WISPy Dark Matter Search with a Dish Antenna Setup in Tokyo

Theory and Experiment

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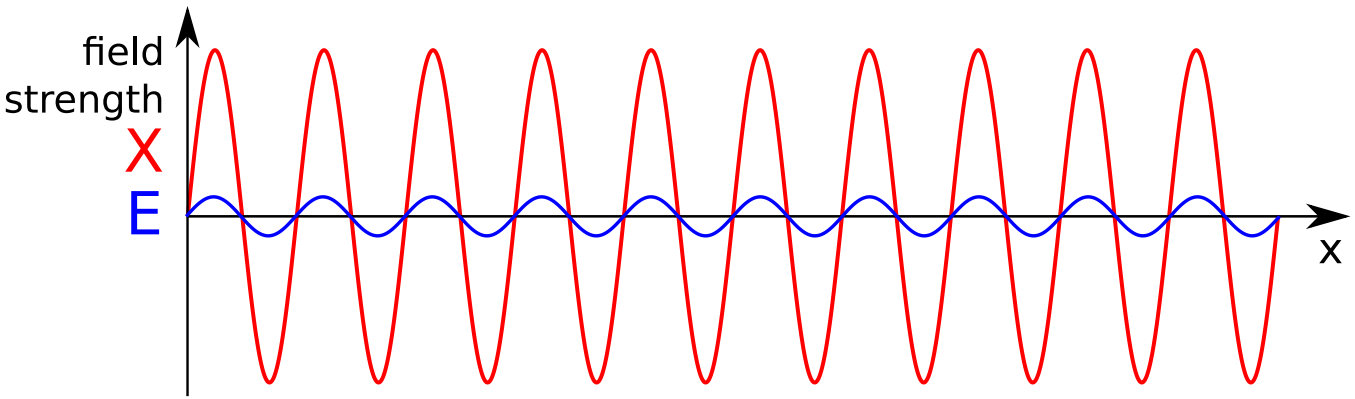
The Hidden Photon - viable dark matter candidate

Lagrangian

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}\tilde{X}_{\mu\nu}\tilde{X}^{\mu\nu} - \frac{\chi}{2}F_{\mu\nu}\tilde{X}^{\mu\nu} + \frac{m_X^2}{2}\tilde{X}_\mu\tilde{X}^\mu + J^\mu A_\mu$$

Kinetic Mixing



$$\mathbf{E} = \chi\mathbf{X}$$

The Hidden Photon - viable dark matter candidate

Lagrangian

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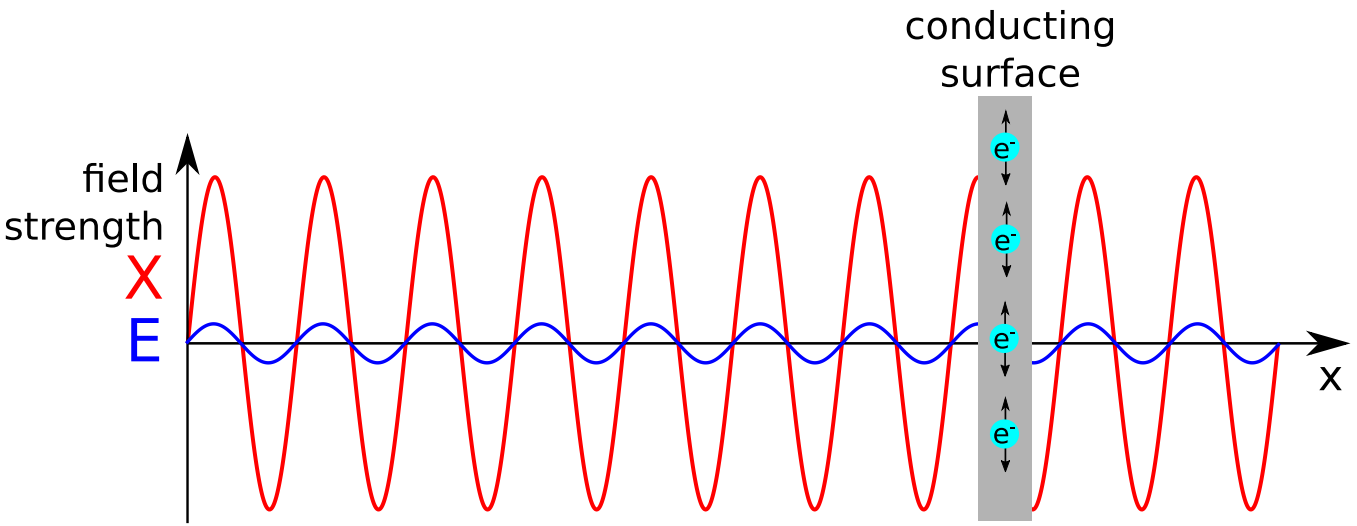

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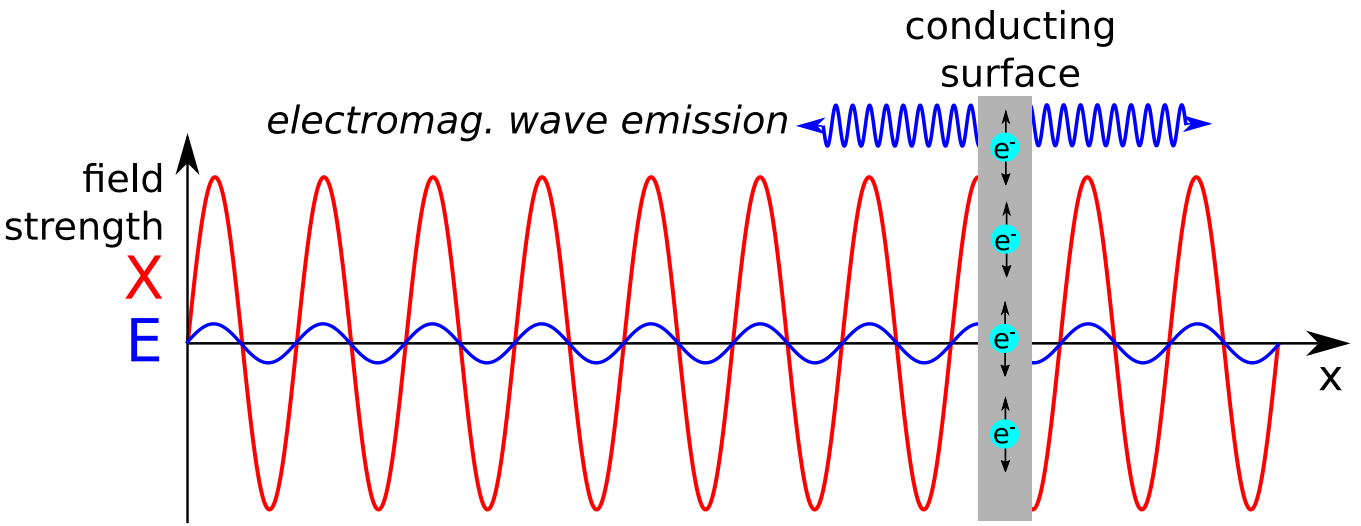
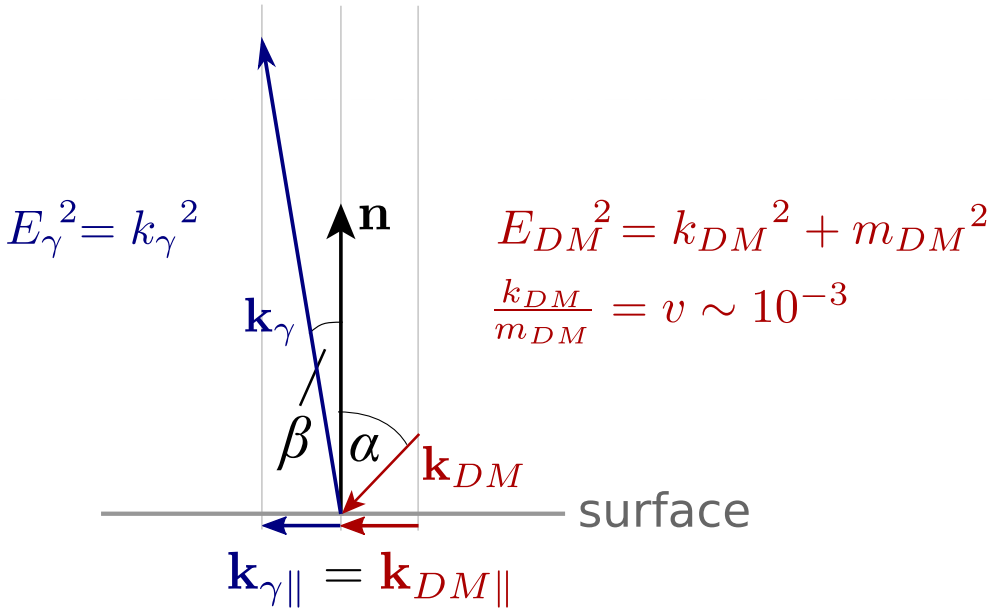
Kinetic Mixing

