Linear and Circular Colliders:
A few topics

Luminosity
Gamma-gamma
Beam polarization

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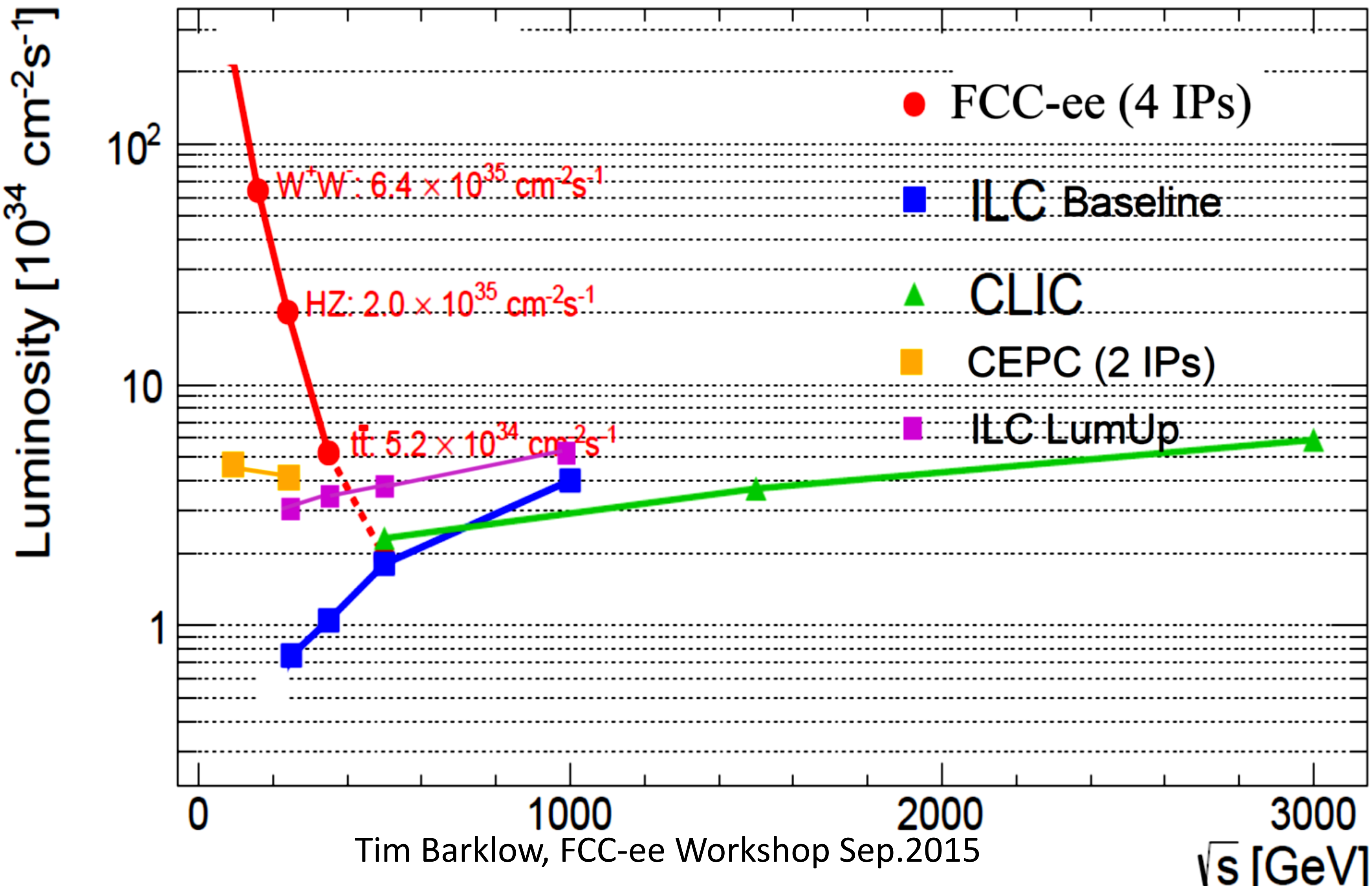
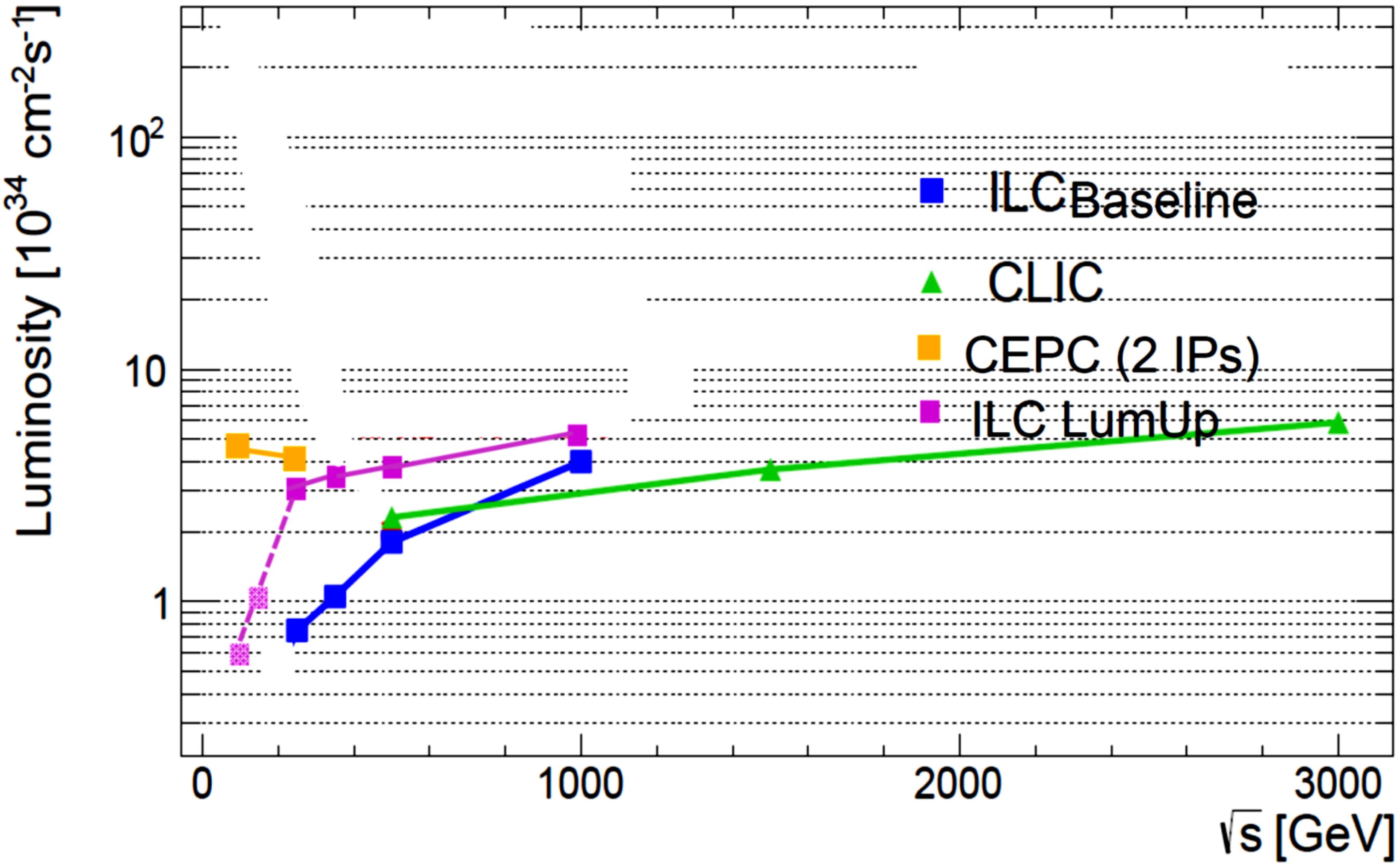
Luminosity Comparison



