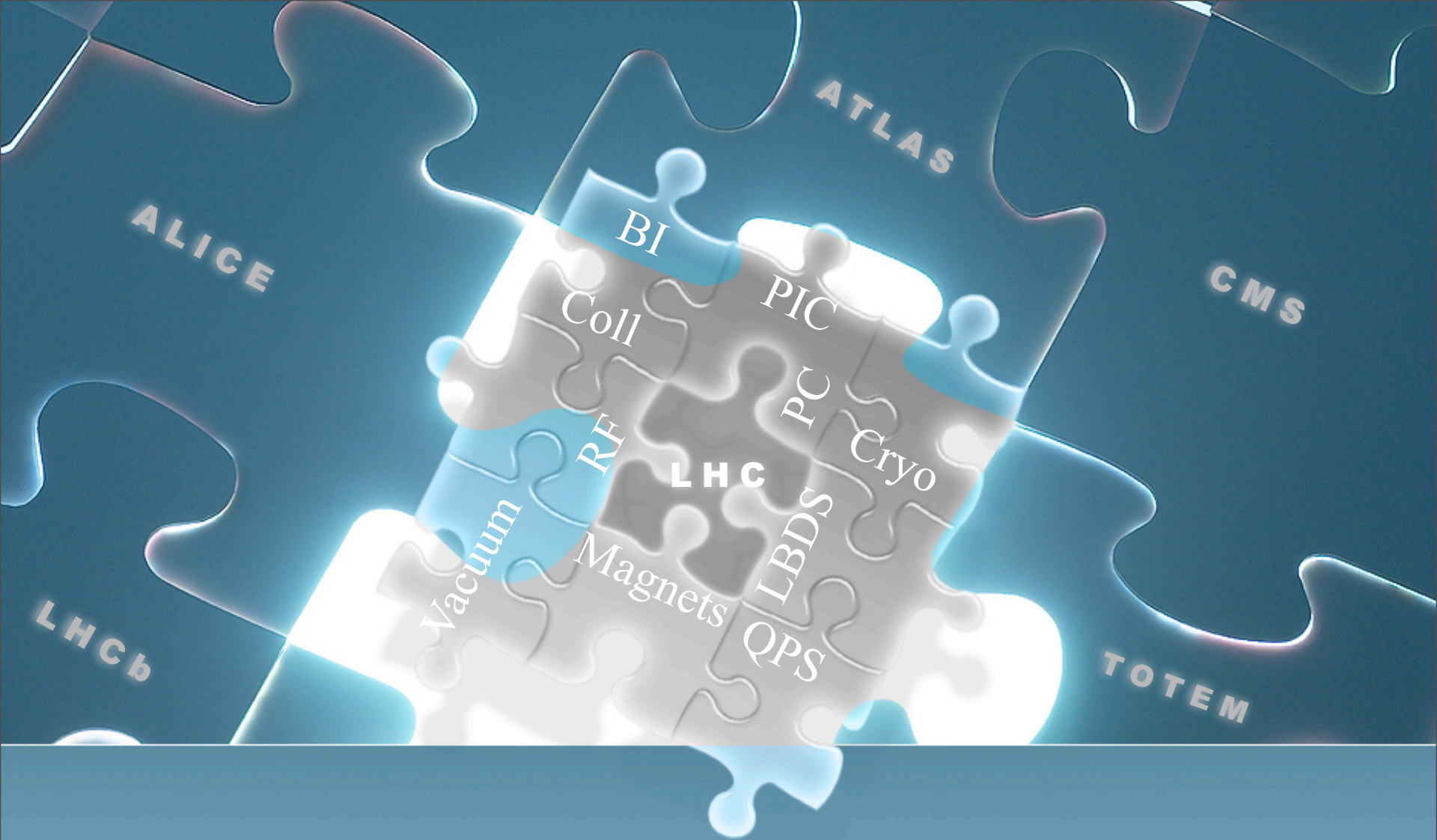




LHC Status & Commissioning



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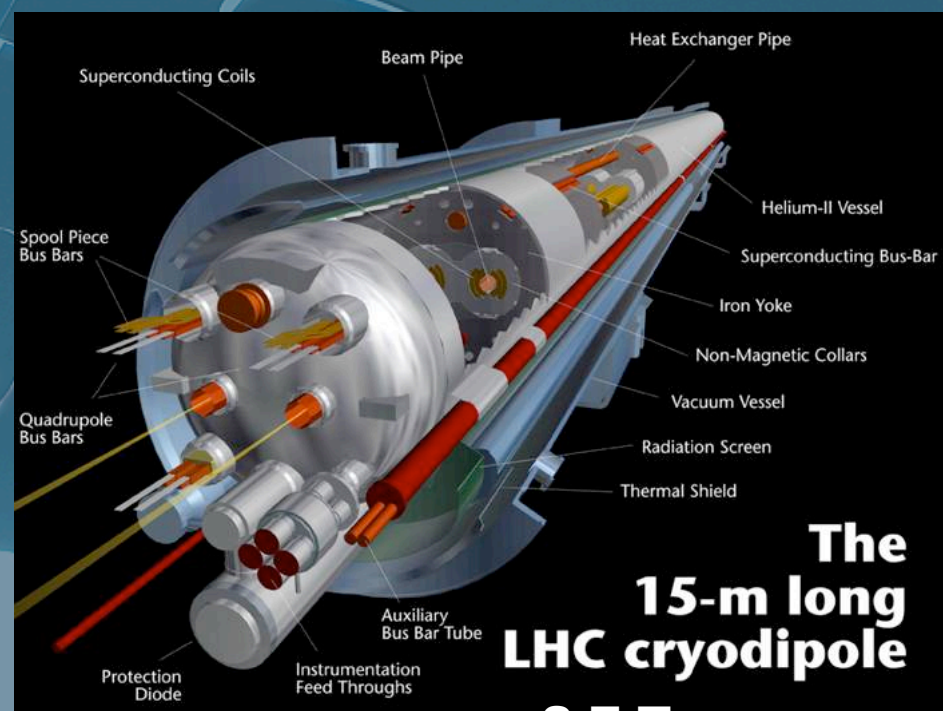
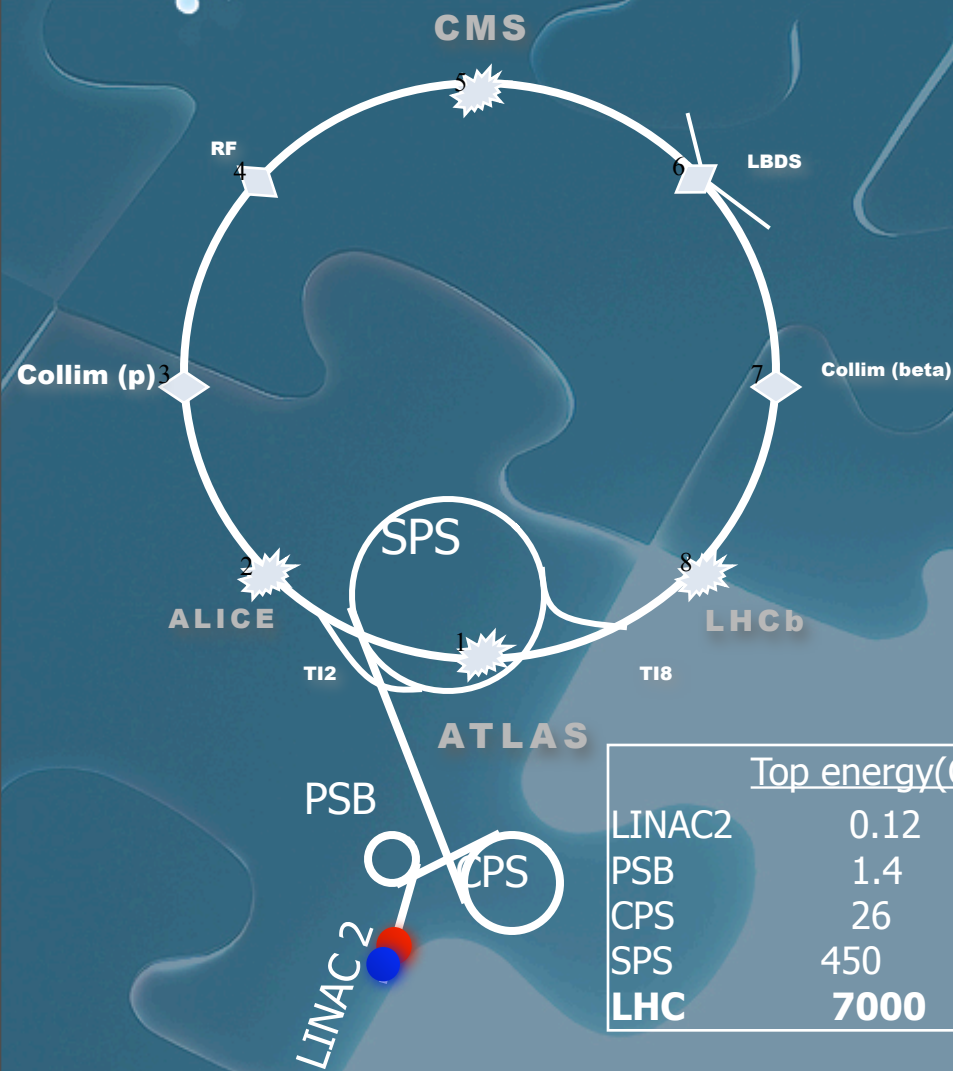
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Accelerator complex for p



**The
15-m long
LHC cryodipole**

8.7 T

11.8 kA / 7 MJ

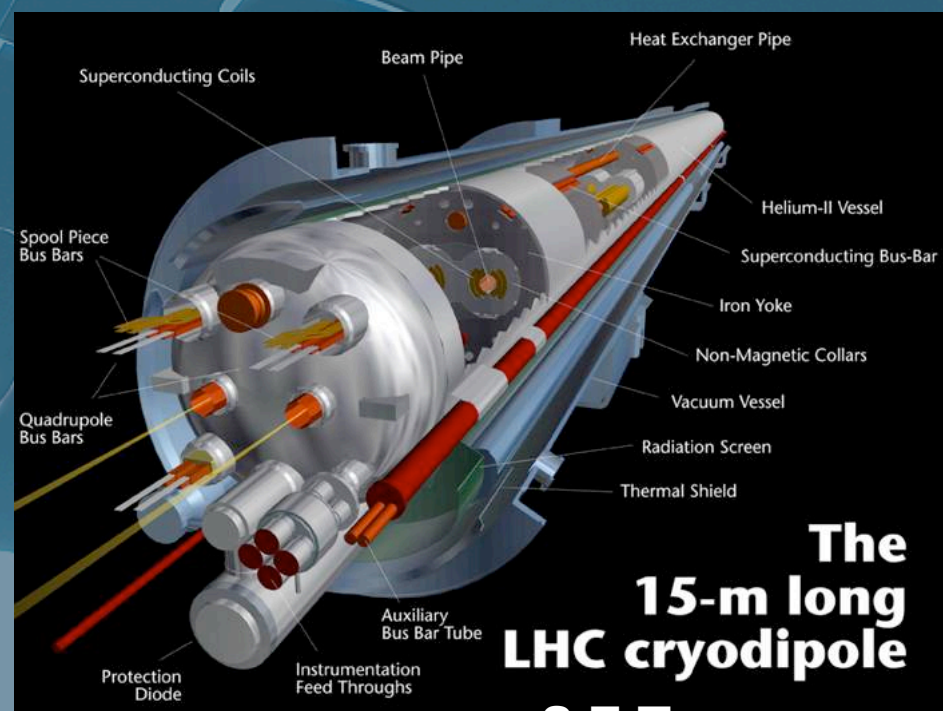
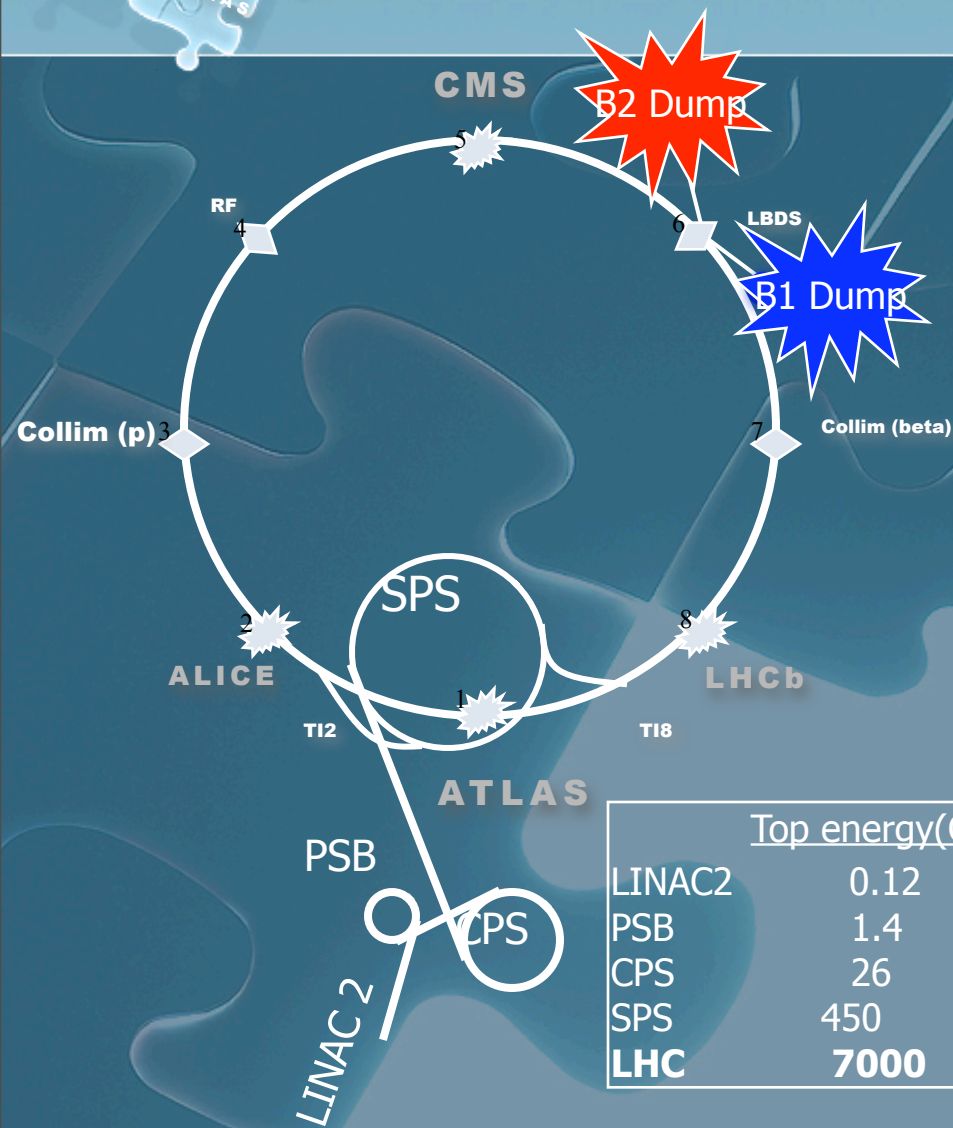
1.9 K

1232 cryodip.

	Top energy(GeV)	Circumference(m)
LINAC2	0.12	30
PSB	1.4	157
CPS	26	628 = 4 PSB
SPS	450	6911 = 11 x PS
LHC	7000	26657 = 27/7xSPS



Accelerator complex for p



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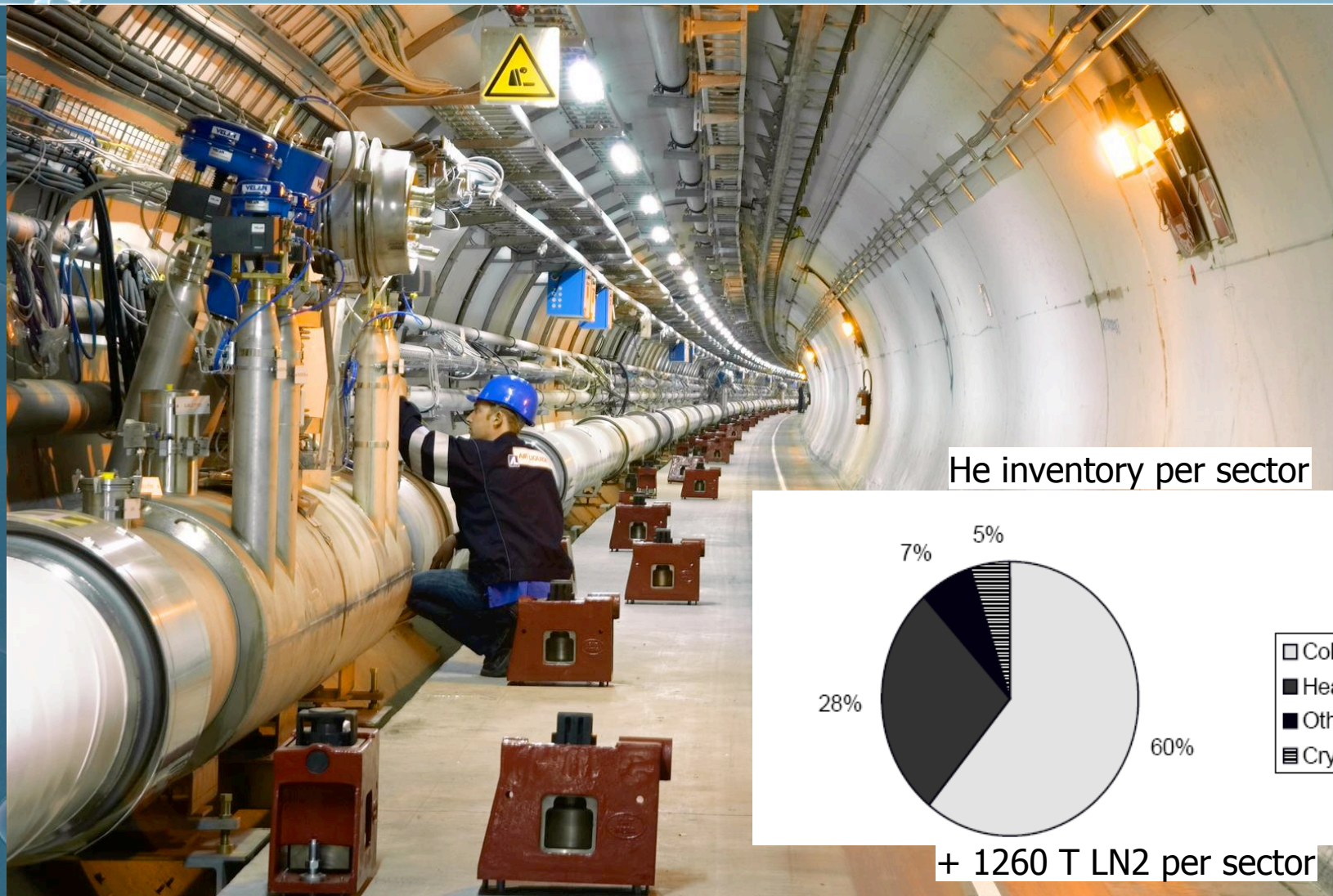


QRL (Cryogenic Line Installation)

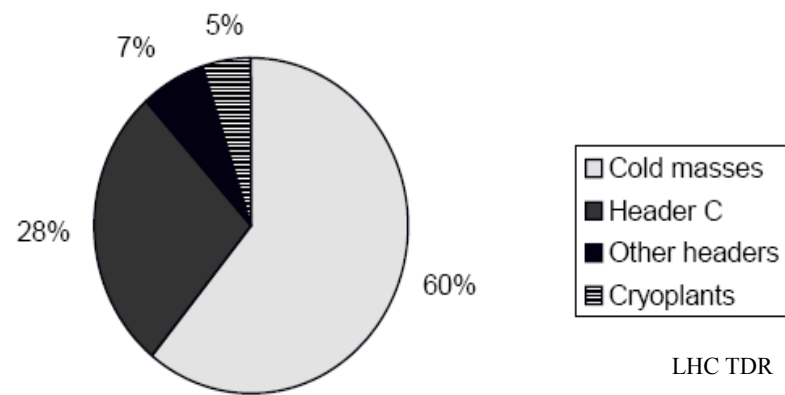




QRL (Cryogenic Line Installation)



He inventory per sector



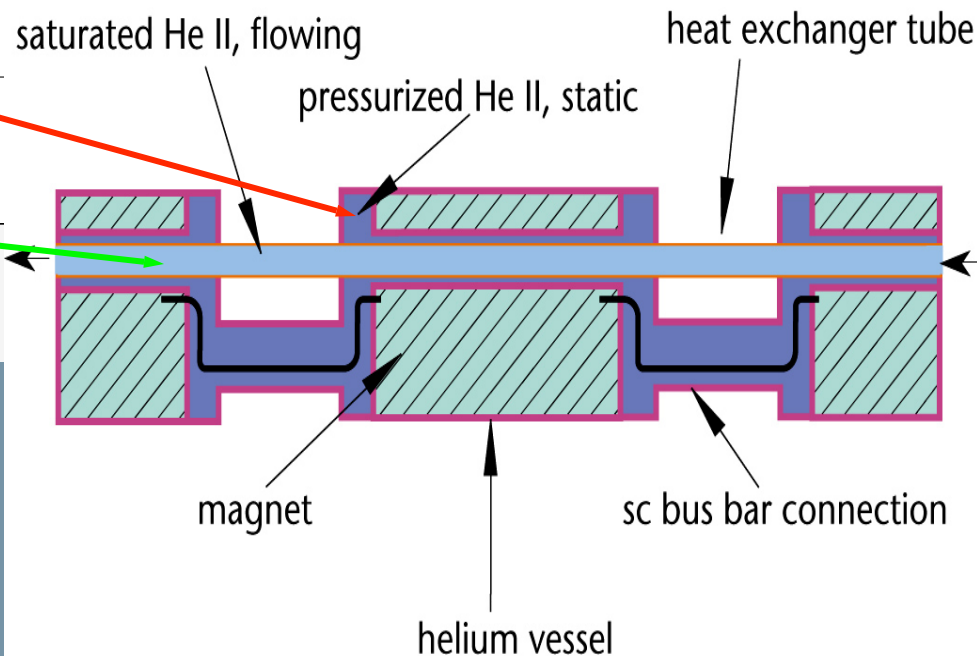
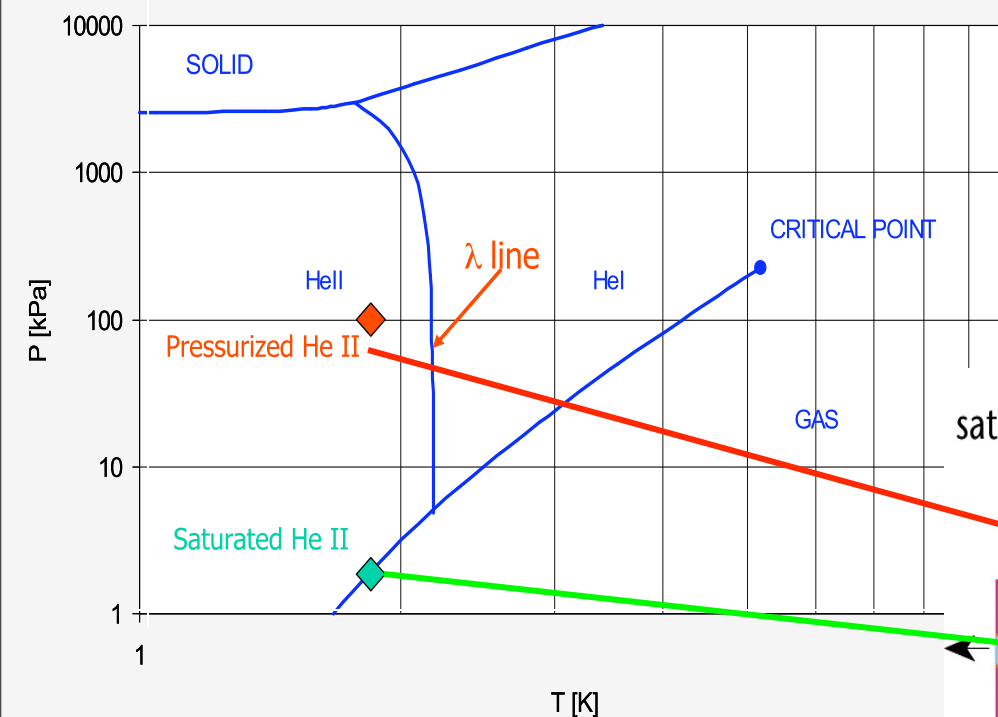
LHC TDR

+ 1260 T LN2 per sector



LHC Cryogenics

- **From RT to 80K:** Precooling with LN2 1200 tons of LN2 (64 trucks of 20 tons) → [Three weeks]
- **From 80K to 4.5K:** Cooldown with He turbines 4700 tons of material to be cooled → [Two weeks]



- **From 4.5K to 1.9K:** Cold compressors (15 mbar) More than 15 tons of helium inventory [One week]
- **Tuning before powering:** Instrumentation, Electrical feed-boxes (DFB's), global process [One week]



LHC Dipoles Installation



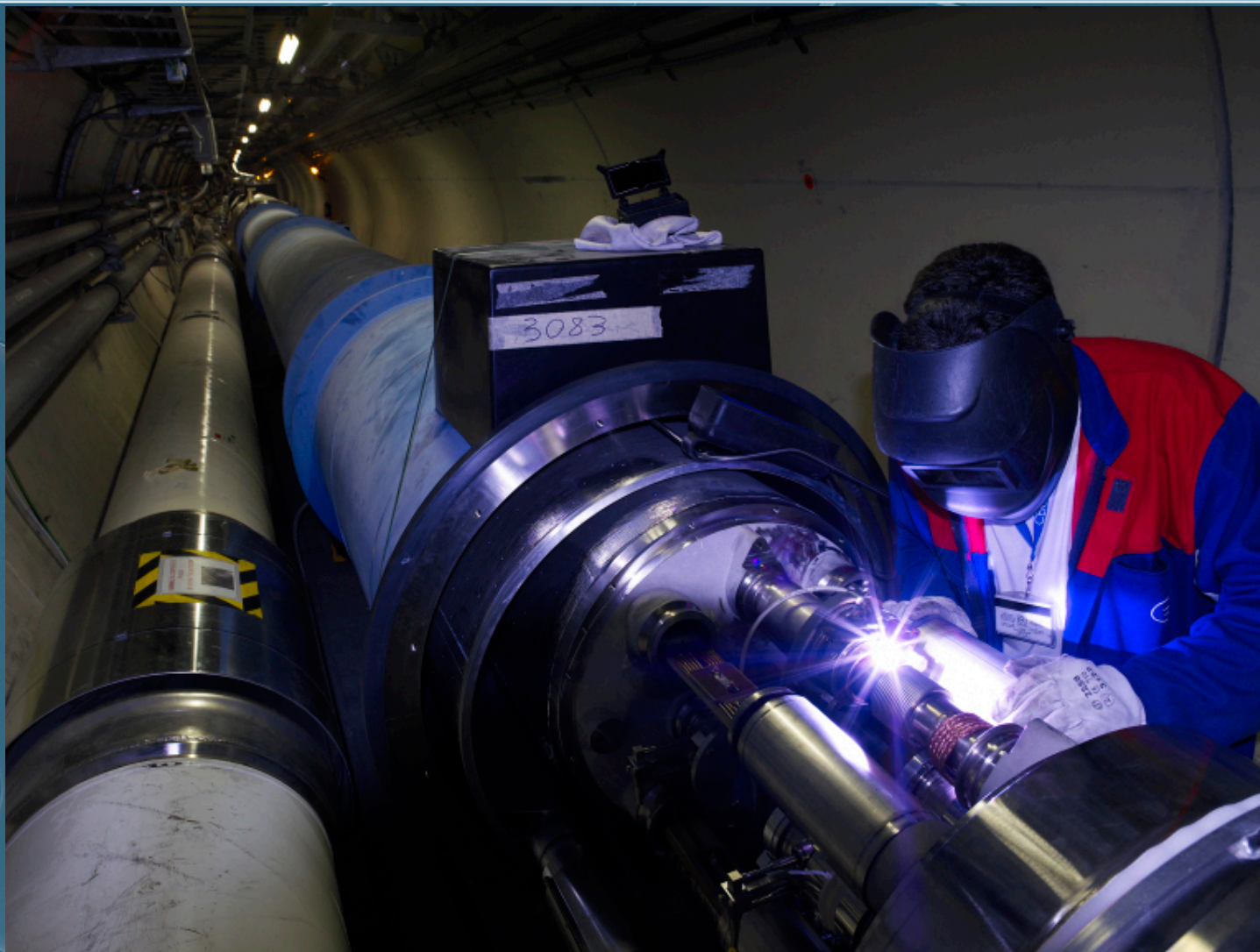


LHC Dipoles Installation





Interconnection





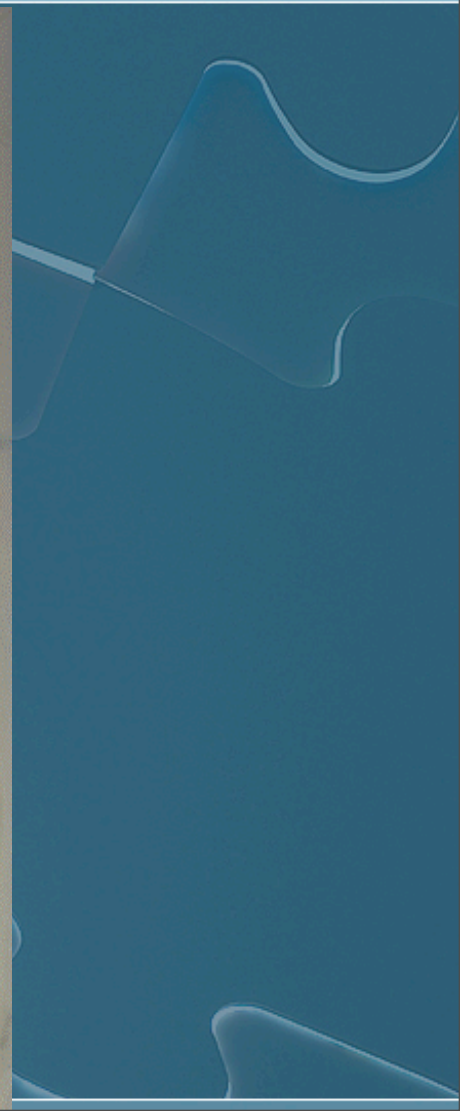
Inner Triplet





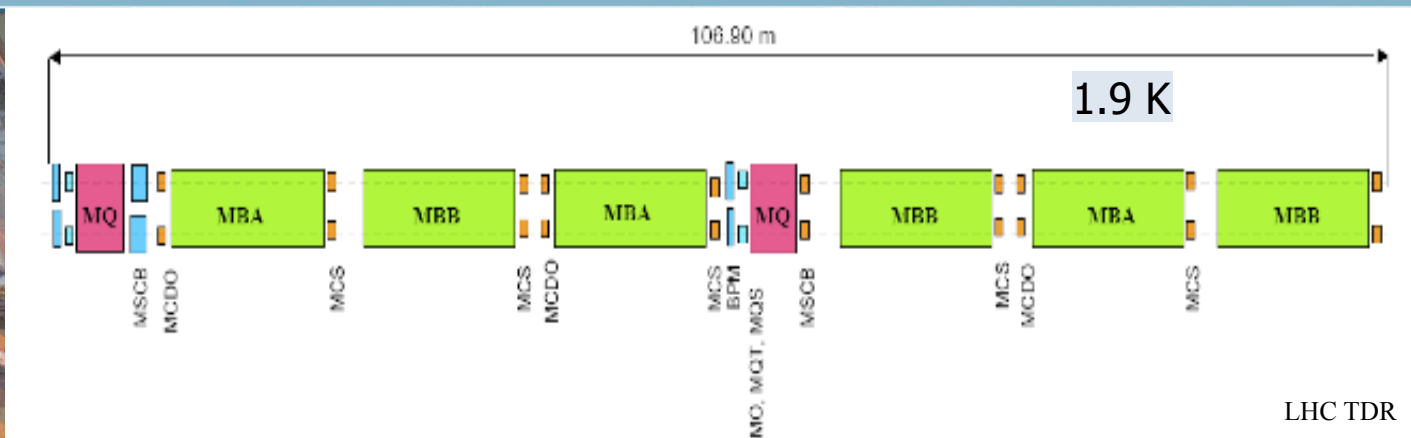
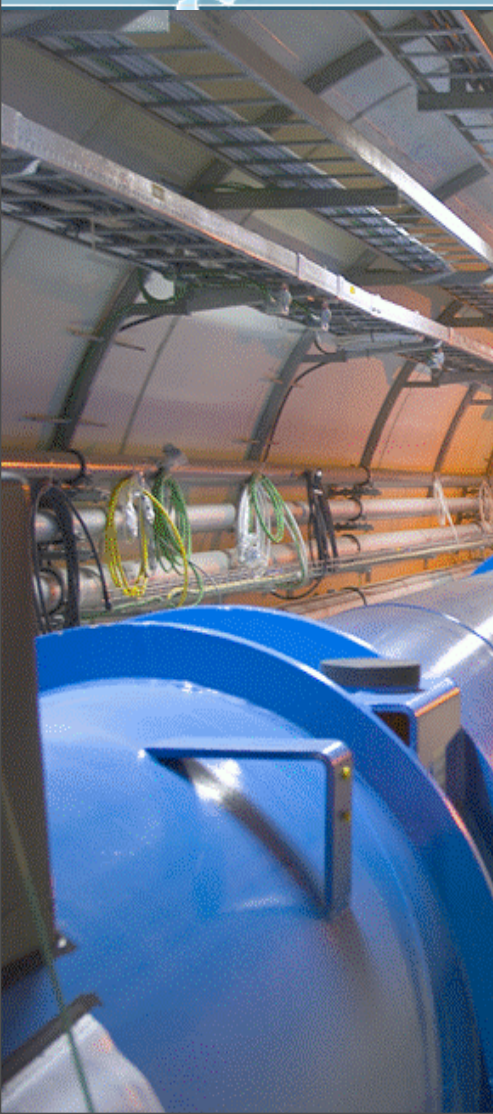


LHC Arc





LHC Arc



- MBB: Main Dipole
- MQ: Main Quadrupole
- MQT: Trim Quadrupole
- MQS: Skew Trim Quadrupole
- MO: Lattice Octupole
- MSCB: Sextupole (Skew Sextupole)+Orbit Corrector
- MCS: Spool Piece Sextupole
- MCDO: Spool Piece Octupole + Decapole
- (BPM: Beam Position Monitor)



LHC Magnet Inventory

Magnet Type	Order	Description	Number of Magnets	Magnet Type	Order	Description	Number of Magnets
MB	1	Main Dipole Coldmass	1232	MO	4	Octupole Lattice Corrector in Arc Short Straight Section	336
MBAW	1	Alice Spectrometer (Muon Dipole)	1	MQ	2	Lattice Quadrupole in the Arc	392
MBLW	1	LHC-b Spectrometer	1	MQM	2	Insertion Region Quadrupole 3.4 m	38
MBRB	1	Twin Aperture Separation Dipole (194 mm) D4	2	MQMC	2	Insertion Region Quadrupole 2.4m	12
MBRC	1	Twin Aperture Separation Dipole (188 mm) D2	8	MQML	2	Insertion Region Quadrupole 4.8 m	36
MBRS	1	Single Aperture Separation Dipole D3	4	MQS	2	Skew Quadrupole Lattice Corrector in Arc Short Straight Section	64
MBW	1	Twin Aperture Warm Dipole Module D3 and D4 in IR3 and IR7	20	MQSX	2	Skew Quadrupole Q3	8
MBWMD	1	Single Aperture Warm Dipole Module Compensating Alice Spectrometer	1	MQT	2	Tuning Quadrupole Corrector in Arc Short Straight Section	320
MBX	1	Single Aperture Separation Dipole D1	4	MQTLH	2	(MQTL Half Shell Type)	48
MBXW	1	Single Aperture Warm Dipole Module D1 in IR1 and IR5	24	MQTLI	2	(MQTL Inertia Tube Type)	72
MBXWH	1	Single Aperture Warm Horizontal Dipole Module Compensating LHC-b Spectrometer	1	MQWA	2	Twin Aperture Warm Quadrupole Module in IR3 and IR7. Asymmetrical FD or DF	40
MBXWS	1	Single Aperture Warm Horizontal Dipole Short Module	2	MQWB	2	Twin Aperture Warm Quadrupole Module in IR3 and IR7. Symmetrical FF or DD	8
MBXWT	1	Single aperture warm compensator for ALICE	2	MQXA	2	Single Aperture Triplet Quadrupole (Q1, Q3)	16
MCBCH	1	Orbit Corrector in MCBCA(B,C,D)	78	MQXB	2	Single Aperture Triplet Quadrupole (Q2)	16
MCBCV	1	Orbit Corrector in MCBCA(B,C,D)	78	MQY	2	Insertion Region Wide Aperture Quadrupole 3.4 m.	24
MCBH	1	Arc Orbit Corrector in MSCBA(B,C,D), Horizontal	376	MS	3	Arc Sextupole Lattice Corrector Associated to MCBH or MCBV in MSCBA, MSCBB, MSCBC and MSCBD	688
MCBV	1	Arc Orbit Corrector in MSCBA(B,C,D), Vertical	376	MSDA	1	Ejection dump septum, Module A	10
MCBWH	1	Single Aperture Warm Orbit Horizontal Corrector	8	MSDB	1	Ejection dump septum, Module B	10
MCBWV	1	Single Aperture Warm Orbit Vertical Corrector	8	MSDC	1	Ejection dump septum, Module C	10
MCBXH	1	Horizontal Orbit Corrector in MCBX(A)	24	MSIA	1	Injection septum, Module A	4
MCBXV	1	Vertical Orbit Corrector in MCBX(A)	24	MSIB	1	Injection septum, Module B	6
MCBYH	1	Orbit Corrector in MCBYA(B)	44	MSS	2	Arc skew Sextupole Corrector Associated to MCBH in MSCBC and MSCBD	64
MCBYV	1	Orbit Corrector in MCBYA(B)	44				
MCD	5	Decapole Corrector in MCDO, (Spool Piece Corrector)	1232				
MCO	4	Octupole Corrector in MCDO, (Spool Piece Corrector)	1232				
MCOSX	3	Skew Octupole Spool-Piece Associated to MQSX in MQSXA	8				
MCOX	4	Octupole Spool-Piece Associated to MQSXA	8				
MCS	3	Sextupole Corrector, (Spool Piece Corrector)	2464				
MCSSX	3	Skew Sextupole Spool-Piece Associated to MQSX in MQSXA	8				
MCSX	3	Sextupole Spool-Piece Associated to MCBXA	8				
MCTX	6	Dodecapole Spool-Piece Associated to MCBXA	8				
MKA	1	Tune kicker	2				
MKD	1	Ejection dump kicker	30				
MKI	1	Injection kicker	8				
MKQ	1	Kicker For Q And Aperture Measurement	2				

~ 9000 magnets powered with
~1700 power converters



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Energy Stored in the Magnets

**~ 11 GJoule (only in the main dipoles*)
corresponds to ...**

... an aircraft carrier at battle-speed of 55
km/h



CMS

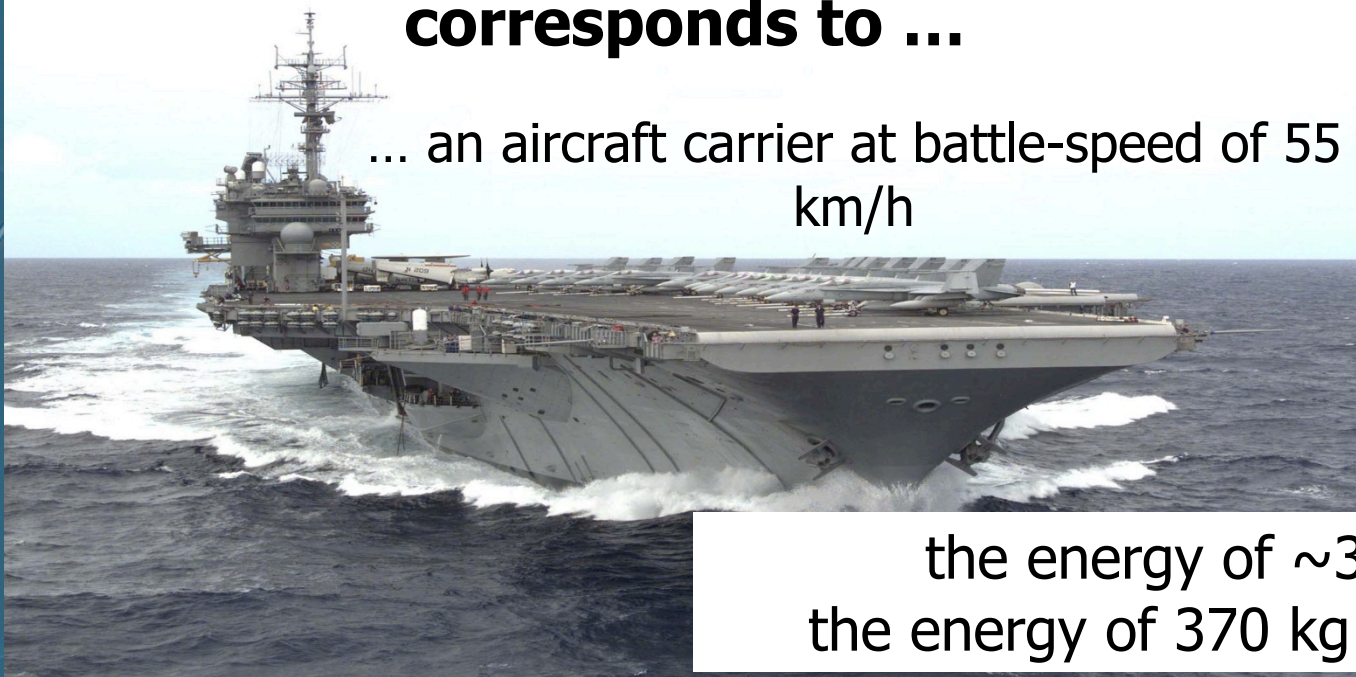
* 400 MJ in the main quadrupoles



Energy Stored in the Magnets

**~ 11 GJoule (only in the main dipoles*)
corresponds to ...**

... an aircraft carrier at battle-speed of 55
km/h



the energy of ~ 3 Tons TNT
the energy of 370 kg dark chocolate

More important than the amount of energy is ...
**How fast (an safe) can this energy be
released?**

* 400 MJ in the main quadrupoles



Energy Stored in the Magnets

If not fast and safe ...



