BMV Project :

Final results on photon oscillations into massive particles

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Detecting axions : an experimental challenge

- Introduced to solve the strong CP problem

- Boson
- Neutral
- Very low mass
- Weak and strong forces : very low cross section

$\Rightarrow$ Hardly interact with ordinary matter

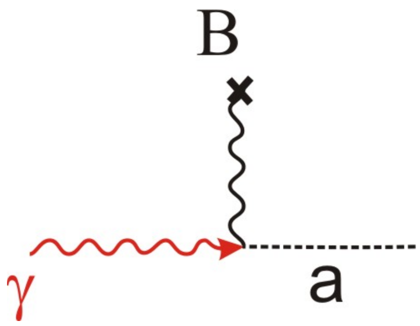
Axion = extremely difficult to detect

Axion coupling to photon

❑ Coupling to photon :

Oscillation between two states :

- photon (polarisation // B)
- axion



Primakoff effect

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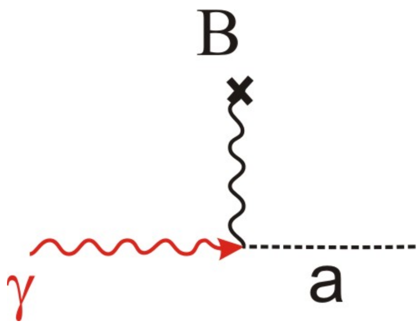


Primakoff effect

❑ In a constant magnetic field B over a length L :

$$p(L) = \left(\frac{2B\omega}{Mm_a^2}\right)^2 \sin^2\left(\frac{m_a^2 L}{4\omega}\right)$$

ω = photon energy

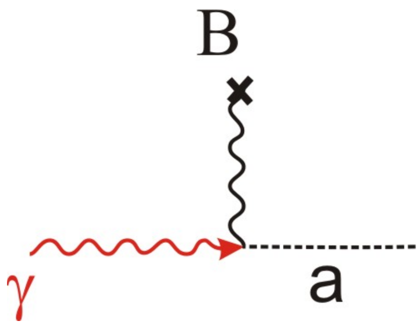
❑ Parameters :

- m_a axion mass
- $g_{a\gamma} = 1/M$ coupling constant

Axion coupling to photon

- **Coupling to photon :**

  Oscillation between two states :
  - photon (polarisation // B)
  - axion



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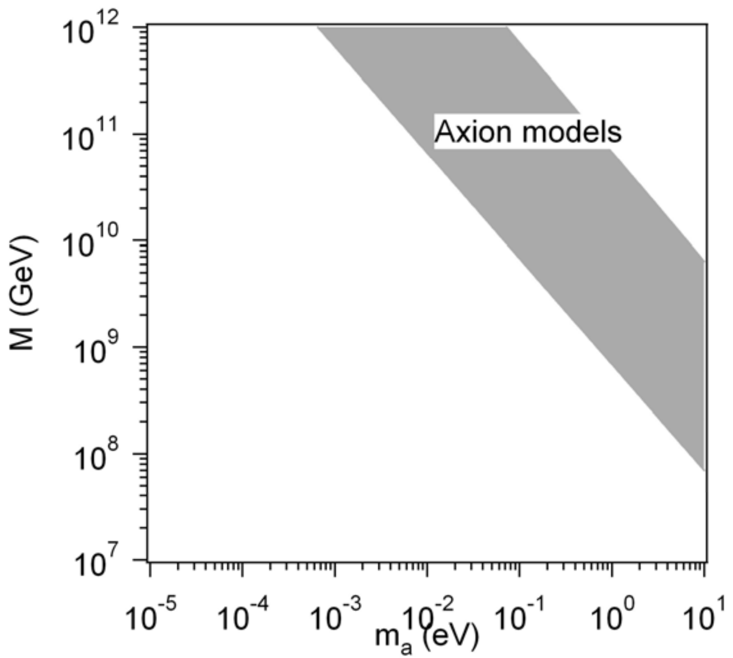


- **Parameters :**
  - m_a axion mass
  - $g_{a\gamma} = 1/M$ coupling constant

Two types of experiments : Solar or cosmic origin

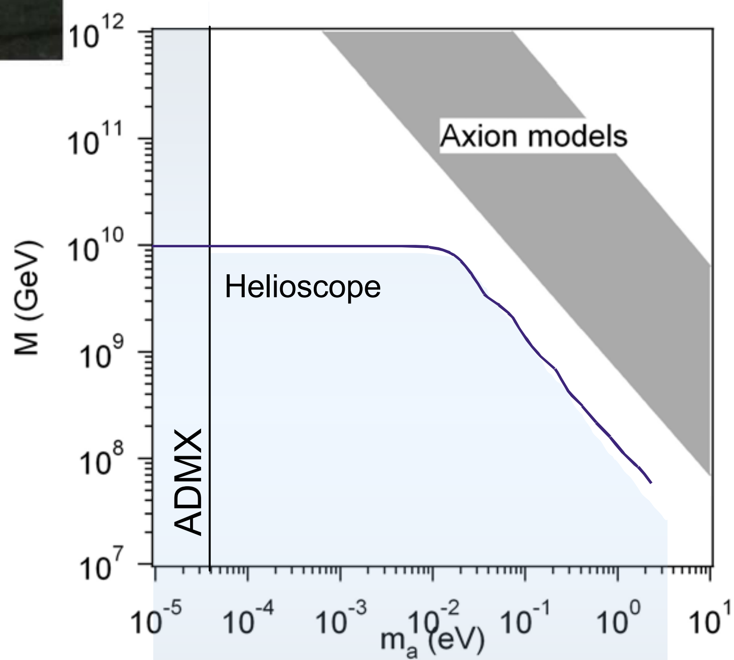
- Axion source :
  - solar origin CAST

  - cosmic origin ADMX

S. J. Asztalos et al., Phys. Rev. D **69**, 011101 (2004)

- Detection : on earth

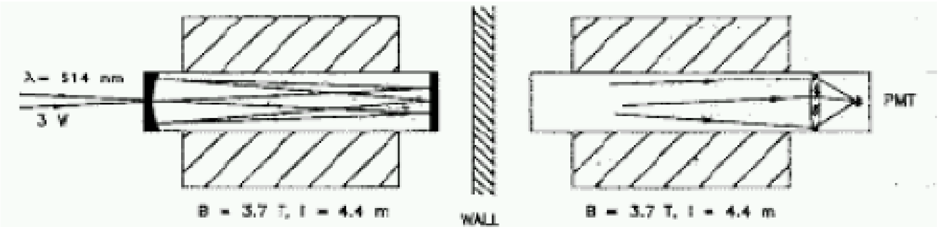
No axion detected



Two types of experiments :
Purely terrestrial experiment

- Axion source and detection : on earth

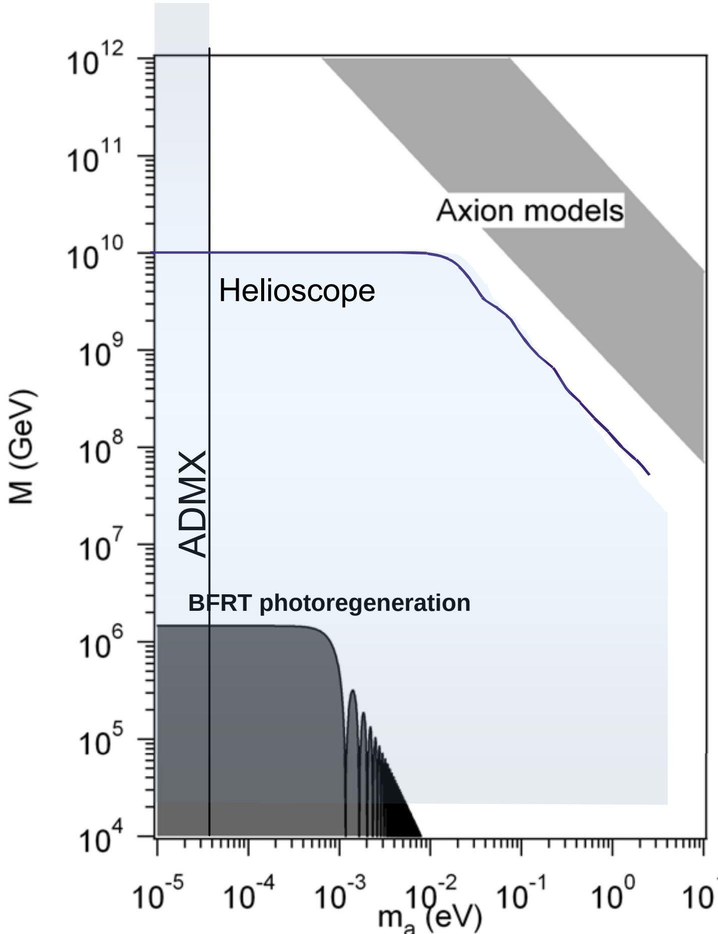
  - Light shining through the wall :



R. Cameron et al., Phys. Rev. D **47**, 3707 (1993)

No axion detected

  - PVLAS (QED test) :



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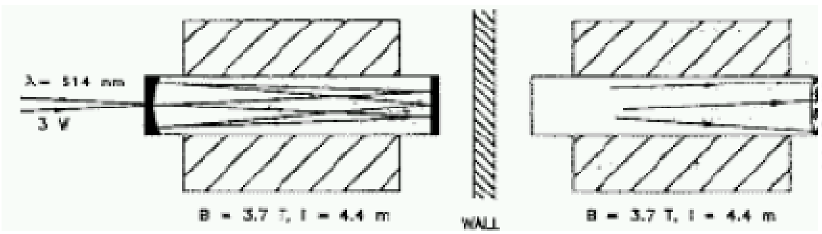
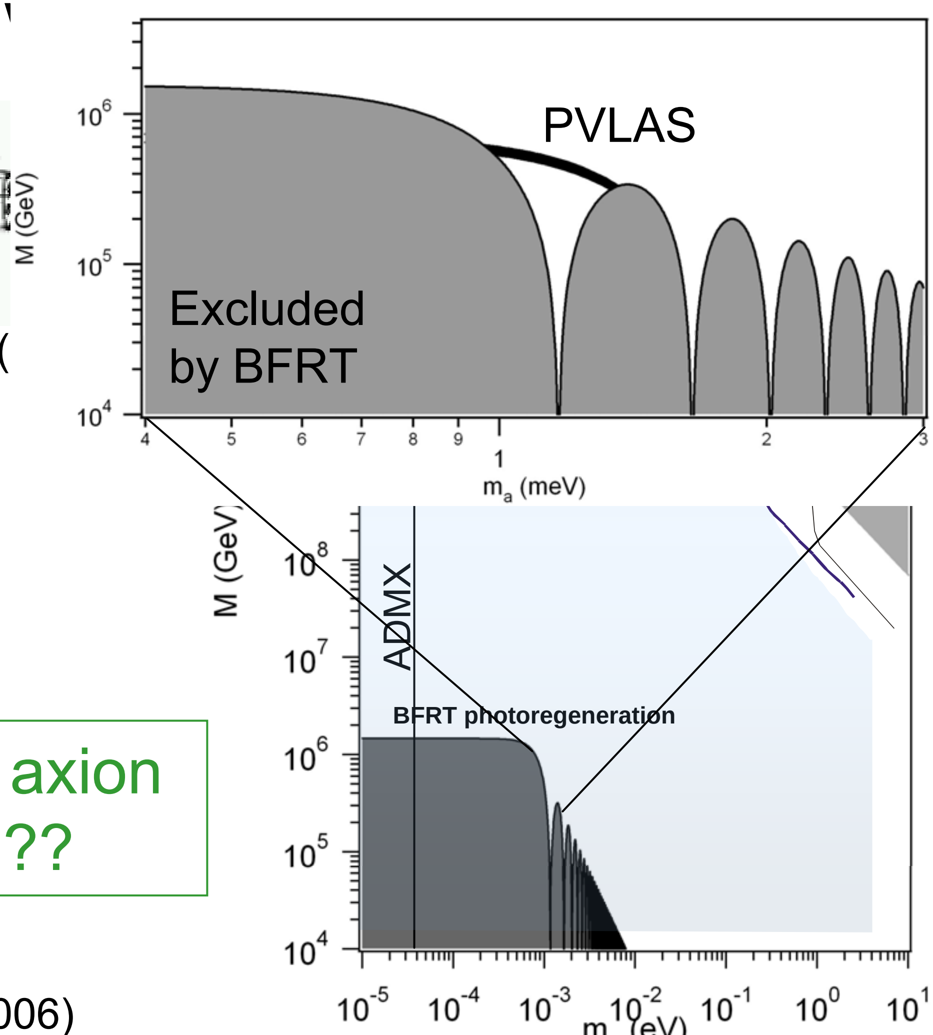


R. Cameron et al., Phys. Rev. D **47**, 3707 (

No axion detected

  - PVLAS (QED test) :

In 2006 : First axion detection ???



