Positron Sources for future lepton colliders

- **Strategy**
- **Positron polarization**
- **Source reqirements**
- **Status ILC positron source**
- **Upgrade for HALHF**
- **Conclusion**

What is the current status of HEP?

- **One Higgs particle discovered in 2012**
  - strongly consistent with Standard Model (SM) predictions
- **Few excesses around…..(e.g. a light scalar at about 95 GeV)**
  - but not (yet) confirmed discoveries
- **Still strong motivation for Beyond SM (BSM) physics**
  - Dark Matter, Gravitational Waves, Baryon-Asymmetry, etc.
- **However, scale of new physics window still unclear**
  - …..the research field might be in great danger

  ➡Therefore, high precision and/or high energy in specific areas needed and additional tools complementary to (HL)LHC analyses required to identify the promising windows
- **But in a responsible, sustainable manner, i.e.**
  - stageable, tuneable, shortest as possible lepton collider(s) with polarized beams and new imminent technologies mandatory

➡Mature e+e- collider design(s) with sane polarization!

(Reasonable) strategy (or Plan 'B')…?

Proposal:

- ***build a Linear Collider, upgradeable to HALHF***
- ***'in parallel' to HL-LHC and FCC-hh !***

would cover precision & energy frontier simultaneously and provide new (and more sustainable(?)) technologies !

Immediate (a.s.a.p.!) need for e+e- collider for

- ***Higgs high precision measurements***
- ***Top quark high precision measurements***
- ***Electroweak high precision measurements***
- ***Opening new windows to BSM physics, CP-violating effects,…***

➡ $\sqrt{s}$=Z-pole, WW,250, 350, ≥500 GeV with polarized beams

Required features

⇨ In order to reveal the structure of the underlying (new) physics:

- ⋆ high energy desirable to reach the scale of new physics
- ⋆ high luminosity needed to get sufficient statistics
- ⋆ high level of experimental flexibility needed
- ⋆ high precision measurements needed to get access to the quantum structure

→ *need to be prepared for the unexpected !*

⇨ Spin and polarization physics is important

- access to quantum properties, structure of couplings, etc.

➡ Exploit polarized beams !

………*what did we learn from the past?*

Remember the past: physics gain of polarized beams

- **Past experience:**
  - **excellent e- polarization ~78% at SLC:**
  - **led to best single measurement of $\sin^2\theta=0.23098\pm0.00026$ on basis of $L\sim10^{30}\ cm^{-2}s^{-1}$ (~600000 Z's)**

- **Compare with results from unpolarized beams at LEP:**
  - **$\sin^2\theta=0.23221\pm0.00029$ but with $L\sim2x10^{31}cm^{-2}s^{-1}$ (~ 17 million Z's)**

➡ **Polarization essential for suppression of systematics**

➡ **can even compensate order of magnitude in luminosity for specific observables!**

➡ ***Polarized e- sources well under control, why also polarized e+ required.....?***

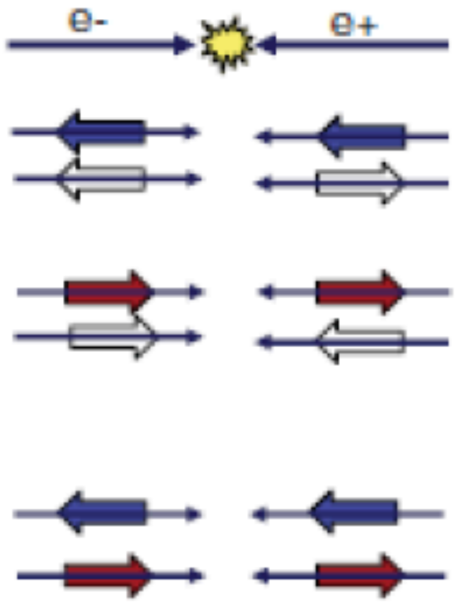
Statistical arguments

- Effective polarization

$$P_{eff} := (P_{e^-} - P_{e^+})/(1 - P_{e^-}P_{e^+})$$
$$= (\#LR - \#RL)/(\#LR + \#RL)$$

- Fraction of colliding particles

$$\mathcal{L}_{eff}/\mathcal{L} := \frac{1}{2}(1 - P_{e^-}P_{e^+}) = (\#LR + \#RL)/(\#all)$$



P_{e-}	P_{e+}	h_{e-}	h_{e+}	cross section	
-1	0	-1	+1	σ_{LR}	
		-1	-1	σ_{LL}	→ 0
+1	0	+1	-1	σ_{RL}	
		+1	+1	σ_{RR}	→ 0
-1	+1	-1	+1	σ_{LR}	
+1	-1	+1	+1	σ_{RL}	

½ of events do not react !

$\Rightarrow$ Enhancing of $\mathcal{L}_{eff}$ with $P(e^-)$ and $P(e^+)$!

Short reminder: why polarized $e^{\pm}$ needed?

- **Important issue: measuring amount of polarization**
  - **limiting systematic uncertainty for high statistics measurements**
  - **Compton polarimeters (up- /downstream): envisaged uncertainties of ΔP/P=0.25%**
- **Advantage of adding positron polarization:**
  - **Substantial enhancement of eff. luminosity and eff. polarization**
  - **new independent observables**
  - **handling of limiting systematics and access to in-situ measurements: ΔP/P=0.1% achievable!**
  - ***allows exploitation of transversely-polarized beams!*** *see talk G. Weiglein*
- **Physics impact: Higgs-Physics, WW/Z/top-Physics, New Physics !**

Literature: polarized e+e- beams at a LC (only a few examples)

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  - Compton polarimeters (up- /downstream): envisaged uncertainties of $\Delta P/P=0.25\%$
- **Higher effective luminosity (higher fraction of collisions)**

$$L_{eff}/L=1-P_{e-}\, P_{e+}$$

$\sqrt{s}$	$P(e^-)$	$P(e^+)$	$P_{\rm eff}$	$\mathcal{L}_{\rm eff}/L$	$\frac{1}{x}\Delta P_{\rm eff}/P_{\rm eff}$
total range	$\mp 80\%$	0%	$\mp 80\%$	1	1
250 GeV	$\mp 80\%$	$\pm 40\%$	$\mp 91\%$	1.3	0.43
$\geq$350 GeV	$\mp 80\%$	$\pm 55\%$	$\mp 94\%$	1.4	0.30

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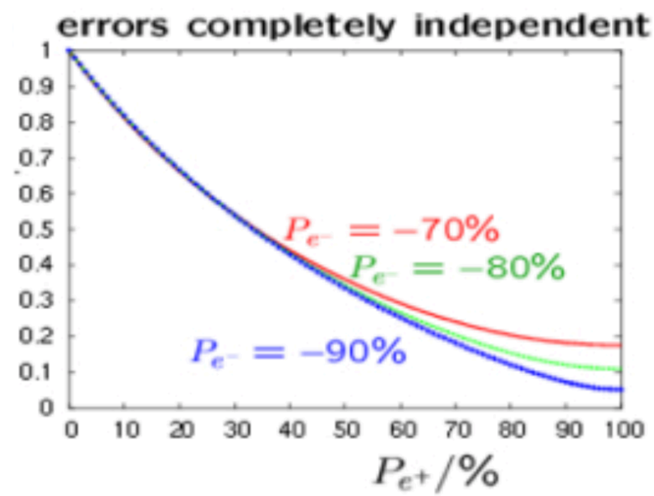
  - **Compton polarimeters (up-/downstream): envisaged uncertainties of $\Delta P/P=0.25\%$**

- **Higher precision and better control of systematics**
  - ➡ $\Delta A_{LR}/A_{LR} \sim \Delta P_{eff}/P_{eff}$
  - ➡ (90%,60%): P_{eff}=97%

    $\Delta A_{LR}/A_{LR}$ =0.27 'gain factor ~3'
  - ➡ (90%,30%): P_{eff}=94%

    $\Delta A_{LR}/A_{LR}$ =0.5 'gain factor ~2'



