LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

ILC positron source: photon vs. electron driven e+ production

ILC project meeting @ DESY

Sabine Riemann (DESY)

3. March 2017

Outline

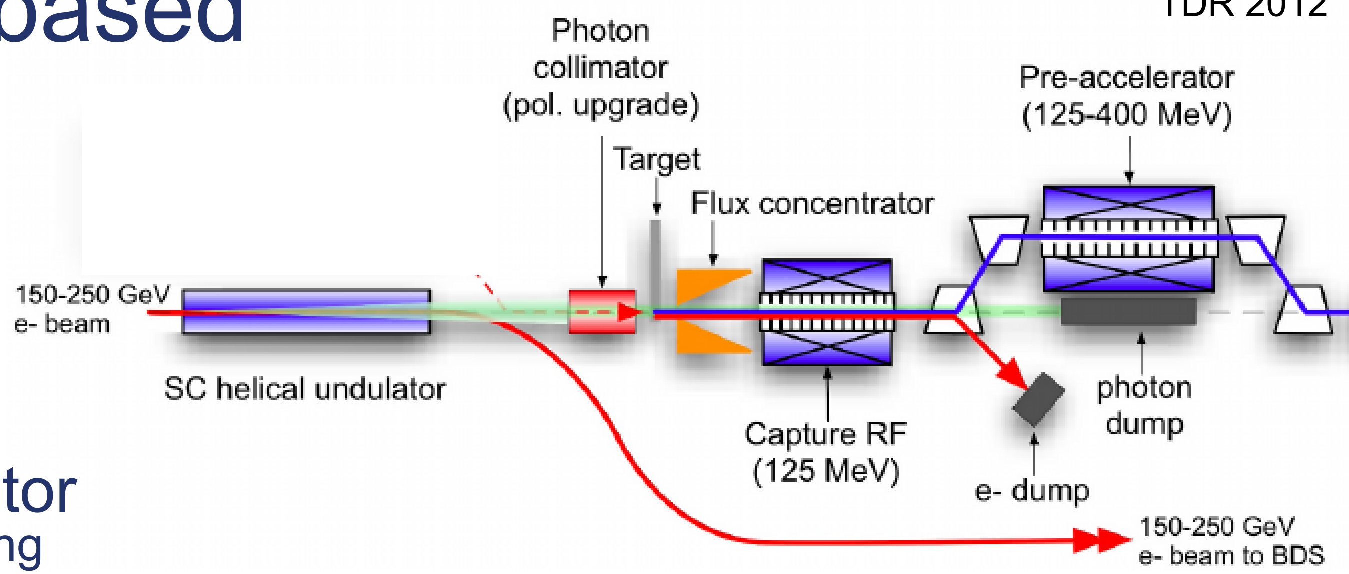
- Status undulator based source
- Status e- driven source
- Work to be done

Remark:

- Jan 2017: new e+ group (WG1) formed under Shin Michizino
- Goal:
  - Evaluate source options (e- and γ driven)
  - Evaluate technical difficulties, cost, commissioning
  - June 2017: plan of R&D for FY 2017-2019
- Members:
  - Japan: T. takahashi, T.Omori, M. Kuriki, T. Okugi, A. Yamamoto, K Yokoya (chair)
  - Germany: A. Ushakov, G. Moortgat-Pick, B. List, SR CERN: P. Sievers
  - US: W. Gai

Undulator based e+ source

TDR 2012



- Helical undulator
  - Superconducting
  - K=0.45…0.92, λ=1.15cm
  - aperture 5.85mm
  - Max 231m active length
- e+ Production Target
  - 400m downstream the undulator
  - 0.4 X0 Ti alloy (Ti6Al4V)
  - Spinning with 2000rpm (100m/s) in vacuum
- Positron Capture:
  - Pulsed flux concentrator + capture RF
- Acceleration, EC, spin rotation → DR

Expected target load on ILC target (undulator)

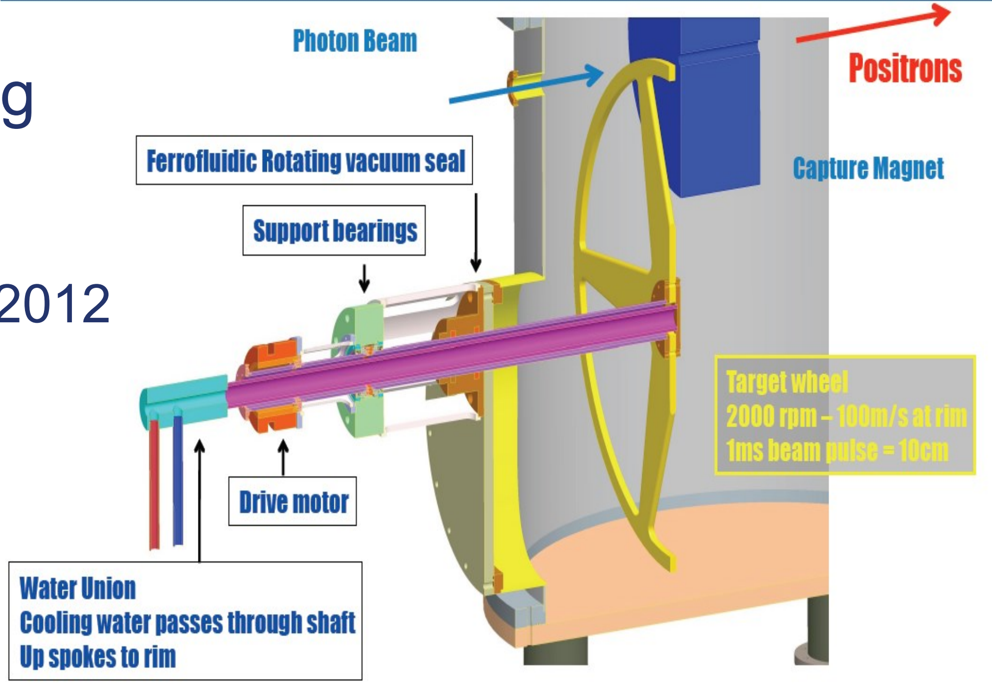
E_{beam} [GeV]	E_{dep} [kW]	ΔT_{max}/pulse [K]	dpa	E_{dep} [kW]	ΔT_{max}/pulse [K]
	Nominal luminosity			High luminosity	
125 Ushakov, LCWS16	**5.4**	82	0.035	-	-
175 Ushakov, LWS16 ILC EDMS	**3.9**	80	0.06	-	-
250 (ILC EDMS)	2.0	130		4.1	195
250 Ushakov, LCWS16	**2.3**	86	0.05	4.6	128

Average energy deposition

- <6kW (nominal L, all energies)
- <5kW (lumi upgrade, 500GeV)
- <8kW (pol upgrade)

Positron Target

- Wheel of 1m diameter spinning with 2000rpm (100m/s) in vacuum
- Challenges: bearing, cooling



- Target prototyping at LLNL
  (Gronberg et al.; work stopped ~2012 due to lack of funding)
  - demonstrated that water cooling is very difficult

- **Alternatives:**
  - **Cooling by thermal radiation**
  - **'Friction cooling' using sliding pads**

Target cooling by thermal radiation

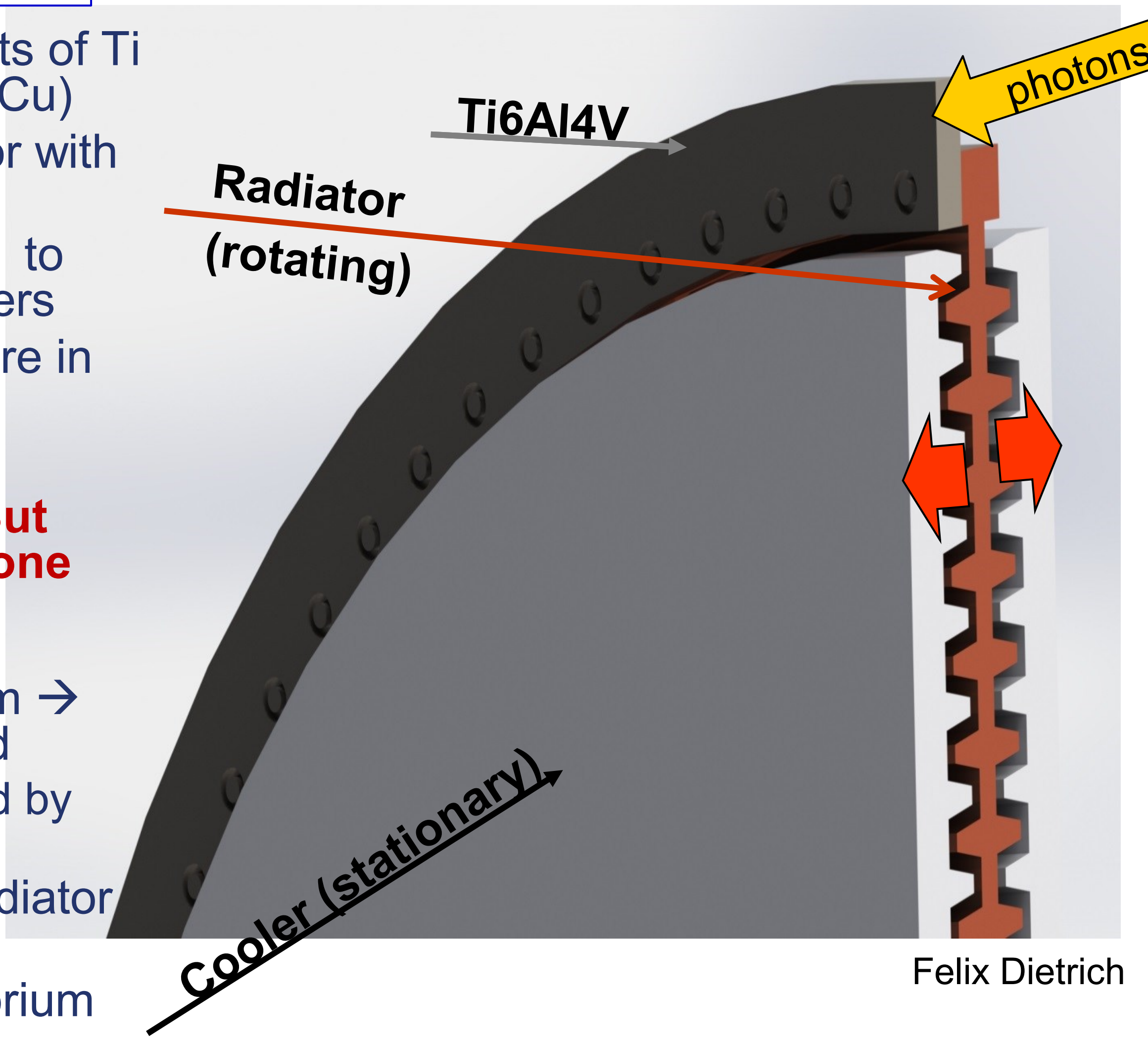
DESY/U Hamburg/P. Sievers

- Rotating target wheel consists of Ti rim (e+ target) and radiator (Cu)
- Heat path from rim to radiator with large surface
- Thermal radiation of radiator to stationary water cooled coolers
- Target, radiator and cooler are in vacuum

