Polarized beams in TLEP??

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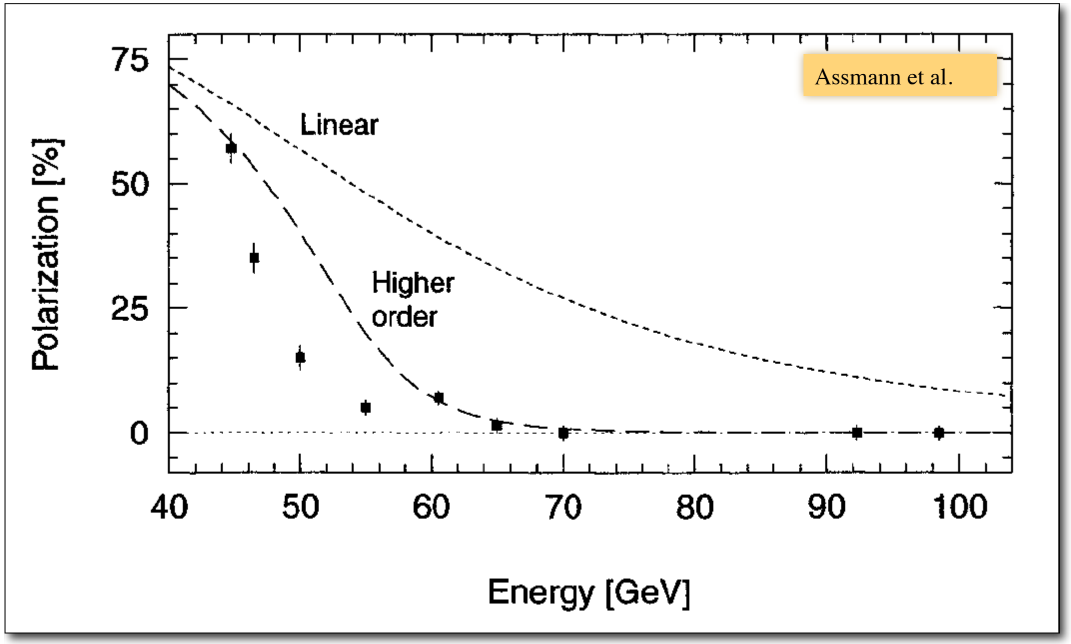
with thanks to EuCARD for support

Motivation (TLEP Design study Draft)

- Running TLEP as a Giga- (Tera-)Z Factory (45 GeV/beam):
  - Polarization gives access to certain physics (e.g. SLC)
  - Want > 50%, maybe at lower luminosity
  - Want pol. e+ as well
- Running TLEP @ WW threshold (80…90 GeV/beam)
  - want energy calibration ($P \geq 5\%$)
- Running TLEP at the Higgs (120 GeV/beam):
  - Polarization not required.
  - Energy calibration?
- Running TLEP at $t\bar{t}$ (175 GeV/beam)
  - Energy calibration?

Introduction: LEP Observations & Data

- LEP has had the highest-energy polarized electron beams
  - Energy spread reduces polarization at highest energy



Polarization time constants

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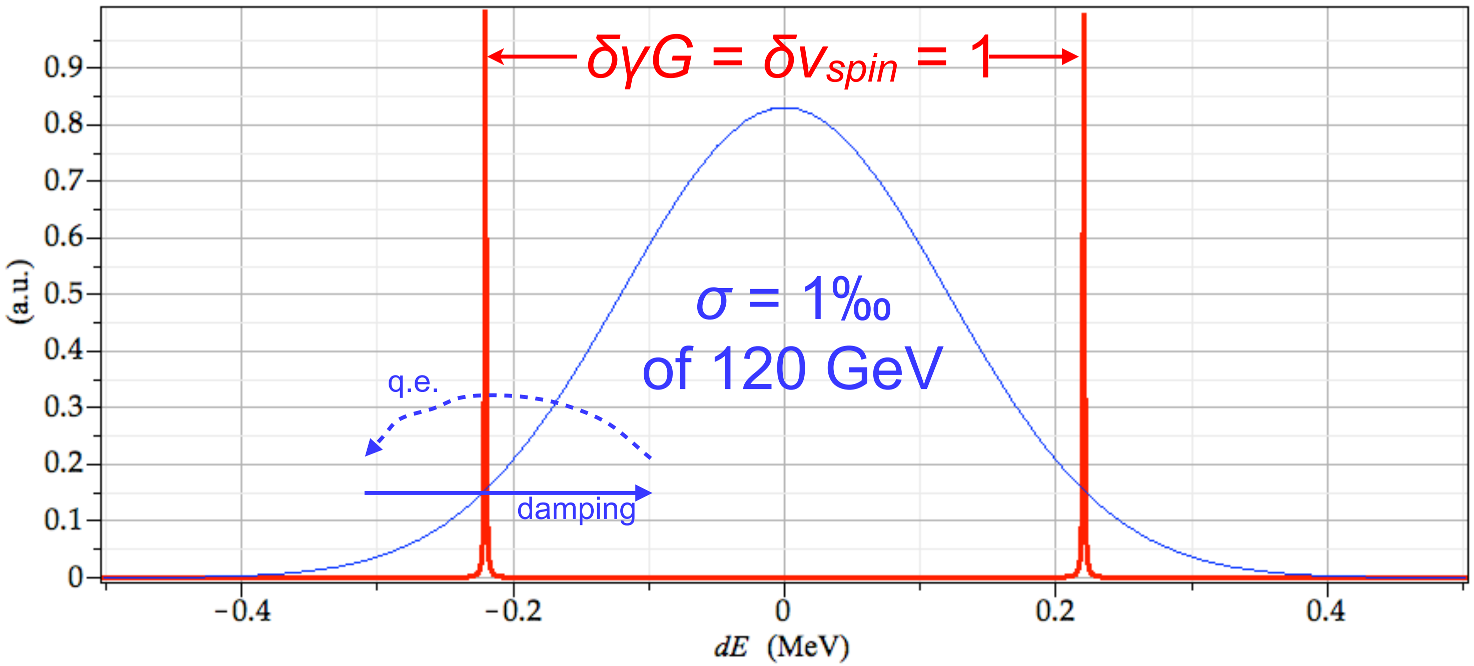
- Sokolov-Ternov polarization:

