ILC Polarized Electron and Positron Sources

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HKIAS Mini-Workshop on Polarization in Future Colliders

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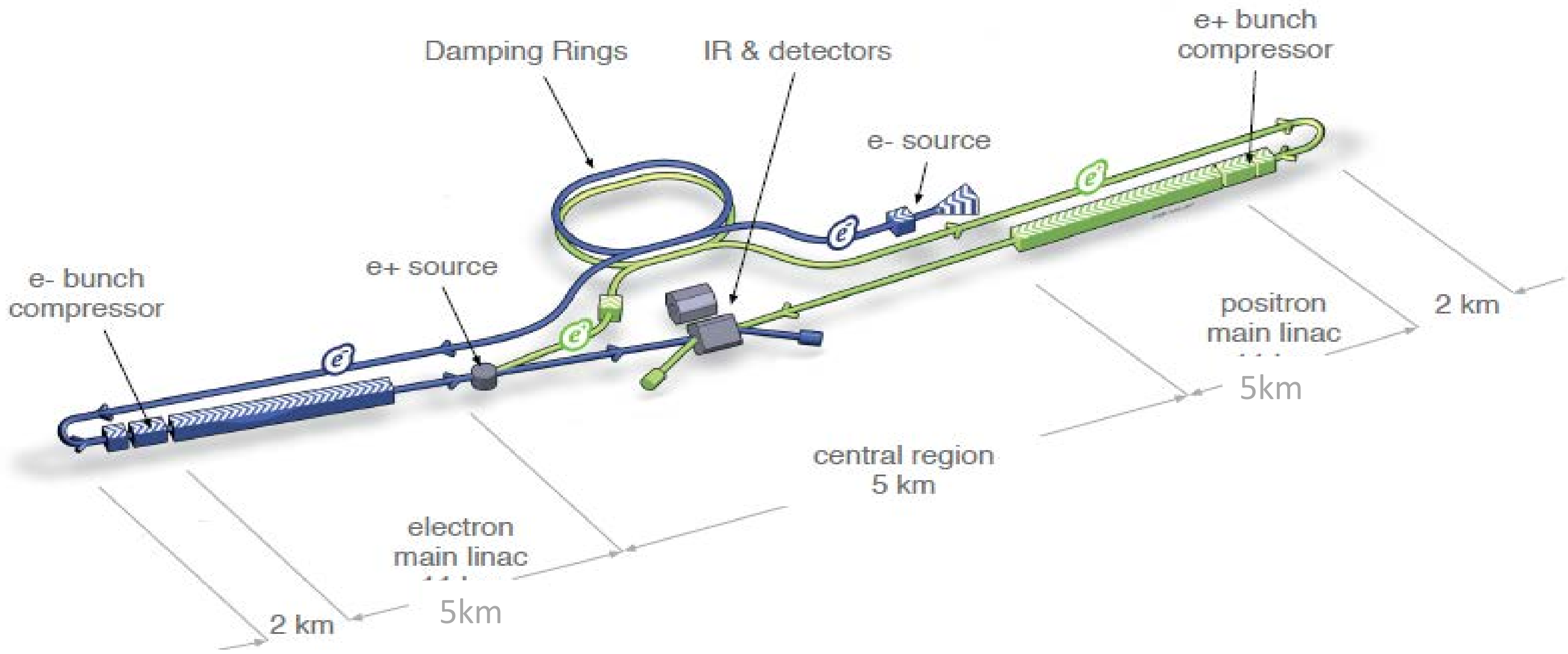
Beam Polarization in Linear Colliders

- Beam polarization is a useful tool in linear colliders
- If a polarized beam source is available, polarized beam collision is easy
  - No (or very small) depolarization during acceleration
  - No resonance (depolarization in damping rings is negligible)
  - Spin rotator is simple
  - Beam-beam depolarization is not serious
- In fact, the electron polarization in the SLC played an important role in spite the luminosity was much lower than in LEP
- But the major issue is the beam intensity (per second)
  - Single pass nature of linear colliders

ILC Layout



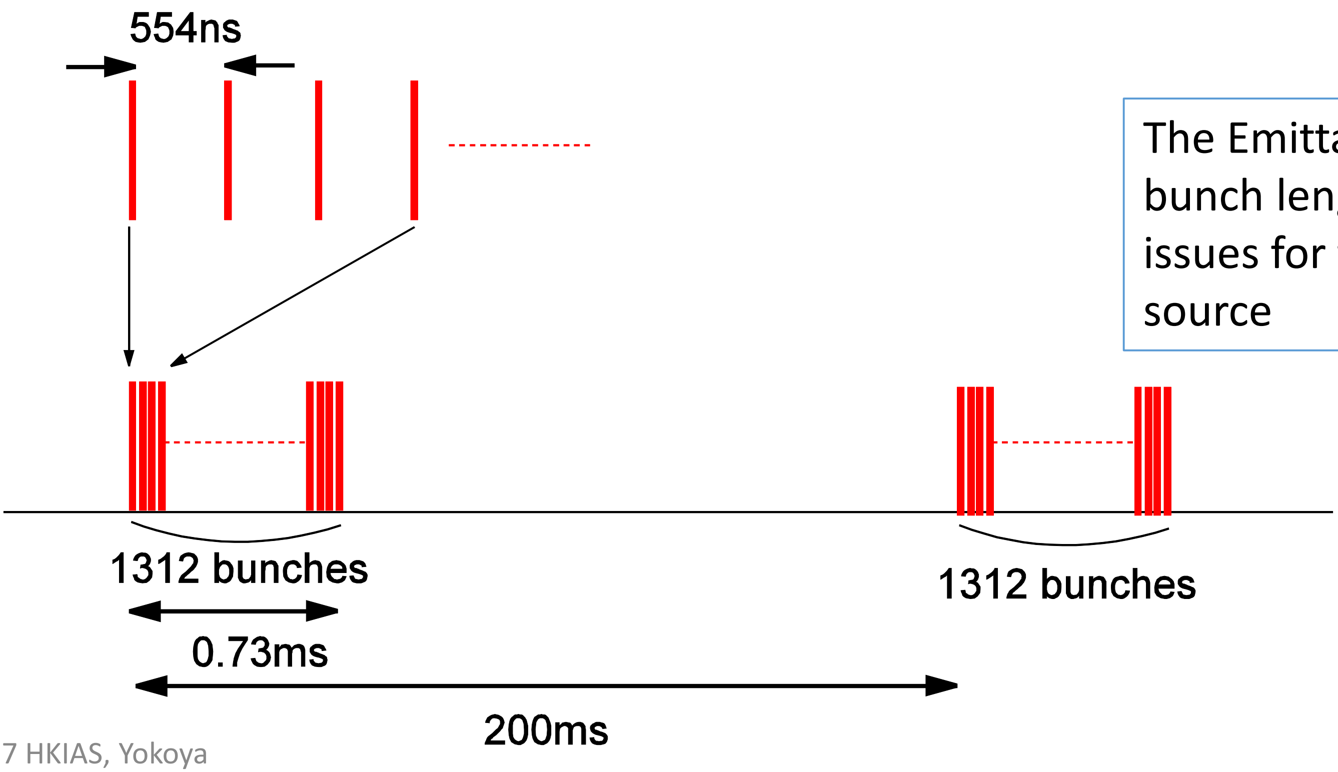
- Recently changed to the mirror image

Required Beam Intensity and Format

Repitition rate	**5Hz**
Number of bunches per pulse	**1312**
Number of particles per bunch	**2x10^10**
Bunch interval	**554 ns**
Rms bunch length	0.3 mm

Horizontal normalized emittance	5 μm
Vertical normalized emittance	35 nm
Horizontal rms beam size at IP	515nm
Vertical rms beam size at IP	7.7nm

Beam Pulse Structure (Low Power)

