LHC Commissioning

Helmut Burkhardt, CERN

BROOKHAVEN NATIONAL LABORATORY

C-AD Accelerator Physics Seminar, Thursday, November 29, 2007

Outline

- Introduction & Motivation : high Energy and Luminosity
- Looking at the machine
- Major challenges, high stored energy
- Pre-accelerators and injection + ramp
- Hardware commissioning and schedule
- Plans for commissioning with Beam

LHC at the Energy Frontier

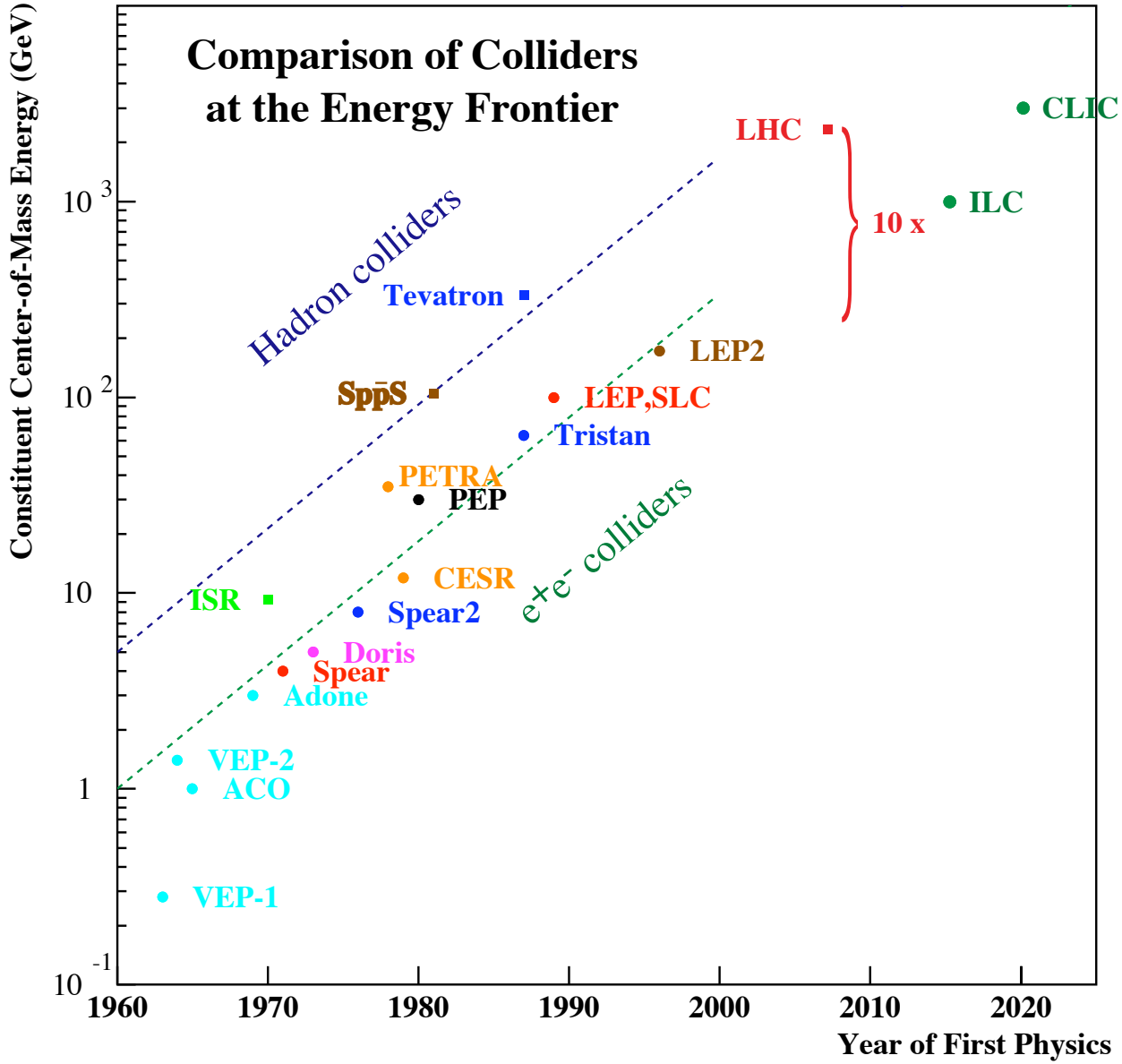
My current version of the Livingston plot :

exponential growth of E_{cms} in time

Starting in 60's with e^+e^- at about 1GeV

Factor 4 every 10 y

pp, $p\bar{p}$: E_{cms} / 6
5 × above e^+e^- at same time
discovery Machines

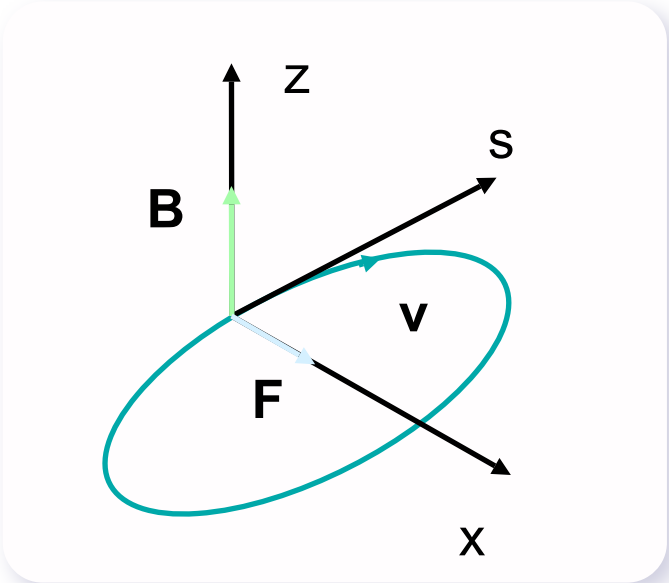


LHC : will take us a big step forward.

Basic machine parameters, Lorentz Force

$$\mathbf{F} = q\,(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

- Electric field **E** provides the acceleration / energy gain
- The magnetic field **B** keeps the particles on their path



Simple case - circular motion :

$$\mathbf{E} = 0 \qquad \mathbf{v} \perp \mathbf{B}$$

$$B = \frac{p}{q\rho}$$

LHC :

- **Momentum p = 7000 GeV/c**
- **LHC bending radius ρ = 2804 m**
- **Bending field B = 8.33 Tesla**
- **Provided by superconducting magnets cooled with He to 1.9 K**

For q = e numerically

$$B[T] = p[GeV/c]\,\frac{3.336\,\mathrm{m}}{\rho}$$

Energy and Luminosity

- **High energy** : to be able to directly produce new particles (Higgs, supersymmetric particles) out of reach of previously existing machines. The LHC will provide 14 TeV from 7 TeV protons on 7 TeV protons.

- The expected cross sections for new particle production are small (fb = 10^{-39} cm^2) **High luminosity** $\mathcal{L} \sim 10^{34}$ [cm^{-2}s^{-1}] is important to obtain sufficient event numbers and allow to observe rare events.

Event rate: $$\dot{N} = \mathcal{L}\,\sigma$$

Tevatron $p\bar{p}$ 1.96 TeV, $\mathcal{L} \approx 3\times10^{32}$ [cm^{-2}s^{-1}]

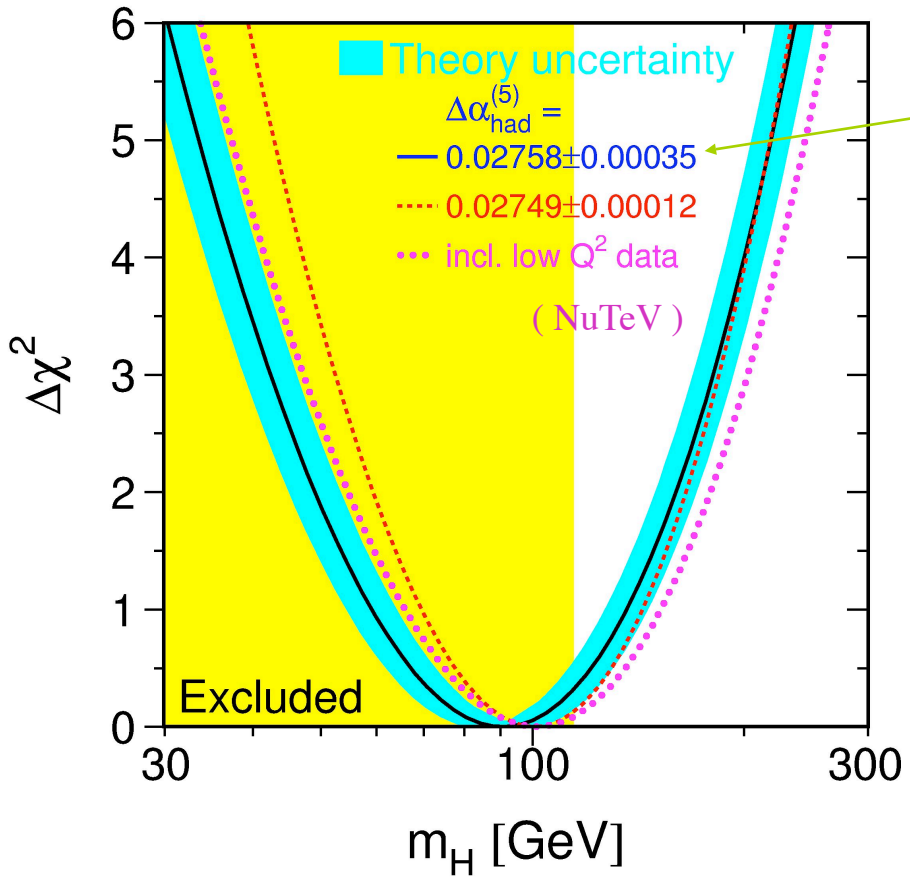
LEP2 e^+e^- 0.209 TeV, $\mathcal{L} \approx 10^{32}$ [cm^{-2}s^{-1}]

~ 1 order of magnitude in E_{cms}

~ 1-2 orders of magnitude in Luminosity at the energy frontier !

LHC : Excellent potential for major discoveries

The Standard Model Higgs is expected well below 1 TeV :



Hadronic contribution to the running of the QED fine structure constant at m_Z,
Burkhardt, Pietrzyk,
Phys. Rev. D72 :057501, 2005

Current limits from E.W. group
lepewwg.web.cern.ch/LEPEWWG/

LEP direct search $M_{Higgs} > 114$ GeV

$M_{Higgs} < 182$ GeV @ 95% CL
from e.w. fits + LEP direct search

LHC must discover Higgs or new Physics below TeV or else unitarity is violated

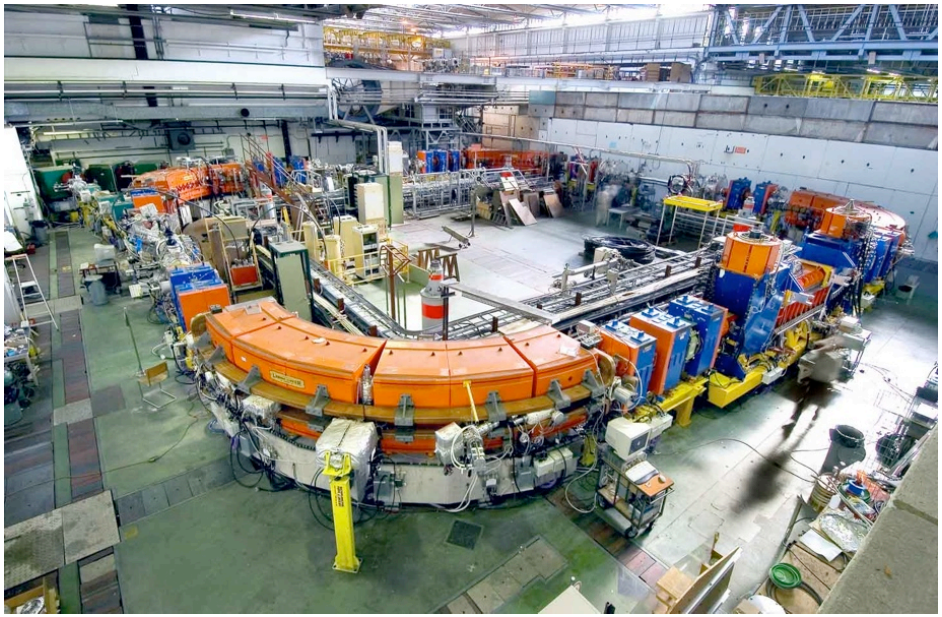
G.F. Giudice at open Symposium, Orsay 30/1/06

Short remark on : Heavy Ion collisions and High β*

In addition to being designed for pp collisions at top energy and luminosity the LHC is also designed as Heavy Ion Collider

The new Low Energy ion Accumulator Ring **LEAR was successfully commissioned in 2006**

Commissioning of ions in the PS - SPS complex is currently in progress
Ions will be available for the LHC – in principle from the beginning.



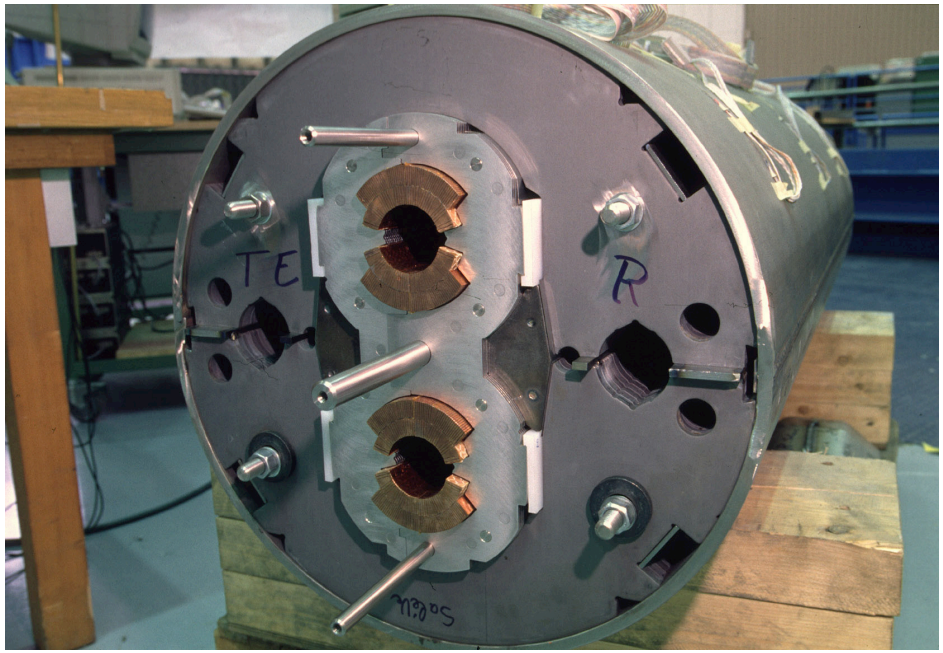
There are further (non pp high luminosity) running options :
Low angular divergence (high-β) collisions for very forward pp scattering measured with *roman-pots* in Totem/CMS and Atlas – total pp cross section and diffractive physics

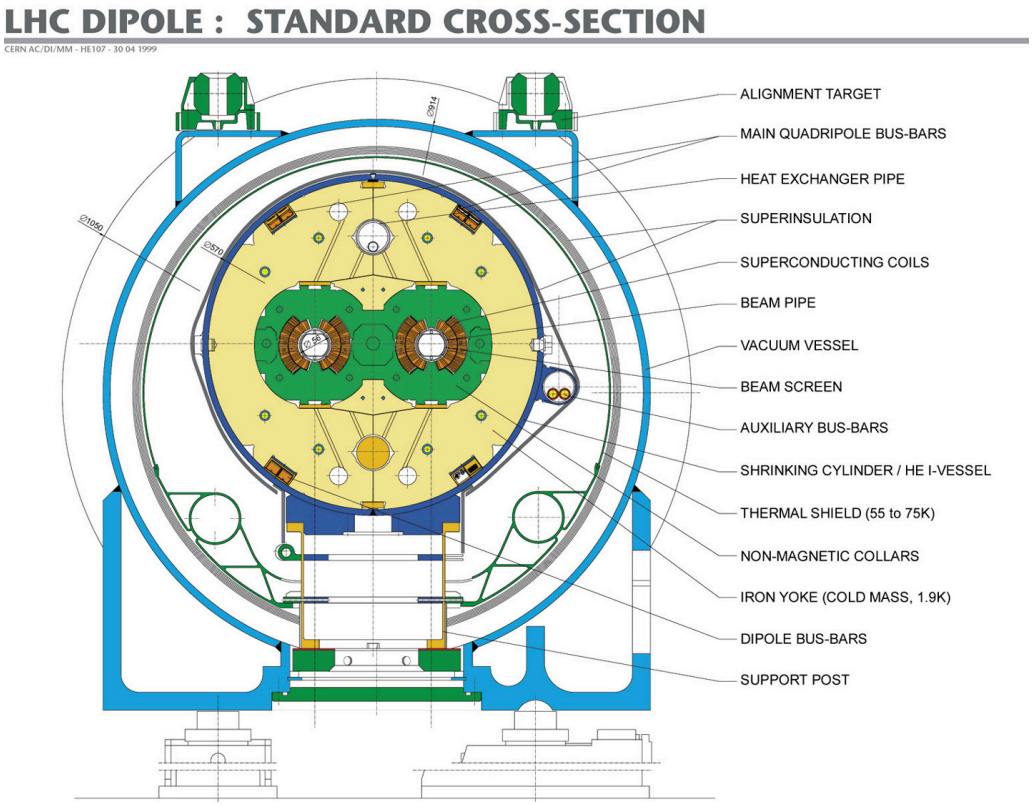
Extra options need commissioning time in the LHC - how much is at present hard to predict – will know much more after the first year of running.
Mostly a question of scheduling and priorities.

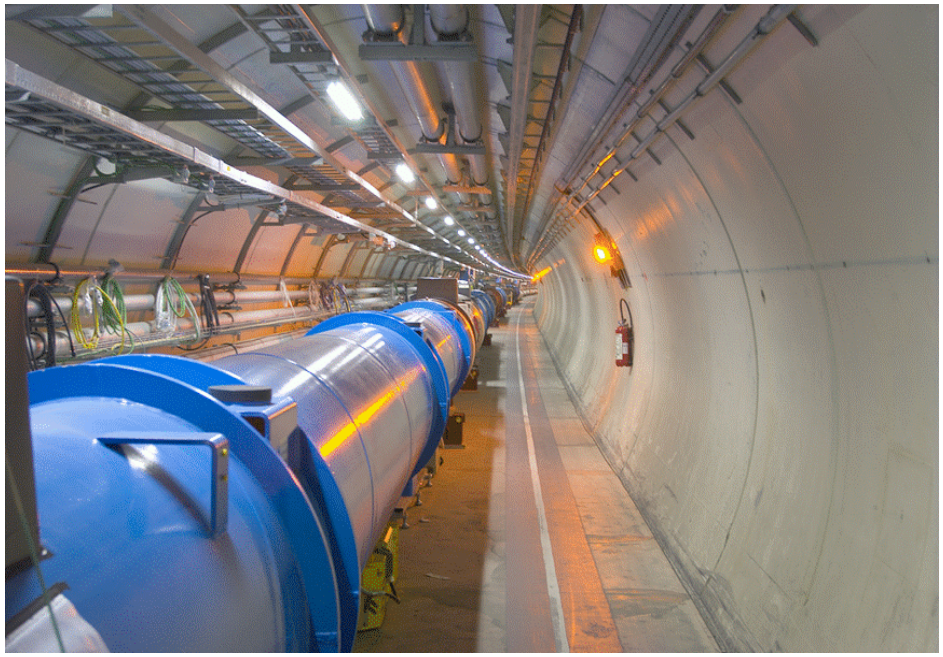
Looking at the machine

LHC dipole magnet

2-in-1 dipole magnet
8.33 T field, 15 m long
mass 30 ton







LHC: From first ideas to realisation

1982 : First studies for the LHC project

1983 : Z discovered at SPS proton antiproton collider

1989 : Start of LEP operation ~ 92 GeV, Z-factory

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1996 : LEP2 operation towards ~ 200 GeV, W^+W^-

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2002 : LEP equipment removed

2003 : Start of the LHC installation - infrastructure

2005 : Start of Magnet installation in LHC tunnel

2007 : Installation complete, starting cooldown

2008 : Commissioning with beam and first collisions

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14 y

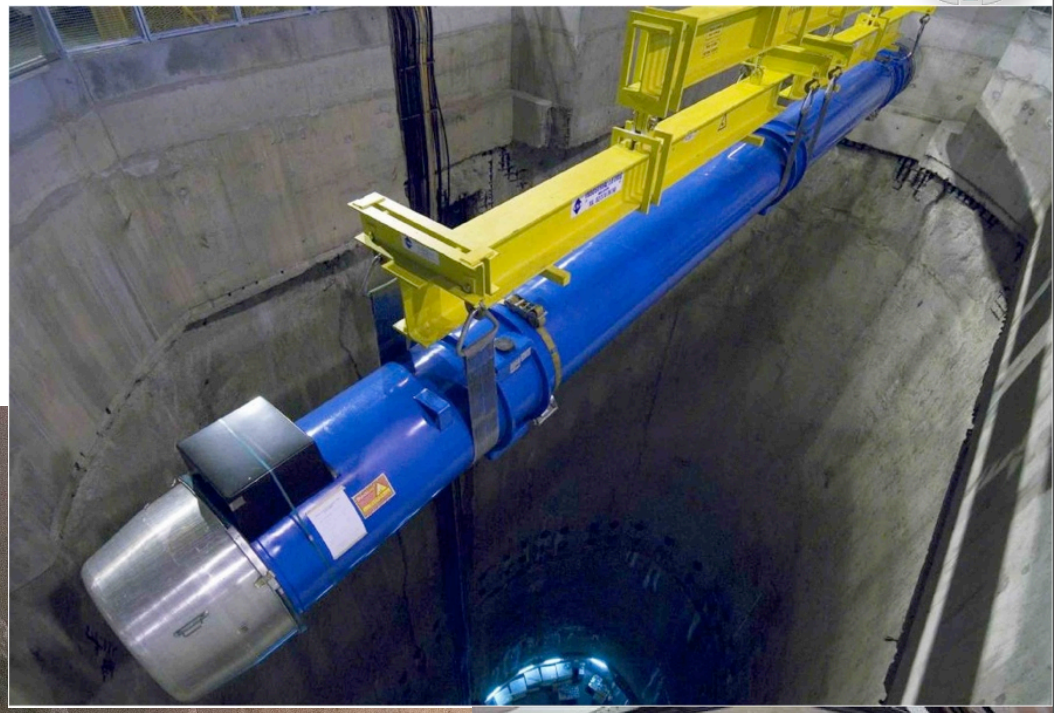
7 y

Dipole lowered to LHC tunnel level

First Dipole #1 : 7 March 2005

Last Dipole #1232 : 26 April 2007

all magnets there, 474 SC quads..



