The Design of the Positron Source for the International Linear Collider

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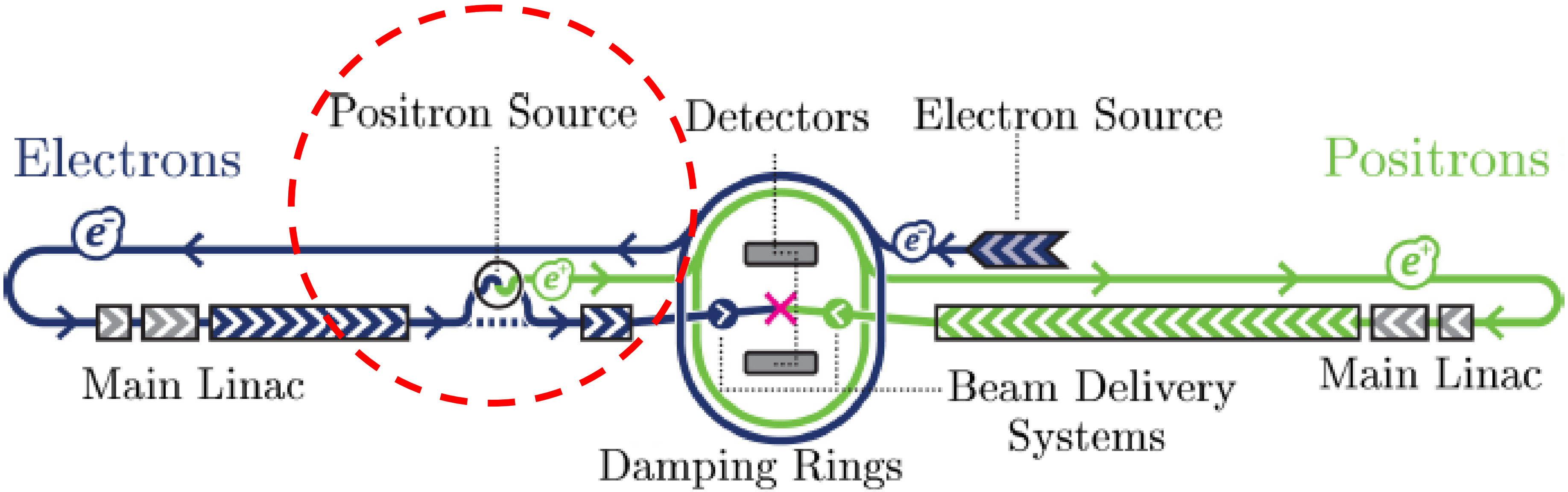
EPAC 2008, Genoa

23rd to 27th June, 2008

What is the ILC?

- The ILC is a proposed **electron-positron collider**
- Both beams have maximum energy **250 GeV**
- Total length of facility **~35 km**
- Peak Luminosity **2 x 10^{34} $cm^{-2}s^{-1}$**



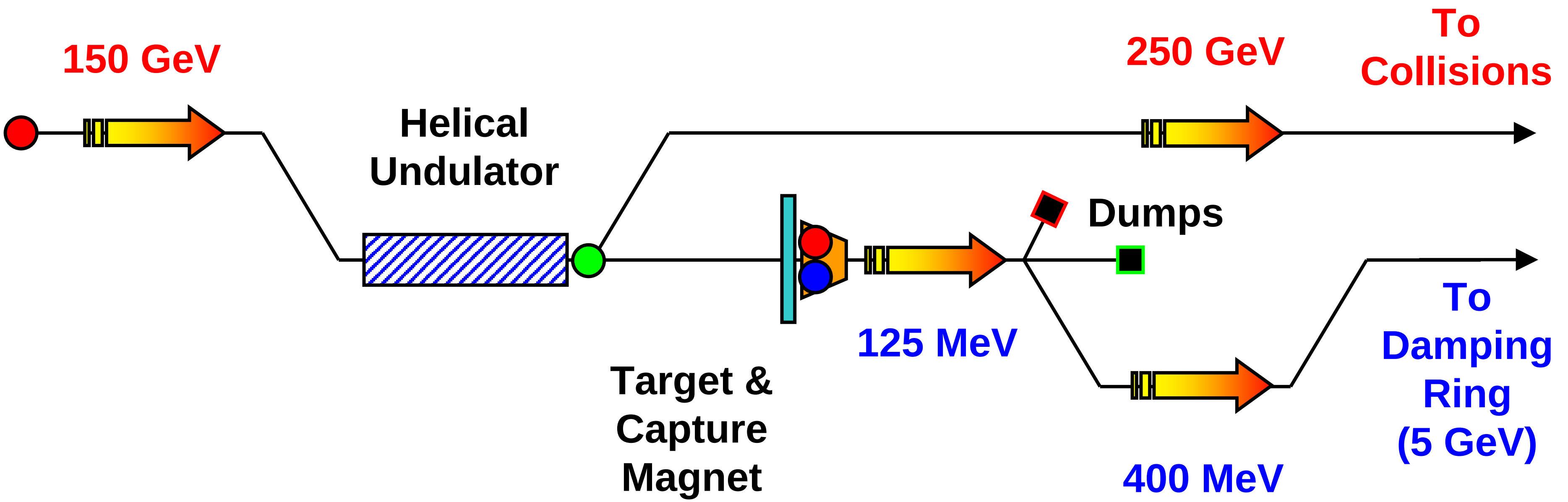
Positron Source Requirements

- The ILC positron source is much more demanding than any other positron source yet built
- Requires ~1000 times more positrons per macropulse than the SLC
- Each bunch must contain **2×10^{10} positrons** (3.2 nC)
- **2625** bunches per macropulse @ **5Hz**
- Additionally, must have upgrade path to provide polarized positrons with polarization **~60%**

Possible Solutions

- Three possible solutions have been proposed:
  - ➔ **Electrons** into a target ('conventional')
  - ➔ ***High energy photons*** into a target
    - Gammas generated by an **Undulator**
    - Gammas generated by **Compton Scattering**
- All three options have been studied and the advantages and disadvantages compared
- When the baseline was established for the ILC in 2005 the **Undulator-based source** was selected as it was judged to be the ***lowest risk option***

