LHC-CC Validity Requirements & Tests

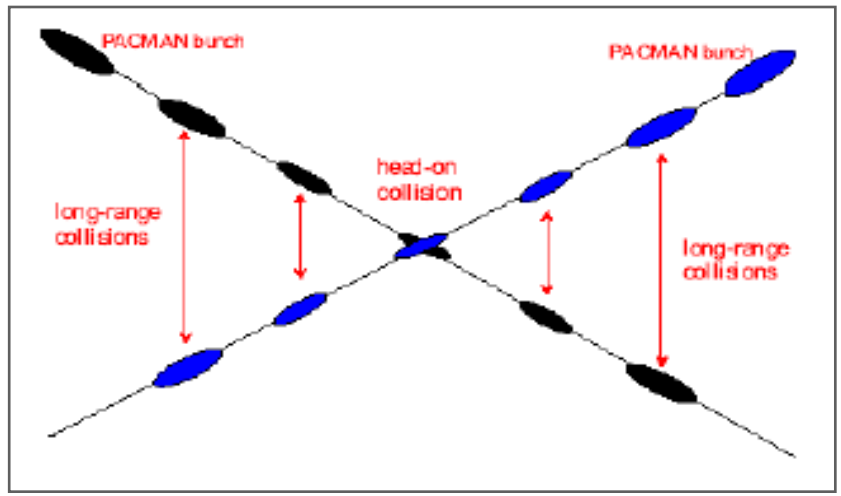
- Motivation for CRAB Cavities in the LHC and upgrade options
- Remarks on using the LHC as a test bed for R&D equipment
- Validation requirements and test goals for CRAB Cavity tests in the LHC
- Summary

Motivation for CRAB Cavities in the LHC

operation with crossing angle:

-crossing angle depends on β^*:

$$sep[\sigma] \approx \theta_c \cdot \frac{\sqrt{\beta^*}}{\sqrt{\varepsilon}}$$

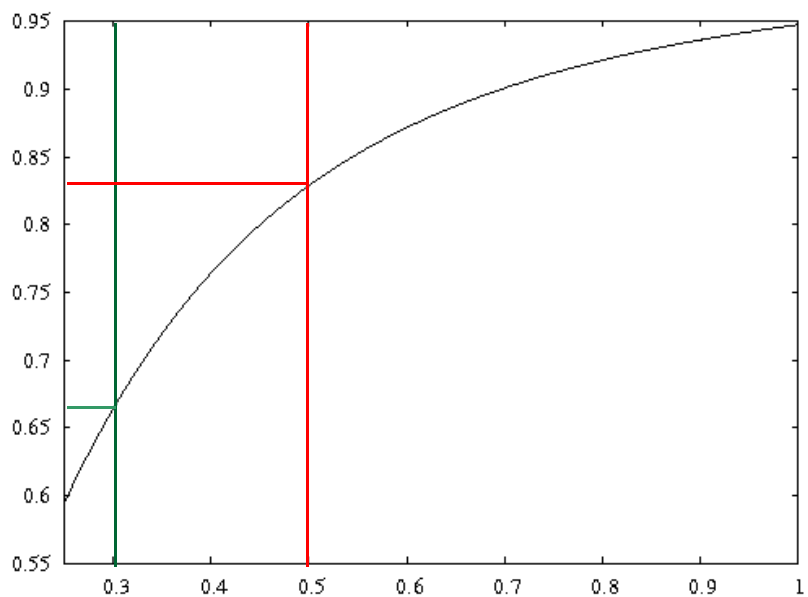


➔ constant normalized beam separation implies larger xing-angle for small β^*

➔luminosity reduction!

