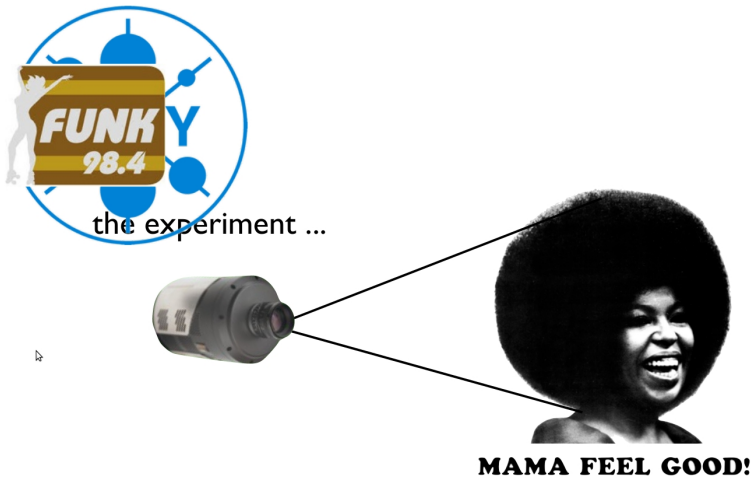
New (axion)/WISP Dark Matter experiments.

DM dish setup with AUGER fluorescence mirror (a.k.a. FUNKY)



