HL-LHC Project Report to the C-MAC

Showing material from all HL-LHC Work Package Leaders

and Collaborators!

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

HL-LHC Project Overview and main Goals:

- Prepare the LHC for a total luminosity of ≈ 3000 fb^{-1}
  - ➔ Radiation and R2E
    - #Shielding and removing equipment from the tunnel
    - (Superconducting link and cold powering)
  - ➔ Radiation hardness of magnets (lifetime)
    - #e.g. triplet and cleaning insertions
  - ➔ Cryogenic and Cooling
- System Upgrades for allowing a peak Luminosity of

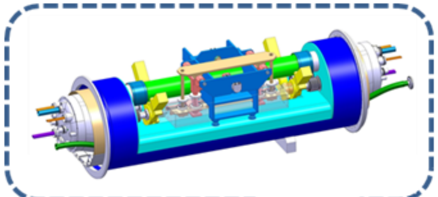
$$L \geq 5\ 10^{34}\ cm^{-2}\ s^{-1}$$

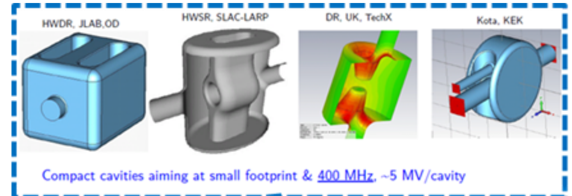
- Consolidation activity for assuring running of the LHC up into mid 2030ies with up to 3000fb^{-1}

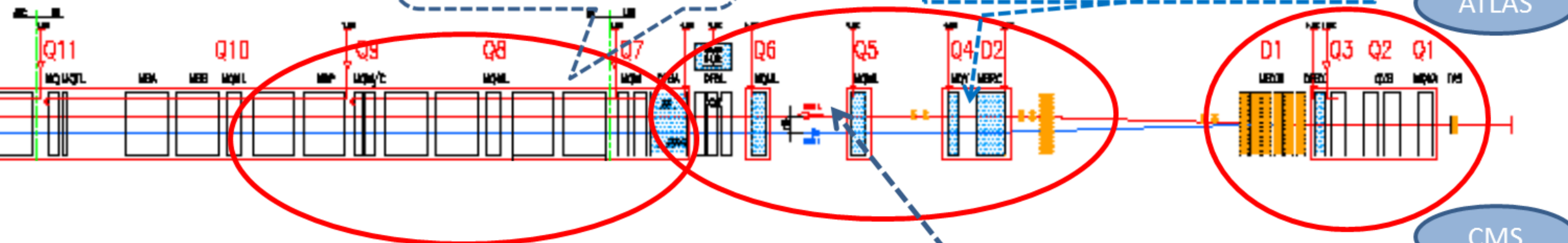
High Luminosity LHC

Changing 300x2 m both ATLAS & CMS

(recent requests from LHC-b & Alice to be examined)



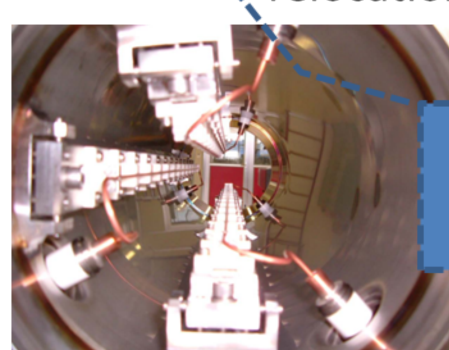




3. For collimation we need to change also this part, DS in the continuous cryostat

2. Deep change also matching section: Magnets, collimators and CC

1. Deep change in the IRs and interface to detectors; relocation of Power Supply

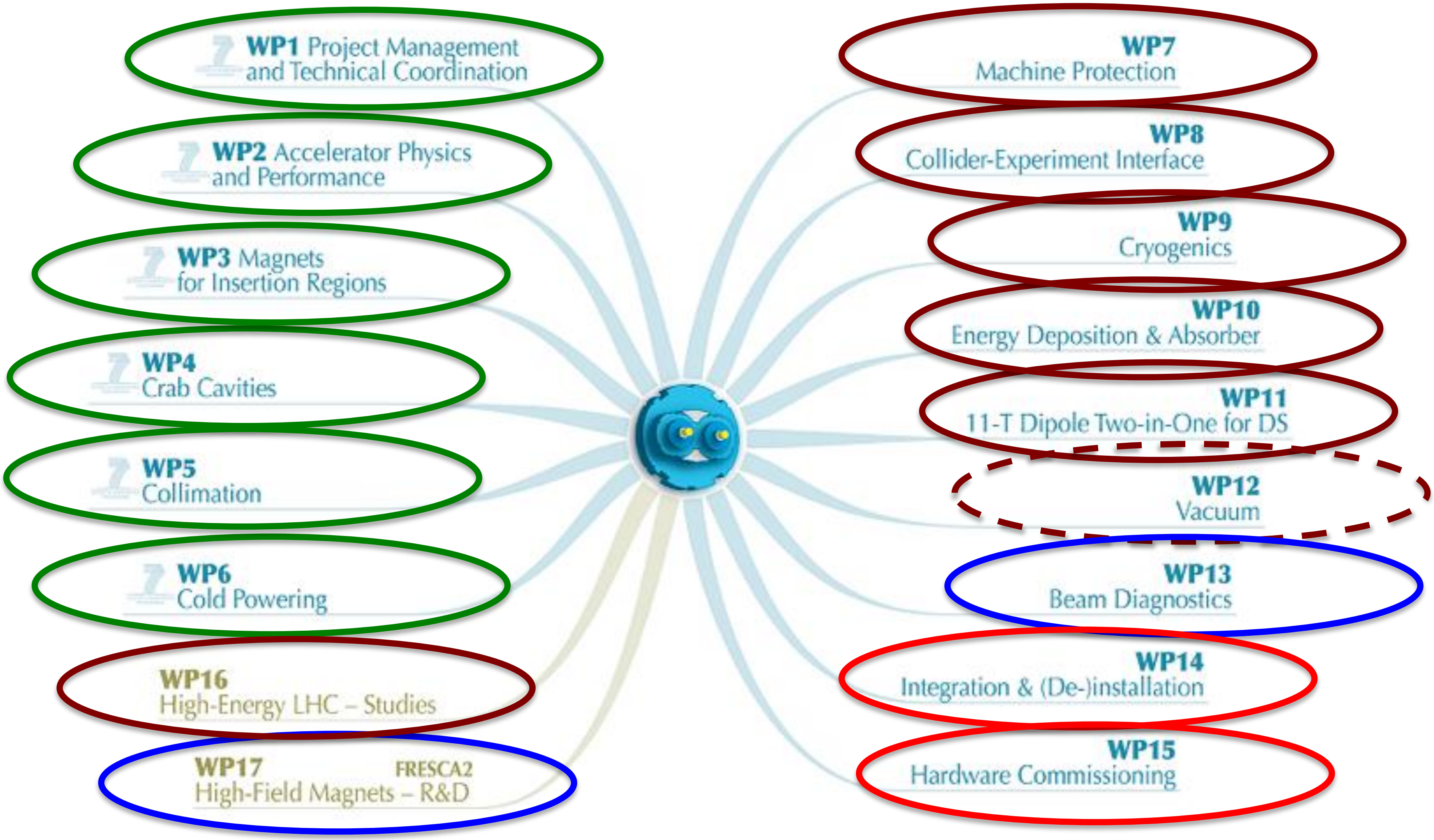


4. LR BB compensation wires

In total > 1.2 km of LHC for all IRs!!

High Luminosity LHC

HL-LHC Structure



High Luminosity LHC

HL-LHC Committees and Regular Meetings

- Steering Committee → WP leaders and deputies

  Including international partners

- HL-LHC Coordination Group → assure coordination among the various entities (HL-LHC Project, Experiments & CERN management):

- Parameter & Layout Committee → most WP leaders and technical groups; approval of key parameters and installations

- HL-Technical Committee: define the technical baseline of the project, asses the various technical systems proposed for the upgrade

HL-LHC Coordination Group (4)

- Coordination of Upgrade and Consolidation Plans (experiments & LIU & LHC) ✔
- Pile-up definition and limitations ✔
- Importance of luminous region size (length) and concept of 'pileup density'→ need for β^* leveling and full crab compensation at start of run ✔
- Preparation for the European Strategy Meeting ✔

High Luminosity LHC

HL-LHC PLC (4)

- Maintain coherent set of parameters and layout (3d):
  - -Goal of reviewing main HL IRs by summer
  - -Establish EDMS data base structure

- Parameters agreed with Coordination Group Meeting:
  - -maximum of 140 events per crossing
    - ➔ $L = 5\ 10^{34}\ cm^{-2}\ sec^{-1}$ for 25ns
    - ➔ $L = 2.5\ 10^{34}\ cm^{-2}\ sec^{-1}$ for 50ns
  - Pile-up density leveling
    - ➔ Leveling options (β^*)?
  - -goal for integrated annual luminosity:
    - ➔ 250 fb^{-1} per year
  - -Total luminosity for HL-LHC project
    - ➔ 3000 fb^{-1} total

Main topics of first HLTC meetings (4):

- Mandate and composition ✔
- Project and Work package Breakdown Structure ✔
- Beam-Beam Long Range Wire Compensation ✔
- Halo removal via hollow electron lens ✔
- Cryogenics overall plans for the HL-LHC ✔
- Remote Manipulations and Diagnostics in radioactive areas

WP2-Accelerator Physics and Performance

Stephane Fartoukh

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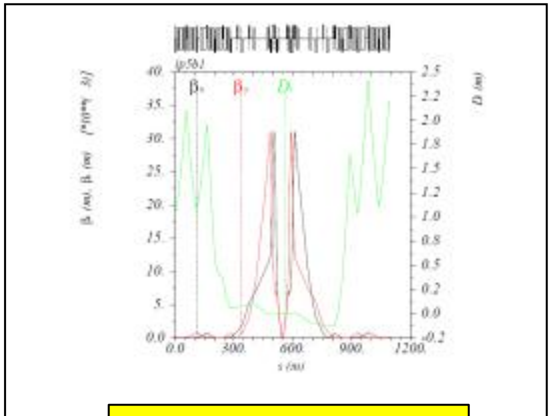
Optics & Layout

- ATS (Achromatic Telescopic Squeeze) established as baseline, including LHCb desiderata for the **new 150mm-140 T/m Nb3Sn inner triplet**

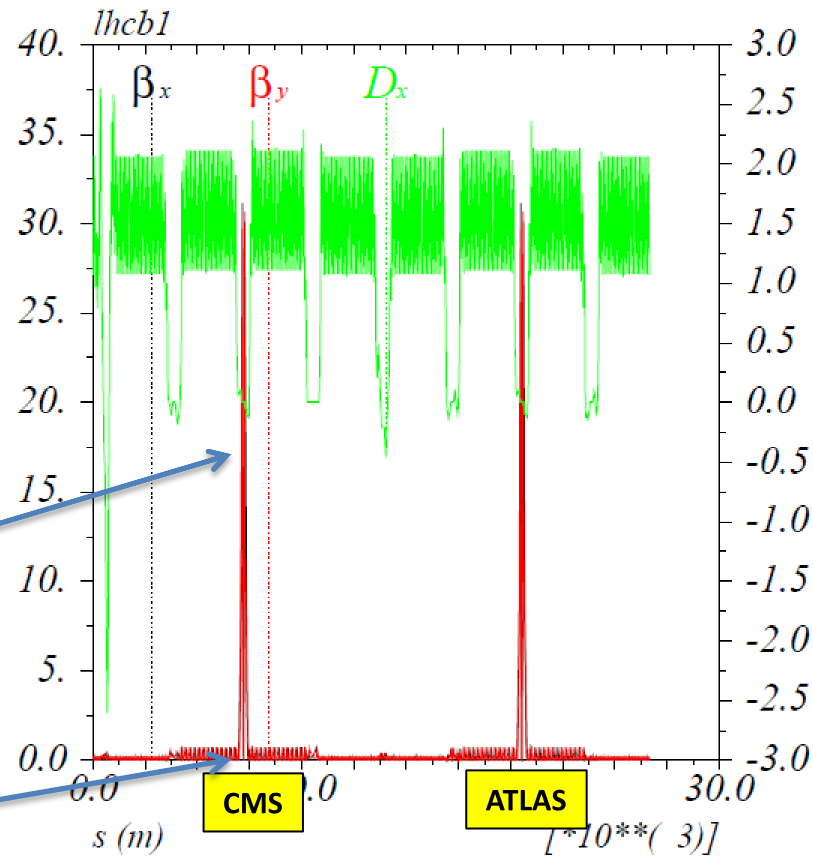
→ β^* **~10 cm** reached in MDs: CERN-ATS-2013-004 MD



ATLAS & CMS: β^*=10 cm

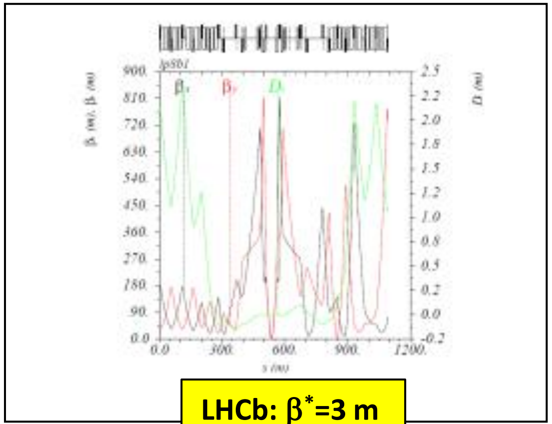
β_{max}~ 25 km !

β_{arc}~ 800 m!

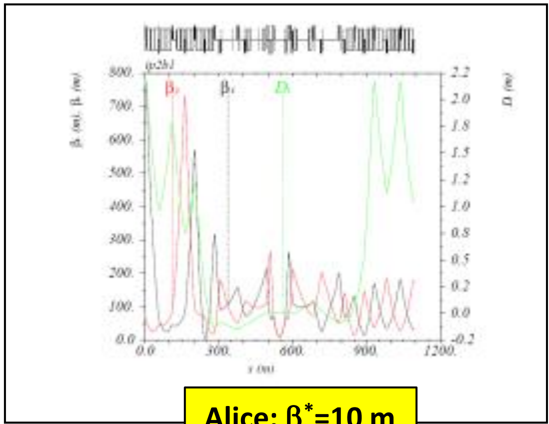


CMS

ATLAS



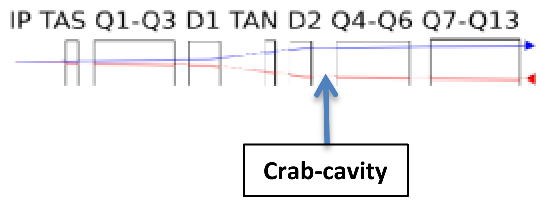
LHCb: β^*=3 m



Alice: β^*=10 m

High Luminosity LHC

Optics & Layout (3/4)



- The main HL-LHC magnet shopping list (excluding corrector)

Equipment to be changed	New (old) Aperture [mm]	Separation [mm] (for 2-in-1)	Performance (T/m, T.m, MV,...)
TAS	60 (34)	n/a	n/a
IT	150 (70)	n/a	140 T/m
D1	160 (80)	n/a	40 T.m
TAN	82/74 elliptical (52/52)	145	n/a
D2	105 (80)	186	40 T.m
Crab-cavity	80	194	**12.5 MV**[1] (per beam and IR side)
Q4	90 (70)	194	400→ 500 T/m×m
Q5	70 (56)	194	750 T/m×m

[1]: **For a full crabbing at β^*=15 cm with 590 μrad crossing angle**. Doubling Q7 might reduce by 30-40% the demand on the CC voltage (with higher β at Q4) but the feasibility and impact studies are still on-going.

Pile-up, leveling and beam-beam (1/2)

- Guidelines from the experiments:

140 pile up events (in average) per bunch crossing, **over a luminous region of ~5 cm r.m.s.**

→ **Leveling with β^* becomes the preferred option**

but leading to a b-b tune shift of up to ΔQ_{bb}=0.033

for 3 experiments (IR1, IR5 & IR8) running with a zero (IR1&IR5 with full crabbing) or very small (IR8) Piwinsky angle.

High Luminosity LHC

WP3-Magnets for Insertion Regions

Ezio Todesco

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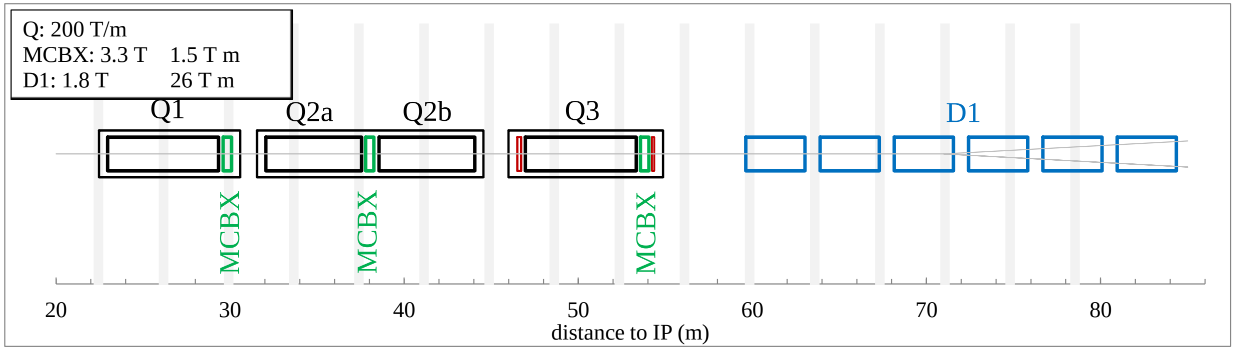
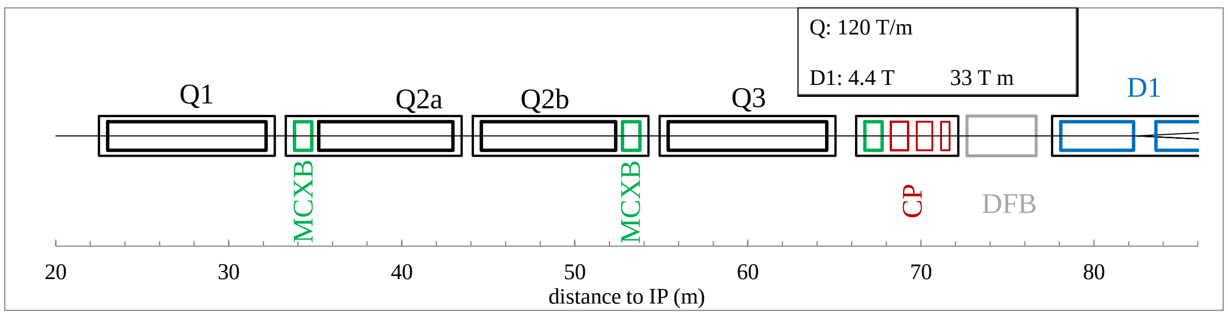
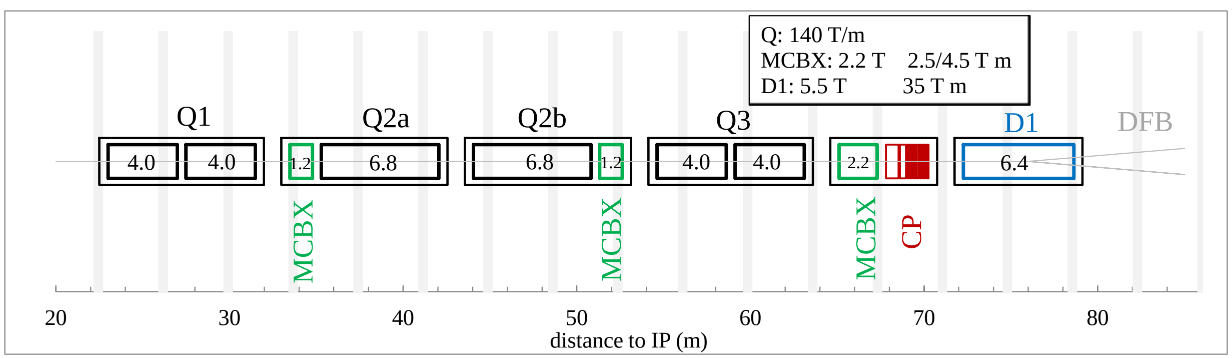
We are close to define a lay out of the insertion



LHC



Phase I

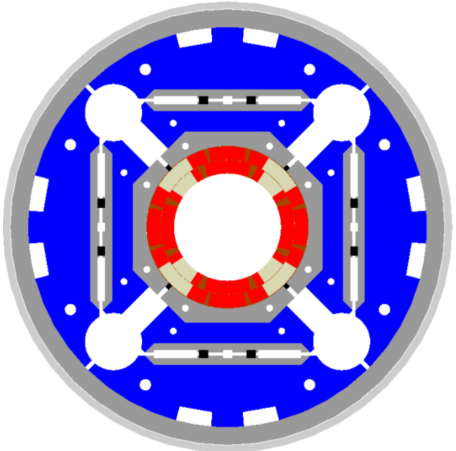


HL LHC

Limits to Hot Spot Temperature

- Larger shielding has pushed us to choose 150 mm aperture to preserve performance

- Main design features of the magnets are being selected
  - Quadrupole design relies on LARP HQ model with 120 mm aperture
  - Nb-Ti technology for other main magnets
  - Superferric technology for high order correctors



Cross-section of the triplet
[G. Ambrosio, P. Ferracin]

- Most urgent deadlines (2013)
  - A layout up to Q4 to have radiation damage and heat loads in correctors, separation dipoles and Q4
  - Having a baseline for powering, cooling and integration
  - Finalize the choice of cable and cross-sections

