High Temperature Superconductors for the Superconducting Links of the Hi-Lumi-LHC Project

Workshop on Radiation Effects in Superconducting Magnets and Materials 2014 (RESMM'14)

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INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI MILANO

RESMM’14 Wroclaw May13th 2014

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.

LASA Laboratorio Acceleratori Superconduttività Applicata

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Outline

- HiLumi-LHC
- WP 6 Cold Powering
- Material Comparison (MgB_2, BSCCO, YBCO)
- Real cable composition and comparison vs. bulk MgB_2
- Towards the final configuration
- Boron consumption
- Fluencies in the LHC upgraded configuration

Previous Experiences on Magnet Energy Deposition (I)

- Study of a new Nb_3Sn design for the LHC insertion quad started in 1995, suggested by the Milan group (L.Rossi)

- Ended in 1998
  (1999 final report)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN/TC-95/25
13 Settembre 1995

G. Ambrosio, F. Ametrano, G. Bellomo, F. Broggi, L. Rossi, G. Volpini.

PRELIMINARY PROPOSAL OF A Nb_3Sn QUADRUPOLE MODEL FOR THE low β INSERTIONS OF THE LHC

INFN **ISTITUTO NAZIONALE DI FISICA NUCLEARE**

Sezione di Milano

INFN/TC-99/04
2 Marzo 1999

STUDY OF THE STABILITY OF THE LHC LOW BETA INNER TRIPLET FOR A NB_3SN DESIGN

Giorgio Ambrosio[1], Francesco Broggi[1], Lucio Rossi[2]

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Previous Experiences on Magnet Energy Deposition (II)

NED (EU) - Candia (INFN); EUCARD – HHH
Study of the LHC Phase II upgrade

- **AMTW** Accelerator Magnet Technology Workshop on beam generated heat deposition and quench levels in LHC magnet, CERN, March 2005

- **3rd CARE-HHH-APD Workshop LHC-LUMI-06**
‘Towards a Roadmap for the Upgrade of the CERN & GSI Accelerator Complex’
IFIC, Valencia, Spain – 16-20 October 2006

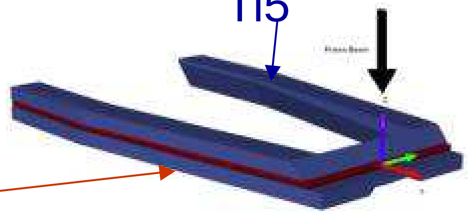
- **CARE-HHH-APD Mini-Workshop IR'07** Frascati, November 2007

High Luminosity LHC

Previous Experiences on Magnet Energy Deposition (III)

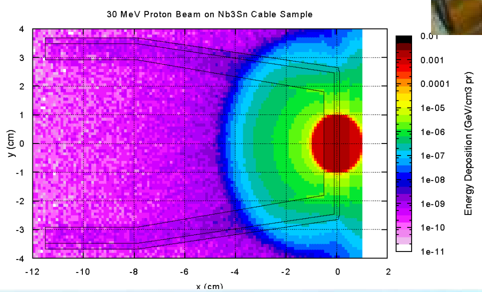
- After the LHC accident there was a stop in the upgrade studies
- Start again with the SIT (Superconducting Irradiation Test) because of lacking on informations and data on radiation effects on the magnet material Nb_3Sn

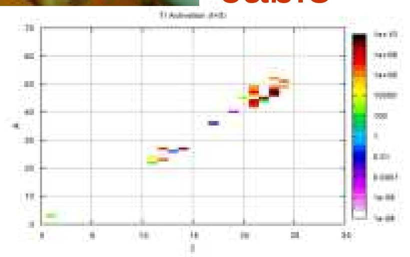
Ti5

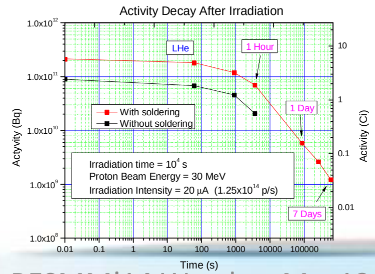


Nb_3Sn cable

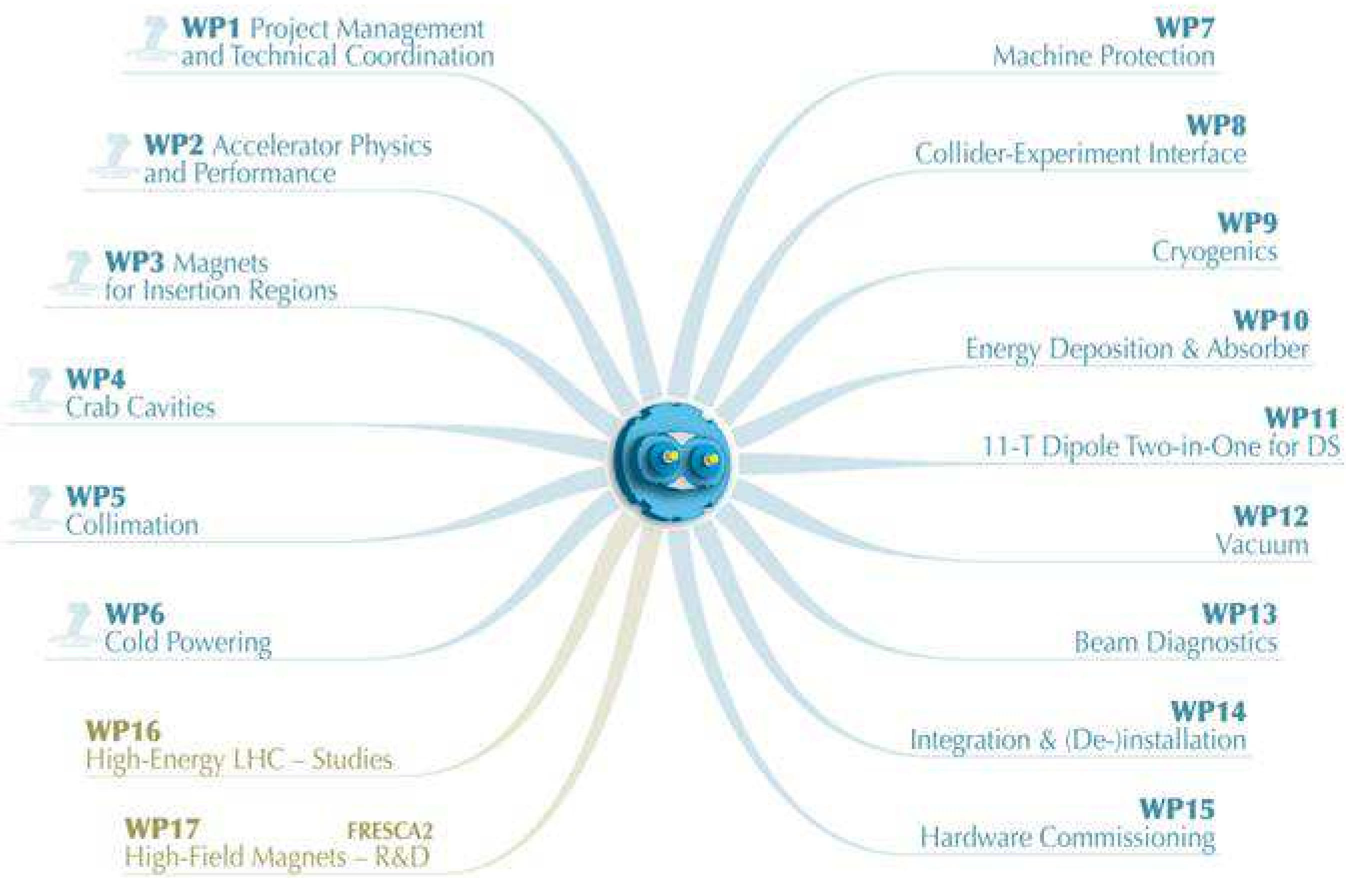
SimpleGeo Plot







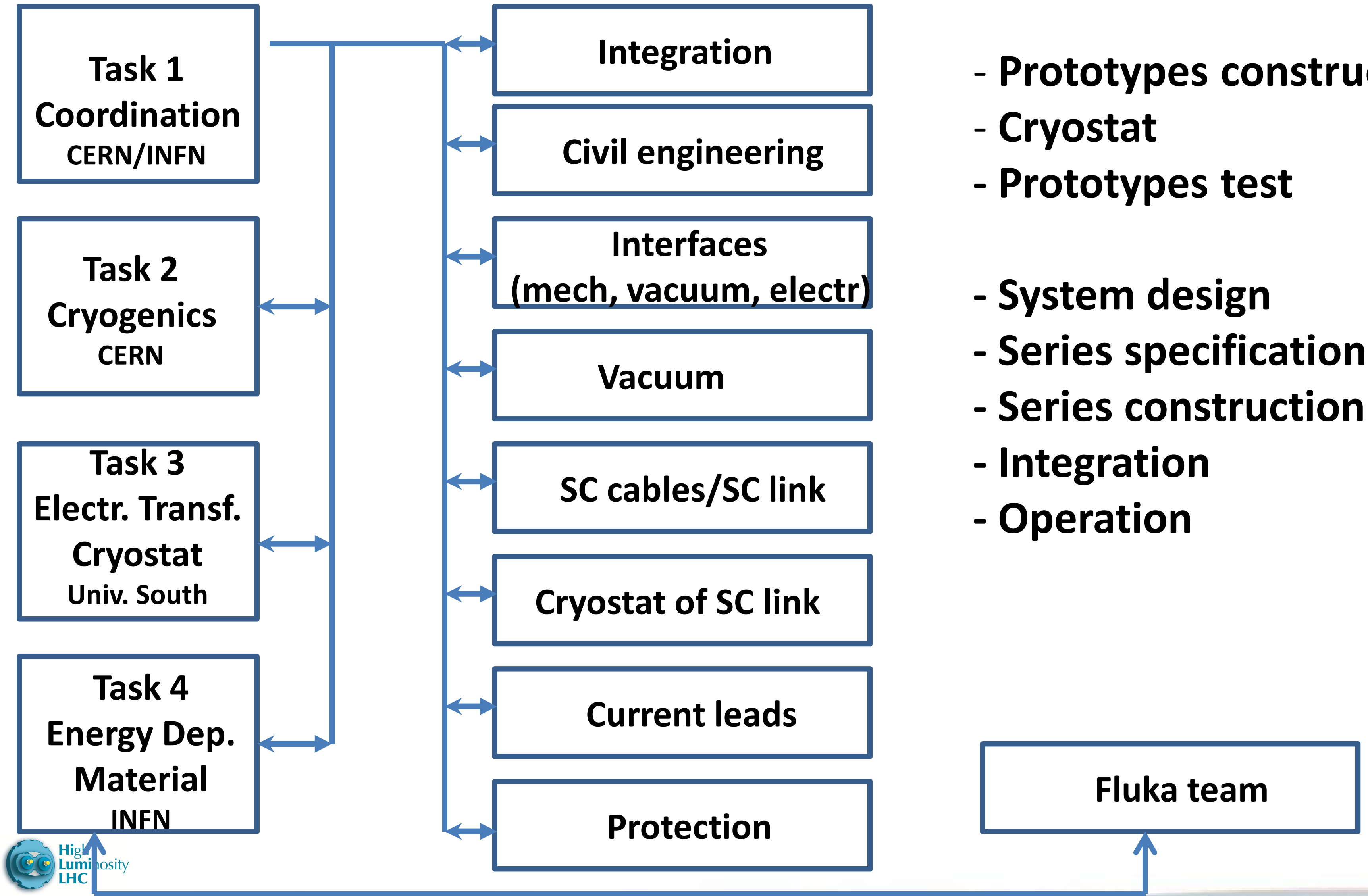
Hi-Lumi-LHC Project



High Luminosity LHC

WP6 Structure (Coordinator A. Ballarino (CERN), Deputy coordinator F. Broggi (INFN))

