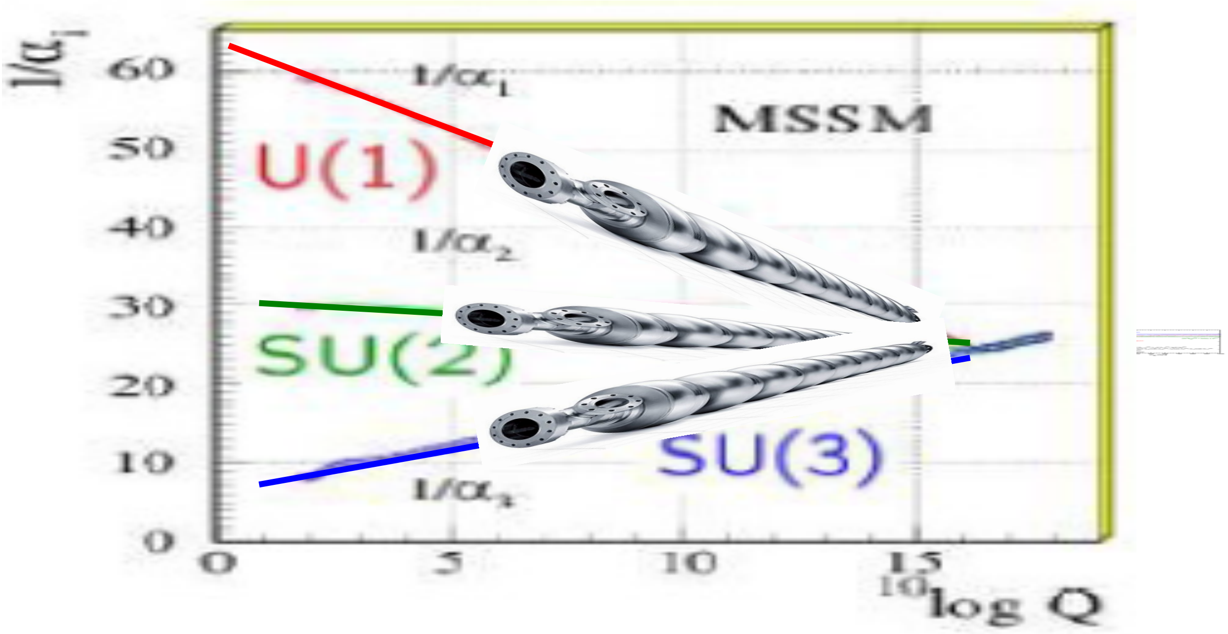
Physics at future Lepton Colliders

G. Moortgat-Pick
(Uni Hamburg/DESY)



LINEAR COLLIDER COLLABORATION

Lecture 4

courtesy of G. Weiglein

e^+e^- Higgs factories

Linear

ILC

Japan

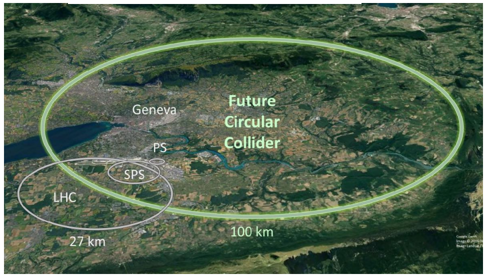
International **L**inear **C**ollider

Circular

FCC-ee

CERN

Future **C**ircular **C**ollider



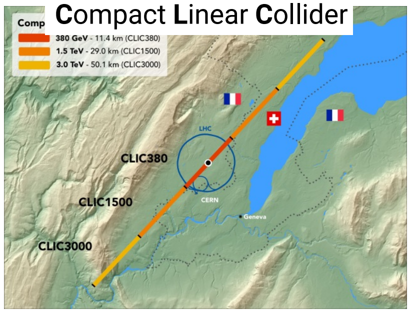
High-level differences:

- Energy reach
- Luminosity

CLIC

CERN

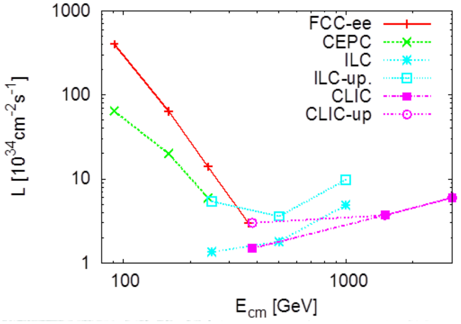
Compact **L**inear **C**ollider



CEPC

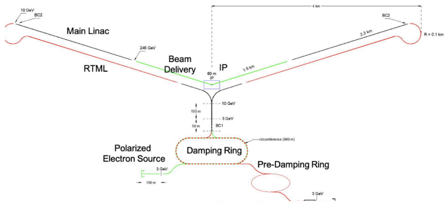
China

Circular **E**lectron **P**ositron **C**ollider



CCC

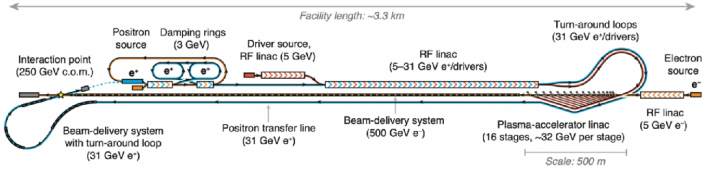
C^3 - 8 km Footprint for 250/550 GeV



- 250 GeV — *ZH* threshold
- 350 GeV — *tt* threshold
- 550 GeV — *HHH* coupling
- ca. 1.5 TeV technology limit

- Based on superconducting RF (liquid nitrogen)
- Proposed at SLAC; very compact machine

HALHF



Source: **Foster, D'Arcy & Lindstrøm,** preprint at arXiv:2303.10150 (2023)

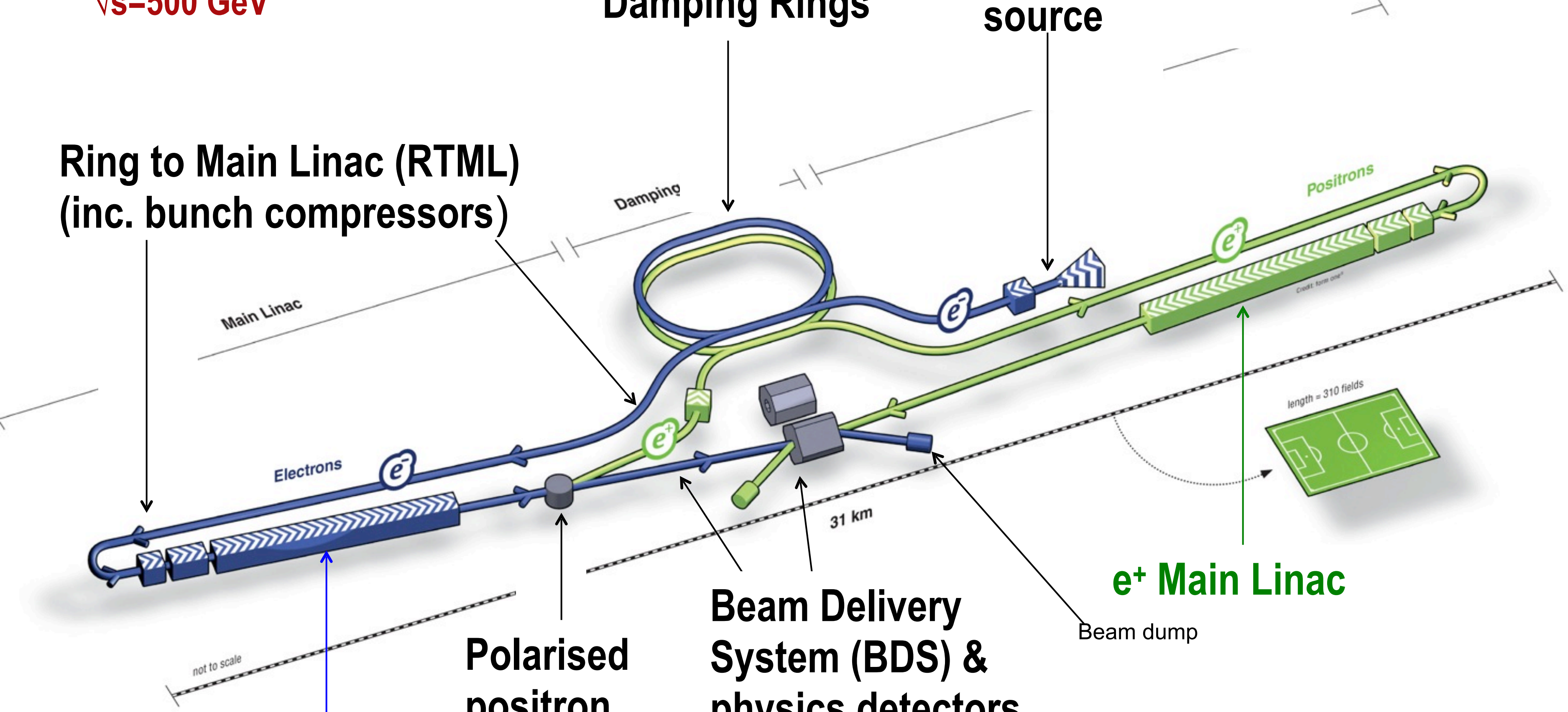
- 250 GeV — *ZH* threshold
- 365 GeV — *tt* threshold
- 10-30 TeV ?? technology limit

- New idea: e^- plasma acceleration, e^+ conventional LinAc
- ca. 10 years R&D needed to demonstrate feasibility
- Extremely compact: 3-4 km size, suitable for national lab

ders Georg Weiglein Workshop on Future Accelerators Corfu 05 / 2024 18

Most mature Design: ILC

$\sqrt{s}$=500 GeV



Damping Rings

Polarised electron source

Ring to Main Linac (RTML) (inc. bunch compressors)

Polarised positron source

Beam Delivery System (BDS) & physics detectors

Beam dump

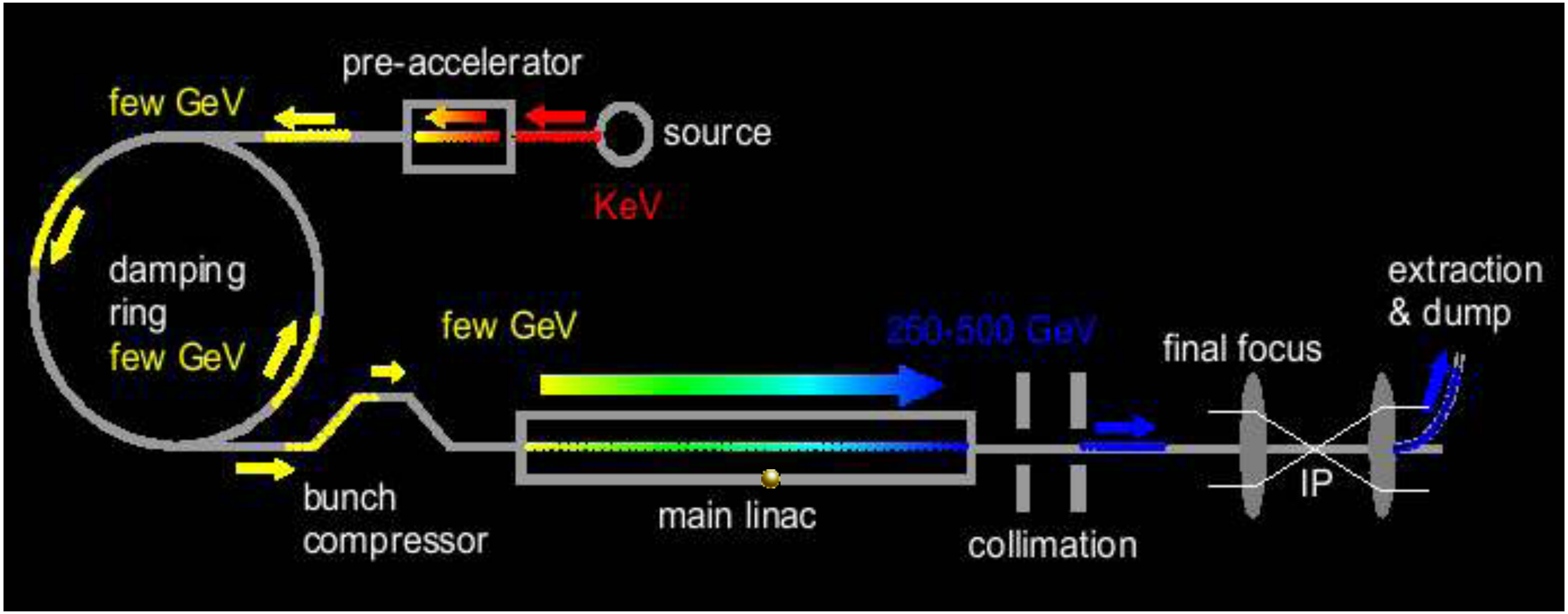
e^+ Main Linac

e^- Main Linac

σ_x / σ_y - 474 nm / 6 nm
Luminosity - 2×10^{34} cm^{-2}s^{-1}
Polarisation (e-/e+) - 80% / 30%

