Status ILC Positron Source

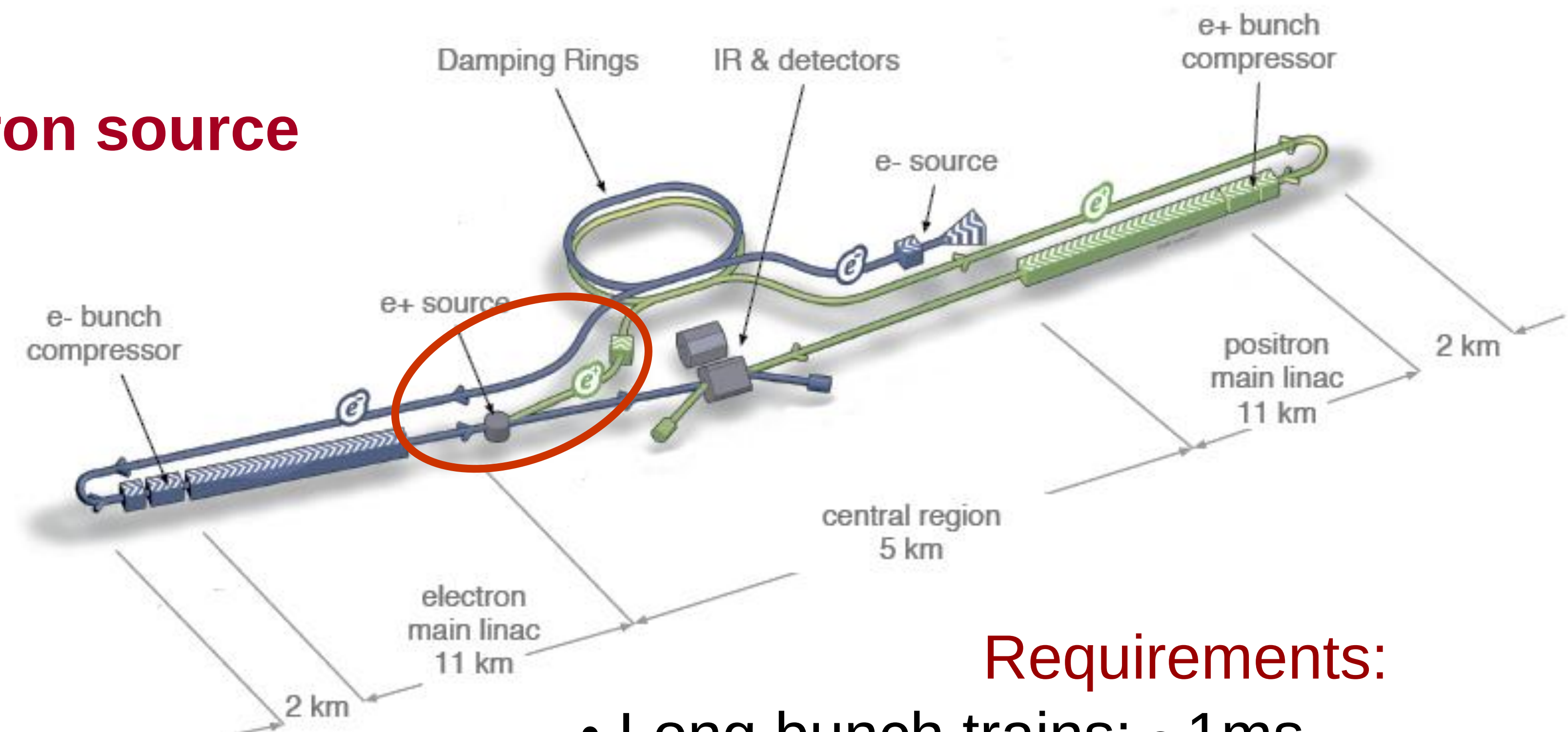
Helmholtz-Alliance Linear Collider Forum
29-30 April 2014
University of Bonn
Sabine Riemann (DESY) for the ILC e+ Group

Outline

- ILC positron source
  - Requirements
  - e+ production
  - Undulator based source
    - Undulator parameters
    - Target
    - Positron capture
    - Source parameters
    - Polarization upgrade
  - ILC e+ source @ E_{cm} = 250GeV
- Alternative: conventional source
- Summary

ILC e+ source

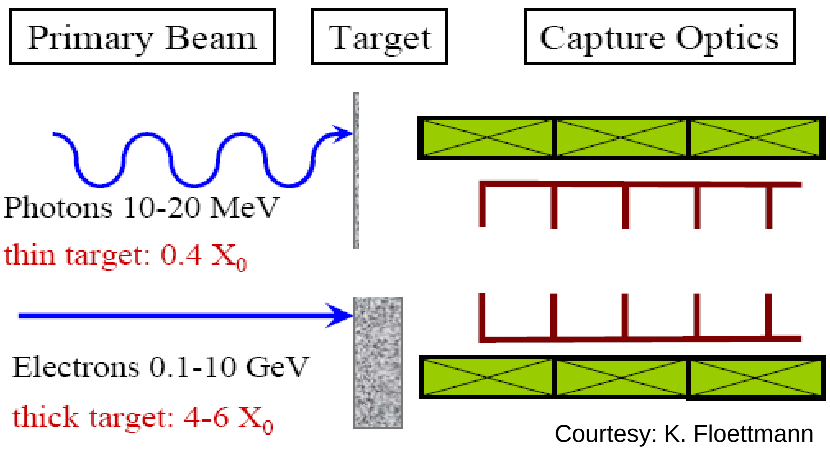
Positron source



Requirements:

- Long bunch trains: ~1ms
  1312 (2625) bunches per train, rep rate 5Hz
  2×10^{10} particles/bunch
- Small emittance
- Beam polarization

