Are large-aperture NbTi magnets compatible with 1e35??

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Contents

- Scenarios from Phase I upgrade
- Results Phase I
- Q0 option
- Optimization Phase I
- Extrapolation to Phase II
- Checks
  - Crossing angle
  - D0 option
  - Tas opening
- Conclusion

Scenarios Phase I

- **Symmetric** Large Aperture

  LHC Project Report 1000: "A Solution for Phase-one Upgrade of the LHC Low-beta Quadrupoles Based on Nb-Ti"

  J. P. Koutchouk, L. Rossi, E. Todesco

- **Compact** Low Gradient Final Focus System

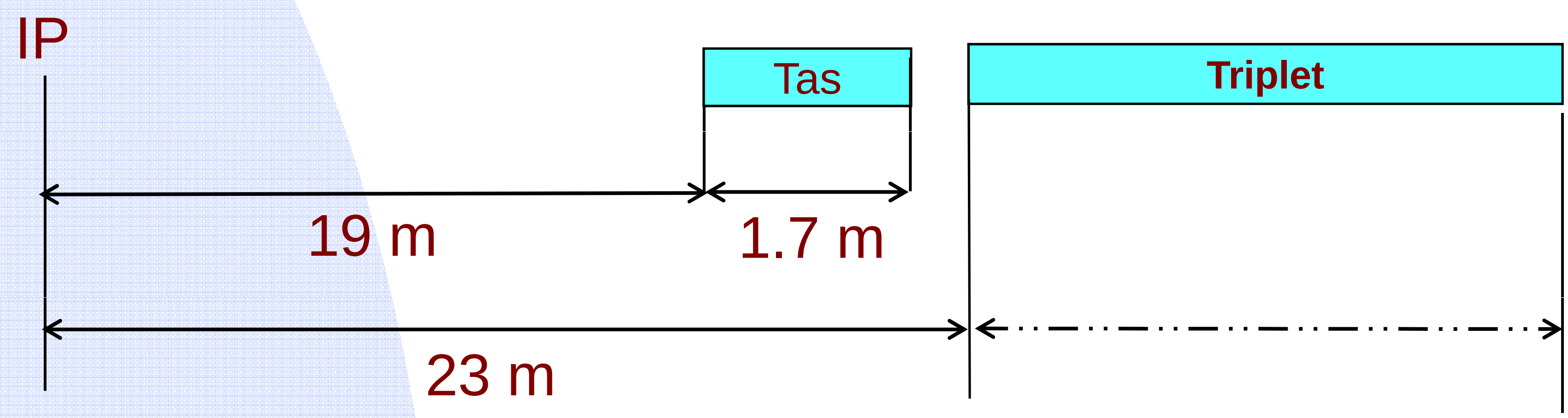
  LHC Project Report 1008: "Low Gradient, Large Aperture IR Upgrade Options for the LHC compatible with Nb-Ti Magnet Technology"

  O. Brüning, R. De Maria, R. Ostojic

  - Proposed layout
  - Layout adapted to available cable

Integration

"Symmetric" and "Compact"



Layout

IP1 **Symmetric**

Q1	Q2	Q3	Q4
130mm	130mm	130mm	130mm
9.20m	7.80m	7.80m	9.20m

37 m

Positive particle

+ → **FDDF**

IP1 **Compact**

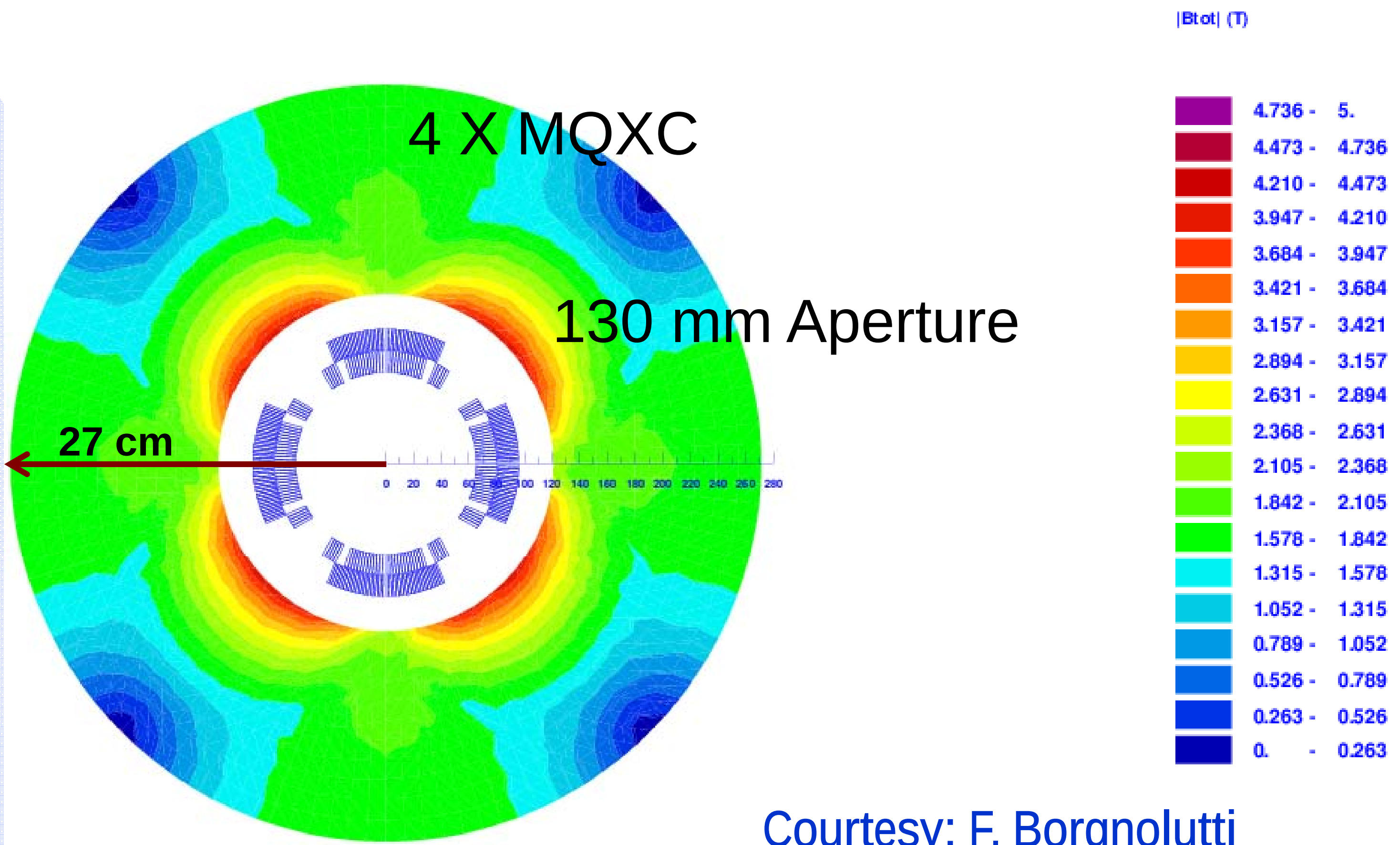
Q1	Q2	Q3	Q4
170/130mm	220/170mm	220/170mm	220/170mm
12.24m	14.20m	11.00m	14.75m

55 m

Magnet data

Magnet	MQXC	IRQB	IRQA	IRQF	IRQE
Config.	Symmetric	Compact1	Compact1	Compact2	Compact2
Gradient [T/m]	120	91.5	68.3	91.5	68.3
Aperture [mm]	130	170	220	130	170
Peak Field [T]	8.7	8.6	8.4	6.8	6.8
Layers	2	2	2	1	1

Magnet models, “Symmetric”

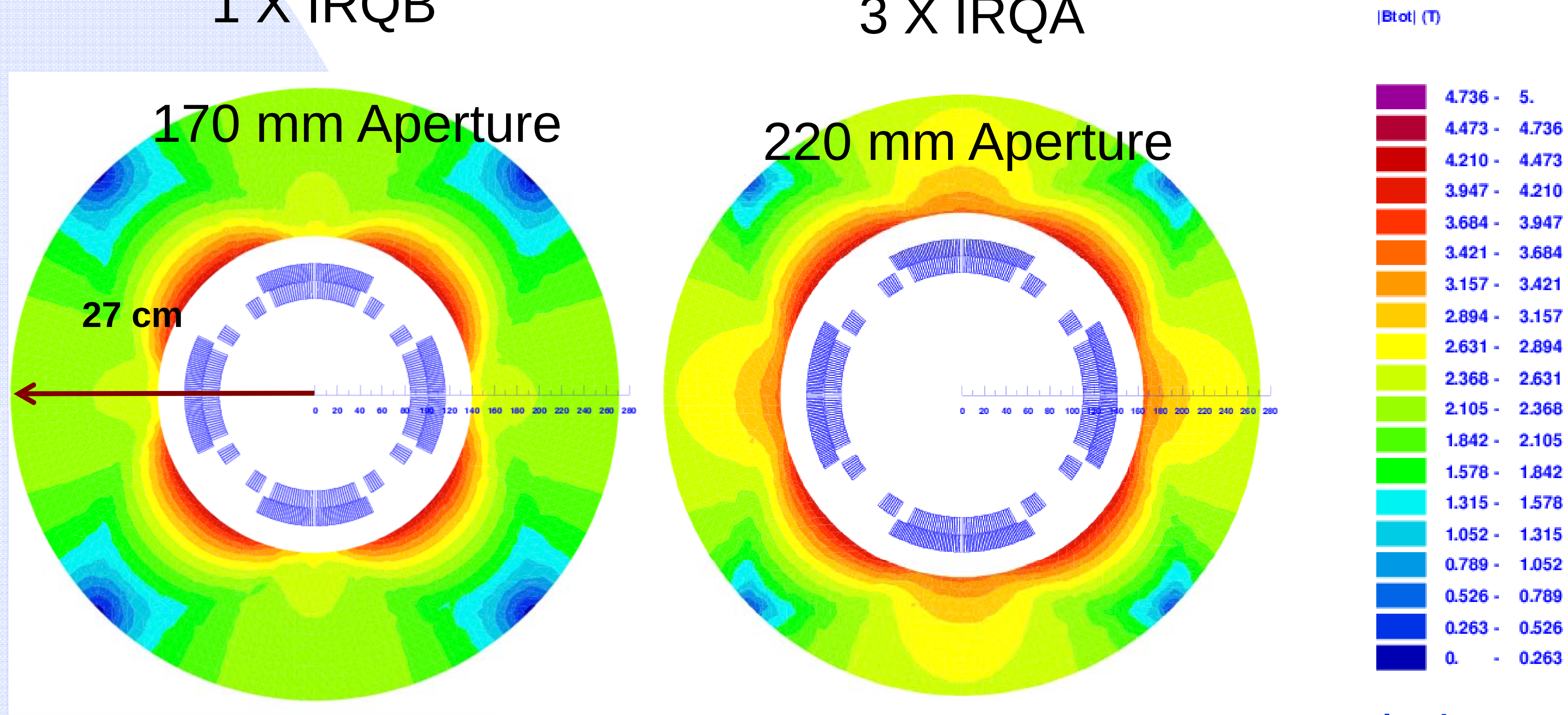


Courtesy: F. Borgnolutti

Magnet models, “Compact 1”

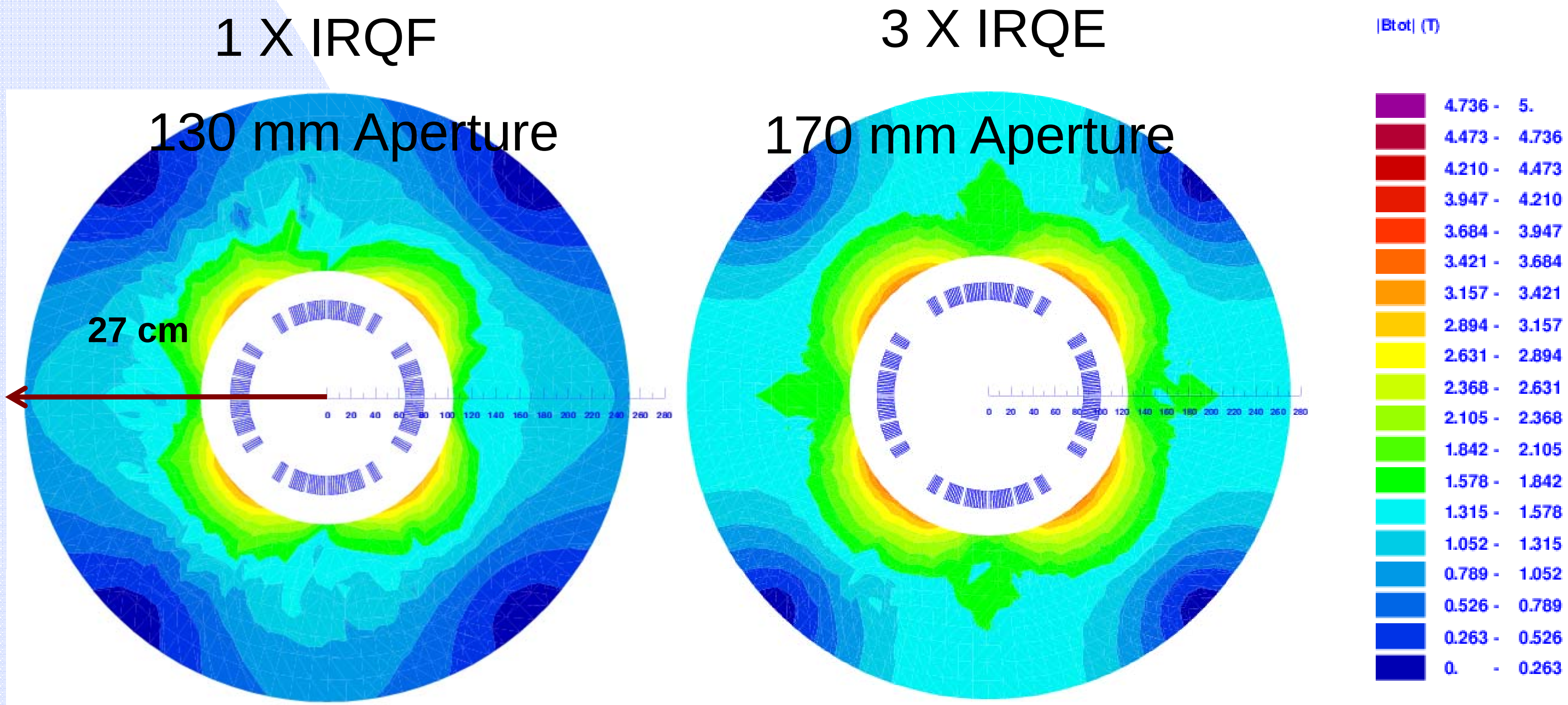
1 X IRQB

3 X IRQA



Courtesy: F. Borgnolutti

Magnet models, “Compact 2”



Courtesy: F. Borgnolutti

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Model (cont.)