$$\tau_{\rm st}^{-1} = \frac{5\sqrt{3}}{8}\frac{r_{\rm e}\gamma^5\hbar}{m_{\rm e}|\rho|^3} = \frac{2\pi}{99}\frac{E^5}{C\rho^2}$$

Machine	E (GeV)	ρ (m)	C (m)	$\tau_{S\text{-}T}$ (h)
LEP(2)	45	3100	26700	6
LEP3	45	2600	26700	4.3
LEP3	120	2600	26700	0.03 (2 min)
TLEP-Z	45	9000	80000	154
TLEP-H	120	9000	80000	1.15
TLEP-t	175	9000	80000	0.17 (10 min)

A simple model to describe the energy limit

- Spin resonances every 0.441 GeV (for e^-)
  - tails in a beam may extend beyond these
  - q.e. causes instantaneous jumps beyond the resonant energy
  - radiative damping causes crossing on the way back => some depolarization.
  - spin tune modulated by Qs => reduces space for spin tune.



"Phenomenological Description"

- If the resonance-crossing causes depolarization *D*, we can make the *ansatz* for the polarization

$$\frac{d}{dt} P(t) = -\frac{P(t)\, e^{-\frac{H}{H\_ave}}\, D}{tau\_e}$$

which can be solved easily:

$$P(t) = \_C1\, e^{-\frac{e^{-\frac{H}{H\_ave}}\, D\, t}{tau\_e}}$$

so the time constant is:

$$tau\_p := \frac{tau\_e}{e^{-\frac{H}{H\_ave}}\, D}$$

H_ave is $\sigma E/E^2$

$$\frac{C\_q\, gammar(E)^2}{Js\, \rho}$$

tau_e is the damping time

$$\frac{C\, \rho}{C\_gamma\, E^3\, c}$$

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- To finish this, we need to know D
- Crossing a depolarizing resonance => we can estimate D using the *Froissart-Stora* formula:

$$1 - \mathrm{D} = 2\, \mathrm{e}^{-\frac{1}{2}\frac{\pi\, wk^2}{\alpha}} - 1$$

  - for our cases, $wk \approx 0.001$ and $\alpha \leq 0.01$ so D turns out to be $1..4 \times 10^{-4}$ per crossing.
- This effect competes with Sokolov-Ternov to reduce the eq. polarization:

$$Pol := \frac{P0}{1 + \frac{tau\_ST\, \mathrm{e}^{-\frac{H}{H\_ave}}\, \mathrm{D}}{tau\_e}}$$

Putting it all together:

$$\frac{P0}{1+\dfrac{49500000000\,\rho\, C\_gamma\, c\, e^{-\frac{dE^2\, m\_e^2\, Js\,\rho}{C\_q\,(1000\,E+m\_e)^2\,E^2}}\left(2-2\,e^{-\frac{1}{2000000000000}\,\frac{\pi\, wk^2\,\rho\, m\_e}{dE\, C\_gamma\, E^3\, G\_e}}\right)}{\pi\, E^2}}$$

- ($dE = (0.5\text{-}Q_s(E))*0.441$ spin-tune-space expressed in GeV)
  - Q_s comes in as the spin tune of each particle is modulated by Q_s

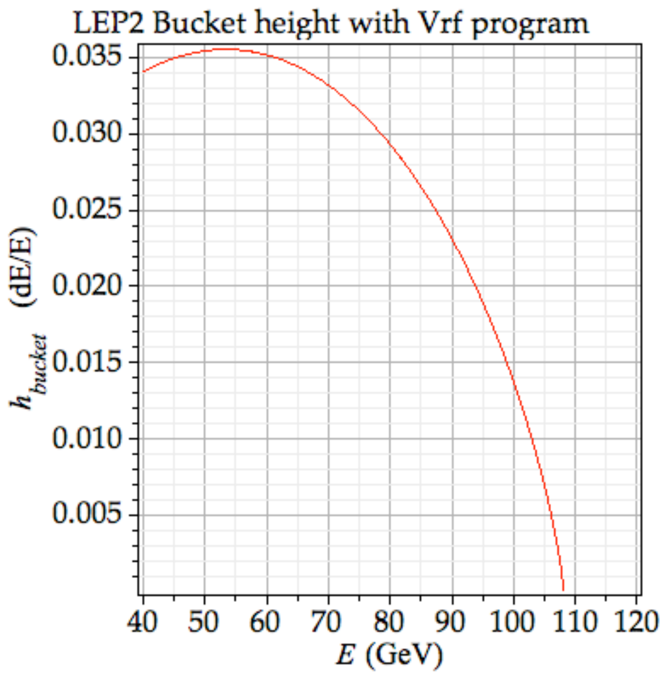
For a realistic estimate of $Q_s(E)$ we need to have an estimate of $V_{rf}(E)$.

