ILC RDR baseline schematic

Electrons   Positrons

Undulator   Detectors   Electron source

Beam delivery system

~147 GeV e⁻   target   pre-accelerator (125-400 MeV)   booster linac (cryomodules to boost energy to 5 GeV)

150 GeV e⁻

helical undulator   collimator (upgrade)   OMD   capture RF (125 MeV)   e⁻ dump   γ dump   Damping Ring

Parameters:

- Optimize the positron yields for known technologies:
  - Superconducting helical undulator.
    - Undulator parameter: K=0.92, λ_u=1.15cm
  - Capturing magnets
    - Optical matching device: FC and ¼ wave transformer
  - Targets: 0.4 X0 Ti, W and liquid Pb also considered (not covered in this talk).
- Damping ring acceptance
  - Energy spread < 1%
  - emittance_x+emittance_y < 0.09 m-rad
- Goal:
  - Achieve yield of 1.5 positrons per electron in the drive beam.
    - No polarization required.
   - Polarization required.

Status of the critical hardware components

- 4 meter cryo-module, two 1.7m long RDR undulator. (Completed, STFC/RAL/Daresbury)

- Target wheel prototype design and test. (Lancaster/Cockcroft/STFC/LLNL)

- Rotating vacuum seal prototype test. (LLNL, ongoing)

- Capturing RF structure. (SLAC, Completed)

- Flux Concentrator prototype design. (LLNL, ongoing)

- New short period, high K undulator. (Cockcroft/STFC, ongoing).
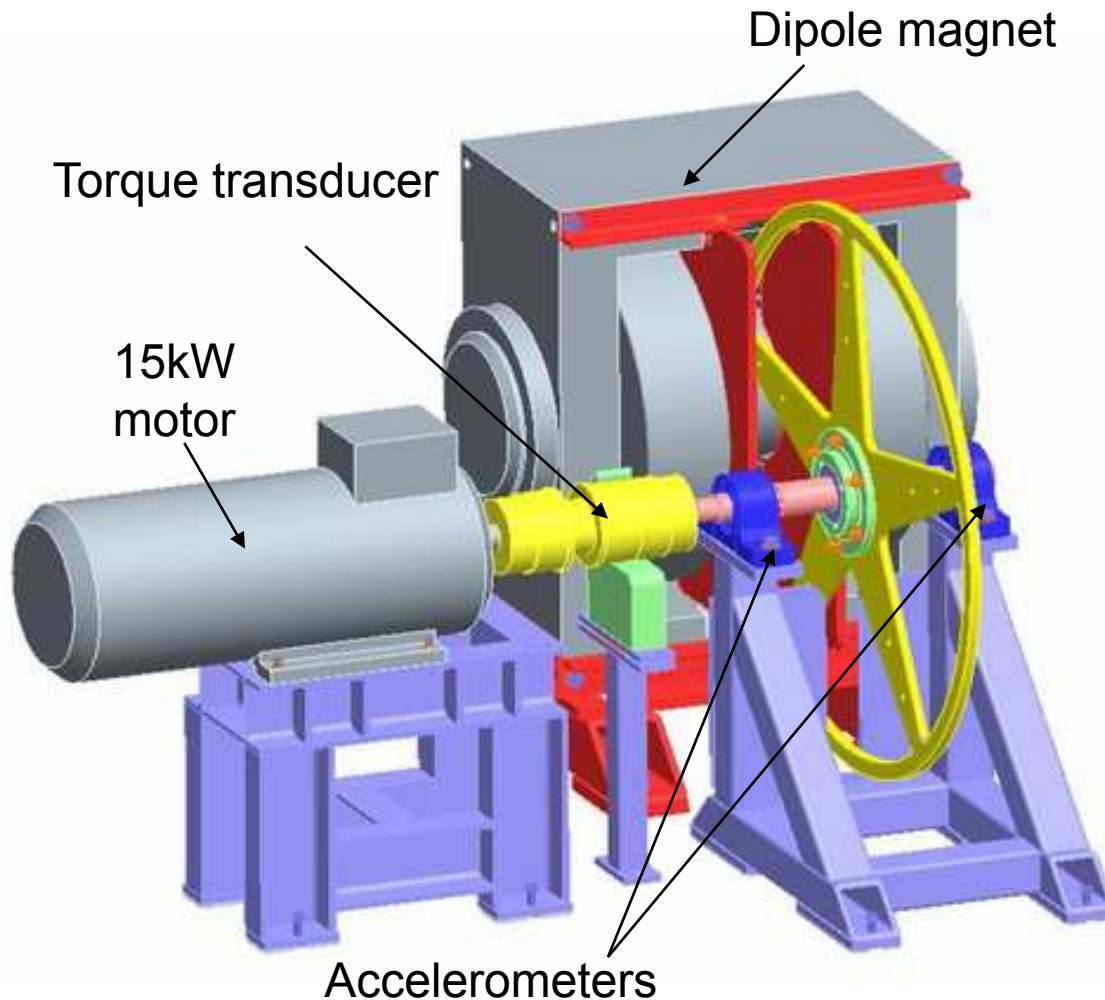
4 metre Cryomodule

- Two 1.7 metre helical undulator magnets have been successfully made using NbTi.

- Magnets positioned back to back in cryostat.
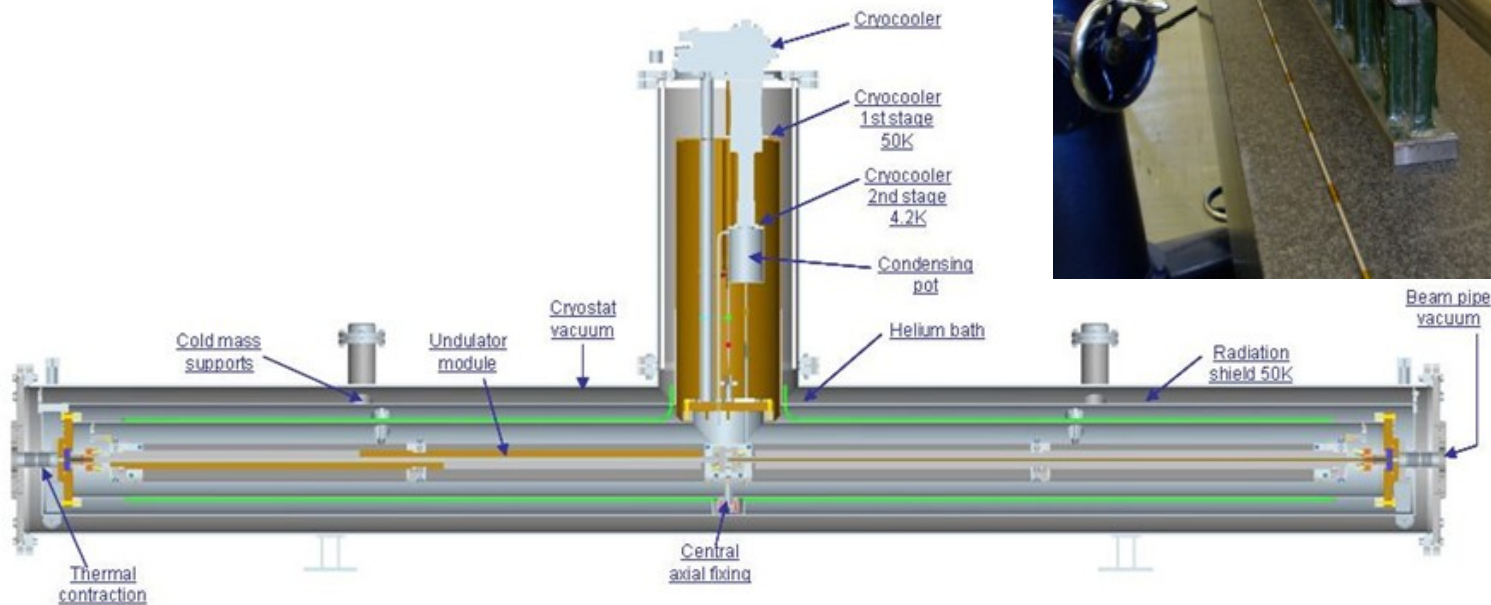
EuCard Meeting, 7-4,
University of Geneva,
8/9 June

ILC Real target:
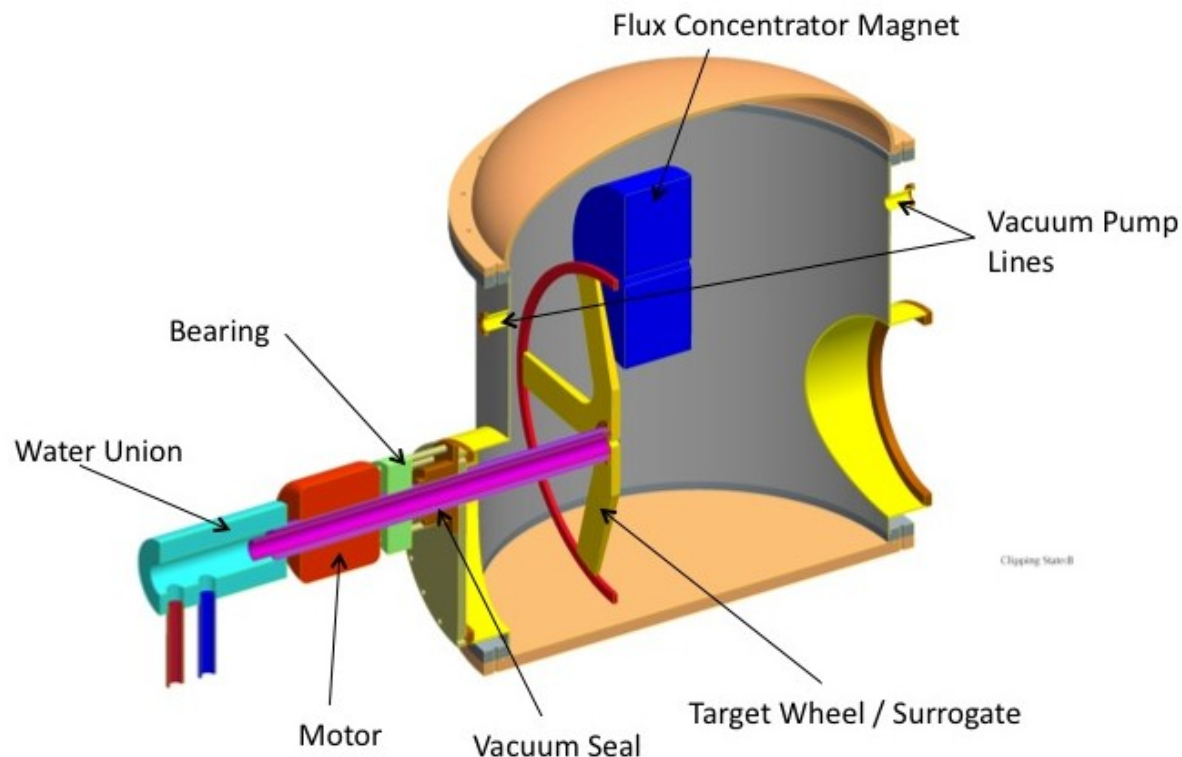Wheel diameter: 2m
Spinning Speed ~ 900 rpm
Thickness: 1.4 cm

Target Prototype Design and Testing (Ian Bailey, Lancaster/Cockcroft/STFC/LLNL): 1 meter diameter; 2000 rpm, Work Completed.