- Detailed models for future optimization
  - Magnets with insulation and more detailed cable
  - Tas
- Aluminum collars
  - Improves the total heat deposition, not peaks
- The magnet yokes are 27 cm

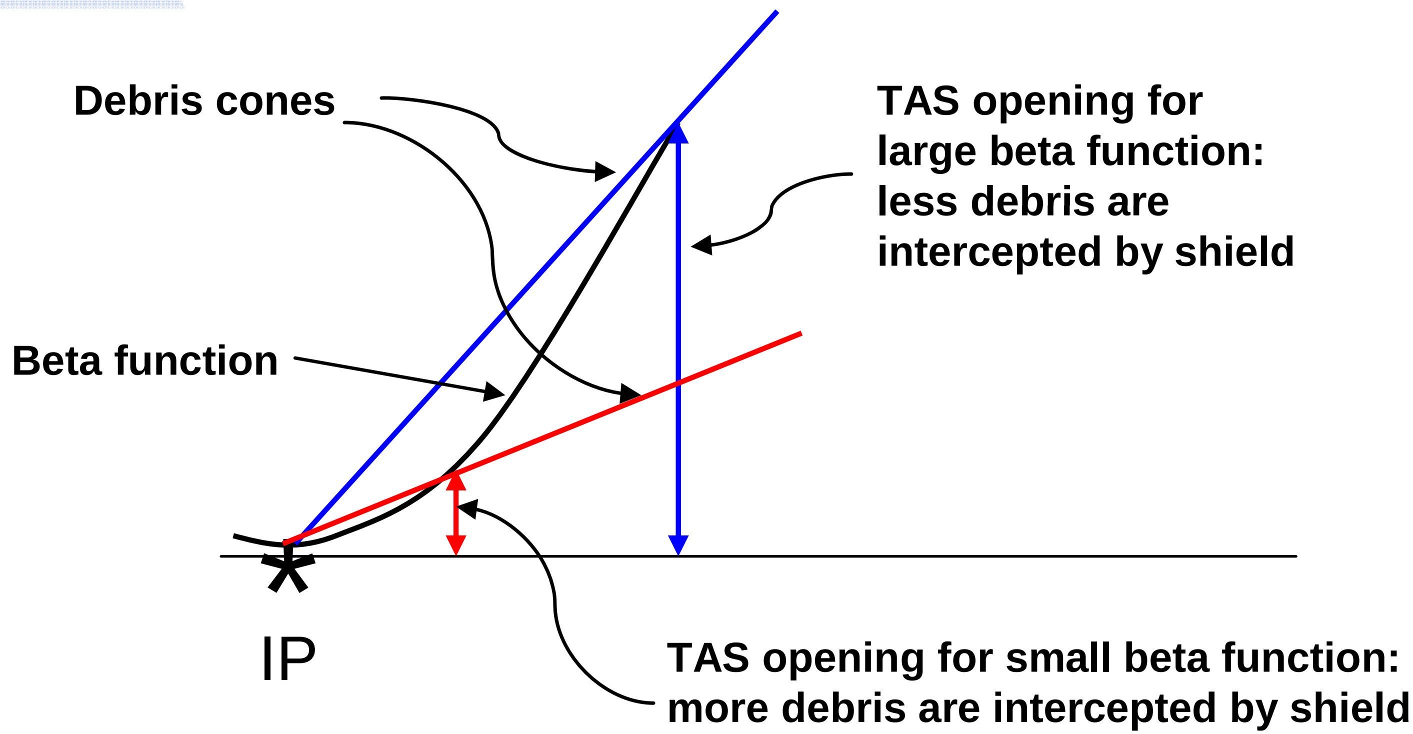
Model (cont.)

- Betastar = 0.25 m
- L=2 E34
- Crossing angle 220 microrad, vertical
- “Fluka” used for the energy deposition calculations
- 5000 particles for “Compact” 1&2, 10000 for “Symmetric”

"FLUKA: a multi-particle transport code",
A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala,
CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773
"The physics models of FLUKA: status and recent developments",
A. Fasso`, A. Ferrari, S. Roesler, P.R. Sala, G. Battistoni, F. Cerutti, E. Gadioli, M.V. Garzelli, F. Ballarini, A. Ottolenghi, A. Empl and J. Ranft,
Computing in High Energy and Nuclear Physics 2003 Conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003

TAS distance to IP

The TAS essentially protects the first magnet



TAS aperture

Depends on β

$$D_{\min} = 1.1 \cdot (9 + 2 \cdot 10)\sigma + 2(d + 3mm) + 2 \cdot 1.6mm$$

β beating

Beam size

orbit

Spurious disp. orbit

Beam sep.

Mech. tol. and alignment

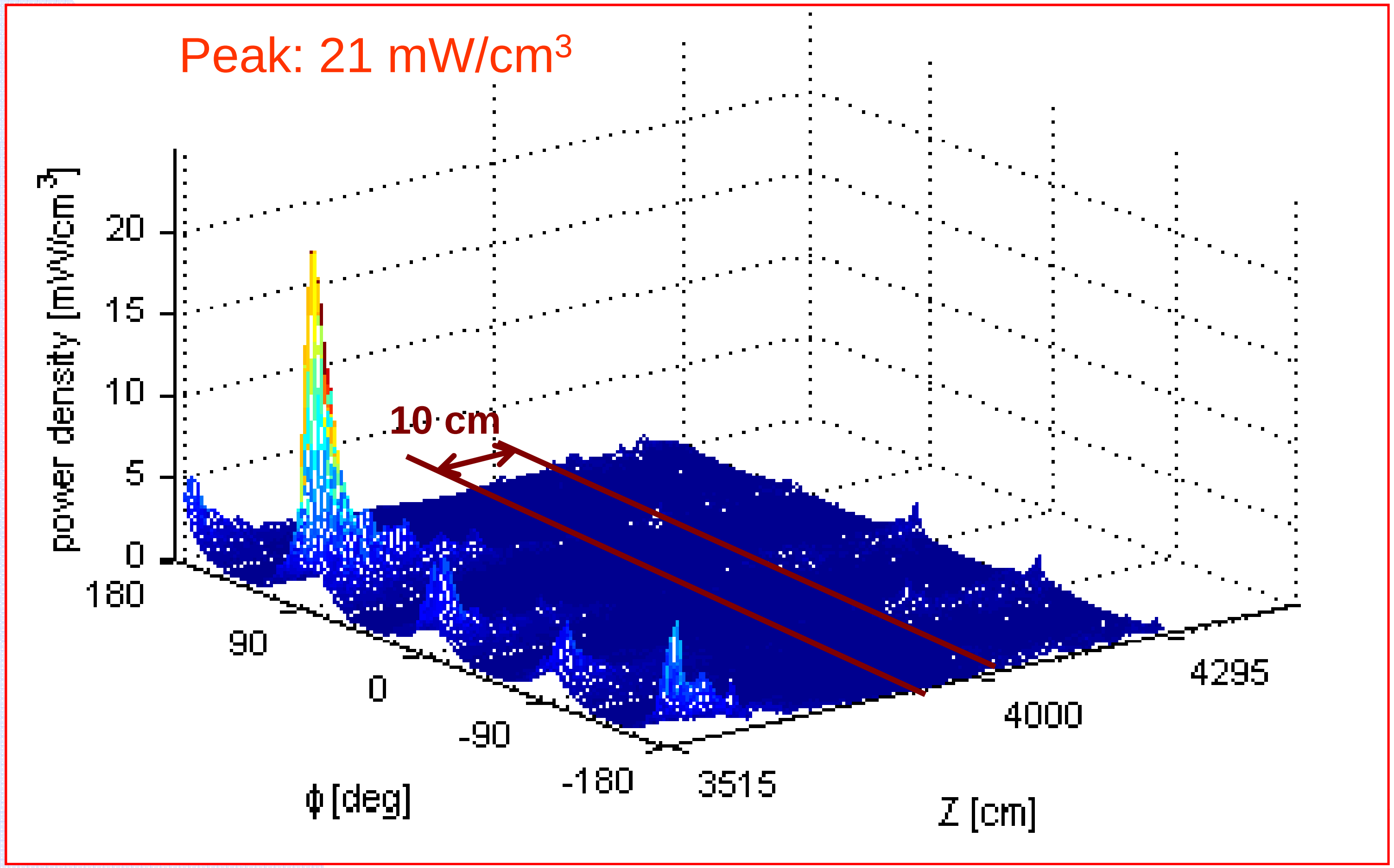
41 mm diameter, same for all 3 cases

Results, what we consider

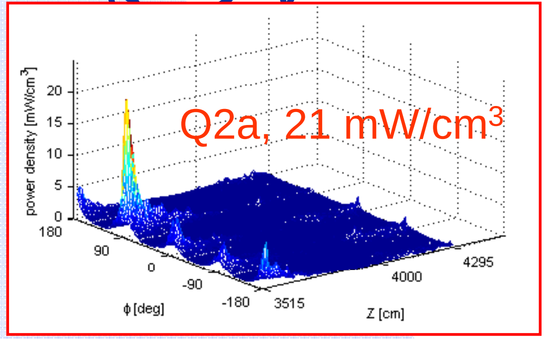
- Cable
  - We make the binning for the scoring so that it corresponds to a maximum volume of equilibrium for the heat transport (cable transverse size, with a length of around 10 cm)
- Total power deposited in the magnets
  - Important to know the volume of the magnet (the model has to be realistic)
- The power deposited per meter of magnet

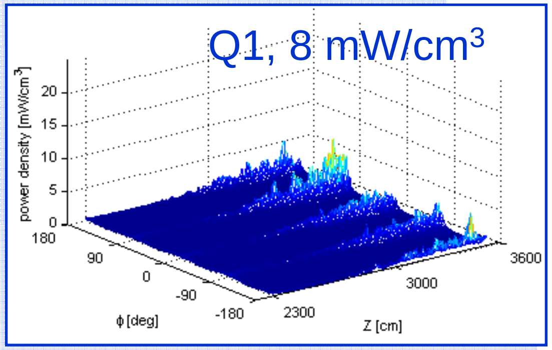
N.B. For the *total* energy deposited we need a "realistic" design of the magnet