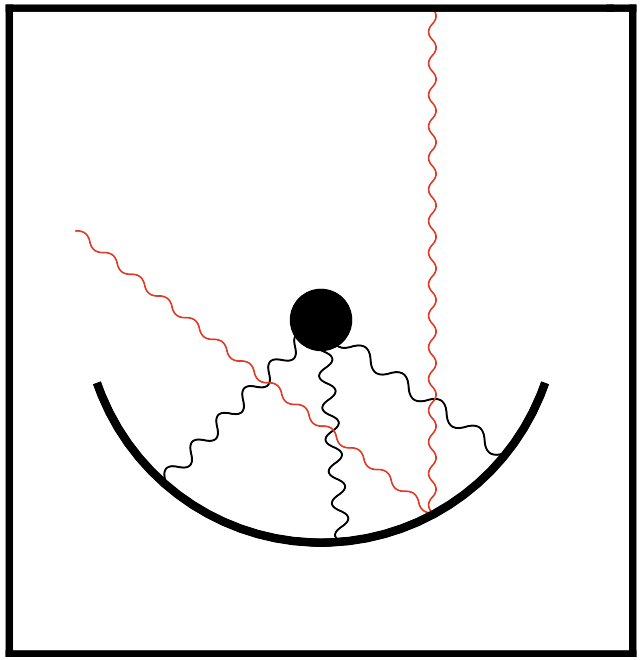


$$\mathbf{E} = \chi\mathbf{X}$$

Dish Antenna Experiments

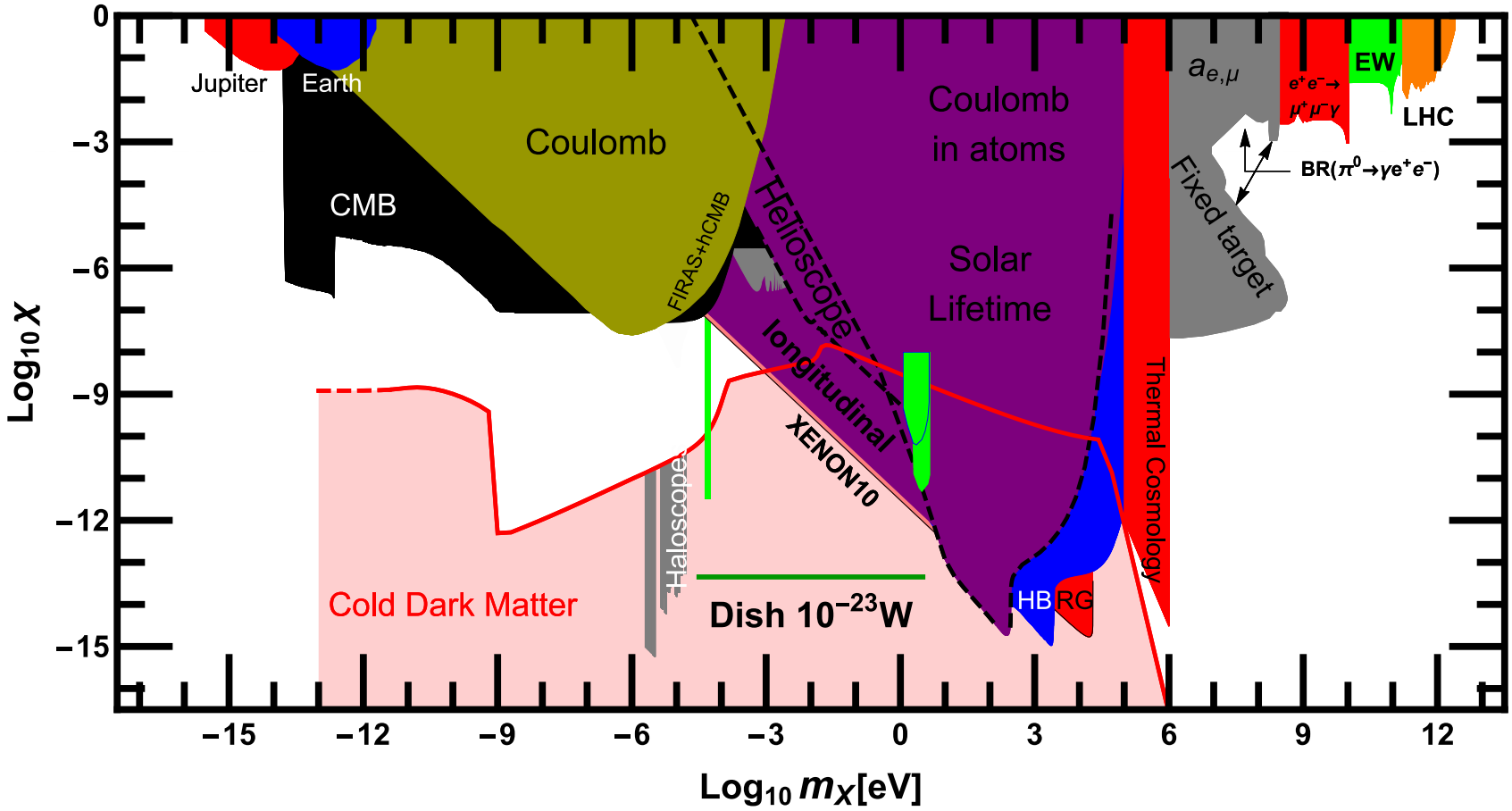


$$\sin(\beta) = v \sin(\alpha) \sim 10^{-3}$$



$$P_{\text{centre}} \sim \chi^2 \rho_{\text{CDM}} A_{\text{dish}}$$

Sensitivity



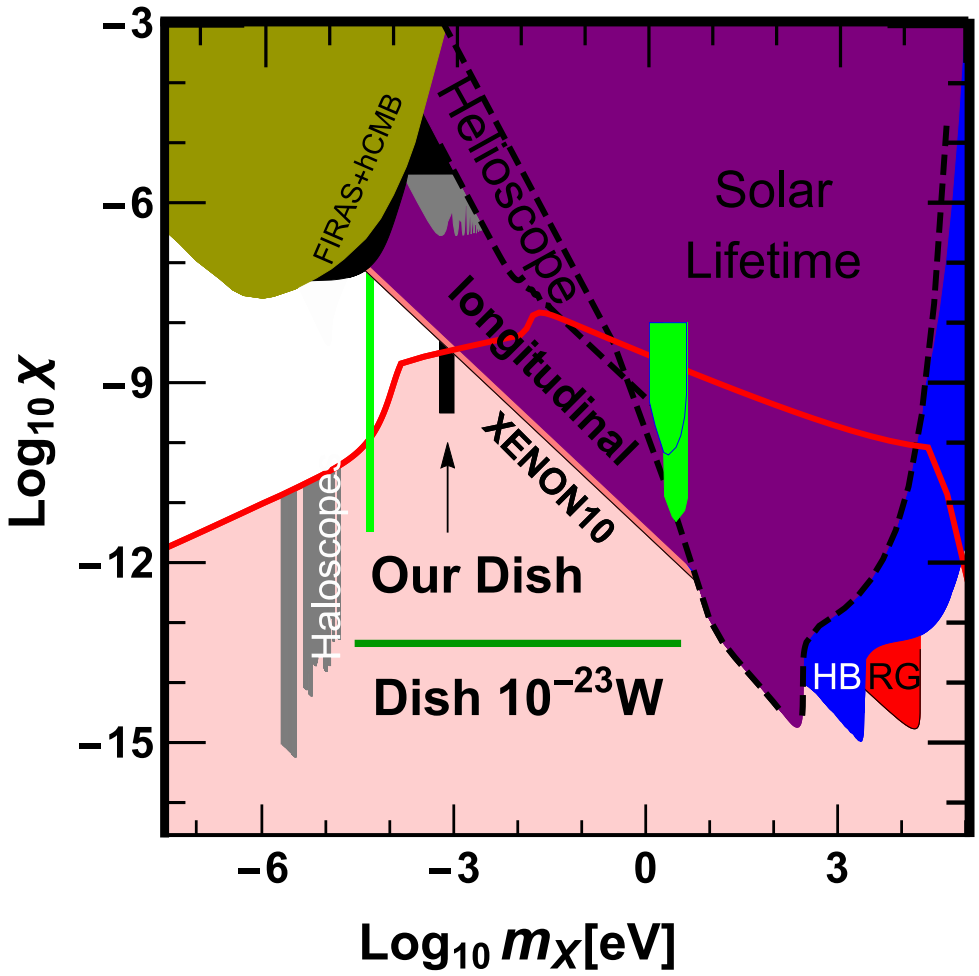
Sensitivity - Limits Comparison

		λ_γ	m_X [eV]	χ
FUNK (Germany)			arXiv:1410.0200, arXiv:1510.05869	
spherical (13 m^2)		optical	$\mathbf{10^0}$	$\mathbf{10^{-11}}$
	⁕	radio	$\mathbf{10^{-5} - 10^{-4}}$	$\mathbf{10^{-13}}$
Minowa (Tokyo)				arXiv:1509.00785
parabolic (0.2 m^2)		optical	$\mathbf{10^0}$	$\mathbf{10^{-12}}$
conversion plate (4 m^2)		radio	$\mathbf{10^{-5}}$	$\mathbf{10^{-12}}$
Our Experiment (Tokyo)				
conversion plate (0.2m^2)	⁕	$\sim$ **mm**	$\mathbf{10^{-3}}$	$\sim \mathbf{10^{-10}}$