Dipole magnet

Torque transducer

15kW motor

Accelerometers

m_{wheel}~18kg

Prototype II - Rotating vacuum seal test

Flux Concentrator Magnet

Vacuum Pump Lines

Bearing

Water Union

Motor

Vacuum Seal

Target Wheel / Surrogate

Clipping State B

- Current design has rotating ferrofluidic vacuum seals
- Cooling water flows along the shaft

- Test leakage of vaccum/fluids from:
  - **Vibration**
  - **Magnetic field effects**
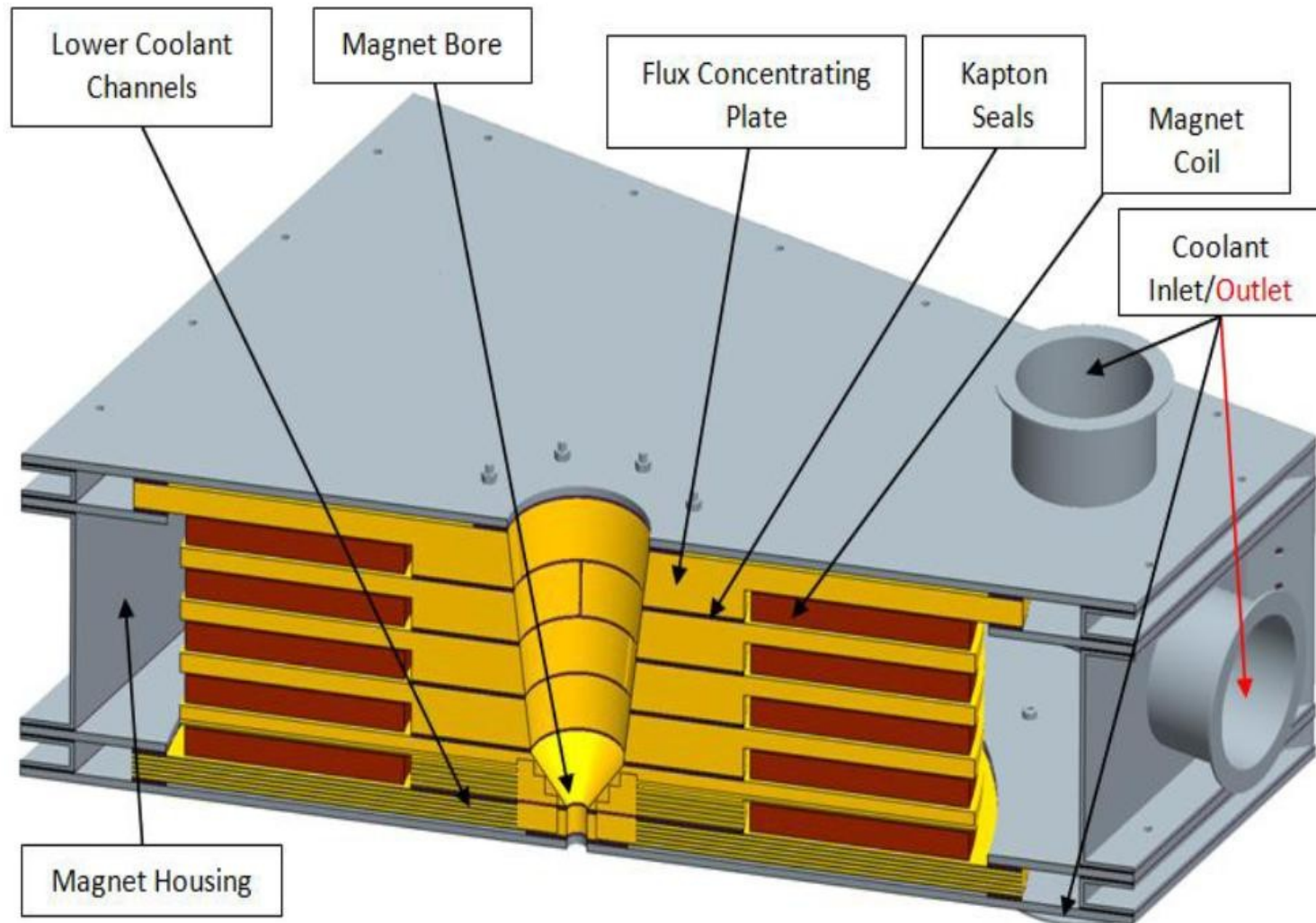
Vacuum seal test
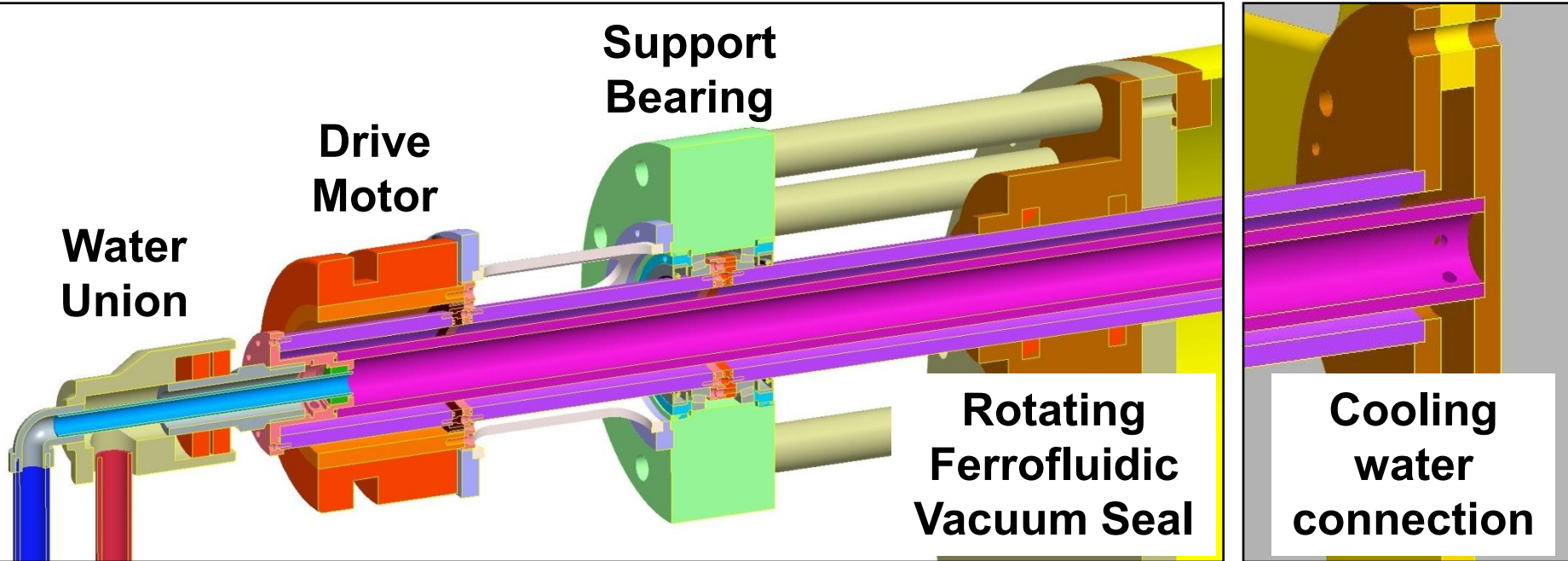
- Altered layout after discussions with Rigaku
- Single-shaft design, larger bore
- Hollow shaft motor Rigaku has used previously
- Water union may not be in this test configuration
  - Daresbury prototype wheel does not have cooling channels
  - Water in shaft only

Vacuum seal test

- Rotordynamics analysis and design for cantilevered layout
  - **Changed layout from Daresbury test**
  - **Requires re-evaluation of vibration modes due to new components and configuration**
- Diagnostics setup (pressure sensors, filter and witness plate chemical analysis, mechanical behavior)
- Developing drawings
- Acquire LLNL ES & H approval for operating plan

Flux concentrator layout

Lower Coolant Channels

Magnet Bore

Flux Concentrating Plate

Kapton Seals

Magnet Coil

Coolant Inlet/Outlet

Magnet Housing

1. <u>Higher gradient (~ 15 MV/m) shorter structures</u>

   Single π mode short SW structure or pair of half length sections fed with 3db hybrid for RF reflection cancellation.

   - It is simpler and feasible (stabilization) for 11-cavity short SW structure.
   - Lower pulse heating.
   - Larger iris size (60 mm diameter) with reasonable shunt impedance.
   - Efficient cooling design.

2. <u>Lower gradient (~ 8 MV/m) longer structures</u>

   TW constant gradient sections with higher phase advances per cell.

   - Using "phase advance per cell" as a knob to optimize the RF efficiency for different length of structure.
   - It is simpler and feasible.
   - Lower pulse heating.
   - Easier cooling design.
   - Easier for long solenoids solution.
   - Less concern on multipacting and klystron protection from RF power reflection.

3. <u>Four types of structures have been designed.</u>
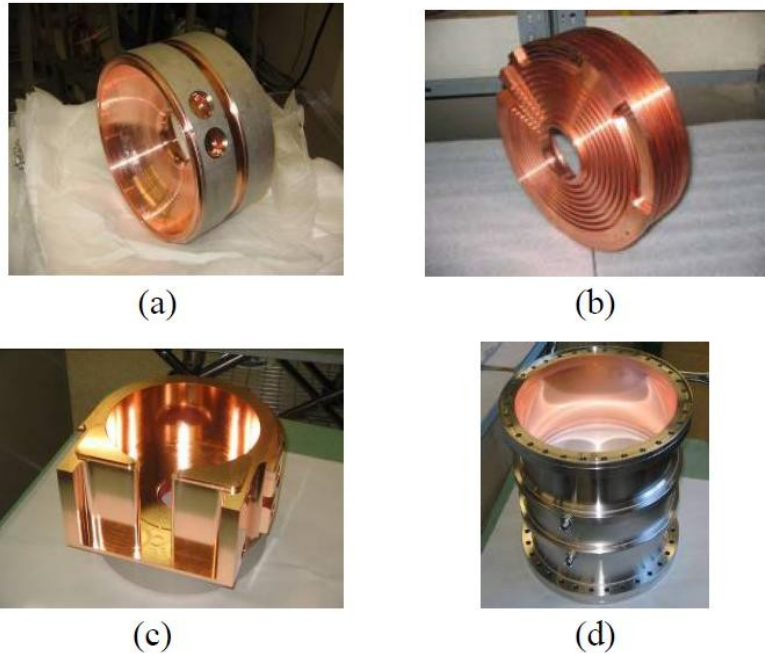
Prototyping a SW cavity for ILC e+ source.

Figure 6.   Some of the subassemblies for the 5-cell SW structure: a completed unit cell (a), a half cell to be brazed on the input coupler (b), coupler subassembly (c) and L-Band RF window (d).
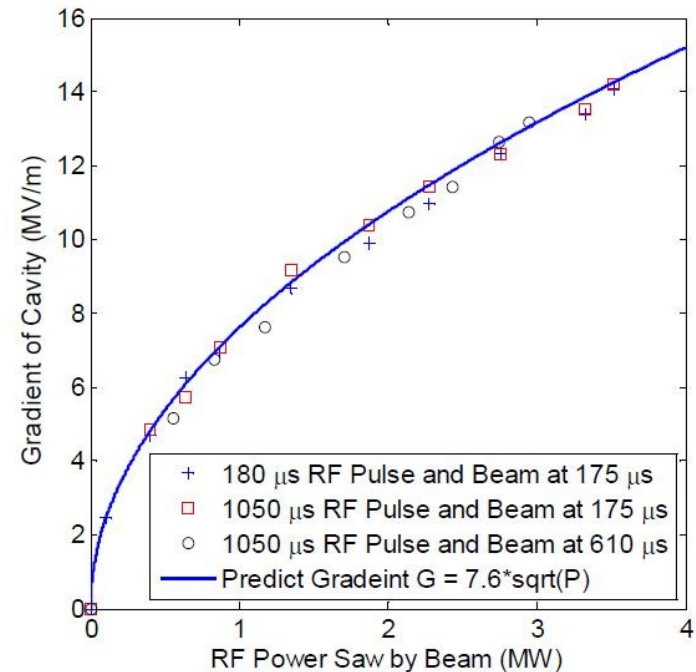
Figure 2:   Gradient prediction and measurement with single bunch versus the net cavity input power (forward – reflected) for different pulse widths and bunch injection times.

