Status and plans of the CAST Experiment and Proposal to search for solar Chameleons and relic Axions

1. **Introduction** - K. Zioutas
2. **Status report** - M. Karuza
3. **New proposal** - G. Cantatore

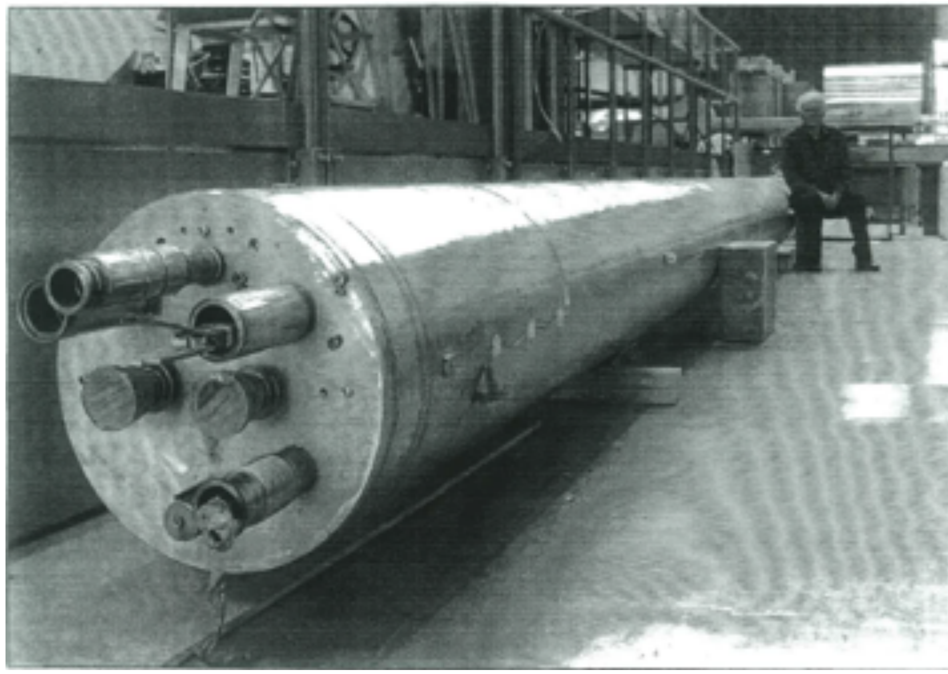
On behalf of the

CAST Collaboration

Introduction

CAST's past + its future

CAST in time: 1999 => 2015 => …



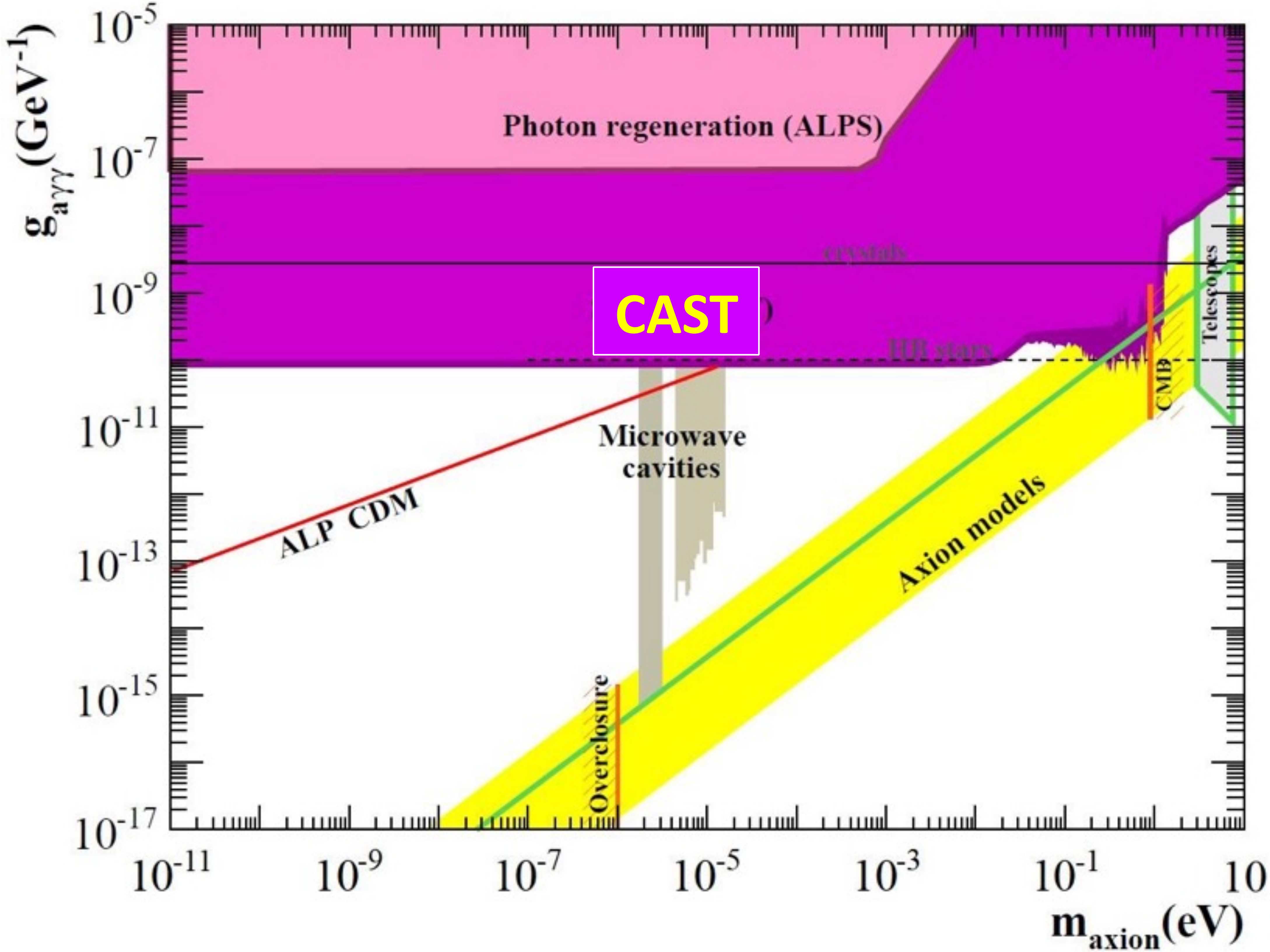
CERN Bulletin 2015

CAST EXPLORES THE DARK SIDE OF THE UNIVERSE

Following the search for axions, candidates for dark matter, CAST is widening its scientific horizon by searching for chameleons, hypothetical particles postulated as an explanation for dark energy.

CAST, CERN's axion solar telescope, moves on its rail to follow the Sun (for an hour and a half at dawn and an hour and a half at dusk)

Axion-to-photon coupling with CAST: - *present experimental limits*
- *improving its own world record*



CAST:

- best performance as axion helioscope
  => best detectors & XRTelescopes and expertise
- keeps promises + is expanding its horizon:
  => the "*first*" chameleon helioscope >> see "*annual report*"
- good reputation + competition
- [reference experiment]: ".. *it is possible to achieve an order of magnitude beyond the CAST level…"* Phys.Rev. D87 (**2013**) 125030
- **(solar) Chameleons + DM axions:** own novel ideas =>
  in collaboration also with people outside CAST from ANL, BNL, CERN, DESY, Saclay, Stockholm, U. Florida, YALE, …
  > **force sensor:** *unique* home made detector in (astro)particle physics
- **has a future *as a multifaceted antenna for the mysterious dark sector* @ *low cost***
- **PATRAS workshops** →

Suggested by
Markus Kuster

Name given by
Axel Lindner/DESY

Chameleons:

>> essential signal enhancement under investigation (β_γ & β_m)

CAST: an inspiring experiment

Beyond CAST:

"*short range physics* **+** *quantum gravity*" [CAST referees]

=> exciting perspective with *a*KWISP

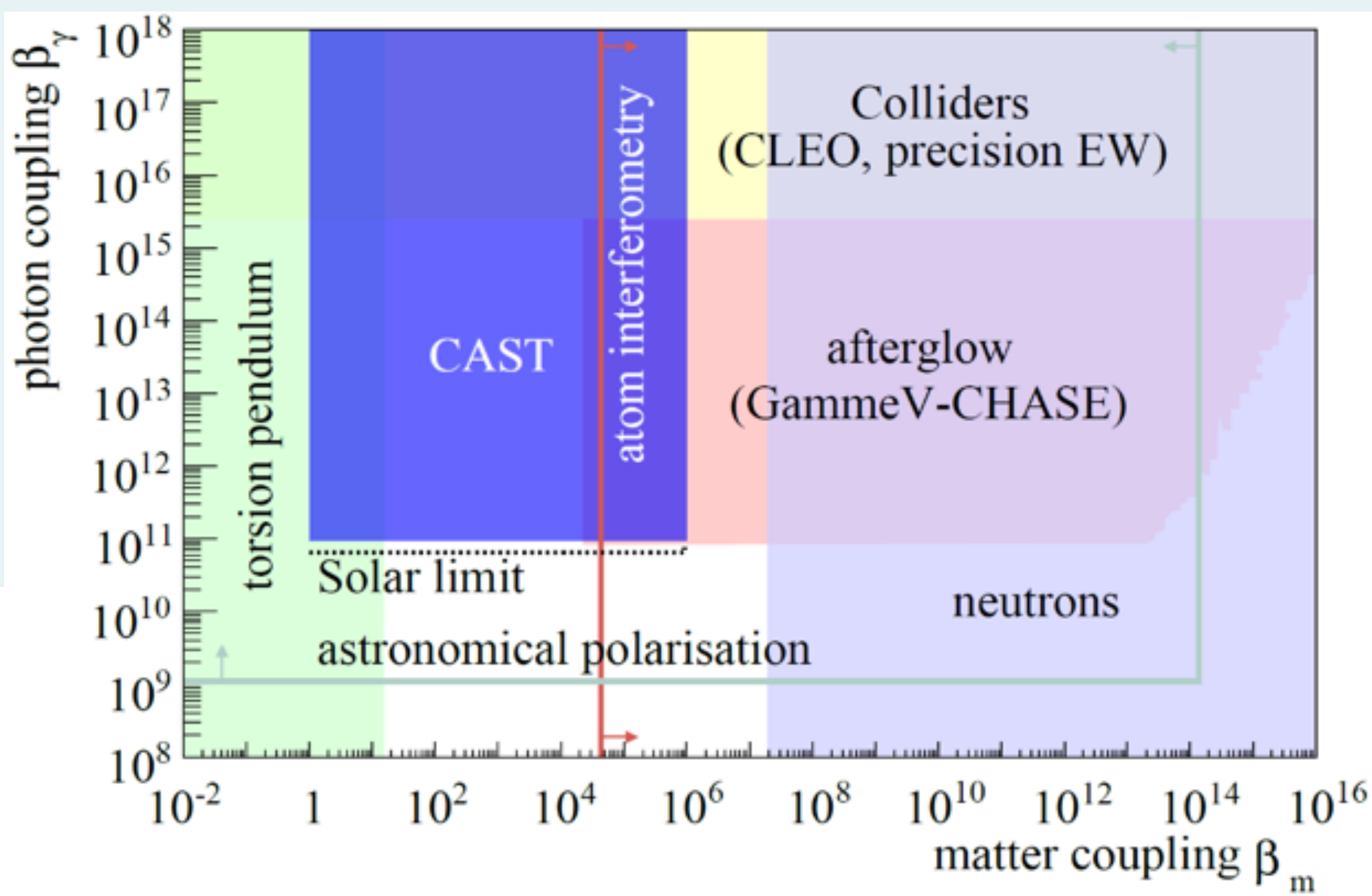
>> under consideration [G. Cantatore, M. Karuza, K.Z., …]

Status report

Chameleon searches with an SDD in CAST

Paper "Search for chameleons with CAST" published in Physics Letters B
http://dx.doi.org/10.1016/j.physletb.2015.07.049

Exclusion region for chameleons in the β_γ–β_m plane



CAST limit:
$\beta_\gamma \leq 9.26\times10^{10}$
at 95% CL
for $1 < \beta_m < 10^6$

Still the world's best published bound for $20 < \beta_m < 4.3\times10^4$

New solar axion searches in CAST with 4He filling

CAST Collaboration (M. Arik (Dogus U., Kadikoy) et al.). Mar 2, 2015. 6 pp.

Published in **Phys.Rev. D92 (2015) 2, 021101**
DOI: 10.1103/PhysRevD.92.021101

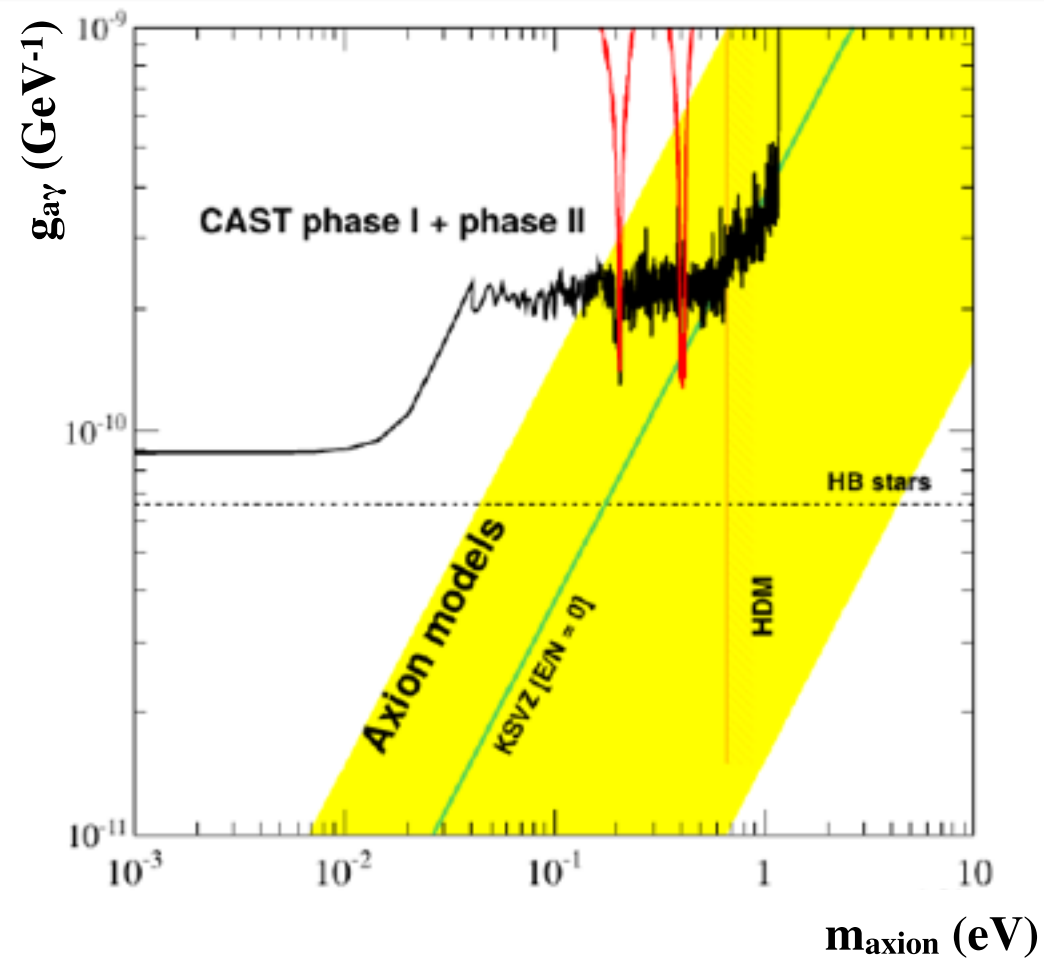
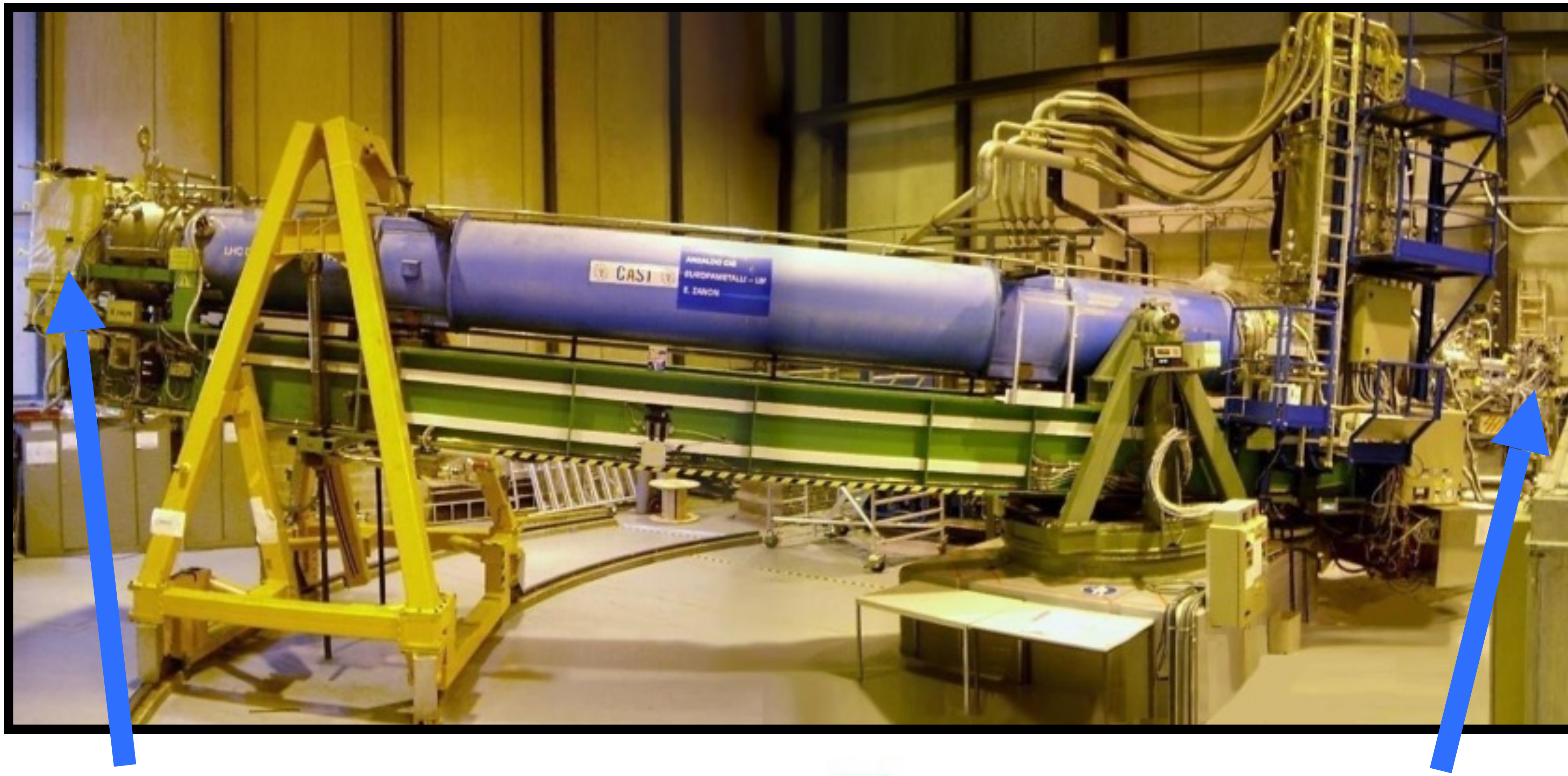
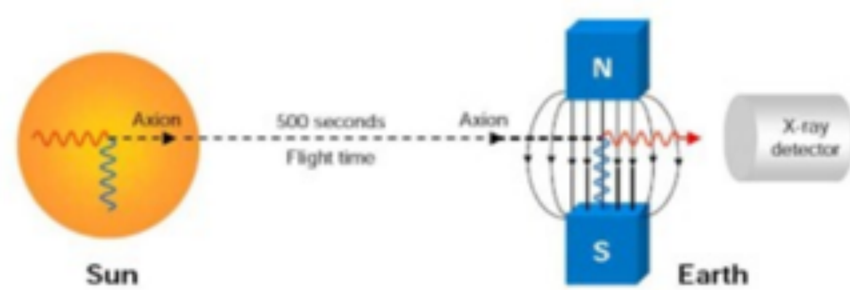


Figure 1: Exclusion regions in the $m_a - g_{a\gamma}$ - plane achieved by CAST in the vacuum phase and with 4He and 3He filling. Also constraints from horizontal branch (HB) stars and the hot dark matter (HDM) bound is shown. The yellow band represents typical theoretical models with $|E/N - 1.95| = 0.07 - 7$. The green solid line corresponds to E/N = 0 as in a typical hadronic axion model. In red we show our new limits near $m_a = 0.2$ and 0.4 eV from our 2012 data taking campaign with 4He gas.

CAST Cern Axion Solar Telescope



Sunset detectors
2 MicroMegas Detectors

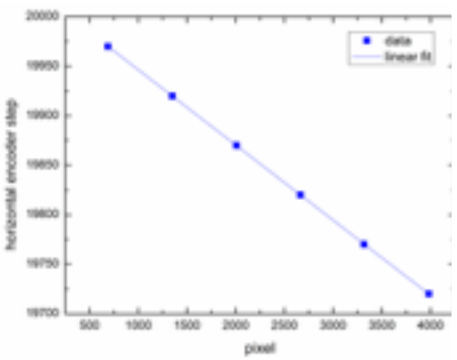


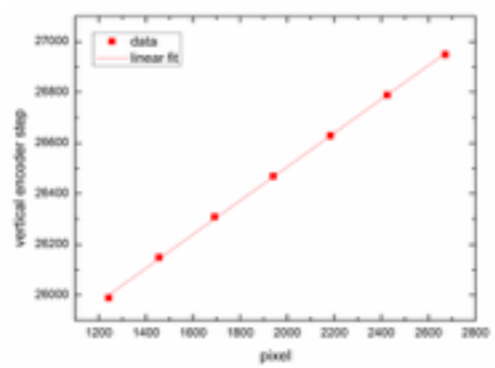
Sunrise detectors
MicroMegas & LLNL XRT,
InGrid & MPE XRT

The start date of this year's run was 19/6/2015.
Between 19/6/2015 (evening) till 15/10/2015 (morning) the number of shifts could be 236.
However due to bad weather and due to the quench 9 evening shifts and 6 morning shifts were canceled. This means that the actual number of shifts is 221.
Therefore the percentage of the shifts is 93.6% (of which 49.3% are evening shifts and 50.7% morning shifts) and the percentage of the days that we did not run 6.4%.

