Summary of WG1 on IR optics, energy deposition, magnets

- Presentations
- Questions for WG1
- Discussions/comments/action items

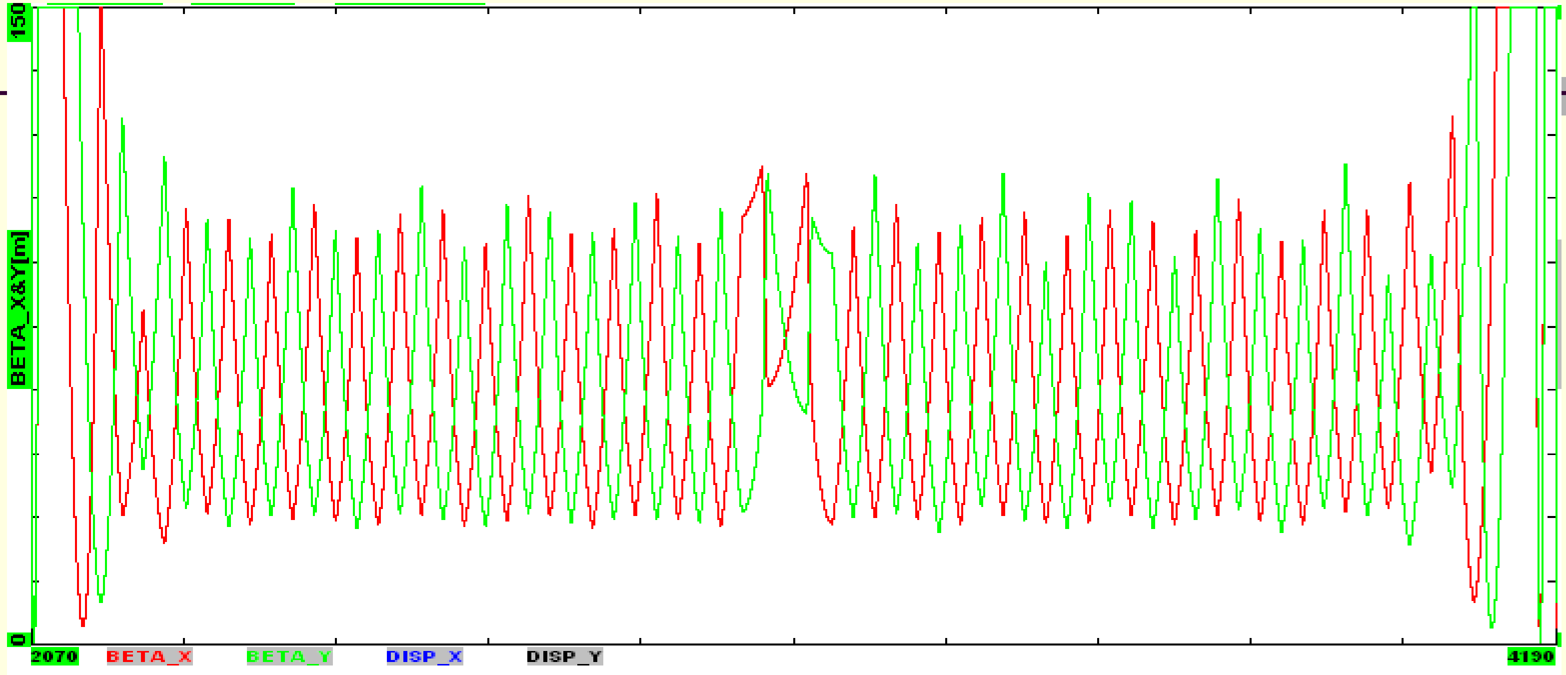
Optics Measurements at the Tevatron

Alexander Valishev, Fermilab

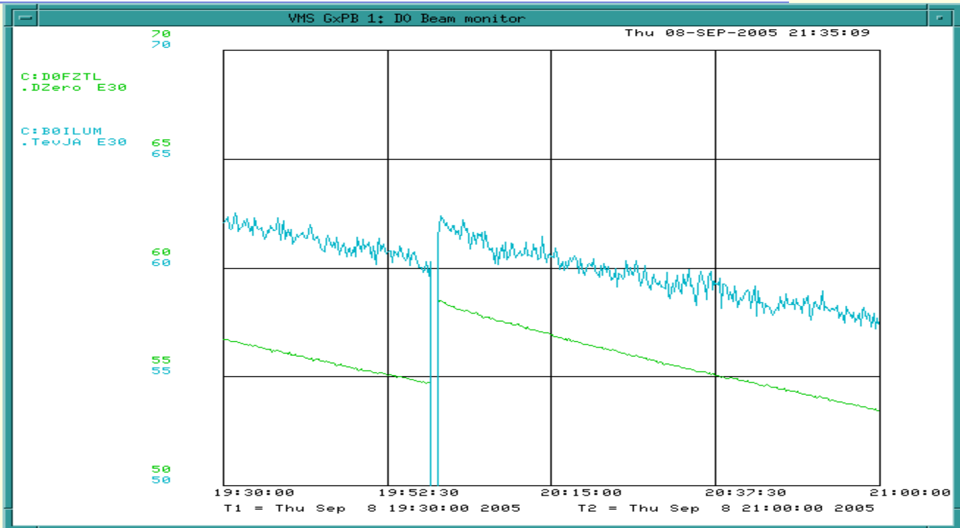
- The response matrix fit method allows to pinpoint gradient errors in the Tevatron of the order of 2E-3. The β-function measurement error is ~ 5%
- Measurements are in good agreement with results obtained by turn-by-turn and tune-shift methods. Single measurement requires ~ 1 hour of the machine time. Data analysis takes ~ 6 hours.
- Based on the fitted model, optics modification have been done to:
  - Correct beta-beating in the arcs
  - Eliminate the difference between the two IPs
  - Decrease β^* from 35 to 28 cm
- Peak luminosity of the collider with the new optics increased by 10% (5% at end of stores owing to hourglass effect for longer bunches)
- **Second order Q' increased by ~30% after reduction of β^* ⇒ decreased luminosity lifetime due to larger tune spread to be accommodated between 5th and 12th order resonances**
- 8.5σ beam separation at the first parasitic collision, can in principle be increased to 12σ by increasing bunch spacing from 21 to 23 buckets ⇒ not accepted by experiments owing to higher event pile-up
- Further improvements are required to achieve better prediction accuracy, e.g. determination of parameters of individual trim elements

Tevatron Beta Functions (short arc)

