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Laser-acceleration of protons for the production of radioisotopes

Compact Accelerators for Isotope Production

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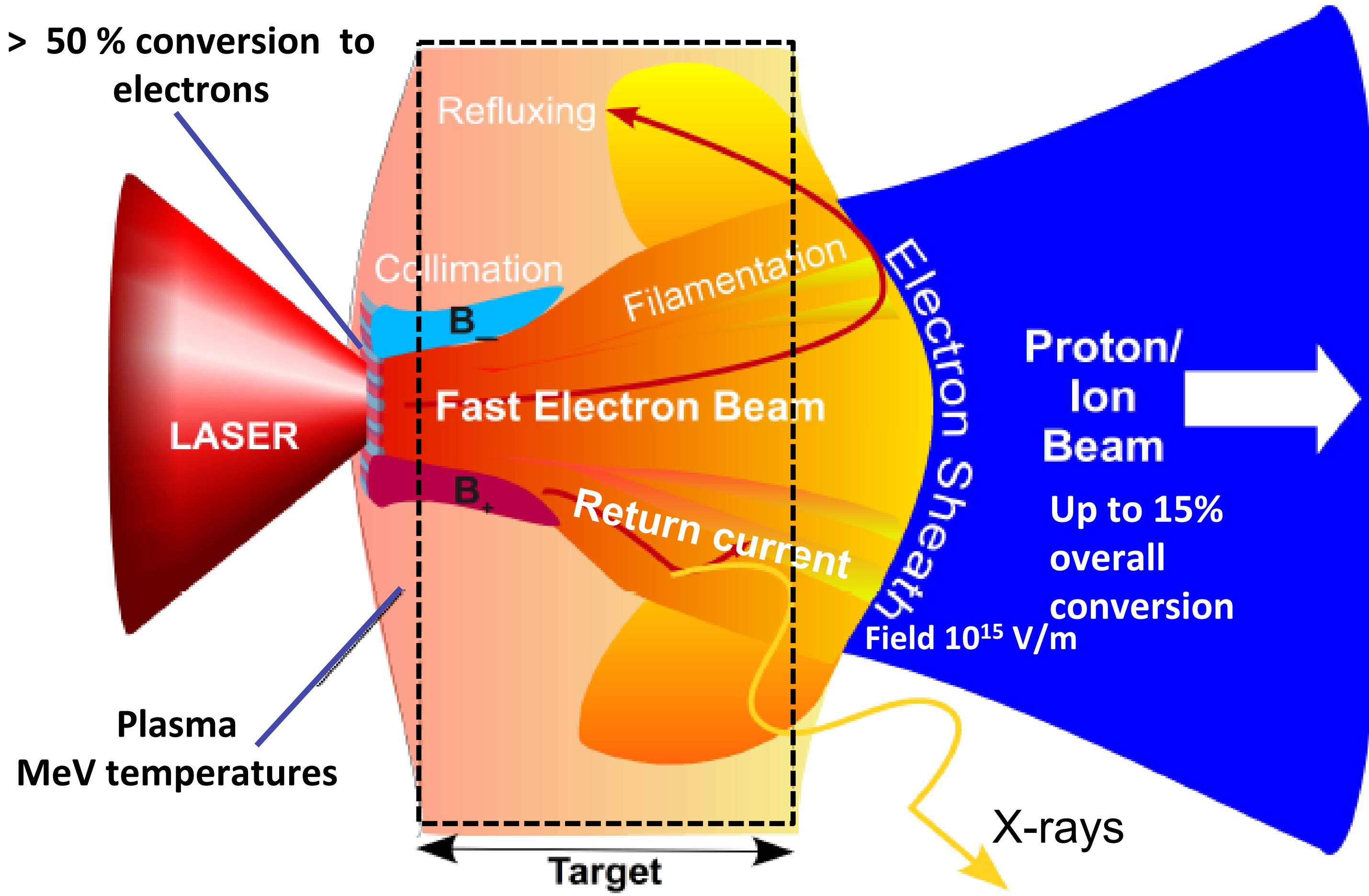
Talk Outline

- Proton acceleration through Target Normal Sheath Acceleration (TNSA)
- Prior work on radioisotope production from laser-accelerated protons
- Recent ^{99m}Tc investigations & potential issues
- Technologies required for realisation
- Future work
- Conclusions

TNSA

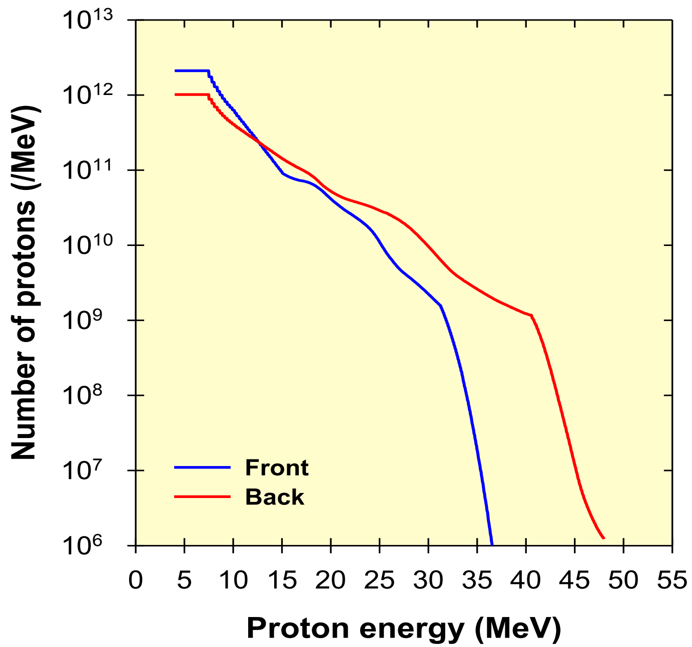


Drawing courtesy M Quinn

Goals for laser-accelerated ions

Primary research area is towards oncology:

High E – 250 MeV
Small energy spread
Low divergence
High uniformity



K. Leddingham *et al* 2004 *J. Phys. D*: Appl. Phys. 37 2341

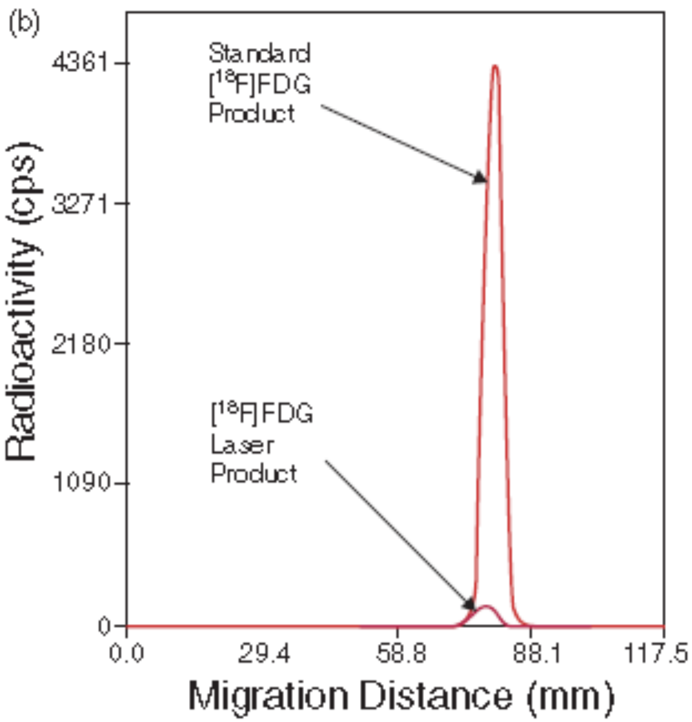
Currently achievable:

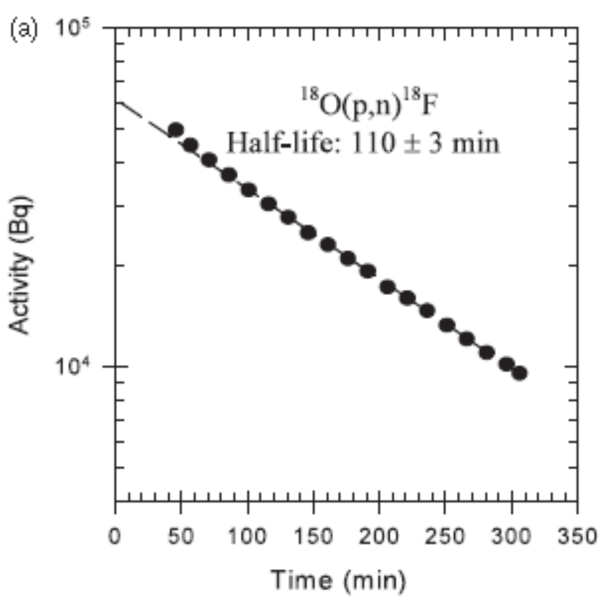
Low E – up to 60MeV
Broad energy spread
high divergence – 10's degrees
Moderate uniformity

Production of radioisotopes

Previous studies have investigated laser-accelerated protons for PET isotope production (^{11}C, ^{13}N, ^{15}O, ^{18}F)....

