.5 microns
  - 150 days of proton physics (assuming similar efficiencies to 2011)

β^* [m]	Collimators	L_{pk} [$cm^{-2}s^{-1}$]	$\int L_{pk} dt$ [fb^{-1}]	Pile-up μ	$\Delta L_{pk}/L_{pk}$
0.9	Intermediate	$5.1 \cdot 10^{33}$	12.1 – 14.5	26	
0.7	Tight	$6.2 \cdot 10^{33}$	14.7 – 17.6	31	+22%
0.6	Tight	$6.8 \cdot 10^{33}$	16.2 – 19.3	35	+10%

LHeC Ring-Ring Layout and Integration



LHeC options: RR and LR



RR LHeC: new ring in LHC tunnel, with bypasses around existing experiments

RR LHeC e-/e+ injector 10 GeV, 10 min. filling time

LR LHeC: recirculating linac with energy recovery, or straight linac

LHeC Planning and Timeline

- We assume the LHC will reach end of its lifetime with the end of the HL-LHC project:

  -Goal of integrated luminosity of 3000 fb-1 with 200fb-1 to 300fb-1 production per year ➔ ca. 10 years of HL-LHC operation

  -Current planning based on HL-LHC start in 2022

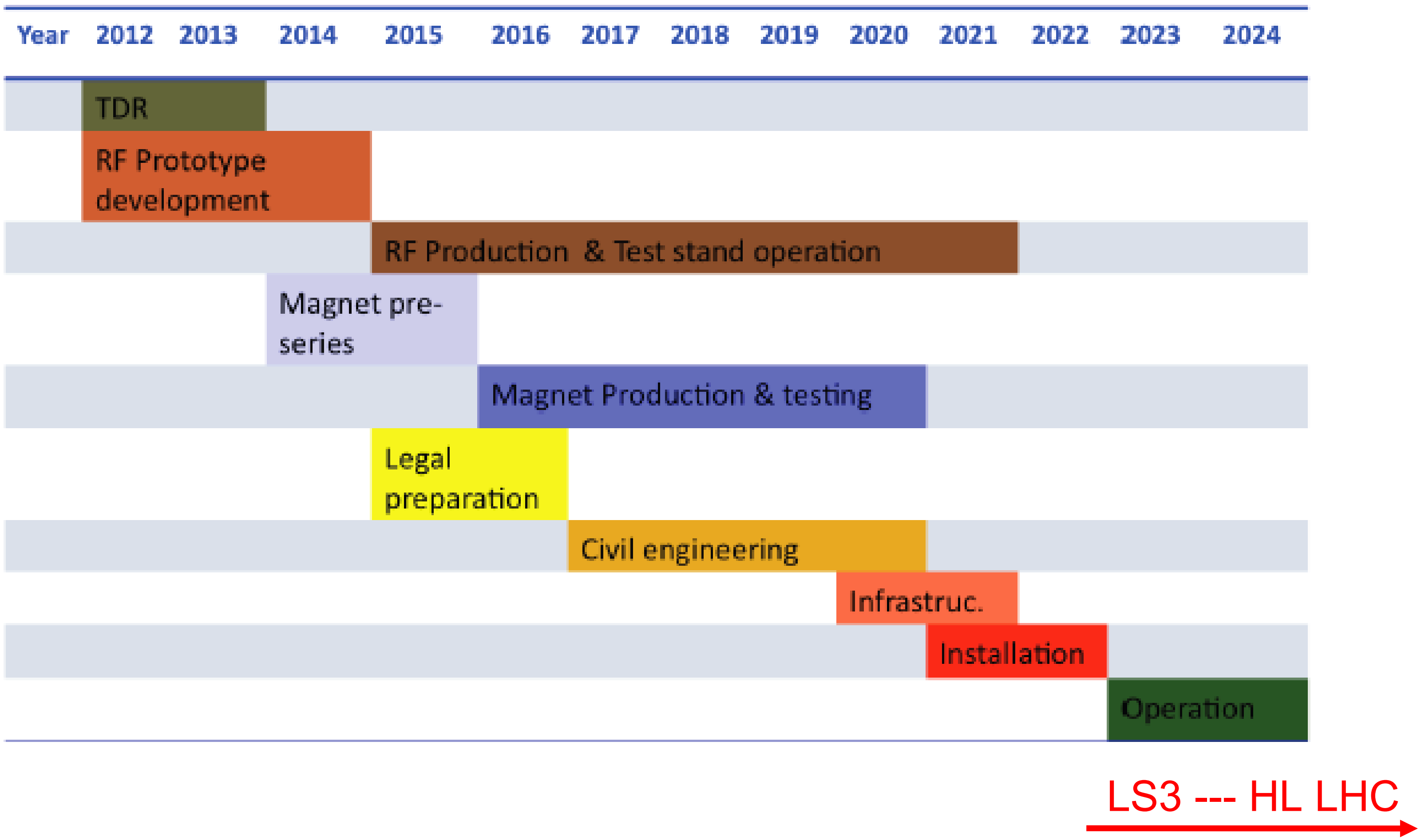
  ➔ end of LHC lifetime by 2032 to 2035

- LHeC operation:

  -Luminosity goal based on ca. 10 year exploitation time (100fb-1)

  -LHeC operation beyond or after HL-LHC operation will imply significant operational cost overhead for LHC consolidation

LHeC Tentative Time Schedule



We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

LHeC Options: Executive Summary

Ring-Ring option:

-We know we can do it: ➔ LEP 1.5

-Challenge 1: integration in tunnel and co-existence with LHC HW

-Challenge 2: installation within LHC shutdown schedule

Linac-Ring option:

-Installation decoupled from LHC operation and shutdown planning

-Infrastructure investment with potential exploitation beyond LHeC

-Challenge 1: technology ➔ high current, high energy SC ERL

-Challenge 2: Positron source