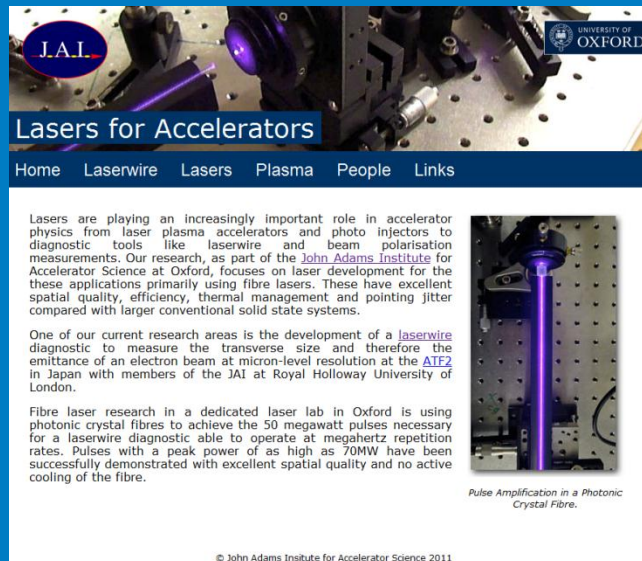


# A SAPPHiRE Laser?

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The screenshot shows the website for the Lasers for Accelerators group. At the top, there is a navigation bar with the following links: Home, Laserwire, Lasers, Plasma, People, and Links. The main content area features a paragraph of text about the group's research, a sub-section on laserwire diagnostics, and a sub-section on fibre laser research. To the right of the text is a photograph of a laser setup with a vertical purple beam. The website footer includes the copyright notice: © John Adams Institute for Accelerator Science 2011.

**Lasers for Accelerators**

Home Laserwire Lasers Plasma People Links

Lasers are playing an increasingly important role in accelerator physics from laser plasma accelerators and photo injectors to diagnostic tools like laserwire and beam polarisation measurements. Our research, as part of the [John Adams Institute for Accelerator Science](#) at Oxford, focuses on laser development for these applications primarily using fibre lasers. These have excellent spatial quality, efficiency, thermal management and pointing jitter compared with larger conventional solid state systems.

One of our current research areas is the development of a [laserwire](#) diagnostic to measure the transverse size and therefore the emittance of an electron beam at micron-level resolution at the [ATF2](#) in Japan with members of the JAI at Royal Holloway University of London.

Fibre laser research in a dedicated laser lab in Oxford is using photonic crystal fibres to achieve the 50 megawatt pulses necessary for a laserwire diagnostic able to operate at megahertz repetition rates. Pulses with a peak power of as high as 70MW have been successfully demonstrated with excellent spatial quality and no active cooling of the fibre.

*Pulse Amplification in a Photonic Crystal Fibre.*

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# Outline and introduction

- Examine baseline laser specifications and assess possibility of such a system.
- Are any of these specifications flexible?
- Options for reusing laser energy –
  - Enhancement cavity
  - Recirculation cavity
- Future laser developments.
- Necessarily brief, very general overview. No detailed designs etc.



# SAPPHiRE: a small $\gamma\gamma$ Higgs factory

<http://arxiv.org/abs/1208.2827>

- $\gamma\gamma$  collider to act as a Higgs factory – high energy  $\gamma$ s created by Compton scattering of laser from 80GeV  $e^-$ .
- Laser specifications from paper:
  - 5J
  - 200kHz
  - 5ps ( $\sigma$  – 8.5ps FWHM)
  - 351nm
- Assume 50% THG conversion efficiency<sup>1</sup> so 10J @  $\lambda \sim 1\mu\text{m}$ , 200kHz, 5ps.
- Total power = 10J \* 200kHz = 2MW.
- Wall plug efficiency between 0.1 – 1% - electricity requirements 200MW – 2GW.
- X 2 for two laser systems.....
- No such MW average power laser. Then huge electricity requirements and complex cooling systems.

