Final doublet optimisation

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Small crossing angle layout workshop
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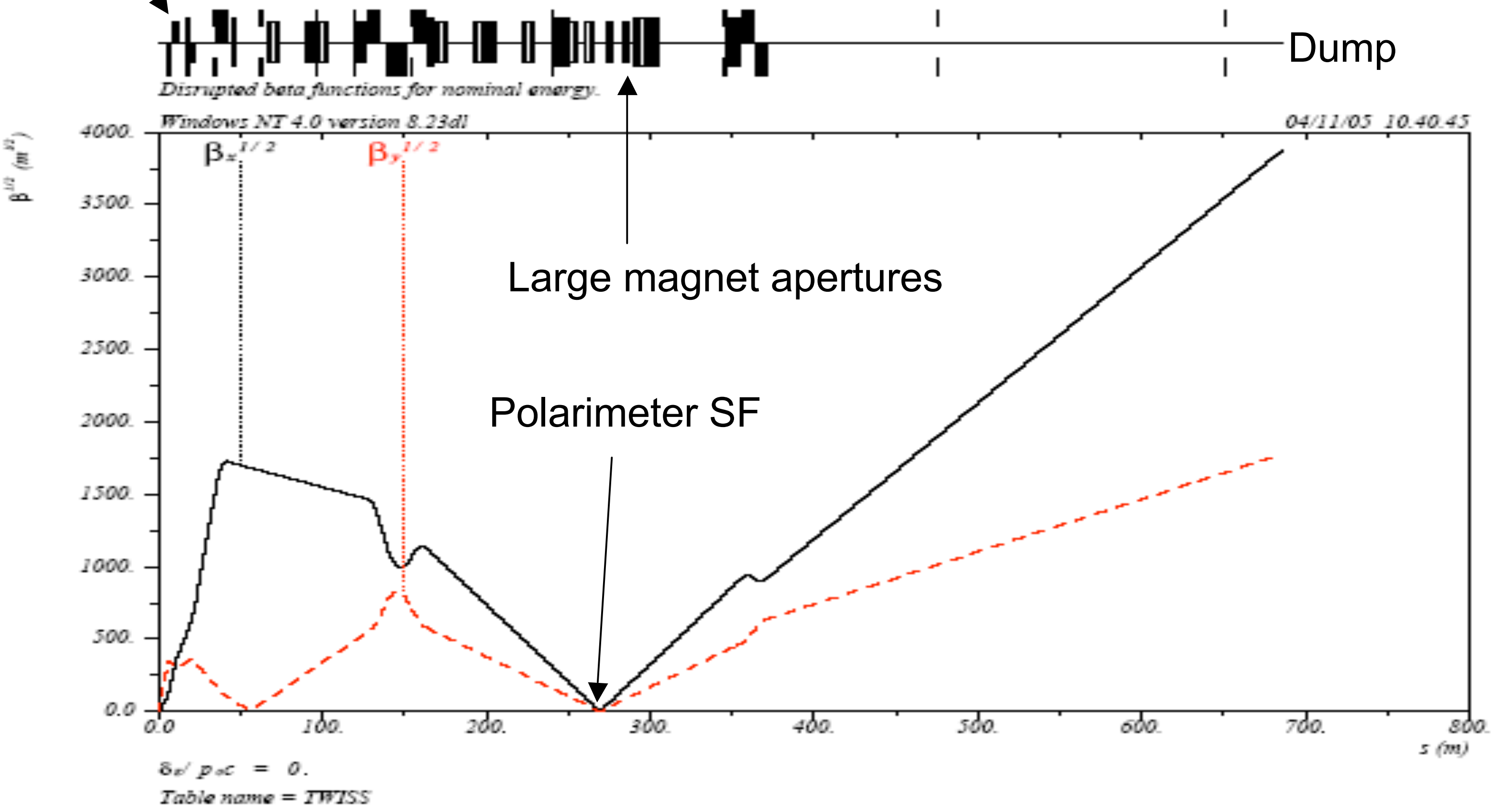
Executive summary