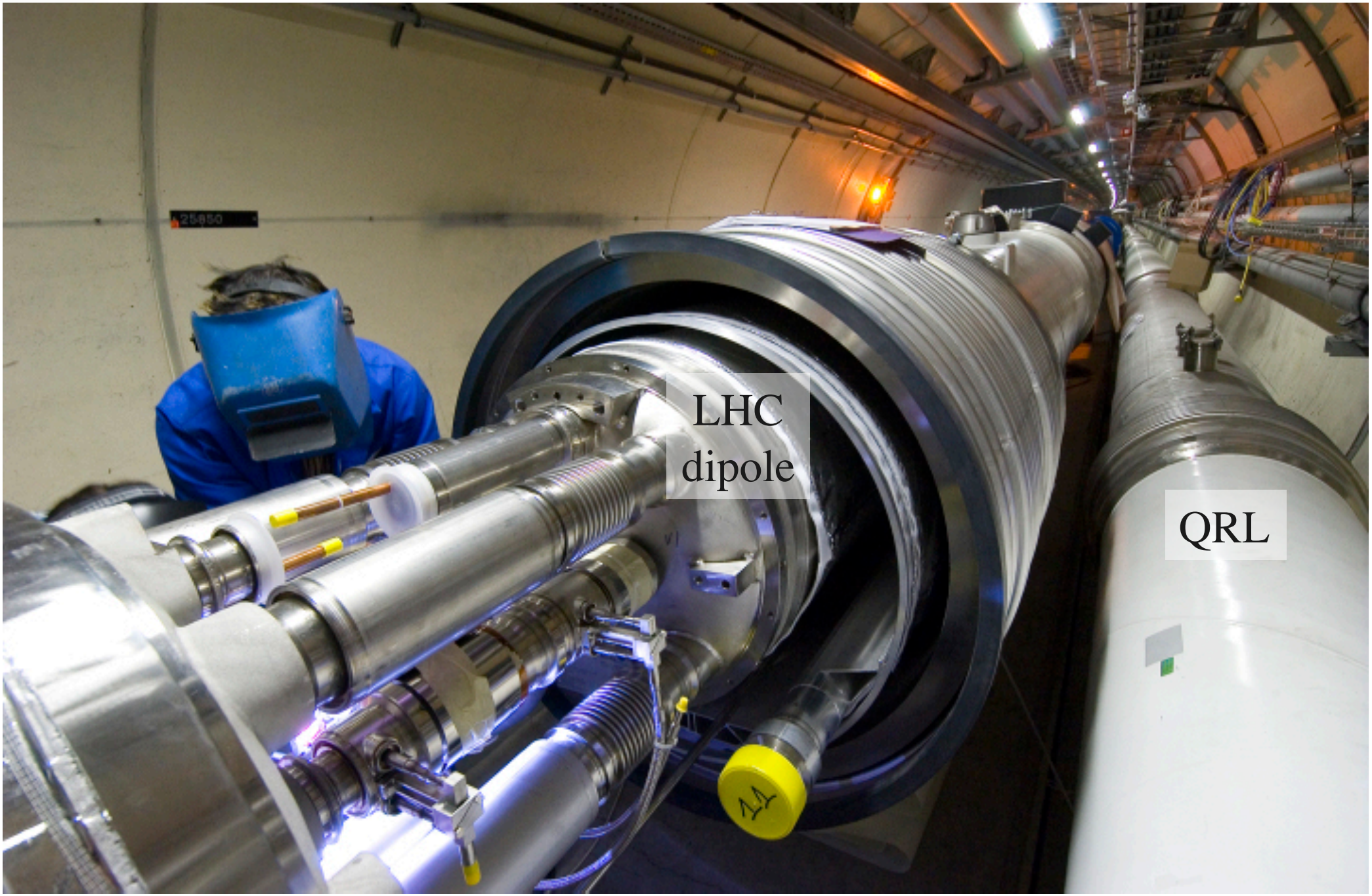
Tunnel between 50 m (this Photo) and 150 m underground

Getting the magnets in place

1600 magnets transported over ~ 15 km

Transfer on jacks

LHC magnet interconnect in the tunnel



Recent News : all magnets connected

featured in CERN Bulletin this week

Bulletin Issue No.47-48/2007
Mon 26th November 2007

The last arc interconnection of Sector 1-2 was completed on Wednesday 7 November, marking the end of a huge project to connect up the LHC

Acceleration System pt. 4

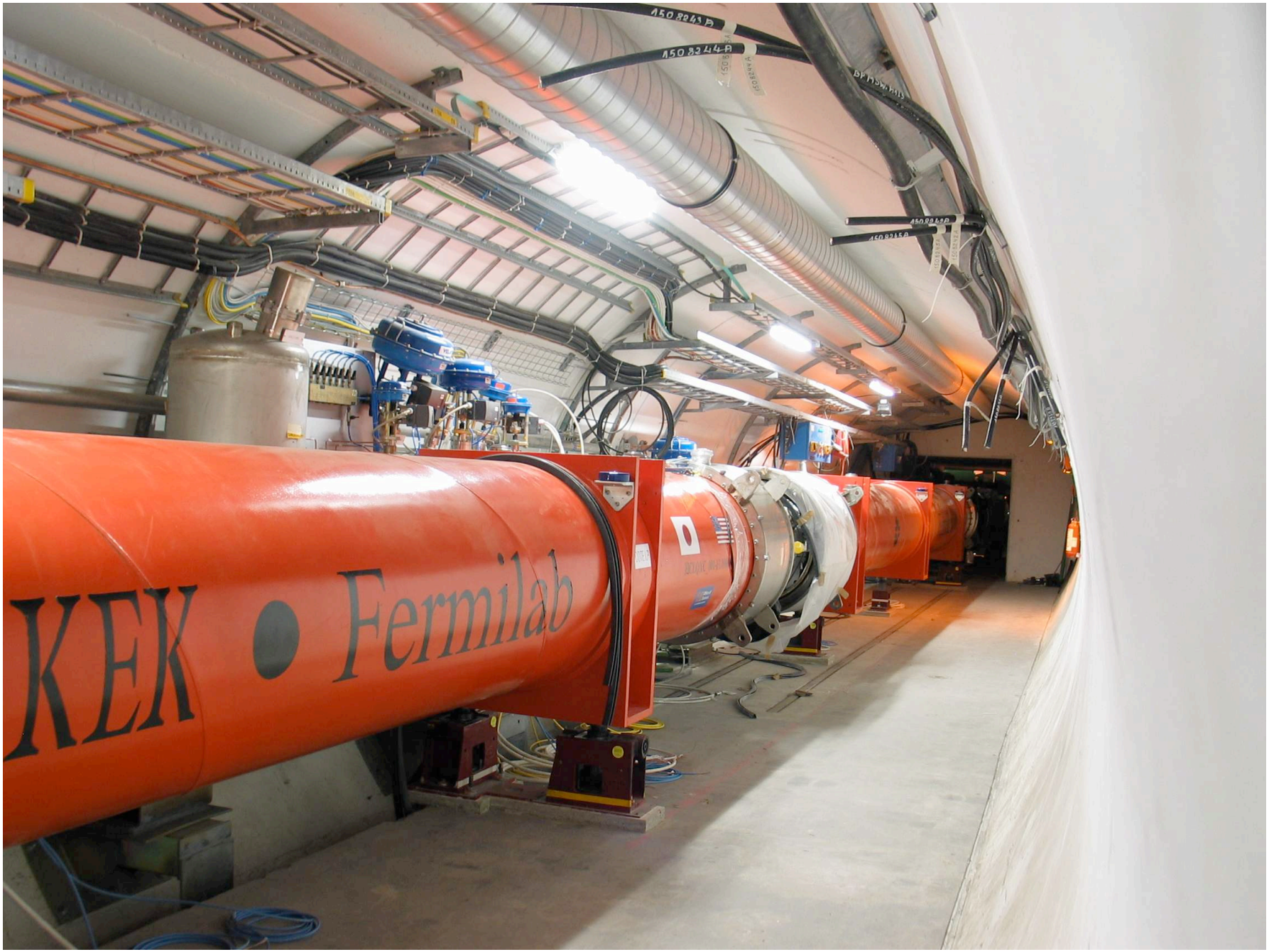
400 MHz superconducting accelerating cavities - 16 cavities in 4 modules, 2 per beam.

Transverse damping kickers - 16 electrostatic deflectors, 8 per beam - Longitudinal monitors – 6 wideband coaxial line monitors

Power amplifiers for dampers

All installed and largely tested

Inner triplet Quads at Point 5



Main dipole converter for sector 7-8

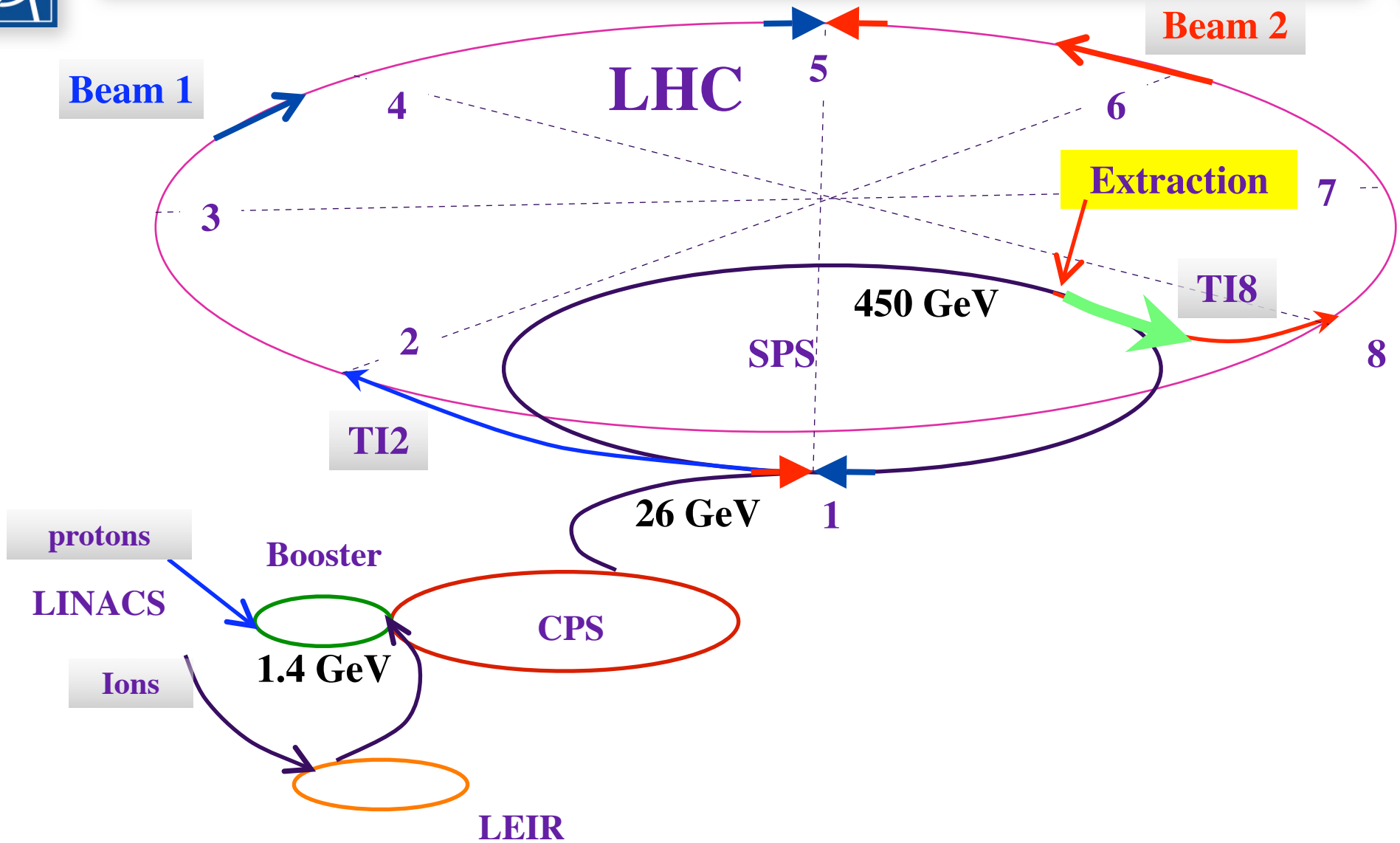
Power Converter Tolerances for LHC

Circuit Type	Nominal Current (A)	Current Polarity	One Year Accuracy (ppm of Inominal)	One day Reproducibility (ppm of Inominal)	1/2 hour Stability (ppm of Inominal)	Resolution (ppm of Inominal)
Main Bends, Main Quads	13000	Unipolar	± 50 ± 20 with calibration	± 10	± 3	1
Inner triplet	8000/ 6000	Unipolar	± 100 ± 20 with calibration?	± 20	± 10	15
Dispersion suppressor	6000	Unipolar	± 70	± 10	± 5	15
Insertion quadrupoles	6000	Unipolar	± 70	± 10	± 5	15
Separators (D1,D2,D3,D4)	6000	Unipolar	± 70	± 10	± 5	15
Trim quadrupoles	600	Bipolar	± 200	± 50	± 10	30
SSS correctors	600	Bipolar	± 200	± 50	± 10	30
Spool pieces	600	Bipolar	± 200	± 50	± 10	30
Orbit correctors	120/60	Bipolar	± 1000	± 100	± 50	30

Precision

Control

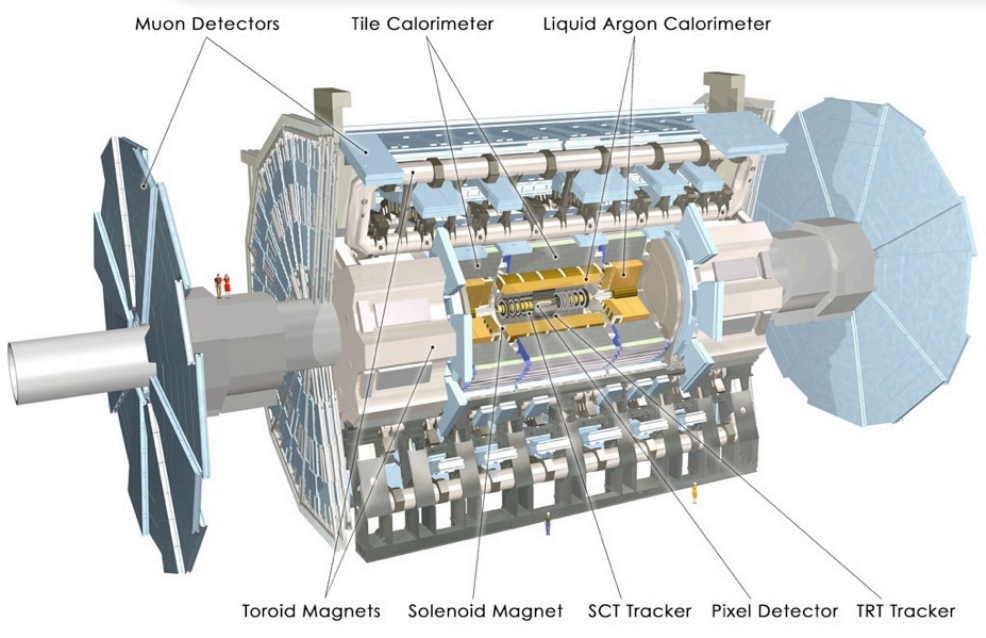
The CERN accelerator complex : injectors and transfer

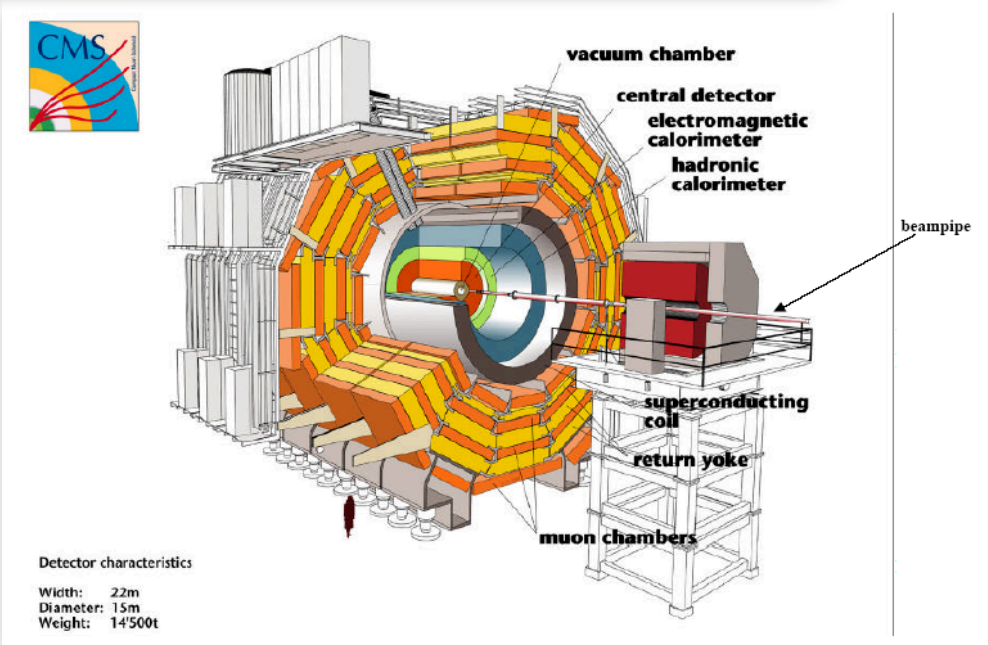


Beam size of protons decreases with energy : area $\sigma^2 = 1 / E$

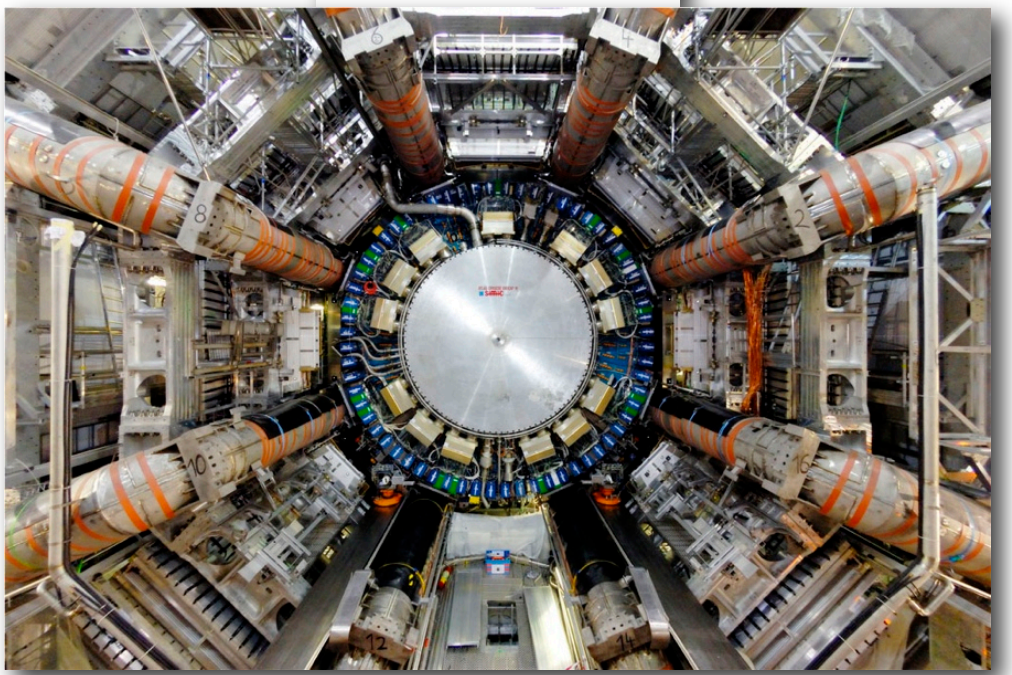
Beam size largest at injection, using the full aperture

High Luminosity IR1, IR5 for the Large Multipurpose Detectors

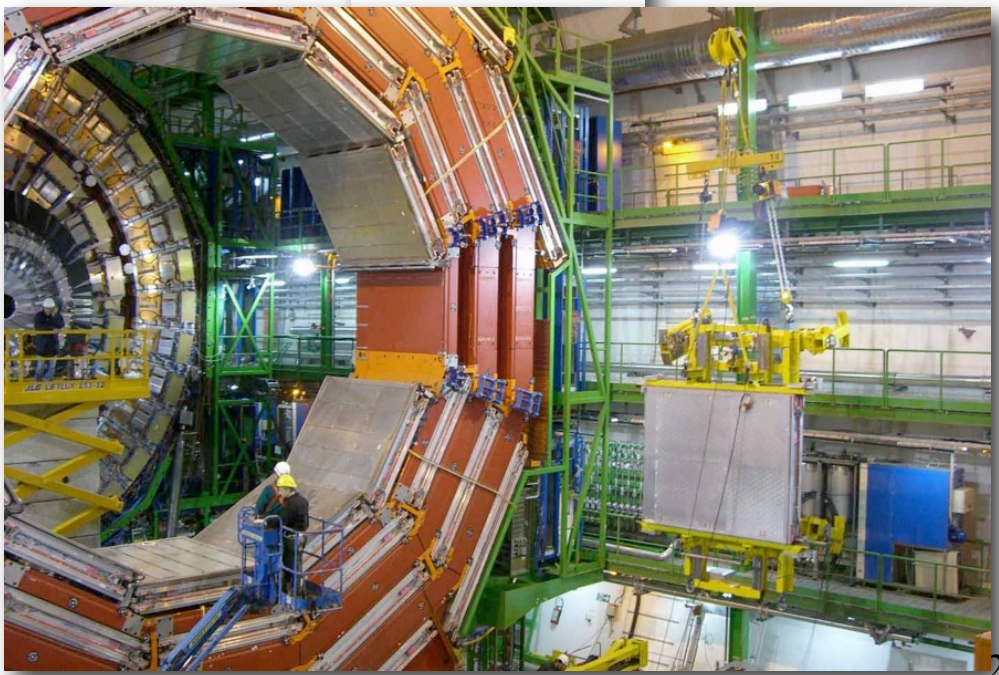




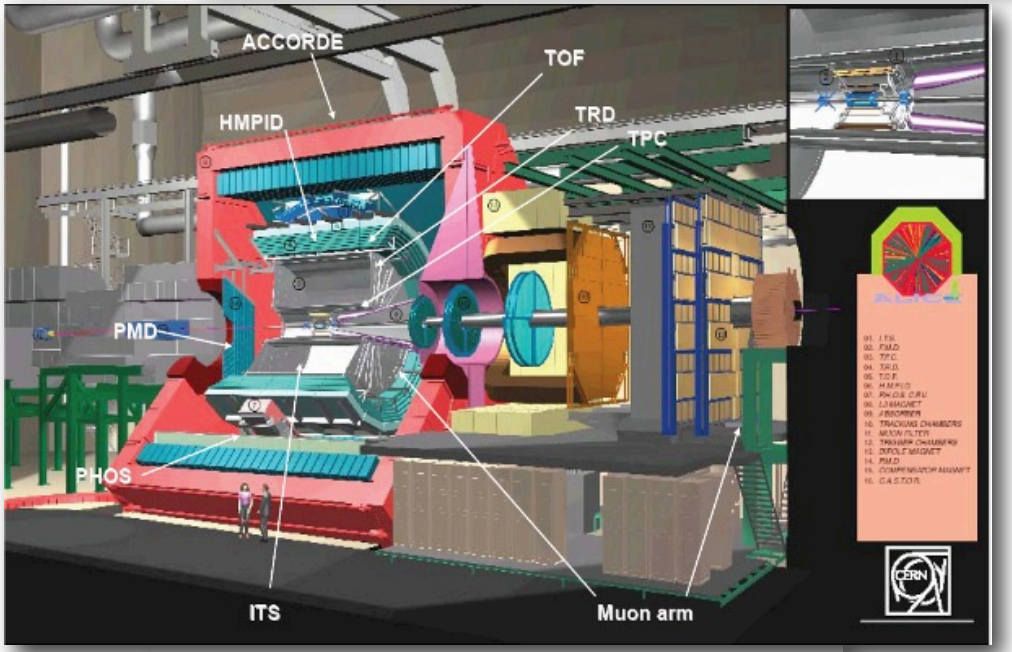
IR1 : ATLAS



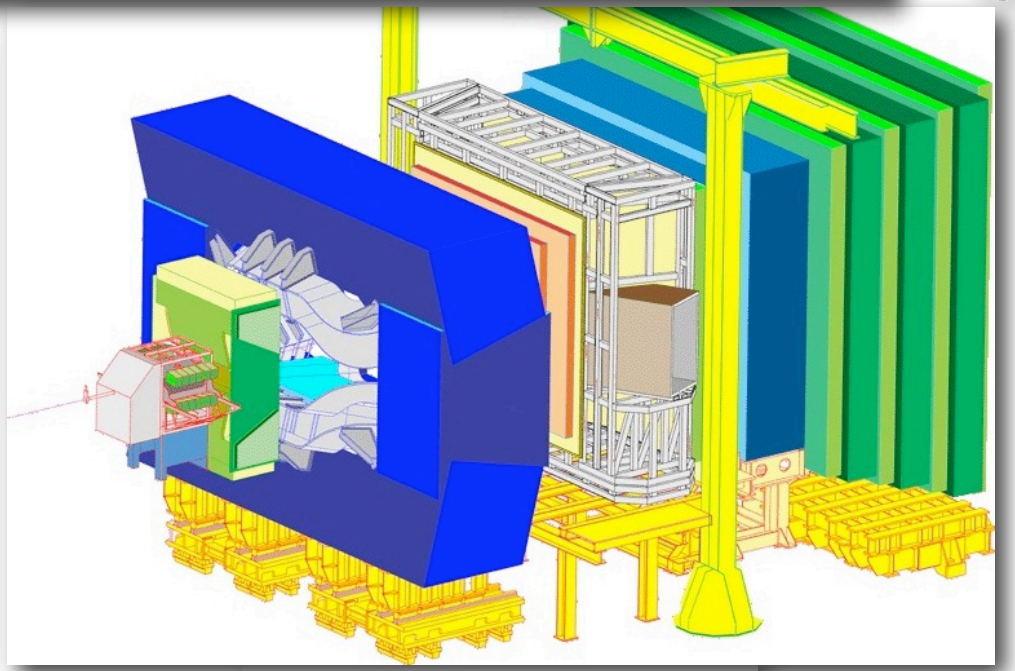
IR5 : CMS



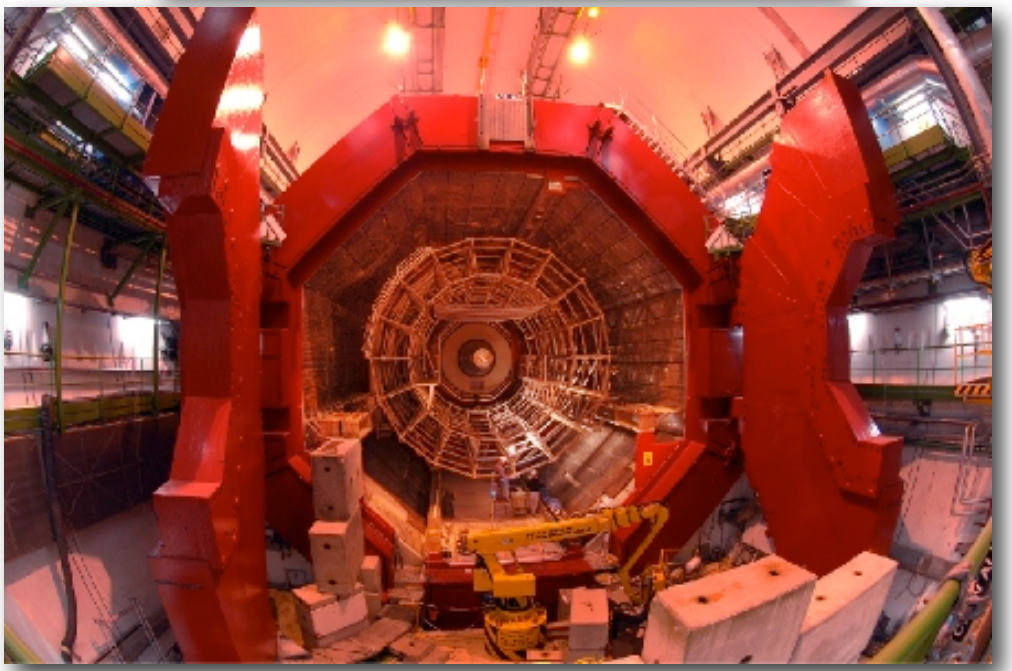
IR2, IR8 for $\mathcal{L} \sim 10^{32}$ cm^{-2} s^{-1} with the more Specialized Detectors

