Photon Monitors

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SKB Review

2016.6.13

Photon Monitors

- XRM: X-ray Monitor
  - Pinhole, Coded Aperture mask, etc.
    - σ_y (σ_x)
- SRM: Synchrotron Radiation Monitor
  - Visible light monitor. Interferometer, streak, gated camera, etc.
    - σ_z, σ_x (σ_y)
- LABM: Large Angle Beamstrahlung Monitor (IR)
  - SR-like radiation from interaction point (~300-600 nm)
  - Can measure size ratios and relative offsets at collision point.

XRM: Status

- HER and LER beam lines commissioned, and taking data with scintillators.
- Template fits implemented for taking data with single-slit, multi-slit and URA masks.
- Calibration studies undertaken:
  - Source-point measurement
  - Overall magnification studies
    - Emittance Knob studies
    - Mask movement studies
    - Source-point movement studies
    - Changing beta function at source point (HER)
  - Light-level dependence (HER)
- Beam studies undertaken
  - Emittance measurements at LER and HER,
  - Electron cloud (LER) and current-dependence (HER)

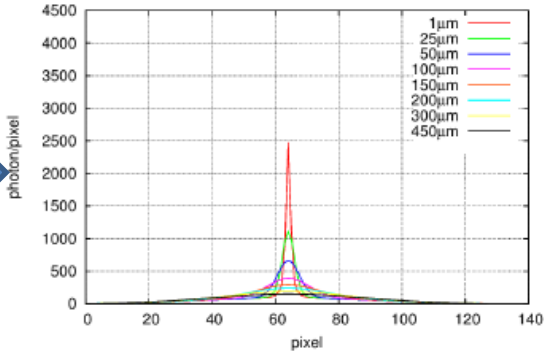
XRM: Principles

Coded aperture imaging (R. H. Dicke, Astrophys. Journ., 153, L101 (1968)), using **template reconstruction**.

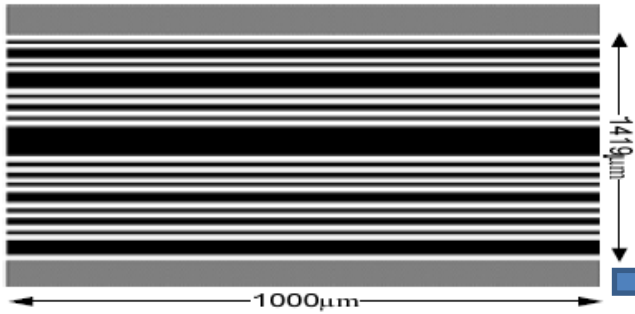
Mask patterns

Single slit, 33 mm wide

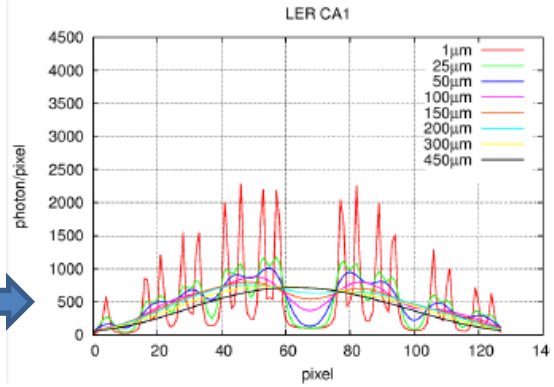
Calculated images for different beam sizes



(a)



Multi-slit mask (E. Mulyani)



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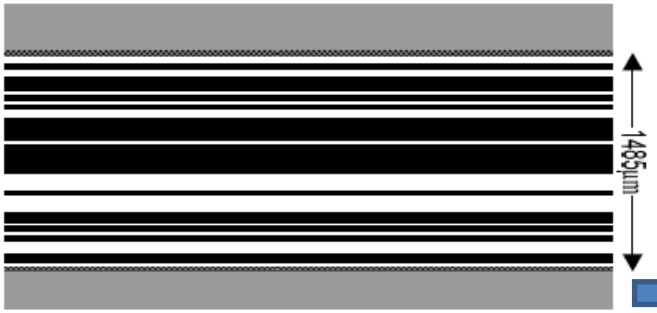
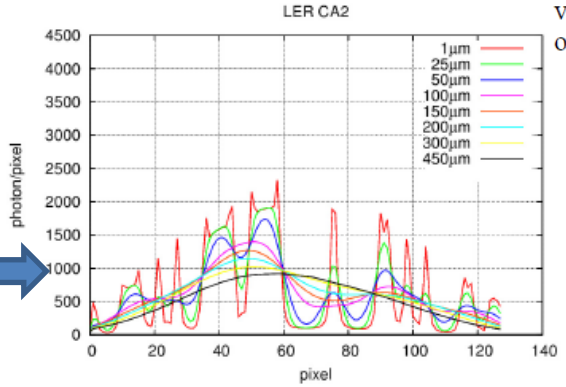


URA mask (E. E. Fenimore, T. M. Cannon, Appl. Optics, Vol 17, No.3, 337 (1978).



Single-shot statistical resolutions expected

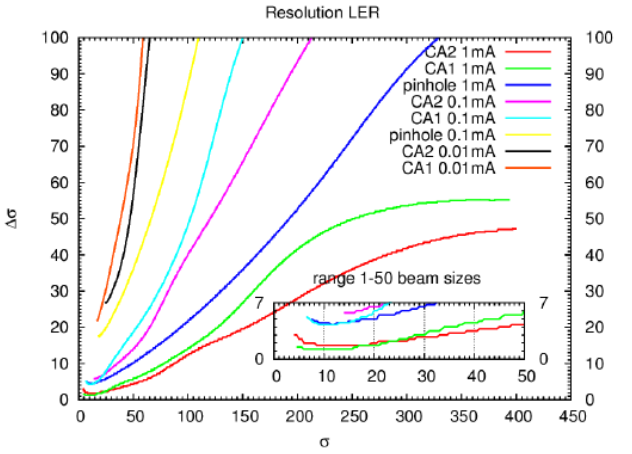
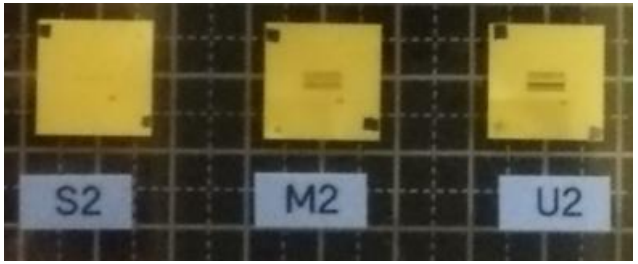


Figure 8: Vertical beam size resolutions at LER for various bunch currents (1 mA, 0.1 mA and 0.01 mA) and optical elements (single pinhole, CA1 and CA2).

E. Mulyani and J. Flanagan, TUPB025, Proc. IBIC2015, Melbourne

XRM: Hardware

X-ray beam line under construction at LER

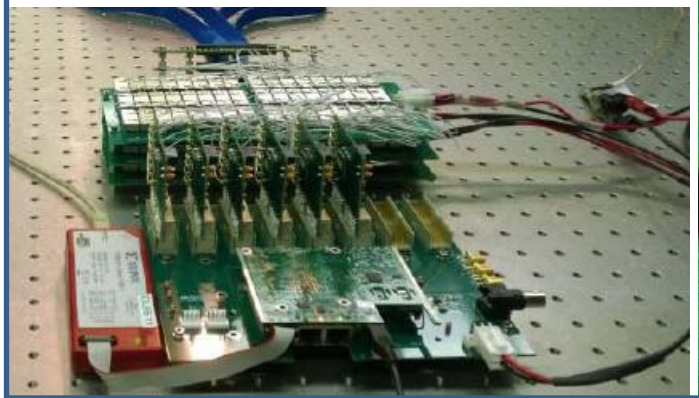


Masks: ~20 μm Au on 600 μm CVD diamond substrate

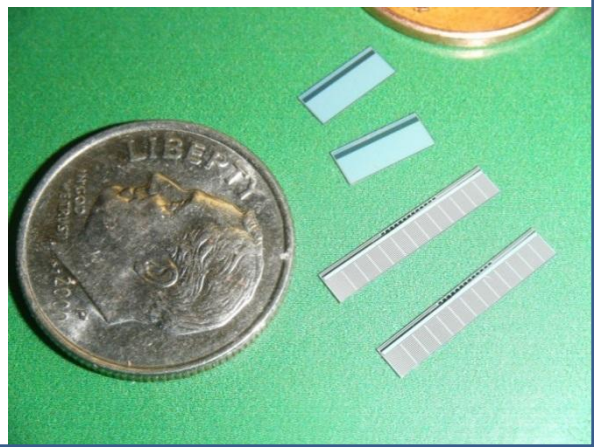
Water-cooled mask holder

US-Japan Collaboration (U. Hawaii, SLAC, Cornell U.)

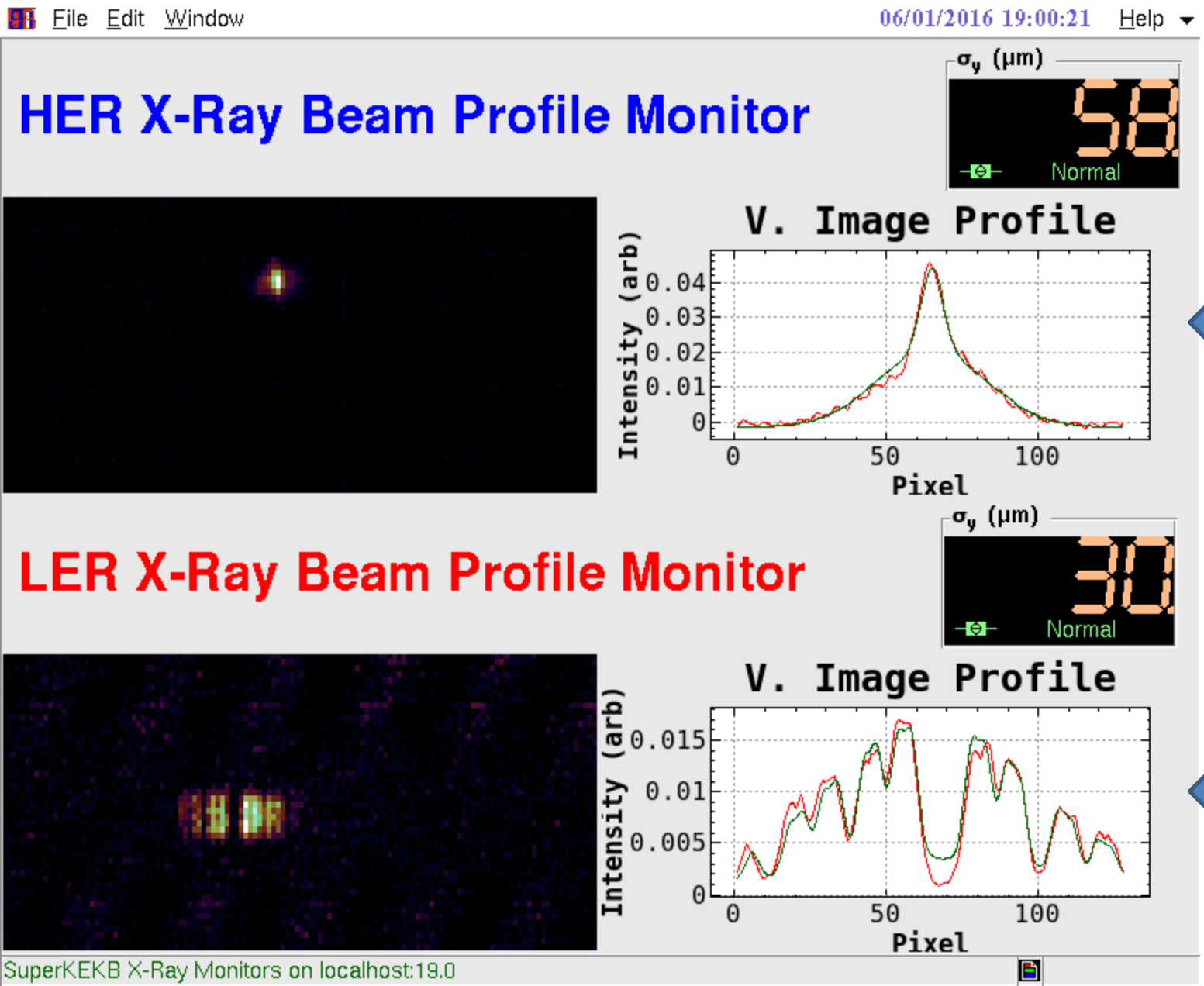
High-speed readout electronics for the X-ray monitor, being developed by U of Hawaii.



Deep Si pixel detector and spectrometer chips for the X-ray monitor, being developed at SLAC.



