Experience with Scintillator Screens at ALBA

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ALBA - CELLS

Joint ARIES – ADA Workshop on
“Scintillation Screens and Optical Technology for Transverse Profile Measurements”
Krakow (Poland) – April 2019

Contents

Screen Monitors @ALBA

- Up to 24 screen monitors at ALBA that use scintillator material
- The most used scintillator @ALBA is YAG:Ce (or simply, YAG)
- YAG:Ce → Yttrium Aluminum Garnet activated by Cerium (Crytur)

Location	Screen Type	# units
Linac	YAG	3
Linac-to-Booster	YAG & OTR	4
Booster	YAG & OTR	4
Booster to Storage Ring	YAG & OTR	3
Storage Ring	YAG	6
Pinhole (SR)	YAG	1
In-air X-ray Detector (SR)	Prelude / CRY19	3

FSOTR @ALBA

Two screens (FS and OTR) held in the same support.
Can be insterted with 2 positions using pneumatic piston:

- FS (YAG:Ce)
- OTR (Al-foil)

<u>YAG Screens:</u>

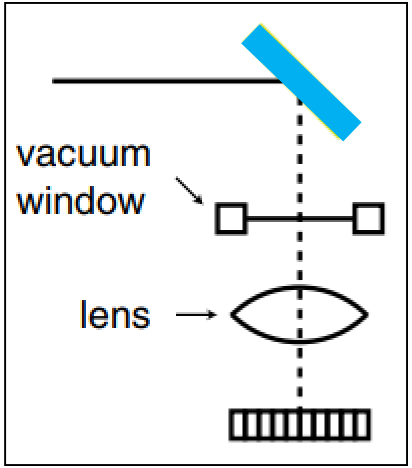
- 0.1 - 0.5mm thick
- Depending on beam charge density, light emission produced by YAG screens can saturate
- Used with low charge beams

<u>OTR - Optical Transition Radiation</u>

- 100nm thick (in a 0.3mm Si substrate)
- Produces little light, but linear response
- Used with high intensity beams

Optical Layouts

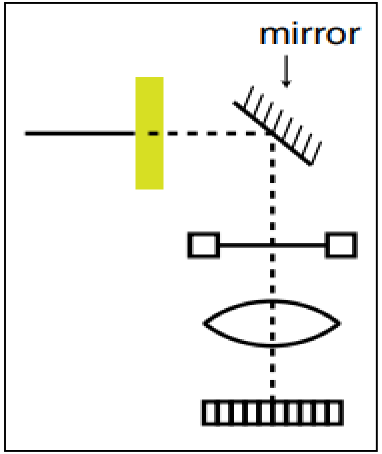
Optical Layout at FSOTR



OTR

YAG/OTR at Vertical plane
Lens/CCD at Horizontal plane
→ Both screens on focus
Tested YAGs 0.1 & 0.5mm

Optical Layout at Pinhole



Tested YAG:Ce screens:
0.1 & 0.2mm

CCD in all cases:

- Basler scA1300-32gm
- Sony ICX445, 1/3”
- 3.75um pixel
- GigE Interface
- 12bits
- Remote trigger
- C-mount

1. Introduction

2. YAG – OTR @ Linac

3. In-Air X-ray Detectors

4. Pinhole Camera

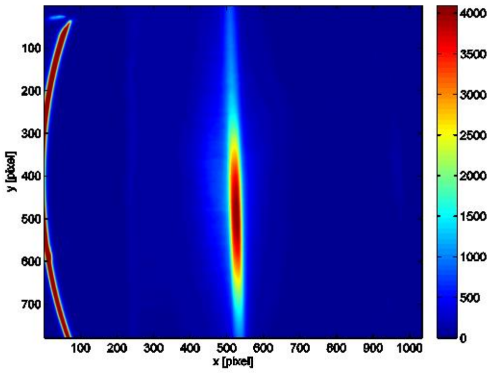
5. Conclusions

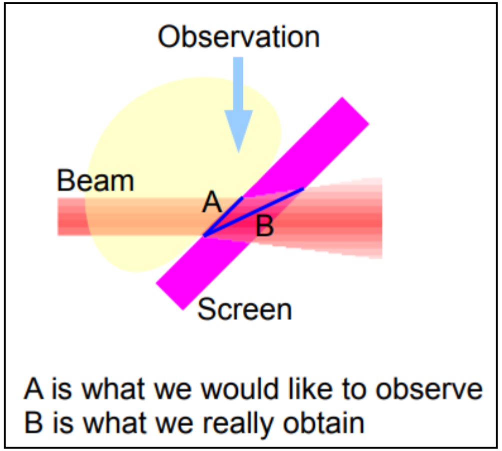
Comparison YAG vs OTR @Linac

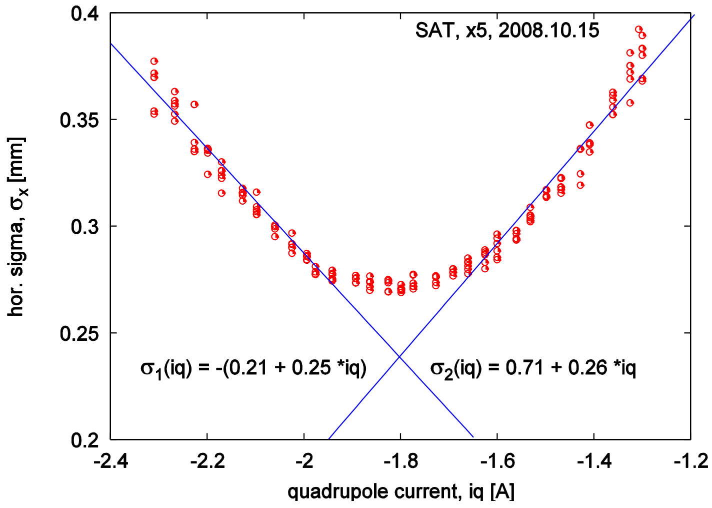
YAG Pros & Cons

PROS: lots of light

CONS: Beam size increase due to YAG thickness*
Significantly affected when beam size ~ YAG thickness
Larger in the YAG tilt direction (horizontal @ALBA)





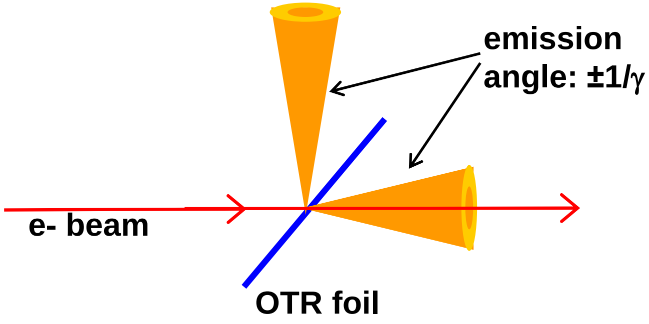


E. Bravin, Transverse Profiles, CAS Diagnostics (2008)
***Experience with YAG and OTR screens at ALBA, U. Iriso et al, DIPAC 2009*

Comparison YAG vs OTR @Linac

OTR Pros & Cons

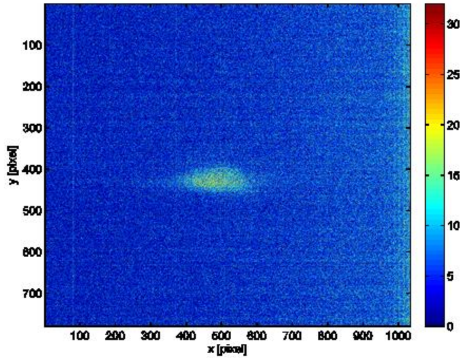
PROS: linear and directional light emission



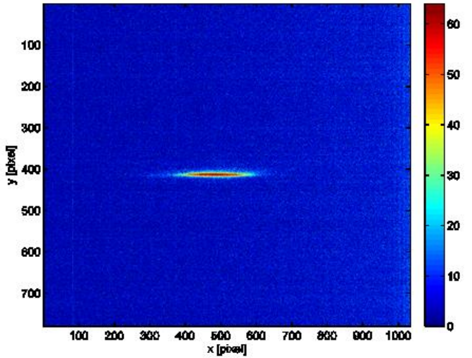
$$N_{ph} = \frac{\alpha}{\pi}(2\ln\gamma - 1)\ln\frac{\nu_2}{\nu_1}$$