⁕: not yet measured

Our Experiment: first setup with mm-wave-technology

Sensitivity



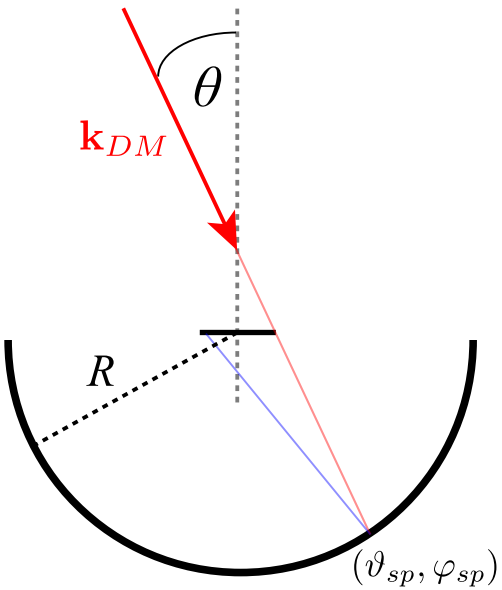
Theory

Directional Resolution

A Directional Search

future option

$$\sin(\beta) = v \sin(\alpha)$$



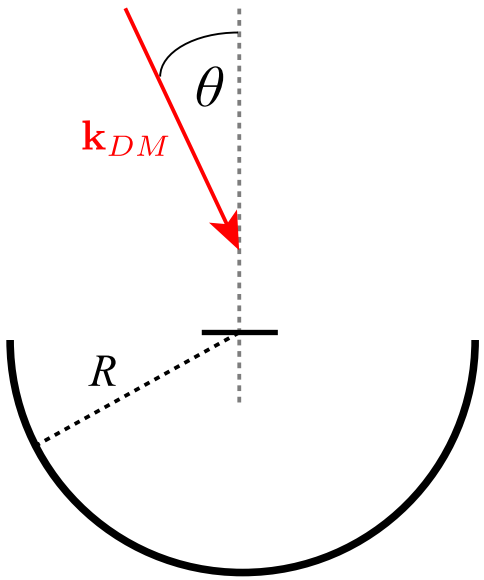
Ray Incident Position:

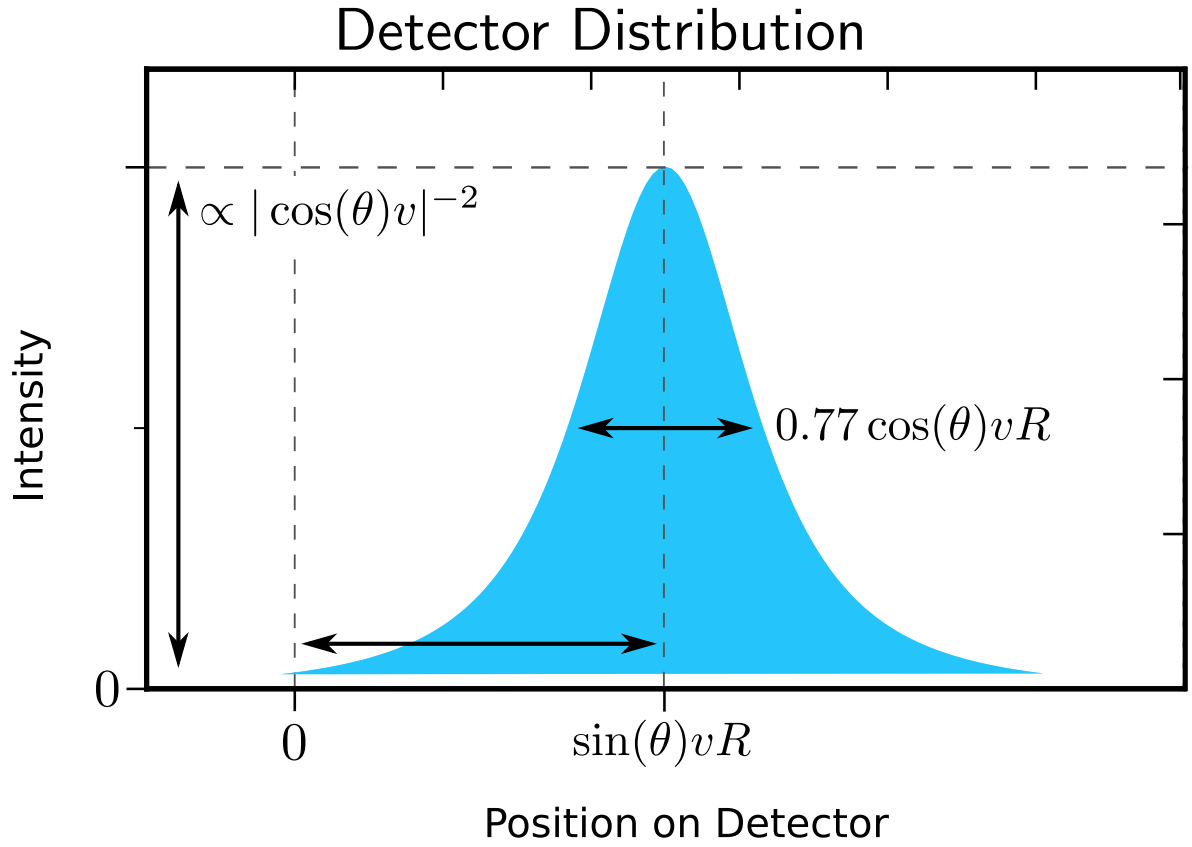
$$\frac{\Delta \mathbf{x}}{R} = \begin{pmatrix} \sin\theta \\ 0 \end{pmatrix} v - \begin{pmatrix} \cos\varphi_{sp} \\ \sin\varphi_{sp} \end{pmatrix} \tan\vartheta_{sp} \cos\theta v + \mathcal{O}(v^2)$$

