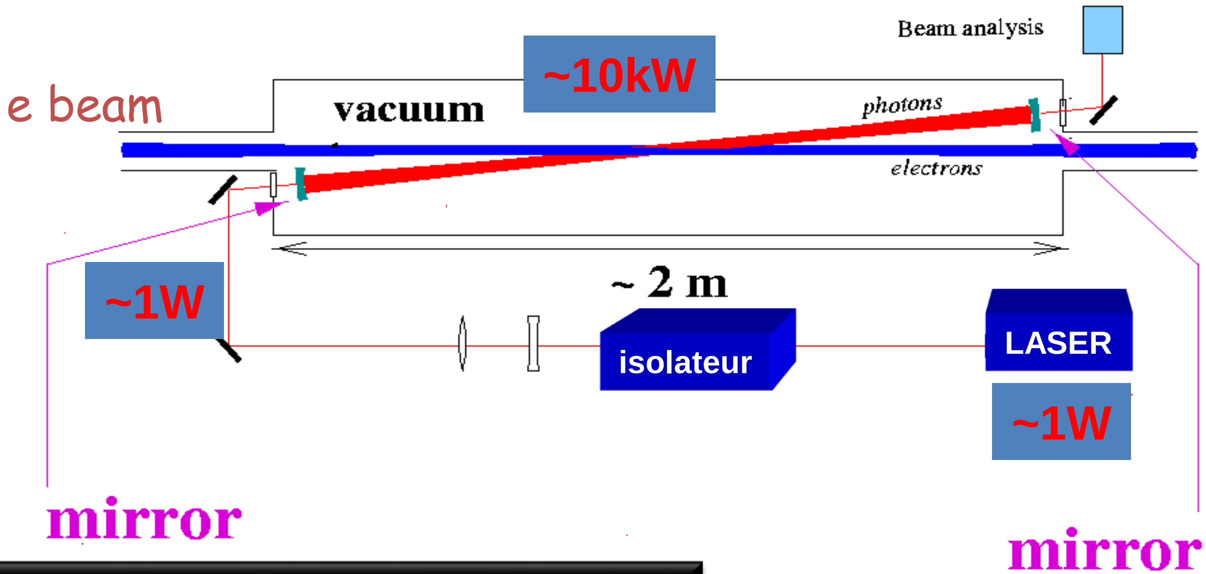
High finesse multi-mirror optical cavities with feedback

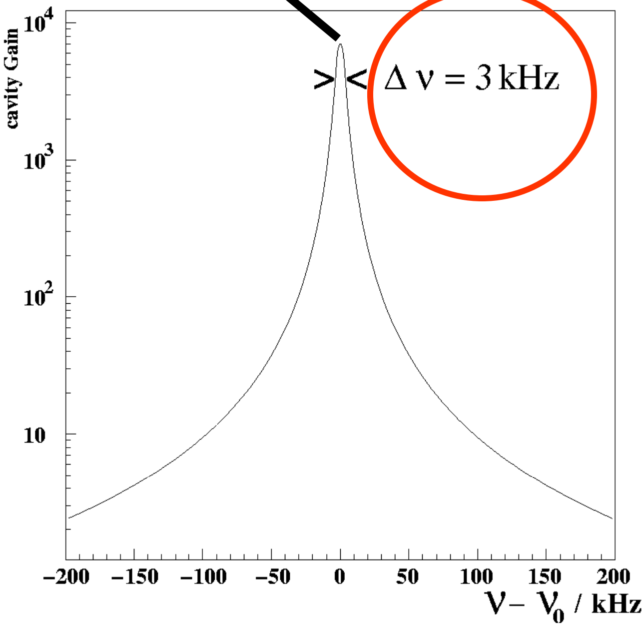
1. Fabry-Perot cavity in cw mode: feedback & optical issues
   1. Comparison with Sapphire parameters
2. Fabry-Perot cavity in pulsed mode
   1. Comparison with Sapphire parameters
3. Present R&D on optical cavities at LAL

F. Zomer, 19, march, 2013

Fabry-Perot cavity: Principle with continous wave



Gain=1/(1-R)~10000



JLAB/Saclay Polarimeter, NIMA459(2001)412
HERA /Orsay Polarimeter, JINST 5(2010)P06005

When $\nu_{Laser} \propto c/2L \Rightarrow$ résonance

•But: $\Delta\nu/\nu_{Laser} = 10^{-11} \Rightarrow$ STRONG & ROBUST laser/cavity feedback needed…

Illustration of one issue : the laser cavity feedback

Sapphire

Cavity finesse : F~100 π

Optical path length : L~150m

Cavity resonance frequency linewidth $\Delta\nu$=c/(LF)~6kHz !

$\Delta\nu/\nu=\lambda/(LF)=\sim 10^{-11}-10^{-12}$

Same numbers as in metrology !!!

$\Delta L=\lambda/F$

- Ultra-Low Expansion (ULE) Glass:

- Typical **length**: 10 cm

→Free spectral range ~ 1.5 GHz

- Typical **finesse**: 300,000

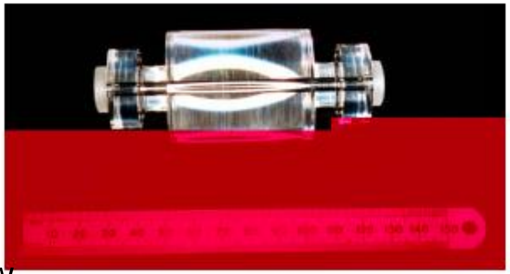
→ linewidth ~ 5 kHz

→ **power enhancement ~10^5**

[applied power (CW): 1 mW

intracavity power (CW): 100 W]

- Single-crystal Sapphire (cryogenic: ~4 K)



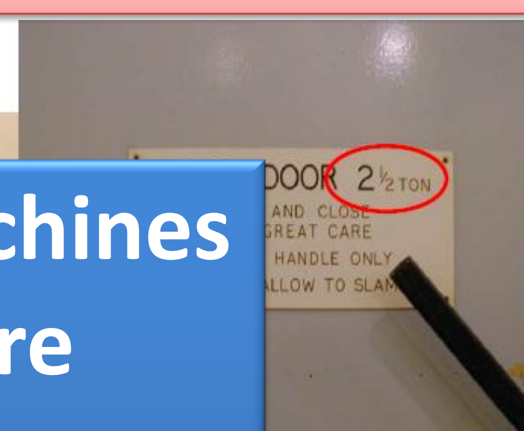
- Mirrors **optically contacted** to spacer

NPL M. Oxborrow

From a feedback point of view:
Locking a '150m' cavity of finesse~ 100 π('gain'~100) is the same as
Locking 0.2m cavity to 300000 finesse !
BUT

The hyper stable small cavity is 'hyper' temperature stabilised

Into an hyper isolated room

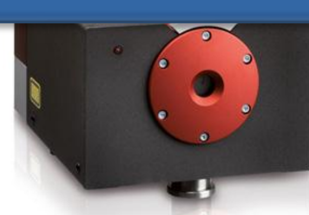


For Sapphire & Compton machines
- ✓'Geant' mechanical structure
- ✓Noisy accelerator environment
- ✓Pulsed laser beam regime
  - ✓□ 1kHz linewidth oscillator
  - ✓Huge average & peak power !

