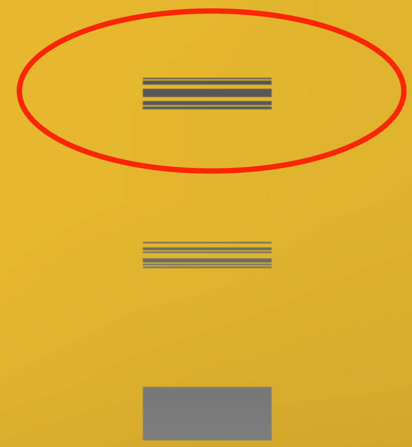
Design of a New Coded Aperture

Dan Peterson, 2013-01-22



Design study by DPP,
John Flanagan and
Brian Heltsley

We are doing this because:

we may need more optics chips for the remainder of the CesrTA program,

the FZP has not been developed and will not be used,

the standard Coded Aperture provides insufficient beam size resolution at "normal" beam current.

Careful design is necessary; the chip costs 15 k$, and has 60 - 90 day delivery.

Design of a Coded Aperture requires an understanding of the x-ray energy spectrum.
The image is an interference pattern and includes effects of semi-transparency and phase shift in the gold.

I will describe the calculation of the energy spectrum,

describe a figure-of-merit for evaluating Coded Aperture designs

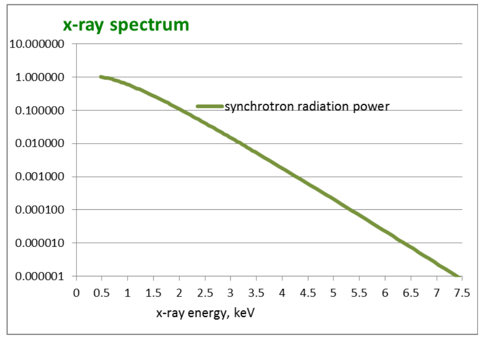
evaluate the performance of several alternative designs

show the chosen design.

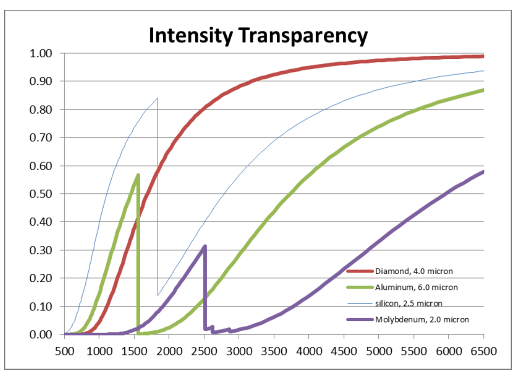
This design study uses the data-driven calculation of the energy spectrum.

Start with the Jackson formula for the energy distribution in the synchrotron plane:

$\delta I(\omega)/\delta\Omega\,|_{\theta=0} = 3/(2\pi)\ e^2/c\ \gamma^2\ \omega/\omega_c\ \exp(-2\omega/\omega_c)$, (Jackson 14.88)



December 2012 data is used to estimate the effects of detector absorption and response. Filters with known transparency are applied to the x-ray beam with the PINHOLE optic.

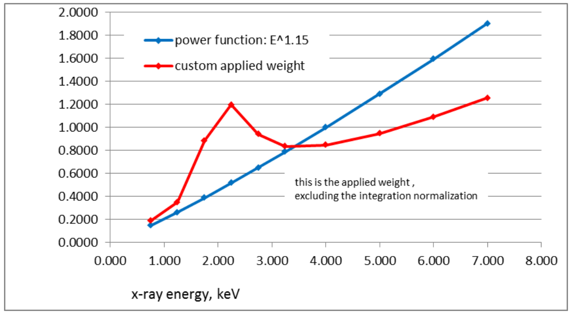


December 2012 data, relative PINHOLE image intensity

	nomalized within energy			
	no filter	diamond	aluminum	molybdenum
1.800 D	1.000	0.332	0.114	0.050
2.085 D	1.000	0.511	0.135	0.066
2.085 C	1.000	0.536	0.167	0.071
2.300 D	1.000	0.630	0.162	0.093

A function describing the detector absorption and response is derived from a fit to the transmission data.

