Session 8: Phase II Strategy

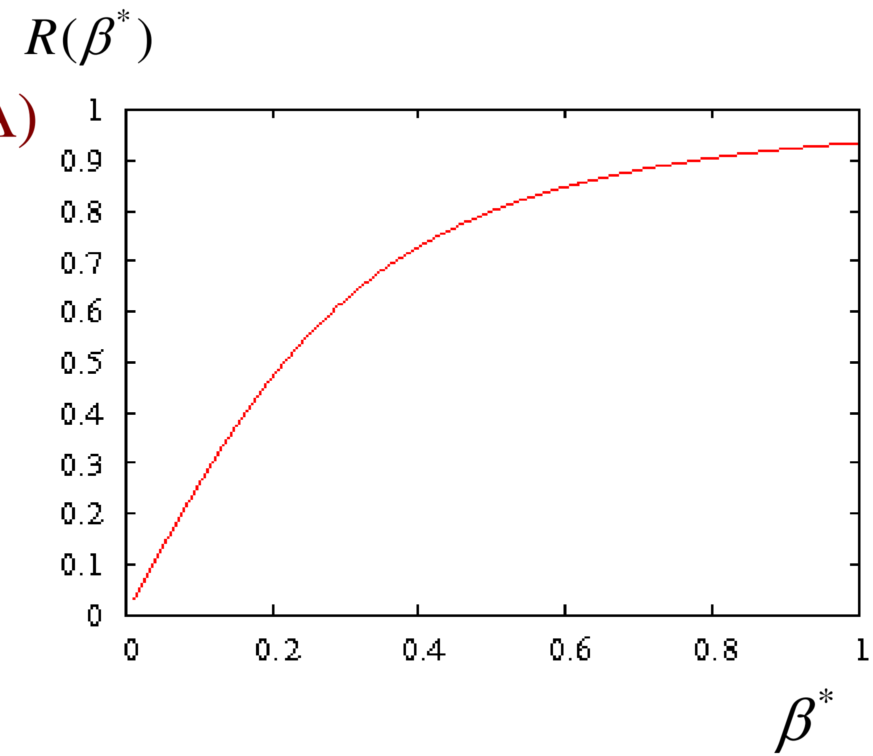
- Summary of the LHC Phase II upgrade options
- CC Phase II Scenarios: Rama Calaga
- IR Installation Issues for CC Phase II: Ranko Ostojic
- CC Phase II Operation: Stefano Redaelli
- Summary

Luminosity Upgrade Options

upgrade options at the beam-beam limit:

$$L \propto \Delta Q_{bb} \cdot \frac{N_b}{\beta^*} \qquad \Delta Q_{bb} \propto \frac{N_b}{\varepsilon} \cdot R(\beta^*)$$

1) keep β* and N/ε constant
   requires controlled ε blow up at top energy



2) keep ε constant and increase N with 1/R (LPA)
   ➔ 1) and 2) imply larger than ultimate beam currents and brightness!

3) keep N constant and vary ε as R
   (referred to as small emittance scheme)
   ➔ requires smaller than nominal emittance

4) compensate R at IP and minimize β^*
   ➔ is compatible with ultimate beam parameters

Luminosity Upgrade Options

different upgrade strategies for operation at beam-beam limit:

-best strategy can only be known with LHC operation experience

-all options require larger triplet magnet apertures and radiation hardness

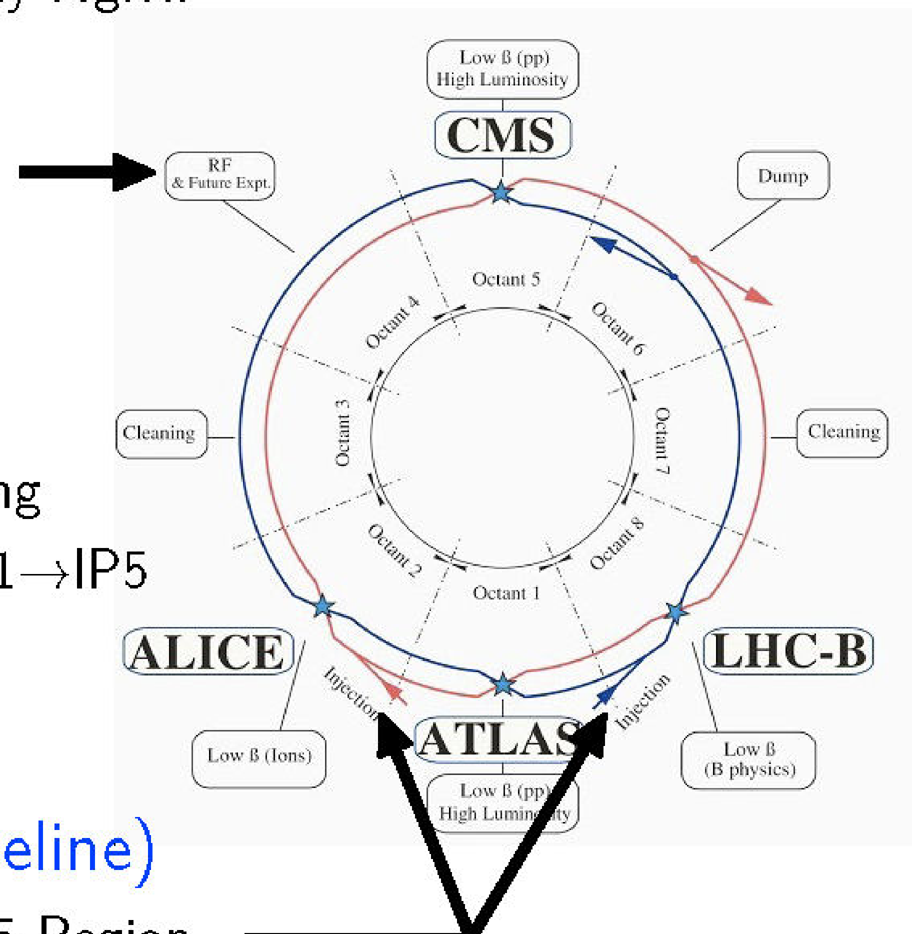
-all but last option require higher performance injector complex
➔ higher beam intensities, tighter collimation requirements,
➔ higher radiation levels and machine protection issues!

