LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

Undulator based e+ source

WG1 group meeting

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Outline

- Undulator based positron source, in particular for E_{cm} = 250 GeV
  - What is the problem at E_{cm} = 250 GeV
    - Modified source parameters ?

- Work to be done
  - Target wheel
  - Flux concentrator
  - Complete prototype

  - photon dump not an issue in this talk

- Overview of resources and requirements

Ecm = 250GeV, 1312 bunches, 5Hz (A. Ushakov)

Ee-	GeV	125
Active L_{und}	m	**231**
K		0.85
Space middle of undulator to target	m	570
Photon yield per electron	γ/e-	393
Average photon beam power	kW	**60.2**
Photon spot size (sigma) on target	mm	1.72
Photon energy (1^{st} harmonic)	MeV	7.5
Average power deposited in target	kW	**5.4**
PEDD in target per pulse	J/g	43.7
ΔT_{max} in target per pulse	K	84
Average power deposited in FC	kW	**3.0**
PEDD in FC (per pulse)	J/g	**33.3**
ΔT_{max} in FC per pulse	K	86
PEDD in capture accelerator:	2 orders of magnitude smaller than in FC	

Reoptimize undulator parameters ?

- higher E_1, E_{ave} of γ beam to increase pair production efficiency
  - $E_1 \sim \frac{1}{\lambda(1+K^2)}$ ⇔ lower K, lower λ_{und}
  - However: $N_\gamma \sim \lambda K^2$
  - Opening angle $\theta \sim \sqrt{1+K^2}$

- First attempts:
  - **K = 0.8, λ = 10.5mm ⇔ Y = 1.5 e+/e-, L_{und} = 202m**
  - **K = 0.8, λ = 10.0mm ⇔ Y = 1.5 e+/e-, L_{und} = 180m**
  - Estimated energy deposition with these parameters:
    - ED in target reduced by ~15…20%
    - PEDD in FC may be lower by ~ 15-20% → most likely still to high

→ Should be studied – including undulator performance for E_{e-} = 125 GeV (large undulator length)
  - Collimators to remove SR in the undulator
  - Magnetic field errors, …

Target cooling by thermal radiation (1)

- Basic idea:
  - Wheel of 1 m diameter with Ti alloy rim mounted on Cu radiator, spinning with ~100m/s
  - Heat radiation to stationary water-cooled cooler
  - Magnetic bearings and drives are placed inside the vacuum; no vacuum tight rotating seal is required

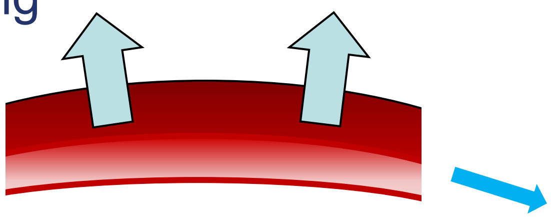
Target cooling by thermal radiation (2)

- Problems
  - Low thermal conductivity in Ti target ⇔ **high temperature in outer region of Ti rim;** possibilities to reduce this temperature are limited
  - Estimated temperatures (in ~3cm high Ti target), emissivity ε=0.6

E_{beam} = 125GeV E_{dep}(target)=5kW	Only Ti rim, No radiator	Ti rim + Radiator (1m^2)	Ti rim + Radiator (2m^2)
T_{ave} in rim [˚C]	700	500	450
T_{ave} in radiator [˚C]	-	330	250

  - Peak temperatures in rim ~80 C higher

- Ti target:
  - must be sliced to avoid radial stress due to heating
  - Creep effects due to centrifugal force?
    - Stress due to centrifugal force ~10MPa (but continuously and at high T)
    - To be checked/studied
  -



Target cooled by thermal radiation

- The 250GeV option is not easy for the current ILC source design
  - **The parameters for the system should be revisited**
    - Optimized undulator parameters?
    - Wheel design for best cooling option
    - Protection of flux concentrator
      - E.g., does a photon collimator upstream the target help?
    - Positron yield (and polarization)
  - **prototyping**