Tim Barklow, FCC-ee Workshop Sep.2015

Low Energy Region (not in TDR)

$\sqrt{s} = 90,\ 160$ GeV



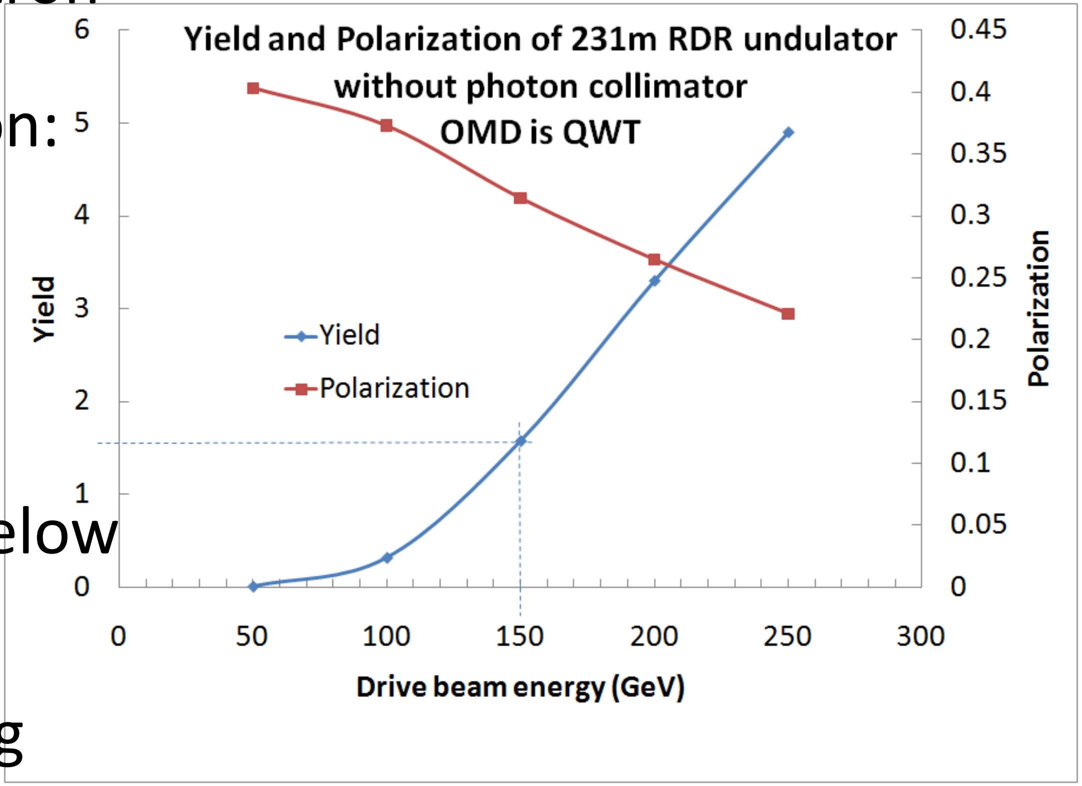
Tim Barklow, CEPC Workshop Aug.2015

Scaling of LC Luminosity to Lower Energies

- One of the advantages of circular collider is the high luminosity at low energy region
- ILC is not suited for E_{CM}<250GeV
- TDR gives serious study results only down to E_{CM}=250GeV
  - No serious study to Z-pole and W-pair
- Often asked to give luminosity values at such energies
- Simplest scaling low
  - Same beta → L proportional to E
- This is a bit optimistic
  - Increased beam divergence angle due to larger geometric emittance would cause background
  - Require deeper beam collimation
  - Final quad should be shorter
  - Linac beam dynamics with lower beam energy

Efforts for Low Energy Operation of ILC

- Another problem: positron production
- Use electron for collision:
  - i.e., $E_e = E_{CM}/2$
- Undulator
  pitch 11.5mm
  K=0.92 (0.86T)
  Helical, NbTi
- Poor production rate below E_e=125GeV
- Study being done for shorter pitch, e.g., using Nb_3Sn, but not ready.
  - Z-pole is anyway impossible



10Hz Operation

- Use every other electron pulse for positron production E_e=150GeV and collision experiment $E_e=E_{CM}/2$
  - → every other pulse with different energies
- Operate the electron linac at doubled rate (10Hz)
- This is mentioned in TDR
- Some components already included in TDR
  - Doubled rep rate of Damping Ring (stronger wiggler, more RF)
  - But details are left out
- There are also other possibilities,
- But no resources now
- **If both ILC & CEPS be built, … we do not need this mode**

Gamma-gamma Collider

- Advantage of LC
  - Not impossible with circular colliders, but the luminosity would be much lower
  - $\gamma\gamma$ luminosity is ~ 1/3 of e+e- luminosity
- Nonetheless, ILC has not been optimized for $\gamma\gamma$
  - $\gamma\gamma$ community is not strong enough
- Crossing angle
  - $\gamma\gamma$ requires larger crossing angle (25mrad thought to be the optimum) for avoiding low energy electrons from multiple Compton scattering
  - ILC TDR: 14mrad
  - It is hard to change the crossing angle after construction
    - Do not want to move the beam dump