-only the last option requires CRAB cavities (it is the only option for Phase II upgrade with ultimate beam intensities)

-apart from last option CC 'only' offer added value of luminosity leveling

Potential Crab Scenarios

- Global
  - Installation in the capture cavity region
  - Extend/Use the IR4 Dog-Leg
  - Lock Ph. Adv IP1→IP5



- Global II – where ?
  - IR4 + Dog-Leg elsewhere in ring
  - Adv: flexibility in phase adv IP1→IP5

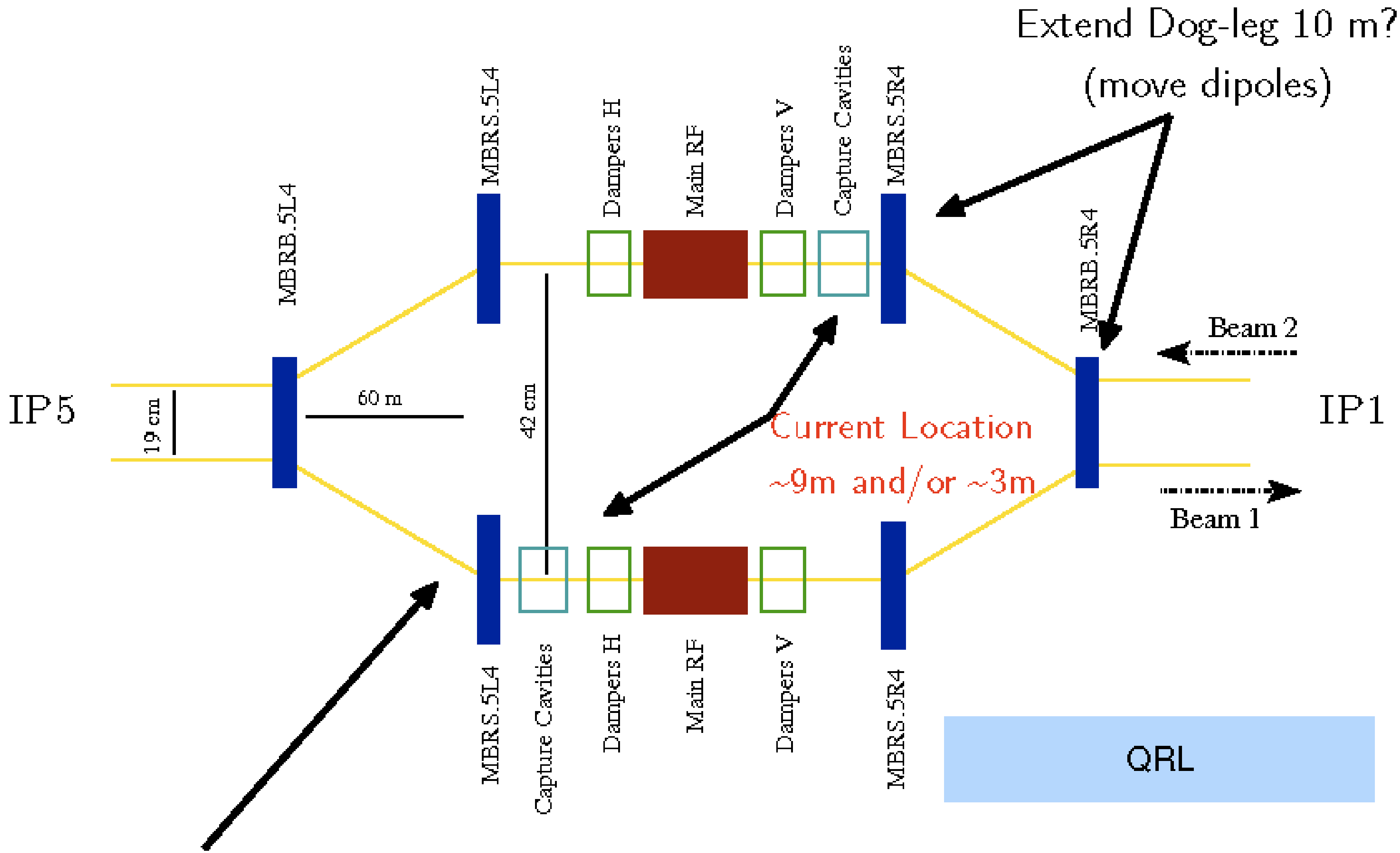
- Local (Phase II current baseline)
  - Dog-legs (if needed) in IR1/IR5 Region
  - Adv: rest of the ring "untouched"

Global Vs. Local

IR4 section has potential options	Beam-to-beam spacing difficult
RF infrastructure/cryogenics	Need IR dog-legs, $$$$
Integration easier, fewer cavities	4 cavities/IP, control (phase...)?
	Impedance, Failures/trips (x2 or x4)
Beam dynamics more complex	Collimation worries are more relaxed
Voltage maybe large for small β^*	Crab voltage is modest (IR Optics)
Ph.Adv IP1$\rightarrow$IP5 no flexibility	Rest of ring is undisturbed

Perhaps many others...