E. Zavattini et al., Phys. Rev. Lett. **96**, 110406 (2006)

Outline

1) **Our light shining through the wall experiment**
   - Setup
   - Key elements : laser, B, detector
   - Synchronization

2) **Results**
   - Interpretation
   - Inverse coupling constant vs axion mass
   - Comparison with other experiments

3) **Oscillations into other massive particles**
   - Paraphoton case
   - Results

Conclusion & Outlooks

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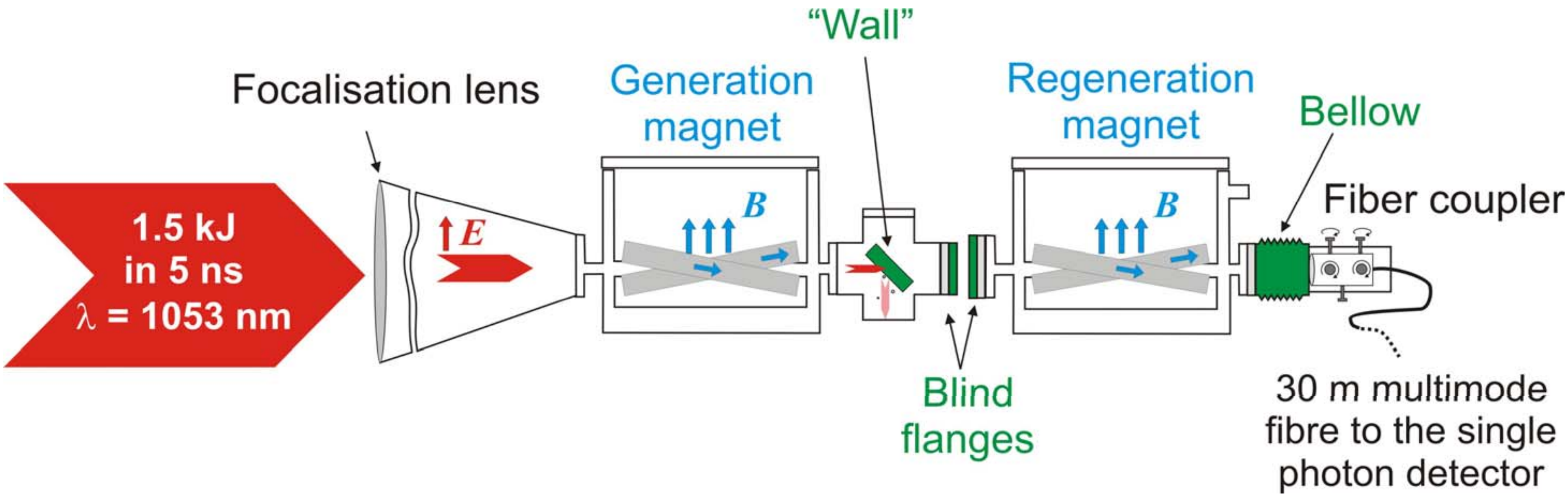
Principle of the experiment



Number of regenerated photon :

$$N_{RP} = \eta \times N_i \left(\frac{BL}{2M} \right)^4 \frac{\sin^4(y)}{y^4} \quad \text{with } y = \frac{m_a^2 L}{\omega}$$

- N_i Number of incident photons
- L magnet length
- η detection efficiency

The three key elements

Number of regenerated photons :

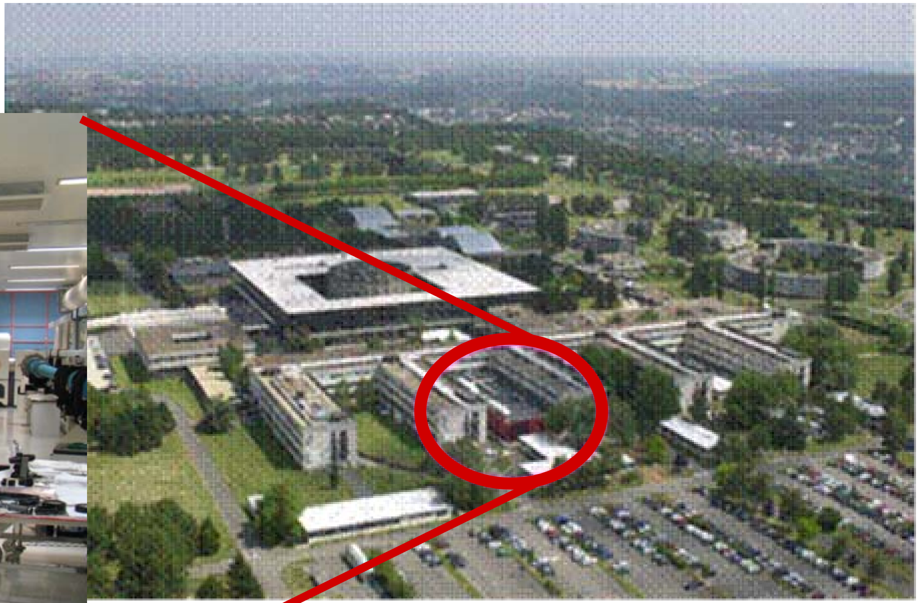
$$N_{RP} = \eta \times N_i \left(\frac{BL}{2M}\right)^4 \frac{\sin^4(y)}{y^4}$$

with $y = \dfrac{m_a^2 L}{\omega}$

N_{RP} as high as possible $\Rightarrow$

1. Laser : High N_i
2. Coils : high BxL
3. Photon detector : high detection efficiency η

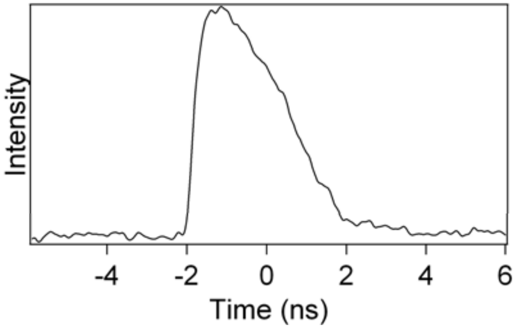
1. Nano 2000 Laser Chain (LULI)



- 1 to 1.5 kJ / pulse
- λ = 1053 nm

$\Rightarrow N_i = 5$ to 8×10^{21} / pulse

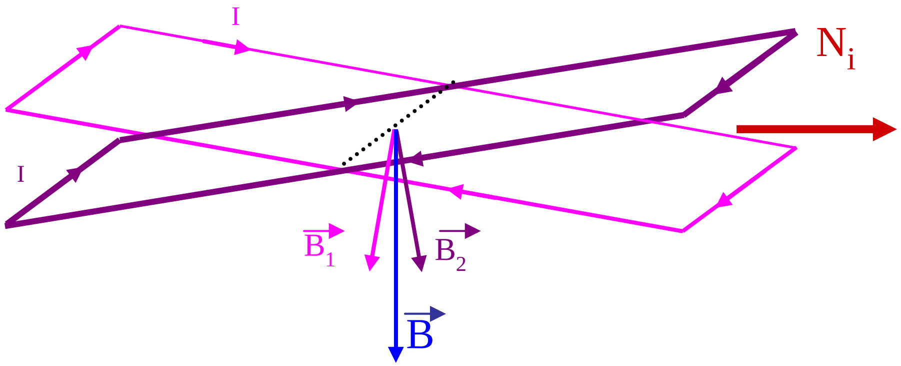
- Pulse duration = adjusted between 3 to 5 ns



- 5 to 6 pulses / day

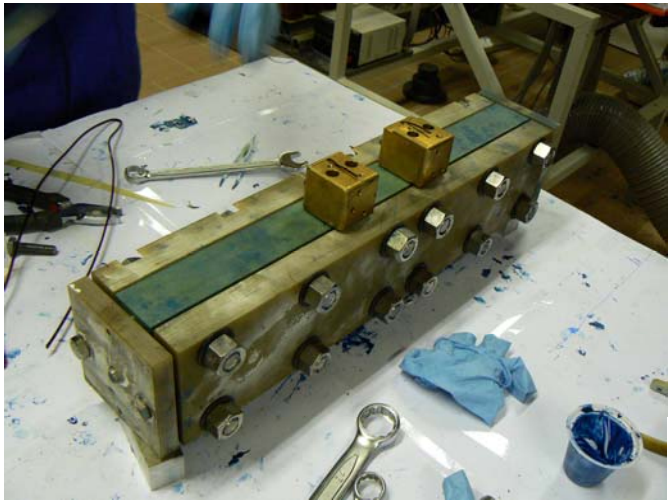
2. Coils Development (LNCMP)

X coil geometry ⇒ high transverse magnetic field

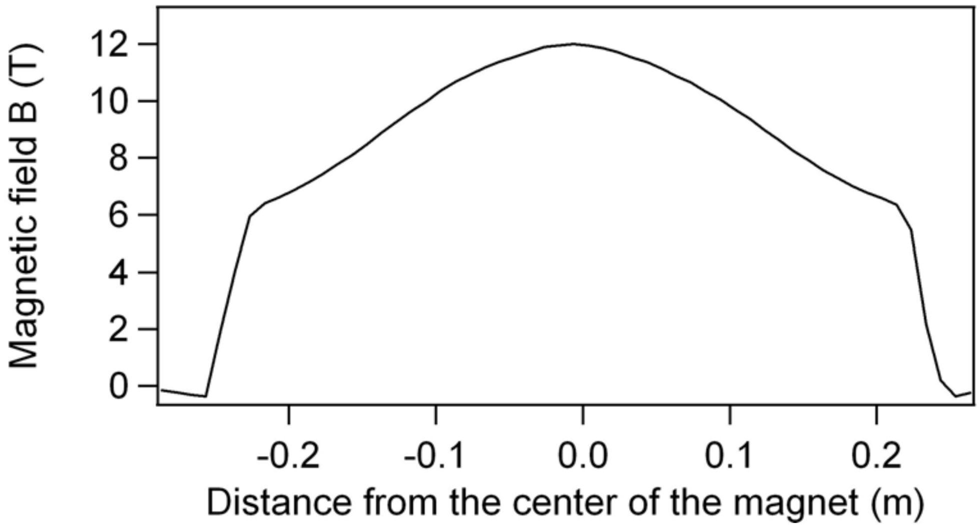


- Length = 45 cm
- Aperture = 12 mm

Coils originally developed for the BMV experiment by S. Batut & O. Portugall.