During magnet test campaign, the 7 MJ stored in one magnet were released into one spot of the coil (inter-turn short)

P. Pugnat



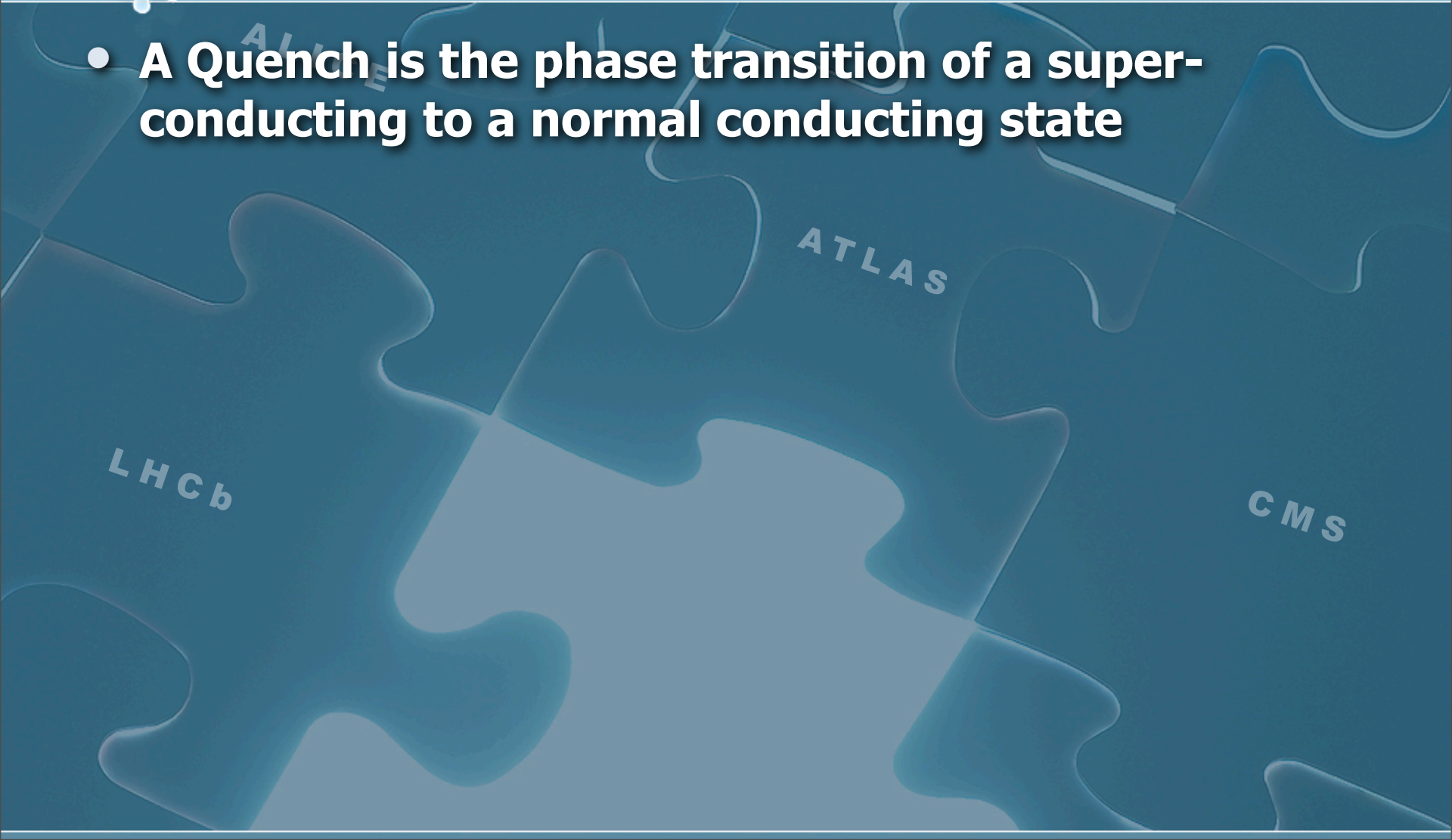
Energy Stored in the Magnets: Quench & Quench Protection System





Energy Stored in the Magnets: Quench & Quench Protection System

- **A Quench is the phase transition of a superconducting to a normal conducting state**





Energy Stored in the Magnets: Quench & Quench Protection System

- **A Quench is the phase transition of a superconducting to a normal conducting state**
- **Quenches are initiated by an energy release of the order of mJ:**
 - **Movement of the superconductor by several μm (friction and heat dissipation)**
 - **Beam losses:**
 - **@7 TeV 0.6 J/cm^3 can quench a dipole; this energy density can be generated by 10^7 protons**
 - **@450 GeV (injection energy), 10^9 protons are needed**
 - **Failure in cooling**



Energy Stored in the Magnets: Quench & Quench Protection System



* On every SC magnet



Energy Stored in the Magnets: Quench & Quench Protection System

- To limit the temperature increase after a quench
 - The quench has to be detected → Quench Detectors*
 - The energy is distributed in the magnet by force-quenching the coils using Quench Heaters*
 - The stored energy is released in a controlled way → Cold by-pass diodes* & Energy Extraction System
 - The magnet current is switched off within $\ll 1$ second → Power Interlock System

* On every SC magnet



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 - Missed quench: damage of magnet, down time 30 days

* On every SC magnet



Energy Stored in the Magnets: Quench & Quench Protection System

Quench Protection System

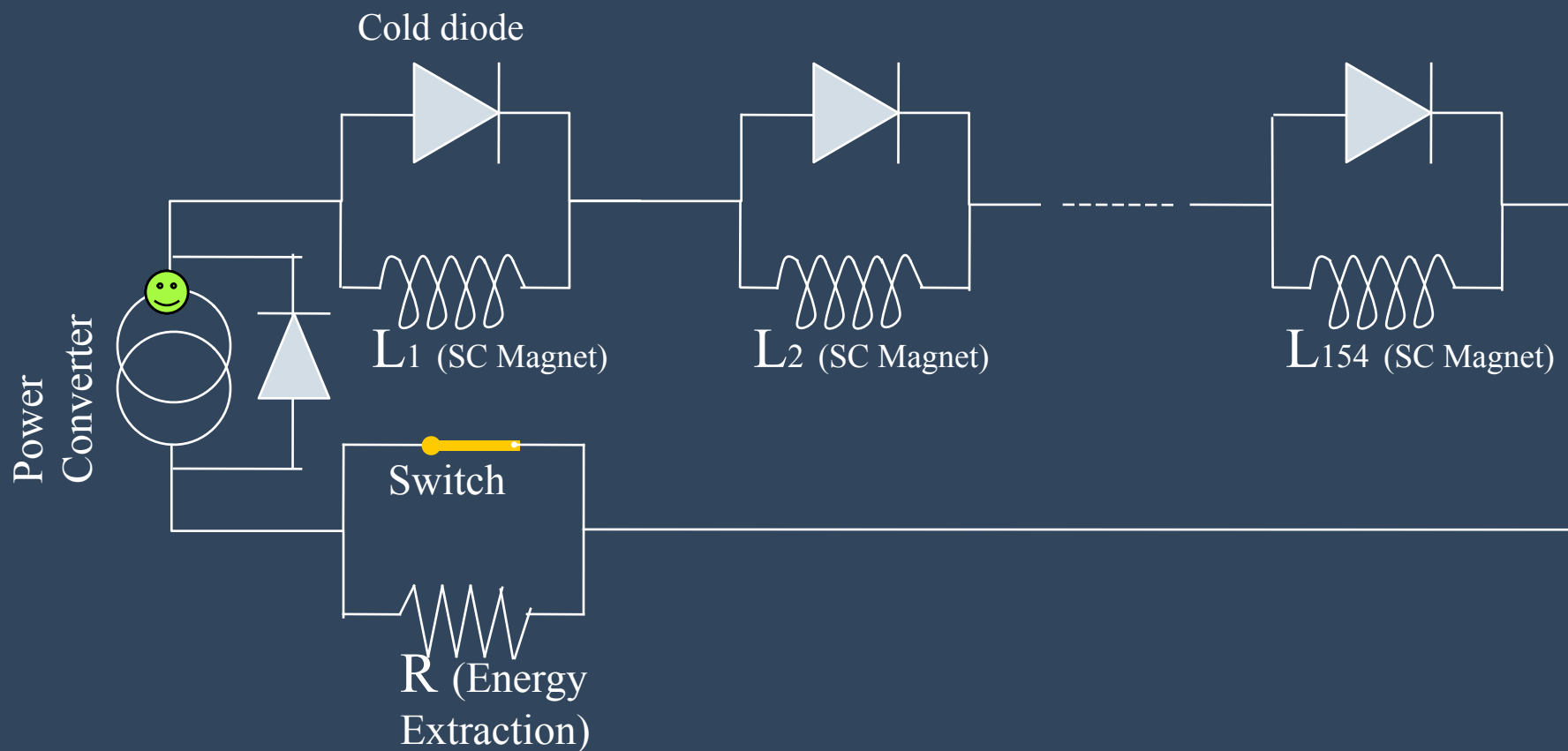
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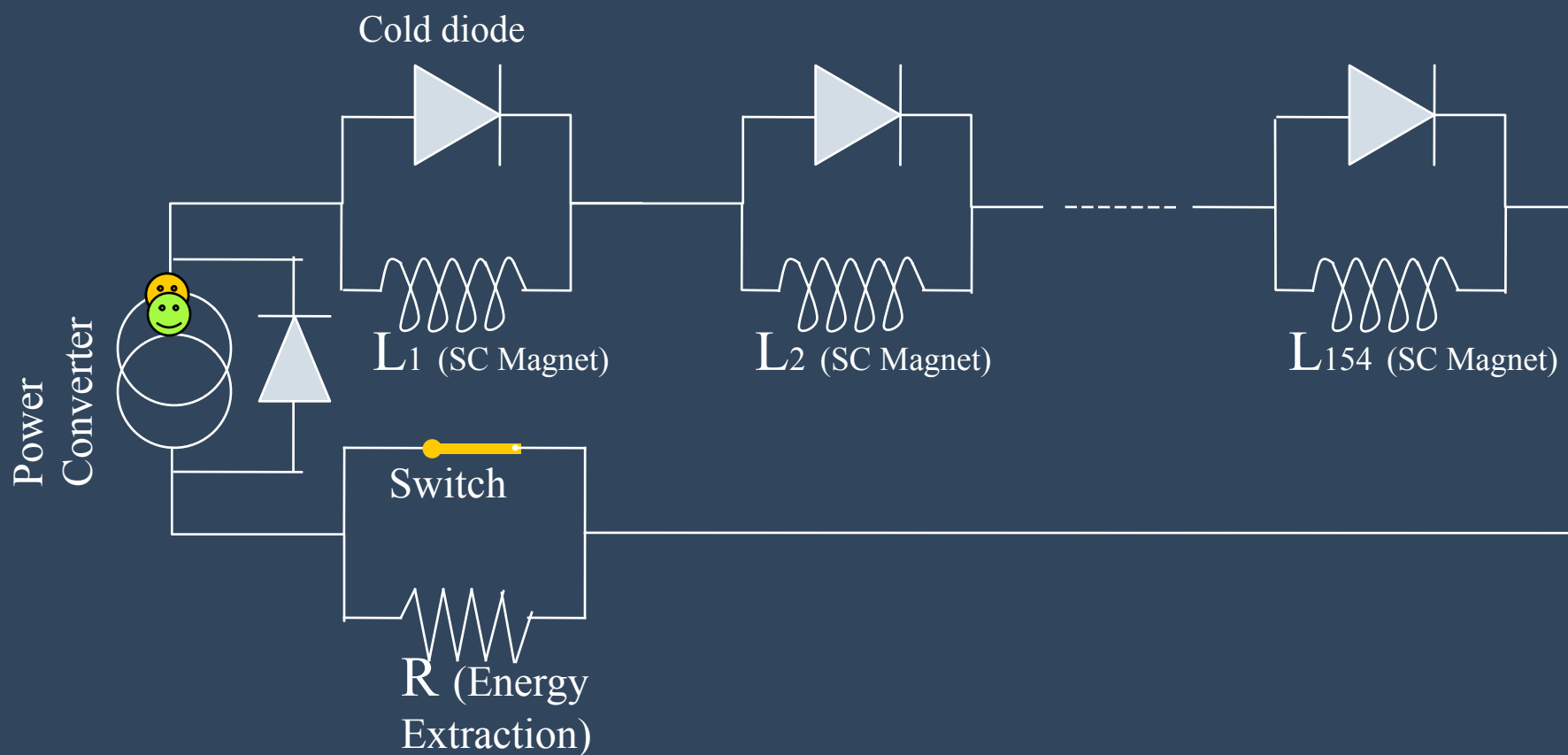
LHC Main Dipole System in one sector





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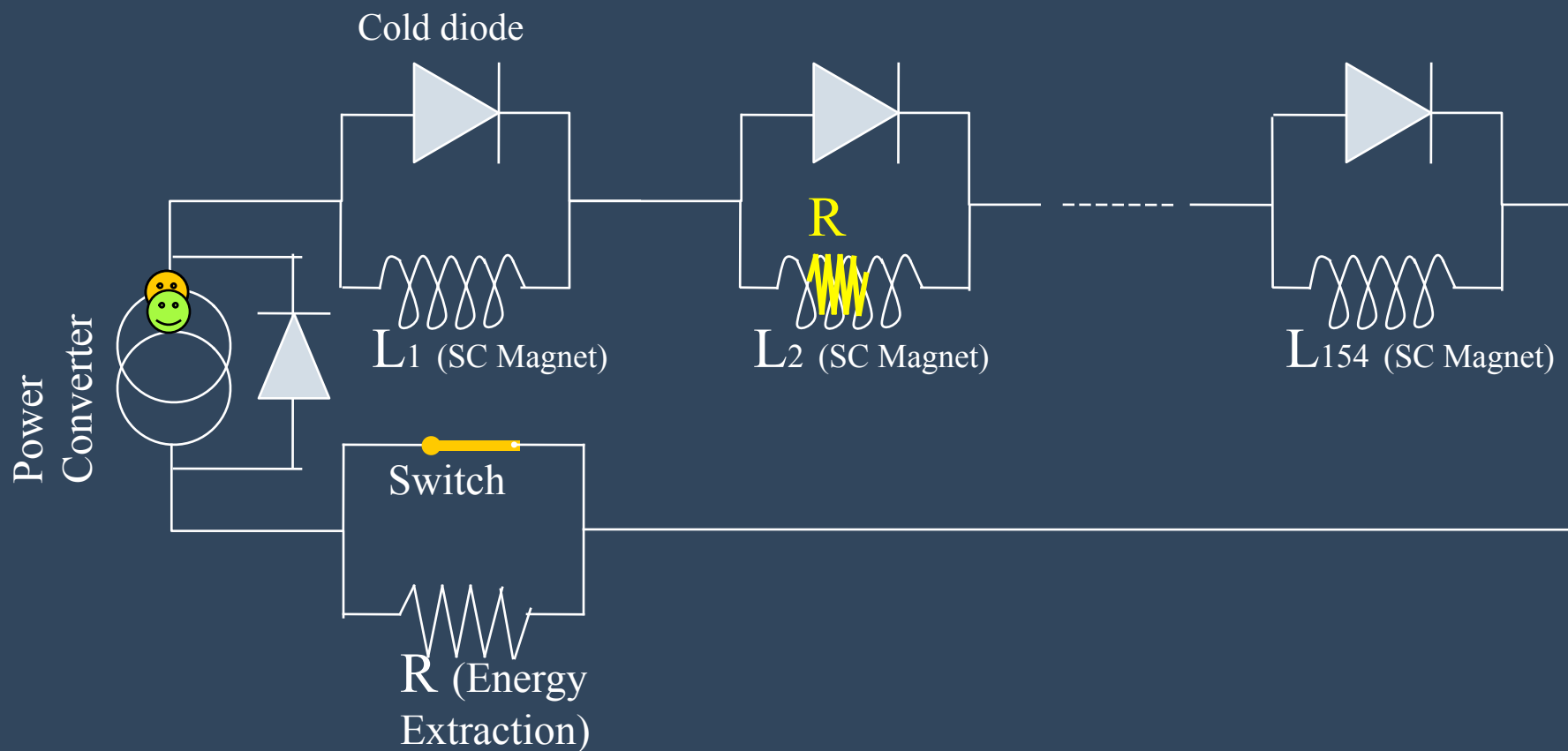
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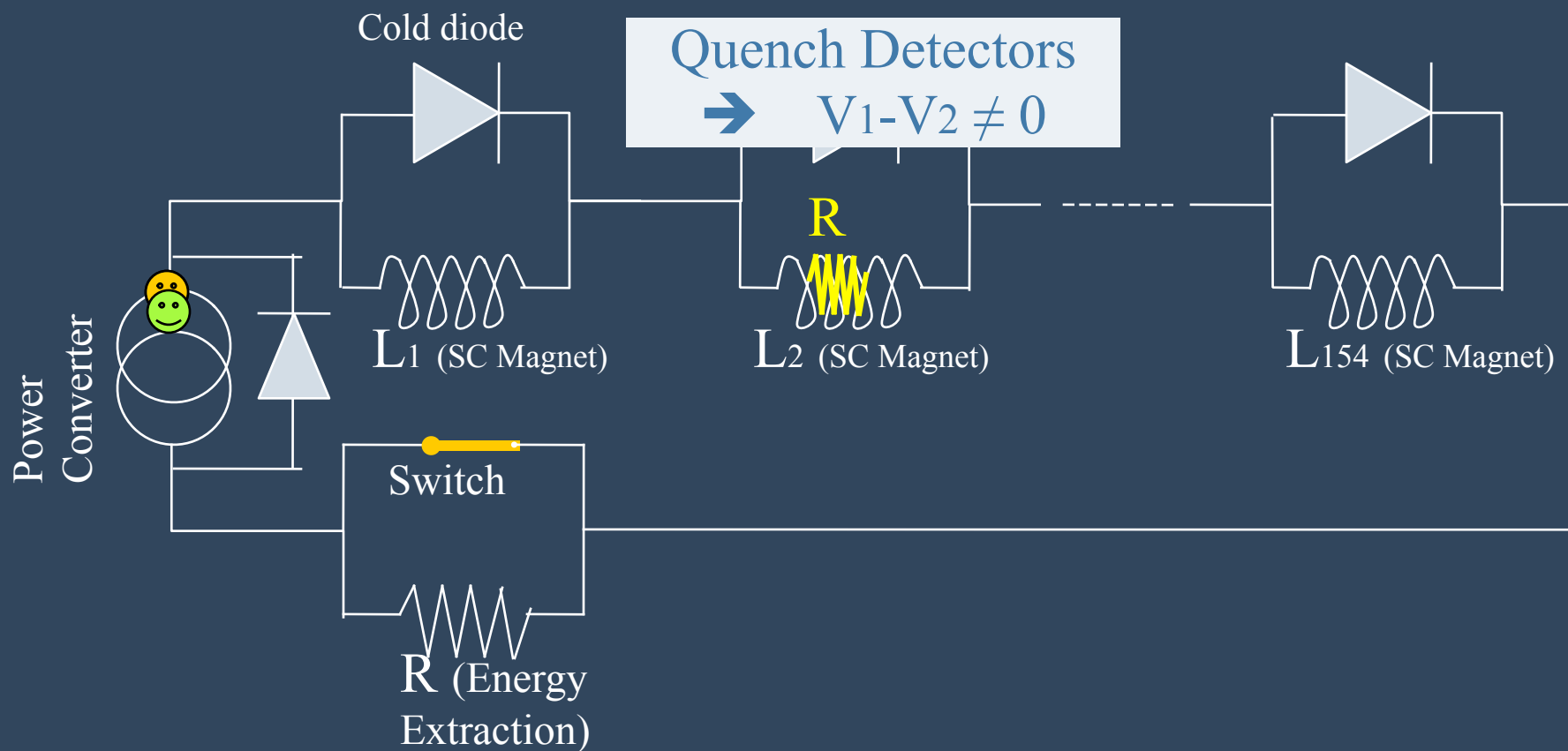
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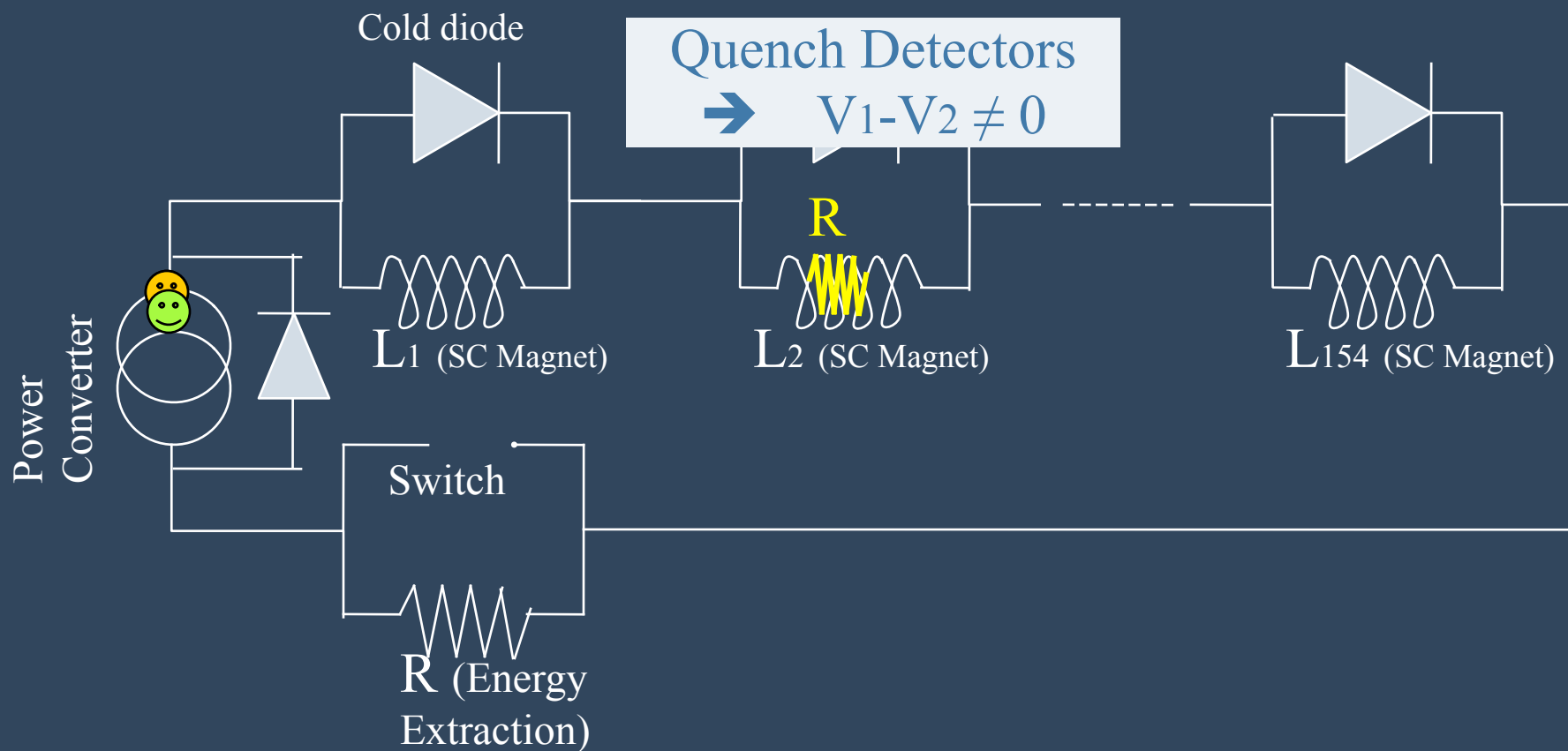
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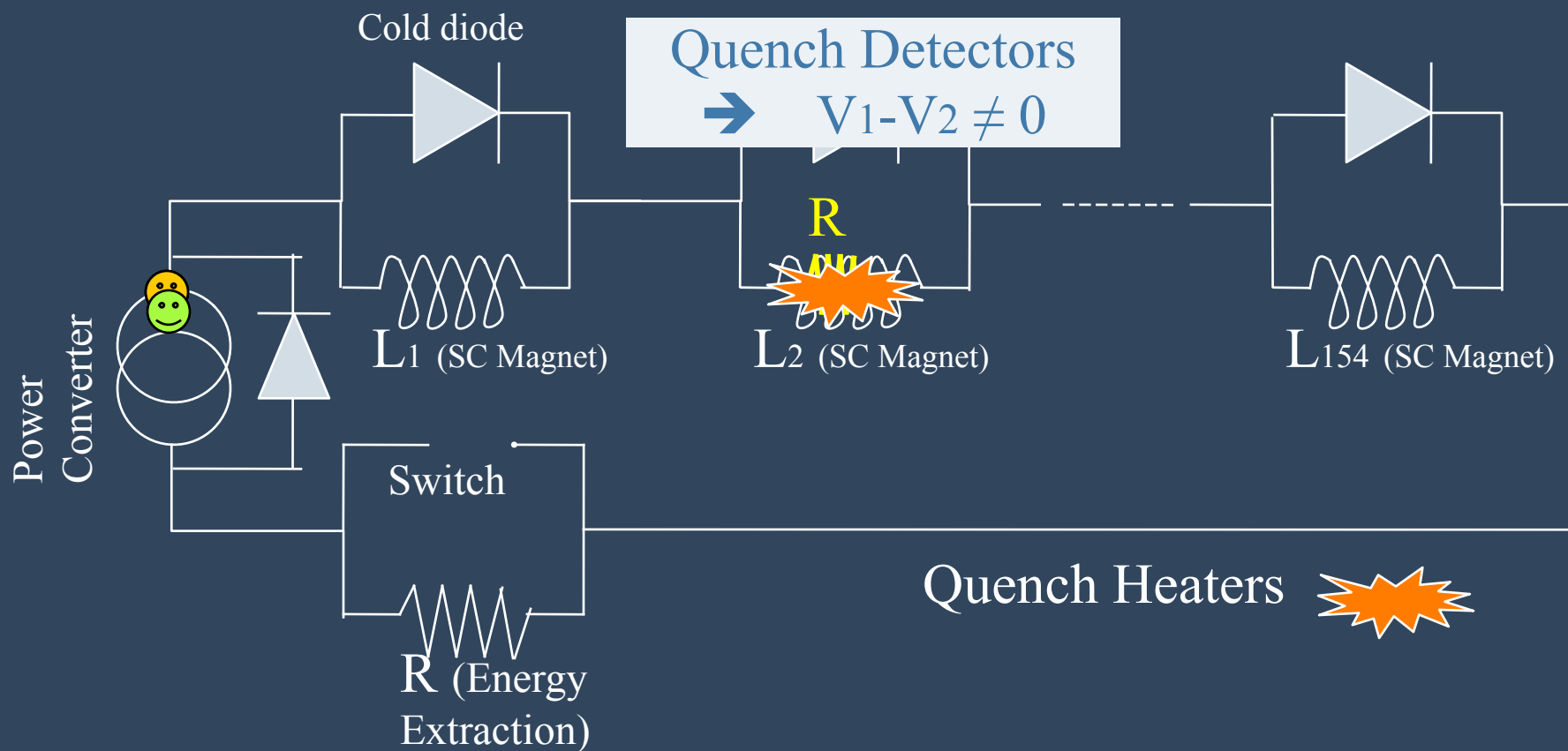
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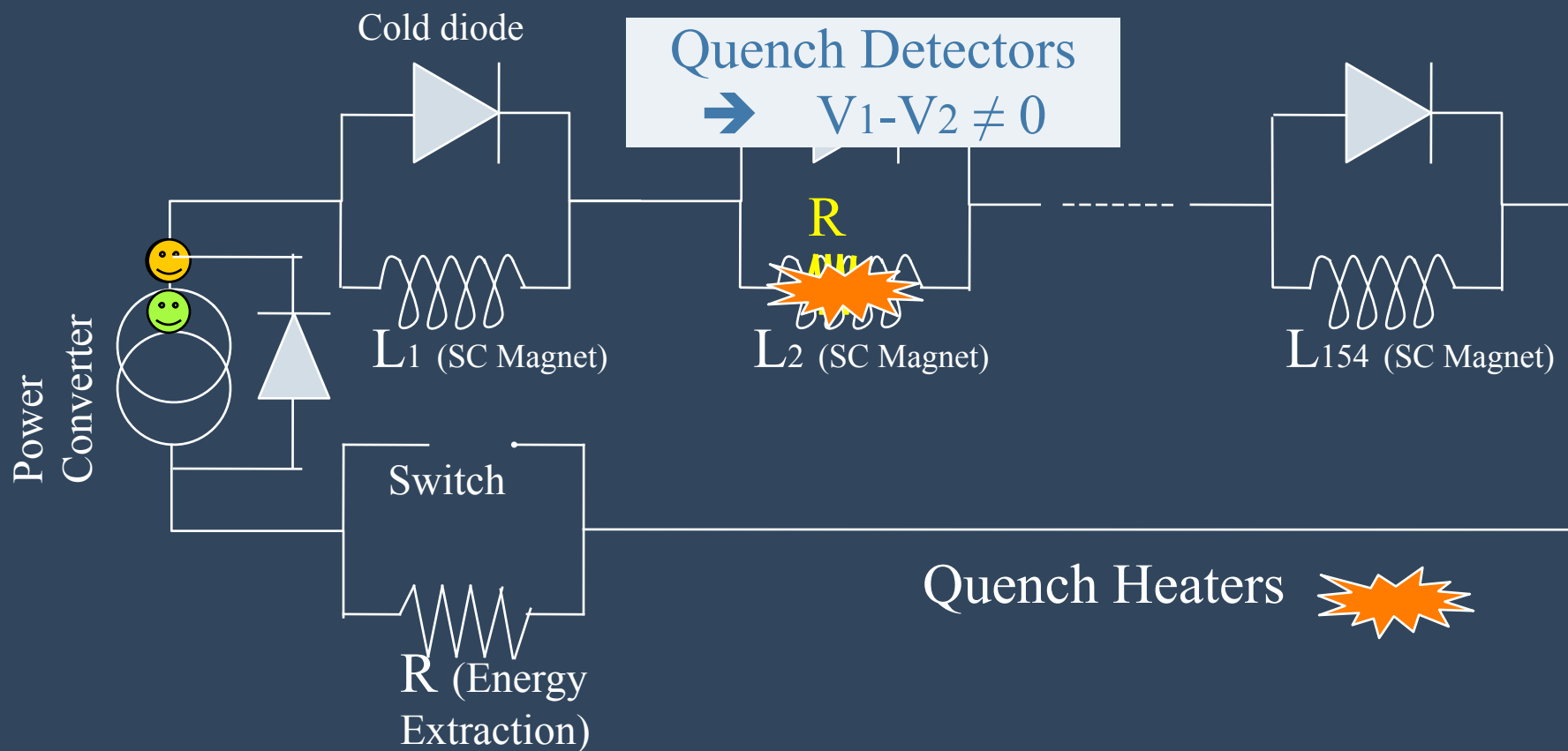
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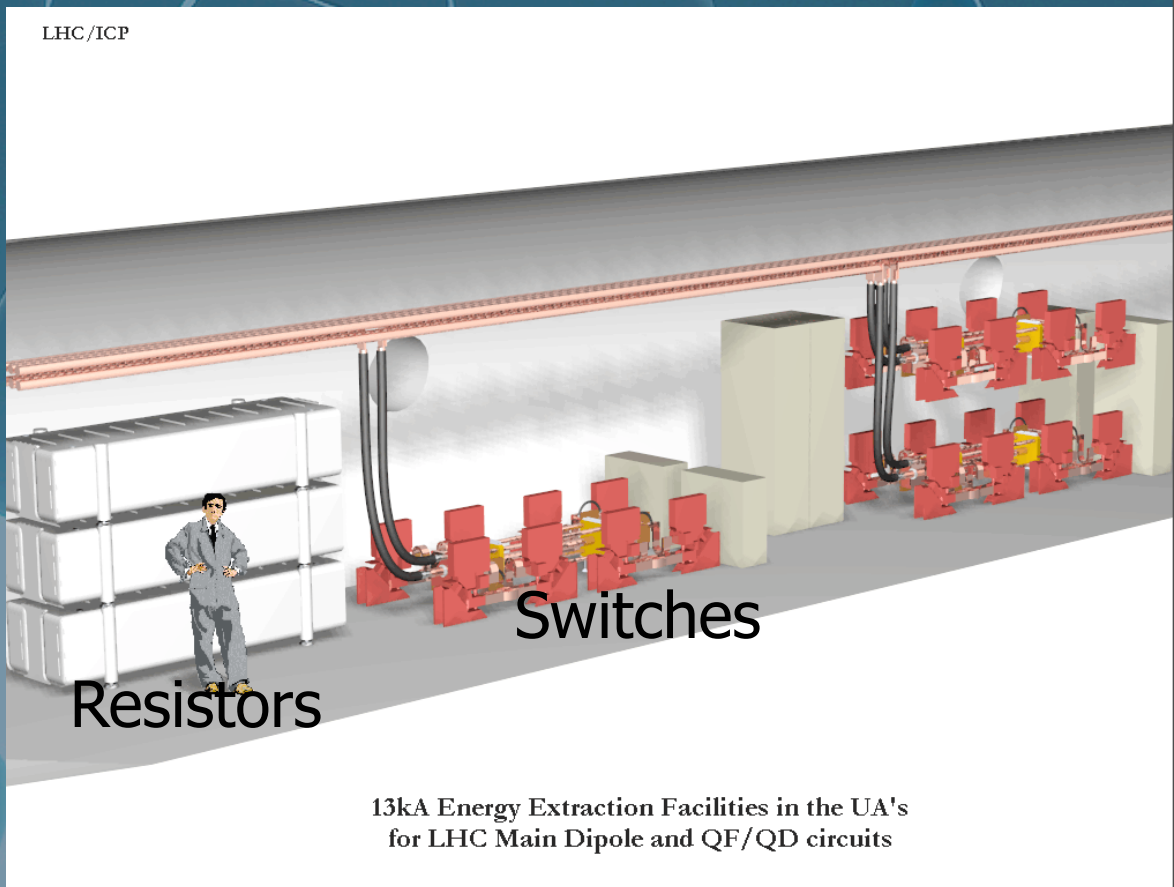




Magnet Energy: Energy Extraction System

ALICE

LHCb

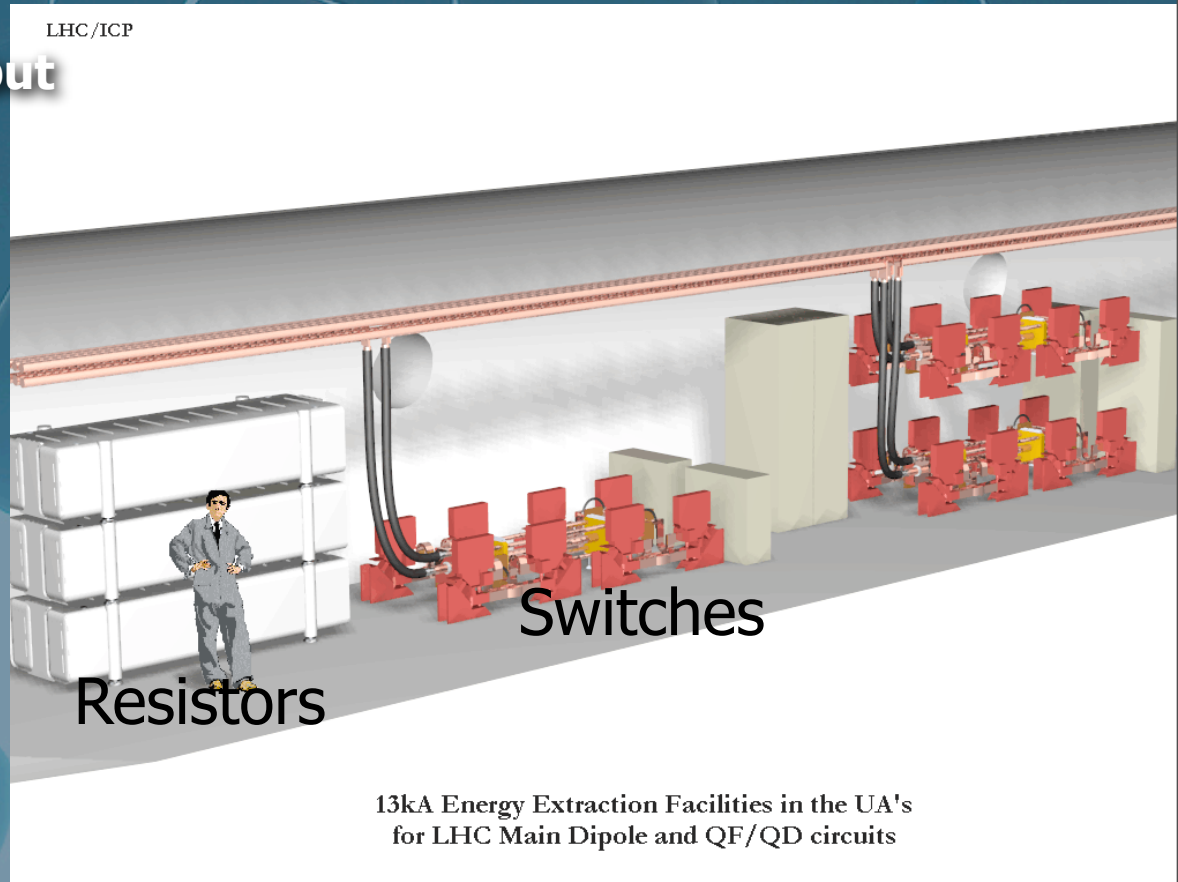


13kA Energy Extraction Facilities in the UA's
for LHC Main Dipole and QF/QD circuits