@ALBA, Nph ~0.02 ph/e

CONS: low photon flux for low charge beams → image analysis difficult



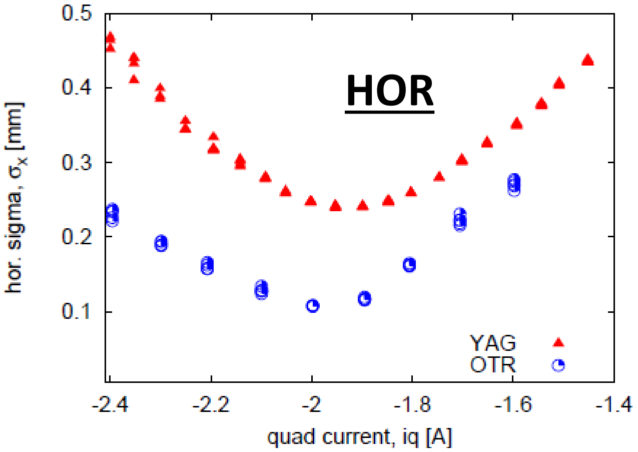
1nC ; σ_y ~ 0.3mm

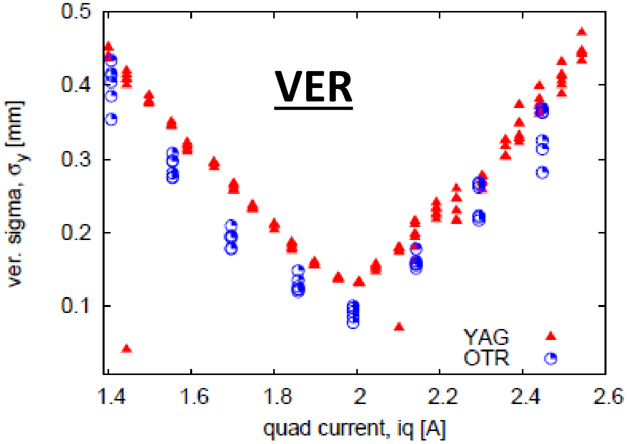


1nC ; σ_y ~ 0.1mm

Comparison YAG vs OTR @Linac

Results from Quadrupole Scans*





YAG, **0.5mm** thickness
Q = 2nC

Hor: factor ~2 larger
Ver: "only" 50%

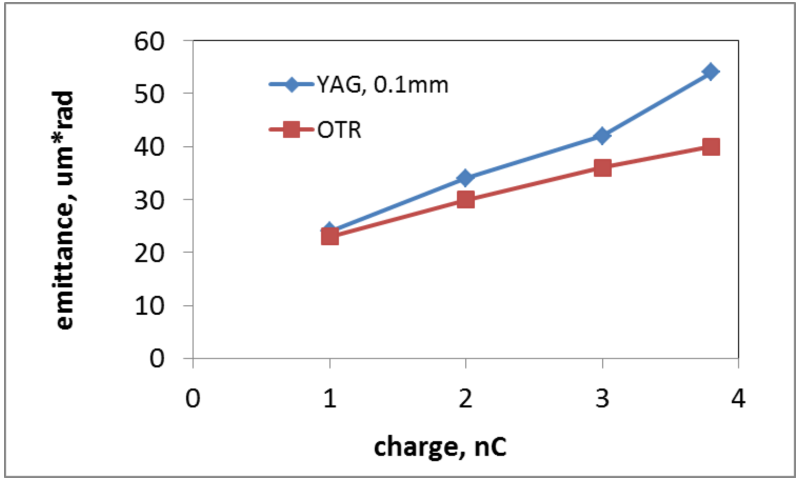
Most critical at beam waist

YAG screens @Linac were exchanged from 0.5mm to 0.1mm in ~2013

**Experience with YAG and OTR screens at ALBA, U. Iriso et al, DIPAC 2009*

Comparison YAG vs OTR @Linac

Emittance Measurements with 0.1mm YAG



YAG and OTR emit measurements coincide for 1nC beams

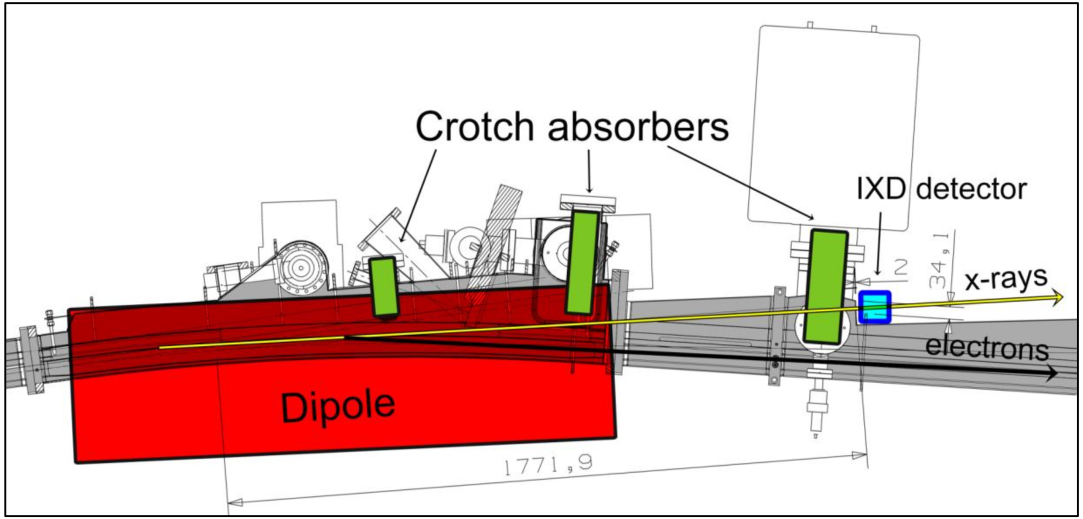
For larger beam charges, YAG still produces an apparent beam size broadening

- At ALBA, Linac charges in operation are ~[0.1 - 1nC], so we typically use YAG screens of 0.1mm thickness for the Linac emittance measurement
- Results agree with theoretical predictions
- The rest of screen monitors are still 0.5mm

1. Introduction
2. YAG – OTR systems @ Linac
3. **In-Air X-ray Detectors**
4. Pinhole Camera
5. Conclusions

In-air X-ray Detectors (iXD)

Based on the projection of the very hard x-rays from synchrotron radiation traversing the dipole absorbers*



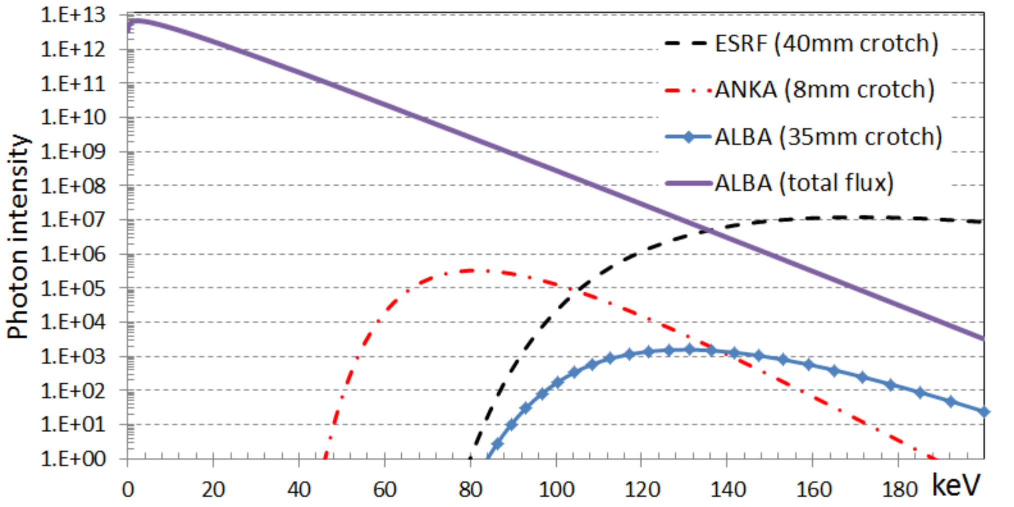
- MOTIVATION: alternative emittance measurement
- PROS: cheap and easy, iXD are located outside vacuum
- CONS: Only vertical beam size is inferred

*K.Scheidt, Proc. Of DIPAC'05; A.Muller, Proc. Of EPAC'06

In-air X-ray Detectors (iXD)

Previous tests at ESRF and ANKA due to favourable conditions
Tests at ALBA required further work on the scintillator to improve light emission

	ANKA	ESRF	ALBA
E, GeV	2.5	6	3
Absorber thickness	8mm	40mm	35mm



~1E4 flux reduction
wrt to ESRF or ANKA

In-air X-ray Detectors (iXD)

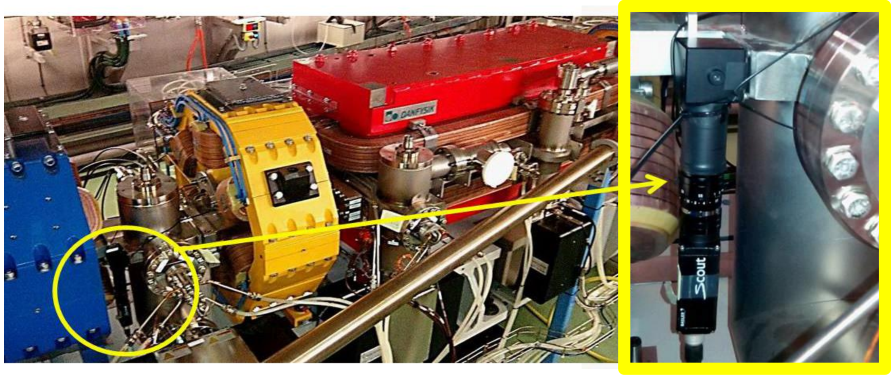
PreLude® 420

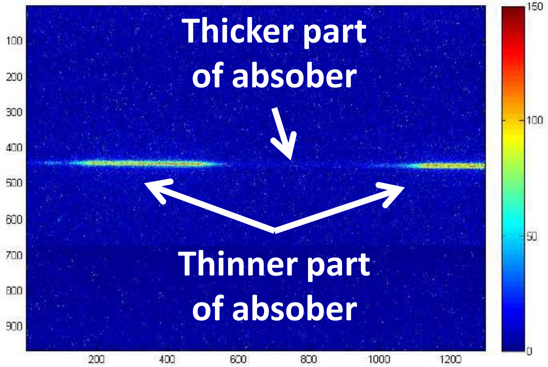
Chemical composition: $Lu_{1.8}Y0_{.2}SiO_5$:Ce
Light yield: 32 photons/keV
Decay time: 41 ns
Scintillation emission wavelength: 420 nm
Thickness for tests: 1 and 2 mm

CRY19 a silicate single crystal for X-ray detectors.

