# *Prototypes and R&D Undulator e+ Source*

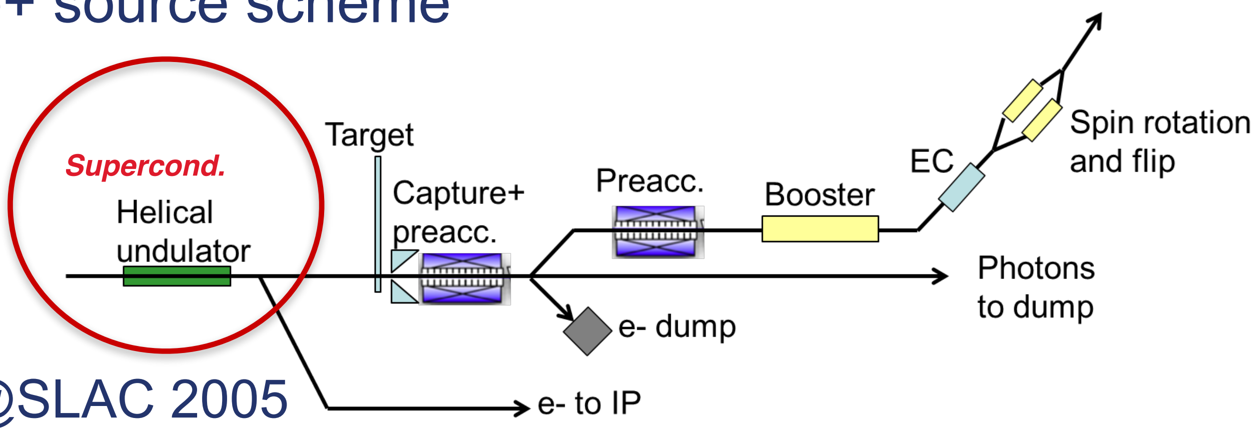
- **Overview**
- **Ongoing ITN work:**
  - **Undulator field simulation**
  - **Target Material Analyses**
  - **Activities towards rotating wheel engineering design**
  - **Prototype Pulsed Solenoid** ***(see Grigory's talk )***
  - **Plasma Lens prototype and simulations** ***(see Manuel & Niclas' talks*****)**
- **First steps towards undulator e+ source for HALHF**
- **Conclusions and plans**

*Gudrid Moortgat-Pick, Sabine Riemann, Peter Sievers*

LINEAR COLLIDER COLLABORATION

# TDR baseline layout of the e+ source

- 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 | $2\times10^{10}$ |
| Number of bunches per pulse | 1312 |
| Repetition rate | 5 Hz |
| Positrons per second at IP | $1.3\times10^{14}$ |

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

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

# TDR baseline layout of the e+ source

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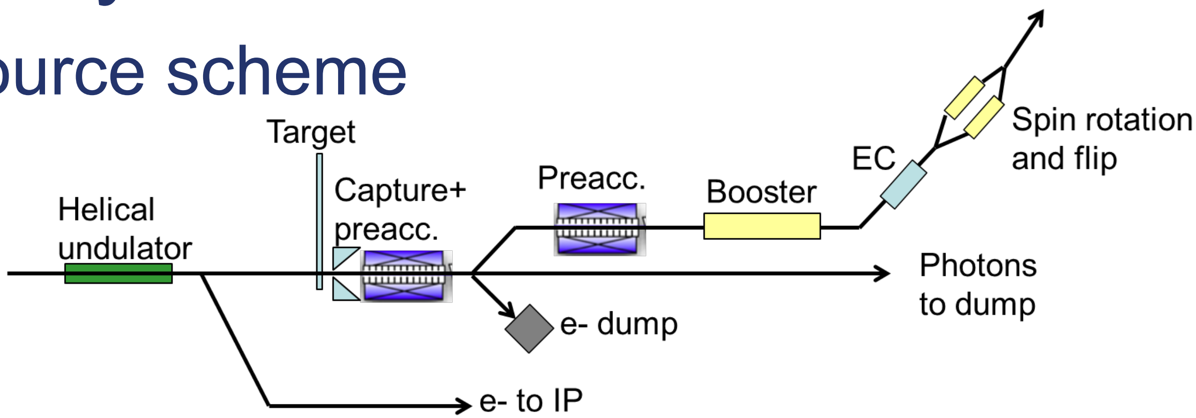


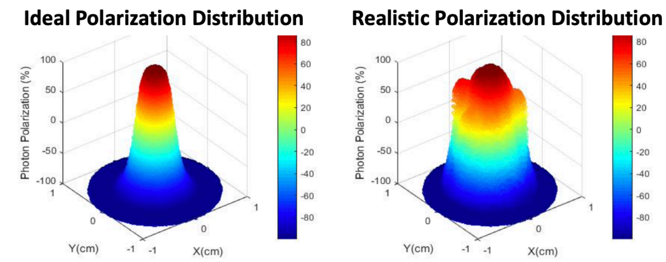

| Work packages | Items |
|---|---|
| WP-5: Undulator | Simulation (field,errors, alignment) √ |
| WP-6: Rotating target | Design finalization, partial laboratory test, mock-up design |
| | Magnetic bearings: performance, specification, test |
| | Full wheel validation, mock-up |
| WP-7: Magnetic focusing system | Design selection (pulsed solenoid, plasma lens), with yield calculation |
| | OMD with fully assembled wheel, prototype |

