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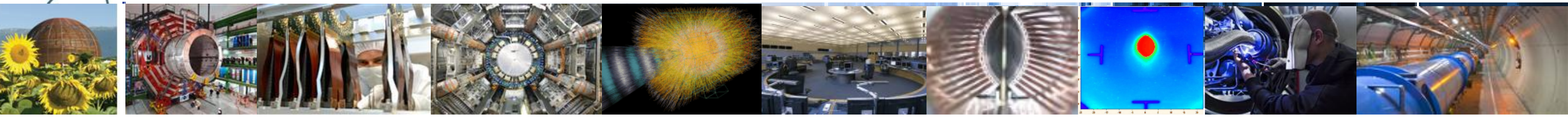
[CERN BE/OP]
[Engineer In Charge of LHC]
Lectures JUAS (16.01.2013)

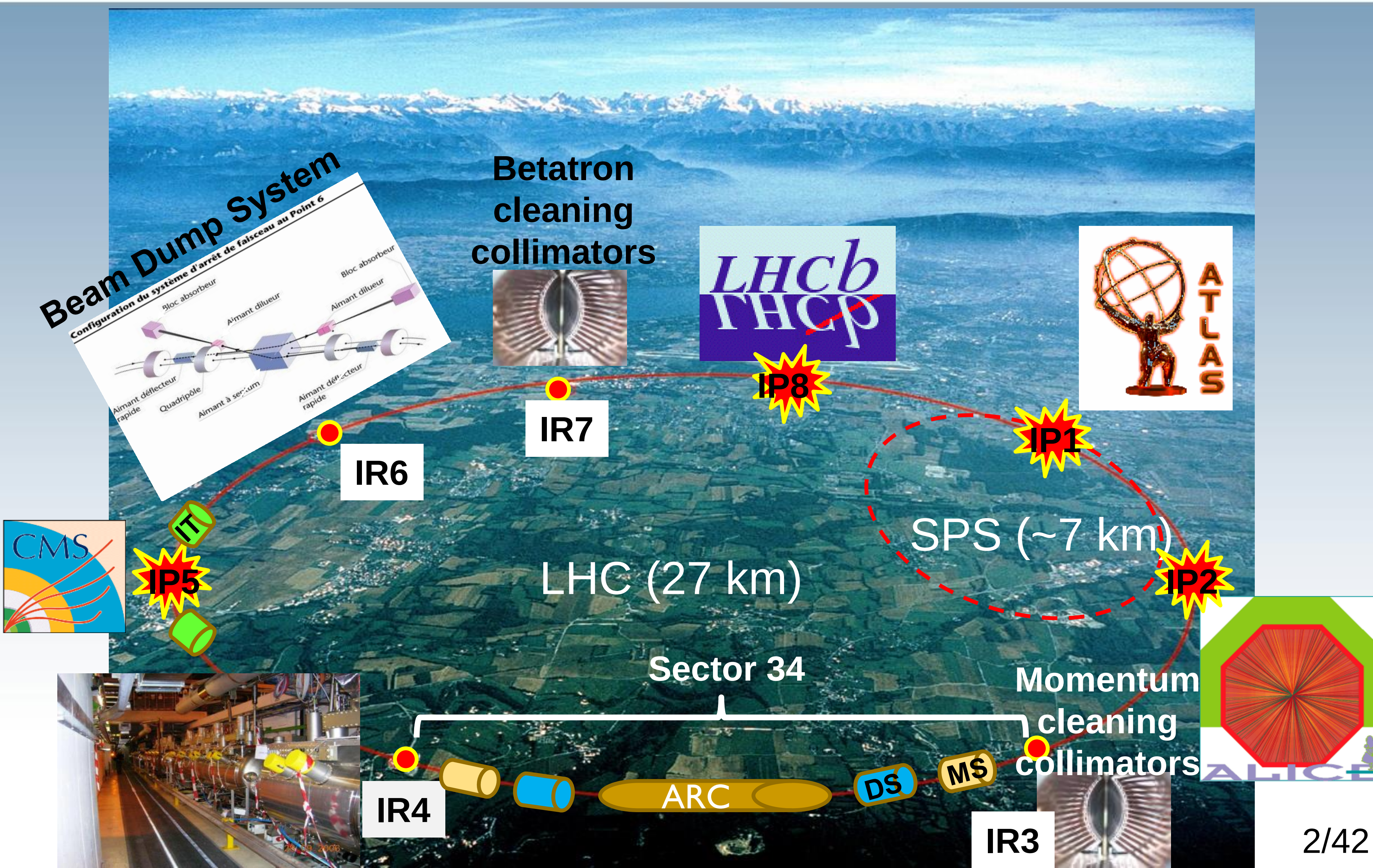
We are here to learn, so please interrupt whenever you don't understand or have a question

The Large Hadron Collider

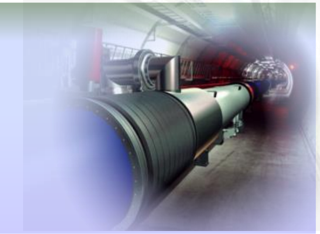
I. LHC layout
II. LHC Operational cycle
III. Beam measurements



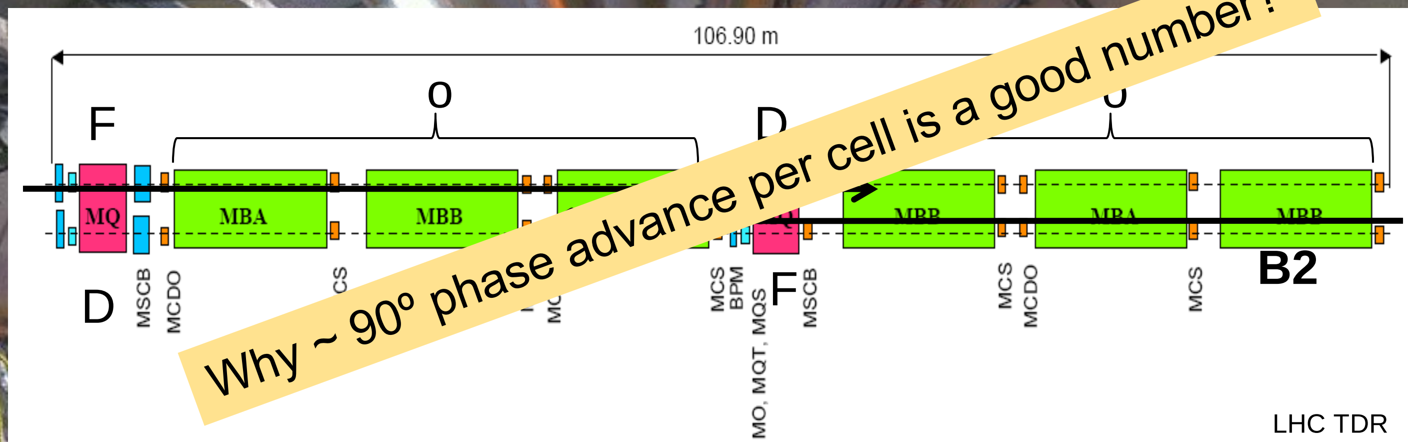
I. Basic layout of the machine



I. Basic layout of the machine: the arc



LHC arc cells = FoDo lattice* with ~ 90º phase advance per cell in the V & H plan



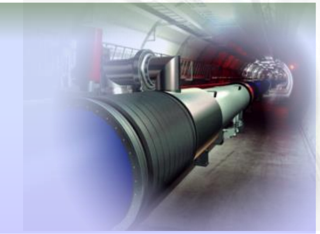
Why ~ 90º phase advance per cell is a good number?

MB: main dipole
MQ: main quadrupole
MQT: Trim quadrupole
MQS: Skew trim quadrupole
MO: Lattice octupole (Landau damping)
MSCB: Skew sextupole + Orbit corrector (lattice chroma+orbit)
MCS: Spool piece sextupole
MCDO: Spool piece octupole + Decapole
BPM: Beam position monitor

The FoDo-Lattice

A magnet structure consisting of focusing and defocusing quadrupole lenses in alternating order with nothing in between.
(Nothing = elements that can be neglected on first sight: drift, bending magnets, RF structures ... and especially experiments...)

I. Basic layout of the machine



Golden formula (you should know by heart)

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

Circumference ➔ FIXED!!! by LEP

FIXED, no choice

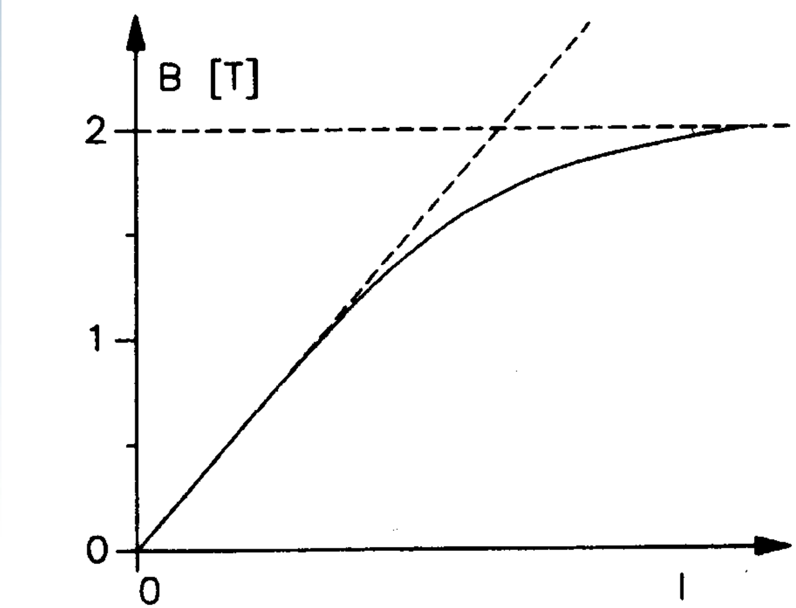
$$\rho \approx \frac{26658.9\ m}{2\pi} \cdot 66\% \approx 2780\ m$$

~ 66% of the lattice elements are dipoles

p = nucleon momentum ➔ defined by the physics case ➔ TeV range ➔ **7 TeV**

$$B = \frac{p}{\rho Z e} \approx 3.33 \frac{p\left(\frac{GeV}{c}\right)}{\rho(m)} = 8.39\ T$$

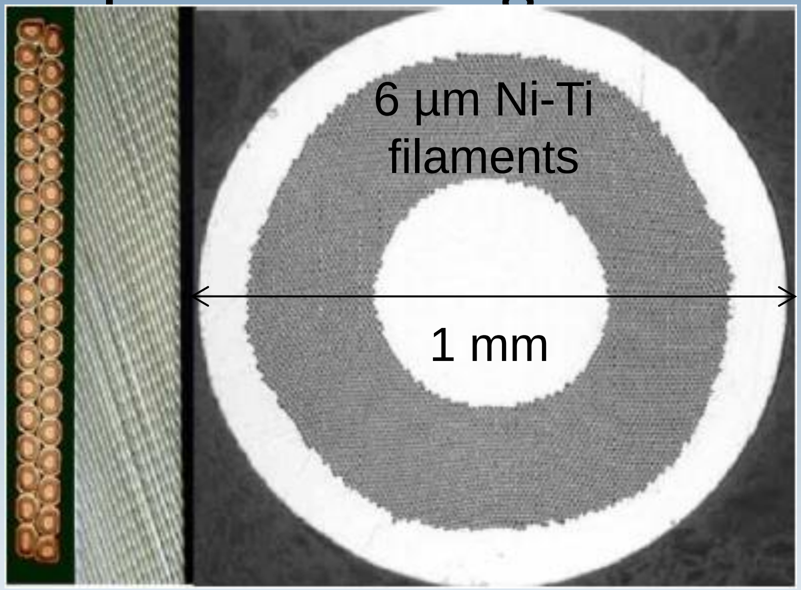
We need SUPERCONDUCTING technology



Field limit for normal conducting magnets due to saturation

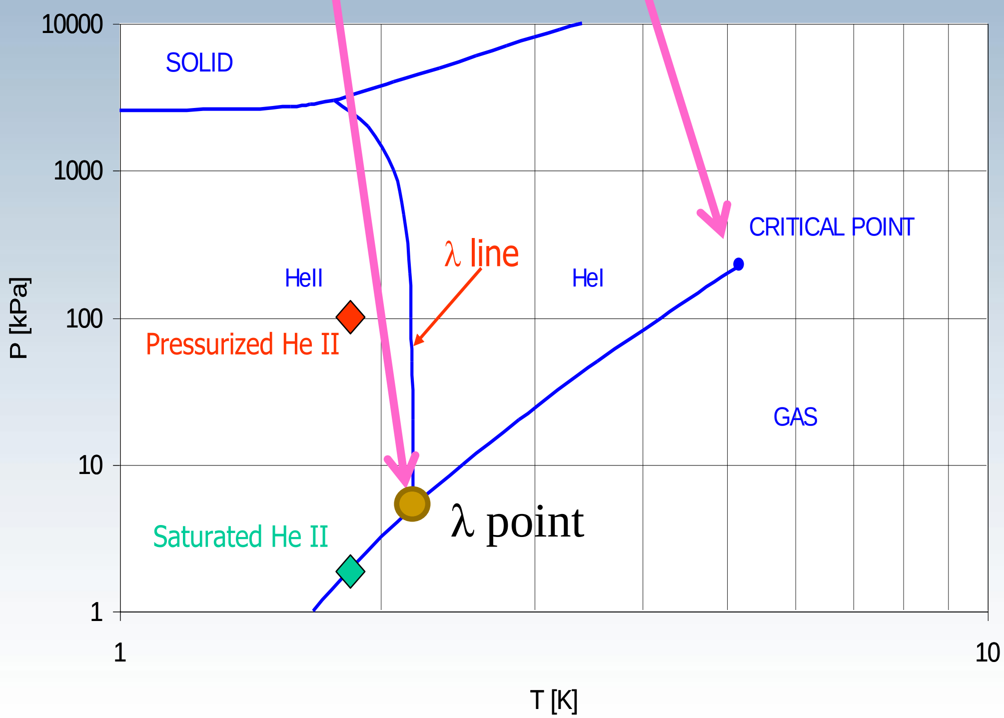
I. Basic layout of the machine: Superconducting magnets

Superconducting cables of Nb-Ti



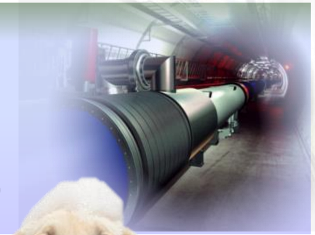
LHC ~ 27 km circumf. with 20 km of superconducting magnets operating @8.3 T. An equivalent machine with normal conducting magnets would have a circumference of 100 km and would consume 1000 MW of power ➔ we would need a dedicated nuclear power station for such a machine. LHC consumes ~ 10% nuclear power station

He gas ➔ liquid @ 4.2 K ➔ superfluid @ 2.17 K

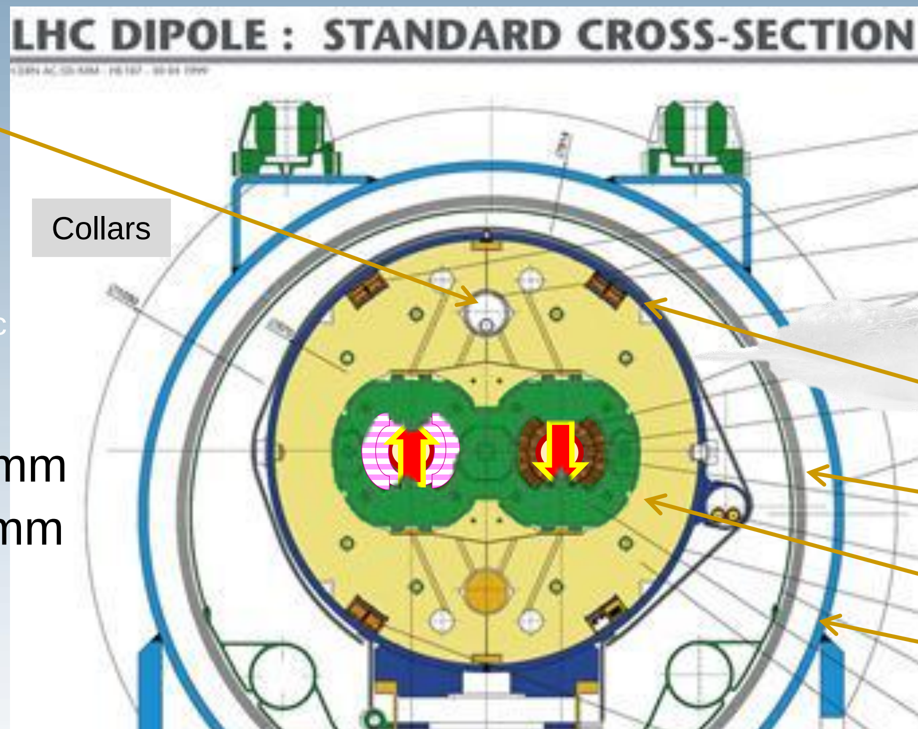


Total amount of He used @LHC ~500-700 T

I. Basic layout of the machine: main cryodipoles (two dipoles in one)



- The geometry of the main dipoles (Total of 1232 cry…s)

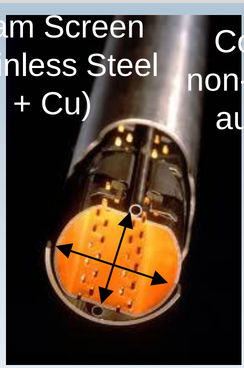


Heat exchanger

Beam pipe (Ultrahigh **beam** vacuum 10^{-10} Torr like at 1000 km over see level)

Collars

Beam Screen (Stainless Steel + Cu)



Cold bore non-magnetic austenitic steel

36.9 mm

46.5 mm

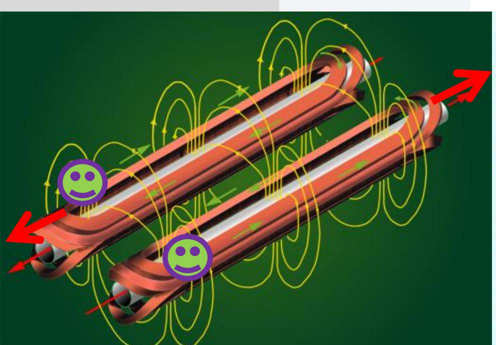
He Vessel

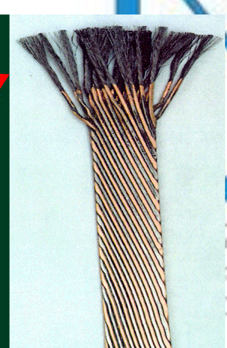
Thermal shield

Iron yoke

Vacuum vessel (10^{-6} mbar)

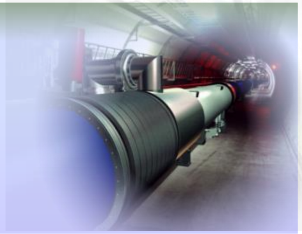
Superconducting coils

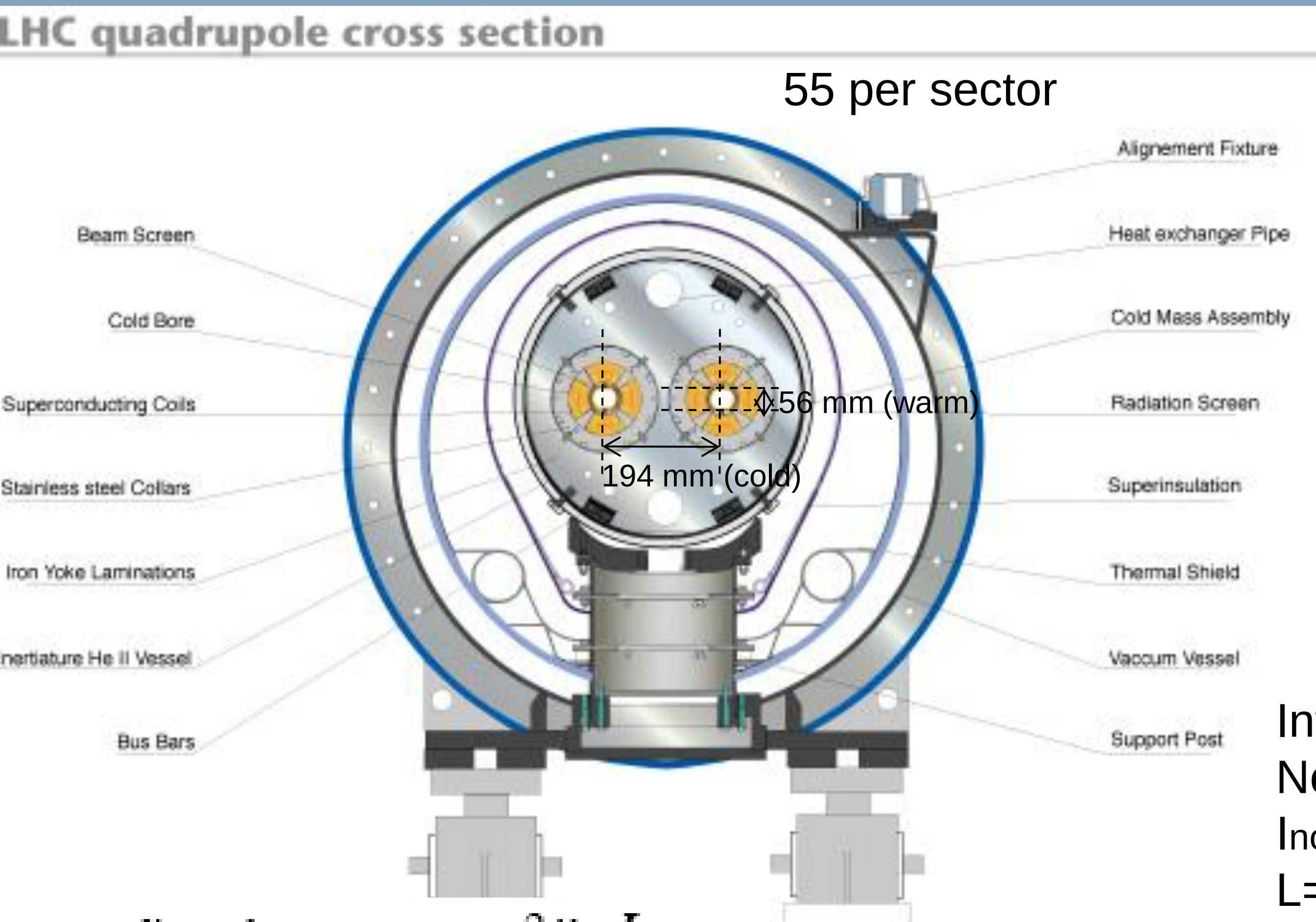




L ~ 15 m
8.3 T, 11.87 kA
T = 1.9 K, ~27.5 ton

I. Basic layout of the machine: main quadrupoles





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gradient of a quadrupole magnet:

$$g = \frac{2\mu_0 n I}{r^2}$$

Integrated gradient = 690 T
Nominal gradient = 223 T/m
$I_{nominal}$ = 11.87 kA
L=3.1 m

I. Basic layout of the machine: main dipoles ➔ Field quality

The magnetic field of the main dipoles:

The **stability** of the geometry of the superconducting coils is essential to the field quality.

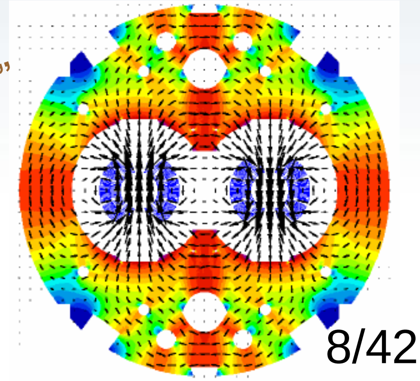
Mechanical stress during coil assembly
Thermal stresses during cool-down
Electromagnetic stresses during operation

= **sources of deformations** of the coil geometry

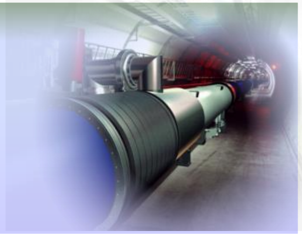
Additional sources of field errors are the **dimensional tolerances** of the magnet components and of the manufacturing and assembling tooling.

The relative variations of the integrated field and of the field shape imperfections must not exceed ~ 10^{-4} and their reproducibility better than 10^{-4}

Reference: LHC Project Report 501
"Field Quality Specification for the LHC Main Dipole Magnets"



I. Basic layout of the machine: main dipoles ➔ Field quality



Why the tolerances are so tight?

➔ Because the field quality determines how long the particles can circulate in the accelerator

$$B_y + iB_x = B_{ref} \sum_{n=1}^{\infty} (b_n + i a_n) \left(\frac{x + iy}{R_{ref}} \right)^{n-1}$$

Normal harmonic

Skew harmonic

17 mm

n = 1 ➔ dipole

n = 2 ➔ quadrupole

n = 3 ➔ sextupole

n = 4 ➔ octupole

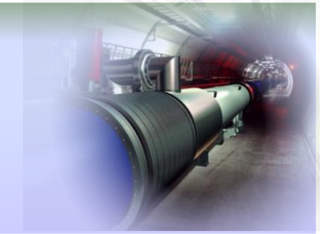
n = 5 ➔ decapole

Up to which order do we care?

