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Accelerators in a new light

OPTIMIZATION OF SUPERCONDUCTING UNDULATORS FOR LOW REPETITION RATE FELS

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EuPRAXIA

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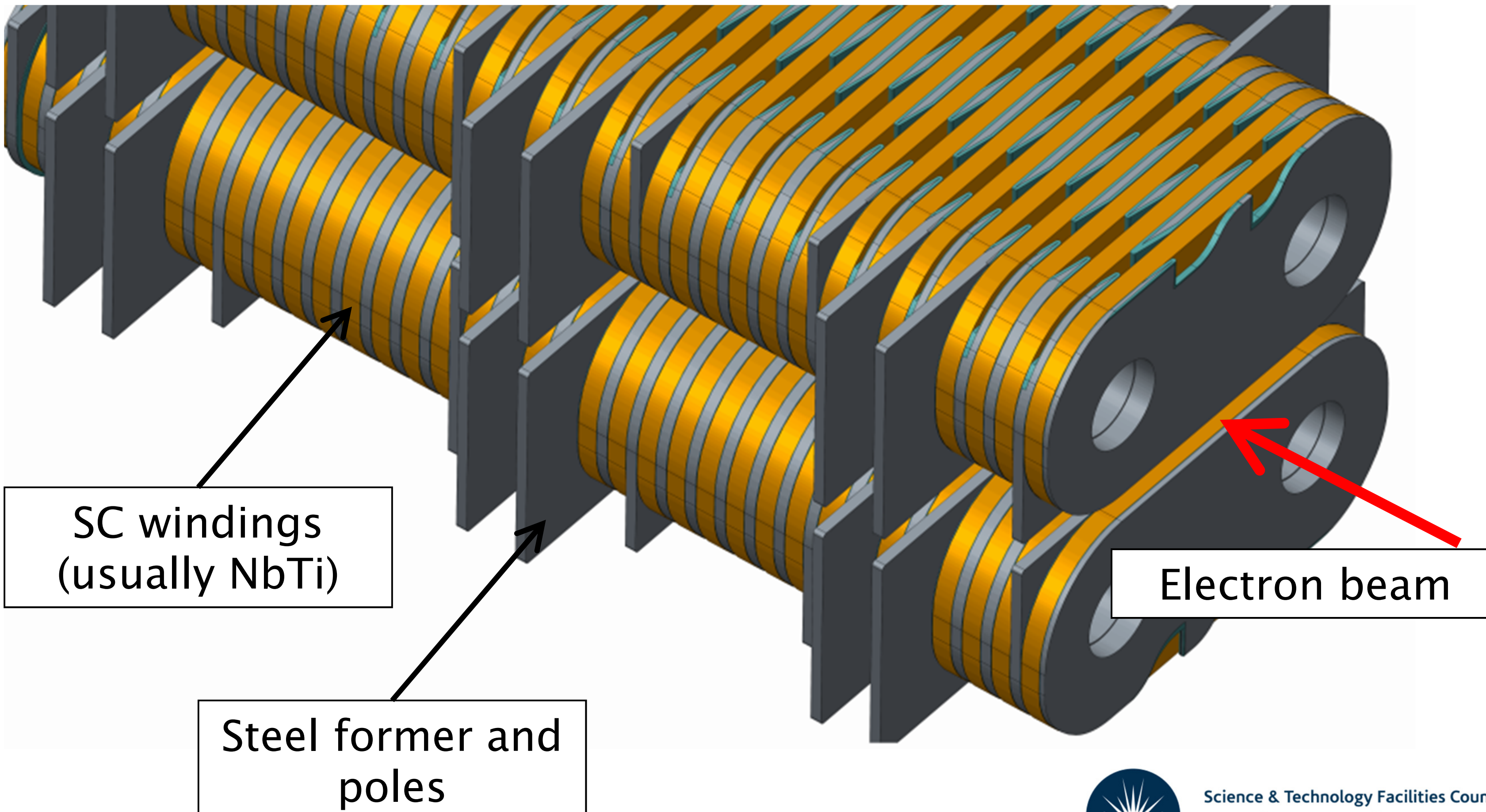
Introduction

- Many groups have been developing Superconducting Undulators (SCUs) for a number of years, especially for storage rings
- Successfully implemented now and in routine use on ANKA and APS
- LCLS-II have strongly considered the use of SCUs

- We have worked on SCUs in the UK for about 15 years (Daresbury, Rutherford, Diamond)
- We have now started to look at the implications of an SCU specifically designed for FELs