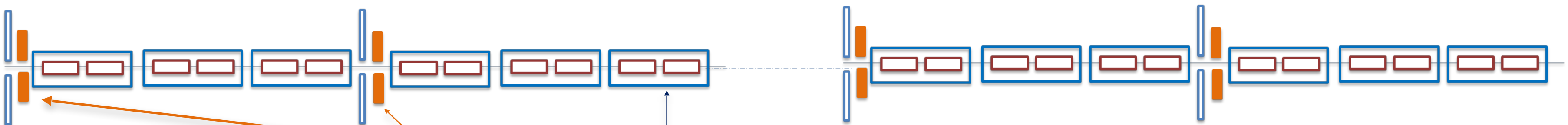
# WP5 Undulator: Simulation (field errors, alignment)

- Misalignments:
  - beam spot increases slightly, yield decreases slightly
- Realistic undulator with B field (K) and period (λ) errors
  - provides beam size, polarization, target load
  - impact depends on K-value!
- Synchrotron radiation deposit in undulator walls
  - Masks protect wall to levels below 1W/m
  - ILC250: power deposition in 'last' mask near undulator exit: ~300W

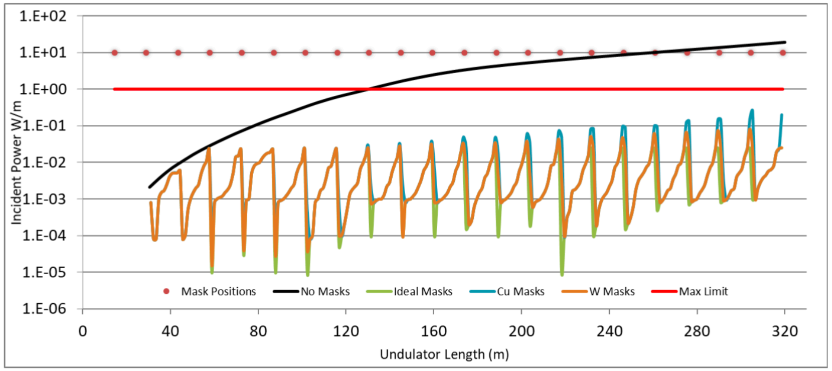
*see A. Ushakov, AWLC18*

*Alharbi, Thesis finished!*




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




- Studied for ILC250, ILC350, ILC500 and GigaZ !

# WP5: GigaZ operation

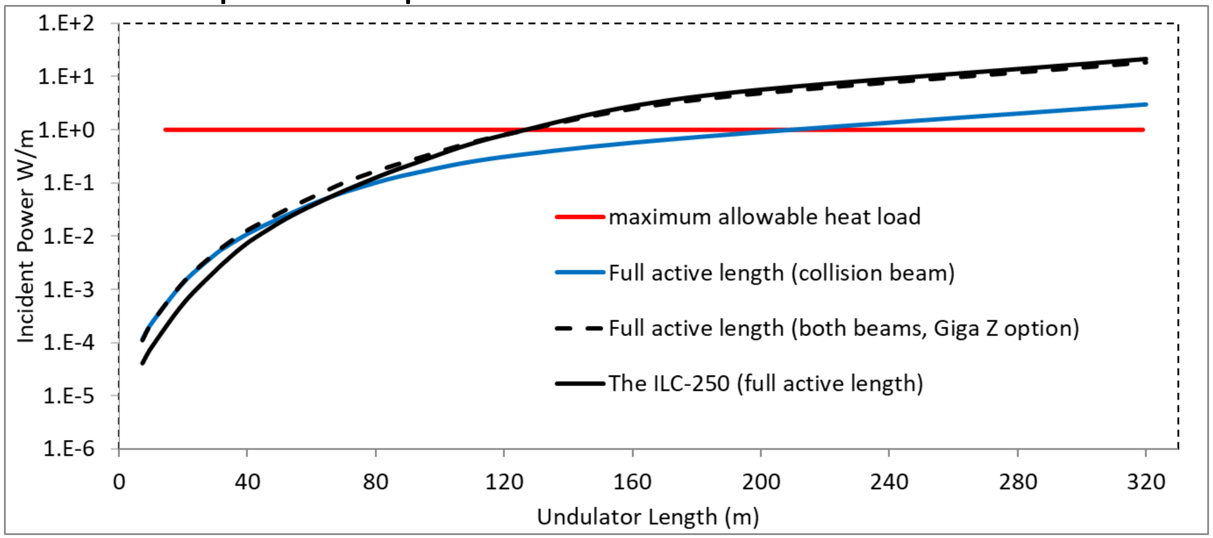
- Parameters for GigaZ operation

  *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

# Analyses of ILC targets

- **News: Paper on dilatometer target tests soon finished !**
- **History: target material tests at Mainz Microtron (MAMI) using e-**
  - **Strategy: electron-beam on ILC target materials, generating cyclic load with same/ even higher PEDD at target than expected at ILC**
  - **Numerous successful tests performed on Ti-Alloy, W** *A. Ushakov et al.*
  - **target analyses with both scanning and synchrotron diffraction methods**
- **Ongoing: (final) tests, analyses and publication**
  - **still one (final?) more test run at MAMI in 9/24** T. Lengler et al.
  - **dilatometer tests: disentangling target damage originating from thermal vs radiation load**
  - **α- and β- phase of Ti-alloy depend on T, have different mechanical properties**
  - **Tested: fast and cyclic stress in the range of T=300$^0$-800$^0$C**
  - **variation of $T_{max}$ as well as different heating/cooling rates of 25$^0$C/s-100$^0$C/s**

