Summary of WG1 (Positron WG) Status

K. Yokoya

2017/6/28 AWLC@SLAC

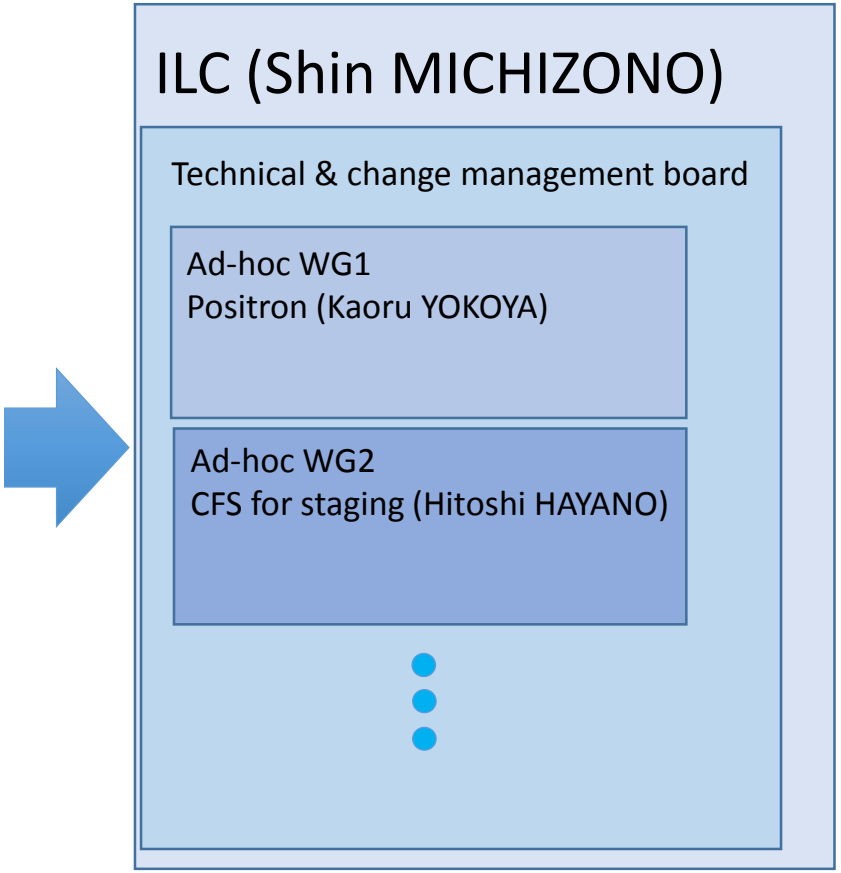
LCC-ILC working groups

LCC Associate Director responsible for ILC Accelerator: M. Harrison (BNL)
- Deputies: H. Hayano (KEK) and N. Walker (DESY)

Sub-System	*Global Leader - Deputy Leader*	*Sub-System*	*Global Leader - Deputy Leader*
ADI	N. Walker (DESY) - K. Yokoya (KEK)	**SRF**	H. Hayano (KEK) - C. Ginsburg (Fermilab) - E. Montesinos (CERN)
e-/e+ Sources	W. Gai (ANL) - M. Kuriki (Hiroshima)	**RF Power & Cntl**	S. Michizono (KEK) - TBD - TBD
Damping Ring	D. Rubin (Cornell) - N. Terunuma (KEK)	**Cryogenics**	H. Nakai (KEK) - D. Delikaris (CERN) - T. Peterson (Fermilab)
RTML	S. Kuroda (KEK) - A. Latina (CERN)	**CFS**	V. Kuchler (Fermilab) - J. Osborne (CERN) - M. Miyahara (KEK)
Main Linac	N. Solyak (Fermilab) - K. Kubo (KEK)	**Radiation Safety**	T. Sanami (KEK) - S. Roesler (CERN) - TBD
BDS	G. White (SLAC) - R. Tomas (CERN) - T. Okugi (KEK)		

Table 1. ILC organization structure and sub-system responsibilities in 2015

Shin Michizono, 2017 Jan



Positron WG Mission given by S.M.

- e+ WG organized by Kaoru YOKOYA:
  - Evaluate undulator? conventional? at 250GeV CM
  - Evaluate technical difficulty, cost (based on TDR), commissioning, …
  - Submit final report by June 2017
    (including essential R&Ds on 2018,2019 and the proposal of positron scheme)

Members

- Members
  - Andriy Ushakov Hamburg Univ./DESY
  - Gudrid Moortgat Hamburg Univ./DESY
  - Sabine Riemann DESY
  - Peter Sievers CERN
  - Tohru Takahashi Hiroshima Univ.
  - Tsunehiko Omori KEK
  - Masao Kuriki Hiroshima Univ.
  - Wei Gai ANL
  - Kaoru Yokoya KEK
  - Benno List DESY
  - Toshiyuki Okugi KEK
  - Akira Yamamoto KEK
  - Nobuhiro Terunuma KEK
- Meetings
  - 8 meetings every other week
  - Staging mini-WS (Apr.5-7) https://kds.kek.jp/indico/event/24127/

Our Plan

1. Fix the design parameters for 250GeV CM by undulator scheme and by the e-driven scheme

Undulator

- Beam parameters
- Length of undulator
- Conceptual design of the photon dump
- Beamline including the possible change of the chicane
- Design of the target (most probably, radiation cooling)
- Target replacement scheme
- Shielding of the target area
- Cost delta
- Commissioning

e-Driven

- Beam parameters
- Design of driver, target, capture section, booster
- Simulation including multi-bunch beam loading
- Target replacement scheme
- Shielding of the target area
- Location
- Cost and power estimation
- Commissioning

2. Evaluate the technical difficulties for each scheme
3. Required R&D for 2018-2019

Submit report by June 2017

What We Did

- 1st Meeting on Mar.2
  - Tentative decision (in view of the limited money and manpower)
    - Continue the on-going works for e-driven in JFY2017
    - Concentrate more on undulator in JFY2018-19
- 2nd meeing on Mar.16
  - R&D Plan for e-Driven
- Staging minWS
- Since then discussion is still going on the parameters for undulator scheme