SCU for Storage Ring

- Most groups have converged on a similar concept for planar SCUs



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SCU for Storage Ring

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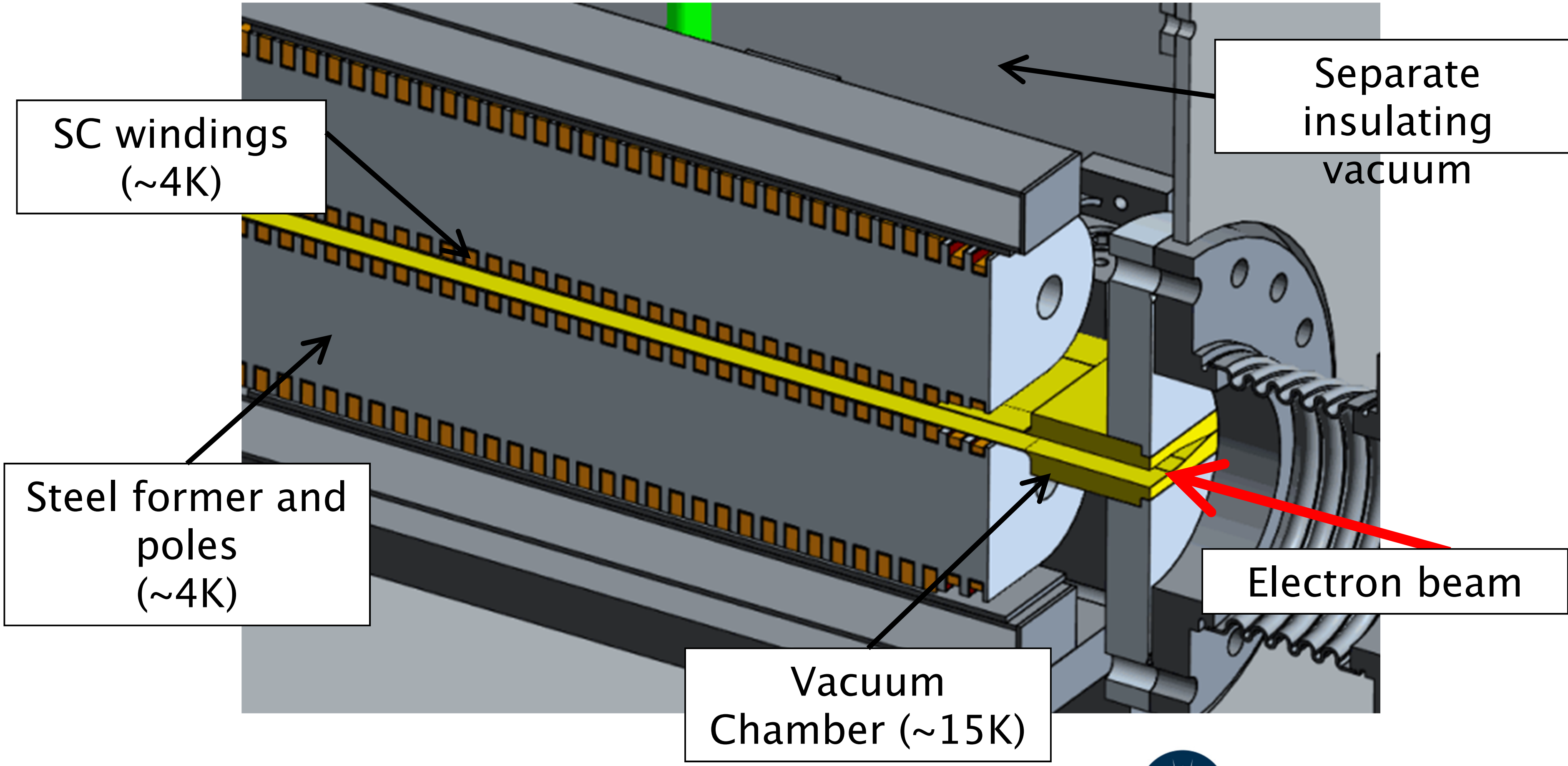

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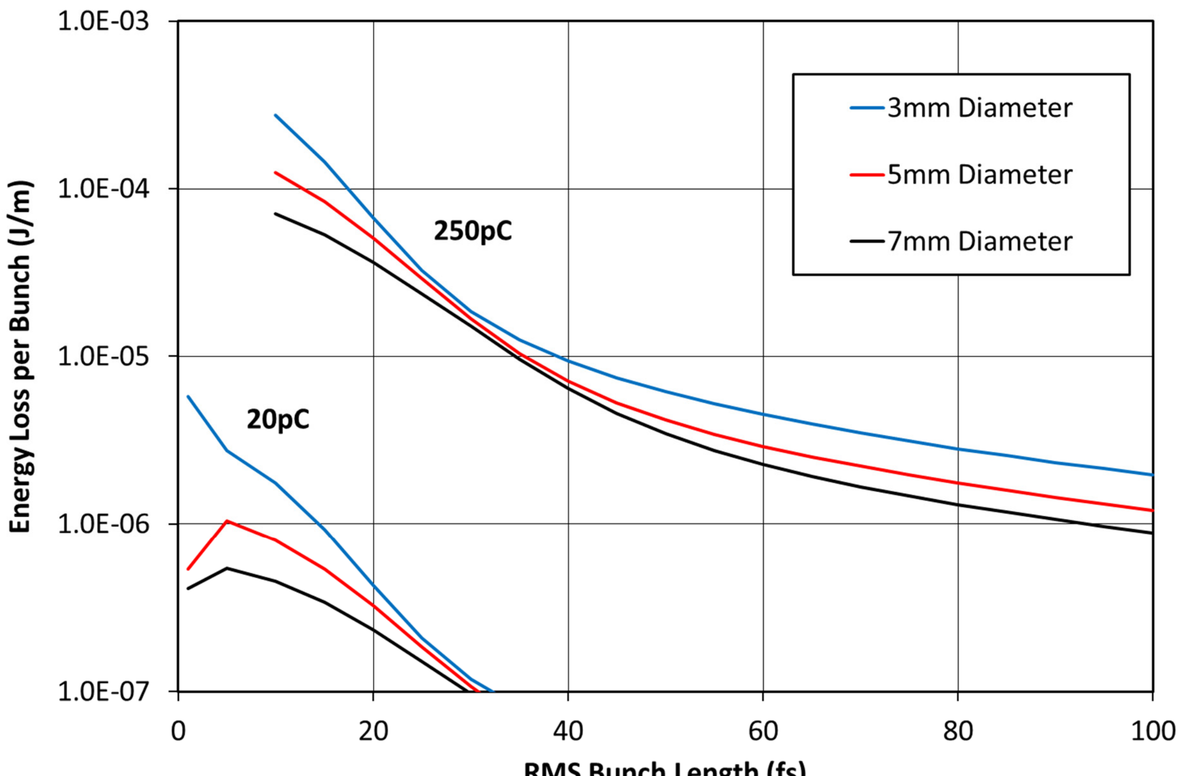
SCU for FELs

