Turn by Turn Visible Light Beam Size Monitor

ECFA Linear Collider Workshop

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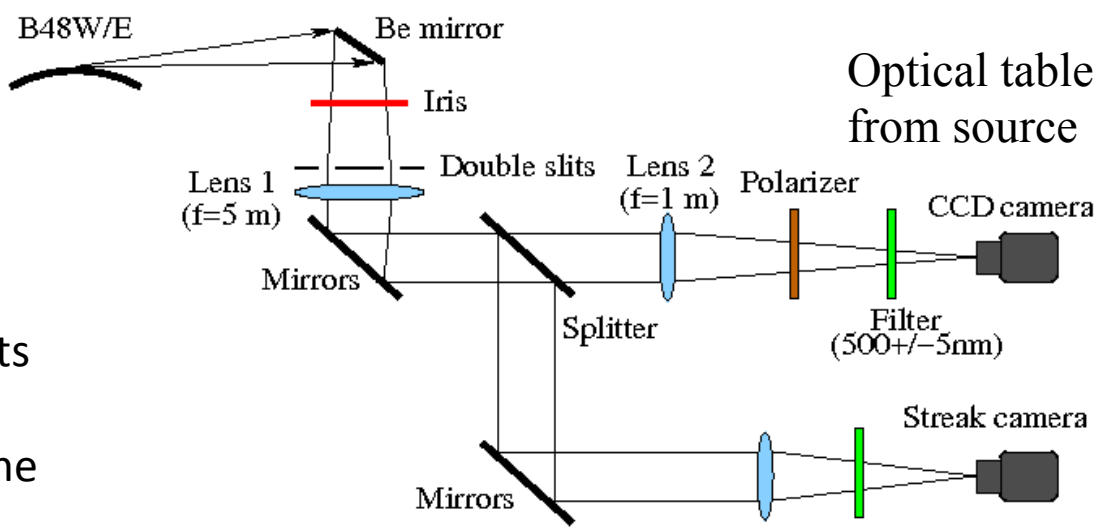
Turn by turn profile monitor

- Goal: turn by turn/bunch by bunch beam size measurement based on visible light synchrotron radiation
  - To eliminate motion of beam and/or optics that may dilute time average measurement
  - In order to measure bunch dependence of horizontal beam size in a train
- Fast readout electronics based on Hamamatsu photomultiplier
- In a low emittance lattice at 2 GeV, a double-slit interferometer is employed to measure the horizontal beam size
- Vertical beam size is acquired by imaging the π-polarized synchrotron radiation.
- Fast monitor is capable of measuring bunch-by-bunch turn-by-turn transverse beam sizes, (and is well suited for electron cloud and IBS studies), and bunch dependent emittance growth

CesrTA vBSM layout

Schematic Design of Visible Light Beam Size Monitor

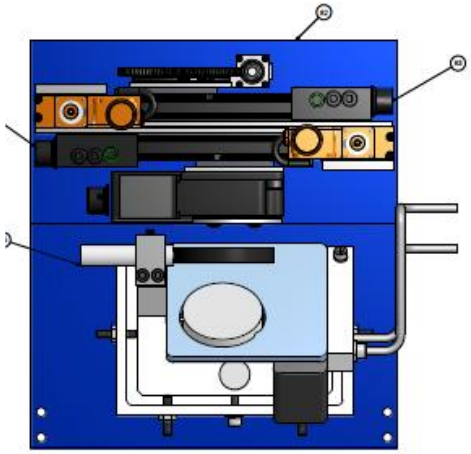
a

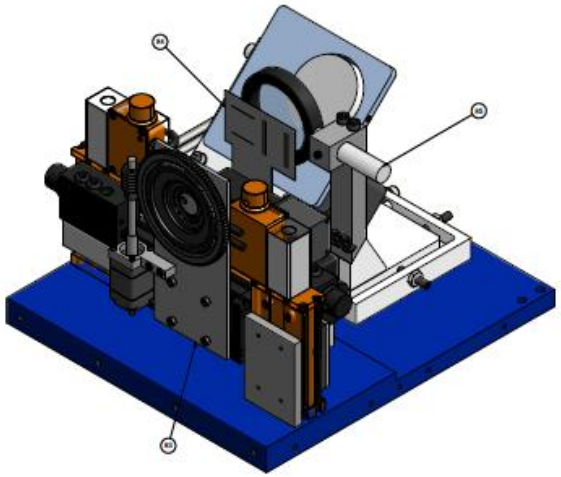


Optical table 27m from source

- Adjustable iris: 3.0 - 22 mm
- Replaceable sets of double slits D=2.0, 2.5, 3.0 mm
- Motorized stages to control the positions of iris and slit sets