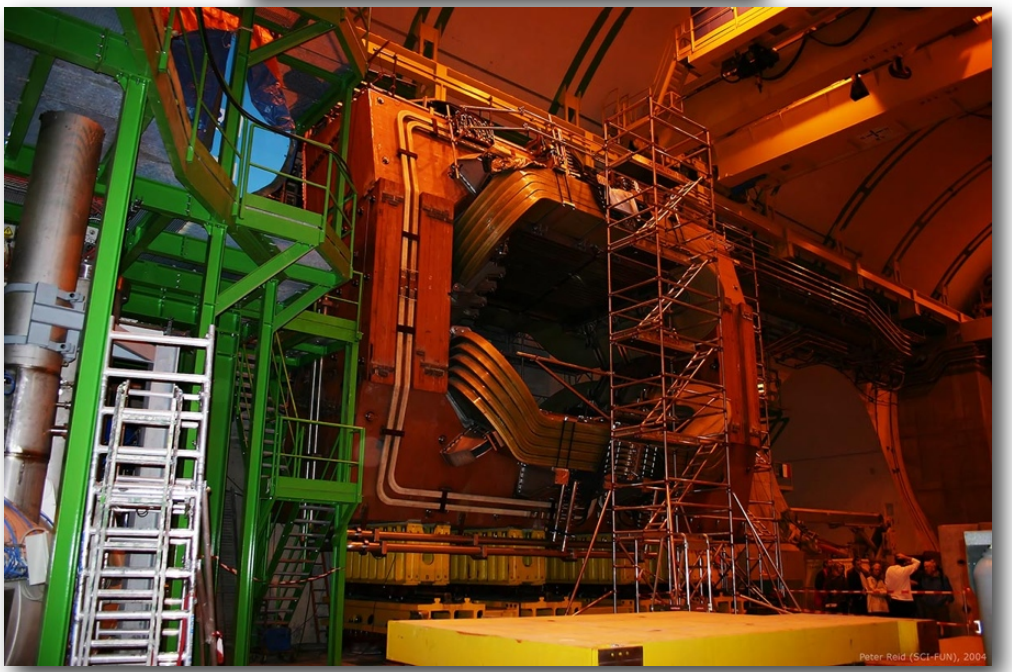


IR2 : Alice – Heavy Ion - Φ



IR8 : LHCb – B - Φ





Major LHC challenges

Centre-of-mass energy of 7 TeV in given (ex LEP) tunnel

- **Magnetic field of 8.33 T with superconducting magnets**
- **Helium cooling at 1.9 K**
- **Large amount of energy stored in magnets**
- **"Two accelerators" in one tunnel with opposite magnetic dipole field and ambitious beam parameters pushed for very high of luminosity of 10^{34} cm^{-2} s^{-1}**
- **Many bunches with large amount of energy stored in beams**

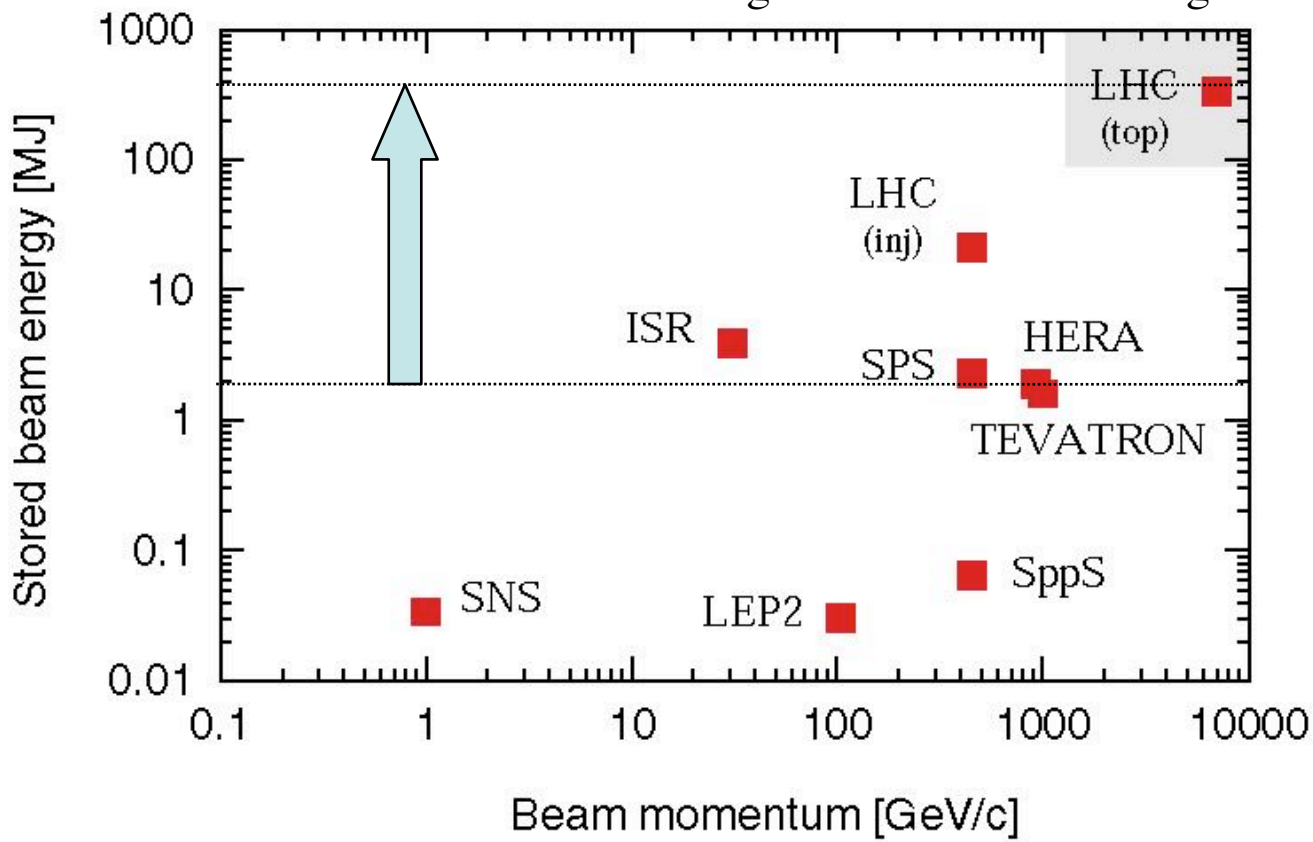
Complexity and Reliability

- **Unprecedented complexity with 10000 magnets powered in 1700 electrical circuits, complex active and passive protection systems,….**

- **Emittance conservation** $\varepsilon_N = \beta \gamma \varepsilon$ const., related to phase space density conservation, Liouville
  in absence of major energy exchange in synchrotron radiation / rf damping clean, perfectly matched injection, ramp, squeeze, minimize any blow up from: rf, kicking beam, frequent orbit changes, vibration, feedback, noise,..
- **Dynamic effects - persistent current decay and snapback**
- **Non-linear fields (resonances, diffusion, dynamic aperture, non-linear beam dynamics** (.. chaos) **)**

The total stored energy of the LHC beams

Nominal LHC design: 3 x 10^{14} protons accelerated to 7 TeV circulating at 11 kHz in a SC ring

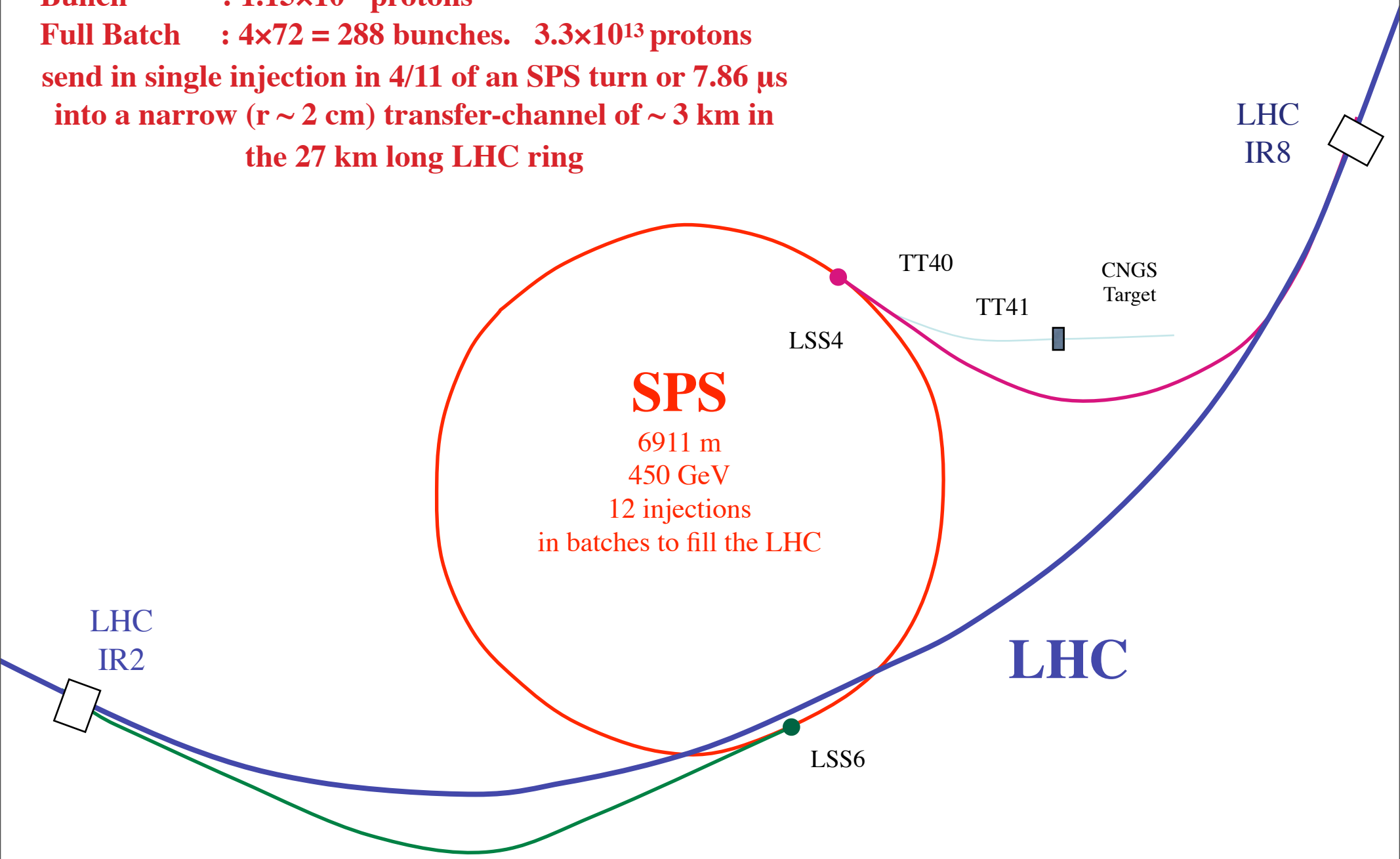


LHC: > 100 x higher stored energy and small beam size: ~ 3 orders of magnitude in energy density and damage potential. Active protection (beam loss monitors, interlocks) and collimation for machine and experiments essential.

Only the specially designed beam dump can safely absorb this energy.

Transfer and injection: SPS and transfer lines to LHC

Bunch : 1.15×10^{11} protons
Full Batch : $4\times72 = 288$ bunches. 3.3×10^{13} protons
send in single injection in 4/11 of an SPS turn or 7.86 μs into a narrow (r ~ 2 cm) transfer-channel of ~ 3 km in the 27 km long LHC ring



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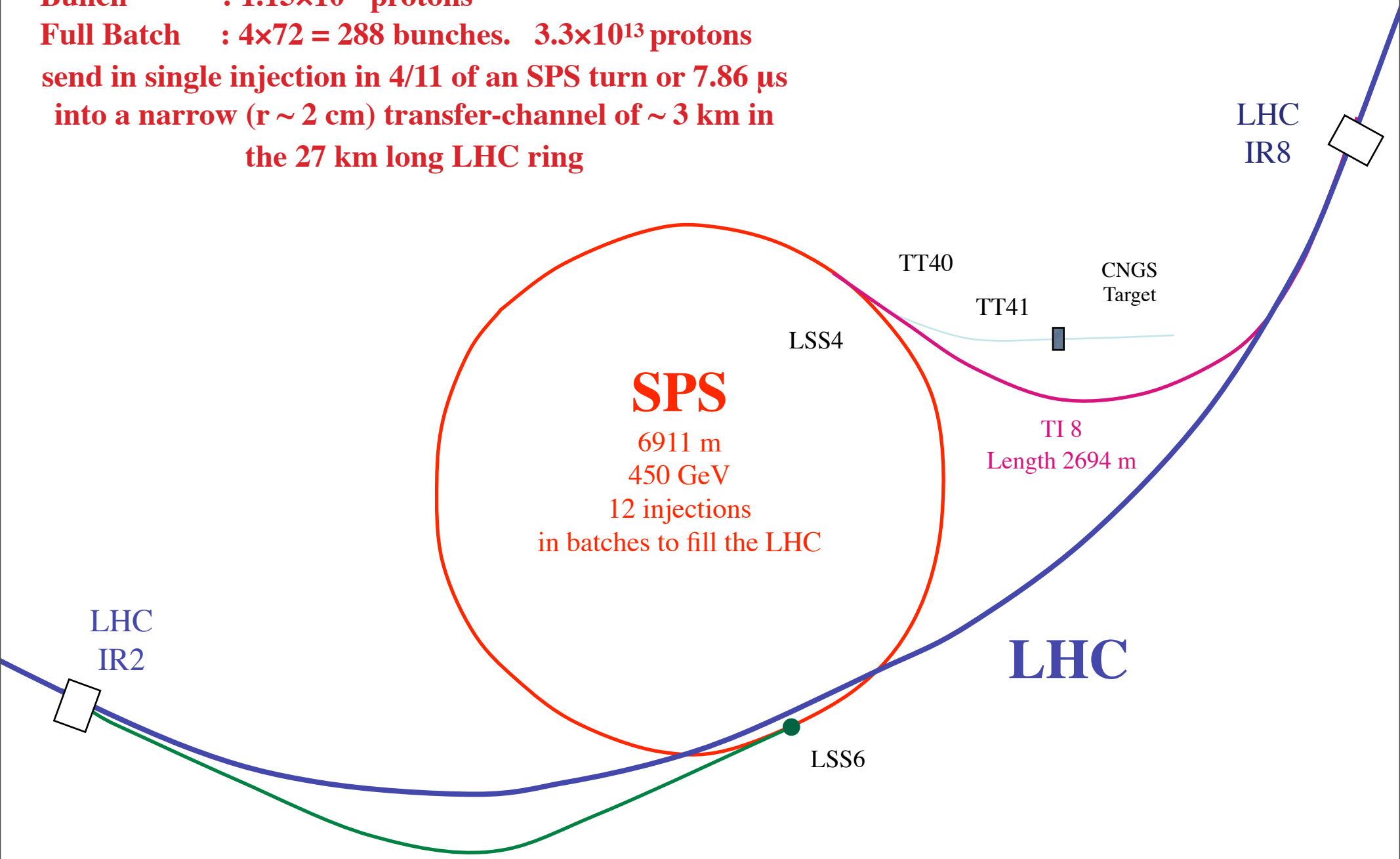

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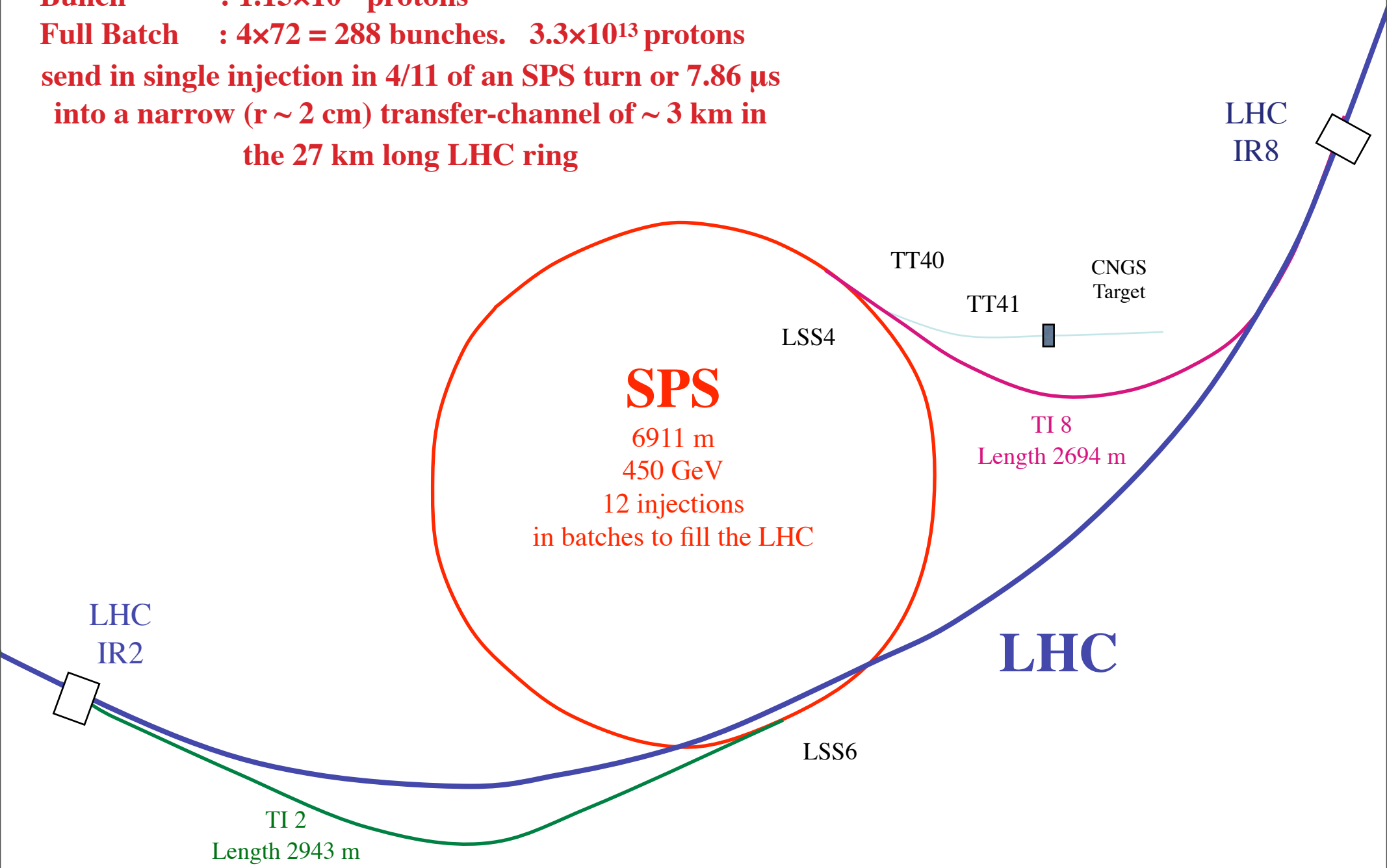
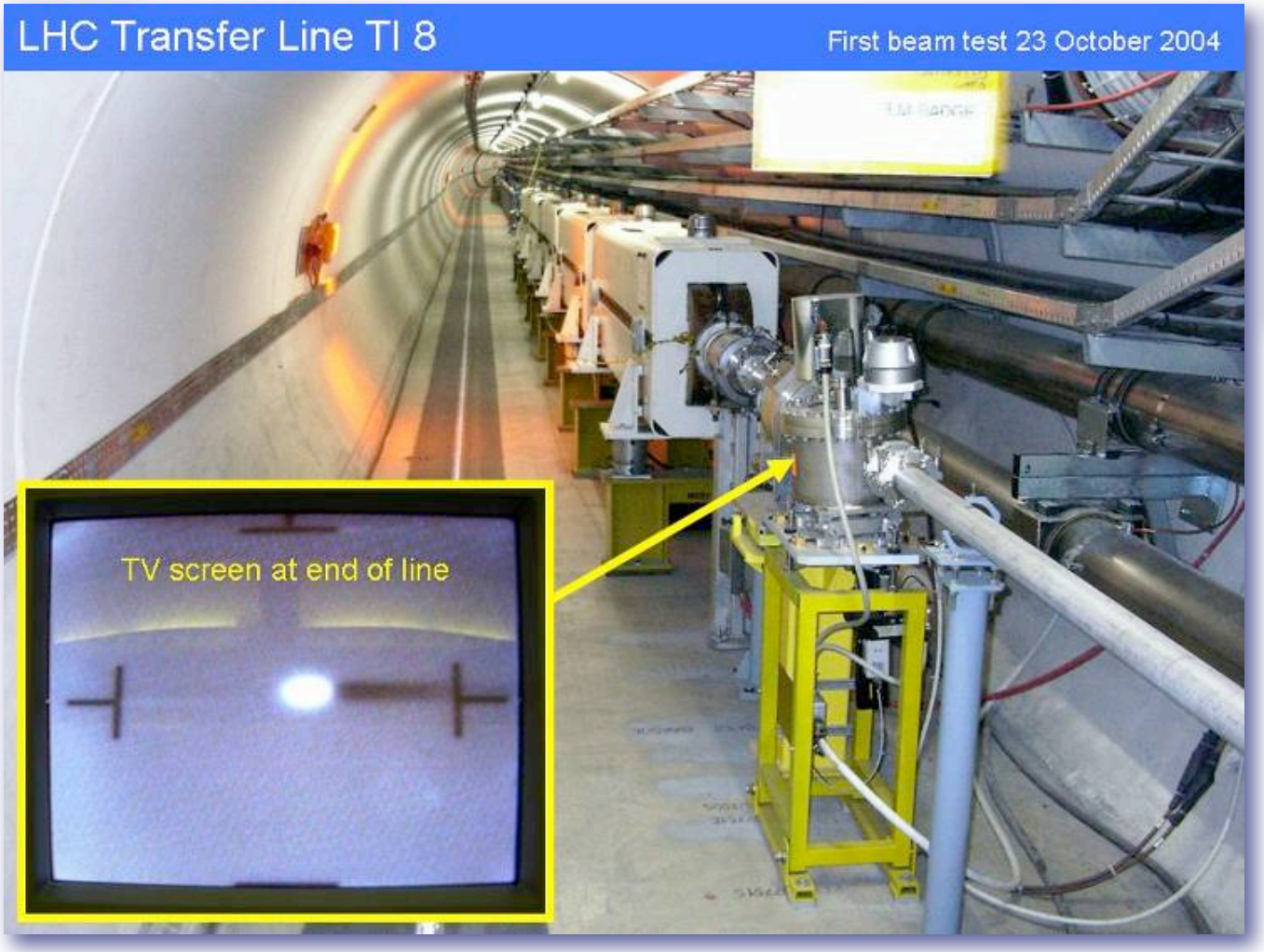


Commissioning of the LHC injectors : Transfer lines to LHC



new tunnels and completely new, normal conducting, pulsed 2.7km and 2.9 km long tunnels and beam lines