(The new function is shown in red, the old $E^{1.15}$ function in blue.)



The RMS is 8% ;

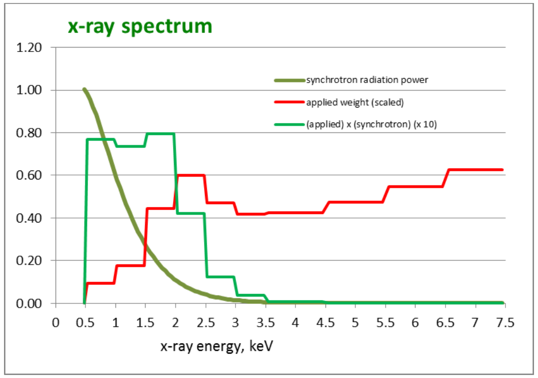
the **maximum deviation is 14%** .

This could be improved with another iteration, but the consistency is as good as the consistency of the data.

({model}-[data})/{data}
relative PINHOLE image intensity

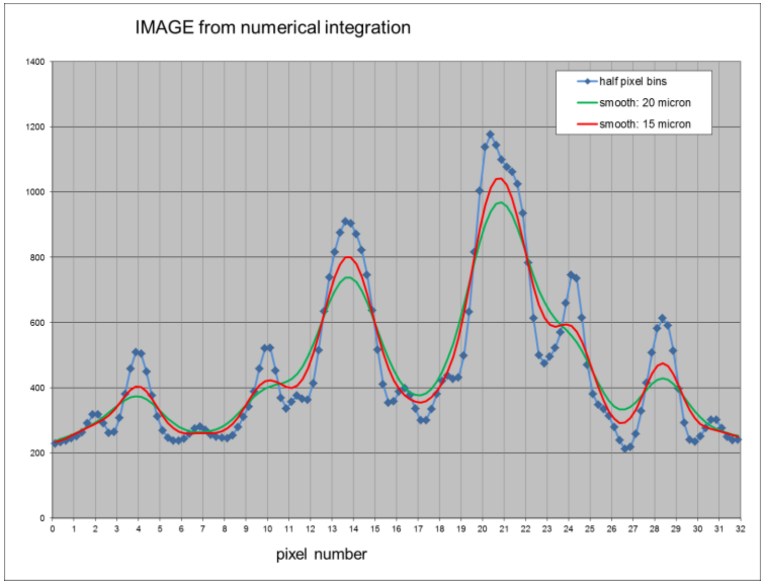
compare to average ofDecember 2012 C-line and D-line data					
	diamond	aluminum	molybdenum		ave
1.800	0.02	-0.08	-0.11	0.02	-0.01
2.085	0.00	-0.14	0.10	0.03	rms
2.300	-0.01	0.08	0.05	0.01	0.08

The x-ray energy spectrum is then the Jackson formula (green continuous line) modulated by the **red line**, shown by the **green binned line**.



I use a figure-of-merit (FoM) for the **optics element / beam energy / filter** based on the ability to resolve beam sizes with the modeled image.

The figure shows an image for 2.085 GeV, diamond filter.
The **red** and **green** lines show smeared images for 15 and 20 μm beam size.



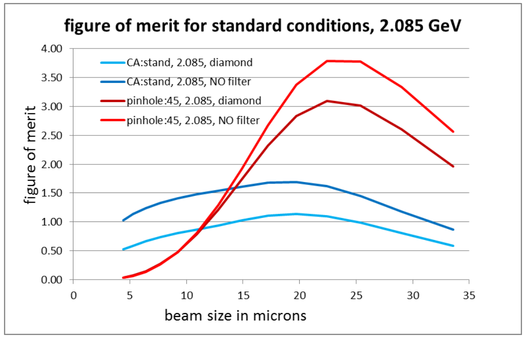
$$\mathbf{FoM} = \sum_{pixel} [\, h(\sigma+\Delta\sigma) - h(\sigma)\,]^2 / h(\sigma)$$

where **h(σ)** is the signal height of a pixel for the given beam size, σ .