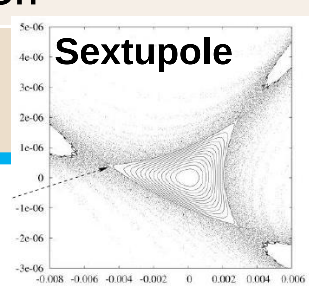
➔ Up to n = 7 at least

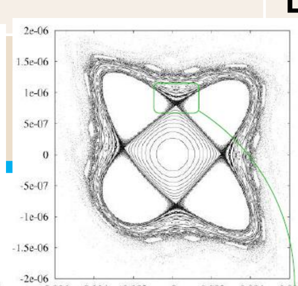
$\sim 10^{-4}$

I. Basic layout of the machine: main dipoles → Field quality



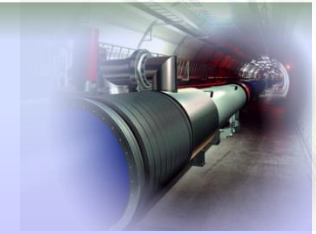
Error	Side effects if error is > few 10^{-4}	Corrected with
a1	Closed orbit perturbations and thus feed-down contributions from higher order multiple errors	Dipole correctors (MCB)
b1		
a2	Linear coupling and vertical dispersion	Skew quadrupoles (MQS)
b2	Tune change, β and dispersion beating	Trim quadrupoles (MQT)
a3	Chromatic coupling and Q”	Skew sextupoles (MSS)
b3	b2 feed-down at injection (persistent current effect) and off-momentum β-beat	Sextupole (MCS)
a4	Dynamic aperture (DA) at injection	
b4	DA and Q” at injection	Octupole (MCO)
a5	DA for off-momentum particles at injection	
b5	DA and Q”’ at injection	Decapole (MCD)
a6 to b7	DA at injection	

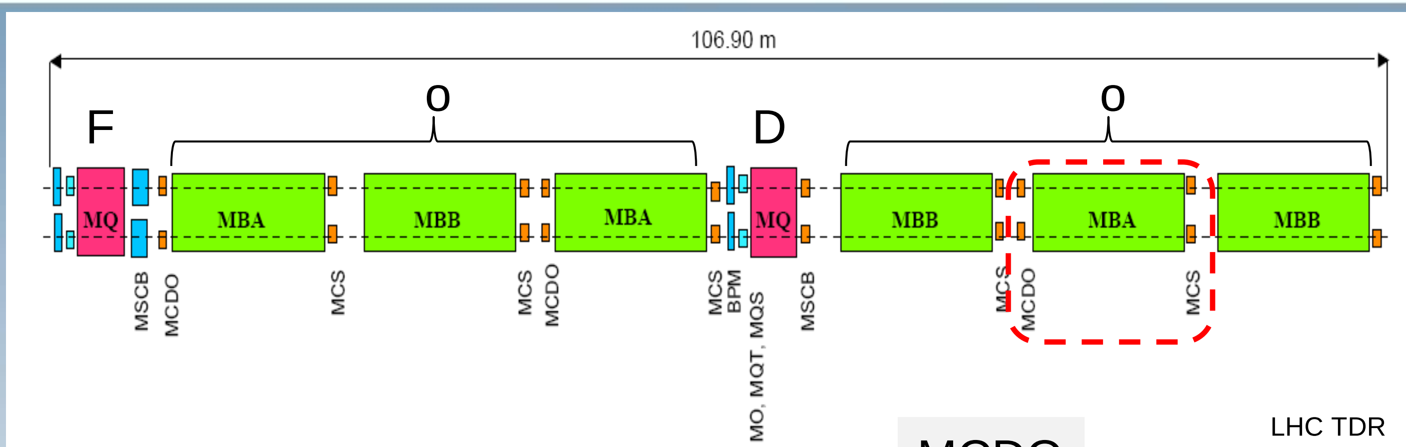




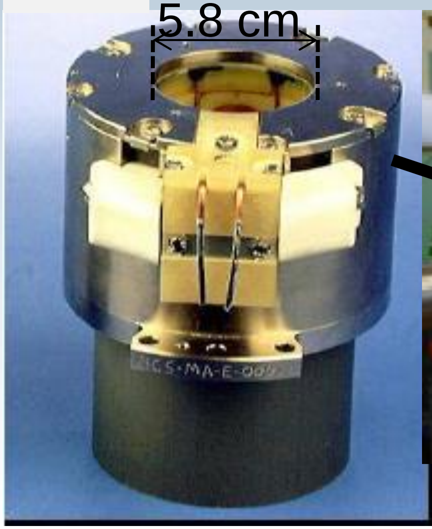
Sextupole+octupole

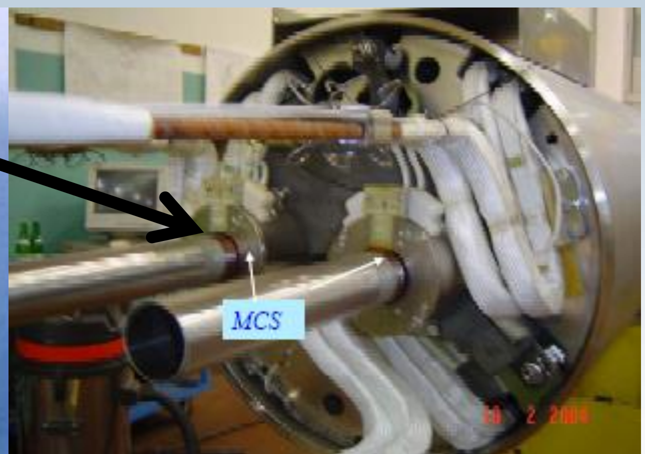
I. Basic layout of the machine: dipole corrector magnets



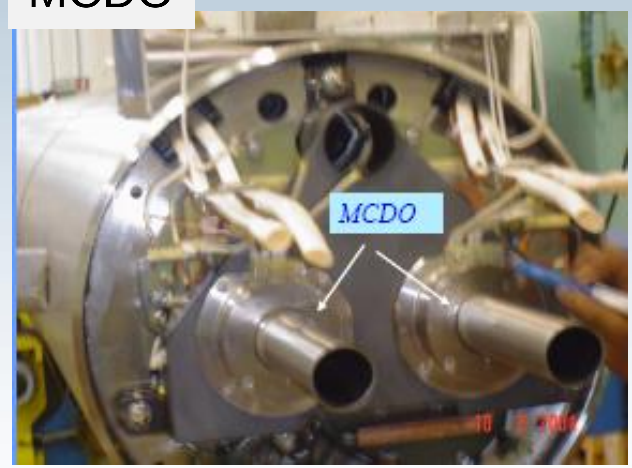


MCS





MCDO

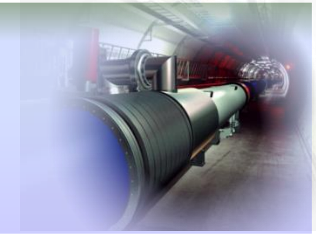


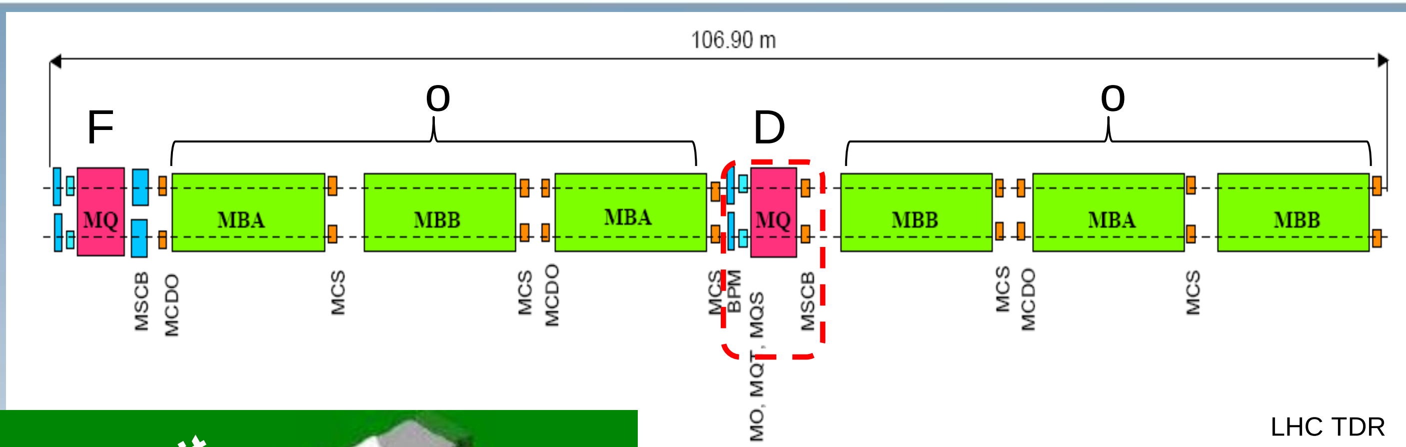
Nominal main field strength = 1630 T/m^2
Inominal = 550 A, 1.9 K,
L=15.5 cm, ~10 kg

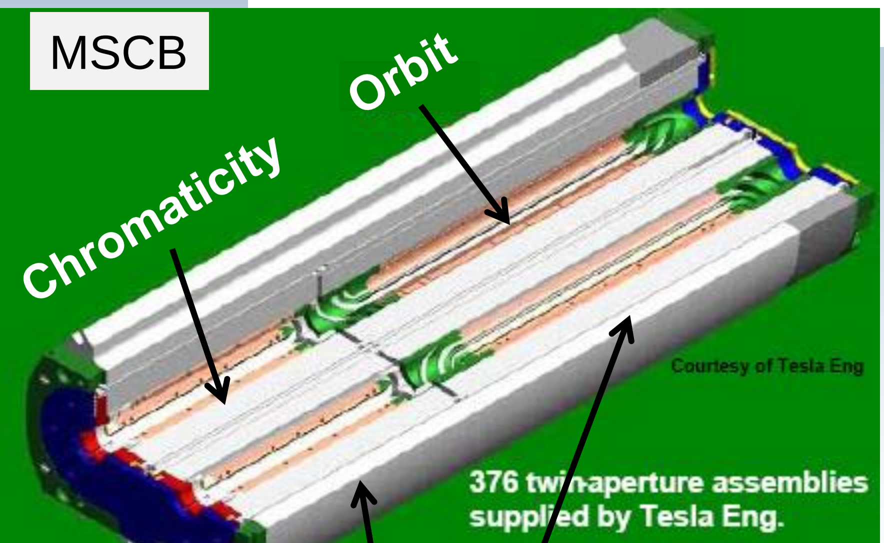
MCD:
Nominal main field strength ~ 120 T/m^4
Inominal = 550 A, 1.9 K,
L=11 cm, ~6 kg

MCO:
Nominal main field strength = 8200 T/m^3
Inominal = 100 A, 1.9 K,
L=11 cm, ~6 kg

I. Basic layout of the machine: quadrupole corrector magnets



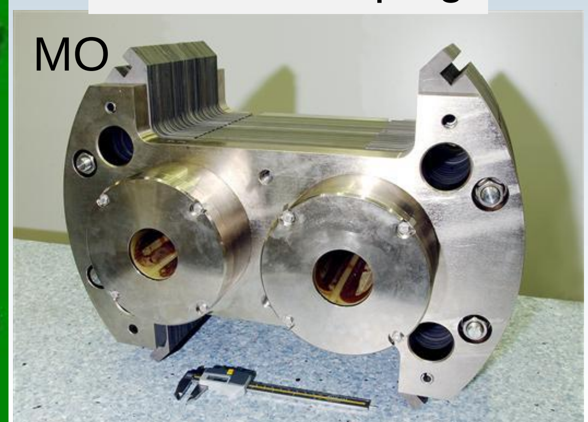




MSM (sextupole):
Nominal main field strength = 4430 T/m^2
$I_{nominal}$ = 550 A, 1.9 K,
L=45.5 cm, ~83 kg

MCBM (dipole):
Nominal main field strength = 2.93 T
$I_{nominal}$ = 55 A, 1.9 K,
L=78.5 cm, ~143 kg

Landau damping

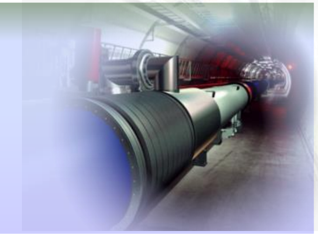


Nominal main field strength = 63100 T/m^3
$I_{nominal}$ = 550 A, 1.9 K
L=38 cm, ~8 kg

MQT/MQS

MQT: Trim quadrupole
MQS: Skew trim quadrupole

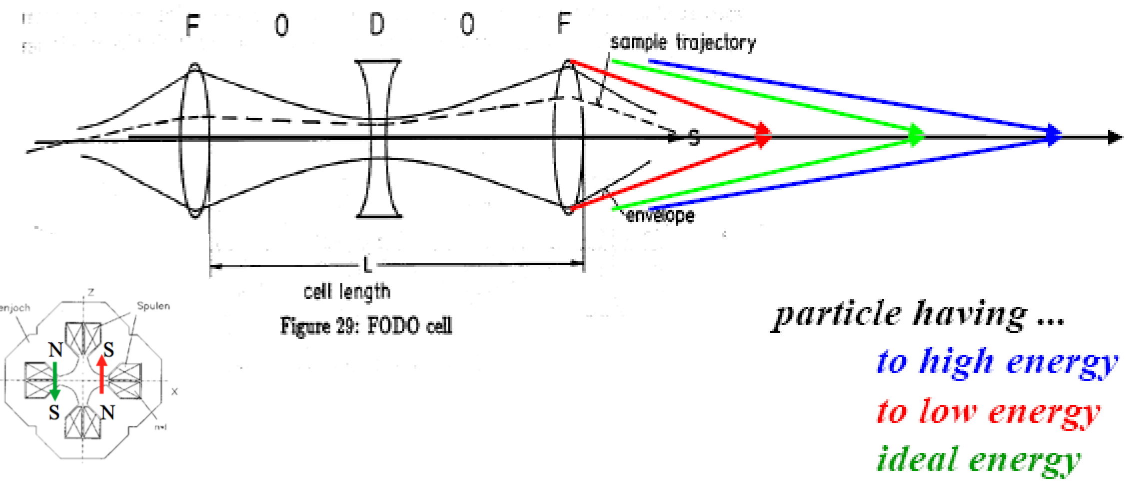
MQT/MQS:
Nominal main field strength = 123 T/m
$I_{nominal}$ = 550 A, 1.9 K
L=38 cm, ~250 kg



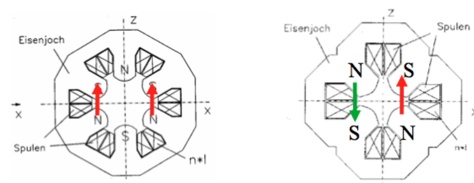
20.) Chromaticity: A Quadrupole Error for $\Delta p/p \neq 0$

focusing lens

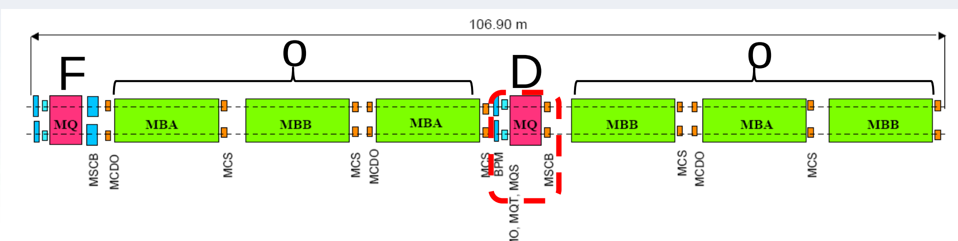
$$k = \frac{g}{p/e}$$



Sextupole Magnets:



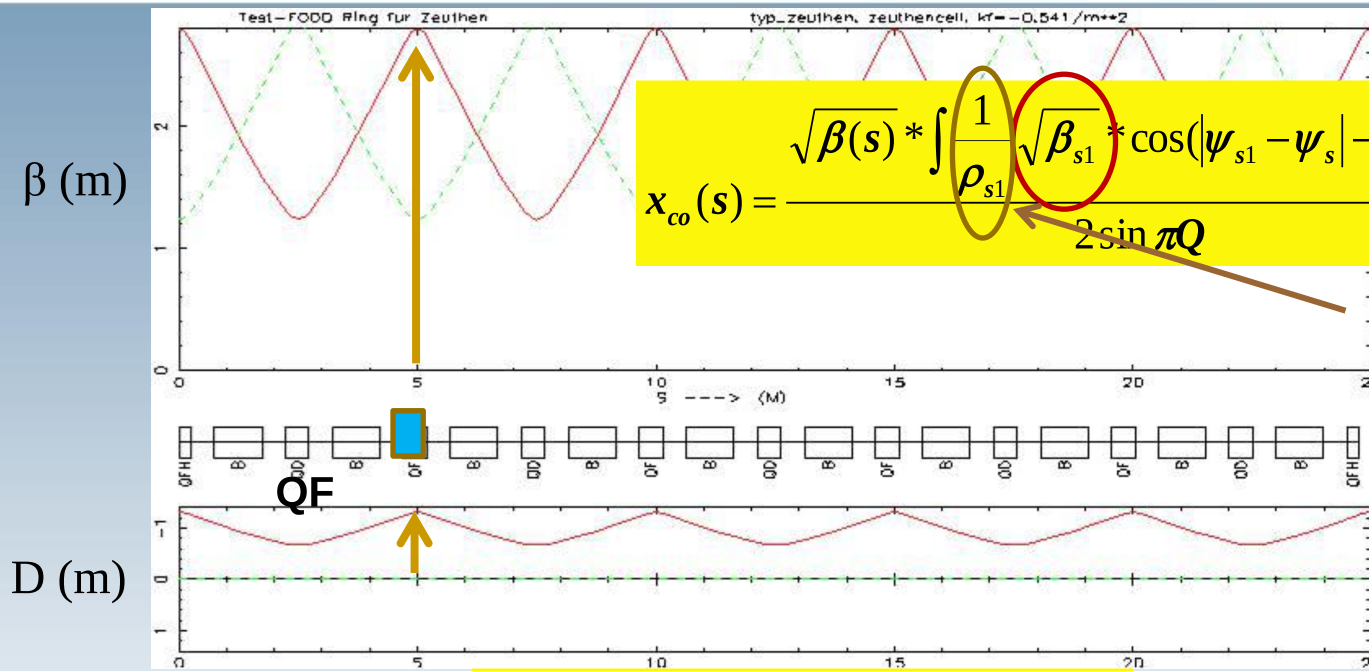
(Courtesy of B. Holzer)



Why the orbit and sextupole correctors are placed close to a quadrupole?

LHC TDR

I. Basic layout of the machine: quadrupole corrector magnets



$$x_{co}(s)=\frac{\sqrt{\beta(s)}*\int\frac{1}{\rho_{s1}}\sqrt{\beta_{s1}}*\cos(|\psi_{s1}-\psi_{s}|-\pi Q)\,ds}{2\sin\pi Q}$$

Magnet strength

$$Q'=-\frac{1}{4\pi}\oint k_{qua}(s)\beta(s)ds+$$ (Natural chromaticity term)

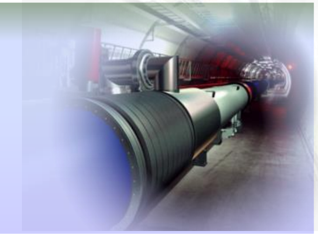
Chromaticity correction terms

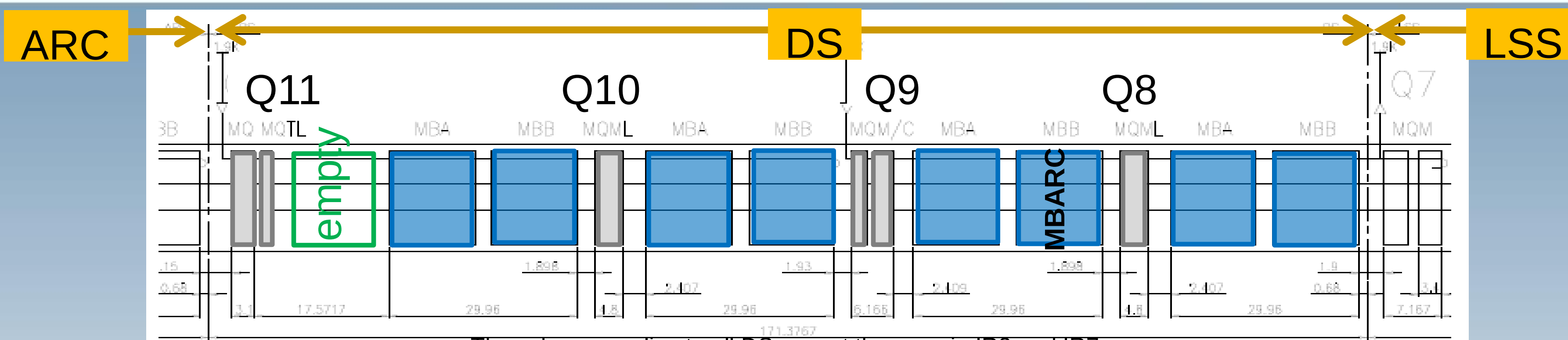
$$+\frac{1}{4\pi}\sum_{FocuSext}k_{sext}^{focu}l_{sext}D_x^{focu}\beta_x^{focu}-$$

$$-\frac{1}{4\pi}\sum_{DeFocuSext}k_{sext}^{defocu}l_{sext}D_x^{defocu}\beta_x^{defocu}$$

I. Basic layout of the machine

I. Basic layout of the machine: Dispersion suppression





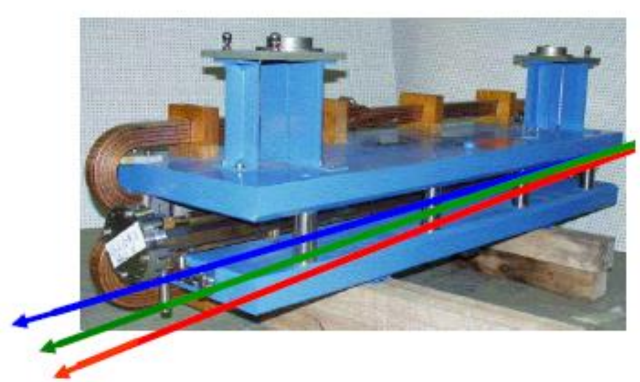
The schema applies to all DS except the ones in IR3 and IR7

- **Cancels the horizontal dispersion** generated on one side by the arc dipoles and on the other by the separation/recombination dipoles and the crossing angle bumps
- Helps in **matching** the insertion optics to the periodic solution of the arc
- If only dipoles are used they cannot fully cancel the dispersion, just by a factor 2.5. Therefore **individual powered quadrupoles are required** (Q8-Q11 with I ~ 6000 A)

dipole magnet

$$\boxed{\alpha = \frac{\int B\,dl}{p/e}}$$

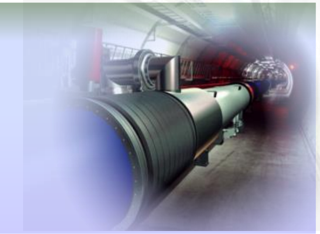
(Courtesy of B. Holzer)

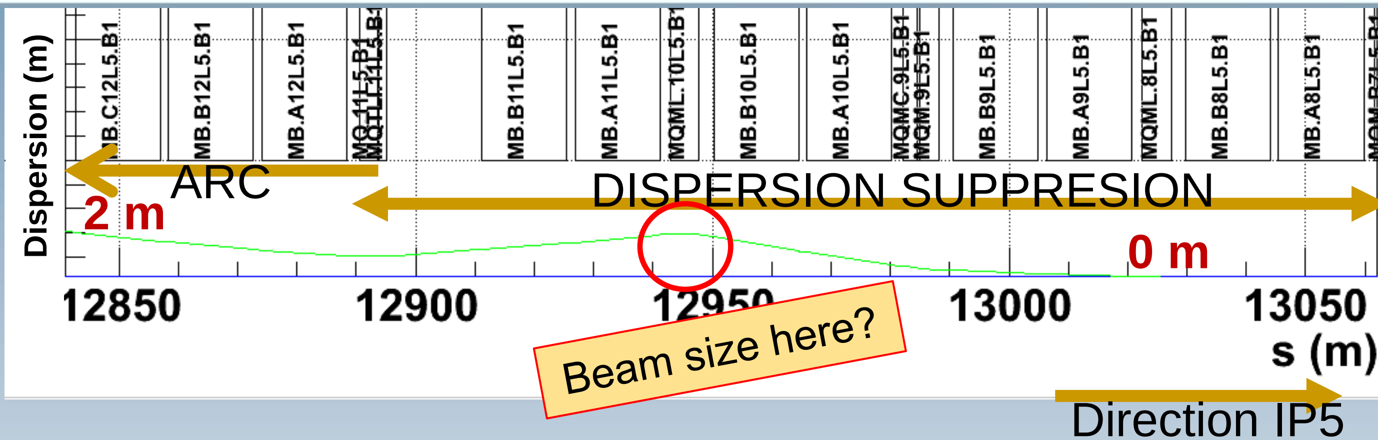


$$x'' + K(s)x = \frac{1}{\rho}\frac{\Delta p}{p}$$

$$x(s) = x_\beta(s) + D(s)\frac{\Delta p}{p}$$

I. Basic layout of the machine: Dispersion suppression





D(s) is **created by the dipole magnets** and afterwards **focused by the quadrupoles**

The inhomogeneous solution **changes the beam size** …

$$\varepsilon = \frac{\varepsilon_n}{\beta_{rel}\gamma_{rel}}$$

$$\sigma = \sqrt{\sigma^2_\beta + \sigma^2_D} = \sqrt{\varepsilon\beta + D^2\left(\frac{\Delta p}{p}\right)^2}$$

At 7 TeV in LHC: ε_n=3.5 μm rad, β=180 m,D=2 m, Δp/p ~ 10^{-3}

$$\sigma = \sqrt{0.084\cdot 10^{-6} + 4\cdot 10^{-6}} \cong \boldsymbol{\sigma_D}$$

What is the beam size at 450 GeV?

