First Considerations on Magnet Needs for the Muon Collider Ring

- Collider Ring Requirements
- Observations on the MAP 3 TeV c.o.m Proposal (version using quadruplet for focusing for small β)
  - General Properties
  - Neutrino Radiation
- First Ideas on further lattice Improvements (contributed by Kyriacos)
- On Magnet Requirements defined for MAP 3 TeV com Lattice
- Remarks
- Summary

Collider Ring Requirements

- Useful luminosity with available muons (large emittances and momentum spread) and their limited life-time
  - Small β^* and short bunches (hourglass effects!)
    - Large βs and beam sizes in inner focusing structure
    - Chromatic effects with large momentum spread
  - Short circumference (increase number of bunch encounters during life-time)
    - High magnetic fields
- Short bunch length (for one cycle lasting ~1000 turns)
- Neutrino radiation issue
    - E.g., only short straights between magnets acceptable
- Protection against heat deposition from muon decay products
  - No collimation foreseen!

Observations on the MAP 3 TeV c.o.m Proposal general Properties

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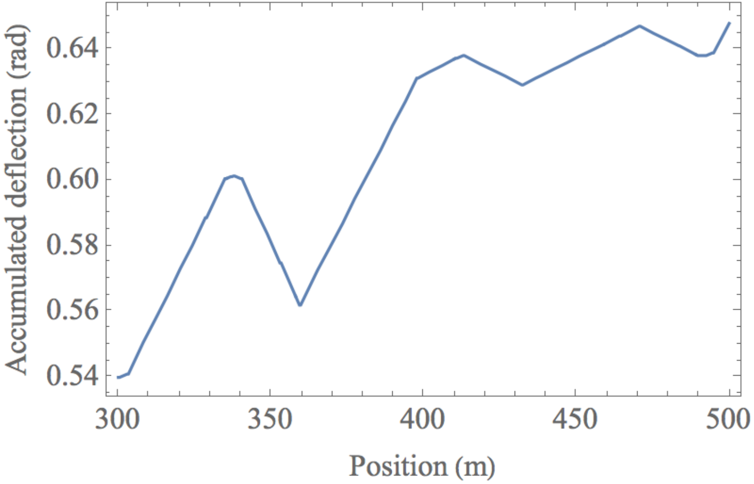
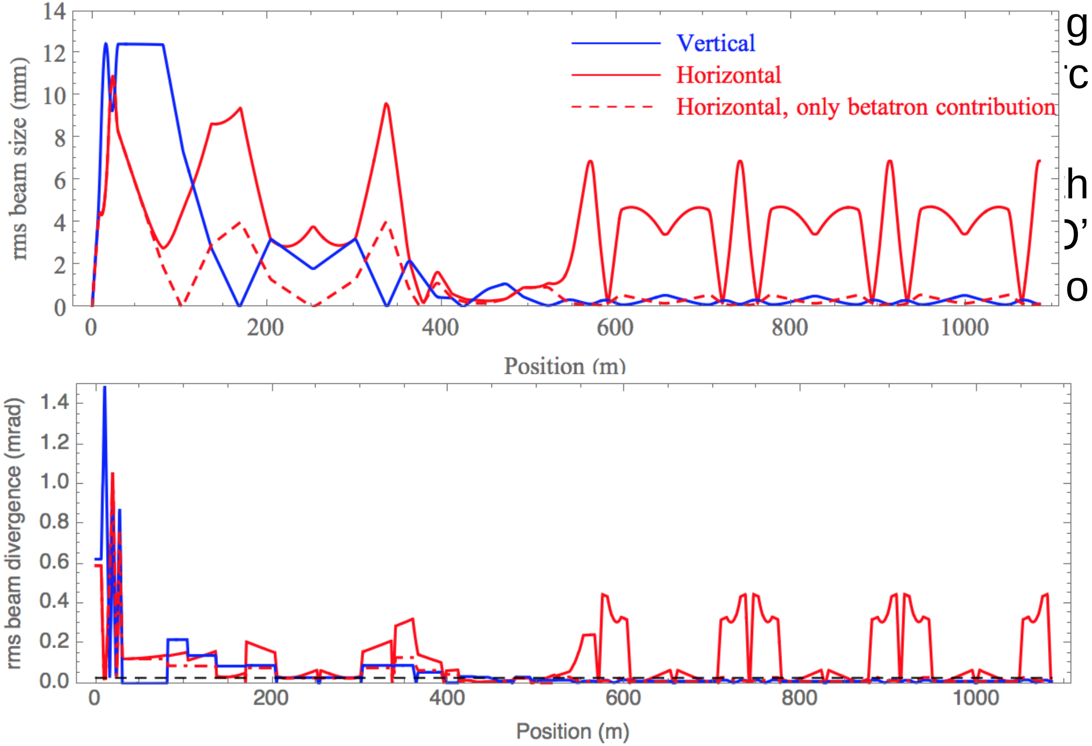
- Self consistent lattice for very working for very large momentum spread
- No straight lines for RF, injection …
- Matching sections with with opposite signs
  - Neutrino radiation from different bends add up
  - Circumference increase and lumi reduction
- Further improvements of MAP lattice possible?