- Redesign of final doublet region of small crossing angle scheme using
  - NbTi SC magnets with g=180 T/m
  - Nb_3Sn SC magnets with g=250 T/m
- This was achieved with an optimisation algorithm
  - Perfect for QD0
  - An approximation for the sextupoles
  - Assumptions made on magnet behaviour
- Result is three new FD layouts
- Appleby and Bambade EuroTeV report 2006-022
- But we need to do better

Motivation + introduction

- The first complete optics for the 2mrad scheme was presented at Snowmass ’05.
- This lattice, designed for 1 TeV, was not completely optimised, both in the final doublet and downstream regions.
  - Apertures of magnets fitted to beam, and very large
  - Beam losses very high
  - Magnet size and sophistication gives high cost and power consumption - magnets are expensive and untenable
  - Furthermore, the extraction line is long (equals cost)
- This work - use realistic magnets, at 2 gradients, to reoptimise doublet region…aims:
  - effective beam (CB and RB) transport
  - explicit optimisation for E=500 GeV
  - how strong must the magnets be to work for all parameter sets
- \+ work done on QD0 Tungsten liners

Status of the 2mrad line



Large power losses

Dump

Large magnet apertures

Polarimeter SF

  - downstream diagnostics
  - Collimators and optics for beam blow-up
- FD region: large-bore SC sextupoles, QD0 with g=160 T/m

Snowmass final doublet losses (All powers in W)

	Beam	QD0	SD0	QF1	SF1
500 GeV	Low P (cb)	7.6	0	0	470
	Low P (rb)	0.39	0	0	0.10
	High L (cb)	91.9	0	0	1400
	High L (rb)	0.97	0	0	0.25
1 TeV	Low P (cb)	756	0	7.6	95.4
	Low P (rb)	1.2	0	0	0.34
	High L (cb)	8431	0	190	878
	High L (rb)	3.6	0	0.1	0.92

cb=charged beam losses   rb=radiative bhabha losses

New magnet technology

- Re-optimisations will exploit higher gradients of new SC magnets
  - **NbTi**, this is achievable now with gradients up to 180 T/m. Good for a safe baseline
  - **Nb_3Sn**, under R+D, with gradients up to 250 T/m. Good for upgrade…or even for baseline?

- Take these two as representative of what is achievable now, and later

Optimisation techniques

- Figure of merit: combined charged beam and radiative Bhabhas losses, including IP offsets and over all parameter sets.
- Assumed constant QD0 pole-tip field and no variation of sextupole field with aperture
- Optimisation algorithm (in brief)
  - Exploit maximum QD0 gradient, and fit QF1 to maintain final telescope demagnification
  - Correct chromaticity by zeroing 2nd order transfer matrix terms across final doublet
    - Fit to T166 and T345 to ensure correspondence to complete final focus optics fit
  - Scan magnet (k, l, a) space for global FoM minimum

NbTi 500 GeV machine doublet

- The optimised machine parameters for 500 GeV CoM give a much shorter QD0. The beam power losses are then (in W):

Beam	QD0	SD0	QF1	SF1
Low P (cb)	0	0	0	0
Low P (rb)	0.05	0.1	0	0
High L (cb)	0	4.1	11.6	0
High L (rb)	0.13	0.25	0.13	0

Nb_3Sn 1 TeV machine doublet

- The optimised machine parameters for 1 TeV CoM, with Nb_3Sn technology give losses (in W)

Beam	QD0	SD0	QF1	SF1
Low P (cb)	17.7	0	34	21
Low P (rb)	0.37	0	0.18	0.11
High L (cb)	277	81	161	256
High L (rb)	1.10	0	0.82	0.33

