Polarization in Super*B*

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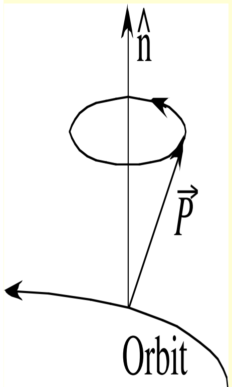
Introduction

- How to Polarize Electrons:
  - Use radiative polarization:
    - Sometimes emission of a photon induces spin flip. The slight difference in probability between parallel and antiparallel to the B-field causes a net polarization built-up: Sokolov-Ternov effect.
    - $$\tau_p^{-1} = \frac{5\sqrt{3}}{8}\frac{\lambda_e}{2\pi} r_e c \gamma^5 \left\langle \frac{1 - \frac{2}{9}\left(\hat{n}\cdot\vec{s}\right) + \frac{11}{18}\vec{d}^2}{\rho^3} \right\rangle$$ (DKM formula)
  - Inject already polarized electrons:
    - In a planar ring, the polarization vector ("spin") precesses (mostly) about the vertical guide field => inject vertically polarized beam
    - The above mentioned radiative (de-)polarization effect still applies.

Introduction (cont'd)

- Polarization build-up time for Super*B*:
  - HER: $\gamma = 13700$ (7 GeV), $\rho = 110$ m, $R = 263$ m: 5…6 h
- > inject polarized electrons into HER.
  - A polarized source of 15 nC/sec is needed to maintain beam current in the SuperB HER. Sources like this are available The SLC gun e.g. delivers 15 nC=1E11 e^-/pulse at 120 Hz (≈2 μA). Polarization can be up to 90%.
- Polarized positrons would require a polarized positron source. This is not a part of the Super*B* proposal at present.



- **Stable spin direction**
  - $\hat{n}=\hat{n}(s)$ is the closed solution for the spin motion around the ring. A polarization vector $\vec{P} \parallel \hat{n}$ remains stationary turn after turn. $\hat{n}$ is usually close to vertical due to the vertical guide field.
  - "spin tune", =γG for a flat ring, # spin precessions per turn.
  - To maintain polarization need to watch the quantity $\vec{d}$ in the DKM formula. It quantifies the variation of the $\hat{n}$-axis with momentum:

$$\vec{d} = \gamma \frac{d\hat{n}}{d\gamma}$$

    Large values of $\vec{d}$ cause radiative *depolarization*.
  - $\vec{d}$ becomes non-zero due to horizontal field components in the ring (vertical orbit & correctors, detector solenoid, vertical betatron oscillations). $\vec{d}$ tends to large values at spin tune near integer values.