Radiation cooling will work. But engineering work has to be done

Issues:

- low heat conductivity in Ti rim → overheating must be avoided
  - Max temperature tolerated by target material?
- large weight of the target+radiator wheel (>100kg)
- Long 'heating' time to equilibrium temperature (hours)



Felix Dietrich

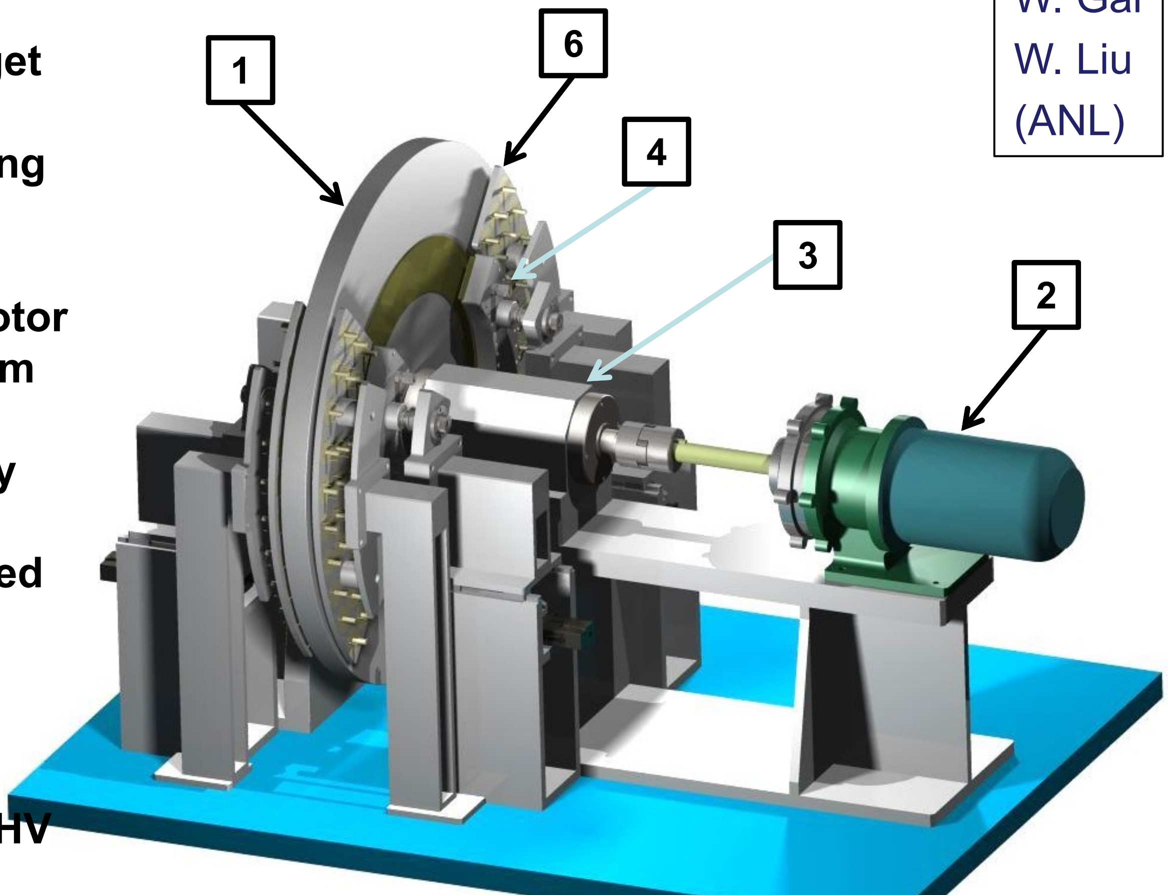
Felix Dietrich

Active Sliding Contact Cooling

Demo Conceptual Illustration

W. Gai
W. Liu
(ANL)

1. Rotating 1meter diameter Target Wheel at 2000 rpm (100 m/s) while extracting ~10kW by using active sliding contact cooling.
2. Target wheel is driven by a magnetically coupled drive motor which separates the motor from the vacuum.
3. Stability of wheel controlled by heavy duty machine spindle.
4. Temperature of wheel controlled by 4 Active Sliding Contact Cooling Pads.
5. Cooling Pad's temperature controlled by water/coolant.
6. Heat applied to wheel using UHV radiant filament heaters.
7. Diagnostic feedback: RPM, Temp and Pressure of Cooling Pads, Temp of Target Wheel, Vibration, etc.



Full Size Target Wheel Ready for Operations in Vacuum

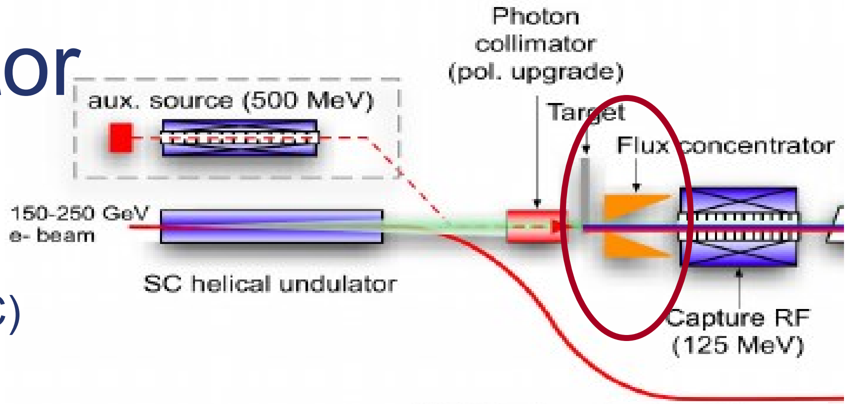
Target cooling with sliding pads

- Tests in air clearly demonstrated that sliding contact cooling concept works

https://phys.org/news/2016-12-cooling-technique-major-component-collider.html#jCp

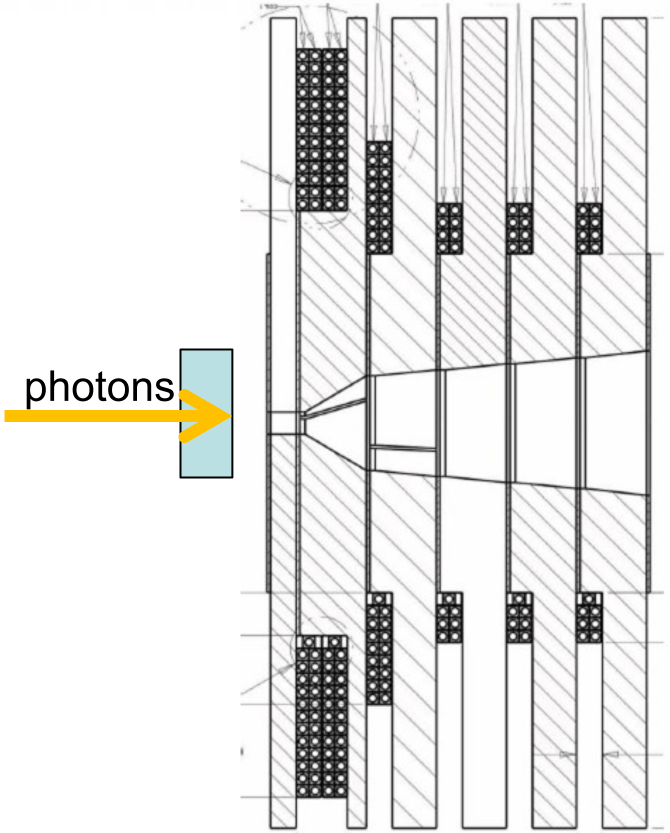
- A fully functional prototype running at full speed over long periods of time in vacuum:
  - Significant funding is required - currently not available

Pulsed Flux Concentrator



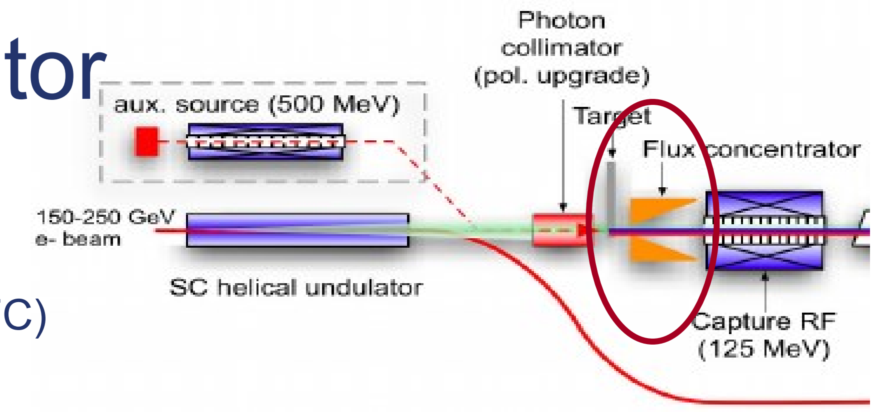
- **capture efficiency ~25%**
- low field on target → low eddy currents (~5mm distance target exit to FC)
- high peak field (3.2T), 1ms flat top
- Within 12cm, the magnetic field goes adiabatically down to 0.5T at capture RF