Put on an

ser is used,

ephisto

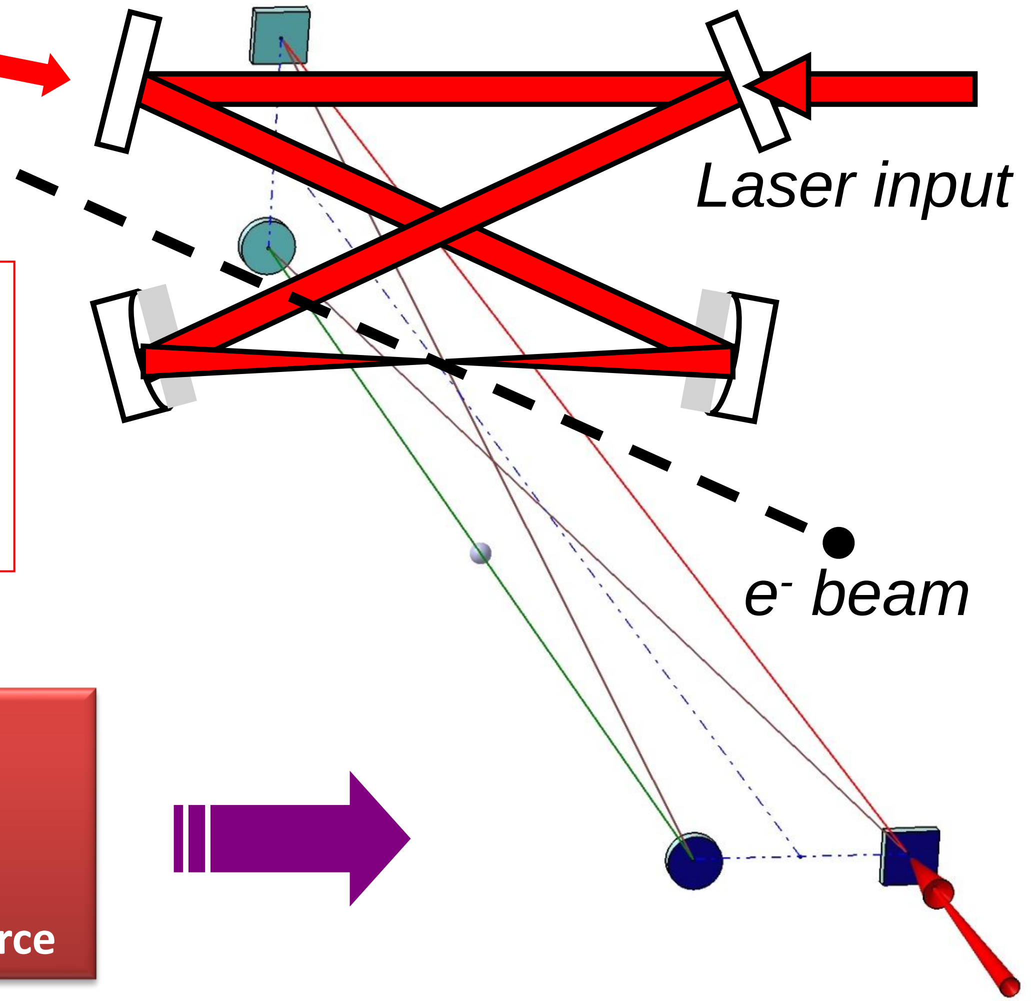


An Optical issue
Small laser beam size +stable resonator
➔ ~~2-mirror cavity~~

Stable solution: **4-mirror cavity**
as in Femto laser technology

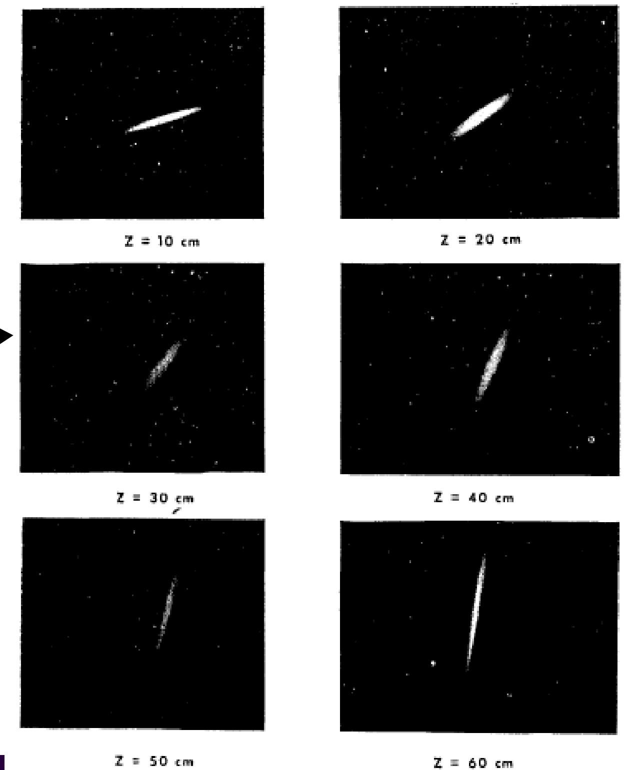
BUT
➔ elliptical & linearly
polarised eigen-modes
which are instable because of vibrations
at very high finesse

