Fibre lasers for gamma-gamma colliders

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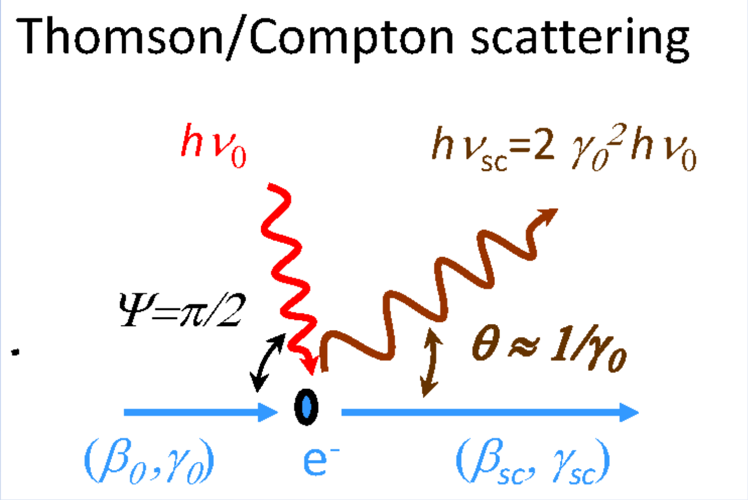
Outline

- Interest in Higgs physics – Higgs factories.
- Compton scattering and γ collider advantages.
- Proposed facilities.
- Laser requirements.
- Potential technology.
- Fibre laser systems.
- Frequency conversion.

Higgs factories

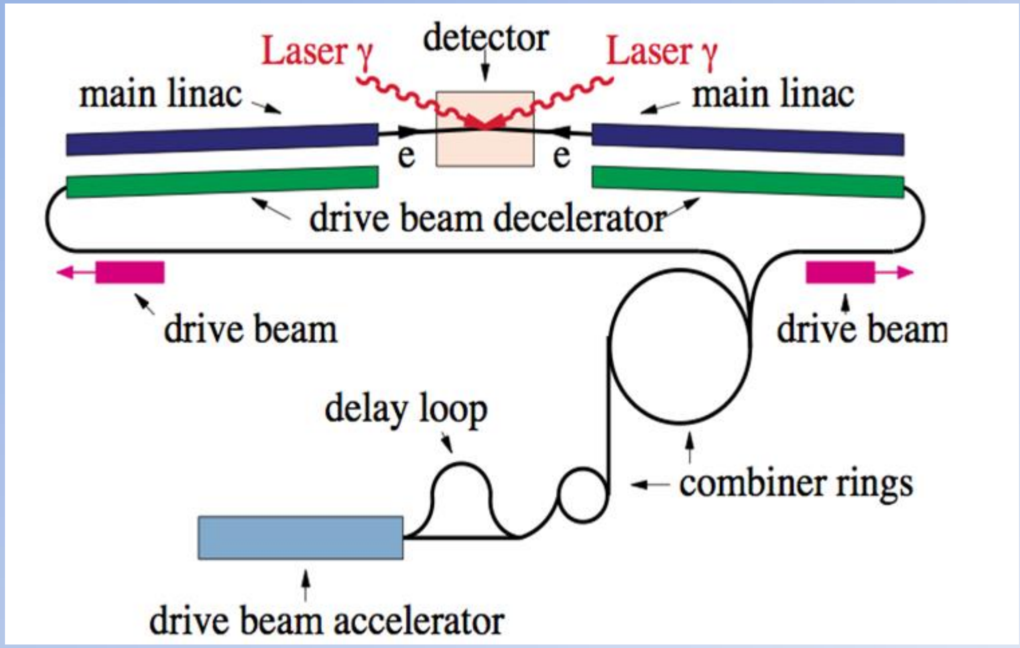
- Now boson discovered (~ 125 GeV) - want to study its properties in 'Higgs factories'.
- Linear collider proposals.
- Renewed interest in $\gamma\gamma$ colliders.



- Inelastic scattering of photon and electron – photon upshifted and scattered.
- Scattering angle – predominantly in $1/\gamma$ cone .
- For relativistic e^- photon scattered close to beam.