Target wheel – To do (1)

1. **Simulation studies** to establish best design for cooling taking into account the weight of the wheel
   - Resistivity of target material (see test in collaboration with Mainz)
   - Efficient and stable thermal connection of target material and radiator
   - **1 year engineer + physicist**

2. **Lab Test of the Heating and the Cooling**
   - Built and test a non rotating sector ('piece of cake') under vacuum:
     - Average heating of the Ti-sector by ohmic or induction heating should be sufficient
     - Cooling via static, water cooled coolers.
   - Adequate instrumentation to check efficiency of the cooling, potential deformation of heated sector,…
   - Construction drawings, manufacture, assembly and test runs:

     1 year, 1-2 engineers, technicians. (50-) 100 k$?

Target wheel – To do (2)

3. Rotating target wheel

- The study of the response of the wheel to the beam load, heating, stress and cooling are under way, (DESY Zeuthen/Uni Hamburg).
  - These studies have now to be converted into engineering solutions by experienced institutes or outside firms (like it has been done for the e-driven source).

    1-2 man over 1 year.

- Dynamic response of the wheel to beam pulses, transient and average heating and thermal expansions, and the magnetic pulses from the FC.
  - Simulations with validated mechanical and electro-magnetic FEM codes by qualified persons.
    2 man years.
    Subcontracted to qualified institutions? Cost: 50k$
  - Manufacturing drawings must be made to estimate the cost of the wheel and to prepare the manufacturing of the final wheel:
    0.5 man years. Cost 50k$

Target wheel – To do (3)

4. Magnetic Bearings

- Write a performance specification serving as an input for a feasibility study for the magnetic bearings.
  This input must contain the results of the studies so far:
  - Mechanical lay out of the wheel, materials, weight,
  - all beam and magnetically induced loads in the wheel.
  - Static and dynamic imbalances, vibrations.
- Vacuum requirements, outgassing, bake out must be considered.

- Find a qualified institute or industry, capable of making this feasibility study based on the above performance specification

0.5-1 man year for a paper study.
Cost: about 50 k$.

Target wheel – To do (4)

5. **Final Lab Tests and Validation of the Wheel**
   - Design and build a lab mock up, to validate the magnetic bearings and the drive motor.
     - In a first step only a “reduced” model, with a small wheel rotating in vacuum could serve to validate the main issues, like the weight.
     - As a second step a full sized wheel with a vacuum tank must be manufactured and tested in the lab.

   Manpower ~1MY + engineers + techn.

   Costs ~100k$?

   - Average heating corresponding to ILC requirements and water cooling must be included
   - Vacuum studies, bake out, thermal transients,.. to be studied.
   - Vibration studies, during the acceleration, deceleration, during stable rotation must be analysed (see also FC).
   - Emergency situations and scenarios and safety aspects to be considered.

OMD

- Problem:
  - Current design: high PEDD at front of the Flux Concentrator close to beam axis
    - Max power deposition = 1.49 kW/cm^3 (FC is stationary!)
  - QWT implies substantially higher load on target
    - Not clear whether/how it will work with radiation cooled target
- **Flux concentrator**
  - Studies (Jeff Gronberg et al.) have to be revisited and updated.
    - Yield optimization
    - Magnetic and mechanical lay out, magnetic forces, stresses, ohmic heating,
    - beam heating (aperture compatible with beam heating)
    - cooling
    - radiation damage