Also done for NbTi at 1 TeV, but not shown here

NbTi 500 GeV magnet parameters

Name	Length [m]	Strength	Radial aperture [mm]	Gradient [T/m]	Pole-tip field [T]
QD0	1.23	-0.1940 m^{-1}	39	162	6.3
SD0	2.5	1.1166 m^{-2}	76	-	2.69
QF1	1.0	0.0815 m^{-1}	15	70	1.02
SF1	2.5	-0.2731 m^{-2}	151	-	2.59

Nb_3Sn 1 TeV magnet parameters

Name	Length [m]	Strength	Radial aperture [mm]	Gradient [T/m]	Pole-tip field [T]
QD0	2.0	-0.12 m^{-1}	44	200	8.8
SD0	3.8	0.6454 m^{-2}	95	-	4.87
QF1	2.0	0.0407 m^{-1}	15	68	1.02
SF1	3.8	-0.1689 m^{-2}	163	-	3.74

Integration and upgrade

- The new final doublets need to be integrated into the rest of the design
  - The downstream extraction line diagnostics (partially done)
  - The final focus (not done)
- The resulting extraction line optics do not display satisfactory properties at the present time

- Need to worry about the upgrade – should we maintain fixed extraction geometry? This means maintaining R22 across all final doublets

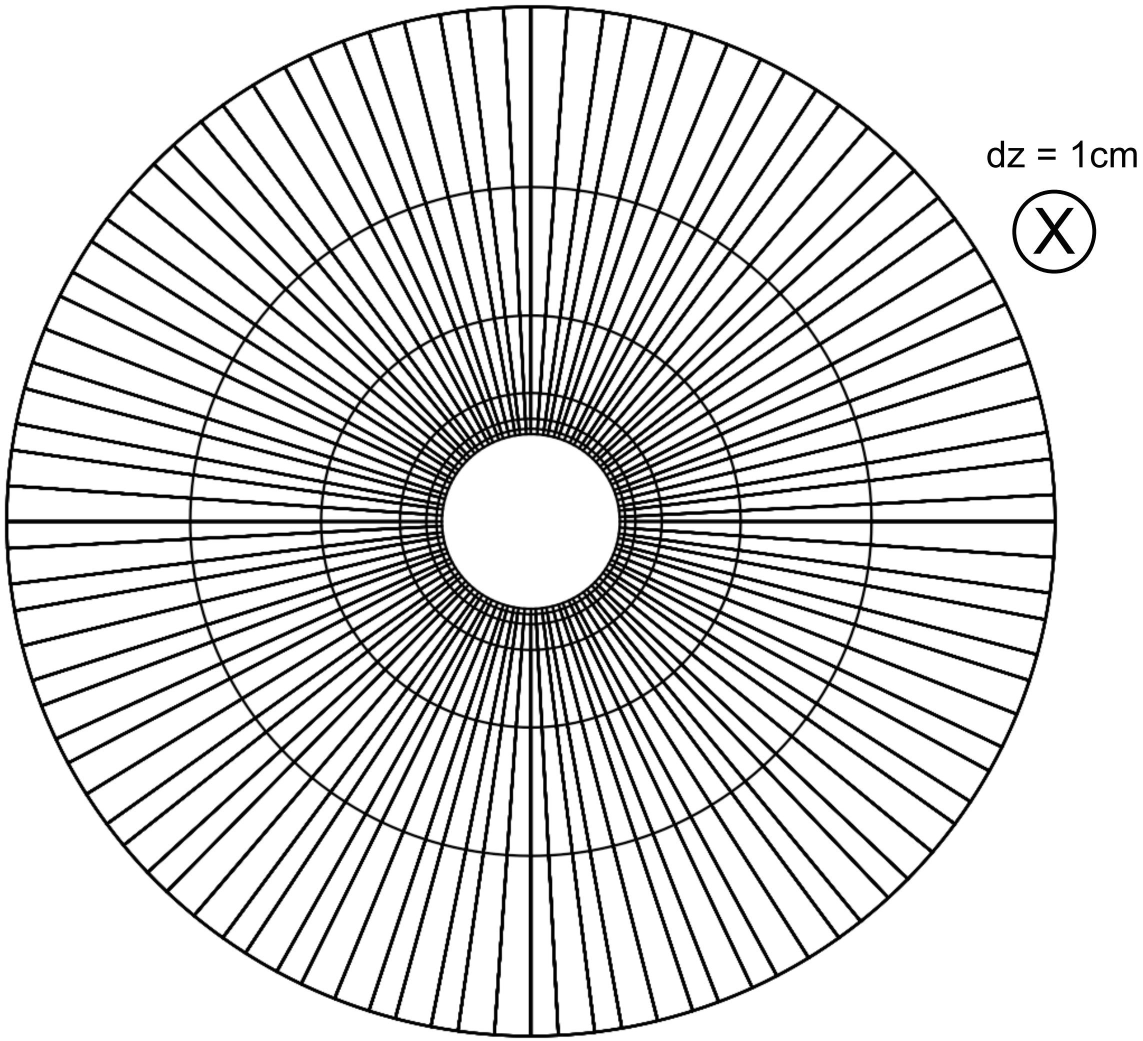
- So, new doublet regions now exist for NbTi at both 500 GeV and at 1 TeV, and for Nb_3Sn at 1 TeV.