- The constraints are different
  - Vacuum levels are more relaxed
  - Good field region requirement much smaller
  - No significant synchrotron radiation heatload from upstream
  - **The energy deposited within the SCU due to wakefields is now under our control – the bunch parameters and repetition rate**

- The engineering becomes simplified
  - Common vacuum system
  - **No internal vacuum chamber, just thin copper foils (like in-vacuum undulators) when the deposited power is low enough**

Resistive Wall Wakefields

- Assuming copper with RRR = 10, circular cross section (parallel plates give similar results)
- Anomalous Skin Effect (ASE) and Extreme ASE regimes considered
- Gaussian bunches



For reference:

LCLS modes

Nominal
150 pC, 40 to 300fs FWHM

Short bunch
20pC, 3 fs FWHM

https://portal.slac.stanford.edu/sites/lcls_public/Lists/machine_faq/FAQ.aspx

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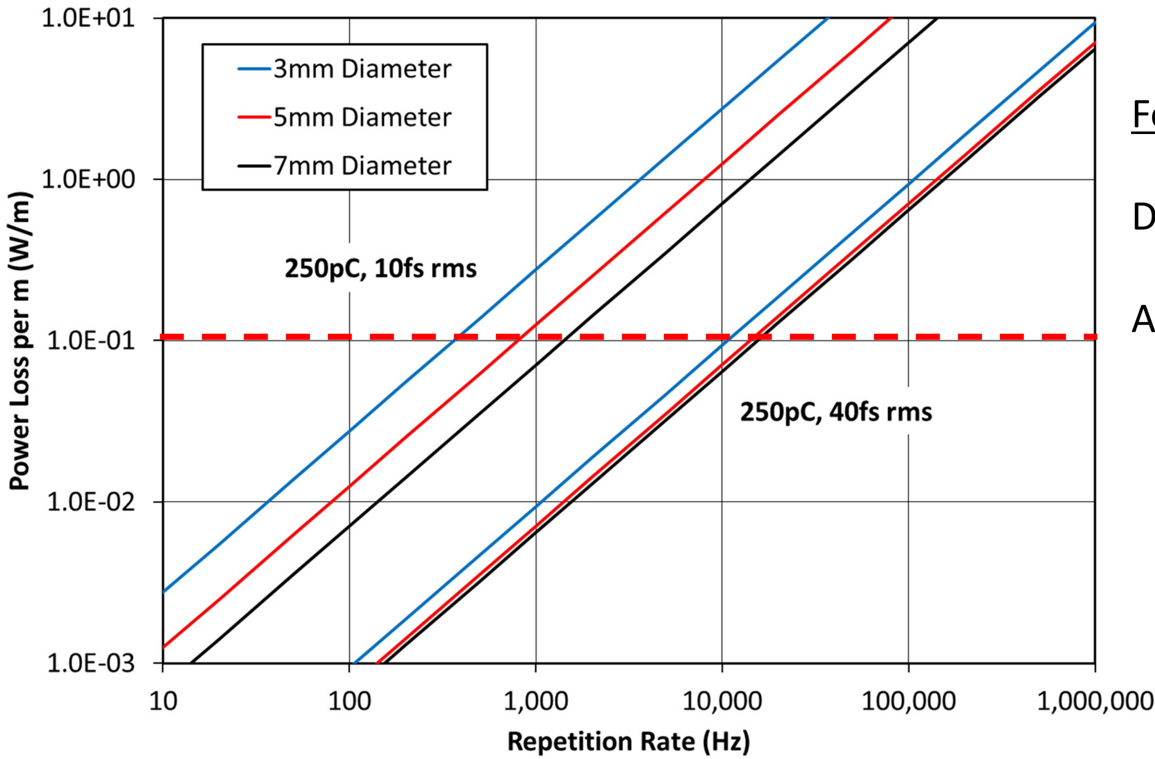
Resistive Wall Wakefields

- Power loss per meter depends on number of bunches per second
- 100mW/m comfortable for cryocooler-based system