Chemical composition: unknown
Light yield: 28 @300K [10^3Ph/MeV]
Decay time: 41 ns
Scintillation emission wavelength: 420 nm
Thickness for tests: 1 mm

In-air X-ray Detectors (iXD)

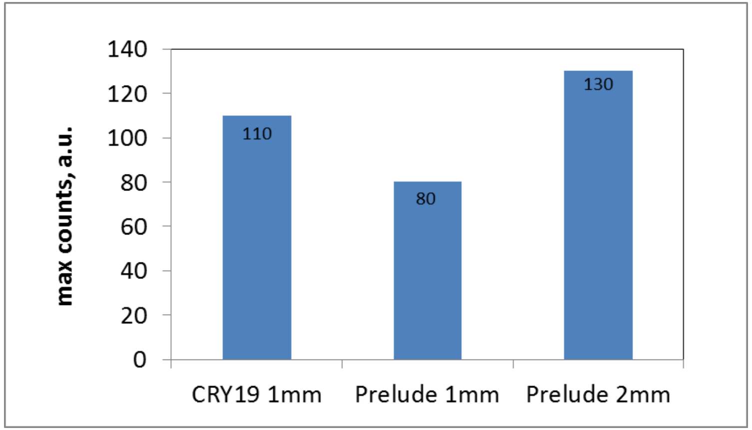




<u>Tests to characterize light emission:</u>

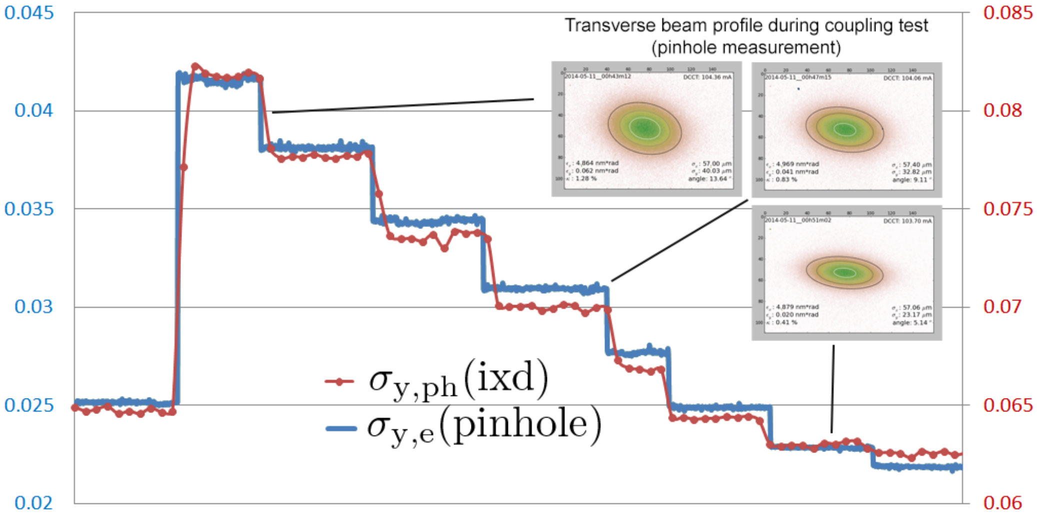
Tests performed going in/out of the tunnel to change scintillator material to avoid changing experimental conditions

Evaluate the max counts at CCD



In-air X-ray Detectors (iXD)

Beam size limited by photon divergence and distance between source point and iXD location



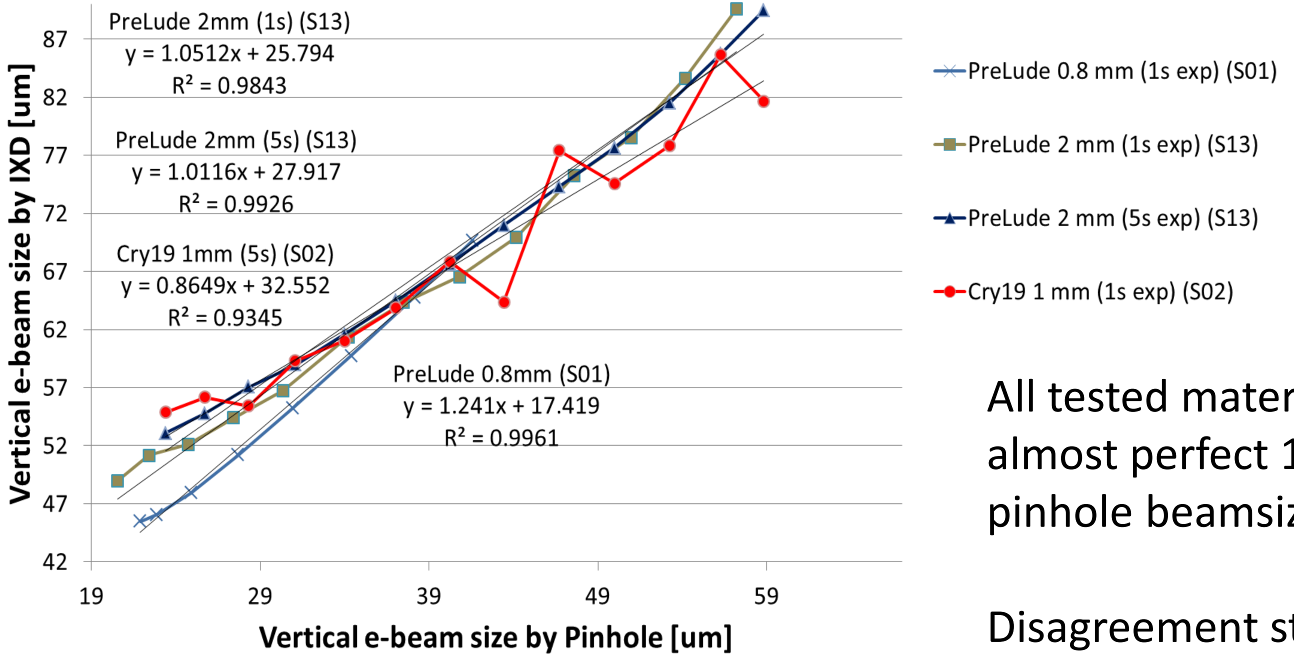
Coupling scans to change beam size at source point

A linear relation exist along the whole range, but iXD shows an offset which is not understood

*A. Nosych and U. Iriso, A compact in-air x-ray detector for beam size measurements at ALBA, Proc. of IBIC14

In-air X-ray Detectors (iXD)

All screens (Prelude & CRY19) are currently in use (but at different locations)
A linear relation exists with all materials, but experimental conditions cannot be compared



All tested materials provide an almost perfect 1:1 linear relation wrt pinhole beamsize

Disagreement still to be understood

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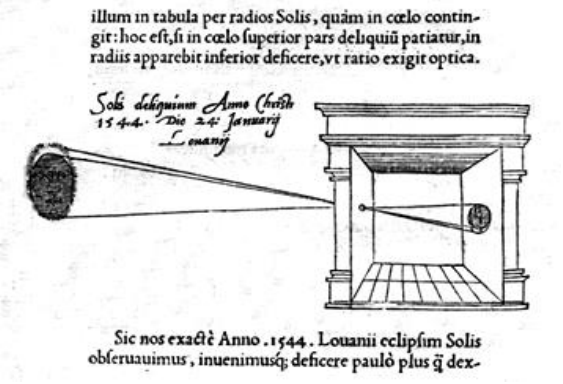
X-ray Pinhole Camera

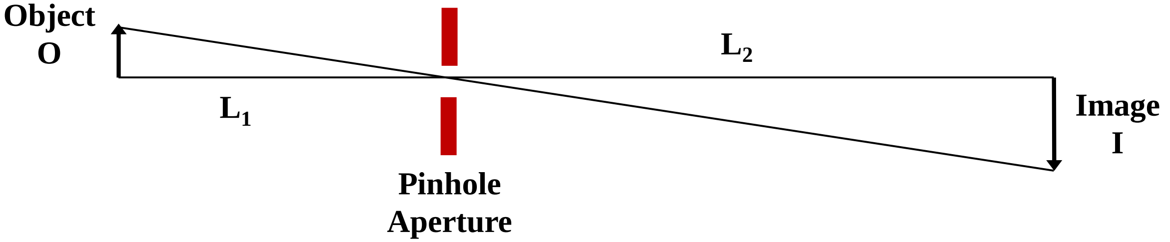
Pinhole, or camera obscura, a “camera without lens”, has been used since SXVI to image solar eclipses

Light going through a small hole, image keeps source properties

Image is magnified by factor **L2/L1** , which is very valuable asset to picture the small electron beams


illum in tabula per radios Solis, quàm in cœlo contingit: hoc est, si in cœlo superior pars deliquiũ patiatur, in radiis apparebit inferior deficere, vt ratio exigit optica.