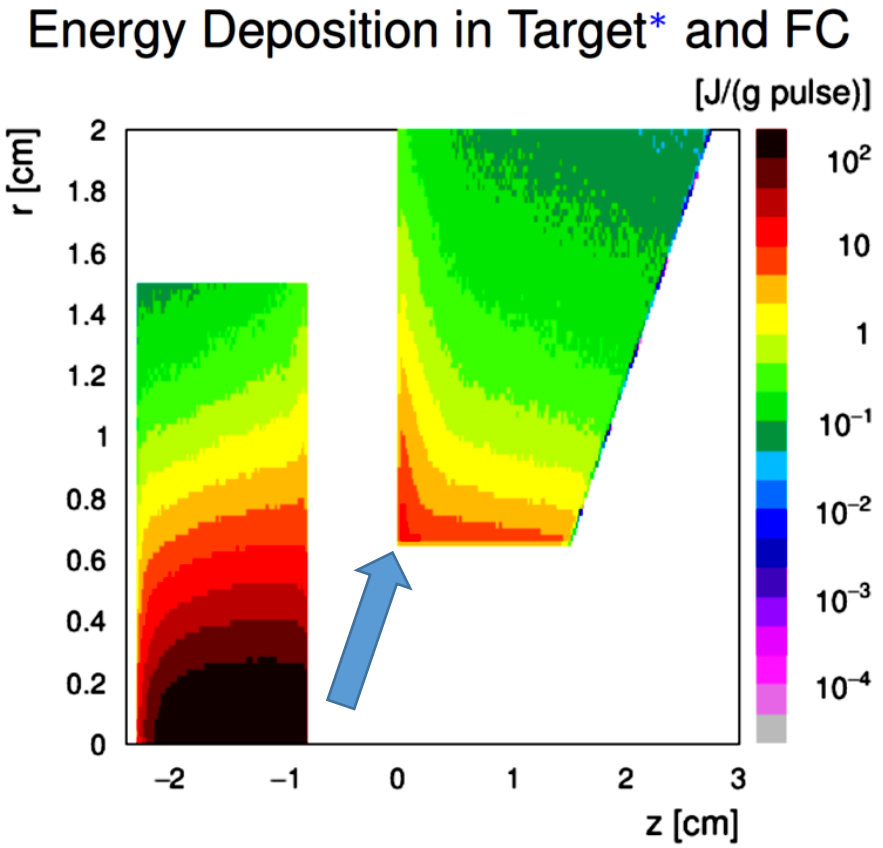
Recent Progresses (1)

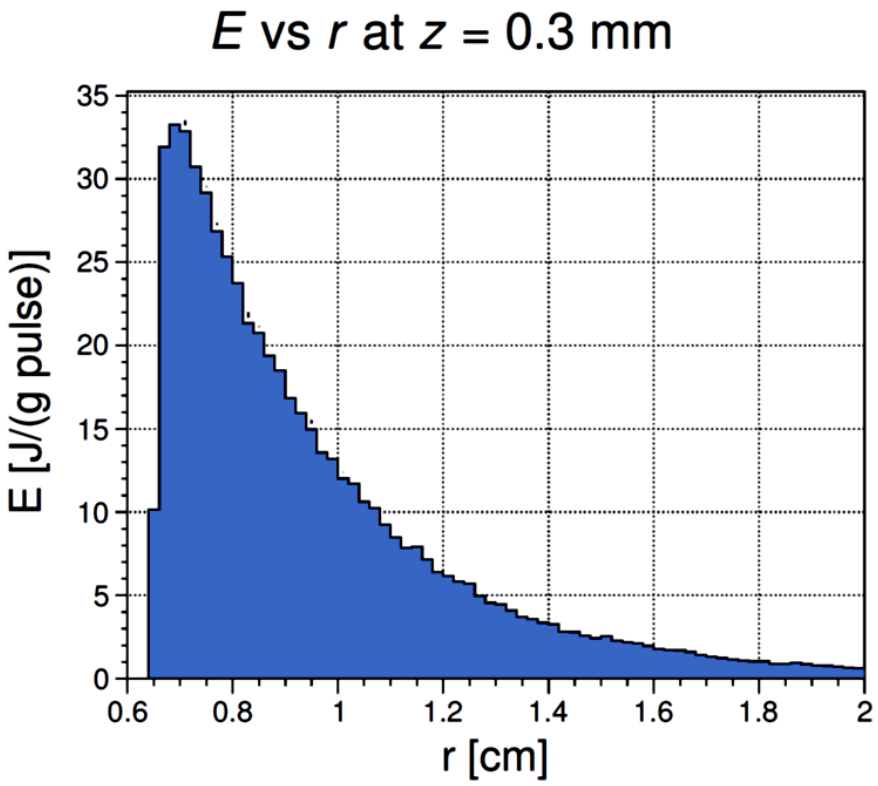
- Problem of heating FC (Flux Concentrator) by photons was found for 250GeV CM.
  - More than factor 3 higher than PEDD (Peak Energy Deposit Density) limit of Copper
    - ~33J/g compared with the limkit 7-12 J/g
  - Seems to be mainly due to large angle from low energy photons
    - This was not an issue for 150GeV beam (though marginal)

Recent Progresses (1) continued

- Several cures proposed
  - Move undulator closer to the target (smaller spot)
  - Estimate the effect of masks (already in TDR, to protect undulators) (kill low energy photons)
  - Thinner target (suppress shower development in target)
  - Collimator just before the target (similar to that for higher polarization but aperture larger)
  - Larger iris of FC (not yet)
- The first 3 will reduce PEDD by factor ~2/3 (some more study needed), but not sufficient yet
- Including last 2,
  - photon collimator r~ 2.5mm
  - FC iris radius 8mm (← 6.5mm in TDR)
    Then, PEDD is now ~12 J/g
    (Progress in this workshop by A. Ushakov)

Energy Deposit in Target and FC with TDR Parameters





* Target without rotation

PEDD = 43.7 J/(g pulse) in rotated target with 100 m/s

$PEDD_{FC}$ = 33.3 J/(g pulse)

ΔT_{inst} = 86.4 K/pulse

PEDD(Cu) < 7 ÷ 12 J/g
[TESLA-FEL-2006-05 Report]

Recent Progresses (2)

