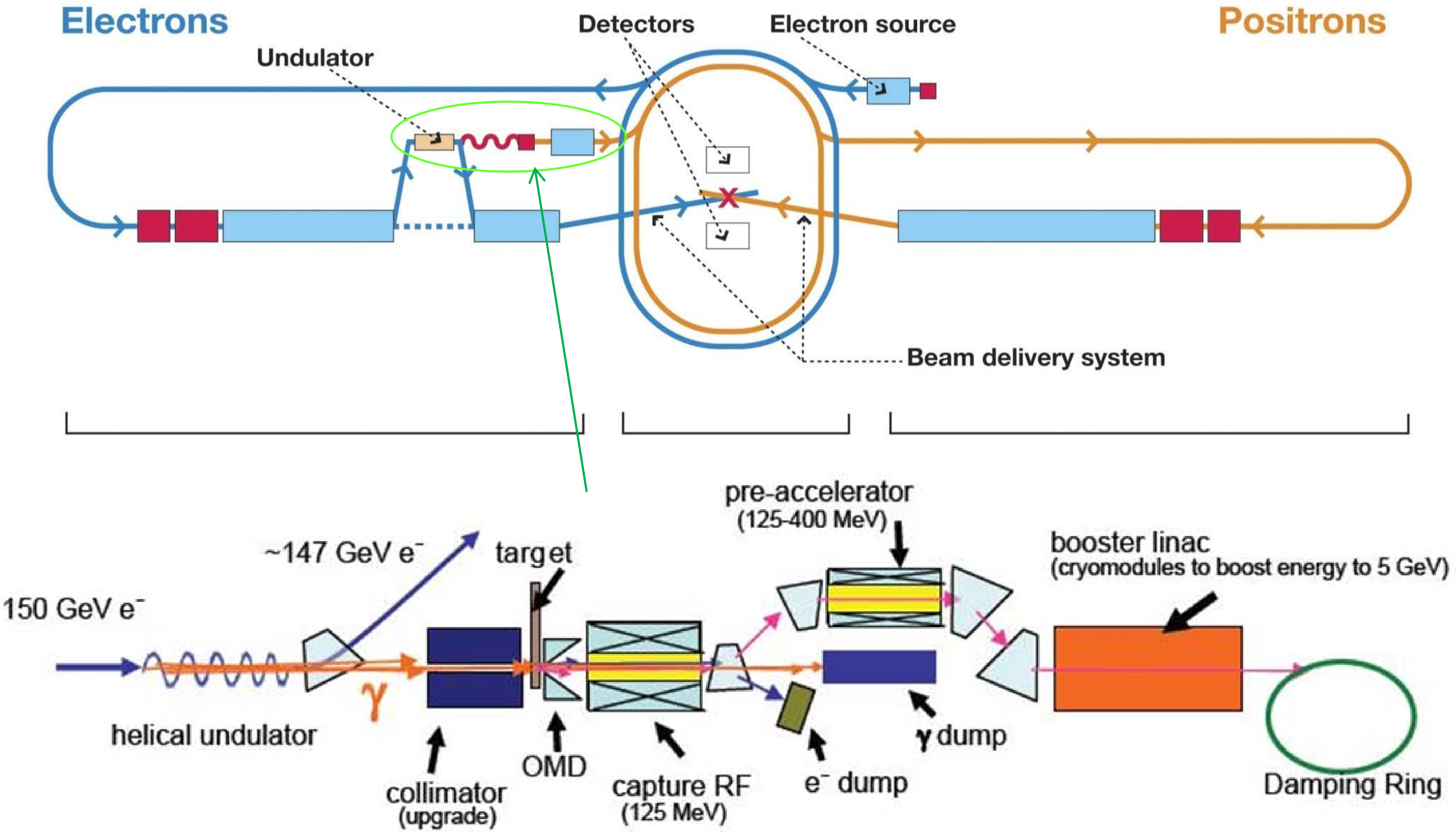
ILC RDR baseline schematic

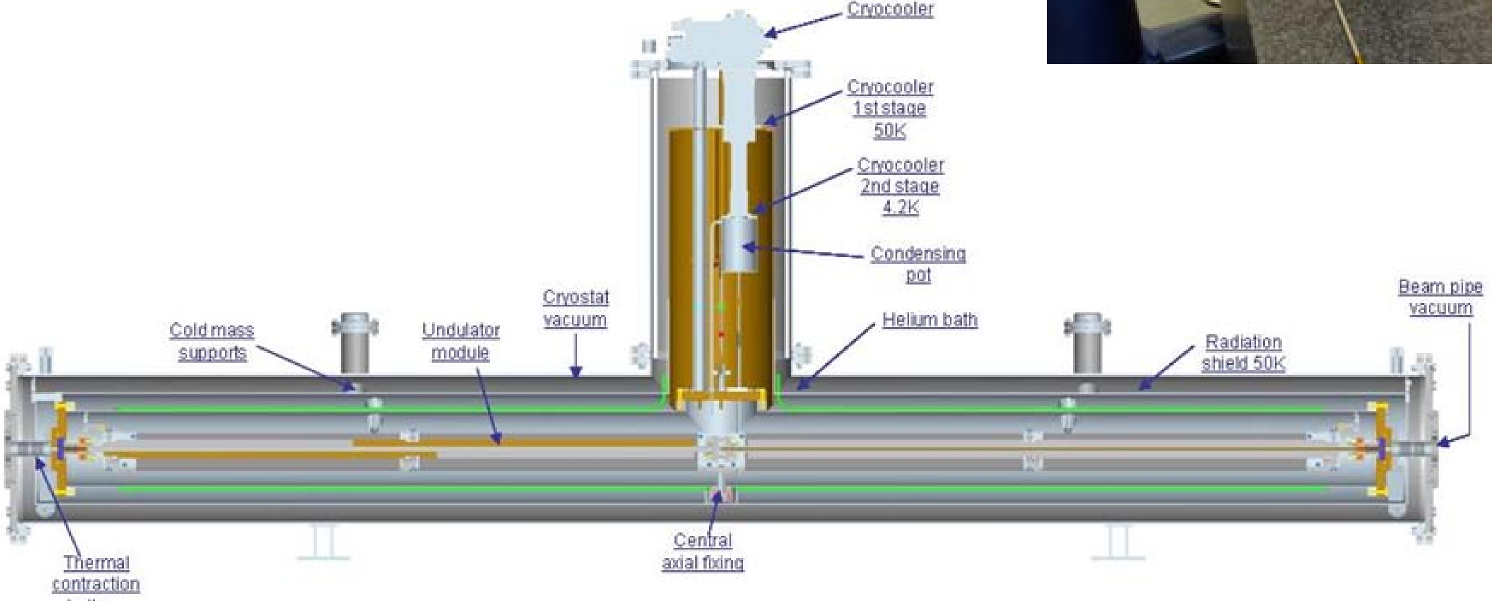


Parameters:

- Optimize the positron yields for known technologies:
  - Superconducting helical undulator.
    - Undulator parameter: $K=0.9$, $\lambda u=1.15$cm
  - 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.