$G=(g\text{-}2)/2\approx 0.0012$,
γG(7 GeV) ≈ 16,
for electrons

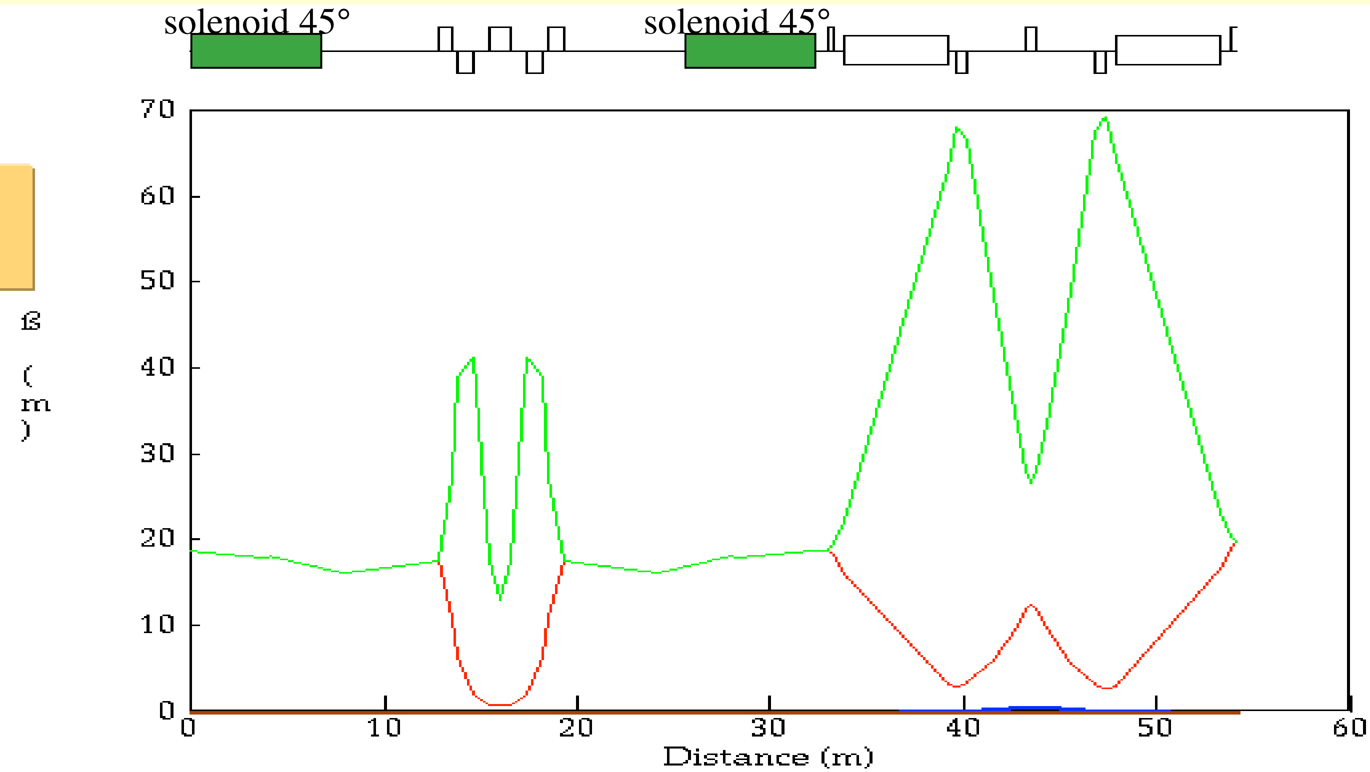
Spin Rotation

- Polarization in the ring will normally be vertical. But needs to be longitudinal at the IP
  - => spin rotators needed before and after the IP to align $\vec{P}$ longitudinally & restore to vertical.
  - This is achieved with dipole fields (horizontal and vertical fields) and/or with solenoids
- The net rotation wanted is by 90° about the transverse horizontal axis
  - Most straightforward way is to use a solenoid (90° about longitudinal axis => radial polarization) followed by a horizontal dipole (90° about vertical axis => longitudinal polarization).
    - solenoids need to be strong since $\Theta_{spin} \approx (1+G)*BL/B\rho$ vs $\gamma G*BL/B\rho$
    - solenoids introduce x–y coupling.