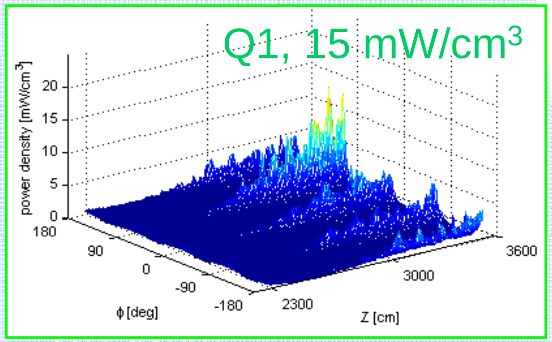
One cable: power deposition

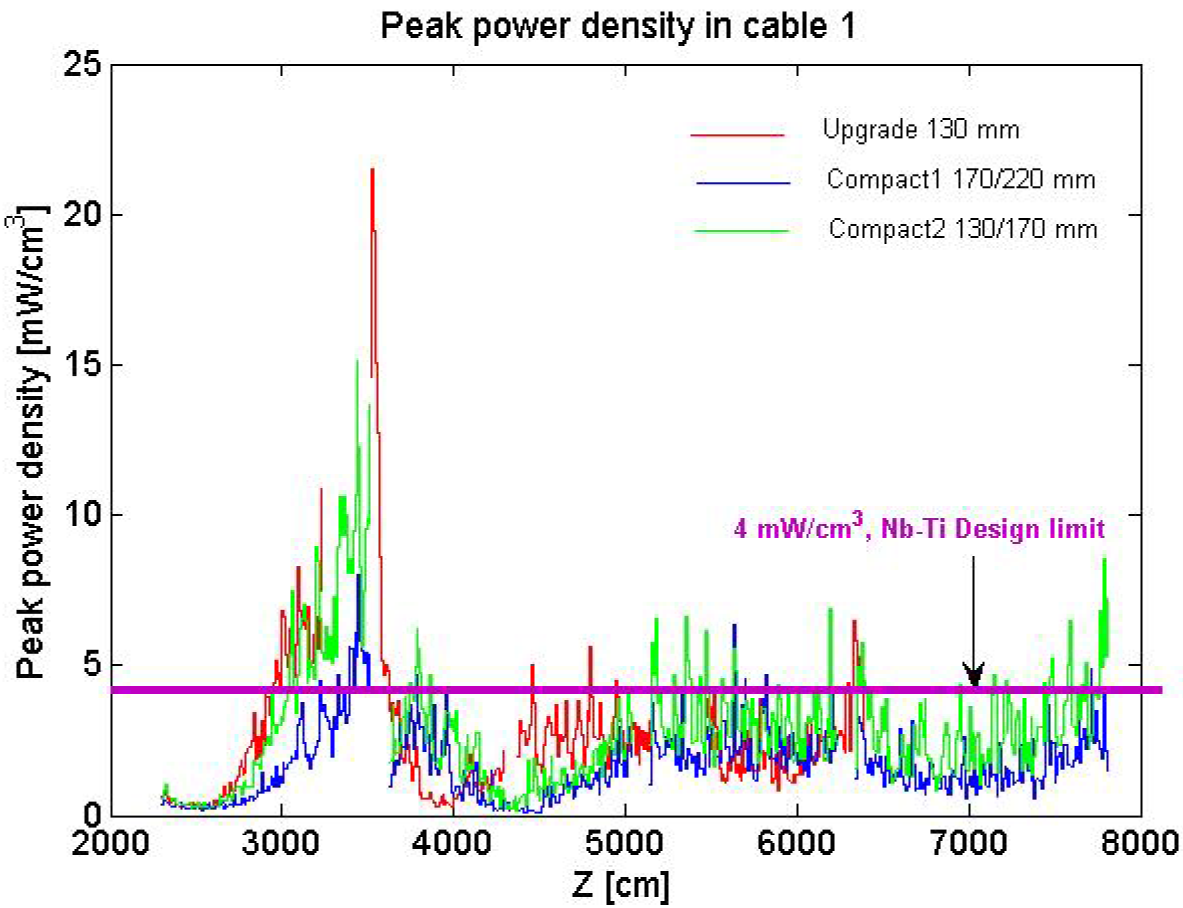


Peak power density







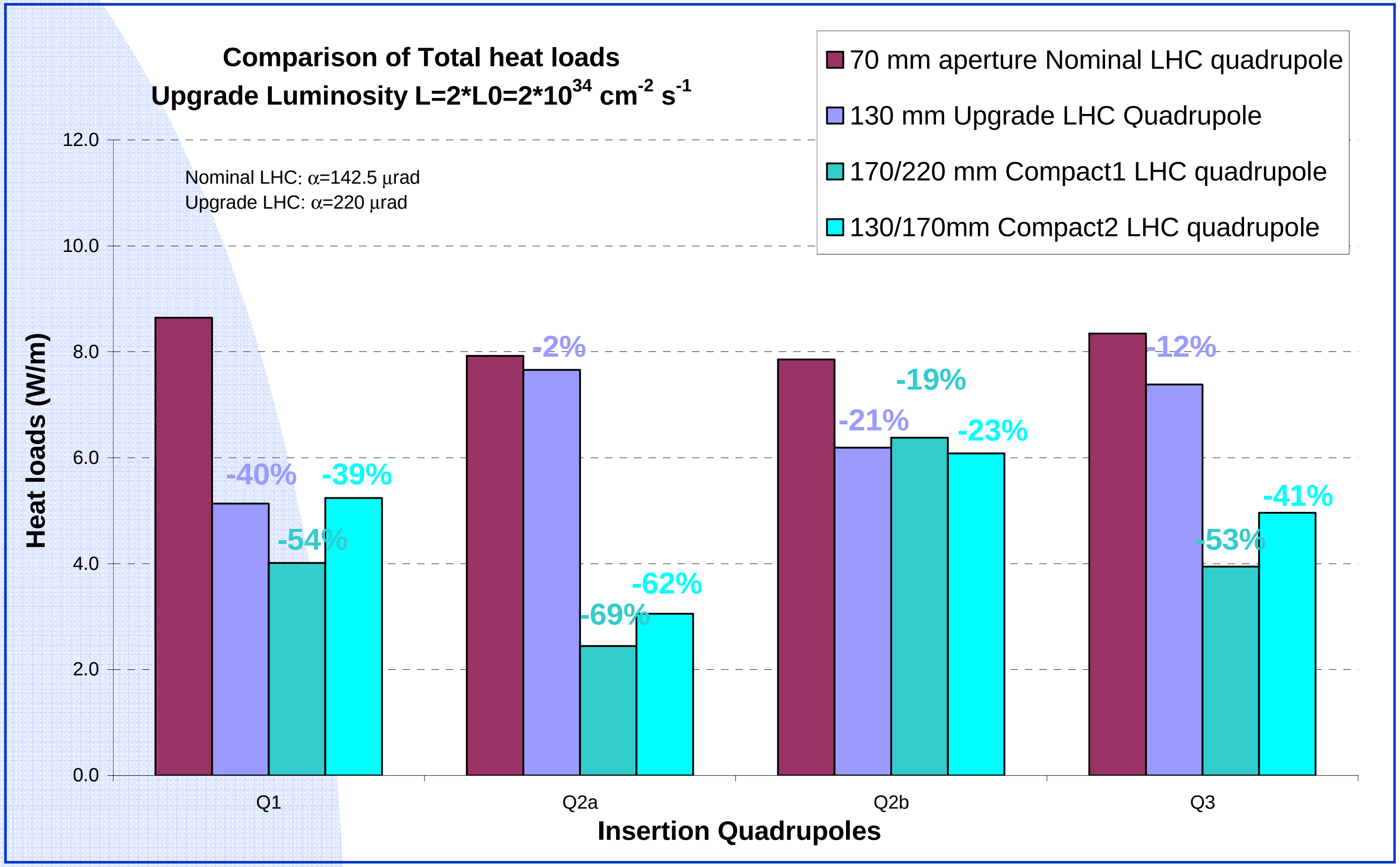


Compact 1 (large aperture) favorable

Total heat loads

Good for comparison between cases only:

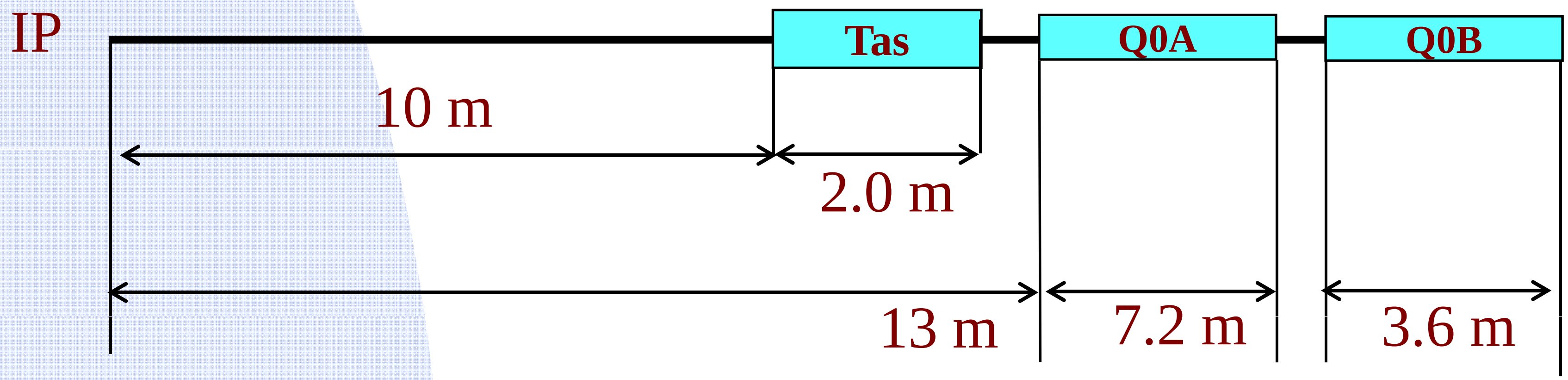
Magnet design not optimized for the scenarios



Integration, Q0

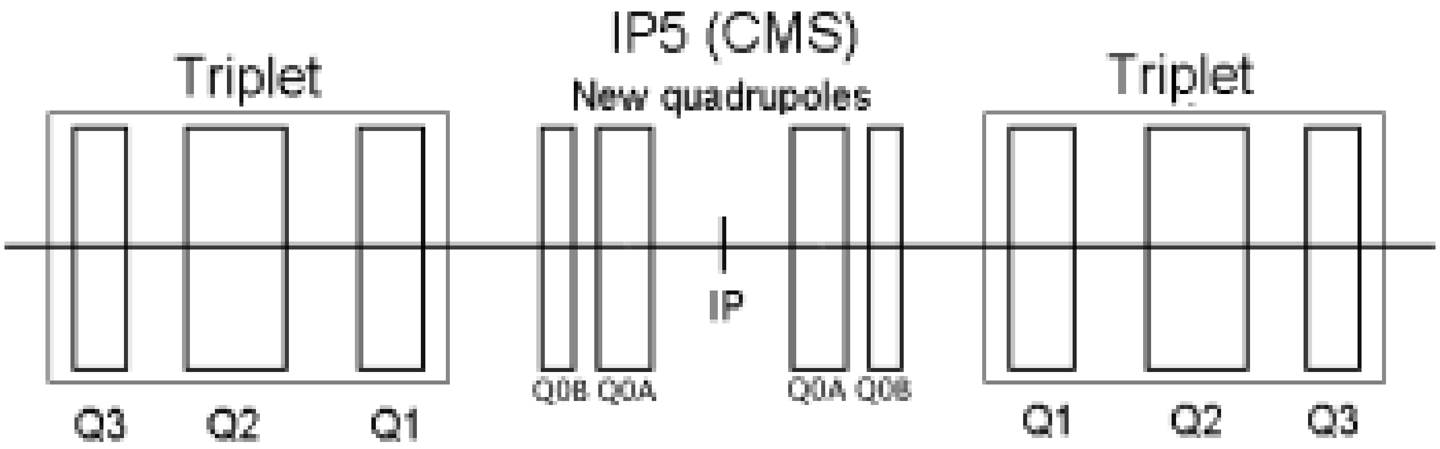
Q0 Option, for Phase II

“A Q0 Doublet optics for the LHC Luminosity Upgrade”, E. Laface, W. Scandale,C. Santoni



Layout, Q0

- Q0 is inserted before the triplet
- The triplet optics is modified

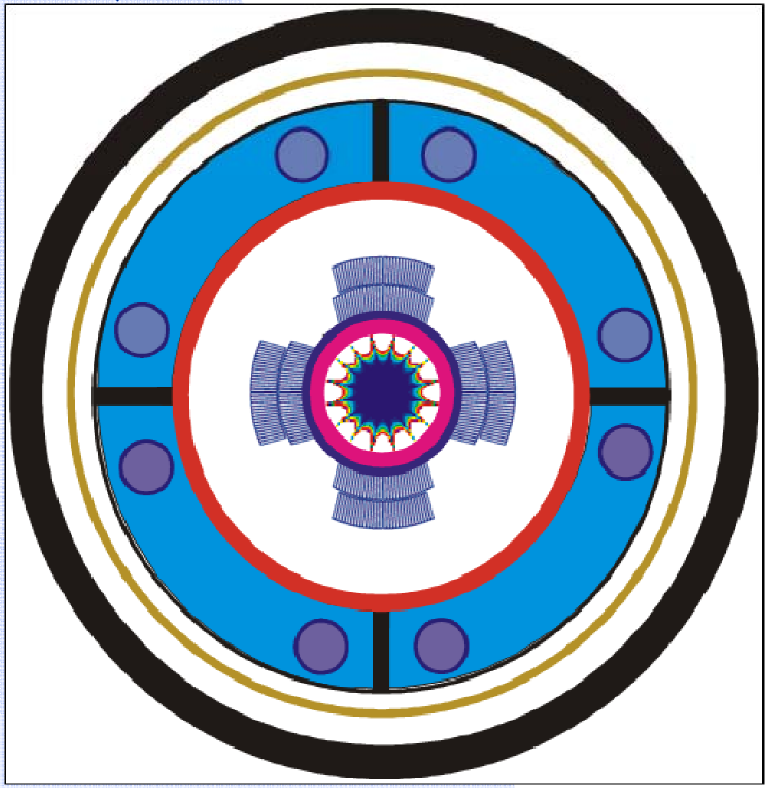


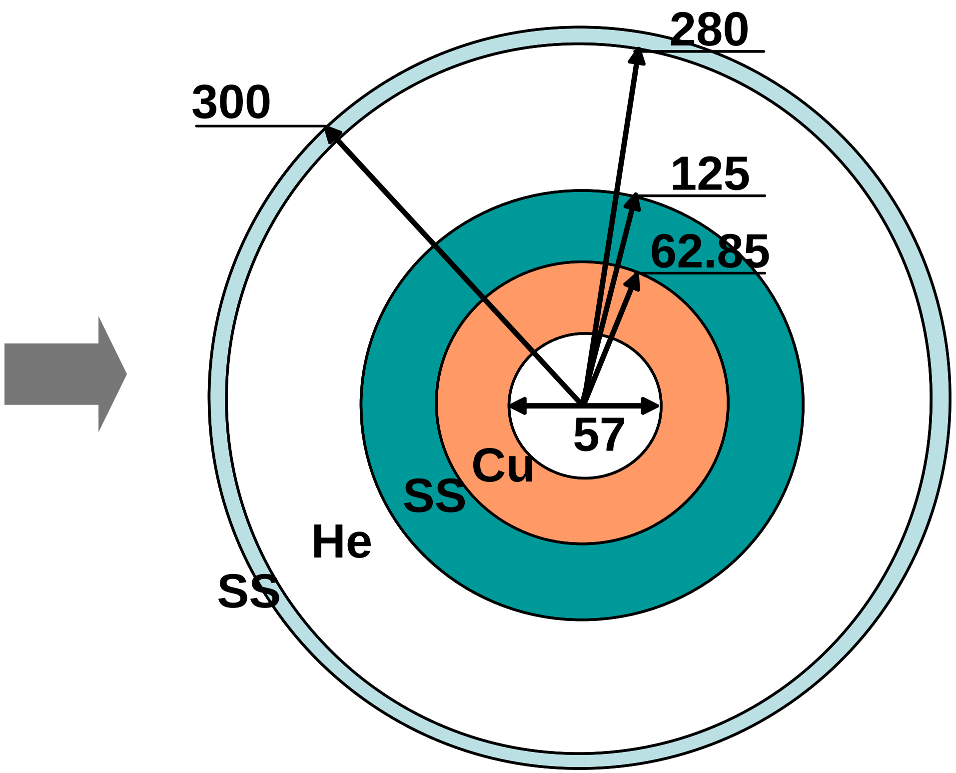
Magnet data, Q0

Magnet	L* [m]	Length [m]	Gradient [T/m]
Q0A	13.0	7.2	240
Q0B	20.8	3.6	196
Q1	25.8	8.6	200
Q2	37.1	11.5	172
Q3	52.0	6.0	160