- Fabricated and conditioned at SLAC, achieved 13.8 MV/m with breakdown of 1/hr.
- Figures from Juwen Wang and Faya Wang

ILC Positron source optimization: Cases Studied:

- Common Input Parameters:
  - Undulator parameter: K=0.92, λu=1.15cm
  - Target: 0.4 X0 Ti
  - Drift between undulator and target: 400m
  - Photon collimator: None
- OMD:
  - Flux Concentrator Capturing (137 m long Undulator).
  - Quarter Wave Transformer Capturing (231 m long undulator).
- Undulator Impacts on Drive Beam
  - Energy Spread and,
  - Emittance
- Target Energy Deposition.
- Path toward higher polarizations
  - Photon collimators

A pulsed flux concentrator

- Pulsing the exterior coil enhances the magnetic field in the center.
  - Needs ~ 1ms pulse width flattop
  - Similar device built 40 years ago. Cryogenic nitrogen cooling of the concentrator plates.

PULSED FLUX-CONCENTRATOR MAGNET   1531

Fig. 4. End view and side section of flux concentrator final design.
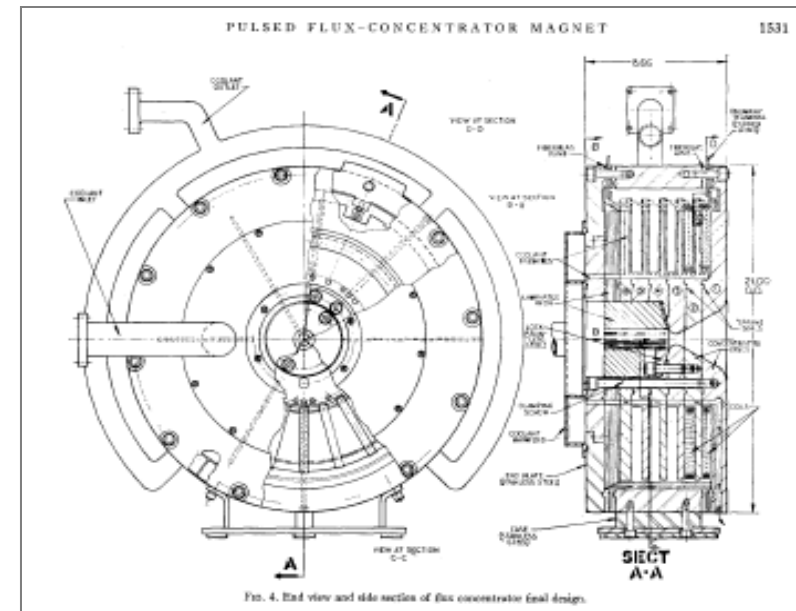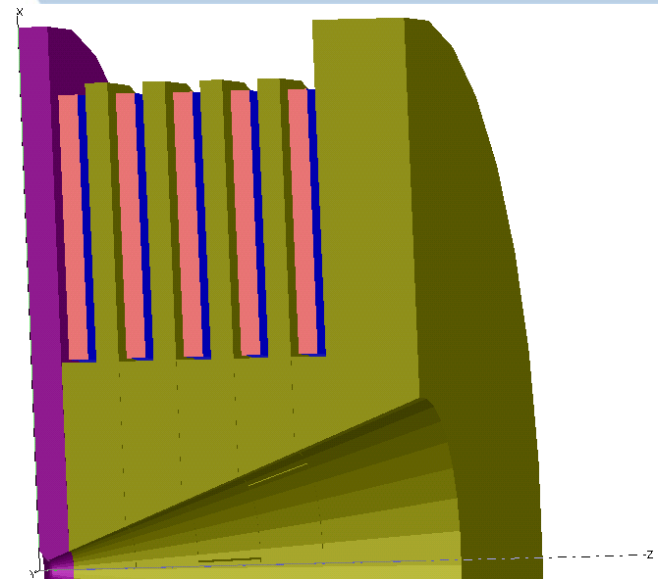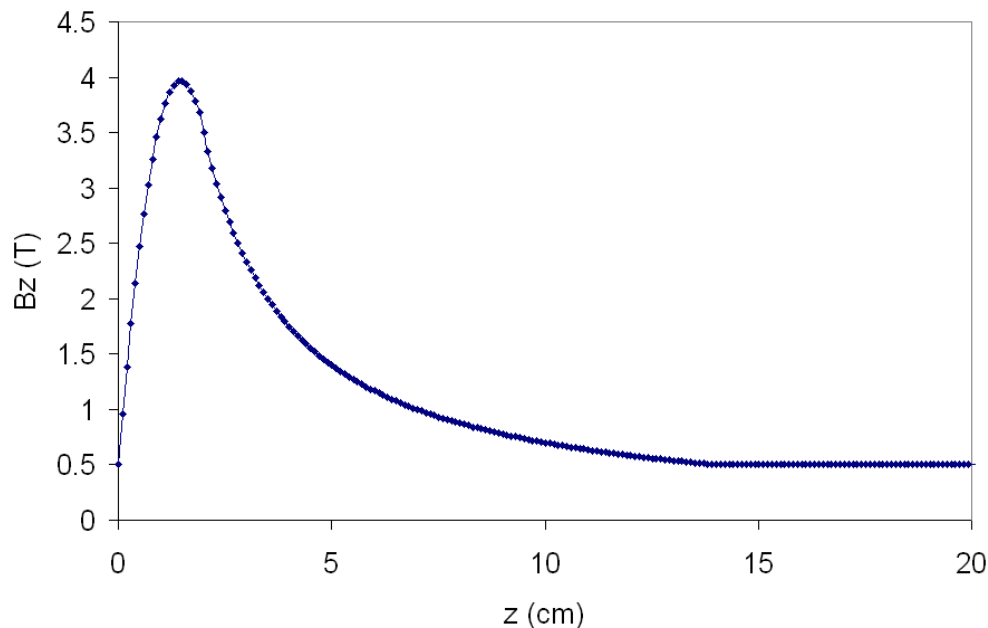
Yield Calculations Using RDR Undulator Parameters (137 meter and FC without photon collimators)

Drive beam energy	Yield	Polarization	Required Undulator Length for 1.5 Yield	Emittance Growth X/Y for 1.5 Yield*	Energy Spread from Undulator for 1.5 Yield
50 GeV	0.0033	0.42	Very long		
100 GeV	0.2911	0.39	685 m		
150 GeV	1.531	0.34	137 m	~ -2.5%/-1.6%	0.17%
200 GeV	3.336	0.27	61 m		
250 GeV	5.053	0.23	40 m	~-1%/-0.4%	0.18%

* No Quads misalignment included.

Emittance growth due to BPM to Quad misalignments
-- From Jim Clark's report

Table 2 Summary of the vertical emittance growth results due to BPM to quadrupole misalignments.

	BPM to quadrupole Error (μm)	Vertical emittance growth (%)	Correction algorithm
ANL	20	5	None
Daresbury	10	8	SVD
Daresbury	20	15	SVD
Kubo	10	2	Kick minimisation
Schulte	10	5	Dispersion free
Schulte	10	10	Dispersion free (restricted energy range)
Schulte	30	10	Kick minimisation

# RDR undulator, Quarter Wave Capturing Magnet (SB2009)

- Undulator: RDR undulator, K=0.92, λu=1.15cm
- Length of undulator: 231m
- Target to end of undulator:400m
- Target: 0.4X0, Ti
- Drive beam energies: 50GeV to 250GeV (SB2009)
- Reference: 150 GeV

