CERN

LHC PICs: what are we talking about?

A 2x mn overview

Preparation work by

- *Alignment: H.M. Durand*
- Beam Instrumentation: R. Jones
- Beam-Screen: R. Kersevan
- Collimation: A. Bertarelli, J. Jowett, S. Redaelli
- Cryogenics: L.Tavian
- *Cryostat: D. Duarte Ramos, V. Parma*
- Heat and radiation loads: F. Cerutti, L. Esposito
- Magnets : E. Todesco with contribution from P. Ferracin, G. Ambrosio and the whole LARP collaboration
- *QPS: R. Denz, D. Wollmann,*
- R2E: M. Brugger
- RP related matters: C. Adorisio, S. Roesler
- SC Link: A. Ballarino

All costs in CERN accounting, evaluation 2011.

No installation and infrastructures costs.

Performance Improvement Consolidation

Integrate luminosity 1000 fb^{-1} by 2035

Assumptions 10 years operations starting from 300 fb^{-1}

160 days of physics per year

Performance goals: PIC 70 fb^{-1} / year

PIC Scenarios 6.5 TeV

Momentum [TeV/c]	6.5
Bunch population in collision [10^{11} p]	1.38
Total RF Voltage	16
e_L*[eV.s] at start of fill	3.6
Bunch length (4 s)[ns]/ (r.m.s.) [cm]	1.33/10
Beam-beam separation [s]	14

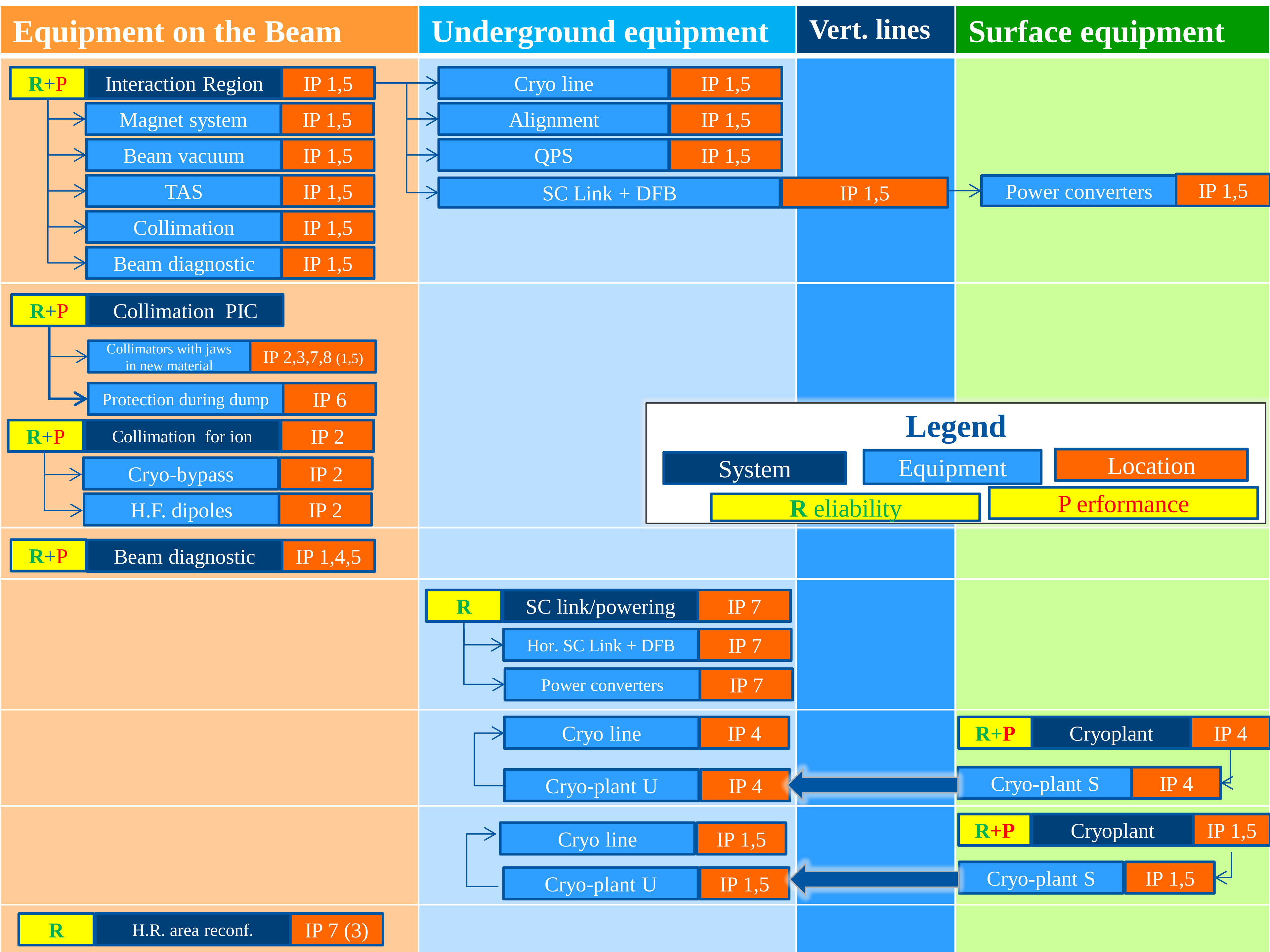
	$e^*_{n\ coll}$ [mm]	# Coll. Bunches IP1,5	Xing angle [mrad]	L_{peak} [10^{34} $cm^{-2}s^{-1}$]
BCMS – 40/20	1.85	2592	364	2.9
Standard - 40/20	2.25	2736	400	2.5
BCMS – 50/25	1.85	2592	326	2.7
Standard – 50/25	2.25	2736	360	2.3

PIC Scenarios 7 TeV

Momentum [TeV/c]	7
Bunch population in collision [10^{11} p]	1.38
Total RF Voltage	16
e_L*[eV.s] at start of fill	3.8
Bunch length (4 s)[ns]/ (r.m.s.) [cm]	1.33/10
Beam-beam separation [s]	14

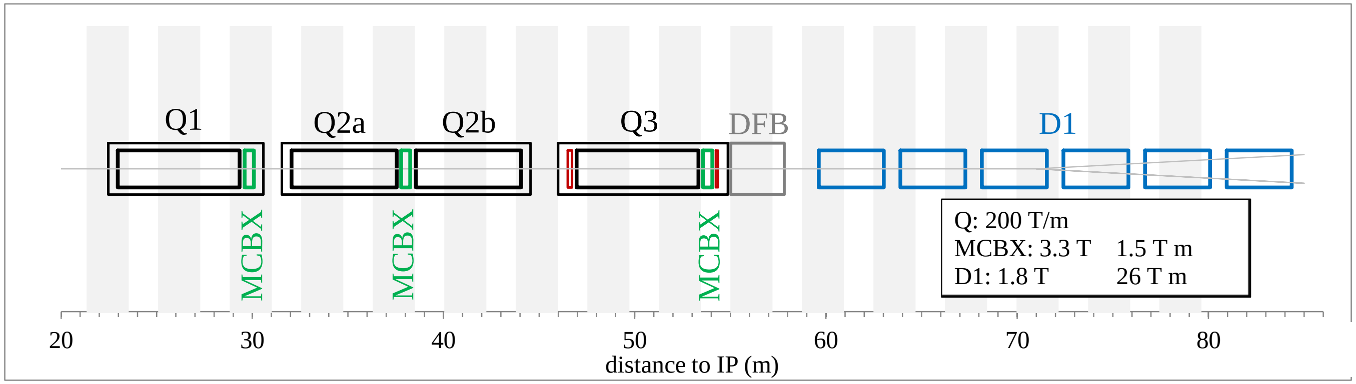
	$e^*_{n\ coll}$ [mm]	# Coll. Bunches IP1,5	Xing angle [mrad]	L_{peak} [10^{34} $cm^{-2}s^{-1}$]
BCMS – 40/20	1.85	2592	351	3.1
Standard - 40/20	2.25	2736	387	2.7
BCMS – 50/25	1.85	2592	315	2.9
Standard – 50/25	2.25	2736	347	2.5

- **See Talk of G. Arduini**
- All hardware shall be compatible with the 7 TeV operation


Equipment on the Beam
Underground equipment
Vert. lines
Surface equipment
R+P
Interaction Region
IP 1,5
Magnet system
IP 1,5
Beam vacuum
IP 1,5
TAS
IP 1,5
Collimation
IP 1,5
Beam diagnostic
IP 1,5
Cryo line
IP 1,5
Alignment
IP 1,5
QPS
IP 1,5
SC Link + DFB
IP 1,5
Power converters
IP 1,5
R+P
Collimation PIC
Collimators with jaws in new material
IP 2,3,7,8 (1,5)
Protection during dump
IP 6
R+P
Collimation for ion
IP 2
Cryo-bypass
IP 2
H.F. dipoles
IP 2
Legend
System
Equipment
Location
R eliability
P erformance
R+P
Beam diagnostic
IP 1,4,5
R
SC link/powering
IP 7
Hor. SC Link + DFB
IP 7
Power converters
IP 7
Cryo line
IP 4
Cryo-plant U
IP 4
R+P
Cryoplant
IP 4
Cryo-plant S
IP 4
Cryo line
IP 1,5
Cryo-plant U
IP 1,5
R+P
Cryoplant
IP 1,5
Cryo-plant S
IP 1,5
R
H.R. area reconf.
IP 7 (3)

INTERACTION REGION MODIFICATION AND RELATED CHANGES

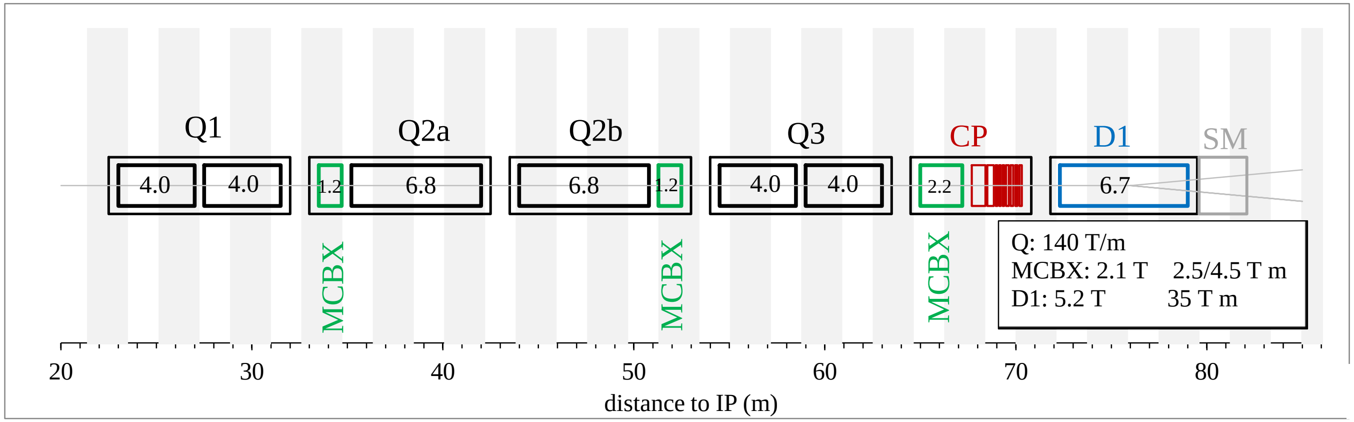
Layouts



LHC

[E. Todesco]

Aperture ~twice the LHC baseline (70 mm to 150 mm), but more compact triplet layout thanks to Nb_3Sn and superconductive D1

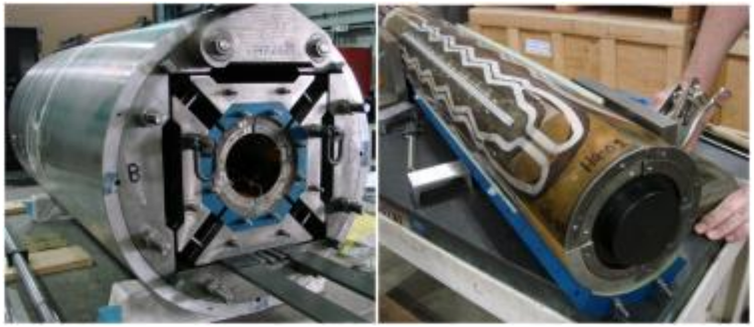


HL LHC

[E. Todesco]

Quadrupoles

- Triplet made with Nb_3Sn technology
  - Long history of development in US, since 2002 (LARP)
    - 120 mm aperture 1 m long model HQ reaching most of the specifications (FQ, performance,…)
    - 90 mm 3.4-m-long model LQ (first long Nb_3Sn coils) succesful
  - HQ performance similar to MQXC (Nb-Ti twin of HQ)



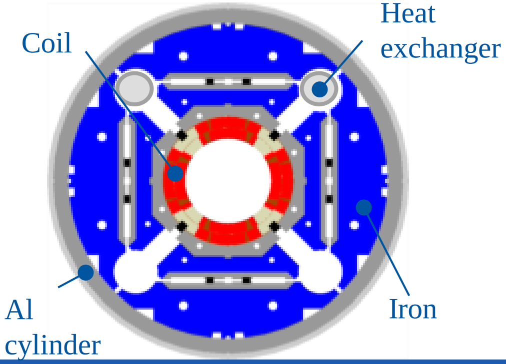
HQ magnet, 120 mm aperture with final structure

[LARP]

LQ magnet, first 3.4 m long Nb_3Sn magnet

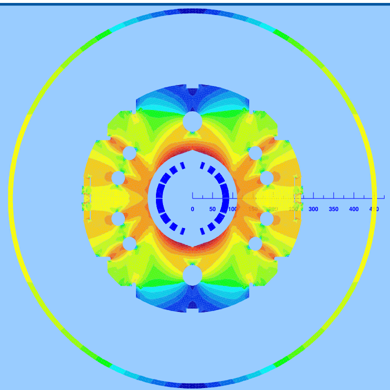
Production shared between US and CERN

[P. Ferracin]



QXF cross-section

Other magnets of the interaction region



D1 cross-section, with cryostat
(Q. Xu, T. Nakamoto)

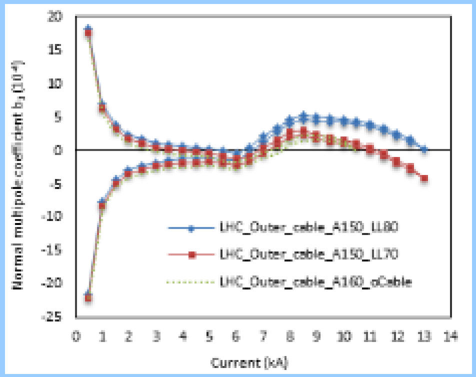
D1

Increase kick from 26 to 35 T m

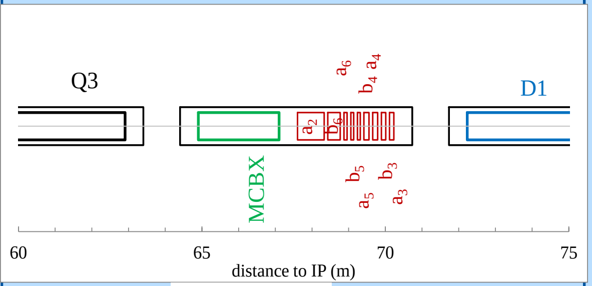
- Nb-Ti technology, ~5 T operational field, ~7 m long
- Challenging field quality, large saturation

Collaboration with KEK (Japan)

- 1st deliverable: one short model by 2015



D1 b3 versus current
(Q. Xu, T. Nakamoto)



[E. Todesco]

Correctors

Orbit correctors:

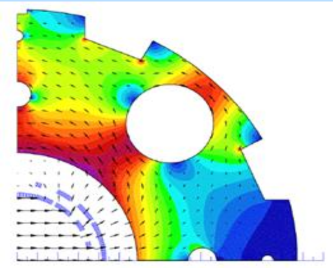
- 2.5 T m at Q1 and Q2, and 4.5 T m at Q3, both H and V
- Nb-Ti technology, nested option to save space (4 m)
- 2.1 T field, giving 1.2 and 2.2 m long magnets
- Collaboration with CIEMAT (ES)

  1st Deliverable: one 1.2-long-magnet in 2016

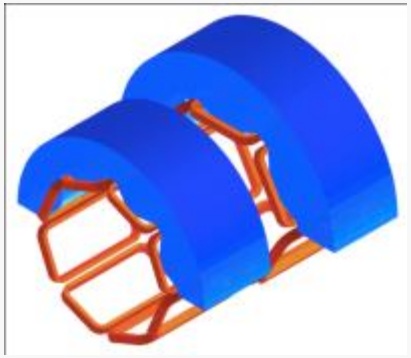
Nonlinear correctors:

- Superferric option, not nested
- Easier operation, short heads, low current
- Typical lenght 15 cm, skew quad 80 cm
- Collaboration with INFN (Italy)

  1st Deliverable: B_2, B_3, B_4, B_5, B_6 correctors by 2016



Proposal for nested MCBX
(M. Karppinen, D. Smekens)



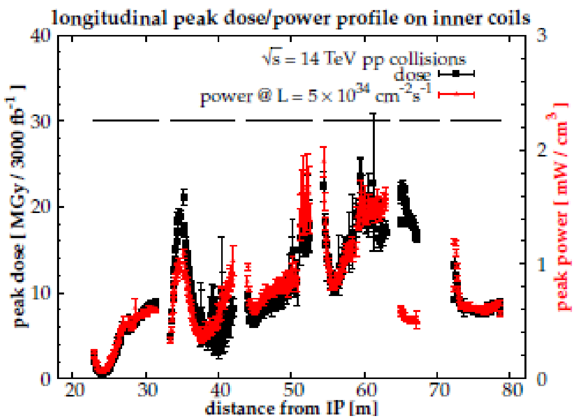
Proposal for nonlinear correctors (F. Toral)

Shielding and beam screen

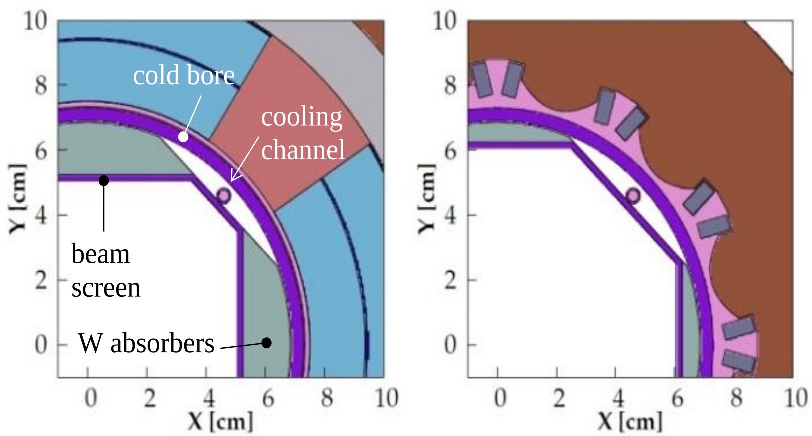
Key element is a shielding to bring radiation dose and heat load down to LHC baseline

- For 1000 fb^{-1} it limits the radiation to the coil to 10 MGy (safe, limit at 30-50 MGy)
- For 3×10^{34} cm^{-2} s^{-1} peak lumi one has 1.5 mW/cm^3 (safe, quench limit at 4 mW/cm^3 in LHC)
- Apart from structural elements we have 6 mm W inserts
- That's a challenging piece – model should be realized in 2014

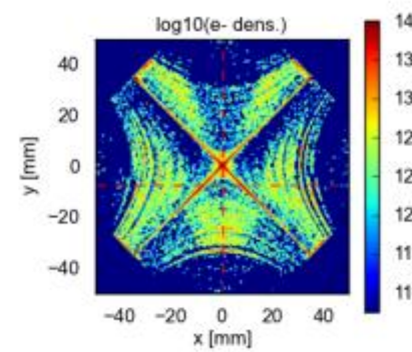
- The large aperture provides the space to insert adequate shielding and to think to mitigation action for e-cloud (in addition to the other e-cloud elimination action already part of the HL-LHC) (see G. Arduini).
- Optimization of cooling design to be completed



Radiation dose and heat load [Cerutti, Esposito]



Beam screen in the triplet and in the correctors[Kersevan]

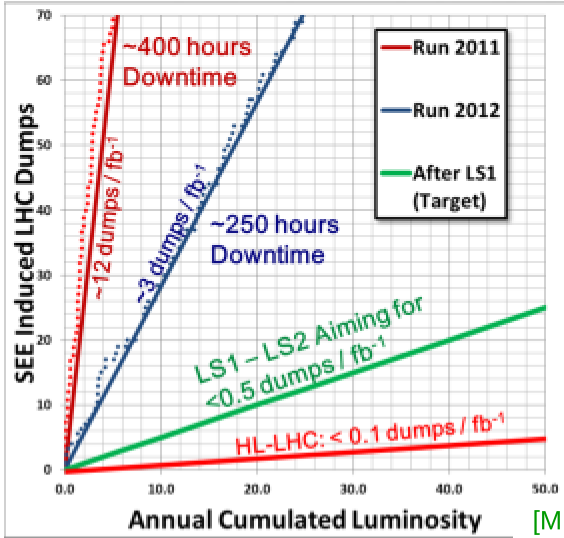


[G. Iadarola]

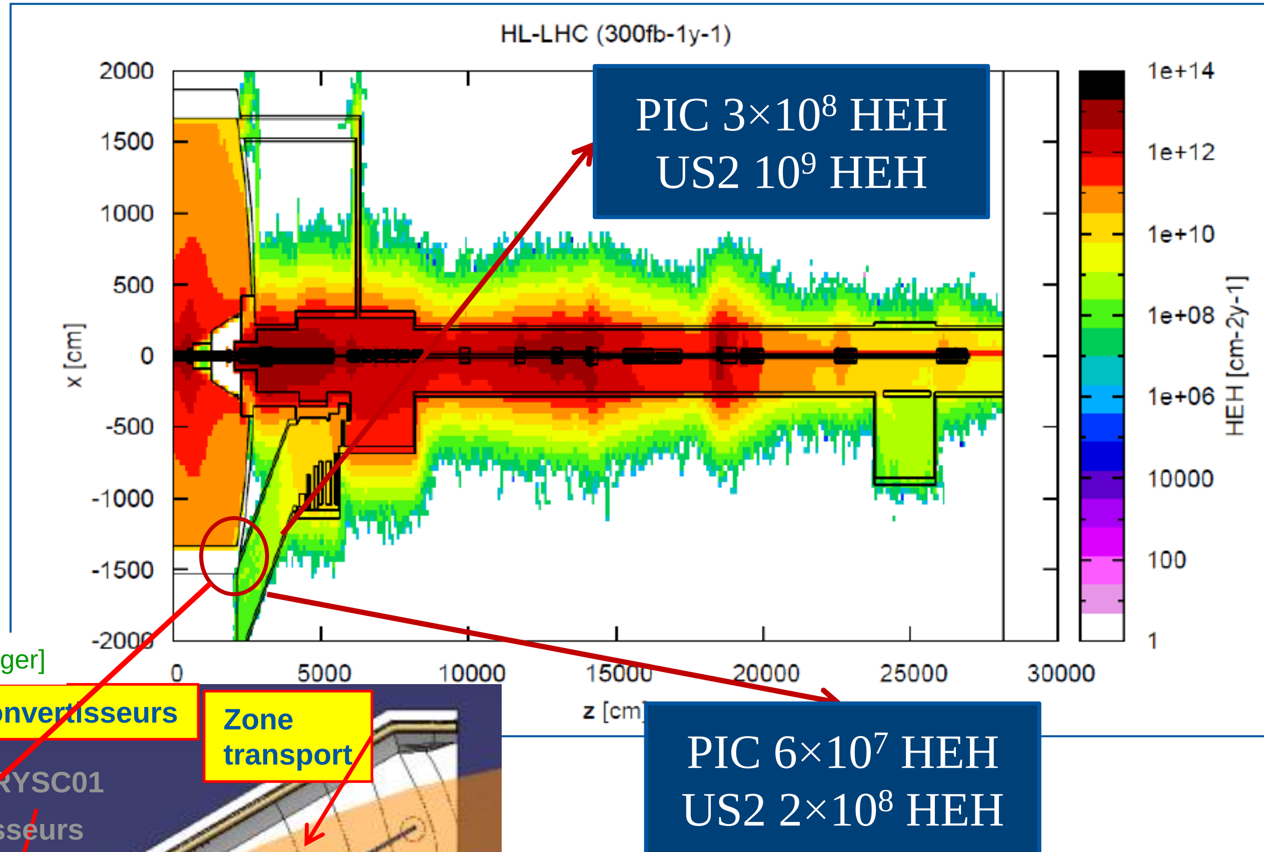
Beam Instrumentation

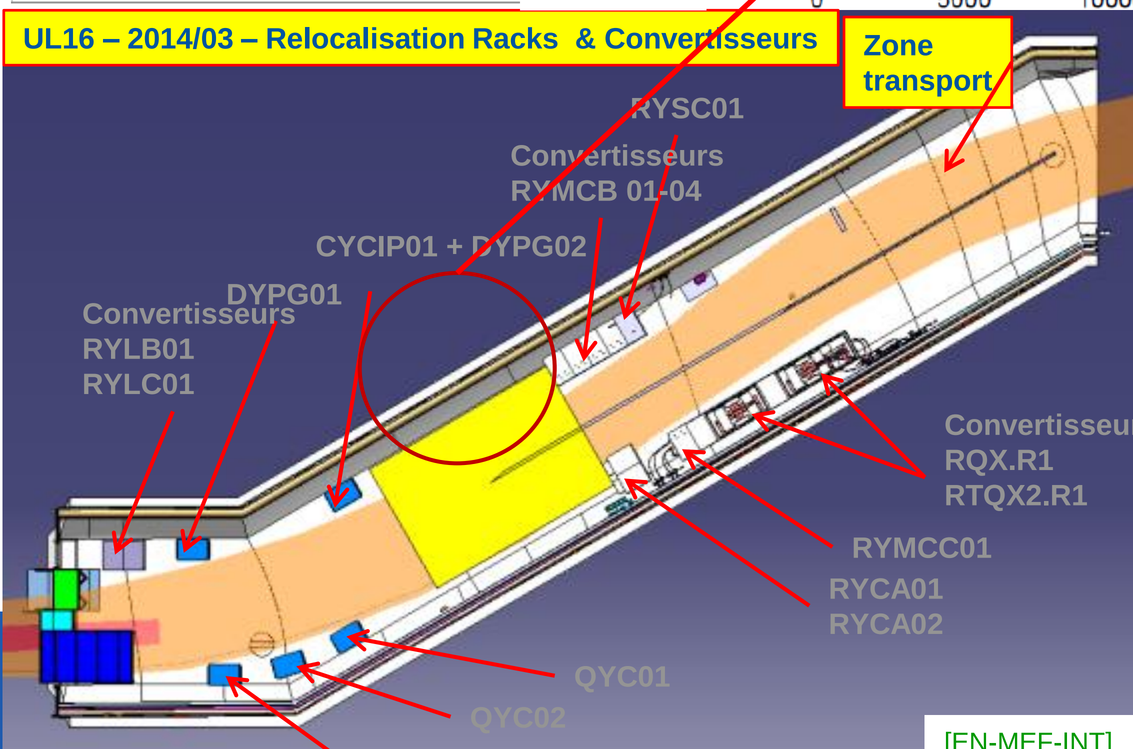
- **Cryogenic BLMs**
  - Current LSS configuration not suitable for HL-LHC
    - Cannot distinguishing dangerous losses from collision debris
  - Detectors for cryogenic environments studied
    - To be placed inside cryostat of the new triplet magnets
    - Dose measured more accurately represents correspond dose deposited in the coils
  - This builds on the
    - Radiation hard electronics (see later)
    - BLM electronics consolidation (see later)
- **New BPMs Q1 to Q5**
  - New design required for new triplet layout
    - Need to minimise transverse impedance
    - Need for tungsten alloy shielding