Several groups report calculations for patient level PET doses (GBq) which could be achieved with laser repetition rates of ~10Hz (operating at 50-100J).





K. Leddingham *et al* 2004 *J. Phys. D: Appl. Phys.* 37 2341

EXPERIMENTAL PRODUCTION OF 99M-TC

Motivation

- In early 2013 we were approached by the UK's Dept of Health (now NHS England) following OECD (Organisation for Economic Co-operation and Development) reports.
  - Could Lasers offer a potential source of radioisotopes – specifically ^{99m}Tc
  - What could the REAL deliverables be on a 5yr timescale
  - Competitiveness to alternate technologies
  - Medium / long term options

Experiment

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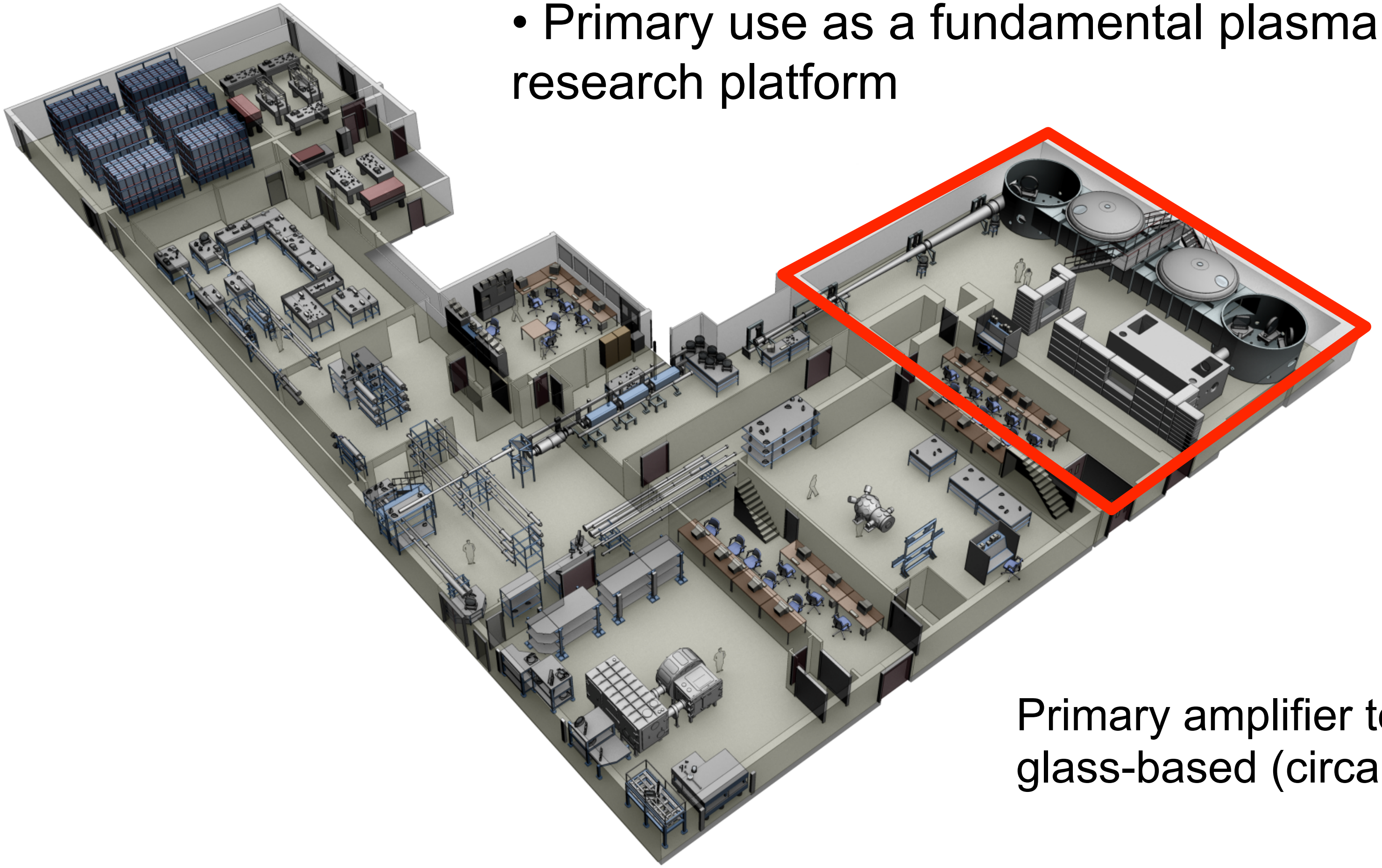
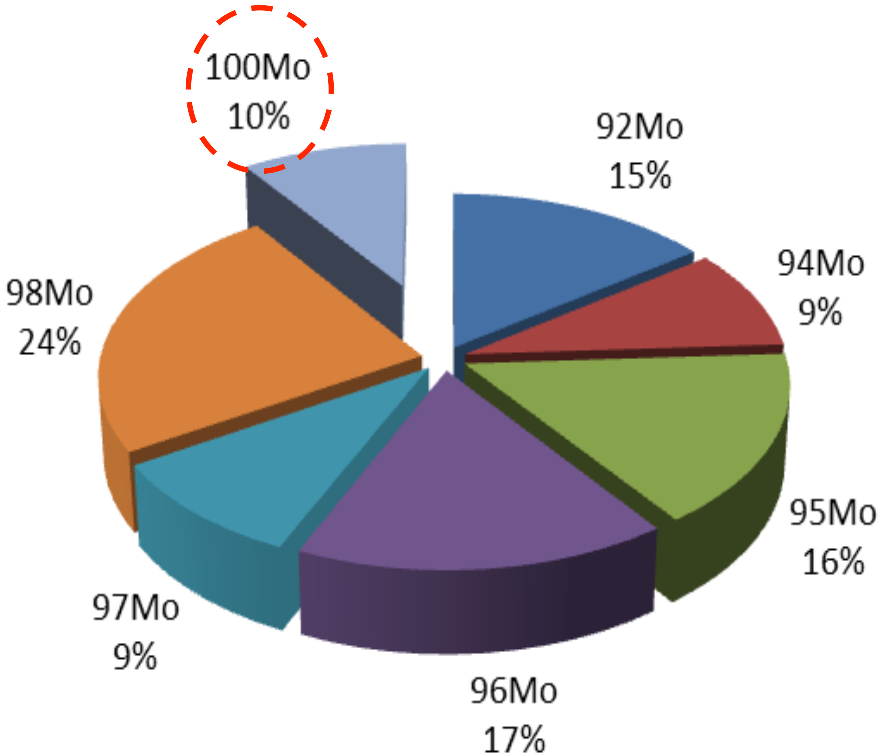
- Vulcan Petawatt beamline
- Sub-apertured to 200mm diameter
- 50J on target, 500fs pulse
- Mid 10^{20}W/cm^2
- Primary use as a fundamental plasma physics research platform



Primary amplifier technology is glass-based (circa 1976)

Laser production of ^{99m}Tc

Protons incident upon a 1mm thick ^{Nat}Mo sample 50mm from target.



