Polarized e^- in the LH*e*C

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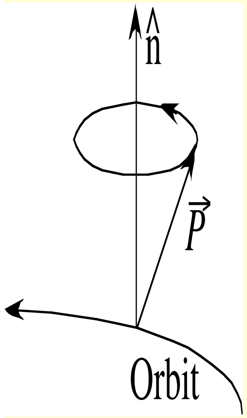
Preliminaries

- LH*e*C: Ring-Linac and Ring-Ring options
- We have worked on Ring-Ring
  - Ring-Linac seems comparatively easy

- > This talk covers Ring-Ring
- > Some thoughts on Ring-Linac at the end.

Polarization

- Sokolov-Ternov self polarization due to sync. rad.
  - slightly different rate for S||B and S⊥B
  - ultimate polarization is 92.4%
  - time scale is $$\tau_{\mathrm{st}}^{-1} = \frac{5\sqrt{3}}{8} \frac{r_{\mathrm{e}} \gamma^5 \hbar}{m_{\mathrm{e}} |\rho|^3}$$
- at E = 60 GeV, ρ = 2700 m, R=27000 m
  - $\tau_{ST} \approx$ 60 min.
  - a little longer than we like but acceptable
  - *note steep energy dependence*



- **Stable spin direction**
  - $\hat{n}=\hat{n}(s)$ is the invariant spin field. A polarization vector $\vec{P} \parallel \hat{n}$ will remain so turn after turn. $\hat{n}(s)$ depends on the position in phase space of the particles but is usually close to vertical due to the vertical guide field.
  - “spin tune”, $=\gamma G$ for a flat ring, # spin precessions per turn.
  - On the closed orbit and on momentum $\hat{n}(s)=\hat{n}_0(s)$.
  - If $\hat{n}$ varies with energy, it undergoes non-adiabatic changes at each γ emission
    - > spin diffusion, characterized by $\vec{d} = \frac{d\hat{n}}{d\delta}$

$G=(g\text{-}2)/2\approx 0.0012$,
γG(60 GeV) ≈ 136,
for electrons

Depolarization

- Depolarizing effects due to spin diffusion:
  - $d\hat{n}/d\delta \neq 0$, esp. near spin-orbit resonances
  - $\gamma G = n \pm mQ_s \pm lQ_y \pm oQ_x$; n,m,l,o: integer
  - Driven by spin-mismatch
    - spin rotators, lattice peculiarities, misalignment/c.o.
- Characteristic depolarization rate:

$$\tau_{DK}^{-1} = \frac{5\sqrt{3}}{8}\frac{\lambda_e}{2\pi} r_e c \gamma^5 \left\langle \frac{1 - \frac{2}{9}\left(\hat{n}\cdot\vec{s}\right) + \frac{11}{18}\vec{d}^2}{\rho^3} \right\rangle$$

- Eq. polarization becomes

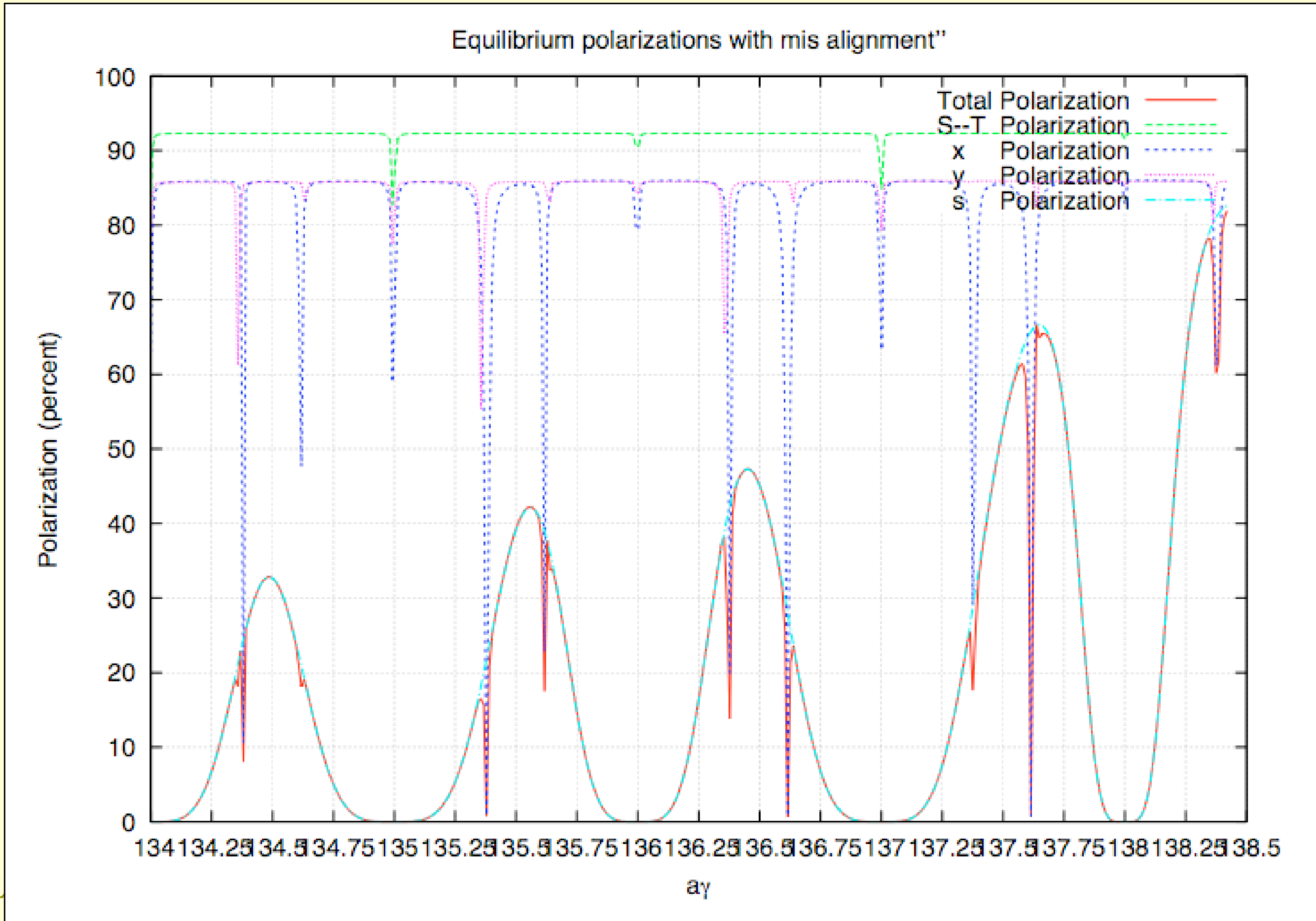
$$P_\infty \approx P_{ST} \frac{1}{1 + \frac{\tau_{ST}}{\tau_{DK}}}$$