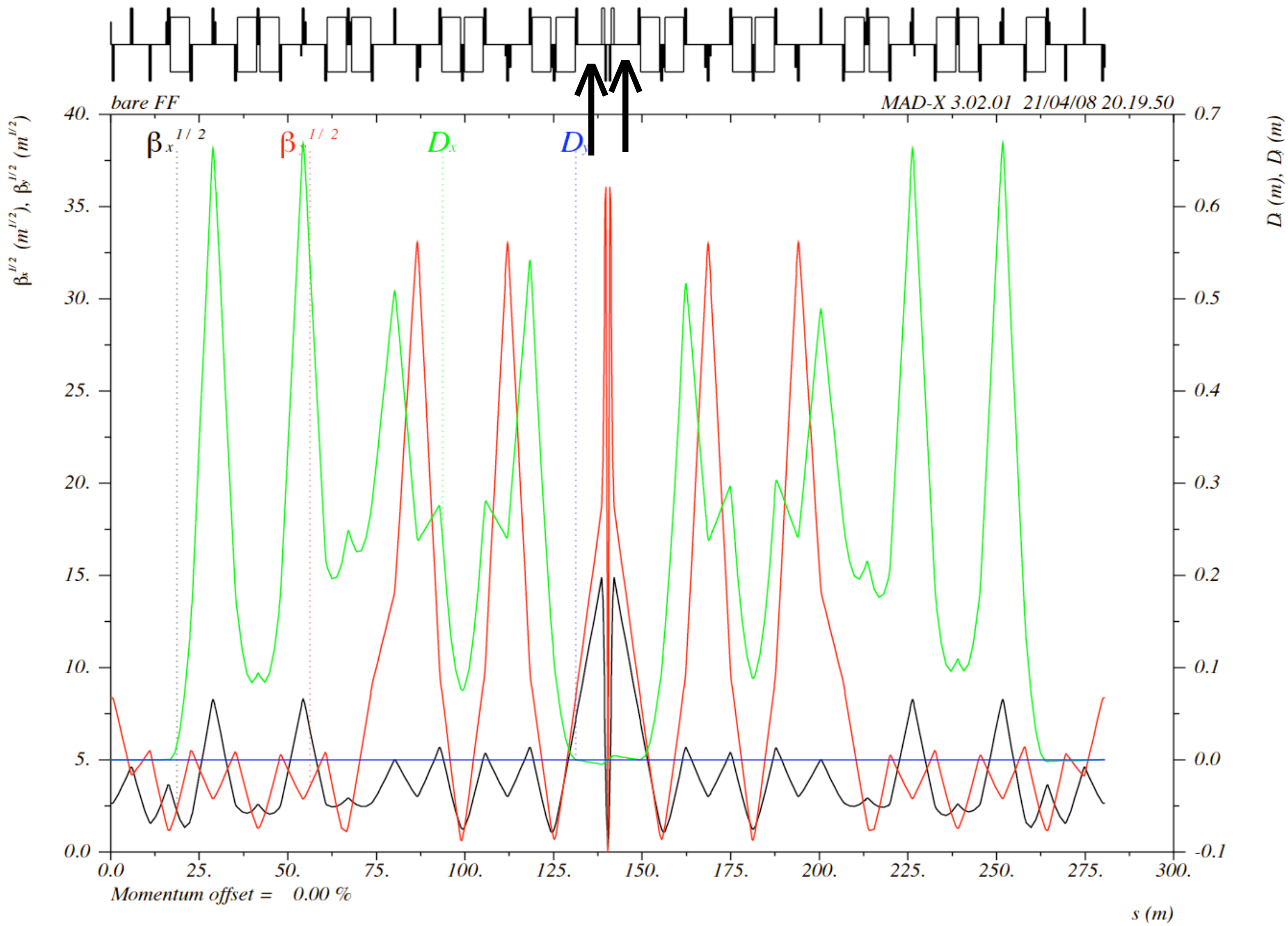
Solenoid Rotator

- $\Theta_{spin}=(1+G)*BL/(B\rho)$ => 36.6 Tm for 90° spin rotation
  - 2.5 T field => 14.66 m total length, 30E6 Amp turns
- Dipole: $\Theta_{spin}=(\gamma G)*BL/B\rho$ => 2.3 Tm, 5.7° orbit for 90° spin
- Zholents & Litvinenko have shown how to compensate the plane rotation of the solenoid by optics in between two 45° solenoids.