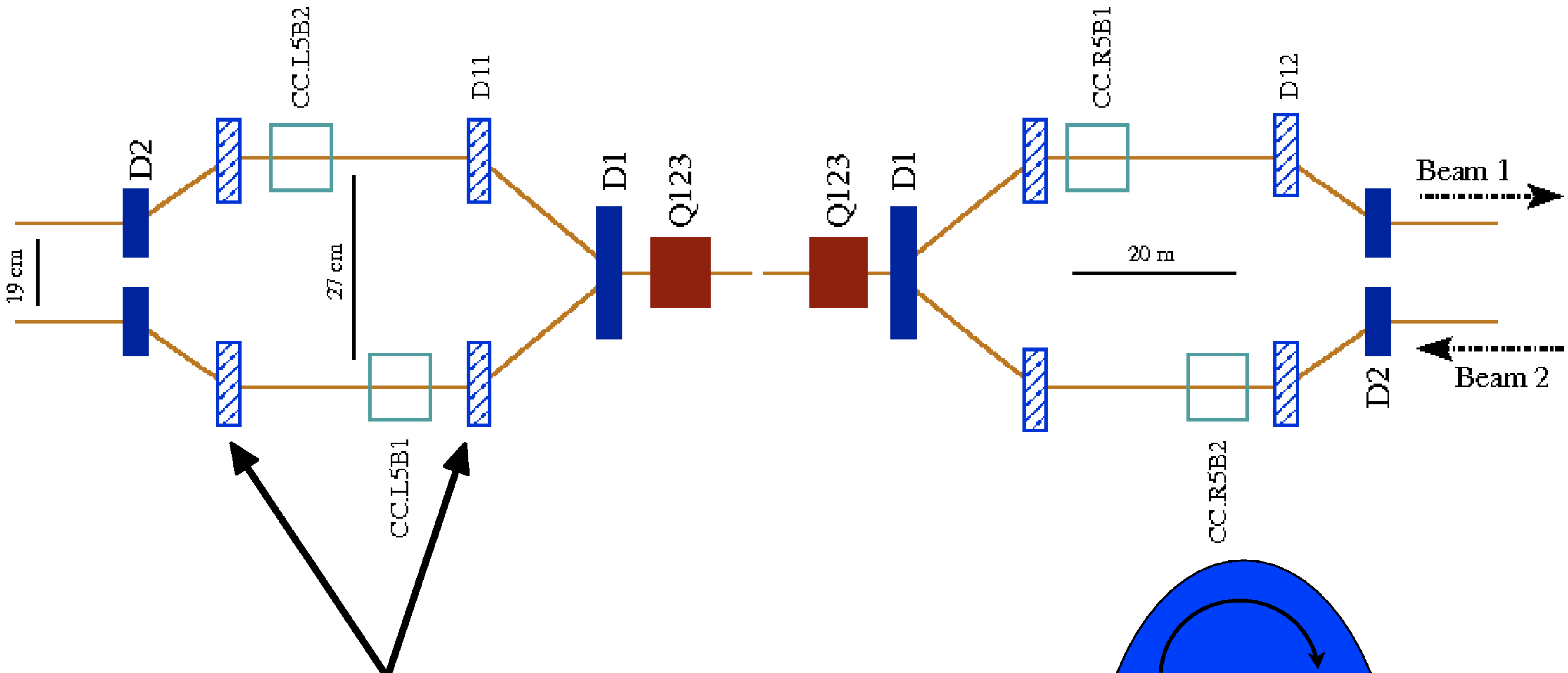
Global Extension, IR4



Other potential location (~37cm separation, synchrotron radiation ?)

Less problematic for Beam 1 due to QRL, compact cavities better

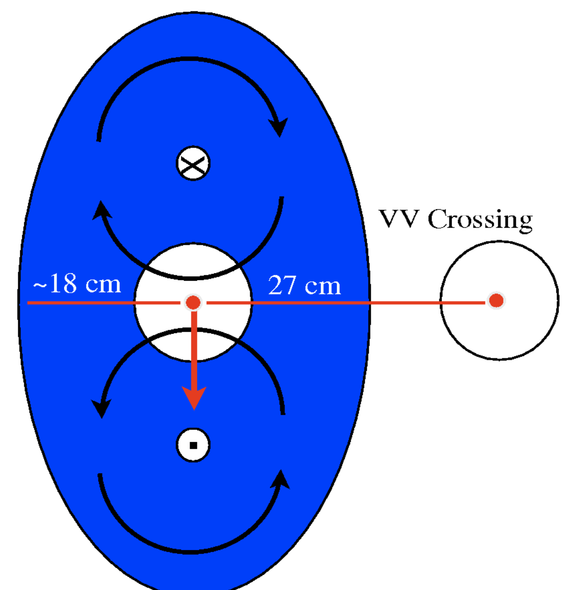
Local Scheme, IR1/5



Two extra dipoles for dog-leg (if needed)

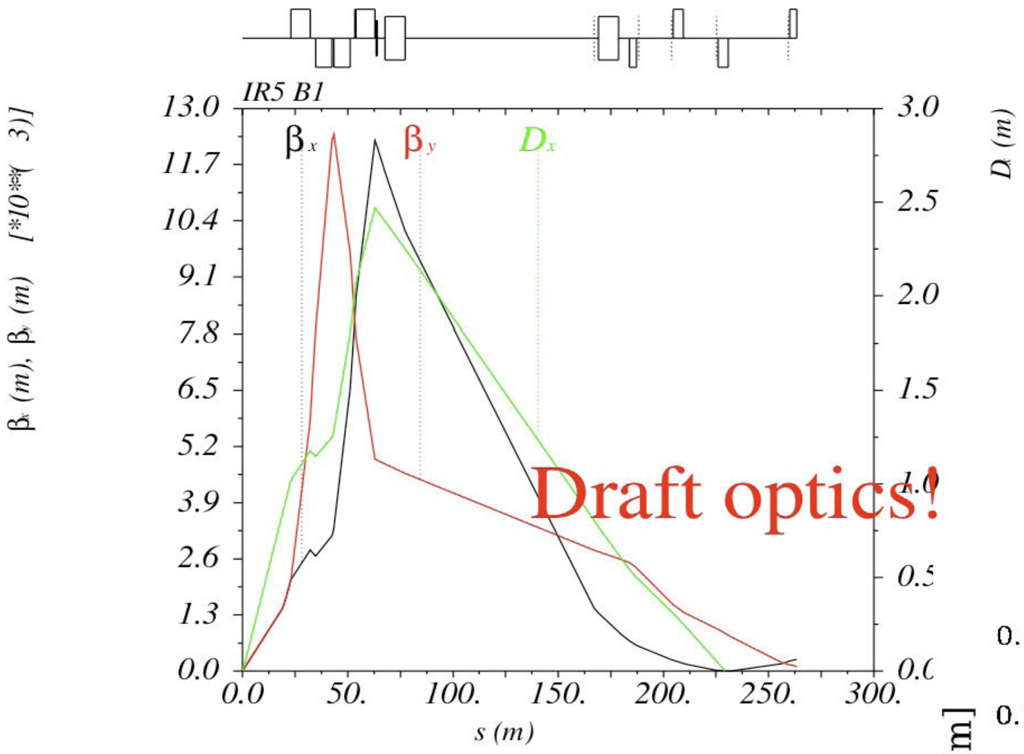
Maximum separation “within” reach of conventional technology (VV X-ing)

