Forward physics options at the FCC

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Future Circular Collider Study, FCC

http://fcc.web.cern.ch   Indico / Projects / FCC

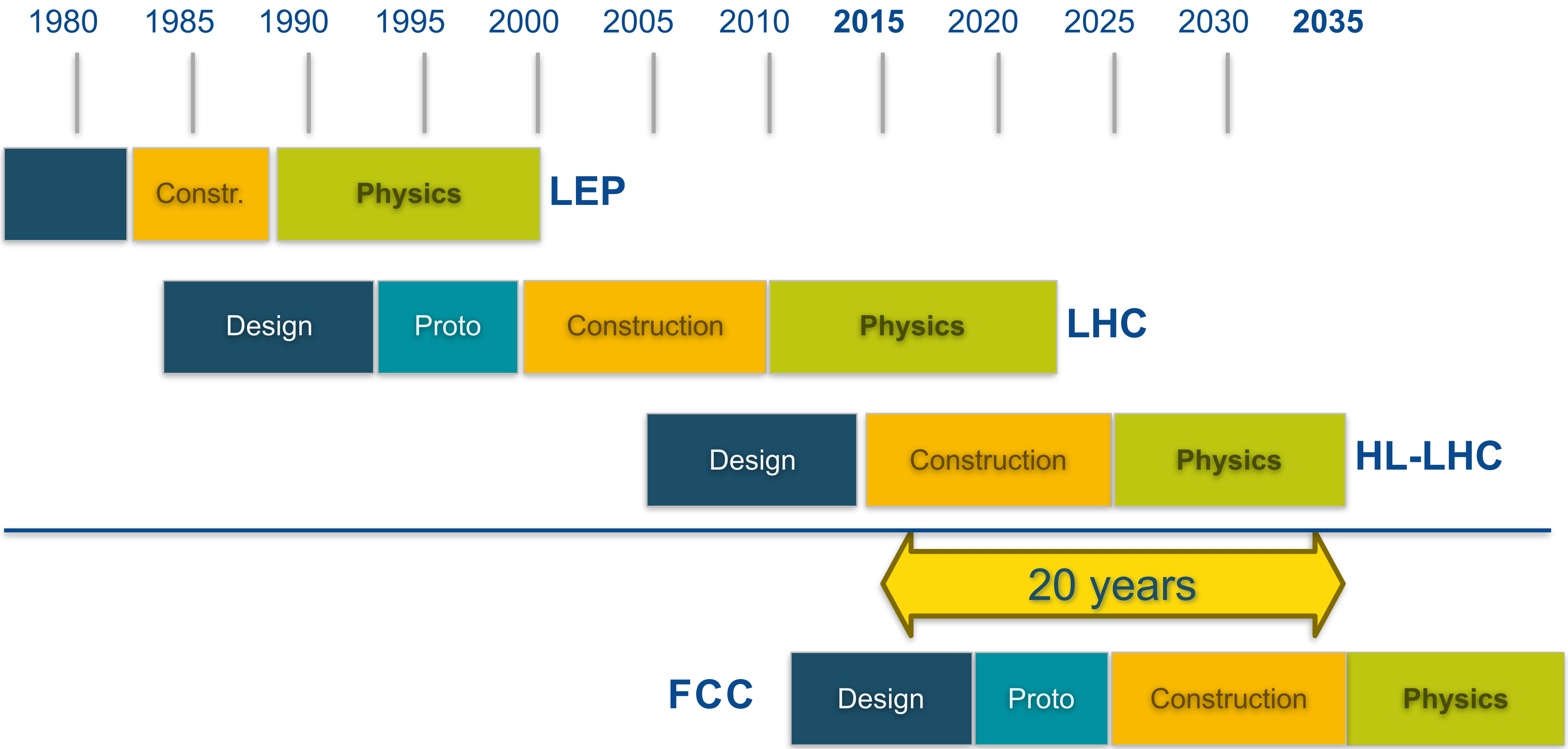
Goal
The Future Circular Collider study has an emphasis on proton-proton and electron-positron (lepton) high-energy frontier machines. It is exploring the potential of hadron and lepton circular colliders, performing an in-depth analysis of infrastructure and operation concepts and considering the technology research and development programs that would be required to build a future circular collider. A conceptual design report will be delivered before the end of 2018, in time for the next update of the European Strategy for Particle Physics.

Studies on the accelerator and machine-detector interface for 2 high luminosity interaction regions are in progress,   energy deposition studies well advanced

Here some early considerations on forward physics options, as seen from the machine side --   recalling and slightly extending what I said last meeting on 27/10/16

Acknowledgment :
discussion with FCC-hh design team,   Daniel Schulte, Xavier Buffat et al.