Production of Positrons



Undulator,
Compton backscatt. (far future)
Large heat load @ target

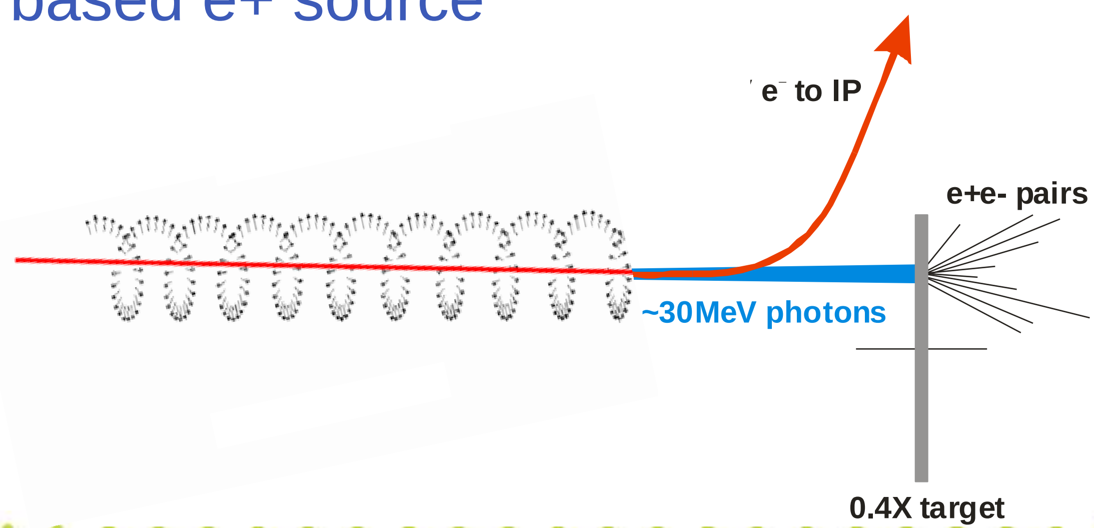
"Conventional"
Huge heat load @ target

ILC baseline: undulator based e+ source

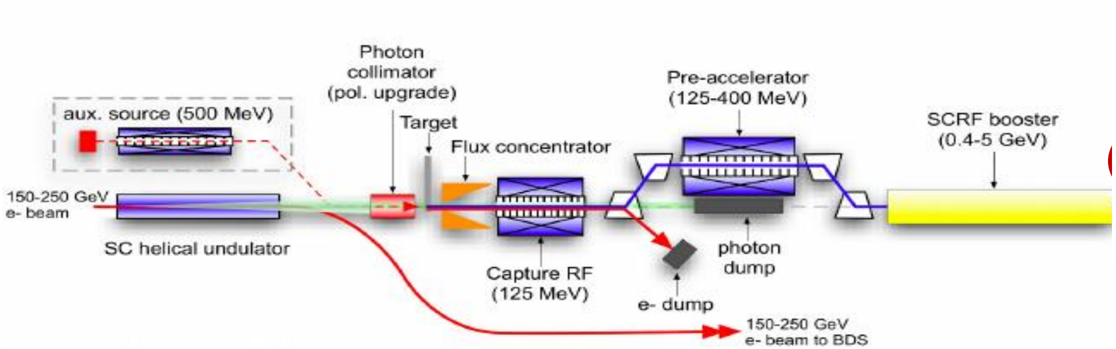
Helical undulator

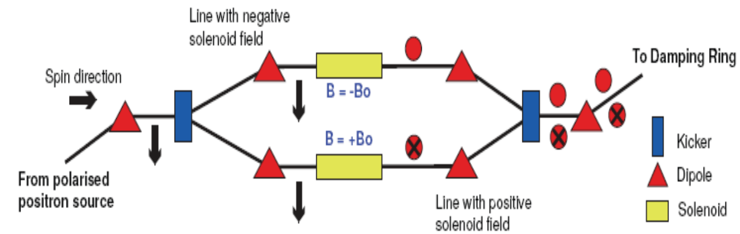
→ Circularly pol. γ

→ Long. polarized e+



ILC Positron Source



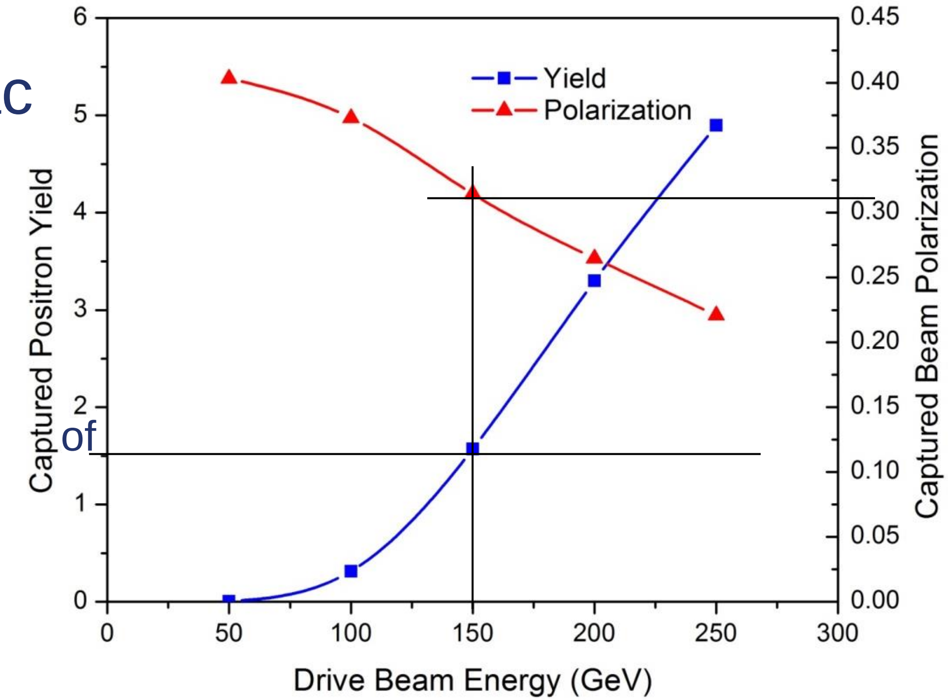


- Undulator
  - Superconducting
  - helical → positron beam is polarized
  - K=0.92, λ=1.15cm, (B=0.86T on the axis)
  - aperture 5.85mm
  - Max 231m active length (needed if photon-Collimator to increase e+ pol)
- e+ Production Target
  - 400m downstream the undulator
  - 0.4 X0 Ti alloy
- Positron Capture: Pulsed flux concentrator + capture RF
- Normal-conducting pre-acceleration up to 400MeV
- e+ polarization
  - ~30% (≤60% with photon collimator and longer undulator)
  - Polarization sign is determined by undulator winding (direction of the helical field)
    → Spin Flipper (2 parallel lines to rotate in opposite direction)
  - Spin manipulation see also talk by Valentyn