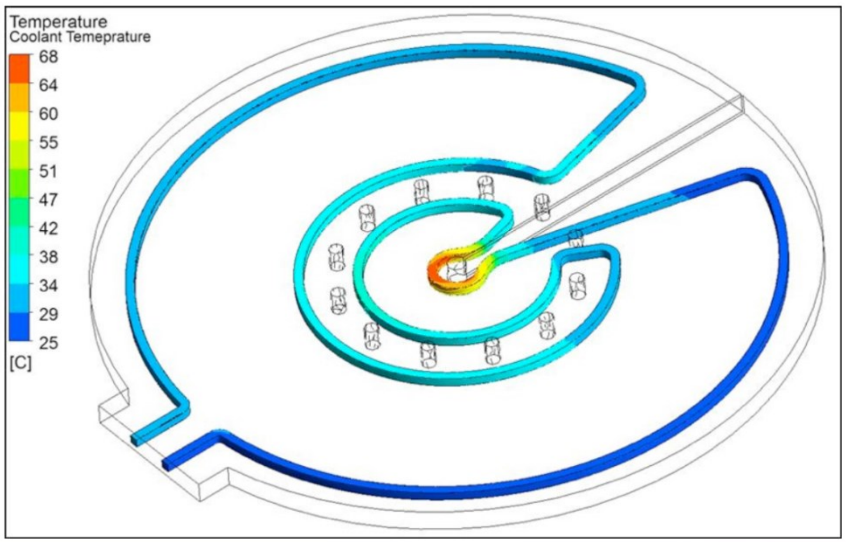
    At least 1 man year of a physicist/engineer of a research institute, familiar with mechanical and electro-magnetic FEM codes

    - To be included, in particular concerning the yield:
      - mutual magnetically induced loads between the FC and the wheel
      - field quality and stability during the pulse and in the "steady state"

  0.5 man years.

Deatailed FC design was presented by J. Gronberg et al., KILC, Daegu, 2012

Initial cut at room temperature cooling with internal water channels - 1500W



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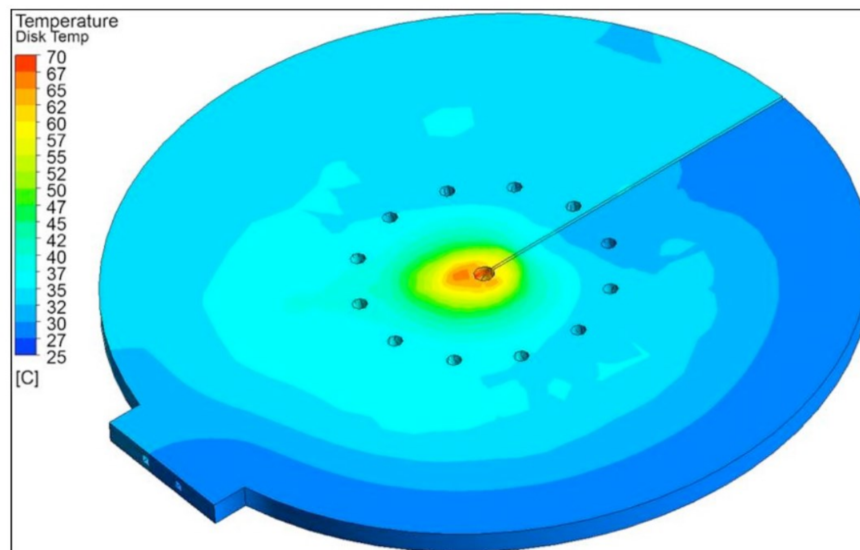
Option:UCRL#   Option:Additional Information   20

Cooling of the FC discs

Steady state disk temperature



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Option:UCRL#   Option:Additional Information