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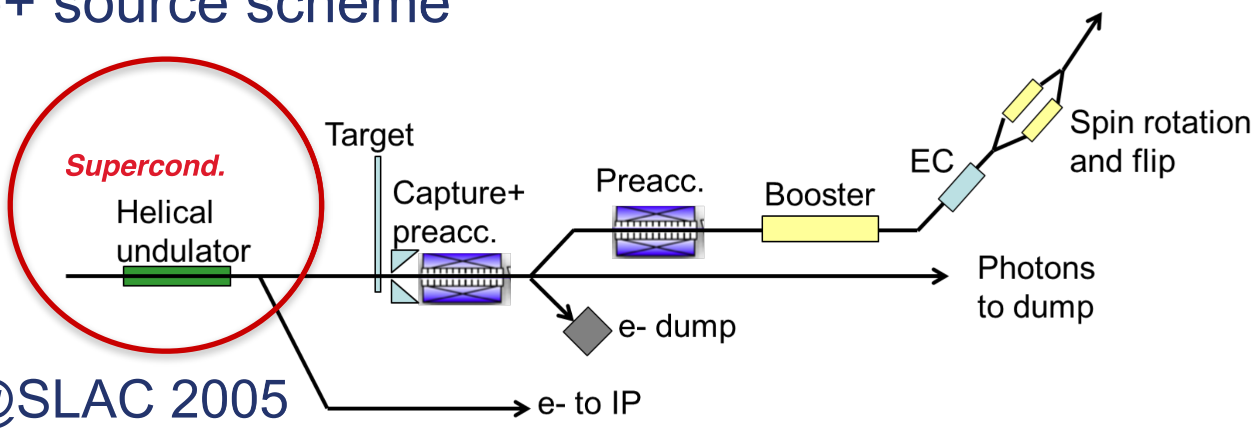
Most mature LC design: ILC

- The polarized e+ source scheme



Principle tested with
E-166 experiment @SLAC 2005

G. Alexander et al., NIMA 610 (2009), G. Alexander et al., Phys.Rev.Lett.100 (2008)

- ILC e+ beam parameters (nominal luminosity)

Number of positrons per bunch at IP	2×10^{10}
Number of bunches per pulse	1312
Repetition rate	5 Hz
Positrons per second at IP	1.3×10^{14}

That's about a factor 100 more compared to SLC!

– Required positron yield: Y = 1.5e+/e- at damping ring

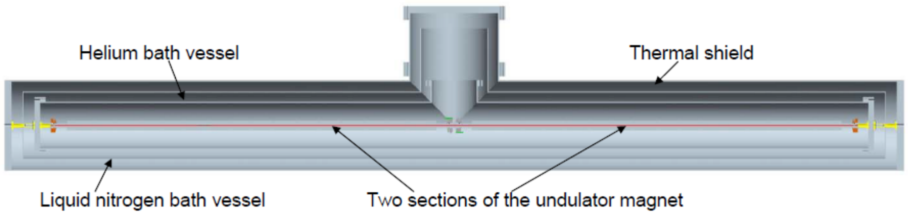
Overview positron requirements

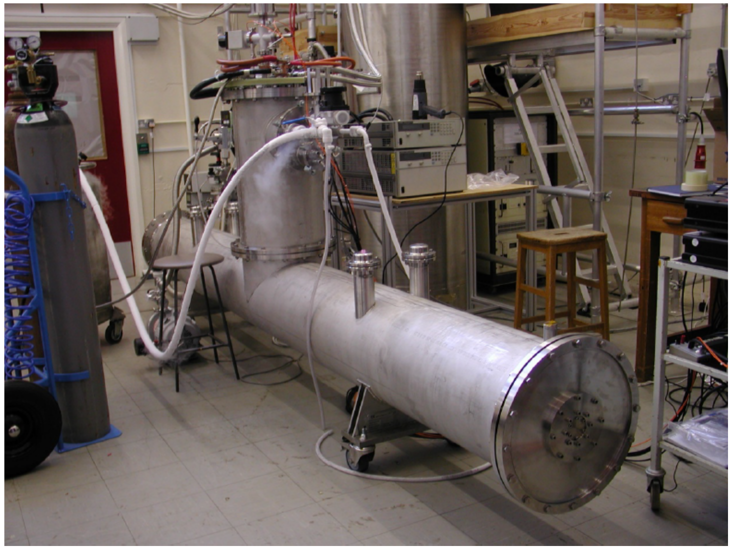
	rep rate/Hz	#bunch/pulse	#e+/bunch	#e+/pulse	#e+/s
SLC	120	1	5×10^{10}	5×10^{10}	6×10^{12}
ILC/Tesla	5	1312	2×10^{10}	2.6×10^{13}	1.3×10^{14}
CEPC	100	1	2×10^{10}	2×10^{10}	2×10^{12}
CLIC	50	312	4×10^{9}	1.2×10^{12}	6×10^{13}
HALHF	10000	1	$2\text{-}3 \times 10^{10}$	$2\text{-}3 \times 10^{10}$	$2\text{-}3 \times 10^{14}$

Undulator technology - Status

- Parameters
  - Undulator period, λ_U =11.5mm
  - Undulator strength K ≤ 0.92 (B ≤ 0.86T); K ~ B·λ_U
  - Undulator aperture 5.85mm
- 4m prototype built and tested (UK)
  - Cryomodule, contains 2 undulator modules of 1.75m length each

D.Scott et al.,Phys. Rev. Lett. 107, 174803 (2011)





- ILC TDR (2013):
  - Max 231m active undulator length available (132 undulator modules in 66 cryomodules]
  - Quadrupoles every 3 cryomodules
    → total length of undulator system is 320m

Progress since TDR

K. Alharbi, PhD 2022
S. Riemann, GMP

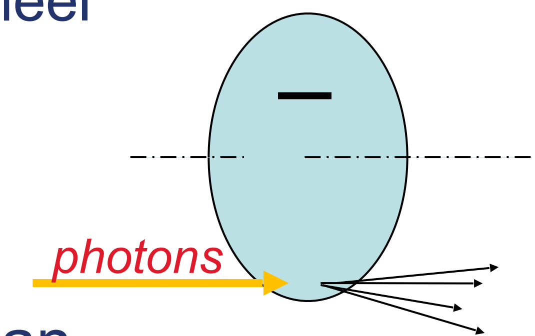
- **Detailed ILC undulator simulations performed:**
  - realistic fields, masks and power deposition, misalignments
- **Undulator operation: experience with long undulators**

W. Decking/XFEL
LCWS21

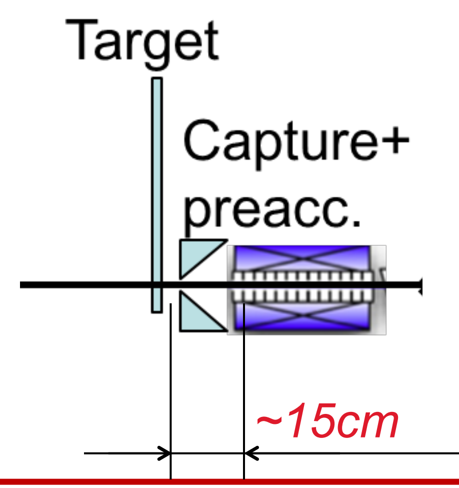
  - XFEL: 91 undulators with 5m length each
  - energy loss due to particle loss negligible small (unmeasurable)
  - beam alignment up to 10-20 microns for 200 m (undulator length), remeasured every 6 months
  - during beam operation: beam trajectory controlled better than 3 micron with both slow and fast feedback systems
- **Stable operation and alignment experience**
  - Beam requirements at XFEL more challenging than at ILC due to FEL requests of photons
  - Tolerances of IlC undulator more relaxed than for XFEL!
- **Result: no operation&alignment issues for ILC undulator**

The positron target

- Is located ~240m downstream the undulator end
- 62 kW photon beam ⇔ about few 10^{16} photons/second
- Only few % of the photon beam power is deposited in the target
- Target is designed as 1m wheel
  material: Ti6Al4V
  spinning in vacuum



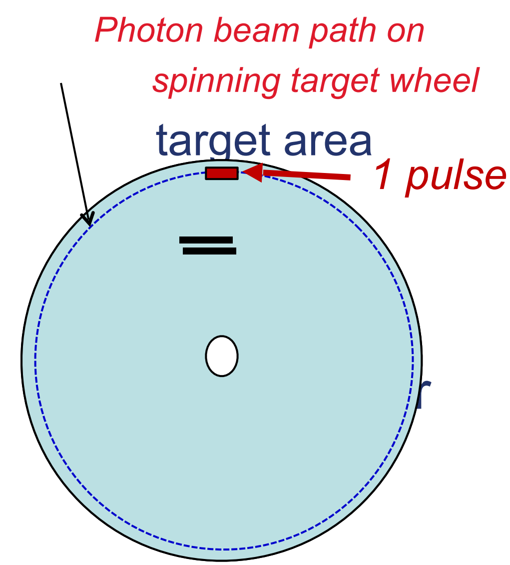
- The e+ are collected with an
  Optical Matching Device (OMD):
  - Maximum magnetic field (≥1T)
    about ~1cm from target exit to achieve
    high e+ yield



G. Moortgat-Pick et al, Future Collider Forum, 10/'21

The positron target

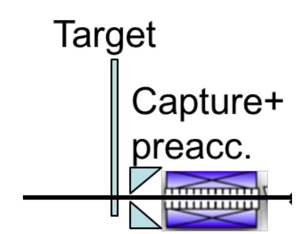
- Photon beam hits wheel at 1m diameter, spinning in vacuum with 2000rpm (100m/s tangential speed) → distribute the heat load
  - One pulse with1312 (2625) bunches occupies ~7 (~10)cm
  - Every ~7-8sec load at same target position
  - in 5000h roughly 2.5×10^{6} load cycles at same



- ILC250, GigaZ: E(e-) = 125GeV
  - Photon energy is O(7.5 MeV);
  - target thickness of 7mm to optimize deposition and e+ yield
- Target cooling

S. Riemann, P.Sievers

  - T^{4} radiation from spinning wheel to stationary water cooled cooler
    - Peak temp in wheel ~550˚C for ILC250, 1312bunches/pulse
      ~500˚C for GigaZ, 1312bunches/pulse
      assuming the wheel is a full Ti alloy disk (~simple design solution).



