

Optimization of High Finesse Fabry Perot Cavity For ThomX

Manar AMER
ALEA group
Accelerator Pole

PHENIICS Fest 2022



Outline

- High Flux X-ray
- ThomX Accelerator
- **Fabry Perrot Cavity**
 - Challenges
- Results



High Flux X-ray

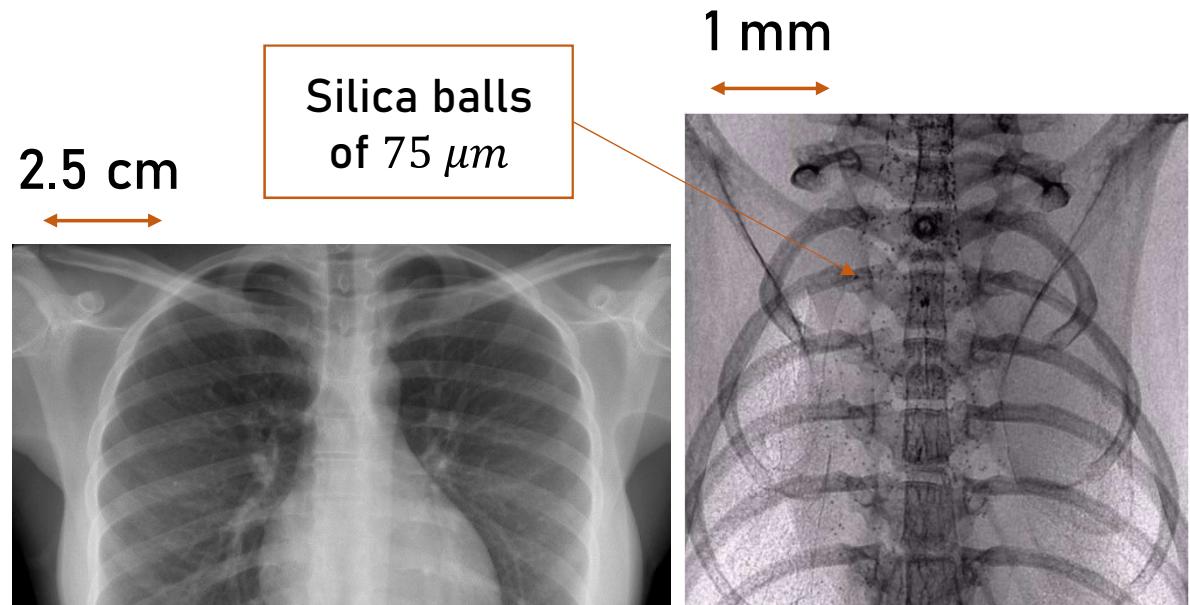
Art History



Pablo Picasso's 1902 painting *Mother and Child by the Sea*

Hidden Pictures, Physics World,
<https://physicsworld.com/a/hidden-pictures/>

Medicine

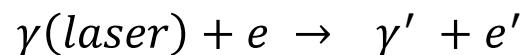


Standard radiography of a human chest
vs
Compton radiography of a mouse chest.



Inverse Compton Scattering as X-ray Source

- Dynamics of process:



- X-ray energy produced:

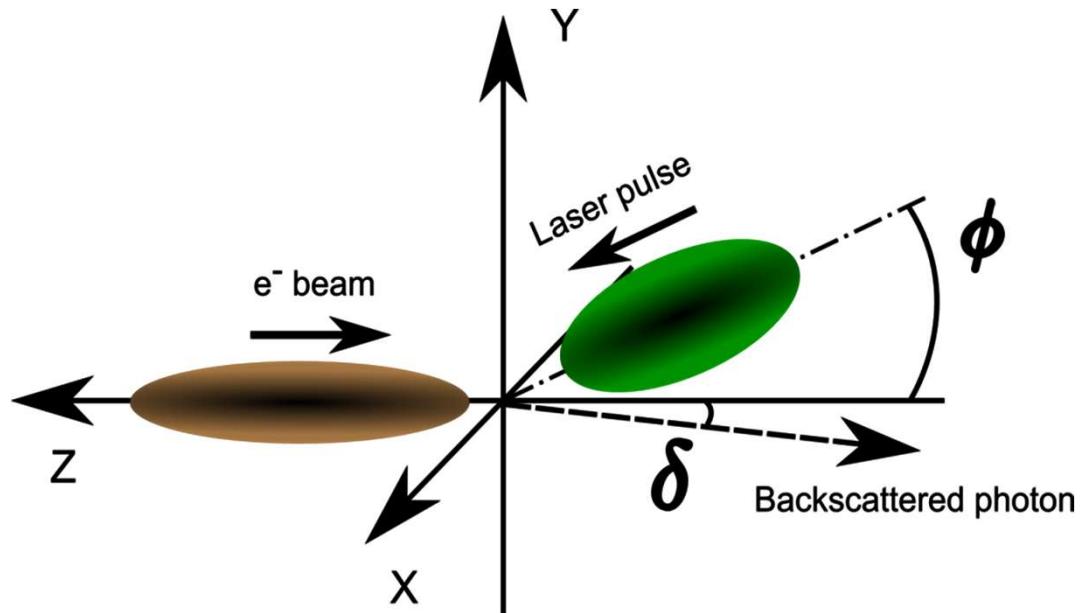
$$E_\gamma \simeq E_L \frac{4\gamma^2}{1 + \gamma^2\delta^2 + \frac{\phi^2}{4}}$$

