UH-FLUX project

Andrei A. Seryi, on behalf of UH-FLUX team
John Adams Institute

EAAC 2015

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a/ JAI, University of Oxford, b/ CI, Lancaster University, c/ ASTeC, STFC d/ JAI, Royal Holloway, UK, e/ Fermilab

JAI Research Directions (& examples)

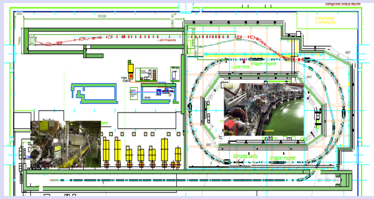
Enabling accelerator techniques for scientific, medical and energy applications

Next generation compact light sources and laser-plasma acceleration FEL

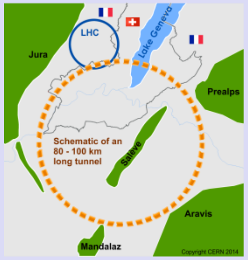
Advanced accelerator Instrumentation and beam diagnostics

Training

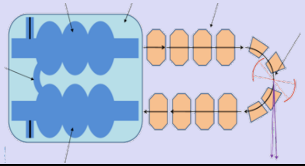
Diamond upgrade



LC Final Focus

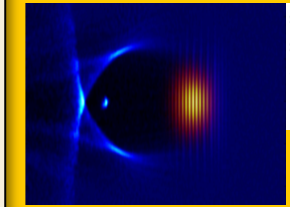


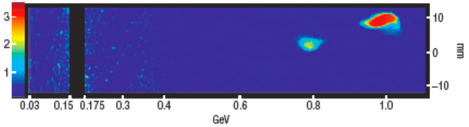
FCC IR & FF

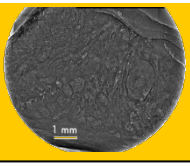


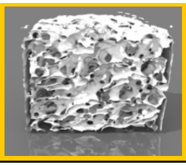
Novel ERL design of UH-FLUX

ESS

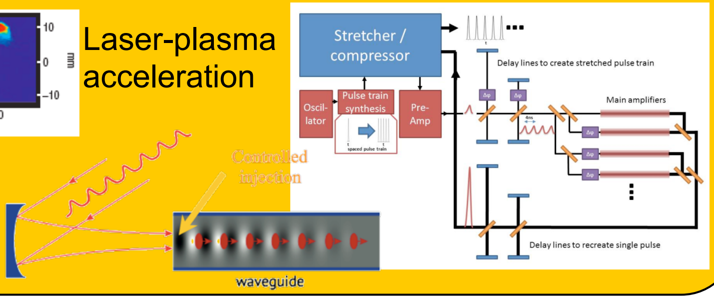


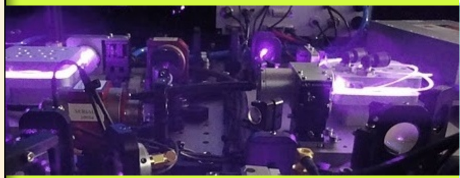




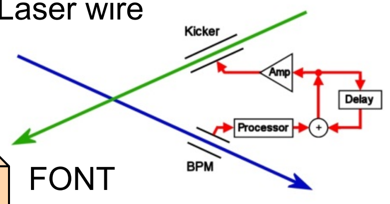


Laser-plasma acceleration

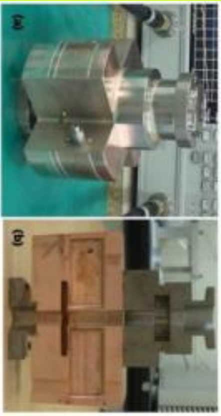




Laser wire

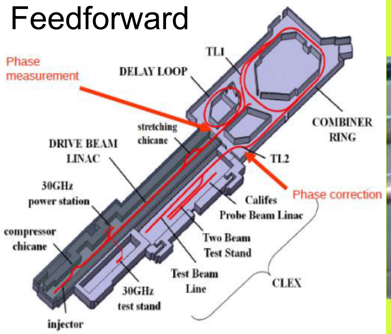


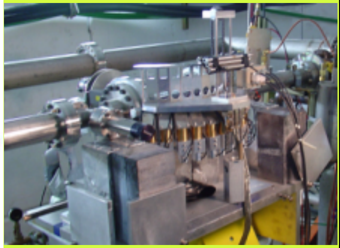
FONT



BPMs

Feedforward





Beam σ_z diagnostics

JAI Research Directions (& examples)

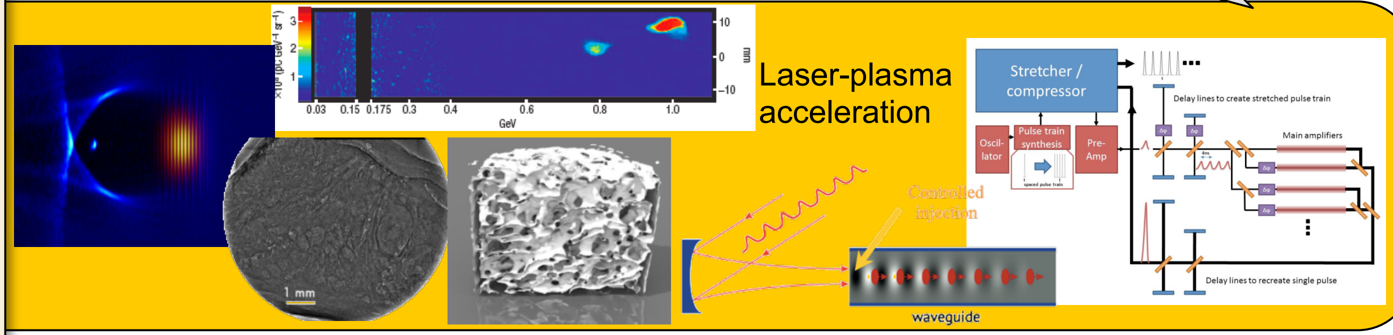
Enabling accelerator techniques for scientific, medical and energy applications

Next generation compact light sources and laser-plasma acceleration FEL

Advanced accelerator Instrumentation and beam diagnostics

Training

- System-wide design approach
- Aiming for high overall efficiency, high brightness
- Working with medical doctors
- Developing the ways to create a novel scientific, technological, and medical instrument in near future



JAI PhD thesis for last 5 years (2010-2014)

"Design of a non-scaling fixed field alternating gradient accelerator for charged particle therapy“
Suzie Sheehy 2010

"Results from the laser-wire at ATF2 and development of a fibre laser for its upgrade“
Laurence Nevay 2011

"Short Pulse X-Ray Generation in Synchrotron Radiation Sources“
Ian Martin 2011

"Laser Wakefield Acceleration of Electrons to GeV Energies and Temporal Laser Pulse Compression Characterization in a Capillary Discharge Waveguide” Paul A.Walker 2013

"Development of Beam Position Monitors for Final Focus Systems at the International Linear Collider“
Christina Swinson 2010

"First investigation on a two-stage CERN PSB collimation system“ (MSc by Research)
Penelope Jackson 2011

"Development of a Laser-Wire Beam Profile Monitor for PETRA-III and CLIC“
Thomas Aumeyr 2012

"Exploring novel regimes for ion acceleration driven by intense laser radiation"
Nicholas Dover 2013

"The Development and Implementation of a Beam Position Monitoring System for the use in the FONT Feedback System at ATF2“
Robert Apsimon 2011

"The development of a novel technique for characterizing the MICE muon beam and demonstrating its suitability for a muon cooling measurement“ Mark Rayner 2011

"Investigation of Coherent Diffraction Radiation from a dual target system at CTF3 and its application for longitudinal bunch profile diagnostics“ Konstantin Lekomtsev 2012

"Ultrafast Dynamics of Relativistic Laser Plasma Interactions“
Matthew Streeter 2013

"Muon capture schemes for the neutrino factory“
Stephen Brooks 2010

"Approaching the radiation pressure regime of proton acceleration with high intensity lasers“
Charlotte Palmer 2011

"CLIC Drive Beam Phase Stabilisation“
Alexander Gerbershagen 2013

"The Development of Intra-train Beam Stabilisation System Prototypes for a Future Linear Collider“
Michael Davis 2014

"Laser Plasma Accelerator and Wiggler“
Stefan Kneip 2010

"Absolute distance metrology using frequency swept lasers“
Matthew Warden 2011

"Step IV of the Muon Ionization Cooling Experiment (MICE) and the multiple scattering of muons“
Timothy Carlisle 2013

“Laser wakefield acceleration in tapering plasma channels: Theory, simulations and experiments employing axial plasma density gradients” Wolf Rittershofer 2014

"Design and beam testing of a fast, digital intra-train feedback system and its potential for application at the International Linear Collider"
Ben Constance 2011

"Optical probing of high intensity laser propagation through plasma“
Ayesha Rehman 2011

"The Development of a Fast Intra-train Beam-based Feedback System Capable of Operating on the Bunch Trains of the International Linear Collider“ Douglas Bett 2013

26 thesis for 5 years, around 5/yr in average

"Development of Longitudinal Diagnostics for Electron Beams based on Coherent Diffraction Radiation"
Maximilian Micheler 2011

"Towards a Free-Electron Laser Driven by Electrons from a Laser-Wakefield Accelerator: Simulations and Bunch Diagnostics"
Svetoslav Bajlekov 2011

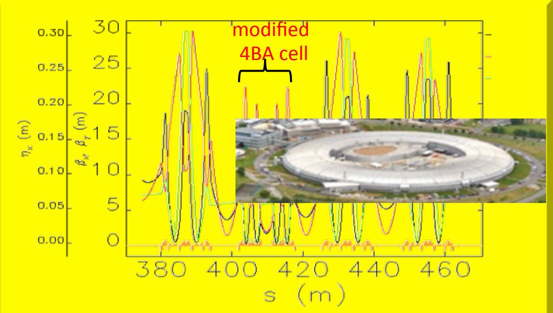
"Design and Analysis Techniques for Cavity Beam Position Monitor Systems for Electron Accelerators“
Nirav Joshi 2013

Enabling accelerator techniques for scientific, medical and energy applications

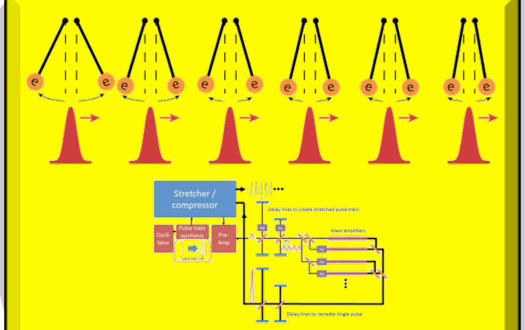
Next generation compact light sources and laser-plasma acceleration FEL

Advanced accelerator instrumentation and beam diagnostics

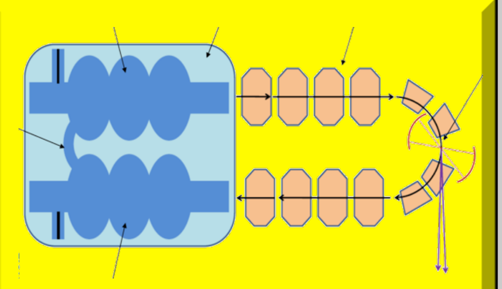
Novel Light sources in JAI research



Diamond upgrade

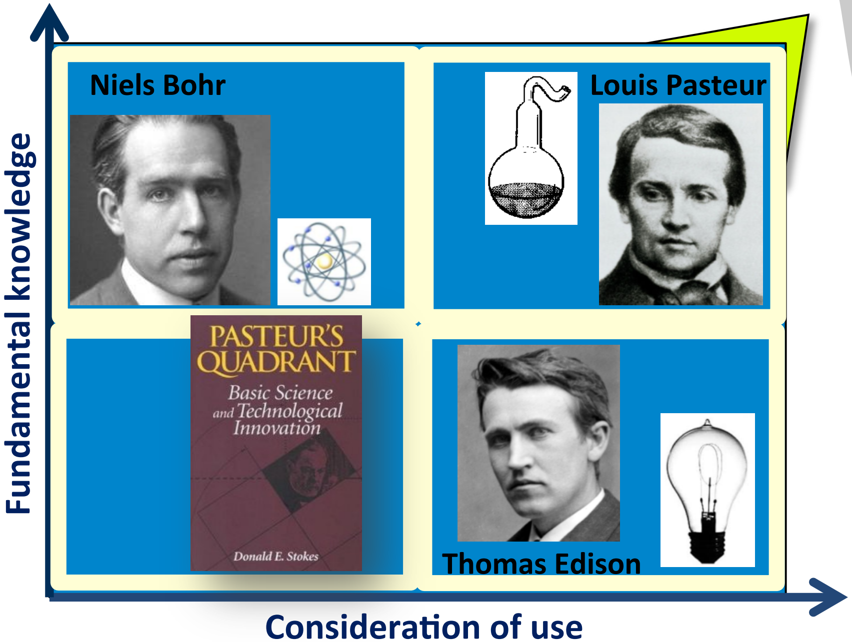


Hi-FLUX



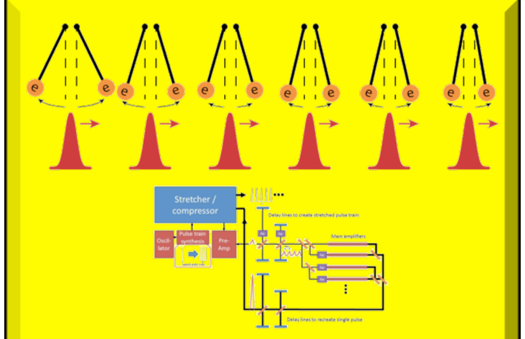
UH-FLUX

Light sources: direction that maximises the impact on both axis



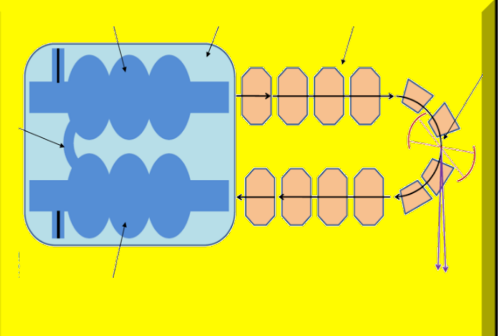
Compact light sources

- **Aim at creating novel instruments for science, technology, medical application**
- **Hi-FLUX – compact X-ray source based on resonant plasma excitation by train of pulses from fiber laser**
  - **Will have high efficiency, ~10% wall plug to light**
    - **Comparing with 0.1% for present high power solid state lasers**
  - **Will have high rep rate, ~10kHz**
    - **Comparing with ~1Hz of present plasma acceleration systems**
  - **Developed proposal with medical experts for cancer diagnostics**
    - **Waiting outcomes of two grant applications**
  - **A ~100MeV demo of the source can be housed in ASL**
    - **The ASL, intended for DWB, is designed, feasibility confirmed, cost updated**
  - **Many positive reviews from colleagues and funding bodies**