750 GeV Diphoton Resonance?

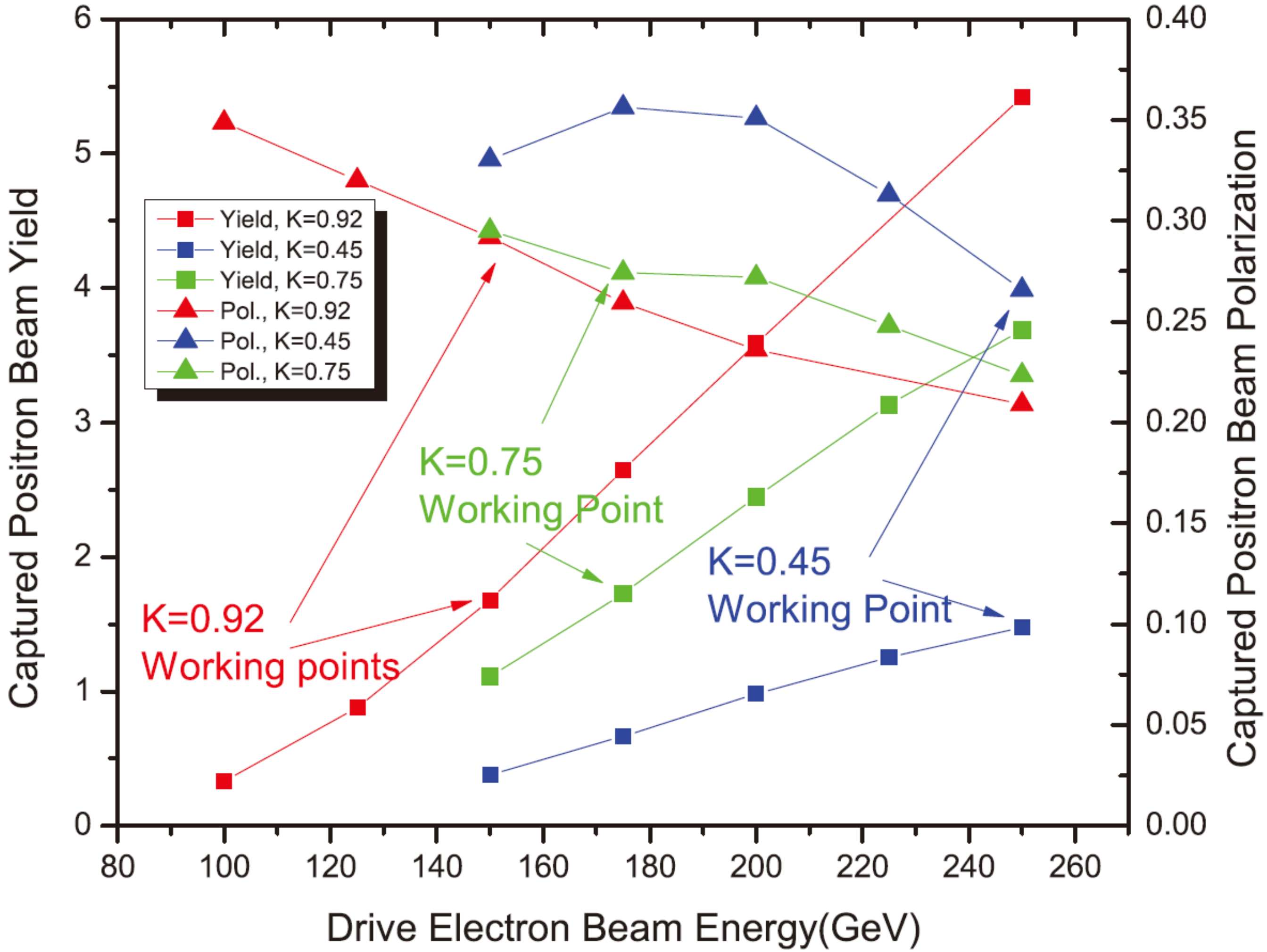
- If this be true, can be a good target of ILC $\gamma\gamma$
  - E_γ ~ $0.8E_e$
  - $E_{\gamma\gamma}$ =700-800GeV is best suited with ILC after extension to E_{CM} = 1TeV
- Expected luminosity > 10^{34}
- Laser technology would be mature by that time
  - Strong motivation would accelerate laser development
  - λ_L = 2μm optimum
- If this possibility to be considered seriously, it can be taken into account now