Time scale



1980 1985 1990 1995 2000 2005 2010 **2015** 2020 2025 2030 **2035**

LEP: Constr. | **Physics**

LHC: Design | Proto | Construction | **Physics**

HL-LHC: Design | Construction | **Physics**

20 years

FCC: Design | Proto | Construction | **Physics**

CDR by end 2018 for next strategy update

Hadron Collider FCC-hh

CERN-ACC-2015-132 of 21/10/2015

Baseline Parameters

100 TeV c.m.s **L = 100 km**

Injection energy 3.3 TeV

Baseline, 25 ns option :

L = 5e34 cm^{-2}s^{-1} leveled

$\int$ Ldt = 250 fb^{-1} per year and IP

#bun = 10600, 1.e11 / protons per bunch

ε_N = 2.2 μm

Non negligible SR:

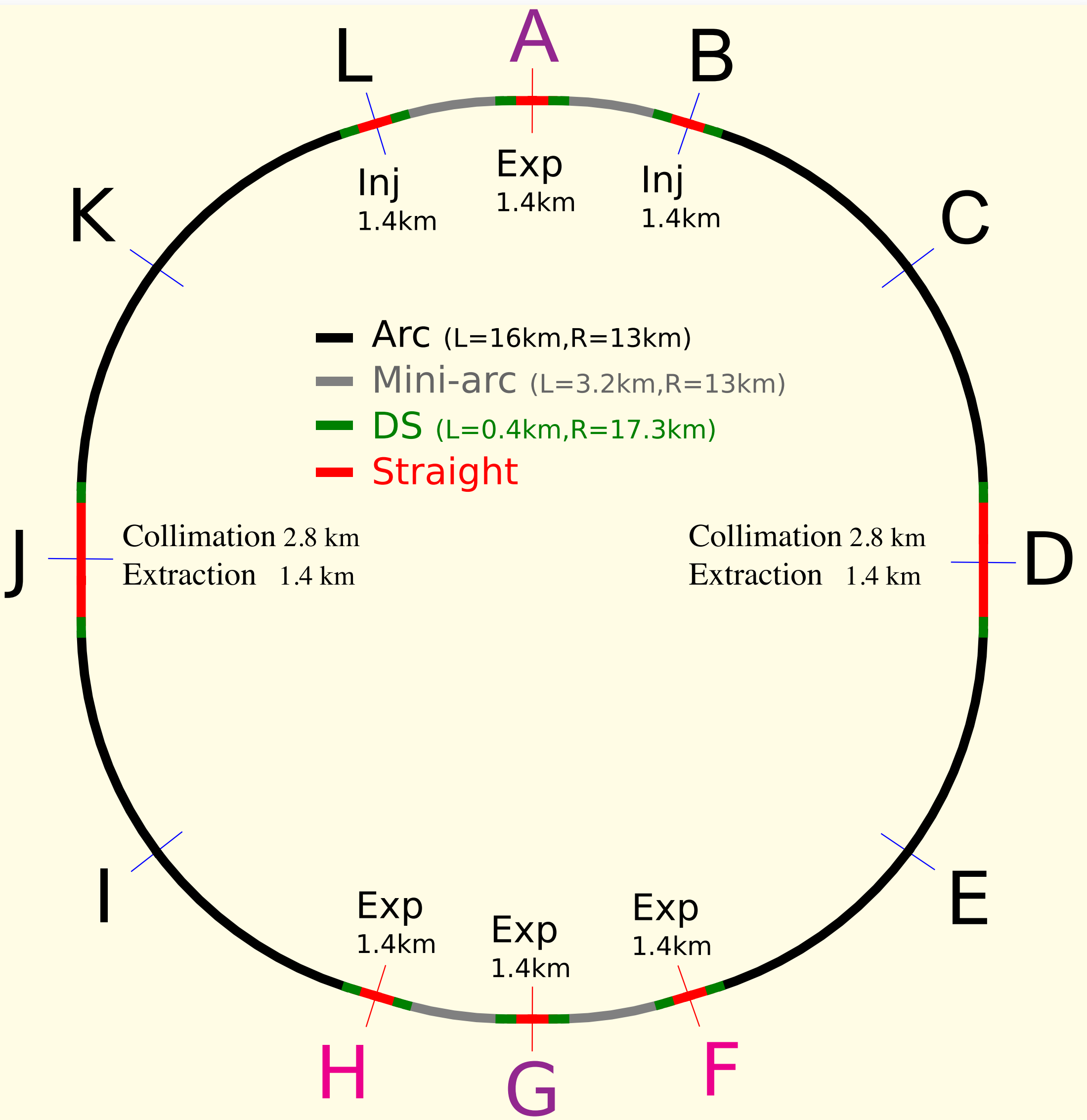
2.4 MW per beam

E_{crit} 4.3 keV (≈ SuperKEKB)

High luminosity IPs A, G :

β^* = 1.1 m, x-ing angle ± 45.5 μrad

IPs **H, F** not yet defined



Schematic collider layout. The straight insertions are shown in red and the arcs in black; the anticipated space for the dispersion suppressors is indicated in green.