- Assumptions for next slides:
  Beam Energy $E_m = 1.5\,\mathrm{TeV}$ (3 TeV c.o.m)
  $N_m = 2\times10^{12}$ muons per beam, $f_r = 12\,\mathrm{Hz}$ repetition rate
  $C = 4340\,\mathrm{m}$ circumference ($\bar{B} = 7.24\,\mathrm{T}$ $d = 100\,\mathrm{m}$) with depth
  Operated for 5000 h per year

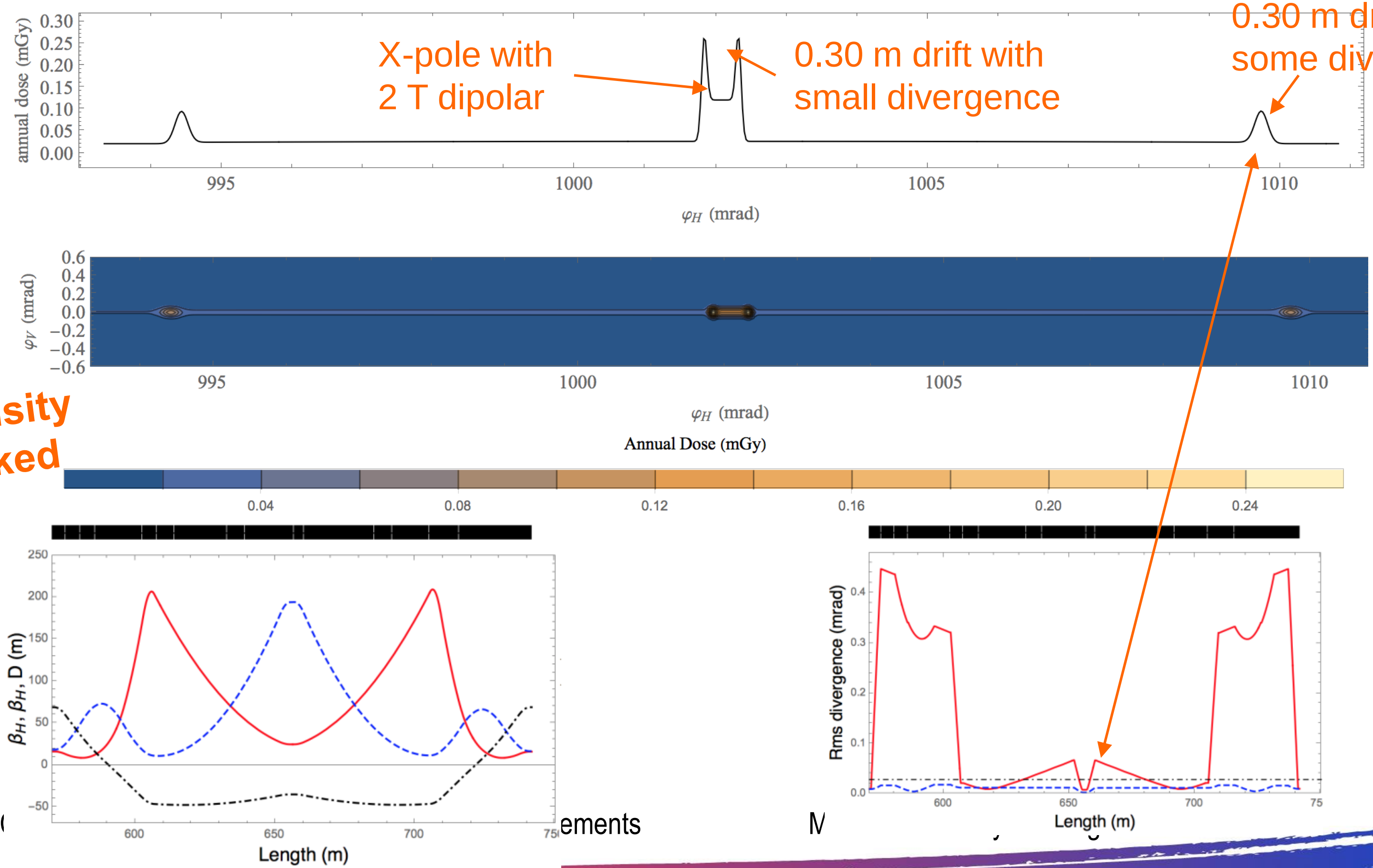
Observations on the MAP 3 TeV c.o.m Proposal
General Properties

