FCC-hh Layout and Parameters

Daniel Schulte for the FCC-hh team

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Introduction

Have a draft version of the short CDR available
But will need to fix some points before finalisation of CDR or decide to address them later

Target parameters did not change much since Berlin

- Maybe choice has not been too bad
- Confirm choice of beam-current, IP beta-function and maximum beam-beam tuneshift

But many improvements in the design to ensure that the target is met

Will not repeat much of what I said in Berlin but focus more on choices before or after CDR

CDR Open Points

Some new proposals need to be decided/integrated

- A new beamscreen design
- A new extraction insertion design
- A new momentum cleaning insertion?
- New operations scenario (not discussed here)
- New working point?

There are good reasons for each proposal but hard to ensure consistency

Some choices will not be made before CDR but mentioned

- Electron cloud mitigation method
- Impedance mitigation method
- Magnet field quality
- New working point?

Some changes will come after the CDR

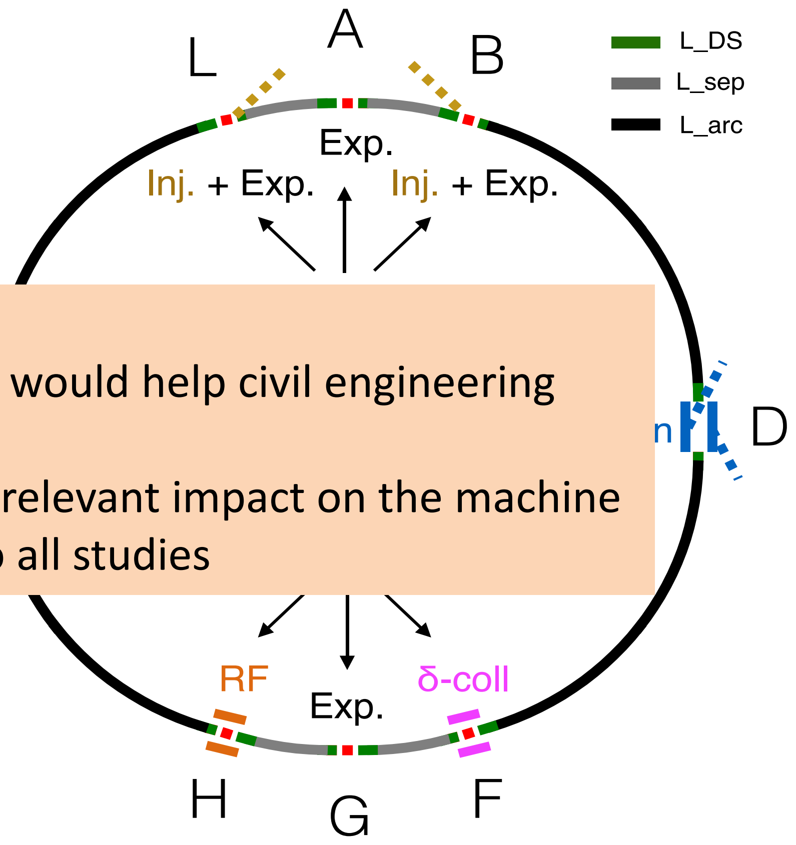
- Layout change for civil engineering
- A new momentum cleaning insertion?
- Further exploration of different bunch spacings

FCC-hh Layout

Layout according to site requirements in 2017

- Two high-luminosity experiments (A and G)
- Two other experiments combined with injection (L and B)
- Two collimati
  - Betatro
  - Momen
- Extraction ins
- Clean insertion with RF (H)

- Circumference 97.75km
- Can be integrated into the area
- Can use LHC or SPS as injector



Plan:

Shorten D and J from 2.8 km to 2.1 km would help civil engineering

Will wait after the CDR and only study relevant impact on the machine

Otherwise too time consuming to redo all studies

Beam Parameters

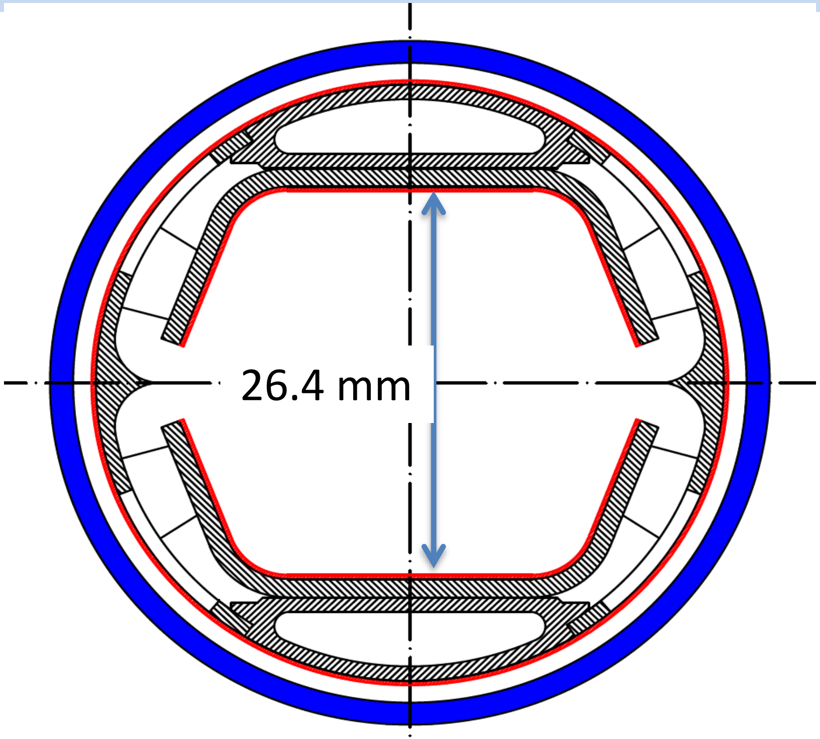
$$\mathcal{L} \propto \frac{N}{\epsilon} \frac{1}{\beta} N n_b f_r$$

