3,4 He Gas Systems for Large Helioscopes

Vistas in Axion Physics

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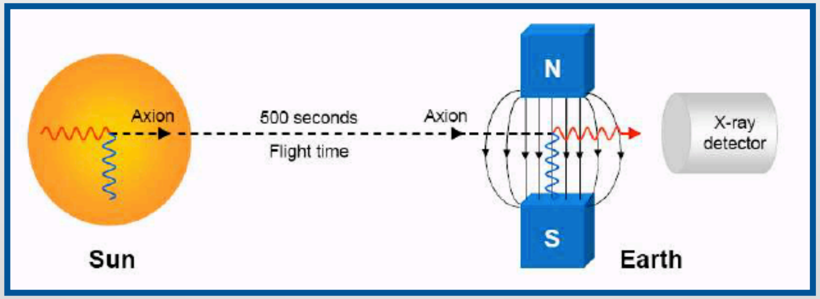
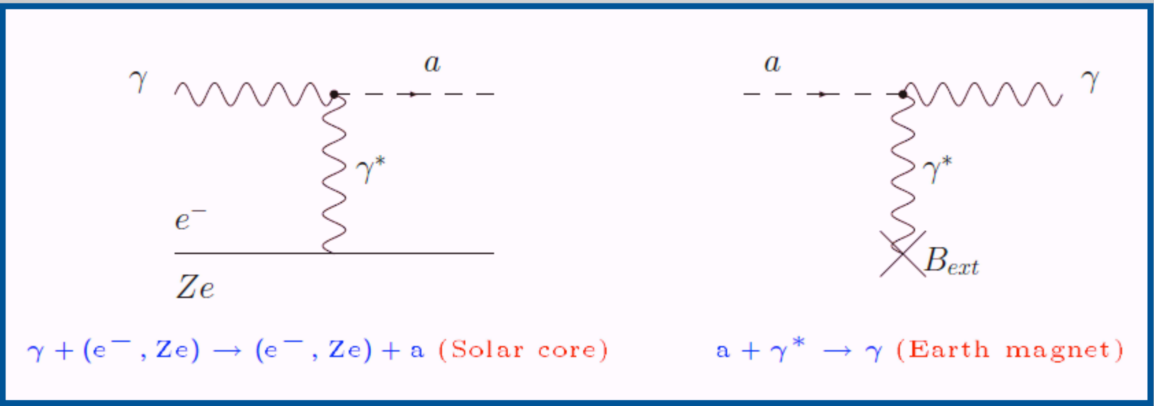
Helioscope Physic's — Axion source

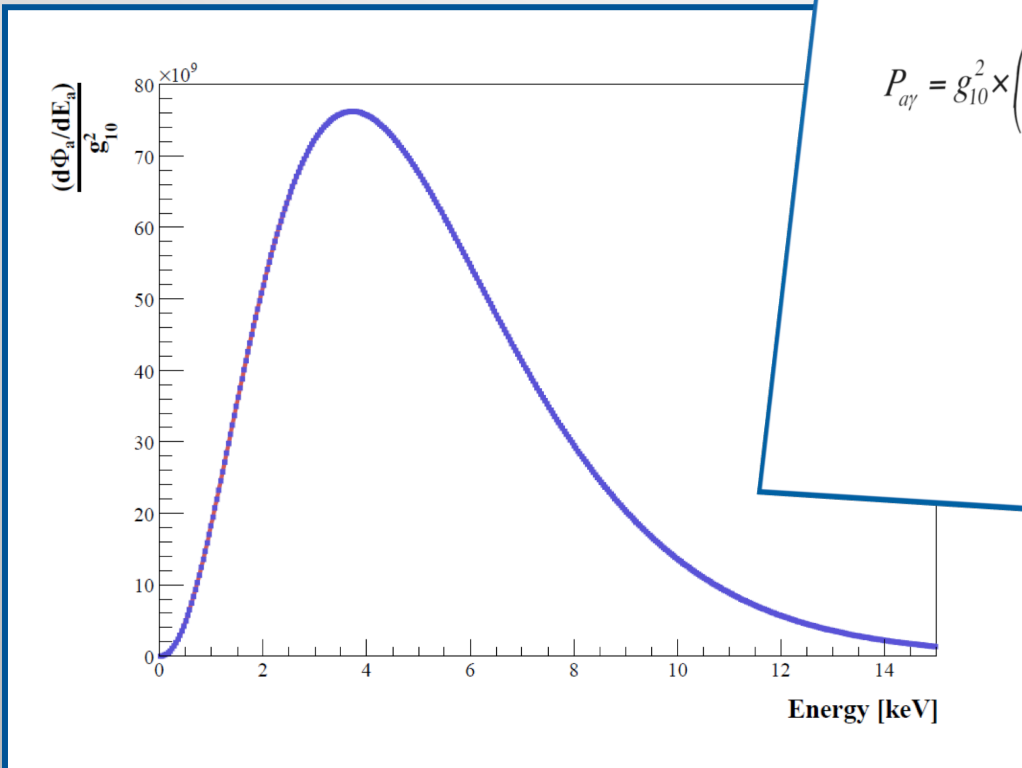
Black body photons of the Solar core could be converted into axions due to the electric fields of the charged particles in the hot plasma



The interaction of an axion converting to a photon via Primakoff effect in the presence of magnetic fields is the proposed detection mechanism for solar axions arriving the Earth



Helioscope Physic's — Principle of detection



Differential axion flux at the Earth surface due to Primakoff production in the solar core

Conversion Probability

$$P_{a\gamma} = g_{10}^{2} \times \left(\frac{B_{\perp}}{2}\right)^{2} \frac{1}{q^{2}+\Gamma^{2}/4}\left[1+e^{-\Gamma L}-2e^{-\Gamma L/2}\cos qL\right]$$