A Directional Search

future option

$$\sin(\beta) = v \sin(\alpha)$$

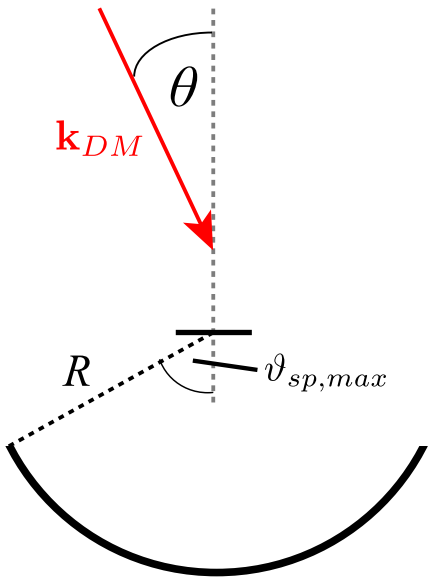


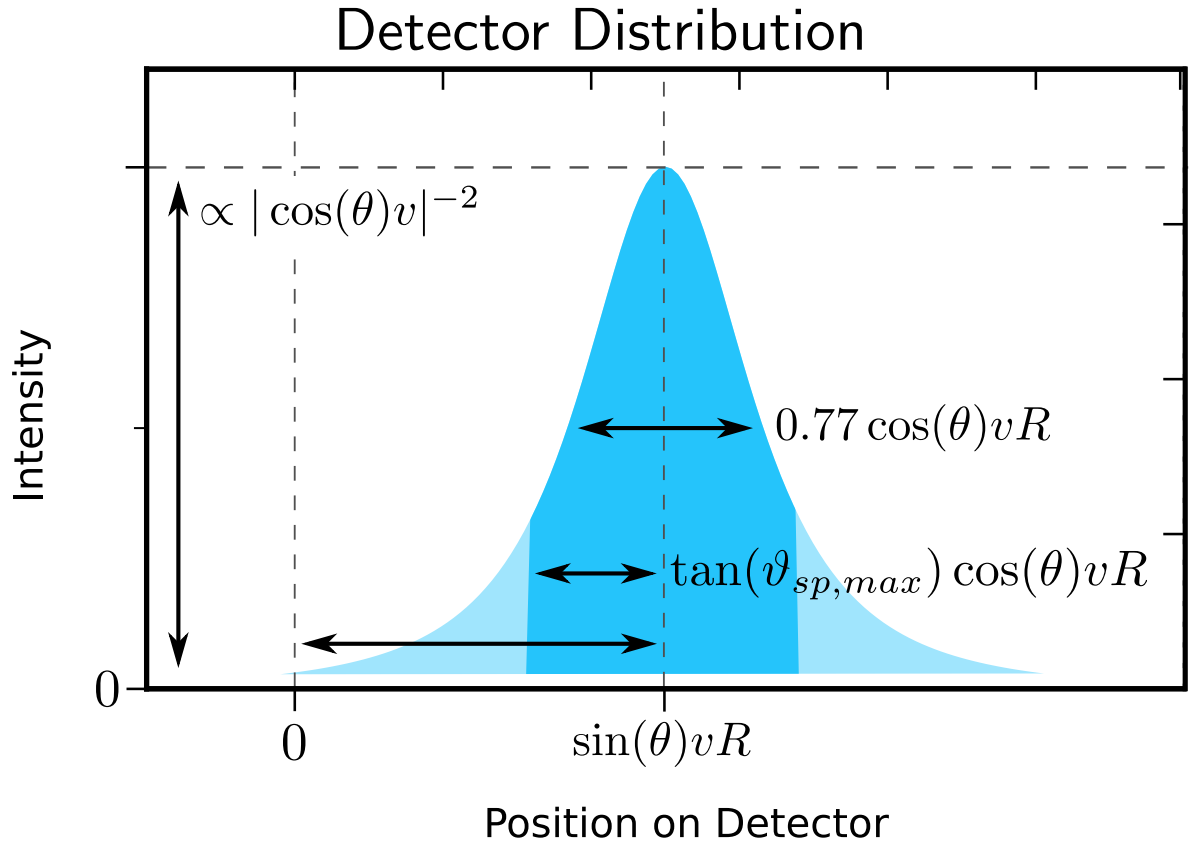


A Directional Search

future option

$$\sin(\beta) = v \sin(\alpha)$$

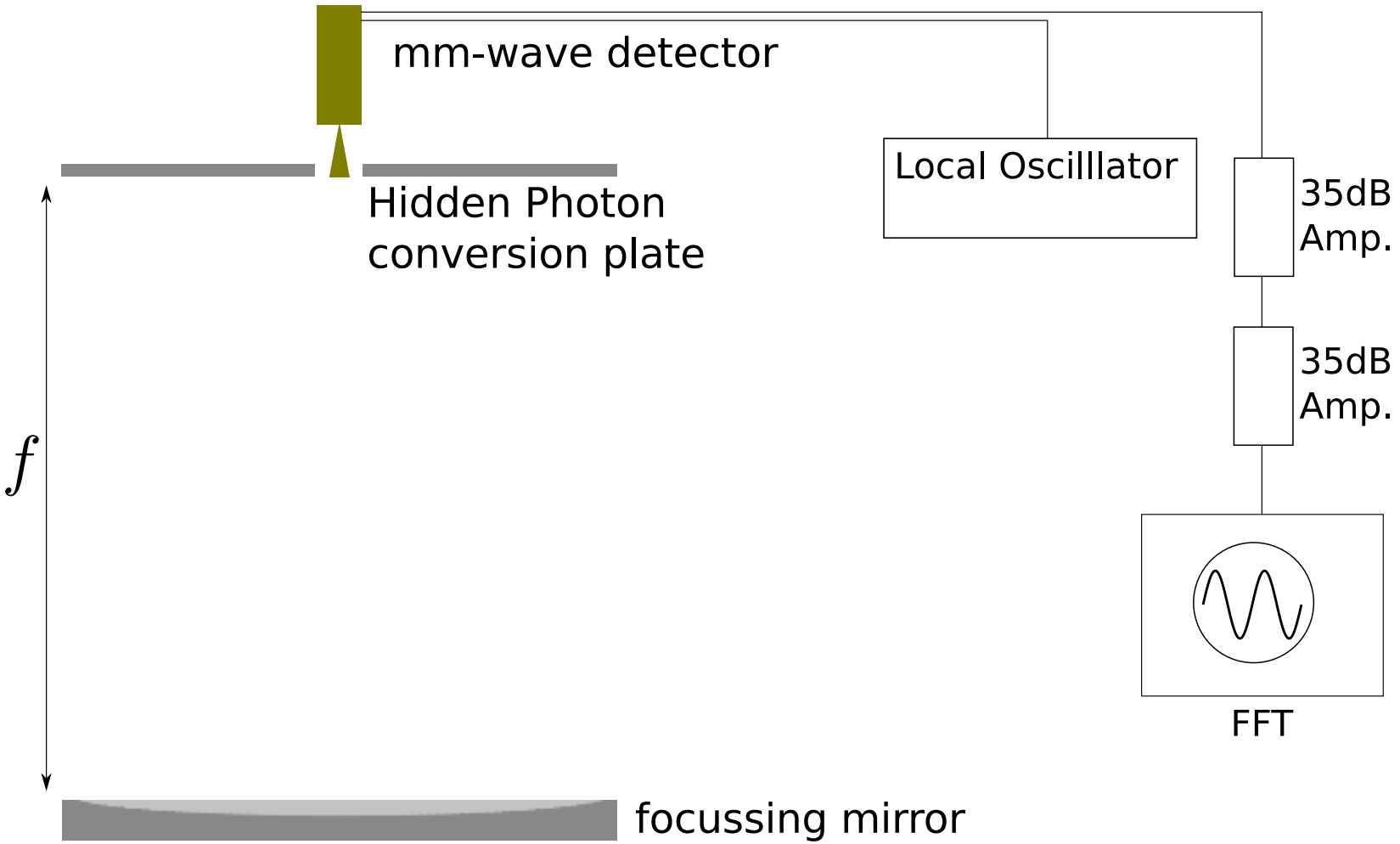




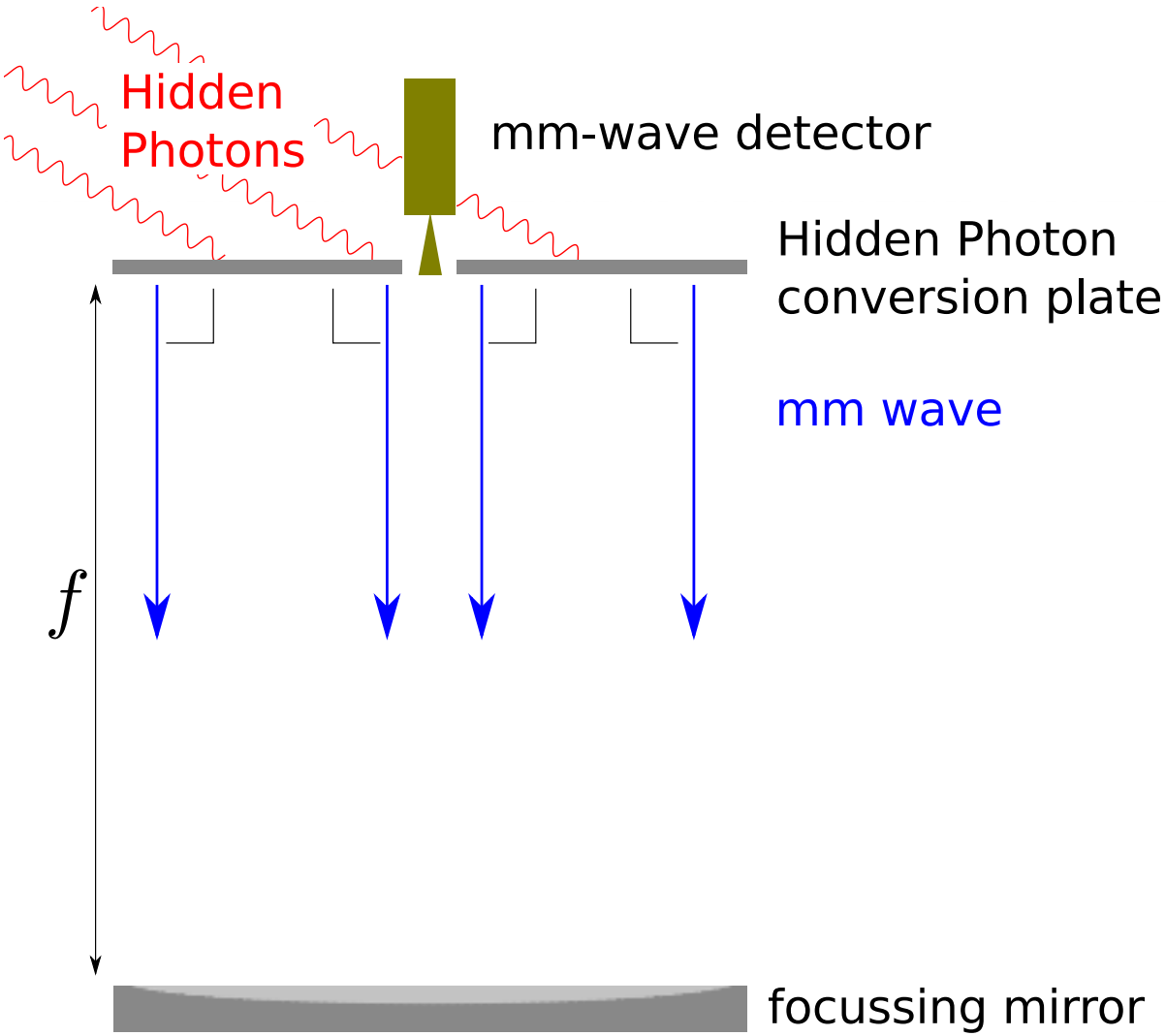
Experiment

our mm-wave setup

Our Experimental Setup - Overview



Our Experimental Setup



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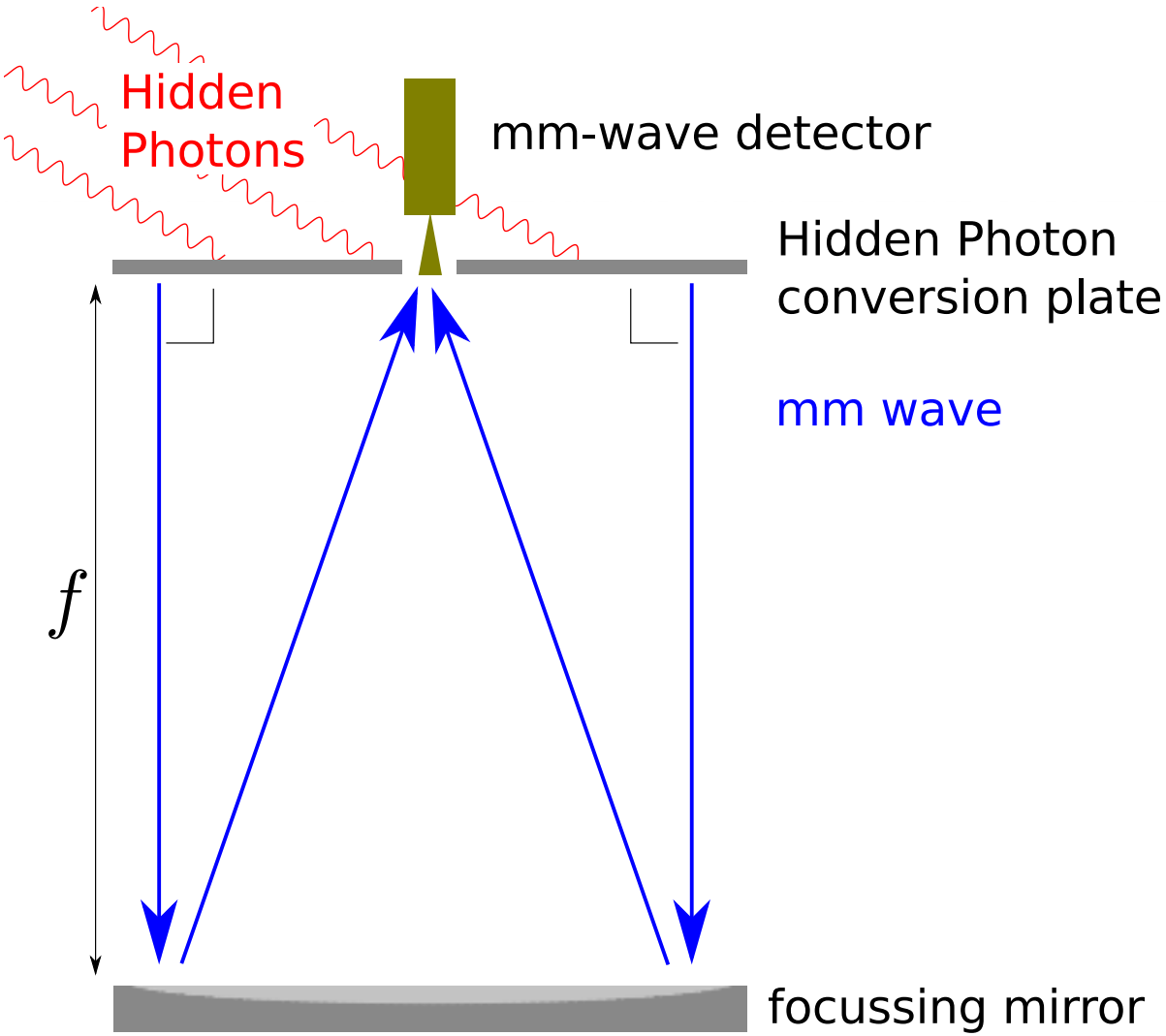

