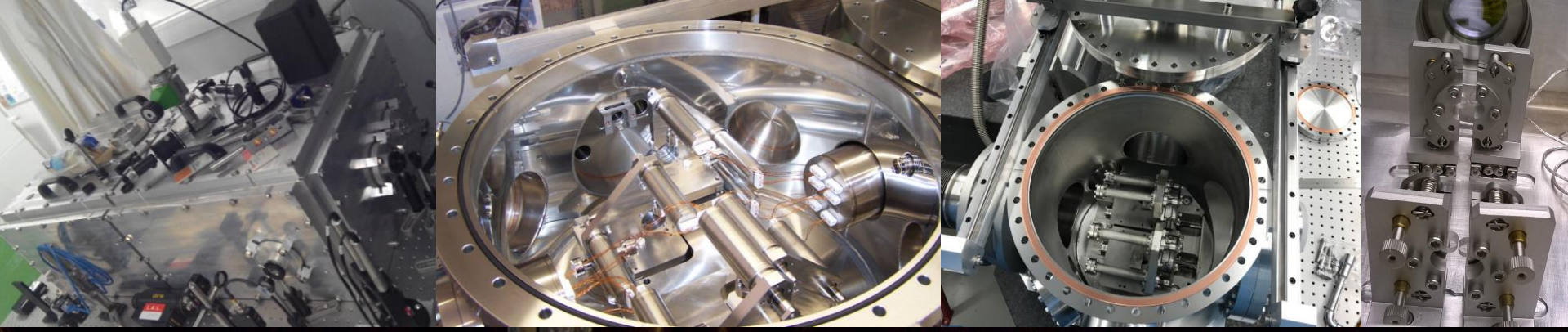


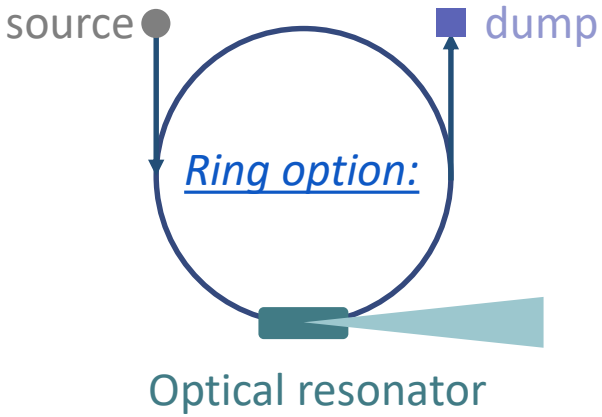
Optical cavities for ICS

Aurélien MARTENS (IJCLab Orsay)

Outline

- Optical cavities for ‘ring’ accelerators
- Optical cavities for ‘linac’ accelerators

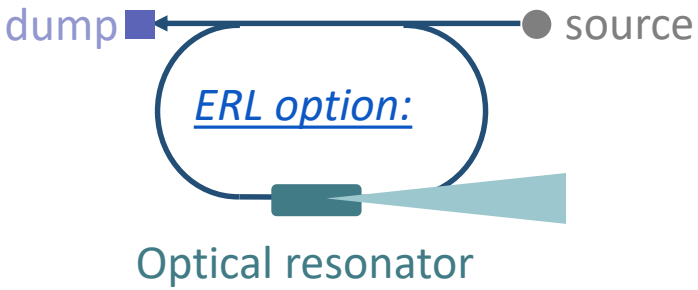
The ‘ring’ option



Examples:
newSUBARU: single shot
HIγS: e-beam driven FEL light
Lyncean: industrial product
ThomX: Demonstrator at Orsay
TTX (upgrade)

Limitations:
Limited flexibility
Non-linearities in optical cavity
Quality determined by equilibrium of ring

Advantages:
High flux up to 10^{13} photons/s (ThomX)



Examples:
cERL @ KEK
PERLE project @ Orsay
BriXSIno @ Milano

Why optical cavities ?

Driving idea:
- $f \approx tens\ of$ MHz

$\sigma_C \approx 0.6$ barn

$$n = \sigma_C f \frac{\mathcal{E}}{E_\lambda} \frac{I}{q} \frac{\mathcal{F}}{4\pi\sigma_y\sigma_x}$$

rate:
- 10^{11}-10^{13} photons/s

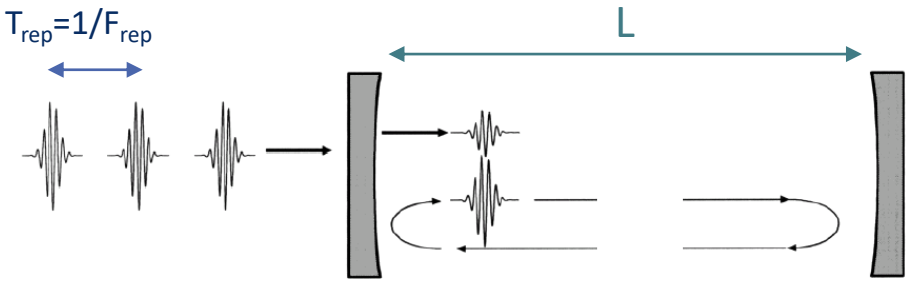
Limiting factor:
- Large average laser power $\bar{P} = f\mathcal{E} > 100kW$

Main challenge !