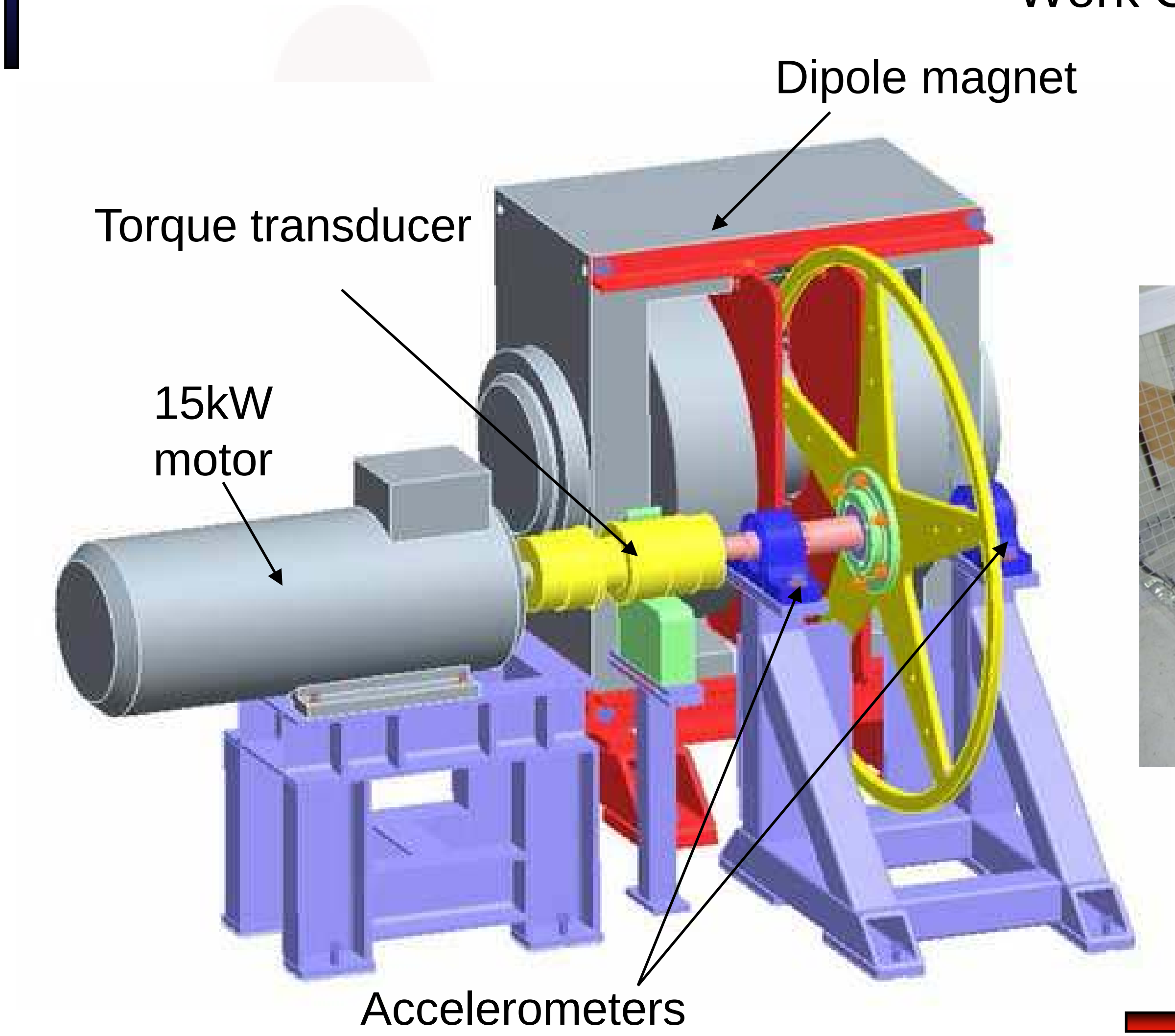
4 metre Cryomodule

- Two 1.7 metre helical undulator magnets have been successfully made using NbTi.
- Magnets positioned back to back in cryostat.



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

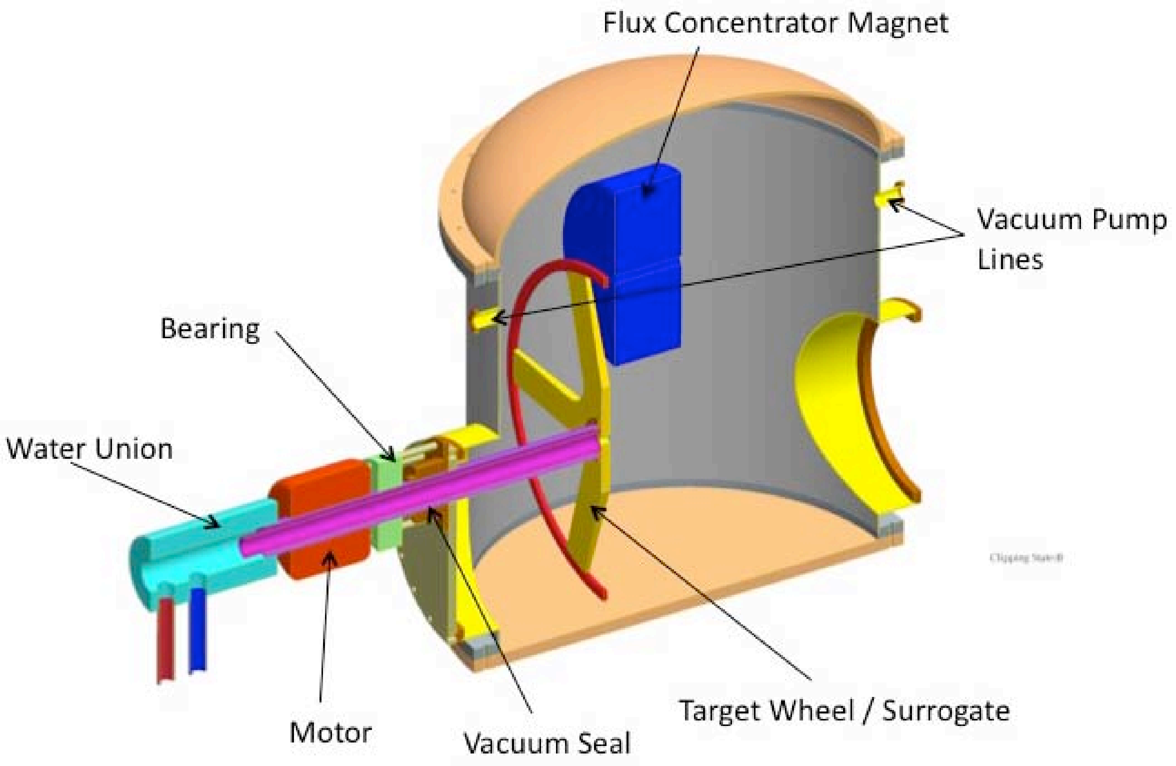
ILC Real target:
Wheel diameter: 2m
Spinning Speed ~ 900 rpm
Thickness: 1.4 cm



m_{wheel}~18kg

Target Prototype at LLNL

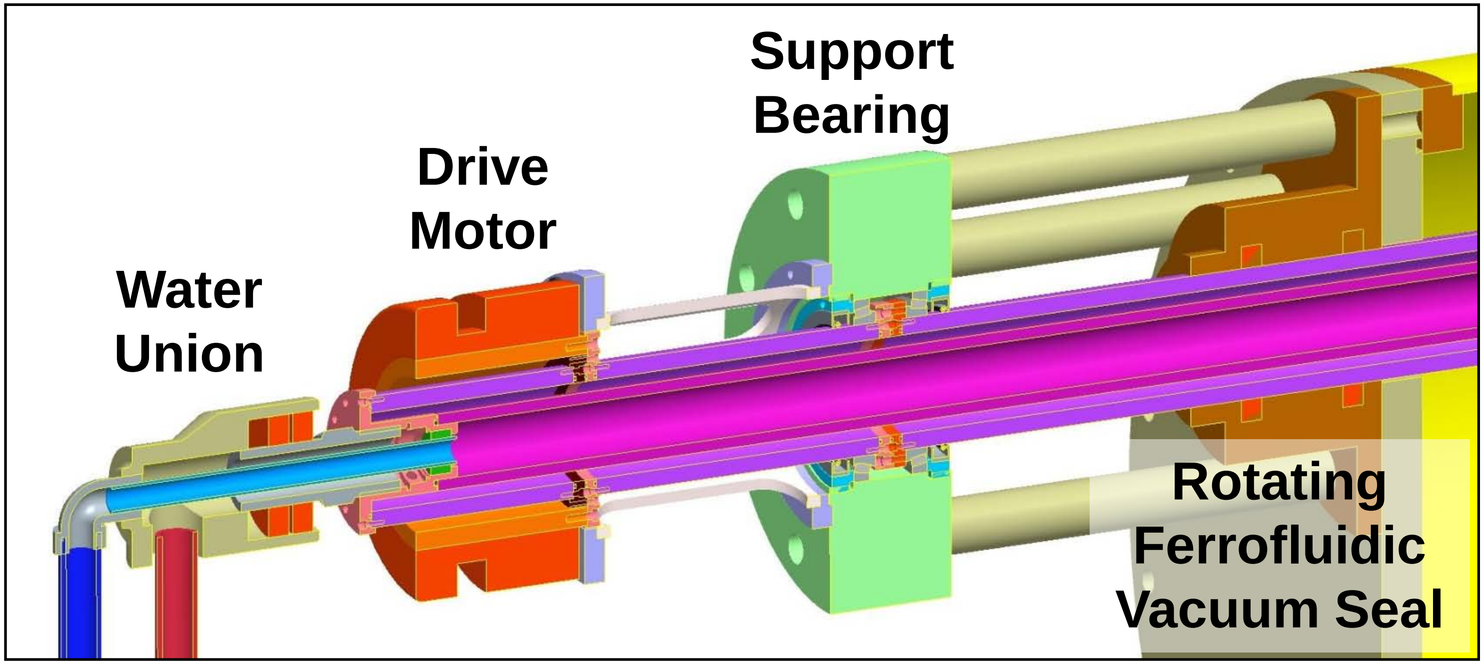
Prototype II - Rotating vacuum seal test

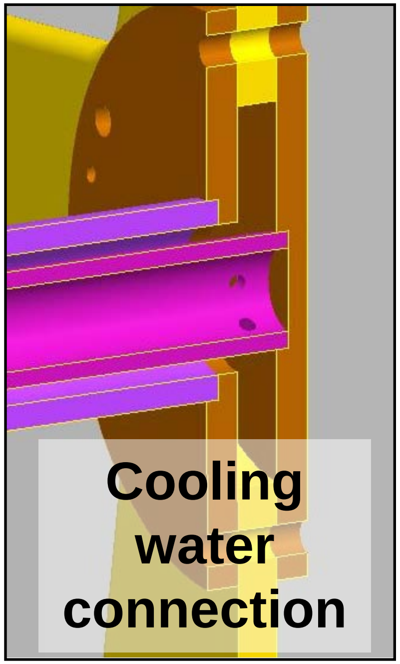


- Current design has rotating ferrofluidic vacuum seals
- Cooling water flows along the shaft

- 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

Types of Accelerator Structures and Basic Properties

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

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. Lower gradient (~ 8 MV/m) longer structures

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. Four types of structures have been designed.