<u>For reference:</u>

Diamond Light Source ~1W/m

Argonne Photon Source ~2.5W/m

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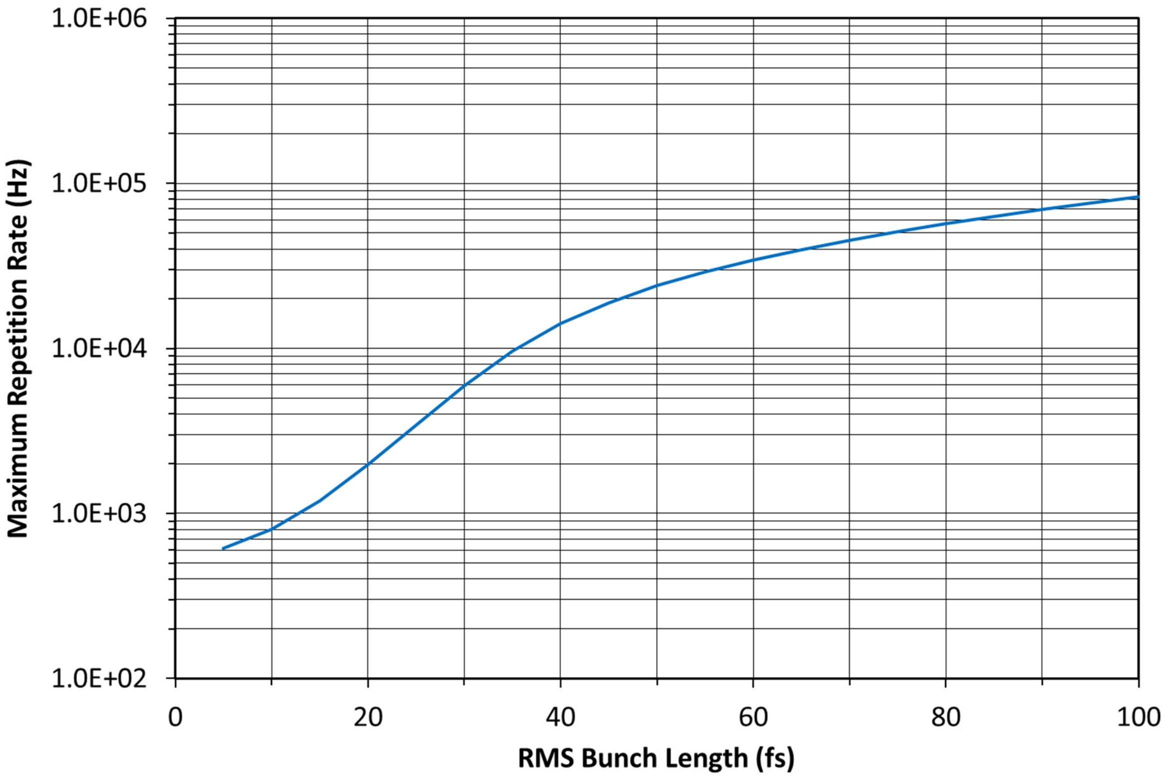
Resistive Wall Wakefields

- Maximum bunch repetition rate assuming 100mW/m
- 250pC bunches and 5mm aperture
- >> 100Hz for all scenarios



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Magnet Gap

- Storage Ring Example:
  - Beam stay clear = 5.0mm
  - Vacuum chamber wall thickness = 2 x 0.5mm
  - Insulating gap between 15K vac chamber and 4K magnet = 2 x 0.5mm
  - **Magnet aperture = 7.0mm**

Magnet Gap

- Storage Ring Example:
  - Beam stay clear = 5.0mm
  - Vacuum chamber wall thickness = 2 x 0.
  - Insulating gap between 15K vac chambe
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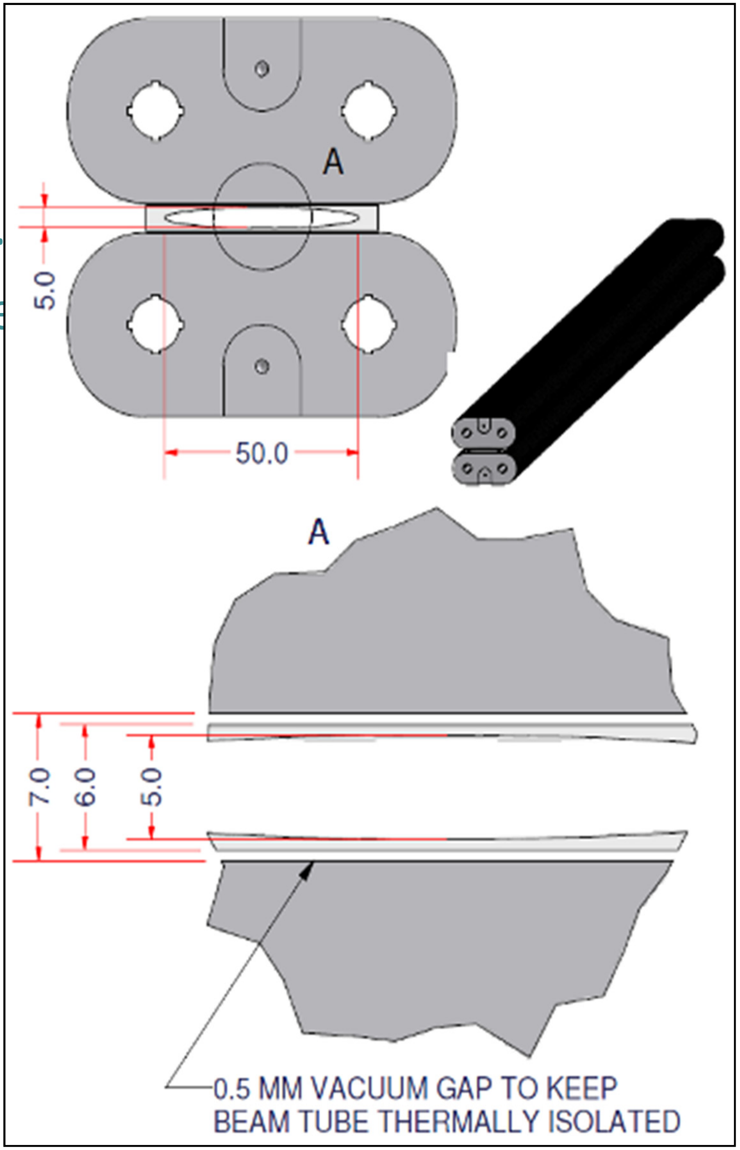

Magnet Gap

- Storage Ring Example:
  - Beam stay clear = 5.0mm
  - Vacuum chamber wall thickness = 2 x 0.5mm
  - Insulating gap between vac chamber and 4K magnet = 2 x 0.5mm
  - **Magnet aperture = 7.0mm**
- FEL Example:
  - Beam stay clear = 5.0mm
  - Vacuum chamber **not required**
  - Copper conducting sheet at 4K = 2 x 0.1mm
  - Insulating gap between vac chamber and 4K magnet **not required**
  - **Magnet aperture = 5.2mm**
- Very significant reduction in magnet aperture