Cooling of the target wheel

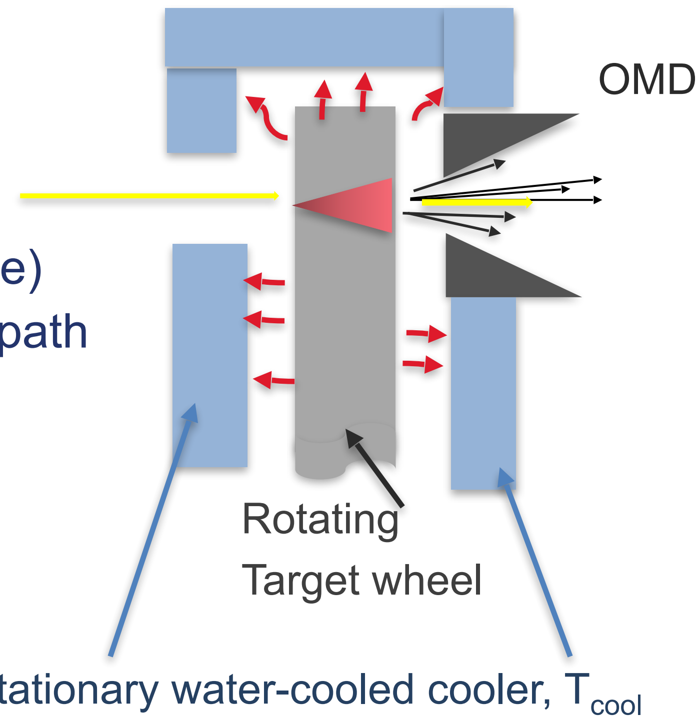
- Few kW heat deposition can be removed with thermal radiation:
  - heat radiates from spinning target to a stationary water-cooled cooler

$$P \sim \sigma \varepsilon A \left(T_{radiator}^4 - T_{cool}^4 \right)$$

ε = effective emissivity

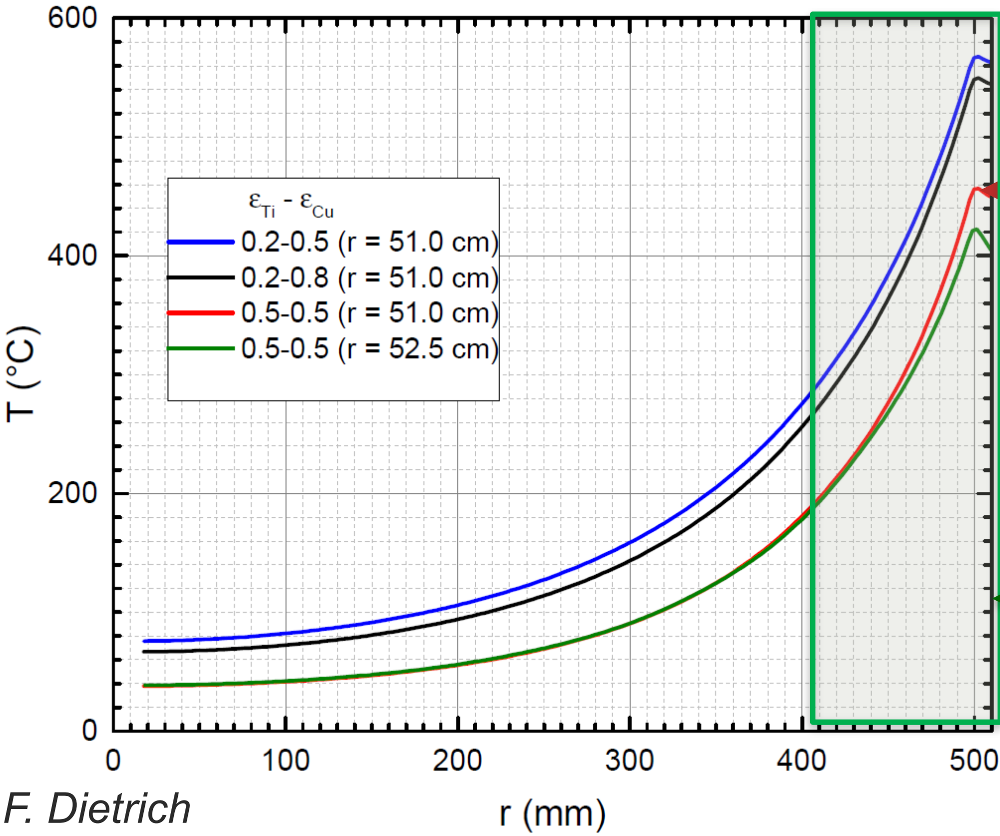
- Ti alloys have low thermal conductivity
  (λ = 0.06 – 0.15 K/cm/s)
  - heat propagation ~ 0.5cm in 7sec (load cycle)
  - heat accumulates in the rim near to beam path

Side view cutout e+ target



Temperature distribution in target

Average temperature in Ti6Al4V wheel as function of radius r for different surface emissivity of target and cooler (Cu); Target wheel assumed as disk



Photon beam impact at r=50cm

Deposited power = 2kW

ε_{eff}= 0.33 for ε_{Ti} = ε_{Cu}=0.5

T_{ave} ≤ 460˚C

max average temperatures can be decreased for larger wheel radius

Main cooling power from area

F. Dietrich

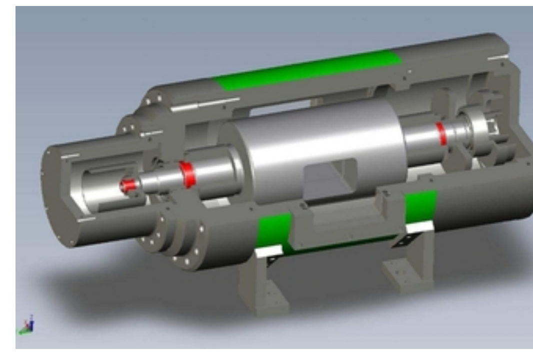
Studies (FLUKA, ANSYS) show that such spinning disk stands heat and stress load

P.Sievers, G. Yakopov

Towards the rotating wheel

Drive and bearings

- Radiation cooling allows <u>magnetic bearings</u>
  - A standard component to support elements rotating in vacuum.
  - The axis is «floating» in a magnetic field, provided by permanent or electro magnets
  - Allows long time operation at high rotation speed without maintenance
  - Among other things,magnetic bearings are used as Fermi-choppers in Neutron Physics and Spallation Sources
- For the specific ILC-application, a technical specification of the required performance and boundary conditions has to be negotiated with the supplier.
  - Specification to be done based on simulation studies
  - Negotations with industrial producer ongoing



Fermi-Choppers für BRISP
Copyright: Prof. Dr. Pilgrim, Philipps-Universität Marburg