Sic nos exactè Anno .1544. Louanii eclipsim Solis obseruauimus, inuenimusq; deficere paulò plus q̃ dex-

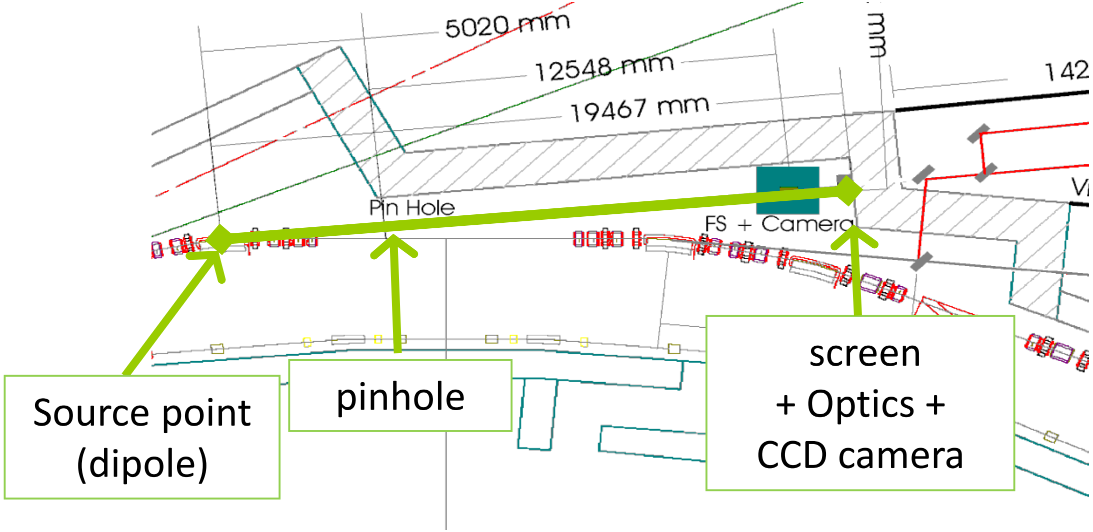


$$\sigma_i = L_2/L_1 \; \sigma_o$$

- First used in synchrotrons by P. Elleaume (ESRF) in 1995
- Widely used around the world: ESRF, ALBA, APS, Diamond, Soleil, Elettra, NSLS…

X-ray Pinhole Camera @ALBA

○ Pinhole: array of Tungsten bars	→ size: 10x10 um
○ L1 = 5.98m ; L2 = 13.6	→ Magnification L_2/L_1 = 2.275
○ Al vacuum window + Cu material to filter x-rays	→ Spectrum ~[10 - 50] keV
○ X-rays passed to vis. light using scintillators	→ YAG:Ce screen, 0.1mm



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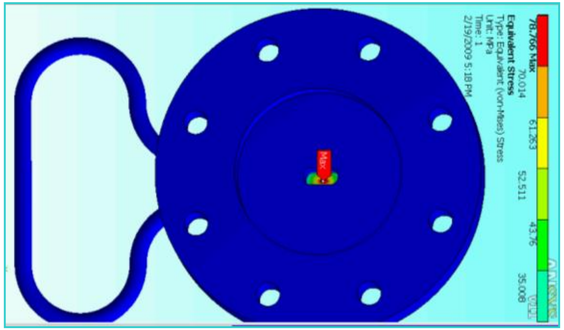
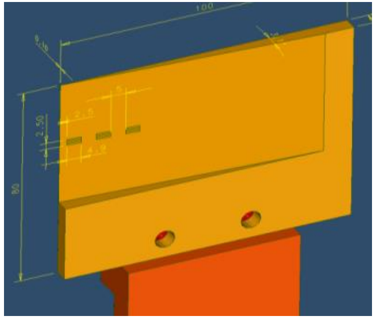
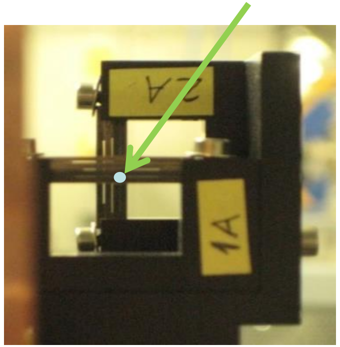
Al Window:
1mm thickness, water cooled



Cu filter:
Thickness 0.1 – 5mm



Pinhole array:
Hole of 10x10 um in operation



X-ray Pinhole Resolution

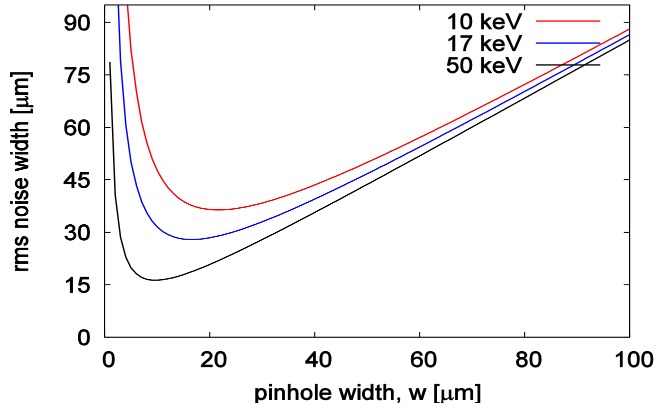
Beam size at YAG is given by the magnification factor and the optics limiting effects
Mainly, diffraction and blurring (Finite Aperture effect):

$$\sigma_{YAG}^2 = [(L2/L1)\,\sigma_e\,]^2 + \sigma_{dif}^2 + \sigma_{blur}^2\,]$$

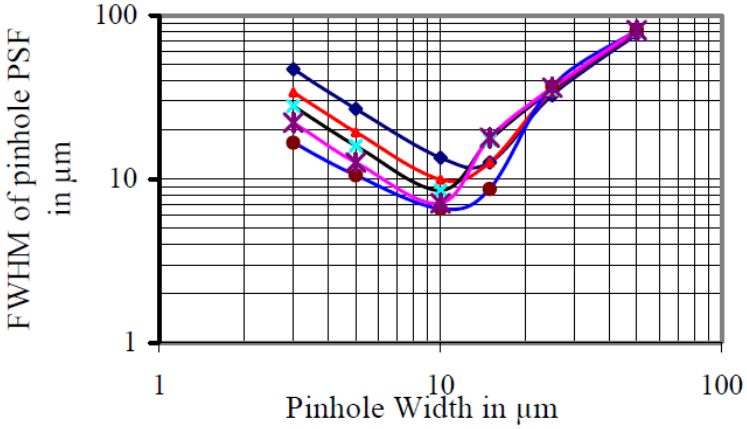
PSF^2

Minimize PSF → optimize pinhole aperture ***w*** at design stage
The optimization can be done analytically, or more in detail with simulations

Analytical Solution @ALBA



SRW Simulations @Soleil*

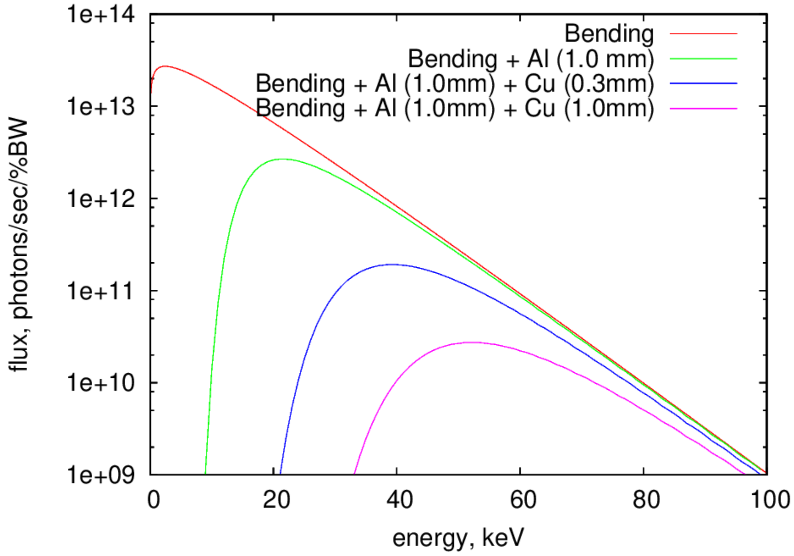


*M.A. Tordeaux, et al, "Ultimate Resolution of Soelil Pinhole Cameras", DIPAC'07

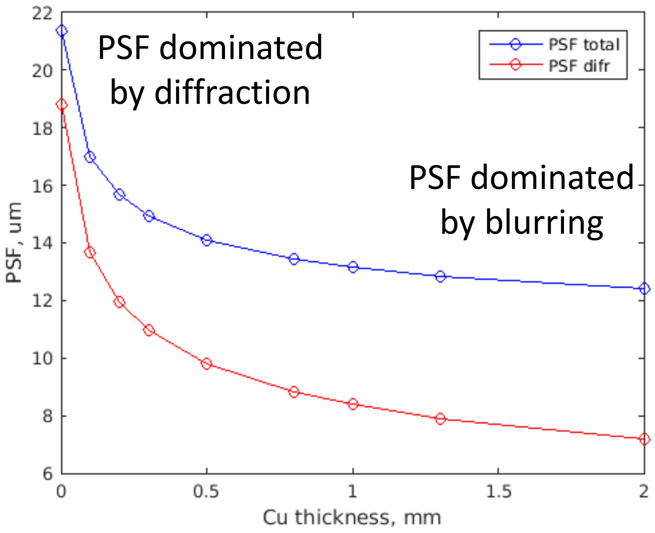
X-ray Pinhole Resolution

Usual set-ups in electron machines allow to change Cu filter thickness from ~[0.1 – 3] mm with two main purposes:

Produces both a flux attenuation and harden x-rays spectra

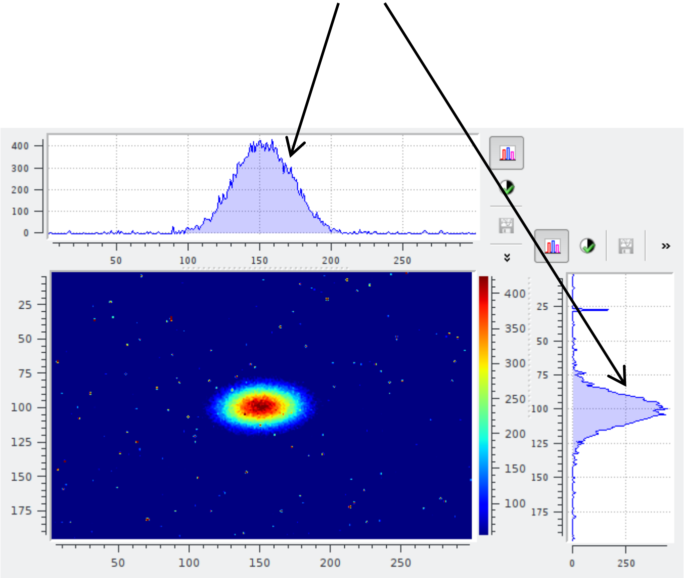


Decrease pinhole PSF

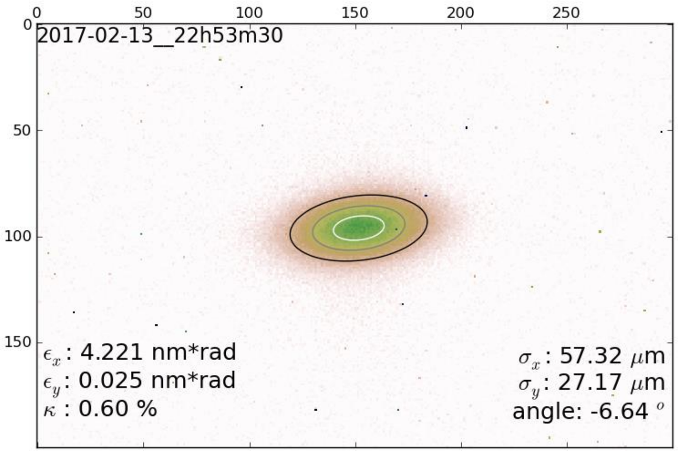


X-ray Pinhole Precision – Image Analysis

Usual recipe:
1. Select a Region Of Interest (ROI)
2. Add pixels in columns (rows)
3. Gaussian Fit for hor (ver) profiles



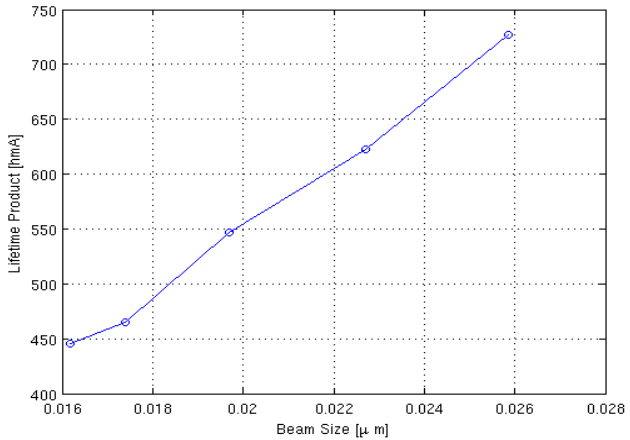
If tilted beam:
1. Select a Region Of Interest (ROI)
2. 2d-Gaussian Fit
3. New ROI using AutoROI at +/-3$\sigma_{x,y}$
4. Back to step 2 until convergence



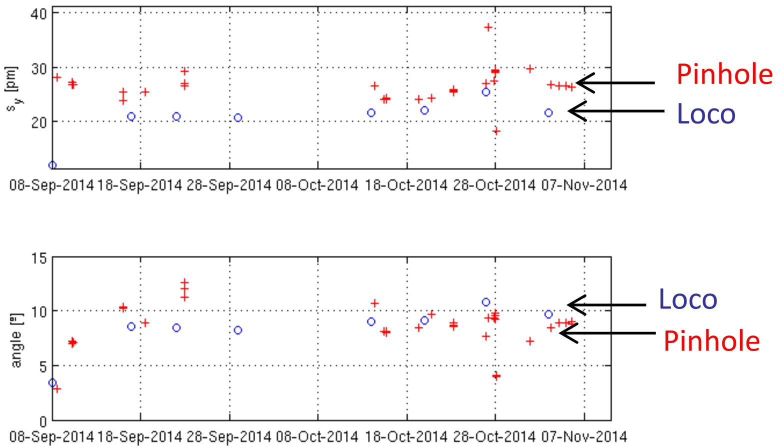
X-ray Pinhole Results

Good agreement is typically found for relative beam size evolution

Good agreement between beam lifetime and beam size during coupling scans



Small differences of beam size and tilt angle wrt LOCO

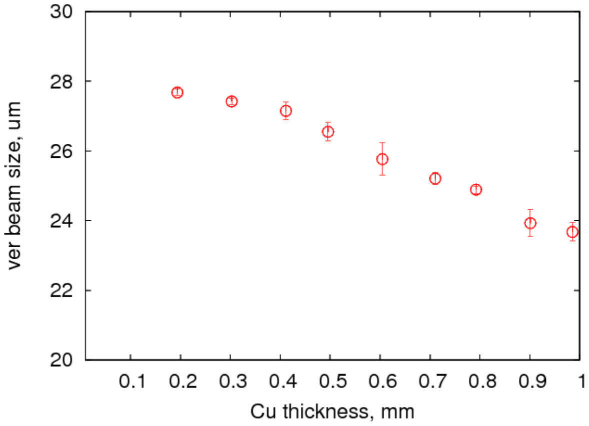


How precise can we determine the **absolute** values?

X-ray Pinhole: Absolute Precision?

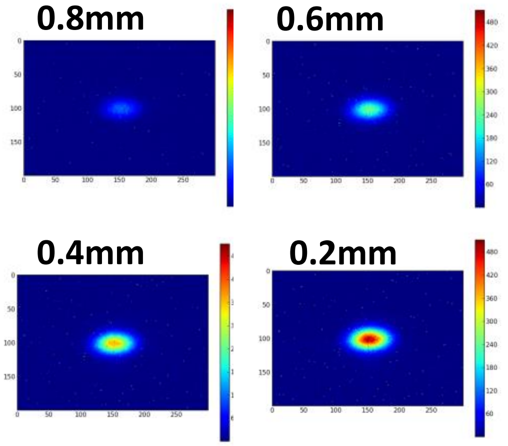
The absolute beam size value depends on the acquisition parameters
Criteria to use a given set of acquisition parameters?

Cu Thickness Influence

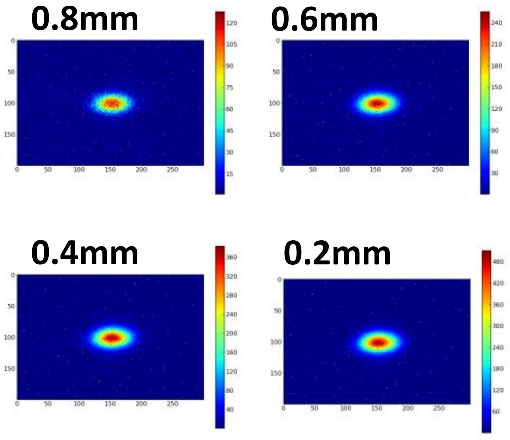


~25% difference!
(PSF already taken into account!)