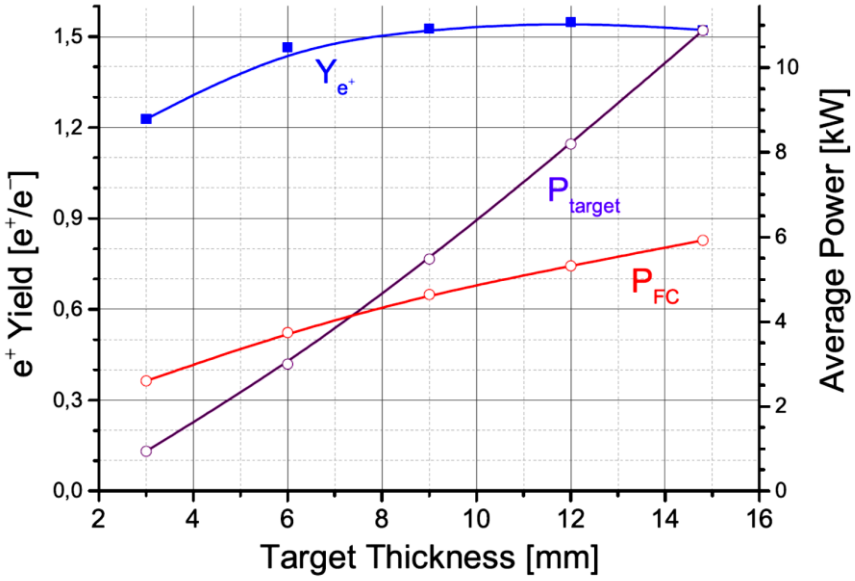
- Positron yield with thinner target
  - By product of study for the issue of PEDD on FC
  - Target thickness 14mm in TDR ($0.4X_0$, Ti Alloy)
  - Thinner target seems to be better for 125GeV electron
  - No yield reduction down to ~7-8 mm
  - Reduction of the energy deposit in the target is quite significant (5.4kW to less than 2kW)
- Now, revisiting the undulator scheme parameters with thinner target (~7mm) for 250GeV staging

- With fixed gain (e+/e-=1.5)

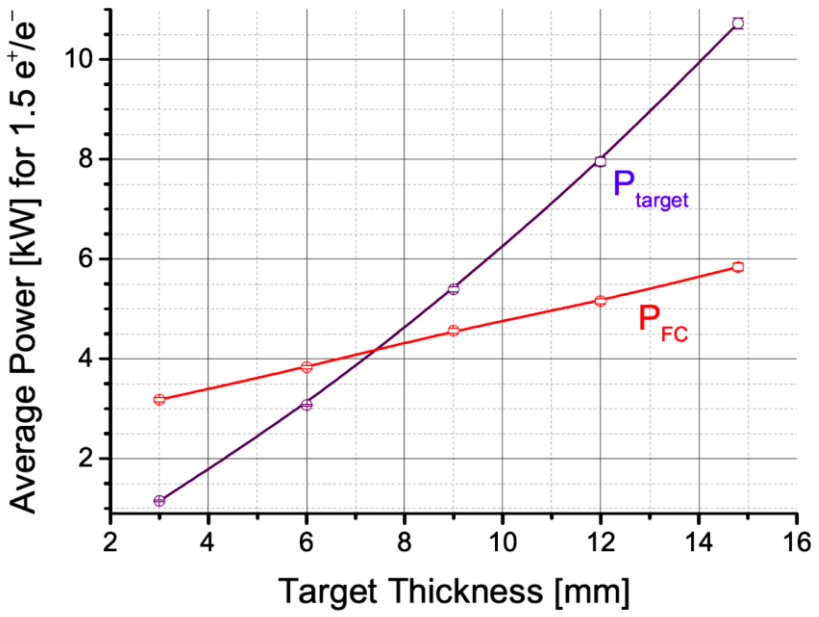
from figure

thickness	undulator length	PEDD on FC	Power on target (2625 bunches)
12 mm	0 %	+1 %	7.9 kW
9 mm	0 %	-3.5 %	5.3 kW
6 mm	+4 %	-9 %	3.1 kW
3mm	+24 %	-19 %	1.2

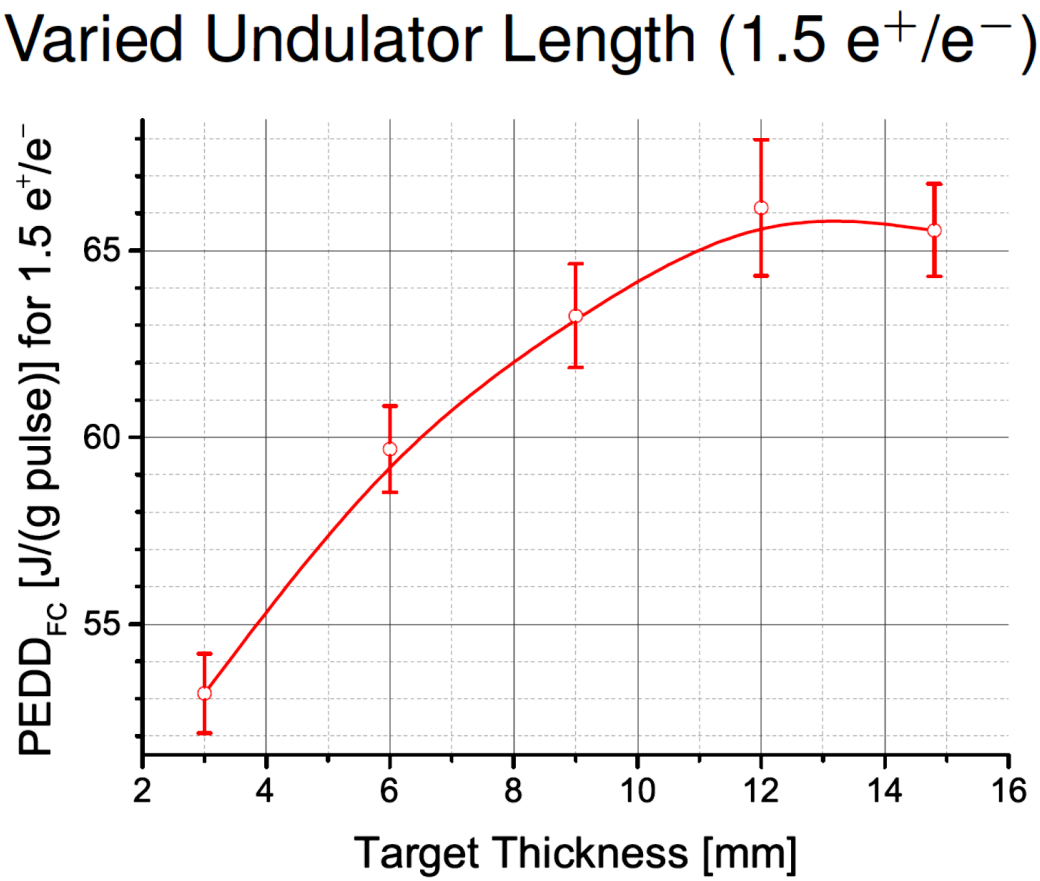
Fixed Undulator Length (231 m)



Varied Undulator Length (1.5 e^+/e^-)



- But the reduction of PEDD on FC is not too large (< ~10%)



