# Photon Monitors & Loss Monitors at SuperKEKB

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SuperKEKB Review

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# Photon Monitors

- SRM: Synchrotron Radiation Monitor (MR, DR)
  - Visible light monitor. Interferometer, streak, gated camera, etc.
  - MR: $\sigma_z$, $\sigma_x$ ($\sigma_y$)
  - DR: $\sigma_z$, $\sigma_x$, $\sigma_y$
- XRM: X-ray Monitor (MR)
  - Pinhole, URA mask, etc.
  - $\sigma_y$ ($\sigma_x$)
- 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.
- Energy measurement based on inverse Compton scattering (MR)
  - Not needed for Phase 1
  - In preliminary planning stages with SLAC.
  - Interest expressed by BINP as well.
  - Will not discuss in this talk.

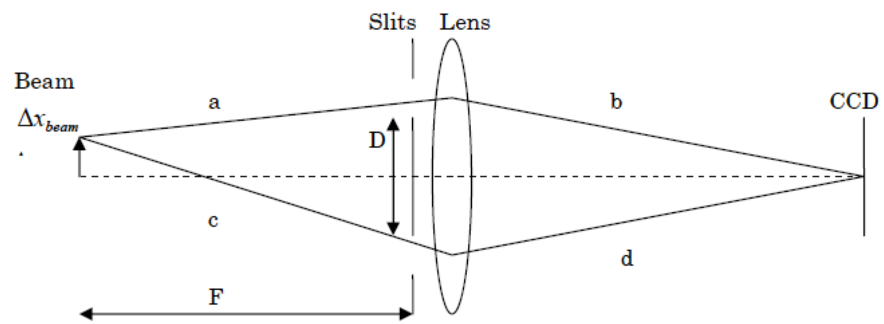
# Loss Monitors

- MR
  - Ion chambers and PIN diodes for monitoring and machine protection (~half are interlock inputs).
- DR
  - Ion chambers for loss detection for beam tuning (not part of interlock system).

# MR SRM: Interferometers

| SR Source Bend Parameter | S-LER1 (BSWFRP) | S-HER (BSWOLE) | Units |
|---|---|---|---|
| $\varepsilon_x$ | 3.20E-09 | 4.60E-09 | m |
| $\kappa$ | 0.27% | 0.24% | |
| $\varepsilon_y$ | 8.64E-12 | 1.10E-11 | m |
| $\beta_y$ | 29.98 | 32.49 | m |
| $\sigma_y$ | 16.1 | 18.9 | µm |
| Beam Energy | 4 | 7 | GeV |
| Bend effective length | 0.89 | 2.90 | m |
| Bend angle | 5.04 | 5.00 | mrad |
| Bend radius $\rho$ | 179.0 | 580.0 | m |
| Observation wavelength $\lambda$ | 4.00E-07 | 4.00E-07 | m |
| SR Opening angle $\theta_c$ ($\lambda$) | 1.0 | 0.7 | mrad |
| Slits opening angle D/F | 0.8 | 0.9 | mrad |
| Max. Visibility (fringe depth) $\gamma_{max}$ | 98% | 97% | |
| Min. measurable beam size $\sigma_{y\ min}$ | 15.7 | 18.5 | 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.

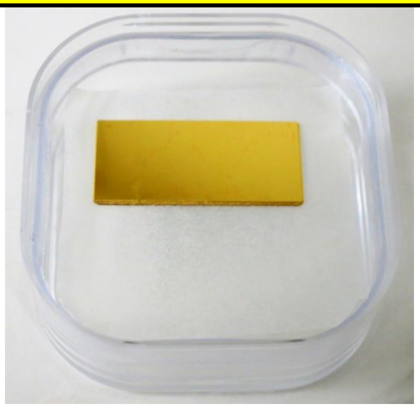



- Will primarily use for horizontal beam size measurements
- Vertical beam size measurement is possible with interferometers, though is near the limit of the interferometer resolution, and single-shot measurement is not possible.
    - But can be useful for cross-calibration purposes at larger beam sizes
- To minimize deformation due to heat load, will use gold-coated diamond mirrors.
- Cavities below optics hut floors in D4 and D8 klystron galleries have been filled to reduce the amount of floor vibration, which had been a problem during KEKB operation.

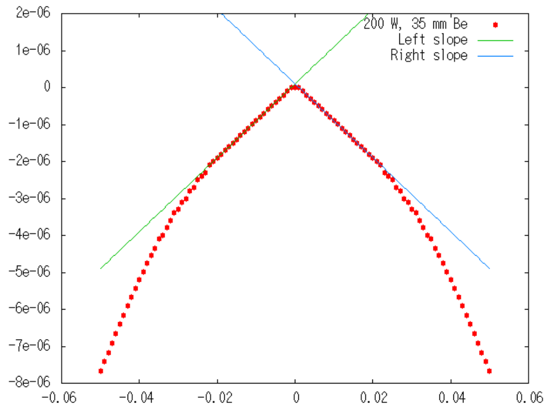
# MR SRM: Diamond Mirrors

| Parameter | KEKB | | SuperKEKB | |
|---|---|---|---|---|
| | LER | HER | LER | HER |
| Energy (GeV) | 3.5 | 8 | 4 | 7 |
| Current (A) | 2 | 1.4 | 3.6 | 2.6 |
| Bending radius (m) | 85.7 | 580 | 177.4 | 580 |
| SR Power (W/mrad) | 48 | 136 | 72 | 149 |