LH*e*C Lattice

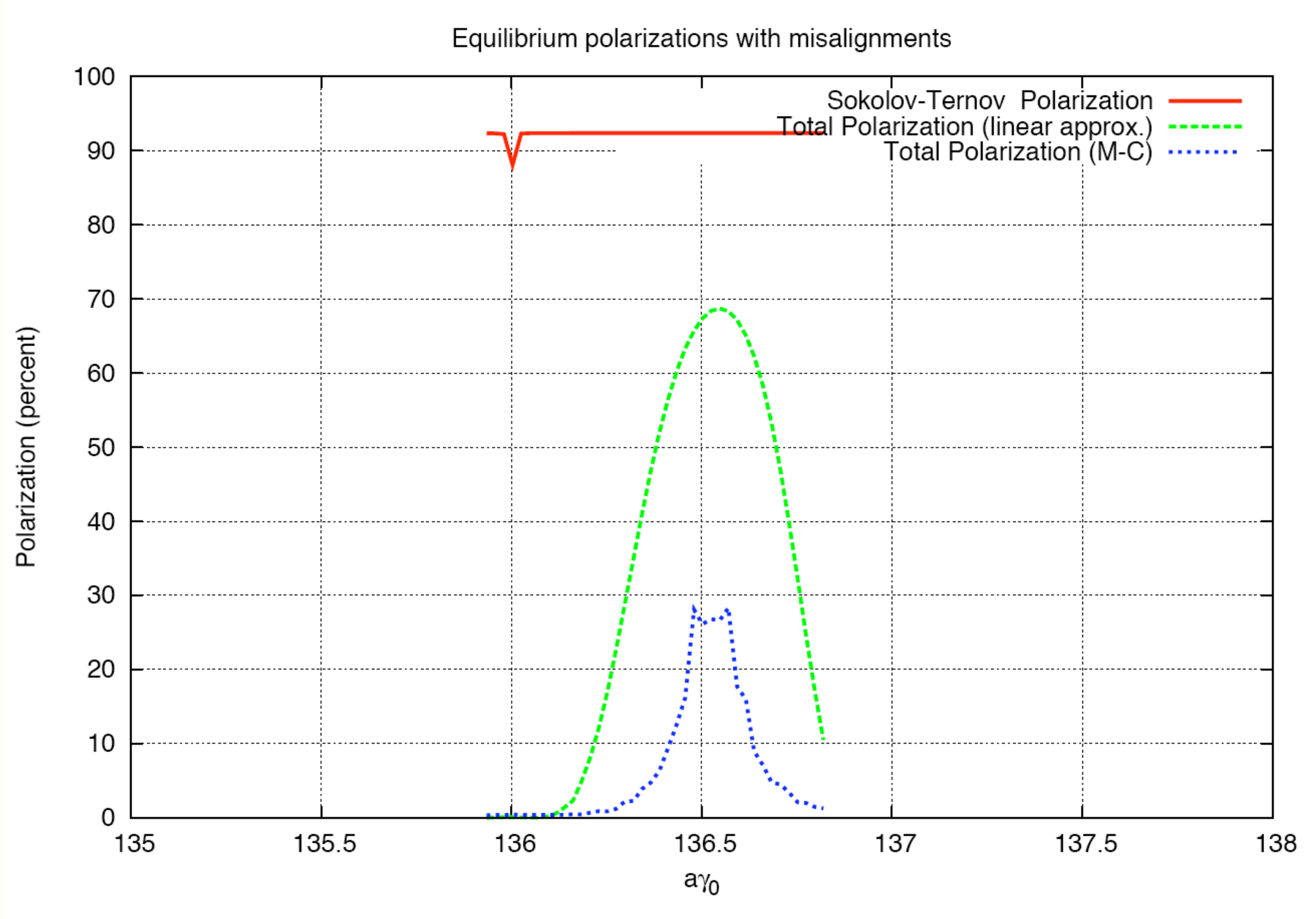
- Flat-ring scenario:
  - M. Fitterer V1.0 lattice
  - no bypasses (not expected to be an issue)
  - no real IR (potential issue due to bending for collisions)
  - 700 MV rf voltage, $\nu_s = 0.067$ (@60 GeV)
- Misalignments
  - 150μm rms quadrupoles, 0.3 mr quadrupole roll
  - orbit corrected (vertic.), *x*-*y* corrector at each quad
  - 50μm rms orbit excursions

SLICK (analytic)

100 μm misal.
195 μm (mx)
52 μm (rms)
res. orbit

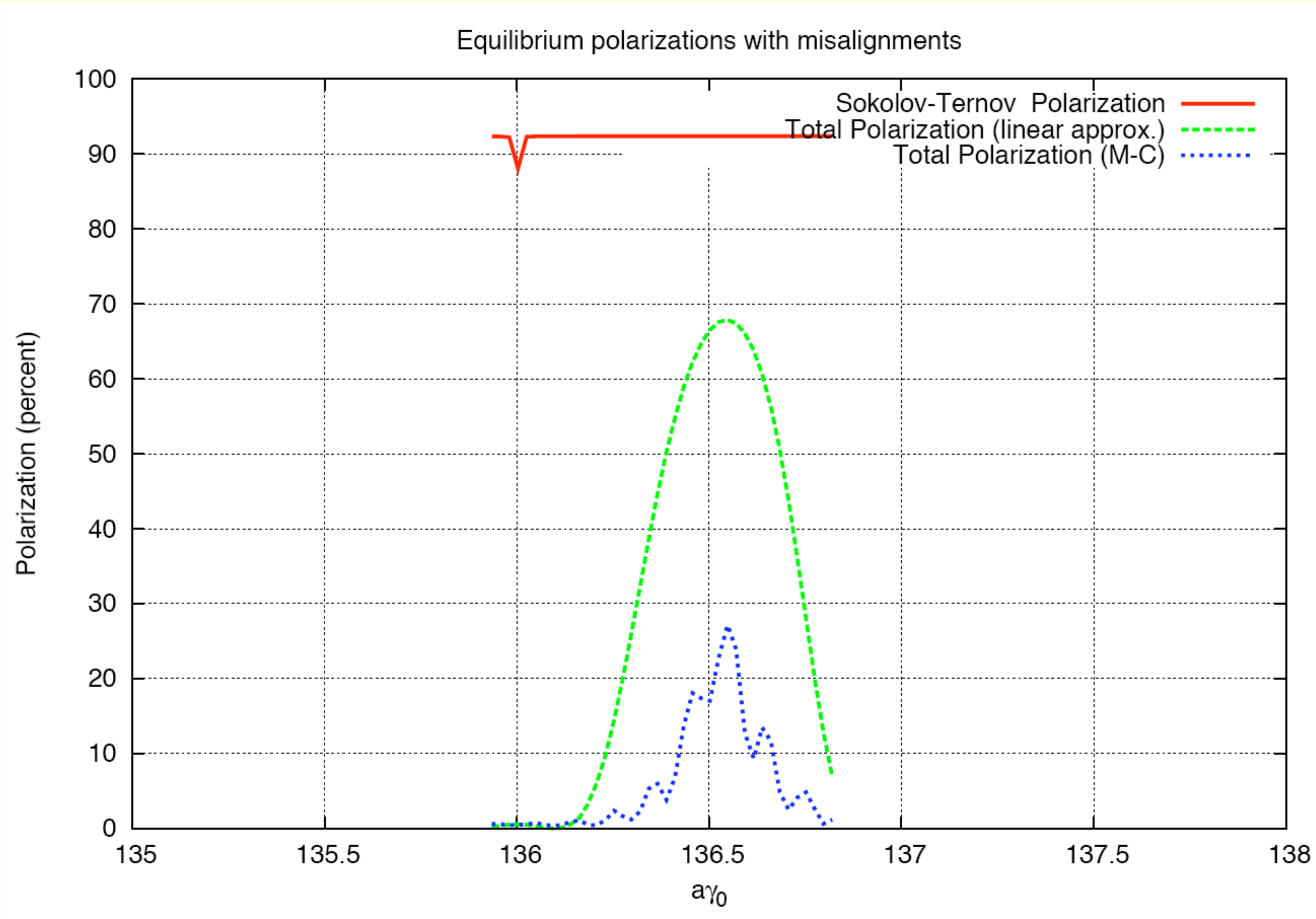


ν_s=0.067



Equilibrium polarizations with misalignments
Sokolov-Ternov Polarization
Total Polarization (linear approx.)
Total Polarization (M-C)
Polarization (percent)
aγ0
100
90
80
70
60
50
40
30
20
10
0
135
135.5
136
136.5
137
137.5
138