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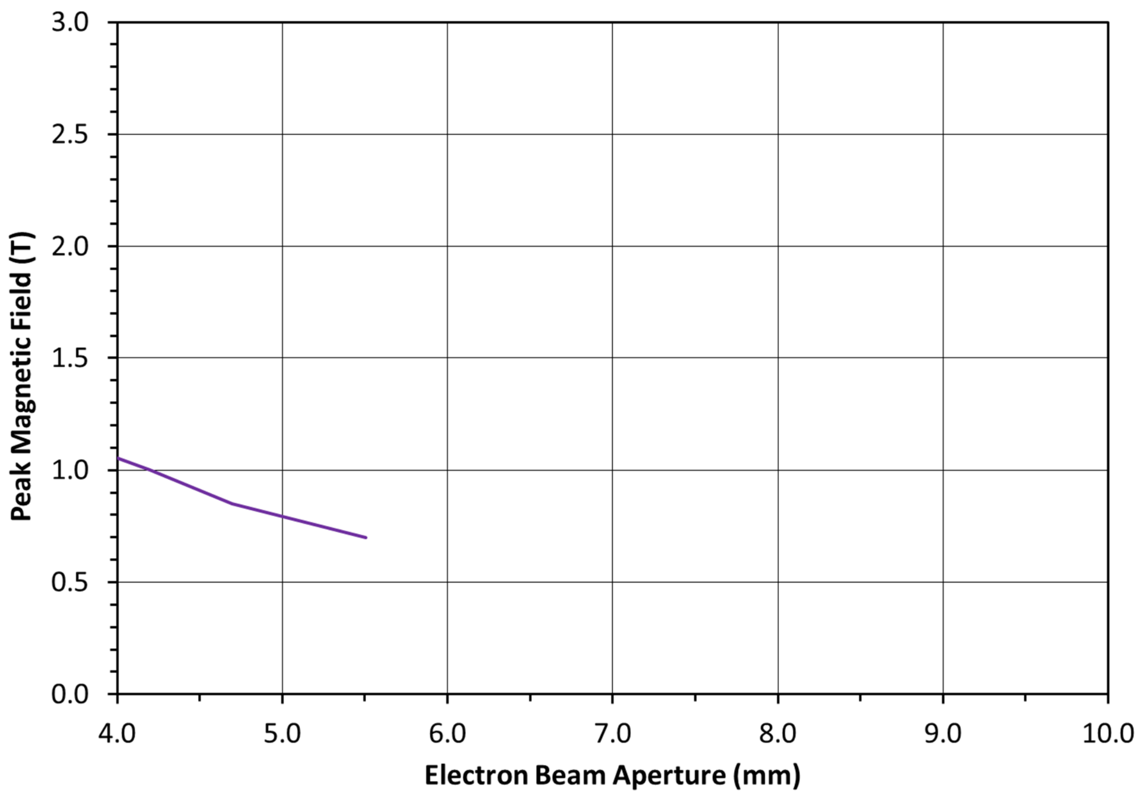
Magnet Modelling

- **Example 15mm period undulator**



Notes

SwissFEL Aramis hard X-ray FEL

In-vacuum hybrid PM undulator

The most advanced undulator type currently in operation on an XFEL

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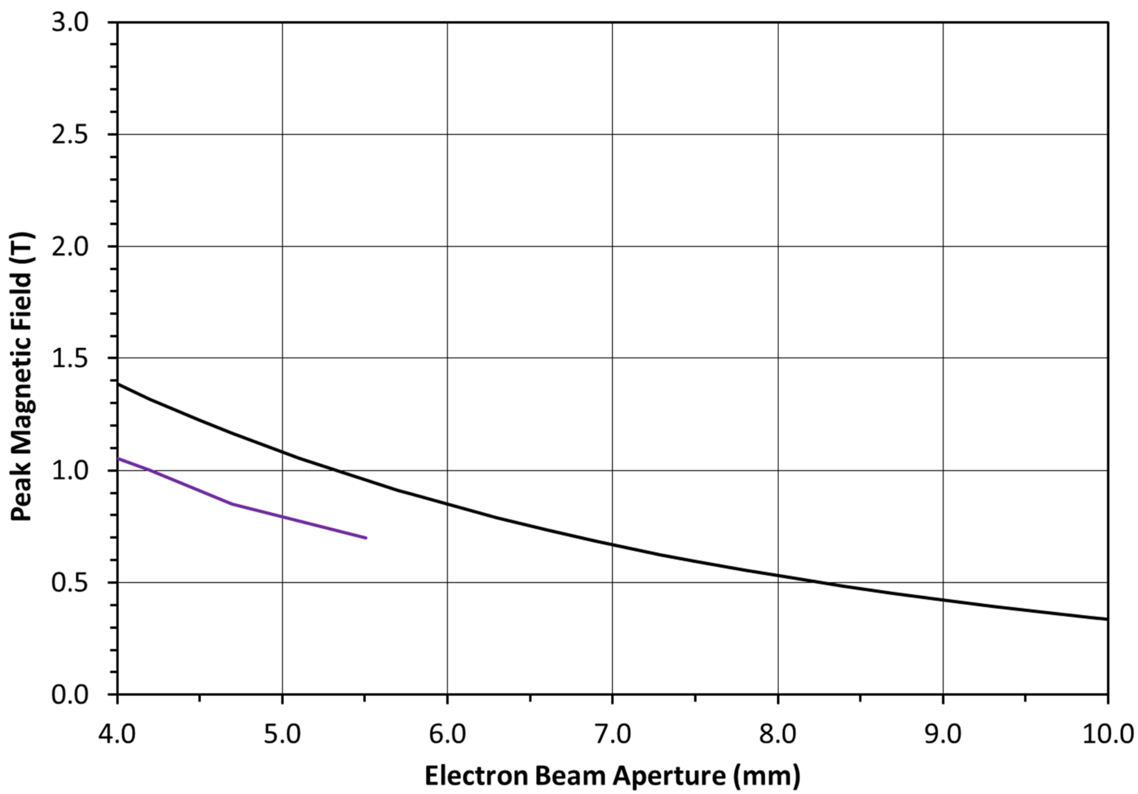
Magnet Modelling