New Undulator Scheme Parameters at 250GeV

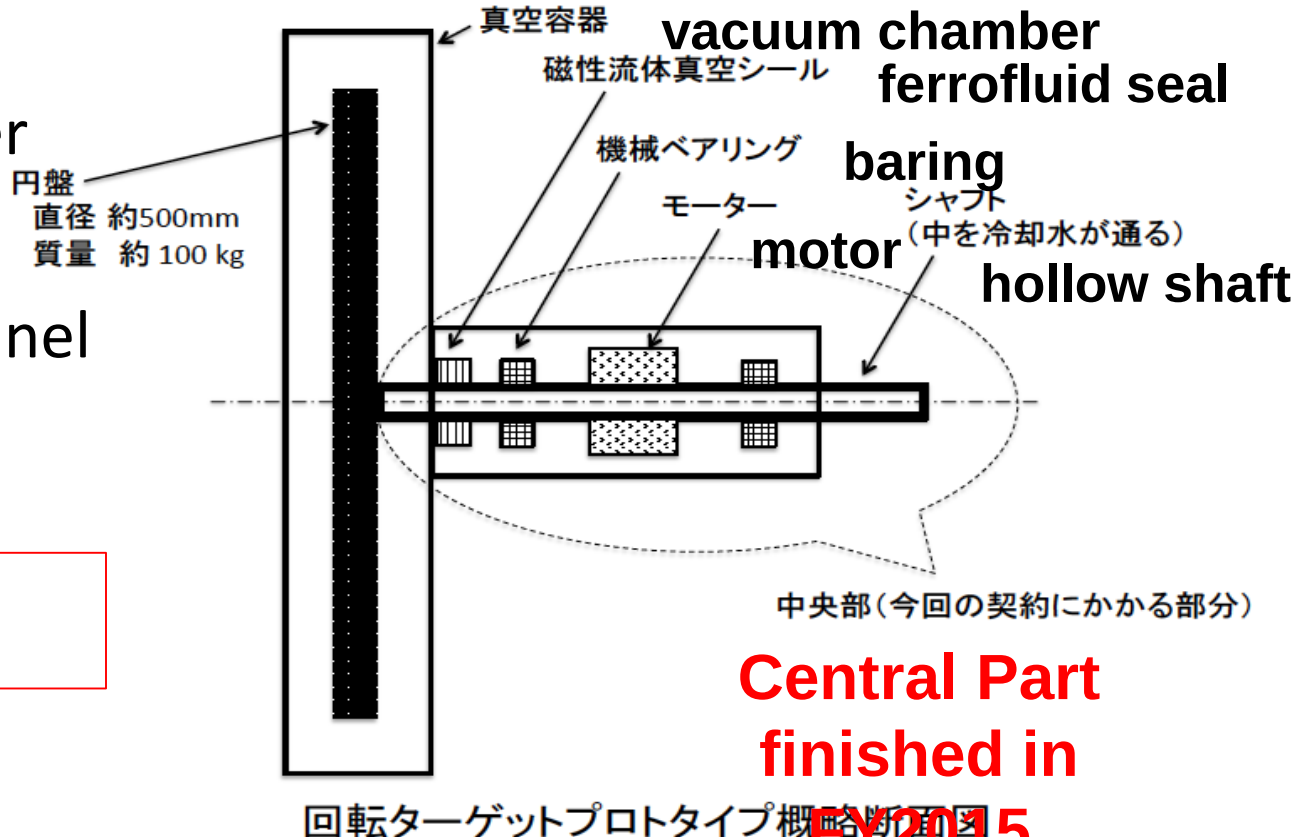
- Still tentative
- The yield with FC is higher than required
- Will be adjusted to 1.5
- Then, the energy deposit would be some 10% lower
- → ~1.6kW on target (used to be 5.4kW)

Undulator System Parameters as of 2017/6/26			
Electron Beam			
	Electron Energy	GeV	128->125
	Bunch population		2.00E+10
	Bunber of bunches		1312
	Repetition rate	Hz	5
	Electron energy loss in undulators	GeV	3
Undulator			
	unit length	m	1.75
	Period	mm	11.5
	K parameter		0.85
	total number of undulators		132
	net length of undulators	m	231
	inner radius	mm	2.9
	radius of masks in undulator section	mm	2.2
Optics in undulator section			
	Distance between quads	m	12
	Number of undulators between quads		6
	Total length of undulator section	m	264
	Distance between undulator section center to target	m	401.1
Target			
	Thickness	mm	7
	radius	m	0.5
	rotation speed at the rim	m/s	100
Flux concentrator			
	Peak field	T	3.2
	Aperture radius	mm	6.5
	distance from target back face to front face of FC	mm	5
	thickness of front plate (in front of Cu)	mm	3
QWT (as bottom line)			
	max field		
Photons			
	Average energy of all photons	MeV	6.28
	Average energy on target (through masks)	MeV	7.3
	Power of all photons	kW	63.4
	Photon power on target	kW	61.5
	Power on masks	kW	1.88
	Power on the last mask	kW	0.32
Energy deposit			
	On target	kW	1.75
	PEDD on target	J/g/pulse	49.5
	PEDD on FC	J/g/pulse	22.7
Positron			
	Positron Yield (e+/e-)		1.68

Recent Progresses (3)

- Target rotation test for e-Driven source
- No disk for now
- Rotation test started in Feb to test magnetic fluid