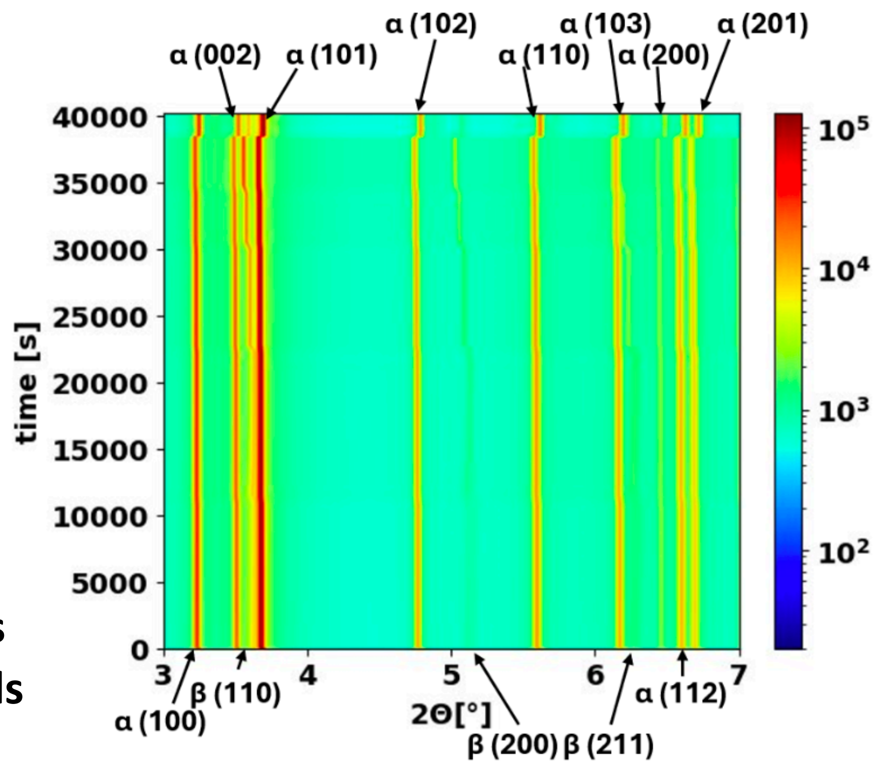
- ***Result: ILC undulator target will stand the load !***

# Analyses of ILC targets

- **News: Paper on dilatometer target tests soon finished !**
- **History: target material tests at Mainz Microtron (MAMI) using e-**

**Example:**
- step-wise heating
- peaks measured of both phases

- Results written up, will be submitted to Journal soon
- In addition: IPAC 24 Paper on radiation damages on e+ source materials




T. Lengler

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

# WP-6: Rotating Target for Undulator Scheme

- Target specification
  - Titanium alloy, 7mm thick (ILC250: 0.2 $X_0$ ), 14mm (ILC500), diameter 1m
  - Rotating at 2000 rpm (100 m/s) in vacuum
  - Photon power ~60 kW, deposited power ~2 kW
  - Radiation cooling
  - Magnetic bearings, widely used for Fermi choppers, vacuum pumps and fast rotating masses

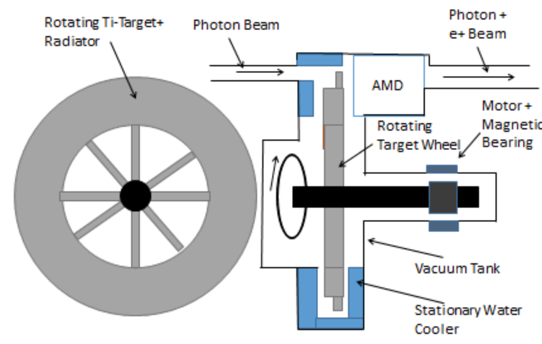
- R&D ongoing
  - Detailed simulations in close contact with OMD design on-going (Grigory's Talk
  - OMD Design finalization, laboratory test of mock-up design
  - Contact with SKF (Canada) started: technical specifications done, engineering design, test

## WP6: R&D activities rotating wheel

### Drive and bearings

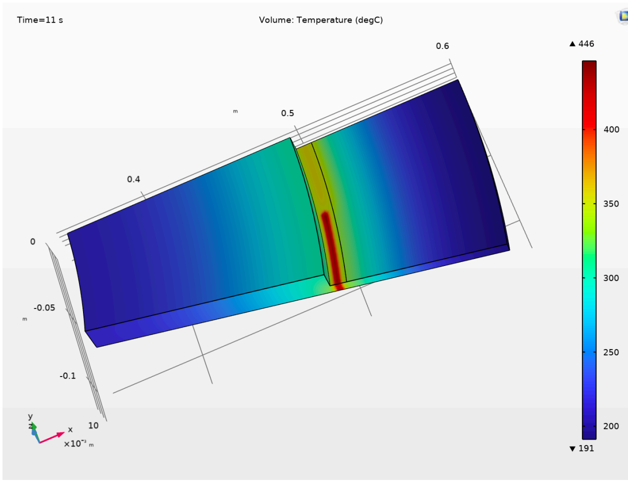
- Radiation cooling allows magnetic bearings
  - A standard component to support elements rotating in vacuum.
  - The axis is «floating» in a magnetic field, provided by permanent or electro magnets
  - Discussion with SKF (Canada) started

Principal Layout: Ti-Wheel with a Diameter of 1.0 m, rotating at 100 m/s, 2000 rpm.