ILC Undulator Parameters

Undulator at end of main linac

→ source parameters depend on e- energy



e+ yield and polarization:

(Quarter wave transformer instead of flux concentrator)

L_u=147m, no photon collimation

➔ P ≈ 30%

Undulator windings: NbTi

Parameter	Value
Period (mm)	11.5
K	0.92
Field on Axis (T)	0.86
Beam aperture (mm)	5.85
First Harmonic Energy (MeV)	10.1
Nominal Drive Beam Energy(GeV)	150

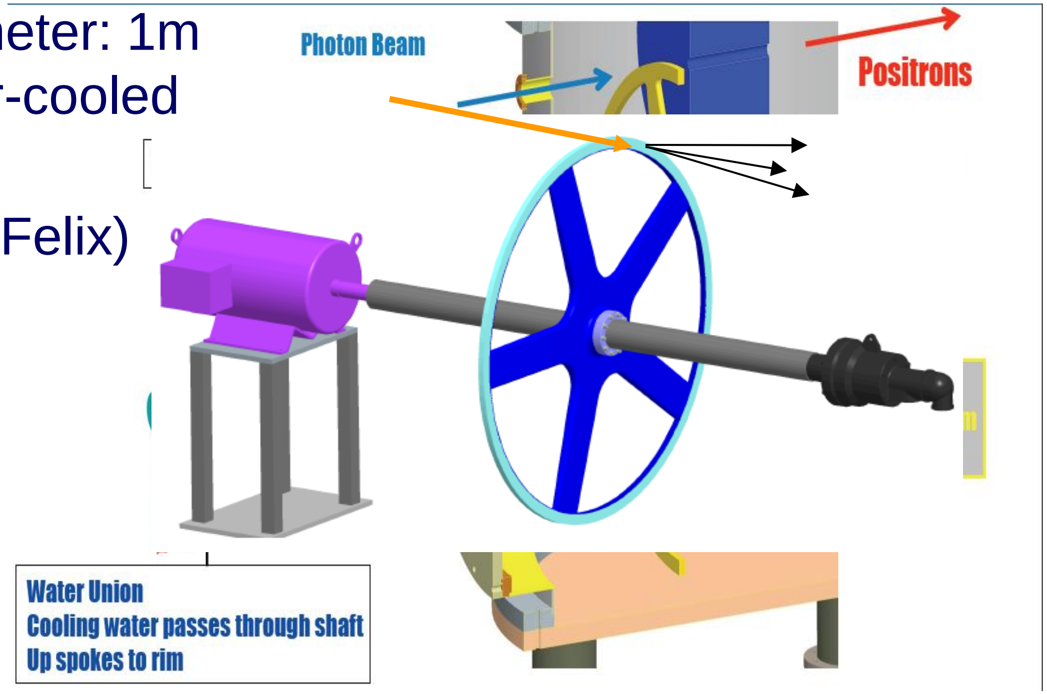
Positron Target

- Titanium alloy Ti-6%Al-4%V, thickness 0.4 X_0 (1.4 cm)
- Small photon spot size on target (~1.2 – 1.7 mm rms) → high peak energy deposition density
- Average power deposition in target: 5-7% (< ~4kW)

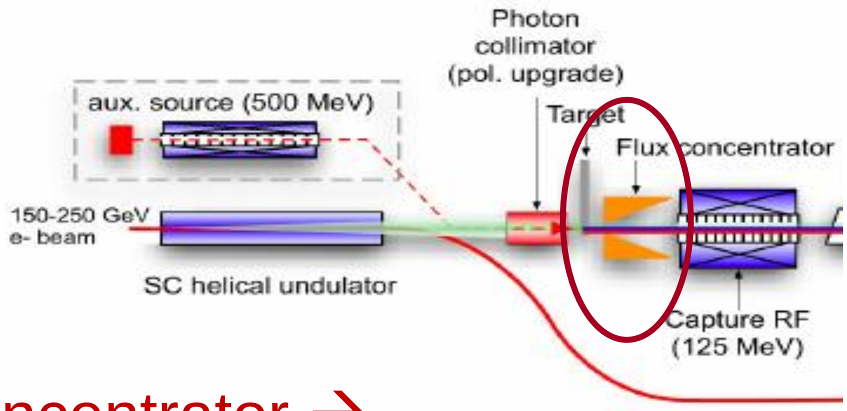
→ spinning wheel to avoid target damage

  - 2000 r.p.m. (100m/s), diameter: 1m
  - Wheel is in vacuum, water-cooled
- Potential problems
  - Stress waves (see talk by Felix)
  - Rotating vacuum seals:
    - Under test at LLNL using Ferromagnetic seal
    - Still unsatisfactory
    - Outgassing spikes still being observed

