Comparison of Undulator and e-Driven Schemes

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2017/6/6

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)

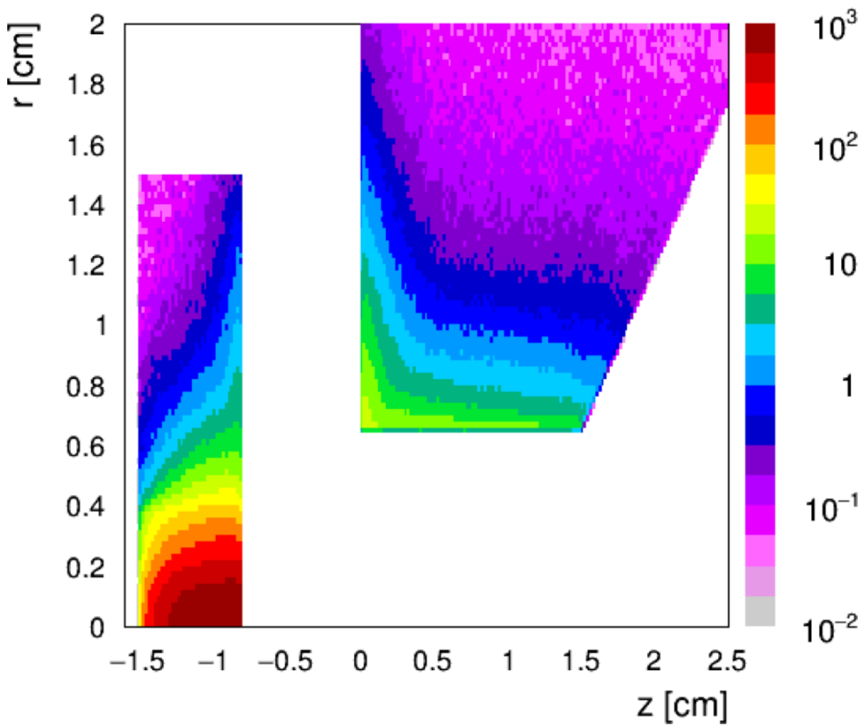
Recent Progresses (1)

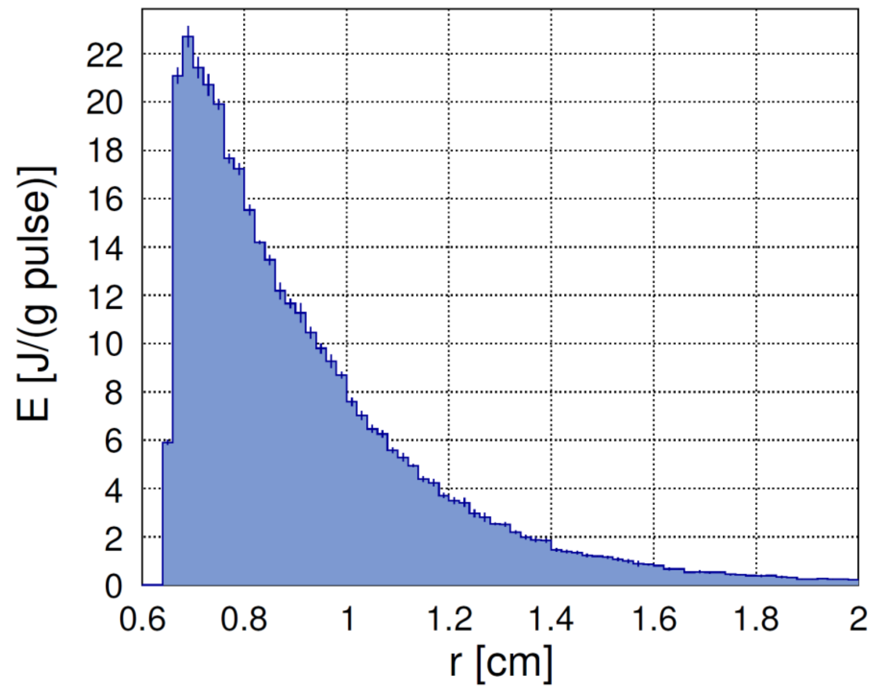
- Problem of heating FC (Flux Concentrator) by photons was found for 250GeV CM.
  - More than factor 3 higher than PEDD (Peak Energy Deposit Density) limit of Copper
  - Seems to be mainly large angle from low energy photons
  - Several cures studied
    - Move undulator closer to the target
    - Estimate the effect of masks (already in TDR., to protect undulators)
    - Thinner 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, but not sufficient yet