b

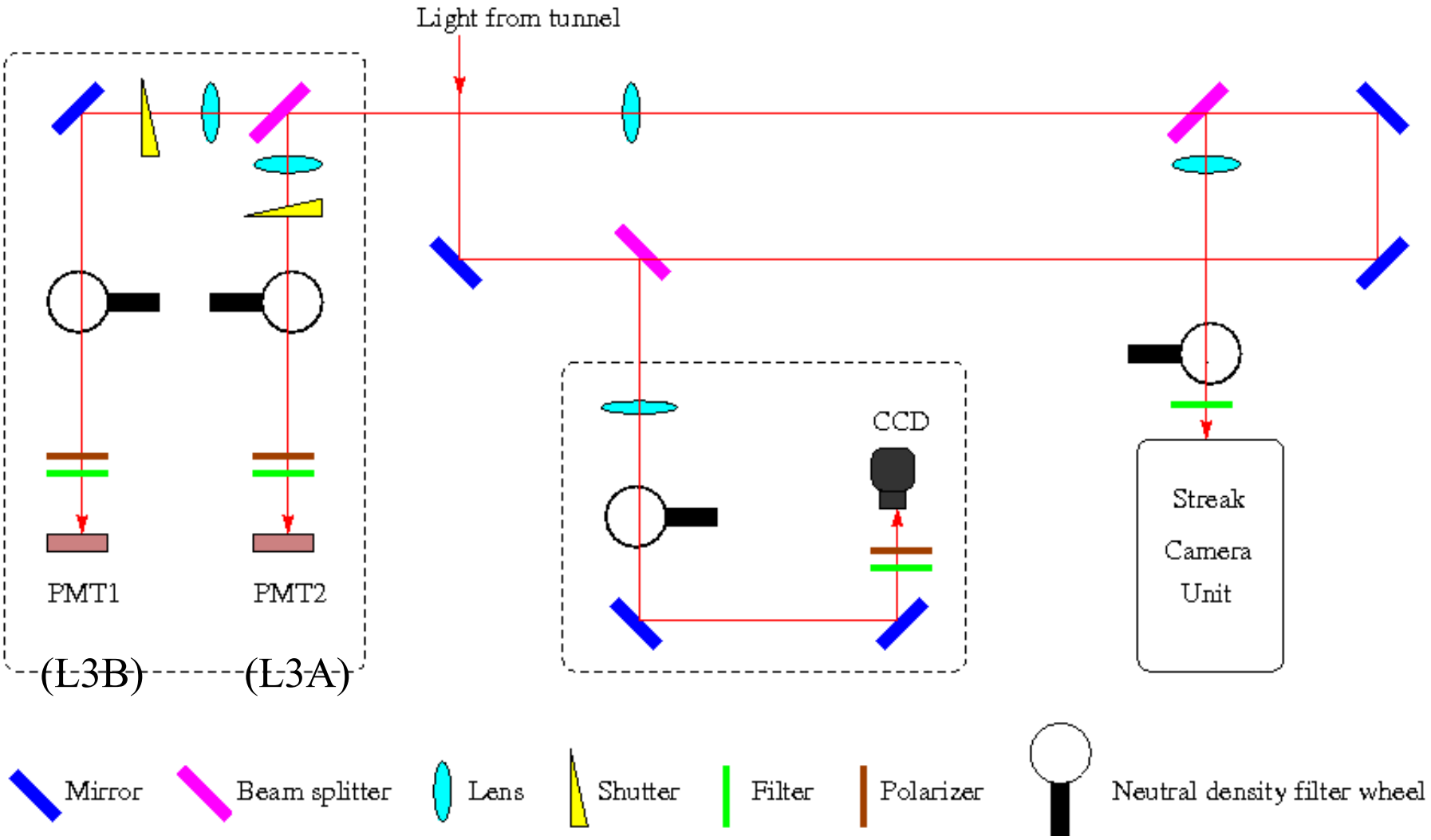




CCD camera exposure time 200-20000 turns

vBSM layout PMT

Layout on the optical table at L3 spur; additional PMT units



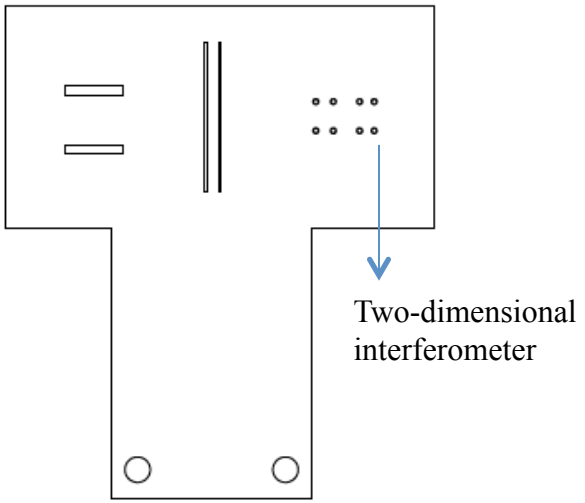
Visible Light BSM

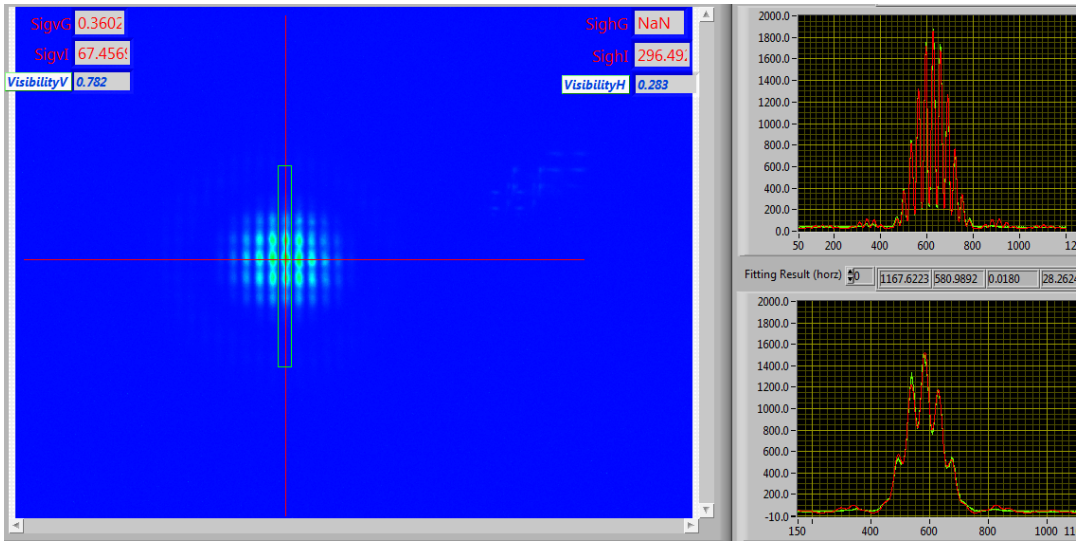
1. Beam size measurements using CCD camera setup

- Reinstall the positron optics box and realign it
- Install a new set of slits for two dimensional interferometer
- Set it up for IBS and ODR shifts

2. Beam size measurements using PMT setup

- Realign the optical elements, check the focusing, timing setups, etc.
- Check the bunch-by-bunch and turn-by-turn capabilities
- Measure the horizontal beam sizes with interferometer
- Measure the vertical beam sizes using π-polarization method





PMT array

- 32-channel linear array of multi-anode PMTs
- 1 mm channel pitch
- 7 mm width.
- Sub-nanosecond rise time.