Positron Source Layout

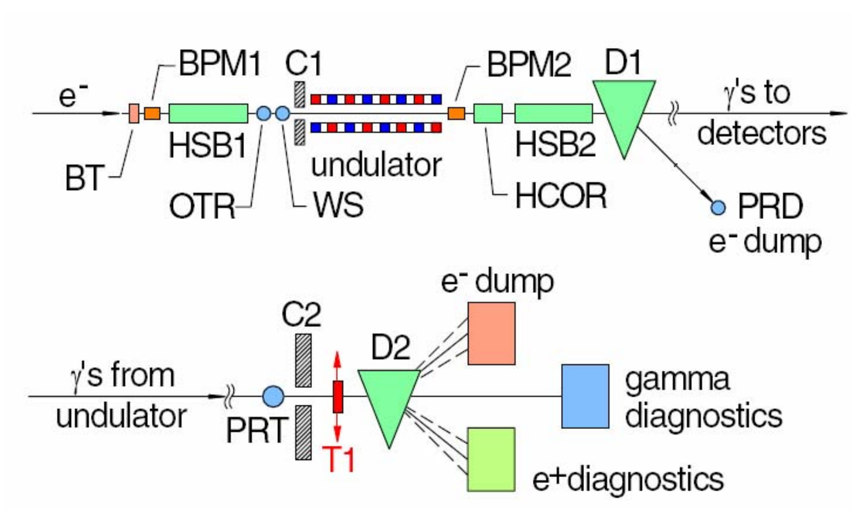


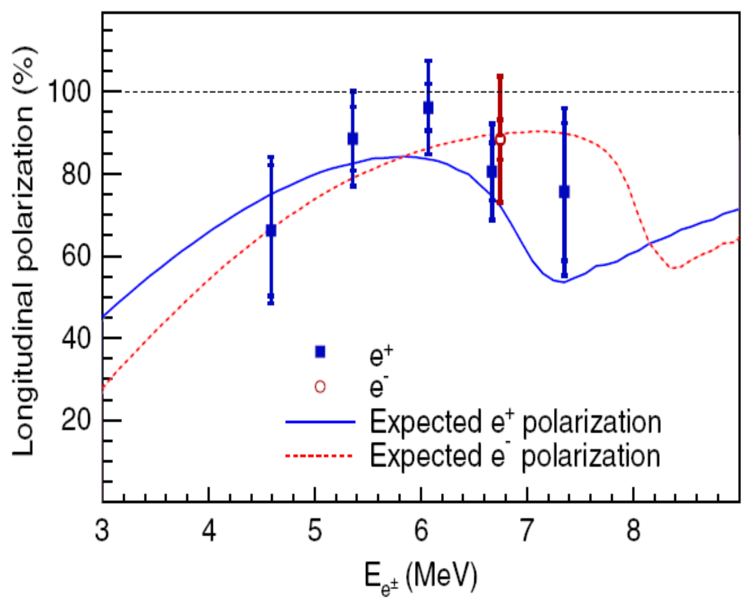
- **10MeV+ photon beam** generated in helical undulator by **150 GeV electrons**
- Photon beam travels ~400 m beyond undulator and then generates e^+e^- pairs in **titanium alloy target**
- Positrons captured and accelerated to 125 MeV
- Any electrons and remaining photons are then separated and dumped
- Positrons further accelerated to **400 MeV and transported for ~5km**
- Accelerated to 5 GeV and **injected into Damping Ring**

E166 – Proof of Principle

- Experiment at SLAC (E166 in 2005) to demonstrate feasibility of this technique
- Successfully generated (polarized) positrons in good agreement with simulations

46.6 GeV electrons
1m long undulator, 0.9mm aperture, λ_u = 2.54mm
Tungsten target





G. Alexander et al, PRL 100, 210801 (2008).

The Undulator

- To generate the photons with a high enough energy (>10MeV) need to use **short period, high field**, undulator
- For sufficient positrons undulator must be **~200m**
- Short period, high field, only possible with **narrow aperture**:
  - ➔ Resistive wall effects
  - ➔ Vessel surface roughness effects
  - ➔ Synchrotron radiation power problems
  - ➔ Generating a vacuum with difficult aspect ratio
  - ➔ Mechanical tolerances
  - ➔ Manufacturing issues
- **Superconducting** technology solution chosen after ‘competition’ with permanent magnet

D.J. Scott et al, PR-STAB, 10, 032401 (2007).

Undulator Details

- Several **short prototypes** have been tested
- Focus now on design, manufacture and testing of a **full cryomodule**
- Daresbury & Rutherford Appleton Laboratories are jointly building a full scale **4m undulator** module
- Cornell have had a similar program of building short prototypes and intended to build a full cryomodule

Undulator Parameters	Symbol	Value	Units
Undulator period	λ	1.15	cm
Undulator strength	K	0.92	
Undulator type		helical	
Active undulator length	L_u	147	m
Field on axis	B	0.86	T
Beam aperture		5.85	mm
Photon energy (1^{st} harmonic cutoff)	E_{c10}	10.06	MeV
Photon beam power	P_γ	131	kW

Undulator Cryomodules

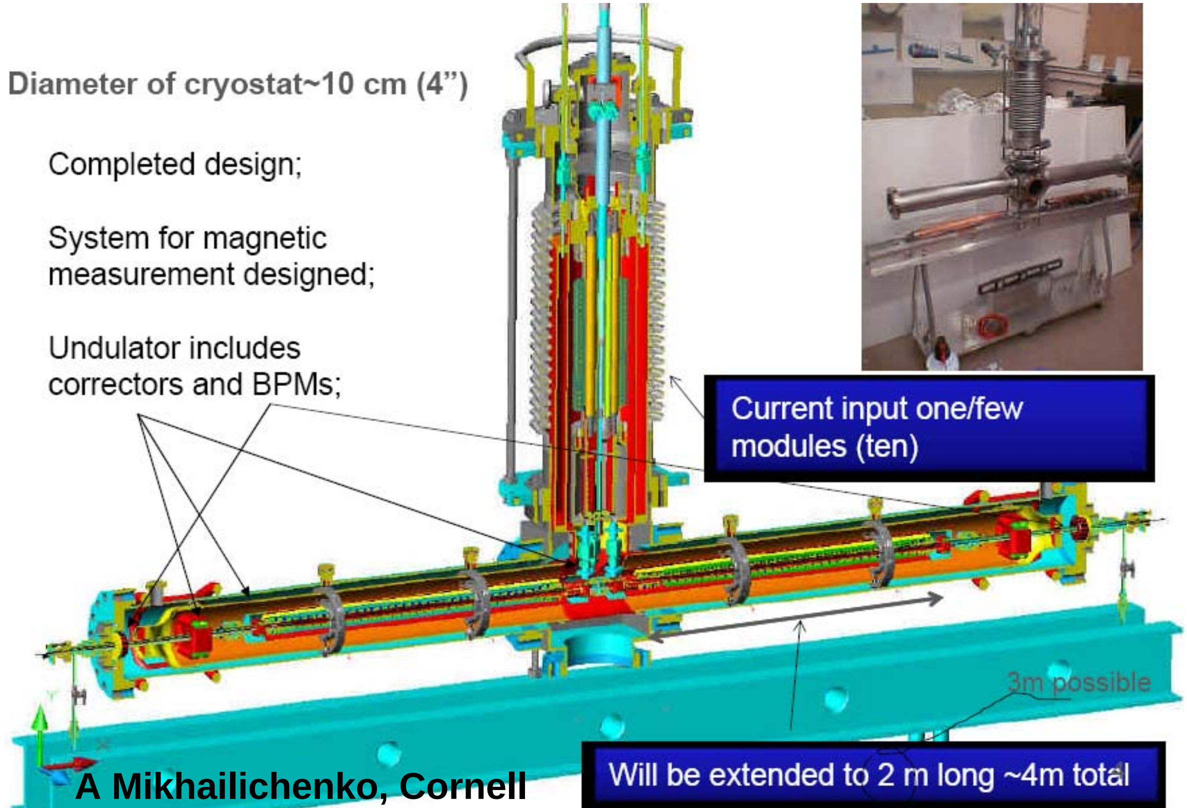
Similar schemes developed by both groups

Diameter of cryostat~10 cm (4”)