Magnet	β Max [m]	D_{min} [mm]
Q0A	2300	57.0
Q0B	4300	68.5
Q1	5780	75.2
Q2	5820	75.4
Q3	5770	75.1

Magnet models, Q0

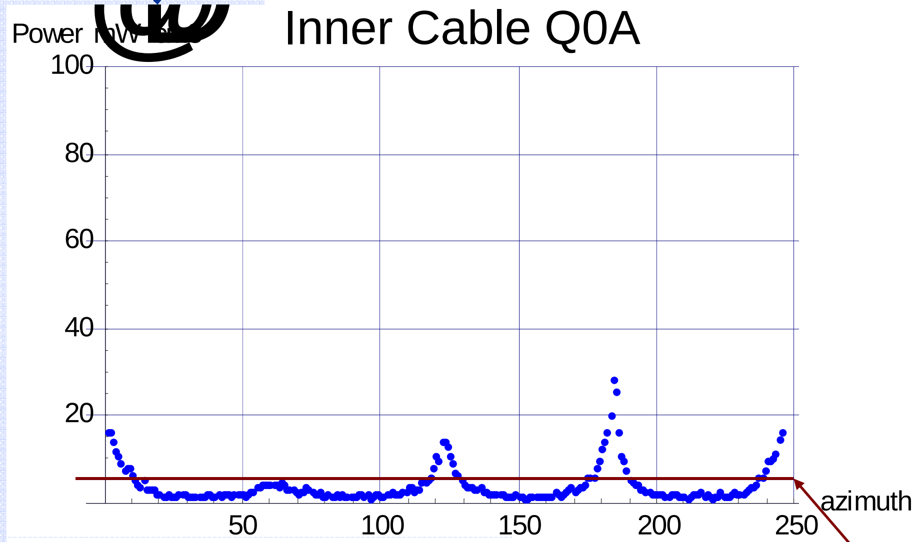


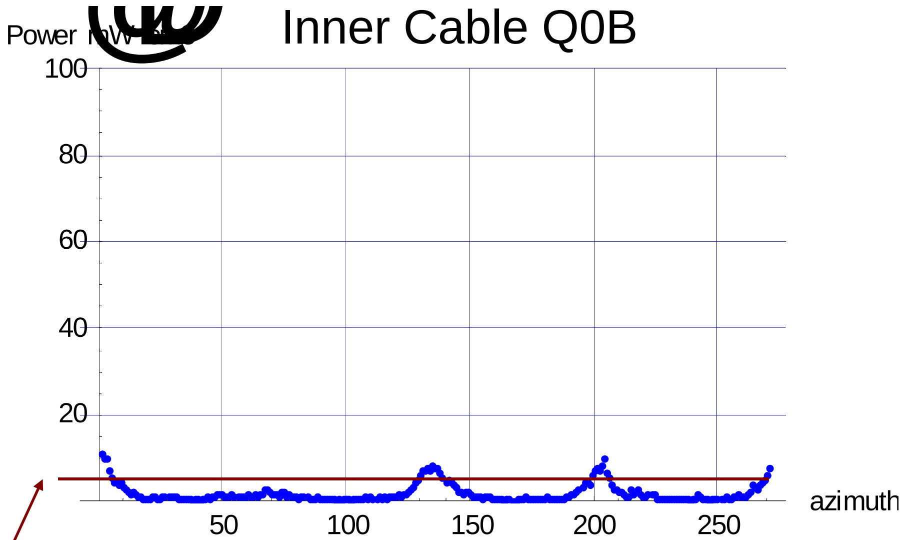


P. Limon, G. Kirby (design & field maps)

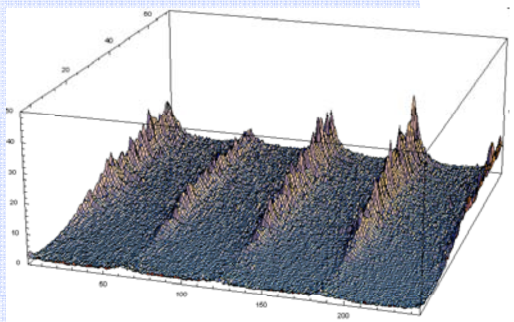
Results Q0, cable

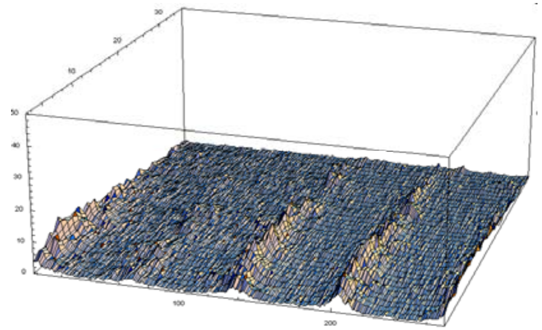
Reference value for LHC cable: 4.3 mW/cm3





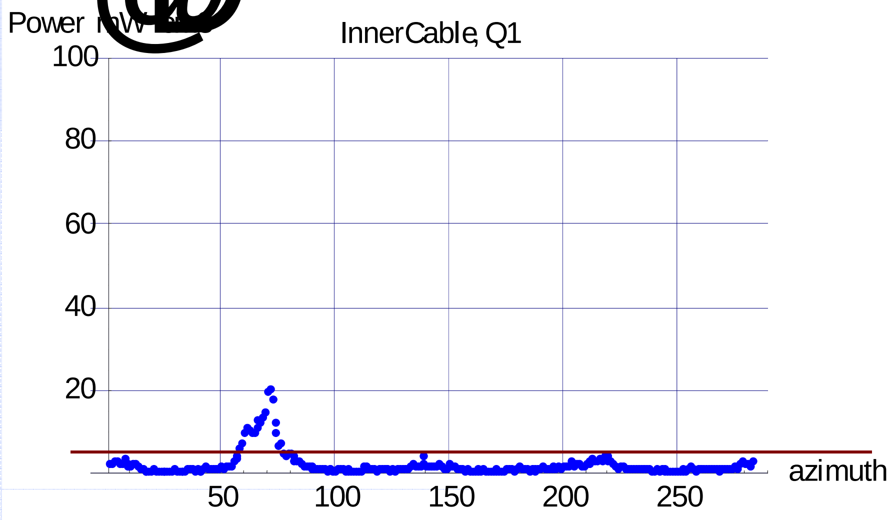
Limit LHC Cable

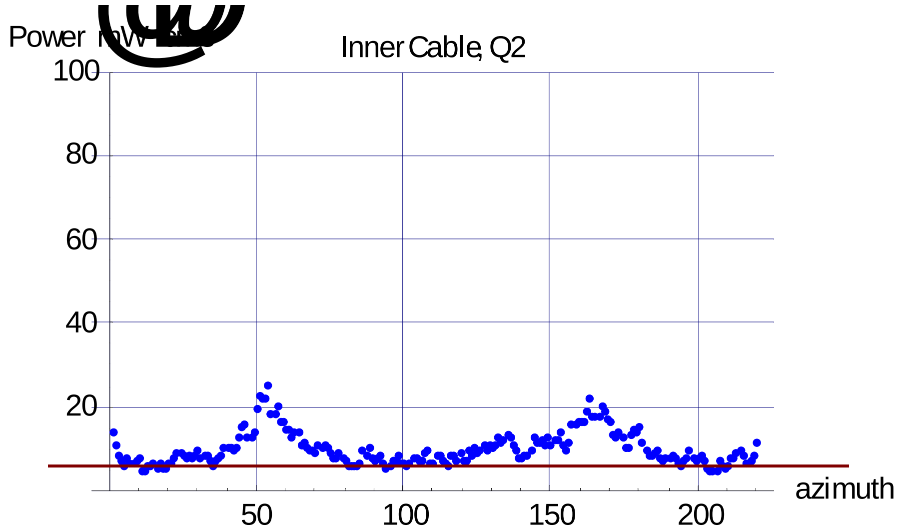


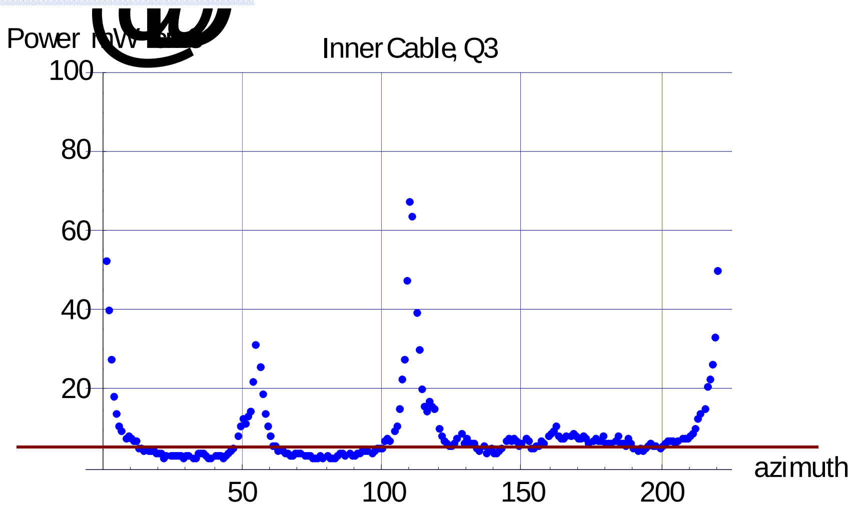


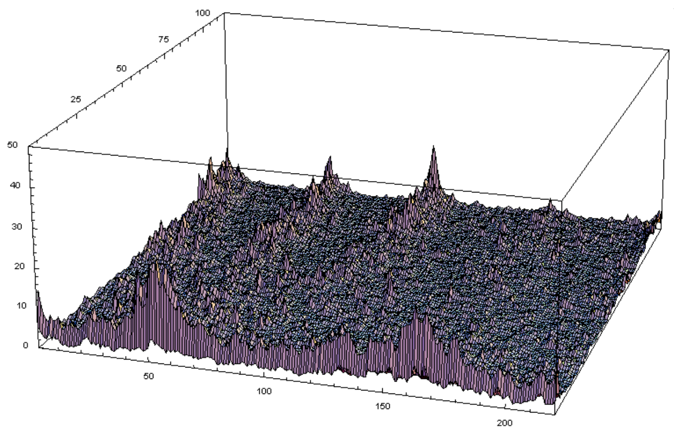
Reference value for LHC cable: 4.3 mW/cm3