$\sigma = \sqrt{\frac{\varepsilon_n}{\beta\gamma}\beta + D^2\left(\frac{\Delta p}{p}\right)^2}$ ➔ γ(@7 TeV)~**7463** γ(@450 GeV)~**480 β≈1**

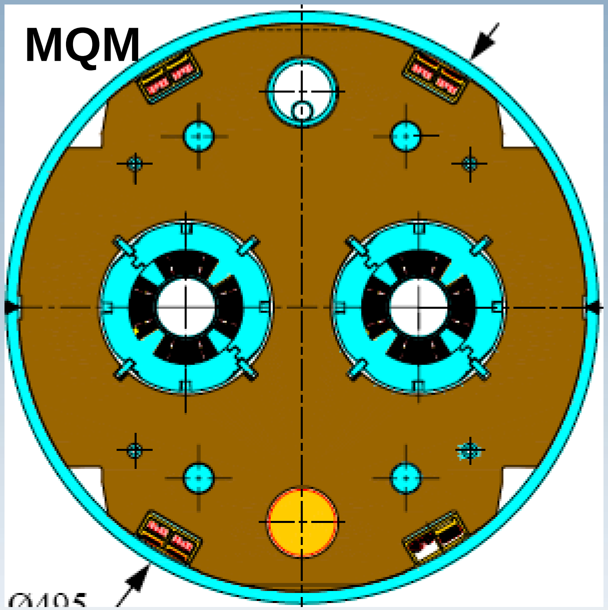
➔ $\sigma = \sqrt{1.3\cdot 10^{-6} + 4\cdot 10^{-6}} \cong \sigma_D + \boldsymbol{30\%\sigma_\beta}$

When you design your beam pipe you have to take into account the contribution of D(s)

Why do we suppress dispersion before reaching the IP?

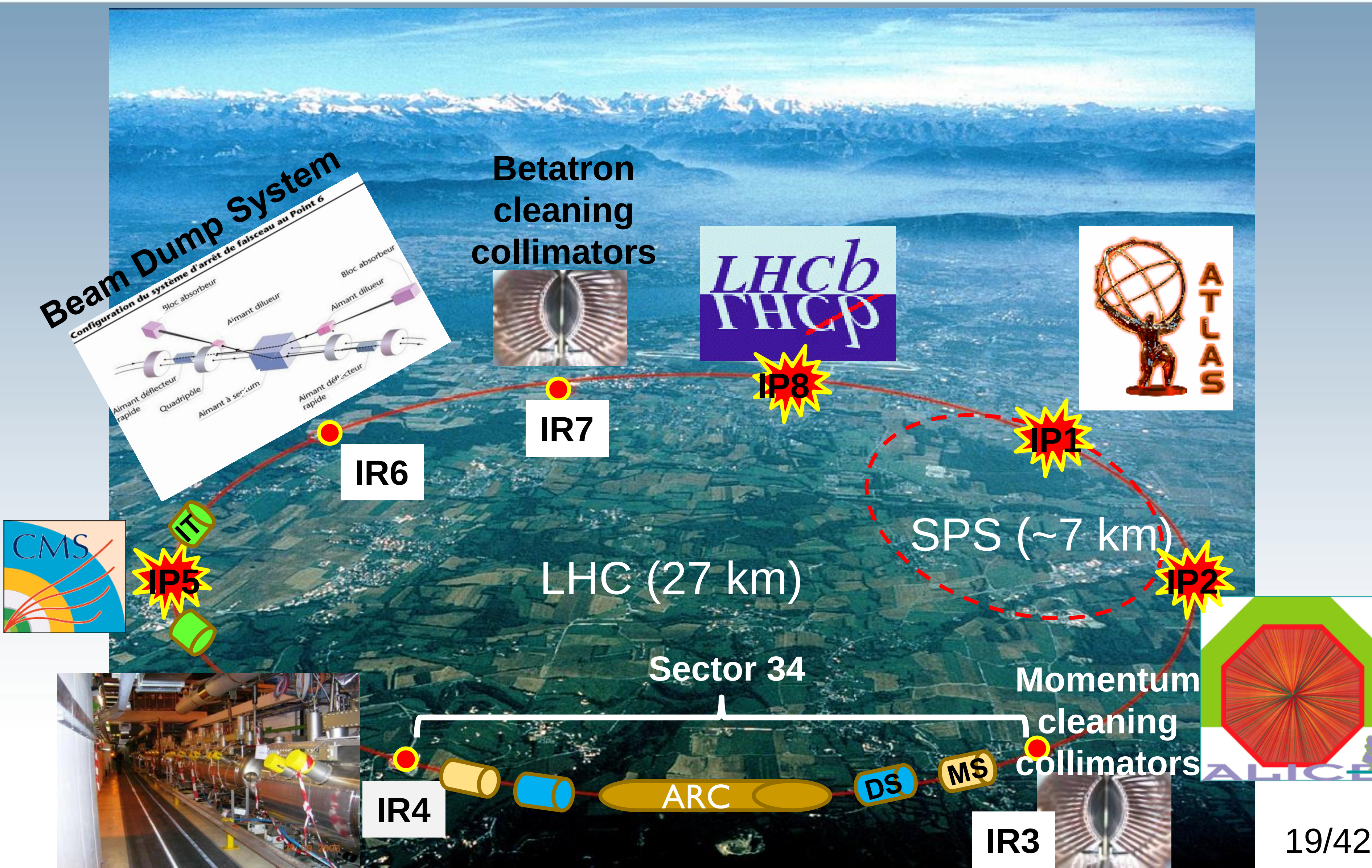
I. Basic layout of the machine: Dispersion suppression

- Quadrupole types: MQ, **MQM**, MQTL

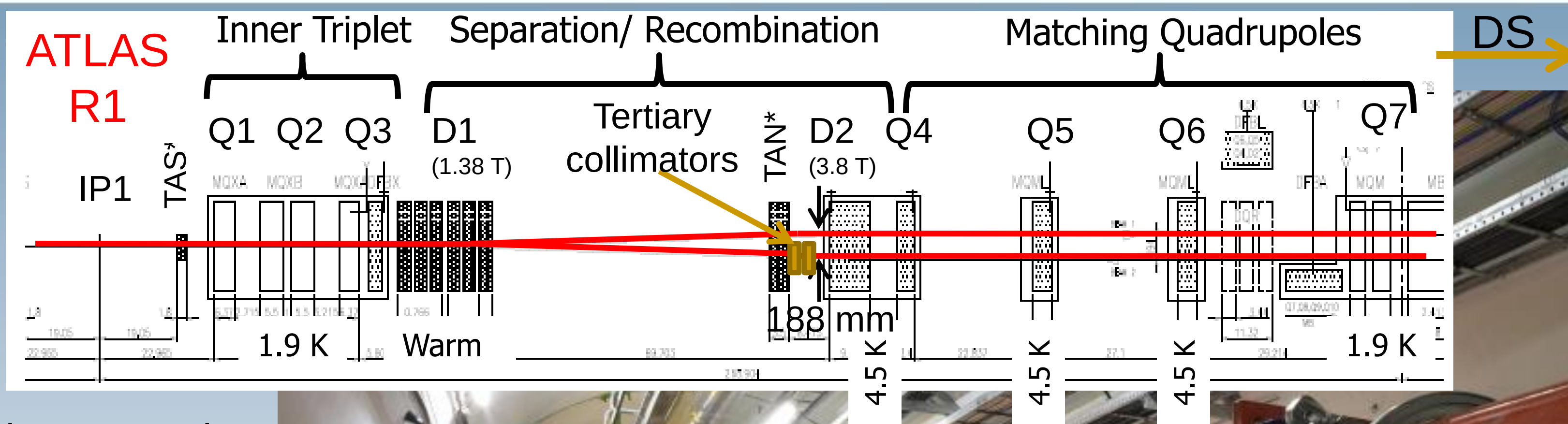


Nominal gradient = 200/160 T/m
$I_{nominal}$ = 5.4/4.3 kA
L_{mag}=2.4/3.4/4.8 m
T=1.9/4.5 K
Cold bore ∅ = 53/50 mm
Individual powered apertures

I. Basic layout of the machine



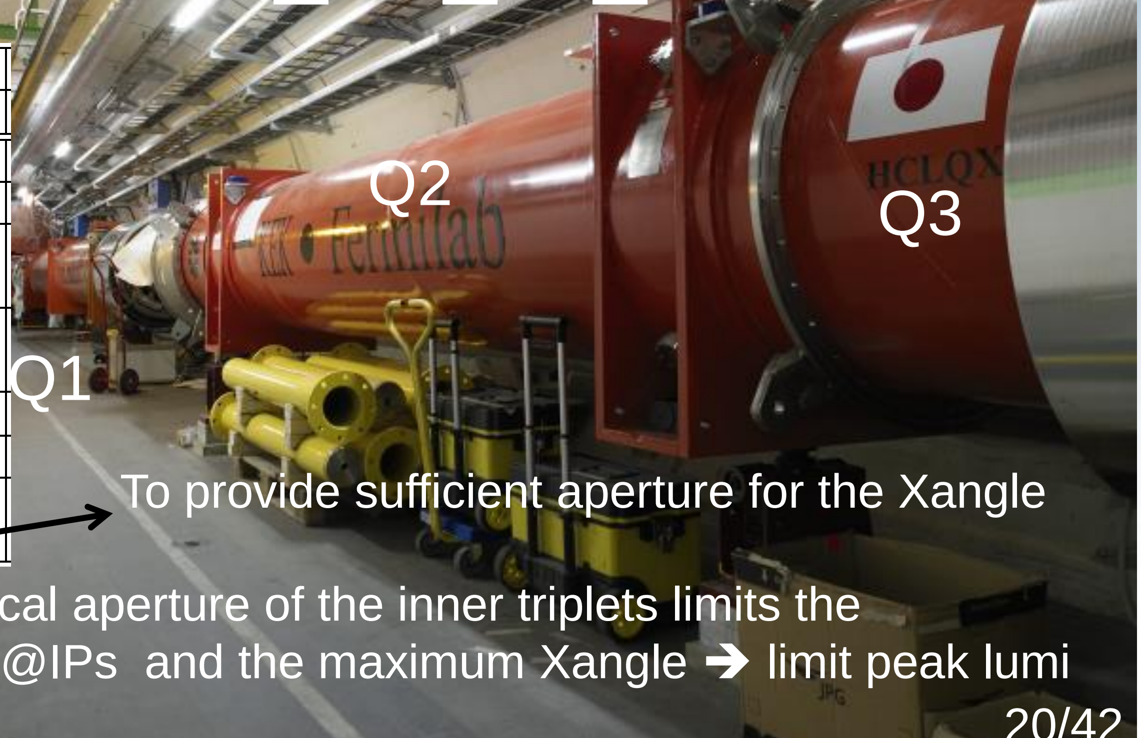
I. Basic layout of the machine: Luminosity insertions



6.45 kA 10.63 kA

	LSS						
	low-β triplet			MS			
Magnet	Q1	Q2	Q3	Q4	Q5	Q6	Q7
#	1	2	1	1	1	1	2
Type: MQ-	XL	X	XL	Y	ML		M
L [m]	6.3	5.5	6.3	3.4	4.8	4.8	3.4
T [K]	1.9			4.5			1.9
G [T/m]	200/205			160			200
r [mm]	23.85 18.95	28.95 24.05		29.0 24.0	22.5 17.6		22.2 17.3

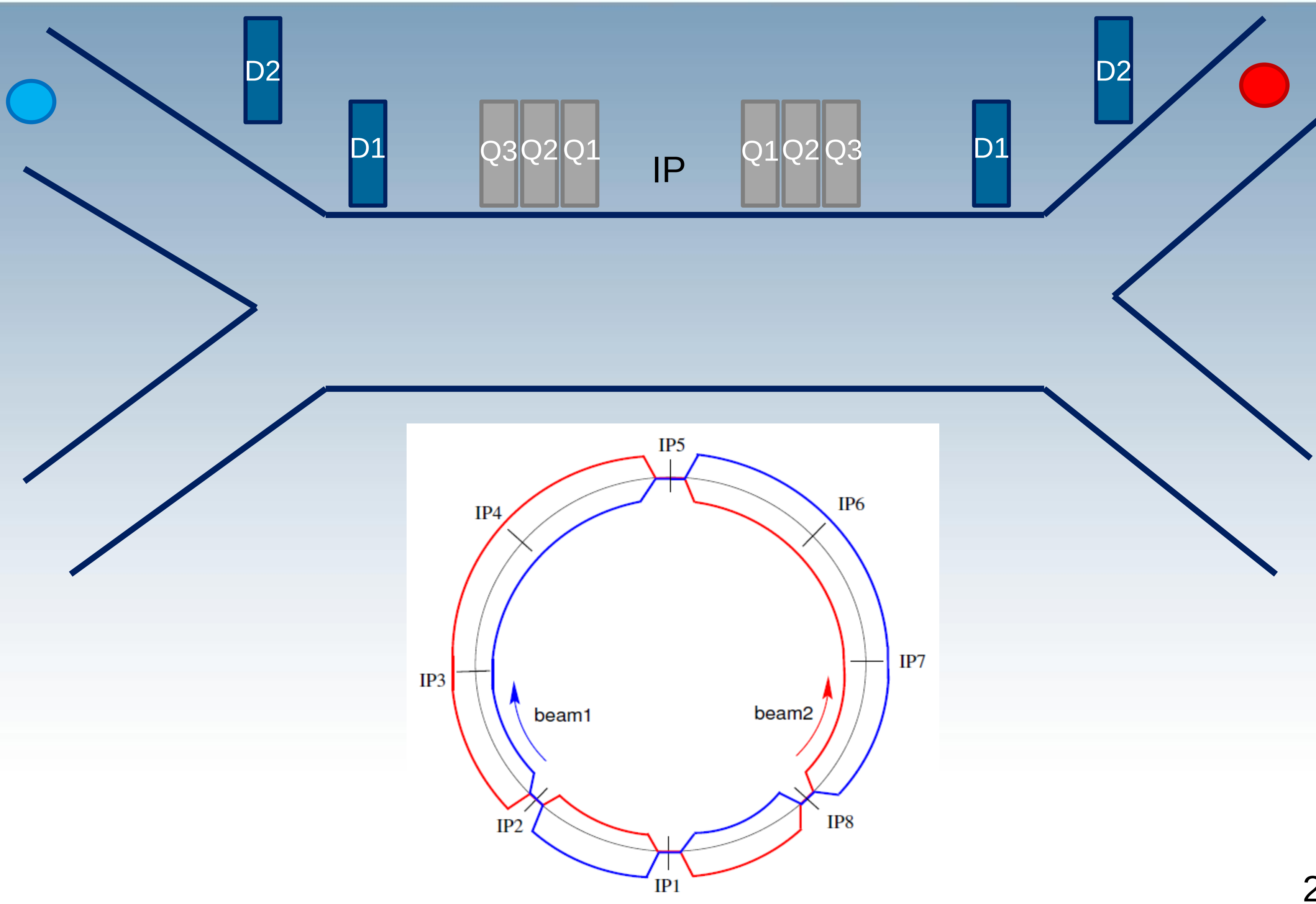
* Protect Inner Triplet (TAS) and D2 (TAN) from particles coming from the IP



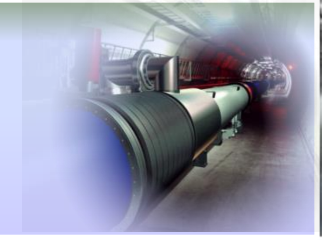
To provide sufficient aperture for the Xangle

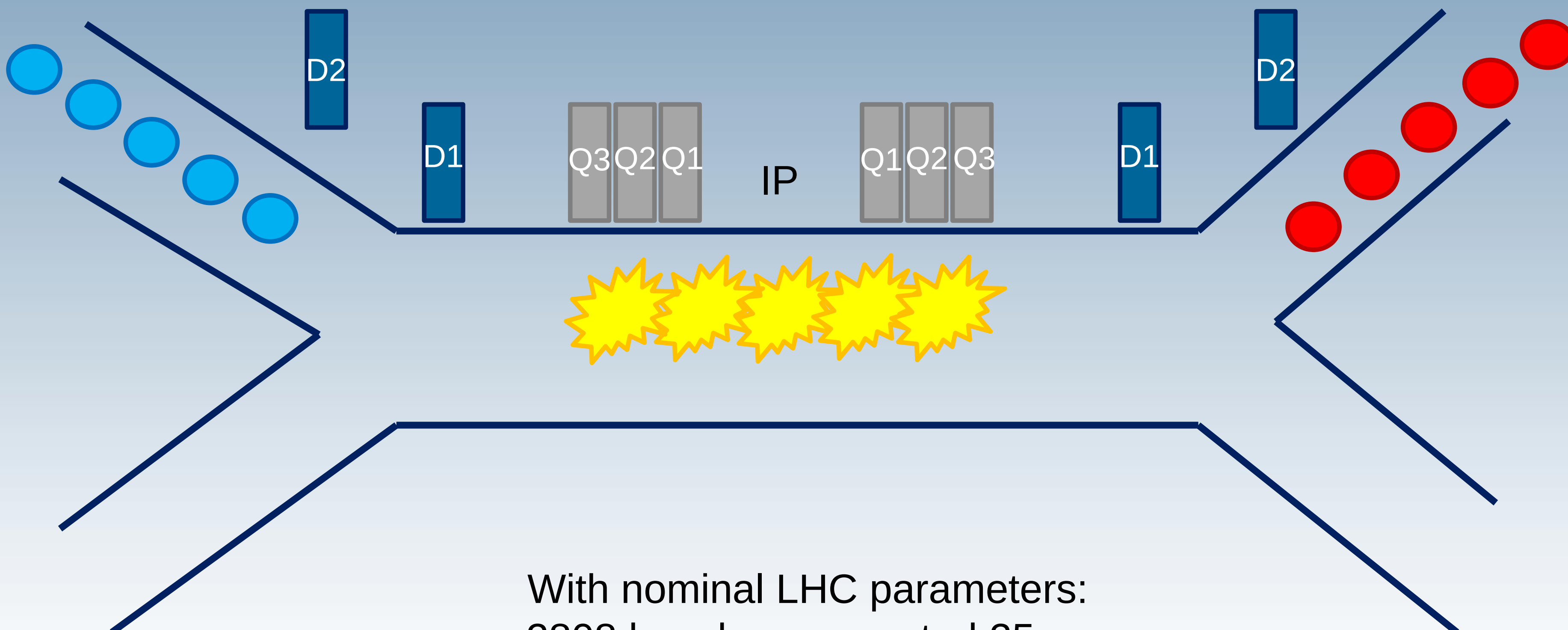
The mechanical aperture of the inner triplets limits the maximum β* @IPs and the maximum Xangle ➔ limit peak lumi

I. Basic layout of the machine: Luminosity insertions



I. Basic layout of the machine: Luminosity insertions

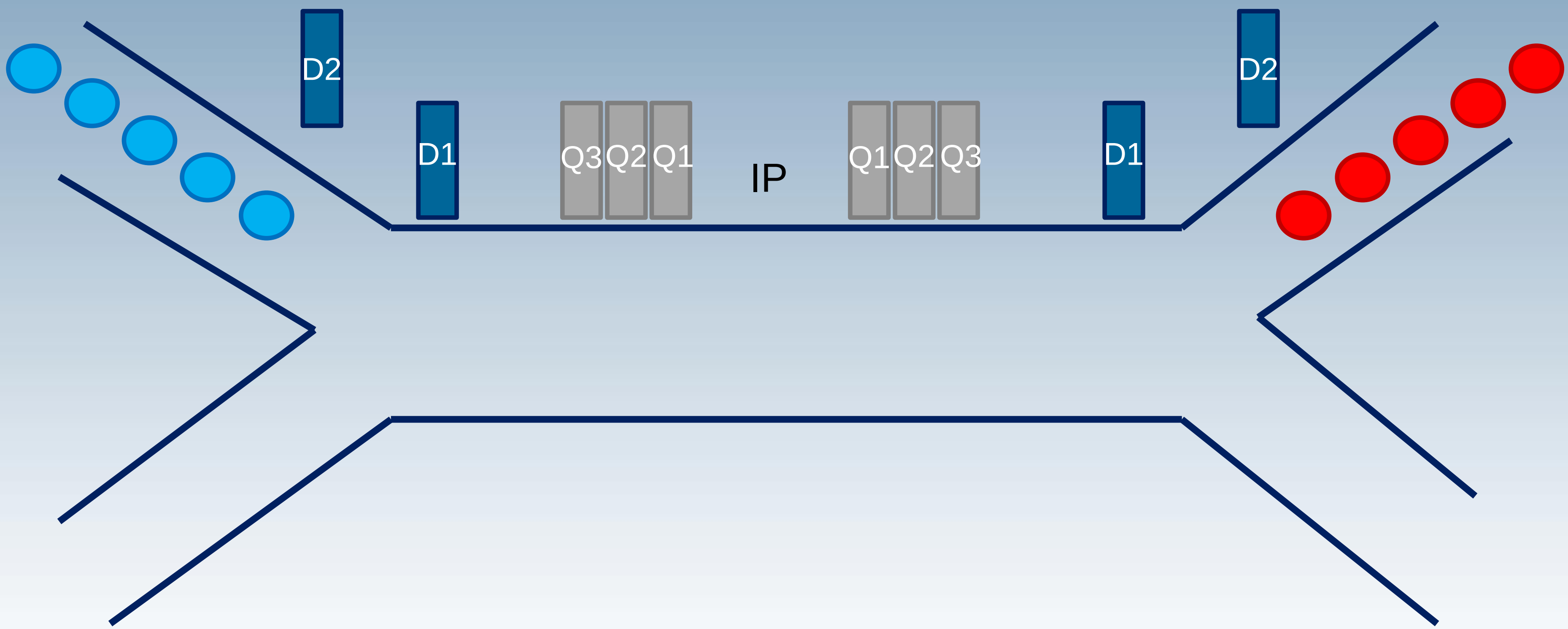


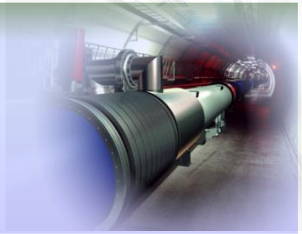


With nominal LHC parameters:
2808 bunches separated 25 ns

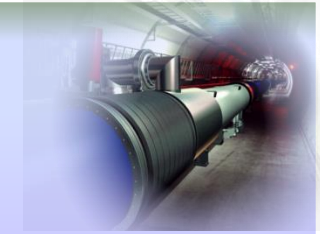
We can have up to **30 parasitic interactions** around the IP

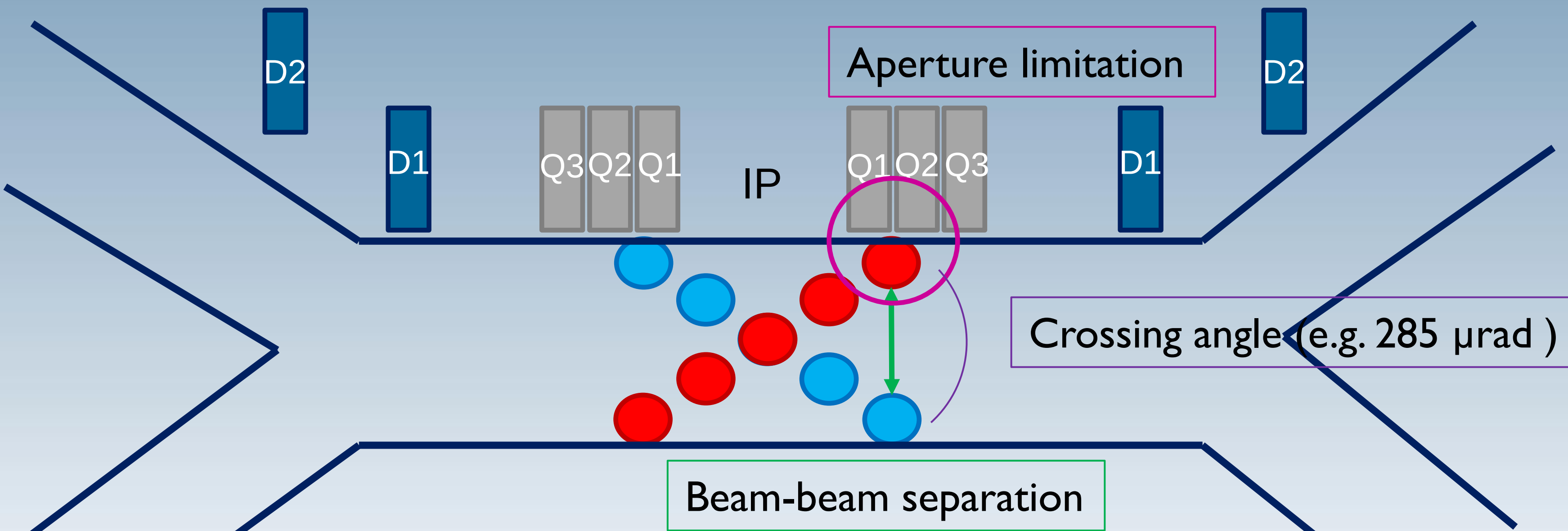
I. Basic layout of the machine: Luminosity insertions