Energy Deposited in FC

126.5 GeV e^-, 1312 bunches/pulse, 231 m undulator with $K = 0.85$

Ushakov. 2017.5.18





PEDD = 22.7 J/(g pulse)

(31.5 J/(g pulse) without collimator)

Note: NO target rotation

PEDD upper limit for Cu = 7 ÷ 12 J/g (XFEL dump, [TESLA-FEL-2006-05])

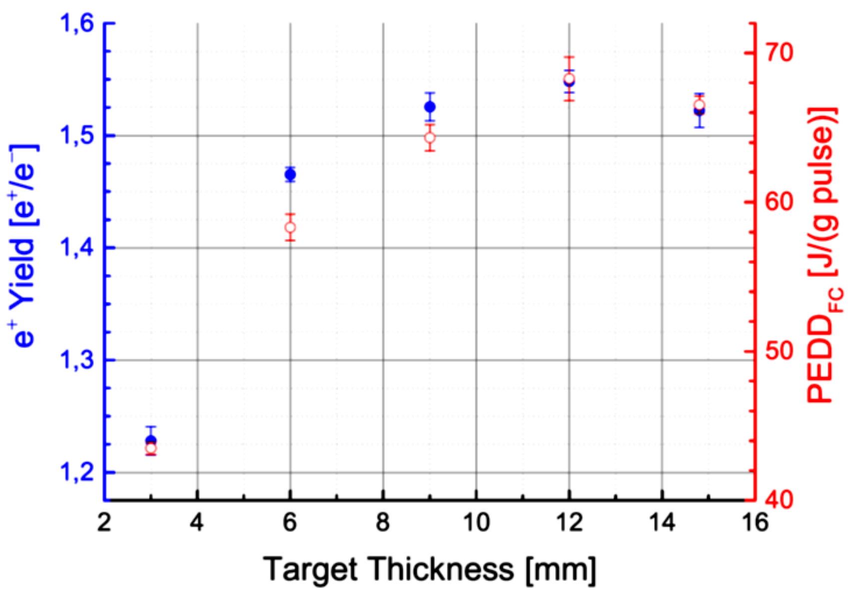
Recent Progresses (2)

- Positron yield with thinner target
  - 14mm in TDR
  - 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@15mm, 5kW@14mm
    → 2.7kW@9mm, 1.5kW@6mm (same e+ yield)
  - Reduction of PEDD on FC is not too large (~10%)
- Now, revising the undulator scheme parameters with thinner target (~7mm) for 250GeV staging

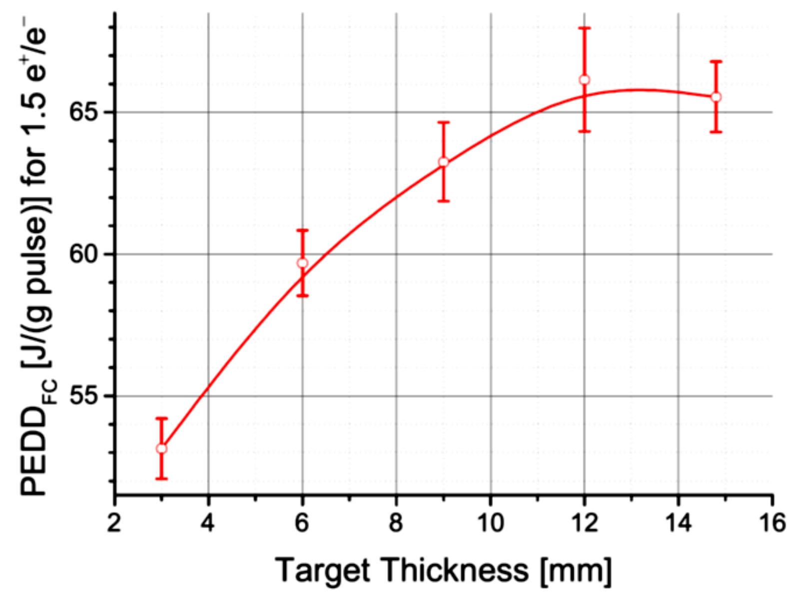
e^+ Yield and PEDD in FC vs Target Thickness

125 GeV e^-, 2625 bunches/pulse, undulator $K = 0.85$

Fixed Undulator Length (231 m)



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



- 9 mm: −3.5% PEDD, approx. same length of undulator L_u
- 6 mm: −9% PEDD, +4% L_u
- 3 mm: −19% PEDD, +24% L_u (+55 m → *compact dog-leg*?)