FCC, current low β IP layout

~ scaled LHC layout

± 177.2 m common pipe

± 59.6 m LHC

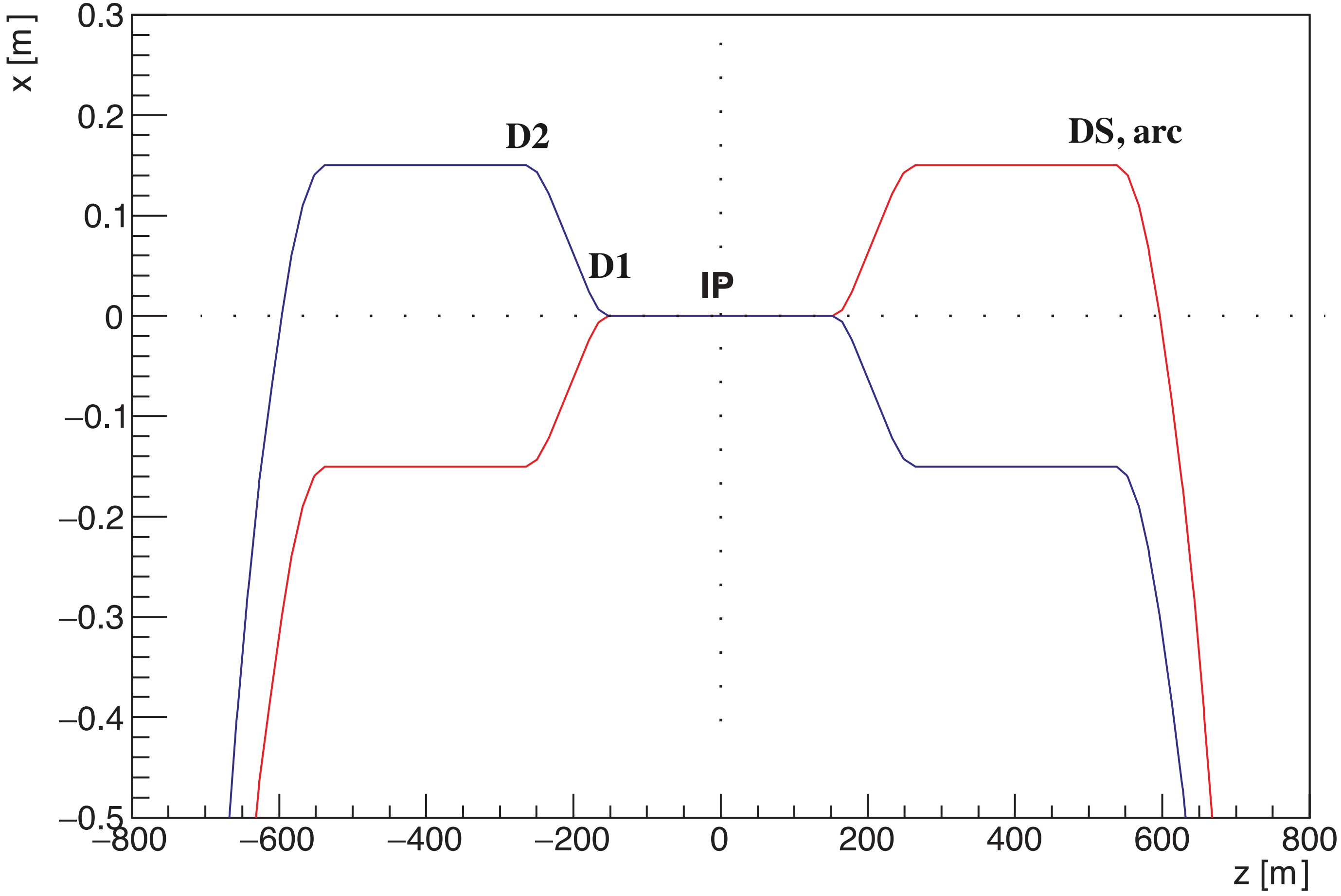
“D1, D2” dogleg

± 15 cm separation

± 9.7 cm LHC

DS from 534 - 1085 m

LATTICE_V4/Baseline



	NAME	KEYWORD	S m	L m	Angle	Ecrit keV	ngamBend	rho m	B T	BETX m	SIGX mm	divx mrad	SRPower kW
D1	MBXA.4L.H1A	SBEND	164.7	12.5	0.0008982	3.219	0.5042	13916.7	11.9843	13833.6	0.7557	0.0008	0.2614
	MBXA.4L.H1B	SBEND	178.7	12.5	0.0008982	3.219	0.5042	13916.7	11.9843	13425.3	0.7445	0.0008	0.2614
D2	MBRD.4L.H1A	SBEND	248.2	15	-0.0008982	2.682	0.5042	16700.0	-9.9869	11487.9	0.6887	0.0008	0.2178
	MBRD.4L.H1B	SBEND	264.7	15	-0.0008982	2.682	0.5042	16700.0	-9.9869	11050.5	0.6754	0.0008	0.2178
DS	MBDS.A8LA.H1	SBEND	551.5	13.47	0.001284	4.27	0.7207	10490.0	15.8992	39.014	0.0401	0.0010	0.4958

Extra IPs

LHC IP2, IP8 - magnet/optics very similar to high-lumi IP1 / IP5
More constraint by injection.

Extra IPs not yet studied in any detail for FCC
Potentially very interesting -- support from physics community (you) essential

Could potentially be used for an optimized lower luminosity, higher β^* forward/diffractive IR
was also considered for the SSC (SSC-88 9/1986, D.E. Groom et al.)

FCC : extra IP's H, F

- **Same 1.4 km length as high luminosity IPs A,G**
- **not constraint by injection**

More dedicated lower luminosity IR :