↓

Coherence Condition

$$\left|m_a^2 - m_\gamma^2\right| << 2\frac{E_a}{L}$$

Axion-to-photon conversion in the presence of a nearly homogeneous magnetic field **B** is only effective when the polarization plane is parallel to the incident particle

Coherence Condition

The axion mass band for which a Primakoff based experiment is sensitive can be extracted from the coherence condition

Vacuum

The converted photons are mass less

$$\left({m_a^2}/{keV^2} \right) << 2 \left(\frac{{E_a}/{keV}}{L \cdot keV} \right)$$

The magnet length sets the range of the axion mass coherence

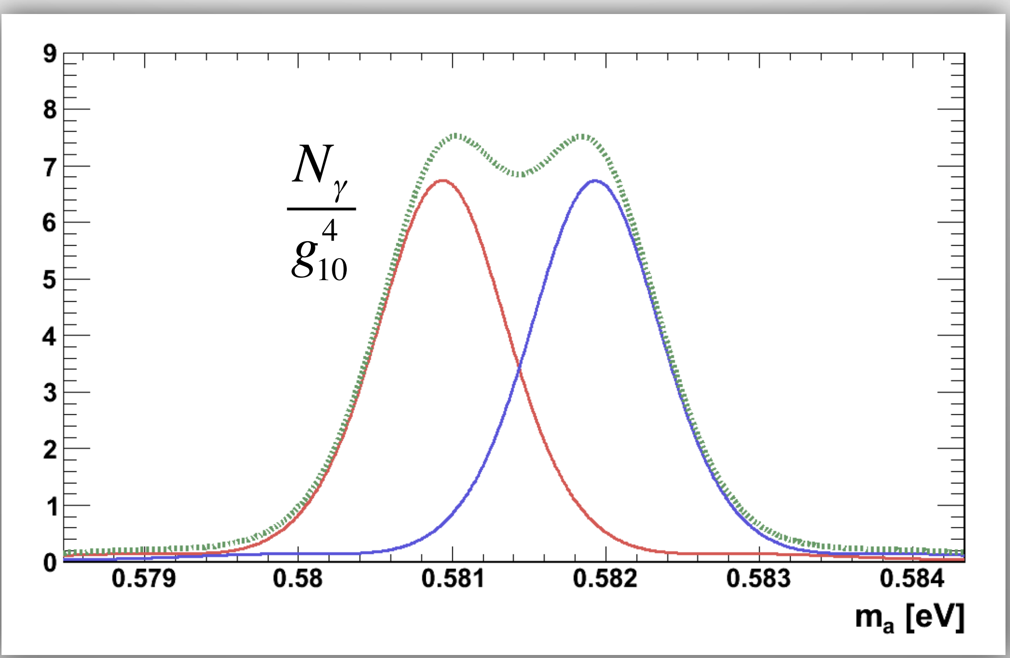
Gas

The converted photons acquire an effective mass

$$\left({m_a^2}/{keV^2} \right) << \left({m_\gamma^2}/{keV^2} \right) + 2 \left(\frac{{E_a}/{keV}}{L \cdot keV} \right)$$

Able to extend the axion mass sensitivity range of an experiment that has a fixed magnet length

The electron density in the magnet media transfers an effective mass to the arising photon from the Primakoff conversion.