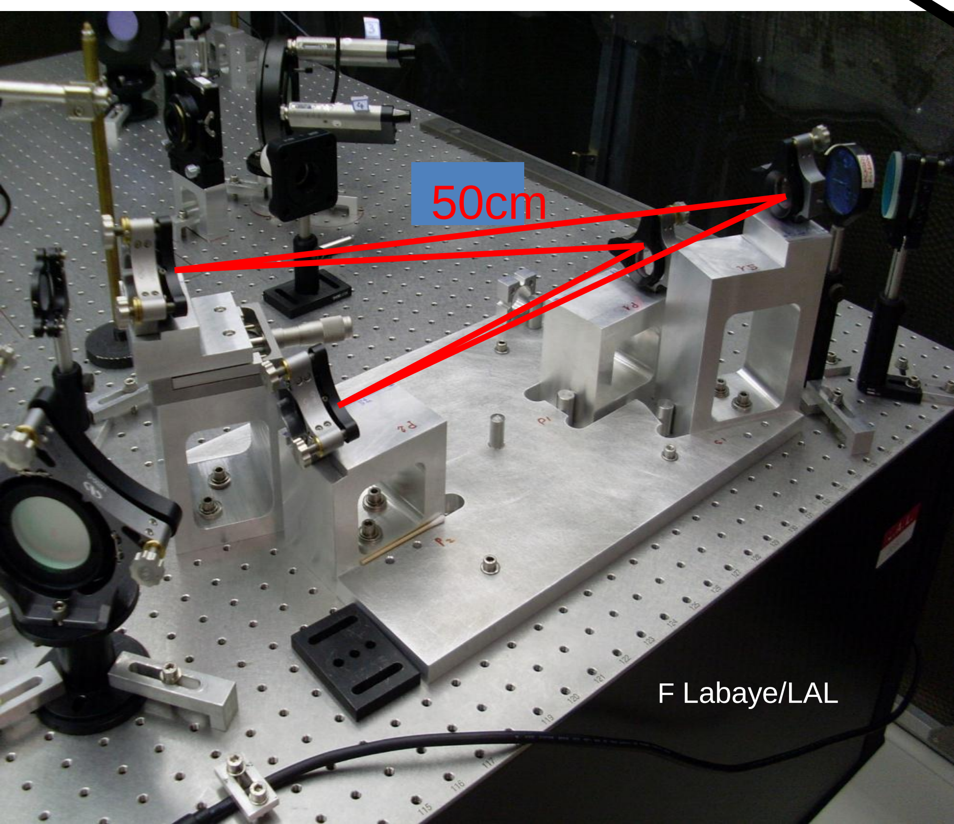
Non-planar 4-mirror cavity
➔Stable & circularly polarised eigenmodes (AO48(2009)6651)
as needed for an ILC polarised positron source

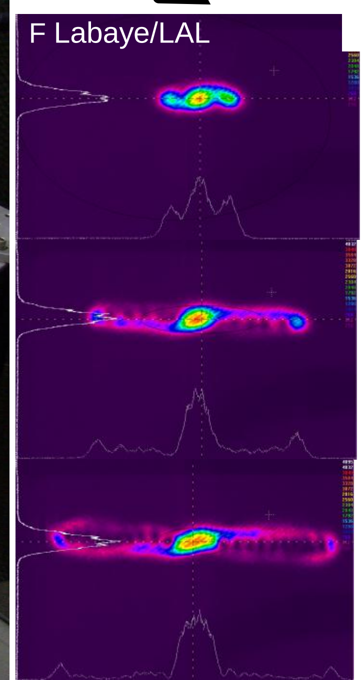


Optical issues for ‘focusing’ resonators ω_0~7µm for sapphire (?)

- Mode focusing → strong ellipticity/astigmatism
- Non-planar 4-mirror resonator & ‘strong’ focusing
  - → general astigmatism (*Arnaud, Bell Syst. Tech. (1970)2311*)
  - → Complex mode structure





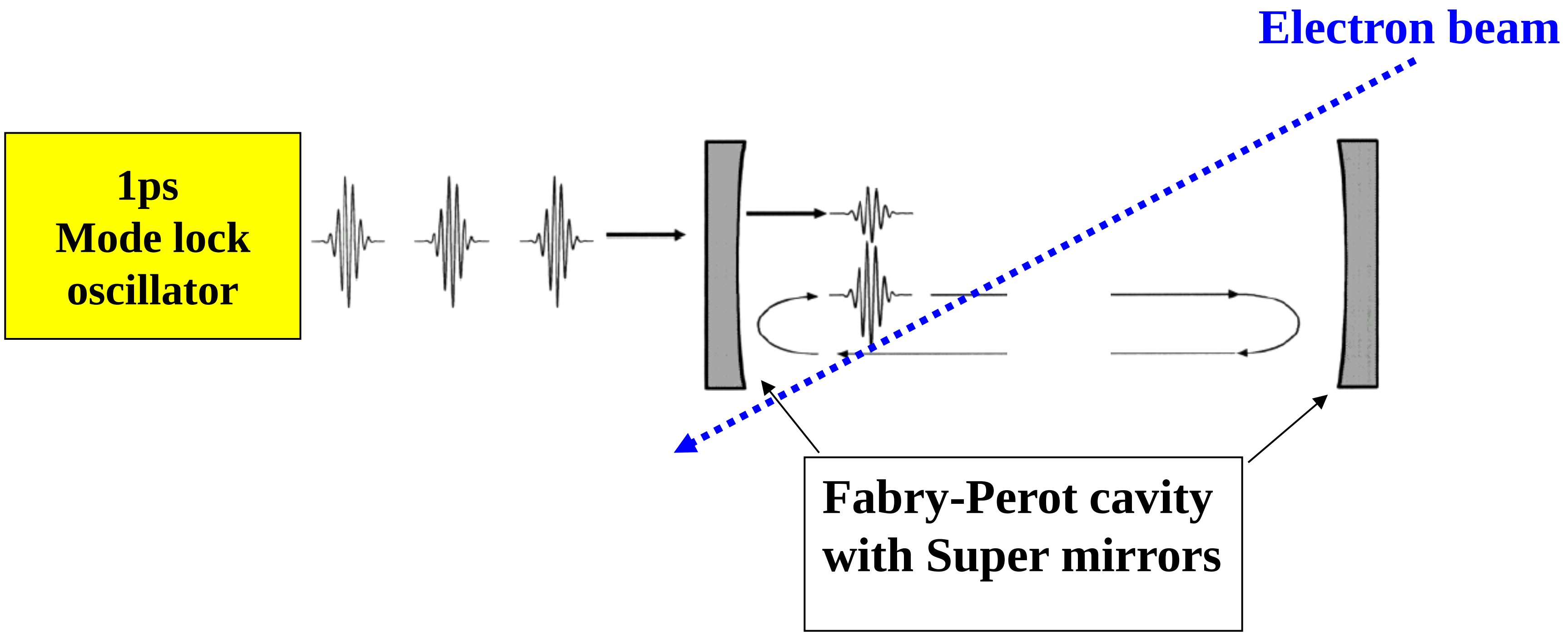


Carreful optical design

→optimize mode shape at the IP

→optimize mode polarization

Fabry-Perot cavity in pulsed regime



Same feedback technics (more complexe) is used in cw & pulsed regime
➔ Well known techniques (analog and numerical)