Magnet Energy: Energy Extraction System

- During normal operation every ramp down of the magnets implies energy extraction, but this takes ~ 20 min $\rightarrow$ too slow in case of a quench

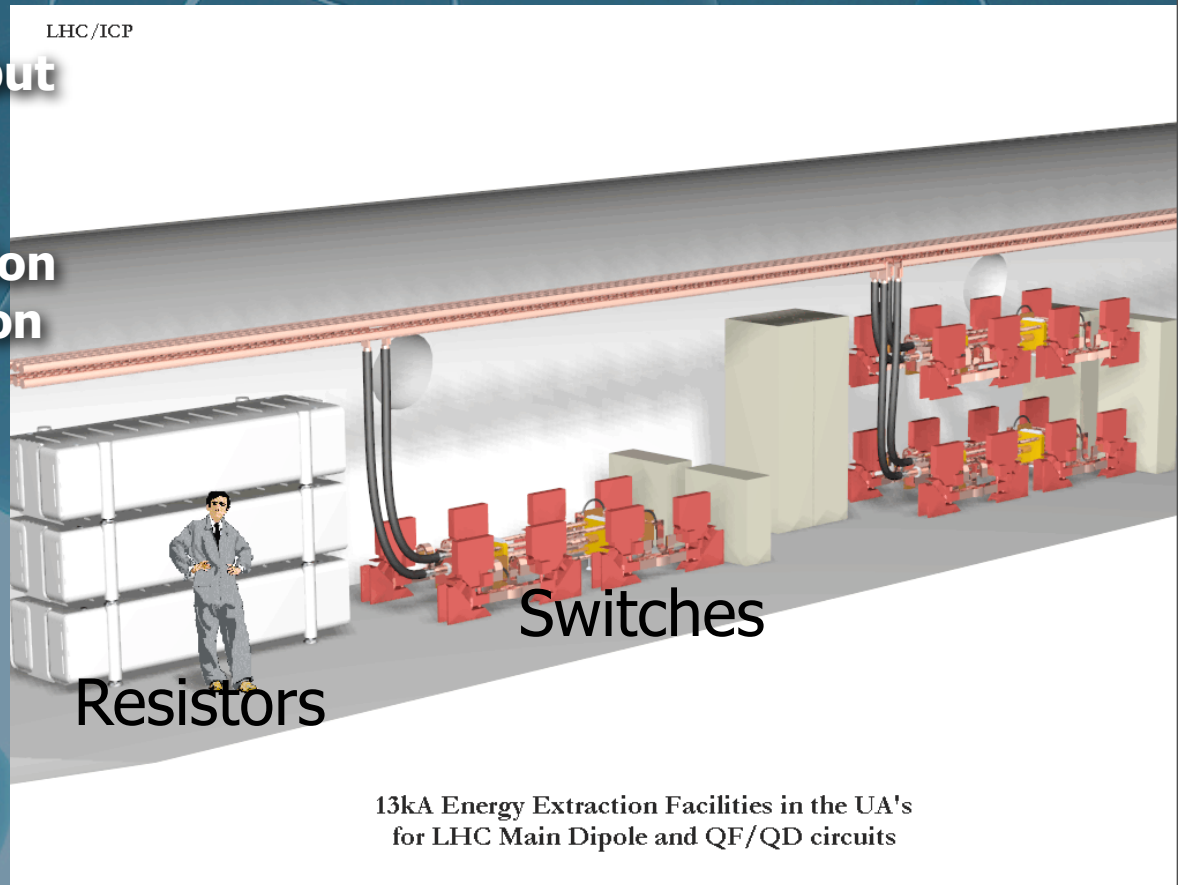


LHCb



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- During normal operation every ramp down of the magnets implies energy extraction, but this takes ~ 20 min $\rightarrow$ too slow in case of a quench
- A dedicated Energy Extraction System for quench protection is needed

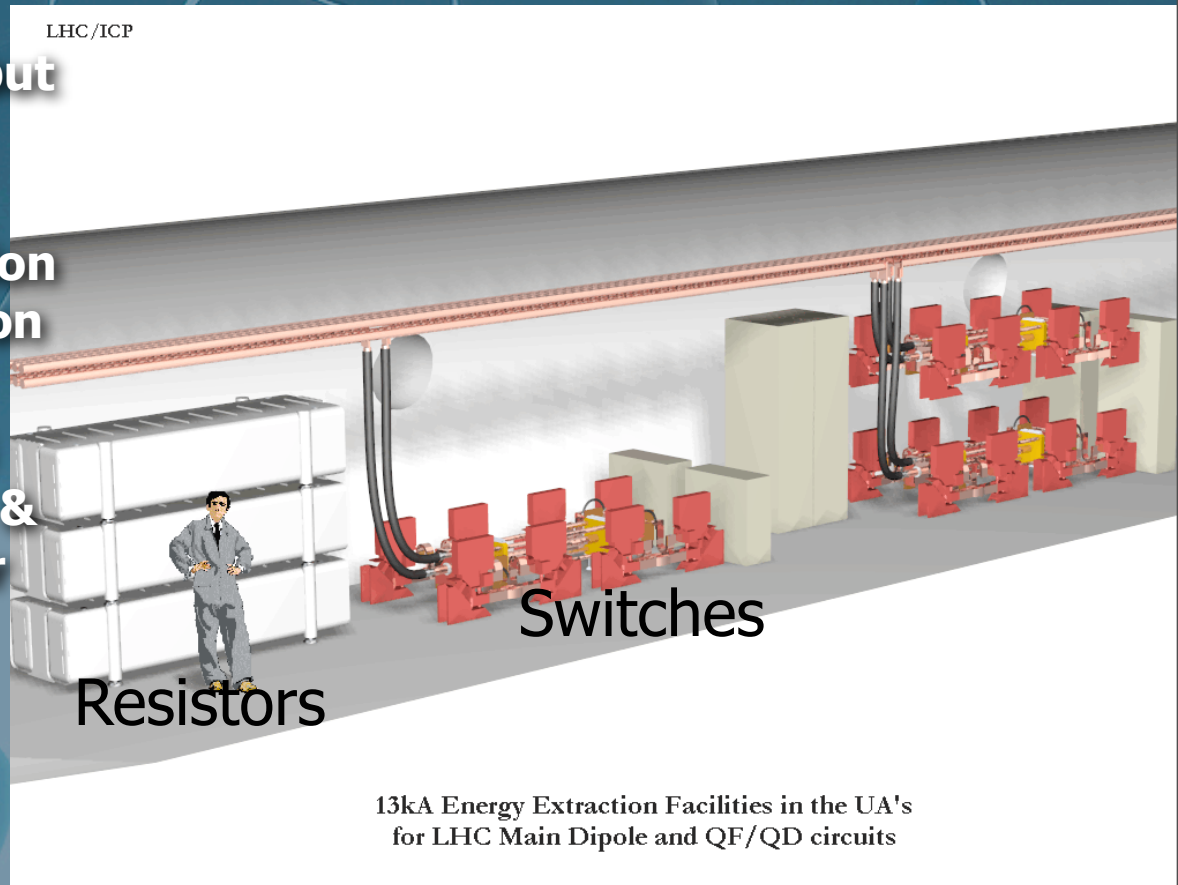


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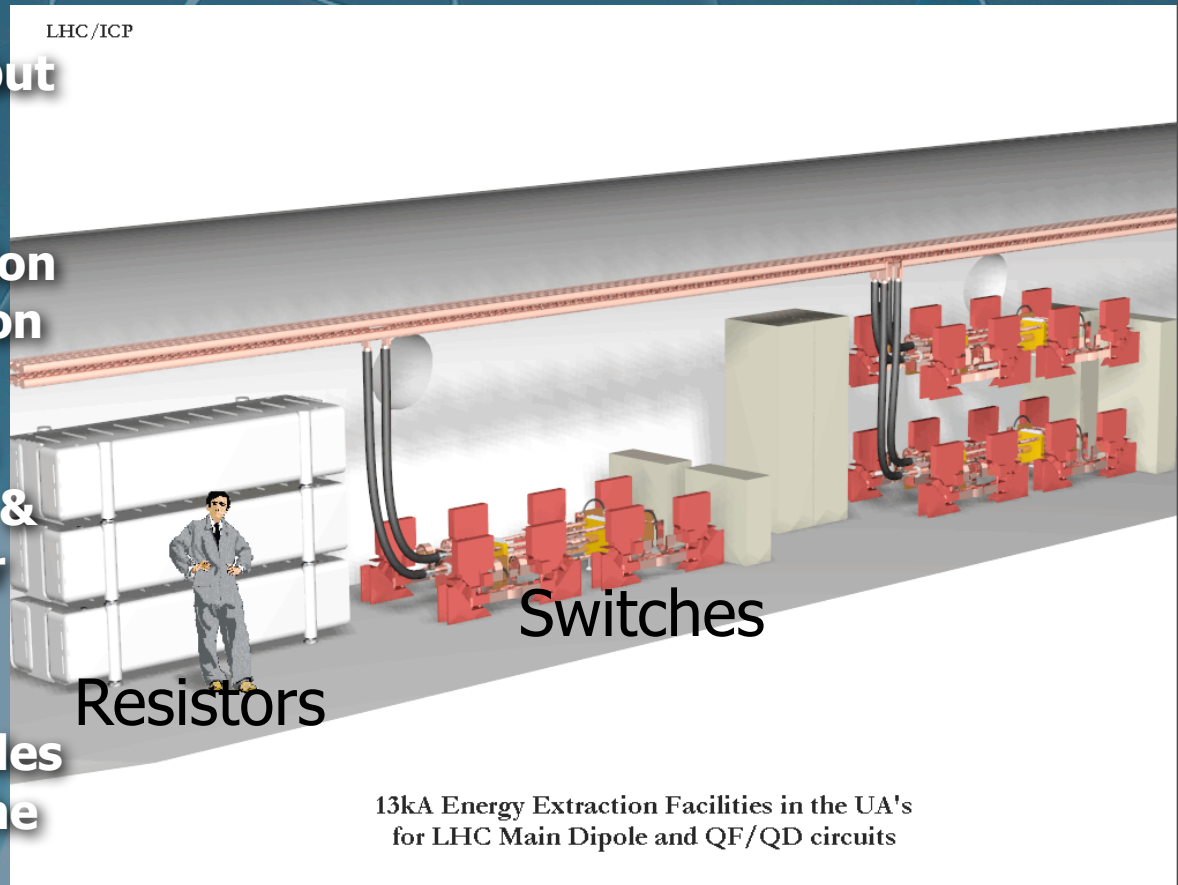
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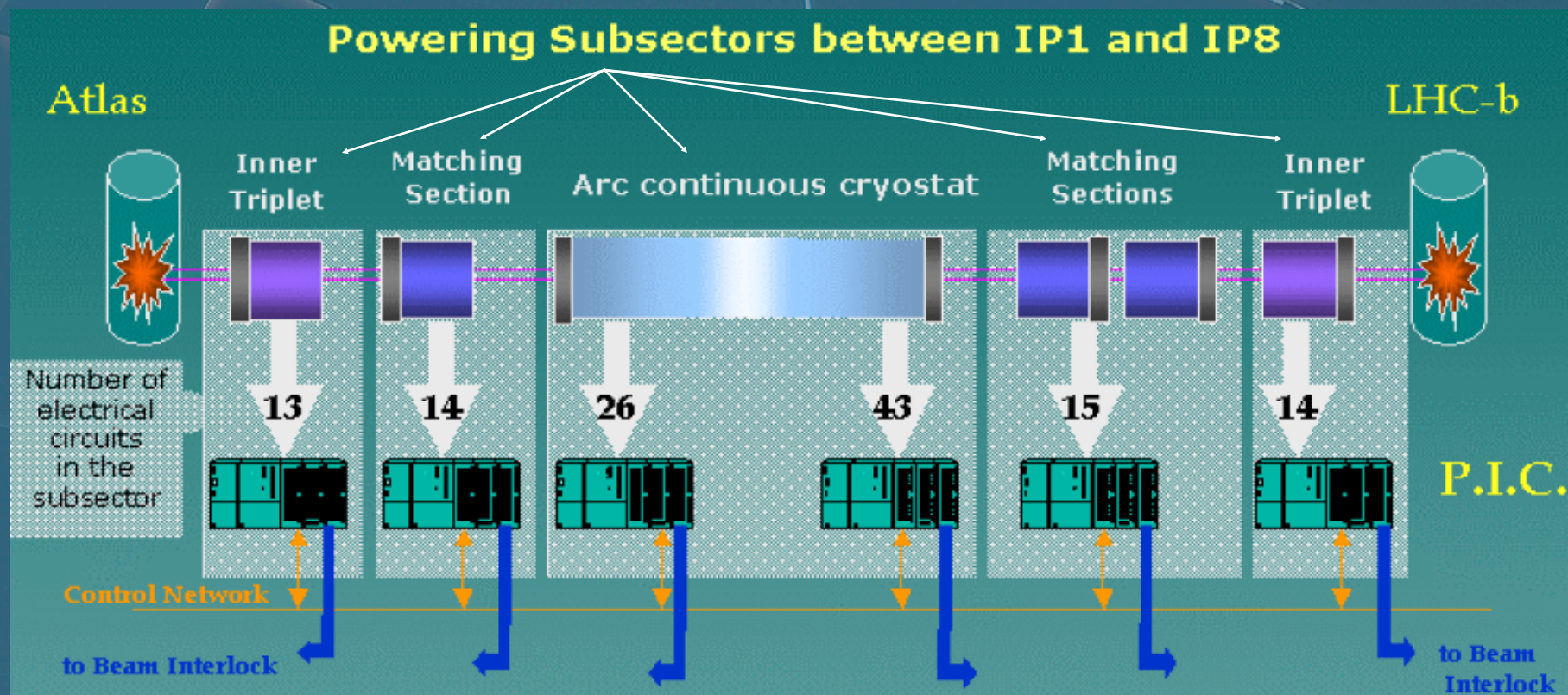
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- A dedicated Energy Extraction System for quench protection is needed
- There are 32 EES for the 24 13kA main circuits (dipoles & quadrupoles) (+ the EES for the 600 A correctors)
- This system releases the energy in 104 s for the dipoles (-125 A/s) and in 40 s for the quadrupoles (-325 A/s)





Magnet Energy: Power Interlock Controller

- 36 PICs in LHC for the SC magnets (warm magnets also have PICs)
- 1 PIC per Powering Subsector

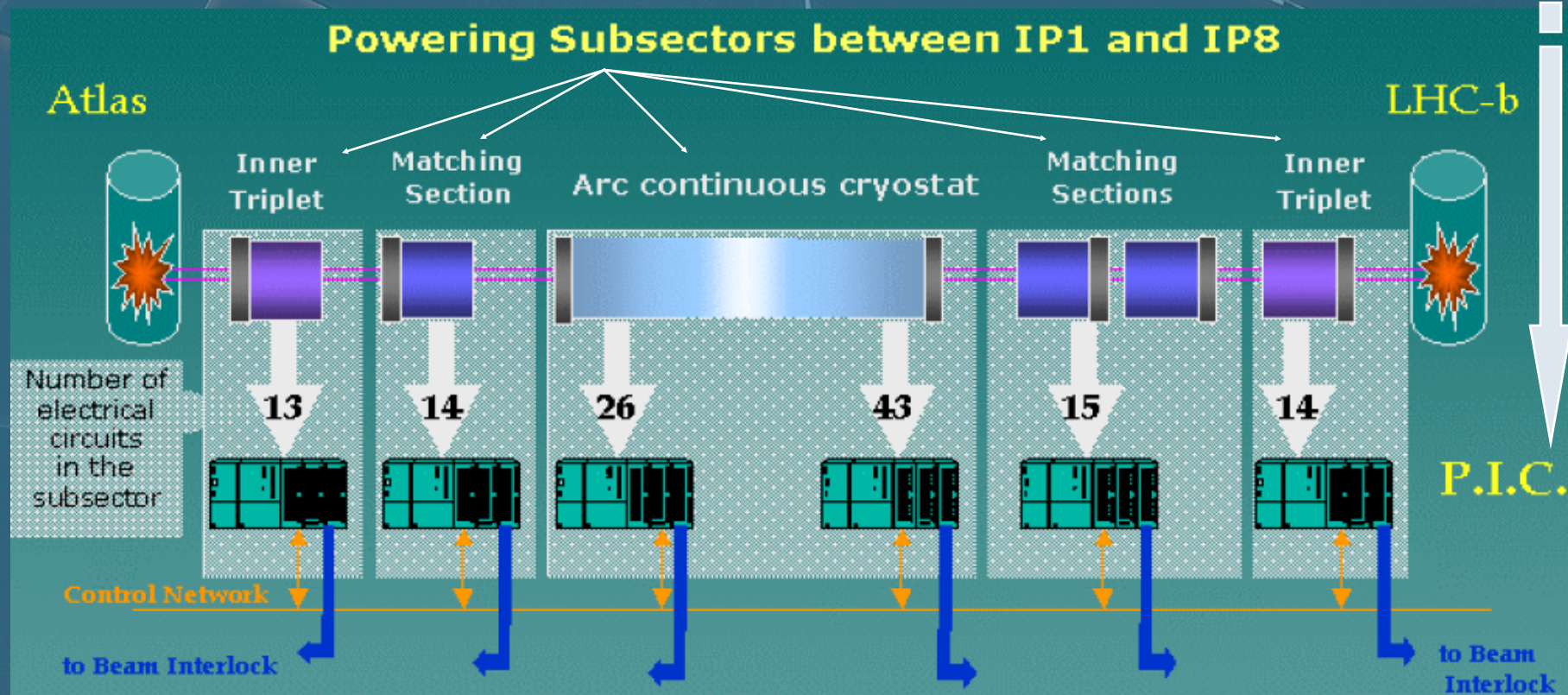




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Power Converters
QPS
Cryo
UPS, AUG

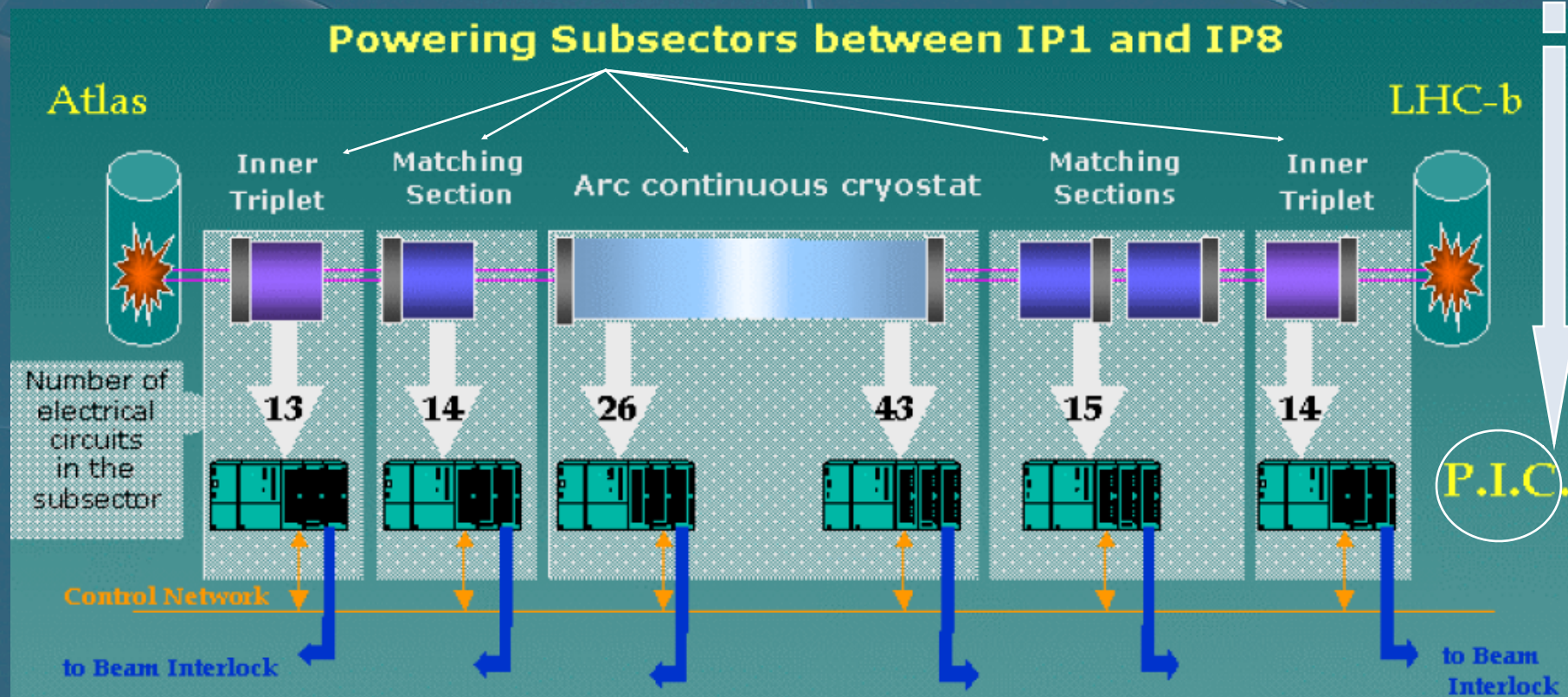




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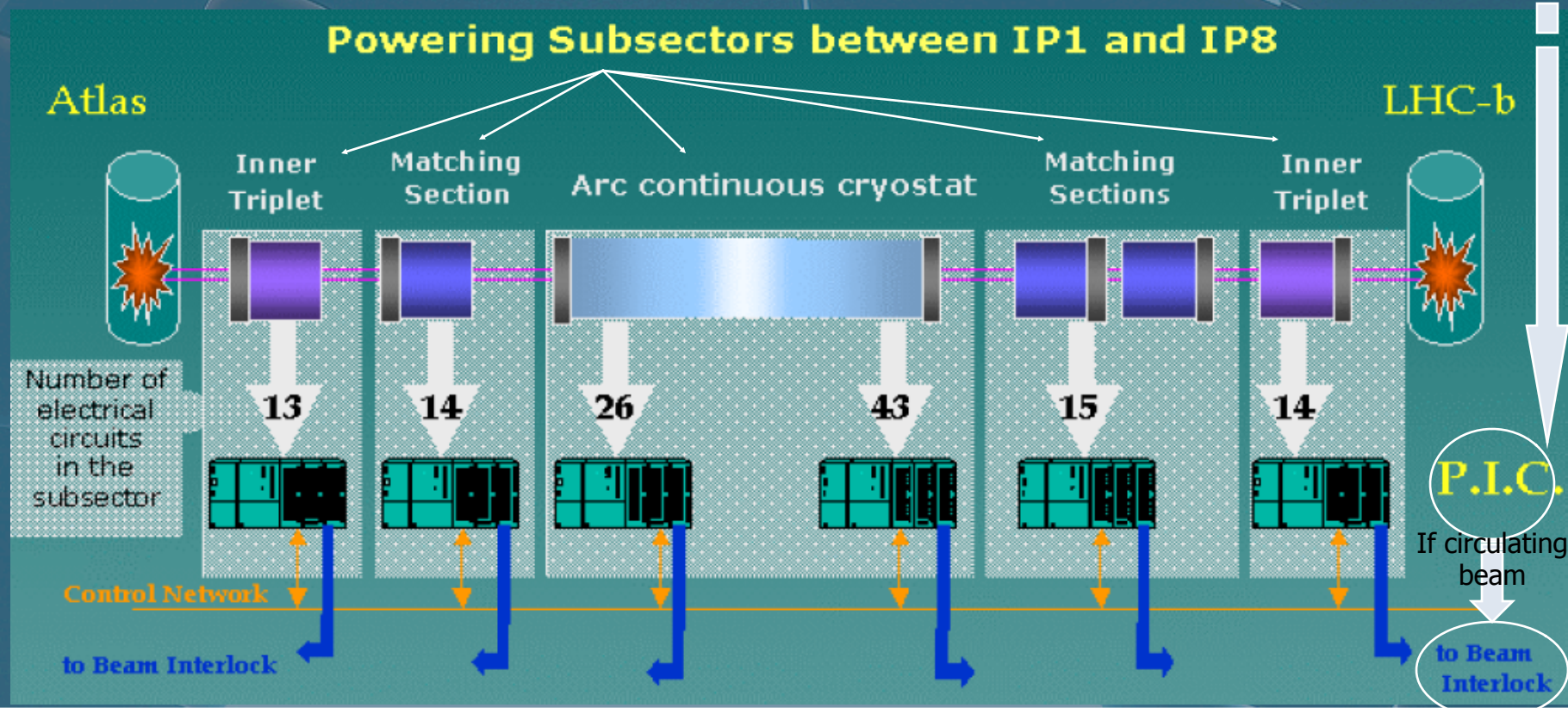




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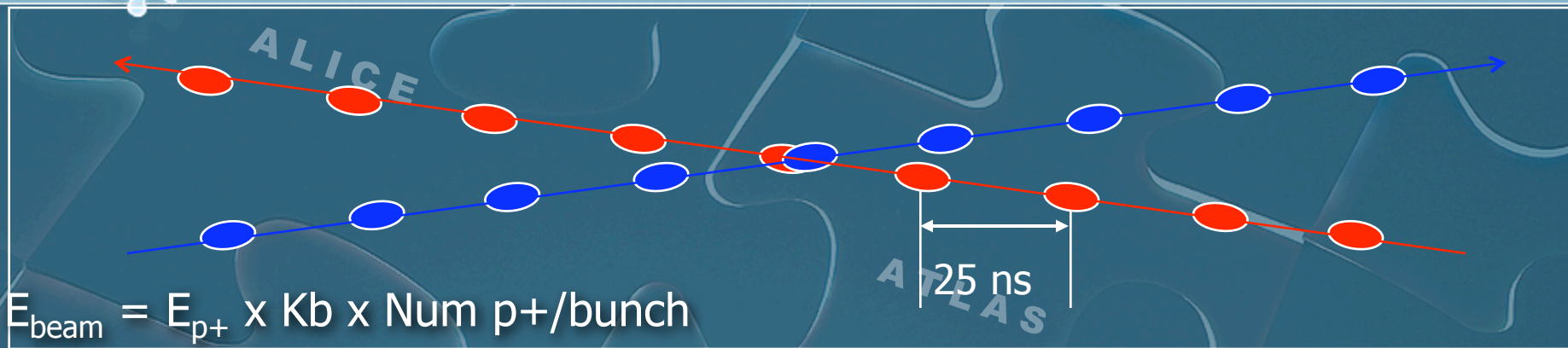


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Energy Stored in the Beams



$$E_{p+} = 7 \text{ TeV}$$

$$K_b = 2808$$

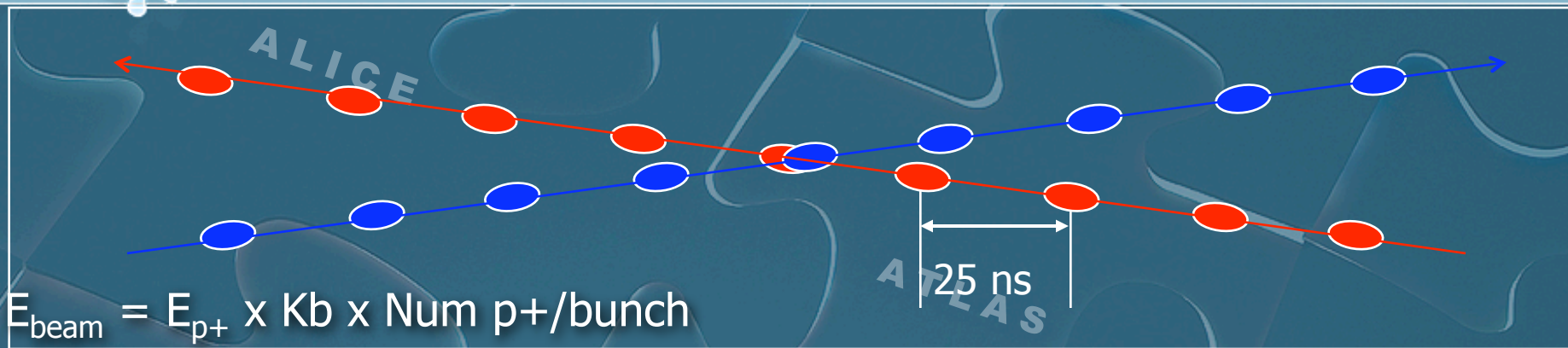
$$\text{Num } p+/\text{bunch} = 1.15 \times 10^{11}$$

$$E_{\text{beam}} = 362 \text{ MJules}$$

} Nominal values



Energy Stored in the Beams



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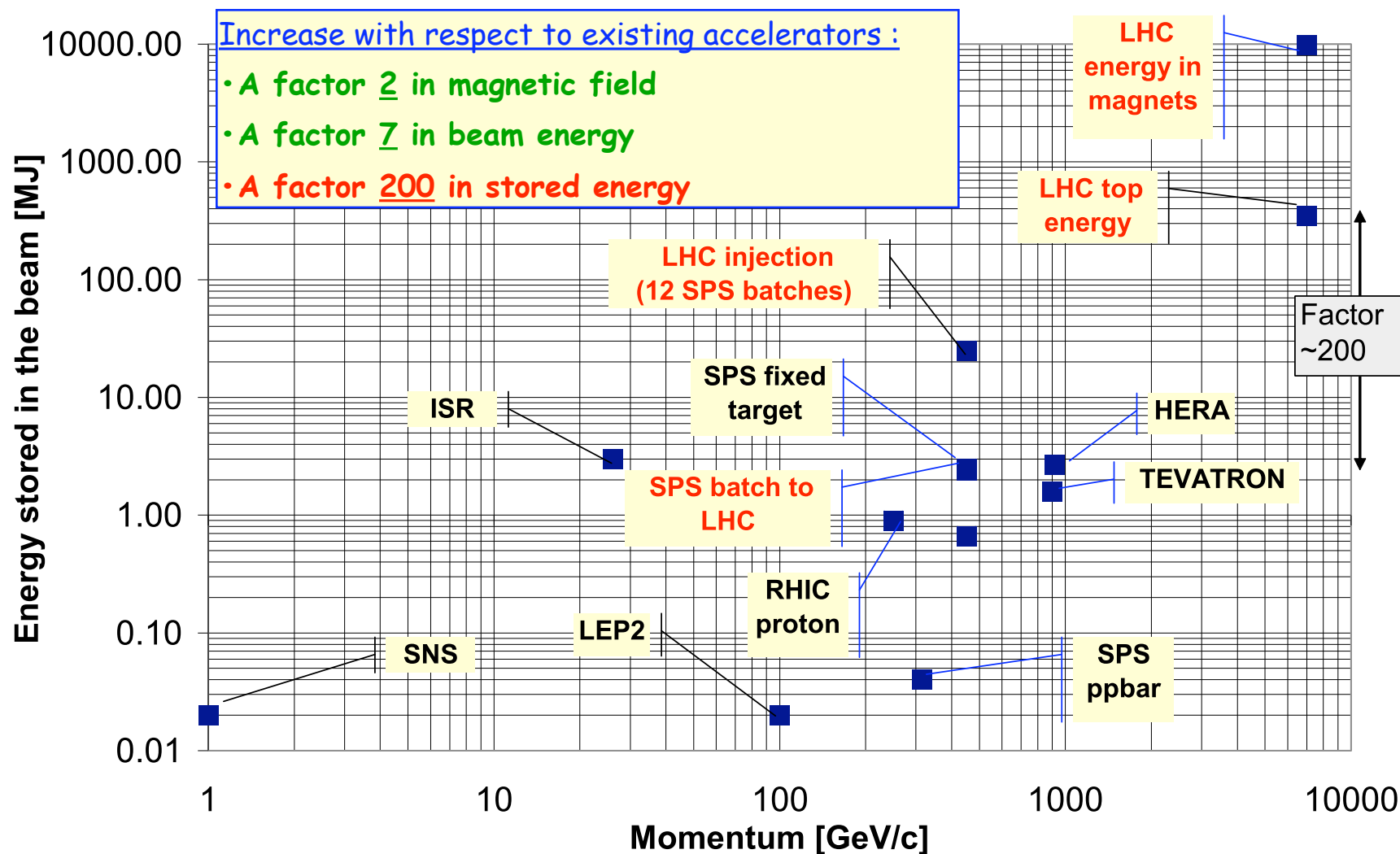
$$E_{\text{beam}} = 362 \text{ MJules}$$

Nominal values

Enough to melt 500 kg of copper



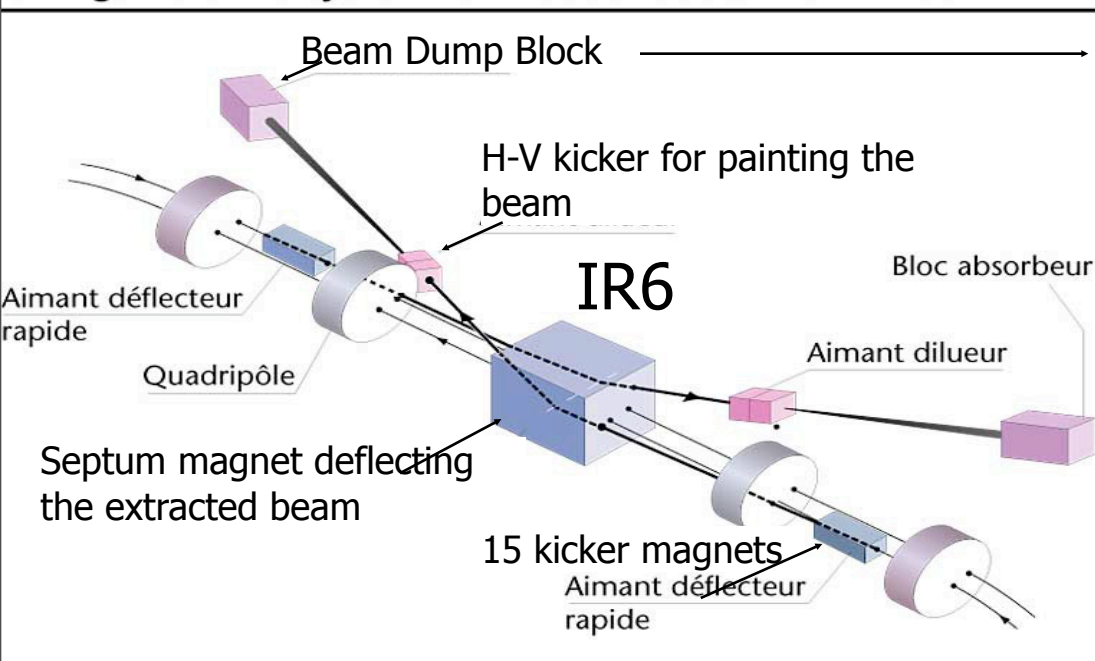
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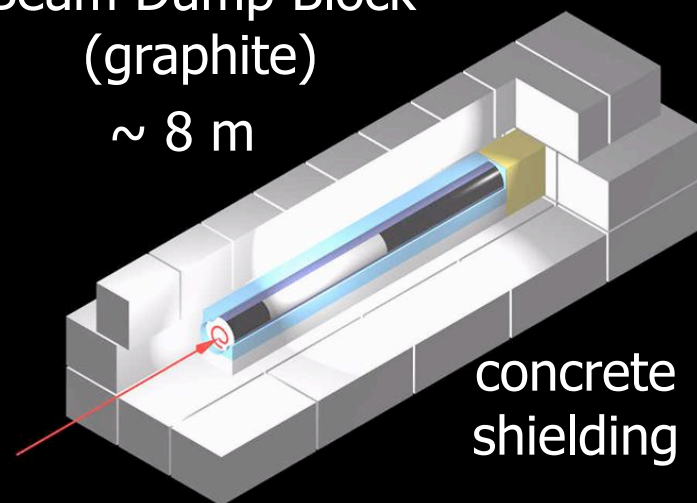


Energy Stored in the Beams: Beam Dump System

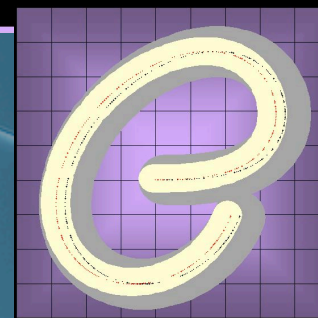
Configuration du système d'arrêt de faisceau au Point 6



Beam Dump Block
(graphite)
~ 8 m

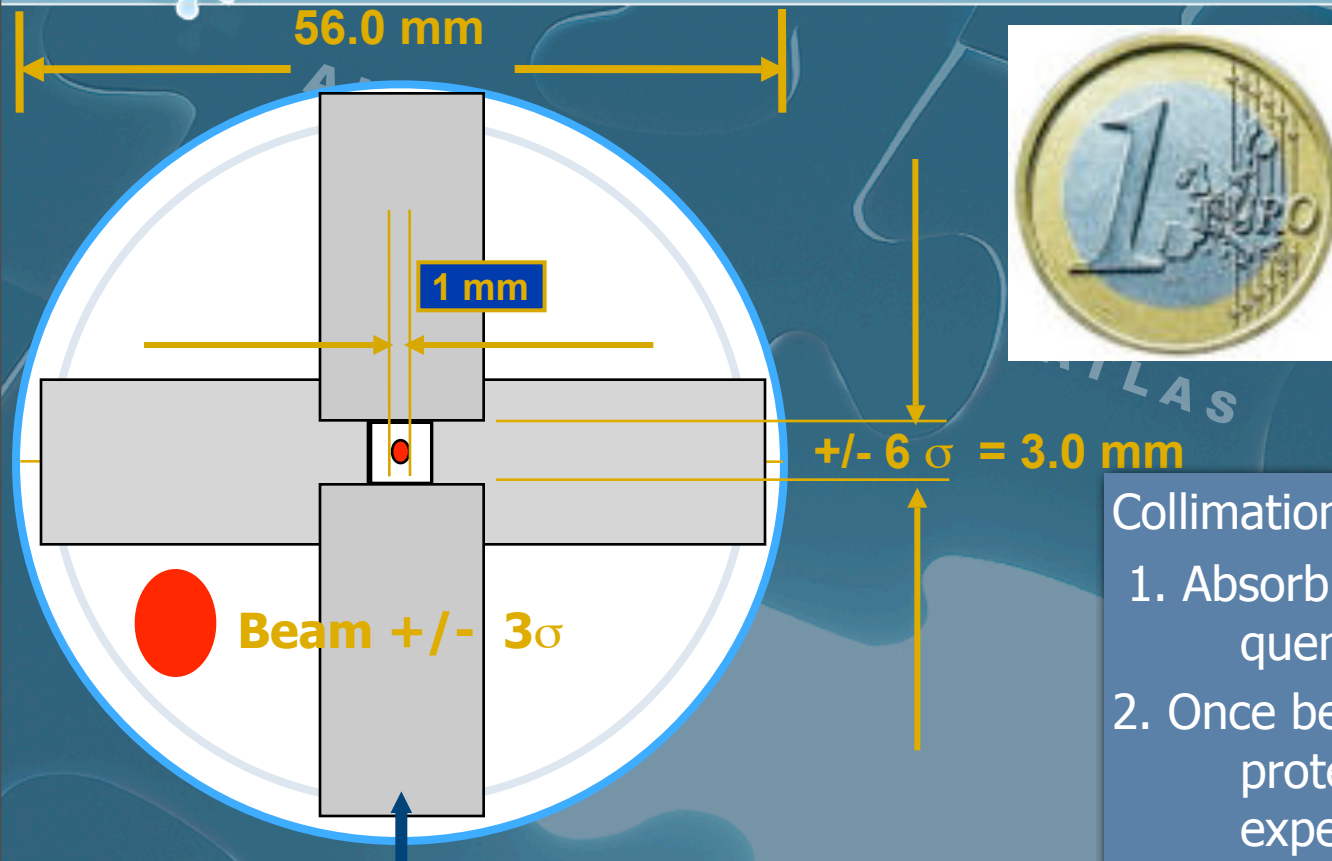


Is the only system in LHC able to
absorb the full nominal beam





Energy Stored in the Beams: Collimation System



Collimation System Functionality:

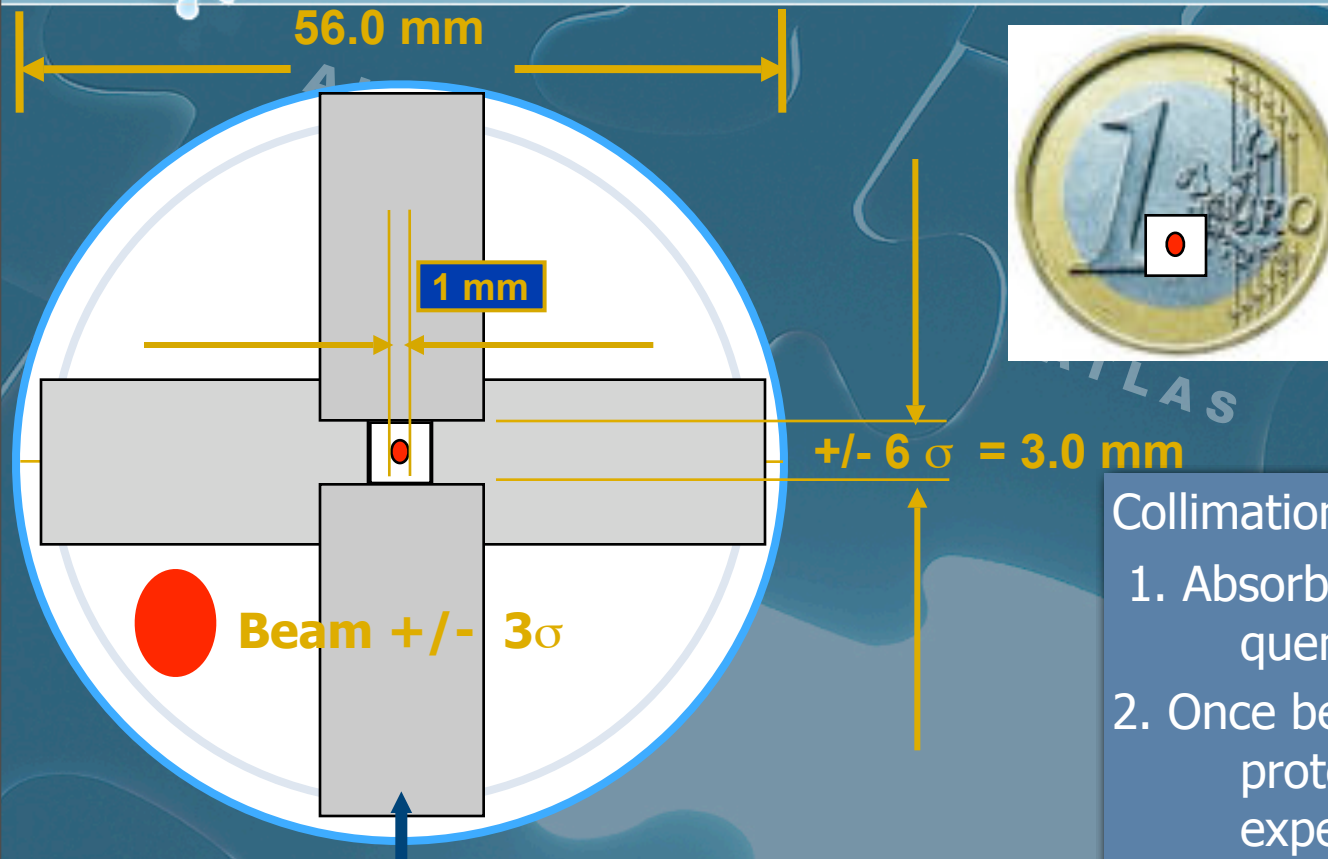
1. Absorb beam halo to avoid quenches
2. Once beam losses appear they protect the equipment and experiments. If BLMCs > Threshold $\rightarrow$ Beam Interlock $\rightarrow$ Beam Dump

E.g. Settings of collimators @7 TeV with luminosity optics

Very tight settings $\rightarrow$ orbit feedback!!