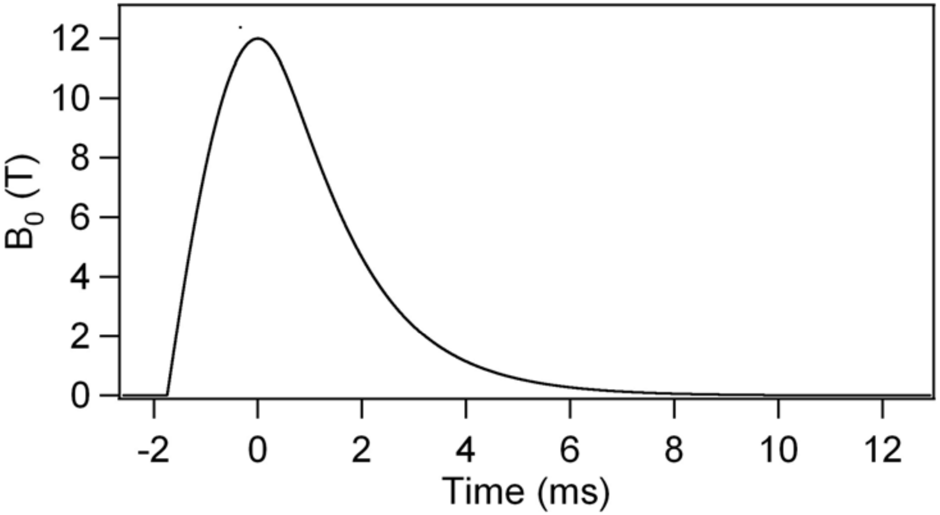
2. Coils test (LNCMP)



B_0 > 12 T over 36 cm

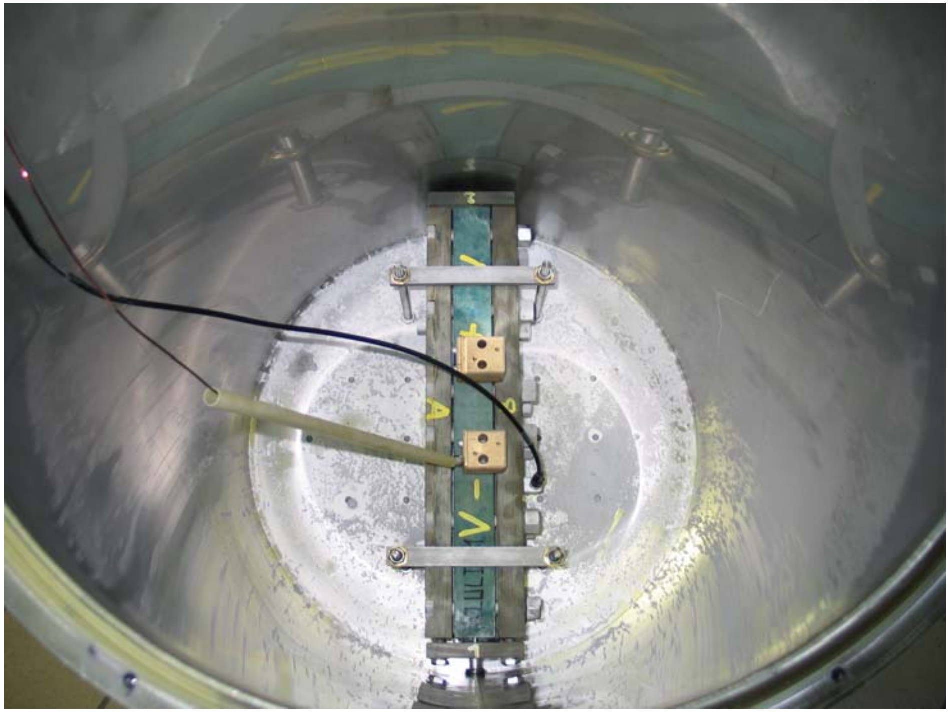
⇒ B.L = 4,3 T.m

- Time duration : 5 ms
- B_0 reached within 1.75 ms
- B_0 (+/- 0.3 %) during 150 μs



2. Coils cryostats (LNCMP)

Immersion in liquid nitrogen



3. Detection

❑ Single photon Detector :

Commercially available from Princeton Lightwave Instruments

- 80x80 mm^2 APD optimizes at 1064 nm
- Geiger mode with detection gate = 5 ns
- Coupling through a fibre

❑ Fibre link :

- 30 m long ⟹ avoid electronic noise due to XCoils

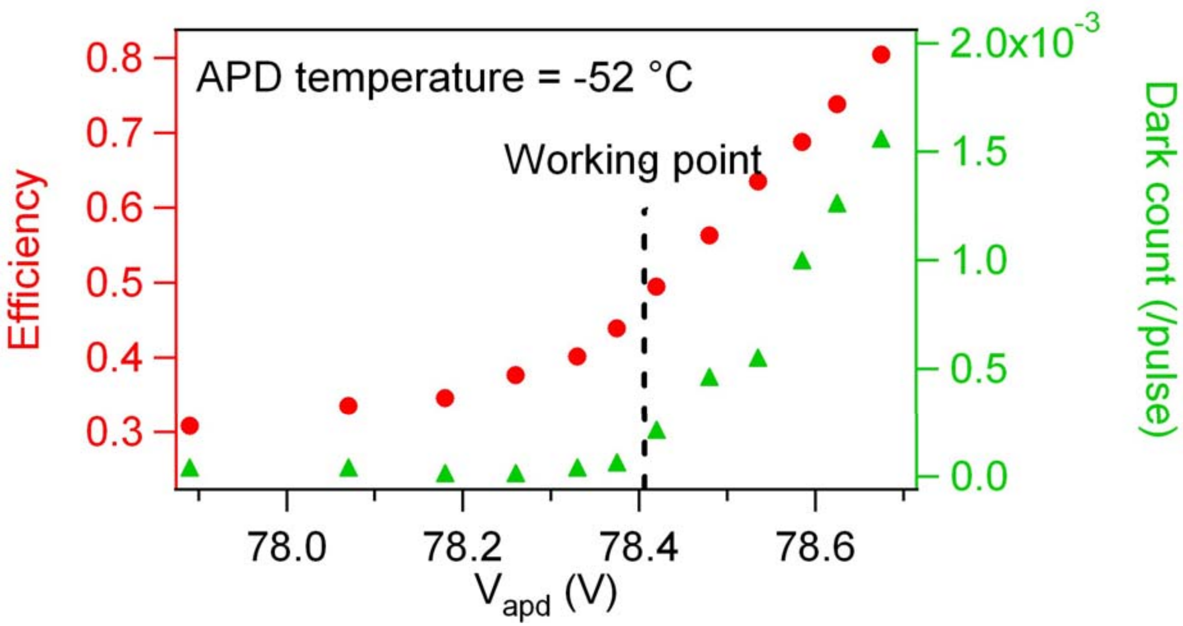
3. Detector Test (LCAR)

❑ Goals :

- High detection efficiency
- low dark count rate

❑ Adjustments :

- Temperature
- Bias voltage
- Discriminator threshold



Tests performed with cw Nd:YAG monomode laser.

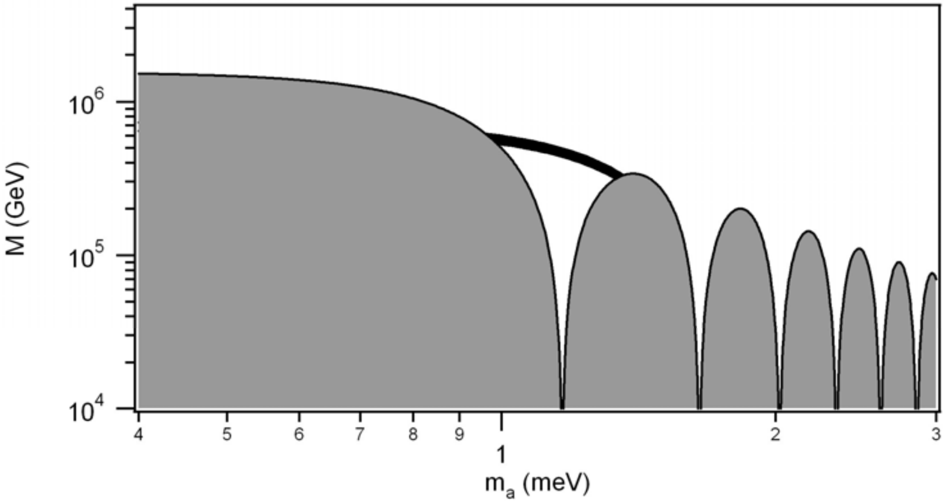
Dark count rate = 2.5×10^{-4} / Pulse

$\eta = 0.48$

Performance

❑ Expected results :

- After 5 pulses : test PVLAS results (2σ confidence level)



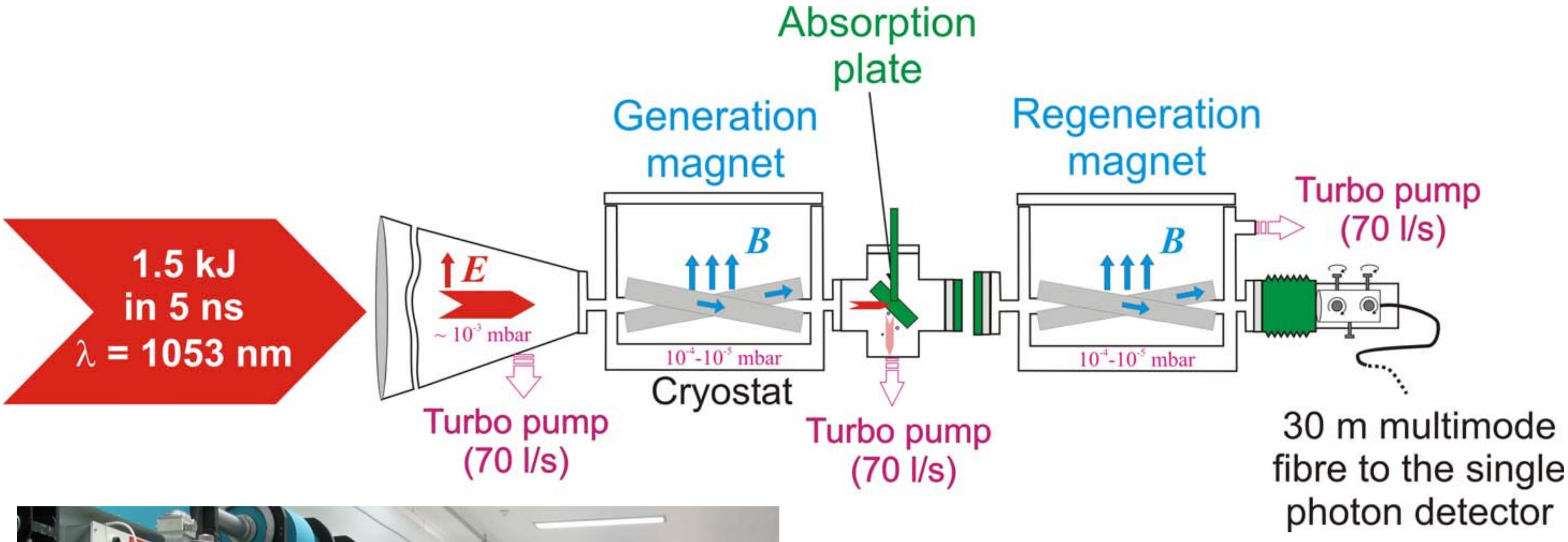
❑ Characteristics of our experiment :