I. Basic layout of the machine: Luminosity insertions





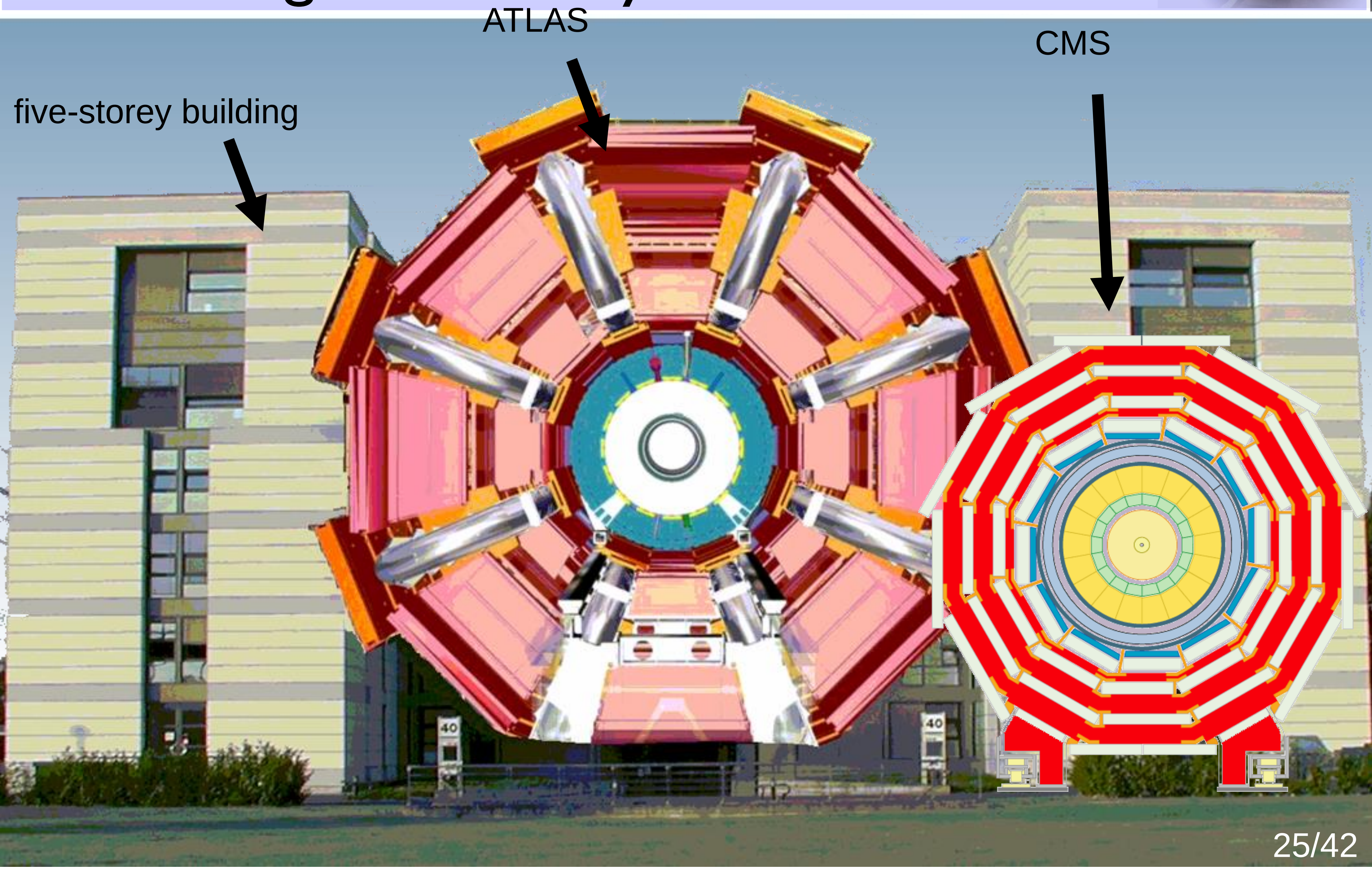
Beam-beam separation = f(σ)
Aperture limitation = f(σ, beam pipe size)

$$\sigma = \sqrt{\beta \frac{\varepsilon_n}{(\beta\gamma)_{rel}}}$$

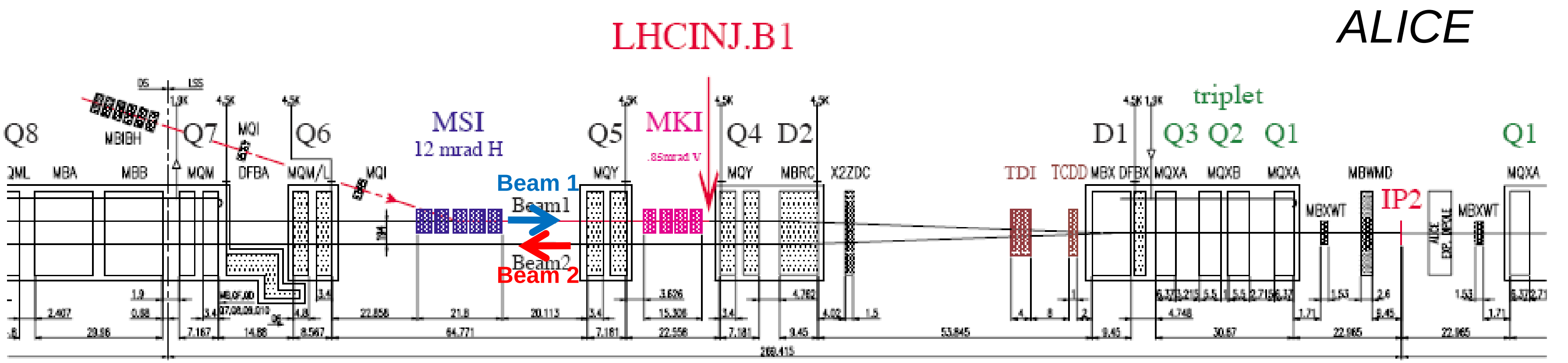
β is very small at the IP, but very big at the Inner triplets ➔ $\beta(s) = \beta^* + \frac{s^2}{\beta^*}$

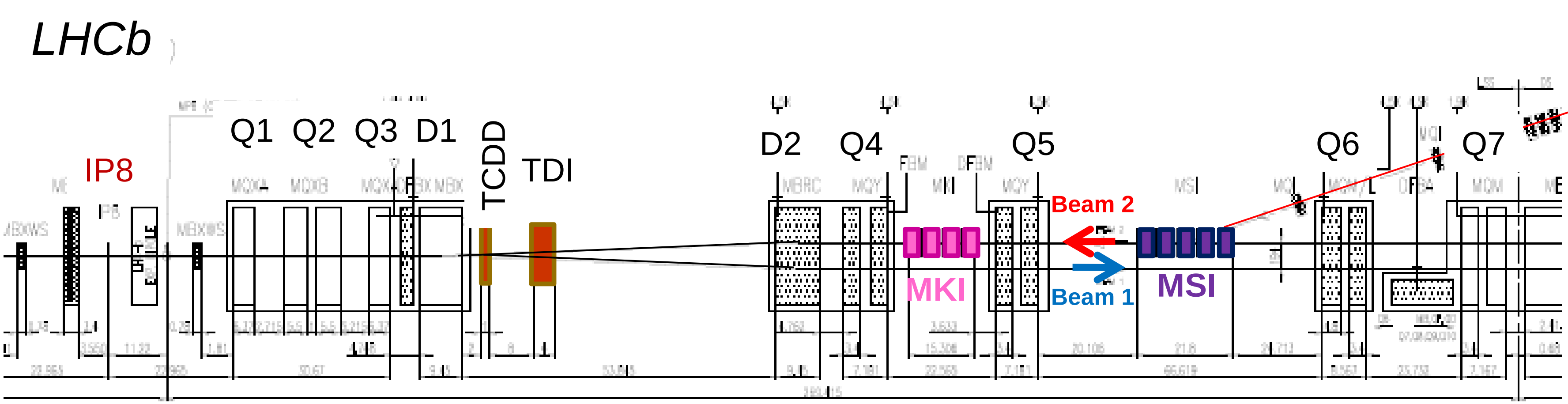
Therefore, the quadrupoles around the IP have such a big apertures

I. Basic layout of the machine: High luminosity insertions



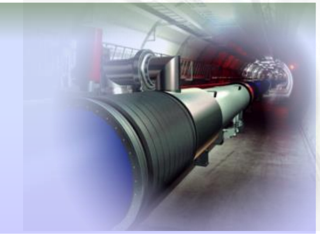
I. Basic layout of the machine: Low luminosity insertions



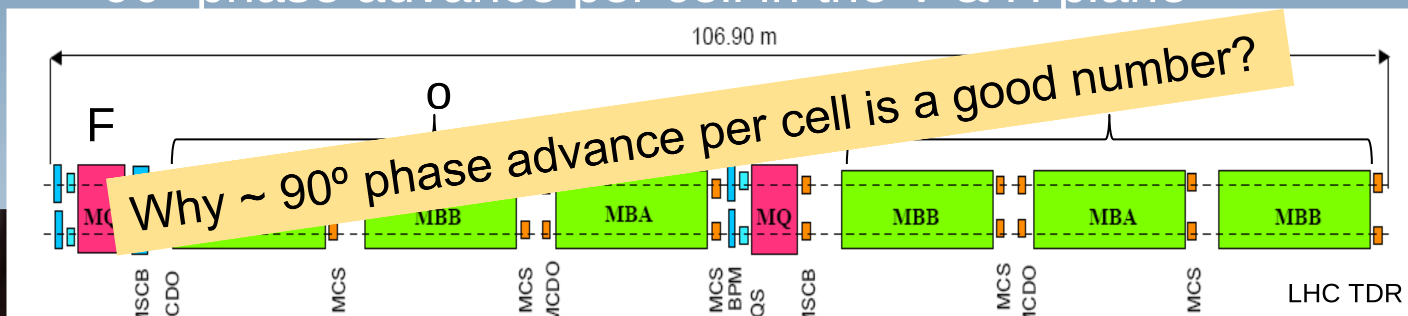


Extra challenge ➔ the lattice has to accommodate the injection region

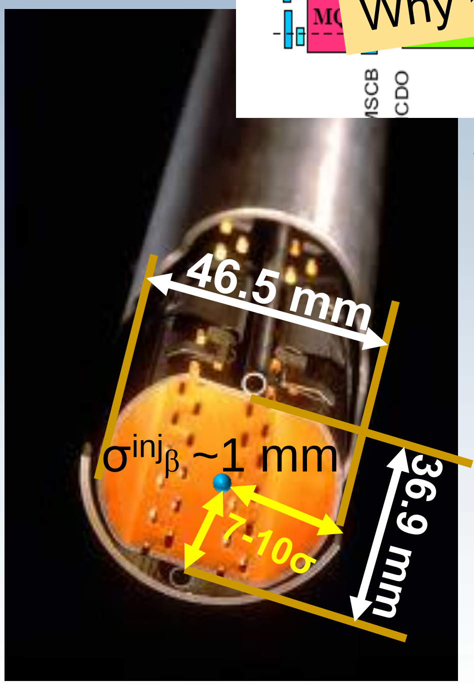
I. Basic layout of the machine



LHC arc cells = FoDo lattice* with
~ 90º phase advance per cell in the V & H plane



Why ~ 90º phase advance per cell is a good number?



Which parameter determines the beam size (ignoring D(s))?

$$r^2 = \varepsilon_x \beta_x + \varepsilon_y \beta_y$$

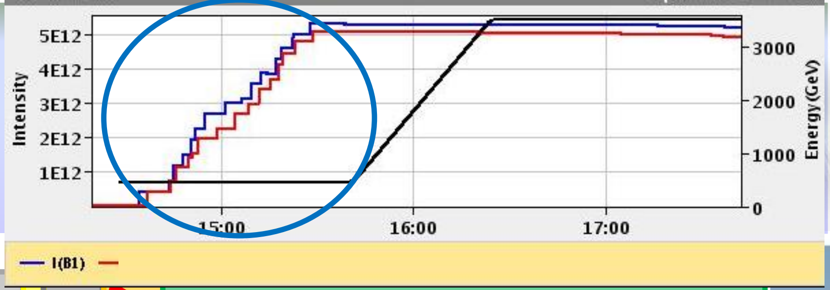
(In general in proton machines $\varepsilon x \approx \varepsilon y$ ➔ beams are round)

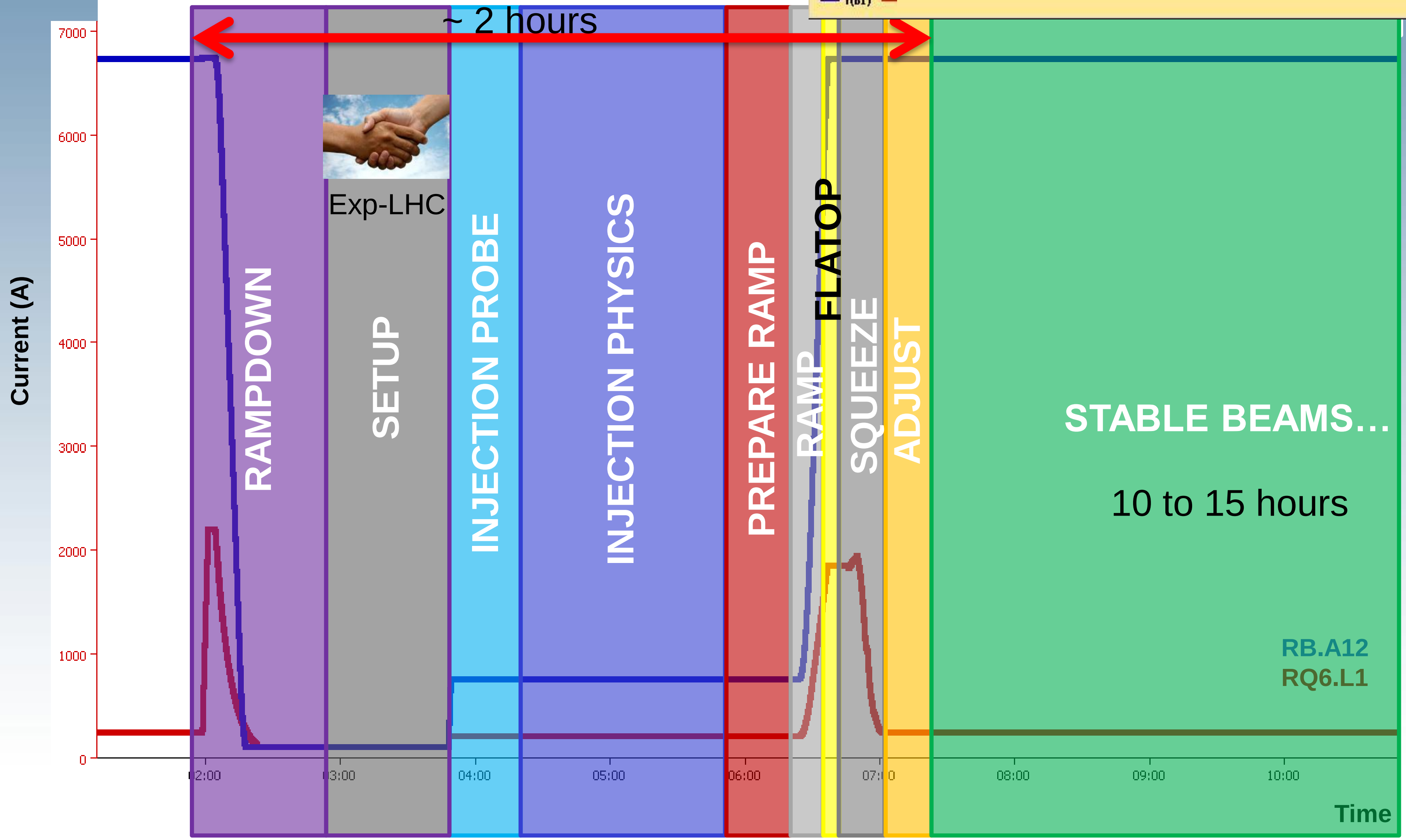
In order to get the maximum aperture possible the β(s) in both planes have to be minimized:

$$\frac{d}{d\mu}\left(\boxed{\beta_{max}} + \boxed{\beta_{min}}\right) = \frac{d}{d\mu}\left(\underbrace{\frac{\left(1+\sin\frac{\mu}{2}\right)L}{\sin\mu}} + \underbrace{\frac{\left(1-\sin\frac{\mu}{2}\right)L}{\sin\mu}}\right) = \frac{d}{d\mu}\left(\frac{2L}{\sin\mu}\right) = 0$$

$$\frac{L}{\sin^2\mu}\cos\mu = 0$$ ➔ μ=90º

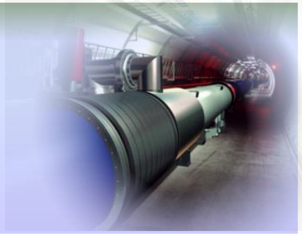
II. LHC Operational cycle

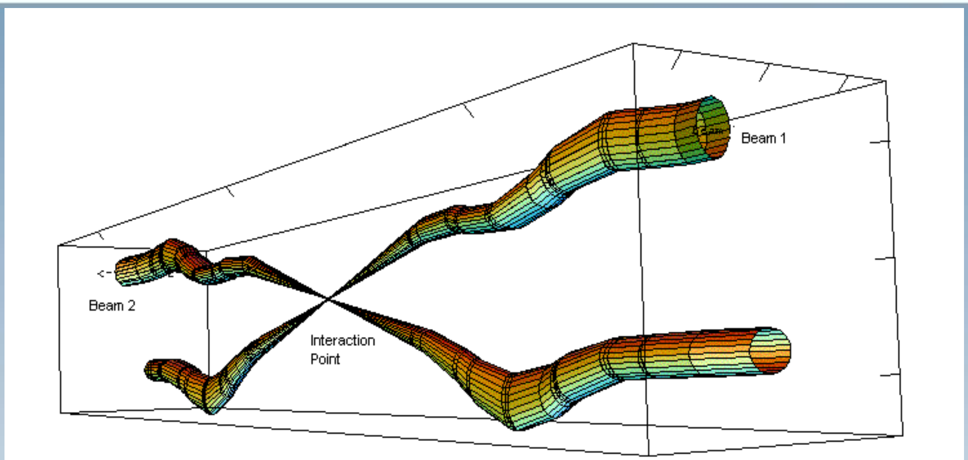




M. Solfaroli Evian 2012

II. LHC Operational cycle: Squeeze ➔ reduce β*





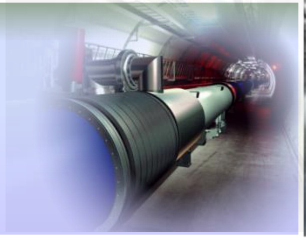
Relative beam sizes around IP1 (Atlas) in collision

Squeeze the beam size down as much as possible at the collision point to increase the chances of a collision

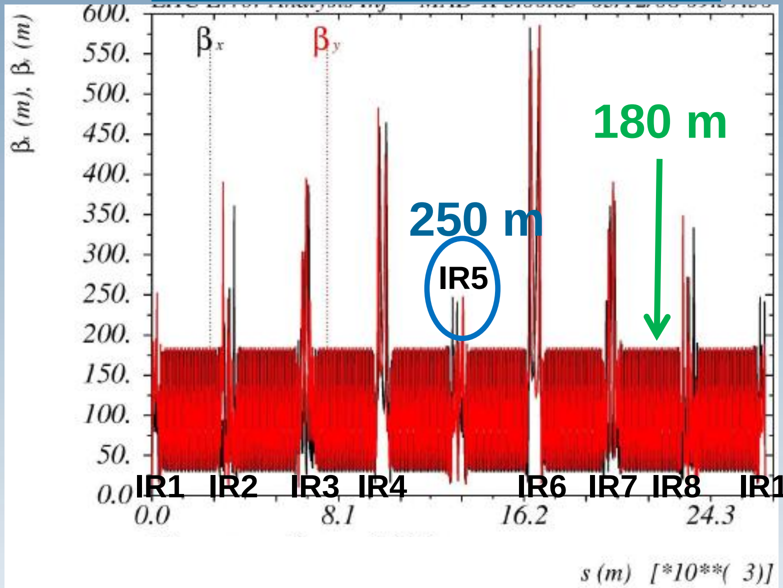
$$L \approx \frac{N_1 N_2 f_{rev} N_b}{4\pi\sigma^2} \rightarrow \sigma = \sqrt{\beta \frac{\varepsilon_n}{(\beta\gamma)_{rel}}}$$

- So even tough we squeeze our $N_{1,2}$=100,000 million protons per bunch down to 16 microns (1/5 the width of a human hair) **at the interaction point**. We get **only around 20 collisions per crossing** with nominal beam currents.
- The bunches cross (every 25 ns) so often we end up with around **600 million collisions per second** - at the start of a fill with nominal current.
- Most protons miss each other and carry on around the ring. The beams are kept circulating for hours ➔ 10 hours

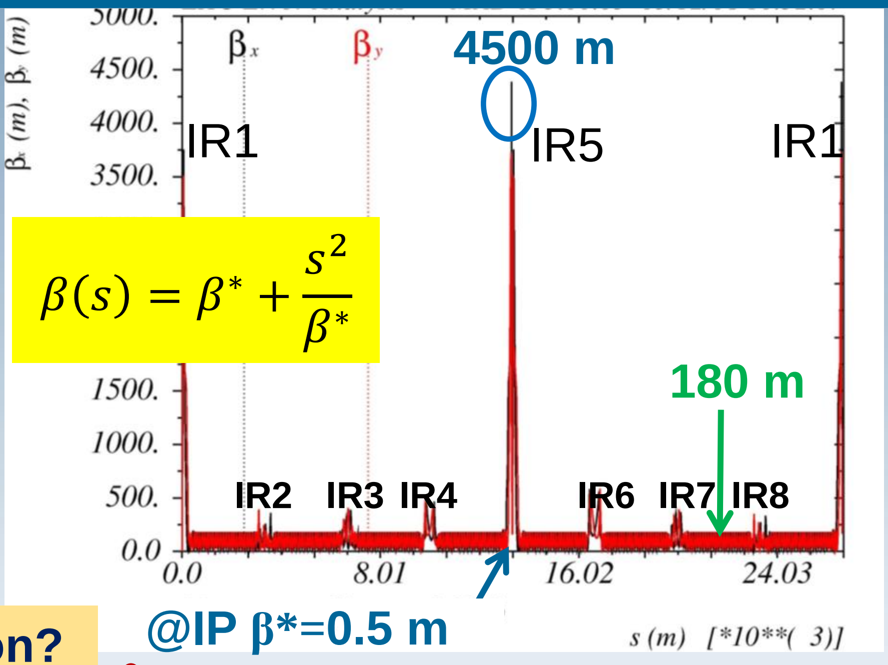
II. LHC Operational cycle: Squeeze → reduce β* (β @IP)



Beta function at Injection



Beta function at top energy and after squeeze



$$\beta(s) = \beta^* + \frac{s^2}{\beta^*}$$

@IP β*=0.5 m

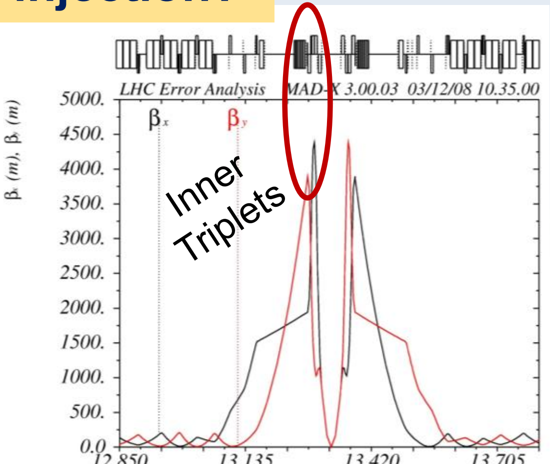
Why we cannot have β*= 0.5 m at injection?

$$\sigma = \sqrt{\beta \frac{\varepsilon_n}{(\beta\gamma)_{rel}}}$$

- β=4500 m
- γ(@450 GeV)~480
- εn=3.5 μm rad

Remember: there is no D(s) here

σ ~ **6 mm !!**



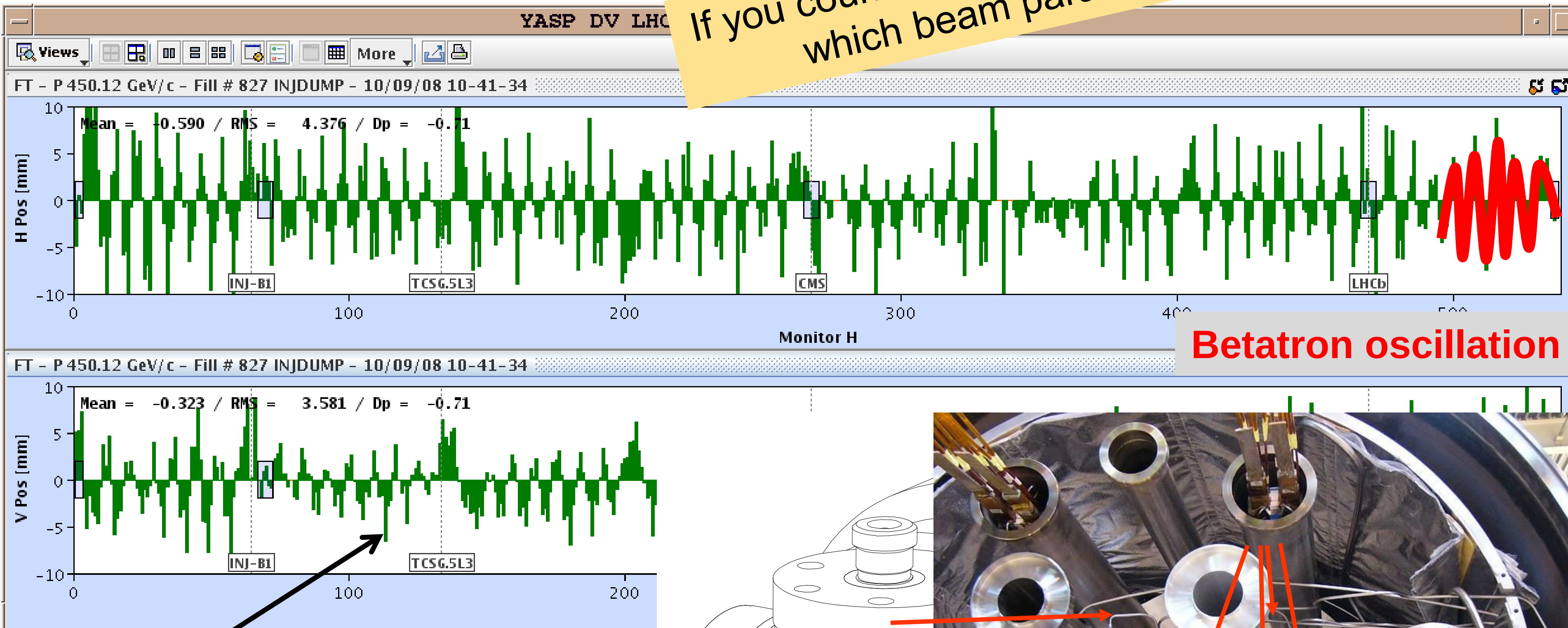
Rbeampipe~29/24 mm we could only accommodate ~ 4 times the beam size and **we need at least 7σ clearance**

@ 7 TeV

σIT ~ **1.2 mm**

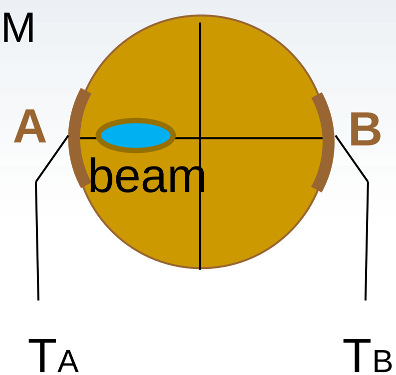
II. Beam measurements: Beam trajectory

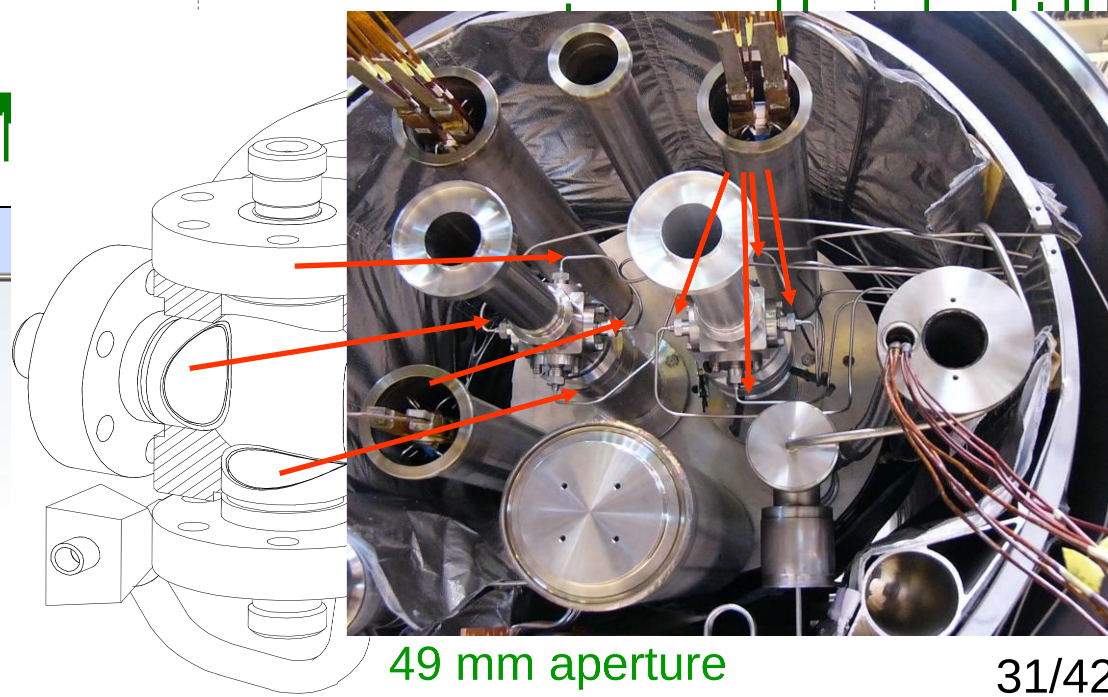
If you count the number of betatron oscillations, which beam parameter do you get?