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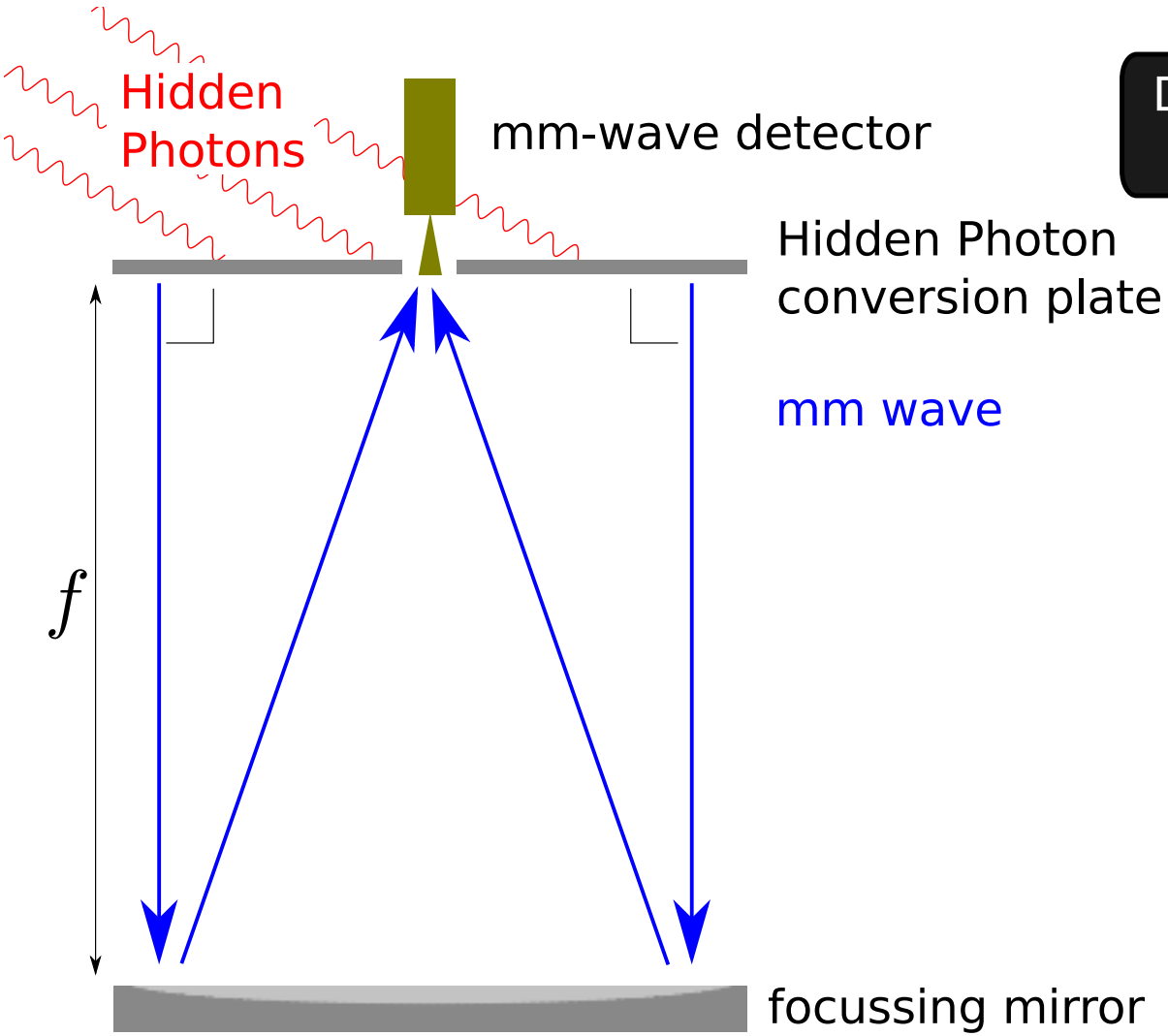
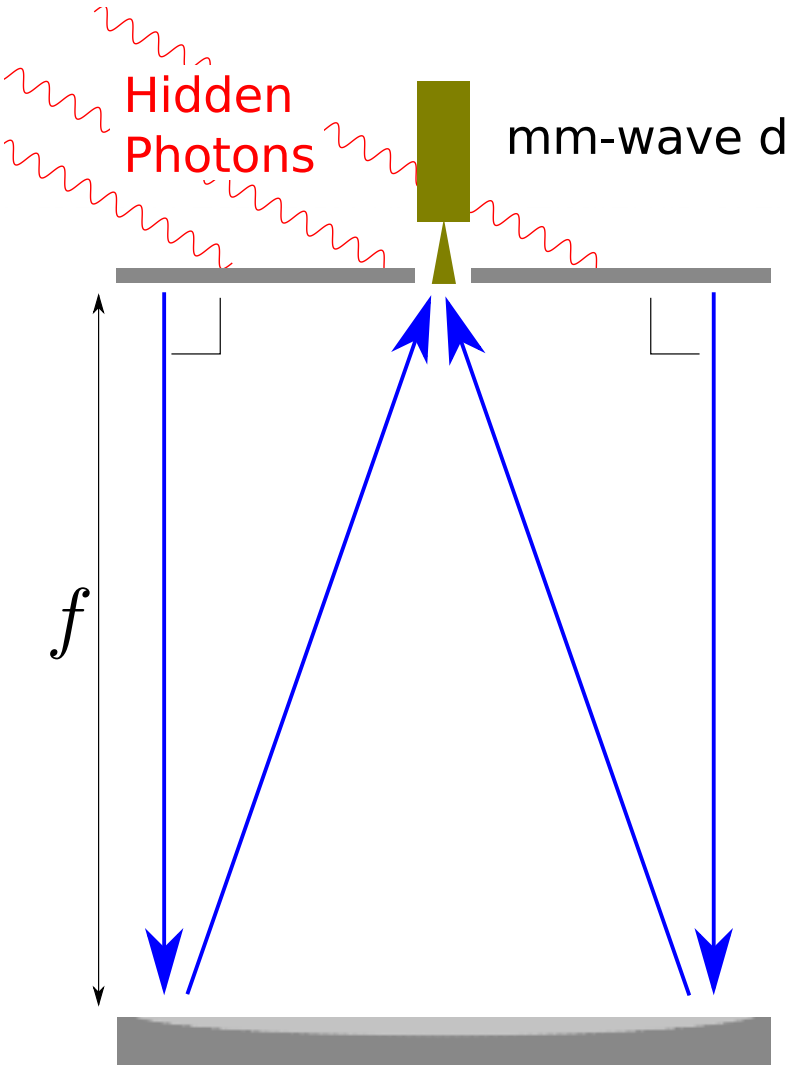