- Prototyping and testing at LLNL
  - FC seems workable but still need to demonstrate full average power operation
  - Run with 5Hz over extended period and full average power with cooling



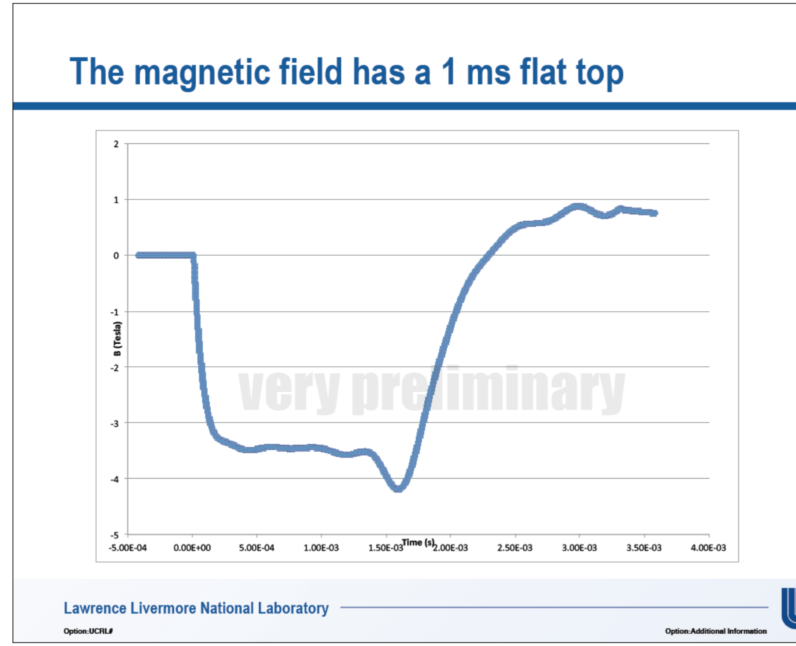
J. Gronberg, LLNL

Pulsed Flux Concentrator



- **capture efficiency ~25%**
- low field on target → low eddy currents (~5mm distance target exit to FC)
- high peak field (3.2T), 1ms flat top
- Within 12cm, the magnetic field goes adiabatically down to 0.5T at capture RF

- Prototyping and testing at LLNL
  - FC seems workable but still need to demonstrate full average power operation
  - Run with 5Hz over extended period and full average power with cooling

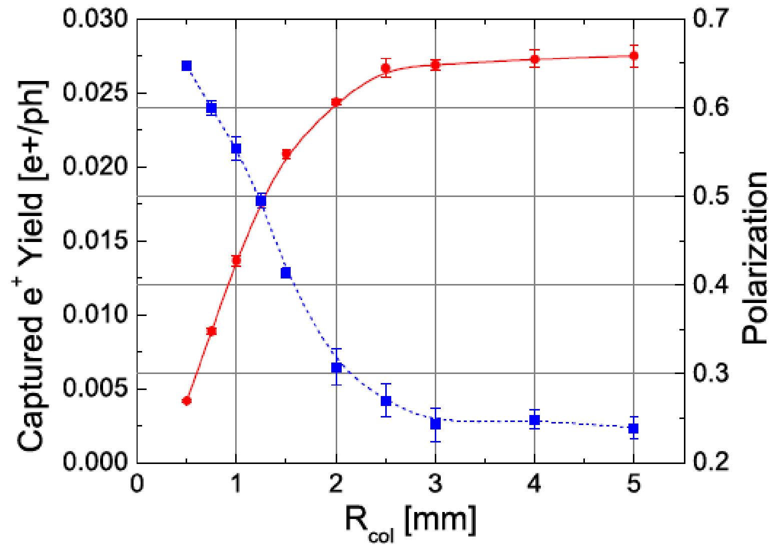


J. Gronberg, LLNL

Polarization upgrade

- Currently not high priority; basic e+ polarization ~30%
- Collimation of photon beam yields higher polarization;‘loss’ of photons compensated by longer undulator
- First collimator design exists; ideal undulator spectrum assumed

Yield and Polarization vs Aperture Radius of Photon Collimator

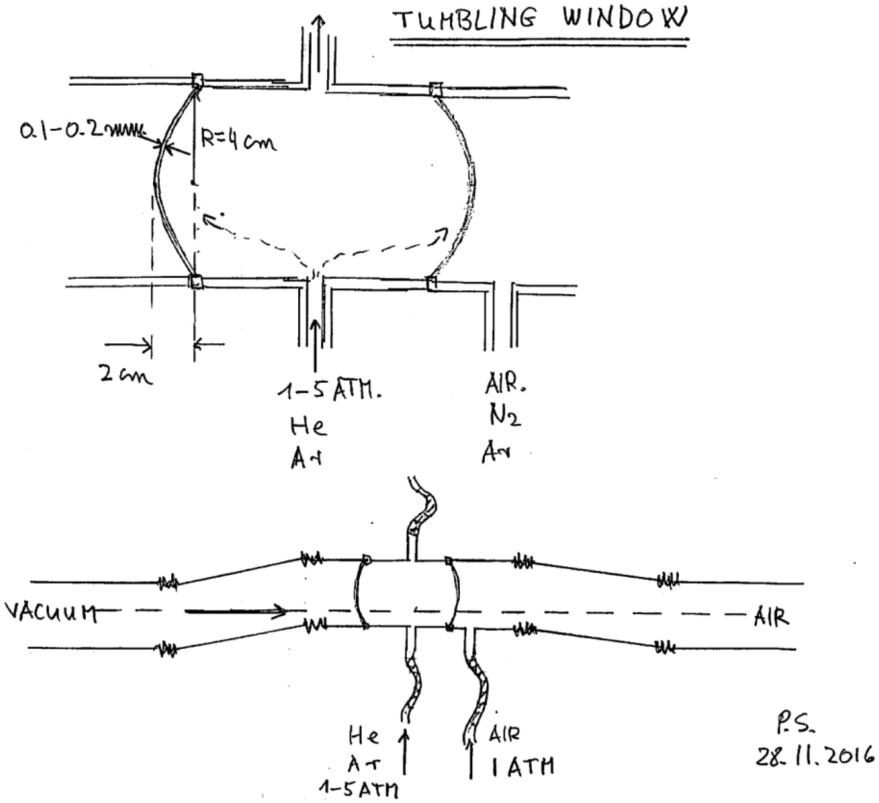


Parameter	Unit	Nominal L, K=0.92, λ =11.5mm			
Ecm	GeV		350	500	
Drive electron beam energy	GeV	150	175	250	
e+ polarization	**%**	**55**	**59**	**50**	**59**
Collimator iris radius	mm	2.0	1.4	1.0	0.7
Active undulator length	m	231	196	70	144
Photon beam power	kW	98	114	83	173
Power absorbed in collimator	%	49	60	52	70

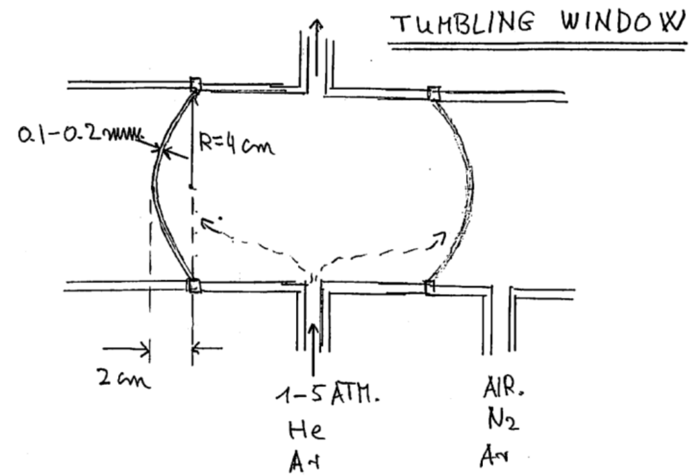
Technical integration of the undulator source

- Important: Photon beam dump
  - Most of the initial power has to be absorbed (<200kW)
  - Focused γ beam with 1-2×10^16 γ/sec (few tens MeV) creates high energy deposition density even in thin windows
    → exit windows to dump must be moved to avoid damage (each bunch train hits another position)
  - graphite dump core gets too hot
  - Design options under consideration
    - Water dump
    - Ar dump