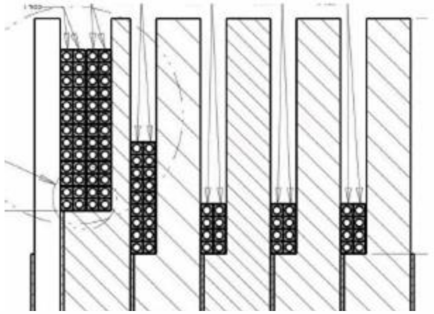
  → More work is needed



Pulsed Flux Concentrator

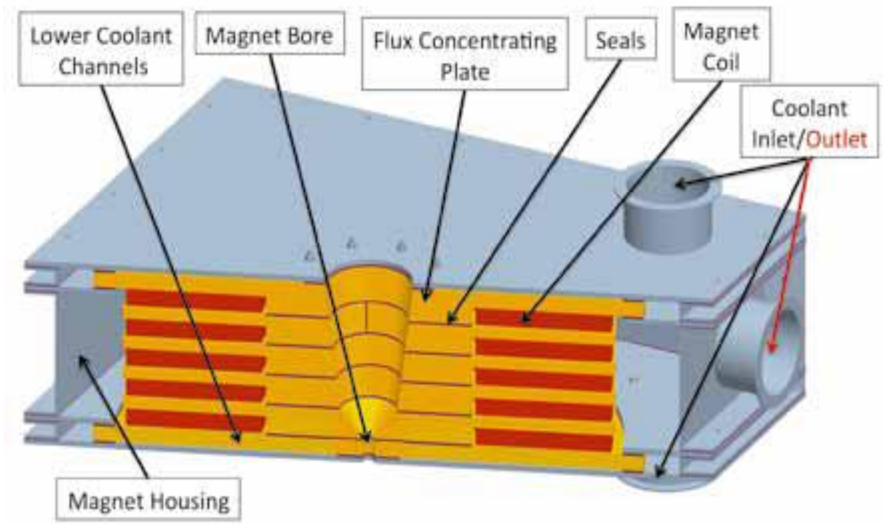


J. Gronberg, LLNL



Pulsed flux concentrator → capture efficiency of ~25%

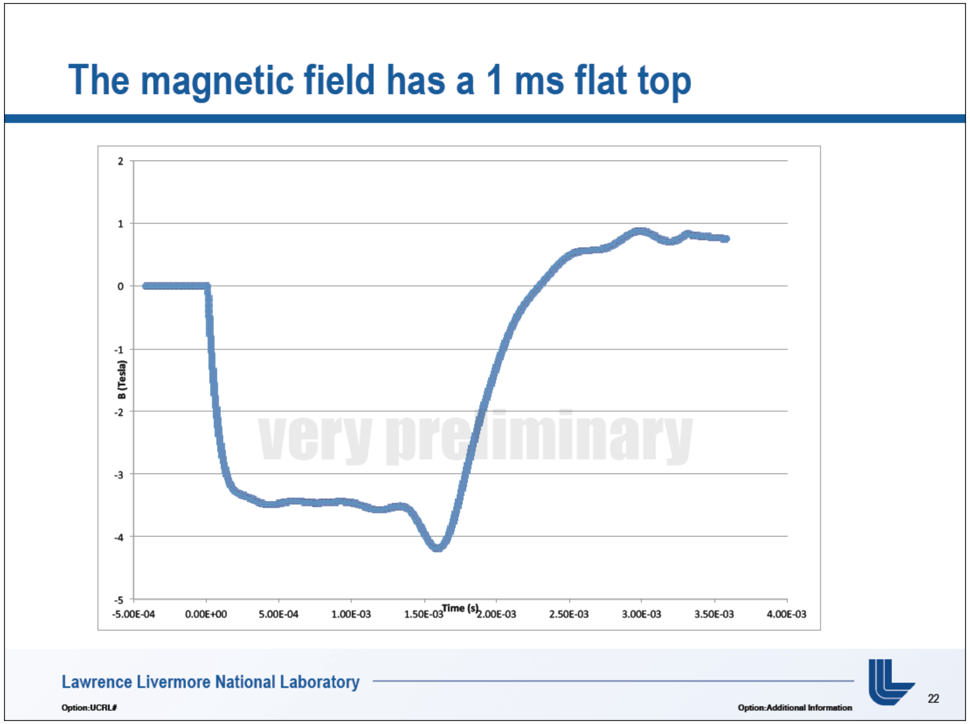
- Quarter wave transformer ~ 15%
- low field on target → low eddy currents
- high peak field (3.2T), 1ms flat top
- Magnetic field goes adiabatically down to 0.5T at capture RF
- Prototyping and testing at LLNL



Flux concentrator

- Full field with 1ms flat top has been demonstrated

J. Gronberg, LLNL



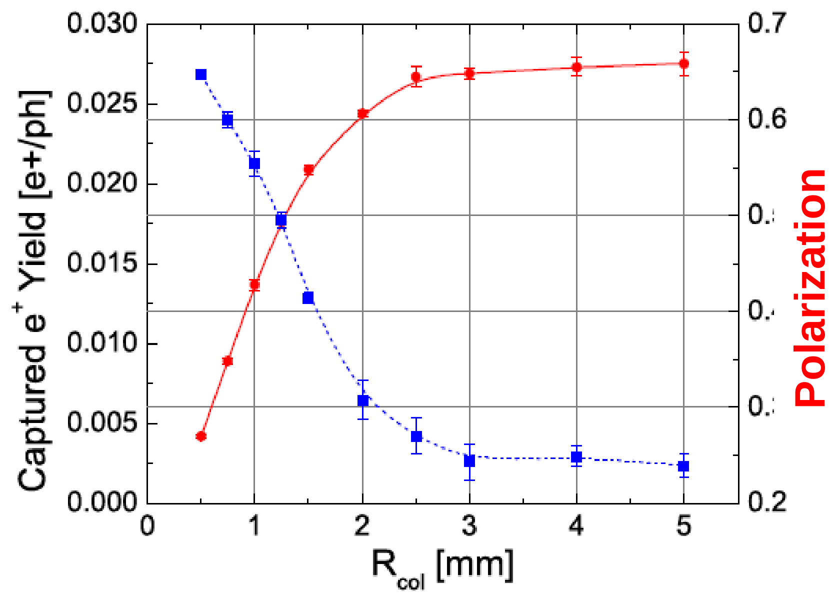
- FC seems workable but still need to demonstrate full average power operation
  - Run with 5Hz over extended period and full average power with cooling