IR Powering



[M. Brugger]





[EN-MEF-INT]

During last year of operation we had a number of radiation induced failures at 10^8 -10^9 HEH

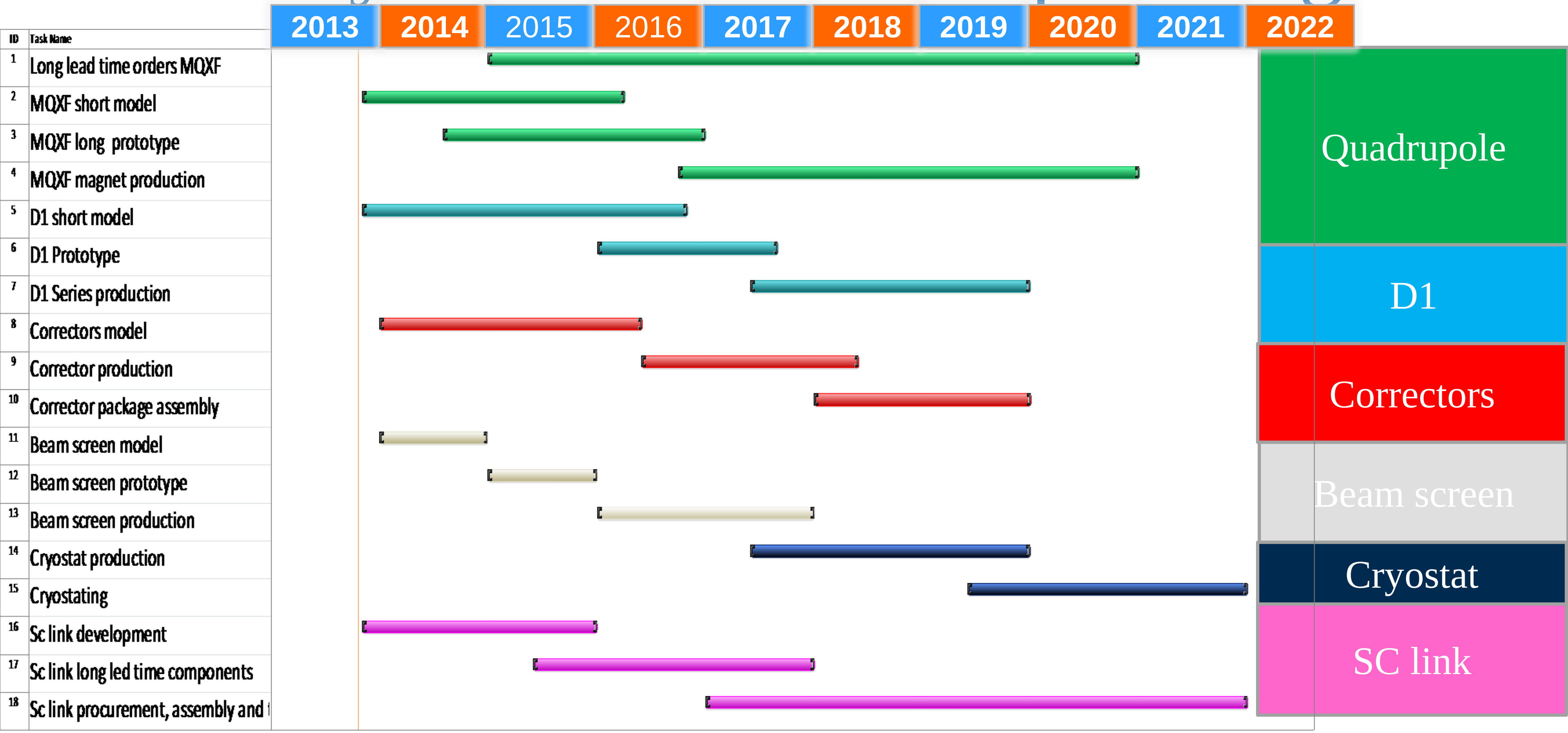
Below 10^7 HEH failures unlikely

HEH: High Energy Hadron fluence

Superconducting Links at P1 and P5 interaction region magnets

- **Two Superconducting Links** per point – from surface to underground areas
- New DFBs installed in **at the surface** **(added value to reduce personal exposure to radiation)**
- Integration studies started
- Need for **civil engineering** to be verified – integration studies in 2014.
- R&D in progress
- Test of full system (DFB and SC Link) at CERN in **2015**
- Installation in LHC during **LS3**
- Procurement of series to be started by end **2016**

Few key data for cost and planning



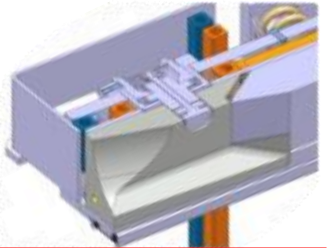
Item	Estimated Cost
Magnet system+TAS	210 MCHF
QPS	3 MCHF
Instrumentation	See later instrumentation chapter
Collimation	See later collimation chapter
SC links	31 MCHF+3 MCHF infrastructures+ 6 MCHF Power Converters

COLLIMATION

DECISIONS RELATED IMPEDANCE ISSUES AND IR7 CLEANING ARE LINKED TO THE OPERATIONAL EVIDENCES AT 6.5 TEV, IN PARTICULAR IP 7 REQUIREMENTS, SEE US1.

"…EXTRAPOLATION OF THE COLLIMATION PERFORMANCE FROM 4TEV TO 7TEV BASED ON COLLIMATION QUENCH TESTS AND ACCOMPANYING SIMULATIONS HAS A NUMBER OF UNCERTAINTIES, …" FROM THE RECOMMENDATION OF THE MAY 2013 COLLIMATION REVIEW

PIC Collimation



Insertion region		Performance - cleaning	Performance - impedance	Performance - beta*, effic.,	Radiation wearing	Mechanical wearing	General spare policy	CONS	HL: PIC
IR7: Betatron cleaning	TCP			(X)	X	X	X	6	
	TCSG		X	X	X	X	X	22	
	TCLA			(X)	X	X	X	10	
	TCSM	(X)	X	X					22
	TCLD	X	(X)						
	TCAP					(X)	X		
IR3: Momentum cleaning	TCP			(X)		X	X	2	
	TCSG		(X)	X		X	X	8	
	TCLA			(X)		X	X	8	
	TCSM								8
	TCLD	X							
	TCAP						X		
IR6: beam dump	TCSG						X		
	TCSP						X	2	
	TCDQ								
	TCLA								4
IR1/5: High-lumi experiments	TCTH/V						X		
	TCTPH/V						X		4
	TCTPX								4
	TCL	X					X	12	
	TCLD	X							
IR2: ALICE and B1 injection	TCTH/V						X		
	TCTPH/V						X		
	TCTPX								2
	TCLIA/B						X	1	
	TDI								
	TCDD						X		
	TCLD -IONS	X							2
IR8: LHCb and B2 injection	TCTH			X		X	X		
	TCTVB			X		X	X		
	TCTPH/V					X	X		
	TCTPX			X					2
	TCLIA/B					X	X	1	
	TDI								
	TCLD								
	TCL								
IR4: RF	--	X							
TI2/TI8	TCDIH/V					X	X		


[A. Bertarelli]

Inermet 180, 72 bunches

Up to 30 units with jaws in Mo-Gr, Mo coated to provide collimation with reduced impedance. Installation staged from 2016 (1 proto).
Collimator equipped with BPM therefore fully functional from LS2

Q4 and Q5 protection during dump

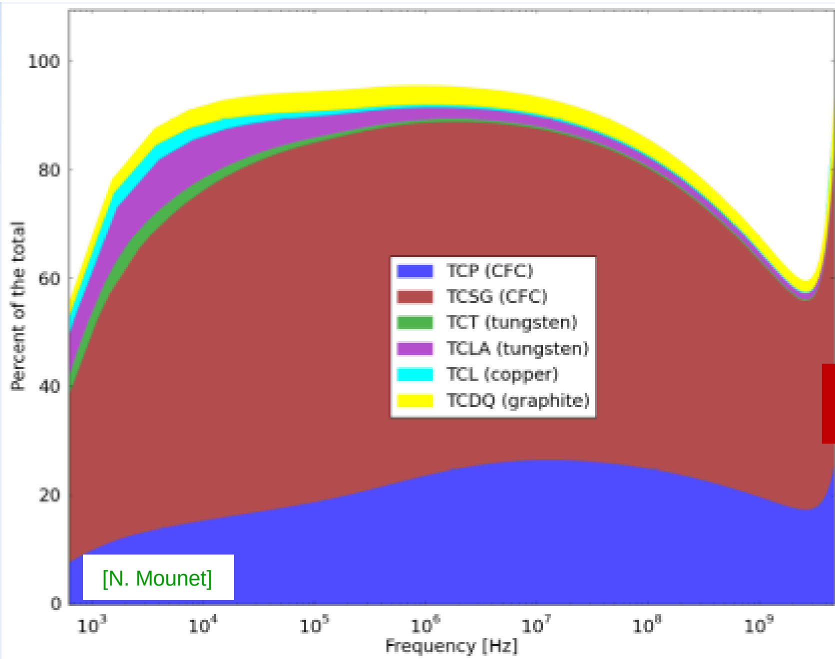
Interaction region
1) Displace the 12 TCL
2) Add 2+2 horizontal collimator in more robust material
3) Add 2+2 vertical collimators to protect Q4 and Q5

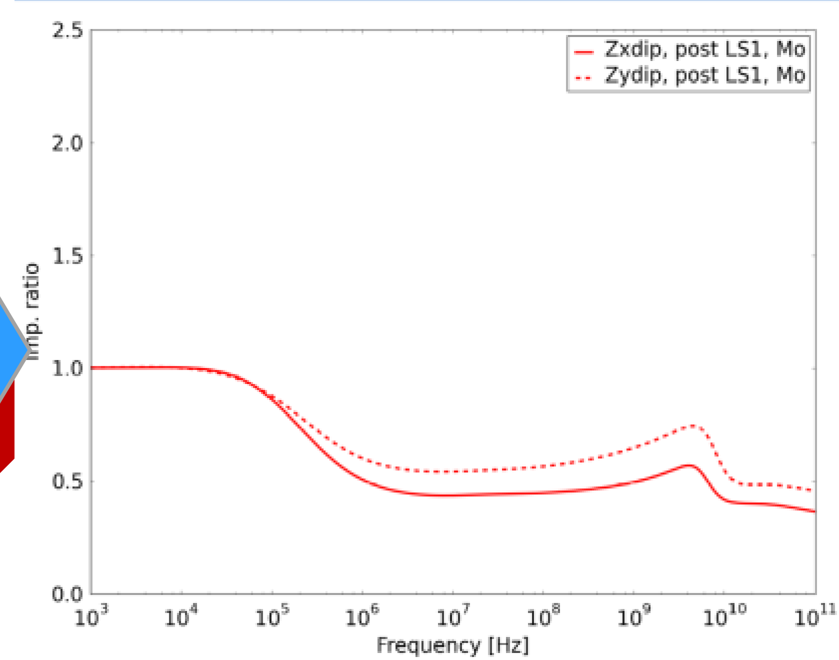
2 TCT horizontal built with more robust material

2 TCLD to protect magnet in the DS during the ion run

2 TCT horizontal built with more robust material

Program for impedance reduction

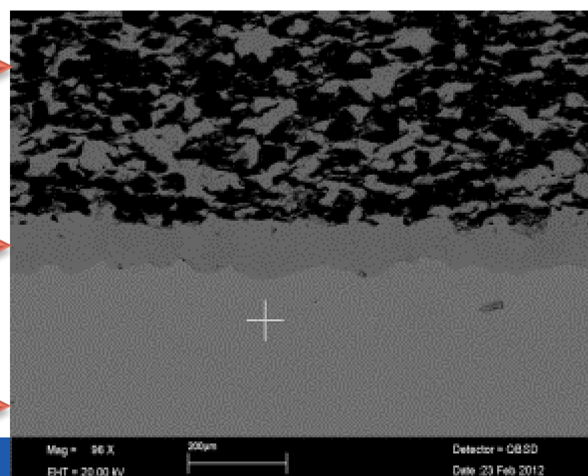




Core:
1 MS/m

Carbide layer:
1.5 MS/m

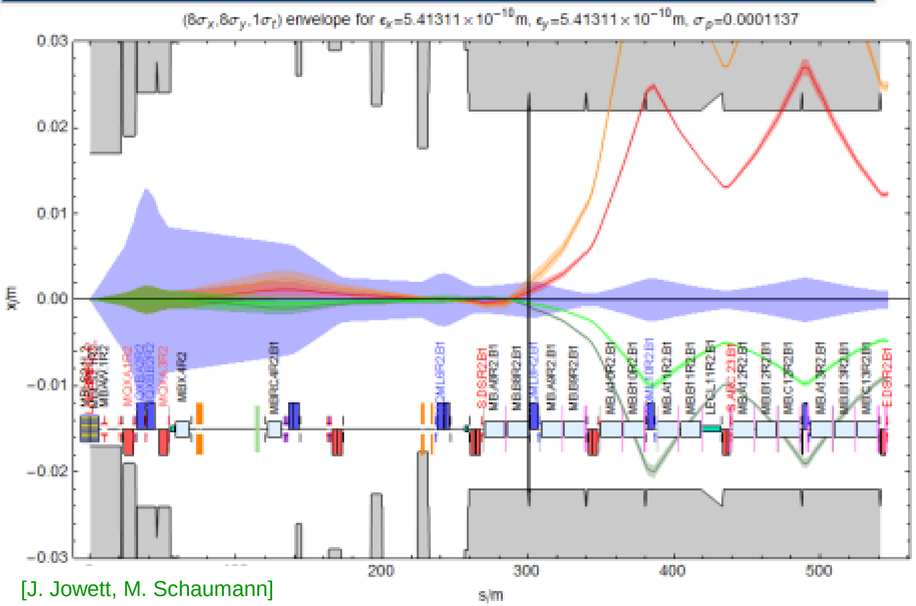
Mo Sheet:
18 MS/m



Ions at point 2 *(see J. Jowett talk tomorrow)*

(same physics and problem in IP1 and IP5, needs linked to the chosen operating scenarios)

Peak luminosity



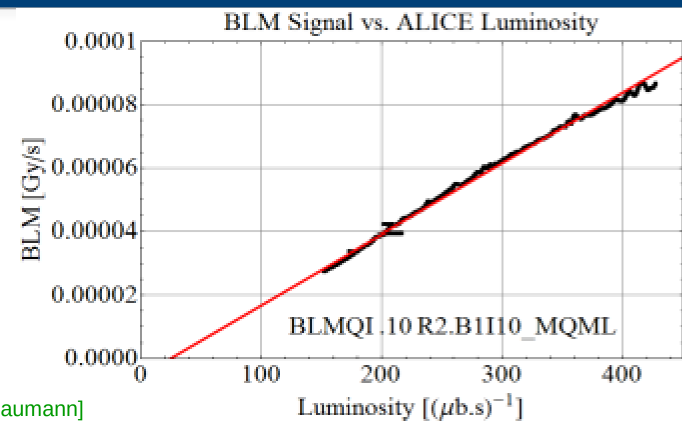
[J. Jowett, M. Schaumann]

Cannot separate BFPP and main beam in warm area (TCLs not useful)
.BFPP beam is smaller than main beam (source is luminous region).

ALICE upgrade luminosity goal for post LS2 is 6×10^{27} cm^{-2} s^{-1} nb^{-1}, 6 times the design value.
P_{BFPP1} =155W. Maximum power density in coil at 7 Z TeV P=15.5 mw/cm^3 (design luminosity)
For upgrade luminosity P=93.3 mw/cm^3 expected respected to the estimated dipole quench limit of 25-50 mW/cm^3 [MB-MQ]

[J. Jowett, M. Schaumann]

Integrated luminosity



[J. Jowett, M. Schaumann]

ALICE upgrade luminosity goal for post LS2 is 10 nb^{-1}, 10 times the 1st phase, 10 nb^{-1}/y
Estimated dose of the most exposed dipole coil of 2.2 MGy/nb^{-1} for a total of 22 MGy

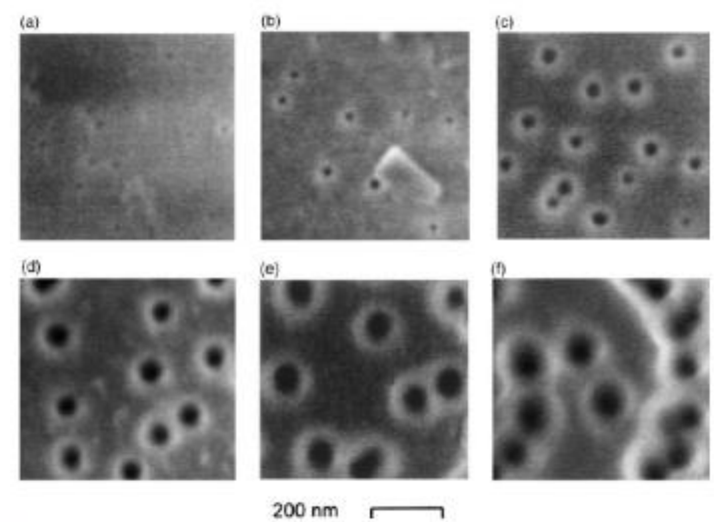
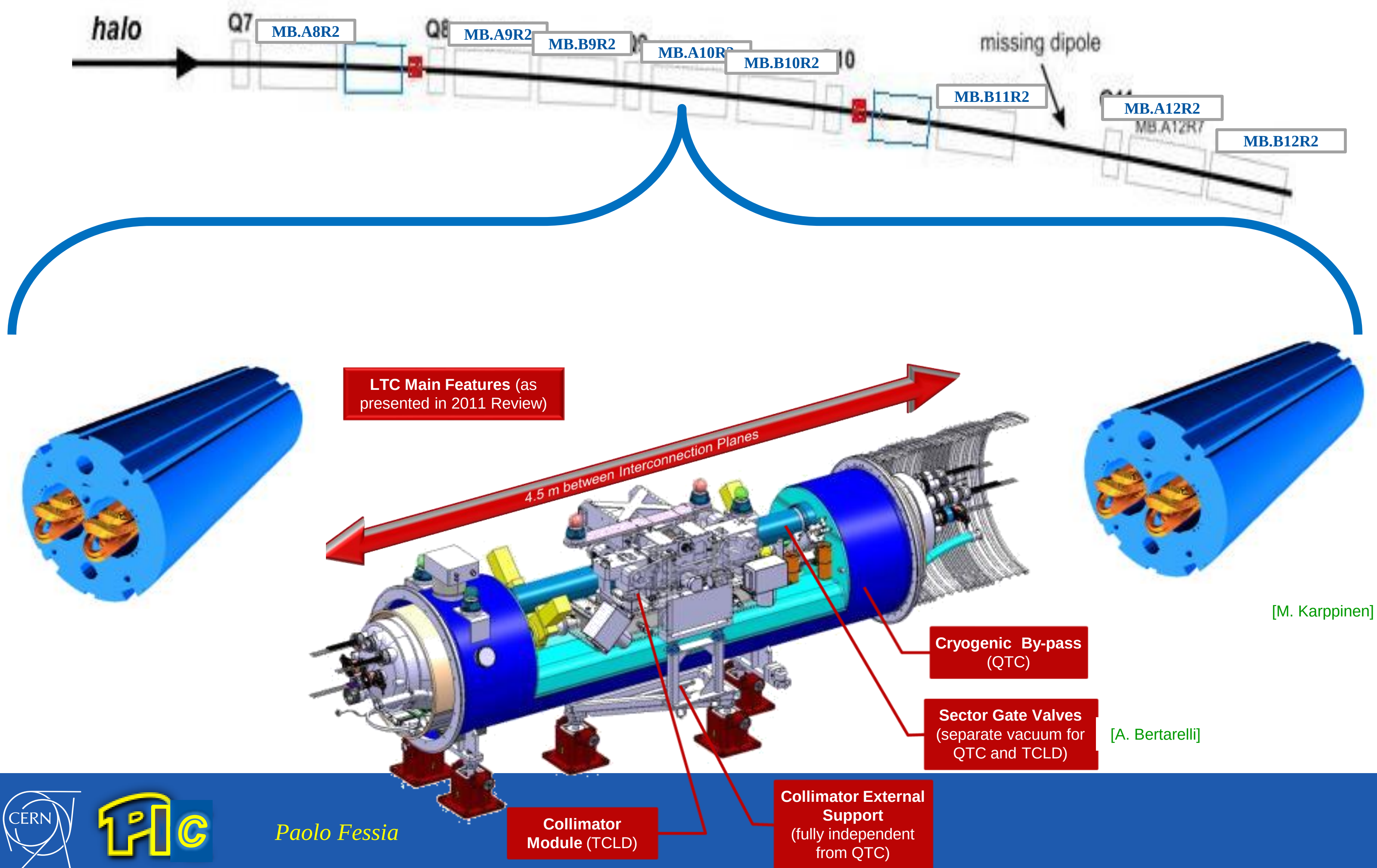


Fig. 1. HRSEM images of etched ^{238}U-ion tracks in polyimide. The etching times of the samples displayed in panels (a), (b), (c), (d), (e) and (f) were 40 s and 1, 2, 3, 4 and 5 min, respectively.

