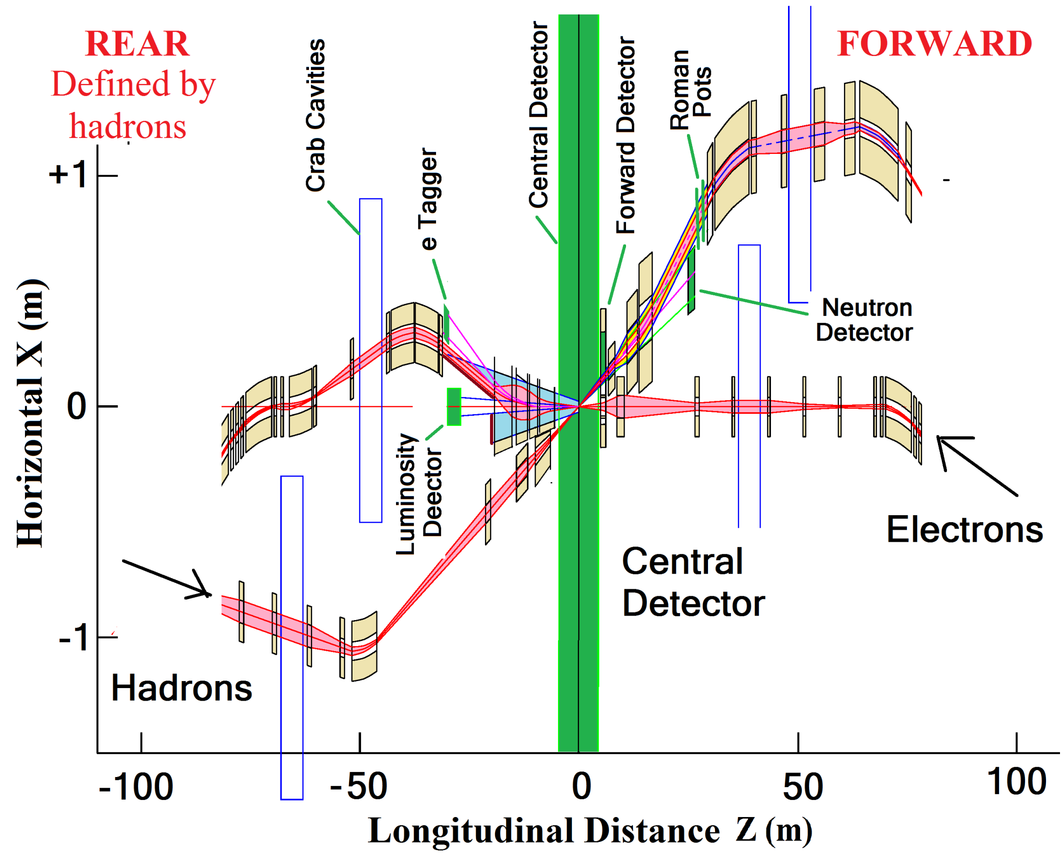
# Status of eRHIC IR Design

3/15/2017

R. B. Palmer

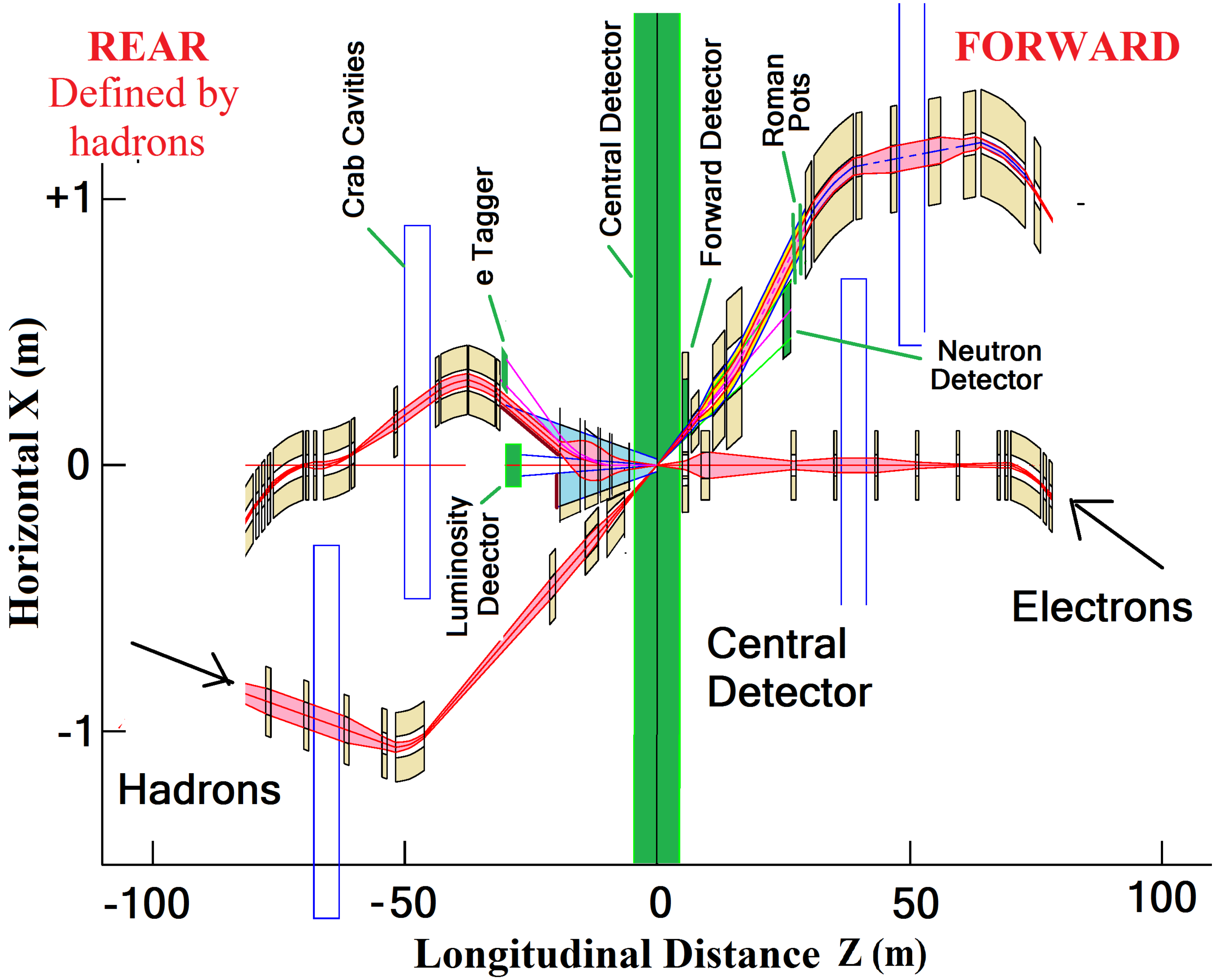
- Lattice Requirements
- Synchrotron Radiation
- Electron betas
- Hadron Magnets
- Hadron betas
- Detector Requirements
- Hadron Detectors
- Electron Detectors
- Conclusions



# Lattice Requirements

- Achieve required betas at IP:
  down to 4 cm in y, and down to 50 cm in x
- Provide locations for crabs with $\beta_x$=1200 m for p, and 250 m for e
- Minimize all other betas to control chromaticity
- Minimize fields in all magnets to allow NbTi at 4 K
- Adequately shield between e and p beams
- Minimize fan of synchrotron Radiation SR in IP and beyond (REAR)