Total length ≈ 55 m/side



Original IR Insertion Optics

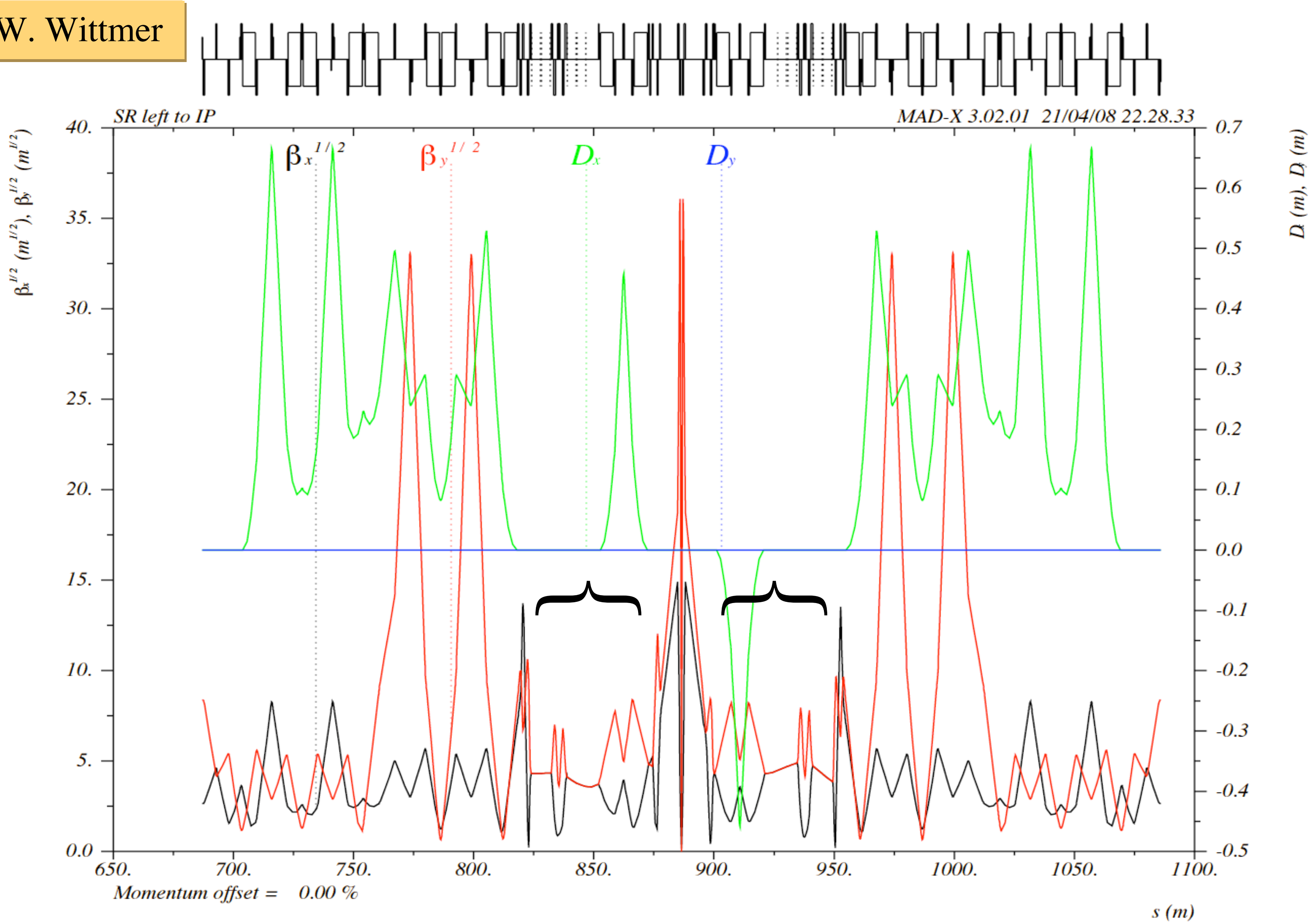


IR with Solenoid Rotator

W. Wittmer

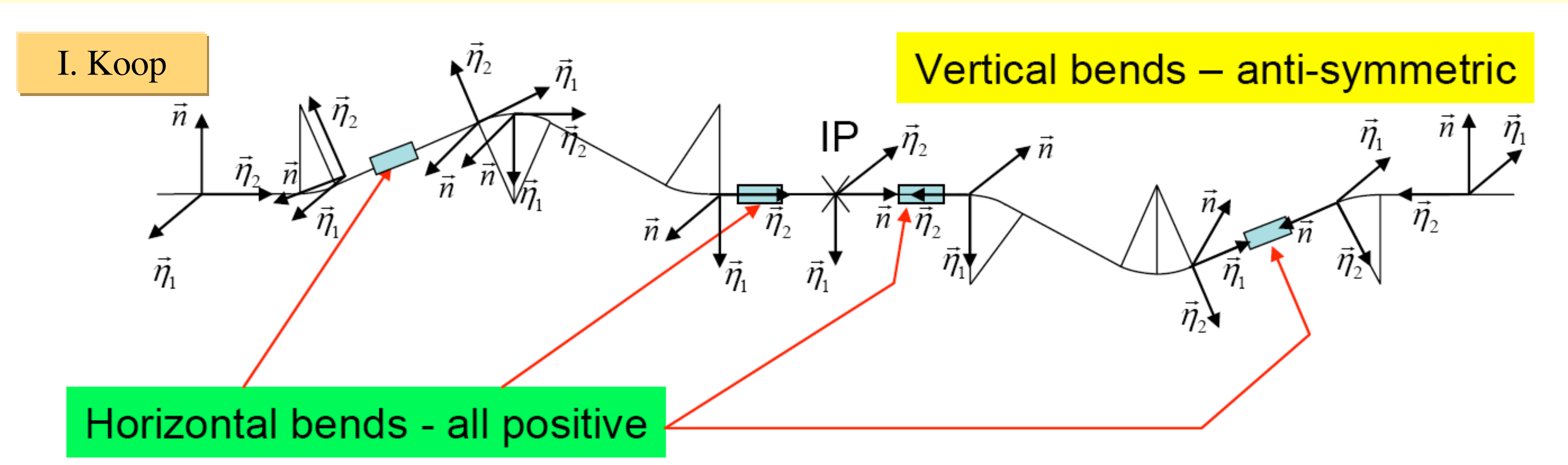
Note:

Not a fully developed solution yet!



Dipole Spin Rotator

- Dipole rotator:
  - 90°(v) — 90°(h) — –90°(v) — 90°(h)
  - Add a vertical “dogleg” to restore vertical elevation.
    - use 6*2 HER dipoles, arranged in DBA cells (per side)
    - need to watch vertical dispersion to maintain vertical emittance.
  - need ≈ 150 m space on either side, only ≈ 100 m “new”



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Polarization with Rotators

- Solenoid Rotators:
  - A pair of *antisymmetric* rotators will be spin matched
    - True for all beam energies, but only for compensated detector sole.
    - Small depolarizing effect from non field-aligned spins in IR
  - A pair of *symmetric* rotators will *not* be spin matched
    - Adds a net rotation, which has no effect *on* energy, but does have an effect *off* energy since $d = \left|\gamma \frac{d\hat{n}}{d\gamma}\right|$ is ≠ 0 (it is about 1.5…2). This may (will) reduce polarization achievable.
- The dipole rotator shown earlier is spin matched.
    - Like the symmetric solenoid rotators it adds rotation, but d stays 0.
    - May have somewhat more intrinsic depolarization from the dipoles than the solenoid rotator, but likely to be still small effect.

Expected Polarization (HER)

– With trickle injection, equilibrium between decay of stored beam and build-up due to injection

$$P = P_{inj}\frac{\tau_{pol}}{\tau_{pol}+\tau_{stor}} + P_{eq}\frac{\tau_{stor}}{\tau_{pol}+\tau_{stor}}$$

- For HER, assume τ_{stor} is 1 h (low current, no collisions)
  - optimal spin match (τ_{pol} = 5…6 h): $P \geq 0.85 * P_{inj}$
  - symmetric solenoid rotator ($d \approx 1.6$, $\tau_{pol} \approx 2$ h): $P \geq 0.67 * P_{inj}$