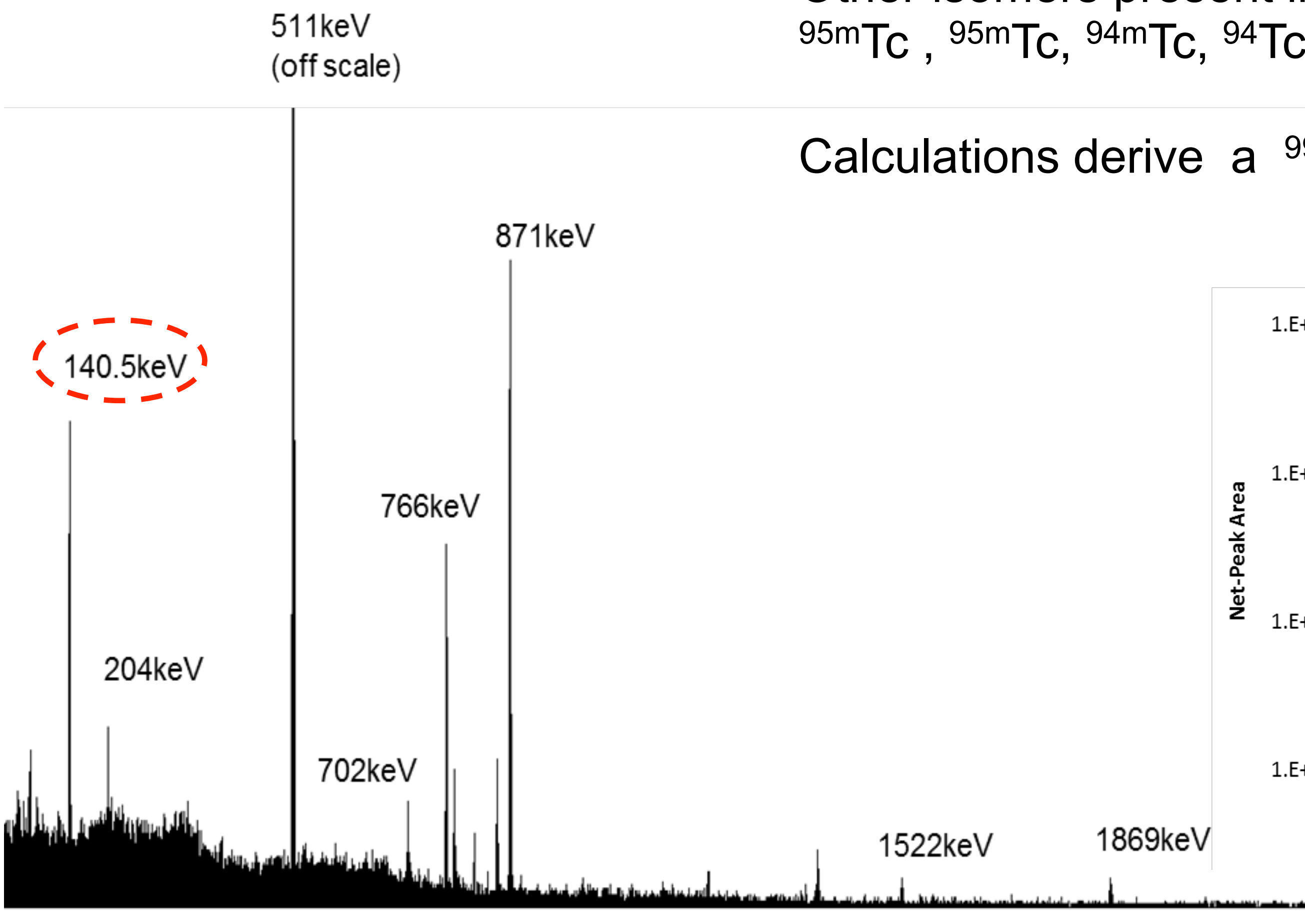
^{Nat}Mo sample extracted and measured in a Ge detector for both emission spectrum and half life

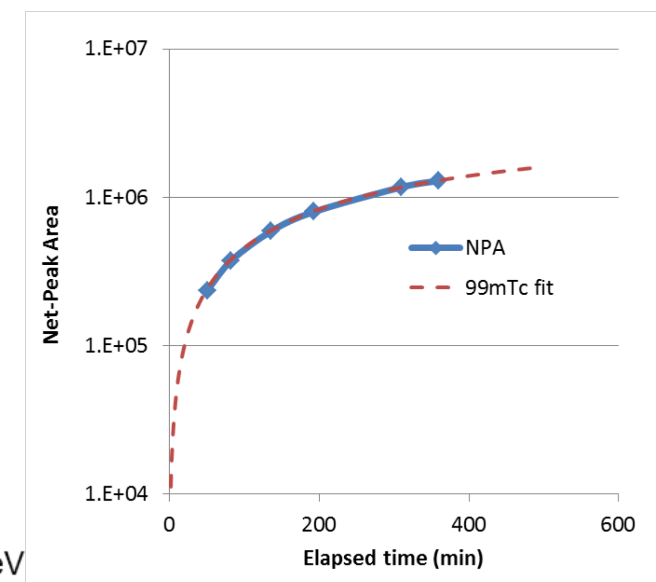
^{99m}Tc Confirmation

Clear 140keV ^{99m}Tc emission observed from the ^{100}Mo (p,2n) ^{99m}Tc reaction & excellent half-life match. *Single shot irradiation on ^{NAT}Mo.*

Other isomers present include
^{95m}Tc , ^{95m}Tc, ^{94m}Tc, ^{94}Tc, ^{96}Tc, ^{93}Tc

Calculations derive a ^{99m}Tc activity of ~ 8 kBq.





^{99m}Tc Scaling to 10 Hz

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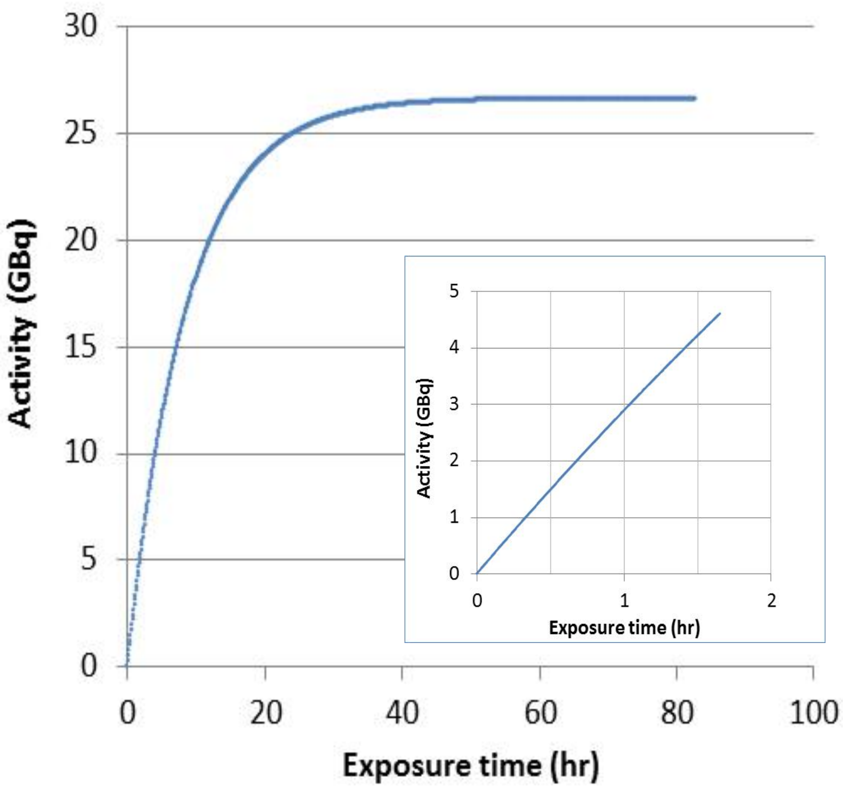


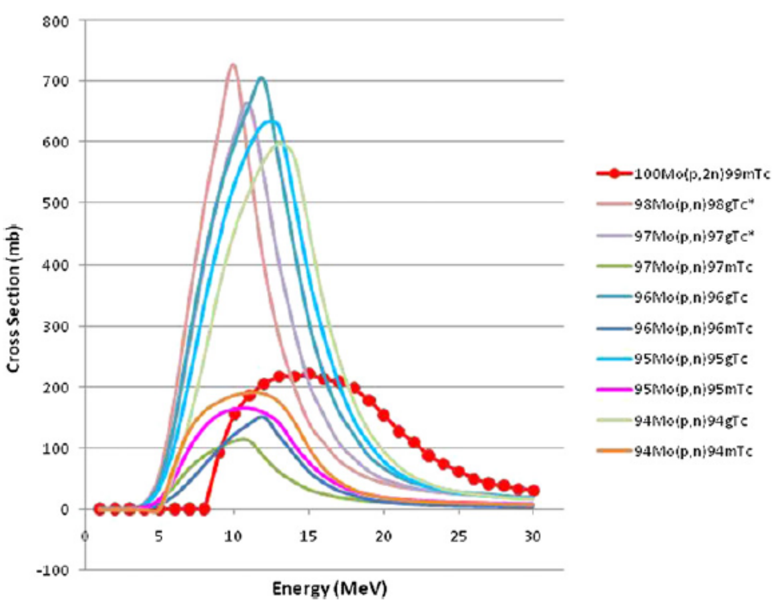
Based on a 10Hz system (technology exists now) operating at the levels produced, saturation yields of 25GBq can be achieved using ~95% enriched ^{100}Mo.

0.8GBq patient doses exceeded after <20 min exposure times.