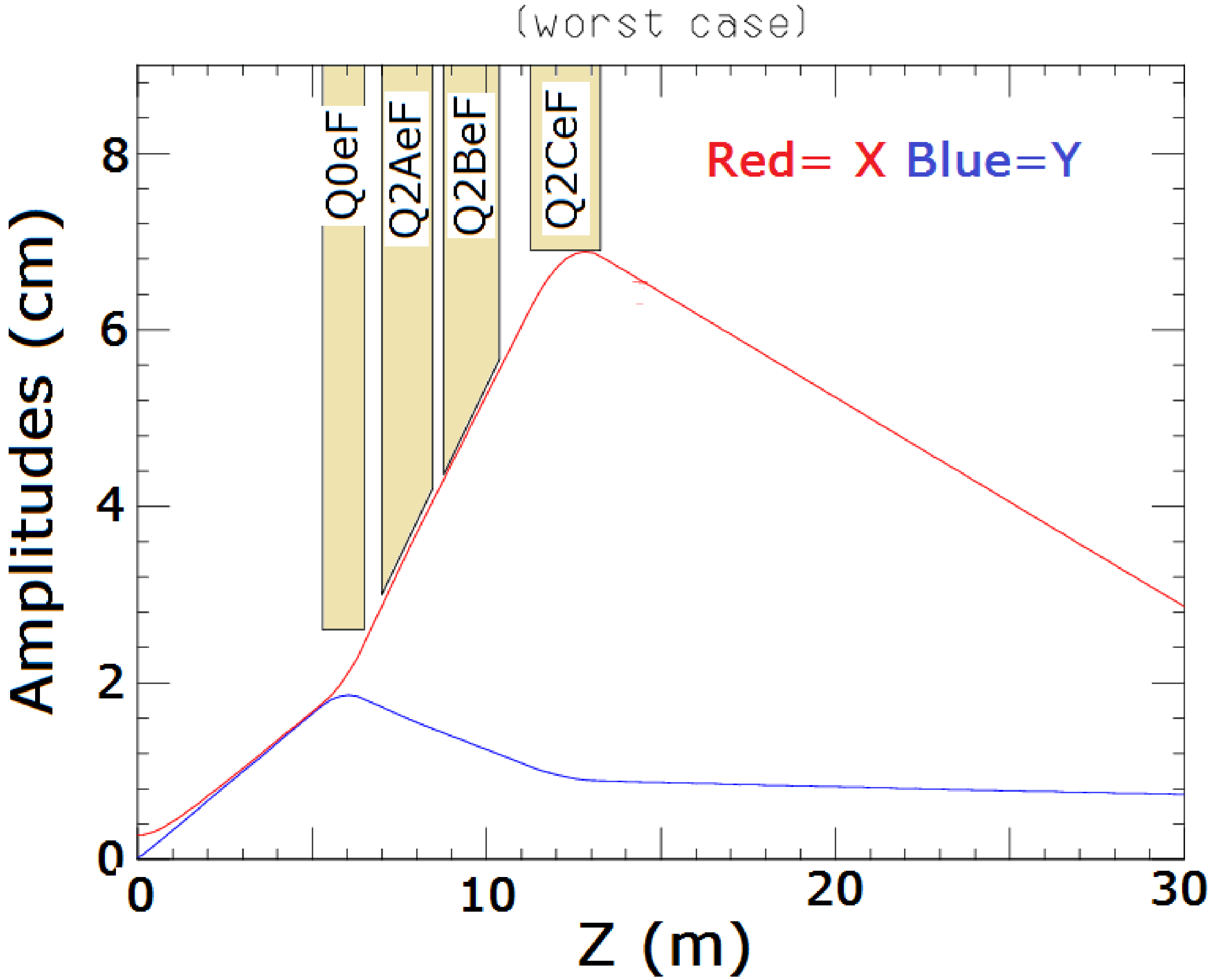
# Layout from pCDR (full4)



# Synchrotron Radiation from incoming electrons 'FORWARD'

- Radiation from electrons up stream must be collimated
- Electron bends upstream near the IP are avoided
- Electron focusing is designed to minimize angular spread (fan) of synchrotron radiation from quads near the IP
- To avoid SR scattering into the central detector, the beam pipes and downstream (REAR) quads have apertures greater than any fan from up to 13.5 sigma upstream electrons collimated elsewhere in ring.
- These fans are smaller if the upstream (FORWARD) quad doublets are weak and far apart
- But this gives higher betas and more chromaticity

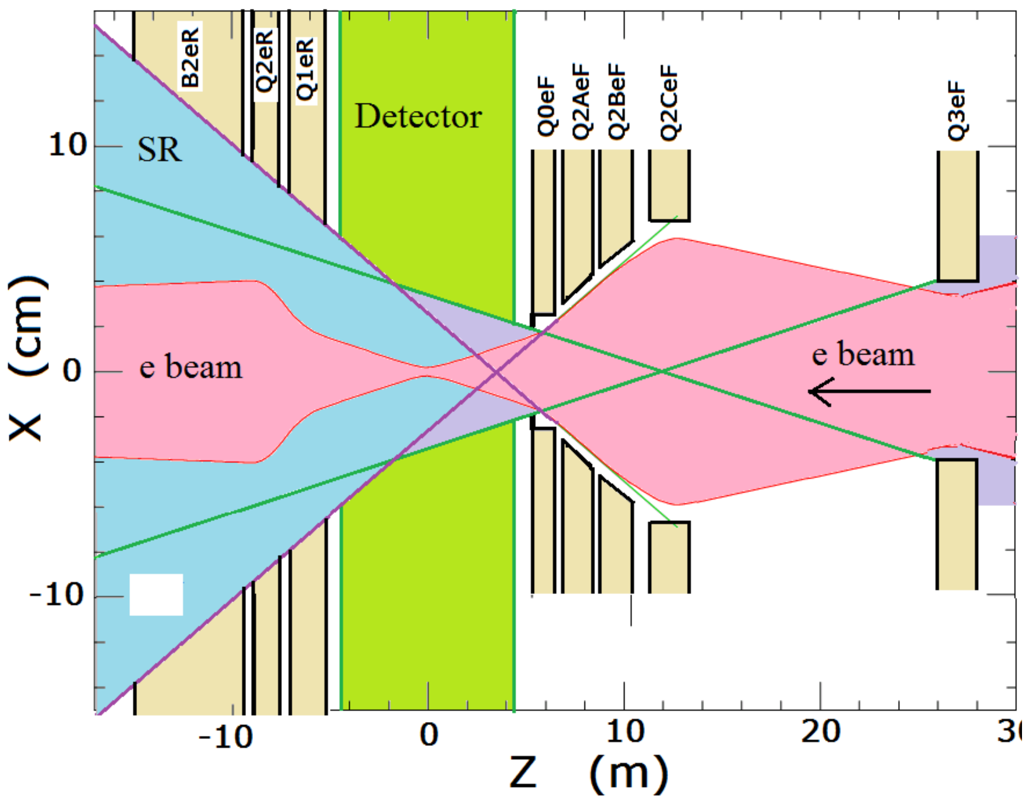
# Incoming (FORWARD) e focusing anne39ac



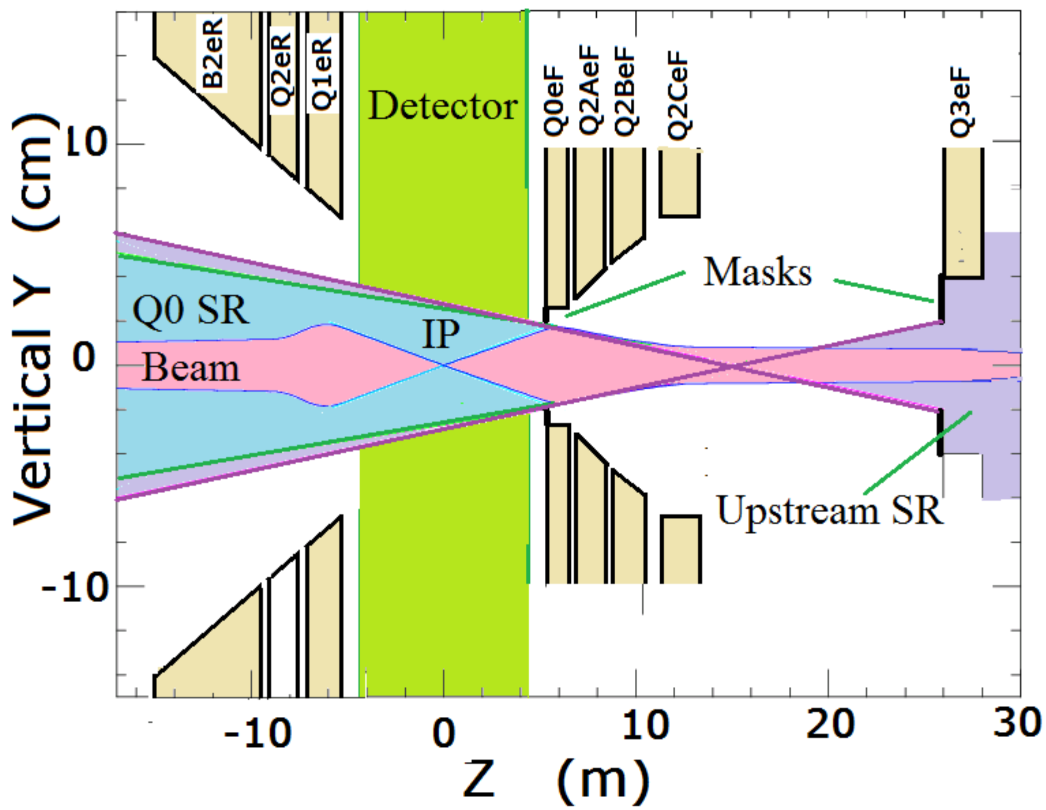

15 sigma beam size for worst case (Div.=220 $\mu$rad), defining the magnet apertures.