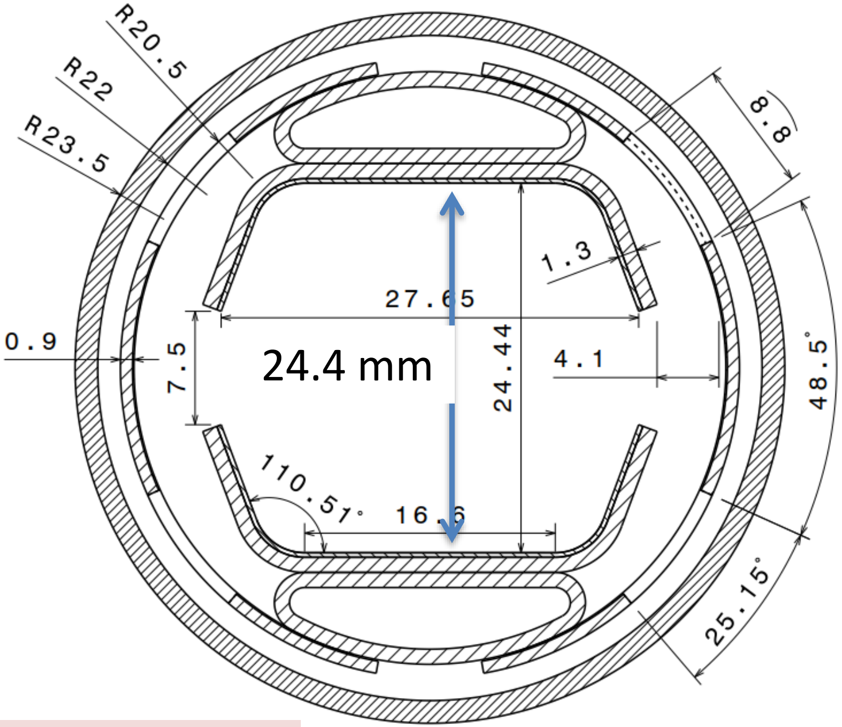
Goal 8 fb^{-1} / day is met

Choice of parameters is confirmed

	FCC-hh Initial	FCC-hh Ultimate
Luminosity L [$10^{34} cm^{-2} s^{-1}$]	5	20-30
Background events/bx	170	<1020
Bunch distance Δt [ns]	25	
Bunch charge N [10^{11}]	1	
Fract. of ring filled η_{fill} [%]	80	
Norm. emitt. [μm]	2.2	
Max ξ for 2 IPs	0.01 (0.02)	0.03
IP beta-function β [m]	1.1	0.3
IP beam size σ [μm]	6.8	3.5
RMS bunch length σ_z [cm]	8	
Turn-around time [h]	5	4

New Beamscreen Proposal





See talks of R. Bruce, S. Molson

Aperture at injection reduced
Impedance effects become worse
⇒ Not yet fully estimated

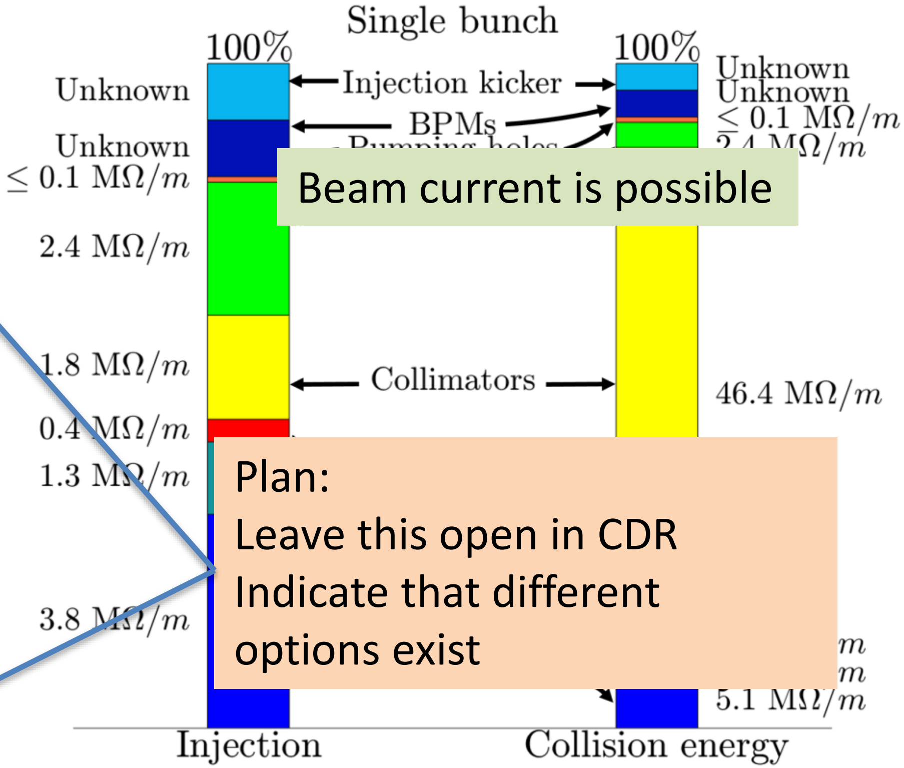
Plan:
Finalise choice for CDR

Impedances and Current

Impedance estimated significantly improved

- Resistive impedance of cold beamscreen: OK
- Impedance of the pumping holes estimated: OK
- Electron cloud mitigation
  - Impedance of the laser treatment against electron cloud: measurements needed, might be high
  - Carbon coating: OK
- Interconnect between dipoles: OK
- Choice of collimators for acceptable trade-off robustness vs. impedance: OK
- Impedance of warm beam pipe of the machine: OK

Mitigation is use of feedback for rigid bunch modes
Octupoles / electron lens (0.6 A) / RF quadrupoles / intra-bunch feedback for other modes