L3 vBSM PMT

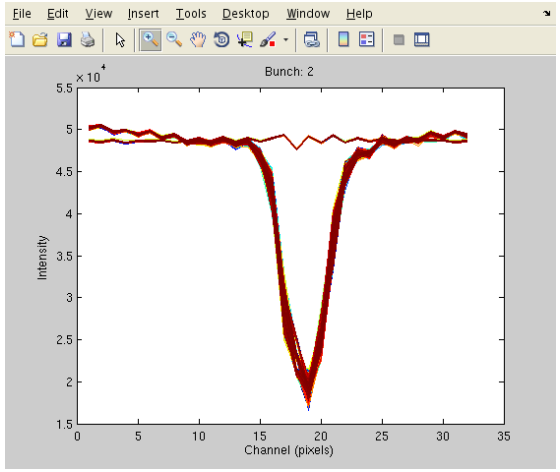
Turn-by-turn capability

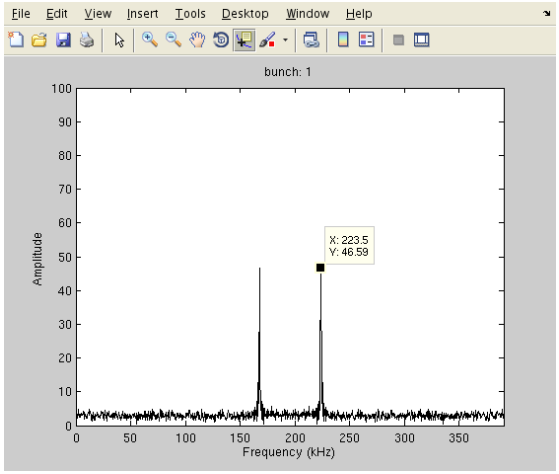
FFT of 1024 turns positions

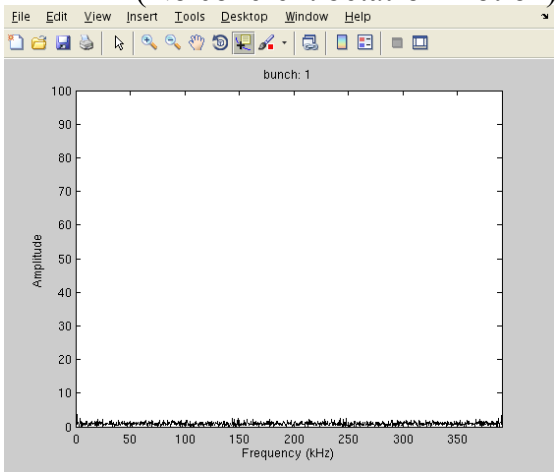
csr feed con 14 = 0
(Betatron oscillations excited)

csr feed con 14 = 1000
(No coherent betatron motion)