Integrated technological solution for point 2

(same solution deployable in IP 7 in case of need)



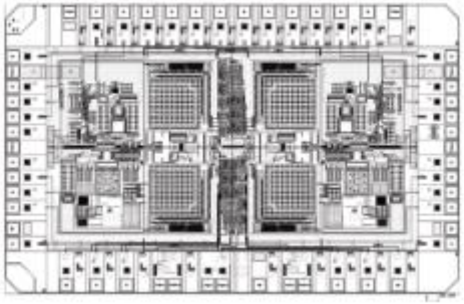
Few key data for cost and planning

- Costs
  - Collimation in warm section
    - Collimators about 0.5 MCHF/unit-> 23 MCHF for the 46 foreseen units (upper bound). Strongly affected by the final choices by the scale up cost reduction of material for jaws and by the embarked rad hard electronics
  - Collimation in cold sections
    - Collimator TCLD: 0.5MCHF/unit-> 1 MCHF for 2 units in point 2
    - Cryo-bypasses for the TCLD: 0.8MCHF/unit-> 1.6 MCHF for 2 units in point 2
    - D11 T: 2×8.5 MCHF/unit-> 17 MCHF
    - Total ion collimation IP2: 20 MCHF
- Main planning milestones
  - Collimation in warm section
    - Parameter to be fixed 5 years before installation
    - From decision of launching series production 3 years to get all the units at CERN (remarked possible staged installation, 1st unit at CERN after 2 years)
  - Collimation in cold section
    - TCLD including cryo-bypasses
      - 4.5 years before installation start proto phase
      - 3.5 years before installation place long lead component orders
      - 2.5 years before installation start assembly to be completed 6 month before installation
    - End 2014 define if other strategies for IP2 are necessary (i.e. study magnet displacement)
    - Beginning 2015: launch final Nb_3Sn conductor production
    - Final D11 T model validation July 2015
    - Cold mass assembly mid 2016->August 2018 (including tests)

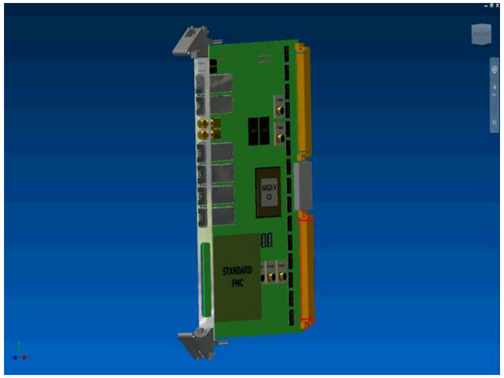
BEAM DIAGNOSTIC

Beam Instrumentation

- **Radiation Hard Electronics**
  - 7TeV quench levels close to noise level of the acquisition system (IR3/IR7/LSS)
    - Due to long cables from detectors to front-end electronics
  - Development started on radiation hard Application Specific Integrated Circuit (ASIC) to remove need for such cables



- **Consolidation of BLM Electronics**
  - Replacement of surface electronics with new digital acquisition system
  - Allows additional BLM functionality not possible with today's system
  - Proposed for 2014-2018 using CONS budget



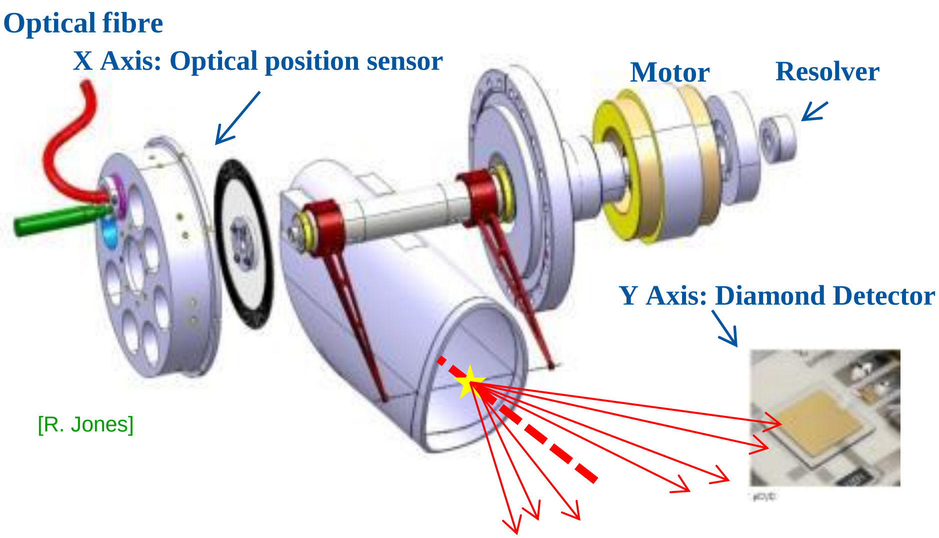
- **Upgrade to Synchrotron Light Monitor**
  - Interlocked abort gap monitor
  - Prototype for LS2 full installation LS3

- **New Wideband Pick-ups for Instability Monitoring**
  - Prototyping phase for crab cavity diagnostics

[R. Jones]

Emittance Measurement (IP4)

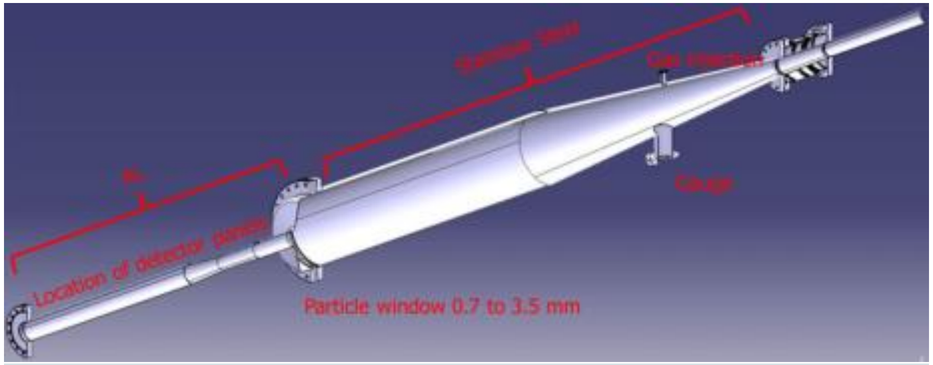
- ## Fast Wire Scanners
  - Would allow average emittance measurement of every batch at injection
    - Currently limited to first 2 batches injected
  - Principle to be tested in SPS in 2014
  - LHC prototype for LS2 & full installation for LS3

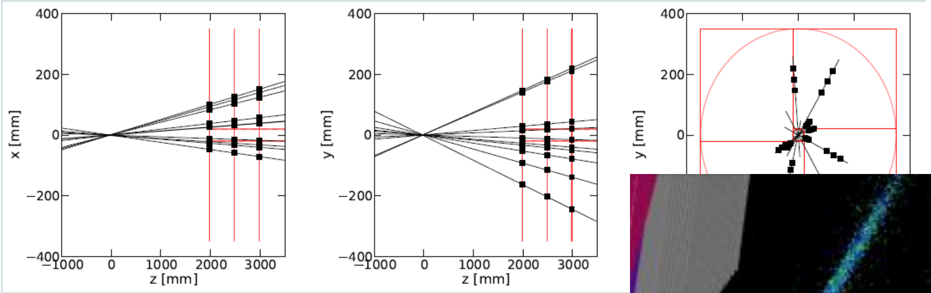


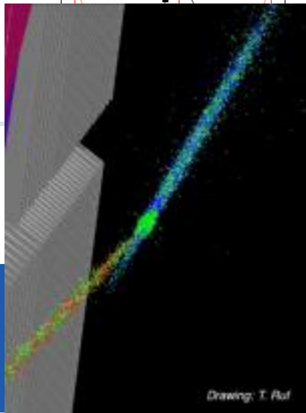
[R. Jones]

All components in vacuum
Eliminates moving bellows
Designed to be faster and to stand higher beam load

- ## Beam Gas Vertex Detector – BGV
  – Prototype underway for installation during/after LS1
  – Full system would significantly enhance emittance measurement capabilities
  – Transparent for the beam, no shower on magnets







[R. Jones]

Few key data for cost and planning

PIC beam diagnostic

- Parameters fixed 4 years before installation
- Main order placed 2-3 years before installation
- Completion of delivery at CERN 1 year before installation

Interaction region instrumentation:

- Parameters fixed/development start 3 years before the installation in the magnet cold masses (probably 2016)
- 1st order placed 2 years before installation in cold masses
- Assembly of equipment 1 year before

Equipment	Approx. cost [MCHF]
Radiation hard electronics	0.6
BLM electronics	1
Synchrotron light monitor upgrade	0.4
Instability monitor	0.2
Fast wire scanner	0.6
Beam Gas Vertex detector	1.1
Cryogenic BLM	1.7
BPM Q1 to Q5	1.2

SC LINK

CAVEAT: THE USE OF RADIATION-HARD POWER CONVERTER (NOT DISCUSSED HERE AND IN ANY CASE NEEDED FOR 120 A) CAN PARTIALLY SOLVE THE RADIATION PROBLEM, BUT PROBABLY NOT THE EXPOSURE TO RADIATION OF THE MAINTENANCE TEAM

Estimated dose for electronics

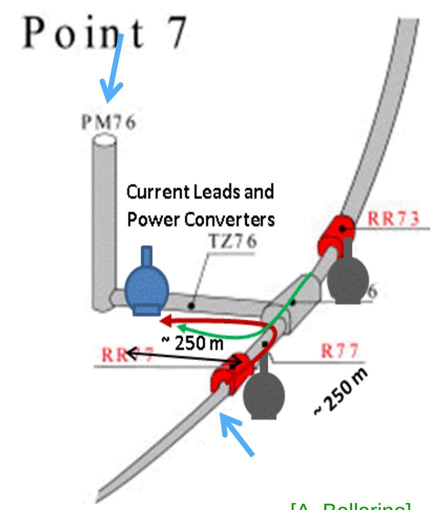
LHC Area	Prediction (HEH/cm^2)	Measured (HEH/cm^2)	Nominal (HEH/cm^2)	HL-LHC (HEH/cm^2)	HL-LHC (Dose/Gy)	PIC (HEH/cm^2)
UJ14/16	1.4E+08	1.6E+08	5E+08	3E+09	6	7E+8
RR13/17	2.0E+08	2.5E+08	8E+08	5E+09	10	1 E+9
UJ56	1.6E+08	1.5E+08	5E+08	3E+09	6	7E+8
RR53/57	2.0E+08	2.5E+08	8E+08	5E+09	10	1E+9
UJ76	2.1E+07	6.0E+07	2E+08	1E+09	2	3E+8
RR73/77	2.9E+07	5.0E+07	2E+08	1E+09	2	3E+8
UX85B	4.3E+08	3.5E+08	4E+08	2E+09	4	6E+8
US85	1.3E+08	8.8E+07	9E+07	4E+08	1	1.8E+8

[M. Brugger]

During last year of operation we had a number of radiation induced failures at 10^8 -10^9 cm^{-2} y^{-1}
Below 10^7 HEH failures unlikely
TID also an issue

Superconducting Link in point 7

- **Two Superconducting Links** installed in underground areas
- Powering of **600 A circuits**
- New DFBs installed in **TZ76**
- **None** or **very limited civil engineering** required
- R&D well advanced: prototype link tested
- Test of full system (DFB and SC Link) in SM-18 by end **2014**
- Installation in LHC during **LS2**
- Procurement of series to be launched in **2015**
- Cost SC link IP 7 5 MCHF



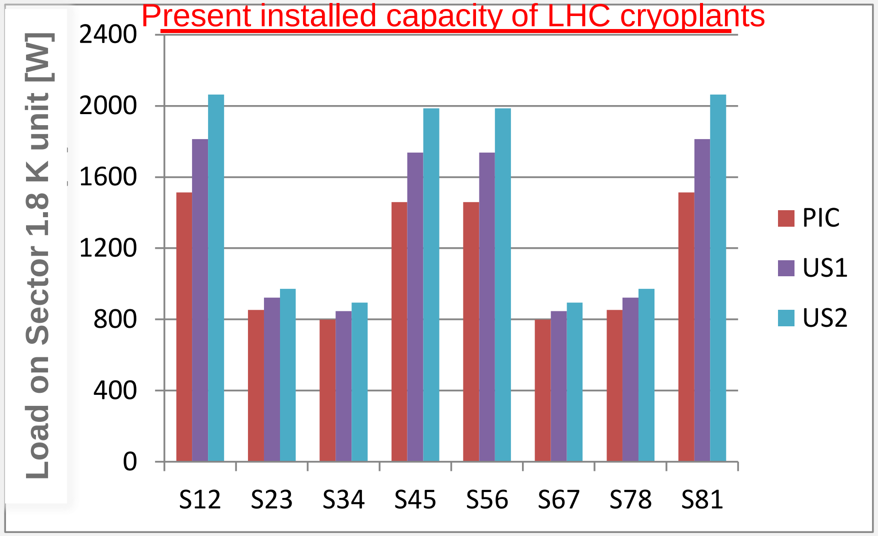
[A. Ballarino]

CRYOGENICS

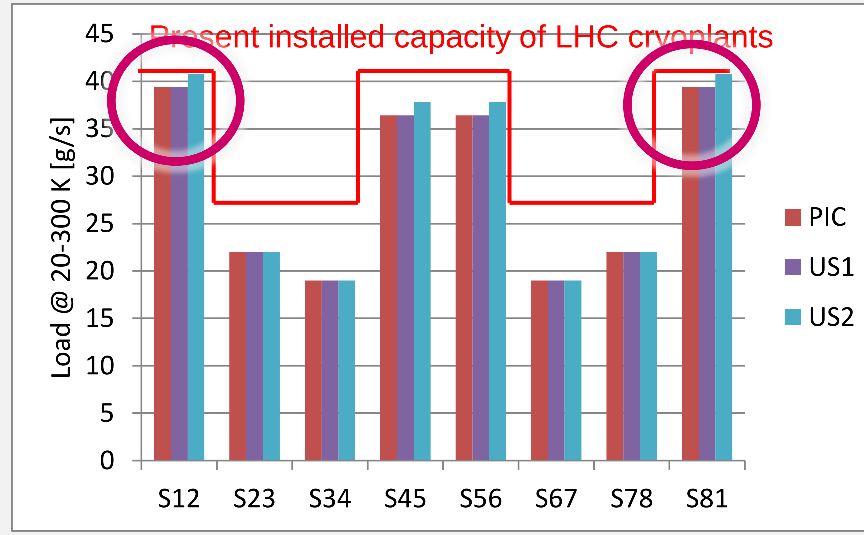
Total load per sector 1.9 K and 20-300 K ranges

TODAY

1.8 K

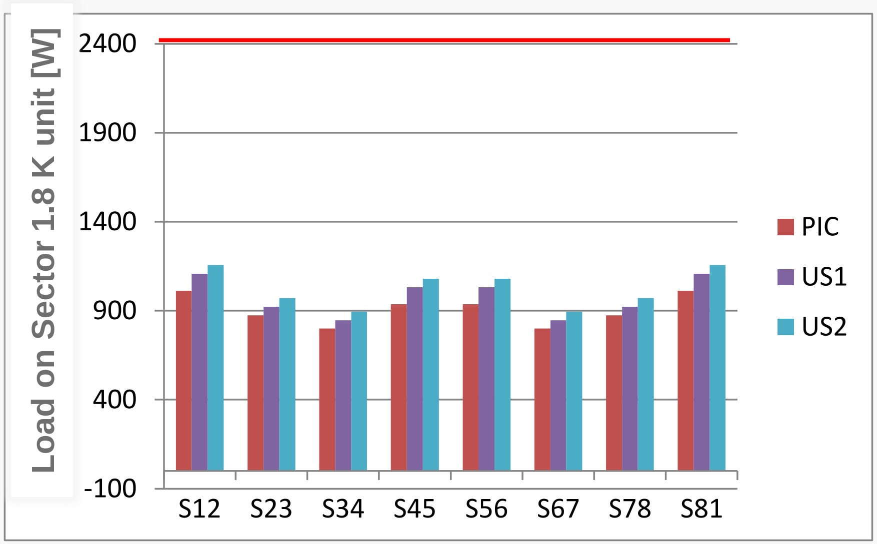


20-300K

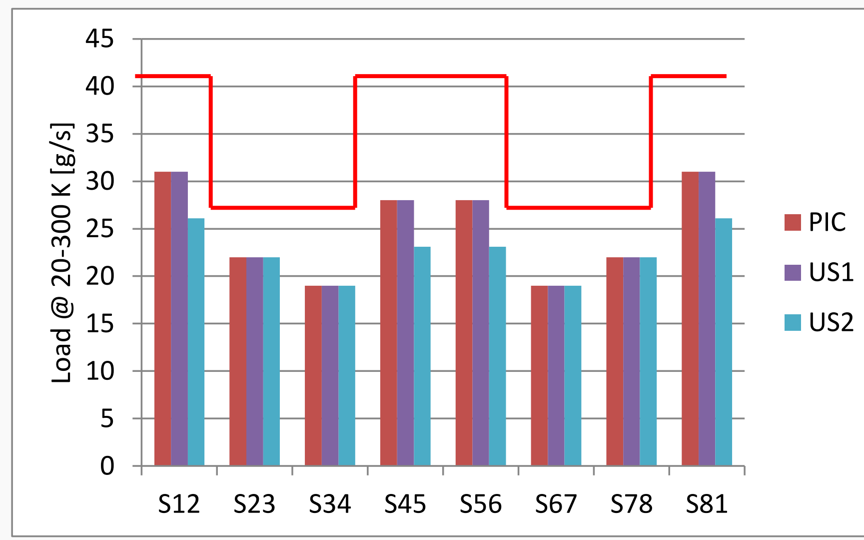


+ IP4 + IP1 + IP5

1.8 K



20-300K

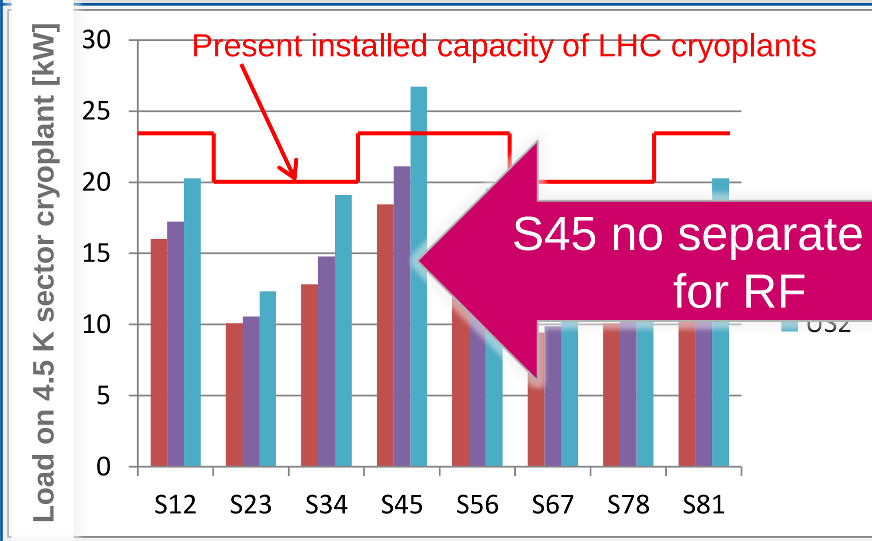


[L. Tavian]

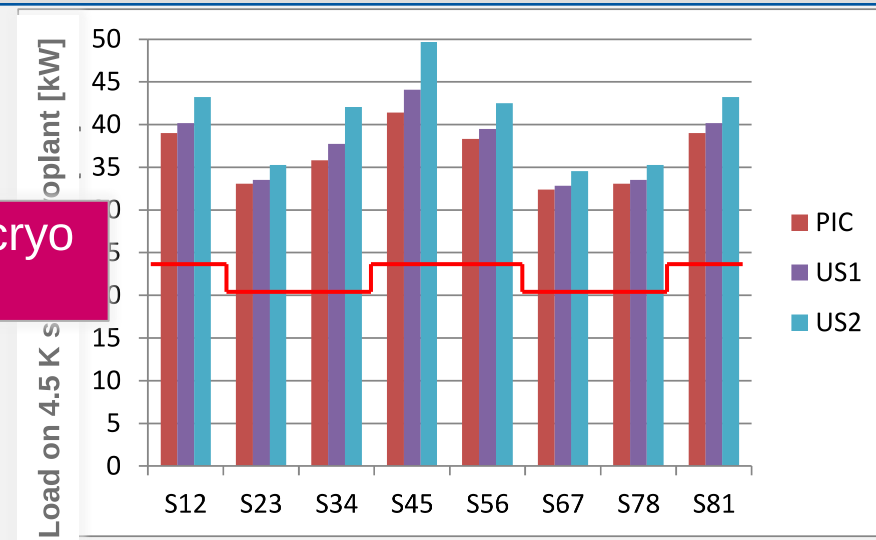
Total load per sector 4.6-20K range

TODAY

4.6-20 K e-cloud Dipole off

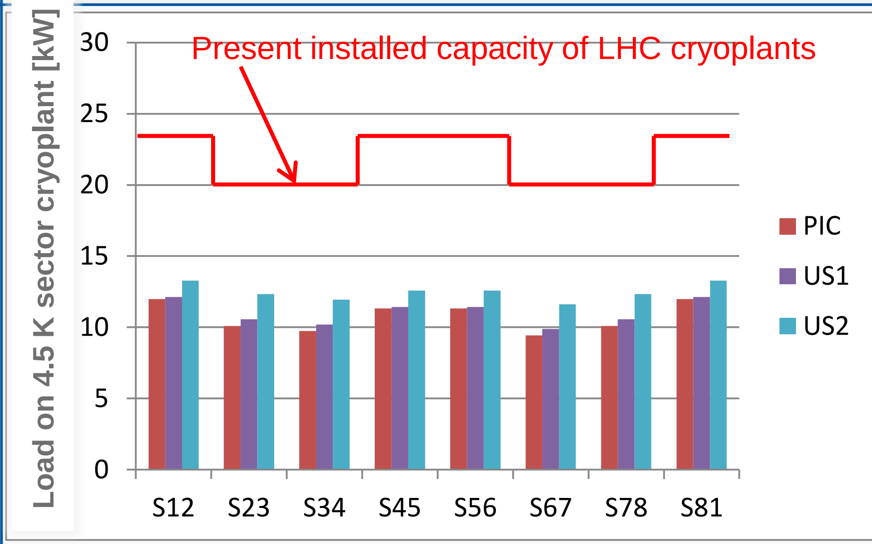


4.6-20 K e-cloud Dipole on

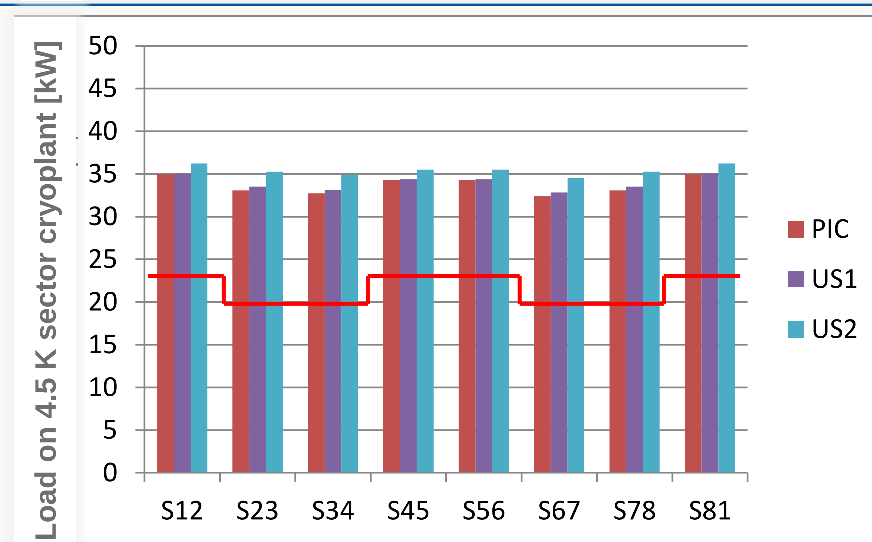


+ IP4 + IP1 + IP5

4.6-20 K e-cloud Dipole off

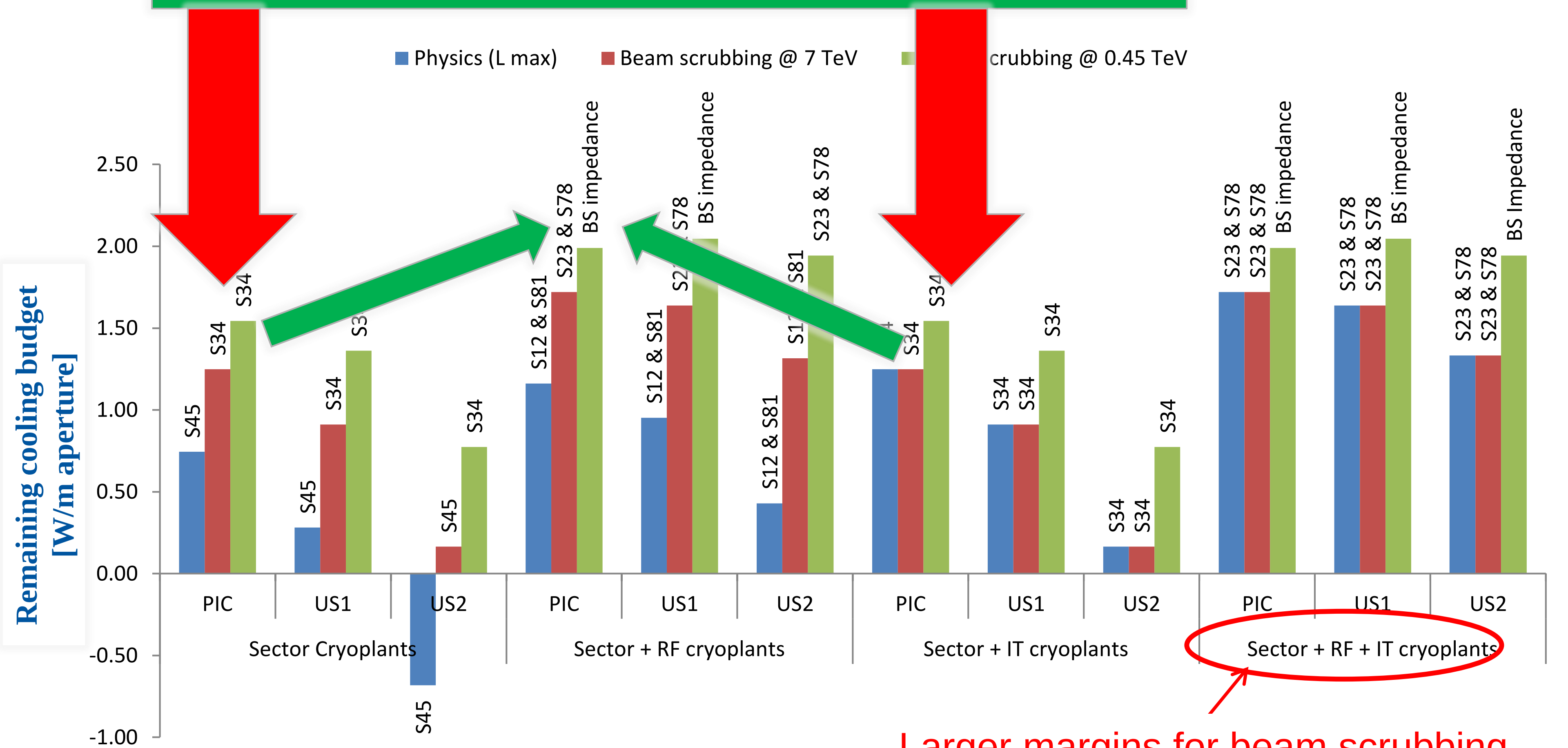


4.6-20 K e-cloud Dipole on



Remaining cooling budget for beam scrubbing: the bottlenecks

RF Plant IP4 gets rid of bottleneck in sector 3-4 and 4-5

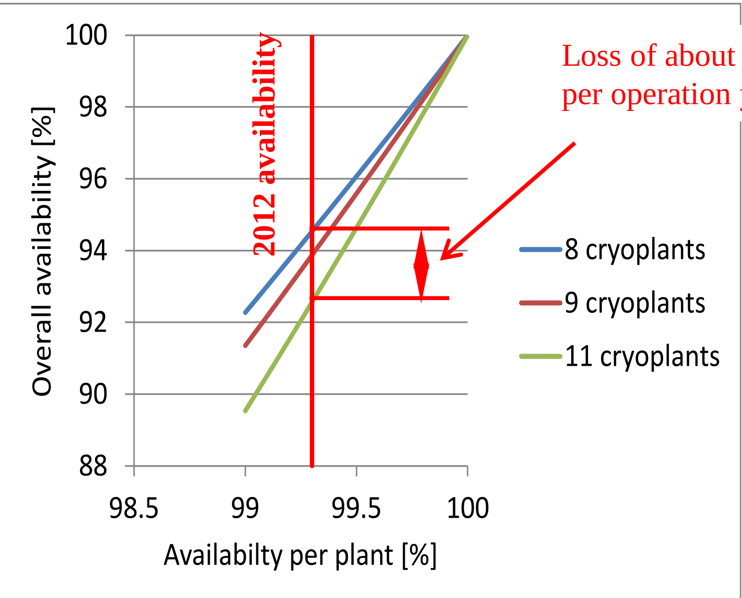


Larger margins for beam scrubbing obtained with additional cryoplants at P4 (RF cooling) and at P1 & P5 (IT/MS cooling)

New cryo-hardware requirement

Hardware	PIC	US1	
New QRL line and Service Modules for IT	Y		
New QRL line and Service Modules for MS	N	Y	
New QRL Service Modules for DS P1 & P5	N	Y	
New Cryoplant for RF at P4	Y/N (1)		
New Cryoplants for IT at P1 & P5	Y/N (2)		

Keep in mind to dimension for future steps and needs i.e. vertical distribution lines…



(1): Y, depending on the required margins for e-clouds and on the required HWC/sectorization flexibility.