- Integration of detectors in IR layout : early planning may allow for integration of forward detectors in *machine sections* and better optimization for higher dispersion
  in the dogleg : Forward physics instrumentation, Rainer Schicker, FCC hadron detector meeting 27/07/2015
  or in the dispersion suppressor (FP420 equivalent for FCC)
- Lower luminosity → less shielding and radiation
  does not necessarily exclude lower β^*. Possible synergies with heavy ion mode

Some principles, high vs low β^*

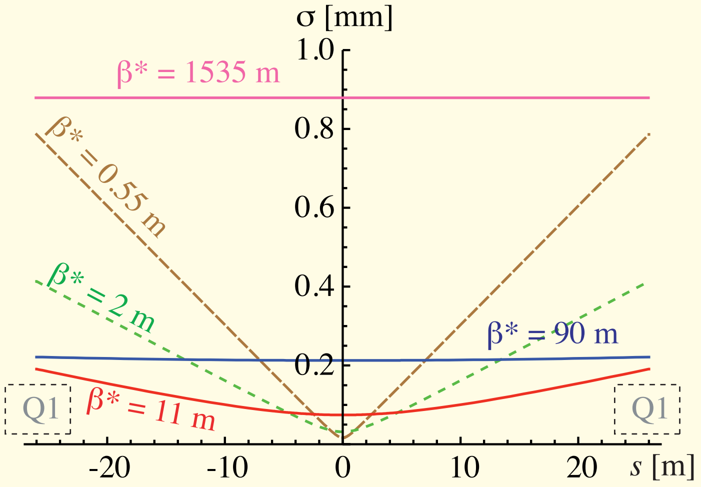
$\beta^* \ll L^*$ **low beta** small beams at IP. 90° phase advance L/R and strong focusing triplet
high angular divergence

$\beta^* \gg L^*$ **high beta** large parallel beams, low angular divergence ~ no phase advance and focusing

LHC design numbers :

$L^* = 26.15$ m (centre of 6.37 m long “Q1”, `MQXA.1R1`)

$\beta^* = 0.55$ m design value of low β^*



FCC-numbers, fcc_ring_v4_baseline, roughly 2× the LHC

$L^* = 46$ m (centre of 20 m long “Q1”, `MQXC.1R`)

$\beta^* = 1$ m design value of low β^*

Scaling, from LHC to FCC

FCC : E, γ increases by factor 100 / 14 = 7 in $\sqrt{\gamma}$ by 2.7 scaling

Beam size at IP $\sigma^* = \sqrt{\beta^* \epsilon} = \sqrt{\beta^* \epsilon_N / \gamma}$

$\sqrt{\gamma}$

Angular beam divergence $\sigma' = \sqrt{\varepsilon / \beta^*} = \sqrt{\varepsilon_N / (\gamma \beta^*)}$