Hi-FLUX X-ray source

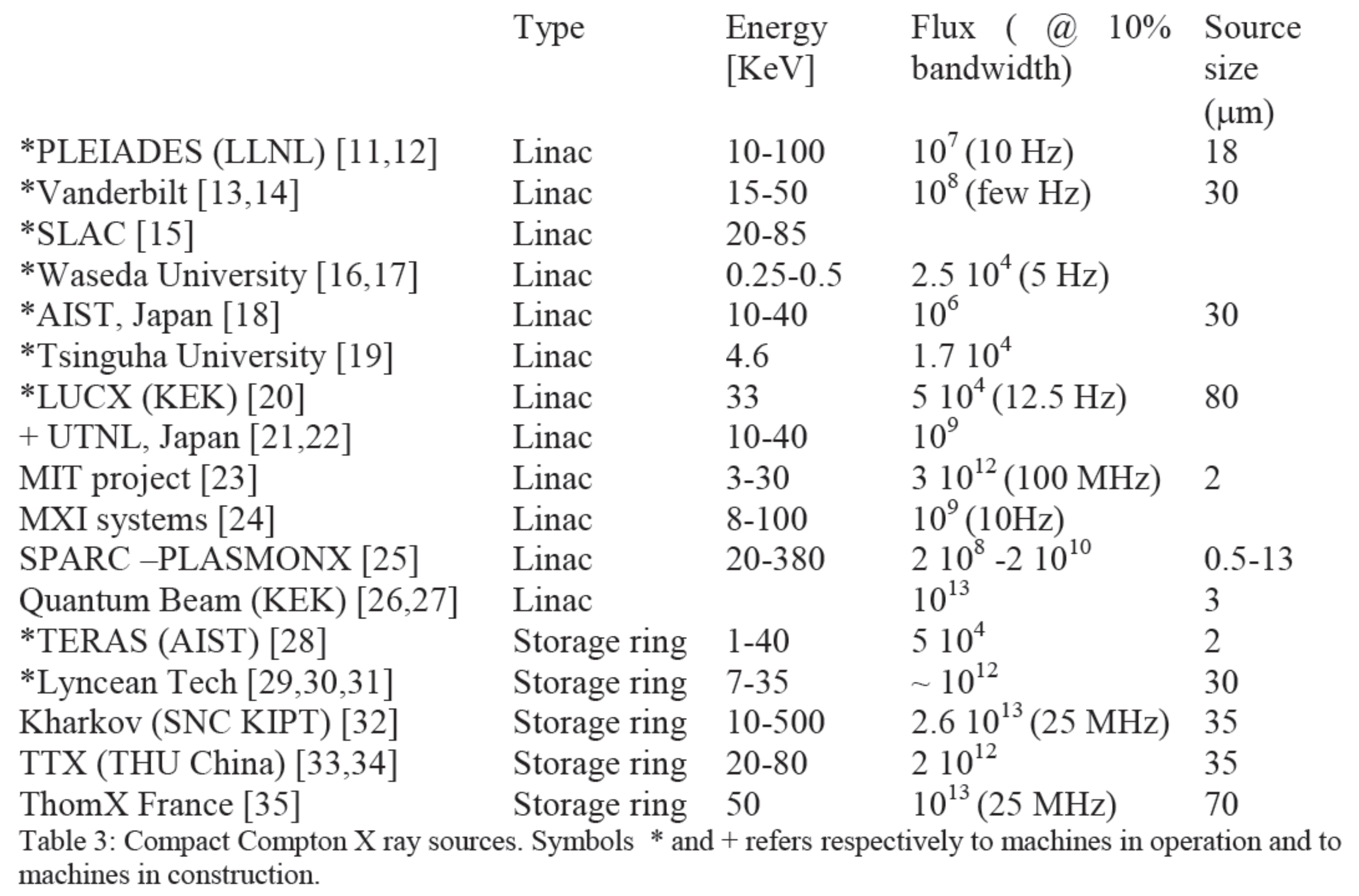
- **UH-FLUX is Compton-based X-ray source based on novel design of coupled SC RF cavities**
  - **Three patents on the technology, publication prepared**
  - **Develop in collaboration**
    - **With Cockcroft and STFC, most recently with Fermilab**
  - **Working with ISIS Innovation and companies**
    - **Niowave company USA and Sheakespear Engineering, UK**
  - **Developing IPS, PRD, Innovate UK grant proposals**
  - **Positive review by JAI AB and peers**



UH-FLUX X-ray & THz src

- **Discussing realisation of the projects with OSI**

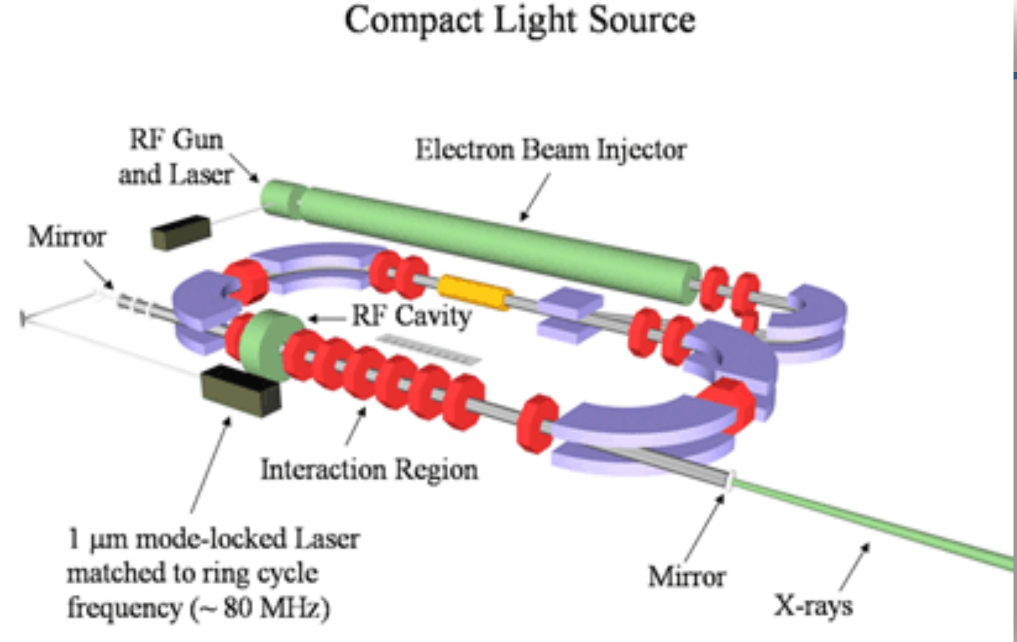
Existing and planned Compton sources



	Type	Energy [KeV]	Flux (@ 10% bandwidth)	Source size (μm)
*PLEIADES (LLNL) [11,12]	Linac	10-100	10^7 (10 Hz)	18
*Vanderbilt [13,14]	Linac	15-50	10^8 (few Hz)	30
*SLAC [15]	Linac	20-85		
*Waseda University [16,17]	Linac	0.25-0.5	$2.5\ 10^4$ (5 Hz)	
*AIST, Japan [18]	Linac	10-40	10^6	30
*Tsinguha University [19]	Linac	4.6	$1.7\ 10^4$	
*LUCX (KEK) [20]	Linac	33	$5\ 10^4$ (12.5 Hz)	80
+ UTNL, Japan [21,22]	Linac	10-40	10^9	
MIT project [23]	Linac	3-30	$3\ 10^{12}$ (100 MHz)	2
MXI systems [24]	Linac	8-100	10^9 (10Hz)	
SPARC –PLASMONX [25]	Linac	20-380	$2\ 10^8$ -$2\ 10^{10}$	0.5-13
Quantum Beam (KEK) [26,27]	Linac		10^{13}	3
*TERAS (AIST) [28]	Storage ring	1-40	$5\ 10^4$	2
*Lyncean Tech [29,30,31]	Storage ring	7-35	~ 10^{12}	30
Kharkov (SNC KIPT) [32]	Storage ring	10-500	$2.6\ 10^{13}$ (25 MHz)	35
TTX (THU China) [33,34]	Storage ring	20-80	$2\ 10^{12}$	35
ThomX France [35]	Storage ring	50	10^{13} (25 MHz)	70

Table 3: Compact Compton X ray sources. Symbols * and + refers respectively to machines in operation and to machines in construction.

From **THOMX** Conceptual Design Report, A.Variola, A.Loulergue, F.Zomer, LAL RT 09/28, SOLEIL/SOU-RA-2678, 2010



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
Clinical High Resolution Imaging System
Micro-tomography
Protein crystallography

Hard X-ray phase-contrast imaging with the Compact Light Source based on inverse Compton X-rays, M. Bech, O. Bunk, C. David, R. Ruth, J. Rifkin, R. Loewen, R. Feidenhans'l and F. Pfeiffer
et al, *J. Synchrotron Rad.* (2009). **16**, 43-47

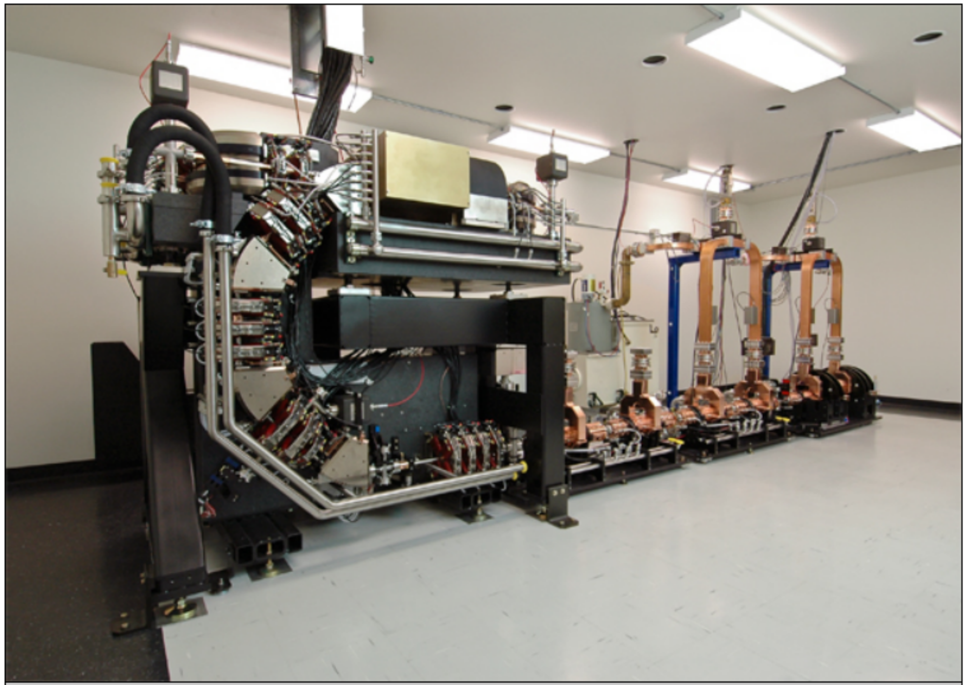
PUBLIC RELEASE: 13-DEC-2012

Lyncean Technologies Inc. sells Compact Light Source to Munich biomedical-imaging research center

LYNCEAN TECHNOLOGIES, INC.

Palo Alto-based Lyncean Technologies, Inc., today announced its first sale of a Compact Light Source, a miniature synchrotron X-ray source employing state-of-the-art laser-beam and electron-beam technology.

A Lyncean "Compact Light Source" (CLS) was purchased by researchers from the newly-formed Center for Advanced Laser Applications (CALA) in Germany, a joint project of the Ludwig Maximilians University of Munich (LMU) and the Technical



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

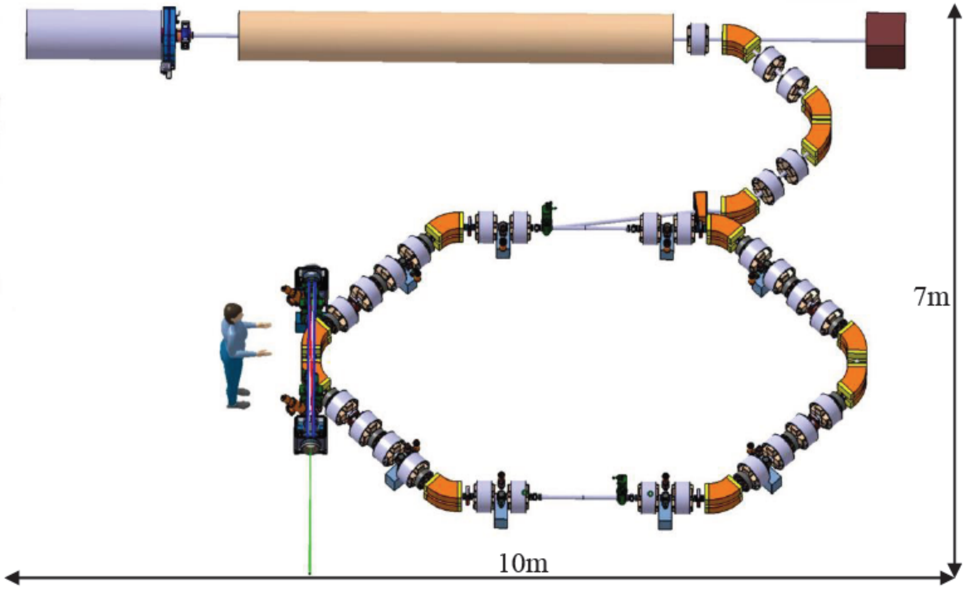
PUBLIC RELEASE: 29-APR-2015

First miniature synchrotron now in commercial operation

LYNCEAN TECHNOLOGIES, INC.

Lyncean Technologies, Inc. today announced the commercial operation of a Compact Light Source (CLS), the world's first miniature synchrotron X-ray source employing state-of-the-art laser and electron beam technology.