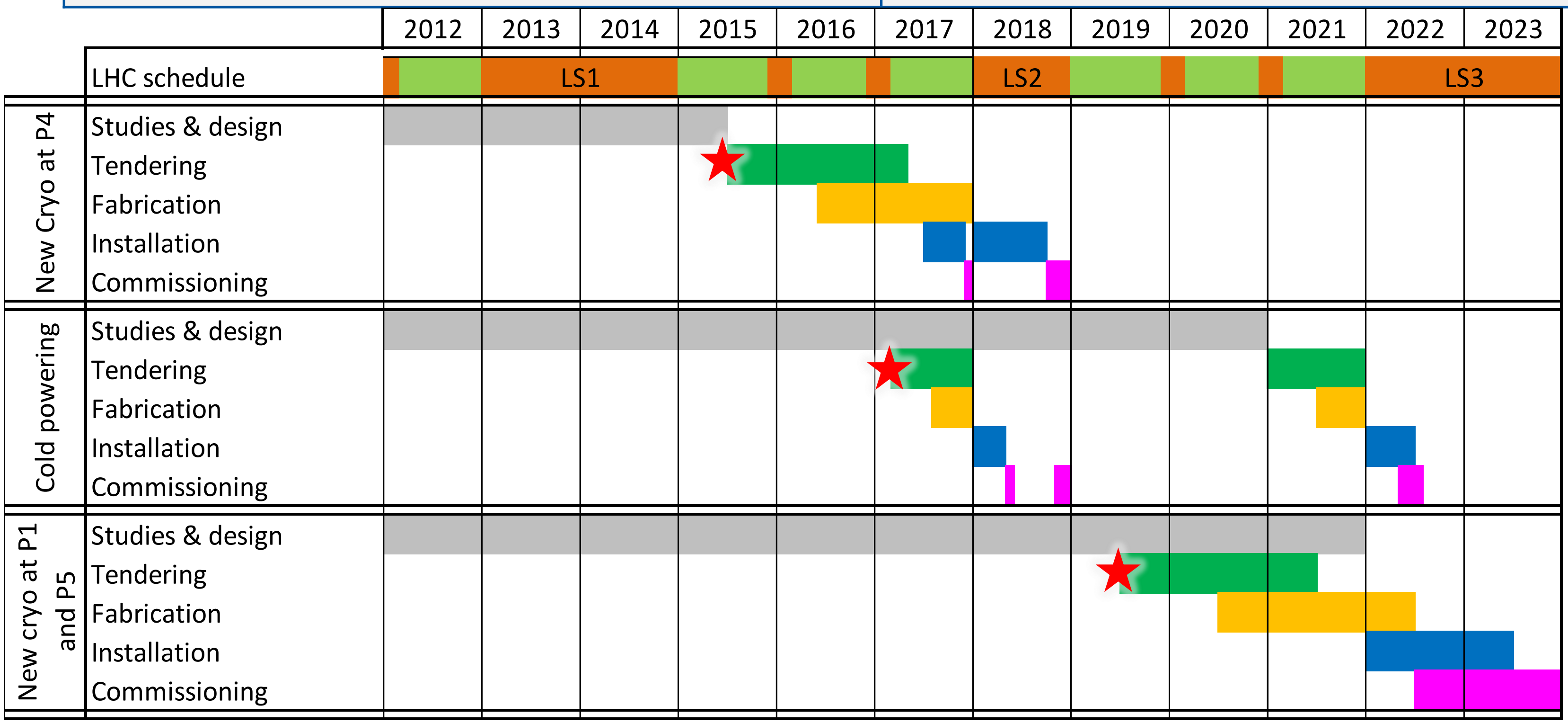
(2): Y, depending on required temperature margins and on the required HWC/sectorization flexibility.

… but reduced-load plants could be more tolerant (lower risk of stops)

… but thank to a new sectorization, possible significant gain of time if specific interventions or HWC are required on RF modules and/or high luminosity insertions (IT + MS)

Few key data for cost and planning

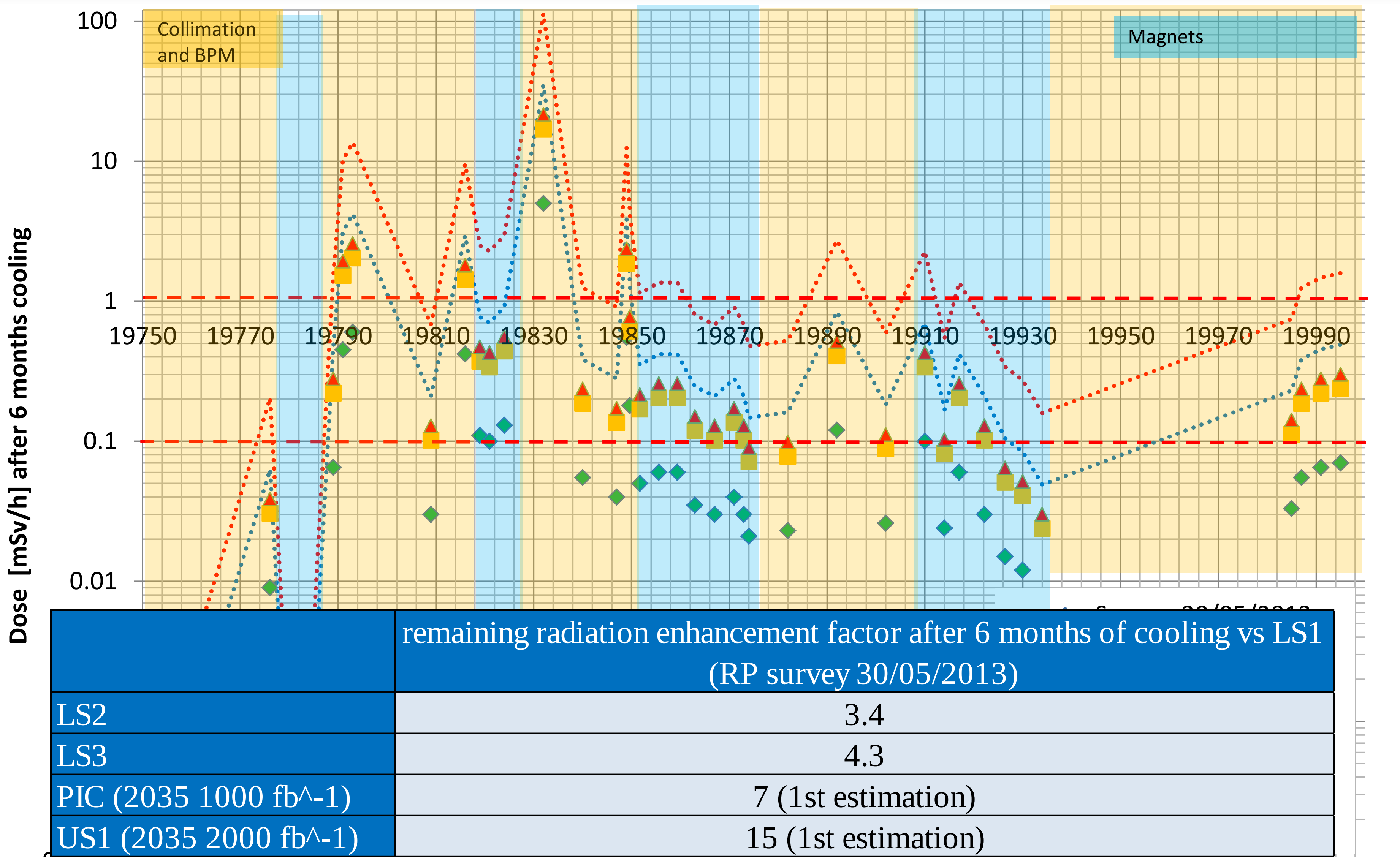
System	Cost
Cryo plant IP4	15 MCHF
Cryo plant IP1	37 MCHF
Cryo plant IP5	37 MCHF



★ : Freeze of heat load requirement

HIGH RADIATION POINT RECONFIGURATION

POINT 7 residual dose at 40 cm after 6 months of cooling



	remaining radiation enhancement factor after 6 months of cooling vs LS1 (RP survey 30/05/2013)
LS2	3.4
LS3	4.3
PIC (2035 1000 fb^-1)	7 (1st estimation)
US1 (2035 2000 fb^-1)	15 (1st estimation)
US2 (2035 3000 fb^-1)	23 (1st estimation)

[S. Roesler, C. Adorisio]

Conclusions

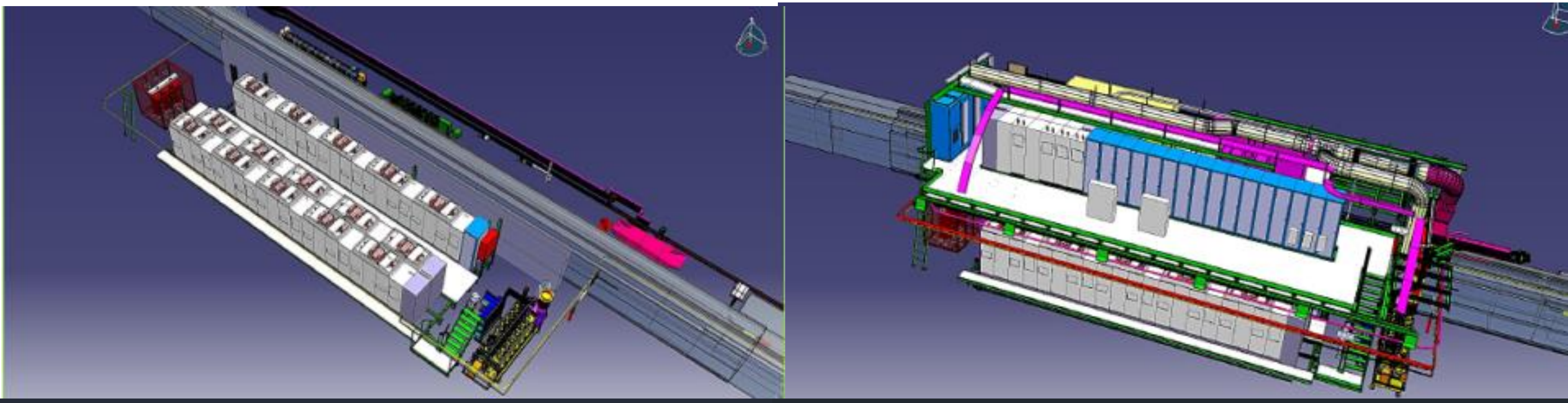
- PIC actions
  - Concern practically all the sectors of the machine
  - The are spread between the 1st long technical stop after LS1 and LS3
- Interaction region interventions in IP 1 and 5 provide safe operation for 2025->2035 years and the required luminosity capacity (See G. Arduini talk)
- Collimation interventions push down the whole machine impedance providing more robust collimators and ensure safe ion run in IP2. Remark: the collimator lifetime is being analysed in this moment. Possible intervention on secondaries could be necessary to provide reliable exploitation after LS2
- Beam diagnostic interventions provide the necessary diagnostic capacity, with hardware compatible with the higher radiation dose
- Sc links provide a solution to radiation electronic issues for the Power converters, but also contribute in reducing collective dose, interventions time and reduce risk of SEE
- Cryoplant at point 4 provides flexibility in the management of the RF interventions and eliminate the 1st machine bottleneck in term of cooling capacity. All cryo installation have to be performed with a long term view from the installation/integration perspective (foresee for future needs)
- High radiation dose point call for radiation management and possible reconfiguration to provide the best as possible reliability and access conditions. Radiation tolerant electronic development (including R&D and testing) will affect several equipment groups (costs, resources)

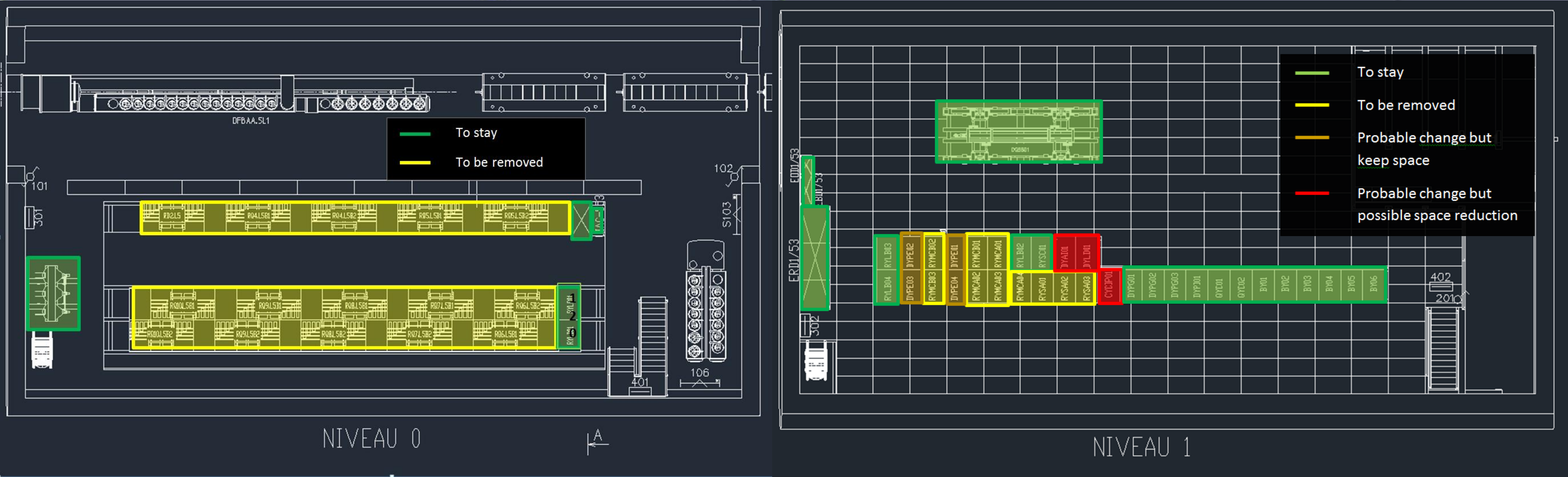
For new and ***unexpected*** *discoveries*

[Angela and Luca]

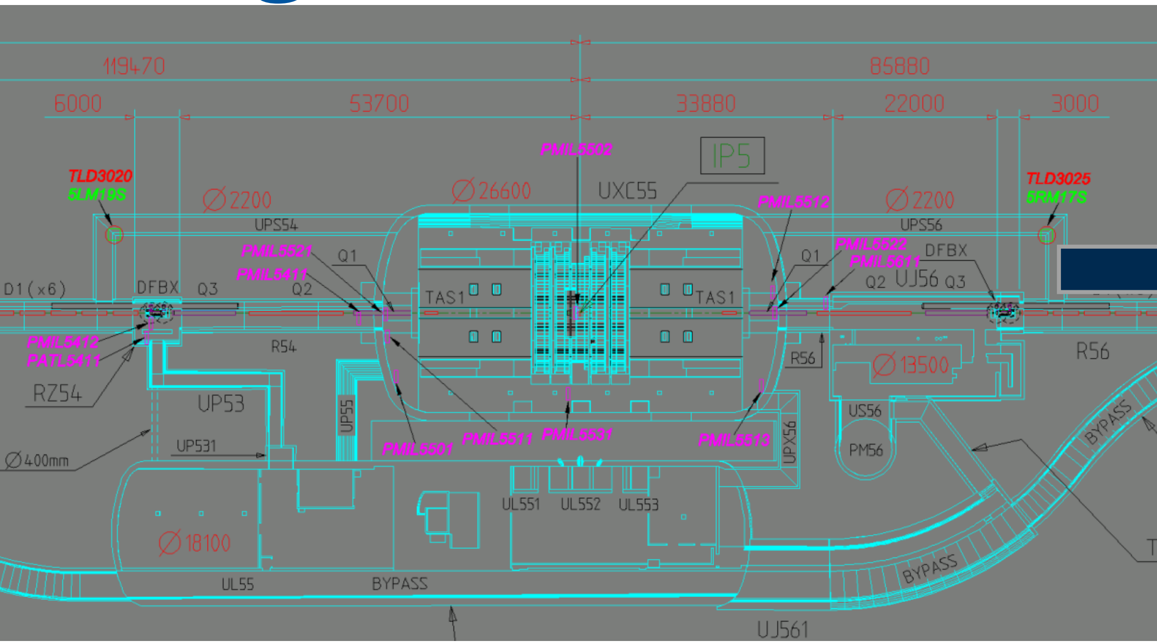
Back up slides

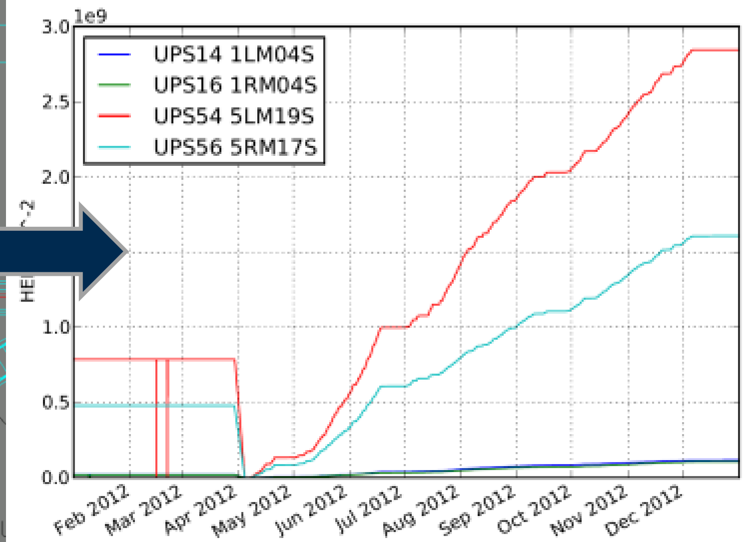
SC link Point 1 and 5 for power converters in the RRs

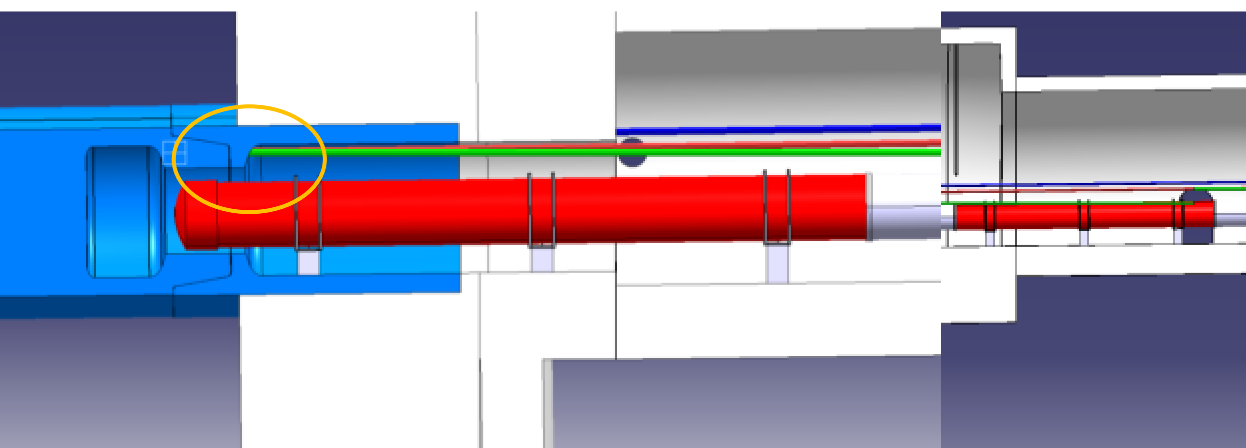




Alignment

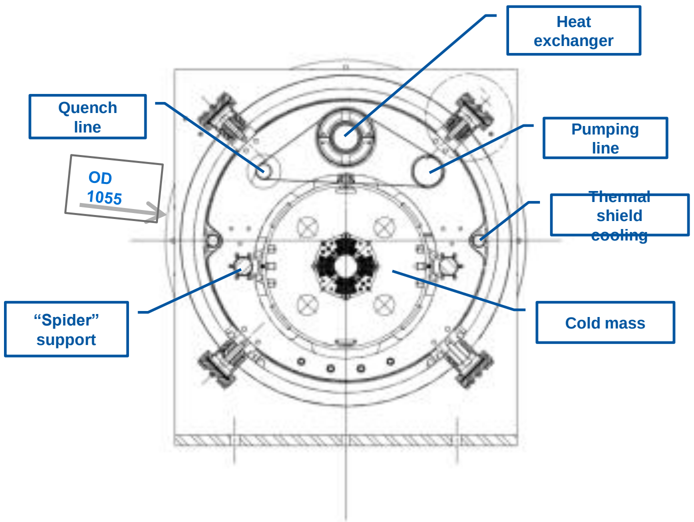




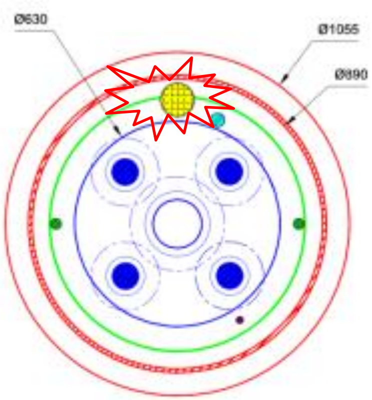


	Scaling factor approx. with luminosity
PIC	3
US1	7
US2	12

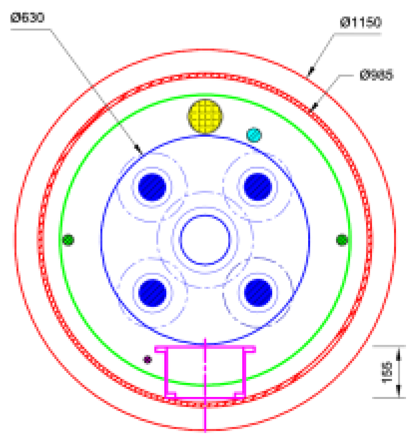
Cryostat system



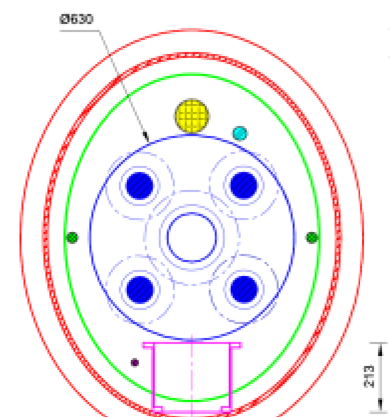
	*Cryo spec**	Possible standard dimensions			Material
		OD	thickness	ID	
HeII in (Y1)	*12*				copper
HeII in (Y2)	*12*				copper
HeII out (pumping line)	*97*	106	3	100	1.4432, welded
BS in (C')	*20*	23	1.5	20	1.4404, seamless
BS capillaries (4x)	*6.5*				
Quench return line	*40*	44.5	2	40.5	1.4404, seamless
Shield in (E)	*30*	35	2.5	30	
Shield out (F)	*30*	35	2.5	30	
Bayonet HX-1	*68*				copper
Bayonet HX-2	*68*				copper
**by Rob Van Weelderen*					