From Juwen Wang/SLAC

Prototyping a SW cavity for ILC e+ source.

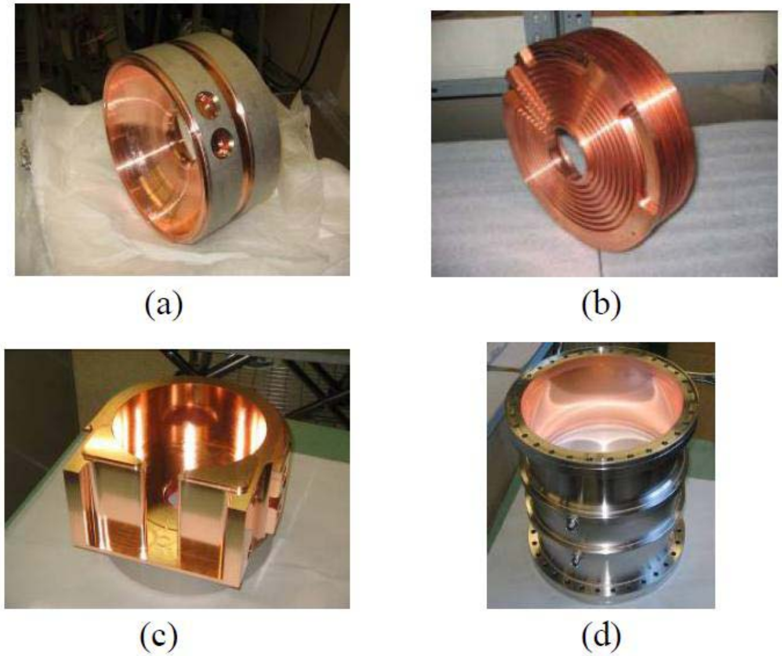


Figure 6. Some of the subassemblies for the 5-cell SW structure: a completed unit cell (a), a half cell to be brazed on the input coupler (b), coupler subassembly (c) and L-Band RF window (d).

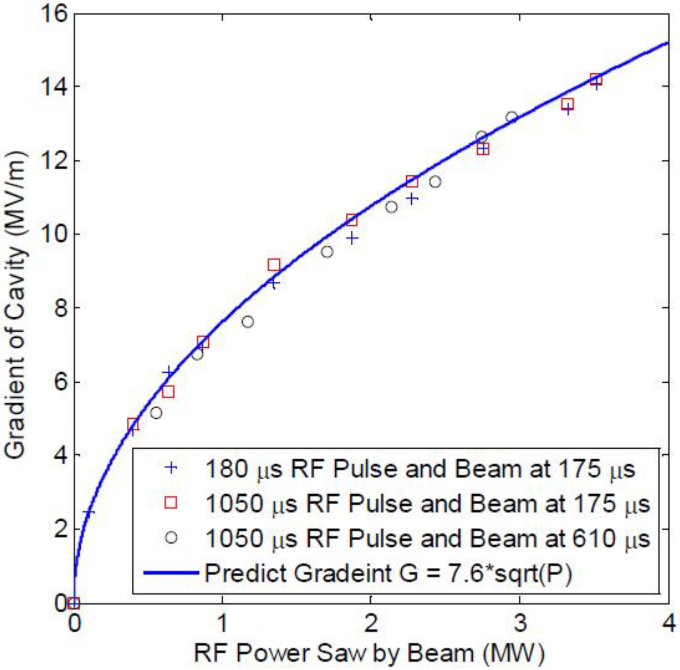


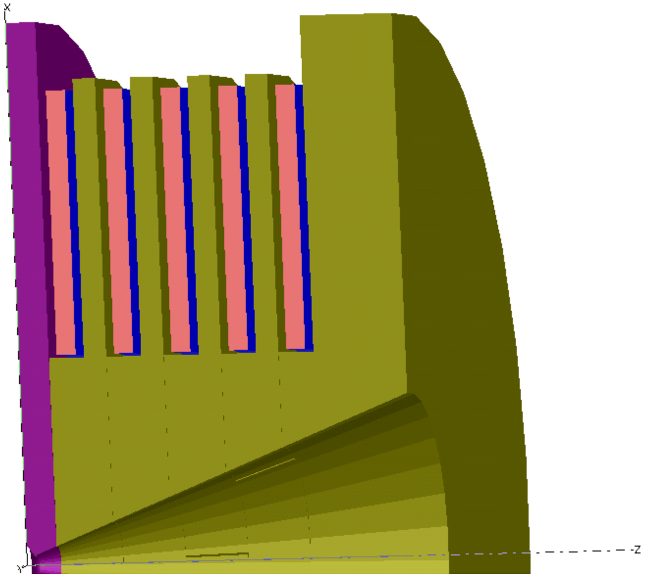
Figure 2: Gradient prediction and measurement with single bunch versus the net cavity input power (forward – reflected) for different pulse widths and bunch injection times.

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

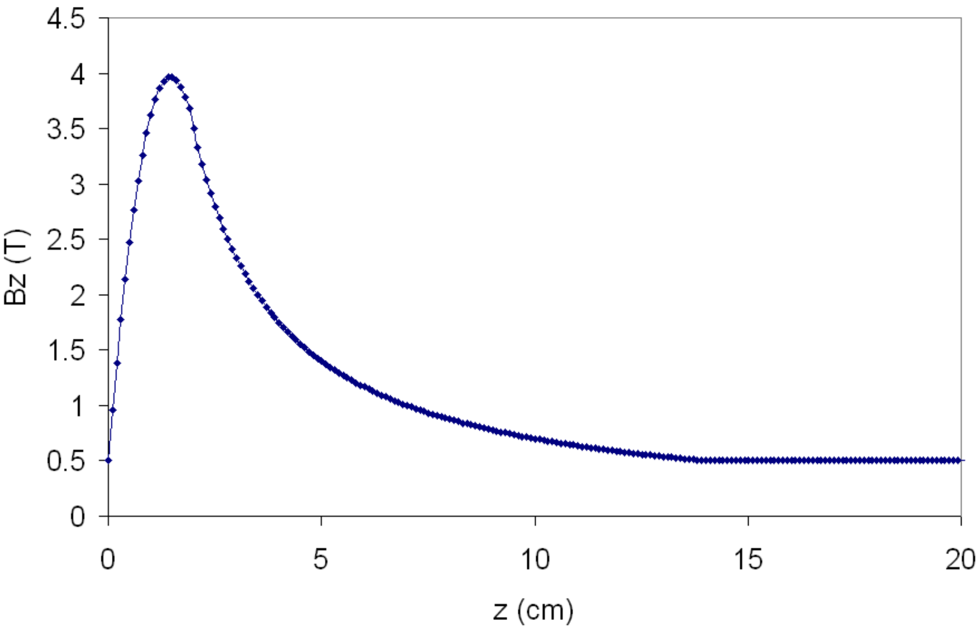
Cases Studied:

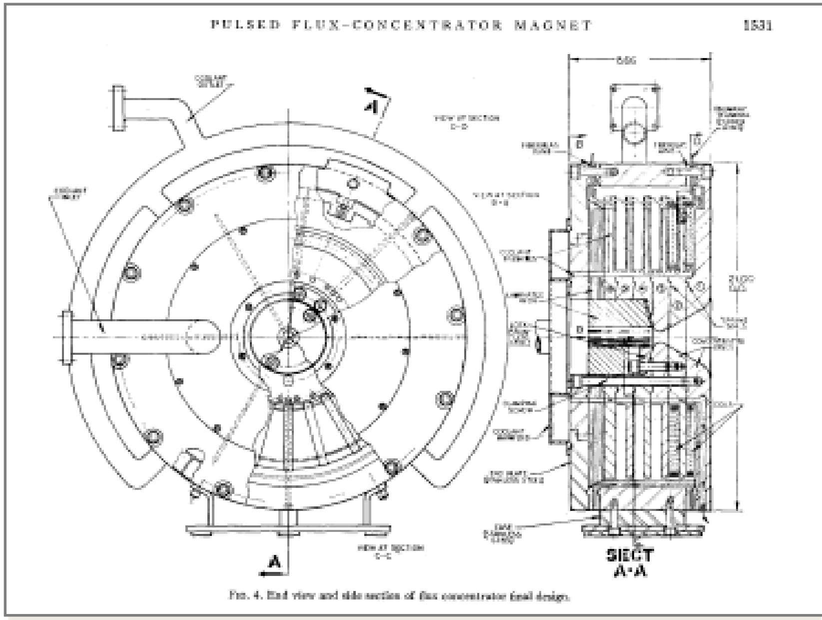
- Common Input Parameters:
  - Undulator parameter: K=0.9, λu=1.15cm
  - Target: 0.4 X0 Ti
  - Drift between undulator and target: 400m
  - Photon collimator: None
- OMD:
  - Flux Concentrator Capturing (137 m long Undulator).
  - Quarter Wave Transformer Capturing (231 m long undulator).
  - 150 GeV
  - 250 GeV
- Undulator Impacts on Drive Beam
  - Energy Spread and,
  - Emittance
- Target Energy Deposition.
- Path toward higher polarizations
  - Photon collimators