Electron beam:
- About 1 nC
- 100µm transverse size RMS

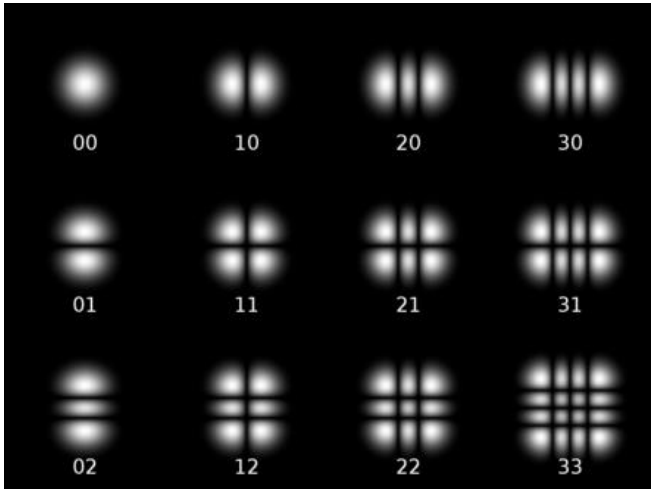
Fabry-Perot resonator

Input laser beam:
Few ps pulse duration



Input laser beam must be matched to the cavity:

- Temporal superposition $2L/c=F_{rep}$
- Transverse mode matching



Resonant at different cavity lengths*

*for a non-degenerate cavity

Fabry-Perot interferometric filter

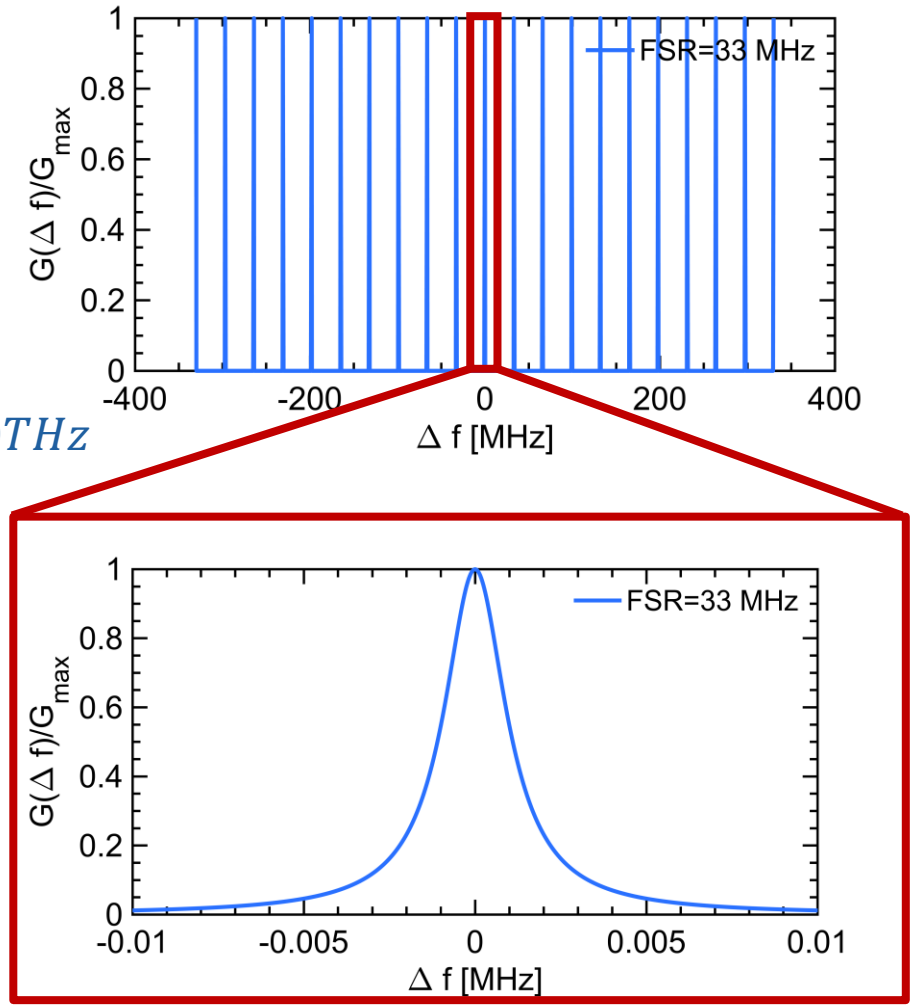
Laser frequency must be precisely tuned
And remain stable !