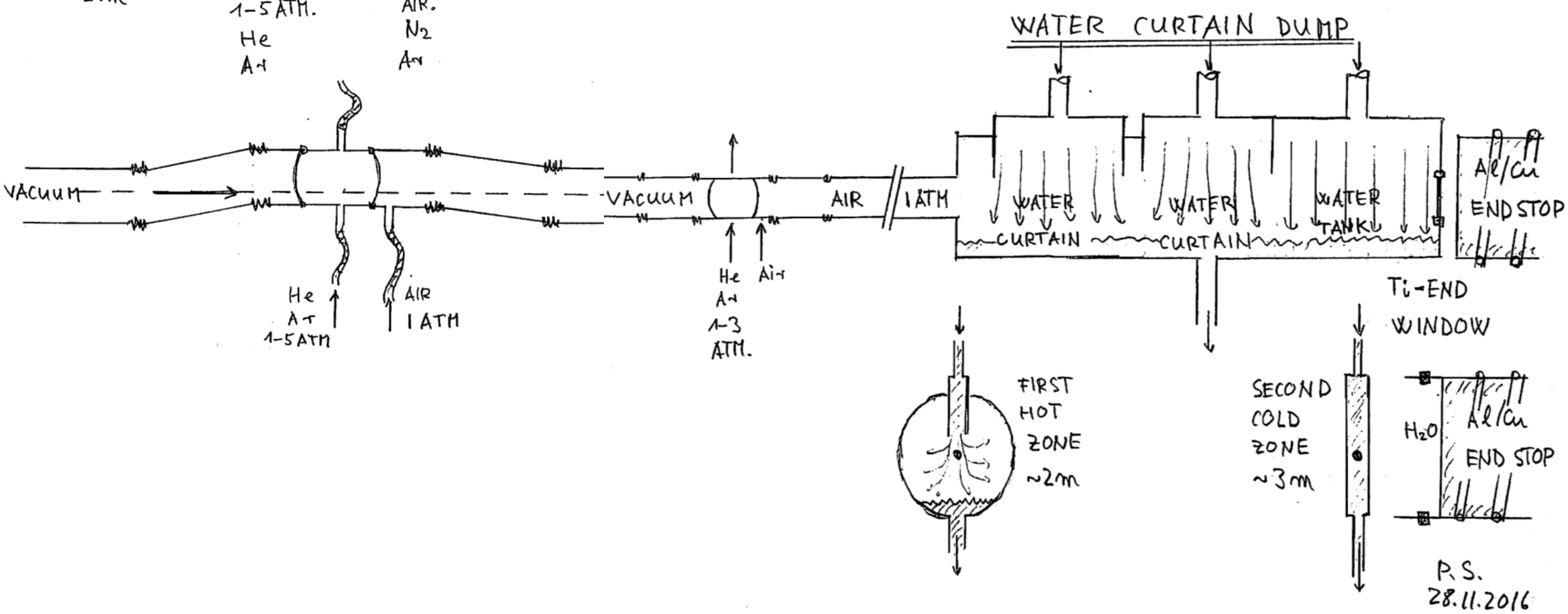
Undulator Positron Source: Photon Dump options



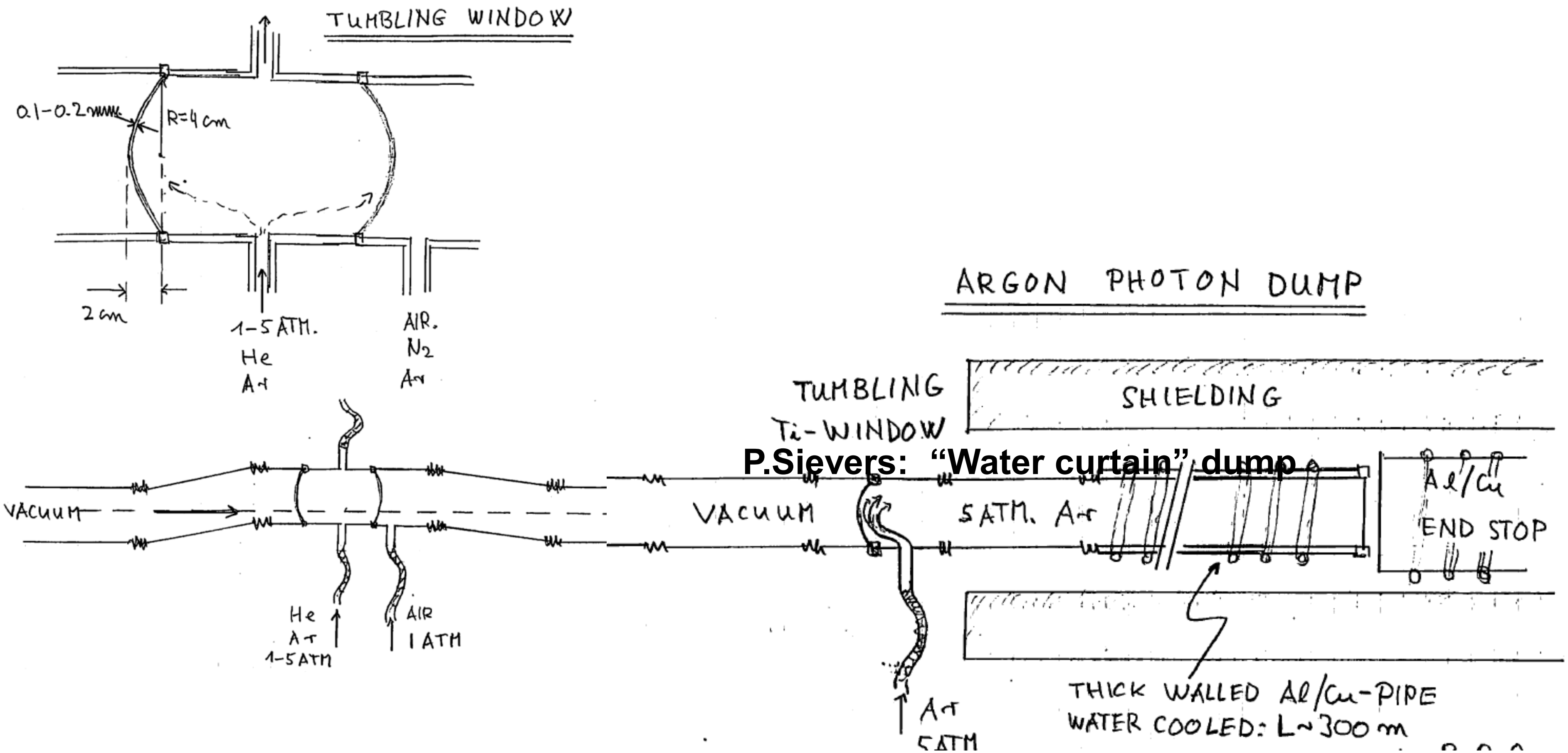
Undulator Positron Source: Photon Dump options



P.Sievers: “Water curtain” dump



Undulator Positron Source: Photon Dump options



P.Sievers: "Water curtain" dump

Technical integration of the undulator source

- Important: Photon beam dump
  - Most of the initial power has to be absorbed (<200kW)
  - Focused γ beam with 1-2×10^{16} γ/sec (few tens MeV) creates high energy deposition density even in thin windows → exit windows to dump must be moved to avoid damage (each bunch train hits another position)
  - graphite dump core gets too hot
  - Design options under consideration
    - Water dump
    - Ar dump

	Near waterfall	Far waterfall	Short Ar	Long Ar
Distance to target (m)	48	1000	48	48
Length (m)	7(water 1bar)+1		60 (Ar 5bar) + 2 (C) + 0.2 (Cu)	300 (Ar 5bar) + 0.2 (Cu)
Cooling	Pump + process		14cm (Ar) + 2cm (Cu) water cool	
Rad. Shield	0.5m iron + 1m concrete		0.5m concrete?	
issues	Dynamic response to 1ms beam			
Concern	Water leak		Ar leak (press), long-lived isotopes	

Material load tests

DESY/U Hamburg/U Mainz

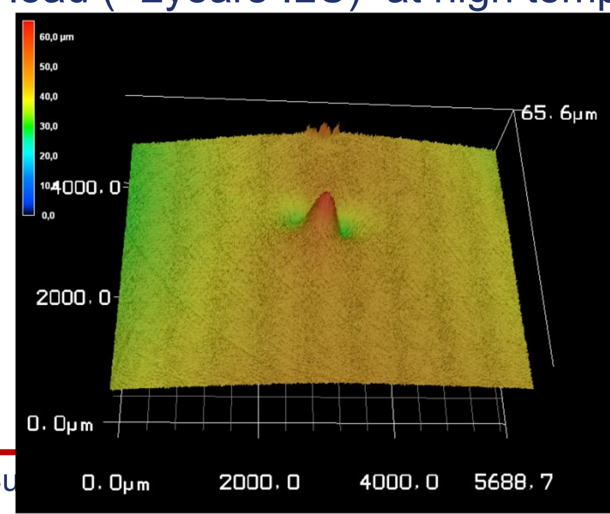
- Test cyclic load expected from photon beam at e+ target (and other components) using MAMI e- beam (BMBF project)
- First results from run with 14MeV electrons:
  - Ti6Al4V targets (1mm,2mm) thick survived high cyclic load of ~7×10^6 cycles heated to at least 690˚C; no damage observed
  - Noticable changes only fo the material exposed to temperatures above 780 ˚C
- Irradiation of Ti and Ti alloy foils with 4MeV e- beam (~4×10^6 cycles)
  - No changes observed (thickness: 0.15 - 0.25mm)

Target #3 (2mm thick)

Before

After

Plastic deformation at front surface after cyclic load (~2years ILC) at high temperatures



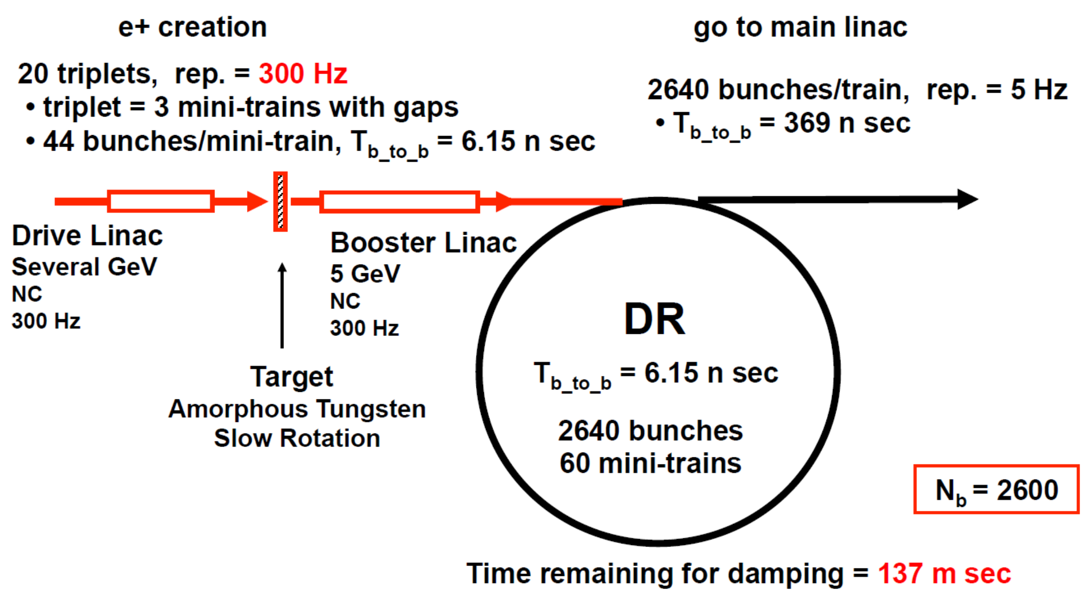
Electron driven positron source

SLC: 6×10^{12} e+/second

- 6X0 WRe target, ~30GeV e- beam
- Experience: Peak load should be smaller than 35J/g

ILC: 6.6×10^{13} e+/second (1.3×10^{14} e+/s lumi upgr.)