"Cold Powering"



Cold Powering via Superconducting Links

Advantages of remote powering:

-Safer long-term operation of powering equipment (power converters, current leads and associate auxiliary devices) located in a radiation-free environment;

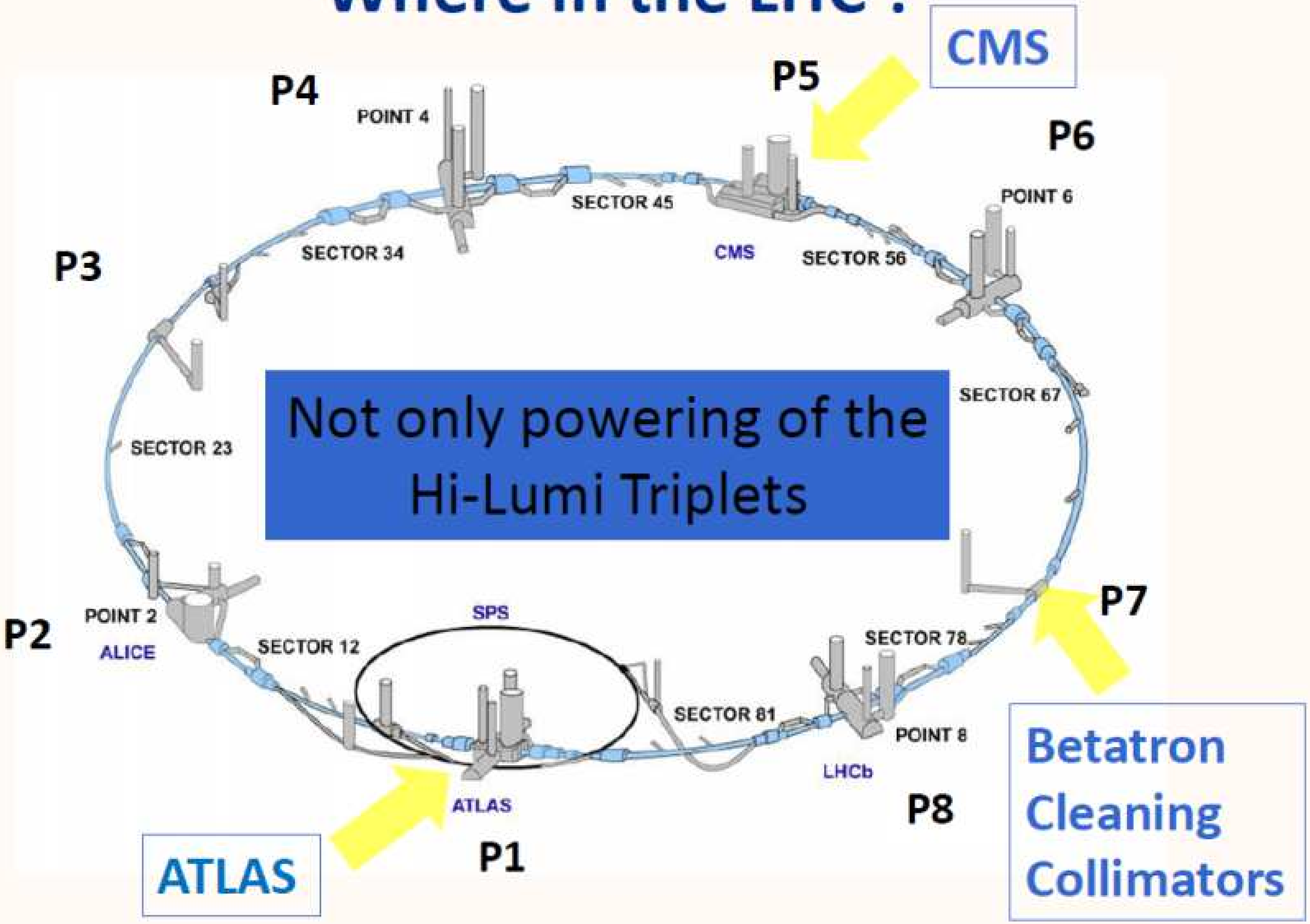
-Safer access of personnel to equipment for maintenance, repair, diagnostic and routine tests interventions;

- Reduced time of interventions on power converters, current leads and DFBs if the powering equipment is located outside of the tunnel areas – gain in machine availability ;

- Free space in the beam areas which becomes available for other equipment.

Courtesy of Amalia Ballarino

Where in the LHC ?

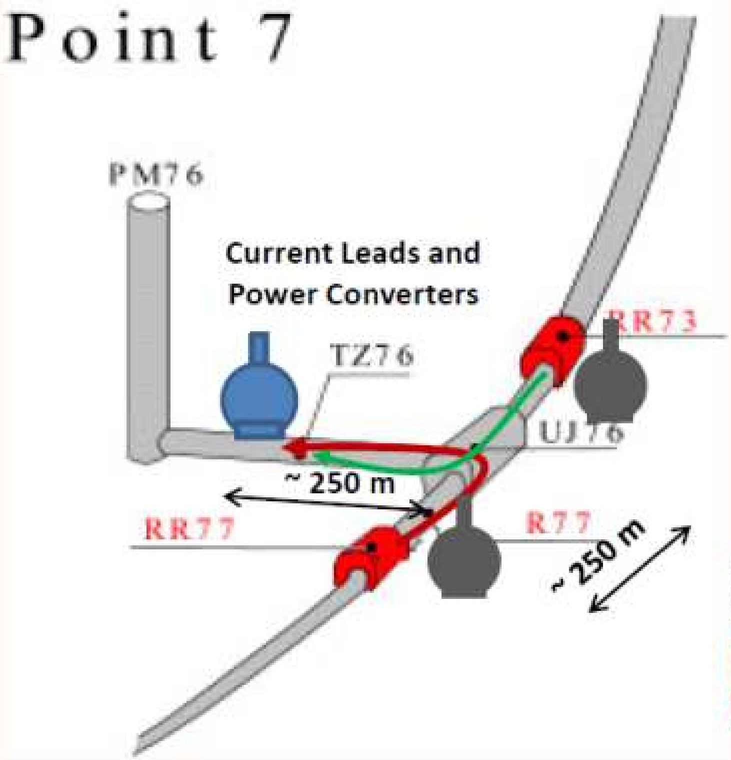


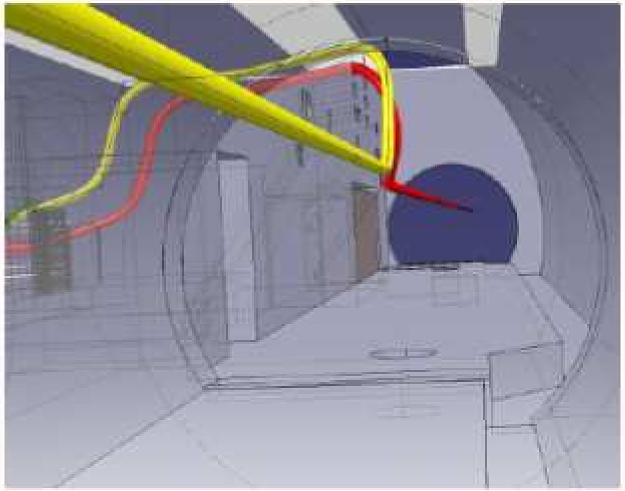
A. Ballarino, 05/03/2014

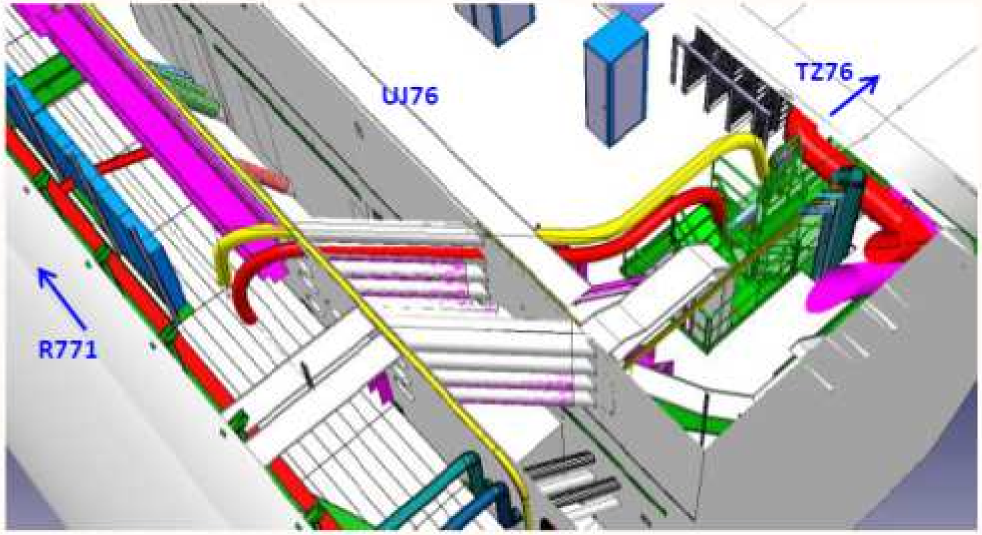
Distribution Feedboxes removed from LHC Tunnel

