John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

Ultra-High Flux project: X-ray/THz Source based on Asymmetric Dual Axis Energy Recovery Configuration

I.V. Konoplev, A. Seryi

JAI, Oxford, UK

G. Burt

Cockcroft Institute, Lancaster, UK

R. Ainsworth

FNAL, USA

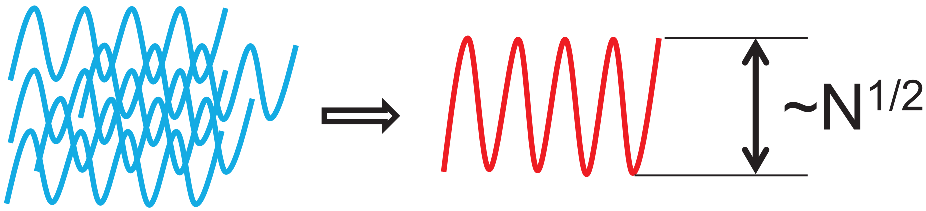
John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

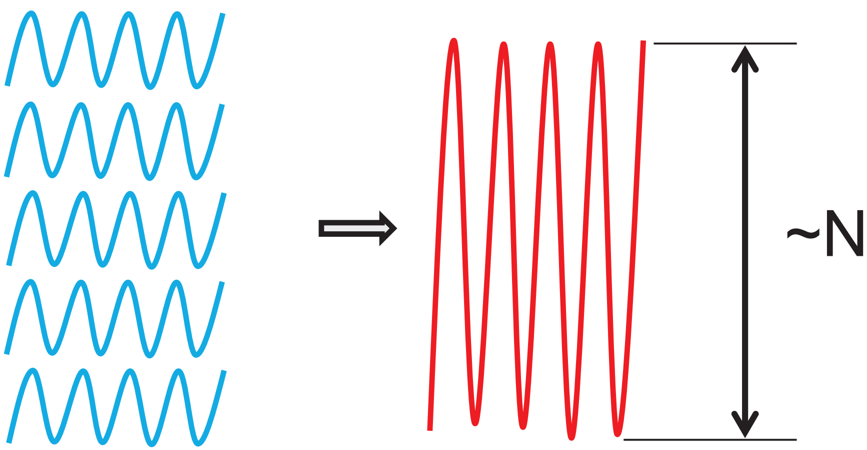
Contents

Evolution of computers and light sources

3^{rd} generation => 4^{th} generation



3rd generation SR sources:
the electrons emit photons with random phases



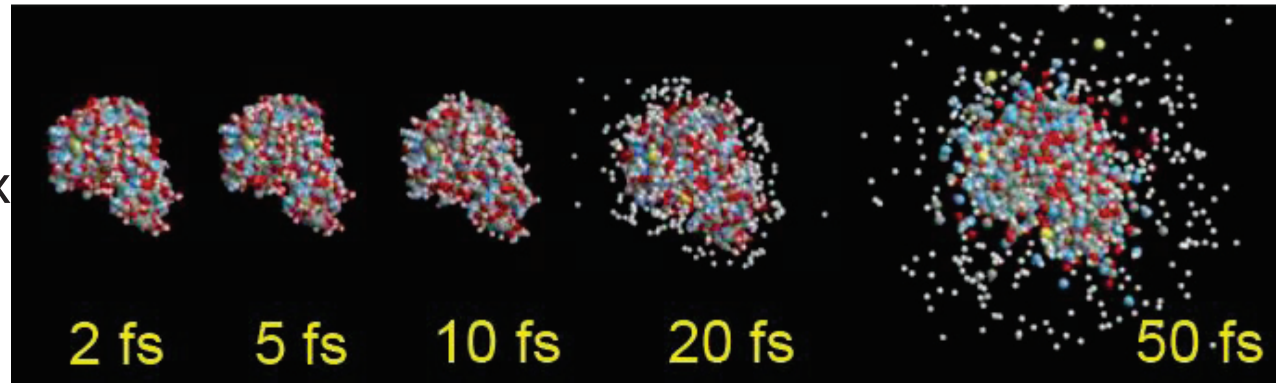
4th generation SR sources:
the electrons emit photons all as one

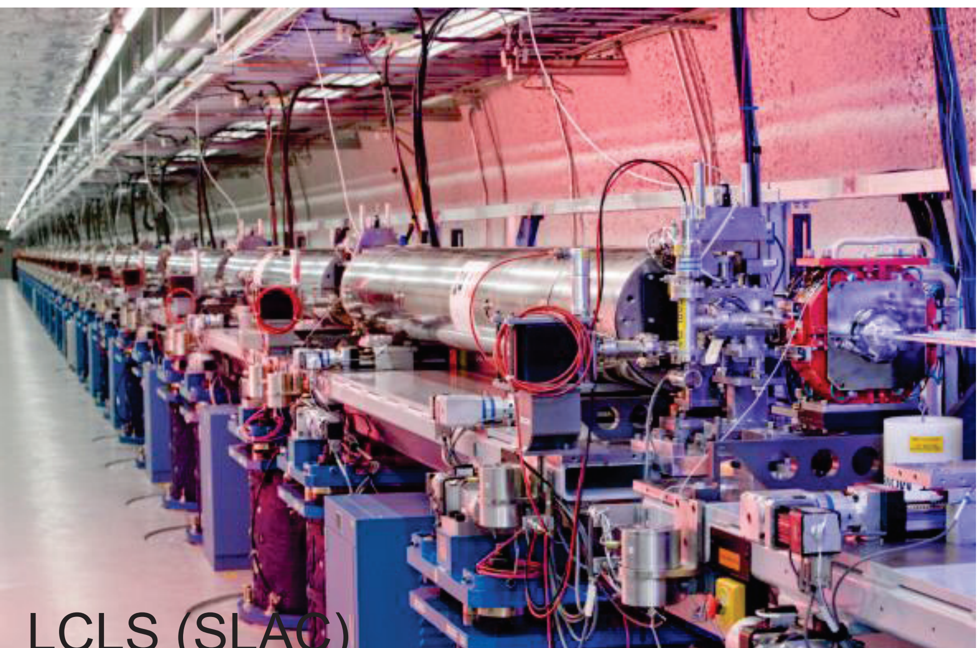
4^{th} generation sources – Free Electron Lasers (FELs)