THOMX – Compton source



X-ray energy 50-90 keV

Flux 1E11-1E13 ph/s

Ring energy 50 MeV

A.Variola, A.Loulergue, F.Zomer, LAL RT 09/28, SOLEIL/SOU-RA-2678, 2010

- Scientific case
  - Cultural heritage application
  - Bio-Medical applications
  - X-ray crystallography

Quantum beam project

Compact (less than 10m) quasi-monochromatic (less than 1%)

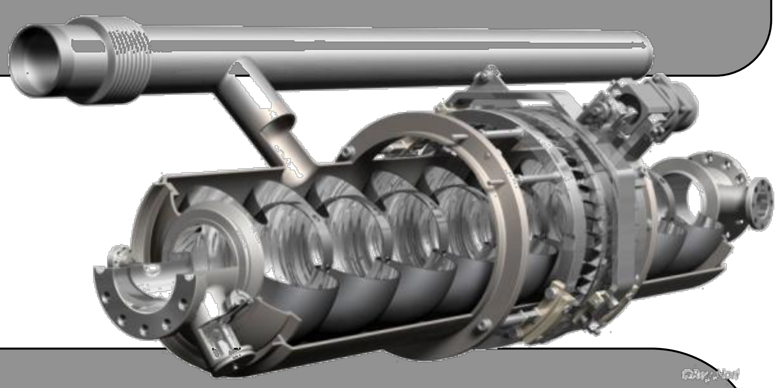
High Flux (100 times than Compact normal Linac X-ray : 10^{11} photons/sec 1% b.w.)

High Brightness (10^{17} photons/sec mrad² mm² 0.1% b.w.)

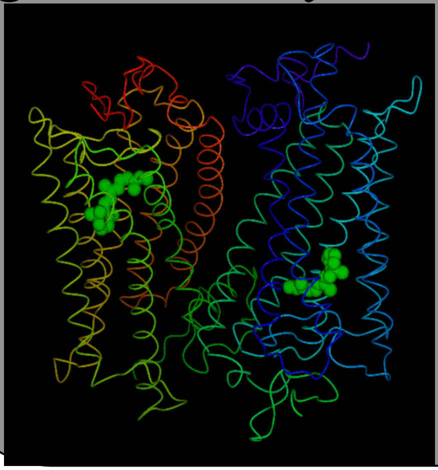
Ultra-short pulse X-ray (40 fs ~)

J. Urakawa, Quantum Beam Project

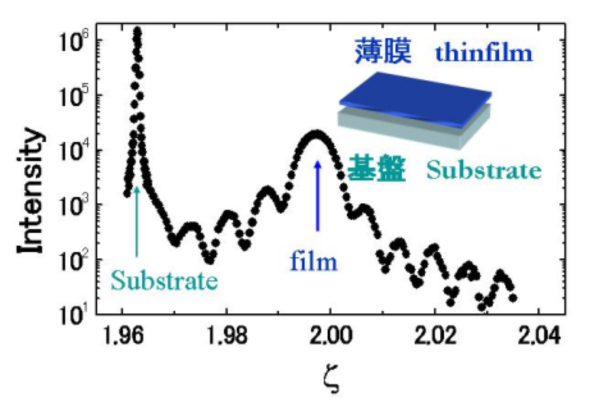
Key: SCRF acceleration technology



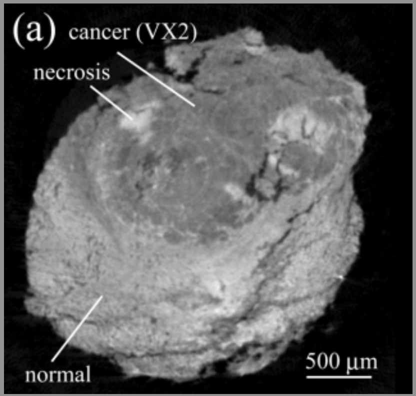
Structural genetic analysis,



Nano-material evaluation,



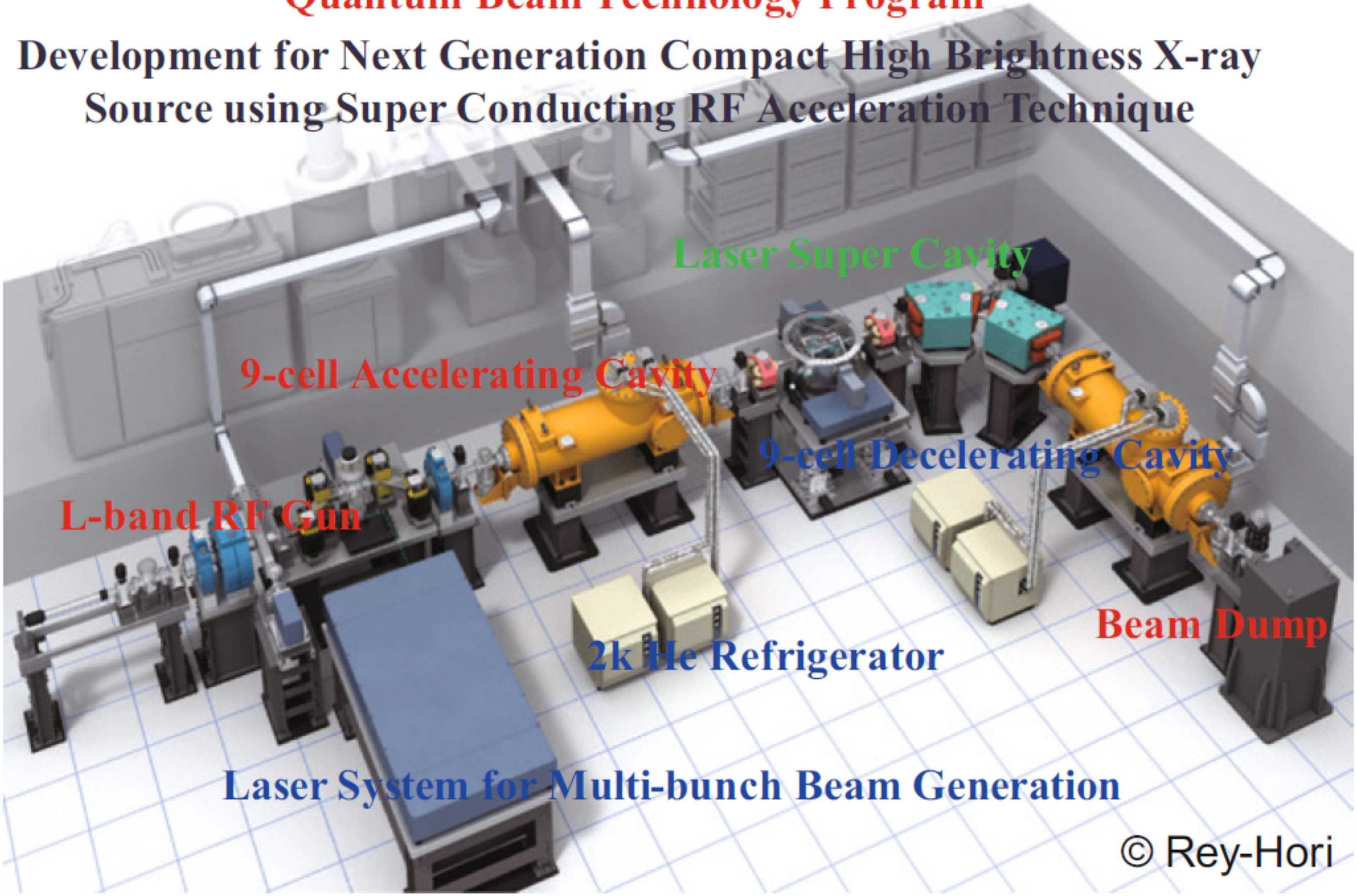
Highly fine X-ray Imaging



http://mml.k.u-tokyo.ac.jp/

Quantum Beam Technology Program

Development for Next Generation Compact High Brightness X-ray Source using Super Conducting RF Acceleration Technique



© Rey-Hori

J. Urakawa, Nucl. Instr. and Meth. A (2010), doi:10.1016/j.nima.2010.02.019

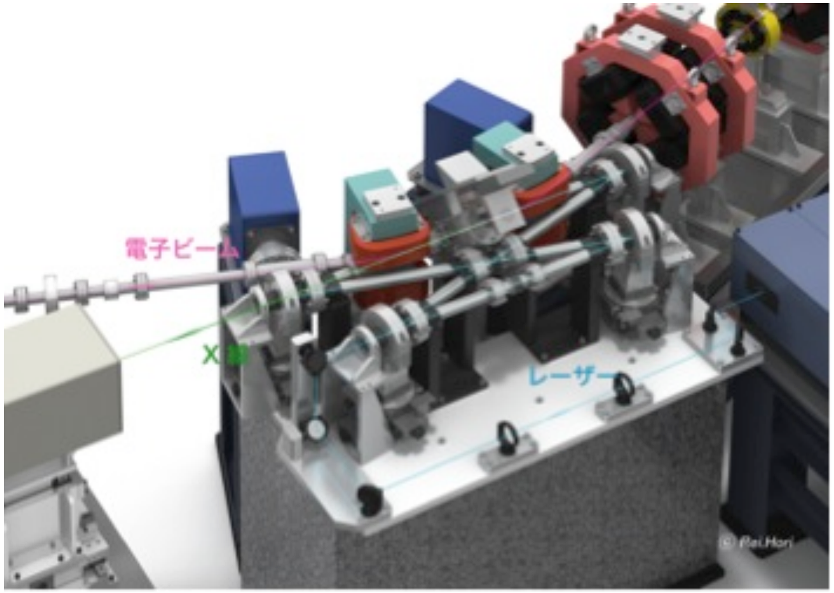
Quantum Beam: state of the art and challenges

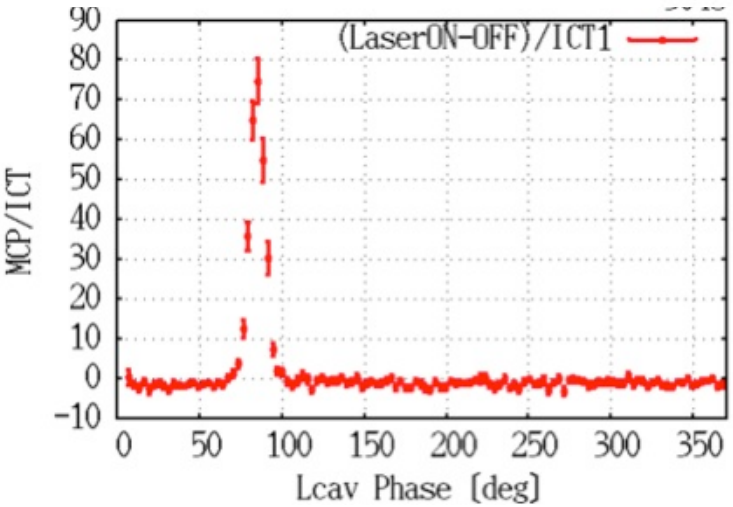
technology	Present status	Target	Key points
Electron source	**300 nC/pulse** **10,000nC/pulse (2008-2009)**	**48,000 nC/pulse (2010-2012)**	Pulse laser, new photo-cathode, **1 msec** pulse length
SC Cavity	**Pulse: 25 MV/m** **CW: 12 MV/m**	**Pulse: 30 MV/m** **CW: 20 MV/m**	**Non-defect and clean surface, Precise electron beam welding, High precision forming, Non-contamination material**
Pulsed laser storage	**0.5 mJ/pulse, Waist: 30 μm**	**50 mJ/pulse, Waist: 8 μm**	**4-mirror optical cavity**
Colliding control	μm beam orbit control	**Sub-** μm beam orbit control	**minimizing environmental effect, Fast feedback control**

J. Urakawa, et al, Quantum Beam Project

Quantum beam status, 2014

- **Actual installation =>**
- **Results – first gen of Compton x-rays with SRF technology**



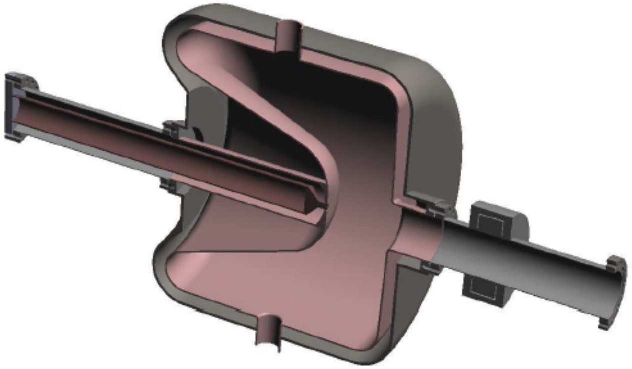


J. Urakawa, et al, Quantum Beam Project

http://newsline.linearcollider.org/2013/04/04/a-spin-off-of-ilc-technology-already/

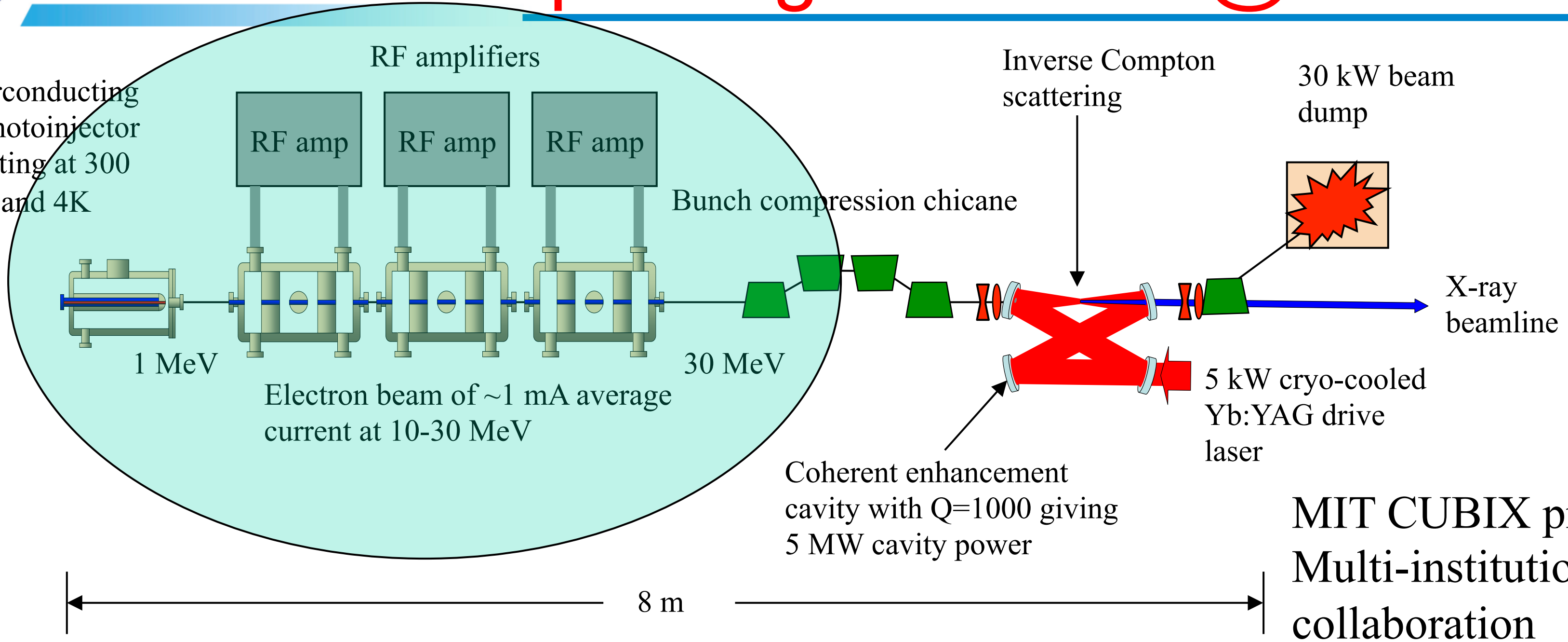
SRF Compact Light Sources @ 4K

- Most existing SRF cavities require or benefit from 2K operation
  - Too complex for a University or small institution-based accelerator
  - Cryogenics is a strong cost driver for compact SRF linacs
- Spoke cavities can operate at lower frequency
  - Lower frequency allows operation at 4K
  - No sub-atmospheric cryogenic system
  - Significant reduction in complexity
- Next generation of SRF injectors
  - 200-500 MHz, 4k, 4MeV, 1mA
  - Naval Postgraduate School, Niowave Inc, and UW-Madison



