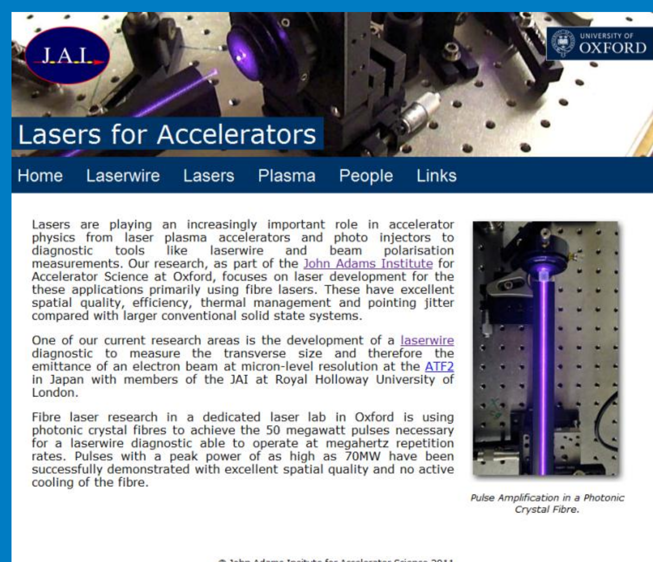
A SAPPHiRE Laser?

Laura Corner

Lasers for Accelerators group (L4A)
John Adams Institute for Accelerator Science, Oxford University, UK



SAPPHiRE workshop, CERN 19th Feb 2013

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 γγ Higgs factory
http://arxiv.org/abs/1208.2827

- γγ collider to act as a Higgs factory – high energy γs created by Compton scattering of laser from 80GeV e^-.
- Laser specifications from paper:
  - 5J
  - 200kHz
  - 5ps (σ – 8.5ps FWHM)
  - 351nm

- Assume 50% THG conversion efficiency[1] so 10J @ λ ~ 1um, 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.

[1] 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?

- λ – driven by cm γ energy and 80GeV e^- - not much room here.
  - But consider increasing e^- energy to 81.7GeV?
  - For γ = 65GeV, E_l = 3.11eV, λ = 400nm.
  - SH of Ti:sapp at 800nm, one fewer conversion step, better efficiency.

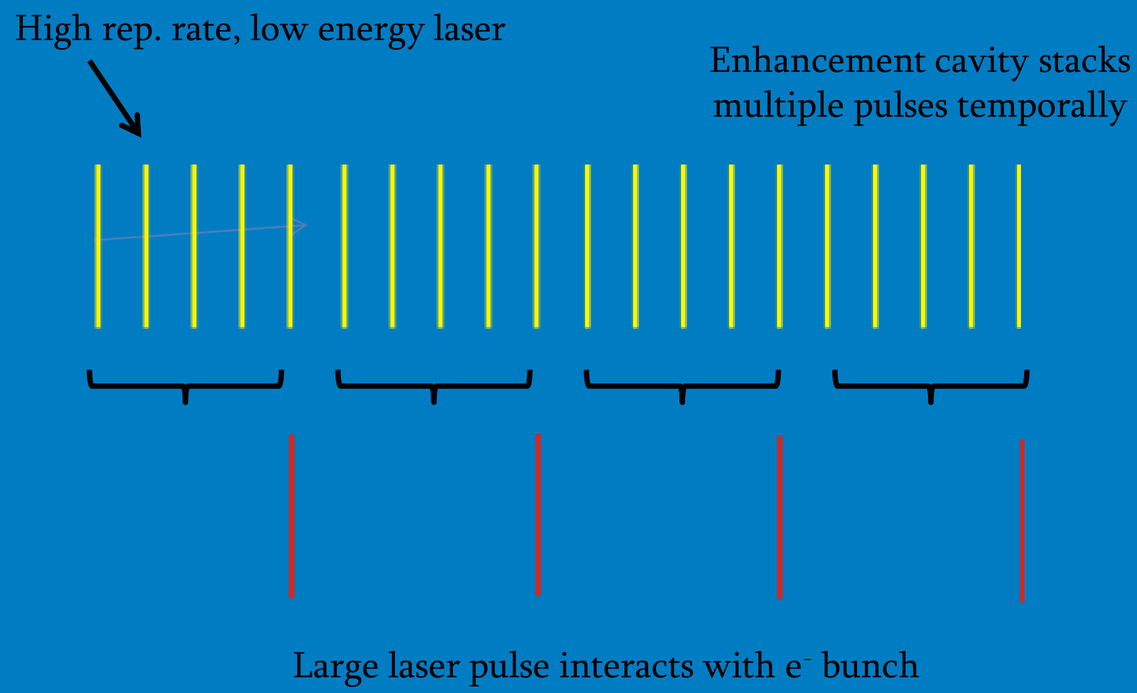
- Repetition rate – determined by luminosity requirements.
  - But could redistribute in bunch trains rather than quasi-cw?

- Energy – required for efficient conversion to γ.
  - Recirculate one pulse?

- Pulse duration – for head on collision no tight requirement, but needs to be ~ 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.



- 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 ~ 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[1]/ILC[2] ~ 100m in length (can this be stabilised?)
- Use 150m length, 10 roundtrips between e^- bunches (per SAPHHiRE paper).
- For different mirror R, how much light reaches CP 2nd time, 10 roundtrips?