# Synchrotron fans SRfanx SRfany

Synchrotron fan set by electrons at 13.5 sigma beam in worst case, as collimated elsewhere in the ring




X




Y

# Minimum apertures to avoid SR fan

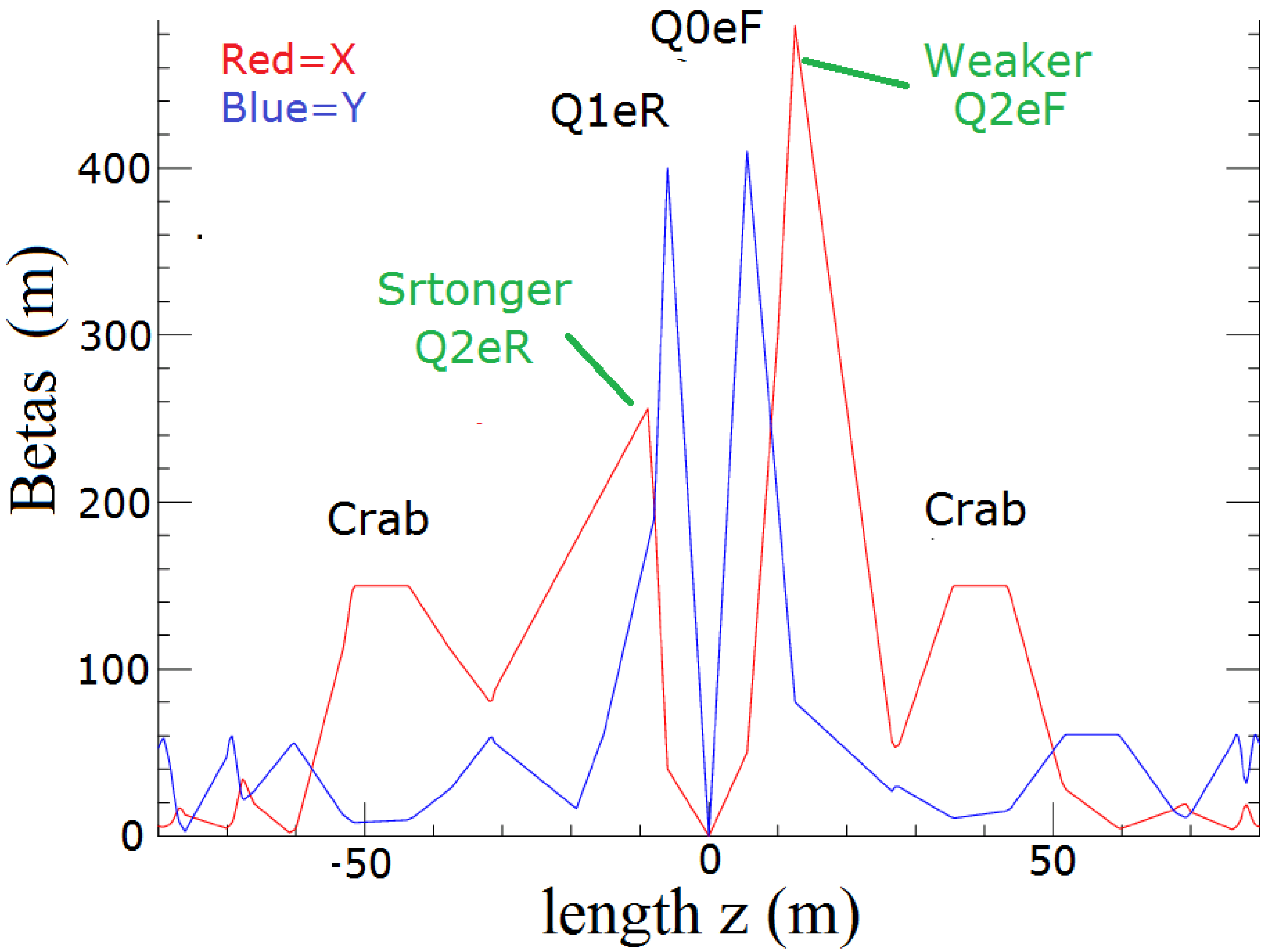
## For elliptical beam pipe in central detector

| z (m) | x (cm) | y (cm) |
|---|---|---|
| -4.5 | 6.0 | 3.3 |
| 0 | 2.6 | 2.5 |
| 4.5 | 1.9 | 1.6 |

## for Q1eR, Q2eR, & B2eR

| | dependence on z |
|---|---|
| width x | x=7.5 $10^{-3}$ (-z + 3.5) (m) |
| height y | y=1.5 $10^{-3}$ (-z + 15) (m) |

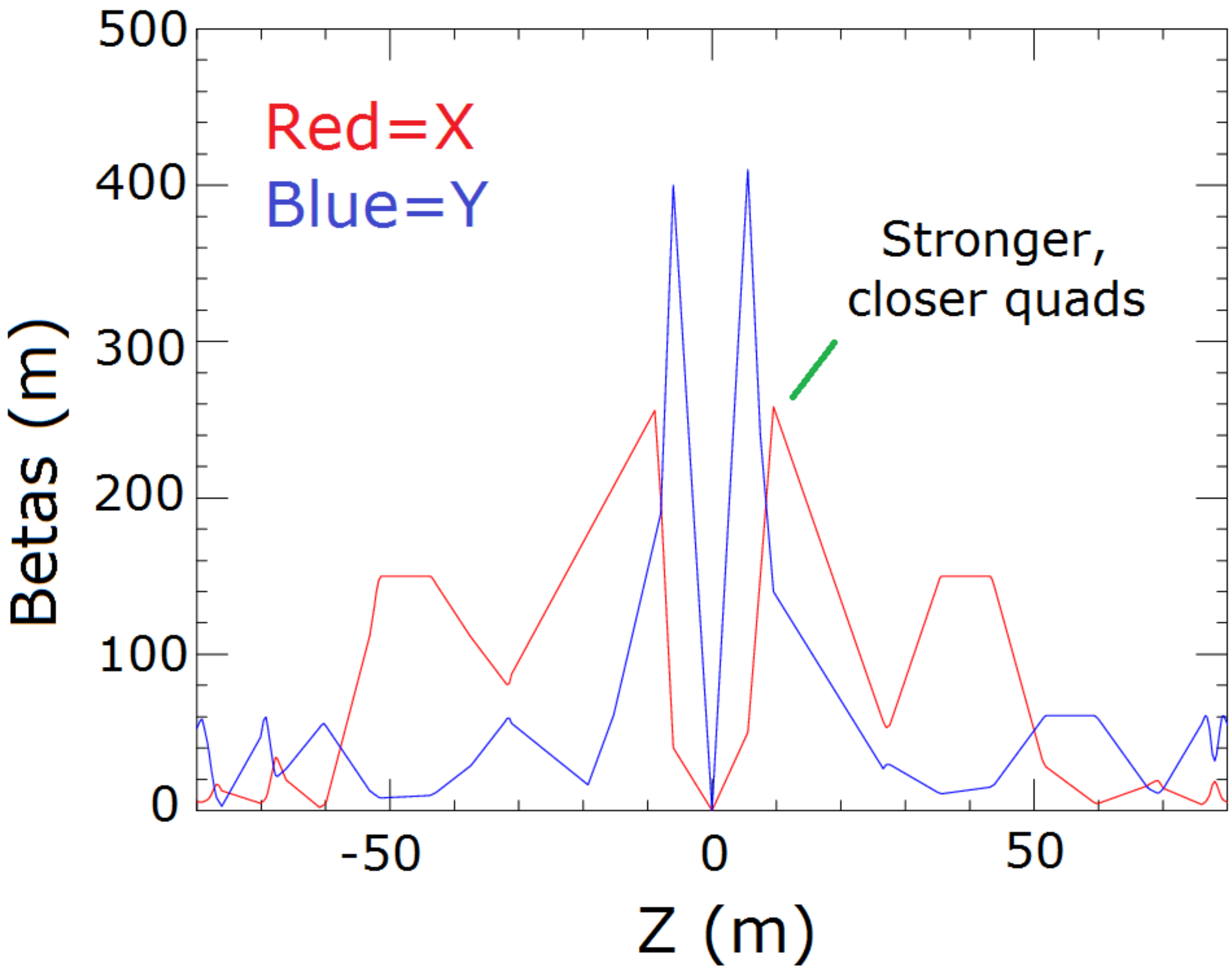
# Worst Case $\beta_e$s (xyebet2c)




Worst Case (Div=220 $\mu$rad) $\rightarrow$ largest SR fan $\rightarrow$ larger quad sep. at incoming (FORWARD) focus