FoM is plotted for constant $\Delta\sigma/\sigma$.

The FoM is a χ^2 ,
measuring the change in the spectrum with an error due to statistics only.

The FoM has units of signal height;
an increase in FoM is equivalent to an increase beam current.

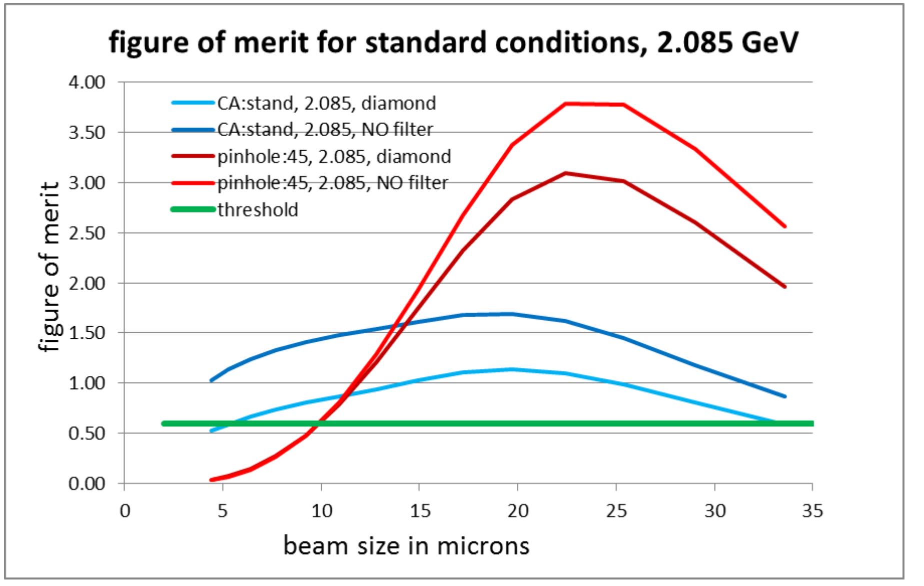


Observations for PINHOLE:

Above 16 µm beam size,
NO Filter is better than **Diamond**.

This is expected above the subtractor
(contribution to the apparent beam size due to the pinhole size).
NO filter has 2x the intensity.

It is surprising that the **diamond** is not better at low beam size.



Observations for Coded Aperture:

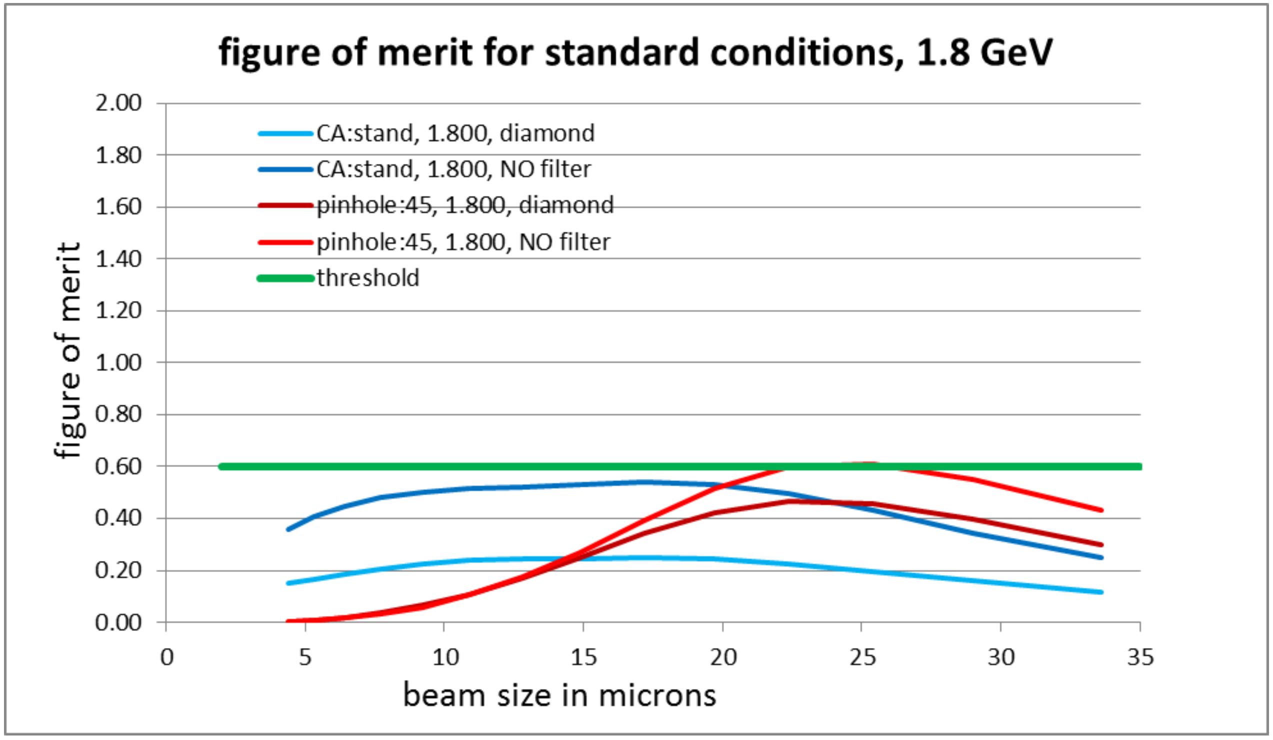
The current Coded Aperture performs better than the PINHOLE below ~13µm beam size, as expected.