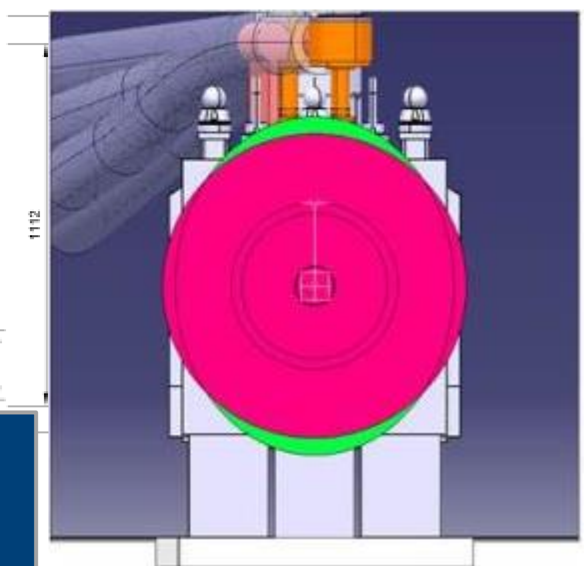
Standard cryostat diameter no solution to accommodate all manifolds



Larger diameter cryostat, but compatible with transport space, feasible but issues (heat loads)



Elliptical cryostat. Very good accommodation but technological challenges



The 2 solutions in the IP 5 shielding

16 October 2013

RLIUP Preparation

CRYOGENICS
PIC-US1-US2
(UPDATED VERSION2)

L. Tavian, TE-CRG

Content

- Beam parameters for IC, US1 and US2
- Heat loads for PIC, US1 and US2
- Margin for beam scrubbing
- Temperature profile (line B pressure drop)
- Cryoplant sizing
- Availability
- New cryo-hardware requirement

Beam parameters (impacting cryo) for PIC and upgrade scenarios

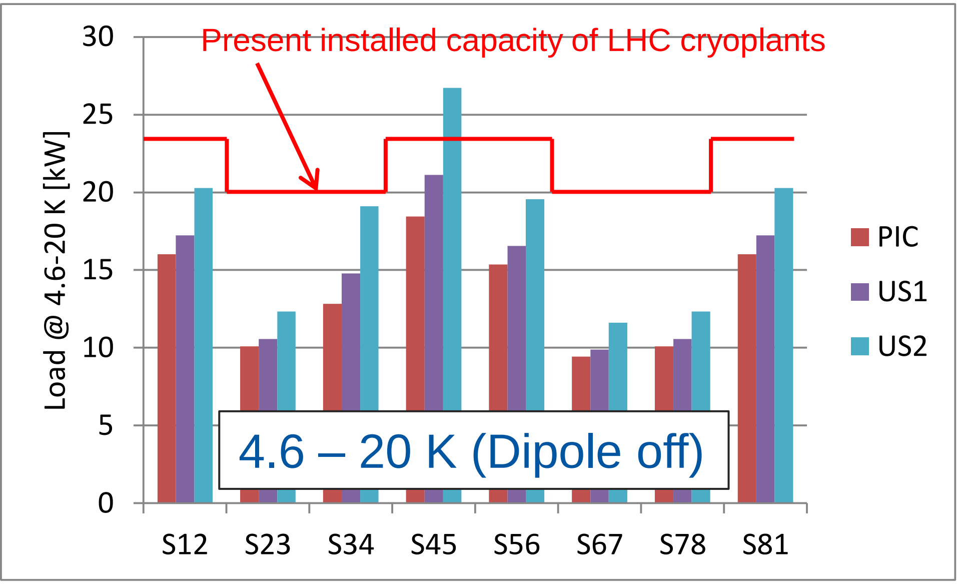
Parameters		PIC	US1	US2
E	[TeV]	7	7	7
Nb	[# p / bunch]	1.38E+11	1.9E+11	2.2E+11
nb	[-]	2760	2592	2760
L	[Hz/cm-2]	2.96E+34	5E+34	5E+34
σ	[ns]	1	1	1

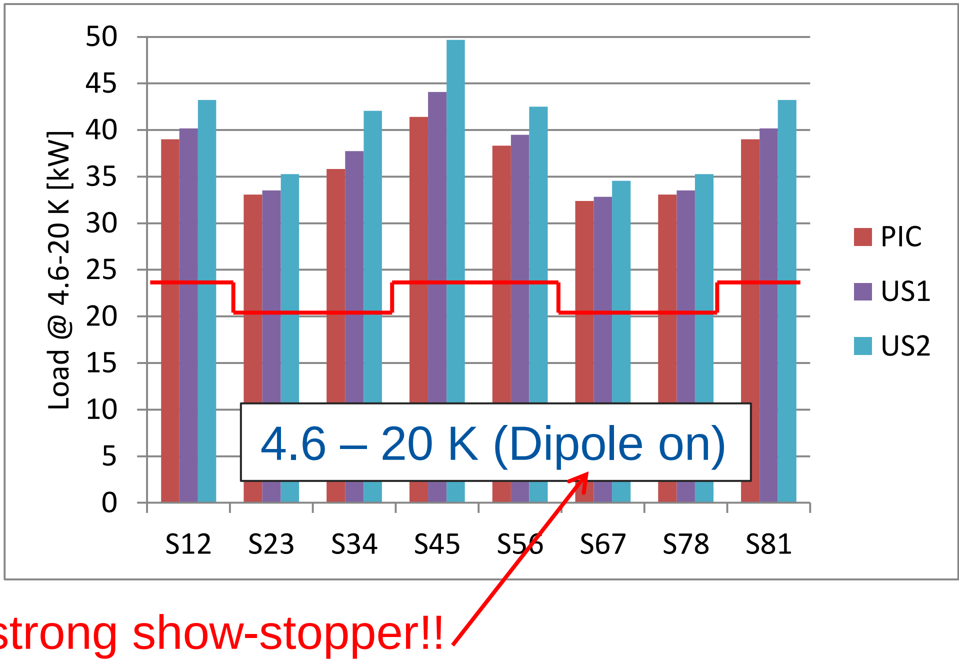
Heat loads

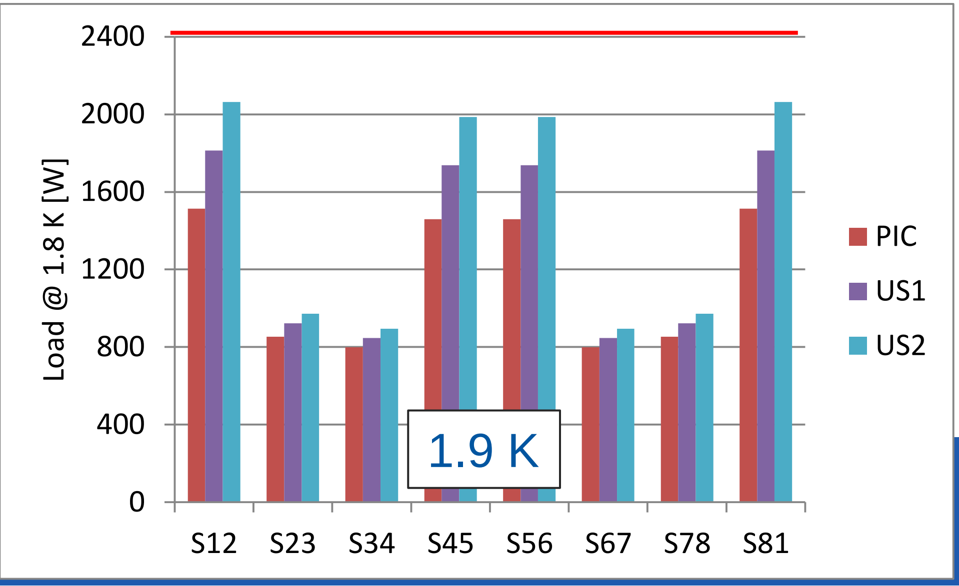
To be validated by the Heat Load Working Group!

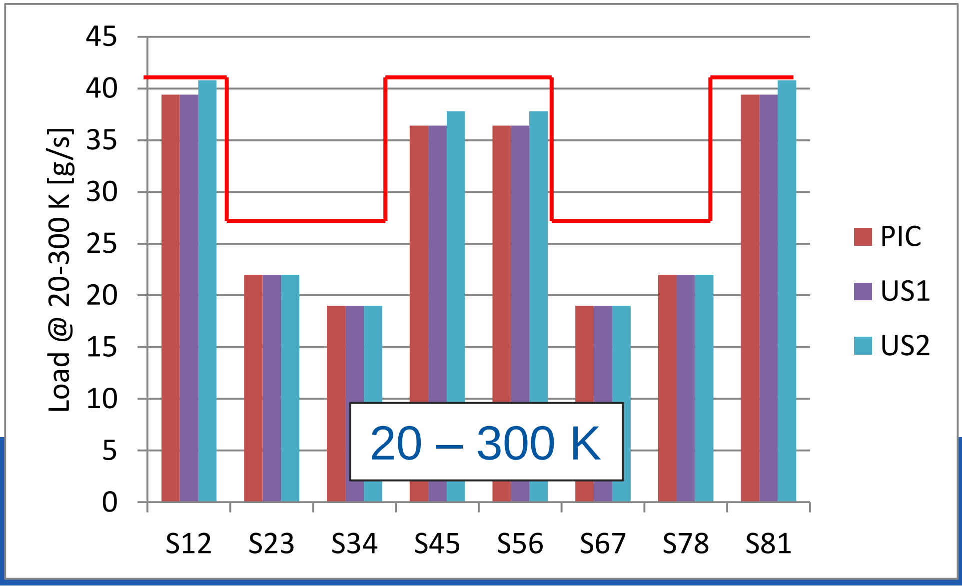
				PIC	US1	US2	Remark
Static heat inleaks	4.6-20 K	Beam screen circuit (arc + DS)	[mW/m]		140		Based on LHC measurement
		Beam screen circuit (IT)	[mW/m]		125		Based on LHC measurement
		Beam screen circuit (MS)	[mW/m]		578		Based on LHC measurement
	1.9 K	Cold mass (arc + DS)	[mW/m]		170		Based on LHC measurement
		Cold mass (IT)	[mW/m]		1250		Based on LHC measurement
		Crab-cavities	[W per module]	0	0	25	Only for US2
	4.5 K	Cold mass (MS)	[mW/m]		3556		Based on LHC measurement
		400 MHz RF module	[W per module]		120		Based on LHC measurement
		800 MHz RF module	[W per module]	0	0	60	Only for US2
		Electron-lens	[W per module]	0	0	12	Only for US2
	20-300 K	Current lead	[g/s per kA]		0.035		Based on LHC current leads
Dynamic heat load	4.6-20 K	Synchrontron radiation (arc + DS)	[mW/m per beam]	195	252	310	Based on scaling from DR data
		Image current (arc + DS + MS)	[mW/m per beam]	205	365	522	Scaling from 2012 measurement
		Image current (IT low-luminosity)	[mW/m]	632	1195	1698	Based on present IT design
		Image current (IT high-luminosity)	[mW/m]	117	210	298	Based on B. Salvant data
		E-clouds (arc + DS) (dipole off)	[mW/m per beam]	204	41	41	Based on Giovanni's data
		E-clouds (arc + DS) (dipole on)	[mW/m per beam]	4265	4097	4097	Based on Giovanni's data
		E-clouds (IT high luminosity)	[mW/m]	9455	9455	9455	Based on Giovanni's data (D1 missing)
		E-clouds (IT low-luminosity)	[mW/m]	5500	5500	5500	Based on Giovanni's data
		E-clouds (MS)	[mW/m per beam]	1912	383	383	Based on Giovanni's data
		Secondaries (IT beam screen P1 andP5)	[W per IT]	456	615	615	Based on F. Cerutti data
	1.9 K	Beam gas scatering	[mW/m per beam]	28	37	45	Scaling from 2012 measurement
		Resistive heating in splices	[mW/m]	56	56	56	Scaling from 2012 measurement
		Secondaries (IT cold mass P1 and P5)	[W per IT]	467	630	630	Based on F. Cerruti data
		Secondaries (DS cold mass P1 and P5)	[W per DS]	137	185	185	Based on scaling from DR data
		Qrf crab-cavities	[W per module]	0	0	24	Only for US2
	4.5 K	Qrf 400 MHz	[W per module]	144	273	366	Based on scaling from DR data
		Qrf 800 MHz	[W per module]	0	0	183	Only for US2
		E-lens	[W per module]	0	0	2	Only for US2
	20-300 K	Current lead	[g/s per kA]		0.035		Based on LHC current leads

Total loads per sectors

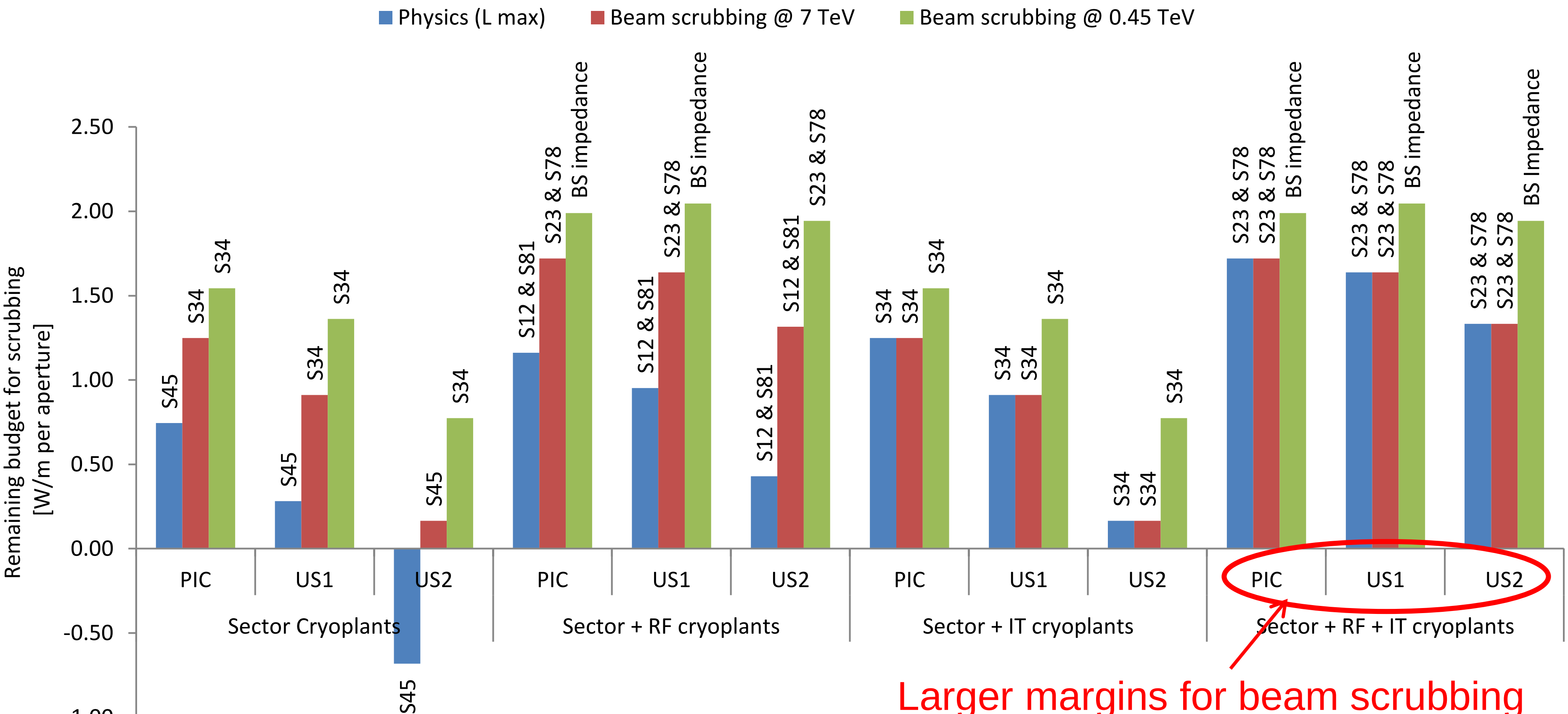






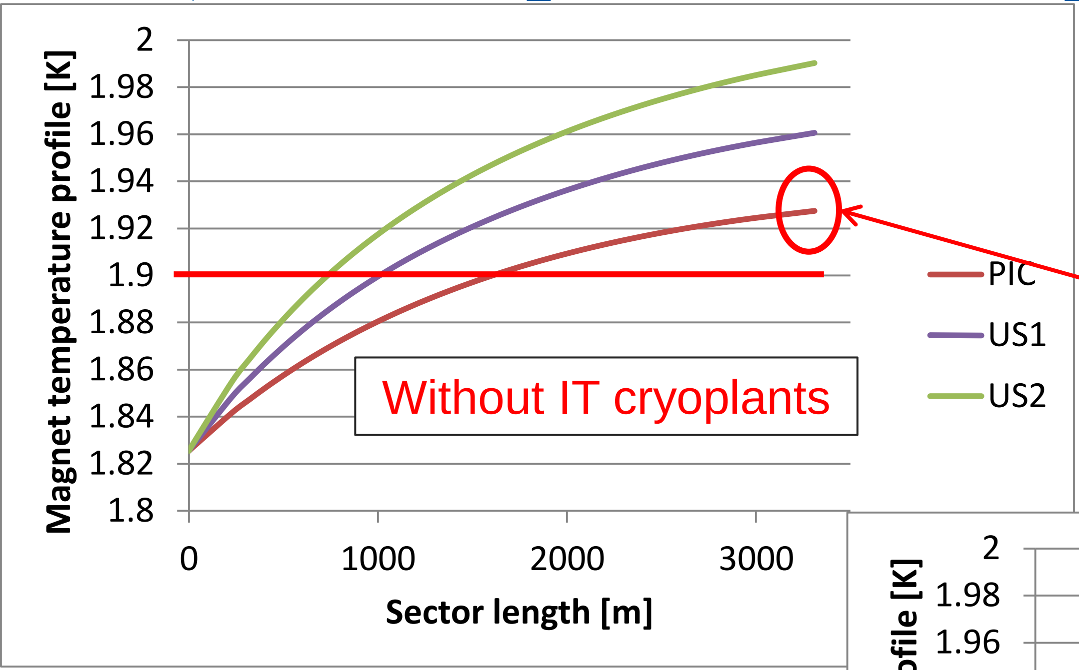


Remaining cooling budget for beam scrubbing

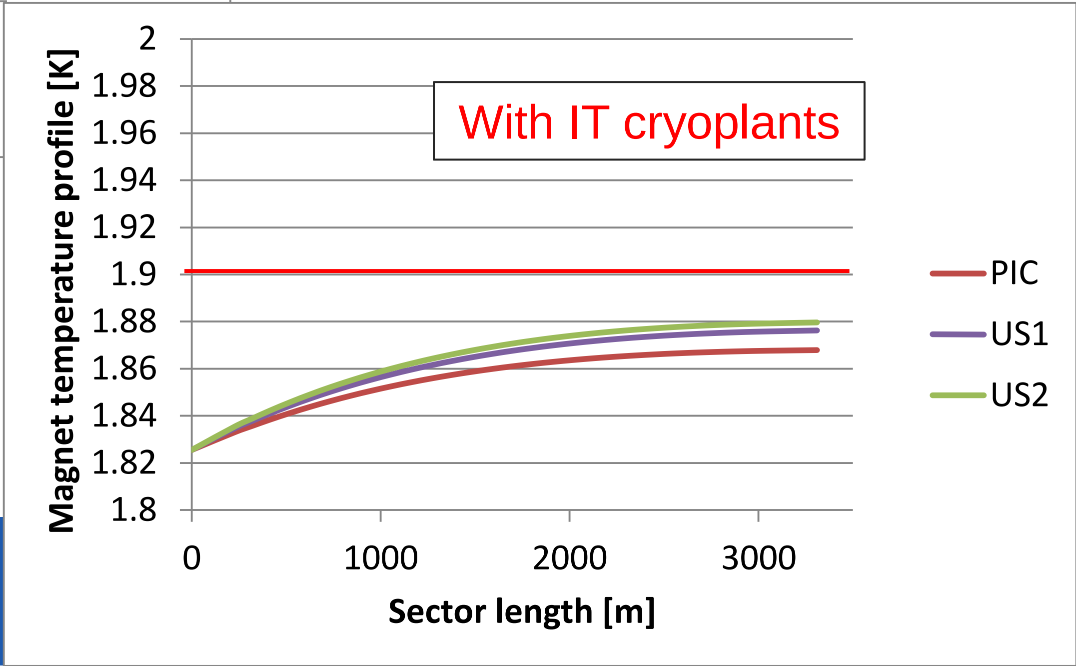


Larger margins for beam scrubbing obtained with additional cryoplants at P4 (RF cooling) and at P1 & P5 (IT/MS cooling)

Magnet temperature profile (Line B pressure drop)



Still acceptable? For new magnets?
For existing magnets (arc and DS)?



New IT cryoplants required for US1 & US2.

Size of new IT cryoplants (provisional)

Uncertainty coefficient, fu: 1.5
Overcapacity coefficient, fo: 1.5

(Qsta*fu + Qdyn)*fo

	Temperature level		Static	Dynamic	Installed	Equivalent installed capacity @ 4.5 K [kW]	
PIC	1.9 K	[W]	138	947	1730	6.8	10
	4.5 K	[W]	0	0	0	0	
	4.6-20 K	[W]	94	1966	3159	1.8	
	50-75 K	[W]	2800	0	4200	0.3	
	20-300 K	[g/s]	8.4	8.4	32	1.4	
US1	1.9 K	[W]	138	1274	2221	8.7	12
	4.5 K	[W]	0	0	0	0	
	4.6-20 K	[W]	94	2293	3651	2.0	
	50-75 K	[W]	2800	0	4200	0.3	
	20-300 K	[g/s]	8.4	8.4	32	1.4	
US2	1.9 K	[W]	433	1380	3045	12	18
	4.5 K	[W]	196	8	452	0.5	
	4.6-20 K	[W]	154	2565	4194	2.3	
	50-75 K	[W]	4900	0	7350	0.5	
	20-300 K	[g/s]	15	15	55	2.4	

To be validated by the Heat Load Working Group!