<sup>1</sup> conservative – can be 80% Opt. Comms. 34, 469 (1980)



# Flexibility – what laser parameters can be changed?

- Brute force approach looks unlikely – any flexibility in specification?
- $\lambda$  – driven by cm  $\gamma$  energy and 80GeV  $e^-$  - not much room here.
  - But consider increasing  $e^-$  energy to **81.7GeV**?
  - For  $\gamma = 65\text{GeV}$ ,  $E_1 = 3.11\text{eV}$ ,  $\lambda = 400\text{nm}$ .
  - SH of Ti:sapp at 800nm, one fewer conversion step, better efficiency.
- **Repetition rate** – determined by luminosity requirements.
  - But could redistribute in bunch trains rather than quasi-cw?
- **Energy** – required for efficient conversion to  $\gamma$ .
  - Recirculate one pulse?
- **Pulse duration** – for head on collision no tight requirement, but needs to be  $\sim e^-$  duration in laser focus for best efficiency.

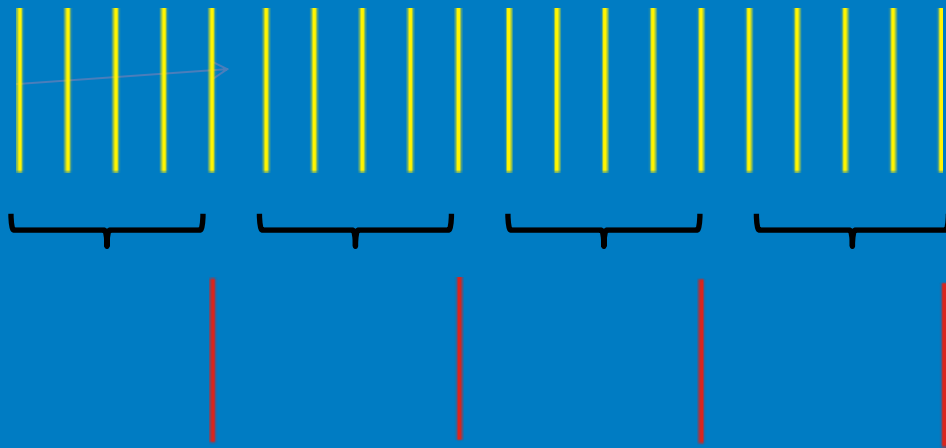


# Reusing laser energy – enhancement cavities

- Most basic implementation of optical storage cavity:
- Pulses injected into cavity through mirror, cavity round trip time laser rep rate.
- Energy stored inside cavity to interact once with  $e^-$  beam (stack and dump).
- Redistributes energy of laser in time.

High rep. rate, low energy laser

Enhancement cavity stacks multiple pulses temporally



Large laser pulse interacts with  $e^-$  bunch

- Most simple implementation does not reduce average power requirement.
- But if pulse recirculated as well can reduce this.
- Issues: injection and build up time, difficulty of injecting 5J pulse through an optic, mode & impedance matching, dispersion for ultrashort pulses.



# Reusing laser energy – recirculating cavity

- Define this as different to enhancement cavity as multiple laser pulses not stacked on top of each other in time.
- Laser pulse injected into cavity directly (not through cavity optic), recirculates around cavity and interacts with  $e^-$  beam multiple times.
- Why possible?
  - $10^{10} e^-$ , 5J @ 351nm  $\sim 10^{19}$  photons – interaction nearly transparent to laser beam.



# Recirculating cavity – practical?

- Assume can make 5J, 5ps pulse at 351nm.
- Is a recirculation cavity possible?
- Ignoring injection, dispersion, simple feasibility analysis.
- Proposed cavities for TESLA<sup>1</sup>/ILC<sup>2</sup> ~ 100m in length (can this be stabilised?)
- Use 150m length, 10 roundtrips between e<sup>-</sup> bunches (per SAPHHiRE paper).
- For different mirror R, how much light reaches CP 2<sup>nd</sup> time, 10 roundtrips?