Jean Delayen, Old Dominion Univ. & Thomas Jefferson National Accelerator Facility
P. Ostroumov and K. Shepard, ANL
W. Graves, MIT

SRF Compact Light Sources @ 4K



Superconducting RF photoinjector operating at 300 MHz and 4K

RF amplifiers

RF amp

RF amp

RF amp

Bunch compression chicane

Inverse Compton scattering

30 kW beam dump

X-ray beamline

1 MeV

30 MeV

Electron beam of ~1 mA average current at 10-30 MeV

5 kW cryo-cooled Yb:YAG drive laser

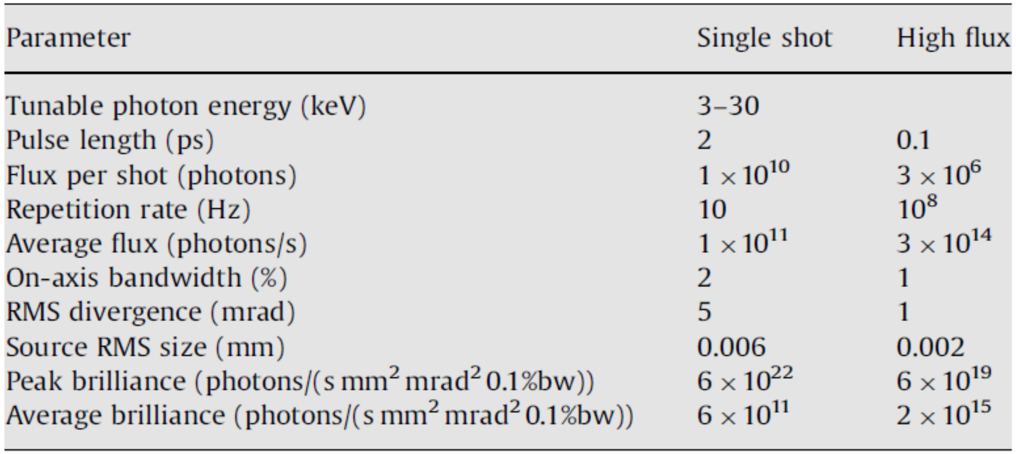
Coherent enhancement cavity with Q=1000 giving 5 MW cavity power

8 m

MIT CUBIX proposal
Multi-institutional collaboration

SRF Linac Parameters	
Energy gain [MeV]	25
RF frequency [MHz]	352
Average current [mA]	1
Operating temperature [K]	4.2
RF power [kW]	30

Jean Delayen CAS, Old Dominion University and Thomas Jefferson National Accelerator Facility



Parameter	Single shot	High flux
Tunable photon energy (keV)	3–30	
Pulse length (ps)	2	0.1
Flux per shot (photons)	1×10^{10}	3×10^{6}
Repetition rate (Hz)	10	10^{8}
Average flux (photons/s)	1×10^{11}	3×10^{14}
On-axis bandwidth (%)	2	1
RMS divergence (mrad)	5	1
Source RMS size (mm)	0.006	0.002
Peak brilliance (photons/(s mm^2 mrad^2 0.1%bw))	6×10^{22}	6×10^{19}
Average brilliance (photons/(s mm^2 mrad^2 0.1%bw))	6×10^{11}	2×10^{15}

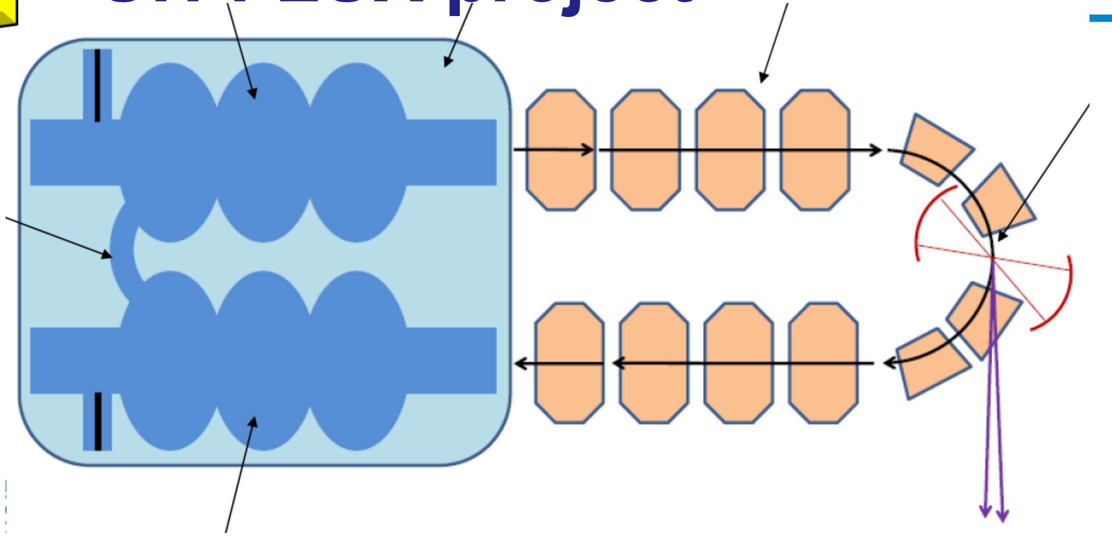
W.S. Graves et al. / NIM A 608 (2009) S103–S105

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

- The collaboration presenting this talk is developing an advanced Compton/THz source
  - This design will surpass any existing designs
- Layout and parameters outlined on the next slides [1]
- More advanced design, which exist, is not reported here, as being presently filed for patent
- [1] International (PCT) Patent Application No. PCT/GB2012/052632 (WO2013/061051) filed on the 26th October 2012

Brightest Compton X-ray Source

UH-FLUX project



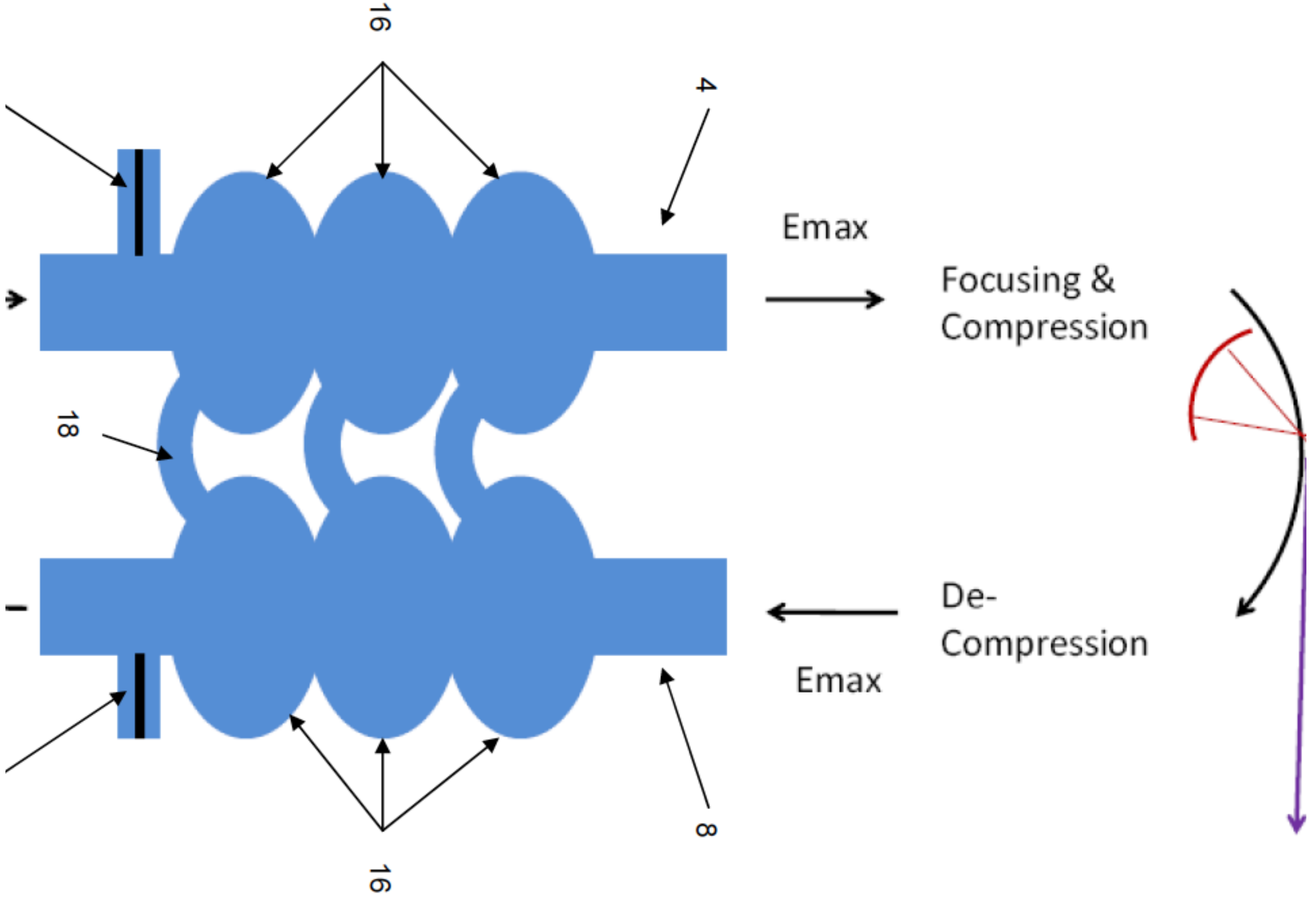
Next steps in Compton/THz sources – UH-FLUX project

- **Collaboration of UK centers JAI, CI, STFC and UK industry is developing an advanced Compton/THz source**
  - **This design will surpass any existing designs**
- **[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**

R. Ainsworth[a], S. Boogert[d], G. Burt[b], L. Corner[a], S. Jamison[c], P. Karataev[d], I.V. Konoplev[a], A. Lyapin[d], P. Mcintosh[c], B. Militsyn[c], S. Pattalwar[b], A. Seryi[a], and A.Wheelhouse[c]

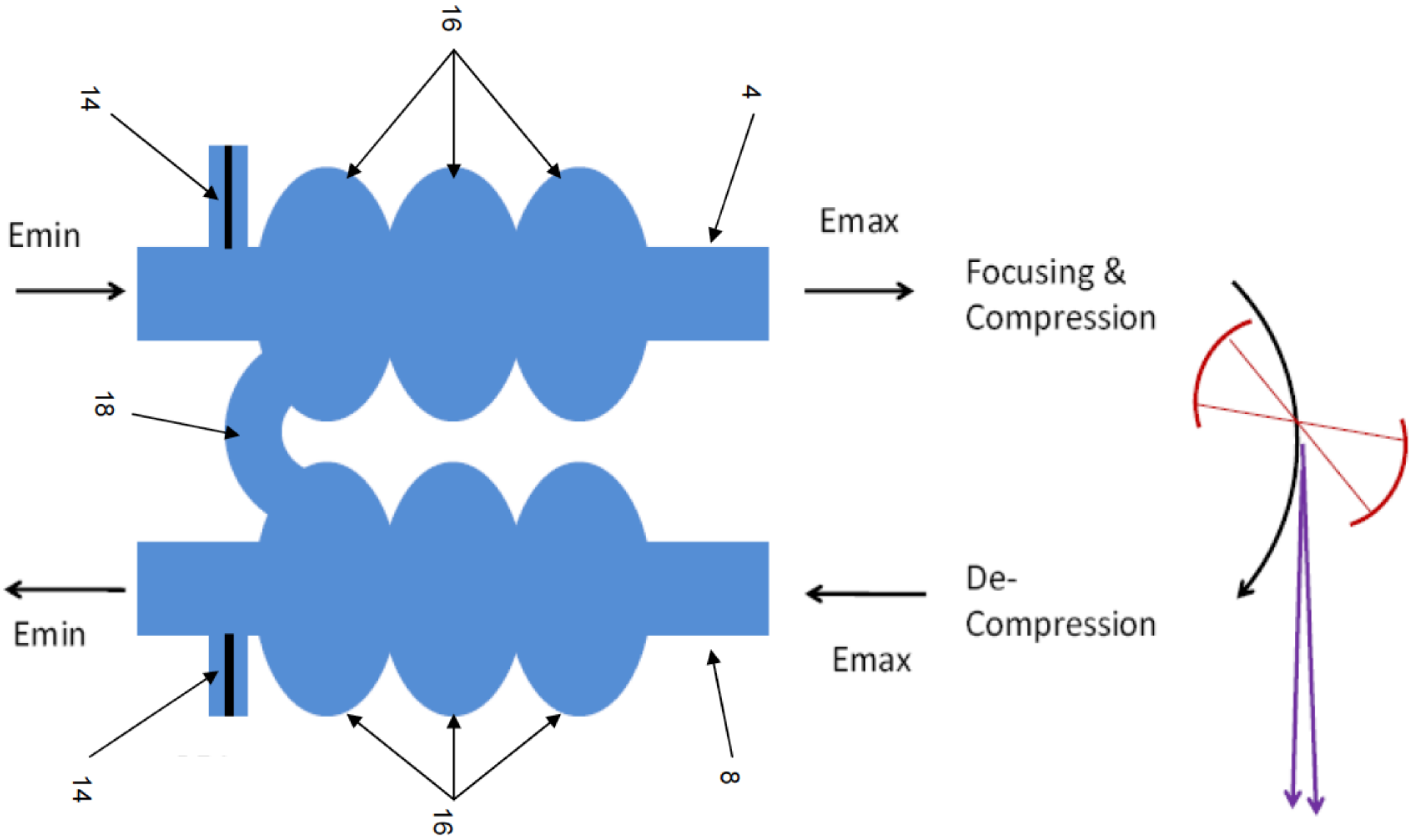
a/ JAI, University of Oxford, b/ CI, Lancaster University, c/ ASTeC, STFC d/ JAI, Royal Holloway, UK