Beam Polarization

- One of the advantages of the ILC is the collision of polarized beams
  - Electron: 80% in TDR
  - Positron: 30% TDR baseline, can be raised to =60%

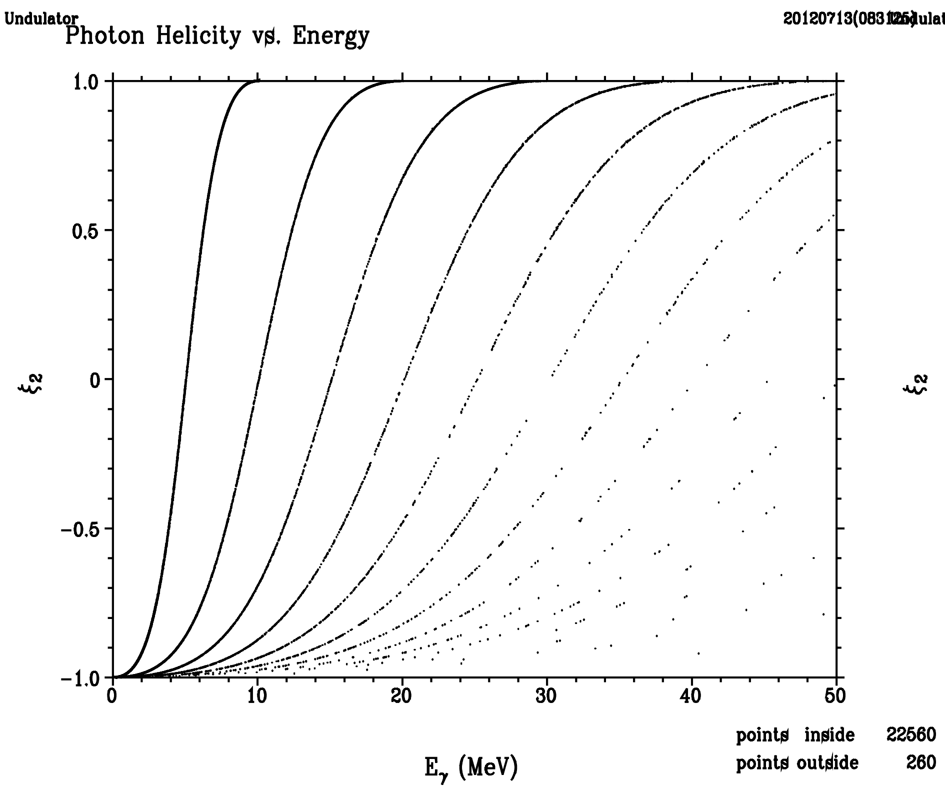
Positron Polarization

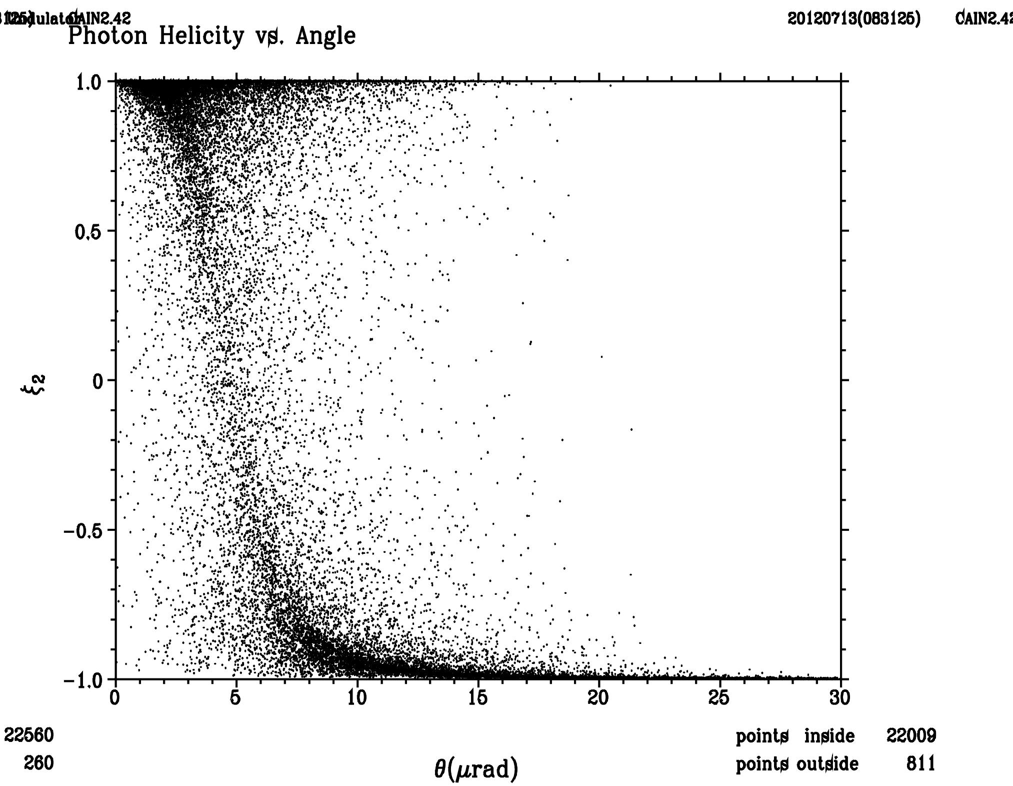
- ~30% comes at free
- Should use lower field (<0.86T) at E_e > 150GeV