L3A – horizontal RD626

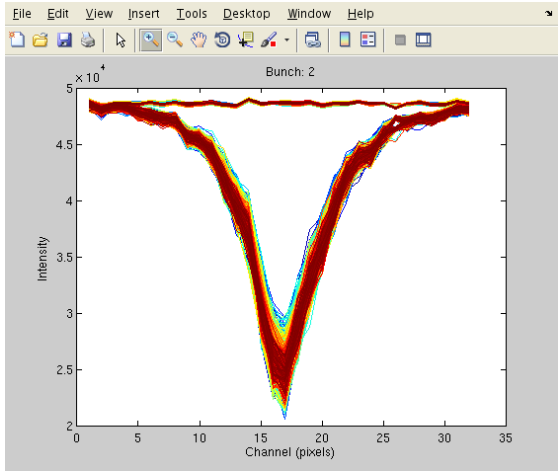


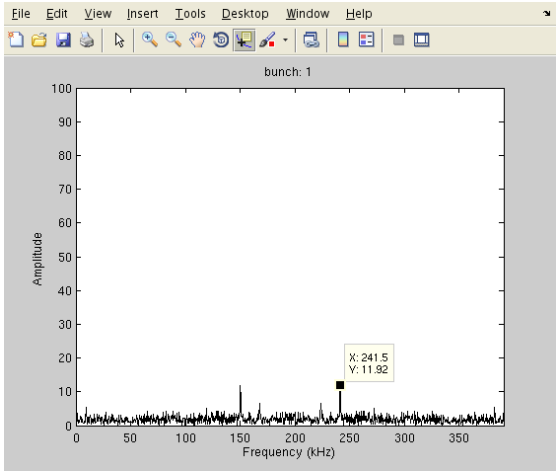


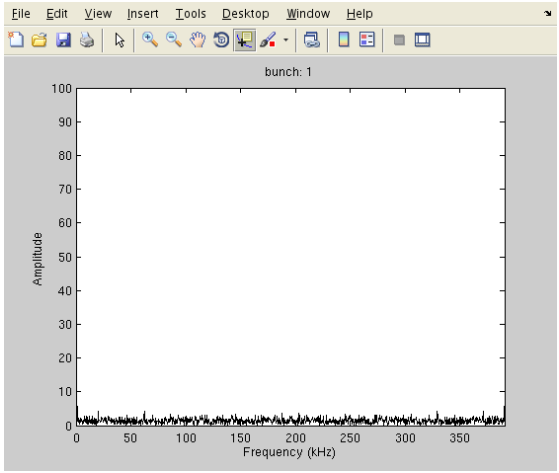


L3B – vertical RD148

Qh=223.5 kHz , Qv=241.5 kHz

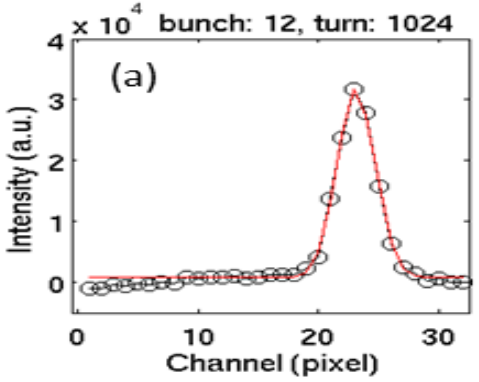




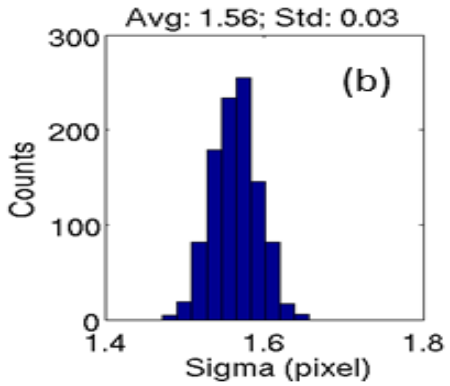


Multi-bunch capability

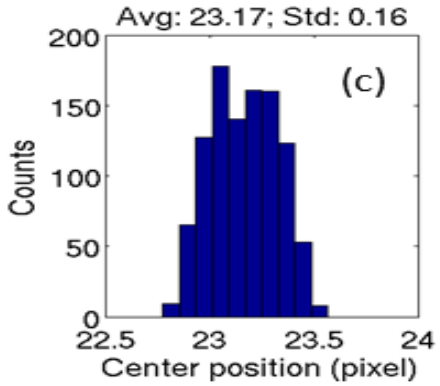
Single turn profile



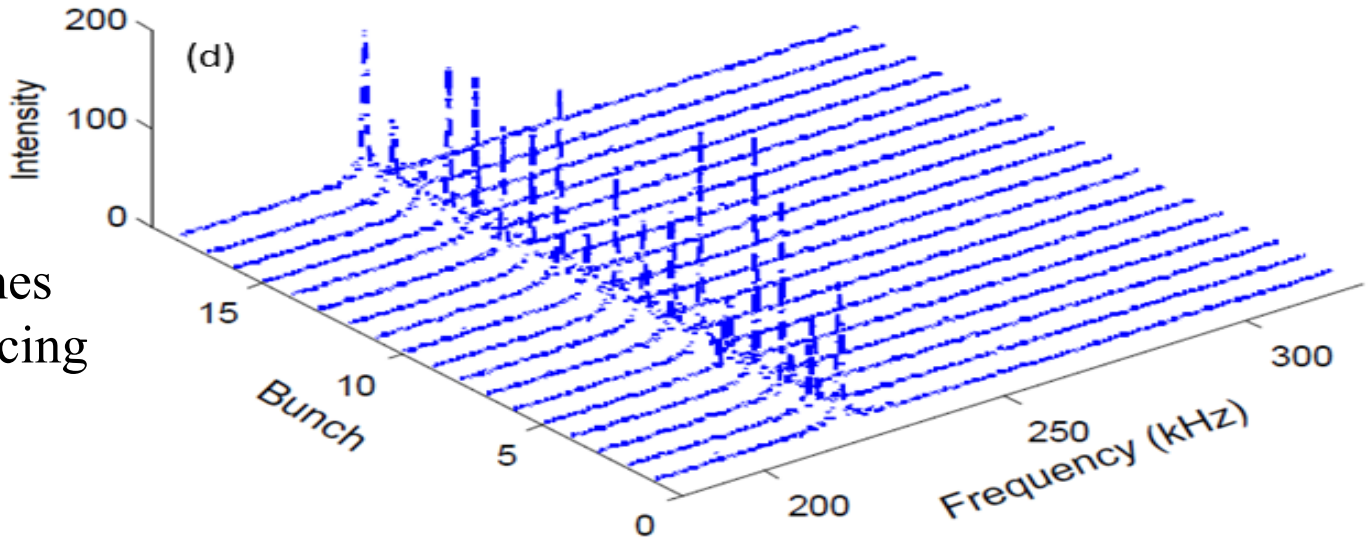
σ for 1024 profiles



Center positions from 1024 turns



18 bunches
14ns spacing



FFT from 1024 turns for all 18 bunches

Interferometry

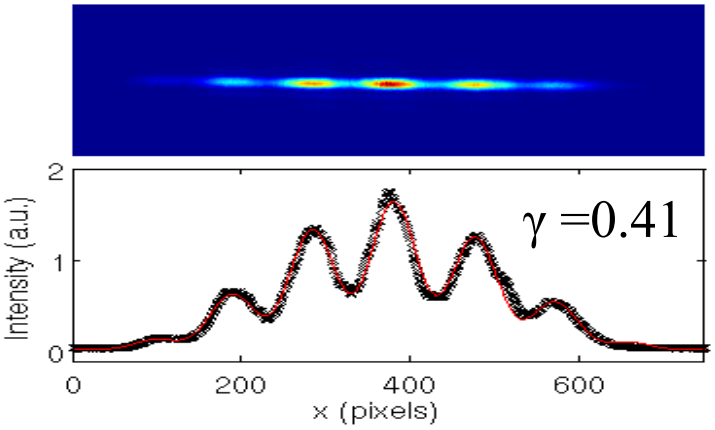
Two slit interference pattern given by:

$$I(x) = I_0 \left[\sin c\left(\frac{2\pi a}{\lambda R} x + \varphi\right) \right]^2 \left(1 + |\gamma| \cos\left(\frac{2\pi D}{\lambda R} x + \psi\right)\right) \qquad (1)$$

Beam size is $$\sigma_x = \frac{\lambda L}{\pi D} \sqrt{\frac{1}{2} \ln \frac{1}{\gamma}} \qquad (2)$$

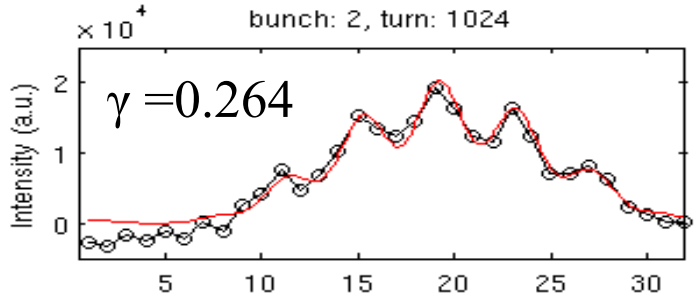
Where γ is the spatial coherence or visibility