What matters is the localised power deposition….

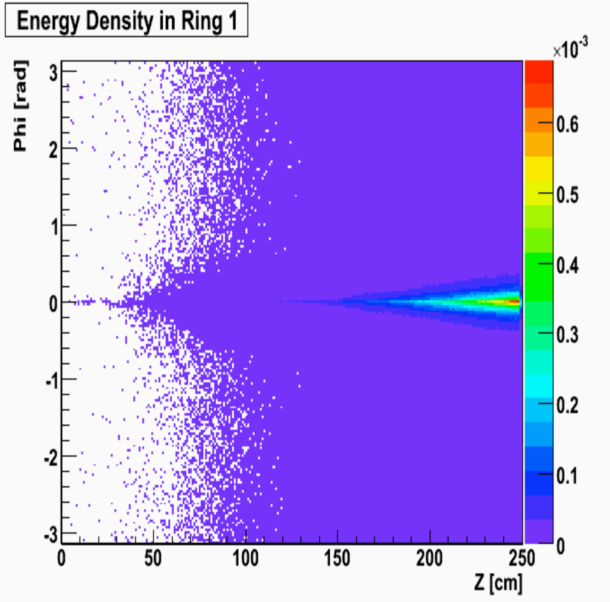
2mrad Losses - Scoring of QD0

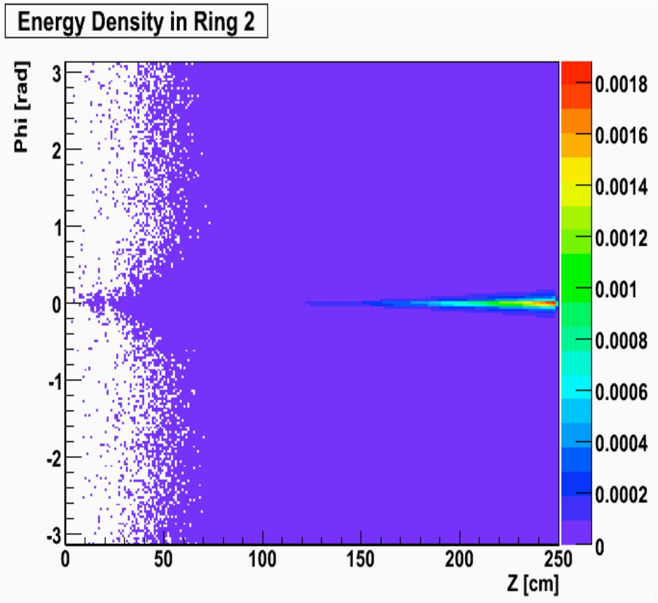
- Ring 1: 200 segments
  3.4 < ~R < 3.5 cm
  Material: Aluminium
- Ring 2: 200 segments
  3.5 < ~R < 4 cm
  Material: NbTi
- Ring 3: 200 segments
  4 < ~R < 5 cm
  Material: NbTi
- Ring 4: 200 segments
  5 < ~R < 8 cm
  Material: NbTi
- Ring 5: 200 segments
  8 < ~R < 13 cm
  Material: NbTi
- Ring 6: 200 segments
  13 < ~R < 20 cm
  Material: NbTi