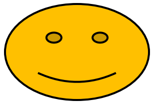
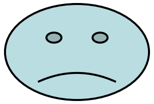
- Idea to avoid overload:
  - stretch the pulse from ~1ms to 63ms
  - Tune the e+ source parameters:
    - 4X0 WRe
    - target wheel Ø = 0.5m,
    - Rotating with ~5m/s



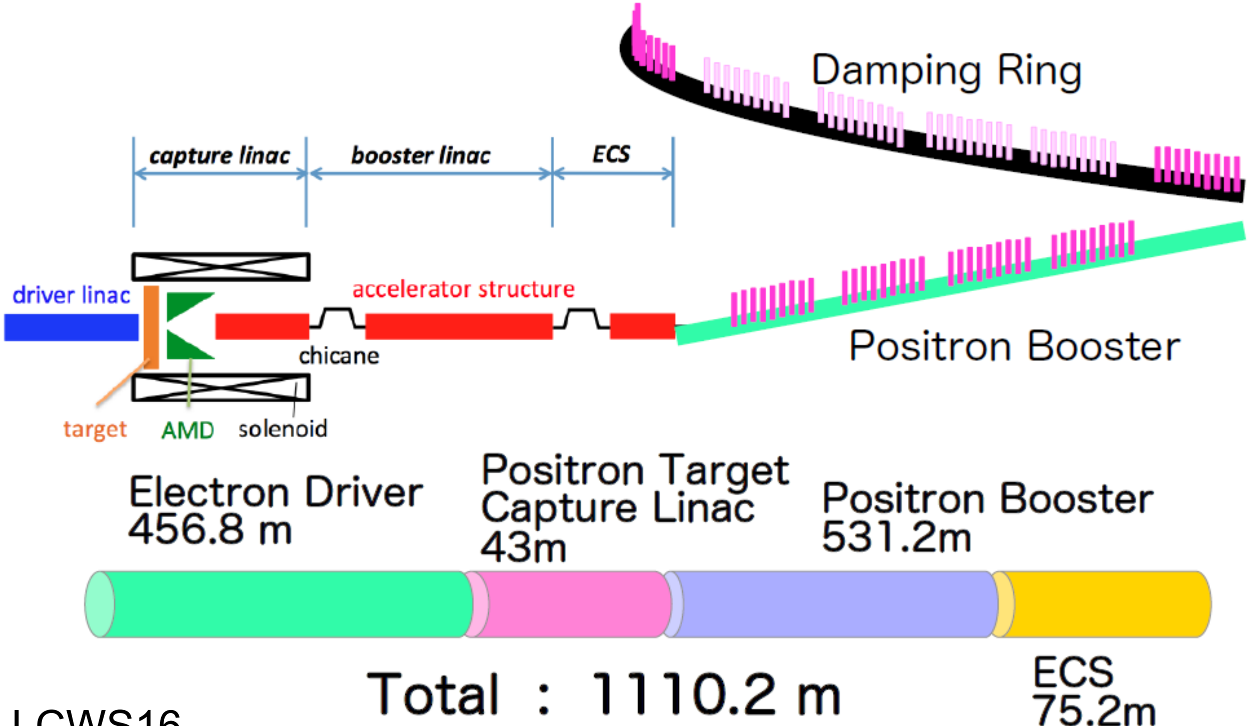
→ peak load on ILC e+ target is comparable to that at SLC

E- driven source:

Backup solution if undulator source has show stopper

- Independent of ILC electron beam 
- unpolarized positron beam ⇔ physics potential 

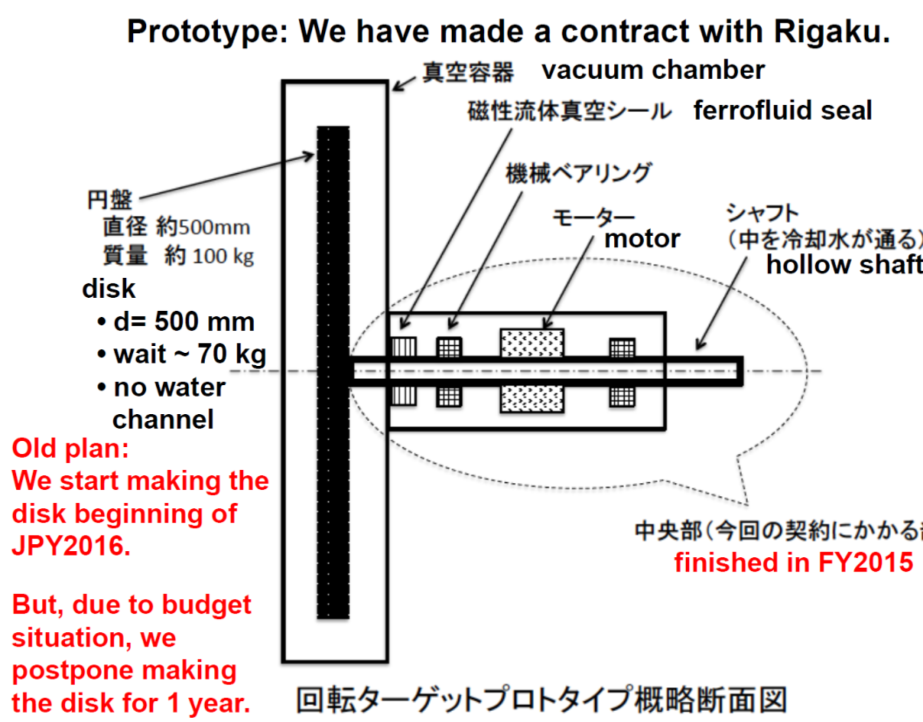
Good progress towards a realistic source design

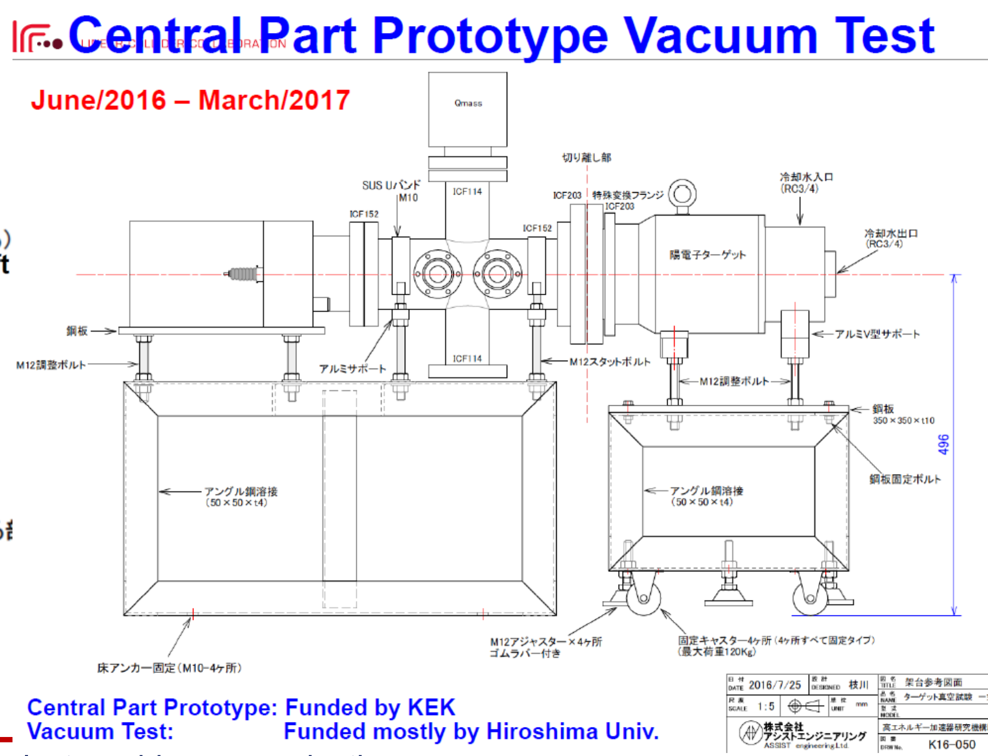


M. Kuriki, LCWS16

Electron driven Source: Target

- Rotation speed 220rpm ⇔ max stress ~540MPa, T_{max} < 500C
- Prototype development