¼ wave solenoid

- Low field, 1 Tesla on axis, tapers down to 1/2 T.
- Capture efficiency is only 25% less than flux concentrator
- Low field at the target reduces eddy currents
- This is probably easier to engineer than flux concentrator
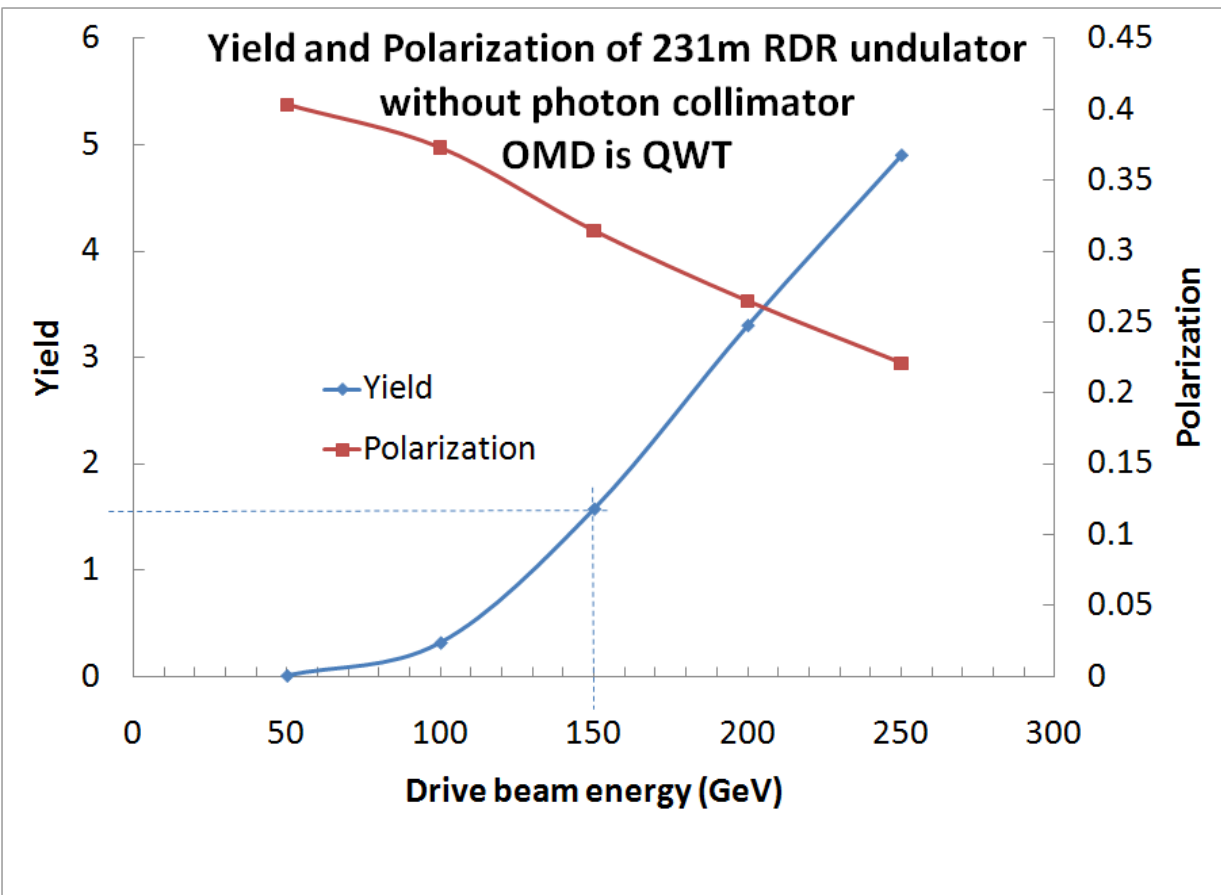- SC, NC or pulsed NC?
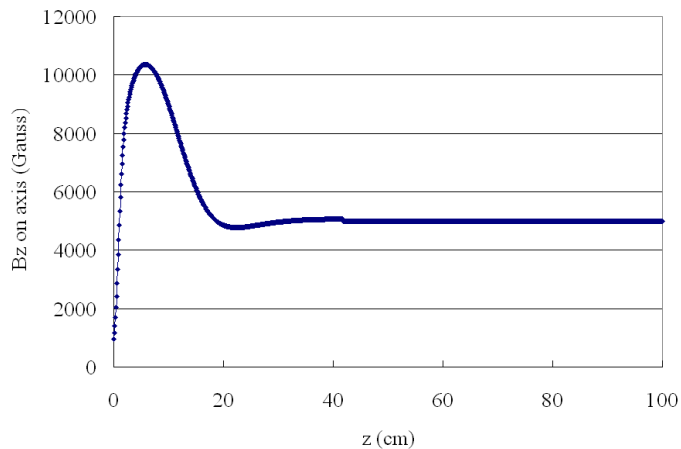
ANL ¼ wave solenoid simulations
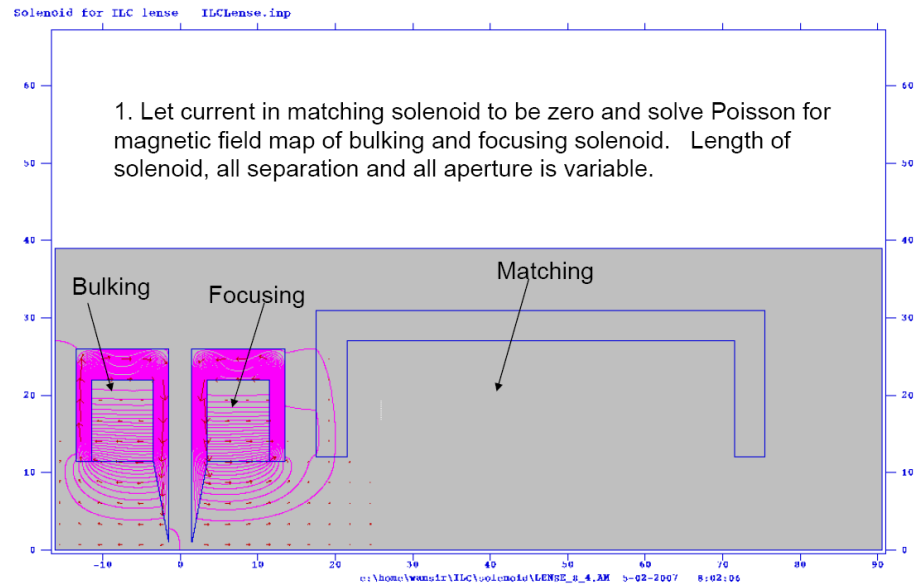
The target will be rotating in a B field of about 0.2T

W. Liu

Yield and polarization of RDR configuration for different drive beam energy (for SB2009)

Yield and Polarization of 231m RDR undulator without photon collimator OMD is QWT

Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield
50GeV	~225MeV	N/A
100GeV	~900MeV	~9.9GeV
150GeV	~2GeV	~4.6GeV
200GeV	~3.6GeV	~3.7GeV
250GeV	~5.6GeV	~3.96GeV

Drive beam energy	Yield	Polarization
50GeV	0.0041	0.403
100GeV	0.3138	0.373
150GeV	1.572	0.314
200GeV	3.298	0.265
250GeV	4.898	0.221

OMD comparison

- Same target
- Beam and accelerator phase optimized for each OMD
- OMD compared:
  - AMD
  - Flux concentrator
  - ¼ wave transformer
  - Lithium lens

OMD	Capture efficiency
Immersed target, AMD (6T-0.5T in 20 cm)	~30%
Non-immersed target, flux concentrator (0-3.5T in 2cm, 3.5T-0.5T 14cm)	~26%
1/4 wave transformer (1T, 2cm)	~15%
0.5T Back ground solenoid only	~10%
Lithium lens	~29%

Energy deposition/accumulation on Target with RDR undulator

Density of accumulated deposit energy (for RDR rotating target)

| 1.5 yield / 3e10 e+ captured,	Ti target (density=4.5 g/cm^3)				
	Thickness for highest yield (X0)	Energy deposition per bunch (J.)	Average power (KW)	Peak energy density	
				(J/cm^3) ;	(J/g)
150GeV,FC (137 m)	0.4	0.72	9.5	348.8	77.5
250GeV, FC (40 m)	0.4	0.342	4.5	318.8	70.8
150GeV, QWT (231 m)	0.4	1.17	15.3	566.7	126
250GeV, QWT (76 m)	0.4	0.61	8.01	568.6	126.4

Shockwaves in the target

- Energy deposition causes shockwaves in the material
  - **If shock exceeds strain limit of material chunks can spall from the face**
- The SLC target showed spall damage after radiation damage had weakened the target material.

- Initial calculations from LLNL had shown no problem in Titanium target
- Two groups are trying to reconfirm result
  - **FlexPDE (S. Hesselbach, Durham → DESY)**
  - **ANSYS (L. Fernandez-Hernando, Daresbury)**
  - **No definative results yet**
- Investigating possible shockwave experiments
  - **FLASH(?)**
  - **https://znwiki3.ifh.de/LCpositrons/TargetShockWave Study**

SLC positron target after decommissioning


Contours of P in MPa

S. Hesselbach, Durham
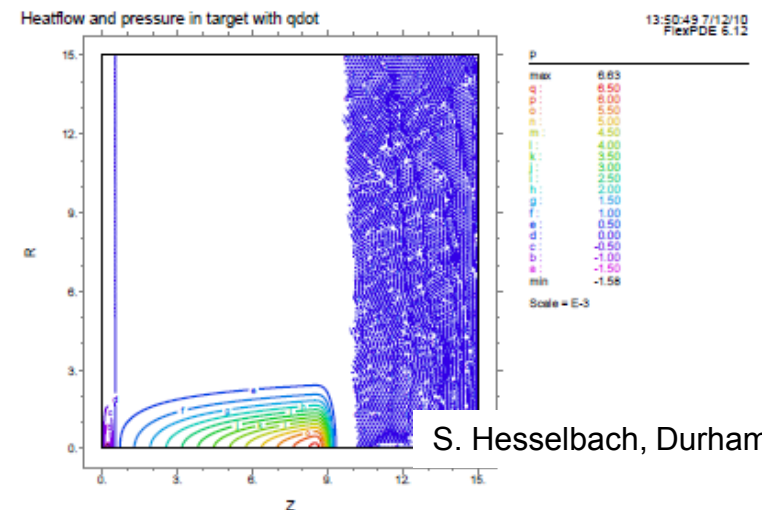
High K and short period λ Undulator Option

- Important to SB2009 scenarios.

- Assumptions:
  - Length of undulator: 231m
  - Drive beam energy: 100GeV
  - Target: 0.4X0, Ti
  - Photon Collimation: None
  - Drift to target: 400m from end of undulator
  - OMD:FC, 14cm long, ramping up from 0.5T to over 3T in 2cm and decrease adiabatically down to 0.5T in 12cm.

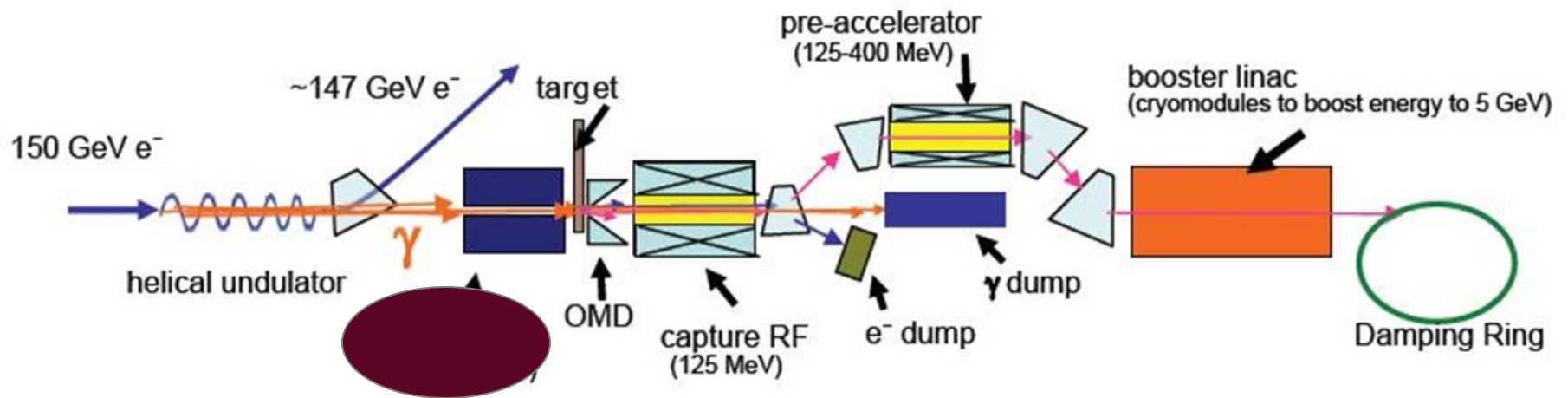- Probably aperture will be relative small (no number yet). Impact to the drive beam to be studied.