- 50cm diameter
- 70kg
- no water channel
- 225rpm

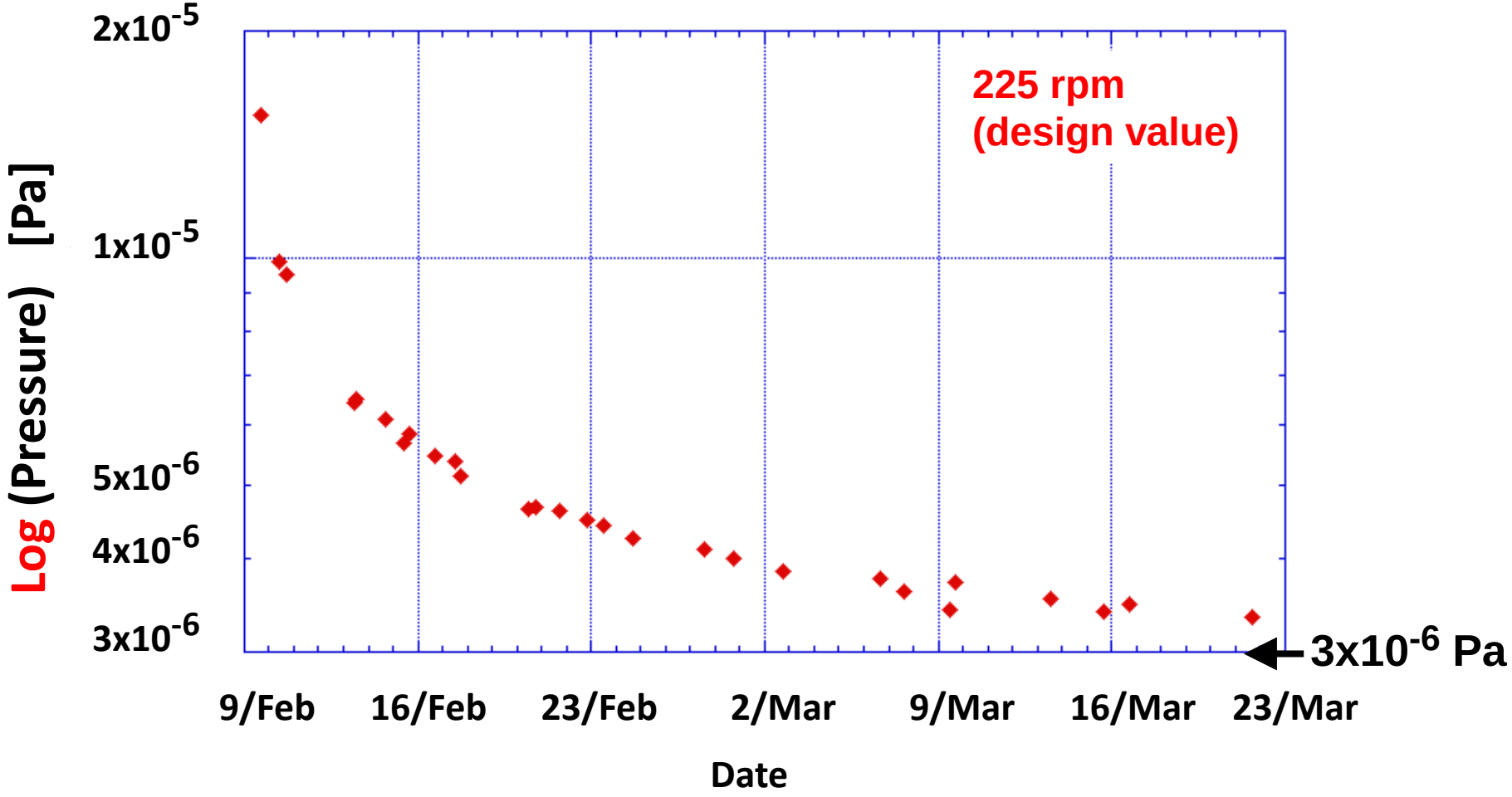


See T/Omori, Tuesday source session

Central Part finished in FY2015

Central Part Prototype Vacuum Test

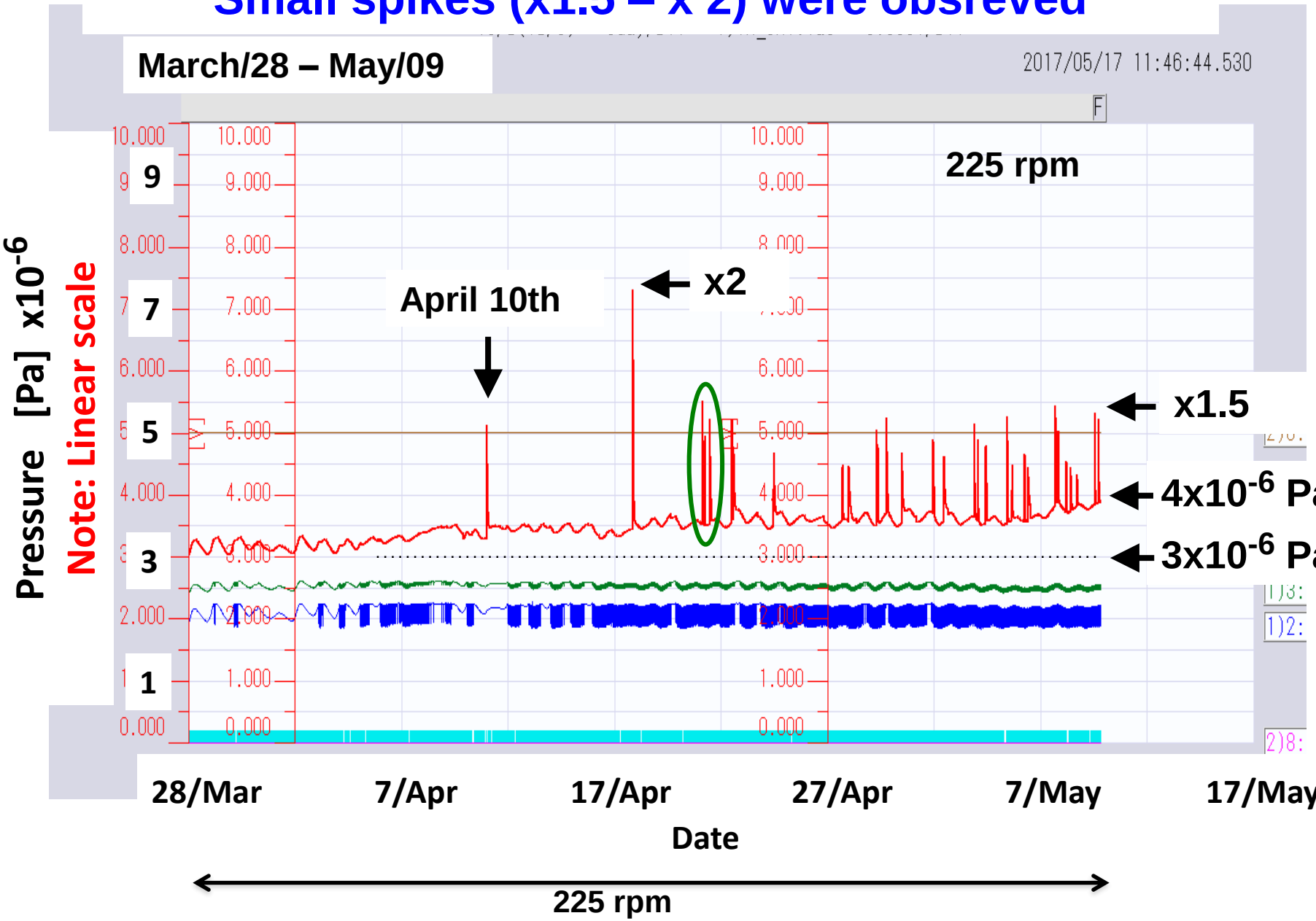
The test started on February 9th with continuous rotation at 225 rpm



The vacuum test started on February 9th with continuous rotation at 225 rpm (design vale). The vacuum level seems to be reasonable in comparison with the expectation. The vacuum level is as good as the ILC TDR requirement. It seems promising. But the prototype has no disk. We will make further study.