- Advantages over e^+/e^-:
  - No positrons.
  - High polarisation of photons and e^-.
  - Lower energy electrons required.
  - Reuse of existing facilities/piggybacking on ones that would be built anyway.

Some proposed facilities: SAPPHiRE



SAPPHiRE
arXiv:1208.2827

Small Accelerator for Photon-Photon Higgs production using Recirculating Electrons

- Based on CLIC technology.
- 80 GeV e^- beams.
- 200 (moving to 100) kHz.

Some proposed facilities: HFiTT

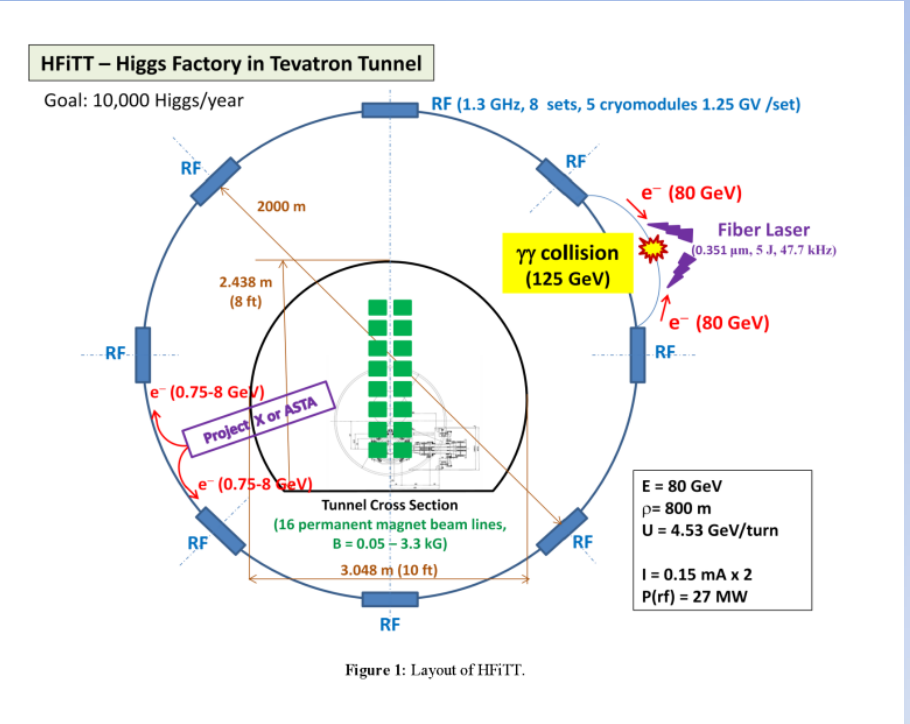


Figure 1: Layout of HFiTT.

HFiTT – Higgs Factory in Tevatron Tunnel.

- Reuse of space in the Tevatron tunnel.
- 80 GeV e^-.
- 47.7 kHz.

Facilities almost certainly not optimised for interaction/beam parameters etc.
But will work with current parameter set to study laser requirements.

HFiTT
arXiv: 1305.202v2

Laser requirements

Closer look at laser parameters for Higgs factory:

	SAPPHiRE	HFiTT
wavelength	351nm	351nm
pulse energy	5J	5J
repetition rate	100kHz	47.7kHz
pulse duration	5ps (FWHM)	1.5ps (σ – 3.5ps FWHM)

- Assume 50% THG conversion efficiency: 10J @ λ ~ 1um, 100kHz / 47.7kHz.
- Total power = 10J * rep. rate = 1MW or ~ 0.45MW.
- Conventional laser wall plug efficiency: 0.1 – 1% (to be improved?).
- Electricity requirements: 45 – 450MW, 100MW – 1GW.
- $\times$ 2 for two laser systems.
  - No such MW average power laser – dwarfs power budget for accelerator.
  - Can't afford the electricity bill……….