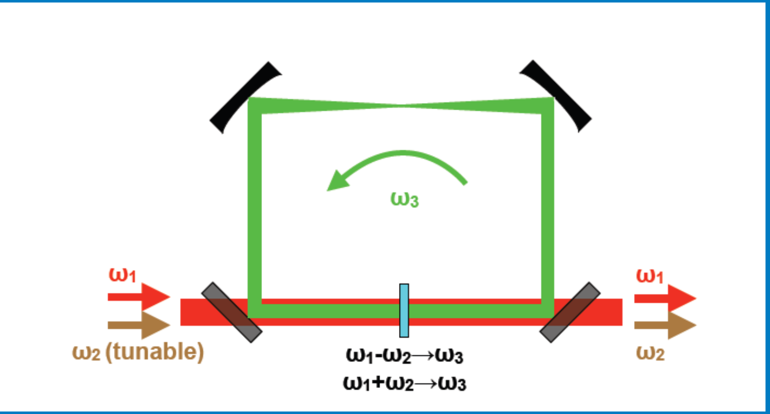
[1]NIM A 472, 79 (2001)
[2]NIM A 564, 212 (2006)

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 – $0.9999 \wedge (8 * 200,000) = 0$.

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 ω, 2ω, TH crystal inside cavity, mirrors reflective at 3ω which is trapped, ω, 2ω dumped.



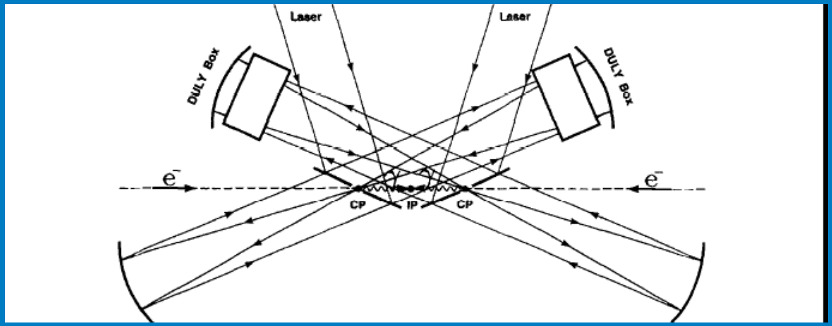
Jovanovic et. al., NIM A 578, 160 (2007)
Shverdin et. al., OL 35, 2224 (2010)

- Suggested in 2nd 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.

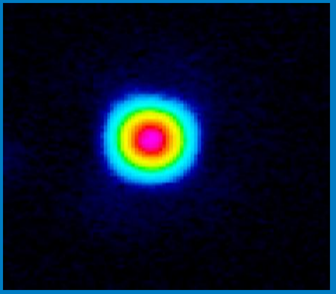
Possible solutions?

- 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 γ collider.

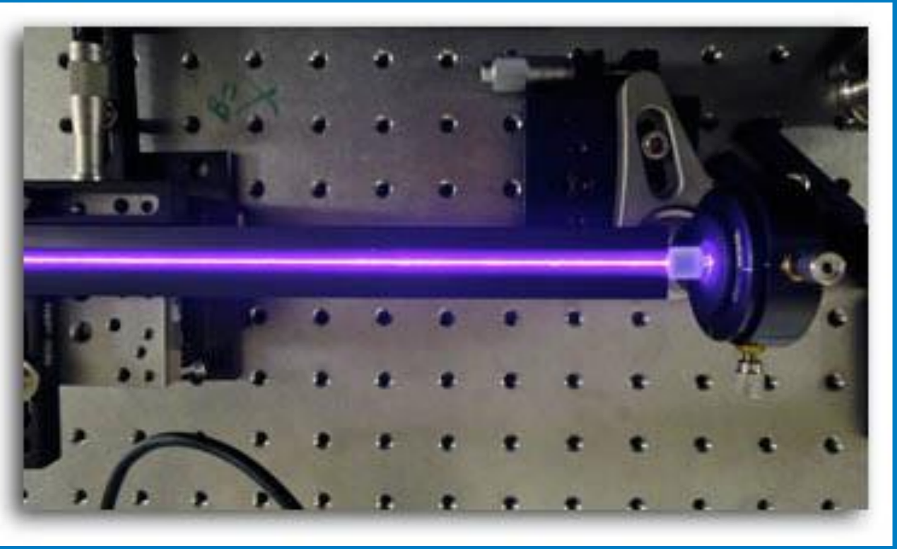
- Aim: demonstration module
  - ~ 30J
  - >10kHz
  - few 100fs
  - 1μm
  - > 10% wall plug efficiency (ideally more)



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 γ colliders look like this in the future?

General considerations for laser/cavity

- Pulse duration?
  - Laser pulse σ 5ps >> e^- 100fs.
  - Nominally for head on collision not an issue but laser is focused.
  - FWHM laser = 8.5ps: 2.6mm.
  - z_R for w_o = 5.6mm is 280μm i.e. $2z_R$ (collimation length) = 0.56mm.
  - $2z_R$ < pulse extent: at FWHM points w = 4.7w_o 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 ~ 100m 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.