•Pulsed experiment

⇒ background not limiting

•Limited number of pulses / year

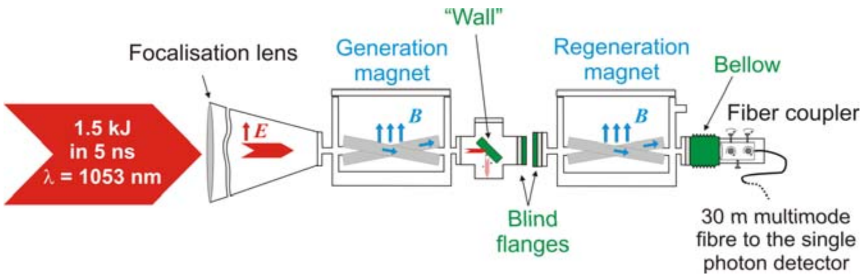
Implementation at LULI

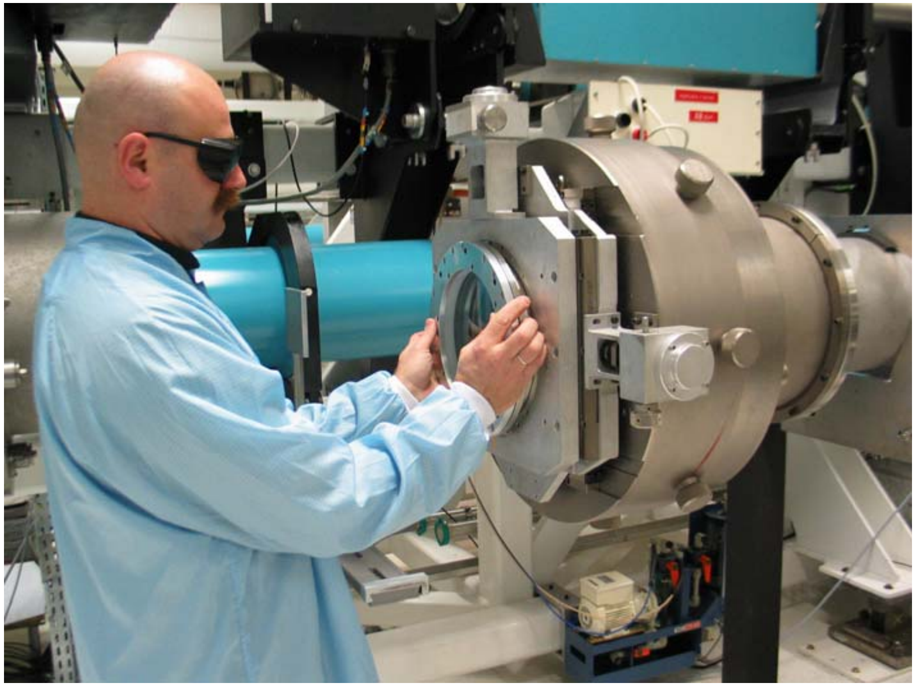


Vacuum :

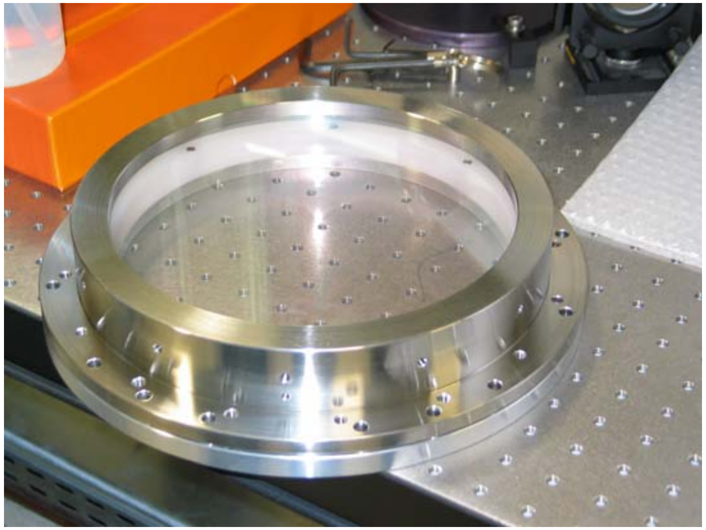
To avoid air ionization

Implementation at LULI

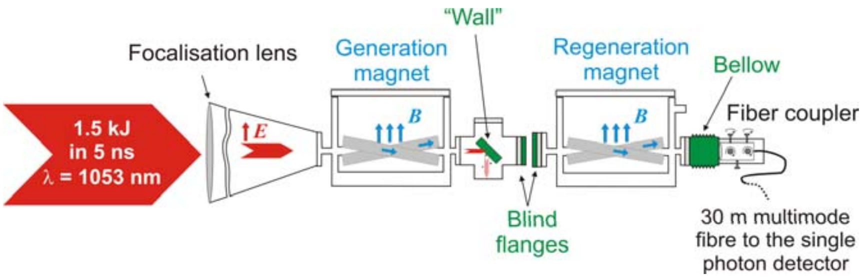




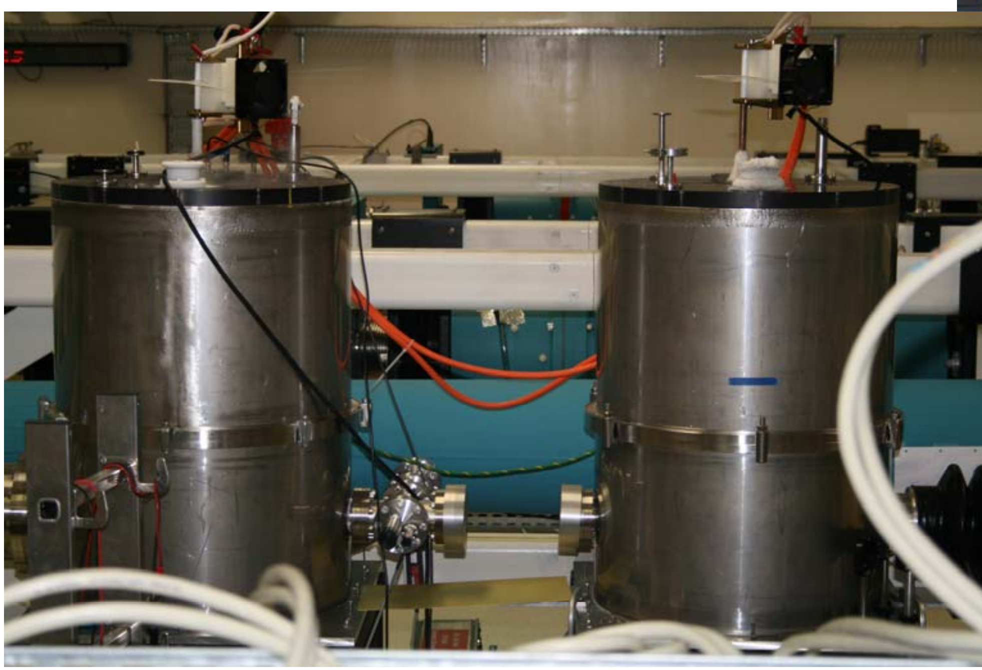
Focalisation Lens : f = 20 m



Implementation at LULI



Coils and their cryostats



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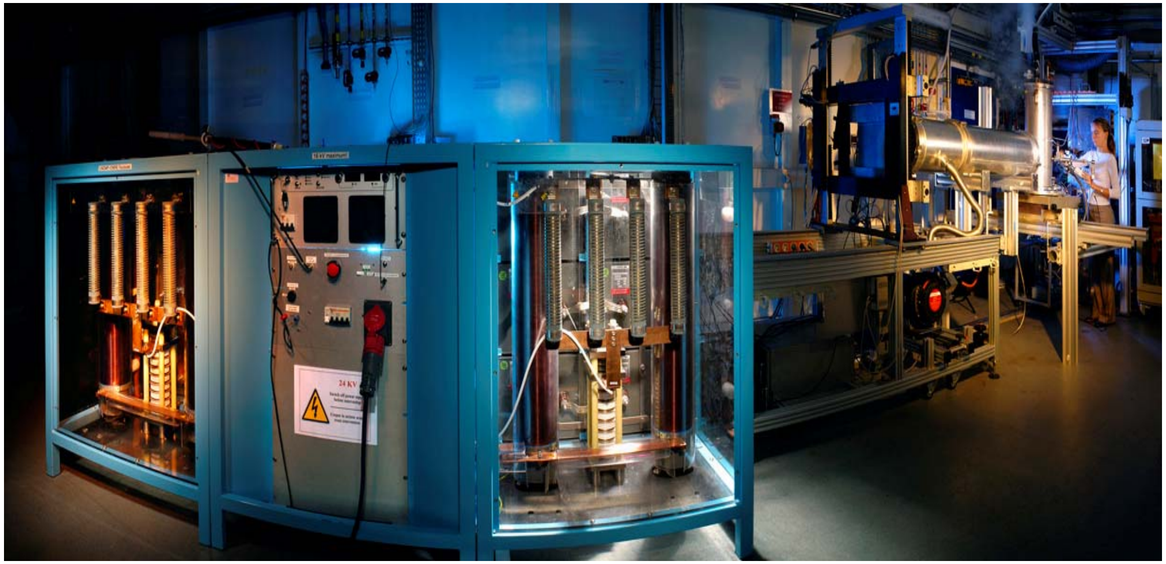


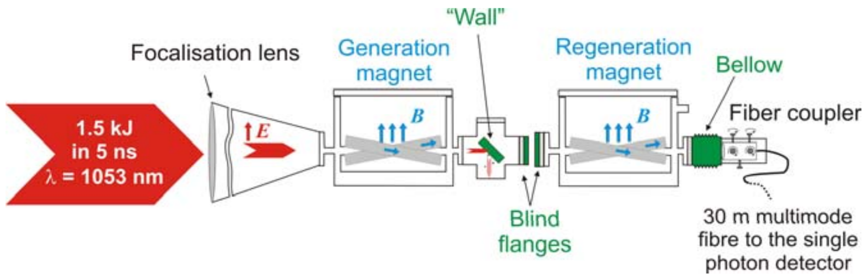
Generator originally developed for experiments at ESRF by P. Frings.