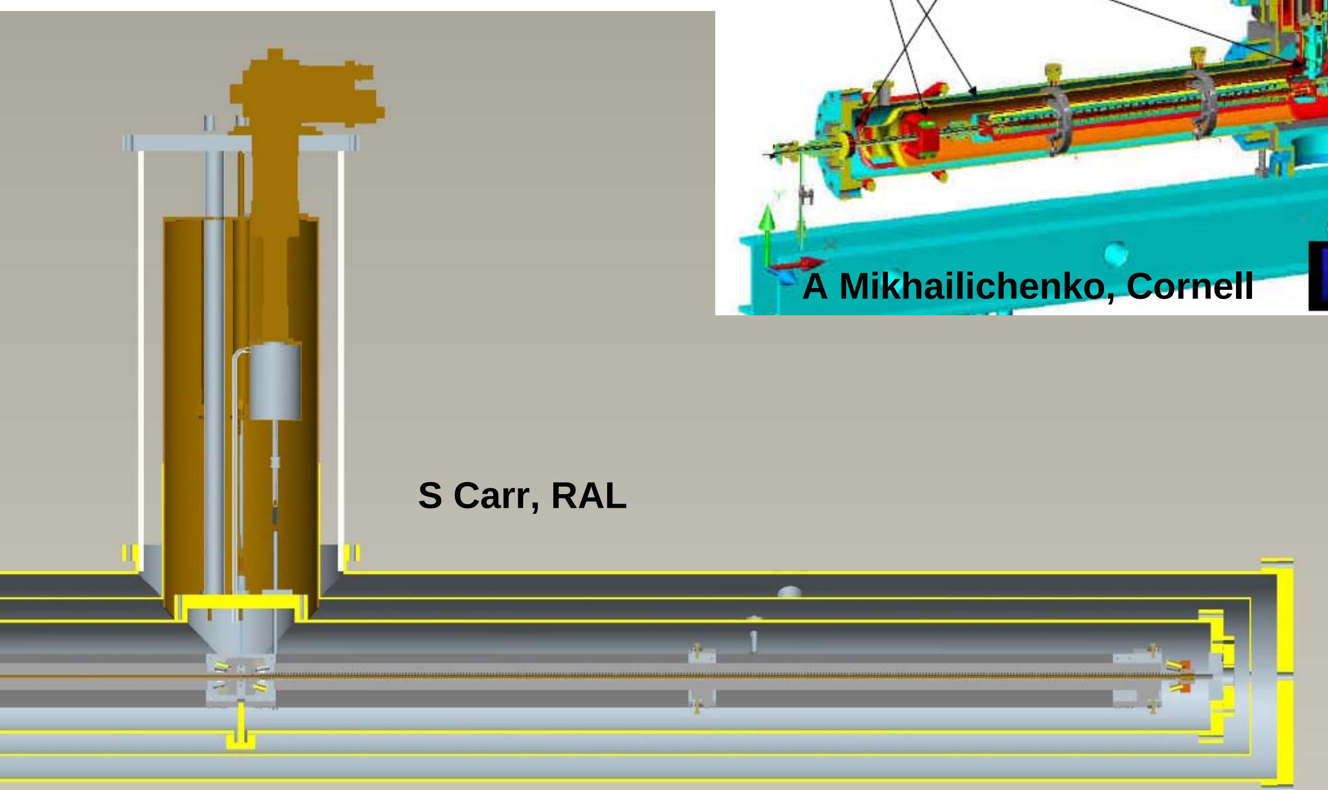
Completed design;

System for magnetic measurement designed;

Undulator includes correctors and BPMs;



A Mikhailichenko, Cornell



S Carr, RAL

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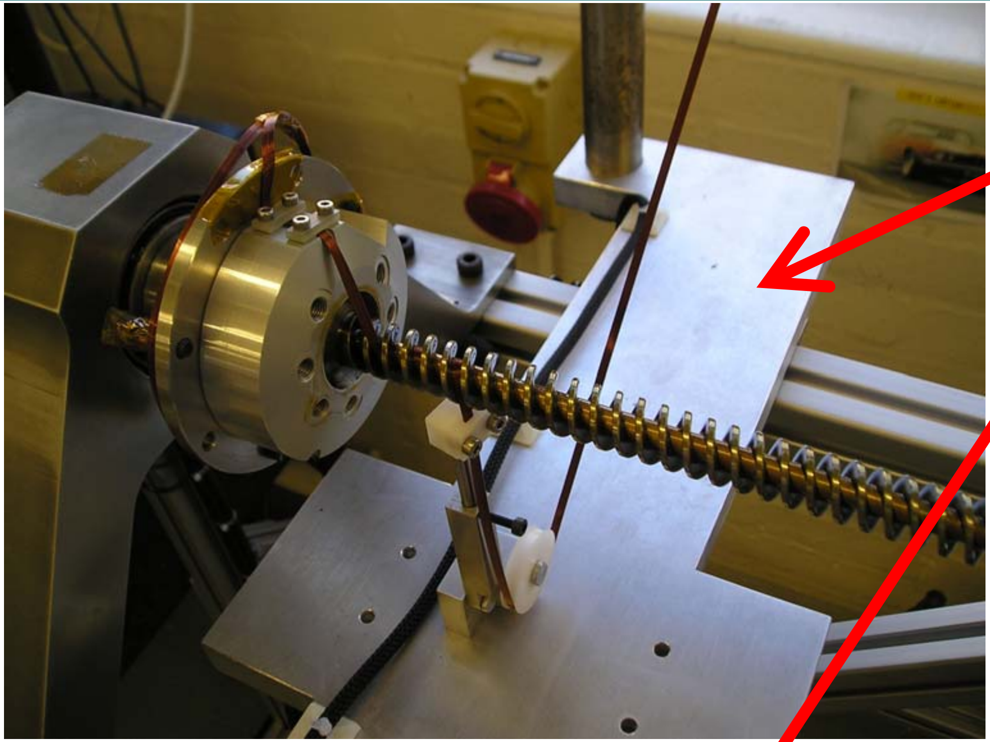
1.75m Undulator Fabrication

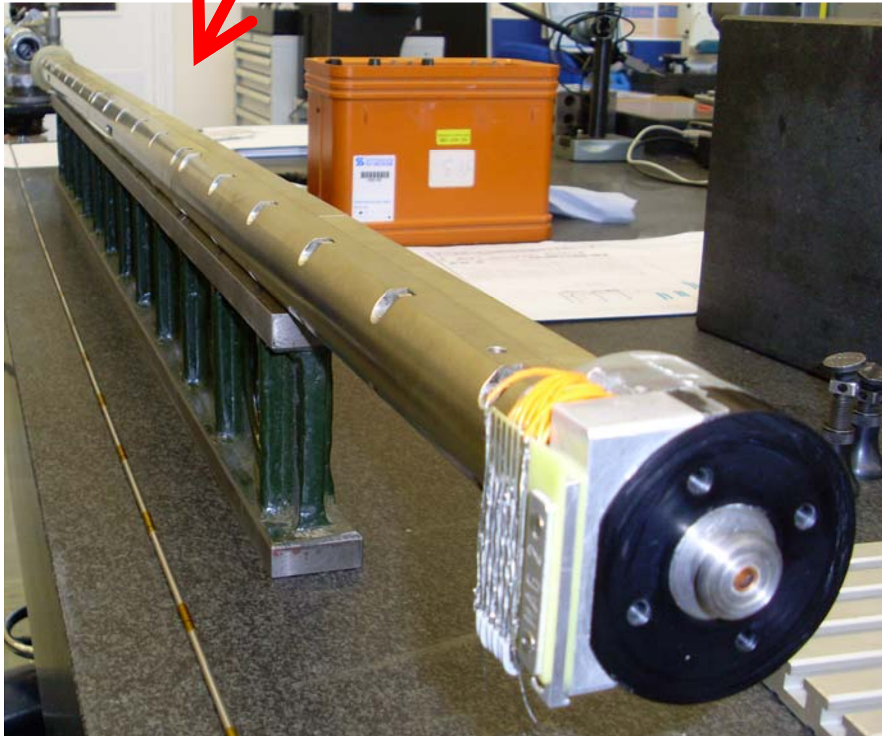
Accelerator Science and Technology Centre