Results triplet (Q0 case), cable



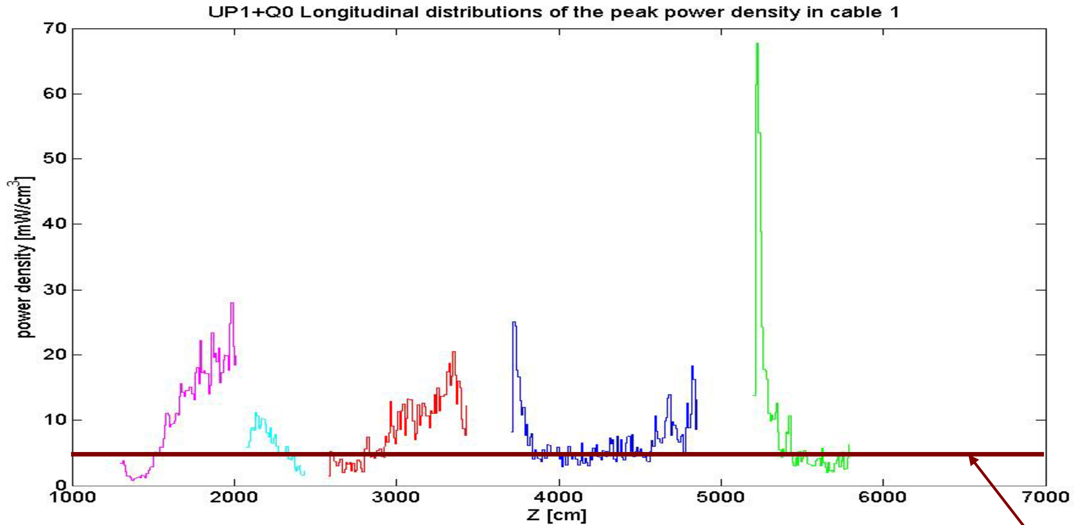


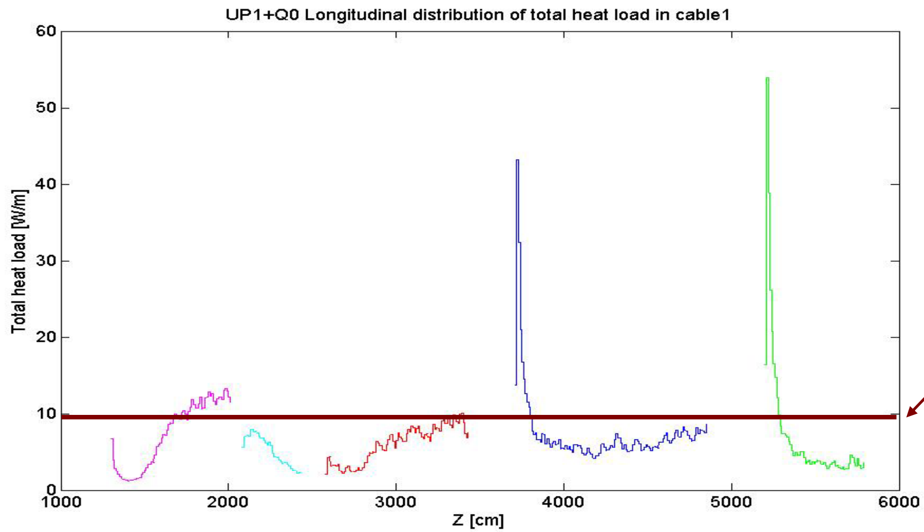




Reference value for LHC cable: 4.3 mW/cm3

Power density, Q0





Reference LHC

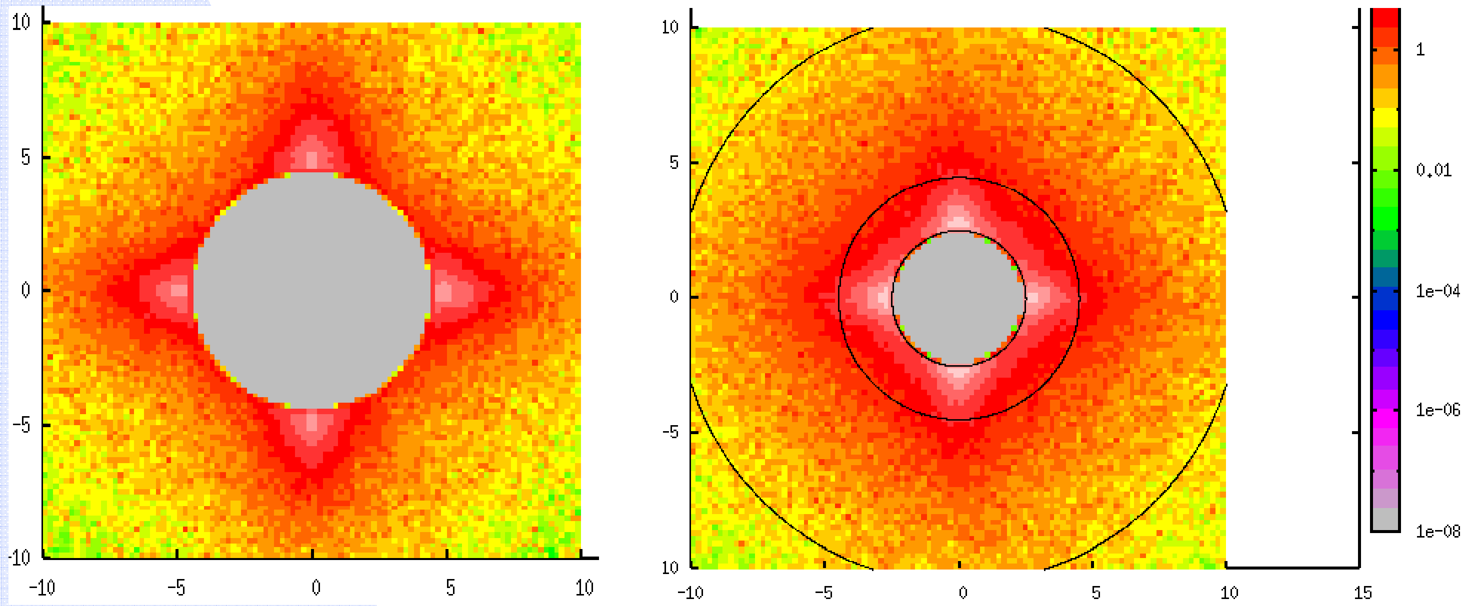
Total power in the magnets

- Difficult to estimate without a complete design of the magnet (influence of the size of the yoke)
- Q01 106 W (14.7 W/m)
- Q02 42.5 W (11 W/m)
- For the triplet only cable and collar simulated.

How to make it work : Liner

Material choice and thickness should be optimized!
In this example it is taken as stainless steel 2 cm thick.

No crossing angle in this example.
This case was calculated for L = 1.0 10^{35} cm^{-2} s^{-1}

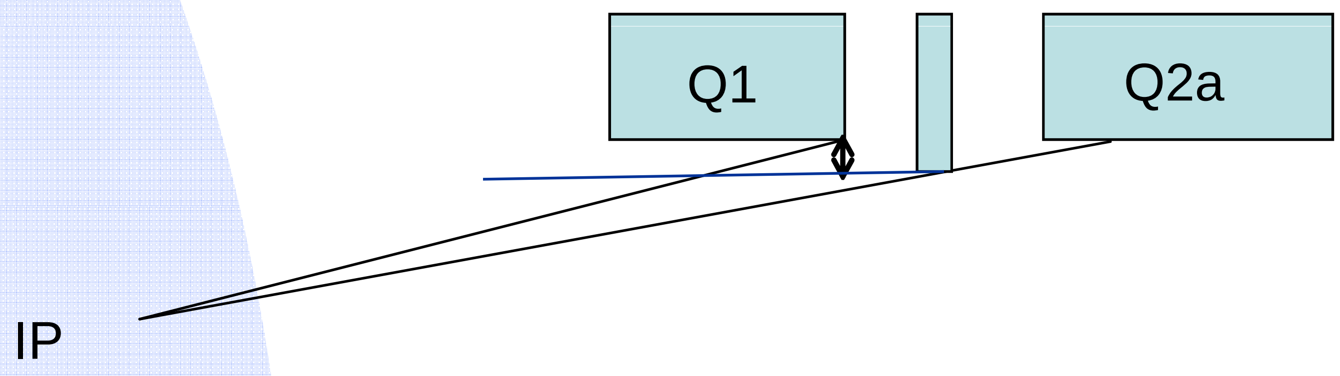


Example from previous study:

Elena Wildner: "Heat deposition and backscattering for one of the configurations of the IR for LHC upgrade",
Internal Note CERN/AT/MCS/ Mars 2007

Possible improvements: Mask

Optimization needed.
In the example the mask is taken as 10 cm long 1 cm thick tungsten ring