Sun filming 2015

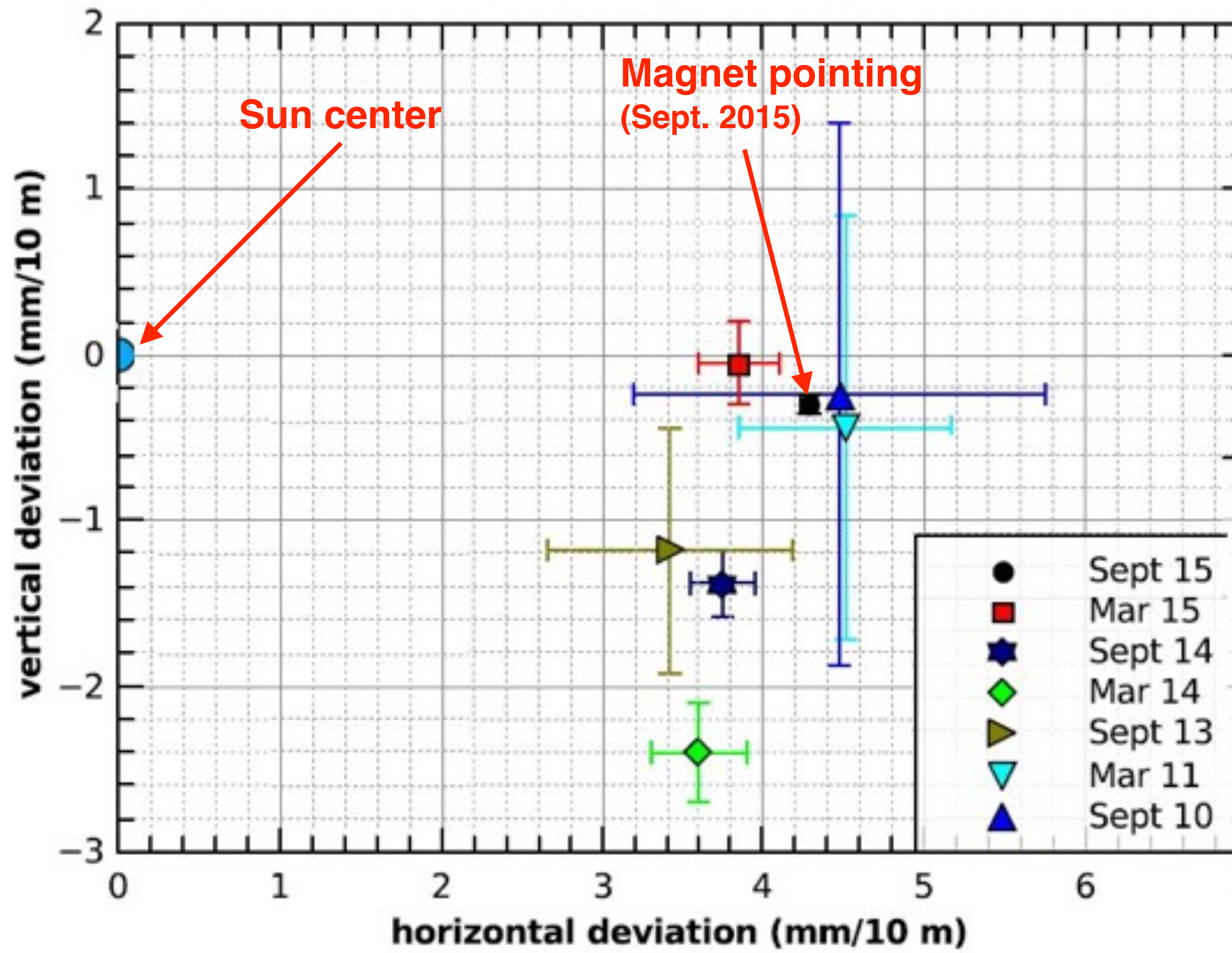
- March & September campaign: 8 + 4 good days
- New camera and supports/movements





	encoder	angle(°)	angle(mrad)	mm/10m	pixel
ΔH	100	0.261	4.54515	45.5	1320
ΔV	100	0.03	0.524554	5.2	150

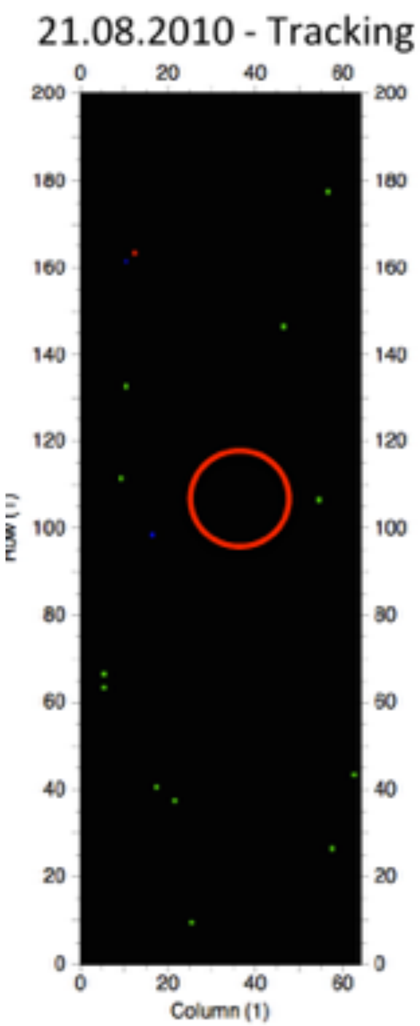
	encoder	angle(°)	angle(mrad)	mm/10 m	pixel
ΔH	100	0.261	4.54515	45.5	1589
ΔV	100	0.03	0.524554	5.2	180

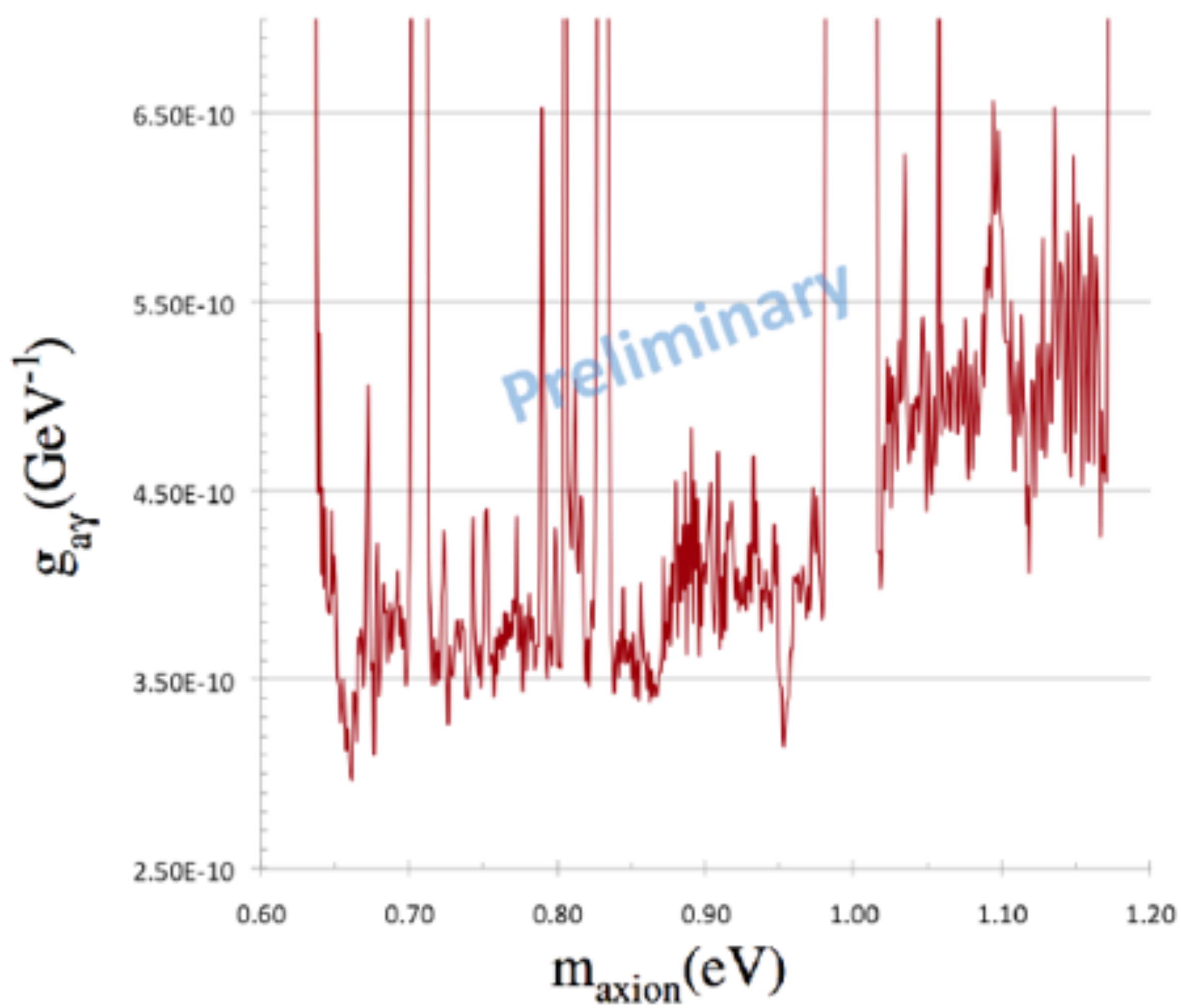


- From year 2010 the same results
- The cause of the offset still remains a mystery

Data analysis

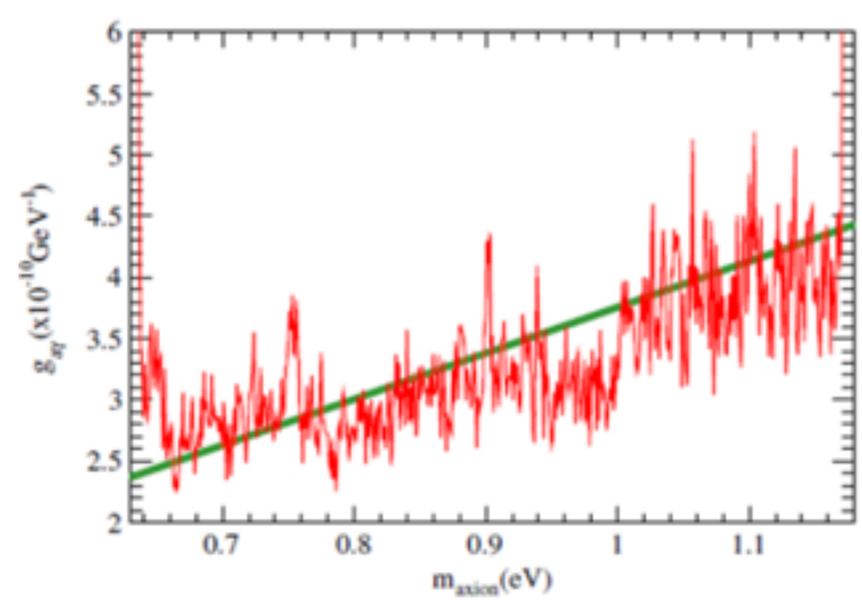
- Reanalyzed all 2009, 2010, 2011 CCD data with new CCD calibration data
- Verified the detector performance, stability and lightcurves
- Extracted the background from the CCD minus SPOT using the first 6*15 min
- Extracted the signal from the SPOT counts
- Results validated against standard analysis





Coverage:

- 2008 He3 data is not included in that plot;
- 2009 - CCD lost 20 out of 132 morning trackings (466->480, 510->5011, 558->562, 583->584, 604->614) ;
- 2010 - CCD lost 13 out of 125 morning trackings (704->728);
- 2011 - CCD lost 5 out of 55 morning trackings (729, 733, 737, 741, 745).



Micromegas 2015 data-taking

Micromegas detectors running quite smoothly this data-taking season.

Sunrise:

Axion-sensitive exposure (at 23 September) is 141 hours.
Background defined over 2861 hours ~8 x 10^{-7} c/keV/cm^2 /s.

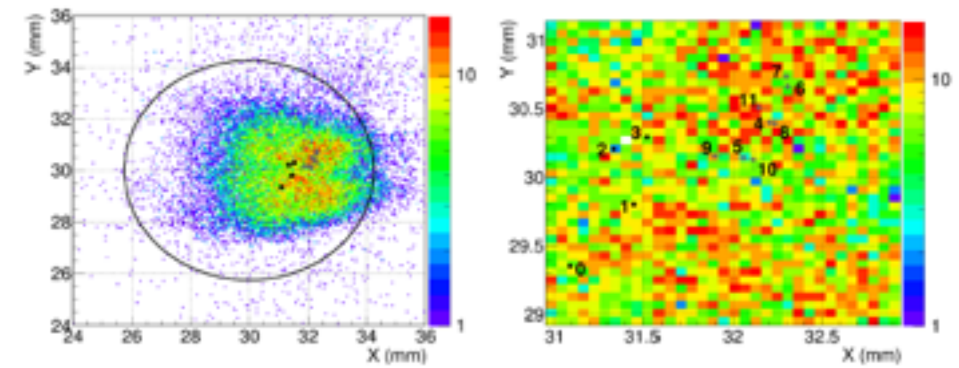
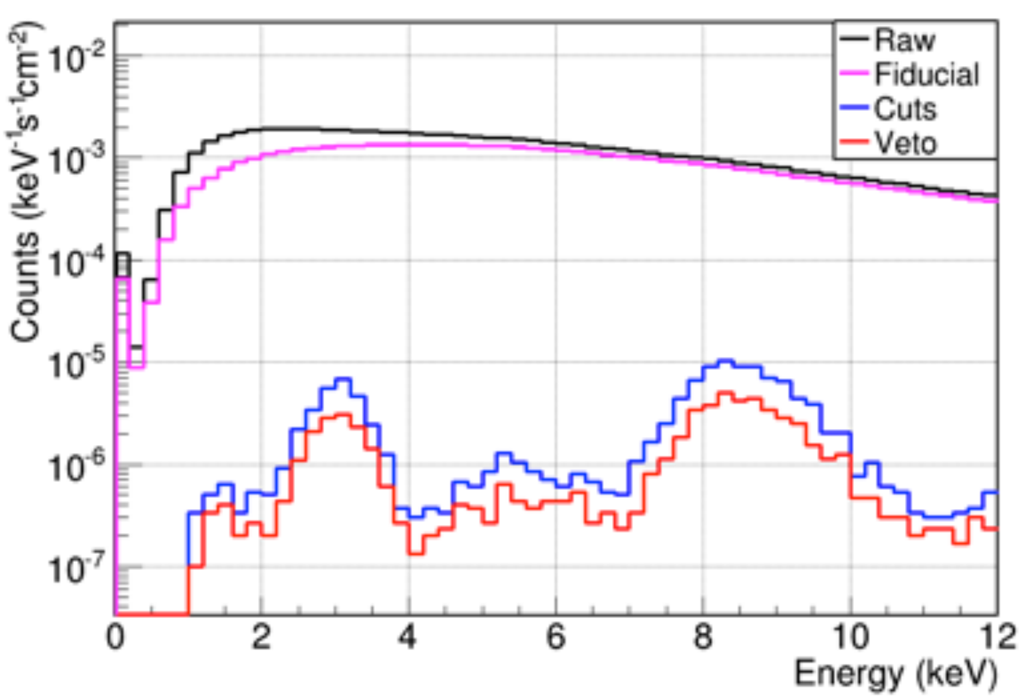


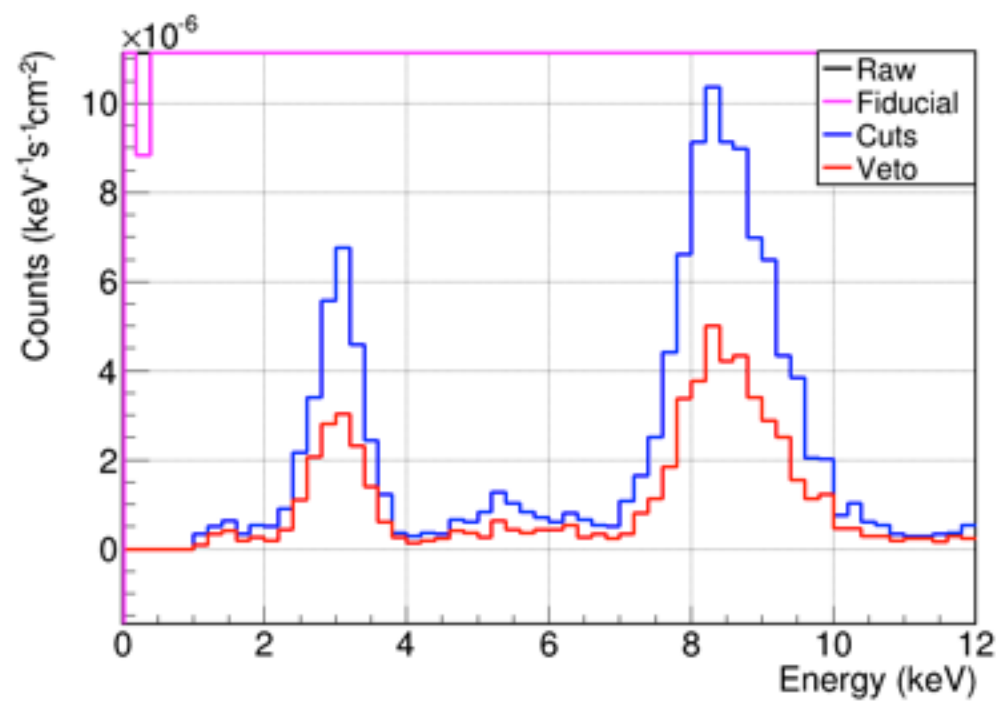
Figure 9.21: Left: spot position (centroid) of the x-ray finger runs of 2014 (gray dots) and 2015 (black dots). Right: an expanded view of the spot positions with labels described in the text.

Sunset:

Axion-sensitive exposure 138 hours (x2 detector = 276 hours).
Background defined over 2520 hours ~1-2 x 10^{-6} c/keV/cm^2 /s.

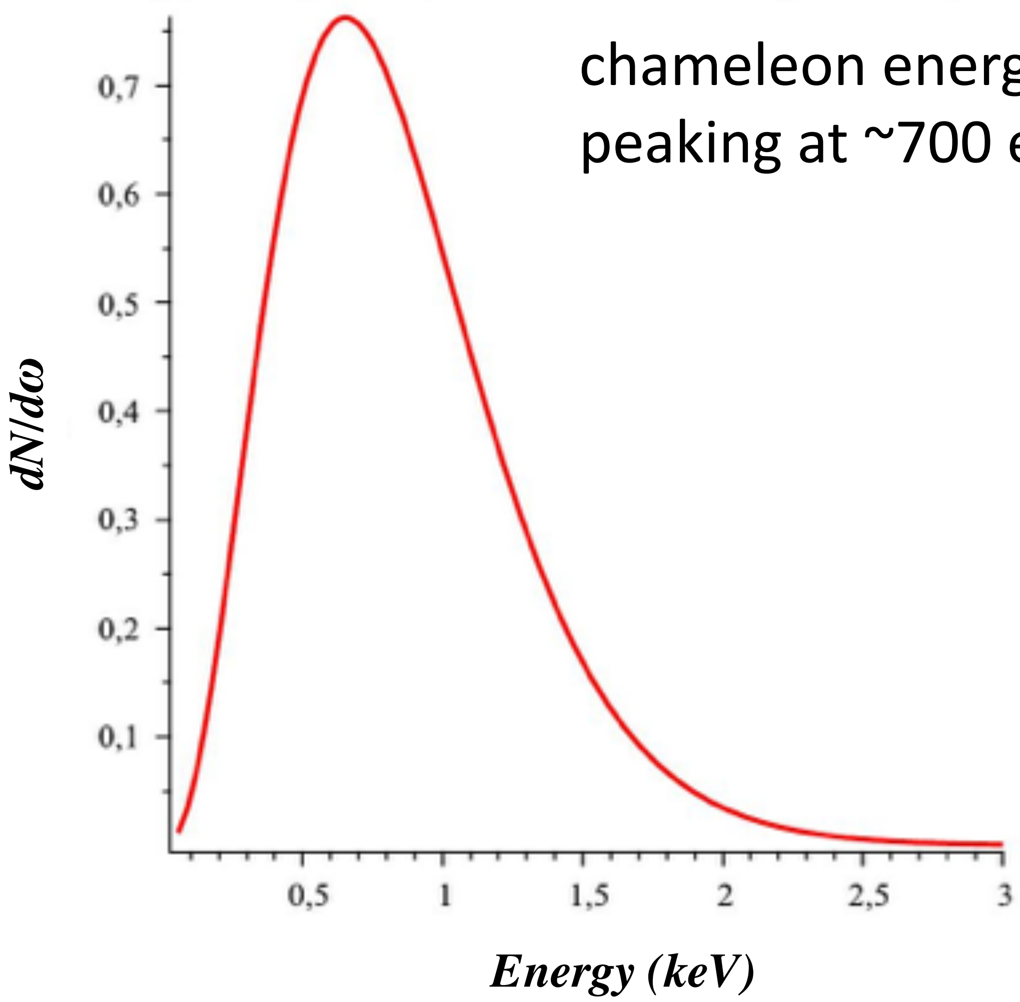
The shift in the x-ray spot due to the magnet movement in X and Y directions is below ~0.5 mm





InGrid detector @ CAST since 2014

- Detector is sensitive to single electrons from photoelectron ionisation
- Pixel counting to measure energy
- 1 electron ~ 1 pixel ~ 25 eV very low energy threshold (~200 eV)
- primary physics goal: search for solar chameleons produced in solar tachocline

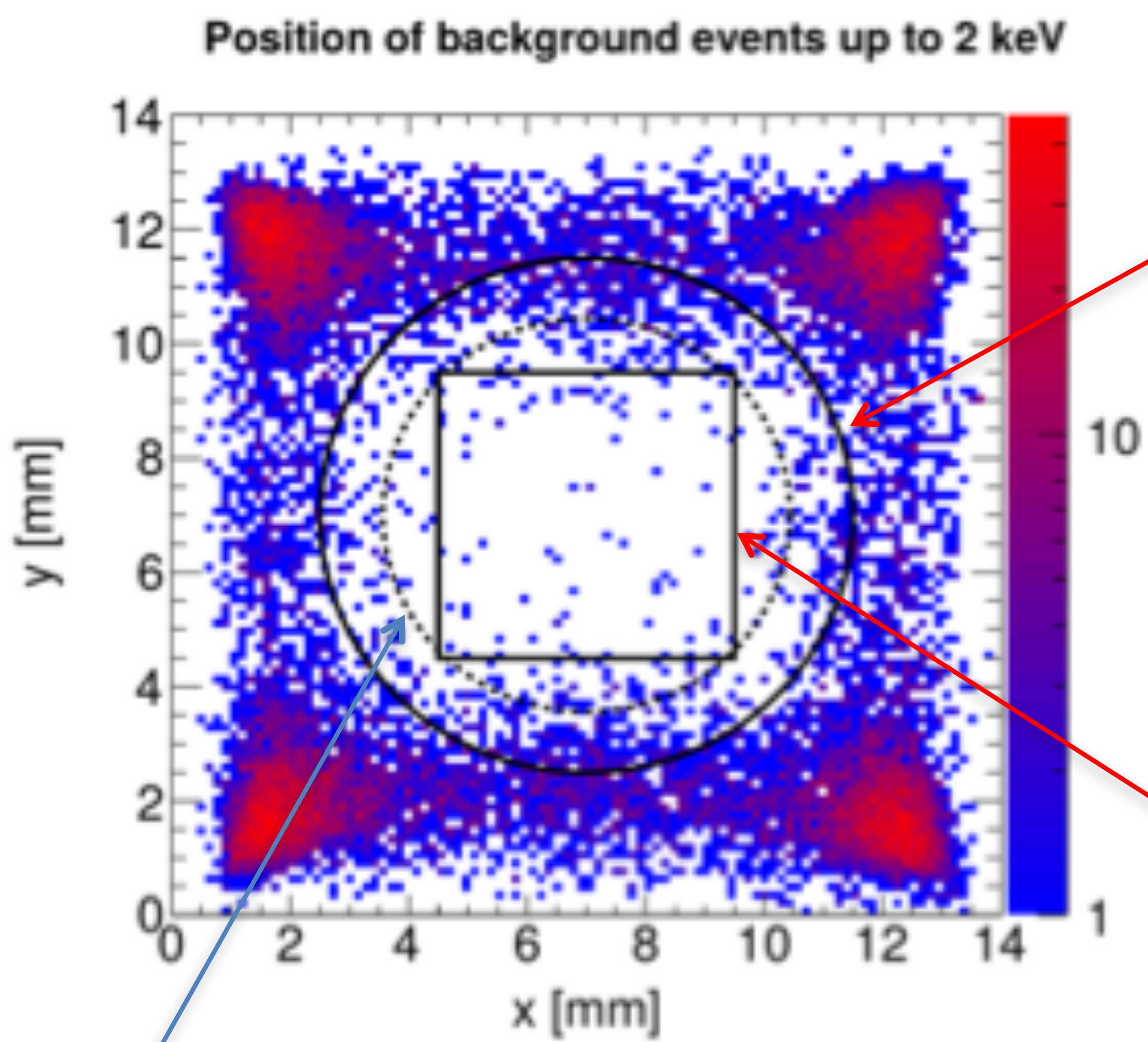


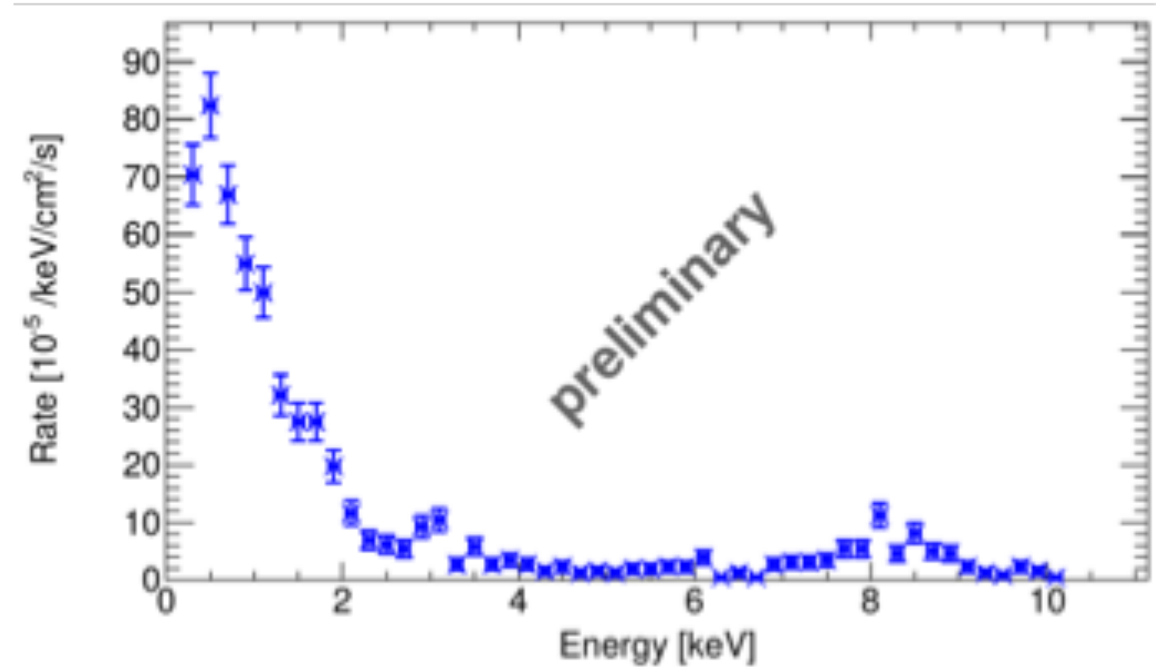
chameleon energy spectrum
peaking at ~700 eV