Polarization upgrade

Collimation of γ beam
→ Higher polarization

Lower yield must
be compensated
By longer undulator

Yield and Polarization vs Aperture
Radius of Photon Collimator



Ushakov

Photon beam collimation

ILC TDR

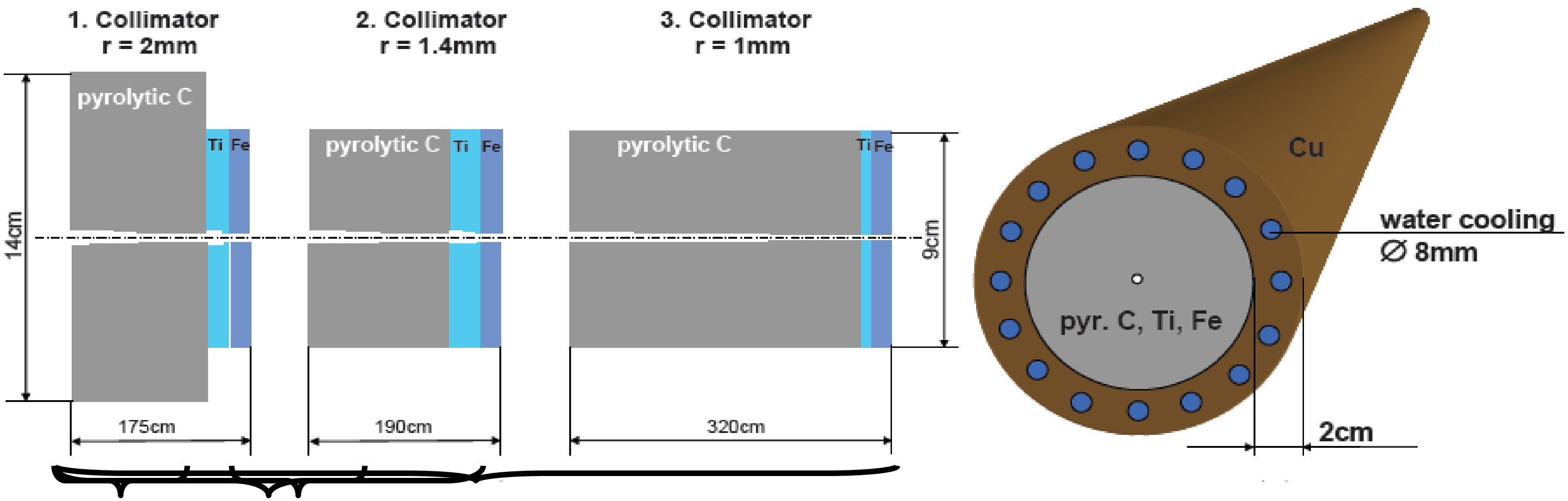
Parameter	Unit					L upgrade
Centre-of-mass energy	GeV	200-250	350	500	500	500
Drive-electron-beam energy	GeV	150	175	250	250	250
Undulator K value				0.92		
Undulator period	cm			1.15		
Positron polarisation	%	55	59	50	59	50
Collimator-iris radius	mm	2.0	1.4	1.0	0.7	1.0
Active undulator length	m	231	196	70	144	70
Photon beam power	kW	98.5	113.8	83	173	166
Power absorbed in collimator	kW	48.1	68.7	43.4	121	86.8
Power absorbed in collimator	%	48.8	60.4	52.3	70.1	52.3

350GeV: 60% e+ polarization ⬄ ~60% of photon beam power absorbed in collimator

500GeV: 60% e+ polarization ⬄ collimator absorbs ~70% of photon beam power → 50% e+ polarization 'sufficient' ?

Photon collimator

- Collimator parameters depend on energy
  → Multistage collimator (3 stages with each pyr. graphite, Ti, Fe)



E_{e-} =150 GeV, E_e = 175 GeV, E_e = 250 GeV

P_{e+} = 50%, P_{e+} ≈ 60%, P_{e+} ≈ 50%

- Potential problem: damage due to long-term irradiation
  – Max values for displacement per atom (dpa) ~ 0.5 at inner collimator surface
  → volume change (swelling); consequences are under consideration