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Possible solutions

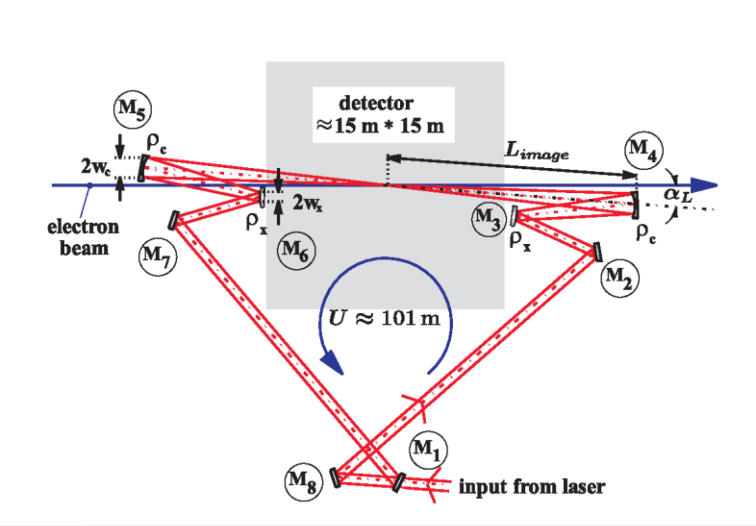
- Recirculating cavity – reuse one laser pulse for multiple interactions.
- Advanced designs developed for TESLA/ILC.
- One pulse injected into cavity and interacts with multiple electron bunches.

10^{10} e^-, 5J @ 351nm ~ 10^{19} photons – interaction nearly transparent to laser beam.

Clever designs but **serious** concerns remain with:

- Stabilisation
- Locking
- Injection
- Optics damage
- Spatial/temporal overlap

See Frisch/Oxborrow/Strain
http://www.hep.lancs.ac.uk/LaserCavity/



G. Klemz et al., NIM A 564, 212 (2006)

Even feasible for SAPPHiRE/HFITT?
Roundtrip times: 10μs (3000m)
21μs (6290m)

Recirculating cavity

- 5J, 5ps pulse at 351nm.
- Recirculation cavity possible?
- Ignoring injection, dispersion, simple feasibility analysis.
- Use 150m length, 20 roundtrips between e^- bunches (SAPPHiRE).
- How much light reaches e^- bunch 2^{nd} time, 20 roundtrips?

Individual mirror R	2 interactions 8 mirror cavity	2 interactions 4 mirror cavity
99.99%	0.984	0.992
99.9%	0.852	0.923
99.5%	0.448	0.670
99%	0.200	0.448

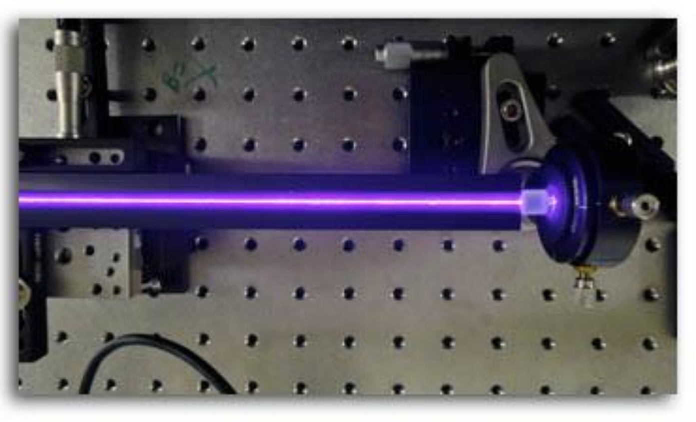
Stringent requirement on cavity losses in difficult environment

Single pass laser/electron bunch interaction?

- 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 nearly exactly the specs required for γ collider.

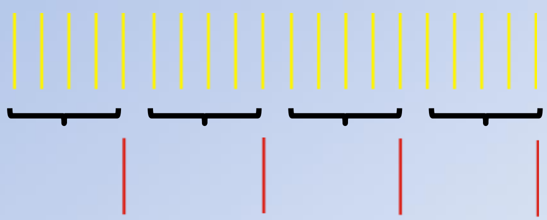
- Aim: demonstration module
  - ~ 30J
  - >10kHz
  - few 100fs
  - 1μm
  - > 10% wall plug efficiency (ideally more)



This laser would not require a recirculating cavity.