Compact cavities ideal for local scheme



Nominal Separation: 19cm

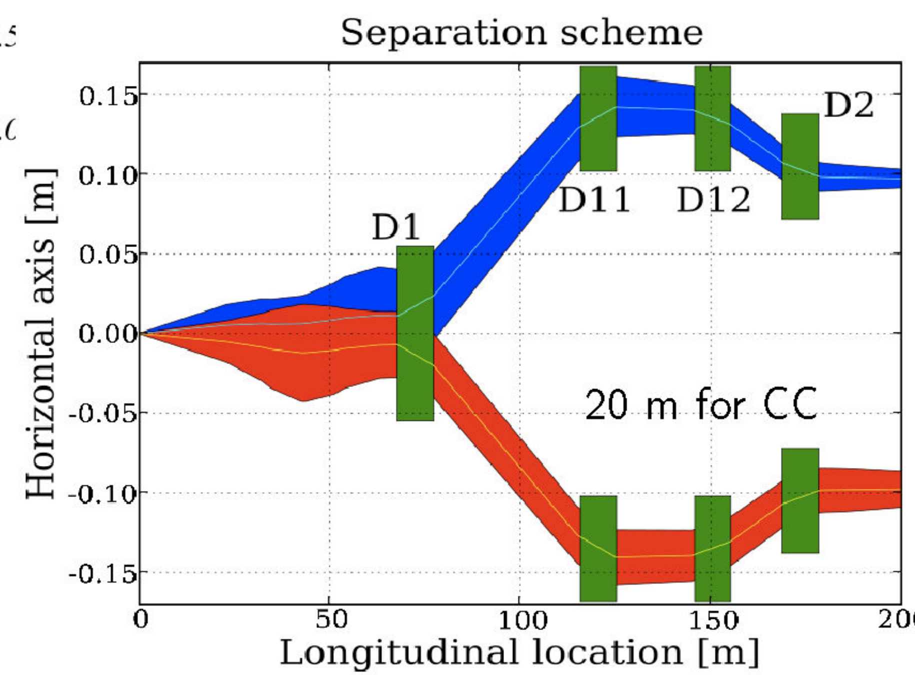
Local Layout & Optics



$\beta_{cc} \sim 5$ km

Voltage < 5 MV (1-2 Cav)

Cryomodule < 10 m



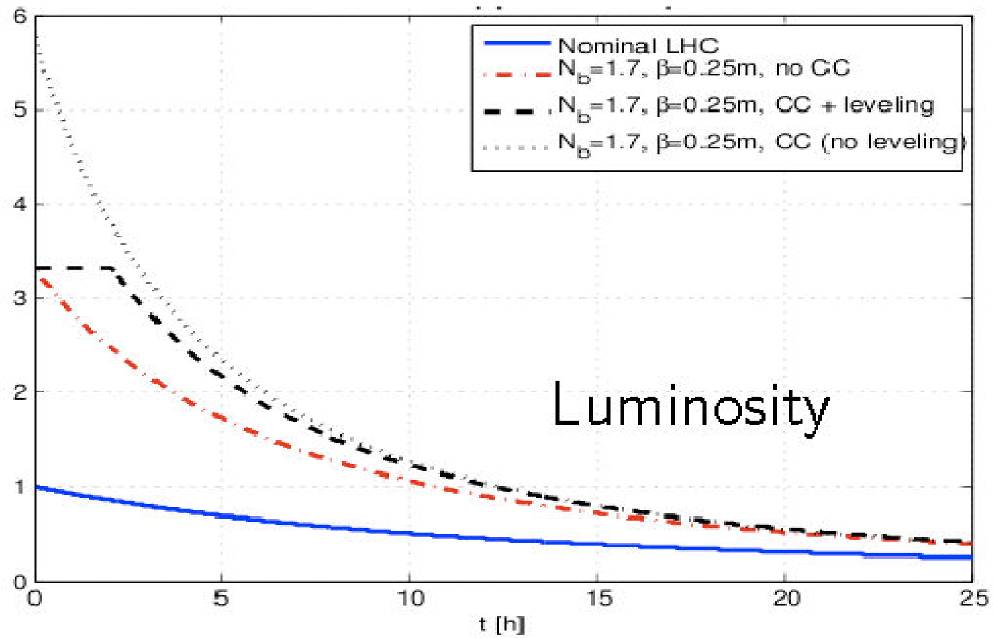
Crossing Scheme: VV (or HV)

Crossing Angle ≥ 0.5 mrad

DA ~ Similar to w/o crabs (Y. Sun)