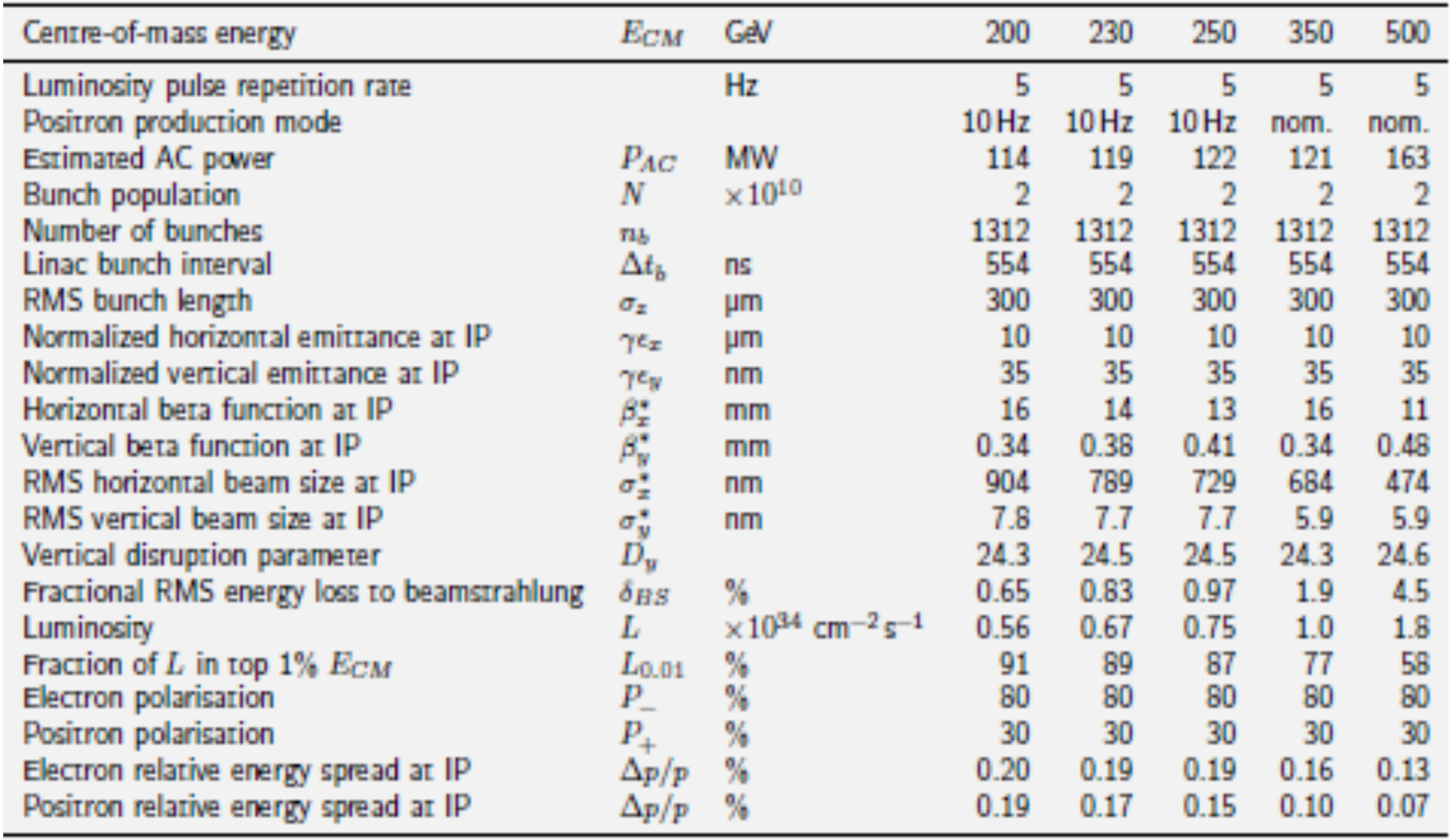
ILC Scheme | © www.form-one.de

Generic Linear Collider



- ***High luminosity:*** **ILC beam structure = 1300 bunches per pulse, pulse every 5 Hz and each bunch contains about 10^{10} particles !**
- ***Challenge:*** **number of $e^{\pm}$ / pulse = factor 1000 higher than at SLC ('88-98) !   (but luminosity even factor 10000!)**

ILC Parameters



Centre-of-mass energy	E_{CM}	GeV	200	230	250	350	500
Luminosity pulse repetition rate		Hz	5	5	5	5	5
Positron production mode			10 Hz	10 Hz	10 Hz	nom.	nom.
Estimated AC power	P_{AC}	MW	114	119	122	121	163
Bunch population	N	$\times 10^{10}$	2	2	2	2	2
Number of bunches	n_b		1312	1312	1312	1312	1312
Linac bunch interval	Δt_b	ns	554	554	554	554	554
RMS bunch length	σ_z	µm	300	300	300	300	300
Normalized horizontal emittance at IP	$\gamma\epsilon_x$	µm	10	10	10	10	10
Normalized vertical emittance at IP	$\gamma\epsilon_y$	nm	35	35	35	35	35
Horizontal beta function at IP	β^*_x	mm	16	14	13	16	11
Vertical beta function at IP	β^*_y	mm	0.34	0.38	0.41	0.34	0.48
RMS horizontal beam size at IP	σ^*_x	nm	904	789	729	684	474
RMS vertical beam size at IP	σ^*_y	nm	7.8	7.7	7.7	5.9	5.9
Vertical disruption parameter	D_y		24.3	24.5	24.5	24.3	24.6
Fractional RMS energy loss to beamstrahlung	δ_{BS}	%	0.65	0.83	0.97	1.9	4.5
Luminosity	L	$\times 10^{34}$ cm^{-2}s^{-1}	0.56	0.67	0.75	1.0	1.8
Fraction of L in top 1% E_{CM}	$L_{0.01}$	%	91	89	87	77	58
Electron polarisation	P_-	%	80	80	80	80	80
Positron polarisation	P_+	%	30	30	30	30	30
Electron relative energy spread at IP	$\Delta p/p$	%	0.20	0.19	0.19	0.16	0.13
Positron relative energy spread at IP	$\Delta p/p$	%	0.19	0.17	0.15	0.10	0.07

SCRF Linac Technology

- solid niobium
- standing wave
- 9 cells
- operated at 2K (Lqd. He)
- 35 MV/m
- $Q_0 \geq 10^{10}$

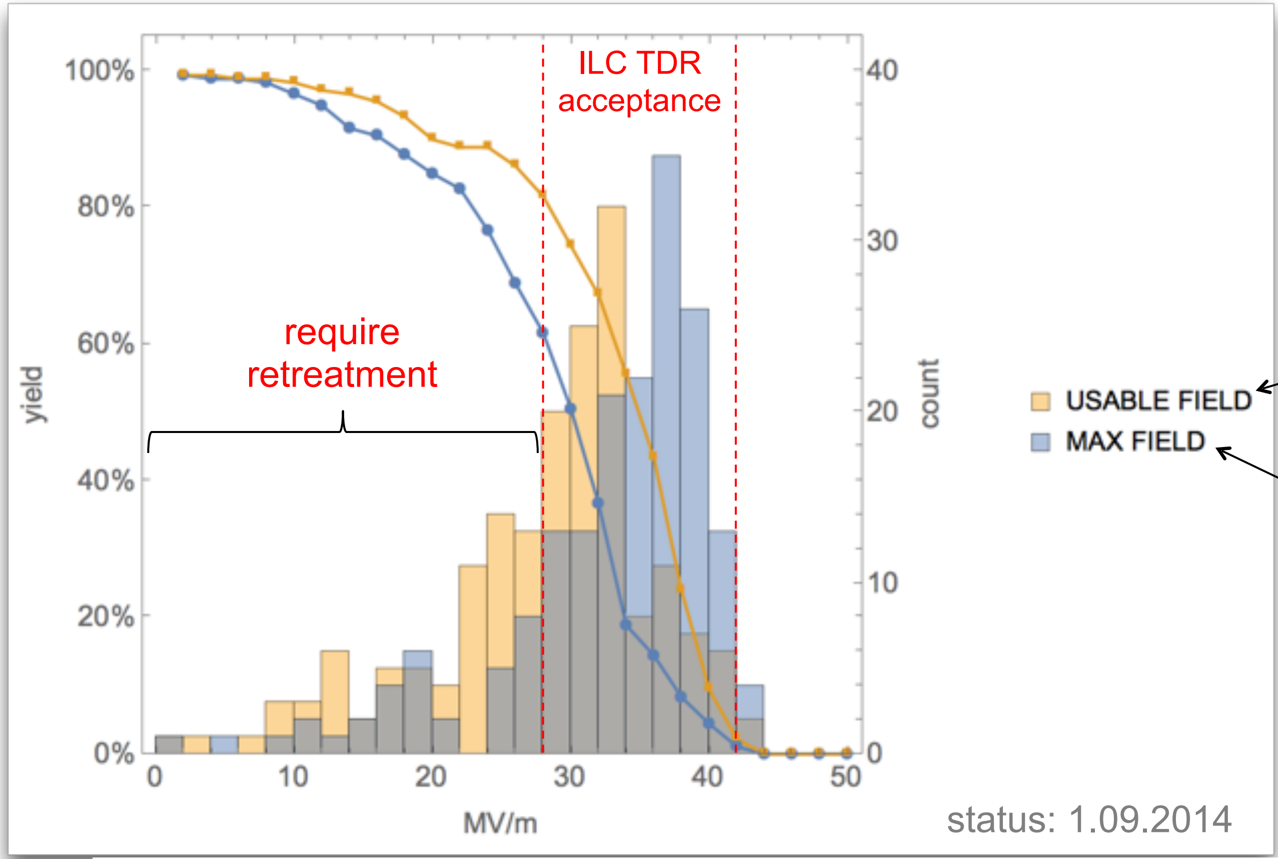
1.3 GHz Nb 9-cell Cavities	16,024
Cryomodules	1,855
SC quadrupole package	673
10 MW MB Klystrons & modulators	436 / 471*

* site dependent

Approximately 20 years of R&D Worldwide → Mature technology

Industrial production - XFEL

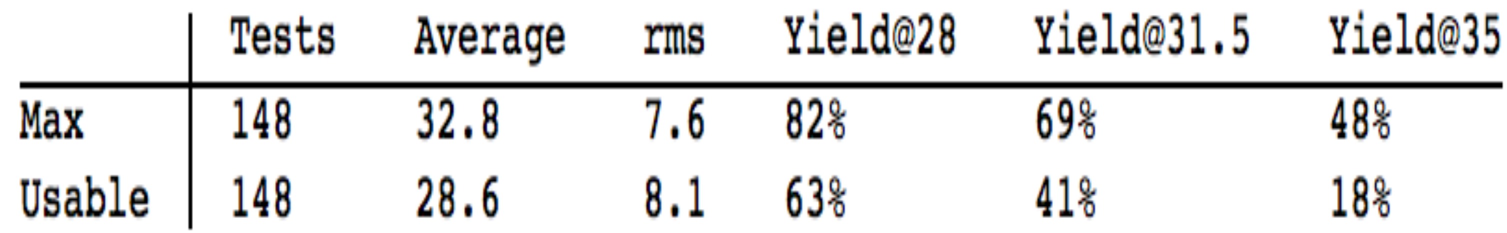
Vendor following ILC baseline recipe (4 per week, final total: 400 cavities)



Field emission limit (XFEL spec.)

quench limit

Thanks to Nick Walker and Brian Foster



	Tests	Average	rms	Yield@28	Yield@31.5	Yield@35
Max	148	32.8	7.6	82%	69%	48%
Usable	148	28.6	8.1	63%	41%	18%

Polarized e- beam at the ILC

Remember again: First polarised e^- beam at a LC at SLAC (1992-98)
with $P(e^-) = [60\%, 78\%]$

How did they polarise the e^-?