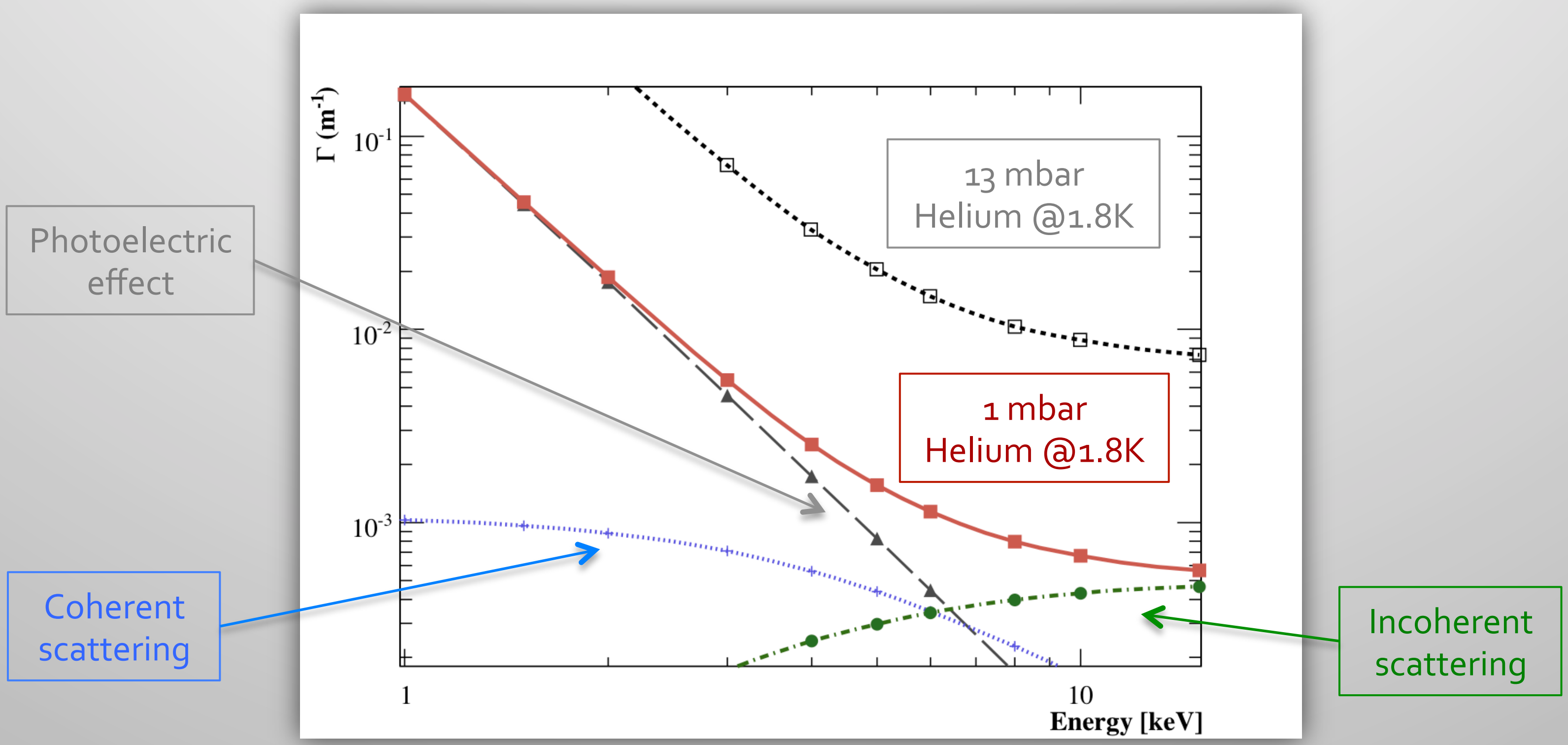


Stepping over different electron densities allows for discrete recoveries of the coherence condition

$$m_\gamma^2 = \omega_p^2 = 4\pi n_e \frac{e^2}{m_e} = 4\pi n_e r_e \quad \Rightarrow \quad m_\gamma^2 = 8\pi \frac{N_A \rho}{W_A} r_e$$

Coherence Condition — Description

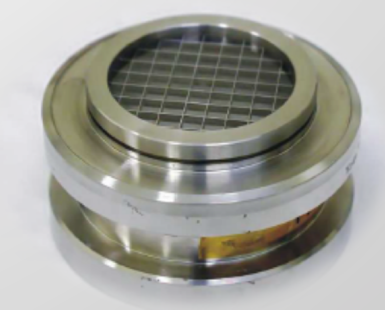
Helium gas is a nice candidate since the free path of x-ray photons is large



The arising photons are not exempt of damping, which affects the sensitivity of the experiment

Technical challenges

Contention of helium gas in magnet bores



- High x-ray transmission →
  - Thin plastic foils
  - Beryllium
- Tightness →
  - Important to keep a constant mass in the system
  - Scarce resources of 3 He gas
- Robustness →
  - Stand cryogenic environment
  - Quenching magnets

Strong magnetic fields are achieved by using superconducting materials in cryogenic environments. Magnets of this kind might quench during operation provoking sudden rises of temperature and pressure in the system.

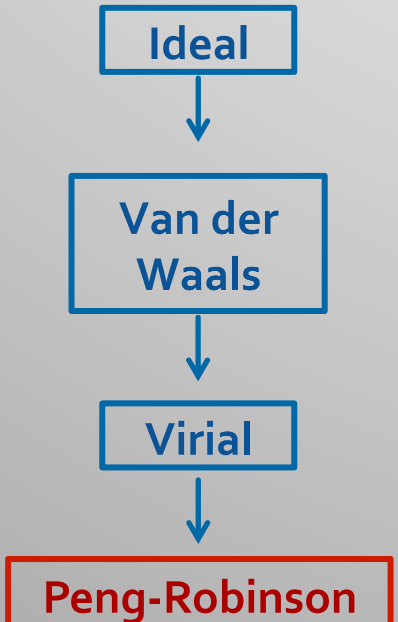
Technical challenges

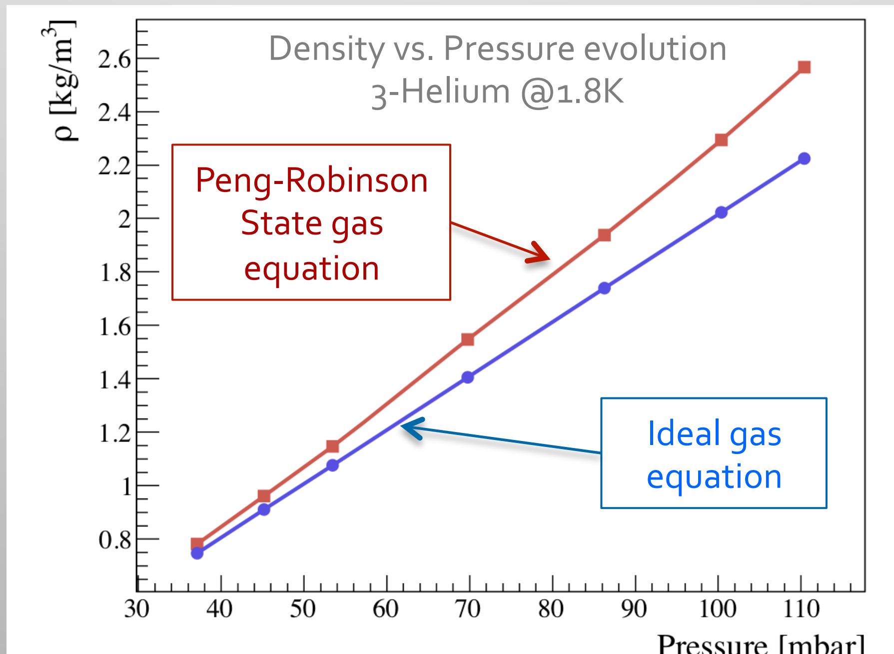
Metering stage and monitoring system

- Reproducibility and stability ⇒
  - Thermally controlled volumes
  - Accuracy of the filling @60ppm
- Purification system ⇒
  - Remove impurities
  - Minimize outgassing contamination
- Monitoring ⇒
  - Evolution of the system
  - Leak detection
  - Active safety