A. Ballarino, 05/03/2014

LHC P7



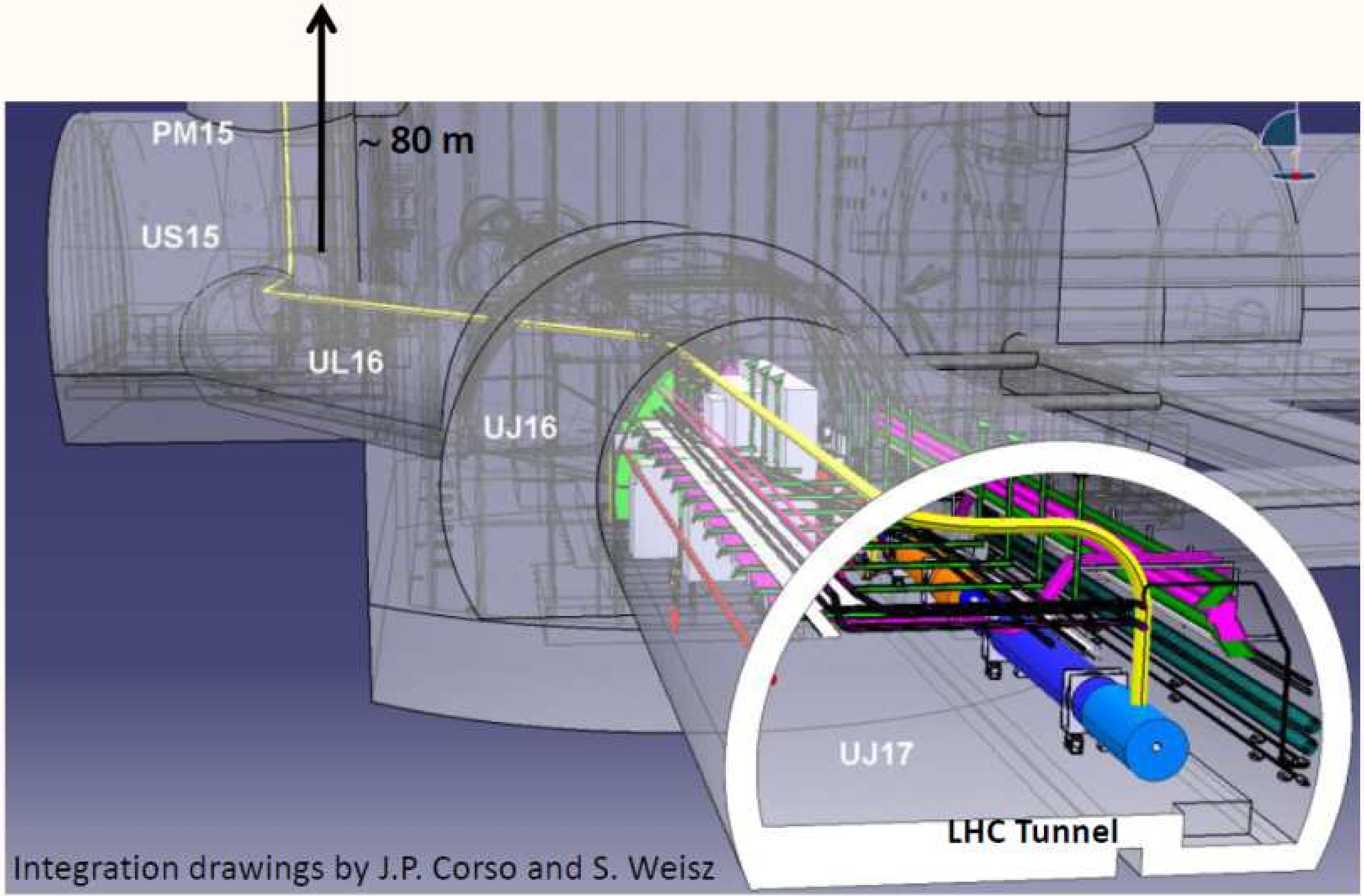




LHC P7: Cleaning Insertions

Underground Installation

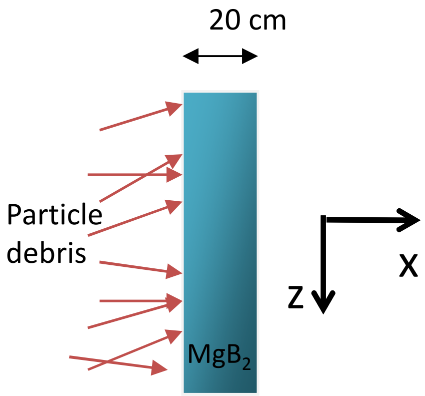
Superconducting Link at LHC P1

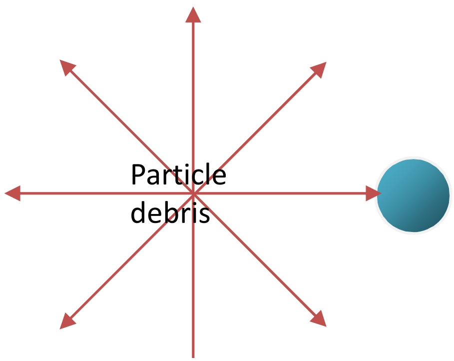


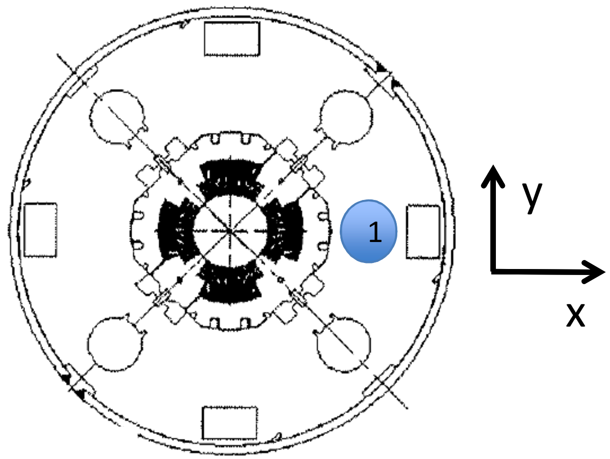
A. Ballarino, 05/03/2014

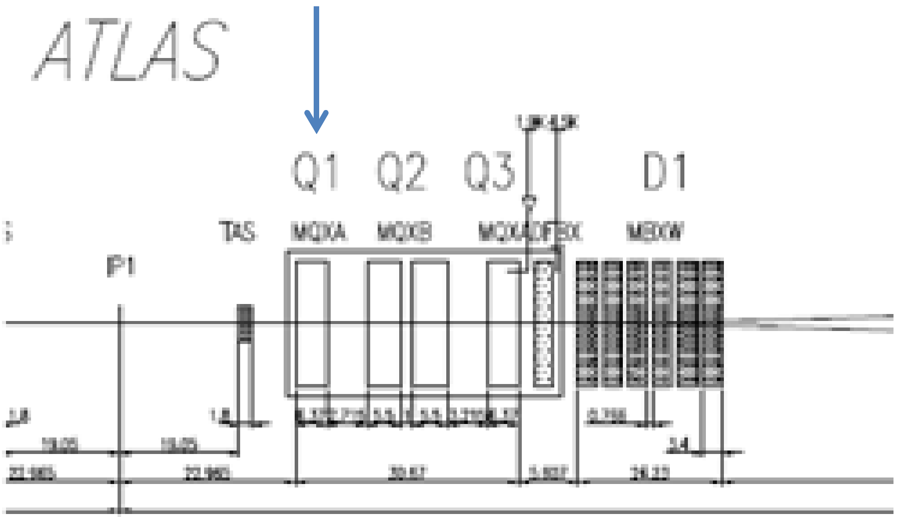
Material Comparison

MgB_2 BSCCO YBCO



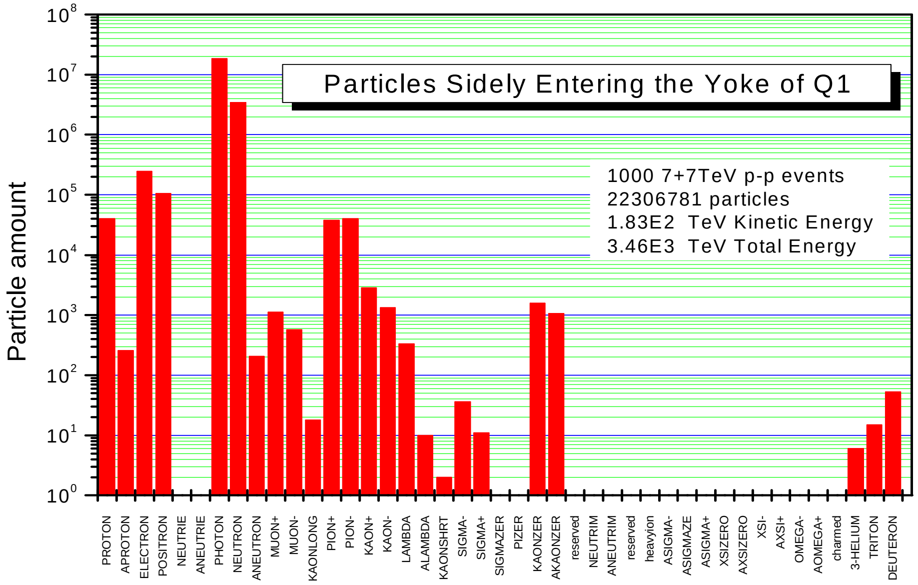


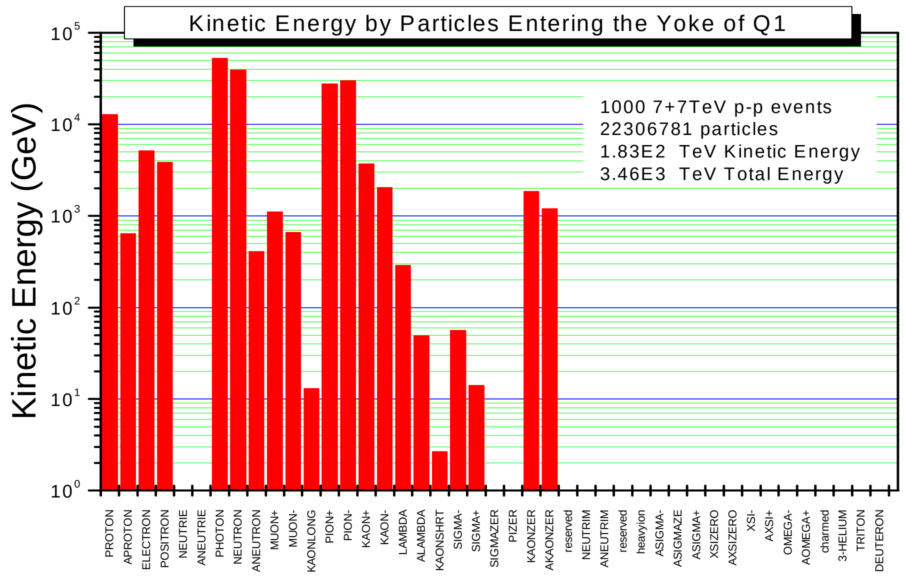




Primary Fluencies

(Q1-Q3 Collar-->Yoke)