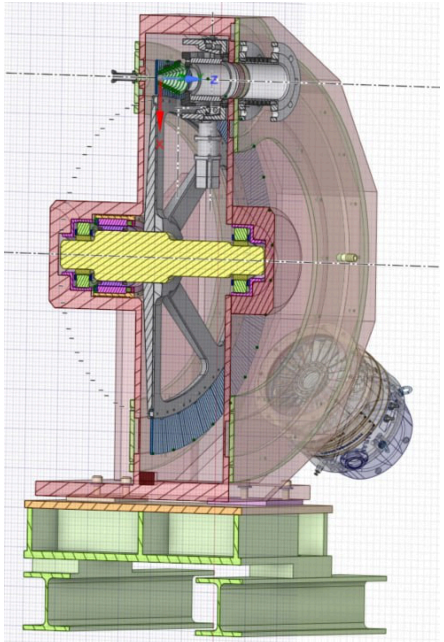
P.Sievers, G. Yakopov

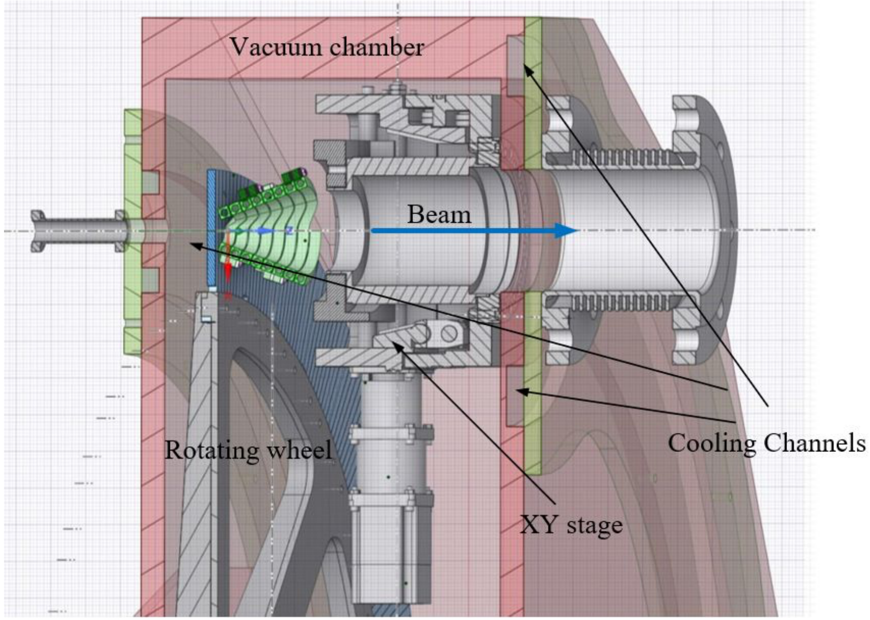
Towards the rotating wheel

Ongoing drawings and

G. Yakopov 2024

- Within ITN initiative: manufacturing drawings at Uni&DESY
- Ongoing discussion with industrial producer of magnetic bearings



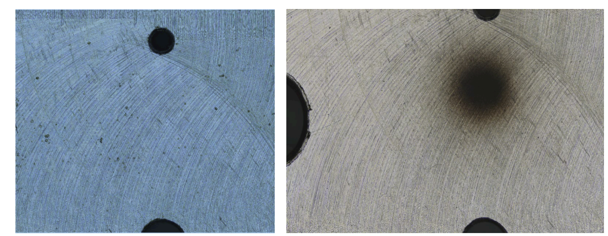


Progress since TDR: Target material tests

- **Mainz Microtron (MAMI): electron-beam on ILC target materials, generating cyclic load with same/ even higher PEDD at target than expected at ILC**
  - analyze target materials via scanning as well as synchrotron diffraction methods
  - advantage of synchrotron diffraction: both surface as well as structure of targets with several mm thickness can be precisely studied
  - Analysis via Synchrotron diffraction: x-rays of 87.1 keV with different beams size

T. Lengler

Target before and after radiation:

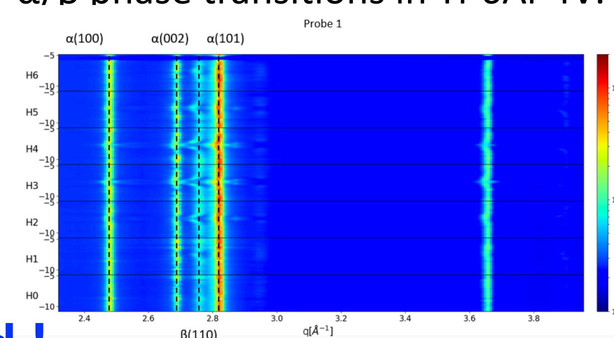


Before After

Results of diffraction method:

- Phase transitions between α- and β-phase in Ti-alloy observed
- only for ‘cw-mode target’ phase transition significant
- In addition: dilatometer measurements
- synchrotron diffraction at PETRAIII: detailed surface analyses and different angle resolution incl. det. of phase parameter

α/β phase transitions in Ti-6Al-4V:



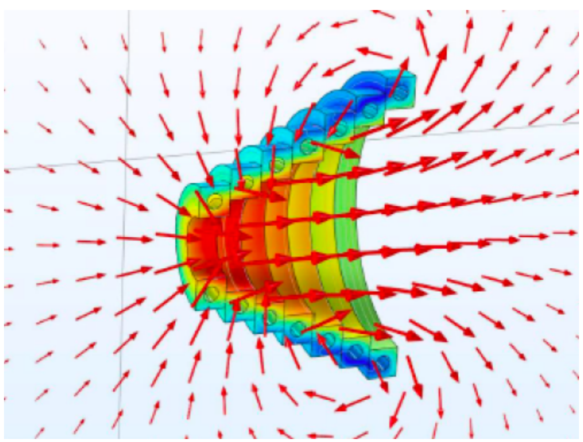
- **Result: ILC undulator target will stand the load !**

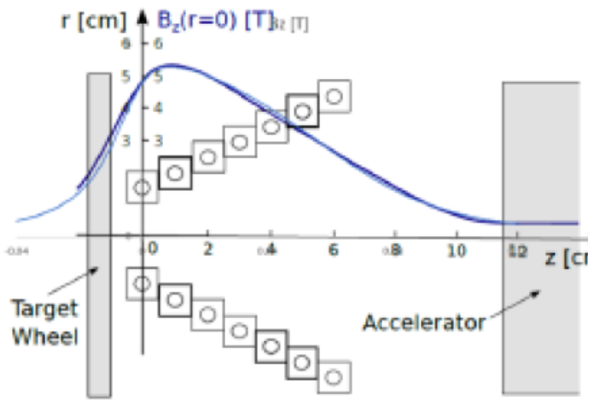
OMD Design: Pulsed Solenoid

'Baseline': Pulsed Solenoid

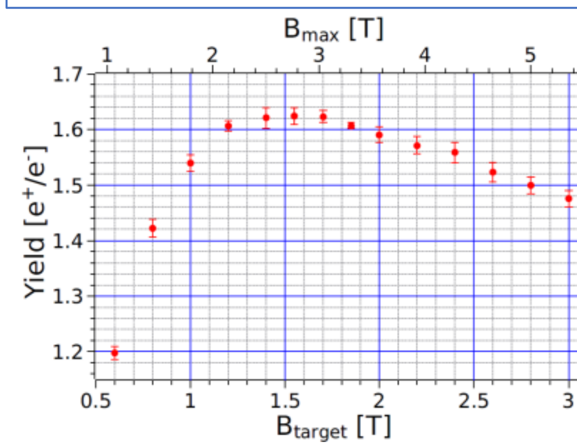
- Yield of e+ (OMD&capture Linac): 1.64-1.81 — Fukuda-san, 2021
- Within ITN initiative: manufacturing drawings at DESY — G. Yakopov 2023
- Planned: prototype tests

M. Mentink, C, Tenholt, G. Loisch, 2021





Yield versus field on the target



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C. Tenholt 2021

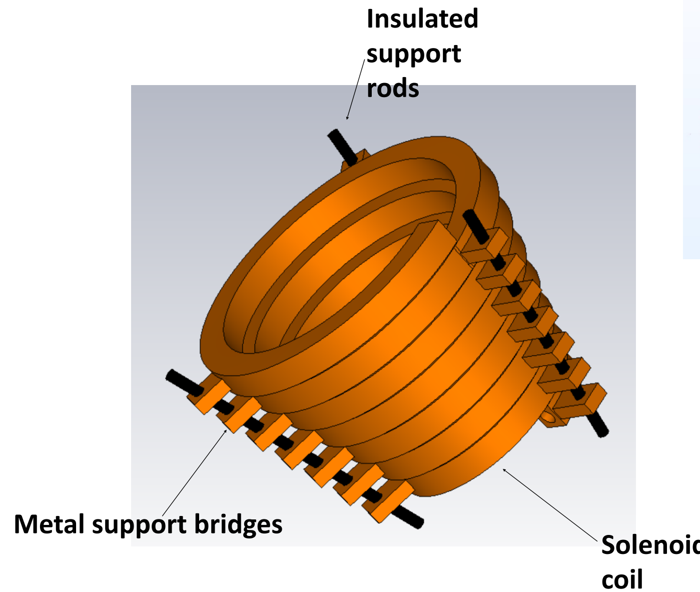
	Beamloss Power				Positron Yield	
	@dogleg	@booster	@EC	@DR	@capture (|Z|<7mm)	@DR
QWT	0.677 kW	0.014 kW	4.01 kW - 5.56 kW	13.15 kW - 14.3 kW	1.07	**~1.1**
Pulse solenoid w/o shield	0.927 kW	0.055 kW	5.86 kW - 7.93 kW	17.39 kW - 16.01 kW	1.81	**1.91**
Pulse solenoid with shield	0.871 kW	0.064 kW	5.58 kW - 7.90 kW	17.73 kW - 16.24 kW	1.64	**1.74**