Pulsed laser/cavity feedback technique

Specificity ➔ properties of passive mode locked laser beams

Frequency comb ➔ all the comb must be locked to the cavity

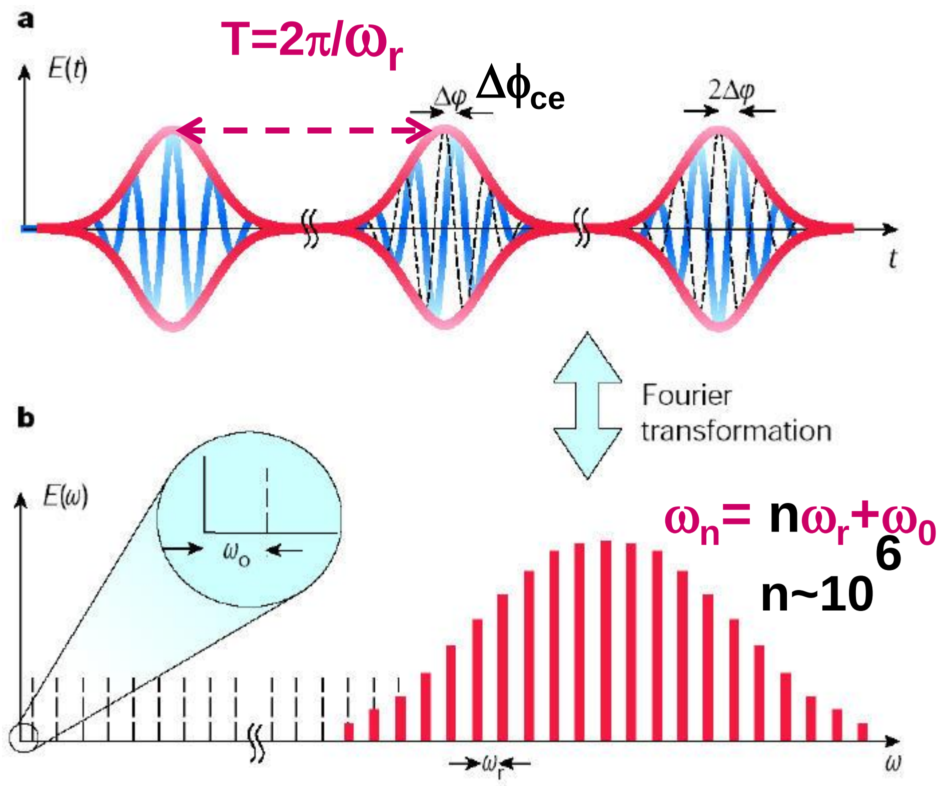
➔ Feedback with 2 degrees of freedom :

control of the

Dilatation (rep. Rate)

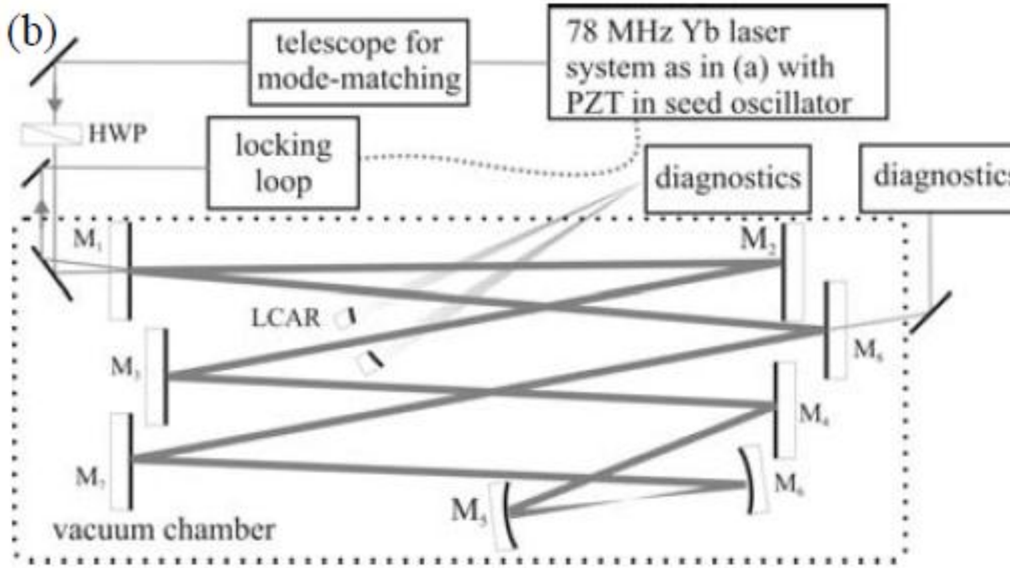
&

Translation (CEP)