Energy Stored in the Beams: Collimation System



Collimation System Functionality:

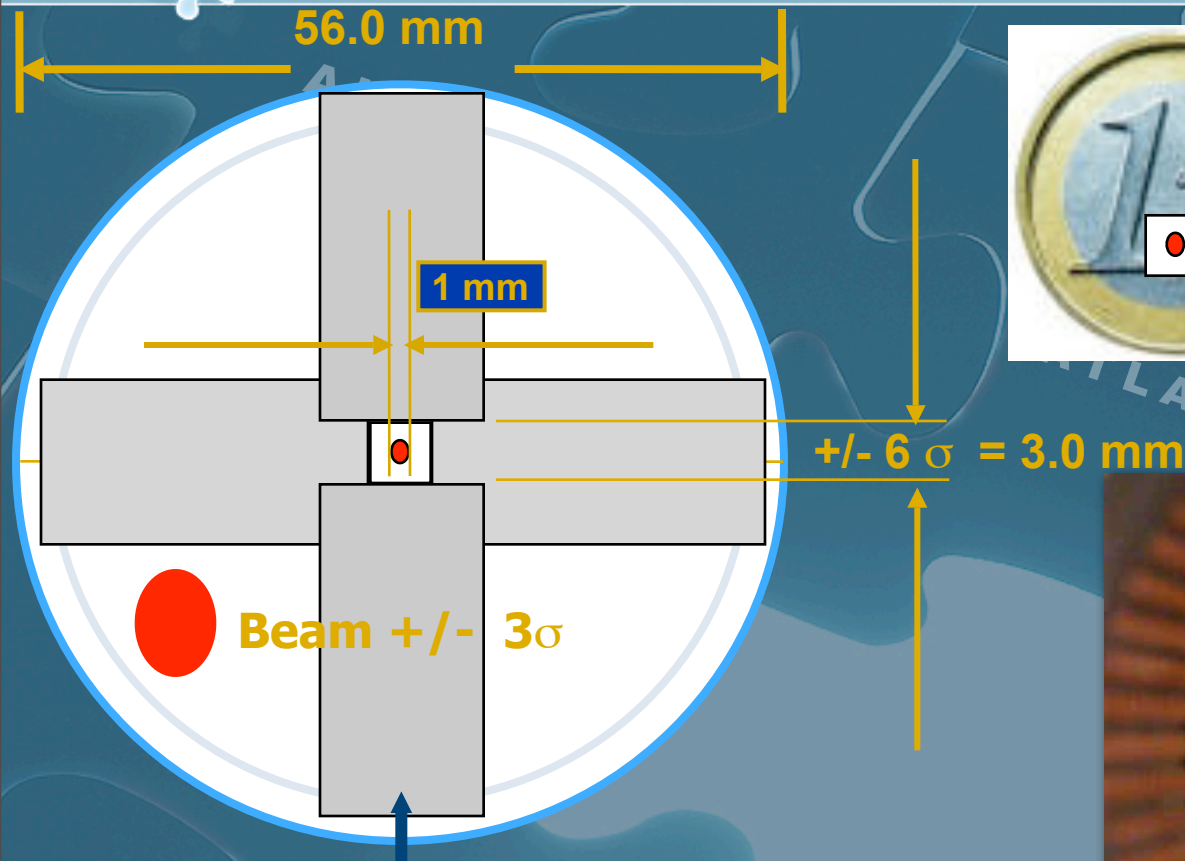
1. Absorb beam halo to avoid quenches
2. Once beam losses appear they protect the equipment and experiments. If BLMCs > Threshold $\rightarrow$ Beam Interlock $\rightarrow$ Beam Dump

E.g. Settings of collimators @7 TeV with luminosity optics

Very tight settings $\rightarrow$ orbit feedback!!



Energy Stored in the Beams: Collimation System



E.g. Settings of collimators @7 TeV with
luminosity optics

Very tight settings → orbit feedback!!

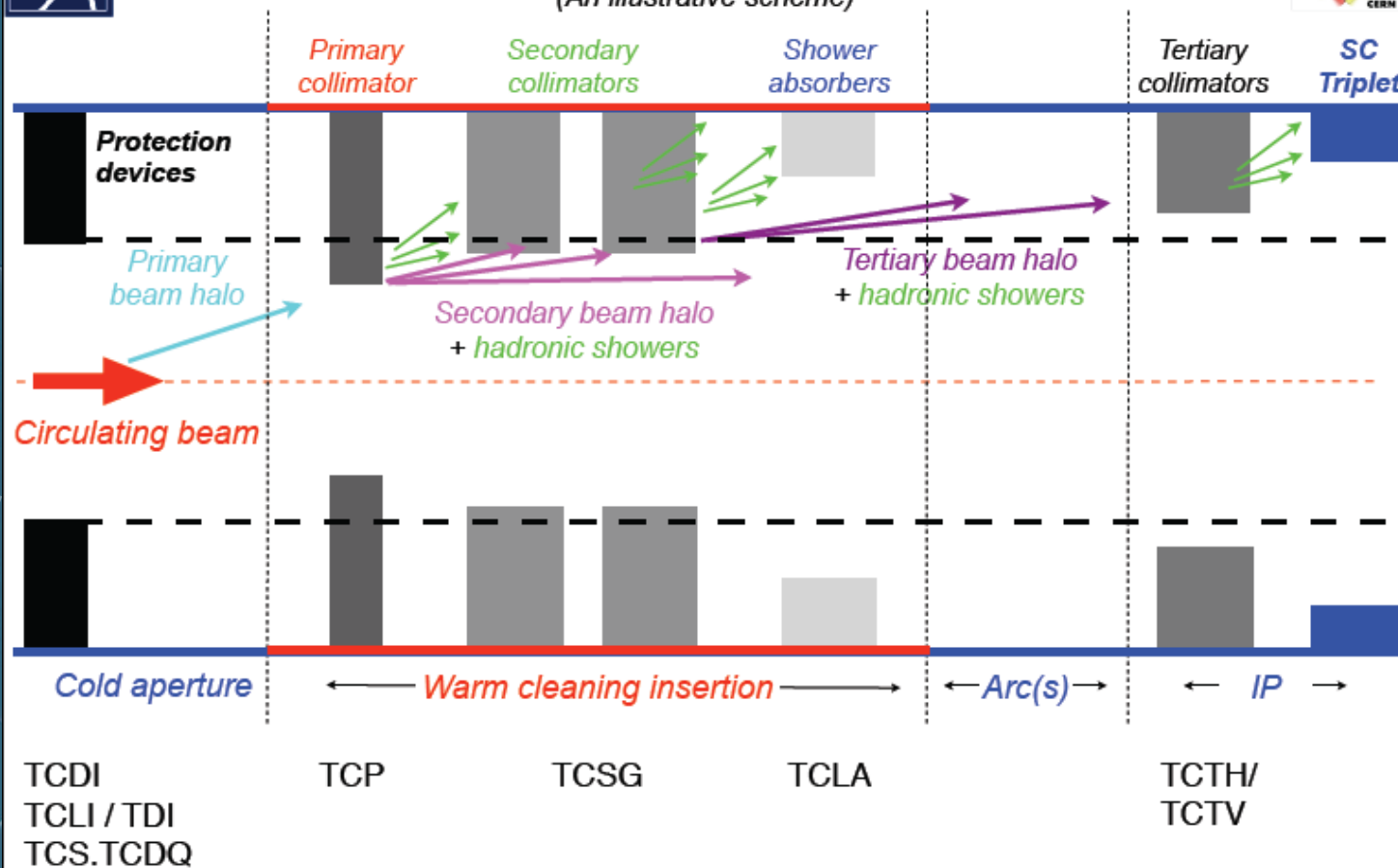


Energy Stored in the Beams: Collimation System



Multi-stage collimation at the LHC

(An illustrative scheme)



Large and distributed system...

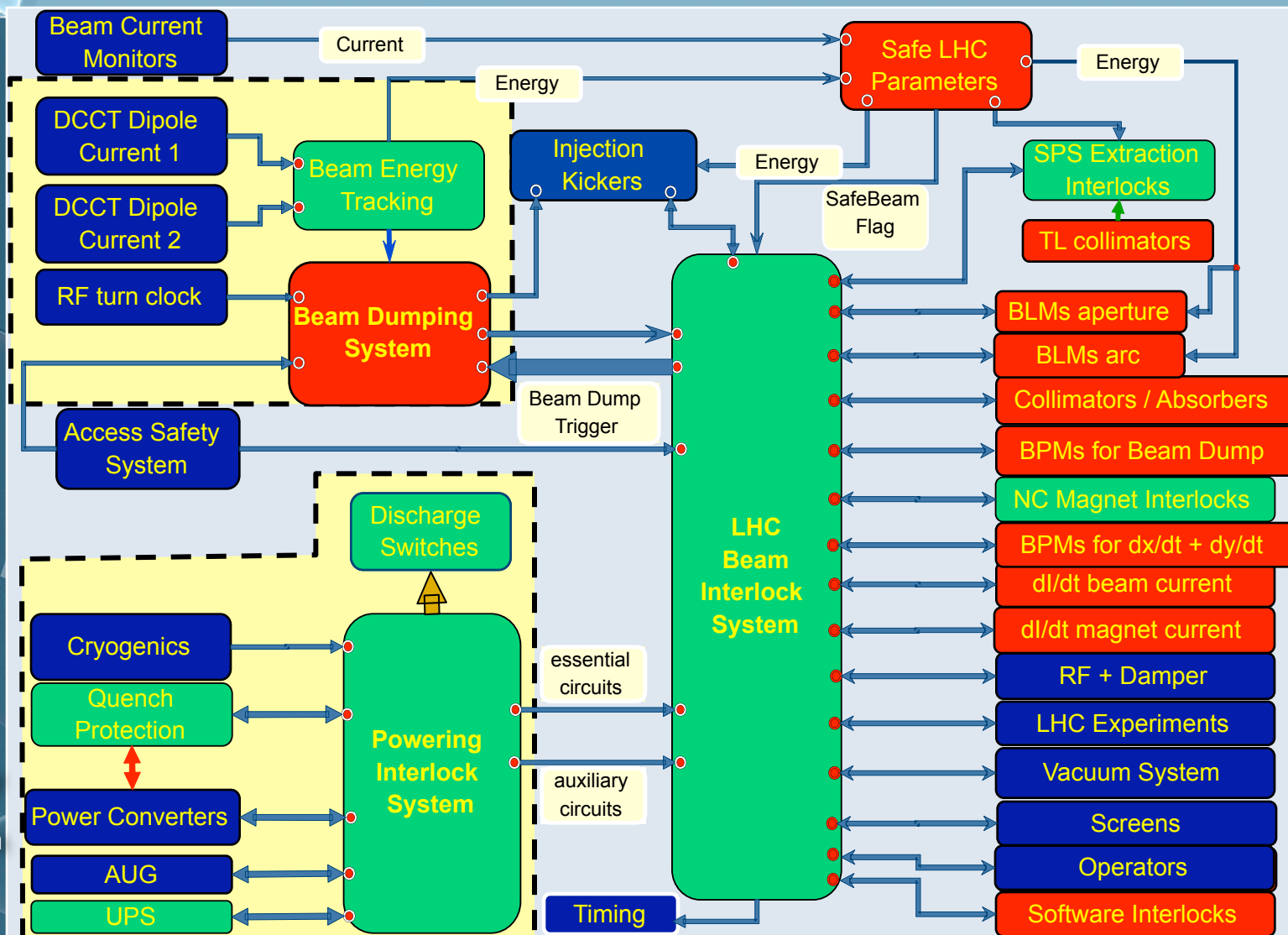


Contents

1. Accelerator complex
2. Energy Stored in the Magnets
 - Quench Protection System
 - Power Interlock System
 - Energy Extraction
3. Energy Stored in the Beams
 - Beam Dump System
 - Collimation System
4. Machine Protection System
5. Overall Strategy for Commissioning:
 - HW Commissioning
 - Machine Checkout
 - Beam Commissioning
 - Stage A
 - Stage B
 - Stage C&D
6. Documentation & Human Resources
7. Conclusions

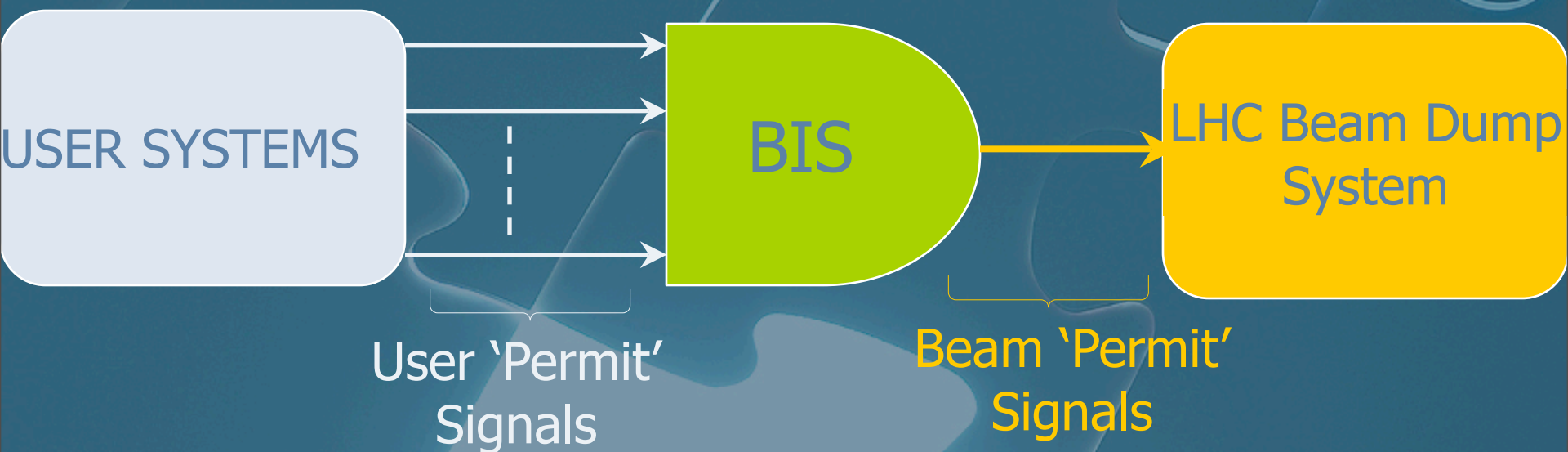


Machine Protection System





Machine Protection System:



153 User Systems distributed over 27 km



Contents

1. Accelerator complex
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Overall Strategy for Commissioning

ALICE

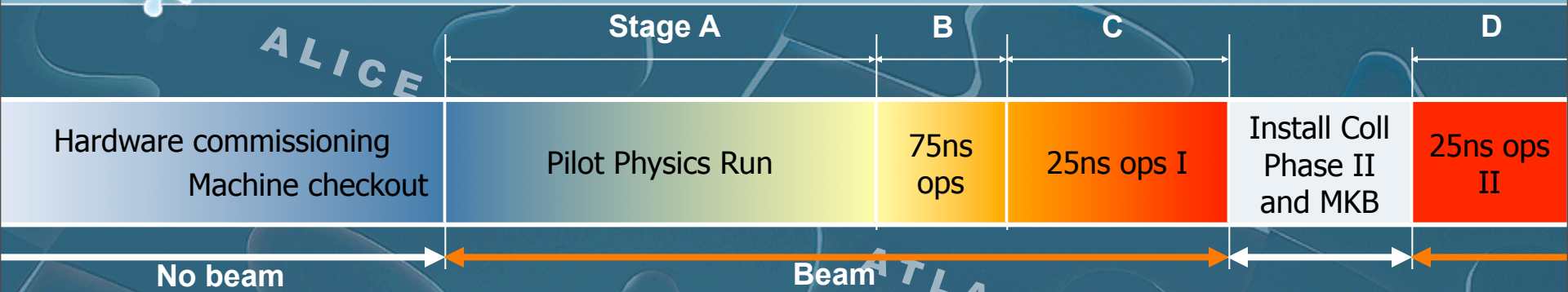
ATLAS

LHCb

CMS



Overall Strategy for Commissioning

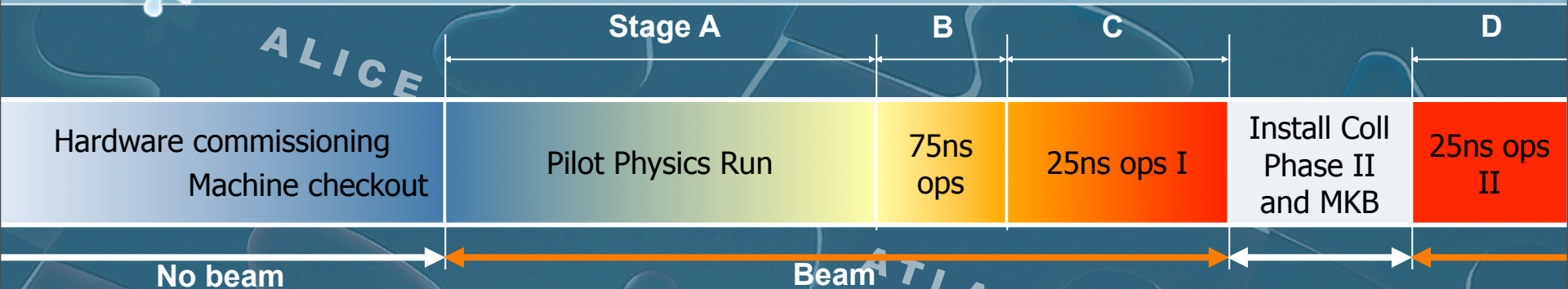


LHCb

CMS



Overall Strategy for Commissioning



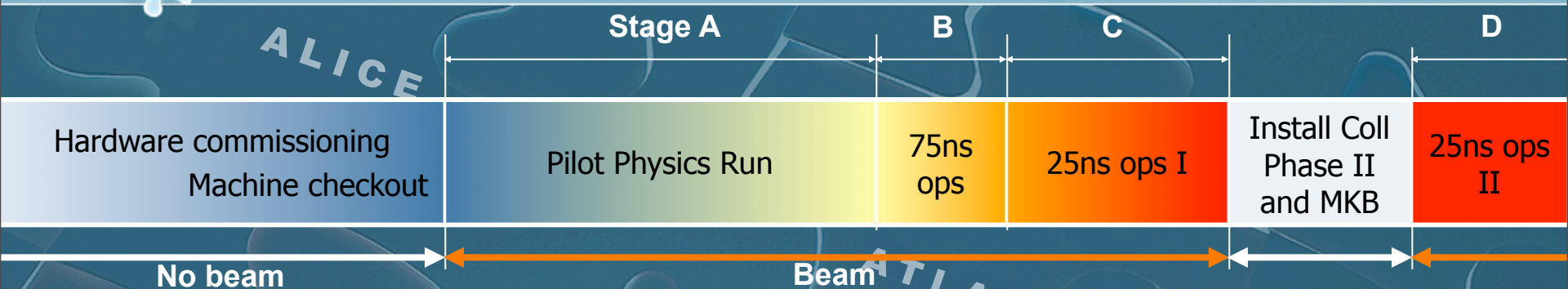
Hardware Commissioning

Thorough commission of technical systems:

- Magnets, vacuum, cryo, PC, quench detection, energy extraction, RF, beam instrumentation, kickers, septa, collimators, absorbers, etc.
- Services: AC distribution, water-cooling, ventilation, access control, safety, etc.



Overall Strategy for Commissioning



Hardware Commissioning

Thorough commission of technical systems:

- Magnets, vacuum, cryo, PC, quench detection, energy extraction, RF, beam instrumentation, kickers, septa, collimators, absorbers, etc.
- Services: AC distribution, water-cooling, ventilation, access control, safety, etc.

Stages:

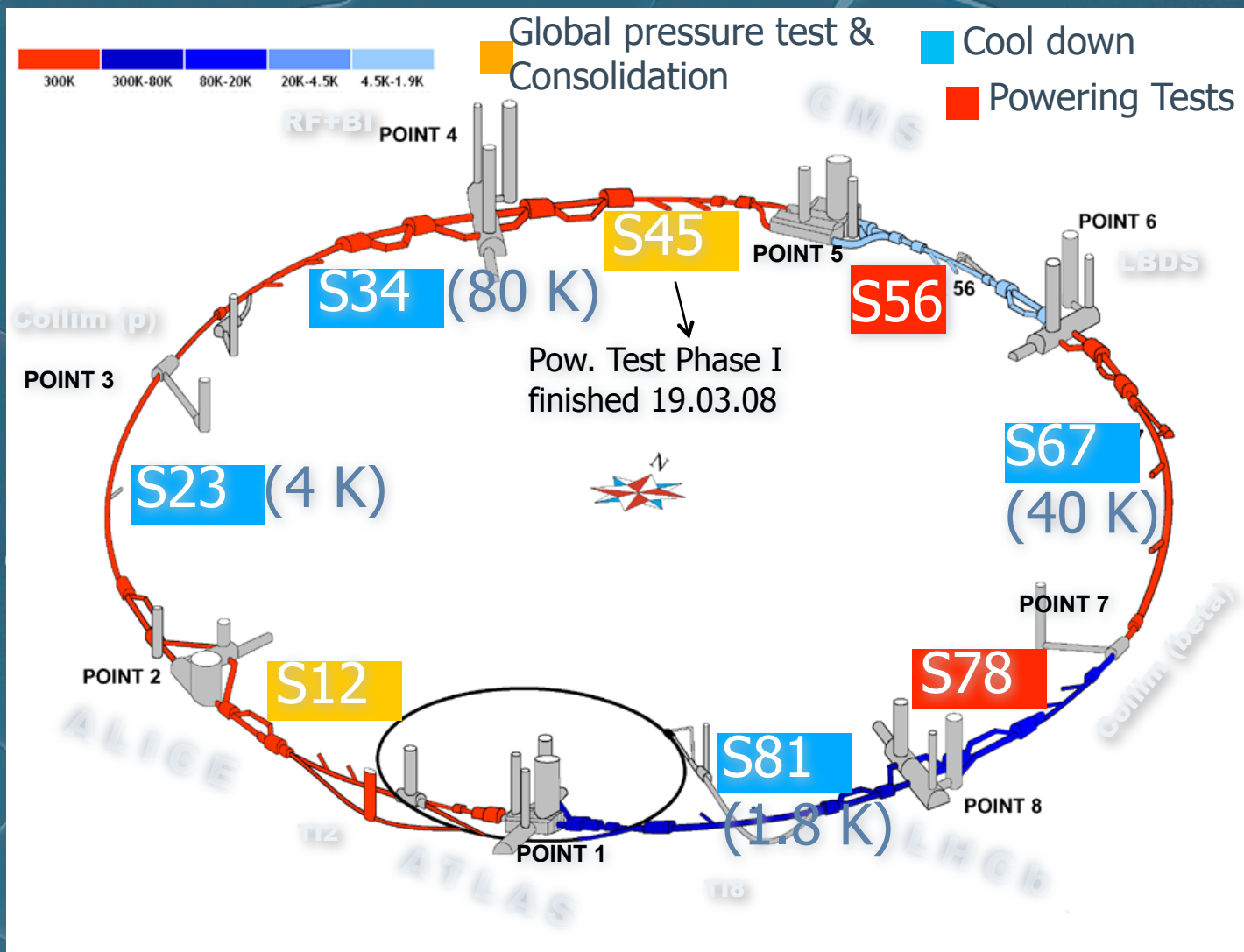
1. Individual system test
2. Global system test

Commissioned energy:

1. 2008 → $E_b = 5.5$ TeV (no training quenches)
2. 2009 → $E_b = 7$ TeV (magnet training required)

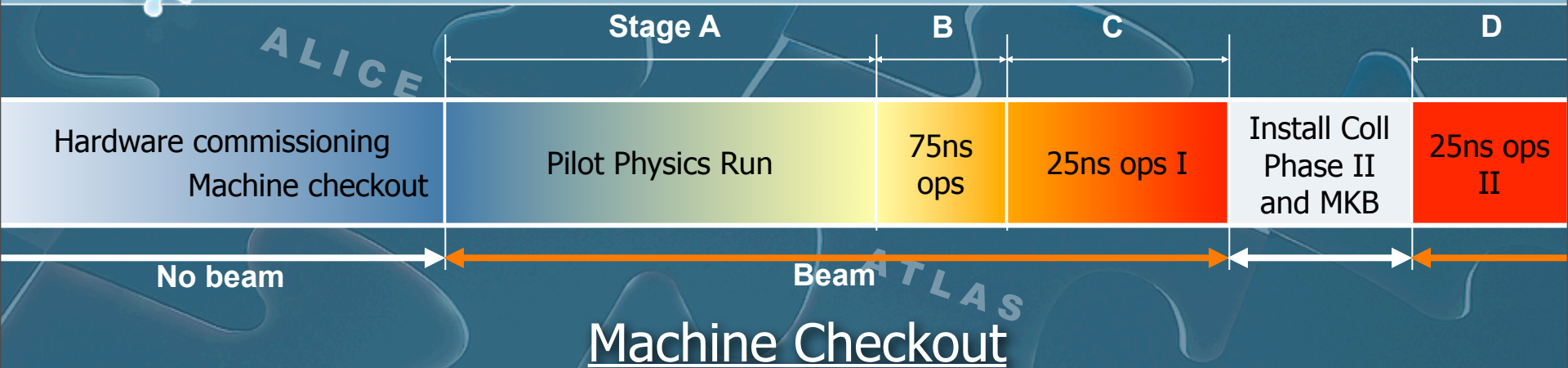


Hardware Commissioning Status



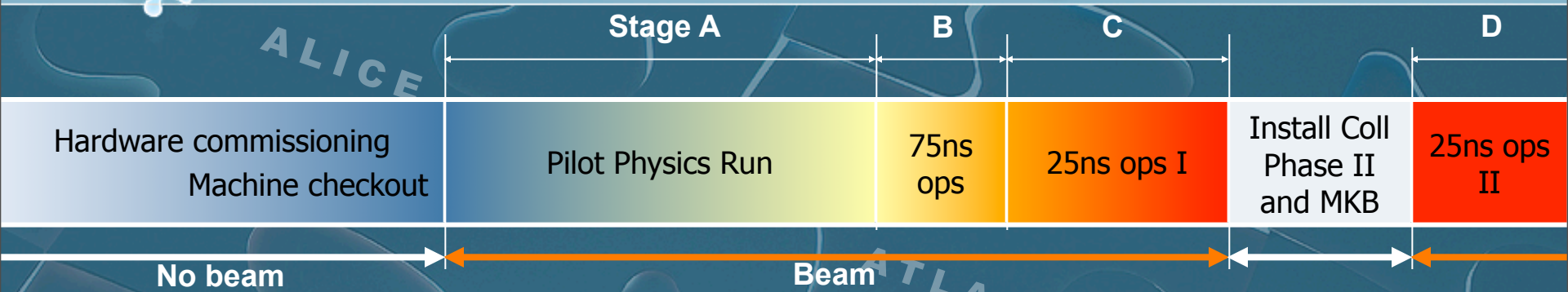


Overall Strategy for Commissioning





Overall Strategy for Commissioning

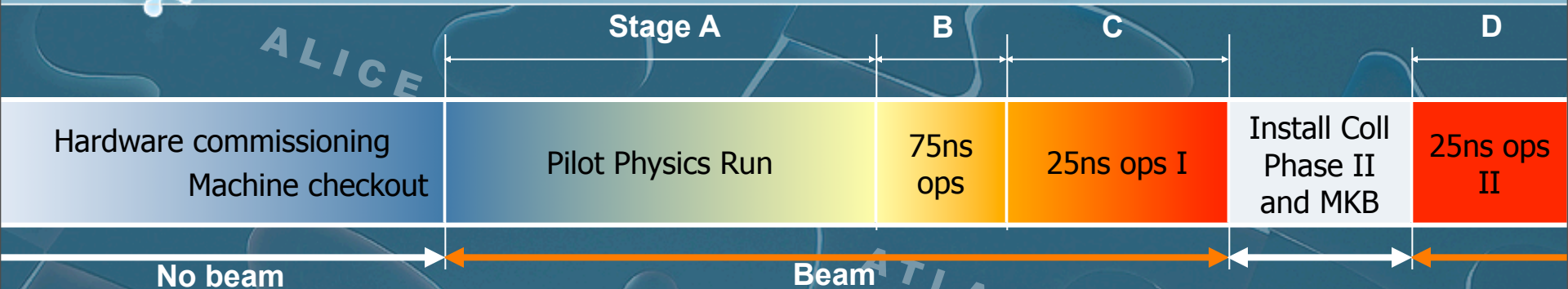


Machine Checkout

- Drive all systems through the standard operational sequence (synchronized)
- Check Control System functionality from CCC high-level software applications
- Check beam instrumentation acquisition chain
- Check timing synchronization
- Check all equipment control functionality
- Check machine protection and interlock system



Overall Strategy for Commissioning



Machine Checkout

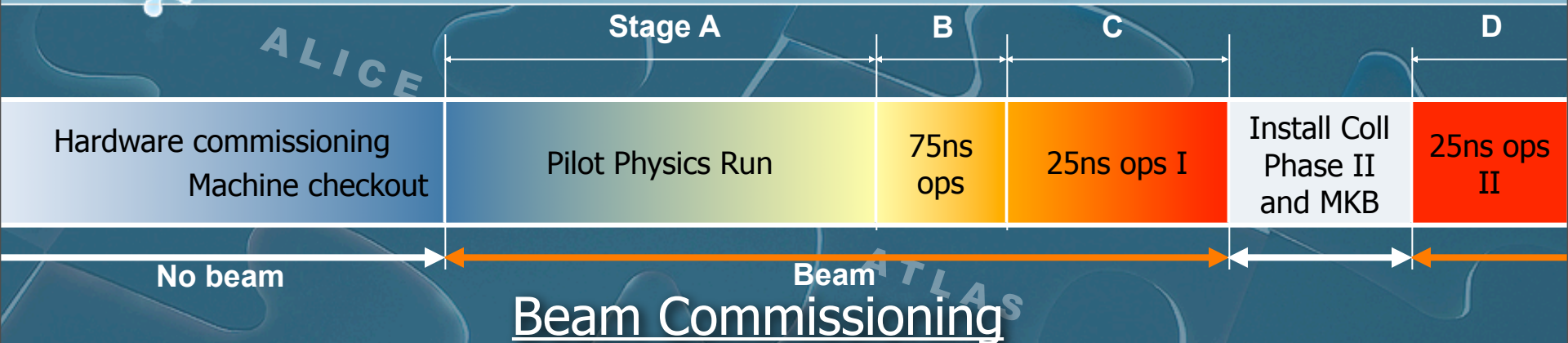
- Drive all systems through the standard operational sequence (synchronized)
- Check Control System functionality from **CCC high-level software applications**
- Check beam instrumentation acquisition chain
- Check timing synchronization
- Check all equipment control functionality
- Check machine protection and interlock system

Stages:

1. Individual system test. First integration into the OP group
2. Multi-system test, e.g. Machine Protection (BLM, BIS, LBDS)
3. Dry run: drive the whole machine through the nominal sequence.