Helicity vs Eγ

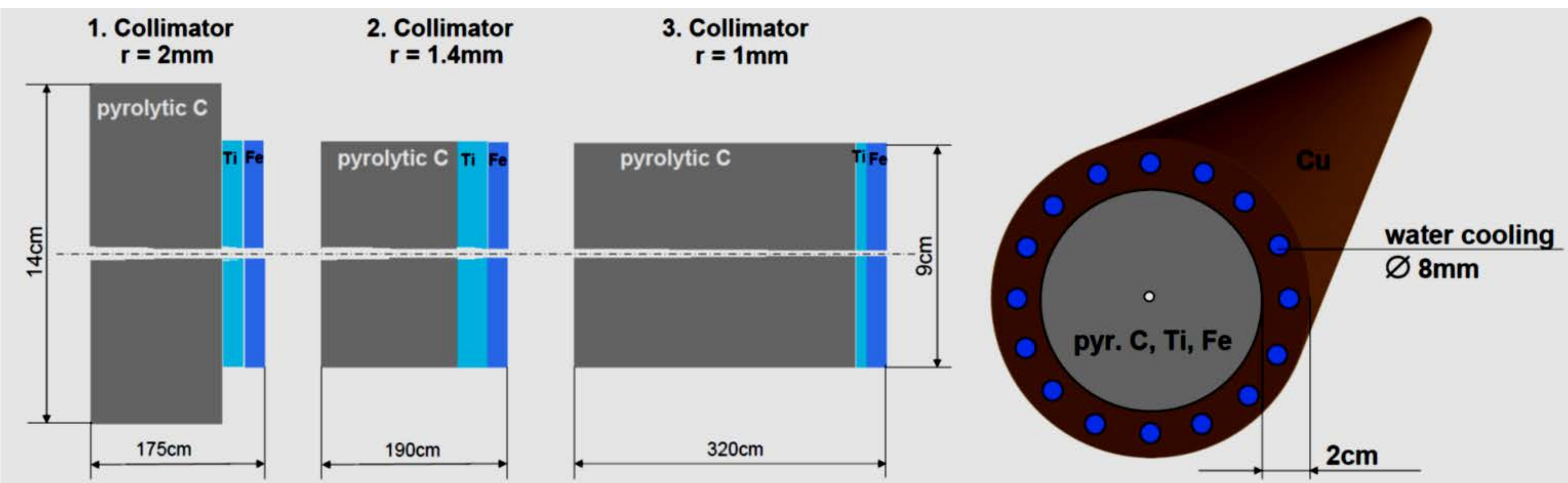
Helicity vs θγ





Photon Collimator

- Higher photon polarization, hence higher positron polarization, can be obtained by collimating the photons from undulator



Depolarization by Beam-Beam Interaction

- 2 reasons of depolarization
  - Below 1% level at ILC
  - But can be significant at CLIC 3TeV
- Precession in B-B field
  - B-B magnetic field causes depolarization
  - For the ring parameters, depolarization per collision is

$\langle \Delta P \rangle$ = 0.3E-4 to 1E-4 for FCC-Z to FCC-t
3E-4 for CEPC-H

  - But the effect does not accumulate over multiple turns.
- Spin-flip radiation

$$\langle \Delta P \rangle = (7/12)\, \Upsilon^2 n_\gamma \quad \text{per collision}$$