ν_s=0.1



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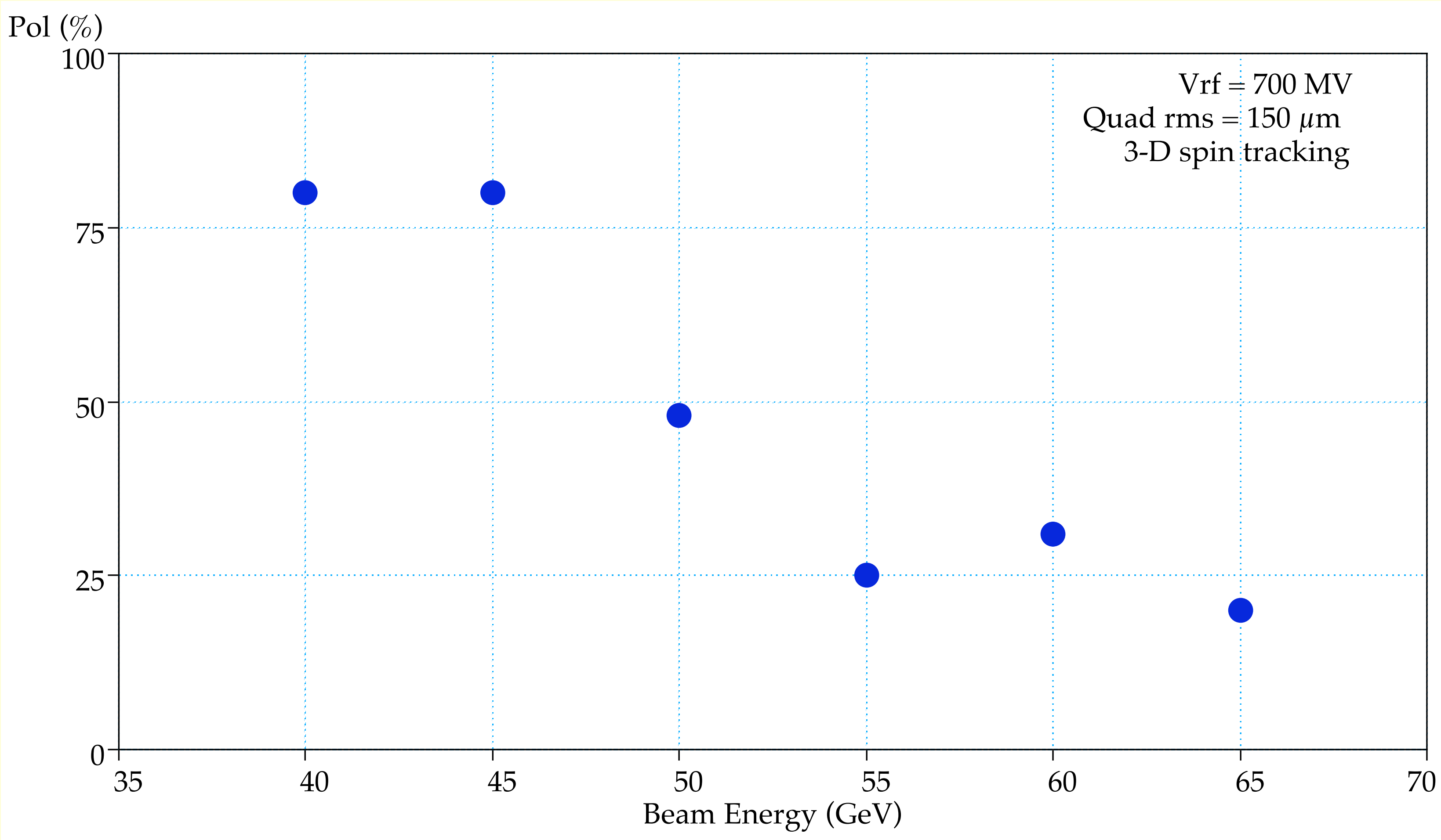
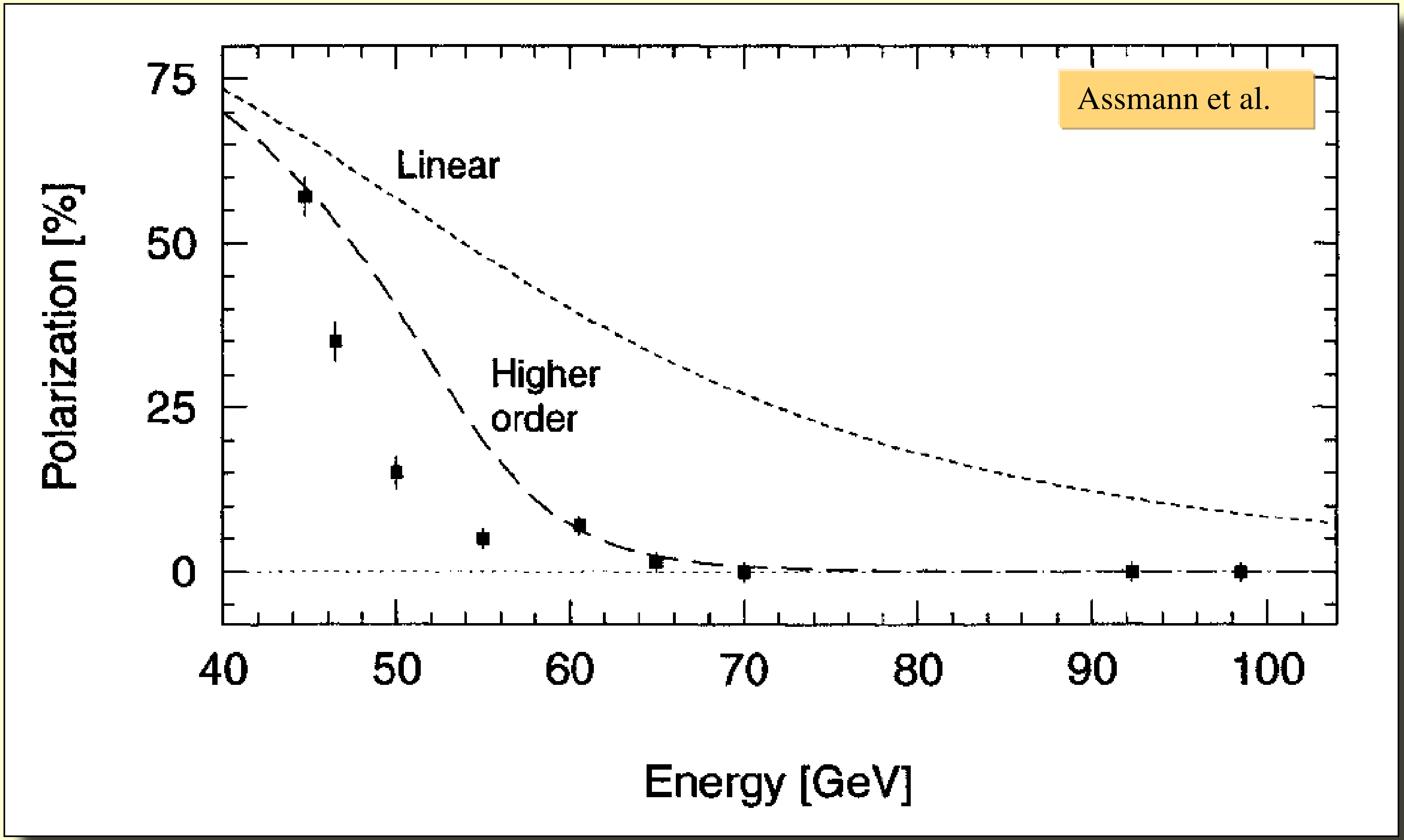
Polarization *vs* Energy



LEP Results

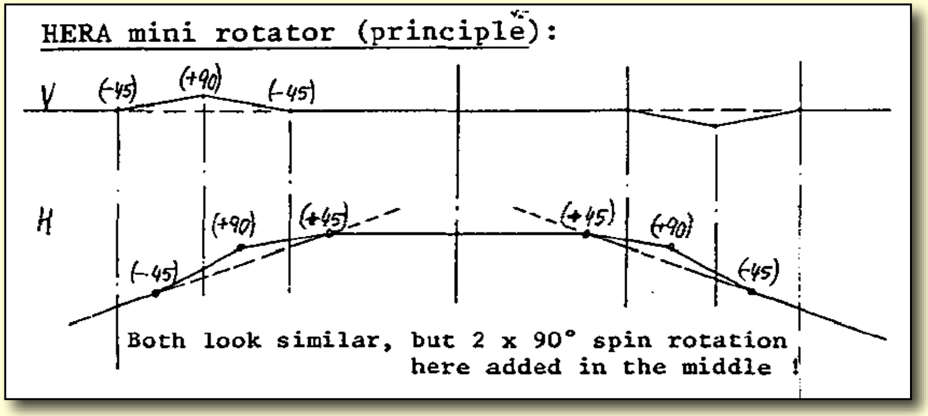


Assmann et al.
Linear
Higher order
Polarization [%]
Energy [GeV]
75
50
25
0
40
50
60
70
80
90
100

