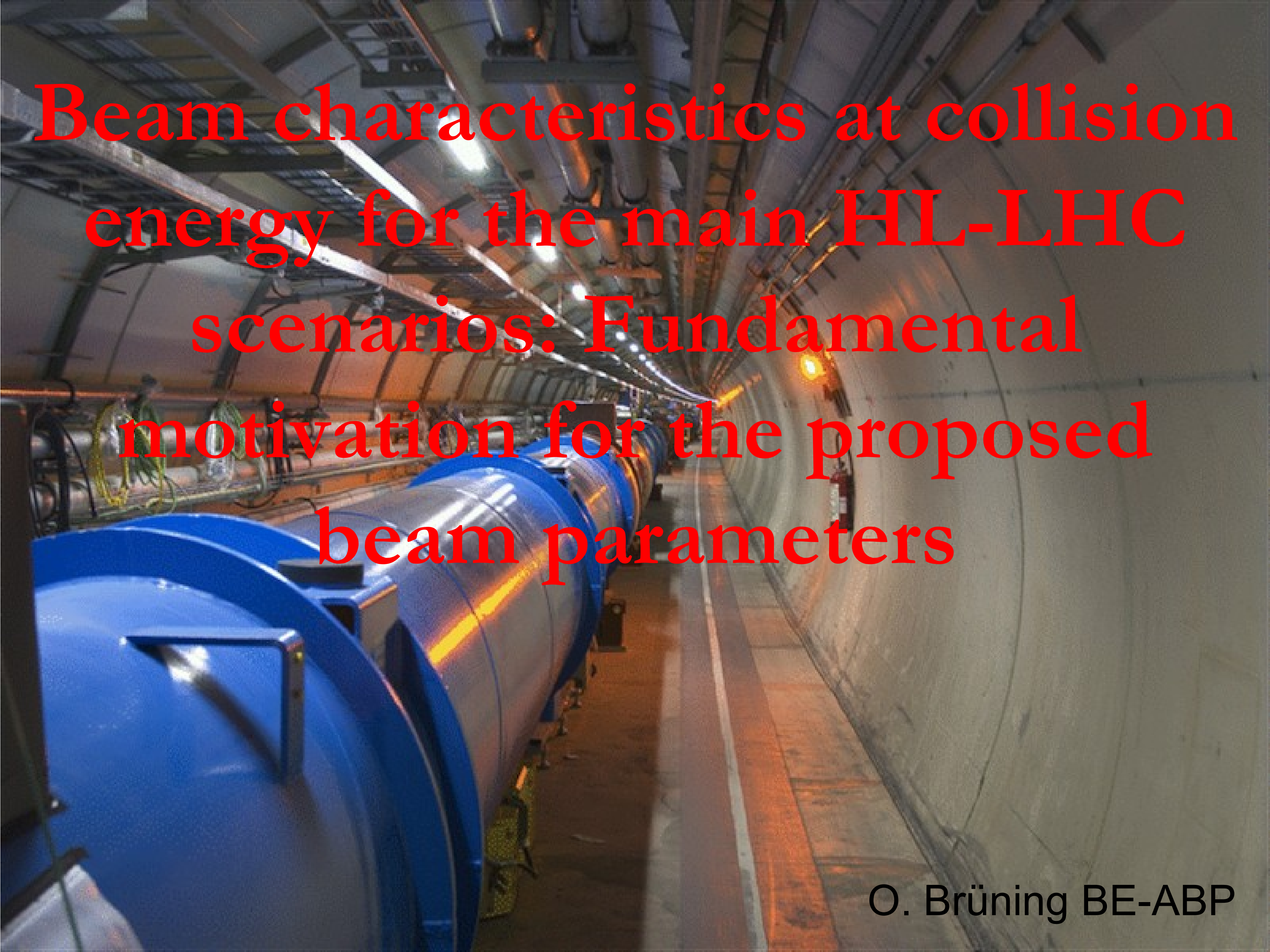


Beam characteristics at collision energy for the main HL-LHC scenarios: Fundamental motivation for the proposed beam parameters

O. Brüning BE-ABP

HL-LHC Performance Goals

- Leveled peak luminosity: $L = 5\ 10^{34}\ cm^{-2}\ sec^{-1}$
- Virtual peak luminosity: $L \geq 10\ 10^{34}\ cm^{-2}\ sec^{-1}$
- Integrated luminosity: 200 fb^{-1} to 300 fb^{-1} per year
  (I assume 250 fb^{-1} per year in the following)
- Total integrated luminosity: ca. 3000 fb^{-1}

Upgrade Considerations: Beam Lifetime

F. Zimmermann, Chamonix 2011

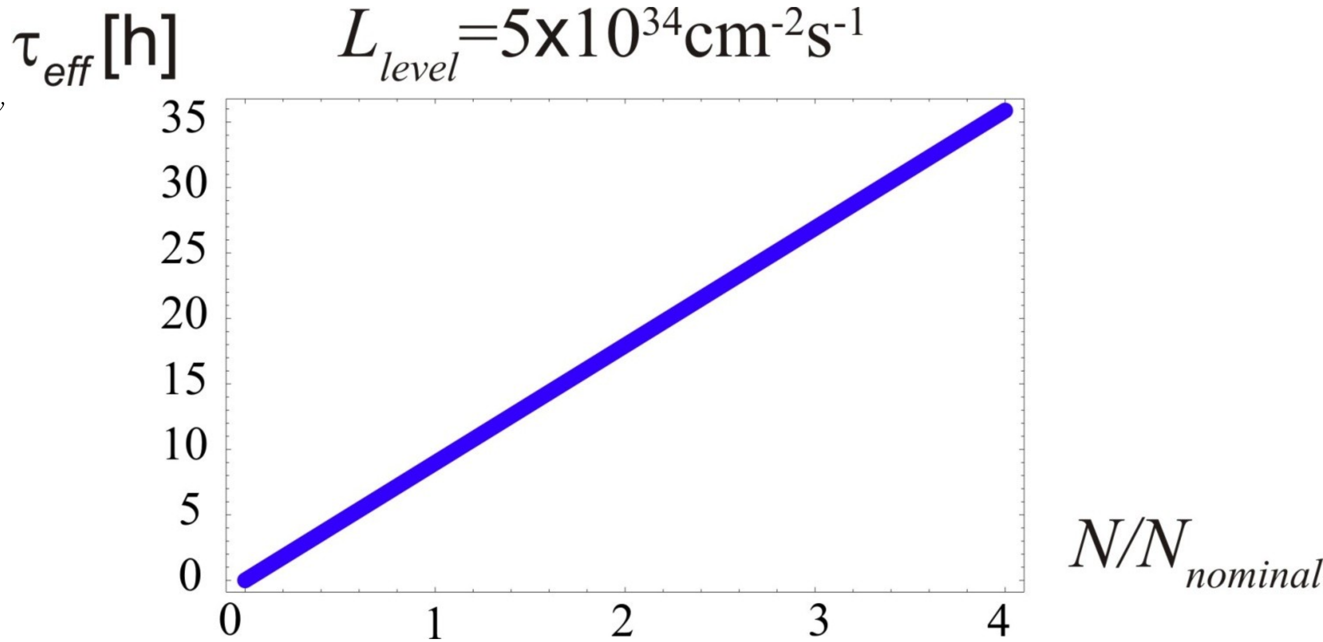
- For given luminosity τ_{eff} scales with total beam current