Detector Coupling & Gain

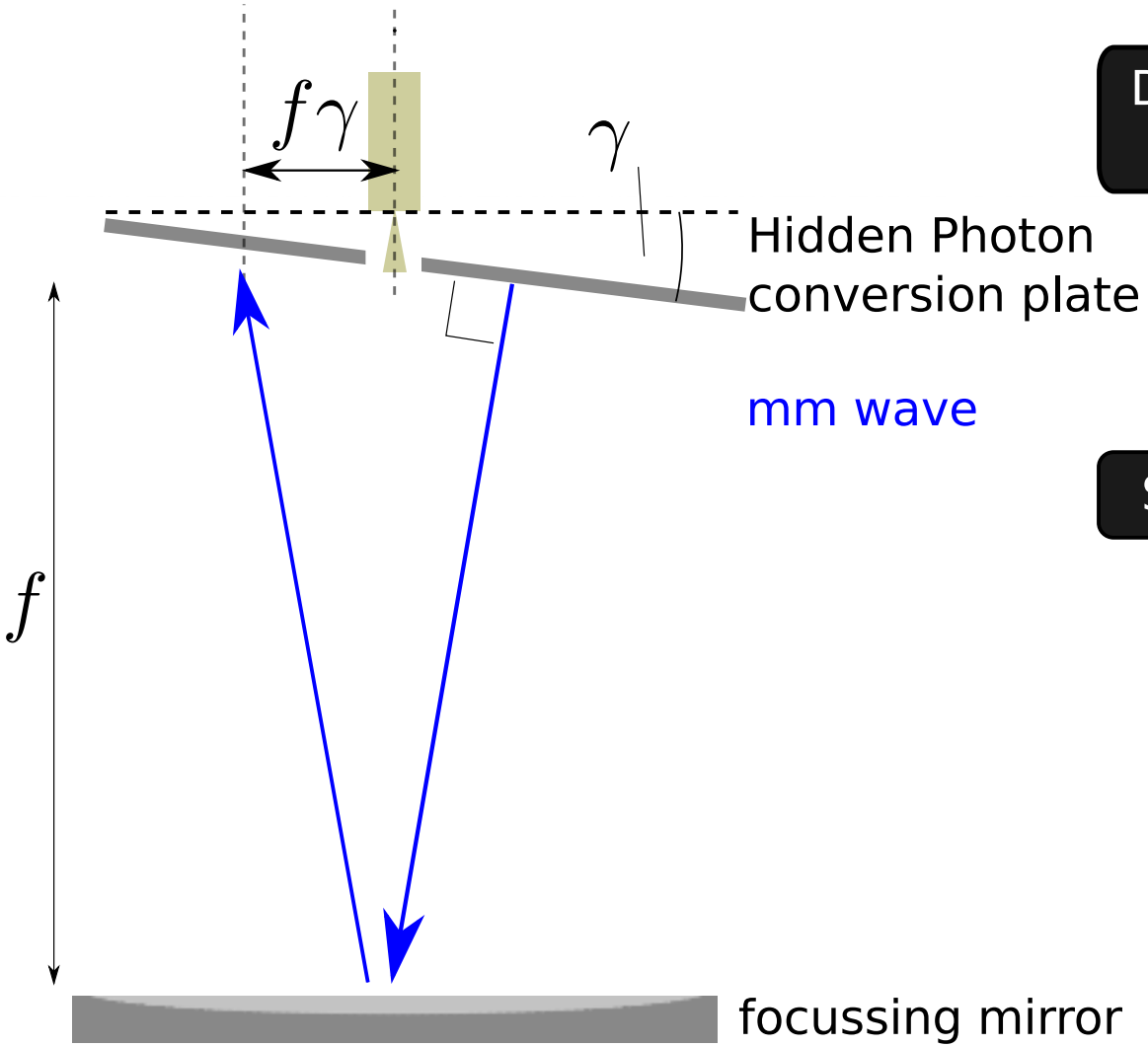
Our Experimental Setup



Detector Coupling & Gain

Setup Alignment

Our Experimental Setup



Detector Coupling & Gain

Setup Alignment

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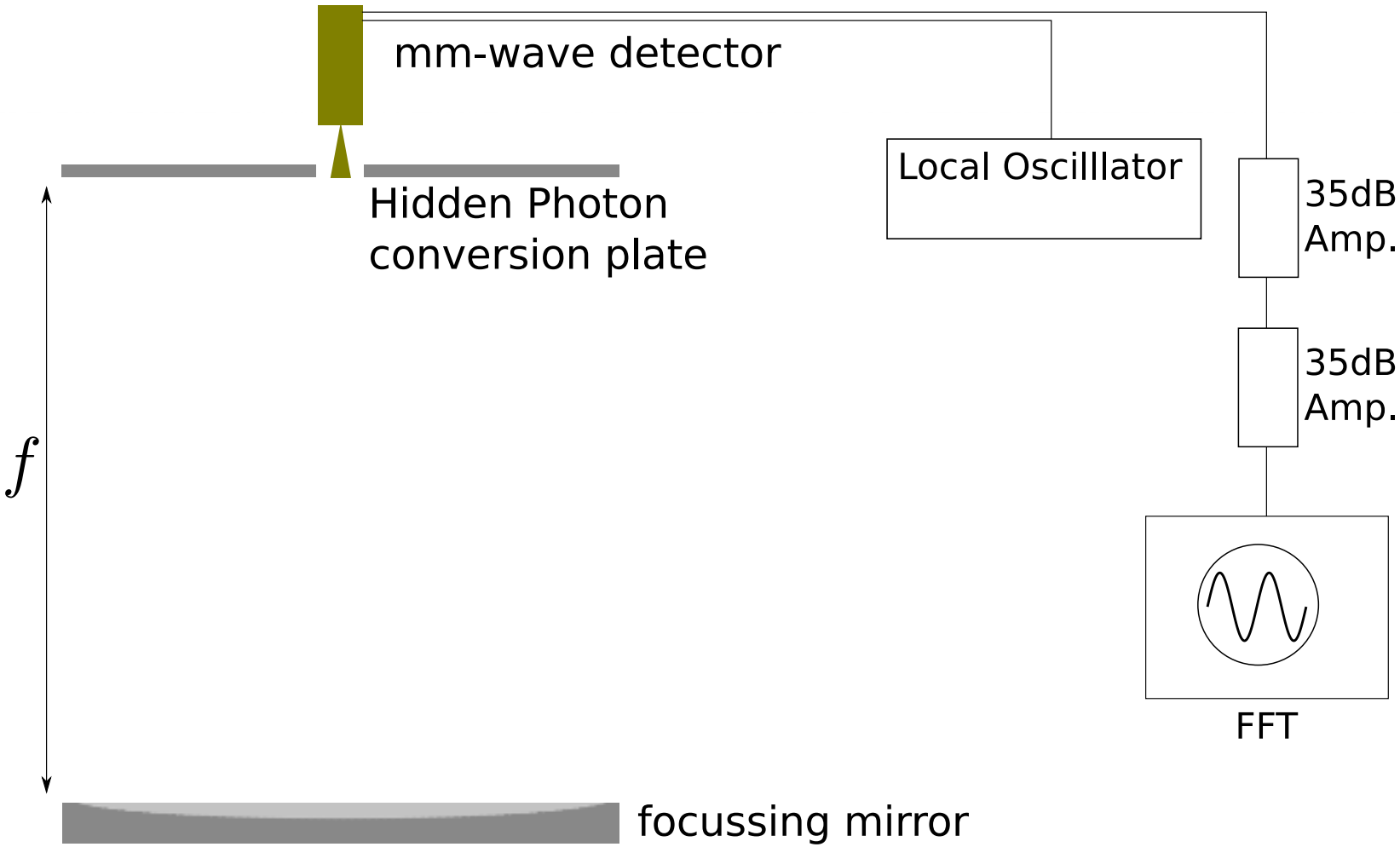

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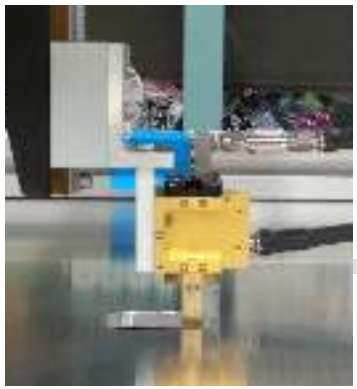


$f_{out} + n\, f_{LO} = f_{in}$

mm-wave detector
(Schottky-Barrier-Diode)

Hidden Photon
conversion plate

mm-wave input

Local Oscilllator
f_{LO}

35dB
Amp.

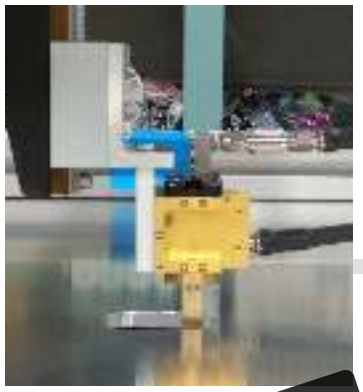
35dB
Amp.

f_{out}

FFT
(BW 4GHz)

focussing mirror

Our Experimental Setup



$f_{out} + n\, f_{LO} = f_{in}$ **1GHz** + 14 x 12 GHz = 169 GHz

mm-wave detector
(Schottky-Barrier-Diode)

Local Oscilllator
f_{LO} ~**12GHz**

35dB Amp.

35dB Amp.

Hidden Photon conversion plate

example

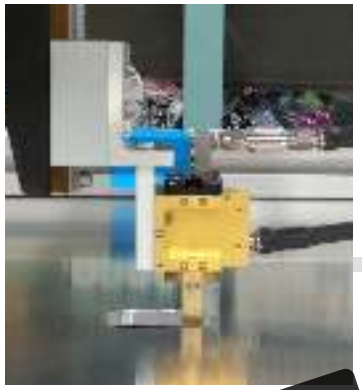
169 GHz
mm-wave input

1GHz

FFT
(BW 4GHz)

focussing mirror

Our Experimental Setup



$f_{out} + n\, f_{LO} = f_{in}$ **1GHz** + 14 x 12 GHz = 169 GHz

mm-wave detector
(Schottky-Barrier-Diode)

Local Oscilllator
f_{LO} ~**12GHz**

35dB Amp.

35dB Amp.