"Symmetric" layout

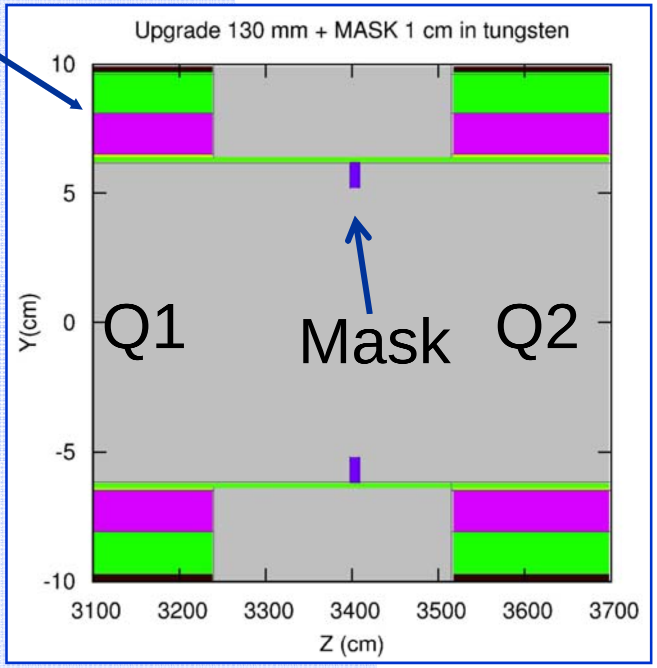
Implementation in model

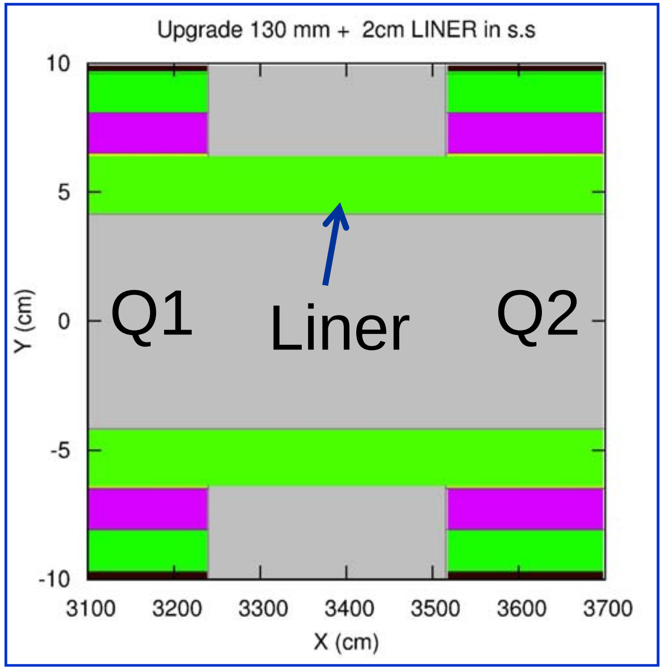
"Symmetric" layout

1 cm MASK in ***tungsten***

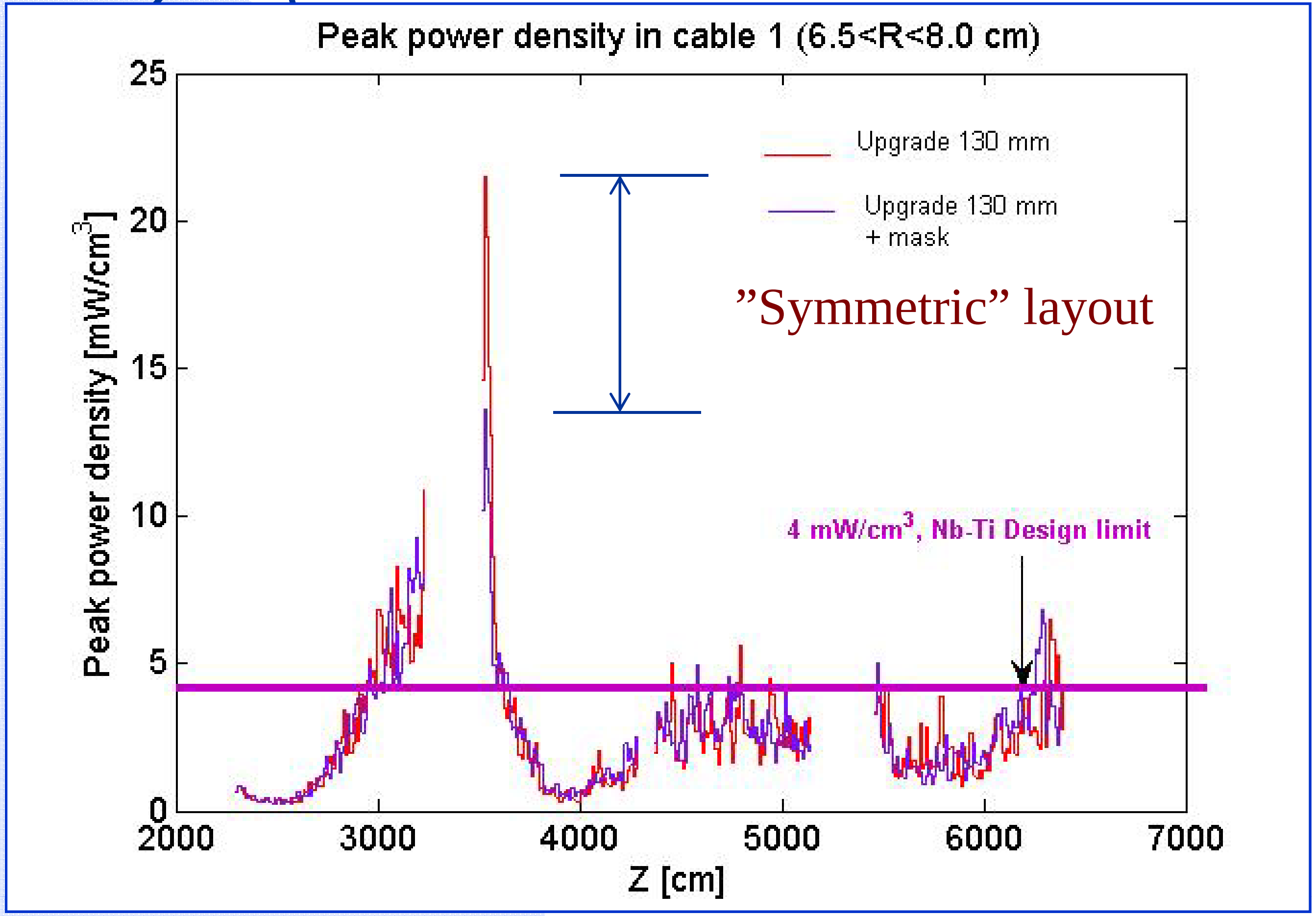
2cm LINER in ***stainless steel***

Cables





Peaks, with mask

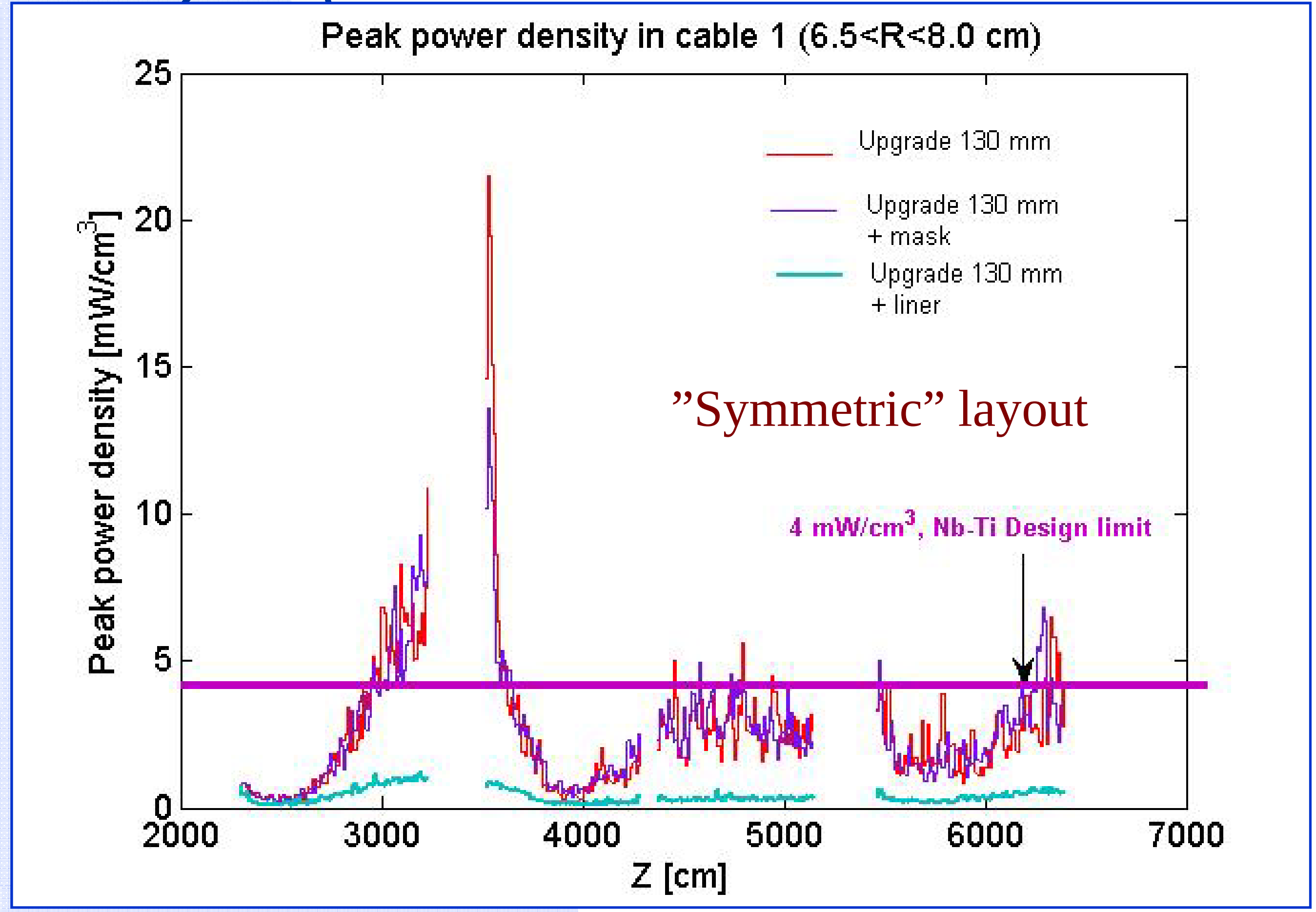


- Same total heat loads in the magnets
- -36 % decrease of the peak:

  21.5 mW/cm^3 to

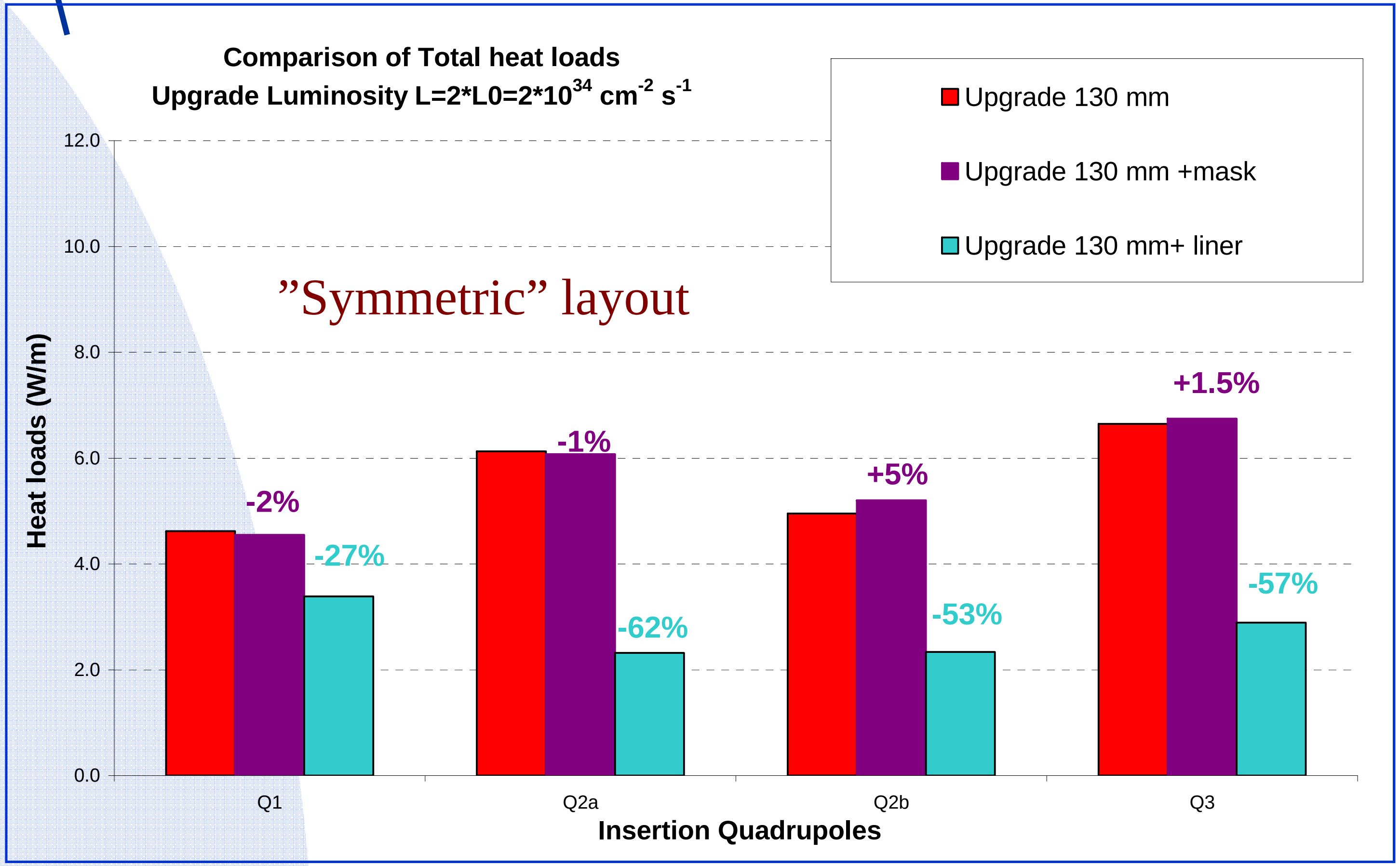
  13.6 mW/cm^3

Peaks, with mask and liner



- Mask 1cm in tungsten
  - 21.5 mW/cm^3 to 13.6 mW/cm^3
  - -36 % decrease of the peak:
- Liner 2cm in stainless steel
  - -95% decrease of the peak
  - 21.5 mW/cm^3 to 1.1 mW/cm^3

Total, with mask and liner



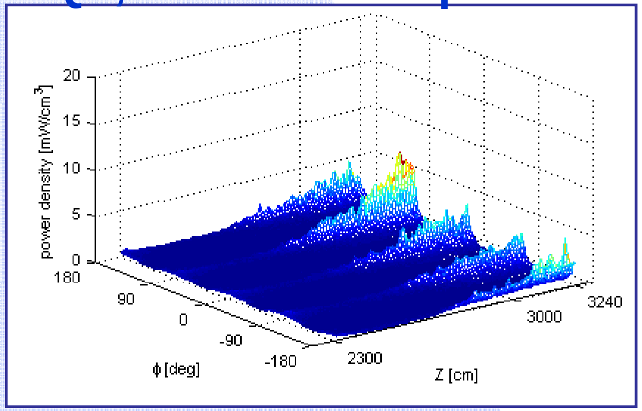
- Mask 1cm in tungsten
  - Same heat loads
- Liner 2cm in stainless steel
  - Decrease of the heat loads <27%

E 35

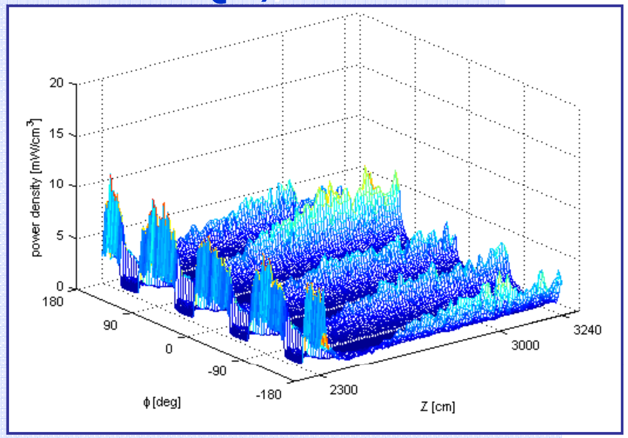
- Calculated Layouts based on Phase 1 upgrade
- Extrapolated Luminosity 1 E35 could be possible by optimizing liners and masks to manage 5 times higher deposited power for all scenarios.
- Energy evacuated from liner (cooling tubes)
- Impact of crossing angle a problem?
- Magnetic arrangements to lower the deposition:
  - D0 may help?