Computational fluid dynamics

– State equation ⇒
- Describes the nature of the Helium gas
- Pairwise attractive inter-particle force
- Non-zero, size, non-sphericity of the molecules





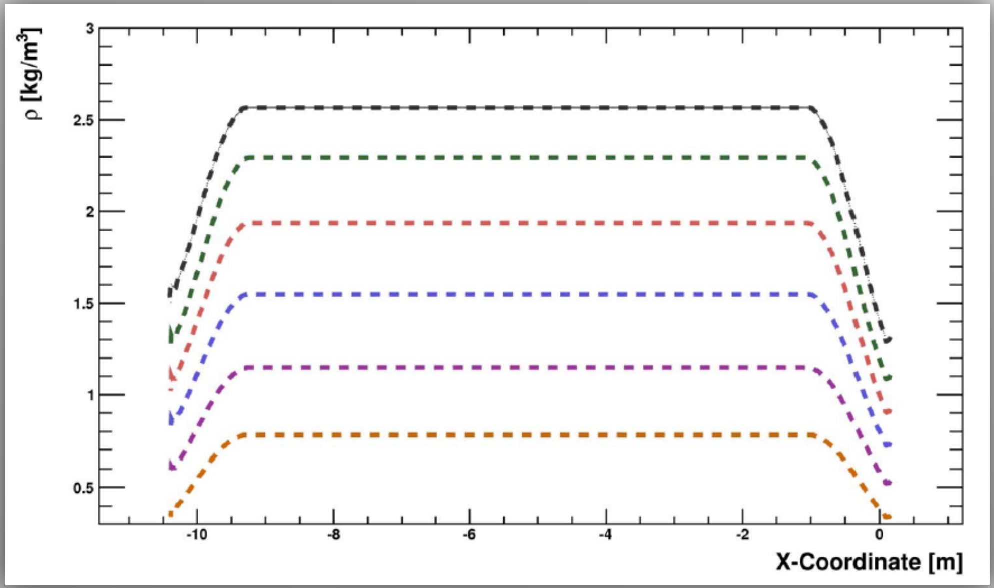
Computational fluid dynamics

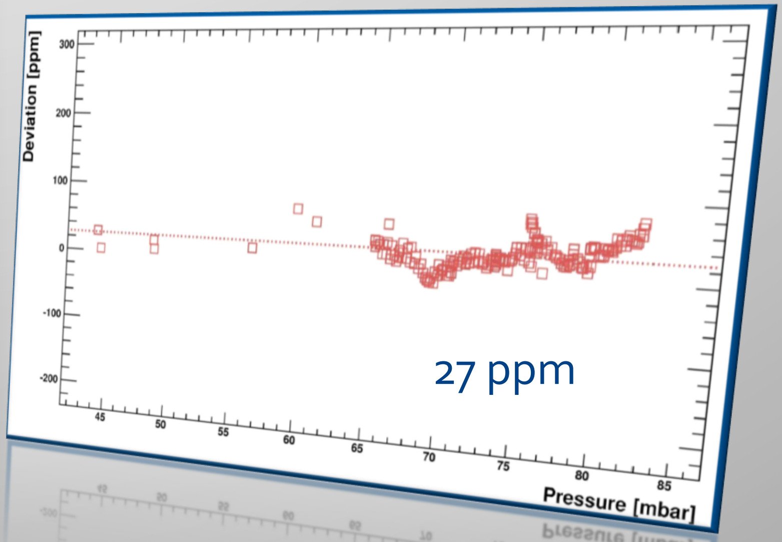
- Geometry of the system ⇒
  - Physical walls
  - Materials
  - Thermal conductivity, gas properties
- Boundary conditions ⇒
  - Temperature sensors
  - Pressure sensors
  - Mass present in the system
- Gravity and heat transfer ⇒
  - Hydrostatic
  - Convection
  - Buoyancy

Computational fluid dynamics

– Density profile

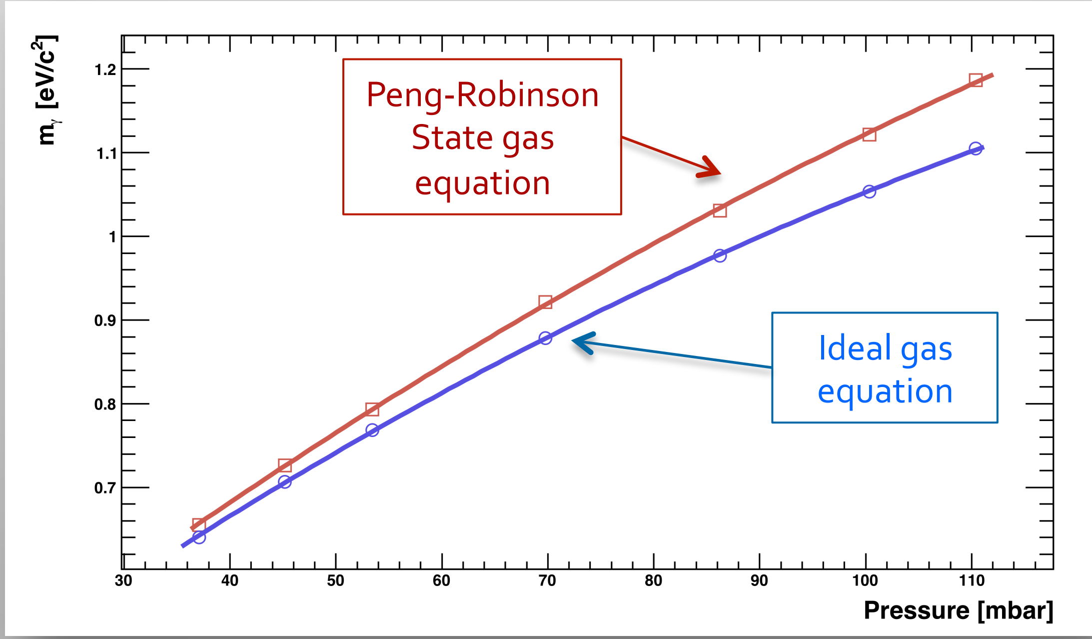
- Stable conditions
- Include all the physics
- Fine tune models
- Compatibility with experimental data