T. Udem et al. Nature 416 (2002) 233

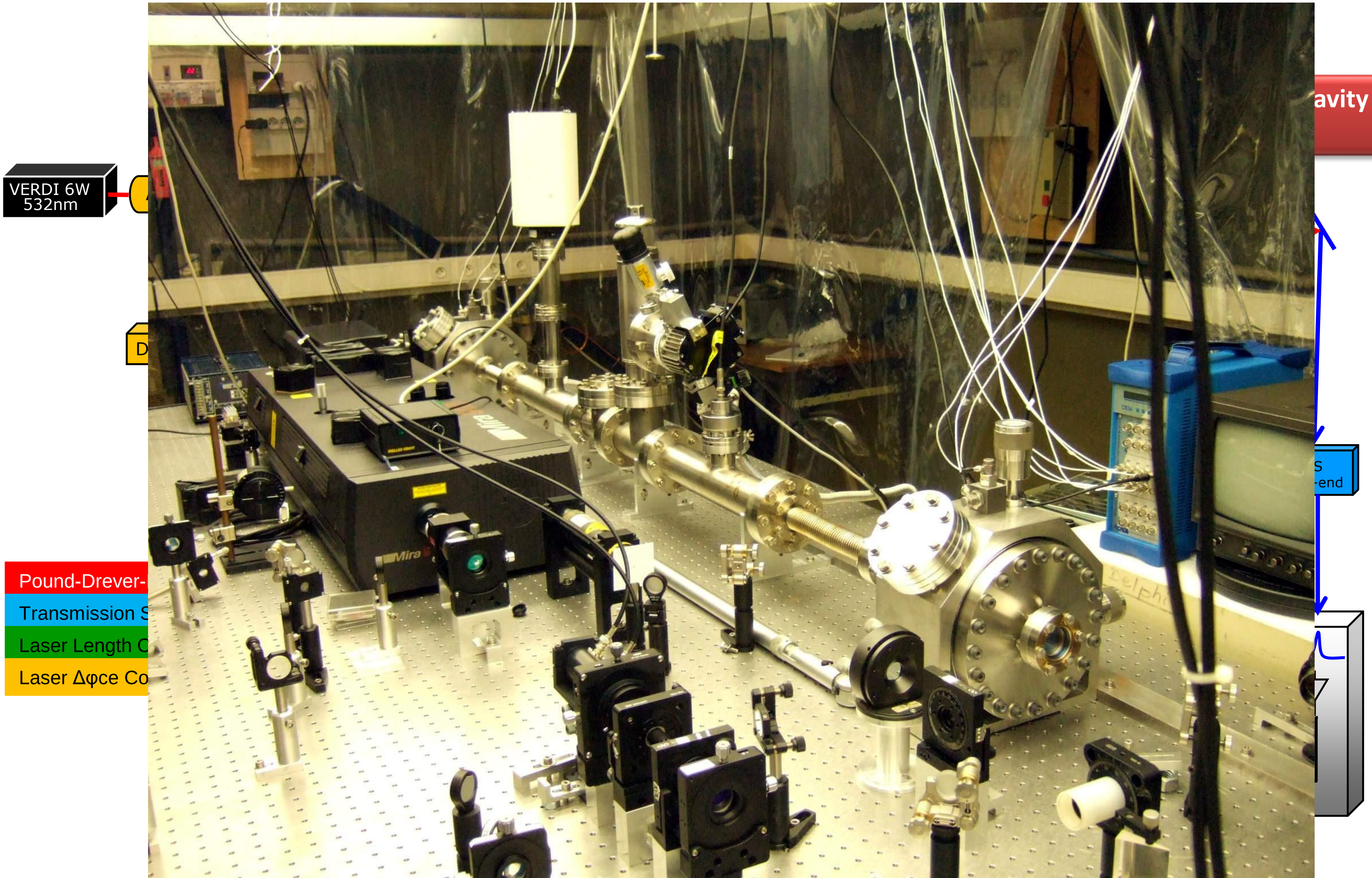
State of **the art (Garching MPI) :**
~70kW, 2ps pulses @78MHz (F~5600)
stored in a cavity (O.L.35(2010)2052)
~20kW, 200fs pulses @78MHz



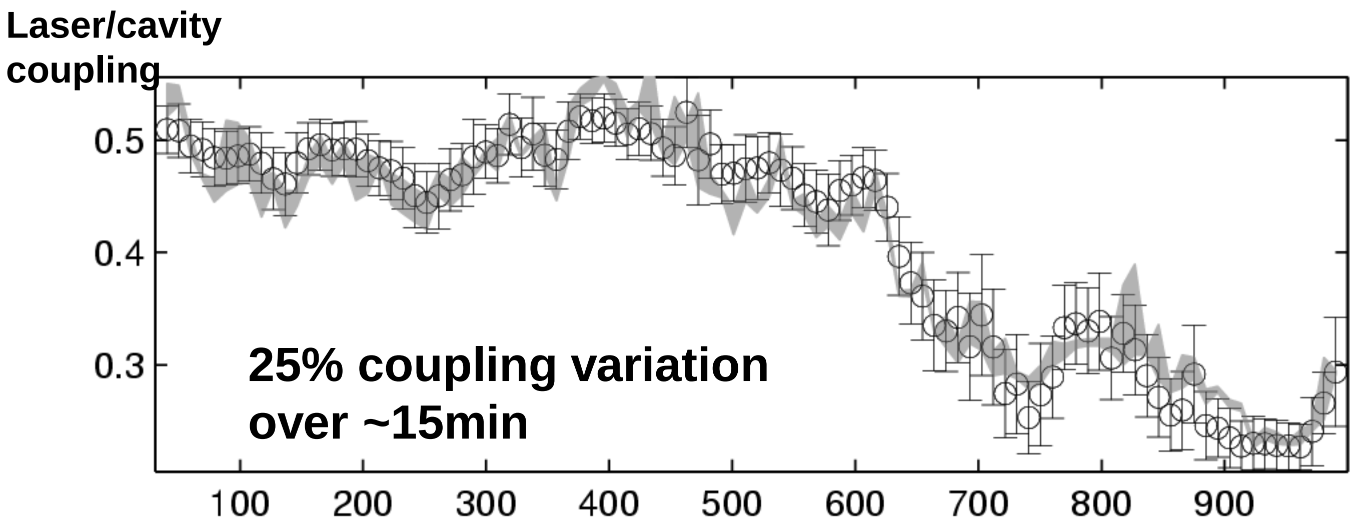
From a feedback point of view:
Locking a '150m' cavity to finesse~ 100 π('gain'~100) @ 350nm is the same as Locking a 4m cavity @ 800nm to ~25000 finesse

R&D done at Orsay
→2ps Tis:apph 76MHz oscillator (~0.2nm spectrum)
→cavity finesse ~28000