- Detector mounted at VT4 behind Abrixas X-Ray telescope
- **Continuous smooth data taking since June 2015**
- Daily calibration with ^{55}Fe X-ray source

InGrid detector: background

- Background for low-E photons depends critically on choice of fiducial region:





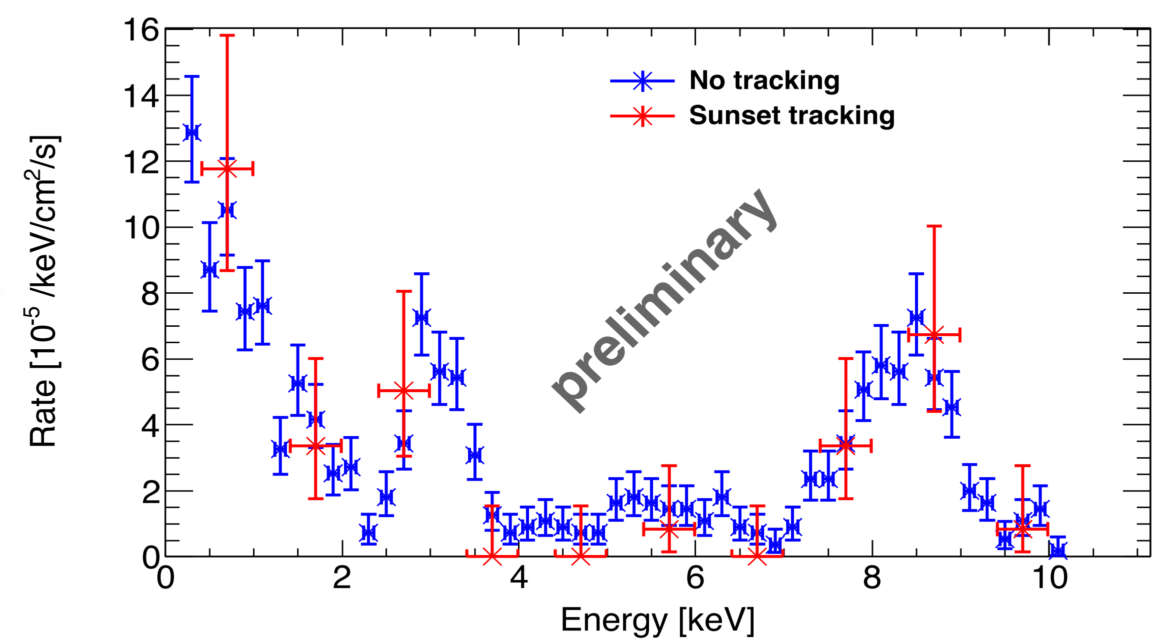


image of cold bore

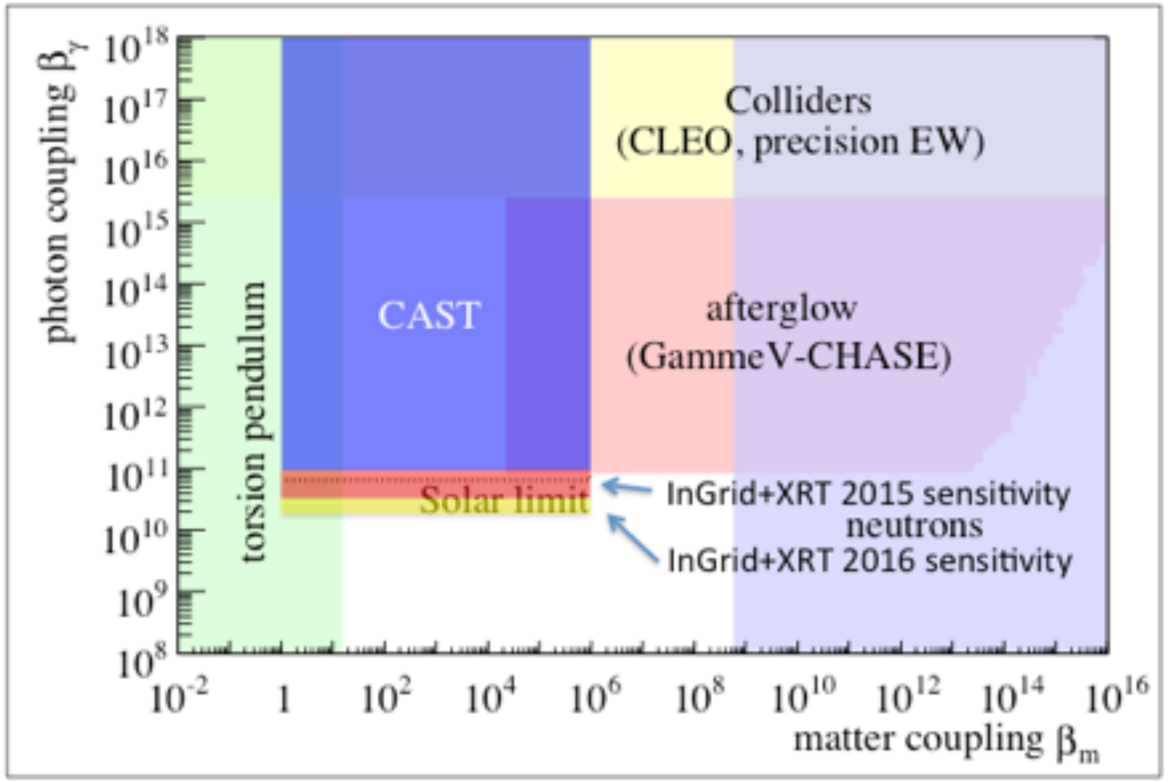
→ background in tighter region factor ~7 smaller

→ origin of background at the corners likely through partially reconstructed cosmic tracks

InGrid detector: sensitivity estimate for 2015

Estimate expected limit on chameleon-photon coupling β_γ from scaling of SDD@CAST result. Scaling factors:

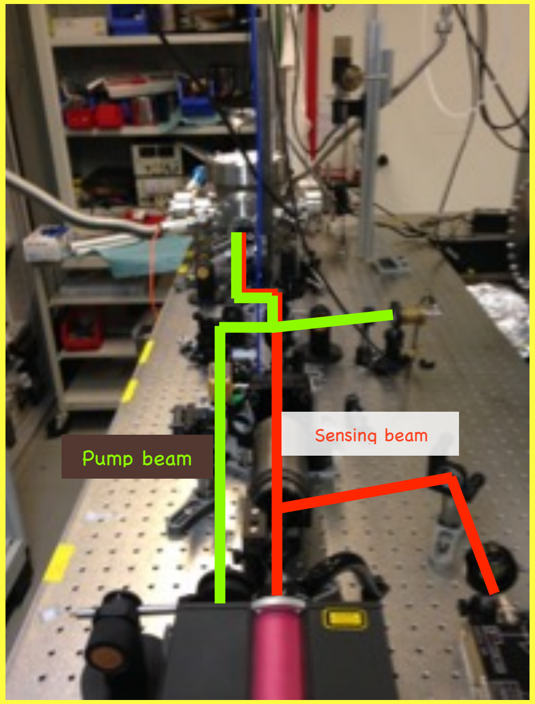
Scaling variable	SDD (Phys.Rev.D)	InGrid 2014+15	Limit improvement detoriation	Scaling law
Tracking time (h)	15,20 h	300 h	x0,689	$x^{-1/8}$
Effective area (mm²)	89	1451	x0,498	$x^{-1/4}$
BG (/cm²/keV/s)	0,001	0,0003	x0,860	$x^{+1/8}$
QE	0,88	0,17	x1,508	$x^{-1/4}$
Total			x0,42	



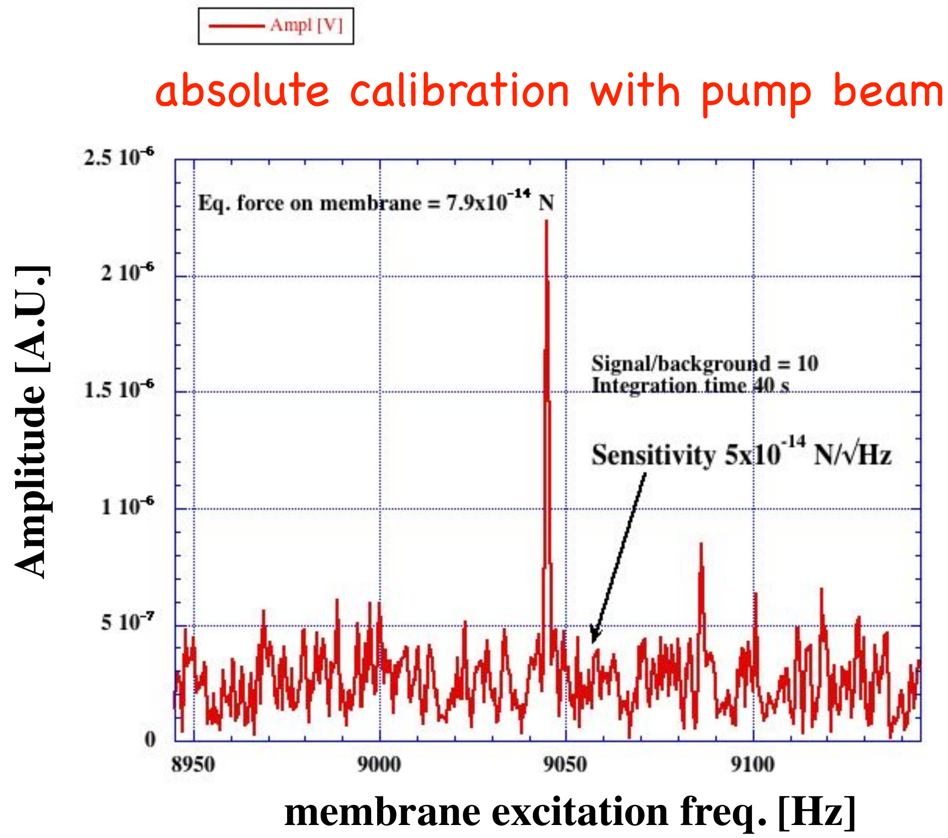
→ **expect coupling limit improvement of factor <u>2.4 better than SDD</u> for this years data (2015) in the range $1 < \beta_m < 10^6$**
→ **world-best limit on chameleon-photon coupling in the range $20 < \beta_m < 10^6$**

This estimate still assumes the „large" fiducial region – expect further improvement when position-dependent background is considered

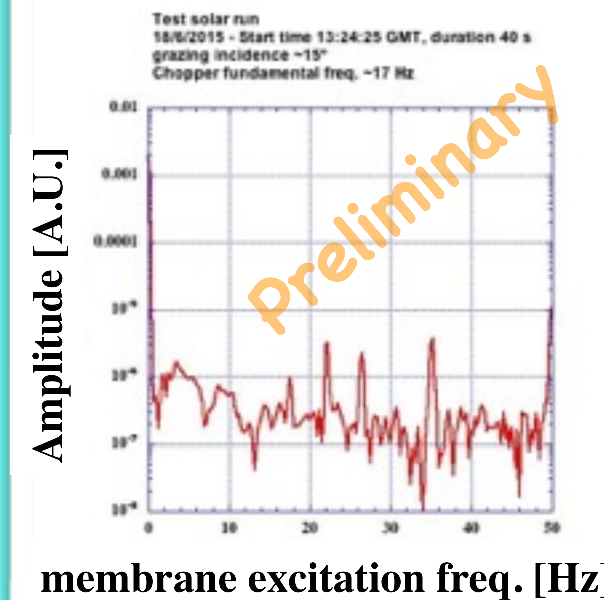
KWISP status I



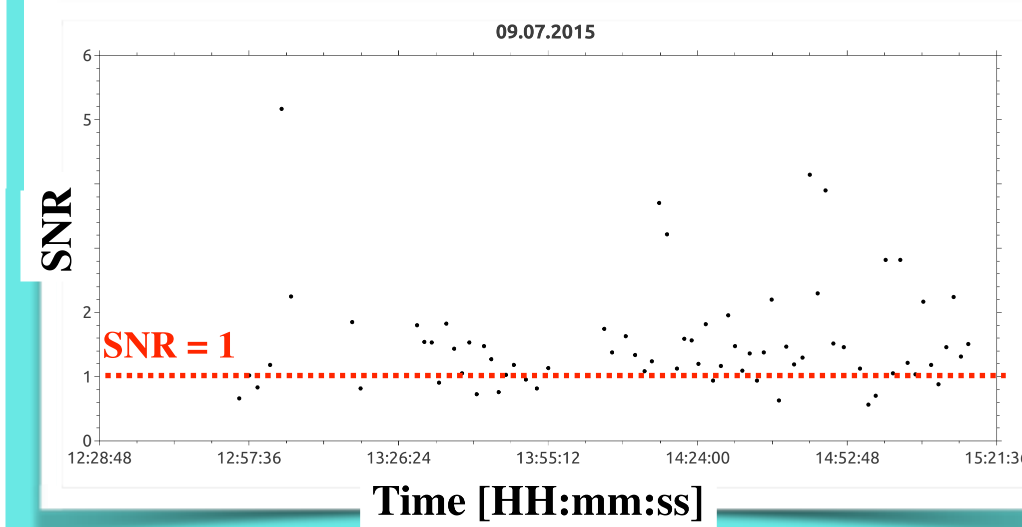
"double-beam" setup

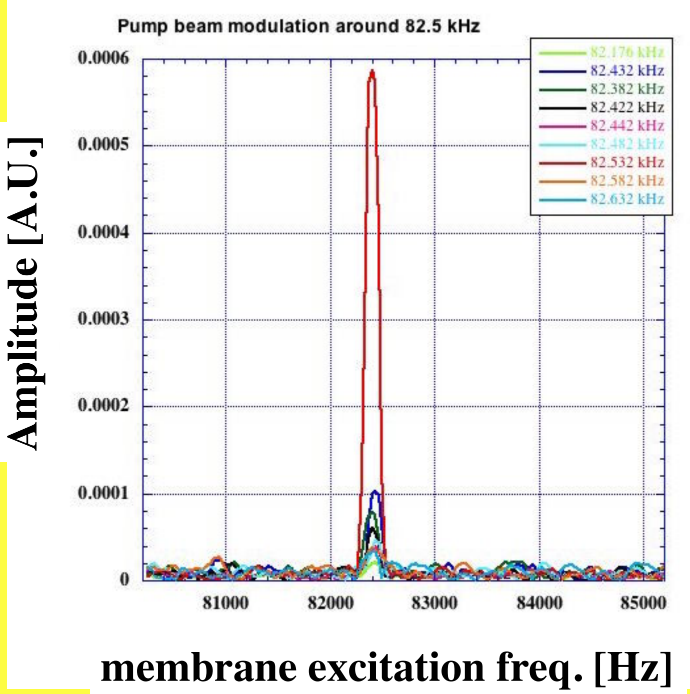


absolute calibration with pump beam

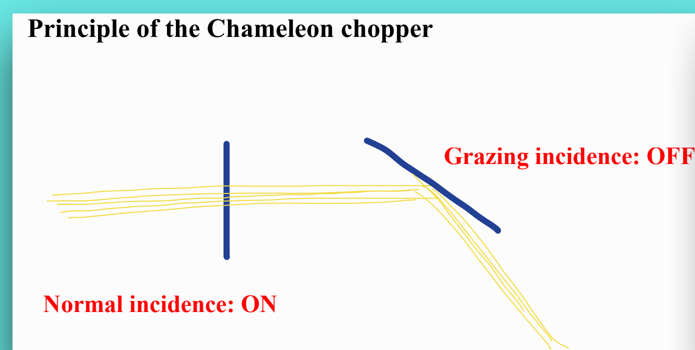


test solar run data





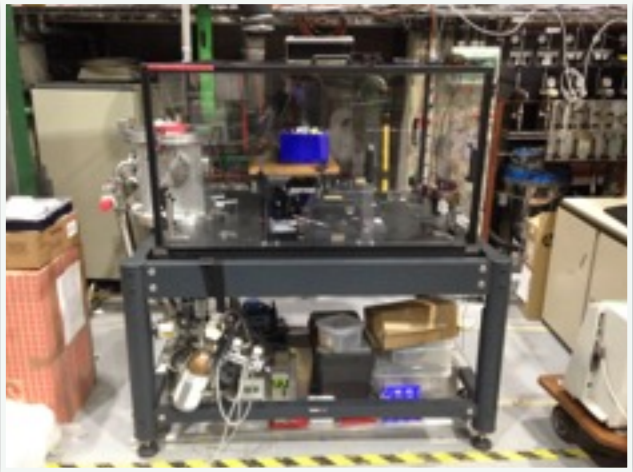
membrane resonance



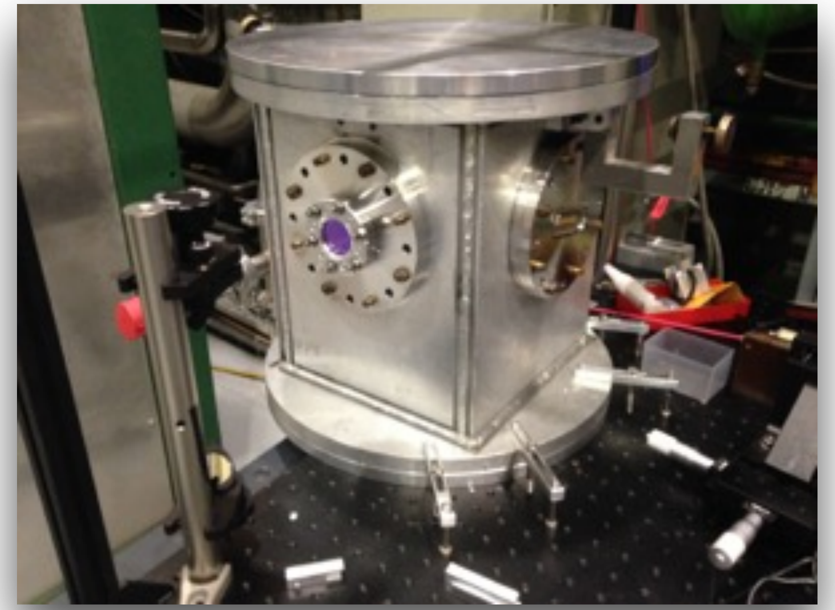
Chameleon chopper

KWISP status II

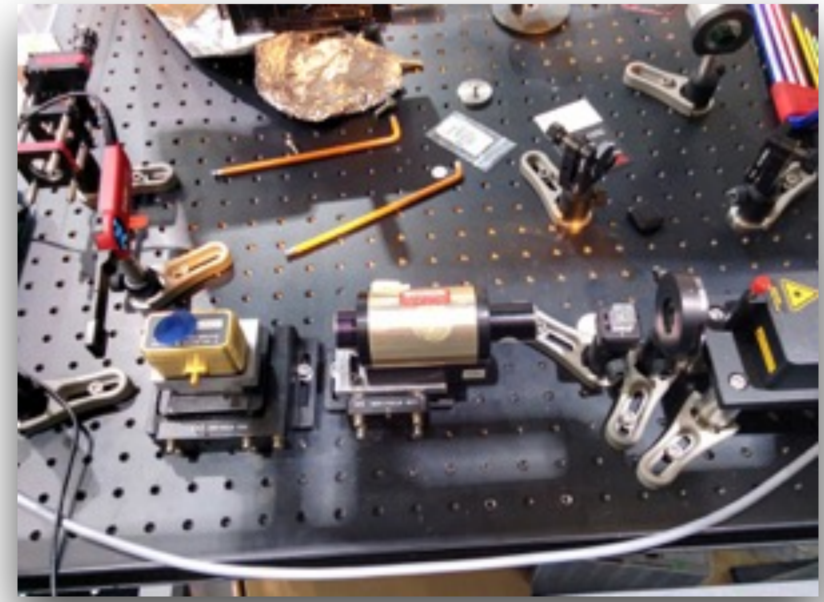
Off-beam



optical bench

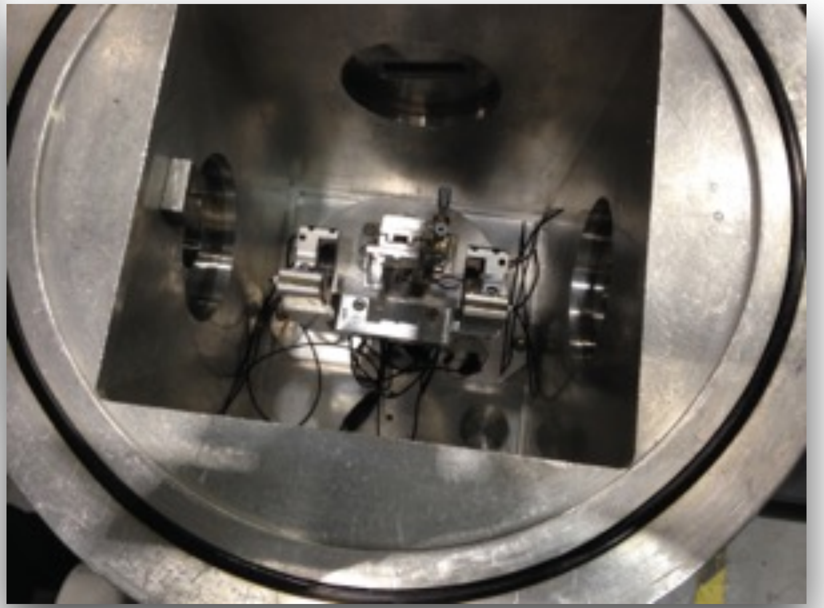


vacuum chamber



laser injection

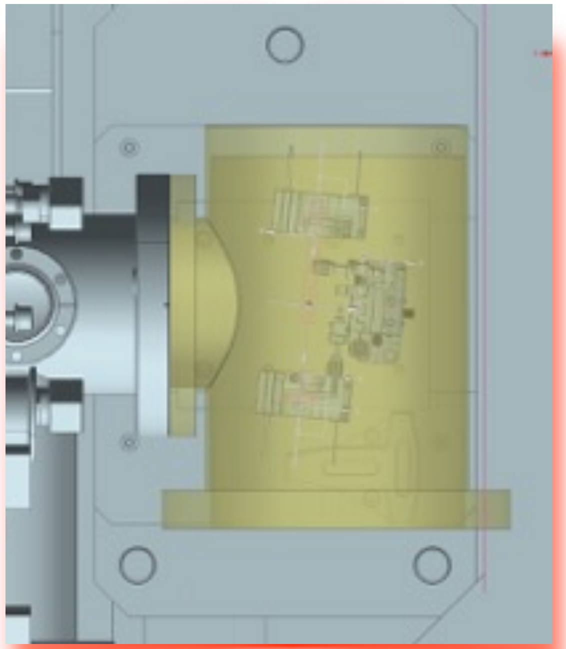
cavity-membane ass.