Interferometry

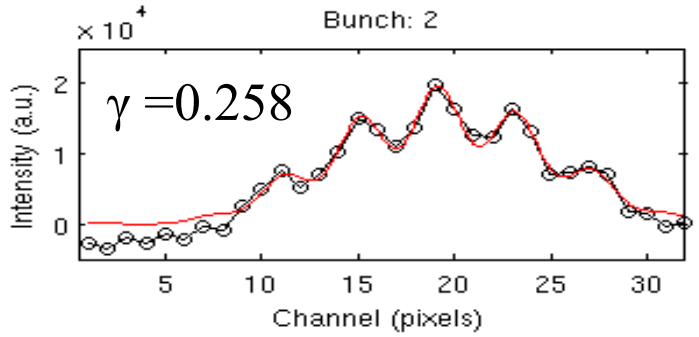


CCD image of interference pattern

Integrated CCD profile



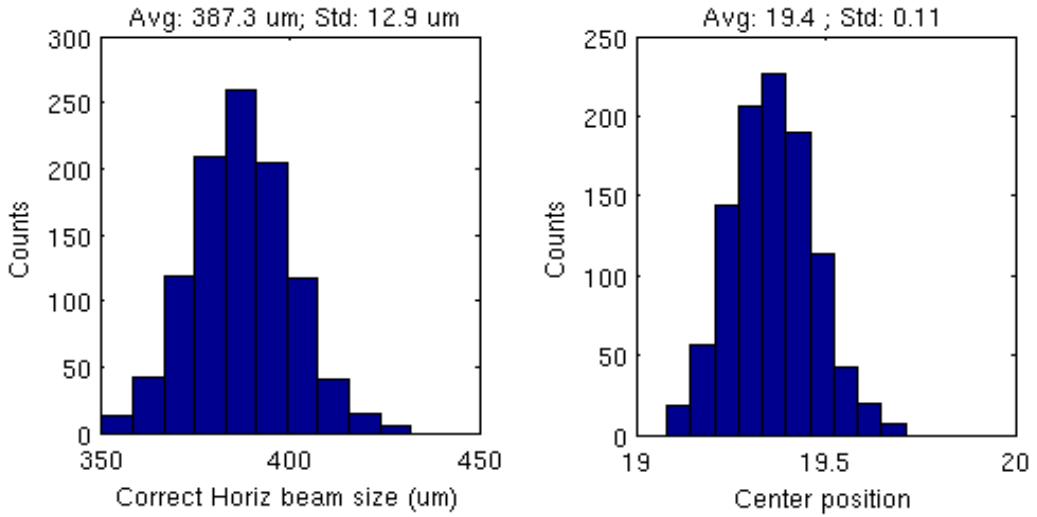
Single turn interference from PMT array



1024 turn PMT array average

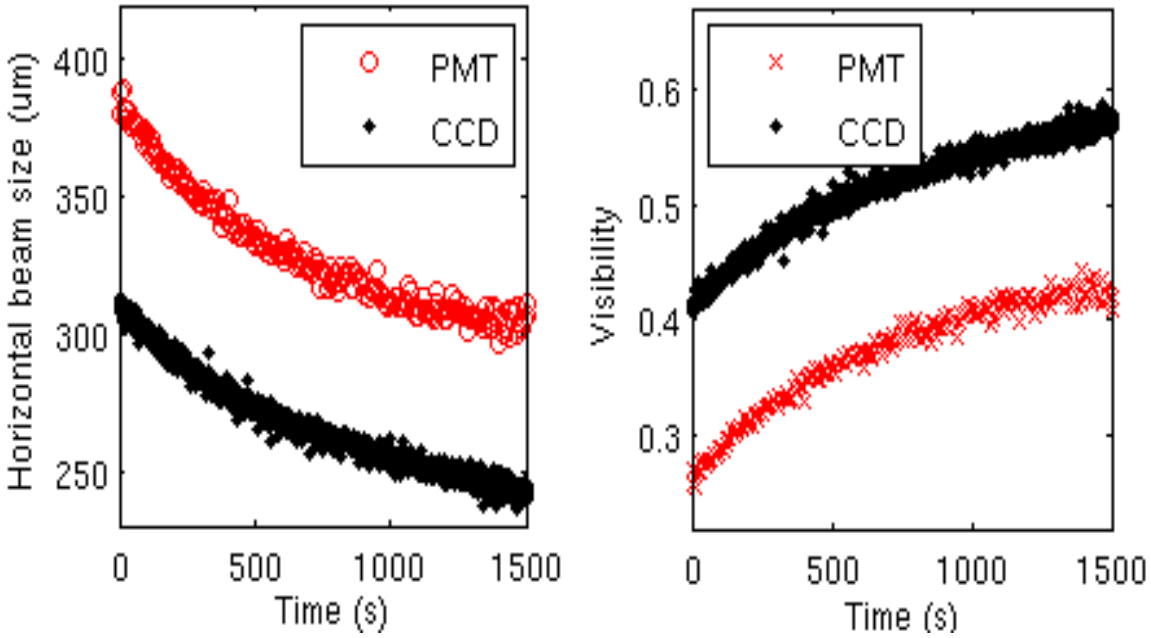
Horizontal beam size

Single bunc electron 6 mA



Histogram of size and centroid for 1024 turns

Horizontal size vs bunch charge



Horizontal beam size (and visibility) as current decays from 6mA-1.5mA
Beam size decreases with bunch charge due to IBS
CCD and PMT are consistent with 70 μm systematic offset ? (Timing error ?)

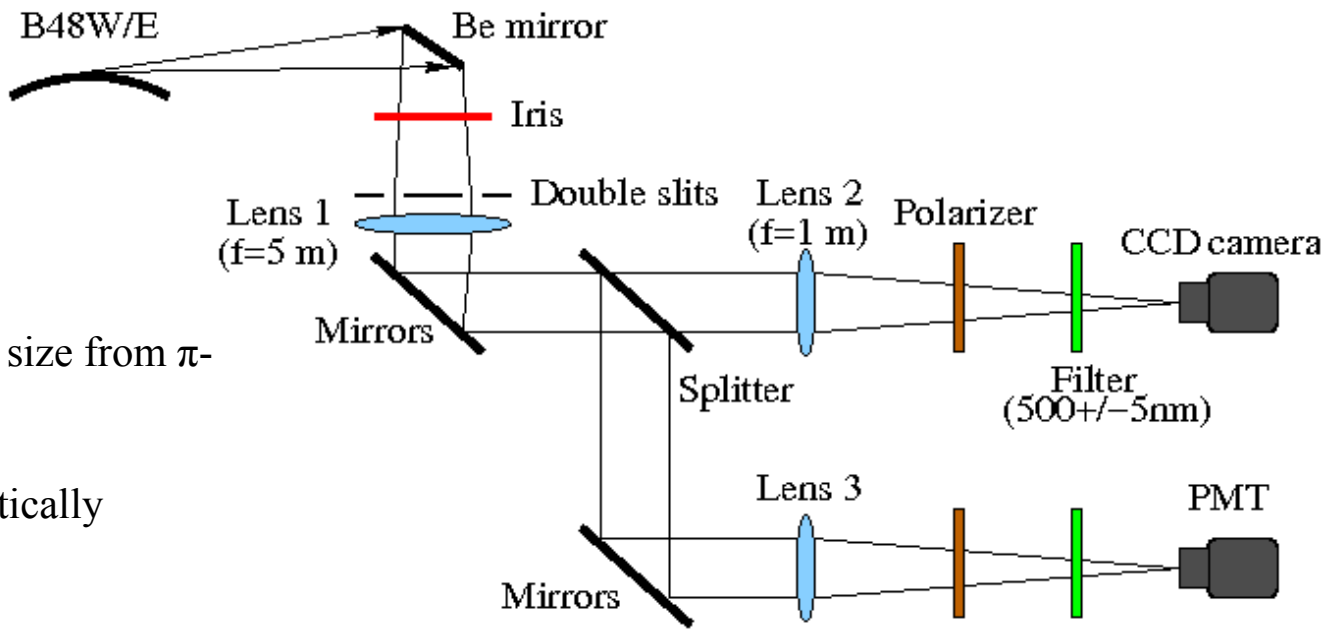
Measurement of vertical beam size

Motivation: to measure small vertical beam size (~ 15 μm) at L3

Two methods to measure the vertical beam size

1. Vertical polarization method
2. Interferometer

Both methods are limited by the Be mirror dimension.