Orsay setup: Picosecond/High Finesse



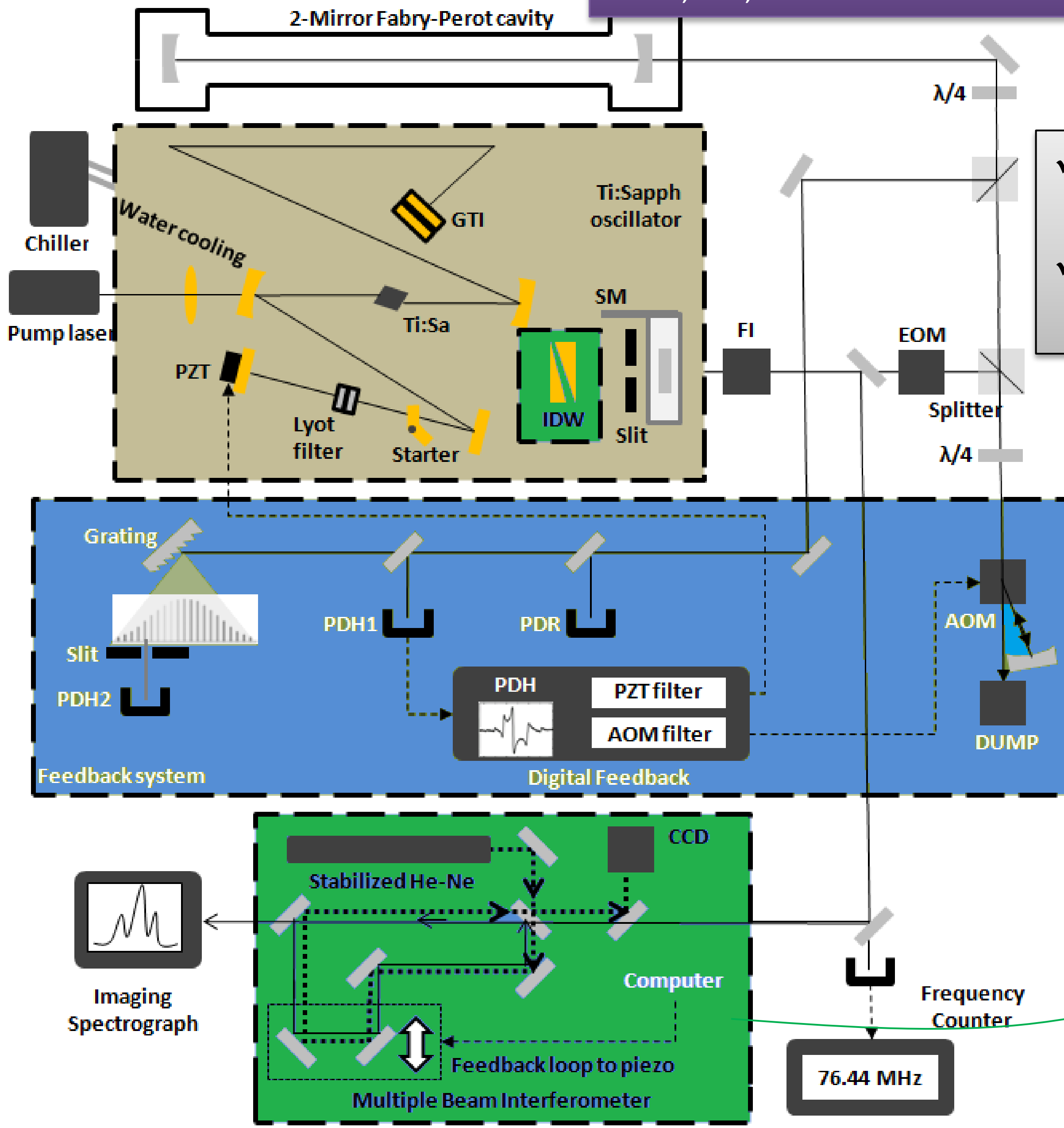
- We locked the laser to the cavity
- But we observed strong free running laser/cavity coupling variations (Finesse~28000)



- → Stacked power variations up to ~60%
- → 'noisy' Stacked power (~7%)
  - → Feedback bandwidth ~100kHz
  - → BW up to a few MHz on the rep. Rate. needed to reduce the noise

CEP effects measurement in picosecond/high finesse regime

CELIA, LAL, SZEGED Univ.



November 1, 2007 / Vol. 32, No. 21 / OPTICS LETTERS 3095

- ✓2ps Ti:Sapph (75MHz) Locked to a ~28000 finesse cavity
- ✓No control of the CEP drift in the feedback loop

Numerical feedback loop

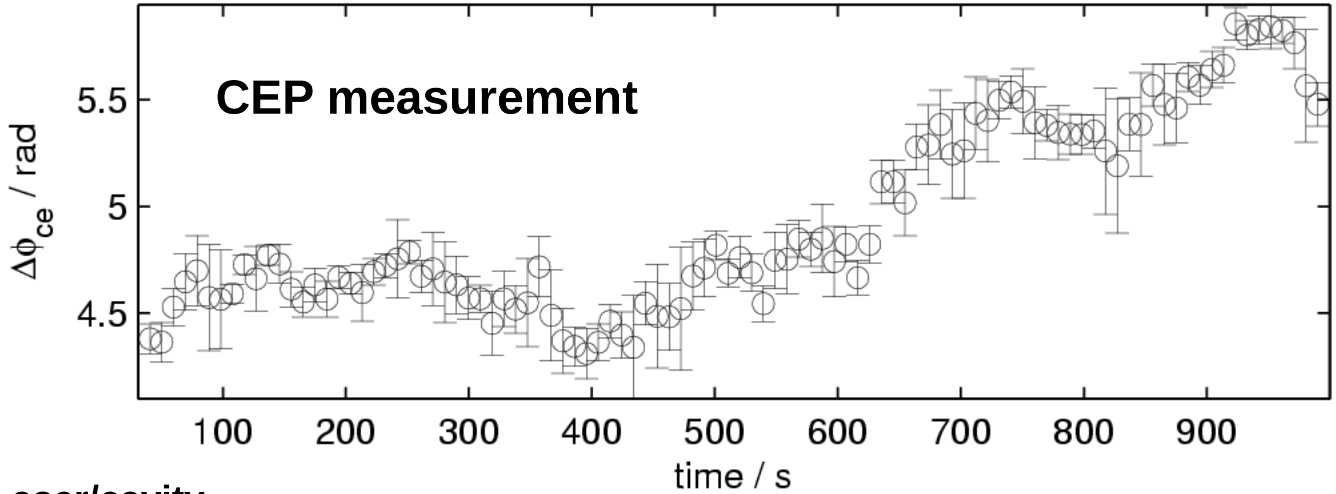
- ✓BW=100-200kHz
- ✓BW ~1MHz needed

✓CEP measured with *Szeged interferometer*

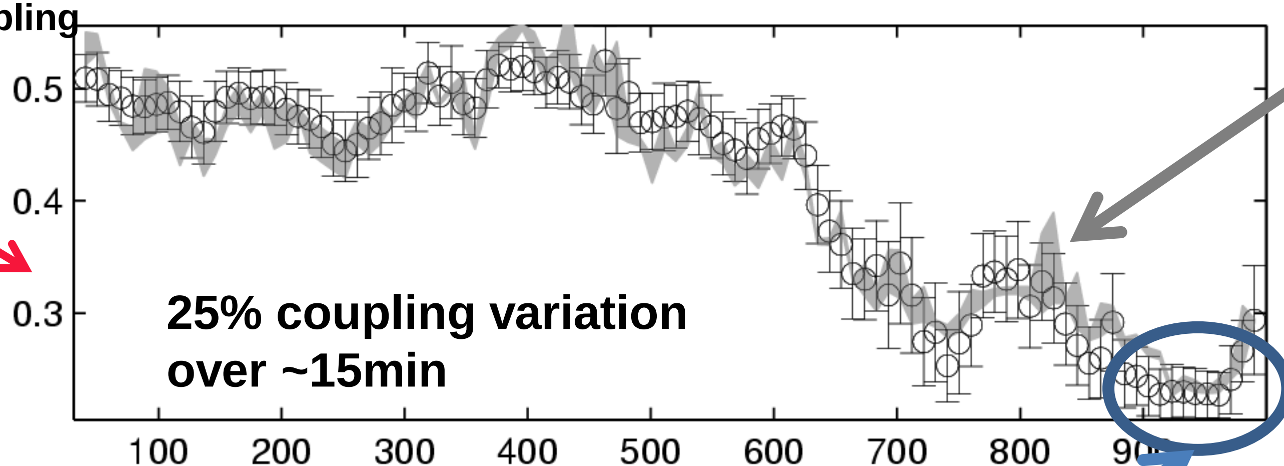
CEOLiT

measurement of Carrier Envelope Offset Phase Drift by a Linear Transmission Ring

We observed strong free running laser/cavity coupling variations (Finesse~30000)