"28cm optics" after 9/21/05



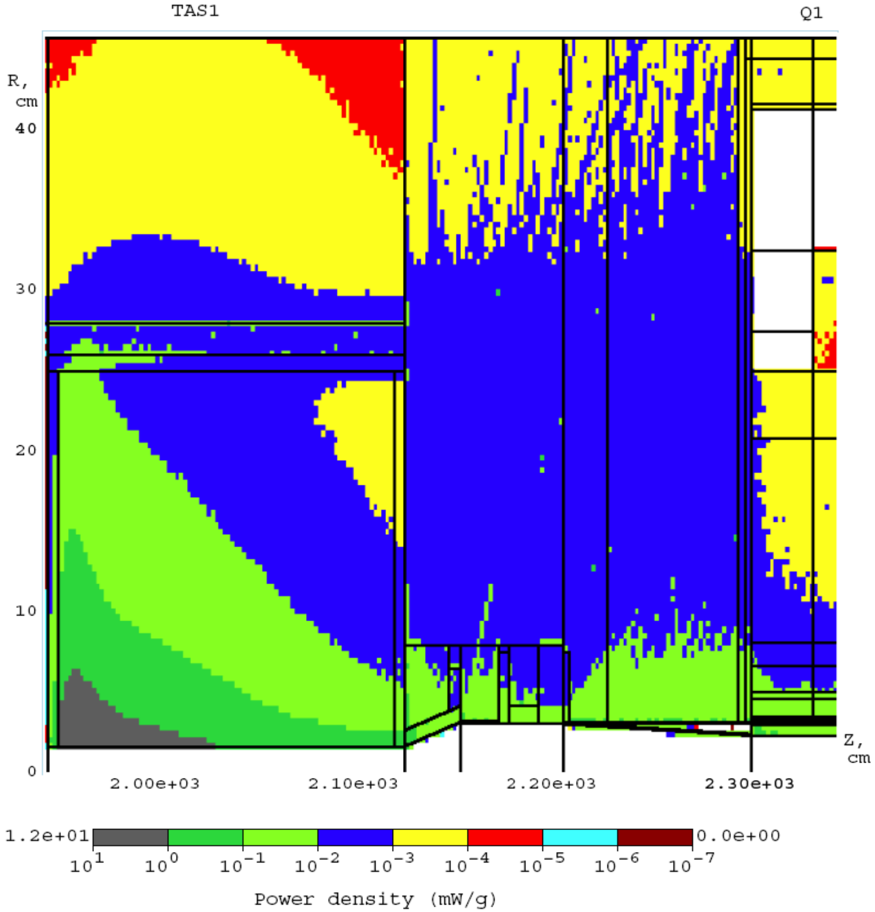
	β_x^* (cm)	β_y^* (cm)
CDF	30.3	29.1
D0	29.2	28.2

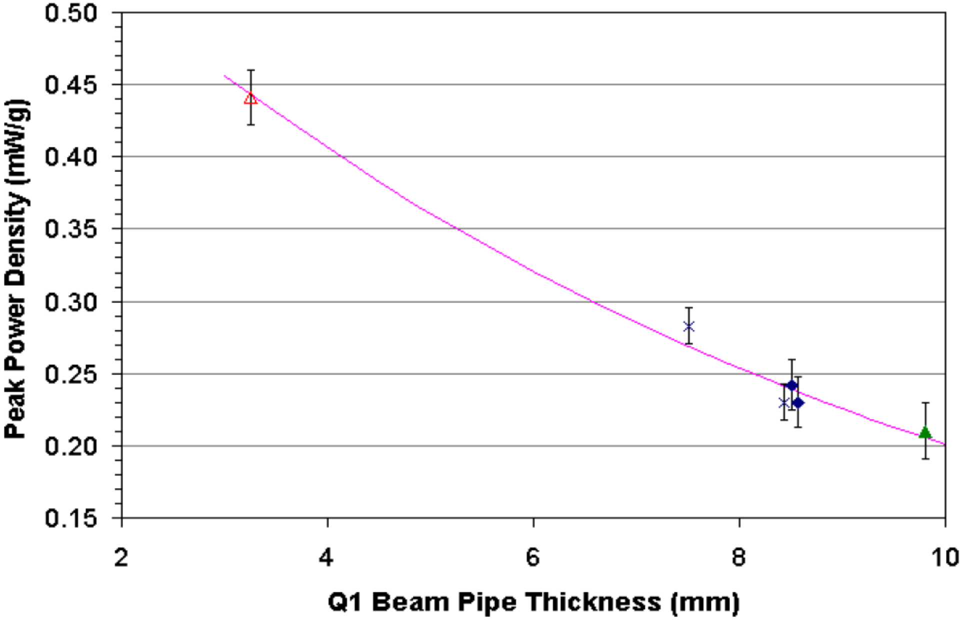


Energy Deposition Issues in LHC IR Upgrades, Nikolai Mokhov, Fermilab

- Quench levels in the LHC IR quads are well understood, more work is needed on other magnets.
- All energy deposition issues have been addressed in IR in detailed modeling at nominal and upgraded luminosities.
- IP1 and IP5 SC magnets and CMS and ATLAS detectors are adequately protected at normal operation and accidental conditions with the local (TAS, liners etc) protection systems, main collimation system in IP3/IP7, IP6 collimators (TCDQ etc), and tertiary collimators TCT.
- LHC upgrade scenarios are quite challenging from energy deposition standpoint, simulation results are encouraging, but more work is needed.
- All three aspects, i.e. *i)* quench limit, *ii)* radiation damage (magnet lifetime), and *iii)* dynamic heat load on the cryo system should be simultaneously addressed in the IR magnet design. *i)* and *ii)* are linked.

TAS AND LINER OPTIMIZATION





Beam screen together with cold bore

Reduces power density at IP-end of Q1 300 times and dynamic heat load to inner triplet by 185 Watts. 5% of incoming energy punch through 1.8-m copper TAS body

Chosen: 6.5 mm in Q1
and 3 mm in Q2-Q3

WG1 Questions/Answers Energy deposition

- Estimated dipole field with TAS in quad first option to reduce peak energy deposition "well below" quench limits ⇒ **15-20 Tm for magnetic TAS**

  Estimated thickness of internal absorbers?

  ⇒ **a 5 mm thick SS absorber reduces peak power by a factor ~2**

  Choose ℓ^*=19 m ⇒ **no results available yet**

- Scaling laws for energy deposition. What are the limits of validity and how can they be improved? Variation with ℓ^*?

  ⇒ **see next action items**

- Impact of orbit corrector D0 inside the experiment on energy deposition in downstream magnets, including detector solenoid field

  ⇒ **see next action items, modest impact of solenoid field on energy deposition (more from fringe fields)**

Action items/comments on energy deposition, Nikolai Mokhov

- Refine and test scaling law for energy deposition in IR magnets with MARS simulations (including dependence on ℓ^*)
- Introduce quench limits to JPK's spreadsheet for NbTi and Nb_3Sn
- Address radiation damage/lifetime issues in all IR magnet design analyses: 7 years at 10^{34} become 8 months at 10^{35} with currently used materials $\Rightarrow$ new (ceramic type) materials for 10^{35}?
- Launch R&D program on beam tests for SC and insulating materials asap: BNL, FNAL, MSU
- Arrive at a clear picture on Dynamic Heat Load limits. How serious is the current 10 W/m limit or 120 W on each side of IR? This becomes 100 W/m and 1.2 kW for 10^{35}. Cooling scheme? Cryoplant capability?