<sup>1</sup>NIM A 472, 79 (2001)  
<sup>2</sup>NIM A 564, 212 (2006)

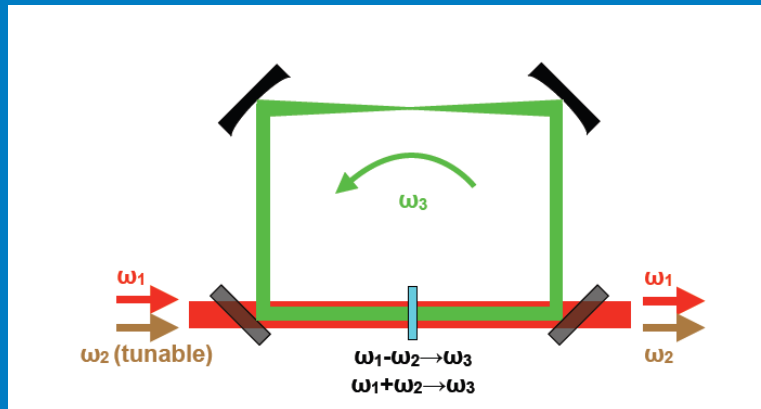
Individual mirror R	2 interactions 8 mirror cavity	2 interactions 4 mirror cavity
99.99%	0.992	0.996
99.9%	0.923	0.961
99.5%	0.670	0.818
99%	0.488	0.669

- If source 10J, 10Hz each pulse has to make 20,000 interactions, 200,000 roundtrips.
- Not possible – no light left –  $0.9999^{(8 * 200,000)} = 0$ .



# Possible cavity designs

- Issue – how to inject light into cavity if not through optic? Not trivial problem for this pulse energy/duration.
- One suggested solution – RING (recirculation injection by nonlinear gating).
- Proposed by LLNL group as method of injecting high energy pulses into cavity.
- Input/outcoupling optics transparent at  $\omega$ ,  $2\omega$ , TH crystal inside cavity, mirrors reflective at  $3\omega$  which is trapped,  $\omega$ ,  $2\omega$  dumped.



Jovanovic et. al., NIM A 578, 160 (2007)  
Shverdin et. al., OL 35, 2224 (2010)

- Suggested in 2<sup>nd</sup> ref. scalable to 100J, 10ps pulses for large enough optics & nonlinear crystal.

Pros: no switching components, traps TH automatically.

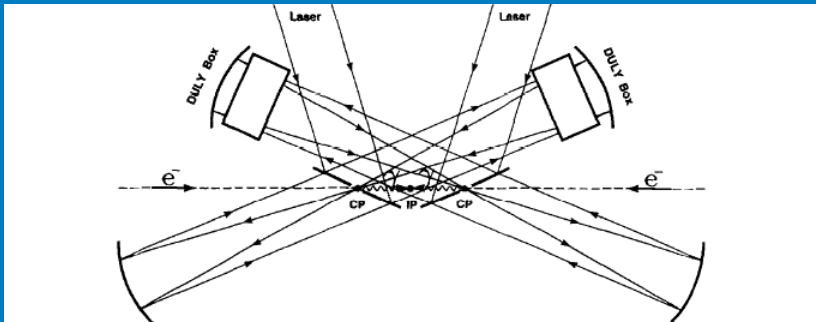
Cons: additional loss in cavity, pulse stretching, crystal damage (optical/radiation).





# Possible cavity designs

- Want to avoid active switch (Pockels cell, moveable mirror) if possible.
- Another solution is to use mirrors with holes.



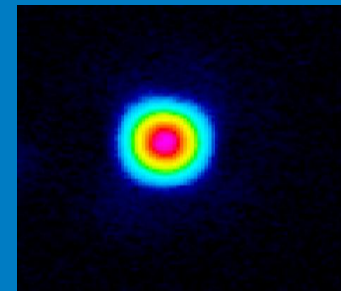
Interesting design by Chen et. al.,  
NIM A 355, 130 (1995)

- More exciting ideas being developed all the time – can we use unusual optics?
- Use of chlosteric liquid crystal as input mirror proposed and demonstrated at low energy – Hao et. al. OL 35, 1361 (2010).
- LC transmits left hand circularly polarised light, reflects right hand, so after odd number of reflections in cavity from normal mirror input pulse is trapped.