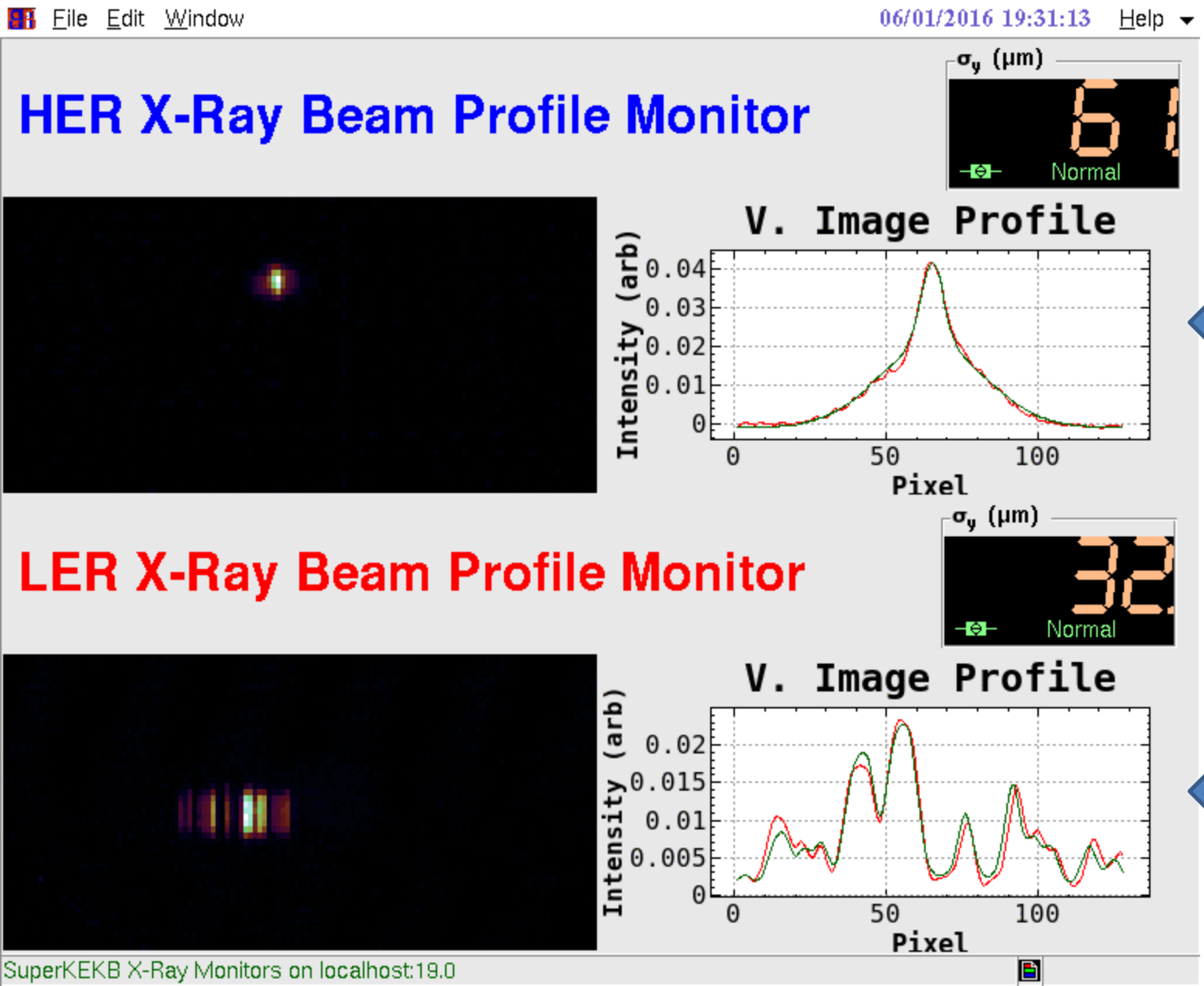
XRM: control room display panel



Single-slit mask

Multi-slit mask

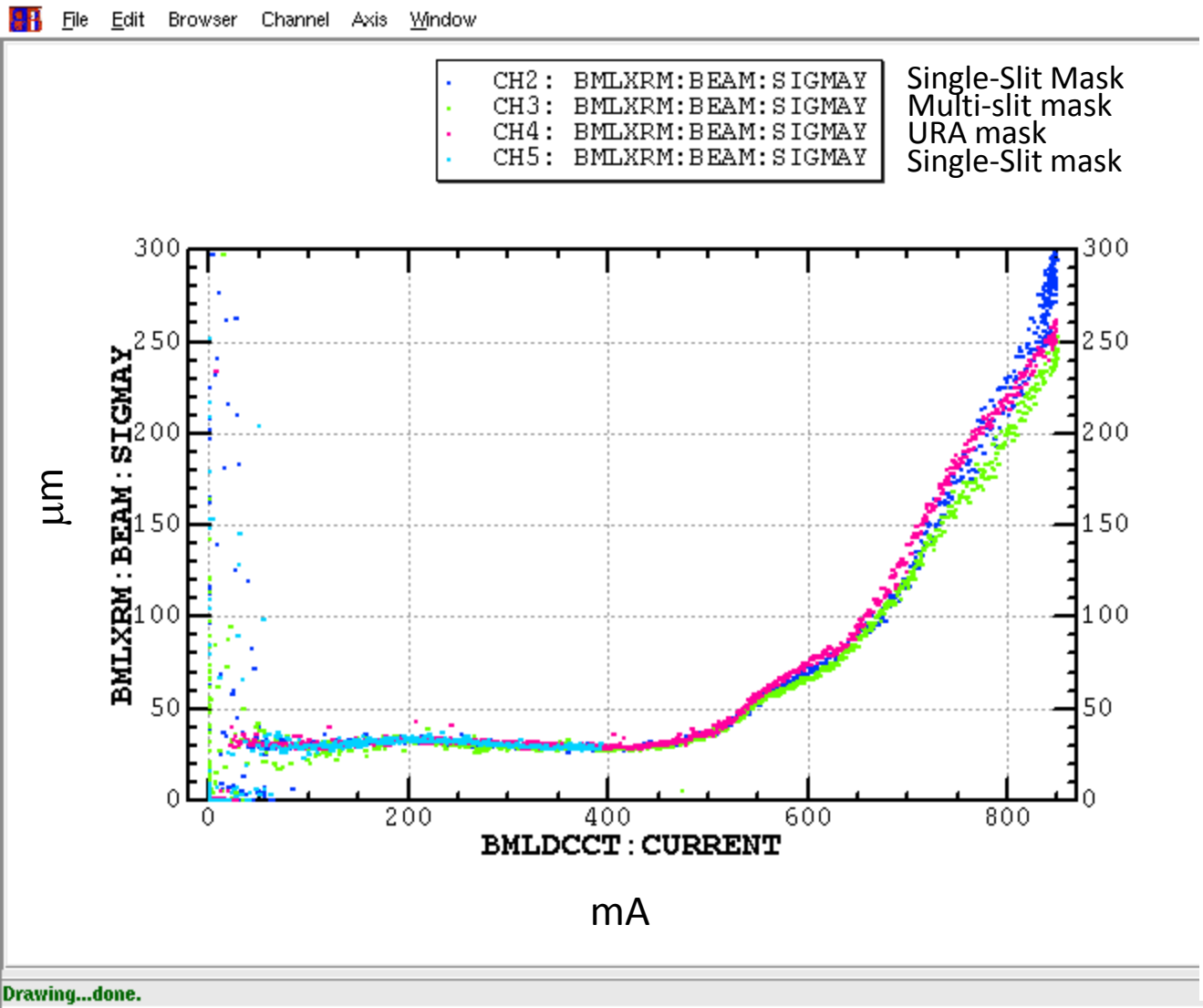
XRM: control room display panel



Single-slit mask

URA mask

XRM: e-cloud blow-up study (LER)

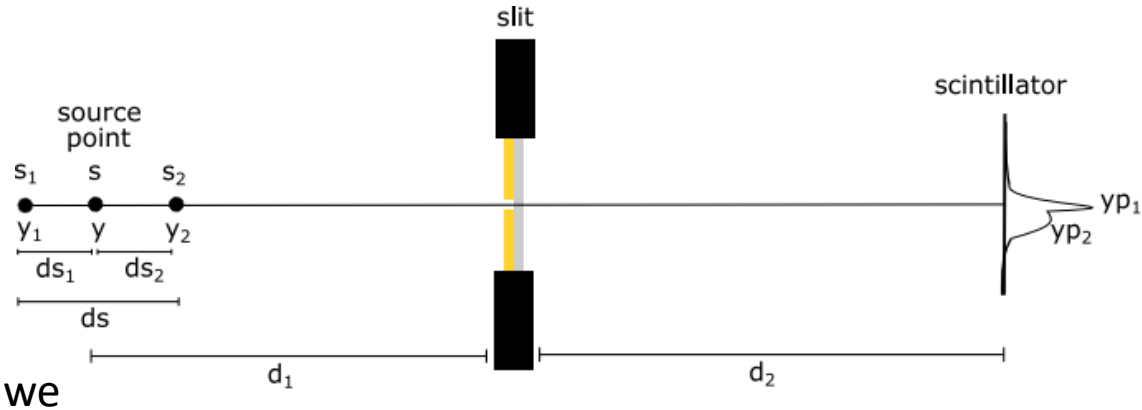


Very good fill-to-fill repeatability

Very good agreement between different masks, especially below 150 μm.

XRM: Calibration

1. Geometric scale factors check



Schematic of XRM beam line (not to scale)

By moving either beam, or mask, and measuring how single-slit peak moves, we can measure M/m or (M+1)/m, where:

M = geometric magnification (d2/d1)

m = scintillator camera scale (μm/pixel)

Parameter	Estimate from design and hand measurements (LER)	Beam-based measurements (LER)	Estimate from design and hand measurements (HER)	Beam-based measurements (HER)
ds1/ds		0.4229 ± 0.0029 (0.69%)		0.4369 ± 0.0038 (0.87%)
M/m	66.21 ± 0.002 (0.003%)	69.45 ± 0.488 (0.7%)	60.87 ± 0.002 (0.003%)	59.23 ± 0.511 (0.9%)
(M+1)/m	85.52 ± 0.002 (0.002%)	86.08 ± 1.56 (1.8%)	79.96 ± 0.002 (0.002%)	79.31 ± 0.10 (0.13%)

Geometric magnification factors agree well with beam-based measurements at both LER and HER

E. Mulyani

XRM: Calibration

2. Emittance Knob Ratio

Based on "SYNCHROTRON RADIATION INTERFEROMETER CALIBRATION CHECK BY USE OF A SIZE CONTROL BUMP IN KEKB" (N. Iida, J. Flanagan, Y. Funakoshi and K. Oide, TUPAN042, Proc. PAC07, Albuquerque) the variation of the vertical beam size by changing the bump height can be represented as :

$$\sigma_y^2 = \sigma_{yo}^2 + A^2(h - h_o)^2$$

$$(\sigma_y^{meas})^2 = (c.\sigma_y)^2$$

$$(\sigma_y^{meas})^2 = (c.\sigma_{yo})^2 + (cA)^2(h - h_o)^2$$

σ_y = true vertical beam size with bump

σ_{yo} = true vertical beam size without bump

σ_y^{meas} = true vertical beam size that mesured

A = linear coefficient of the vertical beam size vs bump height

c = calibration factor

For LER

$$\Delta\varepsilon_y = 73.2(pm) \times (knob)^2$$

$$\Delta\varepsilon_y = 73.2(pm) \times (h - h_o)^2$$

$$\sigma_y^2 = \varepsilon_y \times \beta_y = A^2 \text{ with } \beta_y = 67.1721m$$

For HER

$$(\sigma_y^{meas})^2 = c^2\sigma_{yo}^{\ 2} + c^2 7.63647 \times 59.287(h - h_o)^2$$

This method measures the overall scaling factor between the reported beam size measurements and the true beam size.