γ : lorentz factor for electron energy

E_L : laser pulse energy

ϕ : collision angle

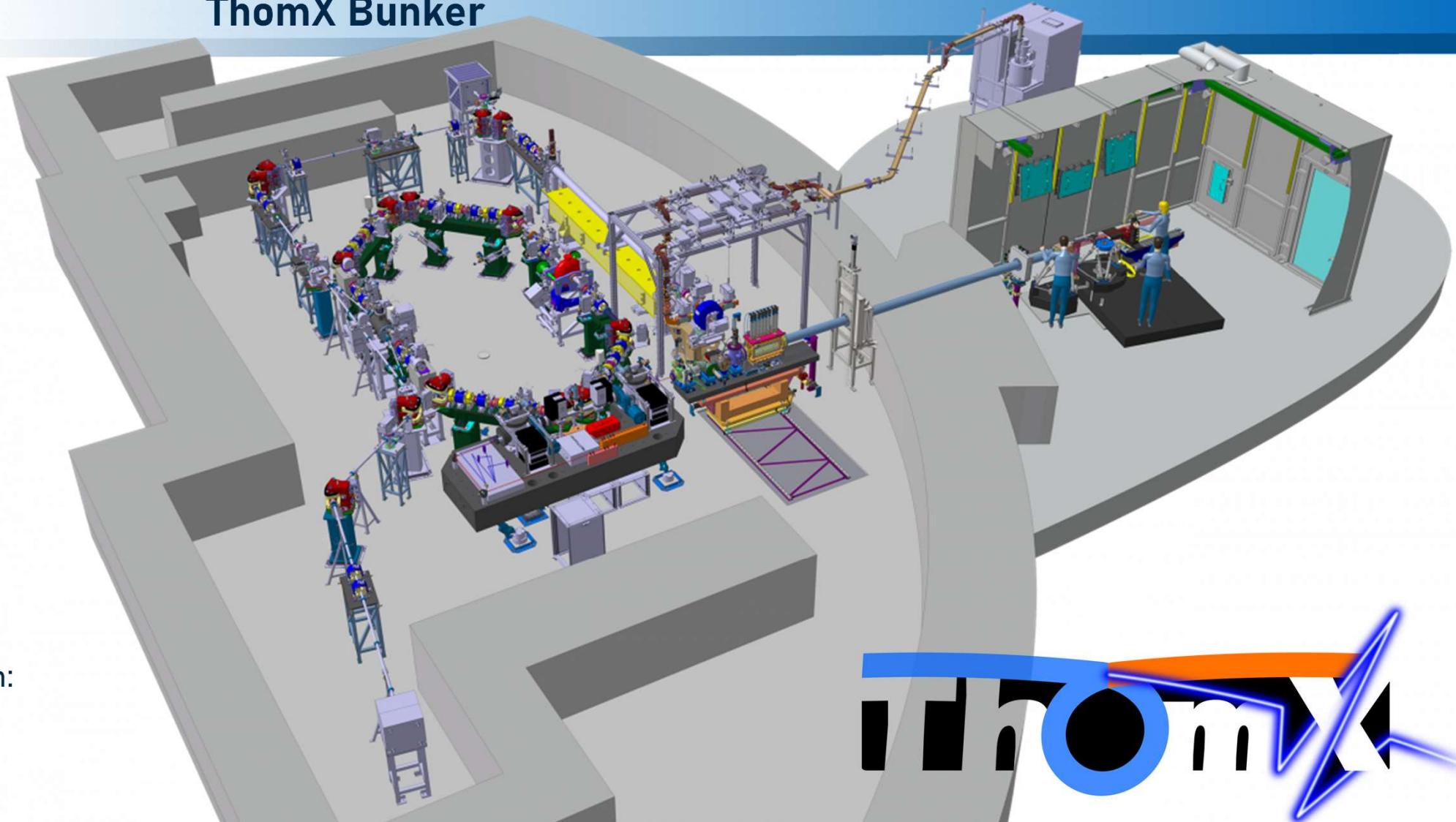
δ : scattering angle of X-ray



- Intrating laser power $\sim 600 \text{ kW}$
- $f_{rep} \sim 100 \text{ MHZ}$
- **x-ray flux $\rightarrow 10^{13} \frac{\text{photons}}{\text{s}}$**



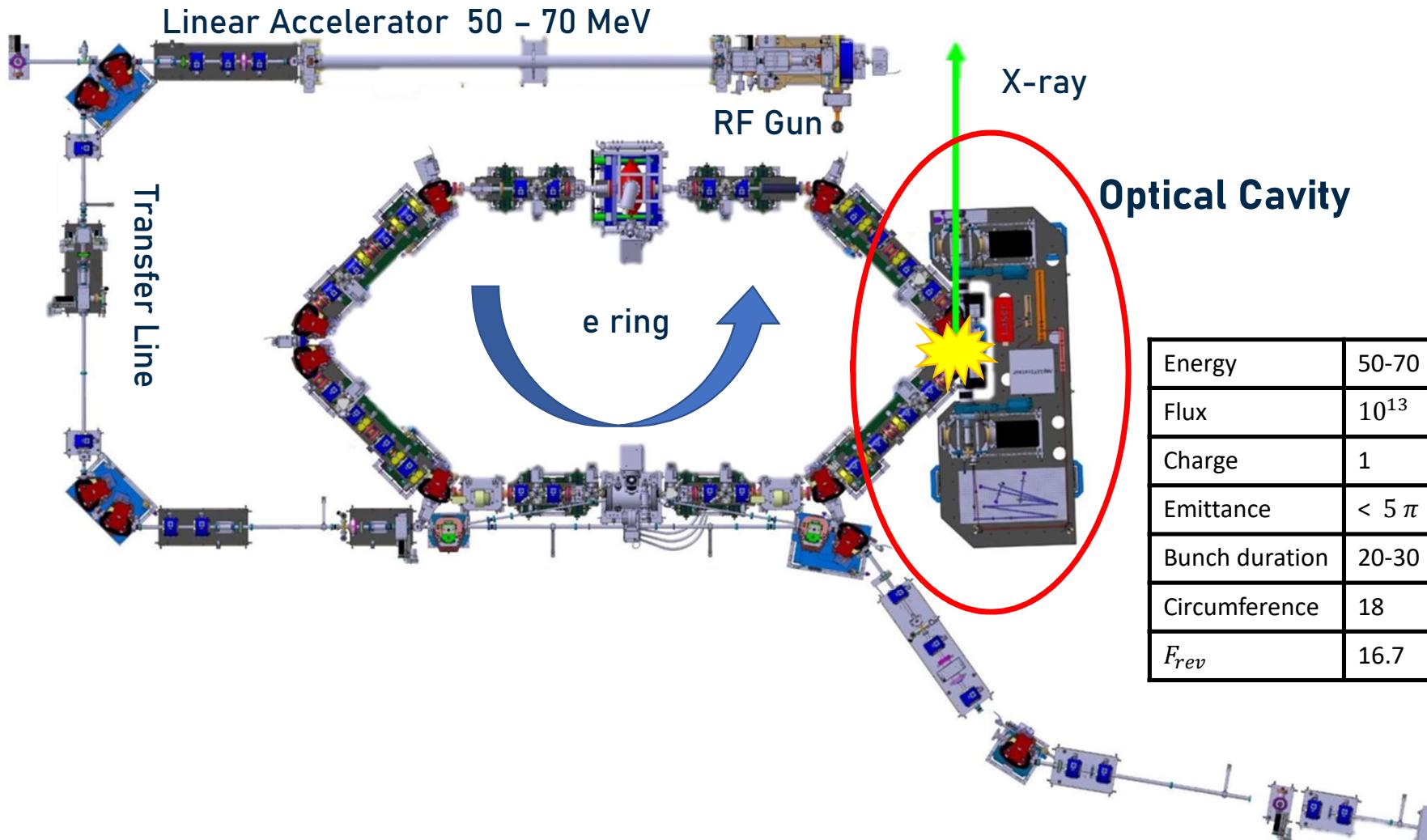
ThomX Bunker



Location:



ThomX : X-ray Production

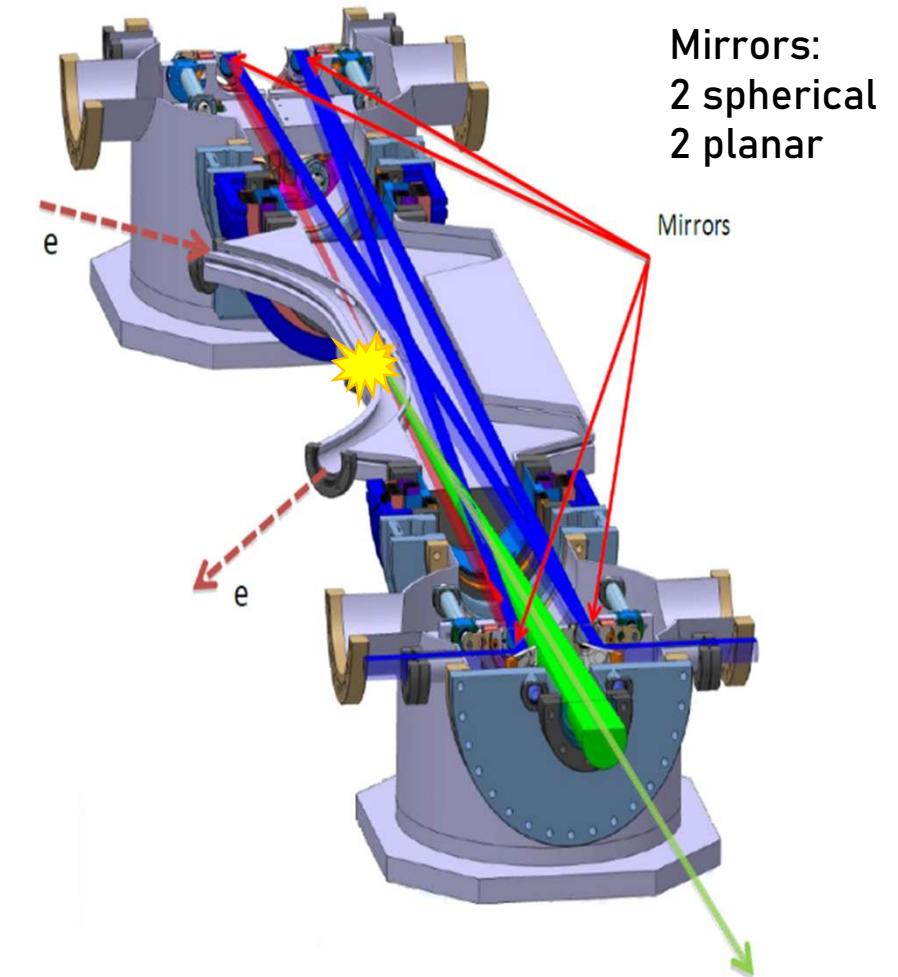




ThomX Fabry Perrot Optical Cavity

Fabry Perrot Cavity (FPC)

Cavity length	9	m
$\lambda_{injected\ laser}$	1030	nm
Laser waist	< 100	μm
Pulse duration	10	ps
Input laser power	50 – 100	W
Stored power	300 – 600	KW
Gain	10000	
Finesse	42000	
FSR	33.33	MHz

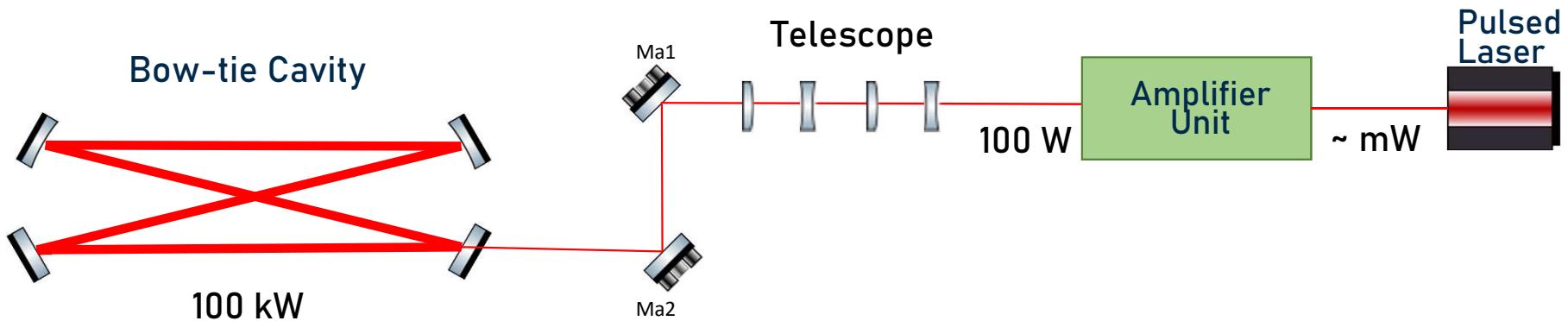




Why Fabry Perrot Cavity ?

- No laser with the required power needed
- Gain Factor from FPC helps store required power
- Control the stability at high power