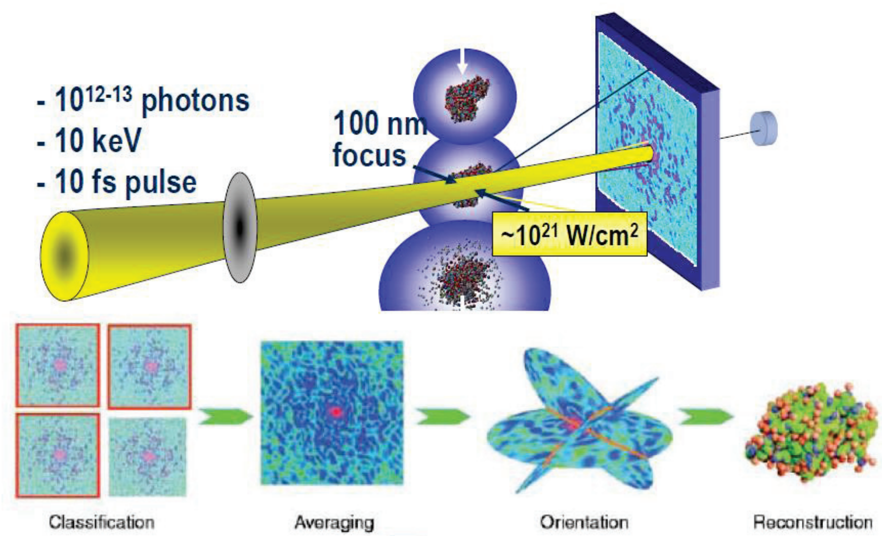
FEL brightness is 10 orders of magnitude higher than brightness of 3rd generation sources

4th generation - FEL at Stanford

Immense brightness - analysis of very complex molecules (proteins)



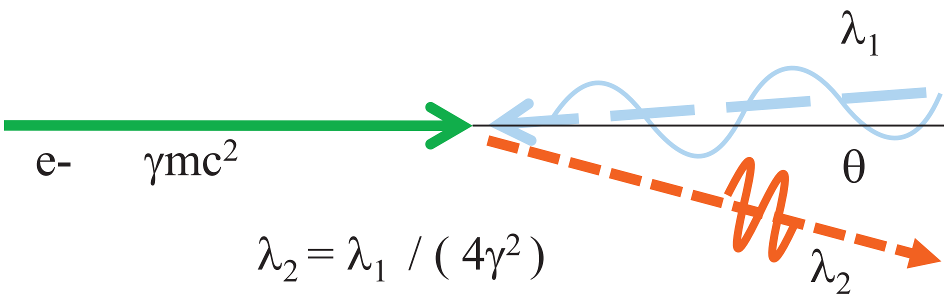


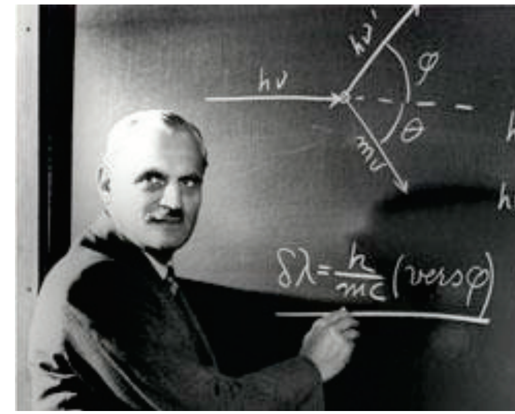


Calculations. in vacuum Neutze et al., Nature 2000 Chapman, Gaffney Science 2007

Compton light sources

Based on the reflection of photons from accelerated electrons with an energy transfer to photons





Arthur Compton

Compact X-ray light source

- 25 MeV accelerator
- X-ray tuneable from a few keV up to 35 keV

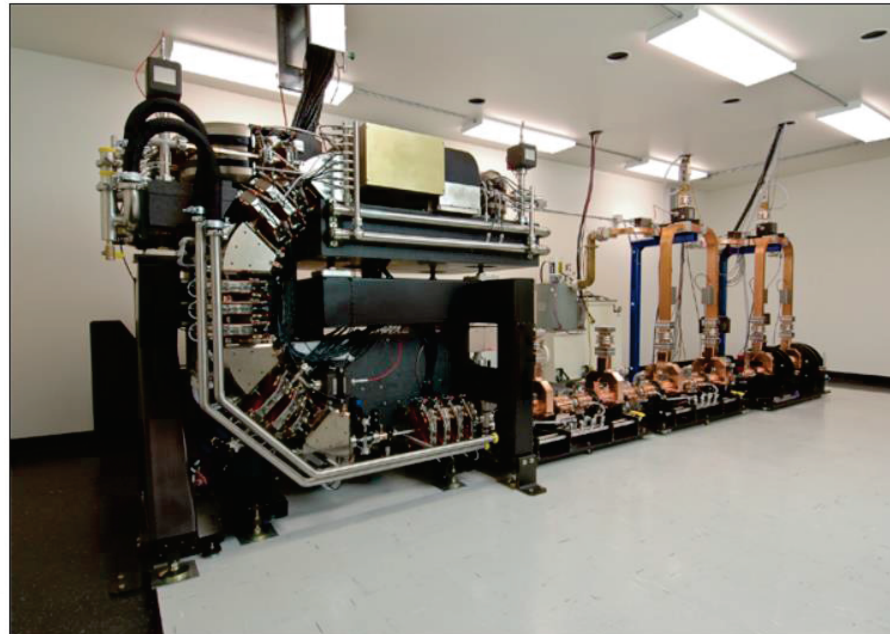
Compton light sources

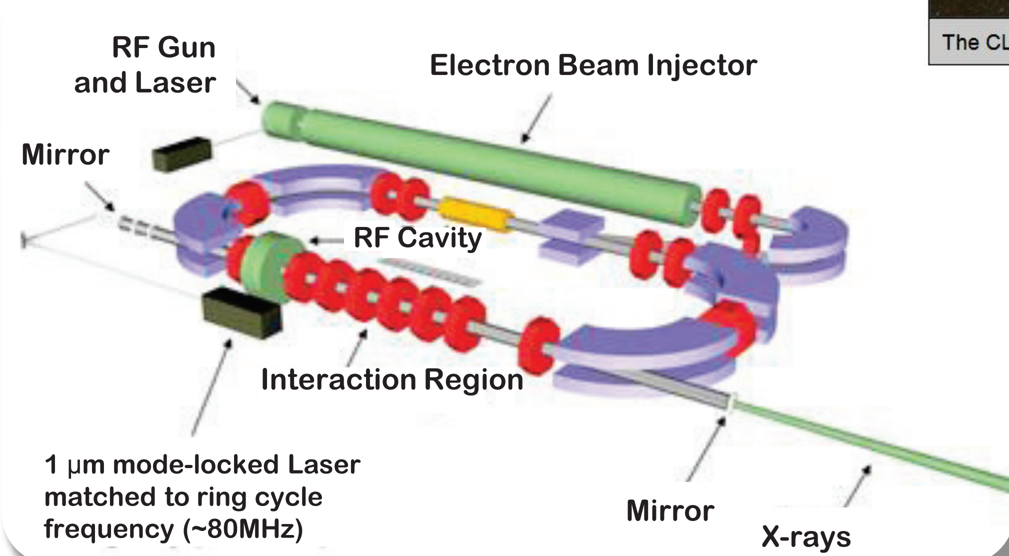
Commercially available, e.g.:
Lyncean Technologies, Inc.