$$\frac{dN_{tot}}{dt} = -\frac{N_{tot}}{\tau_{eff}} = -n_{IP}\sigma L_{lev}$$

$$N(t) = (1 - t/\tau_{eff})\, N_{tot}$$

$$\tau_{eff} = \frac{N_{tot}}{n_{IP}\sigma L_{lev}}$$

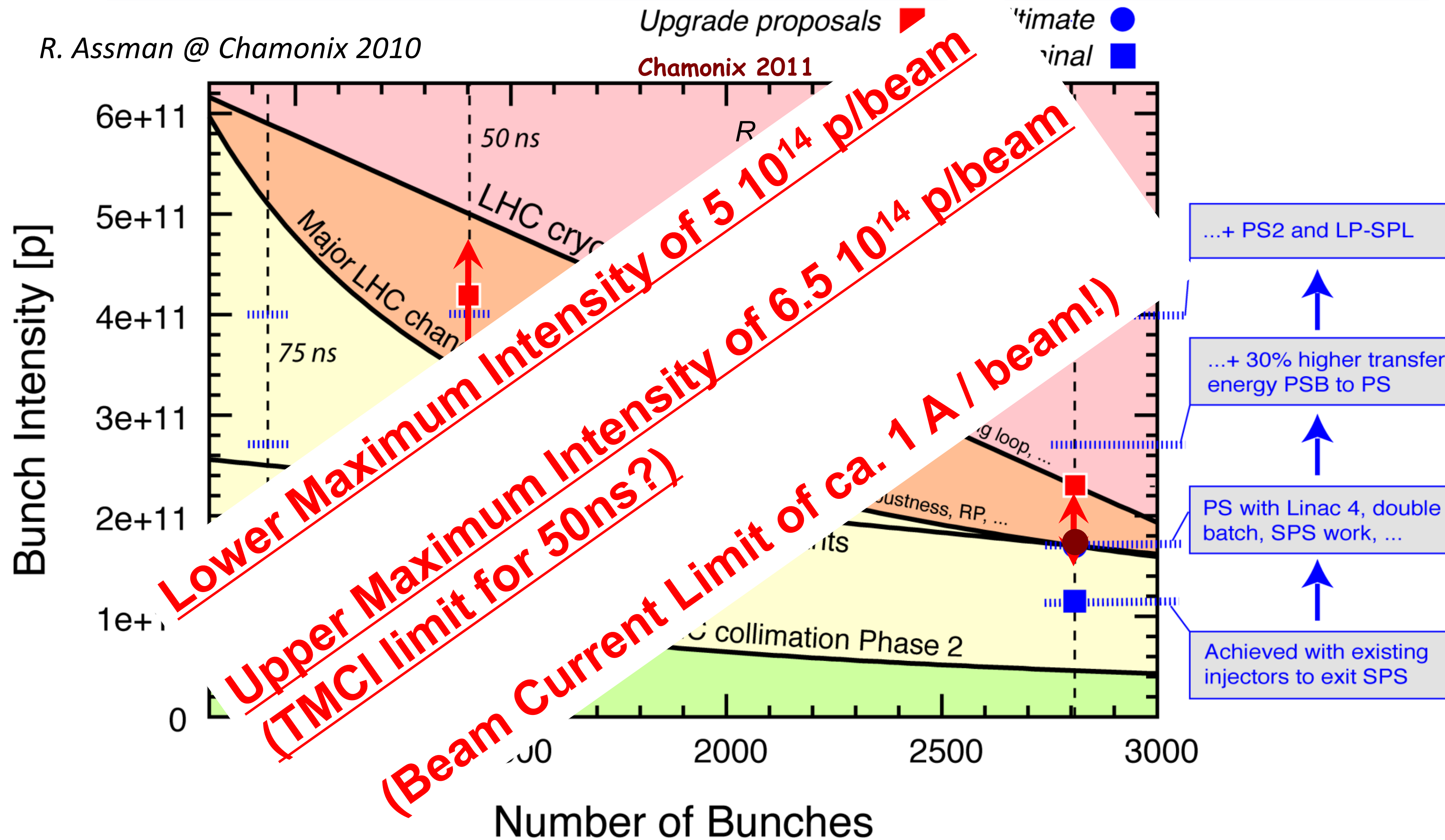
(σ=100 mbarn)



➔ argument for HL-LHC scenarios with maximum beam current

➔ τ_{eff} = 13.9 hours for 5 10^{14} p/beam

Summary of LHC Intensity Limits (7 TeV)



Ideal scenario: no imperfections included!

Note: Some assumptions and conditions apply…

Upgrade Considerations: Beam Lifetime

- Run length assuming leveled luminosity: $L \propto \frac{N_{tot}^2}{n_b}$

➔ virtual luminosity of $k * 5\ 10^{34}\ cm^{-2}\ sec^{-1}$ ➔ $T_{level} = (1-1/\sqrt{k}) * \tau_{eff}$

Assuming: $1.8\ 10^{11}$ ppb @ 25ns & $3.5\ 10^{11}$ ppb @ 50ns (➔ $\approx 5\ 10^{14}$ p/beam)

➔ $\tau_{eff} = 13.9$ hours for $5\ 10^{14}$ p/beam:

k = 2: ➔ $T_{level} = 4.1$ h

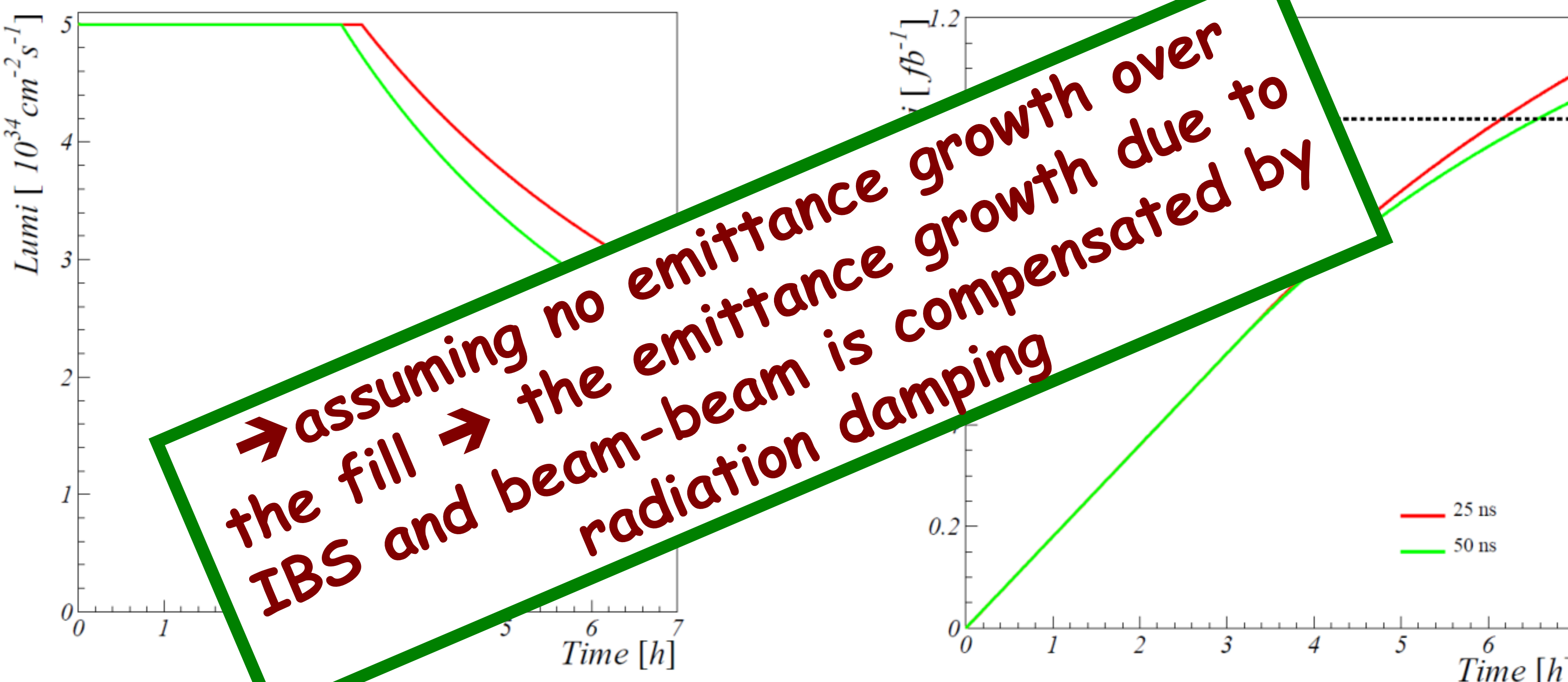
k = 3: ➔ $T_{level} = 5.9$ h

k = 4: ➔ $T_{level} = 7.0$ h

Upgrade Considerations: Integrated Luminosity

- Integrated luminosity: run with luminosity decay

[Stephane Fartoukh]