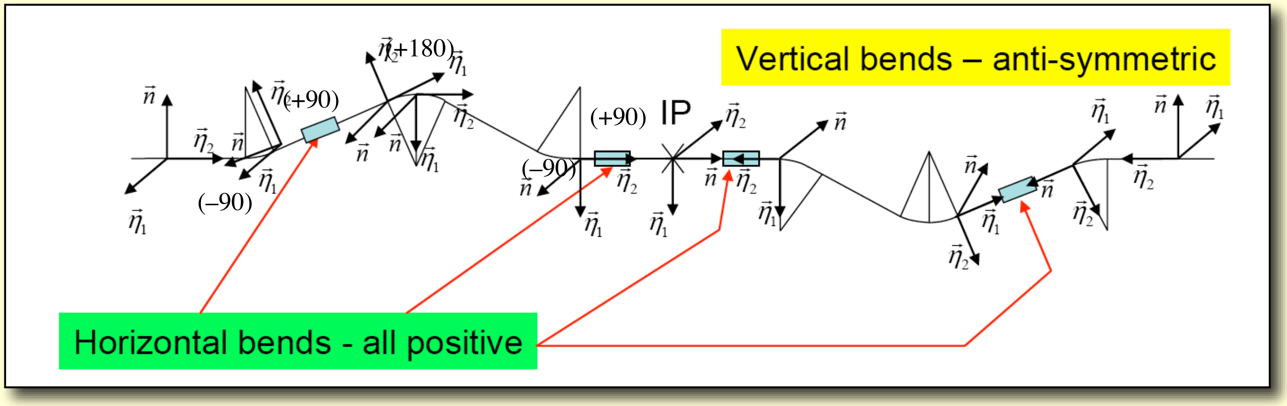
- Polarization drop-off with *E*:
  - seen at LEP
  - direct effect of the energy spread (≈0.1% *rms*)
    - $d\hat{n}/d\delta$ can't be reasonably made 0 near $\gamma G=n$
    - beam-lets near $\delta E=\pm 0.441/2$ GeV get depolarized partially
  - choice of misalignment & ν_s have some effect
    - clearly, better alignment helps
    - choice of ν_s tbi
  - beam energy spread not really a free parameter
    - but may use damping partition to minimize
  - Can run at lower energy
    - but τ_{ST} becomes 5 h at 45 GeV!

Spin Rotators

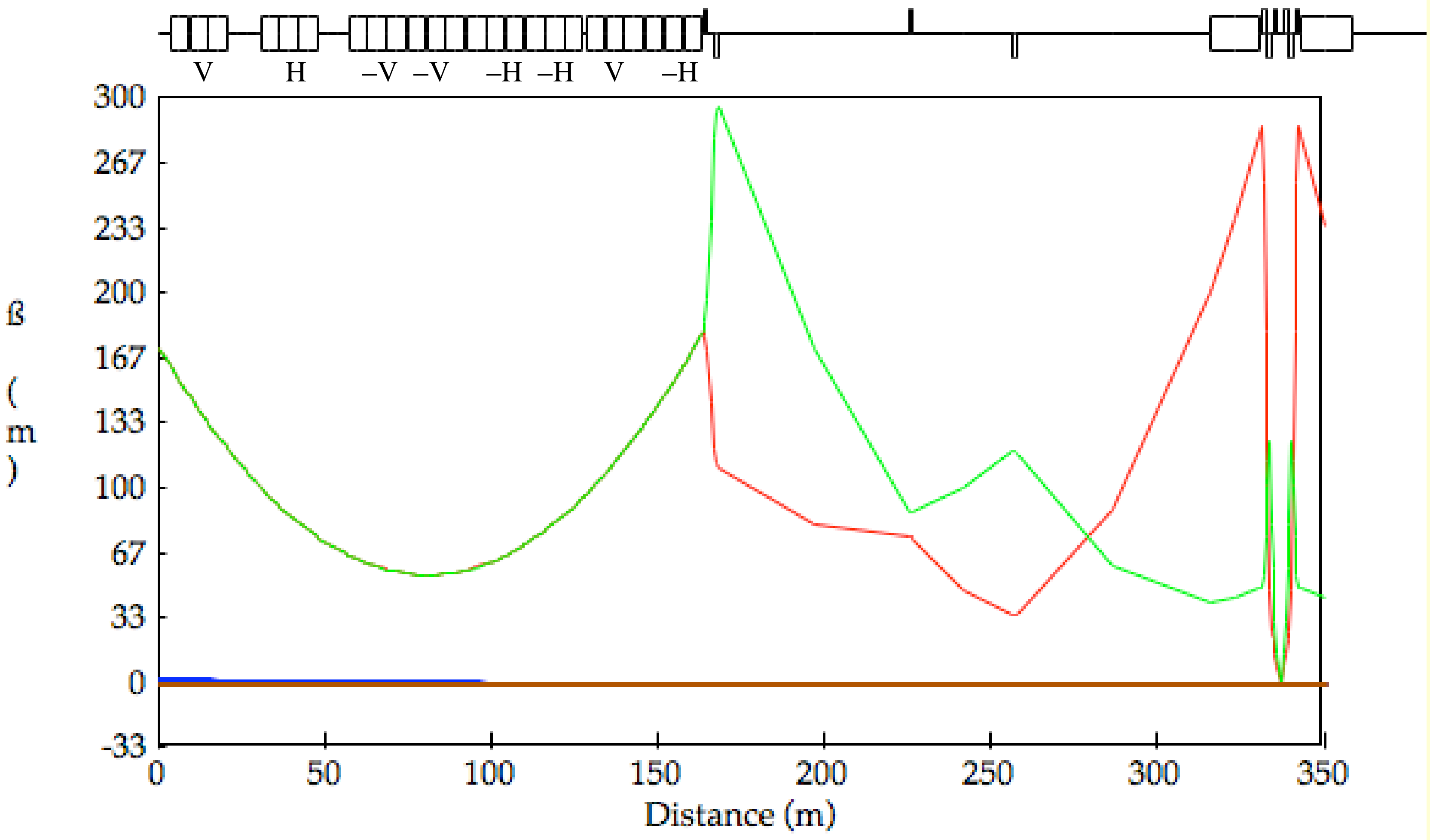
- HERA spin rotator at DESY:



- I. Koop's Rotator proposed for SuperB:

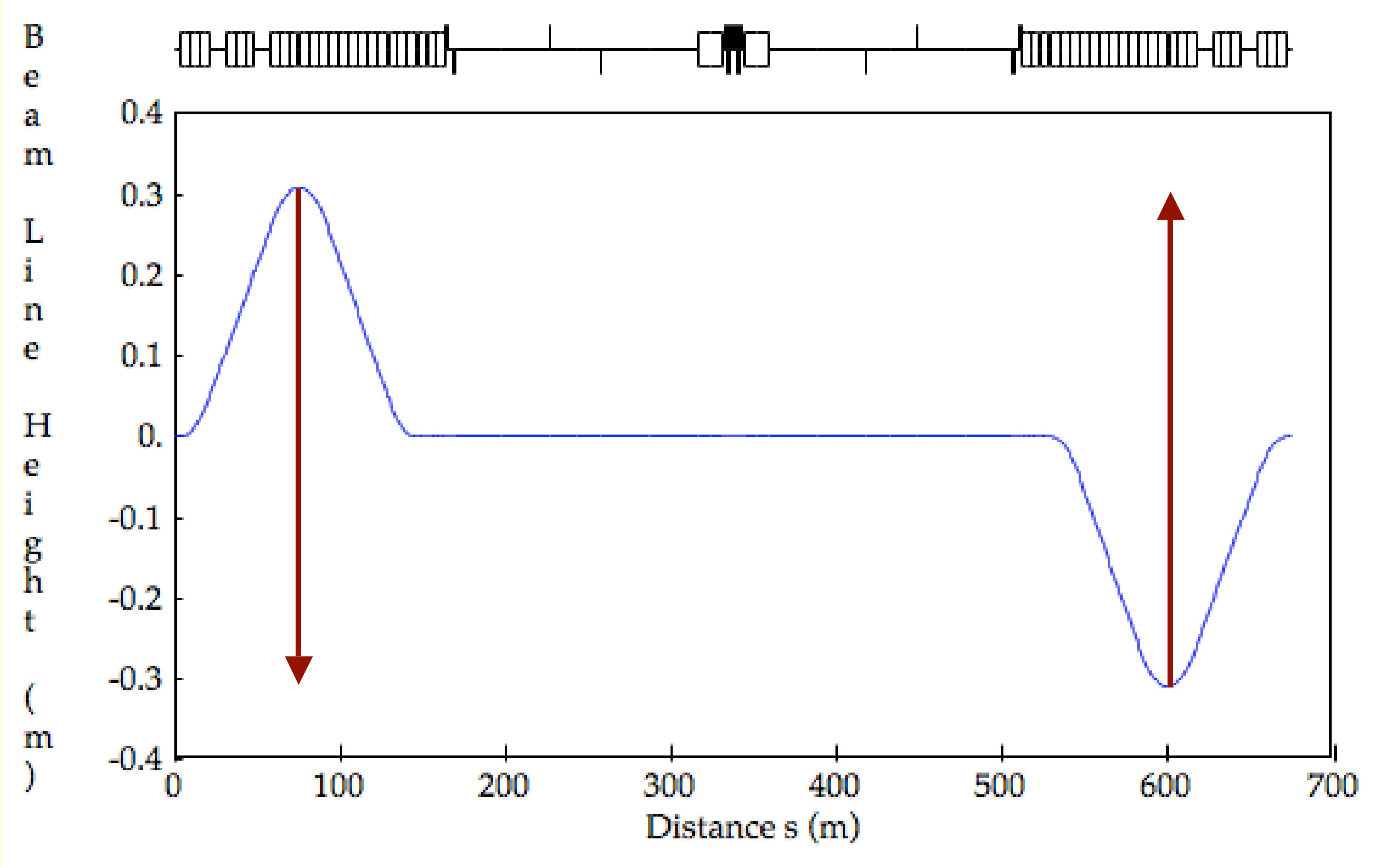


HERA Rotator for LH*e*C (1st att.)