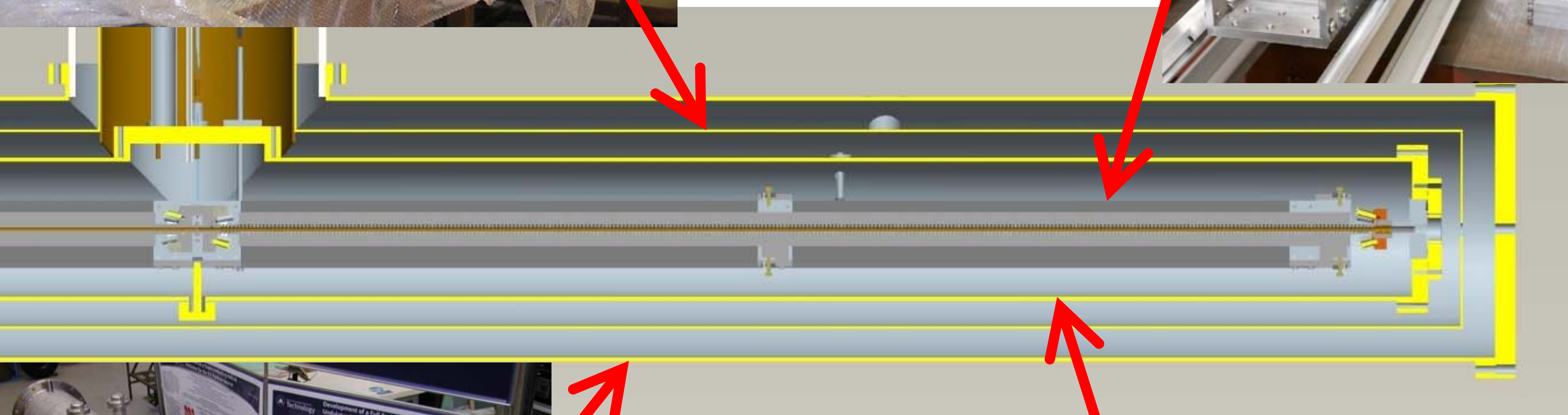
Winding

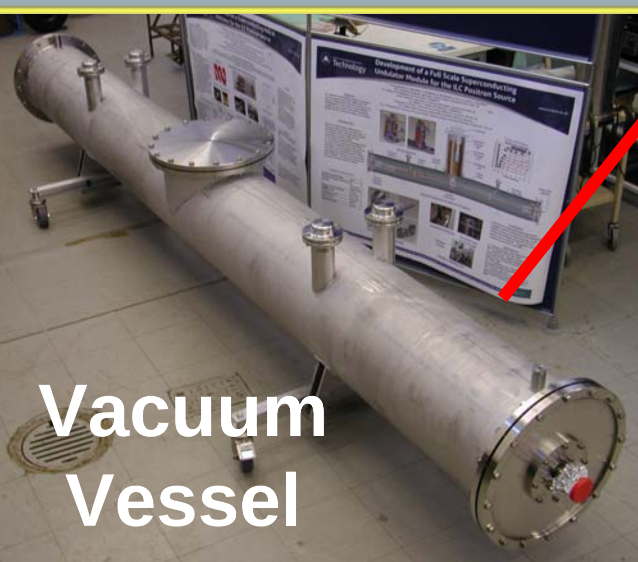
Potted and in one half of steel yoke

Complete magnet

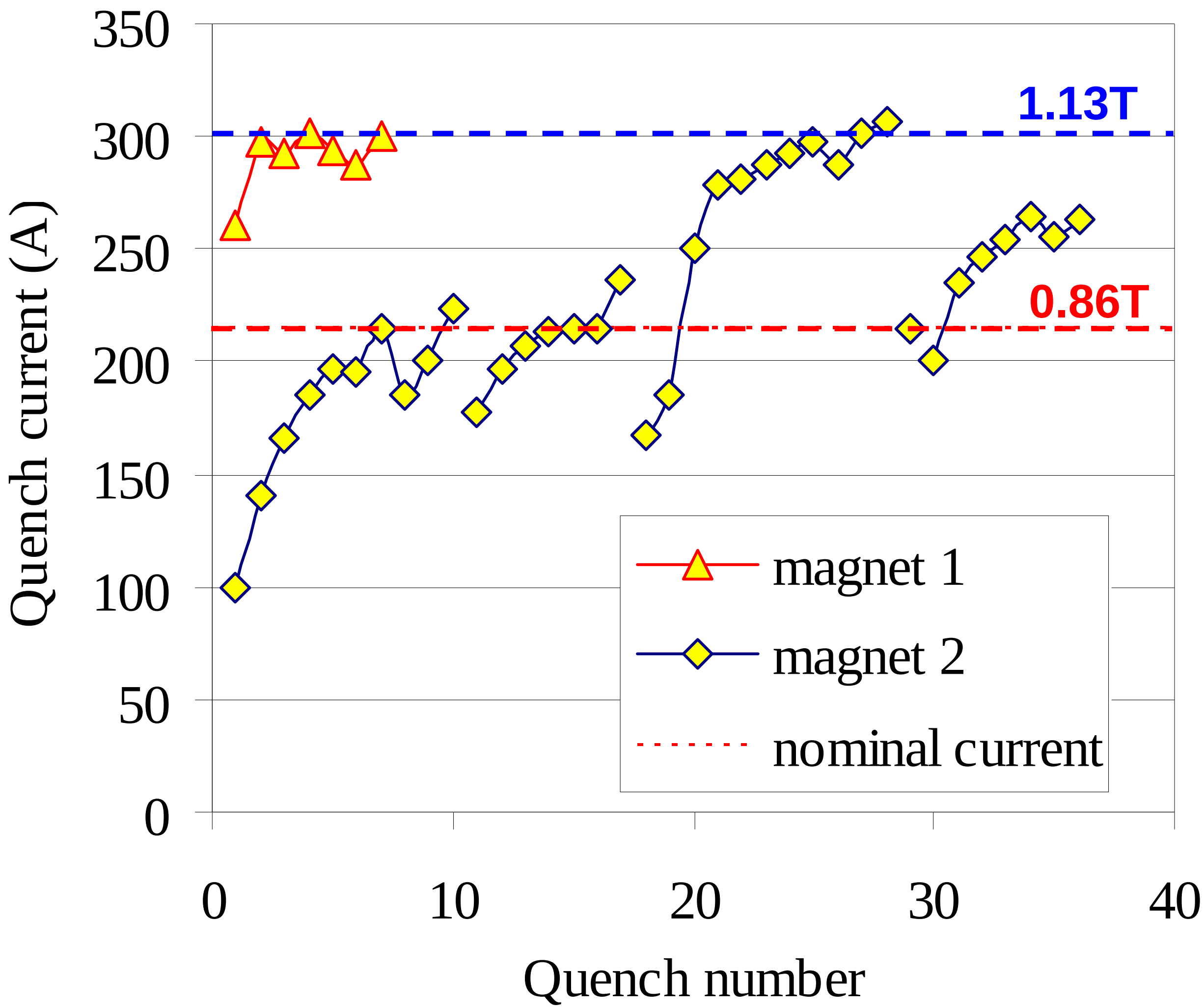


4m Cryomodule Fabrication





Quench Training Data



Both long undulators have **exceeded the design current** (216 A) by **~40%.**

The two nominally identical magnets have quite different behaviours – the reason is **not understood.**

