Muon Collider Design Status

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From Jean-Pierre's talk yesterday:

- We don't know yet if Fundamental Aspects of Muon Beams will/won't be approved in FY16 GARD
- FY15 considered as a transition year to:
  - finish key D&S activities begun in MAP, including initial studies of the most important concepts
  - document our results in publications
  - establish lasting record of our designs
    - Preserve the knowledge and work already done
    - Facilitate revival when the physics will call for it:
      - neutrinos factory (?) post LBNF
      - muon collider in the multi-TeV range (?) for new physics beyond standard model
  - make transition away from facility design and toward fundamental aspects of muon beams assuming future GARD support and funding

Accomplishments

Concepts developed in the course of work on HF, 1.5TeV and 3TeV MC:

- 3-sextupole chromaticity correction scheme
- Quadruplet Final Focus (not implemented in the chronologically first 1.5TeV design)
- New Flexible Momentum Compaction arccell design (High Energy MC)
- β*-tuning section with a chicane (for $E_{com} \geq$ 3TeV)

- Dipole component in IR quad is proven to reduce backgrounds
- Nozzle, cone, masks optimization Backgrounds in 1.5TeV MC (and in HF?) on par with LHC
- Classical cos-theta dipole with inner absorbers found superior to open-midplane
- Magnet studies for 0.125, 1.5 and 3 TeV MC are almost complete, apertures as large as 0.5m do not pose a problem
- Optimum configuration for combine-function magnets – a nested Quadrupole/Dipole magnet – found

Design Parameters

Muon Collider parameters				
Collision energy, TeV	0.126	1.5	3.0	6.0*
Repetition rate, Hz	30	15	12	6
Average luminosity / IP, 10^{34}/cm^2/s	0.0025	1.25	4.6	13
Number of IPs	1	2	2	2
Circumference, km	0.3	2.5	4.34	6
β^*, cm	2.5	1	0.5	0.25
Momentum compaction factor	0.08	$-1.3\cdot10^{-5}$	$-0.9\cdot10^{-5}$	$-0.5\cdot10^{-5}$
Normalized emittance, π·mm·mrad	300	25	25	25
Momentum spread, %	0.003	0.1	0.1	0.1
Bunch length, cm	5.6	1	0.5	0.25
Number of muons / bunch, 10^{12}	2	2	2	2
Number of bunches / beam	1	1	1	1
Beam-beam parameter / IP	0.007	0.09	0.09	0.09
RF frequency, GHz	0.2	1.3	1.3	1.3
RF voltage, MV	0.1	12	85	530
Proton driver power (MW)	4	4	4	2

*requires stronger magnets to keep *L~E^2*
First design attempt made by M.-H. Wang (SLAC),

Collider Ring D&S Work in the New Era

Let us hope that the "Fundamental Aspects of Muon Beams" will be approved, and the collider effort will find its place there.

The following questions – left unanswered by previous studies but of general interest - can be addressed:

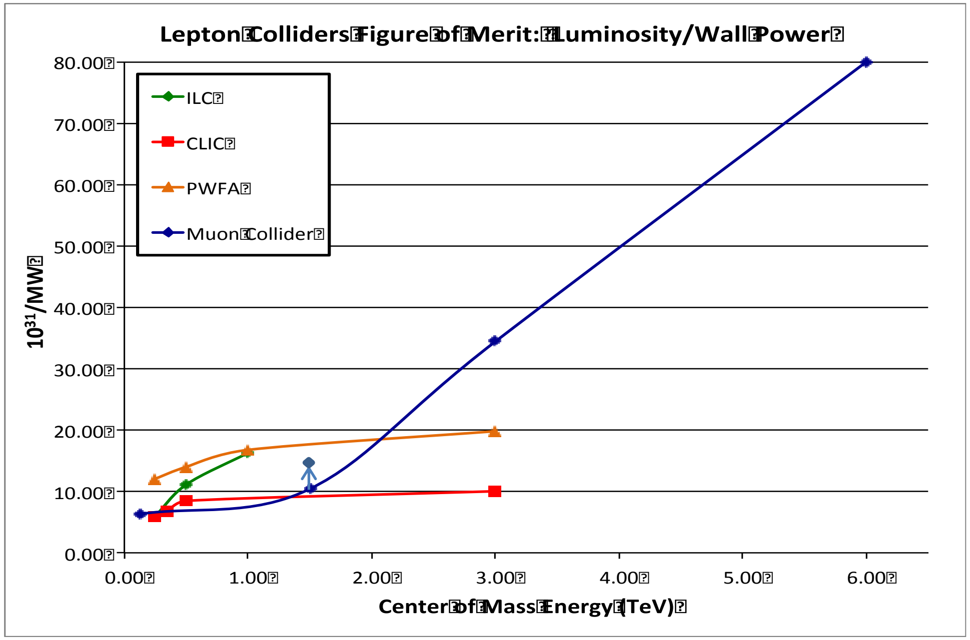
- Design of new types of lattices, e.g. for beams with large $\varepsilon_y/\varepsilon_x$ ratio as discussed by Dave (may help to spread decay neutrinos)
- Studies of different chromaticity correction schemes (e.g. return to classical 4-sextupole scheme - talk by M.-H. Wang)
- Simulation of beam-beam effect and coherent instabilities (can we afford higher beam-beam tuneshifts with large aspect ratio?)
- Study of the effects of random field errors and misalignments, simulation of their correction – very important to understand how to handle very high βmax
- Collimation (halo extraction) - the hope is that with pre-collimated beam bent crystals will be enough