On-beam

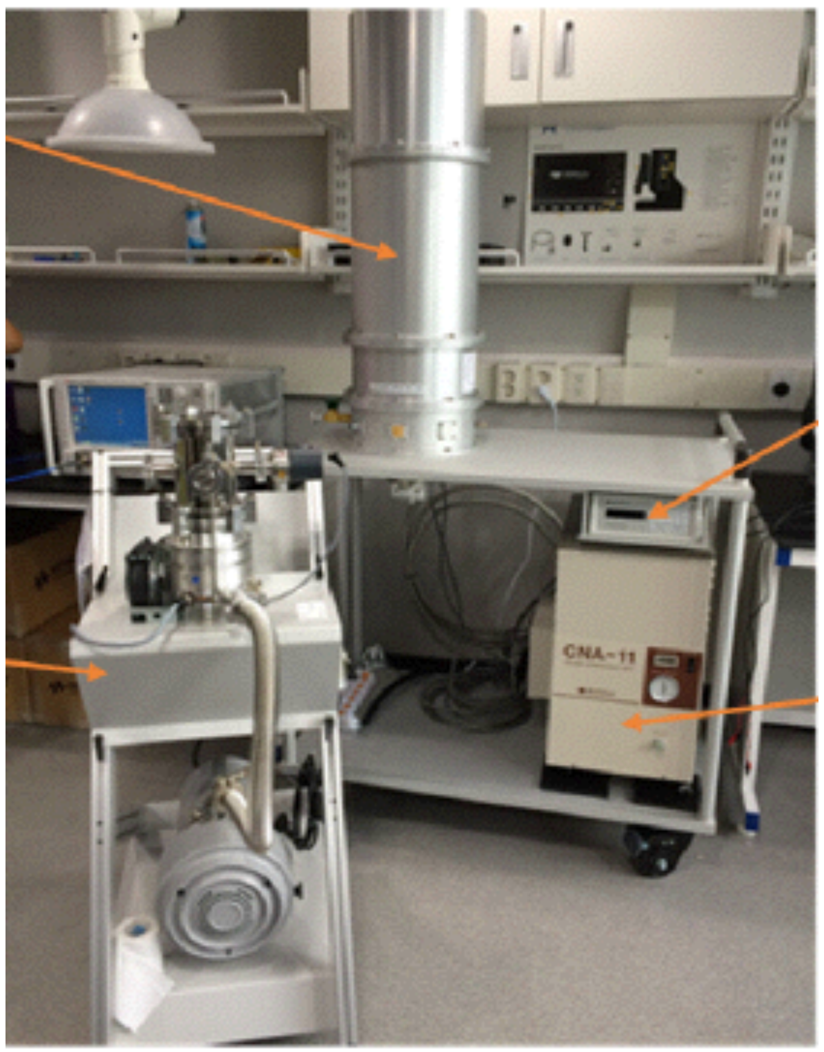
on-beam vacuum chamber

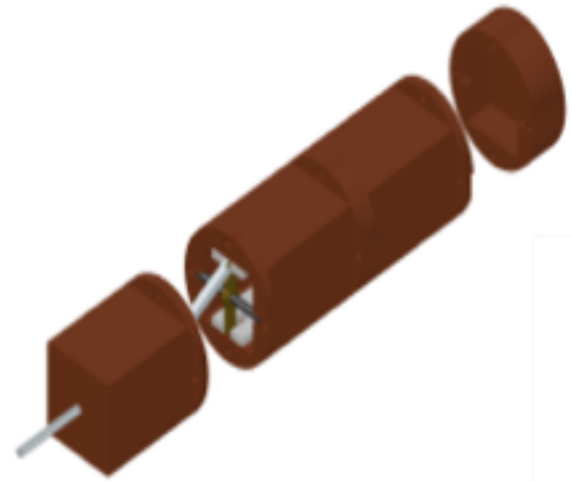
optics assembly

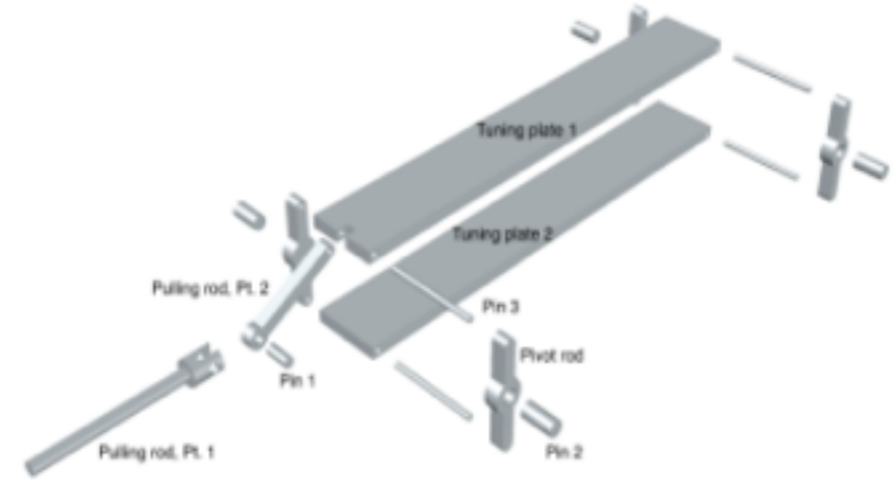


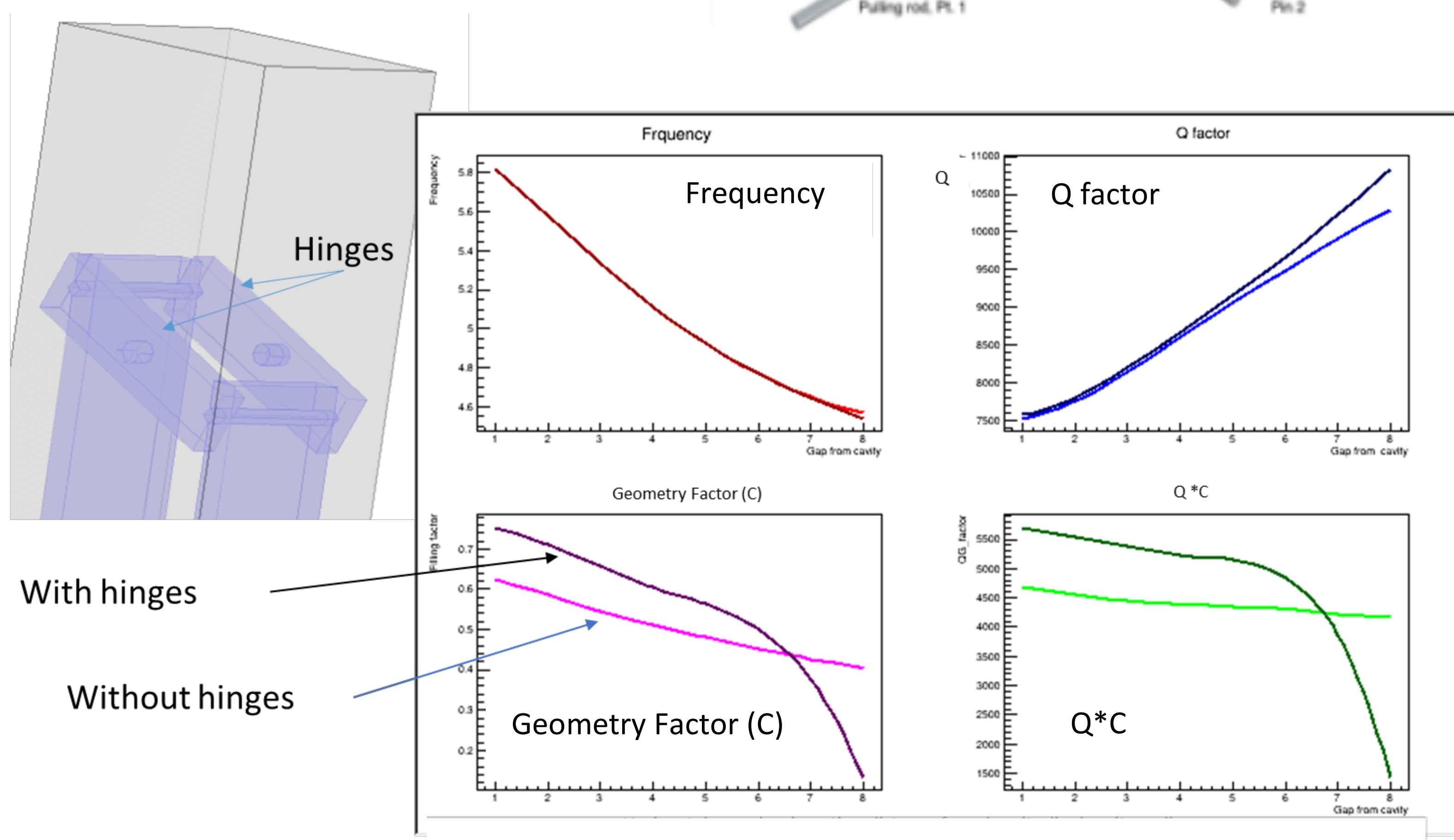
CAPP – relic axions

- **Prototype cavity design and simulations finished**
- **Cryo-refrigerator procured and commissioned for low temperature testing of cavities up to 50 cm length**
- **15 cm long Al cavity tested**









Horizontal Axes: bar insertion distance from longitudinal cavity

2015 Schedule

week	43	44	45	46	47	48	49	50	51	52	53	1	2	3
Monday	19.10.15	26.10.15	2.11.15	9.11.15	16.11.15	23.11.15	30.11.15	7.12.15	14.12.15	21.12.15	28.12.15	4.1.16	11.1.16	18.1.16
Power cut all day												7/01		
Power cut 10sec									14 or18					
CV maintenance														
Data taking														
Stop data taking			X											
X-ray finger run?			X											
Remove InGrid Shielding			X											
Survey XRT & InGrid			X											
Remove InGrid (old) and install new one			X											
Survey?			X											
Add Shielding			X											
X-ray finger run?			X											
Start data taking				XXX										
End of 2015 run						X								
Remove InGrid shielding						X								
Survey XRT & InGrid						XX								
Make mechanical measurements of InGrid position						X								
Remove LHe from Cryostat						X								
Start Warm up						X								
Break isolation vacuum									X					
pump down cryostat again												X		
Remove InGrid						X								
Remove part of InGrid vacuum system						X	X							
Add pumped vacuum window to VT14 on XRT						X	X							
REMOVE SSMM														
REMOVE LLNL XRT ?														
REMOVE SRMM SHIELDING														
REMOVE SRMM Detector?														
Work on KWISP behind telescope							about 2 weeks							
Install mechanically														
Install cabling														
Install vacuum system														
Align with laser from Sunset side														
Survey XRT & KWISP														

Stop data taking install new InGrid

Data taking max 2 weeks new InGrid

Survey XRT + InGrid

Start forced warm-up of magnet

Mechanical installation of KWISP can start

New proposal

Search for solar chameleons and relic axions with CAST

June 8th, 2015

CERN-SPSC-2015-021 / SPSC-P-352
08/06/2015

To be presented by:

G. Cantatore, L. Miceli and K. Zioutas,

on behalf of the CAST collaboration and the external collaborators

S. Baum and A. Upadhye

InGrid detector: further improvements for 2016

In order to improve the chameleon sensitivity in 2016 several improvements of the current detector are proposed and under preparation:

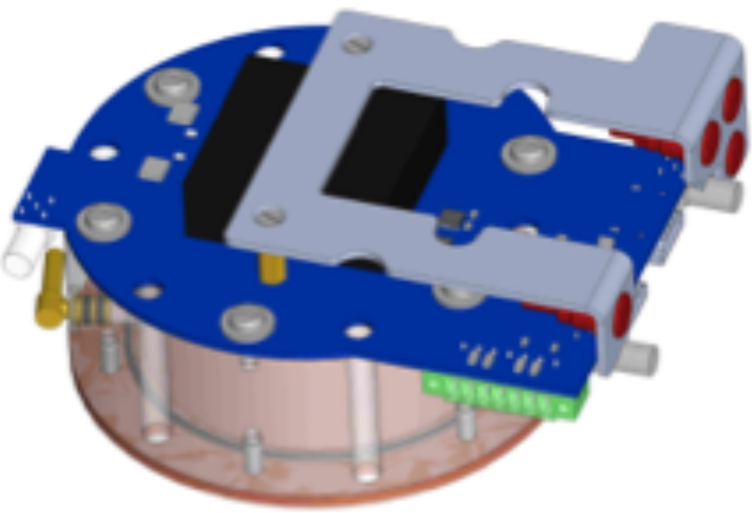
1. **Cosmic veto** using a small scintillator tile readout with Si PM directly behind the InGrid Chip (status: under construction)

2. **Readout** of induced grid signal with FADC to measure time evolution of signal (status: commissioned in lab, needs to be implemented in CAST area)

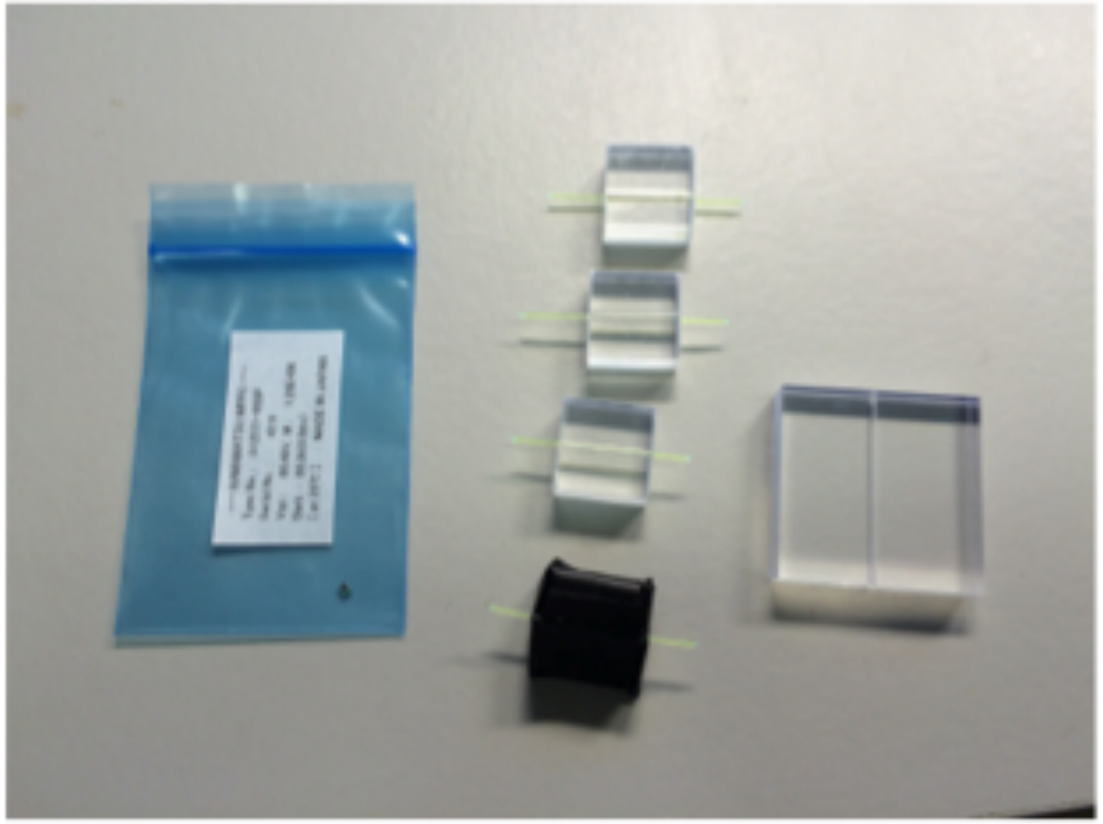
3. **Thin (200 nm) SiN X-Ray windows**
   (status: received first samples for pressure tests from company – delivery of final windows in Feb/March 16?)

Plan to implement 1.+2. still in 2015 (in 2 weeks) to take a small data set before end-of-run.

InGrid detector: further improvements for 2016



new detector drawing



Scintillator tile (4x4 cm^2 and SiPM)

Sensitivity estimate 2016

Scaling variable	SDD (Phys.Rev.D)	InGrid 2016	Limit improvement deterioration	Scaling law
Tracking time (h)	15,20 h	150 h	x0,751	$x^{-1/8}$
Effective area (mm^2)	89	1451	x0,498	$x^{-1/4}$
BG ($/cm^2/keV/s$)	0,001	0,00001	x0,562	$x^{+1/8}$
QE	0,88	0,36	X1,291	$x^{-1/4}$
Total			x0,27	

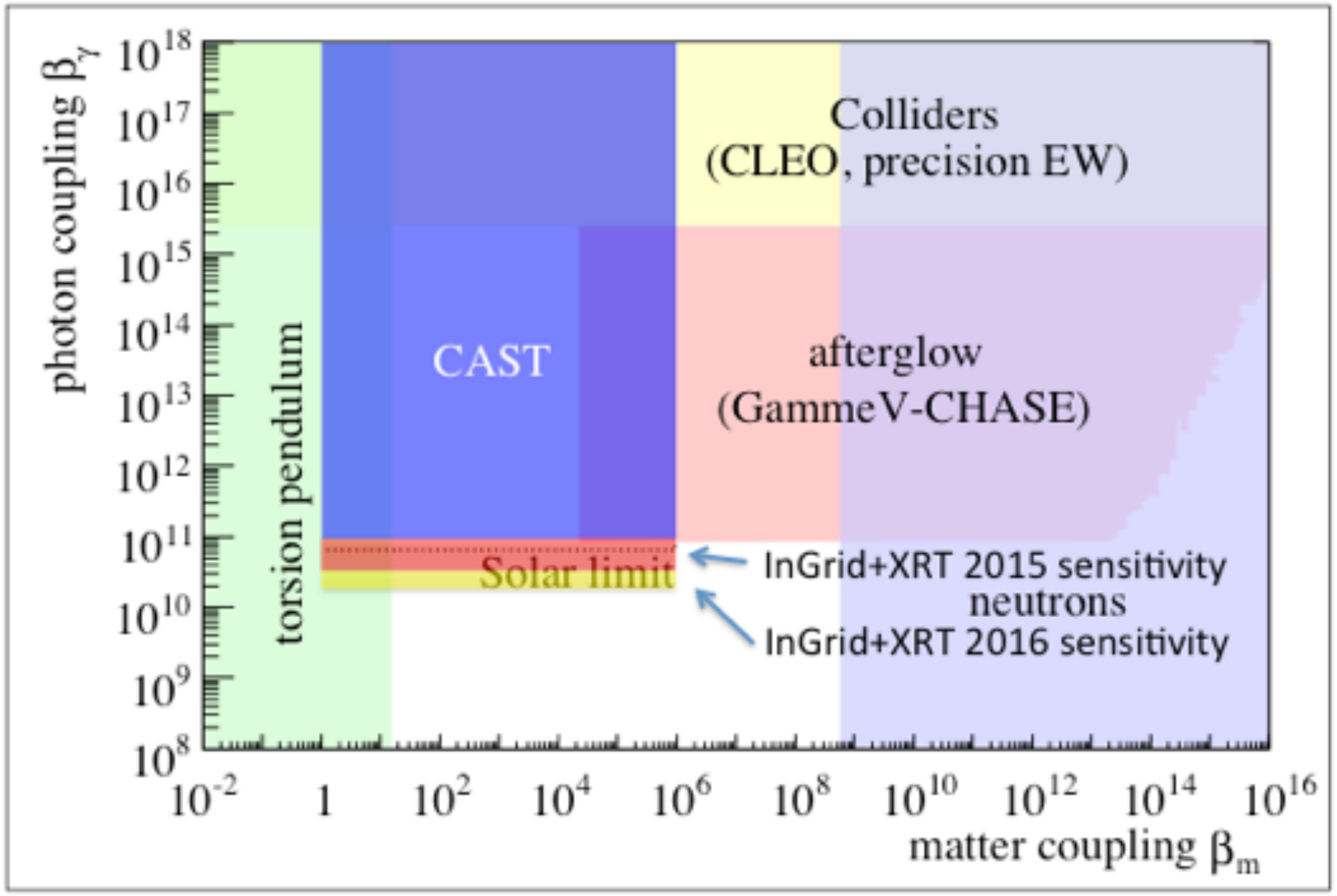
→ expect another limit improvement of factor 1.6 better than InGrid 2015 estimate

This estimate assumes

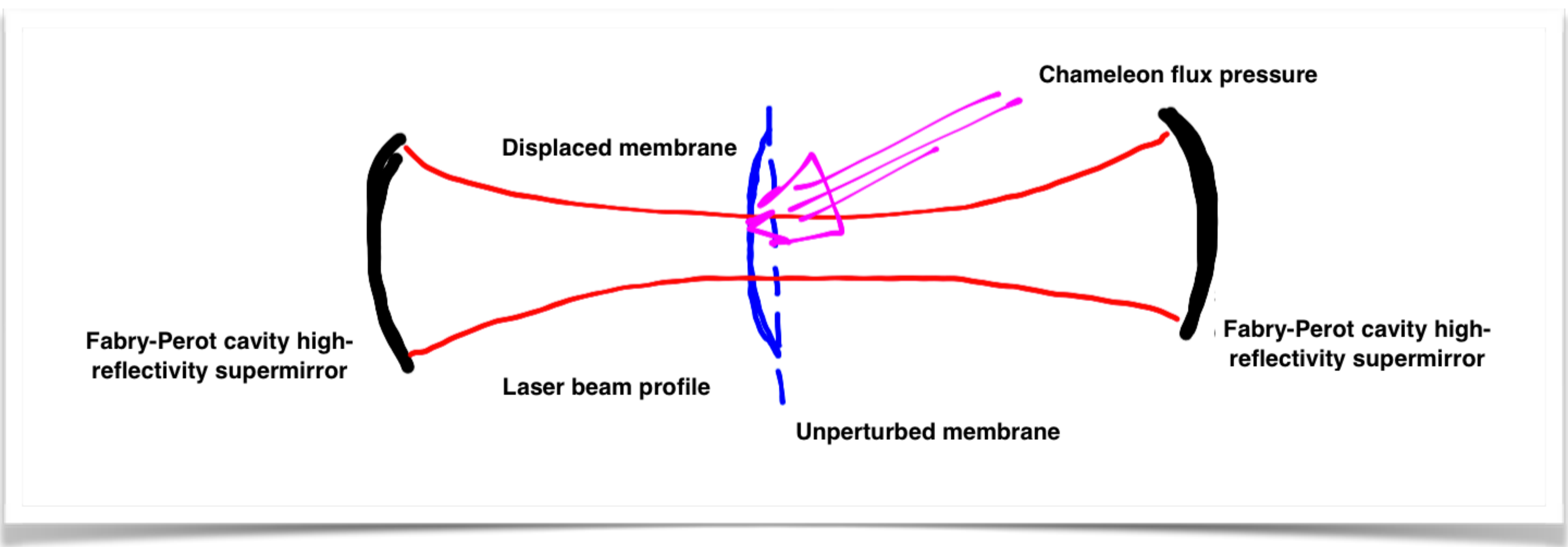
- 200 nm SiN window
- background reduction to 10^{-5} over the sensitive energy region (~400-2000 eV), i.e. factor 2-8 w.r.t to current background from scint. veto + mesh readout + better analysis (realistic)
- 100 days of data taking in 2016