→ assuming no emittance growth over the fill → the emittance growth due to IBS and beam-beam is compensated by radiation damping

→ L_{int} = ca 0.4 fb^{-1} over 3 h for a luminosity decay to 2.5 10^{34} cm^{-2} s^{-1}

Upgrade Considerations: Integrated Luminosity

- Integrated luminosity: leveling to constant luminosity

$$L_{int} = L_{level} * T_{level}$$

➔ $$L_{int} = \left(1 - \sqrt{L_{level} / L_{virt}}\right) \frac{N_{tot}}{n_{IP}\,\sigma}$$

(σ=100 mbarn)

➔ integrated luminosity directly proportional to total current

➔ L_{int} = 0.4 + 0.73 fb^{-1} per fill for N_{tot} = 5 10^{14} ppb and k = 2

➔ L_{int} = 0.4 + 1.25 fb^{-1} per fill for N_{tot} = 5 10^{14} ppb and k = 4

Upgrade Considerations: Integrated Lum[illegible]sity

Phase	Days	Co[illegible]
Commissioning	21	
Scrubbing run	10	
5 MDs	22	
6 Technical stops	[illegible]	[illegible]ys TS plus 1 [illegible]very with beam)
Special requests		[illegible]TEM/ALPHA Intermediate energy run Luminosity scans
Intensity ramp [illegible]	[illegible]9	
Total high [illegible]	~130	
Ion [illegible]	4	
[illegible]	24	
[illegible]	290	

➔ requires between 150 and 220 fills per year to reach 250 fb^{-1} per year!

Can hope for ca. 150 days / year for HL-LHC operation

➔ implies 1 to 1.5 fills per day for previous scenario

M. Lamont March 2011

Upgrade Considerations: Integrated Luminosity

Machine Efficiency:

➔ average Turnaround time of ca. 5 hours

➔ minimum fill-to-fill time = 3h + leveling time + turnaround time

➔ Efficiency = number of fills per day * fill-to-fill time / 24 h

➔ allows comparison with LHC operation: Efficiency = L_{oper} / L_{theor}

Example 1: k = 4 ➔ 1 fill per day with run length of 10h:

➔ fill-to-fill time = 3h + 7h + 5h = 15h — $5\ 10^{14}$ p/beam

➔ Efficiency = 1 * 15 / 24 = 63%

Example 2: k = 2 ➔ 1.5 fills per day with run length of 7h:

➔ fill-to-fill time = 3h + 4h + 5h= 12h — $5\ 10^{14}$ p/beam

➔ Efficiency = 1.5 * 12 / 24 = 75%

Upgrade Considerations: Integrated Luminosity

HL-LHC running scenarios:

➔ Assume average run length is reduced to premature end of fills

➔ assume on average 25% shorter than ideal fill length

➔ average fill time of 5h to 7.5h

5 10^{14} p/beam

➔1.33 * 1 fills per day for k = 4

Efficiency = 1.33 * 1 * (0.75* [3h+7h]+5h) / 24 = 70% (63%)

➔ 1.33 * 1.5 fills per day for k = 2

Efficiency = 1.33 * 1.5 * (0.75* [3h+4h]+5h) / 24 = 85% (75%)

Upgrade Considerations: Machine Efficiency

LHC Operation: theoretical maximum integrated luminosity

→ average Turnaround time of ca. 5 hours @ 3.5 TeV (2.5 h minimum)

→ Peak luminosity: 1.1 10^{33} cm^{-2} sec^{-1}

→ Luminosity lifetime: ca. 20h (35h) exponential ($[1+t/tau]^{-2}$) decay

Can't be explained by burn off (ca. 30h from DR restgas and IBS)!

→ optimum fill length of ca. 14h with rather broad peak

→ minimum fill-to-fill length: 2.5h + 14h = 16.5h

→ integrated luminosity / fill: ca. 40 pb^{-1} (40 pb^{-1}) (fill 1883) (44 pb^{-1})

→ integrated luminosity / day: ca. 58 pb^{-1} (58 pb^{-1}) (65 pb^{-1})

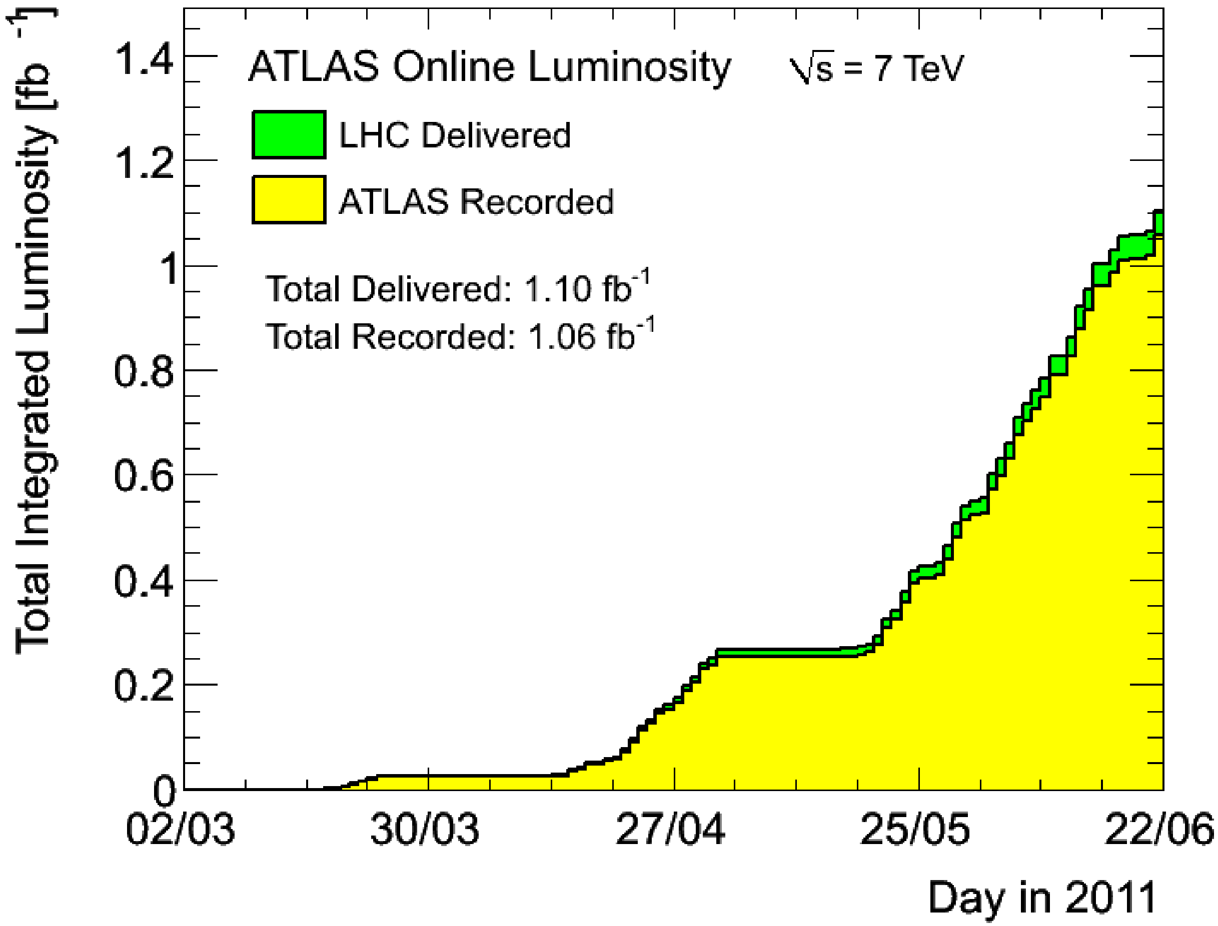
→ integrated luminosity / week: 405 pb^{-1} (405 pb^{-1}) (450 pb^{-1})