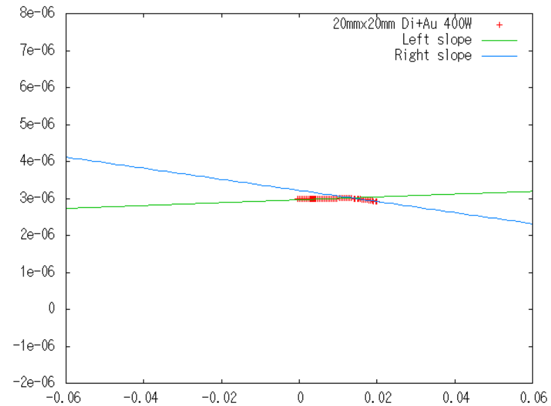
- Monocrystalline diamond:
  - Developed by Cornes Technology
  - 9 mm x 27 mm quasi-monocrystalline CVD diamond substrate.
  - Surface: 1 μm Au, with thin Cr layer below that.
  - Diamond surface is (nearly) a single crystal, so good surface flatness expected (Ra ~ 2 nm, <~λ/50)
  - Very good heat conductance and low thermal expansion coefficient makes apparent change in magnification smaller than that of Be mirrors used at KEKB:
    - Beryllium: δmagnification = 43% @ HER full current
    - Diamond: δmagnification = 3% @ HER full current