Central Part Prototype Vacuum Test

Small spikes (x1.5 – x 2) were obsreved



Technical Feasibility of Undulator/e-Driven Schemes

- There are many pros and cons for both schemes such as polarization, timing constraints, coupling of operation of e+ and e-, etc.
- At this moment the primary issue is the technical feasibility for the **ILC first stage** (250GeV CM, 1312 bunches)
  - How far from realization?
  - What is the expected status after couple of years?
- Other issues such as upgradeability (more bunches, higher energy), cost, power consumption, etc. are only of secondary/tertiary concern.
- Here, we summarize the technical status and future prospects **for establishing the plans for the near future** (not for the choice of scheme).

- 5-rank evaluation
  - A: Complete model or some prototype exists. Can be finalized if tried.
  - B: Basic partial tests done or known to work. No whole prototype.
  - C: Calculation study only. But no show stopper seen yet.
  - D: Break through needed
  - E: Fatal (of course there is no E)
- (Please understand this ranking is not appropriate for some items, e.g., no test because considered to be easy)
- Each component ranked in this way
- Here, driver beam, capture cavity and yield simulation are omitted. These are more or less ranked B. See slides in the Source session on Monday.

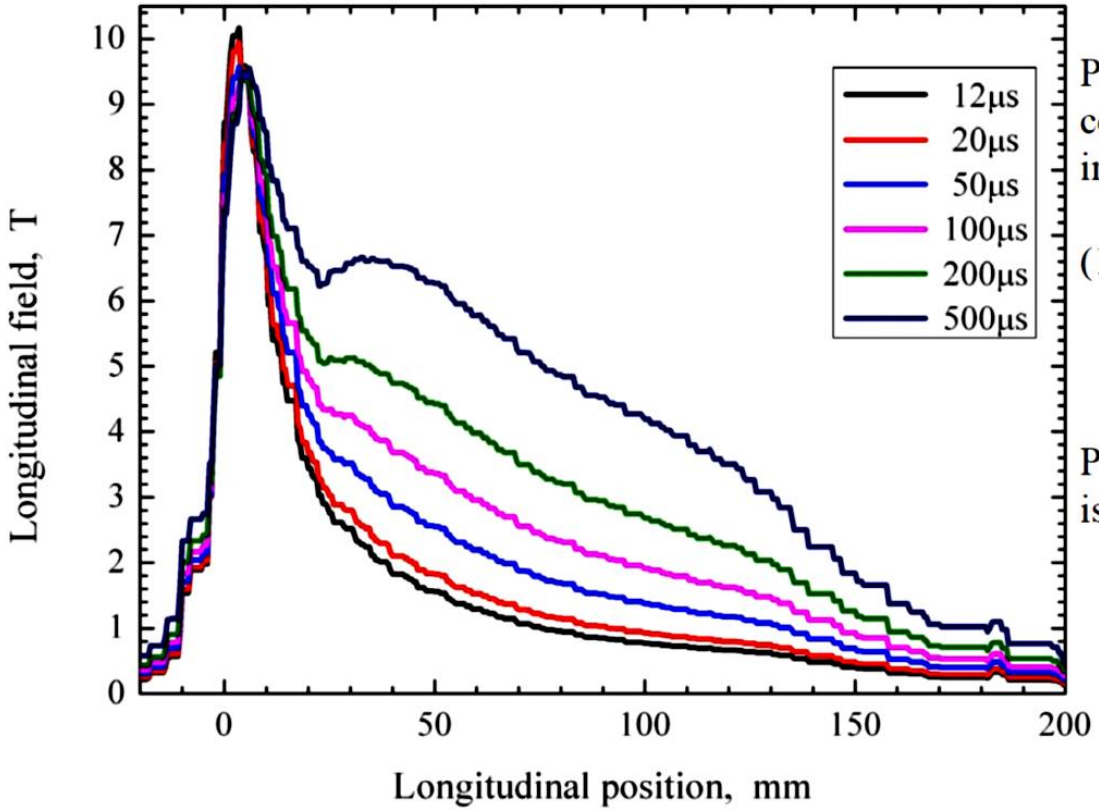
Target

		Undulator		e-Driven	
Specification	Rotation speed	100m/s		5m/s	
	Material	Ti alloy		W or W/Re	
	thickness	$0.4X_0$		$\sim 4X_0$	
	Cooling	radiation		water	
	rotation axis	non-penerate		penetrate	
Issues	Wheel	Specification not determined yet (but coming soon)	B	Durability of Magnetic fluid under radiation confirmed	A
		magnetic bearing under study	C	Rotation test ongoing in vacuum	B
	Cooling	calculation only	C		
		Ti-Cu joint	B	W-Cu joint. Lab tests still to be done with a 50 cm wheel.	B
		Lab test plan proposed for the above 2 issues			

Matching Device

	Undulator		e-Driven	
	FC (Flux Concentrator) (or QWT as bottom line)		Flux Concentrator	
beam pulse length	~1ms		~1μs	
peak field	3.2T		~5T	
Status	no design yet		Close to SuperKEKB design, but larger aperture. Design of the body exists	
Issues	t-dependence of F(z) of FC. Break through needed.	D	water cooling not yet considered	B
	PEDD on FC iris (factor >2 above the Cu limit)	B	Power supply design needed	C
	QWT may be a substitute of FC, but need to study positron yield for QWT (1/1.6 in TDR but not well studied). Also, QWT hardware.	B		

A Problem of Long Pulse FC



Profile of longitudinal field component at different instants of time .

(1-st order of approximation)