Courtesy R. Tomas

Lumi Leveling

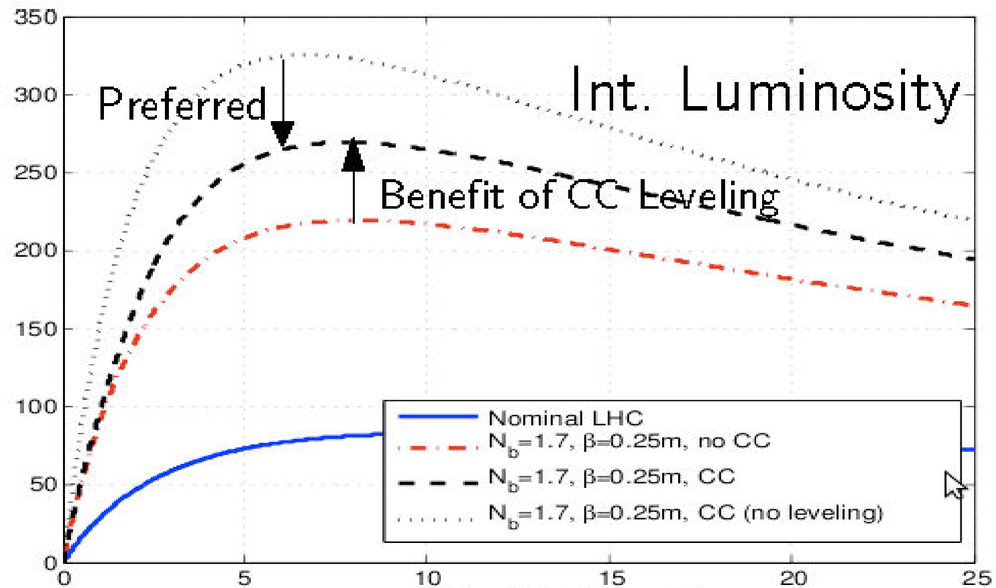


(Assuming only proton burn-off, IBS, rest gas scattering)

Optimum run time $\propto \tau_{lev}$

Assume $T_{tat} = 5$ h

Need to study the effects of modulation of (beam-beam parameter, synchro-betatron resonances, bunch overlap)



Courtesy G. Sterbini

Main Points of Rama's Talk & Discussion:

- Keep CC infrastructure requirements in mind for all other LHC upgrade projects

- Local elliptical CC scheme implies larger D cavity:
  ➔ significant dispersion in CC claimed not to be an issue
  ➔ machine tests?

- Compact CC for local scheme eliminates need for dogleg insertion in RI1 and IR5 ➔ motivates more support for compact CC R&D (even at expense of CC development for a Phase 1 CC tests)

LHC IR Upgrade – Phase-1

Goal of the upgrade:

Enable focusing of the beams to β^*=0.25 m in IP1 and IP5, and reliable operation of the LHC at 2 to 3 10^{34} $cm^{-2}s^{-1}$ on the horizon of the physics run in 2014.

Scope of the Project:

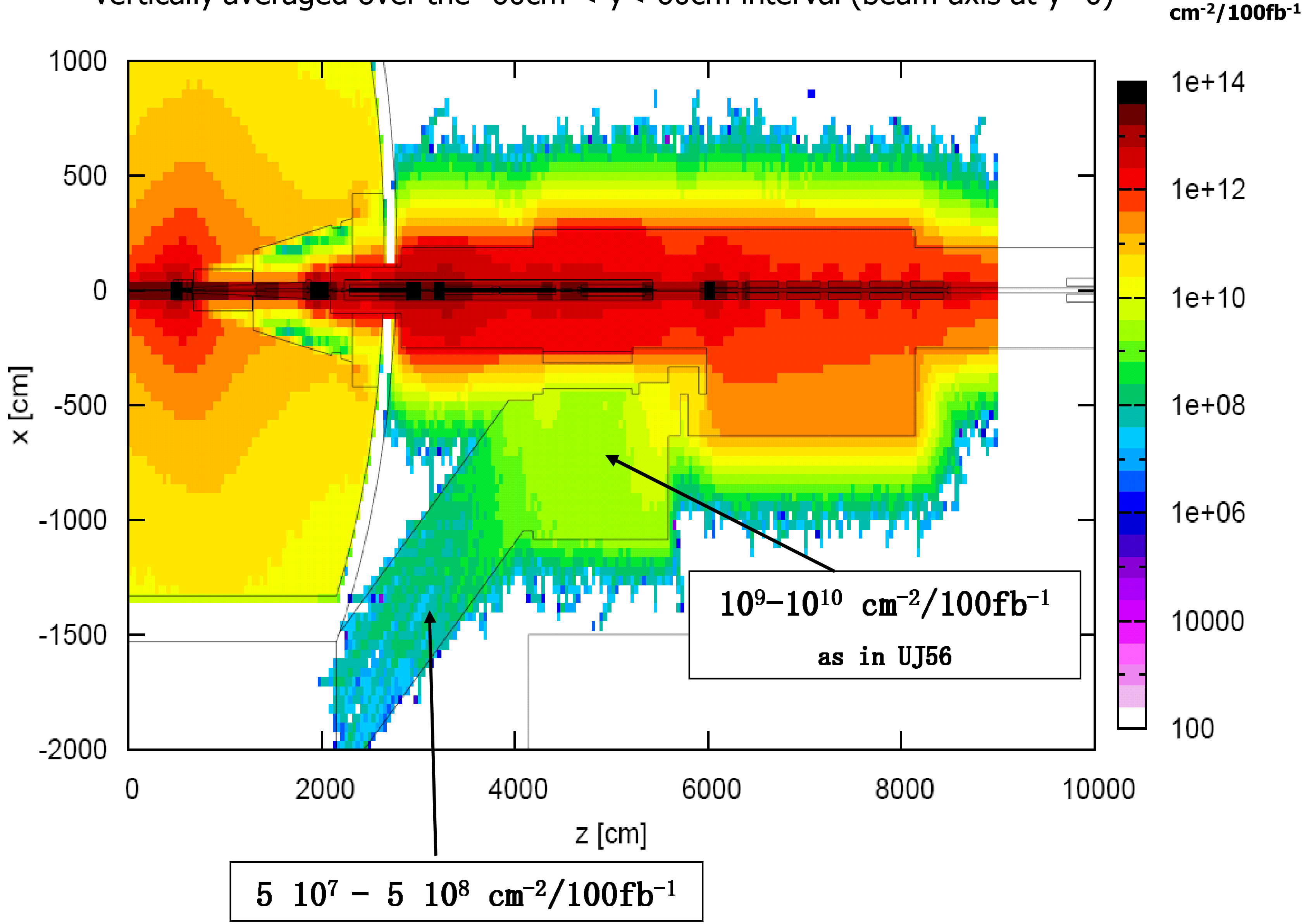
1. Upgrade of ATLAS and CMS interaction regions. The interfaces between the LHC and the experiments remain unchanged.
2. The cryogenic cooling capacity and other infrastructure in IR1 and IR5 remain unchanged and will be used to the full potential.
3. Replace the present triplets with wide aperture quadrupoles based on the LHC dipole (Nb-Ti) cables cooled at 1.9 K.
4. Upgrade the D1 separation dipoles, TAS and other beam-line equipment so as to be compatible with the inner triplets.
5. Modify matching sections to improve optics flexibility and machine protection, and introduce other equipment relevant for luminosity increase to the extent of available resources.