Finding U(1)s of a Novel kind at DESY

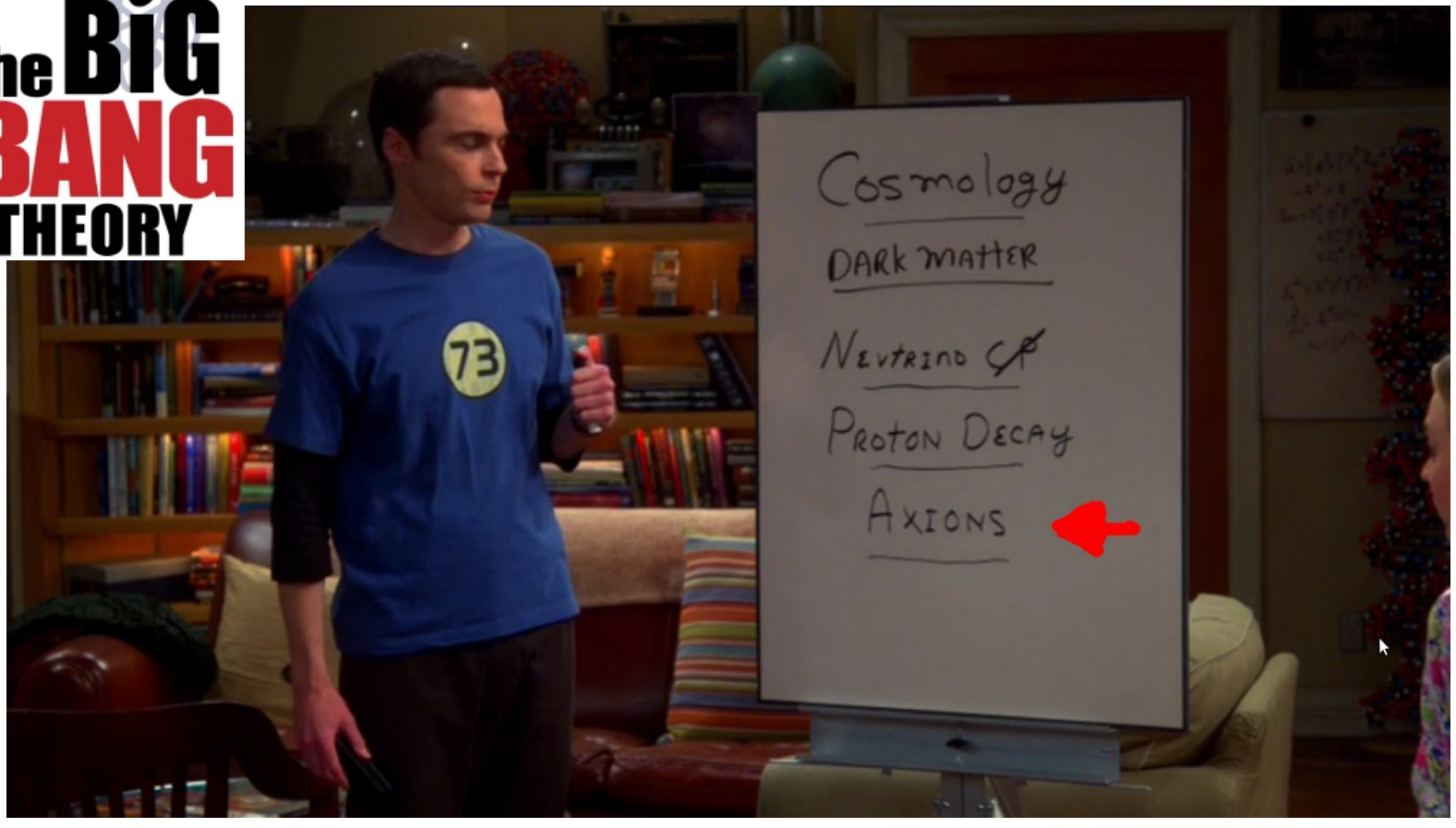
Babette Döbrich

10th Patras conference
CERN, July, 3rd 2014

HELMHOLTZ GEMEINSCHAFT

DESY

Motivational slide – axions in popular culture ☺



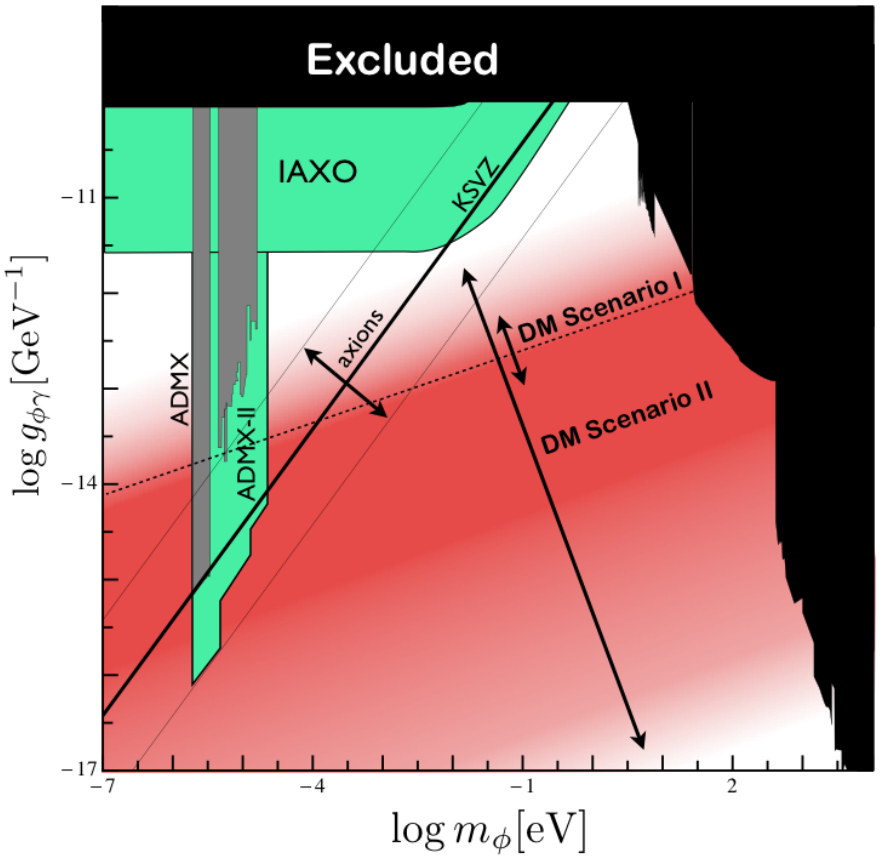
'The Relationship Diremption', Aired April 10, 2014

viable ALP and HP Dark Matter parameter space

DM [Arias et. al, JCAP 1206 (2012) 013]

$$\mathcal{L}_{\rm int} = g_{\phi\gamma}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

[figure below from 1311.5341]



- Axion-like-particle cDM
  - ALP DM through misalingment (scenario II), standard ALP DM $\rightarrow$ darker red m(T) 'QCD-like'
  - ALP DM through strings, DWs etc (scenario I)
  - known H_I would have an impact (under review)

viable ALP and HP Dark Matter parameter space

DM [Arias et. al, JCAP 1206 (2012) 013]

vector DM [Nelson/Scholtz Phys.Rev. D84 (2011) 103501]

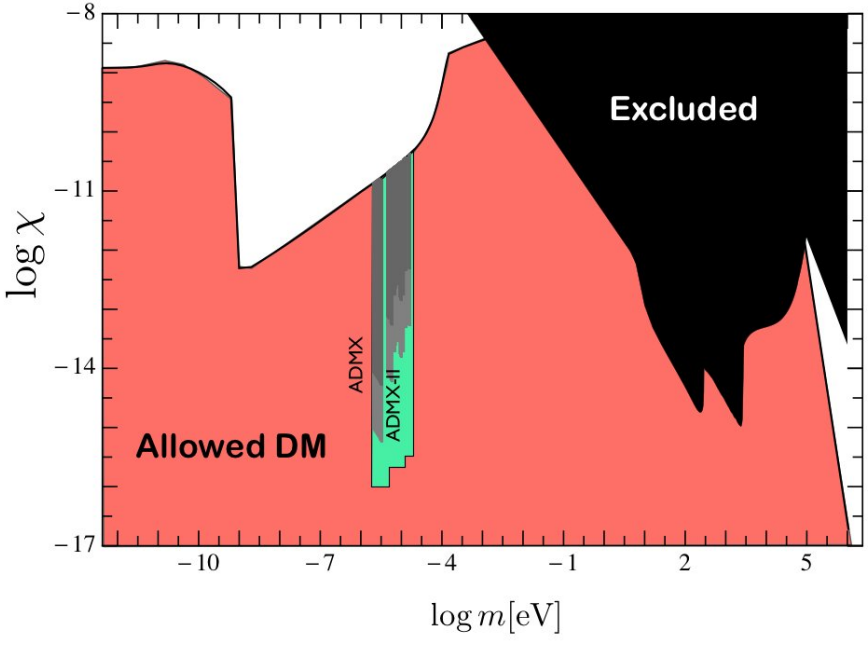
$$\mathcal{L} \sim \chi F_{\mu\nu} X^{\mu\nu} + \frac{m^2}{2} X_\mu X^\mu$$

[figure below from 1311.5341]

[An/Pospelov/Pradler Physics Letters B, Volume 725, 2013]

[Redondo/Raffelt JCAP 1308 (2013) 034]