E_{cm} = 250 GeV

Higgs-Boson measurements

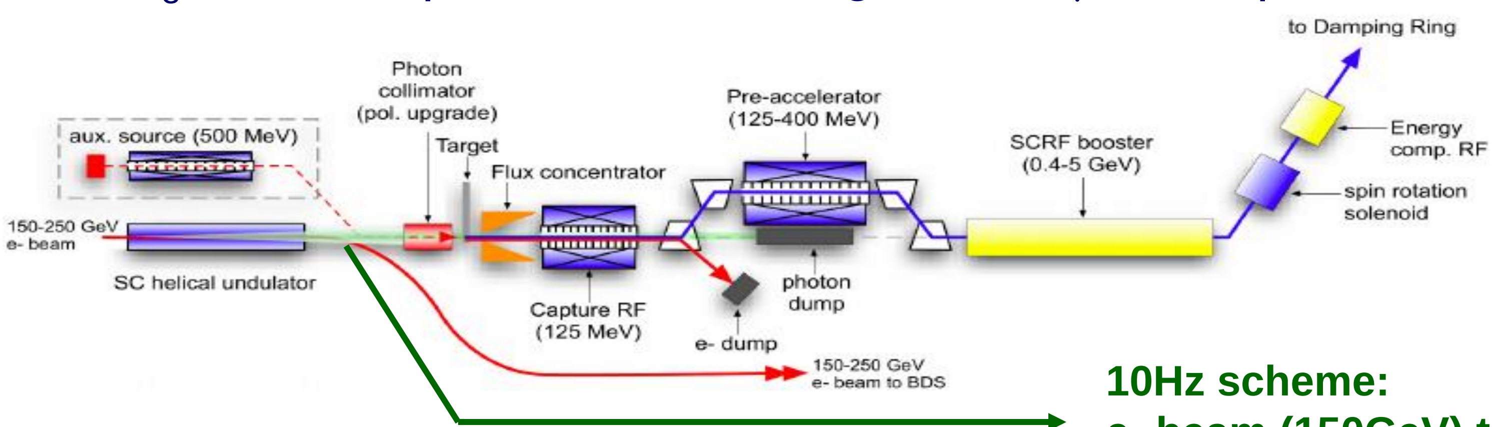
ILC as Higgs factory

E_{cm} = 250 GeV ⇔ E_e = 125GeV

– For E_e < 150 GeV yield is below 1.5 e+/e-

→ TDR: 10 Hz scheme

1. Alternating with e- beam for physics additional e- beam with E_e=150GeV passes undulator generate γ for e+ production



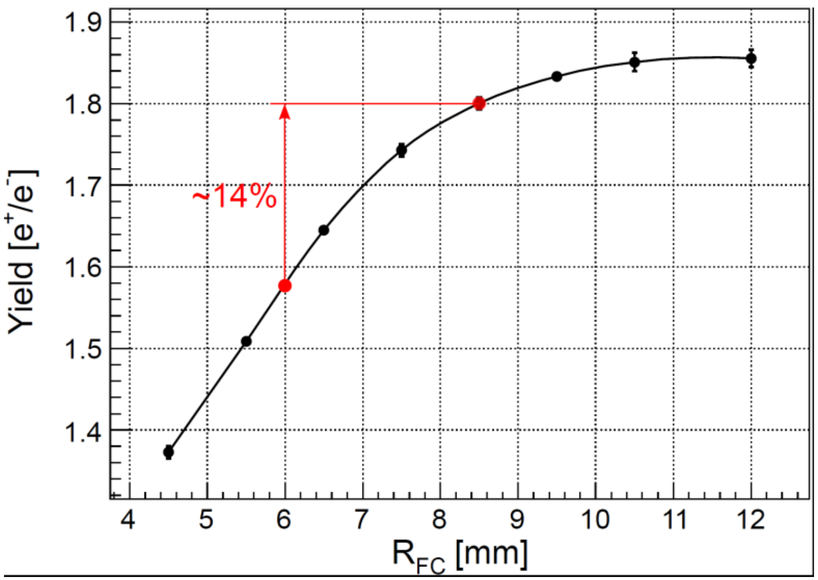
10Hz scheme:
e- beam (150GeV) to dump

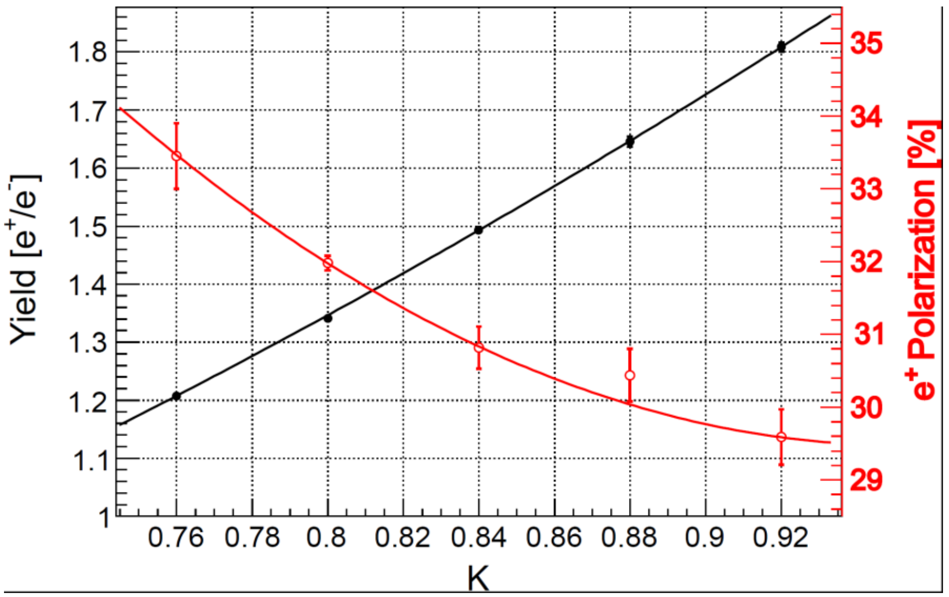
2. Use almost full length of undulator + increased aperture of flux concentrator + optimized system → no 10Hz scheme needed to get 1.5 e+/e-

Positron source at Ecm = 250 GeV

optimzed e+ source parameters to avoid 10Hz scheme

- see A. Ushakov et al., LC-REP-2013-019)



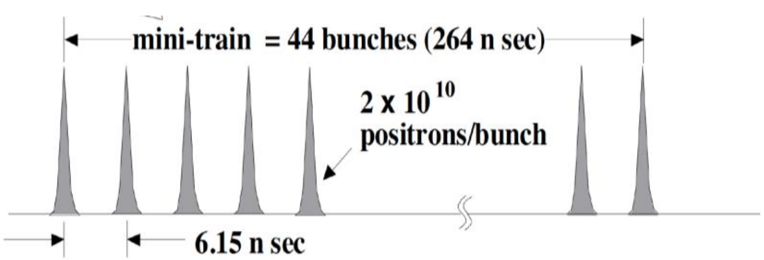


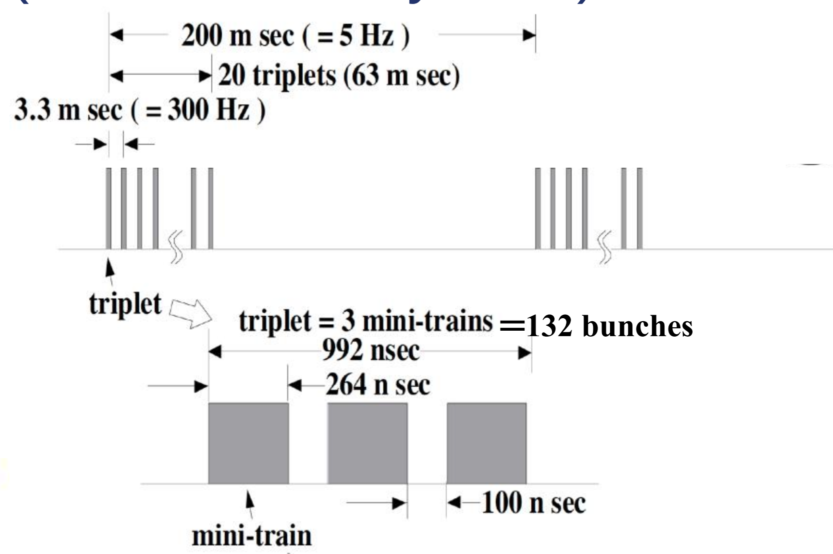
Alternative source scheme

Alternative source: “300 Hz scheme”