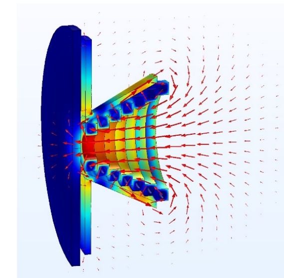
Solenoid construction@Uni&DESY&CERN

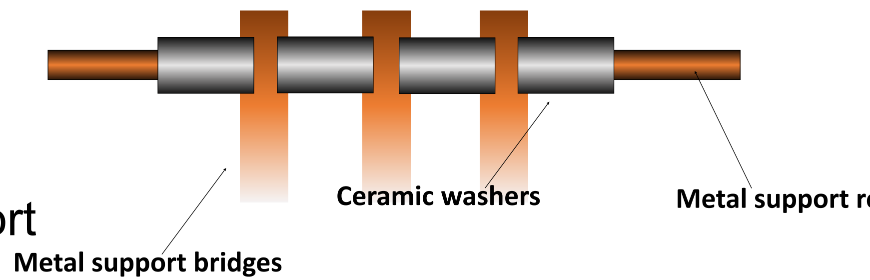
G. Yakopov, 2023

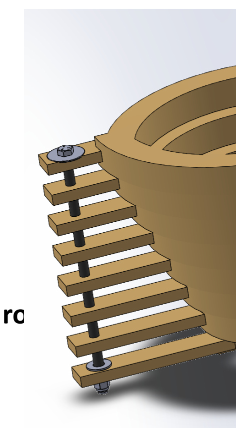
Possible mechanical design

- Solenoid coil
  - Tapered winding
  - 7 planar windings with interconnections
  - Conductor cooled from inside
- Metal supports to hold coil
- Support rods insulated from support bridges
  - Washers e.g. of SiN ceramics
- Magnetic shielding cut at support locations
  - Influence on field to be determined
  - Main shielding to target unaffected









see IPAC 24

OMD Design: Plasma Lens

‘Future’: Plasma Lenses

- increases e+ yield but increases load at target only slightly
- advantages in matching aspect
- downscaled prototype designed and produced

Formela, Hamann, Loisch

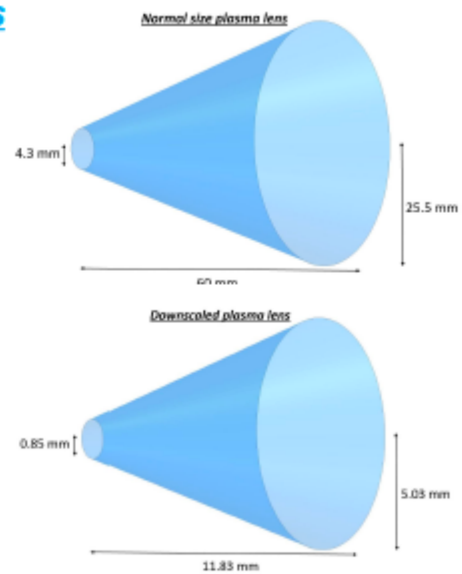
Plasma lens parameters

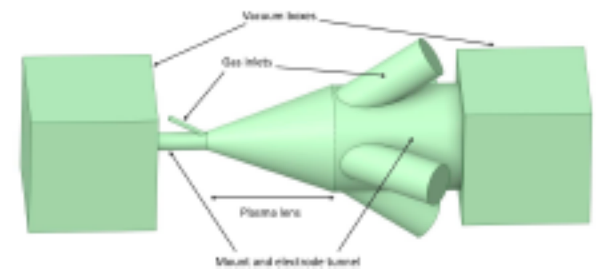
Normal size

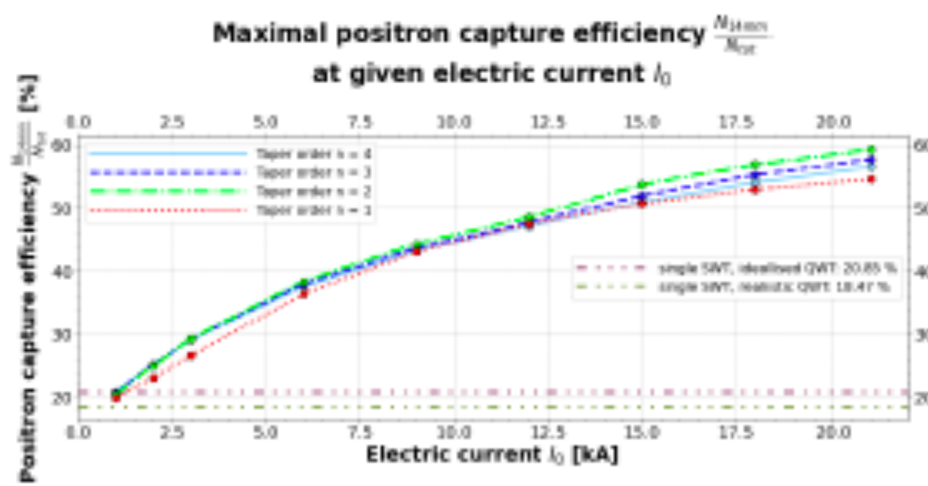
- Starting radius: 4.3 mm
- Exit radius: 25.5 mm
- Taper strength: 0.082 mm⁻¹
- Length: 60 mm
- Taper order: 2
- Total current: 9000 A
- Phase of SWT: 225 deg

Downscaled

- Starting radius: 0.85 mm
- Exit radius: 5.03 mm
- Taper strength: 0.416 mm⁻¹
- Length: 11.83 mm
- Total current: 350 A







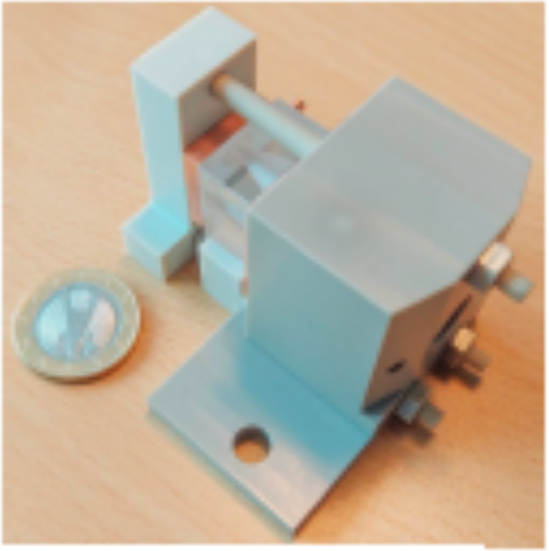
see IPAC 24

OMD Design: Plasma Lens

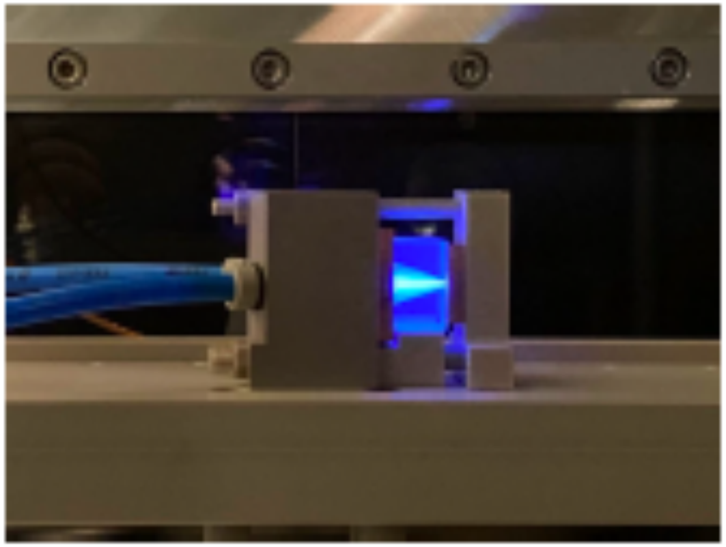
Formela, Hamann, Loisch

Prototype design

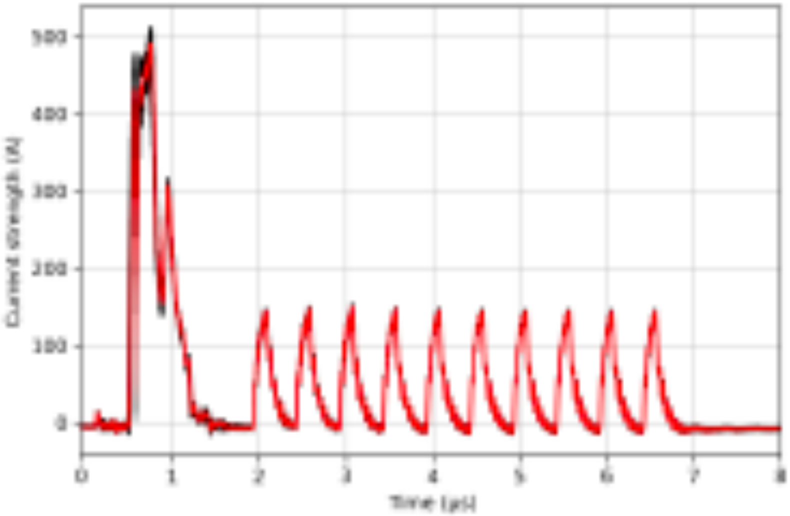
- Principle: lens is pressed in between mounts with threaded rods and sealed with O-rings
- Mounts made out of PEEK
- Electrodes made out of copper
- Plasma lens made out of sapphire block