Side View

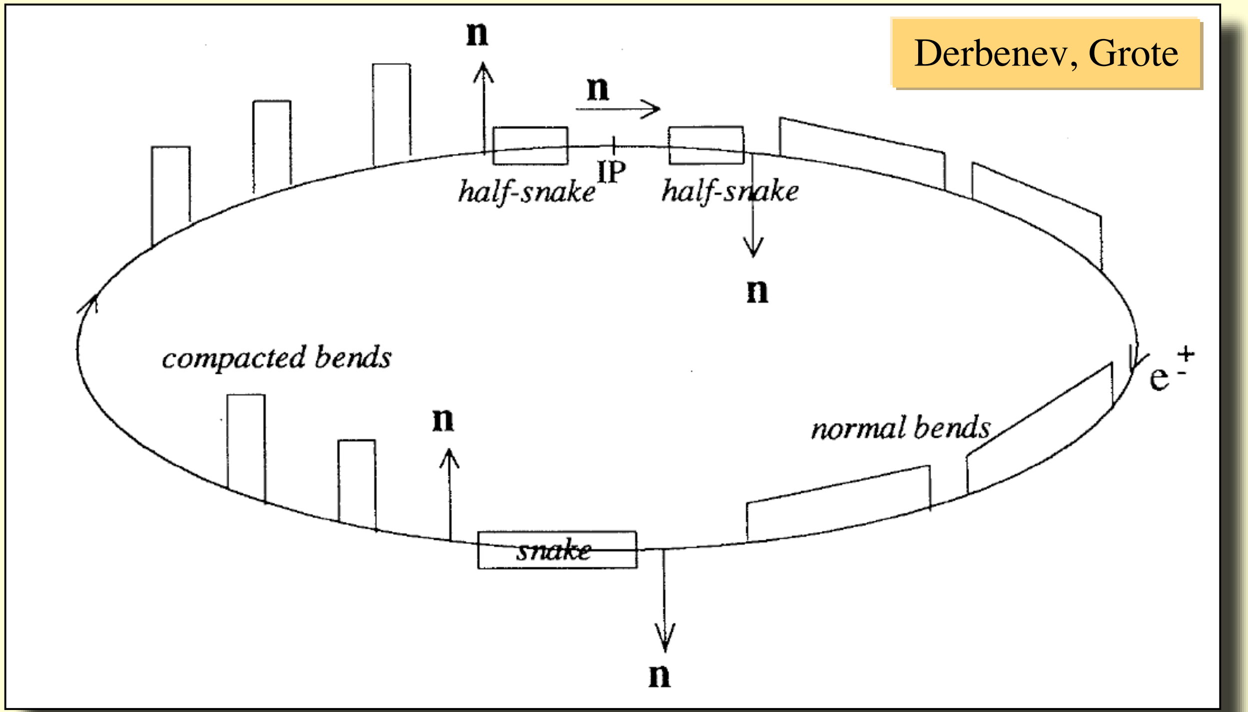
flip vbend for helicity inversion



Alternative: Snakes

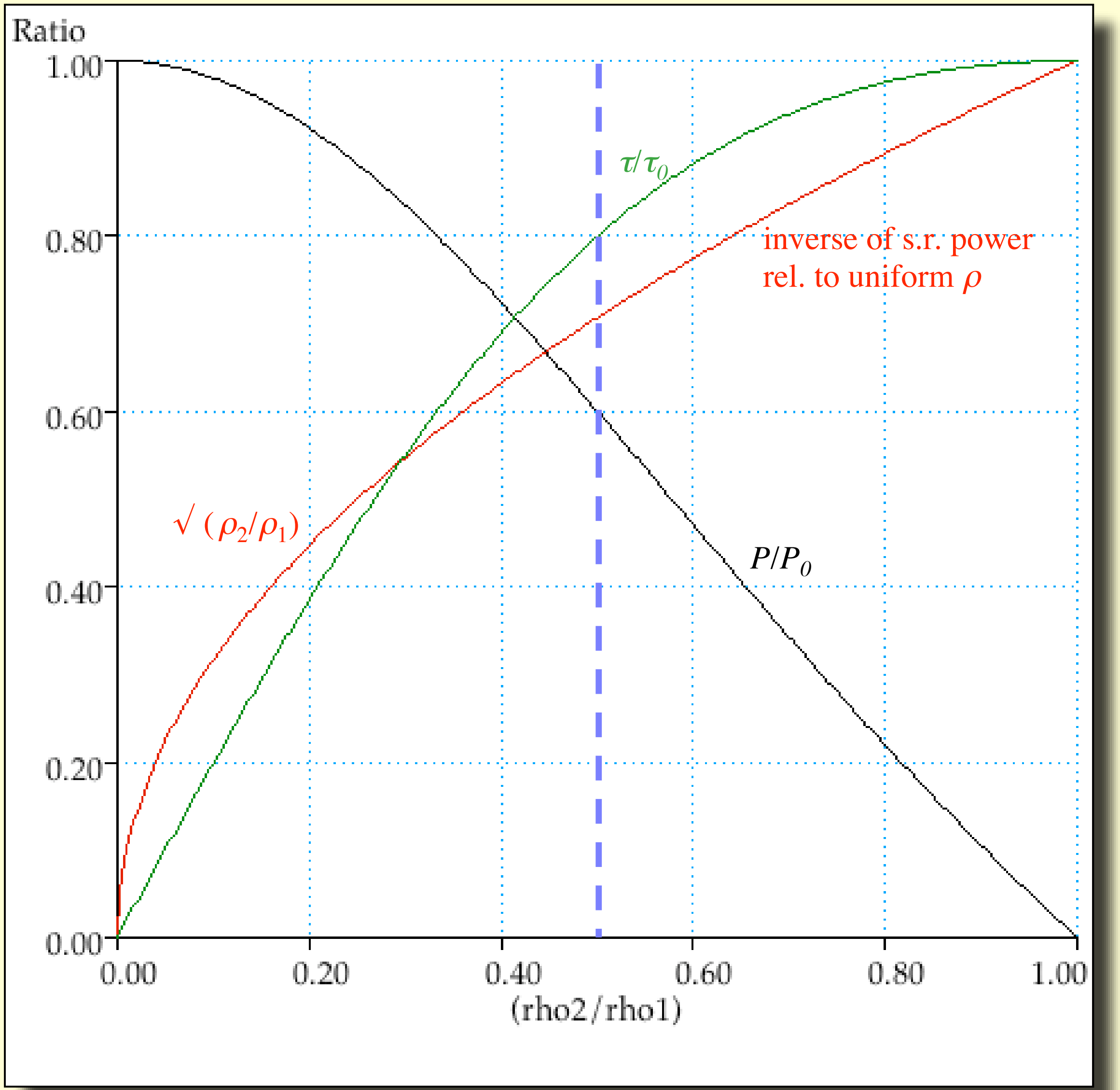
- Type-2 snake (IR) & type-1 snake (opposite region)
  - type-2 snake about *s*, type-1 snake about *x*.
  - n(s) up in one half, down in the other half or the ring
  - type-2 snake integrated w/ spin rotators (& vert. dogleg)
- Polarization from balance of the arcs