↓ Solar limits

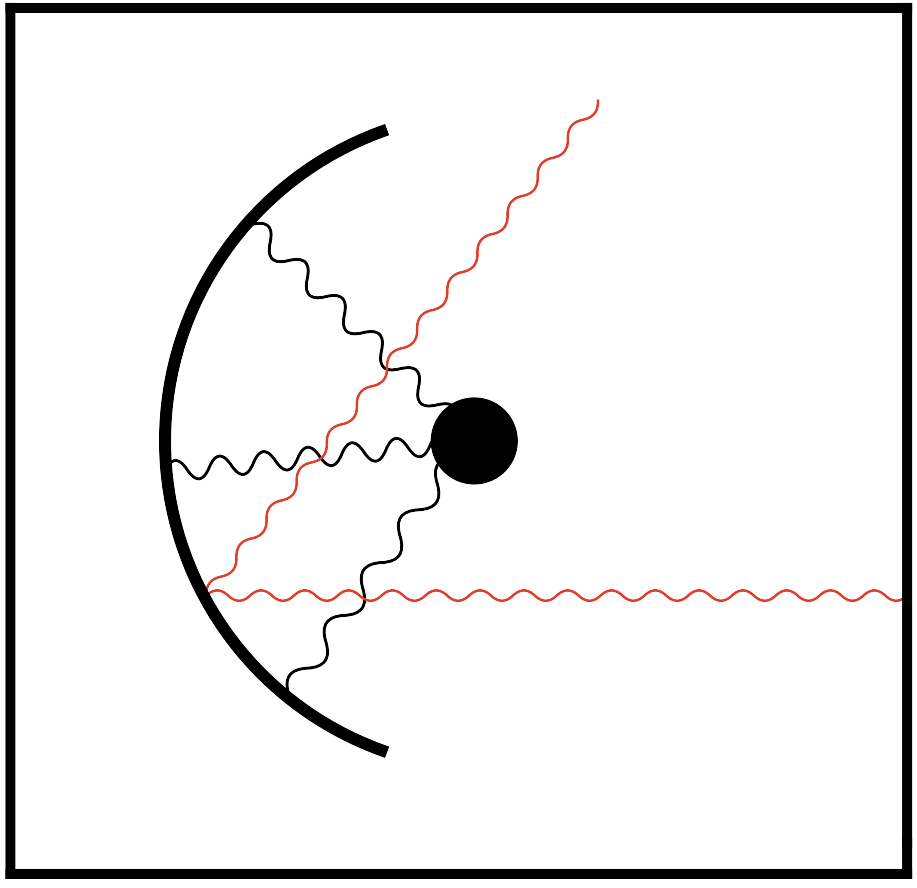


- Axion-like-particle cDM
  - ALP DM through misalingment (scenario II), standard ALP DM → darker red m(T) 'QCD-like'
  - ALP DM through strings, DWs etc (scenario I)
  - known H_I would have an impact (under review)
- Hidden Photon (vector) cDM
  - misalingment possible but initial ampl. unconstrained (no angle)
  - upper limit through CMB distortions, $N_\nu^{\rm eff}$...
  - mass term (Stückelberg, Higgs), cosmology involved (under review)

DESY

Dish antenna concept review Horns et al. JCAP 1304 (2013) 016

Theory is sometimes rather 'flexible'.
Let's do experiments!



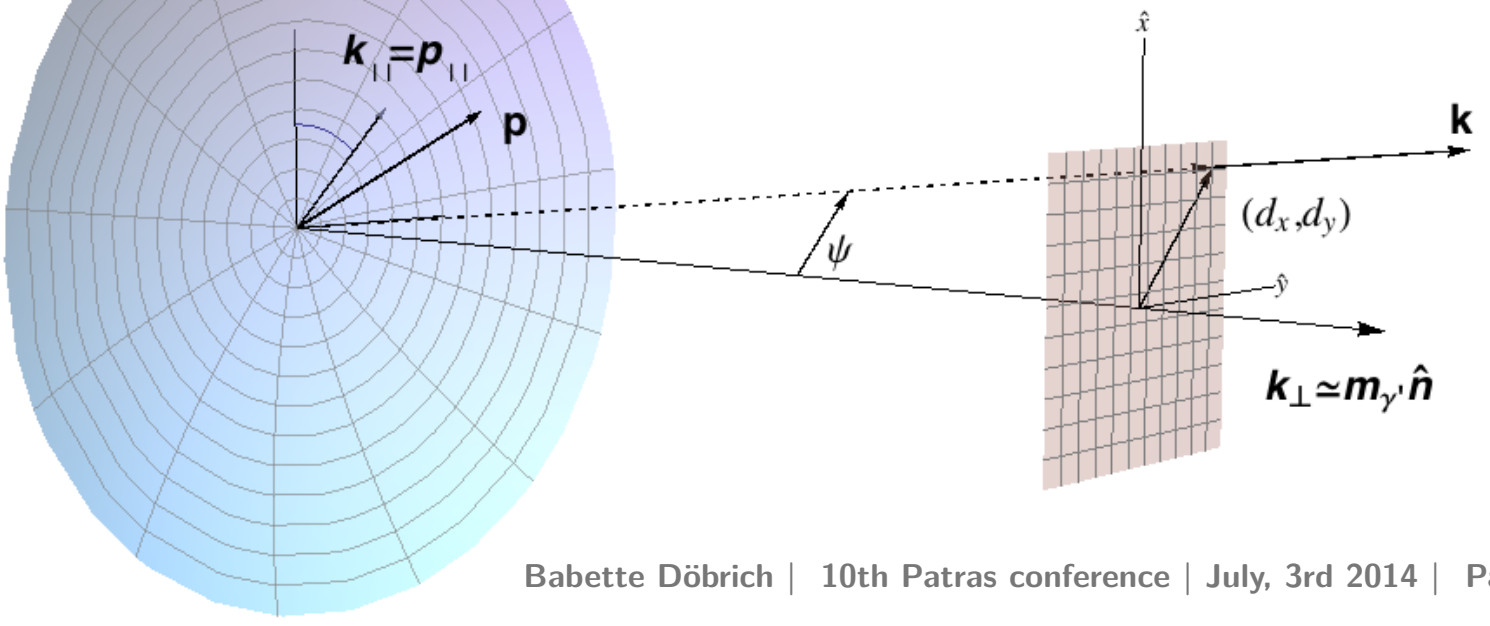
- ALP/HP wide mass range suggests non-resonant search
- ALP/HP-photon mixing implies a 'DM solution' ($\vec{p} \simeq 0$) with a tiny electric field component
- imposing conducting boundary $\vec{E}_{\parallel}|_{\text{surface}} = 0$ leads to surface waves emitted perp. to mirror ('change of $n_{\text{refractive}}$')
- background-supressed at dish! $\rightarrow$ collect light at center of reflecting sphere Jaeckel/Redondo 'a half cavity' [1308.1103]
- ALPs need $\vec{B} \parallel$ surface