Hidden Photon conversion plate

example

169 GHz
mm-wave input

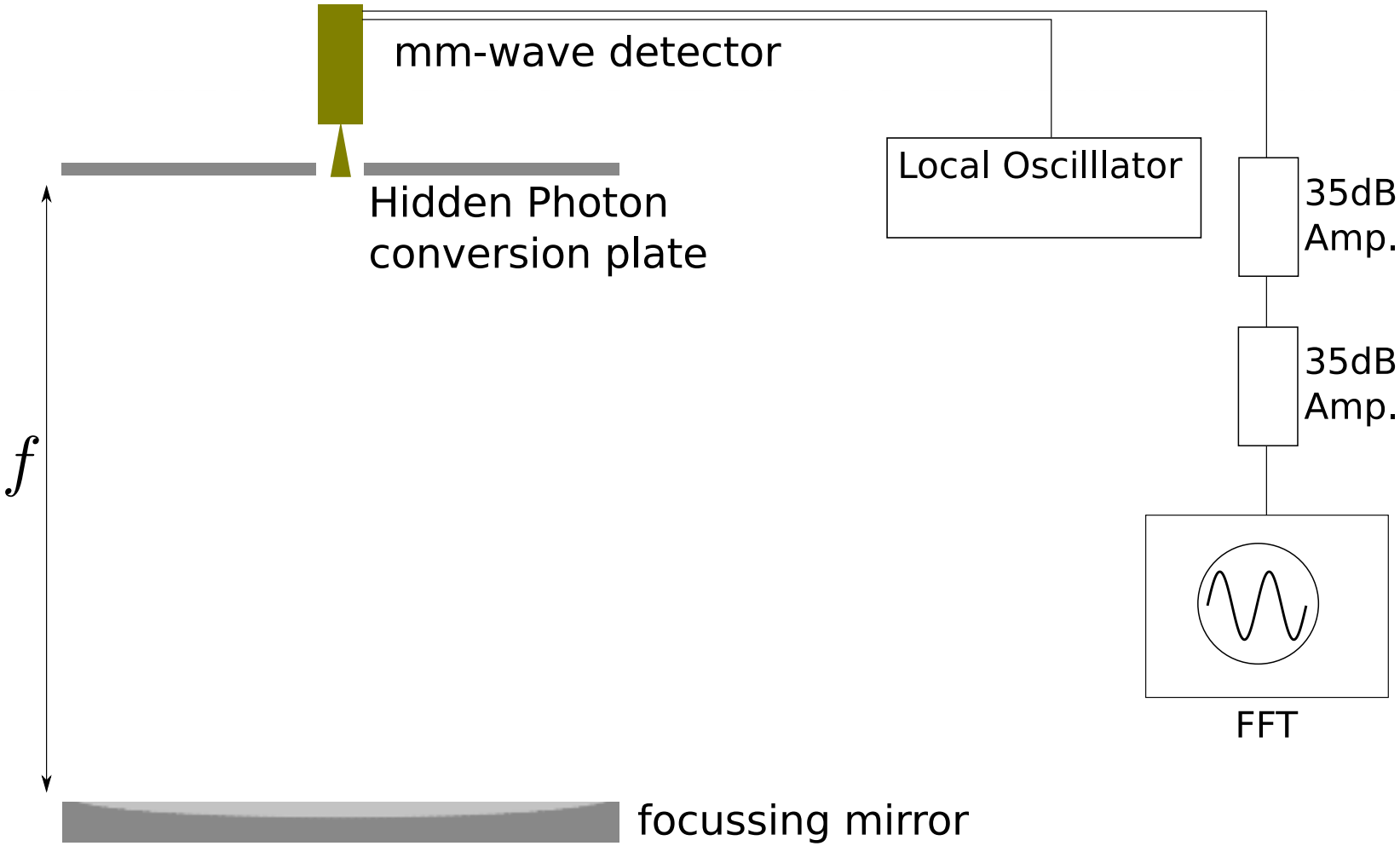
Our Schottky-Barrier-Diode:
$140 - 220\mathrm{GHz}$
$P_N \sim 10^{-14}\mathrm{W}$

1GHz

FFT
(BW 4GHz)

focussing mirror

Our Experimental Setup



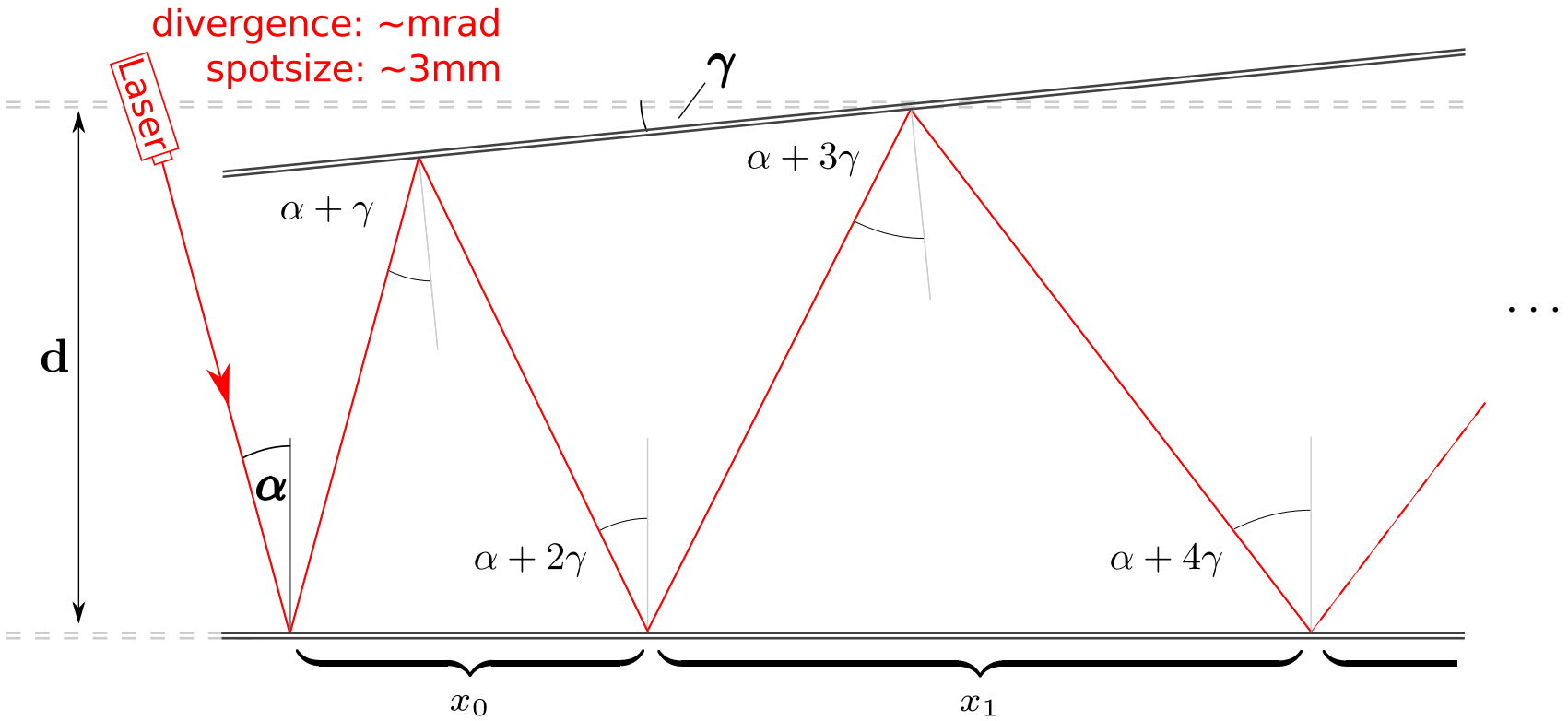
Our Experimental Setup

f=1.5m

Al mirror **Φ=500mm**,
surface **accuracy << 1mm**

Conversion plate (**Al**): 600x600mm
(**~100% reflectivity** for mm-wave)

Alignment Check



$$\gamma = \frac{\Delta x}{4d\cos\alpha} \lesssim \frac{1\text{mm}}{4 \cdot 1480\text{mm}\ \cos(10^\circ)} \sim 2 \times 10^{-4}$$

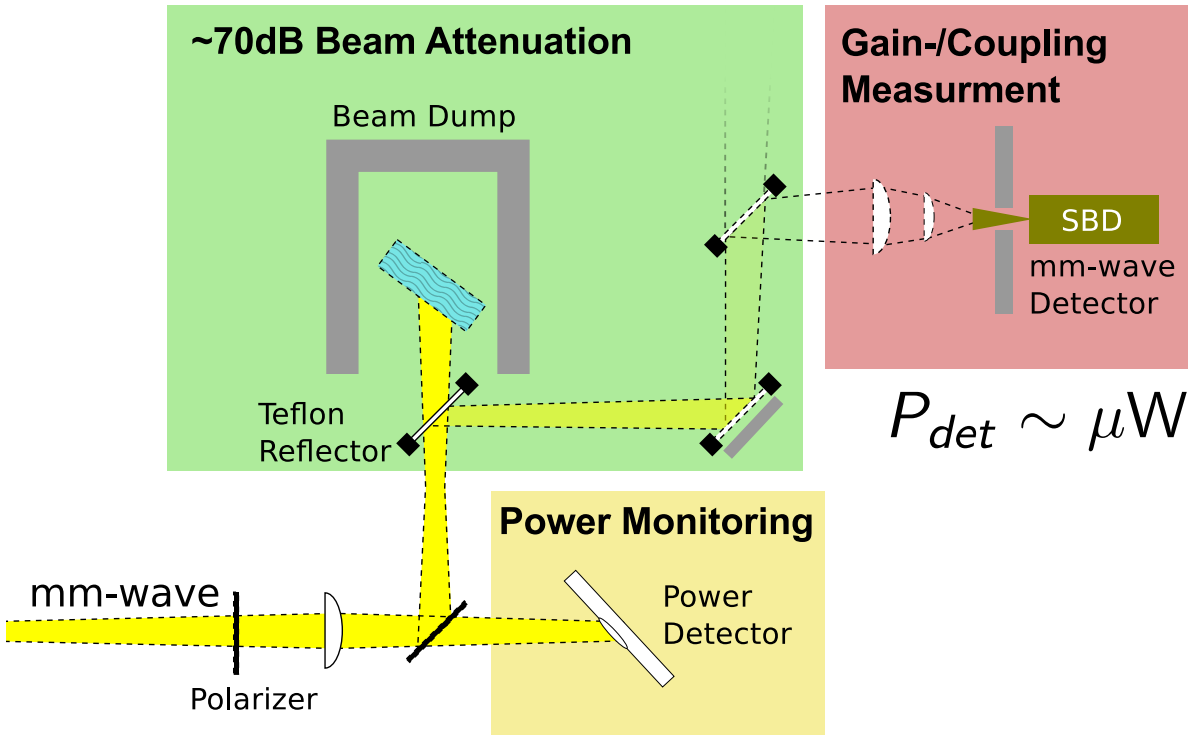
(need $\gamma < 10^{-3}$)