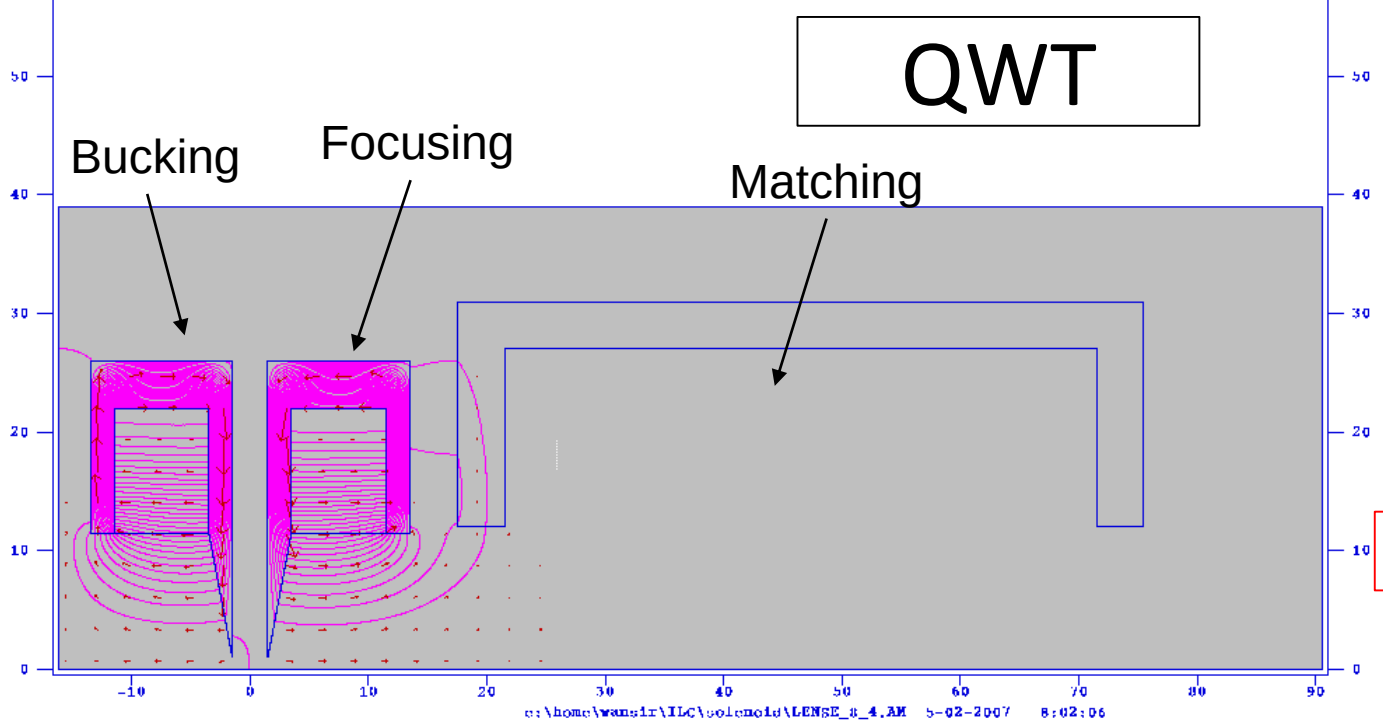
Peak field value fluctuation is from 9.5Tesla to 10.1 Tesla

P.Martyshkin 2014

A skin layer depth becomes deeper in time and as result a magnetic flux through copper conductors also redistributes. These leads to longitudinal field profile deformation through a pulse time. Big profile deformation is observed starting from 100μs pulse time.

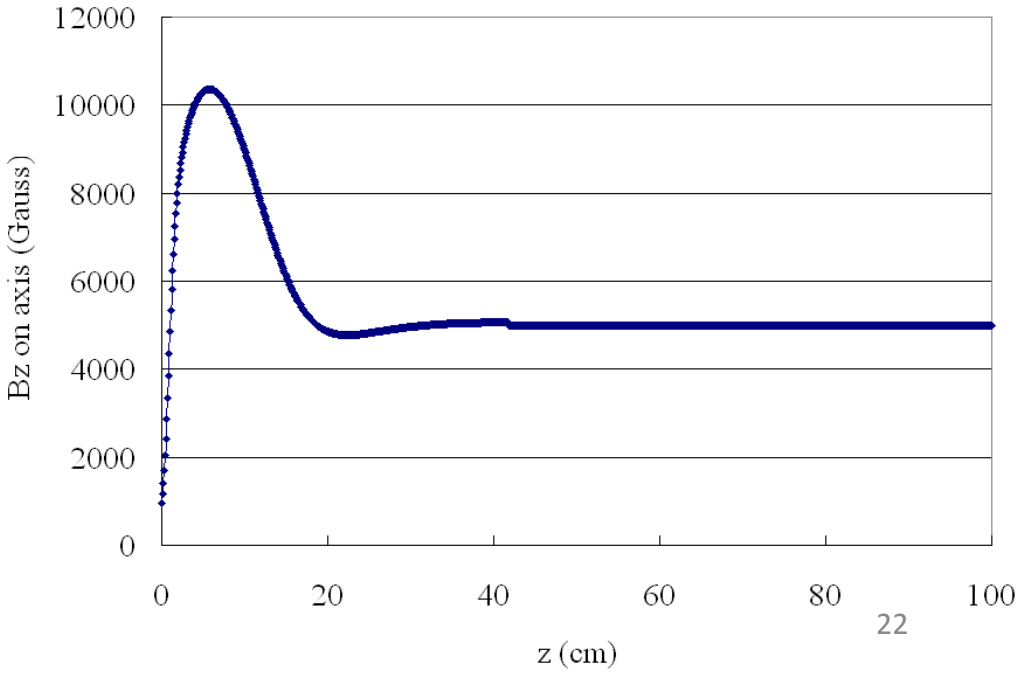
Profiles should be recomputed with 2-nd order of approximation to confirm deformation in time

QWT



Wanming Liu

A study to reproduce this work and to further optimize the yield is on-going.