Betatron oscillation

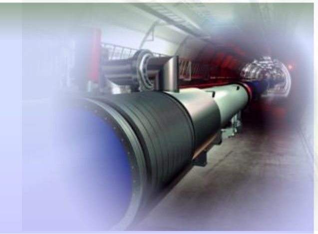
Each point is a BPM (Beam Position Measurement)

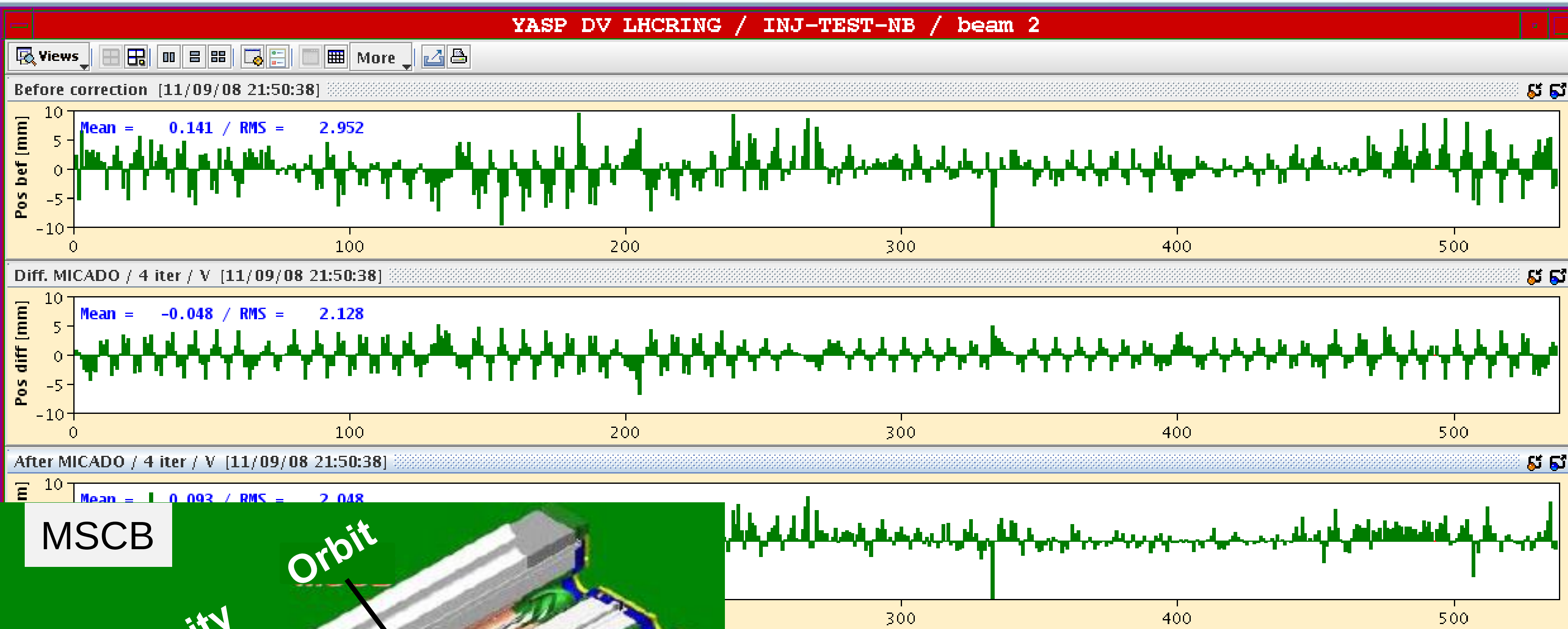


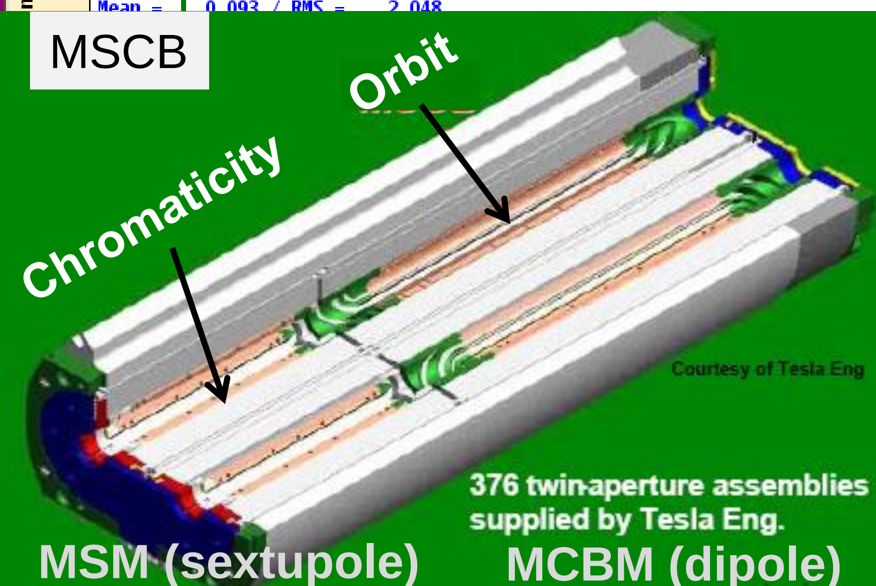


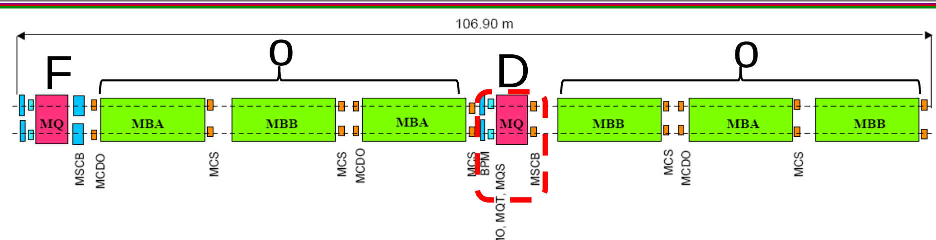
49 mm aperture

II. Beam measurements: Beam trajectory correction





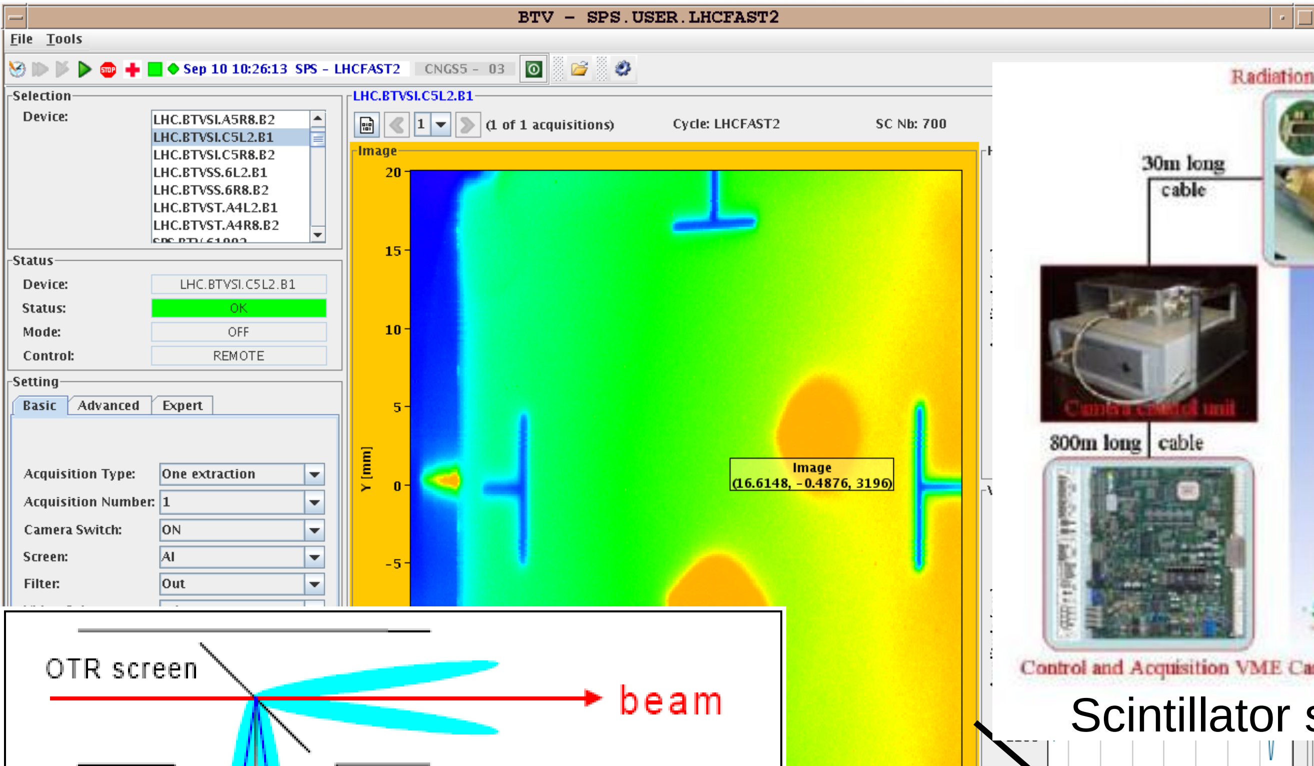


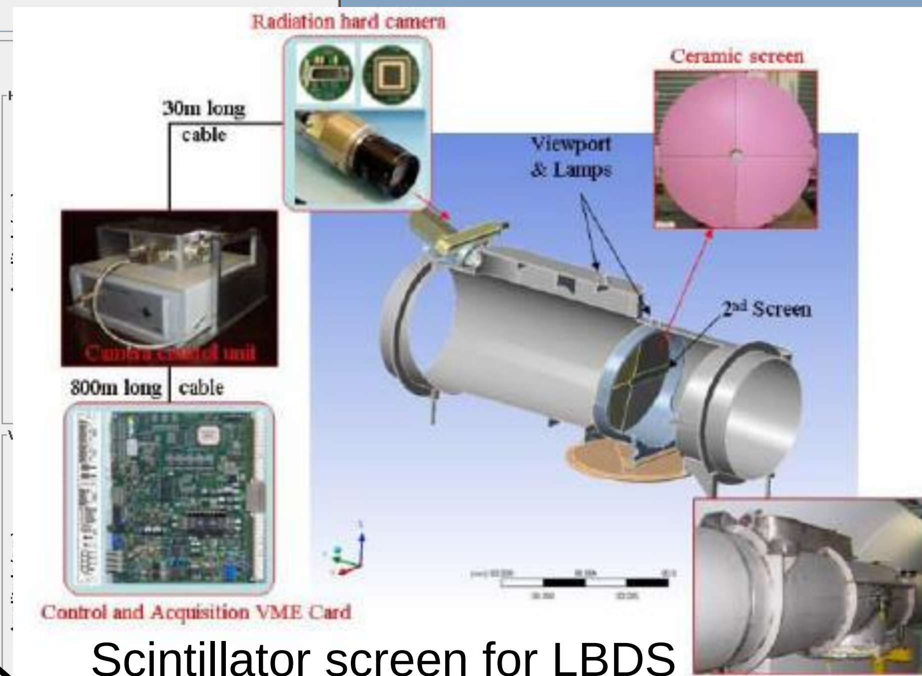


LHC TDR

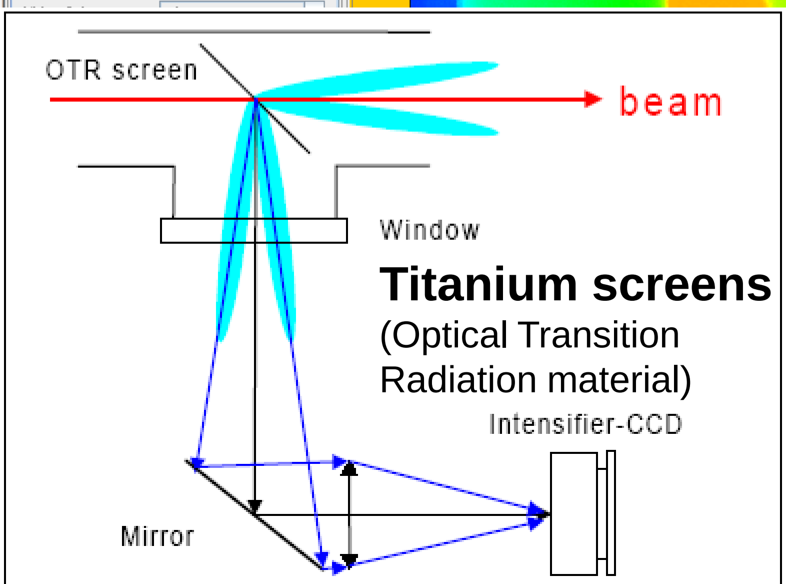
Why the orbit and sextupole correctors are placed close to a quadrupole?

II. Beam profile measurements: Beam 1 on TDI screen – 1st and 2nd turns

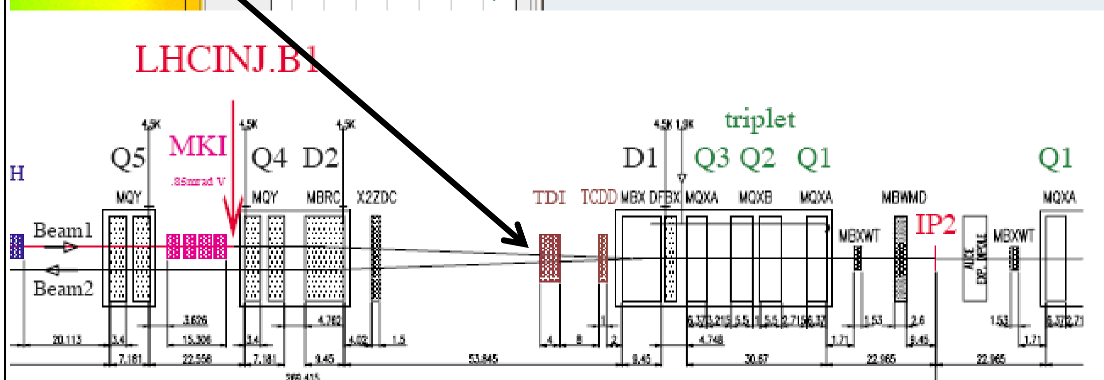




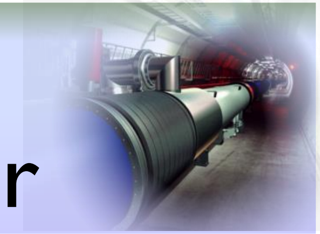
Scintillator screen for LBDS



Titanium screens
(Optical Transition Radiation material)



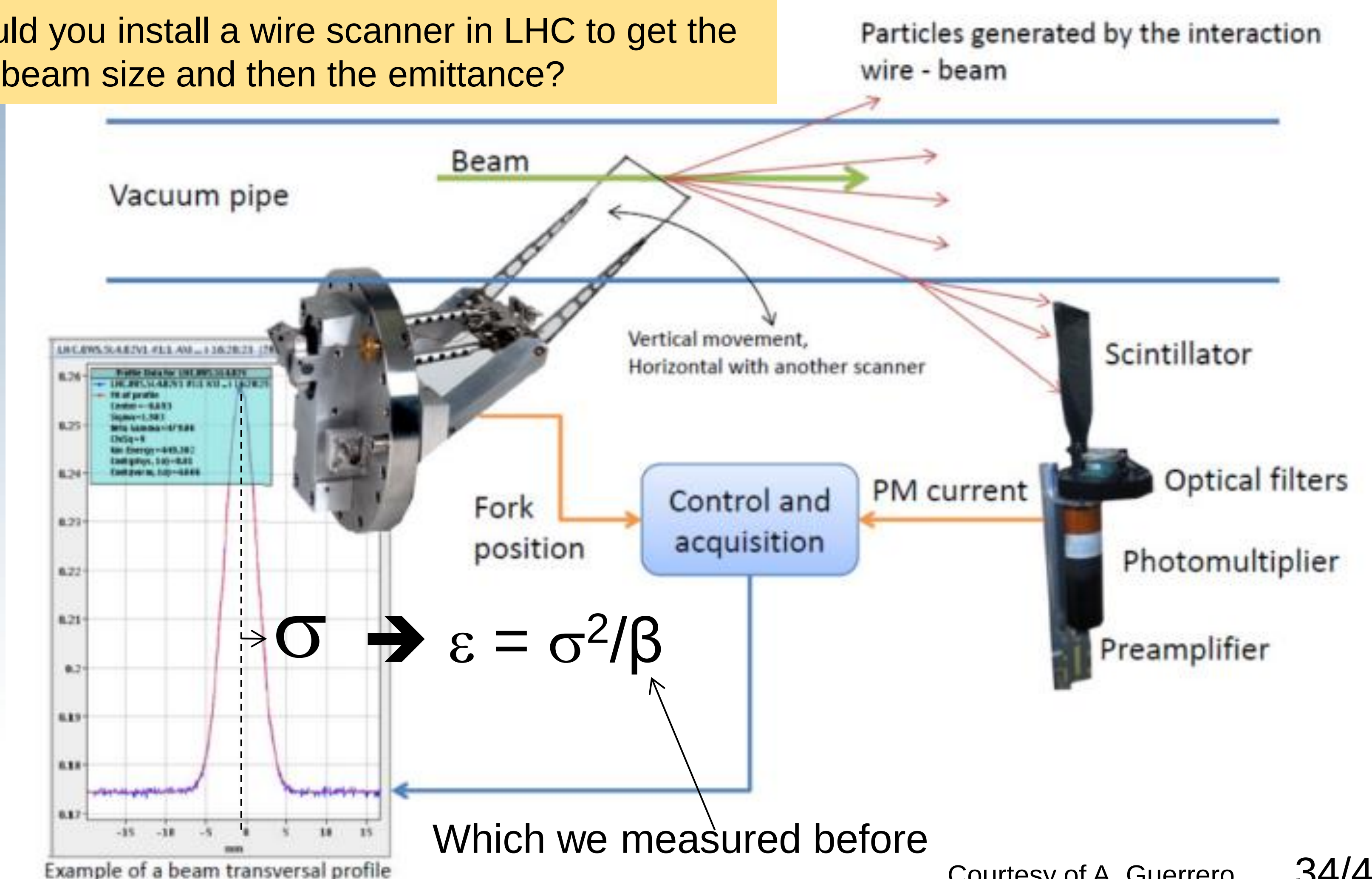
II. Beam profile measurements: Emittance measurement - Wire scanner



Emittance is the figure of merit for profile measurements.

But it is a derived quantity from the beam size ($\sigma = \sqrt{\beta\varepsilon}$)

Where would you install a wire scanner in LHC to get the beam size and then the emittance?