- Large contribution from D and D’ to the horizontal beam width and divergence
  - Even g
    contribution c
  - Many h
    divergence ɔ’
    larger o
    radiation cone



Observations on the MAP 3 TeV c.o.m Proposal

Neutrino radiation around arc cell center



X-pole with
2 T dipolar

0.30 m drift with
small divergence

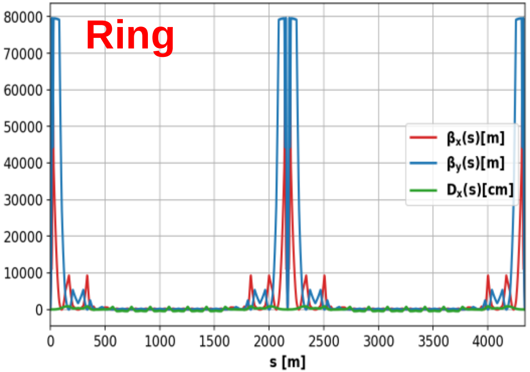
0.30 m drift with
some divergence

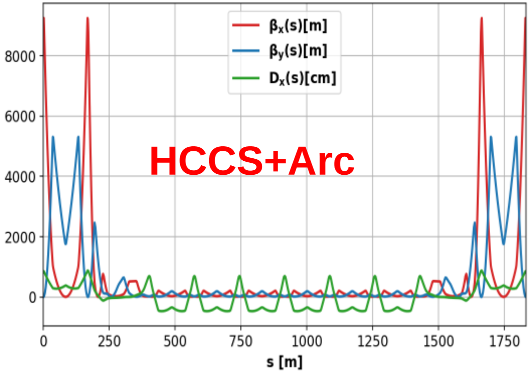
Beam intensity
to be checked

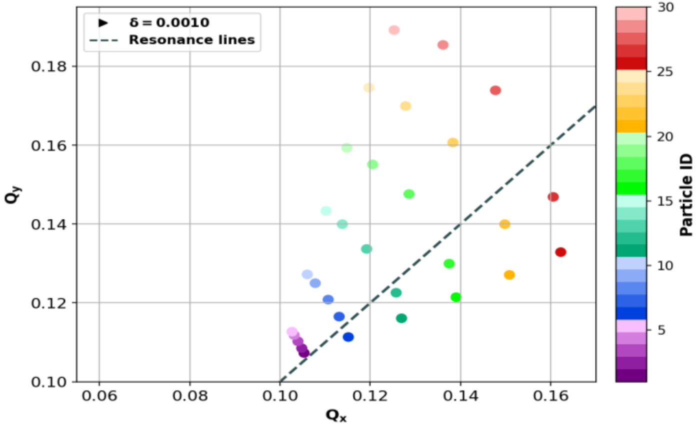
Slide from K. Skoufaris on further lattice optimizations

MAP 3TeV com Lattice

- Negative momentum compaction factor ≤ -10^{-5} with FMC arcs.
- 2T dipoles right after the IP for radiation issues
- Local compensation of Montague chromatic functions and the second order Dispersion at the IP with the HCCS right after the IR.
  - Include negative dipoles
  - Include multipole elements (with strong octupolar component) without reserving lattice sections
- Given the ~2000 turns for luminosty protaction, the observables used for studiying the particle dynamics are (only?) the DA simulations (without RF in the lattice)