Simplified Setup for Injecting power into fabry Perot Cavity

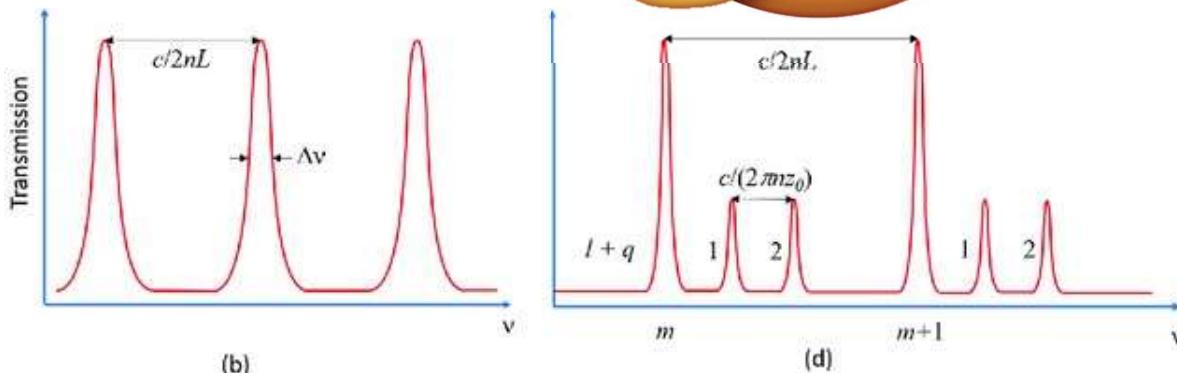




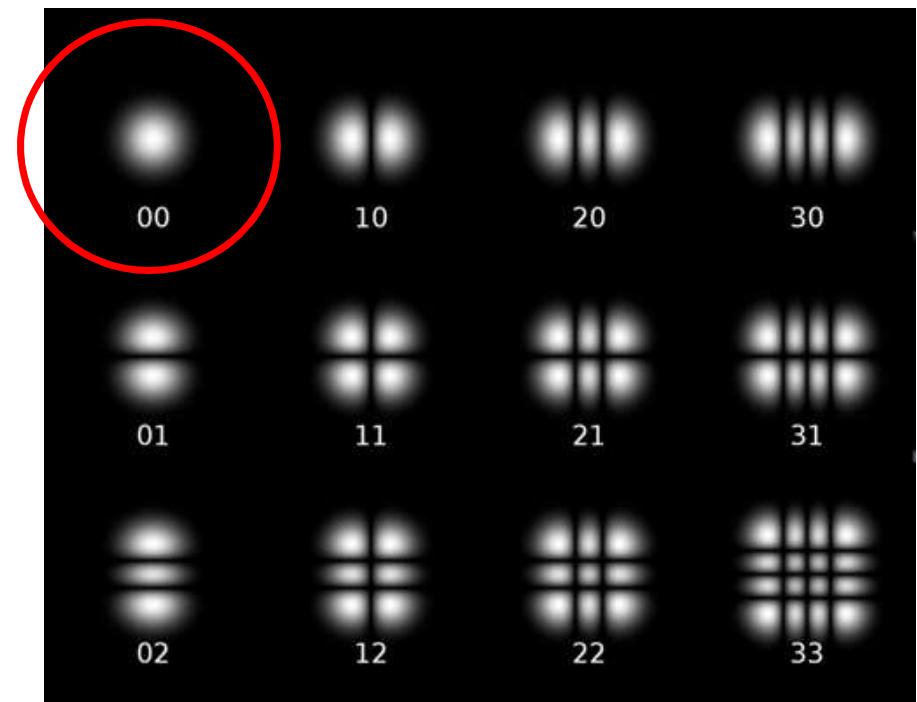
Mode to Amplify ? Hermite Gaussian Modes

All modes are present

- Excite only (00 mode)
- Maximum Finesse



Spatial energy distribution for Hermite-Gaussian modes.



Spatial energy distribution for Hermite-Gaussian modes.

* https://en.wikipedia.org/wiki/Gaussian_beam



Difficulties Faced

- Mirror Quality !! Coming from it's reflectivity
- Thermal effects
- Degeneracy modes



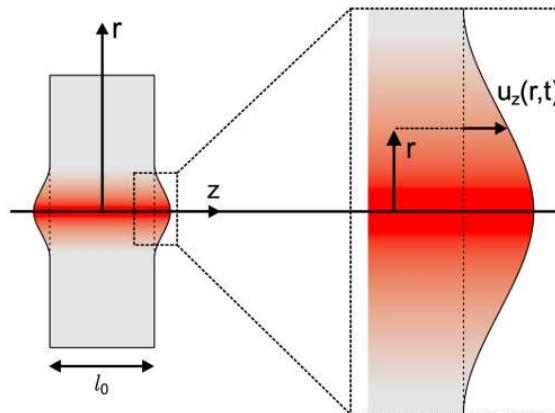
Image of ThomX mirror

Losses in Mirror :

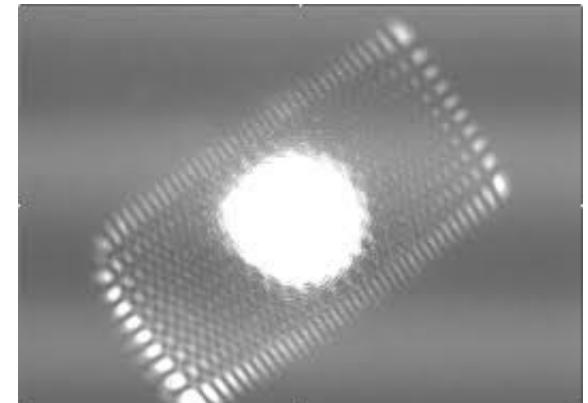
- Transmission T
- Absorption A
- Diffusion D

Reflection : $R \approx 1 - (T + A + D)$

Loss in order of ppm (part per million)



Thermoelastic deformation due to heating of the surface of the mirrors



Degeneracy with fundamental mode observed at transmission point of M2.

*Ref: Etude de cavités Fabry-Perot de hautes finesse pour le stockage de fortes puissances moyennes. Application à la source compacte de rayons X ThomX, Loic AMOUDRY

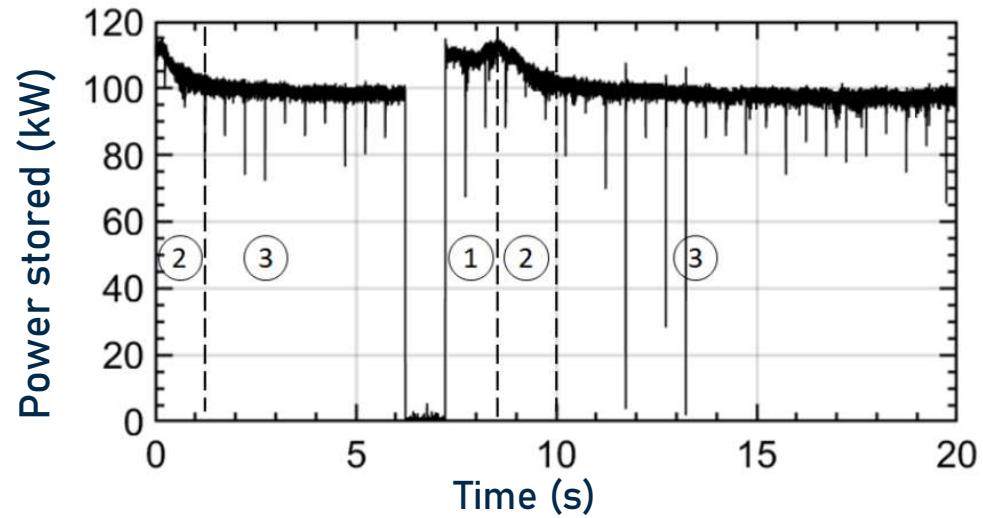
** Luis C. Malacarne, Nelson G. C. Astrath, and Mauro L. Baesso, "Unified theoretical model for calculating laser-induced wavefront distortion in optical materials," J. Opt. Soc. Am. B **29**, 1772-1777 (2012)



ThomX FP power storage Instability

- Power stored in ThomX FP cavity for 20 seconds
- Up to ~ 110 kW
- Unstable

Solution :
suppress higher order modes



Plot regions :