Comparison of 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.
- However, these are well known by now. At this moment the primary issue is the technical feasibility.
  - 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.

Driver Beam

	Undulator		e-Driven	
Input beam	Undulator photons		S-band NC Electron Linac	
	231m undulator for 125GeV electron		3 GeV electron	
Issues	field accuracy	B	300 Hz	B
	alignment	B		
	(better if the undulator pitch is reduced, but for now assume no improvements)			

Alignment/Field accuracy of Undulators

- The photon beam must hit the target with an accuracy better than ~1mm. If this is routinely satisfied, we need not worry about the case that the beam misses the dump window.
- Since the photons are emitted forward of electron, an alignment algorithm of minimizing the electron angle (not position) must be developed.
- Once aligned, a feedback system can keep the photon spot.
- The undulator field must be accurate such that integral B(s) ds / integral |B(s)| < $\sim 10^{-4}$. Otherwise, the electron would be bent by more than $1/\gamma$ in an undulator. I think the first prototype at Cockcroft did not satisfy this.

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	
Status/issues	Wheel	Specification not determined yet (coming soon)	C	Durability of Magnetic fluid under radiation confirmed	A
		magnetic bearing under study	C	Rotation test ongoing in vacuum	B
	Cooling	calculation only	C		
		Lab test plan proposed			
		Ti-Cu joint	B	W-Cu joint. Lab tests still to be done with a 50 cm wheel.	B

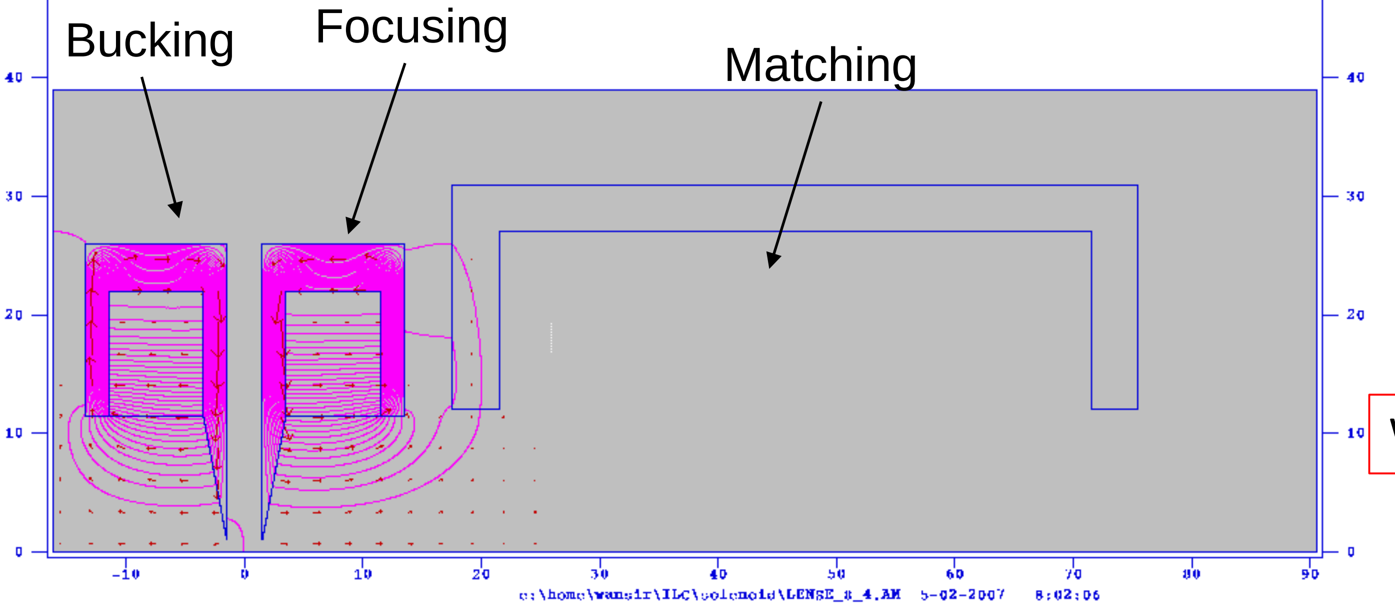
Life Time of the Wheel

- Right now the only criterion is PEDD 30J/g which came from SLC experience
- It can be questioned how general this criterion is.
  - Average power, average temperature, dpa,.....,
- Further tests seem to be non-realistic at least for the time scale of ILC
- Must prepare for frequent target replacement