Possible layout



Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout



Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout – cross-section

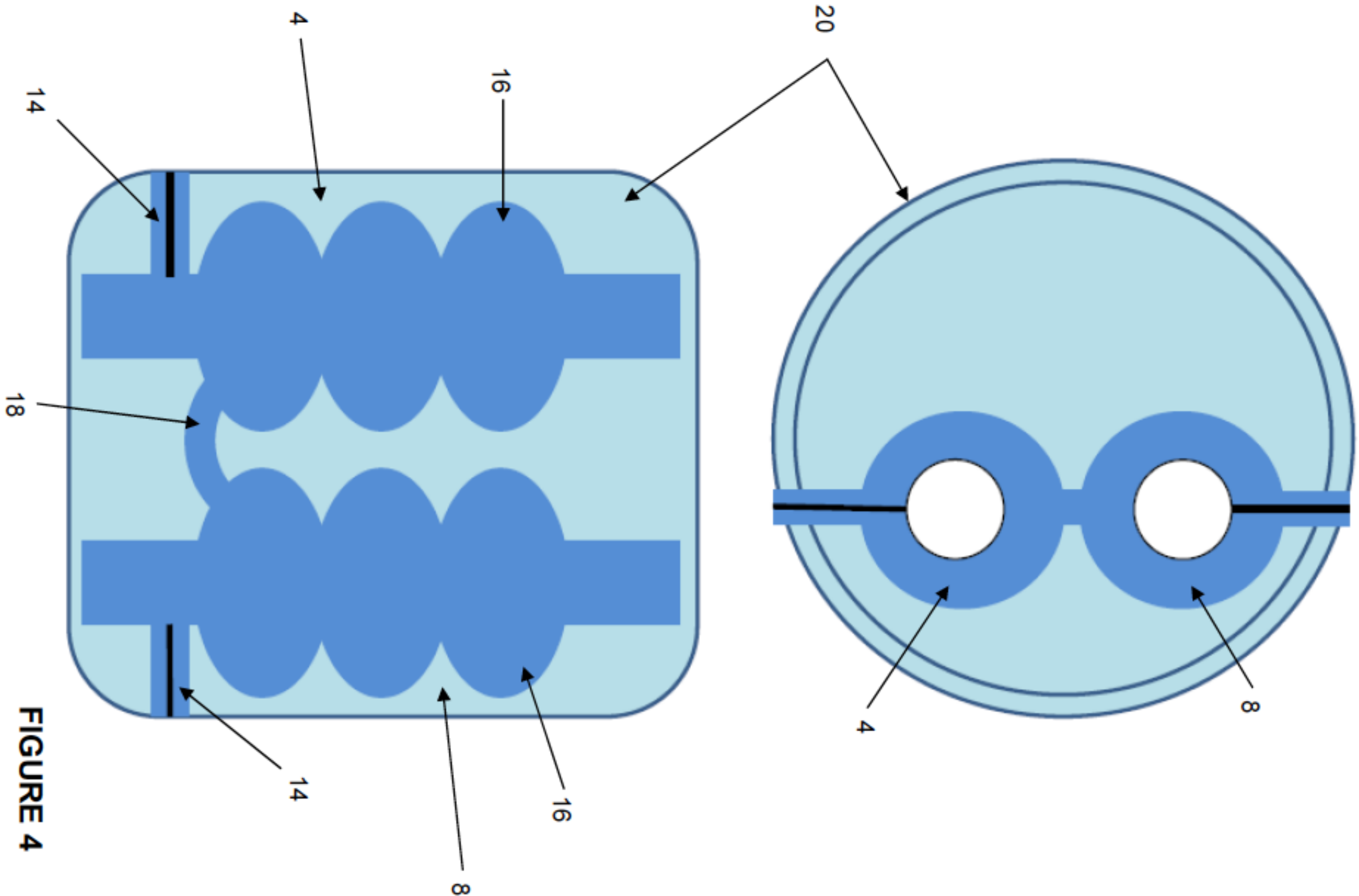


FIGURE 4

Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout – injector options

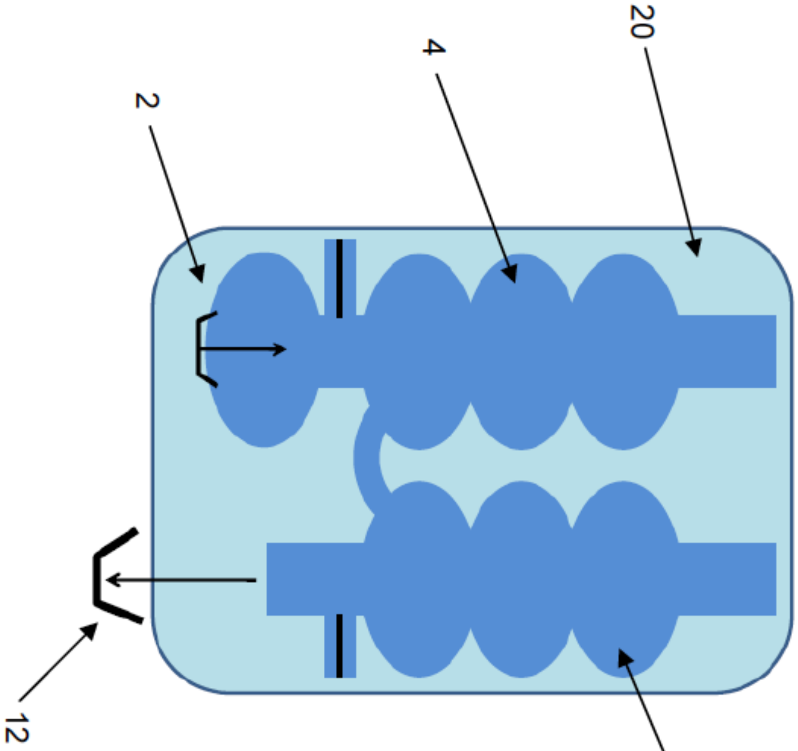


FIGURE 5b

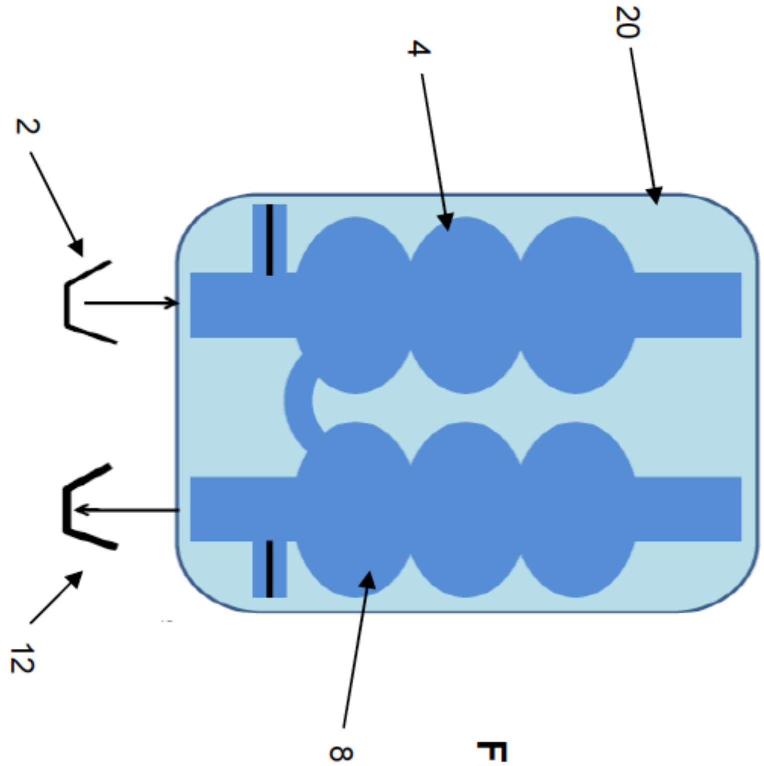


FIGURE 5a

Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout – experiment in cold

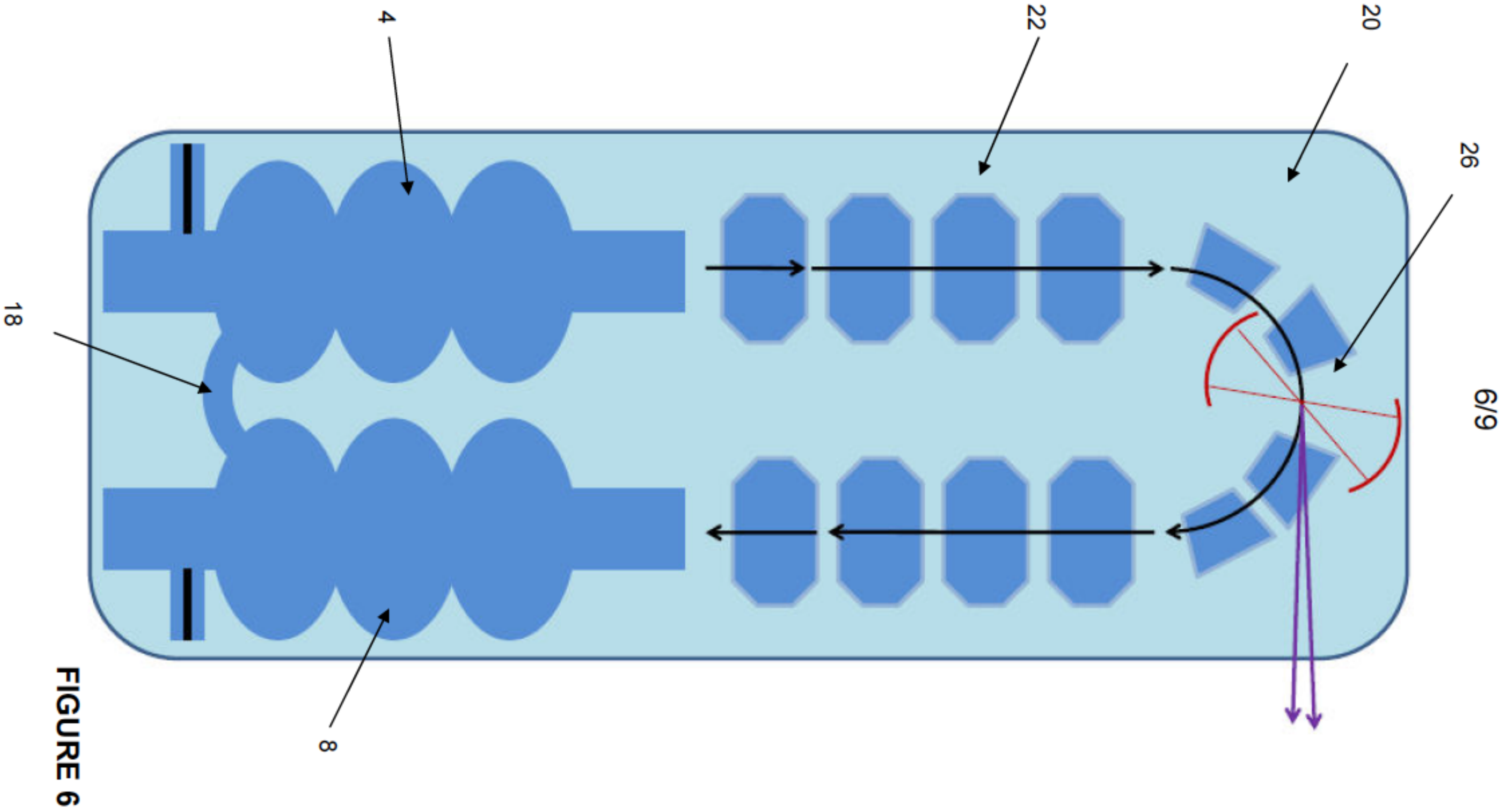


FIGURE 6

Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout – experiment in warm

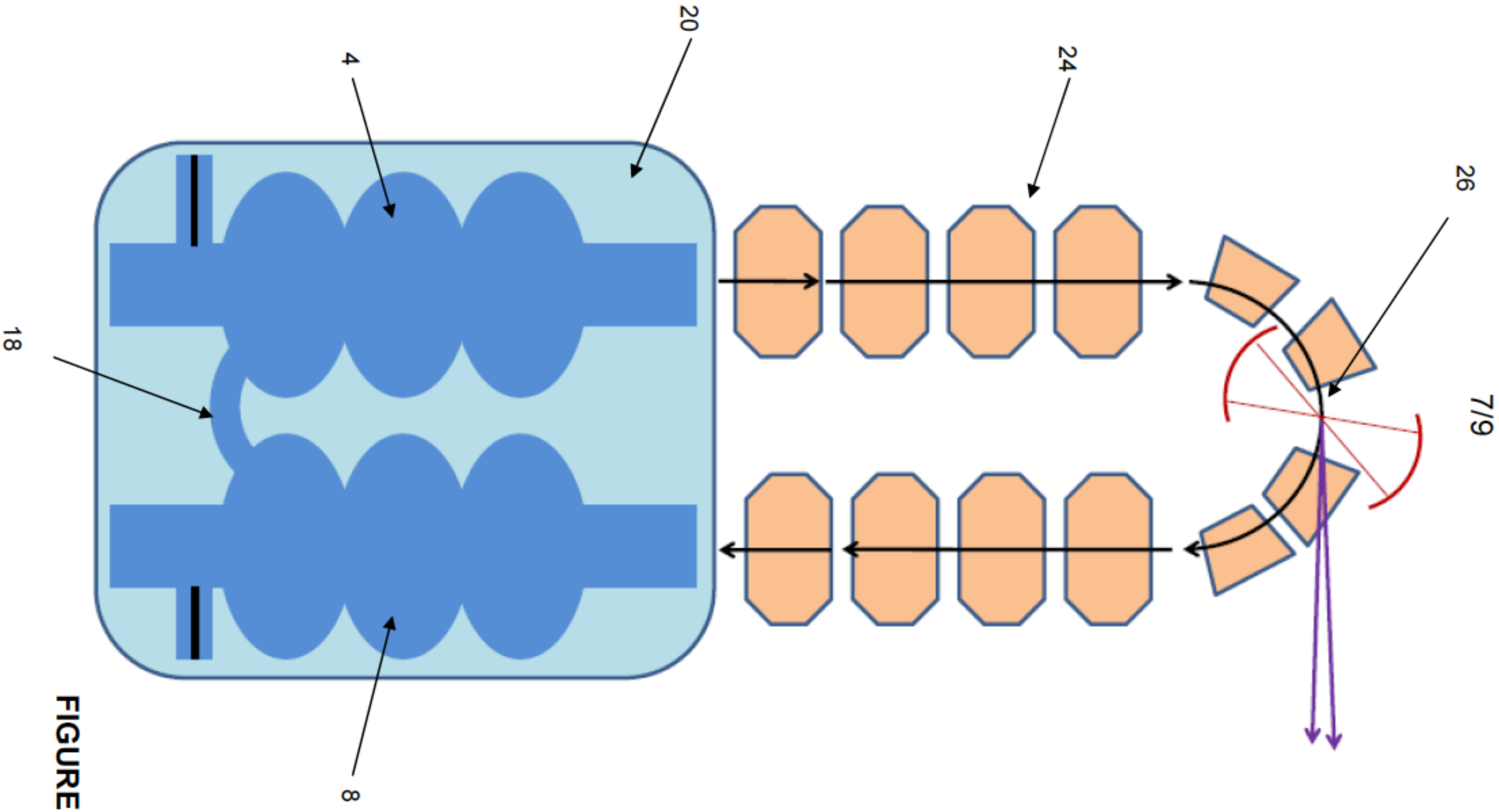


FIGURE 7

Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout – version of experiment

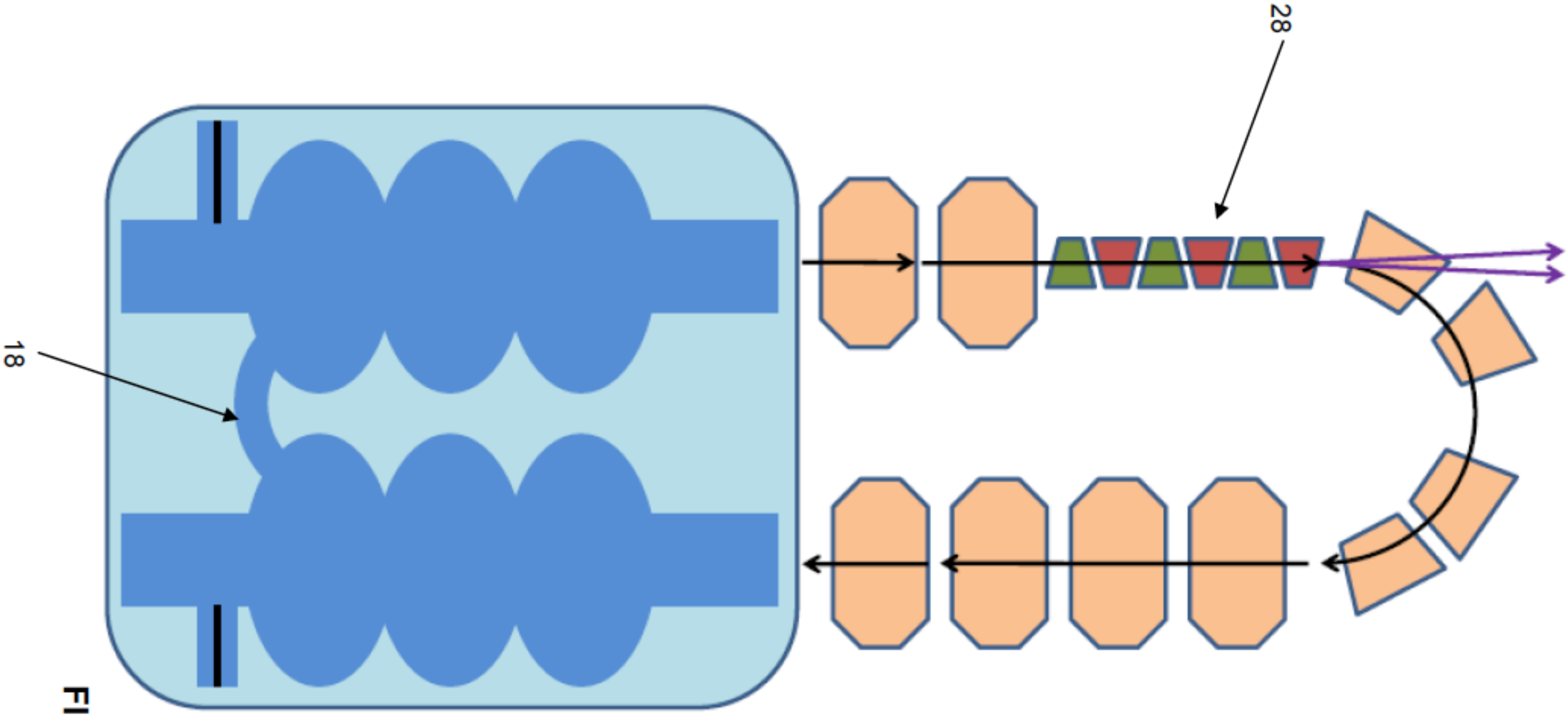


FIGURE 8

Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Possible layout – experiment version

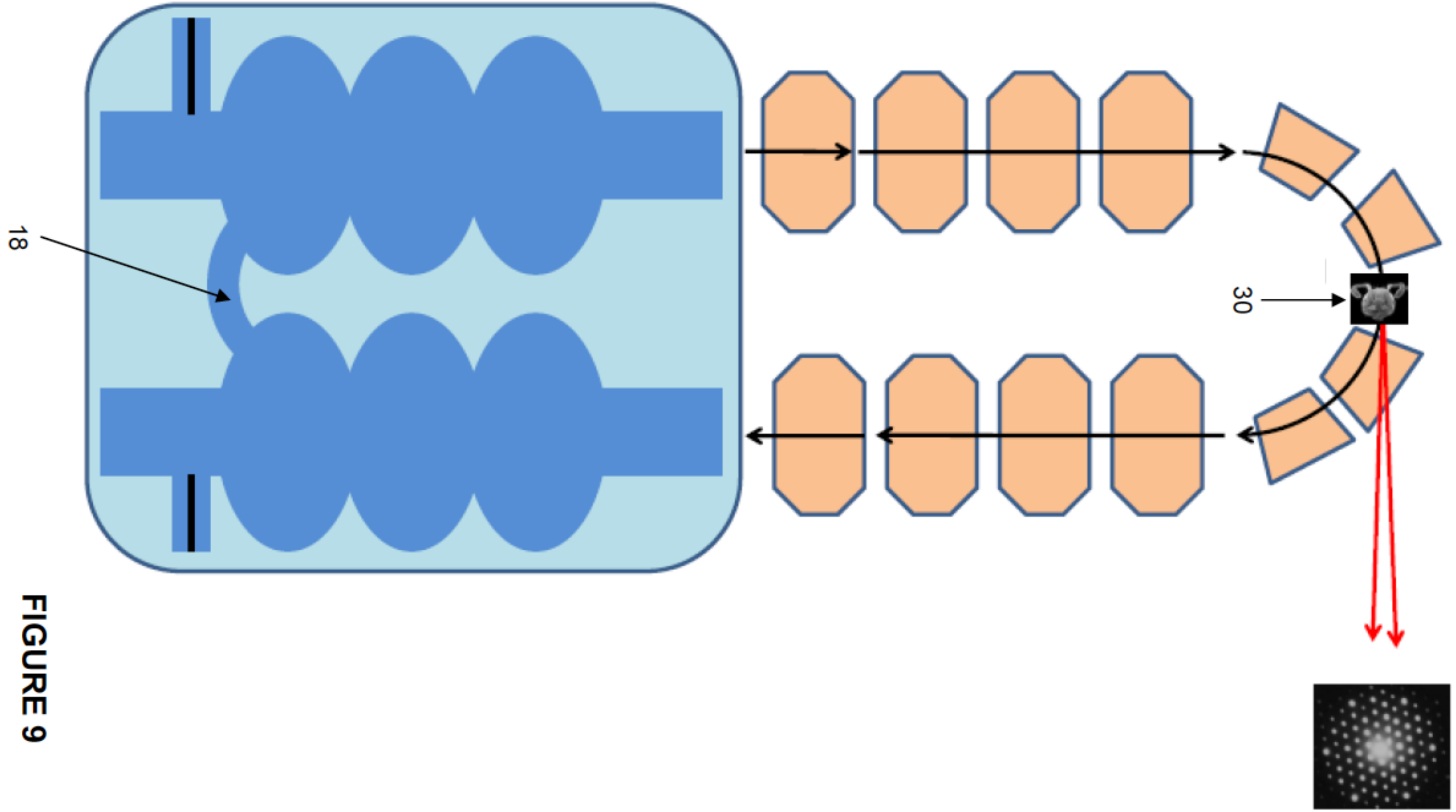