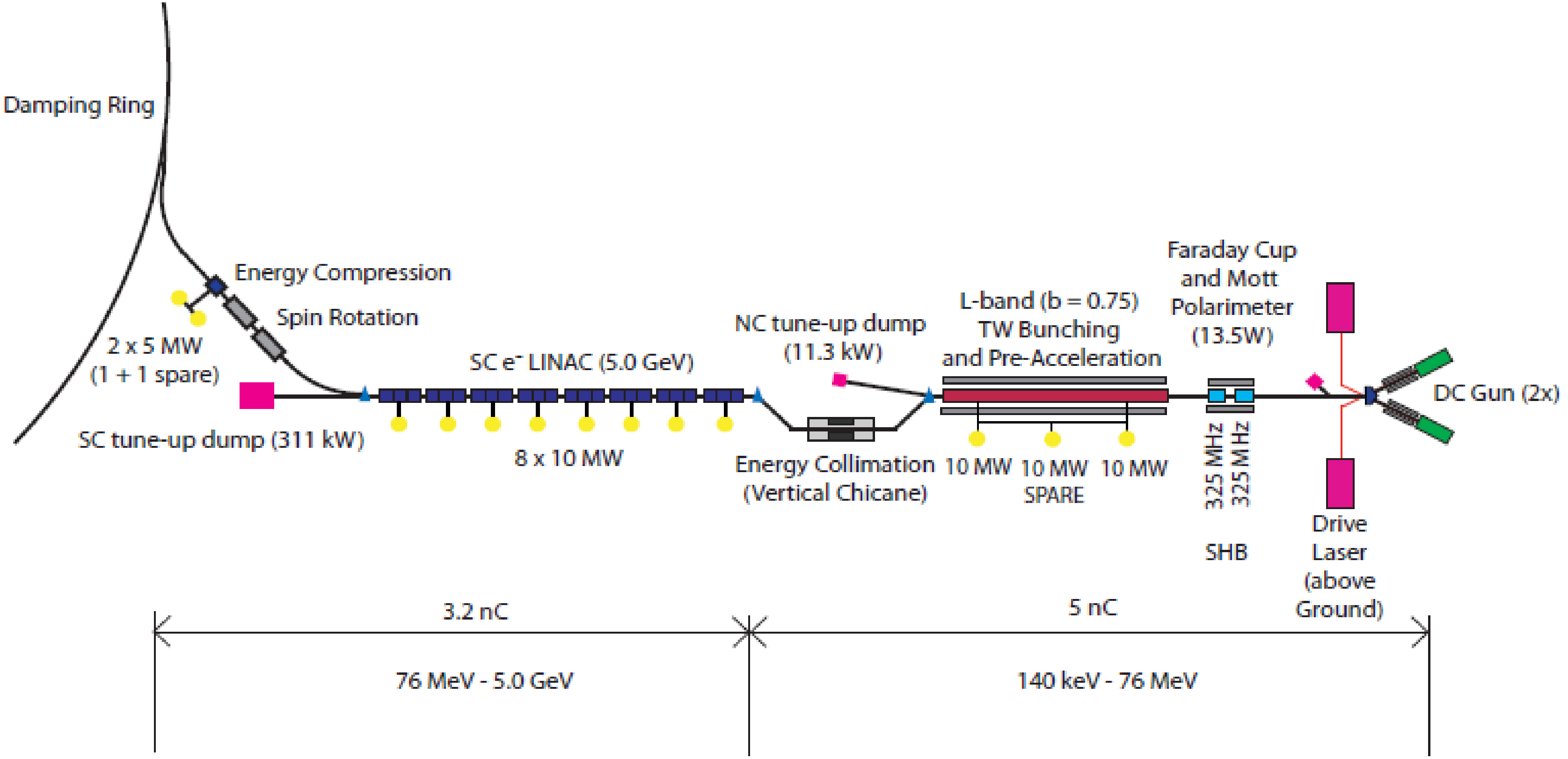


The Emittance and bunch length are not issues for the beam source

- X

Polarized Electron Source

- Polarized beam demanded（>80%）
- SLC reached ~80%
- Now, ~90% achieved by Nogoya Univ. group



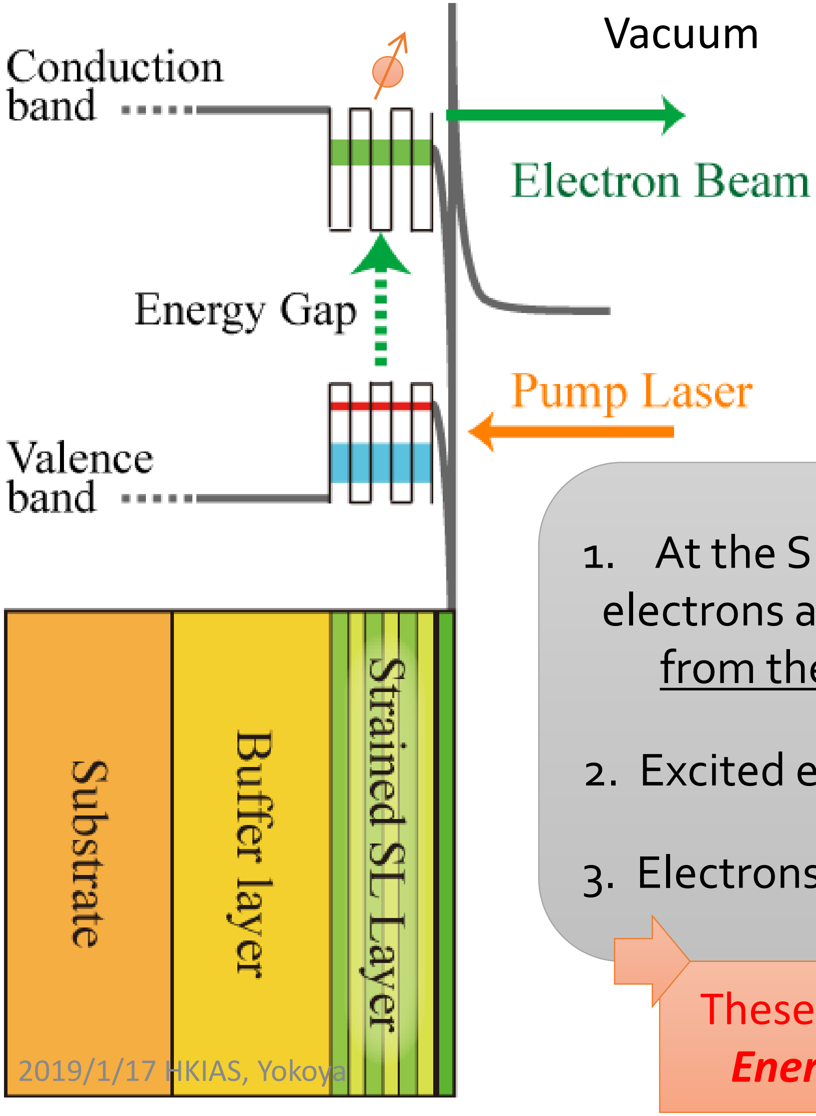
TDR Parameters

- P > 80%
- Photo-cathode quantum efficiency > 0.5%
- Drive laser wavelength 790 +- 20 nm (tunable)
- Single-bunch laser energy 5μJ

Generation of polarized electron

3 step model for electron emission

M.Yamamoto, 2015



3 step model
1. Optical pump
2. Diffusion at conduction band
3. Emission from NEA surface

1. At the SL layers,
electrons are pumped by ***Circularly polarized laser***
<u>from the highest valence band to conduction band</u>.

2. Excited electrons are diffused to PC surface .

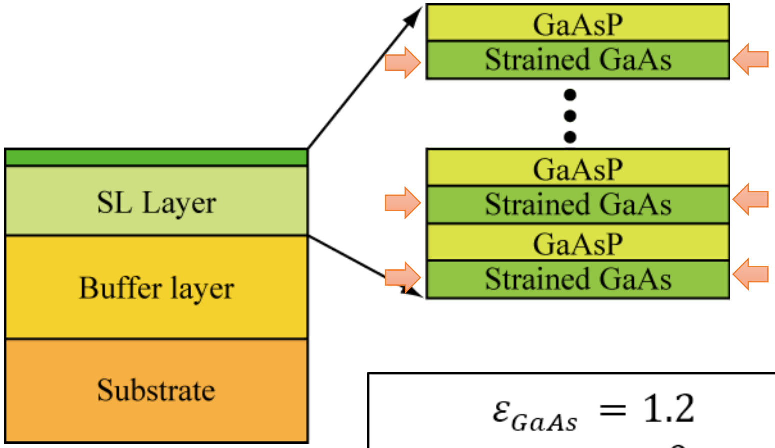
3. Electrons are emitted through the ***NEA surface***.

These processes contribute PC parameters (***Pe, QE***).
Energy Gap (structure design) corresponds to ***λ***.

Higher Polarization & Higher Q.E.

- Thicker strained GaAs layer
  - Limited by accumulated strain
- → Strain-compensated super-lattice

Strained SL

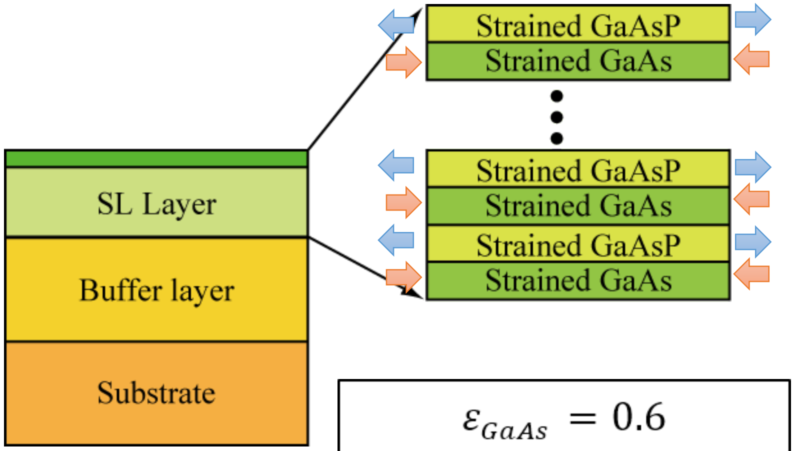


GaAsP
Strained GaAs
GaAsP
Strained GaAs
GaAsP
Strained GaAs
SL Layer
Buffer layer
Substrate

$$\varepsilon_{GaAs} = 1.2$$
$$\varepsilon_{GaAsP} = 0$$
$$L_{GaAs} \cong L_{GaAsP} = 4nm$$

$Net\ strain \cong 0.6$

Strain-compensated SL



Strained GaAsP
Strained GaAs
Strained GaAsP
Strained GaAs
Strained GaAsP
Strained GaAs
SL Layer
Buffer layer
Substrate

$$\varepsilon_{GaAs} = 0.6$$
$$\varepsilon_{GaAsP} = -0.6$$
$$L_{GaAs} \cong L_{GaAsP} = 4nm$$

$Net\ strain \cong 0$

M.Yamamoto, 2015

Results at Nagoya Univ.