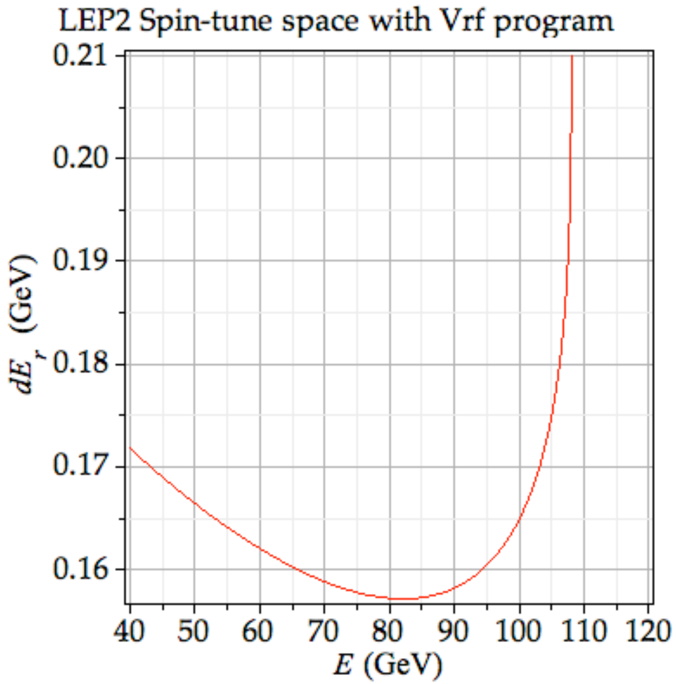
We do this such that the momentum acceptance stays reasonable

- => $V_{rf} \propto E^2$, roughly hitting the nominal values per the parameter table.

LEP2

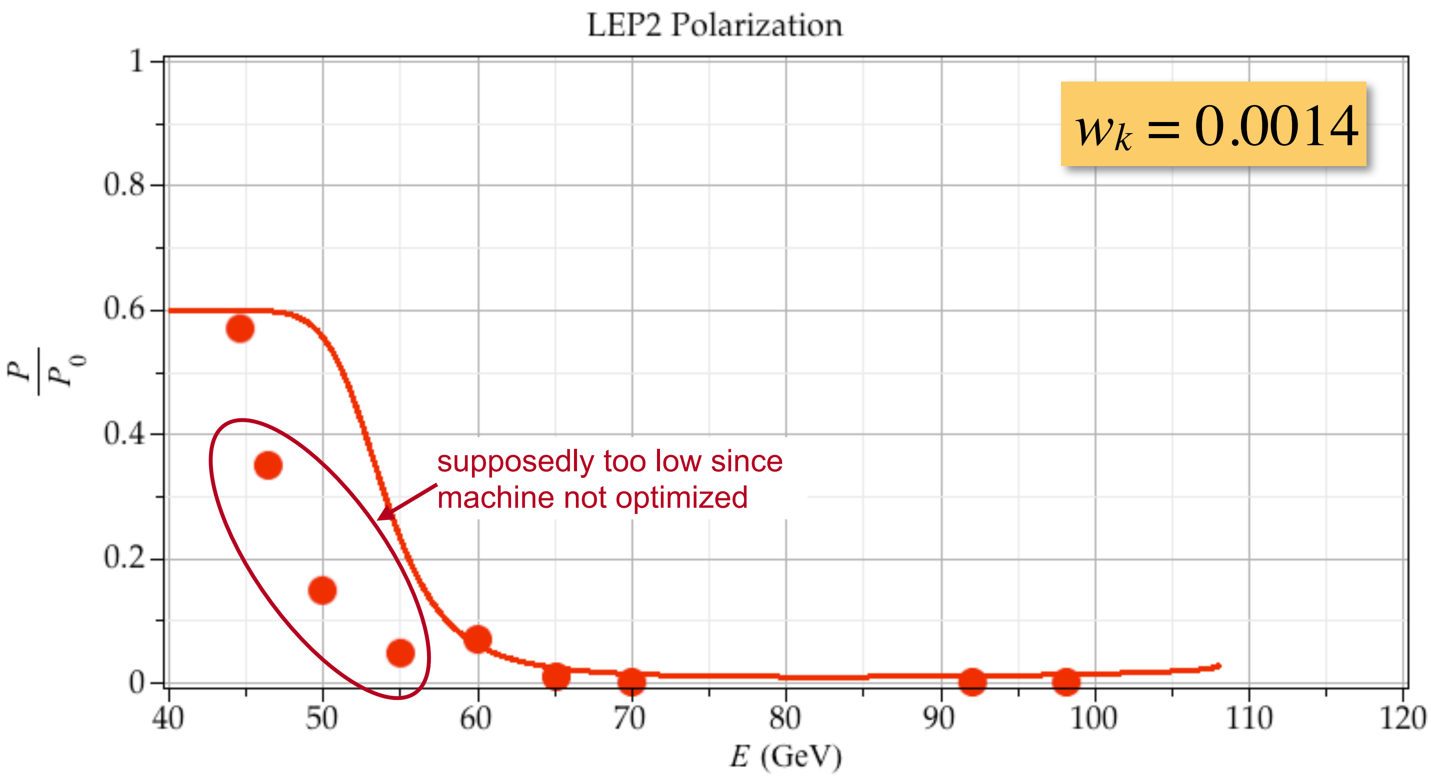
- $V_{rf} = 1/3 * E^2$ (E in GeV, V_{rf} in GV [3.64 GV @ 104.5 GeV])