Laser/cavity coupling



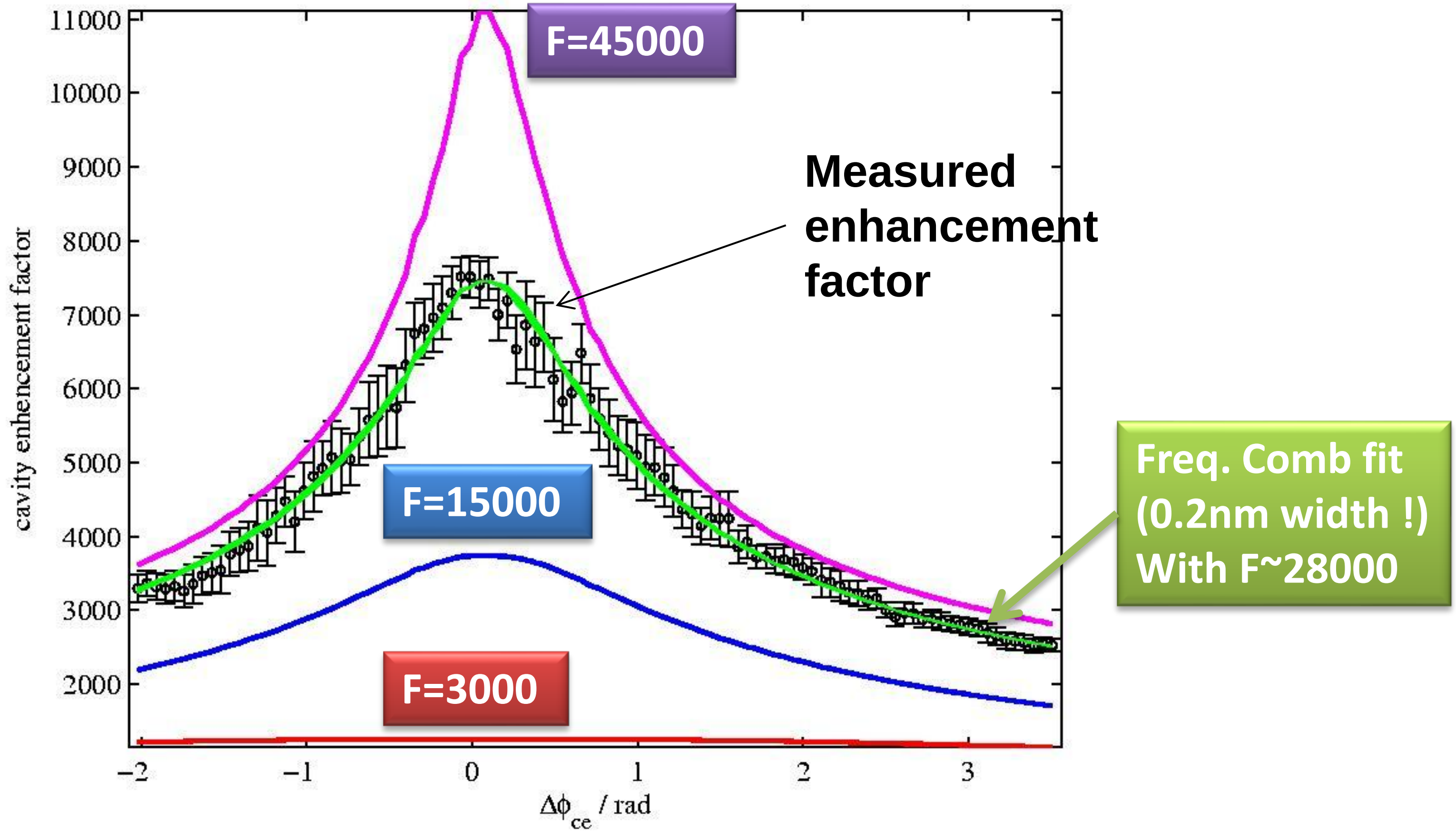
Fit:
Frequency comb $+\Delta\phi_{ce}$ variations

Only 3 free parameters in the fit:
a normalisation,
an offset
the Finesse

Here 80% of the laser power is coupled
→ high quality wave front needed

Variation of the pump power

➔laser/cavity coupling measurement➔effective enhancement factor
➔CEP measurement



➔60% enhancement factor variation if CEP phase □[0,2π] for 2ps & ~28000 Finesse
➔CEP phase must be also controled in high Finesse/picosecond regime
➔Feedback loop BW must be>100kHz

Some laser oscillator issues

✓At present increasing the average power @ frep>2MHz rep rate

➔ Yb fiber technology

- ✓Need to find/build a low noise laser oscillator
- ✓CEP and rep. Rate locking required
  - ✓Possible feedback BW imitations using a 2MHz laser oscillator (➔ R&D on the oscillator & optical reference)

✓Present R&D with Yb fiber oscillators (frep>100MHz)

Broadband Phase-Noise Suppression in a Yb-Fiber Frequency Comb

A. Cingöz,[1,*] D. C. Yost,[1] T. K. Allison,[1] A. Ruehl,[2] M. E. Fermann,[2] I. Hartl[2] and J. Ye[1]

- ✓CELIA-LAL R&D
  - ✓2 commercial Yb (fiber) lasers
  - ✓Fully connectorised (robust) fiber amplifier
    - ✓50W(100W) at present (➔200W for ThomX, see A.Variola)

Bordeaux-Orsay R&D

Financé par ANR

Stable oscillator (Origami Onefive)
0.2W, 1030nm
Δt~0.2ps **frep=178.5MHz**

AOM

1 piezos
1 temp. Ctrl.
1 AOM

Amplifier(s)
photonic fiber
Yb Doped

$\overline{P}$ ~10W→50W→ **100W**

1 piezo

4-mirror
Fabry-Perot cavity
Gain~1000→**8000**

Mixed
Analog-Numerical
feedback

ATF clock

Highly 'tunable' oscillator (Orange Menlo)
0.02W, 1030nm
Δt~0.2ps **frep=178.5MHz**