For the Pulsed magnetic field :

Transportable generator

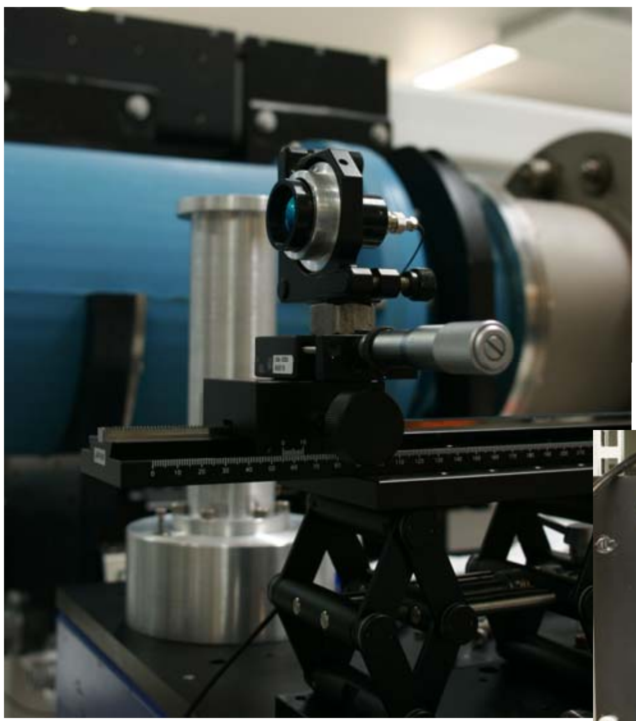
V_{max} = 16 kV
3 x 1 m^3
~ 3 tons

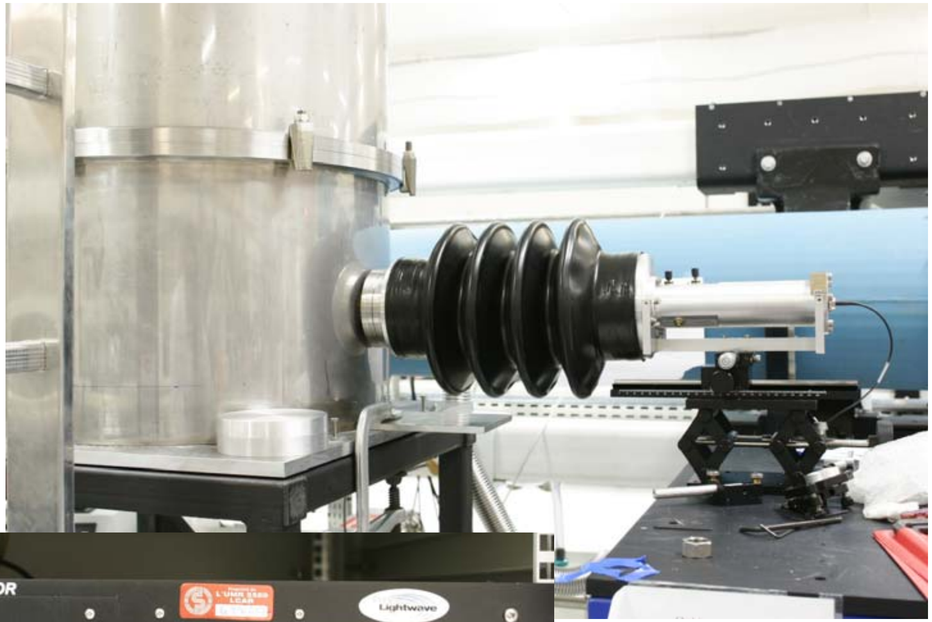
Implementation at LULI



Fibre and coupler

Fibre injection : 80 to 90 %



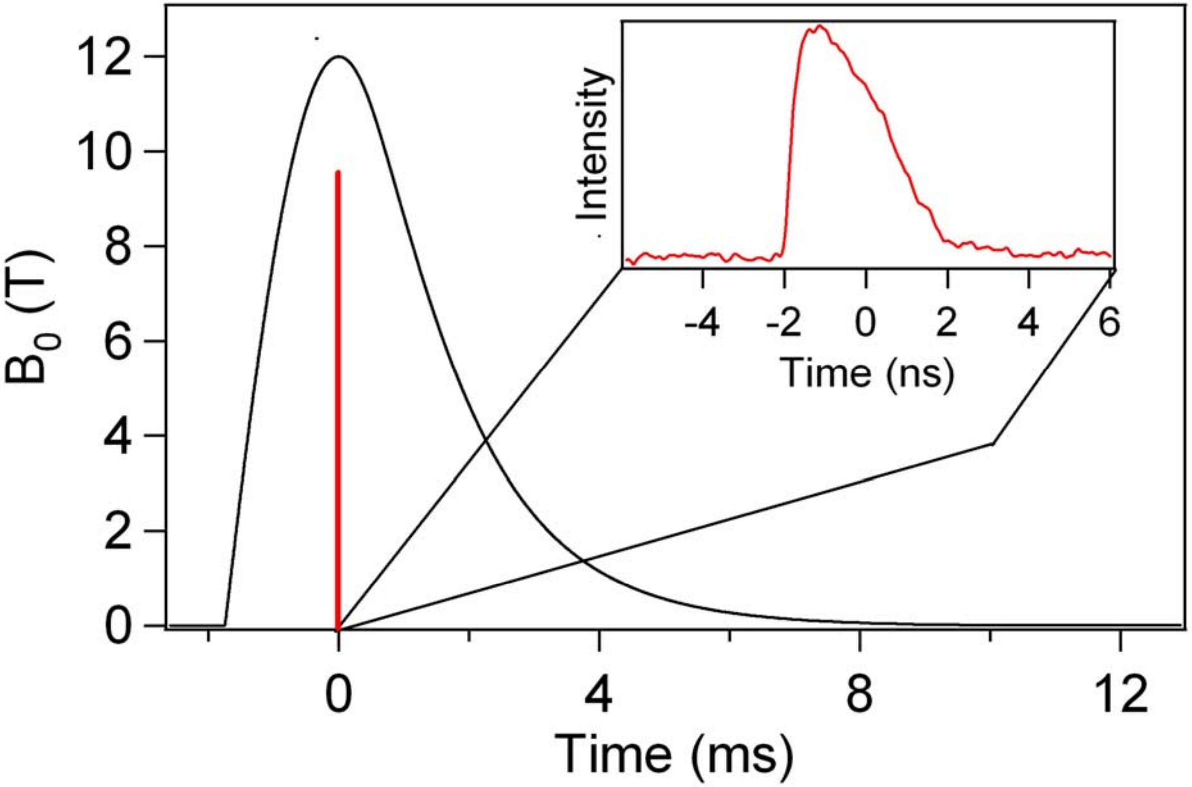


Synchronization “Laser-XCoils”

B_0 (+/- 0.3 %) during 150 μs

Magnetic pulse trigger : from the laser chain

⇒ Ensure laser pulse happens during these 150 μs

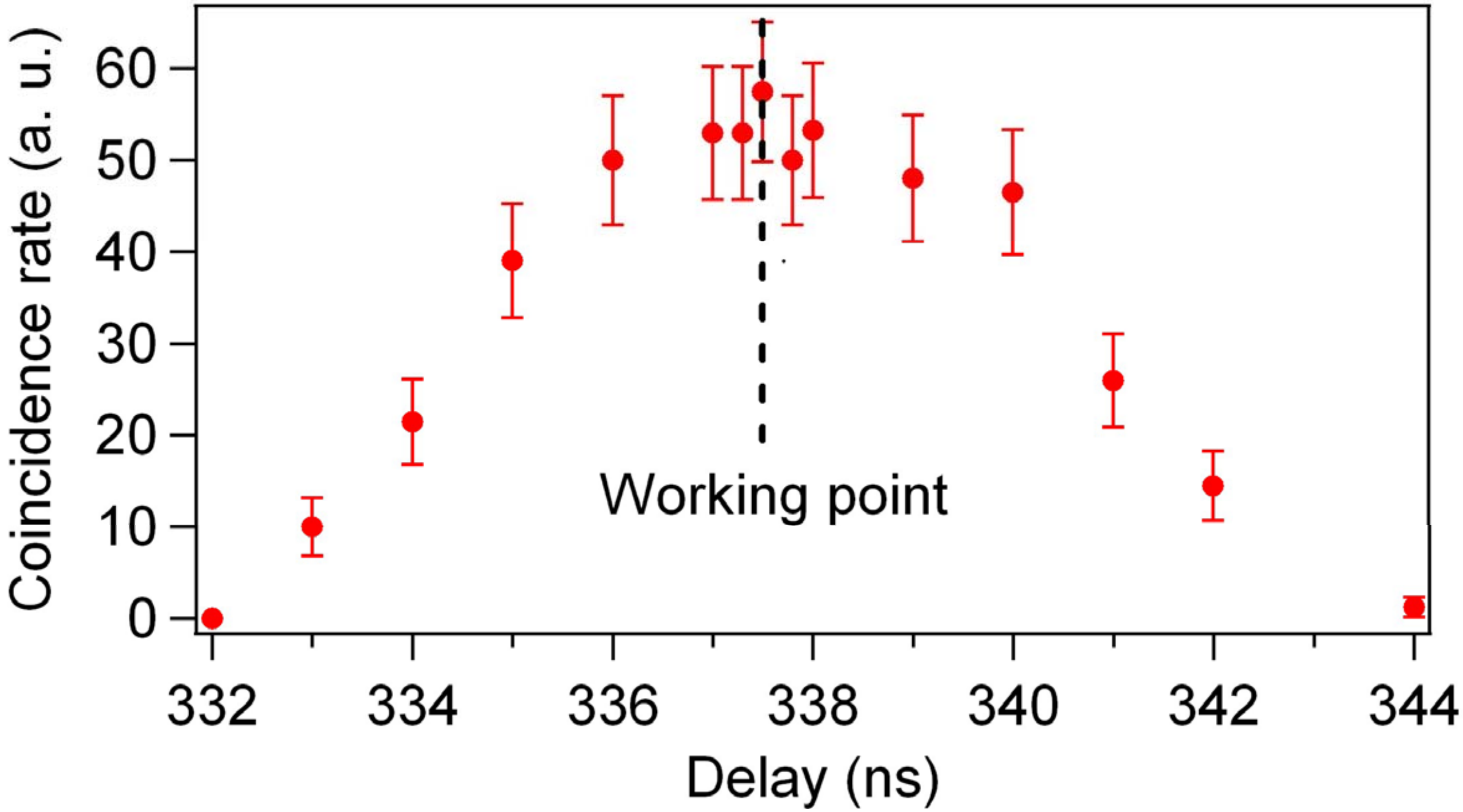


Synchronization “Laser-Detector”

Laser pulse : 3 to 5 ns

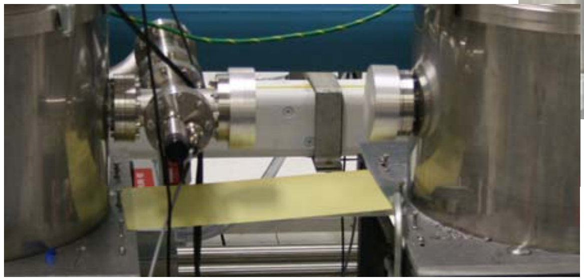
Detector gate : 5 ns ⇒ Trigger = same fast signal as laser with delay lines