FoM threshold for useful xBSM measurements for a typical beam current ~ 0.5ma:
below a beam size of ~10µm, the PH is no longer useful,
the Coded Aperture performance is useful up to a beam size of ~ 30-35 µm.

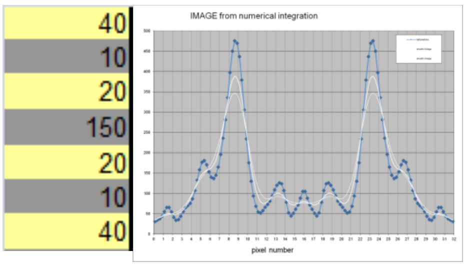
I estimate that the
threshold for resolving the beam size = ~ 0.6 , for the "typical current".

At 1.8 GeV, we do not have a usable optic.

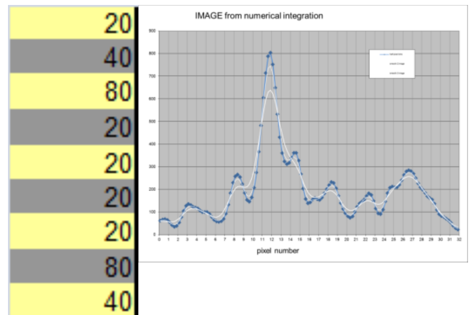
The point of the study is to design the best optic for
beam energy 1.8 GeV for the range of beam size, 10 - 30 μm.



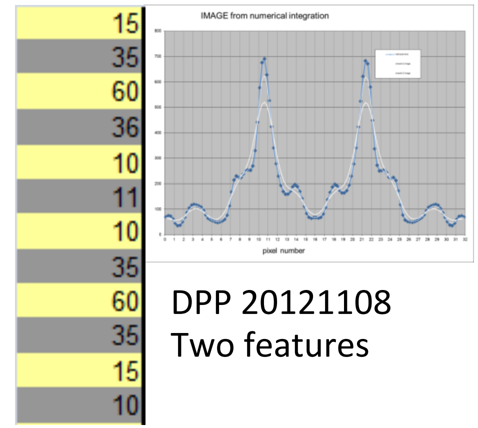
For 1.8 GeV beam energy, several optic designs were tested:



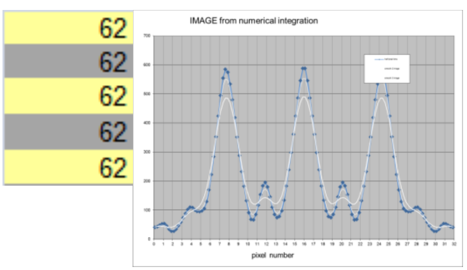
BKH 20121031
two widely spaced features



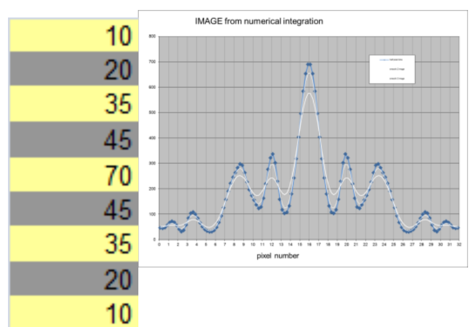
JF 20121114 random array
20µm minimum feature size.