-geometric luminosity reduction factor:

$$R = \frac{1}{\sqrt{1+\Theta^2}}; \quad \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x}$$



LHC IR Upgrade Options

Phase 1: consolidation of 'ultimate' performance with $L > 10^{34} cm^{-2} sec^{-1}$

-large aperture NbTi triplet magnets using existing spare cables with the goal of introducing additional margins for the LHC operation

-no modifications of the experiment interface and cryogenic infrastructure

-opening the option for operation with $\beta^* = 0.3$ m and the 'ultimate' beam parameters yielding a performance reach of $L = 2\text{-}3 \times 10^{34}\ cm^{-2}\ sec^{-1}$

Phase I milestones:

-First quadrupole prototype by 2010

-Installation during 2013 / 2014 shutdown

-Ready for operation with $\beta^* = 0.3$ m during 2014 run

LHC IR Upgrade Options

Phase II:

-aims at operation beyond ultimate luminosity (the goal is integrated L!!!)

-implies operation in extremely radiation hard environment (35 MGy/year[@])

(less than 1 year lifetime for magnets with nominal triplet layout!)

➔ new magnet technology and /or special protection / absorber elements

Phase II milestones:

-Full scale (ca. 4m) prototype by end of 2009 within USLARP funding

-Installation during 2017 / 2018 shutdown?

-Ready for operation with $\beta^* = 0.25$m and tenfold increase in luminosity and radiation levels (requires upgrades of other components like the collimation system)

[@]N. Mokhov et al LPR 633 for ($L = 10\ 10^{34}$ cm^{-2} sec^{-1})

CRAB Cavities for the LHC Upgrade Phases

- CRAB cavities are interesting for the Phase I and Phase II upgrades;
  (potential luminosity increase of 33% and 40% respectively)
  Phase I upgrade is planned for installation in 2013/2014 shutdown
  Phase II upgrade is planned for installation by 2017 / 2018?

➔ requires proof of feasibility with sufficient lead time for final design optimization, production and installation: 3 years?

➔ demonstration of feasibility needed by 2010 or 2014 !?

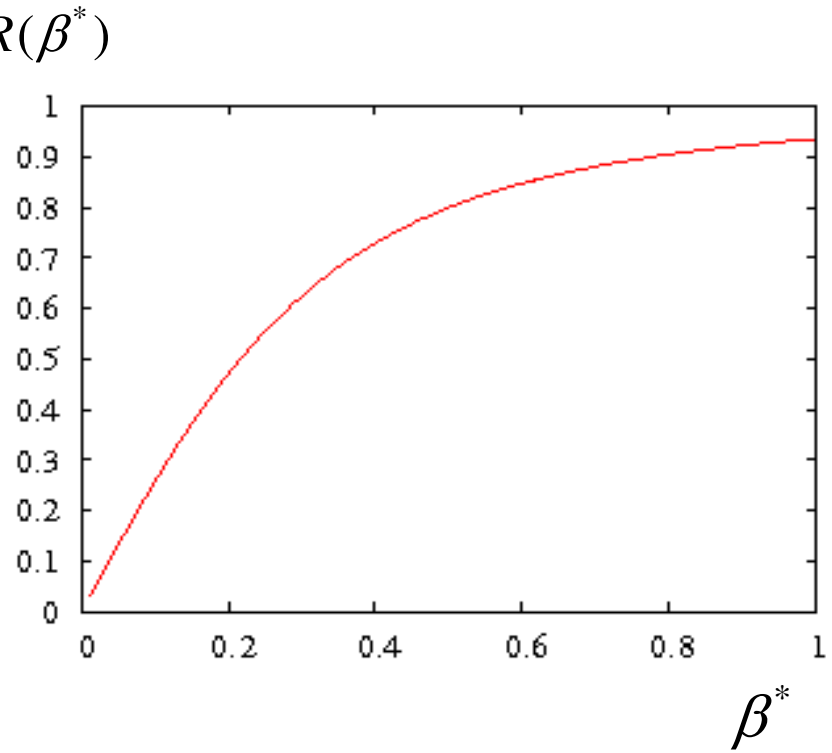
Luminosity Upgrade Options

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

➔ magnet R&D and injector complex upgrade

-last option requires major hardware modifications in insertion regions (local CRAB cavities and / or D0 dipole magnets inside the detectors)