Luminosity, round beams $\mathcal{L} = \dfrac{N^2 f}{4\pi \sigma^2} = \dfrac{N^2 f \gamma}{4\pi \beta^* \varepsilon_N}$ γ

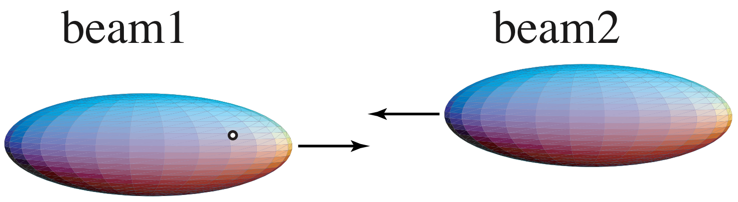
Minimum ***t*** with RP at n_σ $-t_{\min} = \dfrac{2 p n_\sigma^2 \epsilon_N m_p}{\beta^*}$ γ

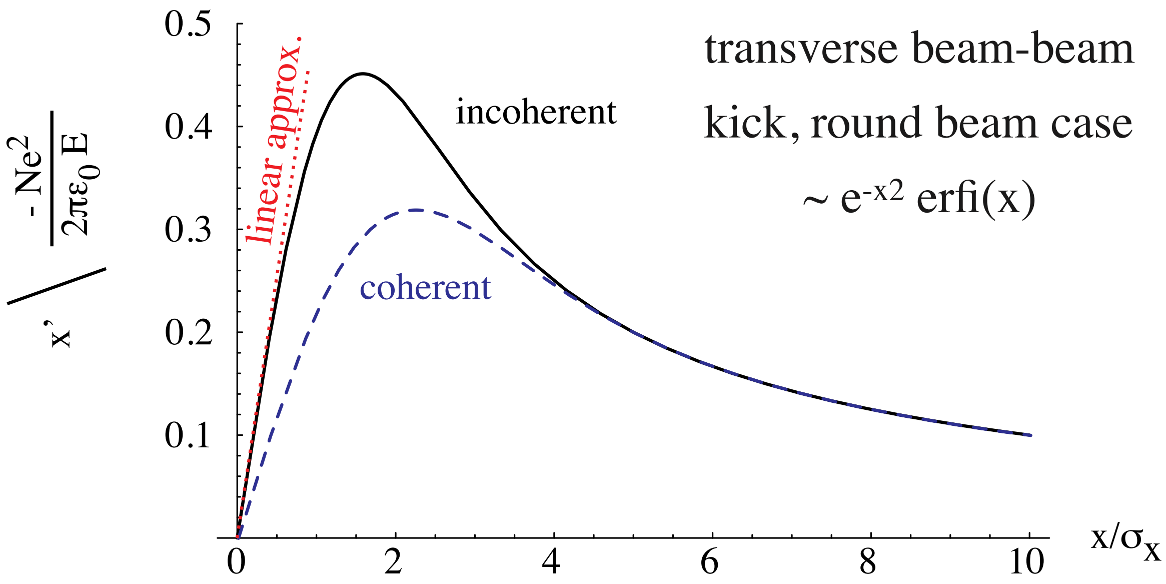
Normalized emittance $\gamma\varepsilon = \varepsilon_N = 2.2$ µm constant in (lower energy) proton machines, determined by injectors, similar for all proton machines. Beams shrink when accelerated.
Difficulty to reach a certain minimum *t* (i.e. Coulomb IR) increases ~ linear at constant ε_N with γ
from β ~ 2 km at LHC (yet to be reached) to ~ 14 km at FCC ?

In FCC, **damping** from SR+RF significant, opens up possibility to get significantly lower emittance
--- **potentially very useful for dedicated runs**

Reminder : Low luminosity ≠ No interference

Beam-beam interaction





transverse beam-beam kick, round beam case

~ e^{-x^2} erfi(x)