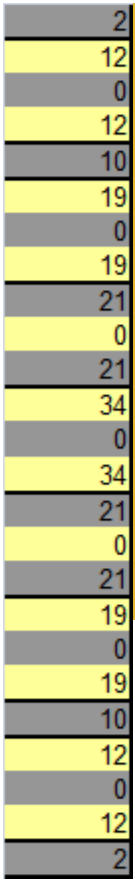
DPP 20121108
Two features

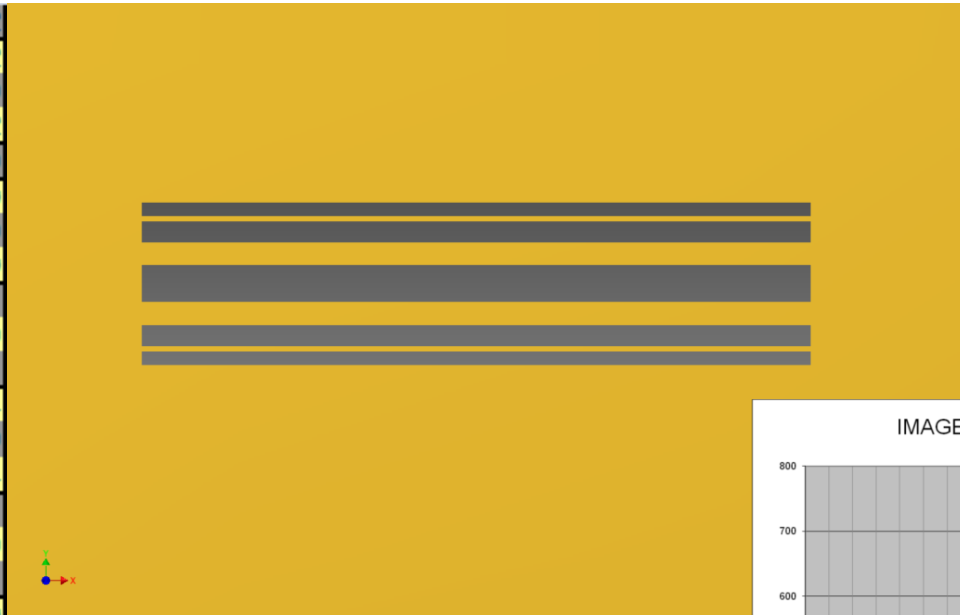


DPP 20111119
"Grating"