Jitter = 150 ps



Final tests

- Optical shielding : no count



- Electromagnetic noise : count

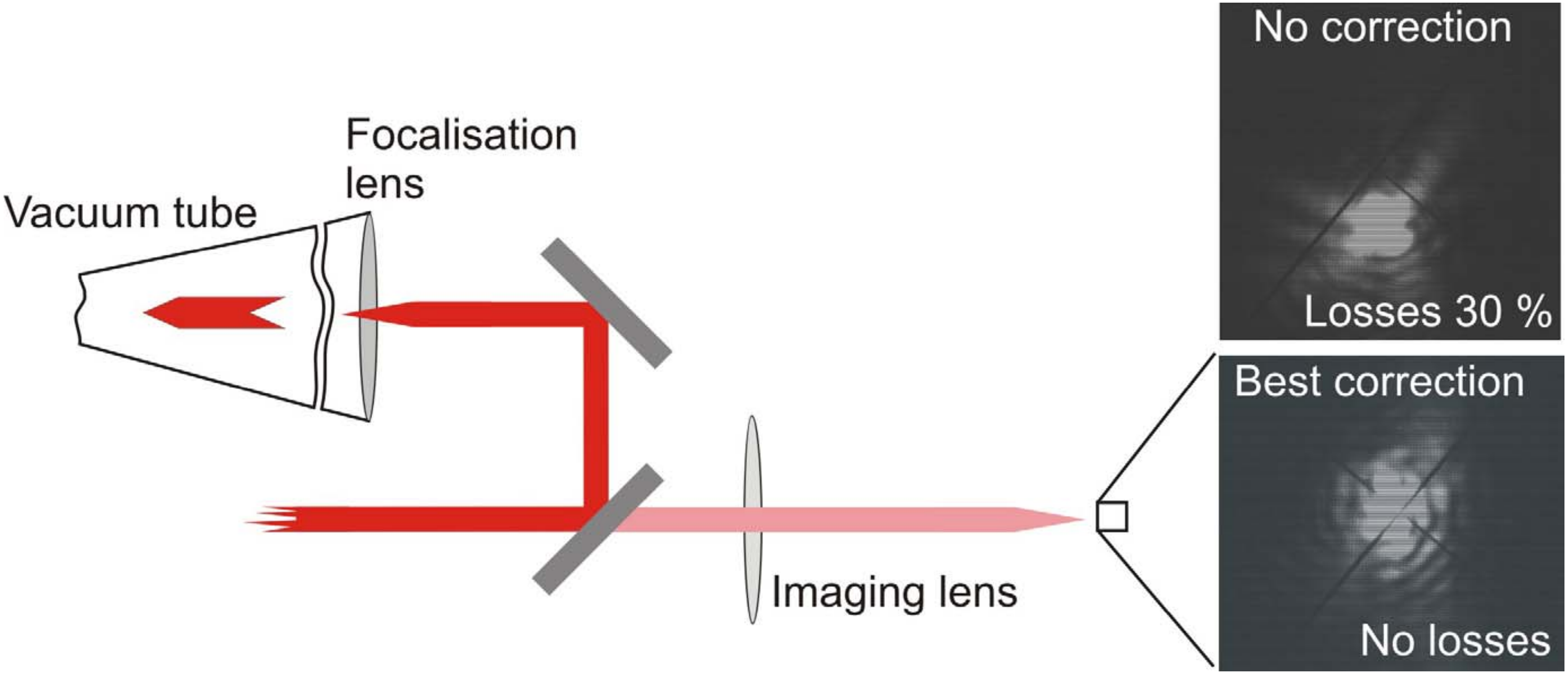
  ⇒ Detector in shielding bay : no count

- Alignment procedure : with the unchopped pilot beam

  ↳ aligned with the high energy pulse

Final tests

How can we be sure that the high energy pulse follows exactly the same optical path ?



- Image recorded for each pulse.
- Estimation of losses

Ready to take data

Ready : end of May 2007

- Strength of our experiment :

  - high laser energy + high B×L
  - laser + B + detector pulsed

    ⇒ Small integration time to test PVLAS claims

    ⇒ Background of detection not limiting

- Efficient experiment :

  - to test PVLAS results

    2 to 2500 regenerated photons / pulse

  - not to detect standard axion

    10^{-21} to 10^{-30} regenerated photons / pulse

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Measurements

1 week in July 2007

PVLAS results excluded : C. Robilliard et al., Phys. Rev. Lett. **99**, 190403 (2007)

1 week in September 2007

2 weeks in January 2008

- Number of pulses : 82
- Total incident energy : 110 kJ
- Number of incident photon : 5.9×10^{23}

Result :

No regenerated photon detected

Limits ?

No regenerated photon detected

- If PVLAS limits confirmed :
  - 2 to 2500 regenerated photons / pulse

- Our limits ? :

• For a : - detection efficiency η

- Confidence level (Ex. : CL = 0.95 ≡ 2σ)

$\rightarrow$ Number *n* of missed regenerated photon

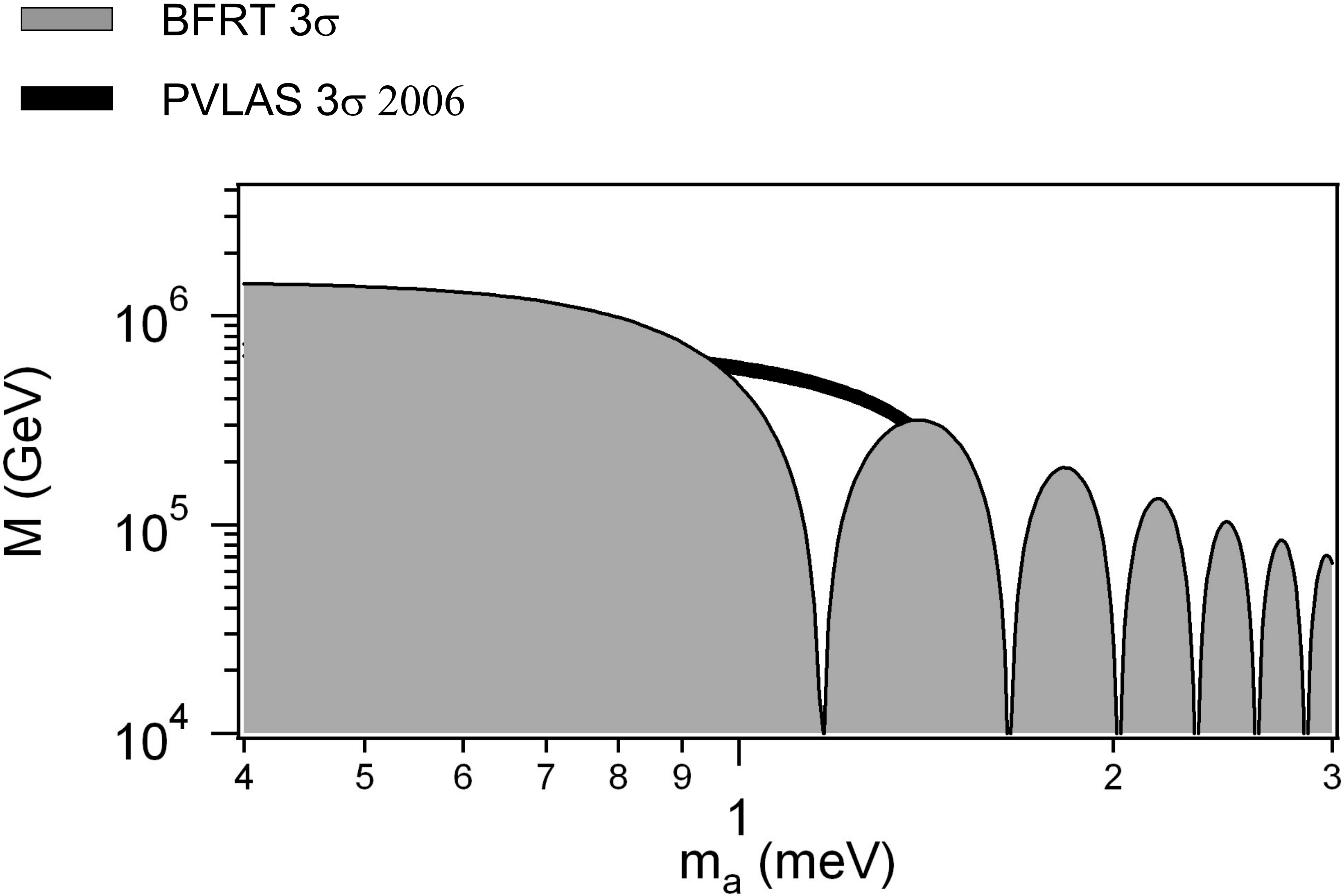
• Numerical integration of $p(L)^2 \times N_i \leq n$

with

$$p(L) = \left| \int_0^L dz' \frac{B(z')}{2M} \times \exp\left(-i \frac{m_a^2 z'}{2\omega} \right) \right|^2$$

$\Rightarrow$ Limits in the (m_a, M) plane

Our present limits



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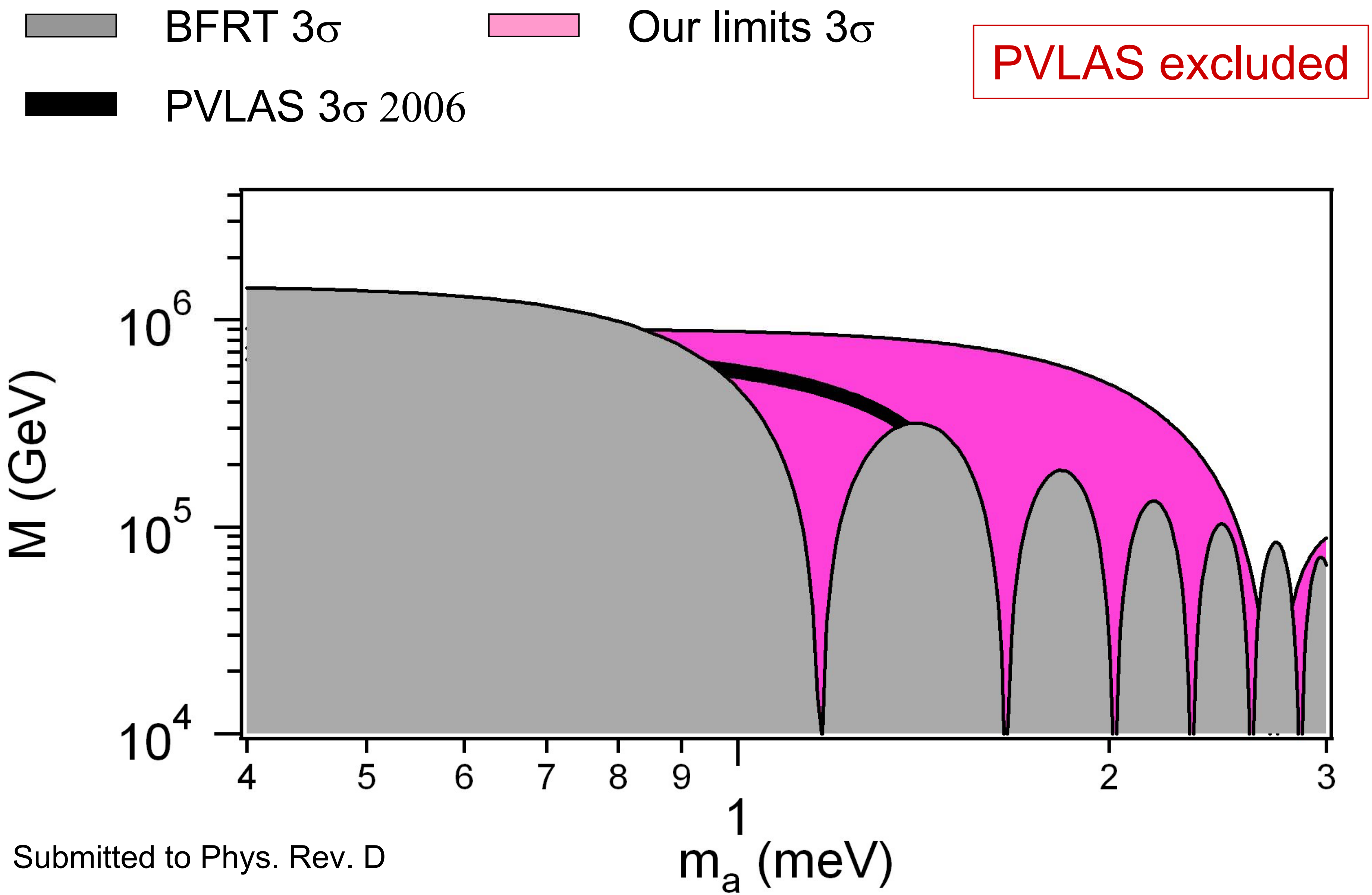
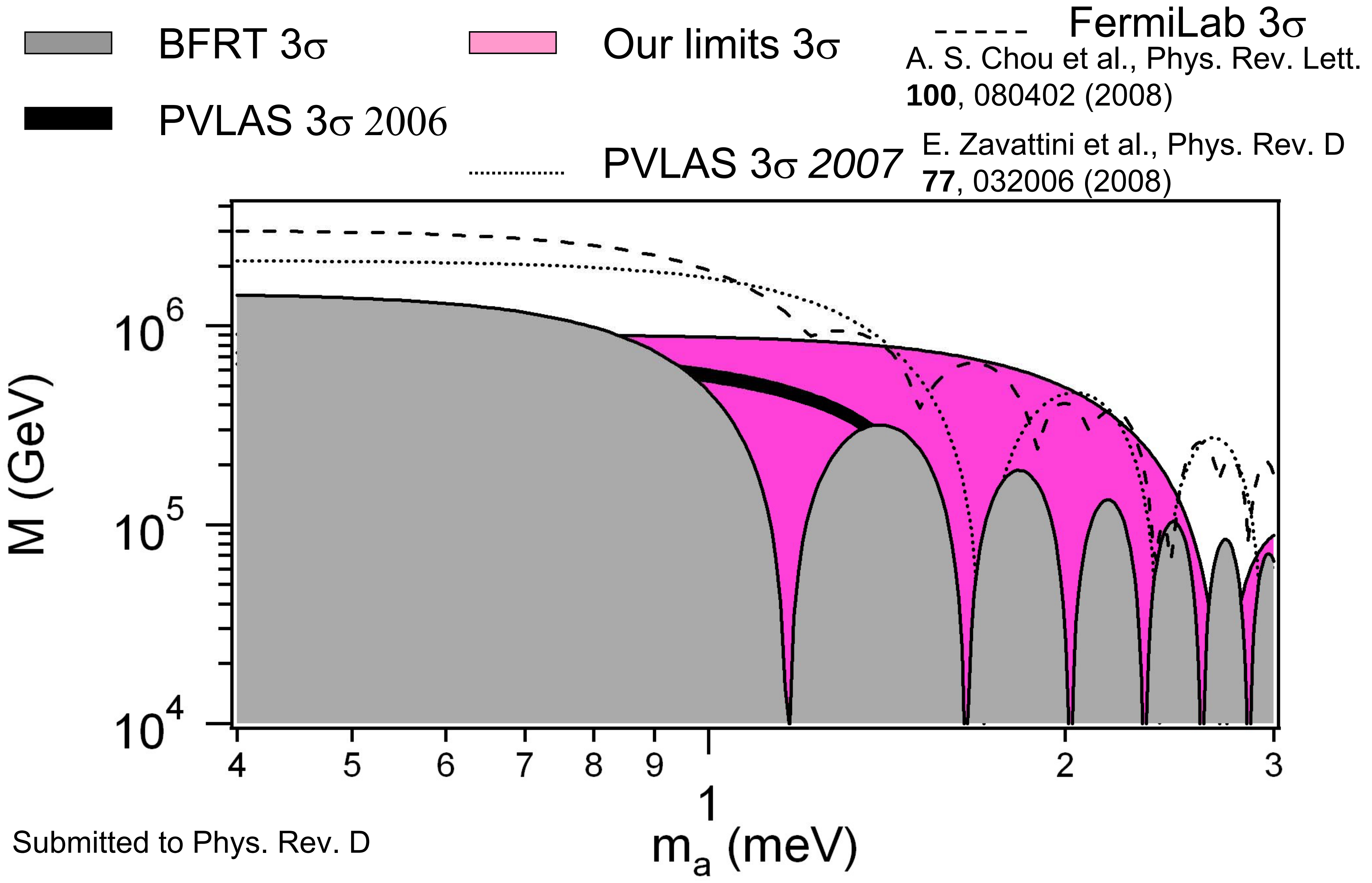