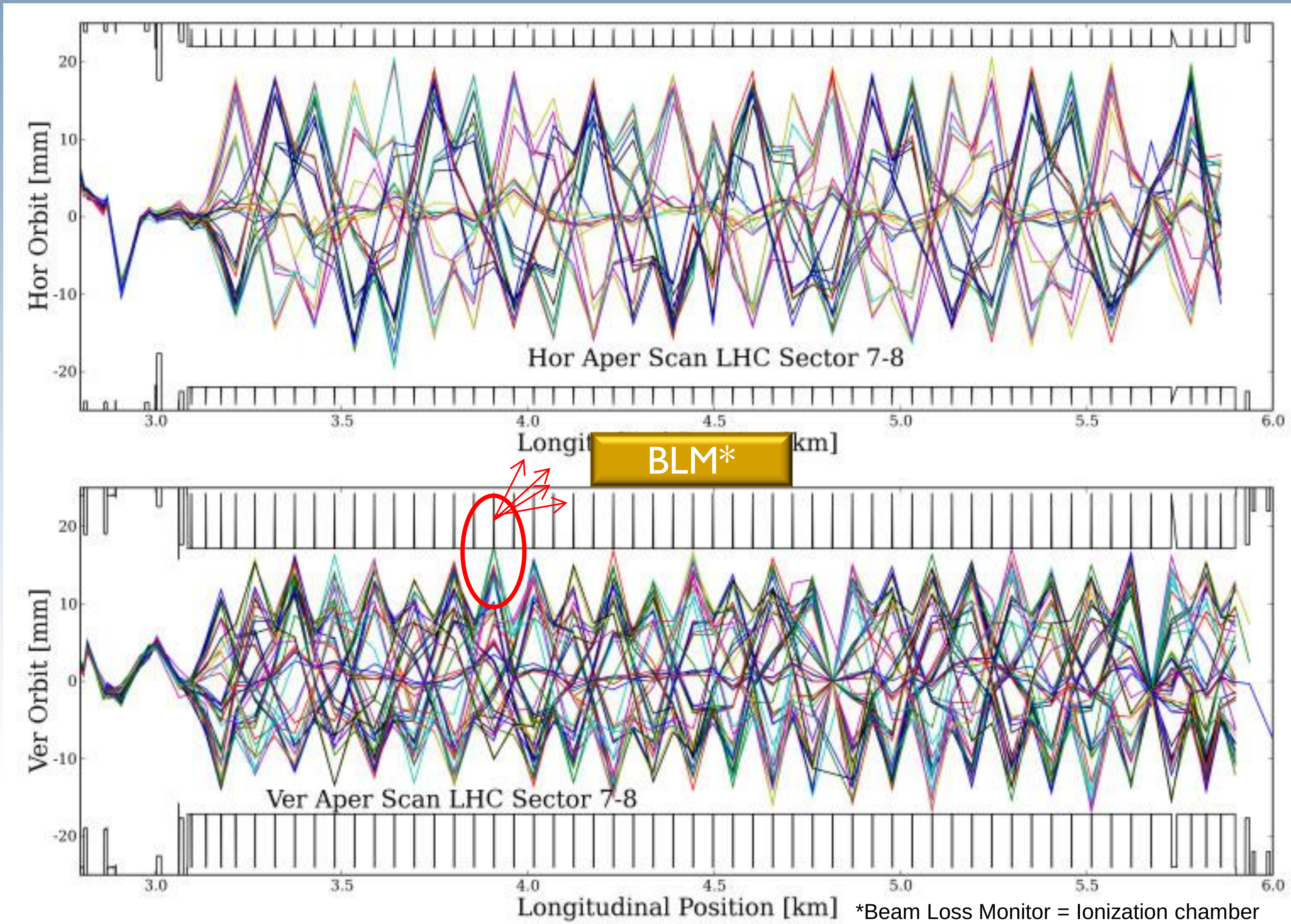
Example of a beam transversal profile

$\sigma \rightarrow \varepsilon = \sigma^2/\beta$

Which we measured before

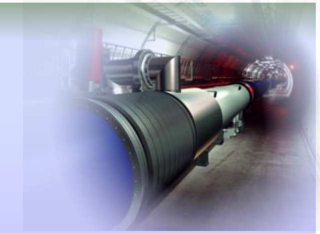
Courtesy of A. Guerrero

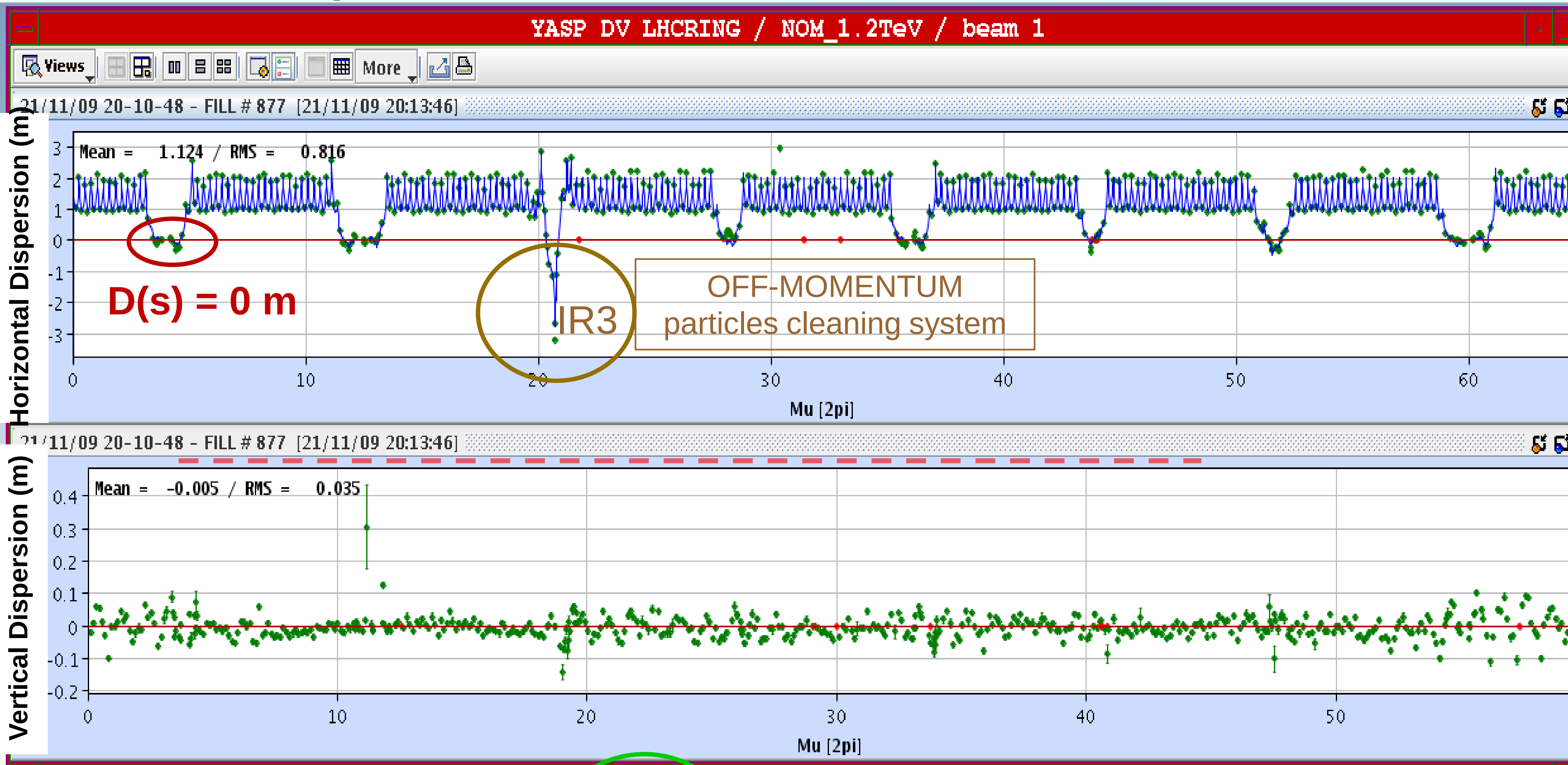
II. Beam measurements: Aperture scan

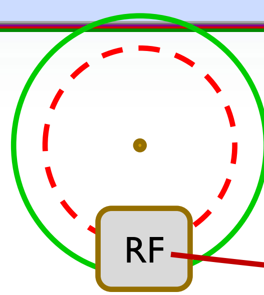


*Beam Loss Monitor = Ionization chamber

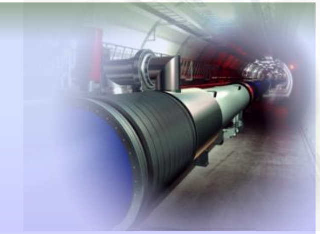
II. Beam measurements:
Dispersion measurement







$$\Delta x = D_x(s)\frac{\Delta p}{p}$$

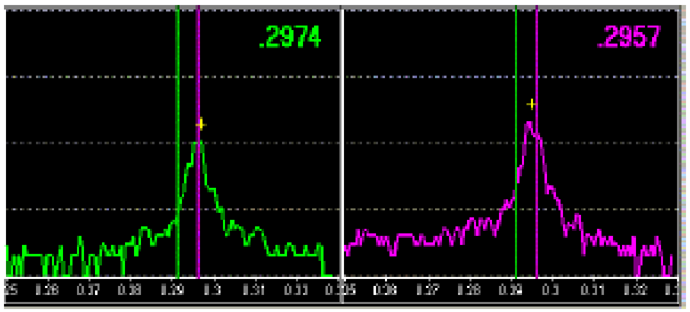


a quadrupol error leads to a shift of the tune:

1st Change quadrupole strength in steps

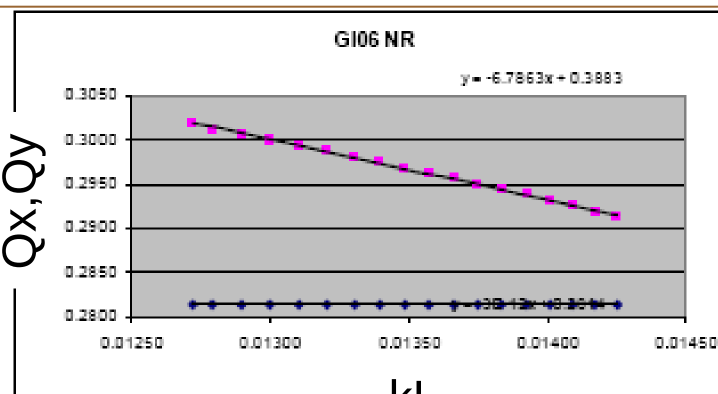
$$\Delta Q = \int_{s0}^{s0+l} \frac{\Delta k \beta(s)}{4\pi} ds \approx \frac{\Delta k l_{quad} \overline{\beta}}{4\pi}$$

2nd Measure Tune



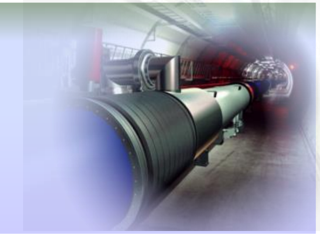
3rd Plot Tune vs Quadrupole strength

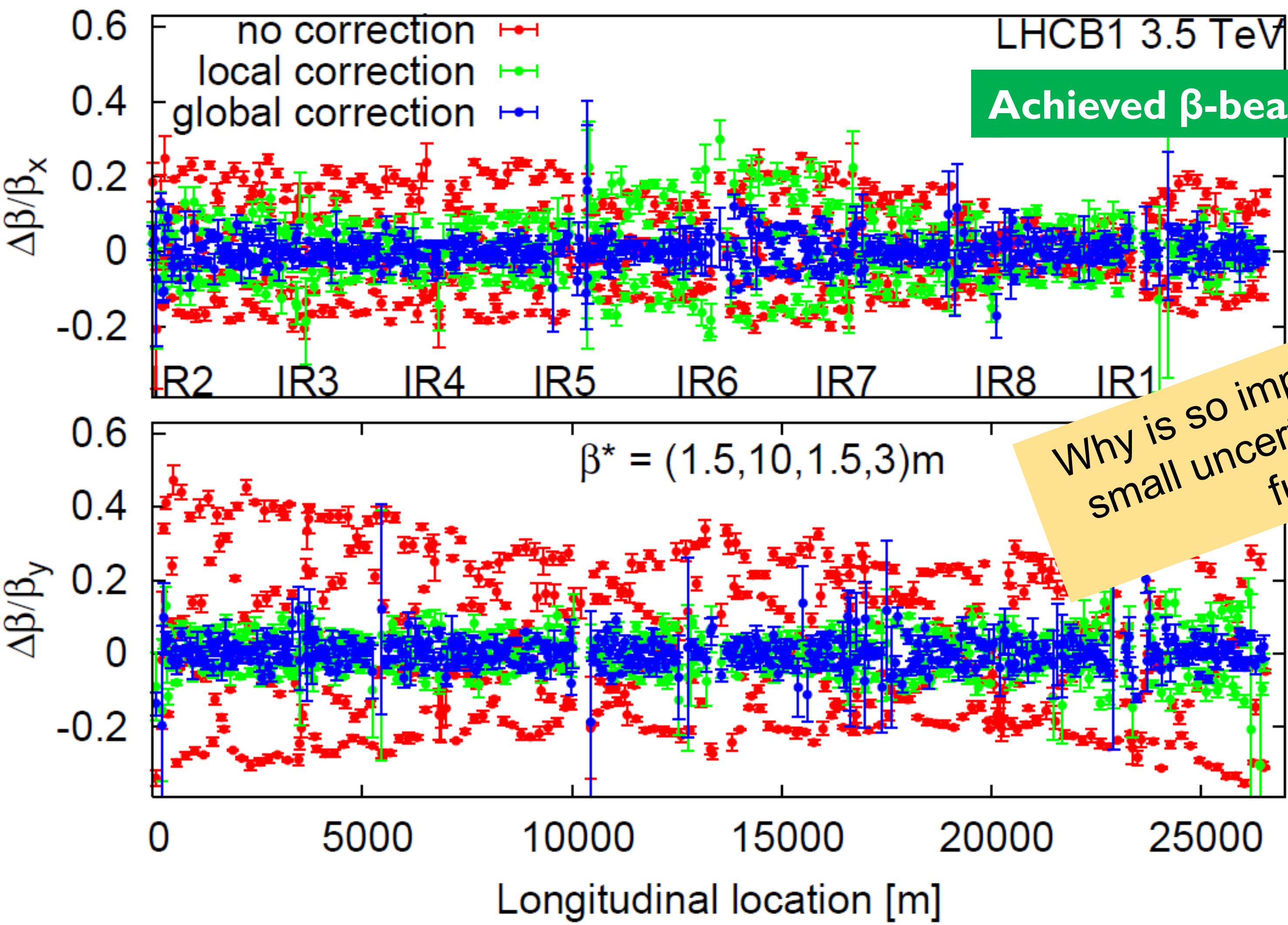
Example: measurement of β in a storage ring: tune spectrum



Courtesy of B. Holzer (lectures)

II. Beam measurements: Beta measurement



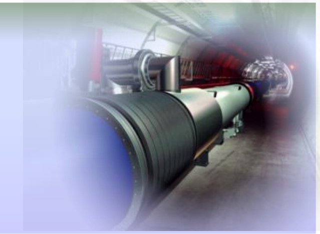


Achieved β-beating error 10% !!

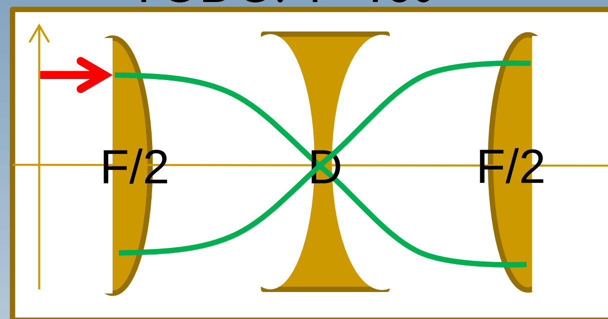
Why is so important to have a small uncertainty in the beta function?

Reference: Record low beta beating in the LHC
Tomas, R. et al. Phy. Rev. Special Topics - Accelerators and Beams15(9).

II. Beam measurements: Non-integer tunes



FODO: Ψ=180°



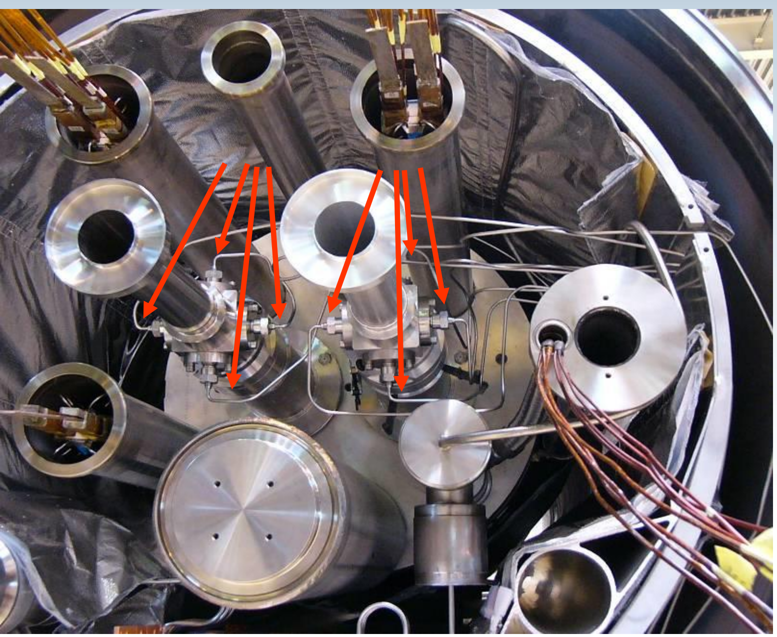
BPM

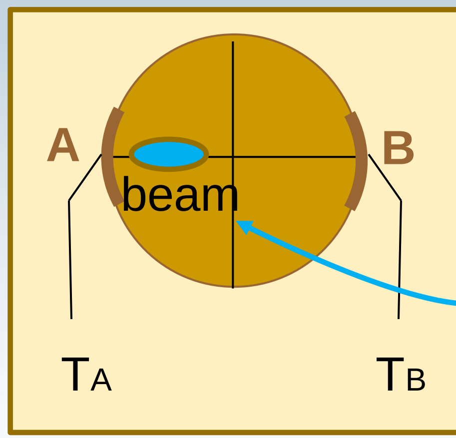
Every 2xT we measure the same position:

$$\frac{1}{2T} = f_Q = Q \cdot \frac{1}{T} = Q \cdot f_{rev}$$

$$\rightarrow Q = 0.5$$

BPM pos ➔ FFT ➔ tune



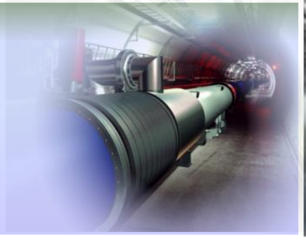


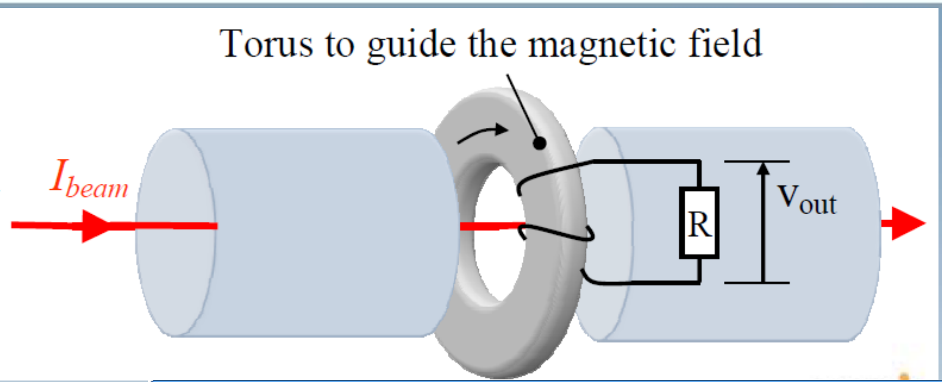
With a frequency of ~3 kHz we measure the same beam position

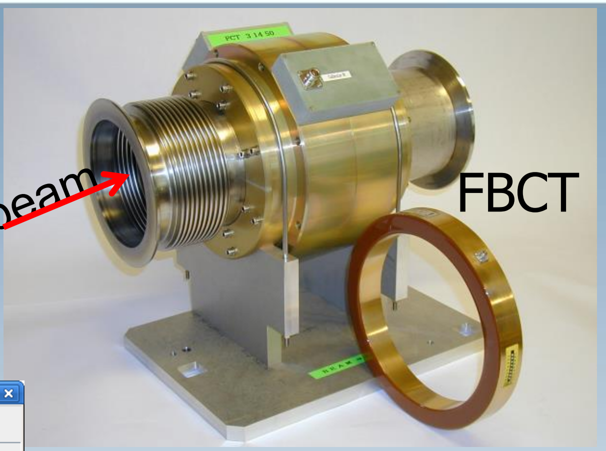
$Q_x \cdot f_{rev}$ = 3 kHz

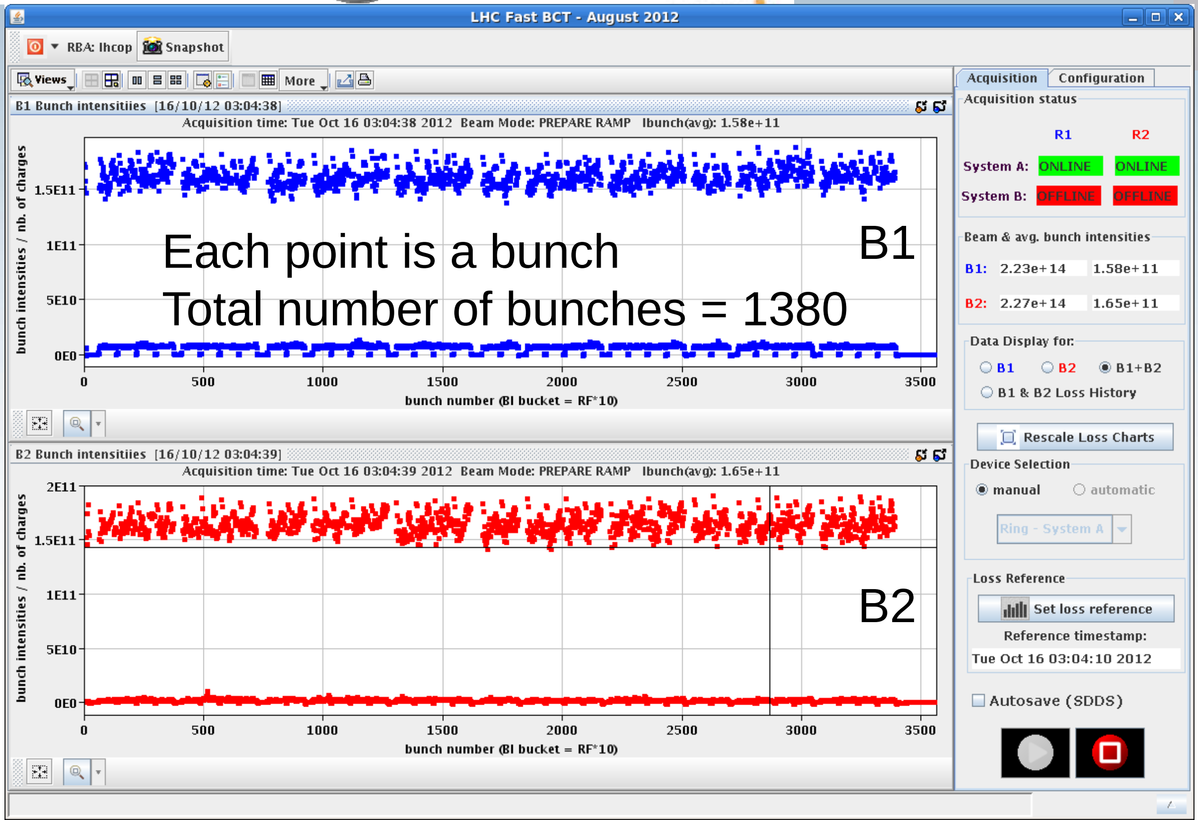
Qx = .279 @LHC
Qy = .310

II. Beam measurements: Fast BCT (Beam Current Transformer)

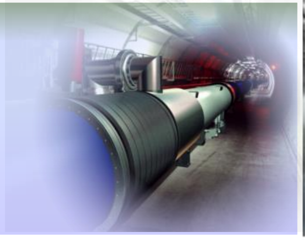






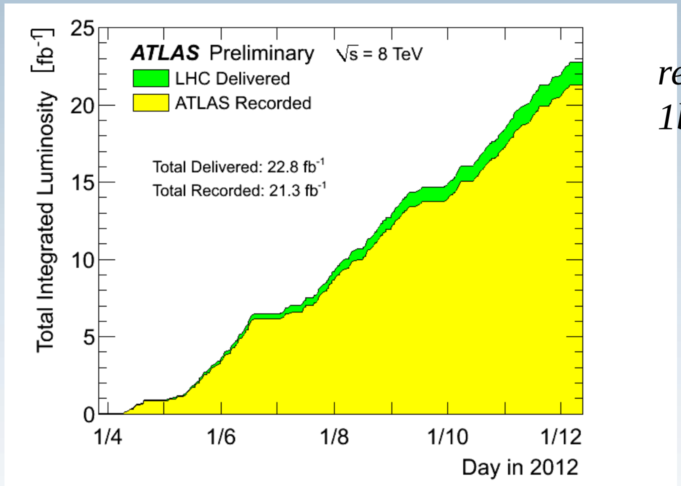


High Light of the LHC

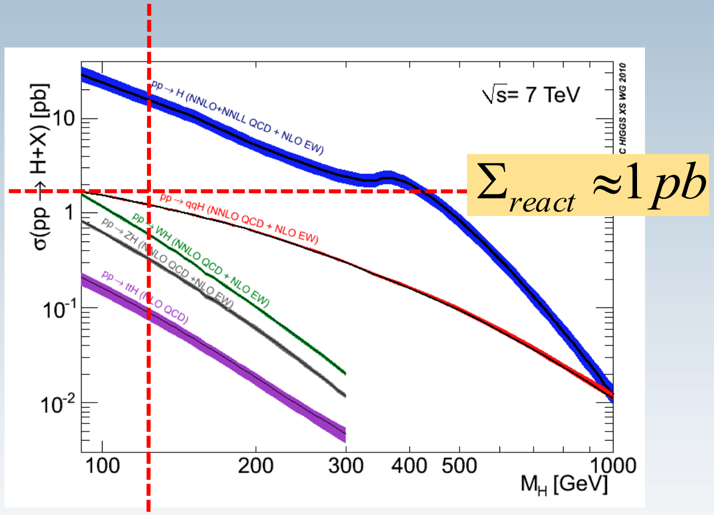


production rate of events is determined by the cross section Σ_{react} and a parameter L that is given by the design of the accelerator:
… the luminosity

$$R = L * \Sigma_{react} \approx 25 \frac{1}{10^{-15} b} 10^{-12} b = some\ 1000 H$$



remember:
$1b = 10^{-24}\, cm^2$

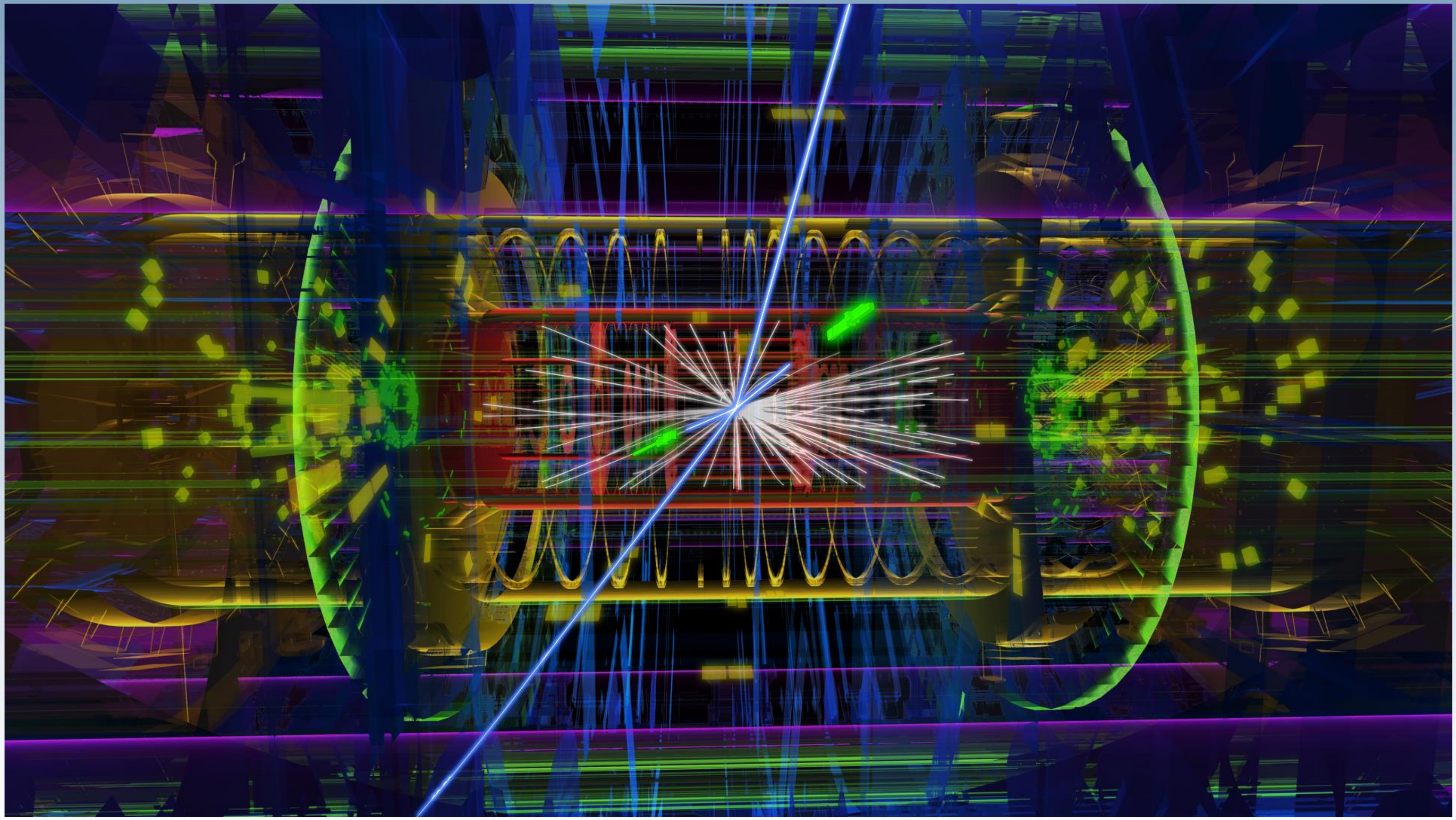


Integrated luminosity during RUN I

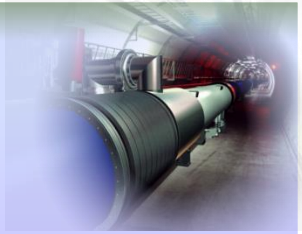
$$\int L dt \approx 25\, fb^{-1}$$

Official number: 1400 clearly identified Higgs particles "on-tape"