DESY

Directionality

Jaeckel/Redondo, JCAP 1311 (2013) 016

- $\vec{p}$ incoming, $\vec{k}$ outgoing, along $k_{\parallel} = p_{\parallel}$ no boundary change
- with energy conservation $\vec{k} = \sqrt{m^2 + |\vec{p}_{\perp}|^2}\vec{n} + \vec{p}_{\parallel} \Rightarrow$ $|\vec{p}| \ll m$ angular off-set $\psi \simeq |\vec{p}_{\parallel}|/m \Rightarrow d_i \simeq \frac{p_i}{m} R$, detector at center R

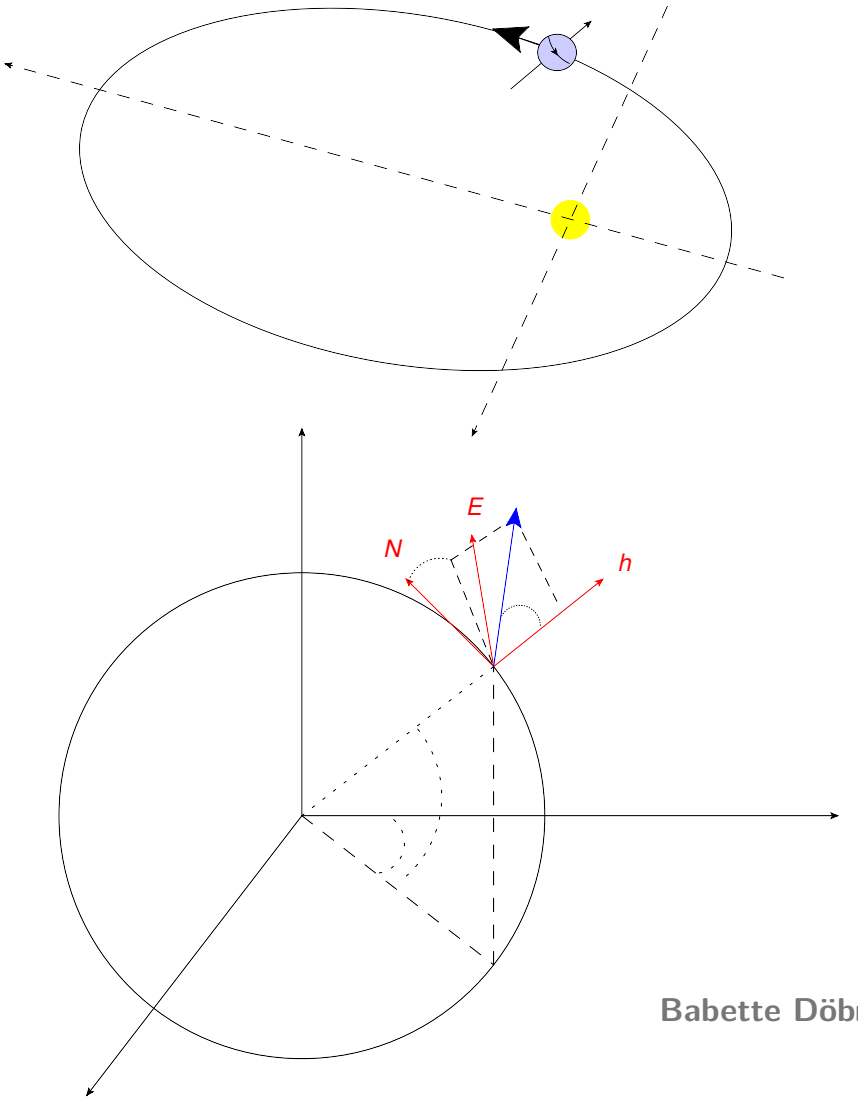


Directionality

Jaeckel/Redondo, JCAP 1311 (2013) 016

DM @ 60° to ecliptic ↘

[see, eg. 1307.5323]