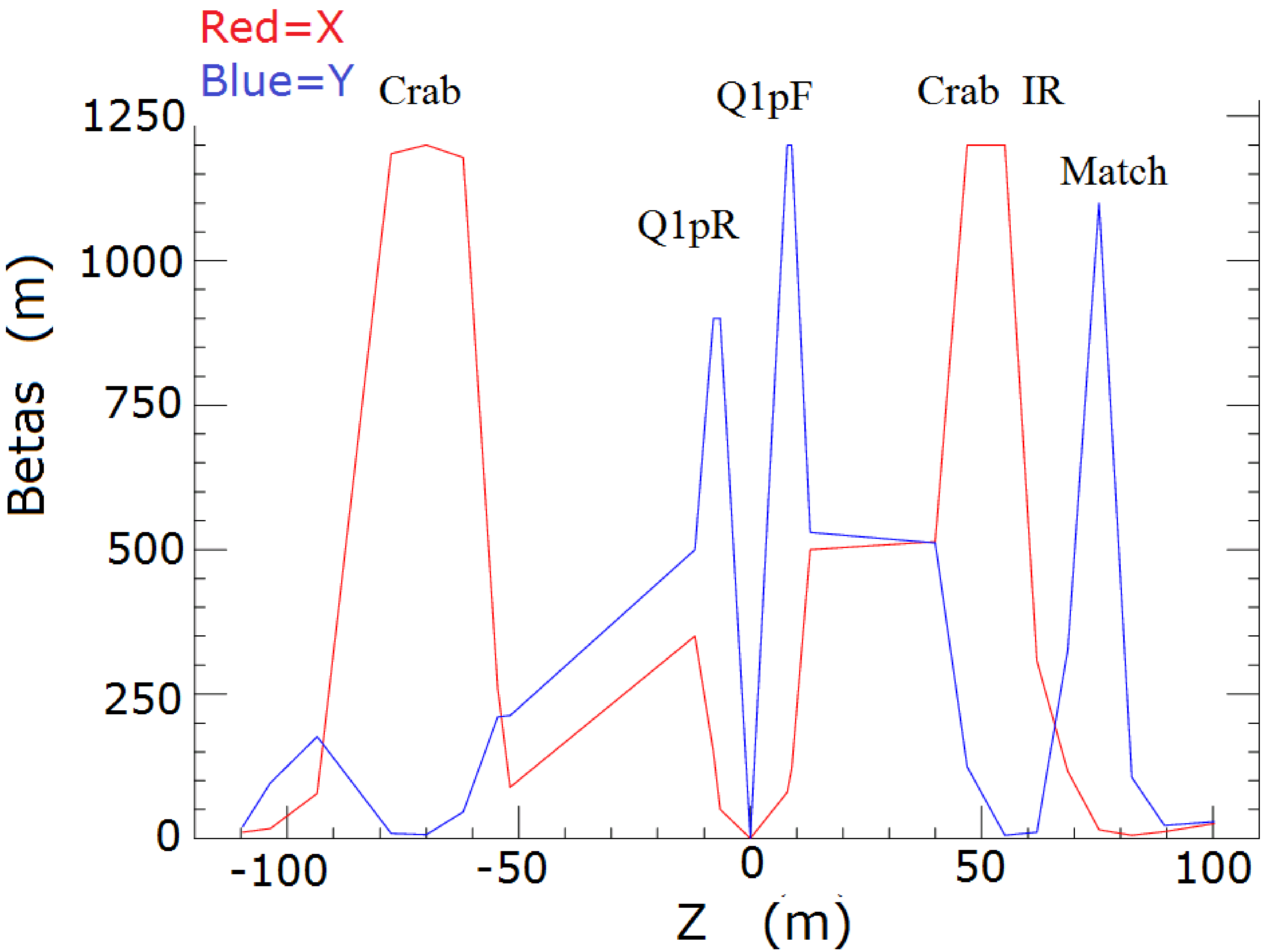
Betas shown use baseline beta*, but emit. to give worst divergence

# Baseline $\beta_e$s (Div$\leq$160 $\mu$rad) (xyebet3c)

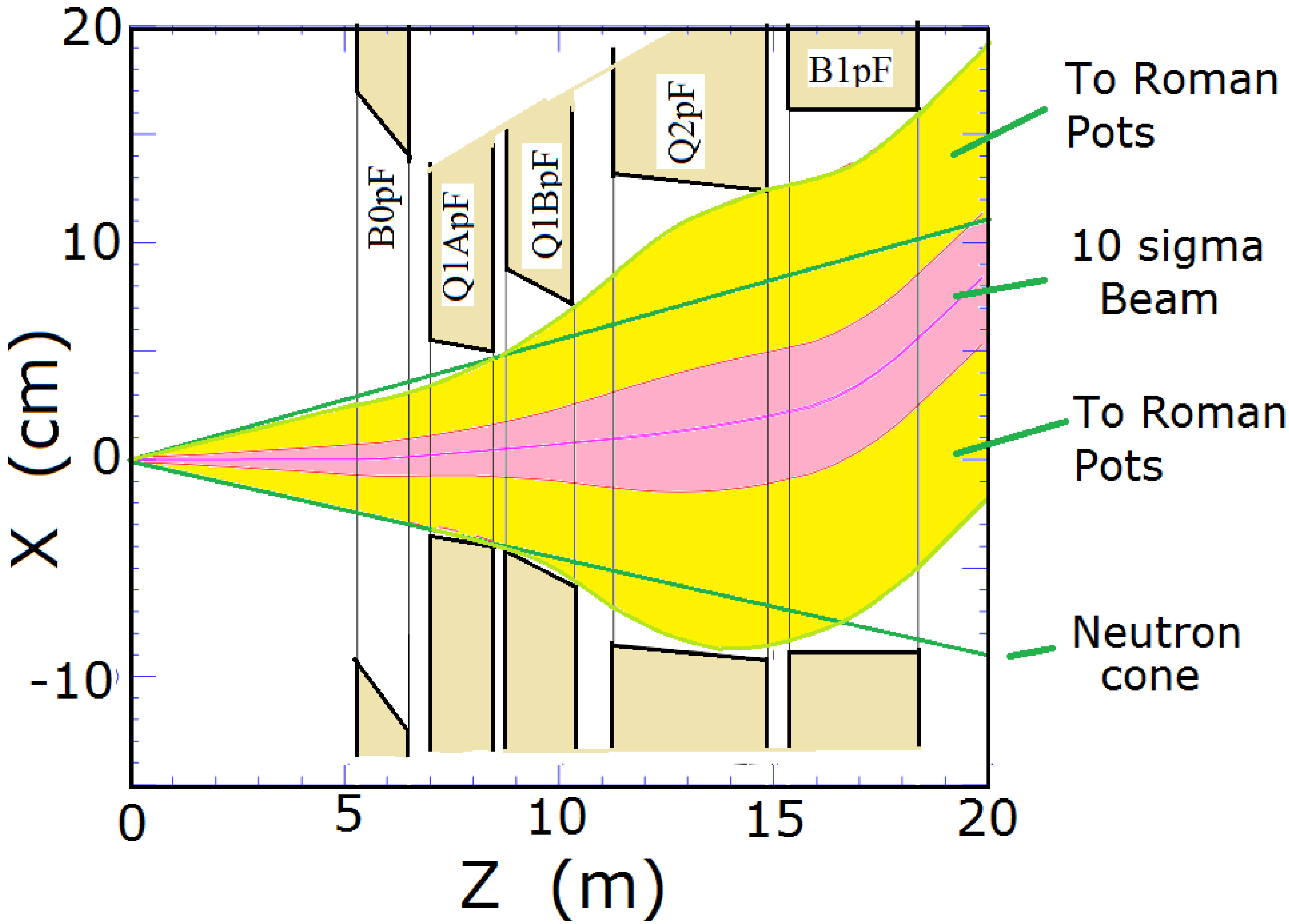



Lower divergences cases allow focus quads stronger and effectively closer together, reducing the beta maximums. Effective movement by currents in multiple magnets.

# Hadron Betas from pCDR (pbetas3)

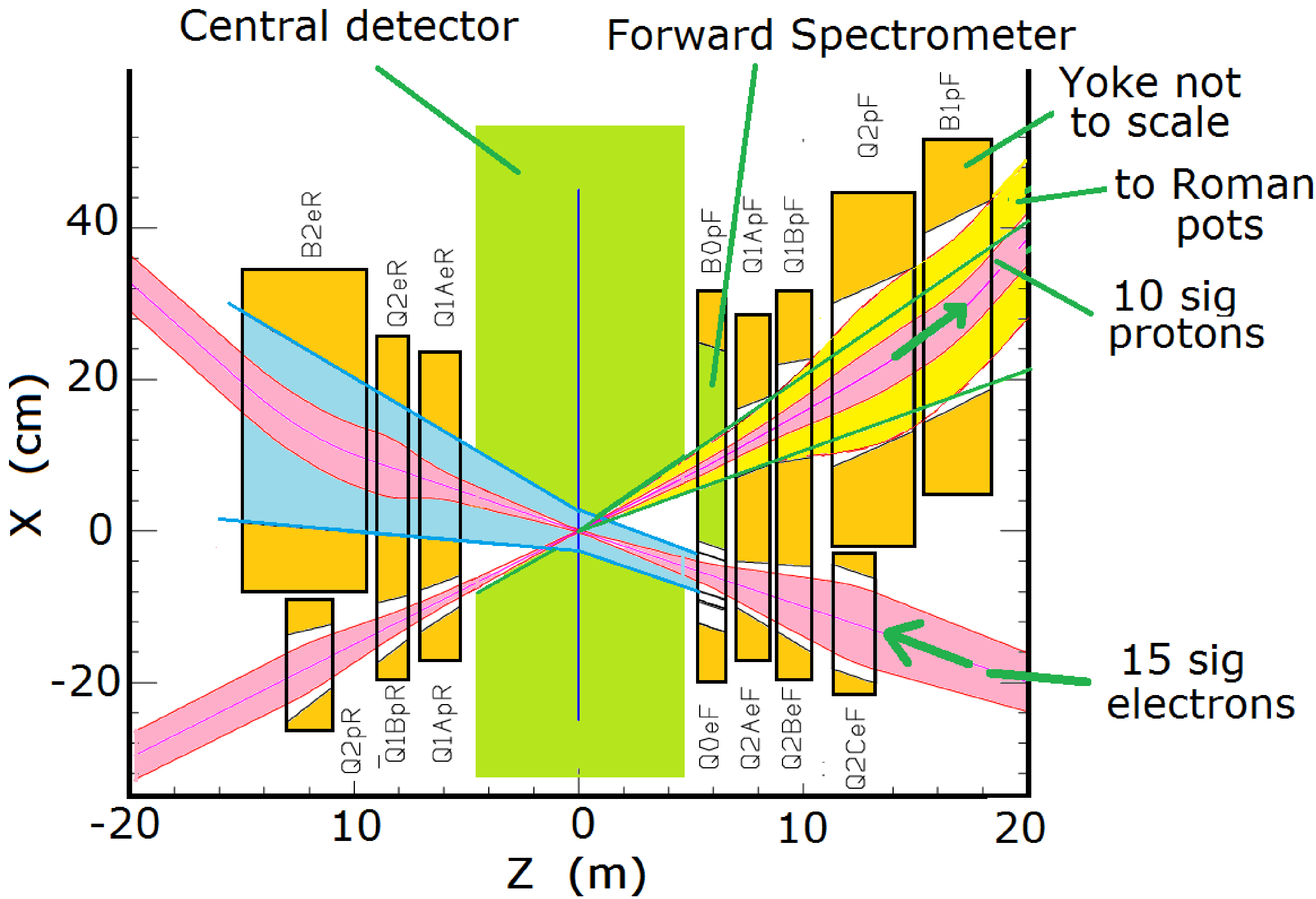


# Forward Hadron Tilts (dnnp336w.png)




Tilting untapered magnets increases space between e and Ion beams. Q1pF is broken into two to decrease size of Q1ApF.