High K, short period, 100GeV drive
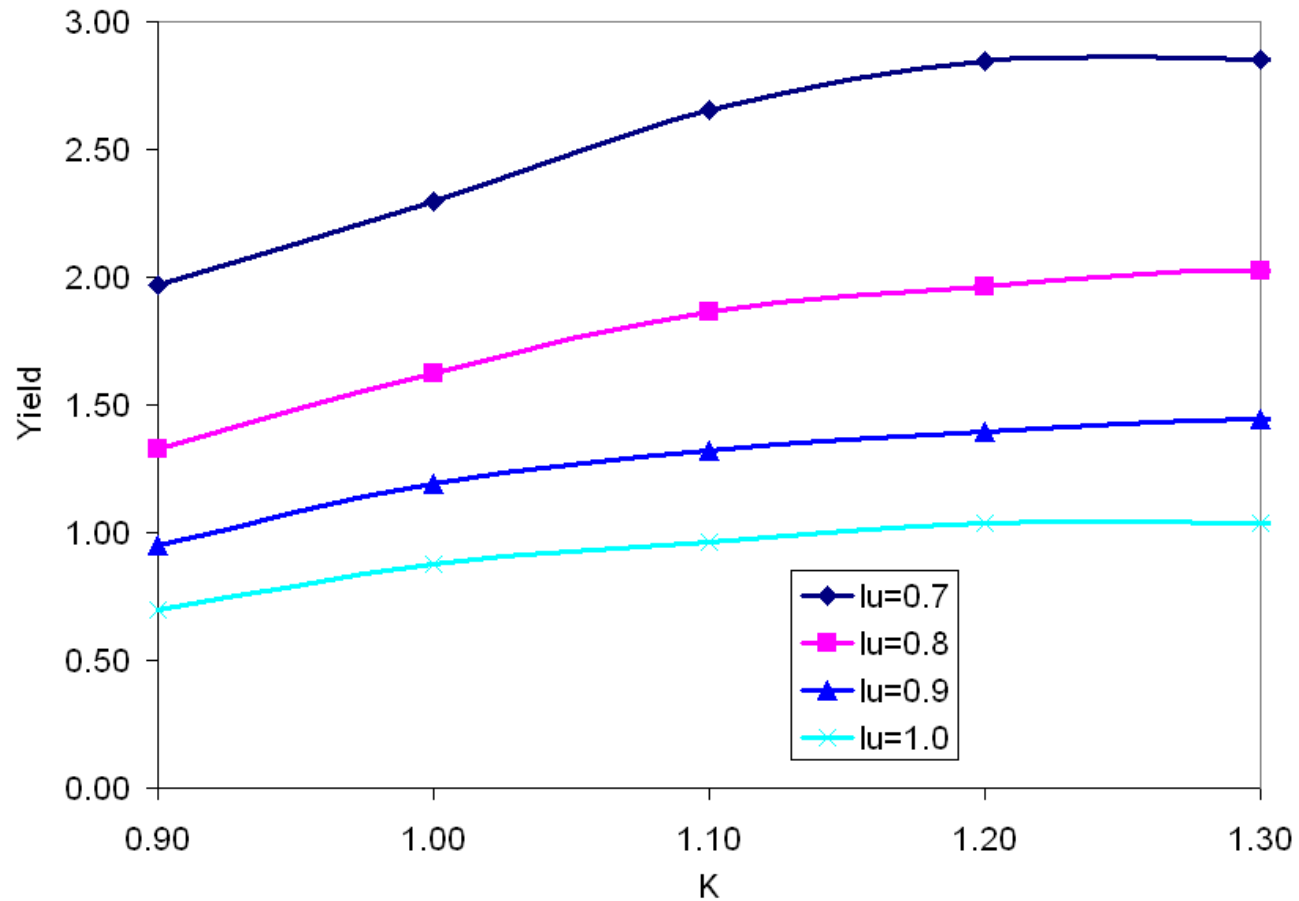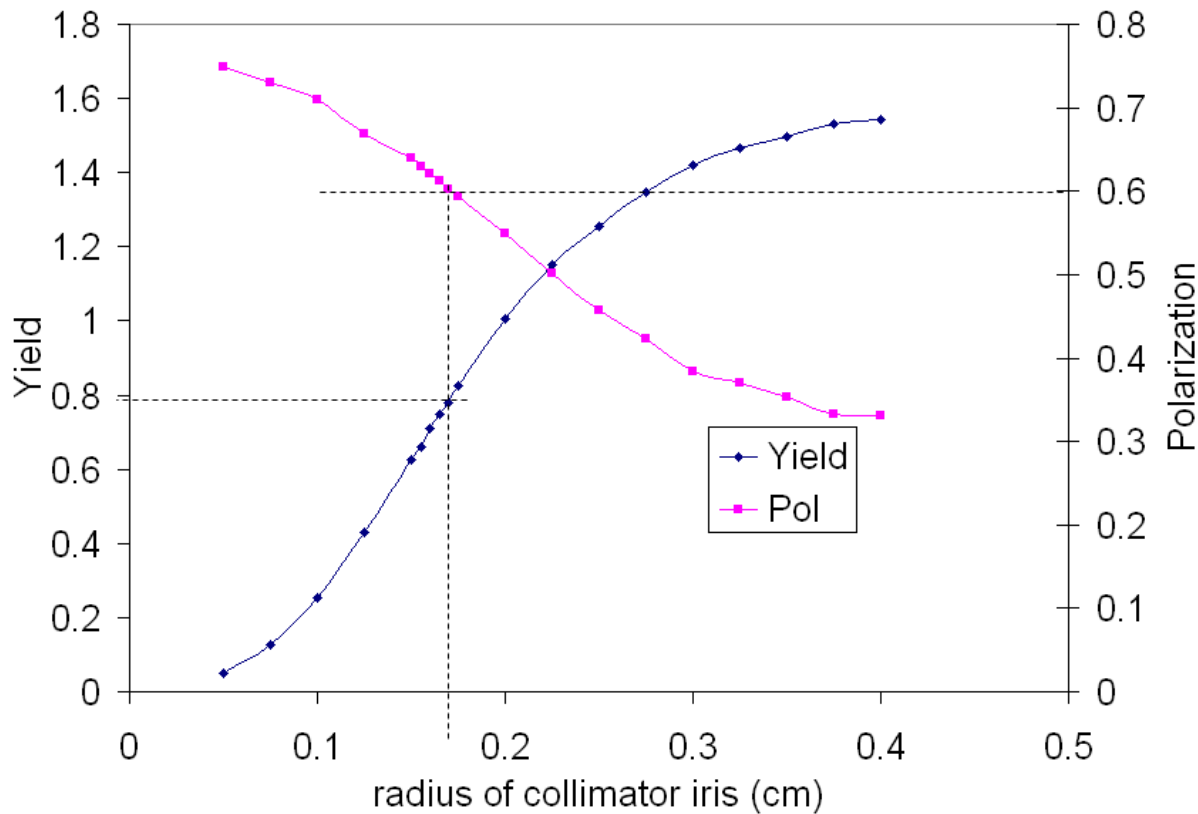
Towards High Polarizations

- Most sensitive parameter: Transverse photon distribution:
  - Photon Collimation would eliminate unwanted off axis photons that have low polarization.
  - Other parameters (drive beam energy and low K undulator) also have influences, but not dominate (skipped from this presentation).

150 GeV e⁻

~147 GeV e⁻   target

pre-accelerator
(125-400 MeV)

booster linac
(cryomodules to boost energy to 5 GeV)

helical undulator

γ

OMD

capture RF
(125 MeV)

e⁻ dump

γ dump

Damping Ring

Polarization upgrade

231m RDR undulator, 150GeV drive beam, ¼ wave transformer

With QWT, with a photon collimator to upgrade the polarization to 60%, the positron yield will drop to ~0.8

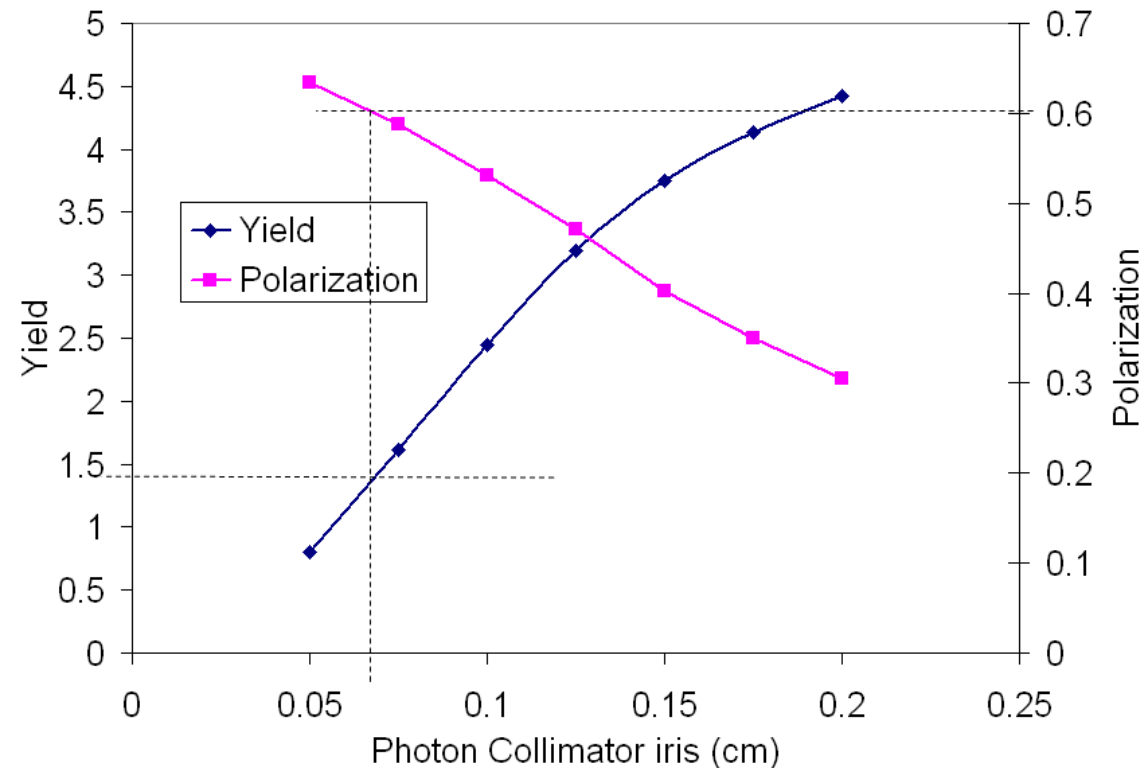| Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield and 60% polarization
150GeV	~2GeV	~8.8GeV