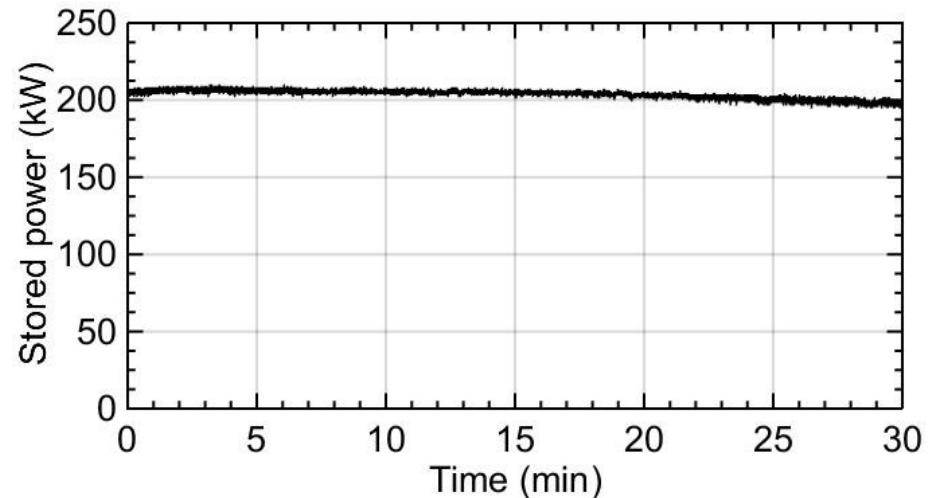
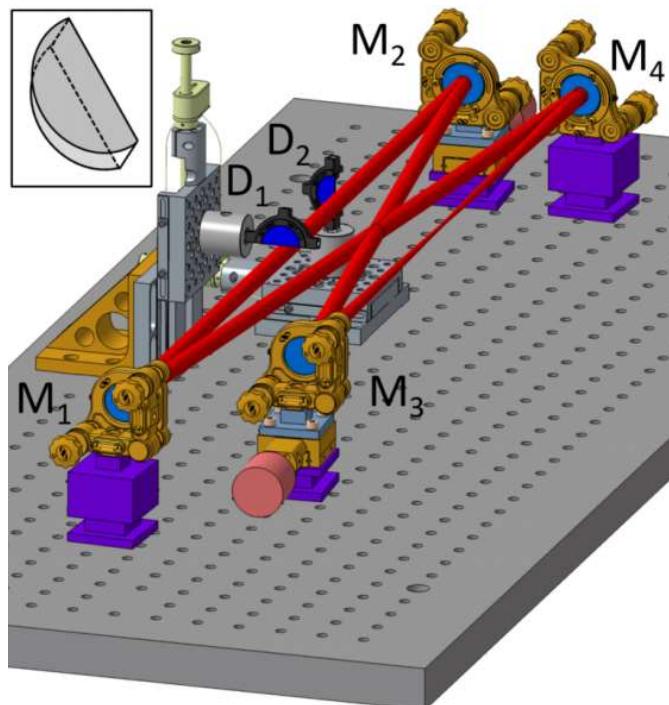
- 1) 00 mode by itself
- 2) 00 mode + degenerate mode
- 3) Stable region for 00 + degenerate mode

[1] Pierre Favier. Etude et conception d'une cavité Fabry-Perot de haute finesse pour la source compacte de rayons X ThomX. PhD thesis, 2017. Thèse de doctorat dirigée par Zomer, Fabian Physique des accélérateurs Université Paris-Saclay (ComUE) 2017.
[2] H. Carstens, N. Lilienfein, S. Holzberger, C. Jocher, T. Eidam, J. Limpert, A. Tunnermann, J. Weitenberg, D. C. Yost, A. Alghamdi, Z. Alahmed, Ä. Azzeer, A. Apolonski, E. Fill, F. Krausz, and I. Pupeza. Megawatt-scale average-power ultrashort pulses in an enhancement cavity. Optics Letters, 39(9) :2595–2598, May 2014. Publisher : Optical Society of America.



Higher Order Modes Suppression (Test Cavity)

- We installed D-shaped mirrors to suppress the higher order modes



Stable power stored for 30 min without loss

- Power increase up to 200 kW
- stable lock and no degeneracy

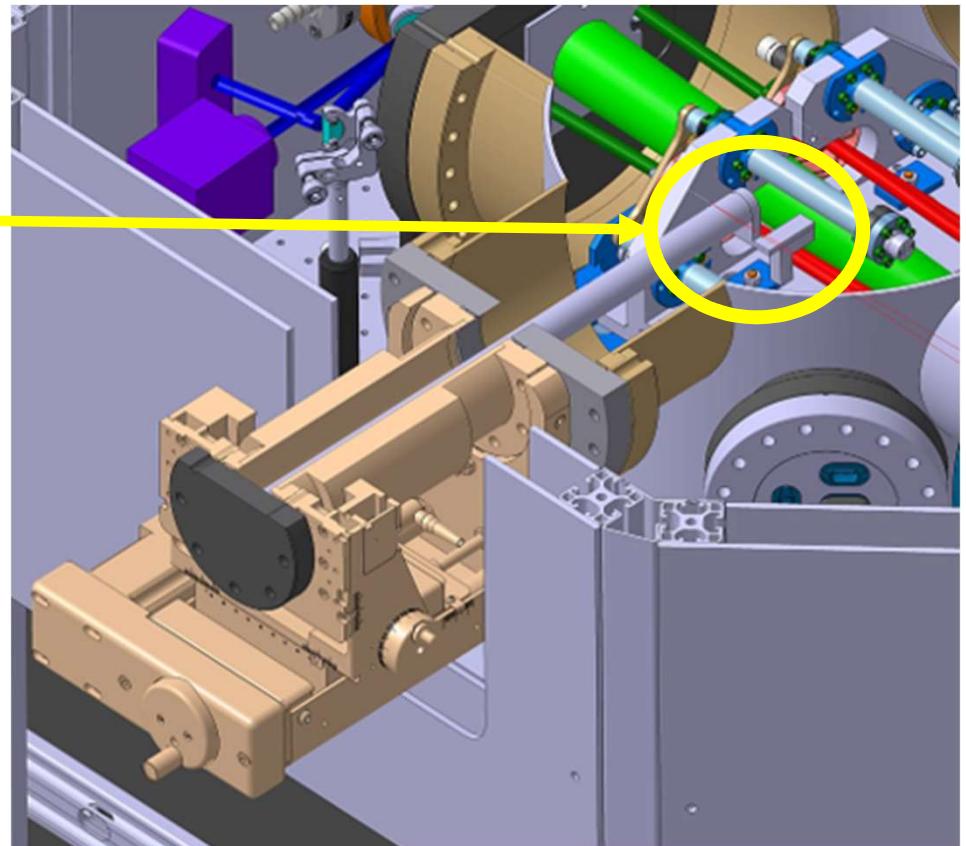
* Loïc Amoudry, Huan Wang, Kevin Cassou, Ronic Chiche, Kevin Dupraz, Aurélien Martens, Daniele Nutarelli, Viktor Soskov, and Fabian Zomer. Modal instability suppression in a high-average-power and high-finesse Fabry–Perot cavity. *Applied Optics*, 59 :116–121, January 2020. Publisher : Optical Society of America.



ThomX FP L-shaped mirror

L-shaped mirror installed in ThomX FP
for Higher order modes suppression

To be tested !!