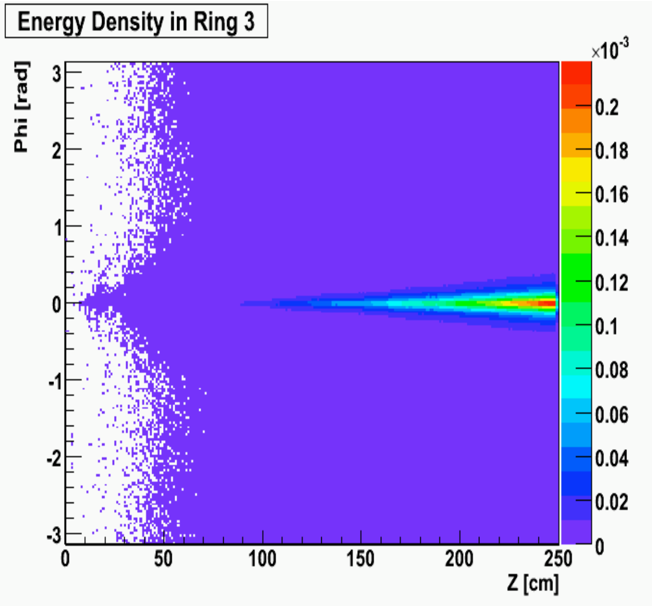
(QD0 Scored into 300000 volumes)



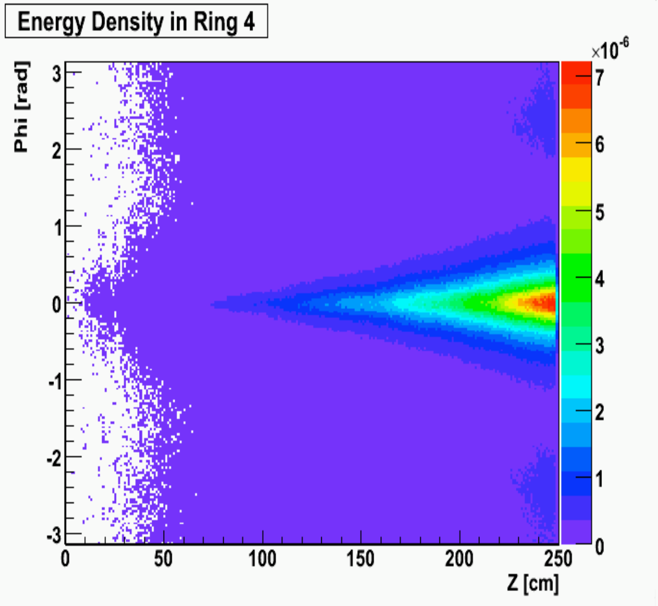
2mrad Losses - QD0 Power Density Maps for 250 GeV beam nominal parameters