➔Not just geometric factors, measures performance of overall system

Analysis: E. Mulyani

XRM: Emittance Knob Calibration

For LER

$\Delta\varepsilon_y = 73.2(\text{pm}) \times (\text{knob})^2$

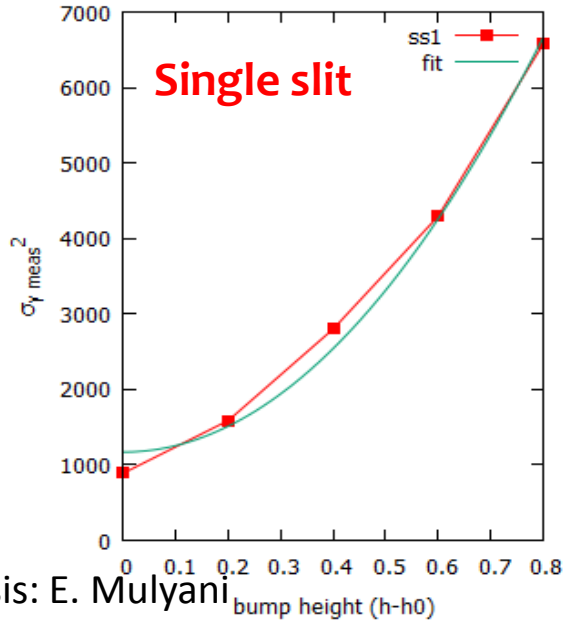
$\Delta\varepsilon_y = 73.2(\text{pm}) \times (h - h_o)^2$

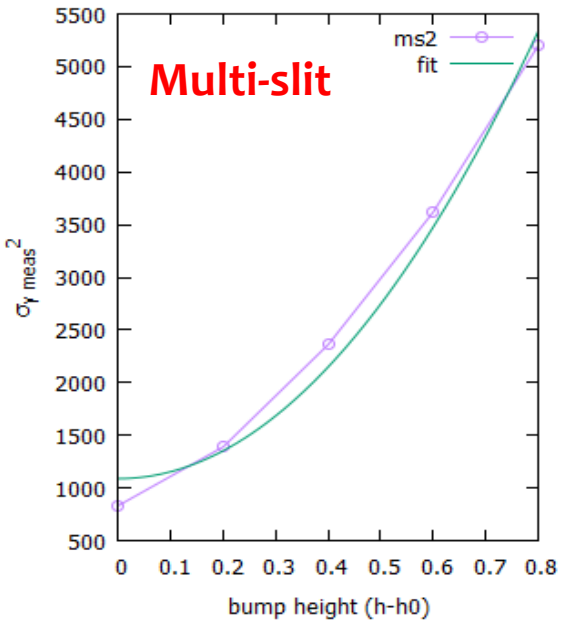
$\sigma_y^2 = \varepsilon_y \times \beta_y = A^2 \text{ with } \beta_y = 67.1721\text{m}$

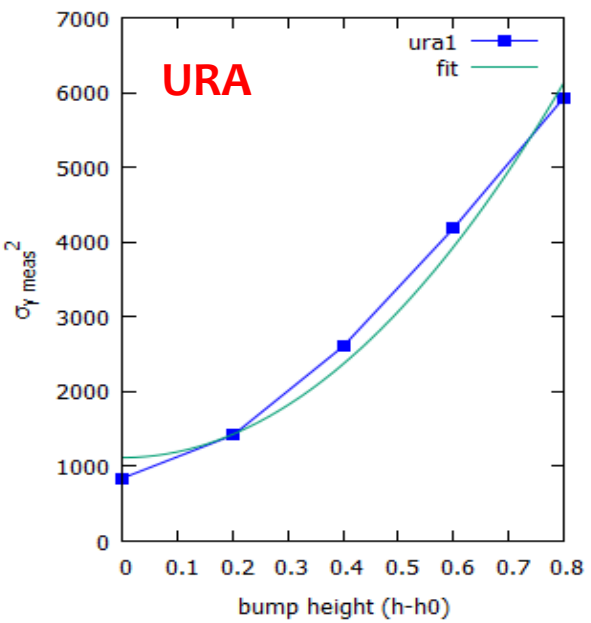
True beam size upper bound (includes possible smearing factors)

Reported/true beam size scaling factor

	LER_ mask	σyo	Calibration factor c
Single slit	ss1	25.89 ± 2.14 (8.2%)	1.3 ± 0.03 (2.54%)
Multi-slit	ms1	27.89 ± 2.59 (9.11%)	1.16 ± 0.037 (3.19%)
URA	ura1	26.5 ± 2.8 (10.58%)	1.26 ± 0.04 (3.36%)



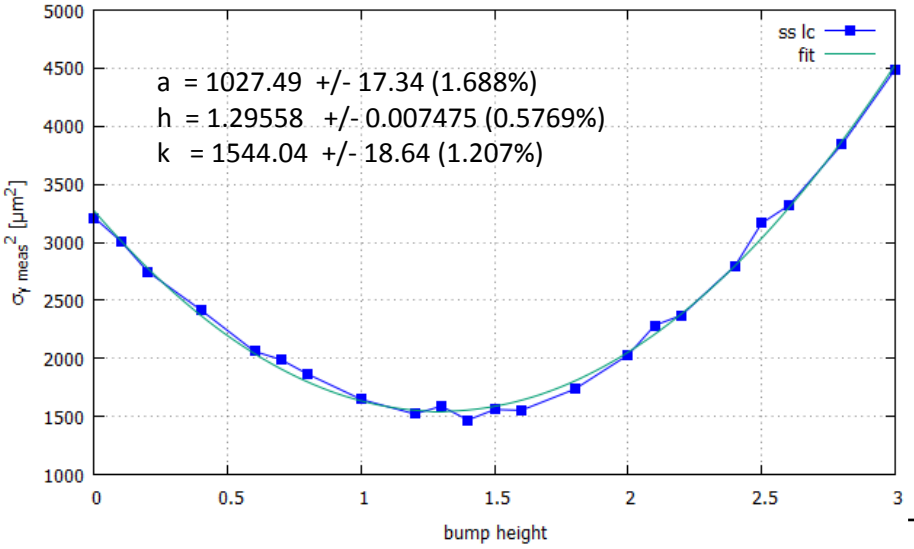


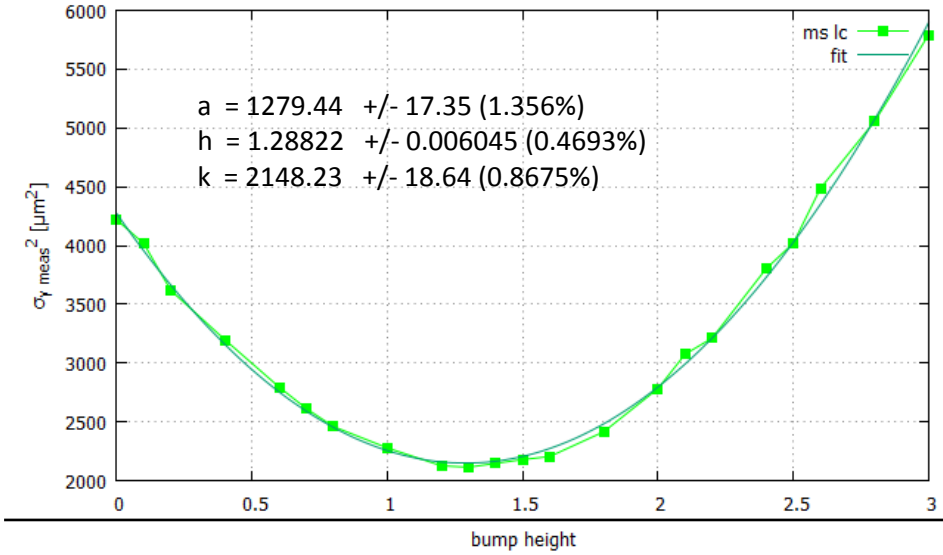


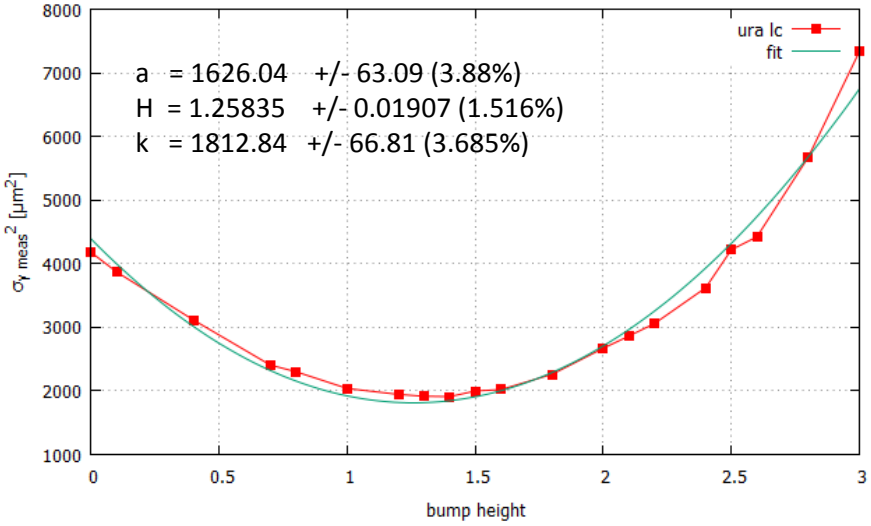
Analysis: E. Mulyani

XRM: Emittance Knob Calibration

HER @ Low Current (30 mA)







LC	A^2	C (cal fac)	σyo	ho
SS	452.74	1.5 ± 0.02	26.1 ± 0.02	1.29 ± 0.007
ms	452.74	1.7 ± 0.02	27.6 ± 0.01	1.29 ± 0.006
ura	452.74	1.89 ± 0.04	22.5 ± 0.04	1.26 ± 0.02

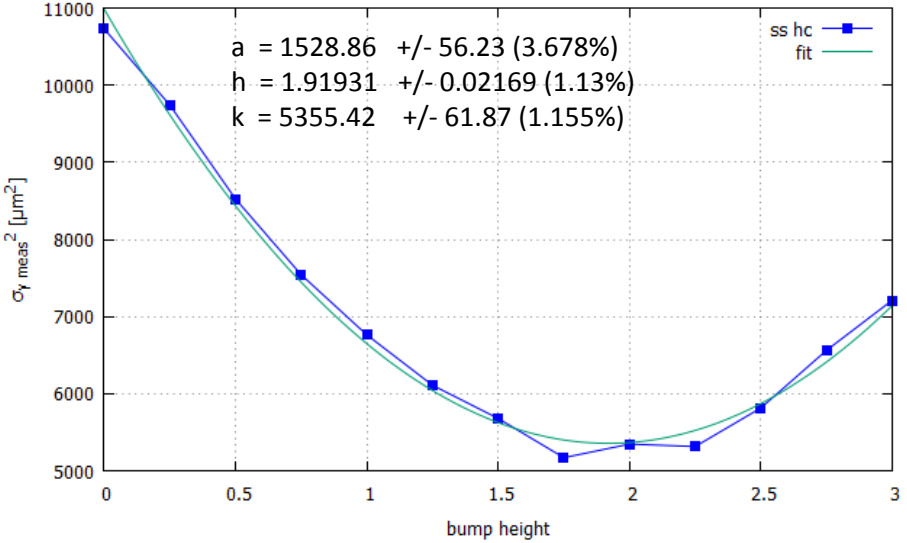
Reported/true beam size scaling factor

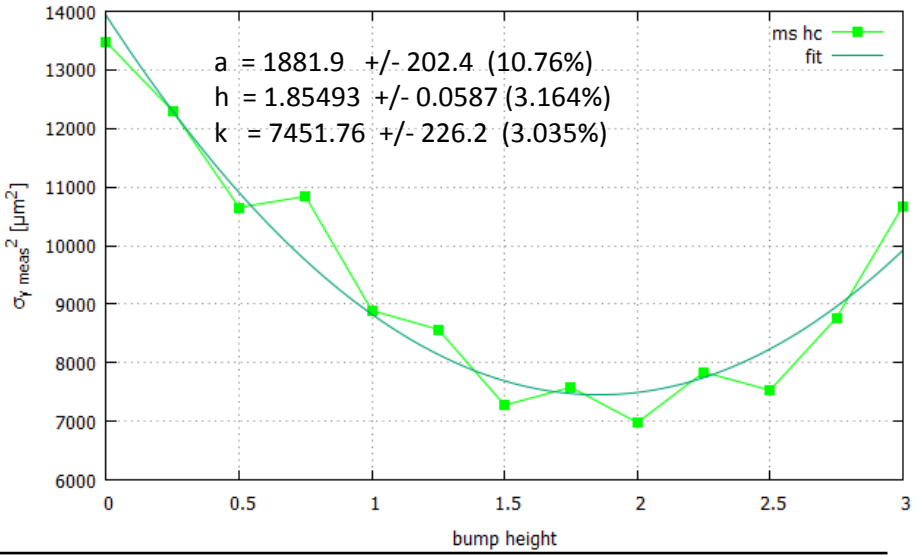
True beam size upper bound (includes possible smearing factors)

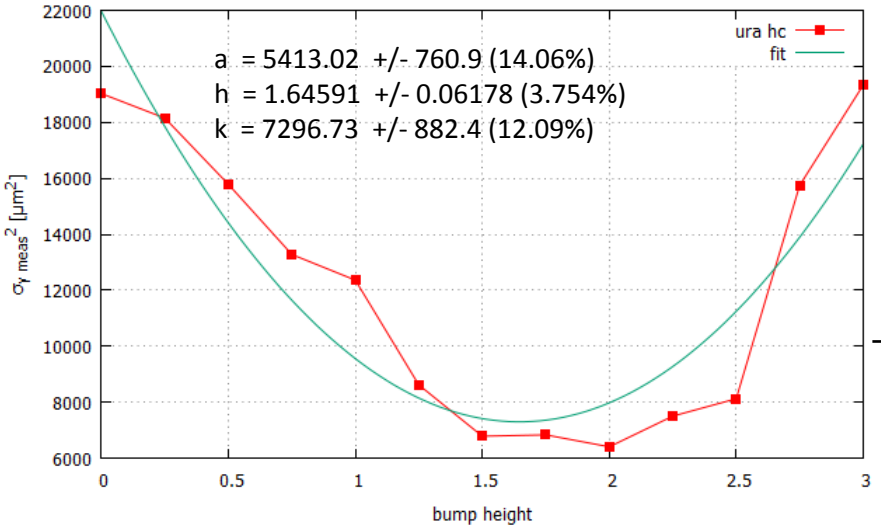
Analysis:
E. Mulyani

XRM: Emittance Knob Calibration

HER @ High Current (740-700 mA)