WP4-Crab Cavities

Erk Jensen & Rama Calaga

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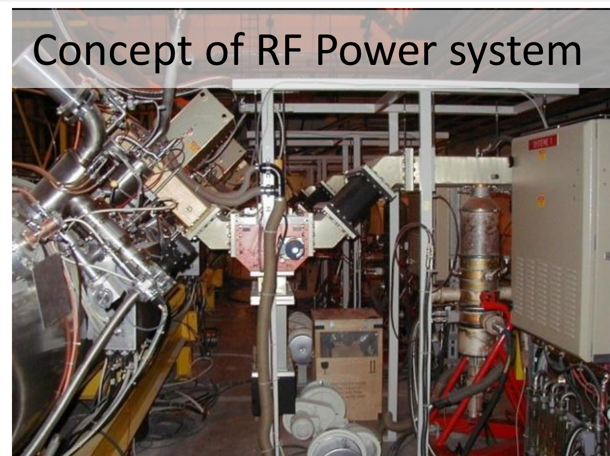
3 Crab Cavity prototypes:


RF-Dipole Nb prototype [ODU-SLAC]

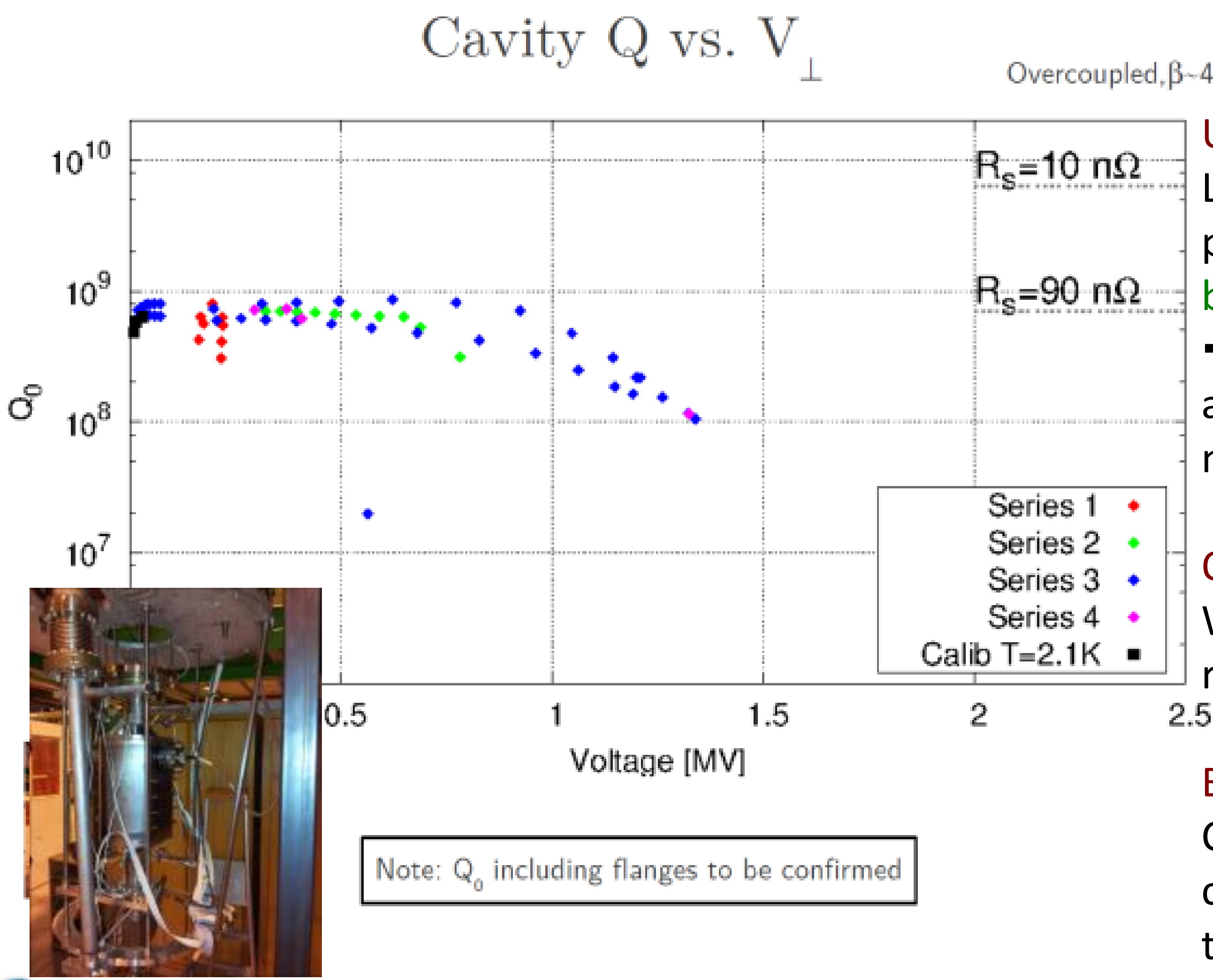

DQWR prototype (17-Jan-2013) [BNL]


4-rod in SM18 for RF measurements [Lancaster UK]


4-rod prepared for rinsing @ CERN


Concept of RF Power system

4-rod tests took place Nov 22-23, 2012



Note: Q_0 including flanges to be confirmed

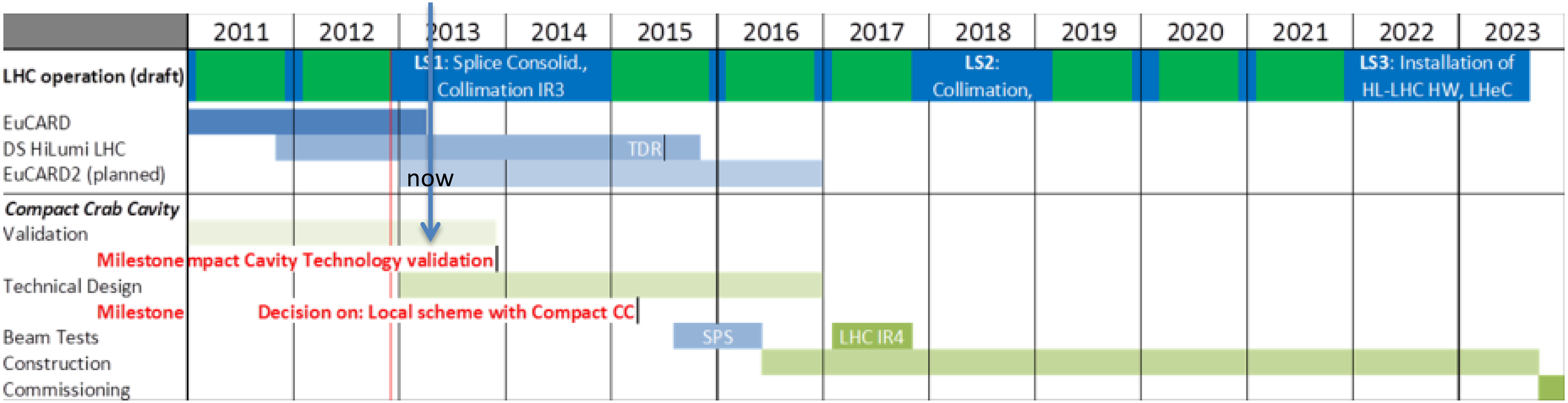
UK 4-Rod:
Limited processing (BCP only), problems with vacuum leak, but got first measurements!
➔ repair, surface chemistry and water rinse in March, next cold test in SM18 in April

ODU RF-Dipole:
Waiting for JLab facility ➔ results foreseen by March

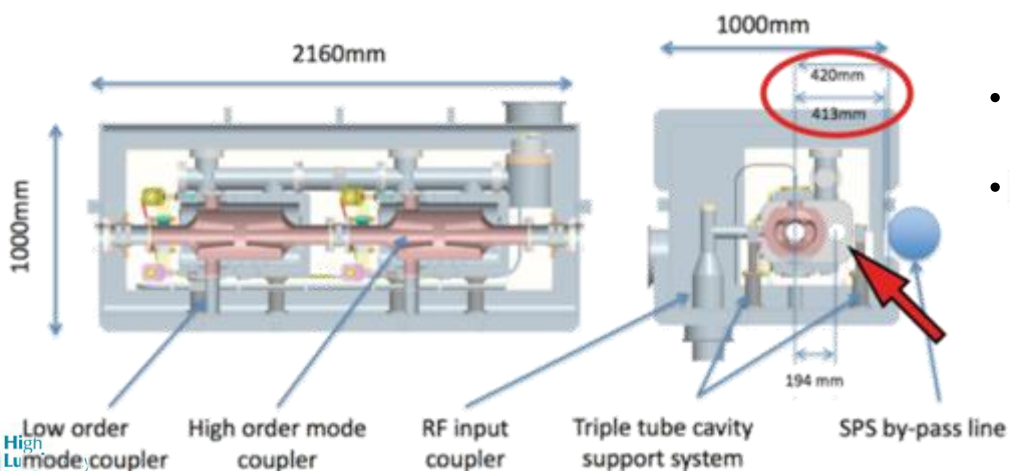
BNL ¼ wave:
Chemistry treatment completed, rinse by March, tests by April ➔ cavity shipped to CERN by summer

Crab Cavities - summary

- Overall time-line



- Preparation of SPS test progressing:



- Engineering meeting took place at FNAL in Dec (https://cds.cern.ch/record/1517047)
- Working group under A. Macpherson "Crab Cavity Technical Coordination" coordinates SPS tests (https://indico.cern.ch/categoryDisplay.py?categId=4482)

High Luminosity LHC

WP5-IR Collimation

LHC Collimation Project CERN

Stefano Redaelli for the LHC Collimation Project team

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Main Achievements

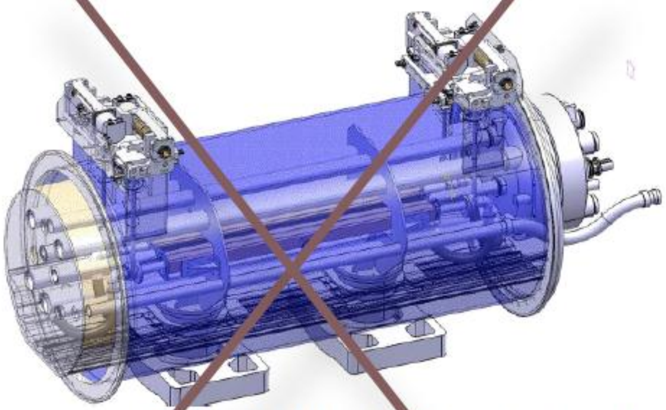
- Set up simulations of multi-turn cleaning and physics debris for HL-LHC optics layouts (ATS)
- Define upgrade strategy for the physics debris absorption in IR1 and IR5 in LS1, in collaboration with WP10 (TCL layouts)
- Strong participation to beam studies at the LHC, to prepare well the future upgrades
  - Settings and hierarchy limits, impedance measurements, quench tests, halo diffusion measurements, TCL cleaning in IR1/5…
- Study limitations for ion operation, for ALICE luminosity upgrade.
- Development and design for the dispersion suppressor collimation
- Advanced collimation concepts: hollow e-lens, crystal experiments
- Development and be new collimator materials

Organizing a project review at the end of May 2013 to finalize project priorities and upgrade strategy

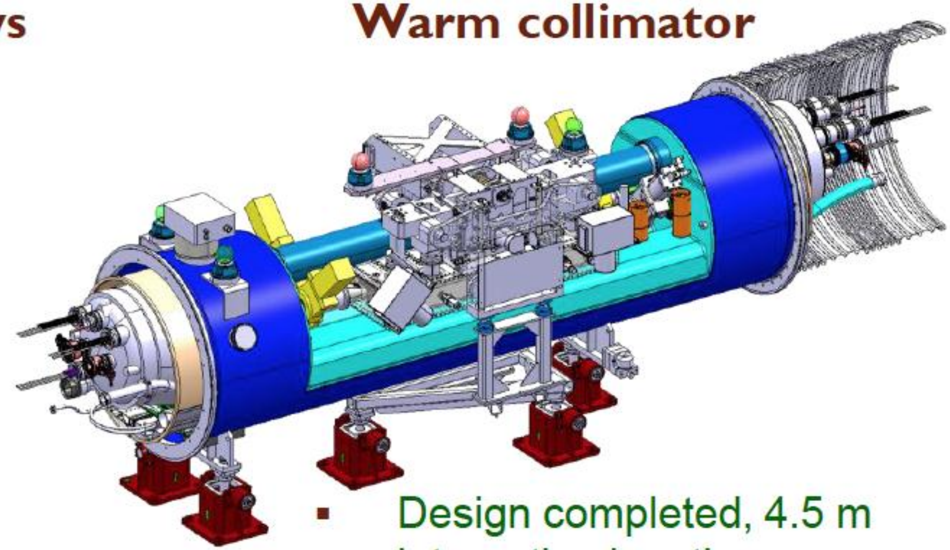
High Luminosity LHC

Technology choice for the DS collimator

Cold collimator vs **Warm collimator**



- ~~Potentially shorter but not feasible within schedule~~
- ~~Many open issues, possible showstoppers~~



- Design completed, 4.5 m integration length
- Prototyping of collimator actuation and cryostat

Work of the Cold Collimator Feasibility Study team: concluded that the “warm” DS collimator with a by-pass cryostat is the best solution for the LHC.

R&D on cold collimation design will continue (EuCARD)

Prototyping of cryogenics bypass

Continued the prototyping of the by-pass crystostat (QTC) for the installation of a warm collimator in the cold dispersion suppressors (EN-MME, TE-MSC).

WP6-Cold Powering

Amalia Ballarino

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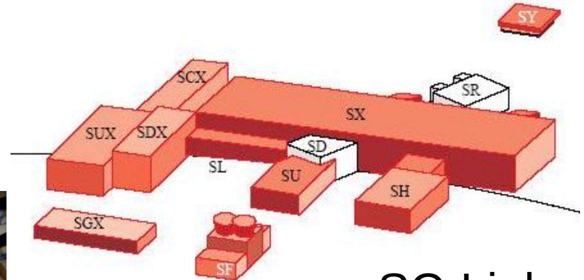
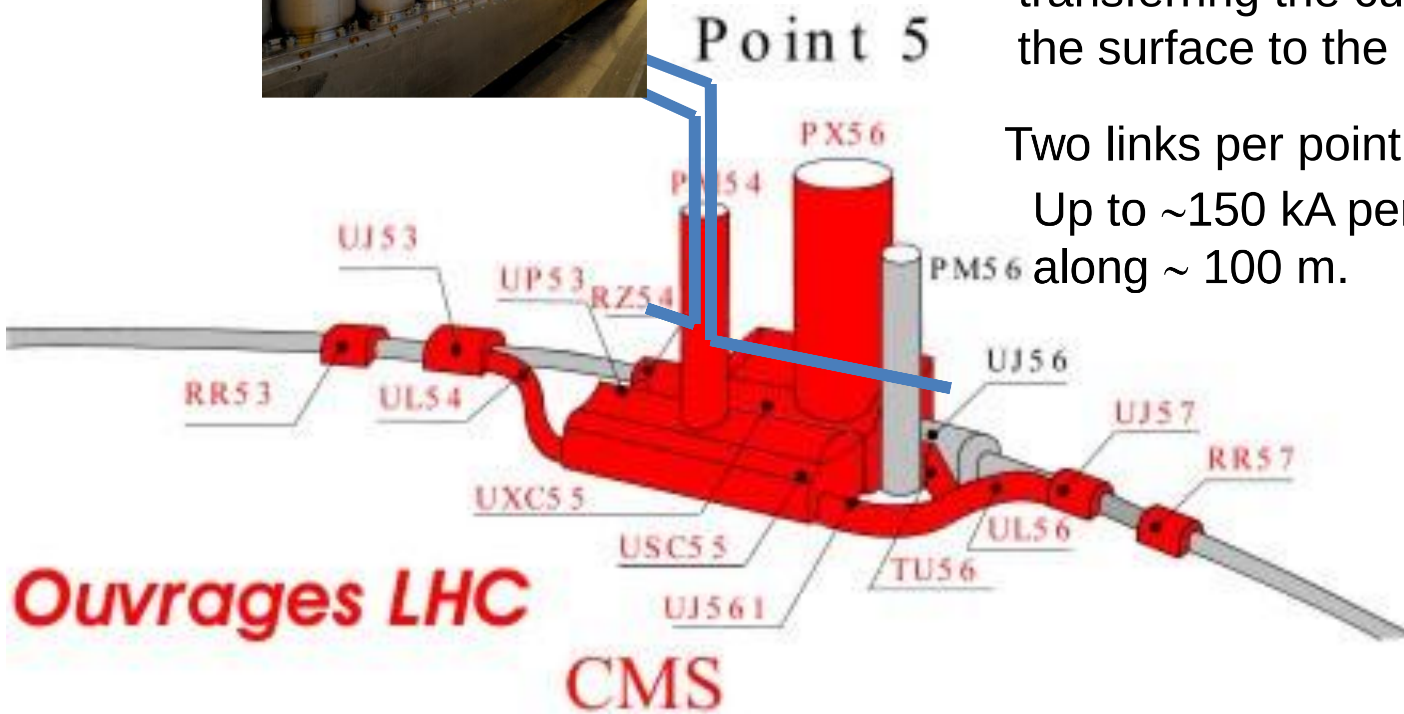
LHC P1 and P5



SC-Links with cables made from novel High-Temperature Superconductors transferring the current from the surface to the magnets in the tunnel

Two links per point each about 300 m long

Up to ~150 kA per link. Vertical transfer along ~ 100 m.



High Luminosity LHC

Main Achievements

- New development of **MgB_2 wires** in close collaboration between CERN and Columbus Superconductors. Successful test at CERN in July 2012 of first Powder In Tube **MgB_2 round wire** with homogeneous superconducting properties.

MgB_2: low-cost novel superconductor with a critical temperature (39 K) sufficiently high to enable safe operation in He gas with generous temperature margin ($\sim$ 10 K).

High Luminosity LHC

Main Achievements

- Conceptual study, design and commissioning at CERN of a test station enabling full characterization of **20 m-long SC-Links** operated in He gas, in a **variable temperature range**, at currents of up to 20 kA (as proposed for the final system).

- Elaboration of a) **powering layouts** for MQXF quadrupoles and of b) **cryogenic cooling options** for the cold powering system.

- Preliminary conceptual study of **electrical feedbox** feeding the current to the SC-Link.

- Preliminary **integration studies** in LHC machine.