separation in σ

Quantified by tune shift parameter ξ

$$\xi = \frac{r_c\, N}{4\pi\, \epsilon_N}$$

head-on, round beams

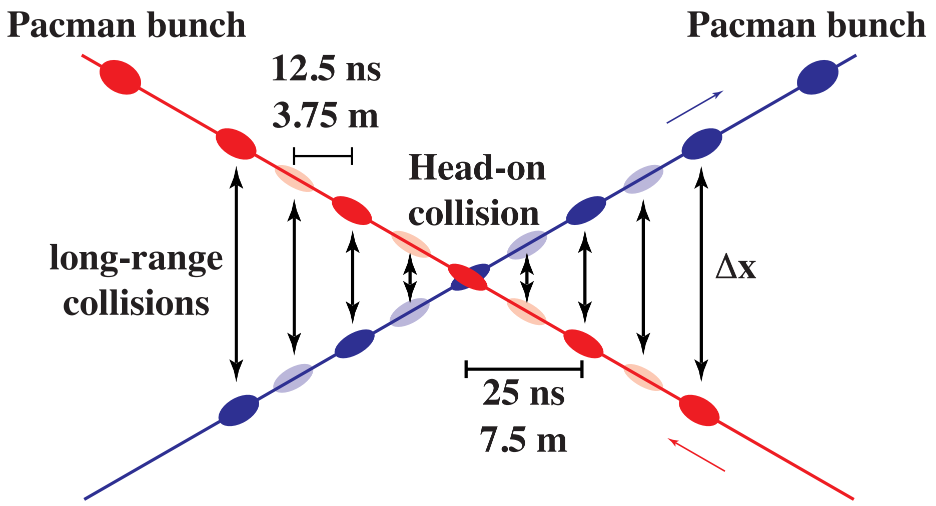
depends only on N / ε_N

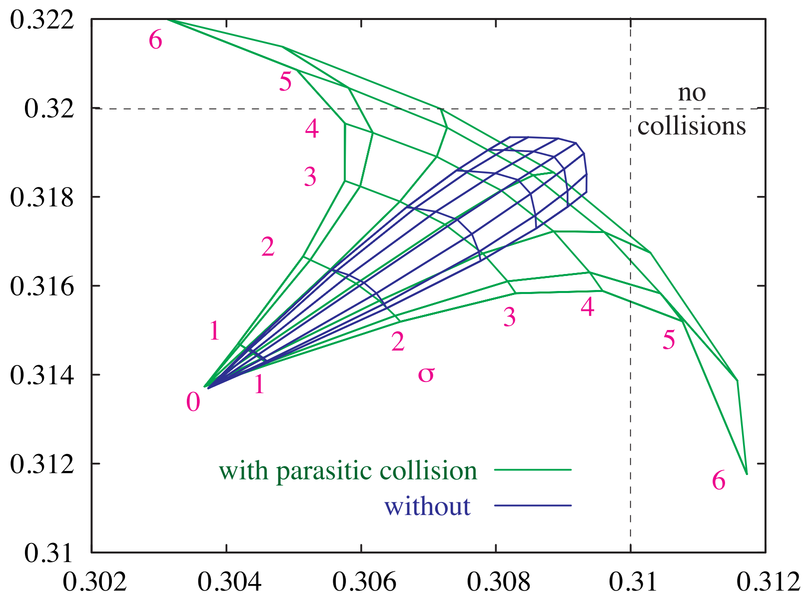
not on energy and **not on β***

Head on : same beam-beam from low lumi high-β as high lumi IPs

To reduce b.b. would require to run separated by several σ

Principle of separation by crossing angle at higher β*





Nominal LHC w/o parasitic collisions

Low β* (< L*)

beam size and separation increase ∝ Δs,

⇒ separation in units of σ about constant around IP

all parasitic crossings adding up with similar contribution

Instead high β* :