Case 1: 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

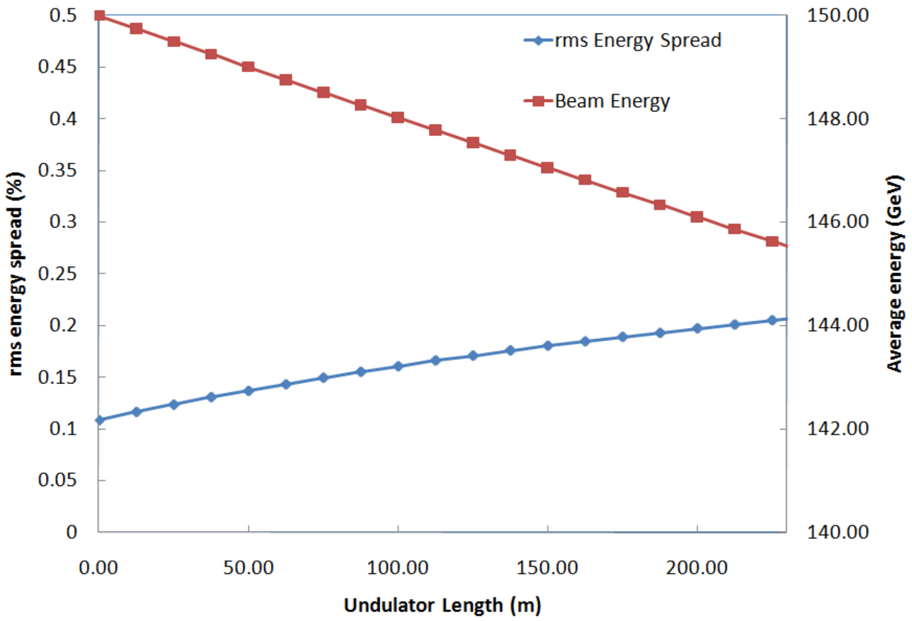
FIG. 4. End view and side section of flux concentrator final design.

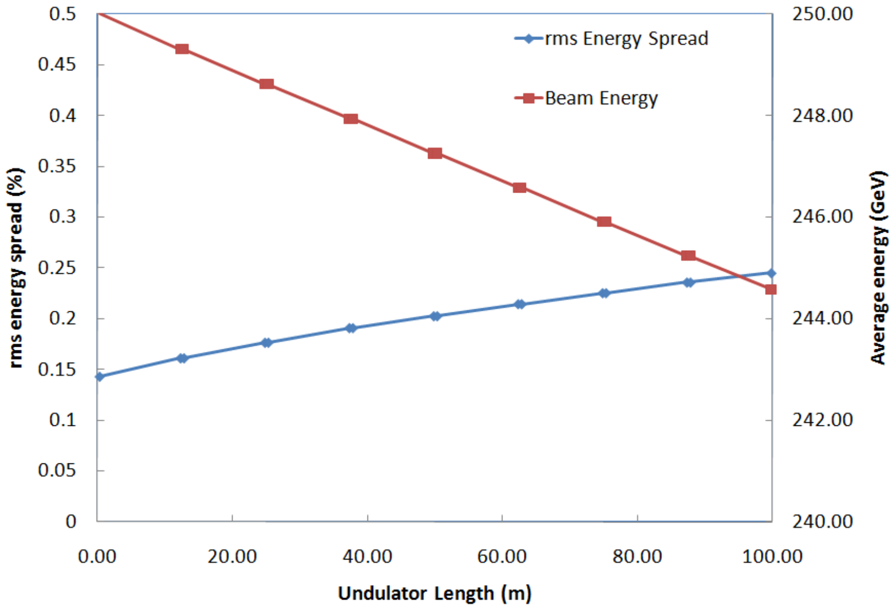
Yield Calculations Using RDR Undulator Parameters (137 meter and FC without photon collimators)

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.

Impact of undulator on the drive beam - energy and energy spread (only from synchrotron radiation)





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

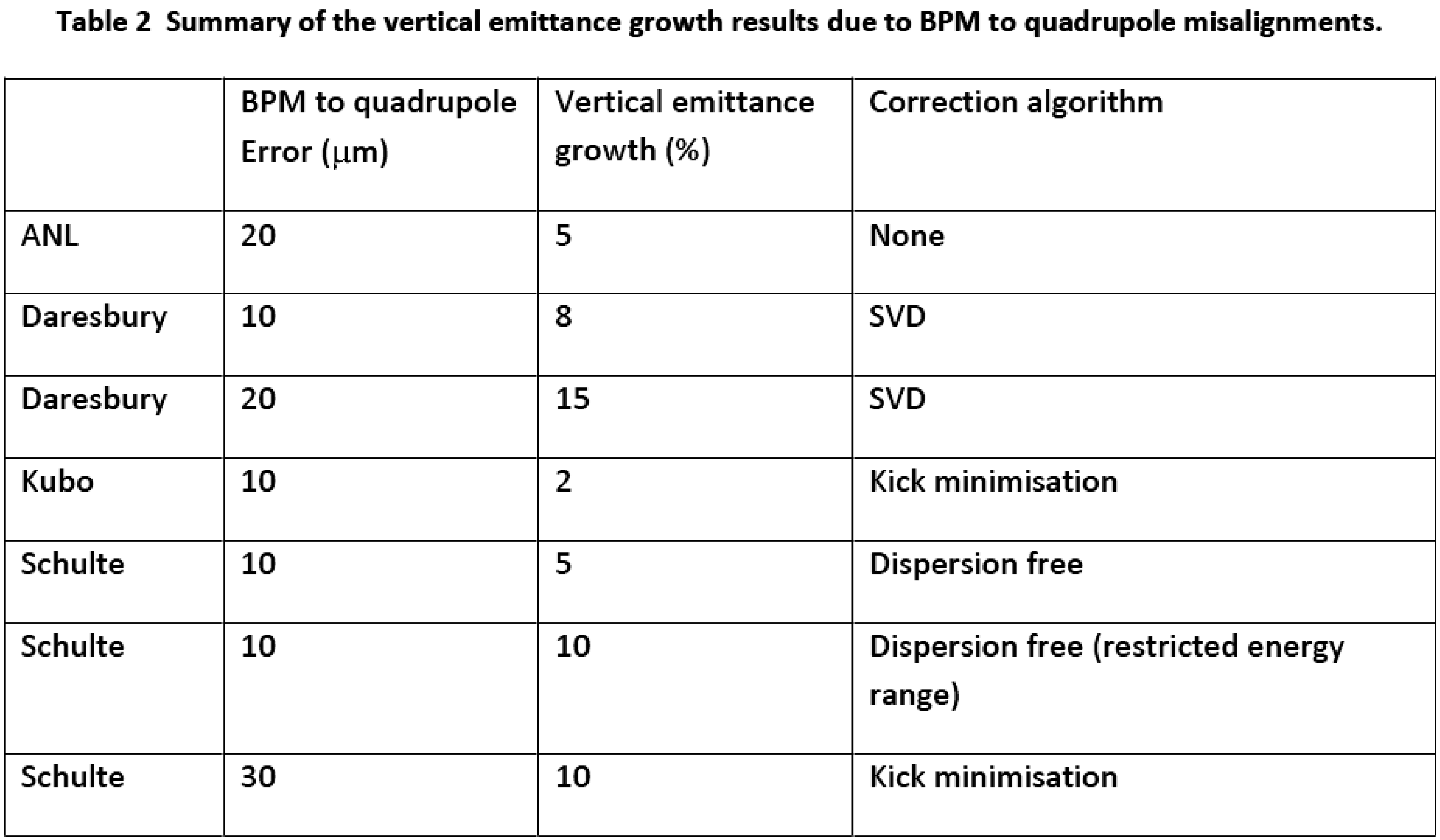


Table 2 Summary of the vertical emittance growth results due to BPM to quadrupole misalignments.