CERN SC-Link Test Station

WP7-Machine Protection

Rüdiger Schmidt, T.Baer, J.Wenninger, D.Wollmann,

M.Zerlauth

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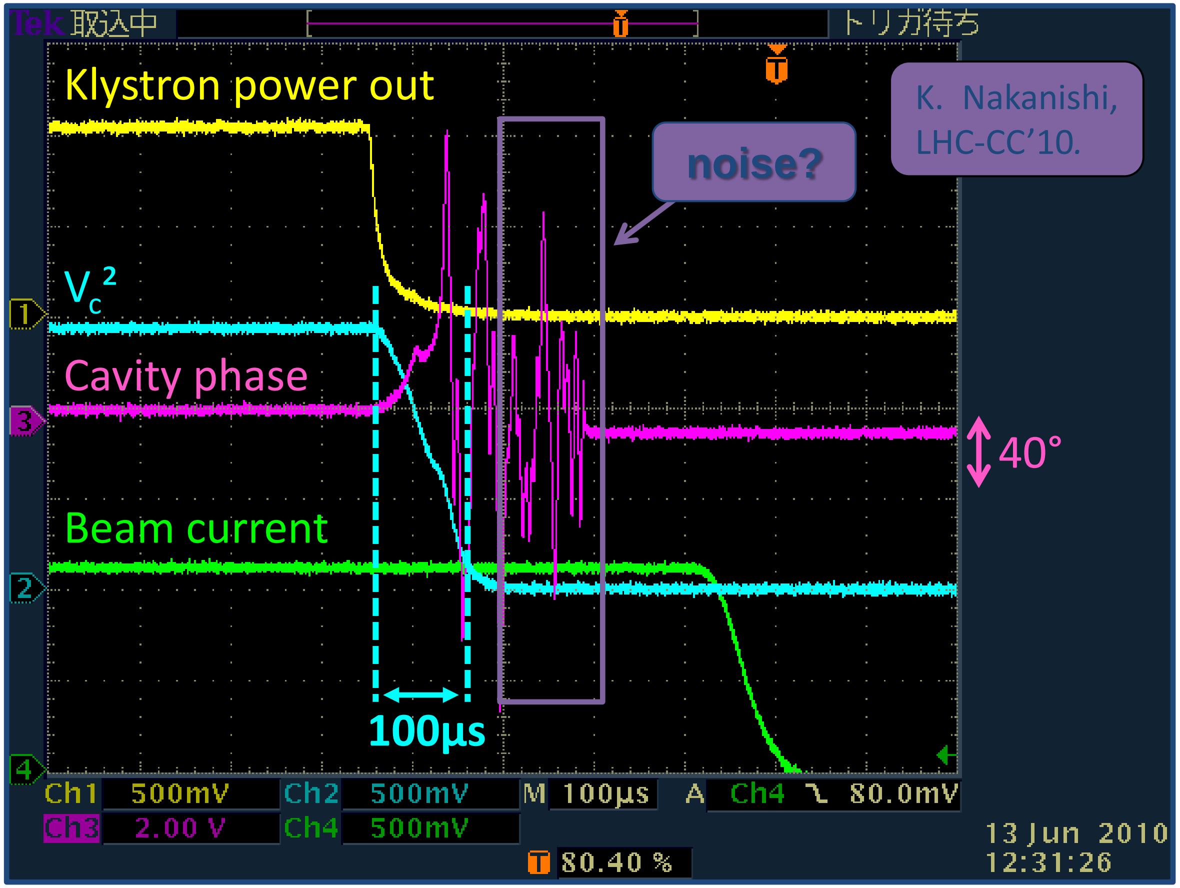
KER Crab Cavity Abort

•Crab cavity behaviour after klystron power abort:

- ***Full voltage decay in 100μs*** *(≈ 1 LHC turn).*
- *Crab cavity* ***phase oscillation****: 90° in ≈80μs.*
- *Unclear: phase measurement with zero voltage.*

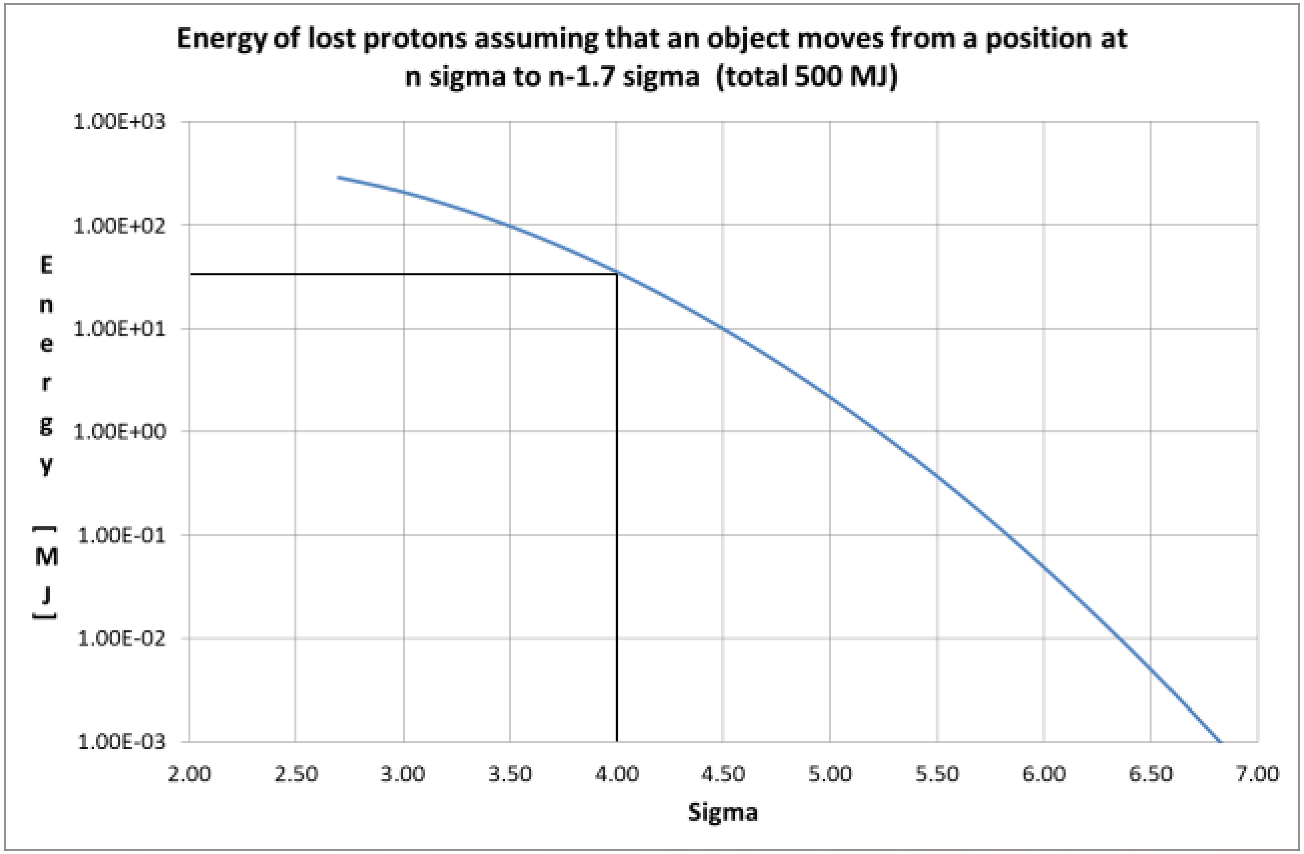


see also: K. Nakanishi et al., IPAC'10, WEPEC022

High Luminosity LHC

CC failure → Gaussian beam cut @ 1.7 σ

- Assume that a collimator sits at 4 σ, and a fast failure happens cutting into the tails by 1.7 σ. The energy loss corresponds to 35 MJ.
- For a collimator at 5 σ and a cut by 1.7 σ, the energy loss is 'only' 2.2 MJ.



Questions related to fast failures…..

- Is it realistic to assume that crab cavities can produce very fast failures?
  - Passive increase of τ for critical failures through LLRF and cavity design (available power, Qext,…) is vital for dependable MP
- If particle free aperture between collimators and beam of, say, two sigma is required….
  - Hollow electron lens for cleaning, or other halo cleaning techniques
  - Dependable measurement & interlocks on tail population
- Ideas for upgrade of protection systems
  - Dependable & fast detection of failures at/close to cavities (within sub μs)
  - Introduce direct links IR1/5-> IR6 for beam aborts?
  - Additional abort gaps?
- Other options
  - Position of the collimator further outside (between 5.5 and 6.0 σ)
  - Understand details of loss scenario, extract beam as fast as possible, possibly accept some damage to collimators if the probability is low (be aware of side effects)

WP8-Collider Experiment Interface

Helmut Burkhardt

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Collider Experiment Interface - WP8

Recent (30 Nov. '12) workshop, organized by L. Rossi, WP8 chair : H. Burkhardt and deputy : Daniel Lacarrère

Review of Accelerator Layout Change requests from LHC Experiments in LS2 & LS3 and their impact on the HL-LHC

Conclusions in form of executive minutes on indico and WP8 shared documents

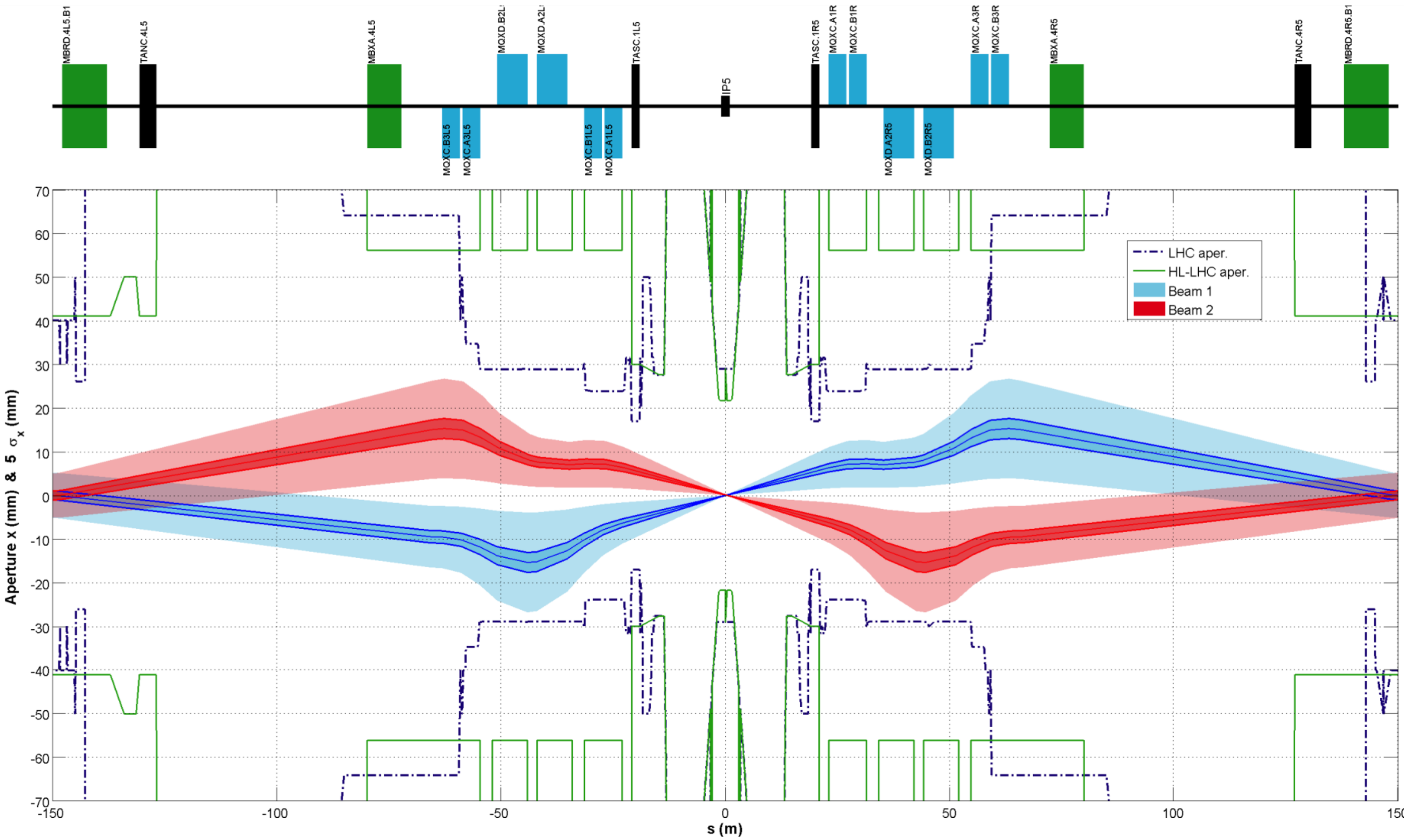
with item list for follow up in WP8 in close collaboration with experiments and other WPs

- **Impedance and heating**
- **Replacement of TAS and TAN devices**
- **New TAS with larger aperture – Energy deposition**
- **Small beam-pipes in the central part of the experiments, consequences of larger TAS**
- **Quality of vacuum – Requirement for a very good vacuum around ALICE**
- **Further collimators**
- **Machine protection for crab cavities and larger TAS**
- **Background and radiation from the machine in the experimental areas**
- **Radiation Protection issues**
- **Remote handling & Engineering** (workshop planned 6 May, see indico)

One key point under study (illustrated in next slide) :
Consequences of the new 2 × larger radius TAS and triplet apertures, combined with the reduced central beam pipes in the experiments

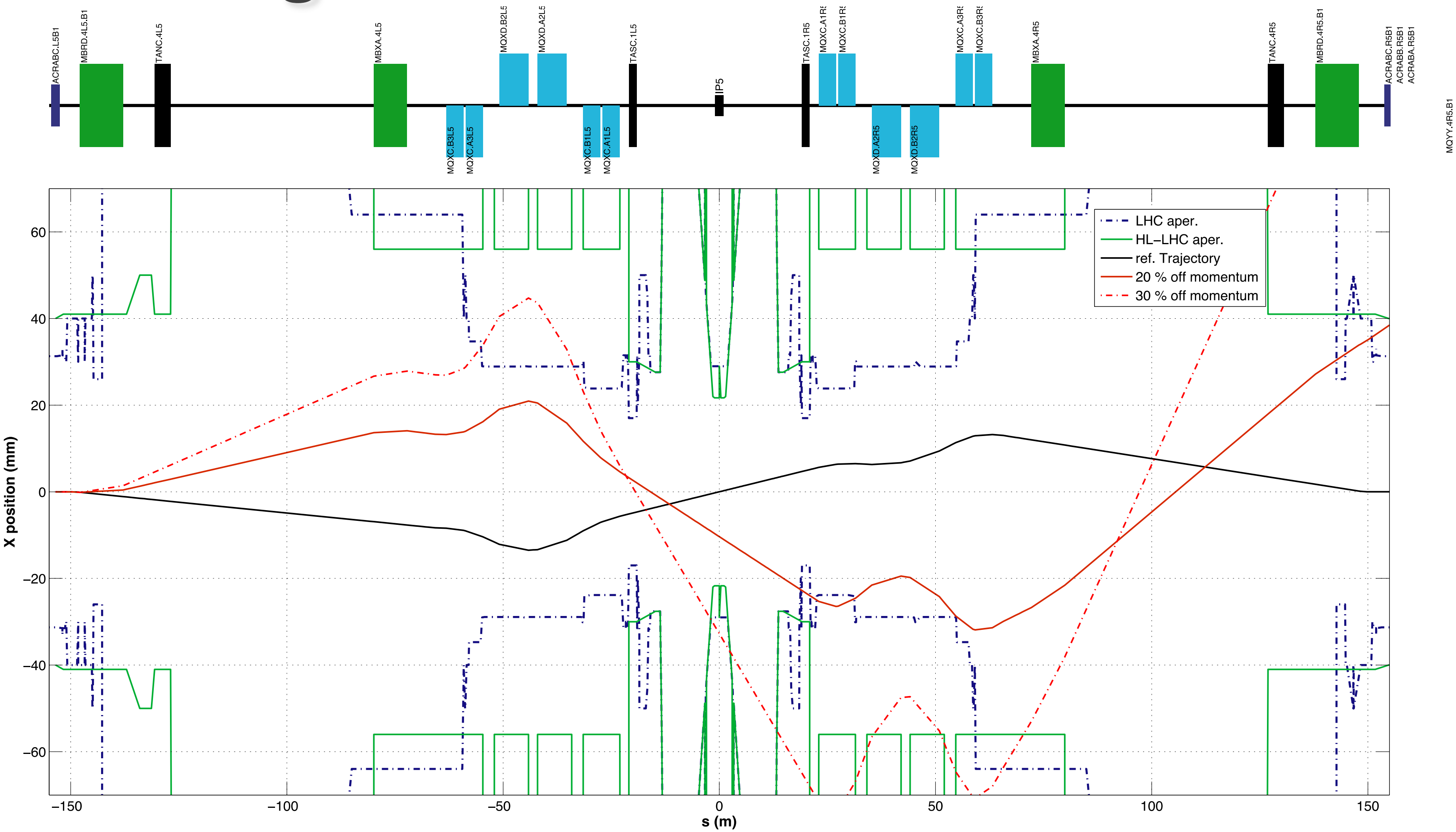
High Luminosity LHC

Beam envelope and apertures



F. Bouly / WP8

Example of off-momentum track reaching reduced chamber



F. Bouly / WP8

WP9-Cryogenics

Laurent Tavian

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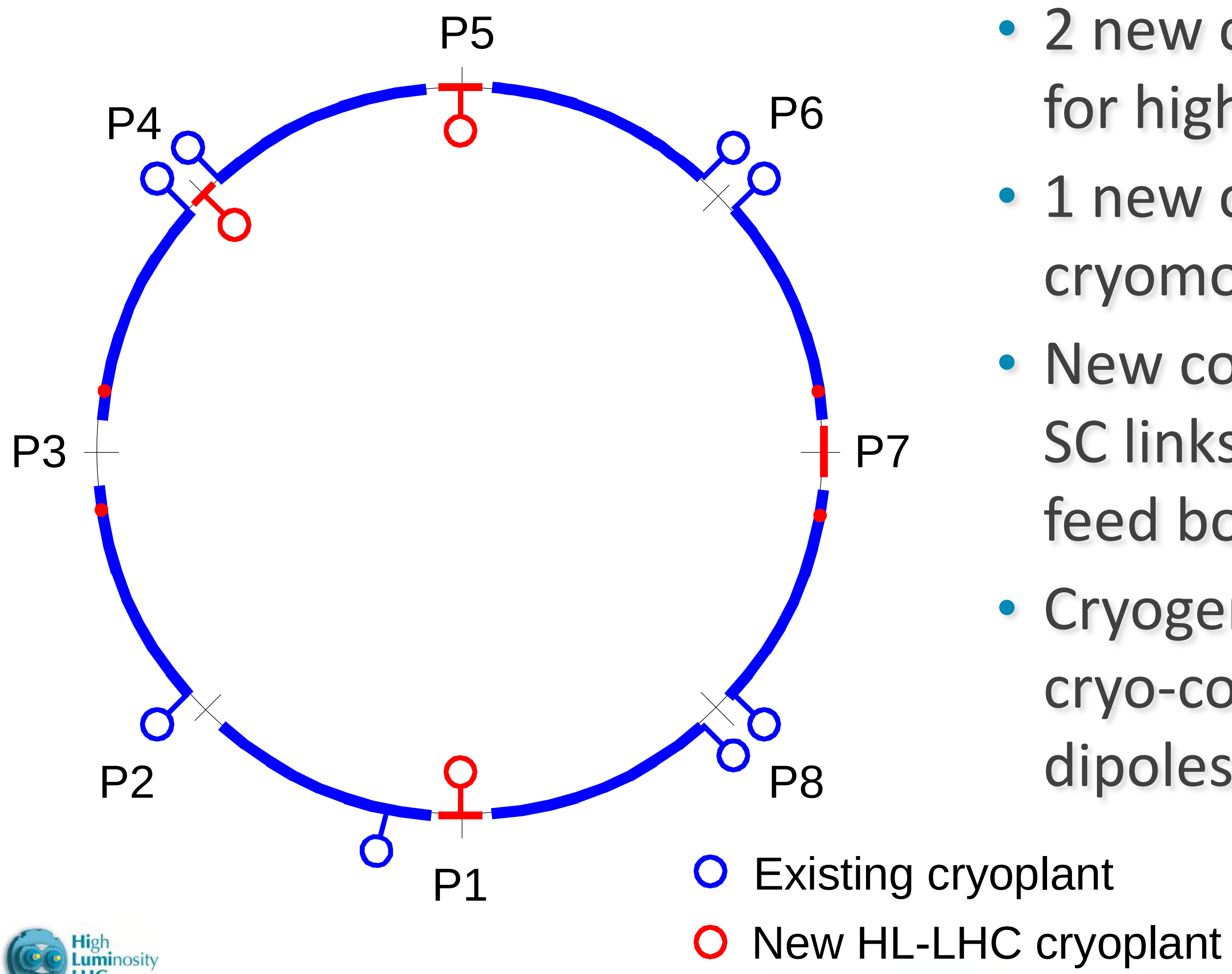
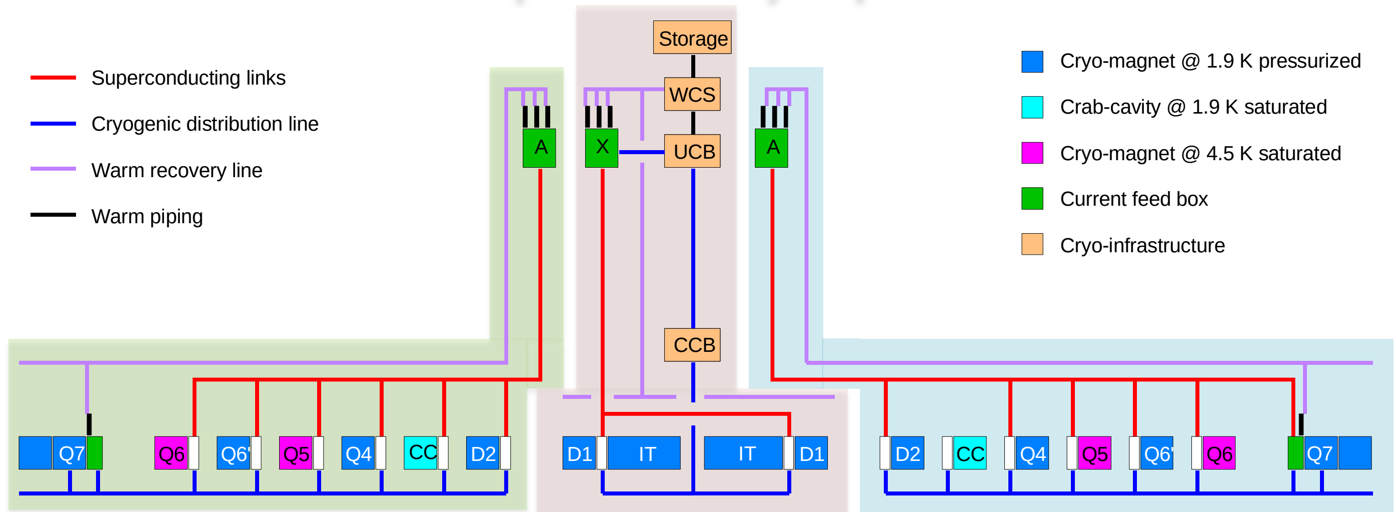
Overall HL-LHC layout