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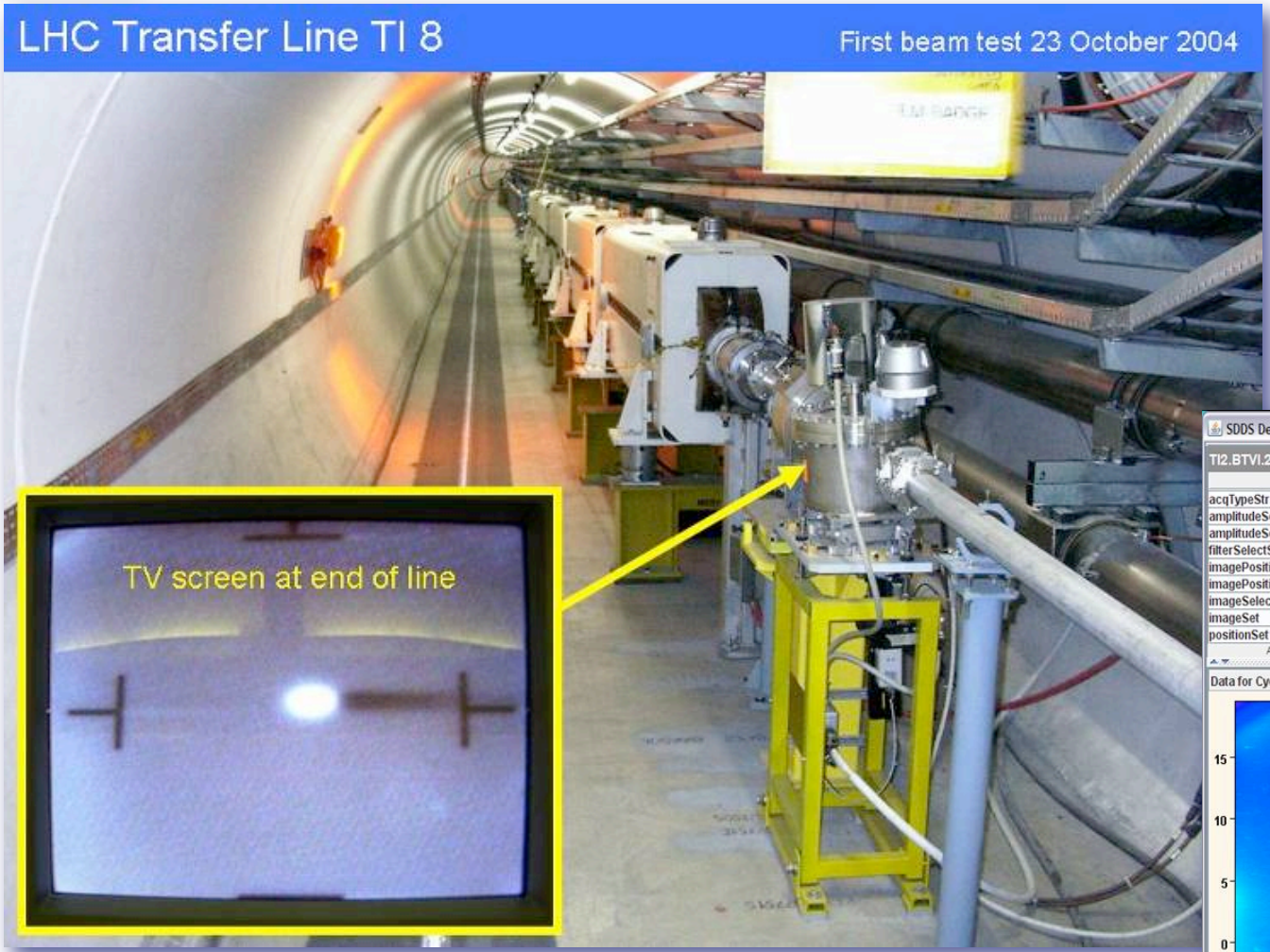

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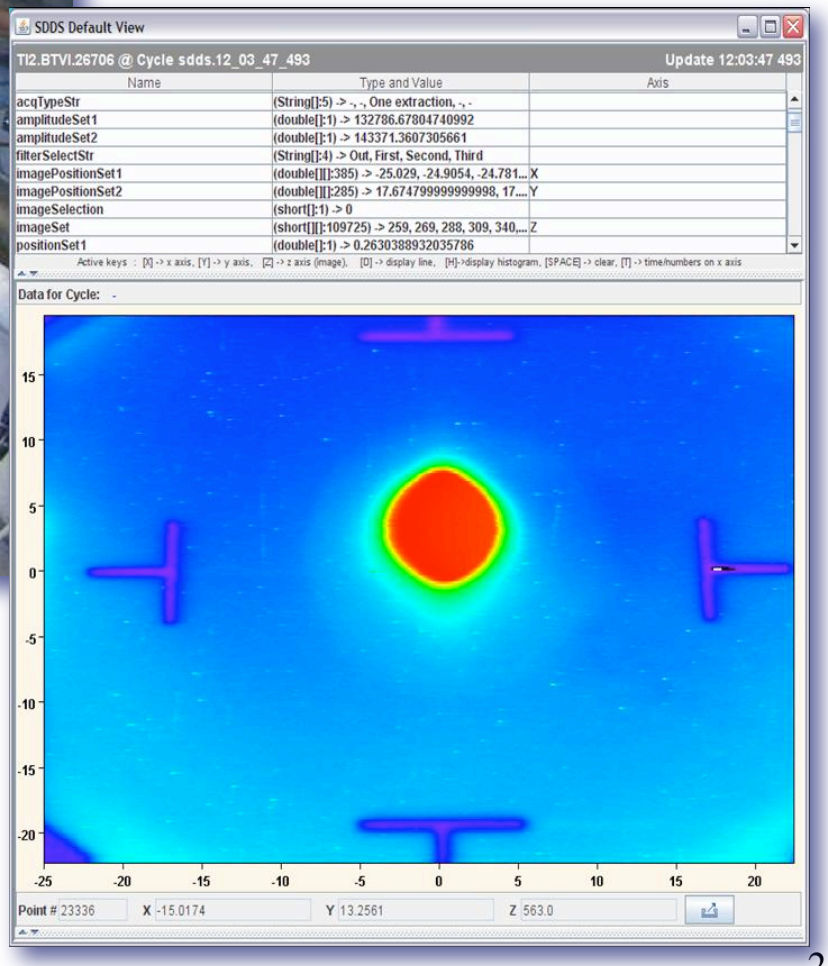
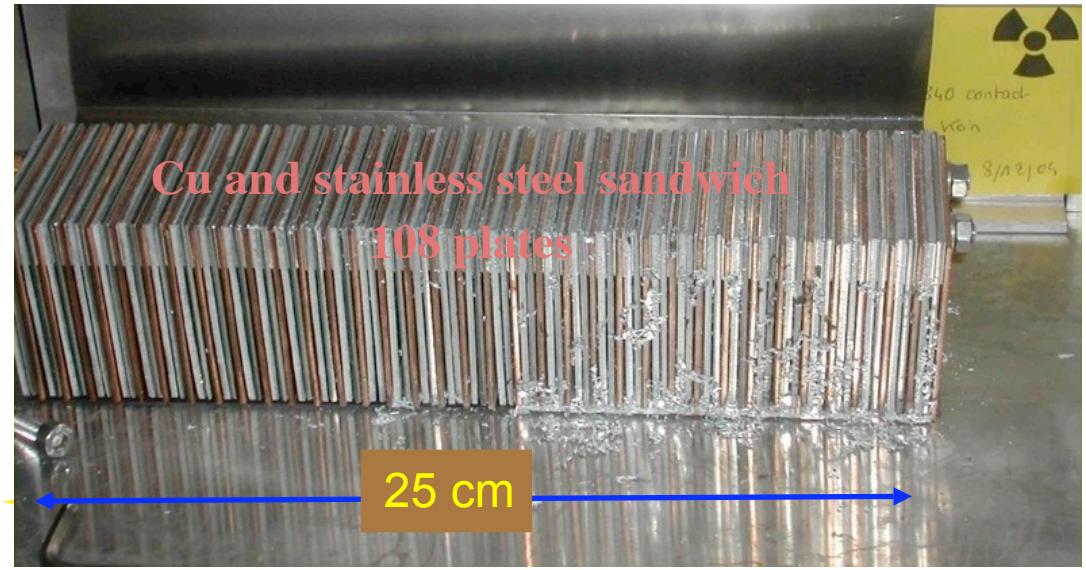


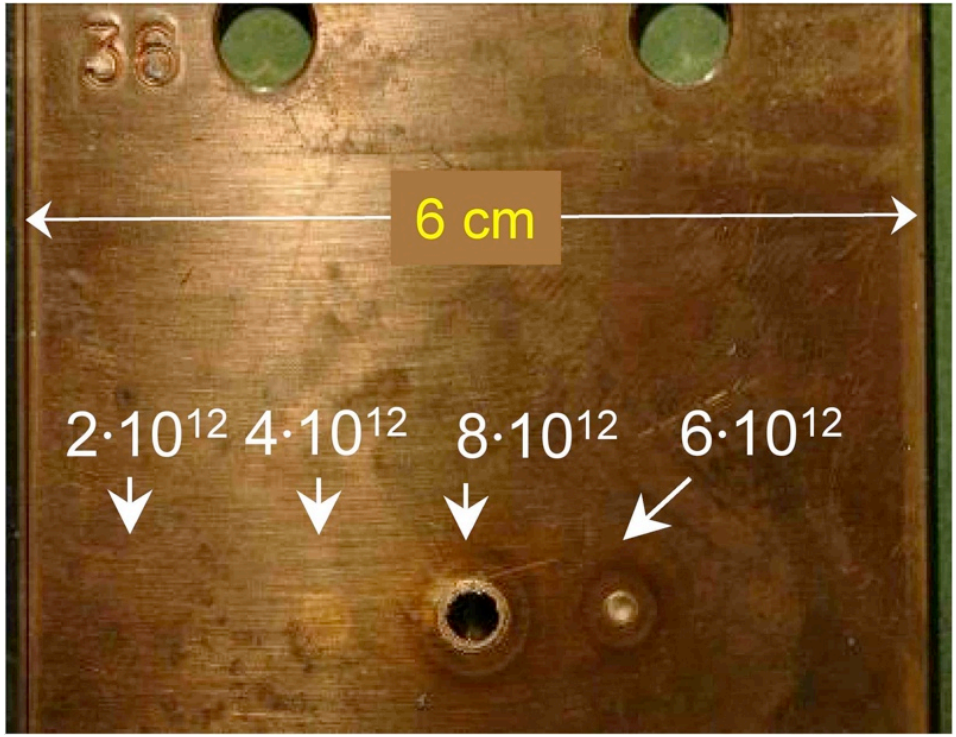
And now again, on the last October weekend 2007 : beam going through TI 2 until the beam stopper 50 m before the end of the line on the first shot !

Damage potential : confirmed in controlled SPS experiment

controlled experiment with beam extracted from SPS at 450 GeV in a single turn, with perpendicular impact on Cu + stainless steel target

r.m.s. beam sizes $\sigma_{x/y} \approx 1$ mm





SPS results confirmed :

8×10^{12} clear damage

2×10^{12} below damage limit

for details see V. Kain et al., PAC 2005 RPPE018

For comparison, the LHC nominal at 7 TeV :
$2808 \times 1.15\times10^{11} = 3.2\times10^{14}$ p/beam
at $< \sigma_{x/y} > \approx 0.2$ mm
over 3 orders of magnitude above damage level for perpendicular impact

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450 GeV protons

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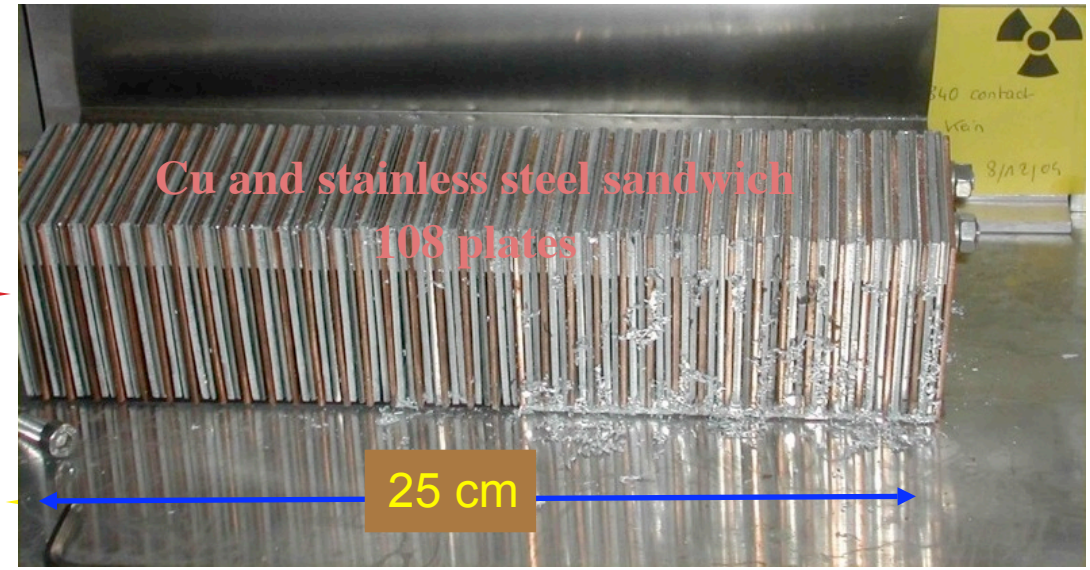

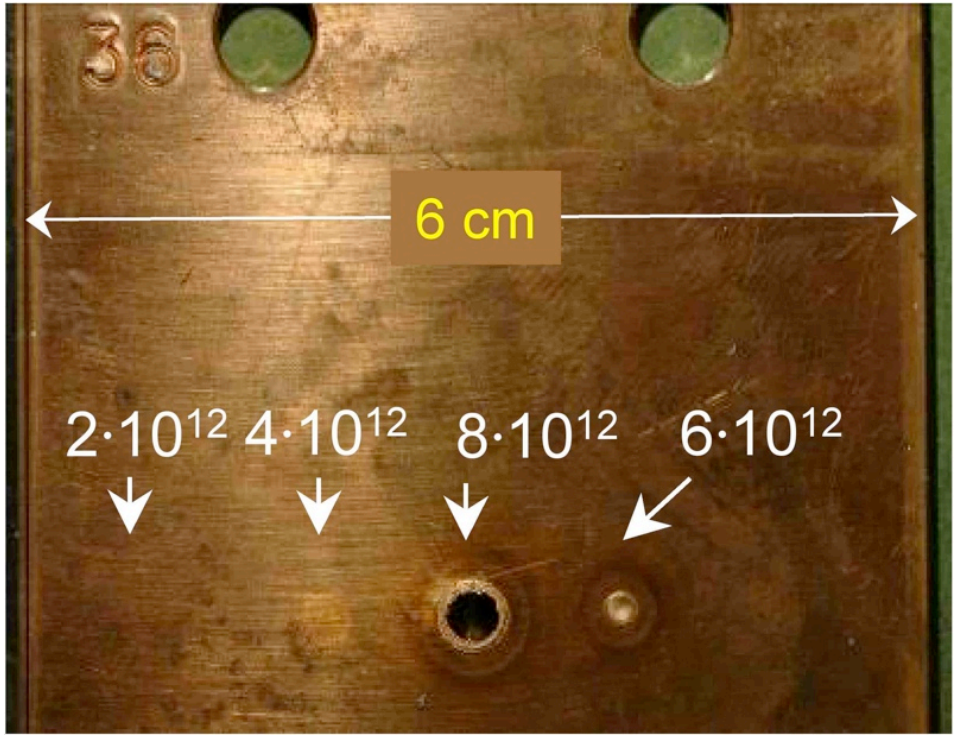

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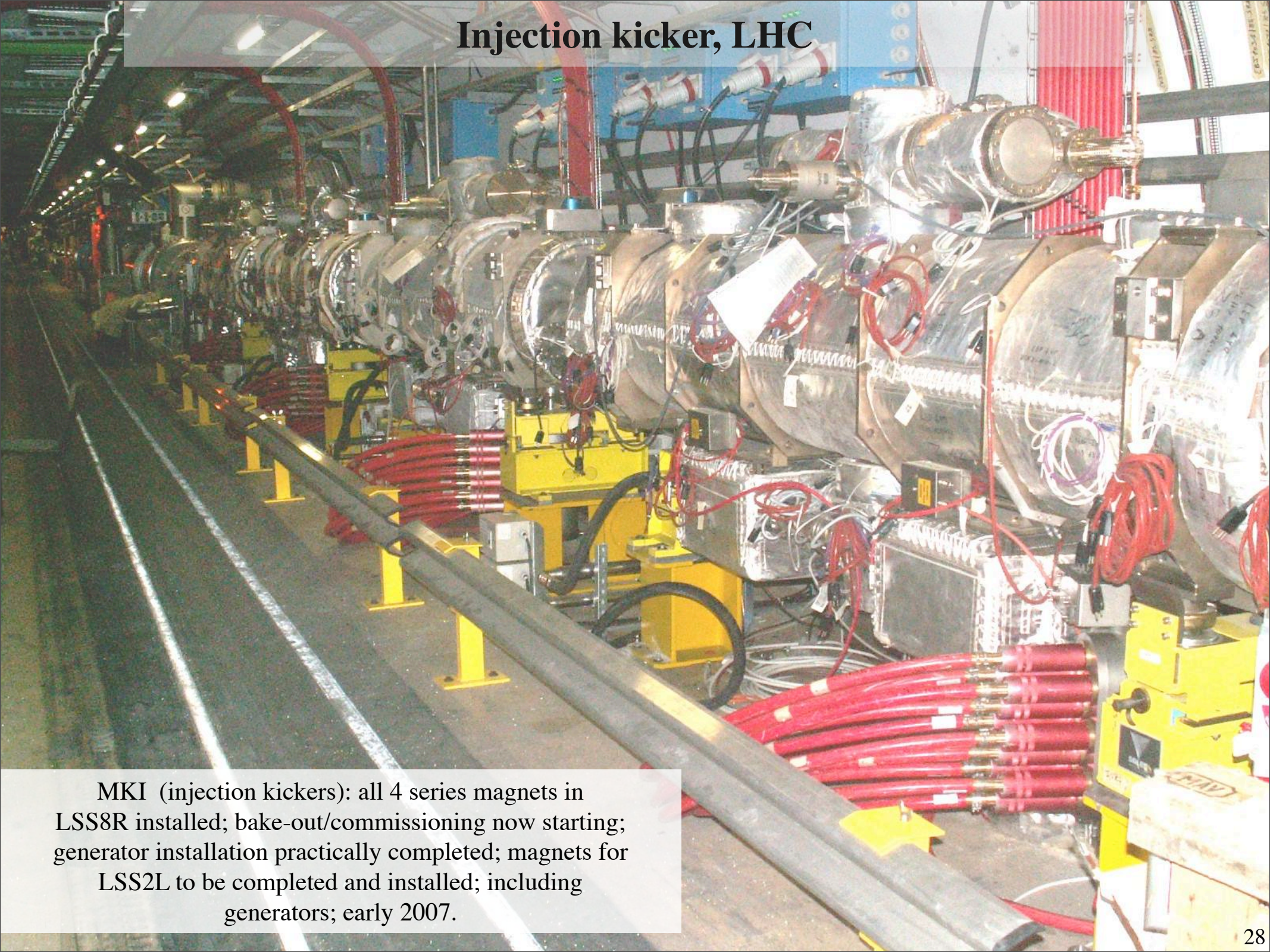
Injection region with TI8 & LHC

Injection kicker, LHC



MKI (injection kickers): all 4 series magnets in LSS8R installed; bake-out/commissioning now starting; generator installation practically completed; magnets for LSS2L to be completed and installed; including generators; early 2007.

Injection with scraping and collimation

Nominal injection intensities will be ~ 20 times above damage and ~ 10^4 times above quench level : major challenge: clean injection into tight aperture, little margin for jitter and mismatch.

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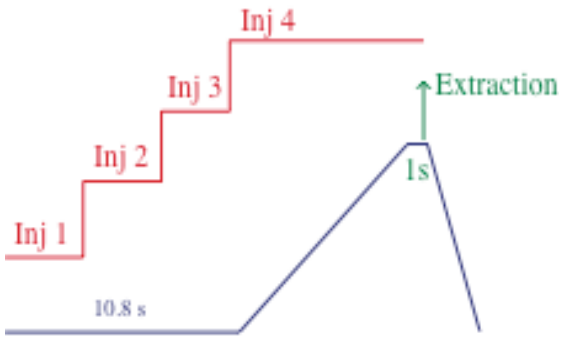
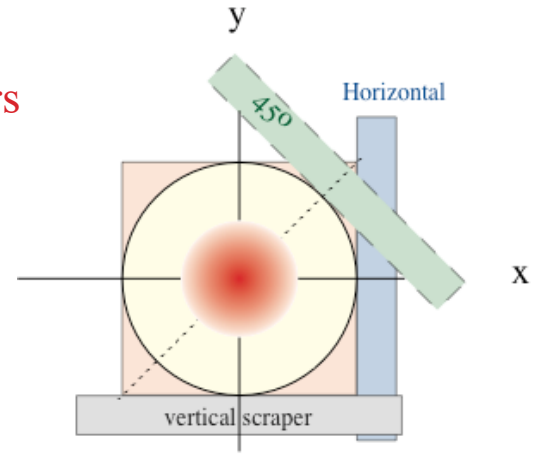


SPS LHC proton cycle total 21.8 s

pilot and 1 batch cycles can be shorter, but always > 7 s

Scrapers
SPS

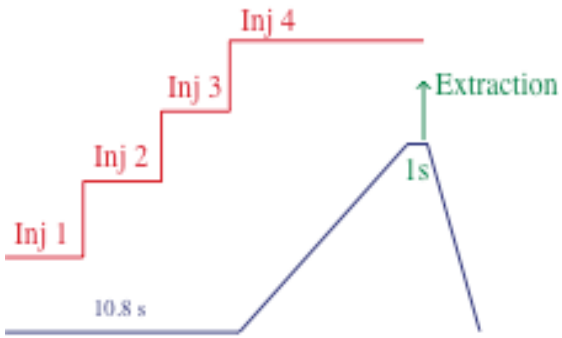


Real space Hor/Vert
x and y

1. LHC collimation at injection starts with H/V/45° scraping in the SPS ; to avoid quenches in the LHC. Set (nominally) at approx. 3.5 σ

Injection with scraping and collimation

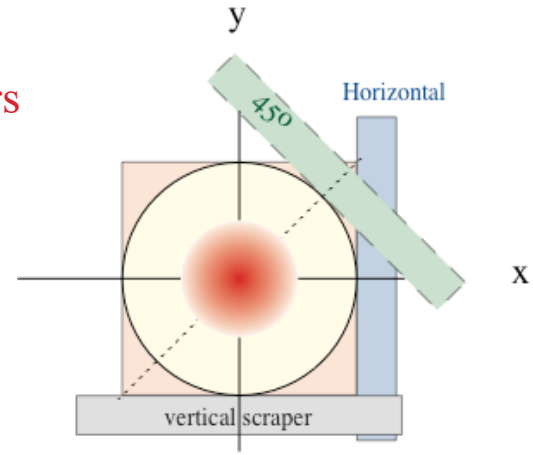
Nominal injection intensities will be ~ 20 times above damage and ~ 10^4 times above quench level : major challenge: clean injection into tight aperture, little margin for jitter and mismatch.



SPS LHC proton cycle total 21.8 s

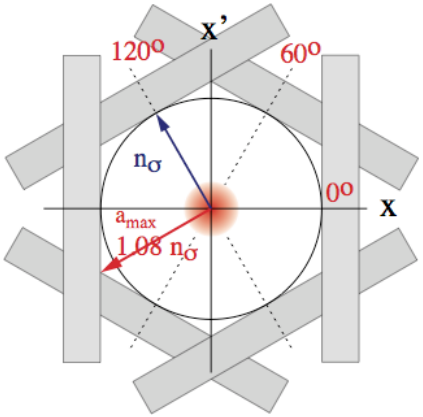
pilot and 1 batch cycles can be shorter, but always > 7 s

Scrapers SPS



Real space Hor/Vert x and y

1. LHC collimation at injection starts with H/V/45° scraping in the SPS ; to avoid quenches in the LHC. Set (nominally) at approx. 3.5 σ
2. The two warm, pulsed transfer lines TI2, TI8 are equipped each with 7 TCDI collimators (Δp, 2× 0, 60, 120°) to protect against damage at injection in case of (rare) failures, at approx. 4.8 σ
3. LHC injection protection, main purpose is protection against injection kicker failures with TDI, TCDI.



Transfer line TCDIs in phase space

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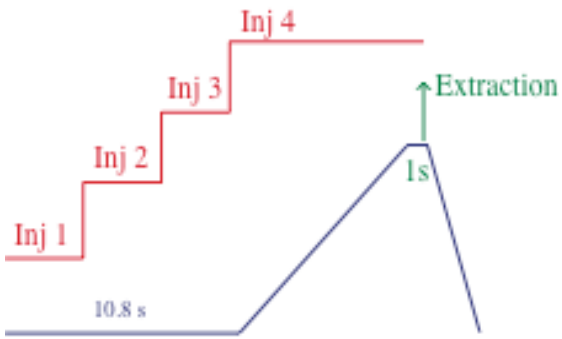

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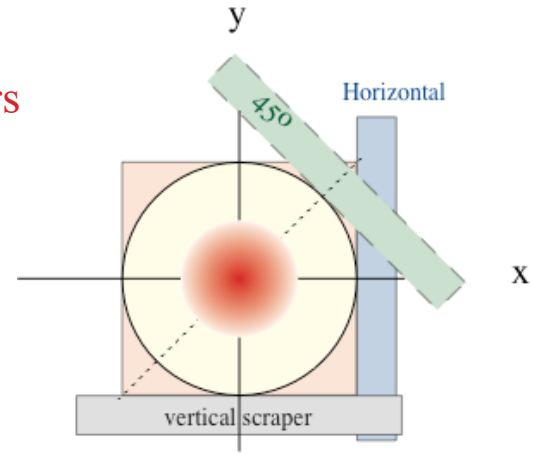

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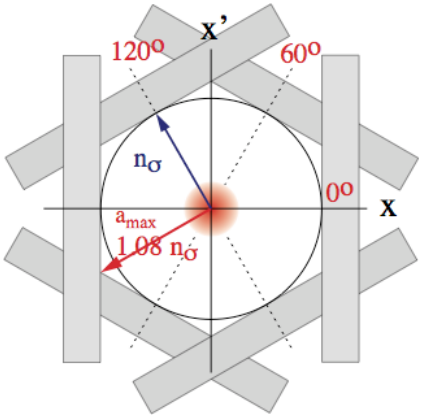
4. LHC cleaning sections ; reached after ~1/2 turn; primary collimators set at approx. 5.8 σ



Transfer line TCDIs in phase space

LHC cold ring aperture is about 7.5 σ incl. tolerances

Filling and Ramping ; off-energy particles (with movie)

Filling: > 9 min (2 x 12 inj. × 21.6 sec.)

