Neutrino Radiation Mitigation Measures from the Machine Side

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- Radiation due to Neutrinos neglecting Beam Divergence
- Radiation due to Neutrinos taking Beam Divergence and Lattice into account
- Application to 3 TeV c.o.m Lattice from MAP study
  - General observations on MAP lattice
  - Radiation from center of arc cell
  - Radiation from Region around IP
- Summary and Outlook

Radiation due to Neutrinos
neglecting beam divergence

Based on:
B.J. King, arXiv:physics/9908017
Aim: reproduce results and extend to
such that realistic lattice can be used

Note: B. King gives results in effective dose D_a in Sv assuming $D_a = (1\,\mathrm{Sv/Gy})\,H$

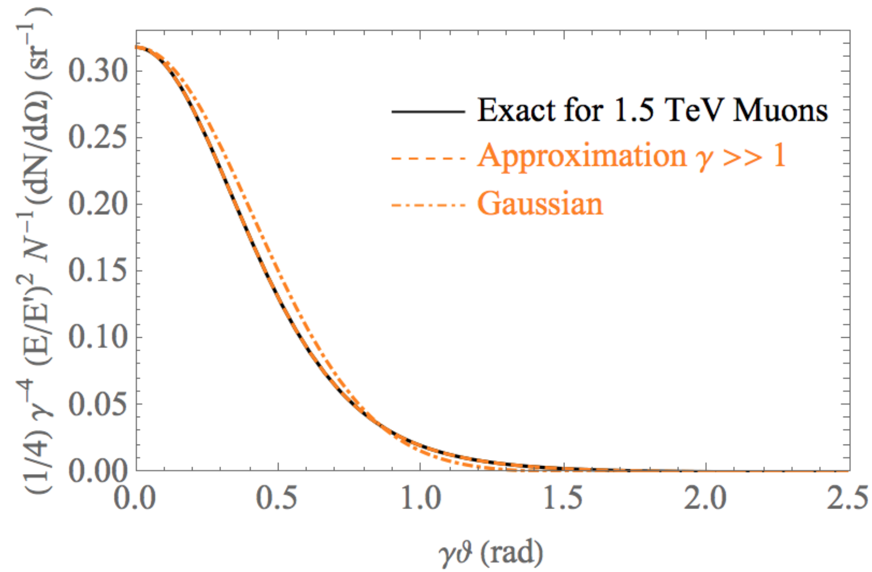
- Absorbed dose rate for short straight section with length Ds and neglecting beam divergence given approximately

$$\frac{dH_a}{dt} = K_S\, E_m^3 f_r N_m \frac{Ds}{L_s^2} \bar{B}\, e^{-3g^2\left(J_H^2+J_V^2\right)}$$

with

$$K_S = 5.37\times 10^{-17}\,\mathrm{Gy}\frac{\mathrm{m}}{(\mathrm{TeV})^3\,\mathrm{T}}$$

  - g the Lorentz factor of the muon beam
  - E_m the muon energy
  - f_r the repetition rate
  - N_m the number of muons per cycle
  - L_s the distance to the observation point
  - $J_{H,V}$ the horizontal and vertical angle between the trajectory of the decaying muon and the neutrino
  - $\bar{B}$ the average magnetic field around the circumference
- Different cross sections etc. for m^+ and m^- decay, but the final results (almost) identical



Neutrino induced absorbed dose is proportional to quantity plotted as function of angle $J = \sqrt{J_H^2 + J_V^2}$

Radiation due to Neutrinos
taking beam divergence and lattice into account

- To take focusing structure and divergence of beam into account
  - Start with Gaussian approximation for radiation cone and assume Gaussian beam
  - Rms opening of radiation cone $1/\left(\sqrt{6}\,\gamma\right)$ and rms divergences of beam to be added quadratically for both planes

$$-3\gamma^2\left(\theta_V^2+\theta_H^2\right)=\frac{-\theta_V^2}{2\cdot 1/\left(6\gamma^2\right)}+\frac{-\theta_H^2}{2\cdot 1/\left(6\gamma^2\right)} \Rightarrow \frac{-\theta_V^2}{2\left(1/\left(6\gamma^2\right)+\varepsilon_V\gamma_V(s)\right)}+\frac{-\left(\theta_H-\hat{\theta}(s)\right)^2}{2\left(1/\left(6\gamma^2\right)+\varepsilon_H\gamma_H(s)+\left(\sigma_p/p\cdot D'(s)\right)^2\right)}$$