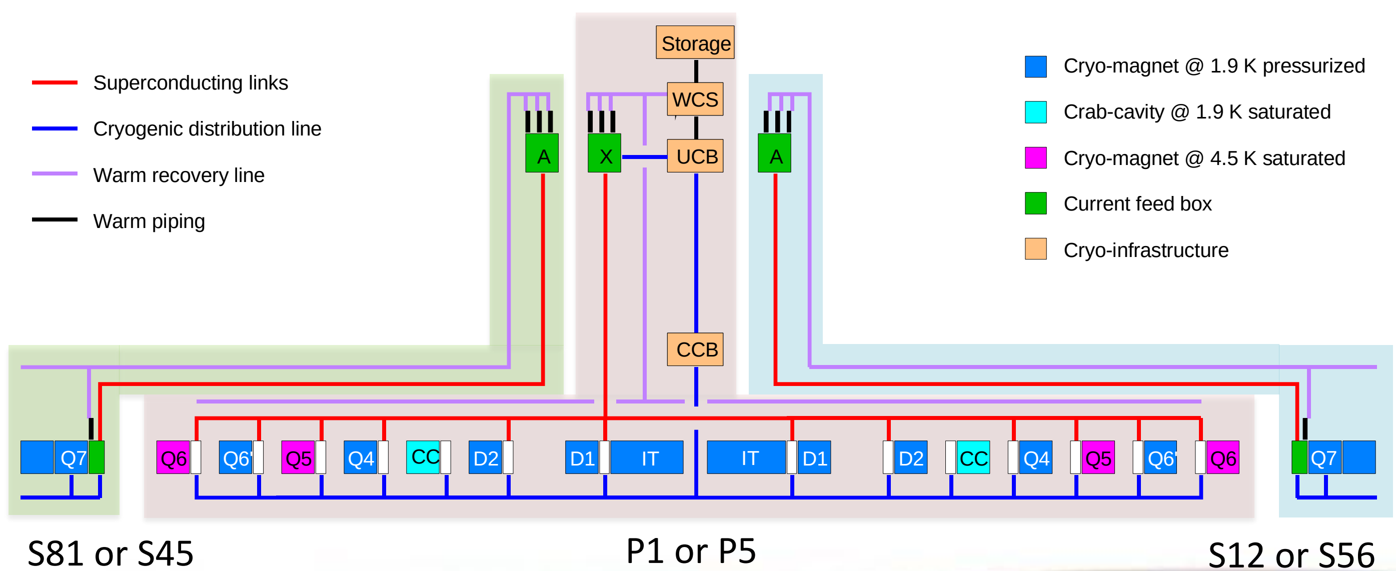
- HL-LHC cryo-upgrade:
  - 2 new cryoplants at P1 and P5 for high luminosity insertions
  - 1 new cryoplant at P4 for SRF cryomodules
  - New cooling circuits at P7 for SC links and deported current feed boxes
  - Cryogenic design support for cryo-collimators and 11 T dipoles at P3 and P7

P1 & P5 layout 1: Matching section cooled with sector or inner-triplet cryoplants

MS cooled with sector cryoplants



MS cooled with IT cryoplants



EN STI FLUKA team & Fermilab MARS team

N. Mokhov
Y. Eidelman, K. Gudima
I. Rakhno, S. Striganov
I. Tropin

LARP

High Luminosity LHC

WP10-Energy Deposition & Absorber

Francesco Cerutti

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DELIVERED

- study of the 140mm Nb_3Sn case (power and dose deposition assessment)
  - ✓ cold bore thickness-material effect (without beam screen)
  - ✓ optics options (crossing plane, flat vs round, divergence, σ_z) and experimental vacuum chamber impact
  - ✓ FLUKA-MARS intercomparison
  - ✓ shielding strategies

- benchmarking against operation (measured and predicted BLM patterns)

- code physics developments

- LHCb upgrade study (no TAS, but a D2 protection) [talks at the HL-LHC Coordination Group on Jan 14 and at the LMC on Mar 27]

- study on the TCL collimator effectiveness in P5 and P1 [synergy with WP5]

- dose to warm magnets in P7 and P3 (measurements, extrapolations and simulation validation)

  [in the context of the collimation working group]

- dose to the present triplet correctors [study just completed]

AHEAD

- new comprehensive energy deposition study for the adopted 150mm quadrupole aperture, including the downstream corrector package and 160mm D1 *(Mar-May 2013)* optics, layout and magnet specs are becoming available and being collected right now (6 – nested – superconducting orbit correctors, 9 superferric high order correctors)

- Ions and DS collimators [to be discussed at the WP5 collimation review *end of May*] Matching section layout (TCL6) and forward physics experiments in P1 and P5 [synergy with WP5 and WP8]

- Further R&D on DPA limits at cryo temperatures (Fermilab-Japan collaboration and CERN program on sample irradiation [R. Flukiger])

WP11-11 Tesla 2-in-1 Dipole Magnets for the Dispersion Suppressor

Mikko Karppinen

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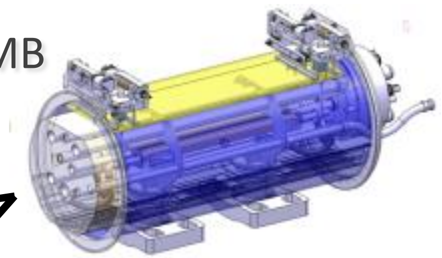
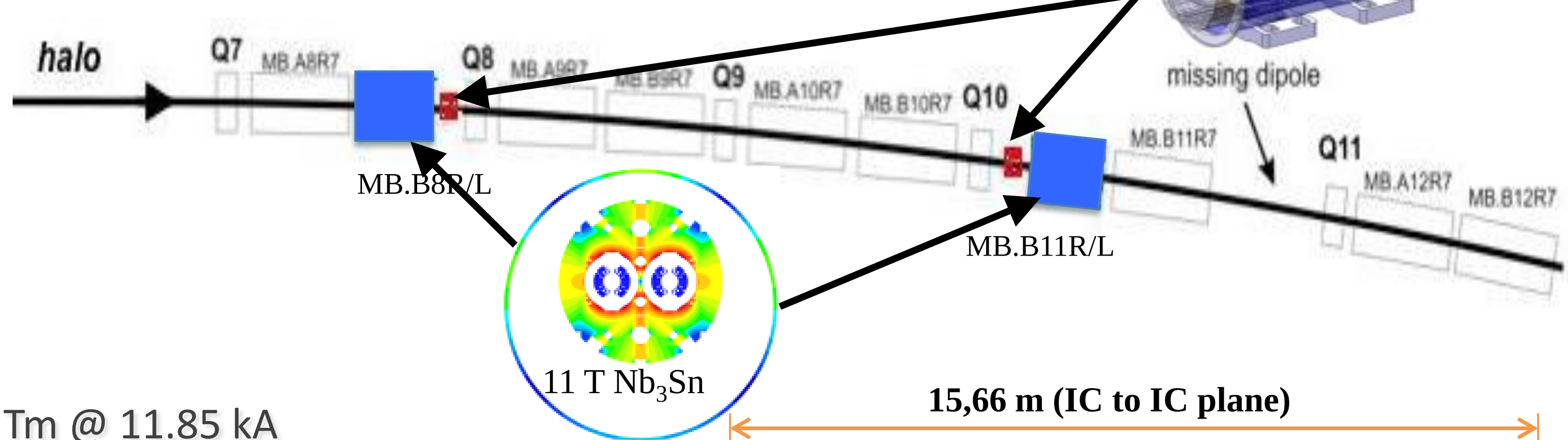
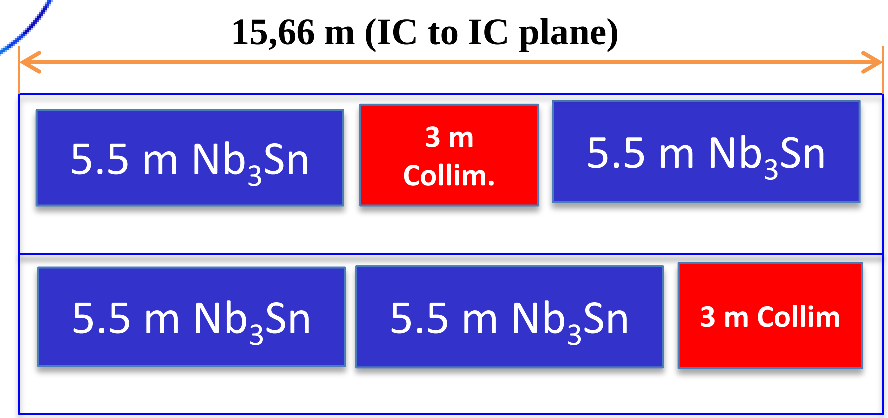
11 T Dipole for DS Upgrade

- Create space for additional (cryo) collimators by replacing 8.33 T MB with 11 T Nb_3Sn dipoles compatible with LHC lattice and main systems.





- 119 Tm @ 11.85 kA
- LS2 2018: IR2
  - 4 MB => 4 x 5.5 m CM + spares
- LS3 2022: IR1,5 and Point-3,7
  - 4 x 4 MB => 16 x 5.5 m CM + spares



- Joint development program between CERN and FNAL underway since Oct-2010.

FNAL: 11 T Dipole Magnet Test

MBHSP01 mechanical and electrical connection to the Top Heat in IB1 (FNAL MTF)

Magnet test at Vertical Magnet Test Facility (FNAL)

Test plan:

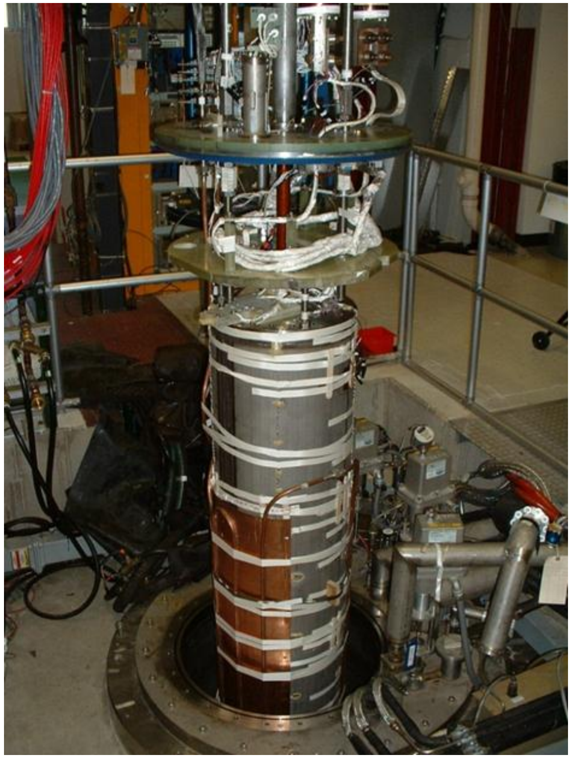
- Temperature range 1.9-4.6 K
- Quench performance
- Magnetic measurements
- Heater study
- AC losses, splice resistance, coil RRR, etc.

Test status:

- MBHSP01 – has been tested in June 2012 reached 10.4 T
- Conductor degradation on the outer layer near the splice

➔ MBHSP02 – test in progress

Magnet installation in vertical dewar (FNAL VMTF)



FNAL: MBHSP02 1-in-1 Demonstrator (1m)

- Design: 1 m version of MBHSP01
- Goals: demonstrate new R&D strand, cored cable, improved process, and reproducibility
- Strand:
  - MBHSP02 – R&D RRP-150/169 strand
  - MBHSP03 – baseline RRP-108/127 strand
- Cable: both models use 40-strand cable with 12 mm wide and 0.025 mm thick SS core
- Coil: optimized end parts and process
- Structure:
  - MBHSP02 – modified MBHSP01 collar
  - MBHSP03 – new collar
  - reinforced bolted skin
- MBHSP02 assembly completed in 6 months
- MBHSP03 coil fabrication is in progress

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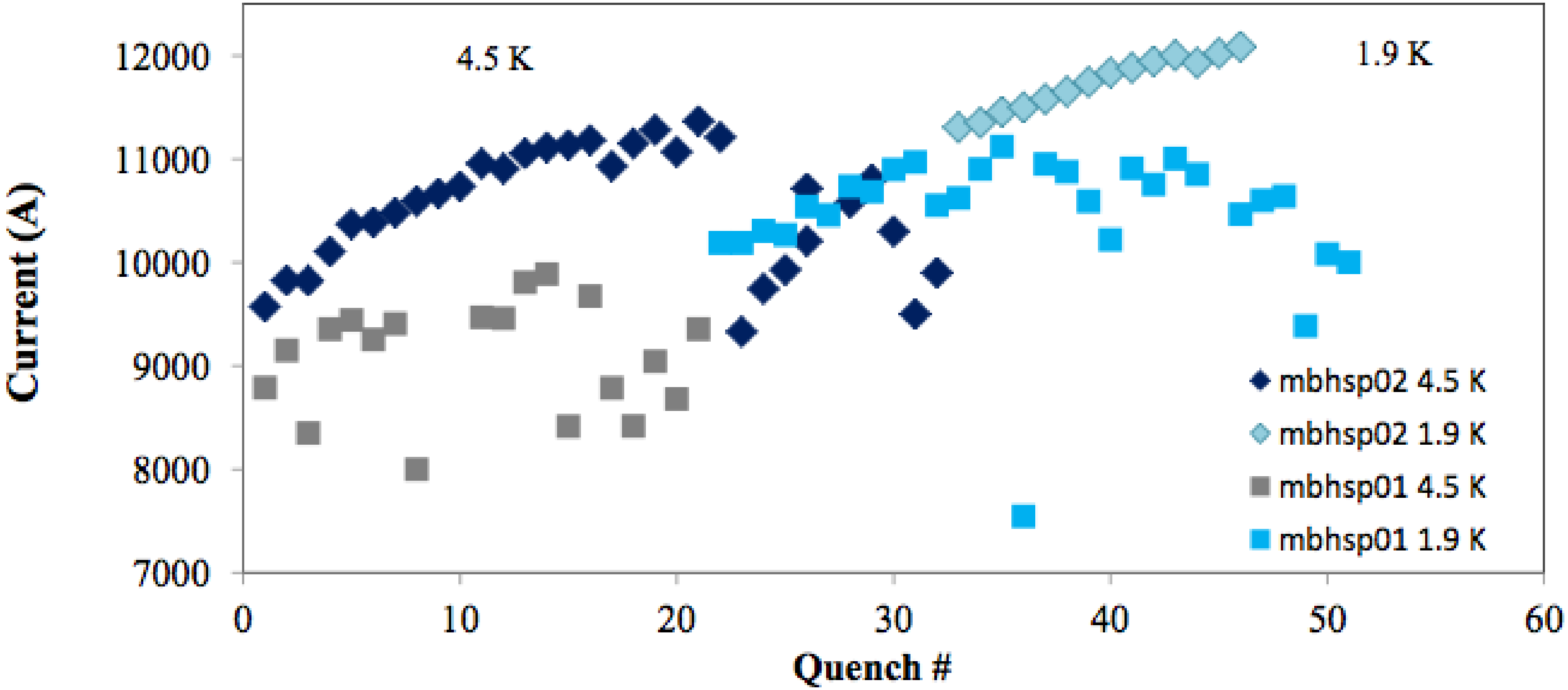
MBHSP02 Quench Performance

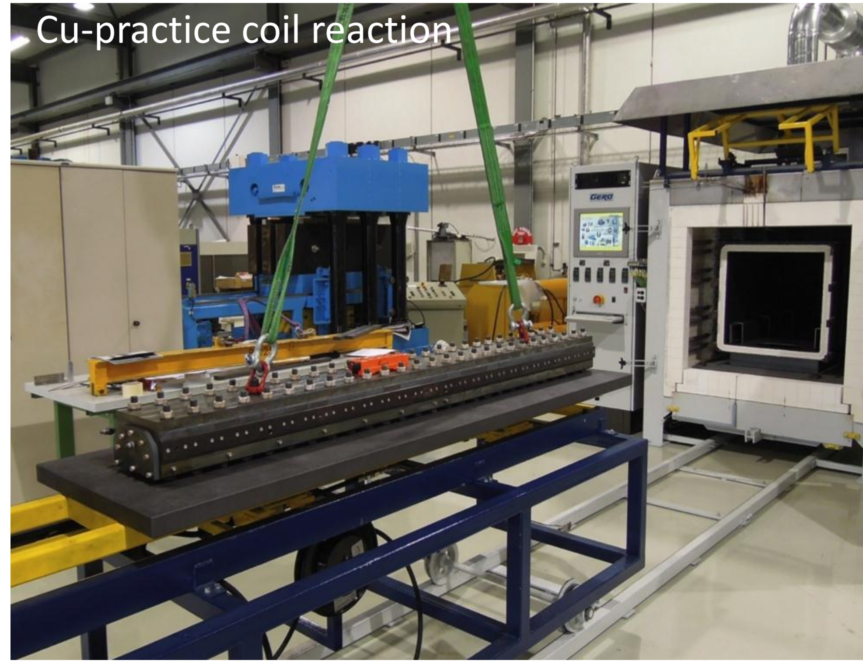


MBHSP02 passed 11 T field during training at 1.9 K with

I = 12080A on 5th March!

CERN Construction Status

- Coil fabrication tooling:
  - Winding, curing, and reaction fully operational
  - Vacuum impregnation system being commissioned
- Practice coil fabrication
  - 2 Cu-coils made
  - 1 Nb_3Sn (low-Jc WST strand) wound and cured
  - RRP-54-61 winding of the outer layer in progress
- Magnet R&D topics:
  - Cable insulation (braided S2-glass & Mica)
  - Coil pre-loading concept ("pole-loading")
  - Magnet protection (inter-layer heater)
- First 1-in-1 magnet (2 m) test Aug-13


Cu-practice coil reaction


Reacted coil with laser-sintered stainless steel end spacers


Vacuum impregnation system

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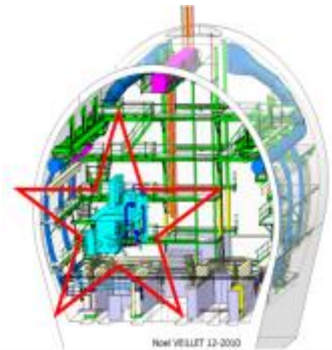
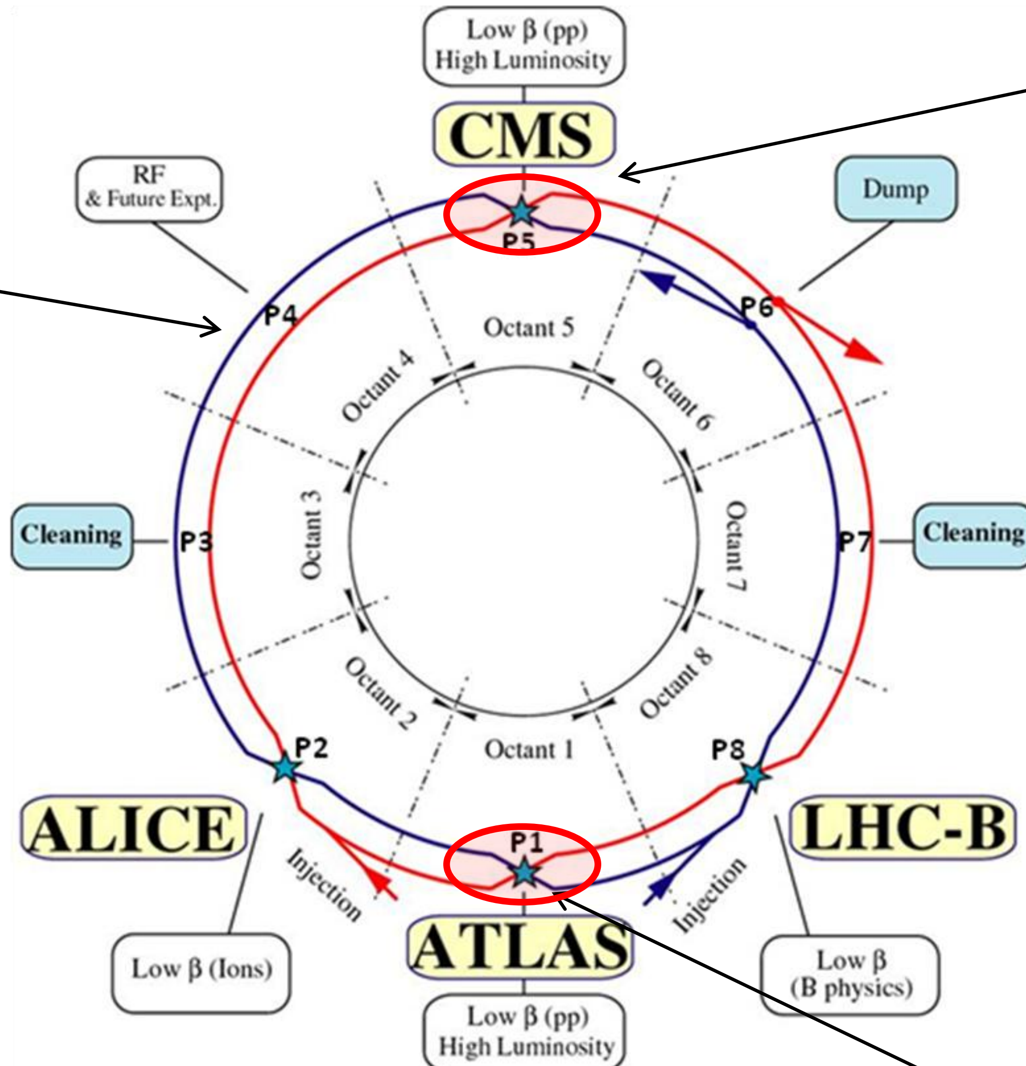
CERN

cern.ch

Cryogenic Upgrade



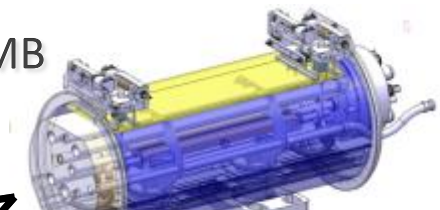
6.5 kW@4.5K cryoplant

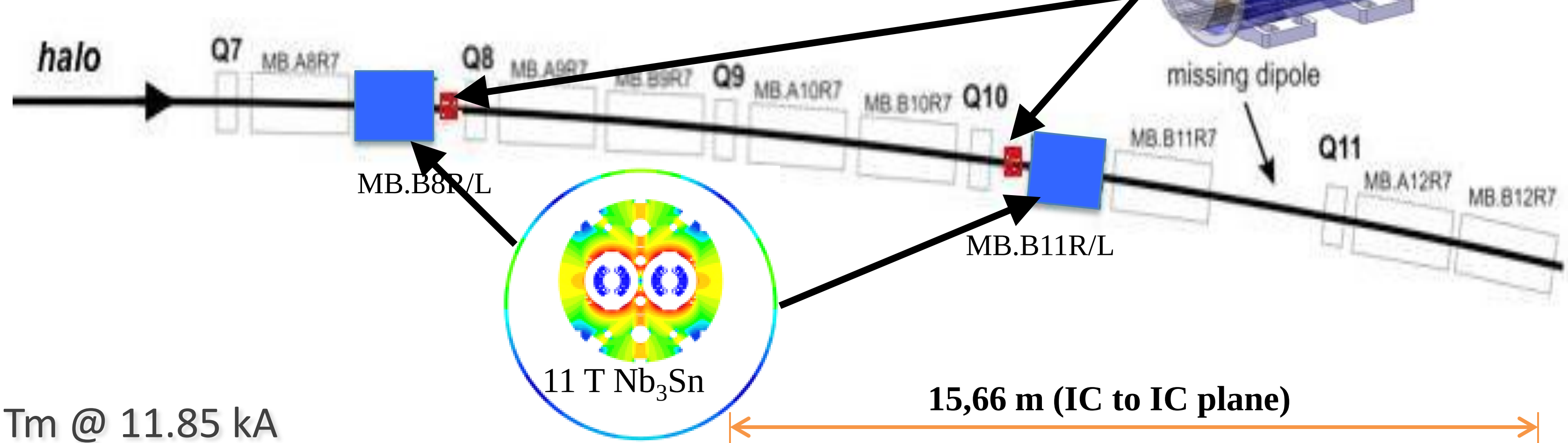


2 x 18 kW @4.5K cryoplants for IRs

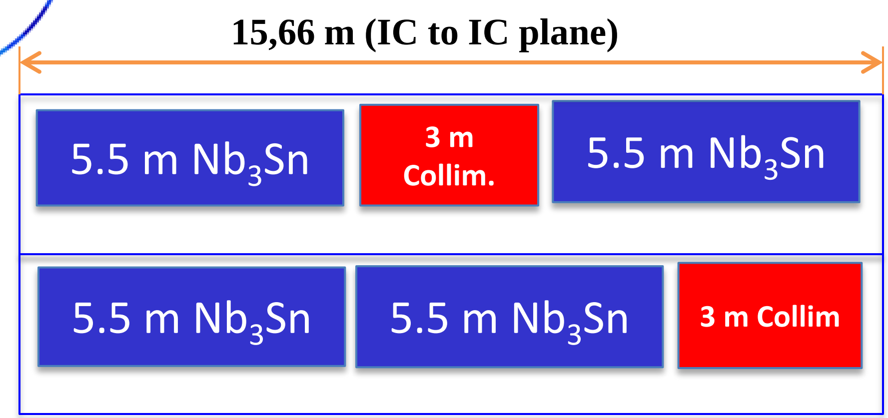
11 T Dipole for DS Upgrade

- Create space for additional (cryo) collimators by replacing 8.33 T MB with 11 T Nb_3Sn dipoles compatible with LHC lattice and main systems.