FIGURE 9

Illustrations from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

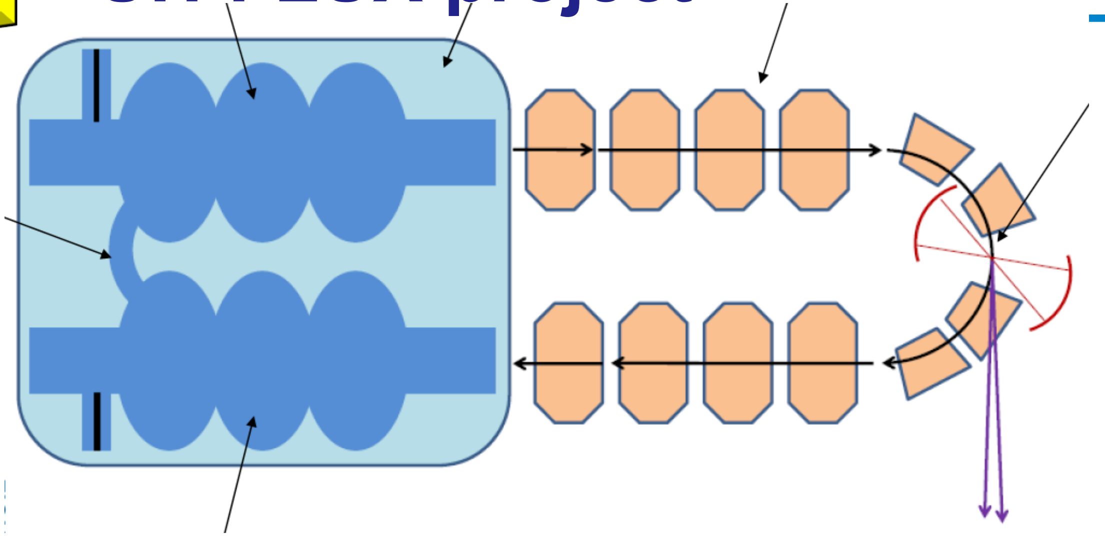
Possible parameters – range

Typical parameters, range	[		]	
Electron beam E, MeV	10	20	30	
Electron bunch charge, nC	0.2	0.5	1	
e-bunch repetition rage, MHz	50	200	1000	
e-beam average current, A	0.01	0.1	1	
e-beam reactive power, MW	0.1	2	30	
e-beam energy at dump, MeV	0.2	0.1	0.1	
laser wavelength	1000	600	300	
X-ray max energy, keV	2	12	60	
X-ray min wavelength, nm	0.6	0.1	0.02	
X-ray flux, ray/s	1.E+15	8.E+15	4.E+16	
approx peak brilliance	2.E+20	2.E+21	8.E+21	ph/(s mm^2 mrad^2 0.1%bw)
approx RF power, kW	2	10	100	
e-Energy recovery coefficient	50	200	300	

Table from the Patent No. PCT/GB2012/052632 (WO2013/061051) filed on 26th October 2012

Brightest Compton X-ray Source

UH-FLUX project



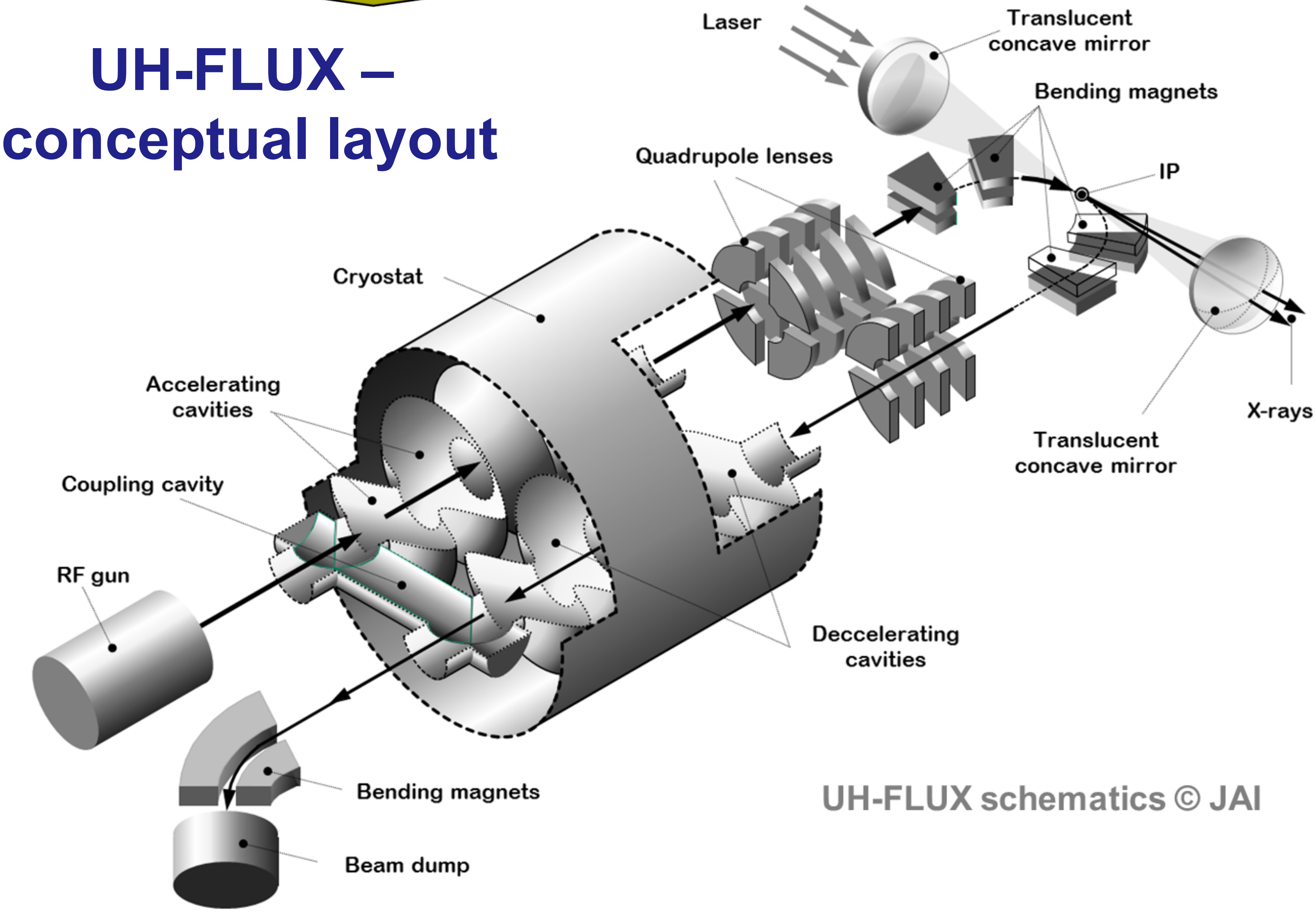
Next steps in Compton/THz sources – UH-FLUX project