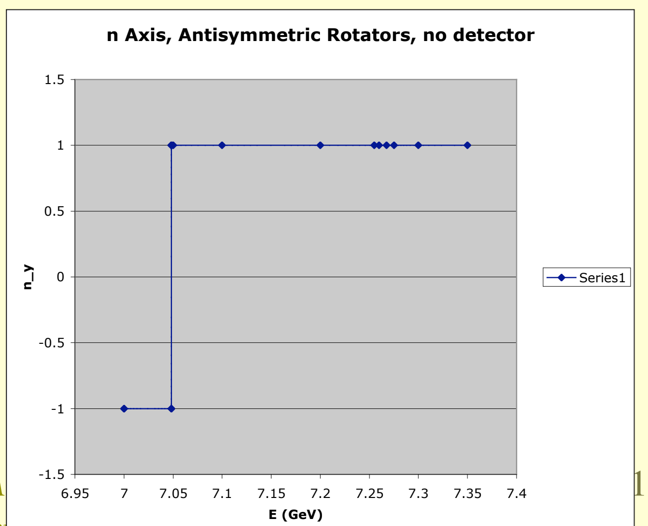
- For HER at full collision τ_{stor} is 5 m (<0.1 h), $P \geq 0.95 \ldots 0.98 * P_{inj}$
- These estimates assume $P_{eq} = 0$.
  The symmetric solenoid rotator case benefits most from $P_{eq} > 0$.

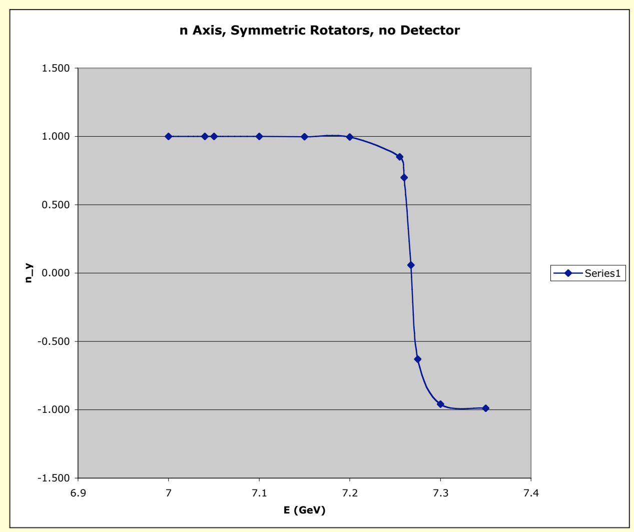
Resonant Energies

– At integer values of the spin tune, the $\hat{n}$-axis rotates into the horizontal plane
  - longitudinal polarization @ IP –> 0.
  - d becomes large => depolarization.

– This happens every 0.441 GeV near γG = integer.

– The width of these depolarizing resonances depends on the degree of spin matching achieved.