# Conceptual Magnet Outlines (detail.png)



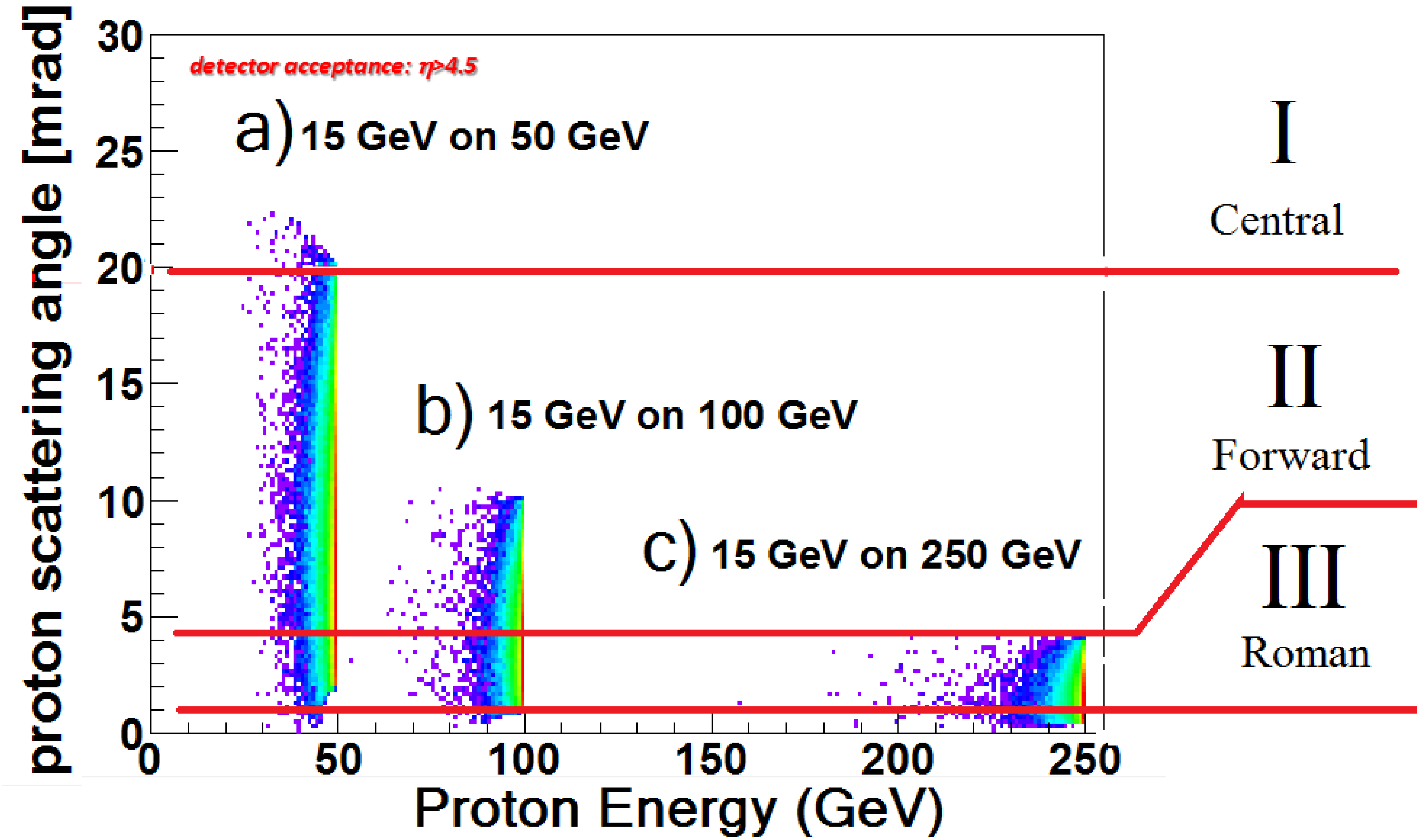

Magnets close to one another must be designed as single units with good isolation one from the other (see Brett Parker talk)

# Detector Requirements

- No quadrupoles in $+/-$ 4.5 m for Central detector for -20 mrad to $+20$ mrad, with REAR e.m. calorimeter down to 50 mrad for Diffractive Physics.
- FORWARD neutron detection up to 4 mrad
  (-4.5 to 5.5 mrad provided)
- FORWARD proton detection for Diffractive physics (see next slide)
- FORWARD proton detection down to pt$=$200 MeV$/$c for all energies
- Tagger for REAR electrons on axis but p $<$ 90% p initial
- Luminosity measurement of by photon detection in REAR on axis.

# Coverage for Diffractive Physics (elke2d.png)

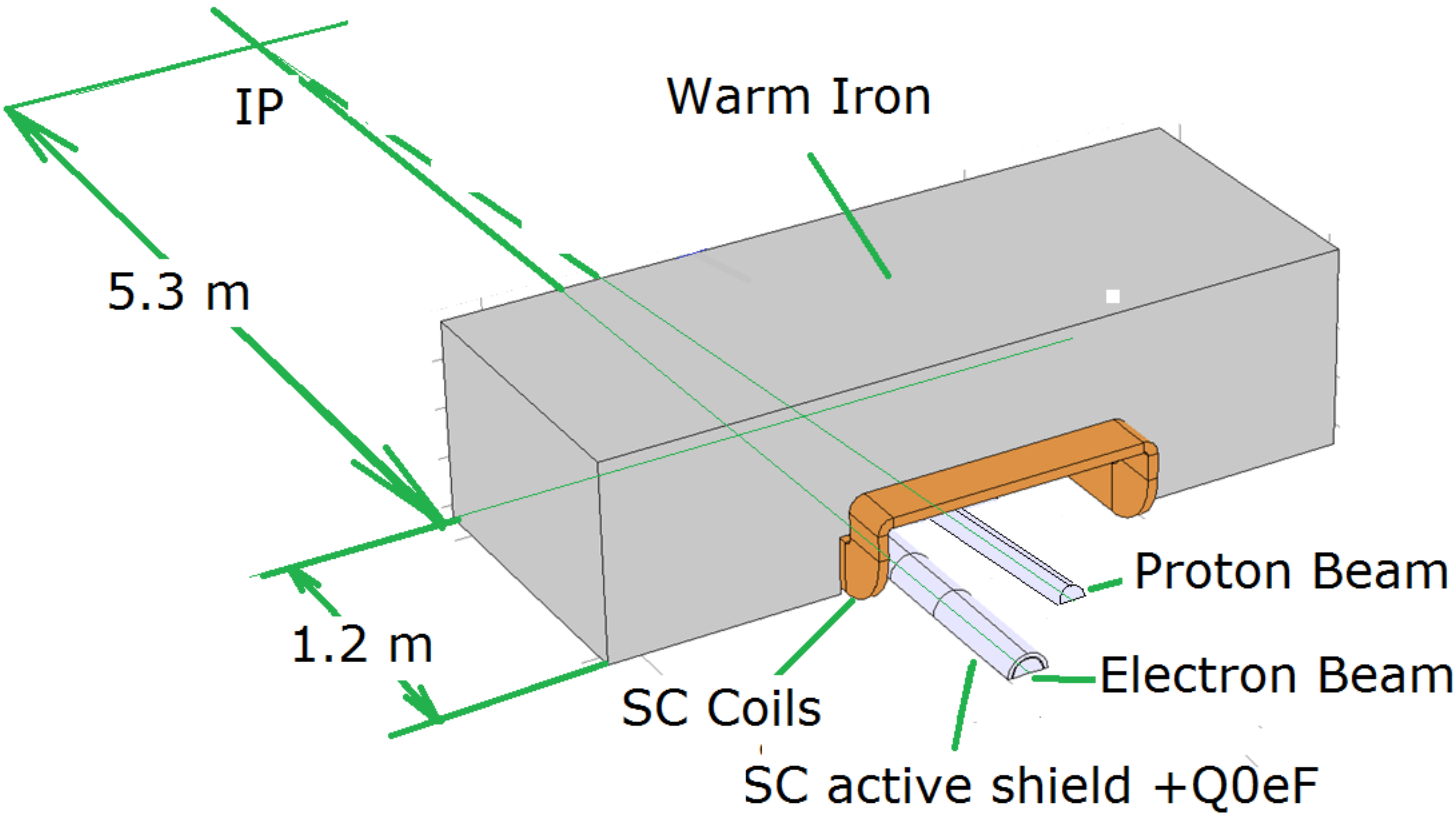
Deeply Virtual Compton Scattering probing gluon distributions