HC	A^2	c	σyo	ho
SS	452.74	1.8 ± 0.04	39.8 ± 0.01	1.9 ± 0.02
ms	452.74	2.0 ± 0.1	42.3 ± 0.03	1.8 ± 0.06
ura	452.74	3.4 ± 0.14	24.7 ± 0.01	1.6 ± 0.06

Reported/true beam size scaling factor

True beam size upper bound (includes possible smearing factors)

Analysis: E. Mulyani

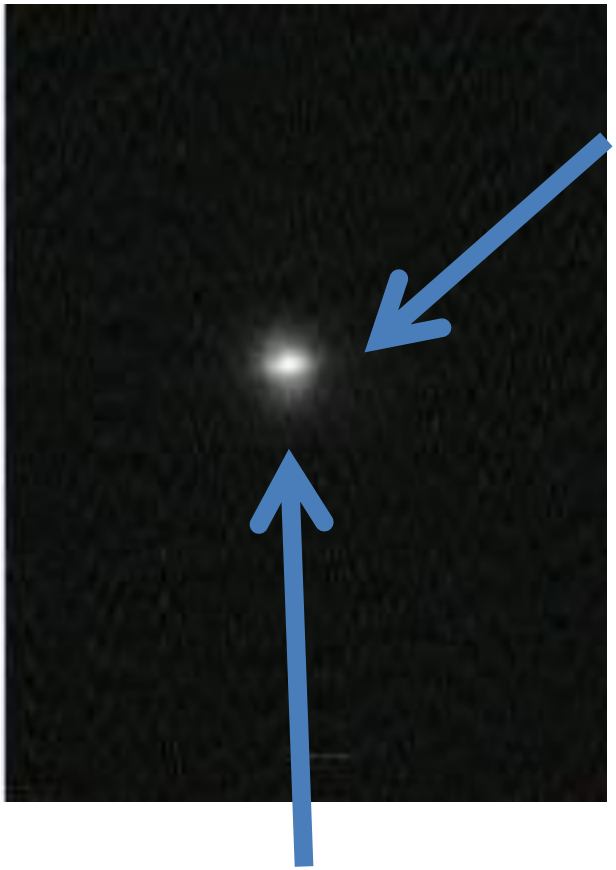
XRM: Calibration Summary

- Geometric factors seem to be well understood, to within a few percent, for both LER and HER.
- Overall performance seems reasonable for LER, and in agreement with optics.
- Issues with overall performance of HER:
  - Large reported/true scaling factors
  - Light-level dependence seen
    - Due to diffuse reflection from wall behind scintillator?
      - Wall much closer in HER than in LER
      - ➔Changing background affecting fits in HER much more than in LER?
  - Nevertheless, from overall pattern blurriness, the beam does not seem all that small, so perhaps not just a fitting problem if beam really is close to design emittance.
    - Beam tilt at source point?
    - …Scattering from walls of rotated holder?

XRM: Single-slit 2-D image

LER

HER



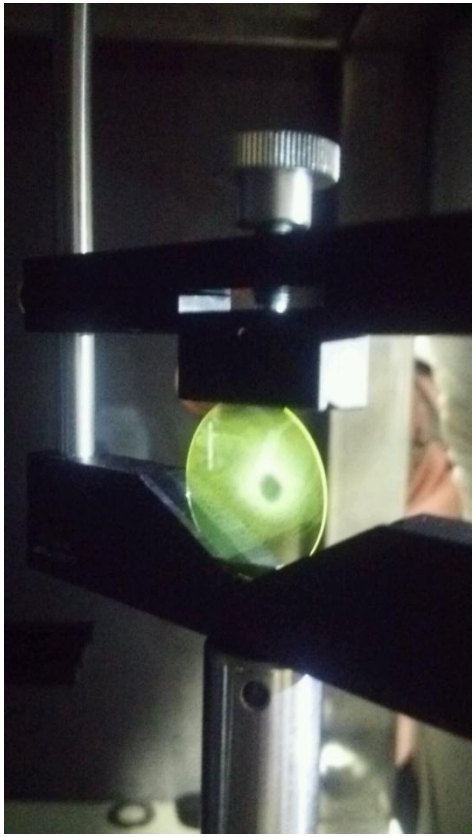
x-y tilt at source point?

Width:
Horizontal clipping due to mask holder rotation?

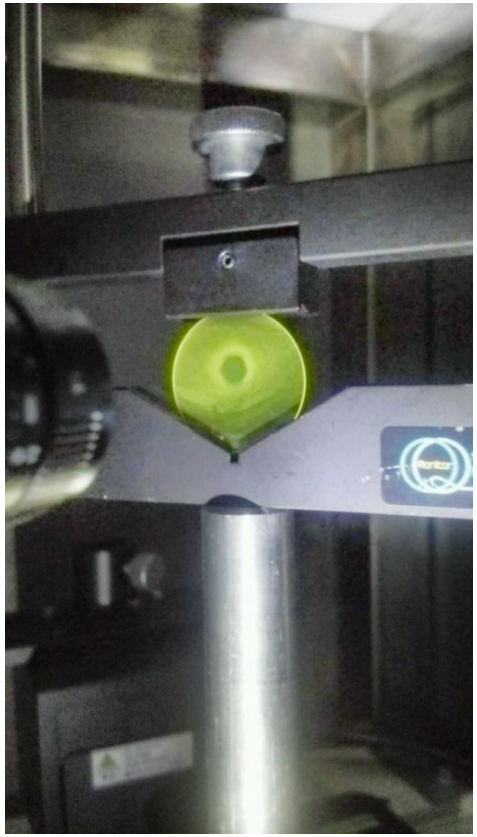
Images taken mid-March

XRM: YAG:Ce scintillators after use

LER

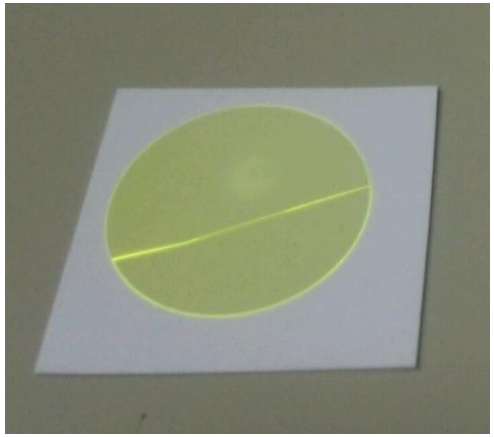


HER



XRM: YAG:Ce scintillators after abuse

Broken while cleaning



Note that some discoloration where beam hits remains even after cleaning. Would helium help reduce surface contamination build-up?

Heat shock?

After (too-rapid?) exposure to unmasked beam at 890 mA. Needs care to expose more gradually!

Visible x-ray path in air (LER, 100 mA):

XRM: To Do

- Reduce diffuse reflected background
  - Install black paper lining in optics boxes next Thursday maintenance
- Extract horizontal profiles from scintillator image for knife-edge H. size measurements (next Thursday maintenance)
- Tilt knob studies at source point (esp. HER)
- Refine model of system using raw data taken during calibration runs
  - Variations in Au depth over mask surface
  - Understanding of background sources (esp. HER)
  - More precise beam line length surveys
- Examine masks after exposure to beam
  - Especially single-slit patterns, with “dips” in measured images
    - Some kind of build-up on mask surface?
  - Evidence of holder rotation in HER?
    - If so, redesign holder to be less sensitive to rotation?
- Improve vacuum pumping ability around optics box
  - Extra NEGs?
- Get fast pixel detector and read-out going
  - Goals:
    - Phase II: 64-channel readouts with InGaAs and/or deep Si detector
    - Phase III: 128-channel readouts with deep Si detector
- Helium enclosure in detector box to minimize scattering and ozone production
- Devise cooling for scintillator in addition to detector?

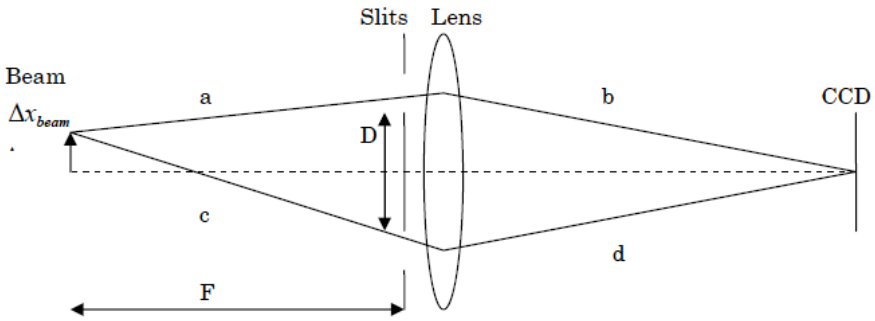
SRM: Status

- Vertical and Horizontal interferometers set up to measure vertical and horizontal beam sizes at LER and HER
- Calibration studies started
- Streak cameras set up
  - Bunch-length measurements made

SRM: Interferometers

SR Source Bend Parameter	S-LER1 (BSWFRP)	S-HER (BSWOLE)	Units
ε_x	3.20E-09	4.54E-09	m
κ	0.27%	0.25%	
ε_y	8.64E-12	1.14E-11	m
β_x	8.86	10.17	m
β_y	30.71	26.92	m
σ_x	168.4	214.9	μm
σ_y	16.3	17.5	μm
Beam Energy	4	7	GeV
Bend effective length	0.89	2.90	m
Bend angle	5.04	5.00	mrad
Bend radius ρ	179.0	580.0	m
Observation wavelength λ	4.00E-07	4.00E-07	m
SR Opening angle θ_c (λ)	1.0	0.7	mrad
Slits opening angle D/F (H)	0.2	0.2	mrad
Slits opening angle D/F (V)	0.8	0.9	mrad
Max. Visibility (H) γ_{max}	90%	90%	
Max. Visibility (V) γ_{max}	98%	98%	
Min. measurable beam size $\sigma_{x\,min}$	164.1	157.4	μm
Min. measurable beam size $\sigma_{y\,min}$	15.7	15.0	μm

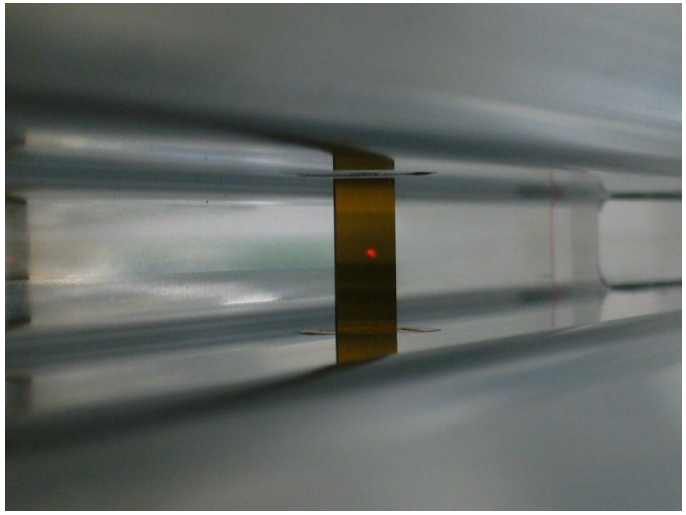
- Resolution fundamentally limited by measurement wavelength and opening angle between slits from beam (D/F).
- Max. slit separation determined by beam spread and mechanical considerations.



- Will primarily use for horizontal beam size measurements
- Vertical beam size measurement is possible with interferometers, though is near the limit of the interferometer resolution, and single-shot measurement is not possible.
  - But can be useful for cross-calibration purposes at larger beam sizes
- To minimize deformation due to heat load, will use gold-coated diamond mirrors.