➔ The sooner we know if CRAB cavities are feasible, the sooner we can select a preferred Phase II upgrade path and focus the required studies

Remarks on using the LHC as a test bed for R&D equipment I

- The CRAB Cavity tests and the required installation work must not compromise the normal LHC operation:

➔ The LHC should only be used as a test bed for R&D work if no alternative options exist for these tests (e.g. tests are not possible in the Tevatron or RHIC) ✓ (LHC-CC '08)

➔ As many tests as possible should be done prior to the CRAB Cavity installation in the LHC tunnel (➔ need for a dedicated test stand? ➔ test program definition, infrastructure and manpower plan?

Remarks on using the LHC as a test bed for R&D equipment III

The CRAB Cavity installation work must not affect - limit the normal LHC operation:

➔ Installation of the Crab Cavities must fall into the shadow of a scheduled LHC shutdowns (timing!).

➔ Time required for the installation of Crab Cavities in the LHC tunnel?

➔ The proposal should include a detailed installation plan.

➔ Time required for hardware commissioning of the Crab Cavities in the tunnel

➔ The proposal should include a detailed commissioning plan

Remarks on using the LHC as a test bed for R&D equipment II

- Preparation of a CRAB Cavity prototype for tests in the LHC :

➔ Regular annual LHC shutdowns (ca. 3 month) are probably too short (➔ possibility of a phased installation in the tunnel?)

➔ what installation work can already be done ahead of the tests?

➔ Installation during extended shutdown periods:

-Phase I IR upgrade during the 2013/2014

(this leaves only 4 years for the design, prototyping and construction of an LHC Crab Cavity!)

Remarks on using the LHC as a test bed for R&D equipment IV

- The CRAB cavity operation – tests must not compromise the nominal LHC operation:

  ➔ The CRAB Cavity test installation must be compatible with the existing infrastructure (e.g. cryo power and space requirements for klystrons and wave guides) ➔ impact of new infrastructure and configurations on the LHC operation (e.g. beam instrumentation).

  ➔ The installed CRAB Cavities must Not limit other upgrade options for the LHC (e.g. one should not sacrifice the 200MHz capture cavities for the CRAB Cavity installation).

Remarks on using the LHC as a test bed for R&D equipment V

The CRAB cavity operation – tests must not compromise the nominal LHC operation:

➔ The installed Crab Cavities must be transparent to the normal LHC operation (no impedance effects on the LHC beam during normal operation ➔ how can we turn the cavities 'off'?)

➔The failure of the installed Crab cavities must not impact on the nominal operation (e.g. quench, cryo break down coupler problems etc.)

➔ The proposal should include failure scenarios and statistics

Validation requirements and test goals for CRAB Cavity tests in the LHC

- Test program with Crab Cavities in the LHC:

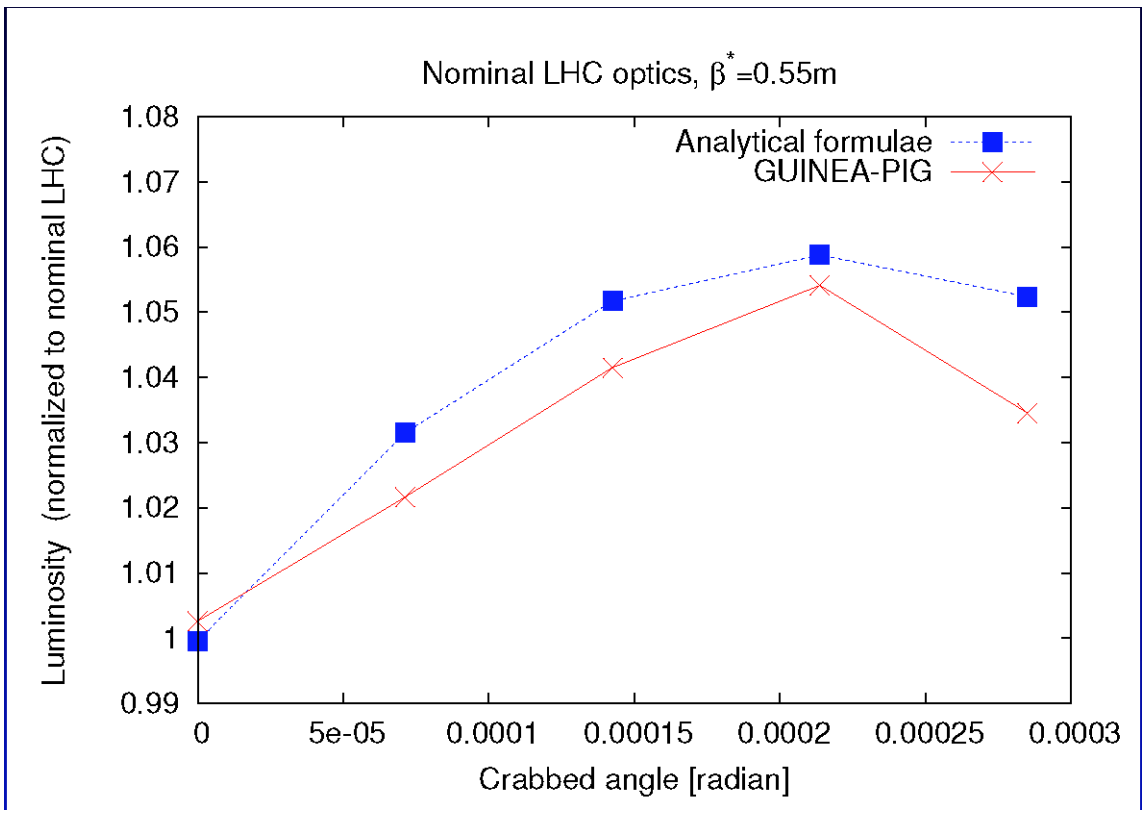
➔ Test program must be able to provide clear evidence of feasibility and benefit of CRAB Cavity operation in the LHC (tests must demonstrate: significant luminosity improvement (> 10%) without emittance growth; while maintaining the losses and background levels of normal operation)

➔ Specification of beam parameters and operation conditions!

Validation requirements and test goals for CRAB Cavity tests in the LHC

- Tests with $\beta^* = 0.55$m provide at best 5% luminosity increase[@]:

Measured effect during tests is smaller than 6%!



[@]Yi-Peng Sun et al at the 2008 workshop

Validation requirements and test goals for CRAB Cavity tests in the LHC

- Test program with CRAB Cavities in the LHC:

  ➔ Compatibility of the CRAB Cavity tests in the LHC with the LHC collimation and machine protection system (the current proposal foresees only the installation of one CRAB cavity which implies distributed bunch oscillations around the LHC machine)

  ➔ Measurement of cleaning inefficiencies and loss patterns?

  ➔ Does this operation mode provide useful results for the desired operation mode of local CRAB cavities?