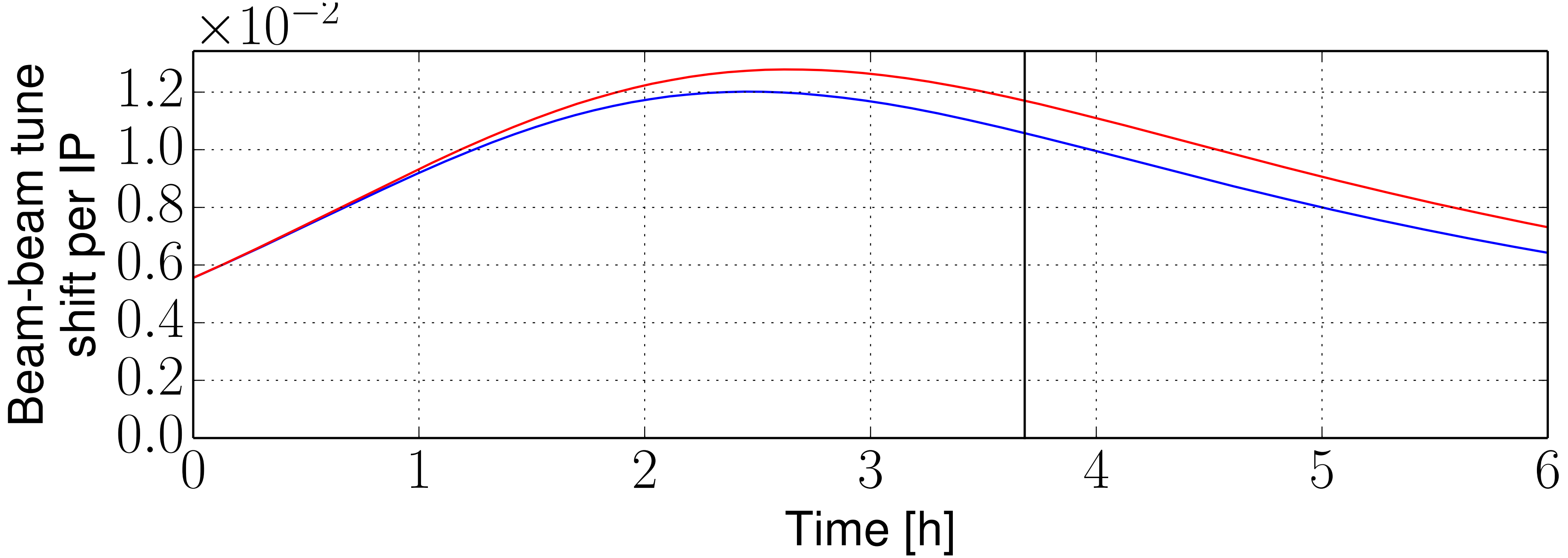


Beam current is possible

Plan:
Leave this open in CDR
Indicate that different options exist

See talks of O. Boine-Frankenheim, S. Arsenyev, C. Tambasco

Note: Beam-beam Tuneshift



Limit of 0.03 for all IP together assumed
Never make it to a total tuneshift of 0.03 for the two main experiments

Total tuneshift limit rather limits additional experiments

Beam-beam Tuneshift and Working Points

Current working point is similar to LHC working point (0.31,0.32)

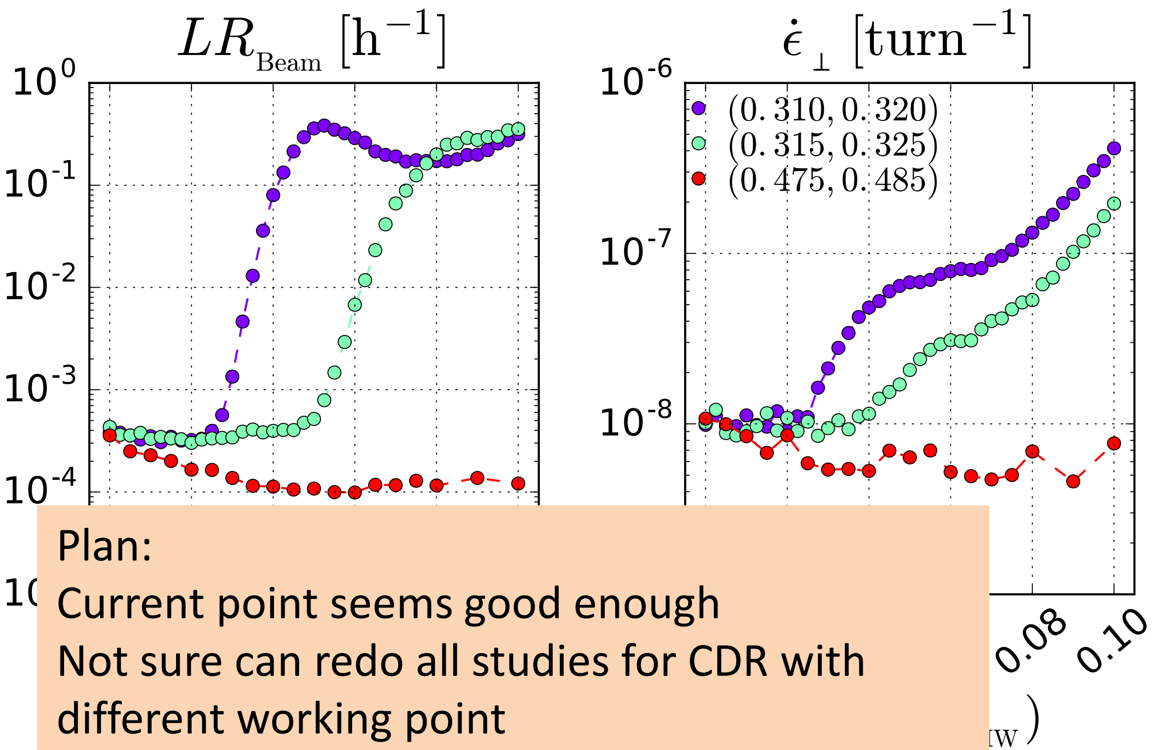
Two better working points are identified for beam-beam (0.315,0.325) and (0.475,0.485)

Tuneshift of 0.03 acceptable at current working point

But might be able to improve

See talks of T. Pieloni

S. V. Furuseth, X. Buffat



Plan:
Current point seems good enough
Not sure can redo all studies for CDR with different working point