Filling, at 450 GeV
RF HV = 8 MV Qs = 0.005834 (171 turns)
RF-acceptance (bucket- 1/2 height) ~ 10^{-3}

Energy acceptance, limited by IR3 momentum collimation to ~ 3×10^{-3}

1 - 3×10^{-3} off-energy particles remain in the machine, migrate around the whole circumference, through the gaps reserved for injection and dump kicker rise times.
The debunching speed is about λ_{rf} / synchrotron period ≈ 50 m/s or ~ 9 minutes for one turn at injection energy, comparable to the nominal fillling time

Shown here: simulation of injection with 3×10^{-4} energy offset over 100 turns or 8.9 ms

Simulation details 6 dim phase space program BeamTrack written in C++ with interface to Higz by H.Burkhardt 8/2003 - 2007, here 10000 particles, 100 turns. few sec on Mac Pro ; using ps -> pdf -> quicktime movie conversion

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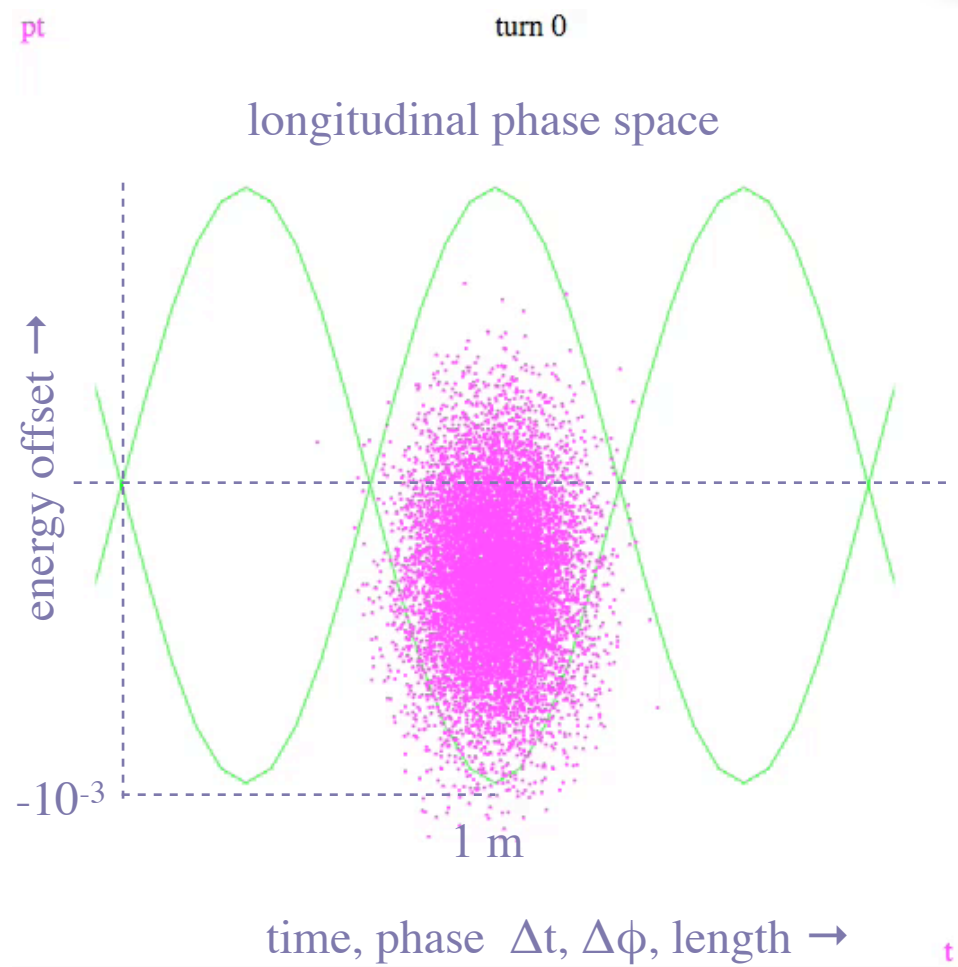

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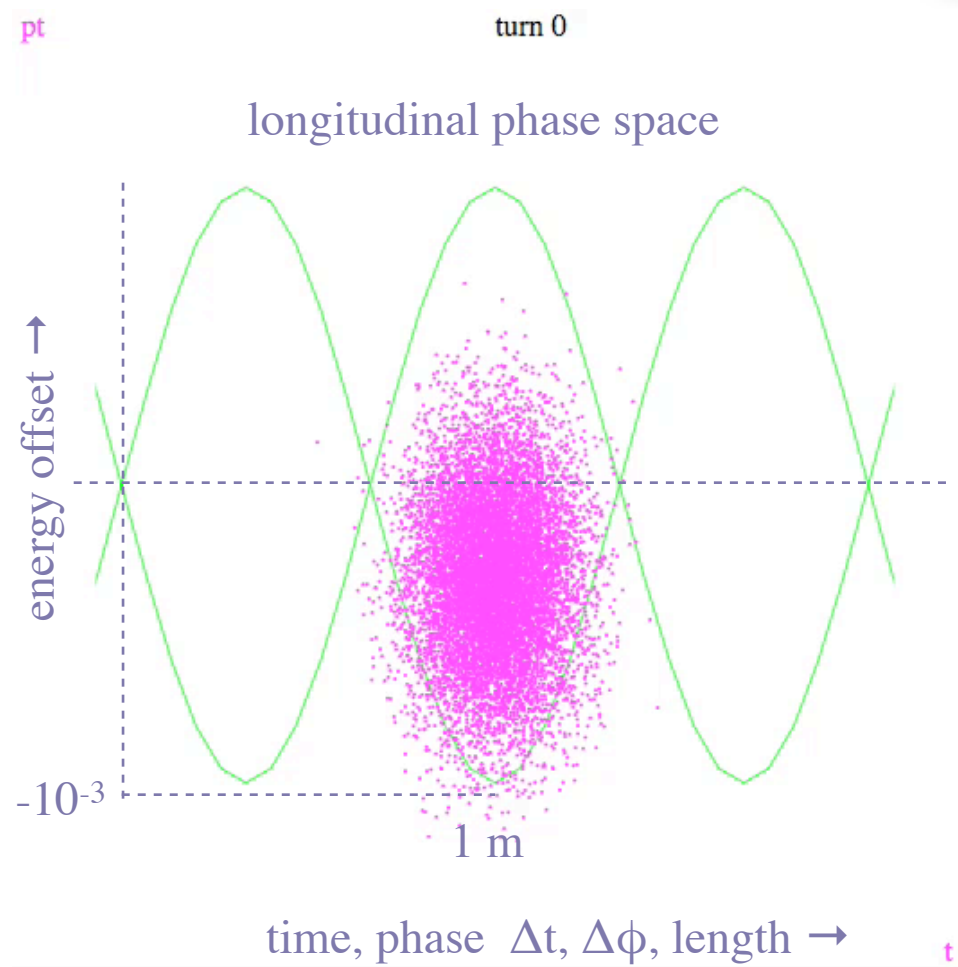

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Filling pattern - bunches, buckets, …

f_{RF} = 400 MHz

λ_{RF} = 0.75 m or 2.5 ns

35 640 RF buckets

Bunches spaced by 25 ns or 10 buckets

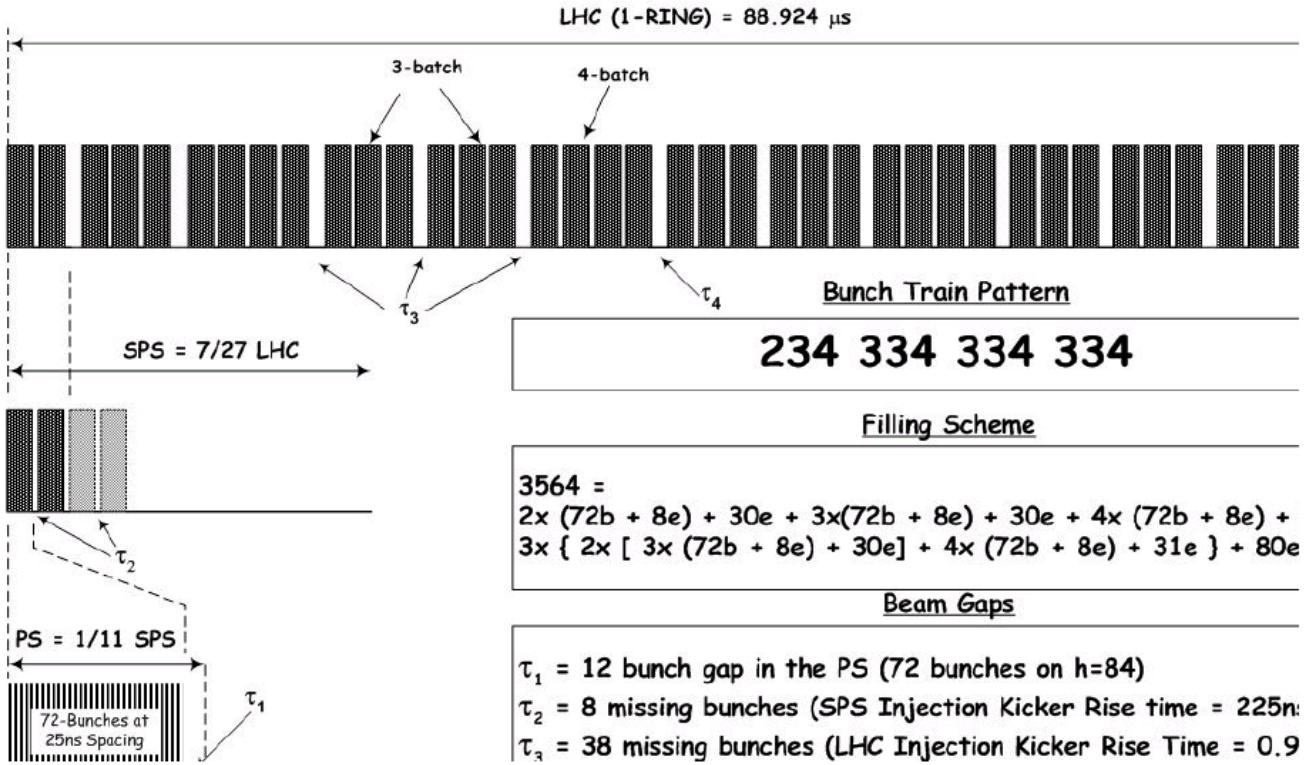
Inject batches of 2, 3 or 4 x 72 bunches

1 batch = 72 bunches

total 39×72 = 2808 bunches

Leave a 119 bunch abort gap free ~ 3 μs

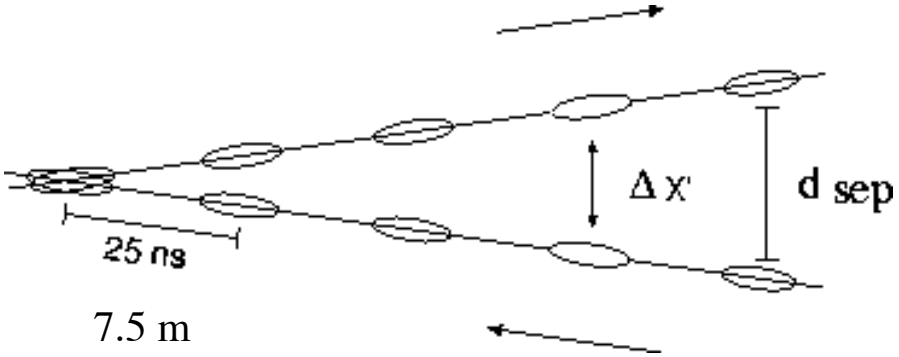
A full LHC turn is 88.9 μs



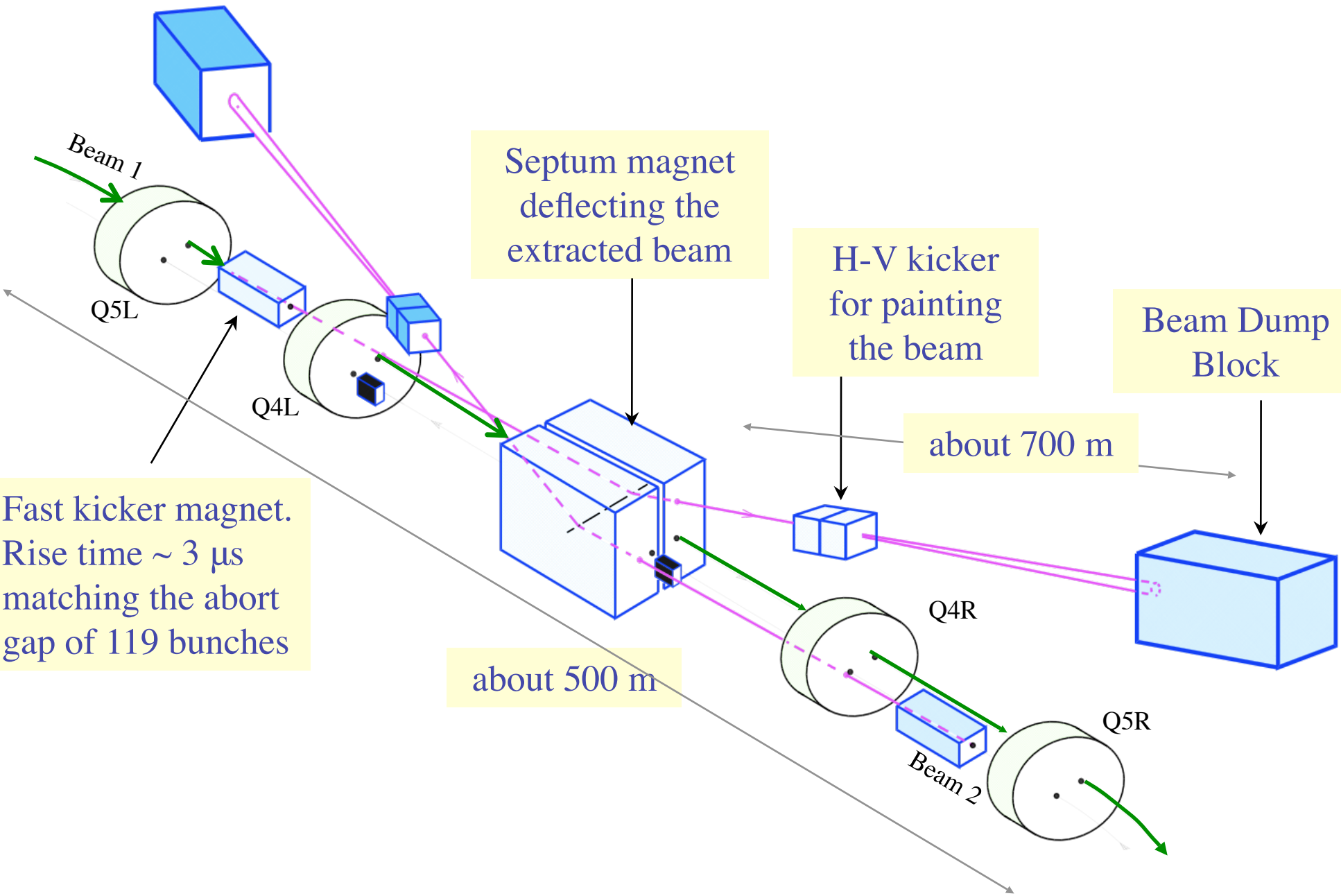
Crossing angle needed for > 156 bunches to avoid encounters closer than ~ 6 σ

Angle needed depends on β*

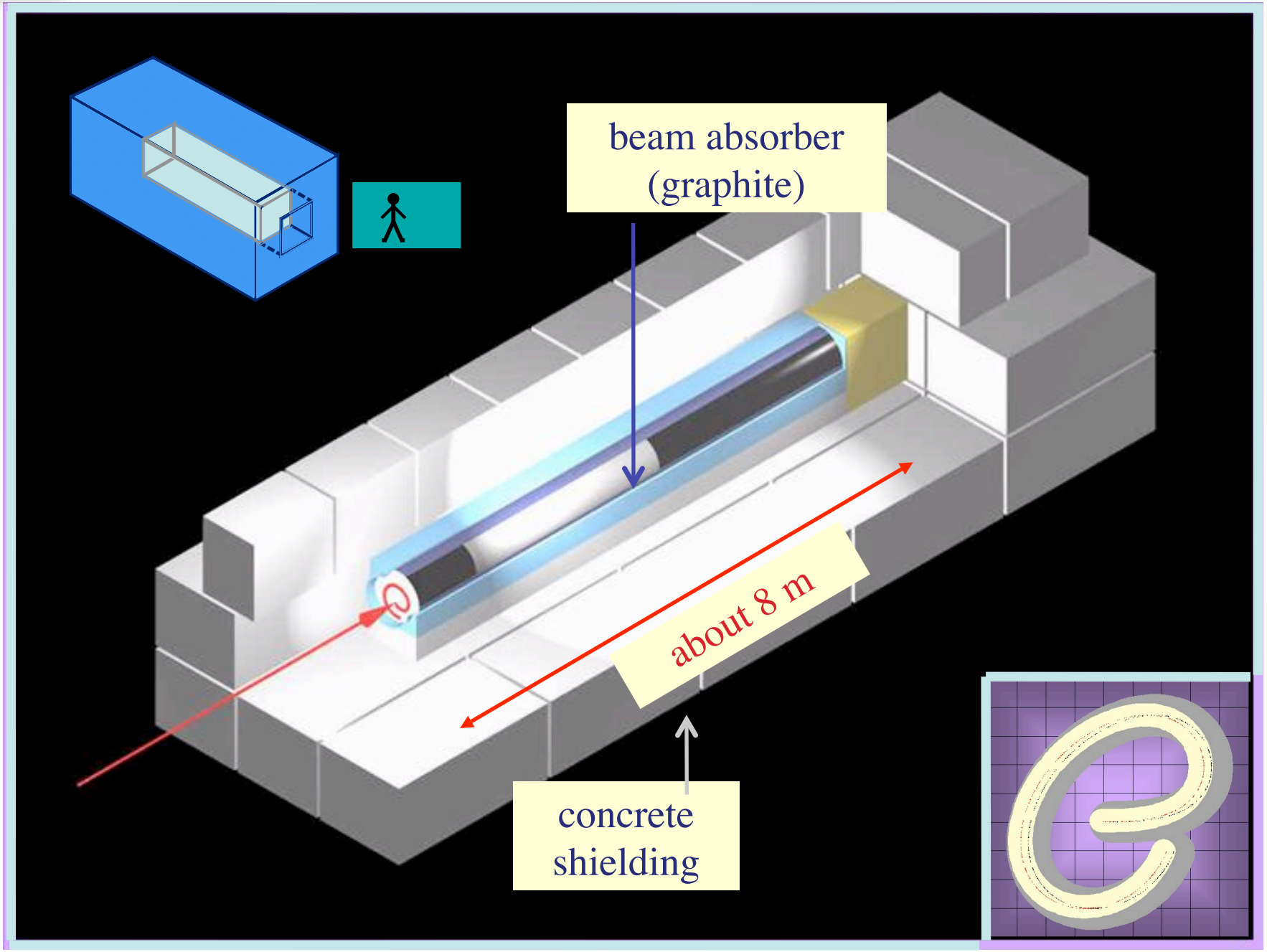
Nominal angle ± 142.5 μrad



Schematic layout of beam dump system in IR6



Dumping the LHC beam

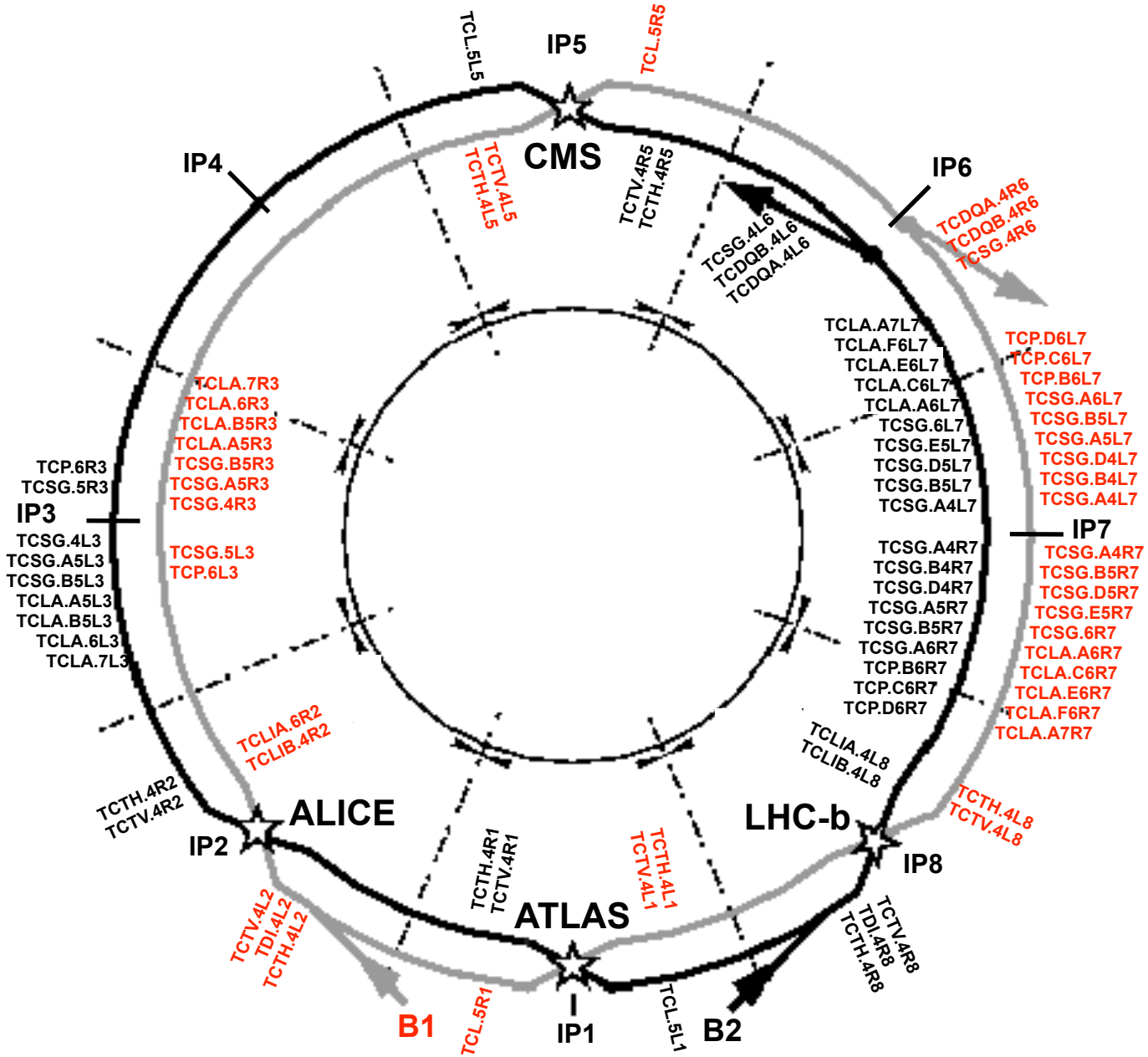


about
35 cm

Layout of the LHC with collimation

momentum collimation

betatron collimation



from Chiara Bracco / coll. team

94 collimators (phase 1)