$$F = \frac{FSR}{\Delta\nu} = 15000 \qquad \Delta\nu = 2.2kHz$$

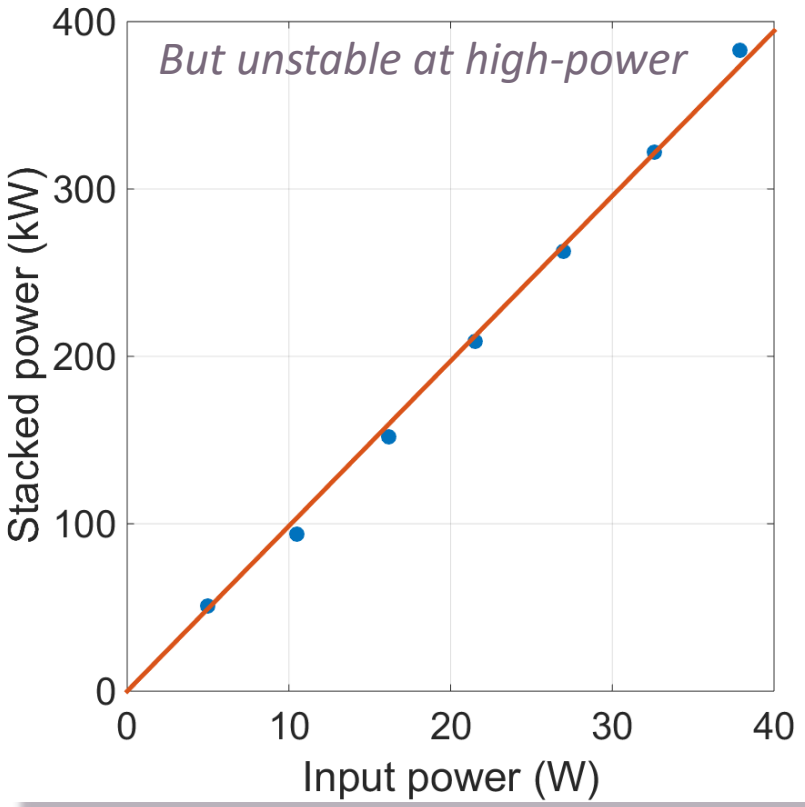
NB: Compare with central frequency of $\nu_0 = 290THz$