Upgrade Considerations: Integrated Luminosity

LHC Operation:

650 pb^{-1} in last 4 weeks

800 pb^{-1} in last 5 weeks



➔ obtained integrated luminosity per week over last month: ca. 163 pb^{-1}

➔ LHC Efficiency: ca. 163 / 405 ➔ 40%

Upgrade Considerations: Integrated Luminosity

- HL-LHC running scenarios: $6\ 10^{14}$ p/beam; ‘k’ = 5

➔ τ_{eff} = 16.7 hours for $6\ 10^{14}$ p/beam:

➔ fill length of 3 + 9.2 hours for k = 5

➔ average Turnaround time of ca. 5 hours

➔ total fill time of 17.2 hours with $L_{int} = 1.7 + 0.4\ fb^{-1}$ per fill

➔ 0.8 fills per day (only leveled run without decay)

➔ requires ca. 57% efficiency of the machine!

Upgrade Considerations: Integrated Luminosity

HL-LHC running scenarios:

- ➔ fill length of 6.3 h and 8.7 h for 4 10^{14} p/beam … ➔ 4
- ➔ Turnaround time of ca. 5 hours

… ca. 11.3 and 13.7 hours

- ➔ 1.7 f… …tual luminosity of 10^{35} cm^{-2} sec^{-1}) …chine efficiency!

- ➔ …2 fills per day (k = 4; virtual luminosity of 2 10^{35} cm^{-2} sec^{-1}) requires 70% machine efficiency!

What virtual performance levels ('k') are within reach for 4 10^{14} p/beam, 5 10^{14} p/beam and 6 10^{14} p/beam?

Upgrade Considerations: Minimum β^* values:

- Limitations for β^* at 7 TeV: Aperture & Chromatic aberrations

- HL LHC Upgrade: New scheme (ATS) for optics

S. Fartoukh

-β^* of 0.15m accessible for round beams @ 7 TeV

➔ implies β-functions of > 20km inside triplet magnets!

➔ limit of Field Quality and aperture

-β^* of 0.3m / 0.075m accessible for flat beams @ 7 TeV

- Aperture at 7 TeV::

➔ interaction with WP3 of the HL-LHC

➔ current aperture goals are consistent with β^* of 0.15m and 10 σ separation

Upgrade Considerations: Maximum Bunch Intensity:

- Bunch Intensity:

1) Collective effects (e.g. single bunch TMCI) ➔ ca. 3.5 10^{11} ppb

2) e-cloud effect ➔ depends on bunch spacing

➔ 2.2 10^{11} ppb at 25ns requires: $\delta_{sec} < 1.3$ and
IR cryo upgrade

➔ TMCI intensity limit for 50ns compatible with: $\delta_{sec} > 1.7$ and
IR cryo upgrade

Upgrade Considerations: Maximum Brightness

Beam-Beam: limits maximum beam by brightness

➔ $\Delta Q = 0.02 - 0.03$ seems feasible based on 2010 experience

➔ maximum acceptable PA? ➔ $\Theta > 2$? (sync-betatron resonances)

➔ Three experiments with head on collisions: ➔ $\xi = 7.7\ 10^{-3}$

➔ assuming the same geometric reduction factor for ξ as for L (0.35 with alternating crossing) and assuming negligible contribution from long range:

➔ $\varepsilon_n \geq 2\ \mu m$ for $N_{bunch} = 3.5\ 10^{11}$ (50ns bunch spacing)

➔ $\varepsilon_n \geq 1\ \mu m$ for $N_{bunch} = 2.2\ 10^{11}$ (25ns bunch spacing)

HL-LHC Performance Estimates

nominal bunch length and minimum β*: 'HL-LHC Kickoff+'

minimum β*

Parameter	nominal	25ns	5…
N	1.15E+11	**2.0E+1…**	
n_b	2808	28…	
beam current [A]	0.58		
x-ing angle [μrad]	300		
beam separation [σ]	10		
β* [m]	0.55		**…5**
ε_n [μm]	3.75		3.0
ε_L [eVs]	2.51		2.5
energy spread	1.00E-04		…00E-04
bunch length [m]	7.50E-0…		7.50E-02
IBS horizontal [h]	80 -> …		**17**
IBS longitudinal [h]	61 -		**16**
Piwinski parameter	0.…		**2.5**
geom. reduction	0.83		**0.37**
beam-beam / IP	3.10E-03	**…3**	**5.0E-03**
Peak Luminosity	1 10^{34}	**7.… …0^{34}**	**8.4 10^{34}**
Events / crossing	19	**141**	**257**

OK for HL goals ('k' = 4)

(Even better if emittances can be further reduced: still a factor 1.2 to 2.5 wrt beam-beam limit)

5.6 10^{14} and 4.6 10^{14} p/beam

➔ sufficient room for leveling (with Crab Cavities)

Virtual luminosity (25ns) of $L = 7.4 / 0.37\ 10^{34}\ cm^{-2}\ s^{-1}$

$= 20\ 10^{34}\ cm^{-2}\ s^{-1}$ ('k' = 4)

Virtual luminosity (25ns) of $L = 8.4 / 0.37\ 10^{34}\ cm^{-2}\ s^{-1}$

$= 22.7\ 10^{34}\ cm^{-2}\ s^{-1}$ ('k' = 4.5)

(Leveled to 5 $10^{34}\ cm^{-2}\ s^{-1}$)

Events / crossing: **95** **190**

Upgrade Considerations: Integrated Luminosity

- HL-LHC 25ns goal: $5.6\ 10^{14}$ p/beam k = 4

➔ τ_{eff} = 15.6 h and leveling time: 7.8 h

➔ Turnaround time: 7.8h + 3h + 5h = 15.8h ➔ 1.5 fills /day

➔ L_{int} / fill = 1.4 fb^{-1} + 0.4 fb^{-1}

➔ 60% efficiency on 150 days ➔ 250 fb^{-1}

- HL-LHC 50ns goal: $4.6\ 10^{14}$ p/beam k = 4.5

➔ τ_{eff} = 12.8 h and leveling time: 6.8 h

➔ Turnaround time: 6.8h + 3h + 5h = 14.8h ➔ 1.7 fills /day

➔ L_{int} / fill = 1.22 fb^{-1} + 0.4 fb^{-1}

➔ 60% efficiency on 150 days ➔ 250 fb^{-1}

HL-LHC Performance Estimates

nominal bunch length and LIU estim[illegible] for injector complex:

Parameter	nominal	25ns (minimum β*)	50ns (minimum β*)
N	1.15E+11	**1.7E+11**	**[illegible].1**
n_b	2808	2808	[illegible]04
beam current [A]	0.58	**0.8[illegible]**	**0.64**
x-ing angle [μrad]	300	[illegible]	430
beam separation [σ]	10	[illegible]	10
β* [m]	0.55	[illegible]	**0.15**
ε_n [μm]	3.75	[illegible]	**2.0**
ε_L [eVs]	2.51	[illegible]	2.5
energy spread	1.00E-04	[illegible]	1.00E-04
bunch length [m]	7.50E-02	[illegible]02	7.50E-02
IBS horizontal [h]	80 -> 106	25	10
IBS longitudinal [h]	61 -> 6[illegible]	21	13
Piwinski parameter	0[illegible]	**2.56**	**2.56**
geom. reduction	[illegible]	**0.37**	**0.36**
beam-beam / IP	3.10E-[illegible]	**3.0E-03**	**5.6E-03**
Peak Luminosity	1 10^{34}	**5.3 10^{34}**	**7.2 10^{34}**

Events / crossing	19	**101**	**274**	**95**	**190**

25ns slightly short of HL goals (k ~ 4)

50ns requires ~ 80% machine efficiency

4.8 10^{14} and 3.5 10^{14} p/beam

➔ intensity and leveling room marginal

Virtual luminosity of
L = 5.3 / 0.36 10^{34} cm^{-2} s^{-1}

= 14 10^{34} cm^{-2} s^{-1} ('k' = 2.8)

L = 7.2 / 0.36 10^{34} cm^{-2} s^{-1}

= 20 10^{34} cm^{-2} s^{-1} ('k' = 4)

IBS growth rates need to be re-evaluated for ATS optics!

Upgrade Considerations: Integrated Luminosity

- LIU 25ns goal: 25ns; 4.8 10^{14} p/beam k = 2.8
  - ➔ τ_{eff} = 13.3 h and leveling time: 5.4 h
  - ➔ Turnaround time: 5.4h + 3h + 5h = 13.4h ➔ 1.8 fills /day
  - ➔ L_{int} / fill = 1 fb^{-1} + 0.4 fb^{-1}
  - ➔ 60% efficiency on 150 days ➔ 225 fb^{-1}

- LIU 50ns goal: 3.5 10^{14} p/beam k = 4
  - ➔ τ_{eff} = 9.7 h and leveling time: 4.9 h
  - ➔ Turnaround time: 4.9h + 3h + 5h = 12.9h ➔ 1.9 fills /day
  - ➔ L_{int} / fill = 0.9 fb^{-1} + 0.4 fb^{-1}
  - ➔ 60% efficiency on 150 days ➔ 115 fb^{-1}

Personal Summary:

➔ CRAB cavities are a vital ingredient for HL-LHC. Without them we will fall short of 250 pb^{-1} goal ($k \geq 4$). CC are the best tool for compensating geometric reduction factor (LRBB wires perhaps partially) (flat beams [SF])

➔ Given equal bunch parameters, 25ns case is clearly better than 50ns (assuming there is no electron cloud limit for 25ns!)

➔ If LHC is limited by total beam current, 50ns offers larger performance reach (higher virtual luminosity for equal lifetime)

➔ Revised beam-beam limits (0.02 to 0.03) opens door for high brightness operation scenarios

➔ 50ns schemes benefit from double batch injection ➔ higher brightness

➔ Rather then lowering the bar for project goals, I would stick to challenging (ideal) goals [while underlining that there is a risk associated to it (like CC & Nb_3Sn for HL)] and to pursue novel schemes (e.g. feedback systems etc.)

Questions for discussion:

➔ What is the smallest emittance LIU can generate for 50ns with 3.3 10^{11}ppb?

➔ What is the highest intensity LIU can offer for 50ns with $\varepsilon_n = 3\ \mu m$?

➔ How confident are we that electron cloud effects will not limit 25ns operation?

➔ What is the emittance and intensity reach for 25ns operation?

➔ Other (than e-cloud and TMCI) intensity limitations in the LHC (e.g. RF)?

➔ Confidence that Nb3Sn magnet technology will be available for HL-LHC?

➔ How confident are we that Crab cavities will be available for HL-LHC?

➔ flat beam option as alternative operation scenario (SF) (β > 40km)

➔ How confident are we that we can reach a better efficiency for HL-LHC than for current operation (➔ see my spare transparencies)?

Spare Transparencies

Potential limitations: minimum β^* values:

- Challenges – Unknowns for operation with small β*:

➔ long range b-b & operation with LPA (synchro-β resonances)

➔ all can be alleviated by increasing β^* ➔ smaller PA

➔ Field Quality in triplet magnets:

➔ all can be alleviated by increasing β^* ➔ smaller peak β

➔ keep β^* of 0.2m and 0.5m as backup values for HL-LHC (but with reduced performance reach)

Potential limitations: high brightness operation:

- Challenges – Unknowns for operation with small β*:
  - ➔ IBS growth rates:
    - ➔ Need to be re-evaluated for ATS scheme (which should help)
    - ➔ Can be alleviated by larger bunch length ➔ larger PA
  - ➔ minimum Turnaround time:
    - ➔ assumed here for HL: 2 * Turnaround time @ 3.5 TeV (ramp & squeeze time)
    - ➔ Can be longer for small β^*: larger than 2 ration (1.5 / 0.15) and ATS scheme, small current in matching section quads

Potential limitations: General worries

- How confident are we that average fill times are longer than 7h?

  ➔ RF trips
  ➔ QPS and PC trips
  ➔ beam abort due to R2E
  ➔ UFO rate

  ➔ Last 30 fills had less then 4 operator initiated EOFs (2-1-1)!!!!!!

- How confident are we that we can overcome e-cloud for 25ns?