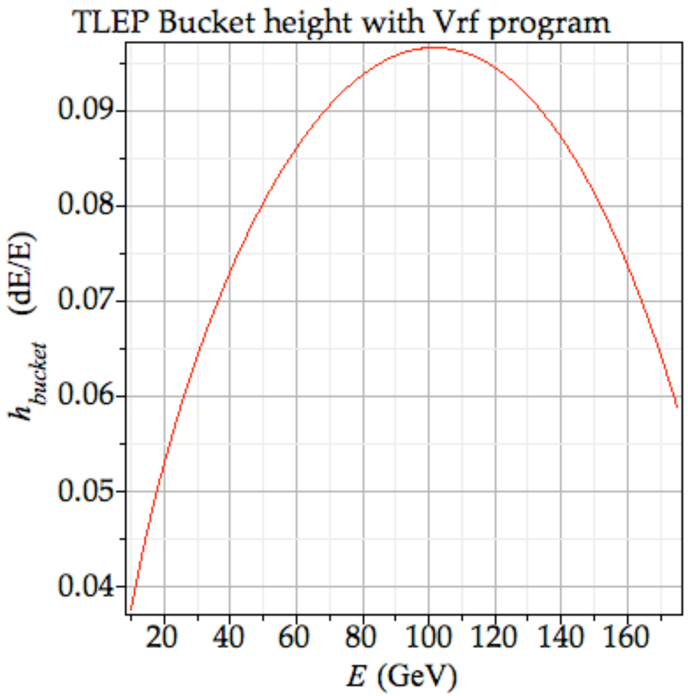


Comparison of model to LEP2 data

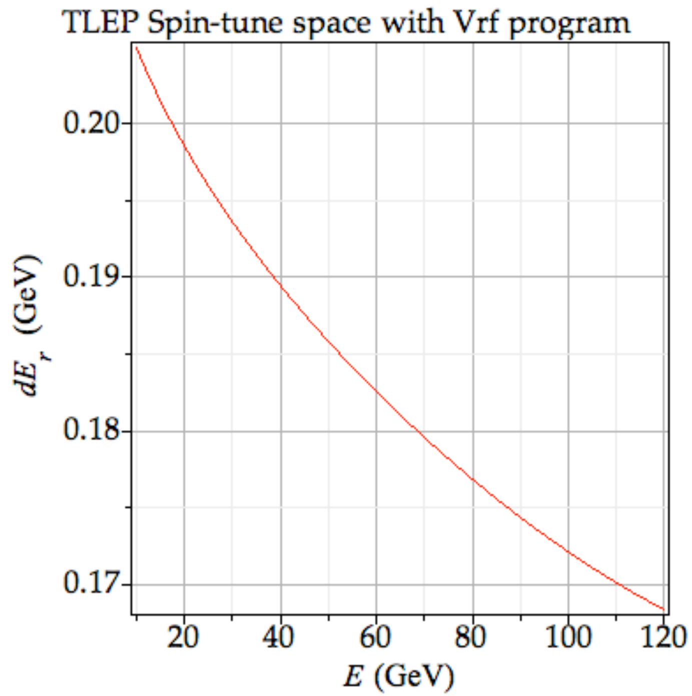
- Assmann (1999) estimates $wk \approx 0.0014$
  - this model would favour $wk = 0.002$