InGrid: overall picture

- InGrid detector has been operated very successfully in 2014 and 2015
- Recorded data set will set world-best limit on chameleon-photon coupling (or observe excess)
- Analysis ongoing – improved background understanding
- Solar tracking data still blinded!
- Improved detector for 2016 under construction – another factor of 1.6
- improvement estimated



The KWISP force sensor



KWISP force and displacement sensitivity

T_{membr}	Measured	Proj.@nominal Q
300 K	$1.5 \cdot 10^{-14}$ N/√Hz $7.5 \cdot 10^{-16}$ m/√Hz	$2.5 \cdot 10^{-15}$ N/√Hz $1.2 \cdot 10^{-16}$ m/√Hz
30 mK		$8.0 \cdot 10^{-18}$ N/√Hz $4.0 \cdot 10^{-19}$ m/√Hz
3 mK		$2.5 \cdot 10^{-18}$ N/√Hz $1.3 \cdot 10^{-19}$ m/√Hz

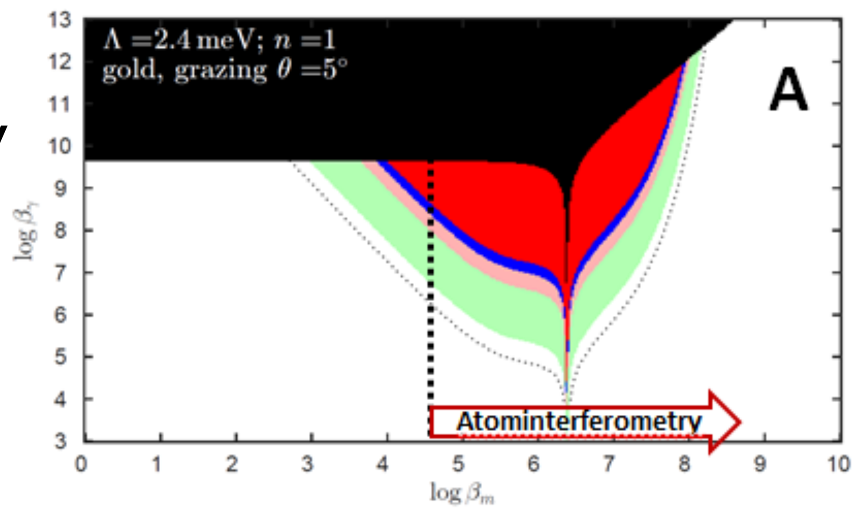
KWISP physics reach in the DE sector

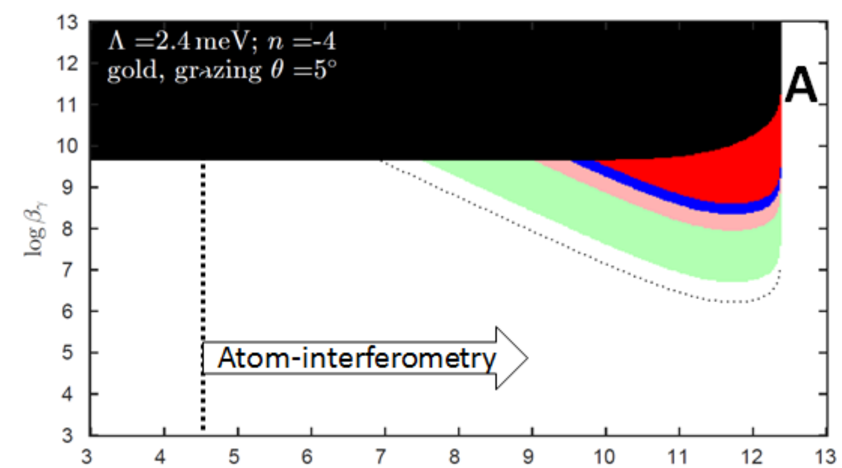
- Main competition: "atom interferometry" (note: different technique, relies on virtual chameleons)
- Comparison heavily dependent on choice of Chameleon potential parameters

choice of Λ

choice of n

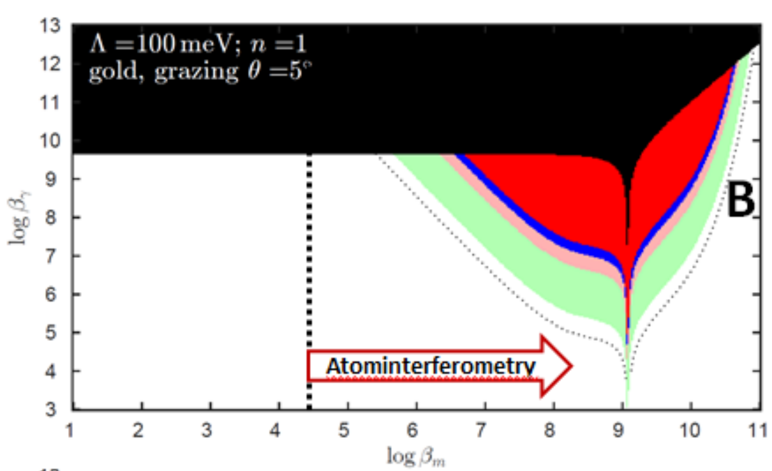
Λ = 2.4 meV

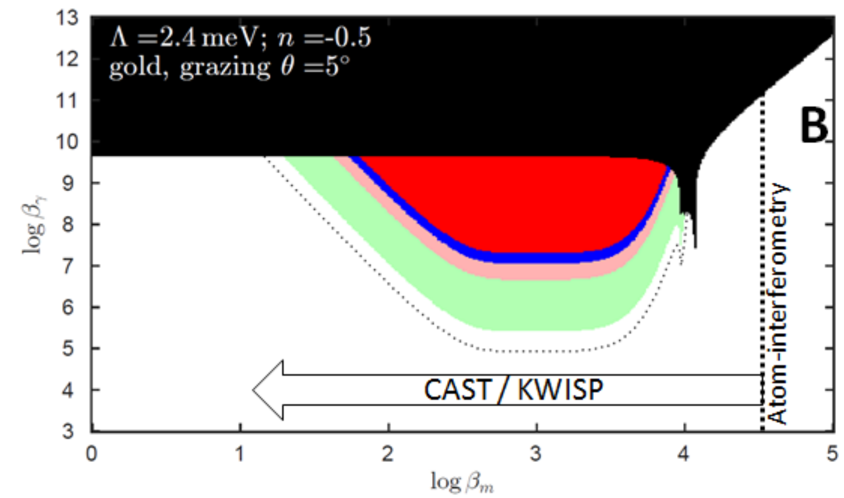




n = -4

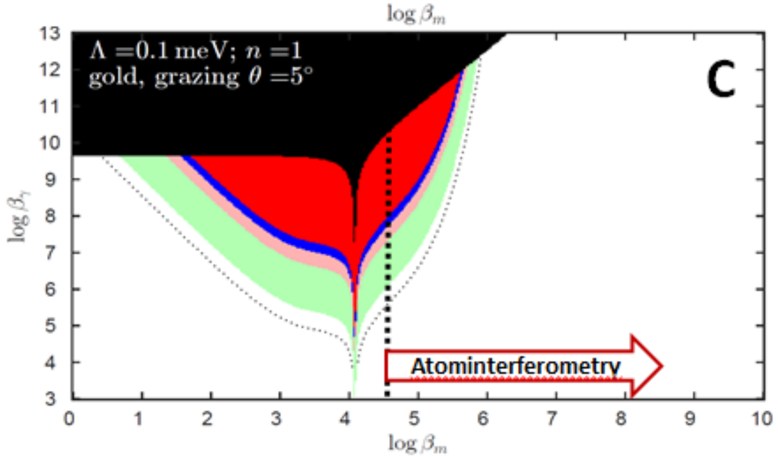
Λ = 100 meV





n = -0.5

Λ = 0.1 meV



Red: 300K, off resonance, force sensitivity $5 \cdot 10^{-14}$ N/√Hz, T = 10^4 s
Blue: 300K, near resonance force sensitivity $1.5 \cdot 10^{-14}$ N/√Hz, T = 10^4 s
Light pink: 300K case assuming Q = 10^5, T = 10^4 s
Light green: projected force sensitivity of $8 \cdot 10^{-18}$ N/√Hz at 30mK, T = 10^4 s

Dotted line: projected 30 mK case with T = 10^6 s

Key KWISP technologies

- Enabling technologies
  - Resonant optical cavity & membrane
    - well under control
  - Pump beam, membrane resonance and Q
    - measurements done, under control
  - **Chameleon chopper: flux modulation and phase-locking for unique particle detection and identification**
    - working low-frequency prototype
    - solutions for high-frequency chopper
  - X-ray telescope
    - key CAST capability (also coupled to sun-tracking)
- Upgrading technologies
  - Chameleon concentrator and recycler
  - homodyne detection
  - membrane customisation
  - membrane cooling

KWISP projected timeline 2016-2018

- 2016 - Intermediate on-beam phase
  - Jan-Feb - install on-beam sensor
  - Feb-Apr - on-beam commissioning
  - Apr-Dec - shut-down for initial upgrades (possibility to go back on-beam at the end of the year)
- 2017 - Perspective: upgraded KWISP phase
  - Jan-June - on-beam measurements with upgraded KWISP
  - June-Dec - sensitivity upgrades (mainly cooling)
- 2018 - Perspective: advanced KWISP phase
  - on-beam commissioning
  - expanding the physics reach

Development and upgrade plan

- Upgraded KWISP
  - homodyne detection
    - common mode rejection of electronic and laser noise
  - chameleon concentrator and bucatini-bundle recycler
    - maximise force on the detector for a given Chameleon flux
  - match chopper frequency to membrane resonant frequency
    - high frequency chopper with fast PZT actuated micro-mirrors
    - fast rotator with Si wafer optically flat plates
- Advanced KWISP
  - membrane optimisation (in contact with Norcada Inc.)
    - maximize surface
    - maximize Q
    - minimize resonant frequency
  - sub-K membrane cooling
    - laser cooling
    - cryo-cooling

The CAST-CAPP/IBS Detector

- Strong physics case
- Strong team from many Institutions
- Adequate resources if approved by IBS

Exclusion Plots

CAST-CAPP Present sensitivity

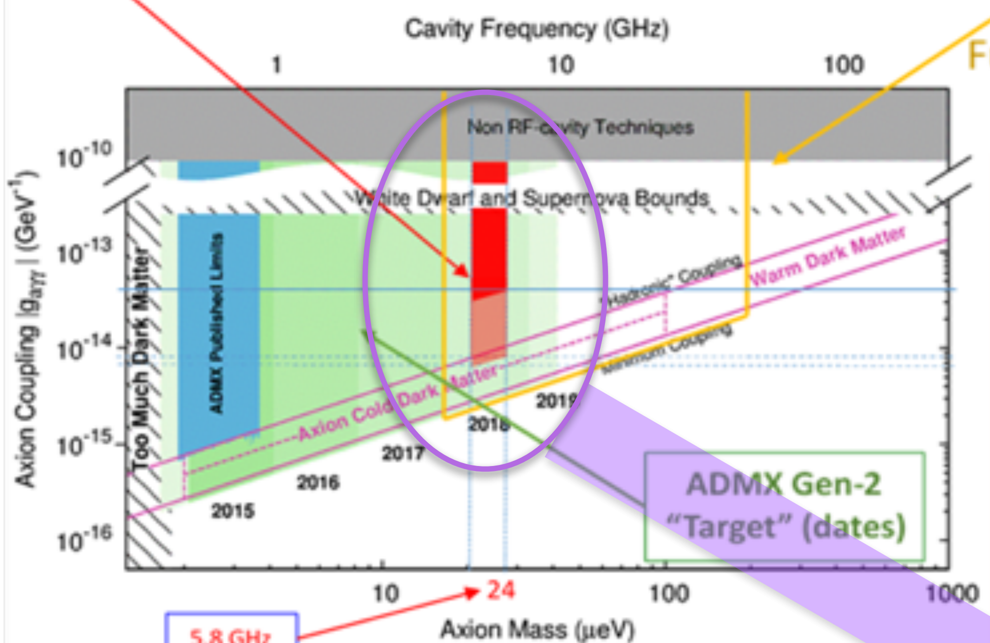
ADMX-HF Projected sensitivity. Present not shown. but similar to CAST-CAPP

Future

CAPP R&D Program

- Full superconducting cavities
- SQUIDS

If cavities in the CAST magnet can be further cooled down, CAST-CAPP will reach much higher sensitivity than HDMX-HF.



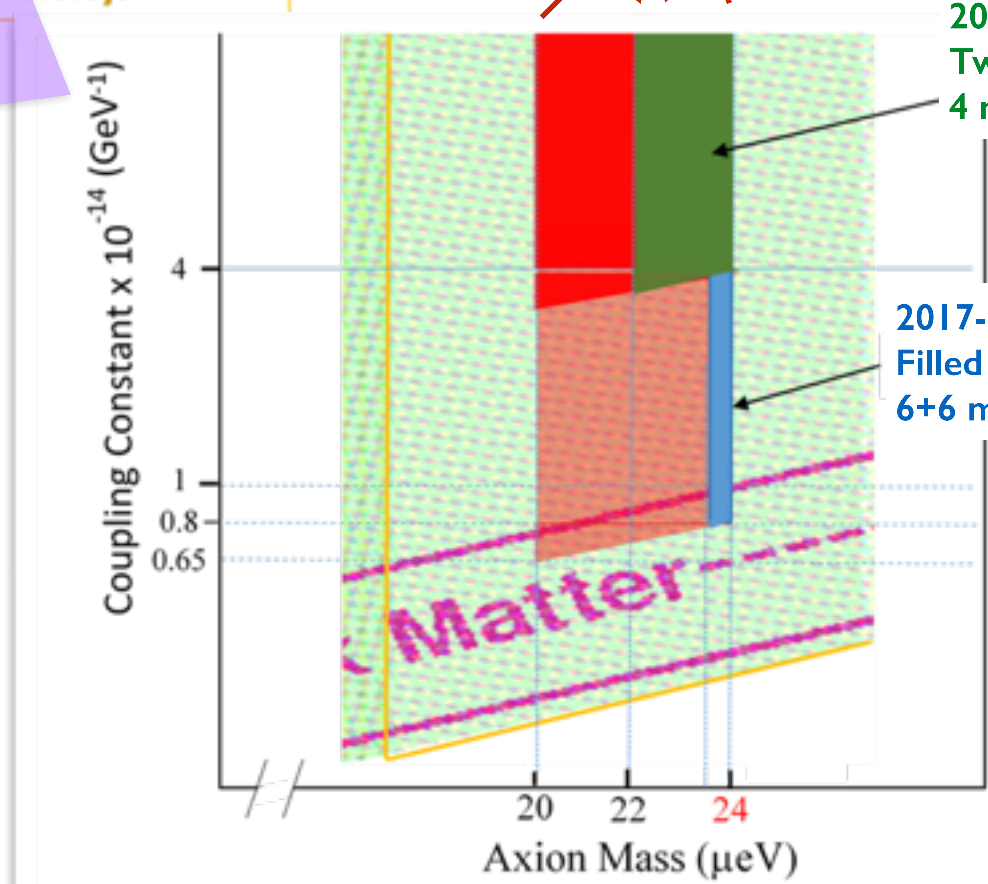
Future

HDMX-HF R&D

- Hybrid superconducting cavities
- Multiple JPAs operated in quantum squeezed state

Several years to reach projected sensitivity.

CAST-CAPP Accessible mass range

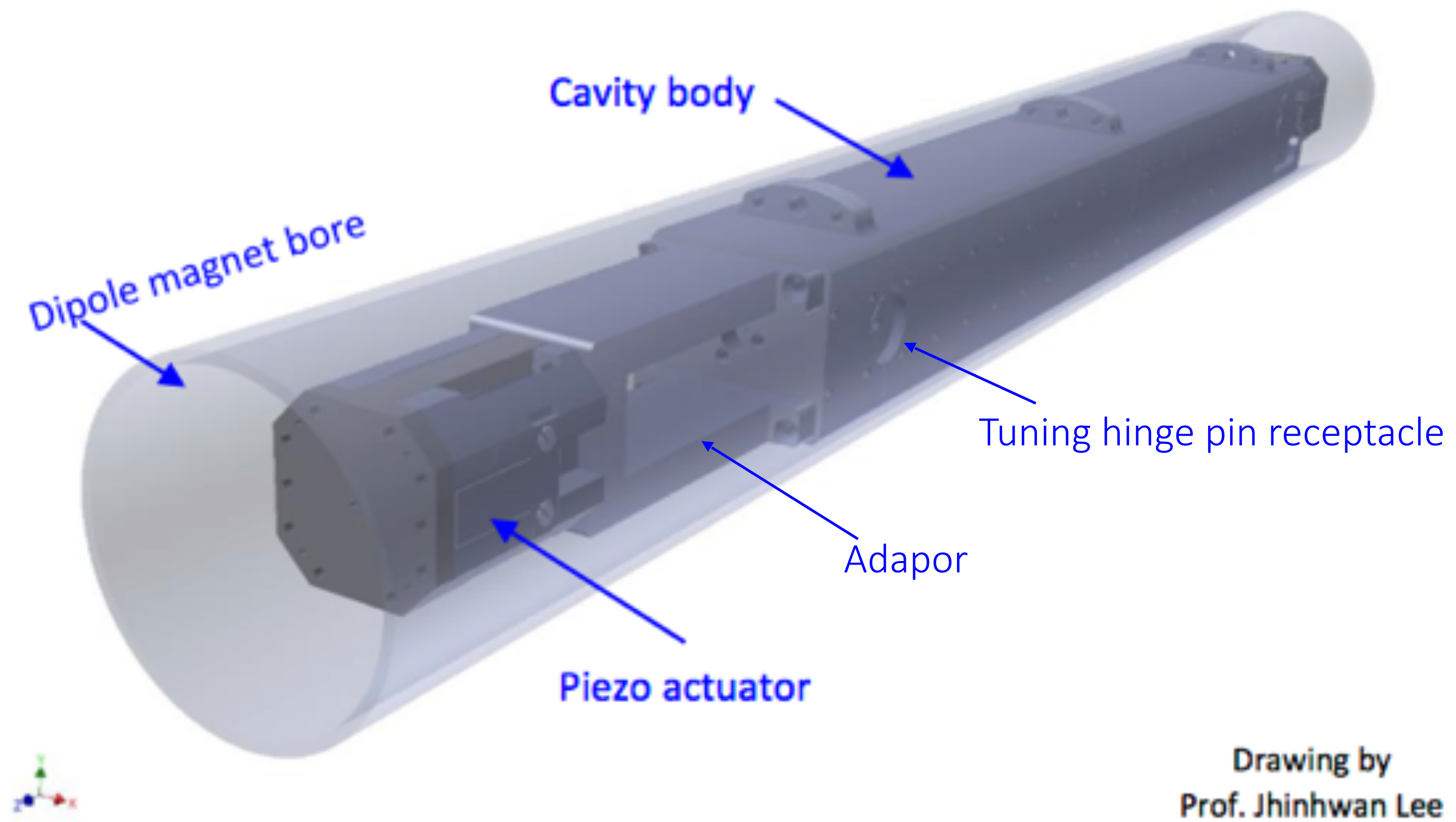


2016
Two cavities
4 months run

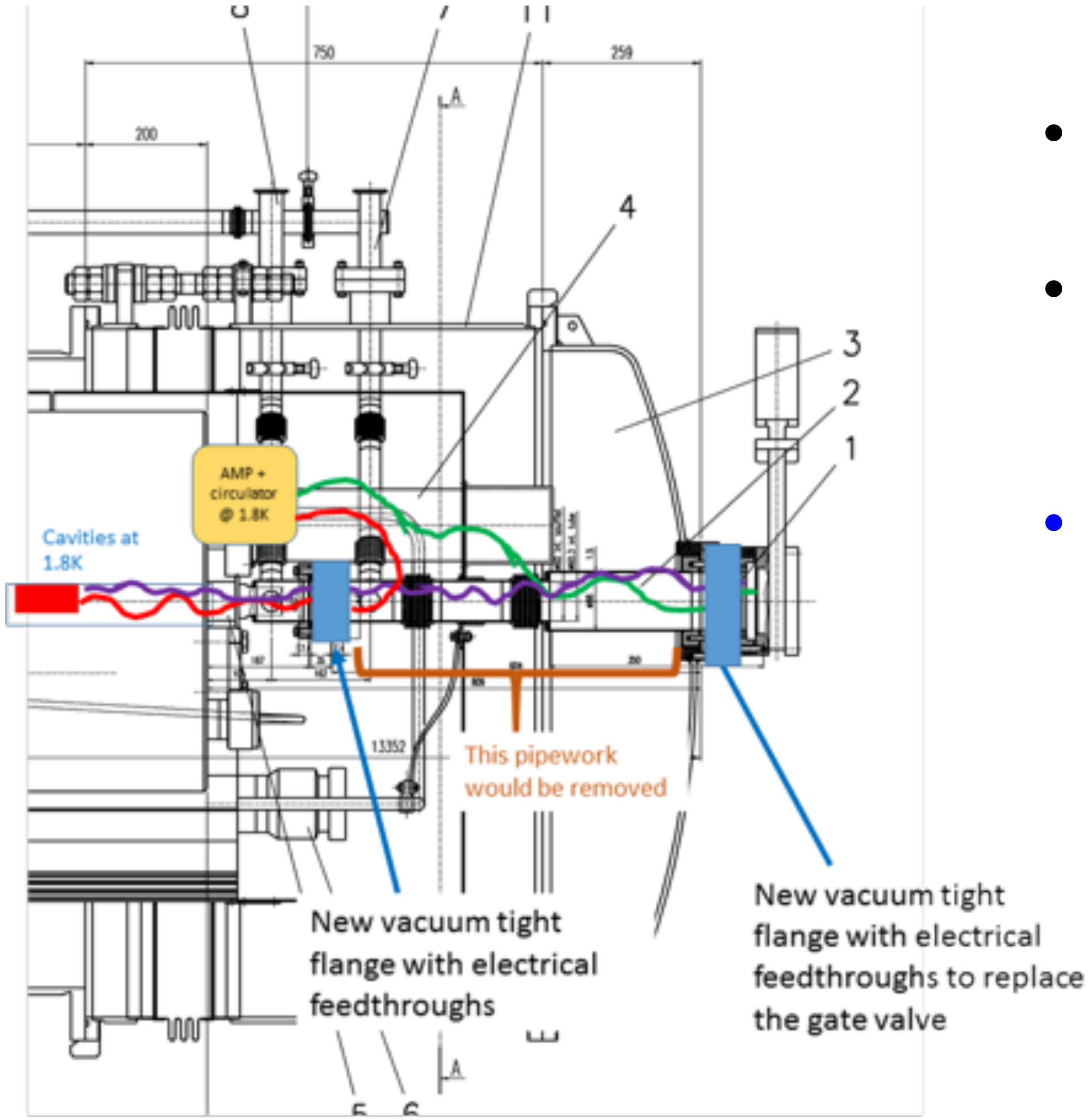
2017-2018
Filled bore
6+6 months runs

Recent Advances: Cavity Design and Prototyping

- Prototypes
  - **Two ready by next week, built at BNL.**
  - Testing: Q, sectioned cavity, tuning mechanism
  - Room and low temperature tests