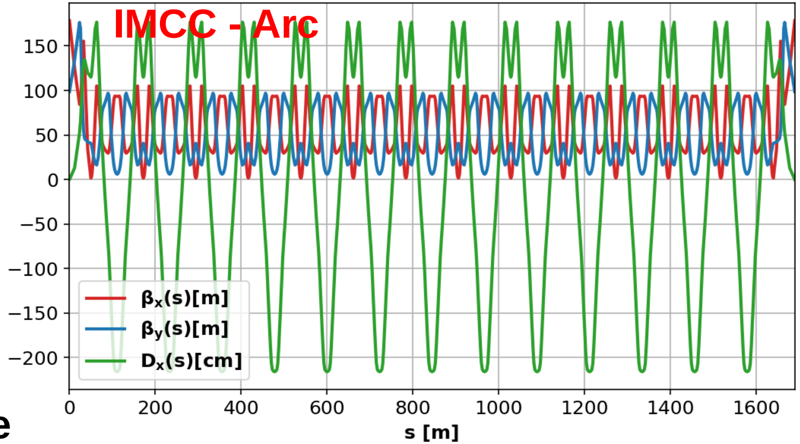


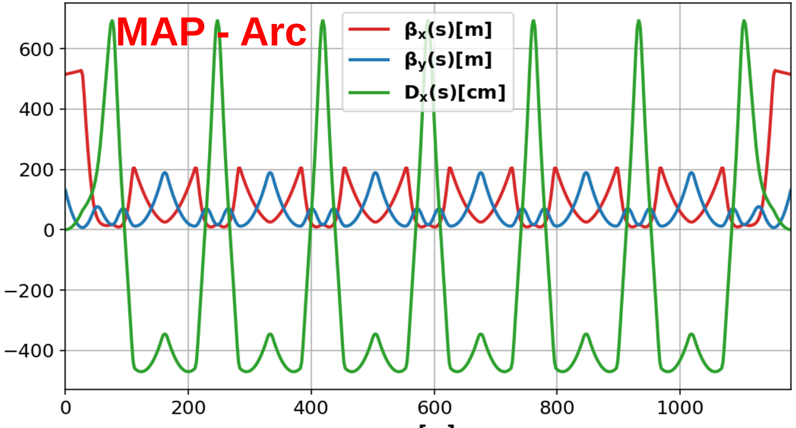


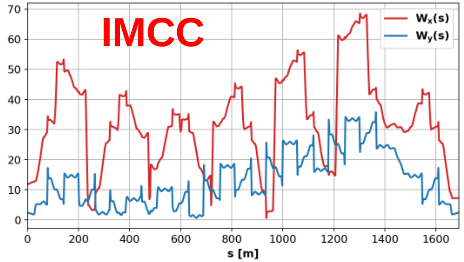
Slide from K. Skoufaris on further lattice optimizations

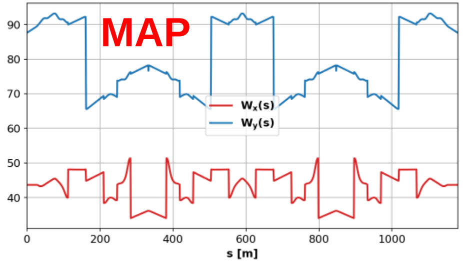
IMCC 3TeV com Lattice

- IMCC arc+disp:
  - maximum dipolar component (~10T) in all magnets for minimization of lattice length
  - arc+disp length equivalent to π rotation (racetrack lattice)
  - use of FMC arc cells (current version a_p=-10^{-6})
  - 3π/2 phase advance per arc cell for -I transform every second cell
  - zero linear chromatisity
  - redaction of the beta values and the Montague chromatic functions compared to MAP arc
  - possibility to use the arc for a remote mitigation of the chromatin functions at the IP









On Magnet Requirements defined for MAP 3 TeV com Lattice

Following
Y. Alexahin et al 2018 JINST13 P11002

- Assumption on required aperture (radius) 5 times rms beam size plus 10 mm (for vacuum chamber, absorbers ..)

$$5Max\left[\left(e_H b_H + (s_p/p)^2 D^2\right)^{1/2}, \left(e_V b_V\right)^{1/2}\right] + 10\,\mathrm{mm}$$

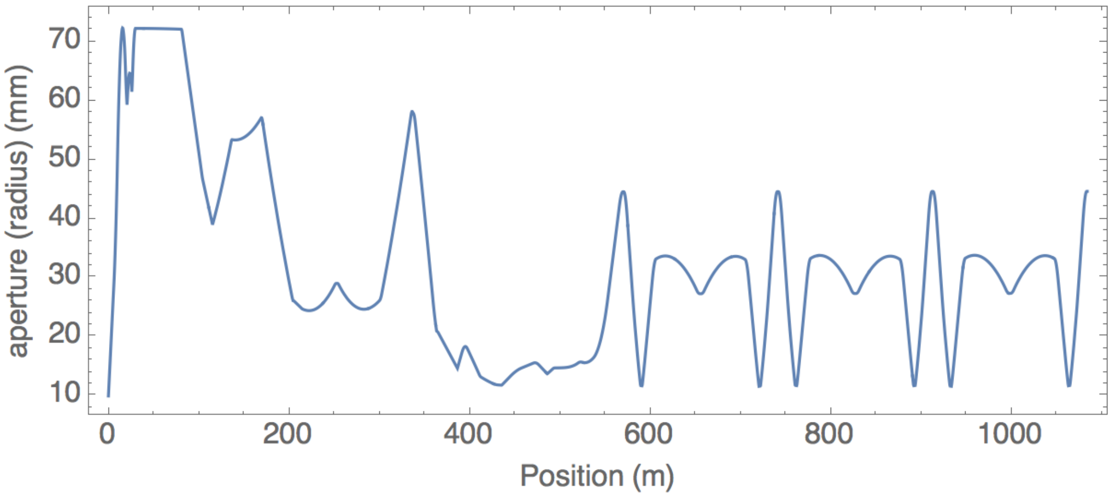
(10 mm for absorbers sufficient?)