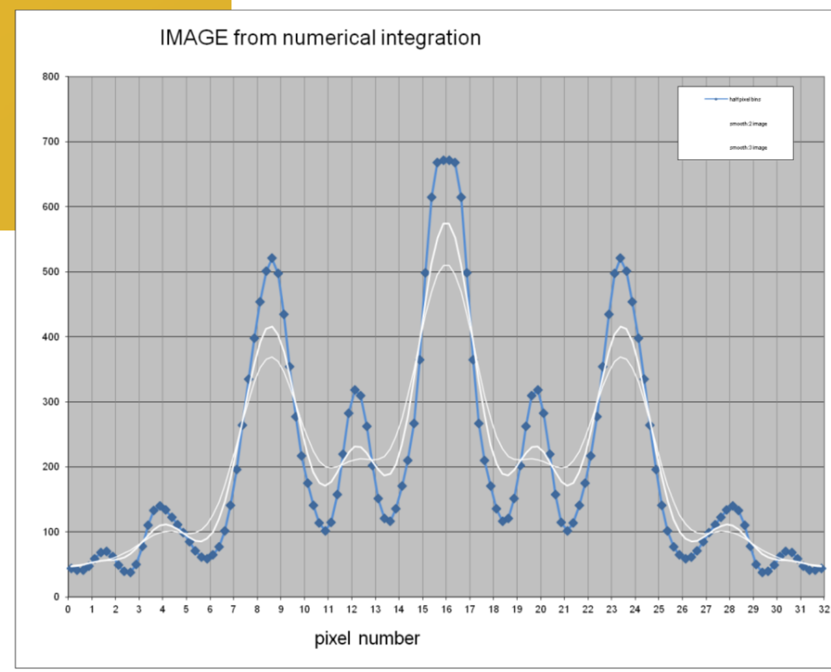


JPA 20111119
"Fresnel Zone Plate"



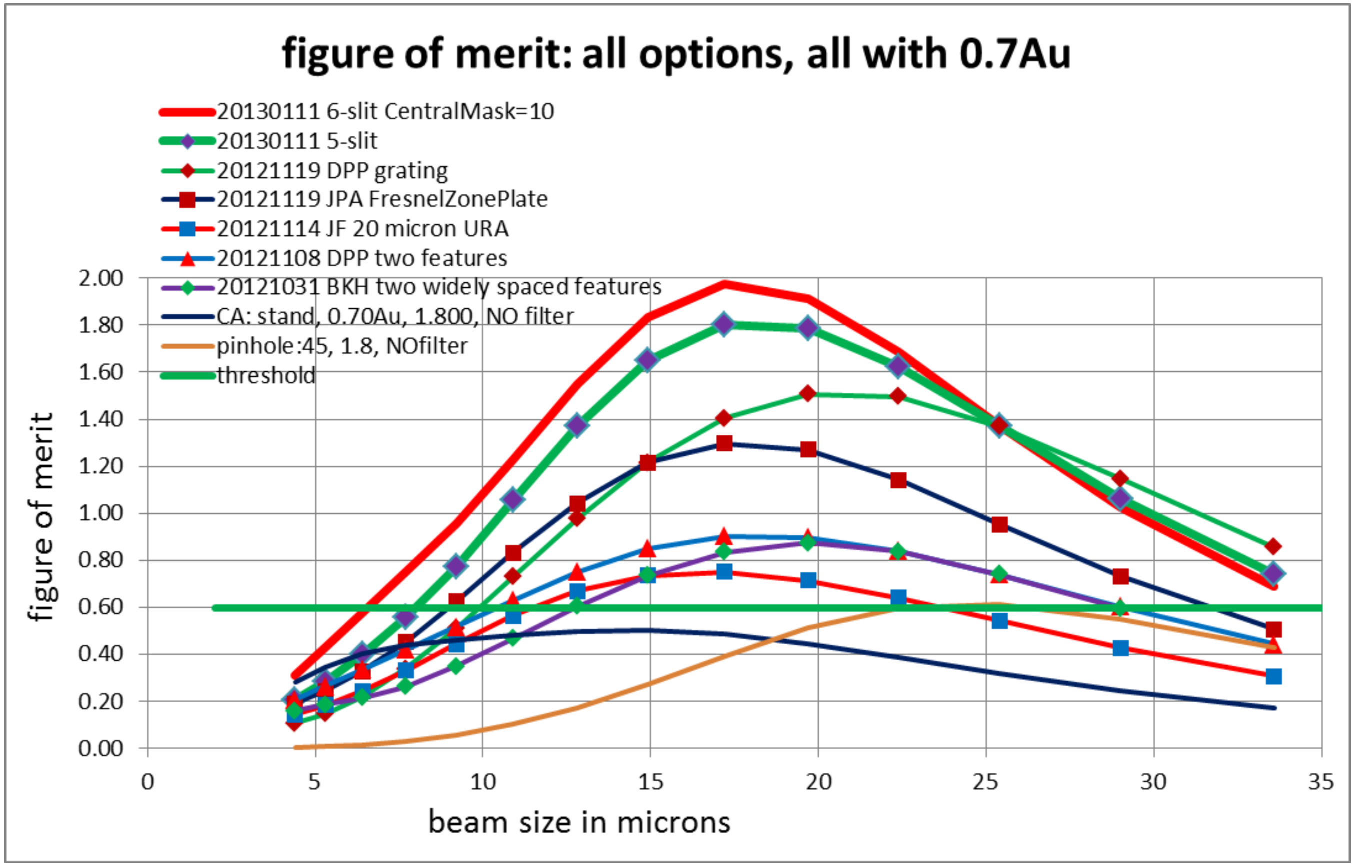


The design that performed the best in 3 independent analyses is "20130111 **5 slits".**
This evolved from the "FZP".