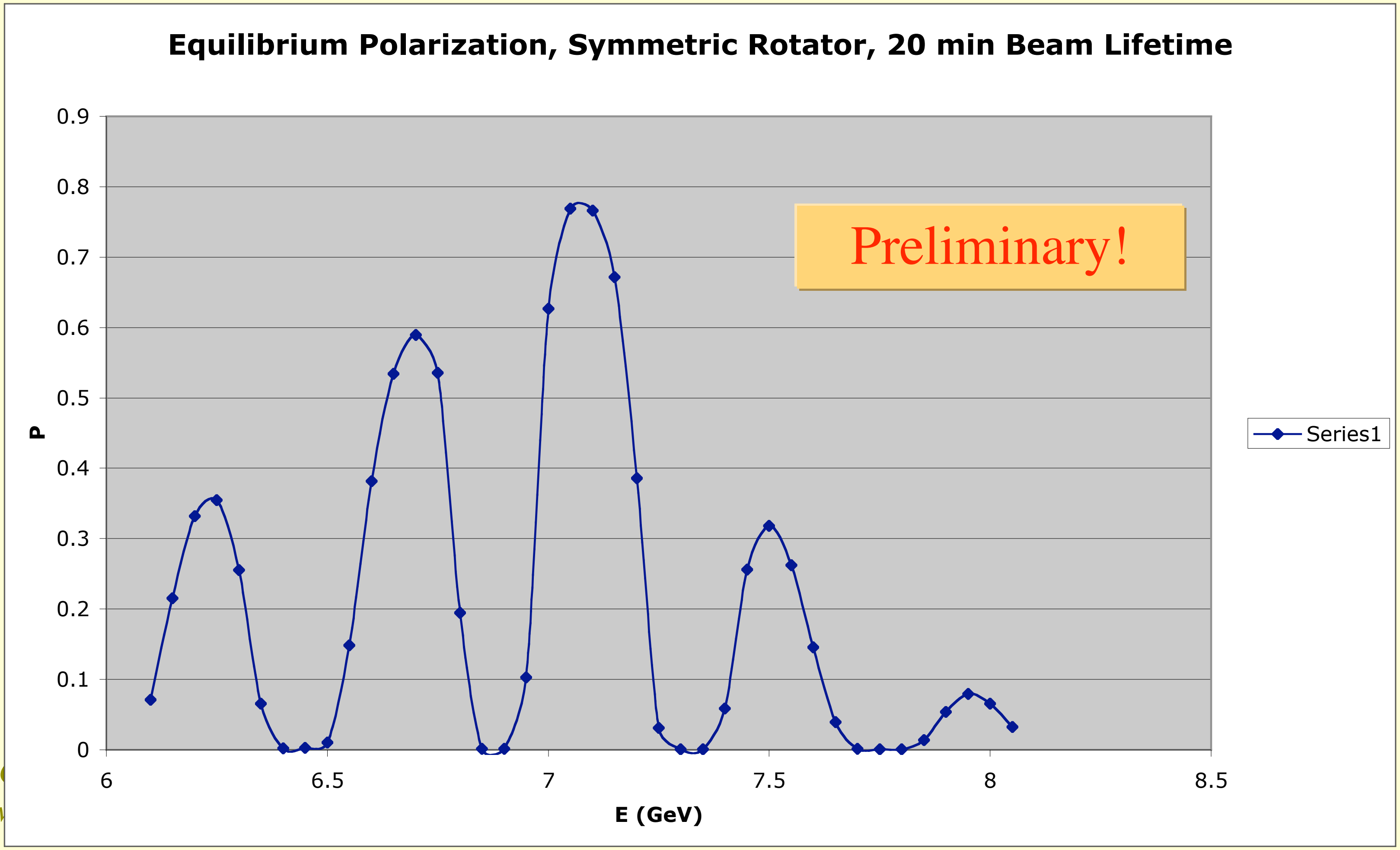


Polarization Estimate for SuperB

– Equilibrium beetween injection & depolarization, $P_{inj} = 0.9$
  - Bad spin match (symmetric solenoid rotators), 20 min beam lifetime

Estimate from variation of d and $\hat{n}$

Energy spread & synchr. oscillation not incl.