- For the specific ILC-application, a technical specification of for performance and boundary conditions required
  - Specification to be done based on simulation studies
  - New simulations studies under work in close collaboration with pulsed solenoid simulations
  - Technical specfication from Peter (done for Juelich) are now getting modified for SKF (Grigory, Peter, Steffen)

S., Patra 2022



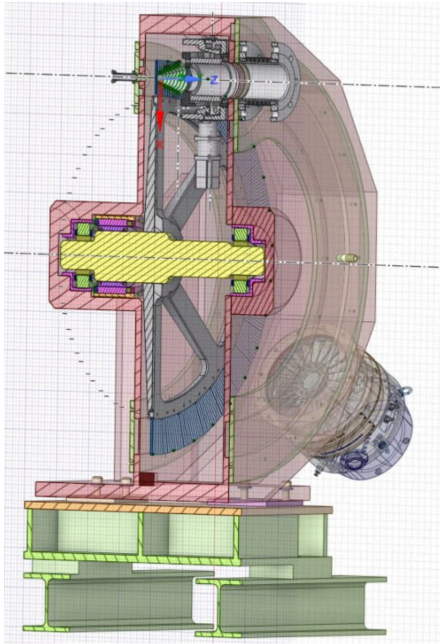
*P.Sievers, G. Yakopov*

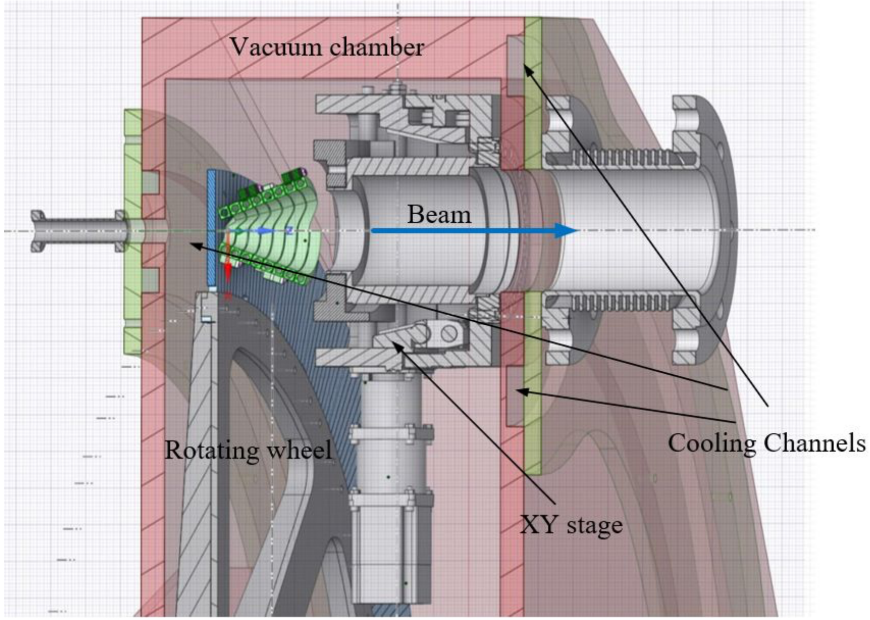
# Towards the rotating wheel

## Ongoing drawings and

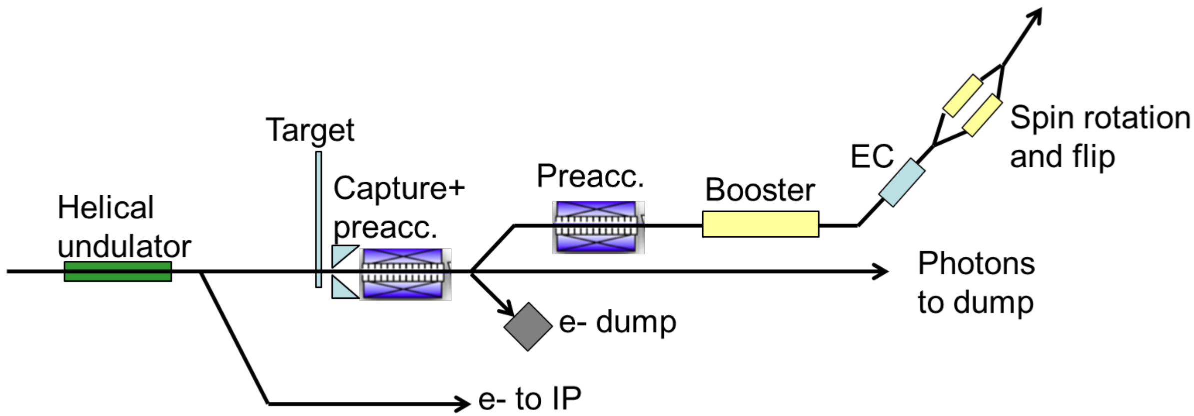
G. Yakopov 2024

- Within ITN initiative: manufacturing drawings at Uni&DESY
- Ongoing discussion with SKF for magnetic bearings/rot. wheel





# WPP-7: Focusing System for Undulator Scheme




- The critical item for the undulator scheme is the magnetic focusing system right after the target
- Possible candidates are: (a) Pulsed solenoid, (b) Plasma lens
- The strongest candidate is (a) pulsed solenoid.
- R&D items ongoing:
  - Detailed simulations for (a) (already on-going)
  - Principal design & engineering for a prototype pulsed solenoid
  - Field measurements with 1kA (pulsed and DC) and with 50kA both in a single pulse mode and finally with pulse duration of 5ms at 5 Hz
  - Prototype plasma lens (funded study on-going)