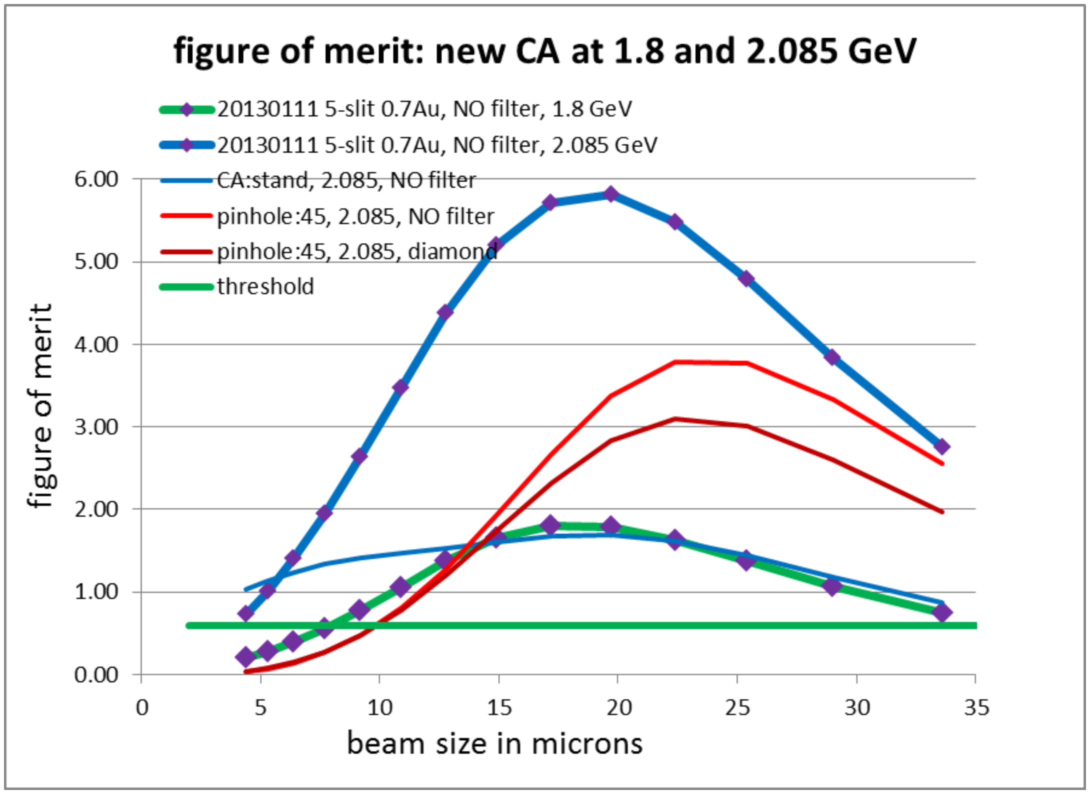
A comparison of optic design options, all with 1.8 GeV beam, 0.7μm Au.
All perform better than the standard Coded Aperture, above 12 μm beam size.

(The 6-slit did not perform as well in the other analyses, and drops off at larger beam size.)



At 1.8 GeV , the new Coded Aperture will provide resolution similar to that of the standard CA at 2.085 GeV above 12 µm .

At 2.085 GeV, the new Coded Aperture will provide resolution better than the PINHOLE, for beam size up to 35 µm .



END

BACKUP

The new coded Aperture chip will remain at the standard gold thickness: 0.7 µm.
Better beam size resolution can be achieved with 0.5 µm gold,
but we recently (April 2012) damaged a chip with this gold thickness
and do not want to take this risk.