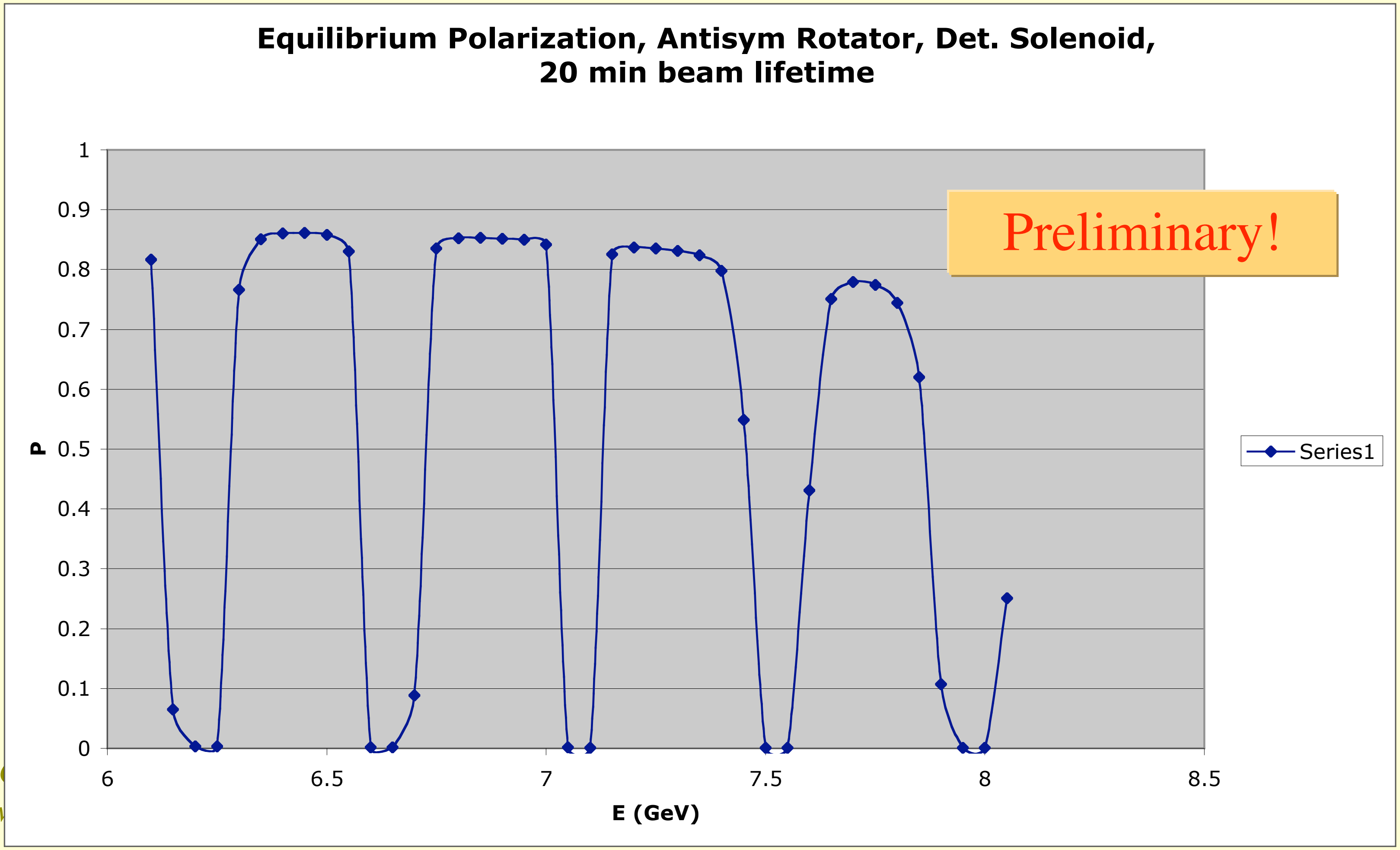


Polarization Estimate for Super*B*

- Reasonable spin match (antisymmetric solenoid rotator, detector left uncompensated). 20 min. beam lifetime. $P_{inj} = 0.9$

Note:

Energy spread & synchr. oscillation not incl.



- Beyond these integer spin resonances, there are other effects limiting the energy choice:
  - "intrinsic" resonances, where $k^*\nu_{spin} = \nu_y$
    - in case of Super*B* $\nu_y \approx 0.5$ => halfway between integer resonances in energy => more restrictive.
  - synchrotron satellites to all of these resonances, which effectively increases the width of each resonance.
- Ignoring any shift from the rotators, the *bad* energies would be 6.830, 7.050 and 7.271 GeV.
  - Corresponding LER energies (for E_{cm}=10.58 GeV) are 4.091, 3.969, 3.848 GeV.

Trade-offs between Polarization & Luminosity

- The solenoid rotator eschews vertical dipoles but has strong solenoids, thus introducing plane coupling. Mitigated by:
  - Compensation of the coupling effect by the plane twister in between the half-solenoids.
  - Lengthening the solenoids thus minimizing effect of the end fields.
- The effect of the dipoles on emittance should be small.
- The rotator adds optical elements in a critical location close to IP
  - Need to get phases right for crab waist & local sextupoles
  - Will add its own chromatic terms… how bad??
  - How sensitive will the plane-twister quad settings be?

Summary

- Polarized beam in Super*B* can be achieved by injection of polarized electrons.
- Feasible spin-rotator designs have been proposed that will provide longitudinal polarization at the IP.
  - Length varies between 50 and 150 m per side of the IP
  - Some of these designs can provide part of the bending required to close the ring.
- Good spin matching can be achieved
- With trickle injection, polarization can exceed 95% of that of the injected beam.
- Integration of rotator with IR critical task
  - Lattice space & geometry, geometric & chromatic aberrations
  - Compare the merits of each rotator design