Fixed Color Scale



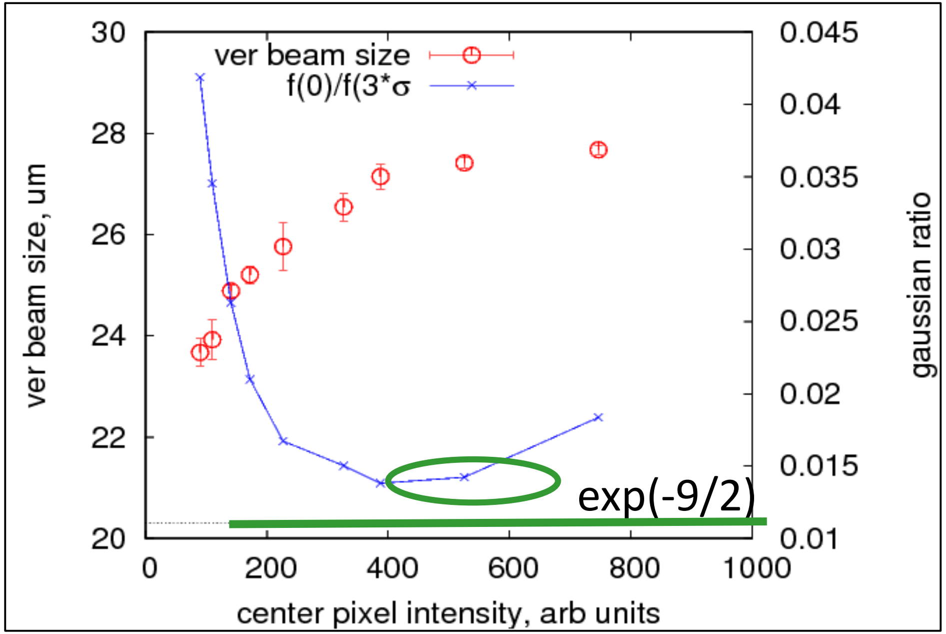
Color scale prop. thickness



X-ray Pinhole: Absolute Precision?

Criteria: compare images of equal "Gaussian" Dynamic Range

1. Perform AutoRoi **+/-3*$\sigma_{x,y}$**
2. Ratio **$f(3\sigma_x, 3\sigma_y)/f(0,0)$ = exp(-9/2)** (closest to ideal Gaussian distribution)



Increasing illumination image (via CCD Exposure Time or Cu filter), the beam size increases up to a certain plateau

We stay at the beginning of this plateau

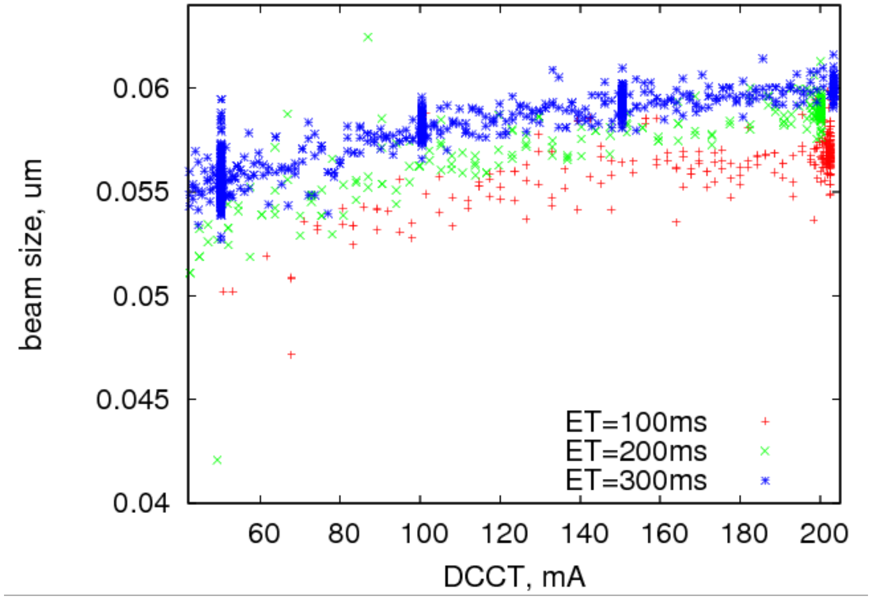
Increasing this illumination increases background level as well, but not necessarily the dynamic range and tails start to appear in the beam image

Not fully using 12bits of the CCD!!

X-ray Pinhole: Absolute Precision?

This also is affects precise Machine Physics experiments

σ_x evolution with beam current



Emmittance growth with current:

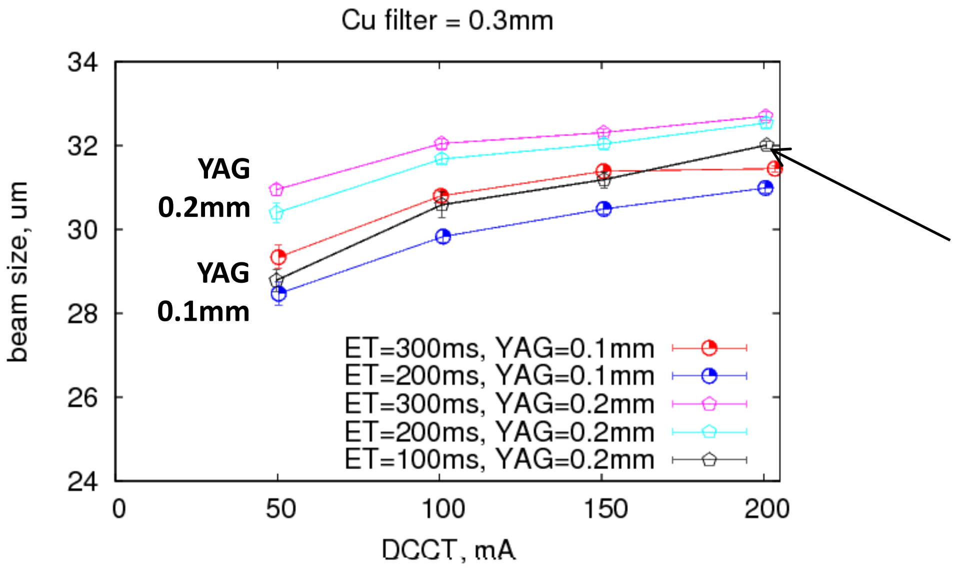
If acquisition parameters are not changed, we have ~10% emittance growth, non-consisten with expectations

An automatic “feedback” system to keep max illumination constant is being prepared

X-ray Pinhole: comparison YAG:Ce thickness

YAG:Ce thickness – 0.1mm vs 0.2mm

Thicker scintillator screens enlarge beam size measurement



But can be compensated with acquisition parameters (i.e. CCD Exposure Time)

YAG - 0.2mm behaves similar to YAG - 0.1mm if ET=100ms

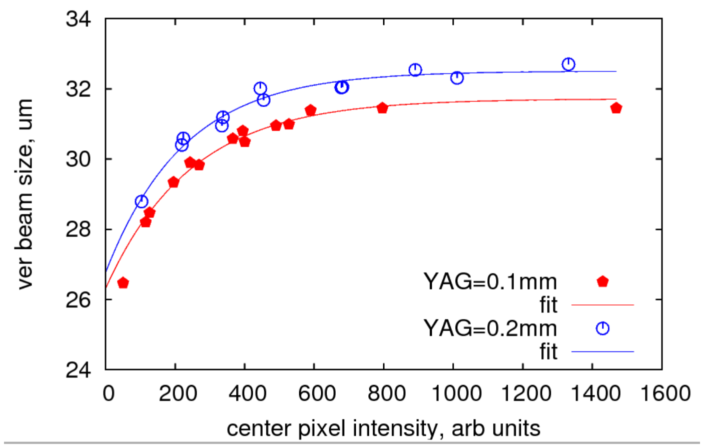
So, how should we properly compare the two screens?

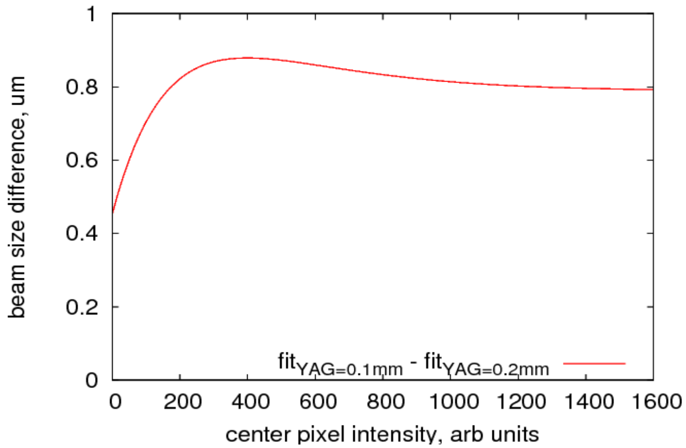
X-ray Pinhole: comparison YAG:Ce thickness

YAG:Ce thickness – 0.1mm vs 0.2mm

No matter if we scan DCCT, CCD Exposure Time, or Cu filter, the beam size lays on a curve which depends on the **max illumination**

In this situation, enlargement produced by screens of 0.1 vs 0.2 mm is <1um for 30um beams (~3%)





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CONCLUSIONS

YAG & OTR @Linac:

- Beam size enlargement due to scintillator thickness limited emittance measurements during quadrupole scans when beam size < scintillator thickness

- Changed from 0.5mm to 0.1mm YAG:Ce thickness. Now emittance measurements agree with OTR if charge smaller than ~2nC

Scintillators for In-air X-ray Detectors

- Tested CRY19 (1mm) and Prelude (1 and 2mm)

- For the 1mm screens, photon flux by CRY19 is ~30% larger than Prelude
- (Although beam size enlargement produced by this IXD is not understood)

CONCLUSIONS

Scintillator for X-ray Pinhole:

- When looking at um precision level, image analysis and acquisition parameters play an important role , and we find more accurate to compare pinhole images based on similar CCD illumination

- For ALBA parameters, going from YAG screens of 0.1 to 0.2mm produces a beam size enlargement of <1um in the vertical plane