	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

Resistive wall wakefield effect
--From Jim's report

	Transverse kick @77K with copper vessel
Daresbury	0.27ev/μm/m (5.85mm diameter)
Kubo	0.6ev/μm/m (4.76mm diameter)
Scott	0.5ev/μm/m (4.76mm diameter)

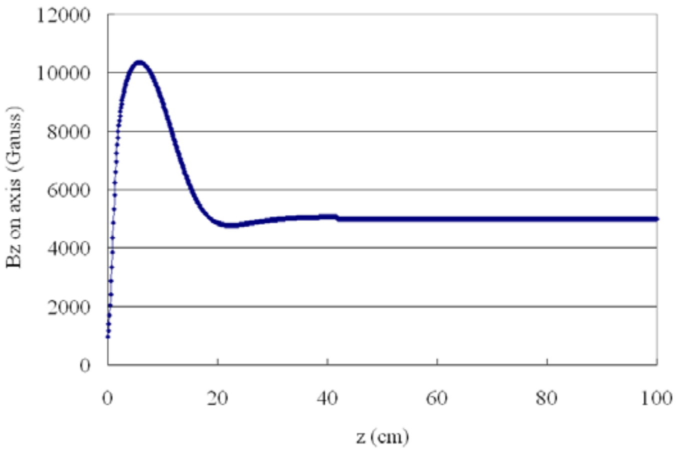
It was shown than in this case the wake would need to be 75 times stronger before angular kicks of the order of the electron vertical beam divergence would be generated for a 200m long undulator by beam jitter of the order of the vertical beam size. The effect of undulator vessel misalignments was also assessed and it was concluded in a simple estimation that to keep the transverse kicks smaller than the electron divergence would require the undulator vessels to be aligned to better than ~240 m. This requirement should be relaxed when correction systems are included in the assessment provided emittance measurement diagnostics are available after the undulator.

Case 2: RDR undulator, Quarter Wave Capturing Magnet

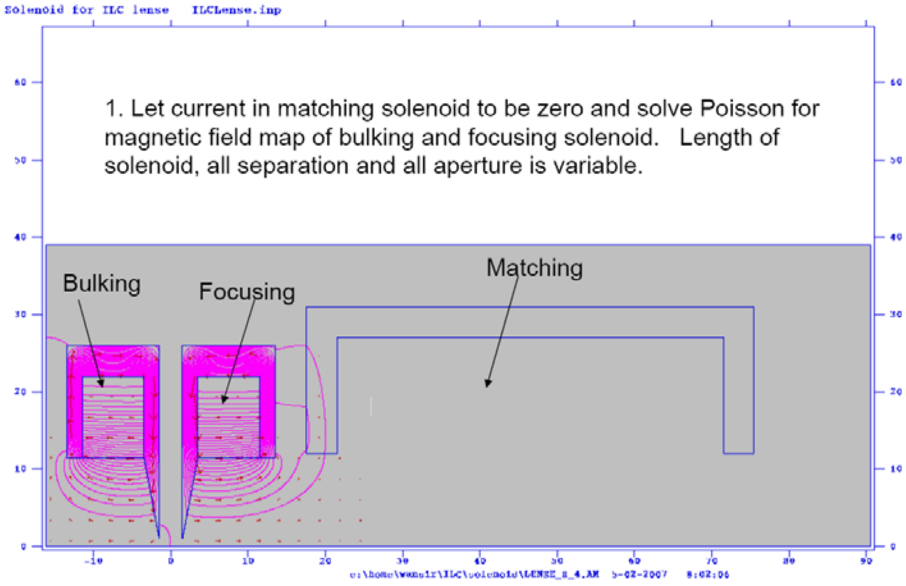
- Undulator: RDR undulator, K=0.92, λu=1.15cm
- Length of undulator: 231m
- Target to end of undulator:400m
- Target: 0.4X0, Ti
- Drive beam energies: 50GeV to 250GeV
- Reference: 150 GeV

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

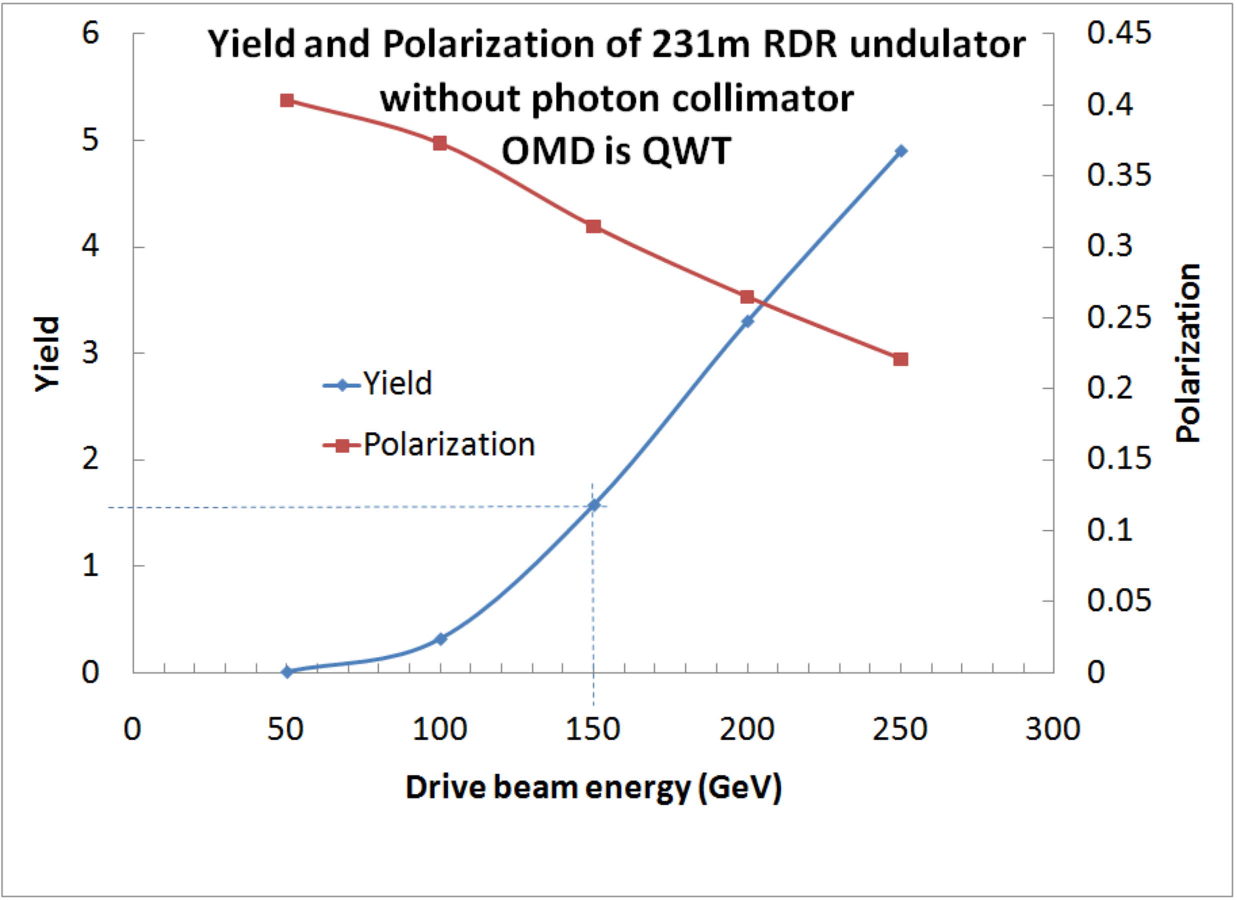


1. Let current in matching solenoid to be zero and solve Poisson for magnetic field map of bulking and focusing solenoid. Length of solenoid, all separation and all aperture is variable.

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



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)

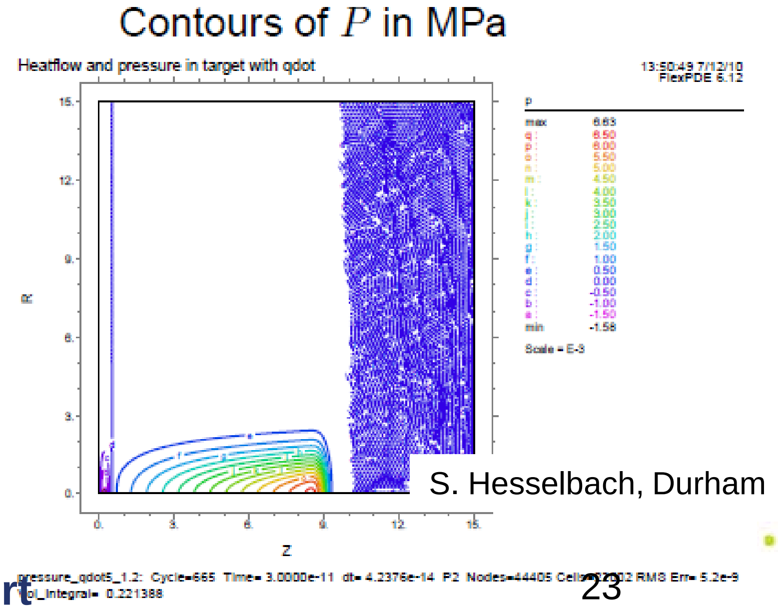
1.5 yield / 3e10 e+ captured,	Ti target (density=4.5 g/cm^3)				
	Thickness for highest yield (X0)	Energy deposition per bunch (J.)	Average power (KW)	Peak energy density	
				(J/cm^3) ;	(J/g)
150GeV,FC (137 m)	0.4	0.72	9.5	348.8	77.5
250GeV, FC (40 m)	0.4	0.342	4.5	318.8	70.8
150GeV, QWT (231 m)	0.4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