- **Collaboration of UK centers JAI, CI, STFC and UK industry is developing an advanced Compton/THz source**
  - **This design will surpass any existing designs**
- **[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**

R. Ainsworth[a], S. Boogert[d], G. Burt[b], L. Corner[a], S. Jamison[c], P. Karataev[d], I.V. Konoplev[a], A. Lyapin[d], P. Mcintosh[c], B. Militsyn[c], S. Pattalwar[b], A. Seryi[a], and A.Wheelhouse[c]

a/ JAI, University of Oxford, b/ CI, Lancaster University, c/ ASTeC, STFC d/ JAI, Royal Holloway, UK

UH-FLUX – conceptual layout

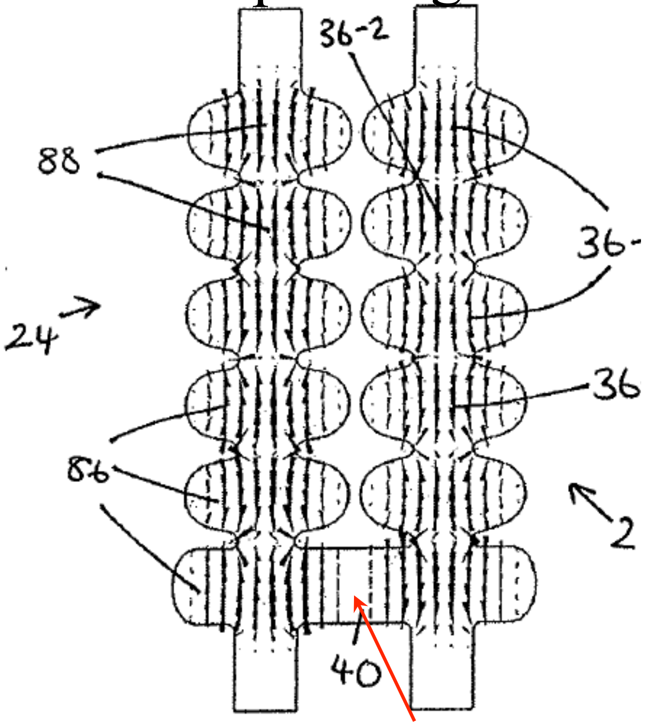


UH-FLUX schematics © JAI

UH-FLUX: Asymmetric Energy Recovery Linac

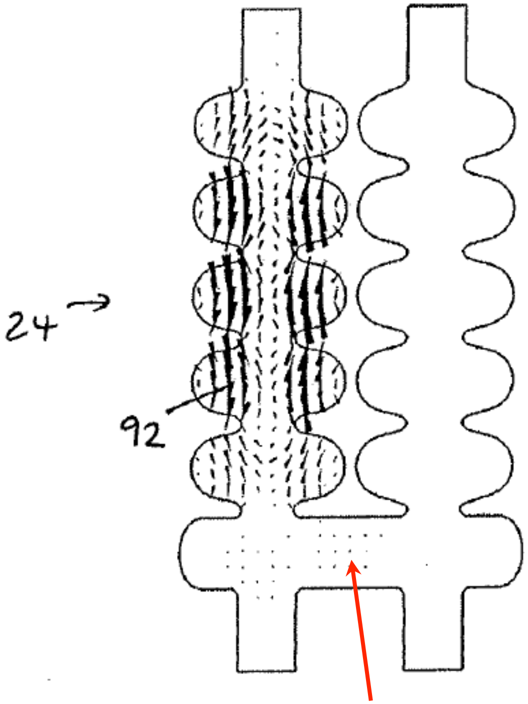
Decoupling all modes except the operating mode

Operating mode



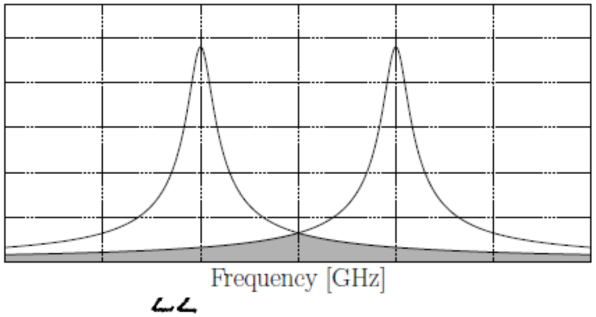
Zero field (operating mode) in the center of the coupler

One of transverse modes

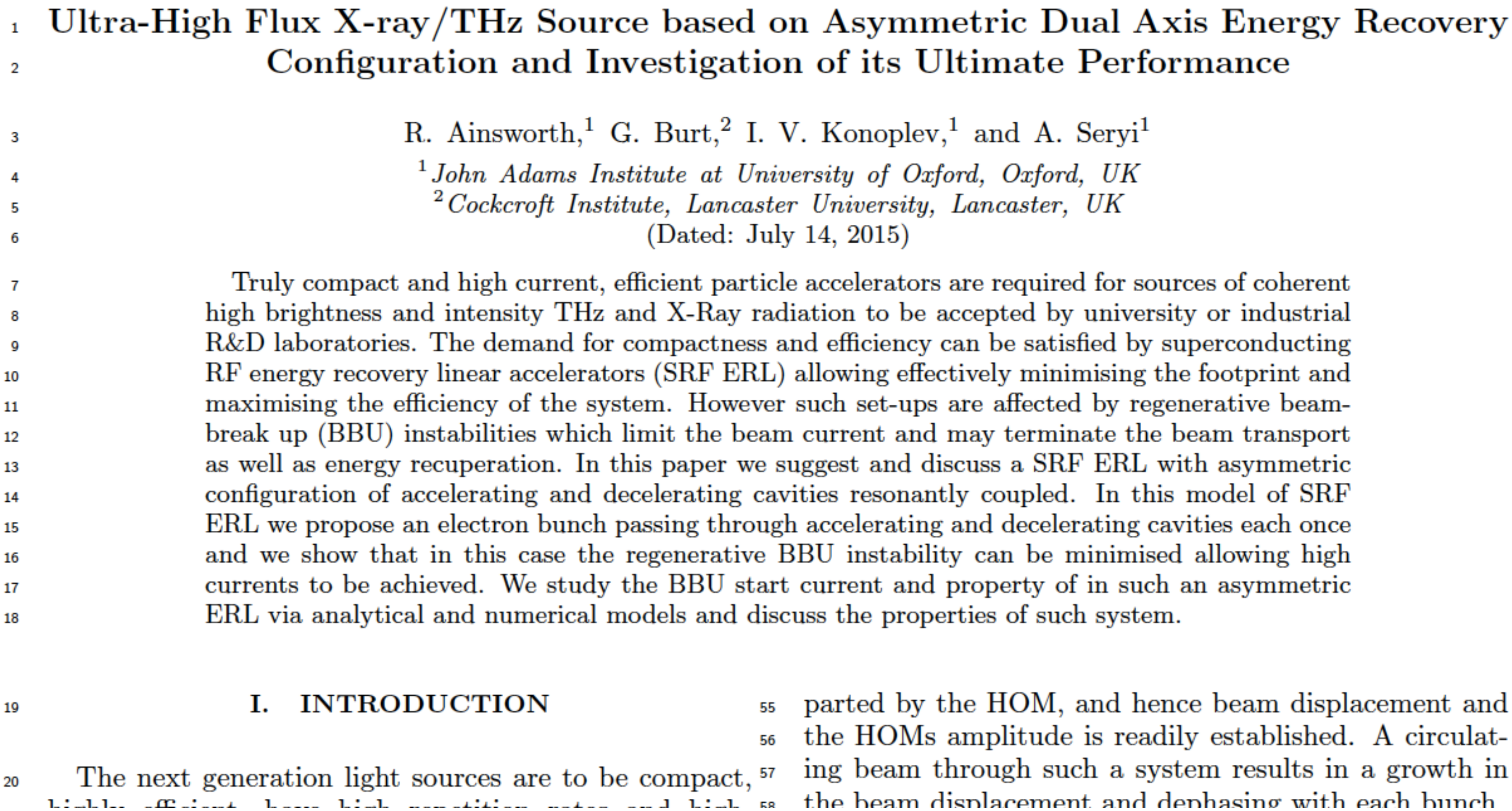


The field is not zero for most other HOMs

HOMs are not overlapping



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



Ultra-High Flux X-ray/THz Source based on Asymmetric Dual Axis Energy Recovery Configuration and Investigation of its Ultimate Performance

R. Ainsworth,[1] G. Burt,[2] I. V. Konoplev,[1] and A. Seryi[1]
[1] *John Adams Institute at University of Oxford, Oxford, UK*
[2] *Cockcroft Institute, Lancaster University, Lancaster, UK*
(Dated: July 14, 2015)

Truly compact and high current, efficient particle accelerators are required for sources of coherent high brightness and intensity THz and X-Ray radiation to be accepted by university or industrial R&D laboratories. The demand for compactness and efficiency can be satisfied by superconducting RF energy recovery linear accelerators (SRF ERL) allowing effectively minimising the footprint and maximising the efficiency of the system. However such set-ups are affected by regenerative beam-break up (BBU) instabilities which limit the beam current and may terminate the beam transport as well as energy recuperation. In this paper we suggest and discuss a SRF ERL with asymmetric configuration of accelerating and decelerating cavities resonantly coupled. In this model of SRF ERL we propose an electron bunch passing through accelerating and decelerating cavities each once and we show that in this case the regenerative BBU instability can be minimised allowing high currents to be achieved. We study the BBU start current and property of in such an asymmetric ERL via analytical and numerical models and discuss the properties of such system.

I. INTRODUCTION

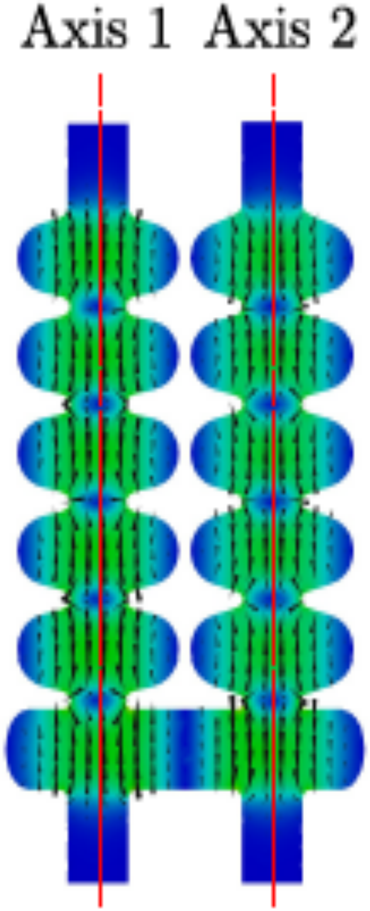
The next generation light sources are to be compact,

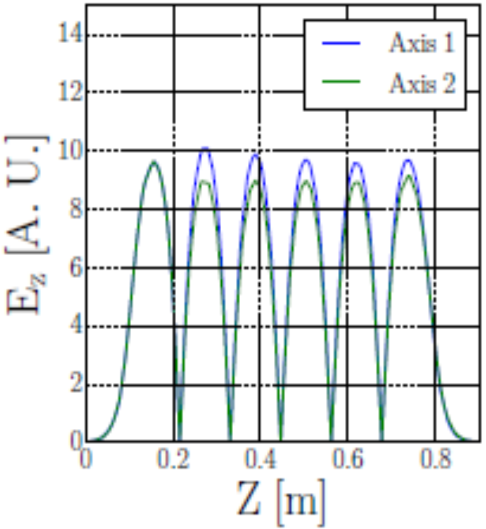
parted by the HOM, and hence beam displacement and the HOMs amplitude is readily established. A circulating beam through such a system results in a growth in the beam displacement and dephasing with each bunch

Paper submitted to journal
arXiv:1509.03675

UH-FLUX: Asymmetric Energy Recovery Linac

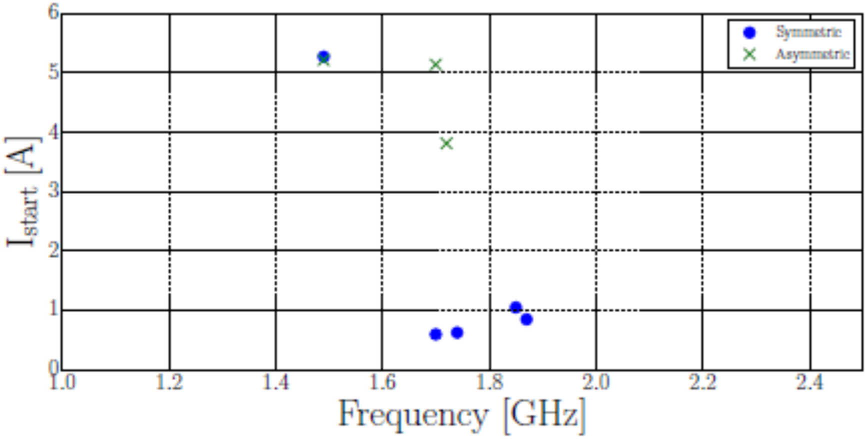
Maximize the BBU start current allowing to transport up to 2A beam without break-up