# OMD Design: Pulsed Solenoid

talk Grigory Yakopov

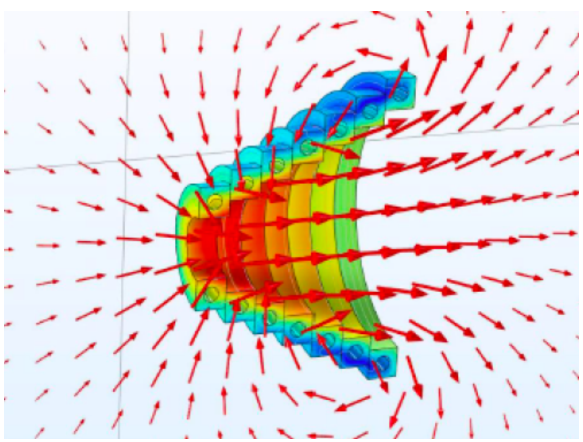
'Baseline' proposal by Peter: Pulsed Solenoid

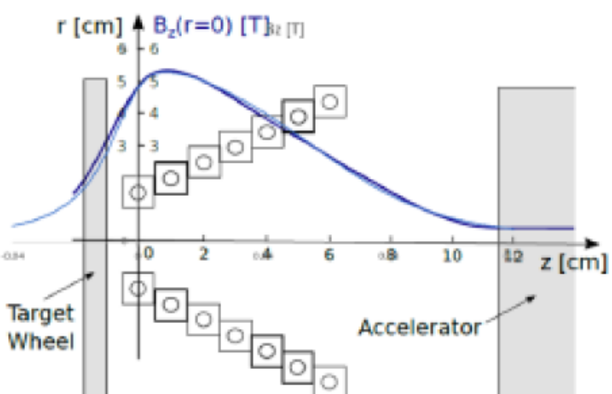
- Yield of e+ (OMD&capture Linac): 1.64-1.81 Fukuda-san, 2021
- ITN initiative: manufacturing drawings for prototype done@ DESY

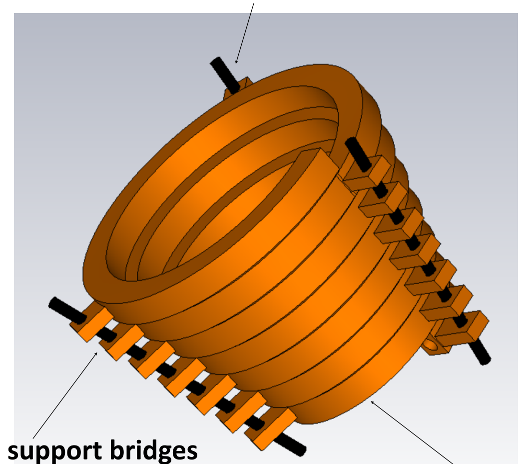
➡ **Absolutely great initiative, thanks a lot!!!**

- advanced design by Grigory (see his talk)
- Planned: prototype tests at CERN
- Close collaboration Grigory, Carmen, Gregor, Peter, Steffen….