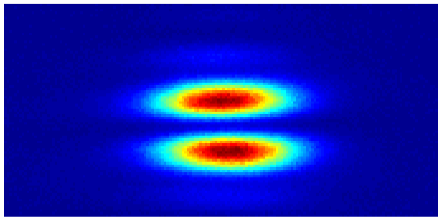


To measure vertical beam size from π-polarized beam profile,

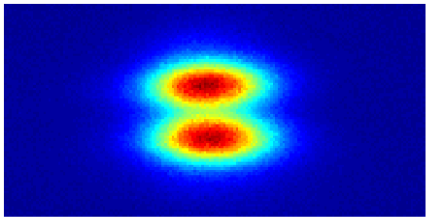
- Remove slits
- Orient linear PMT vertically

Vertical beam size π-polarization

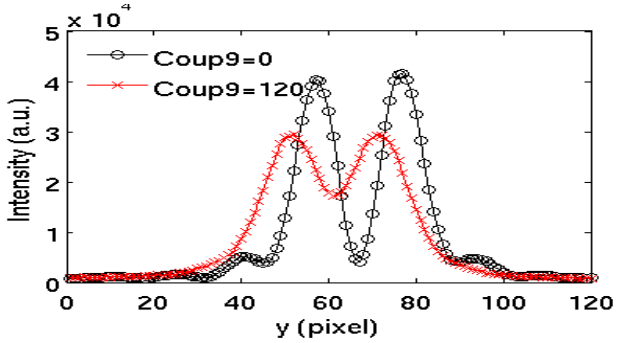
CCD profile of π-polarized light



Nominal beam size (Coupling9 = 0)

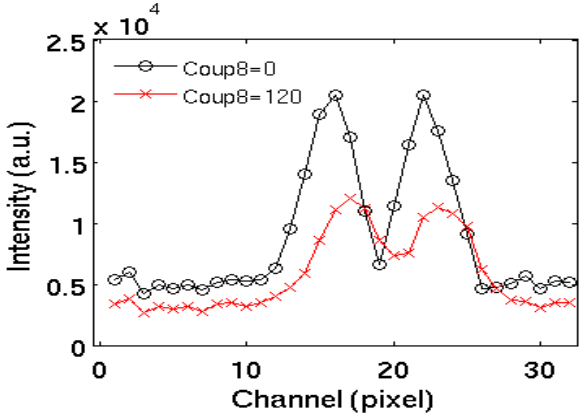


Vertical size artificially enlarged with closed coupling/vertical dispersion bump (Coupling9 = 120)



Integrated CCD profile

PMT single turn profile



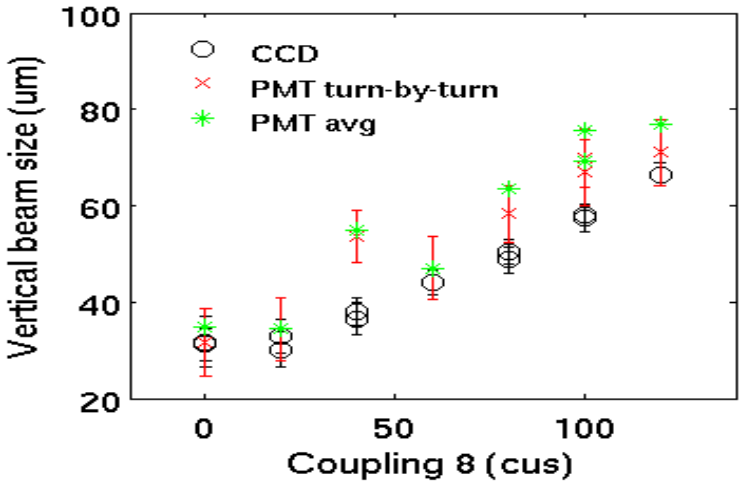
70 times magnification required so that image size comparable to pmt array length.
(Appears we need more magnification and/or smaller pitch)

Small beam (Coupl8=0) and large beam (coupl8=120)

Vertical beam size π-polarization

Comparison of CCD and PMT measurement of vertical beam size

- Turn by turn measurement is not smaller than CCD mulit-turn average => Not limited by motion of beam or optical elements
- CCD and PMT measurements comparable
- Minimum $\sigma_v \sim 32\mu m$, larger than 25μm measured with xray BSM
- Resolution limited by angular acceptance of internal mirror and rather low field of bending magnet source



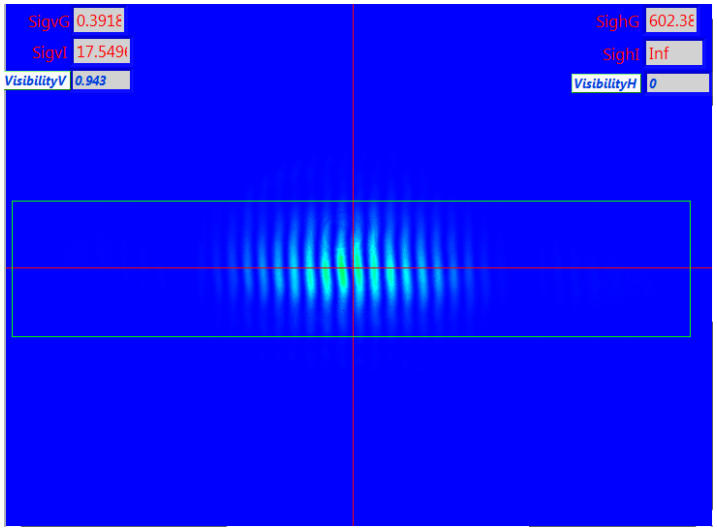
Small beam (Coupl8=0) and large beam (coupl8=120)

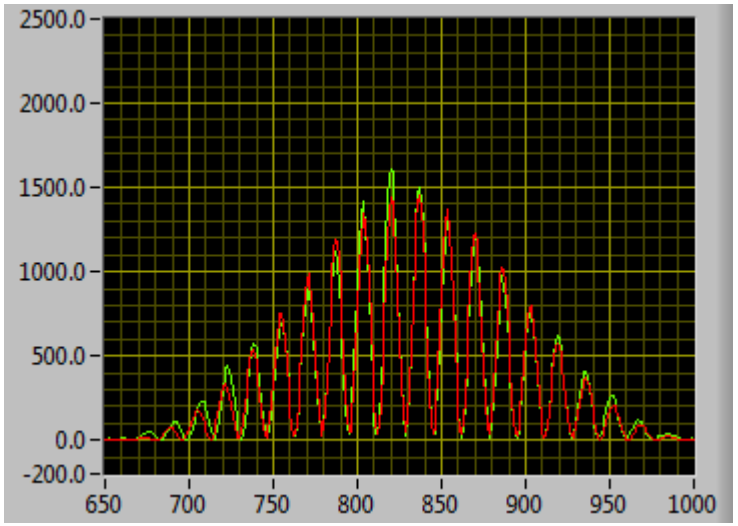
Vertical profile intereferometer

2. Interferometer

Because the vertical dimension of current mirror is 12.6 mm, (small vertical acceptance), the largest separation D for the double slits is 10 mm.