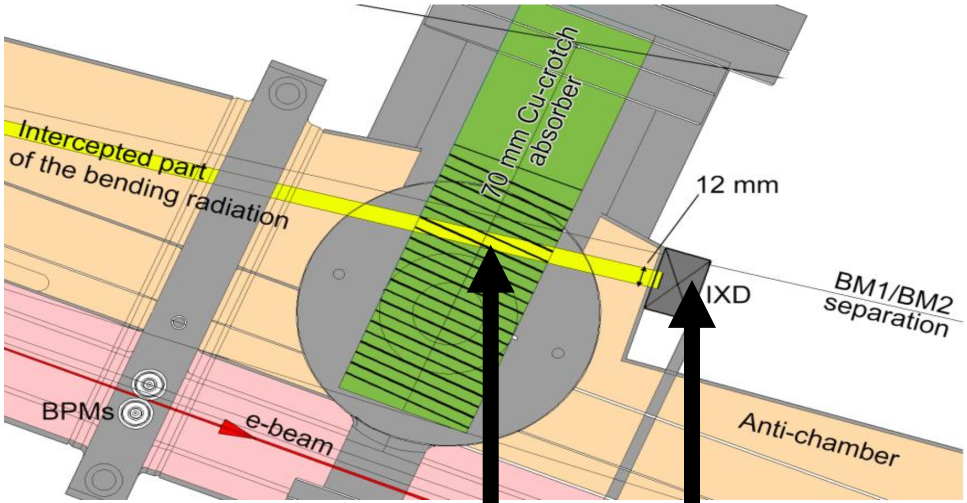
- Currently, a “feedback” system to keep similar CCD illumination is being implemented

Thanks

To ALBA Mechanical engineers, Operation & Linac Groups, Crytur

Extra slides

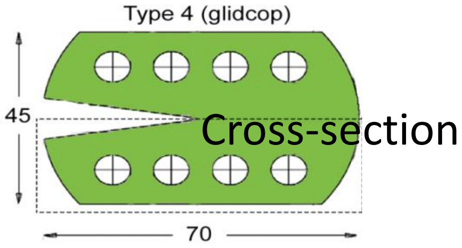
Crotch absorbers

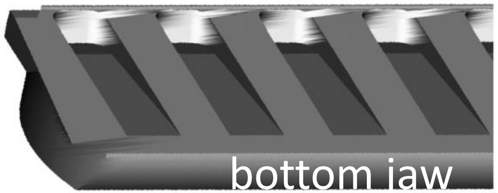


1700 mm
to source

35 mm of Cu

2 mm of steel

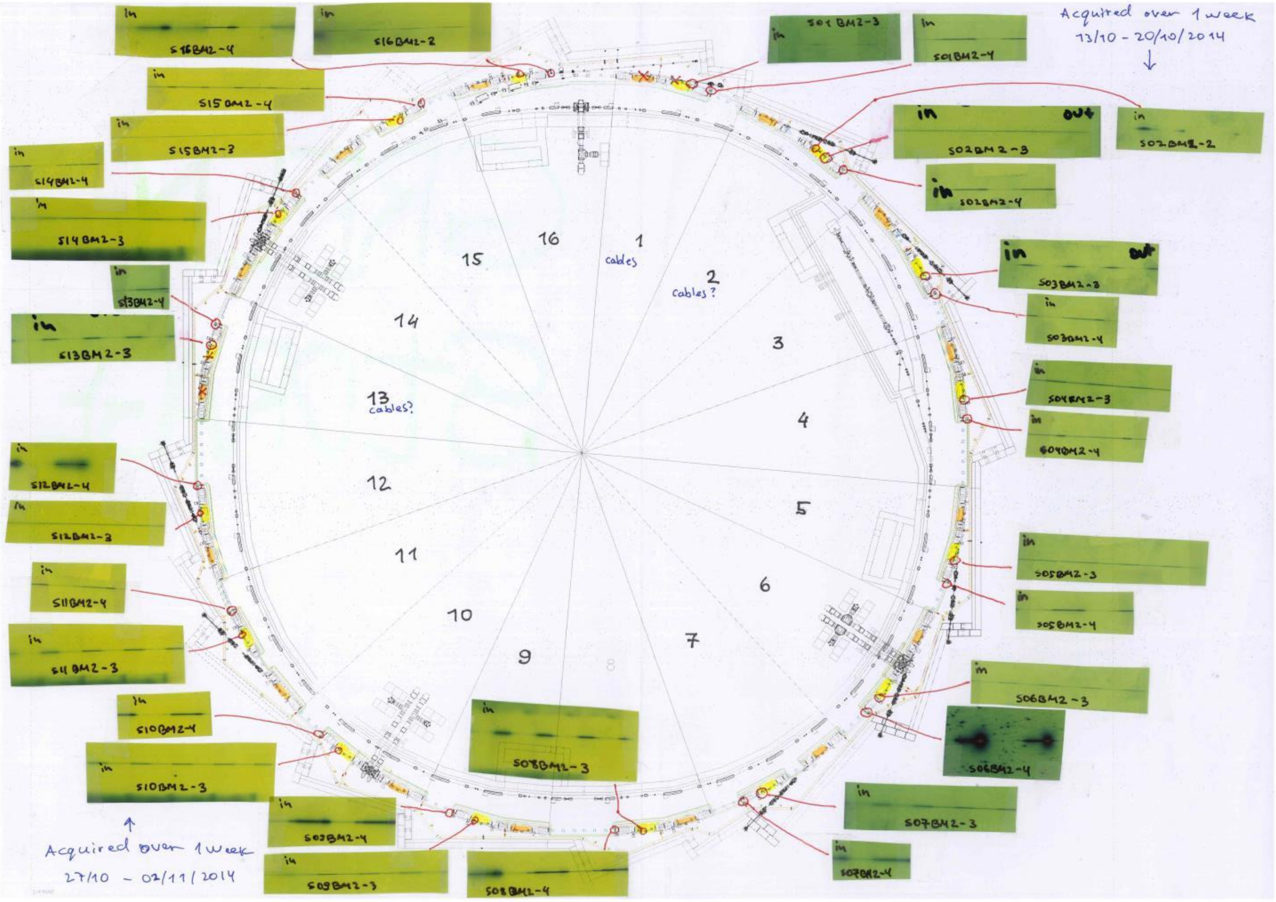


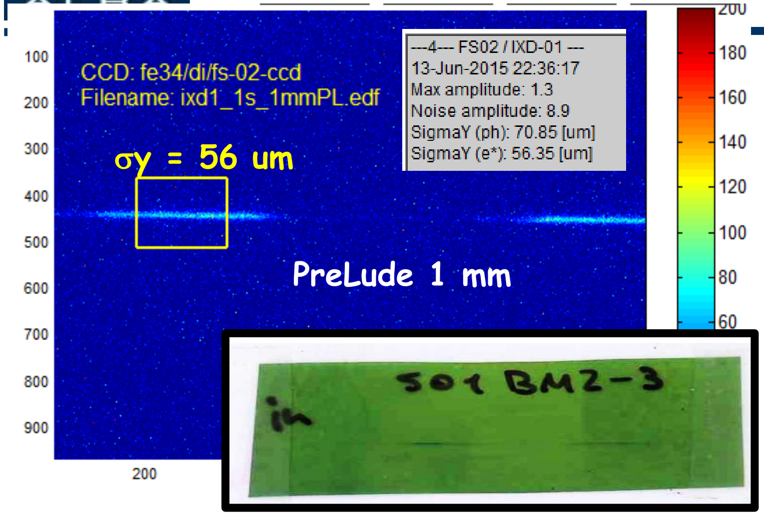


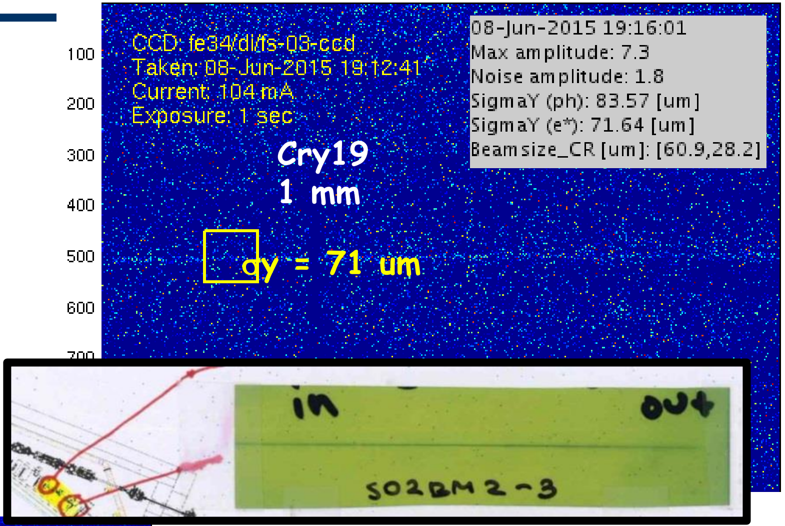
Tooth width: 6 mm

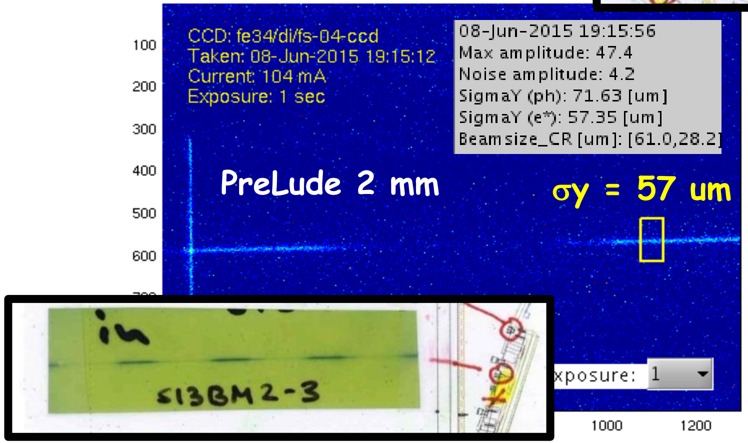
Teeth inclination angle: 8.8º

Ray tracing shows that radiation from previous dipole does NOT pass by the IXD, so we are looking at a single photon source