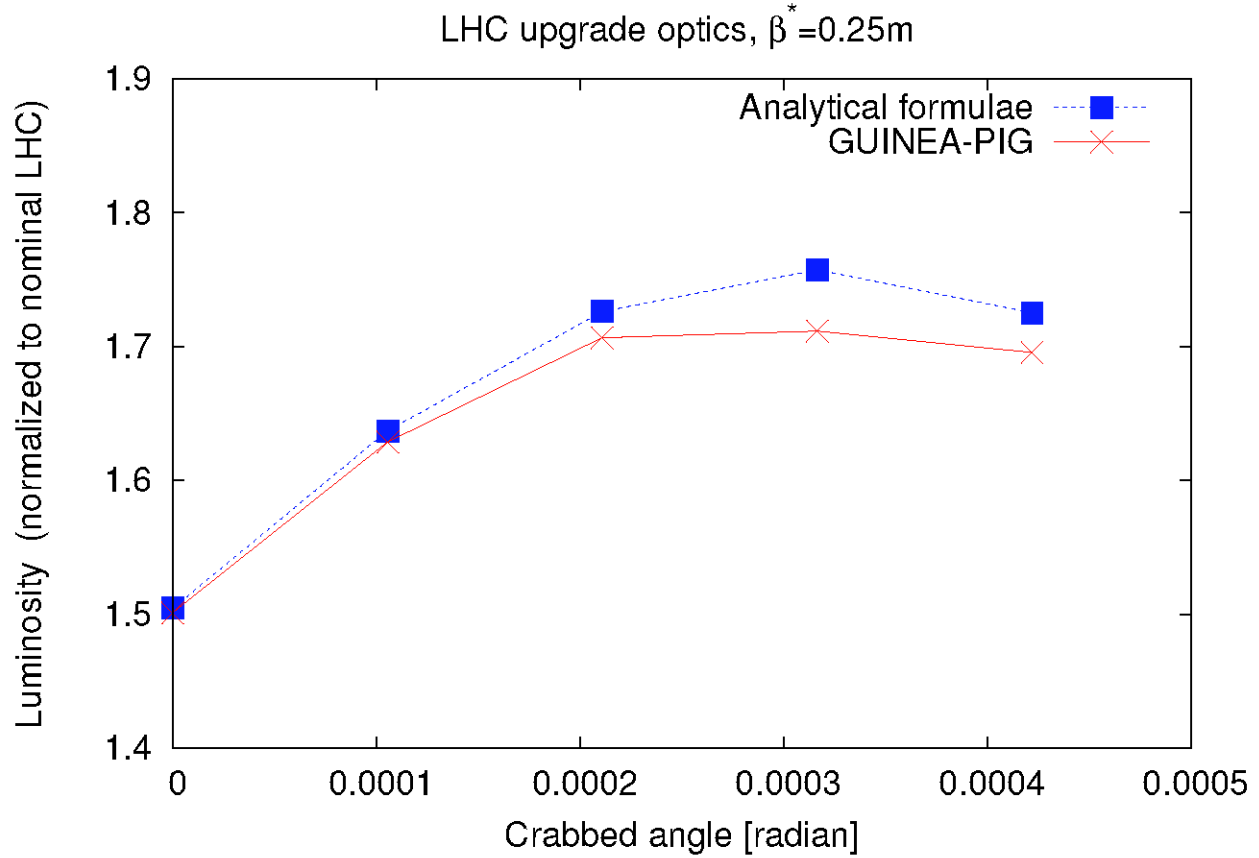
Summary

- Both LHC upgrade Phases could significantly benefit from CRAB cavity installations! ➔ feasibility demonstration by 2010 would be desirable!!!
- Choice for Phase II IR upgrade option depends on feasibility of CRAB cavity technology:
  - ➔ requires feasibility demonstration by the time of Phase I upgrade
- Using the LHC as a test bed for CRAB cavity studies implies:
  - ➔ transparent installation for normal LHC program
    - ➔ impact on test cavity design and installation schedule
  - ➔ can only be justified if tests can provide clear conclusions
  - ➔ if the installation and tests are compatible with MP and Collimation

Validation requirements and test goals for CRAB Cavity tests in the LHC

- Tests with $\beta^* = 0.25$m provide up to 16% luminosity increase[@]:

Measured effect during tests should be larger than 10%!