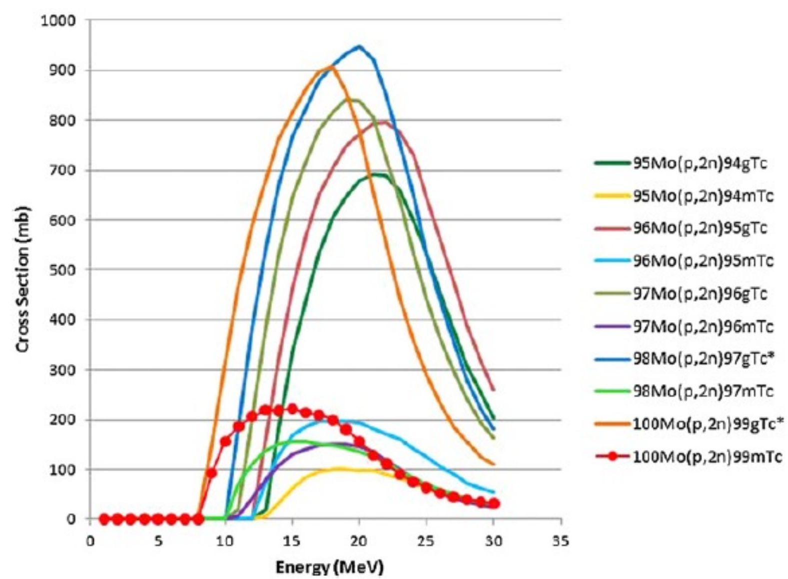
Optimisation of proton beam could improve these figures, as would an increase in rep rate or delivered energy

Contaminants

Sample enrichment, irradiation E, irradiation time, elapsed time from Irradiation all contribute to Contaminants



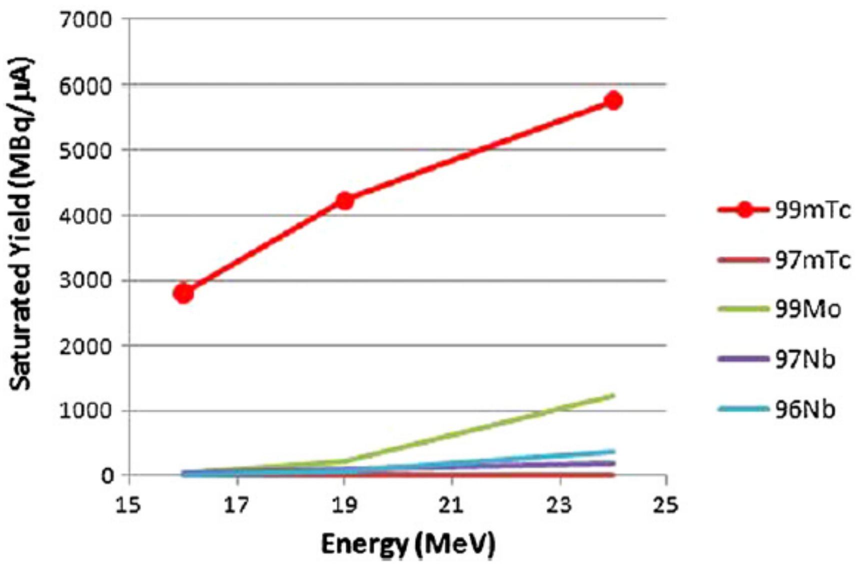
Primary (p,n) reactions



Primary (p,2n) reactions

A. Celler *et al* 2011 *Phys. Med. Biol*. **56** 5469

Overall contaminants



A. Celler *et al* 2011 *Phys. Med. Biol*. **56** 5469

For cyclotron use, 16-19MeV has been identified as the optimal energy range and has been demonstrated* with enriched targets.

How do the contaminants favour with broad-band?
Is there an acceptable ΔE ?

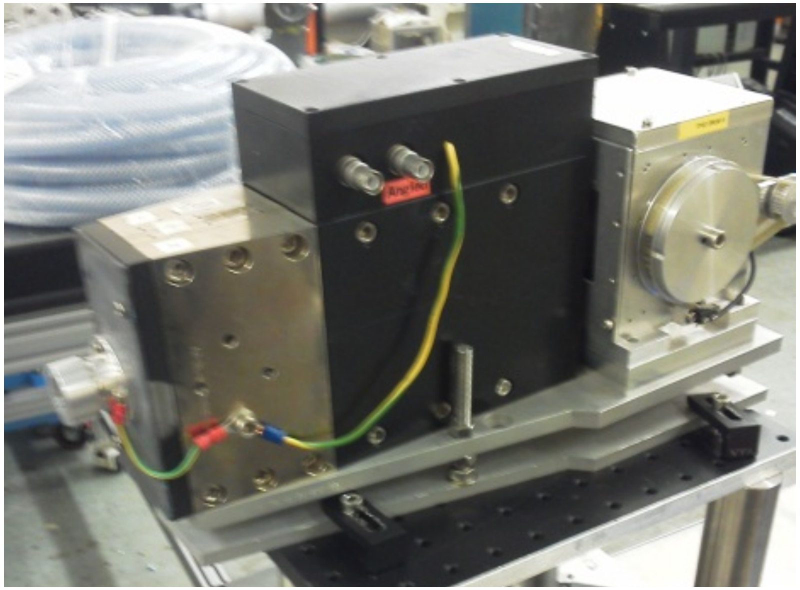
Need to look at this in more detail….

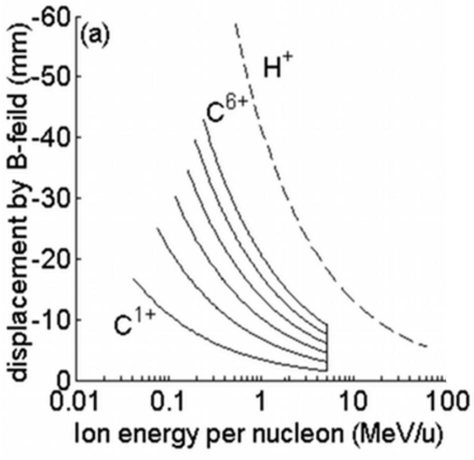
* F Benard *et al*; Implementation of Multi-Curie production of 99mTc by Conventional Medical Cyclotrons; J Nucl Med 2014; 55:1017-1022

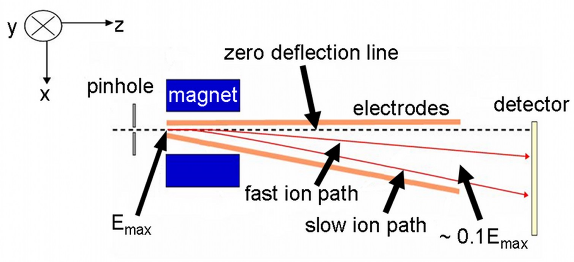
Planned measurements

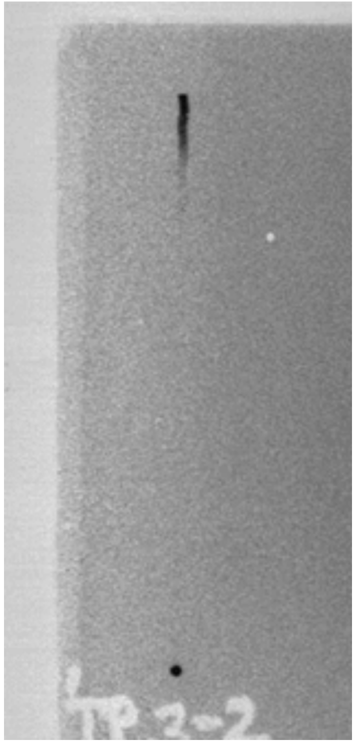
Modify existing CLF ion spectrometers with adjustable slits for energy and bandwidth selection

Can then measure the relative cross sections & generated contaminants in single shot mode as a function of E and ΔE