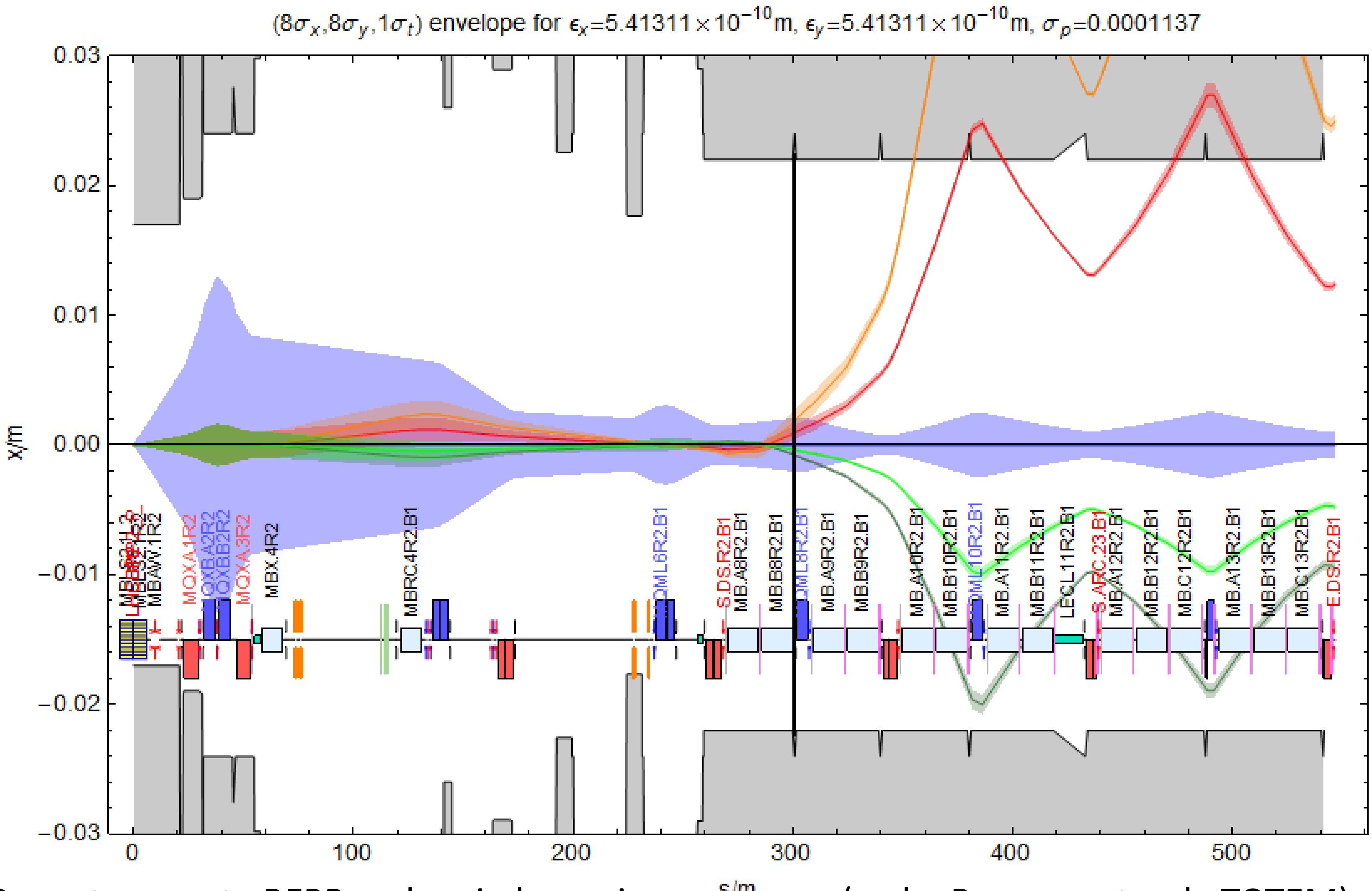


- 119 Tm @ 11.85 kA
- LS2 2018: IR-1,5, and 2
  - 4 MB => 4 x 5.5 m CM + spares
- LS3 2022: IR1,5 and Point-3,7
  - 4 x 4 MB => 16 x 5.5 m CM + spares



- Joint development program between CERN and FNAL underway since Oct-2010.

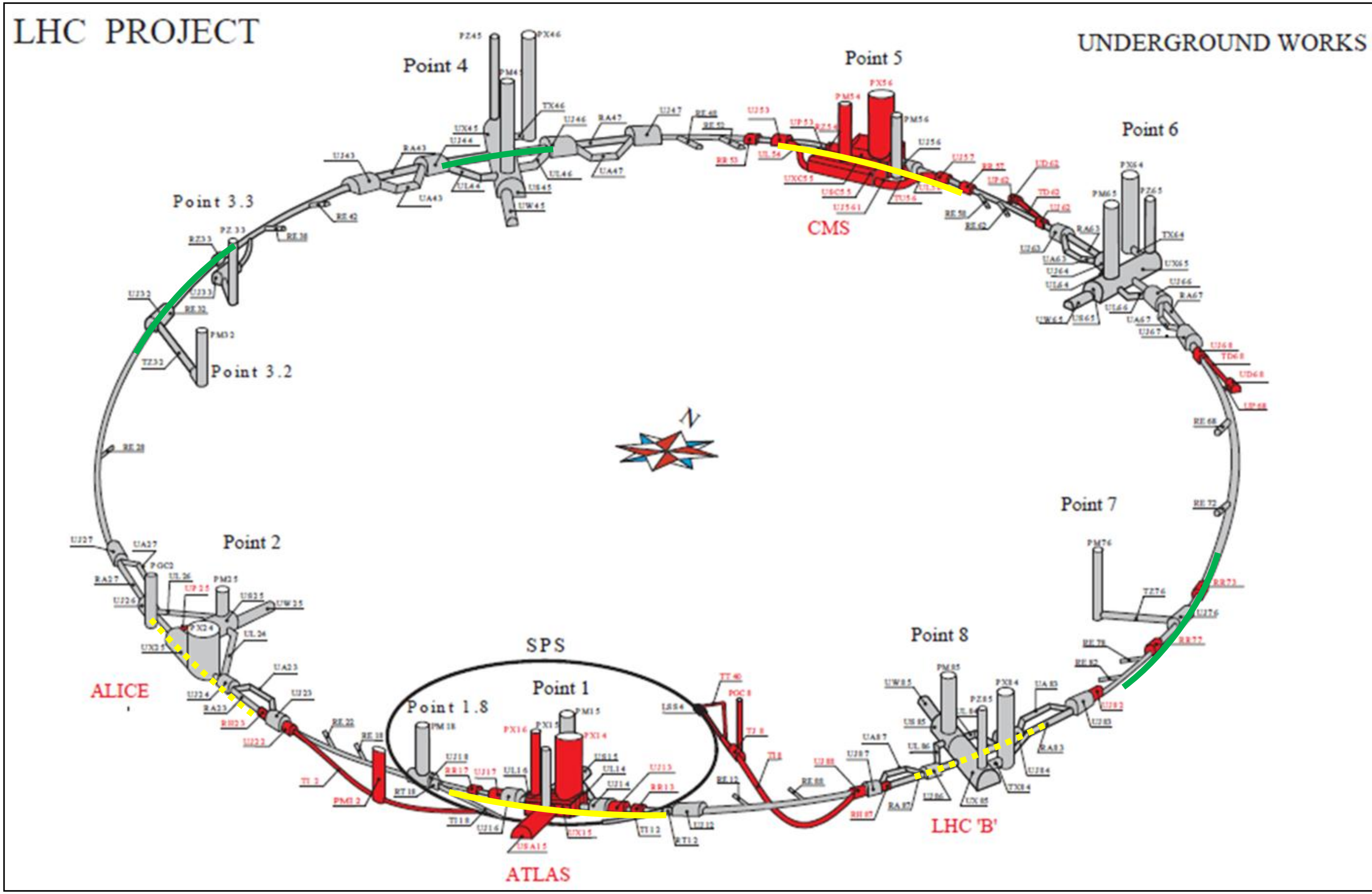
Secondary beams from Beam 1 in IR2



Cannot separate BFPP and main beam in warm area (eg by Roman pots a la TOTEM).

J.M. Jowett, Collimation Upgrade Specification meeting, 16/3/2012

High Luminosity LHC



High Luminosity LHC

In total > 1.2 km of LHC !!

Main topics of first PLC meetings (4):

- Mandate and composition ✔
- Baseline parameters ✔
- Generation of a common Glossary with the experiments ✔
- Approval of triplet coil diameter of 150mm ✔
- Layout and optics ✔
- Triplet beam screen and vacuum ✔
- Cryogenics (current limitations → IR and arcs) ✔
- Beam instrumentation (space reservations) ✔
- Crab cavity (layout and parameters) ✔
- Powering aspects and space requirements in the HL IRs

HL-LHC PLC

Other future topics:

-Survey needs in the IRs

-EDMS data base structure for HL-LHC

-Required corrector circuits

➔ (e.g. triplet, additional octupoles etc)

-Review of the HL-LHC Layout in the insertions ⇦ **Summer**

➔TAS & TAN space, CC, space for additional components, Survey needs

-DS collimators

-IR3 and IR7 warm magnet consolidation options

-Places for higher harmonic RF system and new BI

-Current limitations (e.g. MKI, dump, TDI etc)

-Ion beam parameters during HL-LHC

HL-LHC Performance Estimates

‘Stretched’ Baseline Parameters following 2nd HL-LHC-LIU:

Parameter	nominal	25ns	50ns		
N	1.15E+11	**2.2E+11**	**3.5E+11**		
n_b	2808	2808	1404		
beam current [A]	0.58	**1.12**	**0.89**		
x-ing angle [μrad]	300	590	590		
beam separation [σ]	9.9	12.5	11.4		
β^* [m]	0.55	**0.15**	**0.15**		
ε_n [μm]	3.75	2.5	3.0		
ε_L [eVs]	2.51	2.51	2.51		
energy spread	1.20E-04	1.20E-04	1.20E-04		
bunch length [m]	7.50E-02	7.50E-02	7.50E-02		
IBS horizontal [h]	80 -> 106	**18.5**	**17.2**		
IBS longitudinal [h]	61 -> 60	**20.4**	**16.1**		
Piwinski parameter	0.68	**3.12**	**2.85**		
geom. reduction	0.83	**0.305**	**0.331**		
beam-beam / IP	3.10E-03	**3.3E-03**	**4.7E-03**		
Peak Luminosity	$1\ 10^{34}$	**$7.4\ 10^{34}$**	**$8.5\ 10^{34}$**		
Virtual Luminosity	$1.2\ 10^{34}$	**$24\ 10^{34}$**	**$26\ 10^{34}$**		
Events / crossing (peak & leveled L)	19 -> 28	**210**	**475**	**140**	**140**

$6.2\ 10^{14}$ and $4.9\ 10^{14}$ p/beam

➔ sufficient room for leveling (with Crab Cavities)

Virtual luminosity (25ns) of $L = 7.4 / 0.305\ 10^{34}\ cm^{-2}\ s^{-1}$

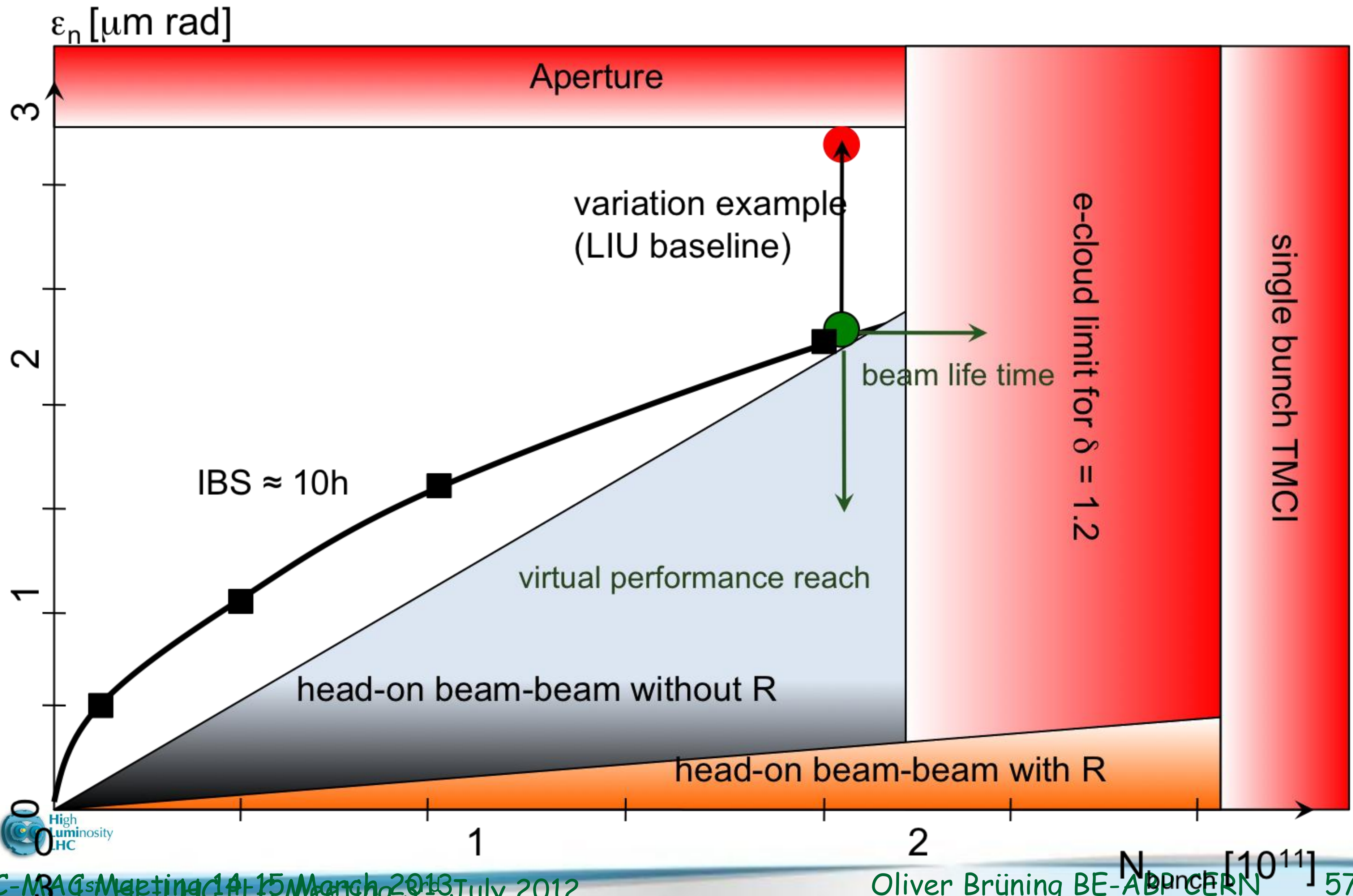
$= 24\ 10^{34}\ cm^{-2}\ s^{-1}$ (‘k’ = 5)

Virtual luminosity (50ns) of $L = 8.5 / 0.331\ 10^{34}\ cm^{-2}\ s^{-1}$

$= 26\ 10^{34}\ cm^{-2}\ s^{-1}$ (‘k’ = 10)

(Leveled to $5\ 10^{34}\ cm^{-2}\ s^{-1}$ and $2.5\ 10^{34}\ cm^{-2}\ s^{-1}$)

HL-LHC parameter space



High Luminosity LHC

WP2-Accelerator Physics and Performance

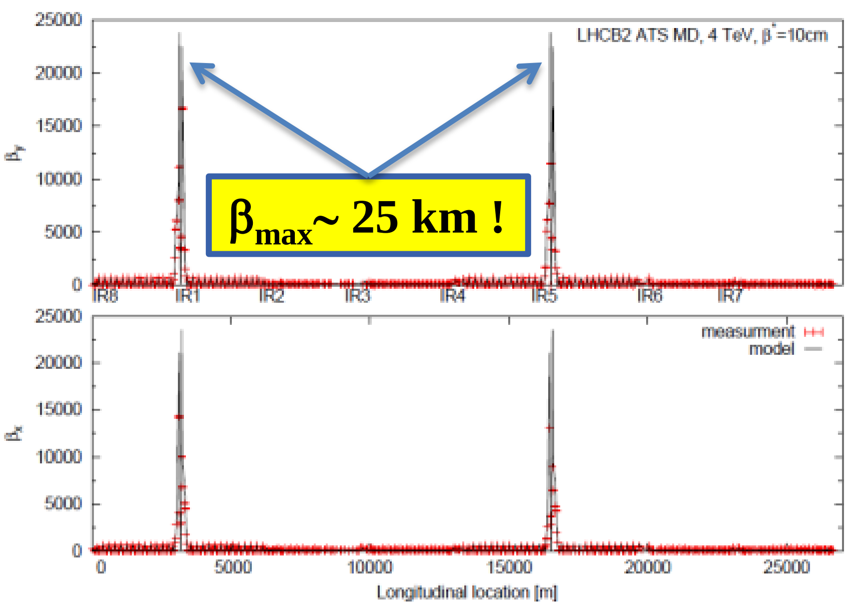
Reserve Transparencies

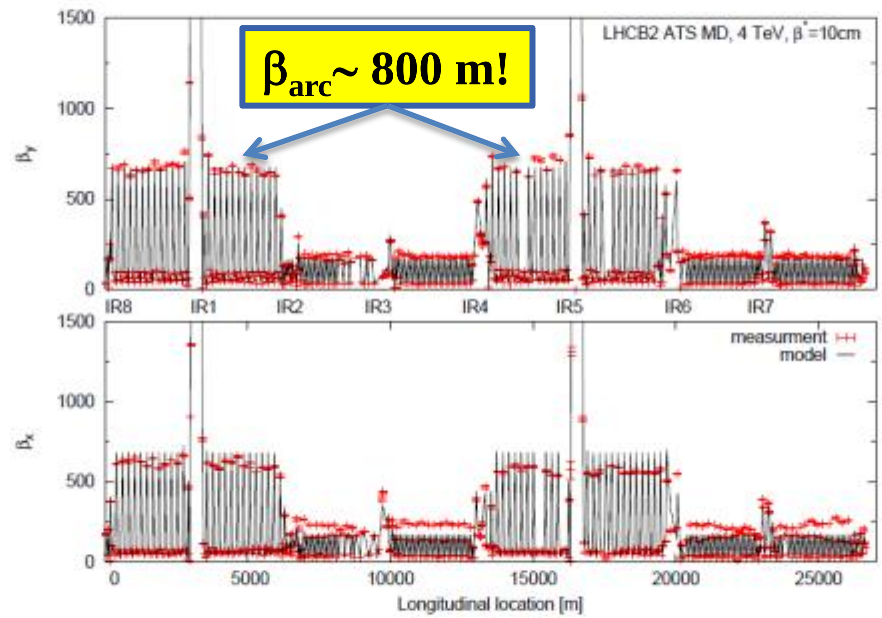
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Optics & Layout (1/4)

WP2

- The ATS (Achromatic Telescopic Squeeze) is now firmly established as baseline for the HL-LHC