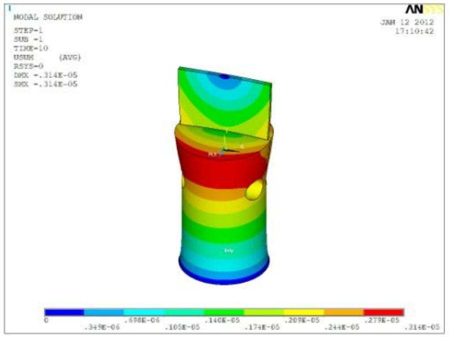
Diamond mirror




Mirror surface distortion due to 200W of SR power at center of Be mirror




Mirror surface distortion due to 400W of SR power at center of Au+Dia mirror

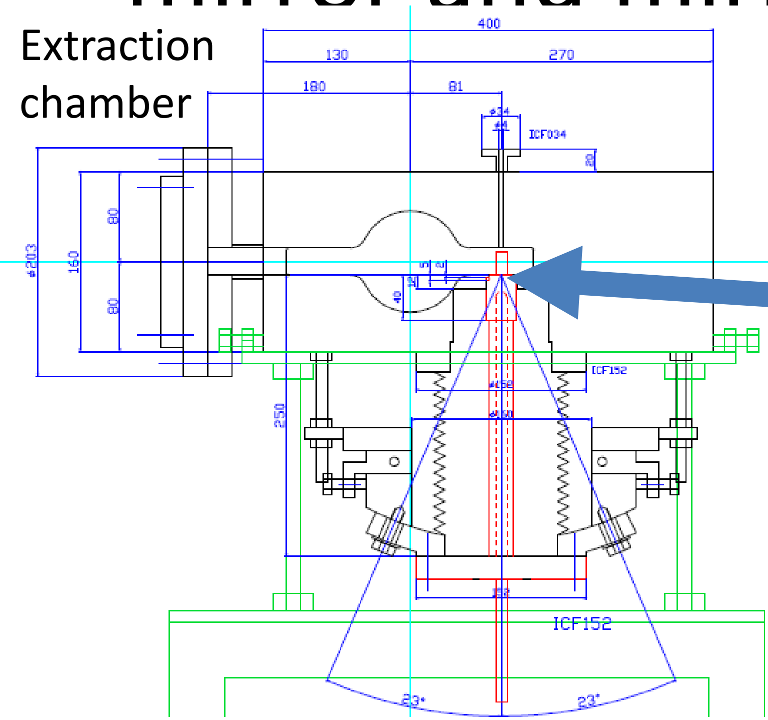


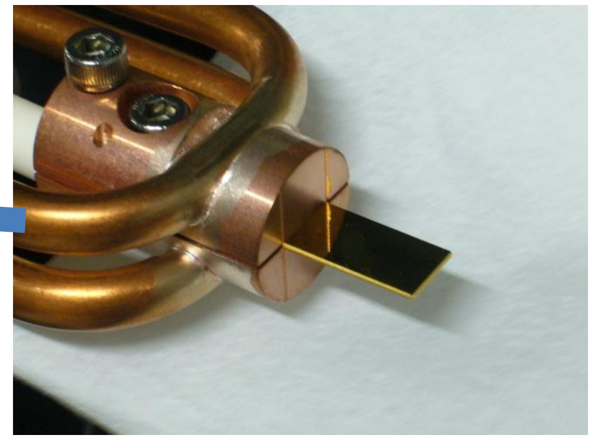

Diamond mirror surface distortion due to 400W of SR power

ANSYS simulations: M. Arinaga

# MR SRM: Extraction chamber, mirror and mirror holder

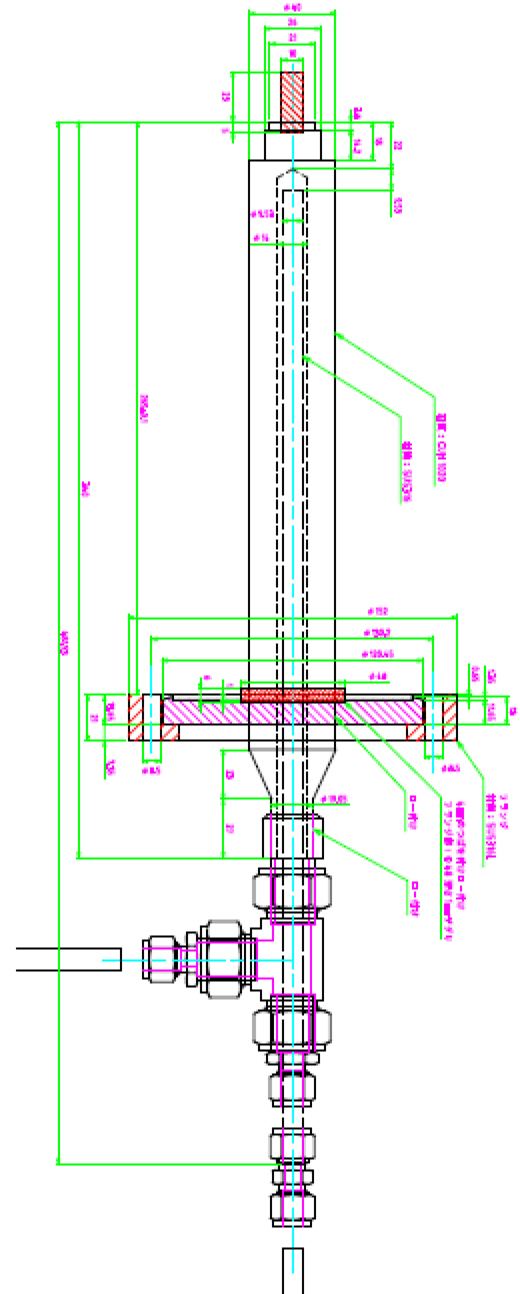
Extraction chamber



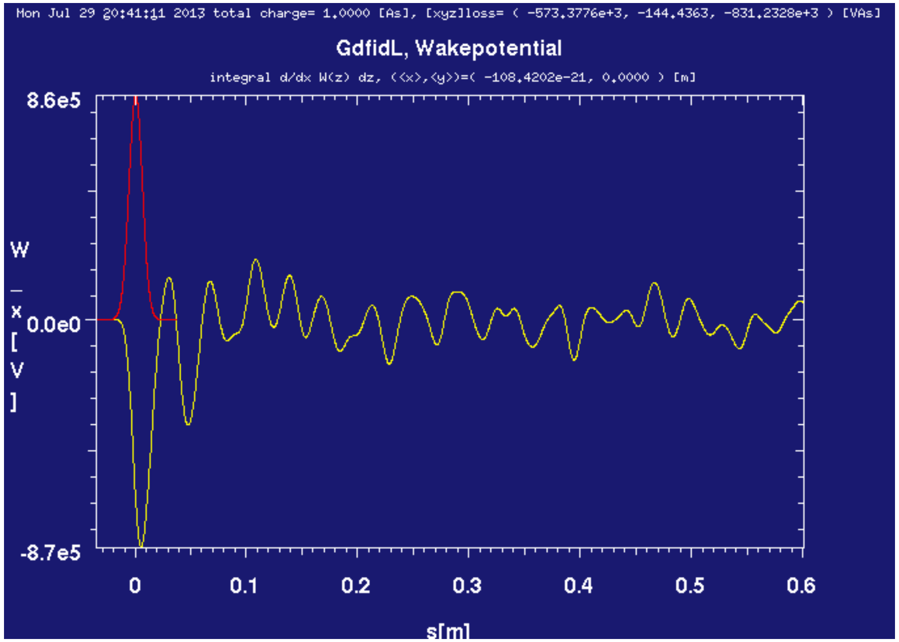
Mirror and mirror holder prototypes

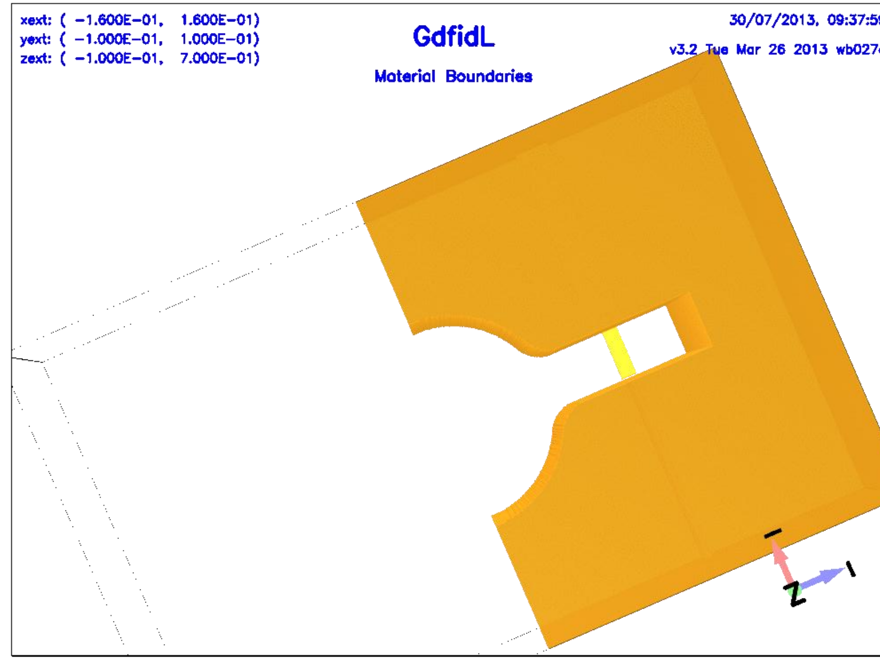
- Final mirror holder design:
  - Borrowed “cooling jet” feature from CesrTA x-ray optics heatsink
  - Mechanically simpler, good heat transfer
  - In fabrication now
- Mirrors in fabrication now
  - 9 mm (W) x 28 mm (H) x 0.8 mm (D)
    - 3 monocrystalline joined segments
  - 1 um Au surface