Possible fibre laser architecture

Adapted from work by Eidam et al. ICAN, CERN June 2013

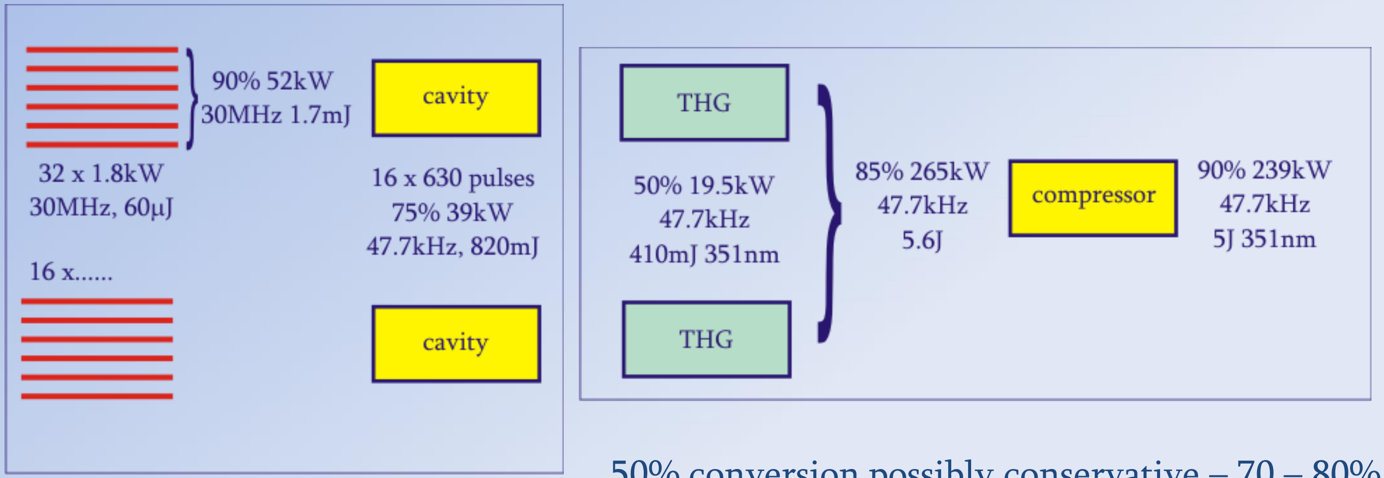


Enhancement cavity:
Multiple pulses stacked temporally.
Large resultant pulse switched out of cavity.

Aim: 10J, 3.5ps, 47.7kHz, ~ 1µm

Frequency conversion

- Need THG conversion to 351nm.
- Some issues: Peak power, average power, bandwidth.
- Peak power? LIFE 16J/cm^2 @ 1ω / 16Hz.
- Bandwidth?
    - Need 3.5ps @ 351nm = 125GHz
    - LIFE laser proposals for 180GHz in uv – OK.
- Single pass interaction: output power @ 351nm = 239kW.
- Massively > current state of the art average power handling (~ 1kW).
    - Convert after each enhancement cavity - < 20 x SOA.



50% conversion possibly conservative – 70 – 80% achieved.

Some thoughts on fibre laser approach

- Still complex set up – here enhancement cavities, could be divided pulses in time or other combination technique.
- All untested for such large numbers of fibres/power levels/pulse durations.
- Much R&D required.

- BUT

- Removes complexity of optical cavity to well controlled laser lab environment, sensible size cavity, known experience.
- Possibly only efficient solution for sensible cost of running?
- Technology development would benefit many other areas of science so opportunities for joint funding of R&D.
- Modular setup – could be possible to build in redundancy and specified engineered up time – look at NIF/LIFE experience here.
- Intrinsically good spatial beam quality for ease of transport and focusing.

Summary

- Gamma colliders interesting prospect for Higgs factory.
- Advantages over e^+/e^- colliders:
  - No positrons.
  - Lower energy e^-.
  - Possible reuse of existing facilities' infrastructure.

- Laser requirements hugely demanding.
- Power consumption major issue.
- Recirculating cavities increase complexity of IR, very hard to do and perhaps not even feasible for gamma collider pulse train specifications.
- Ideally would like single pass, efficient laser.
- Coherent combination of fibre lasers might be solution.
- Possible architecture proposed.
- Frequency conversion also needs to be considered.
- Optimisation of accelerator/laser parameters requires input from both sides.