J.A. Clarke et al, MOPP070

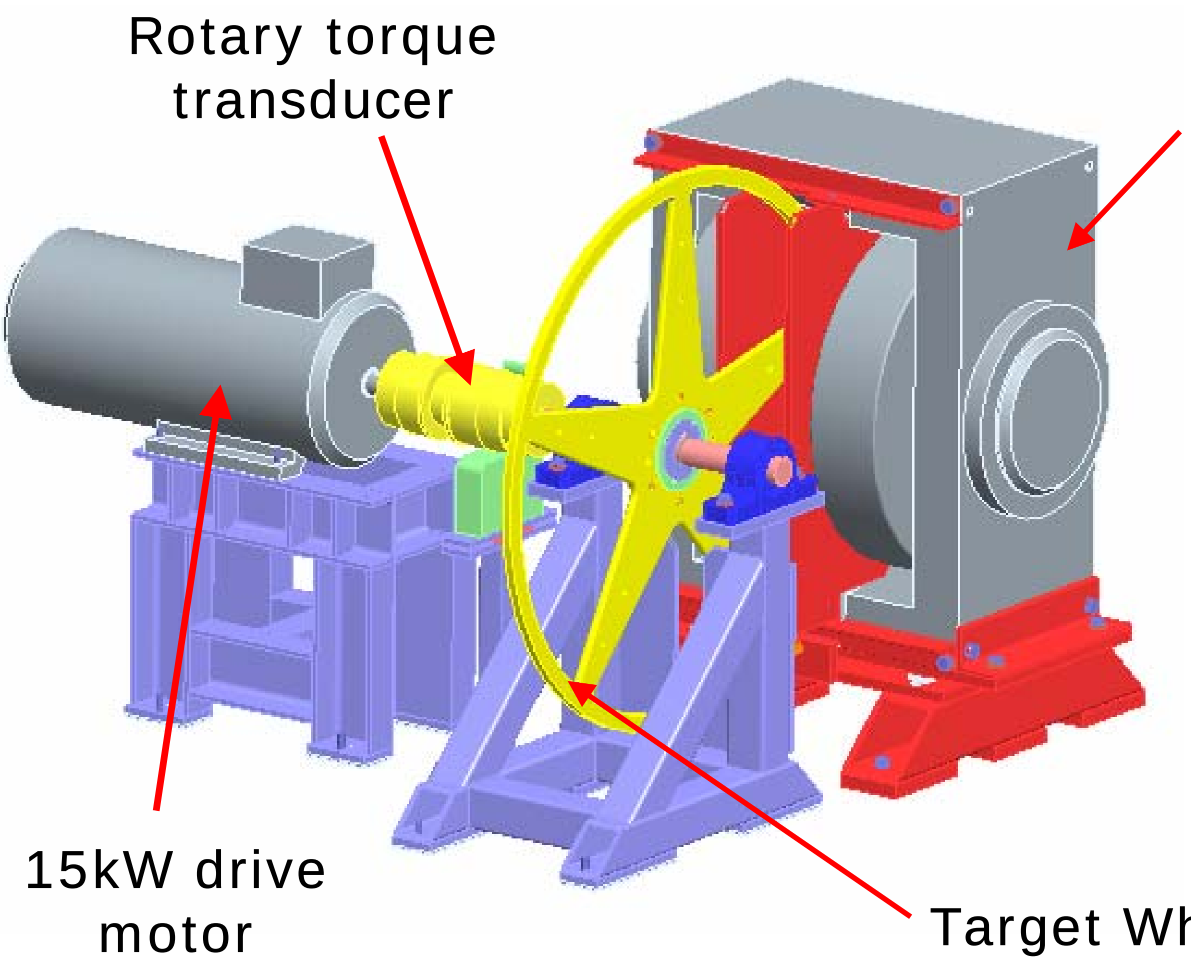
The Target

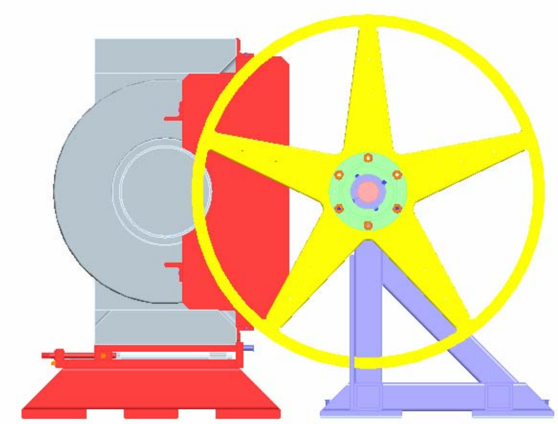
- Several materials have been considered for the conversion target
- **Titanium alloy** selected as has greatest safety margin
- Need to ***rotate*** target to reduce local radiation damage and thermal effects (**1m diameter** selected)
- Positron capture enhanced by magnetic field but **eddy current** effects limit field level
- **Rim & spokes** not solid disk to help mitigate these eddy current effects

Target Parameters	Symbol	Value	Units
Target material		Ti-6%Al-4%V	
Target thickness	L_t	0.4 / 1.4	r.l. / cm
Target power adsorption		8	%
Incident spot size on target	σ_i	> 1.7	mm, rms

Eddy Current Experiment

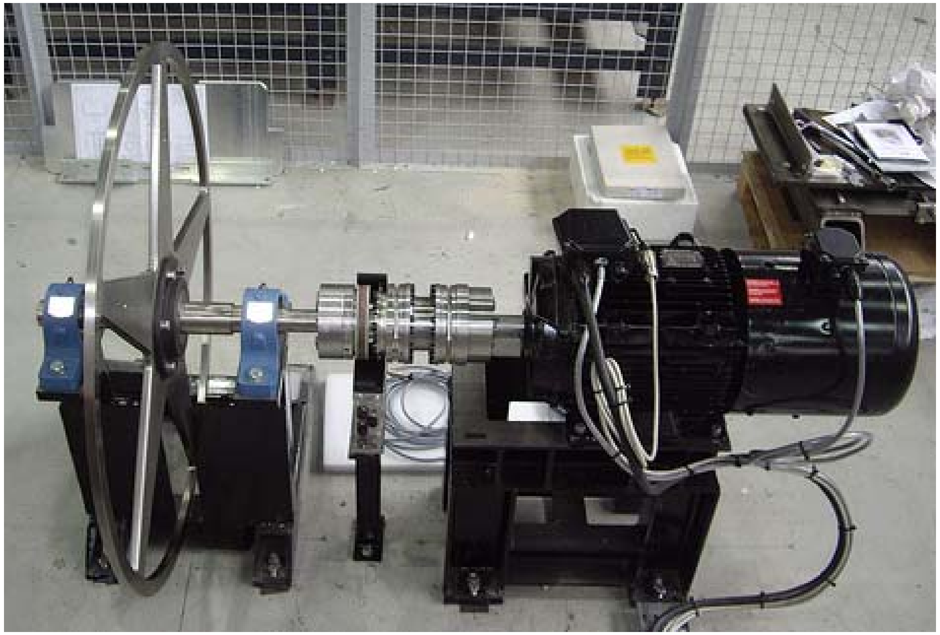
Experiment initiated at Cockcroft Institute/Daresbury Laboratory to monitor ***eddy current*** effects and ***mechanical stability*** of full size wheel at design velocity