Yield with 60% Pol. As function of drive beam energy. 231m long RDR undulator

Flux concentrator is used as OMD
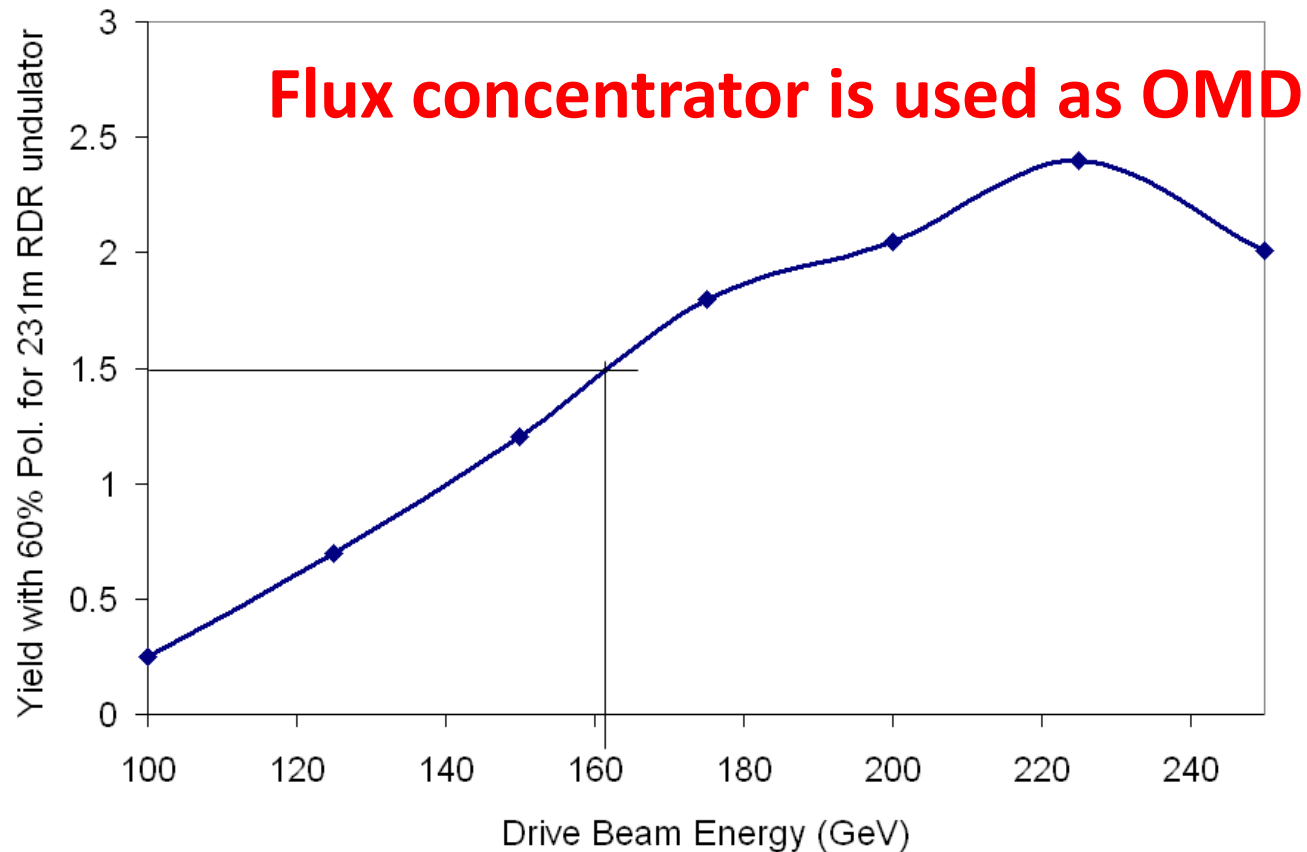
- Yield of 1.5 with 60% yield can be reached with drive beam energy of ~162GeV
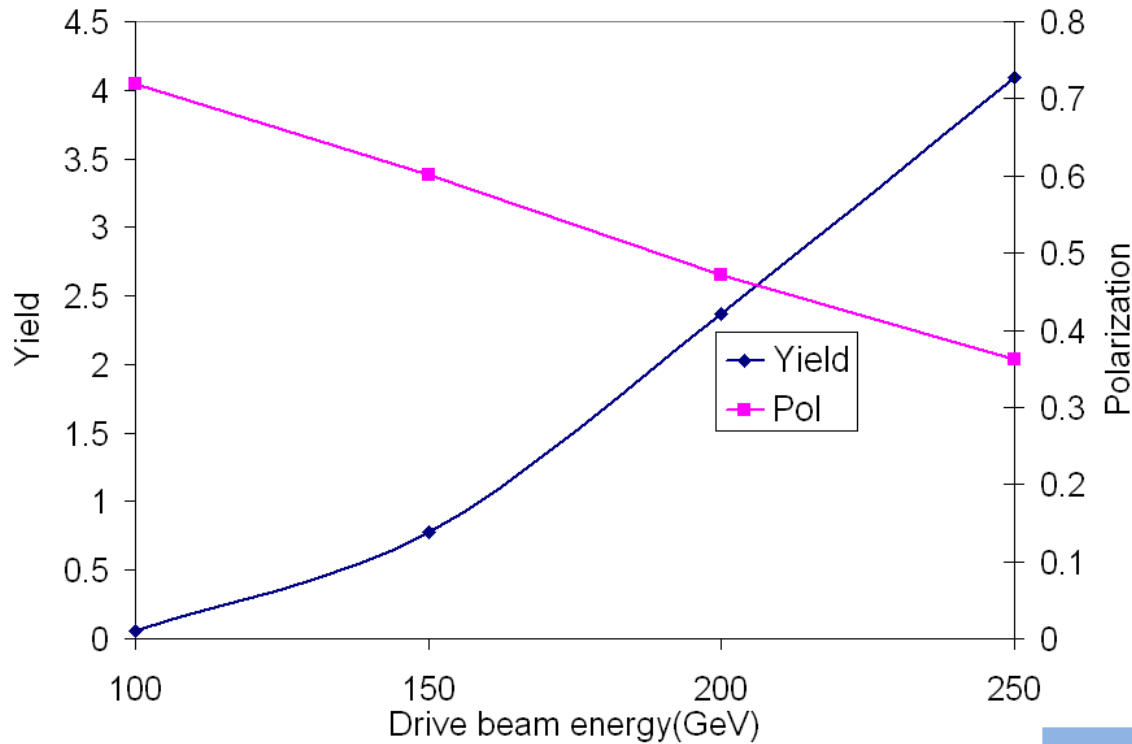
Polarization dependents on Collimator for 250GeV drive beam energy

231 RDR undulator driving with 250GeV beam
OMD is QWT. Target is 0.4X0 Ti

| Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield and 60% polarization
250GeV	~5.6GeV	~13.8GeV

Drive beam energy dependent for a fixed collimator.

231m RDR undulator,
¼ wave transformer,
radius of collimator: 0.17cm

Drive beam energy	Energy lost per 100m	Energy lost for 1.5 yield
100GeV	~900MeV	N/A
150GeV	~2GeV	~8.9GeV
200GeV	~3.6GeV	~5.26GeV
250GeV	~5.6GeV	~4.7GeV

Drive beam energy	Yield	Polarization
100GeV	0.054	0.72
150GeV	0.78	0.60
200GeV	2.37	0.47
250GeV	4.09	0.36

Drive beam energy 150GeV, K=0.9, λu=0.9, 231 meter undulator and Flux concentrator
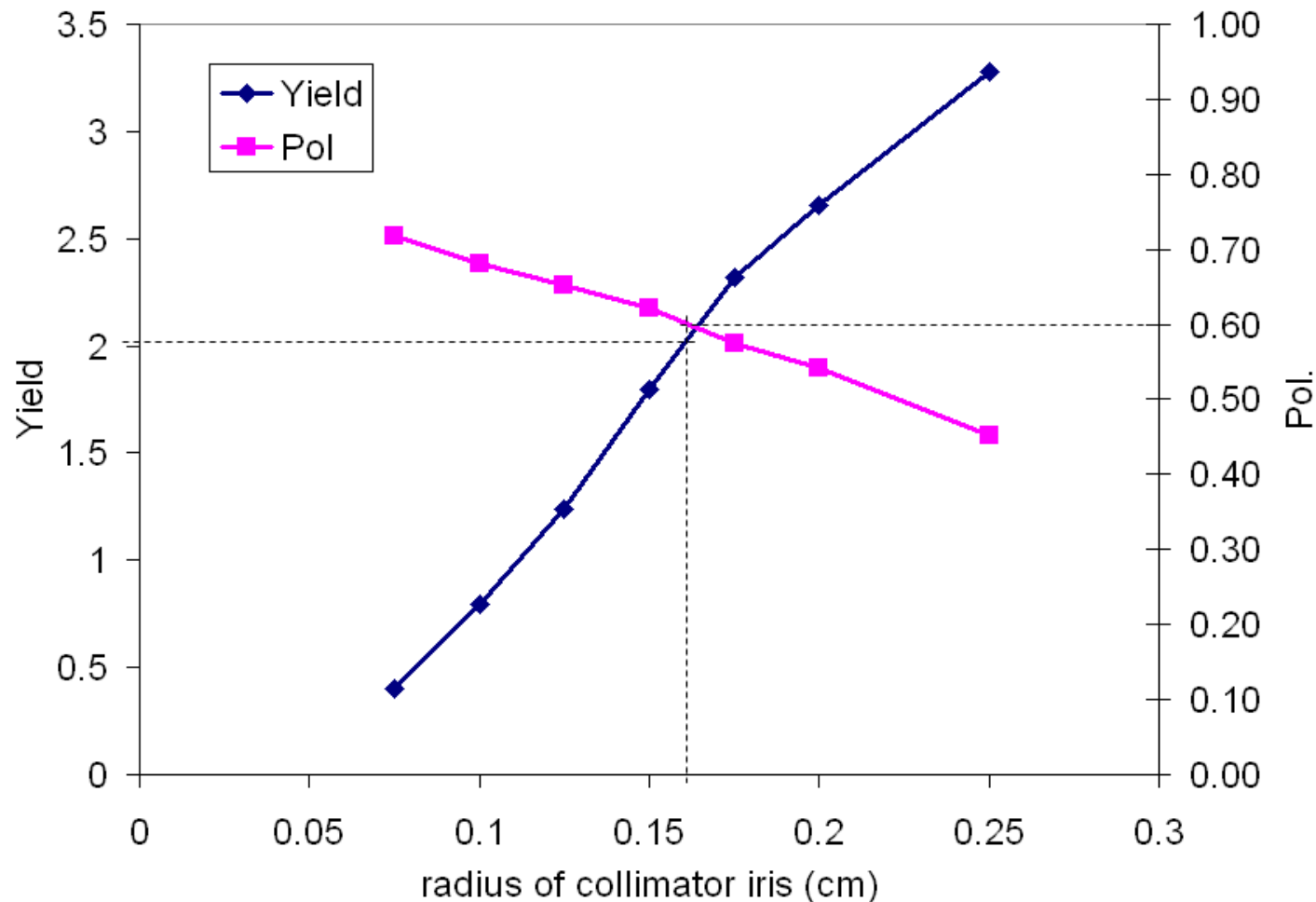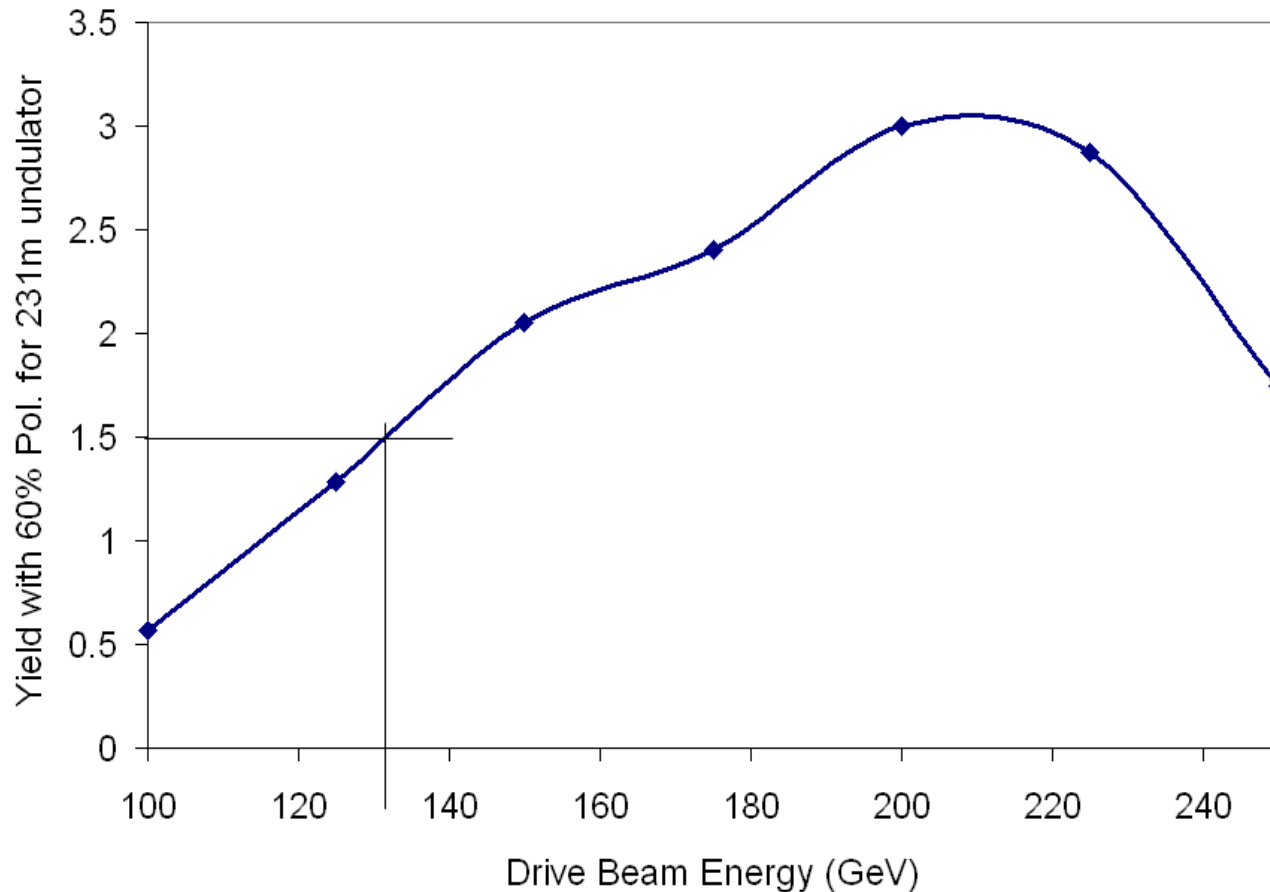

For 150GeV drive beam, 60% polarization required a photon collimator with an iris of ~1.6mm in radius. The corresponding yield is ~2 for 231m long undulator

Yield with 60% Pol. As function of drive beam energy

Flux concentrator is used as OMD

- With 231m long undulator with K=0.9, λu=0.9, 1.5 yield with 60% polarization can be achieved with drive beam energy of about 132GeV

R/Ds
of Alternative Solutions
(from Omori-san)

R/Ds are on going for Alternative Solutions as well

- **Why Alternative Solutions?**
    - **Pursuit better/advanced solutions**
    - **Mitigate Risks**
    - **Back Up**

- **Alternative Solutions**

    "ILC-CLIC e+ generation" group works also for the alternative schemes.