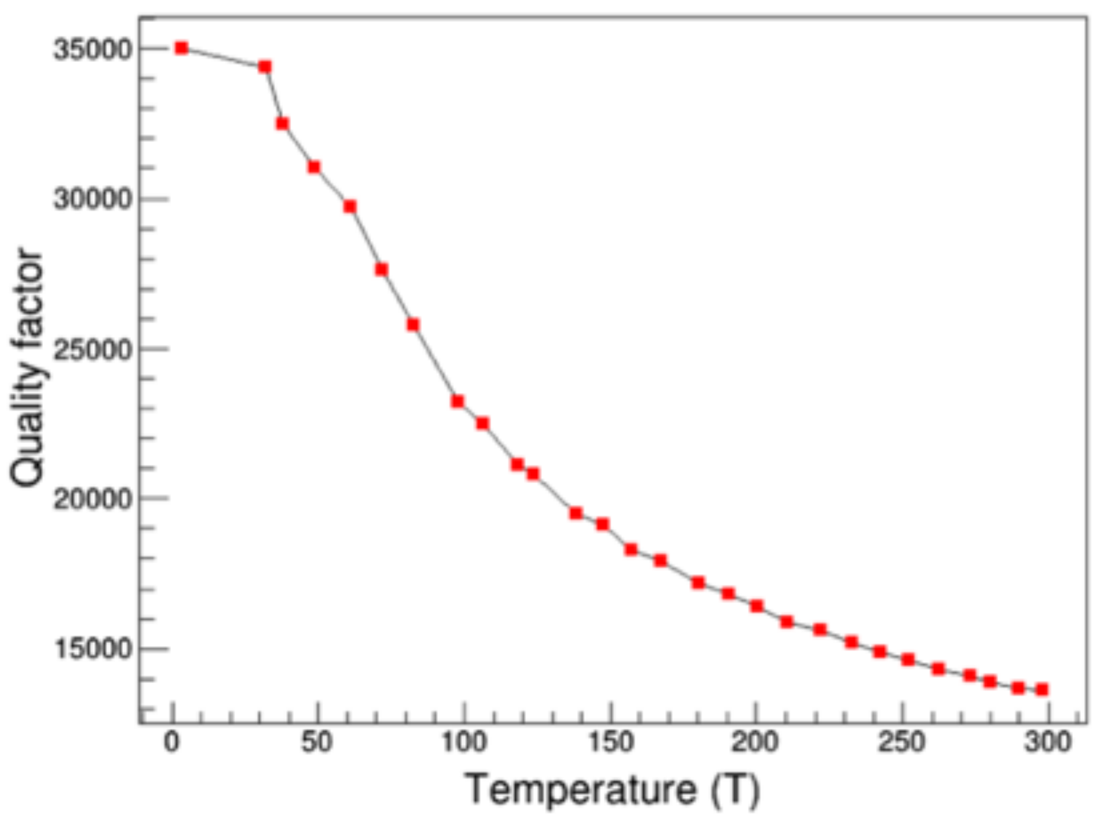


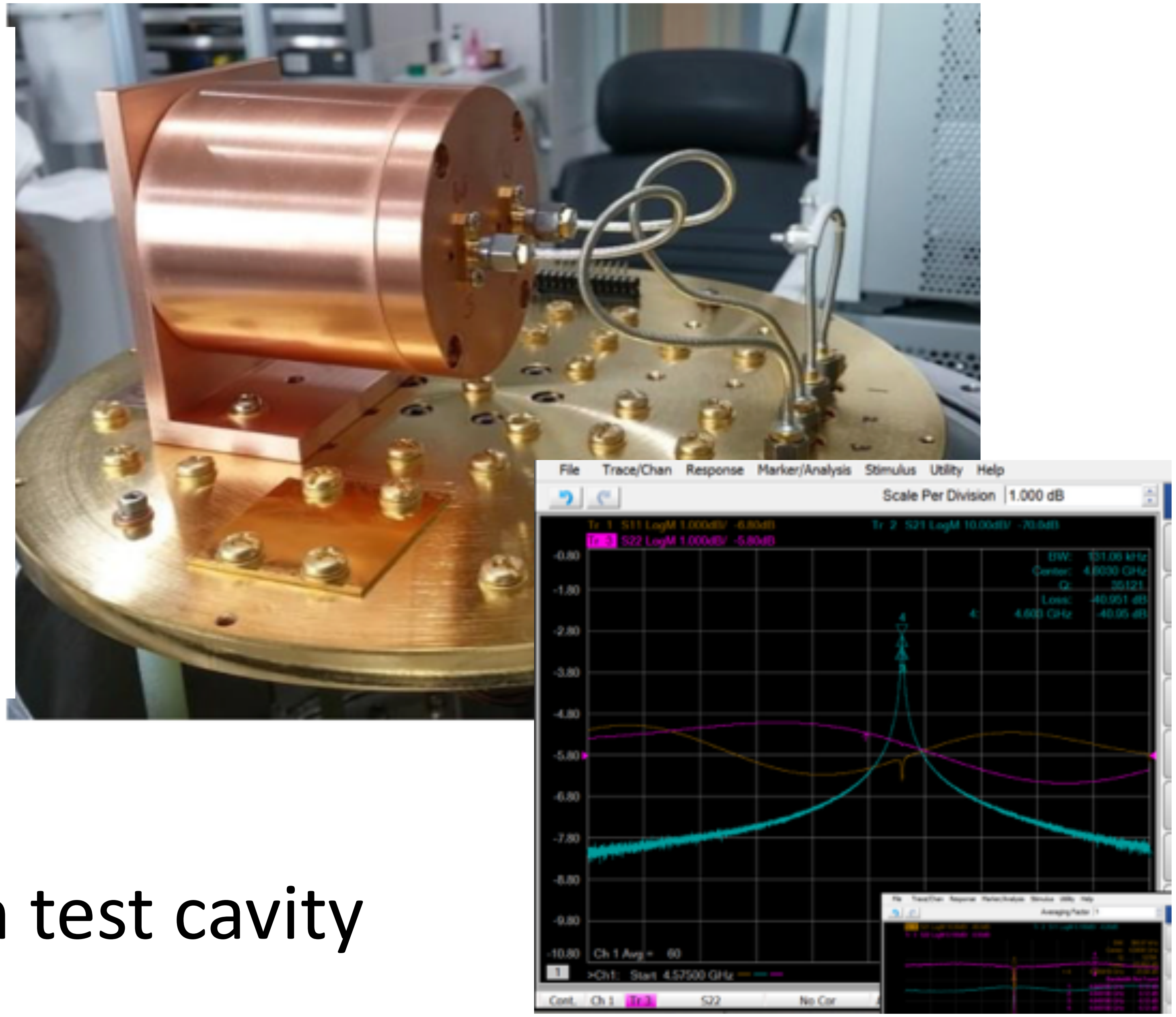
Integration with the CAST Magnet



- Requirements Specifications and Interface documentation started
- Engineering challenges to be expected: we have a clear path to meet them
- Low noise cryo-amplifiers can be placed in a region with no magnetic field at a temperature only 250 mK above 1.8 K (only 5% contribution to system temperature).

CAST-CAPP Cryo-refrigerator Tests
First measurements with a cylindrical test cavity





- Quality-factor studies on test cavity at low temperature

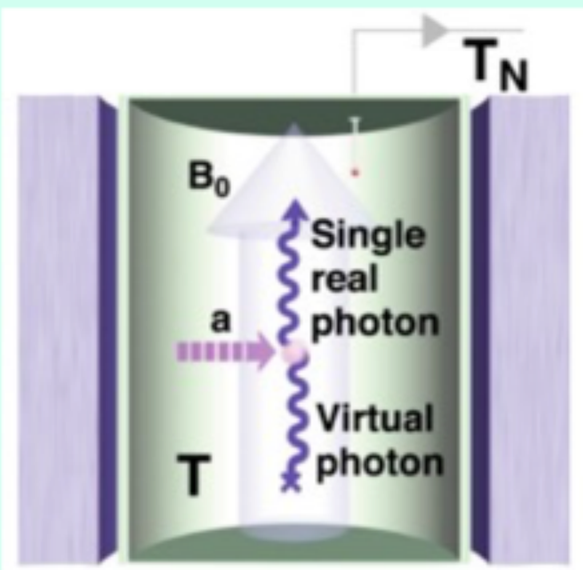
CAST-CAPP Preliminary Schedule

Week	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
	15-Oct-15	31-Oct-15	15-Nov-15	30-Nov-15	15-Dec-15	31-Dec-15	15-Jan-16	31-Jan-16	15-Feb-16	29-Feb-16	15-Mar-16	31-Mar-16	15-Apr-16	30-Apr-16	15-May-16	31-May-16
Design, build and test short prototypes	■	■	■	■	■	■										
Assess magnet environ. and interfaces, design integration	■	■	■	■	■	■	■	■								
Build components for magnet-detector integration								■	■	■	■	■	■			
Modify CAST magnet front-end for detector installation												■	■			
Develop electronics data processing and acquisition	■	■	■	■	■	■	■	■	■	■	■	■	■			
Design, build, and test two, 50 cm long, cavities						■	■	■	■	■	■	■				
Ship detector to CERN													■			
Test detector at CDERN														■	■	
Install detector															■	■

RADES detector

RADES (Relic Axion Detector Exploratory Setup)
- Axion dark matter at high frequencies by high volume cavities

Search for axion dark matter in resonant cavities (Sikivie 1983) : tiny signal

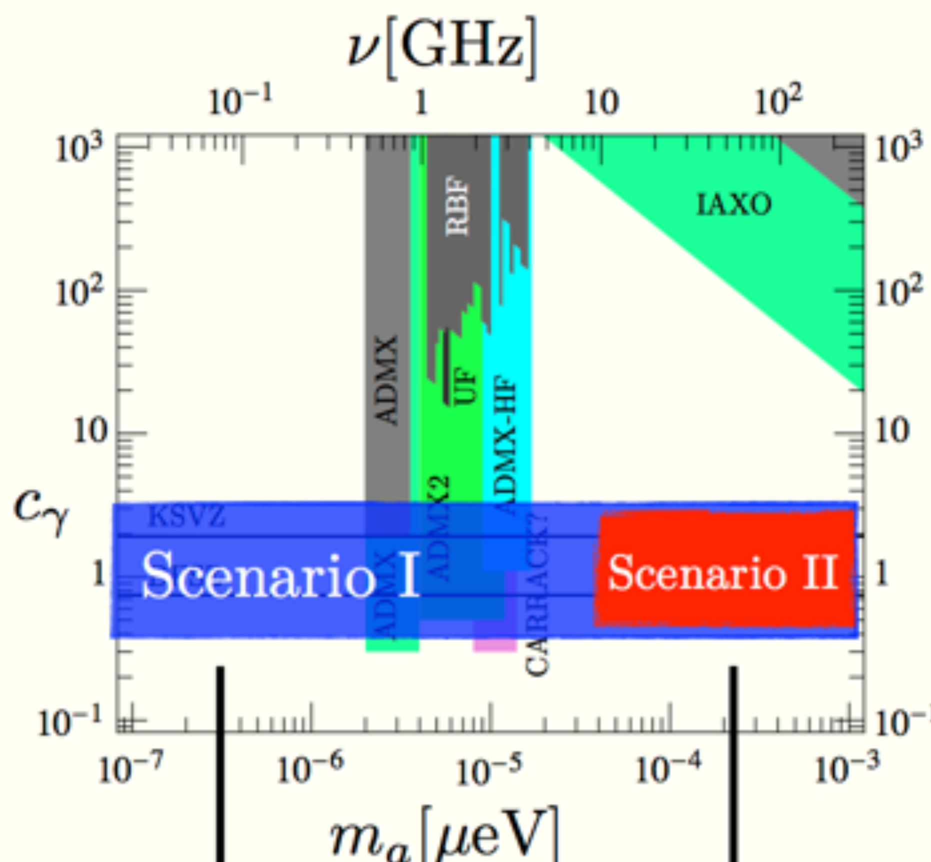


$$\mathrm{Power_{out}} \sim c_\gamma^2 10^{-23}\,\mathrm{Watt}\frac{m_a}{20\,\mu\mathrm{eV}}\left(\frac{B_0}{9\,\mathrm{T}}\right)^2\frac{V}{1\,1}\frac{Q}{10^4}$$

$$\mathrm{Power}_T \sim 10^{-19}\,\mathrm{Watt}\frac{T_N}{5\mathrm{K}}\frac{m_a}{20\,\mu\mathrm{eV}},$$

Experience only with $V \propto m_a^{-3}$

Best motivated axion dark matter scenarios not covered by present/future plans (colors)



Low freq.
large Volume,
large magnet!

High freq.
small Volume,
tiny signal!

Explore experiments combining large number of cavities to have large V at HF to use large exsisting (future) magnets with large(huge) magnetic length!

	ADMX	IAXO	CAST
B [T]	8	2.5 *	9
Dim.[cm]	h,R=100,21	h,R^*=2000,	h,R=920,2.2
Volume	140	8 x 1700	2 x 14
$\|\mathbf{B}\|^2 V$	9000	8 x 35000	2 x 1100

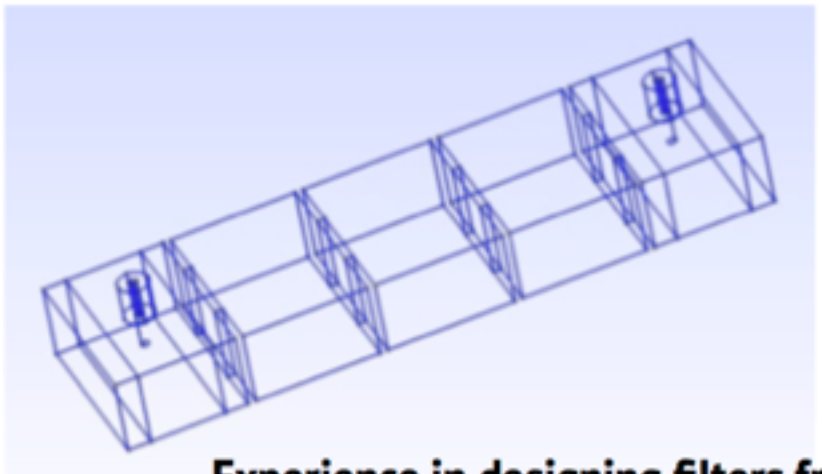
CAST

IAXO?

RADES (Relic Axion Detector Exploratory Setup)
- Develop techniques for axion dark matter cavity searches above 6 GHz

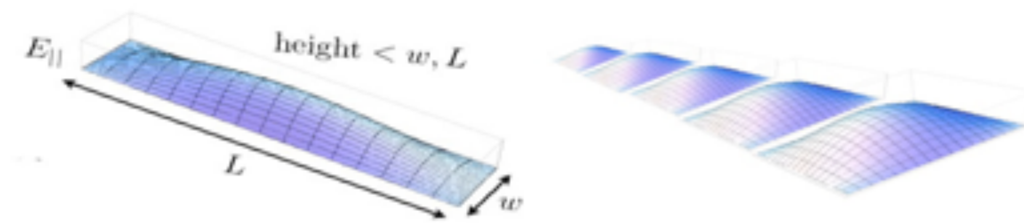
Chebyschev-filter cavity : $V \sim NV_0 \sim Nm_a^{-3}$

$Q \sim Q_0$



Experience in designing filters from M. Guglielmi, B. Gimeno (U. Valencia)

For given h,w,L, these cavities resonate at higher frequencies than a long parallelepiped (CAST CAPP)



Phase I (2016) : no tuning (broad-band?)

$N = 5, \nu \sim 6\text{GHz}, Q \sim 10^4, 35 \times 25 \times 200mm$

commisioning at CAST, ~month data taking

Phase II (2017) : larger N cavity

$N > 5, \nu > 6\text{GHz}, Q \sim 10^4, L \sim O(m)$

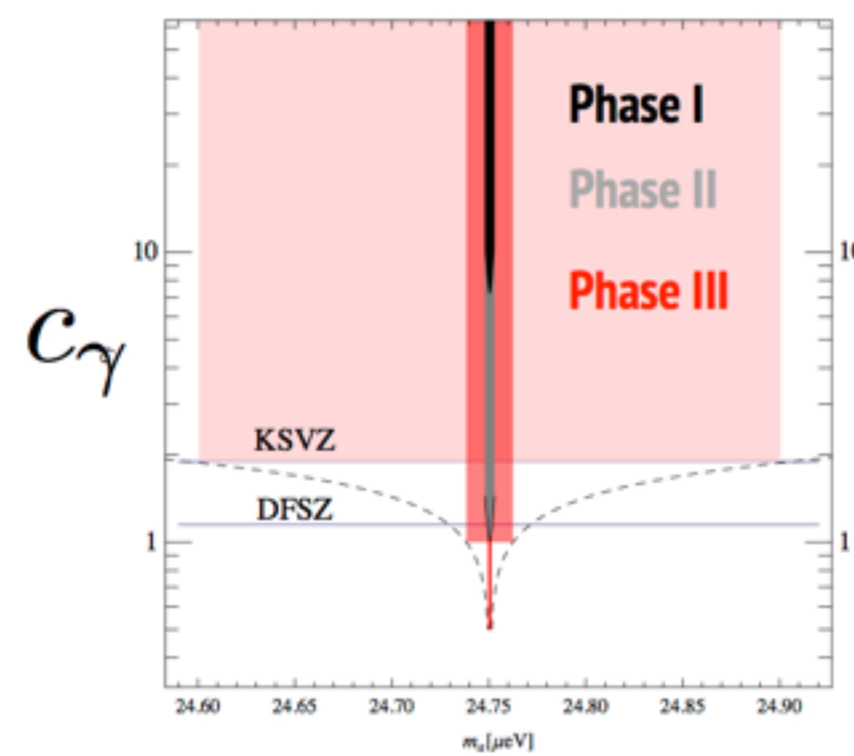
commisioning at CAST, ~month data taking

Phase III (2018) : larger N cavity + tuning

$N > 5, \nu > 6\text{GHz}, Q \sim 10^4, L \sim O(m)$

commisioning at CAST, ~month data taking

Main Goal is gain experience for a large scale future test, but physics results will be relevant

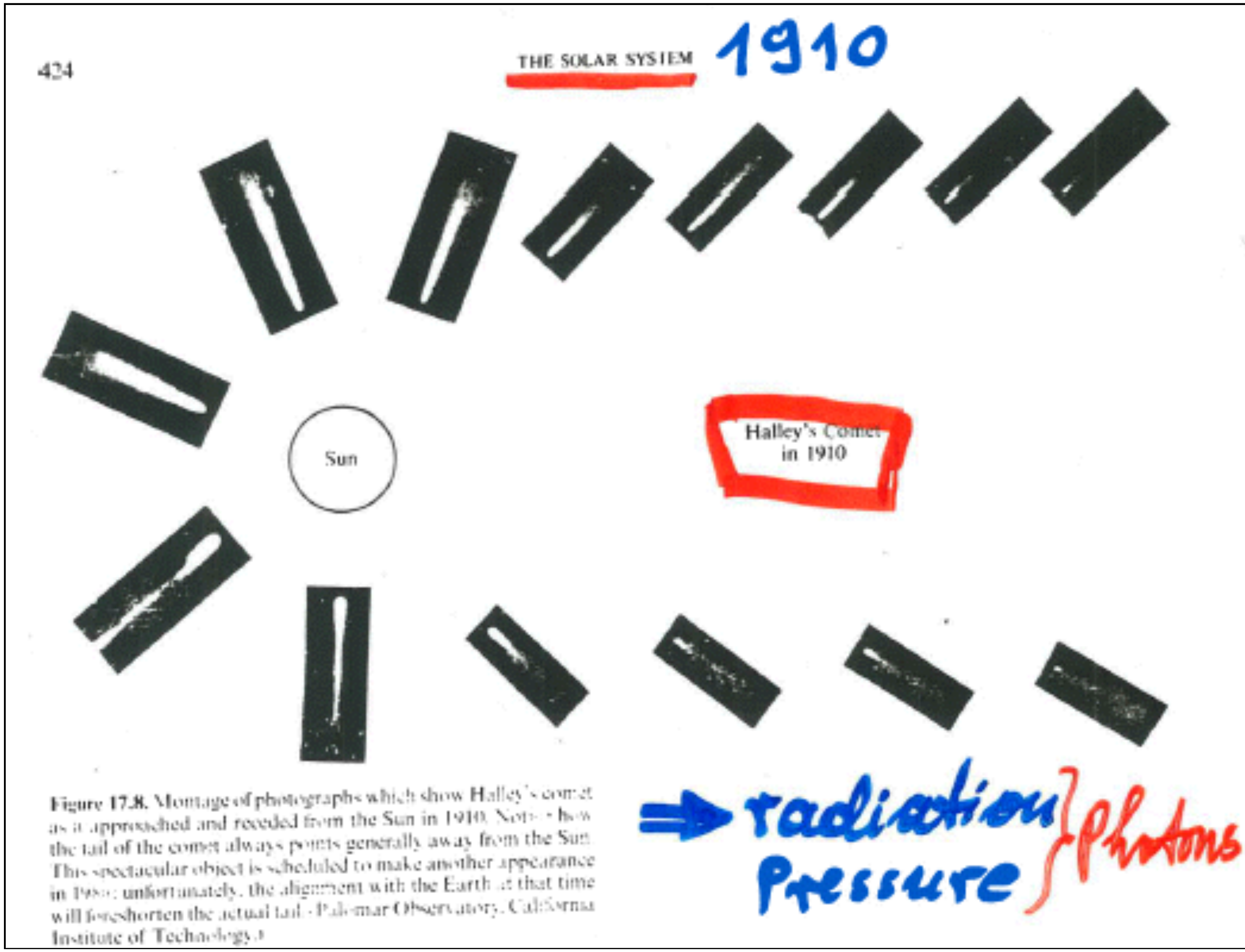


Global projected beam schedule

	Sunrise	Magnet bores	Sunset
	RADES	L ~ 0.2m	SRMM+XRT (low energy test)?
2016			
	CAPP	2x 0.5m L ~ 1m plus tuning	**KWISP -> InGrid**
	RADES	L ~O (1m) depends on 2016 results	t.b.d
2017			
	CAPP	L ~ O (9m) plus tuning	**KWISP**
	RADES	L ~O (m) plus tuning	t.b.d
2018			
	CAPP	L ~ 9m plus tuning	**KWISP**

Additional slides

Radiation pressure in time:



next step with ~chameleons!?