Mentink, Tenholt, Loisch, 2021





# OMD Design: Plasma Lens

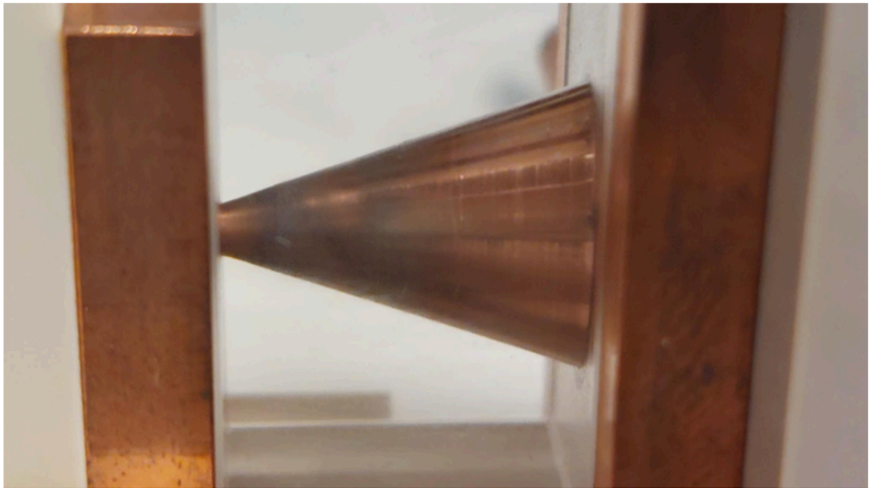
see talks Manuel&Niclas

IPAC 24, Formela, Hamann, Loisch, et al

'Future': Plasma Lenses

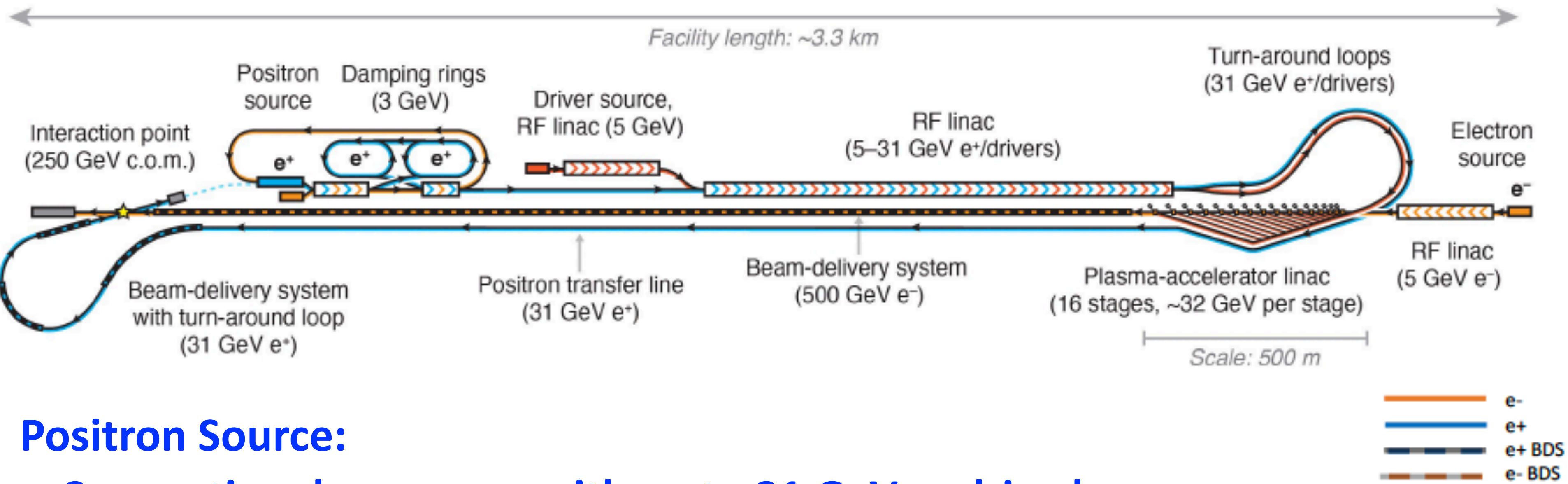
- increases e+ yield but increases load at target only slightly
- advantages in matching aspect
- downscaled prototype designed and produced
- first measurements done
- surprising copper coating from electrodes …other material?
- on simulation side: Ar implementation

➡ please stay tuned, lots of exciting work on prototypes ongoing !



# Plans: undulator e+ source for HALHF

*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**
  - **substantial higher physics potential due to polarization!**

*Just started,*
*1st thoughts only,*
*see next LCWS!* ❤

# 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)
  - ➡ discuss HALHF as upgrade option of ILC250….?

# Reminder: Positron requirements

| | rep rate/Hz | #bunch/pulse | #e+/bunch | #e+/pulse | #e+/s |
|---|---|---|---|---|---|
| SLC | 120 | 1 | $5x10^{10}$ | $5x10^{10}$ | $6x10^{12}$ |
| ILC/Tesla | 5 | 1312 | $2x10^{10}$ | $2.6x10^{13}$ | $1.3x10^{14}$ |
| CEPC | 100 | 1 | $2x10^{10}$ | $2x10^{10}$ | $2x10^{12}$ |
| CLIC | 50 | 312 | $4 x10^{9}$ | $1.2x10^{12}$ | $6x10^{13}$ |
| HALHF | 10000 | 1 | $2\text{-}3x10^{10}$ | $2\text{-}3x10^{10}$ | $2\text{-}3x10^{14}$ |

➡ Similar e+ request as ILC

➡ Adaption of ILC e+ source for HALHF very interesting

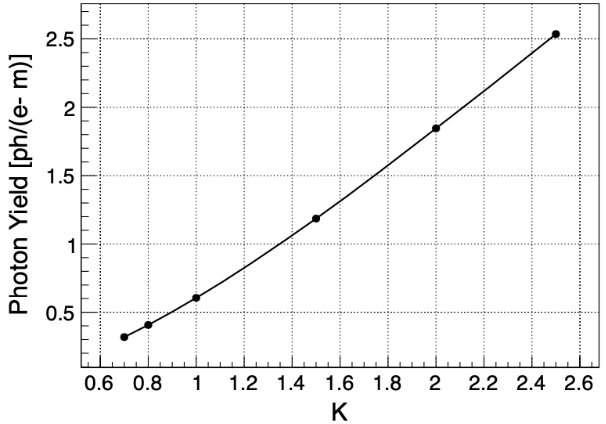
# Undulator with E(e-)=500 GeV

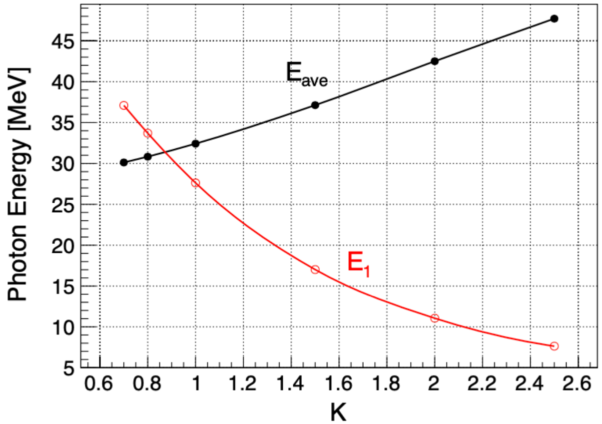
***Goals: high #e+@DR, high P(e+)>30%, target lifetime~1y***

**Proposal: Use new undulator parameters**

*Ushakov ea 1301.1222*

- ➡ **e.g. higher K = 2.5, period λ=43 mm**
- ➡ **leads to more higher harmonics, higher yield,**