$$\sigma_y = \frac{L\lambda}{\pi D}\sqrt{\frac{1}{2}\ln\frac{1}{\gamma}}$$



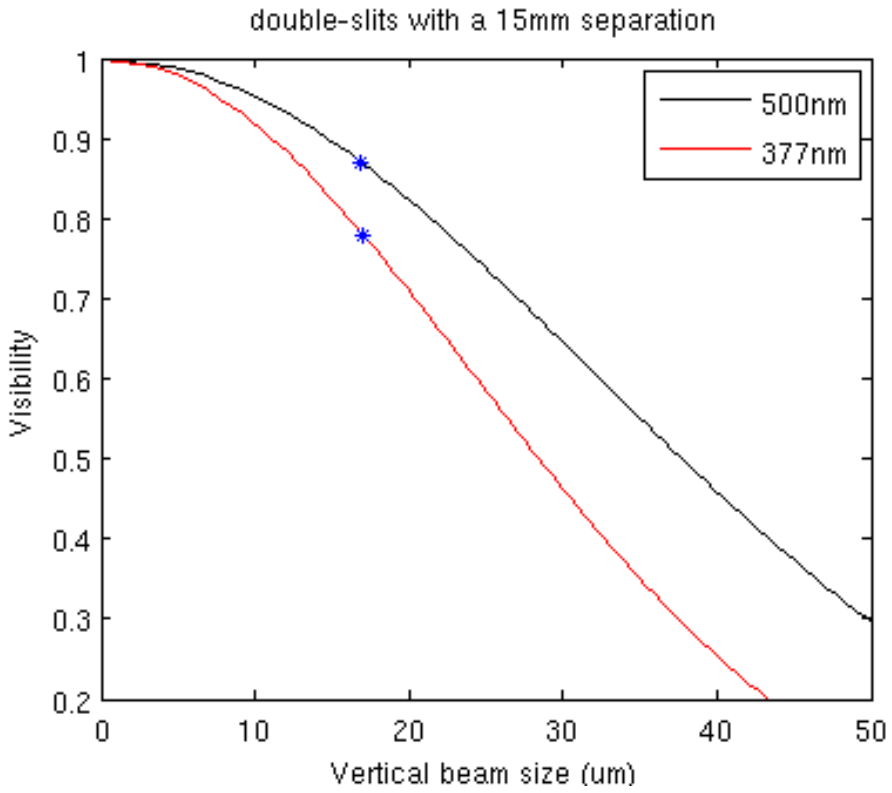


For a point source (coherent laser source), the highest visibility for D=10 mm vertical slits is ~0.95

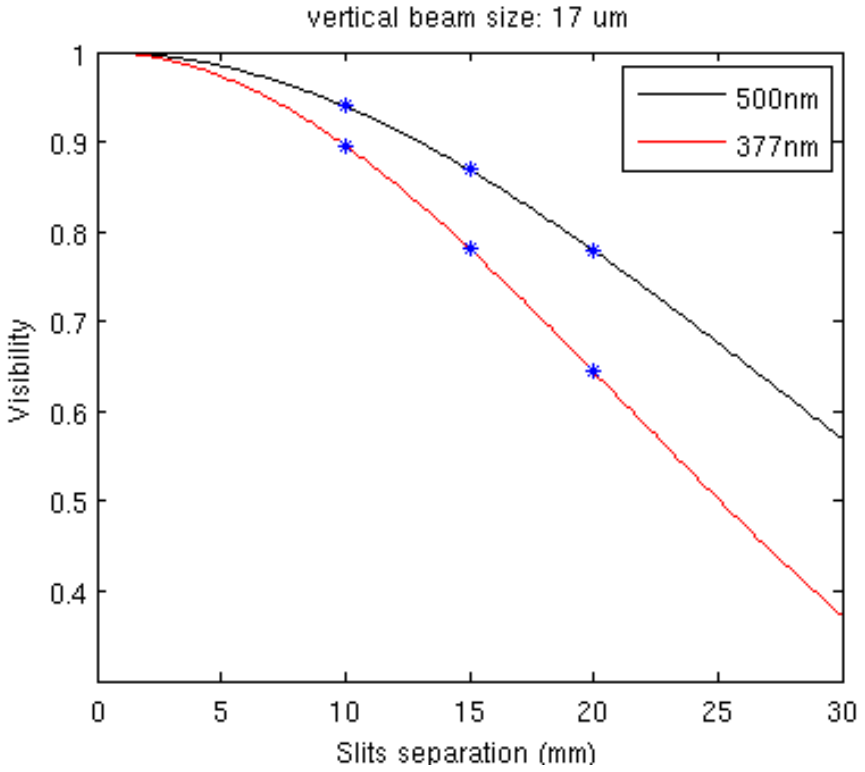
For ε_y= 12 pm σ_y=15.5 μm, with D=10 mm, the visibility γ=0.95, just at the instrumentation limit.
For December run, the measured vertical beam size is always >40 μm.
Density of interference pattern incompatible with 32 channel PMT array