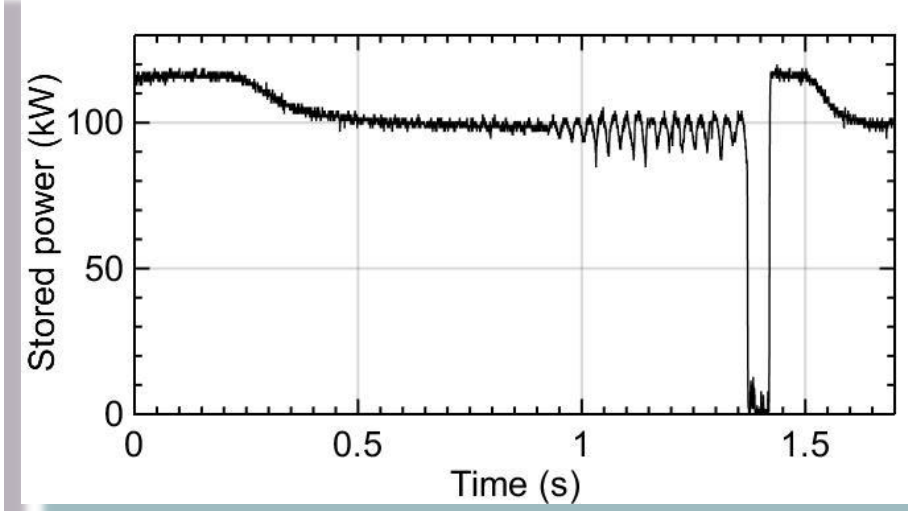
$$\frac{\Delta\nu}{\nu_0} < 10^{-11}$$

Metrology-level requirement !
→careful choice of laser provider



High-order mode instability





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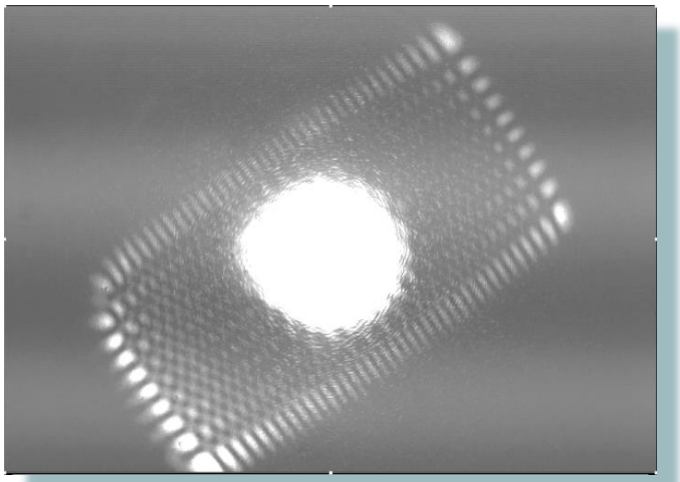
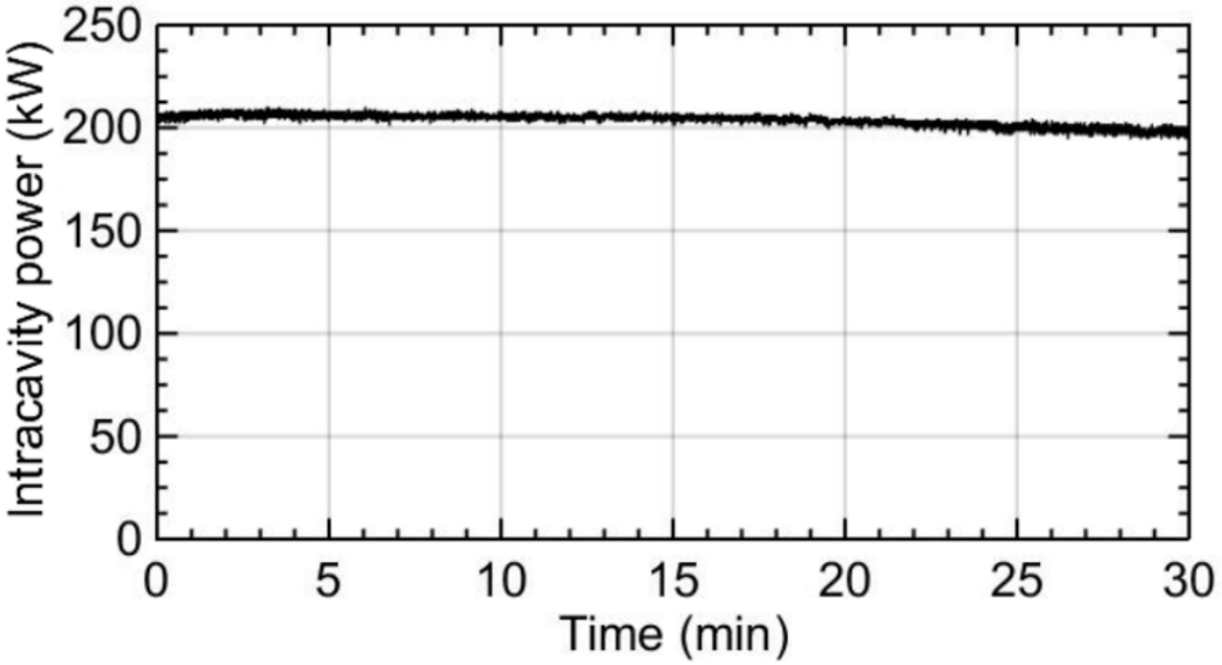


Recent results



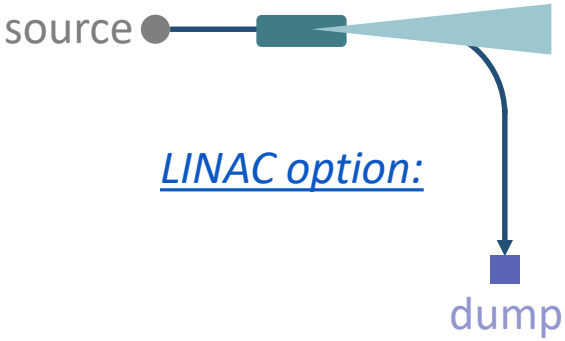
Amoudry L. et al., Applied Optics 59(2020)116

Thermo-elastic deformations need to be accounted for at design stage !

ThomX cavity currently being commisioned

The ‘linac’ option

Single bunch or optical circulator

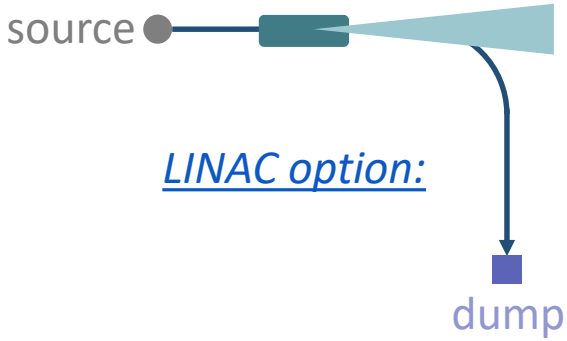


Examples of projects:
ELI-NP-GBS: 32 bunches, S+C-band
STAR: single bunch, S-band
Smart*Light: single bunch, X-band
TTX