Also requires REAR outgoing electrons down to ≈ 50 mrad

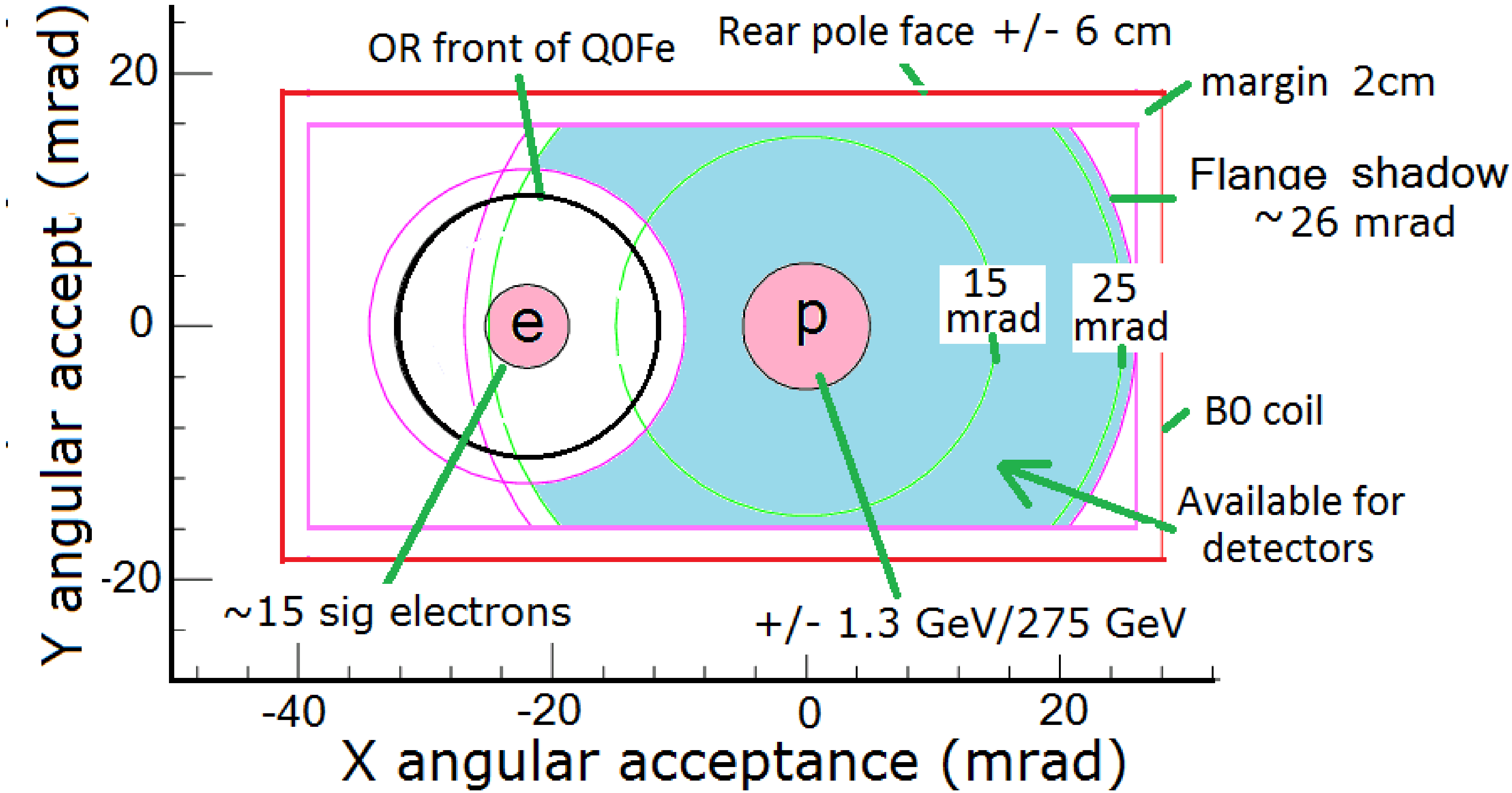
# Forward Spectrometer Magnet B0 (B0)

Covers angles 5 to 25 mrad e.g. for forward p in lower energy DVCS (see above)

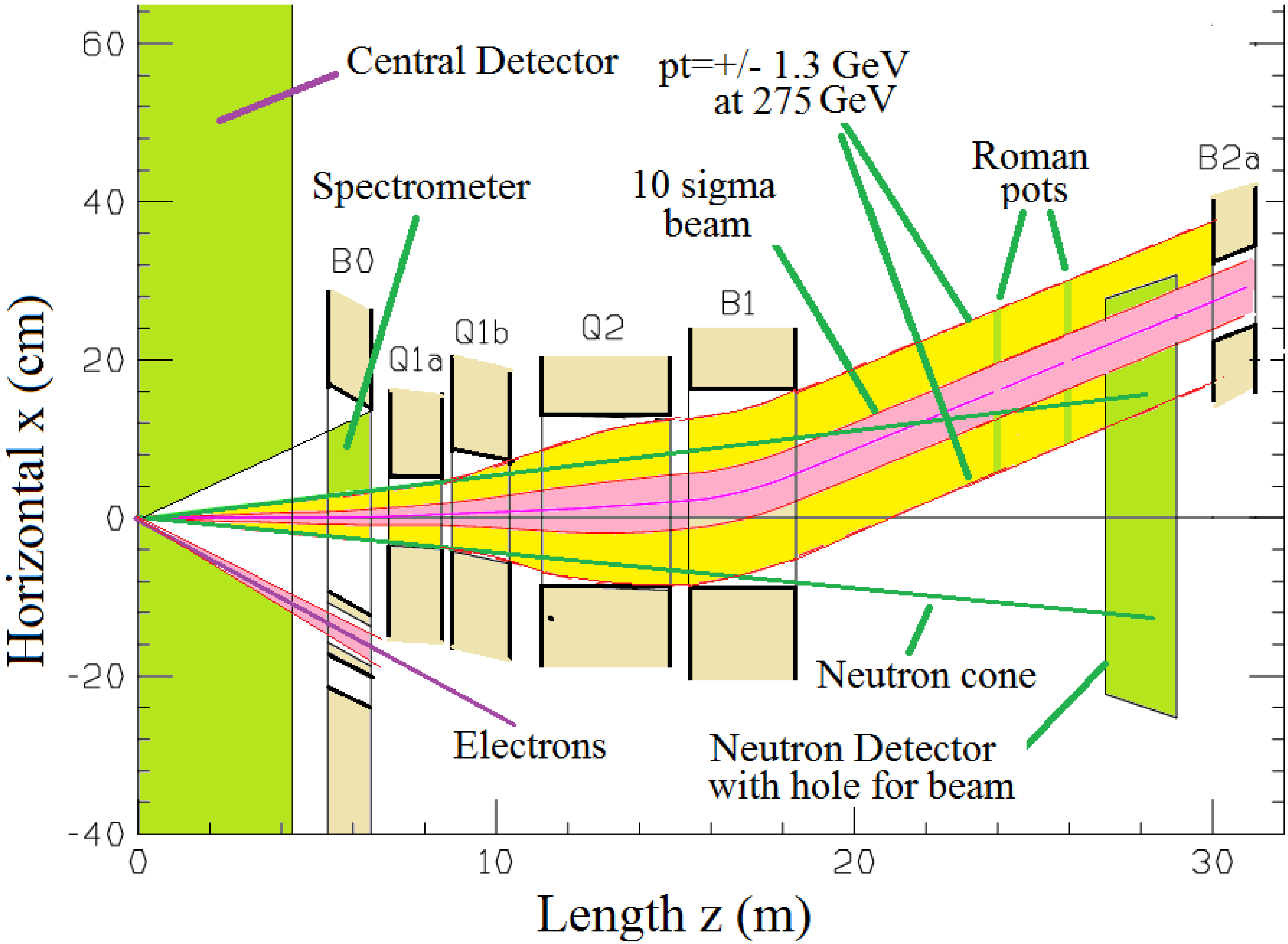



Warm iron and detectors super-conducting coil
Direct wind cancelling dipole over electron beam and Q0eF quad inside