$\rightarrow$ circ. polarised light ($I_z = +1$ or -1) on GaAs cathode

$\Rightarrow P^{-1} = \frac{N_+ - N_-}{N_+ + N_-} = \frac{3-1}{3+1} = +0.5$

How to get higher polarisation?

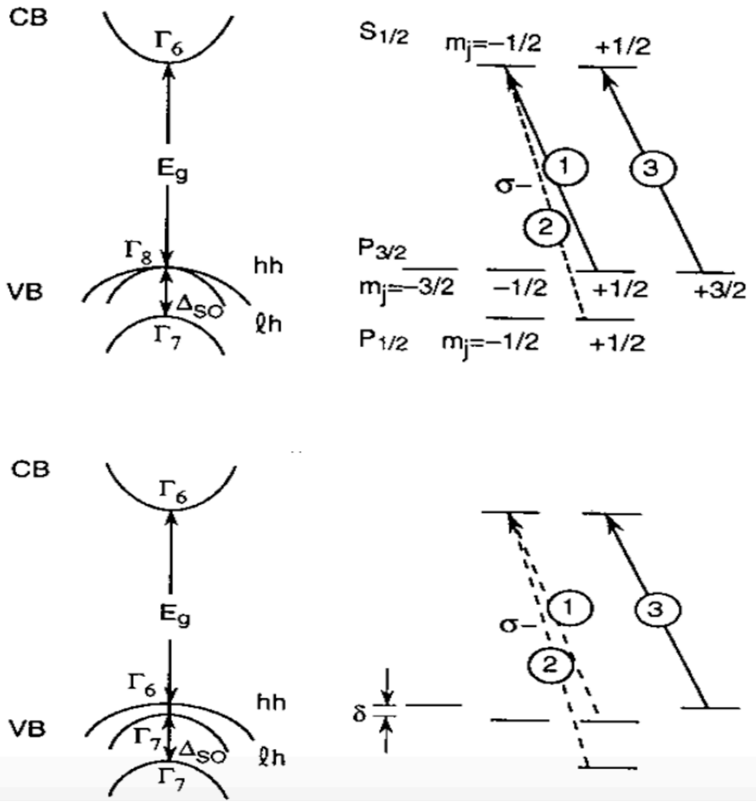
$\rightarrow$ use strained lattice: grow GaAs on substrate with diff. crystal spacing

$\Rightarrow$ removes degeneracy in lower level

If $h\nu = [E_g, (E_g + \delta)]$:

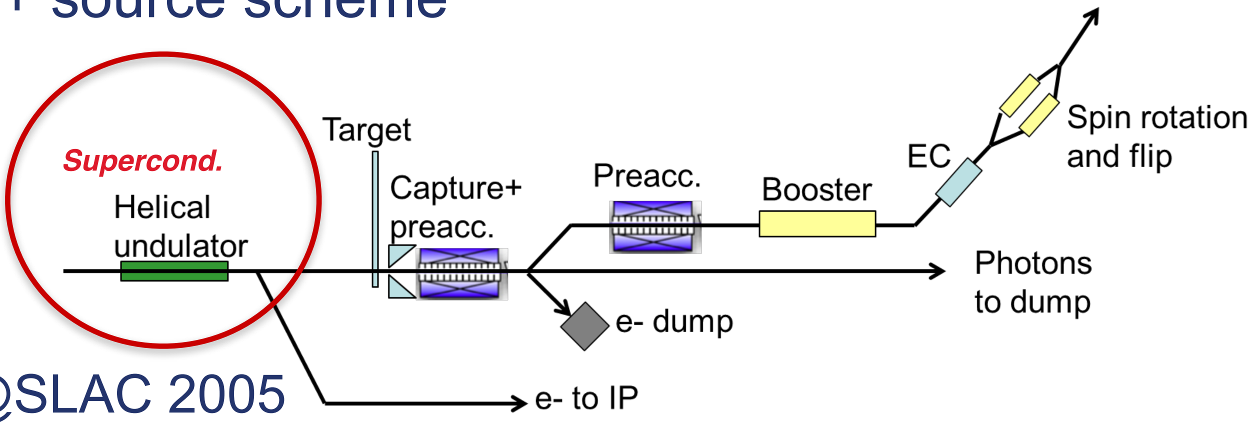
$\rightarrow$ in principle $P^{-1} = 100\%$ possible...

$\Rightarrow P^{-1} = 80 - 90\%$ expected at LC



Polarized positron source at the 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

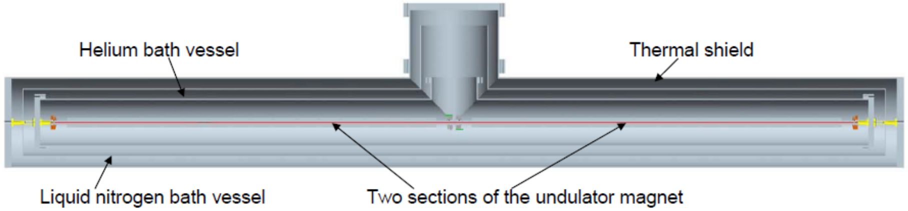
Overview positron requirements

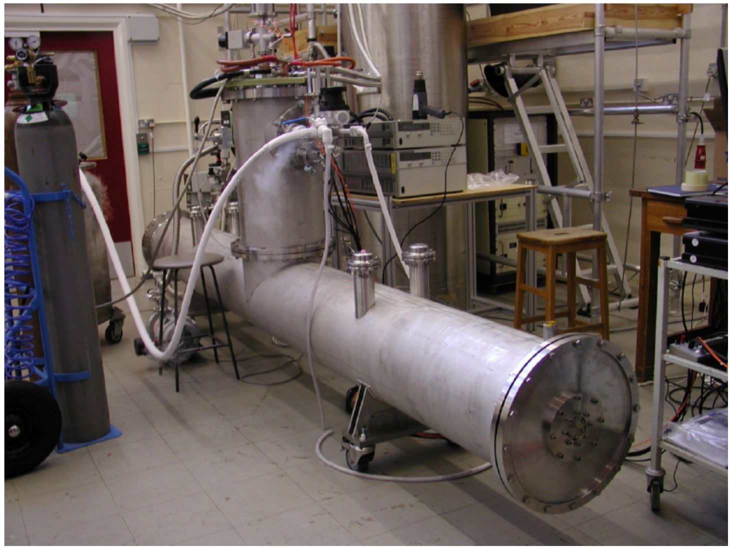
	rep rate/Hz	#bunch/pulse	#e+/bunch	#e+/pulse	#e+/s
SLC	120	1	$5x10^{10}$	$5x10^{10}$	$6x10^{12}$
ILC/Tesla	5	1312	$2x10^{10}$	$2.6x10^{13}$	$1.3x10^{14}$
CEPC	100	1	$2x10^{10}$	$2x10^{10}$	$2x10^{12}$
CLIC	50	312	$4 x10^{9}$	$1.2x10^{12}$	$6x10^{13}$
HALHF	10000	1	$2\text{-}3x10^{10}$	$2\text{-}3x10^{10}$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

Undulator technology - Status

- Parameters
  - Undulator period, $\lambda_U = 11.5\text{mm}$
  - Undulator strength $K \leq 0.92$ ($B \leq 0.86\text{T}$); $K \sim B \cdot \lambda_U$
  - 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**
  - **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**

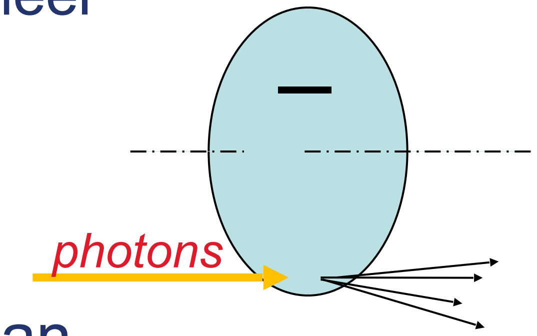
W. Decking/XFEL

LCWS21

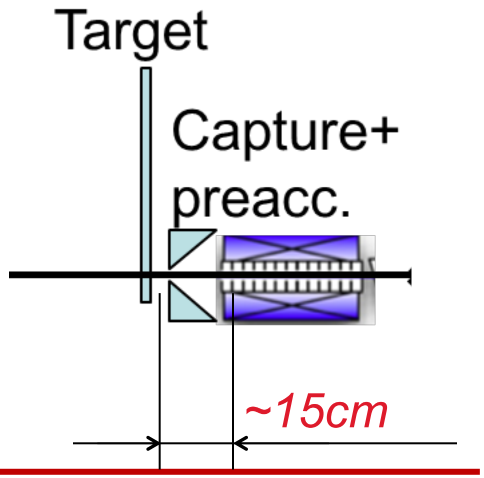
- **Stable operation and alignment experience**
  - **Beam requirements at XFEL more challenging than at ILC due to FEL requests of photons**
  - **Tolerances of IlC undulator more relaxed than for XFEL!**
- **Result: no operation&alignment issues for ILC undulator**

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



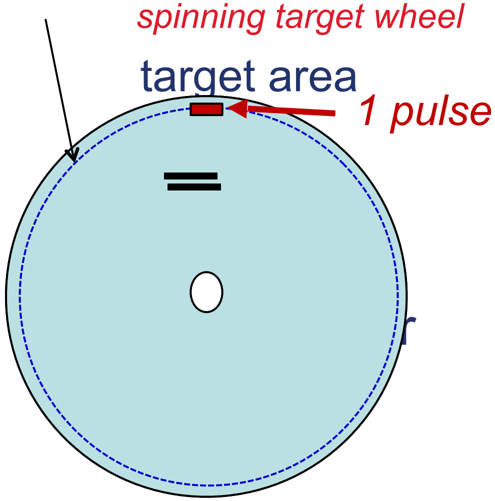
- The e+ are collected with an Optical Matching Device (OMD):
  - Maximum magnetic field (≥1T) about ~1cm from target exit to achieve high e+ yield



The positron target

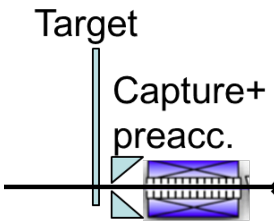
- Photon beam hits wheel at 1m diameter, spinning in vacuum with 2000rpm (100m/s tangential speed) → distribute the heat load
  - One pulse with1312 (2625) bunches occupies ~7 (~10)cm
  - Every ~7-8sec load at same target position
  - in 5000h roughly 2.5×10^6 load cycles at same target area
- ILC250, GigaZ: E(e-) = 125GeV
  - Photon energy is O(7.5 MeV);
  - target thickness of 7mm to optimize deposition and e+ yield
- Target cooling
  - 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).