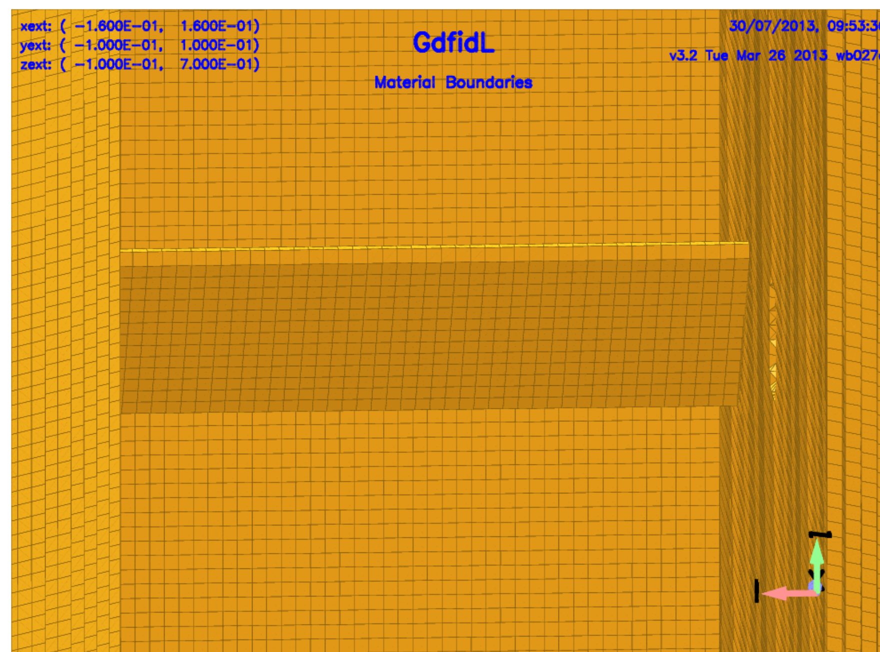


Mirror holder final design (in fabrication)

# MR SRM: Extraction Chamber




- Mirror set in 24 mm-high antechamber
- Loss factor: k = 0.8e-6 V/pC
- P = I^2 k Tb
  - I = 3.6 A
  - Tb = 4 ns
  - ➔ P = 41 mW

# MR SRM: Schedule

- Hut flooring has been strengthened to reduce vibrations. HER hut expanded.
- Vacuum components designed and in fabrication (or already fabricated):
  - Extraction chambers (vacuum group)
  - Mirrors
  - Mirror holders
  - Extraction windows
- Optical transport lines from tunnel to surface to be installed starting from April 2014.
  - Largely re-using KEKB components, with some modifications to reach new chamber location.
- Vacuum components to be installed, optical transport lines aligned, and above ground optical components to be reconstructed by Phase 1 turn-on
- From Phase 1 turn-on:
  - Commissioning of SRM

# XRM: Coded Aperture Imaging

Technique developed by x-ray astronomers using a mask to modulate incoming light. Resulting image must be deconvolved through mask response (including diffraction and spectral width) to reconstruct object. Open aperture of 50% gives high flux throughput for bunch-by-bunch measurements. Heat-sensitive and flux-limiting monochromator not needed.

We need such a wide aperture, wide spectrum technique for shot-by-shot (single bunch, single turn) measurements.

Source distribution:

$$\begin{bmatrix} A_\sigma \\ A_\pi \end{bmatrix} = \frac{\sqrt{3}}{2\pi}\gamma\frac{\omega}{\omega_c}\left(1+X^2\right)(-i)\begin{bmatrix} K_{2/3}(\eta) \\ \frac{iX}{\sqrt{1+X^2}}K_{1/3}(\eta) \end{bmatrix},$$

where

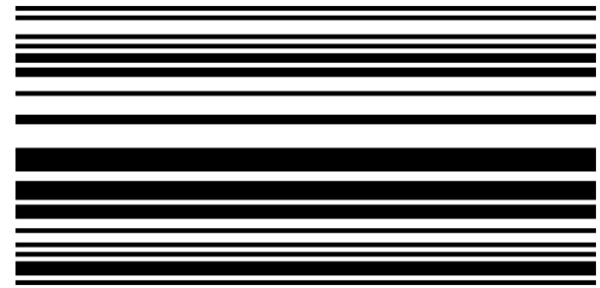
$$X = \gamma\psi,$$

+

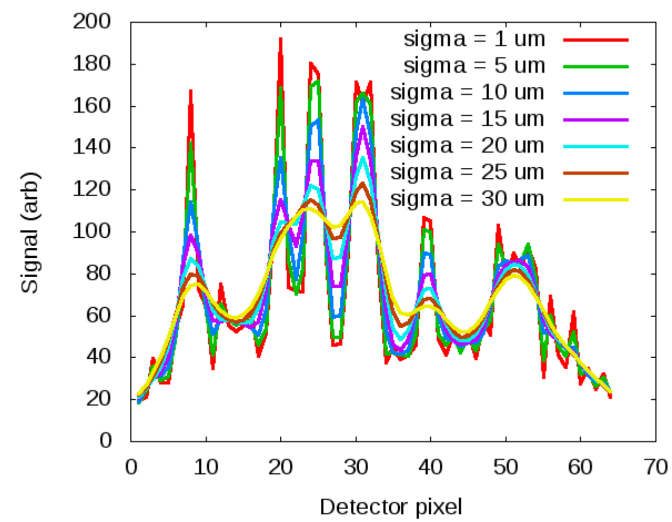
$$\eta = \frac{1}{2}\frac{\omega}{\omega_c}\left(1+X^2\right)^{3/2},$$

Kirchhoff integral over mask (+ detector response) → Detected pattern:

$$A_{\sigma,\pi}(y_d) = \frac{iA_{\sigma,\pi}(\text{source})}{\lambda}\int_{\text{mask}}\frac{t(y_m)}{r_1 r_2}e^{i\frac{2\pi}{\lambda}(r_1+r_2)} \times\left(\frac{\cos\theta_1+\cos\theta_2}{2}\right)\mathrm{d}y_m,$$