SLC positron target after decommissioning

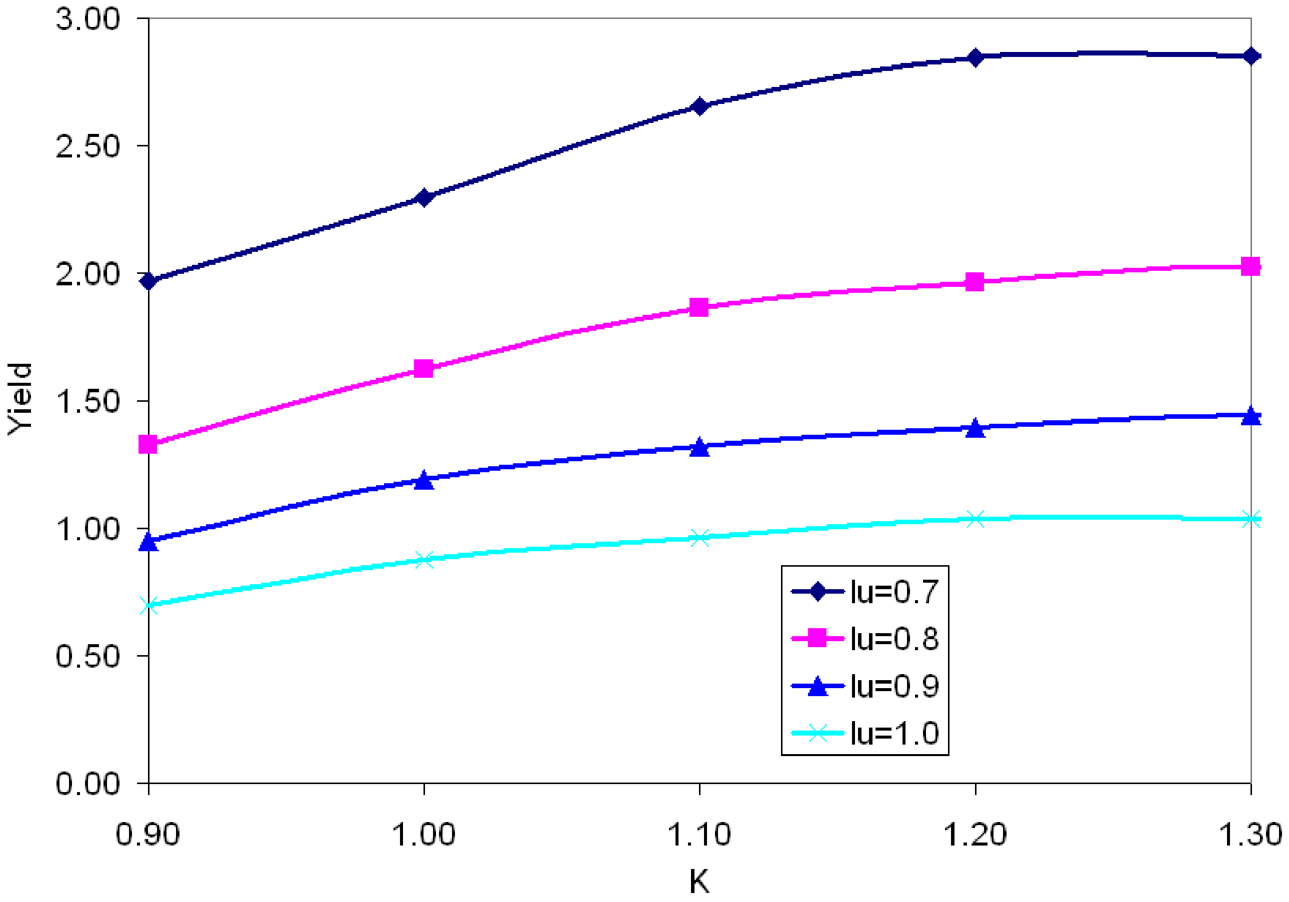


S. Hesselbach, Durham

Case 3: Low K and short period λ Undulator Option

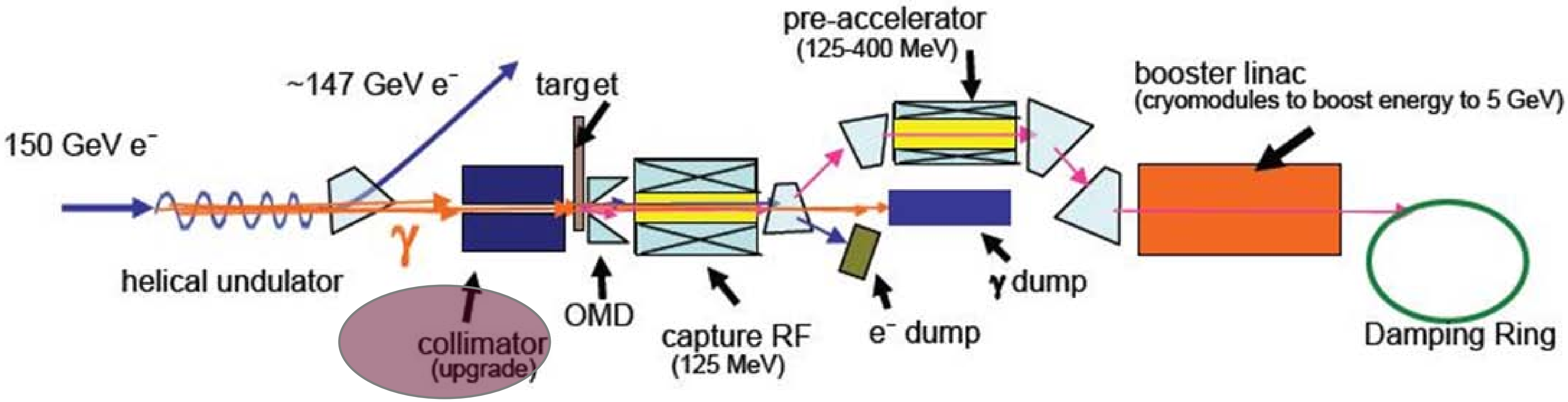
- Important to SB2009 scenarios.
- Assumptions:
  - Length of undulator: 231m
  - Drive beam energy: 100GeV
  - Target: 0.4X0, Ti
  - Photon Collimation: None
  - Drift to target: 400m from end of undulator
  - OMD:FC, 14cm long, ramping up from 0.5T to over 3T in 2cm and decrease adiabatically down to 0.5T in 12cm.

High K, short period, 100GeV drive

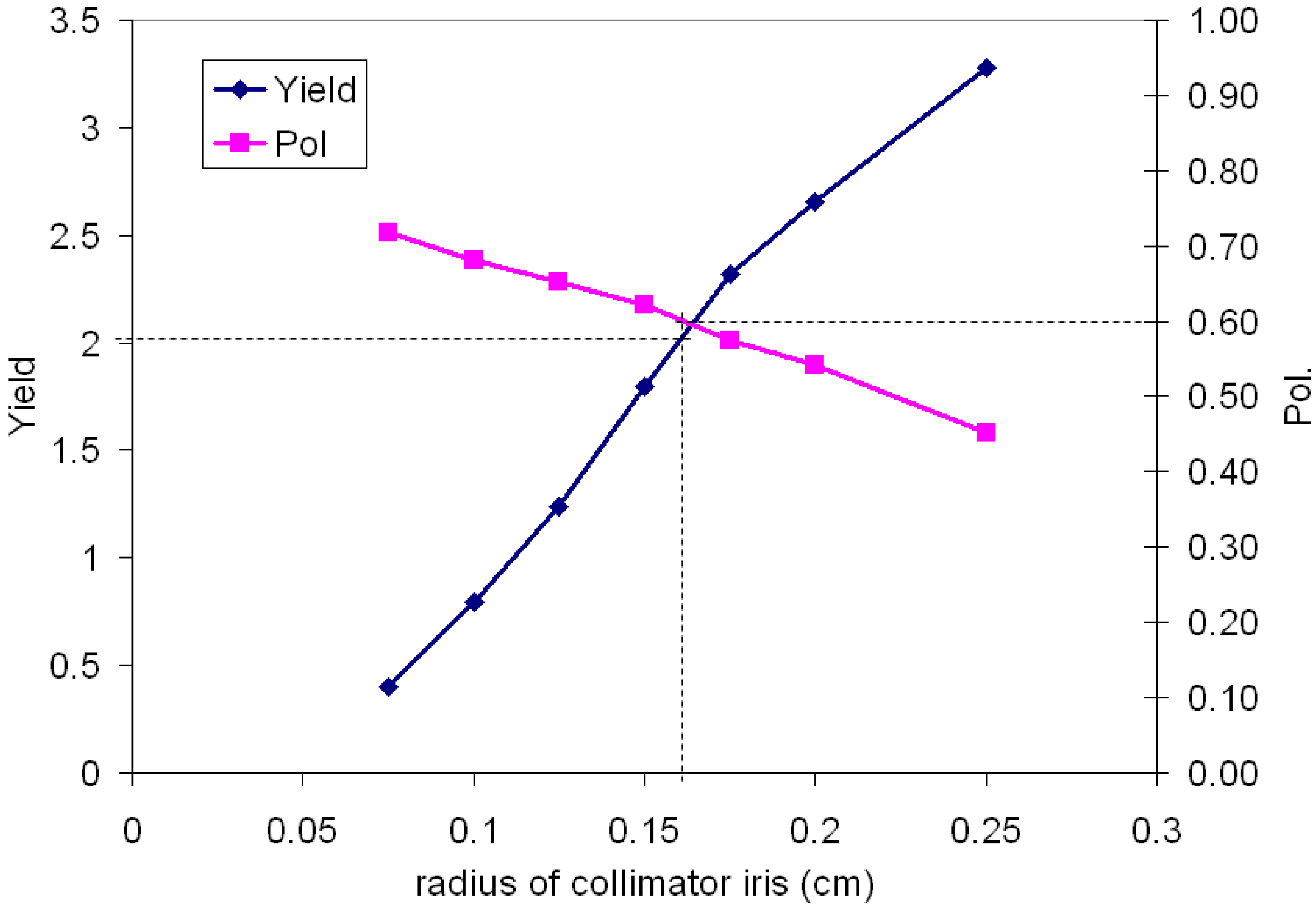


Towards High Polarizations

- 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).