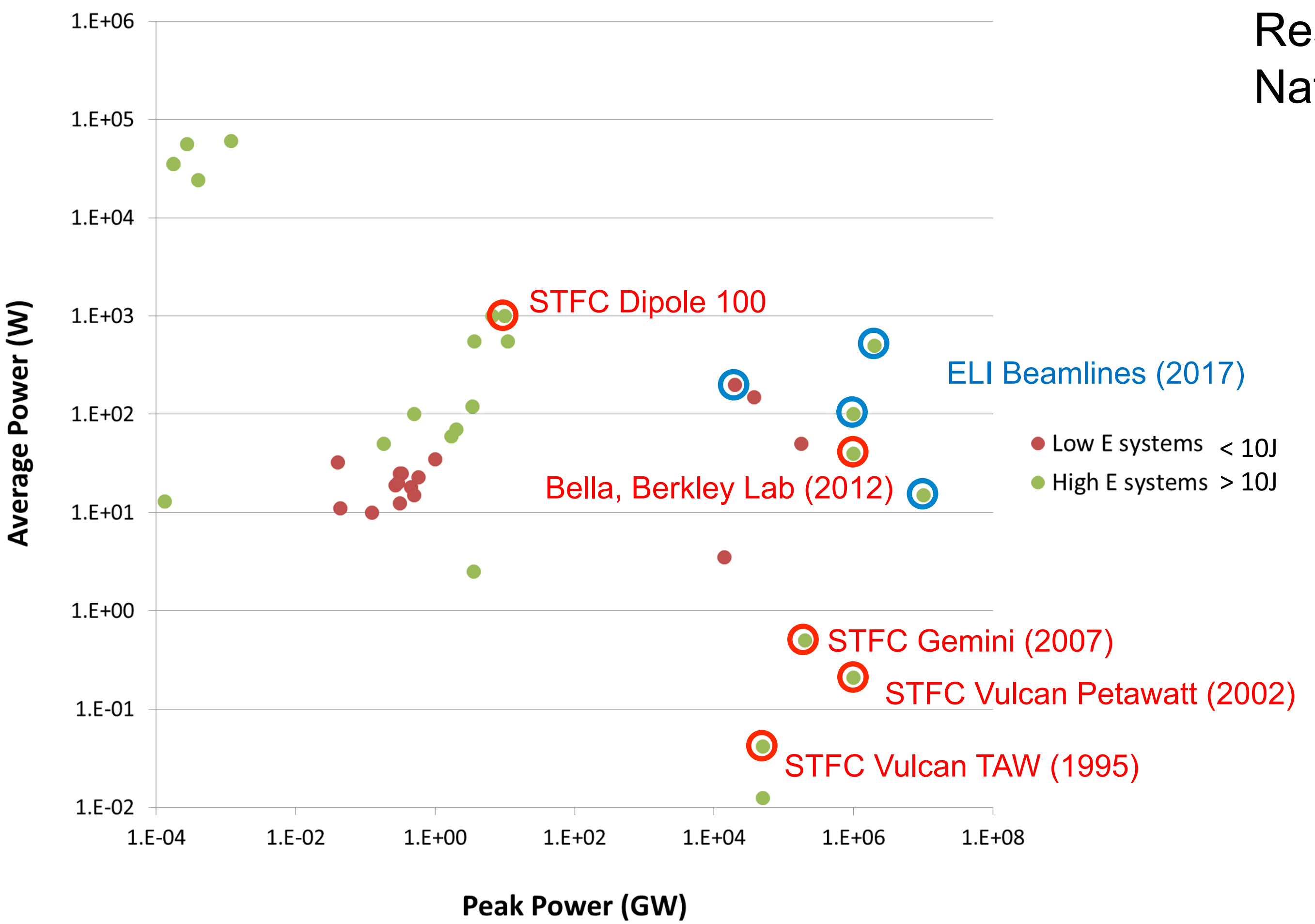




TECHNOLOGIES

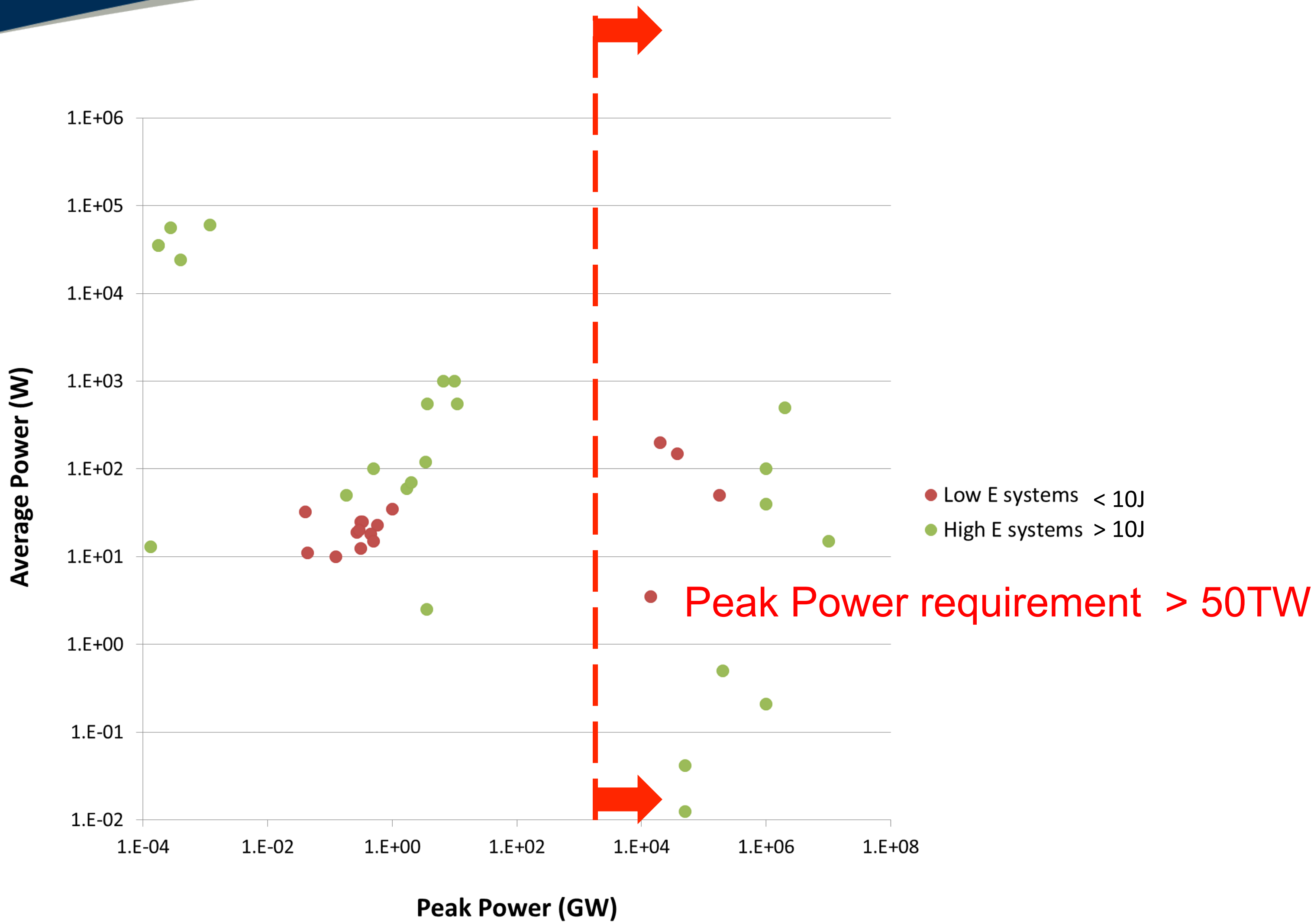
THE LASER

Existing / in-build *(relevant)* laser systems



Commercial…
Research institutes…
National Labs….