But the most important is work on

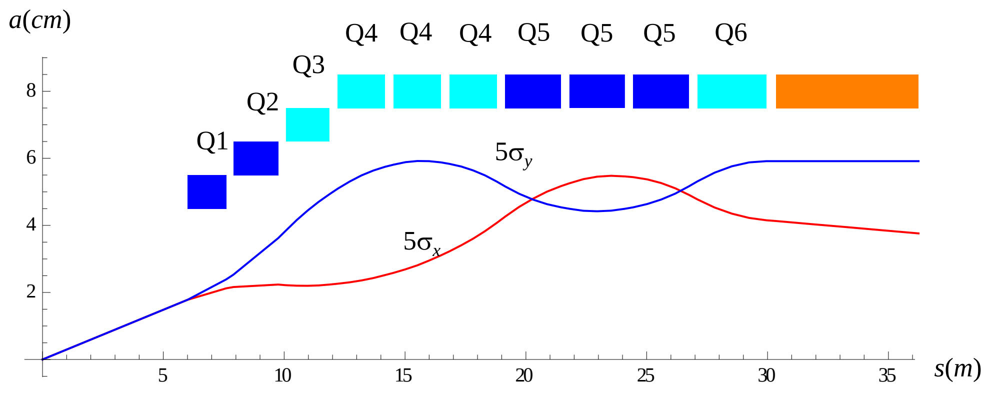
- Magnet design (can we count 15T in quads and 20T in dipoles?)
- MDI and background mitigation (includes code development)
- Heat load management

What to Focus on?

- The $\mu^+\mu^-$ is unlikely to revive (unless there will be evidence of something hidden inside the peak) – abandon for now.
- There is a good chance that LHC will find something beyond the SM (e.g. supersymmetric Higgs, Z' etc.). So we have to be ready with a few TeV MC design – let us concentrate on the 3TeV case.
- At the same time – as Bob pointed out - MC is a competitive discovery machine, so let us develop a higher energy concept (6TeV?)



3TeV IR with Quadruplet FF



5 sigma beam sizes and magnet inner radii

Quad inner radii satisfy requirement

$$R > 5\,\sigma_{max} + 2\text{ cm}$$

which guarantees that the beam will be in a good field region and provides enough space for absorber.

The maximum pole tip field was increased up to 12 T. If this is not feasible, the apertures can be reduced: we do not need 5σ for the beam scraped at 3σ.

	Q1	Q2	Q3	Q4	Q5	Q6
aperture (mm)	90	110	130	150	150	150
G (T/m)	267	218	-154	-133	129	-128
B_0 (T)	0	0	2	2	0	2
$B_{pole\ tip}$ (T)	12.0	12.0	12.0	12.0	9.7	11.6
length (m)	1.6	1.85	1.8	1.96	2.3	2.85