TEST: Radiation Tolerance

Mar 2015

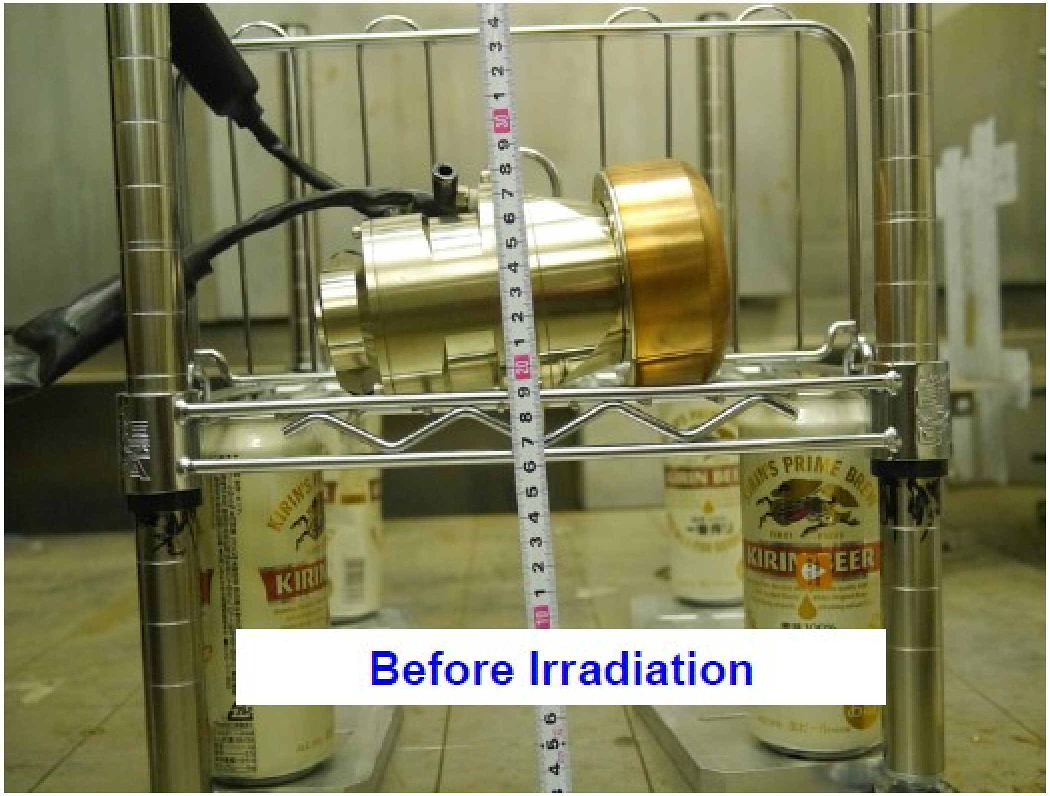
LINEAR COLLIDER COLLABORATION

Irradiation to the small (d=10 cm) off-the-shelf rotation target

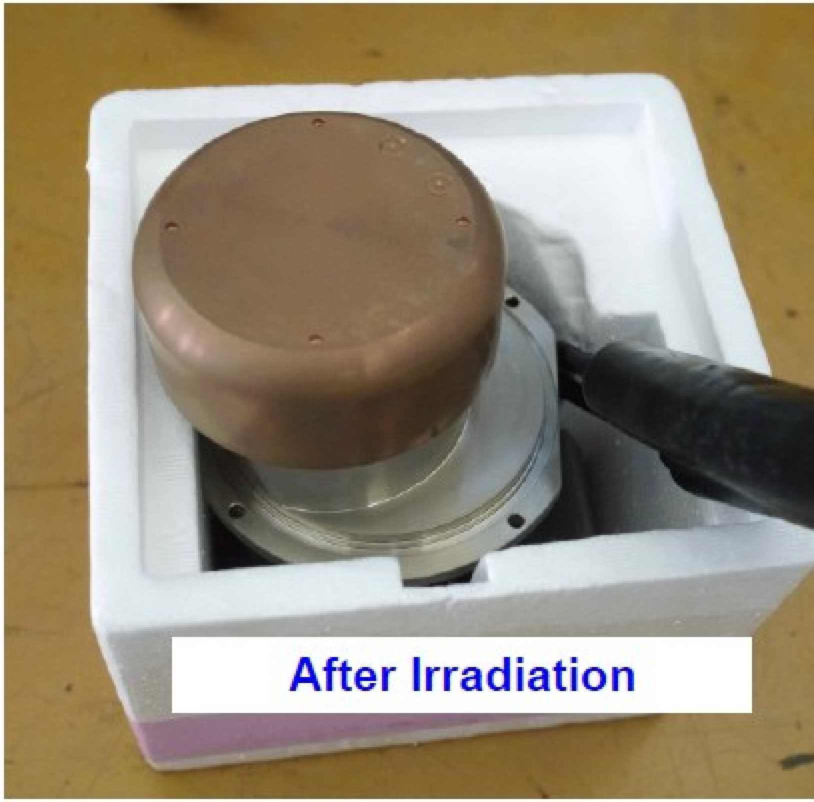
T. Omori et al., LCWS20

Radiation test of the **whole system**: motor, bearing, ferrofluid,,,

0.6 M Gy irradiation on the motor.
corresponds 1 ILC year



Before Irradiation

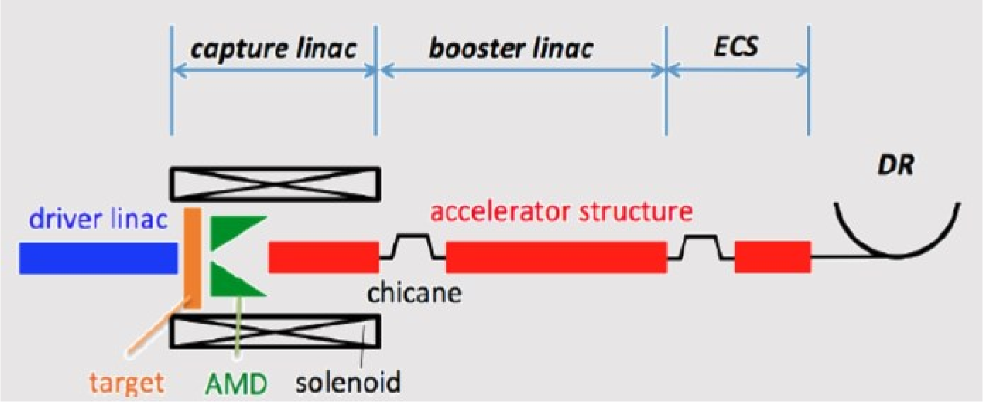


After Irradiation

After irradiation, we made **rotation and vacuum** test.

We found NO problem

- **Capture linac:** improved capture efficiency under realistic RF setup with beam loading

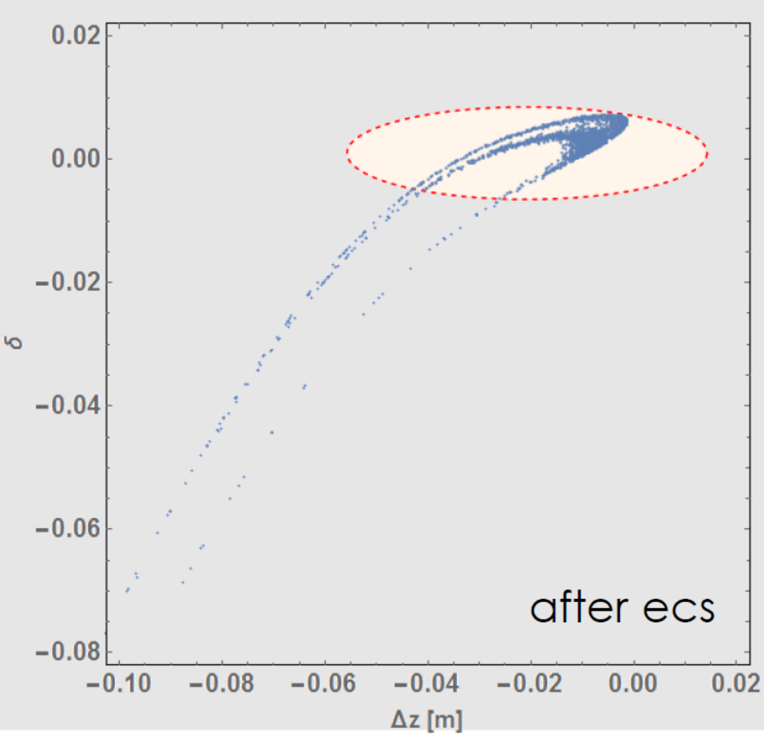


Y. Sumimoto, LCWS2016

- **Booster linac:** improved optimization for better transfer

- **Energy compression system** (ECS)

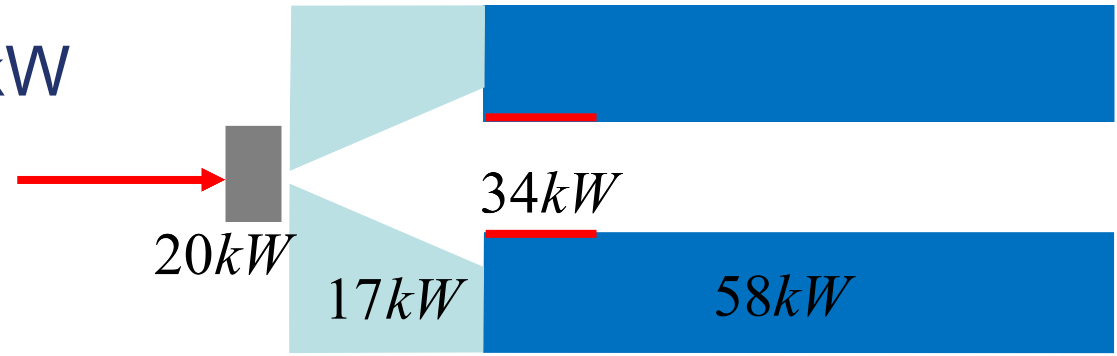
→ Yield = 1.75 e+/e-
(→ relaxed driver intensity)