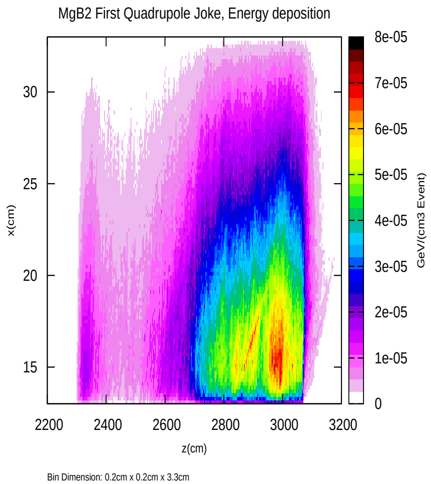


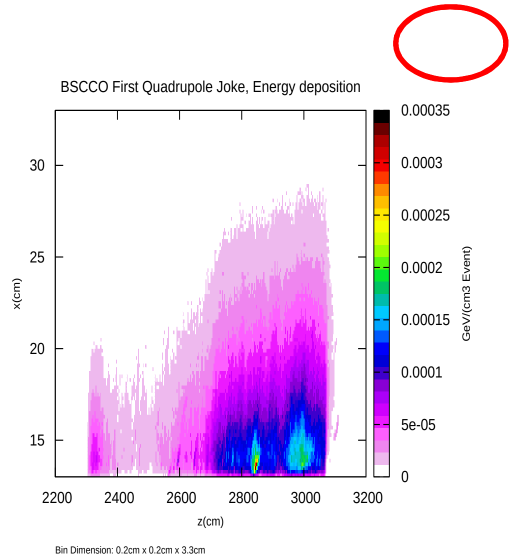
83% of the particles are photons
15% are neutrons

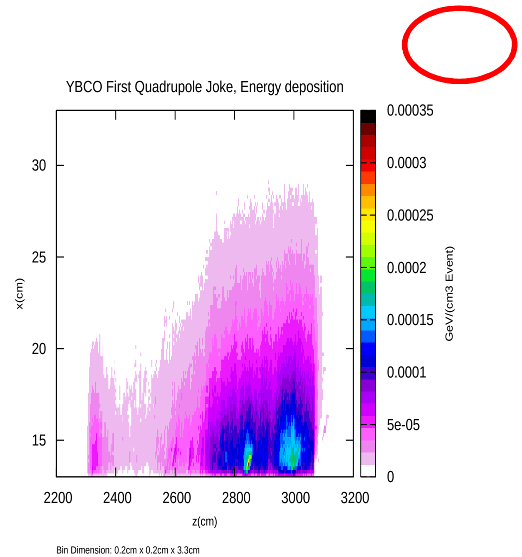
29% of the kinetic energy is from photons
21% from neutrons
31% from pions

1.5% of the total energy is from photons
94% from neutrons

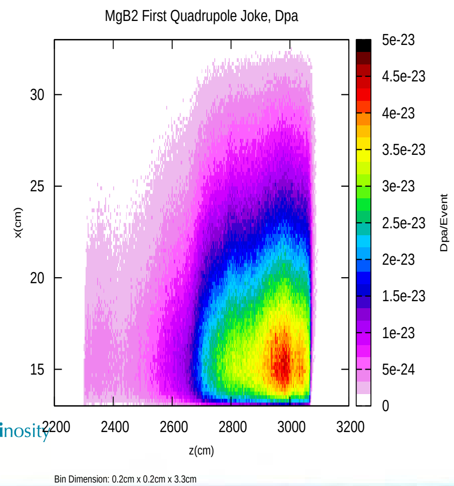
Material Comparison

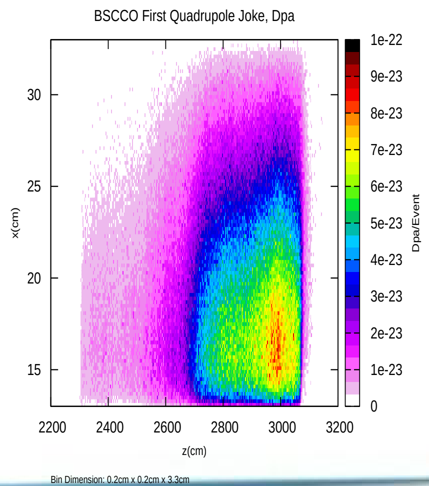


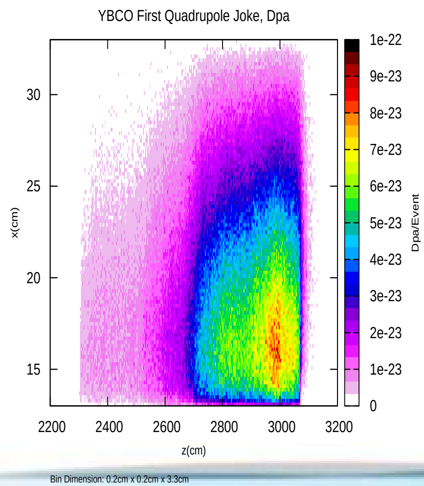




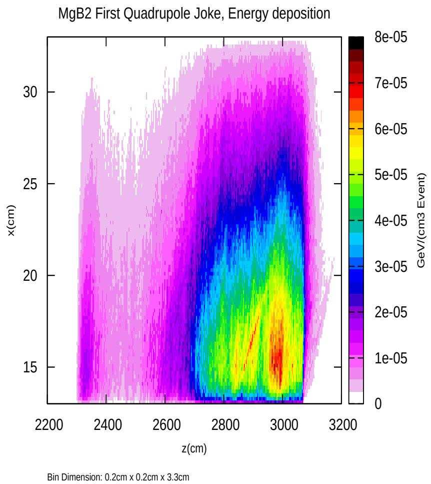
To scale to 3000 fb^{-1} multiply for 3x10^{17} (σ=100 mb)

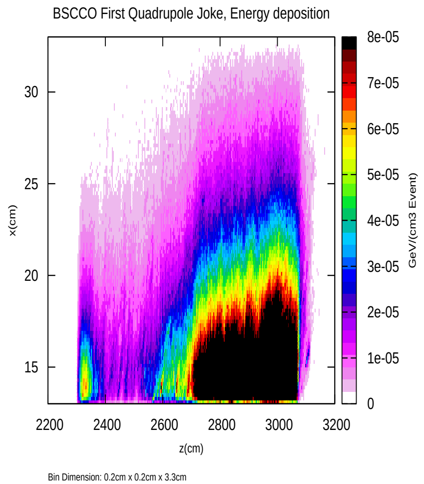


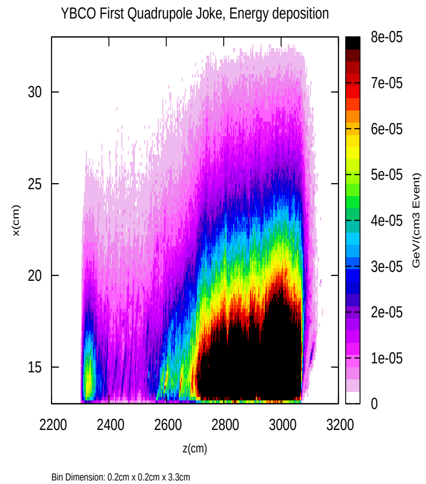


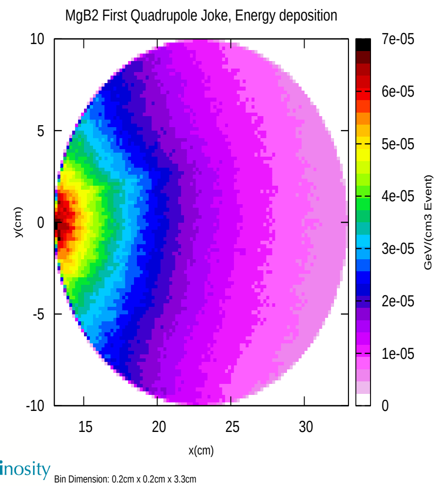


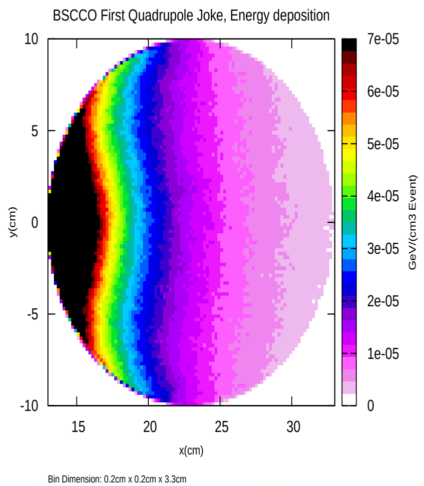
Material Comparison Same scale

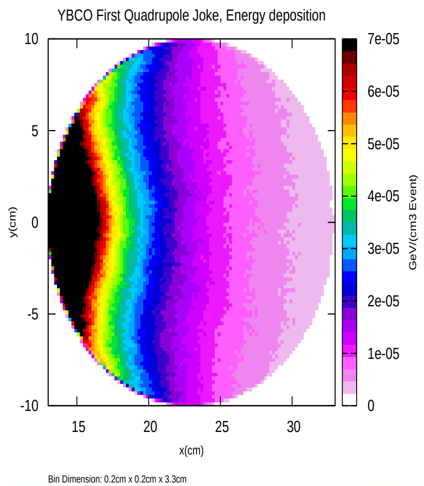










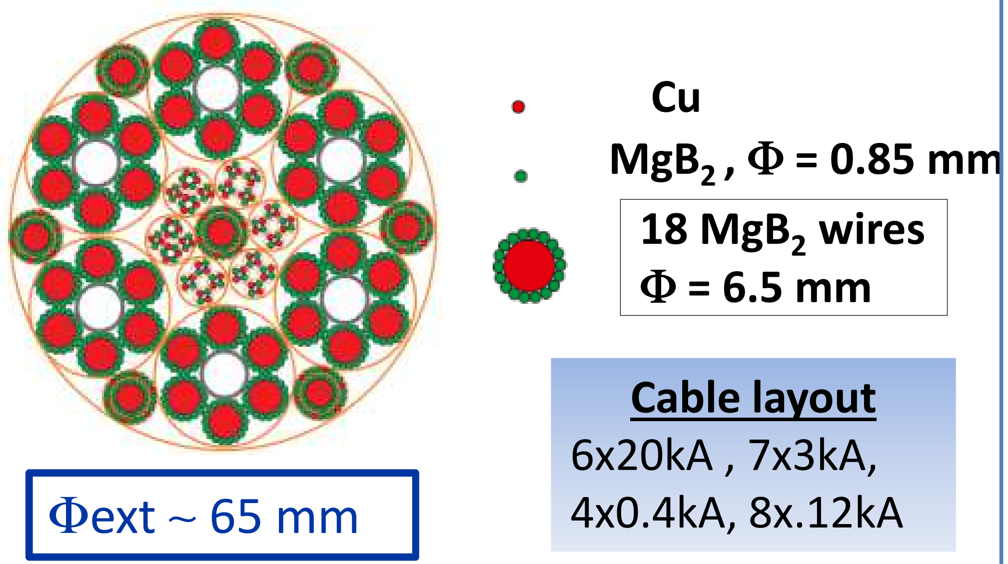


Simulation progress

- BSCCO and YBCO are similar (for the energy deposition and DPA aspects); MgB_2 has a slightly lower energy deposition