Different Bunch Spacing

Experiments would like us to keep exploring smaller bunch spacings

- Less background per crossing

Identified three main alternative scenarios, but need to study them

See talks of B. Goddard, L. Mether

Important improvements of injector system

Higher risk in beam transfer

Electron cloud more severe

			Opt 1	Opt 2	Opt 3
Bunc			12.5	5	5
Proto			0.5	0.2	0.2
Init. h			1.1	1.1	0.44
Init. v			1.1	1.1	0.44
Final hor. transv. emittance [μm]	1.28	0.29	0.25	0.22	0.22
Final vert. transv. emittance [μm]	1.28	0.24	0.2	0.17	0.17
Max. total beam-beam tuneshift	0.01				0.03
IP beta-function [m]	1.1				0.3
Peak luminosity [10^{34} cm$^{-2}s^{-1}$]	5.01				20.1
Max events per crossing	170				137
Optimum integrated lumi / day [fb^{-1}]	2.27				6.2

SPL-type of injector

Higher risk in beam transfer

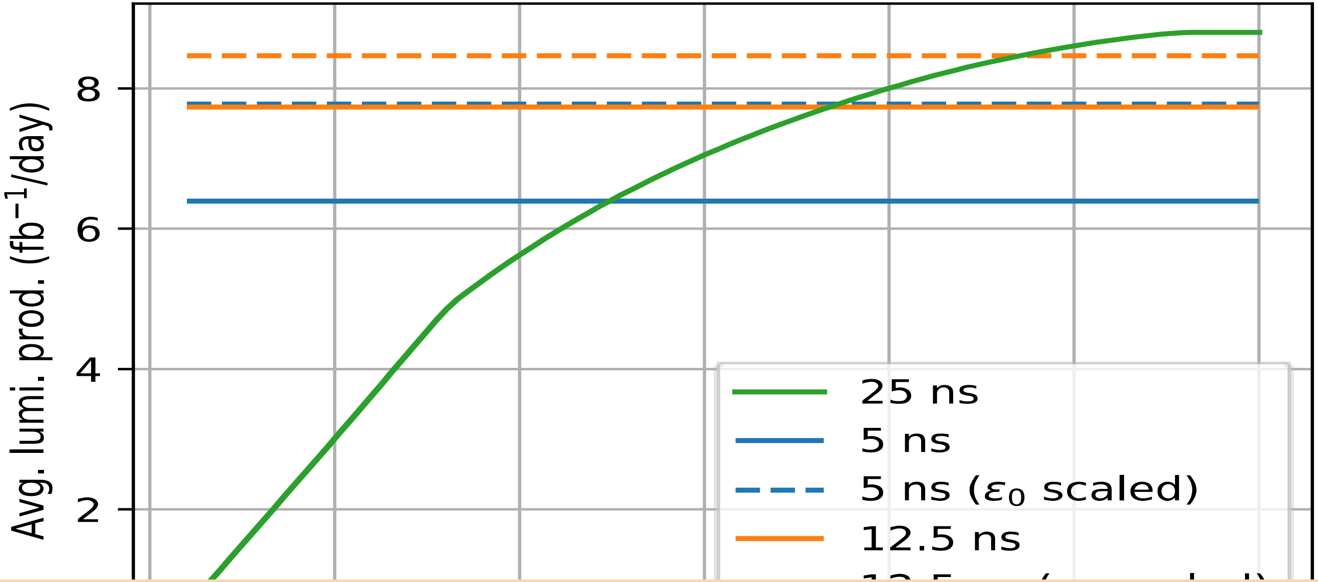
Electron cloud more severe

Alternative: Luminosity Leveling

Luminosity leveling with 25ns beam is an option

Limited luminosity loss for 500 events per bunch crossing

Maybe still acceptable at 330 events



Note: noise is neglected in this

Plan:

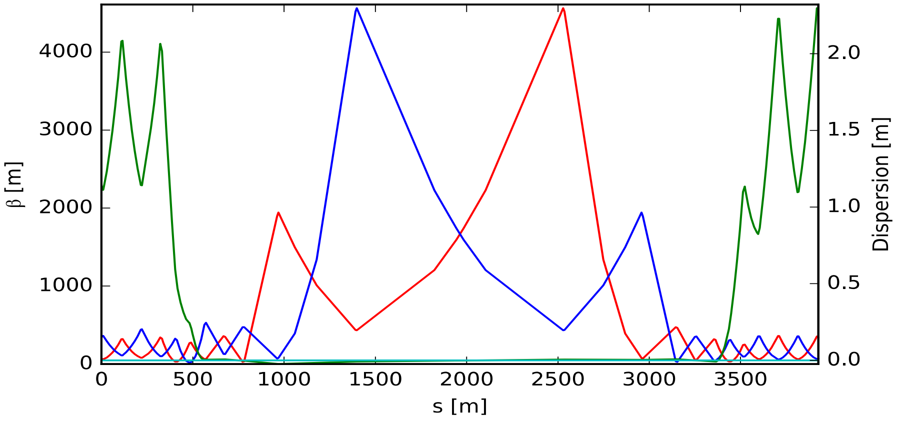
Leave different bunch spacing options as something to be explored

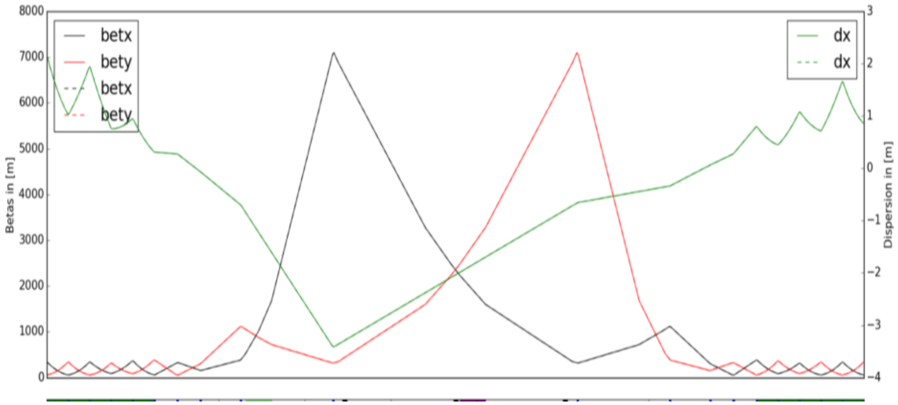
Give some sample performances based on simple operation model

Agreed with detector working group

New Extraction Insertion

New design allows to use superconducting septum (SUSHI)
Just received the lattice decks
$\Rightarrow$ Will need a moment to look at it