SRM: Extraction mirrors and chambers

Diamond extraction mirror for visible light beam size monitor in holder

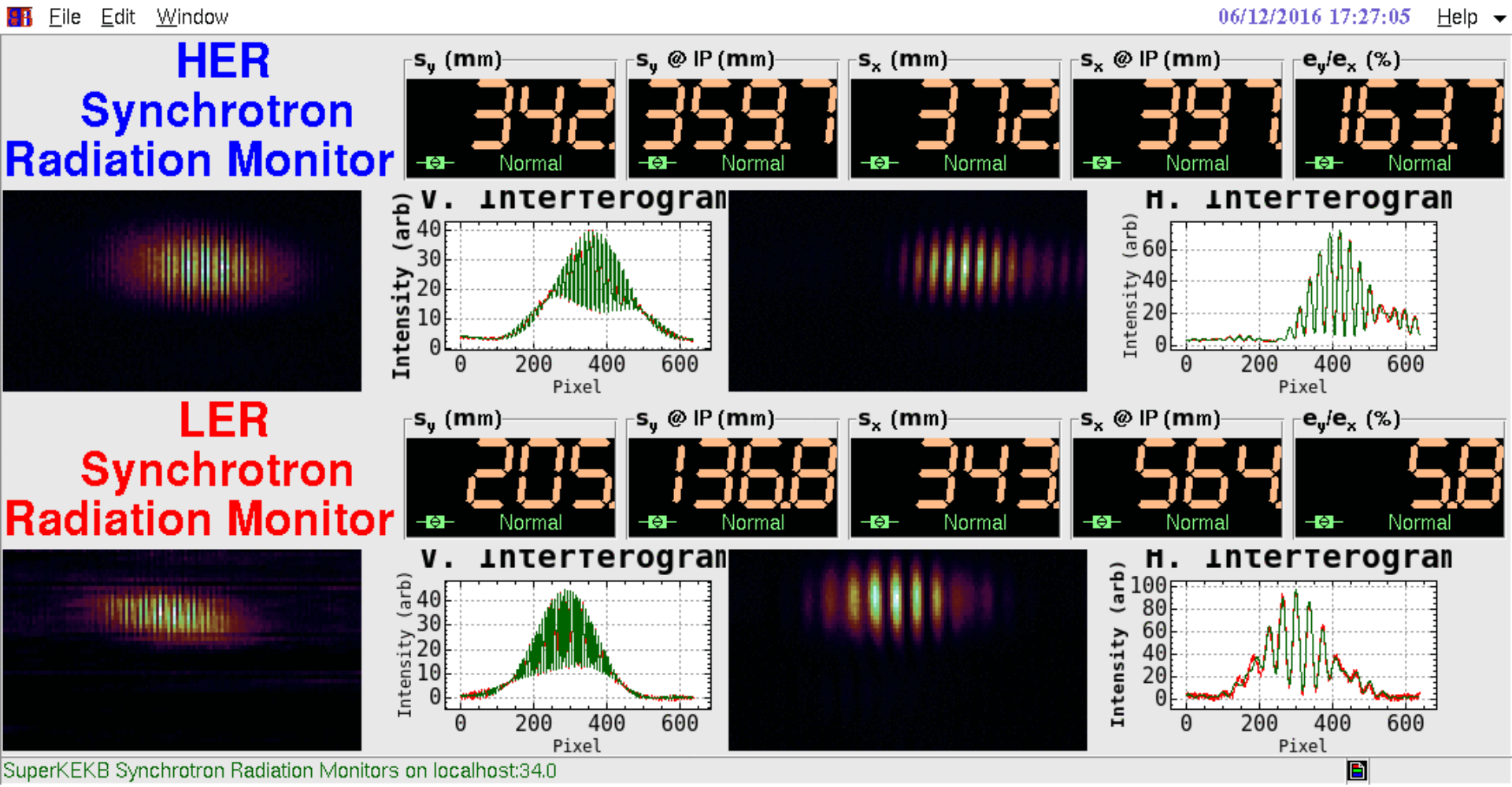


Mirror mounted in extraction chamber.

Extraction chamber installed in tunnel. (Vac. Group)

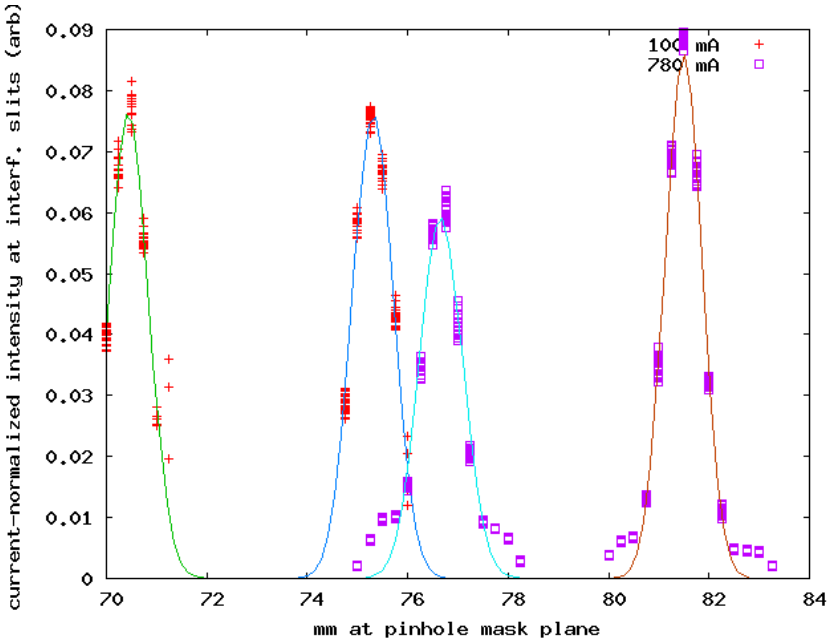
•Diamond mirrors for visible light monitors have been installed in extraction chambers and aligned.

SRM: Control room display panel

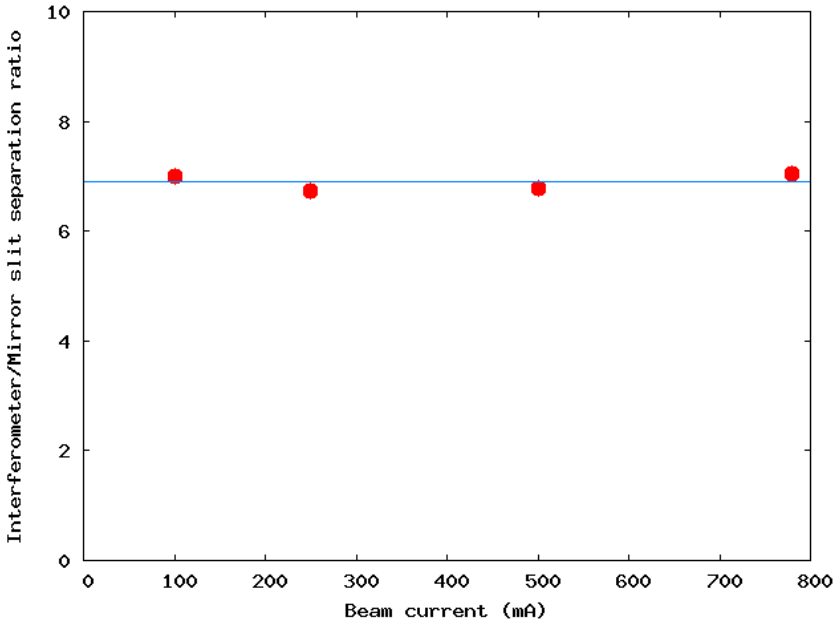


SRM: Calibration measurements

Pinhole slit scan examples: Move pinhole just downstream of extraction mirror, see where on the mirror the light comes from that hits each interferometer slit



Ratio of slit separations between interferometer slit plane and extraction mirror plane:

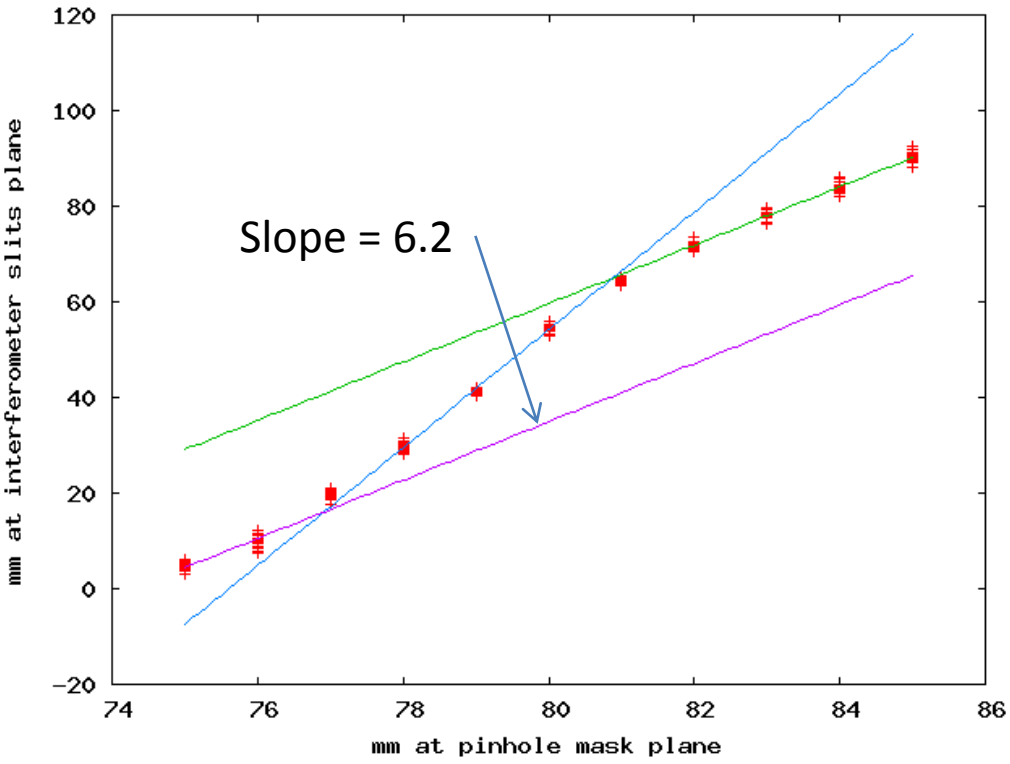


- **Magnification of system shows no beam current dependence up to 780 mA!**
  - **This is exactly what we had hoped for by using the diamond mirrors.**
  - **Will it persist up to full beam currents?**

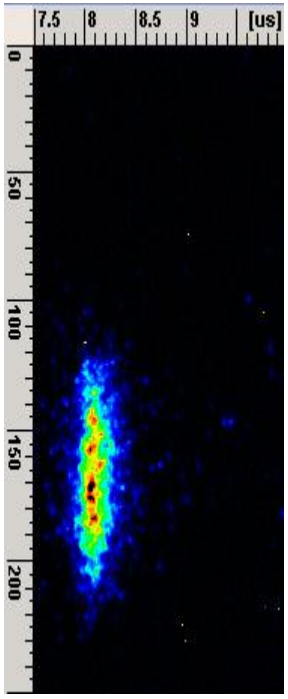
SRM: Calibration measurements

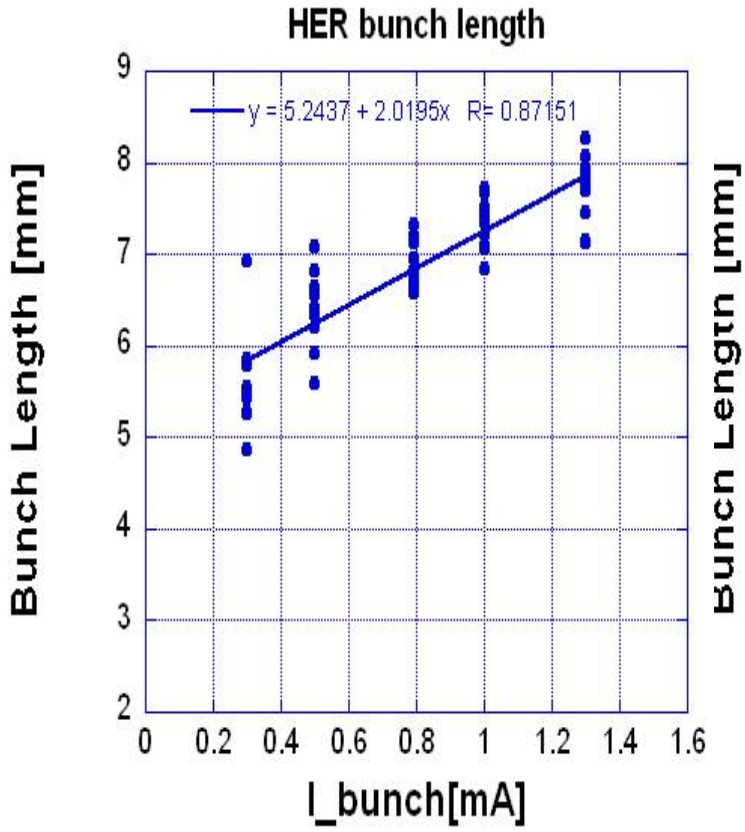
- But, there is a mystery: Why is the slit ratio so large?
  - Measured ratio between slit separation at interferometer plane and mirror plane is ~6.9 at HER, ~5.8 at LER.
  - Geometrically, it should only be about a factor of ~2.5-3…
    - Source point -> mirror = ~24 m in both LER and HER
    - Mirror -> interferometer = <~40 m in both LER and HER
  - …if all mirrors and windows in system are flat
  - …and if distances are correct
    - Are we conceivably not looking at the correct source point? Seems hard to believe…