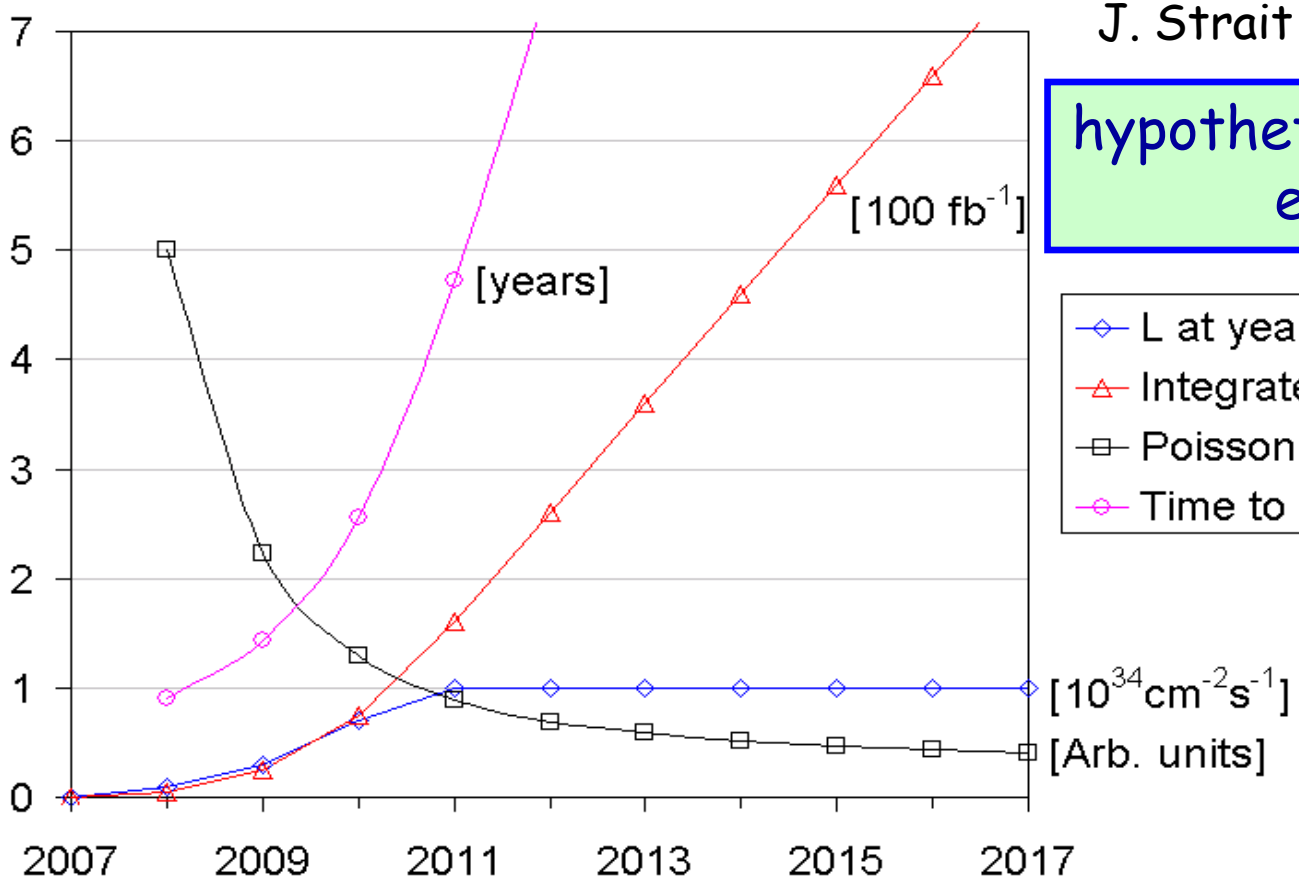


[@]Yi-Peng Sun et al at this workshop

Two Strong Reasons for LHC Upgrade

J. Strait 2003

hypothetical luminosity evolution



1) After a few years, statistical error hardly decreases.
2) Radiation damage limit of IR quadrupoles (~700 fb^{-1}) reached by ~2016

$\Rightarrow$

Time for an upgrade!

@W. Scandale and F. Zimmermann at BEAM'07

Some general observations for the deployment of CRAB Cavities in the LHC

- Several options exist for the Phase II upgrade:
  - -only one requiring CRAB cavities (early separation scheme) and
  - -Two requiring higher than ultimate beam currents
  - -Two requiring higher beam brightness in injector complex
  - -All options are challenging and require further studies; R&D and infrastructure
  - ➔ The sooner we know if CRAB cavities are feasible, the sooner we can select a preferred Phase II upgrade path and focus the required studies accordingly