Computational fluid dynamics

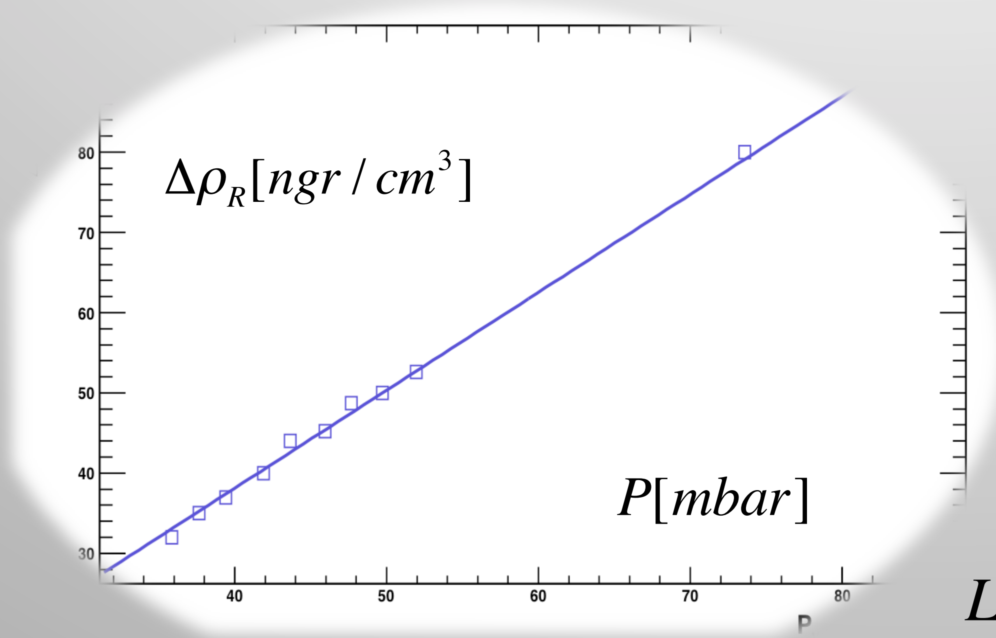
- Determining the effective photon mass ⇒
  - Density profile
  - Input for the analysis



Computational fluid dynamics

– Stability issues ⇒

- Homogeneity of density for a given section
- Effective magnetic field length as pressure rises



Operation conditions

[Temperature of the gas]

Boundary

[Temperature of the physical walls]

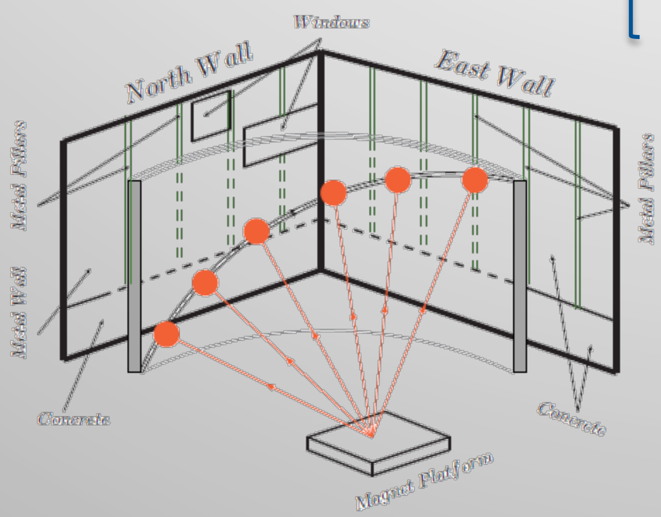
$$L_{eff} = L(P) \quad \text{or} \quad B = B(L)$$

Fluid dynamics Tracking conditions

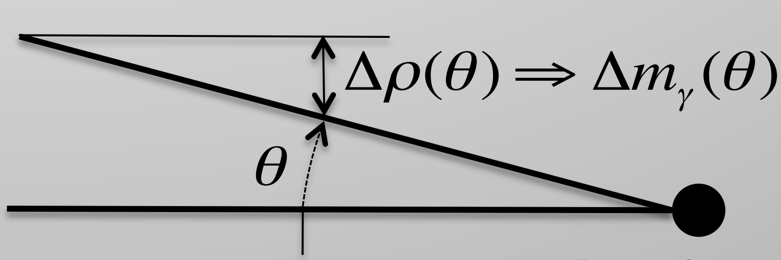
Computational fluid dynamics

- Tracking issues

- Tilting of the magnet modifies hydrostatic and buoyancy conditions affecting the gas density profile.
- Pressure drifts during tracking



Instant effective values of density can be considered.