Action items for Nikolai Mokhov (cont'd)

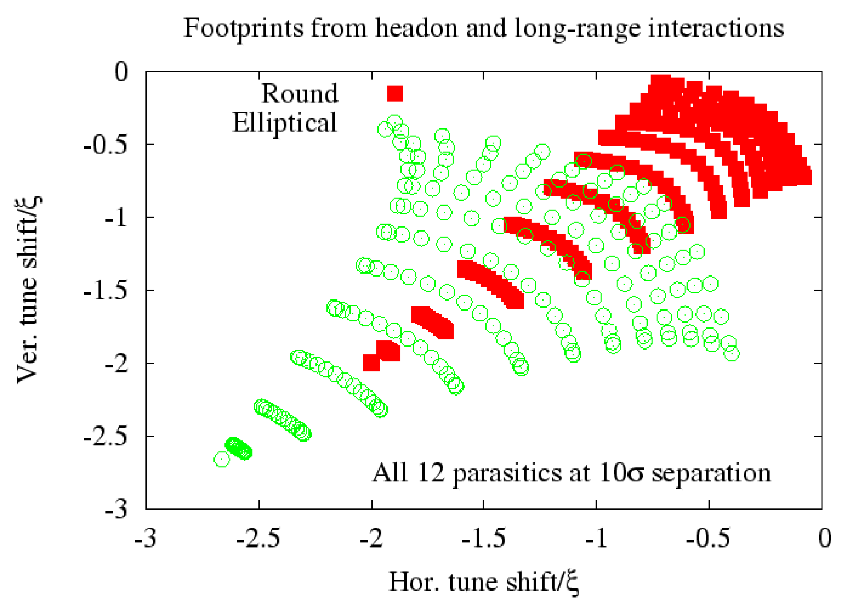
- Perform realistic MARS calculations on viability of a D0 dipole close to the IP: address both energy deposition and background/interference with detectors
- The peak power deposition at the non-IP end of IR magnets is approximately proportional to $\int B d\ell \Rightarrow$

  look at the possibility of shortening IR quads: "quadruplet" focusing with alternating (skew?) FDFD quads or long helical quads as an extreme. One may gain up to a factor 10 in peak power density from smearing energy deposition.
- Refine results on power density reduction versus TAS (passive and active) and liner parameters
- Mid-plane (low-Z) spacers

Doublet focusing optics
John Johnstone (Fermilab)

- Interesting approach, elliptic beams could increase luminosity by ~30% with reduced crossing angle
- Symmetric doublets require separate magnetic channels (e.g., dipole-first) or very special quadrupoles (old VLHC idea)
- Tune footprints are broader than for round beams. More work needed to evaluate nonlinear resonance excitation.
- Probably requires BBLR compensation

Tune Shifts (cont’d)



Courtesy of T. Sen 10.02.05

- Tune footprints extending to 6σ have been calculated for round & elliptical beams assuming 12 parasitics per IR.
- The elliptical beam footprint is significantly larger than that of round beams.

† Long range tune shifts are a concern that needs to be addressed. Avenues to explore might include a D0 trim to separate beams earlier, or re-examine wire compensation schemes, or ....

WG1 Questions/(some) Answers Optics

1. What is the largest coil aperture required (beta*=0.25 m) for each optics layout ?
2. How does the luminosity scale with ℓ^* for a fixed magnet aperture (for quads first and dipoles first, assuming Nb_3Sn technology)
3. Limits on chromaticity, b6 and b10 at collision. What are the upper limits beyond which they cannot be corrected by nonlinear correctors?

   ⇒ see action item on chromatic performance of IR solutions

1. What are the field quality requirements at injection? How does it differ for the different scenarios: quad first, dipole first
2. What is the impact of beam-beam compensation wires on the IR optics? beam size at IP, beam offsets, nonlinear fields?
3. What is the length required for crab cavities and where should they be placed? Constraints on optics functions at the crab cavities.

   ⇒ ~30-40 m can in principle be accommodated after the triplet, where the beam separations is ~50 cm for a large crossing angle of ~8 mrad

Magnet R&D: Gianluca Sabbi and Paolo Ferracin

- R&D models with 90 mm aperture address the critical design issues (magnetic, mechanical, quench etc)
- Using a larger aperture for magnet R&D would likely be less effective (due to cost considerations and other practical constraints)
- There is good confidence that successful results of 90 mm models can be extended to the range of apertures under consideration
- The maximum coil field is a critical parameter to establish the performance characteristics
- "High-gradient" models with 90 mm aperture (HQ) will be used to establish the maximum design field
- IR optimization studies should assume constant pole tip field and optimize aperture/gradient accordingly
- Using 13 T peak field (JPK) is ok for now, but the program aims at 15 T
- JPK model calibration using TQ design: 11 T peak field corresponds to 210 T/m in the 90 mm aperture

LARP Magnet Program Goals

FY09 Milestone:

Demonstrate viability of Nb_3Sn technology for “Quad-first” option

1. Capability to deliver predictable, reproducible performance:

TQ (Technology Quads, 2005-07) D = 90 mm, L = 1 m, G_{nom} > 200 T/m

2. Capability to scale-up the magnet length:

LQ (Long Quadrupoles, 2008-09) D = 90 mm, L = 4 m, G_{nom} > 200 T/m

3. Capability to reach high gradient (pole tip field) in large aperture:

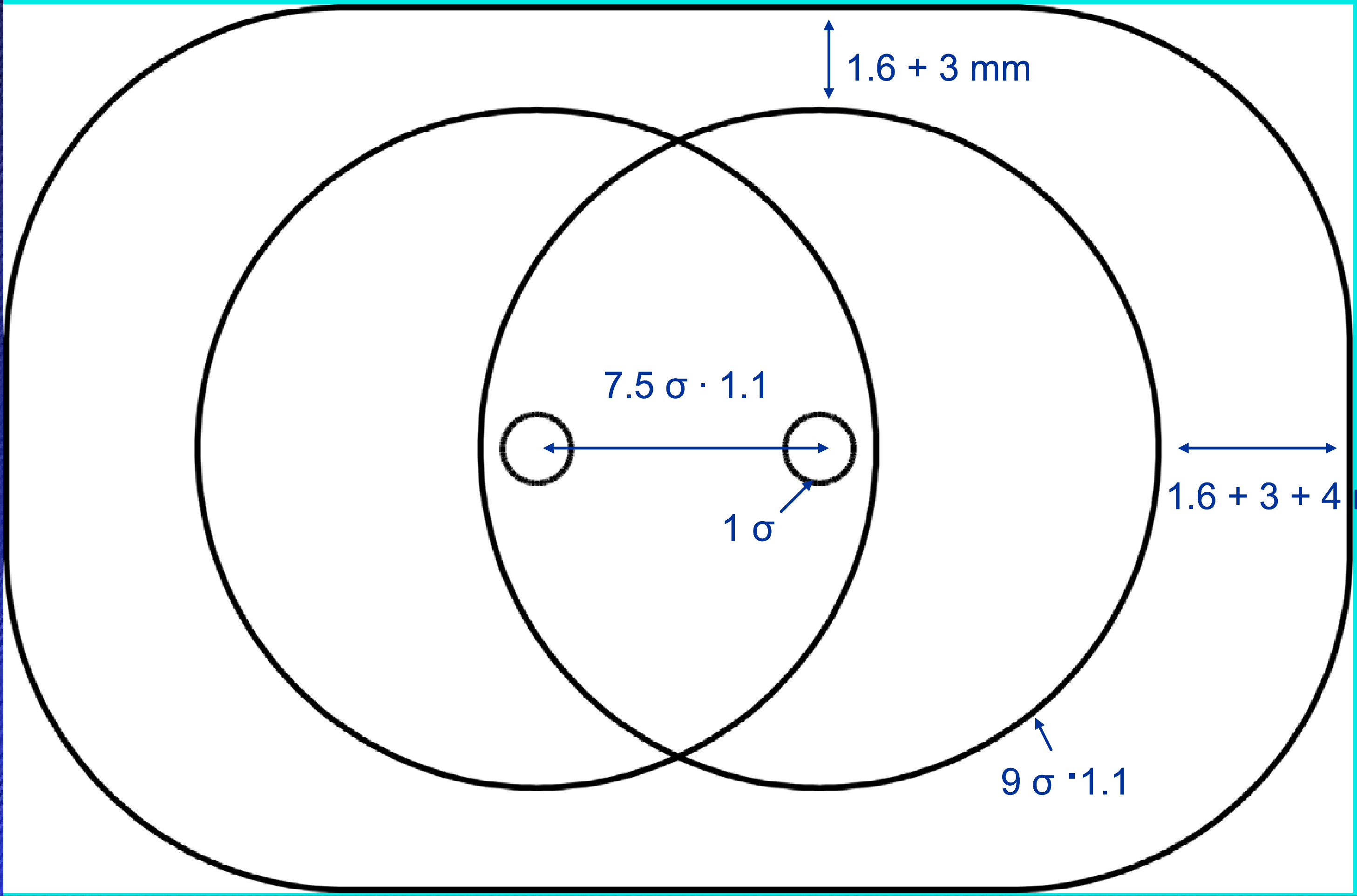
HQ (HighGradient Quads, 2008-09) D = 90 mm, L = 1 m, G_{nom} > 250 T/m