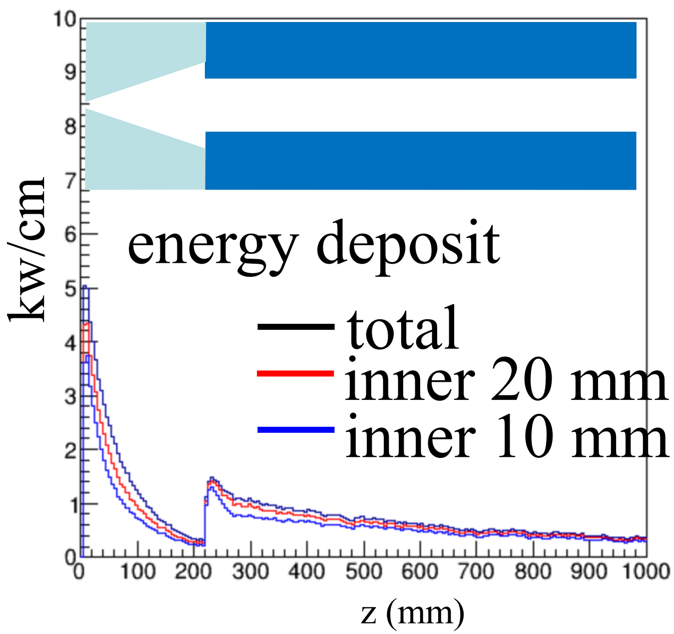


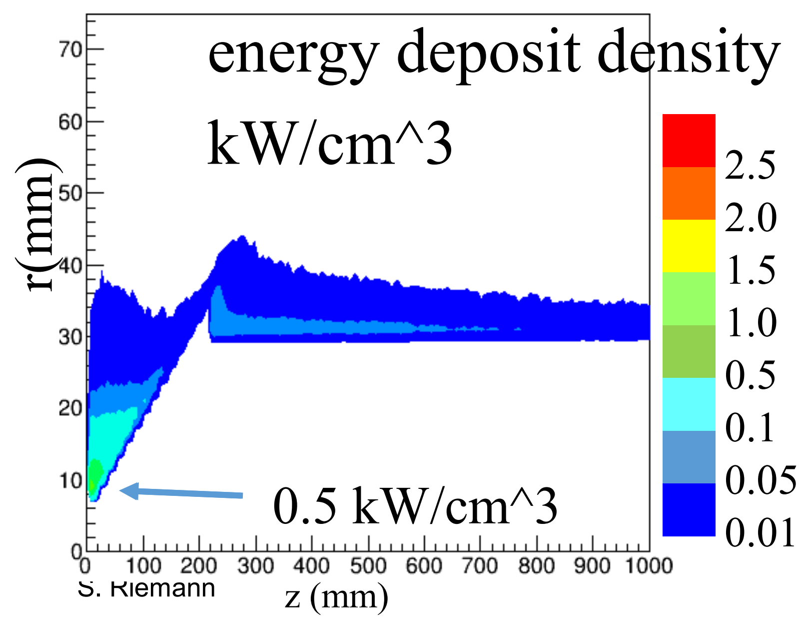
T. Takahashi, LCWS2016

Energy deposition at electron driven e+ source

- e- beam power = 100kW
  - 1320 bunches,
  - 4.8GeV
  - σ = 3.5mm
  - yield = 1.55e+/e-
- → 34kW deposited in first ~1.3m