beam size ~ constant = σ*, separation in σ increases as ΦΔs

where Φ is the crossing angle, dominated by 1st parasitic crossing

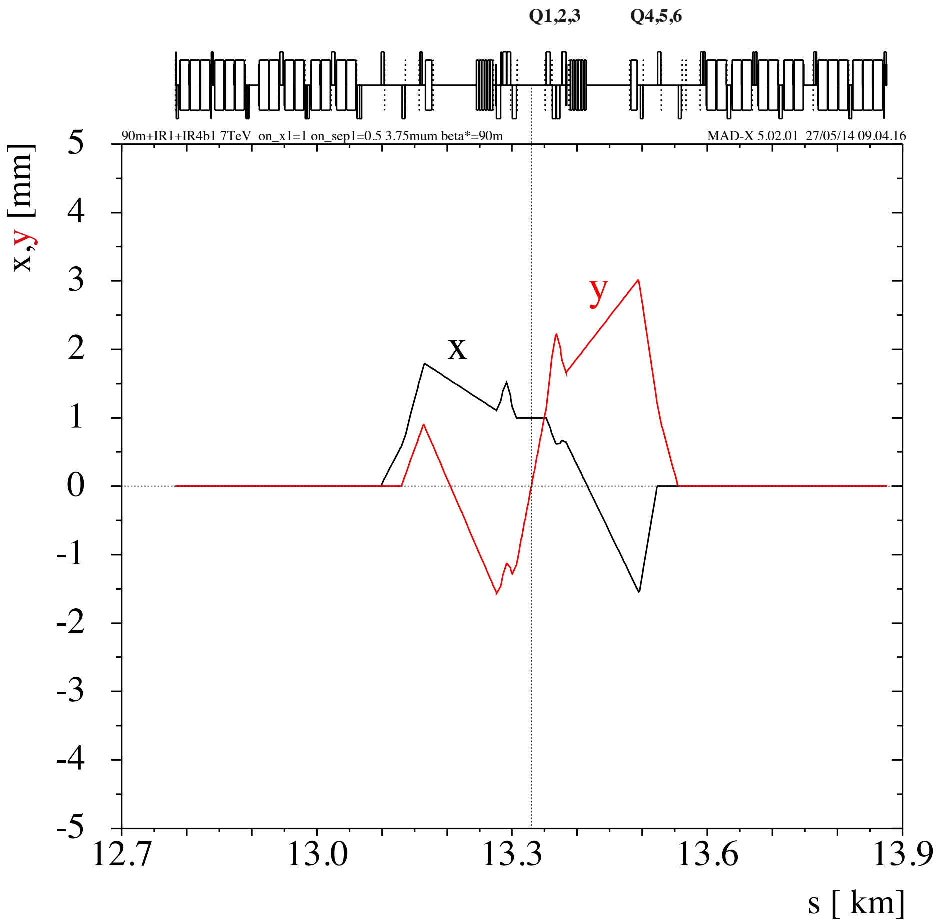
100 ns bunch spacing 4× more separated than 25 ns, used for 90m LHC

and negligible contribution from next 200, 400 ns ...

LHC, separation and crossing bumps at 90 m, IR1, IR5

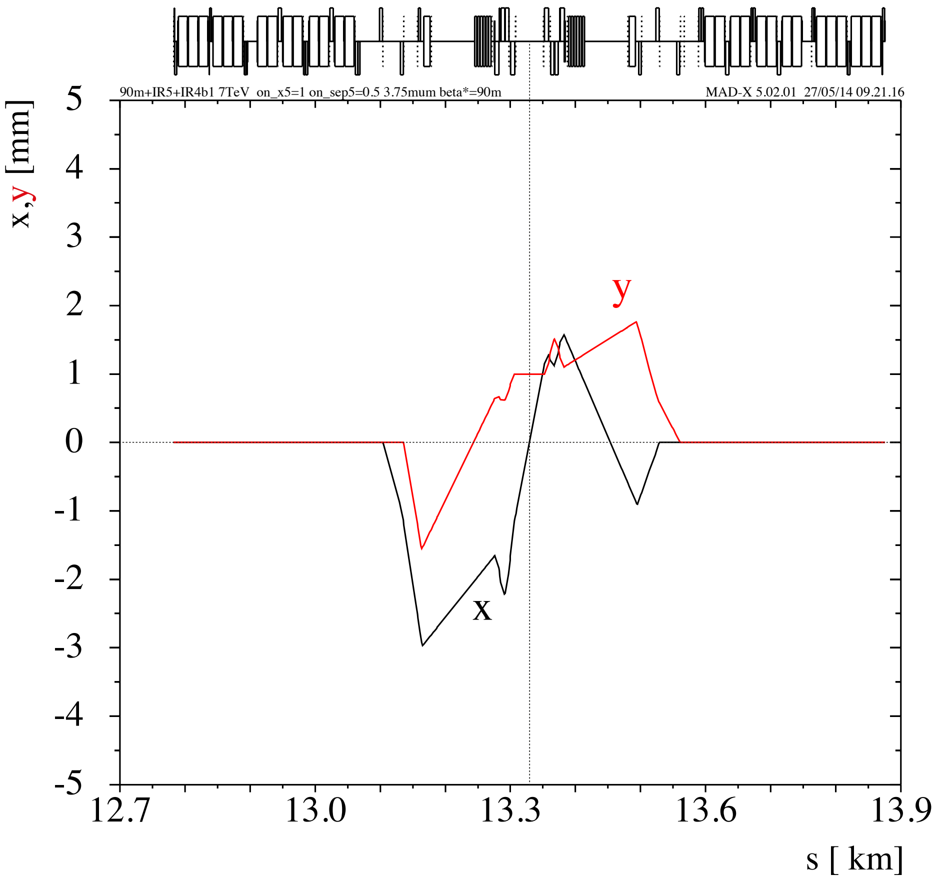
IR1, ATLAS-ALFA

Vertical crossing



IR5, CMS-TOTEM

Horizontal crossing



Shown for ± 1 mm separation

± 50 µrad (half) crossing angle --- limited by corrector strength

(+ injector RF) to 100 ns spacing or 4x reduced #bunches

With sufficient corrector strength and aperture : 25 ns spacing in dedicated FCC IR

Running scenarios (1/2)

Parasitic running in standard physics next to high luminosity IP, with tens of kilowatts of collision debris will be difficult. Important to plan this before.