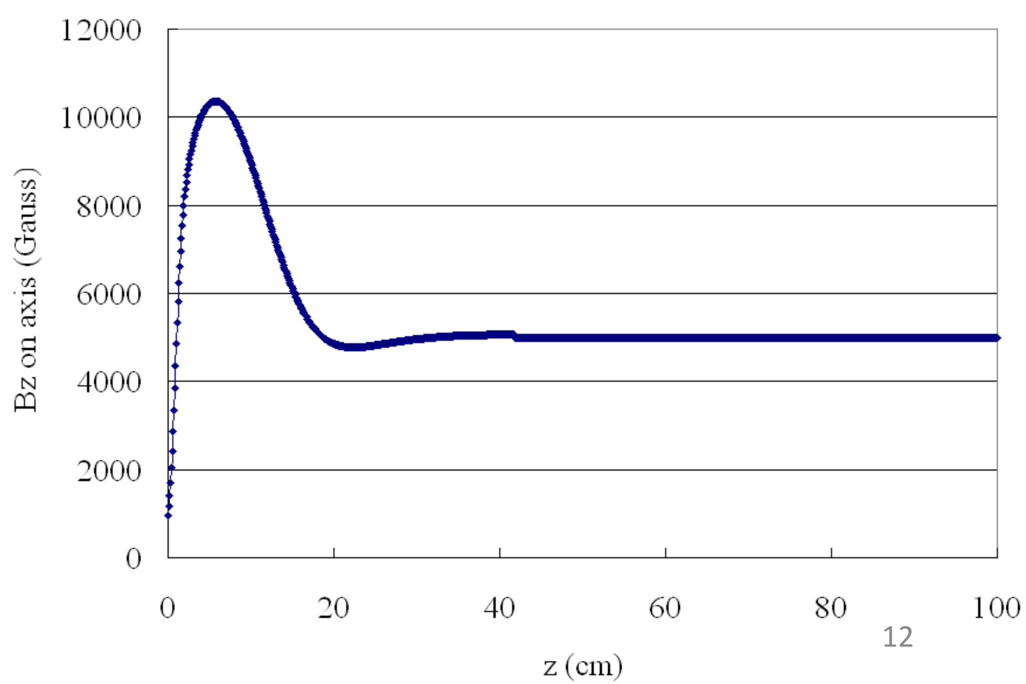
Matching Device

	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 & 2 coils. 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	B
	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		