Peak Power requirements



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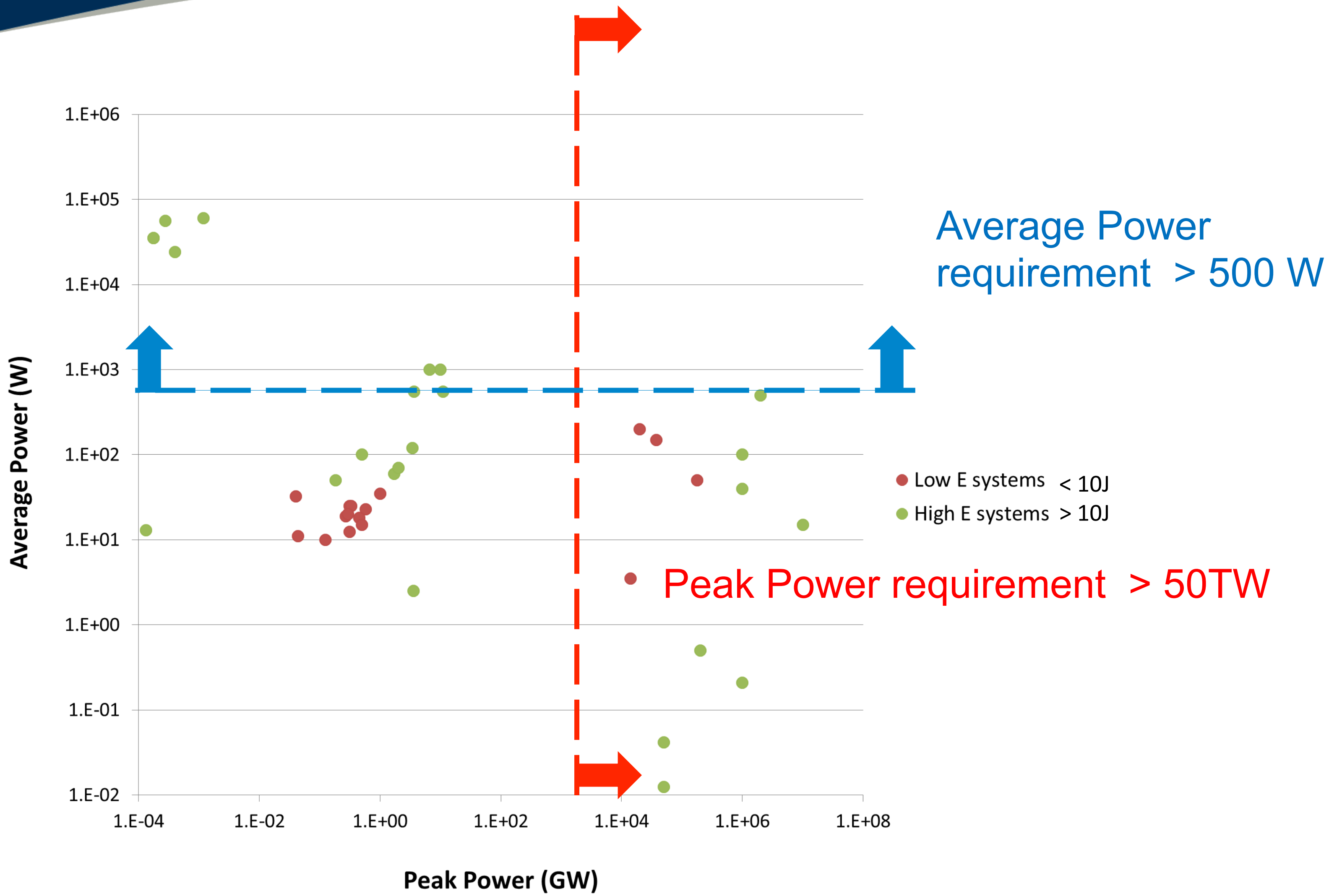
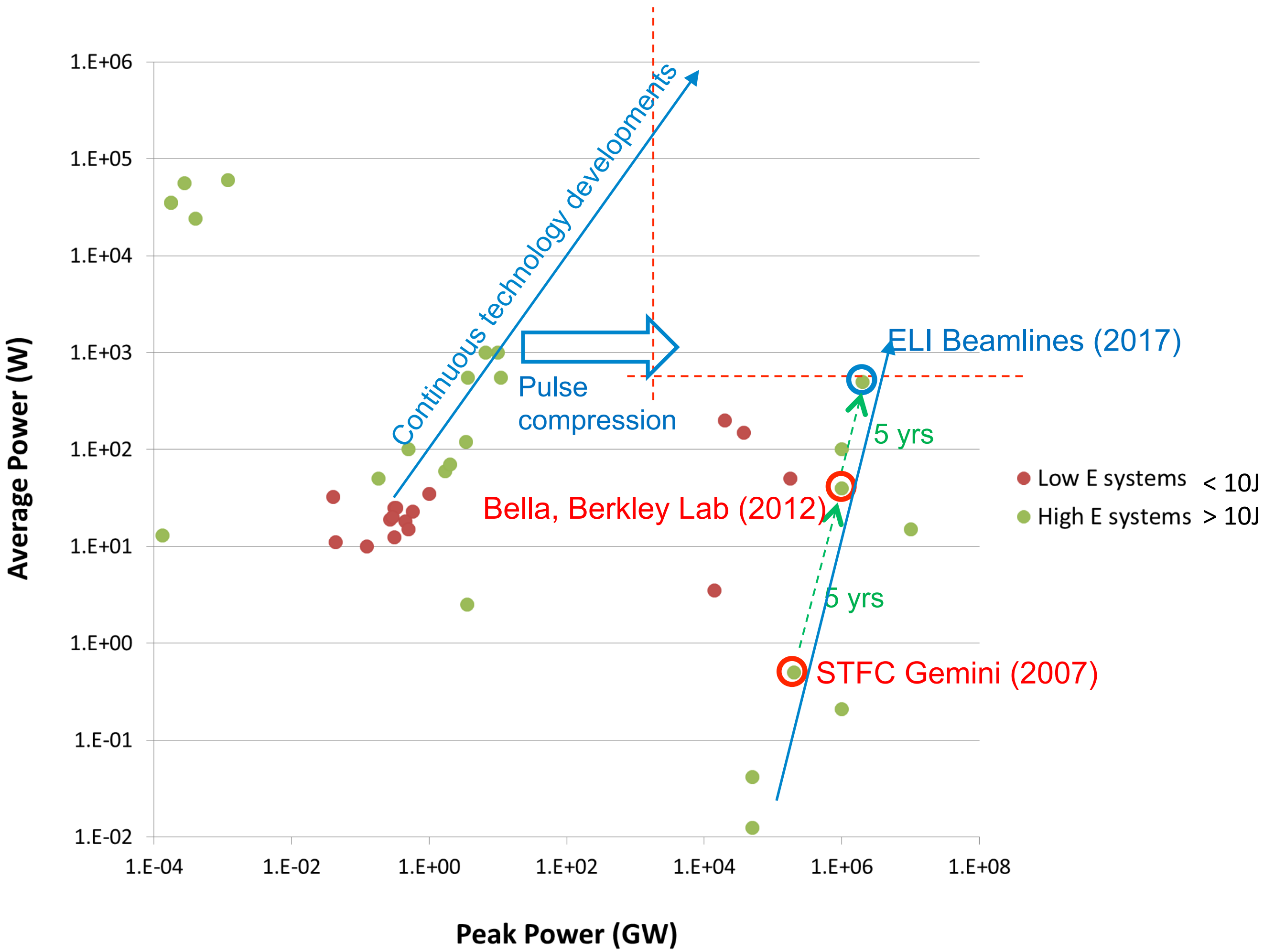
Average Power Requirements



Route forward



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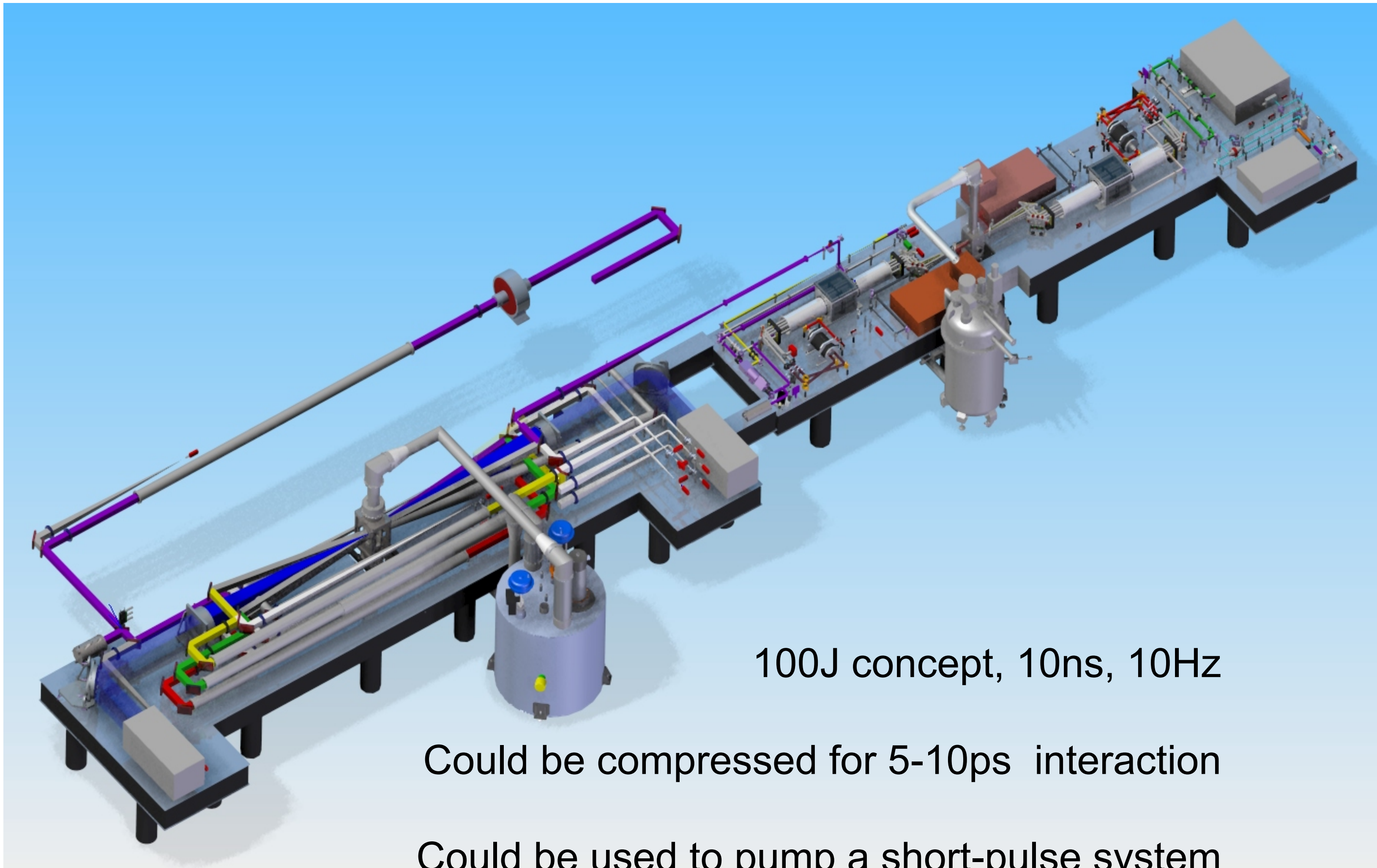
100J DiPOLE concept