Plan:
Try to integrate into the lattice design for CDR

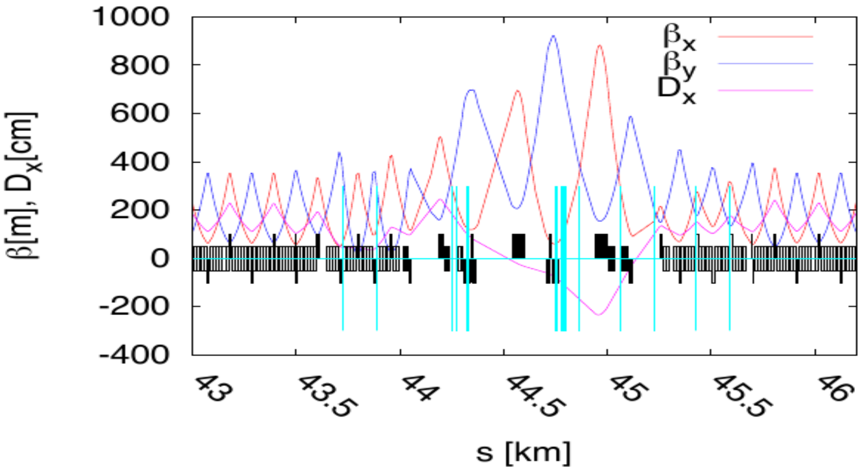
See talks of E. Renner

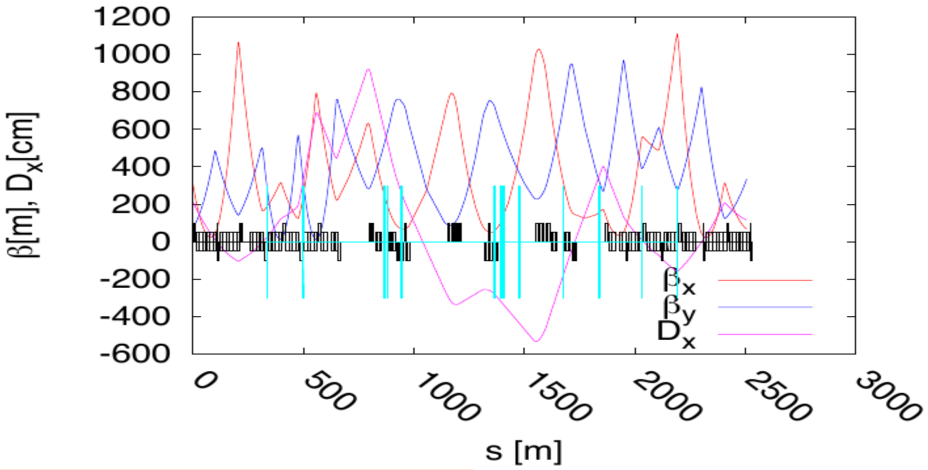
New Momentum Cleaning Insertion

New design from FNAL has better ration of dispersion to beam size

But I worry about large beta-functions in the arcs

See talks of R. Bruce, J. Molson





Plan:
Try to improve matching
If successful try to integrate for CDR
Otherwise address after CDR

Comment: Magnet Field Error Mitigation

Field errors are relatively high
Mitigation of b_2 leads to significant optics change at collision energy
Mitigation of b_3 with spool pieces requires very good alignment (< 100 μm)

Our wish:
Magnet design with reduced field error
Should be important criterion when revisiting choice of magnet design

See talks of B. Dalena, A. Chance

Field errors for new beam distance (204 mm) and 50 μm filament size) (D. Schoerling et al.)

	FCC Dipole field quality version 2 - 3 Oct 2017- R_{ref}=16.7 mm. 3.3 TeV Injection								
	Systematic					Uncertainty		Random	
Normal	Geometric	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field
2	-2.230	-44.610	0.000	-2.230	-46.840	0.922	0.922	0.922	0.922
3	-18.140	17.000	-38.560	-56.700	-1.140	3.000	1.351	3.000	1.351
4	-0.100	-0.930	0.100	0.000	-1.030	0.449	0.449	0.449	0.449
5	-0.690	-0.340	13.660	12.970	-1.030	2.000	0.541	2.000	0.541

Conclusion

CDR is a good basis for further optimisation
- The key design challenges have been identified
  - Should be able to cope with them

Choice before the CDR finalisation
- A new beamscreen design, a new extraction insertion design, a new momentum cleaning insertion?, new working point?

Some choices will not be made before CDR but mentioned
- Electron cloud mitigation, impedance mitigation, magnet field quality, new working point?

Some changes will come after the CDR
- Layout change for civil engineering, a new momentum cleaning insertion?, further exploration of different bunch spacings

Reserve

Parameter Confirmation

Luminosity Drivers

$$\mathcal{L} \propto \frac{N}{\epsilon}\frac{1}{\beta}N n_b f_r$$

Maximise the beam current

Risks:

- High stored energy and losses
- Impedance and electron cloud
- Aperture should be minimised for dipole cost
- High synchrotron radiation load due to high beam energy

Squeeze the beam as much as possible
Harder than in HL-LHC (scaling with energy)
More collision debris due to higher luminosity and energy

Limited by emittance growth and particle losses

Somewhat more difficult than HL-LHC due to longer L^*

For integrated luminosity:

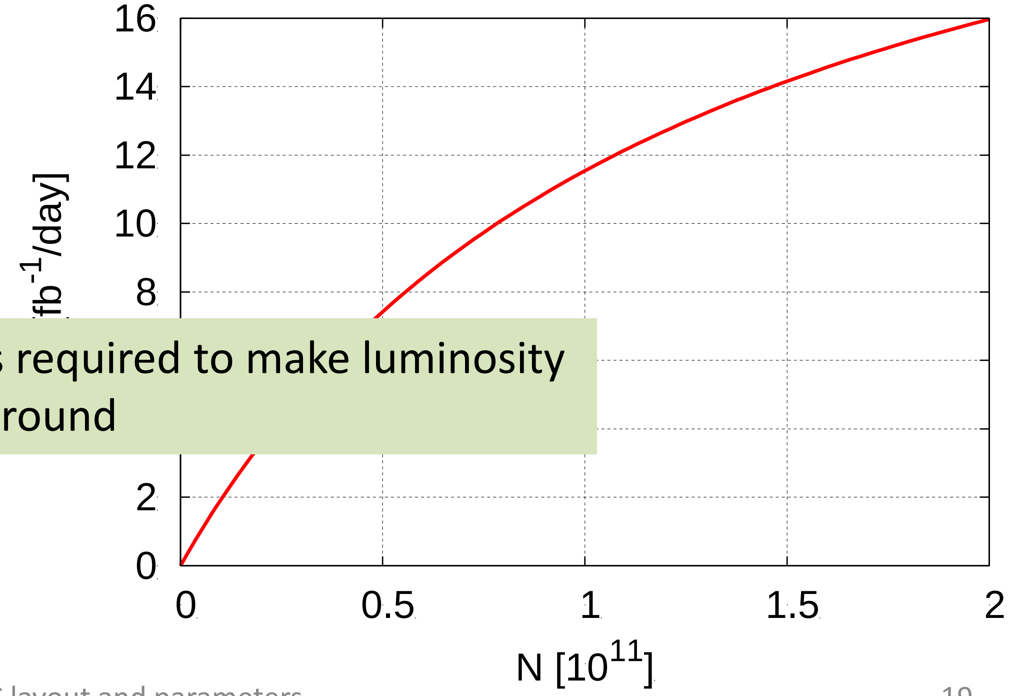
- Fast turn-around critical for luminosity
- Minimise time for stops etc.
- High availability with more components than LHC
- Maximising current also maximises time between new fills

Luminosity per Fill

Our goal is 8 fb^{-1} per day

Maximum luminosity per day 25.9 fb^{-1} due to limit at 3×10^{35} $cm^{-2}s^{-1}$

Naïve optimistic assumption for fills:
All beam is burned at 3×10^{35} $cm^{-2}s^{-1}$ in two experiments
Need 3.2 hours to burn the full beam
Need 4 hours to refill the machine with beam
⇒ Can produce 11.5 fb^{-1}
⇒ Turn-around time is crucial

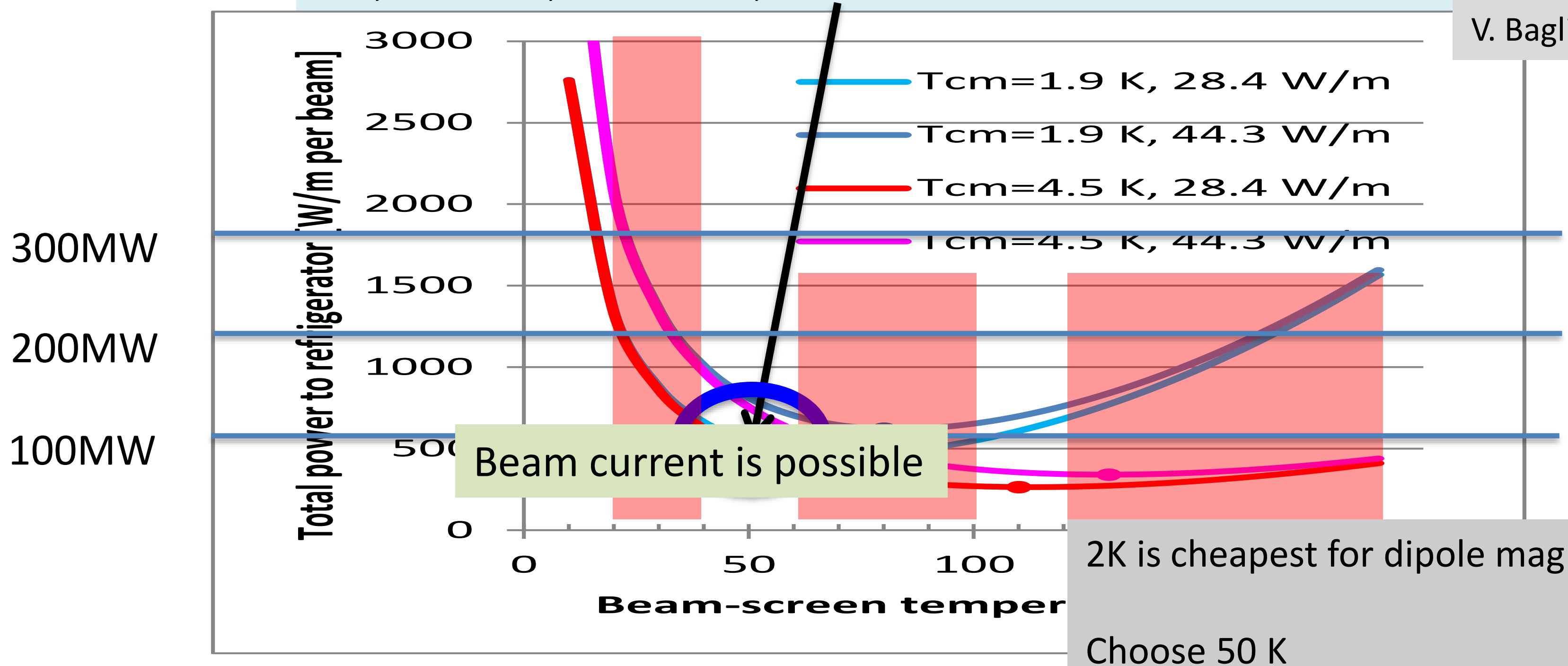


Beam current is required to make luminosity
Or faster turn-around

Reminder: Current Limitation

Can only use some temperatures in order to maintain good vacuum
<20, 40K-60K, 100K-120K, >190K

Ph. Lebrun, L. Tavian, V. Baglin et al.