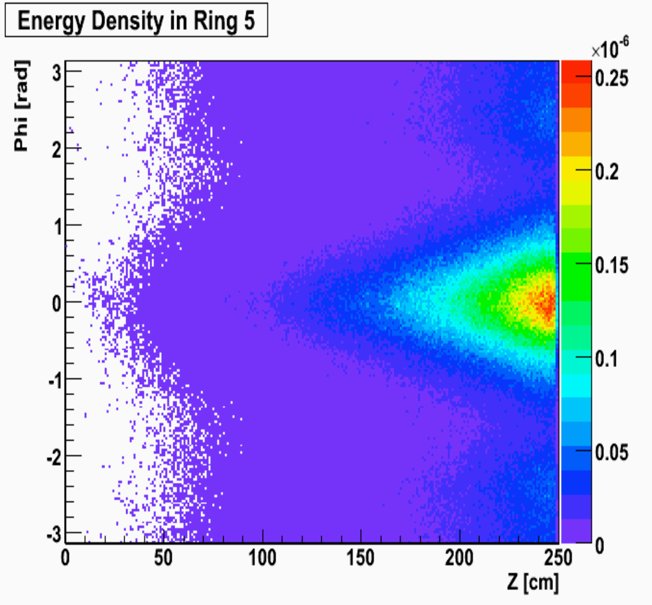






- Power density maps for the first 5 rings (6th ring had no deposits)
- All density units in W/g