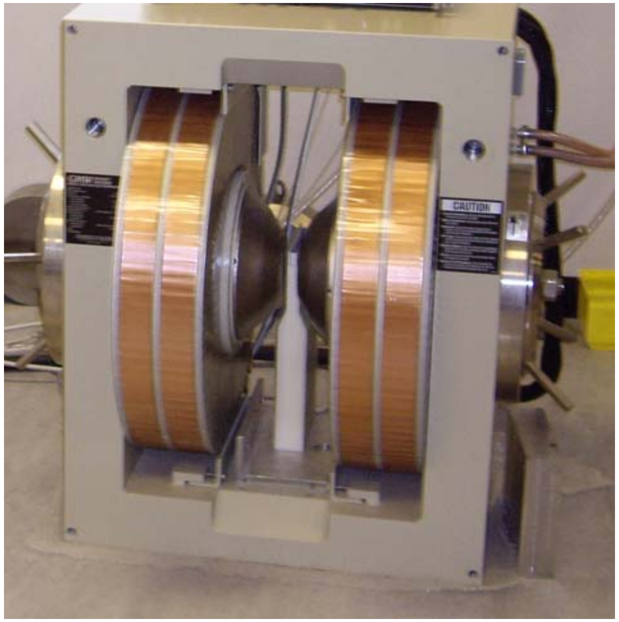




I Bailey et al, MOPP069

Cockcroft Institute Prototype





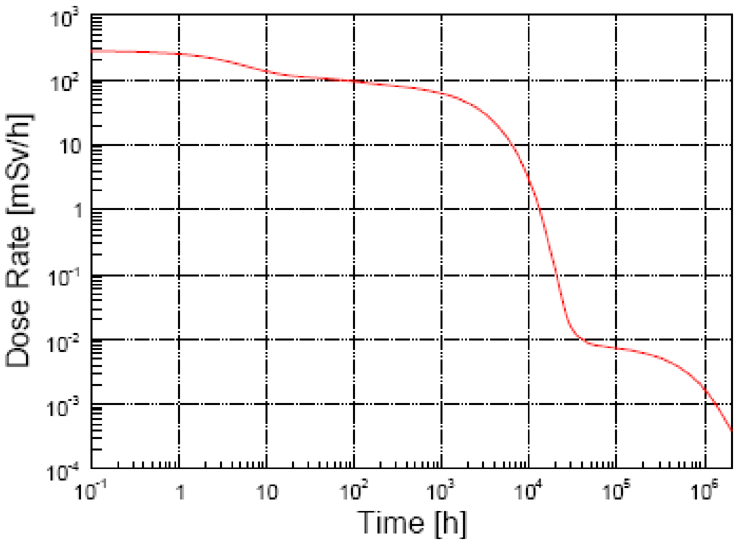
Experiment will start when personnel guards are in place

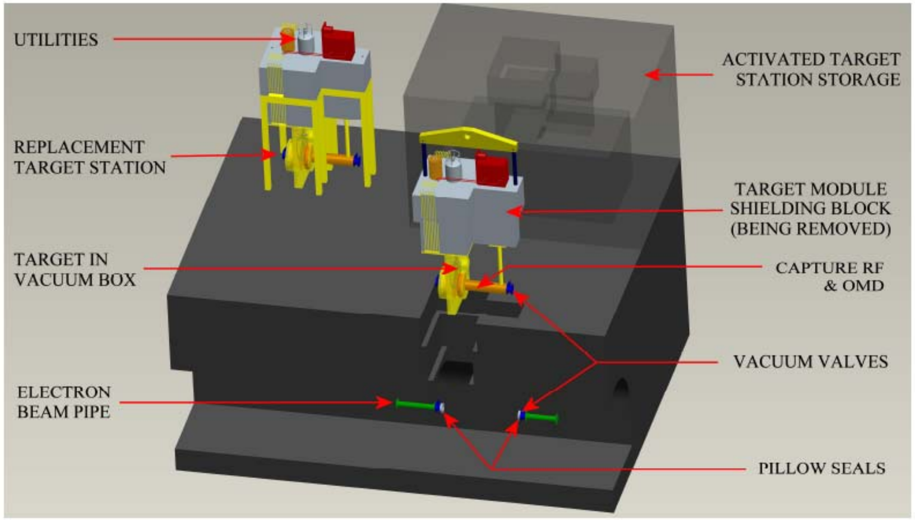
Should be completed *by end of 2008*

Target Activation

- Equivalent dose rate calculated after **5000 hours** of operation at **1m** from the source
- **Remote handling** required so can exchange target modules rapidly
- No intention to make in-situ repairs of the target

	Conventional	Undulator Based
after Source Switch-Off	700	280
after 1 hour	628	248
after 1 day	574	111
after 1 week	469	86

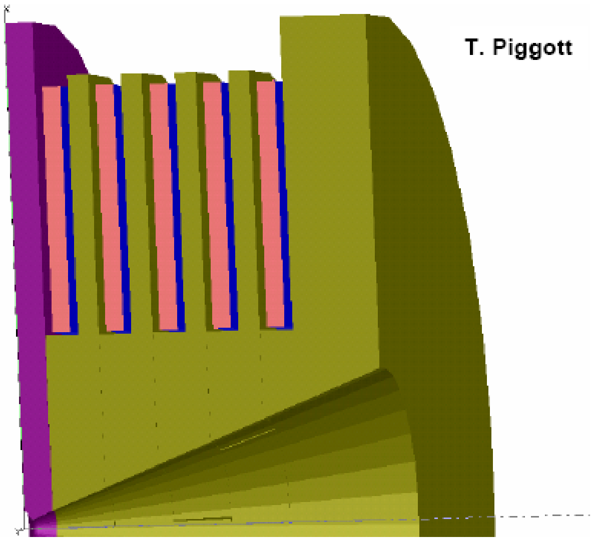




A. Ushakov, MOPP077

Capturing the Positrons

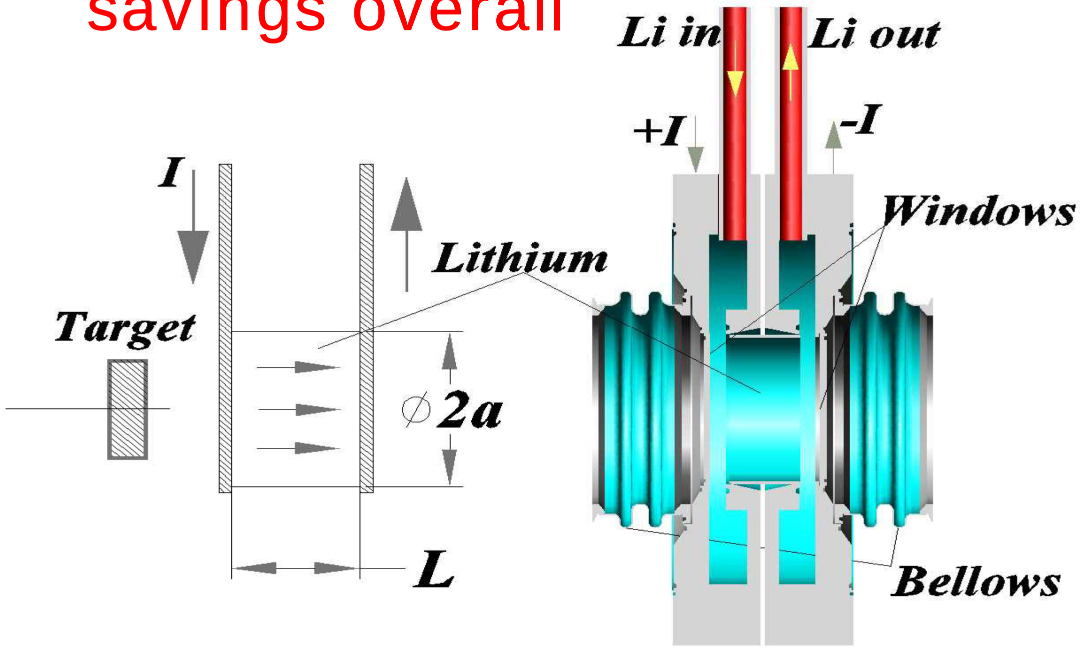
- If a linac is placed directly after the target then **~10% of the positrons are captured**
- Using an appropriate magnetic field can **enhance** the capture significantly
  - ➔ Simple solenoid (QWT, no field on target) **~15%**
  - ➔ Flux concentrator **~21%**
  - ➔ Lithium lens **~40%**