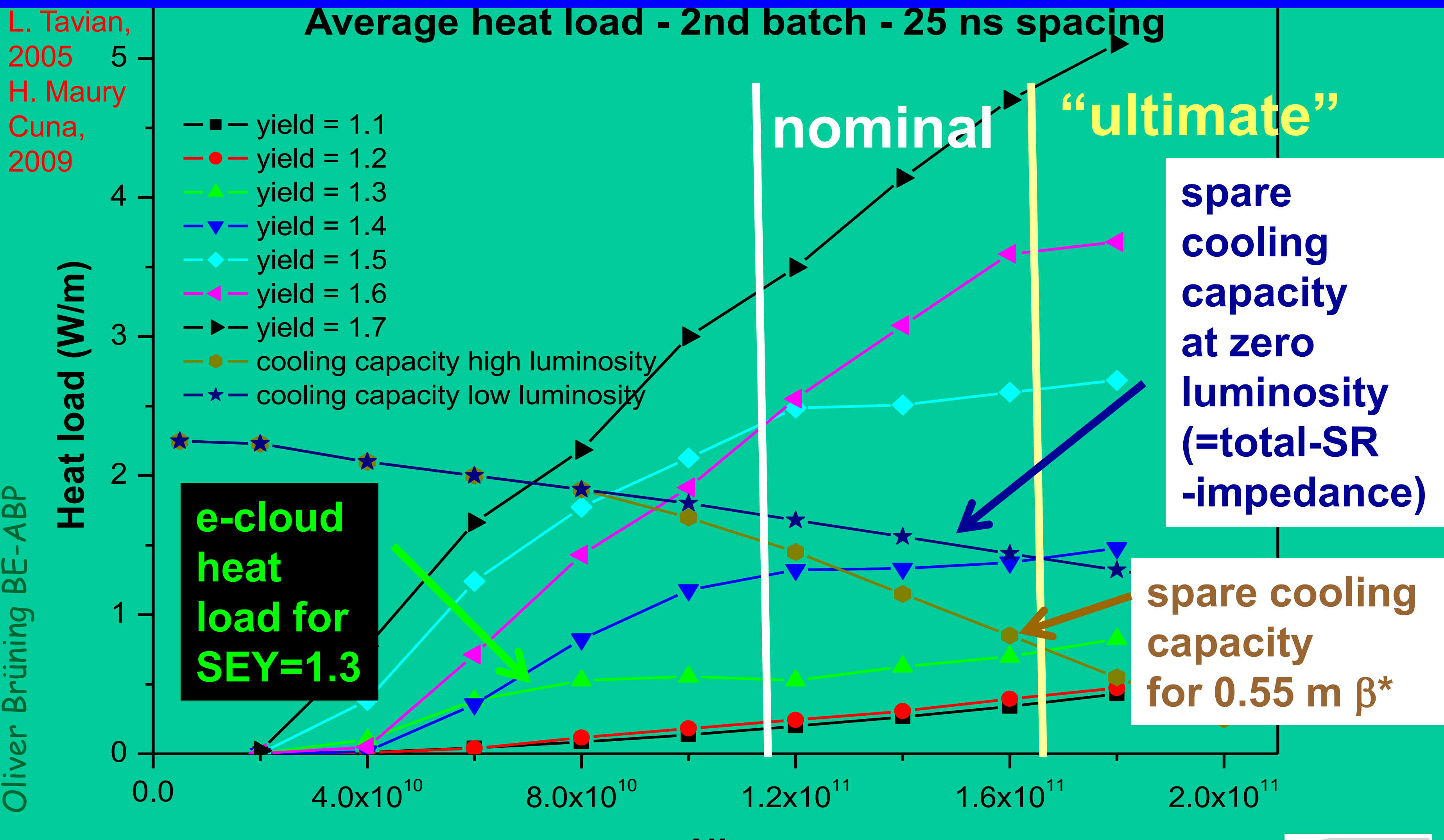
  ➔ HL-LHC goals require above ultimate intensities with sub-nominal ε_n
  - ➔ requires SEY of less than 1.3!
  - ➔ keep 50ns option alive!
  - ➔ apart from pile-up, 50ns has a high performance potential!

Potential limitations: high brightness operation:

No Leveling:

- ➔ ca. 0.6 fb^{-1} in 7 hours for start luminosity of 5 10^{34} cm^{-2} s^{-1}:
  - ➔ 12 hour minimum fill-to-fill time for 5 h turnaround time
  - ➔ need 2.8 fills per day
  - ➔ 1.7 fb^{-1} per day
  - ➔ 250 fb^{-1} in 150 days
  - ➔ requires 100% efficiency to reach HL goals!

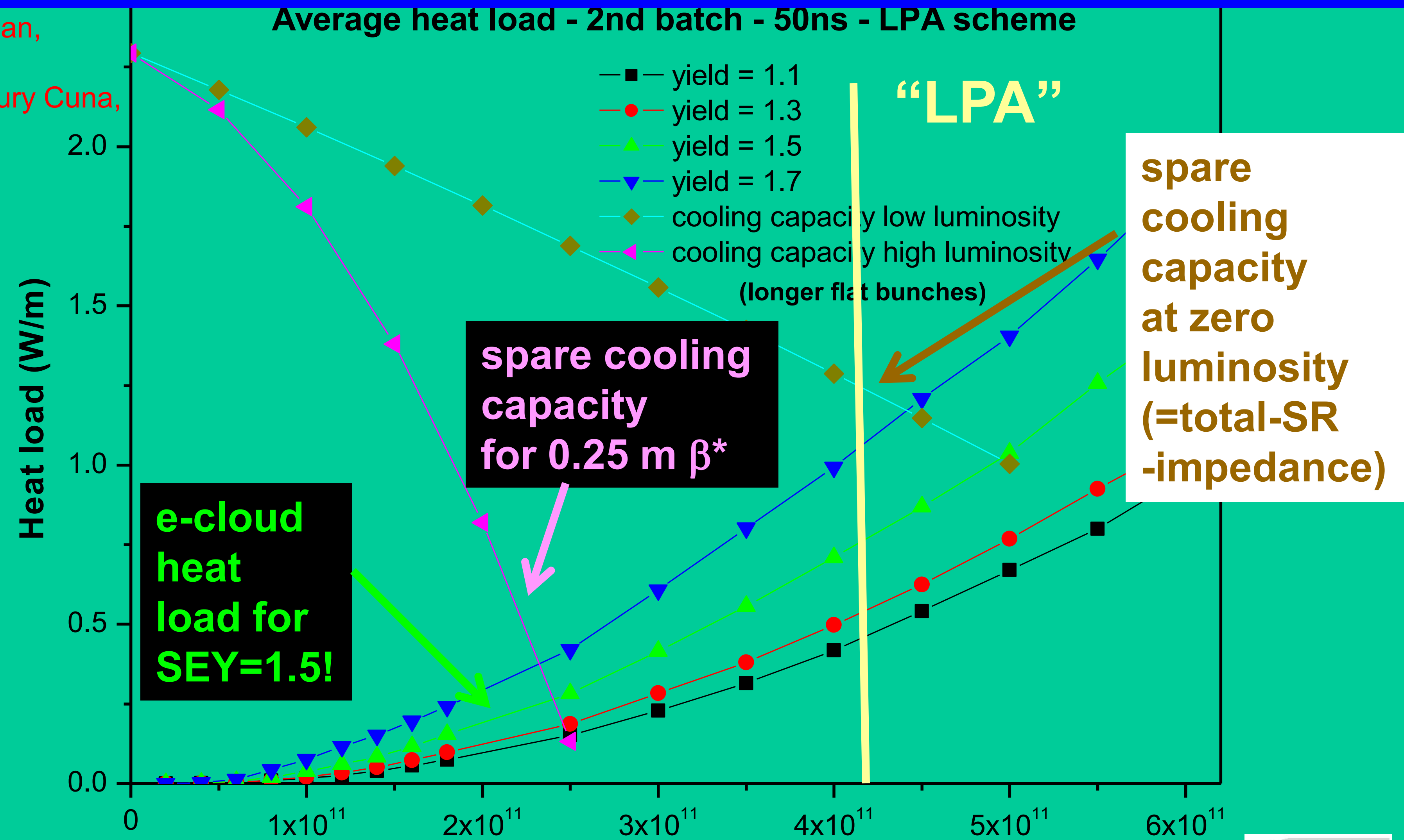
cooling & e- heat for 25 ns spacing



going above N_b=1.7x10^{11} & ultimate luminosity requires dedicated IR cryo plants; limit then becomes N_b~2.3x10^{11}

cooling & e- heat for 50 ns spacing

L. Tavian, 2005
H. Maury Cuna, 2009



going above N_b=2.3x10^{11} & ultimate luminosity requires dedicated IR cryo plants; limit then becomes N_b~5.0x10^{11}

HL-LHC Performance Estimates

nominal bunch length and minimum β*: **6 10^{14} p/beam**

Parameter	nominal	minimum β* 25ns	minimum β* 50ns
N	1.15E+11	2.1E+11	[illegible]
n_b	2808	2808	[illegible]
beam current [A]	0.58	1.1	[illegible]
x-ing angle [μrad]	300	[illegible]	[illegible]
beam separation [σ]	10	[illegible]	[illegible]
β* [m]	0.55	[illegible]	[illegible]
ε_n [μm]	3.75	[illegible]	[illegible]
ε_L [eVs]	2.51	[illegible]	[illegible]
energy spread	1.00E-04	[illegible]	[illegible]
bunch length [m]	7.50E-02	[illegible]	[illegible]
IBS horizontal [h]	80 -> 106	[illegible]	[illegible]
IBS longitudinal [h]	61 -> 60	21	[illegible]
Piwinski parameter	0.68	2.6	[illegible]
geom. reduction	[illegible]	0.37	[illegible]
beam-beam / IP	3.10E-03	[illegible]	[illegible]
Peak Luminosity	1 10^{34}	8.1 10^{34}	[illegible]