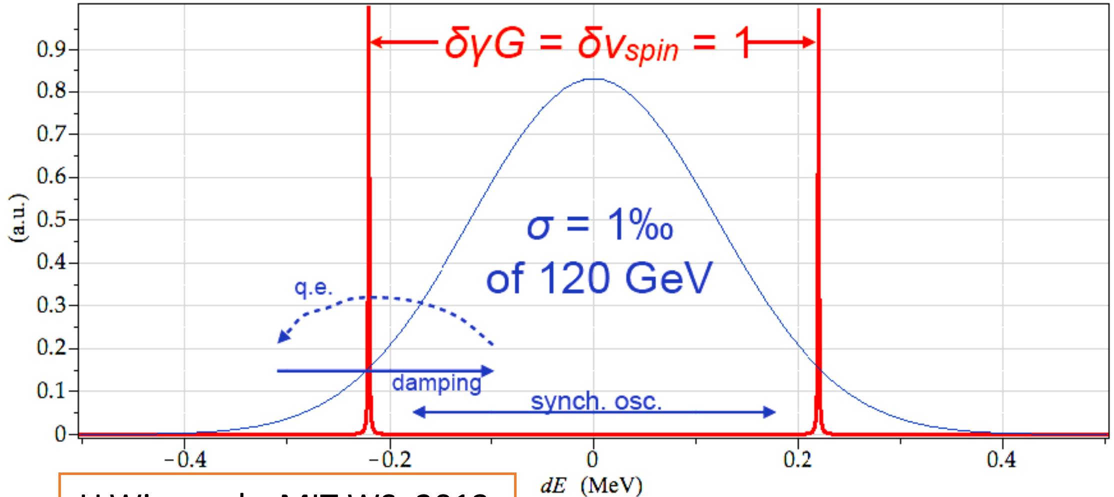
n_γ = number of photons / electron/collision
Υ = Upsilon parameter

  - negligible at ILC 500GeV (but not at CLIC 1TeV)
  - For the ring,
    $\langle \Delta P \rangle$ = 0.33E-8 (FCC-H), 1.25E-8 (FCC-t), 2.6E-8 (CEPC-H)
    Depolarization time ~100min for CEPC-H

Beam Polarization in Circular Colliders

- Use of beam polarization
  - Energy calibration
    - Z mass = 91.1876 +- 0.0021 GeV measured at LEP
      2.3 x 10^(-5)
    - ~5% polarization enough for this purpose
  - Polarized colliding beam experiments (longitudinal polarization) like at HERA
    - Need spin rotator
    - 30-40 % polarization at least
- How to get polarized beam
  - Spontaneous radiative polarization (Sokolov-Ternov effect)
  - Injection and acceleration of polarized beam