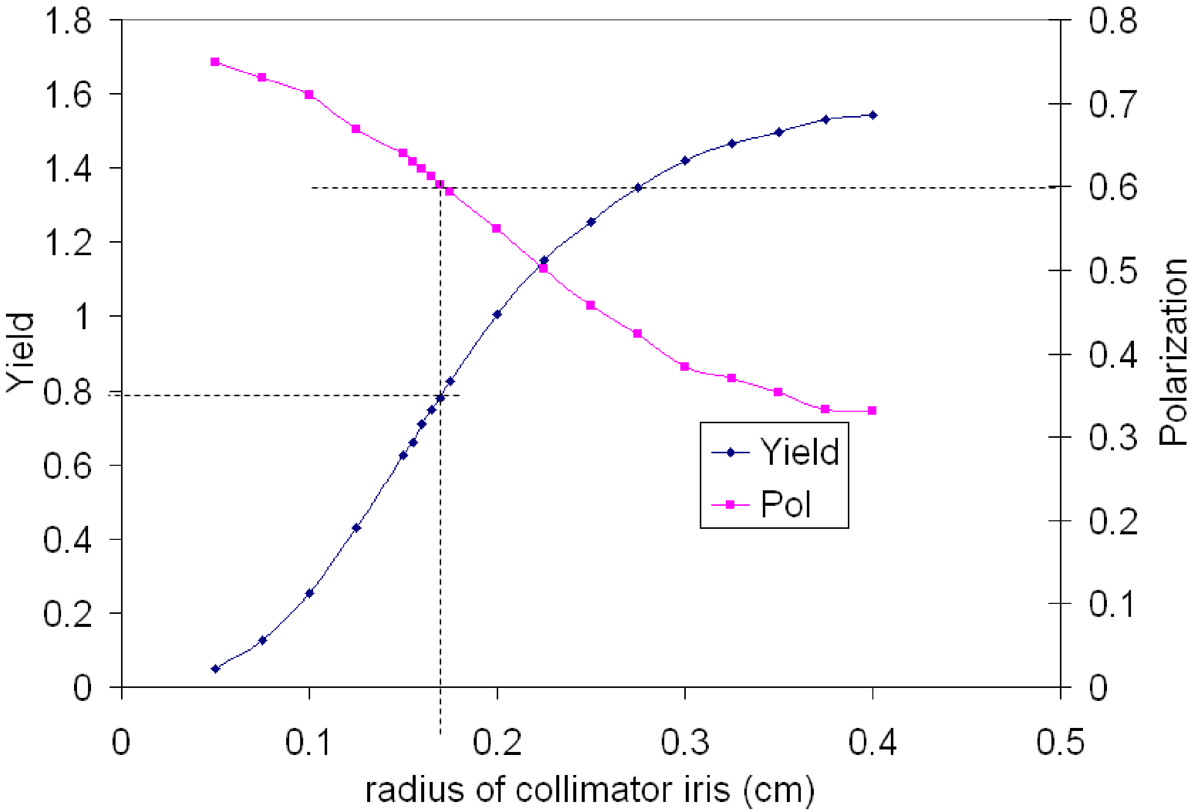
Drive beam energy 150GeV, K=0.9,λu=0.9, 231 meter undulator and Flux concentrator



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

Polarization upgrade

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

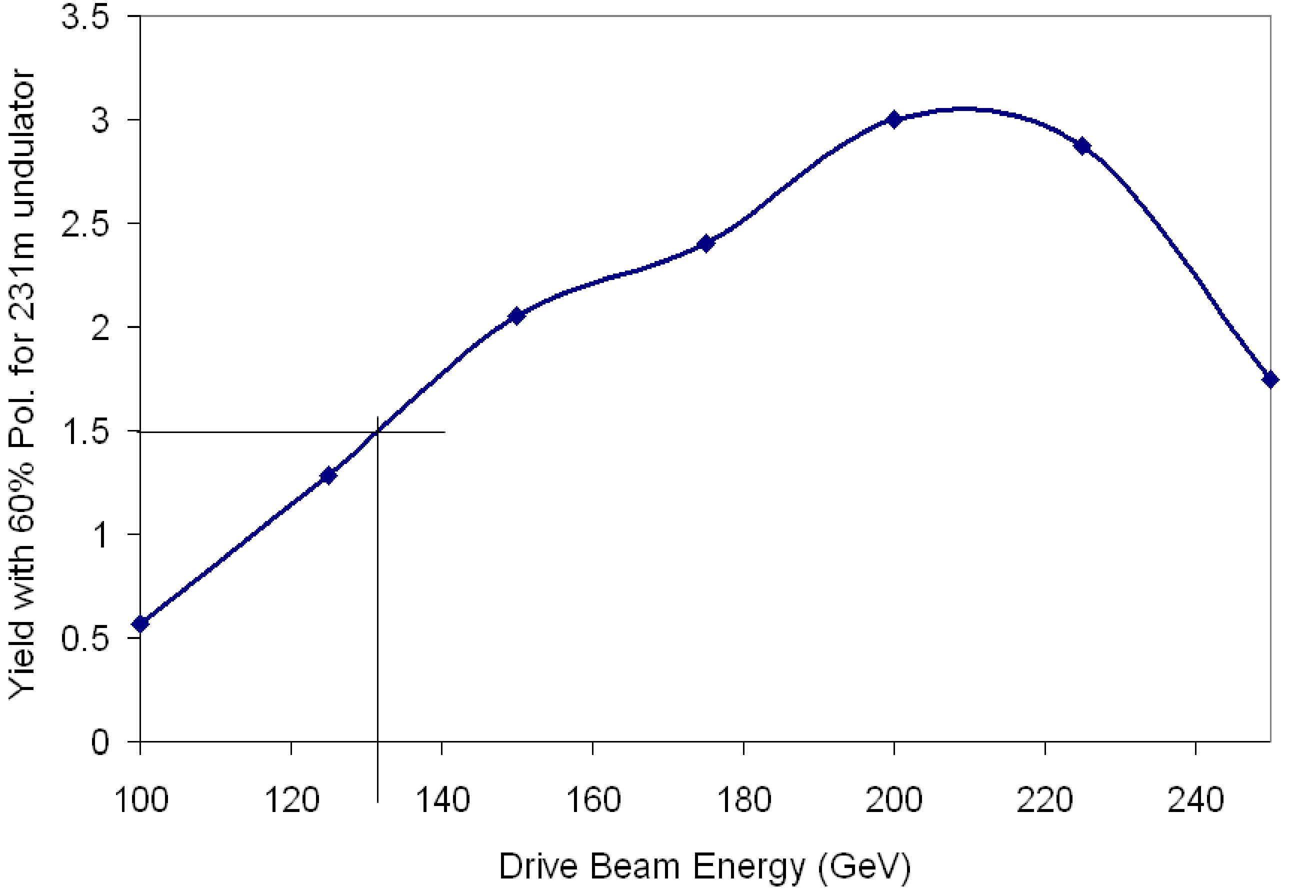


With QWT, with a photon collimator to upgrade the polarization to 60%, the positron yield will drop to ~0.8