S. Riemann, P.Sievers



Photon beam path on spinning target wheel

1 pulse



Cooling of the target wheel

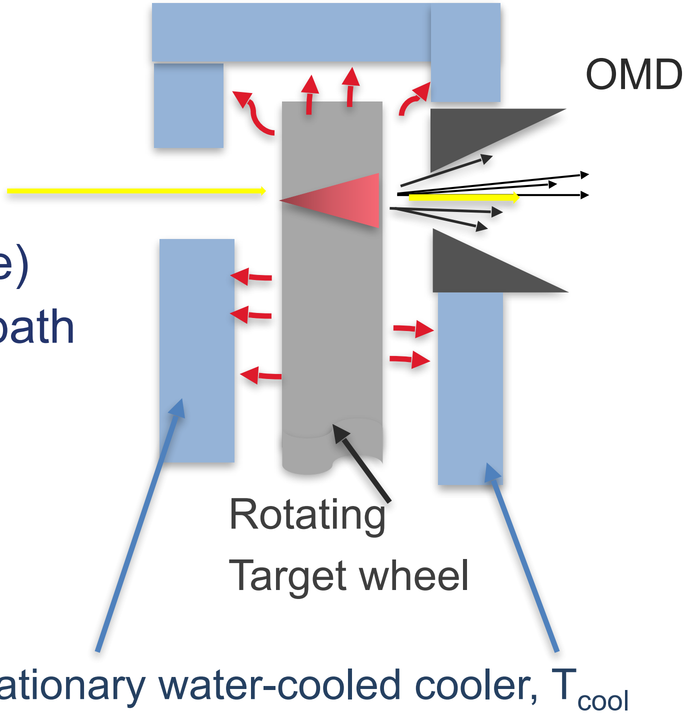
- Few kW heat deposition can be removed with thermal radiation:
  - heat radiates from spinning target to a stationary water-cooled cooler

$$\boxed{P \sim \sigma \varepsilon A \left(T^4_{\text{radiator}} - T^4_{\text{cool}}\right)}$$

ε = effective emissivity

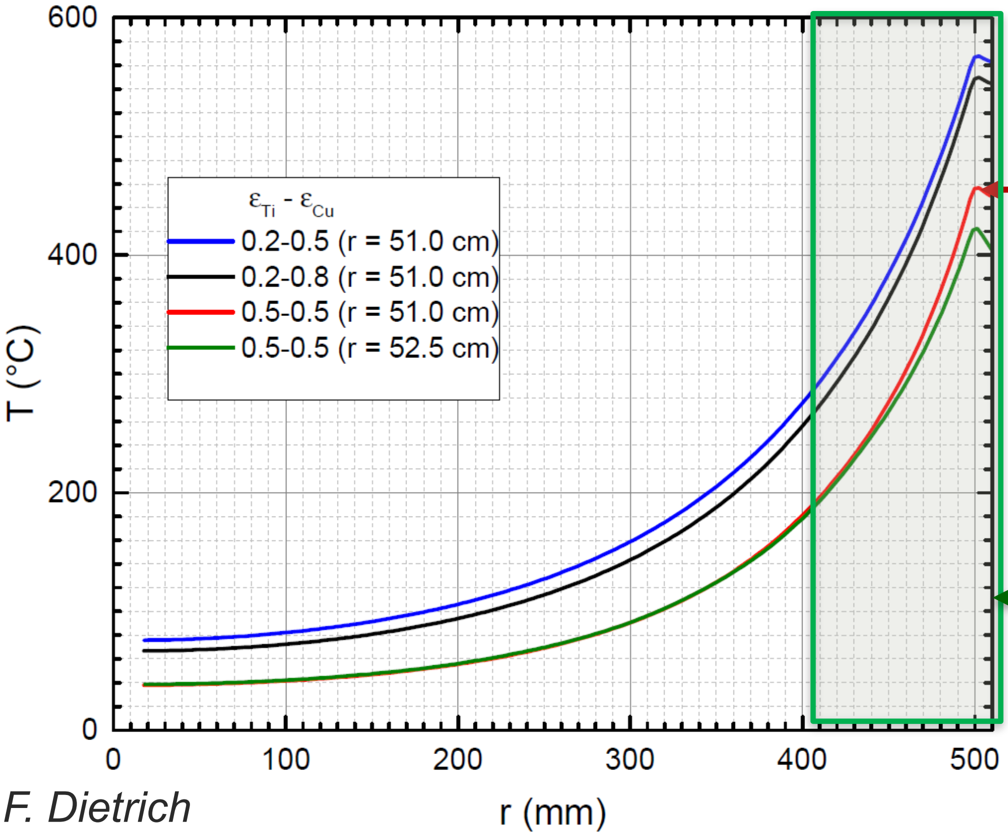
- Ti alloys have low thermal conductivity
  (λ = 0.06 – 0.15 K/cm/s)
  - heat propagation ~ 0.5cm in 7sec (load cycle)
  - heat accumulates in the rim near to beam path

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



F. Dietrich

Photon beam impact at r=50cm

Deposited power = 2kW

ε_{eff}= 0.33 for ε_{Ti} = ε_{Cu}=0.5

$T_{ave} \leq 460^{\circ}C$

max average temperatures can be decreased for larger wheel radius

Main cooling power from area

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

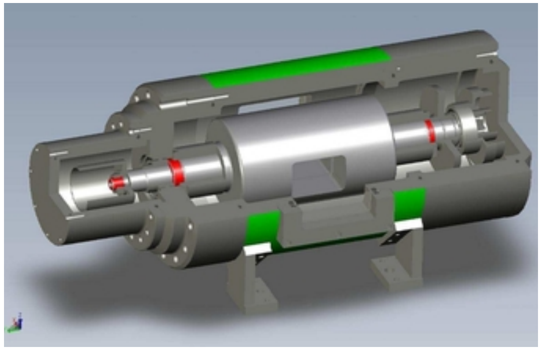
P.Sievers, G. Yakopov

Towards the rotating wheel

Drive and bearings

- Radiation cooling allows 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
  - 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

JÜLICH
FORSCHUNGSZENTRUM



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

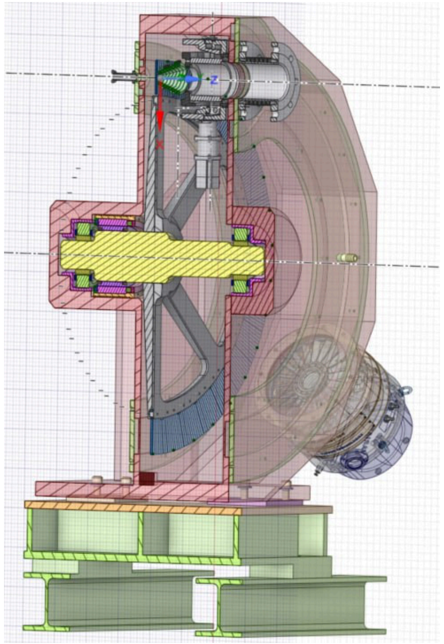
P.Sievers, G. Yakopov

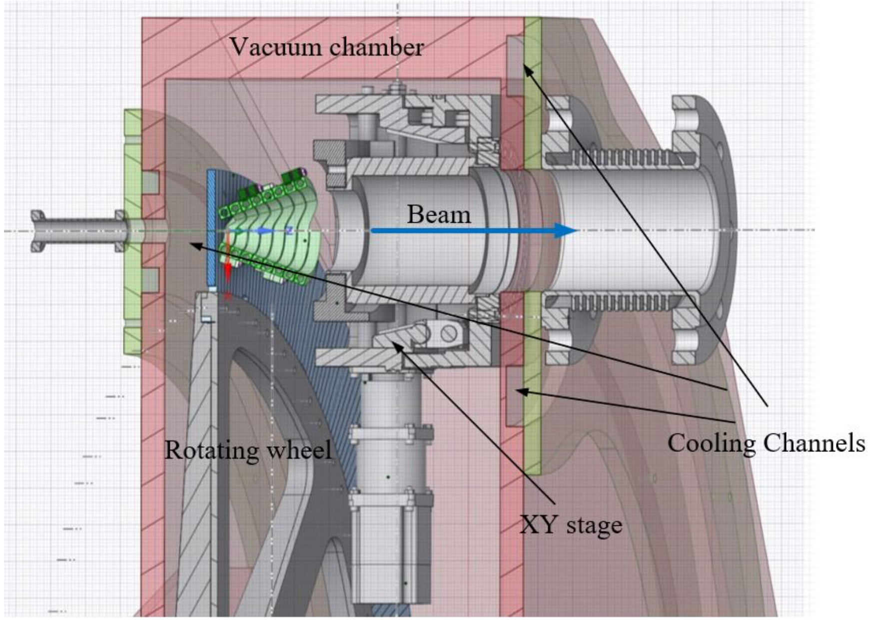
Towards the rotating wheel

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

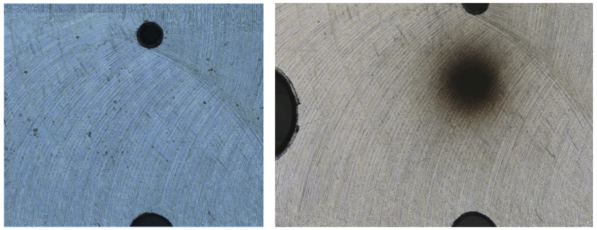
- **Mainz Microtron (MAMI): electron-beam on ILC target materials, generating cyclic load with same/ even higher PEDD at target than expected at ILC**
  - analyze target materials via scanning as well as synchrotron diffraction methods
  - advantage of synchrotron diffraction: both surface as well as 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

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

T. Lengler

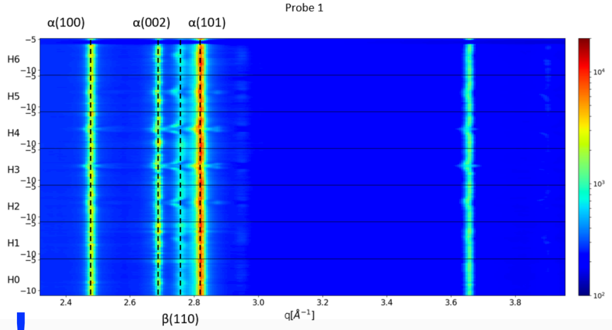
Target before and after radiation:



Before

After

α/β phase transitions in Ti-6Al-4V:



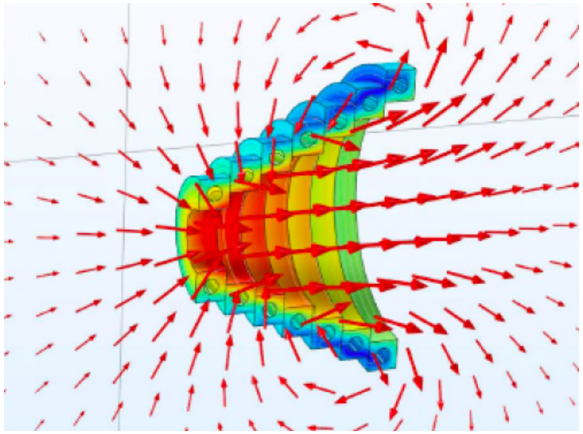
- **Result: ILC undulator target will stand the load !**