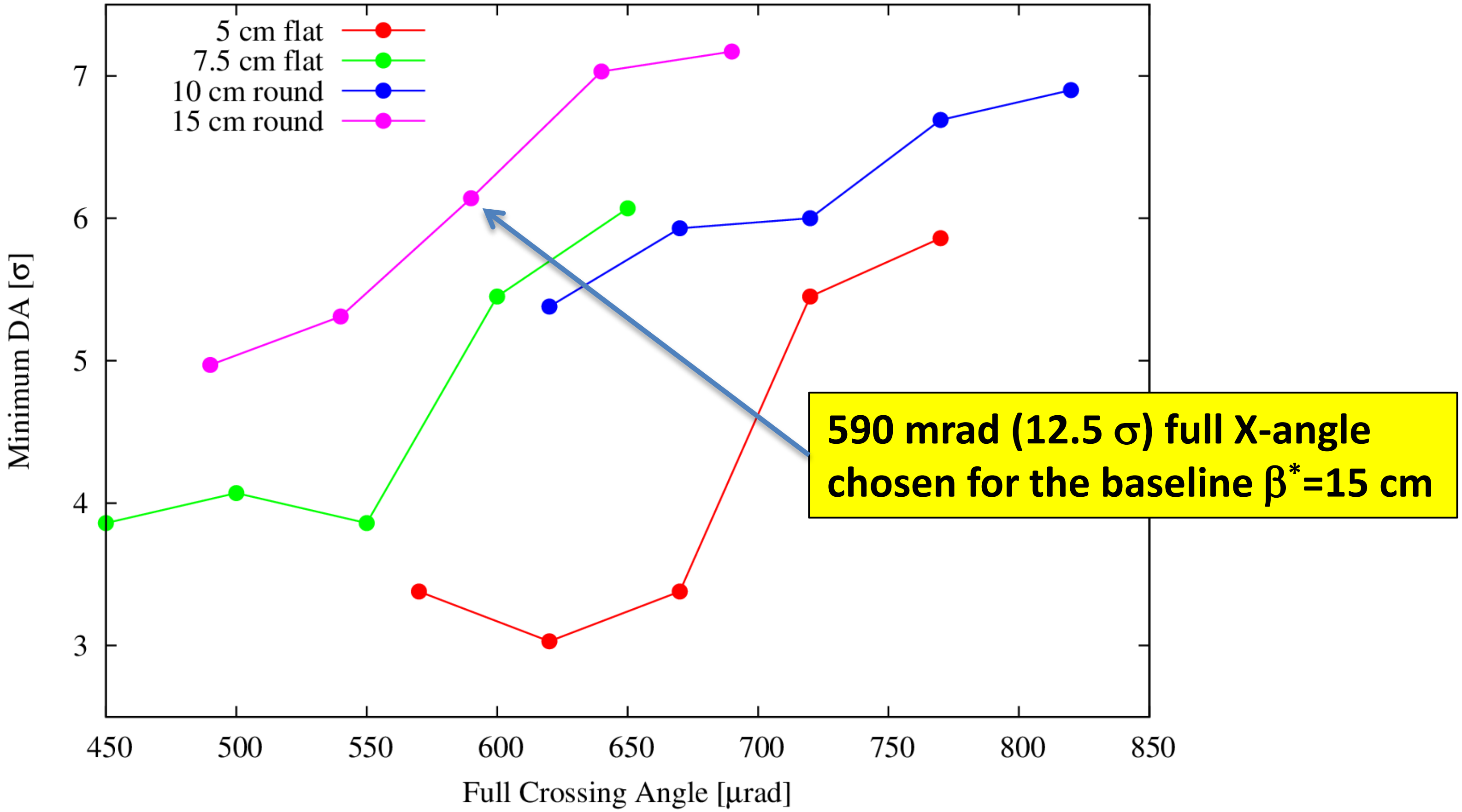




→ **β^* ~10 cm** reached in MD (with some β-beating) including a full chromatic correction, thank to the ATS: CERN-ATS-2013-004 MD

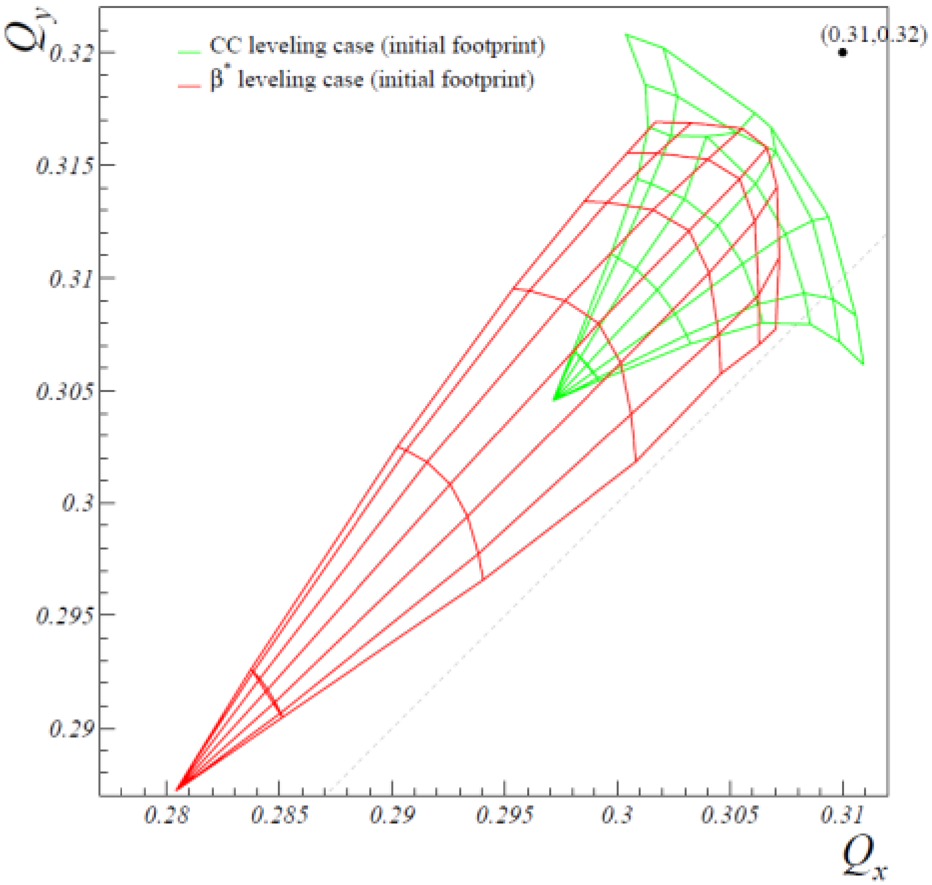
Optics & Layout (4/4)

- Choice of the crossing angle



1'000 000 turns DA vs. crossing angle for various collision optics, round or flat (w/o field imperfections) assuming 25 ns HL-LHC beam parameters (N_b= 2.2E11 p/bunch, $\gamma\varepsilon$=2.5 μm)

Pile-up, leveling and beam-beam (2/2)



Parameters	Leveling with c.-c.	Leveling with β^*
# bunches	2808	
bunch charge [10^{11}]	2.2	
emittance [μm]	2.5	
r.m.s. bunch length [cm]	7.5	
full X-angle [μrad]	590	
initial β* [cm]	15	72
c.-c. initial voltage [MV]	- 6.6	12.5
initial Piwinsky angle	4.76	0
initial lumi loss factor	0.21	1.0
levelled lumi [$10^{34}cm^{-2}s^{-1}$]	5.0	
initial luminous region [cm]	**1.1**	**5.3**
initial bb tune shift for 3 IRs (IR1, IR5 & IR8)	**0.016** (0.011+2×0.0025)	**0.033** (3×0.011)

High Luminosity LHC

WP3-Magnets for Insertion Regions

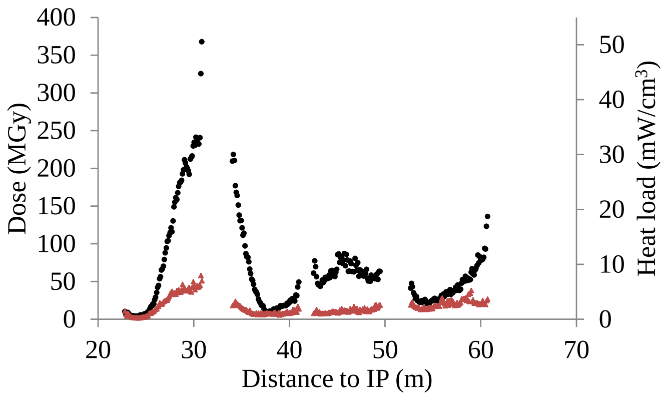
Ezio Todesco

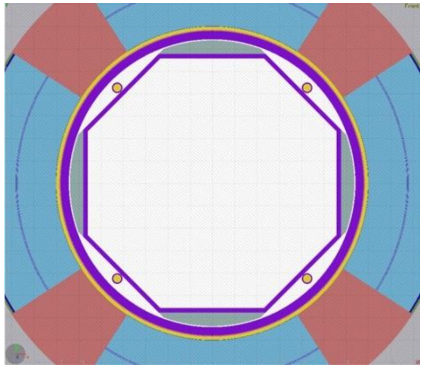
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Main Magnet Features:

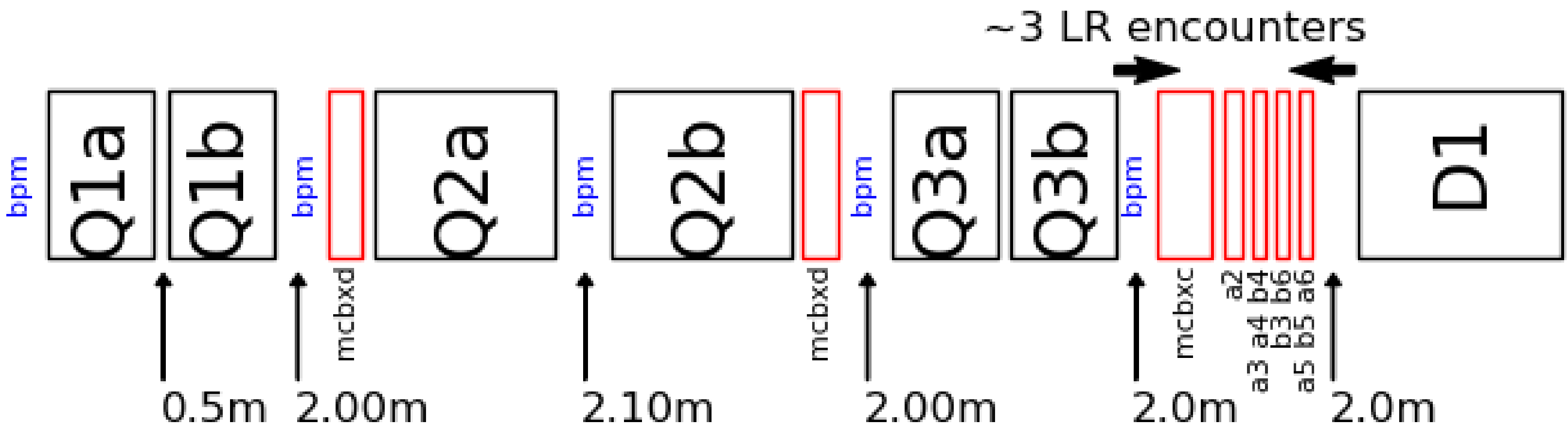
- Target is maximal performance, robustness, simplicity
  - Nb_3Sn chosen for having compact triplet
  - Nb-Ti for the separation dipoles, Q4
- Main ingredient: energy deposition studies
  - Shielding needed for heat removal and protrecting against radiation damage
    - 20 MGy correspond to 4 mW/cm3, i.e. we will be in a situation similar to the LHC baseline thanks to a much larger shielding
- Larger shielding has pushed us to choose 150 mm aperture to preserve performance

Energy deposition in the triplet
[F. Cerutti, L. Esposito]





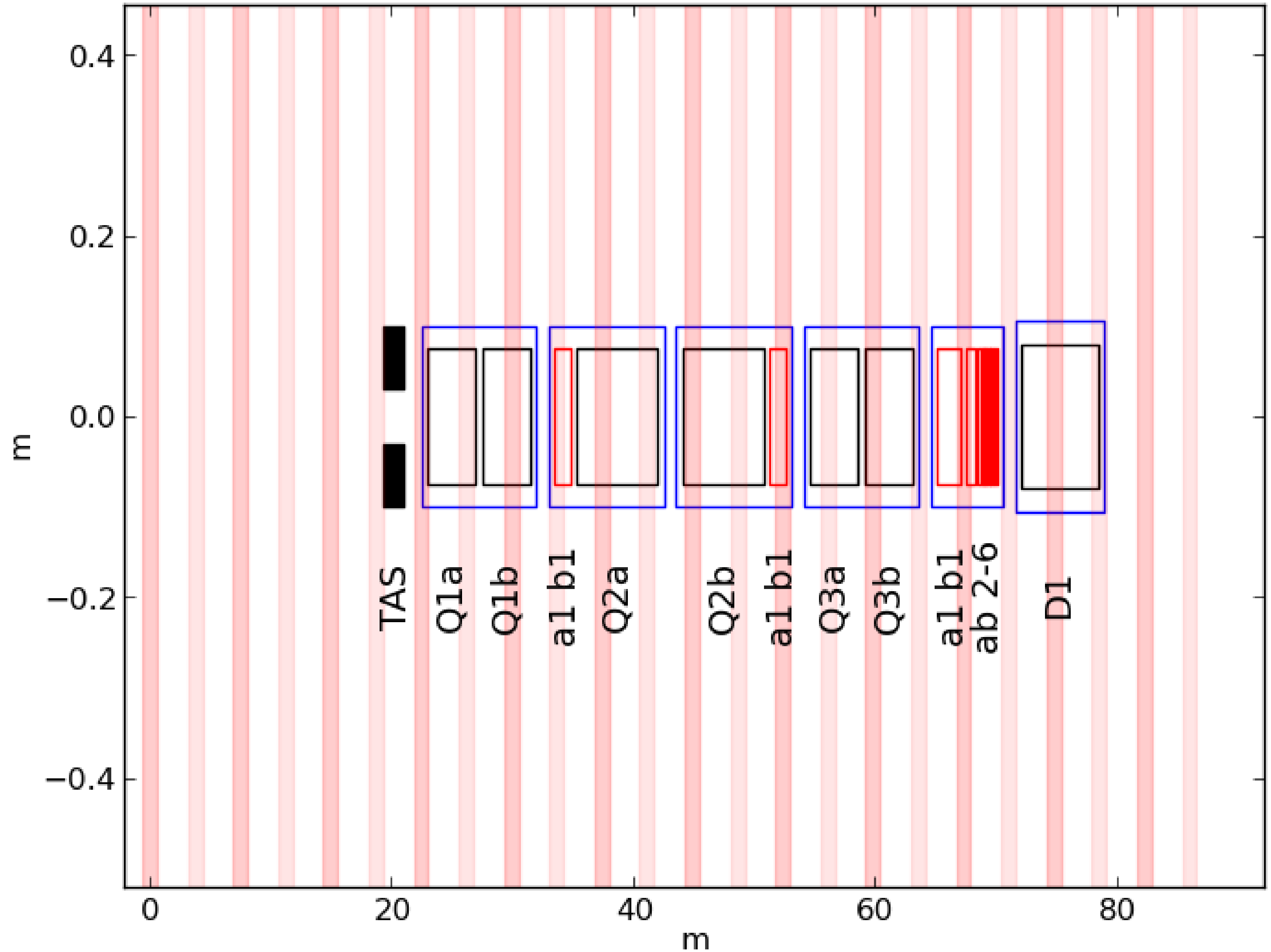
New Layout with 150mm Diameter Triplet



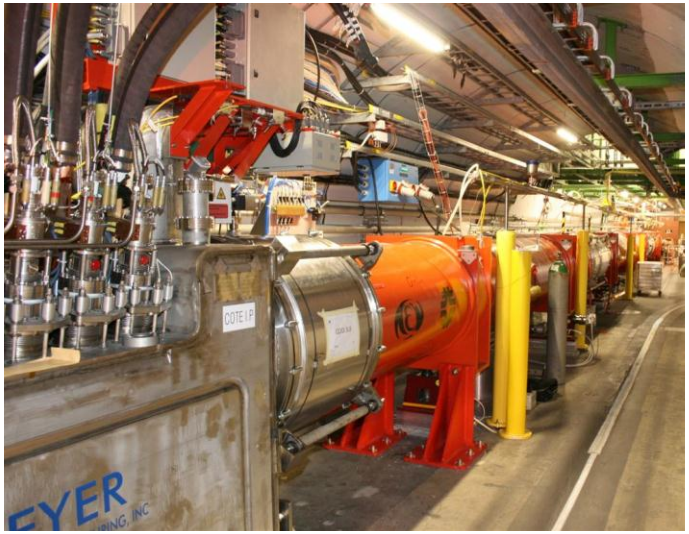
Q1/3 a/b: 3.99m, 140 T/m, 150mm
Q2 a/b: 6.76m, 140 T/m, 150mm
D1: 7.7m, 40 Tm, 160mm

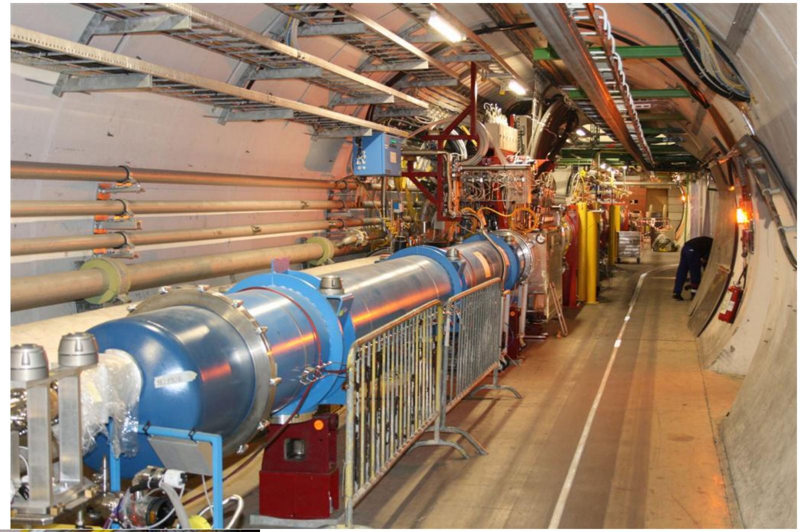
MCBXD: 1.3m, h/v nested orbit corrector
MCBXC: 2.00m, h/v nested orbit corrector
MQSX3: 0.67m, skew quadrupole corrector
MCSTX3: 0.50m, (b3,b6) nested correctors
MCOSSX3: 0.50m, (a3,a4,b4) nested correctors
MCDTSX3: 0.50m, (a5,b5,a6) nested correctors

New Layout with 150mm Diameter Triplet



Magnets: IR





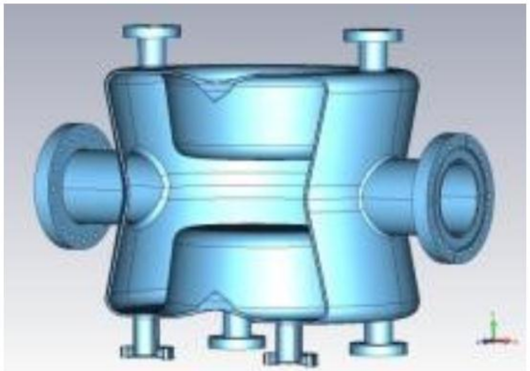
WP4-Crab Cavities

Reserve Transparencies

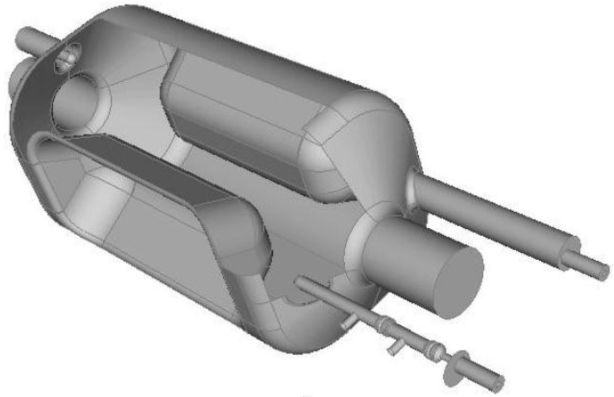
The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