- Definitive definition of the cable geometry and material composition

- Simulation of this cable aside Q1 (P1 geometry), to compare the bulk MgB_2 cable with the composite one



Courtesy A. Ballarino

Cable Material Composition

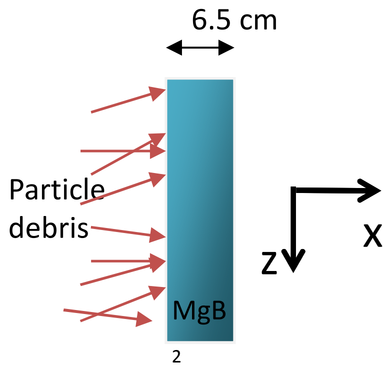
Material composition of the cable for the Monte Carlo simulations

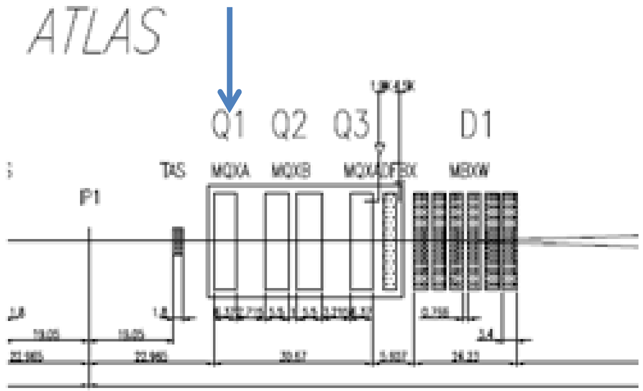
MATERIAL	ATOM CONTENT	PARTIAL DENSITIES (g/cm^3)
MAGNESIUM	0.1225	0.2192
BORON	0.24501	0.195
COPPER	0.48231	2.2563
HYDROGEN	2.03E-02	1.51E-03
CARBON	4.88E-02	4.31E-02
NITROGEN	4.07E-03	4.19E-03
OXYGEN	1.02E-02	1.20E-02
HELIUM	8.89E-03	2.62E-03
IRON	4.05E-02	0.16655
NICKEL	5.55E-03	2.40E-02
CHROMIUM	1.19E-02	4.55E-02

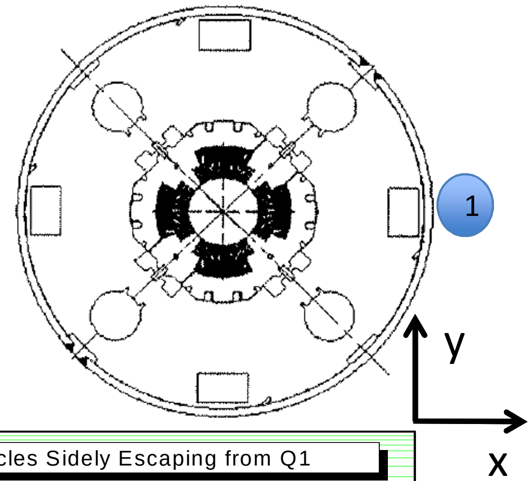
The resulting density of the cable is 2.97 g/cm^3, with a radiation length of 4.846 cm.