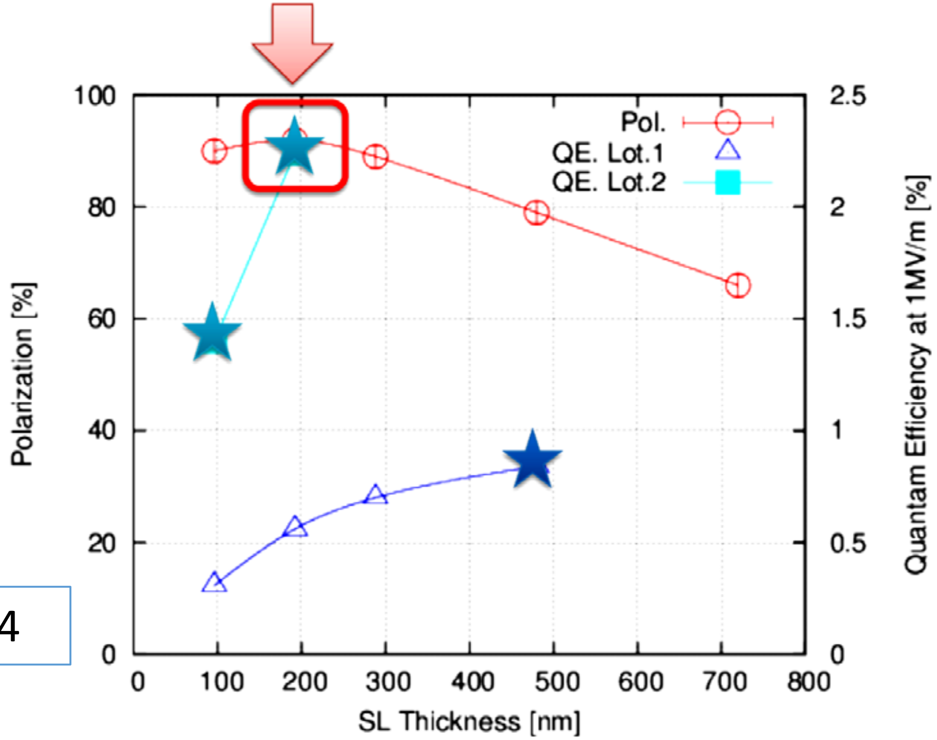
- Strain-Compensated Superlattice
  - Higher crystal quality
  - Thicker superlattice

- Obtained
  - Pol. ~92%
  - With QE 2.2%
- ~90% looks realistic
- Almost no depolarization expected to IP

N.Yamamoto (Nagoya Univ.) LCWS2014

GaAs-GaAsP Strain–Compensated .

Max. Pol. (~ 92%)
QE(~ 2.2 %)   were achieved



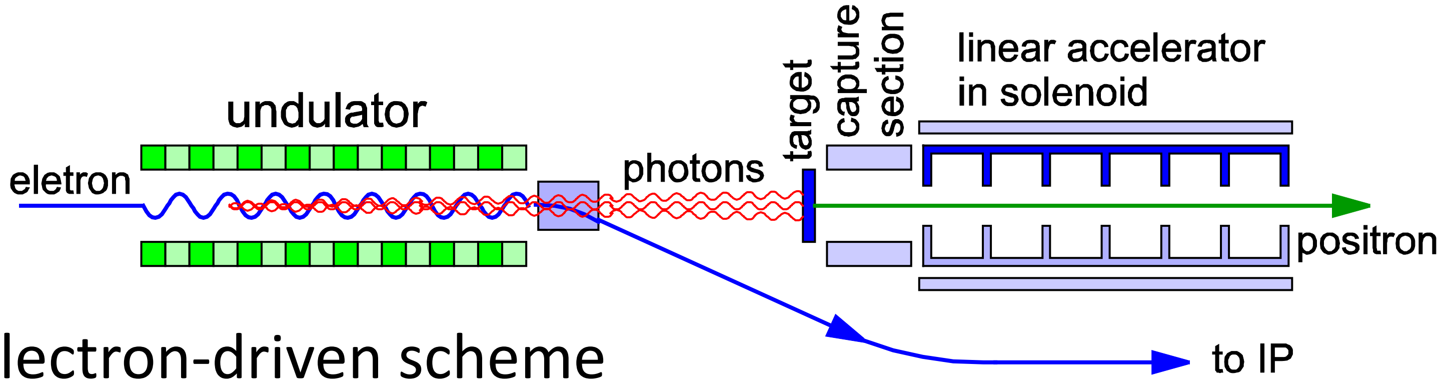
Issues to be Considered

- 1312 bunches / pulse
  - Max current ~5mA, similar to JLab
- Life of the cathode
  - GaAs well experienced
  - No essential difference for super-lattice expected
  - Quick re-activation possible
- Laser
  - Pulse structure similar to that for XFEL, KEK-STF
  - Longer pulse (ns), wavelength around 800nm
  - Need a study but no major difficulties foreseen
- Depolarization from the gun to IP
  - Expected to be small (<1%)
  - No “SLC” bumpy arc

Positron Source

3 possible schemes of positron beam generation

- Undulator scheme



- Electron-driven scheme
  - Hit a few GeV electrons on a target, and collect the generated positrons
  - adopted in many accelerators, well established
  - Issues in the application to ILC
    - Survivability of the target→ OK
    - Emittance of the generated positron → OK (improved DR optics)
    - Transport to DR entrance under study
    - **No polarized positron**
- Laser-Compton scheme (far future)

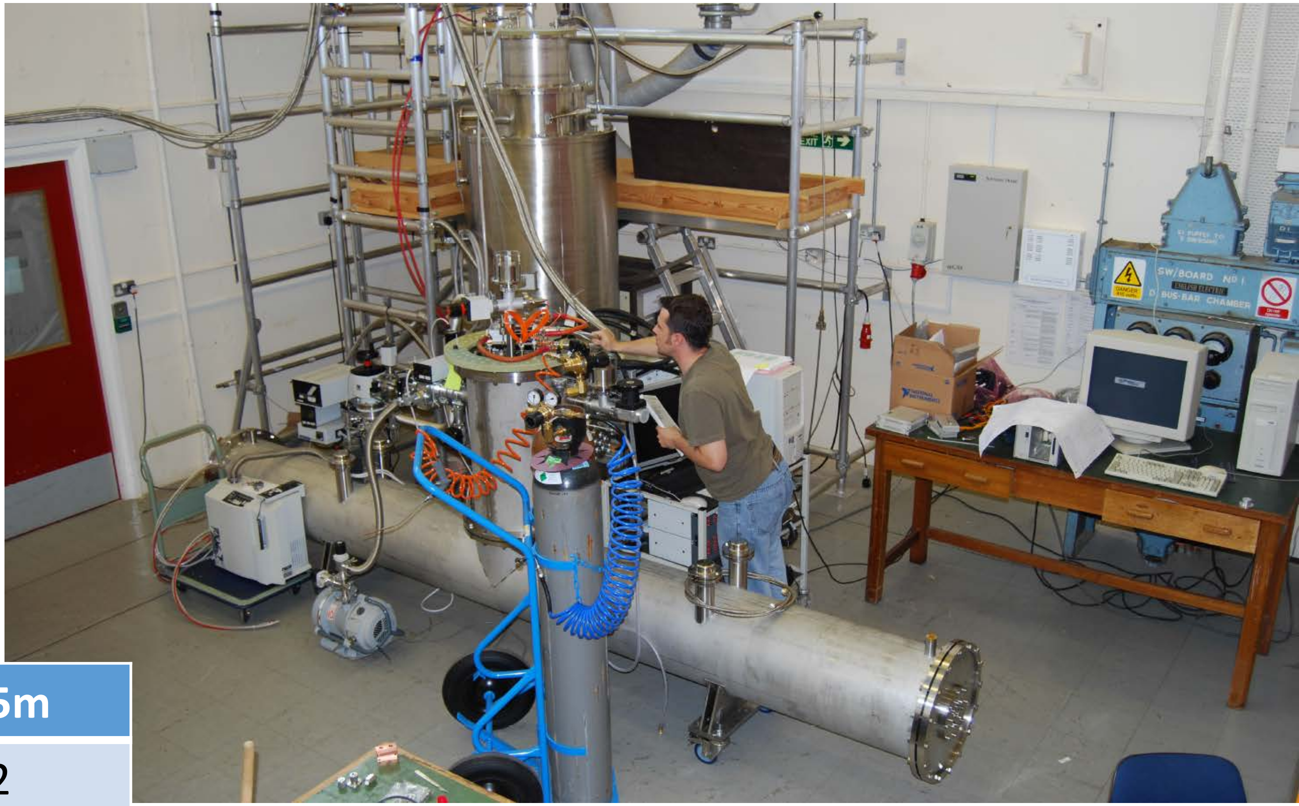
ILC Positron Source

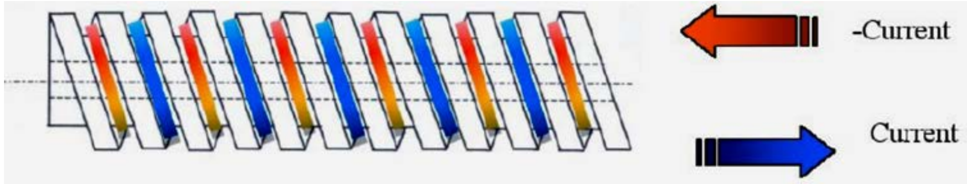
- Adopted Undulator Scheme as the baseline
- e-Driven scheme as the backup
- Advantage of undulator scheme
  - Polarized positron
  - Thinner target
    - The process start with $\gamma \rightarrow e^+e^-$, whereas the first process is electron bremsstrahlung in the e-driven scheme
  - Therefore
    - Less energy deposit on the target
    - Less radiation shield needed
    - Better positron emittance
- However, there is no flexibility in the beam-pulse structure
  - Because the beam must be used for collision experiment afterwards
  - e-Driven scheme can relax the target load by optimizing the pulse structure