Size of new RF cryoplant (provisional)

Uncertainty coefficient, fu: 1.25 for existing component (400 MHz RF module)
1.5 for new equipement

Overcapacity coefficient, fo: 1.5

(Qsta*fu + Qdyn)*fo

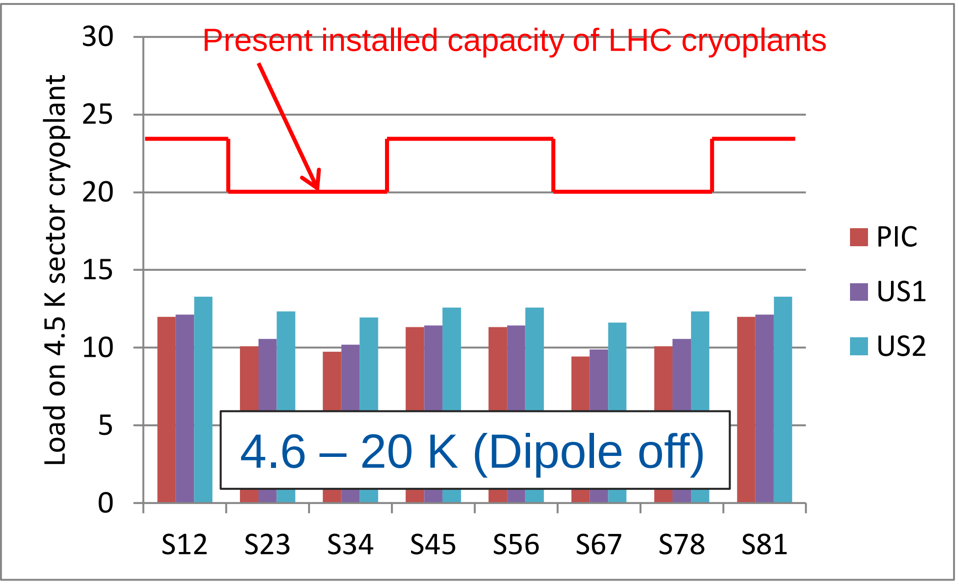
	Temperature level		Static	Dynamic	Installed
PIC	4.5 K	[W]	500	578	1812
	50-75 K	[W]	1000	0	2250
US1	4.5 K	[W]	500	1094	2586
	50-75 K	[W]	1000	0	2250
US2	4.5 K	[W]	744	1736	4007
	50-75 K	[W]	1000	0	2250

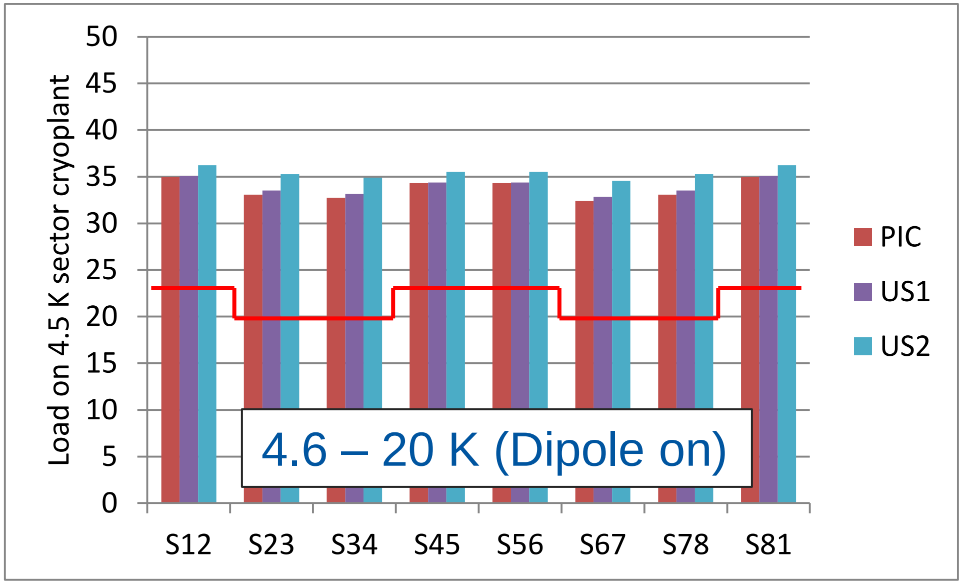
Equivalent installed capacity @ 4.5 K [kW]	
1.9	2.1
0.2	
2.8	2.9
0.2	
4.3	4.5
0.2	

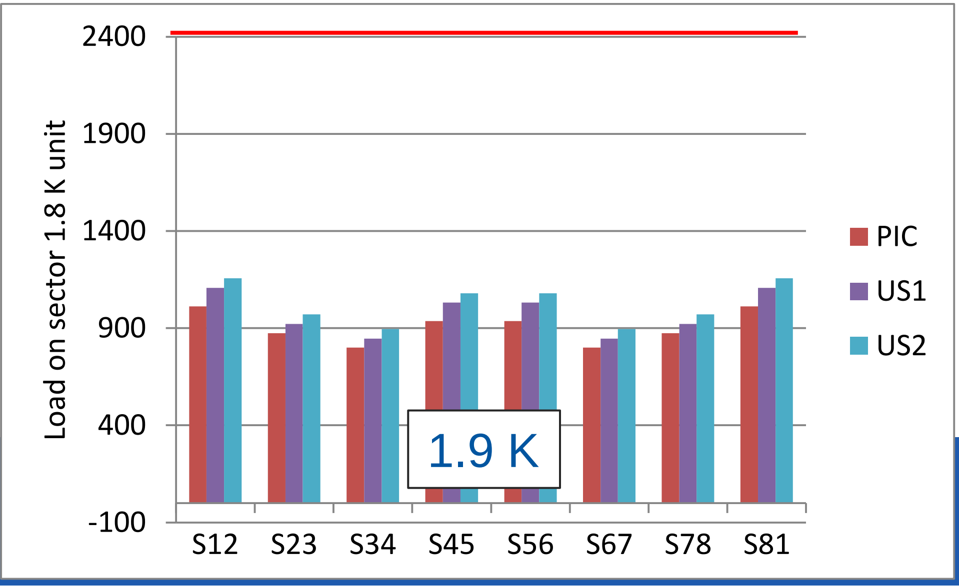
To be validated by the Heat Load Working Group!

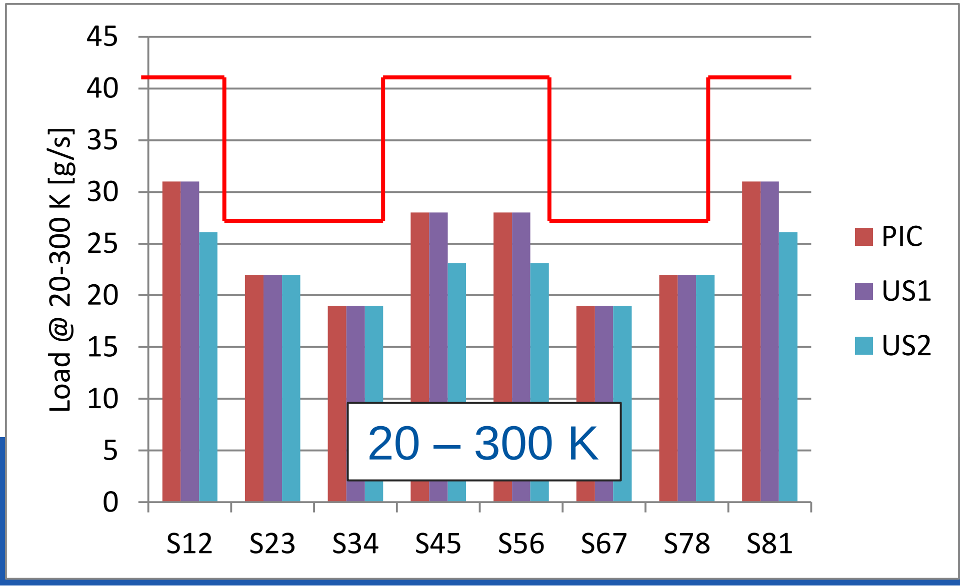
Total loads on sector cryoplants

(with additional cryoplants at P4, P1 and P5)

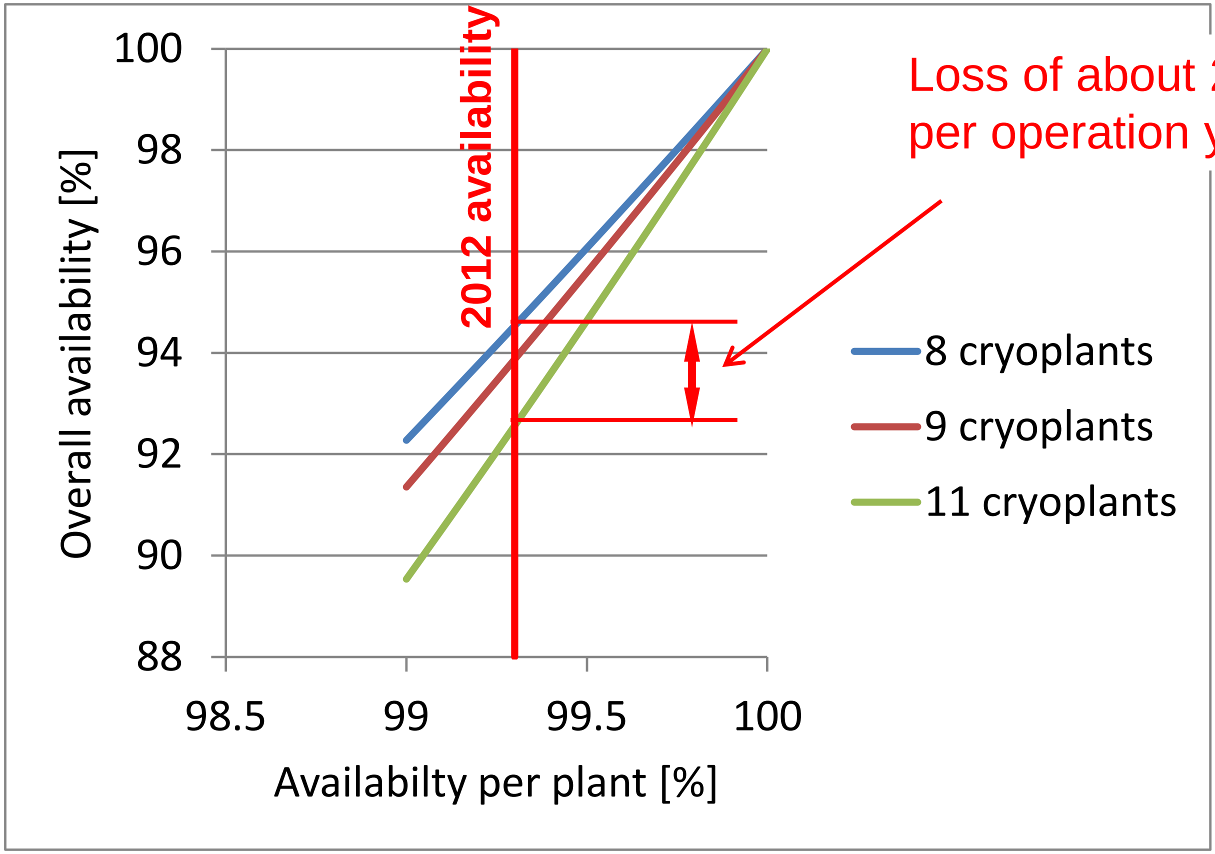








Availability



Loss of about 2 points, i.e. 4 days per operation year (200 d/y)

… but reduced-load plants could be more tolerant (lower risk of stops)

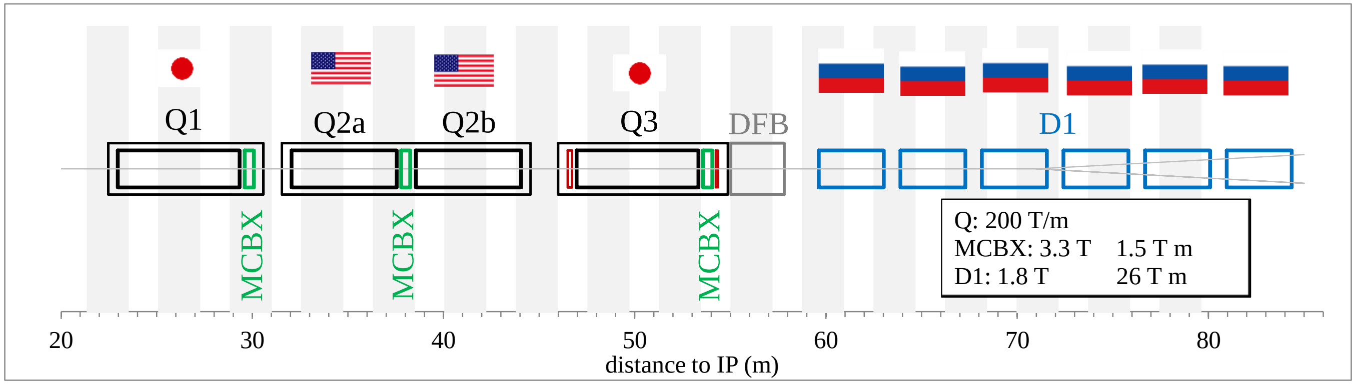
… but thank to a new sectorization, possible significant gain of time if specific interventions or HWC are required on RF modules and/or high luminosity insertions (IT + MS)

New cryo-hardware requirement

Hardware	PIC	US1	US2
New QRL line and Service Modules for IT	Y	Y	Y
New QRL line and Service Modules for MS	N	Y	Y
New QRL Service Modules for DS P1 & P5	N	Y	Y
New Cryoplant for RF at P4	Y/N (1)	Y	Y
New Cryoplants for IT at P1 & P5	Y/N (2)	Y	Y

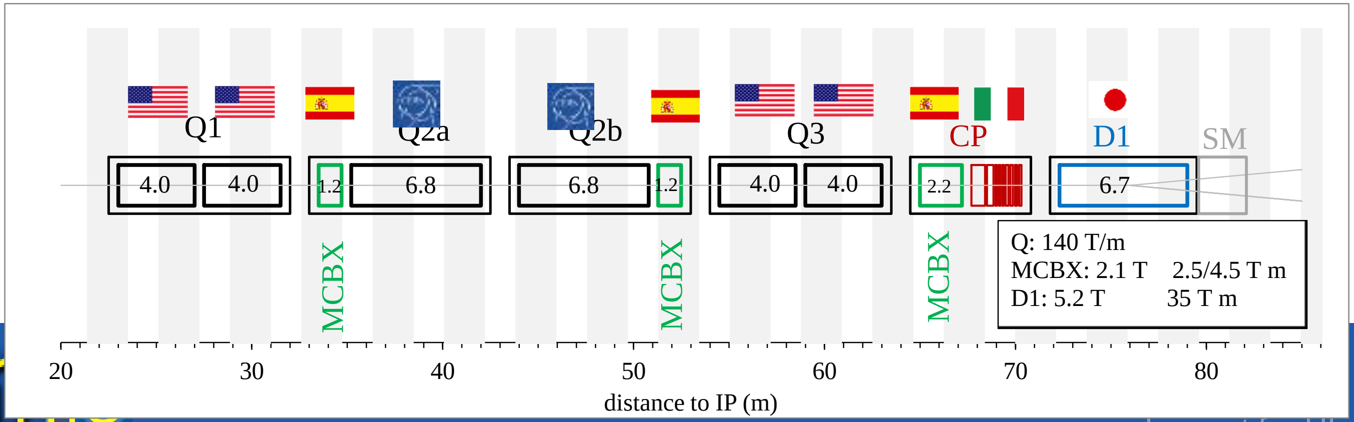
(1): Y, depending on the required margins for e-clouds and on the required HWC/sectorization flexibility.
(2): Y, depending on required temperature margins and on the required HWC/sectorization flexibility.

layouts



LHC

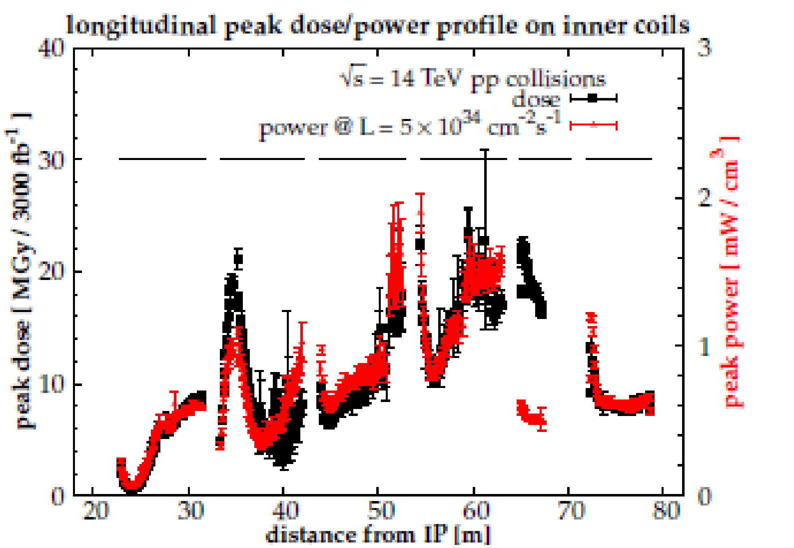
Aperture ~twice the LHC baseline (70 mm to 150 mm), but more compact triplet layout thanks to Nb_3Sn and superconductive D1



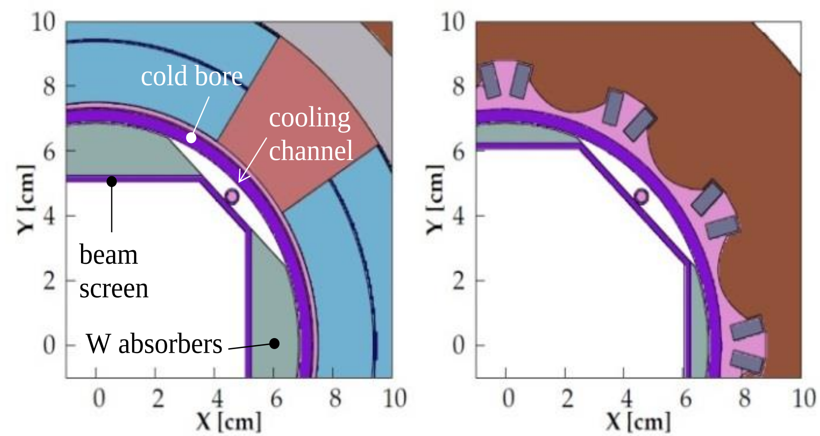
HL LHC

SHIELDING

- One key element is a shielding to bring radiation dose and heat load down to LHC baseline
  - For 1000 fb^{-1} this gives 10 MGy (safe, limit at 30-50 MGy)
  - For 3×10^{34} cm^{-2} s^{-1} peak lumi one has 1.5 mW/cm^3 … W/cm^3 in LHC)

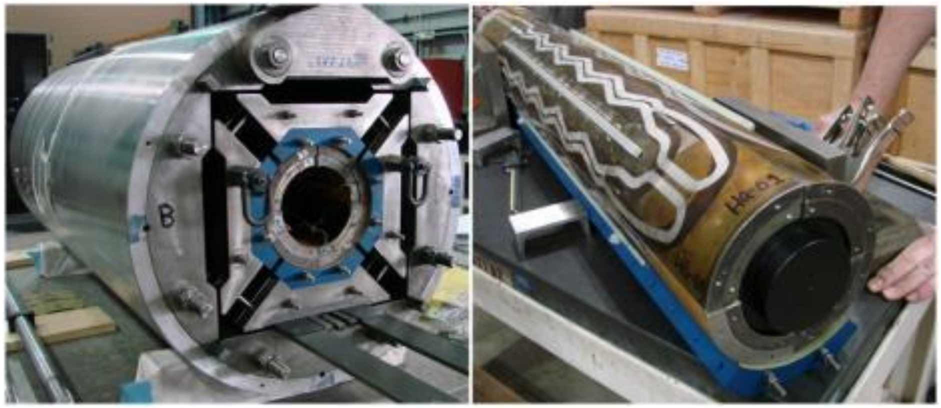


Radiation dose and heat load [Cerutti, Esposito]



Beam screen in the triplet and in the correctors[Kersevan]

QUADRUPOLES

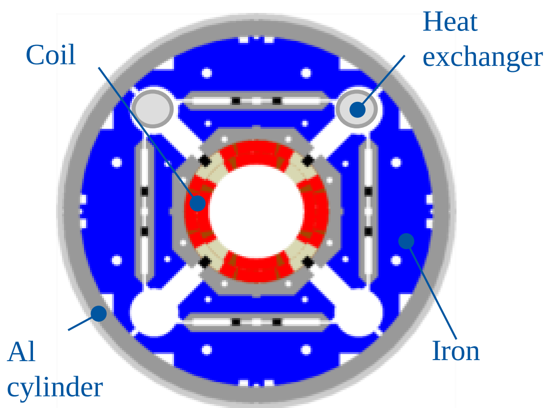


HQ magnet, 120 mm aperture with final structure

LQ magnet, first 3.4 m long Nb_3Sn magnet

- Triplet made with Nb_3Sn technology
  - Long history of development in US, since 2002 (LARP)
    - 120 mm aperture 1 m long model HQ reaching most of the specifications (FQ, performance,…)
    - 90 mm 3.4-m-long model LQ (first long Nb_3Sn coils) succesful
  - HQ performance similar to MQXC (Nb-Ti twin of HQ)

QUADRUPOLES



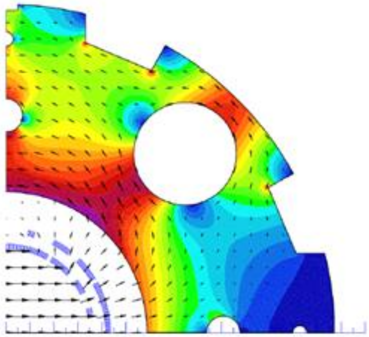
QXF cross-section

Winding of the first practice coil at CERN

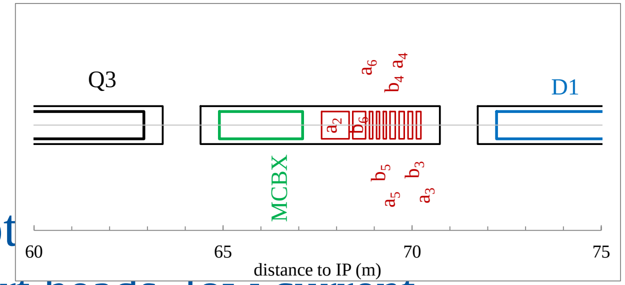
- Production shared between US and CERN
  - Timeline:
    - First short model 2015, First prototype end 2016
    - 2017-2020: production
- Risks

CORRECTORS

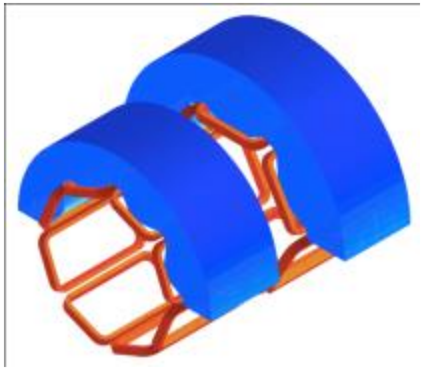
- Orbit correctors:
  - 2.5 T m at Q1 and Q2, and 4.5 T m at Q3, both H and V
  - Nb-Ti technology, nested option to save space (4 m)
    - 2.1 T field, giving 1.2 and 2.2 m long magnets
  - Collaboration with CIEMAT (ES)
    - Deliverable: one 1.2-long-magnet in 2016



Proposal for nested MCBX
(M. Karppinen, D. Smekens)

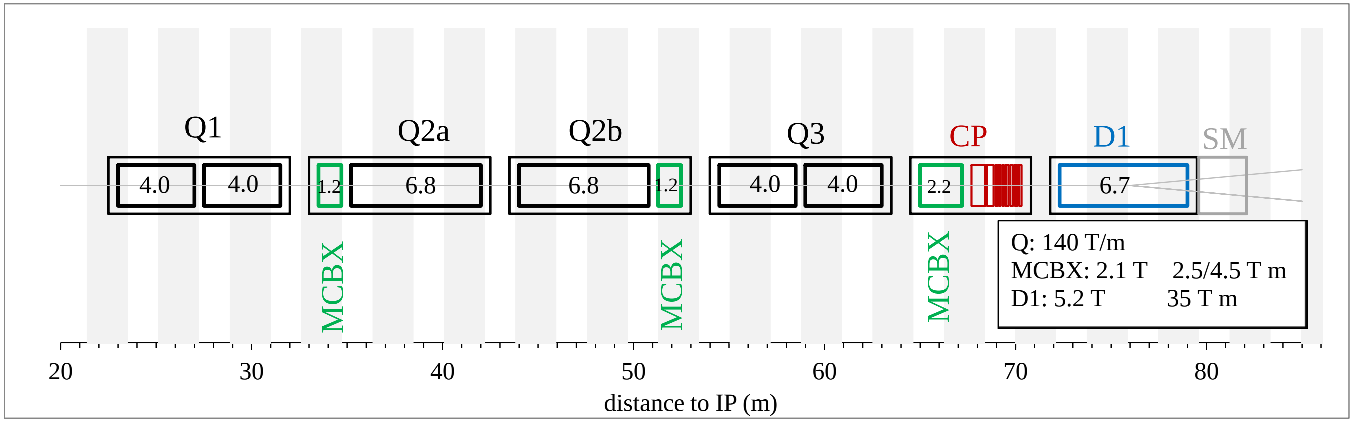


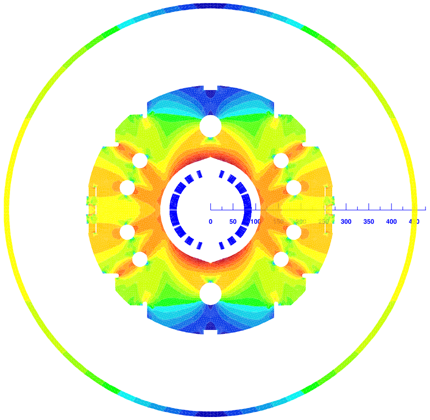
- Nonlinear correctors:
  - Superferric option, not
    - Easier operation, short heads, low current
    - Typical lenght 15 cm, skew quad 80 cm
  - Collaboration with INFN (Italy)
    - Deliverable: B_2, B_3, B_4, B_5, B_6 correctors by 2016



Proposal for nonlinear correctors
(F. Toral)

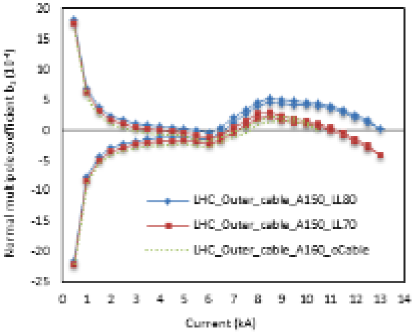
SEPARATION DIPOLE D1





D1 cross-section, with cryostat
(Q. Xu, T. Nakamoto)

- Increase kick from 26 to 35 T m
  - Nb-Ti technology, ~5 T operational field, ~7 m lo
  - Challenging field quality, large saturation
- Collaboration with KEK (Japan)
  - Deliverable: one short model by 2015