High Light of the HEP year

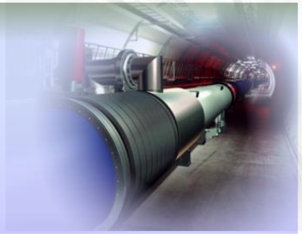


ATLAS event display: Higgs => two electrons & two muons



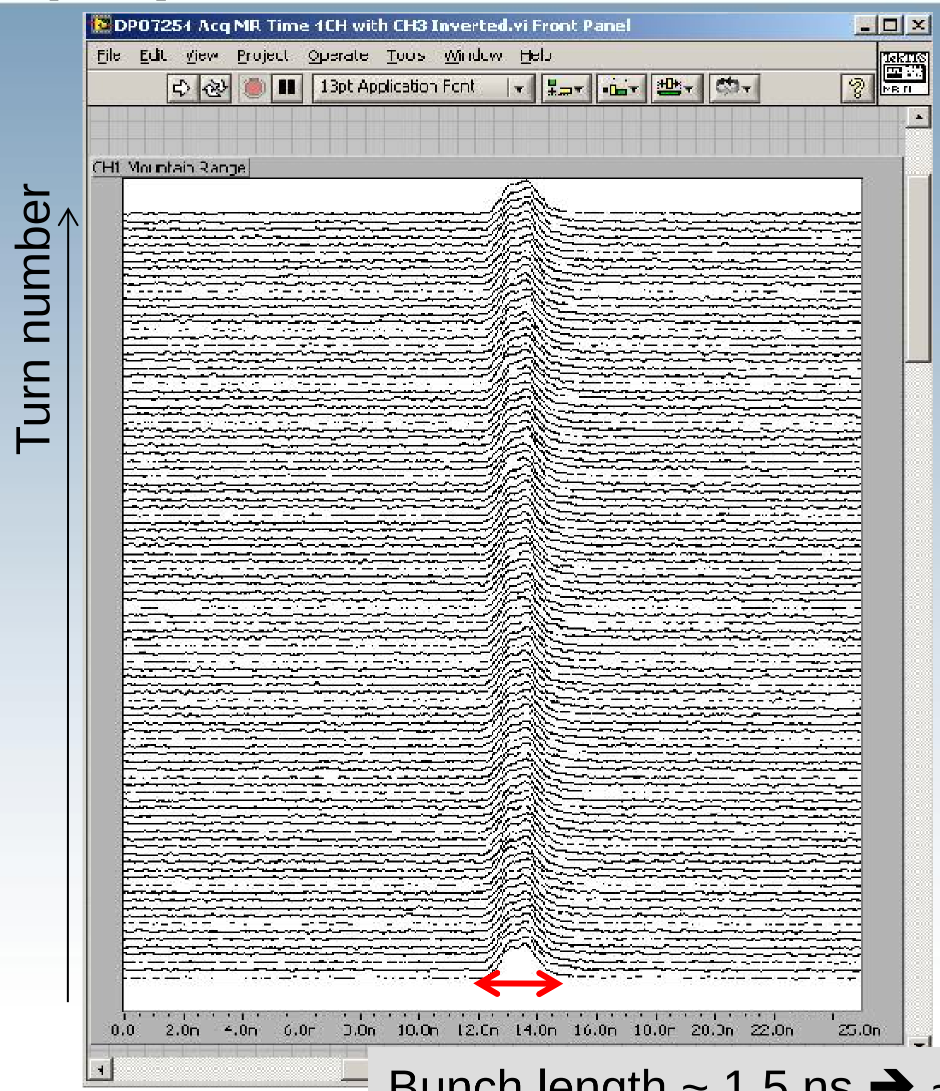
SPARE SLIDES

I. Basic layout of the machine: Superconducting magnets



- Superfluid helium ➔ Why is it so great?!!
  - **very high thermal conductivity**➔ is able to conduct away heat a thousand times better than a metallic conductor like copper
  - **very low viscosity coefficient** ➔ can penetrate tiny cracks, deep inside the magnet coils to absorb any generated heat
  - **very high heat capacity** ➔ prevents small transient temperature fluctuations

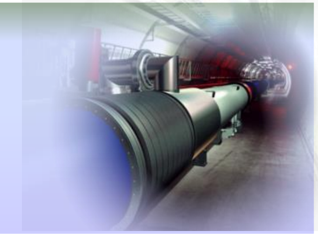
XIV. Beam captured – mountain range display



Bunch length ~ 1.5 ns ➔ ~ 45 cm

Now RF ON

Beam parameters (nominal)



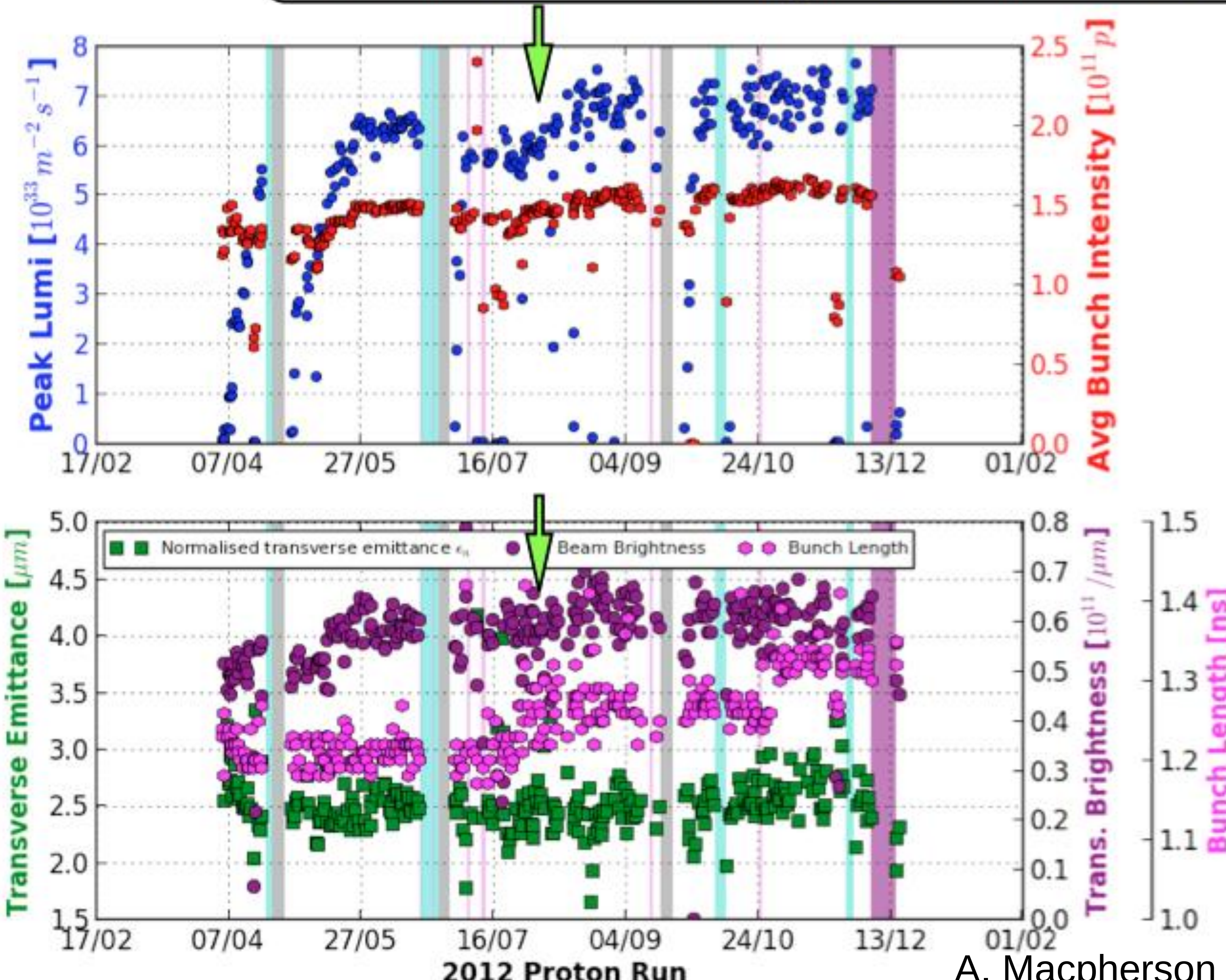
		Injection	Collision	2012
Proton energy	GeV	450	7000	4000
Particles/bunch		1.15×10^{11}		**1.6** $\times 10^{11}$
Num. bunches		2808		1380
Longitudinal emittance (4σ)	eVs	1.0	2.5	
Transverse normalized emittance	µm rad	3.5	3.75	
Beam current	A	0.582		
Stored energy/beam	MJ	23.3	362	
		Peak luminosity related data		
RMS bunch length	cm	11.24	7.55	
RMS beam size @IP1 & IP5 → $\sigma_{x,y} = \sqrt{\varepsilon\beta}$	µm	375.2	16.7	
RMS beam size @IP2 & IP8 → $\sigma_{x,y} = \sqrt{\varepsilon\beta}$	µm	279.6	70.9	
Geometric luminosity reduction factor (F)			0.836	
Instantaneous lumi @IP1 & IP5 ($IP2_{Pb-Pb}$, IP8)	$cm^{-2}s^{-1}$		10^{34} (10^{27}, 10^{32})	$7\ 10^{33}$

$\beta^* = 0.55$ m
$\varepsilon = 0.5$ nm rad

$\beta^* = 0.6$ m
$\varepsilon_n = 2.5$ µm rad

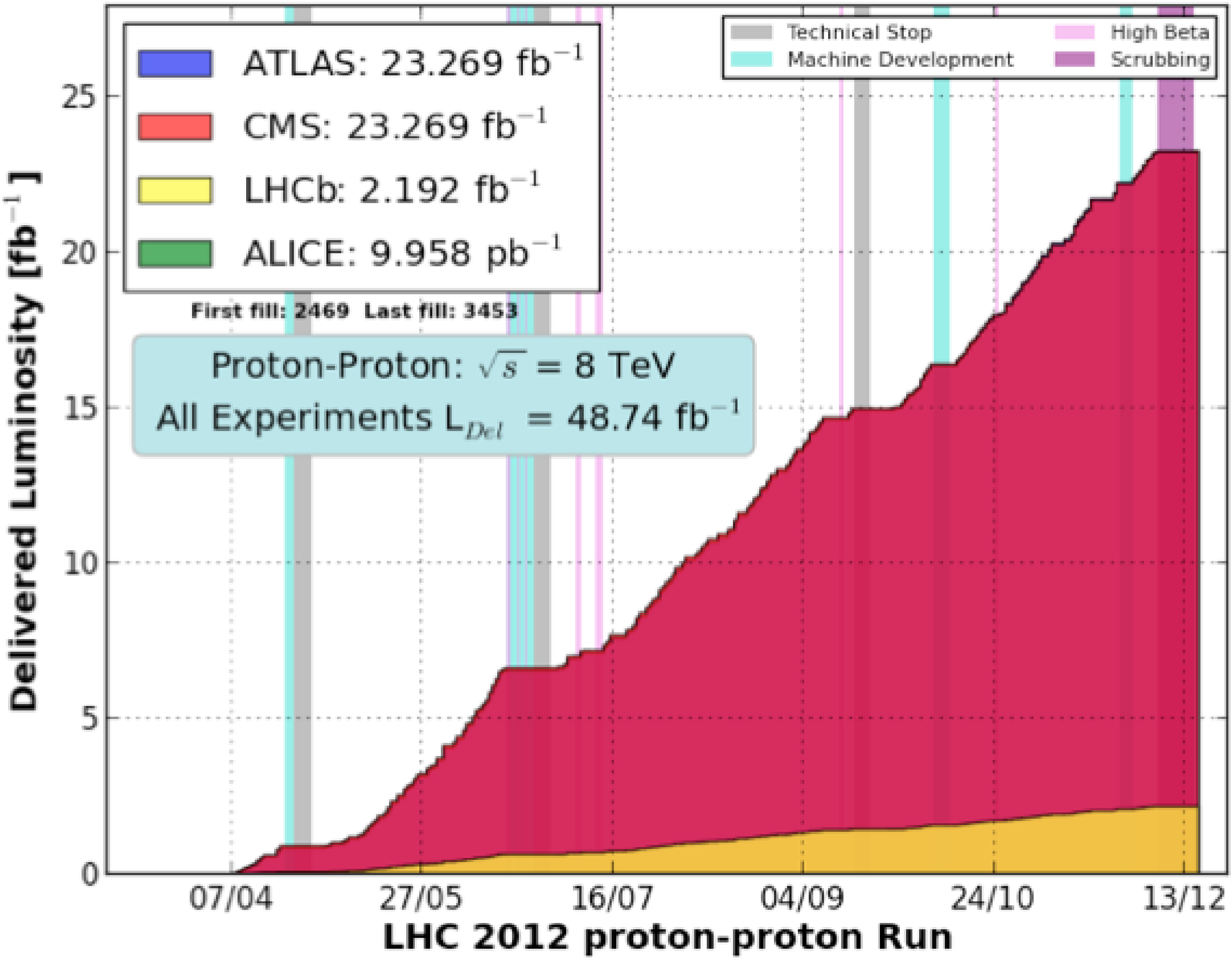
2012 Performance evolution - in one slide

Peak lumi increases with brightness and mean bunch length



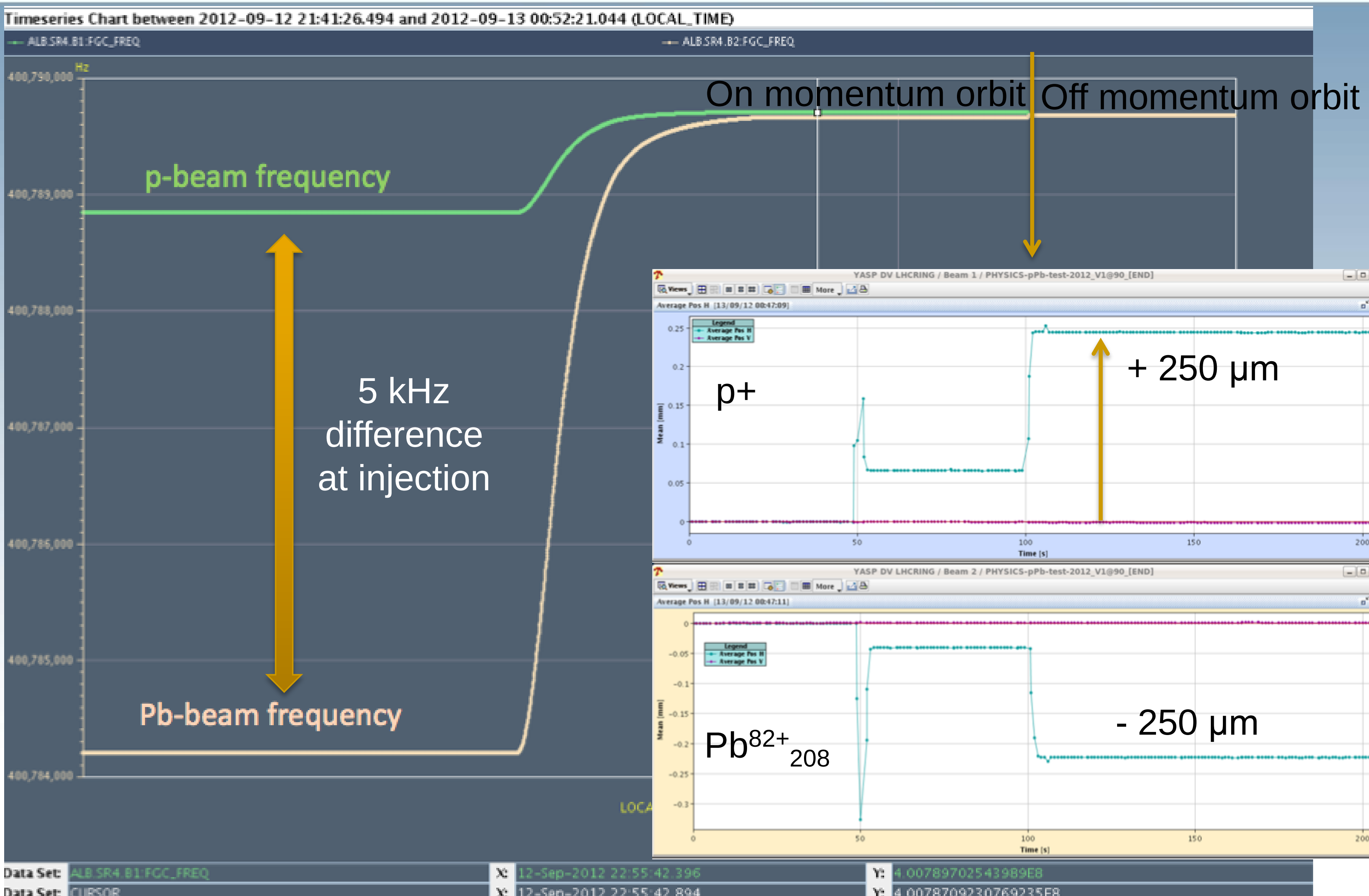
A. Macpherson Evian 2012

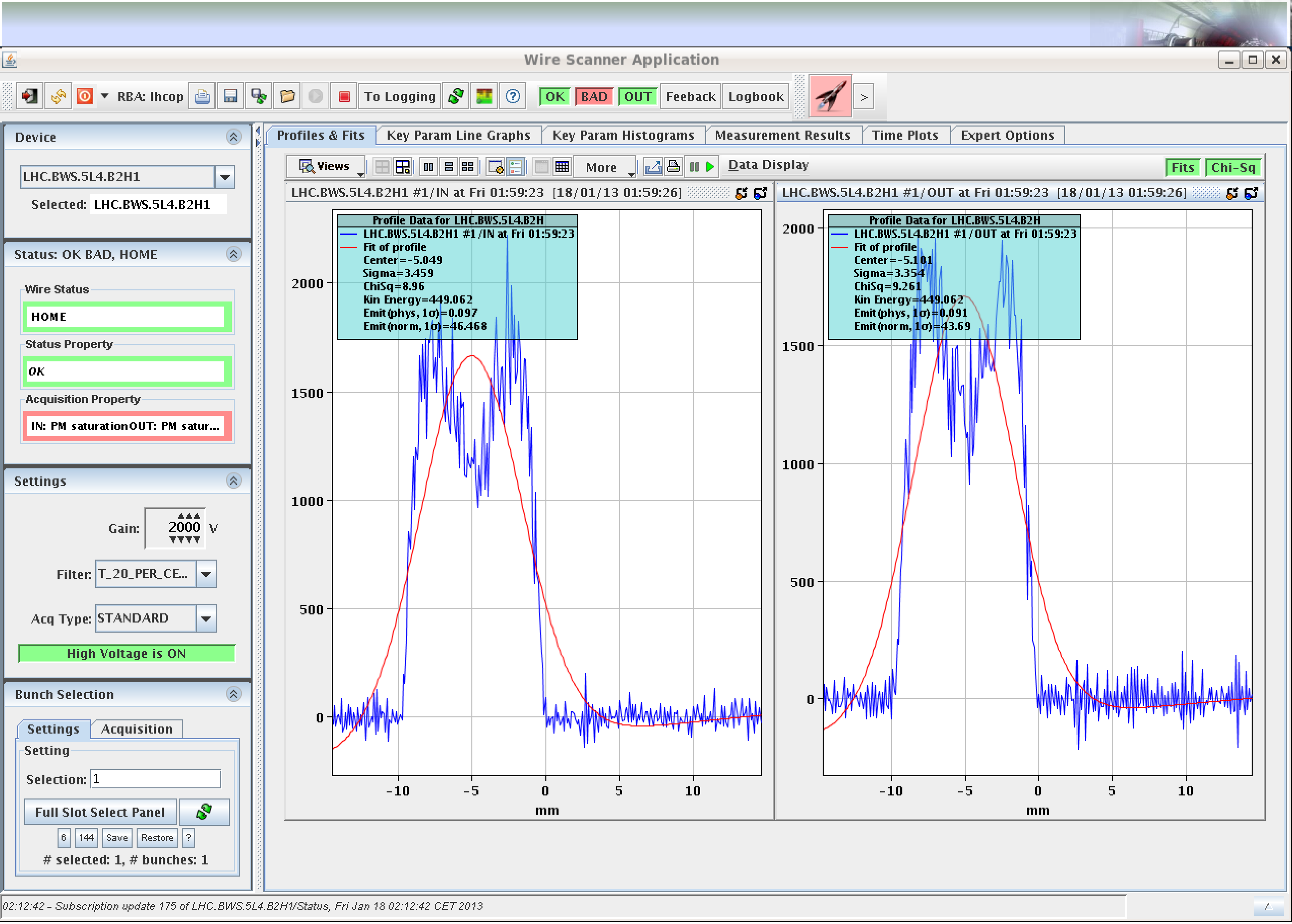
2012 - Luminosity Delivered



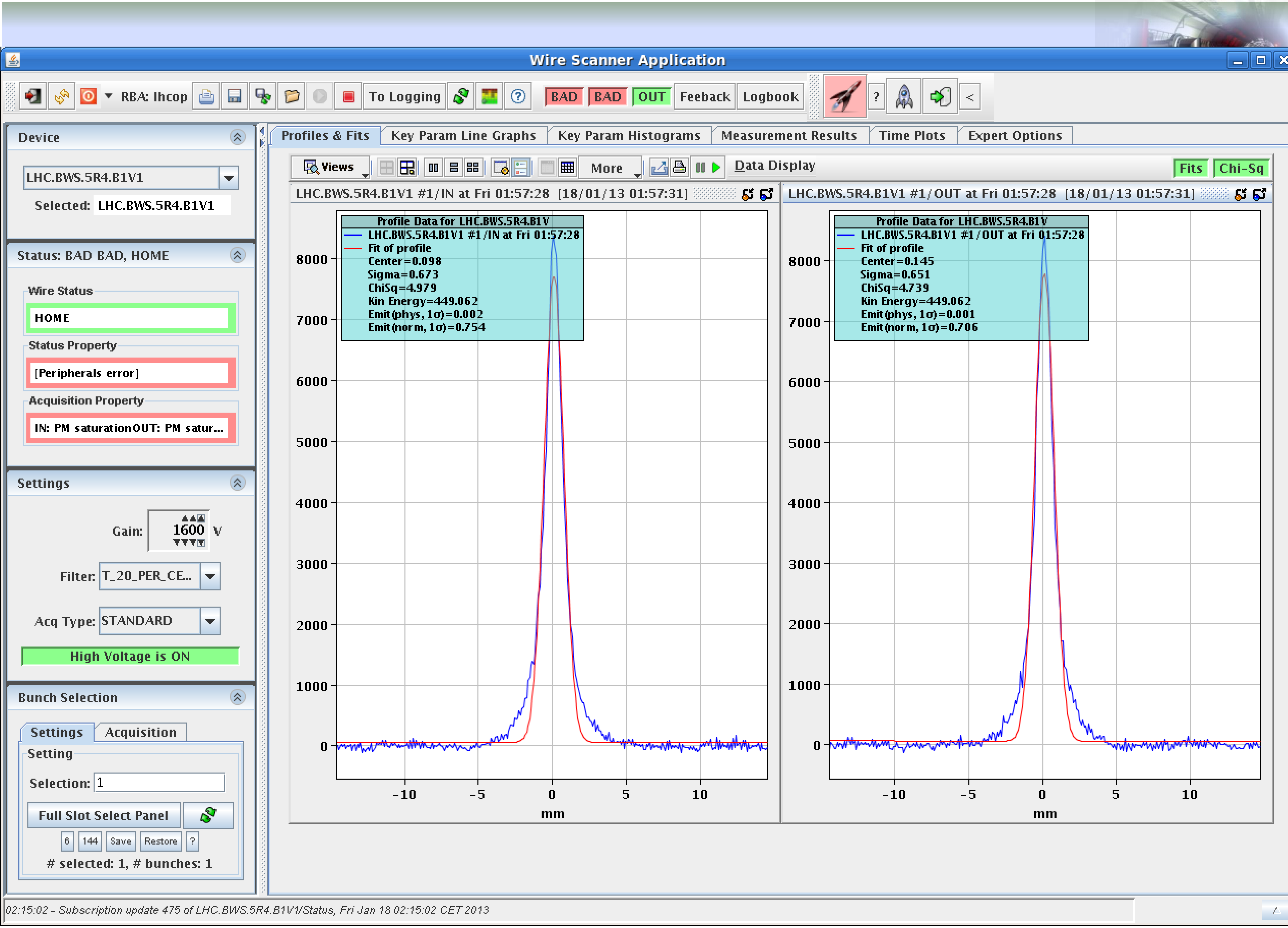
A. Macpherson Evian 2012

pPb physics during 2013



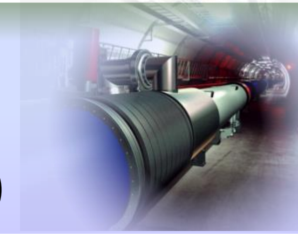


Wire Scanner Application
RBA: lhcop
To Logging
OK
BAD
OUT
Feeback
Logbook
Device
LHC.BWS.5L4.B2H1
Selected: LHC.BWS.5L4.B2H1
Status: OK BAD, HOME
Wire Status
HOME
Status Property
OK
Acquisition Property
IN: PM saturationOUT: PM satur...
Settings
Gain:
2000
V
Filter:
T_20_PER_CE...
Acq Type:
STANDARD
High Voltage is ON
Bunch Selection
Settings
Acquisition
Setting
Selection:
1
Full Slot Select Panel
6
144
Save
Restore
?
selected: 1, # bunches: 1
Profiles & Fits
Key Param Line Graphs
Key Param Histograms
Measurement Results
Time Plots
Expert Options
Views
More
Data Display
Fits
Chi-Sq
LHC.BWS.5L4.B2H1 #1/IN at Fri 01:59:23 [18/01/13 01:59:26]
Profile Data for LHC.BWS.5L4.B2H
LHC.BWS.5L4.B2H1 #1/IN at Fri 01:59:23
Fit of profile
Center=-5.049
Sigma=3.459
ChiSq=8.96
Kin Energy=449.062
Emit(phys, 1σ)=0.097
Emit(norm, 1σ)=46.468
mm
LHC.BWS.5L4.B2H1 #1/OUT at Fri 01:59:23 [18/01/13 01:59:26]
Profile Data for LHC.BWS.5L4.B2H
LHC.BWS.5L4.B2H1 #1/OUT at Fri 01:59:23
Fit of profile
Center=-5.101
Sigma=3.354
ChiSq=9.261
Kin Energy=449.062
Emit(phys, 1σ)=0.091
Emit(norm, 1σ)=43.69
mm
02:12:42 - Subscription update 175 of LHC.BWS.5L4.B2H1/Status, Fri Jan 18 02:12:42 CET 2013