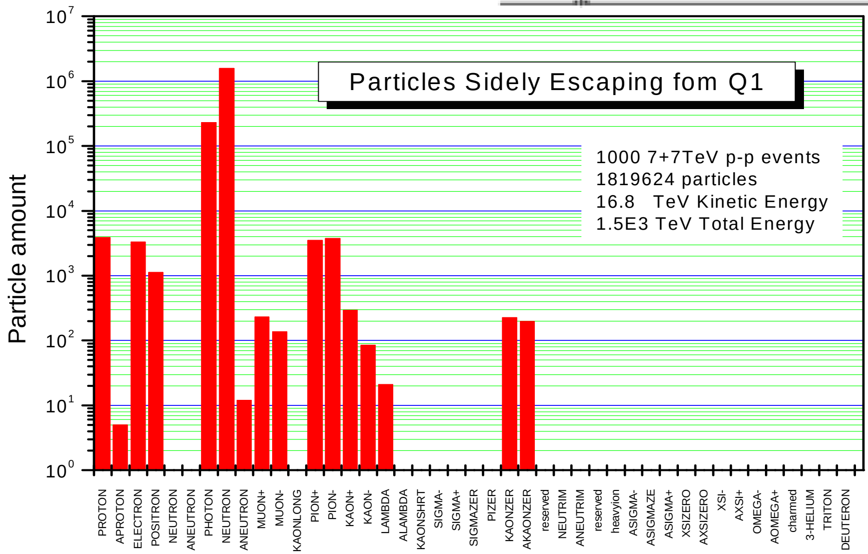
High Luminosity LHC

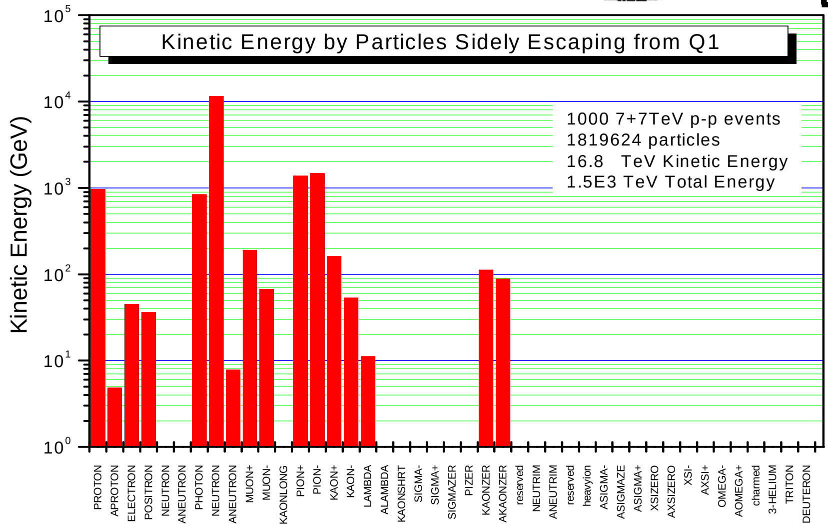
Material (Cable) Comparison











68% of the kinetic energy is from neutrons

17% from pions

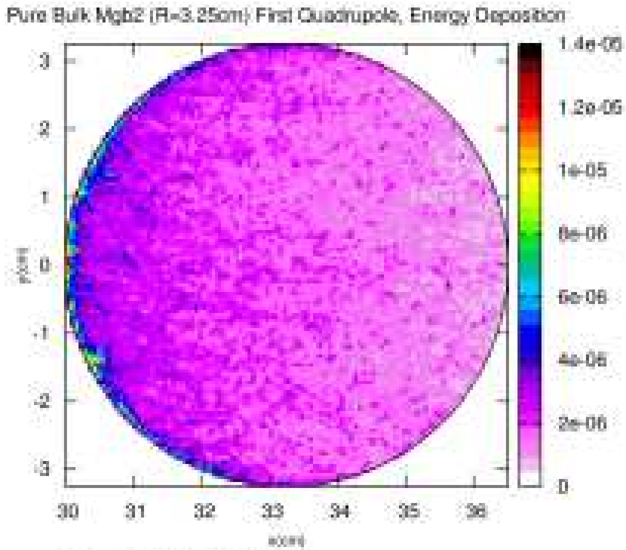
6% from protons

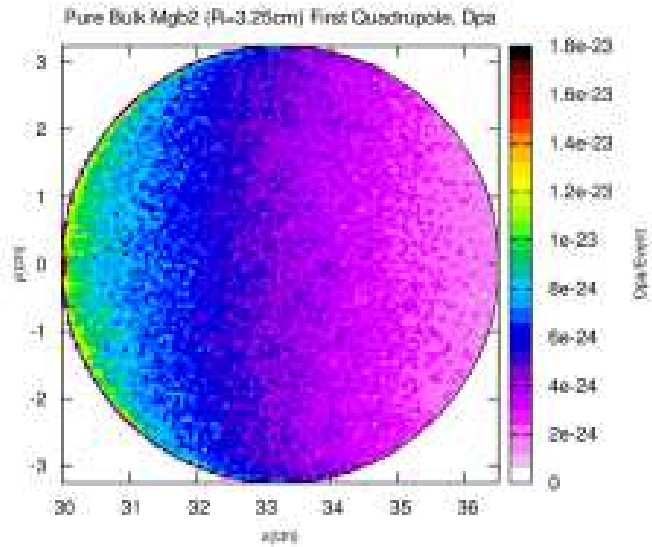
5% from photons

Cable Comparison

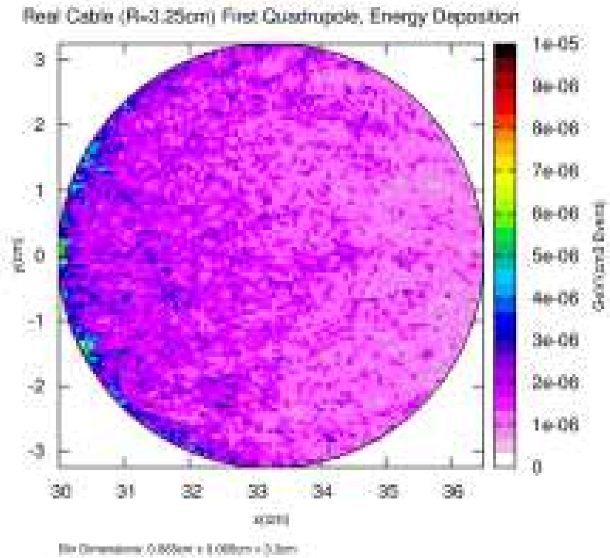
Energy Deposition | DPA

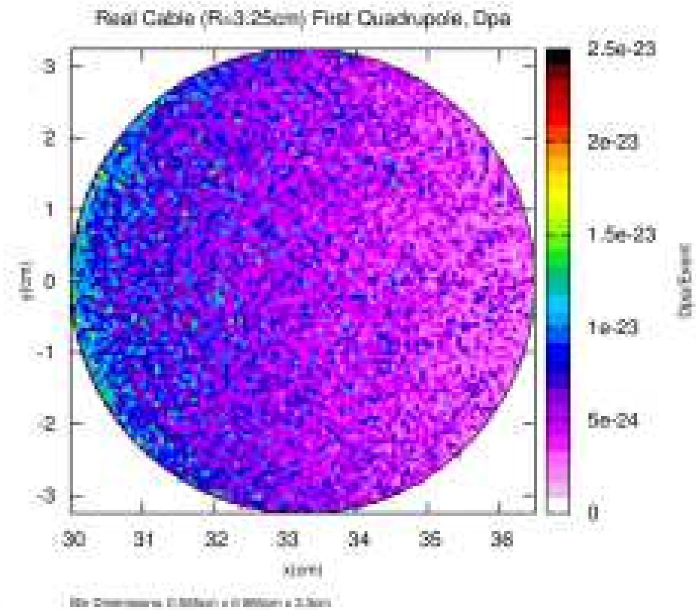
Pure Bulk MgB_2





Real Cable



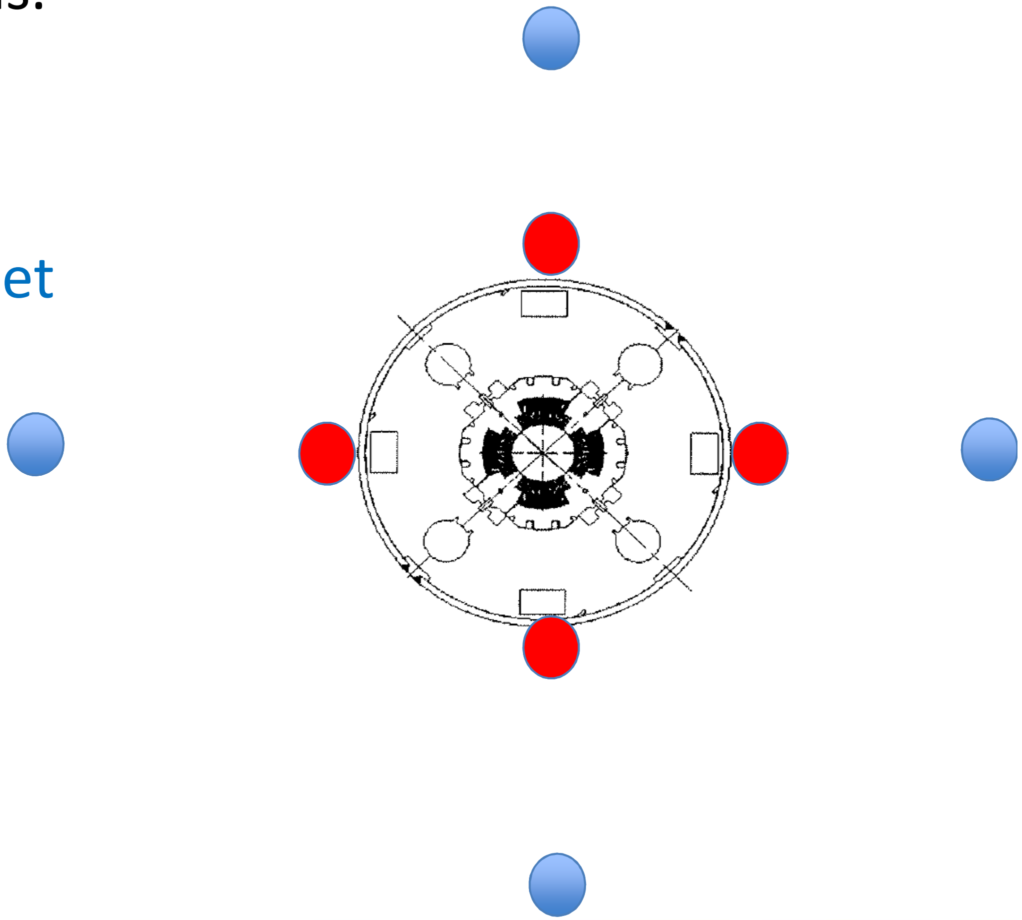


Scaling factor to $3000 fb^{-1} = 3x10^{17}$

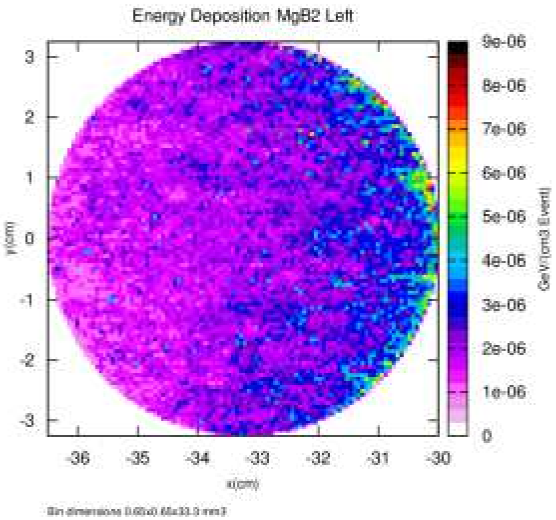
Towards the Final Configuration

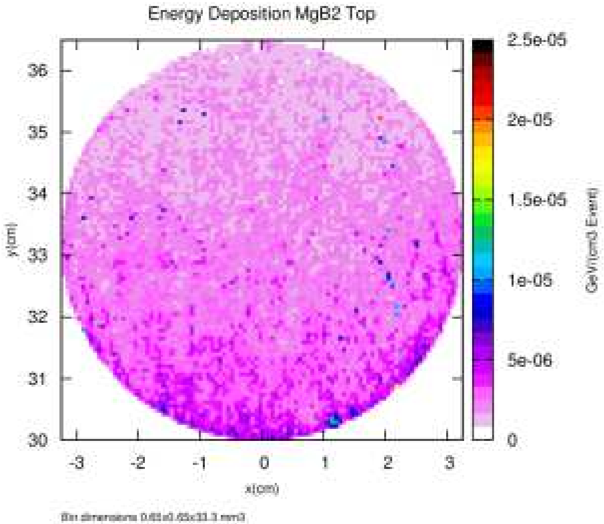
The definitive layout will be frozen in the future, so we simulated the energy deposition in cables running parallel to Q1 (as done so far) located at different positions.

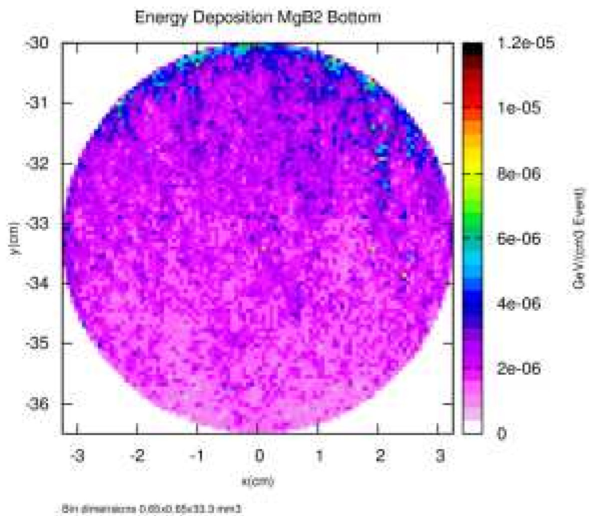
- in contact with Q1 (Near case) at 0°, 90°, 180° and 270°
- at 1 m distance from the magnet (Far case), at the same angular position.

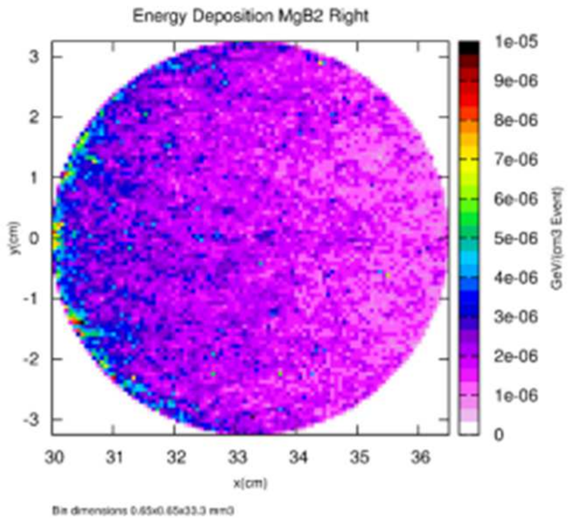


MgB_2 cable aside Q1 (Near case)