    - **Compton (French-CERN-Japanese Collab.)**
        - **Independent Source with Polarization**

            (1) French 4-Mirror Cavity installed in ATF: F-J Collab.
            (2) Multi-bunch observation with 2-Mirror Cavity
    - **Conventional**
        - **only e+ source which we have experience in real accelerators**
        - **300 Hz scheme (expansion in time) to mitigate target issue**

            (3) Liquid Target : Russian-Japanese Collab.
            (4) Hybrid Target : French-CERN-Japanese Collab.
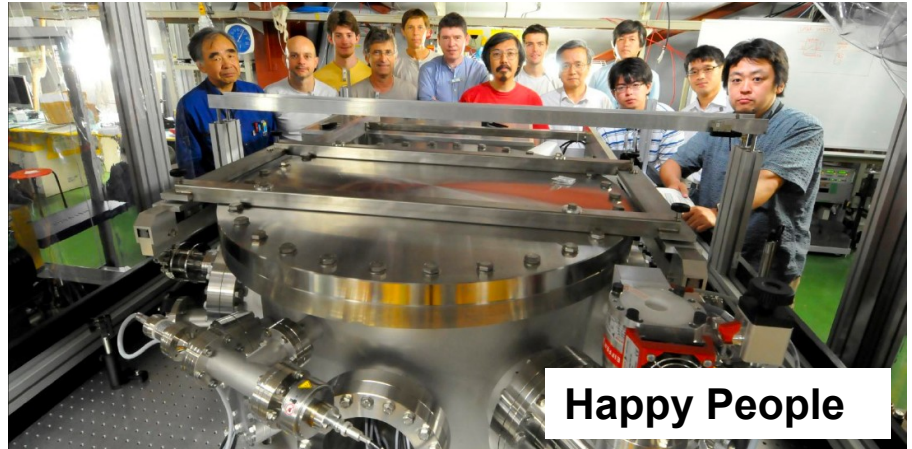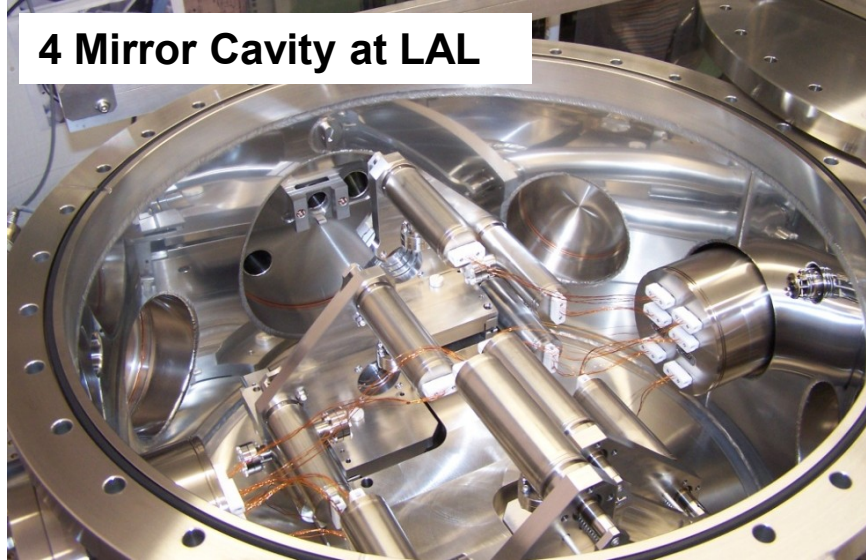   **(5) Truly Conventional (Slow Rotation Target: 4m/s)**

    note: In following each slide, (1), (2), (3), (4), (5), progress in recent 6 months is described.

Compton R/Ds

(1) French 4 Mirror Cavity installed in ATF:
4-mirror cavity has a potential to get a smaller spot

4 Mirror Cavity at LAL

Happy People
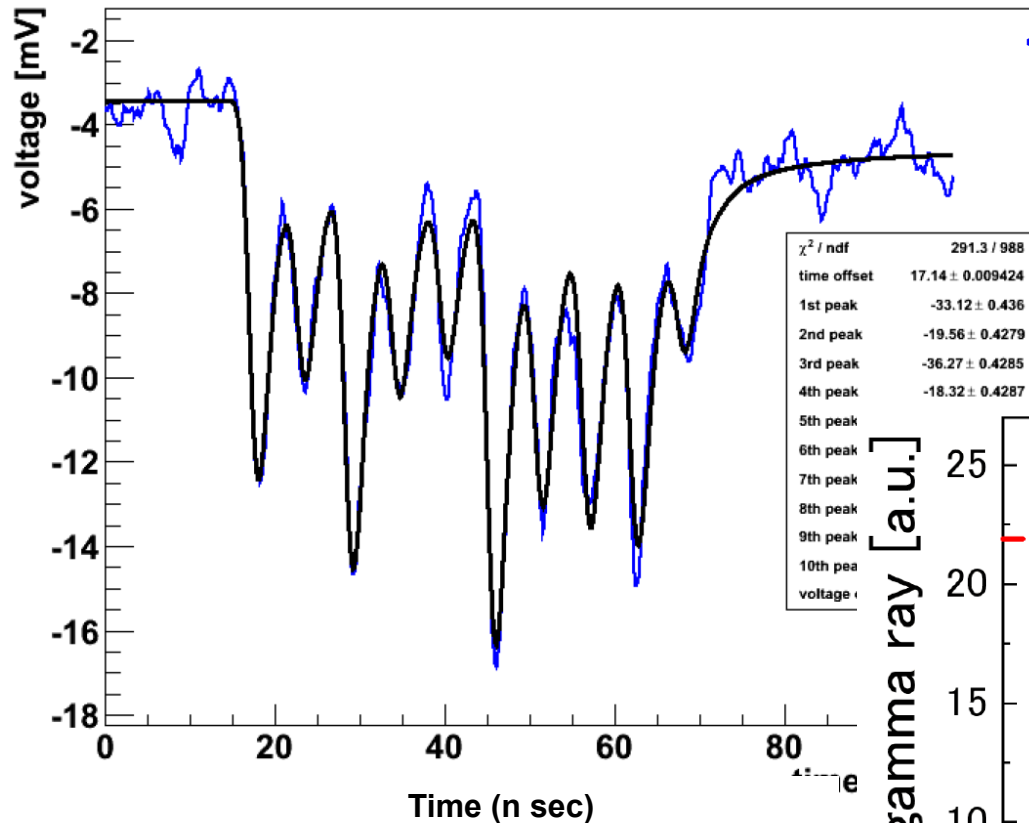

Cavity installed in ATF

2010 Works

- July-Aug **Cavity installed in ATF**
  French Team (9 persons) at KEK
- Aug/30th Laser locked to Cavity
- Sep/24th Cavity locked to ATF
- Oct/25th **1st gamma observed**
- Nov/1st Laser trouble -> sent to Zurich
- Dec/12th Gamma observed again

2011 Schedule

- Feb-May Running and improvements
- Summer Major improvements to
    ultimate enhancement

(2) Multi-bunch γ-ray measurement with 2-M Cavity:
aiming to check bunch-by-bunch uniformity

χ² / ndf	291.3 / 988
time offset	17.14 ± 0.009424
1st peak	-33.12 ± 0.436
2nd peak	-19.56 ± 0.4279
3rd peak	-36.27 ± 0.4285
4th peak	-18.32 ± 0.4287
5th peak	
6th peak	
7th peak	
8th peak	
9th pea	
10th pea	
voltage	

Time (n sec)

<- Bunch-by-bunch data of number of γ-rays. Each peak corresponds each bunch. (10 bunches/train)

A new γ-ray detector was installed to measure bunch-by-bunch γ-ray data.
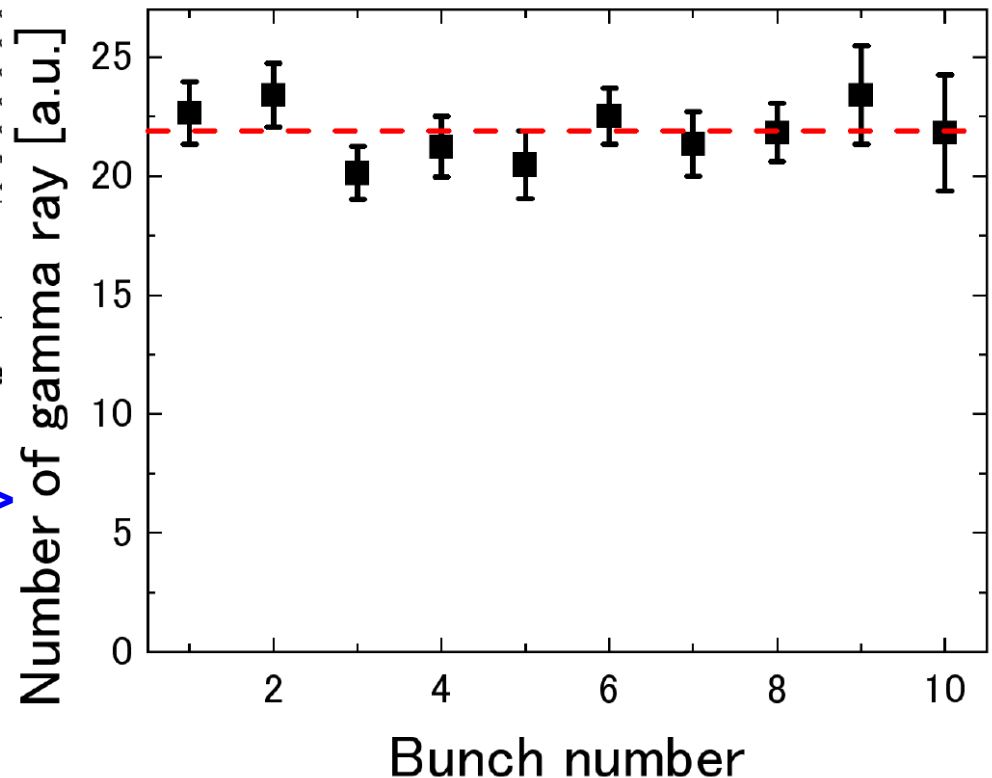
Bunch number vs number of γ-rays. ->