Compact X-ray light source

25 MeV accelerator
X-ray tuneable from a few keV up to 35 keV

Fits in a 10x25 ft room

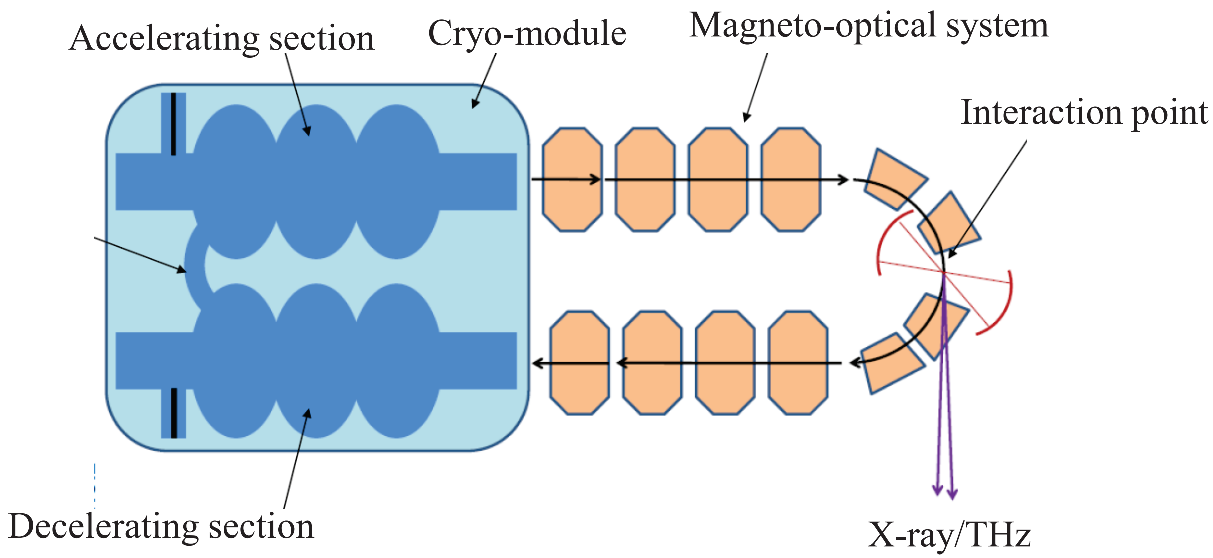

The CLS assembled at the headquarters of Lyncean Technologies, Inc. in Palo Alto, CA



RF power source outside (not on the photo)

http://www.lynceantech.com/index.html

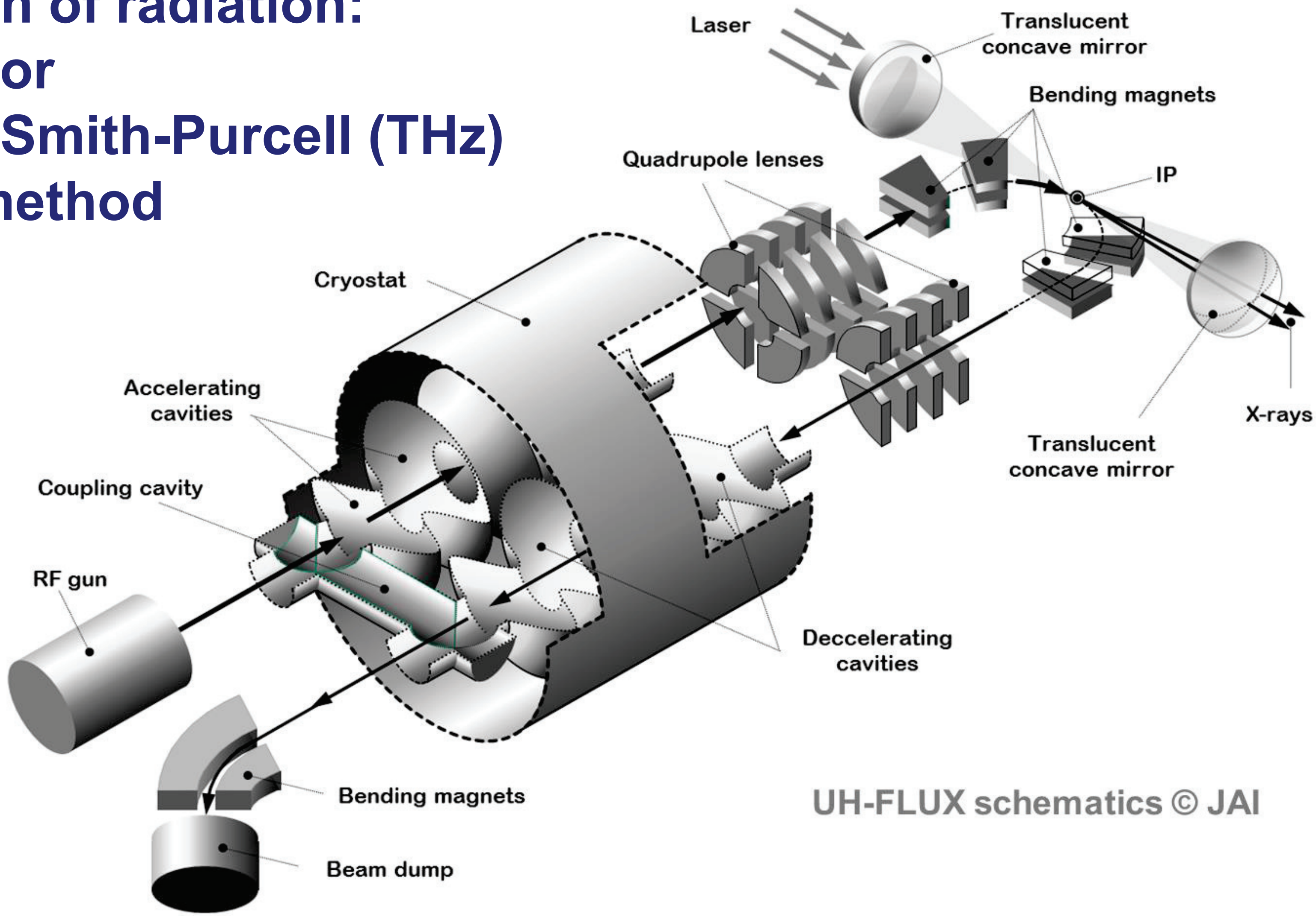
Next steps in Compton/THz sources – UH-FLUX project



- **Collaboration of UK centers JAI, CI, STFC and UK industry is developing an advanced Compton/THz source**
- [1] International (PCT) Patent Application No. PCT/GB2012/052632 (WO2013/061051) filed on the 26th October 2012
- [2] Oxford University Isis Project No. 11330 – "Asymmetric superconducting RF structure" (UK Priority patent application 1420936.5 titled 'Asymmetric superconducting RF structure' filed on the 25th November 2014