TLEP

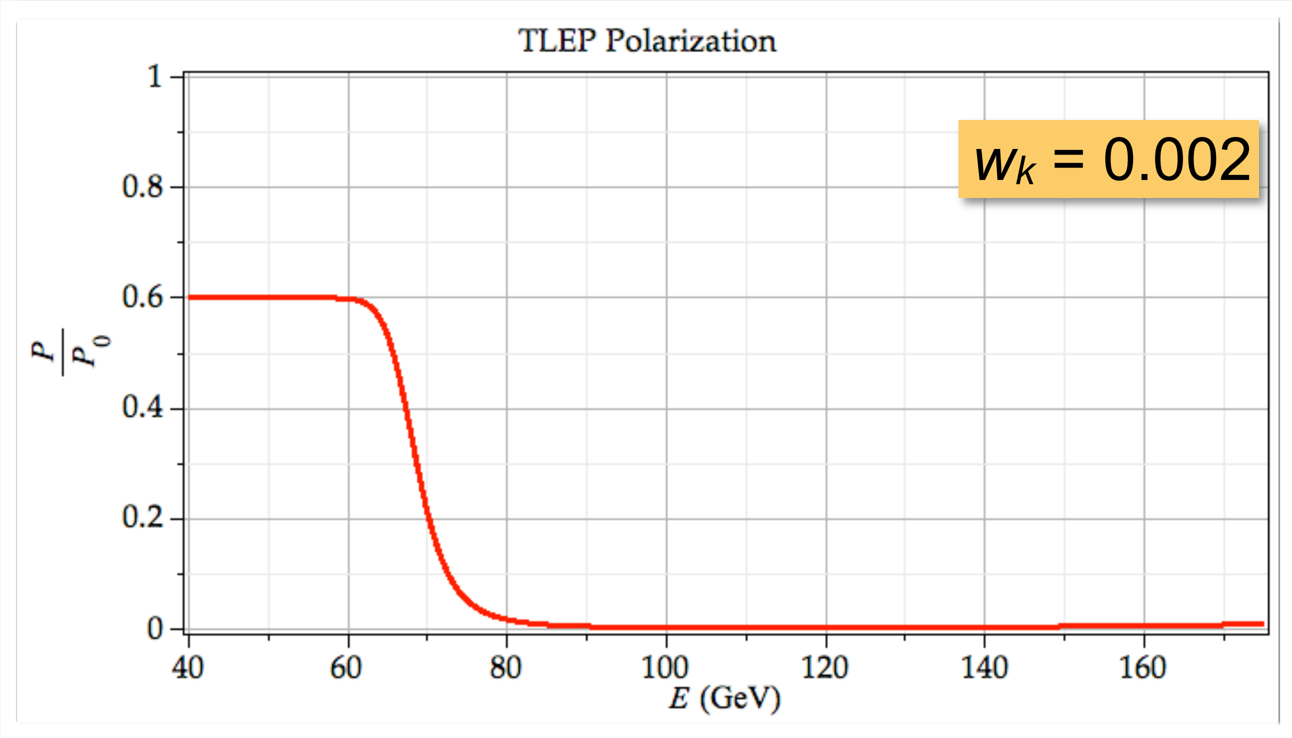


TLEP Bucket height with Vrf program
0.09
0.08
0.07
0.06
0.05
0.04
20
40
60
80
100
120
140
160
E (GeV)
h_{bucket} (dE/E)



TLEP Spin-tune space with Vrf program
0.20
0.19
0.18
0.17
20
40
60
80
100
120
E (GeV)
dE_r (GeV)

TLEP Polarization estimate



Optimizing TLEP

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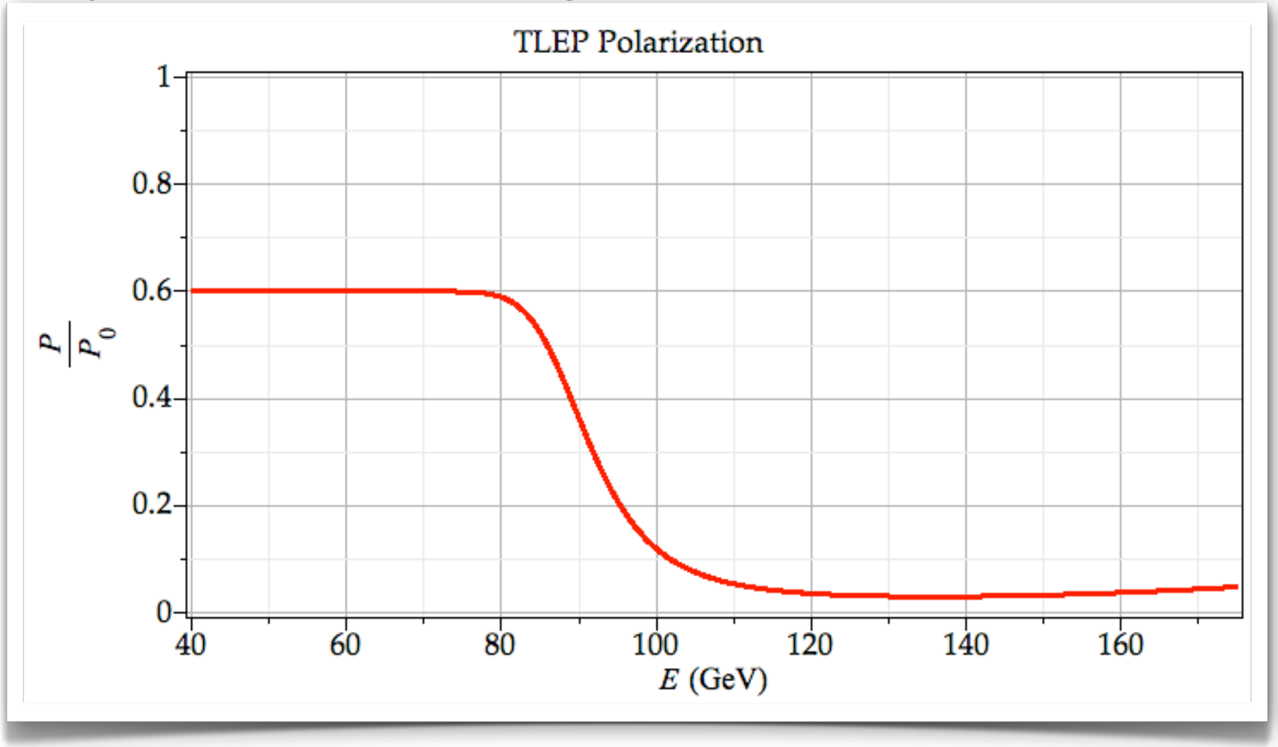
- In this model, we can gain by
  - reducing the energy spread using J_s –> 2
  - being optimistic reducing w_k –> 0.001
    - ✦but note: LEP2 already used quite elaborate algorithm for spin matching
  - reducing the synchrotron tune using α_p –> 5 x 10^{-6}