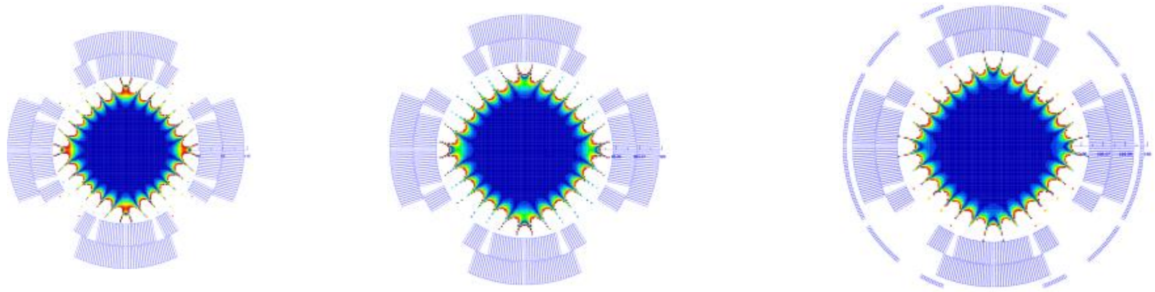
Parameters of the Final Focus quadrupoles

Maximum magnet aperture is noticeably reduced – 150mm vs 180mm – compared to the previous design based on a triplet FF and 10T pole tip field .

A drawback of the quadruplet FF: high βx in IR dipoles

IR Magnet Design

Design performed for a previous version of 3TeV MC with triplet FF (but it does not matter much)

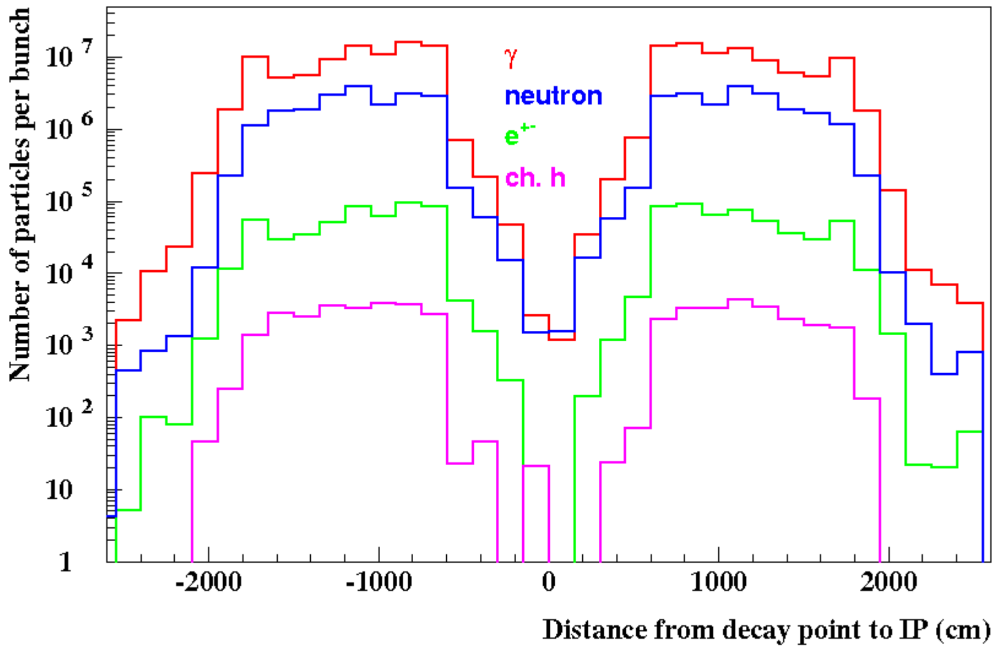


Parameter	Q1	Q2	Q3	Q4-6	Q7	Q8-9
Aperture (mm)	80	100	125	140	160	180
B_{max} coil (T)	14.1	14.3	14.5	14.7	14.8	15.2
G_{max} (T/m)	308	249	202	182	161	127
G_{op} (T/m)	250	200	161	144	125	90
G_{op}/ G_{max}	0.81	0.80	0.80	0.79	0.78	0.71
L (mH/m)	2.42	3.29	4.97	6.11	7.71	9.05
E at G_{op} (MJ/m)	0.66	0.81	1.05	1.19	1.37	1.07
F_x at G_{op} (MN/m)	2.14	2.21	2.50	2.68	2.81	3.32
F_y at G_{op} (MN/m)	2.71	2.81	3.11	3.23	3.36	2.44

There is ~20% margin at 4.5K, can be increased by going to 1.9K

No MDI design and detector background studies yet!