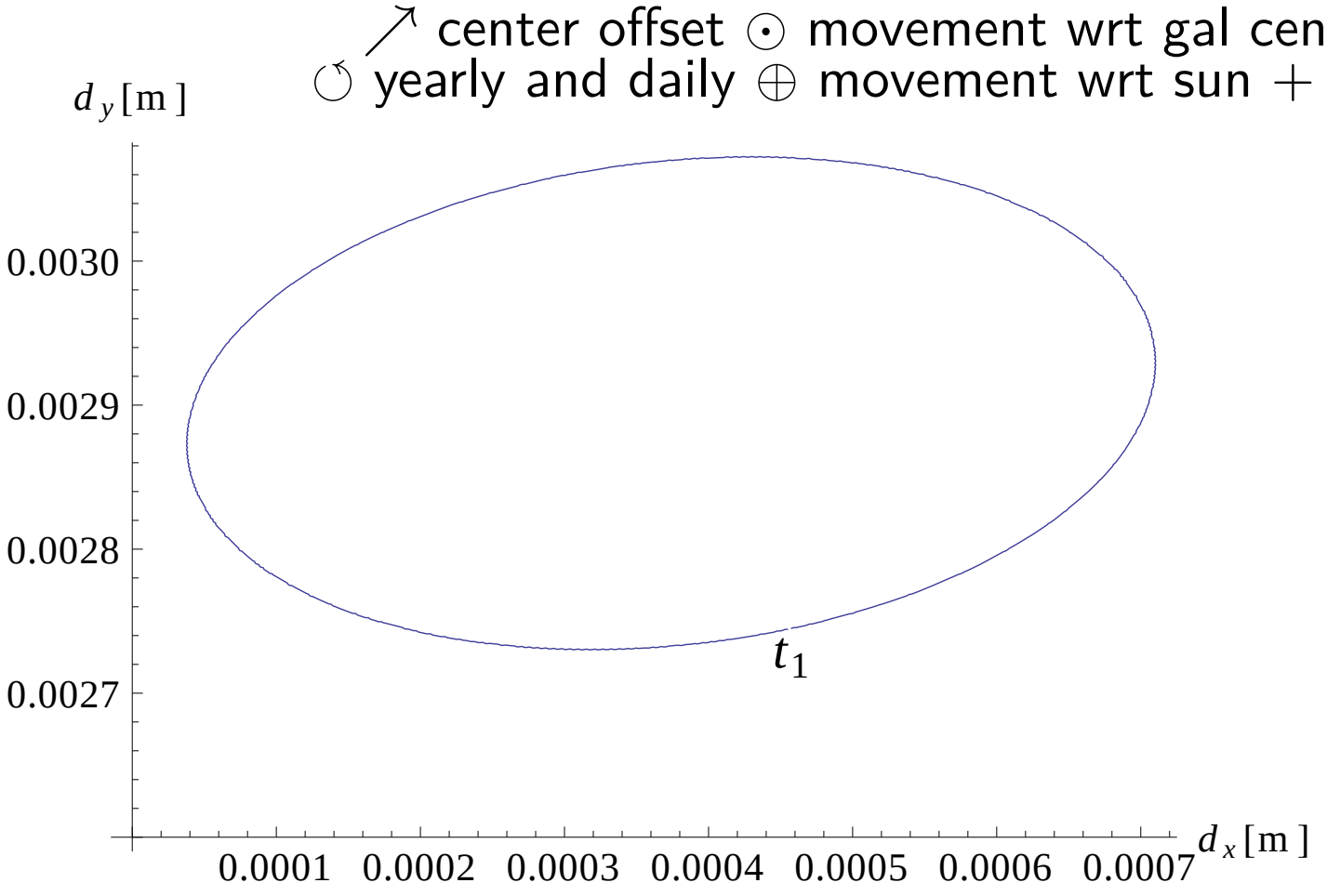


- $\vec{p}$ incoming, $\vec{k}$ outgoing, along $k_\parallel = p_\parallel$ no boundary change
- with energy conservation $\vec{k} = \sqrt{m^2 + |\vec{p}_\perp|^2}\vec{n} + \vec{p}_\parallel \Rightarrow$ $|\vec{p}| \ll m$ angular off-set $\psi \simeq |\vec{p}_\parallel|/m \Rightarrow d_i \simeq \frac{p_i}{m} R$, detector at center R
- spot-**broadening** DM velocity distribution $\Delta d \sim 1\mathrm{mm}(\frac{R}{\mathrm{m}})$ (if $\Delta v \sim 10^{-3}$) +**movement** (in DM frame)

DESY

Directionality

Jaeckel/Redondo, JCAP 1311 (2013) 016



Helpful if a signal is seen!!