$$\tau_{ST} = \frac{2\pi}{99} \frac{E}{C\rho^2}$$



Estimate for Asymmetric Ring

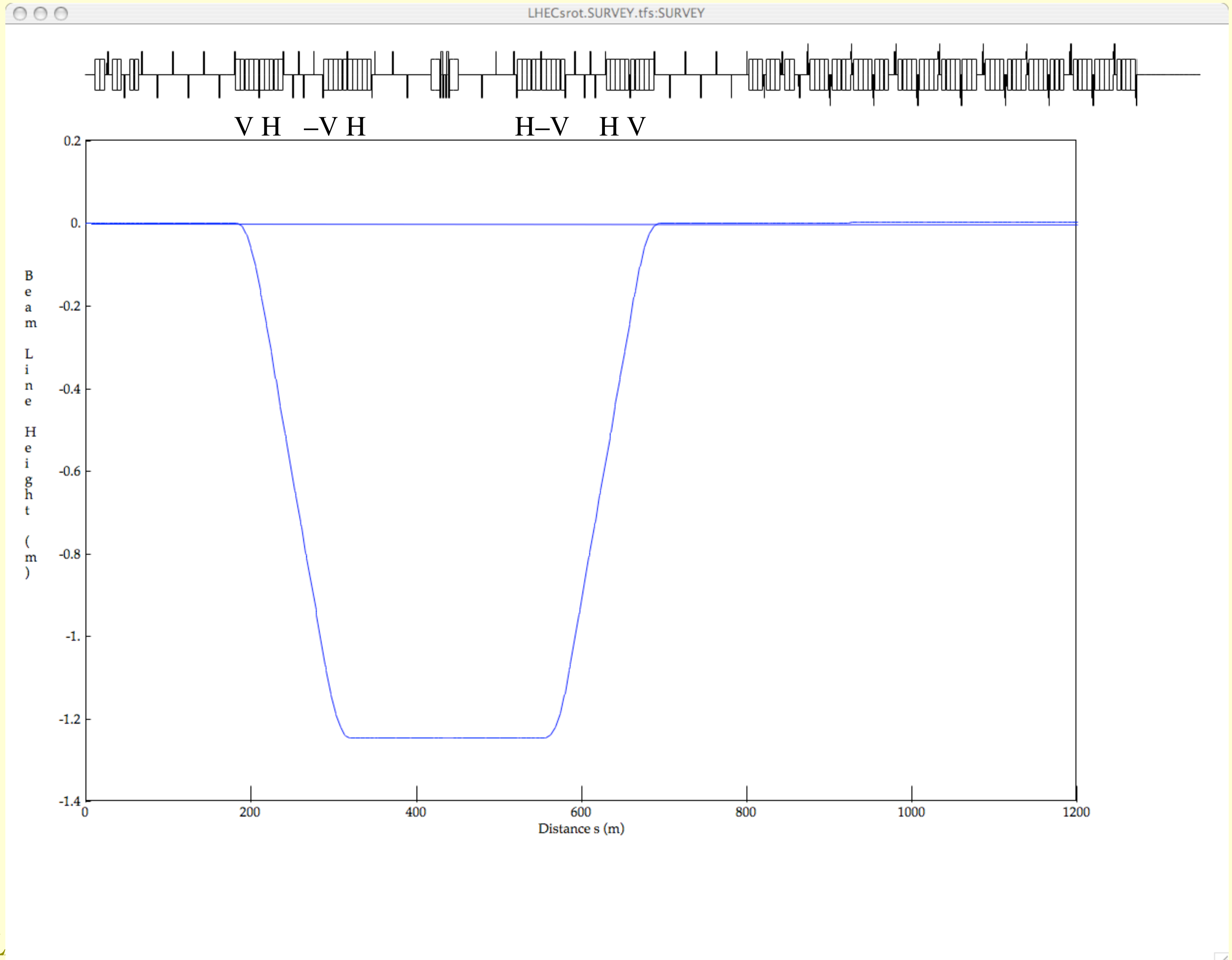
$1/\rho^2$ scaling



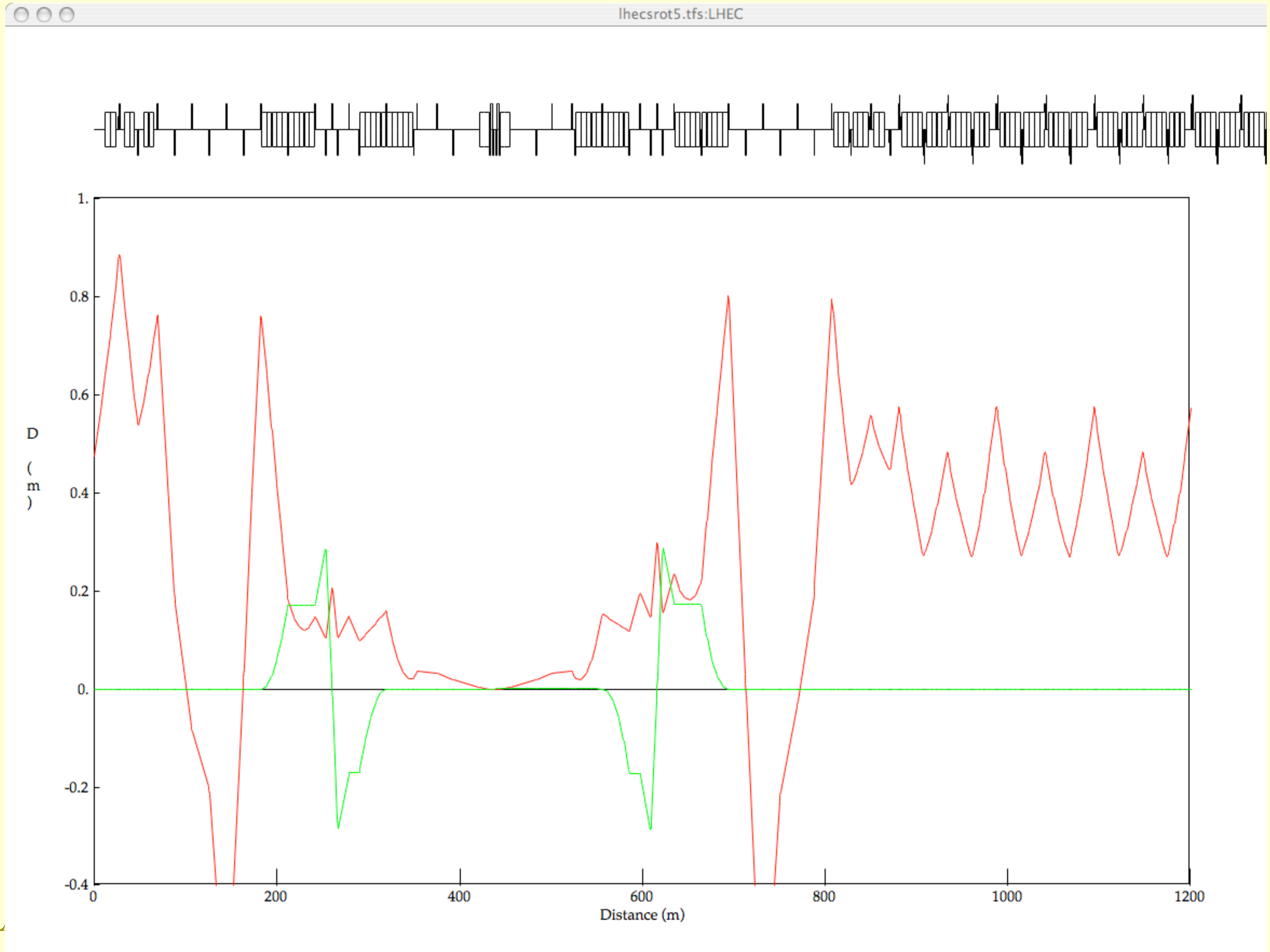
D-G Setup in LH*e*C

- Type-2 snake integrated w/ vertical dogleg
- Type-1 snake ideal thin-lens snake in IR 5
  - a real snake is comparable to a pair of rotators
- 554 bends with double angle (field) in one half of ring
  - ρ = 2671 m regular; 1336 m in polarizing cells.
  - V_0 = 586 MeV
- $Q_x = 124.36$, $Q_y = 88.8$, $Q_s = 0.067$, $\sigma_{co} = 75\ \mu$m
- Tilt of $n_0 \approx 8$ mr *rms*
- $\nu_0 \approx 0.41$ independent of E
  - deviates from 0.5 because of rotator.