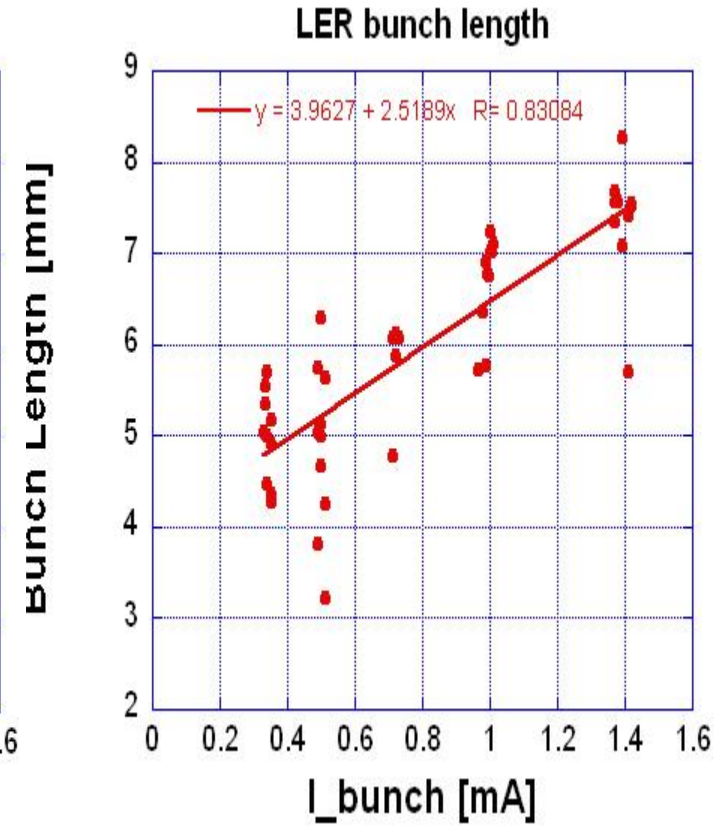
Projection of pinhole at interferometer plane as it is scanned across surface of mirror:

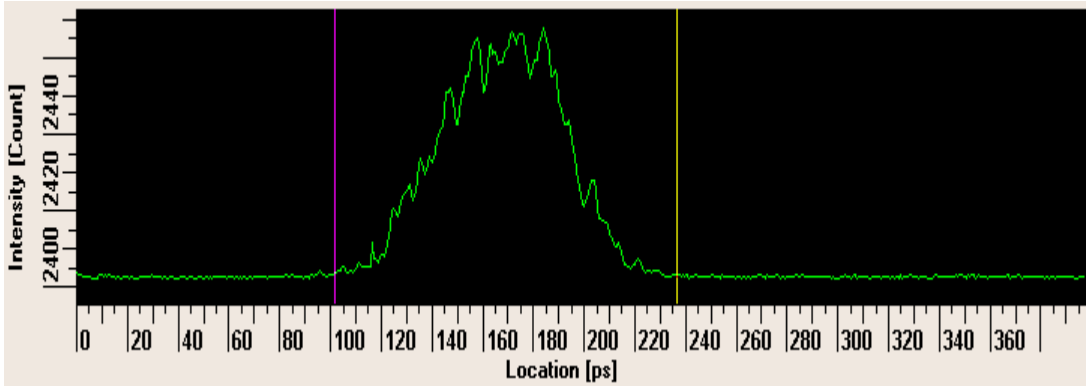


SRM: Bunch Length Measurement with Streak Camera









Pilot bunch

LER: 200-shot integration
HER: 10-shot integration

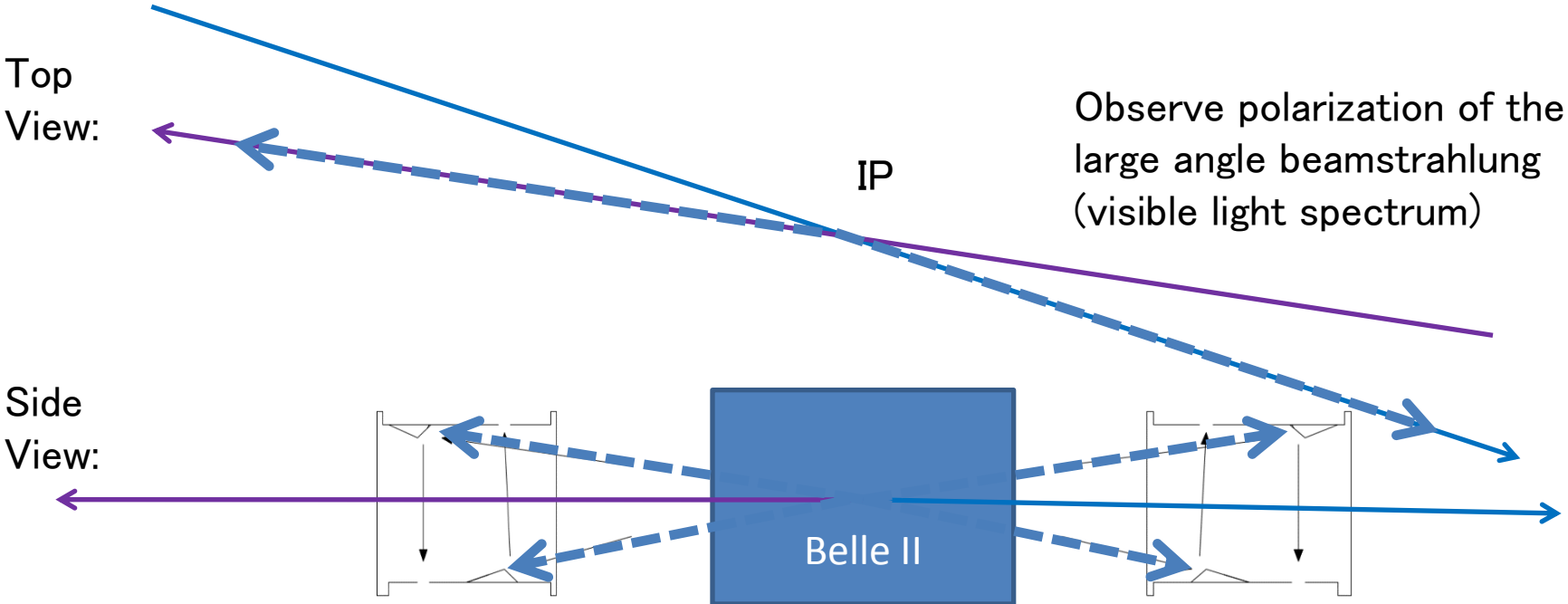
(2016/6/10, Ikeda)

SRM: To Do

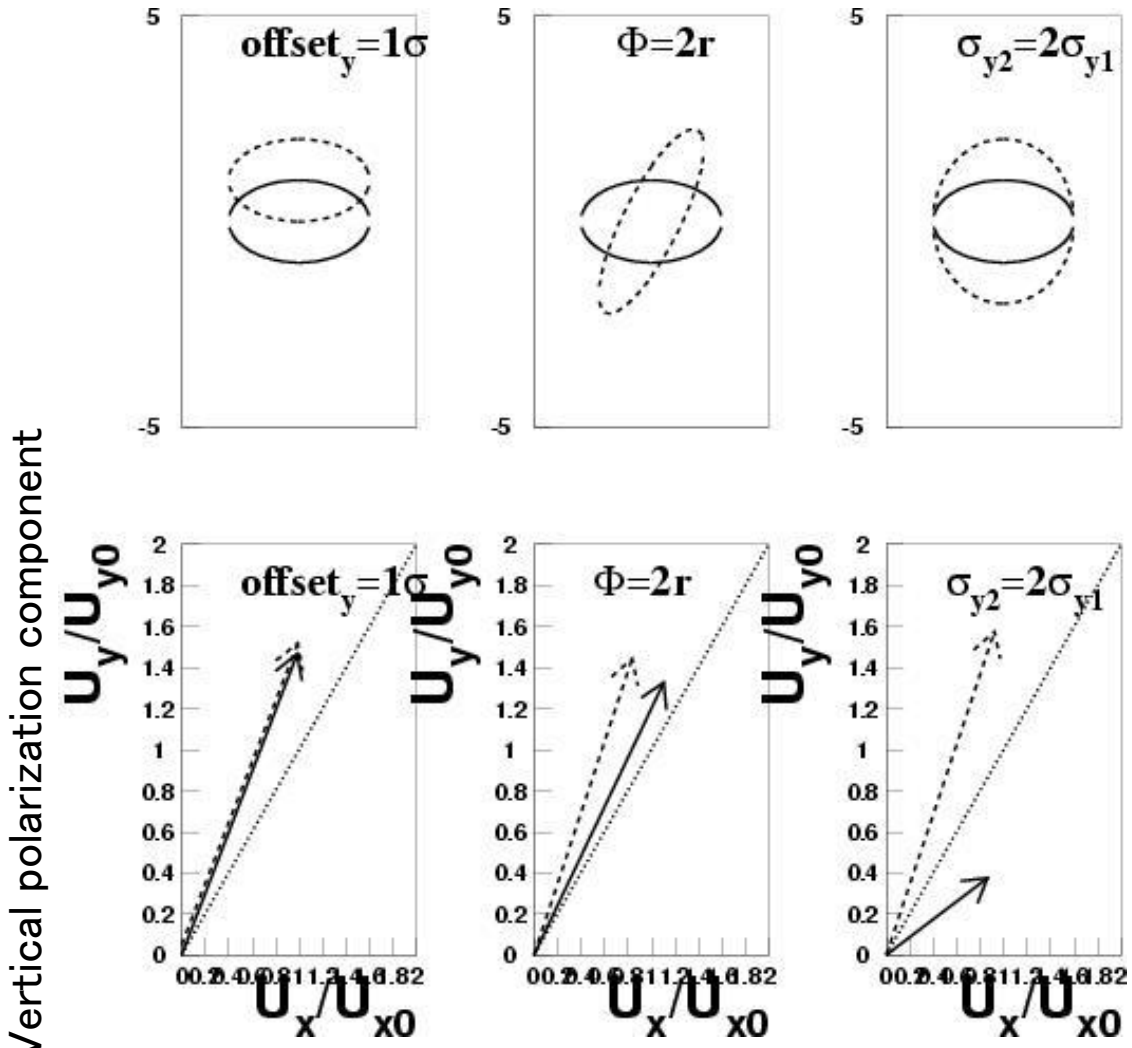
- Investigate higher-than-expected slit ratio of system:
  - Remove masking from pinhole plates next Thursday maintenance, take images of whole mirror shape (and at different beam currents)
  - Local bumps at all components between mirrors and source bends to rule out incorrect source
  - Inject laser from source point to measure slit ratio? (Post-Phase I)
- Investigate shift of optical axis seen in HER, but not in LER.
- Consider possible solutions for low light intensity at streak cameras
  - Wider mirrors, plus full-beam mode might suffice at HER?
    - Mirror width limited by technical capabilities of manufacturer
    - Don’t share with interferometers when using streak camera?
  - …shorter bend radius source magnet at LER…?

LABM: Large-Angle Beamstrahlung Monitor for SuperKEKB (Wayne State U., Mexico City U., Tabuk U. (Saudi Arabia))

- Beamstrahlung: Radiation emitted by the particles in one beam due to the bending force of the EM field of the other colliding beam. Many similarities with SR but also some substantial difference due to very short “magnet”.
- Beamstrahlung <u>polarization</u> at specific azimuthal points provides unique information about the beam-beam geometry.



LABM: Principle



Simulation studies: Examples of beam-beam patterns which could be extracted from the signal reconstruction. Ux and Uy are the x- and y-components of the polarized Beamstrahlung powers [beam 1(2): Solid (Dashed) line]. U0: Power of the perfect beam.

G. Bonvicini

LABM Status

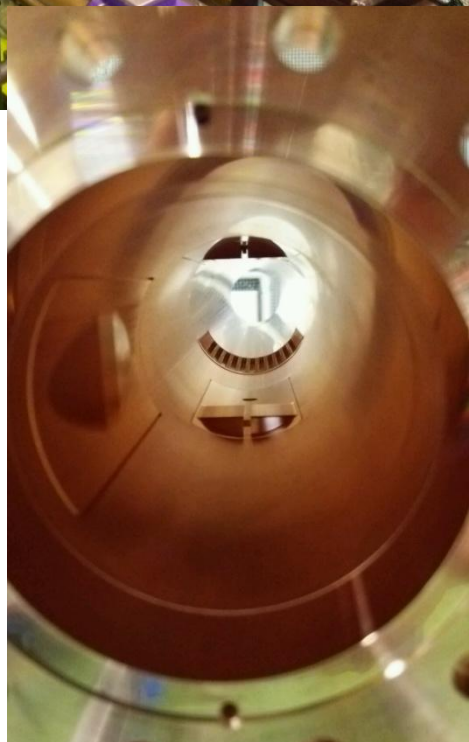
- LABM beam lines and optics boxes installed at IR.
- DAQ and EPICS records developed for Phase I
  - Stand-alone – not yet integrated into accelerator operations.
- Measurements made with beam, using synchrotron light from far side of IP.
  - Measurements being made to refine models of beam line.