*Ref: Etude de cavités Fabry-Perot de hautes finesse pour le stockage de fortes puissances moyennes. Application à la source compacte de rayons X ThomX, Loic AMOUDRY



ThomX FP cavity

FP cavity was moved into the commissioning location of ThomX last May 2021

Start testing its status

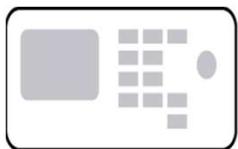


*Ref: Etude de cavités Fabry-Perot de hautes finesse pour le stockage de fortes puissances moyennes. Application à la source compacte de rayons X ThomX, Loic AMOUDRY

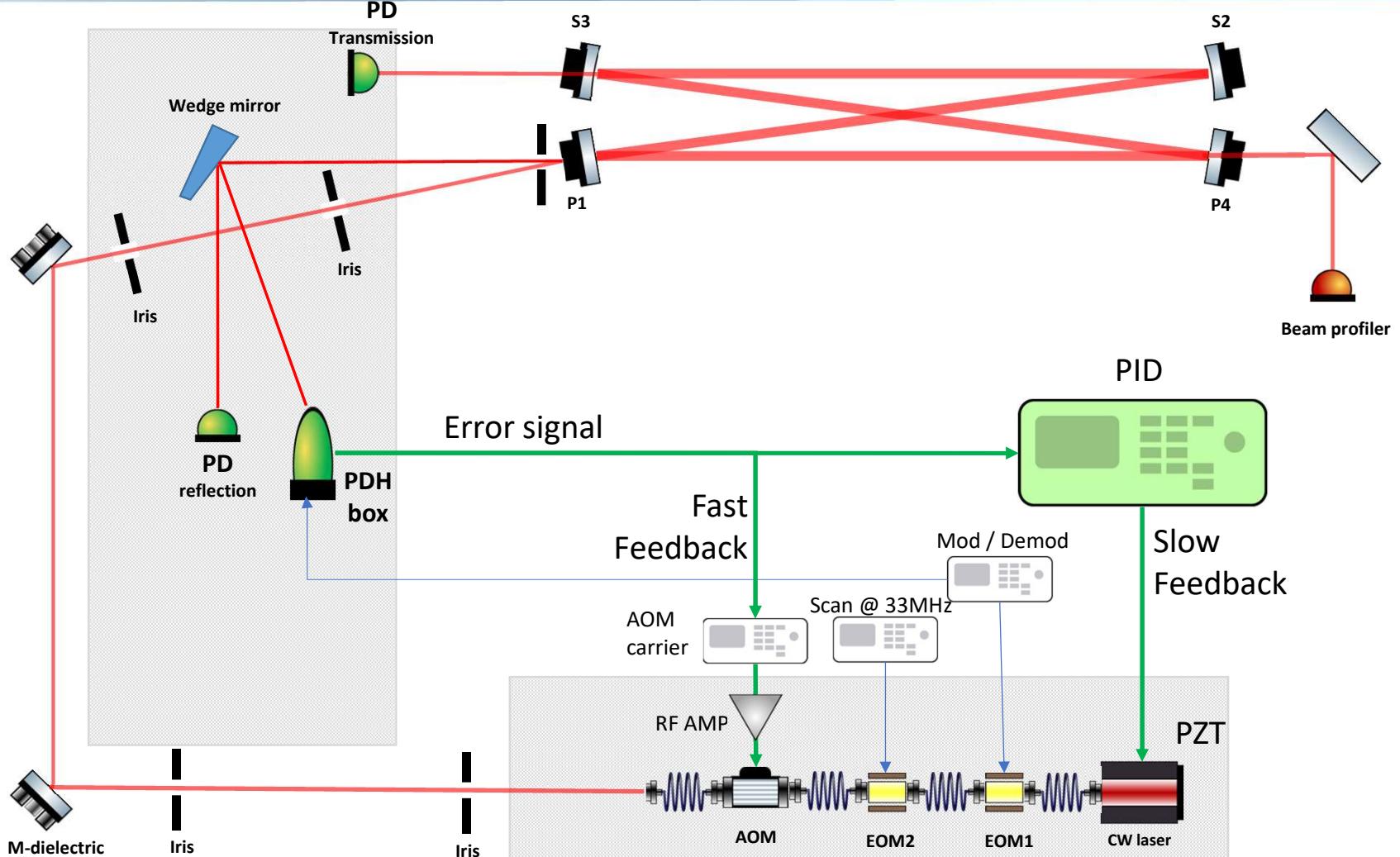


ThomX FP - Finesse Measurement Setup

oscilloscope

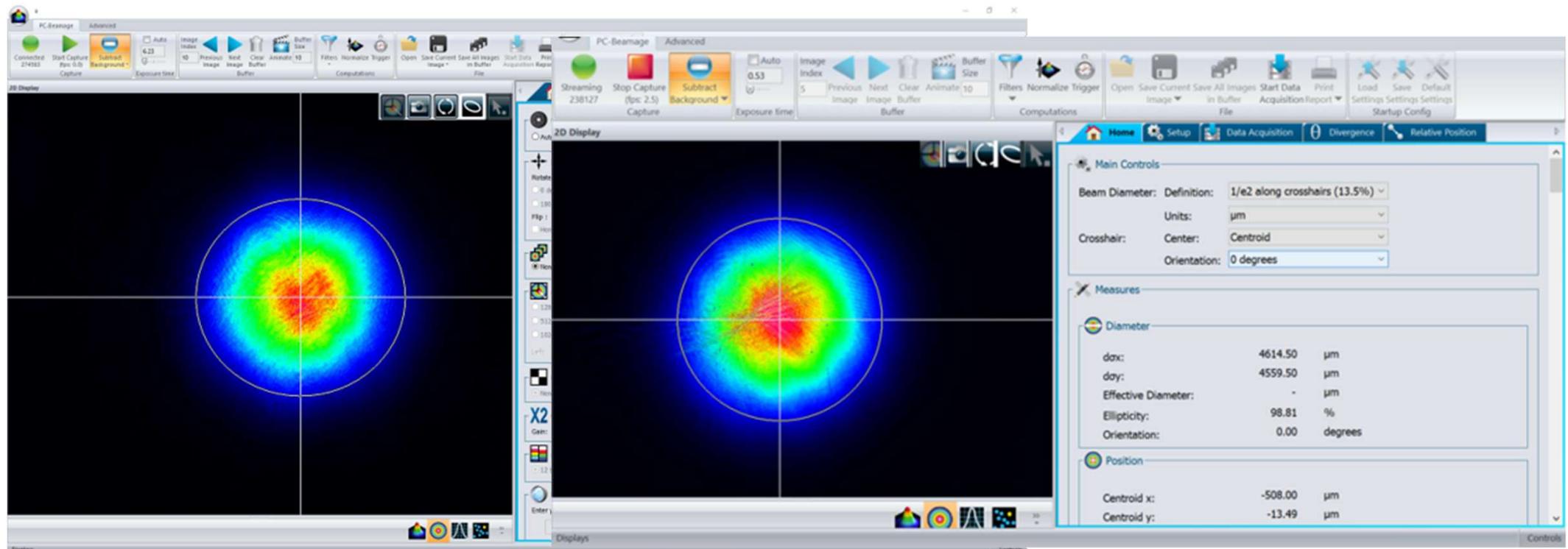


Control Computer





TM00 Mode for ThomX FP cavity



Present beam shape
Using M1 FUSED SILICA

Image from logbook in
November 2019
M1 is the new FUSE SILICA
mirror ($F \sim 17\text{k}$)