Overall Strategy for Commissioning



Stage A: Pilot physics run

- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance
- Performance limit $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ (event pileup)

Stage B: 75ns operation

- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit $10^{33} \text{ cm}^{-2}\text{s}^{-1}$ (evt pileup)

Stage C: 25ns operation I

- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit $2 \cdot 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

Stage D: 25ns operation II

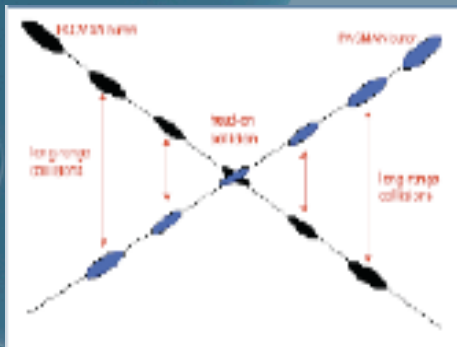
- Push towards nominal performance
- Requires hardware updates: collimators and beam dump system
- Performance goal: $10^{34} \text{ cm}^{-2}\text{s}^{-1}$



Beam Commissioning with p^+

- LHC Design Parameters:

Design Parameters	
Lumi IP 1,5 ($\text{cm}^{-2} \text{s}^{-1}$)	1034
Lumi IP 2,8 ($\text{cm}^{-2} \text{s}^{-1}$)	$5 \cdot 10^{32}$
$\sigma_{\text{IP 1.5}}$ (μm)	16.7
$\sigma_{\text{IP 2.8}}$ (μm)	70.9
Crossing angle (μrad)	285



Nominal Settings	
E_{beam} (TeV)	7
# p^+ /bunch	$1.15 \cdot 10^{11}$
# bunches/beam	2808
E_{beam} Stored (MJ)	362
ϵ_n^{xy} ($\mu\text{m rad}$)	3.75
Bunch length (cm)	7.5
β^* (IP: 1,2,5,8) (m)	0.55, 0.55, 10,

Reyes 25/03/08

Find a balance between
robust operation and
satisfying the experiments

Maximize integrated
luminosity

Minimize event pile-up (to
event + 2)

Avoid quenches (and damage)

Higher b^* to avoid problems in

Beam Commissioning with p^+

Stage A

as possible

meter (k_b, N, β^*) at a time

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

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

- All values for:
 - nominal emittance
 - 7 TeV
 - 2 m β^* (IP: 1&5)

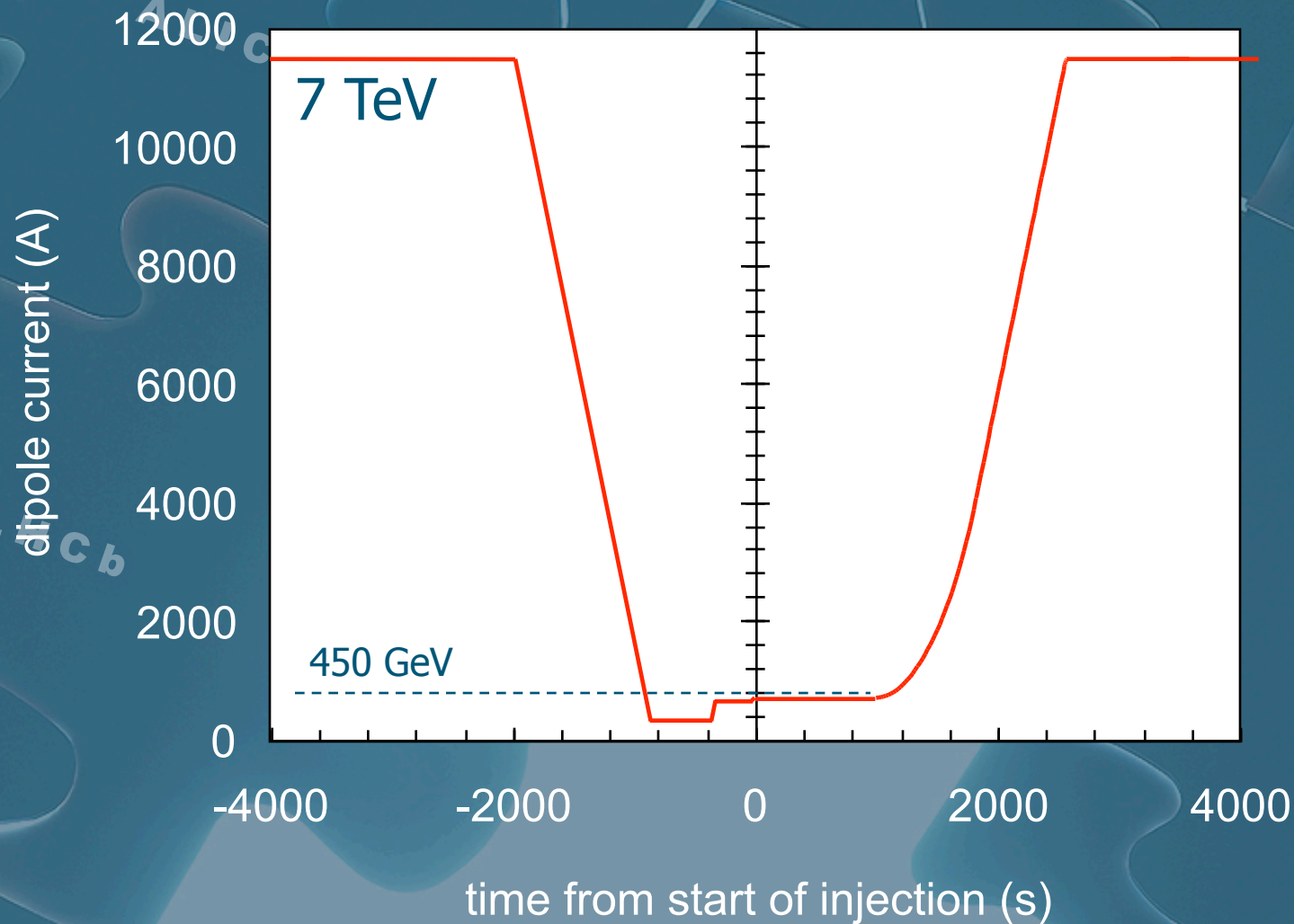
Protons/beam $\leq 10^{13}$
(LEP beam currents)

Stored energy/beam ≤ 10 MJ
(SPS fixed target beam)

Parameters			Beam levels		Rates in 1 and 5		Rates in 2	
k_b	N	β^* 1,5	I_{beam}	E_{beam}	Luminosity	Events/	Luminosity	Events/
1	1010	11	$1 \cdot 10^{10}$	10^{-2}	$1.6 \cdot 10^{27}$	$\ll 1$	$1.8 \cdot 10^{27}$	$\ll 1$
43	1010	11	$4.3 \cdot 10^{11}$	0.5	$7.0 \cdot 10^{28}$	$\ll 1$	$7.7 \cdot 10^{28}$	$\ll 1$
43	$4 \cdot 10^{10}$	11	$1.7 \cdot 10^{12}$	2	$1.1 \cdot 10^{30}$	$\ll 1$	$1.2 \cdot 10^{30}$	0.15
43	$4 \cdot 10^{10}$	2	$1.7 \cdot 10^{12}$	2	$6.1 \cdot 10^{30}$	0.76	$1.2 \cdot 10^{30}$	0.15
156	$4 \cdot 10^{10}$	2	$6.2 \cdot 10^{12}$	7	$2.2 \cdot 10^{31}$	0.76	$4.4 \cdot 10^{30}$	0.15
156	$9 \cdot 10^{10}$	2	$1.4 \cdot 10^{13}$	16	$1.1 \cdot 10^{32}$	3.9	$2.2 \cdot 10^{31}$	0.77

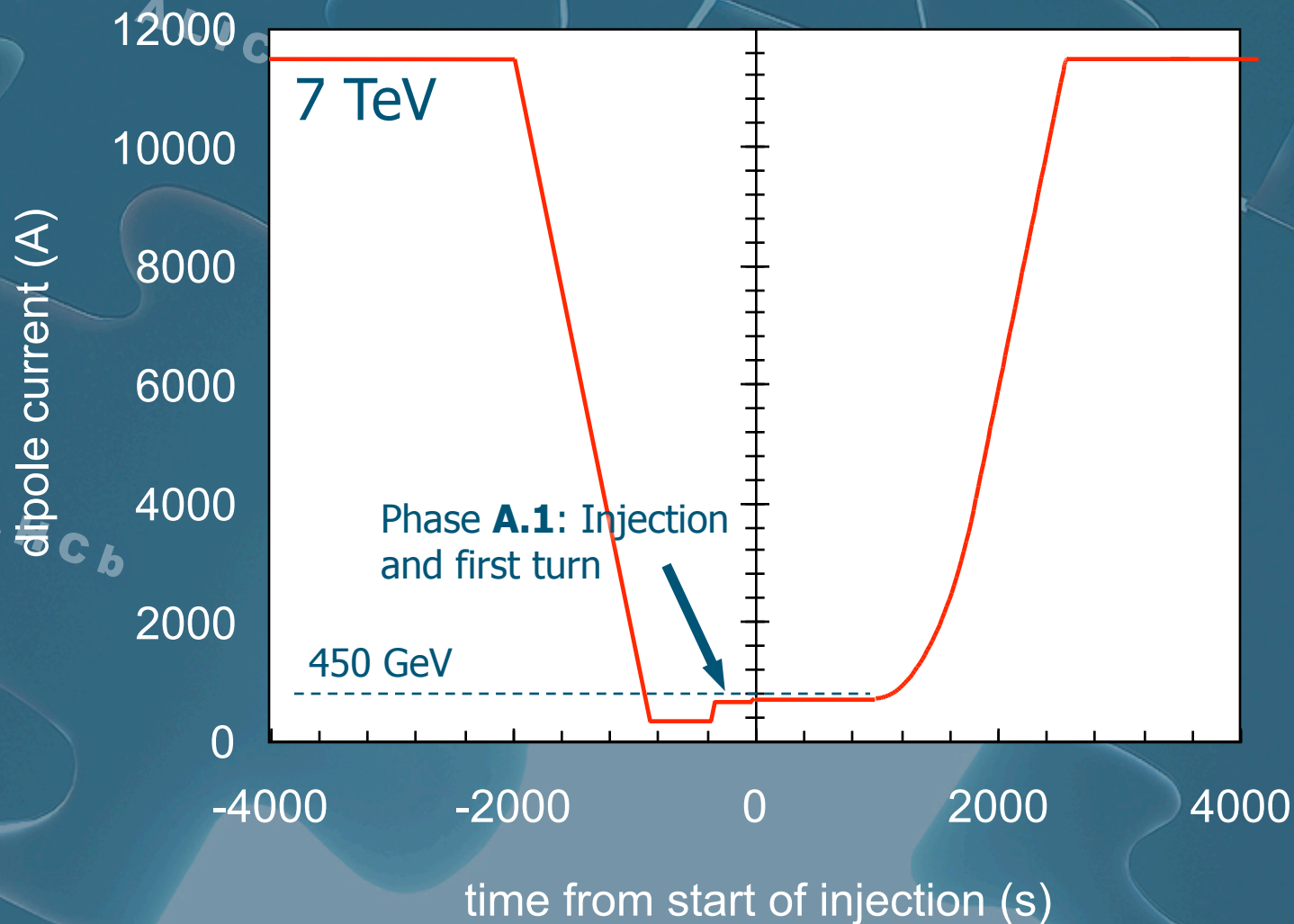


Beam Commissioning with p+ Stage A



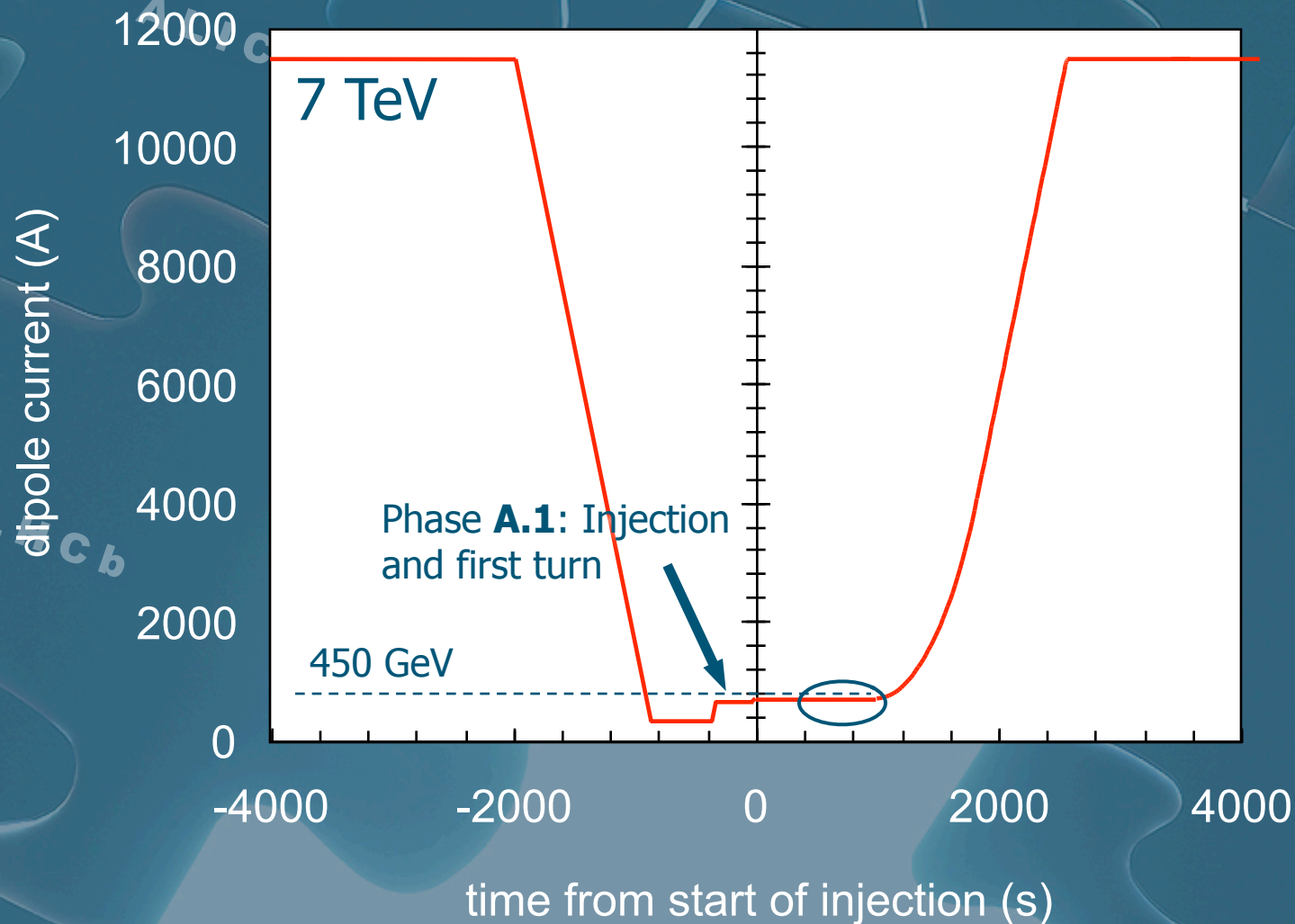


Beam Commissioning with p+ Stage A



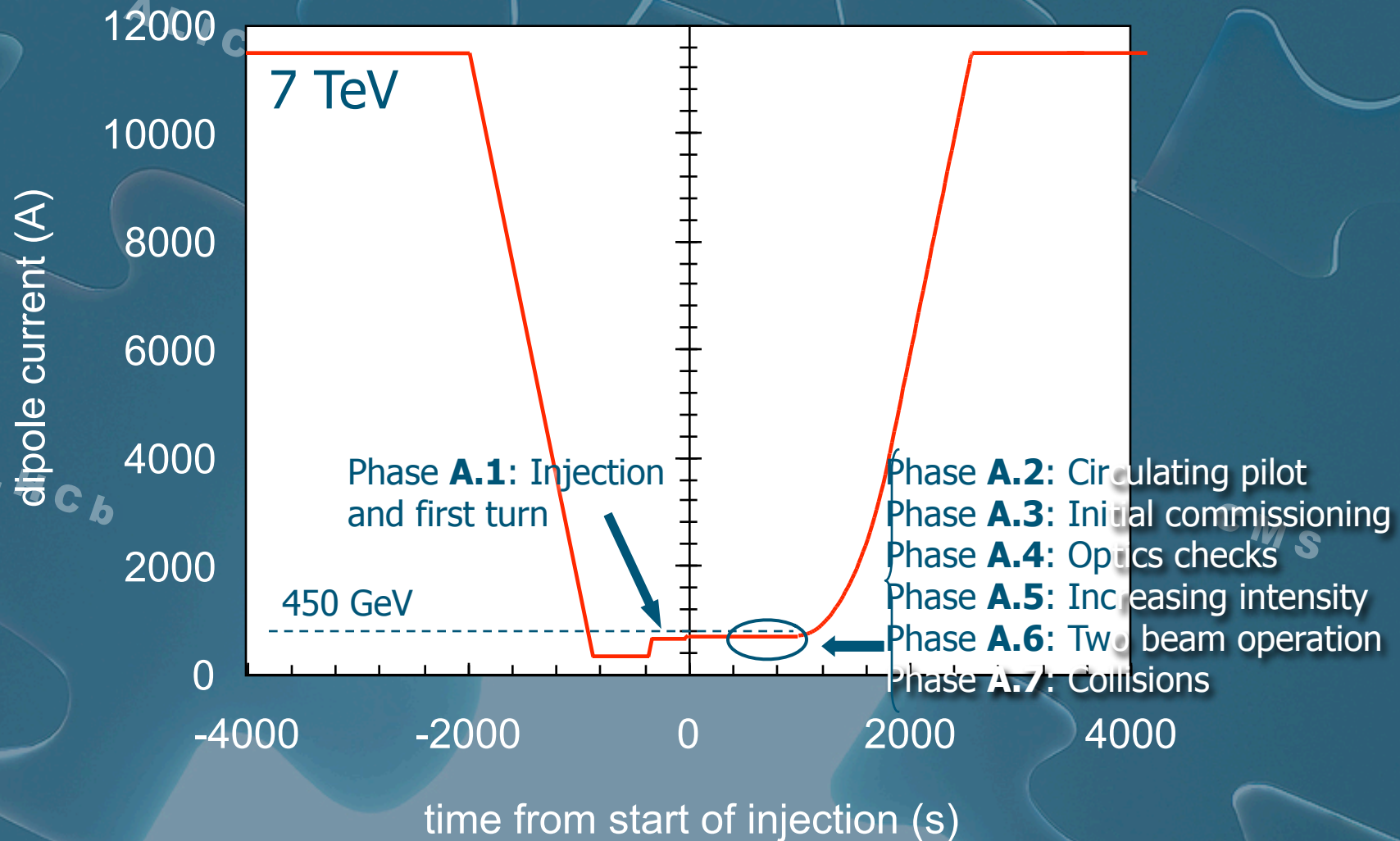


Beam Commissioning with p+ Stage A



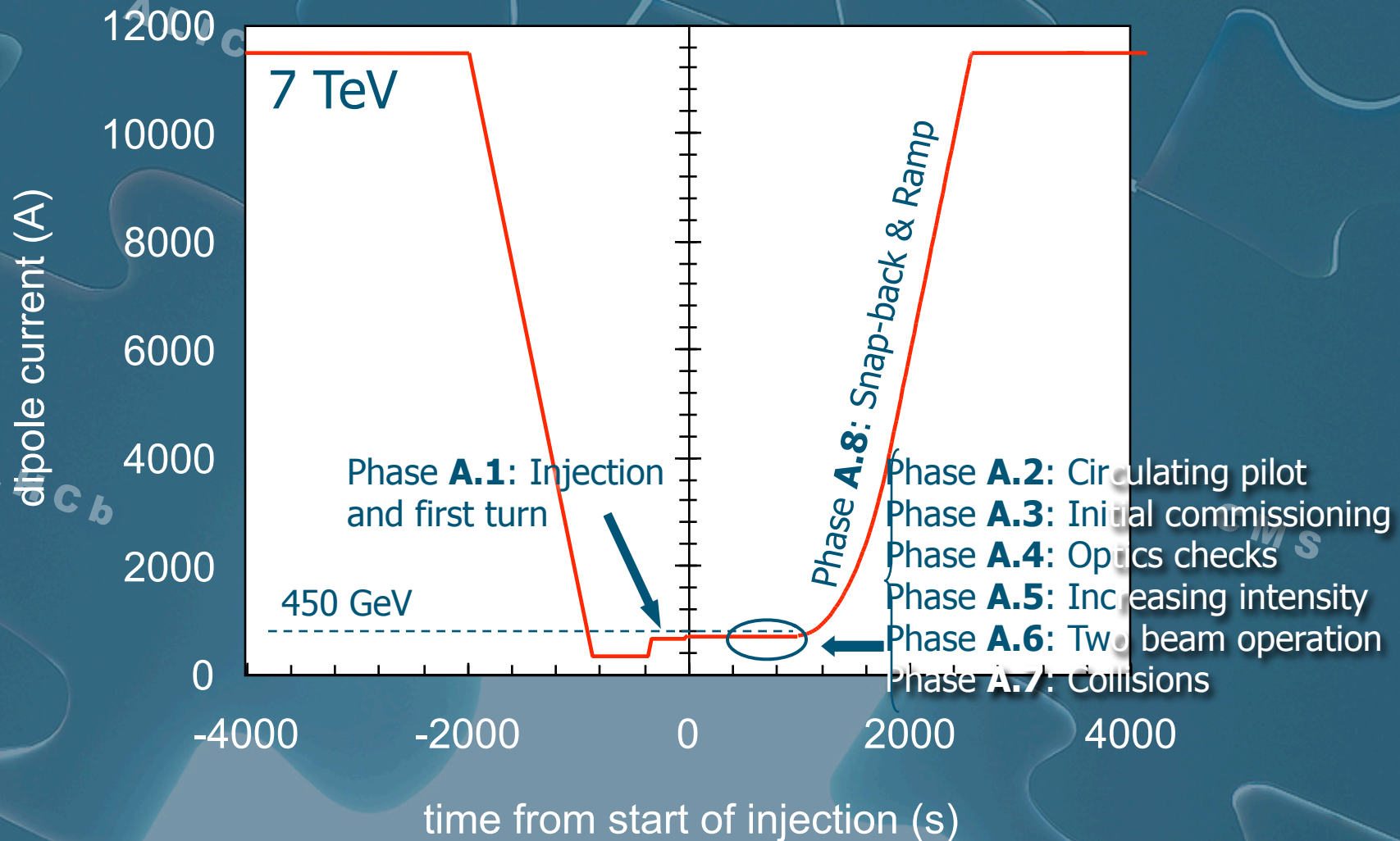


Beam Commissioning with p+ Stage A



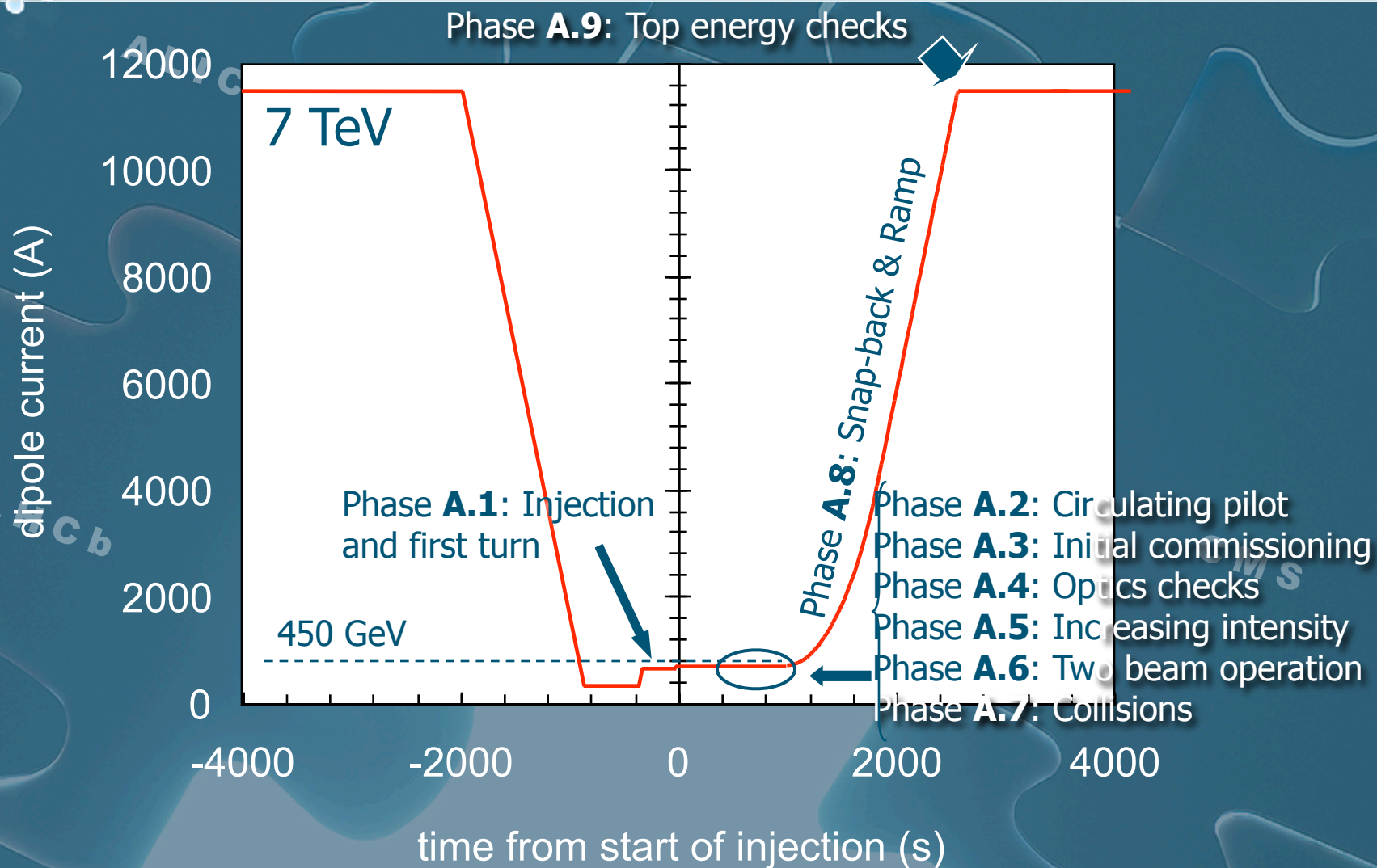


Beam Commissioning with p+ Stage A



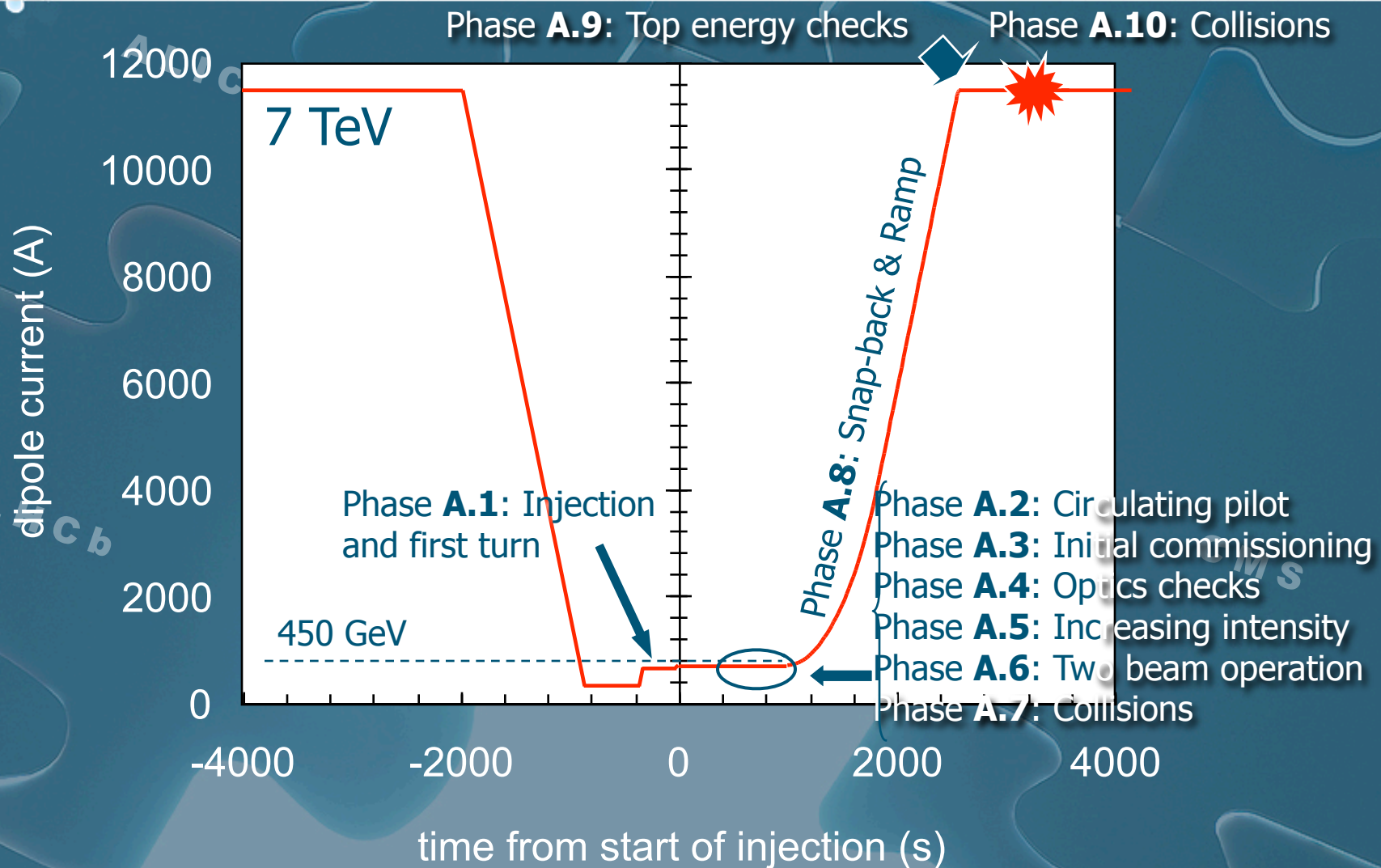


Beam Commissioning with p+ Stage A



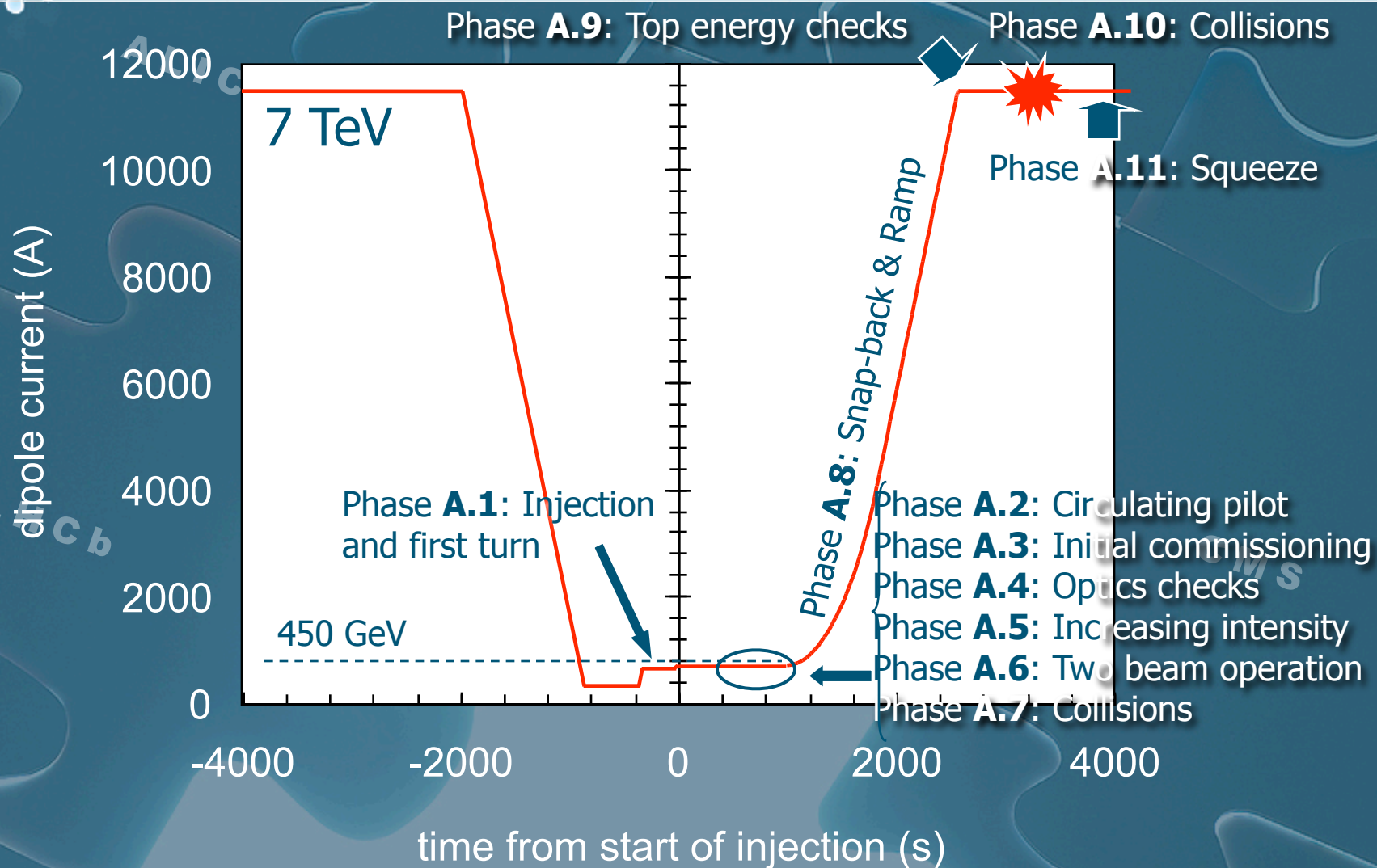


Beam Commissioning with p+ Stage A





Beam Commissioning with p+ Stage A





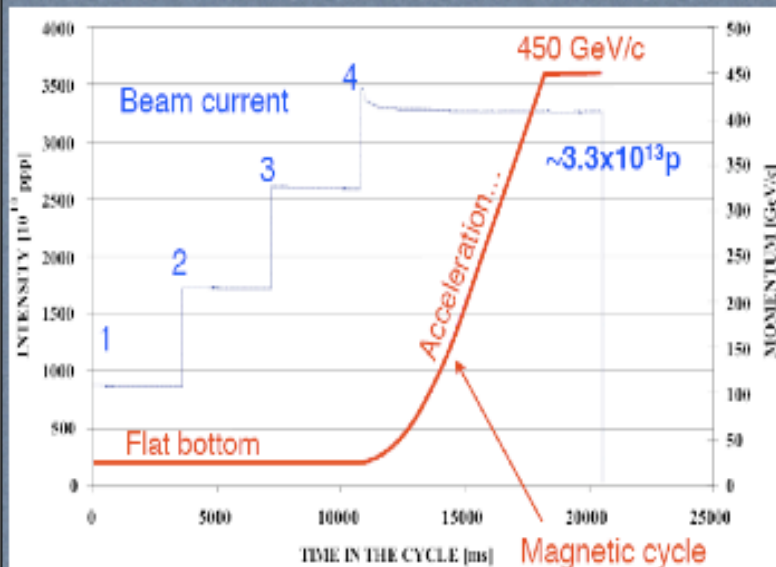
Beam Commissioning in the Injectors



Beam Commissioning in the Injectors



LHC beams at the SPS



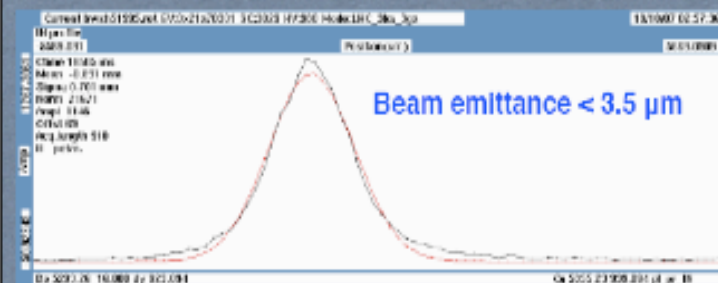
LHC nominal requirements:
 4x72 bunches ~ 3.3 x 10¹³ p
 Beam emittance < 3.5 μm



R. Bailey, P. Collier, LHC Proj. Note 323

Nominal LHC beams basically achieved in the SPS in 2004.

Further studies:
 Consolidation, performance improvement, optimization of cycles for LHC extraction.



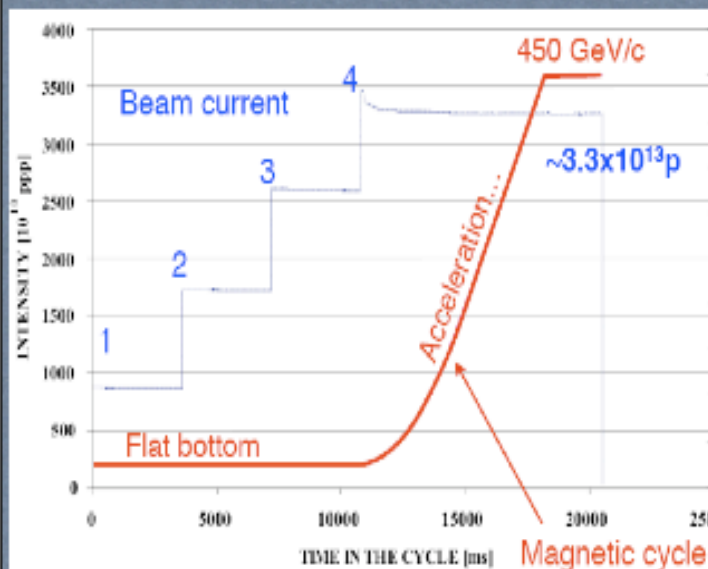
S. Redaelli, LHC beam commissioning, 30.01.2008



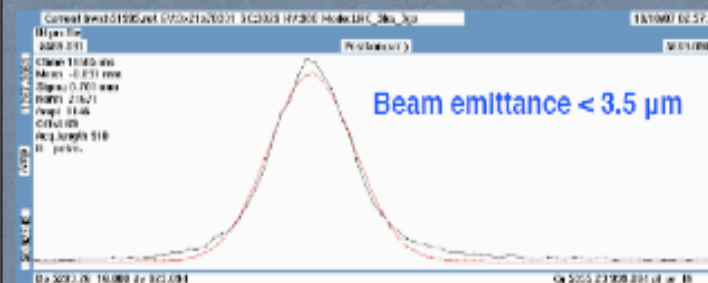
Beam Commissioning in the Injectors



LHC beams at the SPS



SPS 2004 run. Courtesy of G. Arduini, E. Métral



S. Redaelli, LHC beam commissioning



SPS: interleaved B1/B2 extractions



SPS 2007 run Courtesy of J. Wenninger
Beam intensity lower than nominal (no dedicated studies for beam optimization)

Cycle for interleaved extractions of Beam1 and Beam2 successfully set-up in 2007!
"Page 1" could announce that we were ready for "Filling the LHC...."

Shorter cycles also available for lower beam intensities: faster and more flexible operation for commissioning scenarios

S. Redaelli, LHC beam commissioning, 30-01-2008

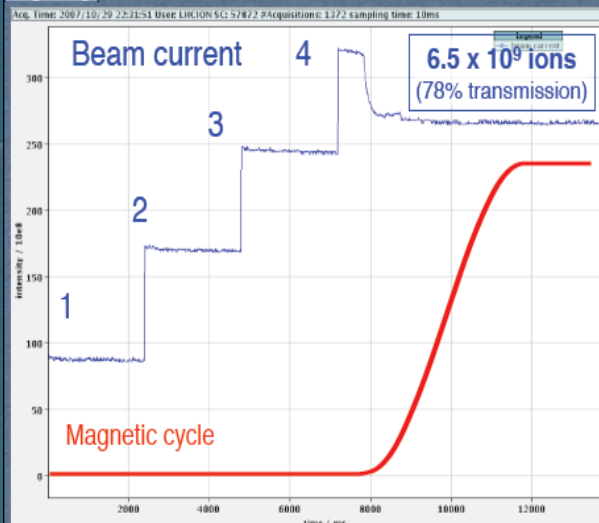
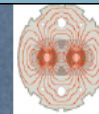




Beam Commissioning in the Injectors



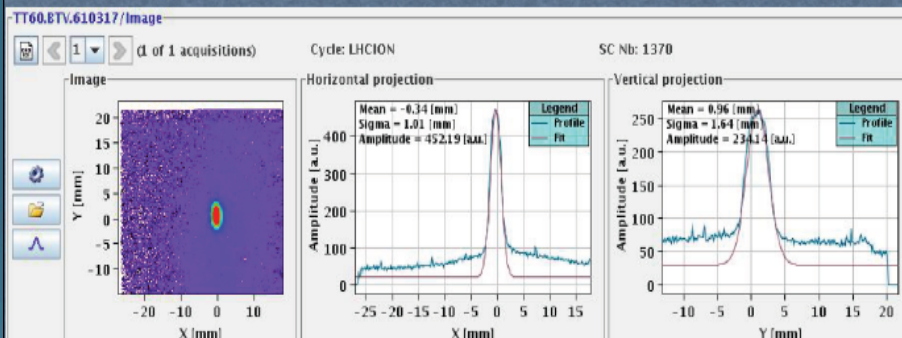
The "early" LHC ion beam is also ready



Summary table of main achievements

	expected	obtained			
		Bunch			
		1	2	3	4
transmission	75%				78%
N_Q	7.4×10^9				6.5×10^9
ϵ/A (eVs)	0.28	0.068	0.076	0.083	0.12
τ (ns)	1.8	0.90	0.94	1.0	1.2
$\Delta p/p$ (10 ⁻⁴)	6.3	2.7	2.9	3.1	3.6

Courtesy of T. Bohl



Extracted Lead ion beam in TT60!

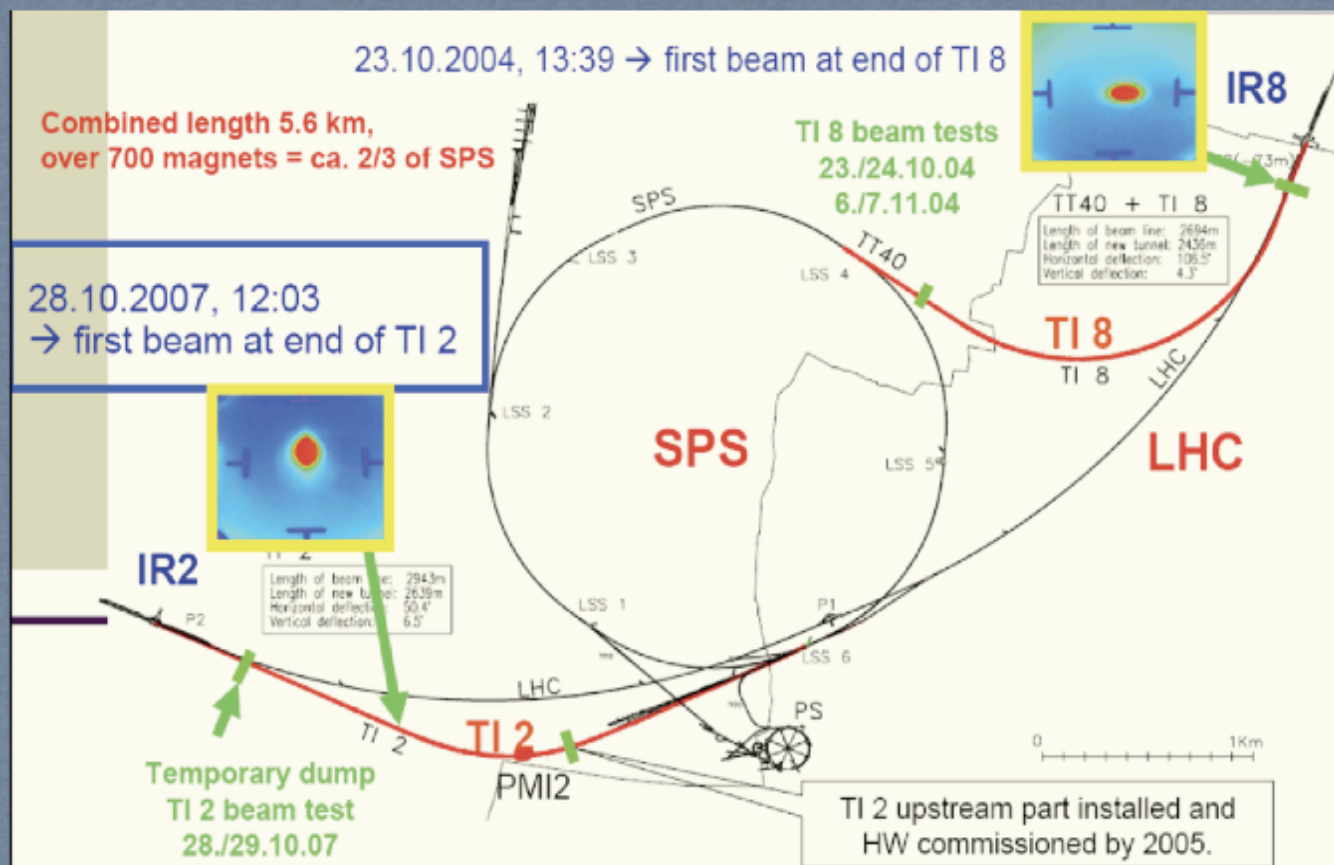
SPS 2007 run. Courtesy of D. Manglunki.