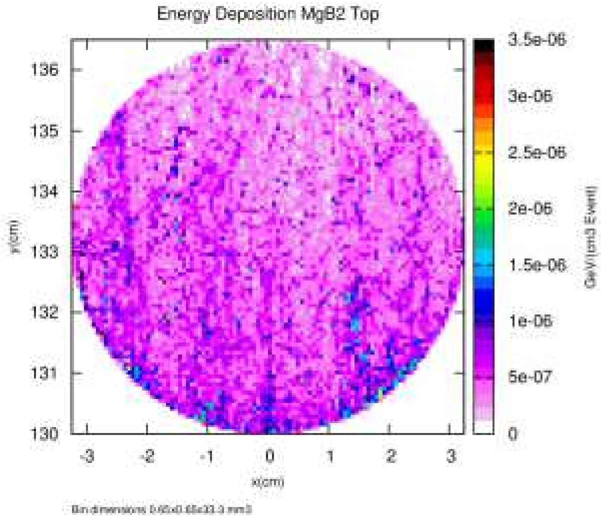


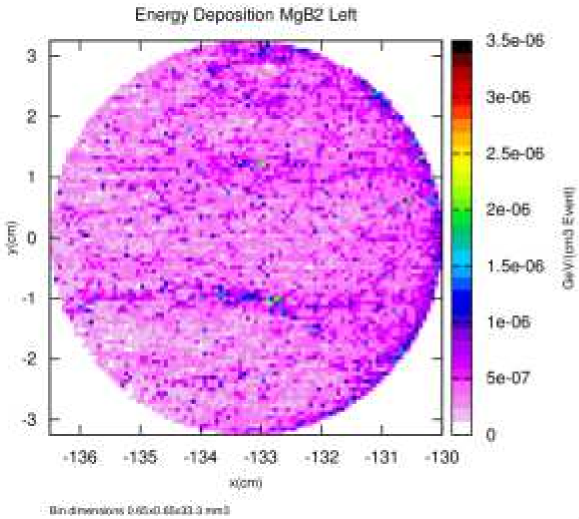


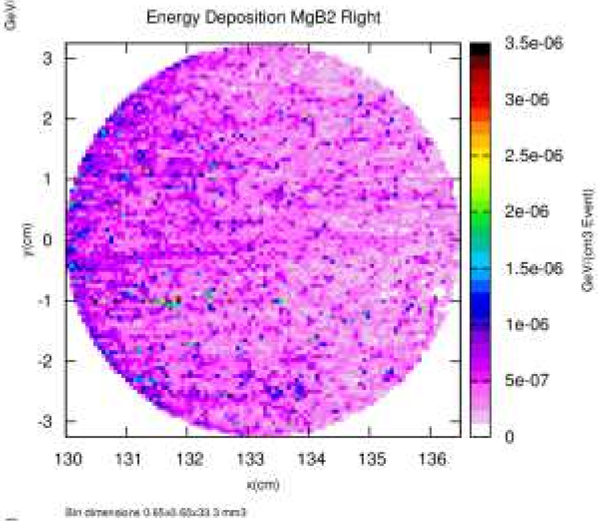


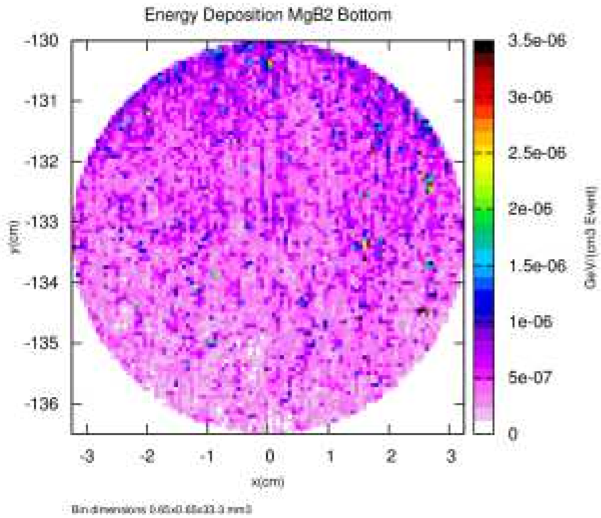


MgB_2 cable at 1 m from Q1 (Far case)









Dose and DPA

Total Dose and Average DPA for the examined cases

(Data normalized at 3000 fb^{-1})

	Near		Far	
Cable	Dose (kGy) ± err%	DPA±err%	Dose (kGy) ± err%	DPA±err%
1 (θ=0°)	32.8 ± 0.5	2.3E-06 ± 0.4	7.1 ± 1.2	4.8E-07 ± 0.8
2 (θ=90°)	38.7 ± 0.3	2.5E-06 ± 0.3	7.6 ± 2.1	5.0E-07 ± 0.7
3 (θ=180°)	35.3 ± 0.6	2.4E-06 ± 0.4	6.5 ± 1.8	4.8E-07 ± 1.0
4 (θ=270°)	34.2 ± 0.5	2.3E-06 ± 0.2	7.4 ± 1.3	4.9E-07 ± 0.6

As we can see the values of dose and DPA should not endanger the cables.
Let's remind that this configuration is a conservative one, being aside the first quad.

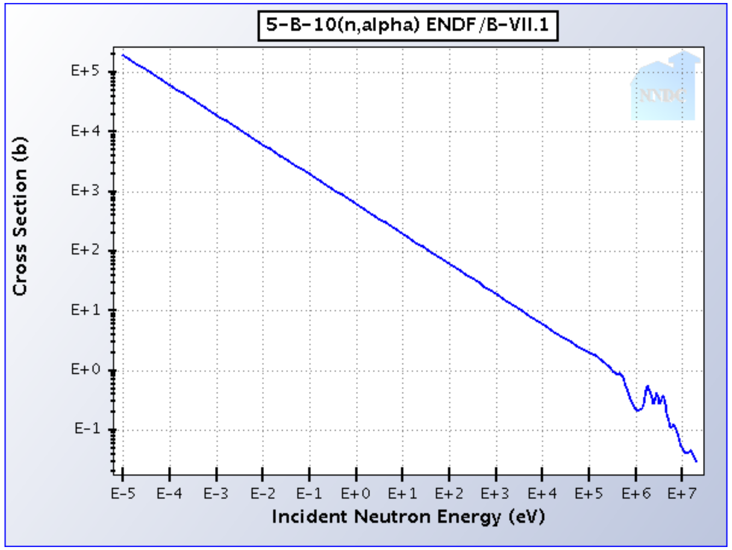
High Luminosity LHC

Boron Consumption

B_{nat}= 80% ^{11}B + 20% ^{10}B

$$^{10}_{5}B + n \rightarrow ^{7}_{3}Li + \alpha$$

^{10}B slow neutron cross section for this reaction is about 4×10^3 barn at room temperature (E_n=0.025 eV) and 1.5×10^4 barn at 20 K (E_n=0.0017 eV)



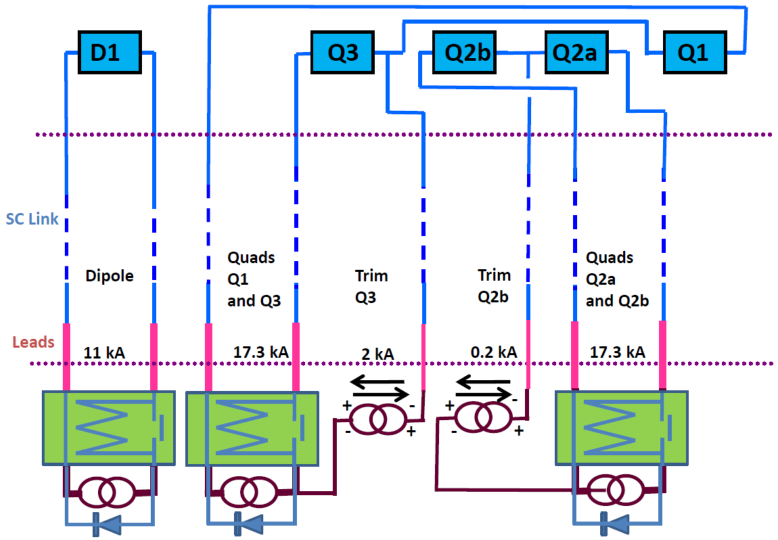
$$\frac{N_{\text{int}}}{N_{B_{target}}} = \frac{N_n \sigma\, n_{^{10}B}\, d}{n_B V} = \frac{N_n \sigma\, n_{^{10}B}\, d}{\frac{n_{^{10}B}}{0.2}\pi\left(\frac{d}{2}\right)^2 l} = \frac{N_n \sigma\, 4}{\pi d l}0.2 = \frac{10^{21}\, 1.5\cdot10^{-20} 4}{\pi 6.51000}0.2 \approx 6\cdot10^{-4} = 0.06\%$$

We assume pure bulk of boron, aside the first quad, with an integrated (on 3000 fb^{-1}) neutron fluence of $N_n=10^{21}$ **(all assumed as thermal, and all focused to the cable)**

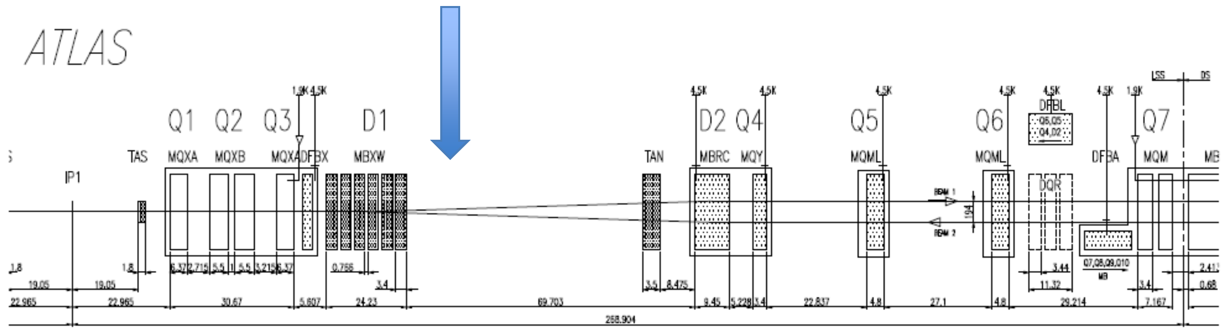
The neutrons impinge perpendicularly to the axis of the cable cylinder.

High Luminosity LHC

Powering Scheme and Links Layout



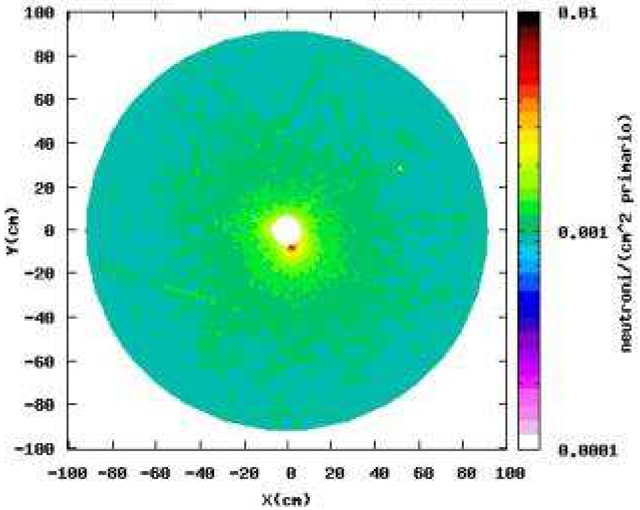
For this configuration the link coming from the surface will arrive just after D1 (at about 80 m from IP) and will run aside the quads