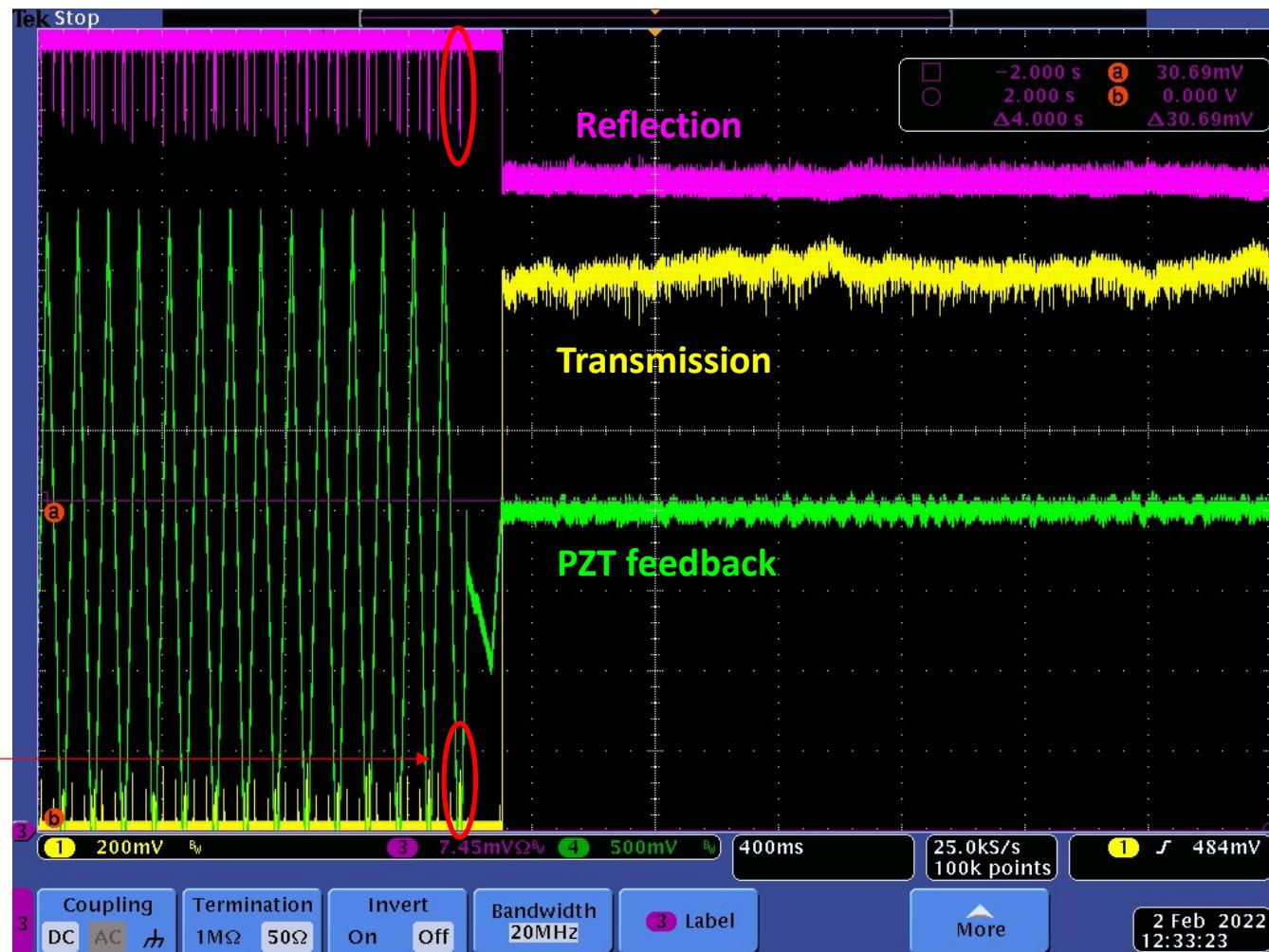
Lock of the cavity

Oscilloscope Screen showing measured voltage for

- Transmission “yellow”
- Reflection “purple”
- PZT (Piezoelectric) “green”: The voltage scan applied on CW laser

Two regions correspond to unstable the stable locking feedback loop

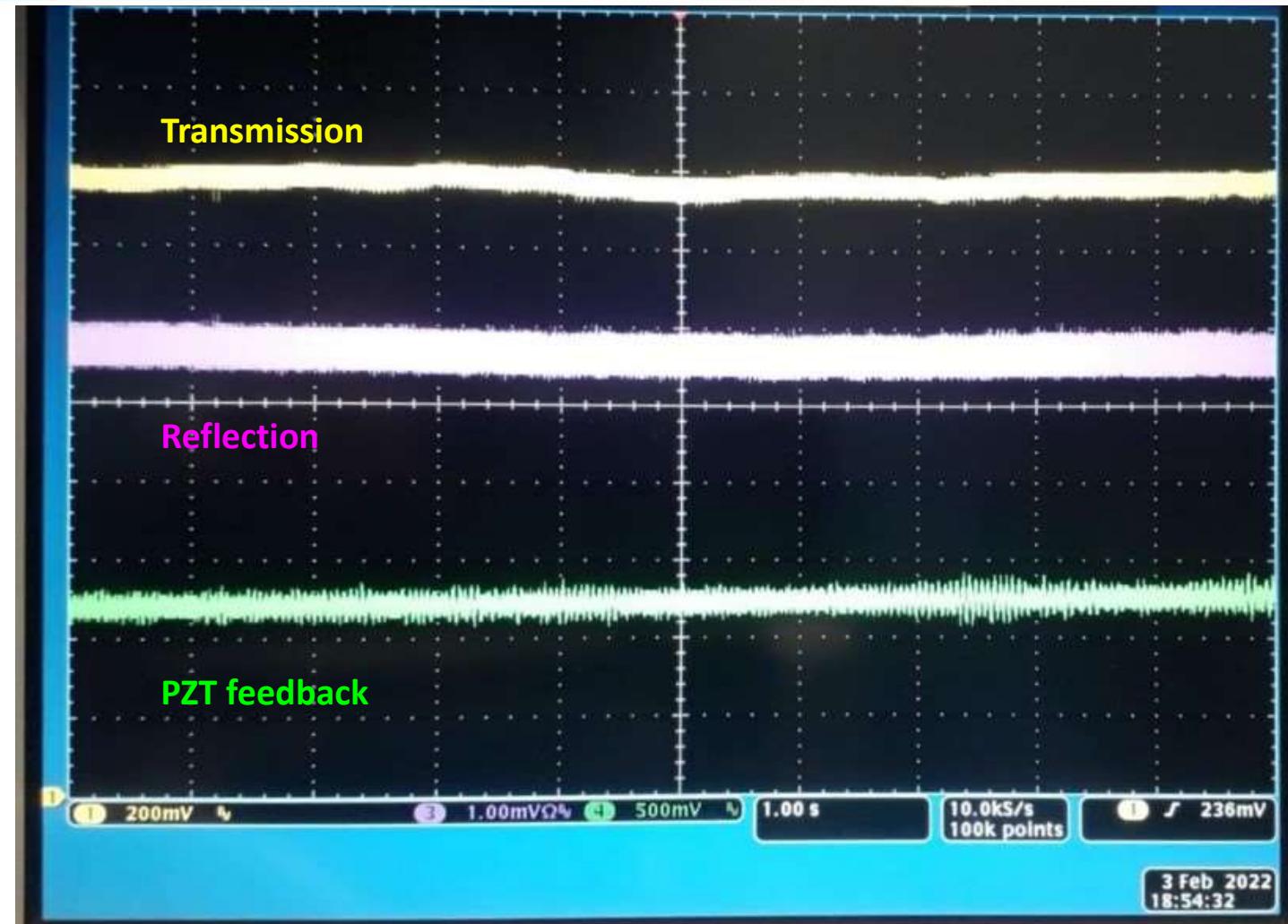
Spikes correspond to 00 mode beating in the cavity