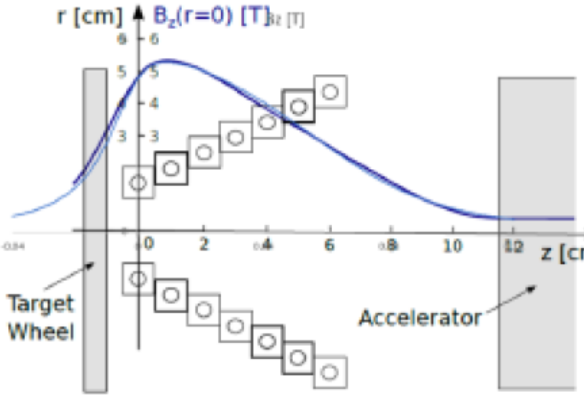
OMD Design: Pulsed Solenoid

‘Baseline’: Pulsed Solenoid

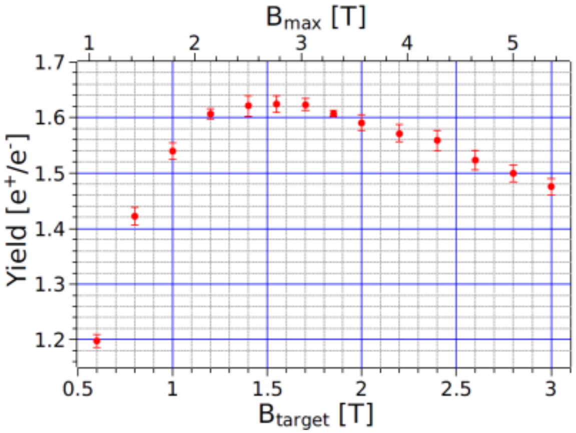
- Yield of e+ (OMD&capture Linac): 1.64-1.81 Fukuda-san, 2021
- Within ITN initiative: manufacturing drawings at DESY G. Yakopov 2023
- Planned: prototype tests

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





Yield versus field on the target



OMD Design: Pulsed Solenoid

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- 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 @ CERN

C. Tenholt 2021

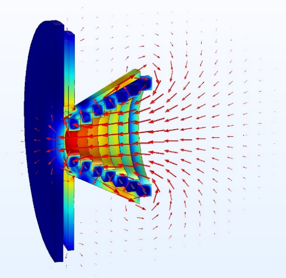
	Beamloss Power				Positron Yield	
	@dogleg	**@booster**	**@EC**	**@DR**	**@capture (|Z|<7mm)**	**@DR**
QWT	0.677 kW	0.014 kW	4.01 kW - 5.56 kW	13.15 kW - 14.3 kW	1.07	**~1.1**
Pulse solenoid w/o shield	0.927 kW	0.055 kW	5.86 kW - 7.93 kW	17.39 kW - 16.01 kW	1.81	**1.91**
Pulse solenoid with shield	0.871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

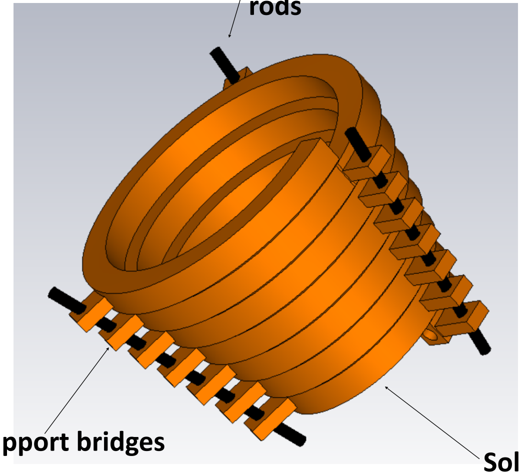
Solenoid construction@Uni&DESY&CERN

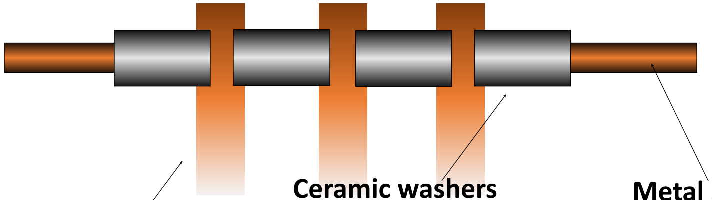
G. Yakopov, 2023

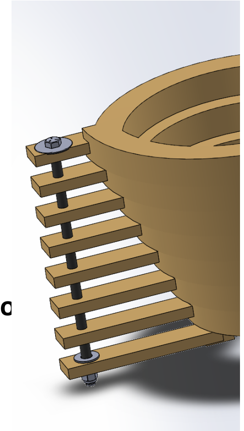
Possible mechanical design

- 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

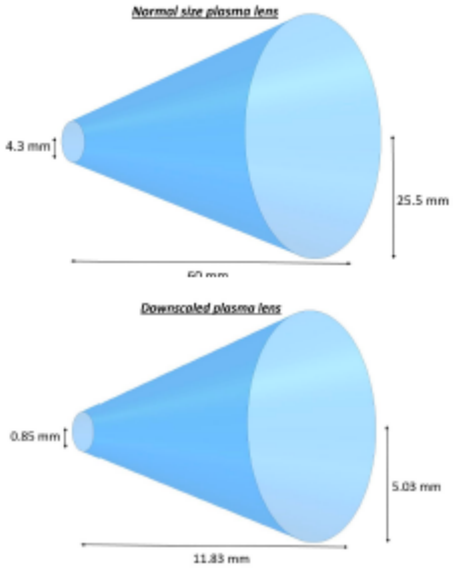
Plasma lens parameters

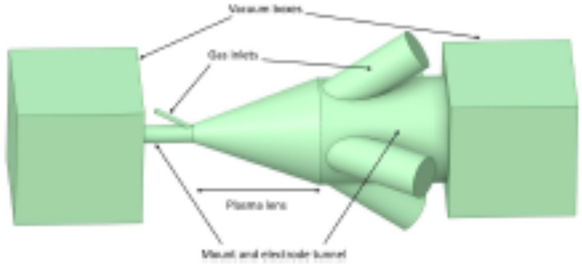
Normal size

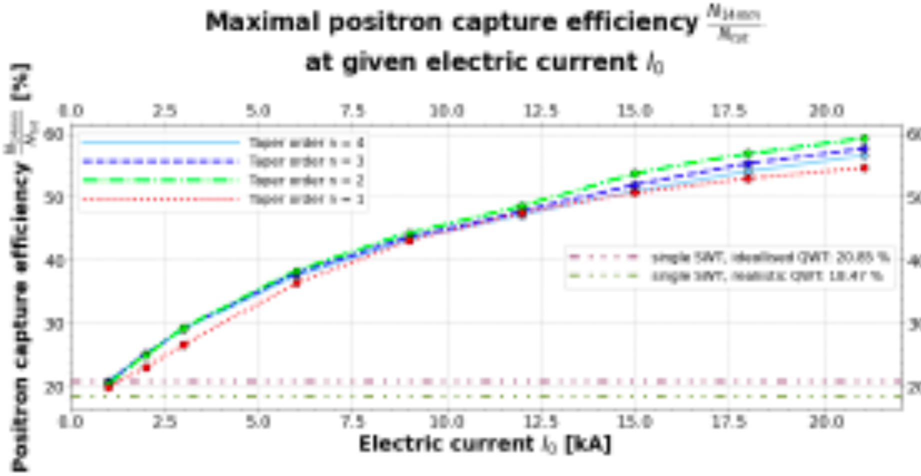
- Starting radius: 4.3 mm
- Exit radius: 25.5 mm
- Taper strength: $0.082\ \text{mm}^{-1}$
- Length: 60 mm
- Taper order: 2
- Total current: 9000 A
- Phase of SWT: 225 deg

Downscaled

- Starting radius: 0.85 mm
- Exit radius: 5.03 mm
- Taper strength: $0.416\ \text{mm}^{-1}$
- Length: 11.83 mm
- Total current: 350 A







see IPAC 24

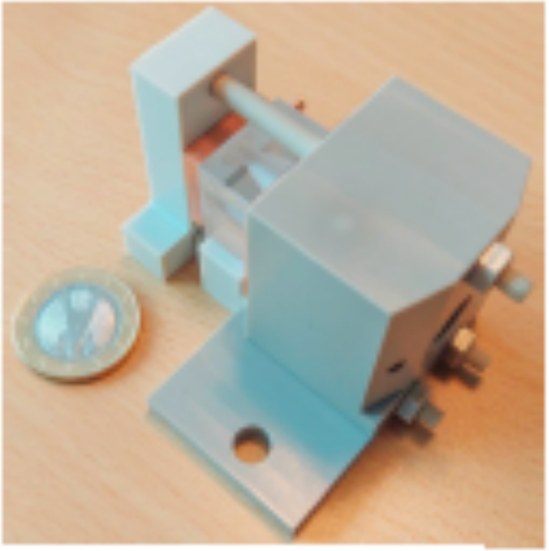
OMD Design: Plasma Lens

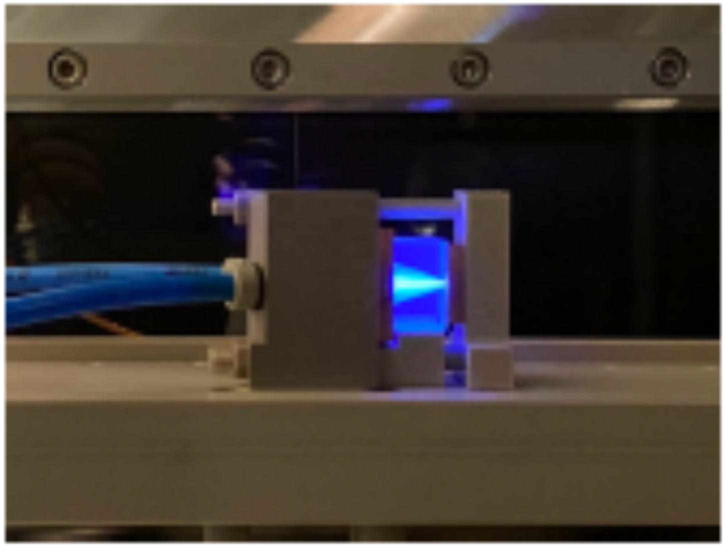
Formela, Hamann, Loisch

Prototype design

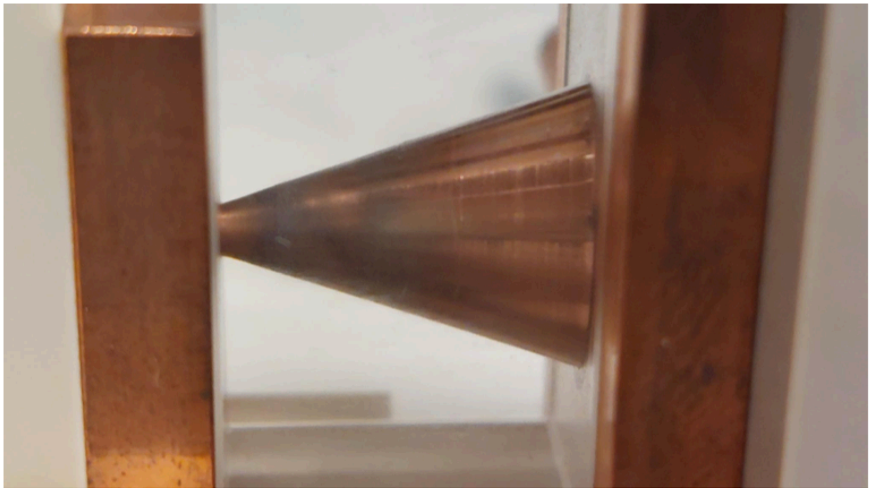
- Principle: lens is pressed in between mounts with threaded rods and sealed with O-rings
- Mounts made out of PEEK
- Electrodes made out of copper
- Plasma lens made out of sapphire block