Acquired over 1 week
13/10 - 20/10/2014
Acquired over 1 week
27/10 - 02/11/2014
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
cables
cables ?
cables?
S01BM2-3
S01BM2-4
S02BM2-2
S02BM2-3
S02BM2-4
S03BM2-3
S03BM2-4
S04BM2-3
S04BM2-4
S05BM2-3
S05BM2-4
S06BM2-3
S06BM2-4
S07BM2-3
S07BM2-4
S08BM2-3
S08BM2-4
S09BM2-3
S09BM2-4
S10BM2-3
S10BM2-4
S11BM2-3
S11BM2-4
S12BM2-3
S12BM2-4
S13BM2-3
S13BM2-4
S14BM2-3
S14BM2-4
S15BM2-3
S15BM2-4
S16BM2-2
S16BM2-4
in
out

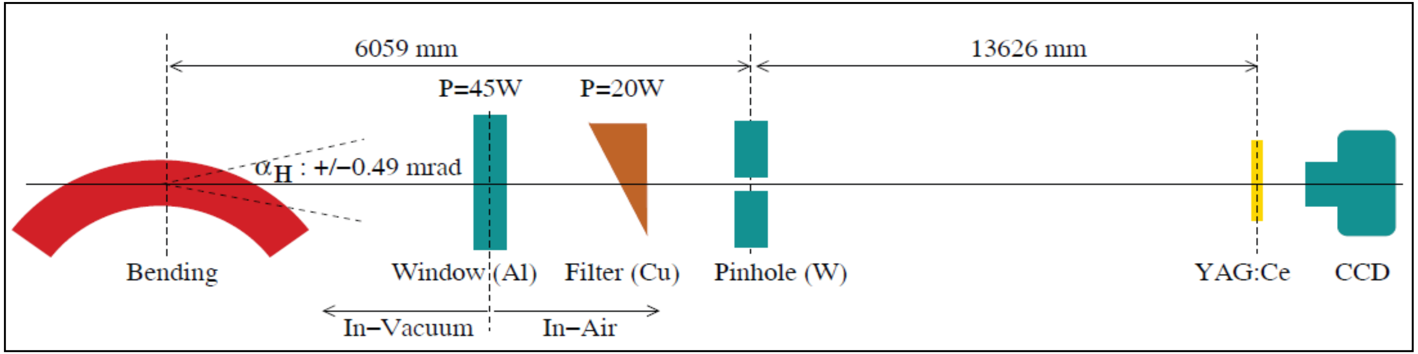

CCD: fe34/di/fs-02-ccd
Filename: ixd1_1s_1mmPL.edf
---4--- FS02 / IXD-01 ---
13-Jun-2015 22:36:17
Max amplitude: 1.3
Noise amplitude: 8.9
SigmaY (ph): 70.85 [um]
SigmaY (e*): 56.35 [um]
σy = 56 um
PreLude 1 mm
S01 BM2-3
in


CCD: fe34/di/fs-03-ccd
Taken: 08-Jun-2015 19:12:41
Current: 104 mA
Exposure: 1 sec
08-Jun-2015 19:16:01
Max amplitude: 7.3
Noise amplitude: 1.8
SigmaY (ph): 83.57 [um]
SigmaY (e*): 71.64 [um]
Beamsize_CR [um]: [60.9,28.2]
Cry19
1 mm
σy = 71 um
in
out
S02BM2-3


CCD: fe34/di/fs-04-ccd
Taken: 08-Jun-2015 19:15:12
Current: 104 mA
Exposure: 1 sec
08-Jun-2015 19:15:56
Max amplitude: 47.4
Noise amplitude: 4.2
SigmaY (ph): 71.63 [um]
SigmaY (e*): 57.35 [um]
Beamsize_CR [um]: [61.0,28.2]
PreLude 2 mm
σy = 57 um
xposure:
in
S13BM2-3

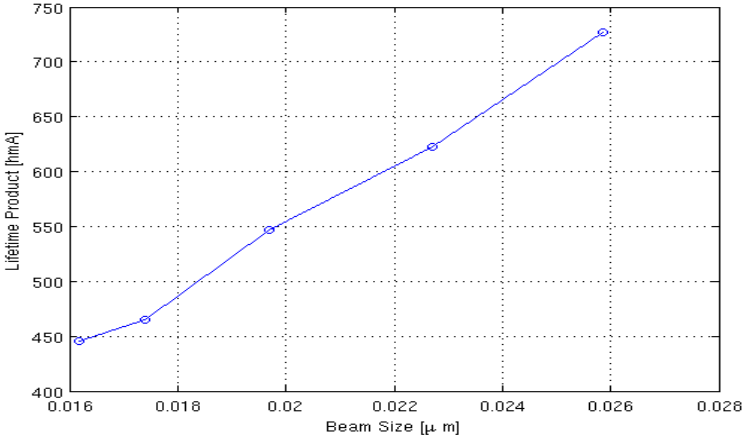
X-Ray Pinhole Camera

- Light from an object (beam) goes through a single aperture (pinhole) and projects an inverted image of the source
- Image is magnified by a factor **L2/L1**
- ALBA magnification factor 2.27 (18m length system)
- Use x-rays: Al-window and Cu-filter (~45keV)

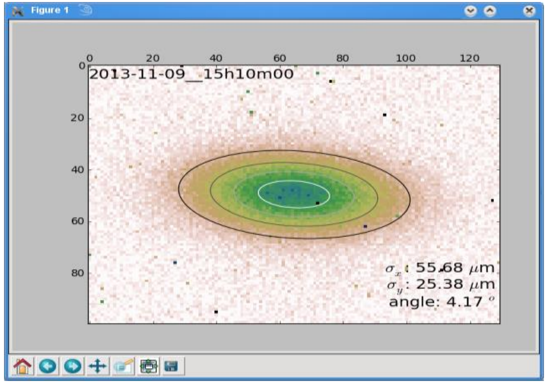


X-Ray Pinhole Results

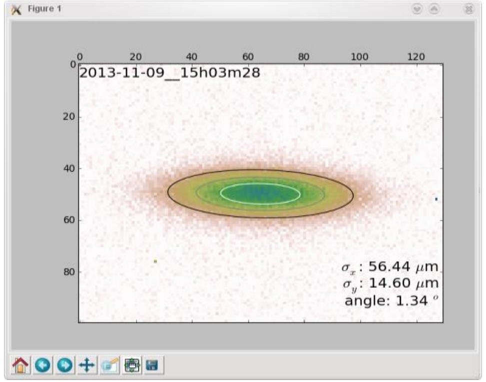
Example: correlation between beam lifetime and beam size while reducing koupling.



Example at 0.5% koupling

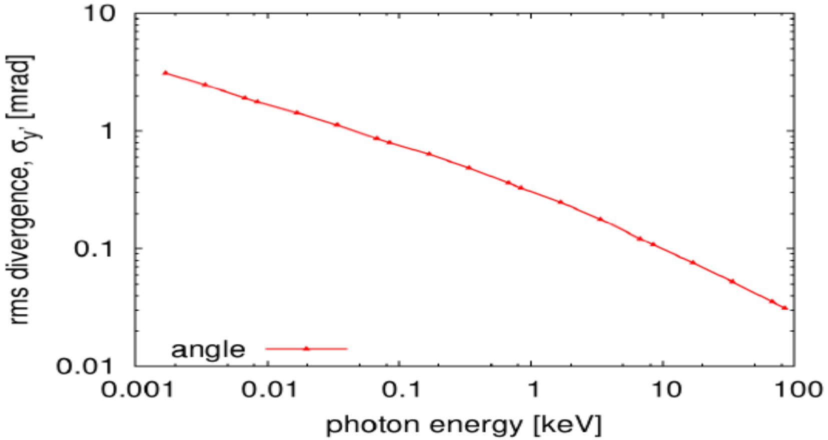


Minimum koupling = 0.1%



In-air X-ray Detector Limitations

- PSF is limited by distance between source-point to iXD location and photon divergence



$$\sigma_{sc}{}^2 = \sigma_b{}^2 + (L\cdot\alpha)^2$$

For this first case, PSF is quite large:

E~130keV; α=0.025mrad; L=1.7m

➔ PSF = ($L\cdot\alpha$) ~ 42um!

At ALBA, need to look for a closer location, and/or use still harder x-rays