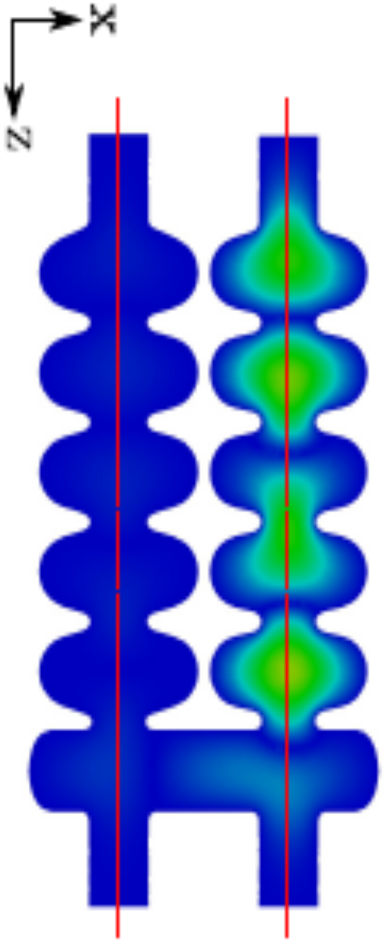




Operating field flatness

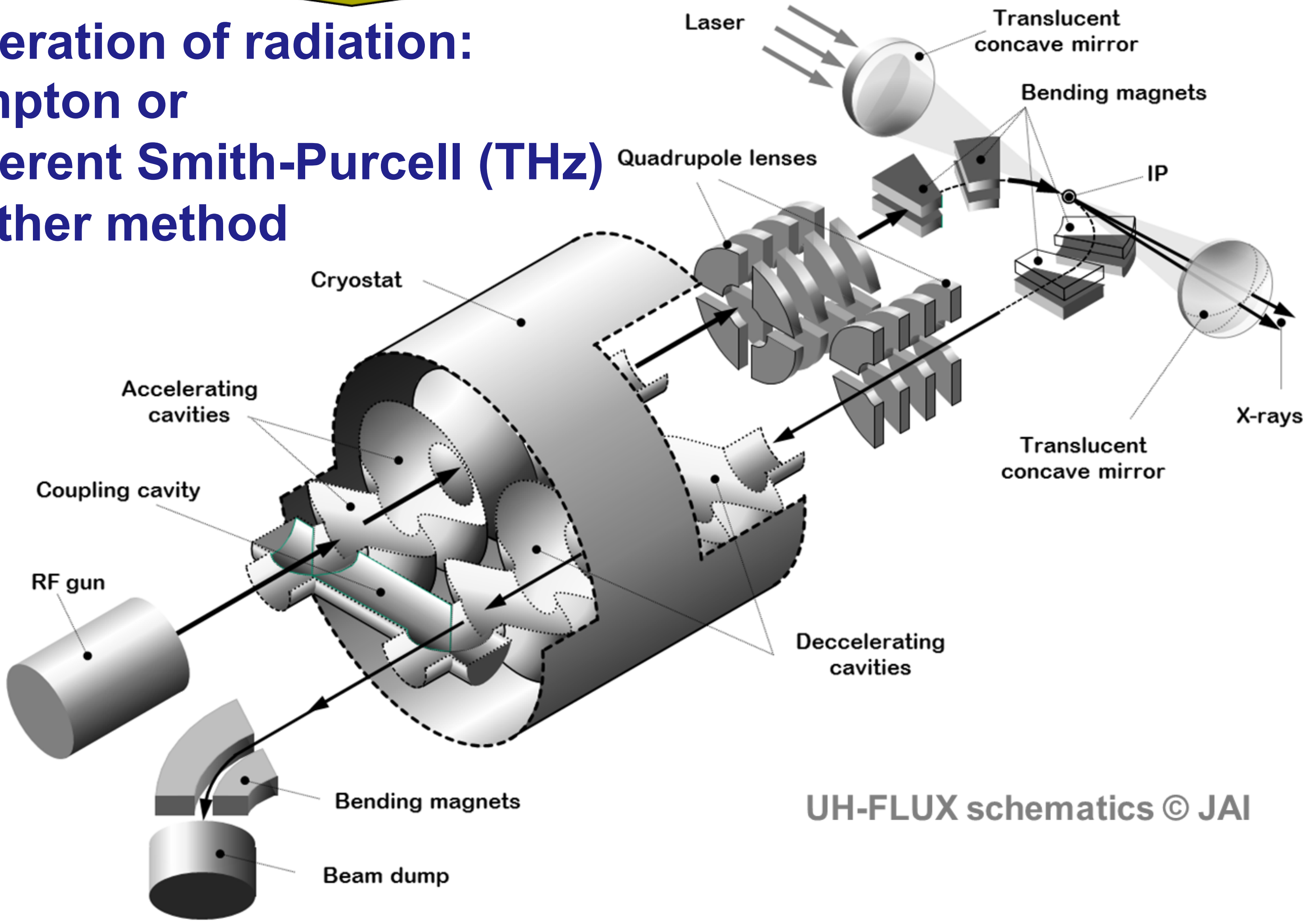
HOMs start currents





UH-FLUX – X-ray or THz

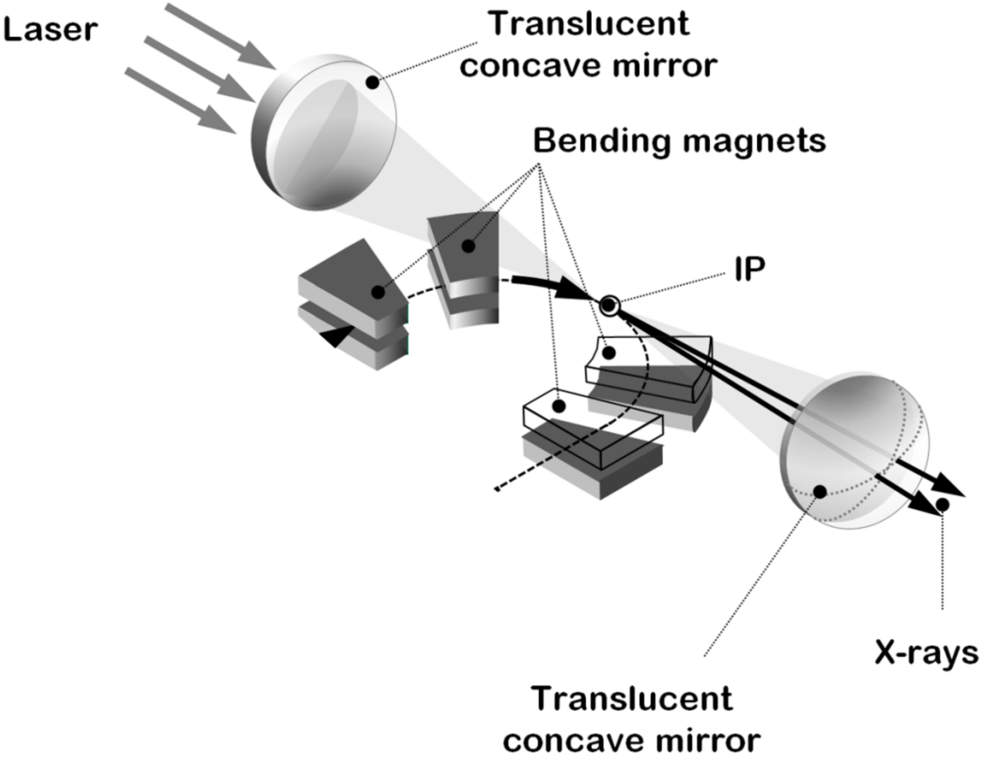
Generation of radiation: Compton or Coherent Smith-Purcell (THz) or other method



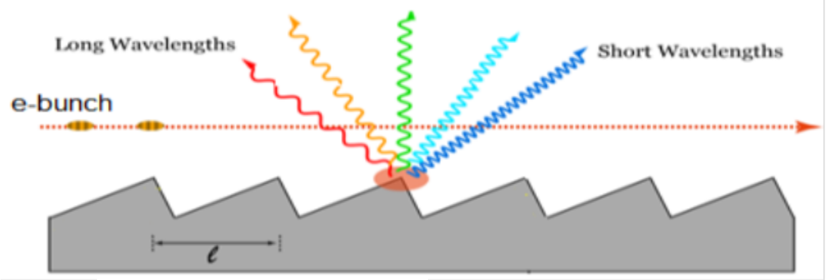
UH-FLUX schematics © JAI

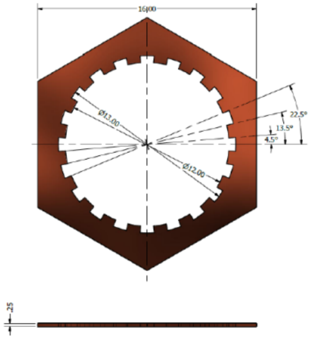
UH-FLUX – X-ray or THz

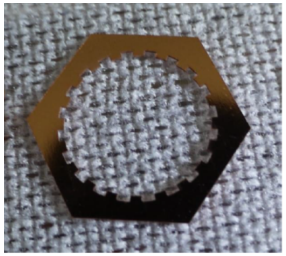
Compton

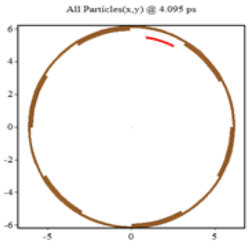


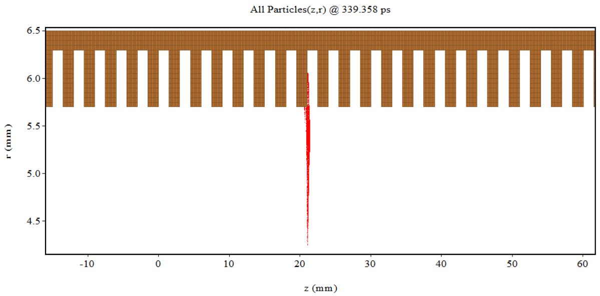
Coherent Smith-Purcell











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

UH-FLUX: AERL – Next steps

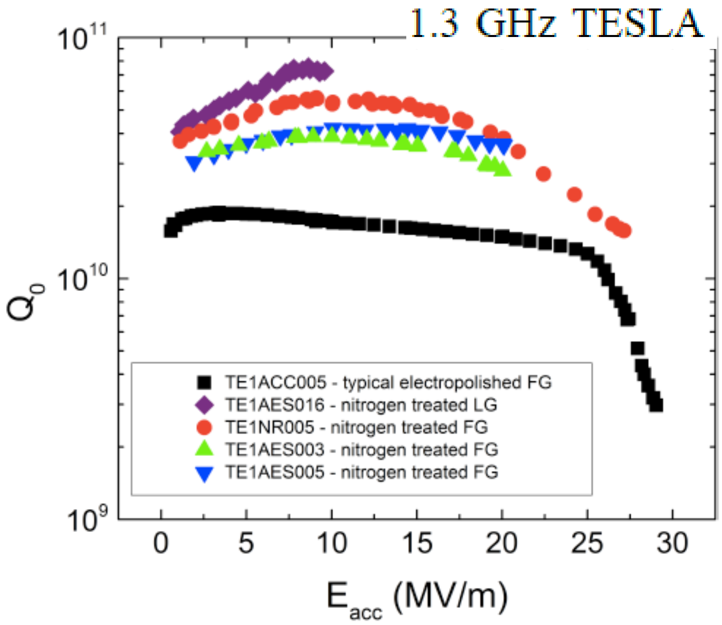
Open Questions:

1/ What photocathode should we use to drive the AERL

2/ What laser system to use to optimise: cost/space/bunch-charge

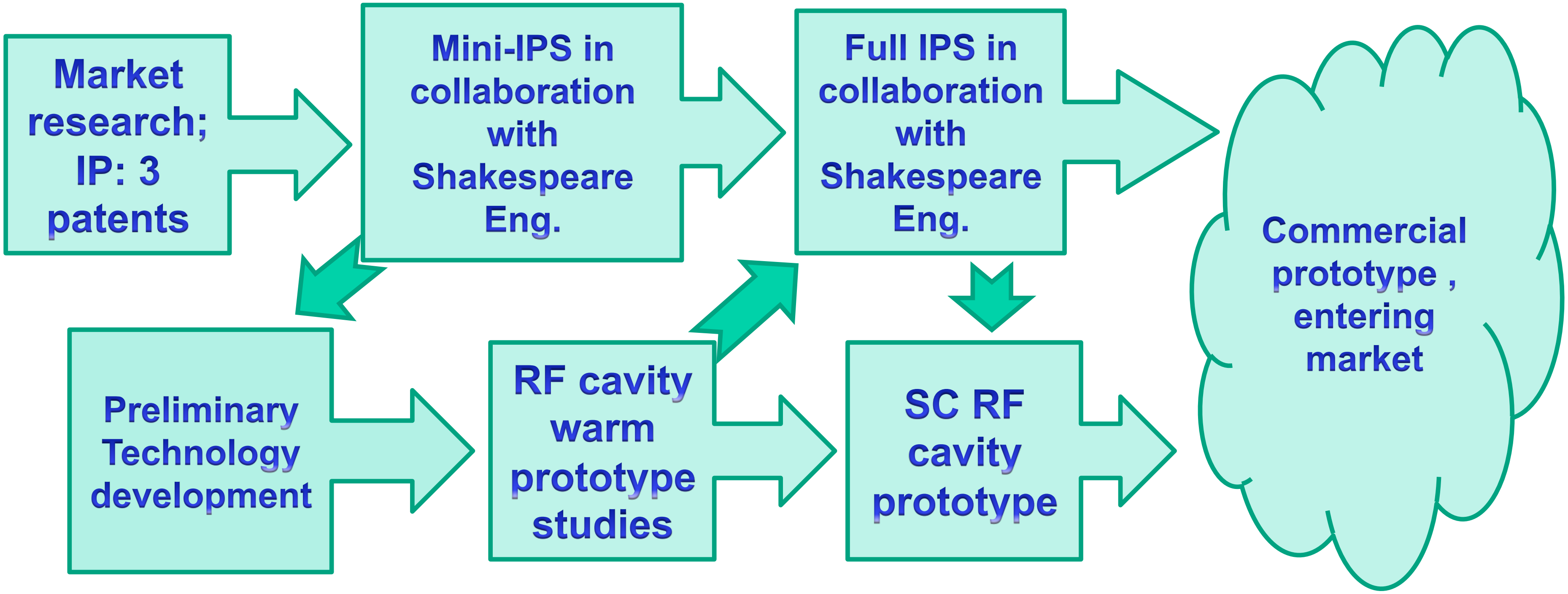
3/ Modulator - we are considering solid state power supply to drive SC RF cavities (if any available at 1.3GHz)

4/ SC RF cavity i.e. materials: pure Nb or Nitrogen doped Nb



A. Grassellino, A. Romanenko, D. Sergatskov, O. Melnychuk, Y. Trenikhina, A. Crawford, A. Rowe, M. Wong, T. Khabiboulline, F. Barkov in Supercond. Sci. Technol. 26 (2013) 102001

UH-FLUX: Asymmetric Energy Recovery Linac – Next steps



Market research; IP: 3 patents

Mini-IPS in collaboration with Shakespeare Eng.

Full IPS in collaboration with Shakespeare Eng.

Commercial prototype , entering market

Preliminary Technology development

RF cavity warm prototype studies

SC RF cavity prototype

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

High flux X-ray/THz compact SCRF Compton Light Source

-- based on novel dual cavity energy-recovery system

-- increased efficiency, much higher current, much higher flux

-- developing the detailed design

-- developing plans for realization of the prototypes of key systems

Thank you for your attention!