Background Source Tagging (1.5 TeV case)



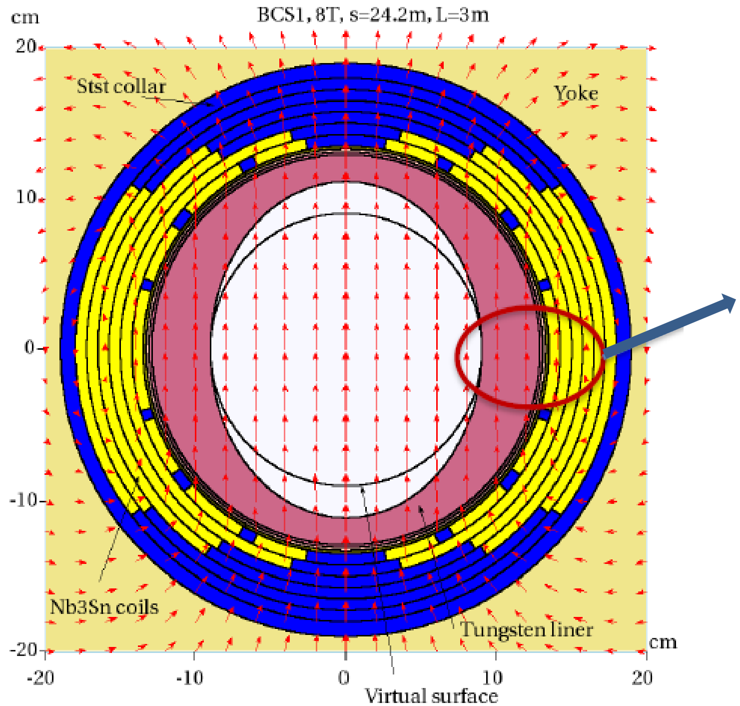
For BH muons the origin within ±100m

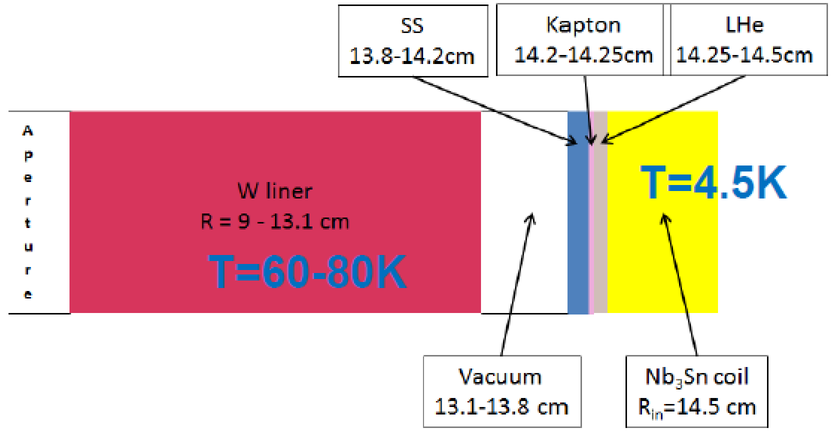
All background species (except BH muons) originate from region ±18m w/o strong dipole field (though there is 2T in defocusing quads).

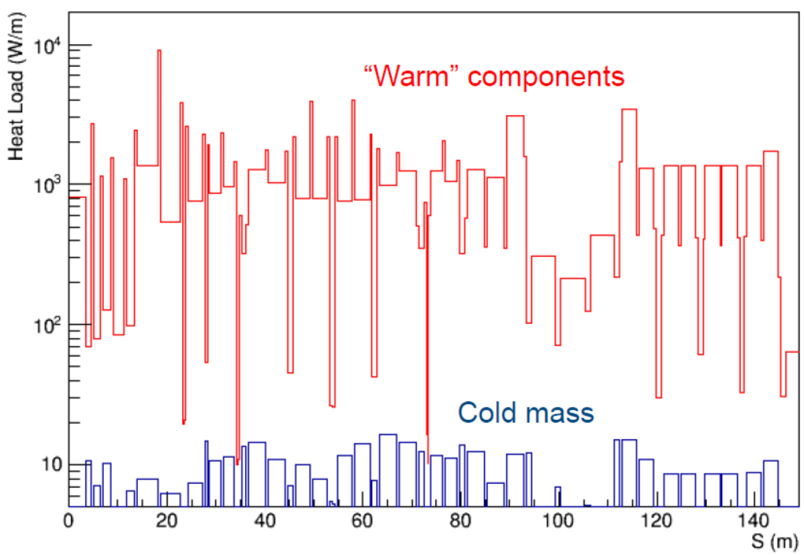
This result settles the discussion if a dipole field in the detector vicinity is a good or a bad thing – it is needed!