Submitted to Phys. Rev. D

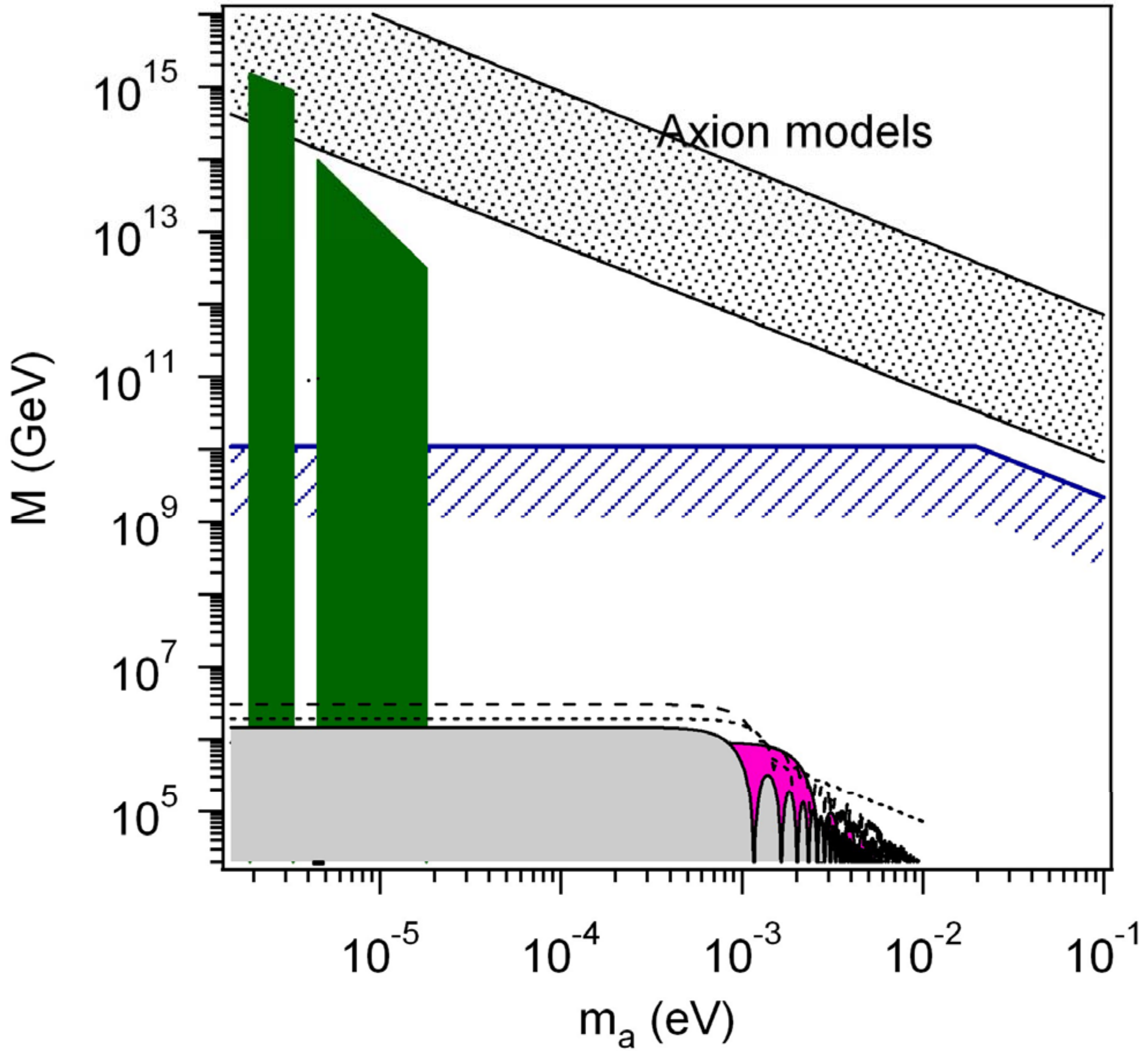
Our present limits



Submitted to Phys. Rev. D

Compared to other experiments

- BFRT 3σ
- Our limits 3σ
- FermiLab 3σ
- PVLAS 3σ *2007*
- Microwave cavity experiments
- CAST



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Paraphoton ?

- Deviation from blackbody curve in the cosmic background radiation

Photon oscillations into massive particle

- Anomaly in the cosmic background radiation not confirmed :

But paraphoton existence not excluded

How to detect it ?

- Photon-paraphoton oscillation :

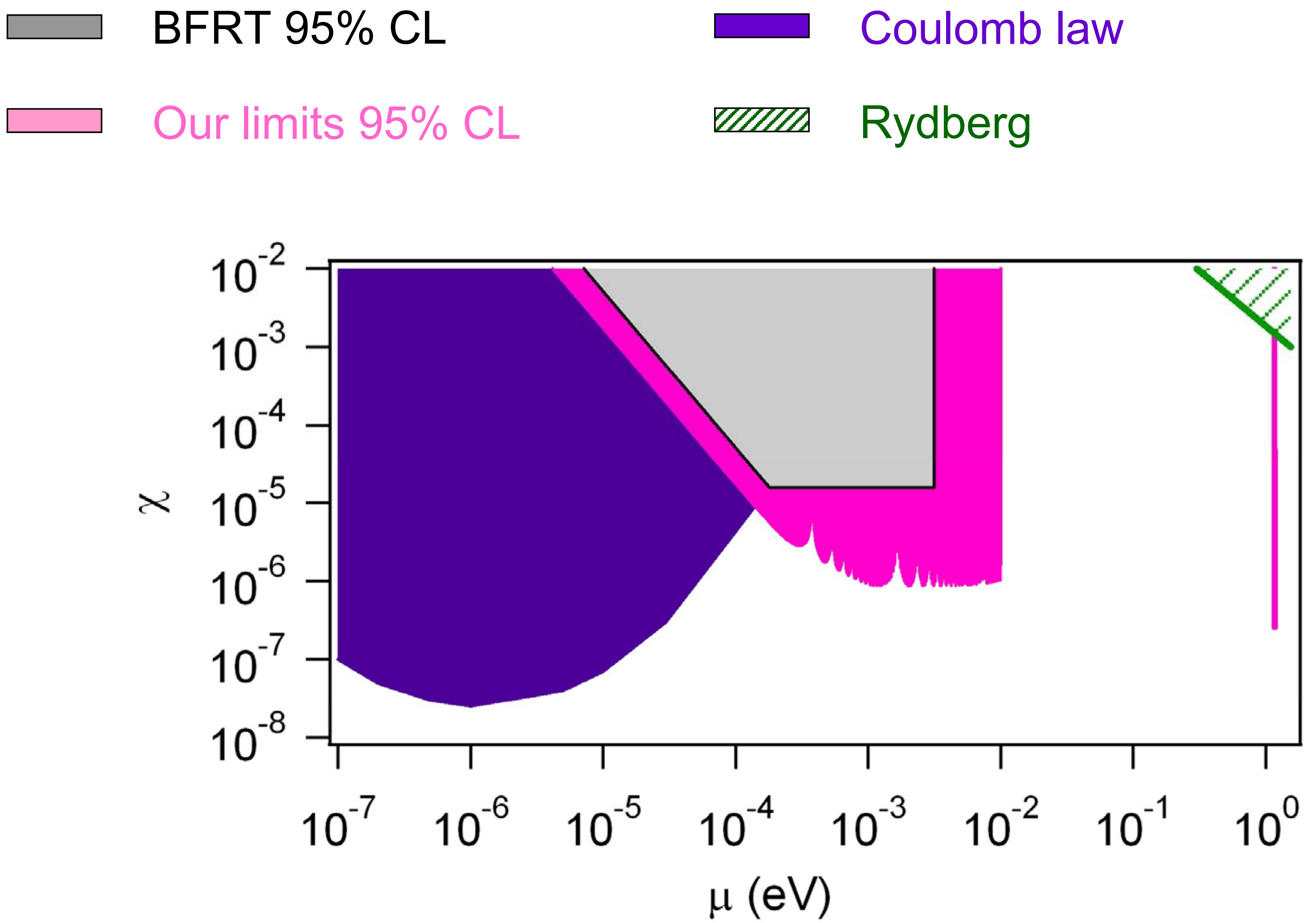
  - Possible without any external field
  - Independent on photon polarization