- *Fabrication of the first two TQ quads (TQS01 and TQC01) has started*
- *TQS01 test in February/March 2006; TQC01 test in April/May 2006*

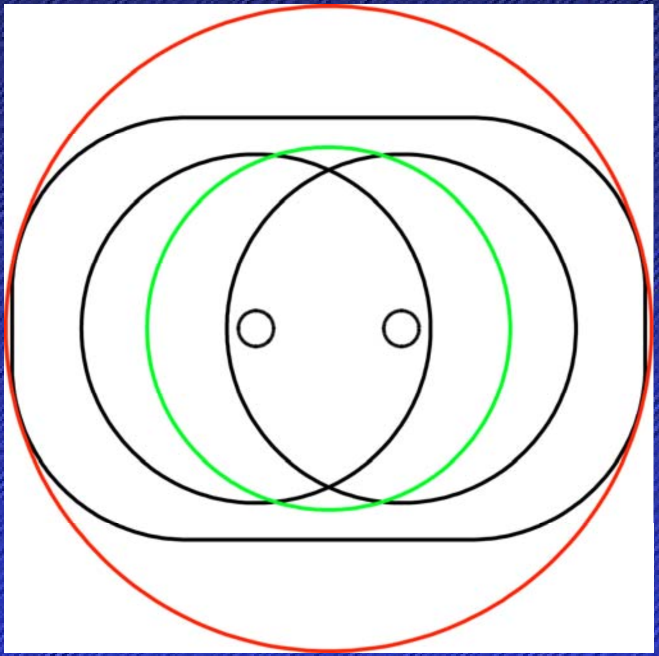
Coil aperture requirements

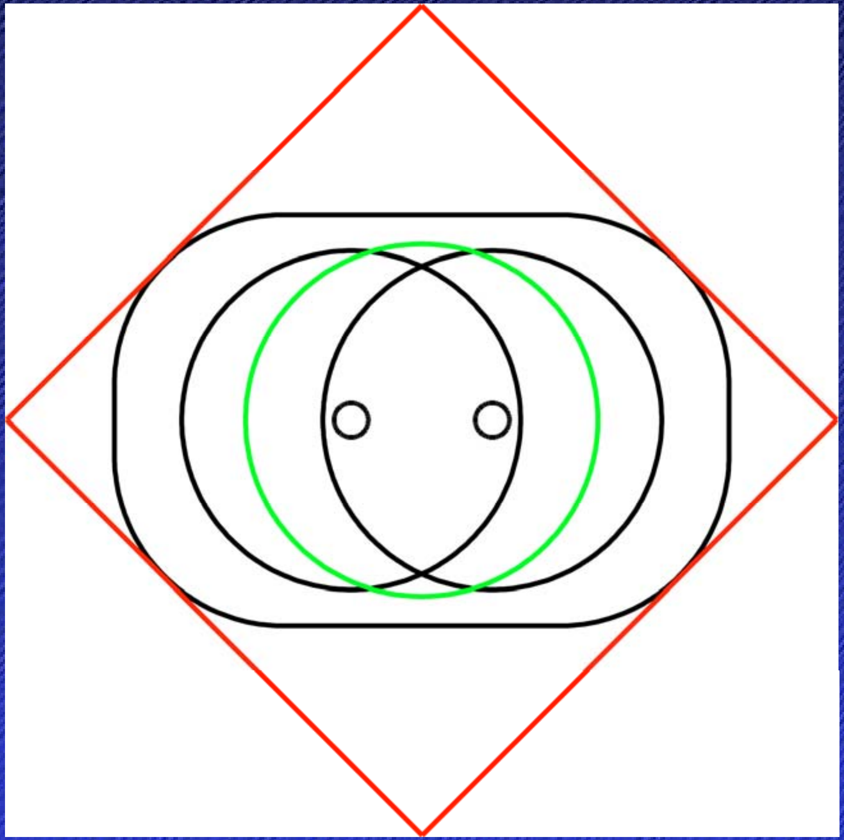
Coil aperture estimates need to be clarified/debugged/improved

$D_{trip} > 1.1 \times (7.5 + 2 \times 9) \cdot \sigma + 2 \times (1.6 + 3 + 4)$ mm



- The beam envelope formula does not correspond to a good field region (green circle)
- Equivalent aperture comparisons should include heat deposition considerations





Action Items

- CERN beam physicists will circulate a draft proposal for aperture and field quality requirements
- CERN beam physicists will circulate a draft proposal to assess and compare the chromatic performance of any IR solution, including quantitative considerations for luminosity or lifetime (possibly based on tune footprints for off-momentum particles)

Questions to WG1 - Magnets

1. What is the limit on quad aperture from magnet design at constant pole tip field? Is the aperture limit different for NbTi and Nb_3Sn?
2. Is there a quad design with either an absorber or low-Z spacers in the horizontal and vertical planes? to minimize energy deposition.
3. Are there lower limits to the systematic errors on b_6 and b_{10} with Nb_3Sn? How does this scale with the pole tip field and aperture?
4. If 90 mm quads with 11-12 T field are demonstrated by 2009, how much confidence is there that larger aperture quads can be built with the same pole tip field?