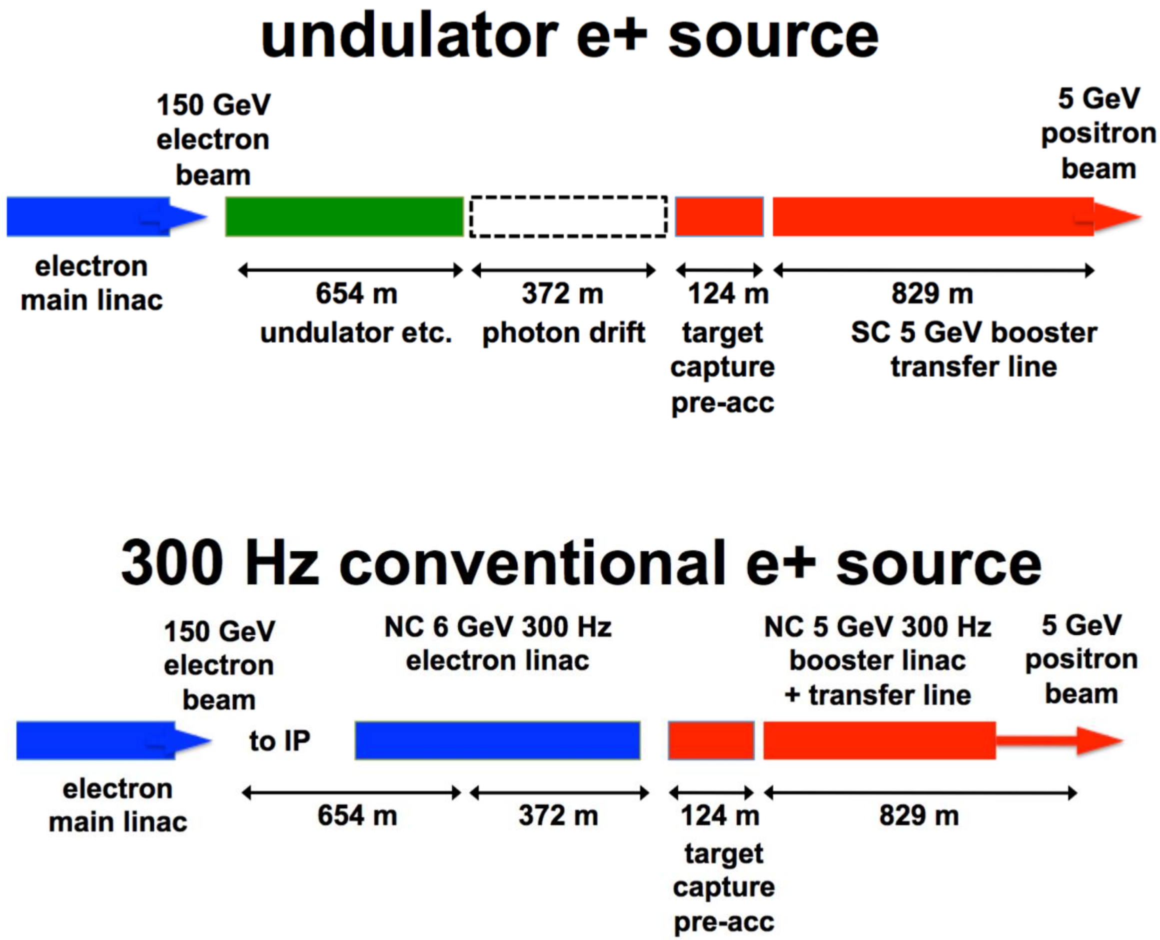
T. Omori

- 6GeV e- beam, 4 X0 tungsten target
- Time stretched generation of e+ bunch train:
  - 63ms instead of 1ms
    → lower peak load on target
  - **2640 bunches** per train; 2640 = 20 × 132
  - Bunch train ⇔ **20 triplets** = 20 × 3 Mini-Trains (3 Mini-Trains = triplet)
  - Triplets are generated with 300Hz
- With beam size σ = 4mm, the peak energy deposition density is below 30J/g (limit from SLC target)
- Dynamic stress under study (see next talk by Felix)





LCWS 2013, talk by T. Omori: start with conventional scheme does not prevent upgrade wit



Summary

- Undulator Scheme
  - Polarized source
  - Spinning target (2000rpm)
  - Flux concentrator development at LLNL
  - Photon collimator for higher polarization
  - Spin manipulation (fast reversal)
  - e+e- collisions at 250GeV possible with Y=1.5 e+/e-
- Conventional (300Hz) Scheme
  - Unpolarized source
  - Moving target (≥~ 5m/s) needed
  - Flux concentrator
  - Overall simulation
    - Confirm the positron yield
    - Including capture, bunch compression, beamloading & energy compression
- Choice of undulator/conventional should not affect tunnel
- R&D work is ongoing

- Backup

Undulator Parameters

- Photon energy (cut-off first harmonic) and undulator K value

$$E_1 \cong 23.7\,\mathrm{MeV}\,\frac{(E_e/50\,\mathrm{GeV})^2}{(\lambda_u/1\,\mathrm{mm})(1+K^2)}$$

$$K \cong 0.0934\,\frac{B_0}{1\,\mathrm{T}}\cdot\frac{\lambda_u}{1\,\mathrm{mm}}$$

λ_u = undulator period

- Number of photons
  - Increase intensity of γ beam by longer undulator

$$\frac{dN_{ph}}{dL} \cong \frac{30.6}{\lambda_u/1\,\mathrm{mm}} K^2 \;\; photons\,/\,m\,/\,e^-$$