2K is cheapest for dipole magnets

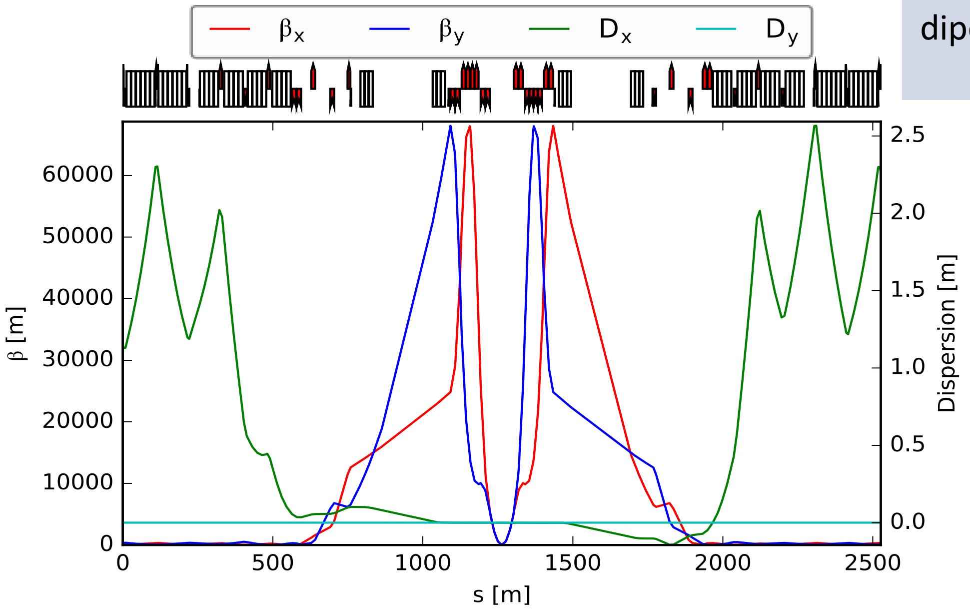
Choose 50 K
Need 20 x 5 MW = 100 MW for cooling

Proton beams emit about 5 MW of synchrotron radiation

Beta-functions

IP β = 0.3 m good enough to produce luminosity

Down to β = 0.2 m can have 35 mm of shielding
Lower values would reduce shielding in triplet
Or aperture in collimators



	Max. dose	Comment
Radiation Triplet	70 (40) Mgy int. L = 30 ab^{-1}	Today's limit 30 MGy Hope to improve limit
Heat load Triplet	4.5 mW/cm^3 L = 3 x 10^{35} $cm^{-2}s^{-1}$	Expected limit (with safety marging) 5 mW/cm^3
Radiation dipole	90 MGy	Today's limit 30 MGy Hope to improve limit Better protection possible

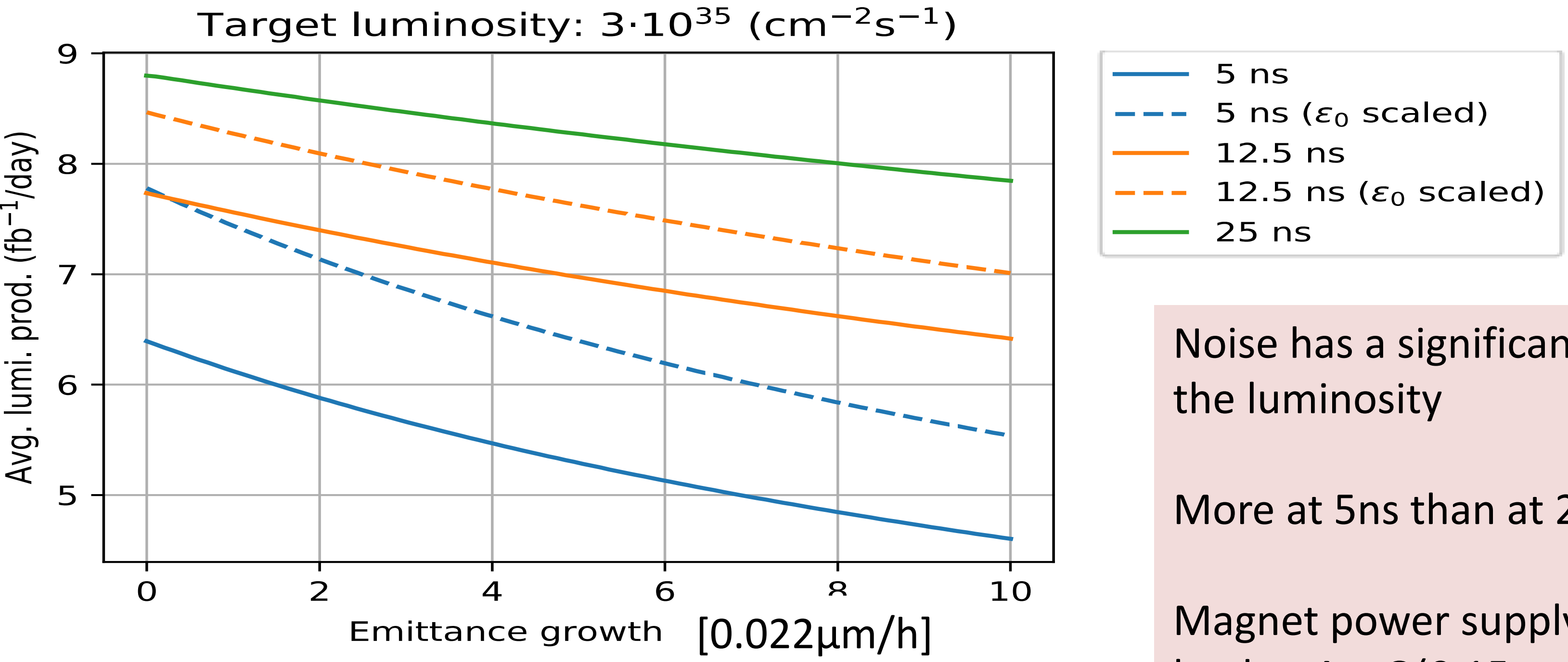
Would not like to decrease shielding, are slightly above radiation limit