Undulator

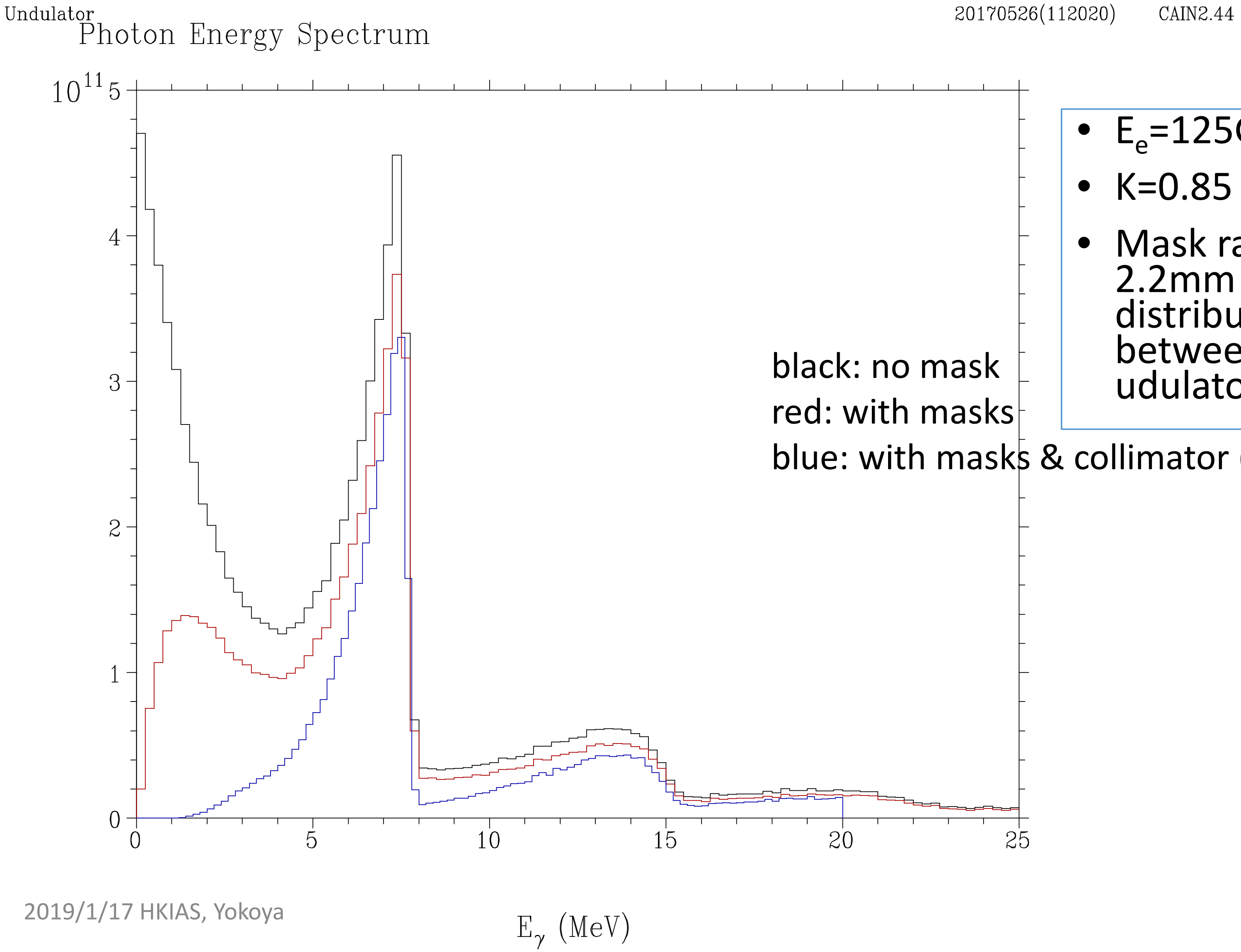
- Superconducting helical undulator developed at RAL
- two 1.75 undulators in a cryostat
- First cooling experiment Sep.2009
- Field strength sufficient (~30% over design)

Period	11.5m
Maximum K	0.92
Max. field on axis	0.86T
Beam aperture (diam.)	5.85
Winding bore	6.35mm
Length	1.75m
Temparature	4K





Photon Energy Distribution on Target



black: no mask

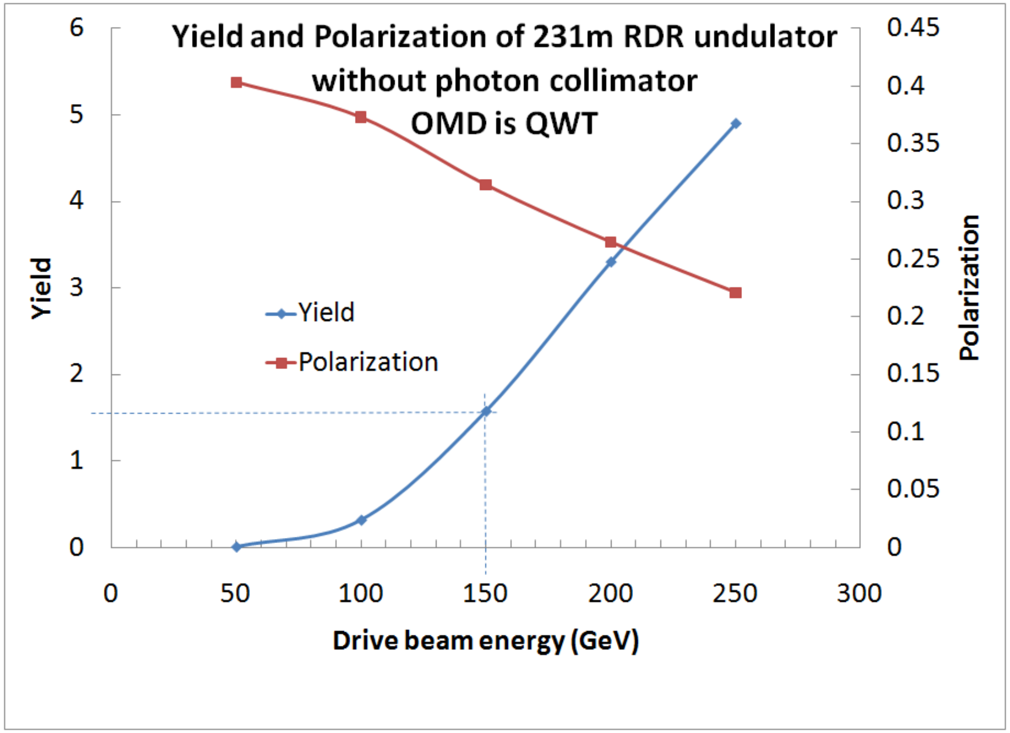
red: with masks

blue: with masks & collimator (r=2.2mm)

- E_e=125GeV
- K=0.85
- Mask radius 2.2mm distributed in between udulators

Recent Design Changes

- ILC now concentrates on E_{CM}=250GeV
- For E_{CM}=250GeV
  - Shortened the distance from undulator to target
  - Thinner target 14mm → 7mm
    See next page
  - Undulator length 147m → 231m
    - Because of the low yield at E_e=125GeV
    - TDR adopted "10Hz operation", i.e., 5Hz for collision and 5Hz for positron production with 147m undulator
    - But 147m → 231m is much cheaper and less operation power
    - The only problem is increased load on the target