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

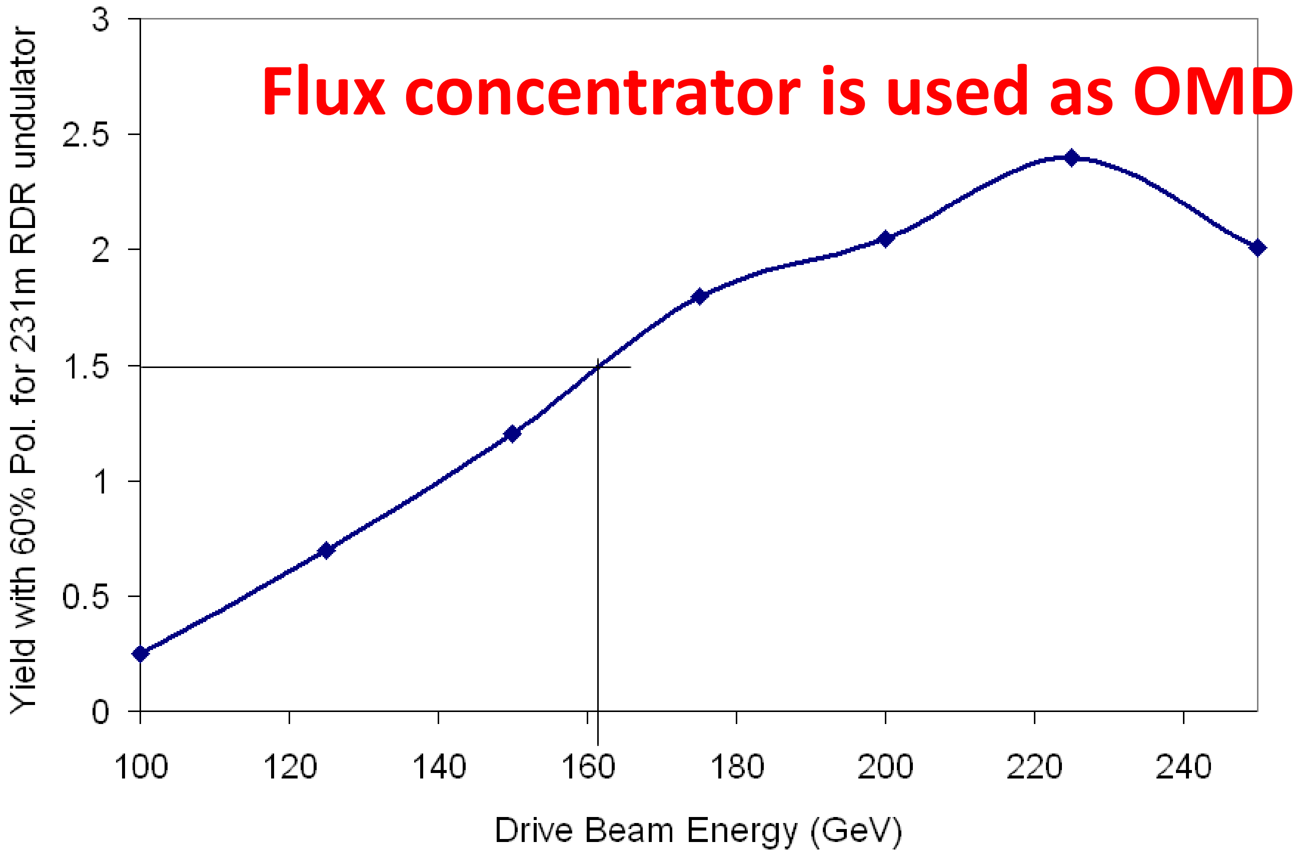
Yield with 60% Pol. As function of drive beam energy

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

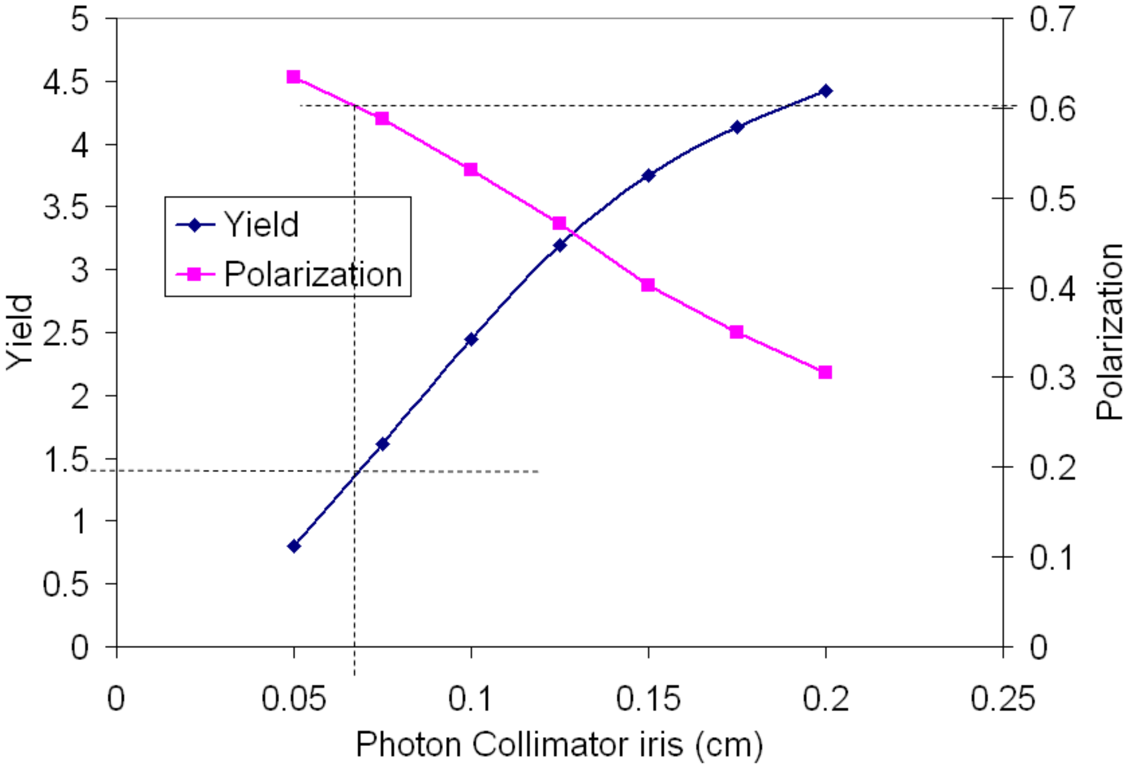
Yield with 60% Pol. As function of drive beam energy. 231m long RDR undulator



- Yield of 1.5 with 60% yield can be reached with drive beam energy of ~162GeV

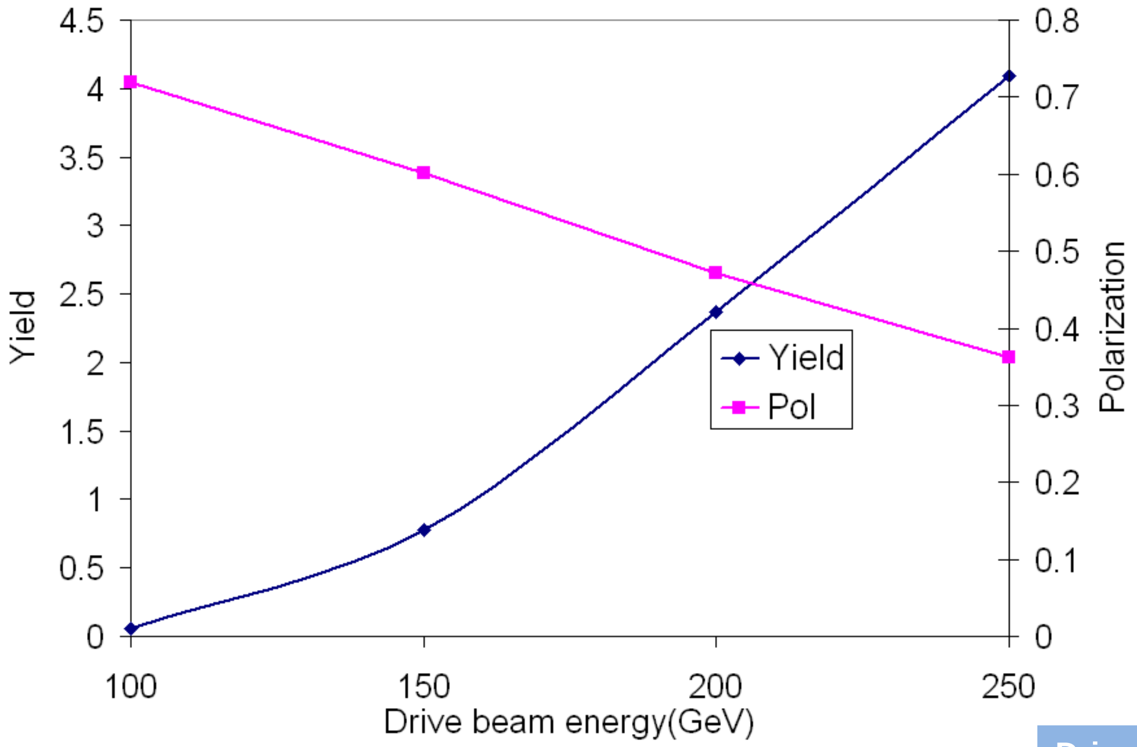
Polarization dependents on Collimator for 250GeV drive beam energy

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

Accelerator design

- The conventional design from SLAC seems to work. With enough cooling.
- But wakefield effects from electron beam before separating from the positron need to be considered.
- Radiation activation the accelerator need to be studied for remode handling purpose.

NC RF linacs for positron capturing

- One1.27m long π mode standing wave high gradient (~15MV/m) structure is used right after the OMD to enhance the capture
- 3x4.3m long 3π/4 mode travelling wave RF linac with gradient of 8MV/m to accelerate the positron beam to 125MeV
- 8x4.3m long 3π/4 mode travelling wave RF linac with 8MV/m to accelerate the positron beam up to 400MeV

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).