Beam Commissioning in the Transfer Lines



Transfer line commissioning



Courtesy of J. Uythoven



Phase A.1: Injection and first turn

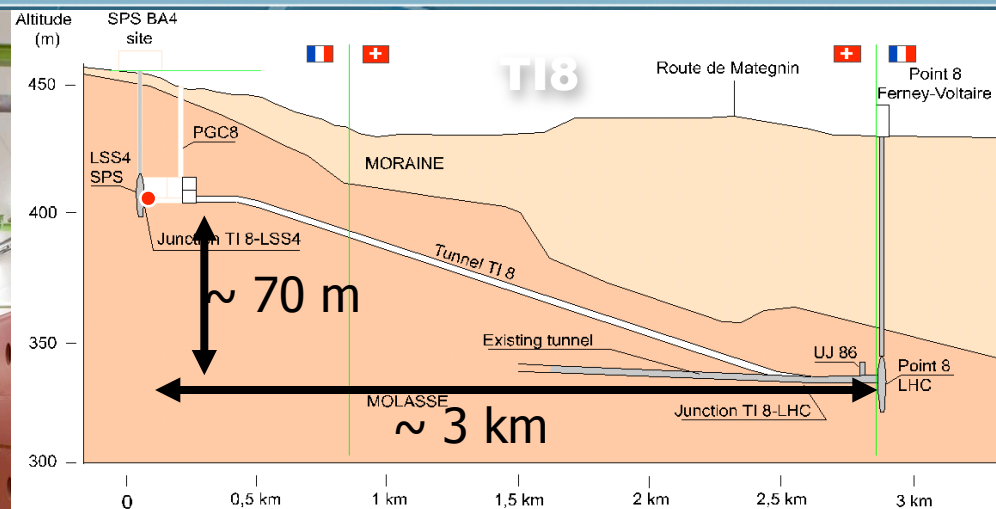
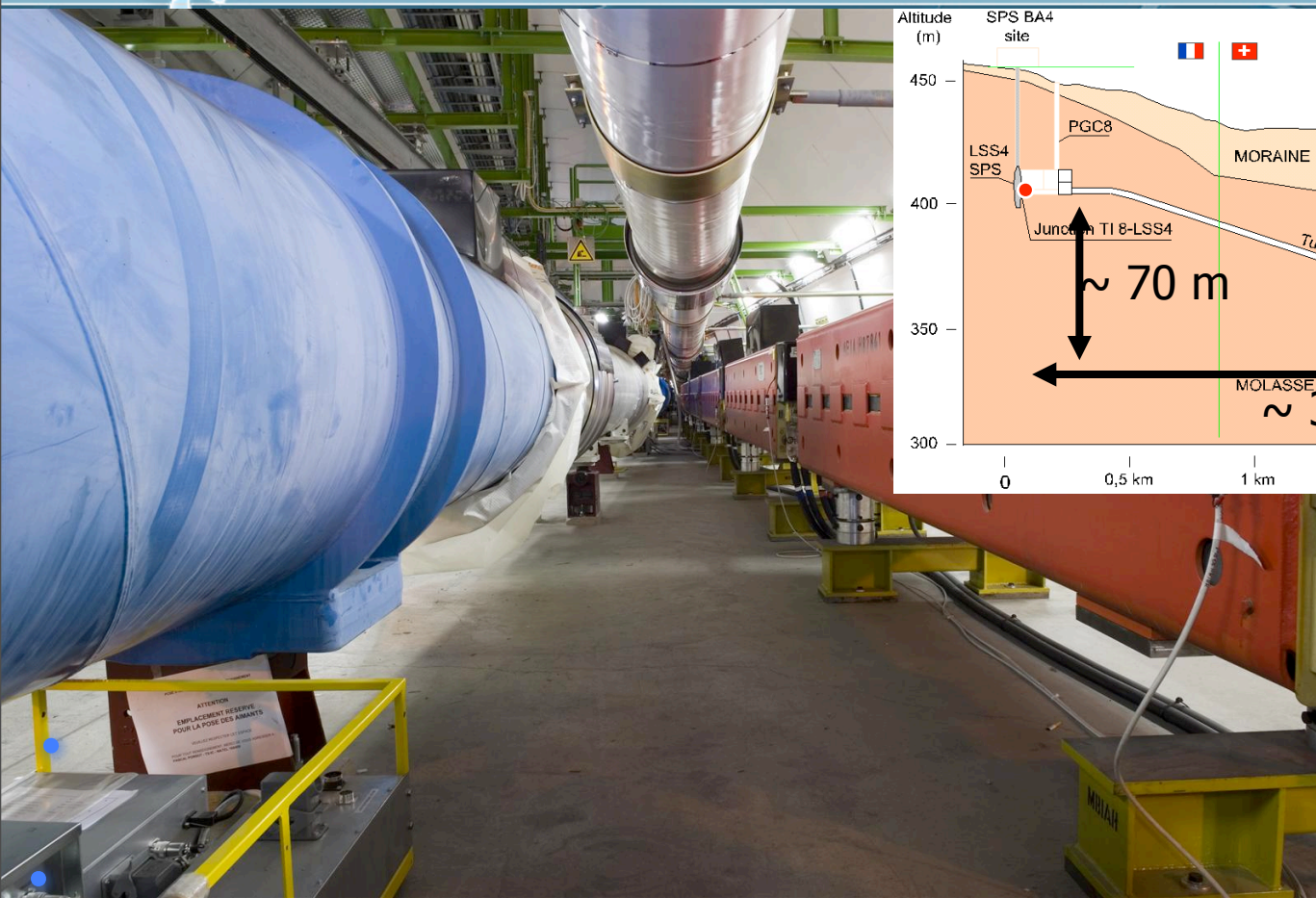


TI8

CMS



Phase A.1: Injection and first turn



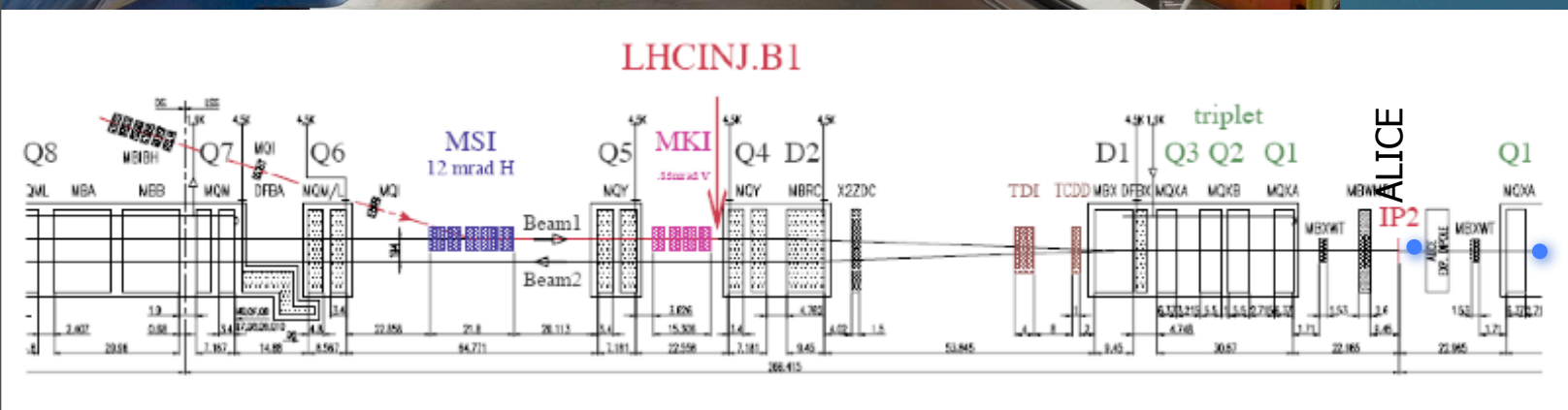
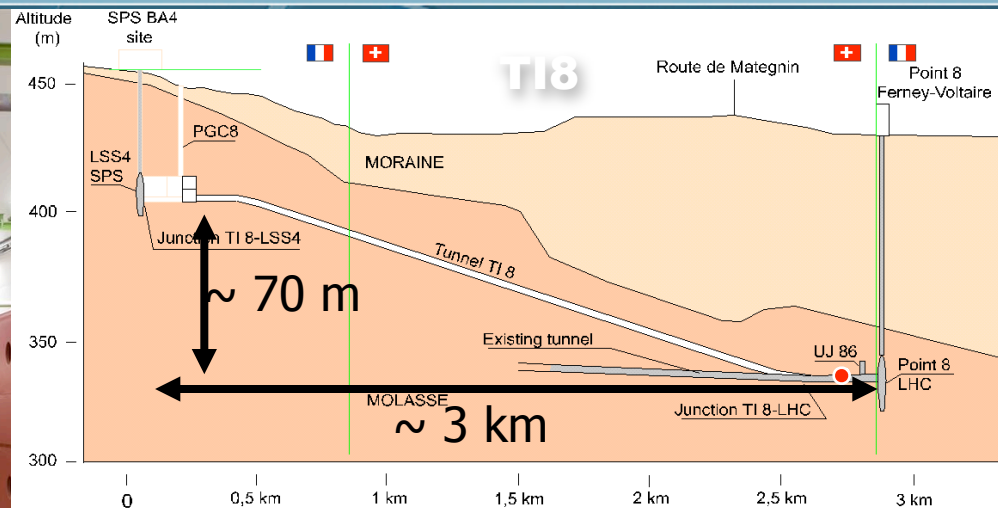
CMS



Phase A.1: Injection and first turn

Objectives:

- Commissioning of the last 100 m of the transfer line and the injection
- First commissioning of key beam instrumentation: BPM, BLM, BTV and FBCT
- Commissioning of the trajectory acquisition and correction
- Threading the beam around the two rings (first turn)
- Closing the orbit to be ready for phase A.2 (establishing circulating beam)



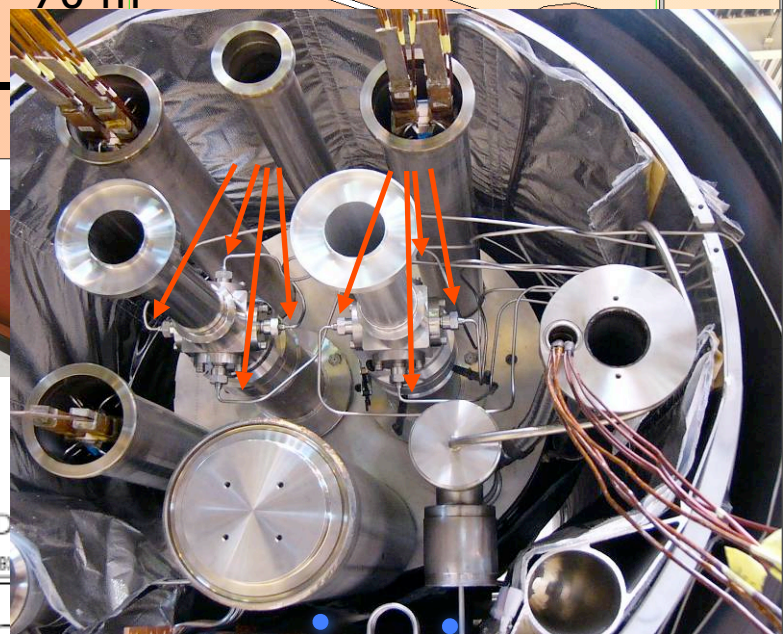
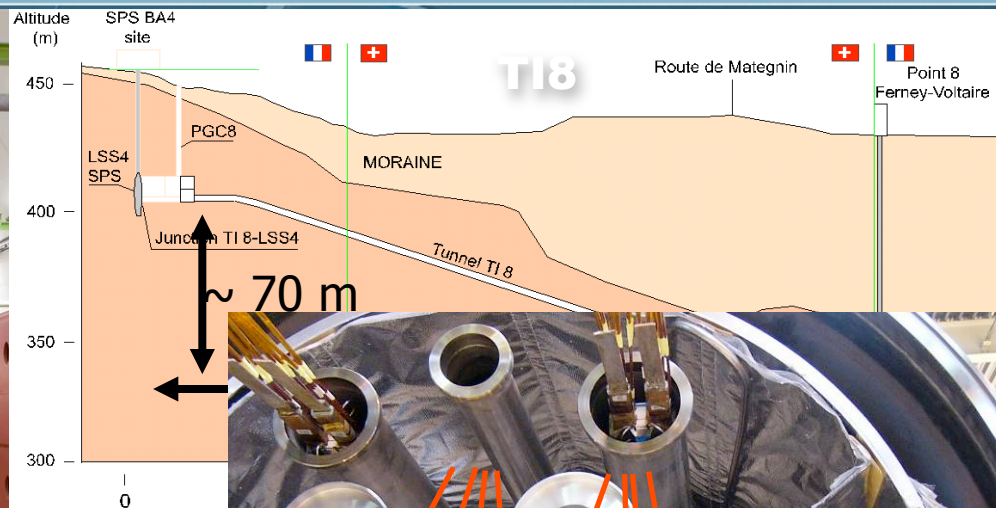
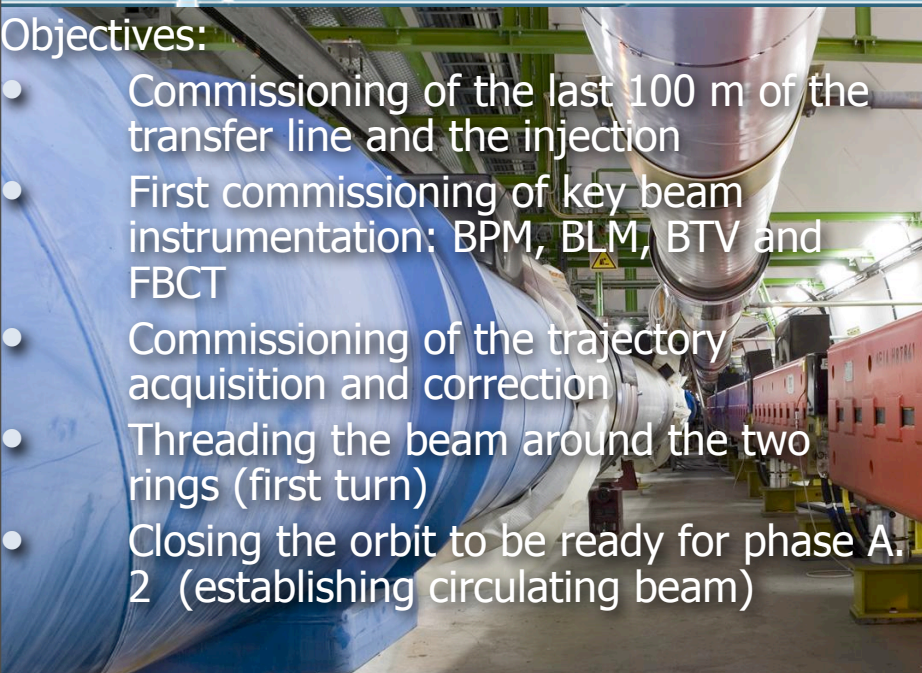
CMS



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A photograph of a particle accelerator tunnel. The tunnel is long and narrow, with a blue and white striped section in the foreground. A red service vehicle is visible on the right side of the tunnel. The background shows the continuation of the tunnel with more blue and white sections. The lighting is bright, and the overall atmosphere is industrial and technical.

- Commissioning of the last 100 m of the transfer line and the injection
- First commissioning of key beam instrumentation: BPM, BLM, BTV and FBCT
- Commissioning of the trajectory acquisition and correction
- Threading the beam around the two rings (first turn)
- Closing the orbit to be ready for phase A. 2 (establishing circulating beam)

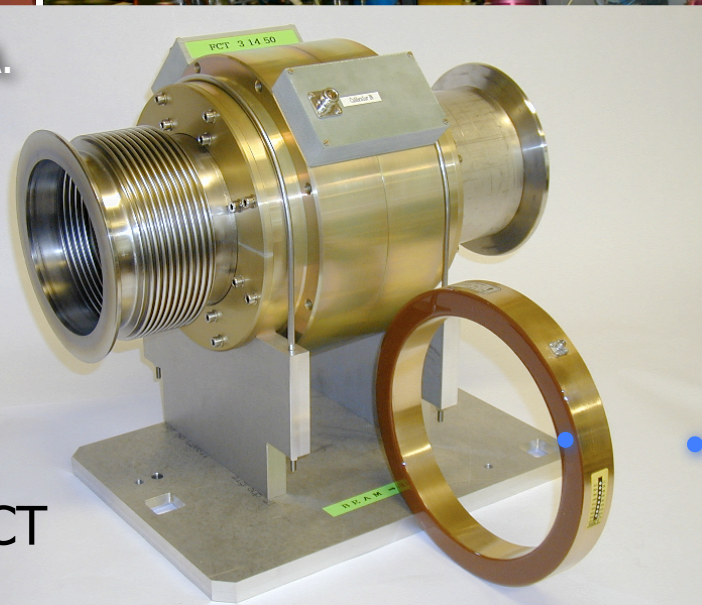
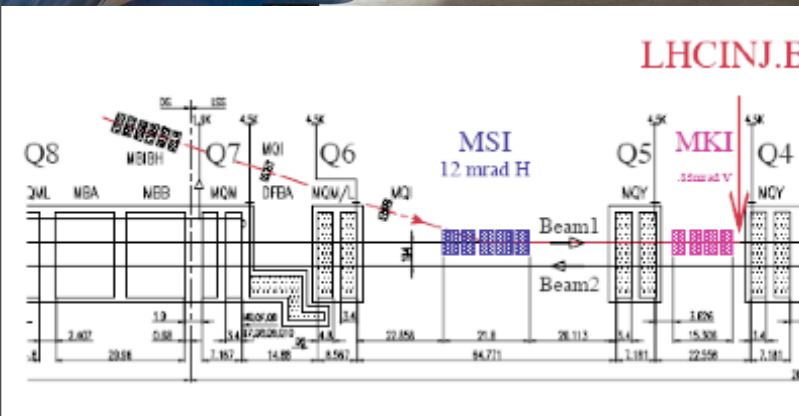
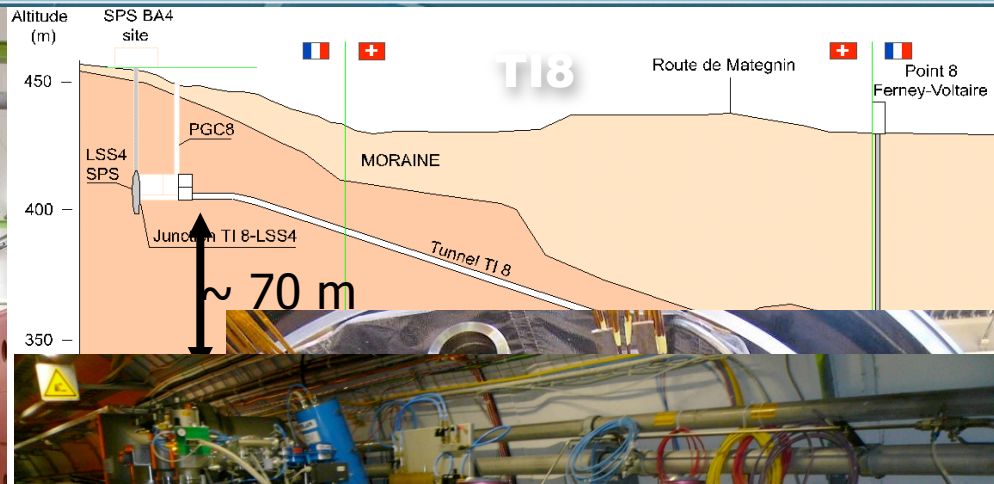
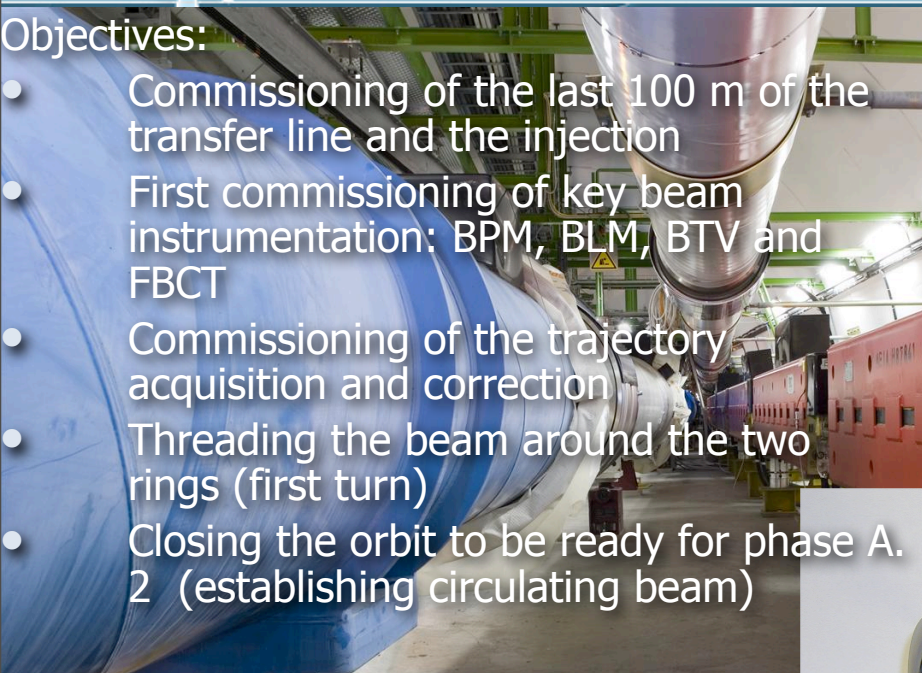




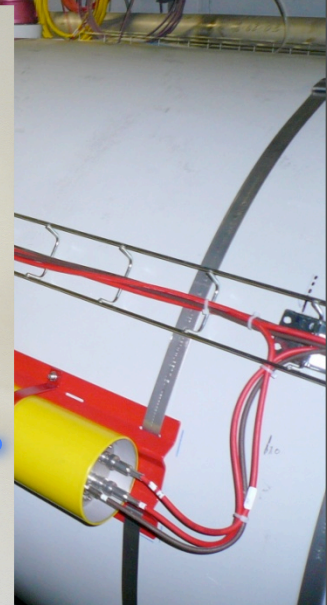
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FBCT

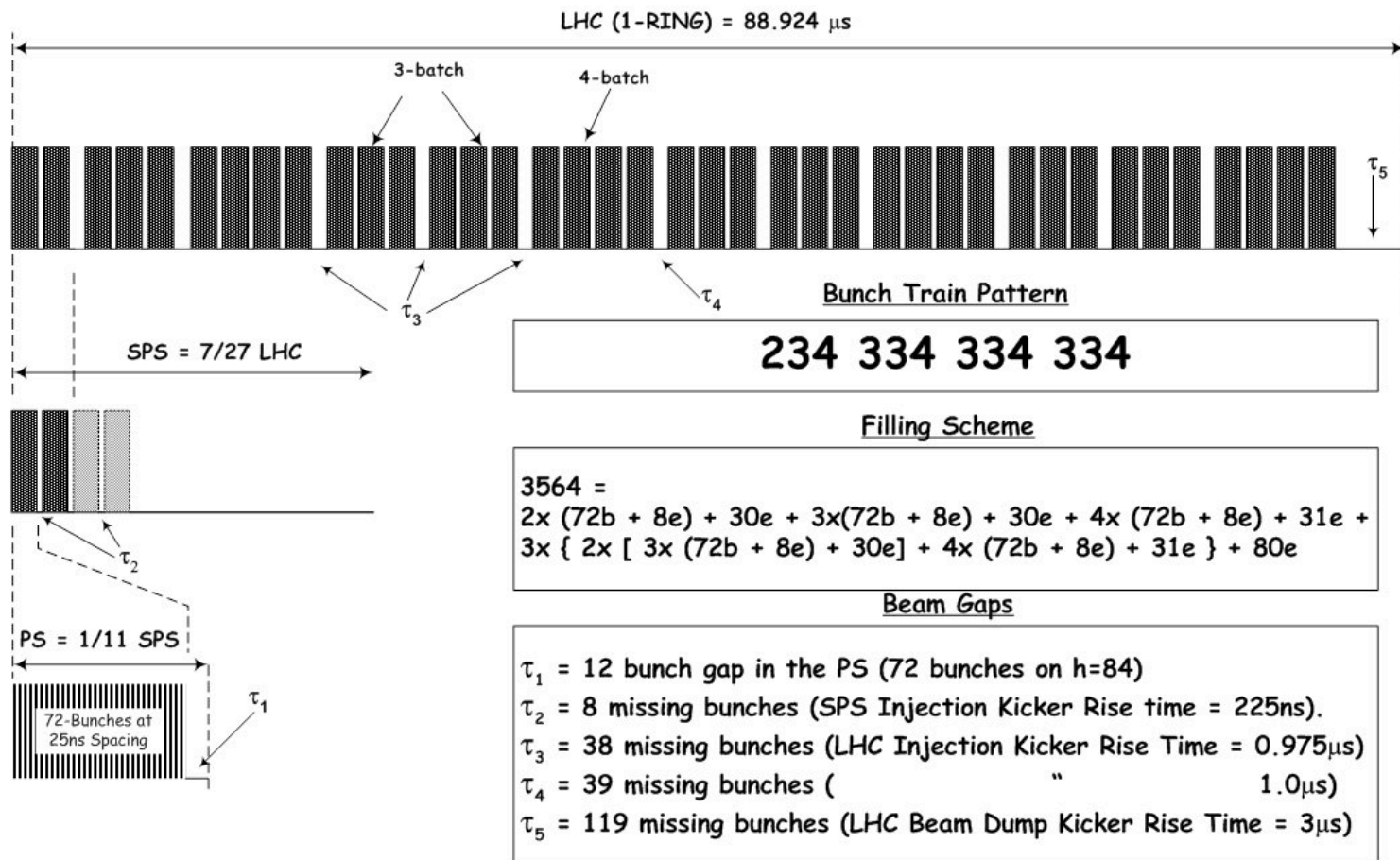




Phase A.1: Injection and first turn

Nominal Injection Schema

Nominal Proton Bunch Pattern in the LHC for 25ns Spacing





Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze

ALICE

ATLAS

LHCb

CMS



Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze



Phase A.10 objectives:

- Get beams into collisions at top energy
- Optimize integrated luminosity with relative luminosity as the main performance parameter
- Keep background low and stable without spikes
- Provide a rough knowledge of the absolute luminosity from beam parameters (beam intensities and sizes)

LHCb

CMS



Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze

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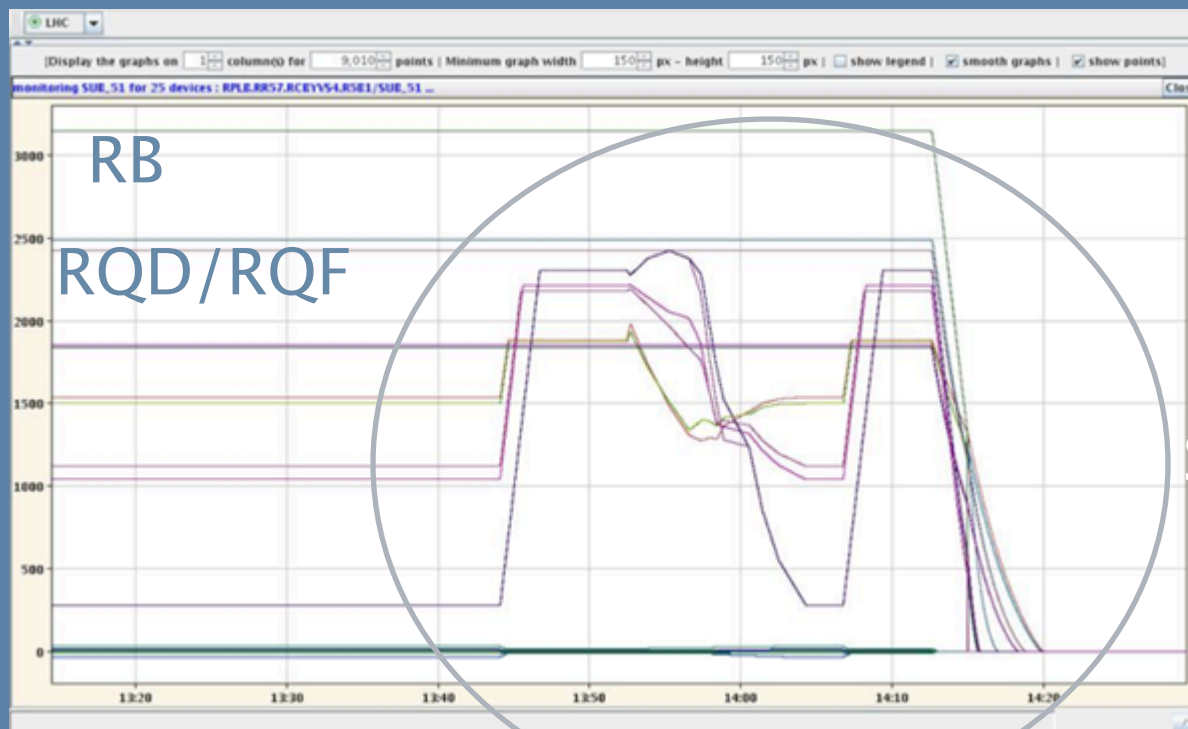
Phase A.11 objectives:

- Commission the squeeze without crossing in IP1 and IP5 at 7 TeV; goal for this phase is $\beta^*=2\text{m}$
- Squeeze of IP8 for LHCb operation with reduced beam intensities ($\beta^*=2\text{m}$)
- **Setup of the required protection**, in particular, commissioning of the **tertiary collimators**, i.e., collimators to protect the experiments

Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze

ARC+ML6+LR5 (156 PCs) @ 5 TeV





Beam Commissioning with p+

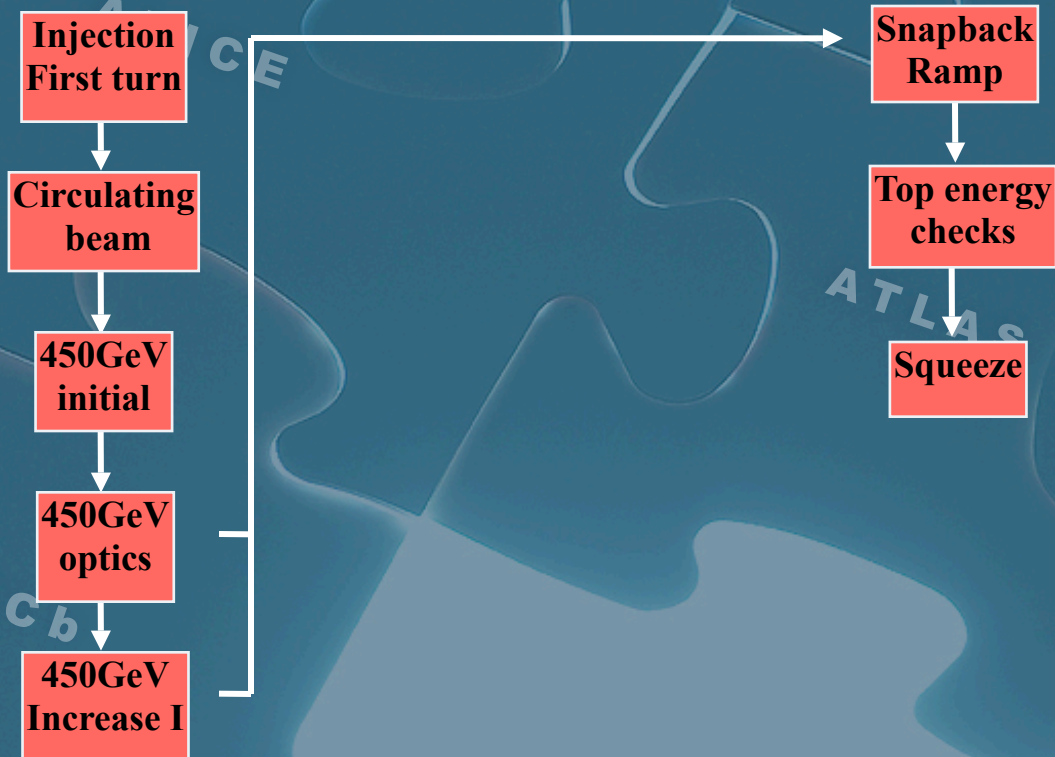
Phase A: commissioning plans





Beam Commissioning with p+

Phase A: commissioning plans

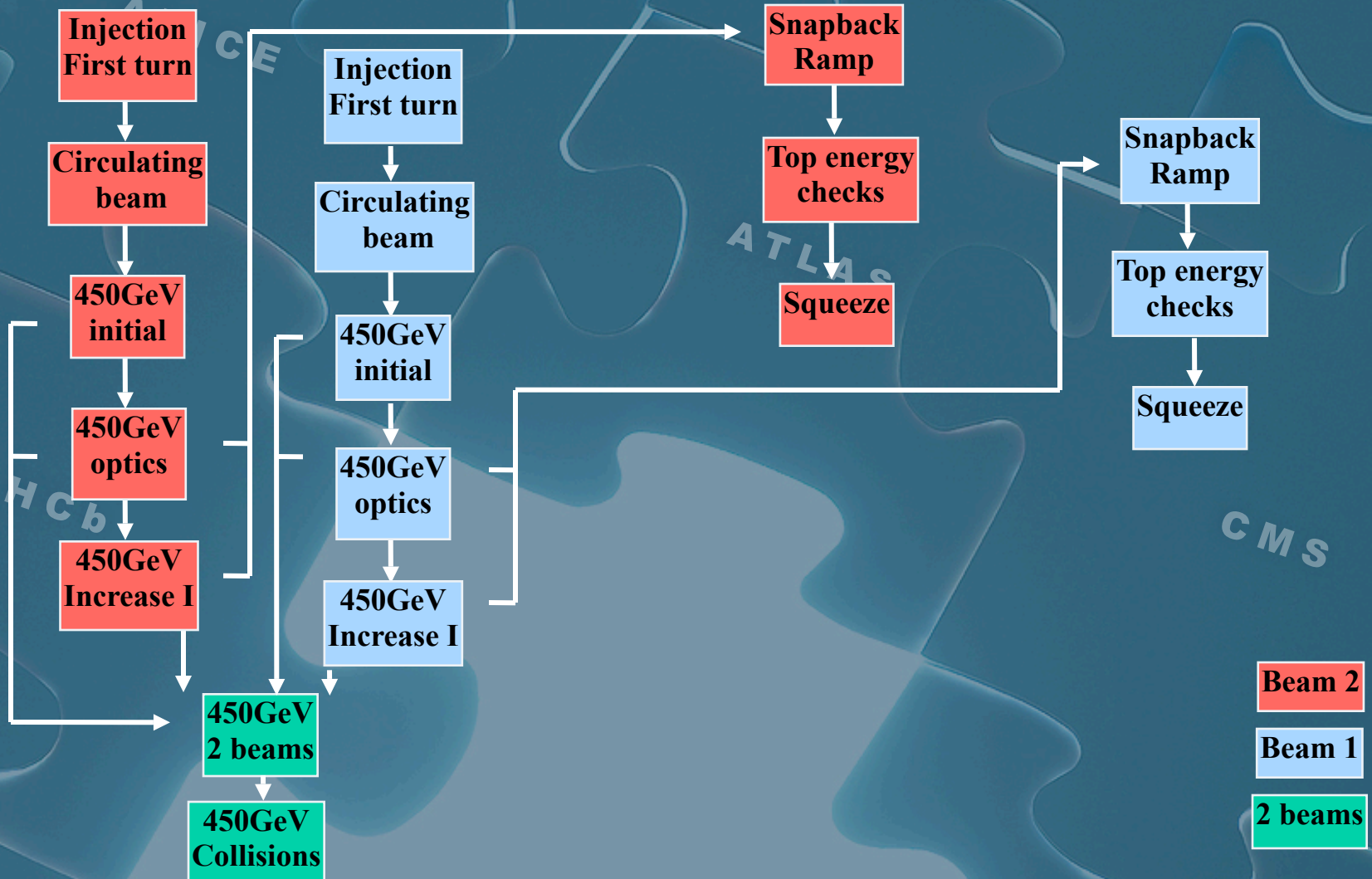


Beam 2



Beam Commissioning with p+

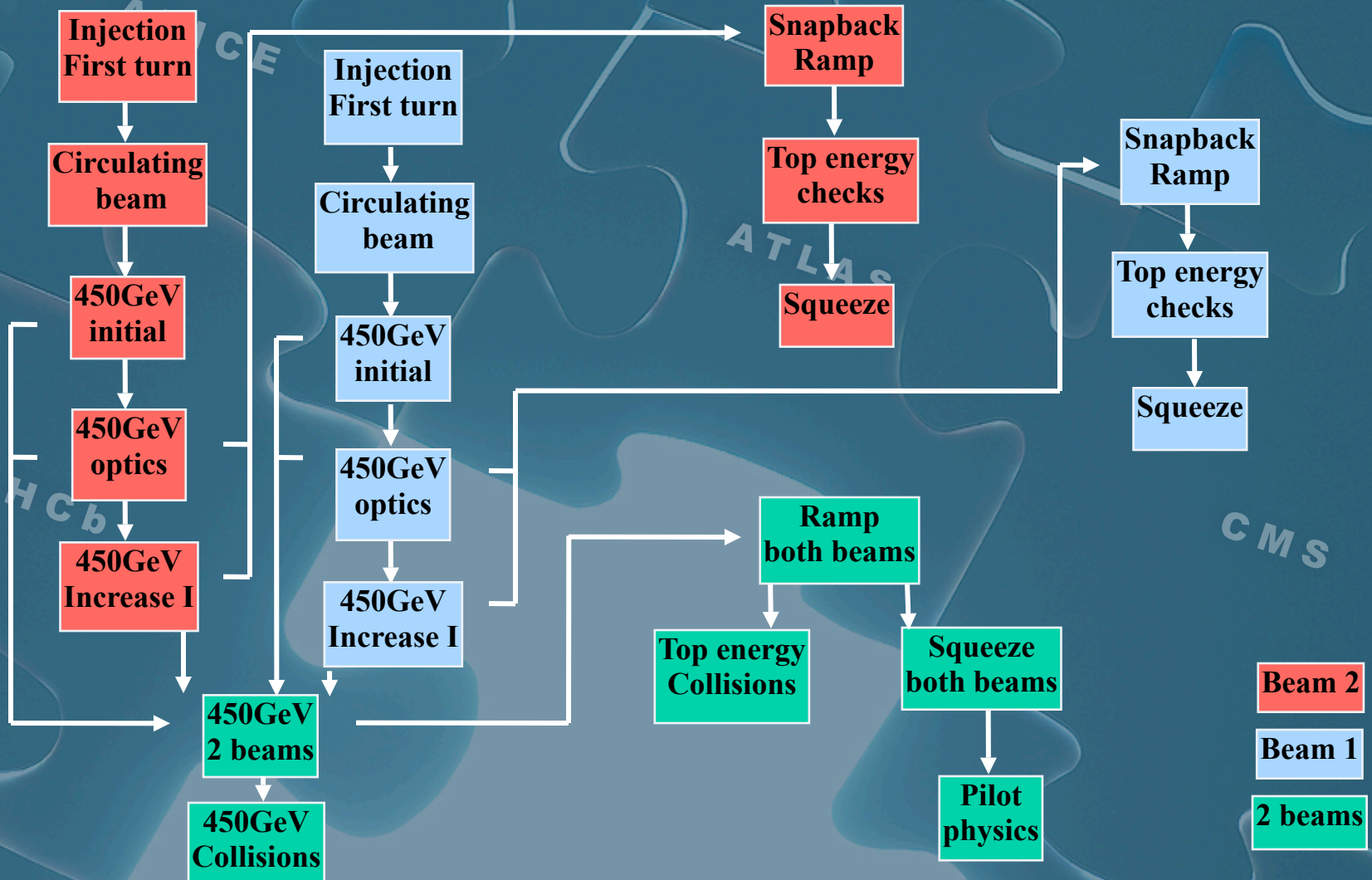
Phase A: commissioning plans





Beam Commissioning with p+

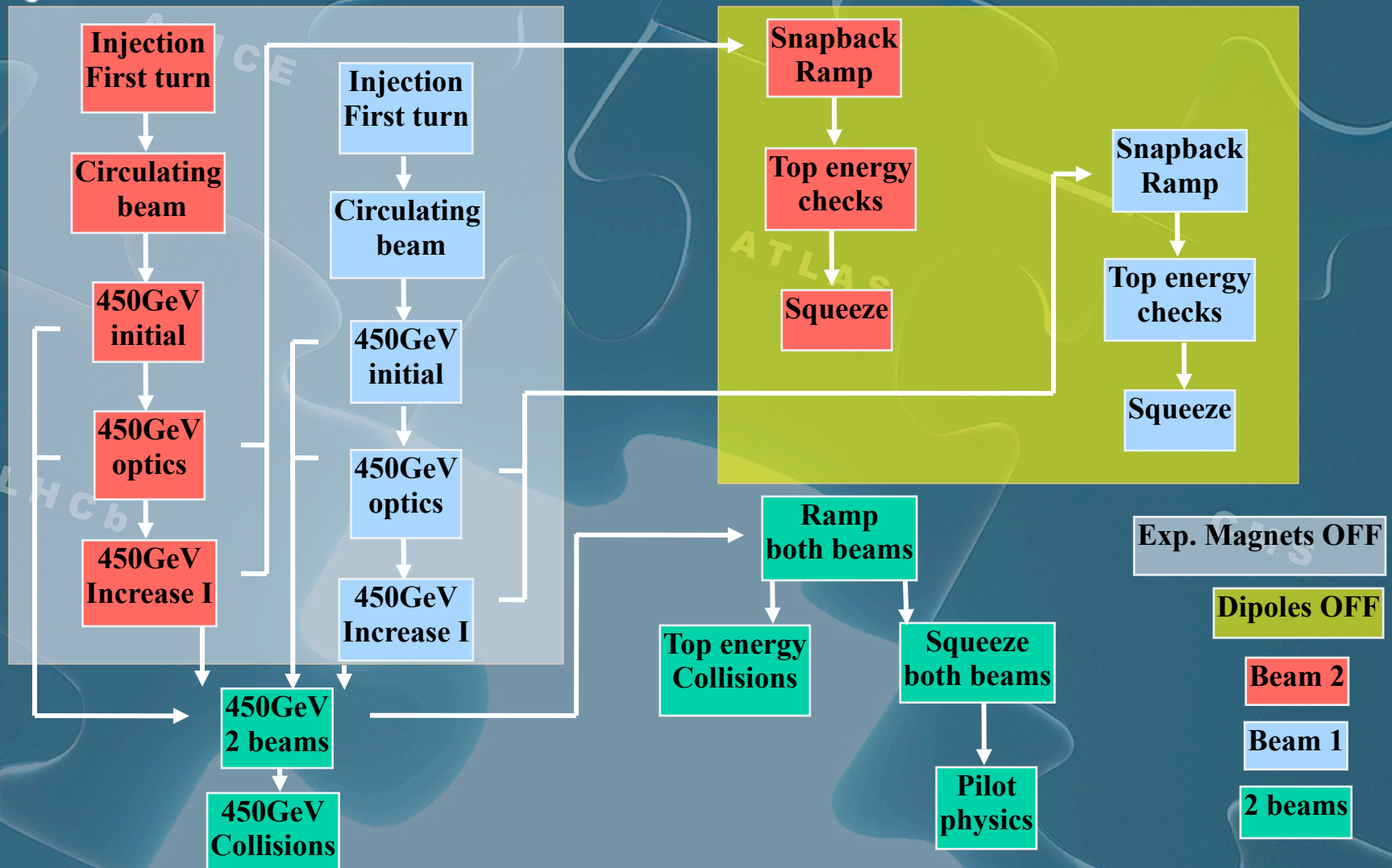
Phase A: commissioning plans





Beam Commissioning with p+

Phase A: commissioning plans





Beam Commissioning with p+

Stage B: Intermediate physics run

- Relaxed crossing angle (250 μrad)
- Start un-squeezed
- Then go to where we were in stage A
- All values for
 - nominal emittance
 - 7 TeV
 - 10 m β^* in points 2 and 8