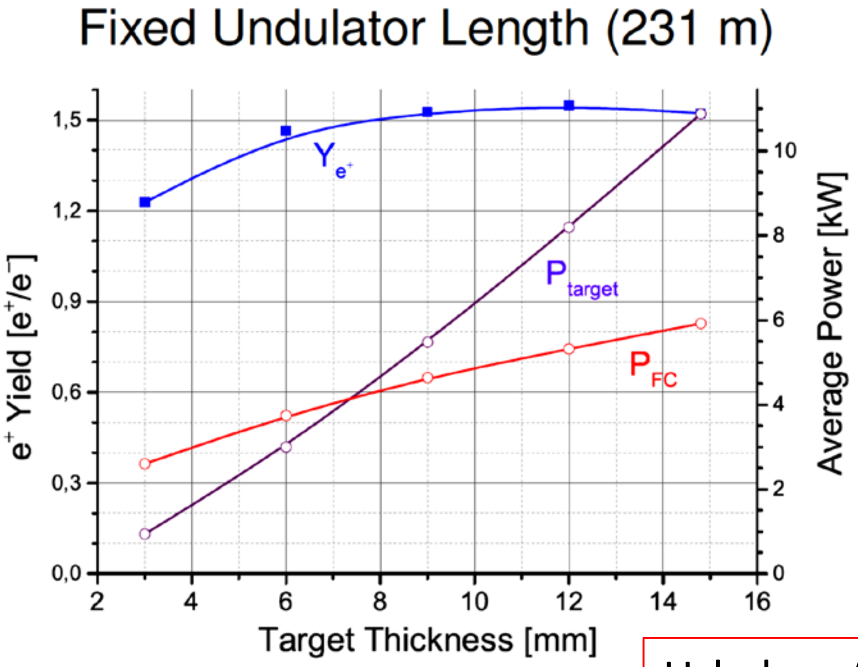
Target Thickness

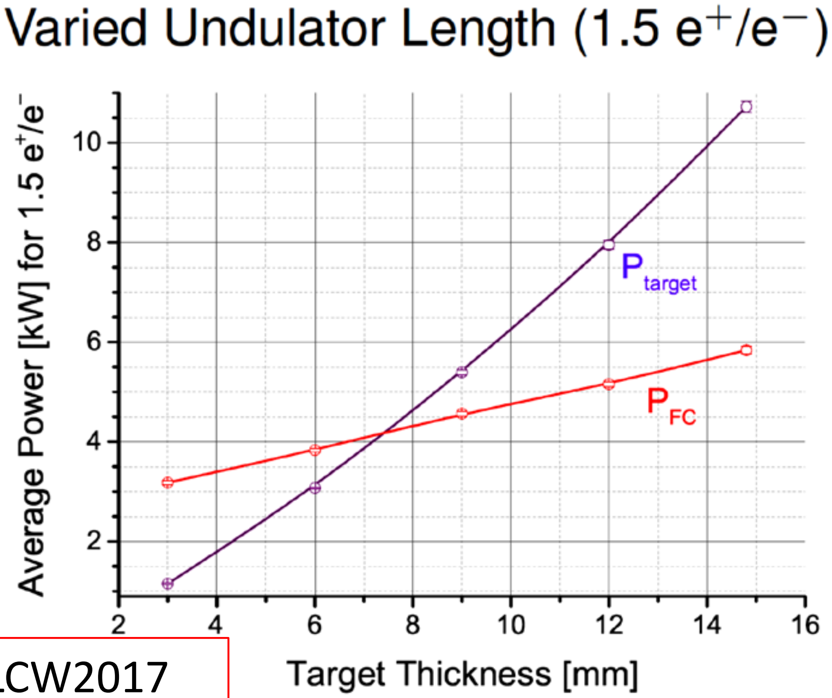
- Positron yield with thinner target
  - 14mm in TDR
  - Thinner target seems to be better for 125GeV electron
  - No yield reduction down to ~7-8 mm
  - Reduction of the energy deposit in the target is quite significant
    - 5.4kW@15mm, 5kW@14mm
      → 2.7kW@9mm, 1.5kW@6mm (at same e+ yield)
- Now, revisiting the undulator scheme parameters with thinner target (~7mm) for 250GeV staging

- With fixed gain (e+/e-=1.5)

from figure

thickness	undulator length	PEDD on FC	Power on target (2625 bunches)
12 mm	0 %	+1 %	7.9 kW
9 mm	0 %	-3.5 %	5.3 kW
6 mm	+4 %	-9 %	3.1 kW
3mm	+24 %	-19 %	1.2

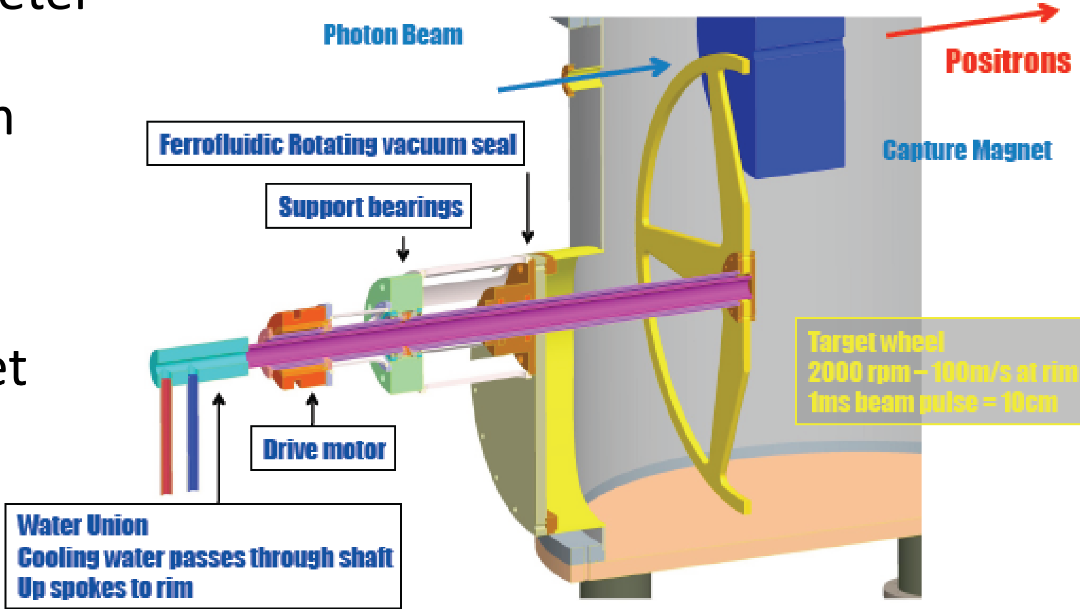

Fixed Undulator Length (231 m)

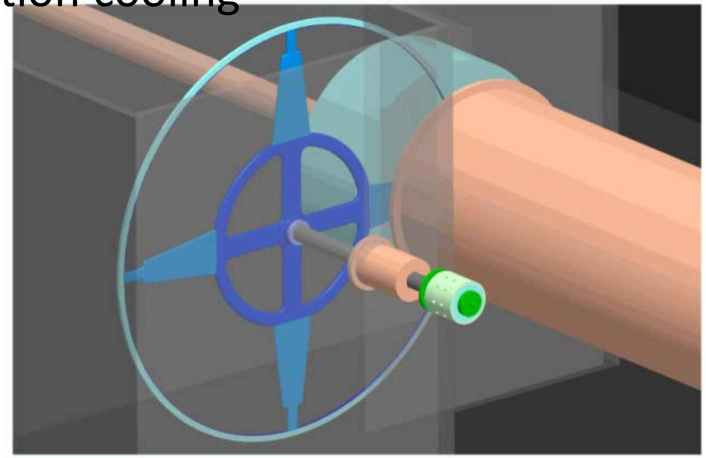

Varied Undulator Length (1.5 e^+/e^-)

Ushakov, ALCW2017

Target

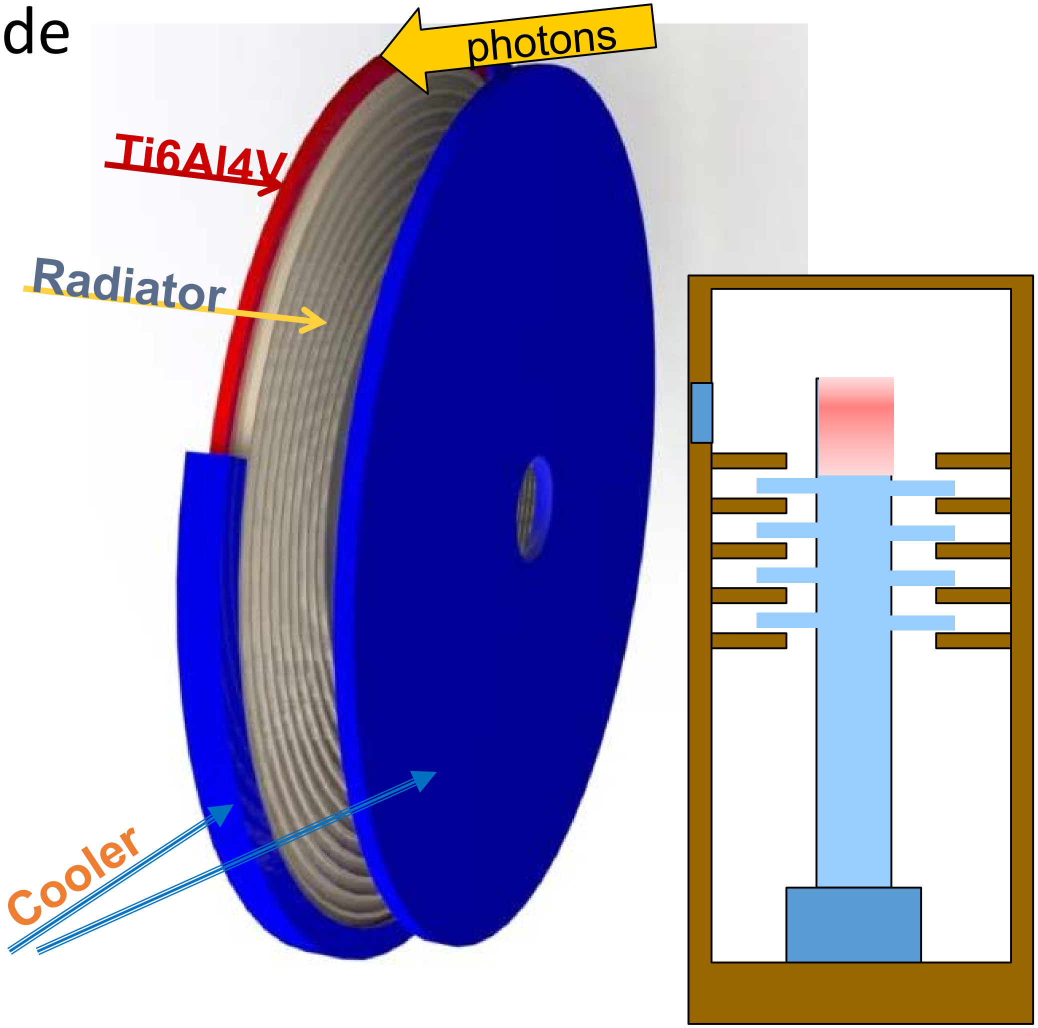
- Wheel of Titanium alloy, diameter 1m
- Thickness $0.4X_0 \rightarrow 0.2X_0$ = 7mm (change since TDR)
- Must rotate at 100m/s (2000 rpm) in vacuum
- Test at LLNL using Ferromagnet seal was not successful
  - Outgassing spikes still being observed
- New idea being studied
  - Radiation cooling