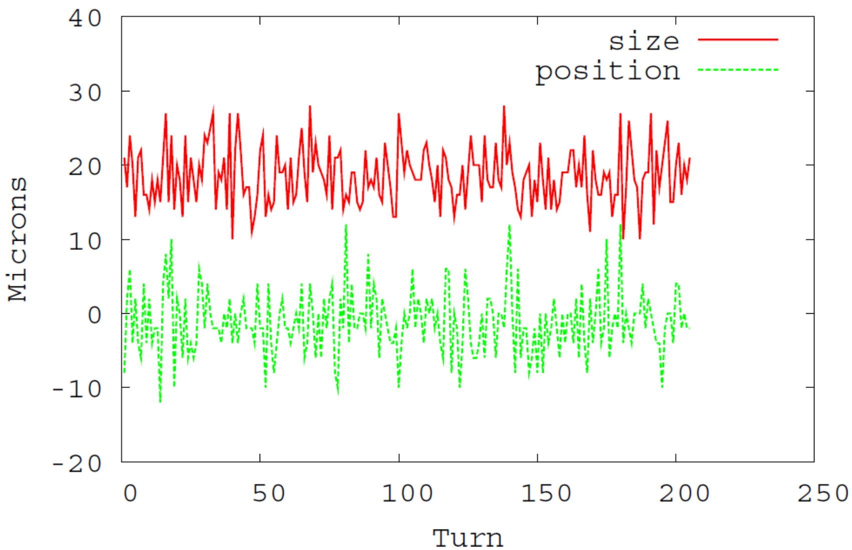


Uniformly Redundant Array (URA) for x-ray imaging to be used at SuperKEKB

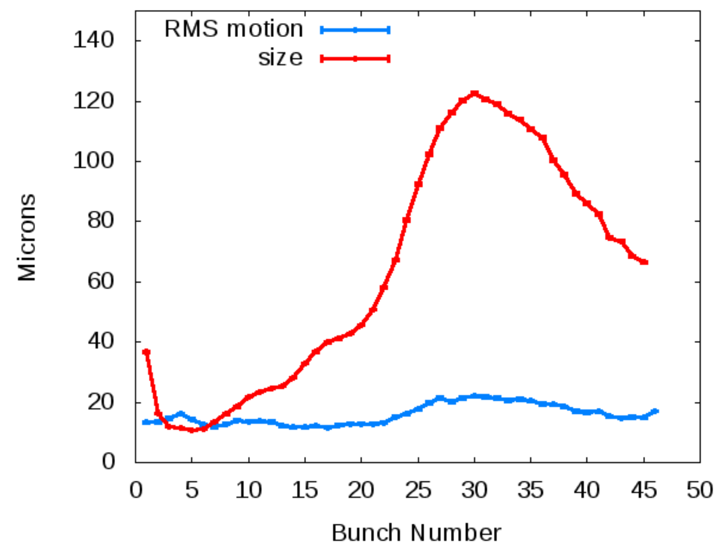



Simulated detector response for various beam sizes at SuperKEKB LER

# XRM: Coded Aperture tests at CesrTA

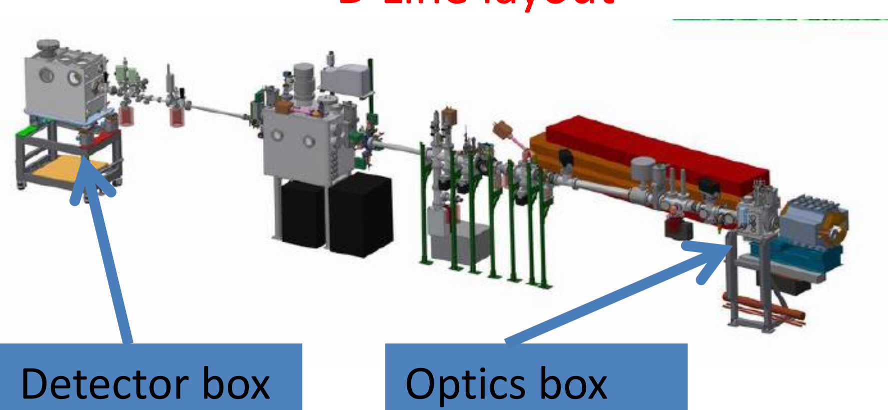



Example of turn-by-turn size and position data (one bunch out of train)

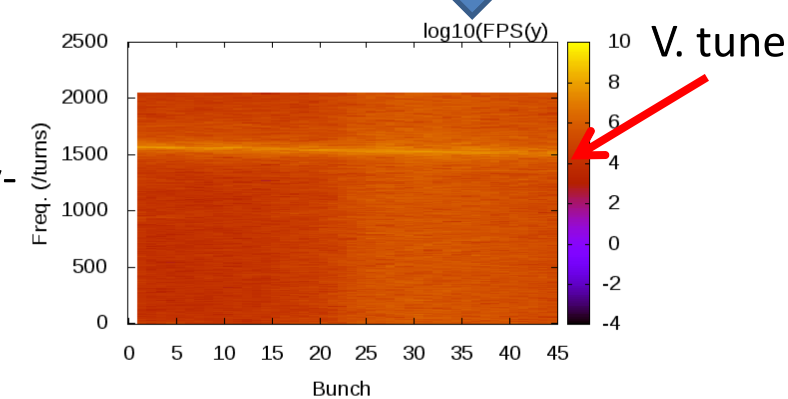



Example of bunch-by-bunch data (electron-cloud blow-up study data)
Single-shot data average for each bunch