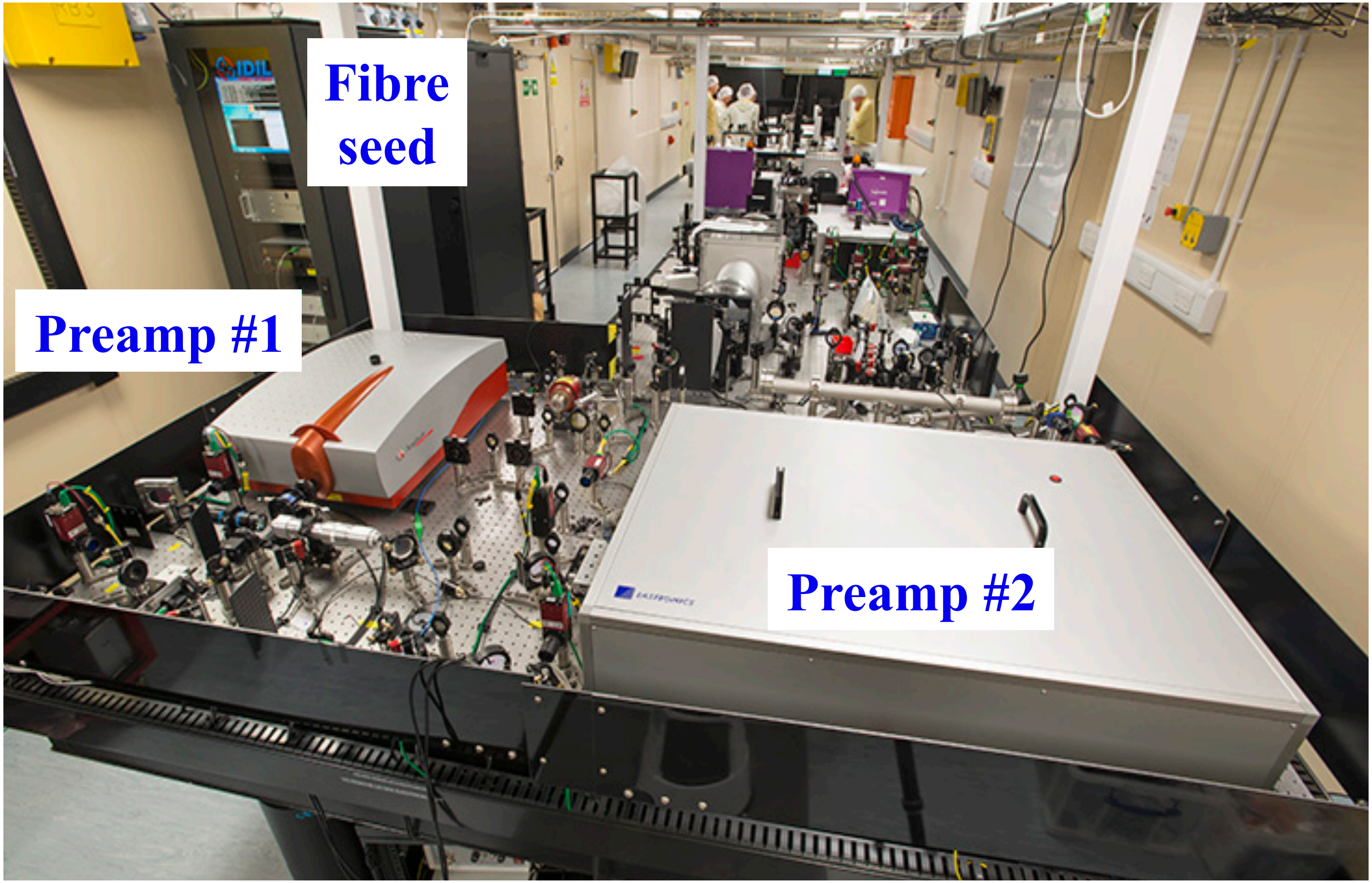


100J concept, 10ns, 10Hz

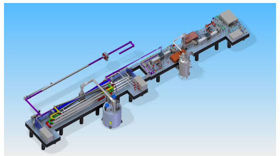
Could be compressed for 5-10ps interaction

Could be used to pump a short-pulse system

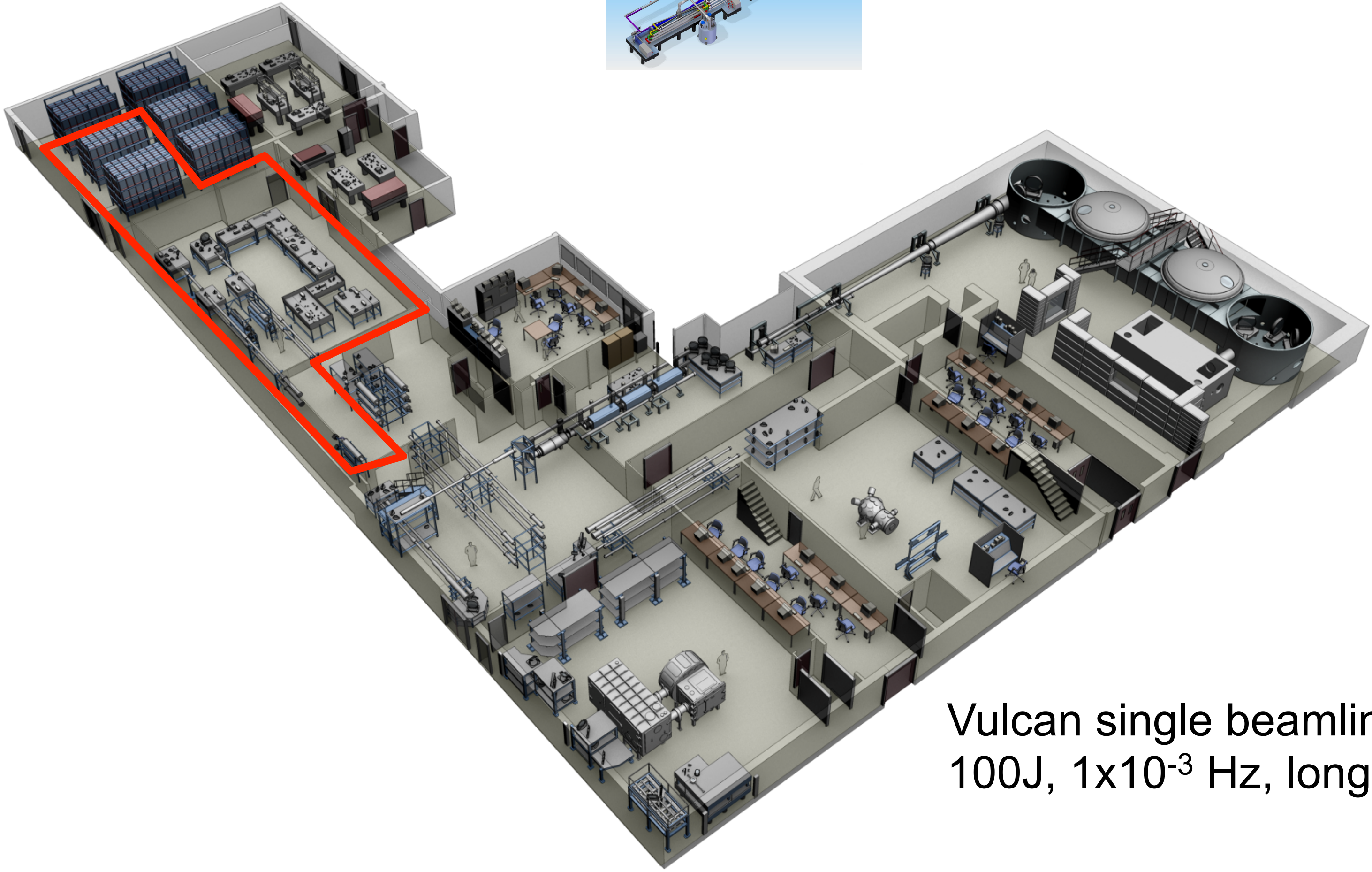
100J DiPOLE reality



"Compact" ??