Radiation-Cooling Target

- Avoid cooling water inside
- Radiation cooling
  $\sim \sigma T^4$
- Heat transfer
  - Ti → Cu : conduction
  - rotating Cu
    → sitting Cu : radiation
  - sitting Cu → water
- Rotation axis supported by magnetic bearing
  - In vacuum
  - No magnetic fluid



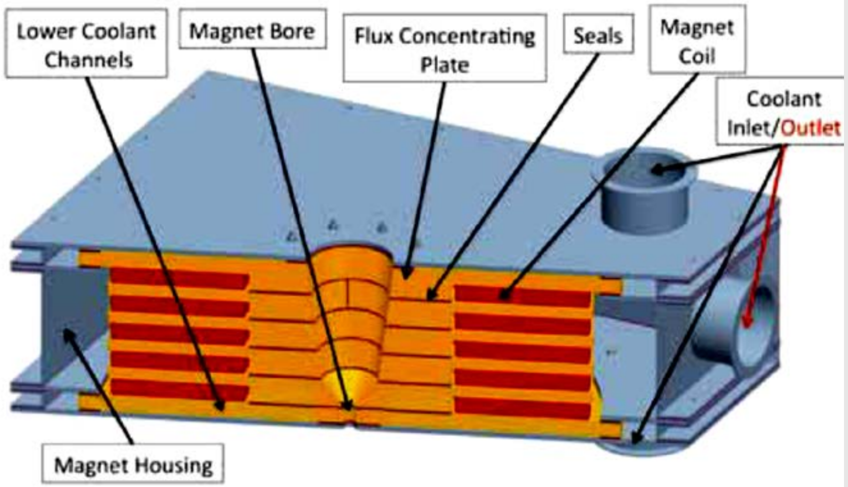
Sketch: Felix Dietrich

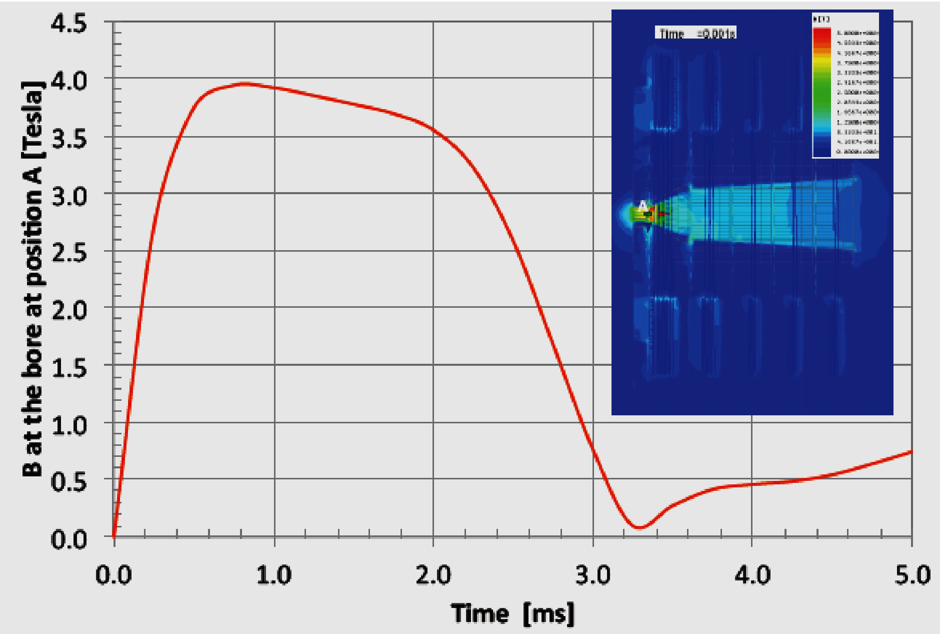
Key Issues on Radiation Cooling Target

- Ti-Alloy - Copper joint
  - Large temperature variation
  - Cyclic stress
  - Eddy current
  - must guarantee thermal conduction
  - 2000rpm
  - Maybe rotating copper omitted
    - Direct radiation from Ti
    - Maybe enough for 2kW (250GeV CM, 1312 bunches)
- Magnetic bearing
  - Weight of the wheel ~ 50kg
- Is Titanium alloy the optimum ?
- No final design design yet
- Pizza slice model being planned as the first step for heat issues

Positron Capture

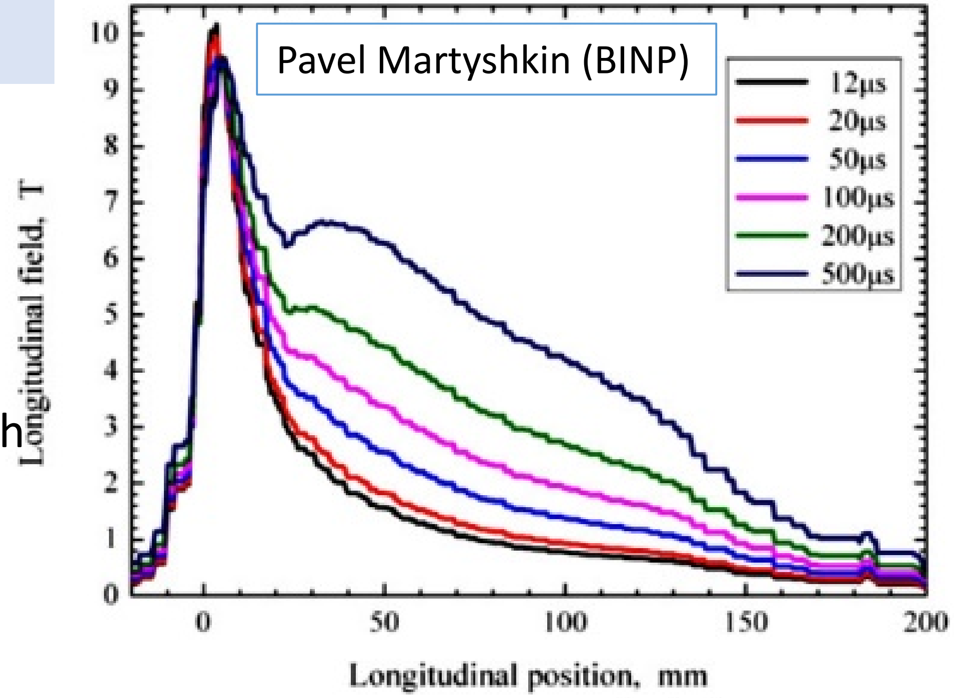
- TDR adopted FC (Flux Concentrator)
  - peak field 5T → 3.2 (turned out to be sufficient)
  - Beam aperture r=6.5mm
  - Pulse length ~700μs (flattop)
- But 2 serious problems realized

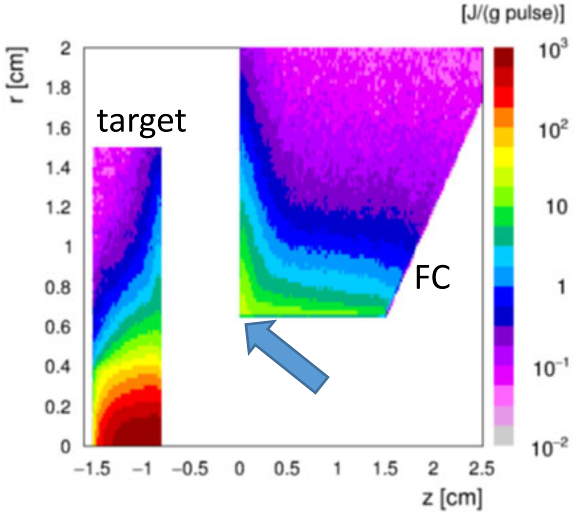




Flux Concentrator

- 2 problems
  - Field F(z) depends on time during ~700μs (beam pulse length)
    - Due to the frequency dependence of the skin depth ~ a few mm (~100Hz)
  - The shower from the target hits the tip of beam aperture for Ee=125GeV
- The first problem is quite serious
- These problems may be solved by QWT (Quarter wave transformer)
  - Larger aperture
  - No skin depth problems





A. Ushakov

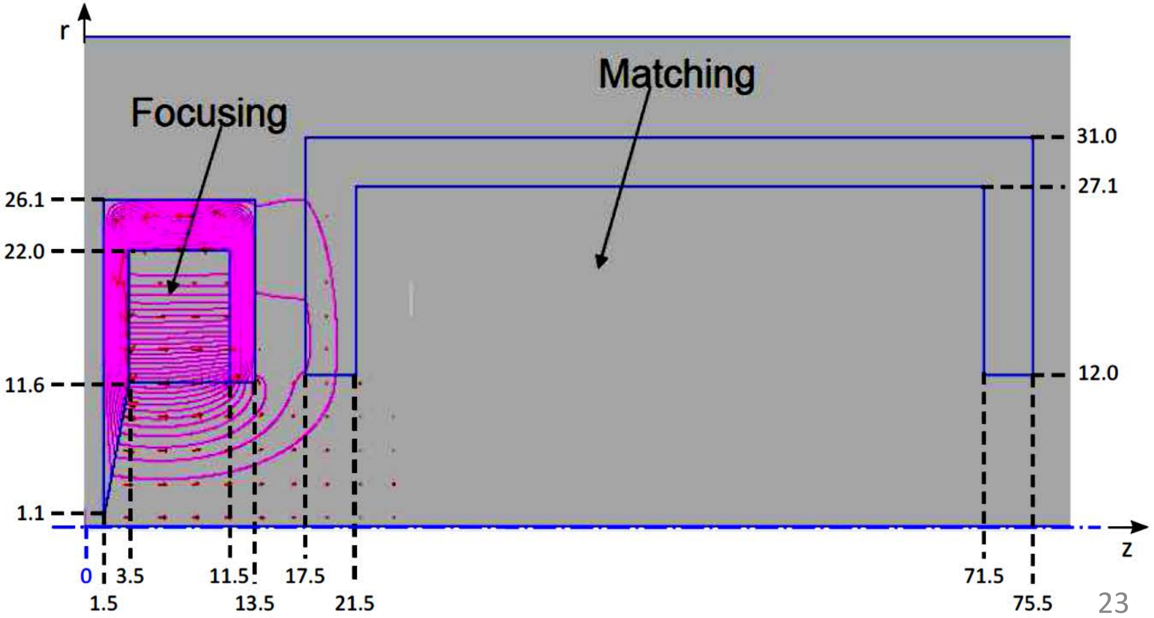
limit for Cu = 7-12 J/g

PEDD = 22.7 J/(g pulse)
(31.5 J/(g pulse) without collimator)