# Possible solutions?

- Issues – average power, rep. rate, pulse energy, possibly pulse duration, efficiency.
- Laser development – rapid progress in solid state and fibre laser technologies.
- One possible approach – harness high efficiency, high average power fibres to make high rep. rate, high peak power fibre lasers by combining smaller systems.
  - Fibre advantages: beam quality, thermal management, extremely efficient (> 80% optical-to-optical), high rep. rates, small, diode pumped.
- **ICAN – International Coherent Amplification Network:** European network aimed at exactly the specs required for  $\gamma$  collider.
- Aim: demonstration module
  - ~ 30J
  - >10kHz
  - few 100fs
  - 1 $\mu$ m
  - > 10% wall plug efficiency (ideally more)

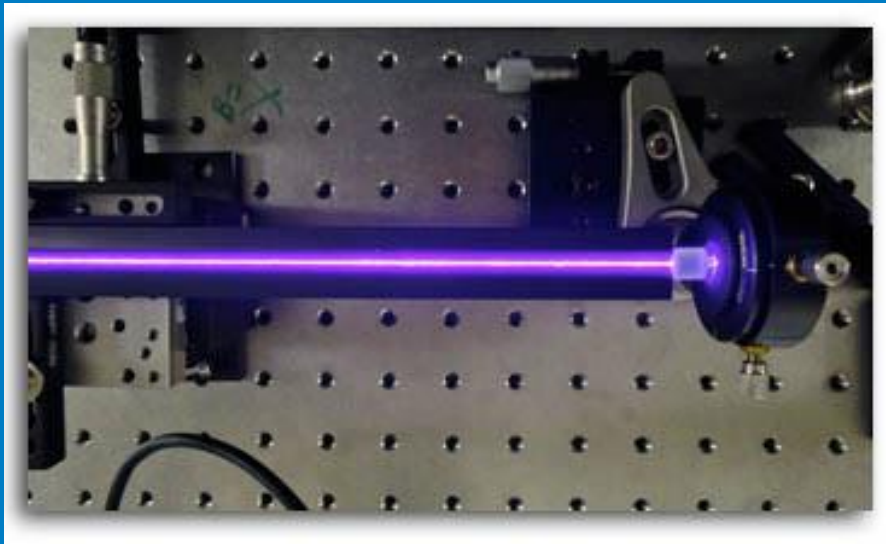


Amplified output in photonic crystal fibre



# Fibre laser based recirculating cavity for SAPHHiRE?

- ICAN based fibre laser – 10J, 20kHz, 300fs – 5ps
- Each pulse undergoes 10 interactions with  $e^-$  bunch i.e. 100 roundtrips.
- 8 mirror cavity – 99.99% mirrors final energy =  $0.923^*$  input.
- 8 mirror cavity – 99.9% mirrors final energy =  $0.450^*$  input.



Will the lasers for  $\gamma$  colliders  
look like this in the future?



# General considerations for laser/cavity

- **Pulse duration?**
  - Laser pulse  $\sigma$  5ps  $\gg$   $e^-$  100fs.
  - Nominally for head on collision not an issue but laser is focused.
  - FWHM laser = 8.5ps: 2.6mm.
  - $z_R$  for  $w_0 = 5.6\text{mm}$  is  $280\mu\text{m}$  i.e.  $2z_R$  (collimation length) = 0.56mm.
  - $2z_R <$  pulse extent: at FWHM points  $w = 4.7w_0$  i.e. area increase factor 22.
  - Need to consider effect on conversion efficiency.
  - Advantage of relatively long laser pulse is stability against temporal jitter.
- **Potentially huge size of mirrors** – proposed  $\sim 100\text{m}$  TESLA/ILC cavities have 120cm mirrors – heavy, expensive, moveable for stabilisation and alignment?
- **Optical/radiation damage** to mirrors, TH crystal for RING.
- Laser wall plug **efficiency** and **cooling** requirements.
- **Laser polarisation** – frequency conversion requires linear polarisation. If circular is required need something like large high damage threshold  $\lambda/4$  plate.