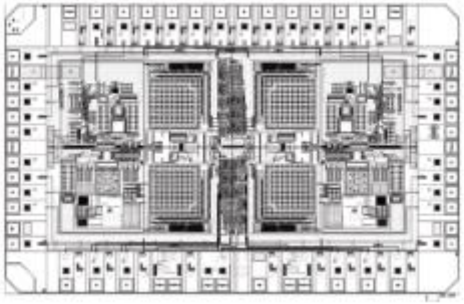
D1 b3 versus current
(Q. Xu, T. Nakamoto)

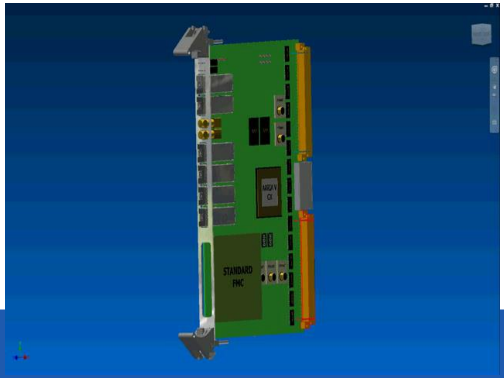
Beam Diagnostics
PIC

Rhodri Jones (BE/BI)

BI-PIC BLM

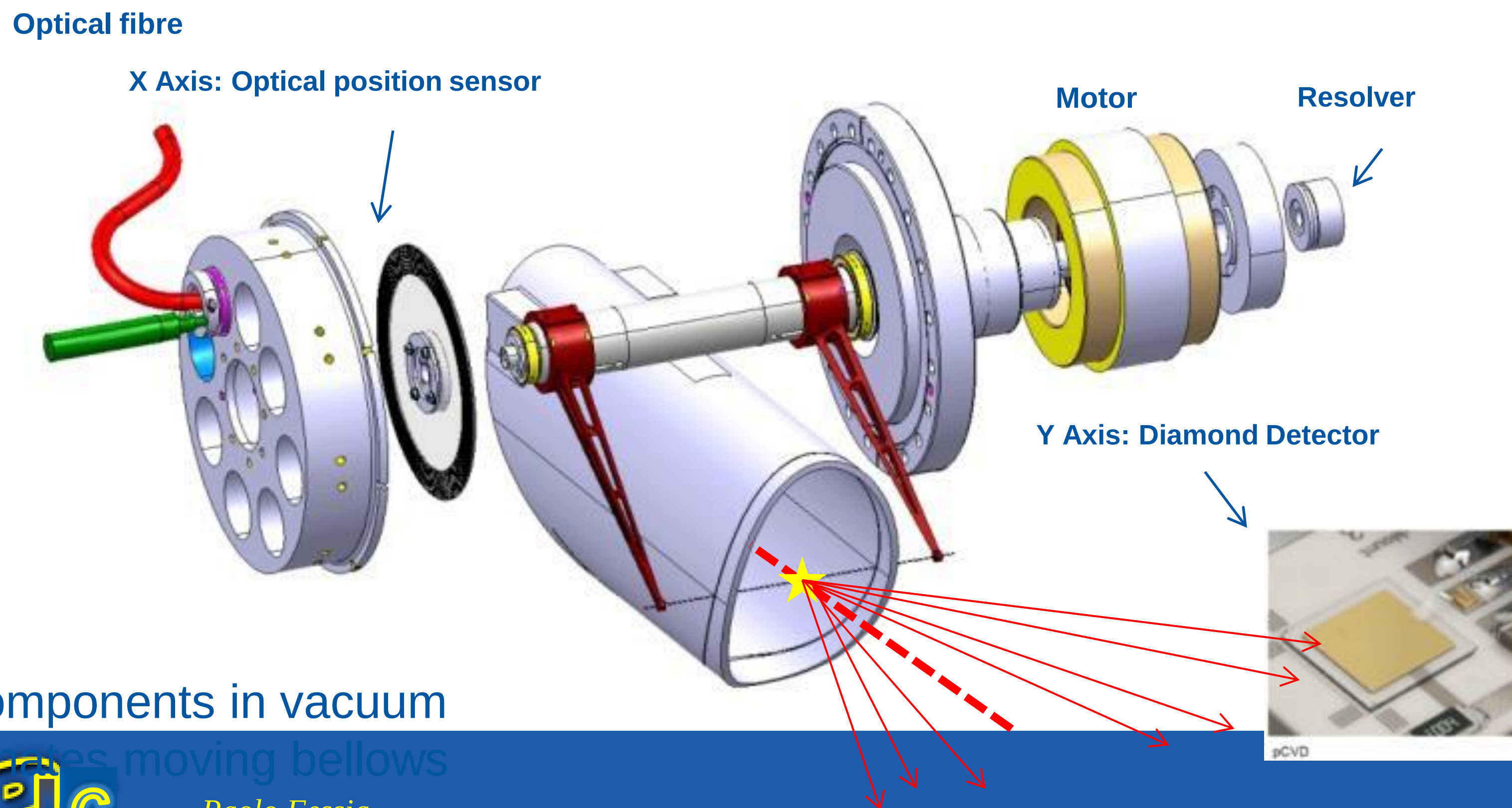
- **Cryogenic BLMs (1.7 MCHF)**
  - Current LSS configuration not suitable for HL-LHC
    - Cannot distinguishing dangerous losses from collision debris
  - Detectors for cryogenic environments studied
    - To be placed inside cryostat of the new triplet magnets
    - Dose measured more accurately represents correspond dose deposited in the coils
- **Radiation Hard Electronics (0.6 MCHF)**
  - 7TeV quench levels close to noise level of the acquisition system (IR3/IR7/LSS)
    - Due to long cables from detectors to front-end electronics
  - Development started on radiation hard Application Specific Integrated Circuit (ASIC) to remove need for such cables
- **Consolidation of BLM Electronics (1 MCHF)**
  - Replacement of surface electronics with new digital acquisition system
  - Allows additional BLM functionality not possible with today's system
  - Proposed for 2014-2018 using CONS budget





BI-PIC Emittance Measurement #1

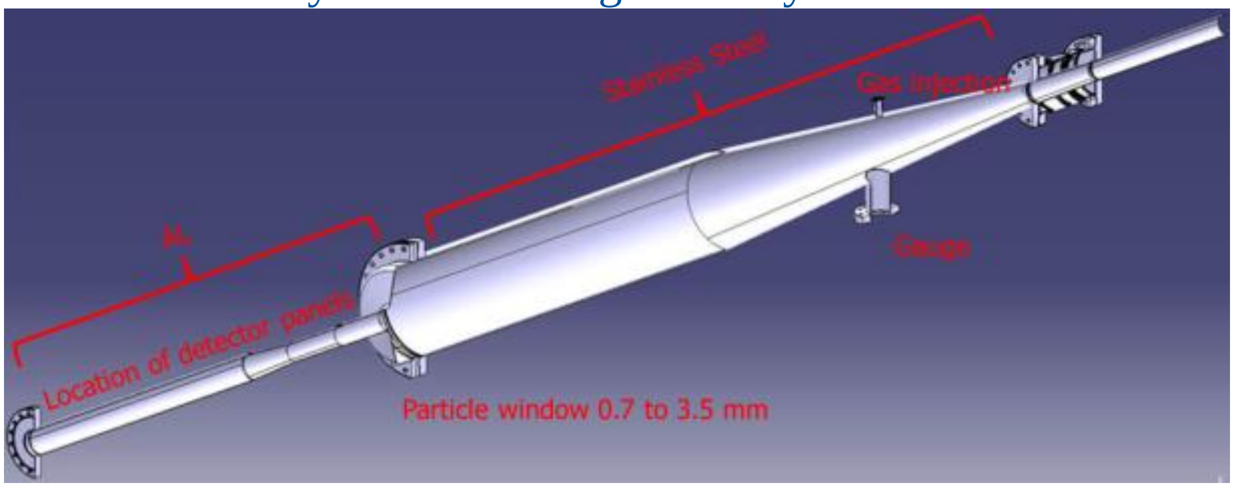
- **Fast Wire Scanners (0.6 MCHF)**
  - Would allow average emittance measurement of every batch at injection
    - Currently limited to first 2 batches injected
  - Principle to tested in SPS in 2014
  - LHC prototype for LS2 & full installation for LS3

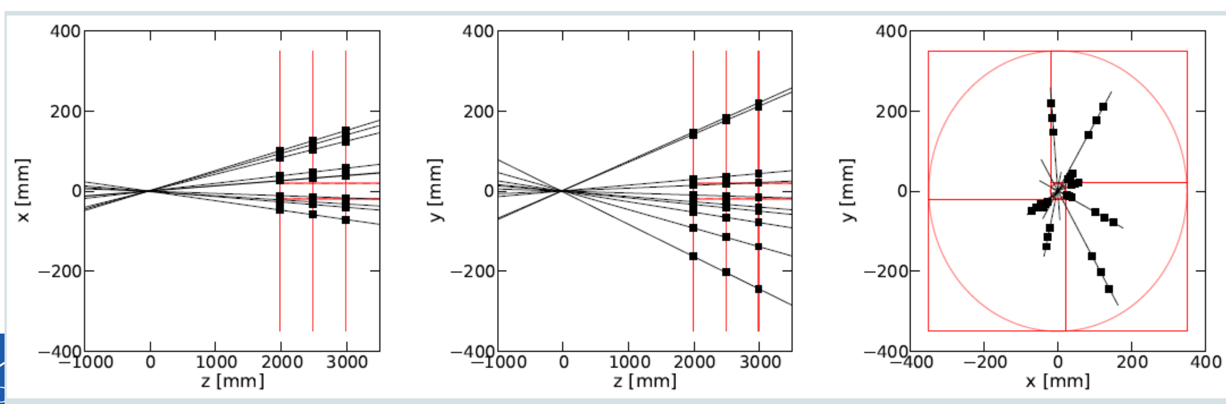


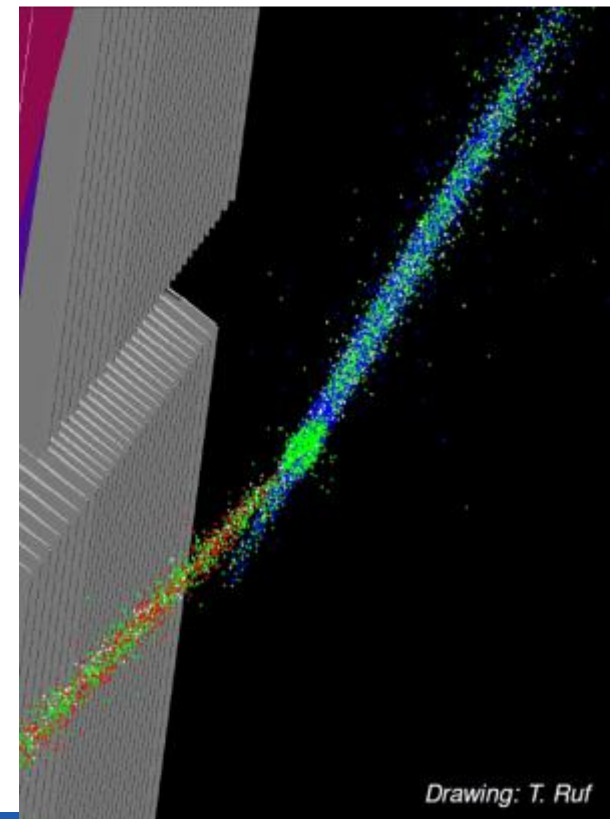
All components in vacuum
Eliminates moving bellows

BI-PIC Emittance Measurement #2

- **Beam Gas Vertex Detector – BGV**
  - 200kCHF for prototype in 2013-2015 & 850kCHF for final installation (LS2)
  - Prototype underway for installation during/after LS1
  - Full system would significantly enhance emittance measurement capabilities







Other BI-PIC

- **New BPMs Q1 to Q5 (1.2 MCHF)**
  - New design required for new triplet layout
    - Need to minimise transverse impedance
    - Need for tungsten shielding
- **Upgrade to Synchrotron Light Monitor (0.4 MCHF)**
  - Interlocked abort gap monitor
  - Prototype for LS2 full installation LS3
- **New Wideband Pick-ups for Instability Monitoring (0.2 MCHF)**
  - Prototyping phase for crab cavity diagnostics
- **Long Range Beam-Beam Compensator Prototype (1 MCHF)**
  - On-going with installation foreseen between LS1 and LS2

Superconducting Links at P7, PIC

- **Two Superconducting Links** installed in undergroun
- Powering of **600 A circuits**
- New DFBs installed in **TZ76**
- **None** or **very limited civil engineering** required
- R&D well advanced: **prototype link tested**
- Test of **full system** (DFB and SC Link) in SM-18 **by en**
- Installation in LHC during **LS2 (2018)**
- Procurement of **series** to be **launched** in **2015**

Superconducting Links at P1 and P5,
Hi-Luminosity Insertions

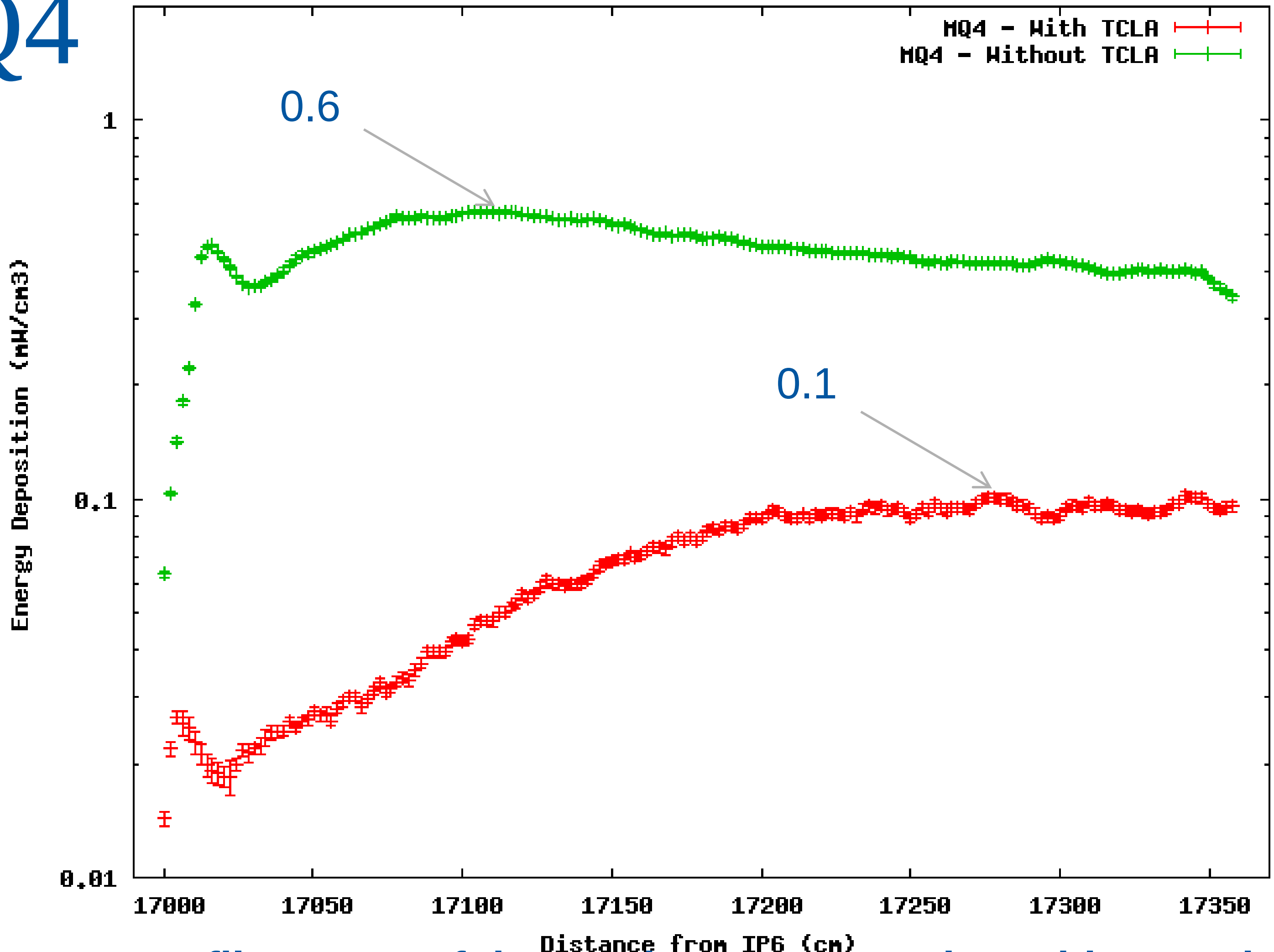
- **Two Superconducting Links** per point – from surface to underground areas
- New DFBs installed in **at the surface**
- Integration studies started
  Need for **civil engineering** to be verified – integration studies in 2014. If needed, LS2 or earlier
- R&D in progress
- Test of **full system** (DFB and SC Link) at CERN in **201**
- Installation in LHC during **LS3 (2022)**
- Procurement of **series** to be started by end **2016**

Superconducting Links at P1 and P5
Matching Sections and Arc

- **Two Superconducting Links** per point – from surface underground areas – for powering of **MSs**
- **Two Superconducting Links** per point – from surface underground areas – for powering of **arcs**
- Need for **civil engineering** to be verified
- R&D Combined with development of system for Triplets → Test of **full system** (DFB and SC Link) in **2015**
- Installation in LHC during **LS3 (2022)** or **LS2 (2018)**
- Procurement of **series** to be started by end **2015** for integration during LS2

IP 6 new TCLAs

Q4



Gain : a factor of **6**

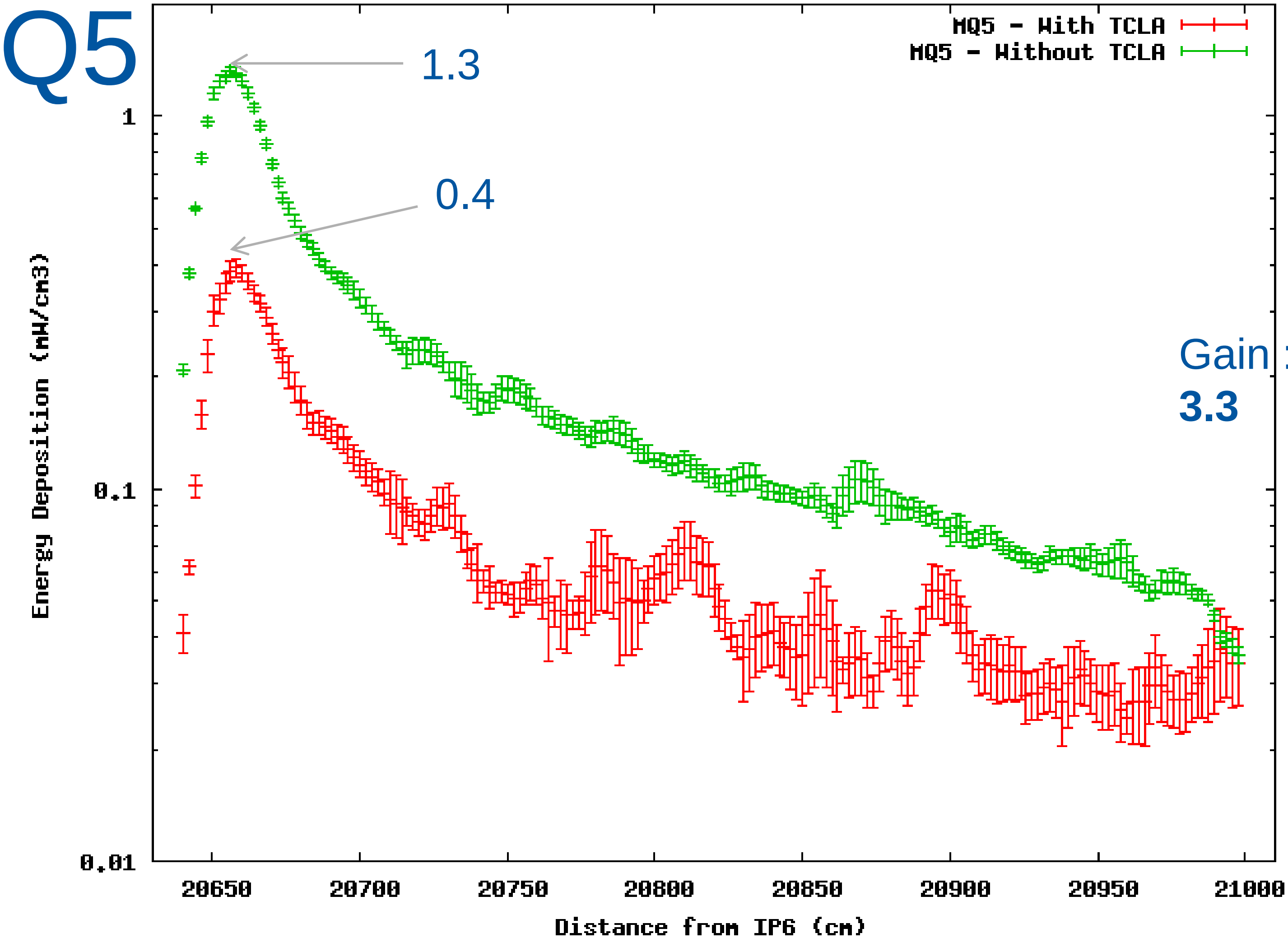
E.Skordis

Profile over Z of the maximum energy deposition on the Q4 coils.

Values are in **mW cm^{-3}**

*Normalisation [2.2 · 10^{11} p/bunch – 2808 bunches lost in 1 hour * (1854/6.4 · 10^{6})]*

Q5



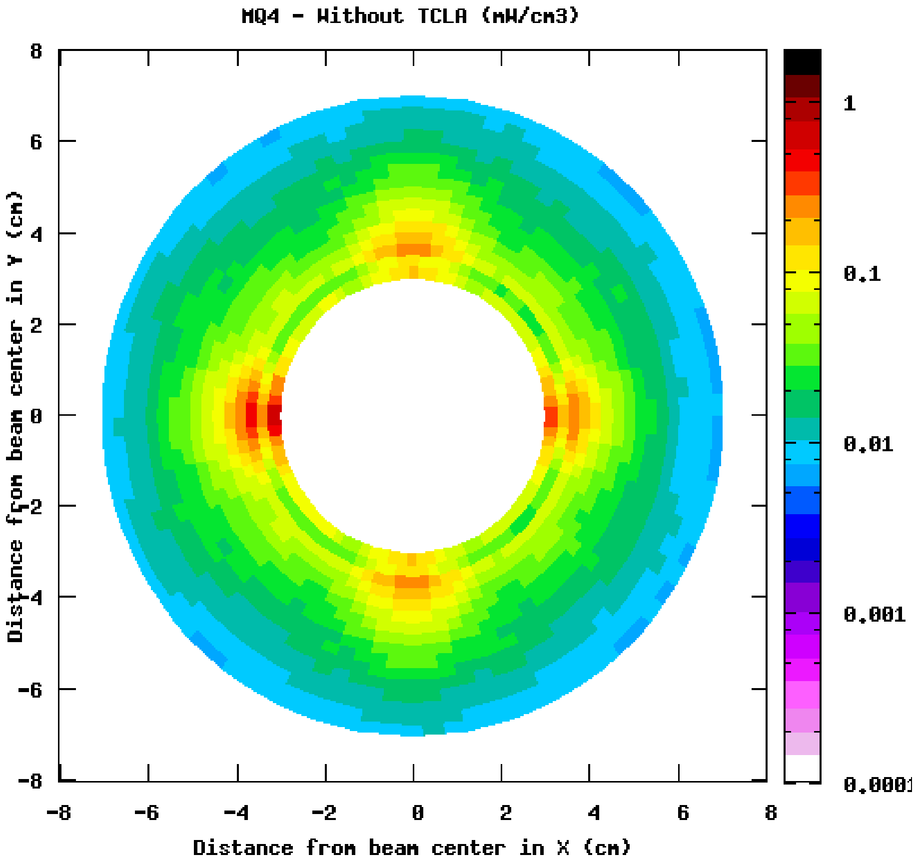
Gain : a factor of **3.3**

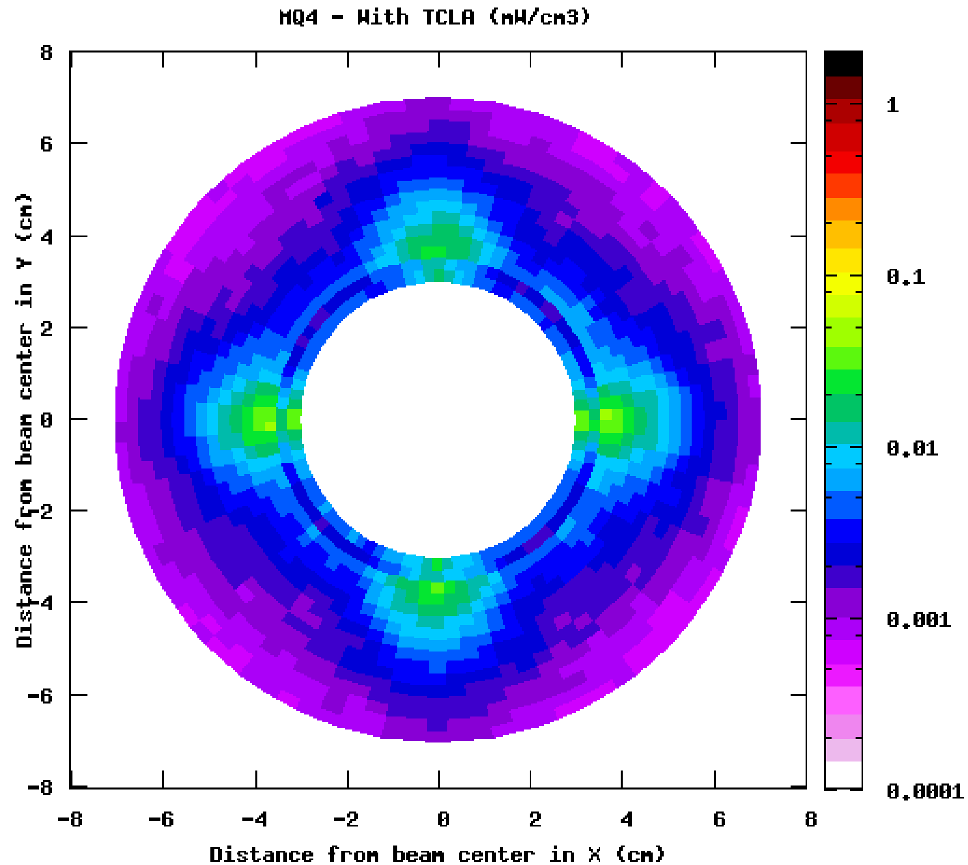
Profile over Z of the maximum energy deposition on the Q5 coils.