QWT (Quarter Wave Transformer)

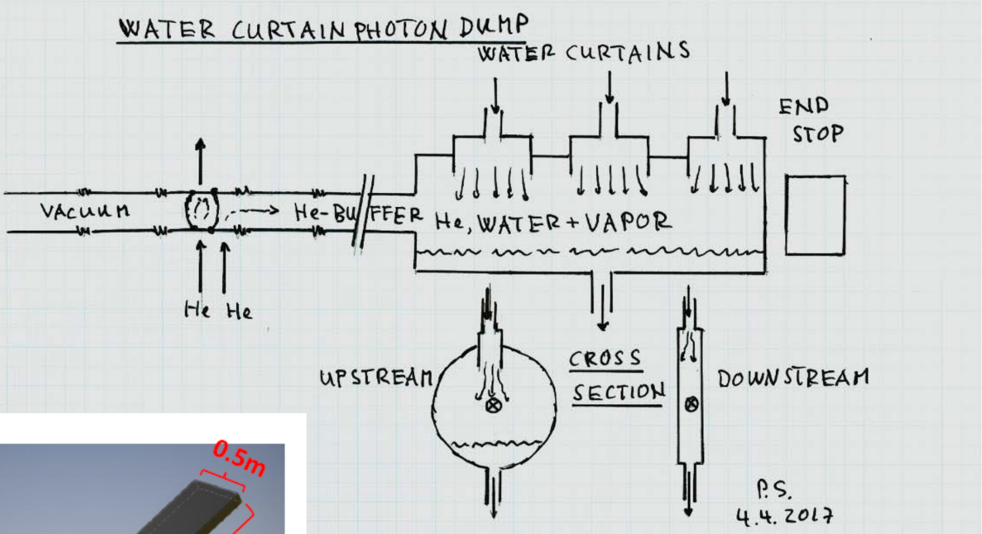
- Beam aperture r ~ 11mm
- Peak field 1.04T (Plus matching solenoid 0.5T)
- **Possible problem is the positron yield**
    - Early study showed yield = 1.3
    - But recent study in more detail gave ~0.8
    - Need higher field or should be closer to the target

Used QWT was based on Wei Gai and Wanming Liu (ANL) model.
Dimensions were taken from M. Fukuda (KEK) AWLC2017 talk.

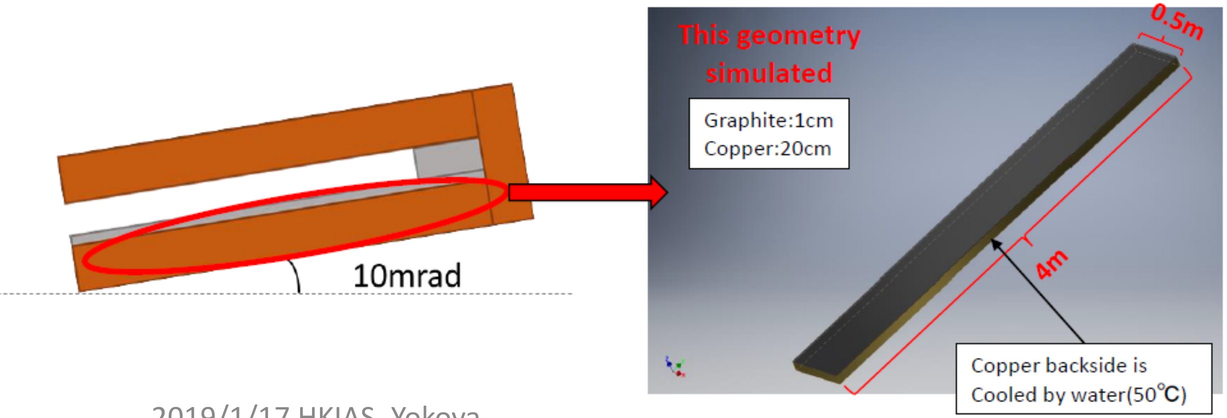


Photon Dump

- TDR design (pressured water) won't work due to high radiation damage (dpa, dislocation per atom)
- Water curtain dump proposed in Santander WS (2016)

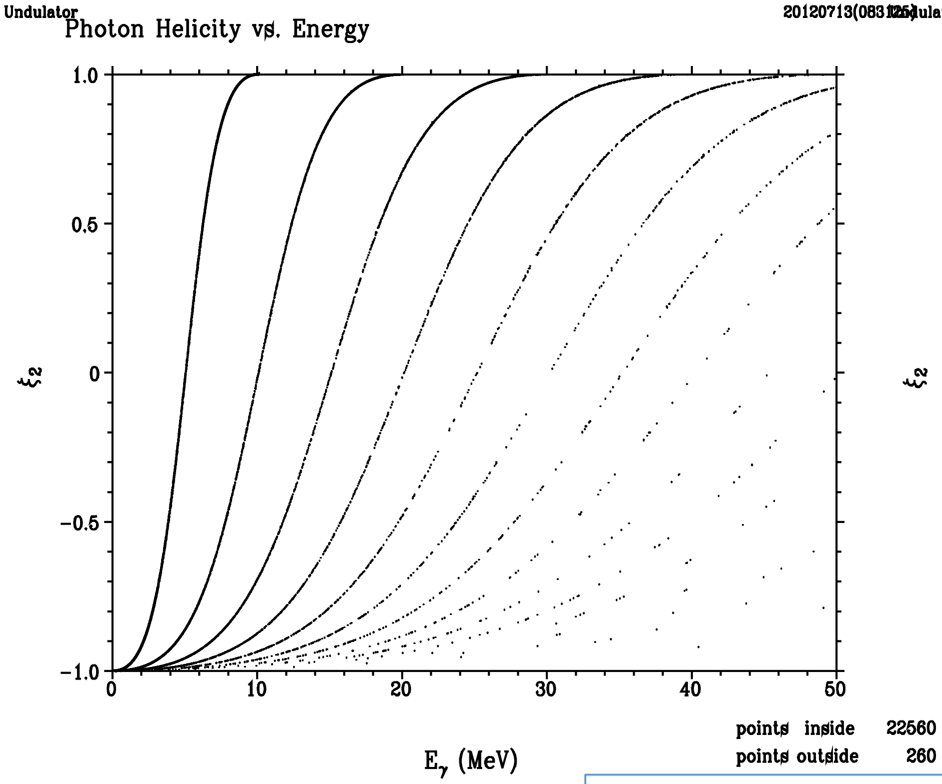


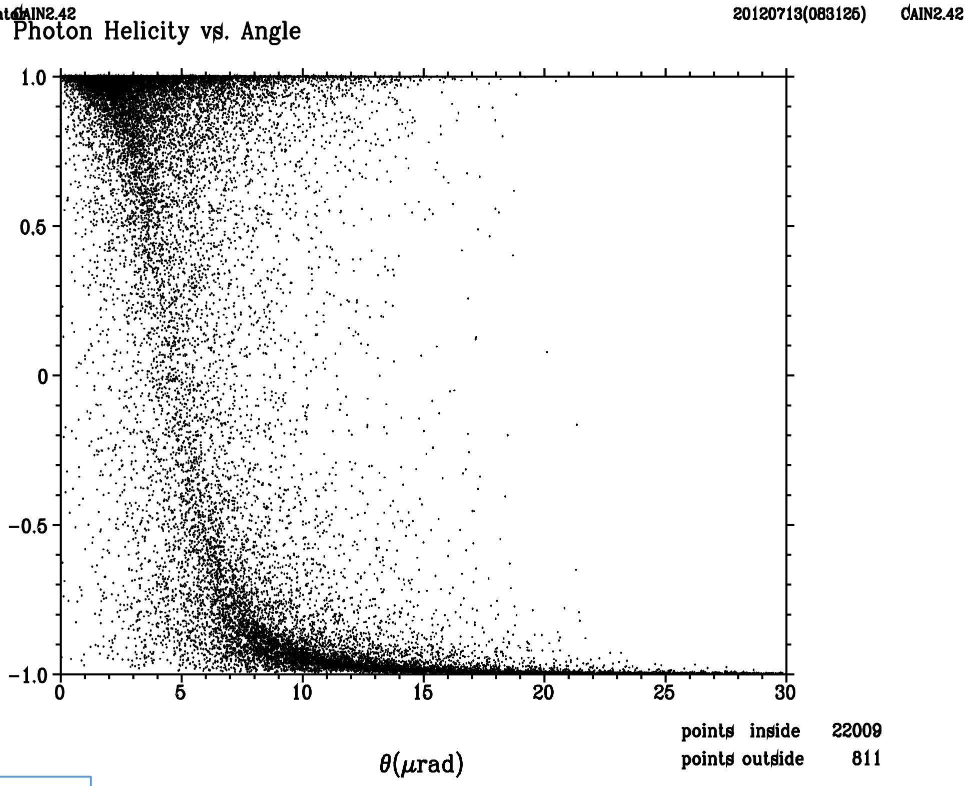
- Another design : graphite with shallow angle (~10mrad) with the beam
- Both of these require further detail