Limitations:
Flux up to 10^9 photons/s
Dedicated optical system for multibunch

Advantages:
Excellent source quality
Low average power optical system
Lower cost

Optical resonator in burst mode

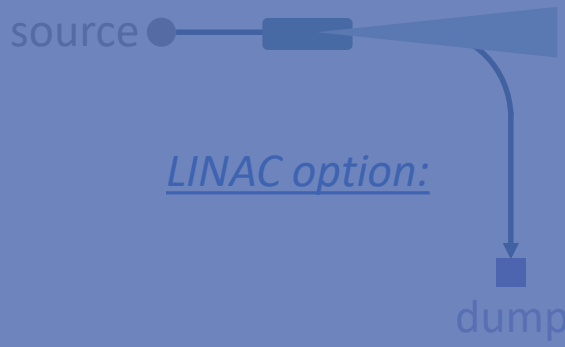


💡: Large number of bunches to overcome flux limitations
- Dedicated gun, Low Level RF
  - RF pulse duration, beam loading
- Develop small optical resonator in burst mode
  - Few 10 cm optical system for 1 to 2 ns bunch spacing
  - Optimize optical parameters

Used for LUCX at KEK
Possible option for upgrades of:
STAR @ University of Calabria
Smart*Light @ TU Eindhoven

The ‘linac’ option

Single bunch or optical circulator



LINAC option:

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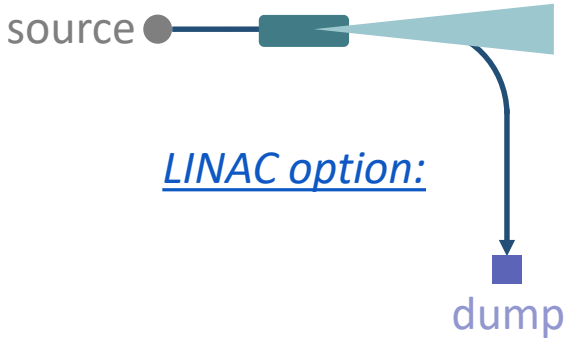

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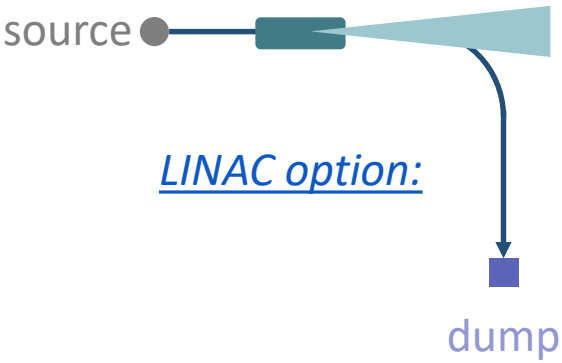
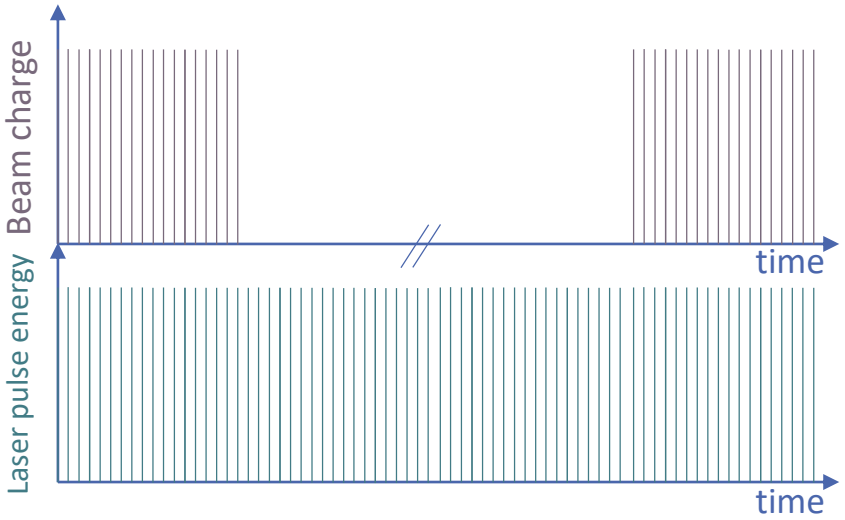
Burst operation of optical resonator



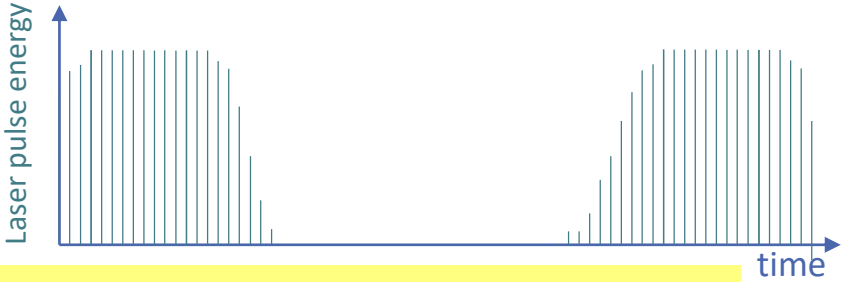
LINAC option:

Optical resonator continuous operation:
limited by average power, flux reduced (duty cycle)



Burst operation of optical cavity: optical duty cycle similar to that of RF

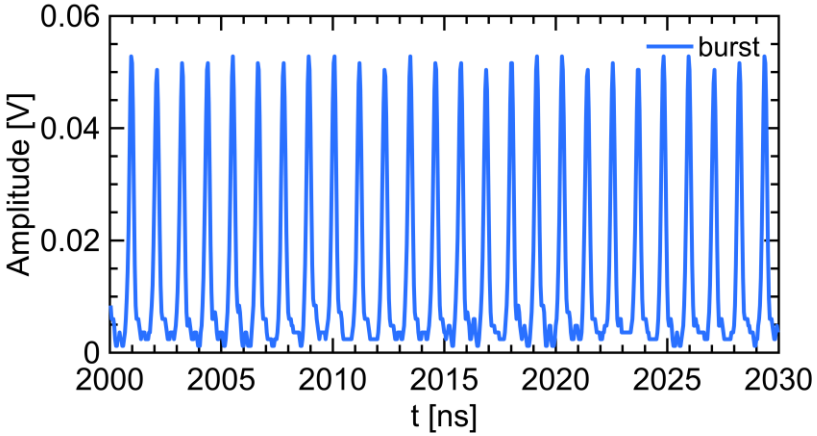
Optical resonator burst operation:
Optimizes peak power useful for collisions

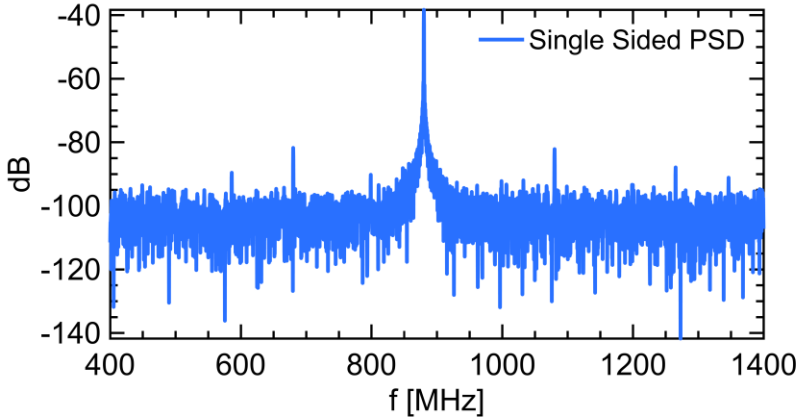


→ High rep-rate optical system (laser and cavity) required

Sakaue et al., Review of Scientific Instruments **89**, 023305 (2018);
Favier et al., Phys. Rev. Accel. and Beams **21** (2018) 121601

GHz laser developments

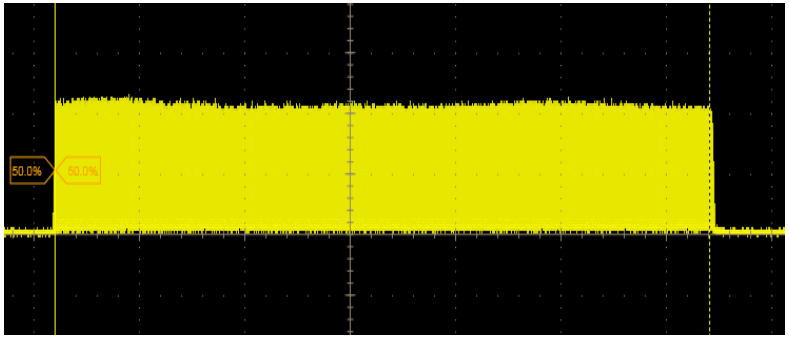




NB: Less stringent requirement on phase stability compared to much longer cavities

GHz laser developments

Example of a 2.5µs flat burst, but flexible burst duration and duty-cycle



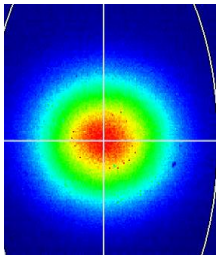
Goal → 10mJ/burst, 10kHz, 5µs burst duration