1. Aperture limits

- From the magnet design standpoint, there is no fundamental limit to increasing the quadrupole aperture (for both NbTi and Nb_3Sn magnets) but more detailed magnet design studies are needed in support of IR designs using very large apertures (120-150 mm?)
- Space considerations will limit the quad aperture, in particular for some of the IR layouts
- Coil volume will increase with aperture; mechanical considerations (stress) may lead to a rate of increase faster than linear

2. Energy deposition issues

- Absorbers and mid-plane spacers can be included in all magnet designs
- Additional space for absorbers (in particular at mid-plane) can be obtained by increasing the coil aperture

3. Field Quality

- Geometric errors are very small and comparable in Nb_3Sn and NbTi quadrupole designs
- Fabrication tolerances will likely dominate the field errors
- Further studies are needed to determine the practical limits on field quality achievable in Nb3Sn quads
- Conventional scaling with aperture applies; field errors can be minimized for all operating fields

4. Aperture scaling

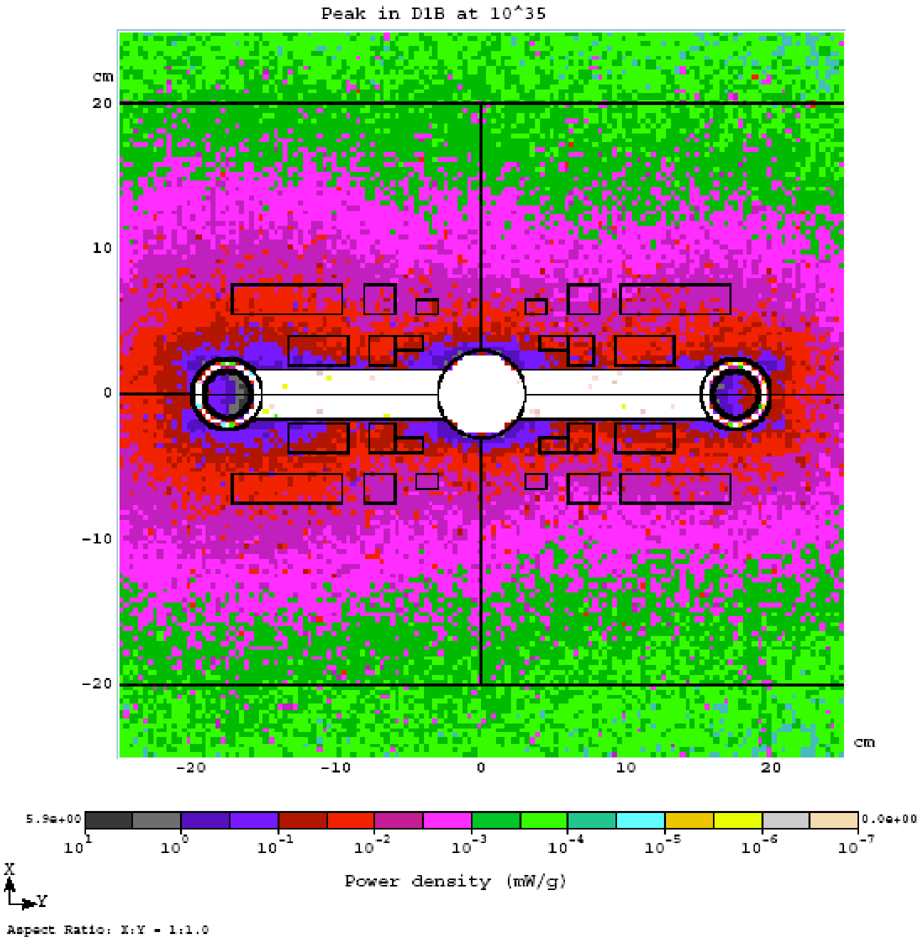
- There is good confidence that the 90 mm models will address the critical R&D issues, applicable to the entire range of apertures being considered
- Based on results from R&D, it will be possible to fabricate prototypes of larger aperture in the same time frame as for 90 mm aperture quads

Tuesday presentations

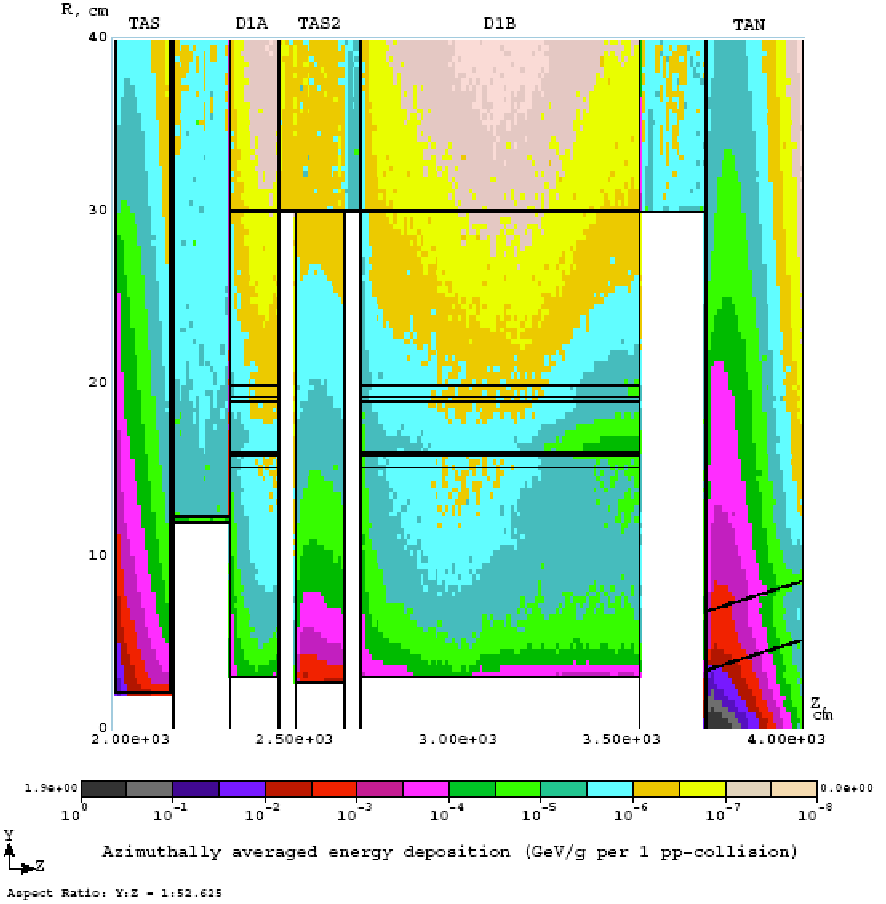
- A Review of Open Midplane Dipole Design Study, Ramesh Gupta (BNL)
- Inner Triplet Cryogenics and Heat Transfer, Roger Rabehl (Fermilab)
- A Structured-Cable Superconducting Quadrupole for High-Heat-Load Applications, Peter McIntyre (Texas A&M Univ.)
- Levitated-Pole Superconducting Dipole for Use in Beam Separators for LHC, Peter McIntyre (Texas A&M Univ.)