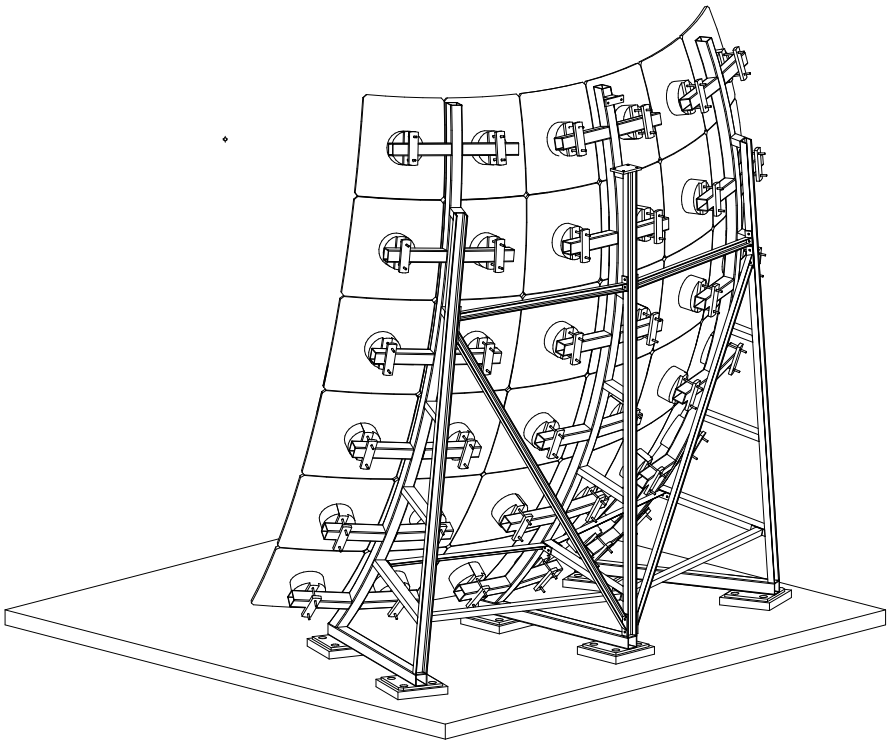
> point-spot-ellipse for $R = 3.4$m, NE orientation at Karlsruhe, GER

AUGER on the Dark Side

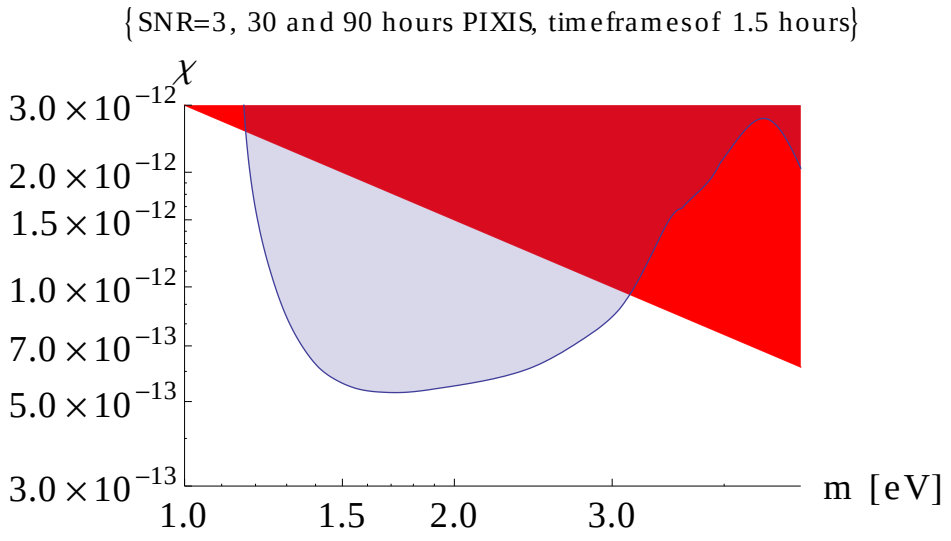
[with R.Engel (KIT), M.Kowalski (Berlin & DESY Zeuthen) and others]
supported by HAP, see [1311.5341]

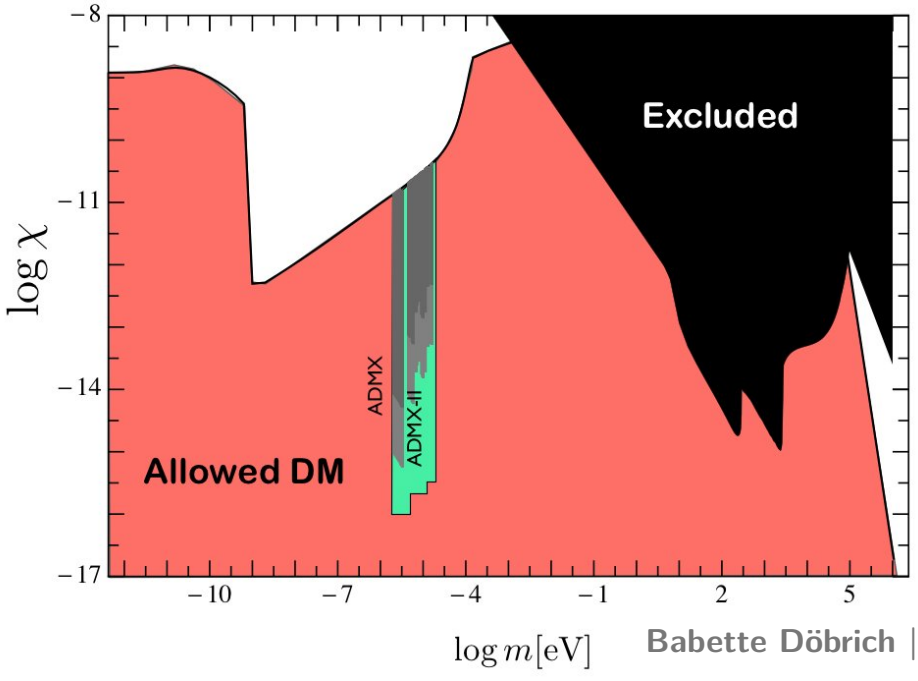
- AUGER fluorescemce detector, test aluminium spherical mirror
- 0th order experiment: optical det. in center

3.6×3.6m!!