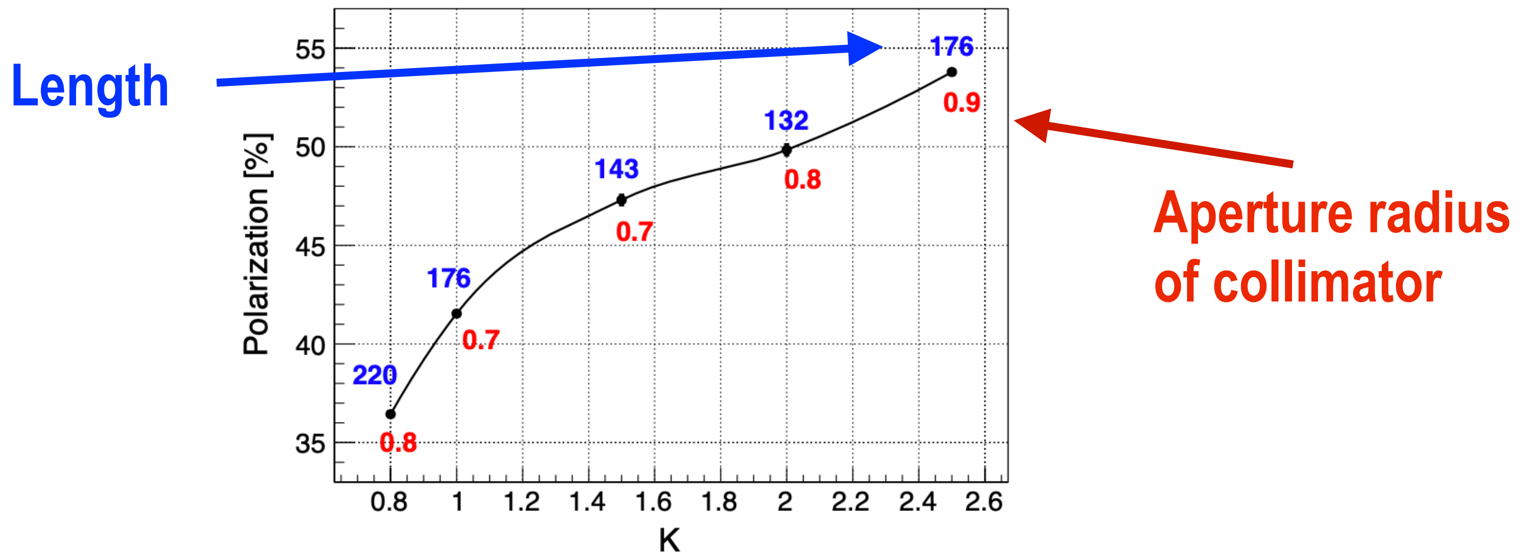




- ➡ **higher $\gamma_{ave}$ energy and higher energy spread**
- ➡ **larger γ spot size**
- ➡ **e+ capture more difficult…..but more know-how (PS, PL) now!**

# Undulator with E(e-)=500 GeV

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

- **Apply photon collimator:**




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

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

➡ **but…..factor 1.5-2 more e+ needed than at ILC….**

# Deposited Energy & Target Stress

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

*Ushakov ea 1301.1222*

- **So far: FLUKA and ANSYS simulation done 'only'**
  - ➡ **for ILC e- beam and 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 and for non-ideal undulator fields!***

*(since deviations between 'ideal' and 'realistic' unduator fields get larger for larger K,….)*

*Khaled Alharbi, Thesis 2024*

# 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**

- **What’s about using HALHF as upgrade of ILC250? ….**
  - ➡ **now: immediately start with ILC250 run (~20 km tunnel length)**
  - ➡ **later: use e- tunnel (10 km) for PWA acceleration (~100 m) and reach with ILC e+ beam & PWA e- beam √s~500GeV**

- **But…..so far no true simulations on target loads etc…. stay tuned…**

# Conclusion and plans

- **ILC undulator-based source mature and feasible:**
  - **Undulator simulations (WP5) done**
  - **Thanks to ITN initiative: prototype work on pulsed solenoid and next steps on rotating wheel ongoing (WP6&7)**
    - **collaboration University Hamburg&DESY&CERN&KEK**
  - **Future OMD design: plasma lens prototypes under tests**

  ➡ **substantial progress since last year and protoypes 'just ahead'**

  ➡ **please remember: Simultaneous $e^{\pm}$ polarization allows highest physics potential, best control of systematics, higher statistics in less running time!**

- **HALHF plans (only short tunnel for e- beam acceleration):**
  - **new technology (PWA) in combination with SRF would allow upgrade to higher energies in short tunnels**
  - **try to adapt undulator-based e+ source for HALHF e- beams, combine R&D issues**
  - **maybe also Laser-Compton scheme applicable……?**

➡ ***ILC can be built NOW and maybe future upgrade as HALHF…?***

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

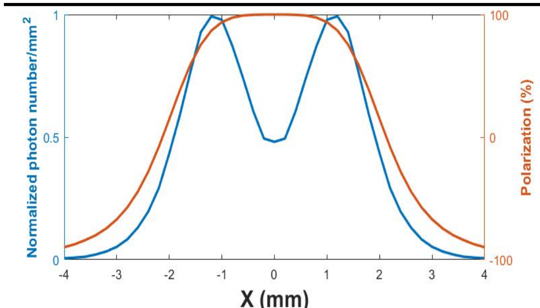
- **Important issue: measuring amount of polarization**
  - **limiting systematic uncertainty for high statistics measurements**
  - **Compton polarimeters (up- /downstream): envisaged uncertainties of ΔP/P=0.25%**
- **Advantage of adding positron polarization:**
  - **Substantial enhancement of eff. luminosity and eff. polarization**
  - **new independent observables**
  - **handling of limiting systematics and access to in-situ measurements: ΔP/P=0.1% achievable!**
  - **Windows to new physics already at low energy!**
- **Substantial physics impact: EWPO, Higgs-Physics, WW/Z/top-Physics, New Physics !**