Energy Deposition in Open Midplane Dipole in Dipole First Optics

Courtesy: Nikolai Mokhov, FNAL

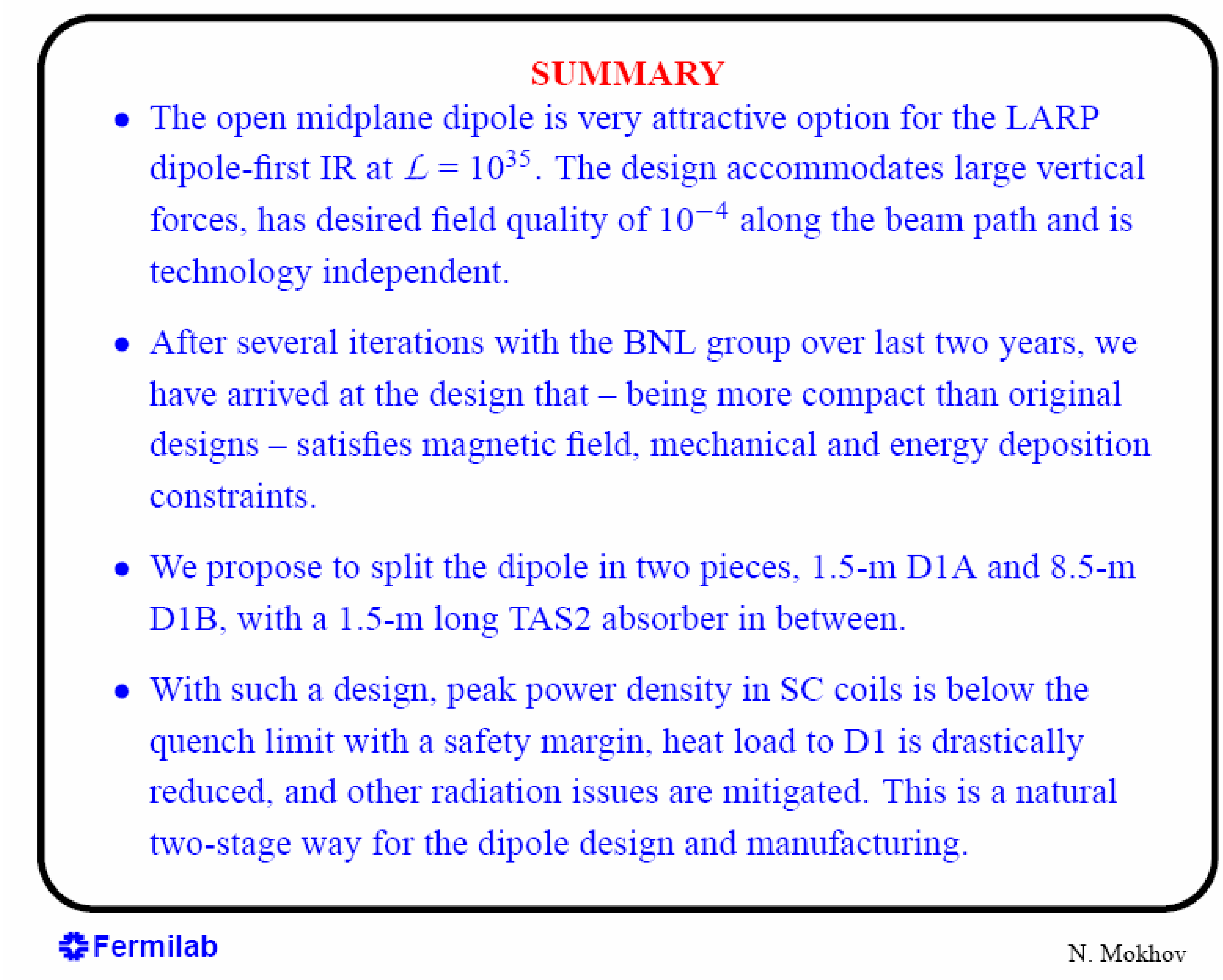


Power density isocontours at the non-IP end of the D1B.



Azimuthally averaged energy deposition iso-contours in the dipole-first IR.

Energy Deposition Summary (Mokhov, 04/05)



SUMMARY

- The open midplane dipole is very attractive option for the LARP dipole-first IR at $\mathcal{L} = 10^{35}$. The design accommodates large vertical forces, has desired field quality of 10^{-4} along the beam path and is technology independent.
- After several iterations with the BNL group over last two years, we have arrived at the design that – being more compact than original designs – satisfies magnetic field, mechanical and energy deposition constraints.
- We propose to split the dipole in two pieces, 1.5-m D1A and 8.5-m D1B, with a 1.5-m long TAS2 absorber in between.
- With such a design, peak power density in SC coils is below the quench limit with a safety margin, heat load to D1 is drastically reduced, and other radiation issues are mitigated. This is a natural two-stage way for the dipole design and manufacturing.

Fermilab

N. Mokhov

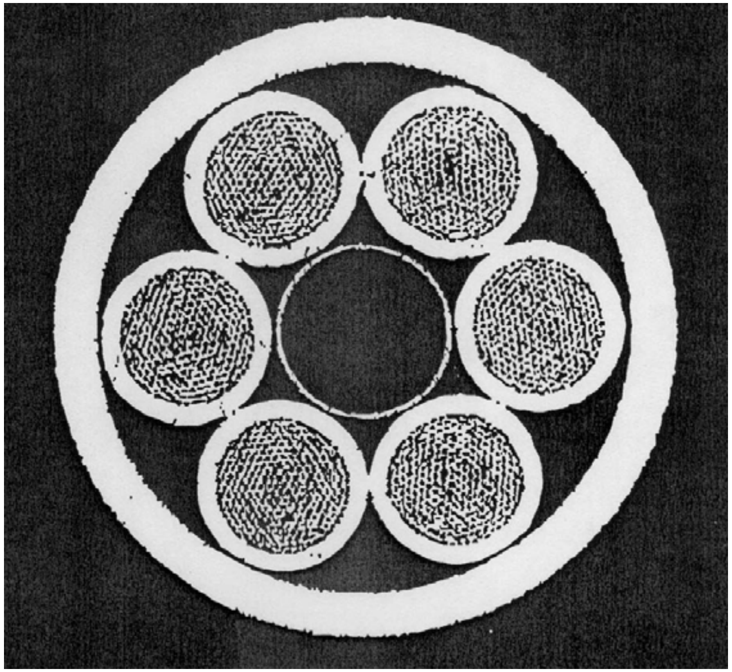
Summary of Design Iterations (A to F)

	A	B	C	D	E	F
H(mm)	84	135	160	120	80	120
V(mm)	33	20	50	30	34	40
V/H	0.39	0.15	0.31	0.25	0.43	0.33
B_o(T)	13.6	13.6	13.6	13.6	15	13.6
B_{ss}(T)	15	15	15	14.5	16	15
J_c(A/mm^2)	2500	3000	3000	3000	3000	3000
Cu/Sc	1	1,1.8	0.85	0.85	0.85	1
A(cm^2)	161	198	215	148	151	125
R_i(mm)	135	400	400	320	300	300
R_o(mm)	470	800	1000	700	700	700
E(MJ/m)	2.2	4.8	9.2	5.2	4.1	4.8
F_x(MN/m)	9.6	10.1	12.3	9.5	10.4	9.6
F_y(MN/m)	-3.0	-6.8	-8.7	-7.0	-5.1	-5.4

IR Cryogenics Studies – Summary

- Heat load scaling of the IR has lead to the identification of thermal design limits.
- A series of design studies is planned to achieve a reasonable temperature drop within the IR. This temperature drop will then be allocated within the IR.