UH-FLUX – conceptual layout

Generation of radiation:
Compton or
Coherent Smith-Purcell (THz)
or other method

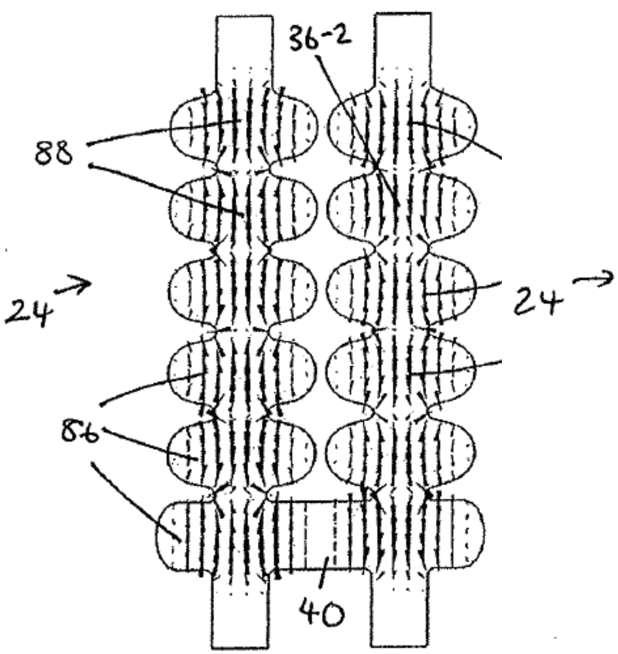


UH-FLUX schematics © JAI

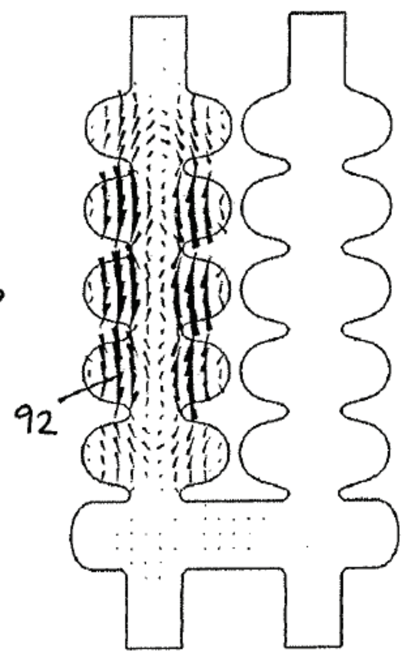
UH-FLUX: Asymmetric ERL

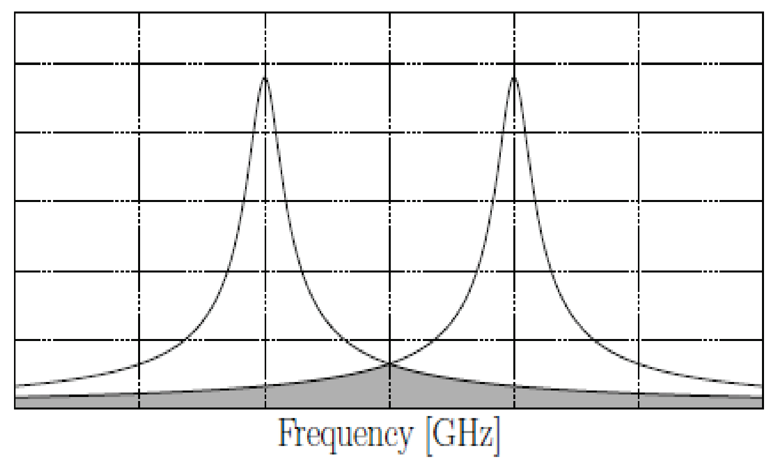
Decoupling all modes except the accelerating mode to maximize the beam current

Acc. mode



One of transverse modes

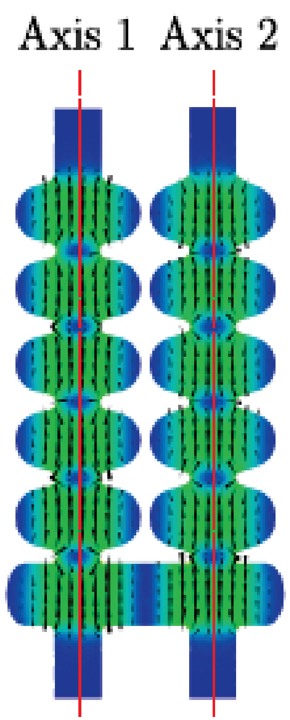




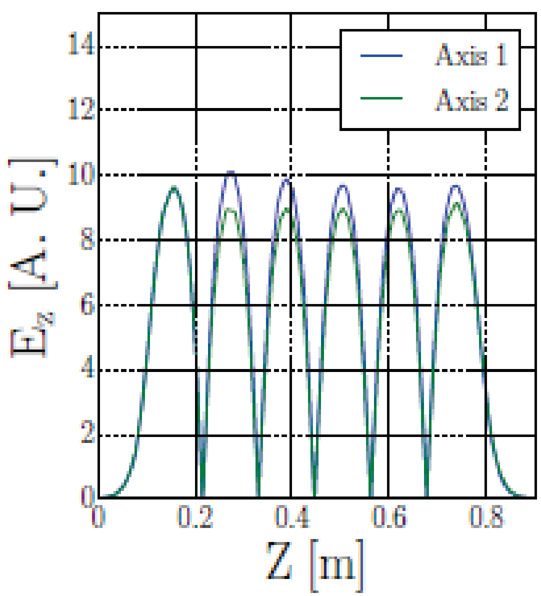
UK Priority patent application 1420936.5 filed on the 25th November 2014

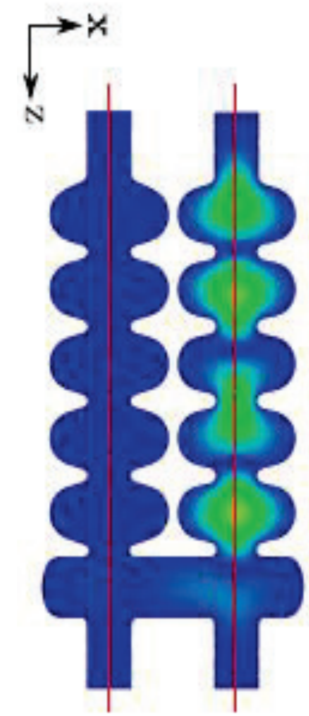
UH-FLUX: Asymmetric ERL

Electric field contour plot of operating eigenmode at 1.3GHz



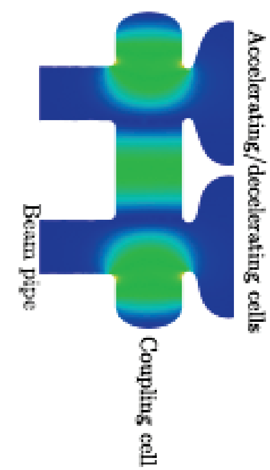
Operating field flatness @1.3GHz





Electric field contour plot of dipole eigenmode at 1.73GHz

Electric field contour plot of resonant coupler eigenmode at 1.48GHz



UH-FLUX: Asymmetric ERL

$$\Delta r \cong -\frac{2c}{\omega}\nabla_{\perp}V(r,\varphi)\frac{L}{W}\mathbf{R_{12}}$$