FC prototype, complete test and commissioning in the Lab

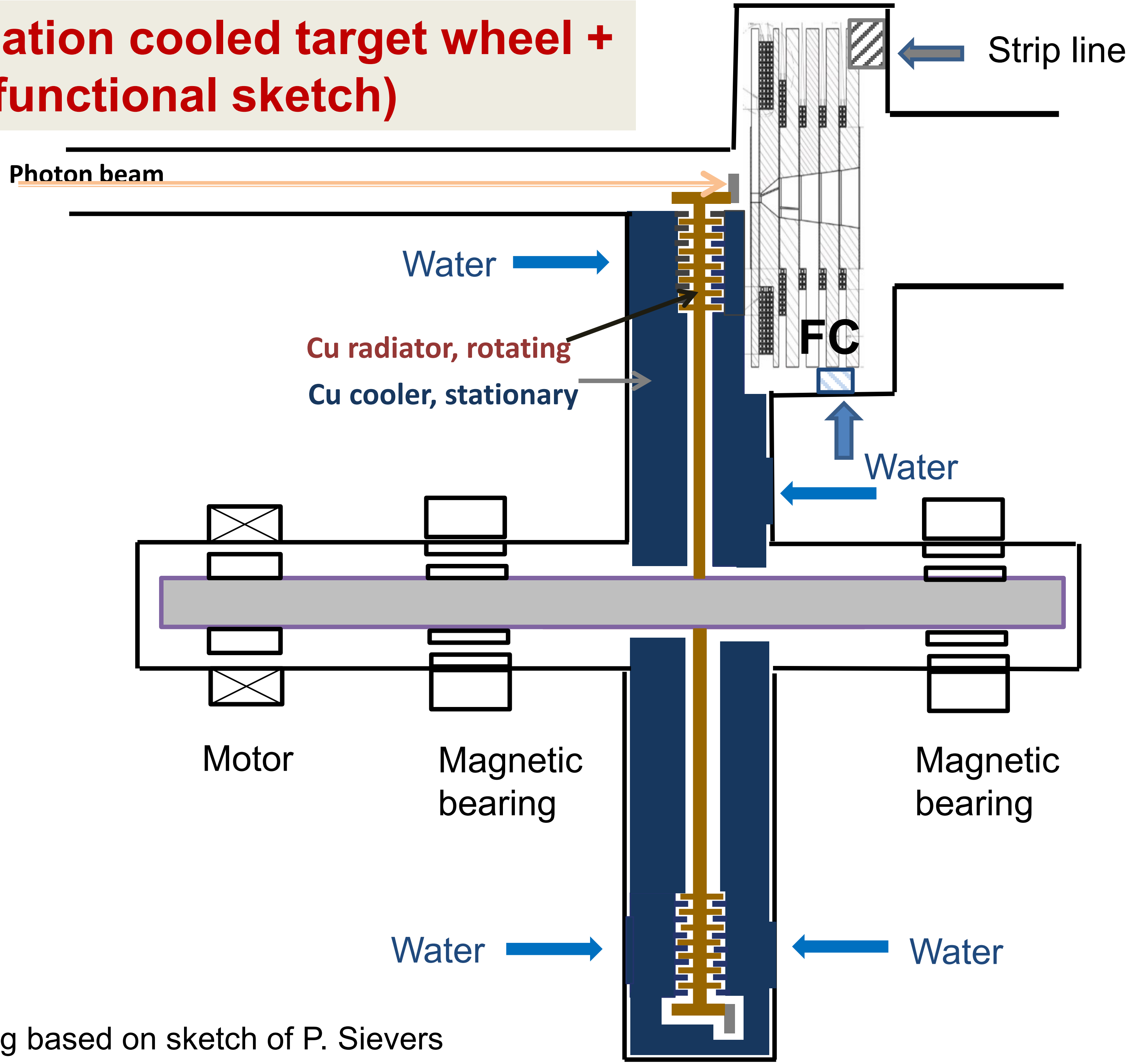
A complete prototype must be designed, manufactured and instrumented for tests in the lab.

About 2 man years plus testing time and test technicians.

Cost close to 1 mio $?

1. **Power supply** (design, construction, commissioning)
   costs ??? (Jeff's presentations).
2. **Measurement of the magnetic field quality and stability and repeatability over short and long term.**
3. **FC integration into vacuum tank with the rotating wheel.**
   - The wheel is heated by induction and the FC is pulsed. All cooling circuits are applied.
4. **The mock up is fully instrumented to analyse and validate the performance. Once the wheel has been irradiated in the ILC, no quick modifications or repairs will be possible.**
   - All possible operational scenarios, including transients, bake out and emergency situations and safety aspects must be validated.
   - Tests of performance and of life time with beam will virtually be impossible before final installation in the ILC.

Radiation cooled target wheel + FC (functional sketch)



Drawing based on sketch of P. Sievers

	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	1MY
	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 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 ???	