Design Q_1 using structured cable



6-on-1 cabling of Nb_3Sn strand around thin-wall Inconel X750 spring tube

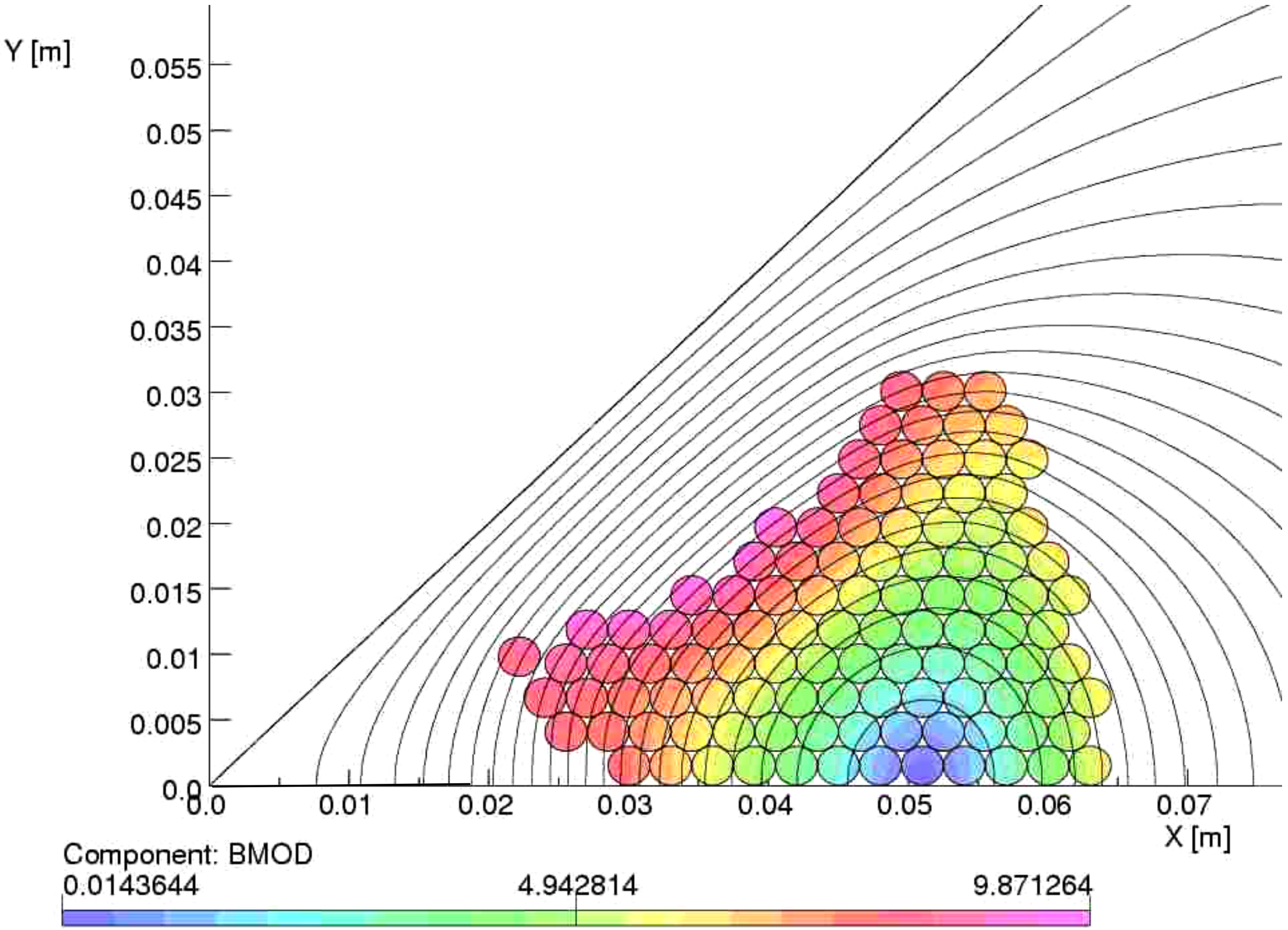
Pull cable into a thicker Inconel 718 sheath, then draw down to gently compress strands