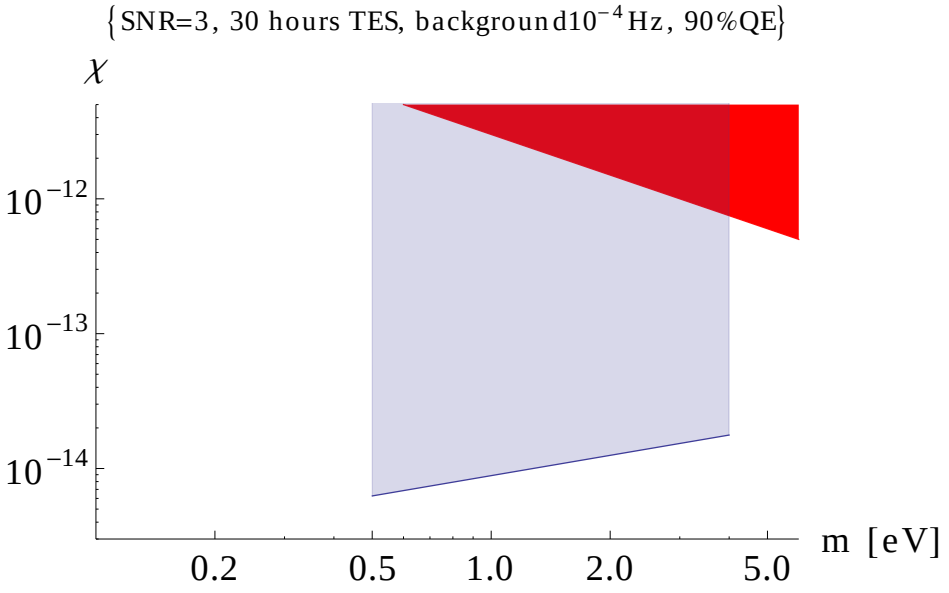
AUGER on the Dark Side

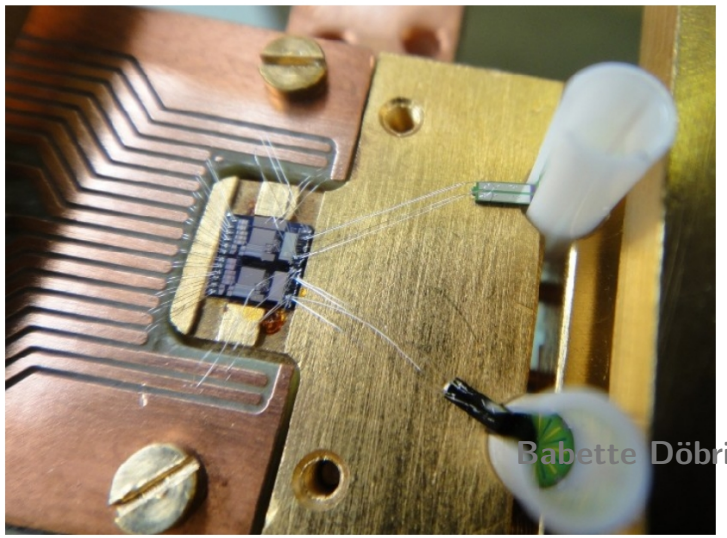




- AUGER fluorescemce detector, test aluminium spherical mirror
- 0th order experiment: optical det. in center
- exemplarily commercial PIXIS sensitivity (PMT similar)