Is a 2T dipole field enough for 3TeV MC? The background studies will tell. _ Can be increased if necessary

Dynamic Heat Load (HF)

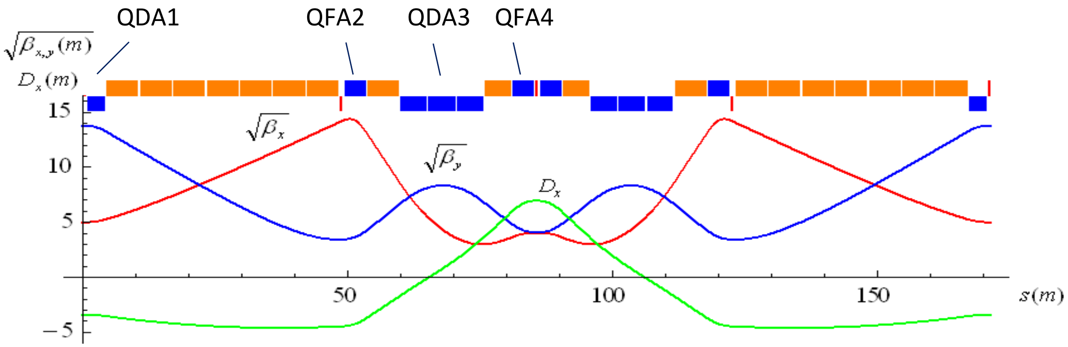






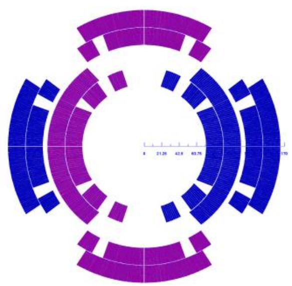
- Due to smaller circumference and higher muon flux the heat load in HF of ~1kW/m is twice higher than in high-energy MC
- A lot of W in a high energy machine. Is there a way to reduce it?

Combined Function Magnets for the Arcs

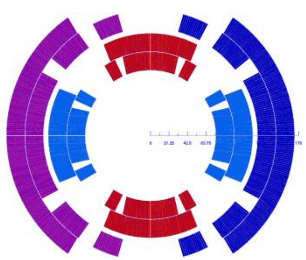


Motivation:

- Spread decay ν's
- Sweep away decay electrons before they depart from median plane – allows for azimuthally tapered absorber