Burst minicav: modeling and R&D

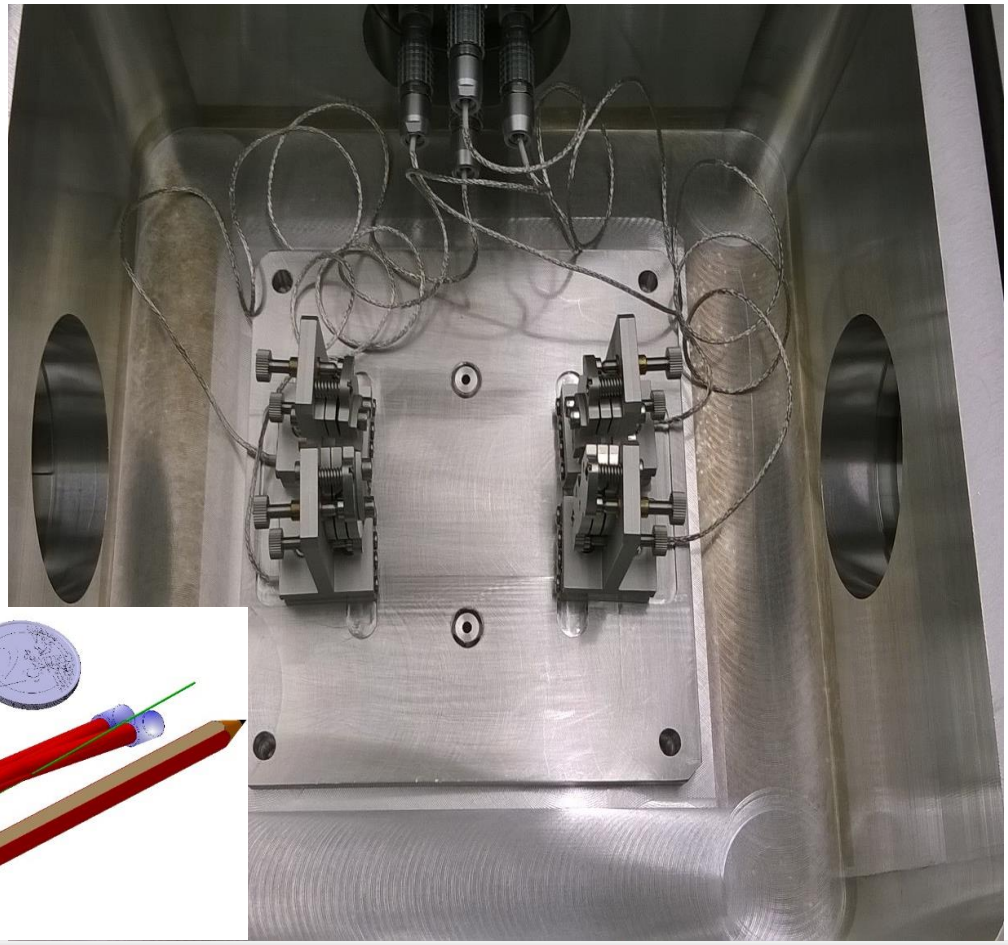
→ Could be considered for upgrades of STAR, Smart*Light sources, etc.

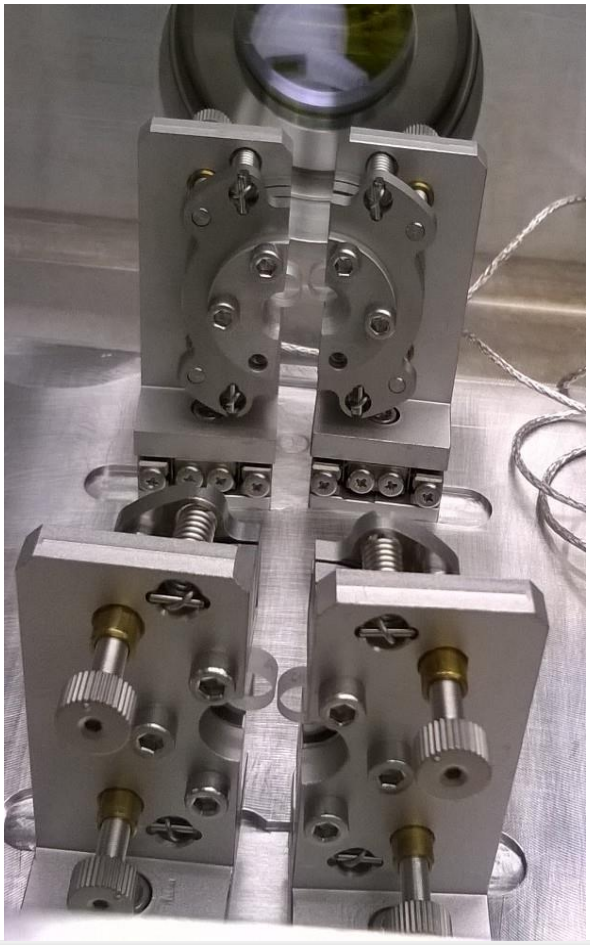
→ Reach peak powers of several 10MW, with small waist ideal for a clean e-beam source