Electron bunch deviation from designed trajectory due to HOM

$$\Delta\tau \cong \frac{1}{2}\left(\frac{\mathbf{R_{12}}\theta}{S_0}\right)^2 T_g = \frac{\Delta r}{2S_0}\frac{\Delta r}{c}$$

Time detuning of the electron bunch due to HOM

$$\Delta\phi \cong \frac{(\mathbf{R_{12}}\theta)\Delta r}{S_0\lambda_0}\pi$$

Phase detuning of the electron bunch due to HOM

$$I_{max} = (D_2 W\omega)/(2rK_m F^{\infty})$$

Maximum electron beam current above which beam transportation will be interrupted due to HOM

$$F^{\infty} = \frac{\sin(\delta\omega_n T_{rep})}{2\cosh(T_{rep}/T_{dec}) - \cos(\delta\omega_n T_{rep})]}$$

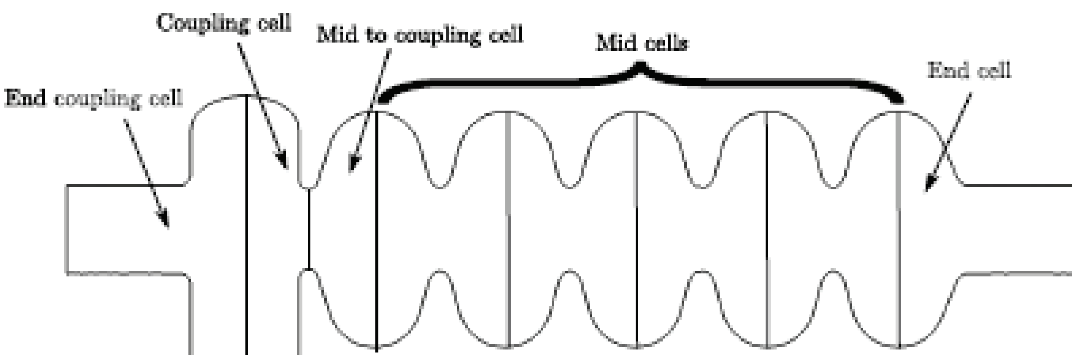
$$|V_2| = \left|V_1 e^{-T_{rep}/T_{dec}}\right| \qquad K_m = c/4[R/Q]_j^m$$

UH-FLUX: Asymmetric ERL

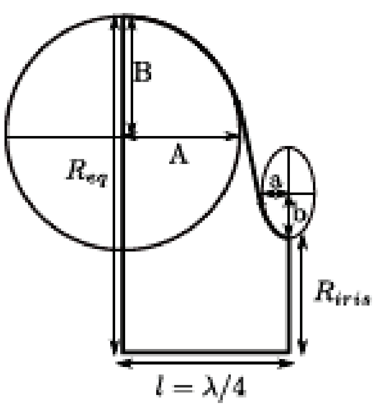
John Adams Institute for Accelerator Science