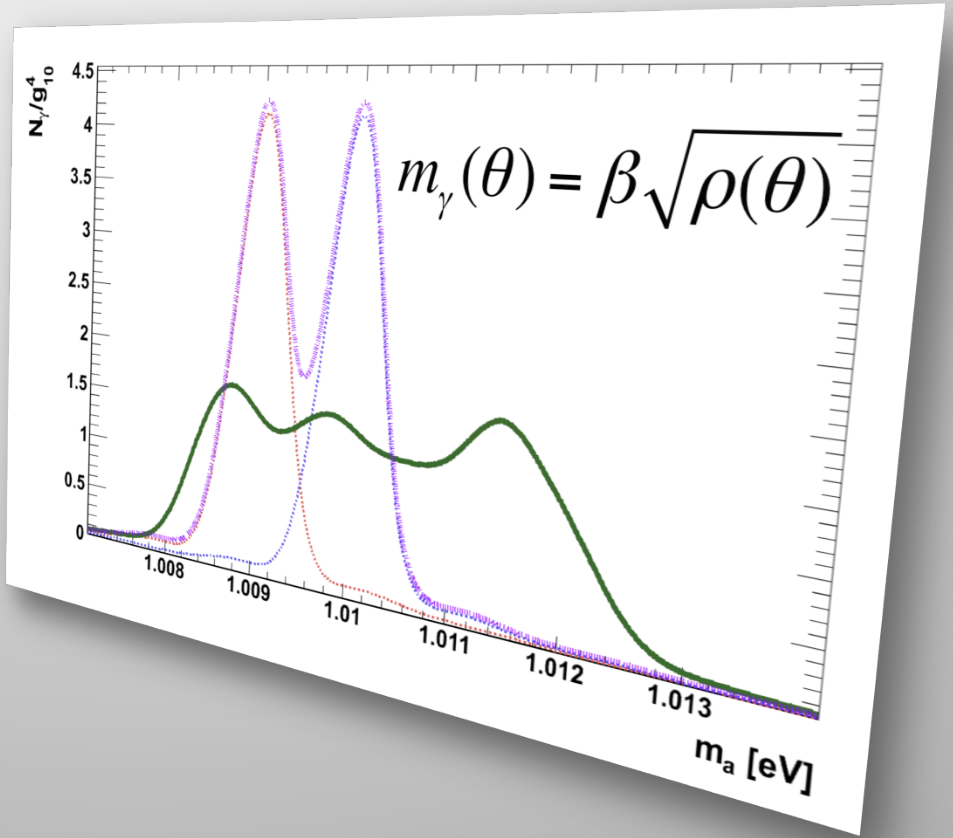


Fluid dynamics Tracking conditions

Such effect can be corrected by applying an effective density to the whole gas column

Considering $\alpha(\theta)$ the factor that accounts for the density in the center of the magnet bore relative to the density at $\theta = 0^o$.

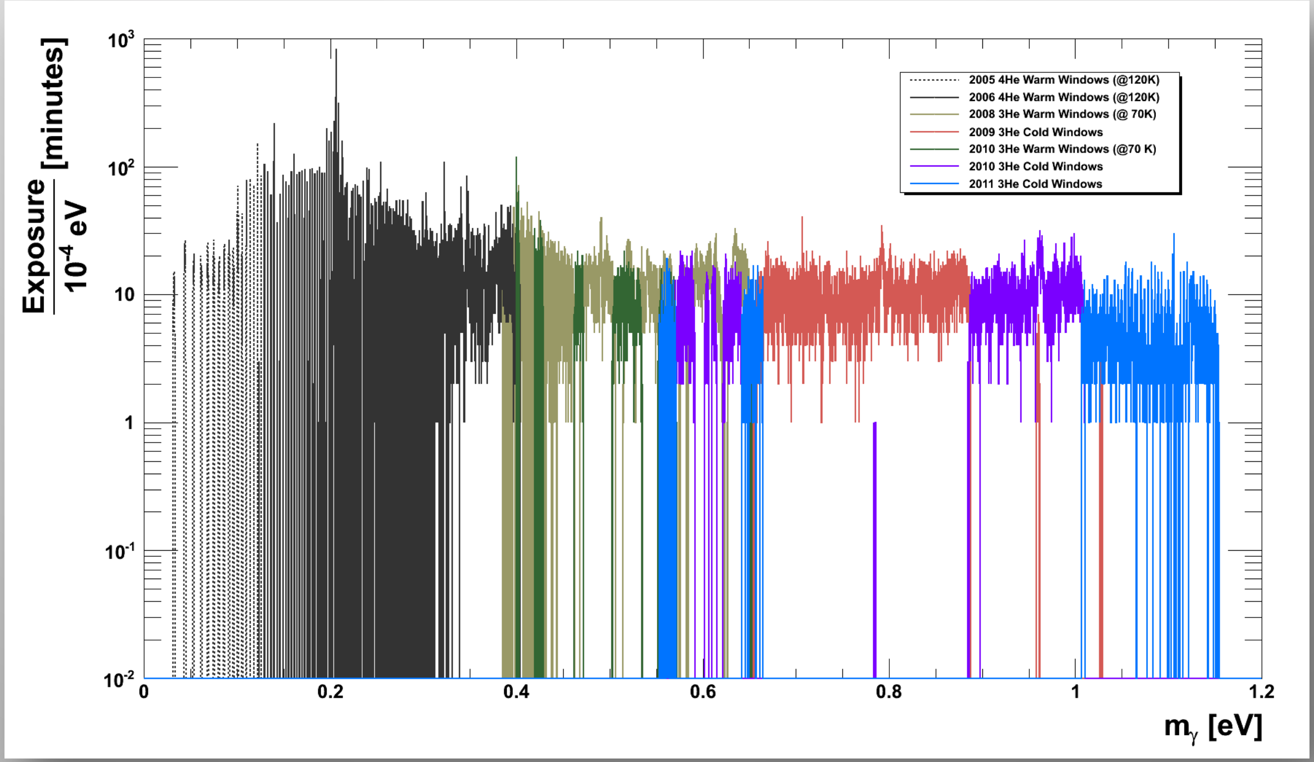
$$\rho(\theta) = [1 + \alpha(\theta)] \times \rho_{center,0}$$