QWT



Wanming Liu

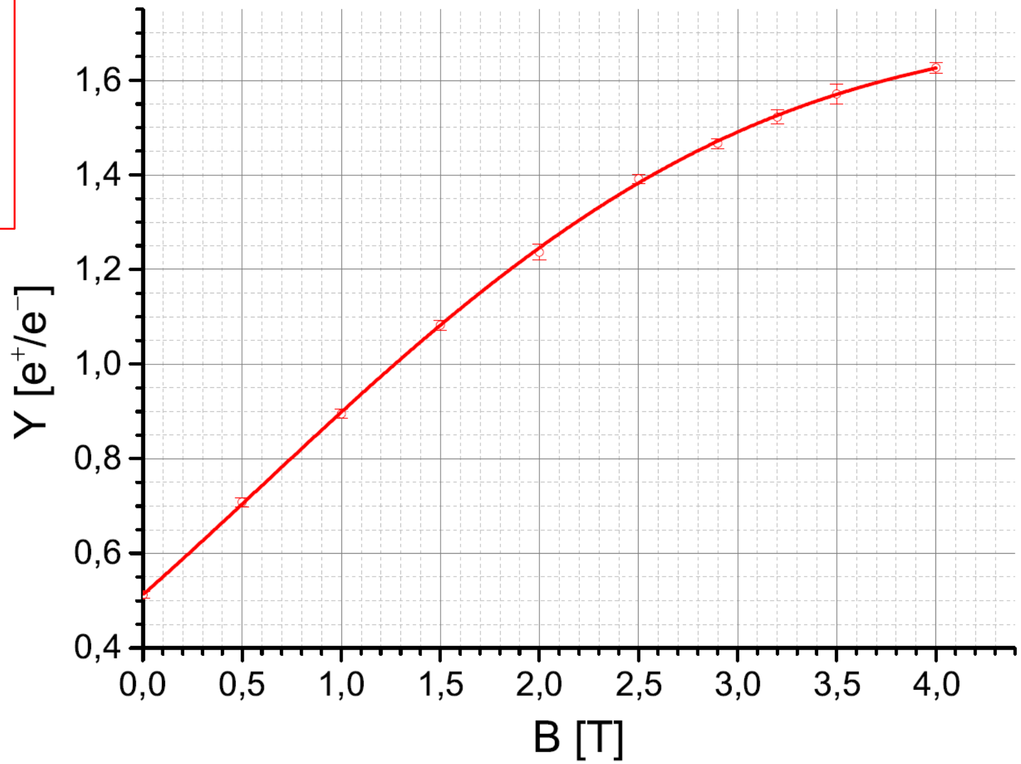


Yield vs Field of FC

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

Capture Cavity

	Undulator		e-Driven	
Specification	L-band NC		L-band NC	
Issues	long pulse NC	A	cavity deformation by heating	B
			transient loading compensation	B
			cooling not yet designed	B
			durability under radiation	B

Beam Dump

	Undulator		e-Driven	
photon dump	TDR scheme does not work. 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

Shielding and Target Replacement

- Definitely needed but not urgent now
- Can be done later
- For both, the civil engineering has to be fixed soon? Access, safety, tunnel size, cranes, transport vehicles, lifts,….

	Undulator		e-Driven	

Upgrade to 2625 Bunches

	Undulator		e-Driven	
Issues	Larger/heavier wheel needed because of doubled average power. The weight of the wheel will be > 100kg. The life may be short.	B	loading compensation difficult if the bunch interval is 3ns (i.e., in case 2nd DR is not built).	D
			If the bunch interval is 6ns (i.e., build 2nd positron DR), there is still a possibility to accept 2625 bunches, but various studies are needed	B

2625 Bunches with Undulator

- The average power deposit on the target with 1312 bunches for the yield e+/e-=1.5 (decelerating capture)

Beam energy (GeV)	125	150	175	250
kW	5.4	3.9	3.3	2.3

Ushakov. Posipol 2016.

- These must be doubled for 2625 bunches
- But recent study showed 5.4kW for 125GeV can be decreased to 1/3-1/2.
- Then, doubled bunch number may still be possible at 125GeV, also at 250GeV.
- Further study needed. The main issue seems to be the required weight of the target wheel. Sabine suggests possible reduction of the weight (thinner body for thinner target, lighter central part)

Overall

	Undulator		e-Driven	
Positron pol.	Yes	A	No	
Timing constraint	Needed		No needed (but will be taken into account)	
2625 bunches	May be OK but more heating	B	Presumably no unless 2nd positron DR is added	D
			May be OK if 2nd DR	B
Target		C		B
Matching device	FC t-dependence of field	D	Improvement from superKEKB	B
	QWT	B		
Capture cavity		A		B
Beam dump		C	(beam dump is not an issue but radiation shielding must be studied instead)	B
Cost		A	No serious evaluation. May be slightly more expensive.	B

R&D Plan (Undulator)

- JFY2017: mainly simulations & specifications
  - Undulator parameters
  - Temparature/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 ???	

Yokoya

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

- e-Driven scheme seems to be closer to reality but we cannot down-select now
  - When can we decide? In 2019 after 2-3 year R&D?
  - Tentative decision in April was
    - Continue the on-going works for e-driven in JFY2017
    - Concentrate more on undulator in JFY2018-19
- Main R&D issue for the undulator scheme is the mechanical performance of the target wheel.
- Flux Concentrator for undulator seems very difficult. A possibility when FC fails is the QWT. TDR says the positron yield with QWT is 1/1.6 times FC (this number must be confirmed). Are we satisfied with a lower luminosity?