Finished Prototype



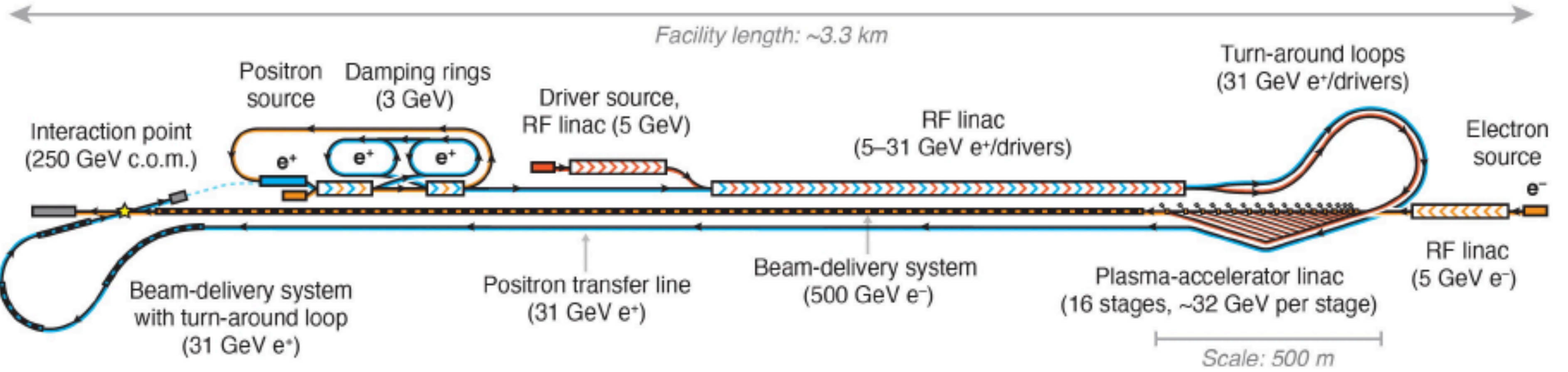


Produced plasma



HybridAsymmetricLinearHiggsFactory Design

B. Foster, R. D’Arcy, C.A. Lindstrom



$$\sqrt{s}=2\sqrt{(E_1*E_2)}$$

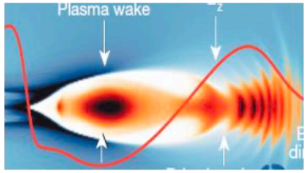
Positron Source:

- **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**

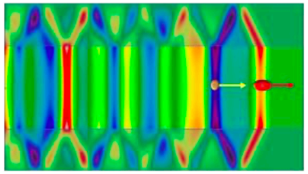
courtesy of J. Osterhoff

Advanced accelerators utilize wakefields to accelerate at >1 GeV/m

- Wakefields driven in **plasma** by **intense** laser beams: **LWFA/LPA**

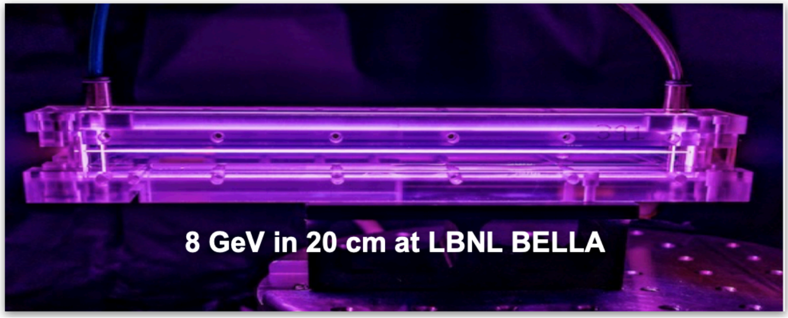


- Wakefields driven in **plasma** by **particle** beams: **PWFA**



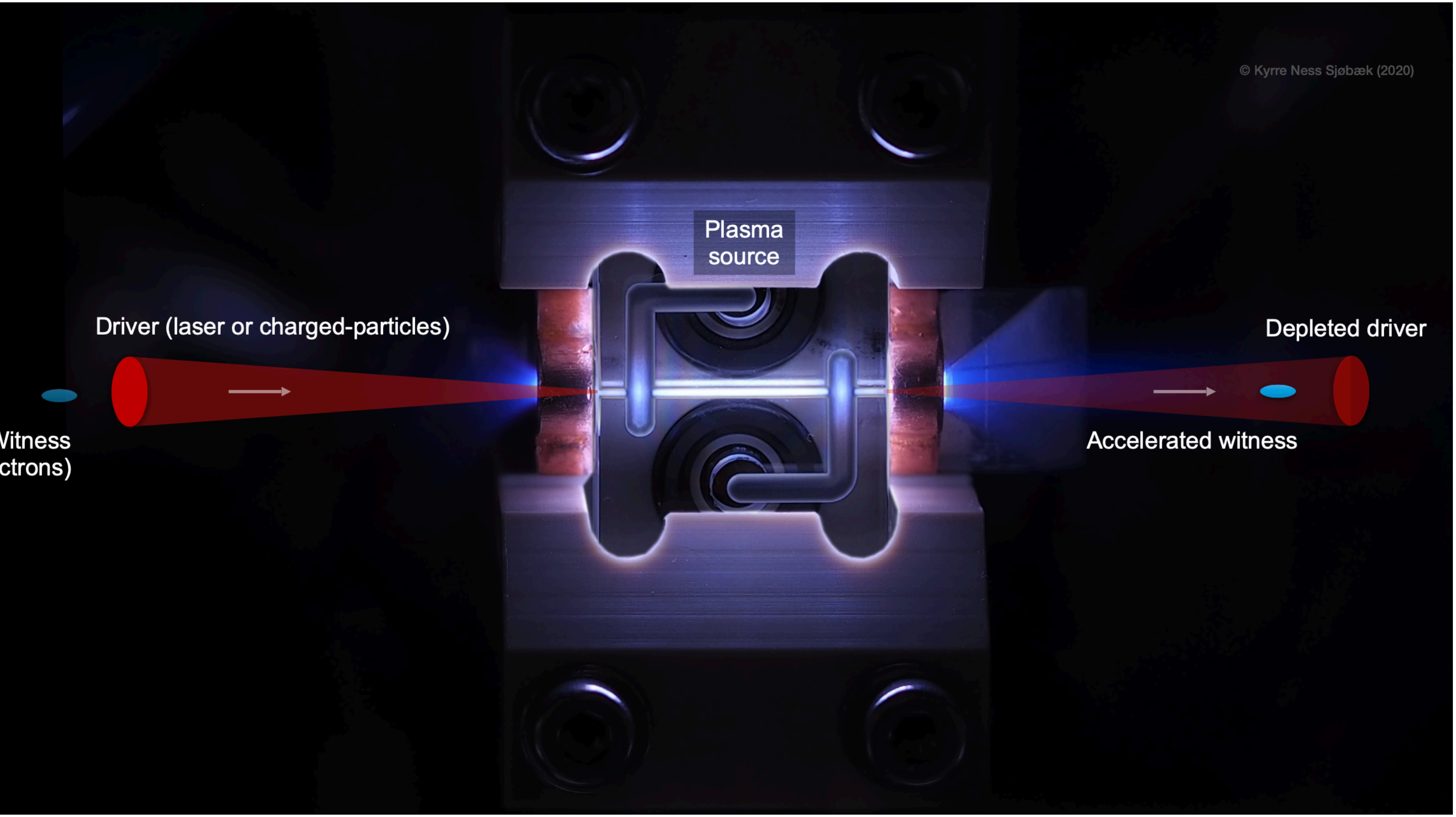
- Wakefields driven in **structures** (e.g. dielectric tubes) by **particle** beams: **SWFA**

8 GeV in ~500 m at SLAC LCLS-II HE

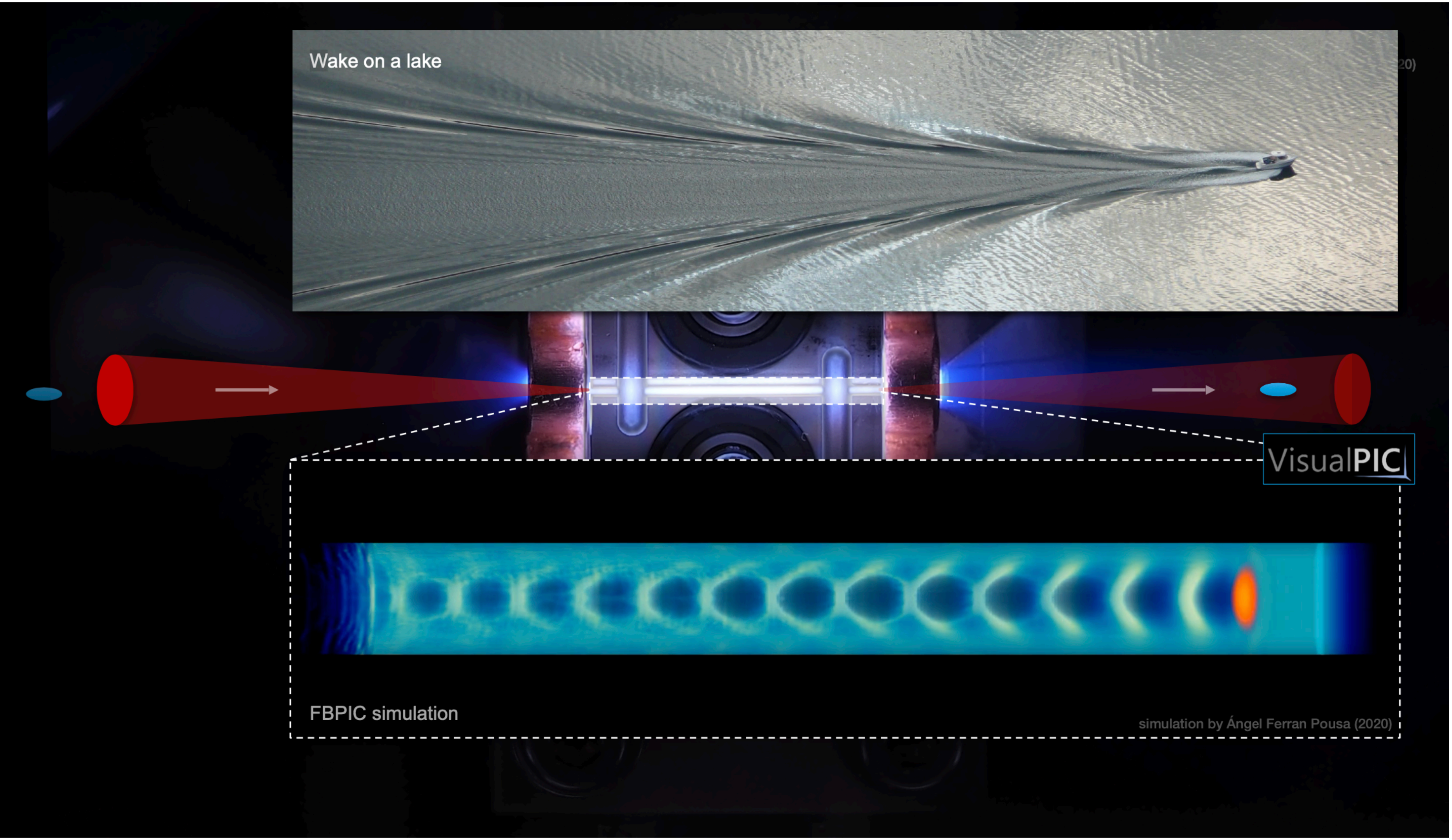


8 GeV in 20 cm at LBNL BELLA

courtesy of J. Osterhoff



courtesy of J. Osterhoff



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

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- **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	$5\text{x}10^{10}$	$5\text{x}10^{10}$	$6\text{x}10^{12}$
ILC/Tesla	5	1312	$2\text{x}10^{10}$	$2.6\text{x}10^{13}$	$1.3\text{x}10^{14}$
CEPC	100	1	$2\text{x}10^{10}$	$2\text{x}10^{10}$	$2\text{x}10^{12}$
CLIC	50	312	$4\ \text{x}10^{9}$	$1.2\text{x}10^{12}$	$6\text{x}10^{13}$
HALHF	10000	1	$2\text{-}3\text{x}10^{10}$	$2\text{-}3\text{x}10^{10}$	$2\text{-}3\text{x}10^{14}$

➡ **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

$$\frac{dW}{d\omega} = \frac{N_p\, q^2\, K^2\, r}{\in_0 C} \sum_{n=1}^{\infty} \left(J_n'(x_n)^2 + \left(\frac{a_n}{K} - \frac{n}{x_n} \right) J_n(x_n)^2 \right) u(a_n)^2$$