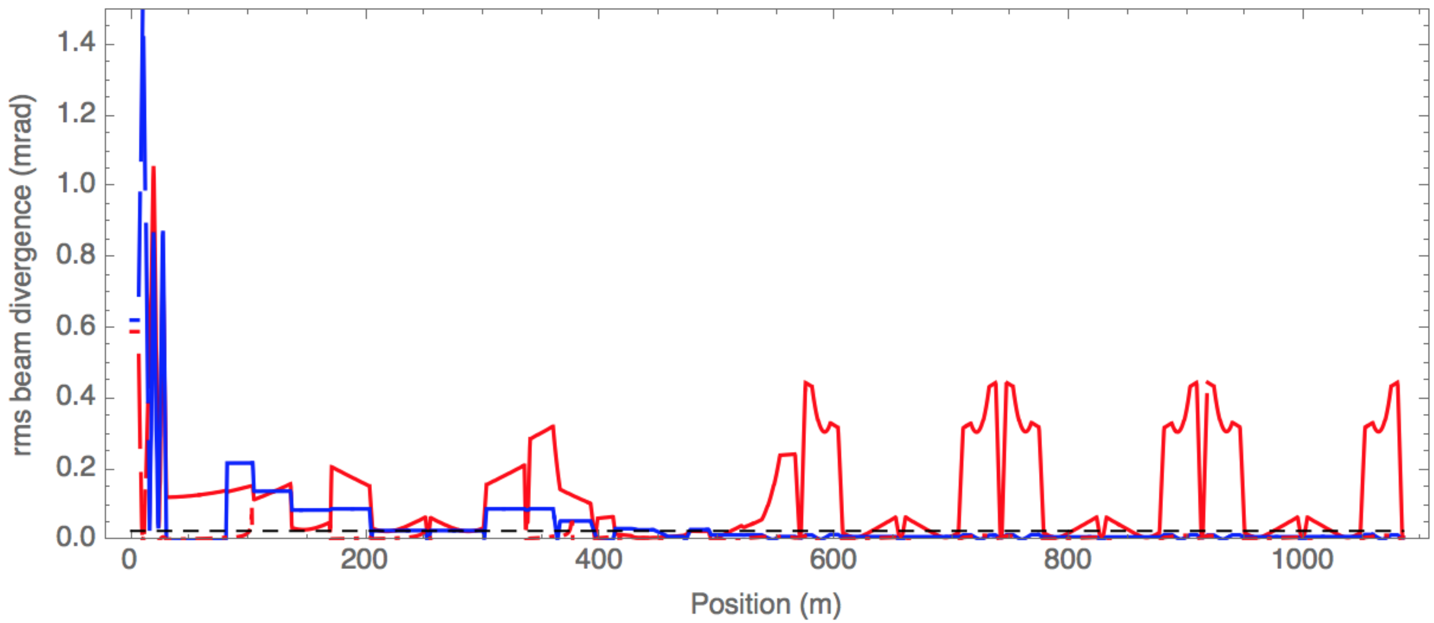
  - Finally

$$\frac{dD_S}{dt}=K_S E_\mu^3 f_r N_\mu \frac{\bar{B}}{L_s^2}\int ds \frac{1/\left(6\gamma^2\right)}{\sqrt{\frac{1}{6\gamma^2}+\varepsilon_H\gamma_H(s)+\left(\frac{\sigma_p}{p}D'(s)\right)^2}\cdot\sqrt{\frac{\gamma^2}{6}+\varepsilon_V\gamma_V(s)}}\exp\left[-\frac{\left(\theta_H-\hat{\theta}(s)\right)^2}{2\left(\frac{1}{6\gamma^2}+\varepsilon_H\gamma_H(s)+\left(\frac{\sigma_p}{p}D'(s)\right)^2\right)}-\frac{\theta_V^2}{2\left(\frac{1}{6\gamma^2}+\varepsilon_V\gamma_V(s)\right)}\right]$$