Relation between photon polarization and E_γ, θ_γ

- There is correlation between ξ_γ, E_γ, and θ_γ
- Positron capture efficiency depends on E_γ, and θ_γ
- Hence, captured positron is naturally polarized (~30%)
- Higher positron polarization (~60%) is obtained by eliminating large angle photons

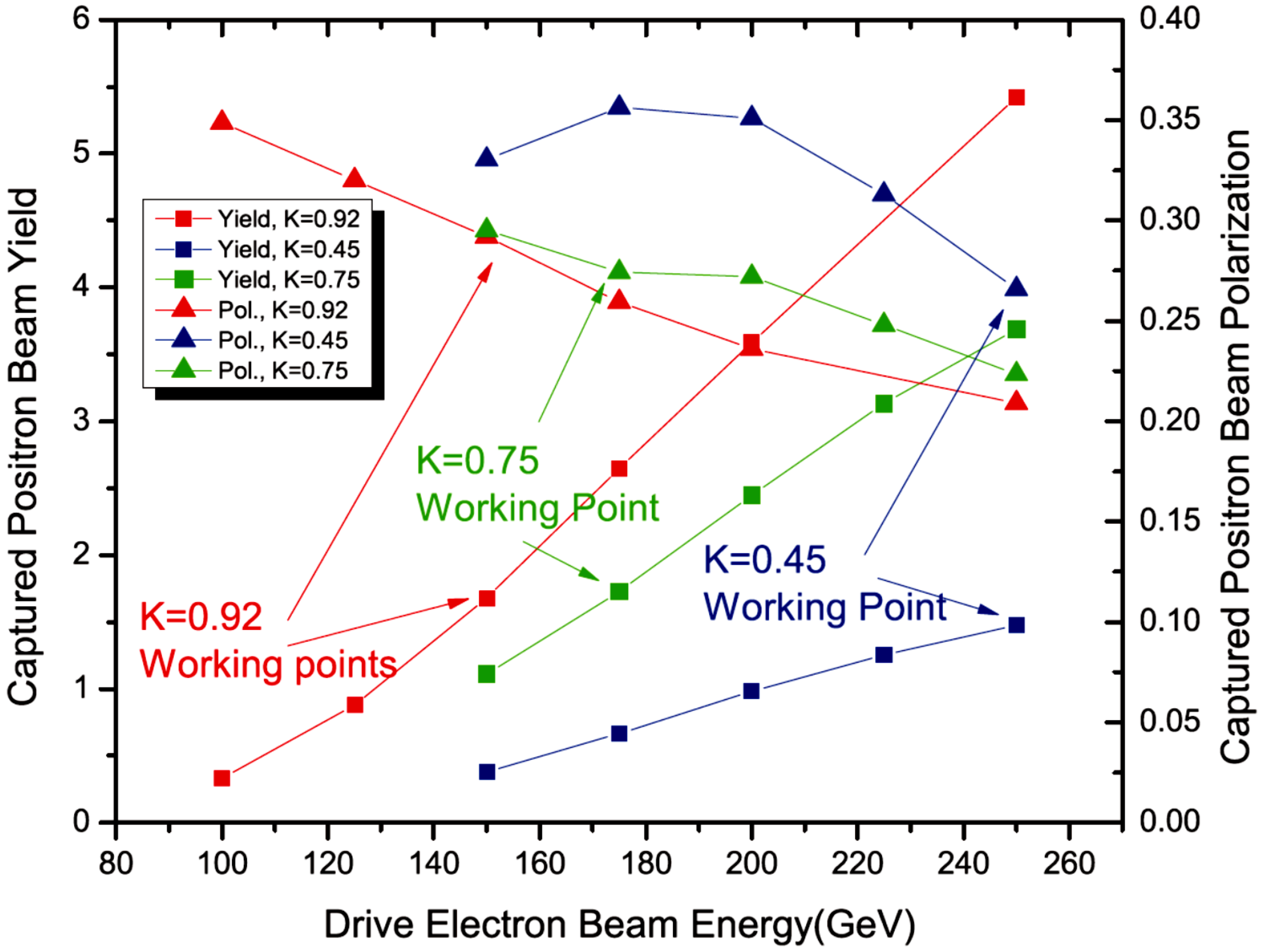




Ee=150GeV, K=0.92

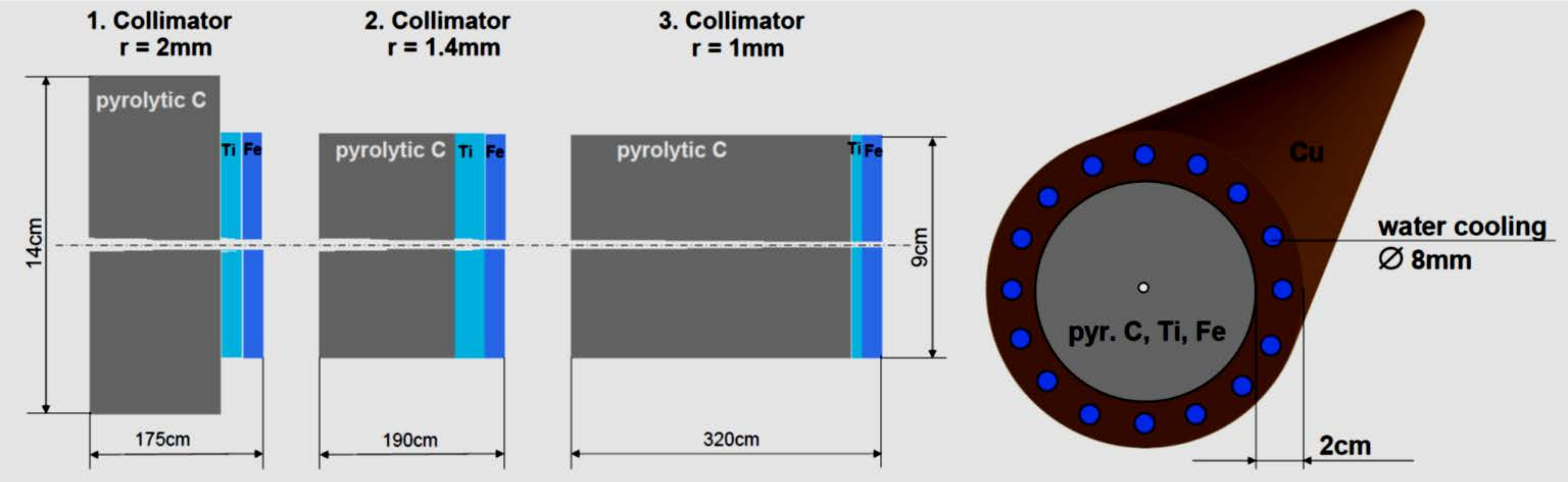
Yield and Polarization

- Total undulator length 147m
- Can reach ~30% for E_{CM} = 250-500GeV
- Taken from TDR
- Use undulator with larger K and longer pitch for 1TeV



Photon Collimator

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



R&D Plan (Undulator)

- JFY2019: mainly simulations & specifications
  - Undulator parameters
  - Temperature/stress distribution (Cu-Ti contact)
  - Wheel design based on new parameters
  - Revisit FC
- JFY 2020
  - Wheel
    - Lab test of radiative cooling and Ti-Cu contact, made with a small subsector of the wheel (<100k$)
    - Feasibility study for rotating wheel (~300k$, should be more))
- Decision on Undulator or e-driven in early 2021

S. Riemann

	issues	action	resources
Undulator	Optimize λ, K, L for E_{cm}=250GeV	Sim.	0.5MY
	Realistic B field		??
	Collimators in undul. (vacuum), …		??
Target wheel	Realistic temperature/stress distribution	Sim	1Y(Eng+Phys)
	Cyclic load resistance of material	MAMI tests	1MY
	Target-radiator contact design	sim	
	Realistic test of radiation cooling	Lab test	1Y, 1-2 Eng+Techn, ≤100k$
	Rotating wheel design Dyn. Respons Vibrations, imbalances, eddy currents,…	Sim, preparation of construction	1.-2MY, + Ext., ≤2.5 MY, 100k$
	Magnetic bearings (performance specification,…)+ ext. study	Feasibility study	2x(0.5-1MY), 2x50k$
	Final Lab test, validation of a small sector of the wheel	Design, built, test a mockup	~1MY+ Eng.+ Techn ~100k$
FC	Studies to reduce energy deposition, optimization of FC	sim	1-1.5MY
	Prototype (design+manufacture+test)	Constr+test	2MY+test time+Techn ~1mio$
FC+wheel	Fully assembled mock-up (wheel+FC)	Ultimate Tests	
QWT ?	reoptimize wheel for QWT ??????	Sim ???	

Summary

- Electron source
  - In good shape
  - ~90% polarization can be expected
  - Need some study on the laser
- Positron (undulator)
  - Many issues still remain
  - Water-cooled target → radiation-cooled target
  - FC → QWT
    - Serious design of QWT needed
  - Photon dump
  - Must select undulator or e-driven in early 2021
- Report by Positron WG (May 2018)
  - http://edmsdirect.desy.de/item/D00000001165115