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

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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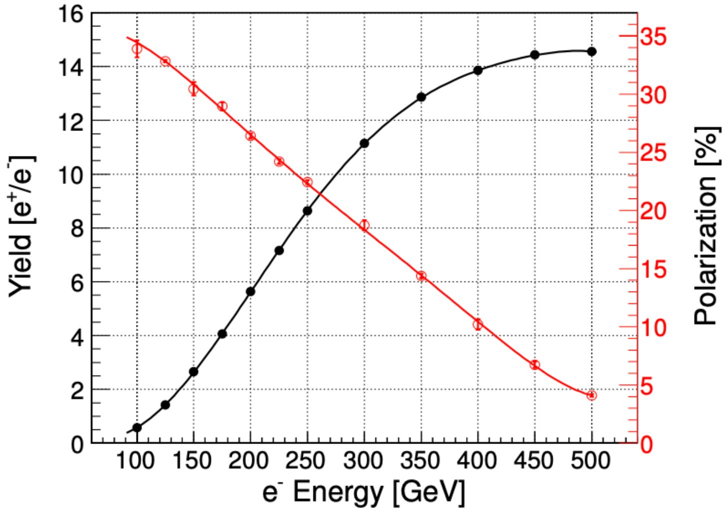
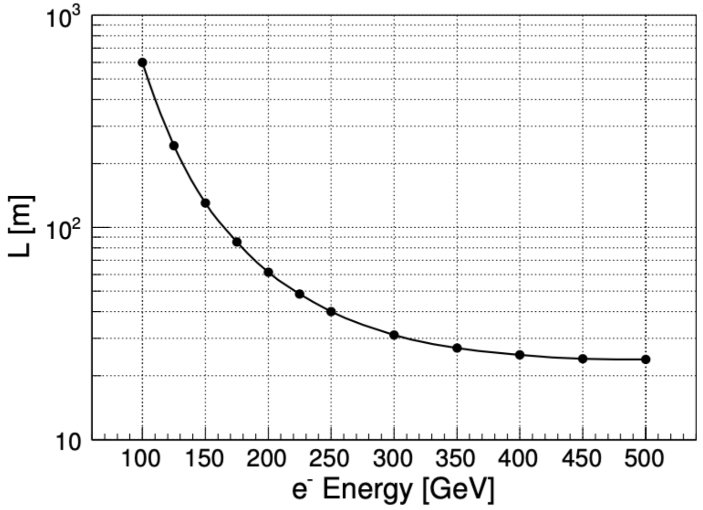
Three possibilities:

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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1301.1222

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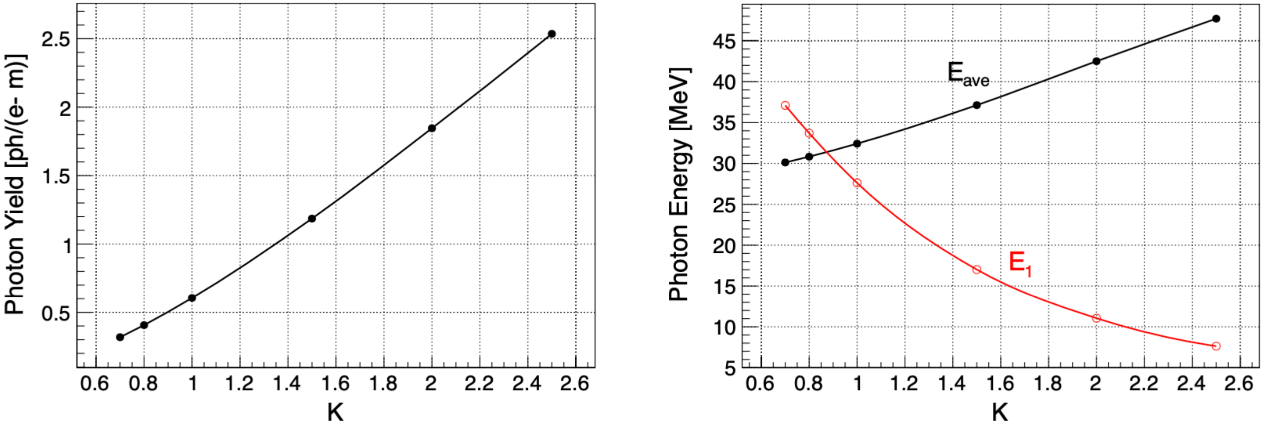
3. **Use new undulator parameters**
   - ➡ **e.g. higher K = 2.5, period λ=43 mm**
   - ➡ **leads to more higher harmonics, higher yield,**



- ➡ **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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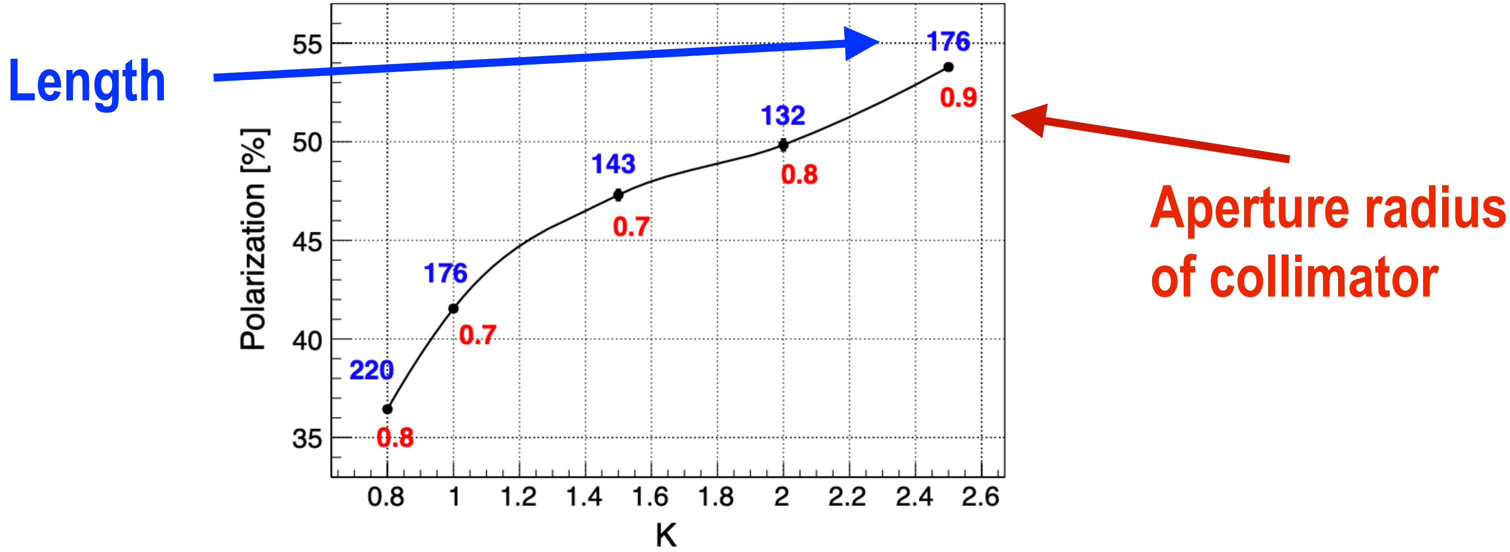

Length

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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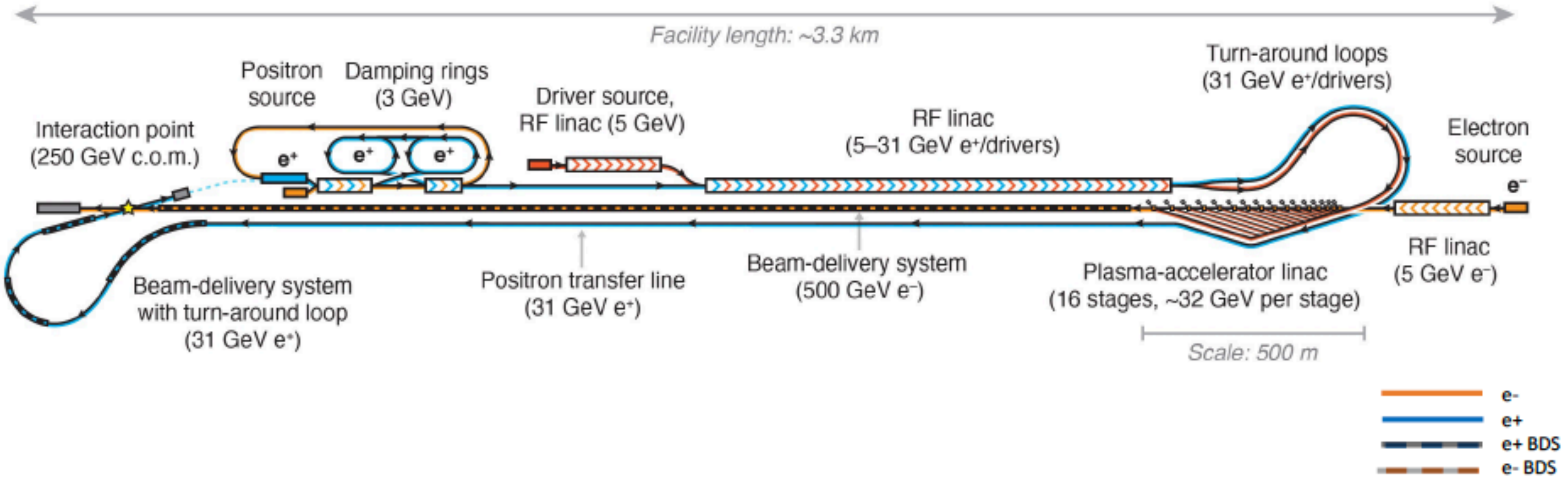
- **So far: FLUKA and ANSYS simulation done 'only'**
  - **➡ for ILC e- beam**
  - **➡ for rotating target wheel with 100 m/s ('ILC target')**
  - **➡ Results: Stress is ~25% tensile yield stress and 44% of fatigue stress of Ti-alloy target (but done without centrifugal forces of wheel and superposition 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 on LC R&D

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

- **Simulaneous 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**

➡***Proposal: ILC can be built NOW, future upgrade as HALHF…***

Be prepared for the ‘Unexpected’…

- the LC +LHC are mandatory………!

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

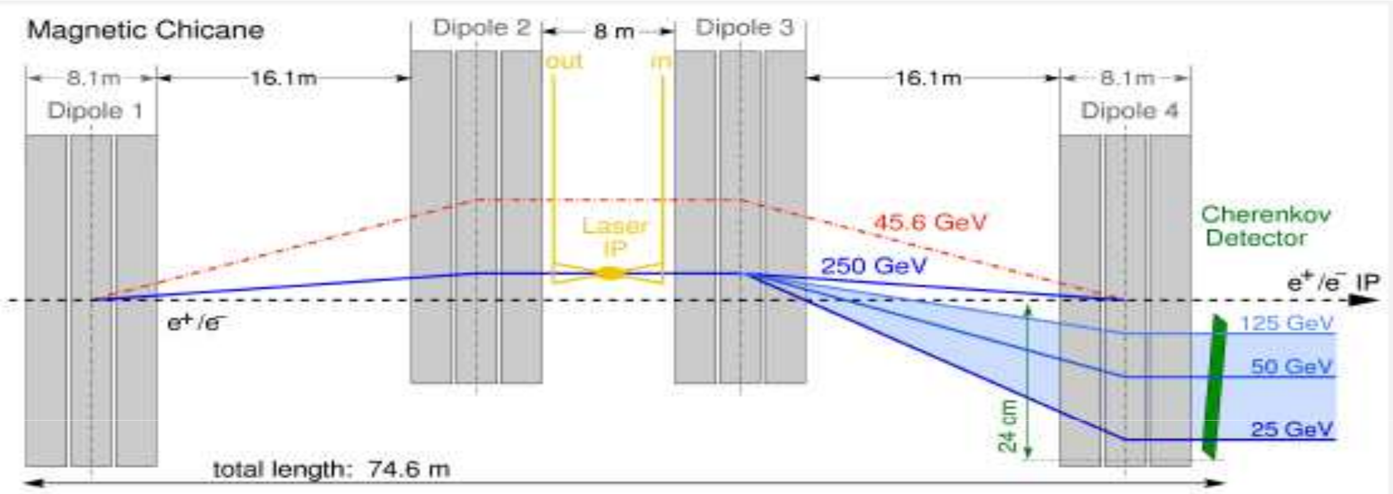
- **Important issue: measuring amount of polarization**
  - **limiting systematic uncertainty for high statistics measurements**
  - **Compton polarimeters (up- /downstream): envisaged uncertainties of ΔP/P=0.25%**
- **Advantage of adding positron polarization:**
  - **Substantial enhancement of eff. 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!**
- **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,….*