$$F = 1 / \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*} \right)^2}$$

Protons/beam $\approx$ few 10^{13}

Stored energy/beam $\leq$ 100 MJ

Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
k_b	N	$\beta^*_{1,5}$	I_{beam}	E_{beam}	Luminosity	Events/	Luminosity	Events/
936	$4 \cdot 10^{10}$	11	$3.7 \cdot 10^{13}$	42	$2.4 \cdot 10^{31}$	$\ll 1$	$2.6 \cdot 10^{31}$	0.15
936	$4 \cdot 10^{10}$	2	$3.7 \cdot 10^{13}$	42	$1.3 \cdot 10^{32}$	0.73	$2.6 \cdot 10^{31}$	0.15
936	$6 \cdot 10^{10}$	2	$5.6 \cdot 10^{13}$	63	$2.9 \cdot 10^{32}$	1.6	$6.0 \cdot 10^{31}$	0.34
936	$9 \cdot 10^{10}$	1	$8.4 \cdot 10^{13}$	94	$1.2 \cdot 10^{33}$	7	$1.3 \cdot 10^{32}$	0.76



Beam Commissioning with p+ Stage C&D: 25 ns Operation

- Nominal crossing angle ($285 \mu\text{rad}$)
- Start un-squeezed
- Then go to where we were in stage B
- All values for
 - nominal emittance
 - 7 TeV
 - $10\text{m } \beta^*$ in points 2 and 8

Protons/beam $\approx 10^{14}$
Stored energy/beam $\geq 100 \text{ MJ}$

Parameters			Beam levels		Rates in 1 and 5		Rates in 2 and 8	
k_b	N	$\beta^* 1,5$	I_{beam}	E_{beam}	Luminosity	Events/	Luminosity	Events/
2808	$4 \cdot 10^{10}$	11	$1.1 \cdot 10^{14}$	126	$7.2 \cdot 10^{31}$	$\ll 1$	$7.9 \cdot 10^{31}$	0.15
2808	$4 \cdot 10^{10}$	2	$1.1 \cdot 10^{14}$	126	$3.8 \cdot 10^{32}$	0.72	$7.9 \cdot 10^{31}$	0.15
2808	$5 \cdot 10^{10}$	2	$1.4 \cdot 10^{14}$	157	$5.9 \cdot 10^{32}$	1.1	$1.2 \cdot 10^{32}$	0.24
2808	$5 \cdot 10^{10}$	1	$1.4 \cdot 10^{14}$	157	$1.1 \cdot 10^{33}$	2.1	$1.2 \cdot 10^{32}$	0.24
2808	$5 \cdot 10^{10}$	0.55	$1.4 \cdot 10^{14}$	157	$1.9 \cdot 10^{33}$	3.6	$1.2 \cdot 10^{32}$	0.24
Nominal			$3.2 \cdot 10^{14}$	362	1034	19	$6.5 \cdot 10^{32}$	1.2



Contents

1. Accelerator complex
2. Energy Stored in the Magnets
 - Quench Protection System
 - Power Interlock System
 - Energy Extraction
3. Energy Stored in the Beams
 - Beam Dump System
 - Collimation System
4. Machine Protection System
5. Overall Strategy for Commissioning:
 - HW Commissioning
 - Machine Checkout
 - Beam Commissioning
 - Stage A
 - Stage B
 - Stage C&D
6. Documentation & Human Resources
7. Conclusions



Documentation

Hardware Commissioning Coordination

■ <http://hcc.web.cern.ch/hcc/>

Machine Checkout

■ <http://wikis/display/LHCOP/LHC+Machine+Checkout>

LHC Commissioning Procedures

■ http://lhccwg.web.cern.ch/lhccwg/overview_index.htm

CERN
CH-1211 Geneva 23
Switzerland



the
Large
Hadron
Collider
project

LHC Project Document No.

LHC-OP-BCP-0002 rev 0.2

CERN Dir./Group or Supplier/Contractor Document No.

LHCCWG

EDMS Document No.
850423

Date: 2007-08-03

Beam Commissioning Procedure

LHC COMMISSIONING WITH BEAM: PHASE A.1 (FIRST TURN)

Abstract

This document describes the LHC beam commissioning procedures for the first turn. It covers the entry conditions, the commissioning procedures and exit conditions of this phase. Possible problems and open questions are also listed.

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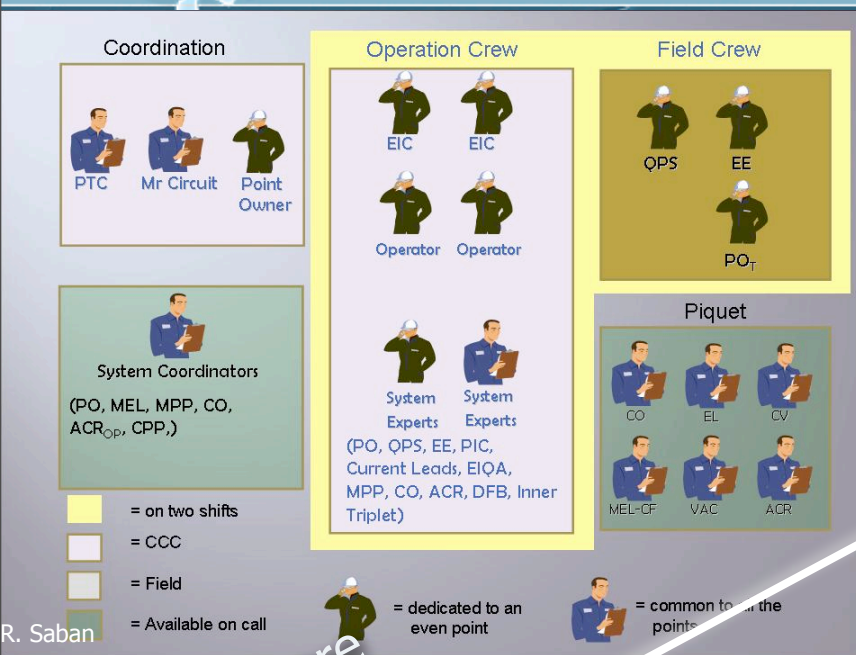


Human Resources





Human Resources



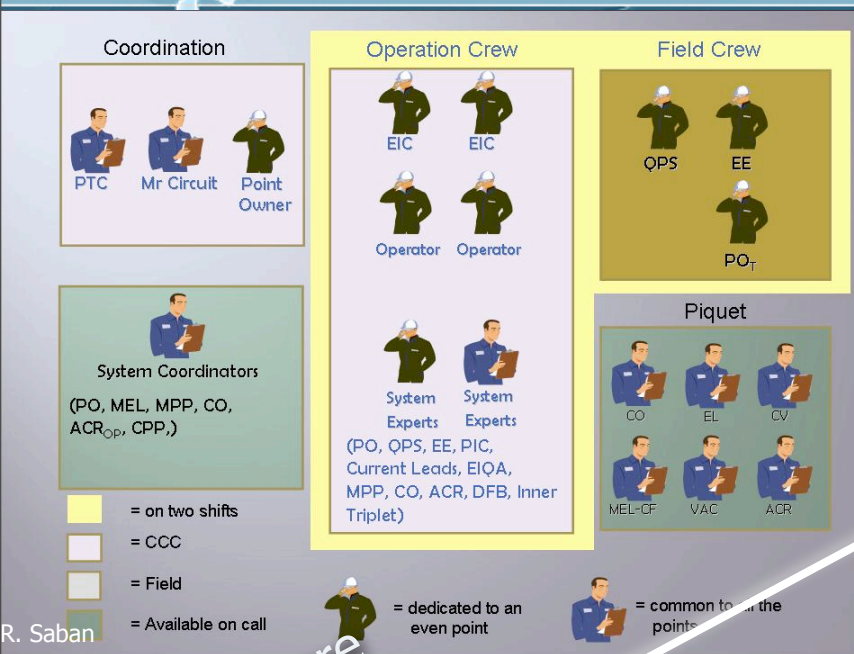
Hardware
Commissioning

ATLAS

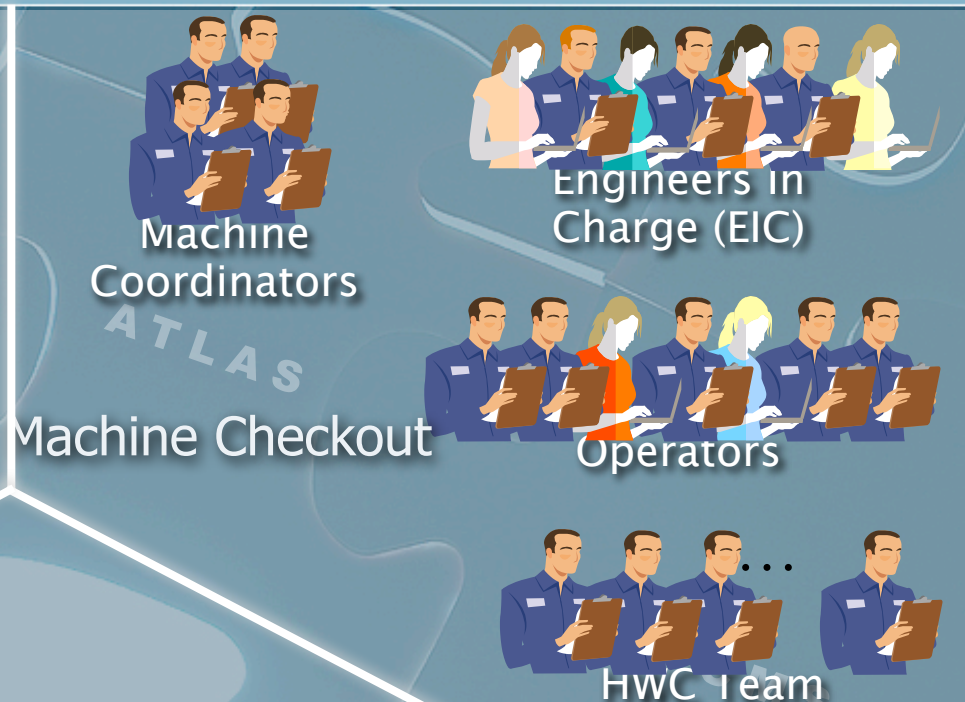
CMS



Human Resources

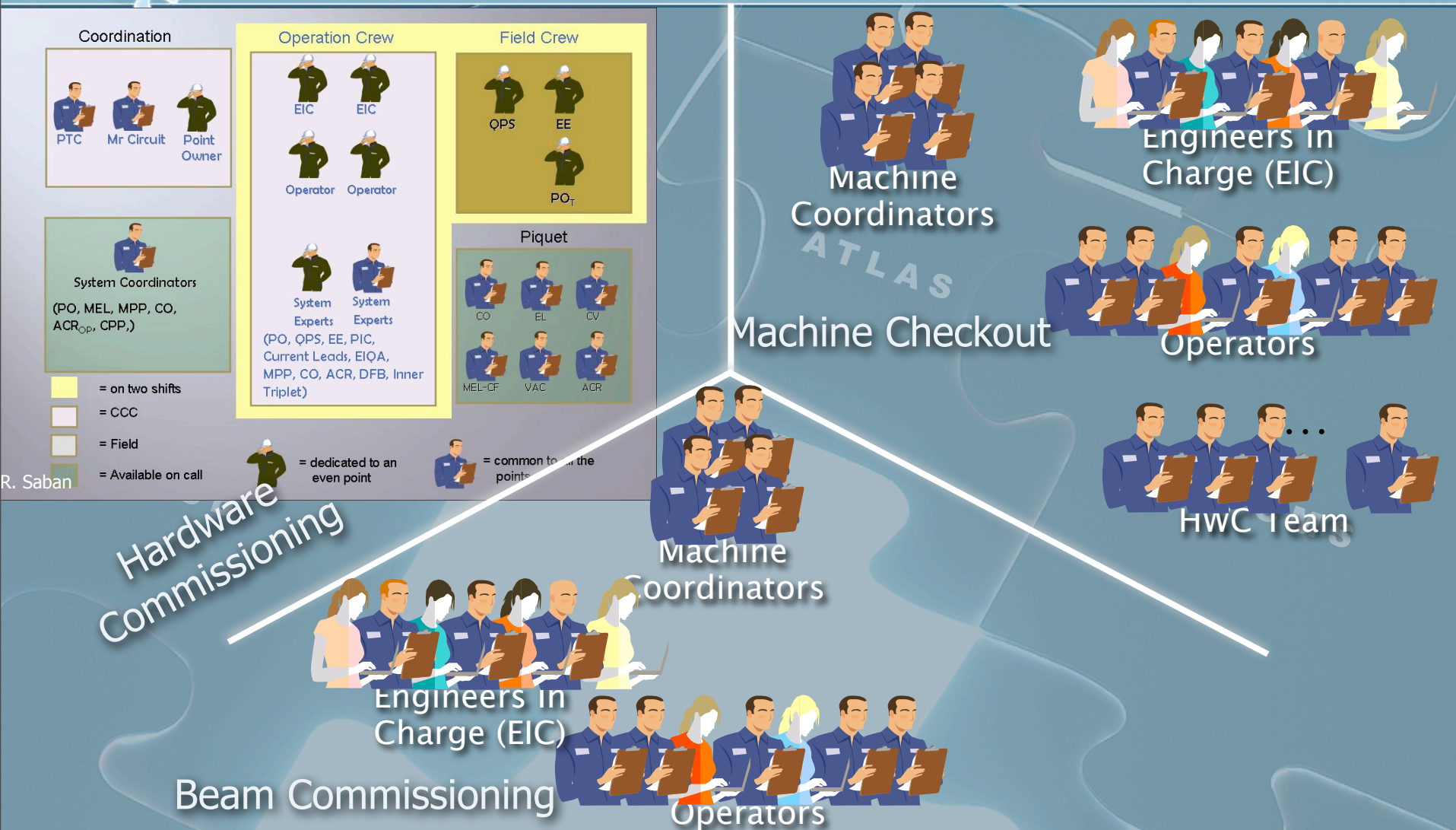


Hardware
Commissioning



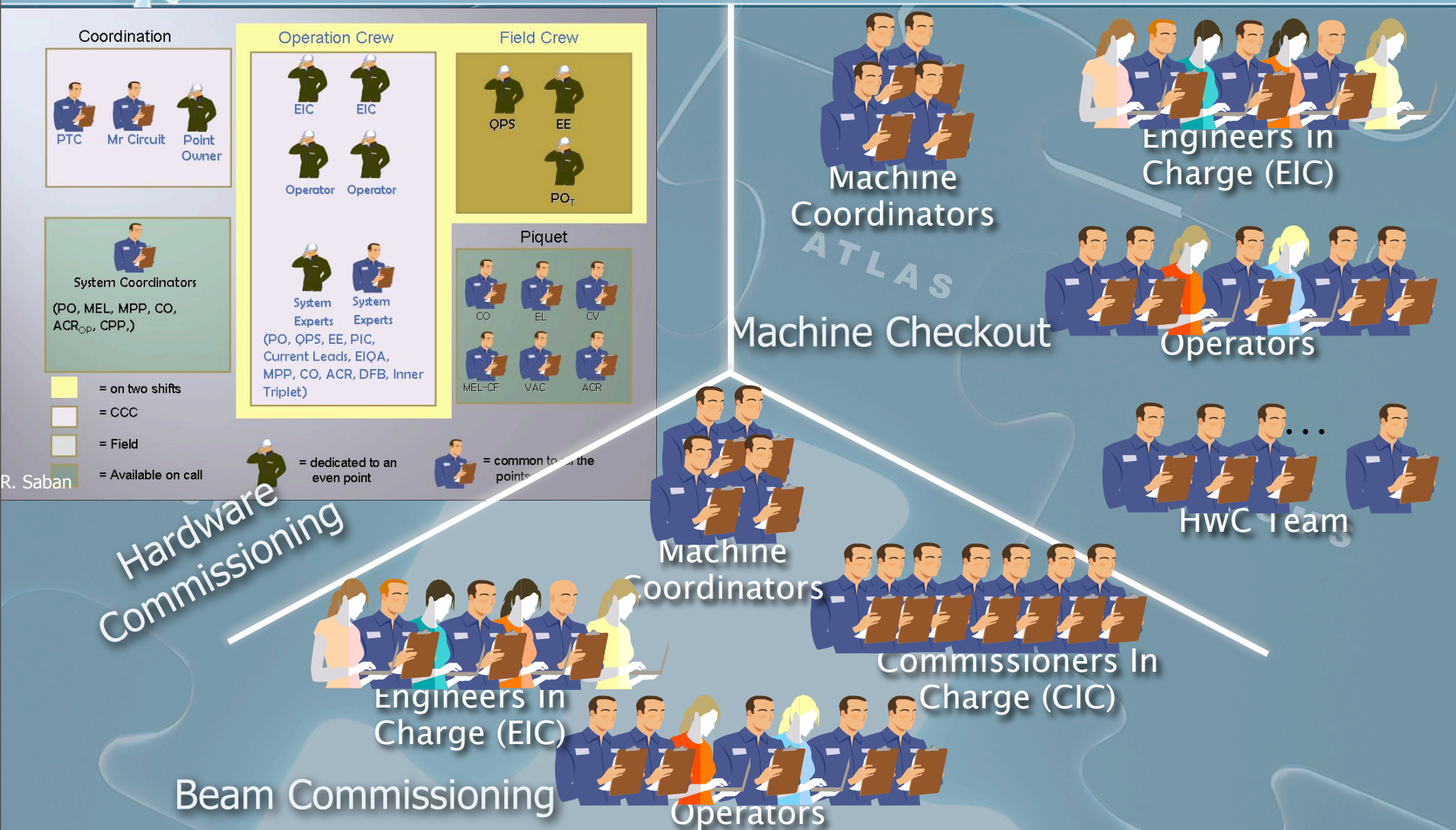


Human Resources



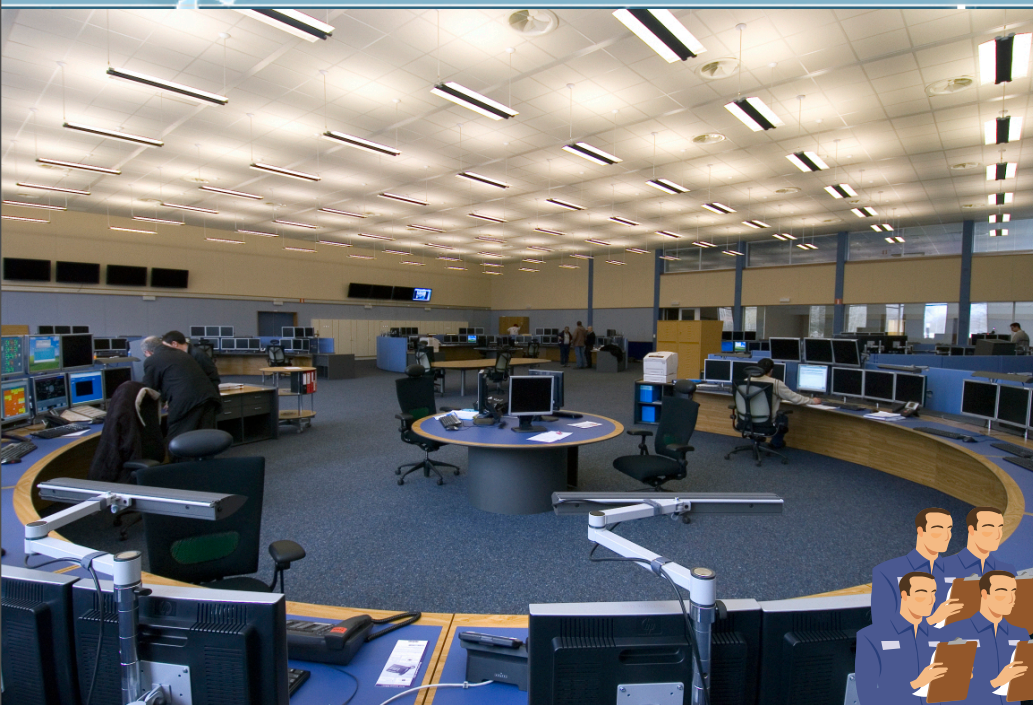


Human Resources





Human Resources



Machine Coordinators



Engineers In Charge (EIC)



Operators



HWC team



Machine Coordinators



Commissioners In Charge (CIC)



Engineers In Charge (EIC)



Operators

Beam Commissioning

Hard Commissioning



Summary

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Summary

- To fully commission LHC three steps are envisaged:
 - Hardware Commissioning
 - Machine Checkout
 - Beam Commissioning



Summary

- To fully commission LHC three steps are envisaged:
 - Hardware Commissioning
 - Machine Checkout
 - Beam Commissioning
- To tackle the machine unprecedented complexity and potential danger (energy stored in the magnets and in the beam), each step is divided in well defined phases



Summary

- To fully commission LHC three steps are envisaged:
 - Hardware Commissioning
 - Machine Checkout
 - Beam Commissioning
- To tackle the machine unprecedented complexity and potential danger (energy stored in the magnets and in the beam), each step is divided in well defined phases
- The success of the commissioning relies, among other things, upon:
 - Carefull elaboration of procedures (Documentation)
 - Perfect matching between the exit conditions of one step or phase with the entry conditions of the next one
 - Have always a « plan B » prepared



Acknowledges

The content of this presentation has been elaborated from material coming from the

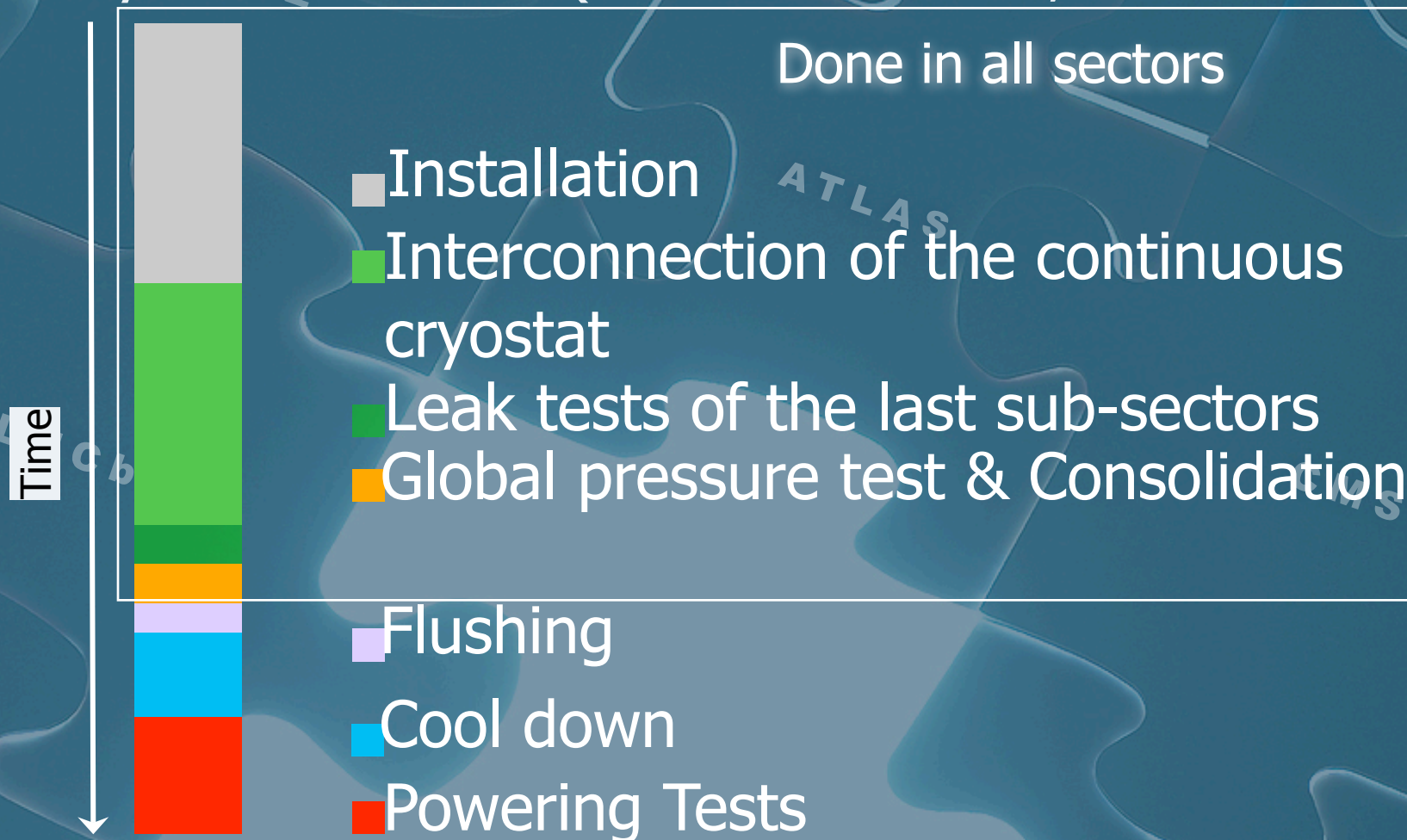
LHC Commissioning Working Group
and

Hardware Commissioning Coordination Group



Hardware Commissioning Status

Life cycle of a sector (after installation, before beam)





Extra Slides



The Phase I LHC collimation system



Multi-stage halo cleaning

Two warm cleaning insertions

IR3: Momentum cleaning

- 1 primary (H) → TCP [C]
- 4 secondary (H,S) → TCS [C]
- 4 shower abs. (H,V) → TCLA [W]

IR7: Betatron cleaning

- 3 primary (H,V,S)
- 11 secondary (H,V,S)
- 5 shower abs. (H,V)
- 3 beam scrapers (H,V,S)

Local cleaning at triplets

- 8 tertiary (2 per IP) → TCT [W]

Physics debris absorbers [Cu]

- 2 TCLP's (IP1/IP5)

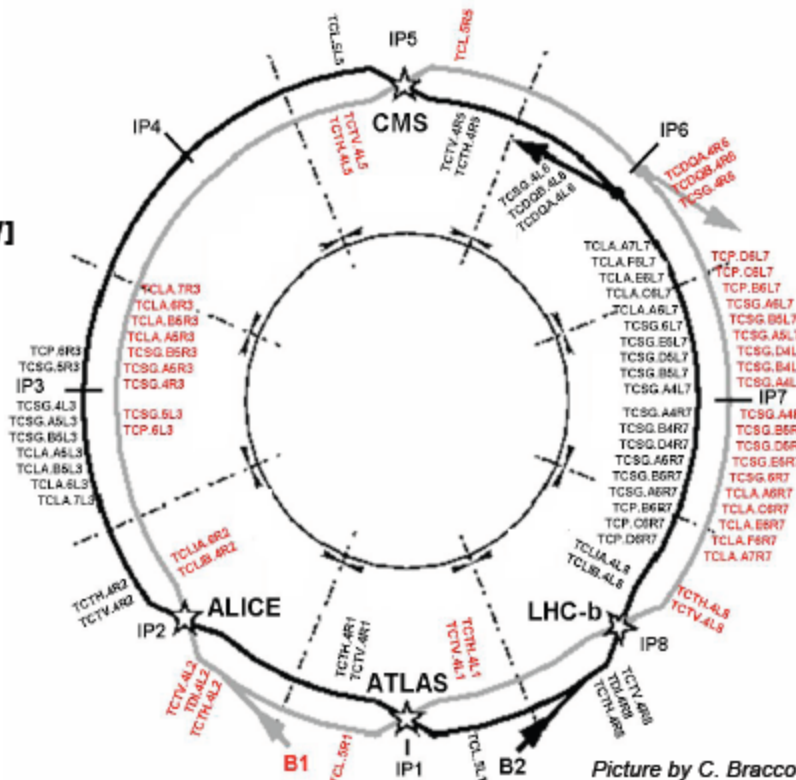
Protection (injection/dump)

- 10 elements → TCLI/TCDQ [C]

Transfer lines

- 13 collimators → TCDI [C]

Passive absorbers for warm magnets



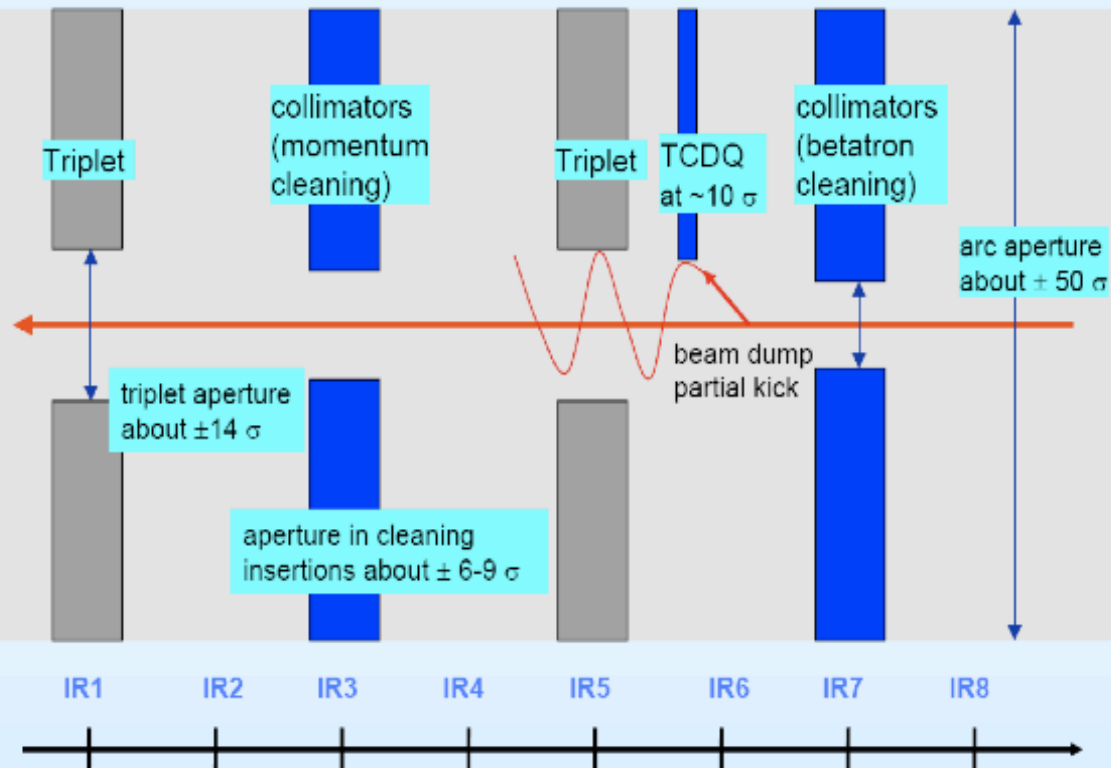
**41 movable ring
collimators per beam!**