Nominal LHC parameters at top energy

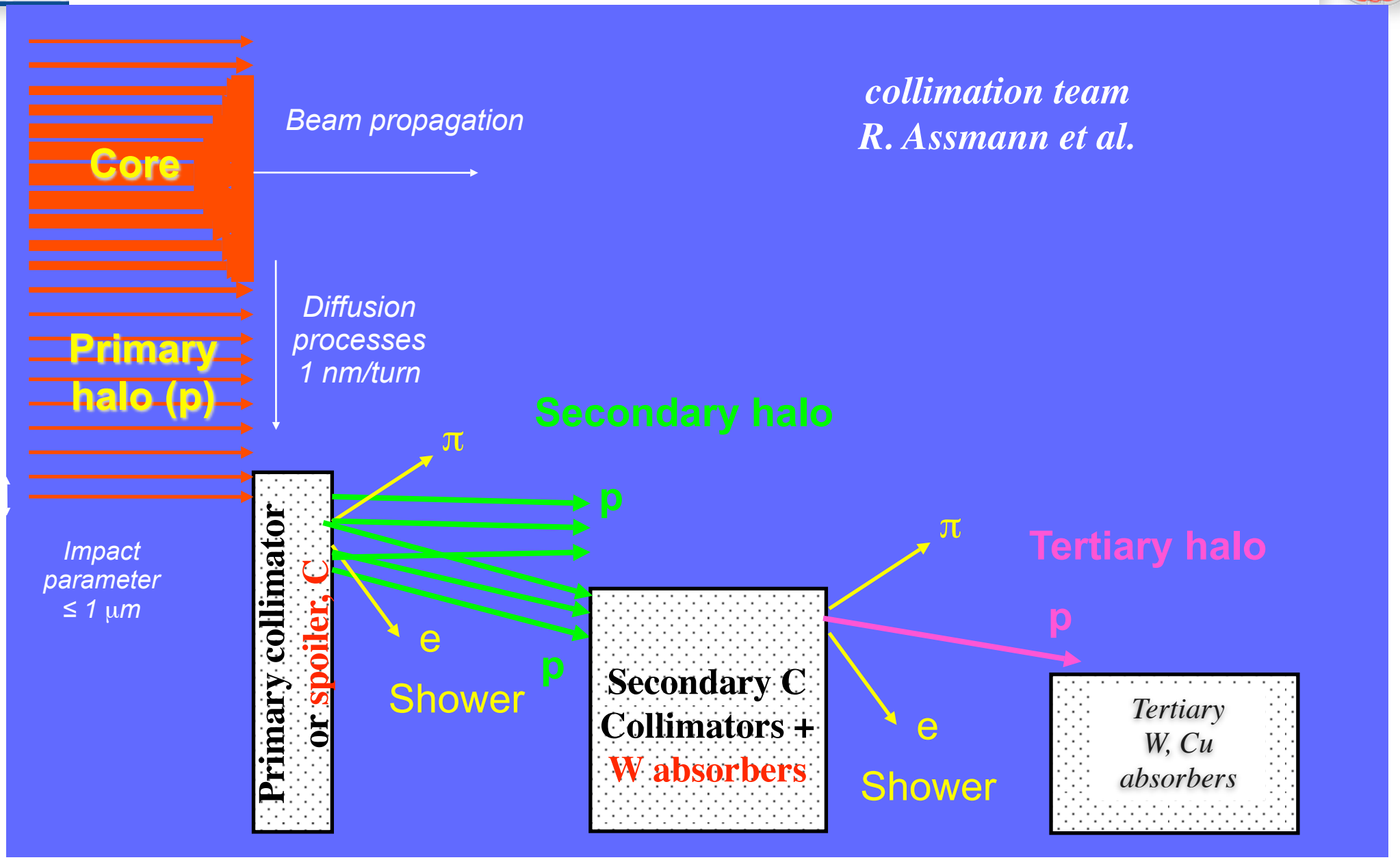
Proton energy 7 TeV	7 TeV
# protons / bunch	1.15×10^{11}
# bunches in each of the 2 beams	2808
# protons / beam	3.23×10^{14}
total energy stored in one beam	362 MJ

Collimation design

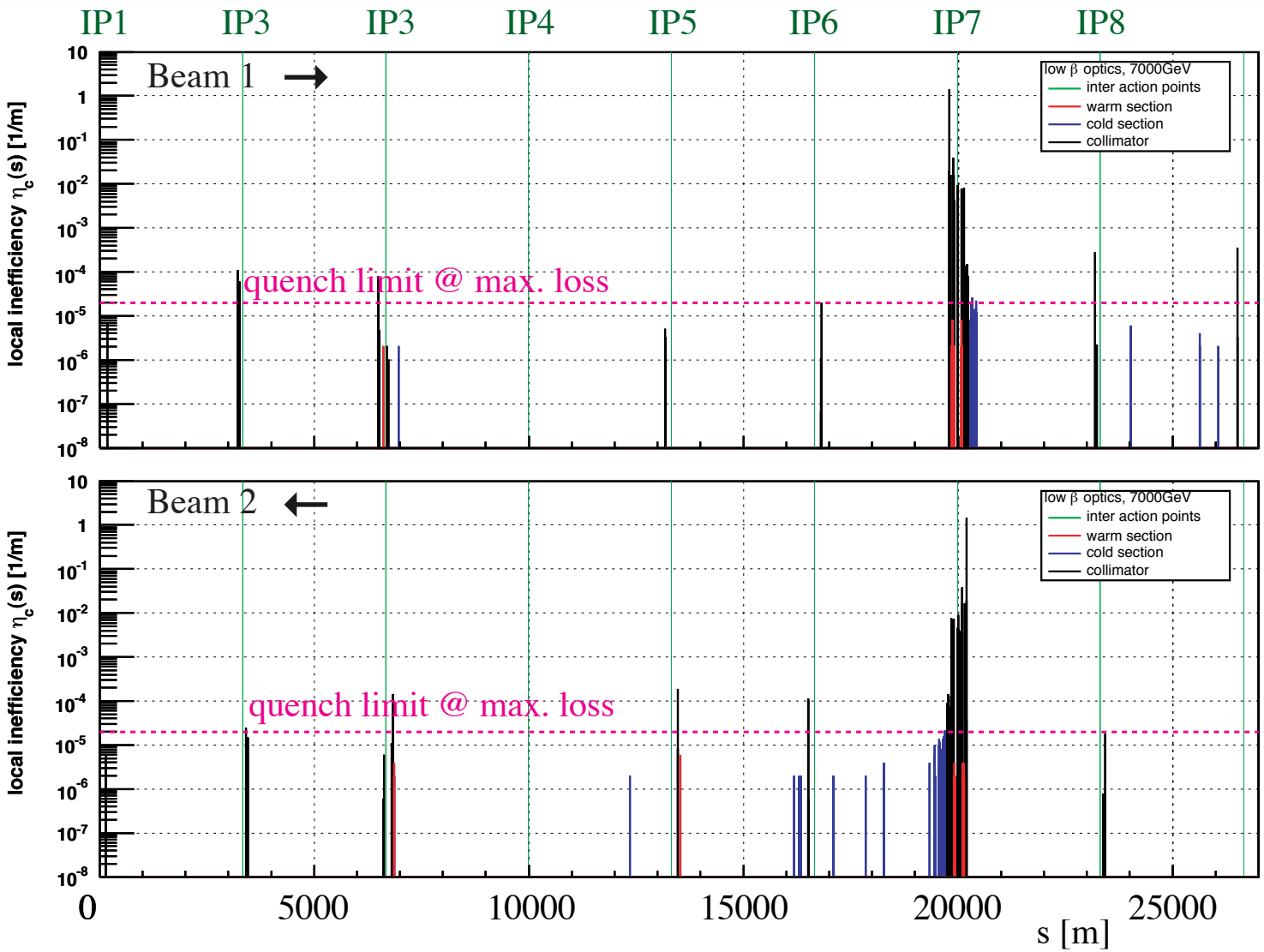
max loss rate (fraction at full intensity)	4.3×10^{11} / s (1.3×10^{-3}/s)
corresponding lifetime at full intensity	0.2 h
power at max loss rate P_{loss}	487 kW
quench limit q_{lim}	8.5 W/m
collimation (in)efficieny $\eta_c = q_{lim} / P_{loss}$	2×10^{-5} /m

LHC Design Report 2004-003

Multiple Stage Collimation System



Horizontal loss map, nominal 7 TeV collision optics



Standard settings; ideal machine. All losses in cold sections below quench limit for max. tolerated loss rate of 4.3×10^{11} prot. / s (0.2h at nom. intensity)

Figure from T. Weiler, collimation team

Not everything is more difficult than before
Synchrotron Radiation is an issue, but much less than for LEP2

LEP2: $E_b = 100$ GeV, $\gamma = 2\text{x}10^5$

energy loss in synchrotron radiation $U_0 = 2.92$ GeV/turn $E_c = 0.73$ MeV

~ $6\text{x}10^{20}$ photons/s, total radiated power for 6 mA beam current 18 MW, $\tau_e = 34$ turns ($J_e = 2$)

down to < 10^5 photons/s in the experiment (few visible γ's in the detector / crossing)

using 154 collimators + local masks for the four experiments

LHC: $E_b = 7$ TeV, $\gamma = 7460$, $U_0 = 6.7$ keV/turn

$E_c = 44$ eV

"halfway (in log E_c) between SPS and LEP2.

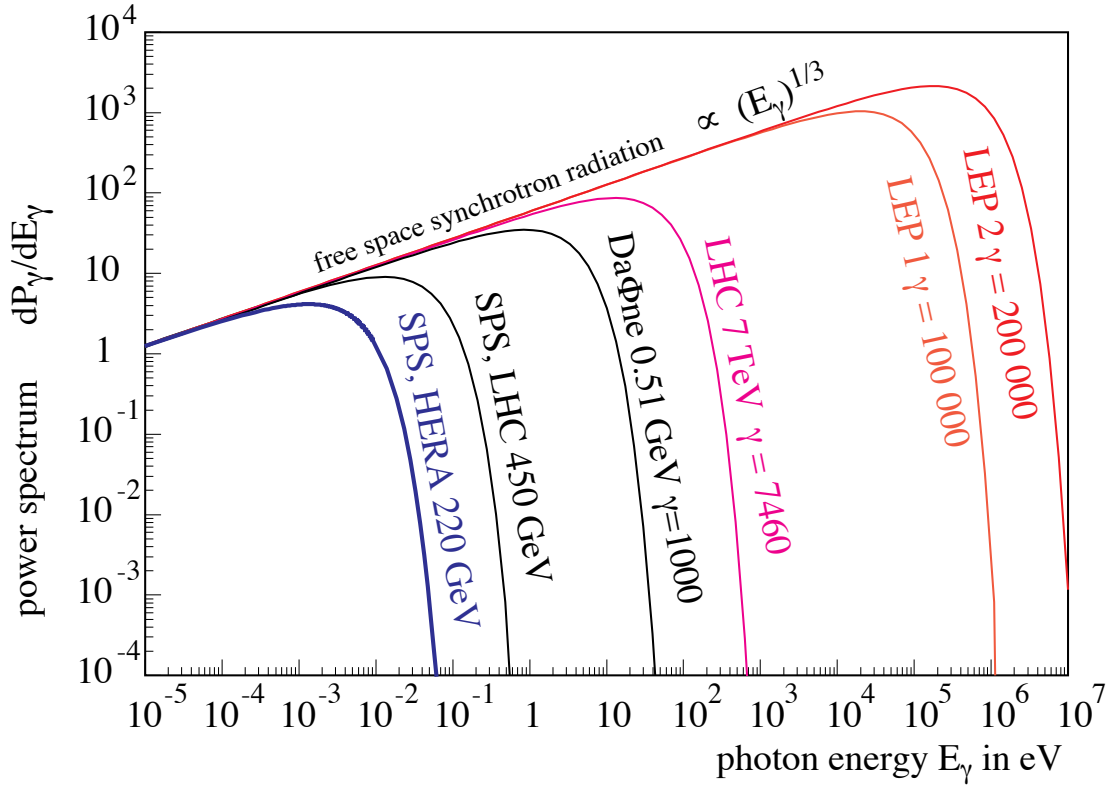
Already well above low energy

electron machines like Daϕne"

total radiated power (1.07 A beam) is 7.2 kW

damping time $\tau_e = 26$ h ($J_e = 2$)

$$E_c = \frac{3}{2}\hbar c \gamma^3/\rho$$



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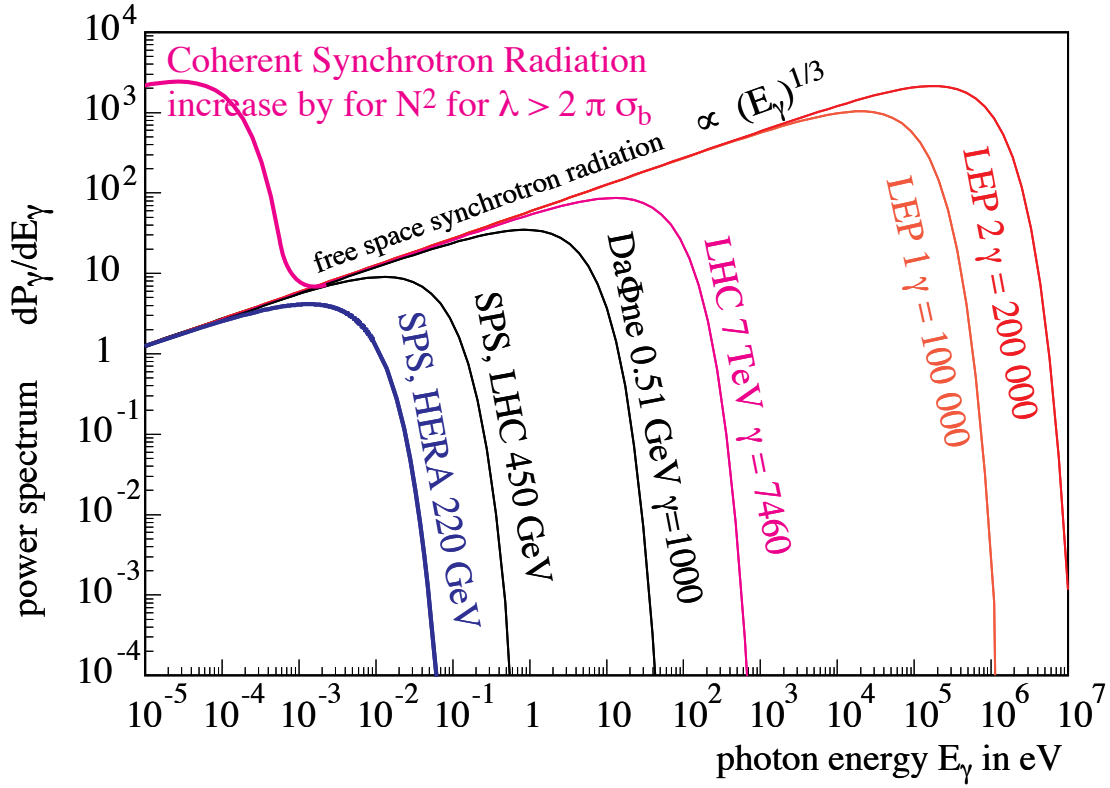

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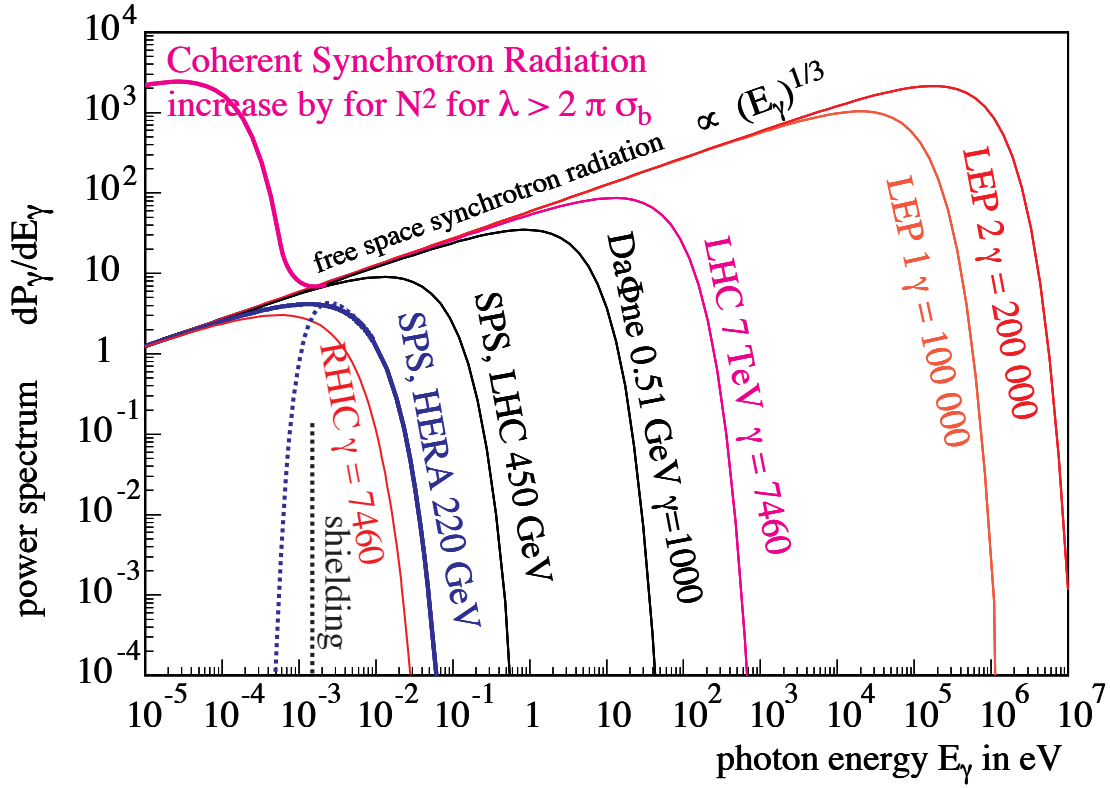
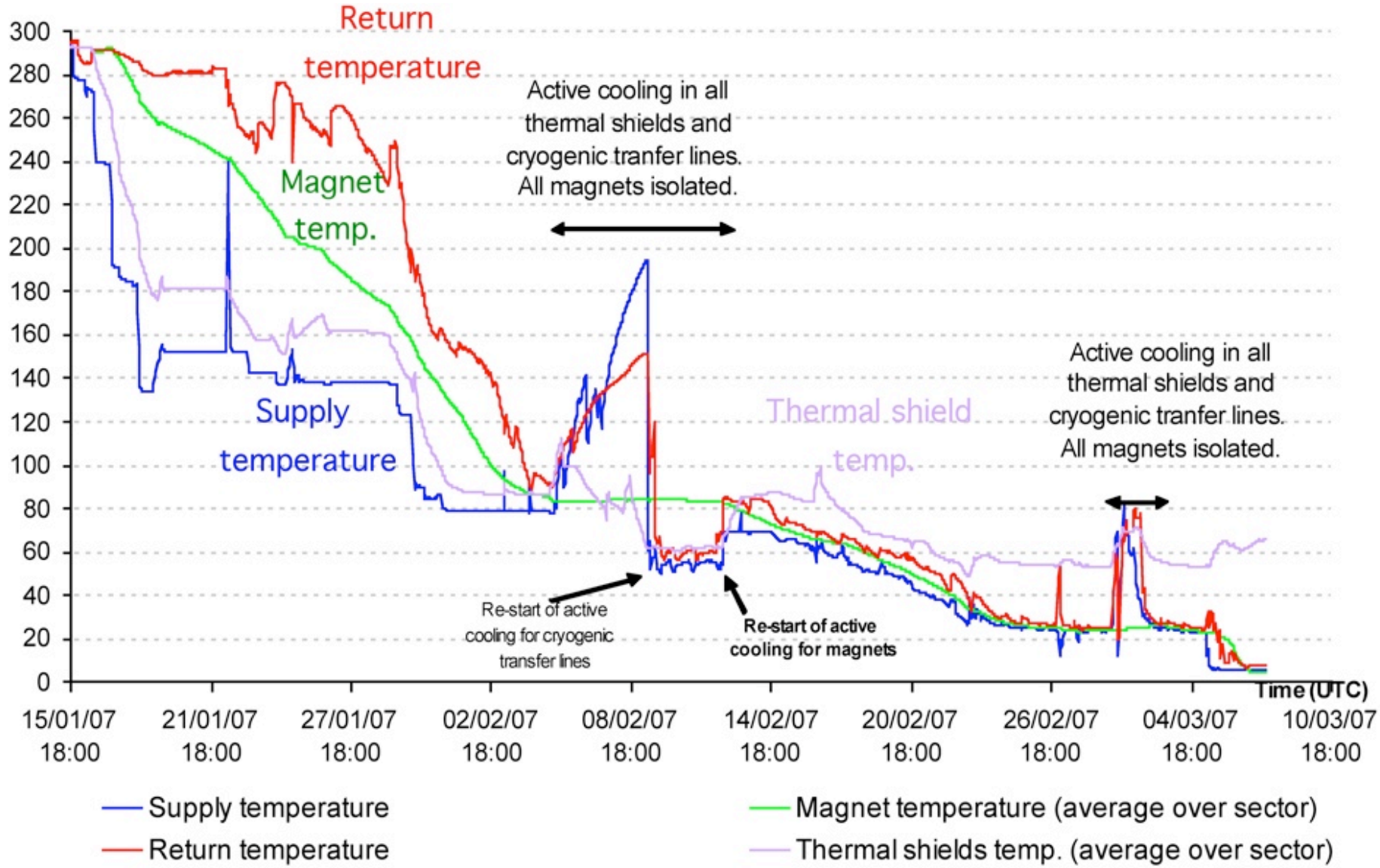


Hardware Commissioning and schedule

First cool-down sector 78



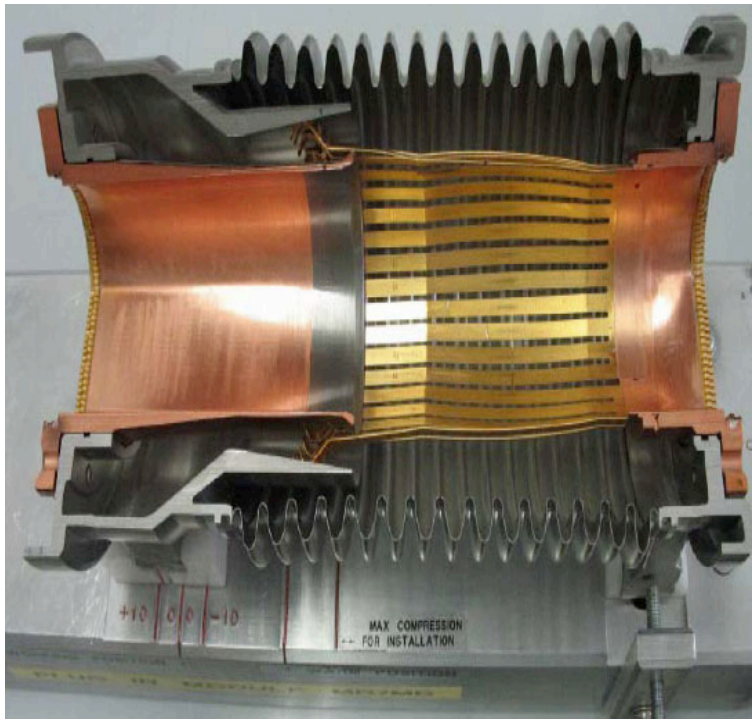
Critical Issues

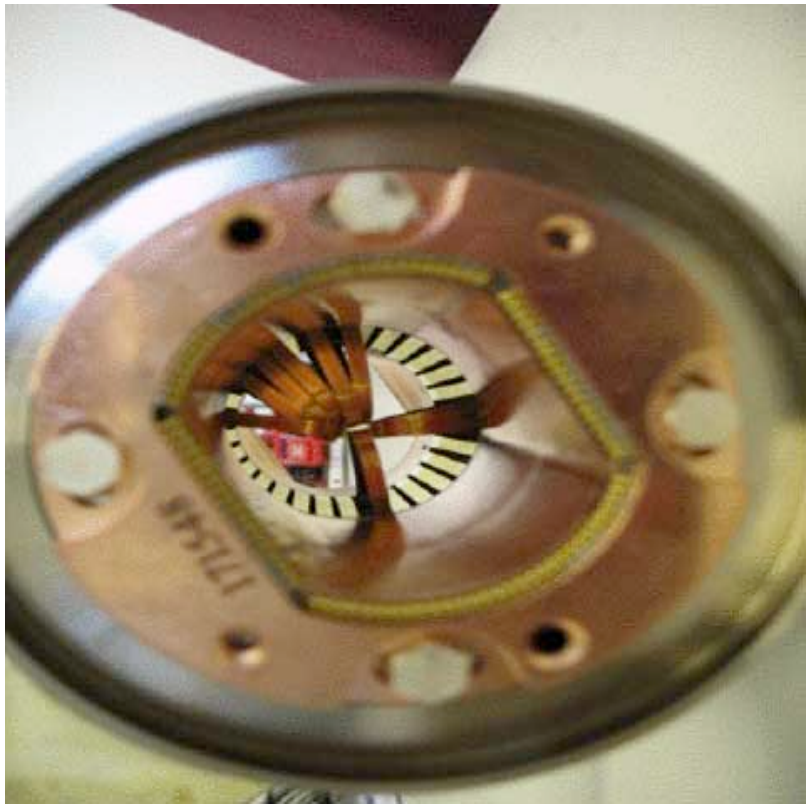
Past

- QRL cryo line (He supply)
- DFB power connections, warm to cold transition
- Triplet quadrupoles - differential pressure