Dipole/Quad



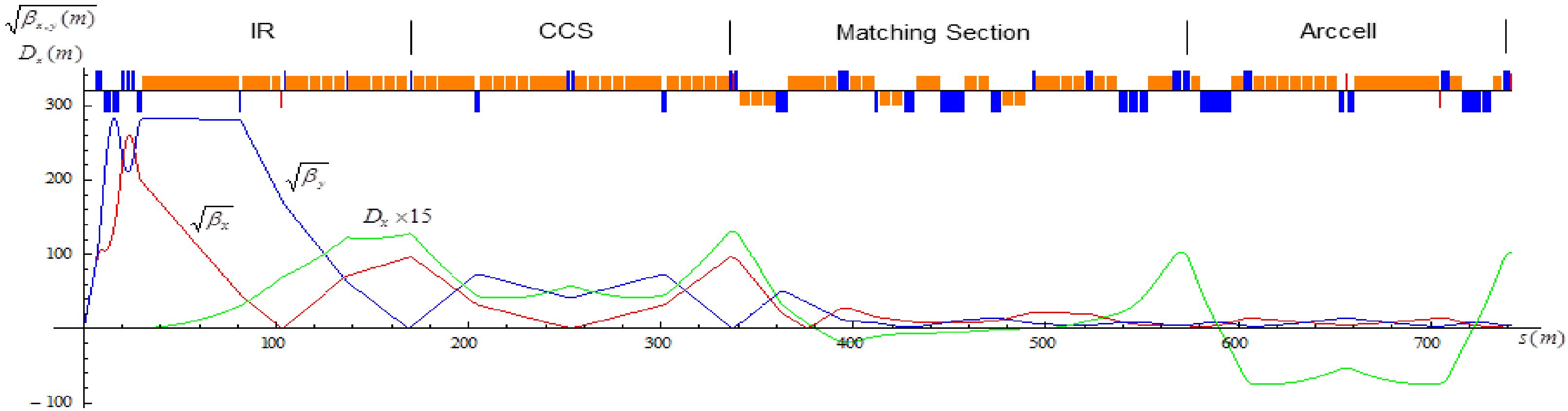
Quad/Dipole

Parameter (4.5K)	D/Q	Q/D	
	QDA1/3	QDA1/3	QFA2/4
Maximum field in coil (T)	16.8/16.7*	16.5/17.5	
Maximum field or gradient in aperture (T or T/m)	9.3/76.7	12.0/72.5	
Operating field or gradient (T or T/m)	9.0/35.0	9.0/35.0	8.0/85.0
Fraction of SSL at the operating field	0.75/0.61*	0.70/0.64	0.75/0.86
Inductance L_{self} (mH/m)	16.0/20.6*	44.2/6.9	
Stored energy E at the operating field (MJ/m)	1.5/0.5	2.9/0.1	2.3/0.6
Horizontal Lorentz force F_x at the operating field (MN/m)	7.7/-0.1#	7.2/2.2	6.1/5.5
Vertical Lorentz force F_y at the operating field (MN/m)	-4.5/-1.6	-4.0/-0.3	-4.5/-1.5
Length (m)	3.34/5.0	3.34/5.0	1.8/2.8
Aperture (mm)	150	150	150

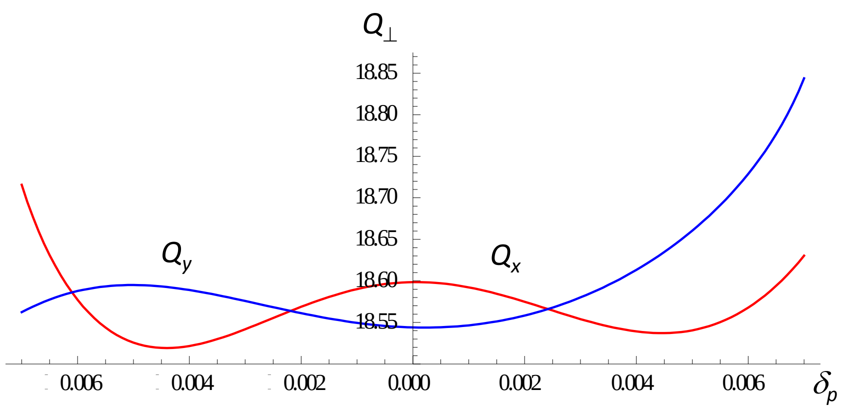
* the first value is for dipole coils, the second one is for quadrupole coils;
\# totals per quadrant in dipole and per octant in quadrupole.

- Quad/Dipole design appears superior
- Preliminary analysis shows heat deposition in coils < 1.5 mW/g with only 2cm thick absorbers. However a thicker absorber can be required to keep the heat load below 10W/m

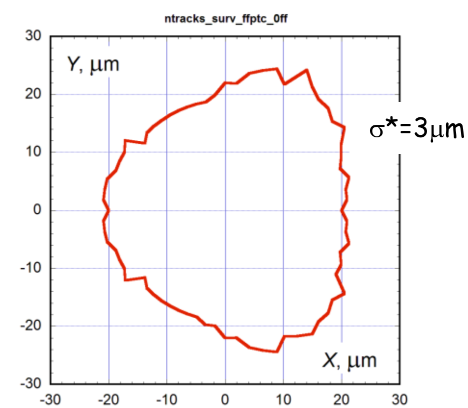
E_{com}=3TeV Collider Lattice Performance



Optics functions from IP to the end of the first arc cell (6 such cells / arc) for β*=5mm



The stable momentum range ±0.7%



The dynamic aperture w/o field errors ≈6σ.

Design Status

E_{com}(TeV)	Lattice design	Magnet design	Heat deposit.	MDI design	Magnet error corr.	Beam-beam & coherent
0.126	✓	✓	✓	✓	✓	✓
1.5	✓	✓	✓	✓	✓	✓
3.0	✓	✓	✓	–	–	–
6.0	–	–	–	–	–	–

If work on the 3TeV Muon Collider will be resumed:

- Improve β*-tuning section,
- design MDI, study backgrounds
- address beam collimation/halo extraction issue
- Study tolerances on random field errors and misalignments – of general importance for understanding the real constraints on beta-functions, momentum compaction factor etc.
- Try larger dipole component in IR quads to reduce backgrounds (if needed)
- Develop cryostat concept integrated with W absorbers and masks