UNIVERSITY OF OXFORD

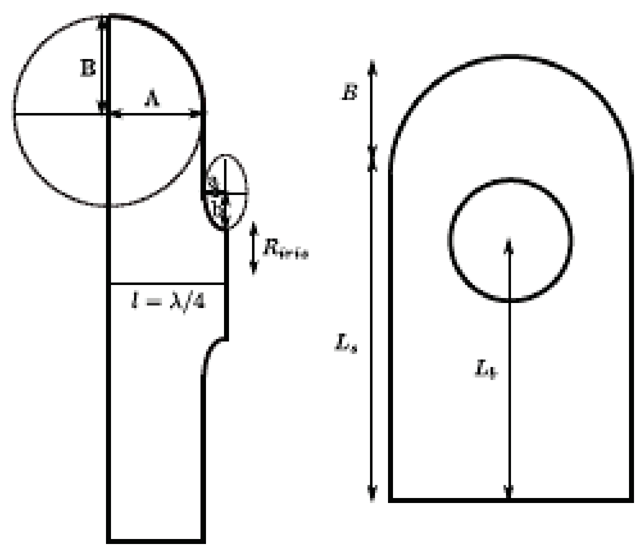
Technical drawing



Midcell



Coupling cell

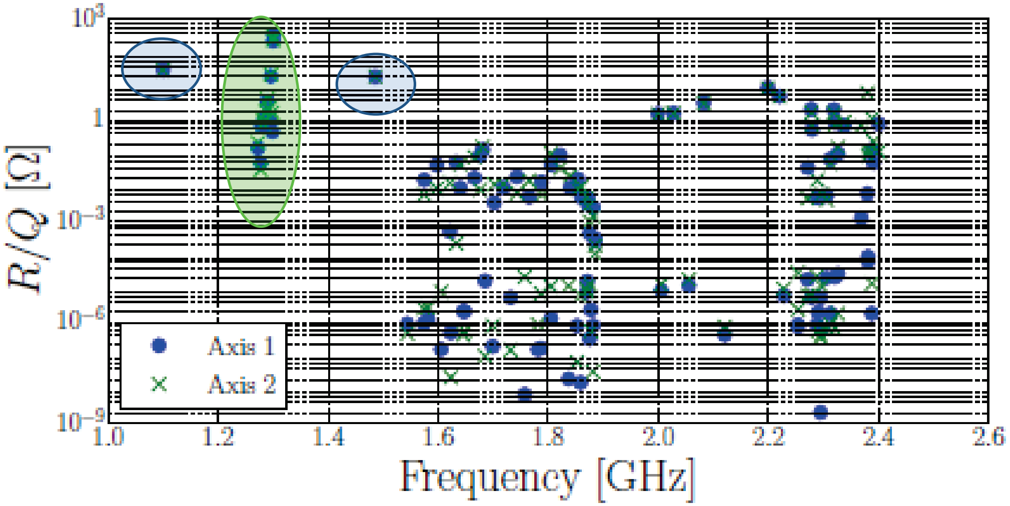


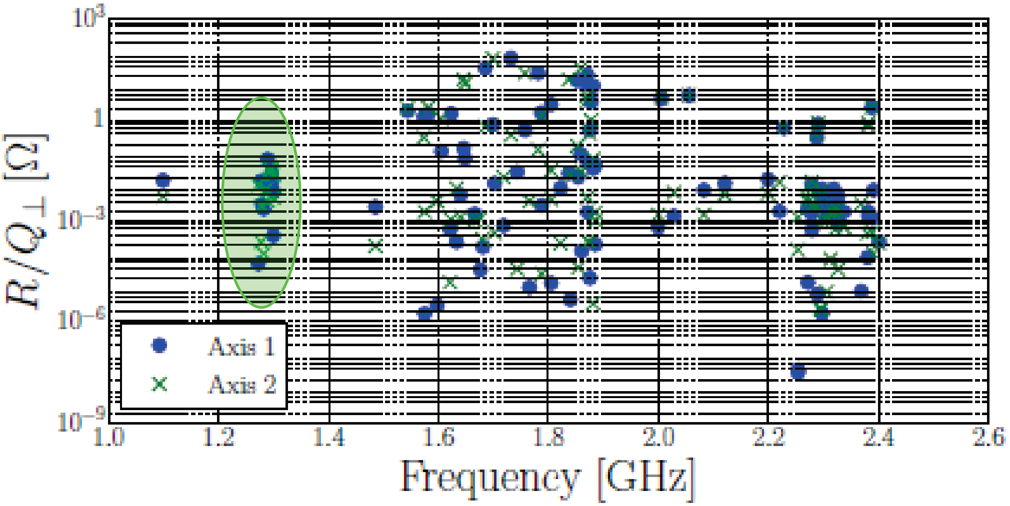
Parameter	Axis 1 cell [mm]	Axis 2 cell [mm]
Mid cells		
R_{eq}	103.3	103.3
A	42	42
B	42	43.1
R_{iris}	35.75	37
a	12.75	11.75
b	18	20
l	57.7	57.7
End cells		
R_{eq}	103.3	104.3
A	42	42
B	42	43
R_{iris}	39	39
a	12.75	11.75
b	18	20
l	58.54	60.96
Mid to coupling cells		
R_{eq}	103.3	104.3
A	42	42
B	43.4	43.5
R_{iris}	35	35
a	12.75	9.69
b	18	20
l	57.7	57.7
Coupling cells		
A	48.052	48.052
B	29	29
R_{iris}	35	35
a	9.6	9.6
b	10.152	10.152
l	57.652	57.652
L_s	150	150
L_b	111	111
End coupling cells		
A	47.5	47.5
B	29.76	29.76
R_{iris}	39	39
a	9.945	9.945
b	9.945	9.945
l	57.652	57.652
L_s	150	150
L_b	111	111

Table of numerical model parameters

UH-FLUX: Asymmetric ERL

First 100 eigenmodes R/Q and $R_\perp/Q$





	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Frequency GHz	R/Q Ω		$R/Q_{\perp,x}$ Ω		$R/Q_{\perp,y}$ Ω	
Highest R/Q						
1.3	348.71	301.51	0.0675	0.0365	0.0074	0.0
1.29943	231.71	247.59	0.0014	0.0059	0.0003	0.0048
1.09966	32.622	32.367	9.5769	9.0660	0.0166	0.0055
1.29532	21.075	23.878	0.0014	0.0267	0.0281	0.0333
1.48554	20.337	20.429	12.094	12.360	0.0026	0.0001
Highest $R/Q_{\perp,x}$						
1.70216	0.0035	0.0127	65.207	0.8680	0.0134	0.0004
1.74343	0.0211	0.0069	61.997	0.4792	0.0294	3.8679
1.87193	0.0050	0.0029	35.500	0.0810	0.0555	0.0002
1.85436	0.0181	0.0091	17.329	0.3260	0.0208	4.2119
1.48554	20.337	20.429	12.094	12.360	0.0026	0.0001
Highest $R/Q_{\perp,y}$						
1.73192	5.4419	1.4736	0.0005	0.0001	72.089	0.3764
1.68526	1.6890	9.9178	0.0024	1.8274	36.312	0.6537
1.78142	1.5499	8.7076	0.0039	0.0070	25.636	0.1329
1.87103	1.6368	7.9211	4.8525	0.0037	22.491	4.0005
1.8523	7.7902	6.4131	0.0033	0.0001	15.388	0.1740

$$R/Q_n = \frac{|V_{\parallel,n}(0)|^2}{\omega_n U_n} \qquad R/Q_{\perp,n} = \frac{|V_{\perp,n}(x)|^2}{\omega_n U_n}$$

$$V_{\parallel,n}(x) = \int_{-\infty}^{\infty} E_{z,n}(x,z) e^{i\omega_n z/c} \mathrm{d}z$$

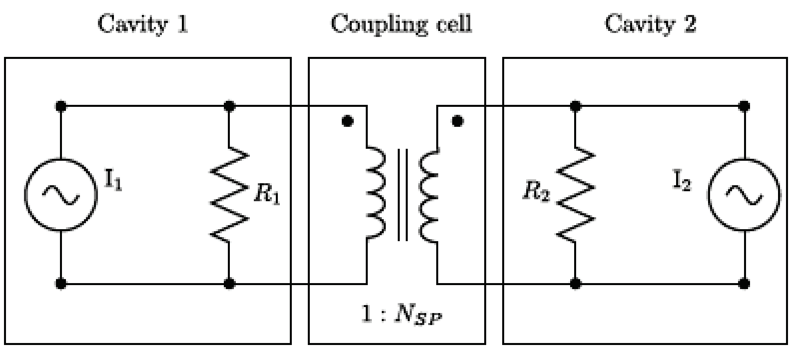
$$V_{\perp,n} = i\frac{c}{\omega_n x}\left[V_{\parallel,n}(x) - V_{\parallel,n}(0)\right]$$

The $R_\perp/Q$ calculated @ 1mm from the axis

UH-FLUX

Maximize the BBU start current allowing to transport up to 2A beam without break-up

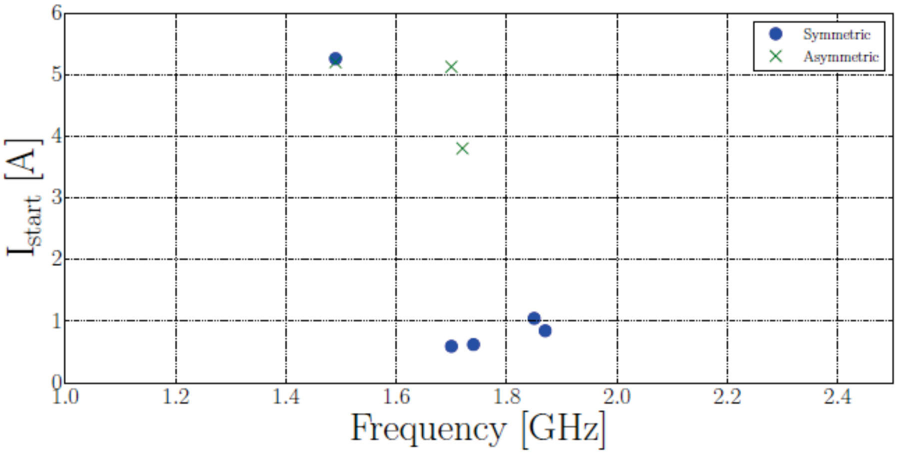
Schematic of RLC diagram of dual axis structure