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

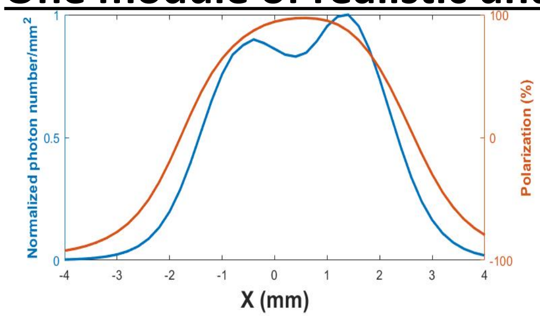

- *LCC-Physics Group: 'The role of positron polarization for the initial 250 GeV stage of ILC', arXiv: 1801.02840*
- *G. Moortgat-Pick et al. (~85 authors) : `Pol. positrons and electrons at the LC', Phys. Rept. 460 (2008), hep-ph/0507011*
- *G. Wilson: `Prec. Electroweak measurements at a Future e+e- LC', ICHEP2016, R. Karl, J. List, LCWS2016, 1703.00214*
- *many more (only few examples): 1206.6639, 1306.6352 (ILC TDR), 1504.01726, 1702.05377, 1908.11299,2001.03011, …*
- *G. Moortgat-Pick, H. Steiner, `Physics opportunities with pol. e- and e+ beams at TESLA, Eur.Phys.J direct 3 (2001)*
- *T. Hirose, T. Omori, T. Okugi, J. Urakawa, Pol. e+ source for the LC, JLC, Nucl. Instr. Meth. A455 (2000) 15-24,….*

# ILC-250 Ideal and Realistic Photon Beam Distribution at Target

**<u>One module of ideal undulator, Y=0</u>**

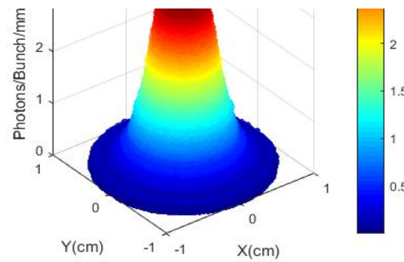



**<u>One module of realistic undulator, Y=0</u>**

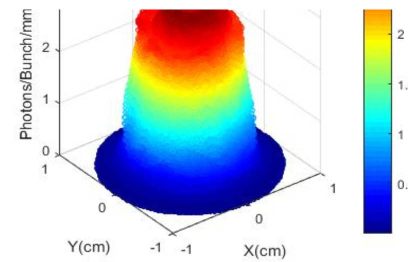



**<u>Full undulator length (132 modules)</u>**

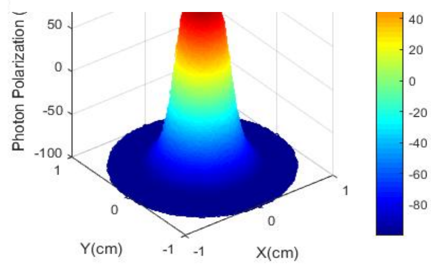
**Ideal Photon Distribution**



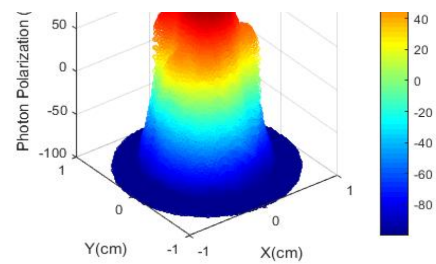

**Realistic Photon Distribution**




**Ideal Polarization Distribution**



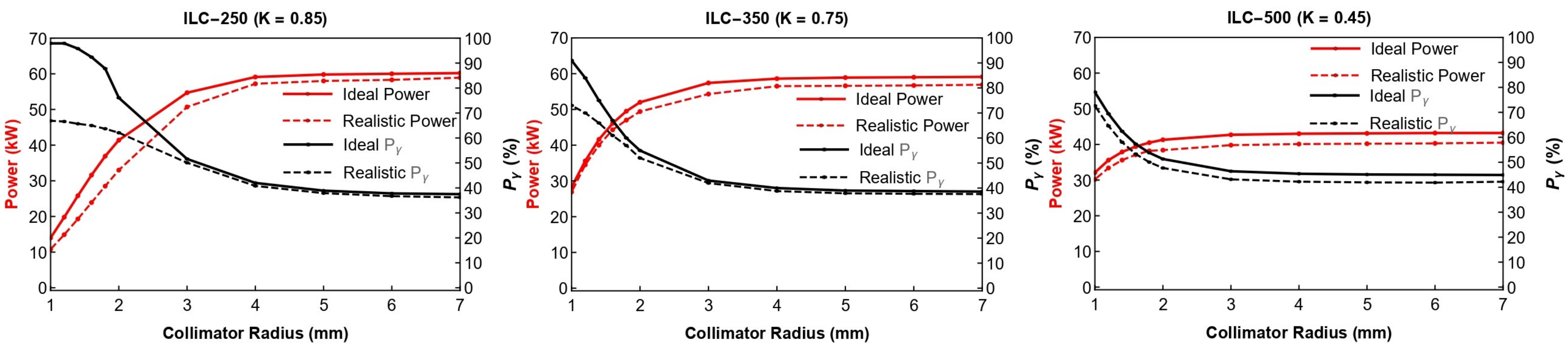

**Realistic Polarization Distribution**




In case of the realistic case: the photon beam is **no longer** at the centre.

# Photon Parameters at Target for Different Photon Collimator Radii

The effect of different photon collimator radii on photon beam parameters at the target for both ideal and realistic undulator cases for ILC-250, ILC-350 and ILC-500:




Substantially lower photon beam polarization for non-ideal undulator, especially, for higher K values.