25ns is OK for HL goals ('k' = 4)

50ns above TMCI stability threshold

→ Sufficient room for leveling (with Crab Cavities)

Virtual luminosity of
$L = 8.1 / 0.37\ 10^{34}\ cm^{-2}\ s^{-1}$

$= 22\ 10^{34}\ cm^{-2}\ s^{-1}$ ('k' = 4.4)

(Leveled to 5 10^{34} $cm^{-2}\ s^{-1}$)

	nominal	25ns		
Events / crossing	19	**154**	**95**	**190**

HL-LHC Performance Estimates

nominal bunch length and minimum β*: **4 10^{14} p/beam**

Parameter	nominal	minimum β* 25ns	minimum β* 50ns
N	1.15E+11	**1.4E+11**	[illegible]
n_b	2808	2808	[illegible]
beam current [A]	0.58	**0.71**	[illegible]
x-ing angle [μrad]	300	430	520
beam separation [σ]	10	10	10
β* [m]	0.55	[illegible]	**0.15**
ε_n [μm]	3.75	[illegible]	**3.0**
ε_L [eVs]	2.51	[illegible]	2.5
energy spread	1.00E-04	[illegible]	1.00E-04
bunch length [m]	7.50E-02	[illegible]	7.50E-02
IBS horizontal [h]	80 -> 106	**23**	**25**
IBS longitudinal [h]	61 -> 60	**18**	**21**
Piwinski parameter	0.68	**2.5**	**2.5**
geom. reduction	0.83	**0.37**	**0.37**
beam-beam / IP	3.10E-03	**3.1E-03**	**4.2E-03**
Peak Luminosity	1 10^{34}	**4.5 10^{34}**	**6.0 10^{34}**

Short of HL goals ('k' = 4) even if CRAB cavities are a viable option

➔ Not enough room for leveling (with Crab Cavities)

Virtual luminosity (25ns) of $L = 4.5 / 0.37\ 10^{34}\ cm^{-2}\ s^{-1}$

$= 12\ 10^{34}\ cm^{-2}\ s^{-1}$ ('k' = 2.4)

Virtual luminosity (50ns) of $L = 6 / 0.37\ 10^{34}\ cm^{-2}\ s^{-1}$

$= 16\ 10^{34}\ cm^{-2}\ s^{-1}$ ('k' = 3.2)

(Leveled to 5 $10^{34}\ cm^{-2}\ s^{-1}$)

Events / crossing	19	**86**	**228**	**95**	**190**

Performance optimization for the LHC

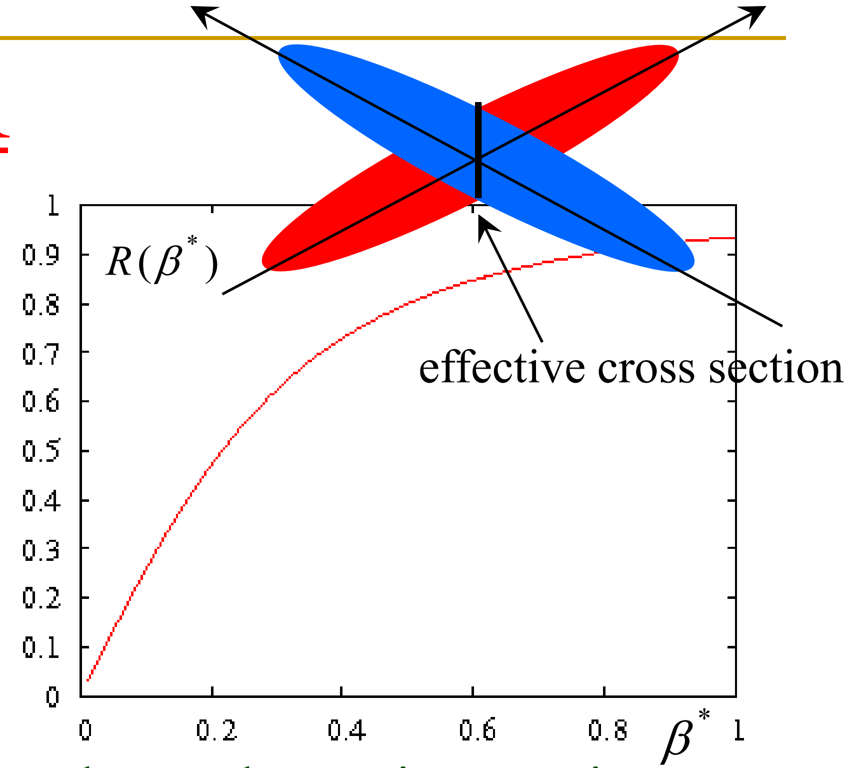
Luminosity (round beams):

$$L = \frac{n_b \cdot N_b^2 \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot R(\phi, \beta^*, \varepsilon_n, \sigma_s)$$

Event pileup & e-cloud

- ➔1) maximize bunch brightness [N_b/ε_n]
  beam-beam limit and injector complex performance
- ➔2) minimize beam size (constant beam power)
- ➔3) maximize beam current (beam power limit)
- ➔4) compensate for ‘R’

LHC Challenges: R



geometric luminosity reduction factor:

Piwinski angle

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

large crossing angle:

- ➔ reduction of long range beam-beam interactions
- ➔ reduction of head-on beam-beam parameter
- ➔ reduction of the mechanical aperture
- ➔ synchro-betatron resonances
- ➔ reduction of instantaneous luminosity
  - ➔ inefficient use of beam current
  - ➔ option for L leveling!

HL-LHC Performance Goals

- Operation at performance limit
  → choose parameters that allow higher than design performance
  → leveling mechanisms for controlling performance during run