D Line layout



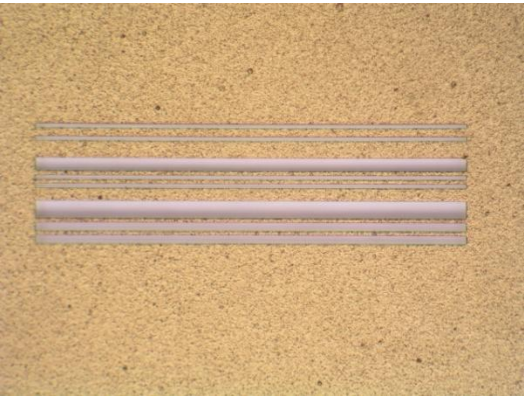

Bunch-by-bunch position spectra



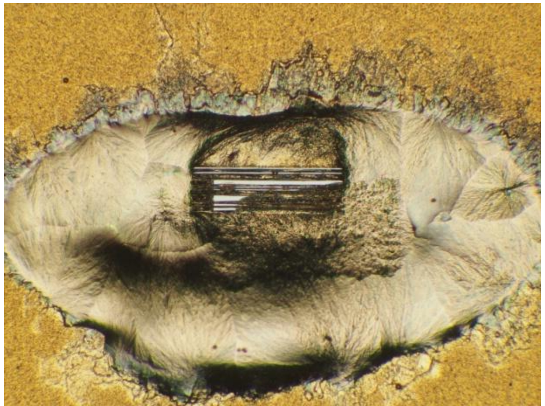
# XRM: Coded Aperture tests at CesrTA

- High-energy mask high-power tests:
  - Au+Si mask tested at 120% of SuperKEKB LER SR power load
    - Melted!
    - Au+Si mask survived at 100% previously.
  - Au+CVD (diamond) mask tested in April 2013
    - **Survived 120% LER power load**
  - Applicable improvements in heat sink design identified -- will change design for SuperKEKB.
- High-energy mask imaging tests
- Detector: Gained familiarity with characteristics of Fermionics InGaAs pixel detector

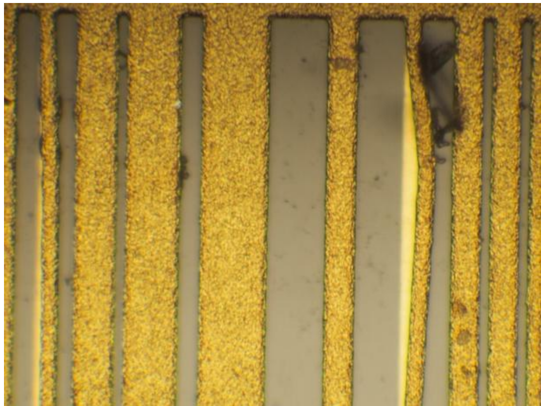
Au+Si mask after 100% SuperKEKB equivalent power:



Au+Si mask after 120% SuperKEKB equivalent power:

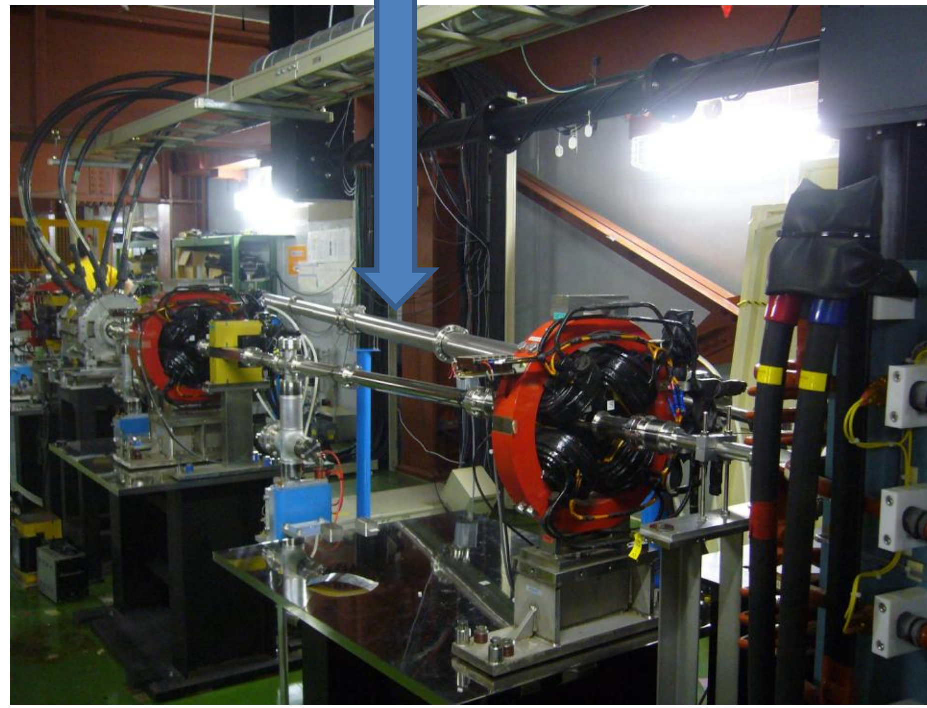


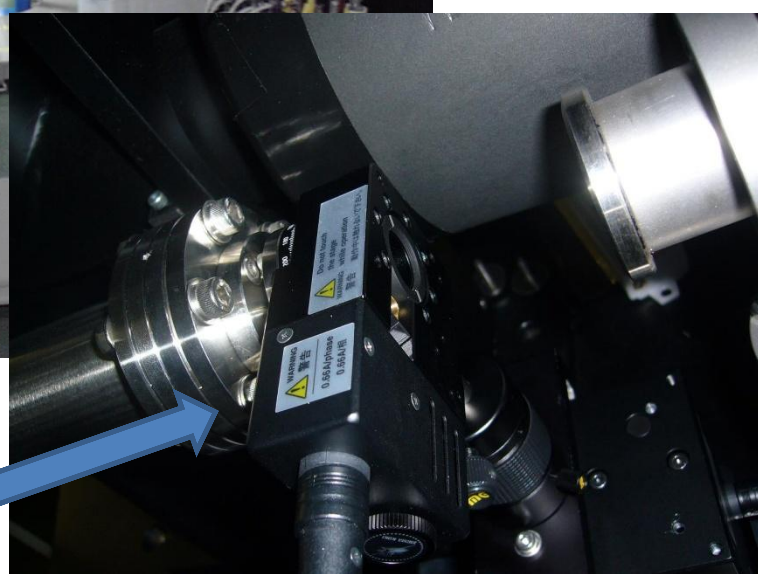
Factory-damaged Au+CVD mask for burn test:



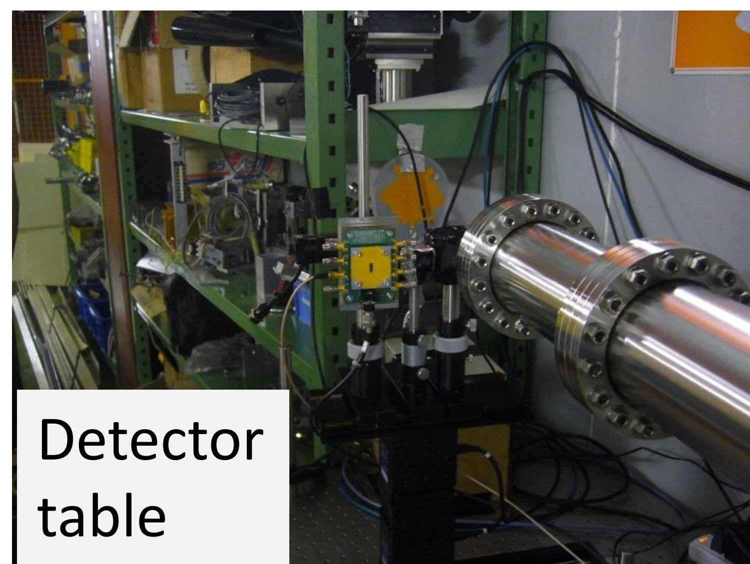
# XRM: Tests at ATF2 beam line

During construction





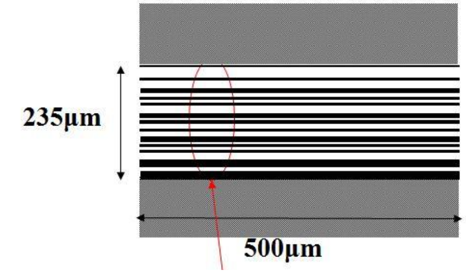
Rotating mask holder

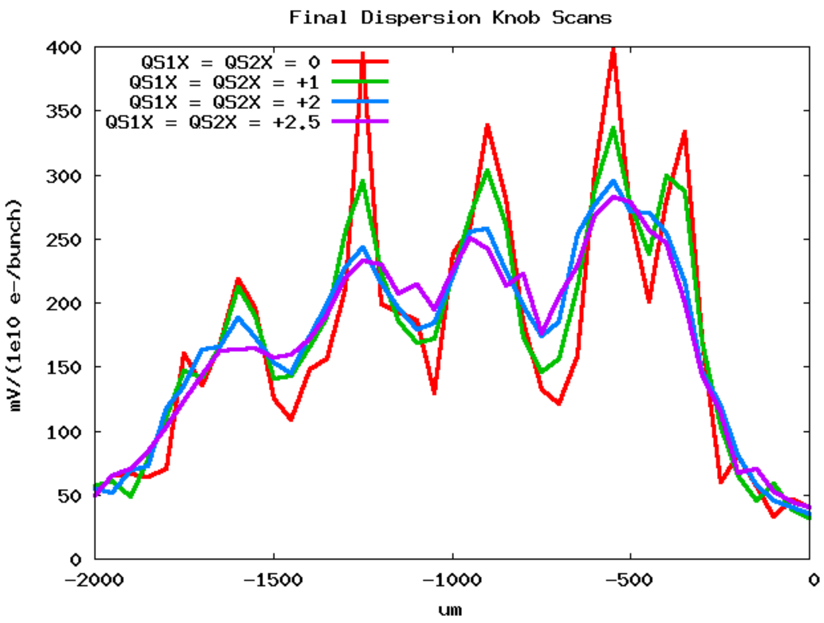


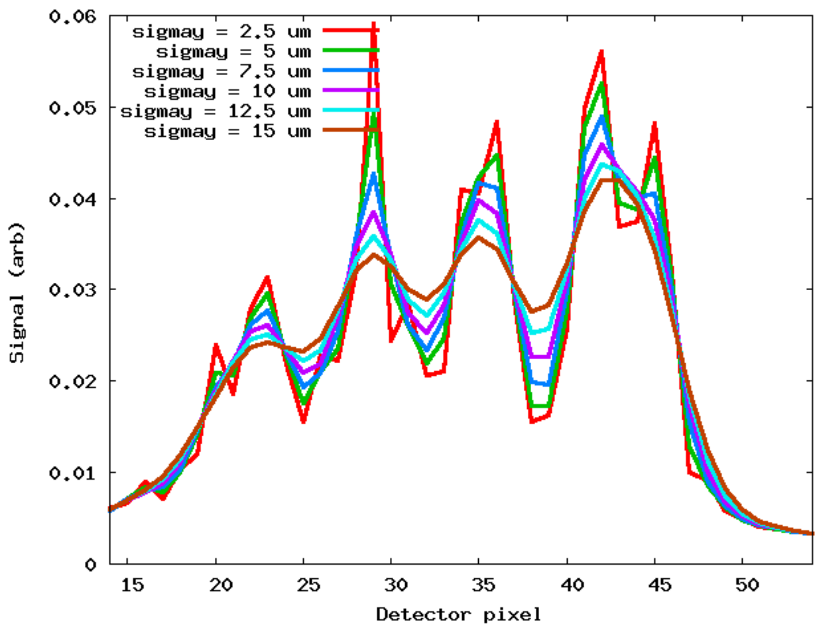
Detector table

# XRM: Coded Aperture tests at ATF2

**Data: Dispersion