Expression used for numerical evaluations

Application to 3 TeV c.o.m Lattice from MAP study

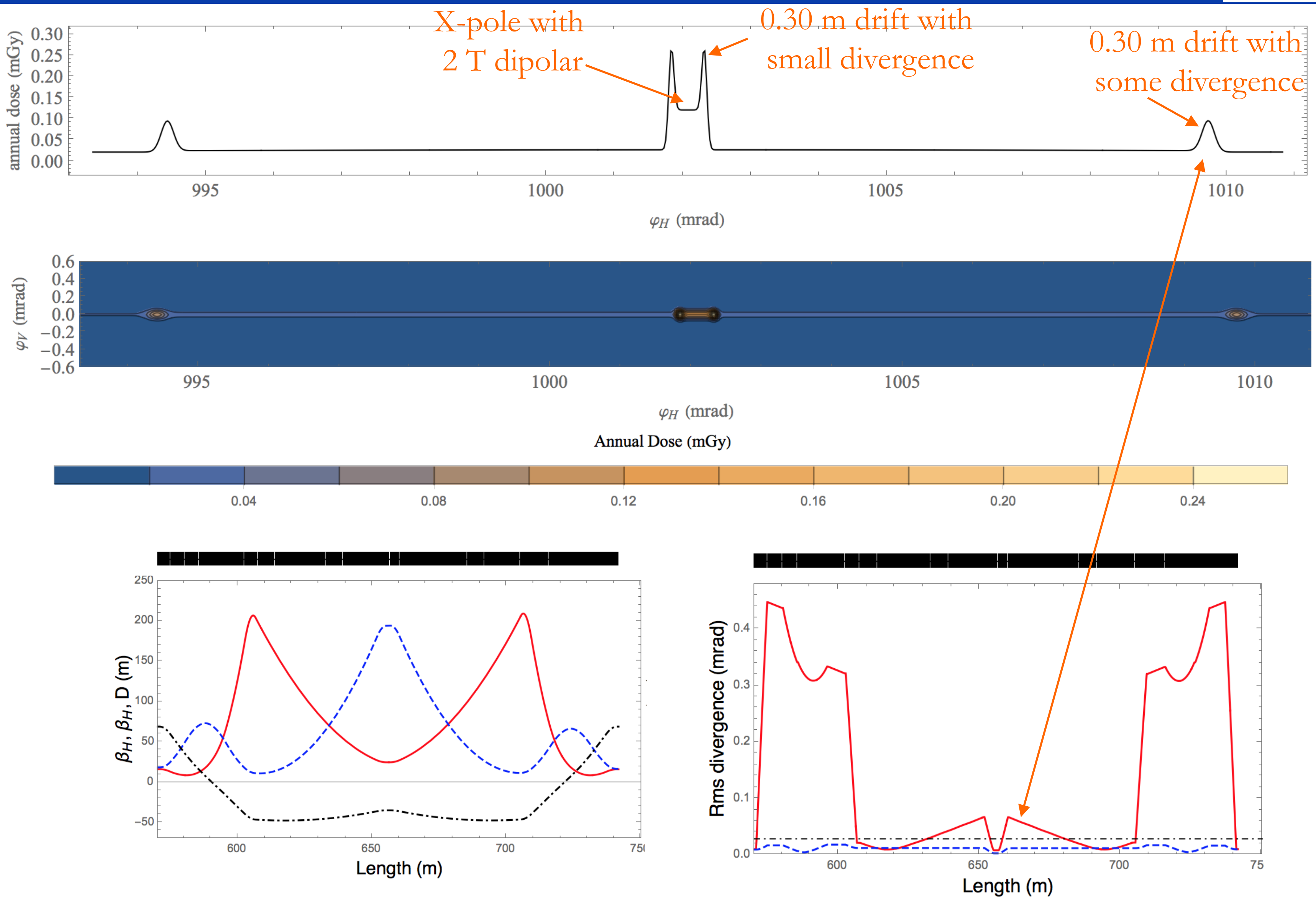
- Beam divergence for one quarter of ring



  - Dashed line: Rms of neutrino radiation distribution (no beam divergence)
  - Many locations where horizontal divergence, dominated by large momentum spread and D', large compared to neutrino radiation distribution (without divergence) …
- No straight lines for RF, injection …
- Assumptions for next slides:
  Beam Energy $E_m = 1.5\,\text{TeV}$ (3 TeV c.o.m)
  $N_m = 2 \times 10^{12}$ muons per beam, repetition rate $f_r = 12\,\text{Hz}$
  $C = 4340\,\text{m}$ circumference ($\bar{B} = 7.24\,\text{T}$) with depth $d = 100\,\text{m}$
  Operated for 5000 h per year