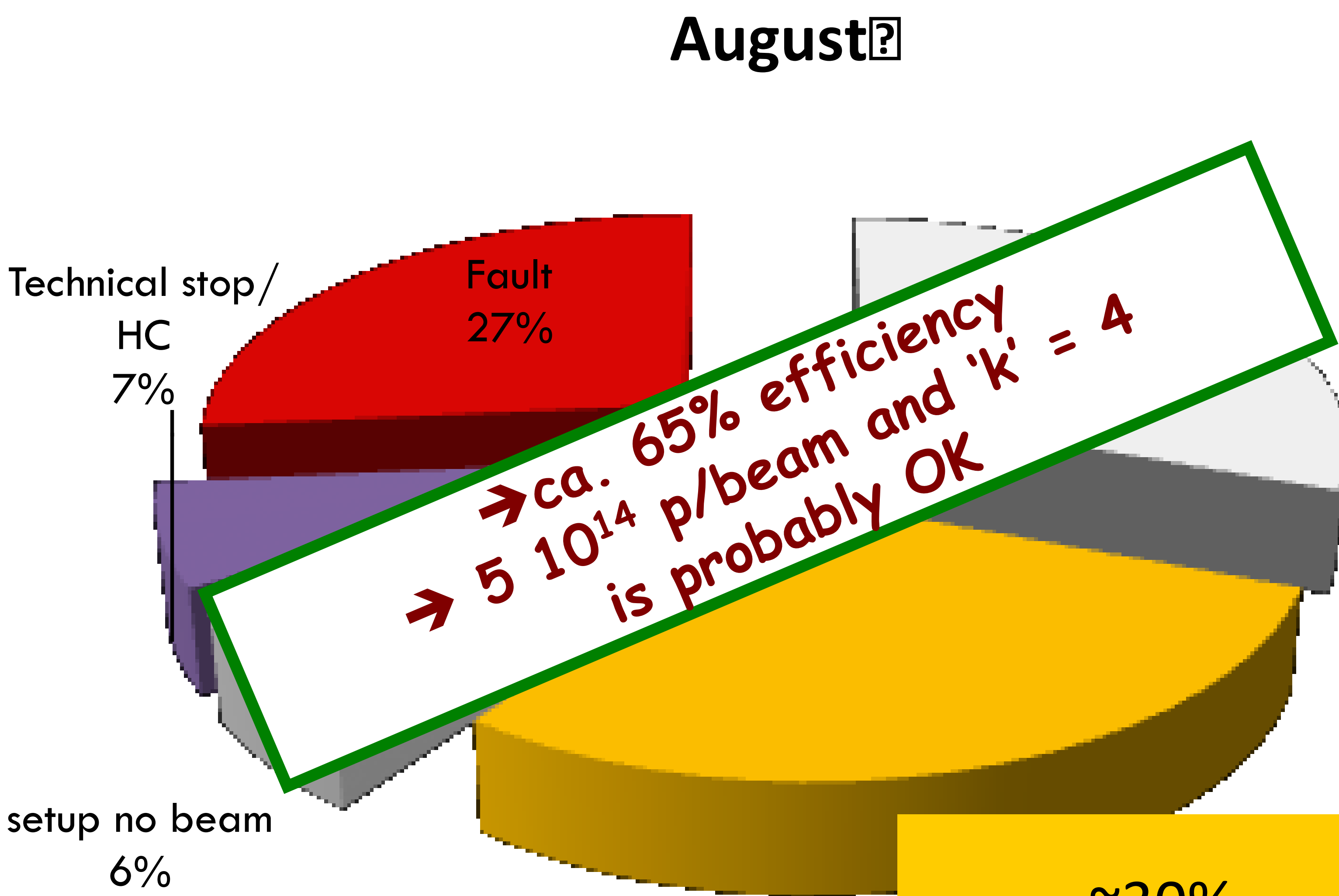
- Preferred leveling mechanism: Crab Cavities

Reservations: technology & MP & field quality

→ Supplementary tools for leveling:

crossing angle and Long-range and
beam-beam wire compensators
transverse offsets at IP
dynamic β^* squeeze

Physics operations

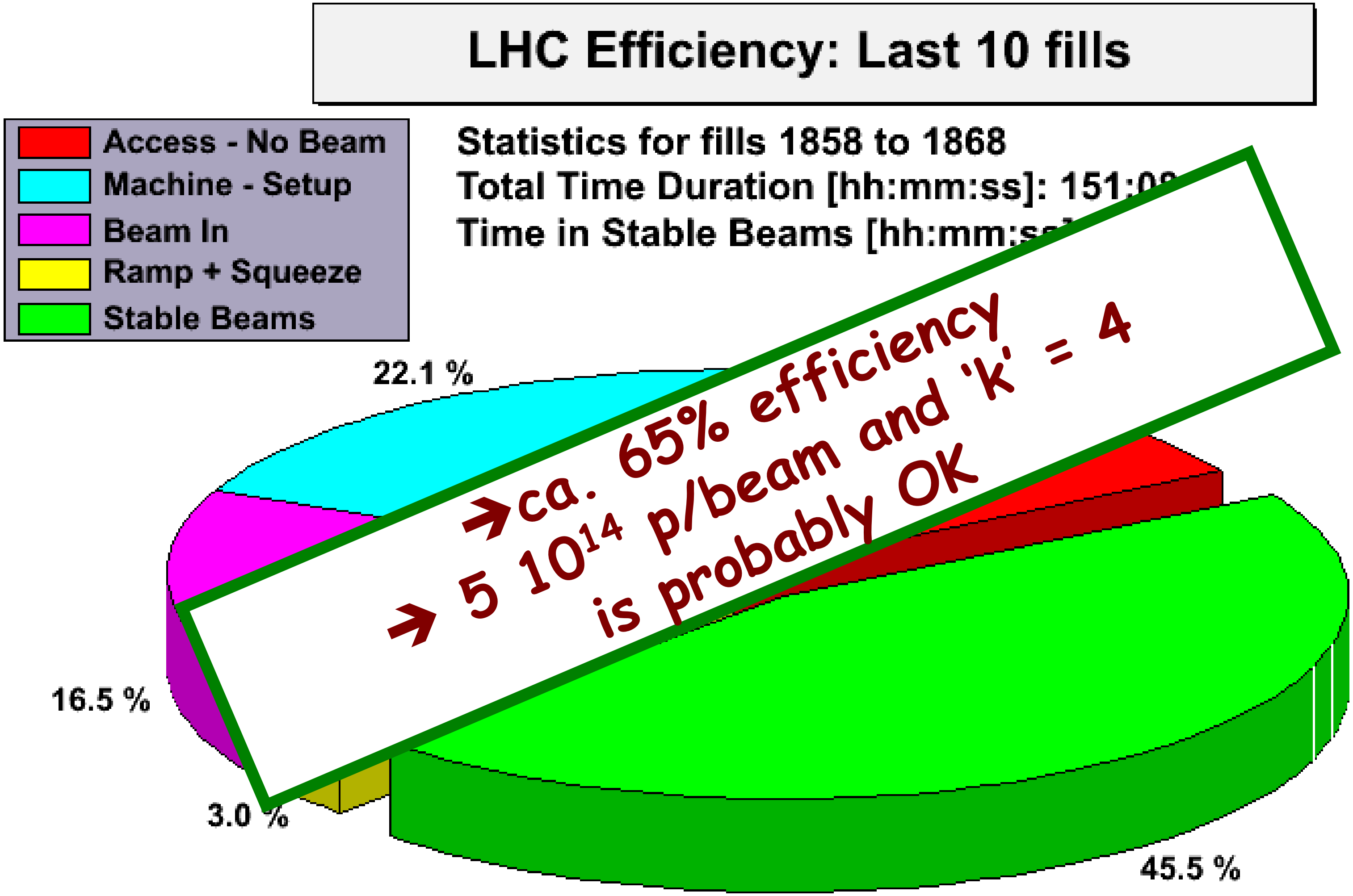


➔ ca. 65% efficiency
➔ 5 10^{14} p/beam and 'k' = 4 is probably OK

~30%
Stable beams!

W. Venturini @ Evian 2011

Efficiency (up to end of fill 1868)



G. Arduini @ LMC 96, 2011

Ultimate LHC parameters:

- **Ultimate LHC:** 25ns; 4.8 10^{14} p/beam; $\varepsilon_n = 3.75\mu m$
  - ➔ τ_{lumi} = 12 h and ideal run length : 7 h
  - ➔ Turnaround time: 7h + 5h = 12h ➔ 2 fills /day
  - ➔ L_{int} / fill = 0.42 fb^{-1}
  - ➔ 60% efficiency on 150 days ➔ 80 fb^{-1}

- **LIU goal:** 50ns; 3.5 10^{14} p/beam k = 4 with 50% efficiency
  - ➔ τ_{eff} = 9.7 h and leveling time: 4.9 h
  - ➔ Turnaround time: 4.9h + 3h + 5h = 12.9h ➔ 1.9 fills /day
  - ➔ L_{int} / fill = 0.9 fb^{-1} + 0.4 fb^{-1}
  - ➔ 60% efficiency on 150 days ➔ 115 fb^{-1}