IR with Type-2 Snake Side view

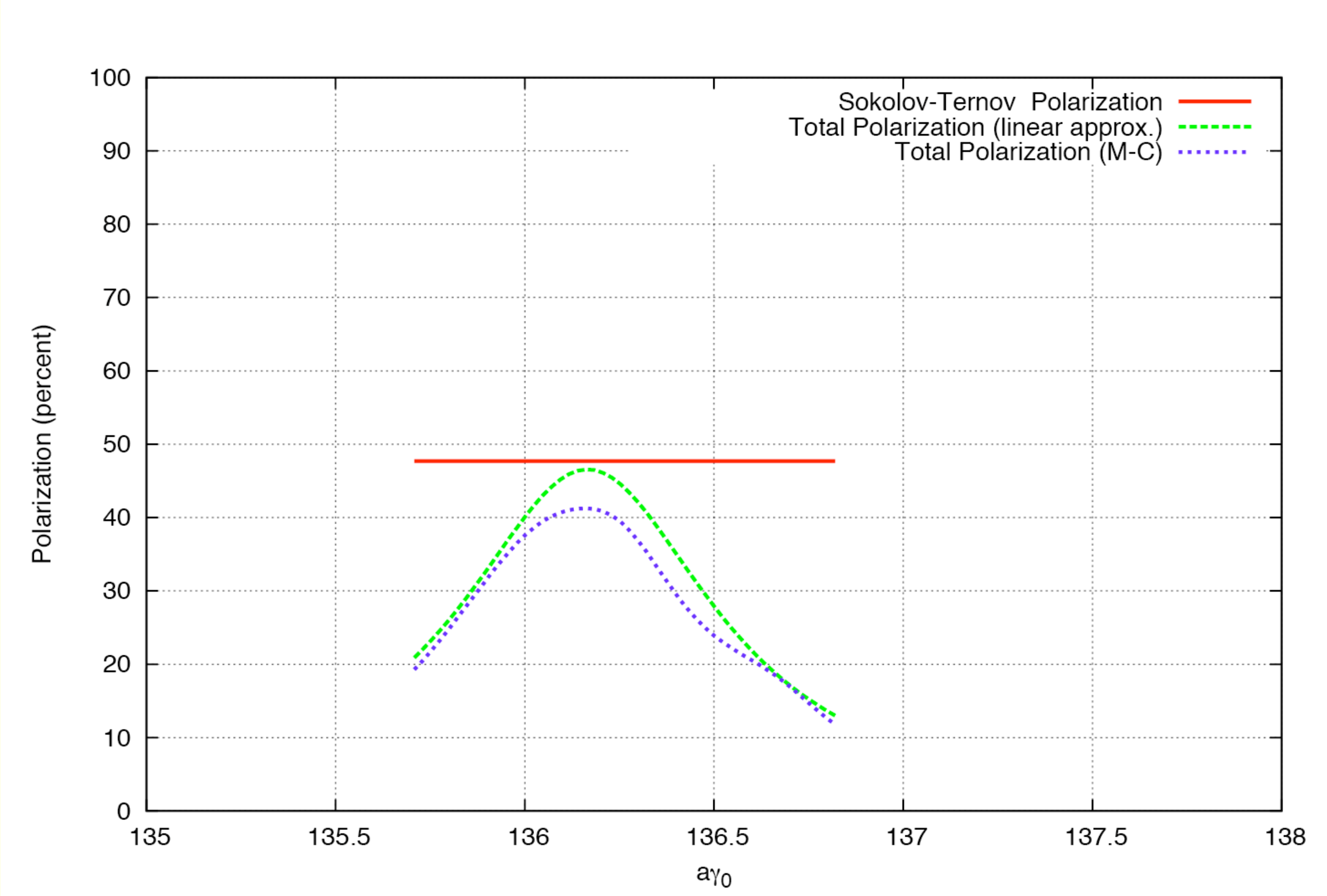


Dispersion plot



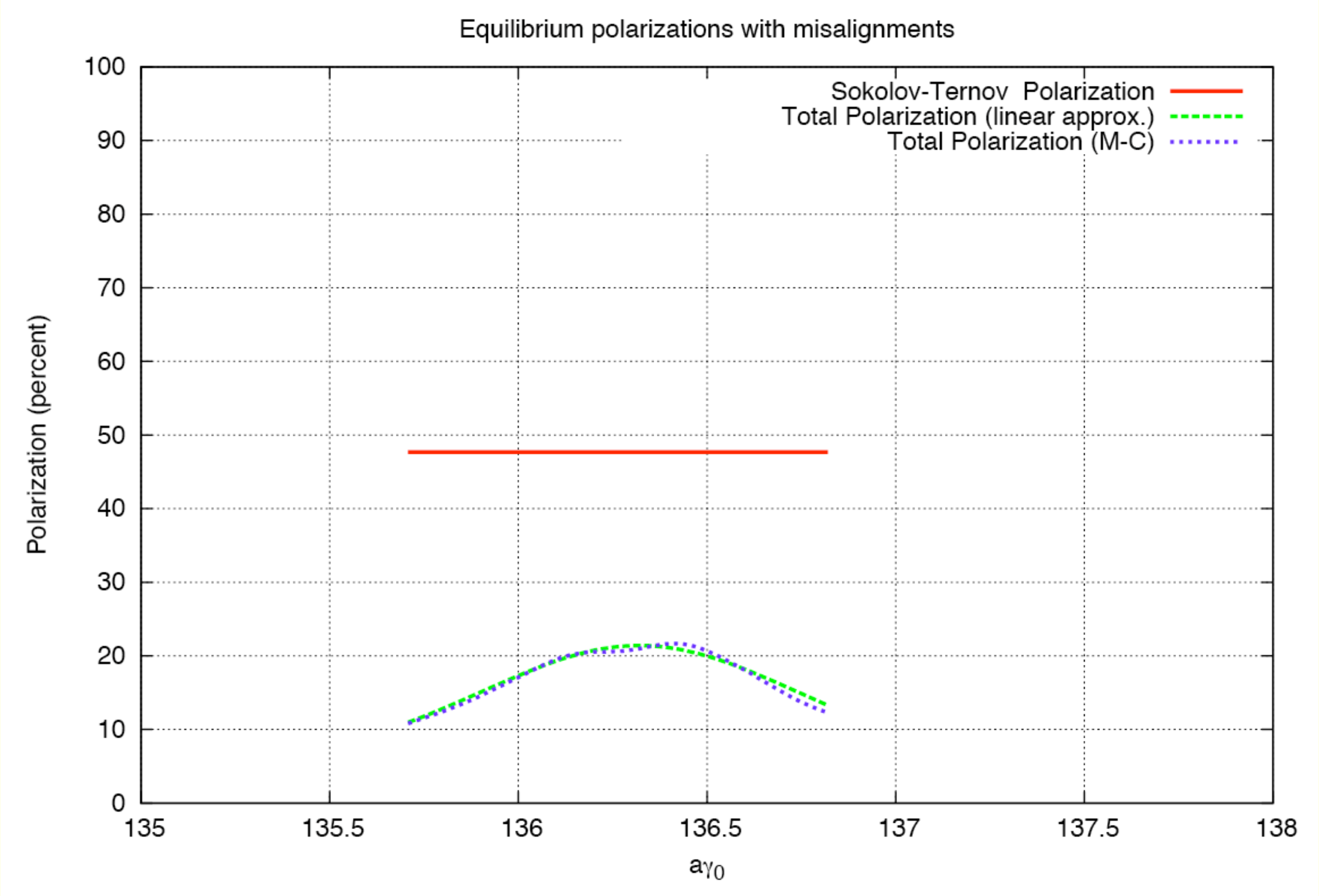
SLICKTRACK, no Misalignment

forced spin match in IR by zeroing out G-matrix elements



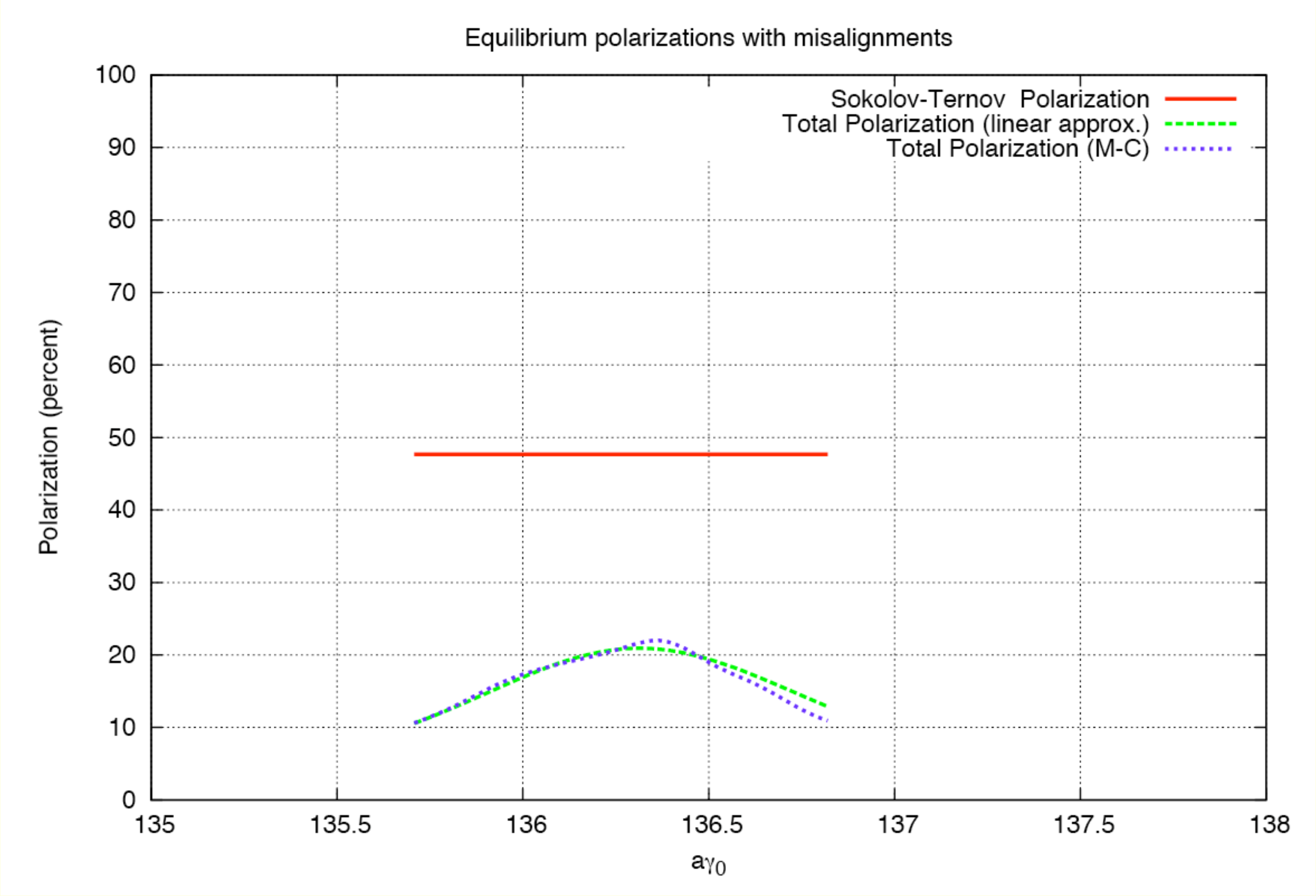
SLICKTRACK with Misalignment

forced spin match by zeroing out G-matrix elements, ν_s=0.067

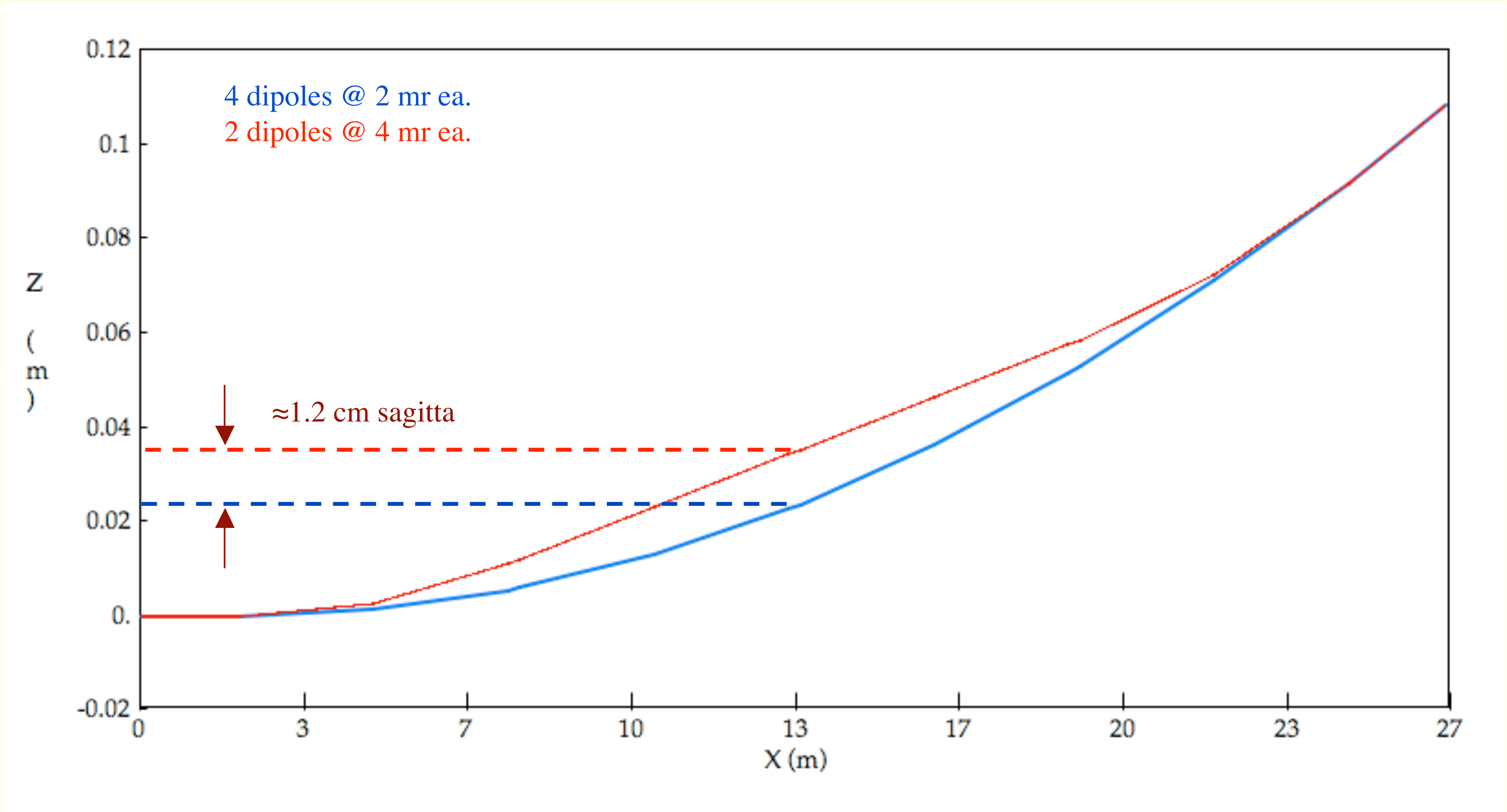


SLICKTRACK with Misalignment

forced spin match by zeroing out G-matrix elements, ν_s=0.1



Switching Dipole Excitation



Summary

- Flat ring + spin rotator:
  - chance of 25…40% polarization at 60 GeV
  - ring energy quantized in 0.441-GeV steps, avoid $\gamma G \approx n$
  - lower energy helps, but S-T time becomes long
    - ≈ 50% increase in τ for 10% decrease in E
  - IR design affected by spin dynamics
    - spin matching, no interleaved x and y bends
- D-G siberian-snake scheme
  - similar polarization, but indep. of energy
  - avoid moveable rotator magnets
    - but need switching of the arc dipole strings for helicity
    - higher s.r. energy loss/turn
  - less impact of synchrotron motion
- In both cases alignment is extremely important

Ring-Linac Option

- Only a few passes (if any)
  - no spin diffusion to speak of, "easy"
  - because of E-spread of beam likely want $\vec{P} \| \vec{B}$ in arcs
    - avoid strong correlation P with δE
- We are left with 3 Challenges:
  - C1: The e^- source
  - C2: preparing the initial spin state
  - C3: Spin Rotators in the IR
    - similar to ring-ring => no further discussion

Challenges for Ring-Linac

- Challenge 1: The e^- source
  - – no suitable extant low-ε high I source
  - – BNL working on several schemes
    - srf, issue is poisoning of cathode by backstreaming ions
      - – test anticipated by end of this CY.
    - "Gatling gun" could potentially deliver 20 mA I_{ave}
  - – MIT-Bates working on hollow-cathode gun
- Challenge 2: The Wien filter
  - – used to align spin vertical.
  - – *E*-fields scale with energy => use at the lowest *E* poss.
  - – several MeV: TOUGH!
  - – Can dipole & solenoid be used?

End of Presentation