Finished Prototype



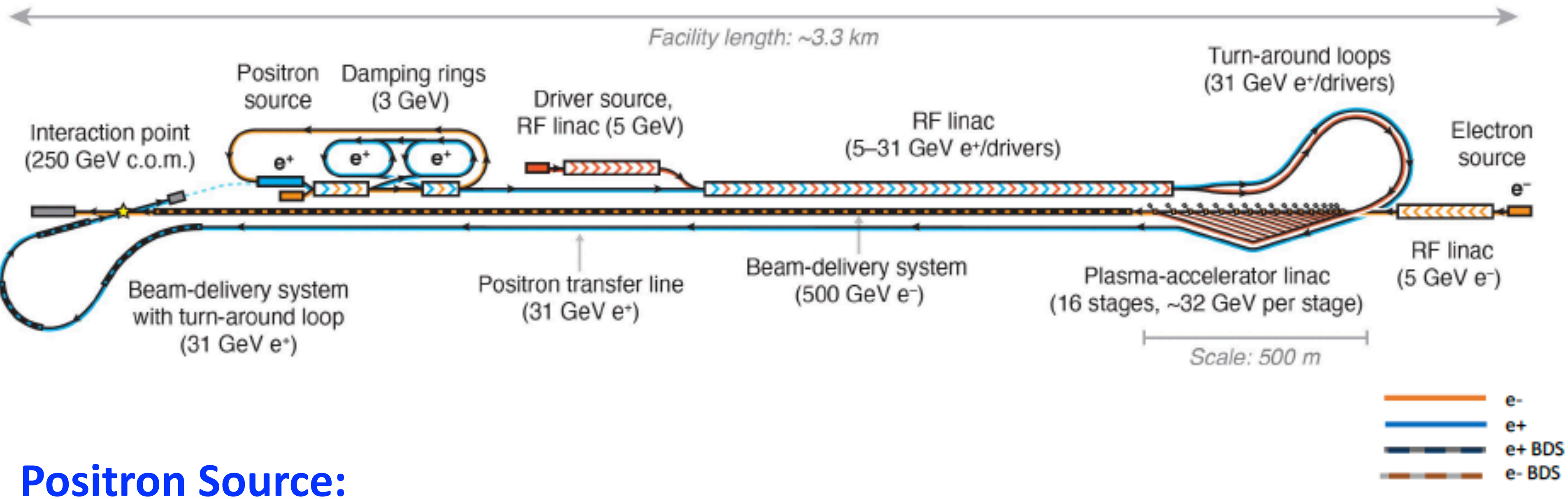
Produced plasma



Ingoing current measured

HALHF Design

B. Foster, R. D'Arcy, C.A. Lindstrom



Positron Source:

- **Conventional e+ source with up to 31 GeV e- drive beam**
  - **needs RF**
- **Undulator-based source: mature for ILC parameters**
  - **'sustainable' double-use of electron drive beam**
  - **higher physics potential**

Status and Strategy

- **Undulator-based positron source:**
  - ➡ ILC e+ source is mature: electron drive beam is 125 GeV
  - ➡ however, 31 GeV as e- drive beam not suitable to get intense undulator photon beam
  - ➡drive beam 500 GeV possible, should be optimized

Ushakov ea 1301.1222

- **Re-cycle ILC simulatons:**
  - ➡ start with helical undulator with for 500 GeV ILC parameters (K-value, length, period)
- **Proposed strategy: use 500 GeV e- beam for e+ undulator**
  - ➡ optimize undulator
  - ➡ synergies with ILC R&D (pulsed solenoid, plasma lens, target wheel)

Reminder: Positron requirements

	rep rate/Hz	#bunch/pulse	#e+/bunch	#e+/pulse	#e+/s
SLC	120	1	5×10^{10}	5×10^{10}	6×10^{12}
ILC/Tesla	5	1312	2×10^{10}	2.6×10^{13}	1.3×10^{14}
CEPC	100	1	2×10^{10}	2×10^{10}	2×10^{12}
CLIC	50	312	4×10^{9}	1.2×10^{12}	6×10^{13}
HALHF	10000	1	$2\text{-}3\times10^{10}$	$2\text{-}3\times10^{10}$	$2\text{-}3\times10^{14}$

➡ Similar e+ request as ILC

➡ Adaption of ILC e+ source for HALHF reasonable and efficient!

Some basics: just as an overview

Basic formula for photon spectrum of Helical Undulator given by Kincaid (1978) [3]:

Khaled Alharbi

$$\frac{dW}{d\omega} = \frac{N_p\, q^2\, K^2\, r}{\epsilon_0\, C} \sum_{n=1}^{\infty} \left(J_n'(x_n)^2 + \left(\frac{a_n}{K} - \frac{n}{x_n} \right) J_n(x_n)^2 \right) u(a_n)^2$$

$N_p = period\ number$, $n = harmonic\ number$, $r = \frac{\omega}{2\gamma^2\omega_0}$, $a_n = \frac{n}{r} - 1 - K^2$, $x_n = 2Kra_n$, J_n = Bessel function

Photon number [4]: $N_\gamma \propto \frac{K^2}{\lambda_u} * L_u$,

K is the deflection, K = 0.0934 $B_o\lambda_u$.

λ_u is the undulator period.

B_o is B-field on axis.

L_u is the undulator active length = $N_p\lambda_u$.

The relationship between the energy of the electron beam (E_e) and the 1st harmonic cutoff energies of the photon spectrum (E_1):

$$E_1 \propto \frac{E_e^2}{\lambda_u(1 + K^2)}$$

The upper half of the energy spectrum at any order n is emitted into a cone of angle:

$$\theta \approx \frac{1}{\gamma}\sqrt{1 + K^2},$$ γ is Lorentz factor.

Undulator with E(e-)=500 GeV

Goals: high #e+@DR, high P(e+)>30%, target lifetime~1y

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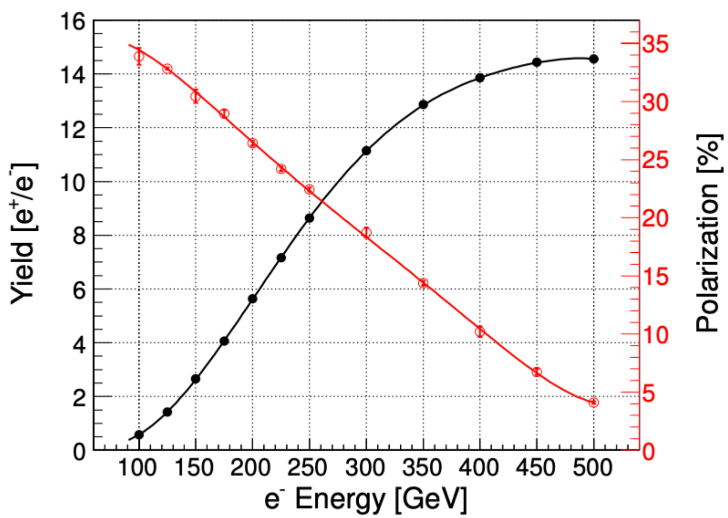
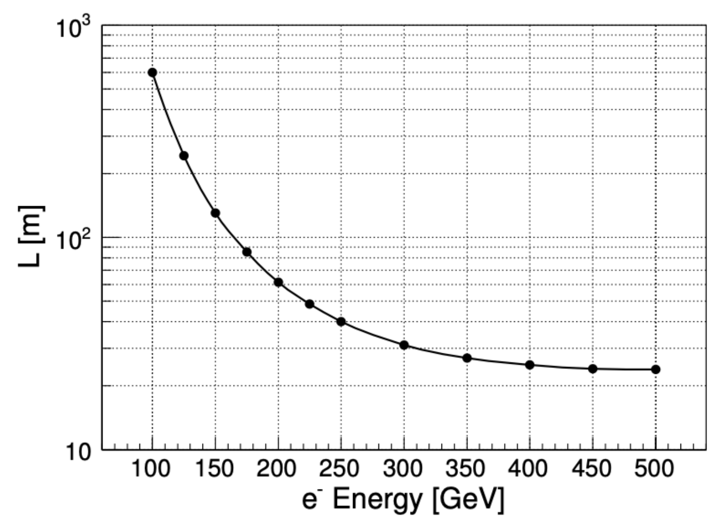
Three possibilities:

1. **Use ILC undulator parameters (K=0.92, period λ=11,5 mm)**

Yield and Polarization



Undulator length



➡ **>1.5 yield achievable with shorter length but low P(e+)~5%**

➡ **not acceptable by physics**

Undulator with E(e-)=500 GeV

Goals: high #e+@DR, high P(e+)>30%, target lifetime~1y

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Three possibilities:

2. **Use new undulator parameters**
   - ➡ e.g. lower K
   - ➡ would result in higher polarization

   but
   - ➡ factor 4 higher energy deposition in target
   - ➡ additionally reduced photon spot size
   - ➡ (probably) technically not acceptable

Undulator with E(e-)=500 GeV

Goals: high #e+@DR, high P(e+)>30%, target lifetime~1y

Three possibilities:

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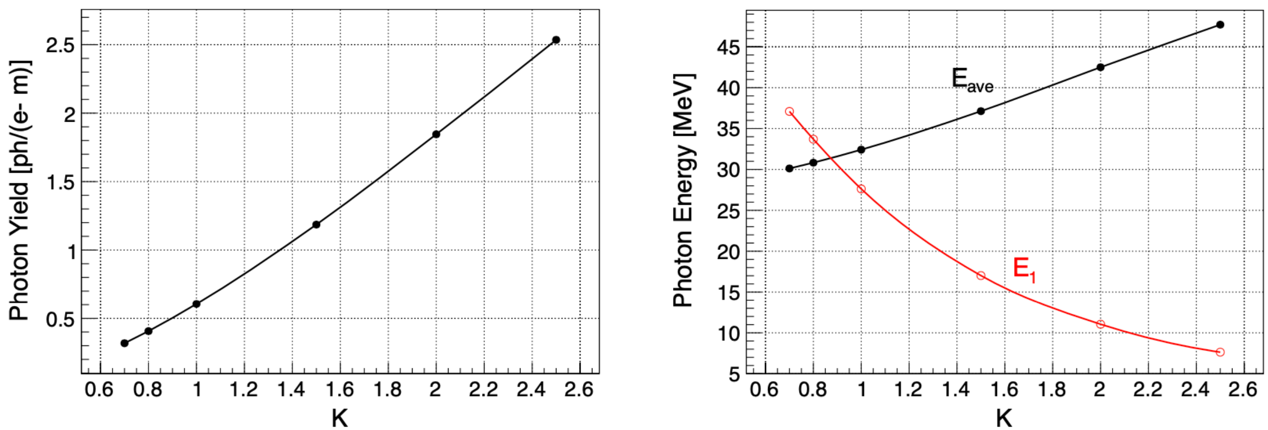
3. **Use new undulator parameters**

➡ **e.g. higher K = 2.5, period λ=43 mm**

➡ **leads to more higher harmonics, higher yield,**



➡ **higher γ_{ave} energy and higher energy spread**

➡**larger γ spot size**

➡ **e+ capture more difficult…..but more know-how (PS, PL) now!**

Polarization@Und$_{E(e-)=500\ GeV}$

Goals: high #e+@DR, high P(e+)>30%, target lifetime~1y

- **Apply photon collimator:**

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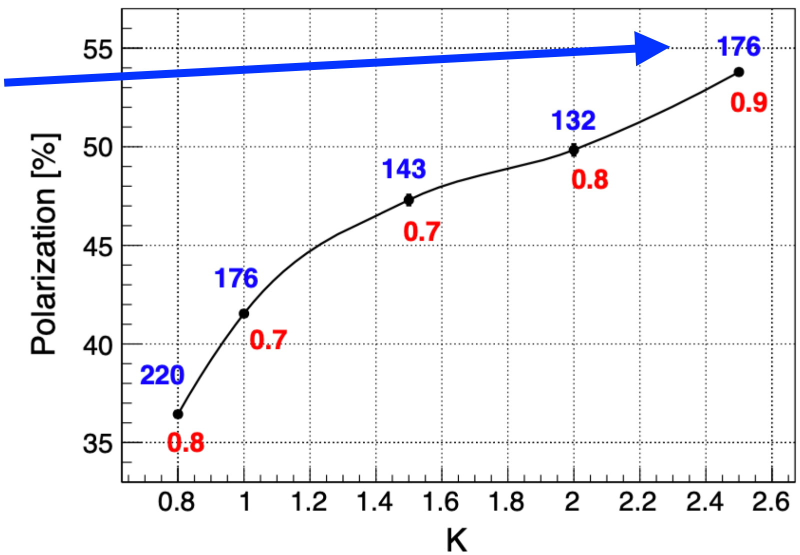
Length



Aperture radius of collimator

- **High P(e+) achievable: ~54%**

➡ **stick to this undulator parameters: capture& target issues**

Deposited Energy & Target Stress

Goals: high #e+@DR, high P(e+)>30%, target lifetime~1y

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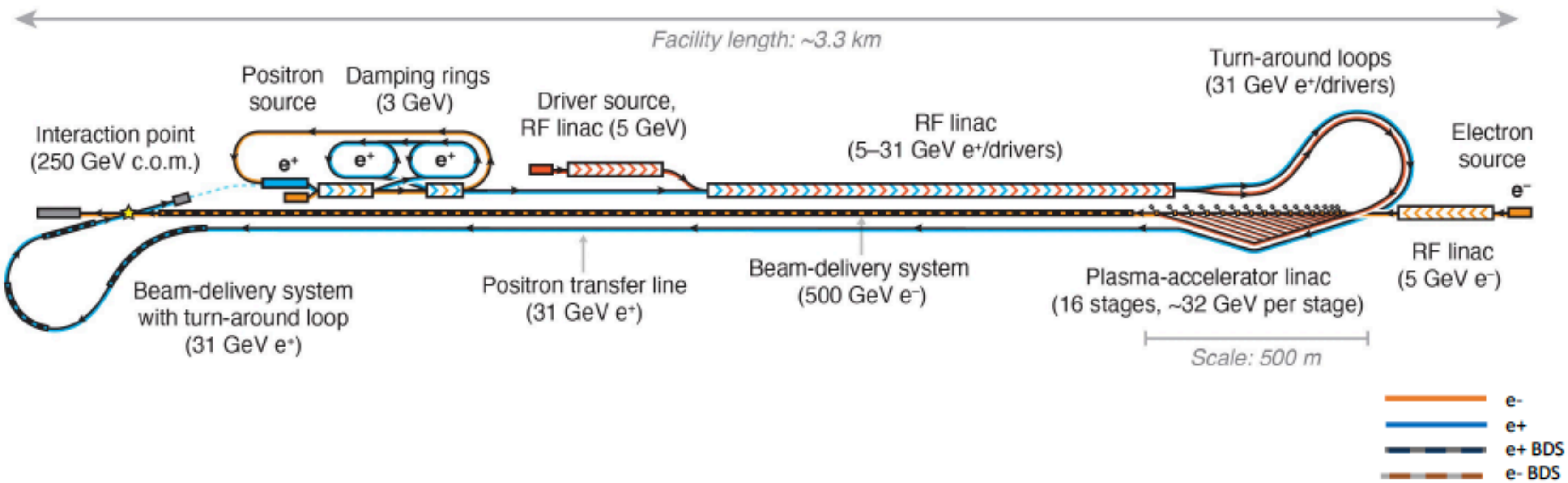
- So far: FLUKA and ANSYS simulation done 'only'
  - ➡ for ILC e- beam
  - ➡ for rotating target wheel with 100 m/s ('ILC target')
  - ➡ Results: Stress is ~25% tensile yield stress and 44% of fatigue stress of Ti-alloy target (but done without centrifugal forces of wheel and superposition effects)....but should be safe (for ILC e- beam)!

Simulations have now to be redone for HALHF e- beam !

HALHF outline?

Goals: implement undulator with L=176m, K=2.5, λ=43 mm and collimator aperture R_c= 0.9 mm



- **Similar as for ILC set-up….. undulator at 'end-of-the-linac'**
  - ➡ **e- emittance growth was a few % and energy loss 3-4 GeV**
  - ➡ **starting point for e+: target = rotating wheel**

  OMD = pulsed solenoid / Plasma

Perfect combination of mature new and known technologies !

Conclusions

Polarized positron sources@ILC from GigaZ to >500 GeV:

- **Simulatneous e+ polarization allows best control of systematics, higher statistics, best physics results**
- **ILC undulator-based source mature and feasible**
- **prototype work on pulsed solenoid and rotating wheel ongoing**
- **New technology for future OMD: plasma lens under tests**

- **HALHF plans (few km for e± beam acceleration):**
  - **new technology (PWA) in combination with SRF**
  - **allows upgrade to higher energies in short tunnels**
  - **adapt e^+-based undulator parameters for HALHF e- beams**

Polarized positron source for future LC optimize physics and involve and combine new technologies!