Compton polarimetry at ILC

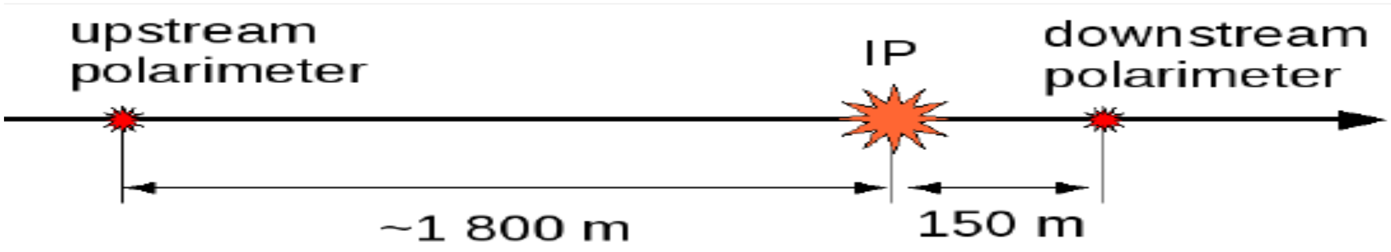
- Upstream polarimeter: use chicane system



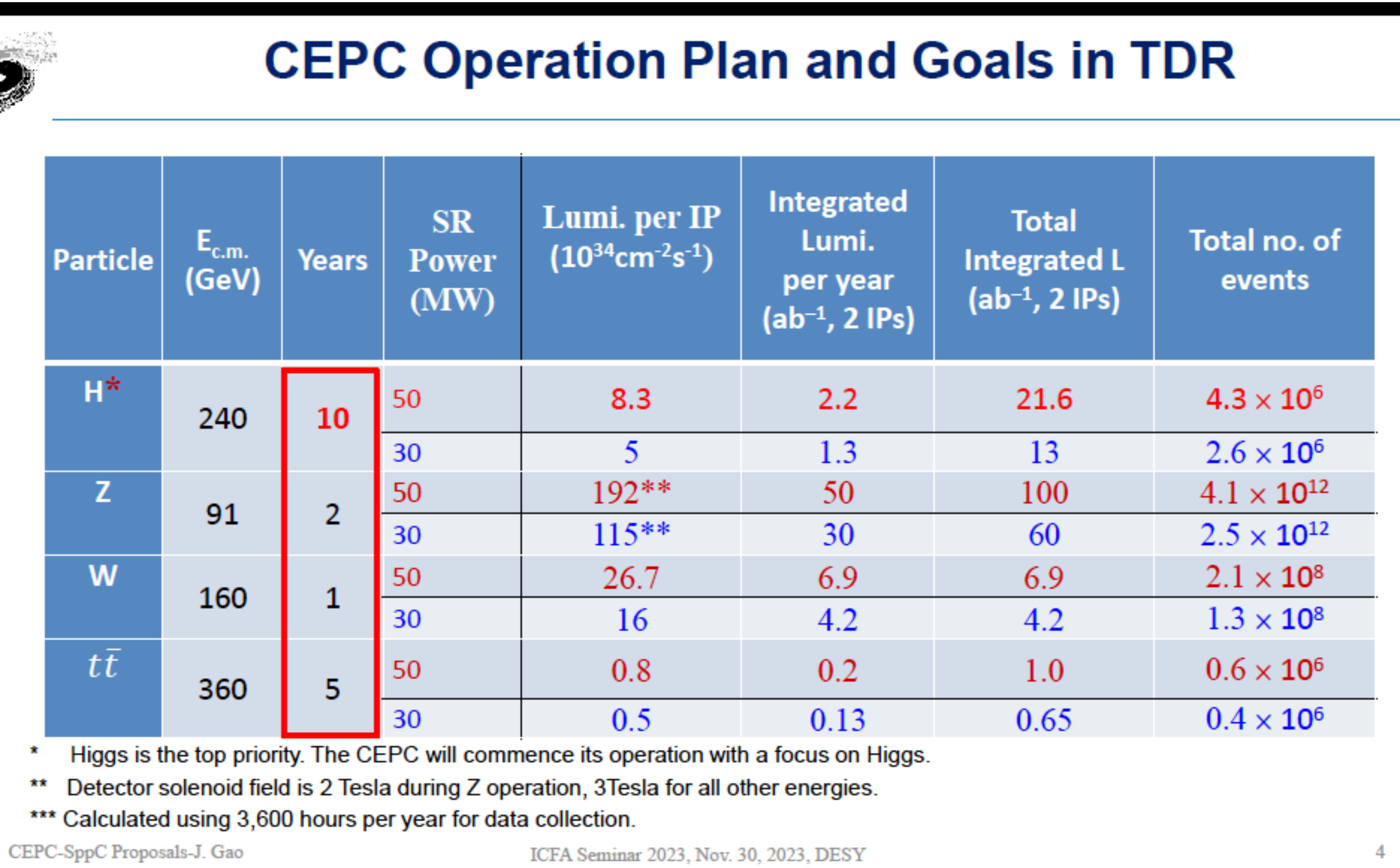
  - Can measure individual e± bunches
  - Prototype Cherenkov detector tested at ELSA!
- Downstream polarimeter: crossing angle required
  - Lumi-weighted polarization (via w/o collision)
  - Spin-tracking simulations required

Polarimetry requirements

- SLC experience: measured ΔP/P=0.5%
  - Compton scattered e- measured in magnetic spectrometer
- Goal at ILC: measure ΔP/P≤0.25%
  - Dedicated Compton polarimeters and Cherenkov detectors
  - Use upstream and downstream polarimeters
    - ➢ Machine feedback and access to luminosity-weighted polarization



  - Use also annihilation data: `average polarization’
    - ➢ Longterm absolute calibration scale, up to ΔP/P=0.1%



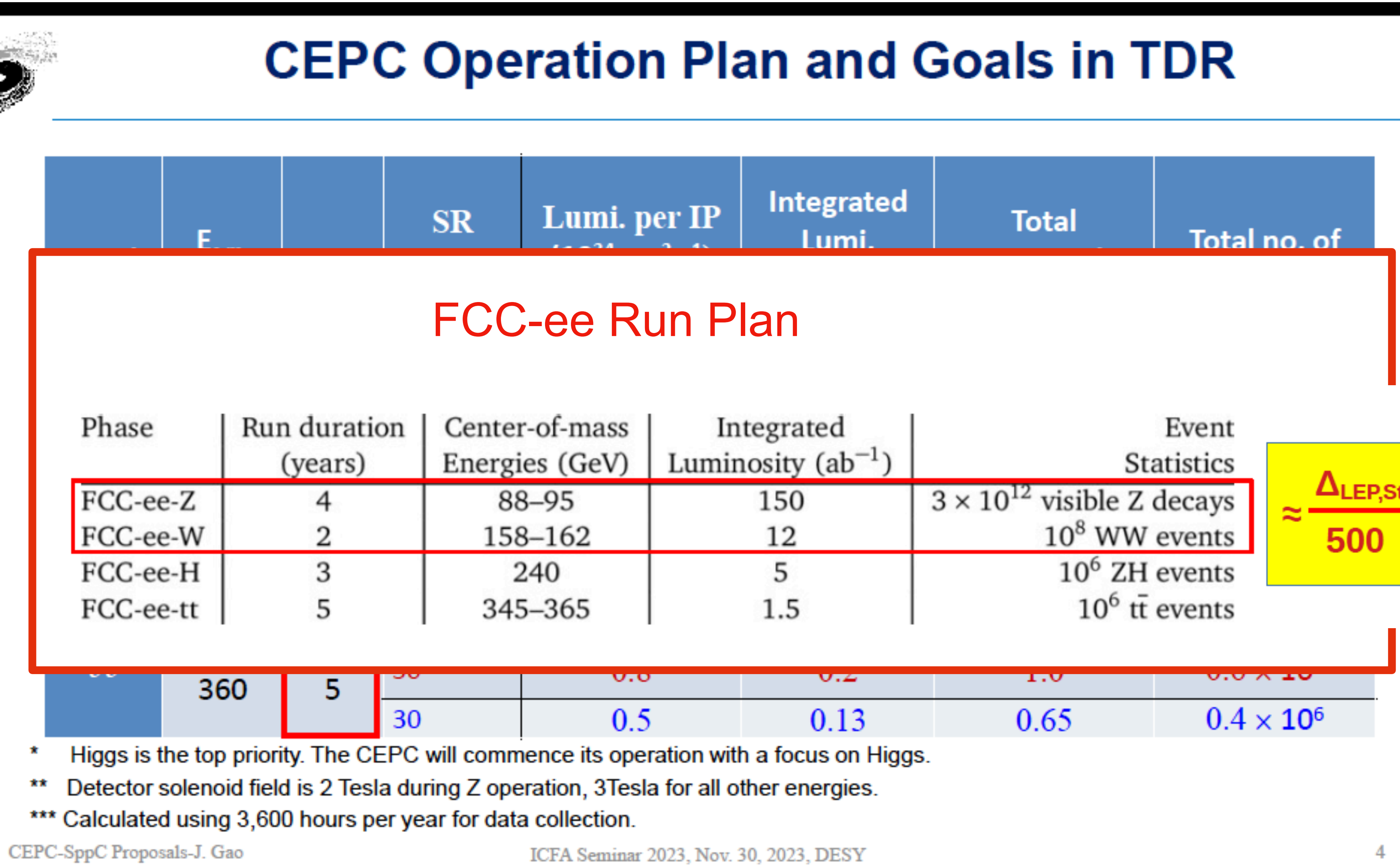
CEPC Operation Plan and Goals in TDR

Particle	$E_{c.m.}$ (GeV)	Years	SR Power (MW)	Lumi. per IP ($10^{34}cm^{-2}s^{-1}$)	Integrated Lumi. per year (ab^{-1}, 2 IPs)	Total Integrated L (ab^{-1}, 2 IPs)	Total no. of events
H*	240	10	50	8.3	2.2	21.6	4.3×10^6
			30	5	1.3	13	2.6×10^6
Z	91	2	50	192**	50	100	4.1×10^{12}
			30	115**	30	60	2.5×10^{12}
W	160	1	50	26.7	6.9	6.9	2.1×10^8
			30	16	4.2	4.2	1.3×10^8
$t\bar{t}$	360	5	50	0.8	0.2	1.0	0.6×10^6
			30	0.5	0.13	0.65	0.4×10^6

* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.

** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.



CEPC Operation Plan and Goals in TDR

	E…		SR	Lumi. per IP	Integrated Lumi.	Total	Total no. of
	360	5	30	0.5	0.13	0.65	0.4×10^6

FCC-ee Run Plan

Phase	Run duration (years)	Center-of-mass Energies (GeV)	Integrated Luminosity (ab^{-1})	Event Statistics
FCC-ee-Z	4	88–95	150	3×10^{12} visible Z decays
FCC-ee-W	2	158–162	12	10^8 WW events
FCC-ee-H	3	240	5	10^6 ZH events
FCC-ee-tt	5	345–365	1.5	10^6 $t\bar{t}$ events

$\approx \frac{\Delta_{LEP,S}}{500}$

* Higgs is the top priority. The CEPC will commence its operation with a focus on Higgs.

** Detector solenoid field is 2 Tesla during Z operation, 3Tesla for all other energies.

*** Calculated using 3,600 hours per year for data collection.

CEPC-SppC Proposals-J. Gao ICFA Seminar 2023, Nov. 30, 2023, DESY 4