Depolarization due to Energy Spread

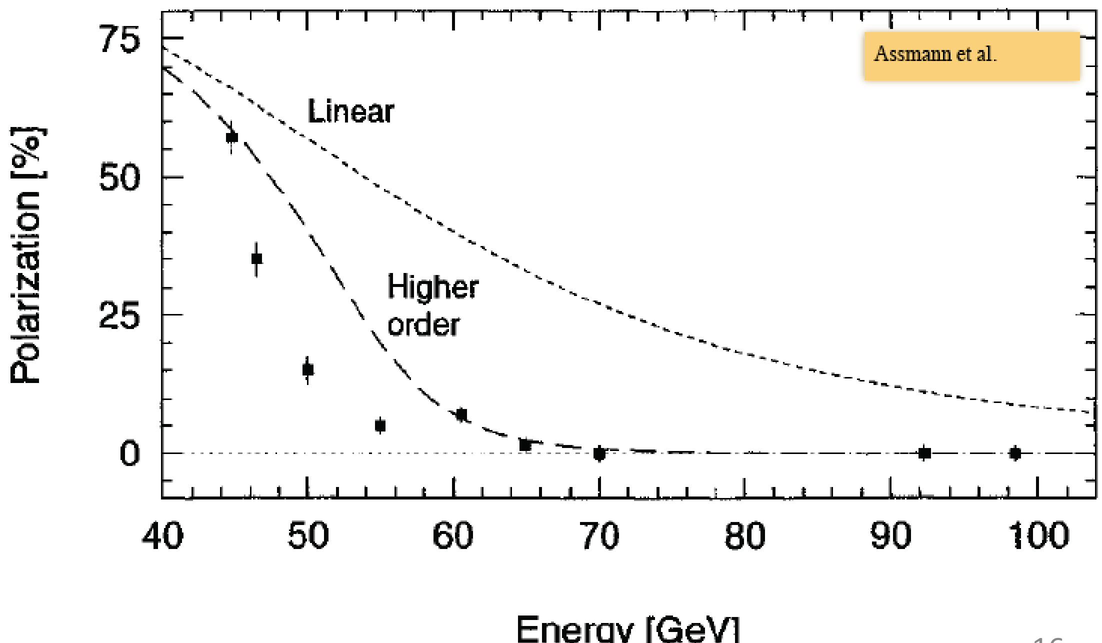


U.Wienands, MIT WS, 2013

- This explanation is too simplistic
- Lots of sophisticated theories since late 1970's

Polarization at LEP

Comparison of theory and observation



Energy scale for TLEP is $3^{1/4}$=1.3 times higher

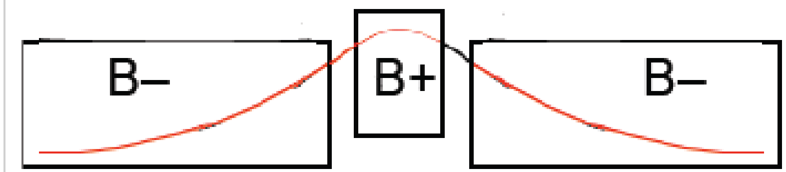
Radiative Polarization Time

- No energy spread problem at FCC-Z and CEPC-Z
- But spontaneous polarization too slow

		FCCee (4IP)			CEPC		
		Z	W	H	Z	W	H
Circumference	km	100	100	100	54.374	54.374	54.374
Bending radius	km	10.424	10.424	10.424	6.094	6.094	6.094
E beam	GeV	45.6	80.4	120	45.6	80.4	120
σ_E (SR)	MeV	24	74	167			156
σ_E (with BS)	MeV	28	84	185			192
U0	GeV	0.037	0.355	1.76	0.063	0.607	3.01
Pol τ	hours	240	14.1	1.90	44.7	2.62	0.35
Beam life		6.7	1.4	0.5			0.8

For Faster Polarization

- LEP type asymmetric wiggler can increase α+, hence reduce the polarization time.
- But the energy spread and SR loss also increase.



$$\sigma_E \propto \sqrt{\frac{I_3}{I_2}} \qquad U_0 \propto I_2 \qquad I_3 = \oint ds/|\rho|^3, \qquad I_2 = \oint ds/\rho^2$$

- Hence,
  $A_P = A_E^2 \times A_U$
  A_P = improvement factor of τ_p
  A_E = increase of σ_E, A_U = increase of U_0
- Polarized beam experiment at FCC-Z, at least A_p~100 needed
  - A_E only up to 1.5-2 allowed（energy spread depol.)
  - Hence A_U ~40 , → beam current must lowered by 1/40
  - Local SR too large at asymmetric wigglers
  - Moreover, spin rotator needed for longitudinal polarization
- Pilot bunch can be used for energy calibration
  - Long beam life (no beam beam)
  - 2-3 hours are enough for CEPC to reach the polarization level needed for calibration (**Most realistic foe CEPC**)

Injection and Acceleration of Polarized Beam

- Injection/acceleration of polarized beams seems feasible
- What's needed?
  - Polarized beam source
  - For positron,
    - CBAF?
    - Compton seems feasible
    - Undulator like ILC?
    - Required intensity much lower than in ILC
  - Resonance crossing in the booster ring (and maybe pre-booster ring) → double Siberian snake
  - Spin rotator in the collider ring (for longitudinal polarization)
    - Local synchrotron radiation is an issue
- Note the depolarization due to the energy spread still exists

My Conclusion on Beam Polarization

- Sokolov-Ternov can still be used for energy calibration at CEPC-Z (54km) and (perhaps) at FCC-W
  - A bit slow but may be possible at FCC-Z
  - If the energy calibration is the only purpose at these energies, pre-polarized beam not needed
  - Issue to be studied is the expected accuracy of the calibration
    - Can we reach 1e-6 (0.1% of σ_E)
    - How large is the energy difference between the pilot bunches and the colliding bunches?
- Collision of longitudinally polarized beam is very hard even with pre-polarized beam