- **Example 15mm period undulator**



Notes

State of the art cryogenic PMU

$Pr_2Fe_{14}B$ with a remanent field of 1.57 T at 77 K

(Latest PM grade with Br = 1.7T will increase fields ~8%)

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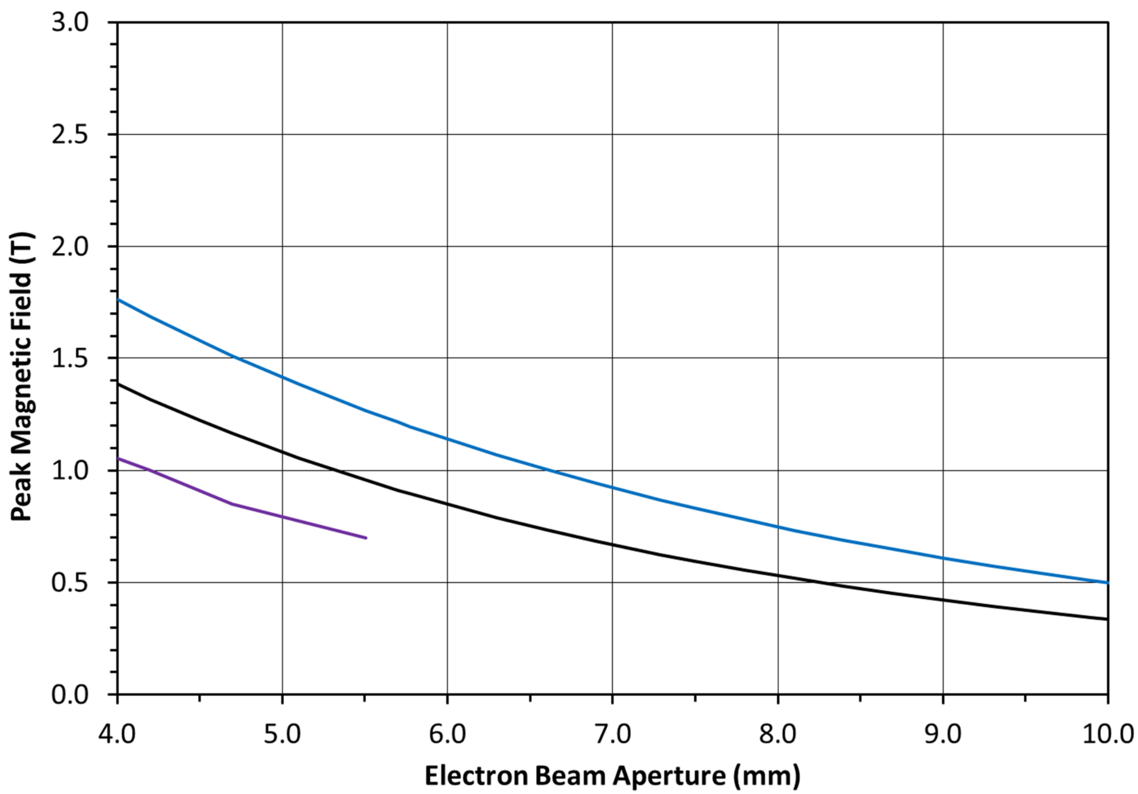
Magnet Modelling

- **Example 15mm period undulator**
- Magnet modelling using Opera 3D
- Commercially available NbTi at 1.8K with safety margin of 10%
- Note at 4K we typically observe a ~10% reduction in field