Energy Stored in the Beams: Collimation System

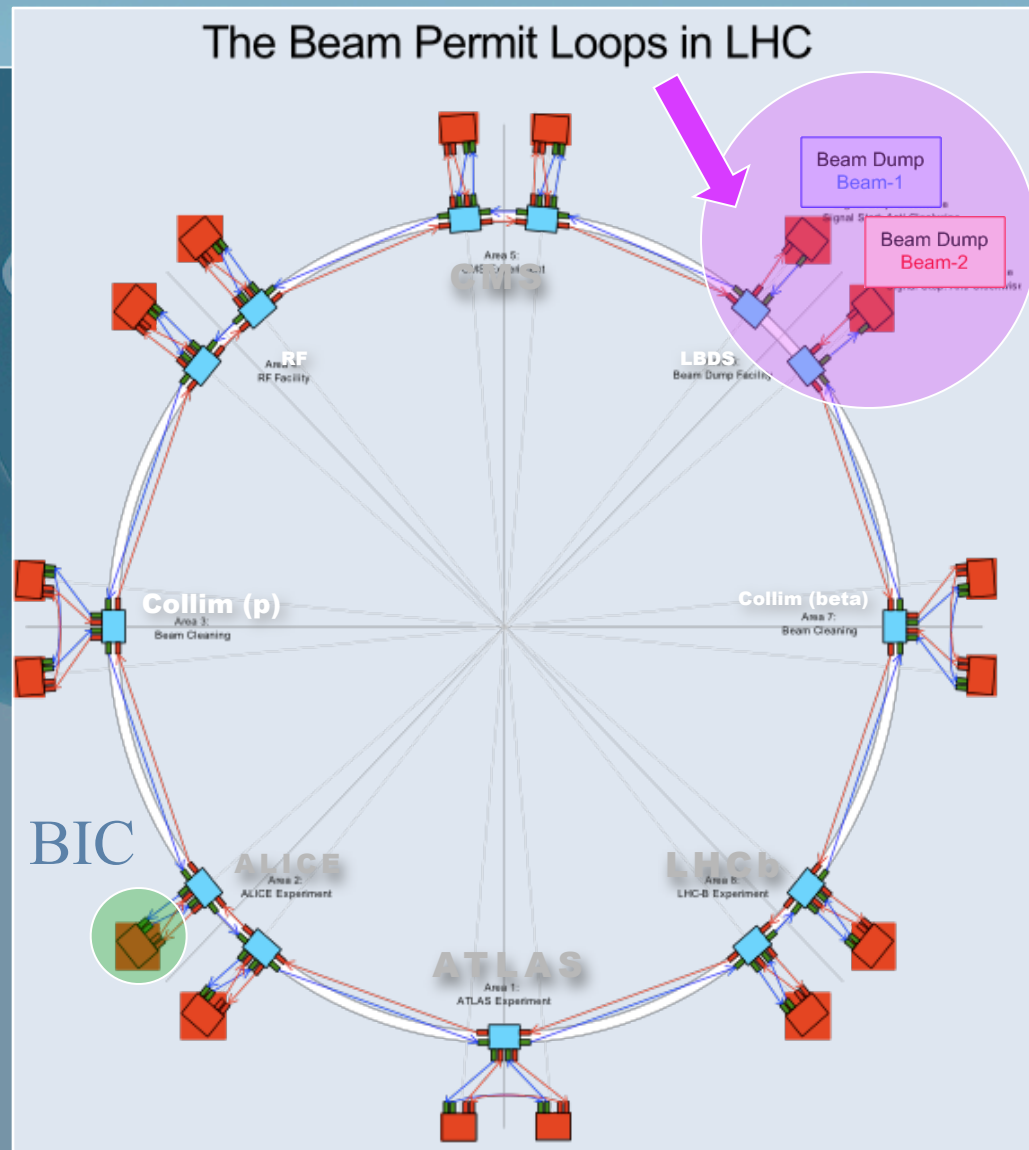
Critical apertures around the LHC

(in units of beam size σ) 7 TeV and $\beta^* = 0.5$ m in IR1 and IR5





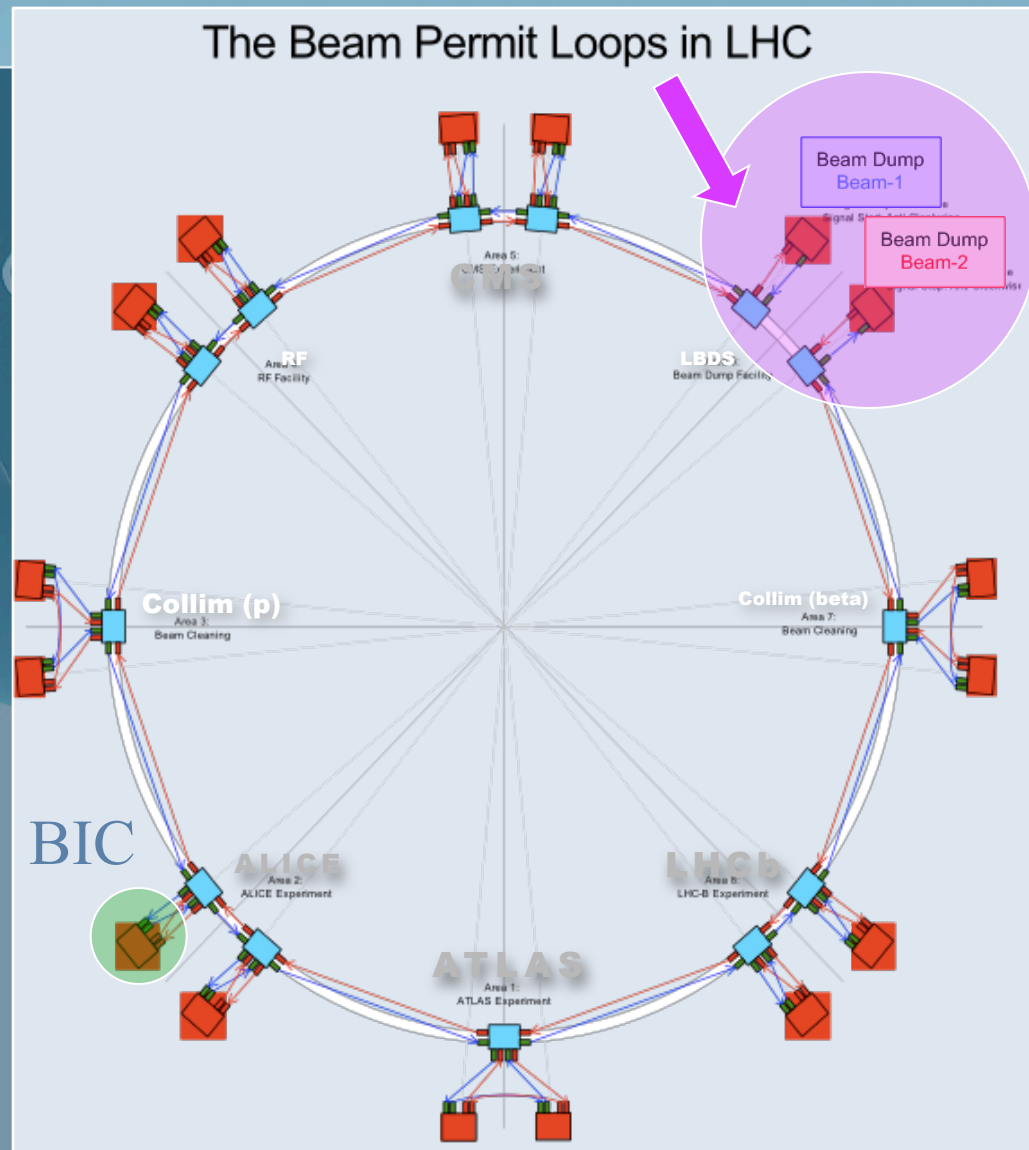
Machine Protection System:





Machine Protection System:

4 fibre-optic channels from IP6
1 clockwise & 1 anticlockwise for
each Beam



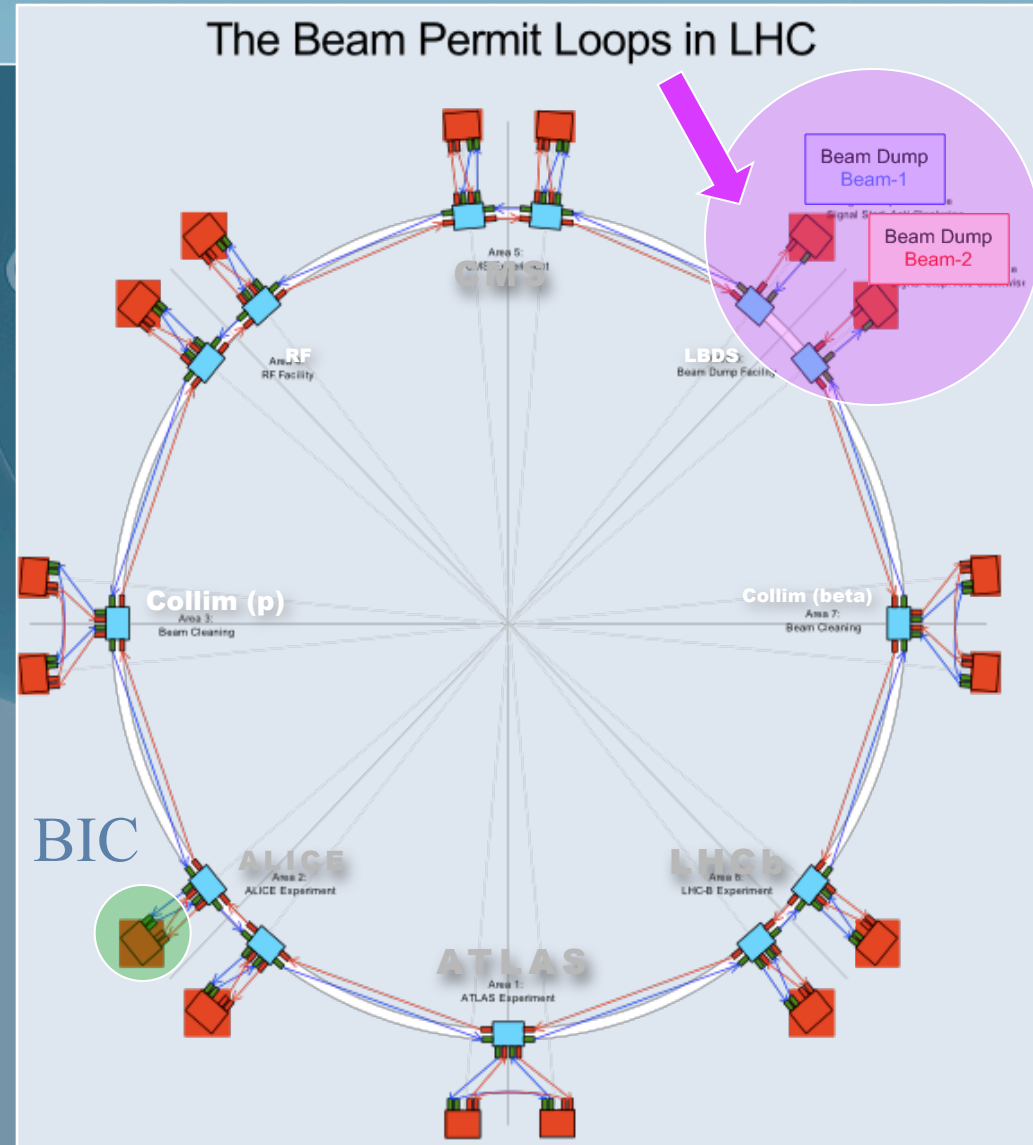


Machine Protection System:

4 fibre-optic channels from IP6
1 clockwise & 1 anticlockwise for
each Beam

10MHz Square wave generated at
IP6

-Signal can be cut by any
Controller





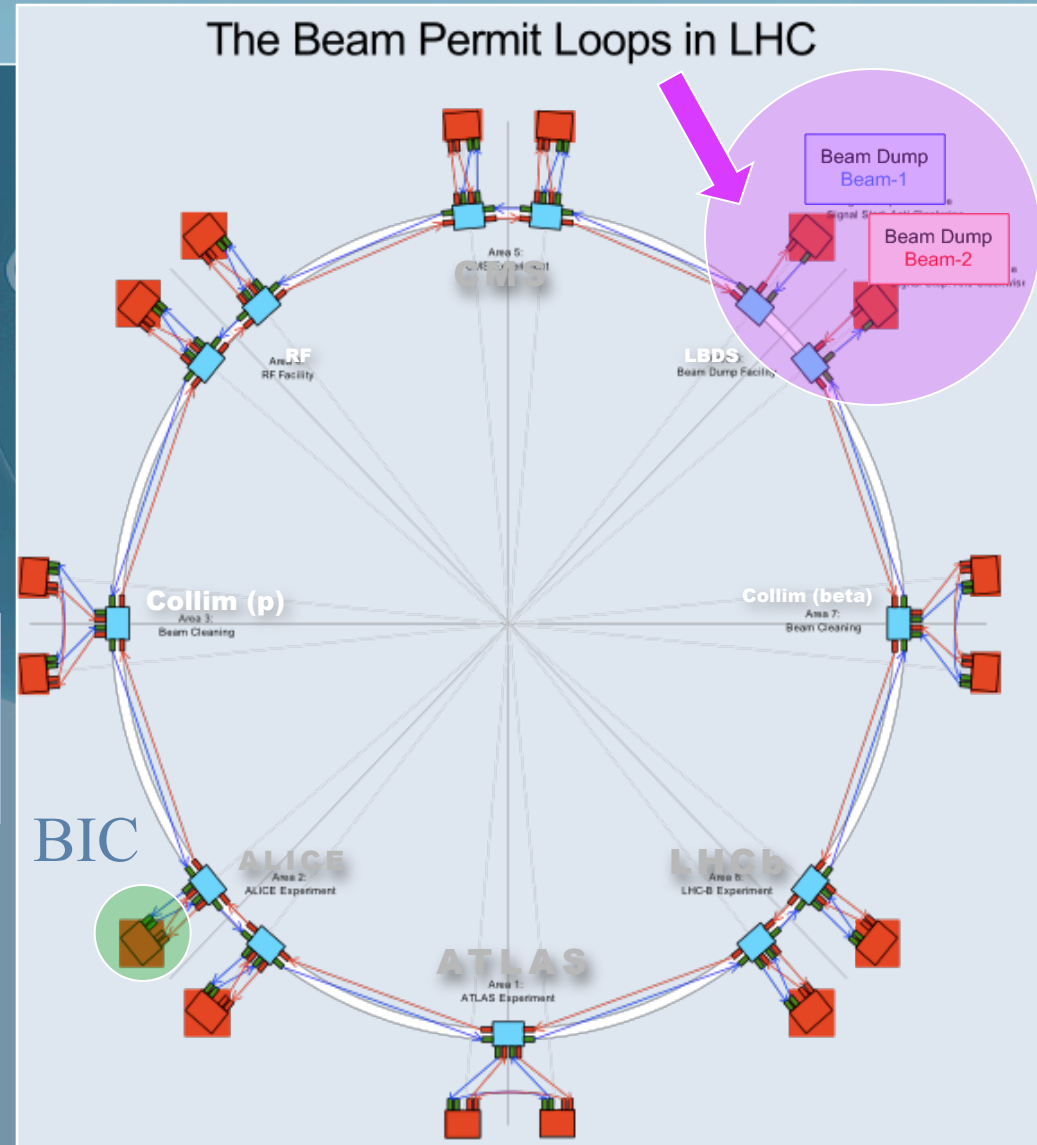
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When any of the four 10MHz
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→ BEAM DUMP!





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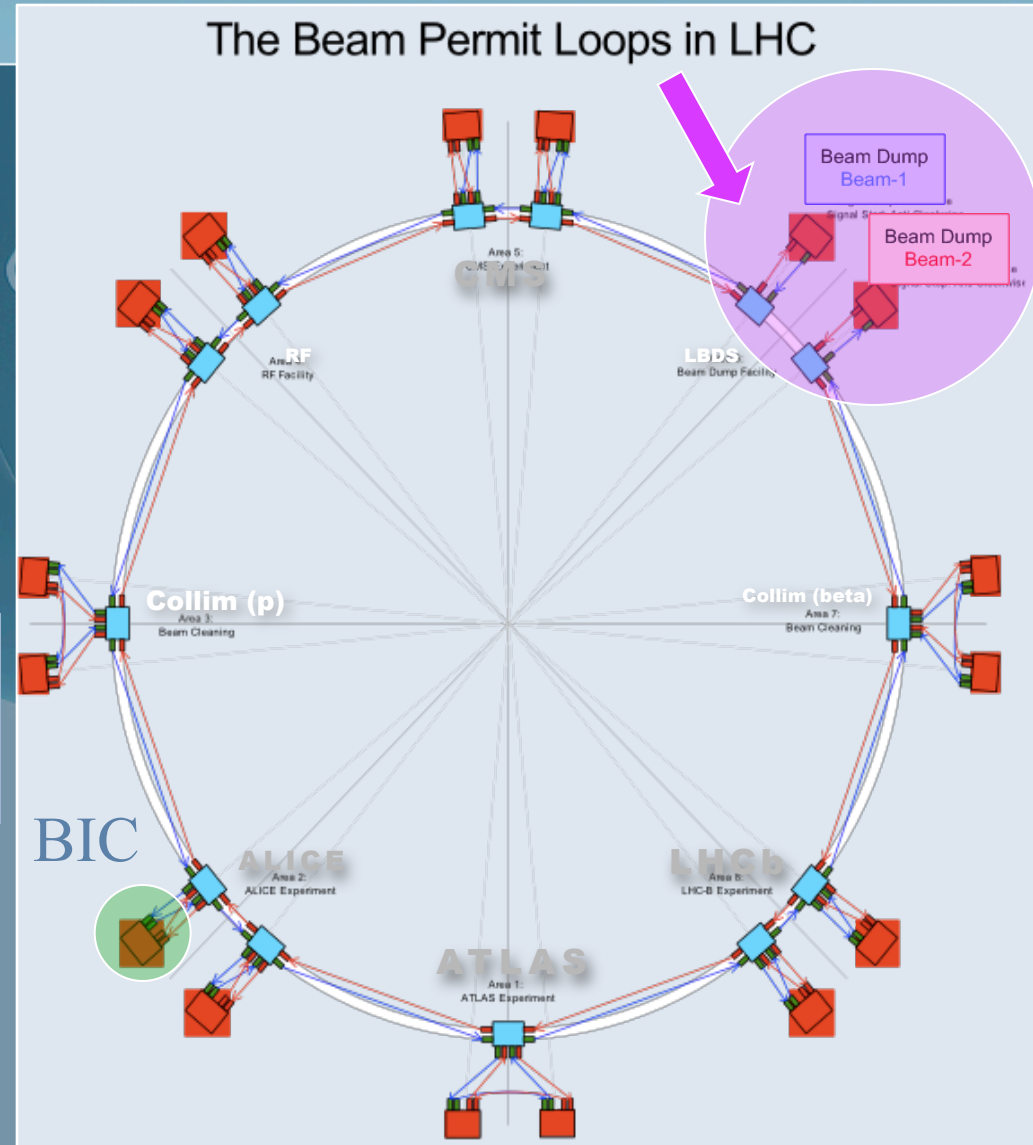
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16 BICs per beam
- Two at each Insertion Point





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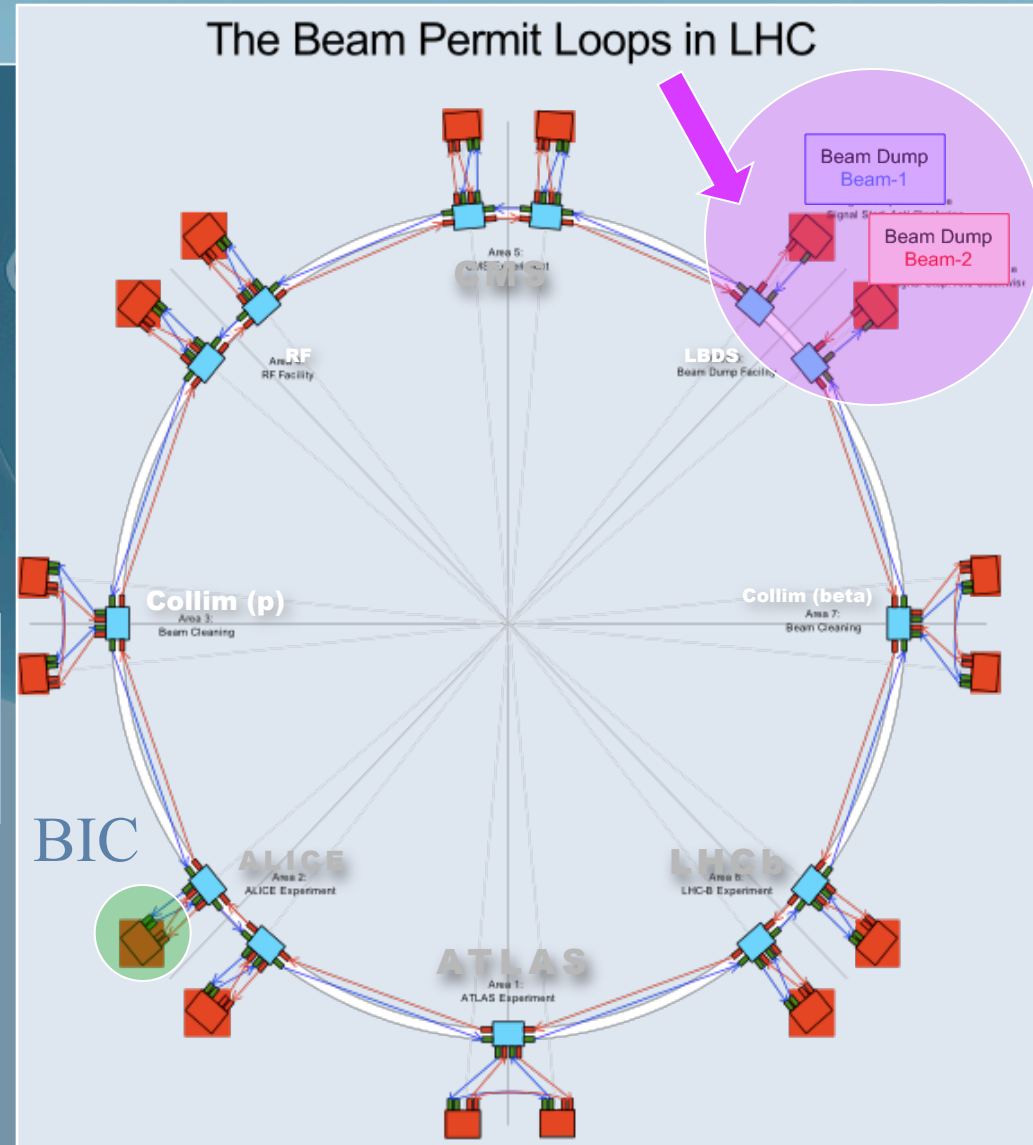
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Up to 20 User Systems/BIC





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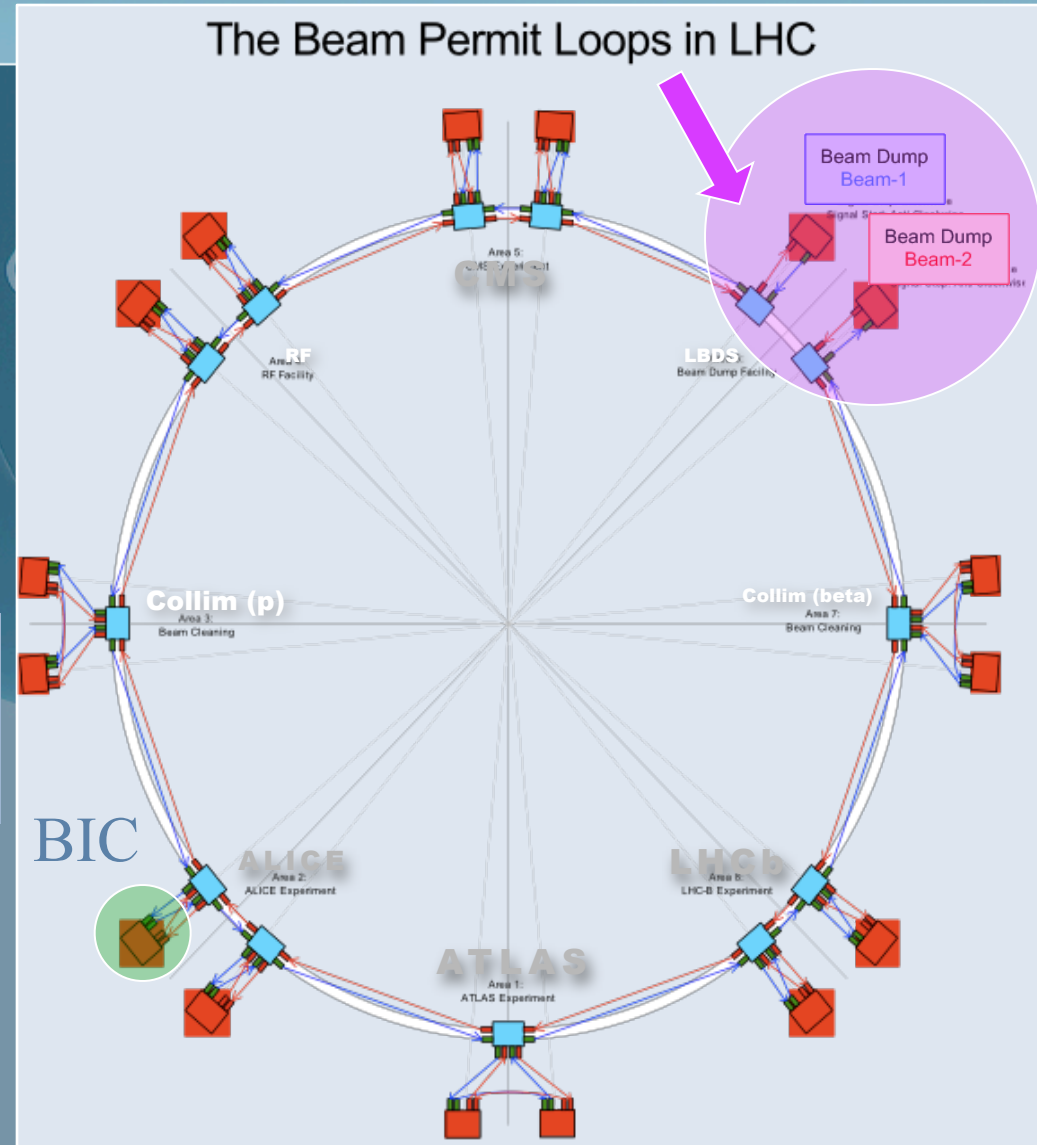
When any of the four 10MHz
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B1 / B2 are Independent!

16 BICs per beam

- Two at each Insertion Point

Up to 20 User Systems/BIC





Phase A.2: Circulating pilot





Phase A.2: Circulating pilot

Objectives:

- Establish closed orbit
- Commissioning of additional instrumentation: BPM intensity acquisition
- Preliminary orbit, tune, coupling and chromaticity adjustments
- Obtaining circulating beam (**few hundred turns at least**)
- SPS-LHC energy matching
- Commissioning of RF capture



Phase A.3: 450 GeV initial commissioning

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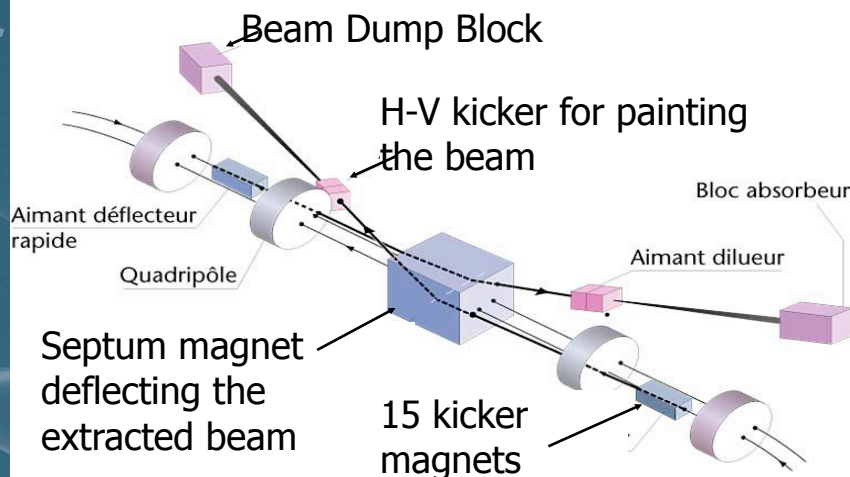


Phase A.3: 450 GeV initial commissioning

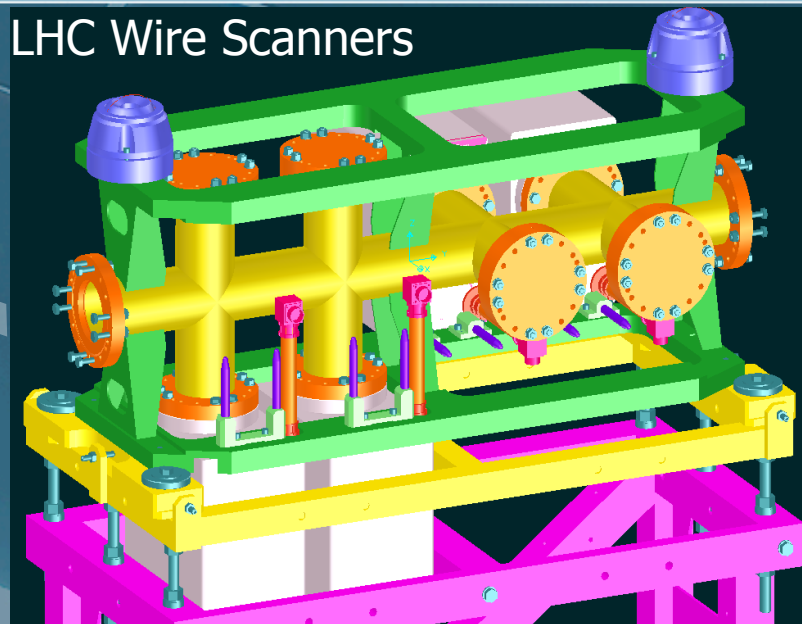
Objectives:

- Commissioning of BI (BWS, BSRT, BCT, BGI, Q, Q', BLM, BPM)
- Improving lifetime
- First optics checks
- **First commissioning of the Dump System**

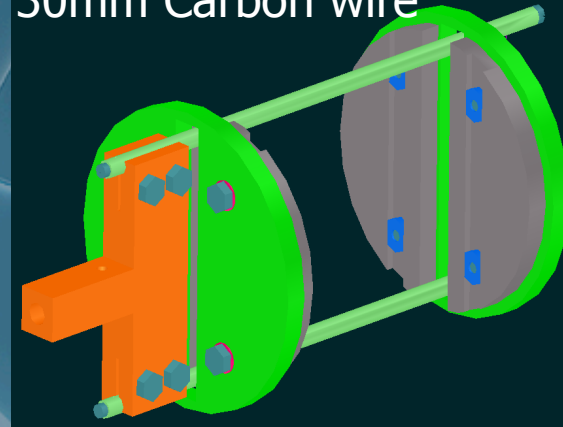
Configuration du système d'arrêt de faisceau au Point 6



LHC Wire Scanners



30mm Carbon wire





Phase A.5: 450 GeV increasing intensity





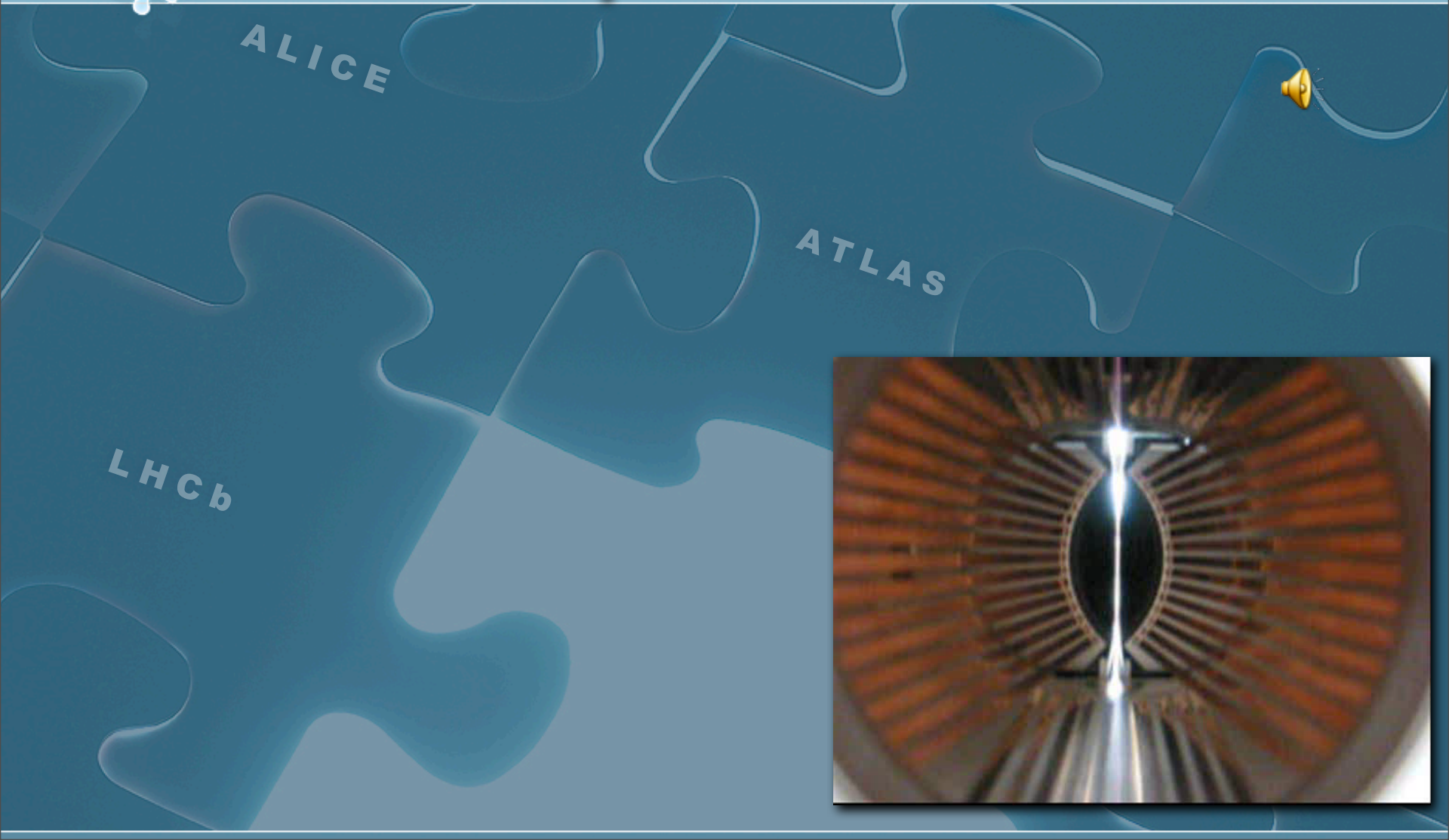
Phase A.5: 450 GeV increasing intensity

Objectives:

- Safe machine operation with up to 1.4×10^{13} p+ at 450 GeV
- Multi-bunch injection commissioned up to $16 \times 9 \times 10^{10}$ p+ and well tuned, including cleaning and protection
- **LHC BIS fully commissioned**
- **Commissioning of the Beam Dump System up to 1.4×10^{13} p+ at injection energy**
- **Collimators set-up for operation up to 1.4×10^{13} p+ at injection energy, in particular, BLM loss pattern established**
- **Improved definition of thresholds for the BLMs**
- Beam instrumentation operational with up to 156 bunches and total intensity of up to 1.4×10^{13} p+
- RF adjusted for injection and circulating multi bunch operation



Phase A.6: Two beam operation





Phase A.6: Two beam operation

Objectives:

- Establish two safely circulating (unsafe) beams with a lifetime of 5 to 10 hours. Separation bumps fully commissioned
- Aperture in triplet and IR verified for both beams
- Interleaved injection working
- Two beam collimation commissioned





Phase A.8: Snap-back & Ramp

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Phase A.8: Snap-back & Ramp

Objectives:

- Single beam through snap-back, checking the key instrumentation and control of the key beam parameters: orbit, tune, coupling, chromaticity
- Stop in ramp and then push on in steps ($\Delta E \sim 1$ TeV) → **commission beam dump and machine protection along the ramp**. Beam based checks would also be possible at these intermediate energies
- Single beam to 7 TeV
- Repeat the process for the other beam
- Repeat the process with both beams at the same time

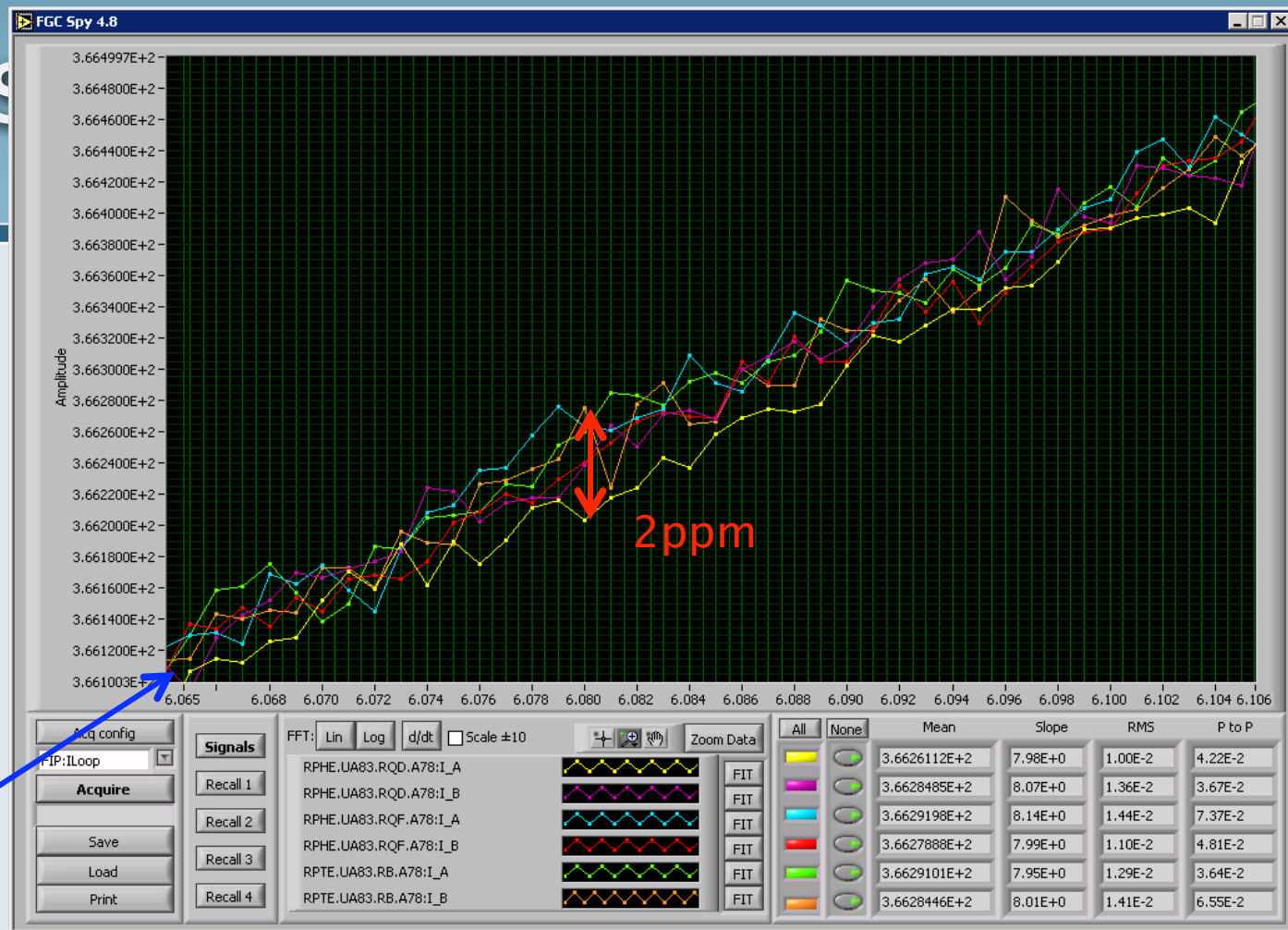


Phase A.8: Snap-back & Ramp





Phase





Phase A.8: Snap-back & Ramp





Phase A.8: Snap-back & Ramp



The magnetic field (the current) in a magnet decays when the current is kept constant, like for example during the injection phase in LHC.

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Phase A.8: Snap-back & Ramp

- The magnetic field (the current) in a magnet decays when the current is kept constant, like for example during the injection phase in LHC.
- The decay of the current gets manifested as a:

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Phase A.8: Snap-back & Ramp

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 - DECAY of the multiple errors seen by the beam at constant current;

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Phase A.8: Snap-back & Ramp

- The magnetic field (the current) in a magnet decays when the current is kept constant, like for example during the injection phase in LHC.
- The decay of the current gets manifested as a:
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 - Fast recovery (SNAP-BACK) when the current is varied again.



Phase A.8: Snap-back & Ramp

- The magnetic field (the current) in a magnet decays when the current is kept constant, like for example during the injection phase in LHC.
- The decay of the current gets manifested as a:
 - DECAY of the multiple errors seen by the beam at constant current;
 - Fast recovery (SNAP-BACK) when the current is varied again.
 - The source of this effect is mainly the Eddy currents flowing in the superconducting cables.



Phase A.9: Top energy checks

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Phase A.9: Top energy checks

Objectives:

- Measure and correct the optics at 7 TeV before colliding/squeezing beams: orbit, tunes, coupling, chromaticity and beta beat
- Transition from injection optics to un-squeezed collision optics
- Aperture measurements at 7 TeV
- Disentangling of triplet alignment errors and D1/D2 transfer function errors; set good conditions for squeeze
- Optimization of beam lifetime
- Optimization of the Beam Dump System before we start collisions or squeeze, and before we increase intensity



Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze

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Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze



Phase A.10 objectives:

- Get beams into collisions at top energy
- Optimize integrated luminosity with relative luminosity as the main performance parameter
- Keep background low and stable without spikes
- Provide a rough knowledge of the absolute luminosity from beam parameters (beam intensities and sizes)

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Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze

Phase A.10 objectives:

- Get beams into collisions at top energy
- Optimize integrated luminosity with relative luminosity as the main performance parameter
- Keep background low and stable without spikes
- Provide a rough knowledge of the absolute luminosity from beam parameters (beam intensities and sizes)

Phase A.11 objectives:

- Commission the squeeze without crossing in IP1 and IP5 at 7 TeV; goal for this phase is $\beta^*=2\text{m}$
- Squeeze of IP8 for LHCb operation with reduced beam intensities ($\beta^*=2\text{m}$)
- **Setup of the required protection**, in particular, commissioning of the **tertiary collimators**, i.e., collimators to protect the experiments

Phase A.10: Top energy collisions

Phase A.11: Top energy squeeze

ARC+ML6+LR5 (156 PCs) @ 5 TeV