- Flux concentrator is an *established* technique
- Needs to be scaled up from **μs to ms** pulse lengths
- Further study needed to prove feasibility
- Would need a prototype
- **Presently assumed solution**

Lithium Lens Capture System

- Current flows co-linearly with positrons
- Induced magnetic field gives **focussing**
- Lithium will be liquid with flow of ~1m/s
- Capture up to **~40%** of positrons
- Would also need ***prototype***
- **Modest** investment needed now for significant savings overall

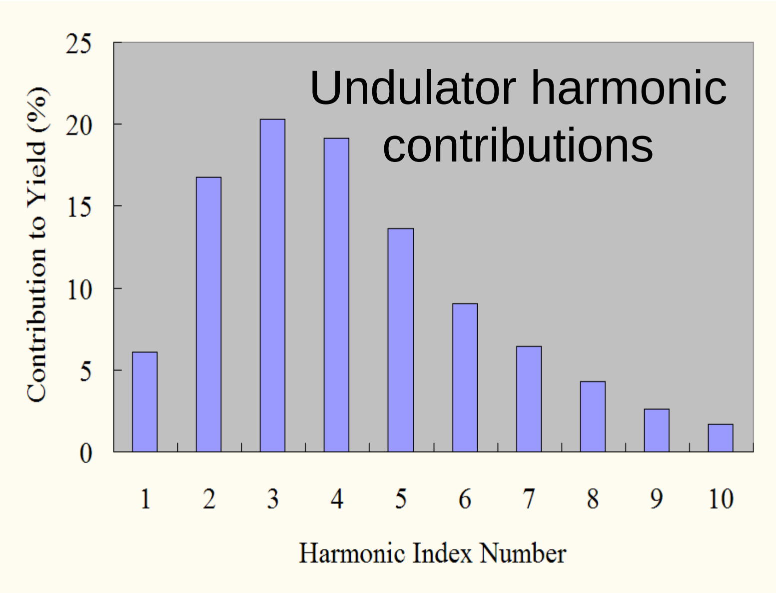


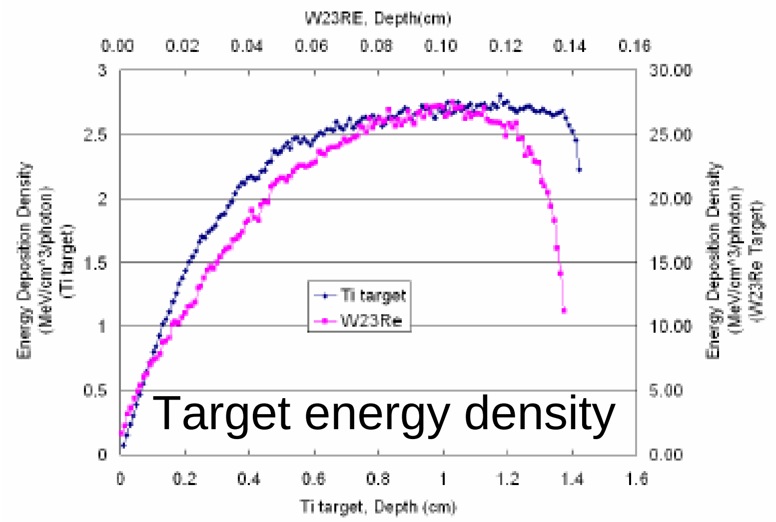
- Concerns mainly about *survivability* of windows
- Radiation damage
- Thermal shock & cycling
- Cavitation of the lithium

A Mikhailichenko, WEPP157

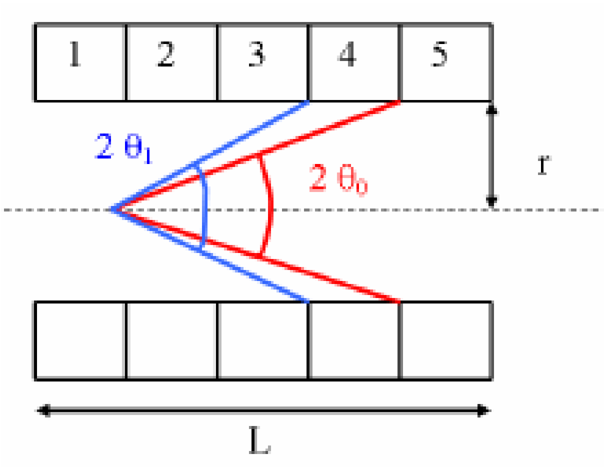
Source Modelling

- Extensive modelling of the source has been carried out by several groups
- Used for global optimisation of undulator, target, and capture section parameters
- Yield simulations include undulator, collimation, target, capture magnet, and linacs
- Modelling of *polarisation* of positrons also included





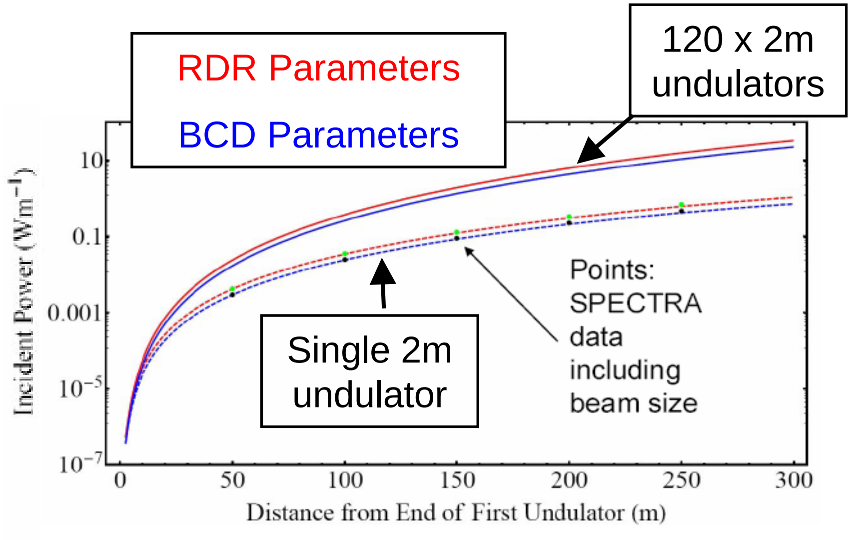
W Gai, W liu



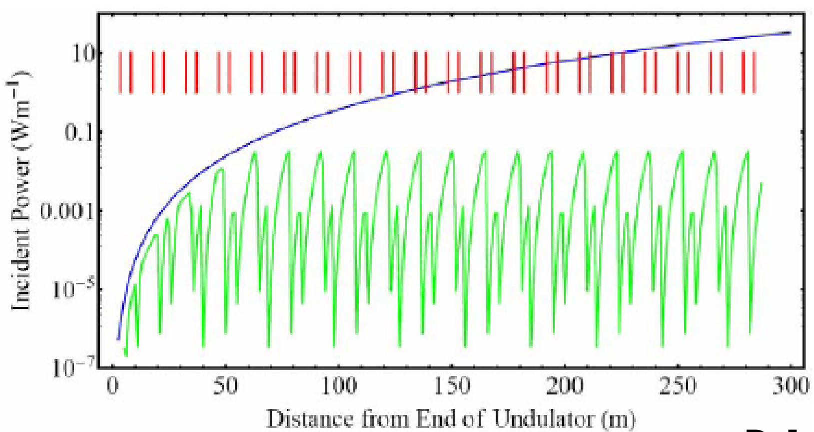
Undulator is **cold bore** (4K) and will **quench itself** unless (low power) **collimators** are included in the cryomodule string