1 piezo
1 EOM
1 trans. Stage
1AOM
1 pump current

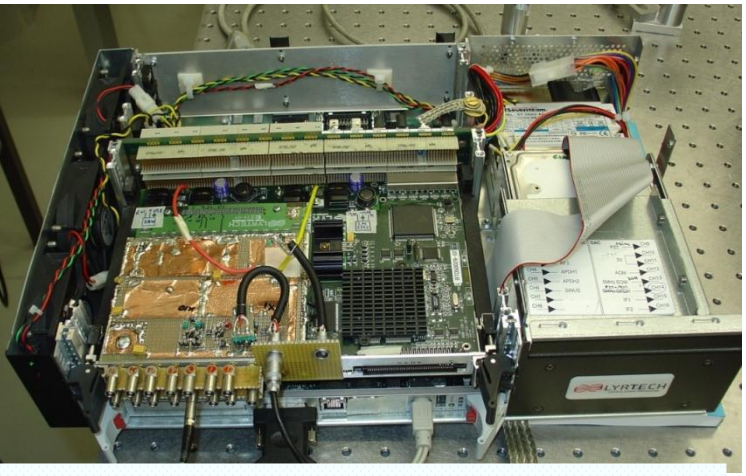
10MHz feedback bandwidth needed…

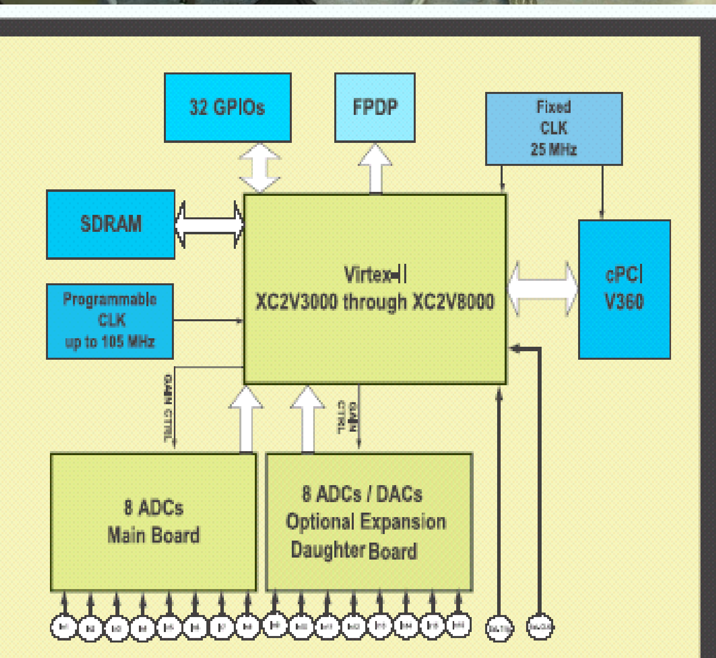
- **Setup required feedback (10kHz→10MHz BW)**
- **Setup a robust fiber amplifier**
- **Study noise induced by the amplifier**
- **Push the cavity stored power at maximum**

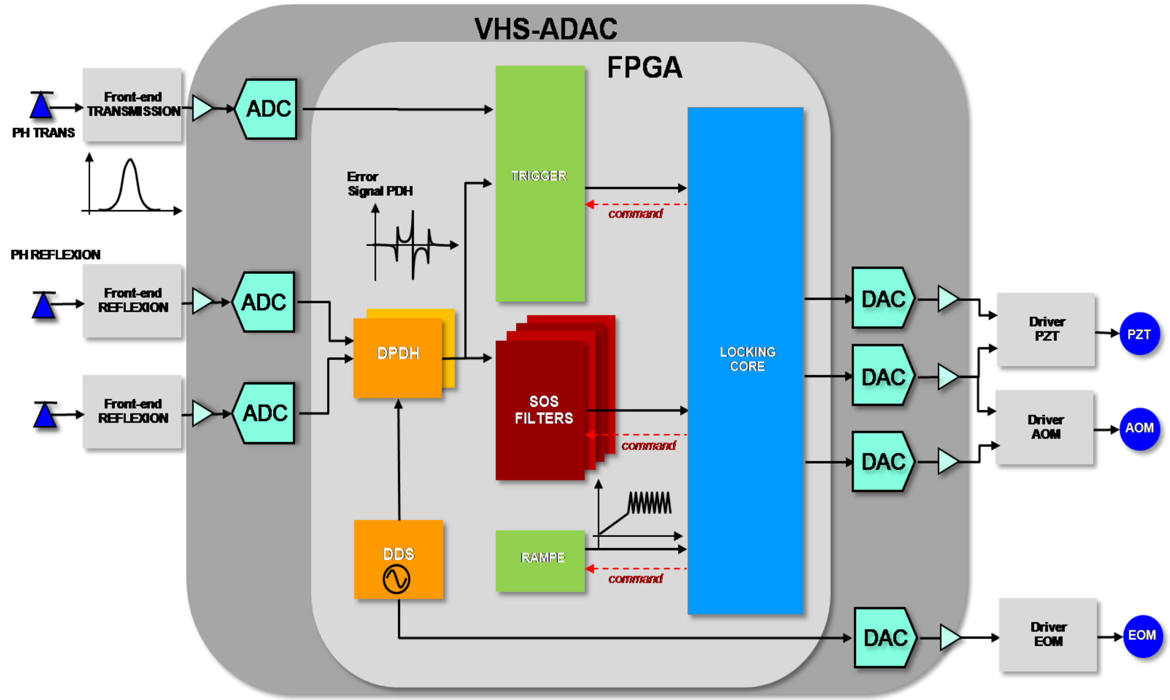
Summary

- Fabry-Perot cavity
  - Advantages
    - Very high gain (eventually)
    - ‘easy’ laser-electron synchronization
    - Stable transverse & longitudinal modes
    - Though painful, laser/cavity feedback techniques are well know
  - Disadvantages for Sapphire
    - Very long cavity
      - technical noise (?)
      - Tight feedback as difficult as a highest finesse table top experiment…
        - » (BW may be limited by the laser frep)
    - Very small laser waists & circ. Polar. (?) ➔ careful optical design of the geometry and mirror shape
- Optical issues
  - High peak power
    - coating damage threshold➔ large mirrors
  - Large average power: thermal load effects
    - Thermal lens in the coupling mirror (cf VIRGO upgrade with >600kW)

Laser/cavity numerical feedback development







Rétroaction on laser frequency

Clk = 100 MHz
8x ADC 14 bits
8x DAC 14 bits => Filtering => 18 bits / 400 kHz
FPGA Virtex II