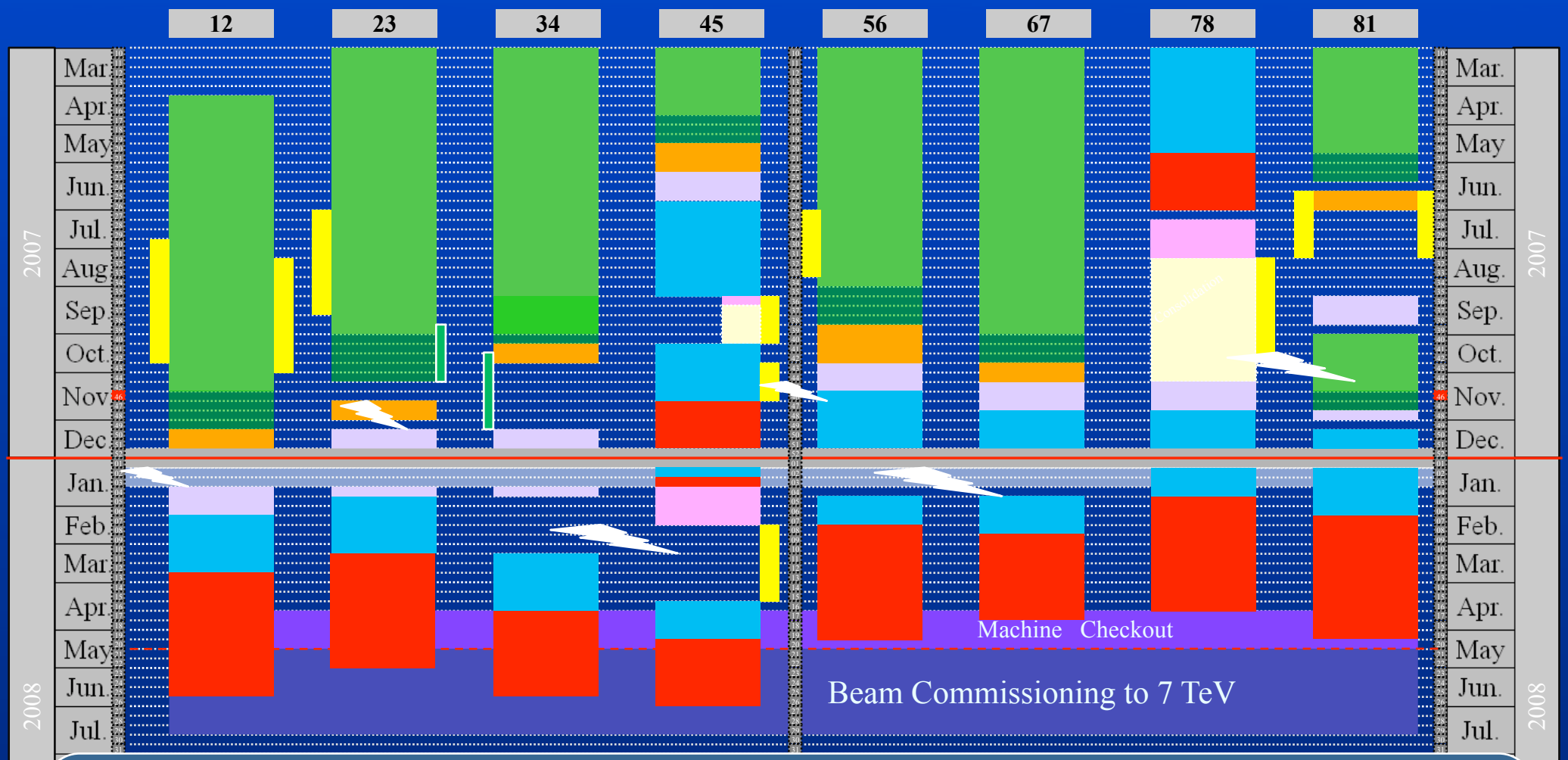
Present

- Vacuum Leaks
- PIM plug in module with bellow



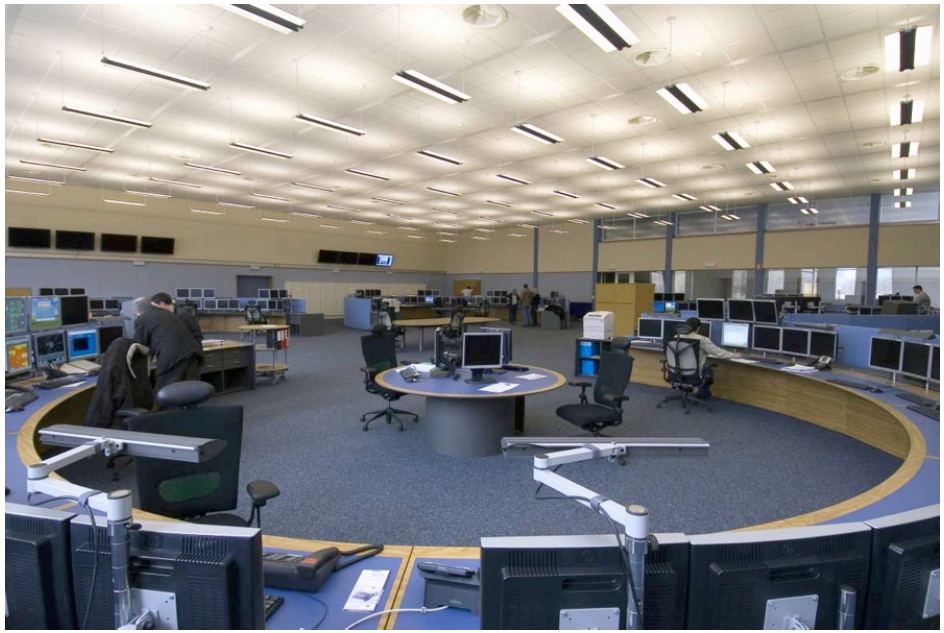


Reference schedule, ICC – November 16



- Interconnection of the continuous cryostat
- Leak tests of the last sub-sectors
- Inner Triplets repairs & interconnections
- Global pressure test &Consolidation
- Flushing
- Cool-down
- Warm up
- Powering Tests
- CV maintenance

Plans for Commissioning with Beam



LHC Commissioning Working Group - LHCCWG

chaired by R. Bailey – using some of of his slides

detailed commissioning procedure -- on the web **http://lhccwg.web.cern.ch/**

Beam commissioning to 450 GeV and 7 TeV collisions

		Rings	Total [days]
1	Injection and first turn	2	4
2	Circulating beam	2	3
3	450 GeV – initial commissioning	2	4
4	450 GeV – detailed optics studies	2	5
5	450 GeV increase intensity	2	6
6	450 GeV - two beams	1	1
7	450 GeV - collisions	1	2
8a	Ramp - single beam	2	8
8b	Ramp - both beams	1	2
9	7 TeV – top energy checks	2	2
10a	Top energy collisions	1	1
	TOTAL TO FIRST COLLISIONS (beam time)		30
11	Commission squeeze	2	6
10b	Set-up physics - partially squeezed	1	2
	TOTAL TO PILOT PHYSICS RUN (beam time)		44

23 days

14 days

R.Bailey, 2007

Stage A: routes through the commissioning phases

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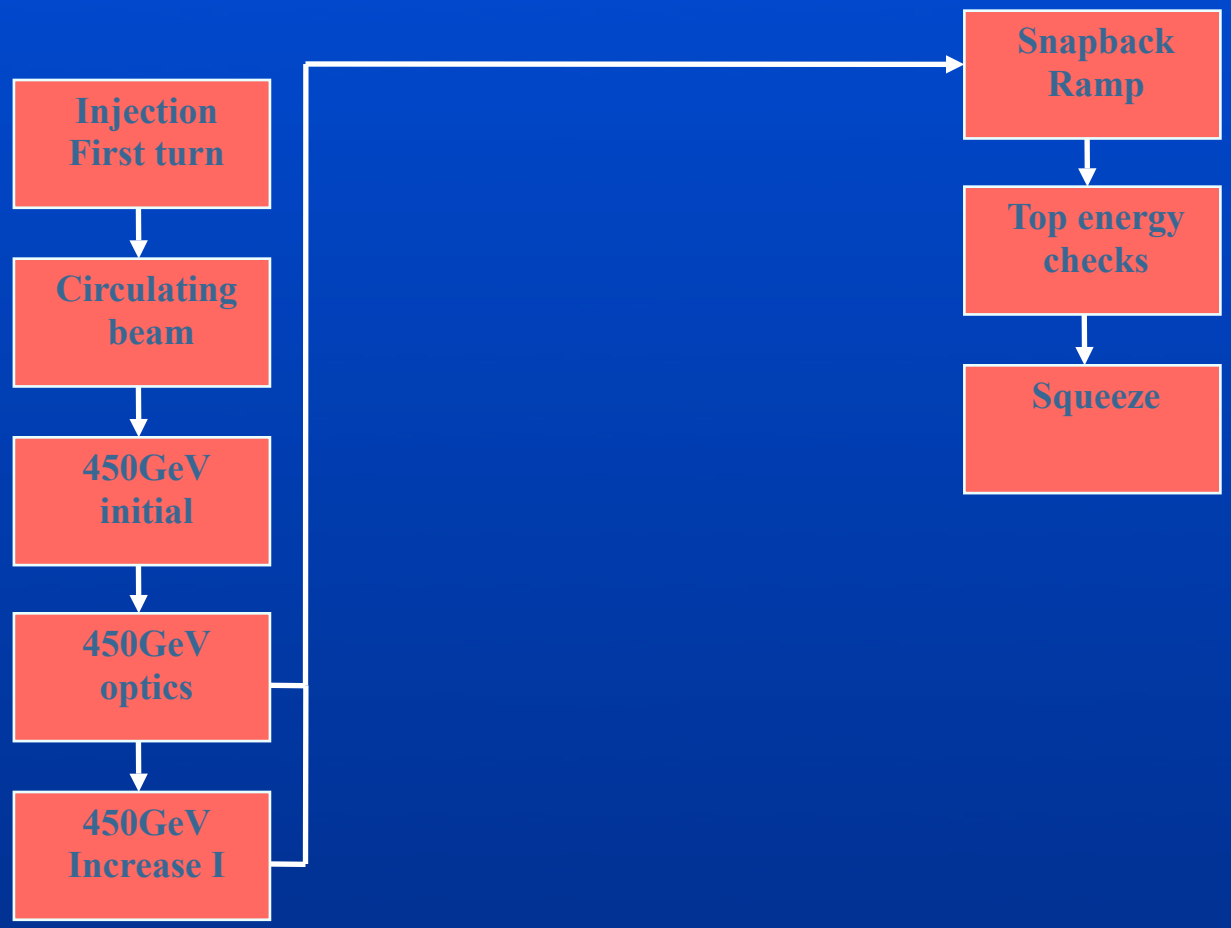
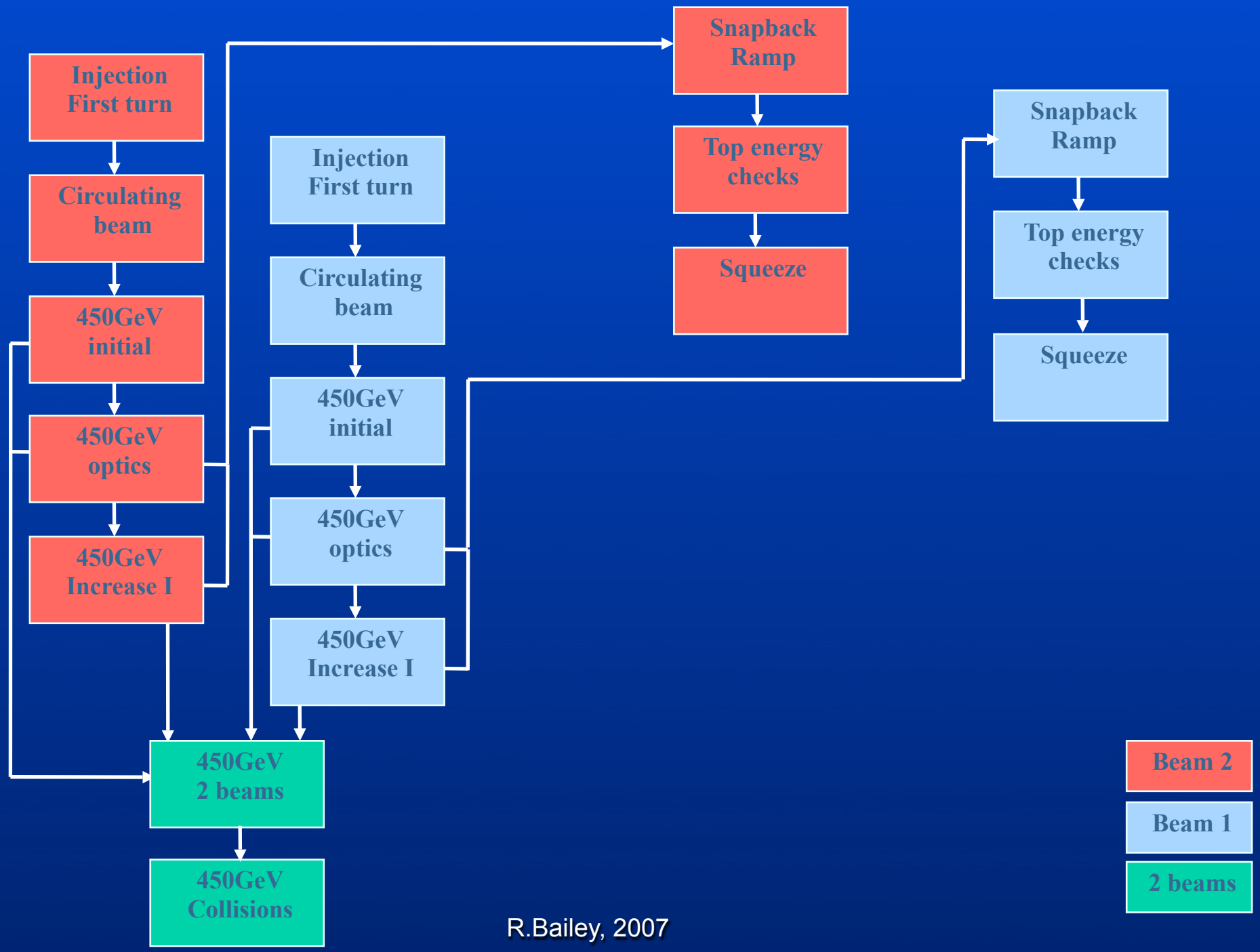


Beam 2

Stage A: routes through the commissioning phases



R.Bailey, 2007

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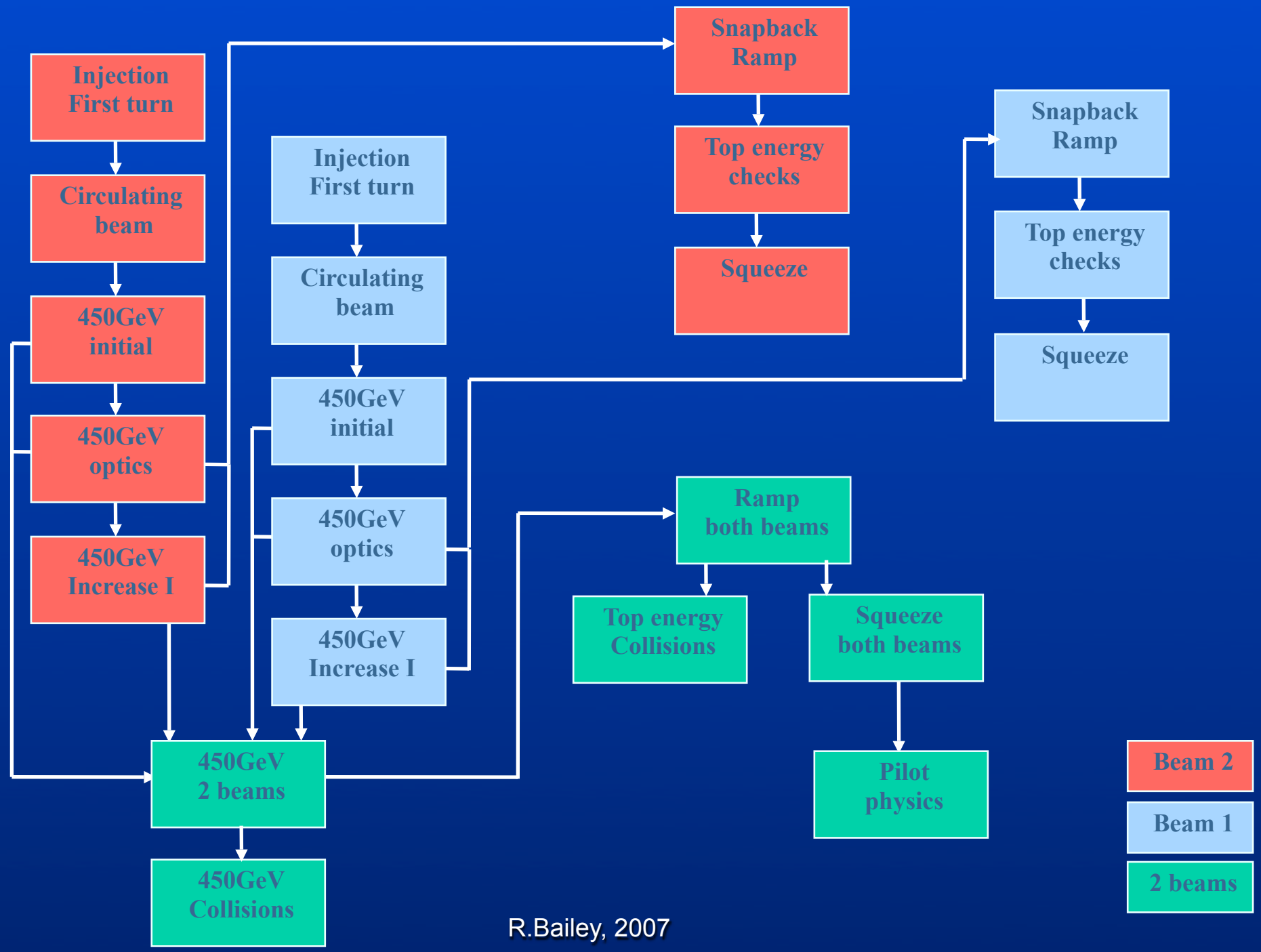

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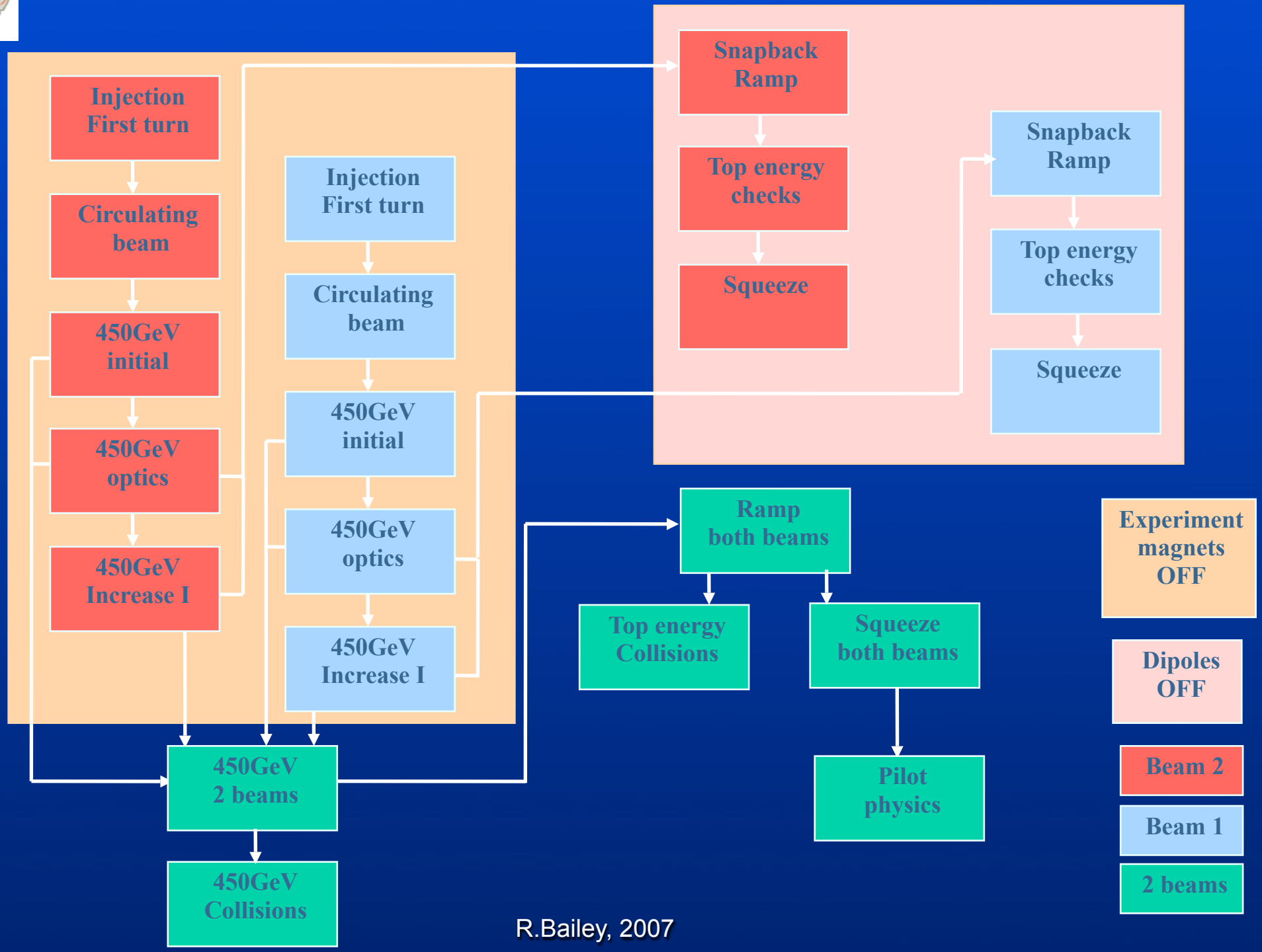
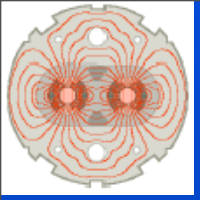


R.Bailey, 2007



Stage A physics run

$$L = \frac{N^2 k_b f \gamma}{4\pi\varepsilon_n \beta^*} F$$

$$Eventrate / Cross = \frac{L\sigma_{TOT}}{k_b f}$$

- Start as simple as possible
- Change 1 parameter (k_b N $\beta^*_{1,5}$) at a time
- All values for
  - nominal emittance
  - 7TeV
  - 10m β^* in point 2 (luminosity looks fine)

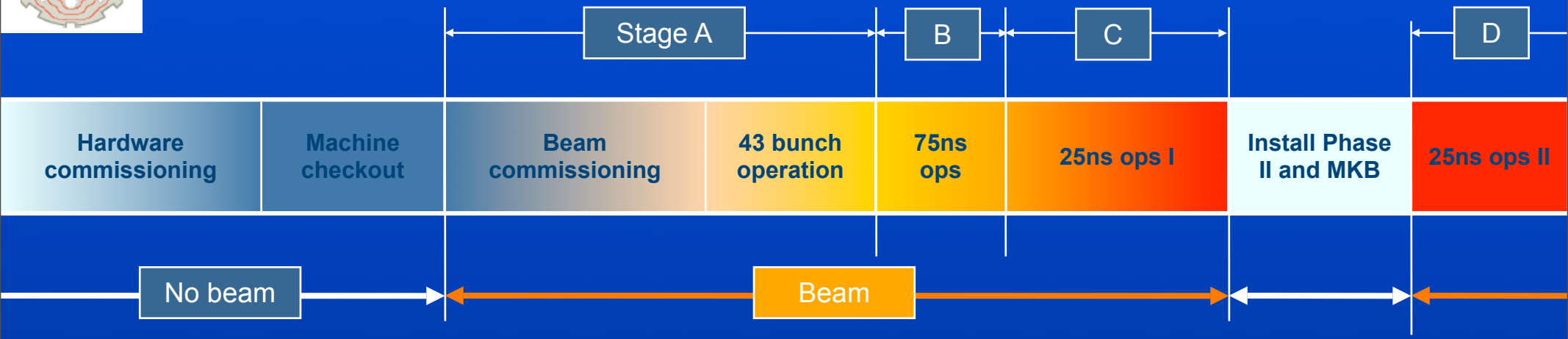
Protons/beam $\lesssim 10^{13}$
(LEP beam currents)

Stored energy/beam $\lesssim$ 10MJ
(SPS fixed target beam)

Parameters			Beam levels		Rates in 1 and 5		Rates in 2	
k_b	N	β^* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1	10^{10}	11	$1\ 10^{10}$	10^{-2}	$1.6\ 10^{27}$	<< 1	$1.8\ 10^{27}$	<< 1
43	10^{10}	11	$4.3\ 10^{11}$	0.5	$7.0\ 10^{28}$	<< 1	$7.7\ 10^{28}$	<< 1
43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	2	$1.1\ 10^{30}$	<< 1	$1.2\ 10^{30}$	0.15
43	$4\ 10^{10}$	2	$1.7\ 10^{12}$	2	$6.1\ 10^{30}$	0.76	$1.2\ 10^{30}$	0.15
156	$4\ 10^{10}$	2	$6.2\ 10^{12}$	7	$2.2\ 10^{31}$	0.76	$4.4\ 10^{30}$	0.15
156	$9\ 10^{10}$	2	$1.4\ 10^{13}$	16	$1.1\ 10^{32}$	3.9	$2.2\ 10^{31}$	0.77

R.Bailey, 2007

Overall commissioning strategy for protons



I. Pilot physics run
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

II. 75ns operation
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

III. 25ns operation I
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm^{-2} s^{-1}

IV. 25ns operation II
- Push towards nominal performance

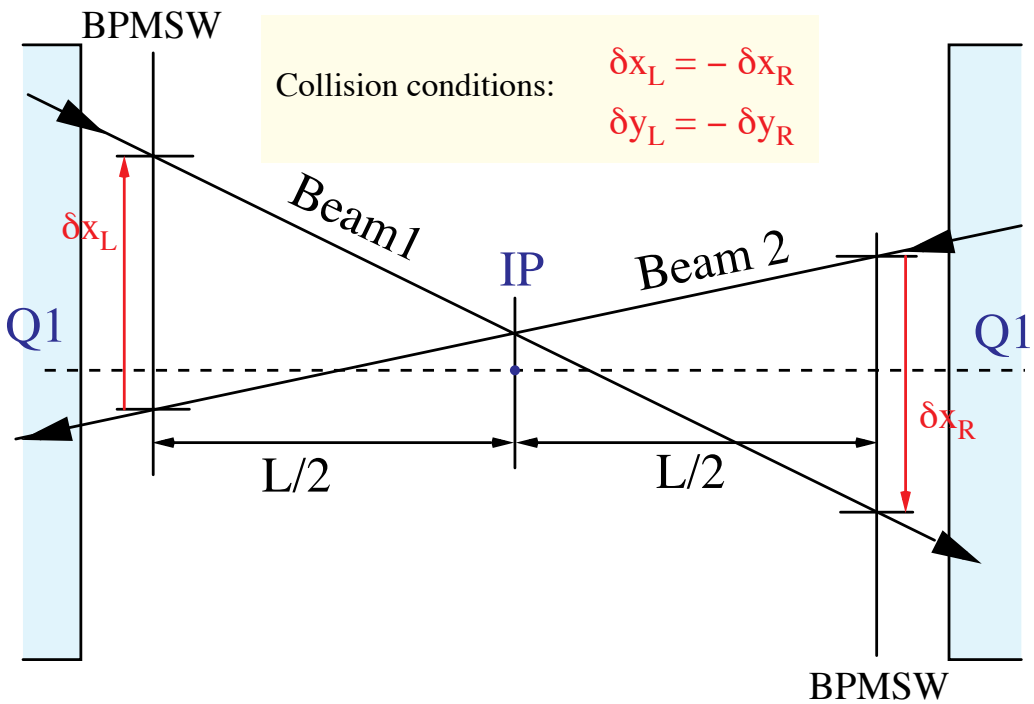
Minimise
- *Complexity*
- *Beampower*
- *Losses*(β^*)
- *Pileup*

Optimise
- N
- k_b
- β^*

R.Bailey, 2007

Get beams colliding : BPM resolution

Adjust orbits such, that the beam 1 and 2 difference left/right of the IP is the same.
measured with special (beam-) directional stripline couplers BPMSW at about 21 m L/R from IP in front of Q1. There are 2 each in IR1 (Atlas), IR2 (Alice), IR5 (CMS) and IR8 (LHCb)
Beams must then collide. This is independent of mechanical offsets and crossing angles.