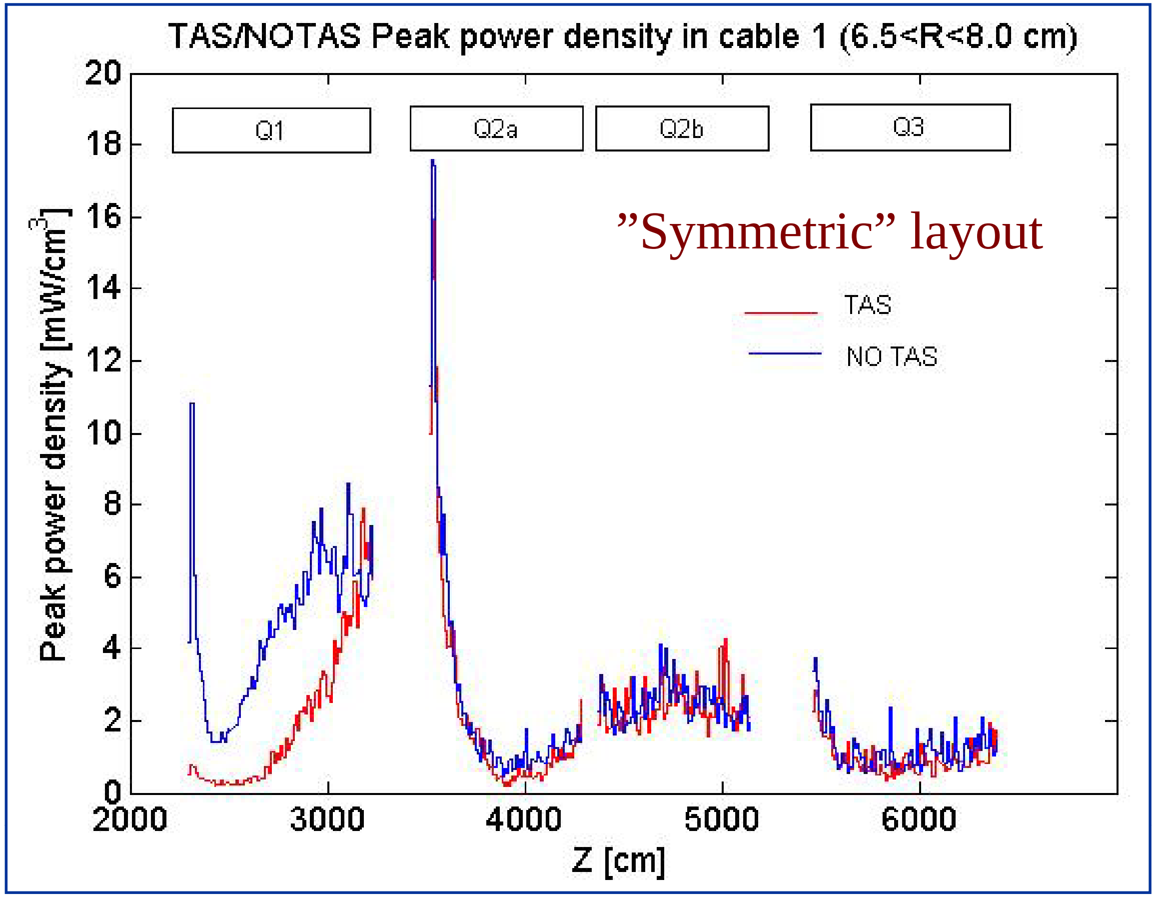
TAS/ noTAS

Q1, TAS 40 mm aperture



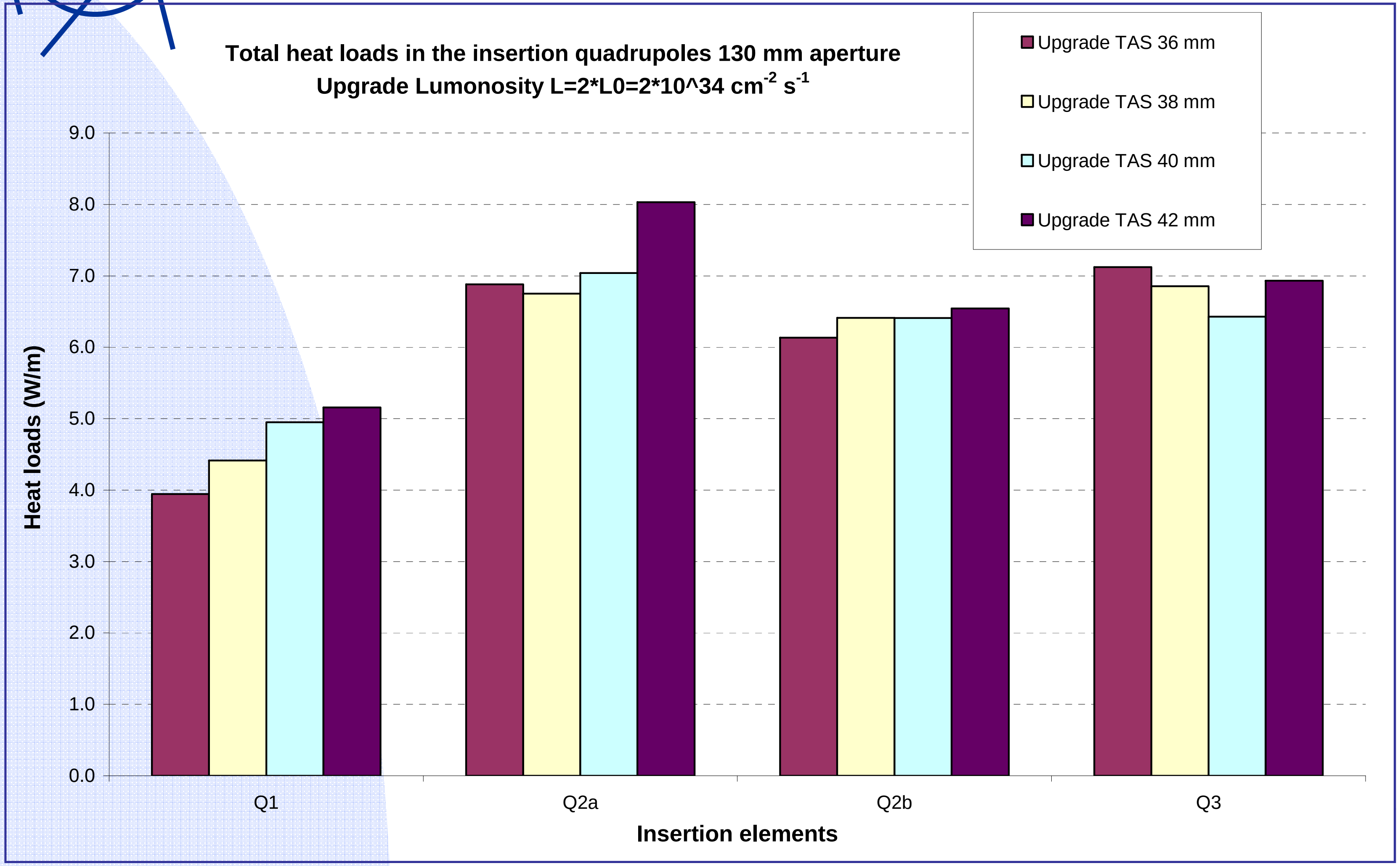
Q1, no TAS





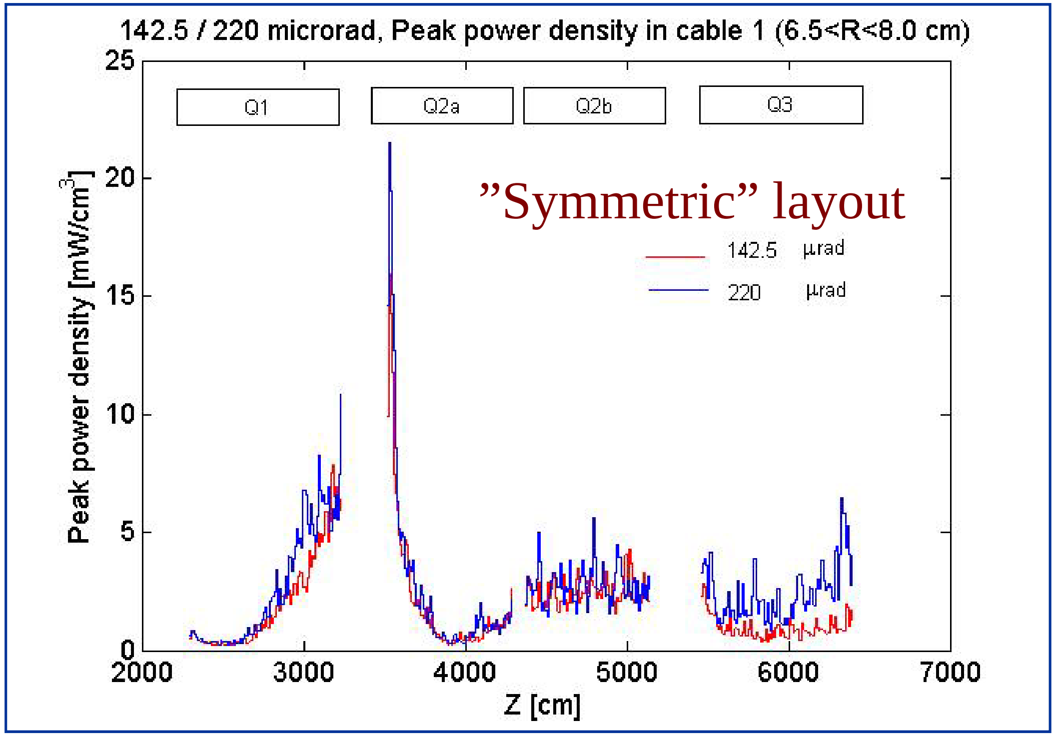
Variation of TAS aperture

"Symmetric" layout



Half crossing angle

Peak power density



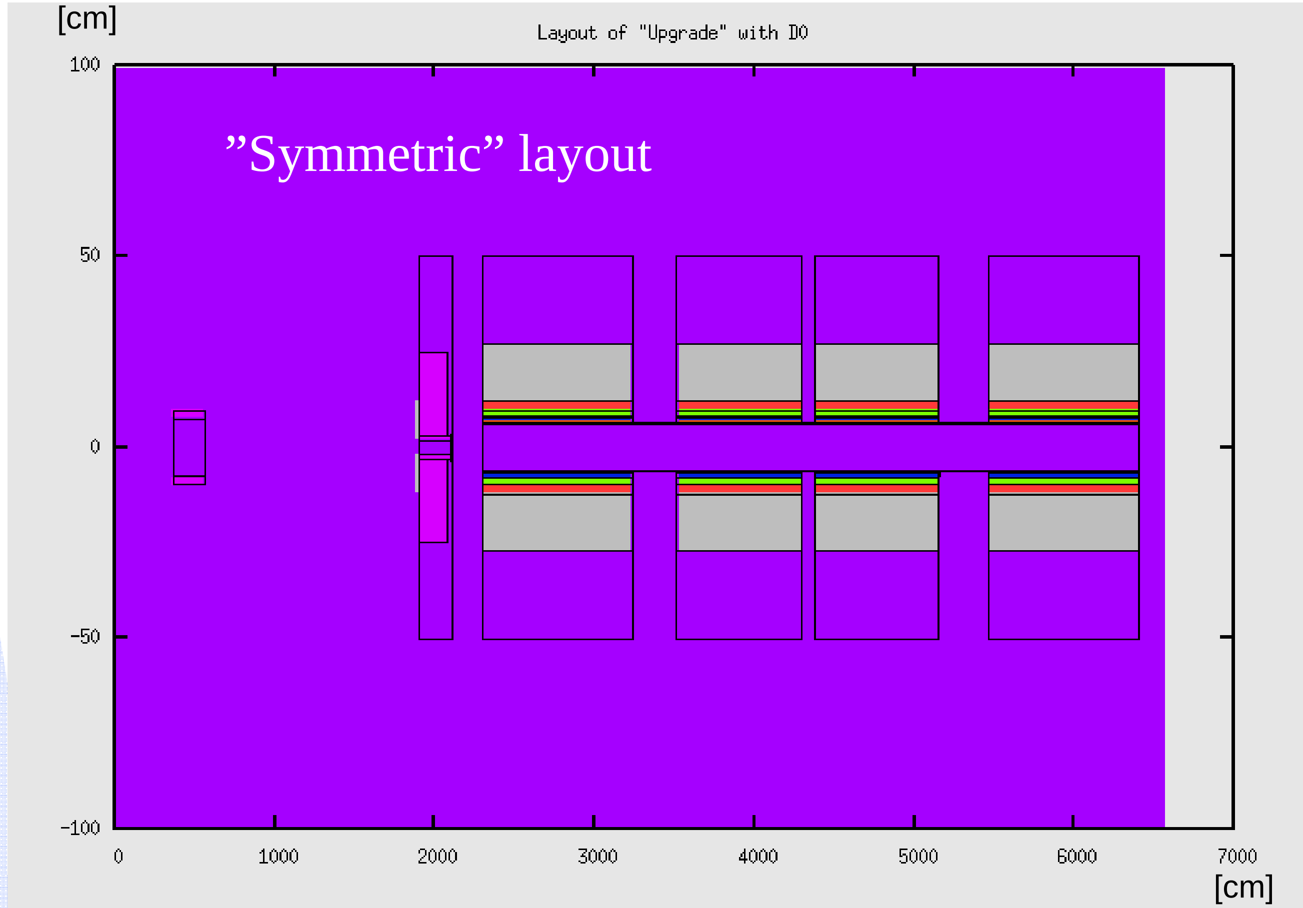
Total heat loads

FLUKA	142.5 microrad	220 microrad
	Power deposition (W)	Power deposition (W)
TAS	40	41.2
BP	15.4	16.8
TAS	321.2	315.6
Q1	46.5	48.2
Q2a	54.9	59.7
Q2b	50.0	48.3
Q3	60.4	69.4
TOTAL QUADS	211.9	225.7

- Same total heat loads in the quadrupoles
- Increase of the peak in Q2

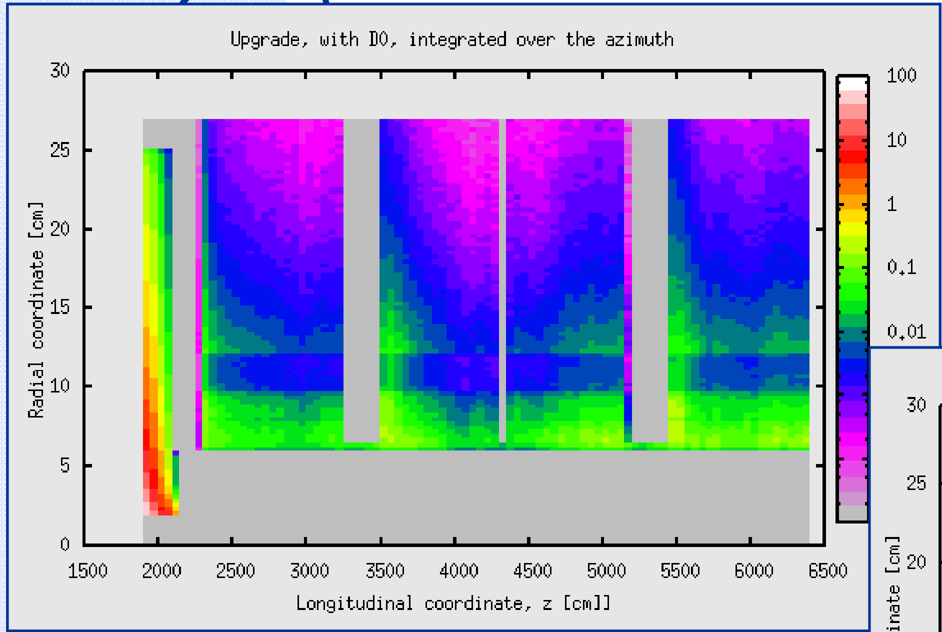
Insertion of D0

D0 (Close to experiment)
Aperture 15 cm
Length 2 m
Gradient 3T/m (vertical)
3 m from experiment