Remarks to the proposed model

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- The inspiration to this model came from a paper by Derbenev, Kondratenko and Skrinsky.
  - Their condition for correlated multiple resonance crossings is *violated*.
- On the other hand; the resonance-crossing model used here has also issues due to small # of synchrotron oscillation periods
- The interesting difference between these descriptions:
  - D-K-S: a higher Q_s *helps* polarization (for correlated crossings)
  - this model: a higher Q_s *hurts* polarization
- Also, at very high energy, D-K-S allow for an increase in polarization
  - high polarization rate trumps depolarization rate
  - this model allows for that as well
- Neither has higher-order or spin-betatron resonances.
  - significant e.g. in LHeC tracking

Linear vs nonlinear Spin Tracking (SLICKTRACK, LHeC, Q_s=0.15)

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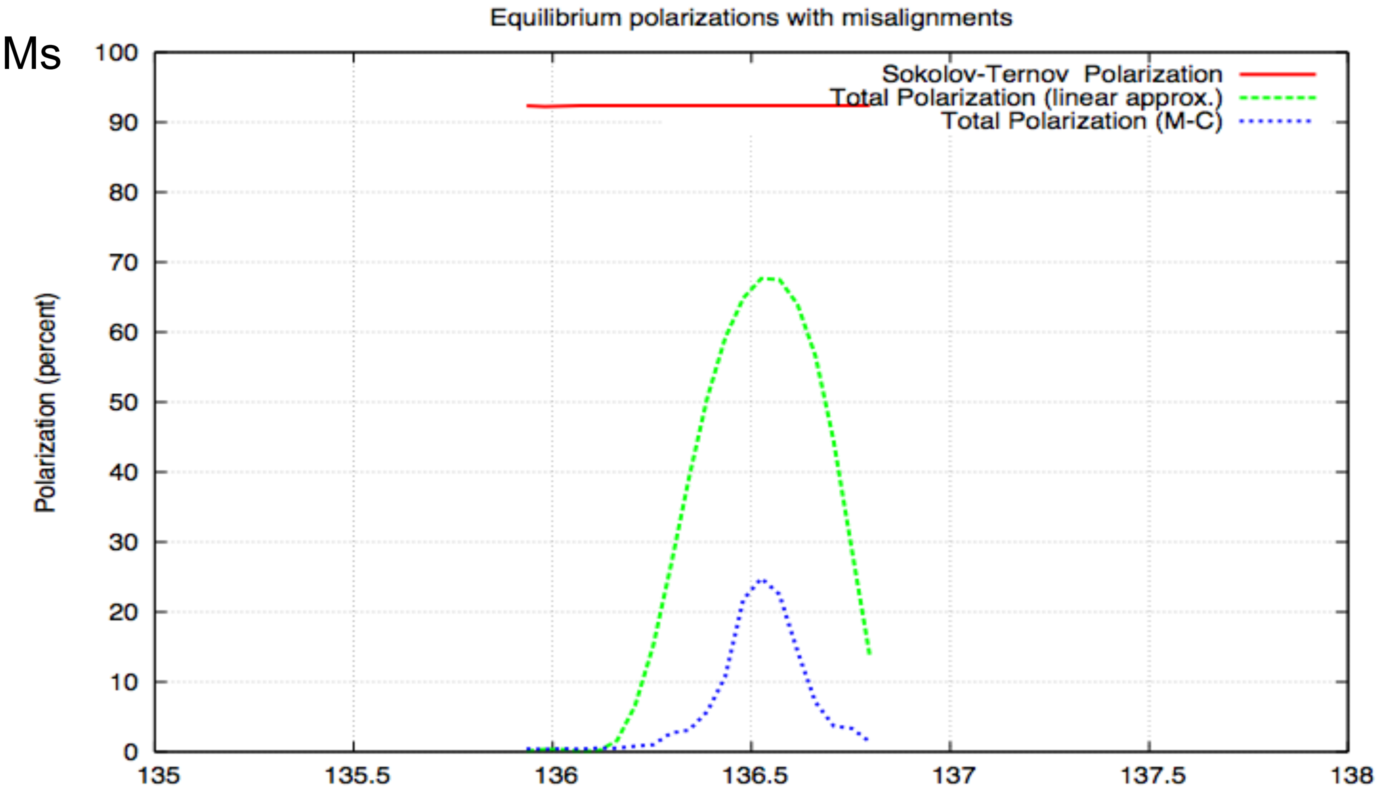
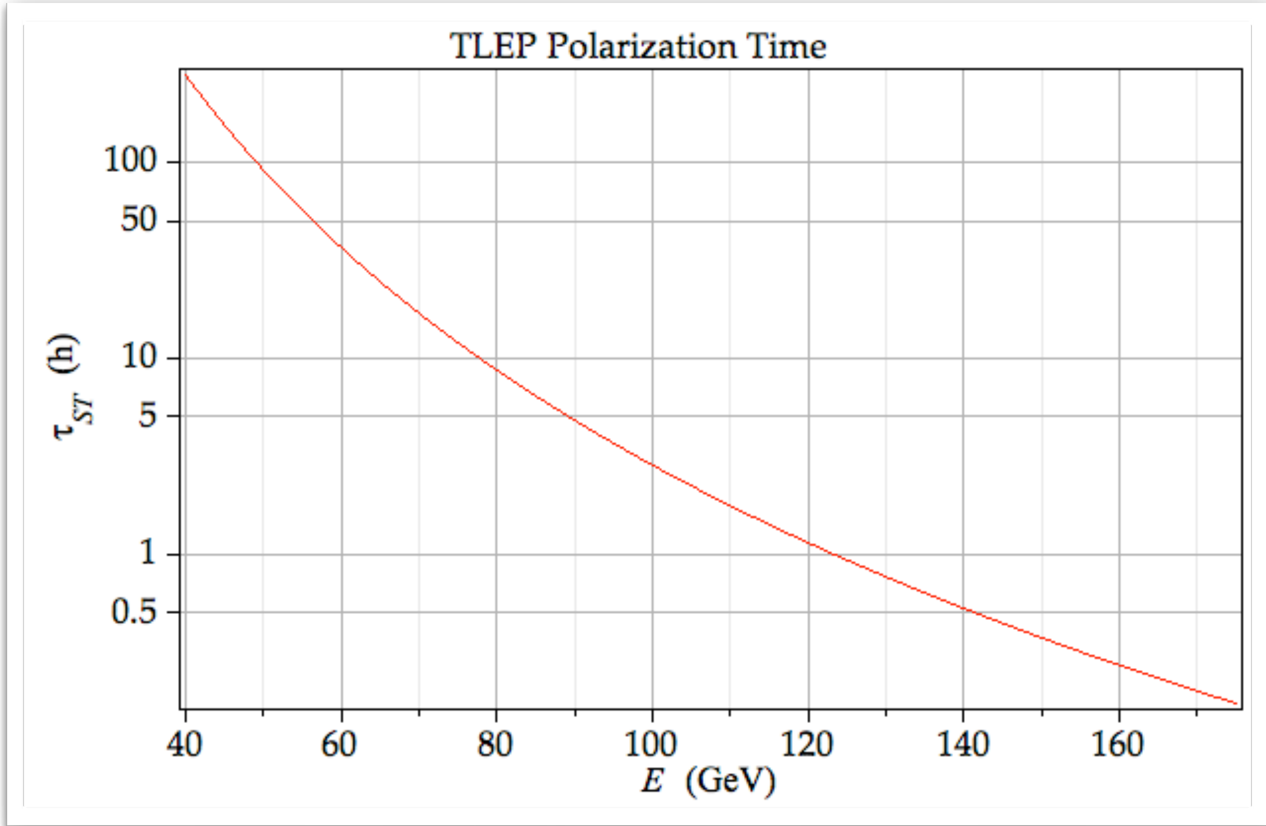
150 μm rms misal.
150 μr
50 μm BPMs
no spin-matching