Current realistic resources (DESY, Hamburg U, ...)

- manpower
  - **Uni Hamburg:**
    - **Andriy Ushakov** (contract until spring 2018/; topic: Material load studies using an e- beam)
    - Gudrid Moortgat-Pick
  - **DESY (Zeuthen)**
    - **SR**
    - Felix Dietrich is writing his master thesis. Hopefully we can hire him after he finished (from June)
    - Further plan: PhD from Saudi Arabia (Khaled Alharbi). He will start later in spring this year.
  - **Peter Sievers**
- No money at DESY/UHH to build prototypes etc. ☹
- But we can contribute to studies (see ☆ at next page):
  - Depending on circumstances as term of contract also participation in prototype tests could be possible

- Without resources and collaboration with experienced institutions the final, validated design will not come

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QWT ?	reoptimize wheel for QWT ??????	Sim ???	

Draft plan for initial discussions about activities in JFY 2017 and 2018-19

- 2017: mainly simulations & specifications
  - Undulator parameters (0.5MY)
  - Realistic temperature and stress distribution (1Y – Eng + Phys)
  - Contact target material to radiator (1MY)
  - Start wheel design
    - Plan the Lab test of radiative cooling
    - Initialize collaboration with external institutions (dynamic response , vibrations, bearings, …)
  - Start revisiting FC
- 2018-19
  - Continue wheel design
    - Lab test of radiative cooling (in total 1Y, Eng+Tech, ≤100k$)
    - Feasibility study for rotating wheel
      - dynamic response, vibrations, …; prepare manufacturing (≤2.5MY, 100k$)
      - Magnetic bearings (performance specification, vacuum, …) (<1MY, 50k$)
      - Perform the feasibility study (<1MY, 50k$)
      - Lab test, validation of wheel (1 MY+ Eng.+ Techn, 100k$)
  - FC (in total 1-1.5 MY)
  - start prototyping of target wheel + FC (design, manufacturing and test) – most likely beyond 2019

backup

Andriy Ushakov @ POSIPOL 2016

Electron beam energy	GeV	125		150		175		250		
Capture field type		decel.	accel.	decel.	accel.	decel.	accel.	decel.	accel.
Undulator active magnet length	m	231	>231	147					
Undulator K		0.85	>0.92	0.8	0.92	0.66	0.73	0.45	0.47
Photon yield per 1m of undulator	ph/(e- m)	1.70	-	1.52	1.96	1.07	1.29	0.52	0.56
Photon yield	ph/e-	392.7	-	223.9	287.5	157.3	189.5	76.1	82.8
Photon energy (1st harmonic)	MeV	7.5	-	11.3	10.1	17.6	16.5	42.9	42.3
Average photon energy	MeV	7.3	-	10.4	10.7	13.7	13.9	26.8	26.9
Average photon beam power	kW	60.2	-	48.8	64.6	45.2	55.3	42.9	46.8
Electron energy loss in undulator	GeV	2.9	-	2.3	3.1	2.2	2.6	2.0	2.2
Energy deposition per photon	MeV	0.7	-	0.8	0.8	1.0	1.0	1.4	1.4
Relative energy deposition	%	9.0	-	8.0	7.8	7.3	7.2	5.3	5.2
Average power deposited in target	kW	5.4	-	3.9	5.1	3.3	4.0	2.3	2.4
Photon bunch energy	J	9.2	-	7.4	9.8	6.9	8.4	6.5	7.1
Energy deposition per bunch	J	0.83	-	0.60	0.77	0.50	0.61	0.35	0.37
Space from middle of undul. to target	m	570	-	500					
Photon spot size on target (sigma)	mm	1.72	-	1.21	1.40	0.89	0.95	0.50	0.51
PEDD in target per bunch	J/g	0.40	-	0.49	0.54	0.66	0.72	1.19	1.28
PEDD in target per pulse	J/g	43.7	-	41.0	50.3	42.4	49.7	45.8	48.4
Polarization of captured positrons	%	30.7	-	29.4	31.6	30.8	33.9	24.9	30.1