$$I_{asymmetric} > \frac{\left(1 + N_{SP}^2\right) I_{symmetric}}{2 N_{SP}}$$

N_{SP} is the voltage transformer ratio

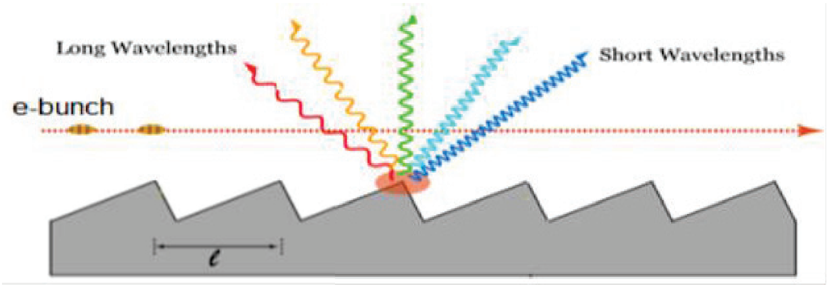
HOMs start currents

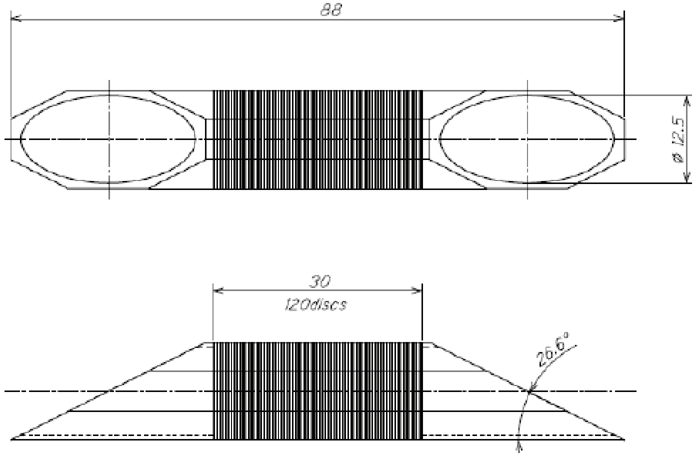


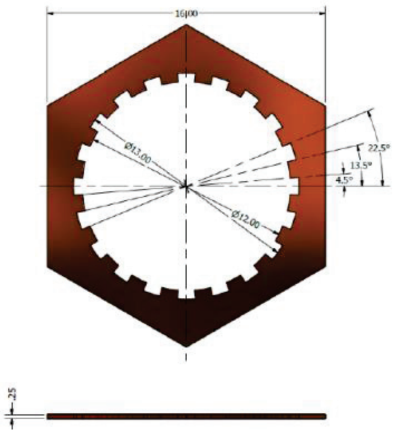
The smallest current is above 3.8A for the AERL configuration

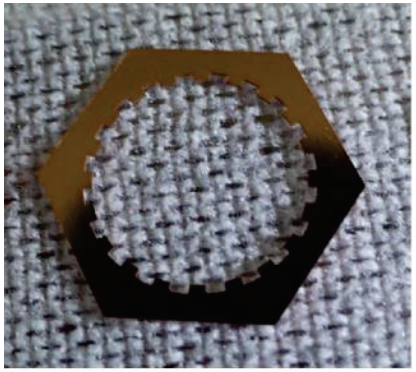
UH-FLUX –THz

Coherent Smith-Purcell



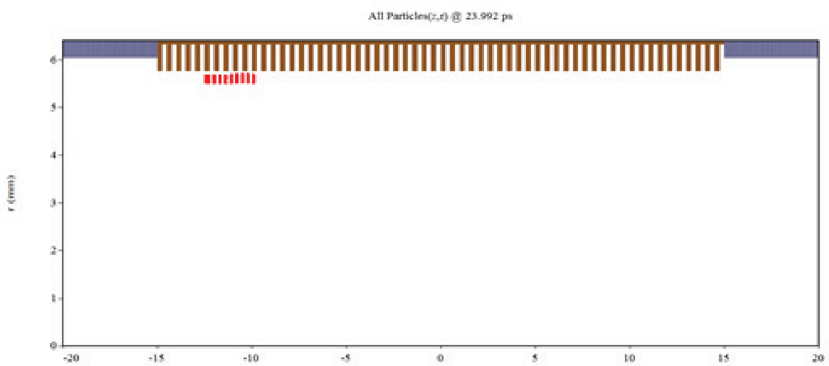




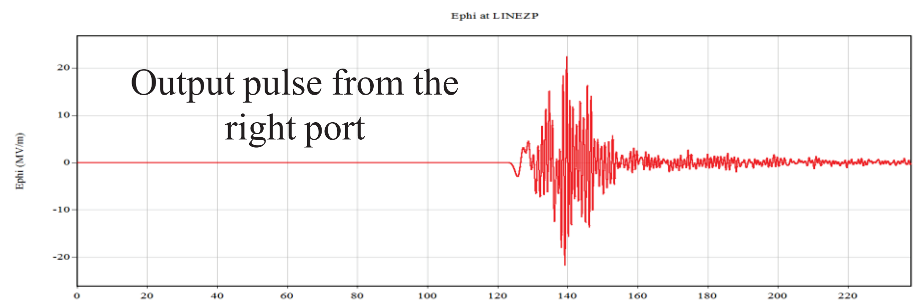


UH-FLUX –THz

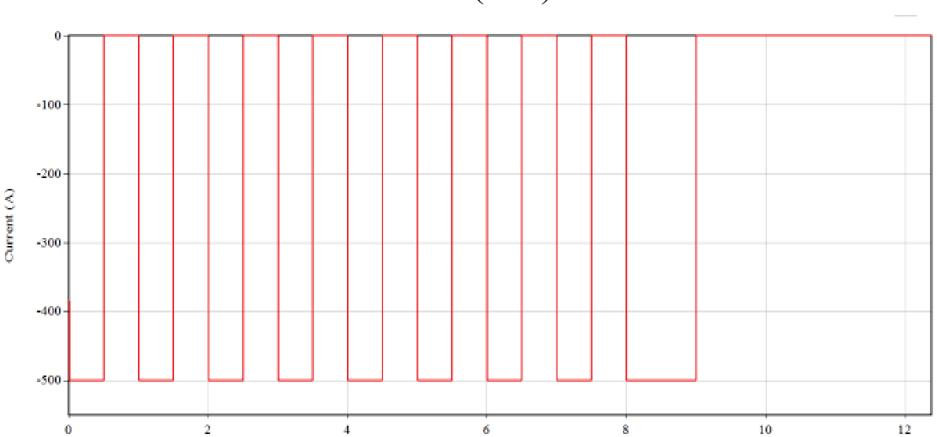
Coherent Smith-Purcell



Z (mm)