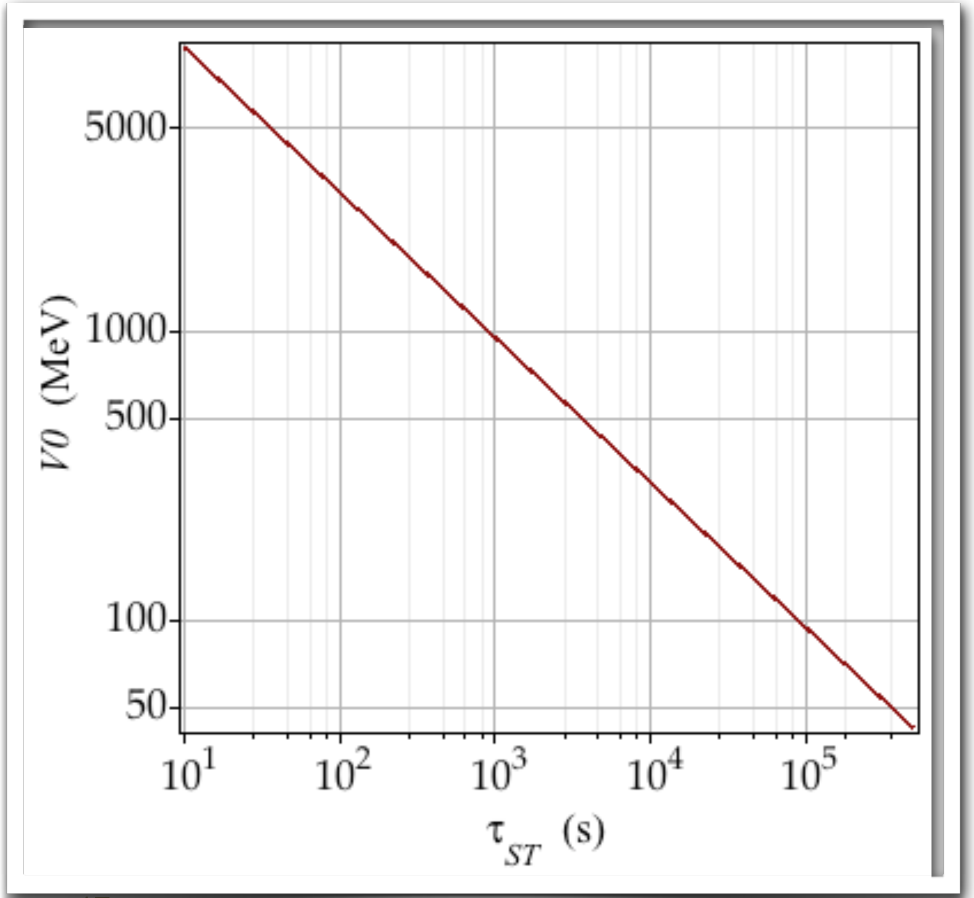
spin tune

TLEP Polarization time



TLEP Polarizing Wiggler @ 45 GeV

Note:
100 s => V0 ≈ 3 GeV
≈ 3E34 lumi
for 50 MW sr power,
most of power goes
into wiggler(s) ☠



Where does this leave us?