Both planes (x, y) together

$$\delta_{\mathrm{IP}} = \sqrt{\left(\frac{\delta x_L + \delta x_R}{2}\right)^2 + \left(\frac{\delta y_L + \delta y_R}{2}\right)^2} = \sqrt{2}\,\sigma_{\mathrm{BPM}}$$

Each plane $\delta_{\mathrm{IP}} = \sigma_{\mathrm{BPM}}$

Expected resolution for small separation and 0 crossing angle
In each plane.

~ 50 µm using selected, paired electronics ; otherwise ~ 100 - 200 µm
beam 1 and beam 2 have separate electronics

~ 10 µm with extra button pickups for large bunch spacing, using identical electronics for b1 and b2 (planned, pers. comm. Rhodri Jones / AB-BI)

Get beams colliding ; procedure and requirements

Luminosity with separation

$$\frac{\mathcal{L}}{\mathcal{L}_0} = \exp\left[-\left(\frac{\delta x}{2\sigma_x}\right)^2 - \left(\frac{\delta y}{2\sigma_y}\right)^2\right]$$

$\frac{\delta x}{\sigma_x}$	$\frac{\delta y}{\sigma_y}$	$\mathcal{L}/\mathcal{L}_0$
0	0	1.0000
0.1	0	0.9975
0.2	0	0.9901
0.3	0	0.9778
0.4	0	0.9608
0.5	0	0.9394
0.5	0.5	0.8825
1	0	0.7788
1	1	0.6065
2	0	0.3679
2	2	0.1353

Procedure :

- **End of ramp / squeeze, beams separated**
- **Turn off separation, based on BPM information ; fine tuning using separator scans : use best position as new default**

Required, in radius roughly **:**

$\delta_r < 2\ \sigma$ to see collisions

$\delta_r < 0.5\ \sigma$ to optimise luminosity and equalise between experiments

$\sqrt{2}$ better in each plane x, y : $\delta_{x,y} < 1.4\ \sigma$ and $\delta_{x,y} < 0.35\ \sigma$

Eb, TeV	β*	σ*	$\delta_{x,y}$	$\delta_{x,y}$
TeV	m	μm	μm	μm
0.45	11	293	414	104
7	11	74.4	105	26
7	2	31.7	45	11
7	0.55	16.6	23	6

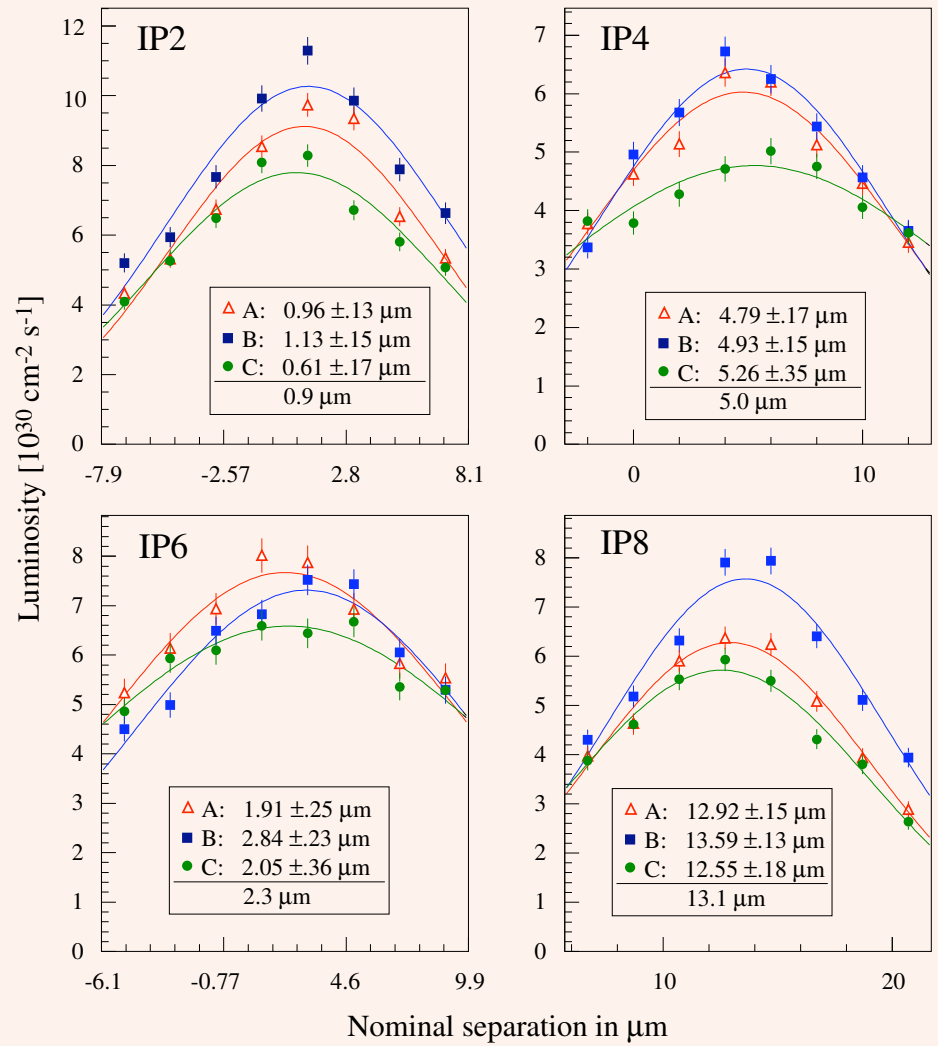
450 GeV ok, even without BRAN

BPM ok to get collisions

Optimise collisions : separation scans (pioneered by Van der Meer @ ISR)

LEP example:
vertical separation scans using LEP luminosity detectors in operation with 4 bunch trains of each 3 bunches
Time: about 5 min / IP

should be faster in the LHC
but needed in two planes x/y



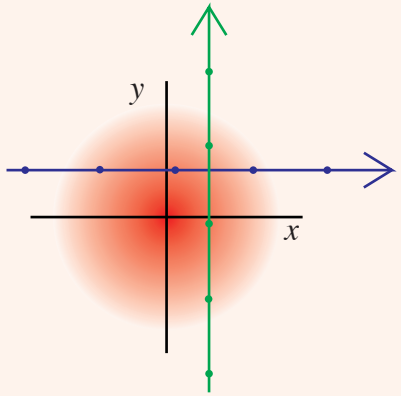
Separation scans in the LHC should allow for reliable beam size measurements at the IPs.
Precise separation measurement : bump (and BPM) calibration (response matrix analysis)

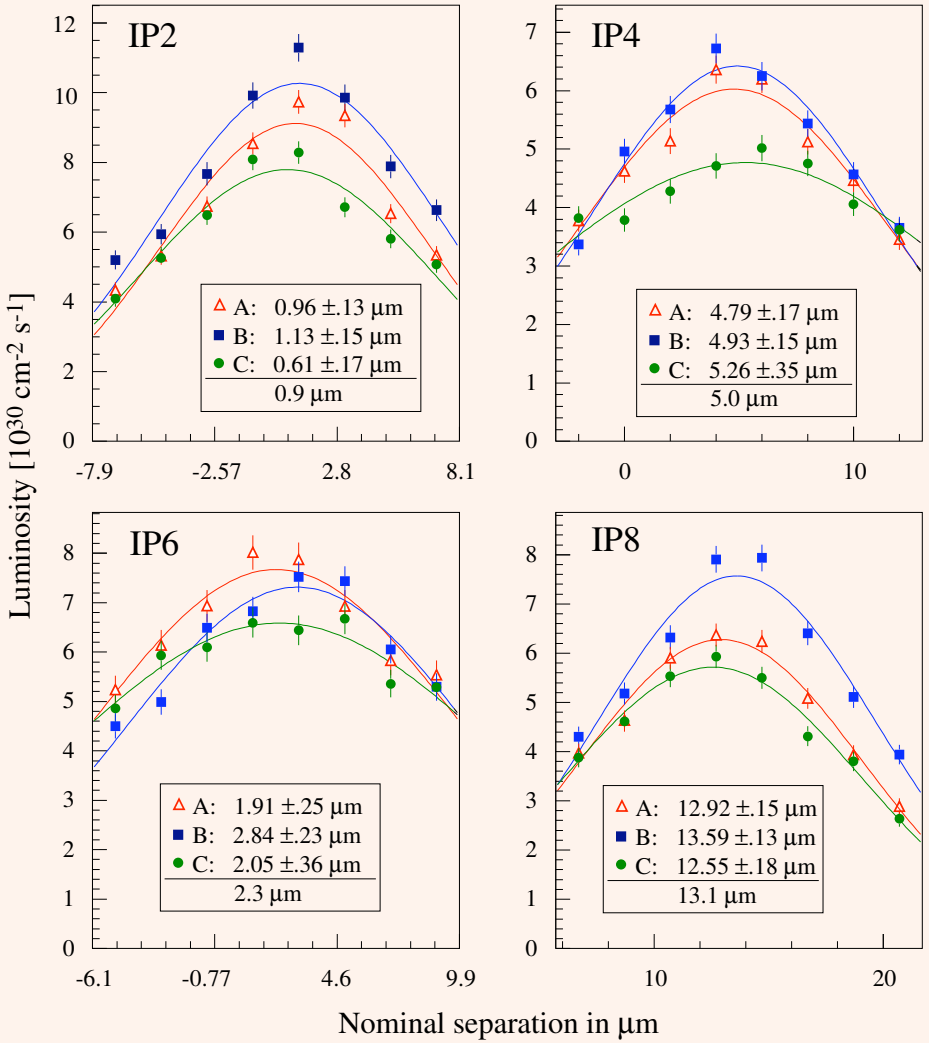
Optimise collisions : separation scans (pioneered by Van der Meer @ ISR)

LEP example:
vertical separation scans using LEP luminosity detectors in operation with 4 bunch trains of each 3 bunches
Time: about 5 min / IP

should be faster in the LHC
but needed in two planes x/y

planned :
orthogonal
x / y scans



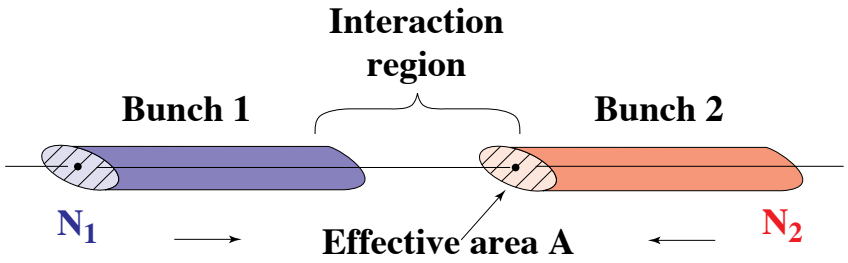


Separation scans in the LHC should allow for reliable beam size measurements at the IPs.
Precise separation measurement : bump (and BPM) calibration (response matrix analysis)

Absolute Luminosity from Machine Parameters

without need for a reference cross section

$$\mathcal{L} = \frac{N_1 \, N_2 \, f}{A_{\text{eff}}}$$



Beam intensities and crossing frequency are known with good accuracy
The effective overlap area A can be determined by scans in separation

Commissioning is without crossing angle and $\beta^* > \sigma_z$ (negligible hour-glass)
close to simplest case where $A_{\text{eff}} = 4 \, \pi \, \sigma_x \, \sigma_y$

Details : LHC Report 1019 by Grafstrøm and myself, http://cdsweb.cern.ch/record/1056691

Subject of PhD thesis of Simon White ; started 9/2007 with me as his CERN and Patrick Puzo / Univ. Paris XI Orsay as his university supervisor

Experimental Conditions and Backgrounds, Workshop

from the executive summary LHC Machine Advisory Committee this summer , June 07, on Experimental Conditions and Detector Beam Induced Backgrounds :

The MAC is pleased to see this important activity being carried out as a joint Detector-Accelerator concern.
Given the wide experience with these matters at other cryogenic hadron colliders such as the Tevatron, HERA and RHIC, the MAC suggests that a workshop involving the detector and accelerator experts from the corresponding laboratories would be very beneficial in highlighting the various effects and their cures.
Beam induced detector backgrounds have been a challenge at all colliders.

Preliminary Planning for a Workshop Beginning of April 2008 on :
Experimental Conditions and Beam Induced Detector Backgrounds
1 day + half day summing up or possible extension
organized by myself for the LHCCWG and M, Ferro-Luzzi for the LHC Experiments.
Session 1 : Experience and recommendations from Tevatron, HERA and RHIC
chaired by machine coordinator (Mike Lamont), scientific secretary Reyes Alemany
1.1 Tevatron : Sources of background
1.2 Tevatron : Techniques to cure background problems
1.3 DESY : Background in HERA
1.4 BNL : Background in RHIC
1.5 LHC : Plans how to deal with backgrounds in LHC operation

Concluding with two citations

- **The LHC is a global project with the world-wide high-energy physics community devoted to its progress and results**
- **As a project, it is much more complex and diversified than the SPS or LEP or any other large accelerator project constructed to date**

International Machine Advisory Committee, chaired by Prof. M. Tigner

- **No one has any doubt that it will be a great challenge for both machine to reach design luminosity and for the detectors to swallow it.**
- **However, we have a competent and experienced team, and 30 years of accumulated knowledge from previous CERN projects has been put into the LHC design**

L. Evans, LHC Project Leader

Backup Slides

Abort gap cleaning

Abort gap monitoring and active gap cleaning is foreseen.

Cleaning will be done using the transverse damper, W. Höfle et al., RF-group

i.e. with the device that can act on bunches and damp or in this case excite transverse oscillations to amplitudes where they are removed by the cleaning collimators.

Was tested in the SPS (in 2002 and again this year, reported in LHCMAC 21)

Off energy particles are lost in ramping.

The smaller beam sizes at 7 TeV allow for momentum collimation at ~10^{-3}
the rf acceptance is also reduced to ~ 3.5×10^{-4}
The energy loss in synchrotron radiation $\Delta E_{sync.rad} / E \approx 10^{-3}$ / min and results in natural cleaning on the timescale of 1 min.

details : E. Shaposhnikova et al. Chamonix 2003 and EPAC 2004

Get beams colliding : longitudinal position

The two beams could still miss each other in presence of both a crossing angle and longitudinal offset.

To exclude this, a new electronic card was developed. It uses the BPMs around the IP and existing infrastructure and allows to measure the relative beam arrival times with sub ns resolution.

Rhodri Jones, AB/BI

LHC Optics and Parameters

Optics : currently finalizing V6.501 - first larger re-optimization (aperture at injection) since design report in 2003

Nominal parameters : <u>weblink</u> no change from design report

Target tunes H/V : injection 64.28 / 59.31 collision 64.31 / 59.32

1.15e11 protons per bunch, 2808 bunches, 0.582 A current / beam

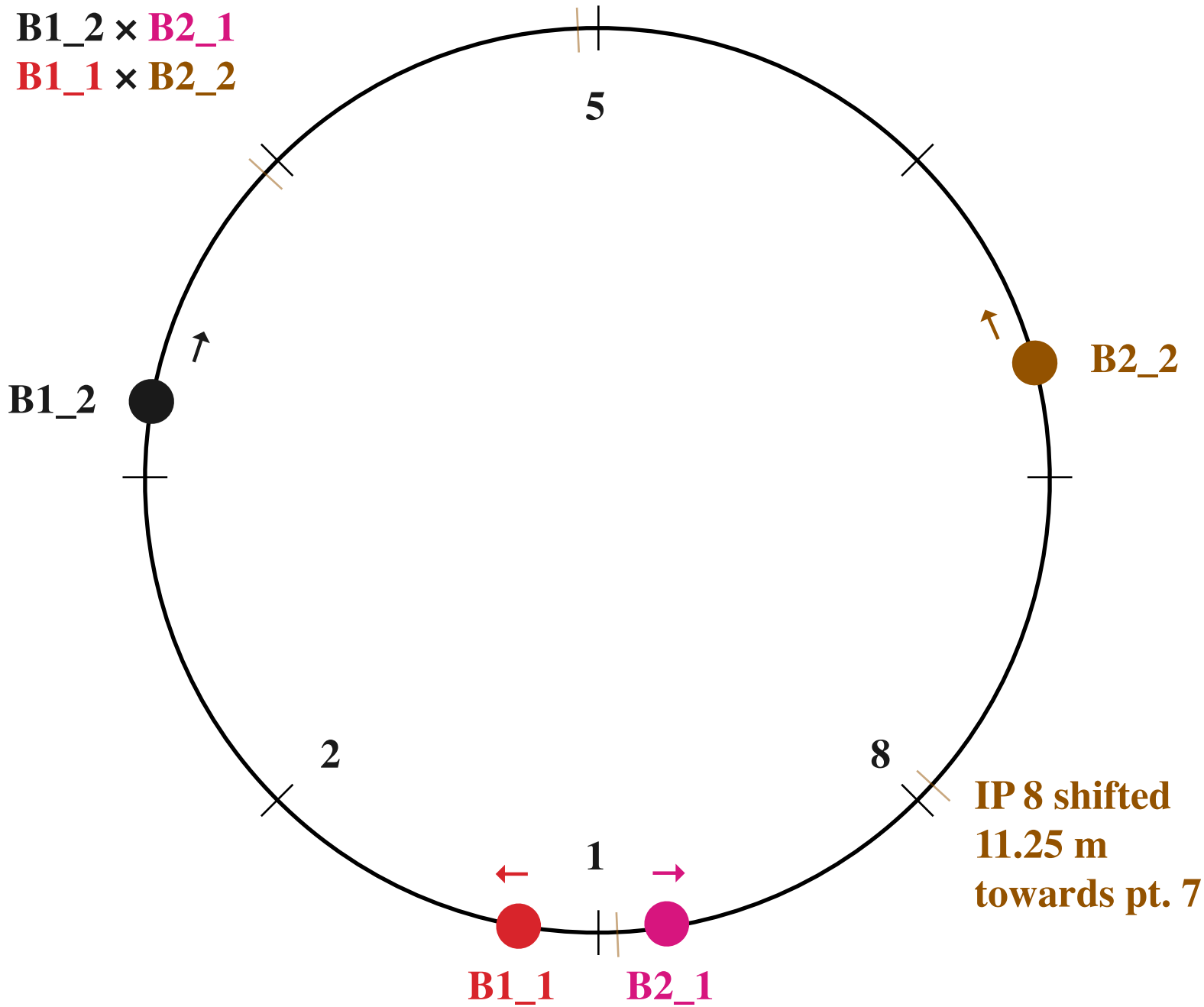
normalized emittance 3.75 um - round beams

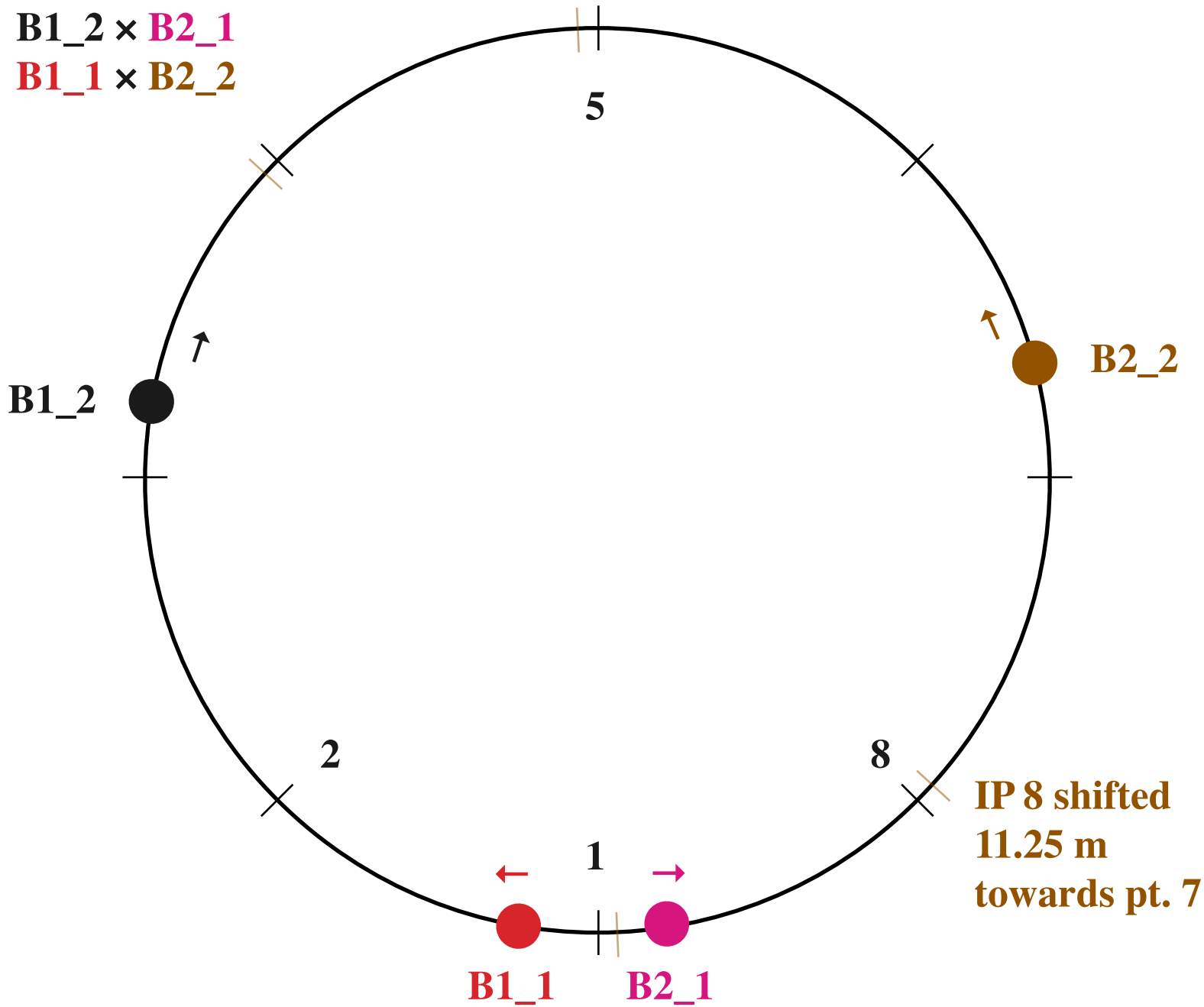
$\beta^* = 0.55$ m L = 1.0e34 cm^-2s^-1

b.b. tune shift parameter both planes 0.0037

Collision schedule, example with 2 × 2 bunch collisions

IP1 & 5 : B1_1 × B2_1 + B1_2 × B2_2 (offset)
IP2 : B1_2 × B2_1
IP8 : B1_1 × B2_2



Collision schedule, example with 2 × 2 bunch collisions

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