DiPOLE 100
100J, 10 Hz, long-pulse



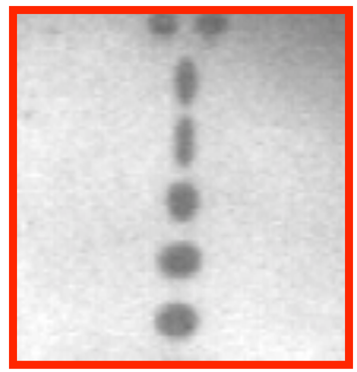
Vulcan single beamline
100J, $1x10^{-3}$ Hz, long-pulse

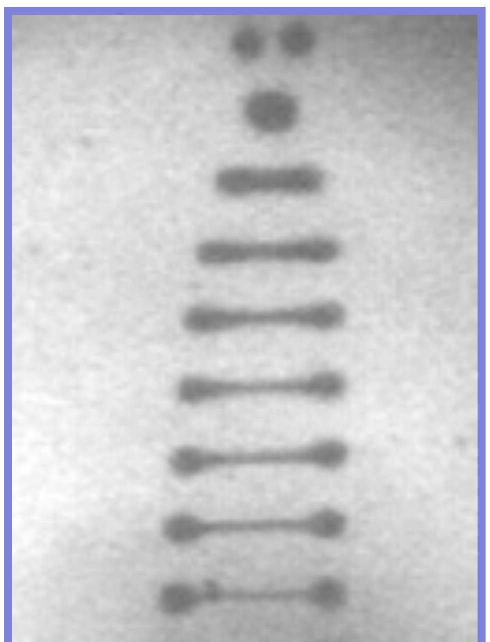
TARGETS

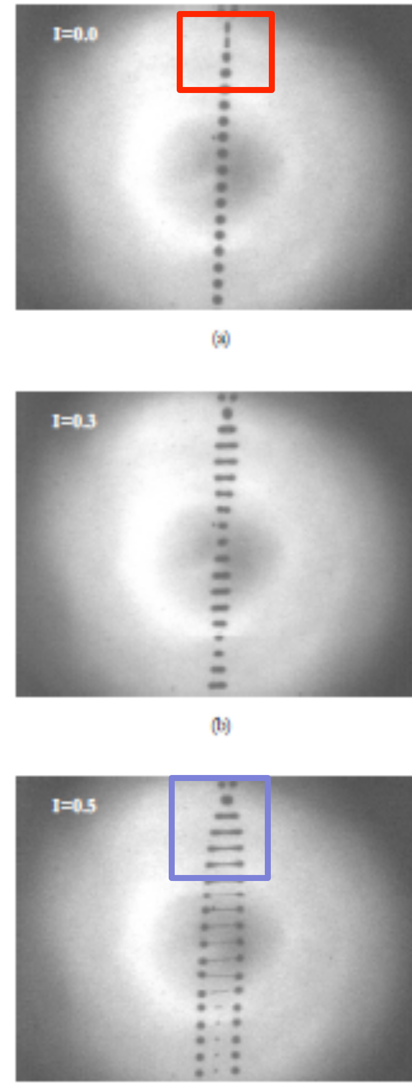
High Reteption Targetry

Tape drives not ideal

Colliding Liquid droplets show the potential to form thin targets with limited debris







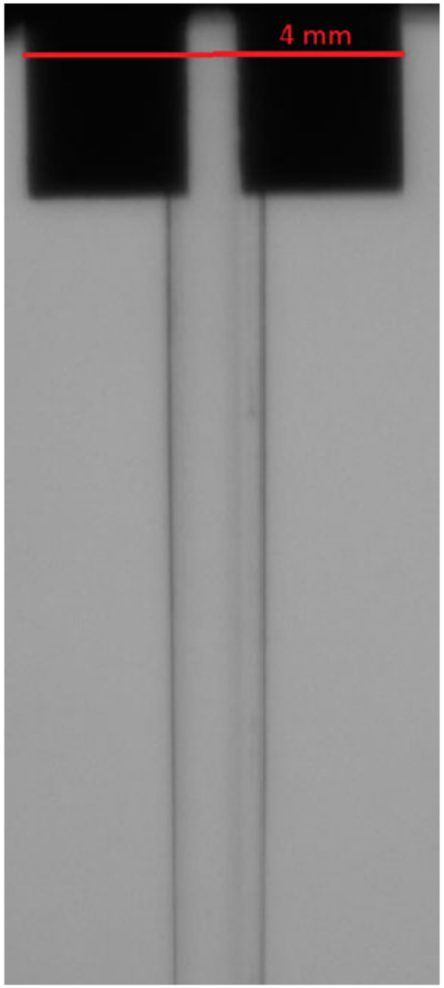
(c)

Pergamalis H 2002 PhD Thesis, Imperial College

Cryogenic Hydrogen

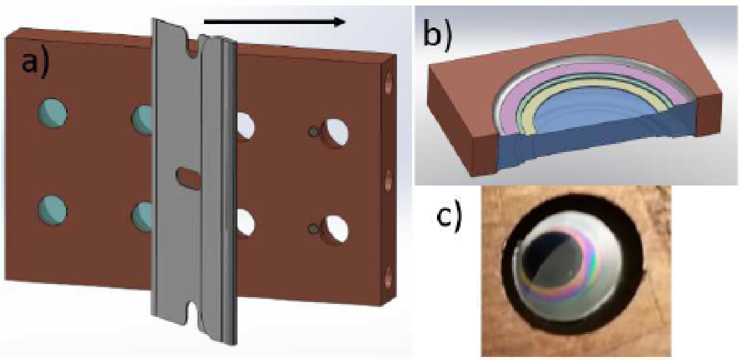
Continuously extruded Cryo H target 100μ and 50μ thick (1mm wide) extruded over 7hr period

Working towards thinner targets

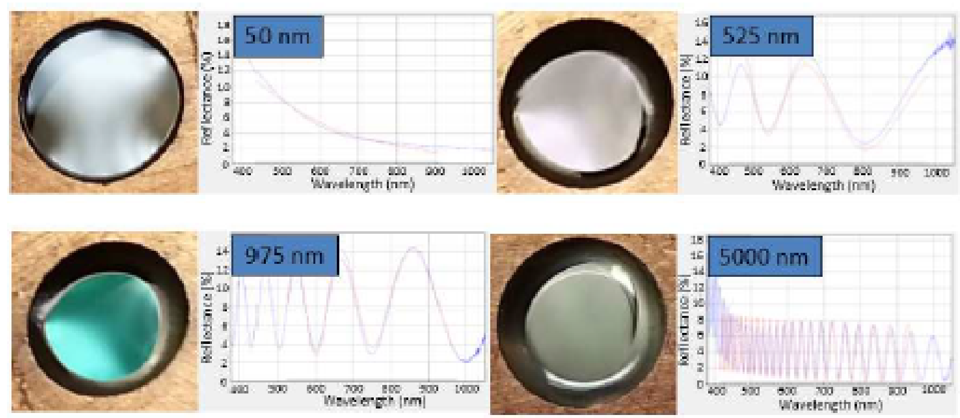


S. GARCIA, D. CHATAIN, AND J. P. PERIN
Laser and Particle Beams (2014), *32*, 569–575.

Liquid crystals



Liquid crystals laid using “wiper blade”.
Potential for high repetition rate
Very new !!



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arXiv:1405.5901v1

Next steps

- Continued technology developments

- Modelling of contaminants with broad-band source
  - Impact
  - Modified spectrum & subsequent impact?
  - *Looking for collaboration.....*

- Cross section & contaminant measurements
  - Assess single-shot flux available as function of bandwidth

Conclusions

- First demonstration of 99mTc generation from laser systems.
- Scaling to 10Hz could derive patient doses
- Contaminants are the primary issue:
  - Modelling & experimental verification required
  - Other isotopes? – ^{18}F already demonstrated
- Technologies for implementation?
  - Progressing on their own but still a few years……
  - Main issue is funding for technology developments
- Competitiveness to Cyclotrons?
  - Not yet...