<u>Notes</u>

Storage Ring SCU with 7.0mm magnet gap

Includes internal vacuum chamber

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Magnet Modelling

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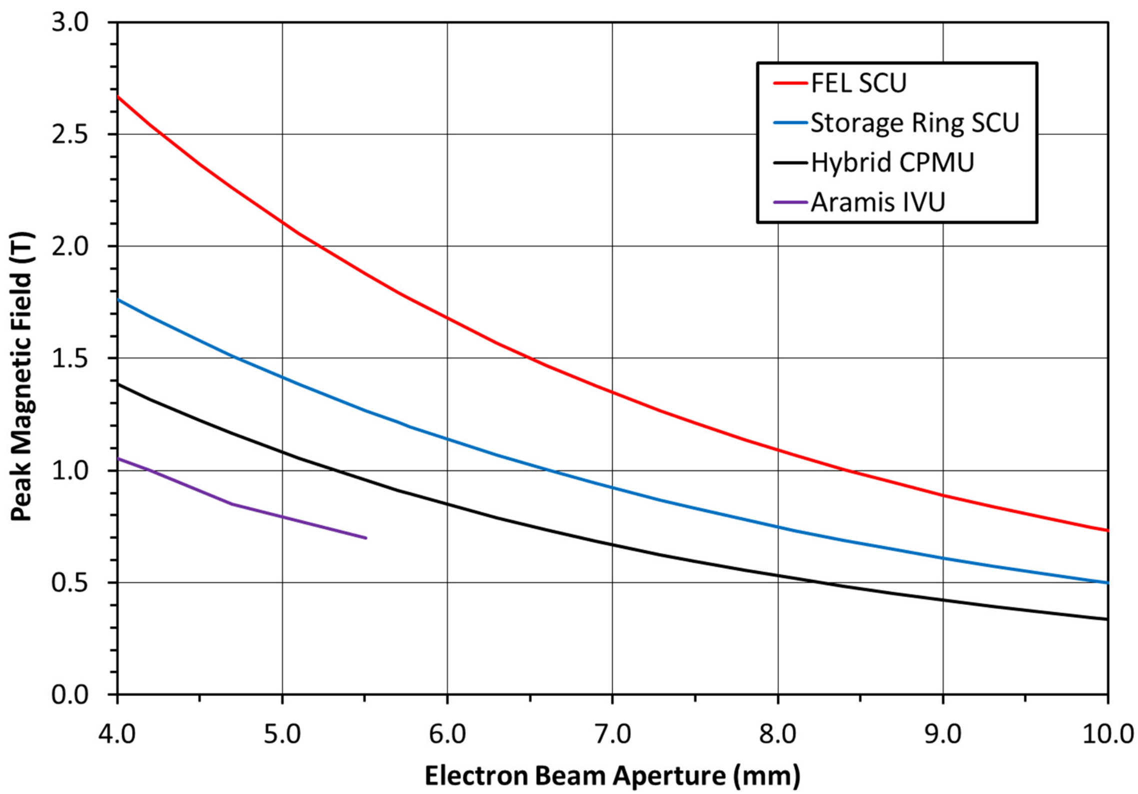

Notes

FEL SCU with 5.2mm magnet gap

No internal vacuum chamber, only high conductivity copper liner

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Impact on FELs

- Use SwissFEL Aramis as an example
  - Wavelength range 1 to 7Å
  - In-vacuum undulator with **15mm period and K = 1.2**
  - Tune wavelength by changing beam energy between **5.8 and 2.2 GeV**
- FEL SCU Option 1
  - **K = 1.2 at period of 10.3mm**
  - Tune wavelength by changing beam energy between **4.8 and 1.8 GeV**
- Impact
  - Maximum electron energy reduced by **1GeV**
  - Saturation length reduced by **~20%**
  - FEL power reduced by **~25%**

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Impact on FELs

- Use SwissFEL Aramis as an example
  - Wavelength range 1 to 7Å
  - In-vacuum undulator with **15mm period and K = 1.2**
  - Tune wavelength by changing beam energy between **5.8 and 2.2 GeV**
- FEL SCU Option 2
  - **15mm period and K = 2.9**
  - Tune wavelength by changing K and beam energy between **5.8 and 3.8 GeV**
- Impact
  - Wavelength tuning at fixed energy (e.g. **1 to 3Å at 5.8 GeV**)
  - Saturation length unchanged
  - FEL power increased ~ x2 at long wavelengths

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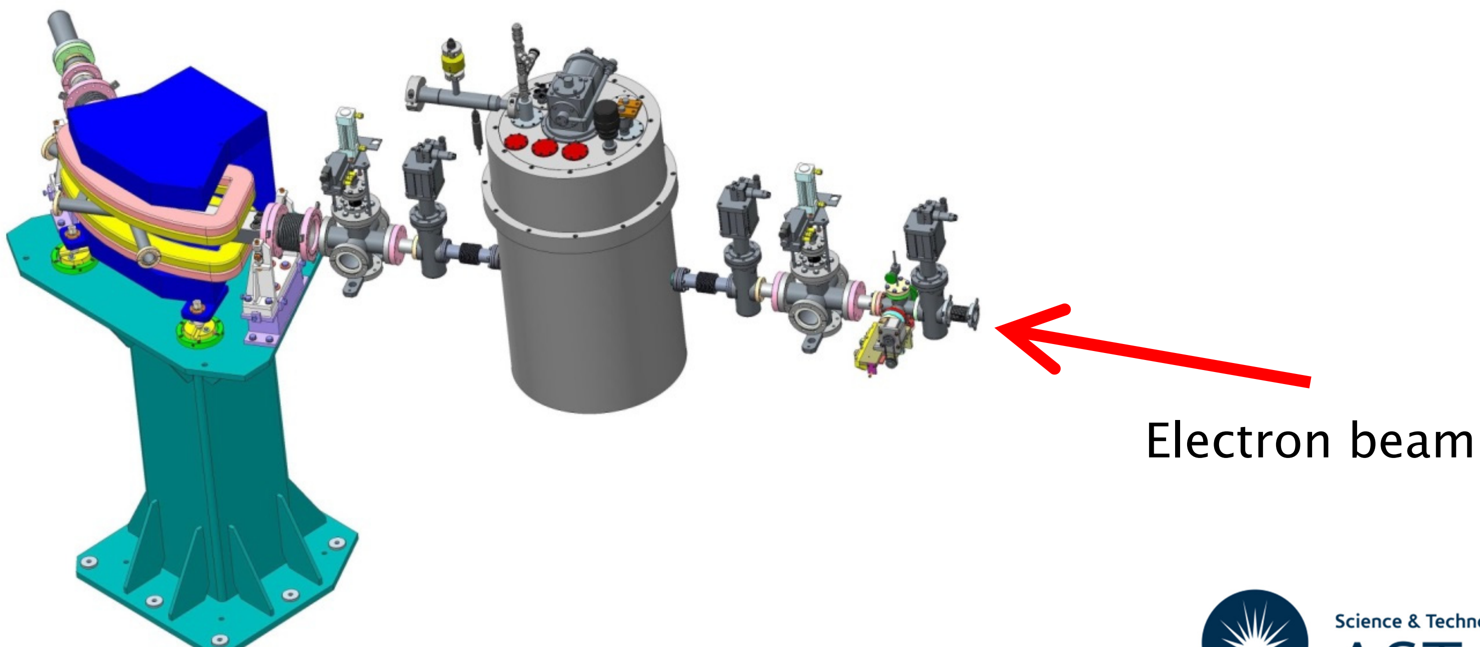
FEL SCU Demo on CLARA