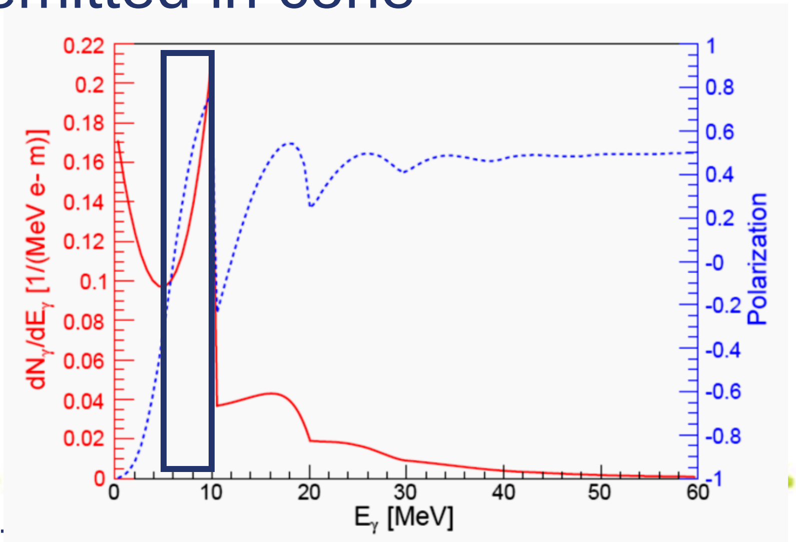
⇔ Y = 1.5 e+/e- @ DR

- Upper half of energy spectrum is emitted in cone

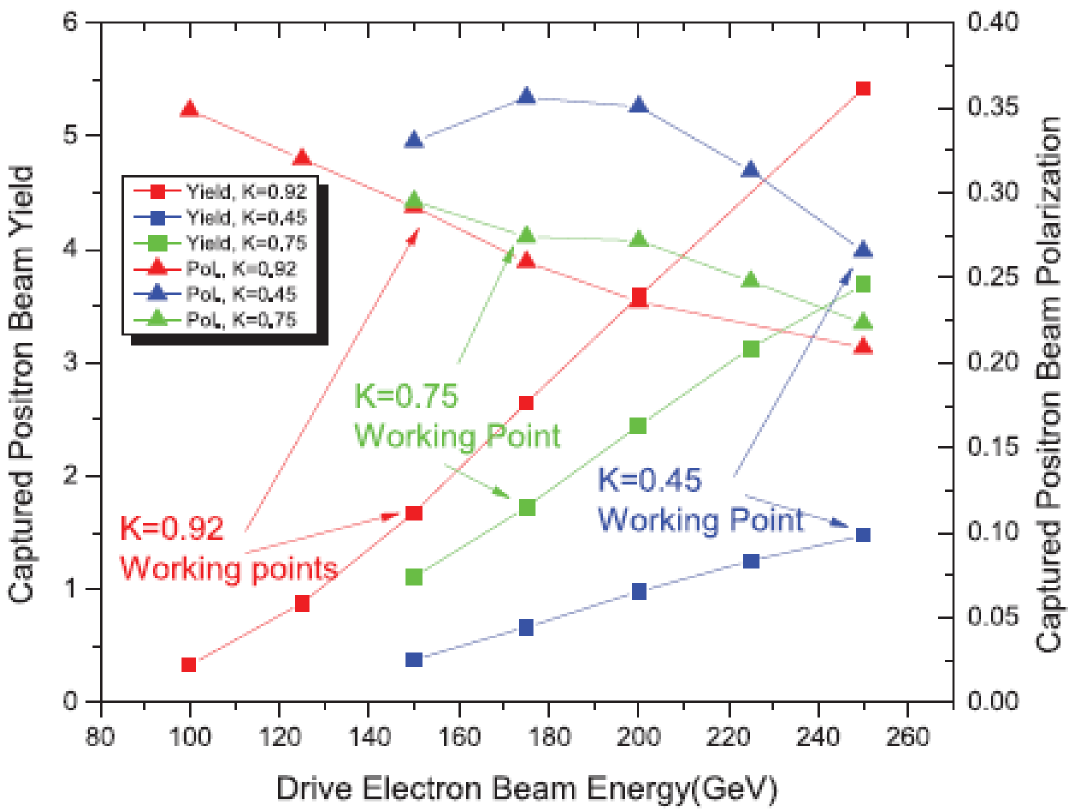
$$\theta = \frac{\sqrt{1+K^2}}{\gamma}$$

- Photon spectrum

  → Higher polarization with γ collimation



- e+ source is located at end of the linac ➔ polarization and yield are strongly coupled to the electron beam energy!
- Optimum undulator parameters (K, undulator length) depend on E_e
- With higher energies smaller beam photon beam spot size on target → high polarization is difficult to achieve for high energies (heat load on target and photon collimator)



ILC TDR

e- Beam Parameters for e+ generation	Ecm (GeV)						
	200	230	250	350	500	500 L upgrade	1000
e+ per bunch at IP (×10^{10})	2			2	2	2	1.74
Number of bunches per pulse	1312					2625	2450
Undulator period (cm)	1.15					1.15	4.3
Nominal 5Hz mode							4Hz
Undulator strength (K value)				0.92	0.75	0.45	1
Beam energy (GeV)				178	253	253	503
Undulator length (m)				147		147	132
10Hz alternate pulse mode							
Undulator strength (K value)	0.92						
Beam energy for e+ prod.(GeV)	150						
Undulator length (m)	147						
Beam energy for lumi (GeV)	101	117	127				
e- beam bunch separation (ns)	554					366	366
Power absorbed in e+ target (%)	7			7	5.2	5	4.4
Spot size on target (mm rms)	1.4			1.2	0.8	0.8	
Peak power density in target (J/g)	51.7			65.6	67.5	101.3	105.4
Polarization (no collimator) (%)	31			30	29	29	19

e- Beam Parameters for e+ generation	**Ecm (GeV)**				
	240	**350**	**500**	**500 L upgrade**	**1000**
e+ per bunch at IP (×10^{10})	2	2	2	2	1.74
Number of bunches per pulse	1312			2625	2450
Undulator period (cm)	1.15			1.15	4.3
Nominal 5Hz mode					4Hz
Undulator strength (K value)	**0.84**	0.92	0.75	0.45	1
Beam energy (GeV)	**120**	178	253	253	503
Undulator length (m)	**192**	147		147	132
10Hz alternate pulse mode					
e- beam bunch separation (ns)	554			366	366
Power absorbed in e+ target (%)	**9.2**	7	5.2	5	4.4
Spot size on target (mm rms)		1.2	0.8	0.8	
Peak power density in target (J/g)	**44**	65.6	67.5	101.3	105.4
Polarization (no collimator) (%)	**31**	30	29	29	19