Constraints

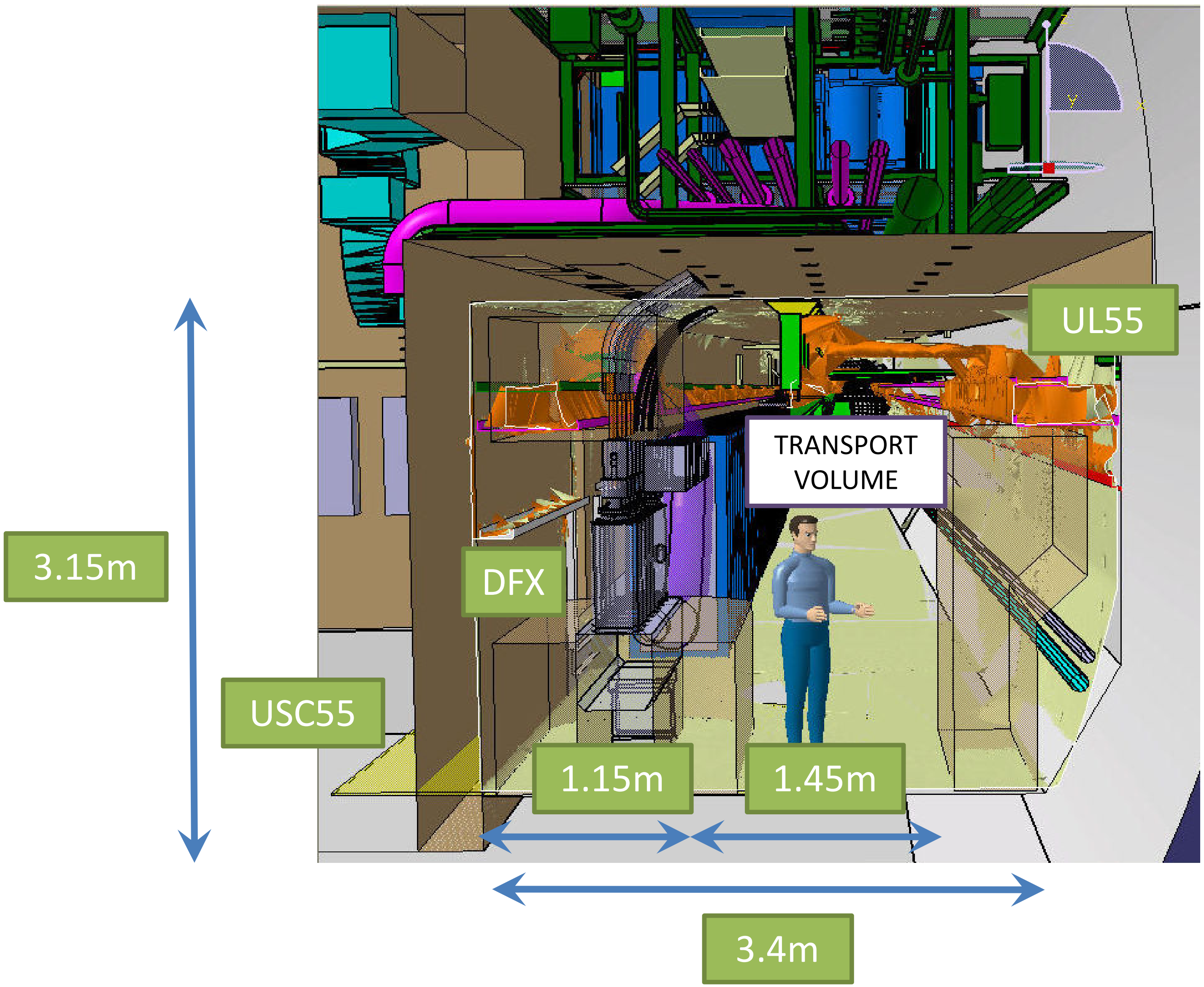
- Interfaces with the experiments: Very tight interfaces between the triplet, TAS, shielding, vacuum and survey equipment, and beam instrumentation; no possibility of reducing L* (23m).
- Cryogenics: Ultimate cooling capacity is 500 W@1.9K in each triplet. Replacement of triplets in IR1/5 requires at present warm-up of 4 sectors.
- Chromatic aberrations: Reduction of β^* drives chromatic aberrations all around the LHC. A new optics solution for all arcs and insertions is necessary.
- Accessibility and maintenance: All electronics equipment for the triplets should be located in low-radiation areas. Severe space constraints around IP1 and IP5 for any new equipment. New magnets must be similar in size to the LHC main dipole.
- Upgrade implementation: during the extended shutdown, compatible with CERN-wide planning (Linac4 commissioning, phase-1 upgrade of the experiments).