Values are in **mW cm^{-3}**

*Normalisation [2.2 · 10^{11} p/bunch – 2808 bunches lost in 1 hour * (1854/6.4 · 10^{6})]*

Q4





Total Energy deposition

Without TCLA : 2.76 W

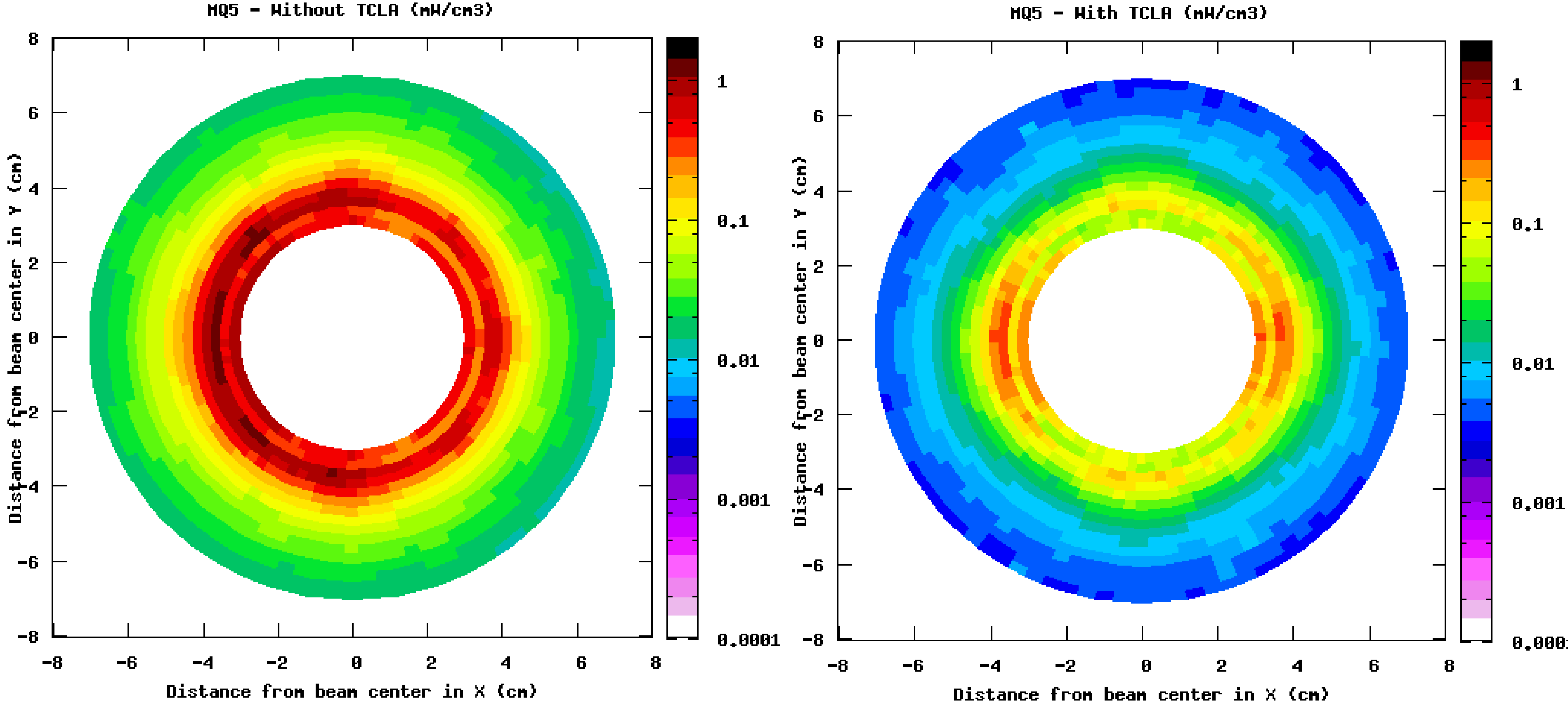
With TCLA : 0.40 W

X,Y cross section at the Z of the maximum energy deposition on the Q4

Values are in **mW cm^{-3}**

*Normalisation [2.2 · 10^{11} p/bunch – 2808 bunches lost in 1 hour * (1854/6.4 · 10^{6})]*

Q5



Total Energy deposition

Without TCLA : 2.15 W

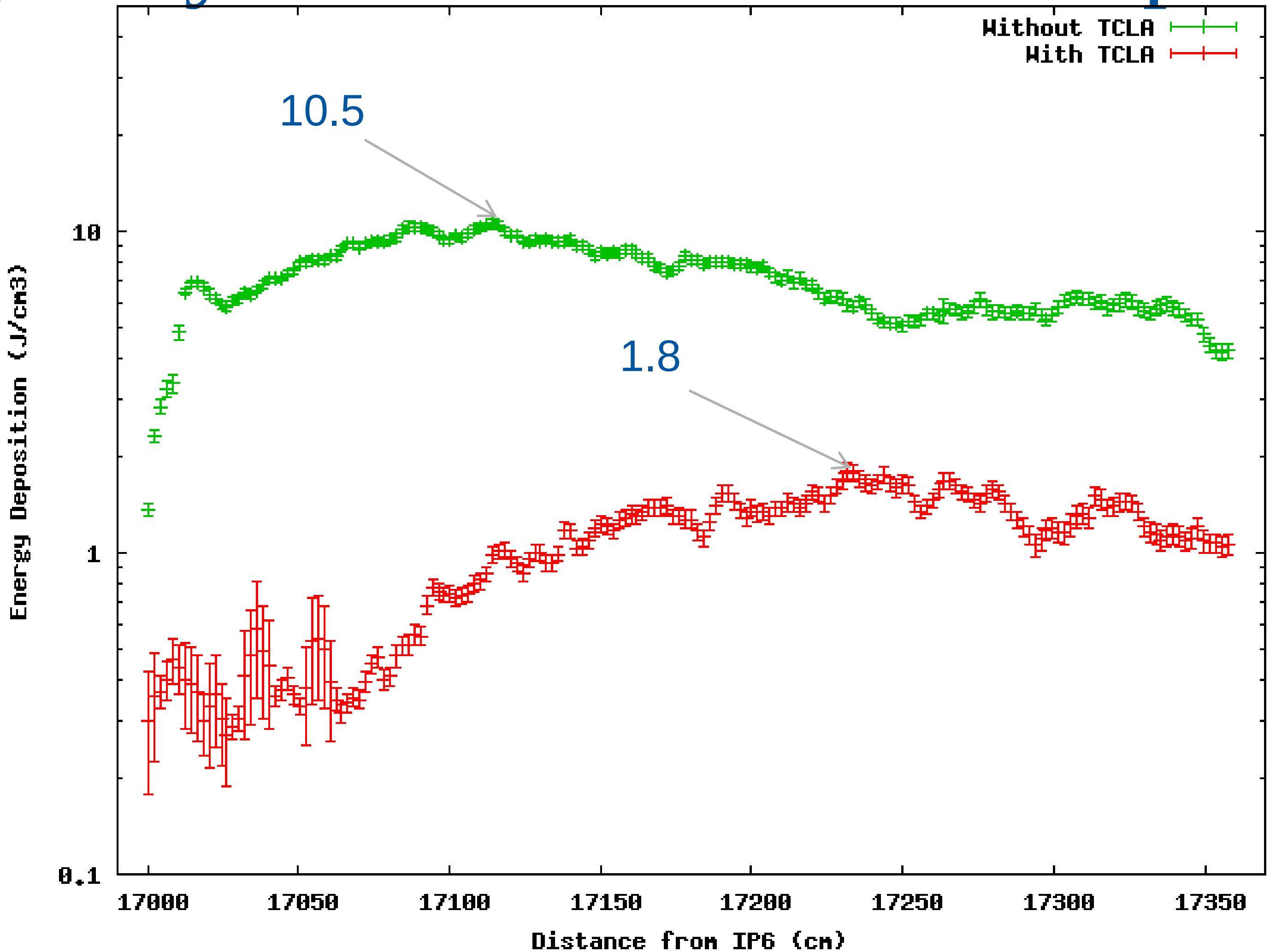
With TCLA : 0.66 W

X,Y cross section at the Z of the maximum energy deposition on the Q5

Values are in **mW cm^{-3}**

*Normalisation [2.2 · 10^{11} p/bunch – 2808 bunches lost in 1 hour * (1854/6.4 · 10^{6})]*

Q4 Asynchronous Beam Dump



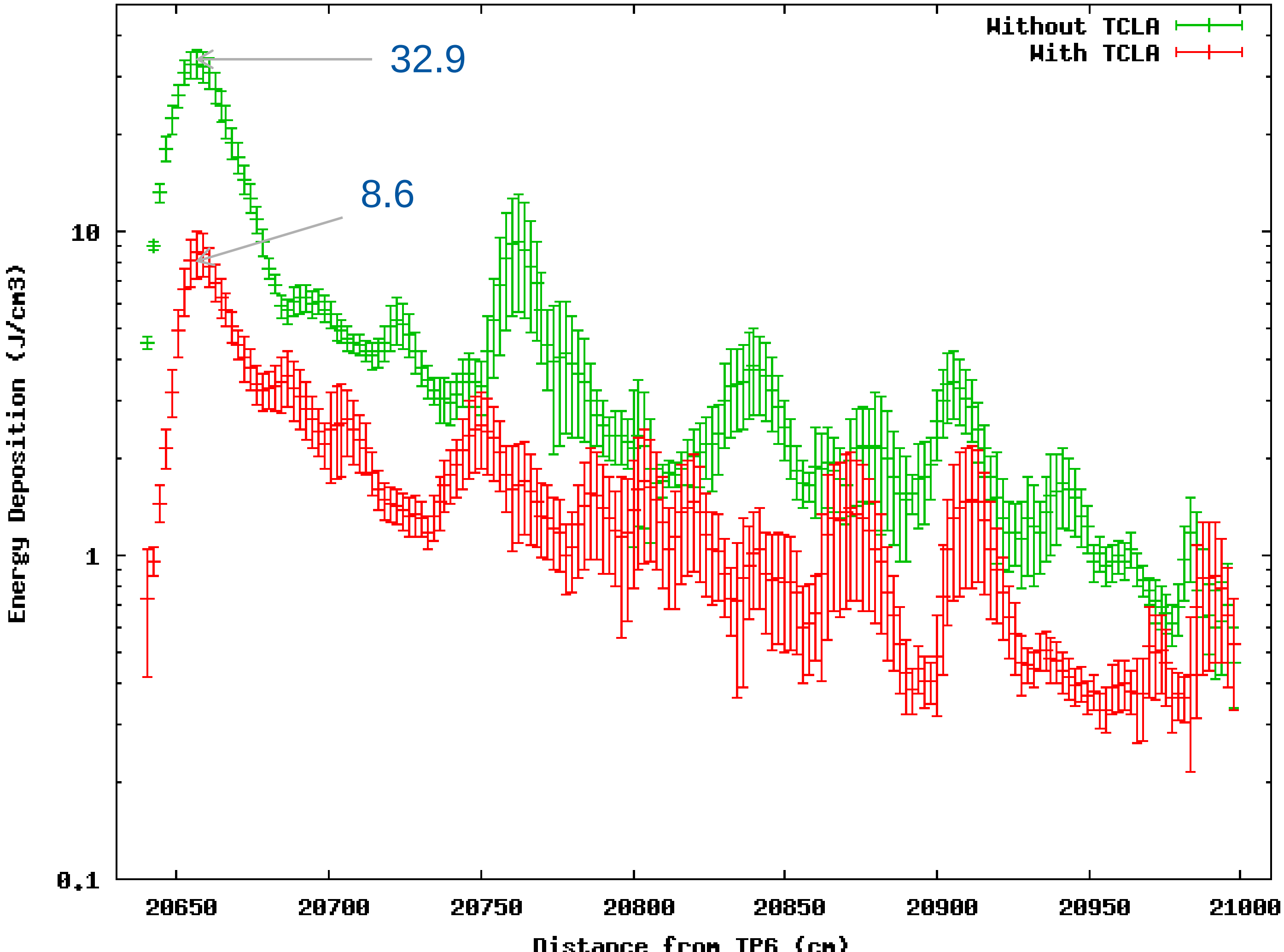
Gain : a factor of **5.8**

Profile over Z of the maximum energy deposition on the Q4 *coils*

Values are in **J cm^{-3}**

Normalisation [2.2 · 10^{11} p/bunch – 40 bunches]

Q5 Asynchronous Beam Dump



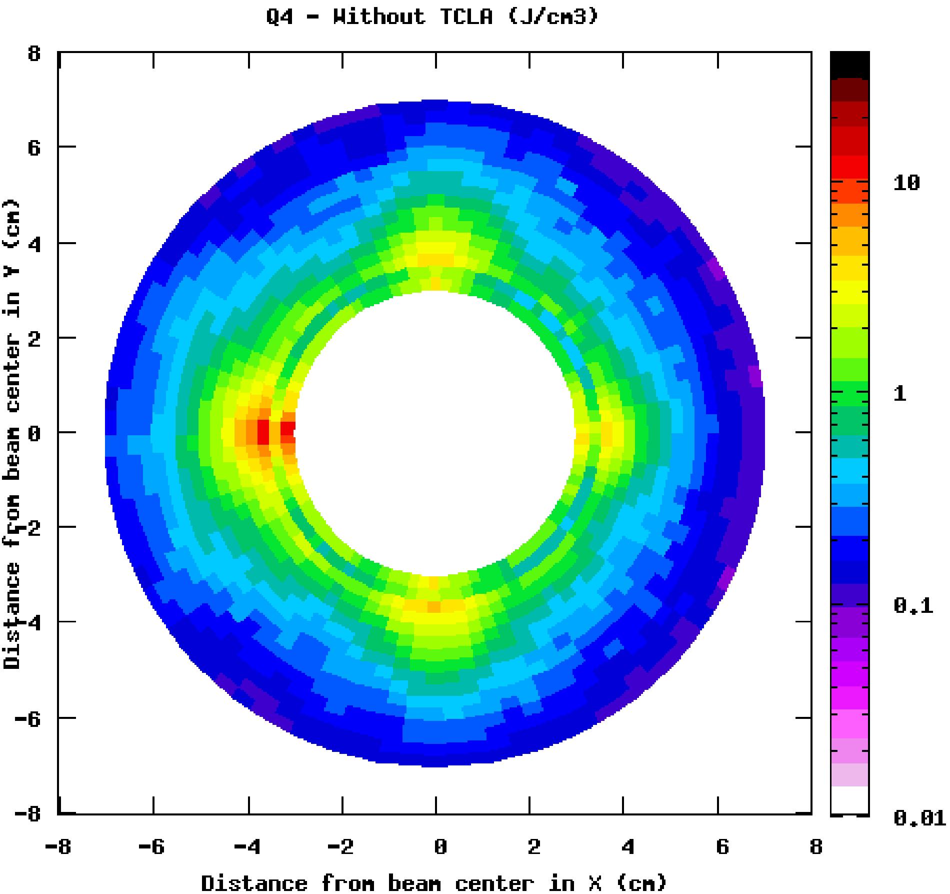
Gain : a factor of **3.8**

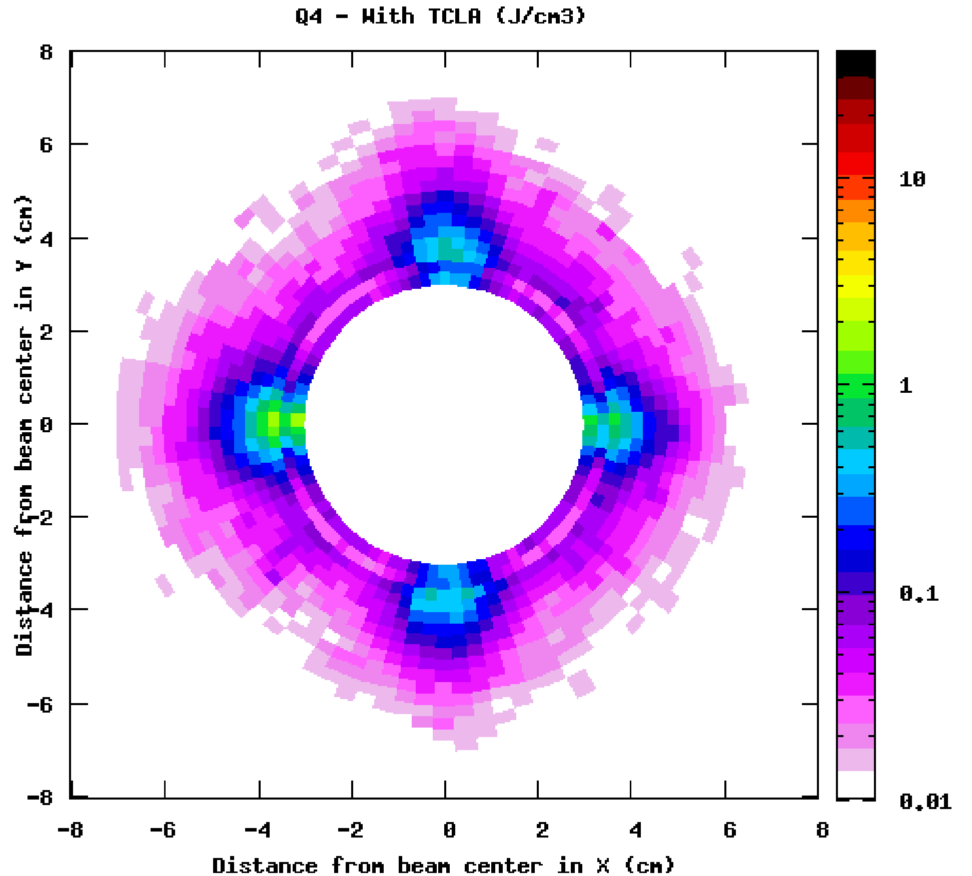
Profile over Z of the maximum energy deposition on the Q5 *coils*

Values are in **J cm^{-3}**

Normalisation [2.2 · 10^{11} p/bunch – 40 bunches]

Q4





Total Energy deposition

Without TCLA : 49.34 kJ

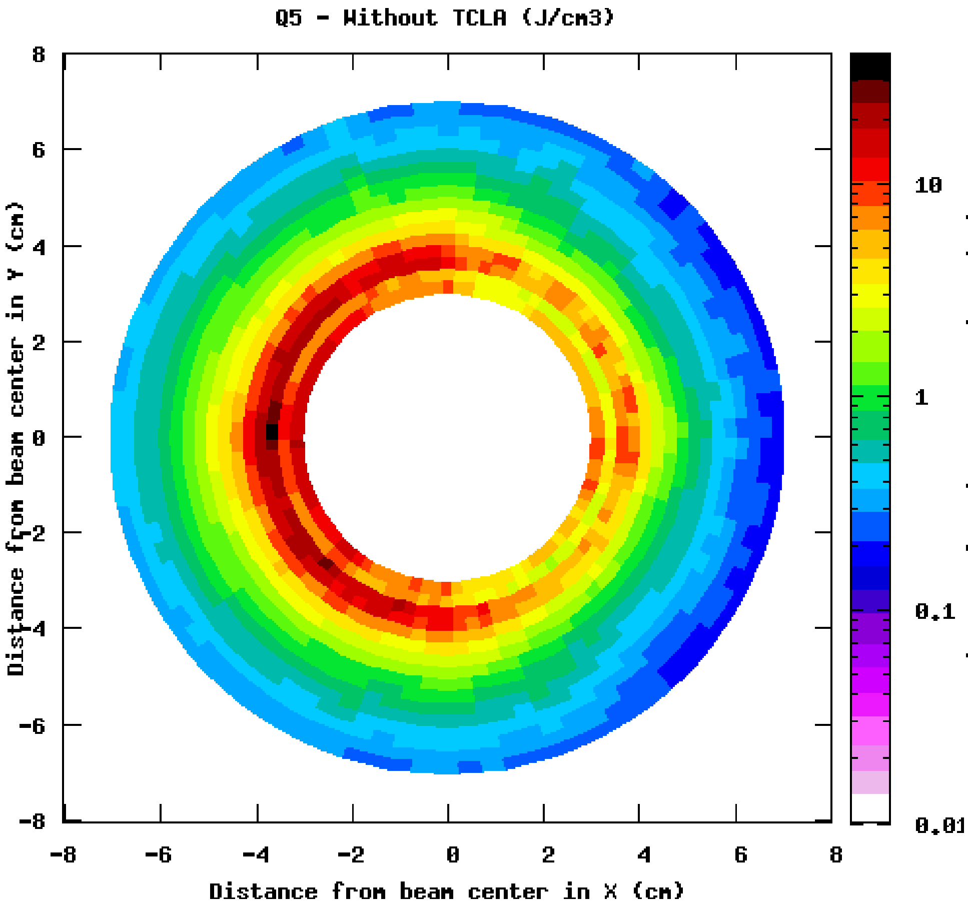
With TCLA : 14.22 kJ

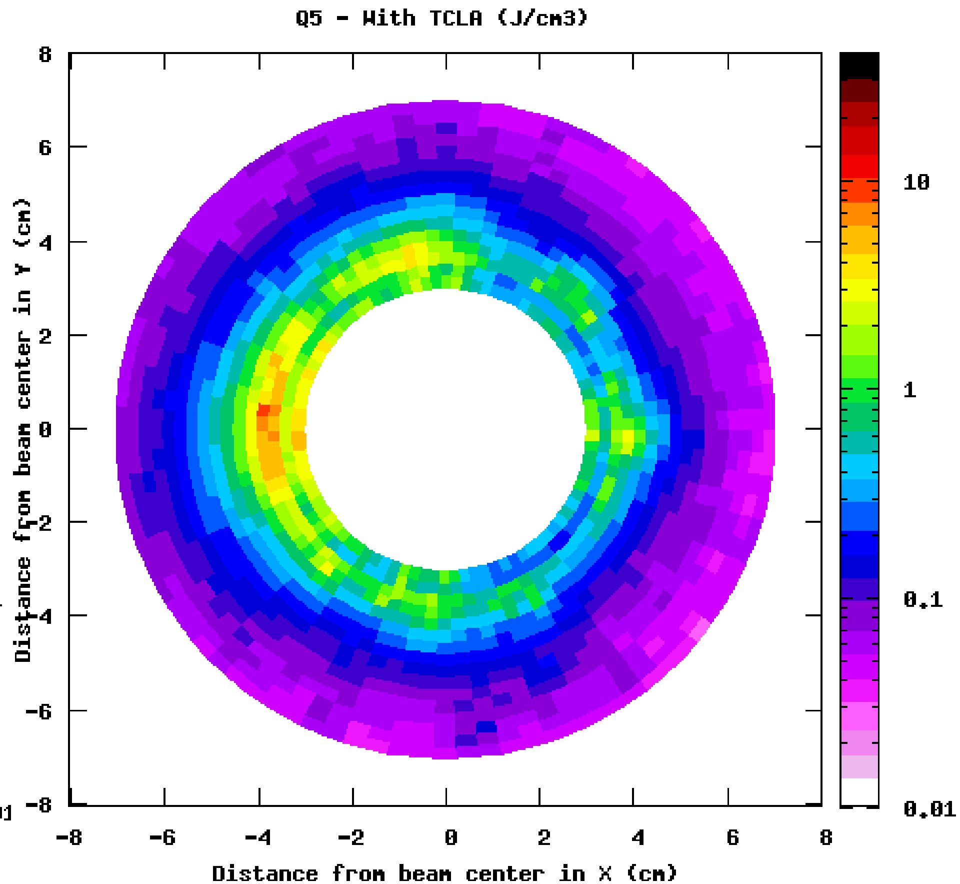
X,Y cross section at the Z of the maximum energy deposition on the Q4

Values are in **J cm^{-3}**

Normalisation [2.2 · 10^{11} p/bunch – 40 bunches]

Q5





Total Energy deposition

Without TCLA : 32.08 kJ

With TCLA : 8.157 kJ

X,Y cross section at the Z of the maximum energy deposition on the Q5

Values are in **J cm^{-3}**

Normalisation [2.2 · 10^{11} p/bunch – 40 bunches]