# Spectrometer Angular Acceptance (B0-rect)

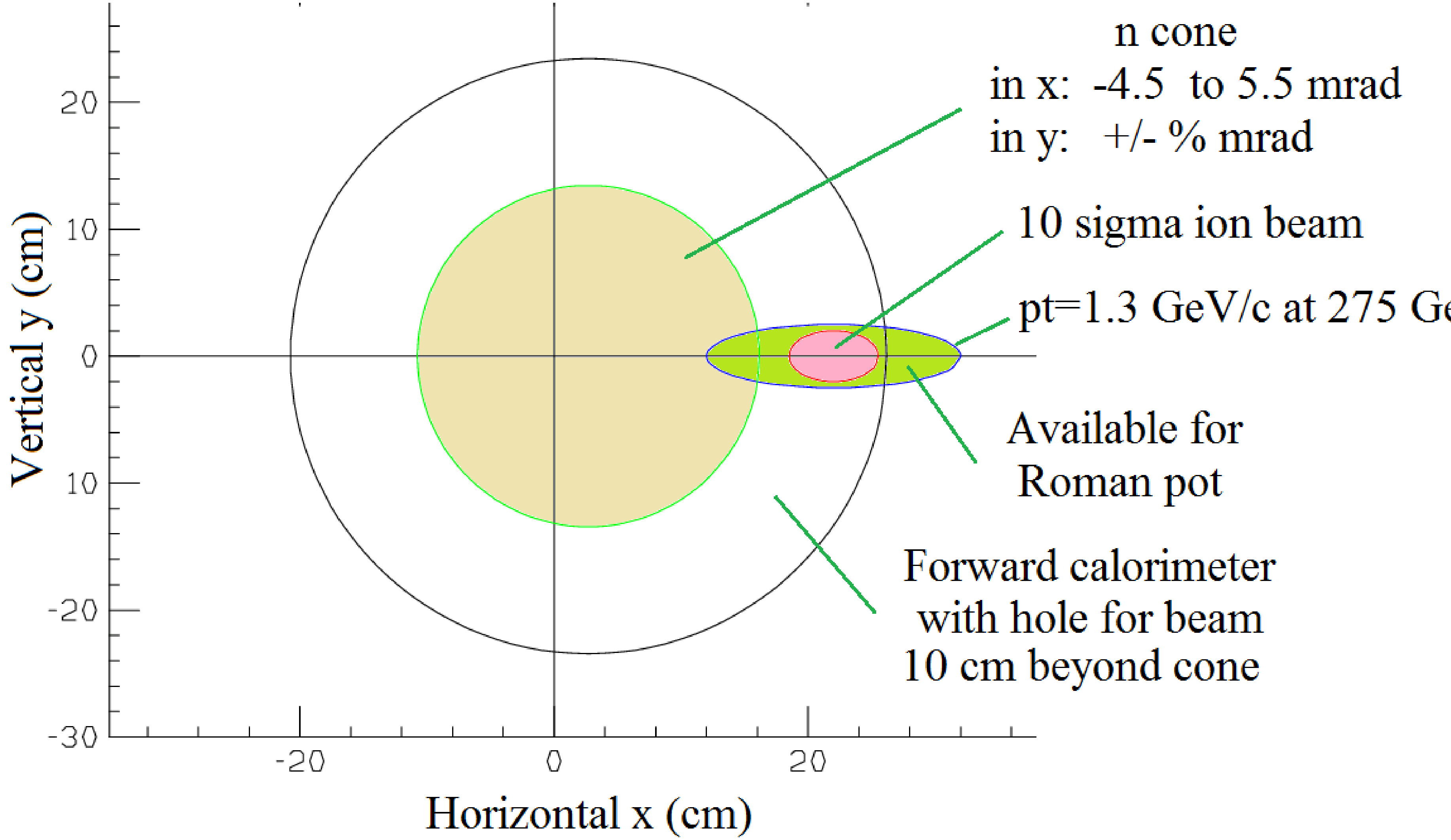


# Other Hadrons Detectors (dnnp337x)



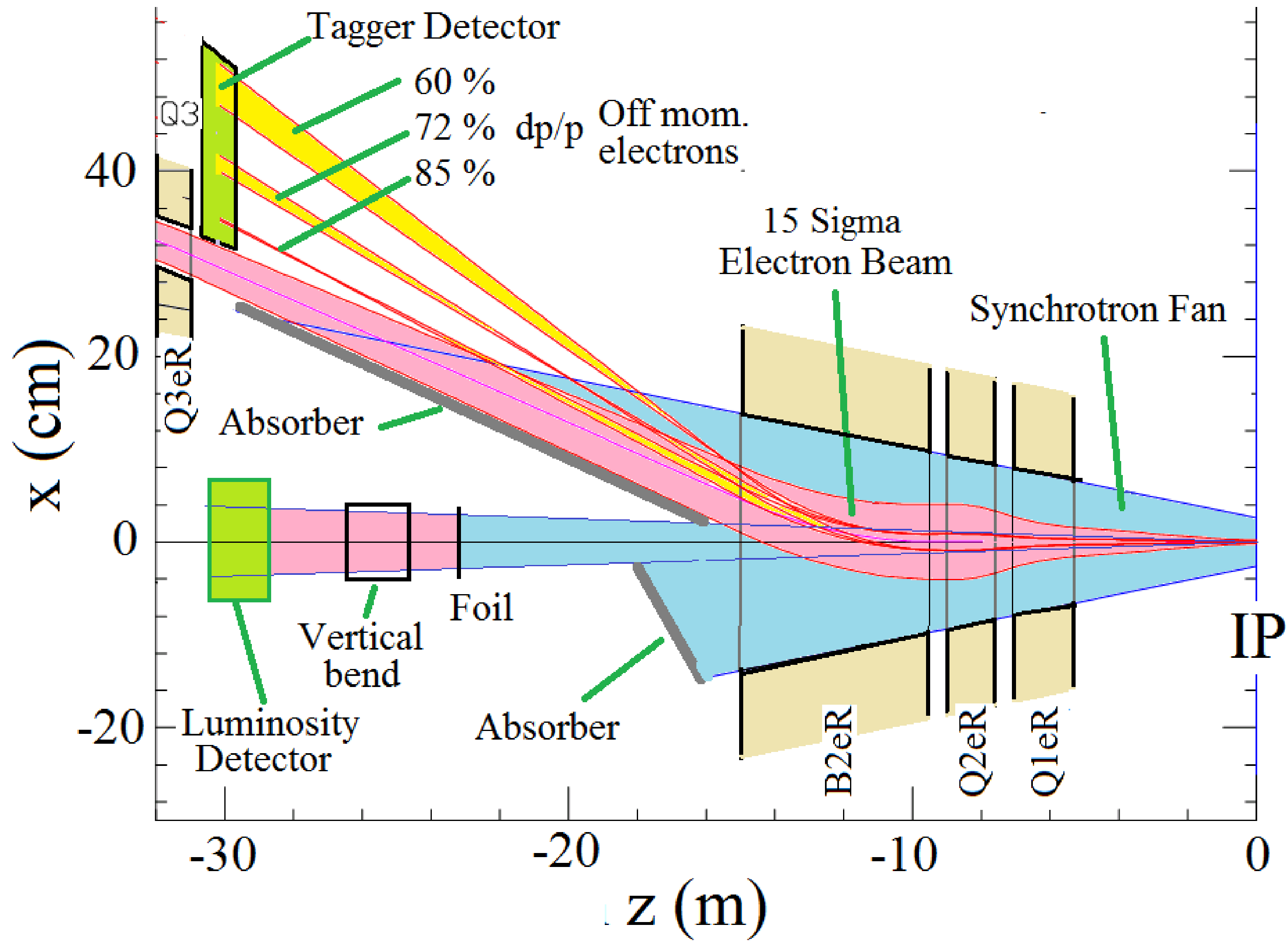
# xy of beam, Calorimeter, & Roman Pots

Fcal2




The minimum Pt observable, defined by the 10 sigma beam size, is $\approx$ 450 MeV/c. For 200 MeV/c pt tracks "High Acceptance" beam parameters with higher $\beta_x^*$ and lower luminosity are used.

# Rear Electrons & Detectors tag2.png




Polarization measurement will be in another straight

# Summary

| | | pCDR | Now | JLab |
|---|---|---|---|---|
| Crossing | mrad | 22 | 25 | 50 |
| $L^*_{hadron}$ FORWARD/REAR | m | 6.7/5.5 | 7.0/5.3 | 7/3.6 |
| $L^*_{electron}$ FORWARD/REAR | m | 5.0/5.5 | 5.3/5.3 | 2.96/2 |
| Baseline $\beta^*_{hadron}$ x/y | cm | 90/4.3 | 90/4.3 | |
| Worst $\beta^*_{hadron}$ x/y | cm | 90/4.3 | 90/4.3 | 6/1.2 |
| Baseline $\beta^*_{electron}$ x/y | cm | 83/8 | 61/7.5 | |
| Worst $\beta^*_{electron}$ x/y | cm | 42/5 | 42/5 | 4/0.8 |
| Baseline $\hat{\beta}_{hadron}$ in x/y | m | 1200/1400 | 1200/1400 | |
| Worst $\hat{\beta}_{hadron}$ in x/y | m | 1290/1500 | 1300/1500 | 4200/4200 |
| Baseline $\hat{\beta}_{electron}$ in x/y | m | 1050/500 | 500/400 | |
| Worst $\hat{\beta}_{electron}$ in x/y | m | 2000/1000 | 1000/640 | 1100/1100 |
| Maximum $B = Grad \times App$ | T | 5.6 | 4.3 | 6 |
| Hadron Local Chromatic corr. | | no | no | yes |
| Electron Local Chromatic corr. | | no | no | no |

# Comments on last slide

- eRHIC "Baseline" has no cooling at c of m 140 GeV
- eRHIC "Worst cases" have cooling at c of m 105 or 140 GeV
- The JLab data from Vasiliy Morozov.
- BNL Baseline has c of m energy of 140 GeV and no cooling
- The electron maximum betas in Steve Tepikian's talk are higher than those given here because he was still using the pCDR IR design.