Hadron fluence in IP1

vertically averaged over the -60cm < y< 60cm interval (beam axis at y=0)



Phase-1 Upgrade Equipment in IR5



Separation dipoles

	D1 Phase-1 (Phase-2)	D11	D12	D2 (nom LHC)
Strength (Tm)	30 (70)	70	40	38.7
Field (T)	4 (7)	7	4	4.1
Operating temp (K)	1.9	1.9	4.5	4.5
Beam stay-clear (mm)	140 (134)	106	78	69/53
Coil aperture (mm)	180	130	100	80
Beam separation (mm)	-	270	270	188
Eff. Coil-coil separation (mm)	-	40	70	48
Yoke diameter (mm)	645	940	910	645
Cryostat diameter (mm)	914	914	914	914

- Potential problem with beam separation (too small for separate aperture magnets)
- Yoke diameter too large

Some conclusions

- The Phase-1 Upgrade of the LHC interaction regions relies on the mature Nb-Ti magnet technology, while maximising the use of the existing infrastructure.
- Any new equipment in IR1 and IR5 (CC and separation dipoles) must conform in size with the transport zone.
- Phase-2 triplets will require new cryogenic plants in IR1 and IR5. Additional requirements from CC and separation dipoles need to be developed to optimize their design.
- It seems that additional tunnel alcoves in IR1 and IR5 for Phase-2 cryogenics and machine equipment (and moving power convertors from the RRs) is unavoidable.

Ion commissioning procedures

Commissioning plan elaborated by ion team. Specific aspects tackled separately:

RF, BI, Collimation, protection, BLM quench thresholds

Web documentation addresses specific ion aspects for each step:

http://lhc-commissioning.web.cern.ch/lhc-commissioning/ions/stage_1_EarlyIons.htm

Stage I: From start to first collisions of Early Ion Beam

Assume we slice commissioning procedures to the minimum required to get 2 Early Ion beams to 7 Z TeV (or some lower energy to be decided upon) and collide them unsqueezed. We should be starting from a machine that already does the equivalent with protons so many procedures can be skipped or compressed.

The time estimates for each step are provisional pending experience with protons. Some steps may be skipped or adapted at short notice according to circumstances and priorities.

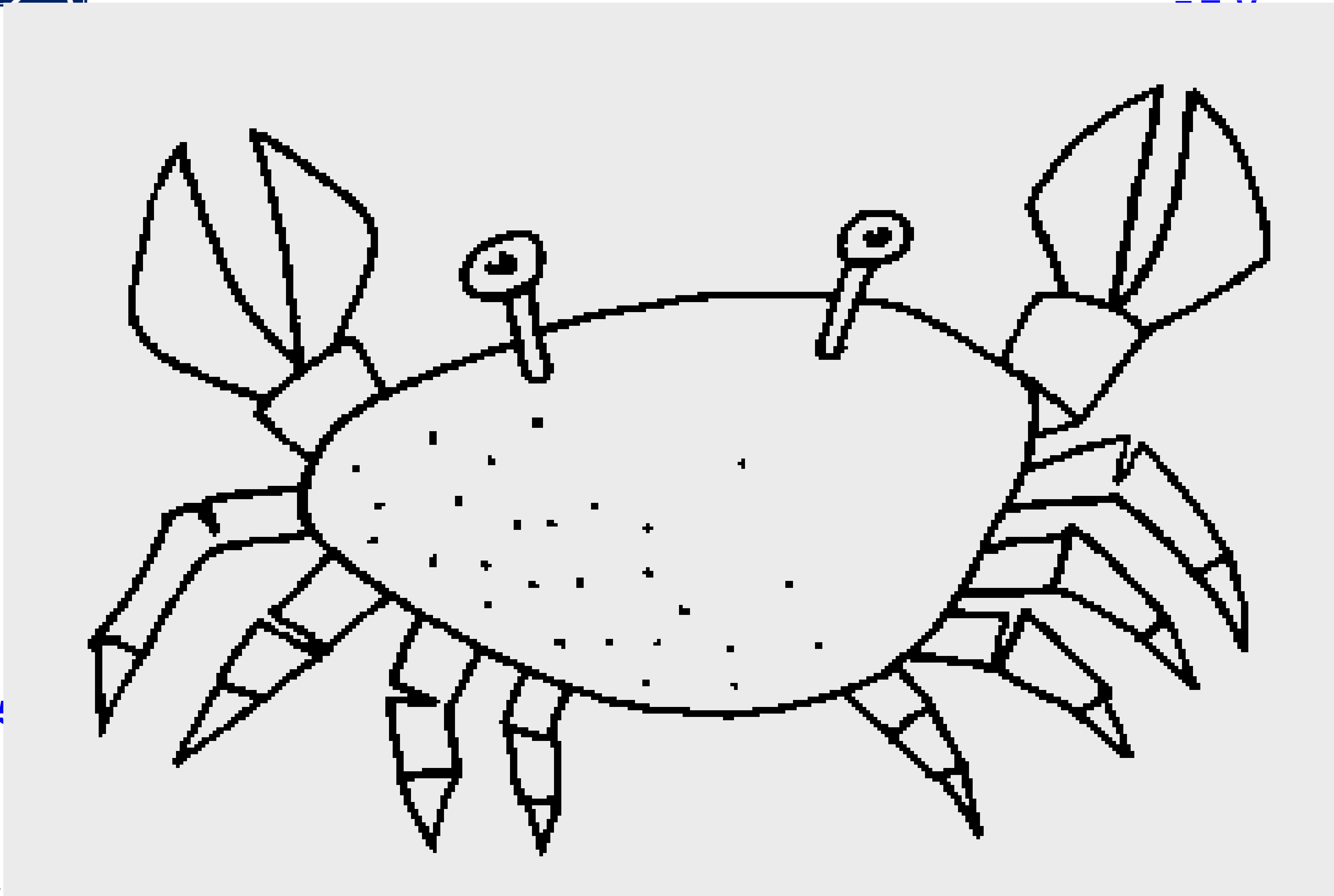
		Ring factor	Total Time [days] both rings	Comments
I1	Injection and first turn	2	0.25	Magnetically identical to protons; 1 bunch/beam.
I2	Circulating beam	2	0.25	Magnetically identical to protons. Synchronisation of tr -5 kHz frequency shift. Check lifetime in particular (IBS?).
I3	450 Z GeV initial commissioning	2	0.25	Beam instrumentation slightly different. Optics OK.
I4	450 Z GeV optics measurements	2	.5	Magnetically identical to protons but do minimal check
I6	450 Z GeV - two beams	1	.5	>0.4 nominal bunch intensity, otherwise magnetically i
I7	Collisions at 450 Z GeV	1	1 ?	If interesting. Performance to summarise.
I8	Snapback and ramp	2	0.5	Single and then two beams, Magnetically identical to pr Check beam dump at various energies.
I9	7 Z TeV flat top checks	2	0.5	Single beam initially, performed following successful ra
I12	Commission experimental magnets			Included already since done for protons.
I10	Setup for collisions - 7 Z TeV	1	0.5	
	Physics un-squeezed	1	-	Zero crossing angle in ALICE, leave as-is in CMS & A
	TOTAL to first collisions		6	
I11	Commission squeeze	2	2	Commission squeeze of ALICE to same as presently ac ATLAS (with ATLAS and CMS unsqueezed). May ha Check separation. Include CMS & ATLAS squeeze depending on time.
I5	Increase intensity	2	1	Increase bunch number to 62 (Early Scheme).
	Set-up physics - partially squeezed.	1	2	
	Pilot physics run			Parasitic measurements during physics (BLMs, ...) of g