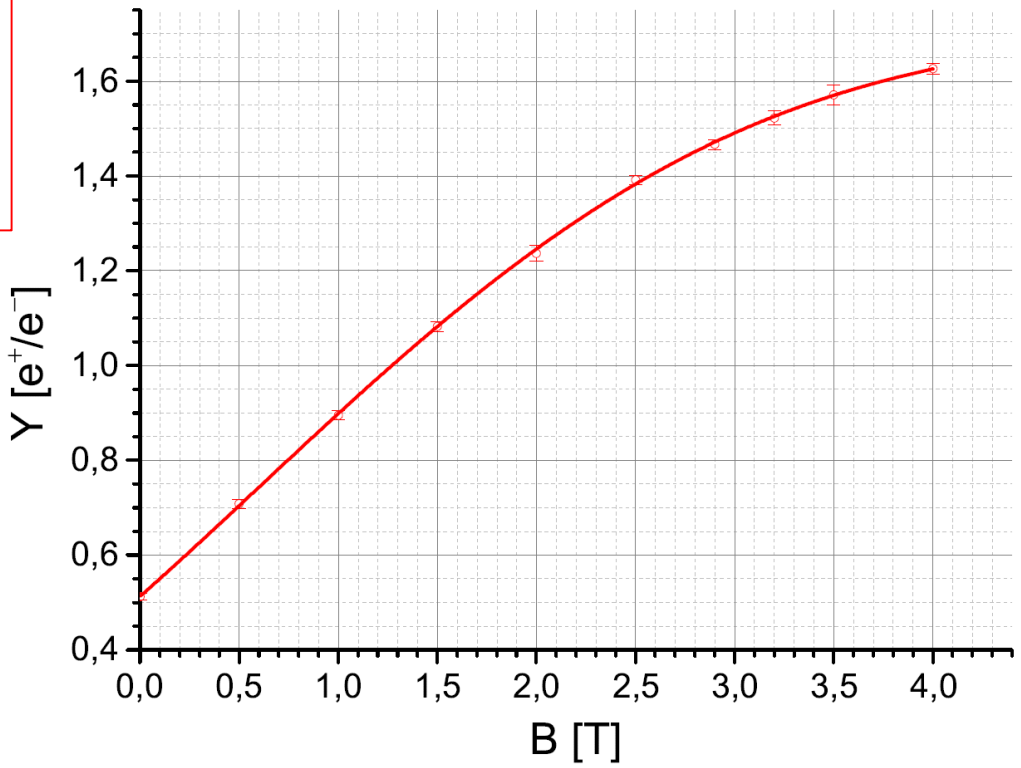


Yield vs Field of FC

125 GeV e^-, 231 m undulator with $K = 0.85$, TDR dogleg

Ushakov. 2017.4.5

QWT not the same as in previous page



e^+ source with lower field ($B < 3.2$ T) of FC or Quarter Wave Transformer (QWT) with max. field of 1 T or 1.5 T will require TDR undulator with length more than 231 m

Beam Dump

	Undulator		e-Driven	
photon dump	TDR scheme does not work. There are a few candidates. No.1 candidate is water curtain dump with tumbling window	C	Necessary but not a big issue because only a small fraction of the energy deposit comes to photon/electron dump (This means radiation shielding is important)	A
	Simple illustration only	C		
electron dump		A	must also consider the case of target absence (accident or commissioning)	A

Overall

	Undulator		e-Driven	
Target	Wheel design. Cooling calculation. Mechanical performance (magnetic bearing). Ti-Cu contact.	C	Further test of vacuum seal. W-Cu contact.	B
Matching device	FC t-dependence of field	D	Improvement from superKEKB Design of cooling	B
	QWT	B		
Capture cavity		A	Thermal deformation. Cavity cooling design.	B
Beam dump	Detailed design of the photon dump.	C	(beam dump is not an issue but radiation shielding must be studied instead)	B

R&D Plan (Undulator)

- JFY2017: mainly simulations & specifications
  - Undulator parameters
  - Temperature/stress distribution (Cu-Ti contact)
  - Wheel design based on new parameters
  - Revisit FC
- JFY 2018-19
  - Wheel
    - Lab test of radiative cooling and Ti-Cu contact, made with a small subsector of the wheel (<100k$)
    - Feasibility study for rotating wheel (~300k$, should be more))
  - FC
  - JFY 2020-
    - prototyping of target wheel & FC

S. Riemann

	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	
	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 a small sector of the 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 ???	

R&D Plan (e-Driven)

(Assume 1$=100yen)

- JPY 2017
  - Vacuum seal test on-going at 225rpm
  - Target: full-size prototype (50cmϕ, but no water circuit, no tungsten) 150k$
  - Simulation studies. Re-optimization for 1st stage. Radiation issues (to be continued to 2018)
- Following items are needed before construction. May be after JFY2019?
  - Target :
    - Cu-W braizing test, back up solution with bolts is a robust option.
    - prototype (water circuit, W, vacuum, heating test) desired. 600k$?
  - FC
    - Prototype
  - Capture cavity
  - Remote handling

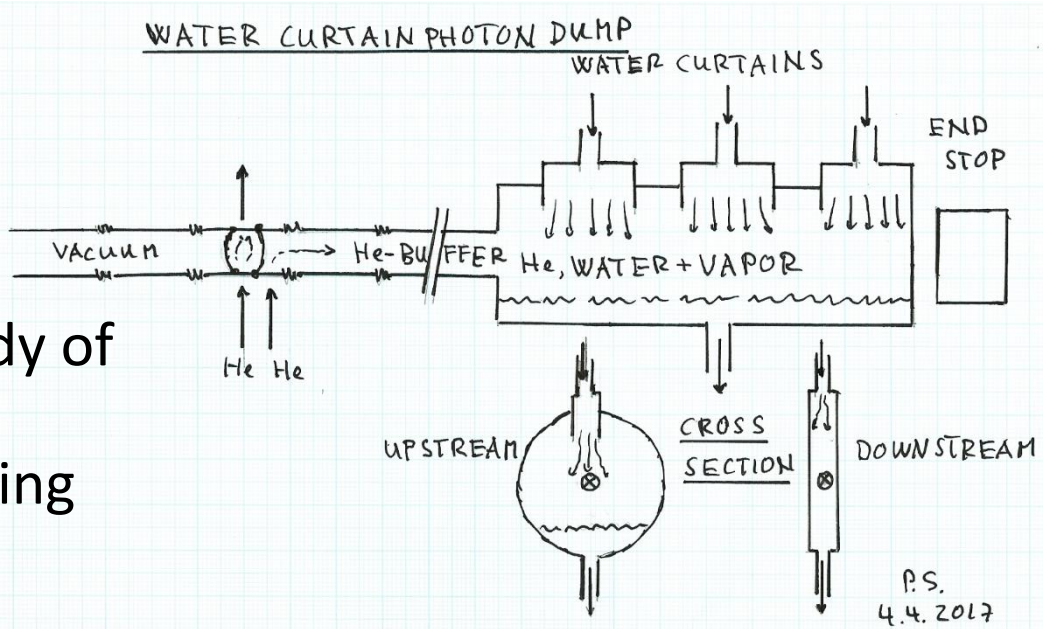
Conclusions on the Technical Feasibility

- Neither scheme is not ready now.
- e-Driven scheme seems to be closer to reality
- But obviously undulator scheme is better (polarization) if feasible
- So, we cannot down-select now
  - When can we decide? In 2019 after 2-3 year R&D?
- Main R&D issue for the undulator scheme is the mechanical performance of the target wheel.
- Flux Concentrator for undulator seems very difficult due to the time dependence of the field. A possibility when FC fails is the QWT. The positron yield is lower with QWT than with FC. Optimization of QWT needed. What level of yield is acceptable?

Photon Dump as of Staging miniWS

- Strongest candidate: water curtain @km with tumbling, thin window
  - Can avoid window to touch water
  - Can avoid heating/dpa problem
  - Easy replacement of window

- Problems to be studied
  - He or air
  - Detailed FEM study of beam-water interaction including pressure wave
  - Shielding
  - Tritium, Be^7, etc
  - Accident



WG Plan

- Would like to start to write the first report on the R&D plan
  - First draft soon, then email and, maybe ~2 meetings
- Design issues
  - Photon Dump
  - Target replacement
  - Shielding of target region
  - At least to the level that CRWG can start discussion on the electron-side tunnel