- Hadron $L^*$s similar between BNL and JLab
- Electron $L^*$s less for JLab
- Electron maximum betas are similar for the two labs.
- The JLab maximum hadron betas are approximately 3 times higher than BNL's

# Conclusion

- Meets all Given Requirements
- Significant improvements since pCDR:
  - Peak magnet fields (5.6$\rightarrow$ 4.3)
  - Max electron $\beta_x$ (1050 $\rightarrow$ 500)
- Minor increase in crossing angle 22$\rightarrow$ 25 (mrad)
- Hadron L* distances are not very different from JLab's but they have significantly lower $\beta^*$s and higher $\beta$ maximums.
- Lowering electron $\beta$s and reducing the SR fans by bringing electron quads inside the detector is being studied.

# BACK UP

In the following

- L1 is the location of the magnet end closest to the IP
- IR1 is the inside radius closer to the IP; IR2 is that further from the IP.
- x is the horizontal position of the magnet ends closest to the IP, with respect to a Z axis passing through the IP parallel with the electron beam at the IP
- $\theta$ is the angle between the magnet axis and the Z axis
- Baseline Parameters, used for all but the "worst cases", are those without cooling and High Divergence:

E(hadron)=275 GeV; E(electron)= 18 GeV
$\beta^*$(hadron) x/y = 90/4.3 (cm)
$\beta^*$(electron) x/y = 83/8.0 (cm)
$\epsilon$(hadron) x/y = 20/6.1 (nm)
$\epsilon$(electron)vu x/y = 22/3.3 (nm)

# FORWARD Proton Magnets mnnp336

mom = 275

| | | L1 | DL | gap | x | $\theta$ | IR1 | IR2 | OR | B1 | B2 | B | Grad1 | Grad2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | m | cm | mrad | cm | cm | cm | T | T | T | T/m | T/m |
| B0 | 3 | 5.30 | 1.20 | 0.50 | 13.3 | 0.00 | 17.00 | 17.00 | 30.0 | 0.000 | 0.000 | 1.300 | 0.000 | 0.000 |
| Q1a | 5 | 7.00 | 1.46 | 0.30 | 18.5 | 21.85 | 4.50 | 4.50 | 0.0 | 3.506 | 3.506 | 0.000 | -77.903 | -77.903 |
| Q1b | 7 | 8.76 | 1.61 | 0.90 | 24.2 | 15.00 | 6.50 | 6.50 | 0.0 | 4.097 | 4.097 | 0.000 | -63.028 | -63.028 |
| Q2 | 9 | 11.27 | 3.60 | 0.50 | 30.5 | 23.11 | 10.80 | 10.80 | 0.0 | 4.291 | 4.291 | 0.000 | 39.736 | 39.736 |
| B1 | 11 | 15.37 | 3.00 | 20.90 | 42.1 | 25.00 | 12.50 | 12.50 | 0.0 | 0.000 | 0.000 | 4.570 | 0.000 | 0.000 |

# FORWARD Electron Magnets

mnne39d4.tab

## Worst case

mnne39d4

mom = 18

| | | L1 | DL | gap | x | $\theta$ | IR1 | IR2 | OR | B1 | B2 | B | Grad1 | Grad2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | m | cm | mrad | cm | cm | cm | T | T | T | T/m | T/m |
| Q0 | 3 | 5.30 | 1.20 | 0.50 | 0.0 | 0.00 | 2.60 | 2.60 | 0.0 | 0.451 | 0.451 | 0.000 | -17.335 | -17.335 |
| Q2a | 5 | 7.00 | 1.46 | 0.30 | 0.0 | 0.00 | 3.00 | 4.20 | 0.0 | 0.168 | 0.235 | 0.000 | 5.586 | 5.586 |
| Q2b | 7 | 8.76 | 1.61 | 0.90 | 0.0 | 0.00 | 4.36 | 5.66 | 0.0 | 0.218 | 0.284 | 0.000 | 5.008 | 5.008 |
| Q2c | 9 | 11.27 | 2.00 | 18.72 | 0.0 | 0.00 | 6.90 | 6.90 | 0.0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

## Baseline case mom = 18

mnne39d4

mom = 18

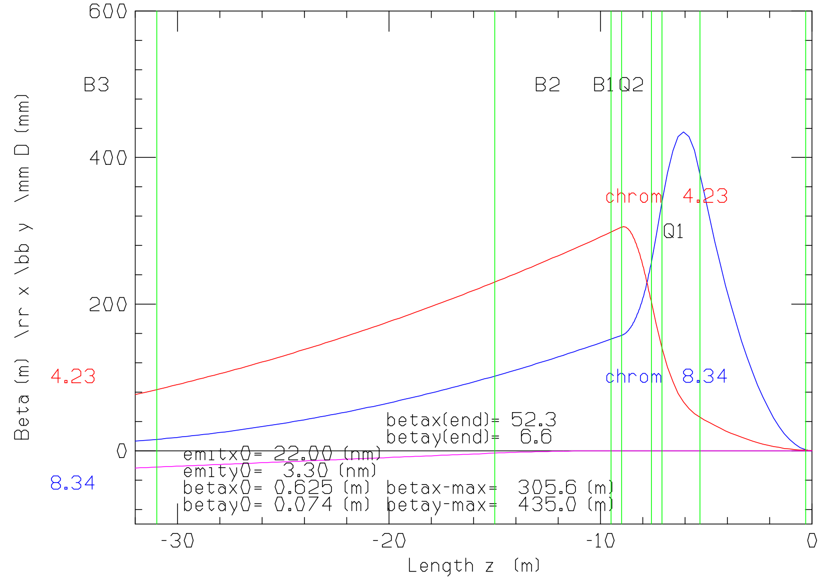
| | | L1 | DL | gap | x | $\theta$ | IR1 | IR2 | OR | B1 | B2 | B | Grad1 | Grad2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | m | cm | mrad | cm | cm | cm | T | T | T | T/m | T/m |
| Q0 | 3 | 5.30 | 1.20 | 0.50 | 0.0 | 0.00 | 2.60 | 2.60 | 0.0 | 0.331 | 0.331 | 0.000 | -12.713 | -12.713 |
| Q2a | 5 | 7.00 | 1.46 | 0.30 | 0.0 | 0.00 | 3.00 | 4.20 | 0.0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Q2b | 7 | 8.76 | 1.61 | 0.90 | 0.0 | 0.00 | 4.36 | 5.66 | 0.0 | 0.067 | 0.087 | 0.000 | 1.541 | 1.541 |
| Q2c | 9 | 11.27 | 2.00 | 18.72 | 0.0 | 0.00 | 6.90 | 6.90 | 0.0 | 0.266 | 0.266 | 0.000 | 3.852 | 3.852 |

# REAR Hadron Magnets with Tapered Q1ApR (mnnp3R7t)

| | | L1 | DL | gap | x | $\theta$ | $IR_1$ | $IR_2$ | B | $Bpt_1$ | $Bpt_2$ | $Grad_1$ | $Grad_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | m | cm | mrad | cm | cm | T | T | T | T/m | T/m |
| Q1ApR | 3 | 5.30 | 1.80 | 0.50 | -14.8 | -25.00 | 2.01 | 2.77 | 0.0 | 1.585 | 2.187 | -78.833 | -78.833 |
| Q1BpR | 5 | 7.60 | 1.40 | 2.00 | -21.3 | -25.00 | 3.00 | 3.00 | 0.0 | 2.365 | 2.365 | -78.833 | -78.833 |
| Q2pR | 7 | 11.00 | 2.00 | 21.40 | -30.8 | -25.00 | 5.00 | 5.00 | 0.0 | 3.713 | 3.713 | 74.250 | 74.250 |

Lower pole tip fields should allow direct wind & tapered Q1ApR

# REAR Electron magnets mnne3R7a




mom = 18

| | | L1 | DL | gap | x | $\theta$ | $IR_1$ | $IR_2$ | B | $Bpt_1$ | $Bpt_2$ | Grad) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | m | m | m | cm | mrad | cm | cm | T | T | T | T/m |
| Q1eR | 3 | 5.30 | 1.80 | 0.50 | 0.0 | 0.0 | 6.60 | 7.95 | 0.000 | 0.851 | 1.026 | -12.900 |
| Q2eR | 5 | 7.60 | 1.40 | 0.50 | 0.0 | 0.0 | 8.32 | 9.38 | 0.000 | 1.048 | 1.181 | 12.600 |
| B2eR | 9 | 9.50 | 5.50 | 15.98 | 0.0 | 0.0 | 9.75 | 13.88 | 0.180 | 0.00 | 0.000 | 0.000 |

Q1eR is tapered with constant gradient