Lock of the Cavity

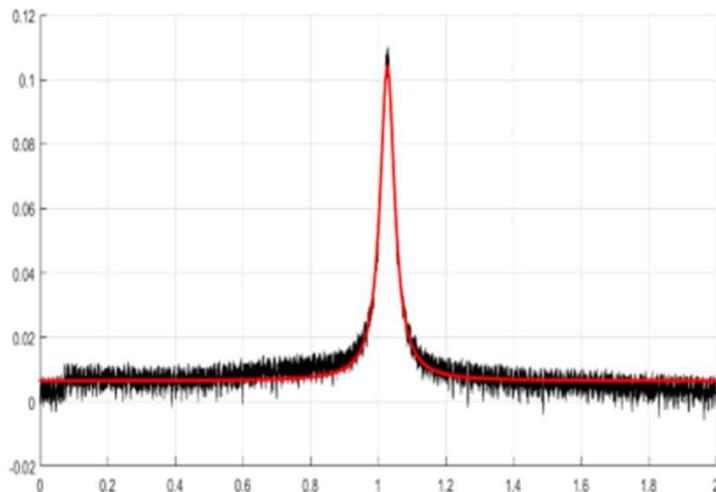
- Coupling of ~ 20% obtained





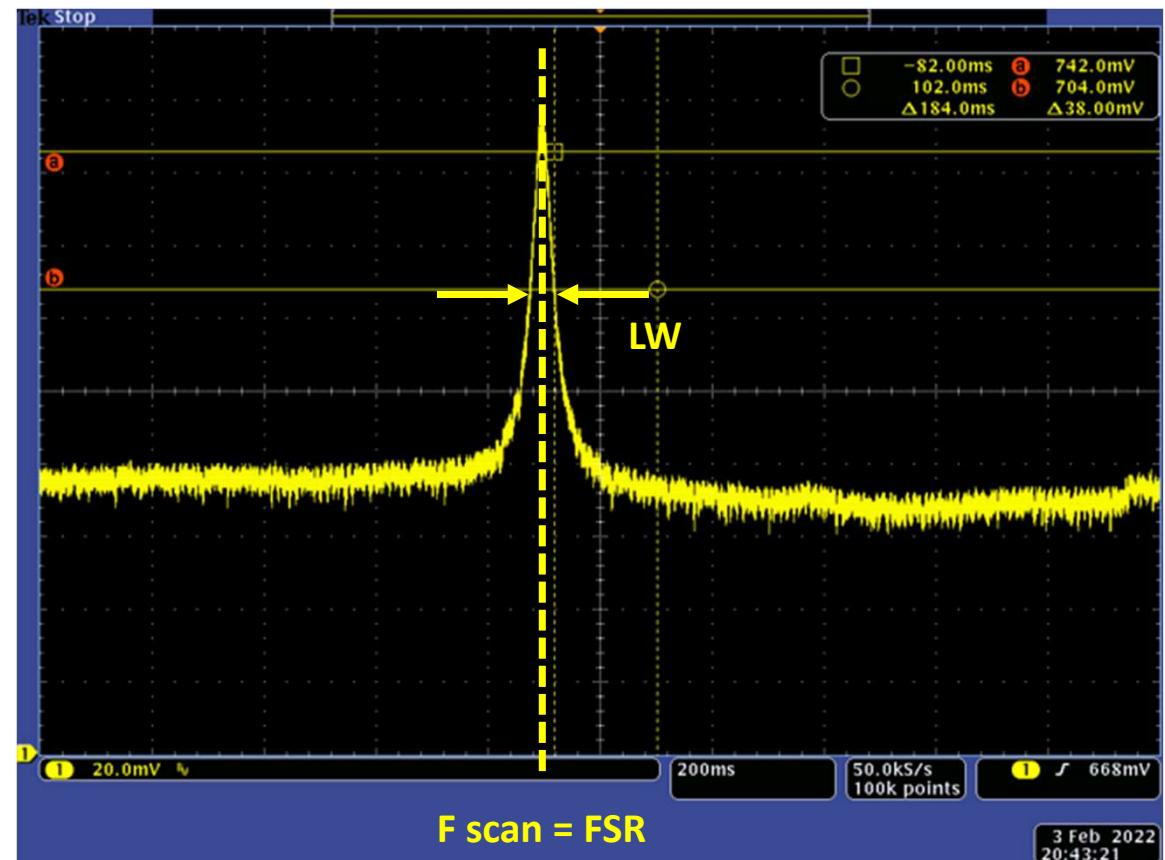
Finesse Signal Analysis

Scan speed = 300kHz / 2s = 15kHz / div



Airy peak fit => LW (*FWHM*) = 8 KHz

$$\mathcal{F} = \frac{FSR}{FWHM} = \frac{33.34\text{MHz}}{8\text{KHz}} \boxed{\cong 4200}$$



Oscilloscope signal for transmission



Theoretical and Measured Finesse and Gain

Mirrors parameters : Laboratoire des Matériaux Avancés (LMA)

Miroirs à 1031 nm, incidence moyenne 1,146°, TohmX
Empilements Quart d'onde

Référence LMA	Absorption à 1064 nm (ppm)	Diffusion moyenne à 1064 nm (ppm)	Diffusion moyenne à 1064 nm au centre (ppm)	Transmission à 1064 nm, au centre (ppm)	Transmission simulée à 1031 nm (ppm)
C16116/11+C16111/11 Concave – sub n°5 ULE T<5 ppm à 1031 nm	0,27	6 Ø 16 mm	4,5 Ø 6 mm	1,5	#1,5 ppm
C16116/11+C16111/11 Plan – sub n°6 ULE T<5 ppm à 1031 nm	0,24	8,5 Ø 16 mm	4,5 Ø 6 mm	1,5	# 1,5 ppm
C16116/11+C16111/11 Concave – sub n°7 ULE T<5 ppm à 1031 nm	0,24	14 Ø 16 mm	10 Ø 6 mm	1,5	# 1,5 ppm
S19063 Plan Fused Silicate	< 1	2,6 D 12 mm	<2,6	172	140 ppm

Theoretical Finesse:
=> F = 37k / G = 20k

Realistic Finesse with + 10ppm losses/mirror
=> F = 30k / G = 13k

Best measured: F = 17k / G = 4k
=> + 50ppm losses/mirror

Present measured: F = 4,2k / G = 250
=> +330ppm losses/mirror

To Improve the Finesse:

- Alignment
- Restore the mirrors quality, Inspect it and by Cleaning dust particles.
- New Mirrors (Ordered from LMA)

$$G = \frac{T_1}{(1 - \rho)^2} \cdot T_1 \left(\frac{F}{\pi} \right)^2$$

$$\rho = r_1 r_2 r_3 r_4$$



Thank you for your Attention