A similar approach is recommended for the crab-cavity commissioning procedures:

You should prepare one document that presents consistently for each phase the specific aspects related to the commissioning with CC.

A lot of detailed work is required - a few aspects will be mentioned in the following.

Steps affected by CCs



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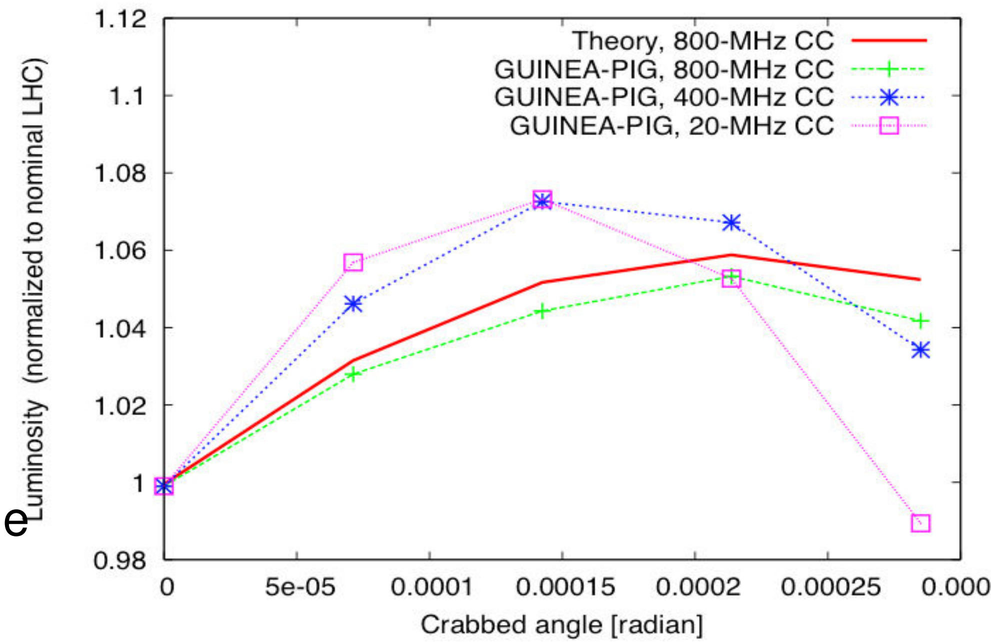
Luminosity tuning and leveling

Detailed procedure to be established, largely based on the Phase I experience.

Define an optimum set of parameters for initial commissioning (number of bunches, I_b, crossing angles, beta*, ...)

Assume that:

- Luminosity optimization without crabbing is well established!
- Reliable luminosity measurements available



BUT:

High risk: Need to define a set of **SAFE conditions for tests**. Little aperture margin available with squeezed beams + crossing.

Already commented on the required beam tests even before CC installation...

I see two additional possible options:

1. Collisions at lower energies

2. Anti-crab to REDUCE luminosity at top-energy WITHOUT crossing

Main Points of Stefano's Talk & Discussion:

- Develop detailed commissioning and operation planning"
  → will help in identifying potential conflicts with existing operation procedures
  → will help in identifying beam instrumentation requirements and potential upgrades of the nominal LHC instrumentation

- Proposal to a low risk 'negative' demonstration of the CC functionality sounds promising and should be studied in more detail

Summary

- Crab Cavities are strictly speaking only required for one of the LHC Phase 2 upgrade options. But this is the only option that provides Phase 2 performance levels with 'only' ultimate beam parameters
  - ➔ Keep this option alive until we know intensity limitations in the LHC
  - ➔ Justification based on luminosity leveling not sufficient. It is a nice side effect but can hardly justify the investment
- Need for compact Crab Cavities:
  - ➔ support for compact CC R&D seems well justified
  - ➔ development of a dedicated test stand?
- Phase 0 test in the LHC:
  - ➔ not sure if strictly required with KEK results (other machines?)
  - ➔ 'negative test' proposal seems interesting!