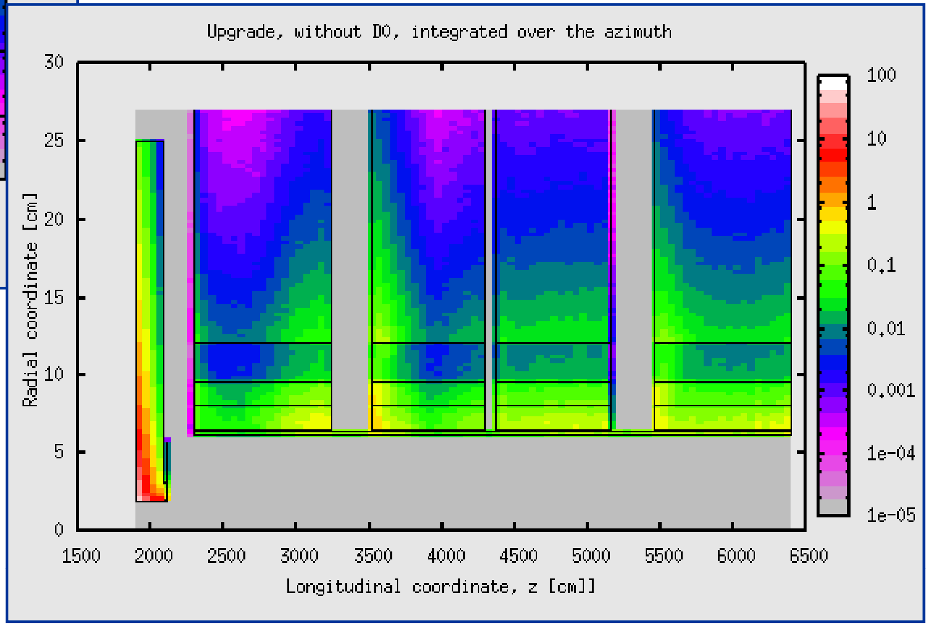


Longitudinal overview, D0

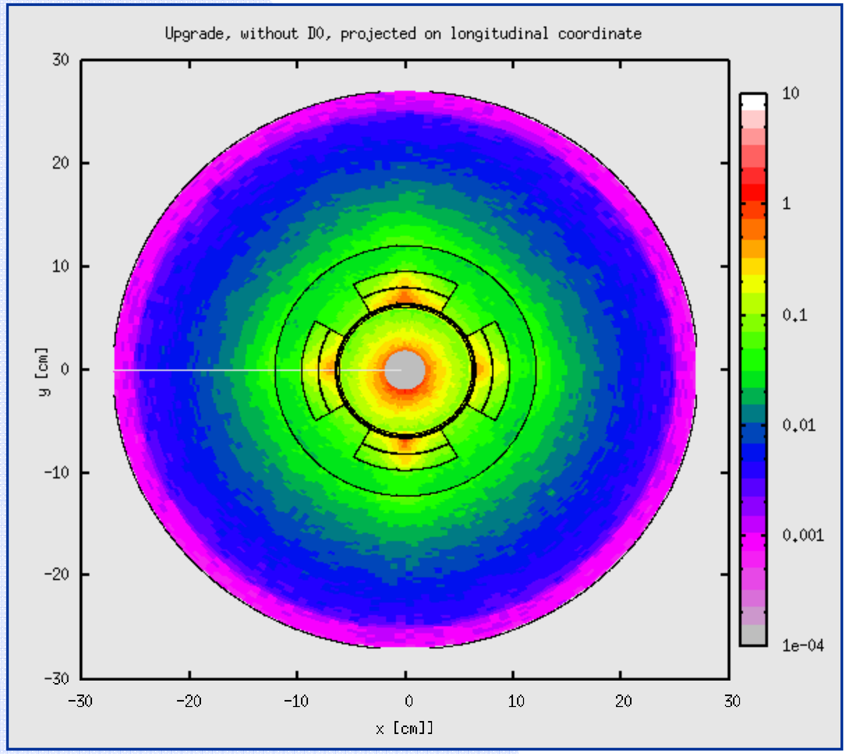
"Symmetric" layout

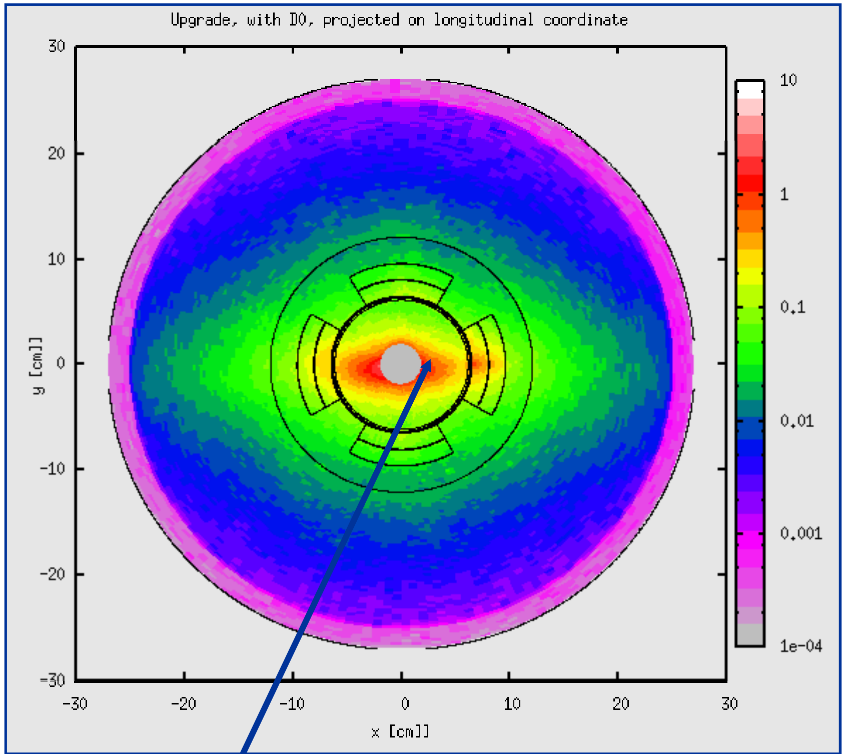


mW/cm3



Projection along magnet axis



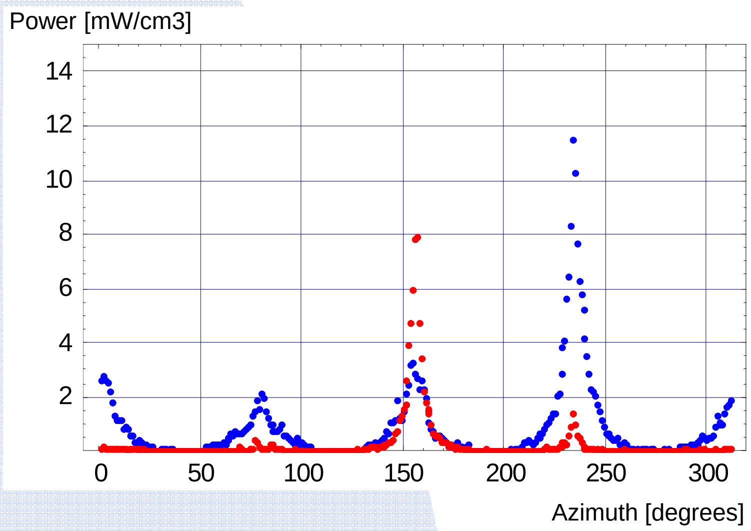


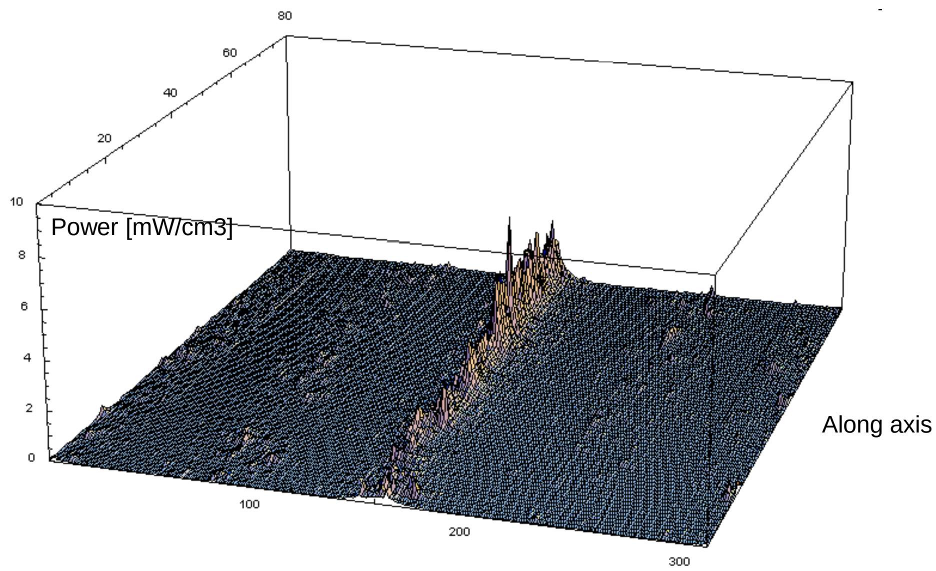
Peak in TAS

"Symmetric" layout

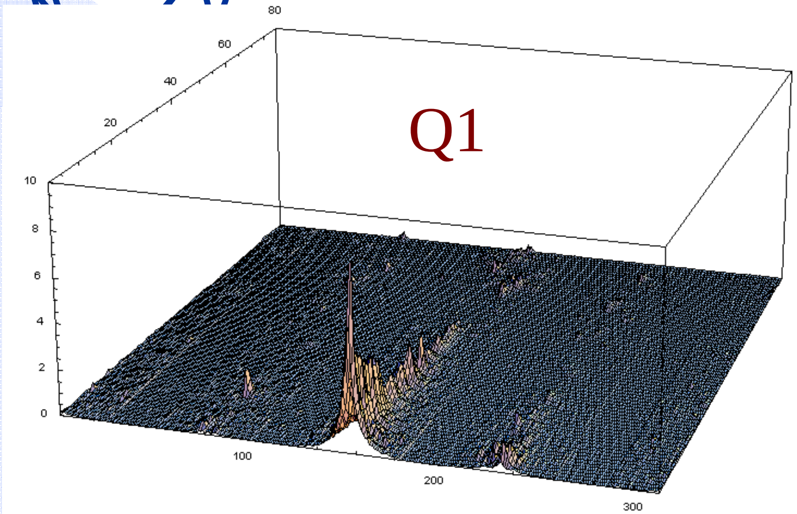
Peak of deposited energy with D0

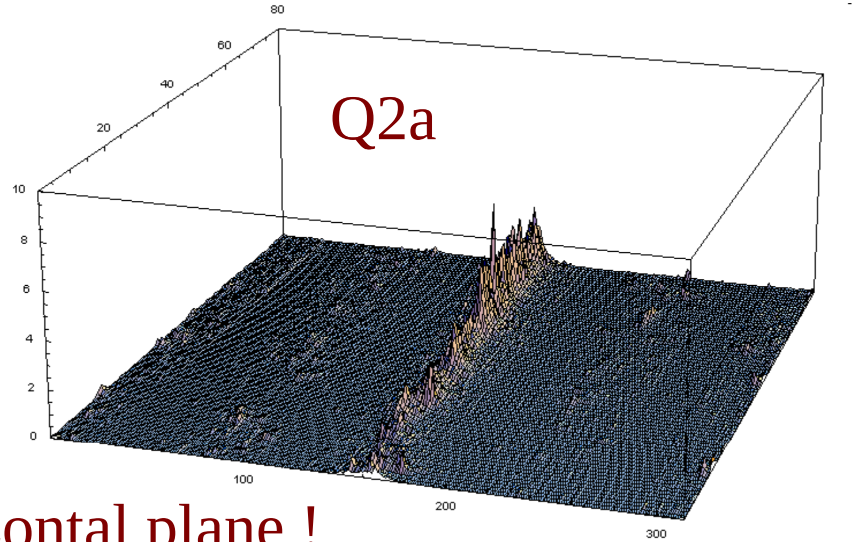
Peak in second magnet, red with D0 on



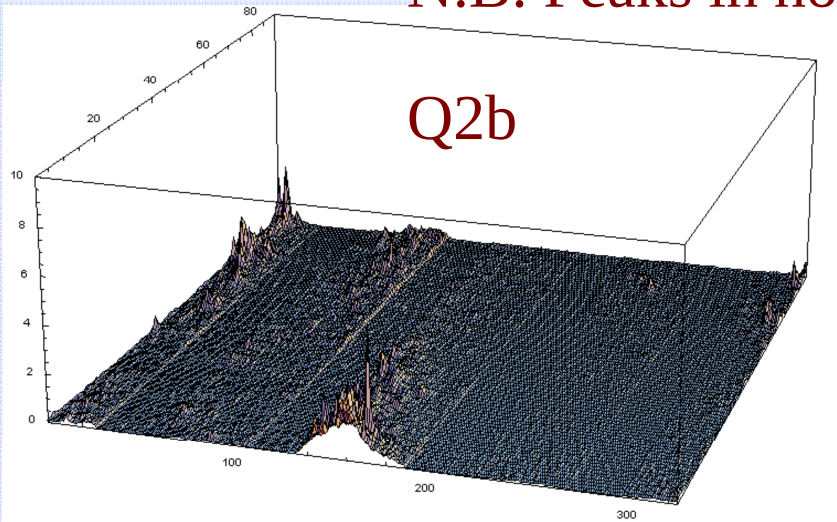


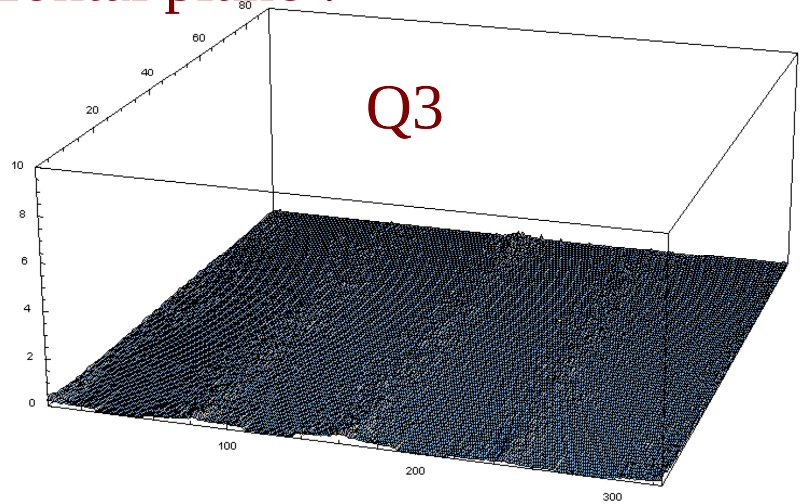
Peak of deposited energy with D0





N.B. Peaks in horizontal plane !





Summary

- Scenarios overall similar: they all have high peak deposition
- “Compact 1” (large aperture) most favorable
- A liner of 2 cm reduces the deposited peak energy to
  ~1 mW/cm3 along the magnets (checked case: “Symmetric”).
- For the option Q0 we may need some more optimization (larger apertures).
- We may improve even more by magnetic arrangements (like D0)
- Crossing angle has a limited impact (<15 %)
- Optimization for L= 1 E 35 $cm^{-2}s^{-1}$ seems a possibility (magnets)
- Backscattering to experiments?

Acknowledgements

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Francesco Cerutti

Glyn Kirby

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