Wire Scanner Application
RBA: lhcop
To Logging
BAD
BAD
OUT
Feeback
Logbook
Device
LHC.BWS.5R4.B1V1
Selected: LHC.BWS.5R4.B1V1
Status: BAD BAD, HOME
Wire Status
HOME
Status Property
[Peripherals error]
Acquisition Property
IN: PM saturationOUT: PM satur...
Settings
Gain: 1600 V
Filter: T_20_PER_CE...
Acq Type: STANDARD
High Voltage is ON
Bunch Selection
Settings
Acquisition
Setting
Selection: 1
Full Slot Select Panel
6
144
Save
Restore
?
selected: 1, # bunches: 1
Profiles & Fits
Key Param Line Graphs
Key Param Histograms
Measurement Results
Time Plots
Expert Options
Views
More
Data Display
Fits
Chi-Sq
LHC.BWS.5R4.B1V1 #1/IN at Fri 01:57:28 [18/01/13 01:57:31]
Profile Data for LHC.BWS.5R4.B1V
LHC.BWS.5R4.B1V1 #1/IN at Fri 01:57:28
Fit of profile
Center=0.098
Sigma=0.673
ChiSq=4.979
Kin Energy=449.062
Emit(phys, 1σ)=0.002
Emit(norm, 1σ)=0.754
LHC.BWS.5R4.B1V1 #1/OUT at Fri 01:57:28 [18/01/13 01:57:31]
Profile Data for LHC.BWS.5R4.B1V
LHC.BWS.5R4.B1V1 #1/OUT at Fri 01:57:28
Fit of profile
Center=0.145
Sigma=0.651
ChiSq=4.739
Kin Energy=449.062
Emit(phys, 1σ)=0.001
Emit(norm, 1σ)=0.706
8000
7000
6000
5000
4000
3000
2000
1000
0
-10
-5
0
5
10
mm
02:15:02 - Subscription update 475 of LHC.BWS.5R4.B1V1/Status, Fri Jan 18 02:15:02 CET 2013

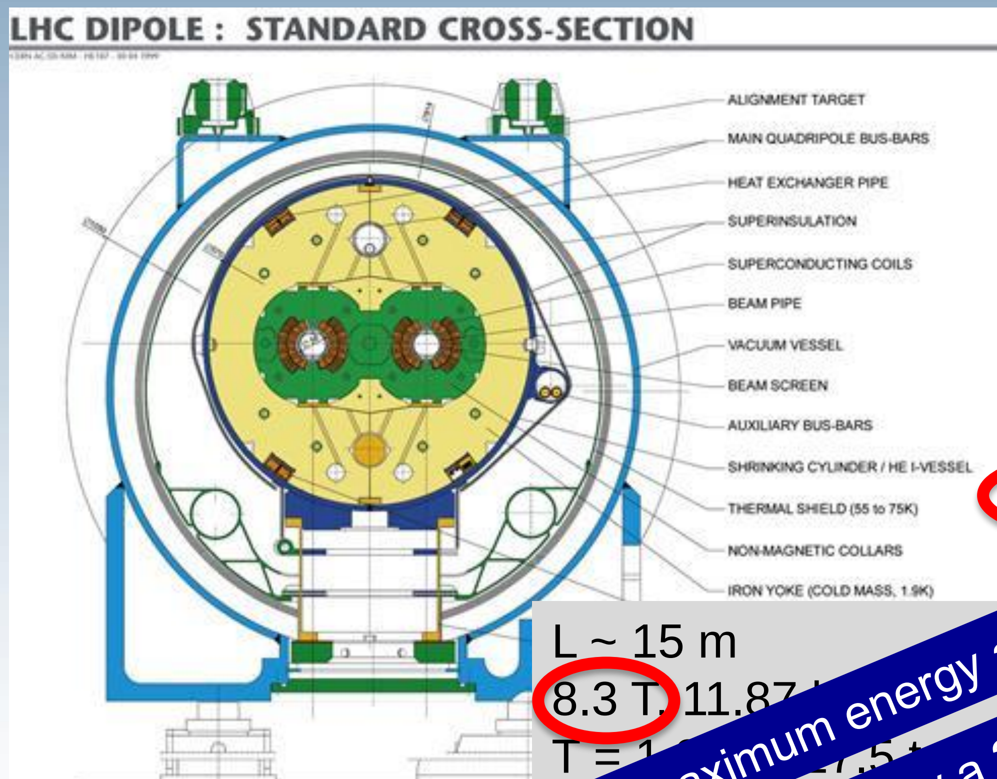
I. Basic layout of the machine: main cryodipoles (two dipoles in one)



- The geometry of the main dipoles (Total of 1232 cryodipoles)

VERTICAL PLANE

The theoretical shape of the beam channels is a straight line, while the natural shape has ~ 0.3 mm deflection between two supports at 5.4 m distance



L ~ 15 m

8.3 T, 11.87

T = 1.

HORIZONTAL PLANE

Length of the bend part =14.3 m

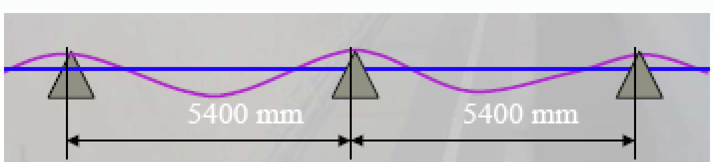
ρ = 2.8 km

(R = 4.3 km)

Dista... ...een ... 194.5 mm

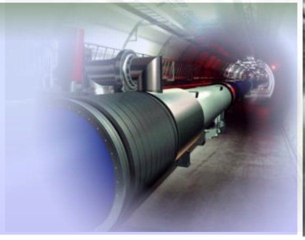
What is the maximum energy a proton can reach?

What is the maximum energy a 208Pb82+ can reach?

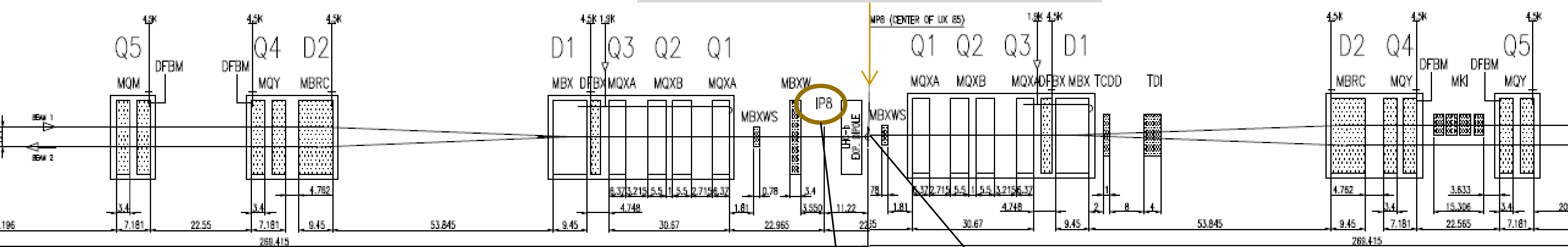


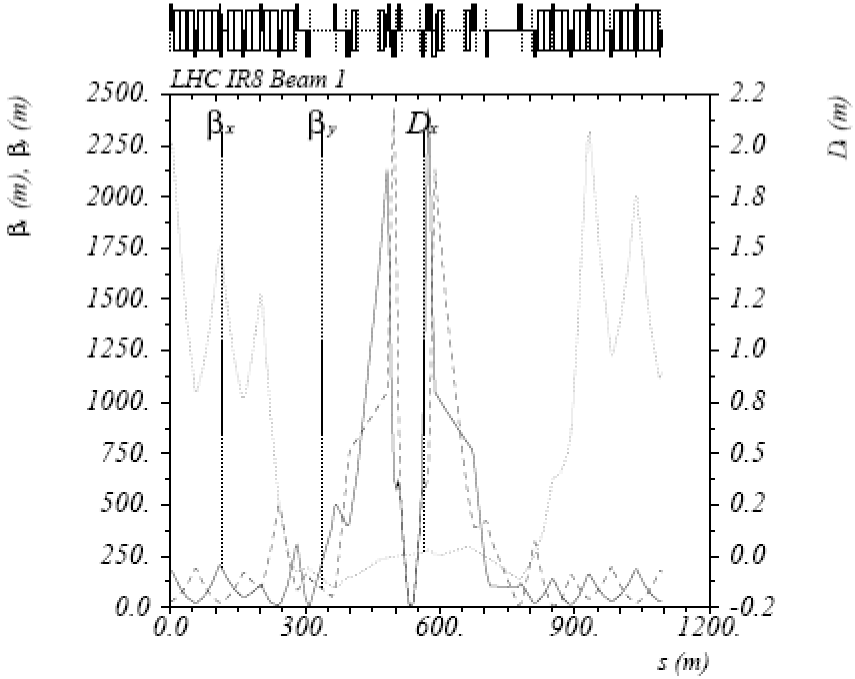
...acti... ...of the cold mass is bent in ...izontal plane with an angle of ... mrad with ρ = 2.8 km. The shape of the two beam channels is identical.

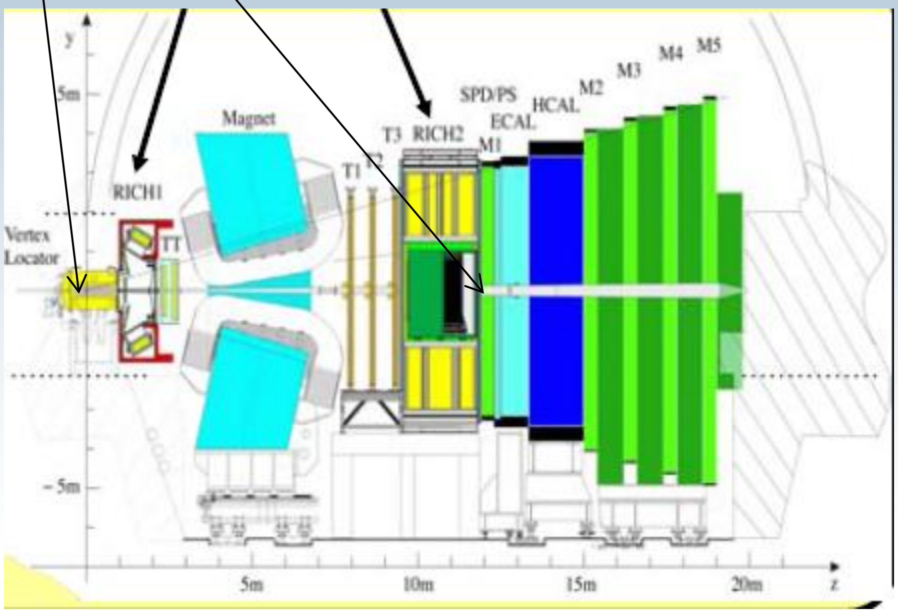
II. The experiments:
Low luminosity insertions: LHCb



Centre of the exp cavern

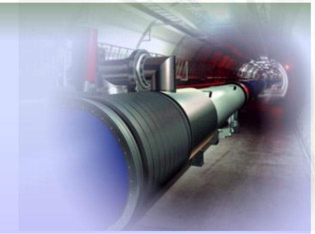


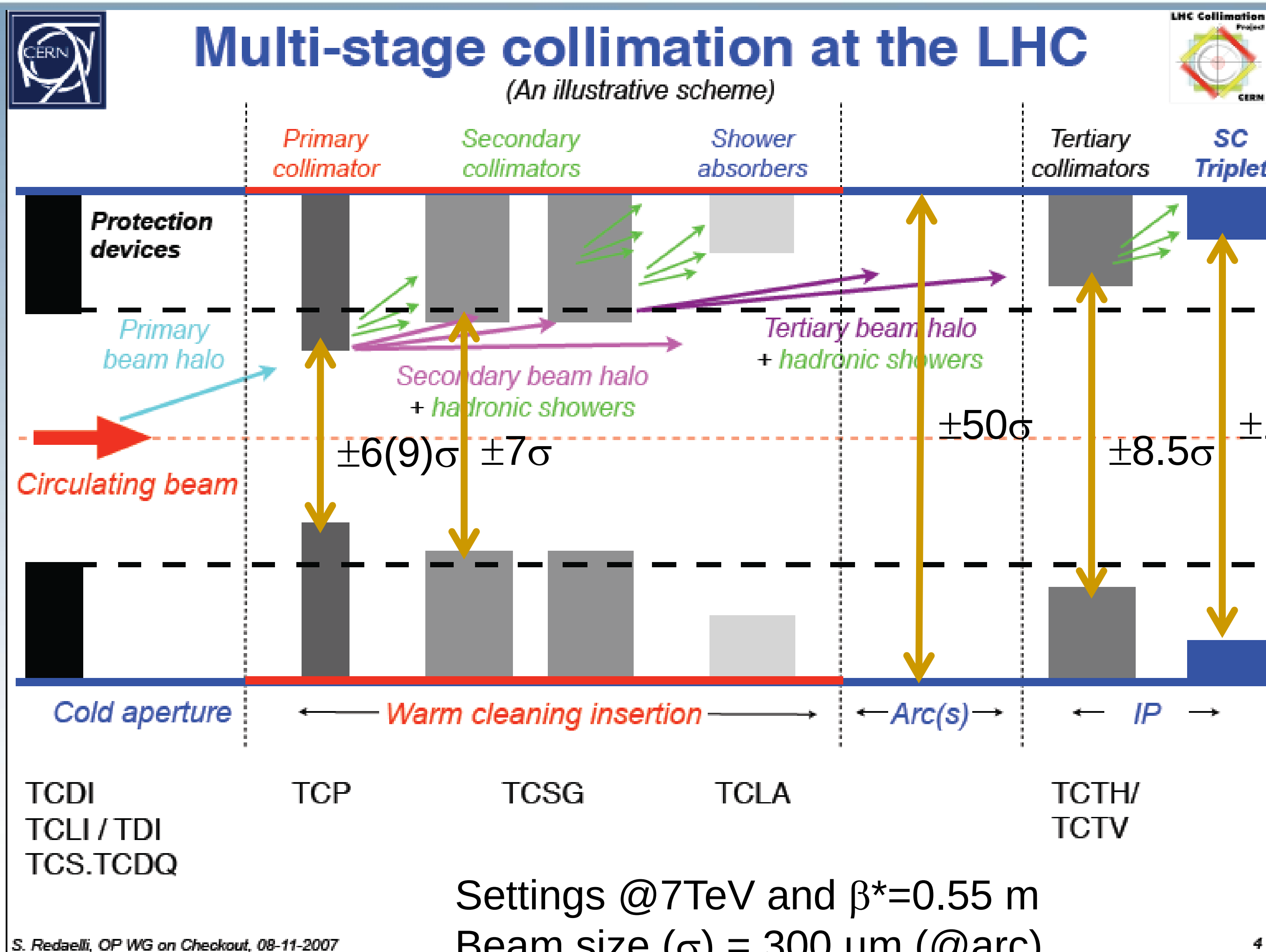




(c) Beam 1, collision optics

IV. Momentum and betatron cleaning insertions (IR3, IR7)



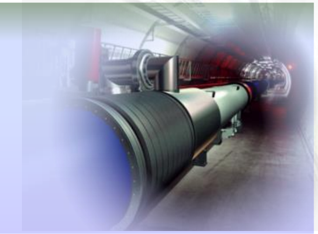


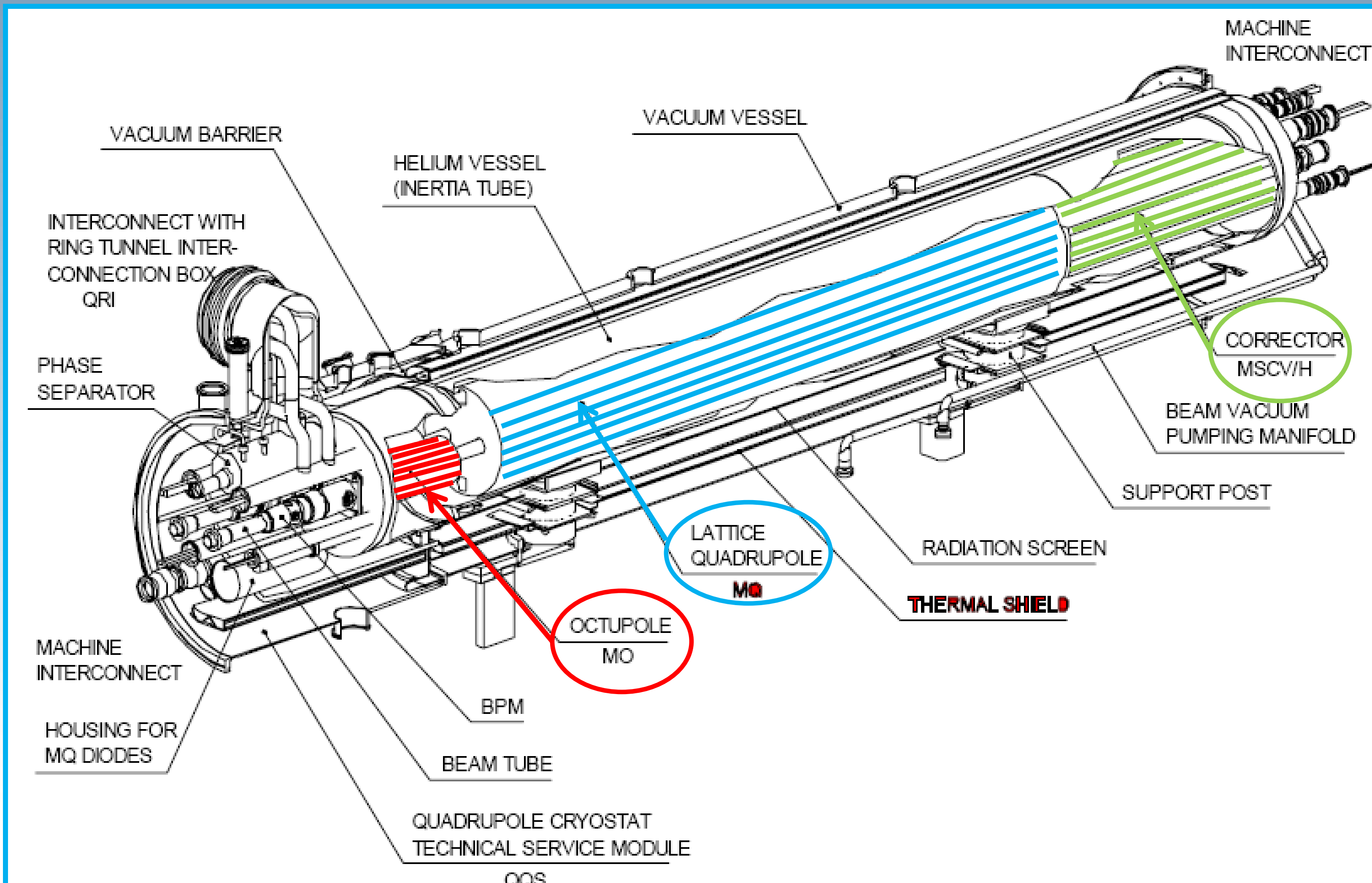
Settings @7TeV and β*=0.55 m

Beam size (σ) = 300 µm (@arc)

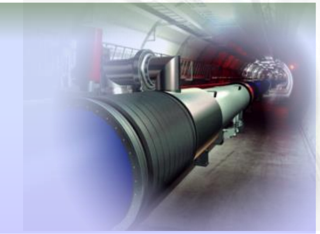
Beam size (σ) = 17 µm (@IR1, IR5)

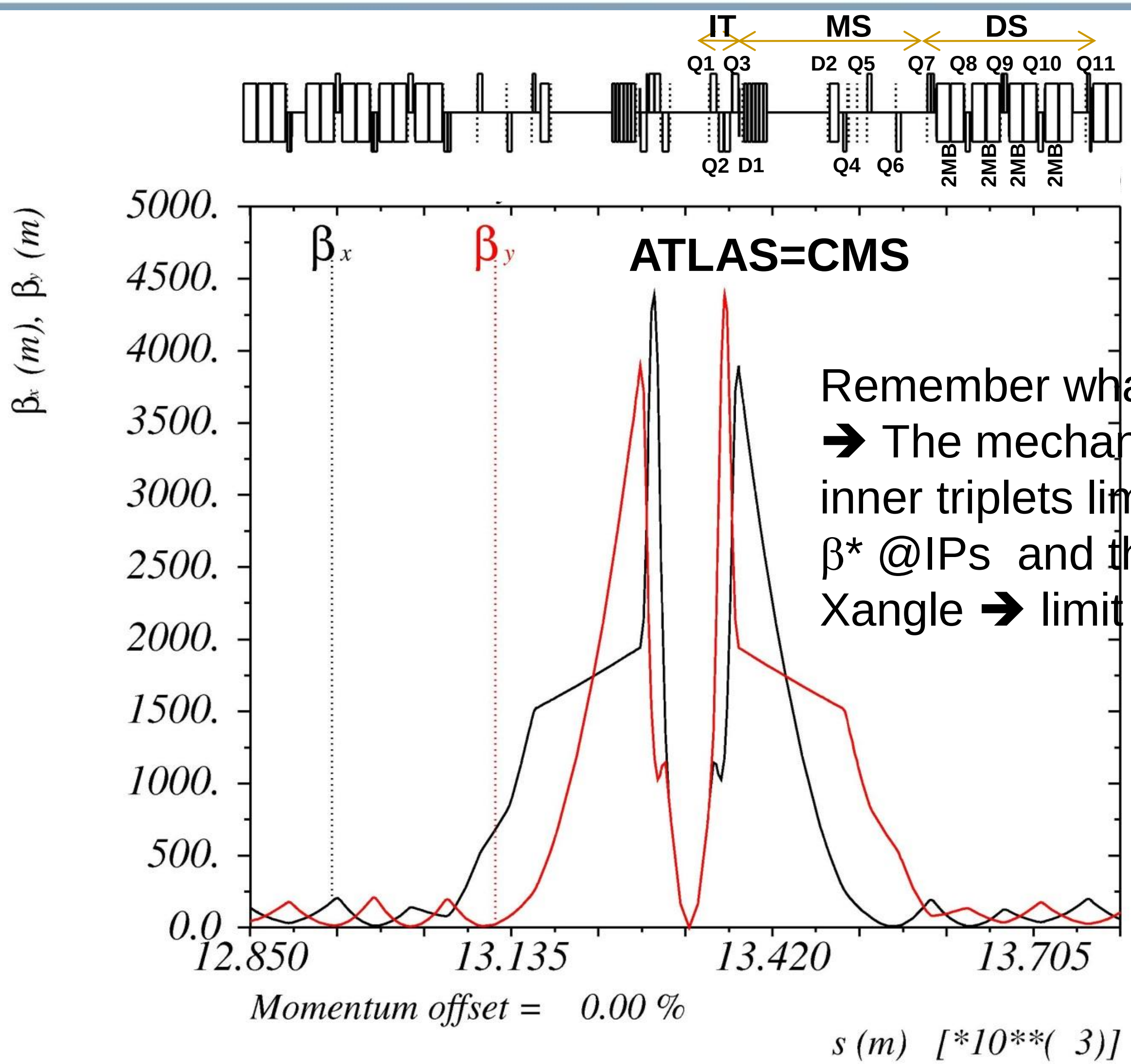
I. Basic layout of the machine: quadrupole corrector magnets





II. LHC Operational cycle: Squeeze ➔ reduce β*





Remember what I said in slide 23 ➔ The mechanical aperture of the inner triplets limits the maximum β* @IPs and the maximum Xangle ➔ limit peak luminosity

II. Beam measurements: Integer tunes