- Sokolov-Ternov polarization in TLEP appears to be difficult to achieve
  - @ Z energy: good polarization, but excessive build-up time (150 h)
    - Alain proposes wigglers — power density [MW/small divergence] manageable??
  - @ 90 GeV: enough polarization for an energy calibration may be possible.
    - here wigglers could help
  - @ H energy: even under optimistic assumptions not much left
    - enough for an energy calibration??? 1 hour build-up time would be enough for this.
  - @ $t\bar{t}$ energy: very fast build-up (10 min), maybe some polarization
    - enough for energy calibration?.
    - it would be very interesting as a test case for the theory!
- Can snakes come to the rescue??

Siberian Snakes (180° Spin Rotators)

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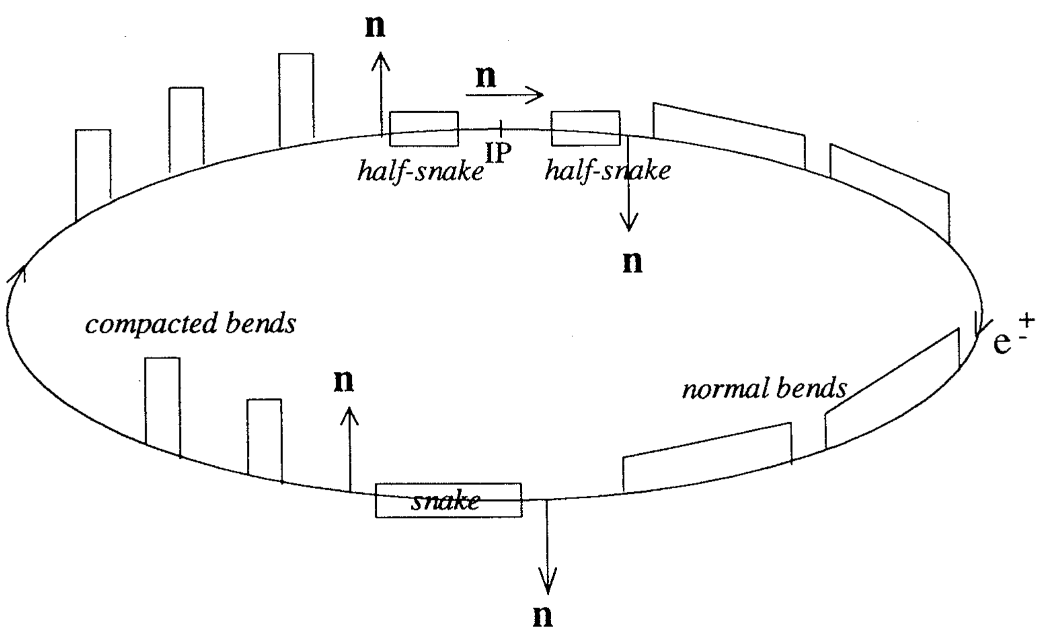
- A pair of snakes with longitudinal/radial axis can suppress depolarizing resonances & stabilize $\frac{\partial \hat{n}}{\partial \delta}$ (up to a point).
  - Spin direction opposite in the two halves of the ring => no radiative pol.
  - One of the snakes can double-up as IR spin rotators.
  - Derbenev-Grote proposal for LEP
  - For TLEP:
    - inject polarized
    - no "compacted" bends (but wigglers could work)
    - Similar arrangement of snakes in the injector ring
    - 18.5…37 Tm of dipole required for each snake



A conceivable scenario for TLEP ?

- Use Siberian Snakes to accelerate a polarized beam to 45 GeV
  - would need pairs of longitudinal & radial snakes, depending on resonance strength
  - snake pair in the collider to maintain polarization (for ≥ 1/2 h)
    - Allows polarized physics running @ the Z.
    - Snakes will prevent energy calibration with polarization
- At 90 GeV, τ_{pol} ≈ 5 h and P ≈ 0.2…0.4 (no snakes)
  - enough to get an energy-calibration point.
- At 120…175 GeV, τ_{pol} ≈ 1 h…10 min
  - might get enough polarization for energy calibration

Summary

- Achieving polarization in TLEP will be challenging
  - caught between Scylla (long polarization time) and Charybdis (depolarization due to unavoidable energy spread)
  - Polarizing wiggler(s) present power-handling challenge
- Siberian Snakes may come to the rescue
  - would need to accelerate polarized beam & maintain polarization
  - vertical bends => potential to blow up vertical emittance
  - needs a polarization-capable injector chain.
  - no polarized posi's ☹
- A hybrid scenario may be conceivable
  - Snakes for physics running @ Z energy
  - self polarization with snakes off @ ≈ 80…90 GeV for energy calibration
- The theoretical situation is not particularly clear & may hold surprises.