Cosmic relics

CMB	2.73K	400000 years	~411/cm^3	✓
CνB	1.95K	1 s	~112/cm^3	
CaB	10^{-35}K #	10^{-12} – 10^{-20} s $ CDM defreezing	~10^{12} cm^3	($m_{axion}c^2 \approx$ meV)
CwimpsB	10^9 K &	~10^{-11}s	~0.01 /cm^3	($m_{WIMP}c^2 \approx$ 100 GeV)
CgwB	??K	??? s	??/ cm^3	

gw = gravitational waves

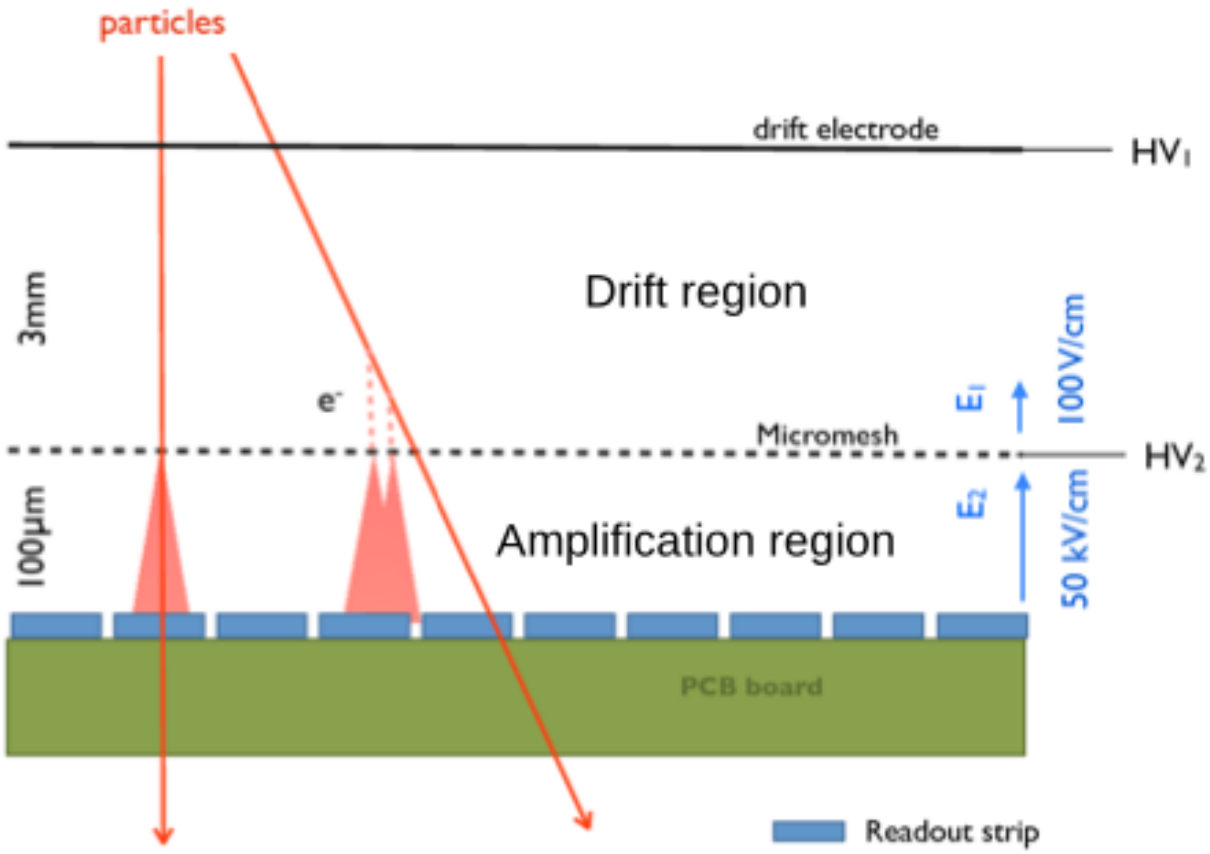
$ Joerg Jaeckel

Pierre Sikivie

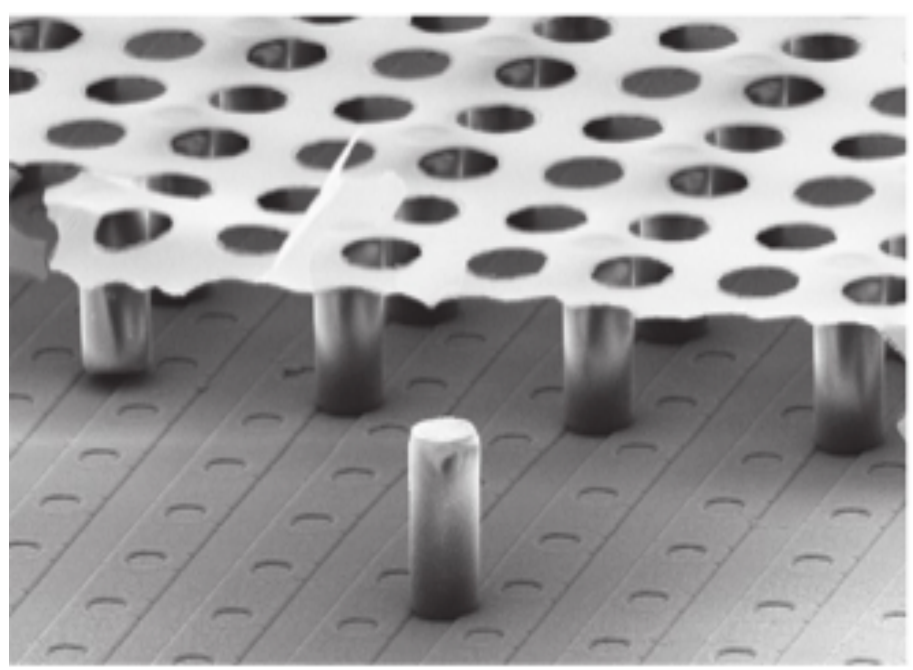
& Laura Baudis

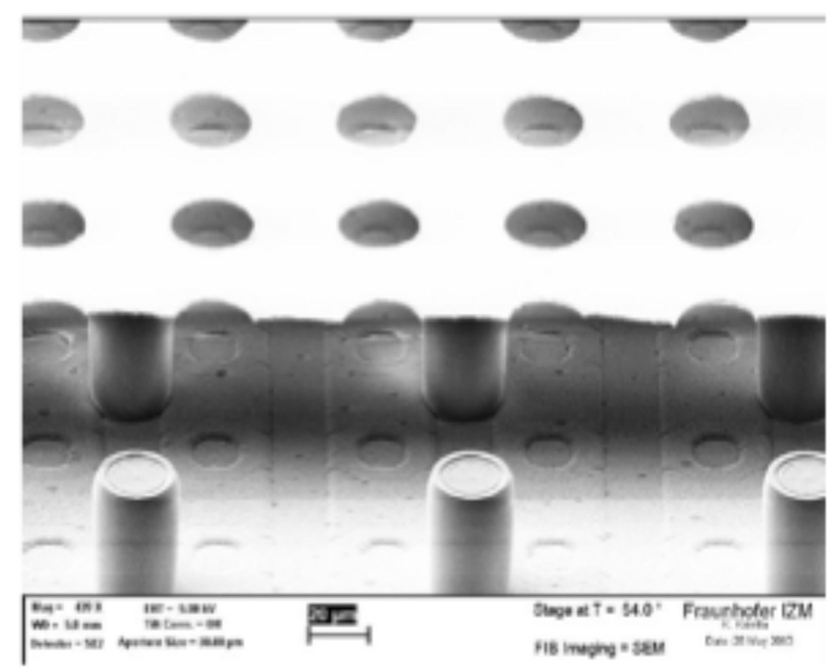
Backup slides

InGrid detector @ CAST



Micromegas mounted on a pixel chip
via photolithographic post-processing

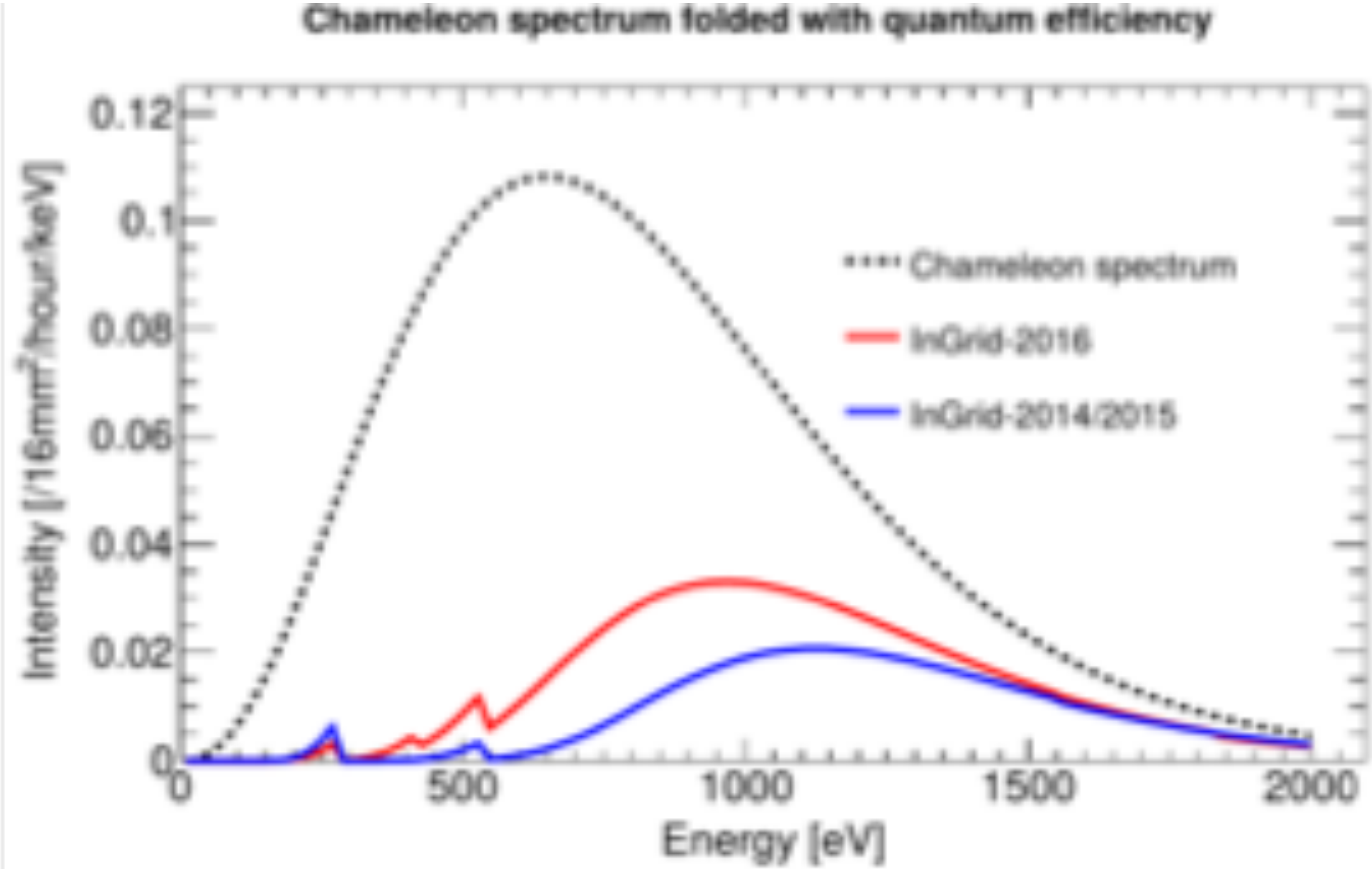




Timepix

InGrid

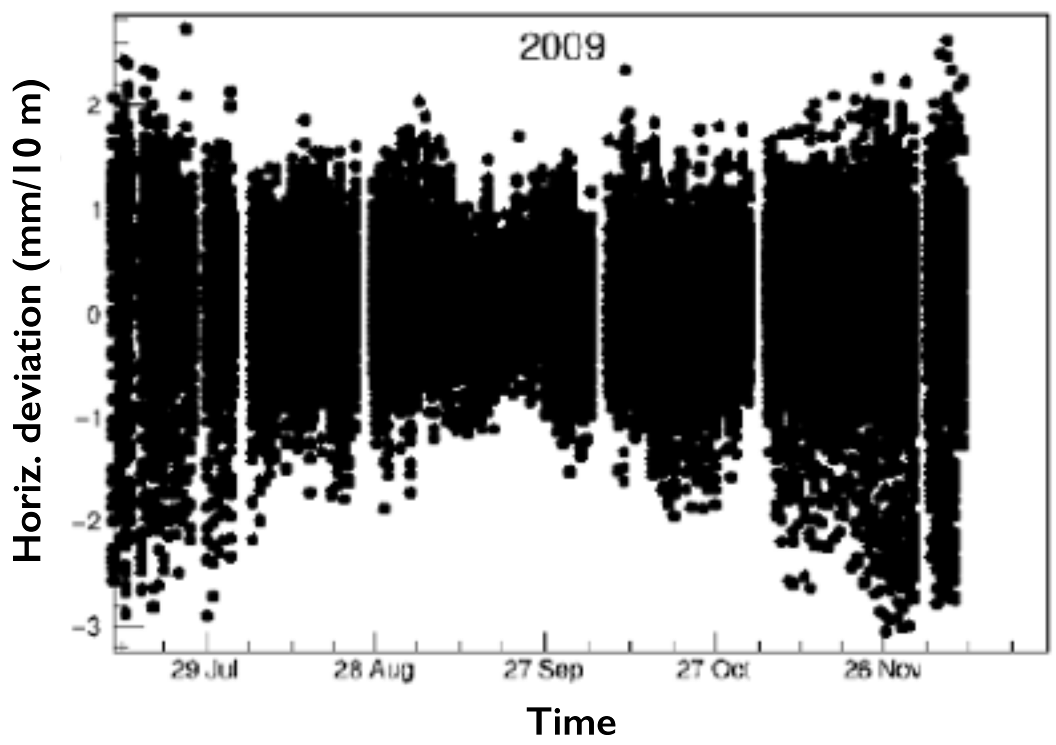
InGrid detector: chameleon efficiency

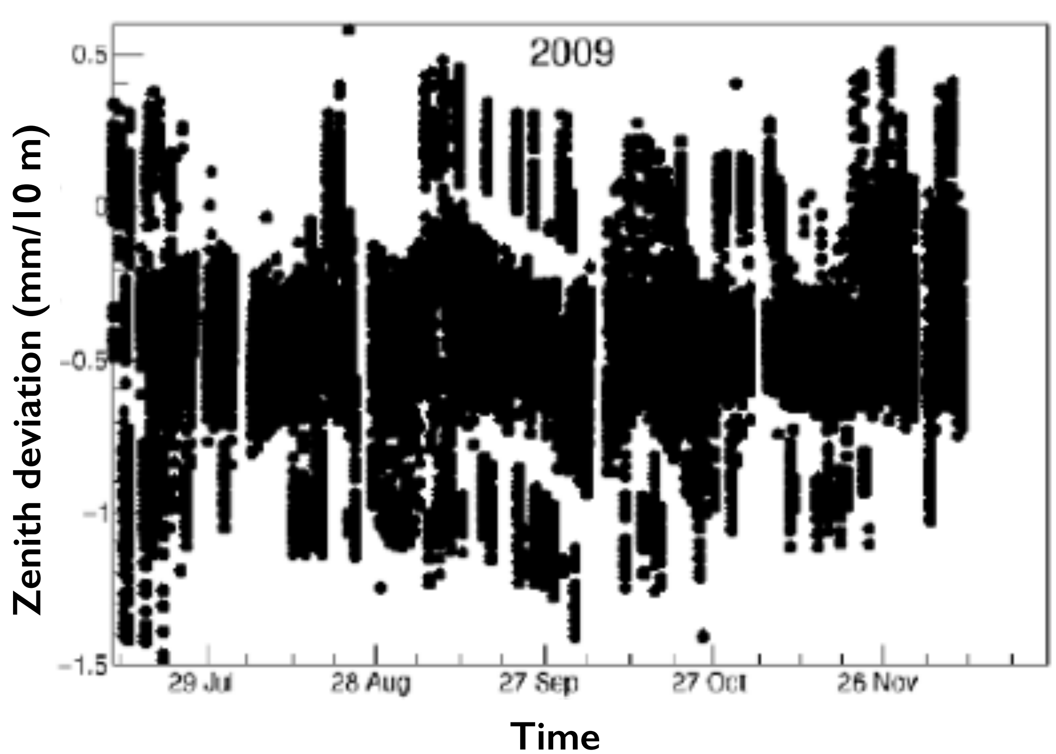


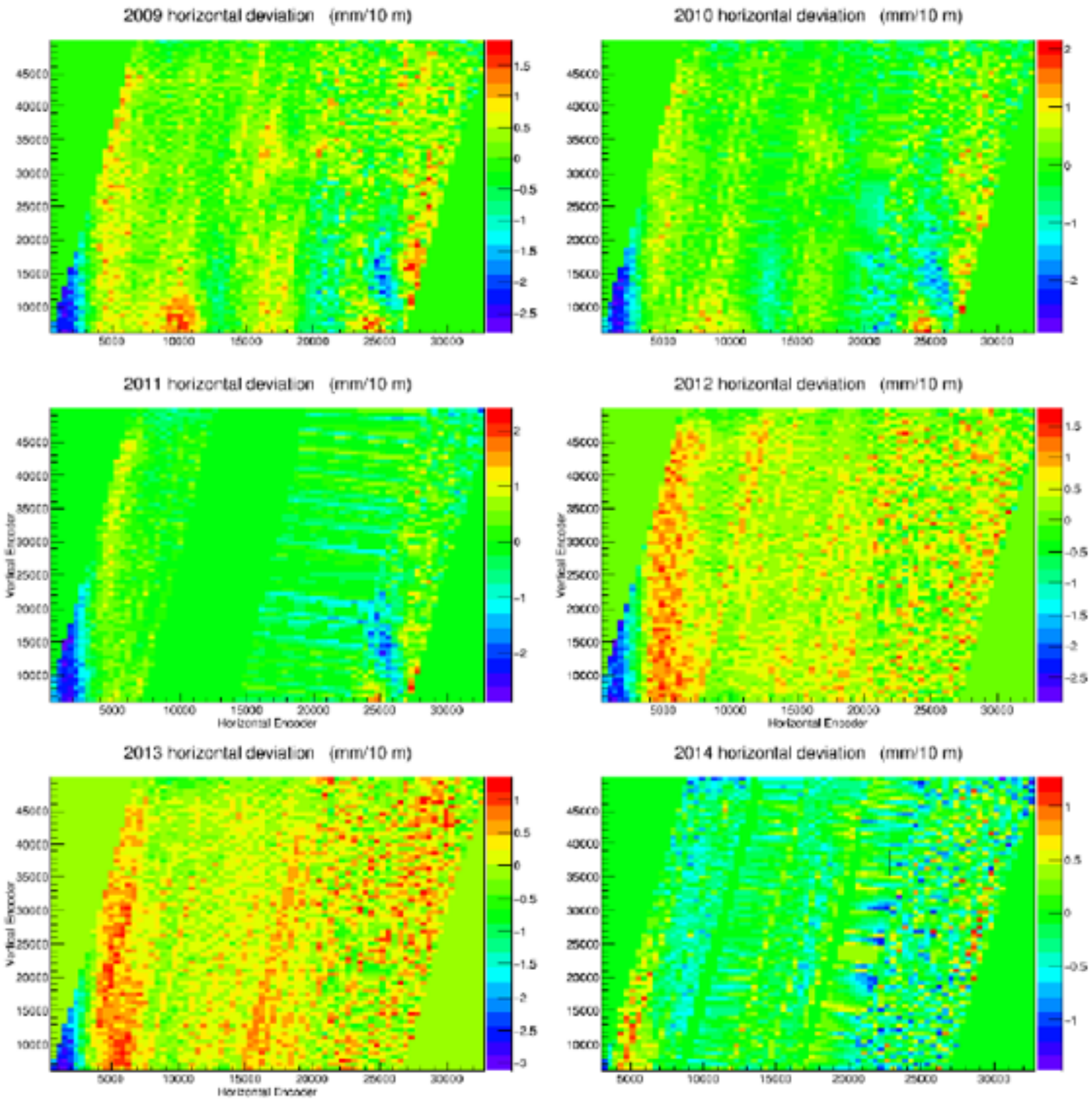
- Efficiency limited by X-ray window
- 2014/15: 2 µm Mylar $\varepsilon_{Chameleon}$ ~ 17 %
- 2016: aim for 200 nm SiN $\varepsilon_{Chameleon}$ ~ 36 %

Tracking

- Extensive study, comparison between NOVAS and logfiles
- **Max deviation 3 mm/10 m azimuth and 1.5 mm/10 m zenith**







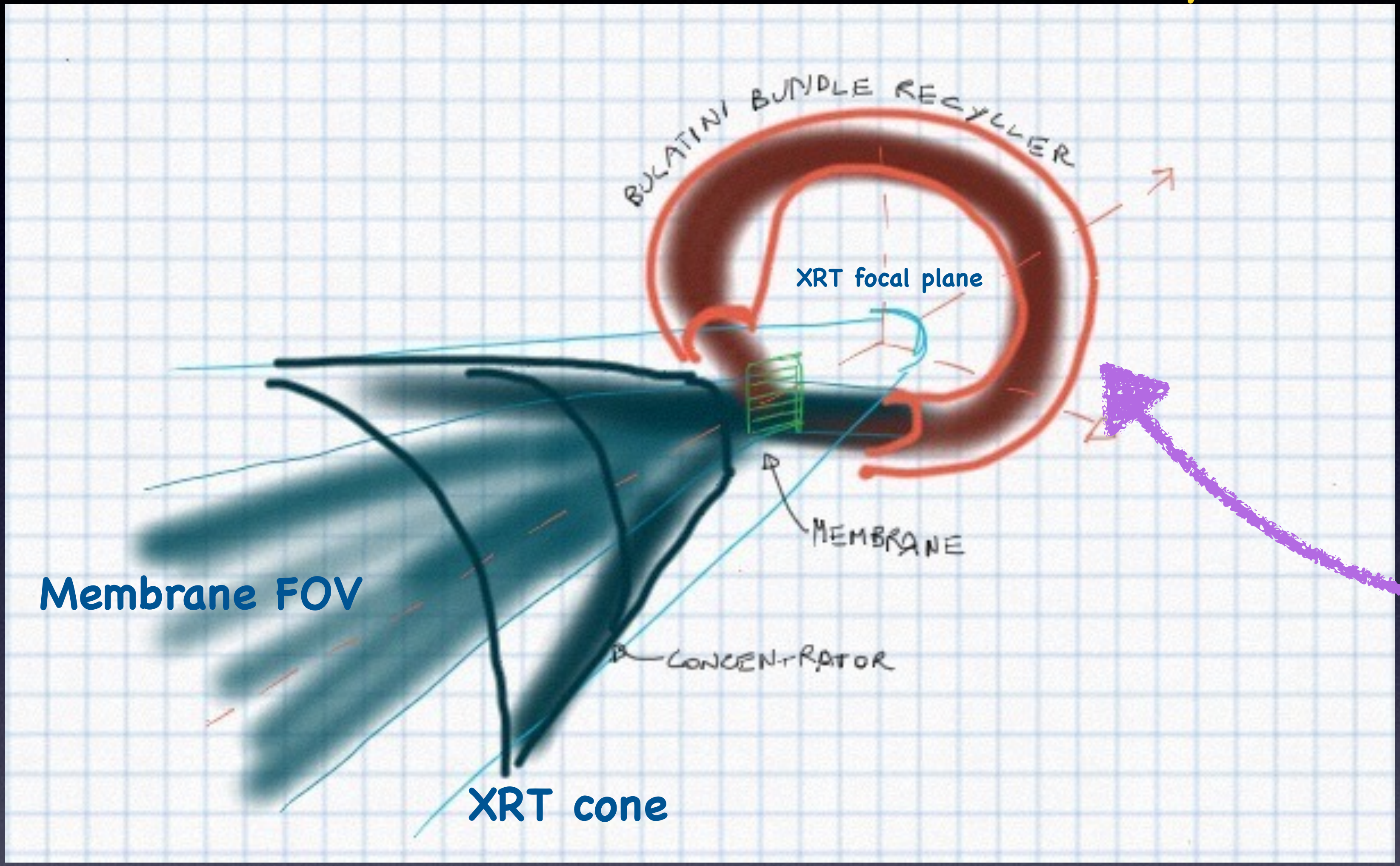
CAPP - Schedule for 2015

- Design, build and test short prototypes
- Assess magnet environ. and interfaces, design integration
- Develop electronics data processing and acquisition