Heat load would be problematic

β = 0.3 m is possible

See talks of R. Martin, F. Cerutti

Impact of Noise



Noise has a significant impact on the luminosity

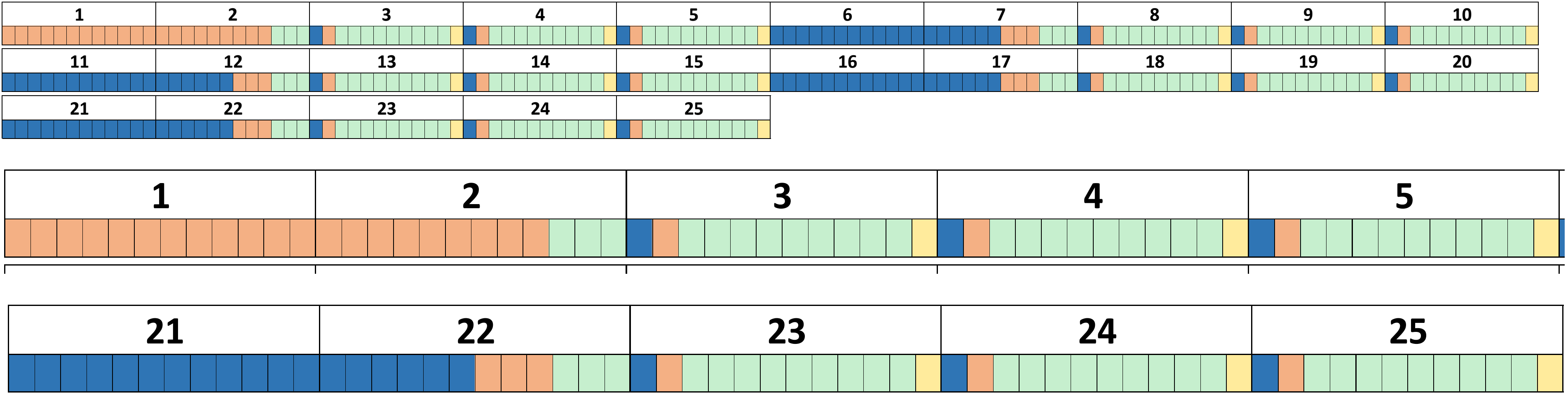
More at 5ns than at 25ns

Magnet power supply ripple will lead to Δε=O(0.15μm/h)

Operation

Operational Scenario (Old)

V. Mertens, A. Niemi et al.



Per cycle about 1000 days for physics

- 70% availability leads to goal of $5ab^{-1}$ per ultimate run
- For ions 3x30 days, i.e. 10% of integrated luminosity?

New 6 year cycle planned

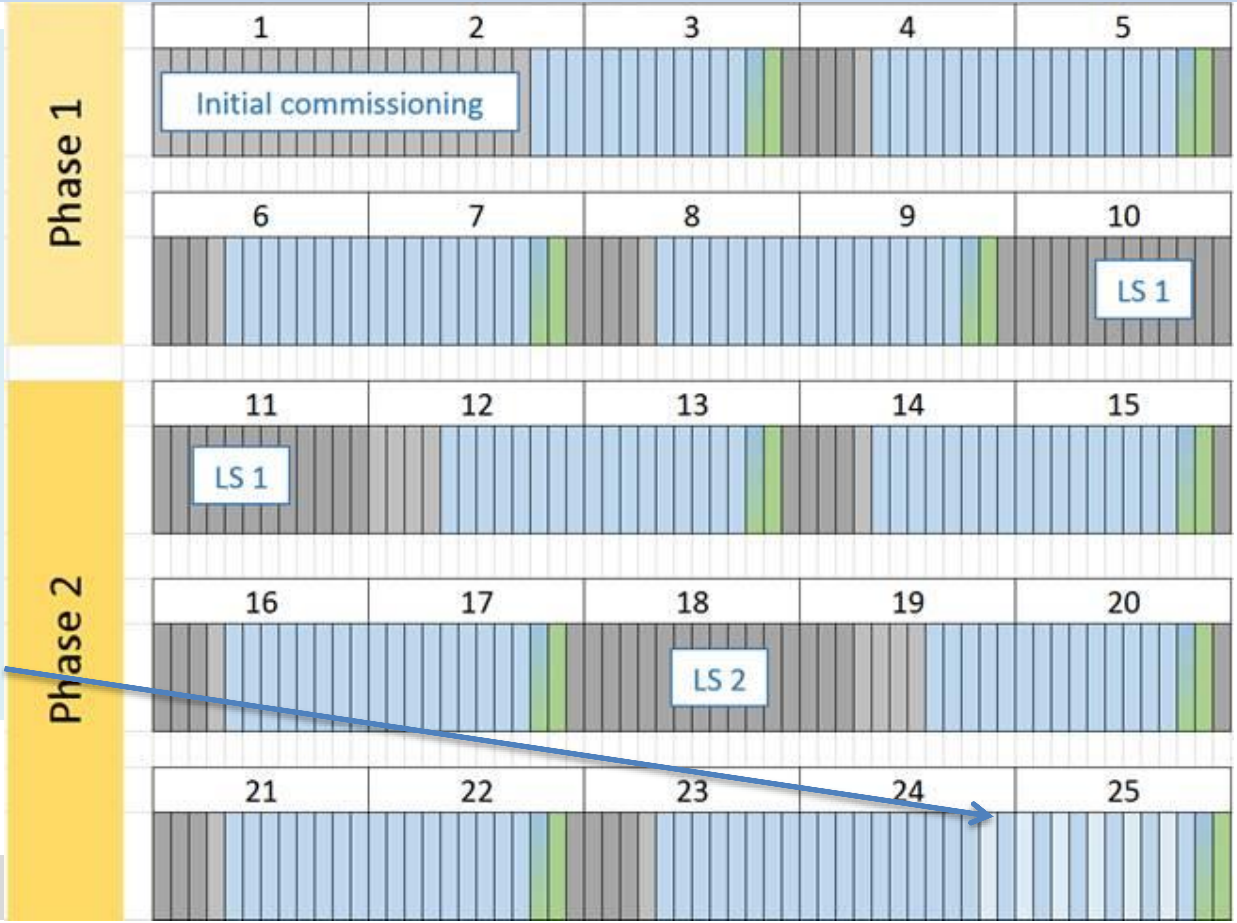
Operational Scenario (Proposed)

From 5 year to 9 year cycles

For 5 year cycles:
18 m shutdown
9 m stops and commissioning
33 m physics (~1000 days)

- 70% availability leads to goal of $5ab^{-1}$ per ultimate run
- For ions 3x30 days, i.e. 10% of integrated luminosity?

Now 184 months of physics until here



V. Mertens, A. Niemi et al.