AUGER on the Dark Side

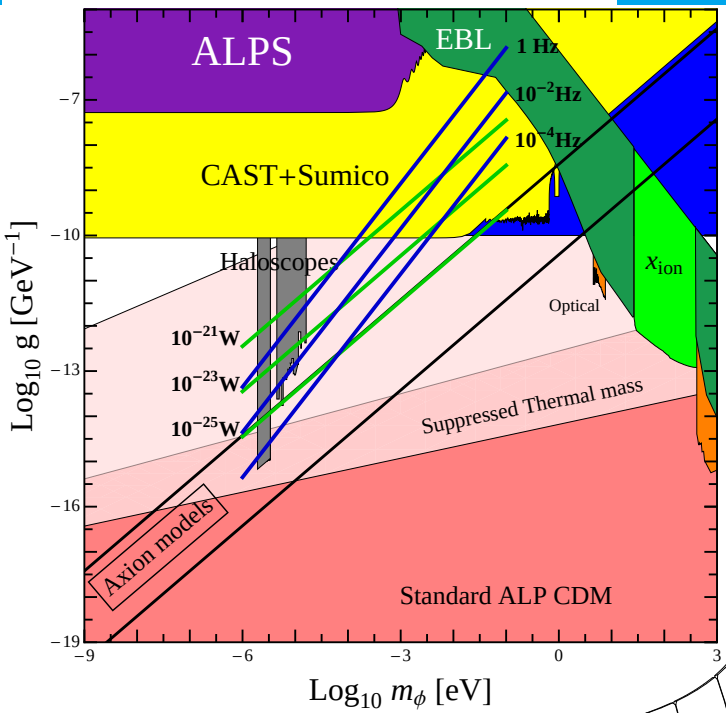




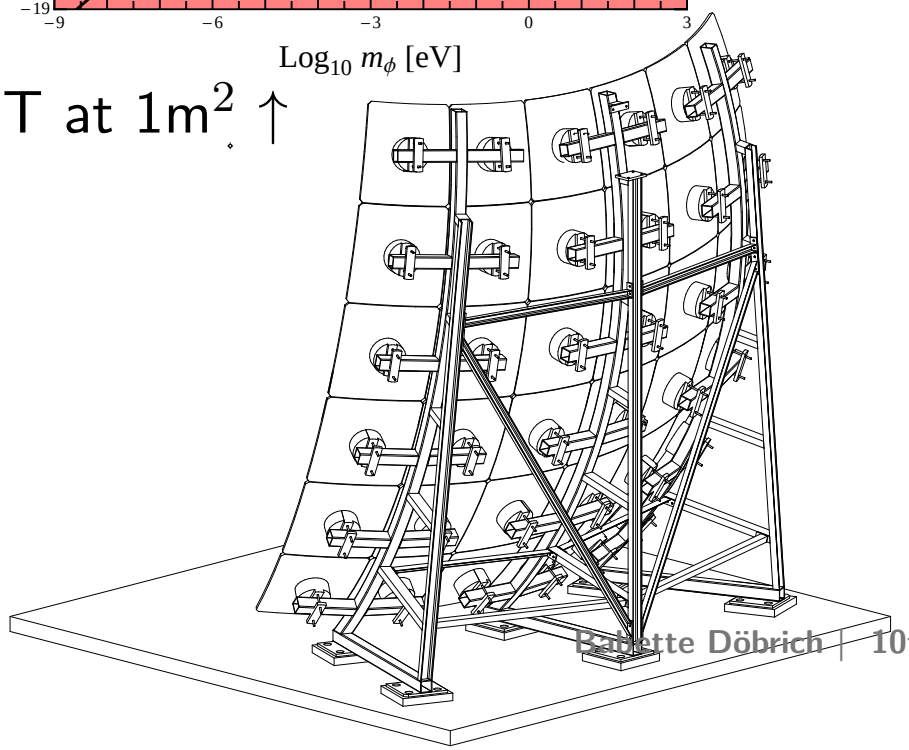
- AUGER fluorescemce detector, test aluminium spherical mirror
- 0th order experiment: optical det. in center
- exemplarily commercial PIXIS sensitivity (PMT similar)
- infrared: TES (see talk be J.Dreyling-Eschweiler)
- even lower freq: bolometer + filter (general problem: narrow band signal in large bandwidth detector?)

DESY

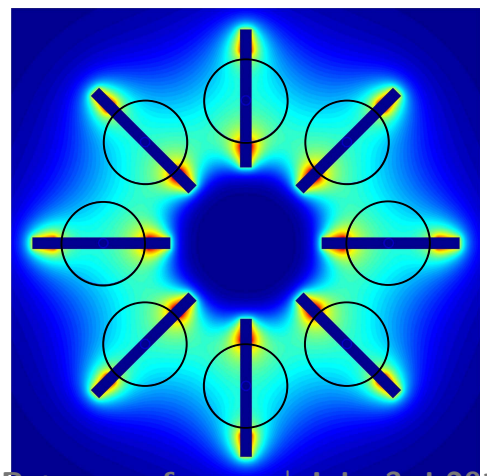
Magnetized AUGER mirror?



5T at 1m^2 ↑



- permanent magnets on back side?
- configuration with superconducting solendoids?
- Toroid?
- 'conclusion': Fit dish to magnet, not the other way around!



(a)

Summary

- Dish-concept nice for broadband WISP-DM (ALPs, HPs)
- nicely, we got people from AUGER interested
- at first physics reach is unprecedented but limited, however novel and instructive for future setups (spot movement, backgrounds...)
- THANKS for listening, **comments very welcome!**

Acknowledge FUNKY supporters and contributors

R. Engel, I. Irastorza, J. Jaeckel, M. Kowalski, H. Krüger, A. Lindner, A. Lobanov, J. Redondo, A. Ringwald , J.-E. v. Seggern, D. Trines + more whom I forgot (sorry!) + Support of the Helmholtz Alliance for Astroparticle Physics

More? → Backup

Bonus material

Dish calc detail

Horns et al. JCAP 1304 (2013) 016, Jaeckel/Redondo 1307.7181

From axionic/HP mixing equations

- First order plane wave DM solution $\vec{p} \simeq 0$ (note: $|\vec{p}| \sim 10^{-3} m$ is what leads to the off-set from the center)

$$\left(\begin{array}{c} \mathbf{A} \\ \mathbf{X} \end{array} \right) \Big|_{\mathrm{DM}} = \mathbf{X}_{\mathrm{DM}}(\mathbf{p}) \left(\begin{array}{c} -\chi \\ 1 \end{array} \right) \exp(-i(\omega t - \mathbf{p} \cdot \mathbf{x})).$$

- $\chi \rightarrow$ tiny electric field component

$$\left(\begin{array}{c} \mathbf{E} \\ \mathbf{E}_{\mathrm{hidden}} \end{array} \right) \Big|_{\mathrm{total},\parallel} = \mathbf{E}_{\mathrm{DM},\parallel}(\mathrm{inc}\, \vec{p} + \mathrm{outg}\, \vec{k}) \Big|_{\mathrm{surface}} = \left(\begin{array}{c} 0 \\ \mathrm{unaffec.} \end{array} \right)$$

DESY

Auger mirror detail J. Abraham *et al.*, Nucl. Instrum. Meth. A 620, 227 (2010)

- 20 mm thick aluminium, diamond-milled to $R = 3.4$m
- reflective surface was created by gluing a 2 mm sheet of AlMgSiO5 alloy, UV-optimized senis (200-400)nm
- 2mm thickness should mean that the light in the visible does not see what's below the surface
- imperfections (roughness) below 10nm
- Finally, a 90 nm thick aluminum-oxide layer was applied to the surface by chemical anodization to provide additional protection.