Detector Performance

Gyrotron (Fukui)

$P_{out} \sim 20\text{W}$

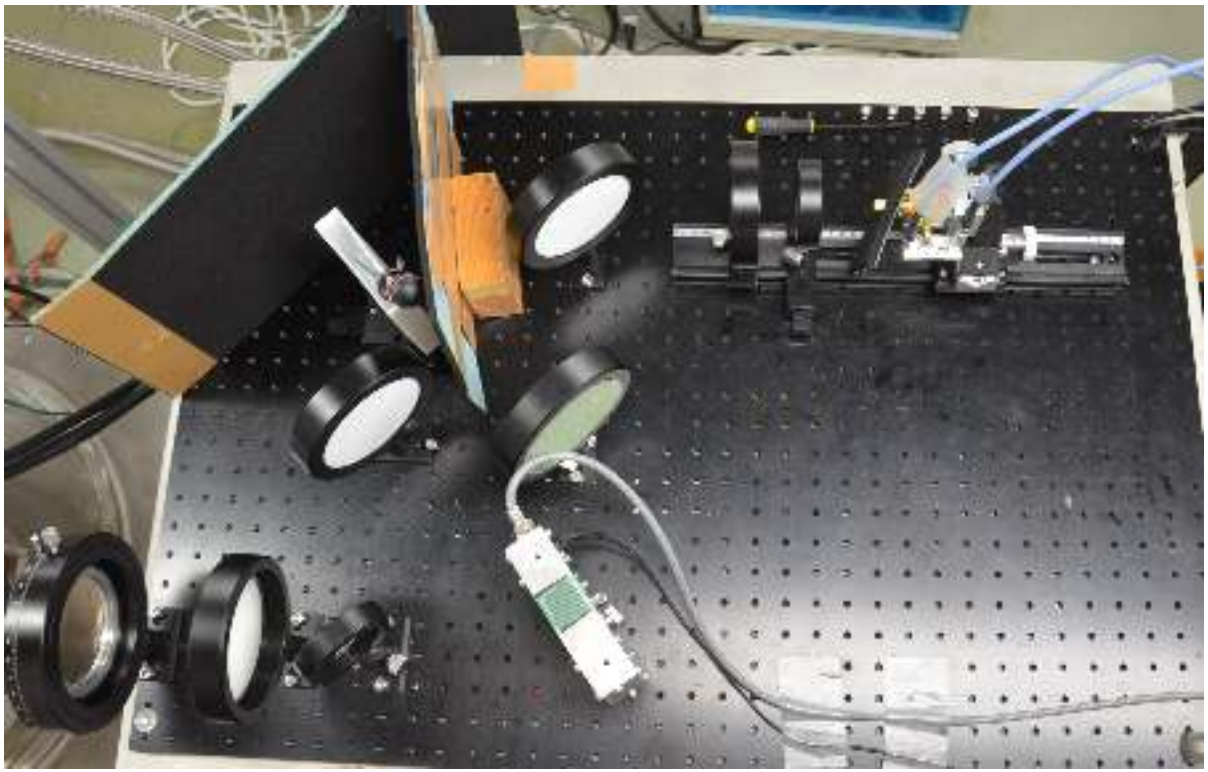
$\lambda_{out} \sim 1.6\text{mm}$



$P_{det} \sim \mu\text{W}$

Detector Performance

Gyrotron (Fukui)



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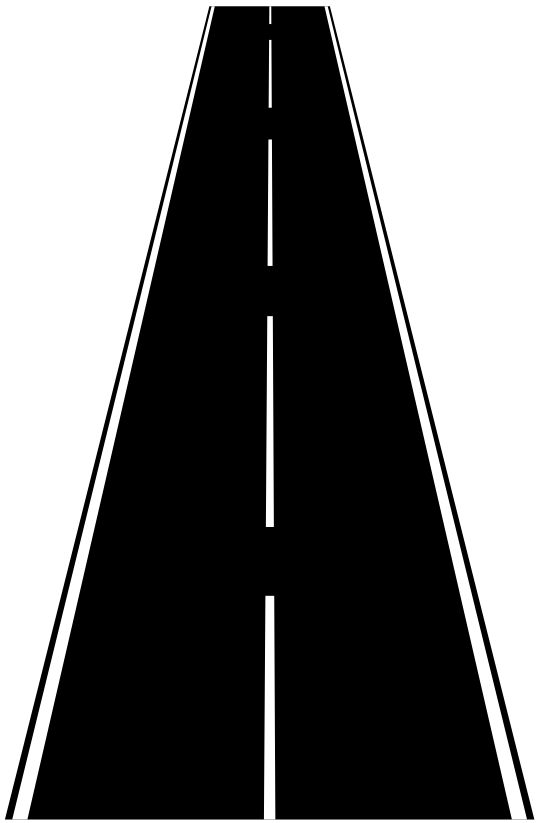
Roadmap & Outlook

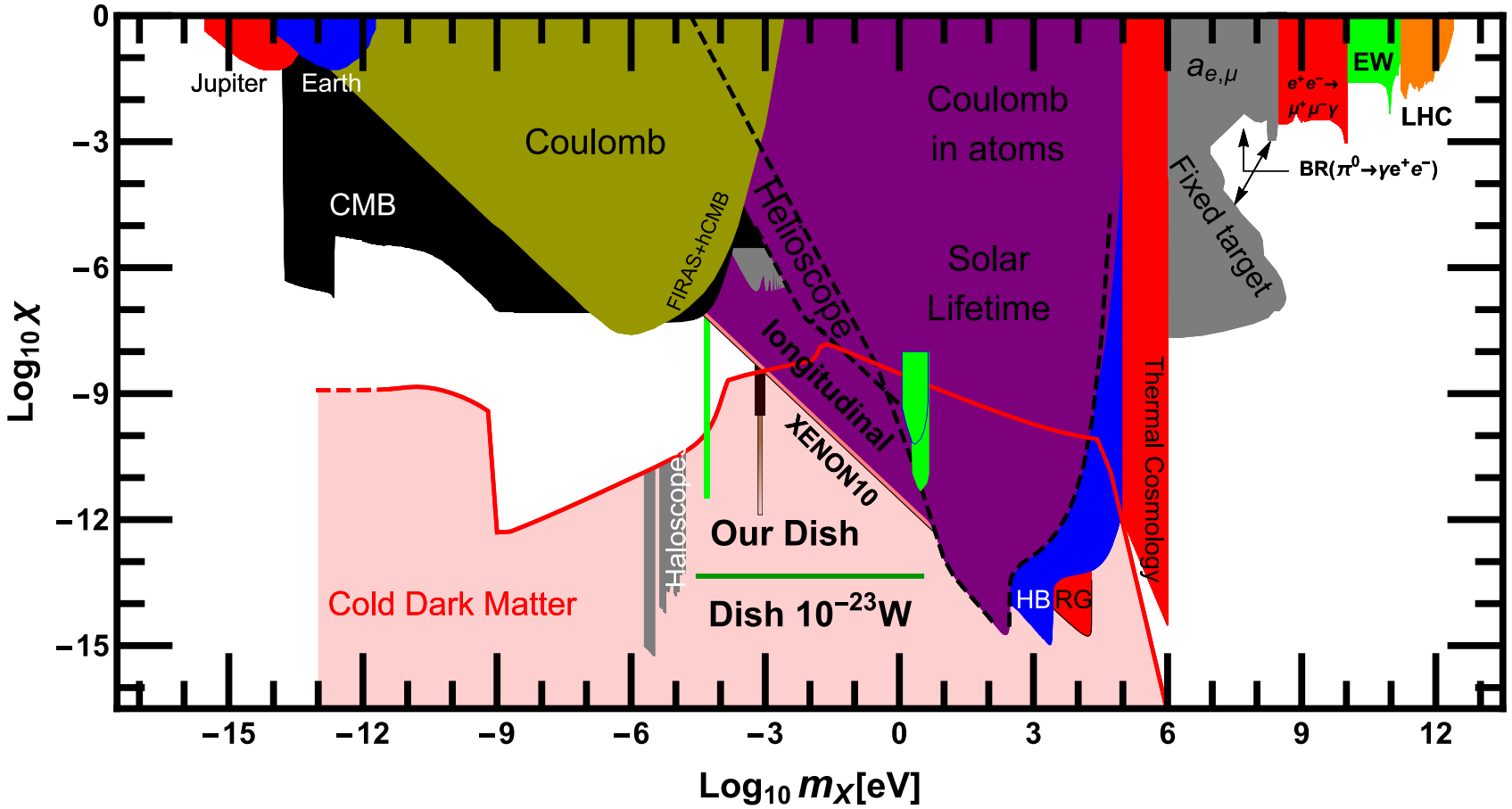


October - November
first actual DM measurement,
first preliminary result

from December
re-measurment of detector performance to improve limit

from around mid 2017
Dielectric Multi-Layered-Dish to increase signal
(c.f. DESY-PROC-2016-03)

Conclusion


Jupiter
Earth
CMB
Coulomb
FIRAS+hCMB
Helioscope
longitudinal
Coulomb
in atoms
Solar
Lifetime
$a_{e,\mu}$
$e^+e^- \to \mu^+\mu^-\gamma$
EW
LHC
BR($\pi^0 \to \gamma e^+e^-$)
Fixed target
Thermal Cosmology
XENON10
Haloscope
Our Dish
Dish 10^{-23}W
HB
RG
Cold Dark Matter
$\mathrm{Log}_{10} X$
$\mathrm{Log}_{10} m_X$[eV]
0
−3
−6
−9
−12
−15
−15
−12
−9
−6
−3
0
3
6
9
12

Thank you very much