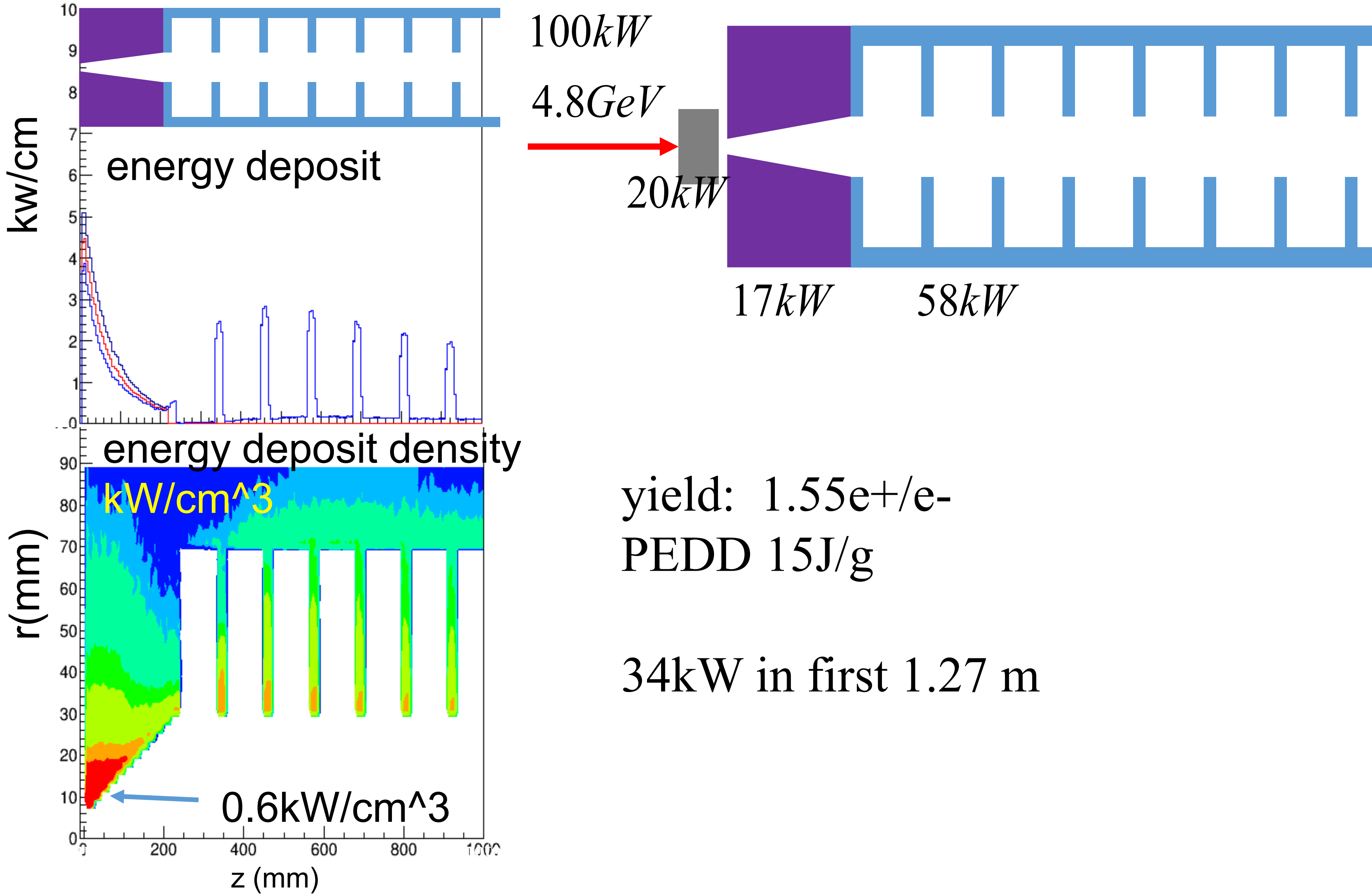






Ee = 4.8GeV, target thickness 16 mm
sigma of E beam = 3.5mm

T. Takahashi, LCWS2016

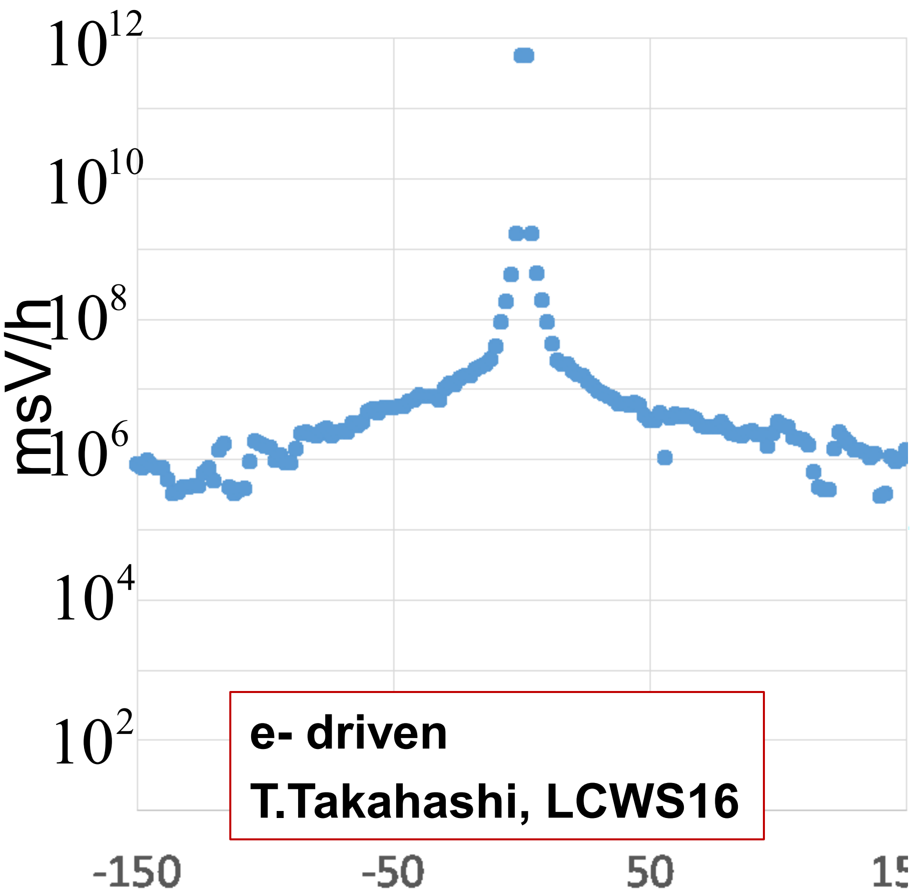


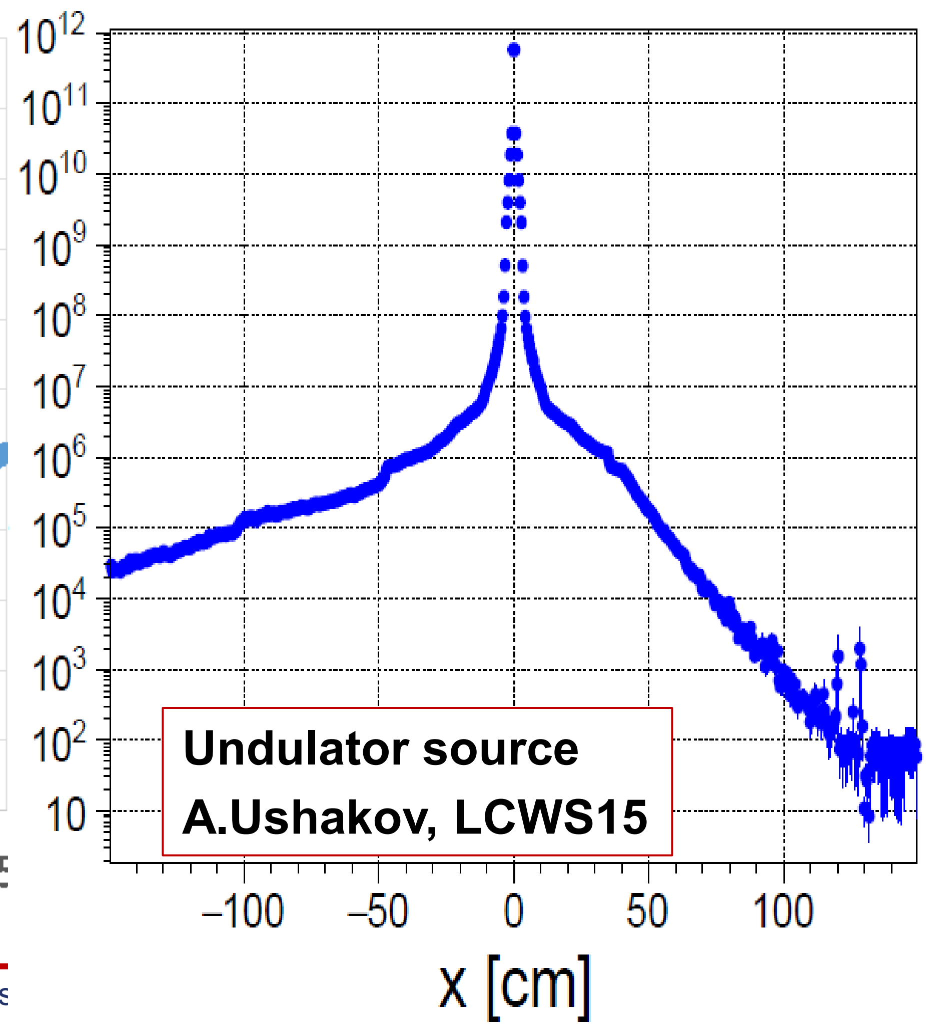
yield: 1.55e+/e-
PEDD 15J/g

34kW in first 1.27 m

Radiation level at the e+ sources

Effective dose rate [mSv/h]





Comparison γ vs e- driven (nominal L)

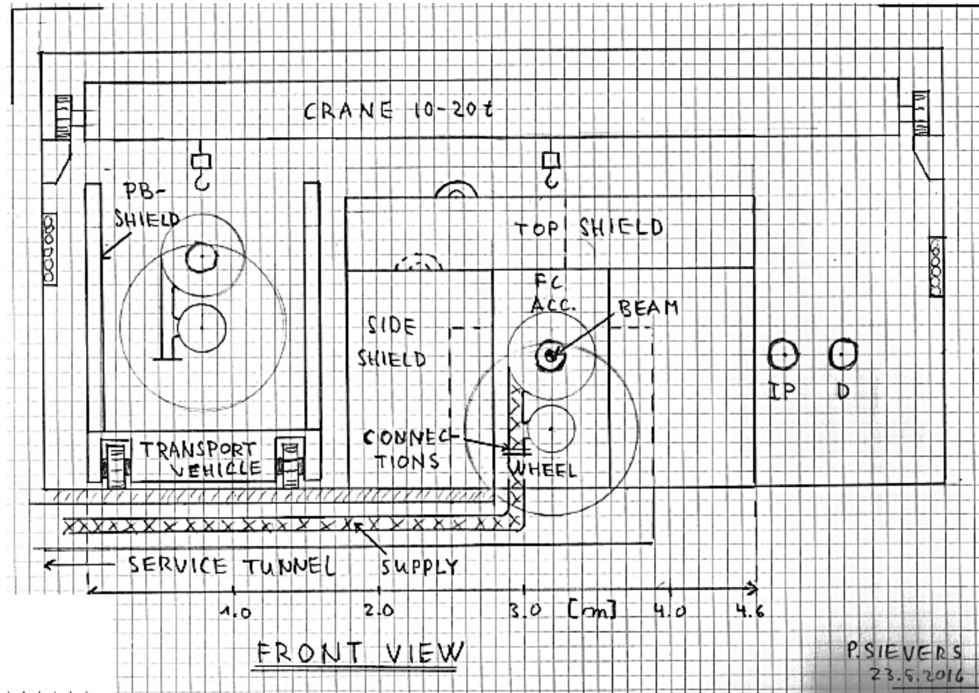
	Unduator (γ)	e- driven
	dependent on e- beam for physics	Independent on e- beam for physics
	231m long sc helical undulator	Acc ring to get 5 GeV e- beam
Target material	1.5cm Ti alloy	1.6cm WRe
Beam power	P_γ = <60kW	P_{e-} = 100 kW
Power deposition in target	~ 2-7.5kW	20kW
Power deposition in matching device	~ 2-8kW	17kW
Time structure	ILC (t_{tpulse} <1ms)	Stretched (t_{pulse} = 63ms)
Target wheel	R = 50cm	R = 25cm
Rotation speed	2000rpm (100m/s)	<220rpm (<5m/s)
Target cooling	Thermal radiation	Water cooling
E+ polarization	30% (upgrade poss.)	--

- Both sources need R&D
  - Simulation & optimization
  - No showstopper identified for undulator-based source; but engineering work necessary. For E_{cm}=250GeV some parameter optimization would be helpful.

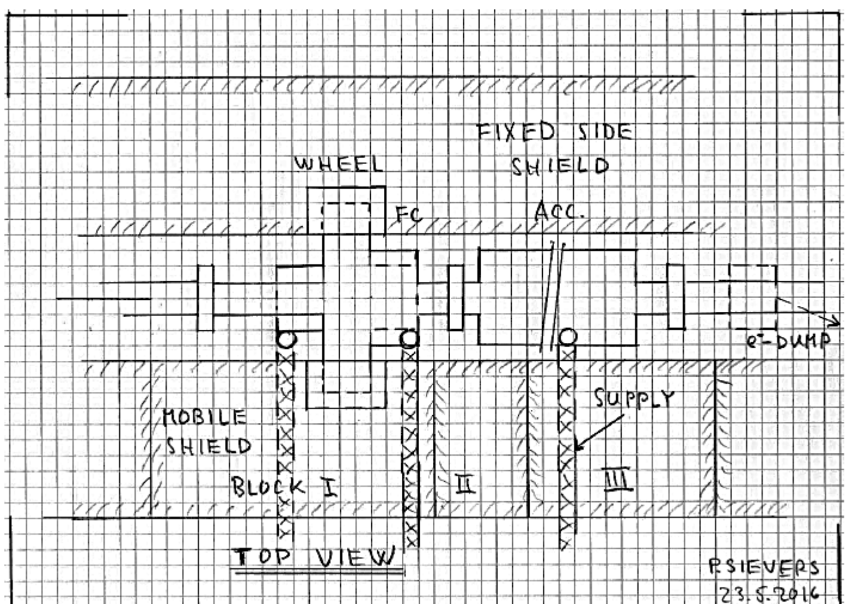
- Important for both sources:
  - Mechanical design (bearing, vacuum seals, ...)
  - Cooling
  - Radiation protection
  - Target maintenance scenarios
    - Remote handling
    - Storage area, transportation, etc.
    - First ideas exist and are under discussion

Target maintenance Scenarios

(first ideas – P. Sievers)



Top View



Important: Required shielding of the target region including

- Target replacement
- Where/how waste targets to be stored
- Path to take waste target to the surface
- etc.

To do

- plan of R&D for FY2017-2019 until June 2017
  - Main target: Answer to Nomura triangle issues
  - Include cost estimation for the R&D
- Consistent design to the level which is sufficient for the central region group to discuss about the electron-side BDS tunnel

- Discussion within KEK
  - KEK budget situation
    - Minimum amount in JFY2017 (starting Apr.2017)
    - Significant budget might come in JFY2018-19
      - It is not reasonable in this budget request to have 2 parallel schemes
  - KEK should be active for the baseline undulator scheme (must request budget of JFY2018-19 for undulator scheme)

WG 1 plan

- e-Driven Scheme
  - Concentrate on 1312 bunches
  - Target
    - Prove feasibility within JFY2017
    - Evaporation of magnetic fluid?
    - 50cm diameter model (not tungsten)
  - downstream part (FC, capture cavities) should be OK for 1312 bunches. Simulation studies are still needed but don't need money
  - Should finish e-driven study within JFY2017
- Undulator
  - Concentrate on radiation cooling
  - Key issues
    - Target itself (Ti-radiator contact, magnetic bearings, ..)
    - Photon dump
- Both:
  - Target replacement scenario
  - Shielding of target region
  - costs