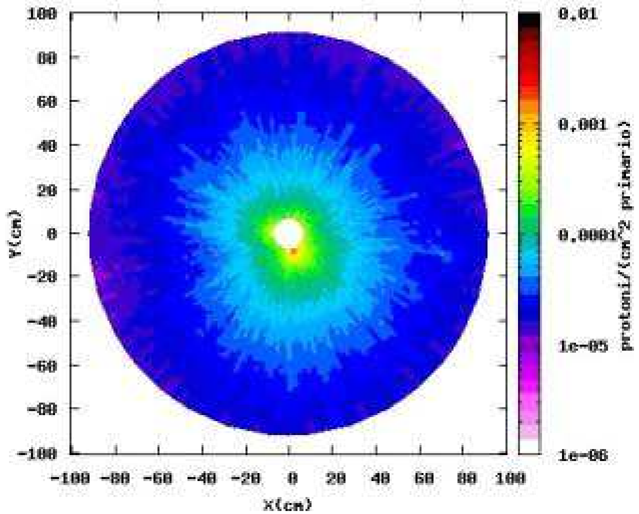
Particles Fluencies (after D1)

integrated over z at 80-84 m from IP

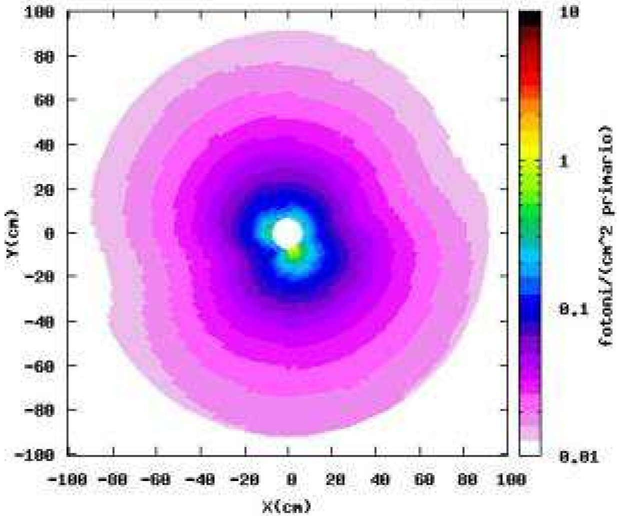
Neutrons



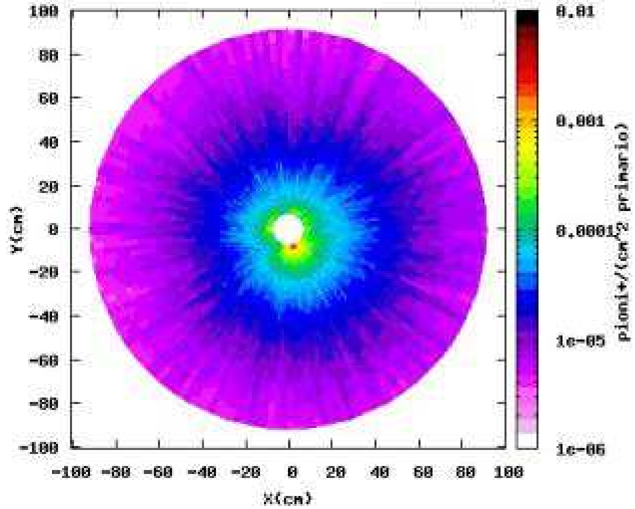
Protons



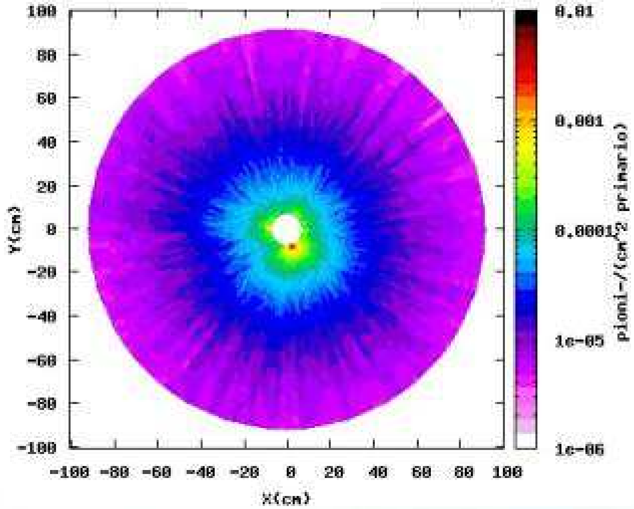
Photons



Pions +



Pions -



What's Next

- Implement the Links geometry in the LHC Layout in FLUKA

- Simulations for Point 5 It can be guessed a more relaxed situation as from previous studies on the energy deposition in the low-β coils.
  IR'07 Frascati 8 November 2007 :
  https://care-hhh.web.cern.ch/CAREHHH/IR07/Proceedings/IR07%20Session%205/S5-1-Broggi_IR07_A4.pdf,
  http://indico.cern.ch/event/19477/session/4/contribution/21/material/slides/2.pdf

High Luminosity LHC

Acknowledgment

Thank You for Your attention

- F.Cerutti , LS Esposito (CERN FLUKA Team)

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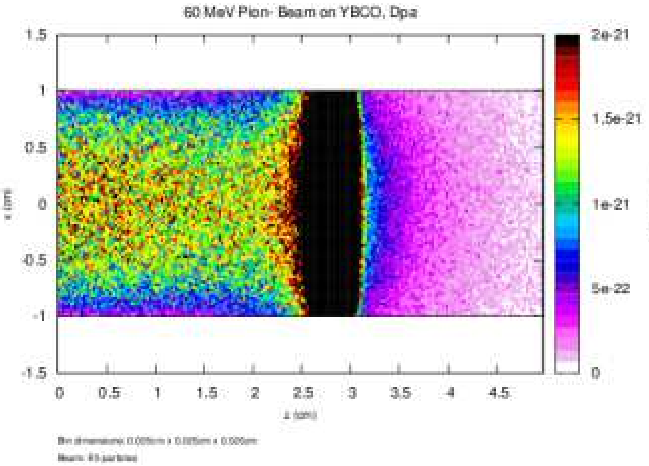
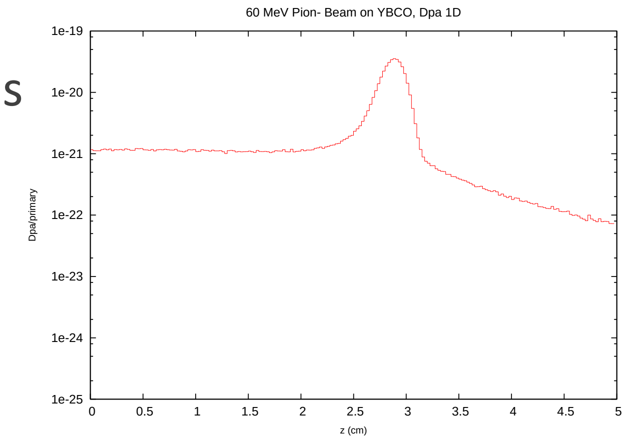
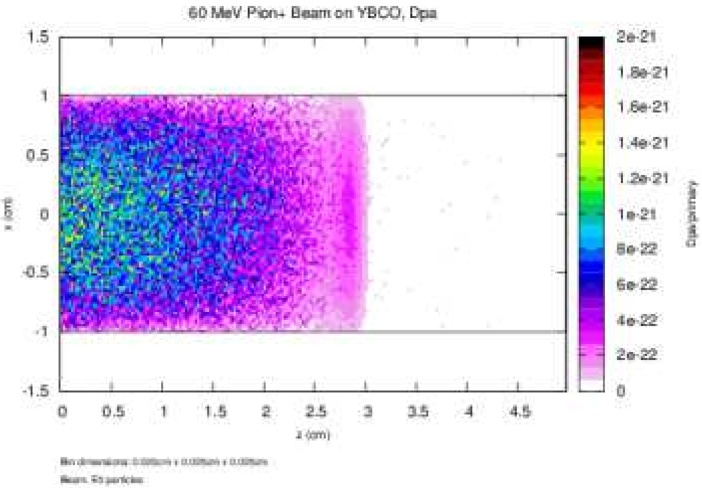
Ancillary Studies (interaction of π^+ and π^- with matter)

- Different way of interaction for π^+ and π^-

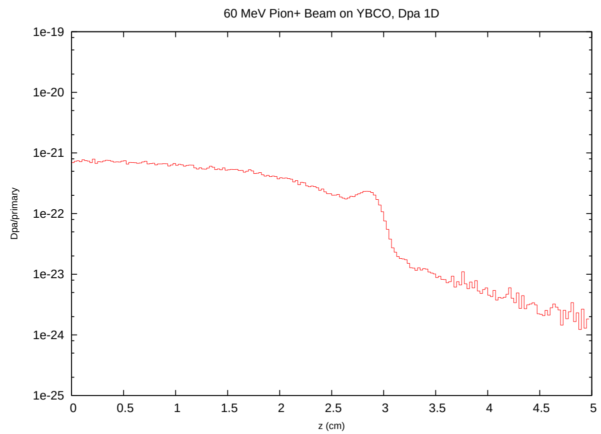


The different behaviour is due to the absorption of the π^- by the nucleus ($\pi^- + p \rightarrow n + \gamma$),





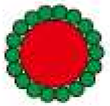
while the π^+ are not absorbed and decay ($\pi^+ \rightarrow \mu^+ + \nu_\mu$)

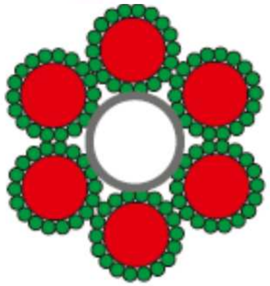


Layout of SC Link at LHC P1 and P5


Cu


MgB_2, Φ = 0.85 mm

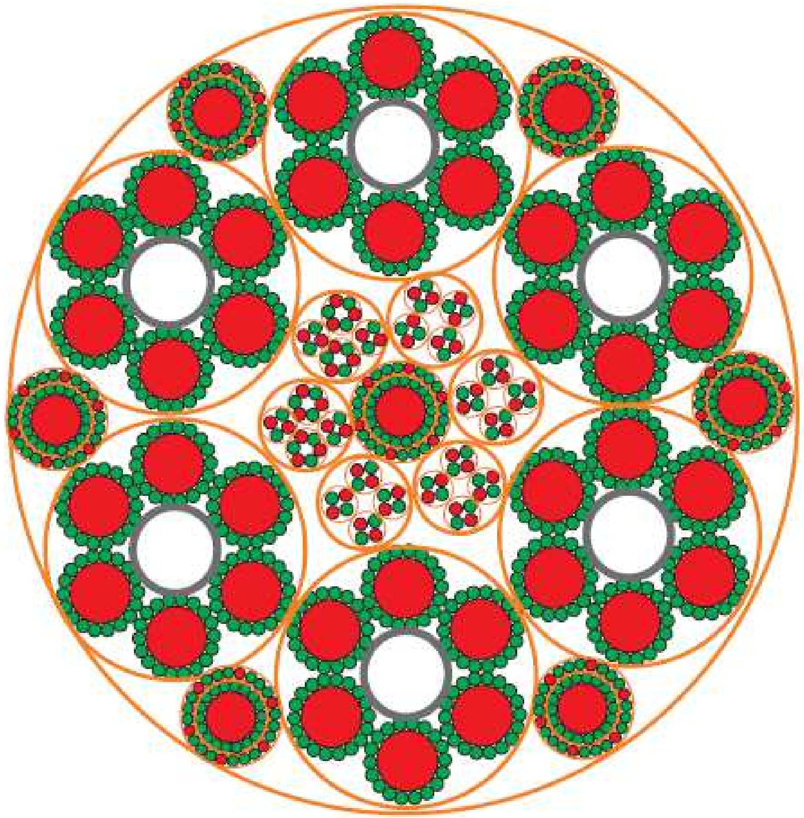

18 MgB_2 wires
Φ = 6.5 mm


20 kA
Six cables, Φ = 19.5 mm


Concentric $\pm$ 3 kA
Seven cables, Φ = 8.4 mm


0.4 kA
Four cables


0.12 kA
Eighteen cables



Φext ~ 65 mm