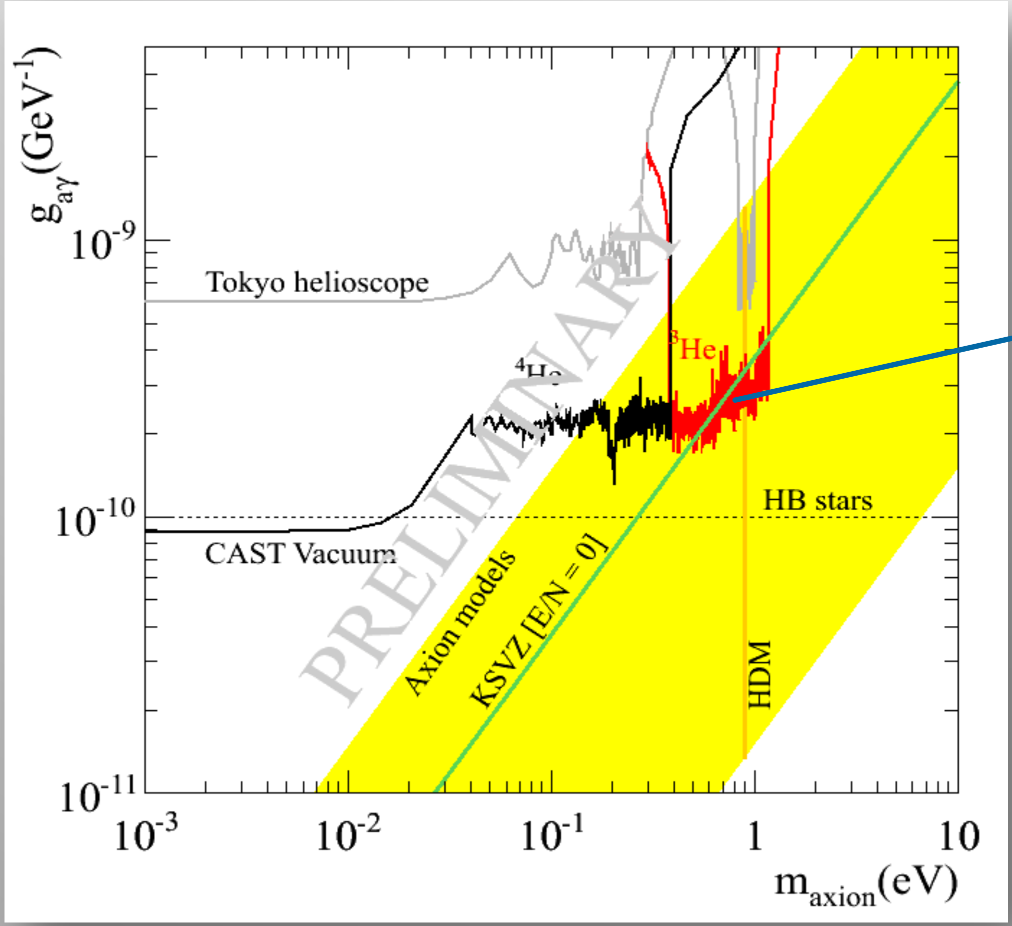
Fluid dynamics

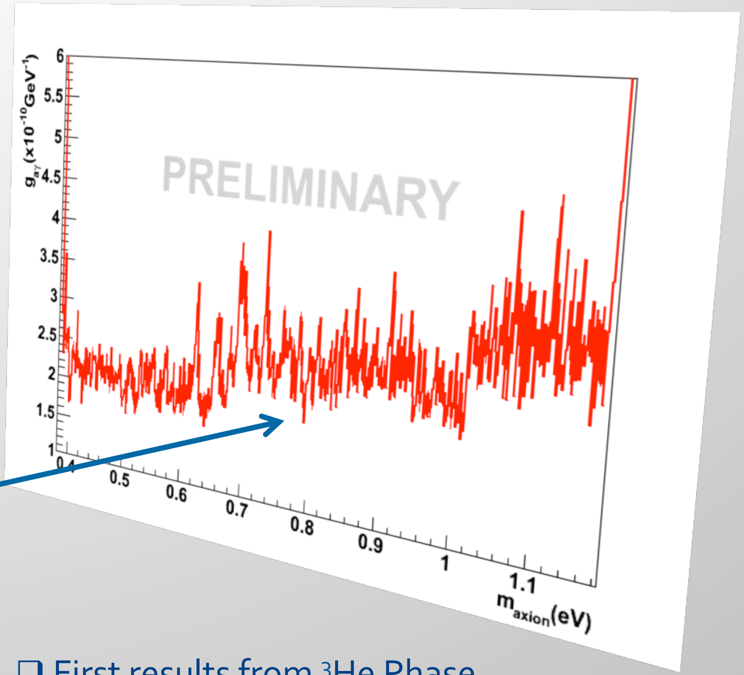
Sensitivity impact

The exposure of helioscopes like CAST to different axion masses has to take into account the density evolution in the magnet bore. This corrections scale with the density set. An effective axion mass range is scanned while tracking