Load strands against sheath so they are immobilized without need of impregnation

Interior is not impregnated – only region between cables in winding

Volumetric cooling to handle volumetric heating from particle losses

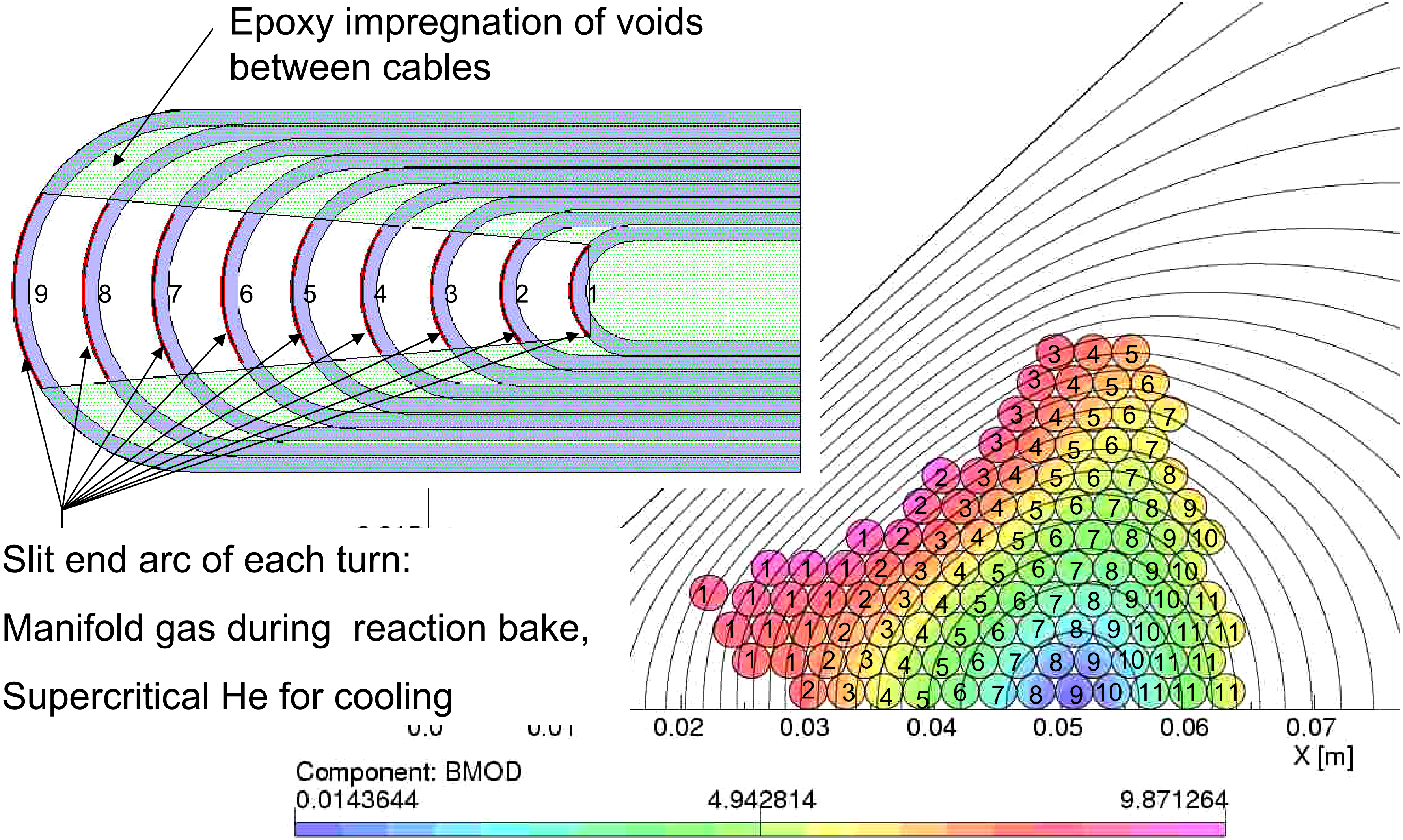
Ironless Quadrupole for Q_1



340 T/m **48 mm aperture**

4.5 - 6 K supercritical cooling

Cooling channels provide manifolds for parallel He flow through coil



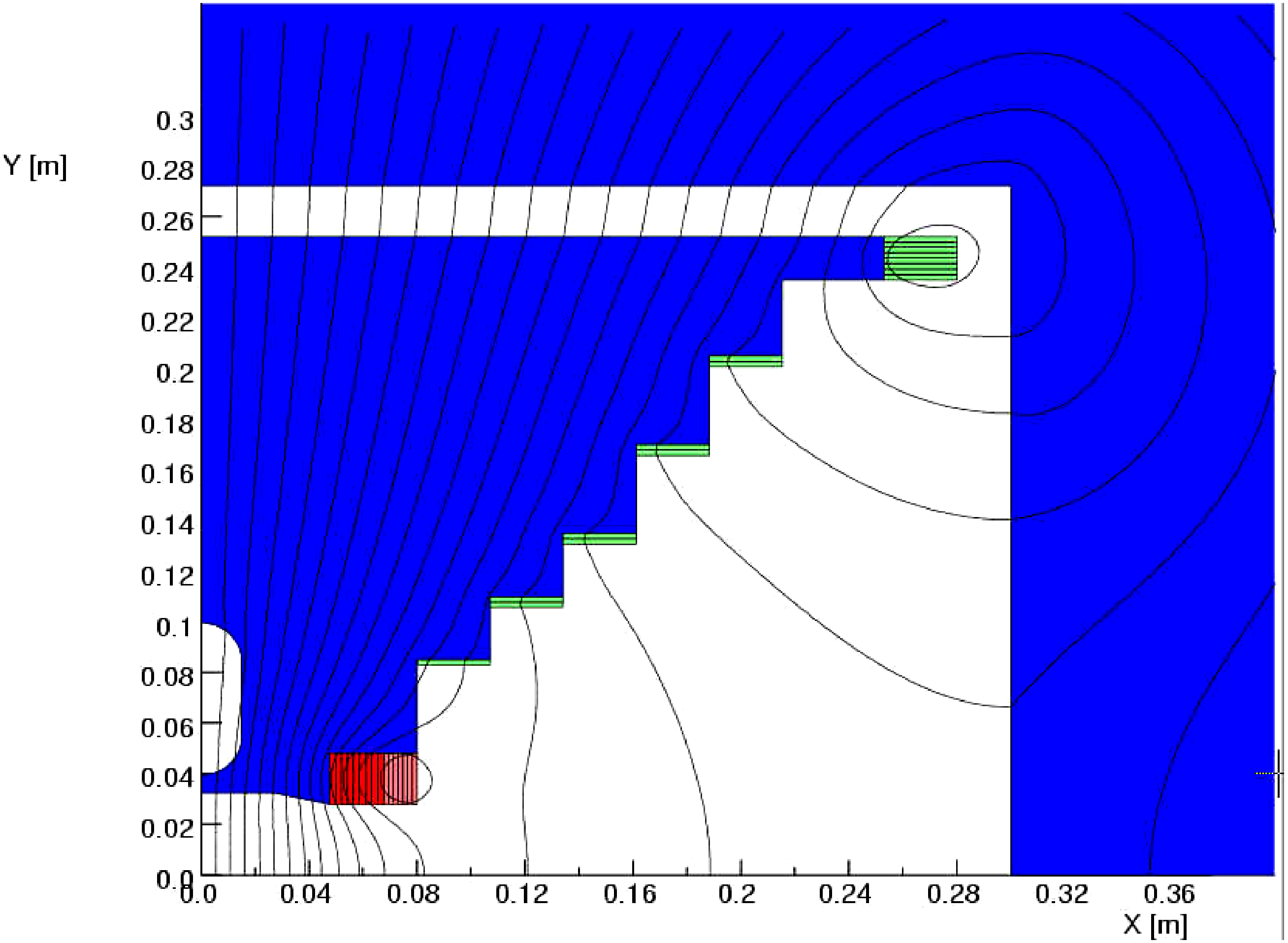
Epoxy impregnation of voids between cables

Slit end arc of each turn:

Manifold gas during reaction bake,

Supercritical He for cooling

Latest design: 9 Tesla @ 4.5 K



All windings are racetracks.

Only pole tip winding is Nb_3Sn.

All others are NbTi.

Support each pole piece using tension struts (low heat load).

56 mm clear aperture

Potential impact of novel magnet technology for IR elements, Peter McIntyre

- Designs have been suggested for novel magnet technology to mitigate limitations from heat deposition and radiation damage from deposition of secondary particles in the quadrupole triplet and separation dipole. One example is an ironless quadrupole using structured-cable Nb3Sn conductor, which could provide 390 T/m gradient at a location as close as 12 m from the IP, and compatibility with supercritical helium flowing throughout the coils. A second example is a 9 T levitated-pole dipole for D1, which would open the transverse geometry so that secondaries are swept into a room-temperature flux return.
- In order to evaluate the potential benefit of these concepts it is necessary to model the heat deposition and radiation damage in the more compact geometries, and to examine potential interference with the performance of the detectors.
- Of particular importance is to undertake a consistent examination of the impact of reducing $\ell*$ on the ensemble of issues that impact achievable $\beta*$ the interface of the IR with the machine lattice (chromaticity and dispersion, multipole errors, orbit errors, etc.), and the strategy for accommodating long-range beam-beam effects.
- Also of interest is to evaluate the pros and cons of the alternatives for operating temperature (superfluid, two-phase, or supercritical cooling) for the IR elements that must operate with substantial heat loads.

Thank you all for the excellent work done during these two days!