- We are now assembling a 30cm SCU Demo
- 15.5mm period, 7.4mm gap, B = 1.25T, K = 1.8
- Install and test on CLARA FEL Test Facility at Daresbury



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Helical SCU Option

- FELs could instead use the classic bifilar helix undulator which generates a helical field
  - Circular polarisation
  - Increased FEL coupling factor
  - Circular beam aperture
- This type of undulator is very well matched to FEL SCU engineering
- We plan to carefully compare this type with the planar type in the future

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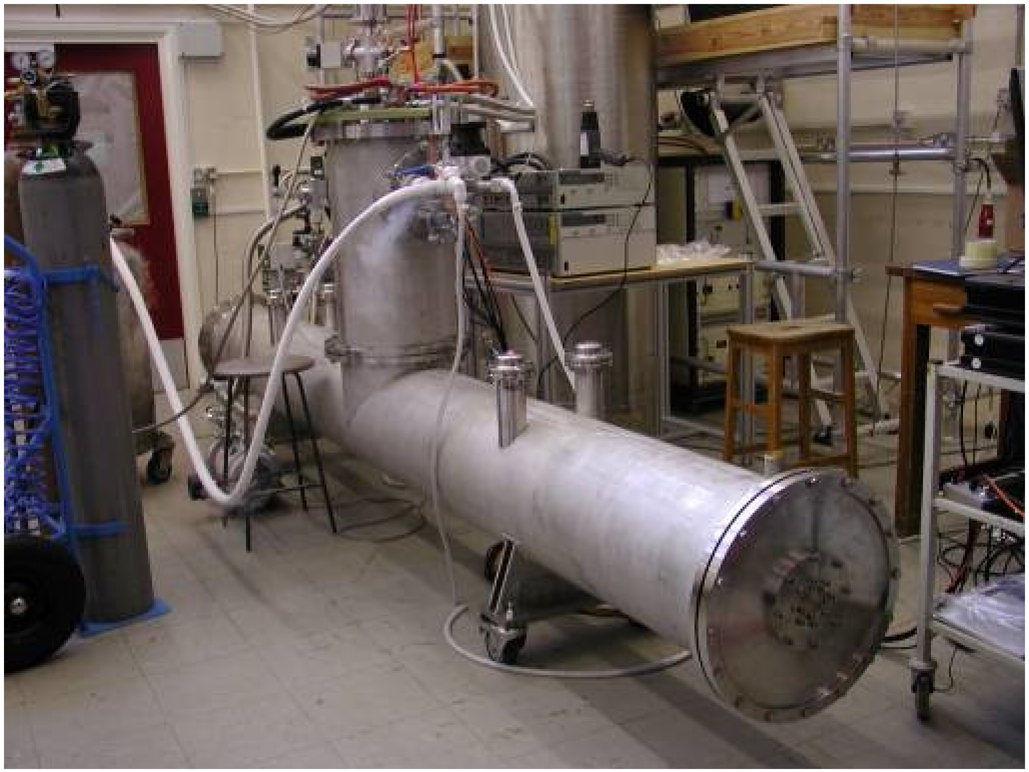
Example Helical Undulator

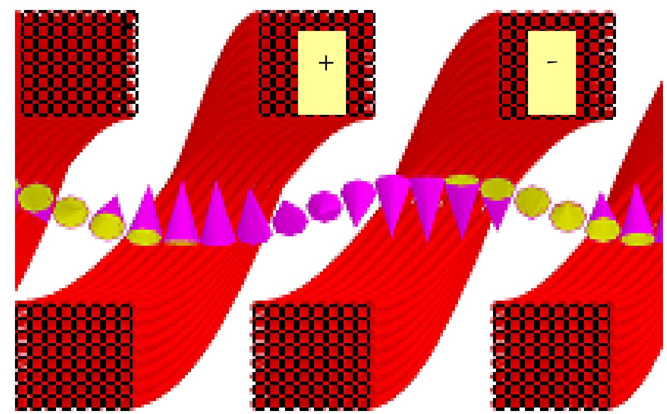


D J Scott et al, Phys Rev Lett, 107, 174803 (2011)

ILC Positron Source undulator under test at RAL (2009)

11.5mm period, Bx=By=1.1T successfully demonstrated

4m module contains 2 x 1.75m helical undulators, circular beam aperture diameter = 5.25mm



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Summary

- SCUs are already in routine operation in a couple of storage rings
- FELs offer different constraints on the engineering of SCUs
- At lower repetition rates (>>100Hz) much **smaller magnet gaps** are possible
  - **No change to electron aperture**
  - **No fundamental change to SCU design required**
  - **Much higher magnetic fields than any other technology**
- This will positively impact the optimization of new XFELs in terms of beam energy and wavelength coverage
- Helical SCUs are also compatible with these findings
- A demo of this new type of SCU will be tested on CLARA in 2018