Full ~200m undulator made up of many ~2m sections, each treated separately

Power per metre without collimators **>10W/m**. Limit of cryosystem is **~1 W/m.**



Inclusion of 5mm diameter **photon collimators** (shown in red) in room temperature sections reduces power level to **~0.05 W/m**



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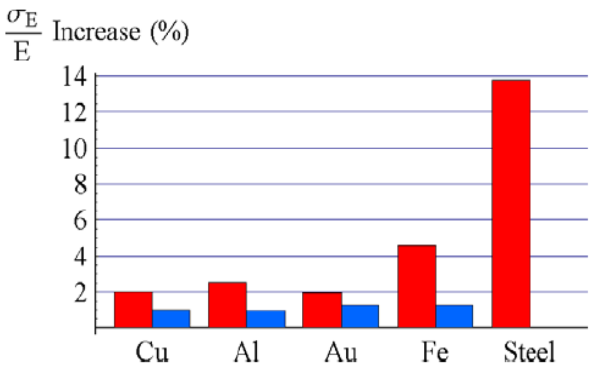
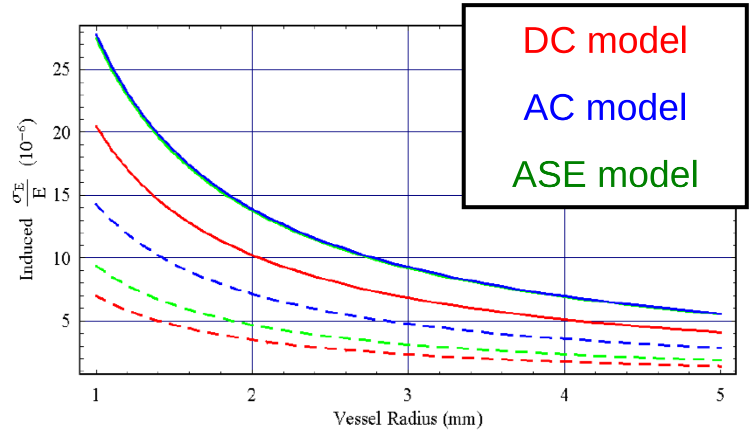
Wakefield Studies

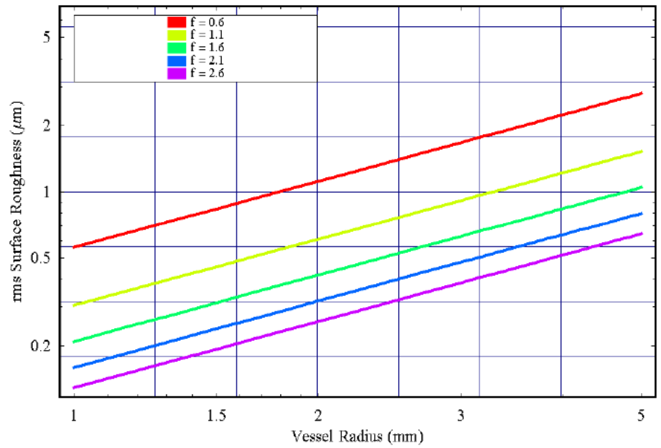
Energy spread increase of electron beam for 200m long undulator at room and cryogenic temperatures for alternative vessel materials due to **resistive wall impedance**



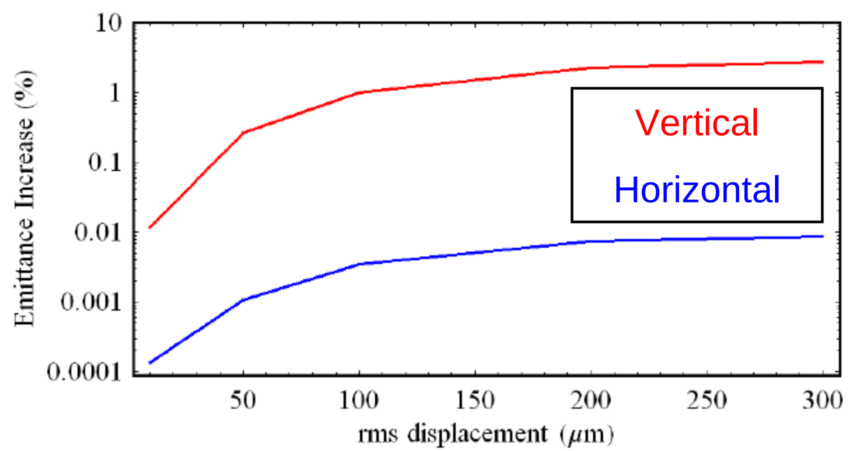
Energy spread increase of electron beam at room (solid) and cryogenic (dashed) temperatures for copper vessel due to **resistive wall impedance**



Surface roughness necessary to produce an energy spread of 0.005% (nominal for ILC is 0.05%) for different vessel radii and form factors.



Mean **emittance increase** due to **geometric wakes** of misaligned taper sections and photon collimators in undulator section.



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Positron Polarization

- Helical undulator generates ***circularly polarised light***
- This then produces longitudinally ***polarized positrons***
- Selecting **photons near axis** maximises polarisation rate
- **Baseline** source generates **~30% polarization** (already very useful!)
- Upgrade by ***collimating photon beam*** to select the appropriate photons and by ***lengthening undulator*** to make up for subsequent loss in intensity
- Can readily achieve **~60% polarisation**

Summary

- The ILC positron source requires **~1000 times more positrons** per macropulse than ever before achieved
- The positrons are generated by **>10MeV photons** which are produced by a **150GeV electron beam** in a long superconducting undulator
- The upgrade to a **polarized positron source** is simple and straightforward
- A **full scale undulator module** has been successfully fabricated
- A **conversion target eddy current experiment** is in progress
- Other critical subsystems will need **prototyping** in the future – eg Lithium lens & Flux concentrator (*some investment needed!*)
- All simulations show the source to be **feasible** and any potential detrimental effects to be **small**
- Detailed **engineering and integration** of the full source has now been initiated

Thanks To The Team !

I.R. Bailey
D.P. Barber
E. Baynham
V. Bharadwaj
T.W. Bradshaw
A. Brummitt
A. Bungau
F.S. Carr
N.A. Collomb
J. Dainton
R. Dollan
W. Gai

J. Gronberg
A.F. Hartin
S. Hesselbach
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Y. Ivanyushenkov
L.J. Jenner
K. Laihem
A. Lintern
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O.B. Malyshev
L.I. Malysheva

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D.J. Scott
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A. Ushakov
L. Zang