All Prototypes in Bulk Niobium

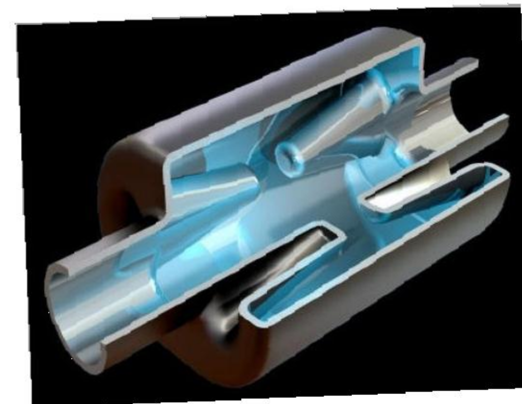
BNL DQWR



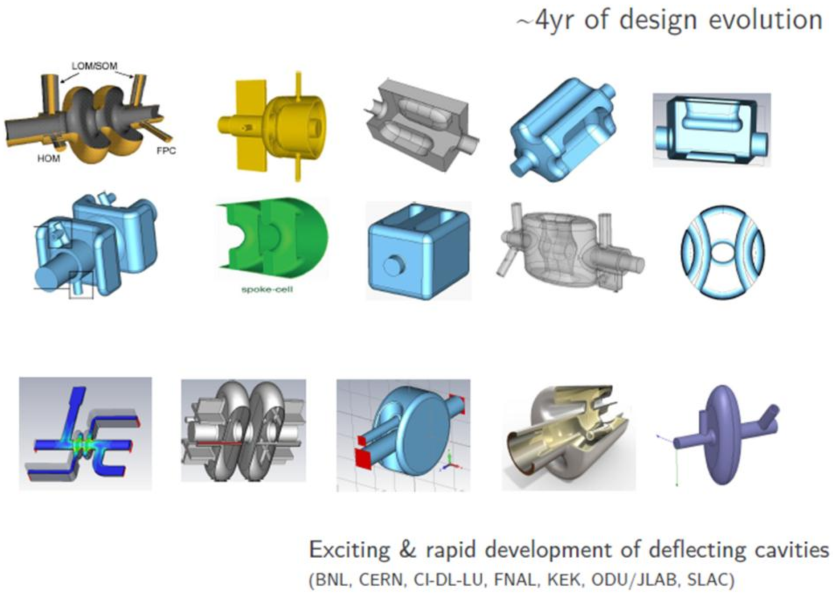
ODU-SLAC RF Dipole

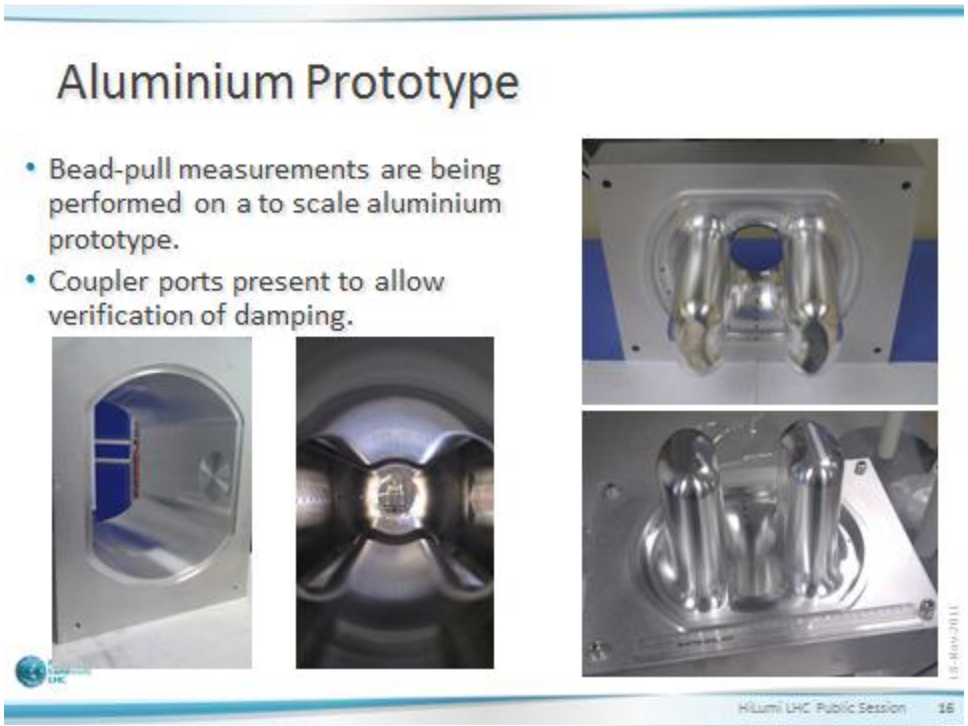


Lancaster 4-rod Design



CC


~4yr of design evolution
LOM/SOM
HOM
FPC
spoke-cell
Exciting & rapid development of deflecting cavities
(BNL, CERN, CI-DL-LU, FNAL, KEK, ODU/JLAB, SLAC)

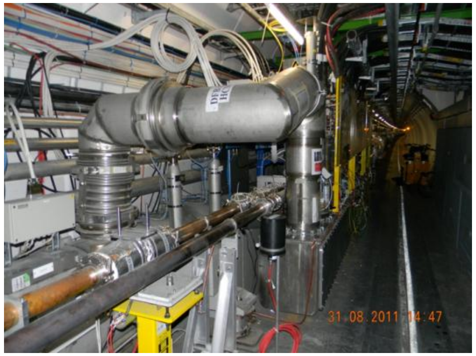

Aluminium Prototype
• Bead-pull measurements are being performed on a to scale aluminium prototype.
• Coupler ports present to allow verification of damping.
HiLumi LHC Public Session
16

First action in addition to R&D (LS1 - 2014)

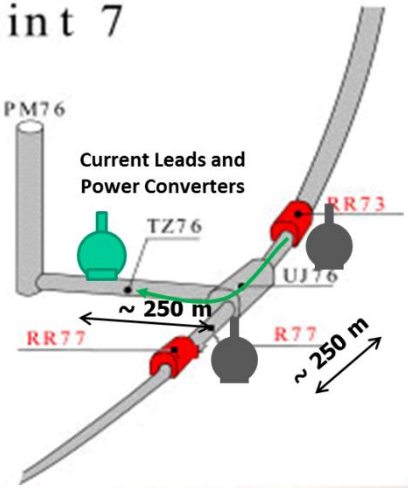
- Test Crab in SPS

Cold box
In BA4

- Horizontal SC link in P7: RR with many 600 A EPCs in RR just downstream betatron cleaning



Point 7



High Luminosity LHC

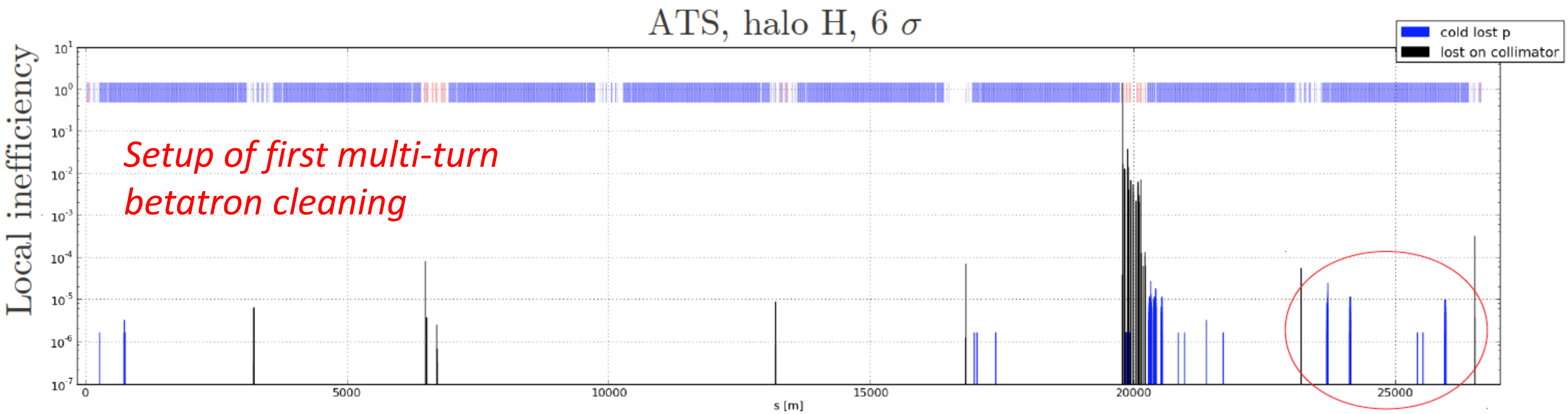
WP5-IR Collimation

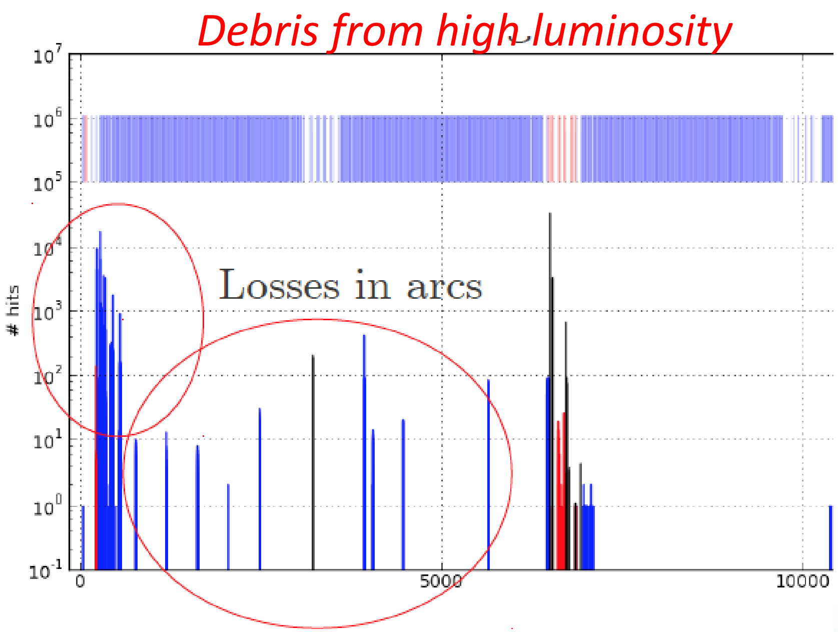
LHC Collimation Project
CERN

Stefano Redaelli for the LHC Collimation Project team

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Halo cleaning for HL-LHC optics





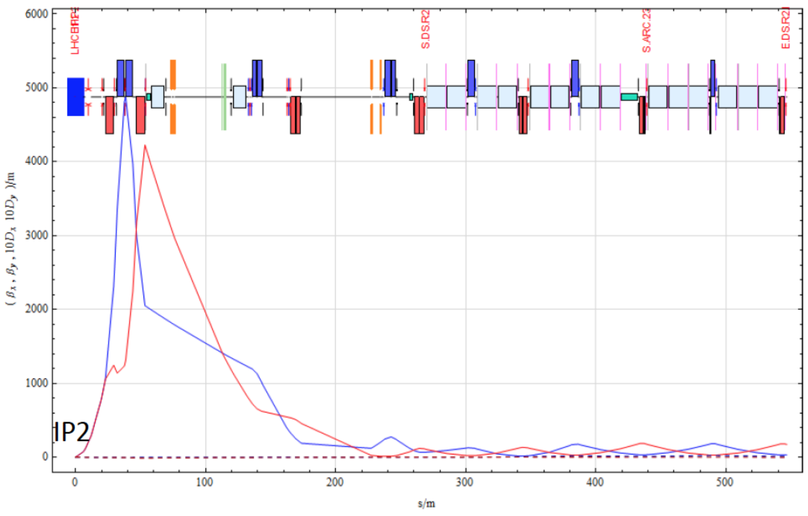
Setup of first complete loss maps with HL optics baseline (ATS for 15cm). Identified possible critical loss locations outside DS of IR7 -> need to improve the IR7 cleaning!

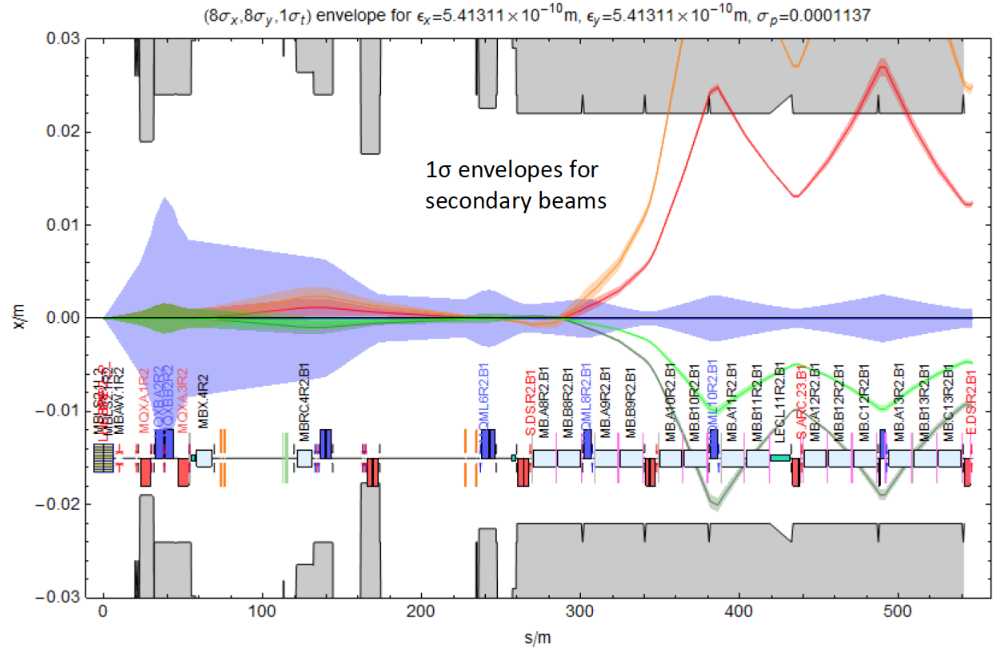
Simulation of physics debris losses for proton collisions.

A. Marsili, BE-ABP

Ions: collision debris cleaning in IR2

$E = 6.5\,Z$ TeV
$\beta^* = 0.5$ m (Nominal optics for 2019)
Half-crossing angle $p_y = 80\ \mu$rad





J. Jowett, BE-ABP

Proposed location for one dispersion suppressor collimators in cell 9 of IR2.
Ongoing: optimization of collimator material and length for ALICE luminosity upgrade.
Relying on 11 T dipole development for a possible installation in LS2.
Detailed comparisons ongoing against results of the LHC quench tests in Feb. 2013.

WP6-Cold Powering

Reserve Transparencies

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Milestones

- Demonstrate feasibility of the proposed cold powering system via the development of superconducting links and associated feedboxes and cold equipment. Develop and test a cold powering system incorporating SC-links operated in the horizontal and vertical configuration.
- Choose the most promising SC technology (MgB_2 vs YBCO and BSCCO) on the basis of cost/performance characteristics.
- Optimize and define cryogenic and electrical layout for cold powering system.
- Finalize integration of SC-link in the LHC machine (define need for surface buildings and civil engineering for new shafts).

High Luminosity LHC

SC links

Magnet: MS Q7 with it's DFB

Specific cryogenic studies and tests (or what differs from the LHC design ?)

- Cooling circuits for large heat deposition:
  - on 1.9 K cold masses up to 10 W/m
    → heat extraction from SC cables and quench energy margin
    → Generic heat flow in magnet cross section
  - on beam-screens up to 13-20 W/m (image current effect ?)
- Cooling of HTS SC links and current feed boxes
- Validation tests on SC link, crab-cavities, magnets, beam screens…
- Reactivation of the Heat Load Working Group
- Quench containment and recovery (cold buffering ?)
- Large-length cable (150 m) for cold-compressor controls and drives
- Large capacity (750-1500 W) sub-cooling heat exchangers
- Larger turndown capacity factor on 1.8 K refrigeration cycle: up to 10?

From users to cryogenic infrastructure

WP7-Machine Protection

Reserve Transparencies

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Progress and Issues

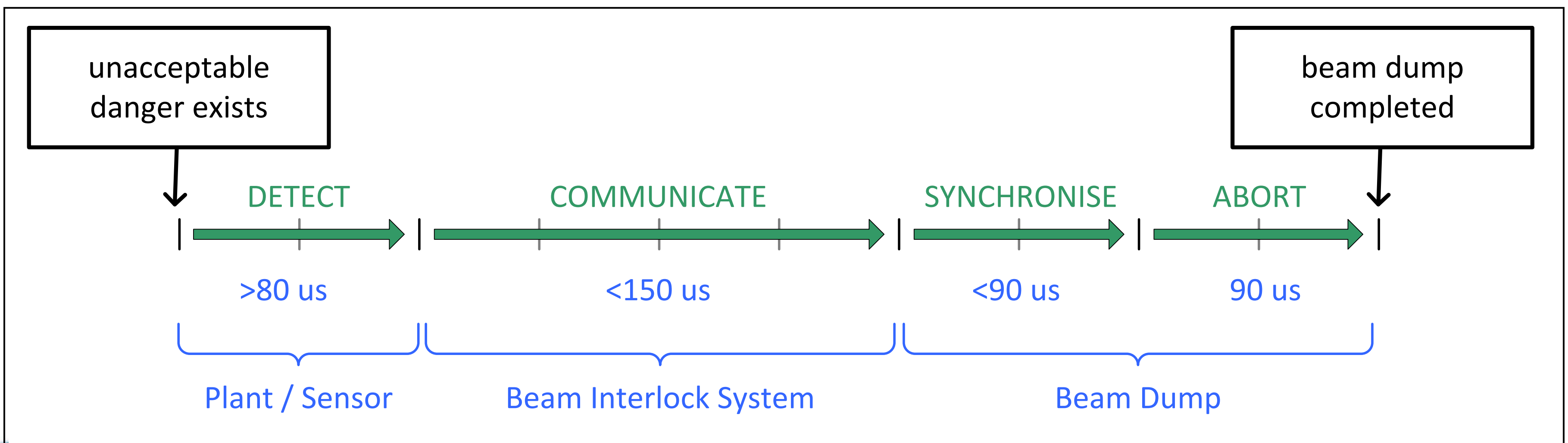
- Coordination of Machine Protection related issues through expertise in LHC Machine Protection Panel (MPP).
- LHC experience shows very well protected machine (several levels of redundancy) in absence of (very) fast kicker failures.

Identified list of main topics that are being addressed in view of HL-LHC

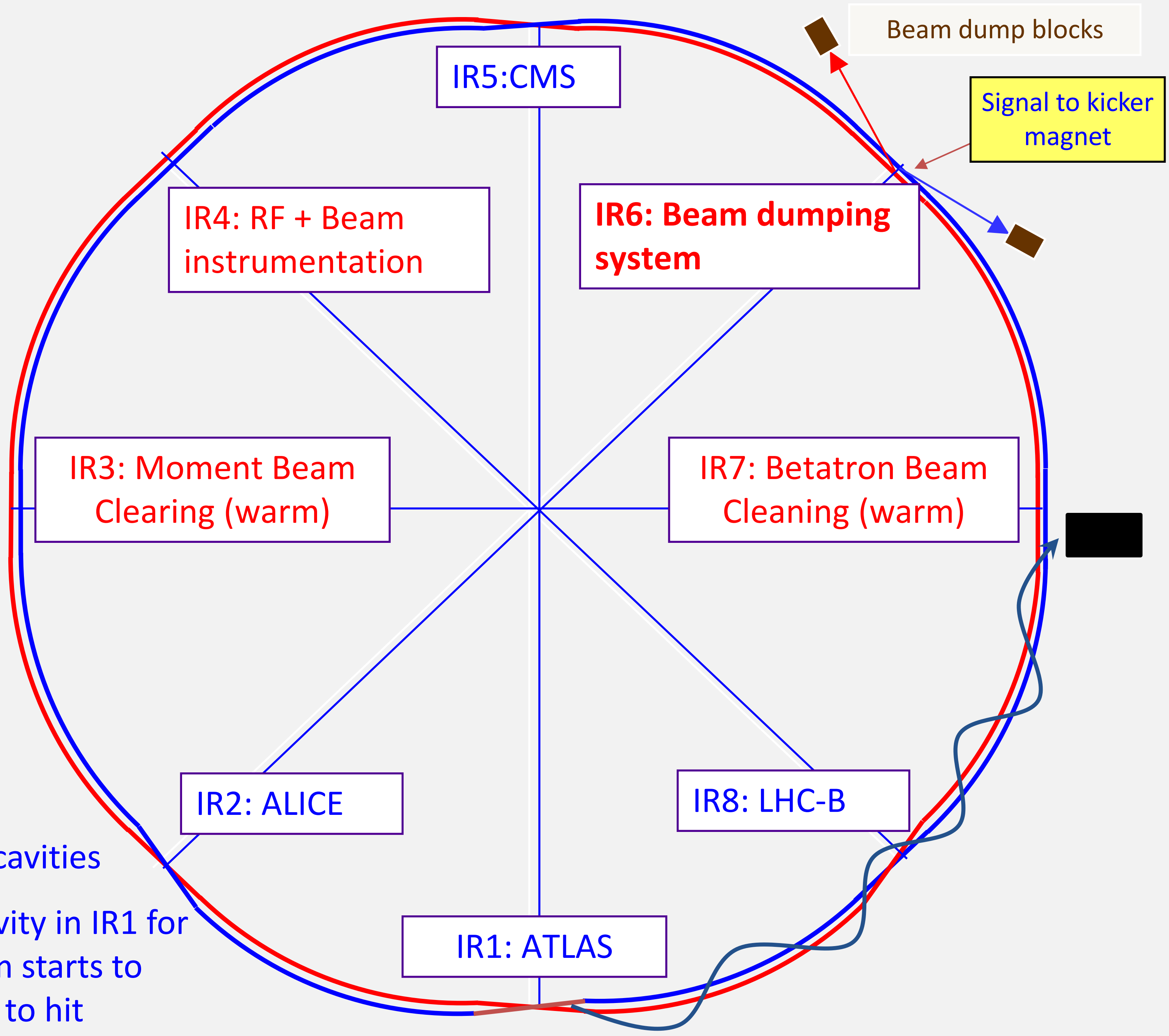
1. Crab cavities
   - might require to operate with beams that have limited number of particles in the tails
2. Machine Protection for beams without tails (or very weak tails)
3. Modification of powering system and impact on machine protection
4. Fast vacuum valves (not coupled to HiLumi LHC)

MP implications of crab cavities

- Machine protection needs to assume the worst case, in this case quenching of a one crab cavity in less than a turn
- MPS response by dumping the beams not sufficient for very fast failure cases that take only few turns of less
- For single cavity quench case, beam deflection leading to an amplitude of 1.7 σ, this requires, say, about 2 σ aperture margin