- Physical rms emittance

$$e_H = e_V = 25\,m\mathrm{m}/14200 = 1.76\,\mathrm{nm}$$

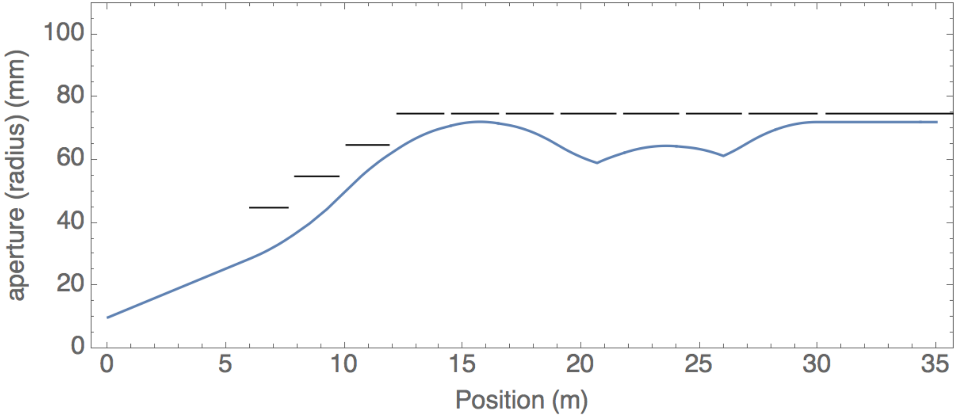
- Rms relative momentum spread

$$s_p/p = 10^{-3}$$



On Magnet Requirements defined for MAP 3 TeV com Lattice

- Around IP



Following
et al 2018 JINST13 P11002

Parameter	Q1	Q1	Q3	Q4	Q5	Q6	B1
Aperture (mm)	90	110	130	150	150	150	150
Gradients (T/m)	267	218	-154	-133.5	129	-128	0
Field (T)	0	0	2.00	2.00	2.00	2.00	6.86
Length (m)	1.60	1.85	1.8	1.96	2.30	2.85	5.90

Remarks

- Minimum distance between magnets (straights with 20 cm or 30 cm in lattice designs)
  - Details of magnetic field around magnet ends to be taken into account
- Field quality requirements
  - Very large (vertical) βs make machine sensitive, but beam has to survive only ~1000 turns
  - Higher order momentum compaction effects with large momentum spread?
- Straight sections for equipment (injection .. possibly no RF)
- Machine tuning with combined function magnets
  - Quads, sextupoles .. with dipolar component
  - Need to shift working point, adjust chromaticity (chromatic functions) …
  - Low β^* adjustment? Start with simple optics and gradually (from shot-to-shot) reduce β^*?
- Open mid-plane magnets?
- Possible further constraints from neutrino mitigation measures
  - Additional vertical aperture for time varying vertical closed orbit
  - “Wobbling” (time varying movements of whole machine and thus magnets) of machine

Summary

- Magnet requirements extrapolated from MAP 3 TeV com lattice
  - Qualitative description of needs
  - Details will depend on energy, technological choices made and collider design made
- High field magnets with large apertures
  - Combined functions magnets with large dipolar components
    - Independent adjustment of dipolar and other components for tuning?
  - Magnetic field around magnet ends an issue (field free regions as short as possible)
  - Geometry of combined function magnets (curved magnet such that dipolar field constant?)
  - Field quality requirements to be discussed, understood and defined
  - Open mid-plane magnets?
  - Likely further constraints from neutrino mitigation measures (aperture, “wobbling”)
- Definitive list of required magnets outcome of iterations between different work packages
  - Collider design, magnets, MDI, radiation protection (neutrino radiation), magnet protection ..

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Thank you for your attention