Bunch-by-bunch number of γ-rays were observed to be approx. uniform
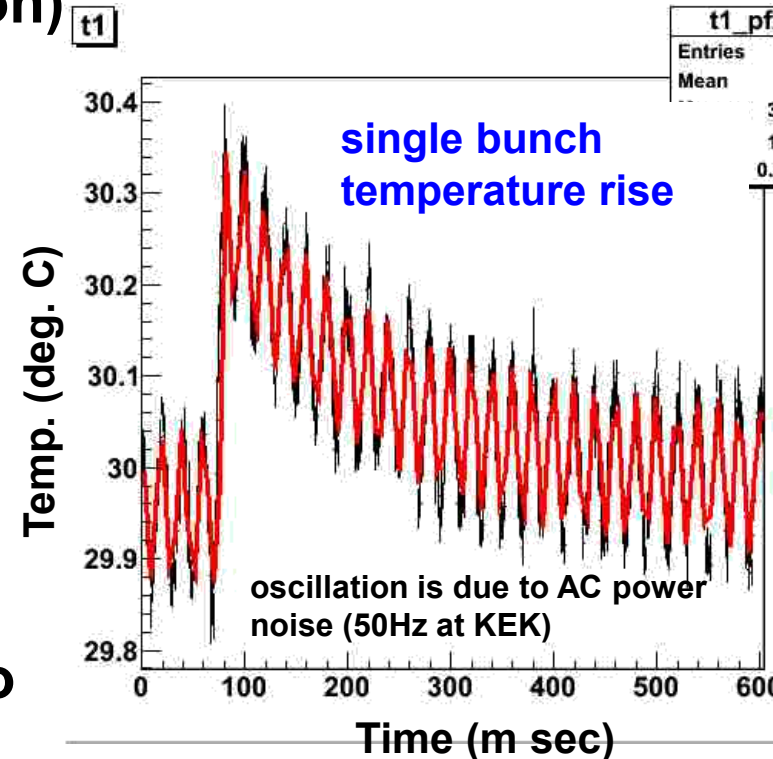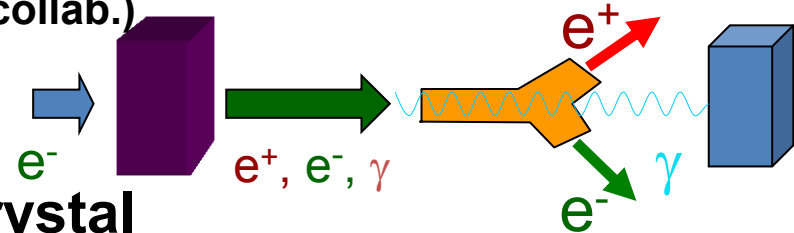
Conventional R/Ds

(3) Hybrid Target : get data and compare with simulation
Hybrid target test was performed at KEK linac.

note: the idea of hybrid target is resulting from long-term investigations
with experiments in CERN (Franco-Russian collab.)

e⁻ → e^-

e^+, e^-, γ

e^+

γ

e^-

We took systematic data.

- Hybrid target
  - 1-mm thick tungsten single crystal
  - amorphous tungsten plate with various thicknesses
- Conventional target (for comparison)
  - with various thicknesses
- impinging 8-GeV electron beams
- e+ momentum 5, 10, 20 MeV/c
- temperature
  - at equilibrium
  - single bunch temp. rise
- beam profile

• Hybrid: The systematic data allows us to test the simulation.

• Conventional: the data is also useful to evaluate conventional target.

• We seek a possibility for both hybrid and conventional.

single bunch temperature rise

Temp. (deg. C)

oscillation is due to AC power noise (50Hz at KEK)

Time (m sec)

t1

t1_pf

Entries

Mean

(4) Liquid Target : destructive test of the BN window

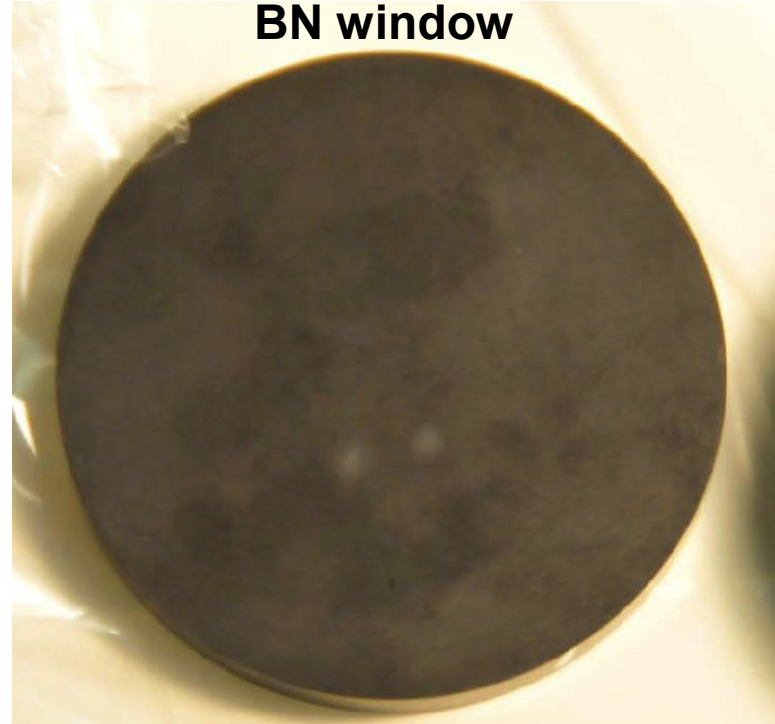BN window test of liquid target was performed at KEKB 8 GeV ring.

Sample S:3 (charge=2)

charge =2:
2 x "instantaneous E deposit" (by 132 bunches) of 300 Hz scheme (2x96J/g)

W radiator (acting Liq. lead)

BN window

2 spots (reduced brilliance) were observed by eyes.
We can see them in photo.

2 spots (reduced brilliance) were observed by eyes.
We can see them in photo.

No damage, defect, or crack was observed.

(5) Truly Conventional (Slow Rotation Target 4 m/s):
explore "$T_{target} - E_{baem}$" space to seek a solution

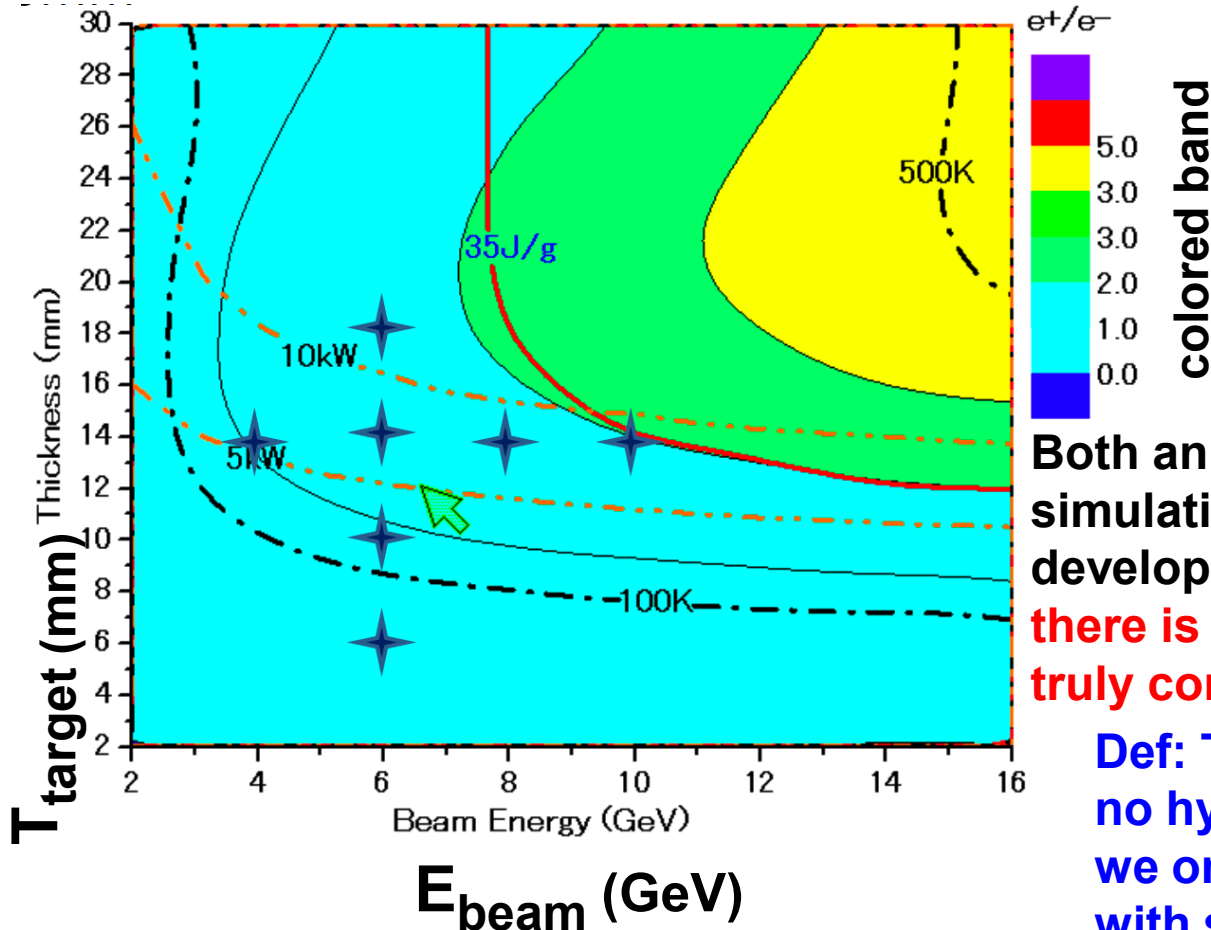**Parameter Plots for 300 Hz scheme**

e- directly on to Tungsten
$\sigma = 4.0mm$

colored band:	accepted e+/e-
———————	: PEDD J/g
— · — · — · —	: dT/triplet (132 bunch)
— · · —	: Total deposit kW

(*) analytic estimation based on the formula of CLIC-note 465
(T. Kamitani & L. Rinolfi)

Both an analytic estimation (*) and a simulation (✦ by PPS-SIM developed by DESY) shows that there is no show stopper in the truly conventional solution.

Def: Truly conventional solution : no hybrid target, no liquid target, we only assume tungsten target with slow rotation (single target).

Summary

- Systematic parameters scans studied for the RDR undulator using Quarter Wave and Flux concentrator
  - Flux concentrator scheme (under-development) uses undulator length to 137 m. A conservative scheme that uses quarter wave magnet (no development required) uses 231 m.
  - Also FC reduces the target energy deposition load when compared with quarter wave.
  - Impact on the drive beam parameters from undulator investigated and no major effect observed for both schemes.
  - Target energy deposition issues explored. For the required yield, power and peak energy depositions calculated. Further investigations are needed for the target damage thresholds.
  - Polarization issues are investigated, and it is a complex process and key is the collimation technology development
- For SB2009, which has low energy option, a new undulator might simplify the schemes proposed (10 Hz operation).
- Alternative technologies are being investigated as backup plans.