LABM Beamlines

Left (Nikko) side

Right (Oho) side

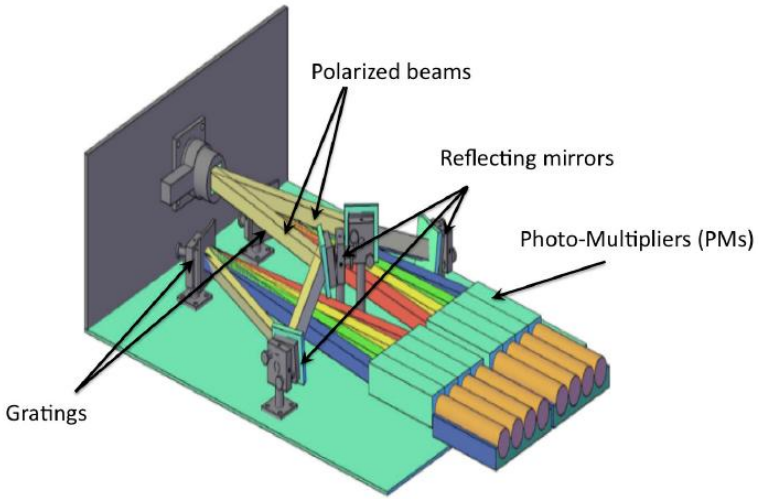
Test fit of LABM extraction mirror (left) and extraction window (right) on IR beam pipe.



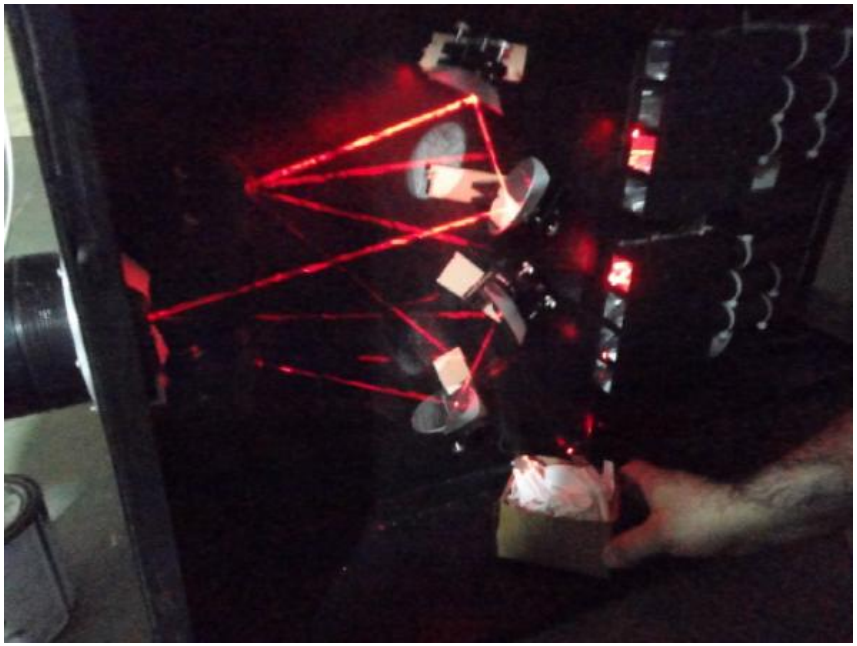
Inside view of LABM extraction mirror inside HOM-protection slot in IR beam pipe.

LABM

Schematics of the optical box

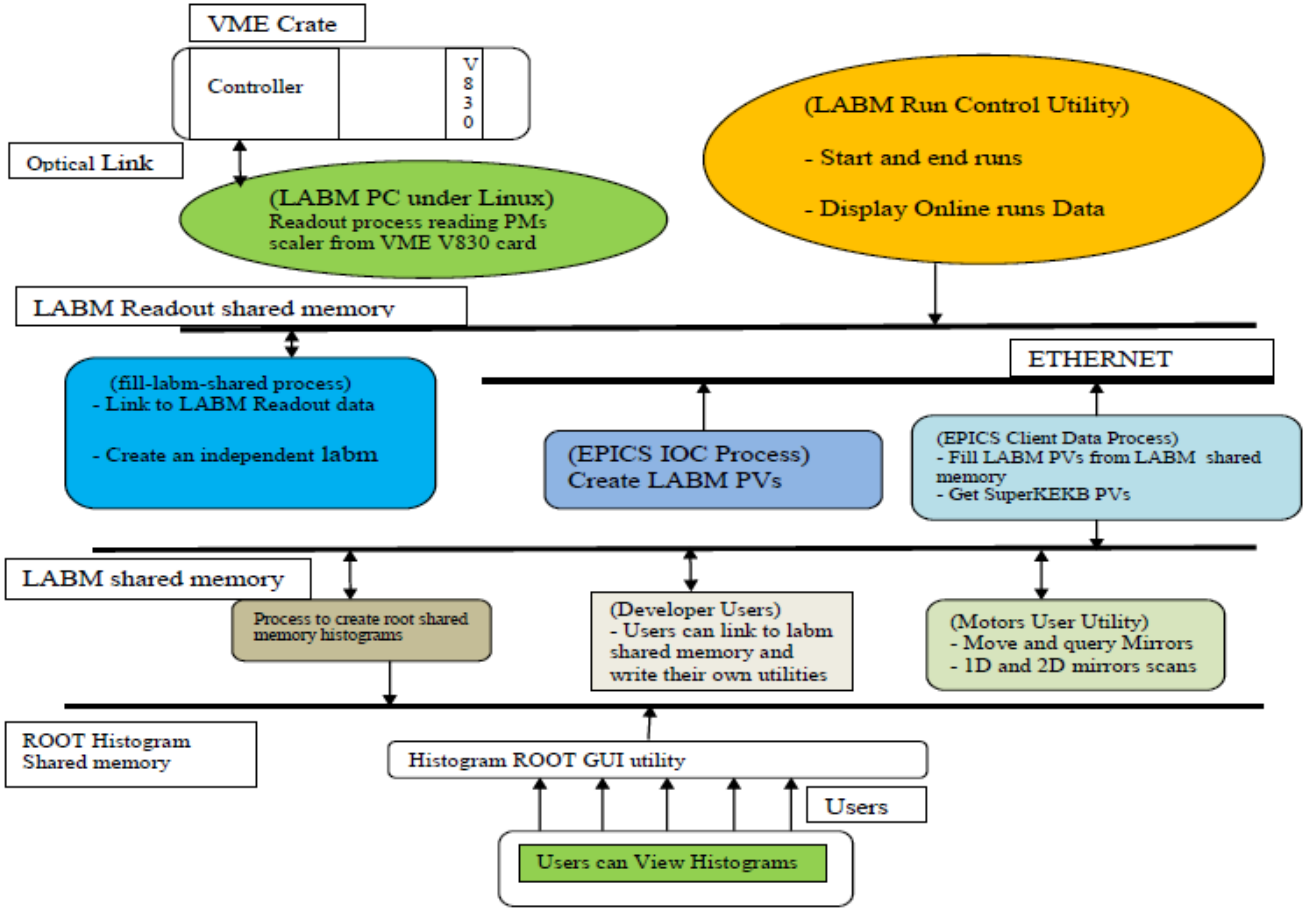


The constructed optical box



G. Bonvicini

LABM



- LABM DAQ Structure

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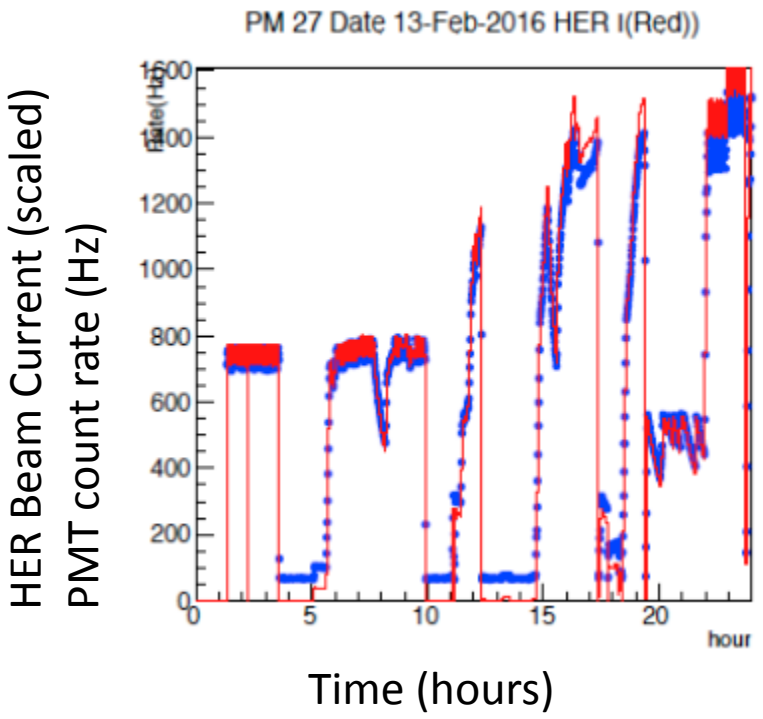
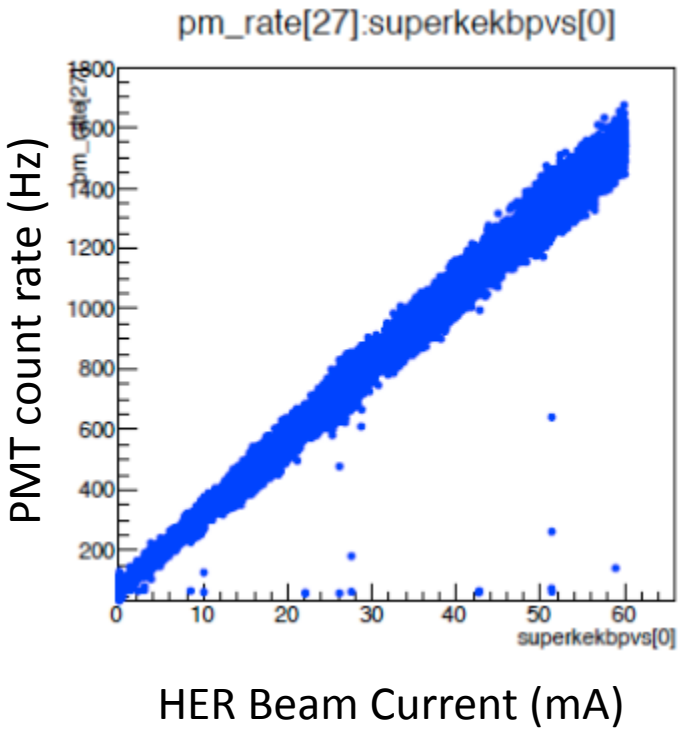
LABM





- Rate versus current for one of the LABM PMTs.

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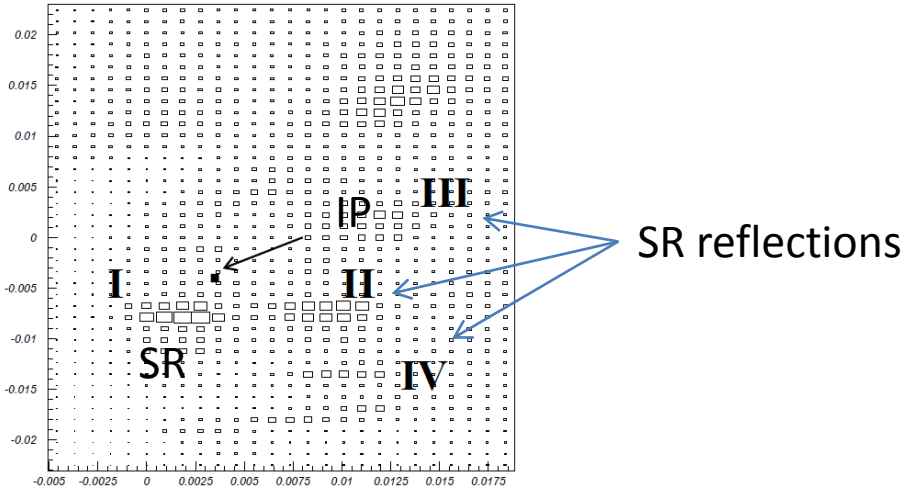
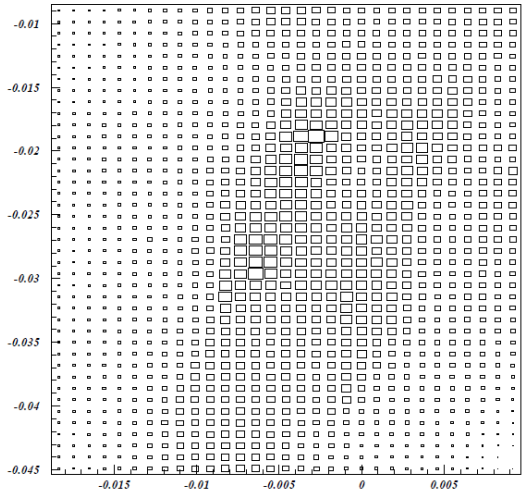
LABM: Data taking with SR from other side of IP

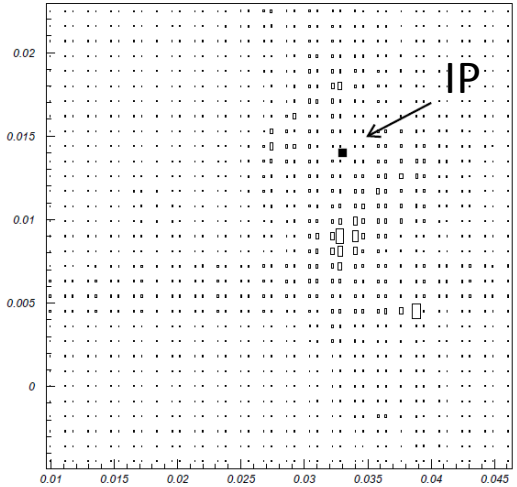
Nikko Down angular scan with “red“ PMT.