Can be detect with a light shining through the wall experiment

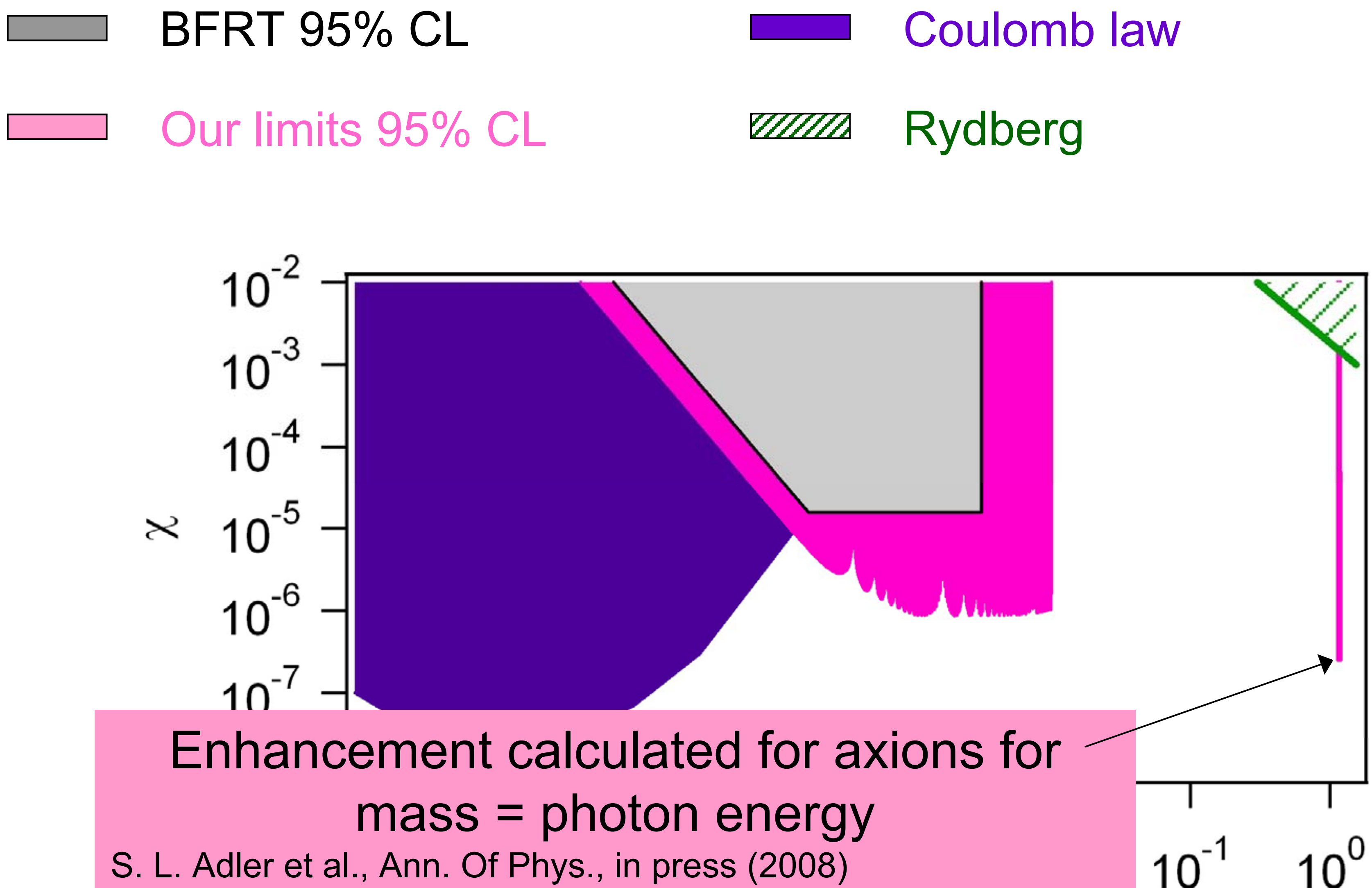
- Conversion probability :

$$p(L) = 4\chi^2 \sin^2\left(\frac{\mu^2 L}{4\omega}\right)$$

Paraphoton results



Paraphoton results



Enhancement calculated for axions for mass = photon energy

S. L. Adler et al., Ann. Of Phys., in press (2008)

⇒ extrapolated to paraphotons

Conclusion

- PVLAS results not confirmed

  ⇒ Axion is still running

- Strength of this experiment

  ⇒ Useful to test numerous theories beyond standard model in the low energy window :

  - Paraphoton
  - Chameleon
  - …

- Axion search :

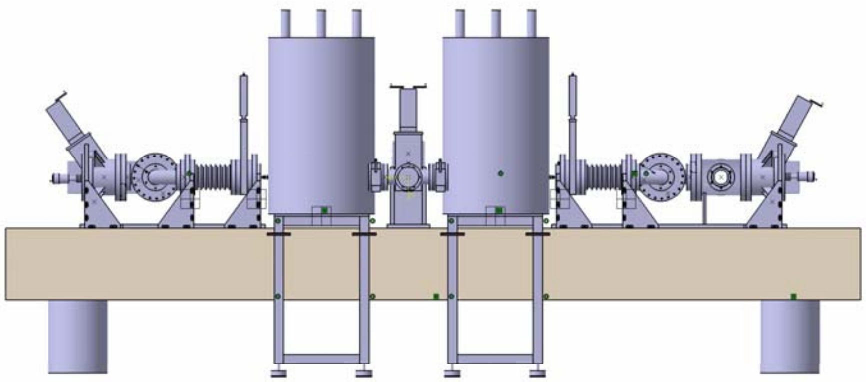
  To test standard axion with this setup : far more difficult

  ⇒ Different design

The BMV experiment in Toulouse

- Goal :

  measurement of the QED magnetic birefringence of vacuum



- Improvement on axions :

  One or two orders of magnitude compared to purely terrestrial axion searches

Collaborators

LCAR

Carlo Rizzo

Cécile Robilliard

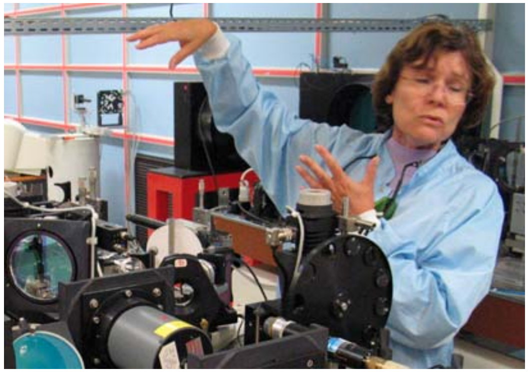
Rémy
Battesti

Julien
Mauchain

LNCMP

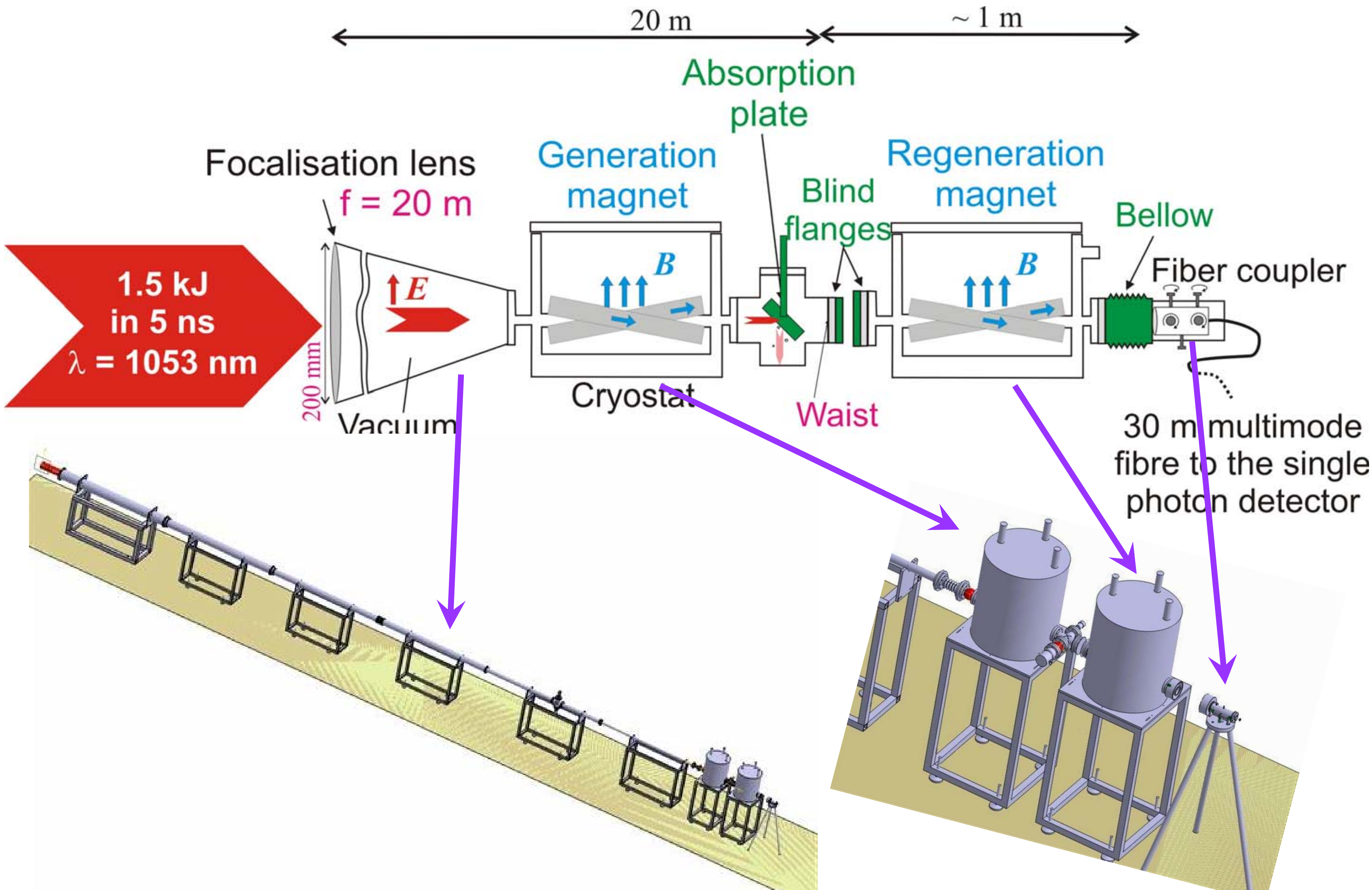
LULI

Anne-Marie
Sautivet



François
Amiranoff

General set-up (LCAR)



Detection checking

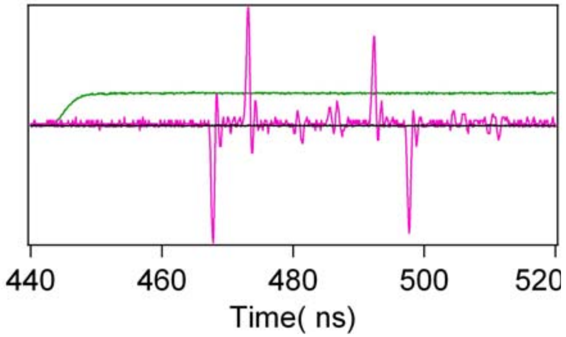
- High energy optical path :
  - image recorded for each pulse
- Synchronization :
  - 2 oscilloscopes

- Laser trigger
- Magnetic field

⇒ magnetic field - laser synchronization checking

⇒ B_0 measurement

- Laser trigger
- Detector trigger
- Detector monitor
- Photon TTL



⇒ detector - laser synchronization checking

⇒ checking of the APD polarisation