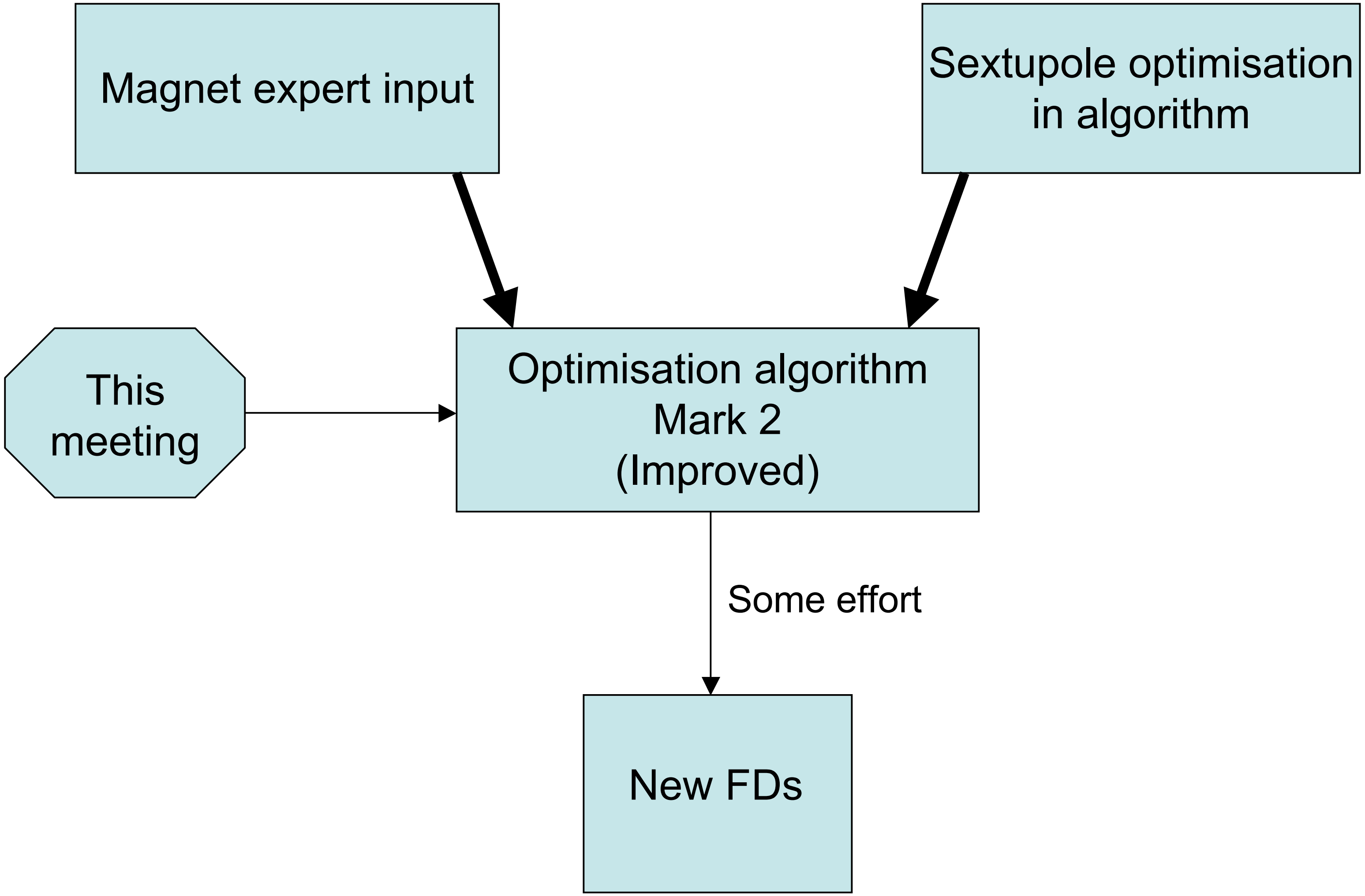


2mrad Losses - Radiative Bhabhas into QD0 (using SiD Solenoid Field)

- Tracking in BDSIM with shower development to give energy deposition
- Assumed Coil is 100% NbTi with density 5.6g/cm^3 @ 4Kelvin from R=35mm to 200mm (i.e. no support structure or gaps between 4 coils, etc. accounted for).
- Using Tungsten liner with 3mm thickness (~1 radiation length), density = 19.3g/cm^3
- Total energy deposits recorded per segment with showers tracked down to 10KeV (charged and neutral)

		Total Extracted Power [W]	Total Incident Power [W]	Total Power deposited in beampipe & Coils R<20cm [W]	Peak Power Density in Beampipe [mW/g]	Peak Power Density in NbTi Coils [mW/g]
cs11	No Liner	70.498	0.45 ± 0.01	0.27 ± 0.01	0.71 ± 0.03	1.90 ± 0.07
	Tungsten Liner		0.61 ± 0.02	0.13 ± 0.004	0.26 ± 0.01	0.11 ± 0.01
cs15	No Liner	161.37	1.07 ± 0.09	0.60 ± 0.05	1.60 ± 0.15	4.27 ± 0.41
	Tungsten Liner		1.44 ± 0.12	0.32 ± 0.03	0.61 ± 0.05	0.27 ± 0.02
cs21	No Liner	179.12	1.12 ± 0.07	0.65 ± 0.04	1.35 ± 0.08	4.11 ± 0.23
	Tungsten Liner		1.49 ± 0.09	0.34 ± 0.02	0.67 ± 0.04	0.30 ± 0.02
cs25	No Liner	483.03	3.61 ± 0.31	2.08 ± 0.18	4.41 ± 0.38	13.7 ± 1.2
	Tungsten Liner		4.95 ± 0.43	0.69 ± 0.07	1.40 ± 0.15	0.62 ± 0.07

Improved optimisation



Magnet expert input

Sextupole optimisation in algorithm

This meeting

Optimisation algorithm Mark 2 (Improved)

Some effort

New FDs

(with optimised quadrupoles and sextupoles)

Magnet questions

- We need input and advice from experts
  - We assumed the quadrupole pole-tip field stays constant with changing aperture. Is this correct? Should we think in terms of gradient and not pole-tip field?
  - How does the sextupole field scale with aperture?
  - Is flux jumping an issue?
  - What is the maximum tolerable power deposition for the quadrupoles and the sextupoles, for NbTi and for Nb_3Sn SC materials?

Summary

- The charged beam and radiative Bhabhas losses are large in the final doublet region of the current 2mrad layout.
- By exploiting new magnet materials with a higher gradient, these losses can be controlled
- We have presented three new doublet layouts for the 2mrad scheme
  - NbTi QD0, explicitly optimised for 500 GeV CoM
  - NbTi QD0, explicitly optimised for 1 TeV CoM
  - Nb_3Sn, explicitly optimised for 1 TeV Com
- We have also studying what magnetic gradients are required to make the 2mrad work for all parameter sets
- The localised power deposition in QD0 can be controlled using Tungsten liners.
- See EuroTeV report 2006-022
- Now the algorithm needs to be improved
  - Include sextupoles in optimisation
  - Input from magnet experts