Backup slides

Concentrator and recycler concepts

Concentrator and Bucatini-bundle recycler

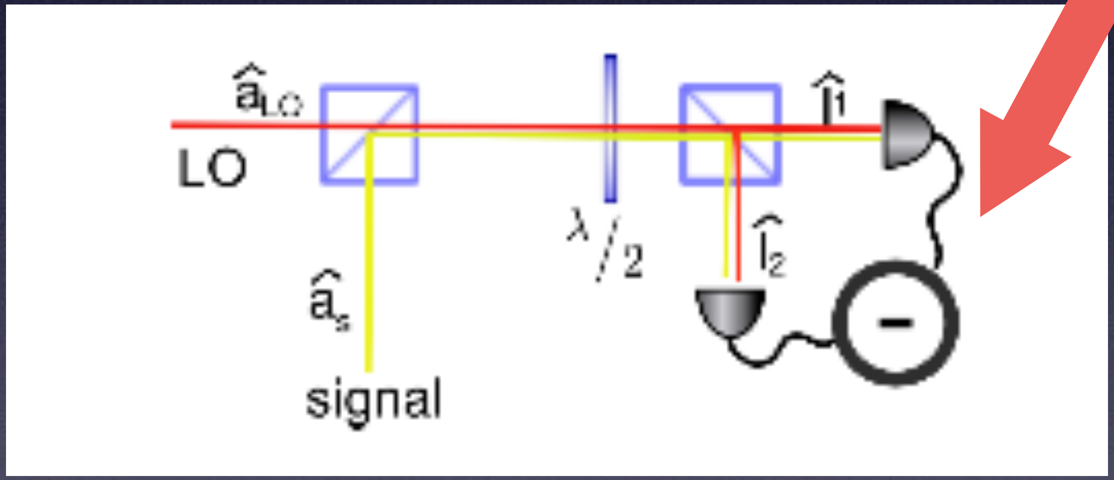


from discussions with K. Zioutas

Direct homodyne detection

fotorivelatore bilanciato

oscillatore locale (LO) - direttamente dal laser



(*)

"signal" - fascio in uscita dalla cavità FP

(*) da P. Piergentili, "Optical cooling of a mechanical micro-oscillator revealed by homodyne detection", Tesi di Laurea Magistrale, Univ. di Camerino (2013)

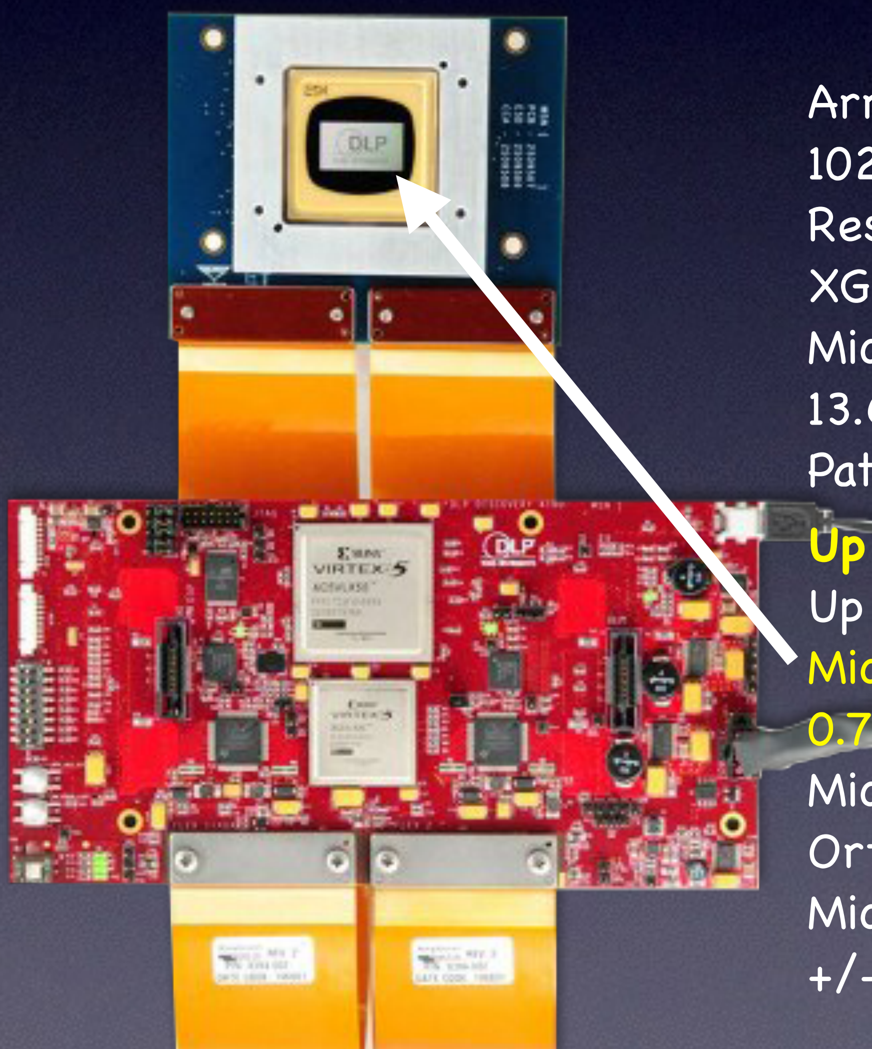
HF chameleon chopper

1500 Hz

17000 rpm ~ 280 Hz

Micro-mirror array

(suggestion by M. Karuza)

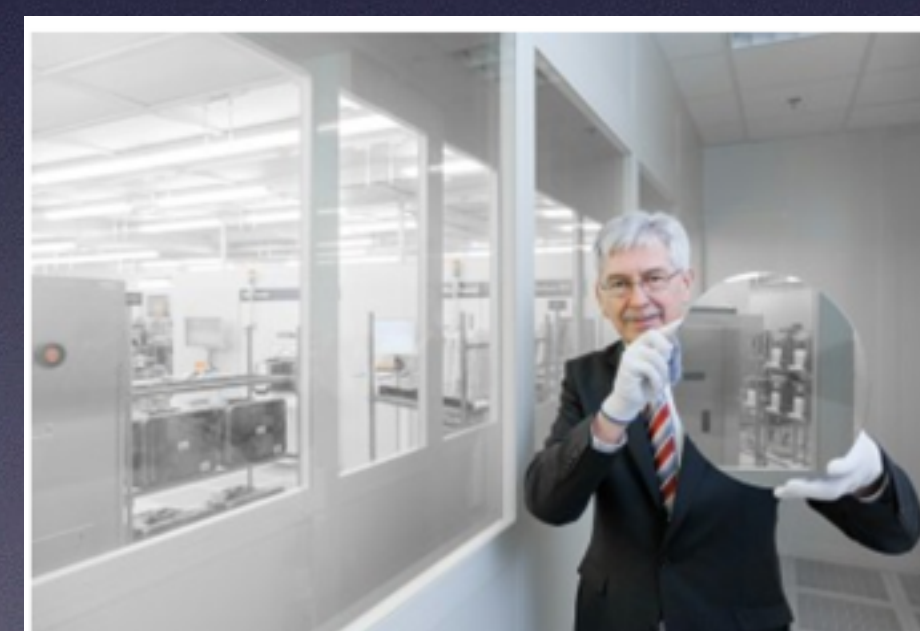


Texas Instrument DLP Discovery 4100

Array size
1024 x 768
Resolution
XGA
Micromirror pitch
13.6μm
Pattern display rate
Up to 32,000 Hz binary
Up to 1,900 Hz 8-Bit grayscale
Micromirror array diagonal
0.7 inch
Micromirror orientation
Orthogonal
Micromirror tilt angle
+/- 12 degrees

Rotor built with Si-wafer optical surfaces (roughness < 0.4 nm)

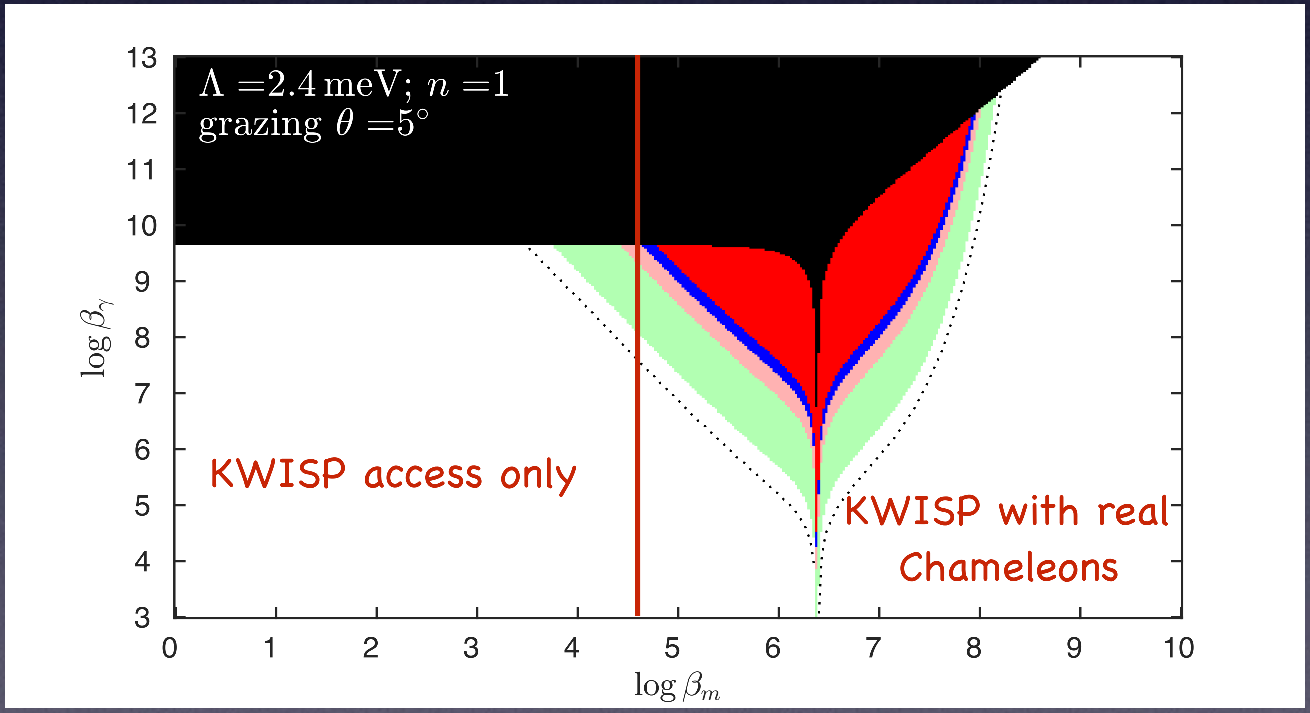
(suggestion by K. Zioutas)

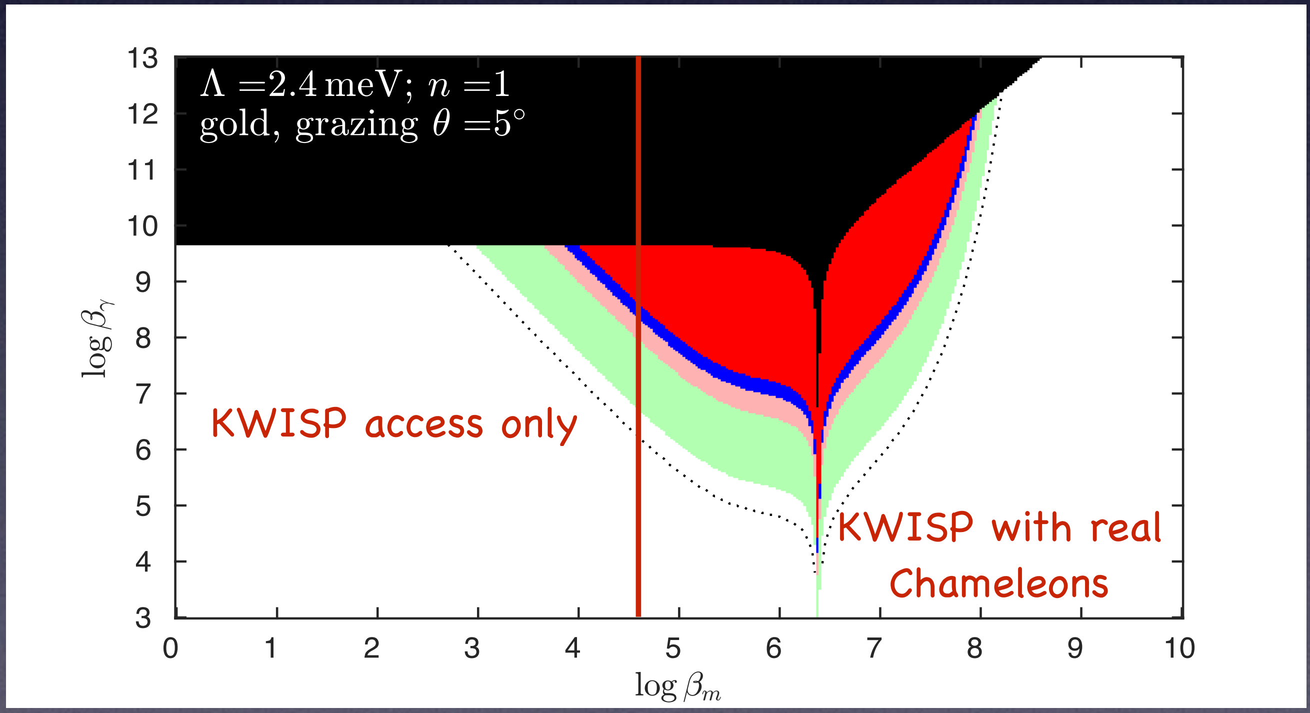


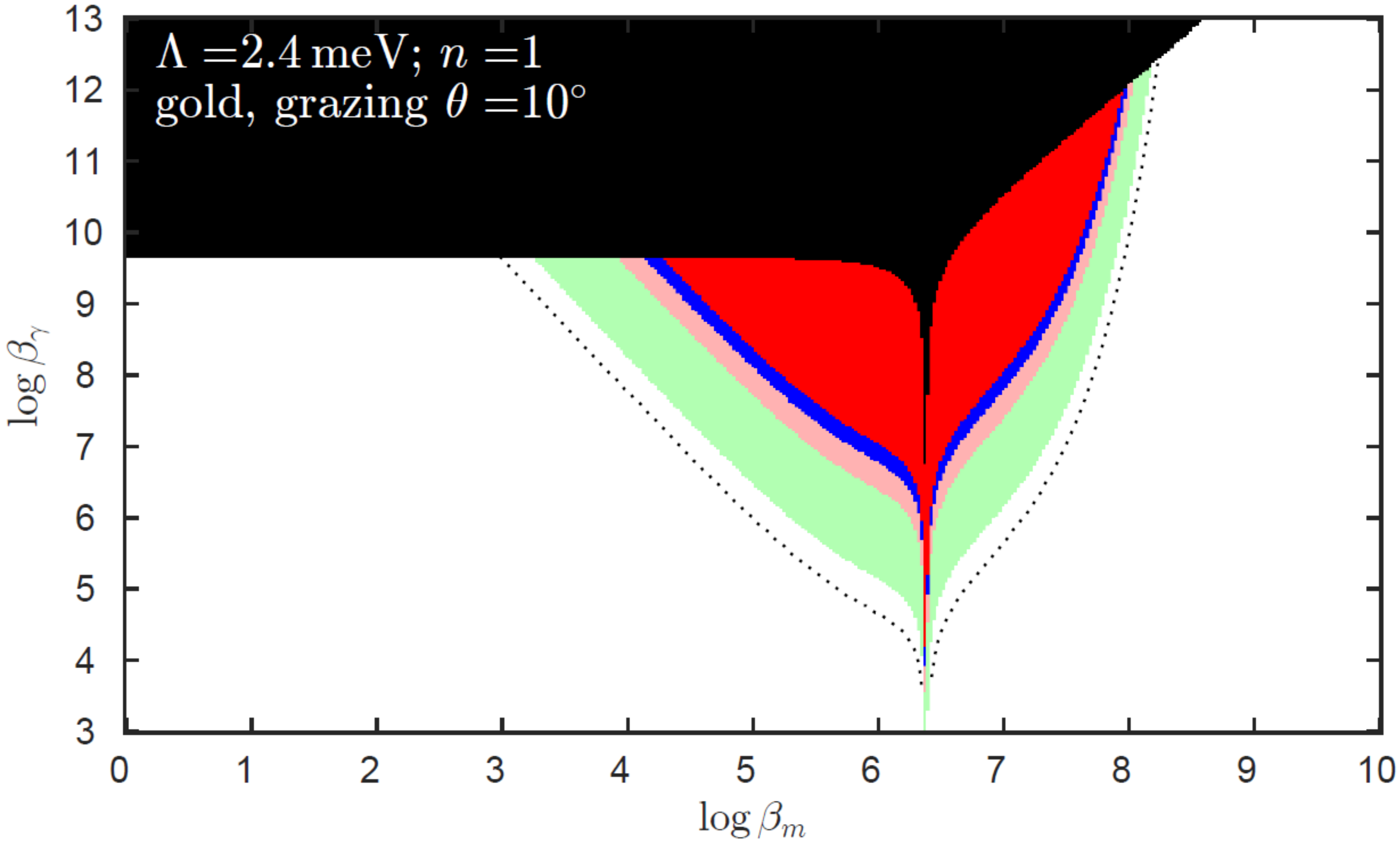
Johann Schandl's "finishing/epitaxy 300 mm" facility manufactures hyperpure silicon wafers with a highly polished mirror-like effect.

http://www.wacker.com/cms/en/100years/people/schandl.jsp

Spazio dei Chameleon solari (esempio)



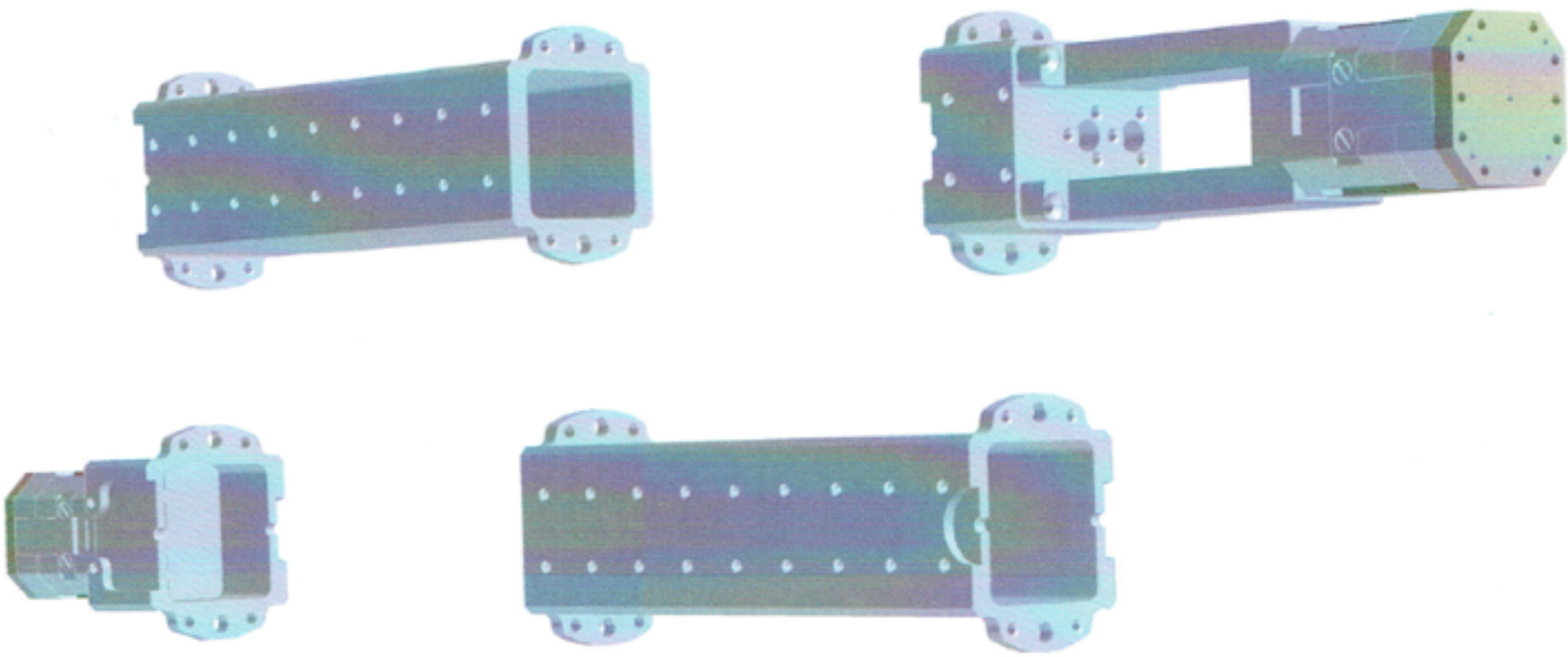




$\Lambda = 2.4\,\mathrm{meV};\ n = 1$
gold, grazing $\theta = 10^\circ$
$\log \beta_\gamma$
$\log \beta_m$
13
12
11
10
9
8
7
6
5
4
3
0
1
2
3
4
5
6
7
8
9
10

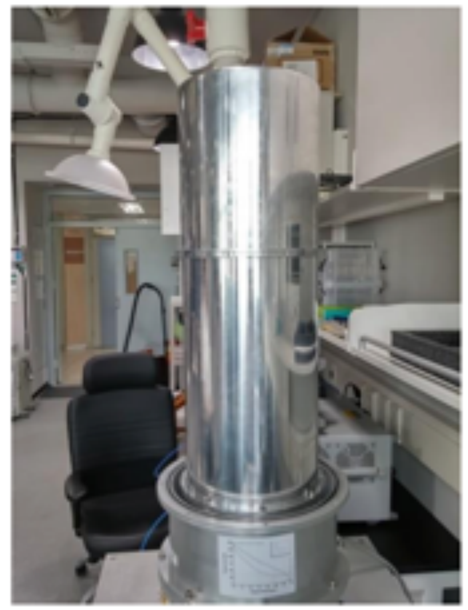
Backup slides

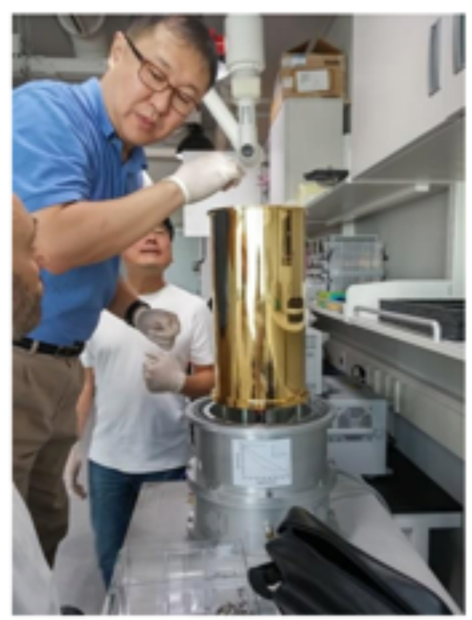
Recent Advances: Cavity Design and Prototyping

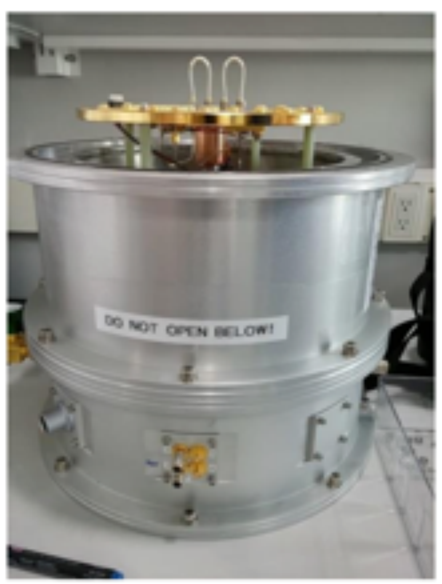


CAST-CAPP Cryo-refriegerator Tests
First measurements with a cylindrical test cavity

CAPP
Center for Axion and Precision Physics Research







Cryo-Refrigerator (at CAPP)