IJCLab designed a “small” optical cavity to increase bunch repetition rate to a couple of GHz



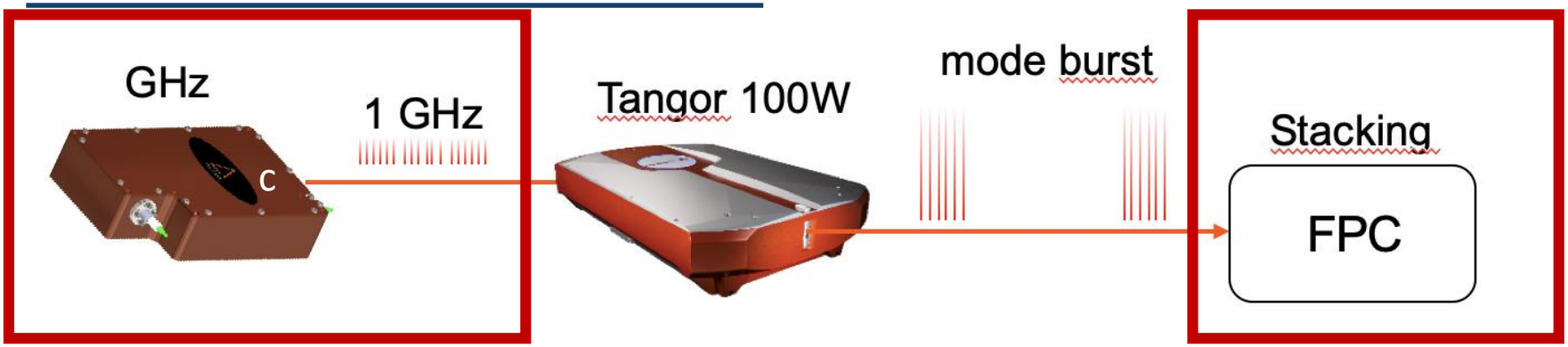
waist 15µm

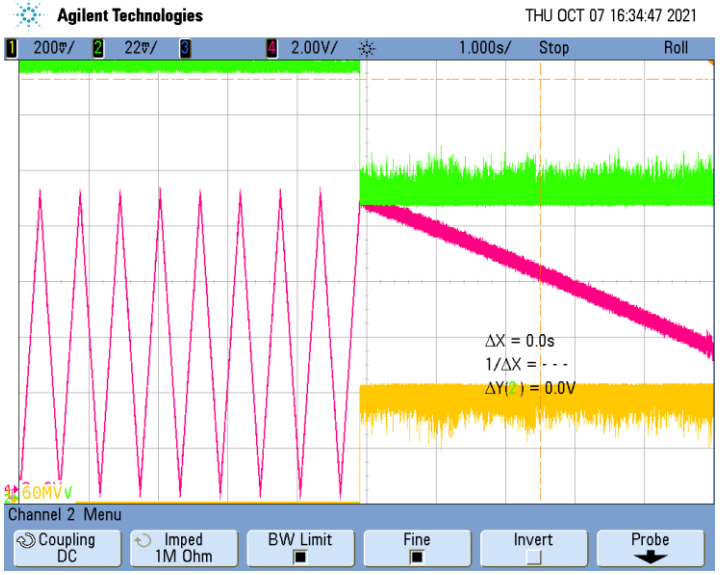




Favier et al., Phys. Rev. Accel. and Beams **21** (2018) 121601

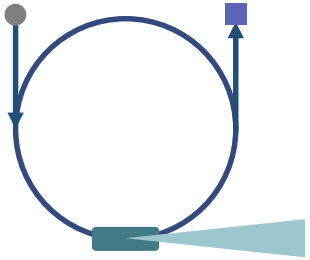
Very recent results

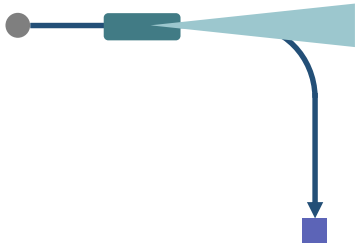




→ Current system being upgraded with amplifier

Conclusion & prospects





High average power optical resonator ideal for rings/ERL

Burst mode optical cavities ideal for high repetition rate burst LINACs

Challenging but feasible technology: Laser and resonator

Technology currently getting mature: laser and resonator

Average power >200kW demonstrated
Photon bandwidth limited by e-ring
High rates of 10^{11}-10^{12} photons/s possible

Peak (optical) power >10MW are expected
0.1% photon bandwidth may be feasbible
High rates of 10^{11}-10^{12} photons/s possible ?

Lyncean, ThomX are demos of this kind
BriXSIno → coupled to ERL (new)

Actual ICS demonstrator expected in coming years

Martens A. et al., Phys. Rev. Accel. Beams **24** (2021) 091601