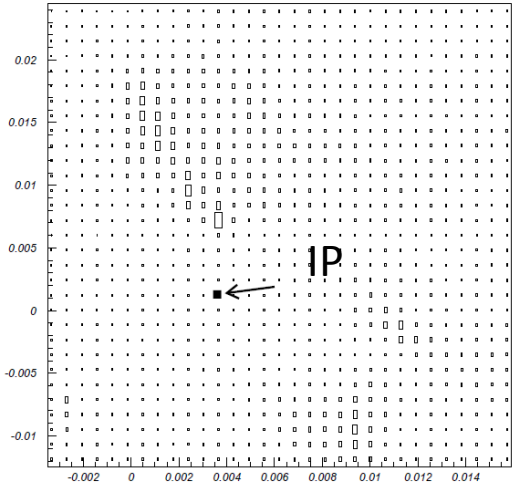
Nikko Up angular scan with “red" PMT.



Oho Down angular scan with “red" PMT.



Oho Up angular scan with “red" PMT.



G. Bonvicini

LABM: To Do

- Dismantle beamline above tunnel-floor level at conclusion of Phase I
- Re-install beamline just before Phase II turn on
- Modify some components based on experience at Phase I
  - Wollaston prism alignment, beam pipe lengths, …
  - Further development of readout system.

Summary

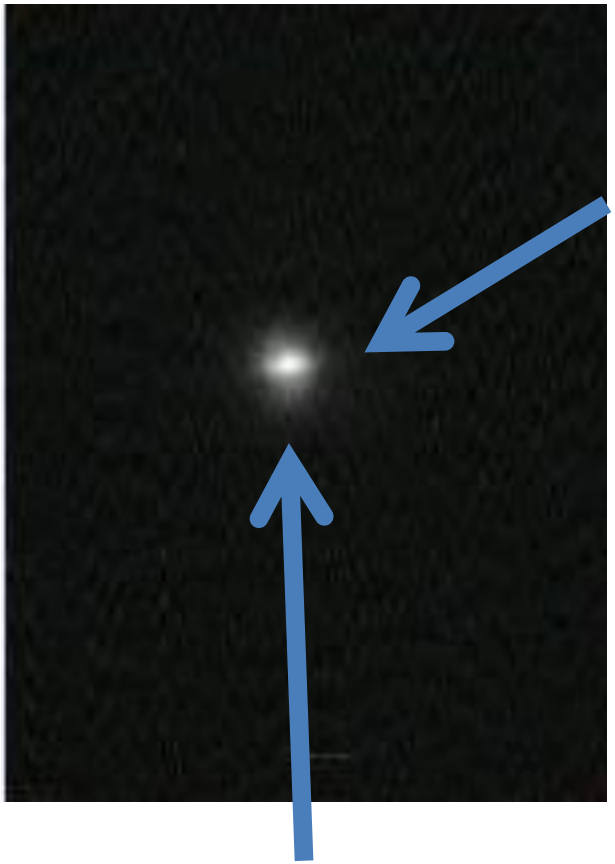
- Photon monitors have undergone first round of commissioning.
- Basic functionalities demonstrated.
  - LER XRM looks to be reasonably well-understood, and in agreement with optics group's estimates.
  - Diamond SRM mirrors show excellent performance in terms of lack of sensitivity to beam current.
  - LABM measuring SR from other side of IP.
- Systematics issues undergoing further analysis
  - HER XRM:
    - Excessive scattered light background on scintillator images?
    - Beam tilt at source point?
  - SRM higher than expected geometric magnification in system
- Hardware issues identified to work on between Phase I and Phase II.

Spares

シンチレーターで見るシングルスリットのイメージ

LER

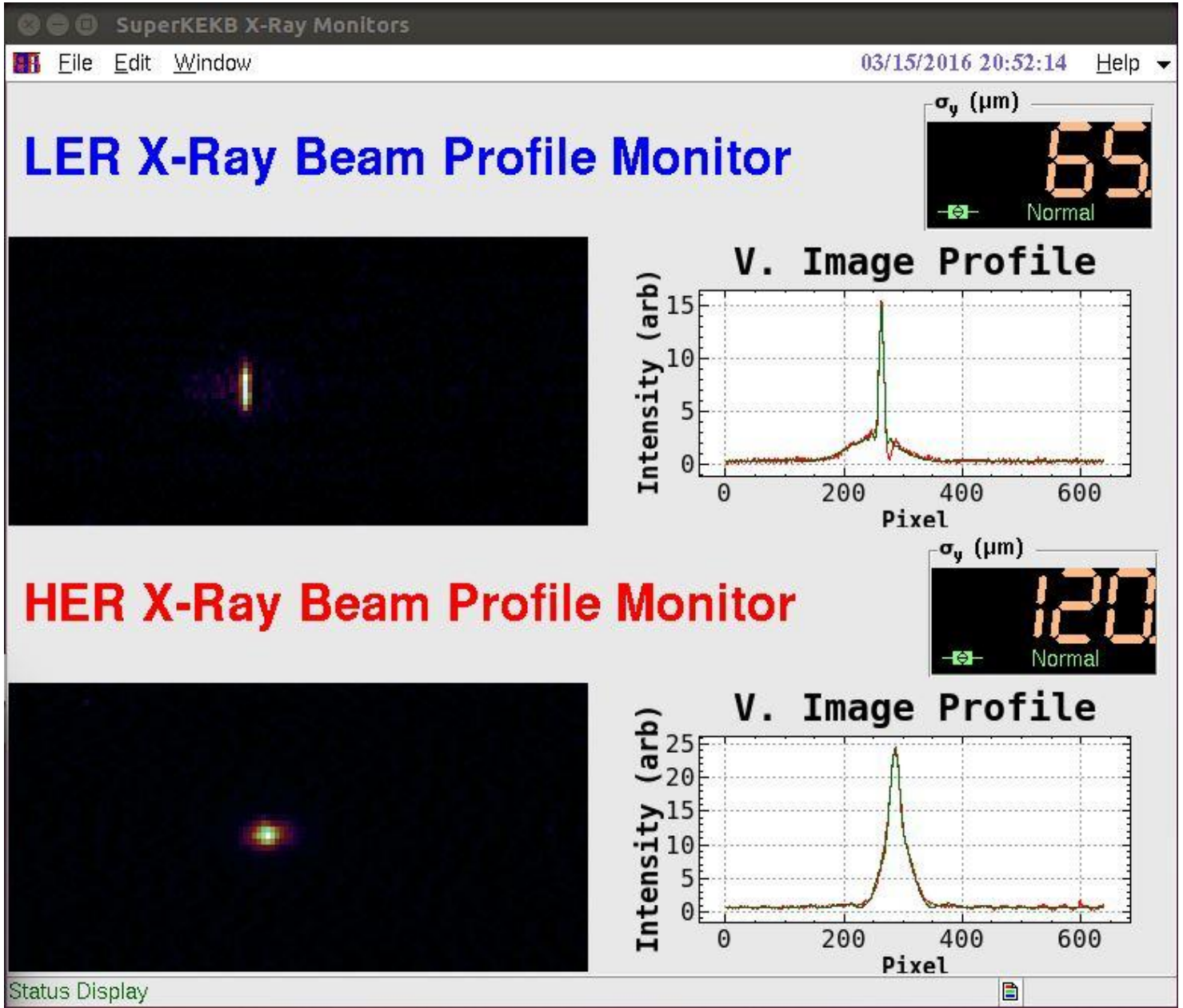
HER



傾き:
光原点で
x－y
カプリング？

幅:
マスクホルダーの回転
（今日調整する予定）

x 線モニターのパネル


SuperKEKB X-Ray Monitors
File Edit Window
03/15/2016 20:52:14
Help
LER X-Ray Beam Profile Monitor
σy (μm)
65
Normal
V. Image Profile
Intensity (arb)
Pixel
HER X-Ray Beam Profile Monitor
σy (μm)
120
Normal
V. Image Profile
Intensity (arb)
Pixel
Status Display

Machine Parameters

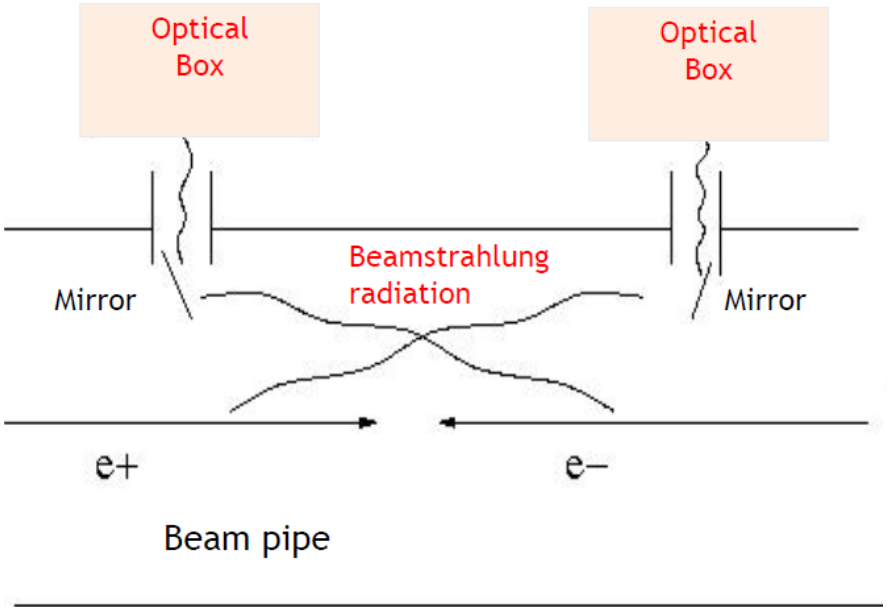
2013/July/29	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28	%	includes beam-beam

- LER:
  - β_y＝67m
  - σ_y＝65μm
  - ➔ε_y＝63pm
    - κ_{xy}＝～3．3%

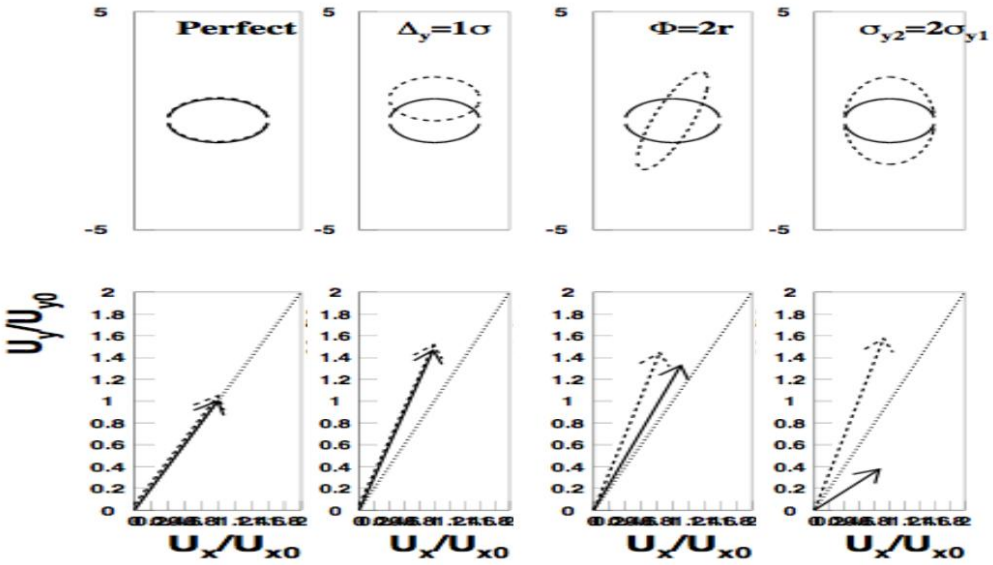
    （ゼロカレントのε_x設計値を使う時）
- HER:
  - β_y＝10m
  - σ_y＝120μm
  - ➔ε_y＝1440pm
    - κ_{xy}＝～33%

    （ゼロカレントのε_x設計値を使う時）

Large-Angle Beamstrahlung Monitor (LABM)



Schematics of the Large Angle Beam Monitor to be installed at SuperKEKB.



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