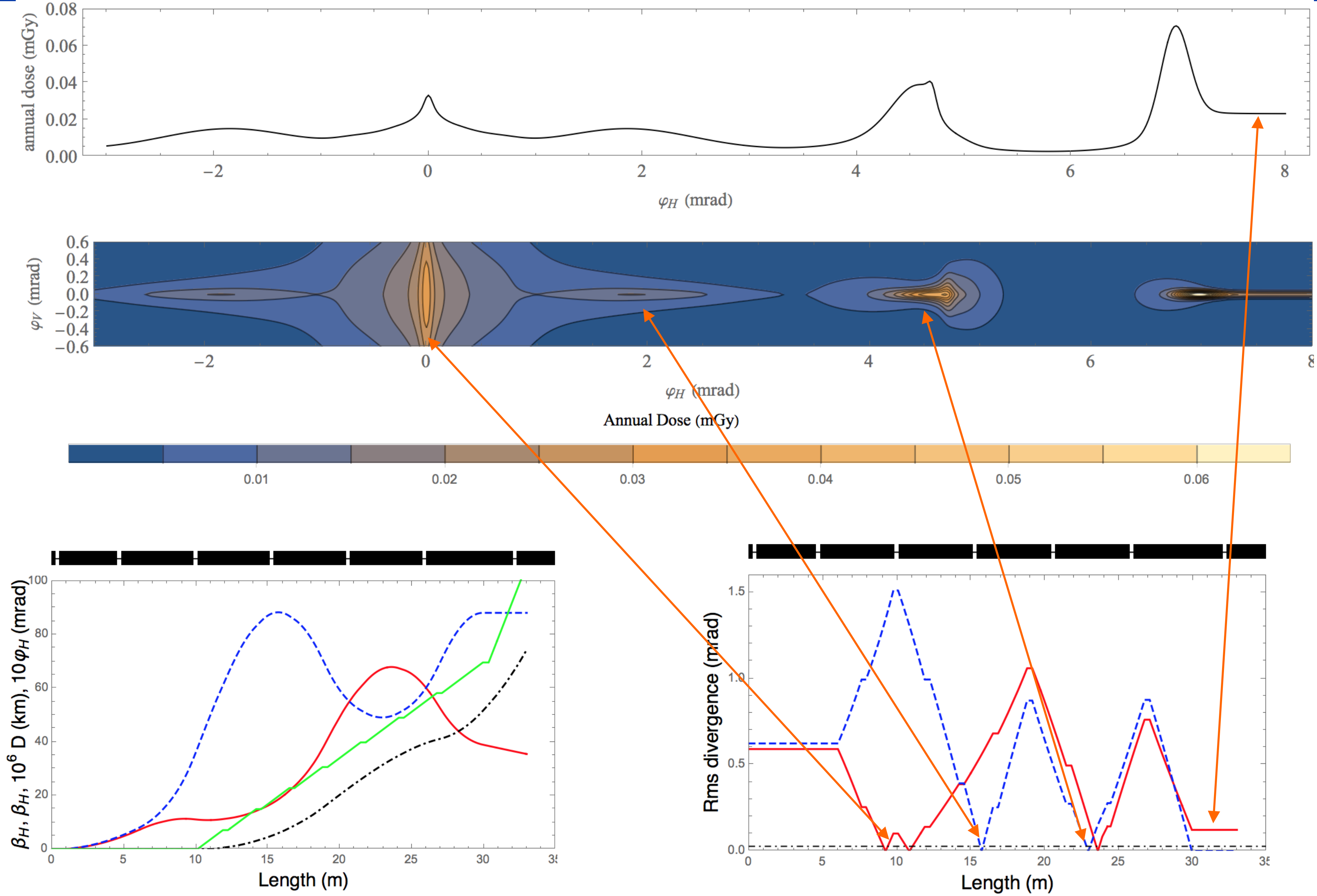
Application to 3 TeV c.o.m Lattice from MAP study

Radiation from center of arc cell



Application to 3 TeV c.o.m Lattice from MAP study

Radiation from region around IP



Summary and Conclusions

- Equations to estimate radiation due to neutrinos
  - Gaussian reproduces reasonably well radiation cone
  - Extension of formalism to take details of lattice into account
- Applications to 3 TeV c.o.m. MAP lattice (1.5 TeV muon beams)
  - Detailed neutrino radiation distributions for center of arc and IP
  - Beam divergence not always negligible (contribution from D' with large momentum spread!)
    - Mitigates radiation from straight sections
  - Combined function magnets with (too) low dipolar components to be avoided
- Outlook
  - Attempts to further improve/refine lattice design underway (at least for arc)
    - Avoiding straight sections with D' = 0?
    - Increased dipolar component of combined function magnetic
    - Avoid magnets bending beam towards outside
  - Other measures to mitigate (maximum) radiation due to neutrinos (time varying closed orbit distortions or "wobbling" whole machine)
  - Minimum straight length between magnets?
  - Expect iterations with magnet design, radiation protection and, possibly, other teams