Fluid dynamics Sensitivity impact





- First results from ^{3}He Phase
  Phys.Rev.Lett. 107:261302, 2011
- Axion mass :

$$0.39\ eV \le m_a \le 0.65\ eV$$

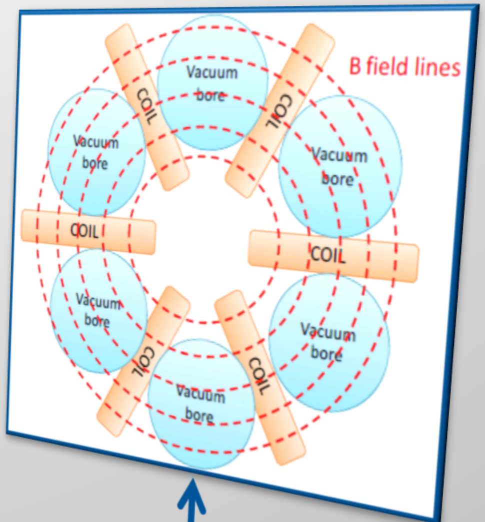
$$g_{a\gamma} \le 2 - 2.5 \times 10^{-10}\, GeV^{-1}$$

Future Helioscopes

- ❑ **CAST has gained valuable expertise on the helioscope technique**

- ❑ **Future improvement:**
  - New low background detectors
  - X-ray focusing devices
  - New, more powerful magnet

- ❑ **Entering the QCD modes:**
  - Very big volumes
  - Scarce 3-Helium
  - Avoid cold gas to restore coherence

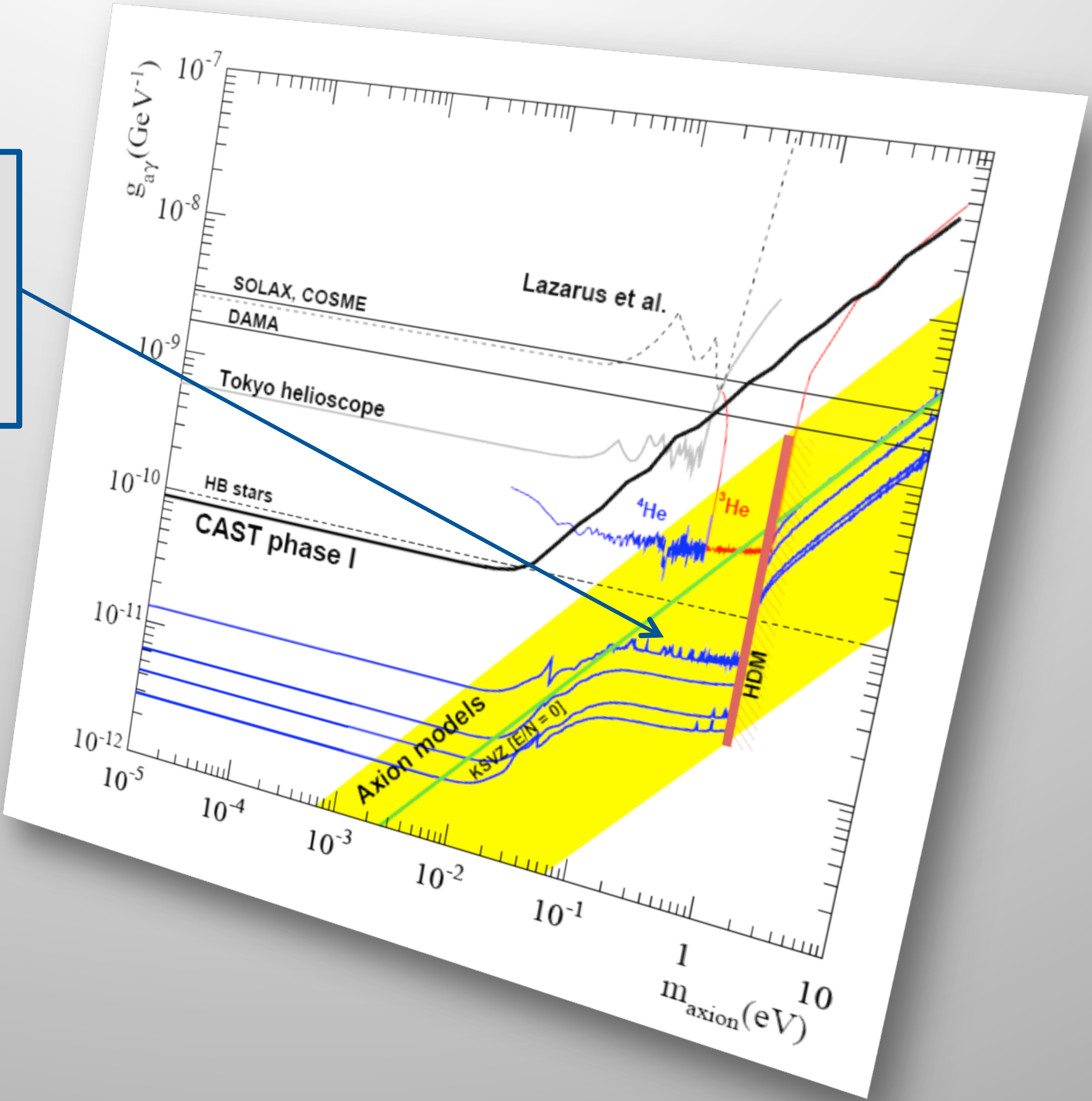


See Igor's talk

ANTI CRYOSTAT → **No need of 3-Helium** / **Stability of the gas**

Towards a new generation of axion Helioscopes

Large parts of the QCD favored models could be explored in the coming decade



Conclusions

- **Extending the axion mass sensitivity is possible**
  - The use of 3,4-Helium has become a standard technique for helioscope experiments
- **Model system**
  - Obtain the gas density profile in the magnet region
  - Crosscheck with experimental data to validate the evolution of the system
- **Monitor evolution**
  - Allows to find systematics in the analysis, such as leaks and strange behavior
- **Apply models**
  - Fight systematic
  - Impact to the sensitivity of the experiment
- **Towars a new generation of Axion Helioscopes**

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