Vertical interferometer

$$\sigma_y = \frac{L\lambda}{\pi D}\sqrt{\frac{1}{2}\ln\frac{1}{\gamma}}$$



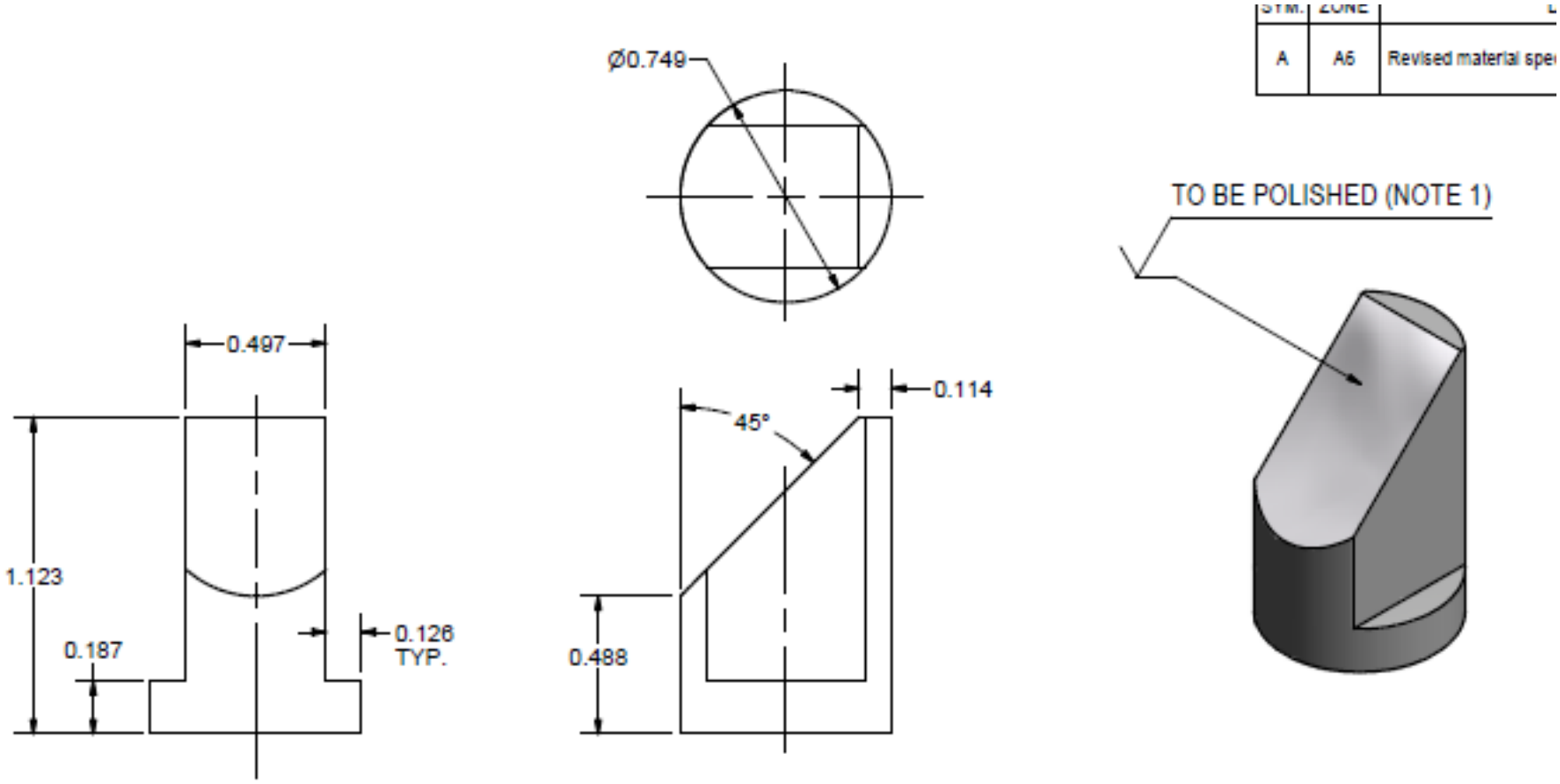
Dependence of visibility on σ_v



Dependence of visibility on slit separation (D)

Mirror design

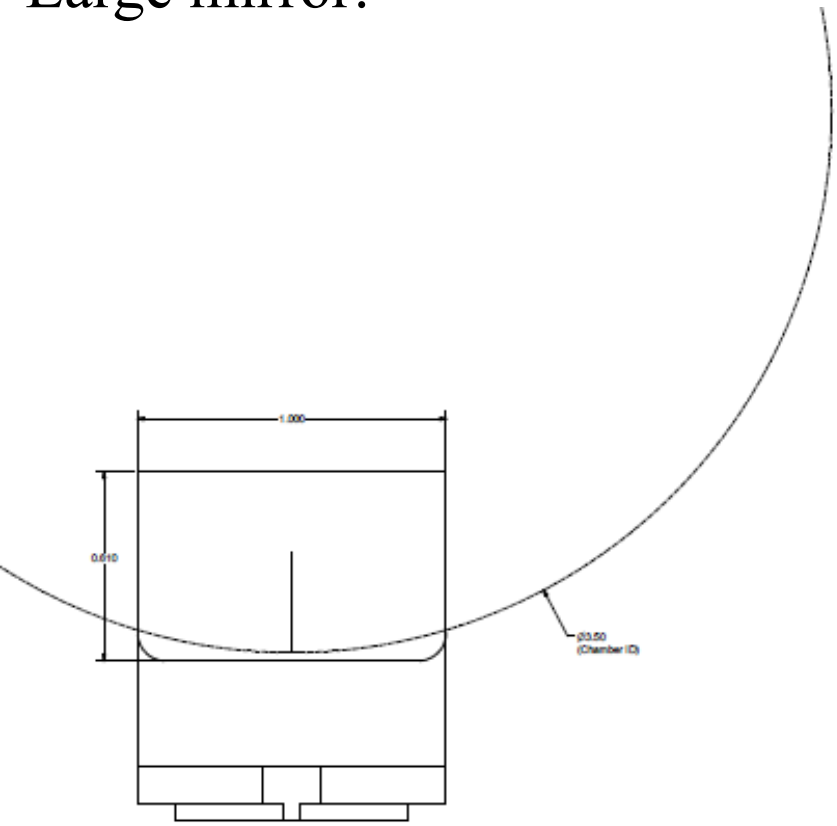
Current mirror:

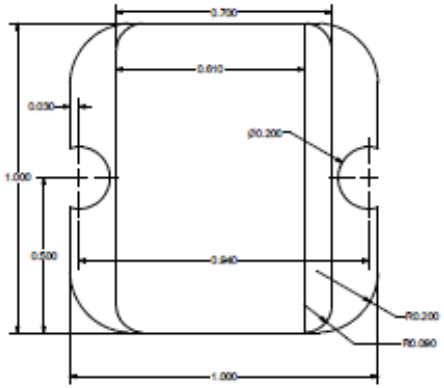


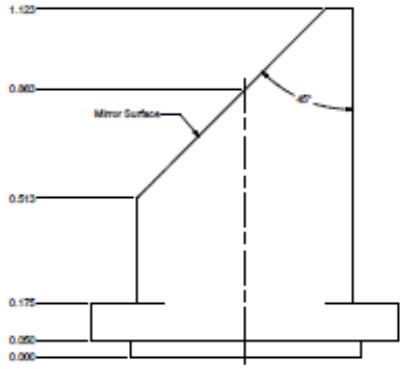
Be mirror is clamped on to the Cu cooling post.

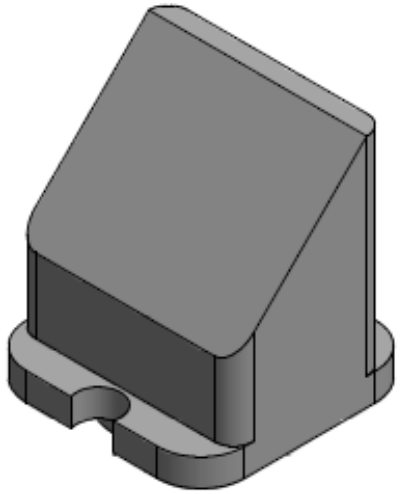
Mirror design

Large mirror:









1. Same horizontal dimension but double the vertical dimension (~ 1 inch).
2. Same mounting scheme as before and retractable.
3. Need slight modification of the vacuum chamber.

Conclusion

- Developing capability for turn by turn and bunch by bunch measurement of horizontal and vertical beam size with visible synchrotron light
- Horizontal beam size: systematic 70μm offset of turn by turn versus CCD multi-turn measurement (timing error?)
- Vertical beam size
  - Resolution of π-polarization measurement limited by source B-field
  - Interferometry limited by angular acceptance and slit spacing

Plan to double vertical dimension of internal mirror (an therefore double angular acceptance and slit spacing