Consider 3 scenarios - of which 1.+2. best at dedicated lower luminosity IP

1. Dedicated very high β* operation for cross section measurements

Few bunches, no crossing angle. Few dedicated runs.

Roman pots very close (few sigma).

Minimize beam-beam (no collisions in other IPs, moderated bunch intensities) :

Profit from SR/RF radiation damping : $\varepsilon_N = 2.2\ \mu m \times \exp(-t/\tau)$

where $\tau = 1$ h. After ~ 4 hours at **reduced equilibrium emittance**, maybe as low as ~ 0.05 µm

β* ~ few km could be sufficient, very high β* > 10 km may not be needed

at reduced bunch intensities, more bunches compatible with no crossing angle to get sufficient luminosity

to be checked and optimized : damping partition, beam-beam, bunch schemes, IBS

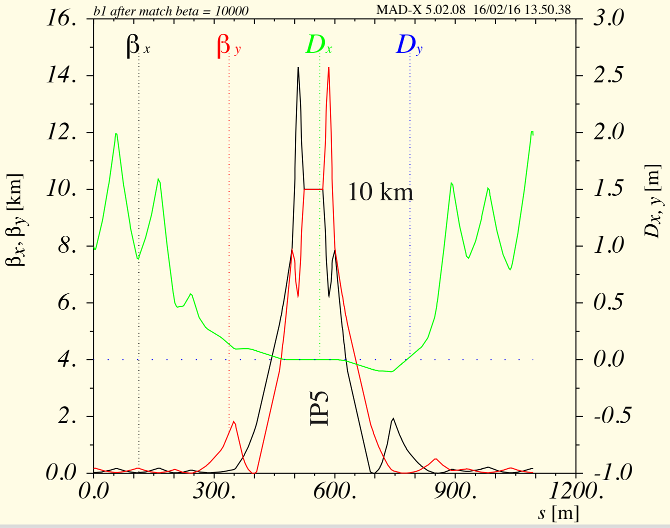
On the other hand there should be

no principle problem to go to very high β*

like tenths of km if this is taken into account in the IR design

Key ingredients for very high β* :

- flexible quadrupole powering (bipolar) and large aperture
- sufficient # (≳ 6) of independently powered quads IP to RPs
- well separated IR, DS sections
- getting there - de-squeeze from β* > L*



Running scenarios (2/2)

2. Moderately high β* ~ 100 m operation for forward / diffractive physics

(and minimum bias, proton vs / ion calibration ..) with kind of "ALICE+TOTEM" IR and detectors

Design IP such that enough corrector strength and aperture available for sufficient crossing angle (≳ 10 σ) and parallel separation to operate with full number of bunches with 25 ns spacing

Aim : **compatible with standard physics** --- no need for limited special runs

Roman pots at ~ 10 sigma ? (after some h in physics)

3. Very forward detectors in very high luminosity insertions A/G "FP420"

tagging of protons (ξ in the range 0.01 - 0.10 ?) at full luminosity

using detectors in the dispersion suppressor

needs early planning --- space and integration with magnet / cryo / collimation design

Goals and required machine parameters

For discussion :

contribute to FCC-hh CDR ?

- **physics motivation**
- **requirements in terms of target machine parameters**

For each of the running scenarios considered, define the requirements :

- **phase advance between IP and RPs**
- **plane (x, y), w/o crossing angle**
- **local dispersion between IP and RPs ("ξ" acceptance, $D / \sqrt{\beta}$)**
- **detector acceptance (η - ranges)**
- **closest approach of RPs to beam axis n_σ and real space (mm, w/o dead space)**
- **if required limits on transfer matrix magnification $\nu = r_{1,1}$ eff. length $L = r_{1,2}$**
- **$\int L\,dt$**
- **Pile-up**

1st step to get something is to ask for it

Concluding remarks

On a brain-storming level

--- there appears to be very good potential for forward / diffractive physics at FCC

2 extra IRs not yet studied / assigned

Could profit a lot from :

- More dedicated interaction region
- More space and flexibility
- Reduced emittance (significant SR/RF damping)
- Potentially compatible with standard operation
- Detectors in higher dispersion sections (dogleg, DS)