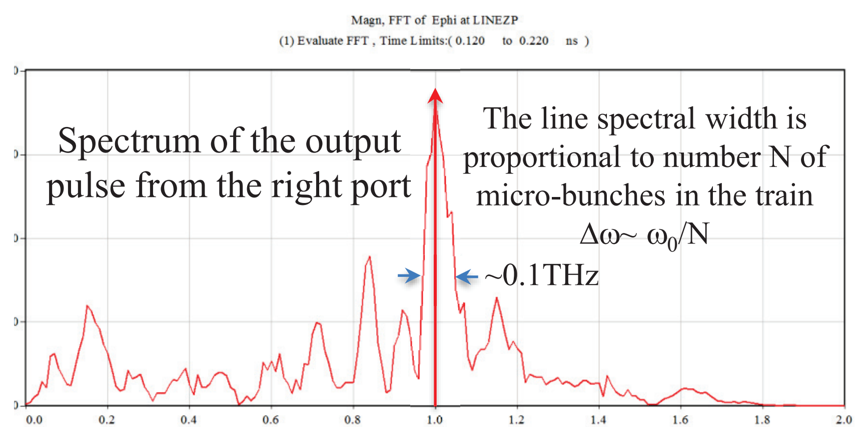


Time (ps)



Time (ps)

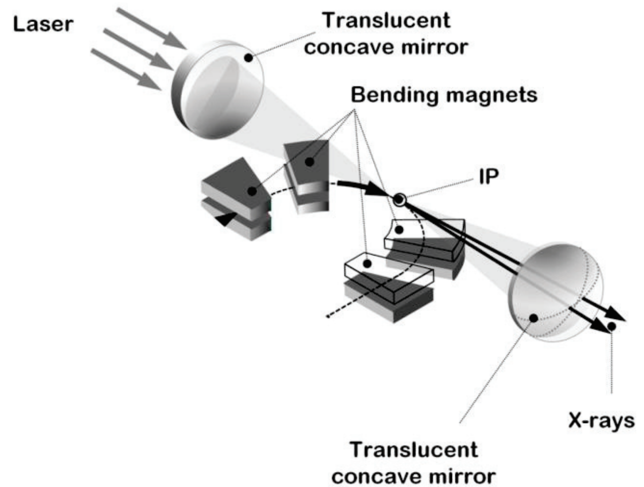
9 Micro-bunches were generated



Frequency (GHz)

UH-FLUX – X-ray

Compton source



1/ The peak brightness ~10^{23} -10^{24} photons /(mm^2 × mrad^2 × s × 0.1%bandwidth)

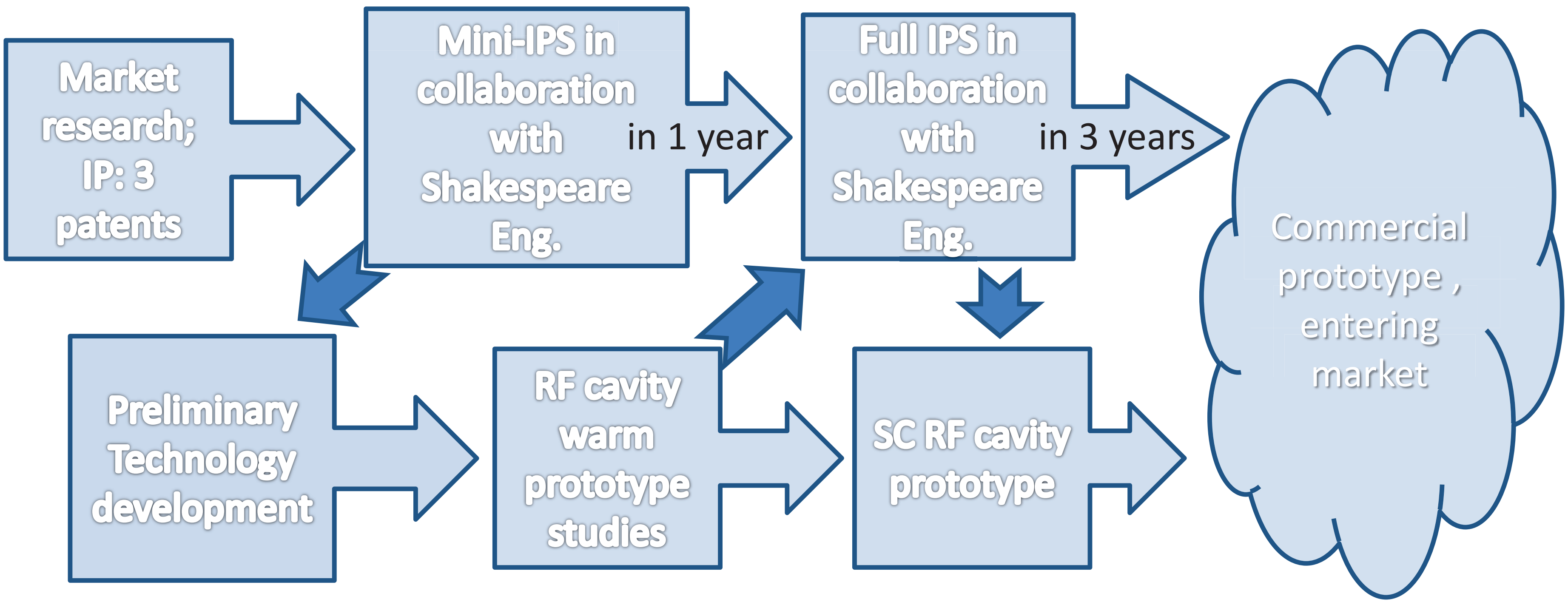
2/ X-ray flux ~9×10^{12} - 3×10^{13} photons/second inside a 0.1% bandwidth

3/ Average brightness ~10^{14} photons/(mm^2 × mrad^2 × s × 0.1%bandwidth)

at 15keV photons for 20MeV beam

We are studying the range of possible applications of UH-FLUX technology, including medical direction

UH-FLUX: Asymmetric Energy Recovery Linac – Next steps



1/ *PCT international patent application PCT/GB2012/052632 titled 'X-ray Generation' filed on the 24th October 2012.*
2/ *PCT/GB2013/053101 titled 'Distributed electron beam collector" filed on the 25th November 2013.*
3/*UK Priority patent application 1420936.5 titled 'Asymmetric superconducting RF structure' filed on the 25th November 2014.*

Summary

UH Flux: X-ray/THz compact SCRF AERL Light Source

- Based on novel dual axis asymmetric cavity energy-recovery system
- Energy-recovery SCRF system = increased efficiency
- Asymmetric structure = high current (>1A)
- High current = high flux of THz or X-ray photons
- New distributed electron beam collector – to reduce impact of high current electron beam

Thank you