Polarization measurement

- **Compton polarimeters: up- and downstream**
  - envisaged uncertainties of ΔP/P=0.25% (at polarimeters!)
  - But that's is not enough for IP!
- **Use collision data to derive luminosity-weighted polarization**
  - single W, WW, ZZ, Z, etc.: combined fit

$$P^{-}_{e^\pm} = -|P_{e^\pm}| + \tfrac{1}{2}\delta_{e^\pm} \qquad P^{+}_{e^\pm} = \quad |P_{e^\pm}| + \tfrac{1}{2}\delta_{e^\pm}$$

Karl, List,1703.00214

  - helicity reversal is important
  - non-perfect helicity-reversal can be compensated
  - 0.1% accuracy in ΔP/P is achievable at IP!
  - *NOT achievable without Pe+!*

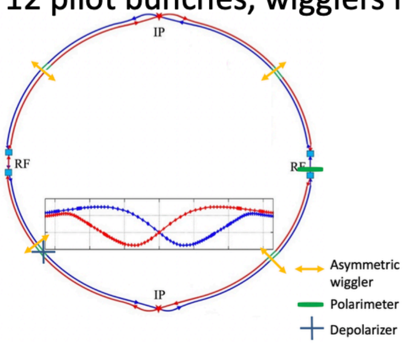
Remember: even if no Pe+ (SLC! dedicated experiment at SLACs Endstation A), the P_{e+}~0.0007 had to be derived a posteriori for physics reason!

Two schemes of polarization generation for RD

Scheme 1: self-polarization in the Colliders

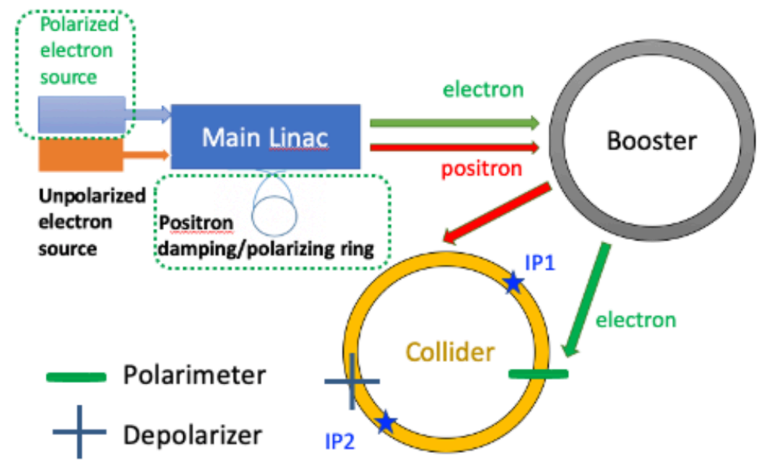
(FCC EPOL, arXiv:1909.12245)

- Z-pole: >20 hour to reach 10% polarization
  - 10 **asymmetric wigglers** switched on to reduce to 1~2 hours
  - Incompatible with high luminosity (increase in U_0, energy spread) -> **1~2 hours dead time for physics at each fill**
  - ~144 pilot bunches dedicated for RD measurements
- W: ~2 hour to reach 10% polarization
  - ~12 pilot bunches, wigglers not needed



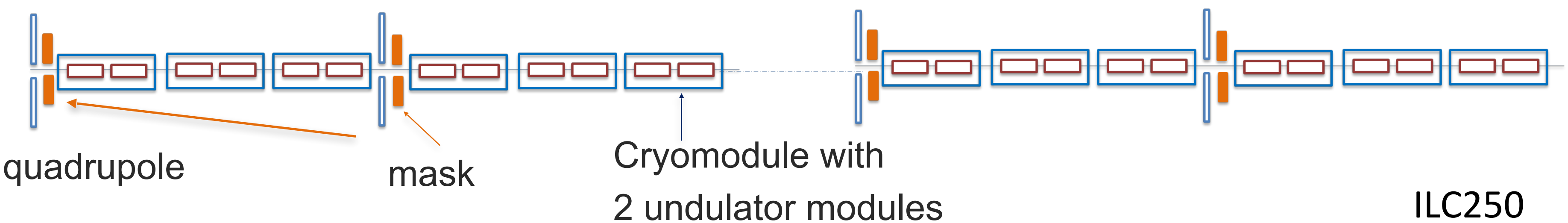
Scheme 2: Injection of polarized beams

- Polarized beams from the source
  - Polarized e- gun: **> 85% polarization**
  - e+ damping ring(1.1 GeV -> 1.98 GeV) : **> 40% polarization after 10 min store**
- **Polarization loss in the Booster is small requiring no additional hardware (** Chen et al, PRAB 26, 051003, 2023**)**
- **No dead time for physics at each fill**



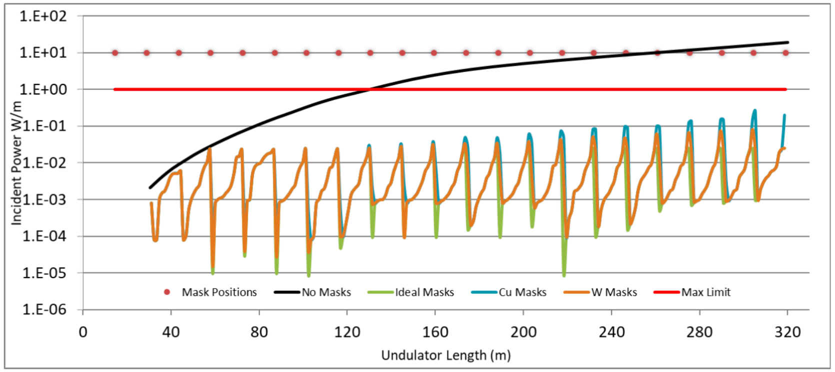
Undulator: Simulation (field errors, alignment)

- Misalignments:
  - beam spot increases slightly, yield decreases slightly (***see A.Ushakov, AWLC18***)
- Realistic undulator with B field (K) and period (λ) errors
  - Results consistent with previous works — ***Alharbi, Thesis 23***
  - provides beam size, polarization, target load — ***S. Riemann***
- Synchrotron radiation deposit in undulator walls
  - Masks protect wall to levels below 1W/m
  - ILC250: power deposition in 'last' mask near undulator exit: ~300W



- ***Result: Masks substantial but sufficient in all cases!***

- Studied for ILC250, ILC350, ILC500 and GigaZ !



GigaZ operation

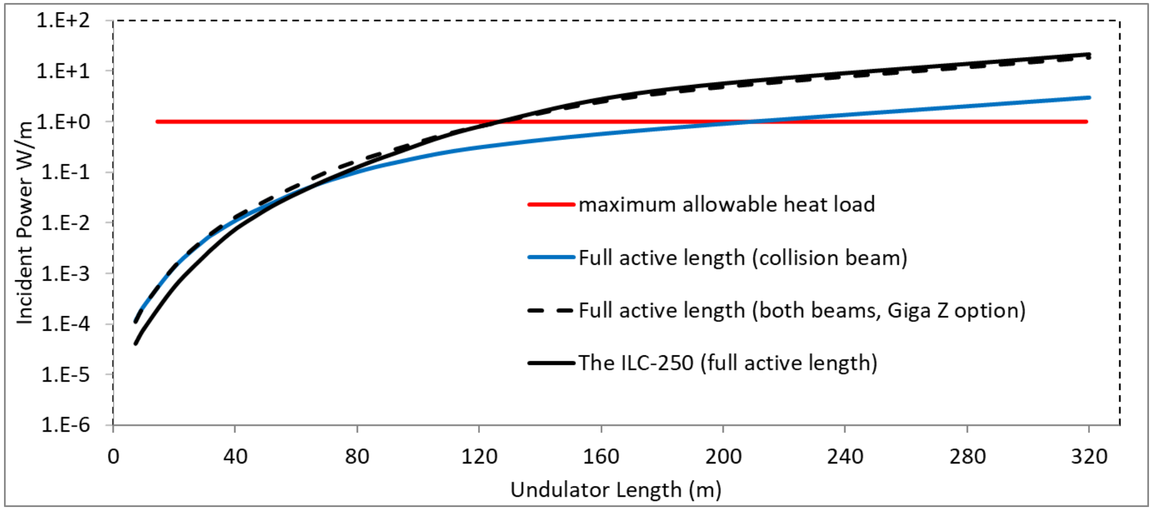
- Parameters for GigaZ operation

  Yokoya-san, 1908.08212

Parameters	e^+ production	collision	Unit
Final beam energy	125	45.6	GeV
Average accelerating gradient	31.5	8.76	MV/m
Peak power per cavity	189	77.2	kW
Beam pulse length	0.727	0.727	ms
RF pulse length	1.65	1.06	ms
Repetition rate	3.7	3.7	Hz

- Incident power at undulator walls: Compare GigaZ and ILC250

power deposition in wall without masks



➡ Incident power at GigaZ below /comparable with ILC250

➡ Mask protection will also be sufficient for GigaZ running