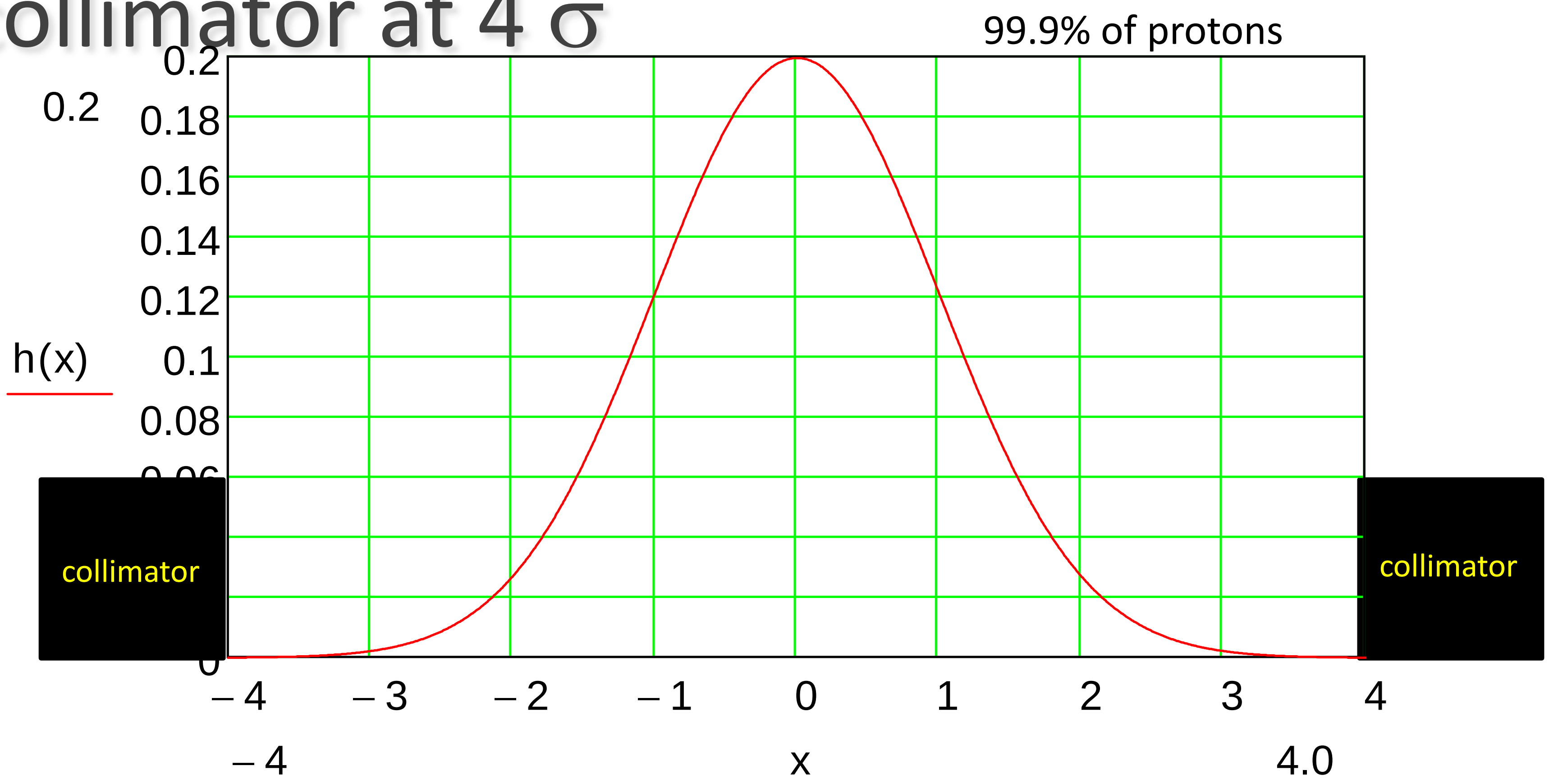
LHC Layout



Failure with crab cavities

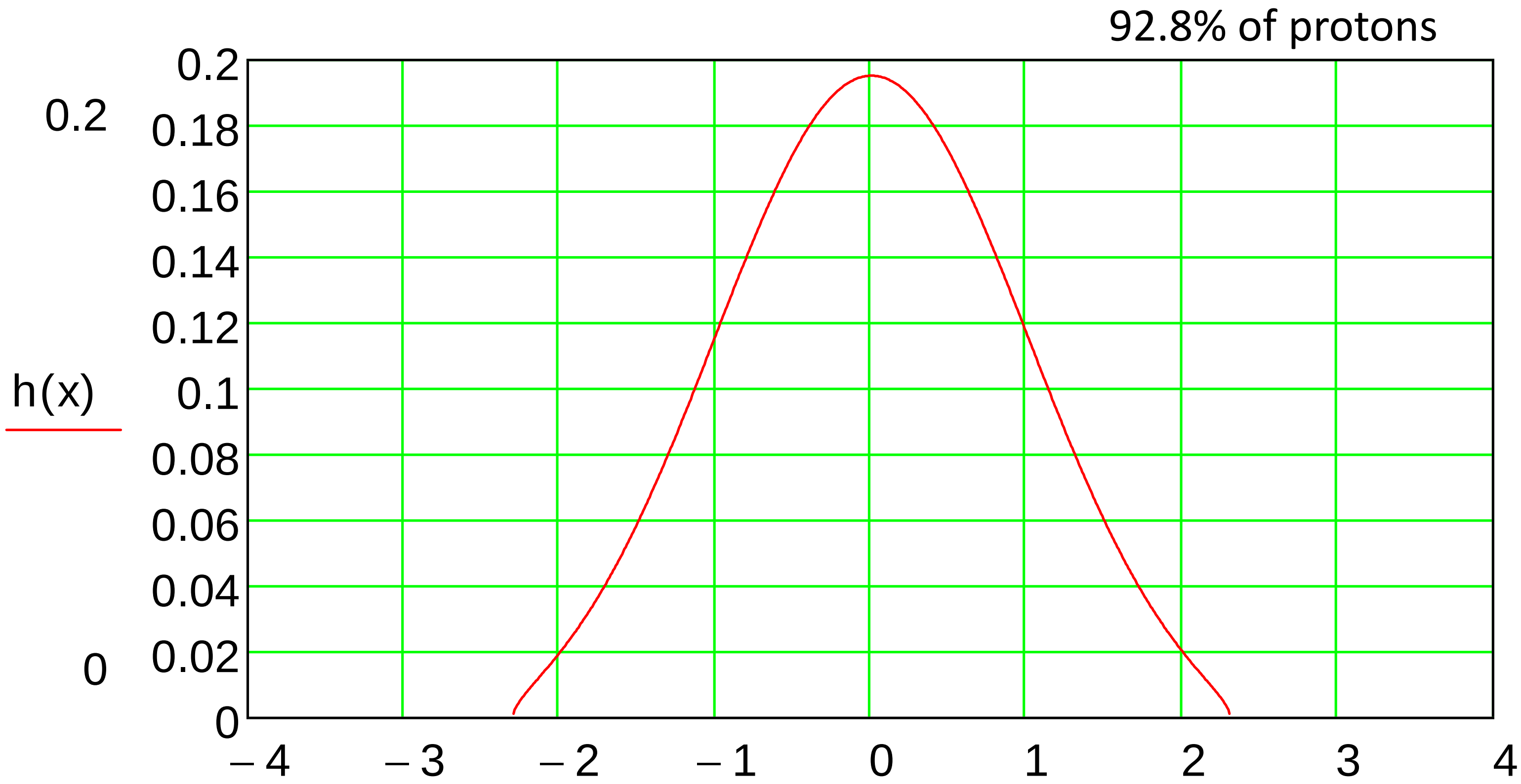
Assume trip of cavity in IR1 for beam 2. The beam starts to oscillate and risks to hit collimators in IR7.

Example: Gaussian beam with a collimator at 4 σ



Example: a collimator is positioned at 4 σ, and a crab cavity trips. The beam starts to oscillate with an amplitude of 1.7 σ. All particles beyond 2.3 σ are lost during a few turns.

Gaussian beam collimated at 2.3 σ



- Assume that the total energy stored in the beam is 500 MJoule
- Assume beam edge is close to the collimator at a position of 4.0 σ
- Assume a trip of a crab cavity (or another fast failure)
- Assume the that beam starts to oscillate with a maximum amplitude of 1.7 σ
- Assume that all particles above 2.3 σ are lost => corresponds to energy deposition of 35 MJ

Questions related to fast failures…..

- Is it realistic to assume that crab cavities can produce very fast failures?
  - Passive increase of τ for critical failures through LLRF and cavity design (available power, Qext,…) is vital for dependable MP
- If particle free aperture between collimators and beam of, say, two sigma is required….
  - Hollow electron lens for cleaning, or other halo cleaning techniques
  - Dependable measurement & interlocks on tail population
- Ideas for upgrade of protection systems
  - Dependable & fast detection of failures at/close to cavities (within sub μs)
  - Introduce direct links IR1/5-> IR6 for beam aborts?
  - Additional abort gaps?
- Other options
  - Position of the collimator further outside (between 5.5 and 6.0 σ)
  - Understand details of loss scenario, extract beam as fast as possible, possibly accept some damage to collimators if the probability is low (be aware of side effects)

Other studies

- Using diamond beam loss monitors for beam loss diagnostics + active protection, could gain in time between detection and dump by about 40 us
- Measurements and additional simulations to better understand quench behaviour of crab cavities should be undertaken
- Accept asynchronous dumps + local damage (e.g. new collimator materials and/or spare surfaces) ?
- Re-iterate (realistic) damage thresholds for different failure cases
  - E.g. protection against magnet powering failures (cold D1 at β* ~ 15km, new insertion layout)
  - Optics required to study failure scenarios
- Absence of long range beam-beam kick during beam dump on the other beam => to be watched out, but seems to be less critical
- Also to be addressed for higher beam intensity
  - Injection protection (TCDI, TDI, injection lines,…)
  - Dump protection (TCDQ,..)

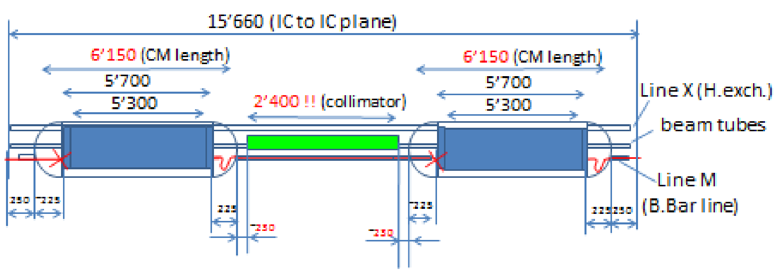
WP9-Cryogenics

Reserve Transparencies

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Collimation

Longitudinal layout (Option 3)



Collimator space reduced by 600 mm (w.r.t option 2)

First cold catcher tested FAIR 2011

WP11-11 Tesla 2-in-1 Dipole Magnets for the Dispersion Suppressor

Mikko Karppinen

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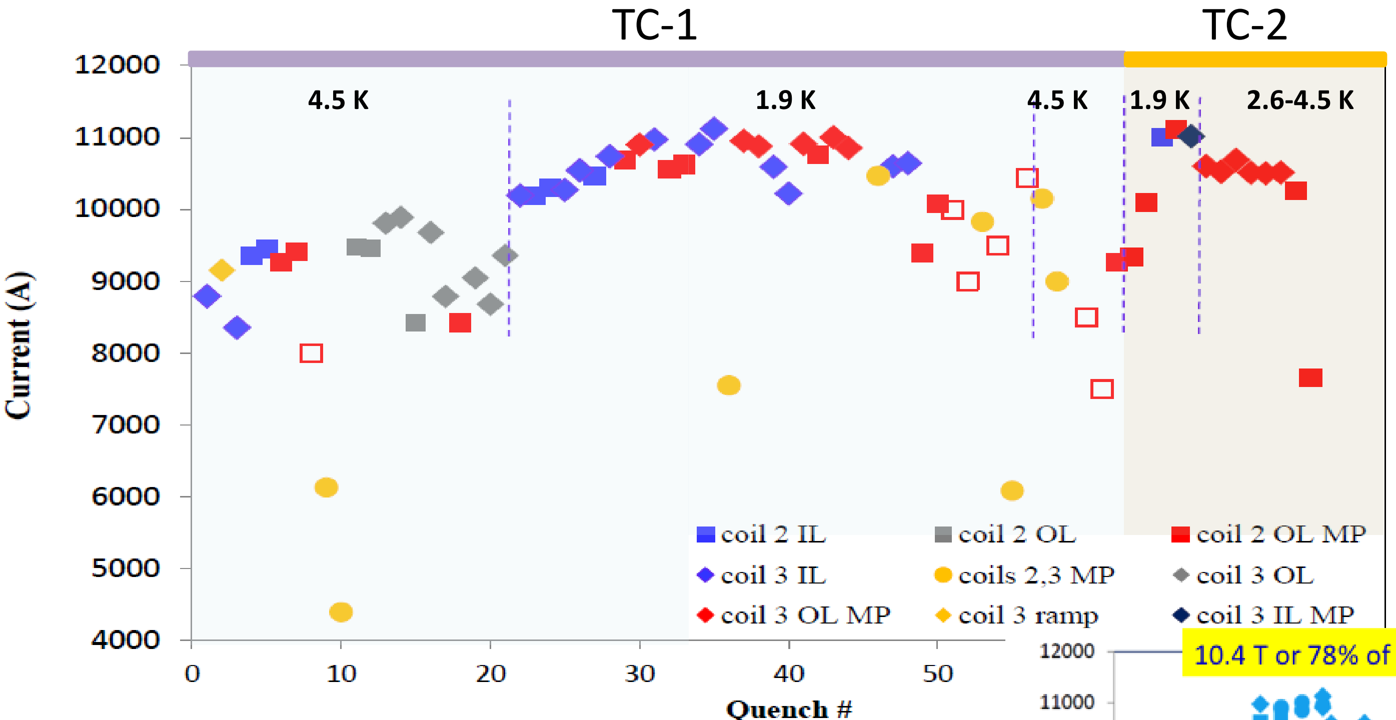
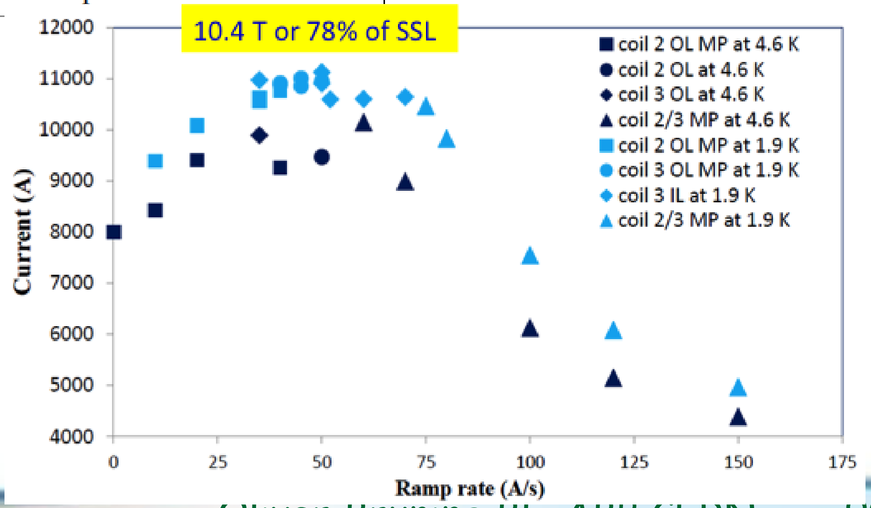
MBHSP01 Quench Performance

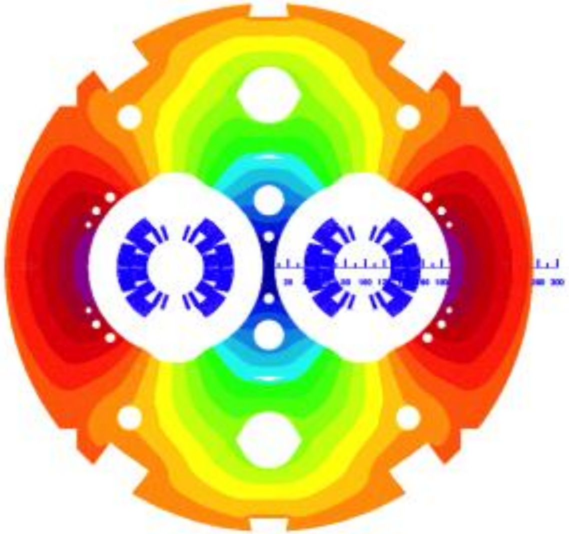


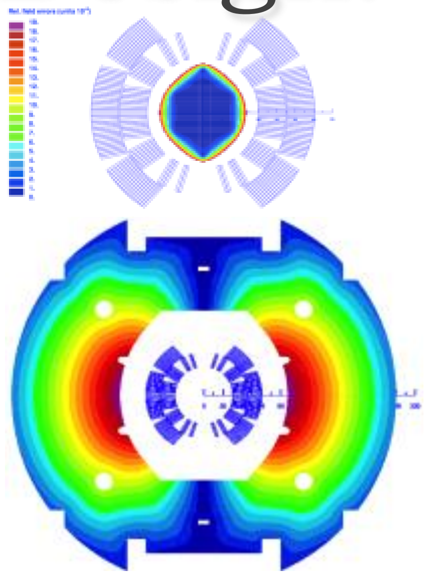


Limited quench performance:

- Magnet reached 10.4 T @ 1.9 K and 50 A/s
- Max. steady state current was 8 kA @ 4.6 K
- Strong inverse ramp-rate dependency points to conductor degradation on the outer layer near the splice.

11 T Dipole Design: FNAL + CERN

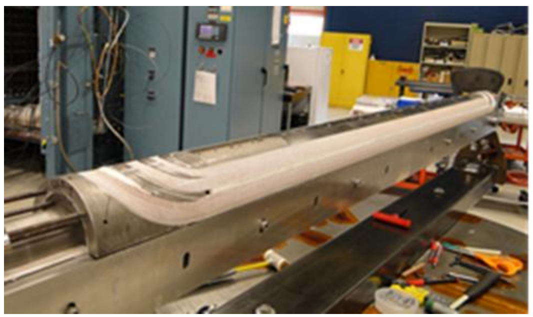




- 11.25 T at 11.85 kA with 20% margin at 1.9 K in
- 60 mm bore straight CM
- Systematic field errors below the 10^{-4} level
- 6-block design, 56 turns (IL 22, OL 34)
- 14.85-mm-wide 40-strand Rutherford cable, no internal splice
- Coil ends optimized for low field harmonics and minimum strain in the cable

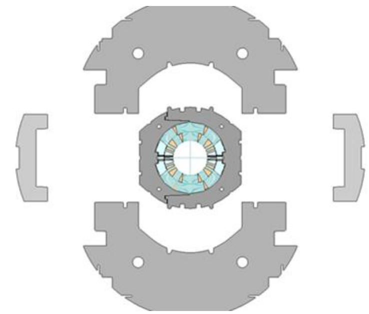
FNAL: MBHSP01 – 1-in-1 Demonstrator (2 m)

40-strand cable fabricated using FNAL cabling machine



Coil fabrication

Collared coil assembly



Cold mass assembly

Magnet development and fabrication was done in record time – 18 month!

High Luminosity LHC

WP12-11 Vacuum

Roberto Kersevan

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Main ACtivities

1) Increased synchrotron radiation (SR) fans due to the new orbits and higher magnet strenghts/gradients in the triplet areas (D2 to Q1) has been identified;

2) Need for additional shielding on the beam screen (BS) in order to reduce the power load generated by collision debris for the outgoing beam. FLUKA calculations show a peak power deposition in the Q1-Q2 area, making it mandatory the installation of a high-Z shield around the BS, or a thicker cold-bore on the Q1-Q2 SC magnets;

3) Increased internal diameter (ID) of the quadrupole triplet, fixed now at 150 mm for the coils. This calls for a new design of the BS. As a starting point a solution similar to the one proposed for the Phase-1 Upgrade has been evaluated;

4) SYNRAD+, a ray-tracing Montecarlo code, has been used to analyse the power deposition and calculate the photon-induced desorption profile in the triplet area (Q1 to D1, but including the radiation generated in D2 by the incoming beam);

5) Molflow+, a ray-tracing Montecarlo code, has been used to calculate the pressure profiles along the triplet area under a number of configurations: static vacuum, colliding beams, different pumping speed on the BS pumping slots;

Main Activities

6) The results of 4) and 5) have shown that the additional SR power generated by the off-axis beams is well within the limits of the cryogenic system.

- It should be noted that the mentioned photon flux is not going to contribute much to the dynamic gas load, even under the pessimistic assumptions of a high photon-to-molecule production rate coefficient, eta.
- For a unitary eta, the SR-induced outgassing rate would be 1.53E-7 mbar*l/s, distributed over a lenght of several meters, with effective pumping speeds of the BS pumping slots of ~670 l/s/m for H2. This would assure an average pressure better than the upper limit of 6.7E-10 mbar, which corresponds to the 100 hour beam lifetime from nuclear scattering on the residual gas;

7) Open issues and milestones: the vacuum group plans to develop a mock-up of the cold-bore and beam-screen before the end of 2013, in order to verify that the tight tolerances imposed by the need to maximize the space inside the BS for the HiLumi beams and their envelopes may be met. So far the magnet group has assumed a BS-to-CB clearance of only 0.5mm, which looks very challenging to meet if commercially available seamless tubes are used.

8) A decision on the use of special coating materials on the inside of the beam screen, such as amorphous-carbon, is left to tests which will be carried out after LS1 on the Coldex experiment in the SPS.