Knob Scans** **Simulations**

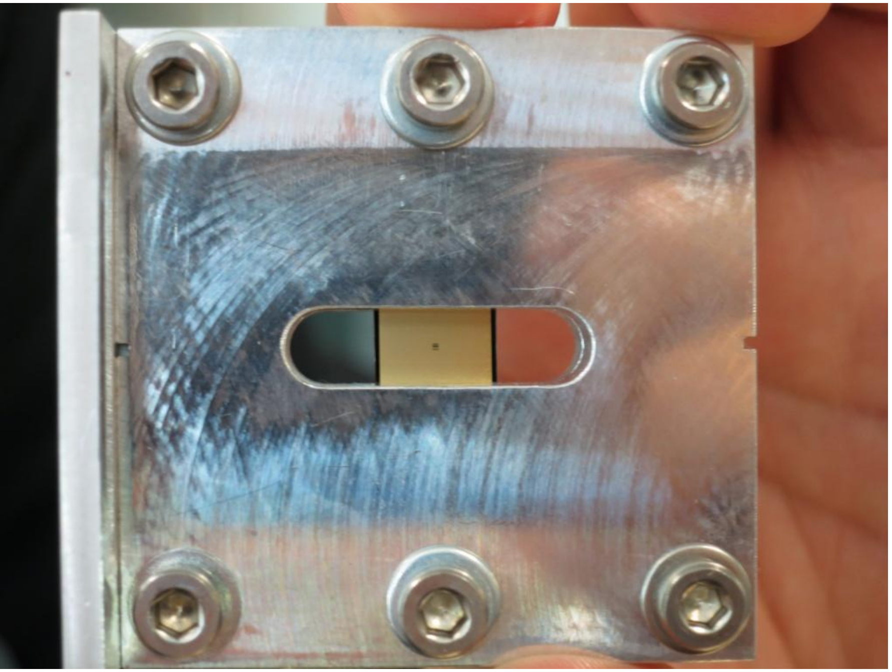


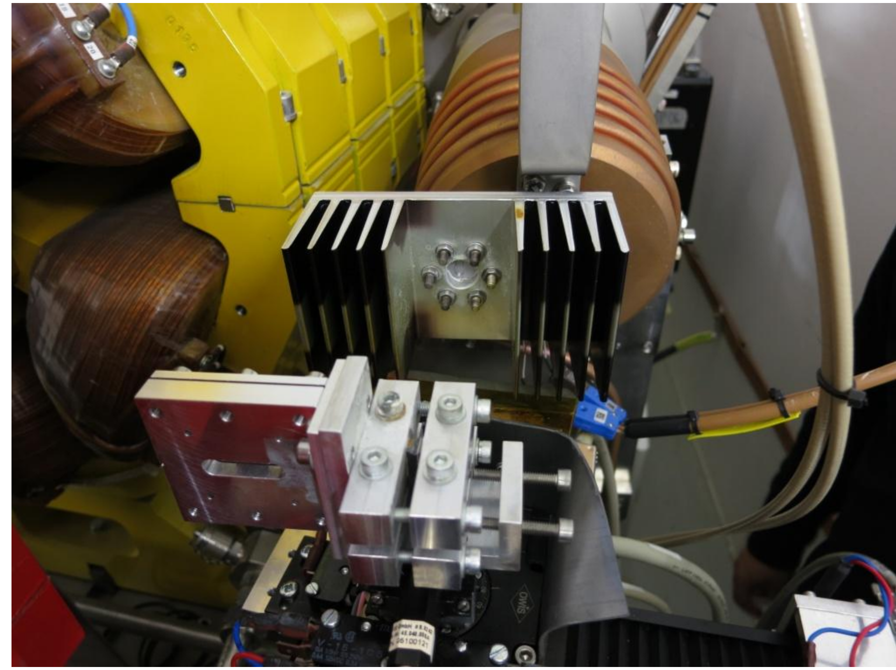



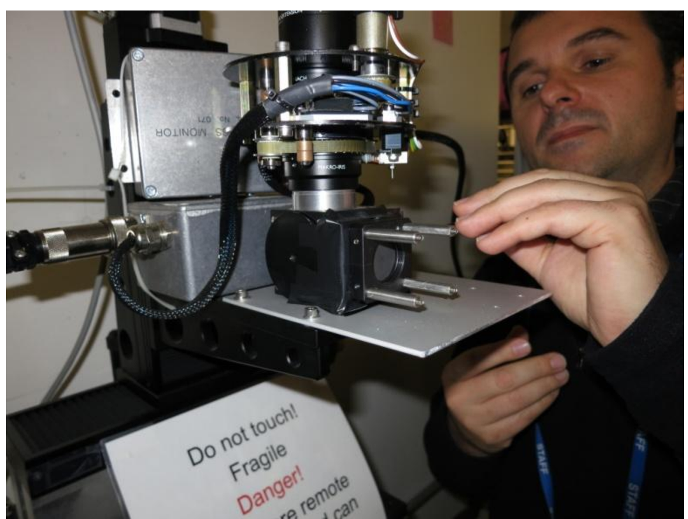




Measured beams of <7.5 um with scanned-pixel measurements
→World record for low-energy coded aperture measurements

# XRM: Coded Aperture at Diamond LS

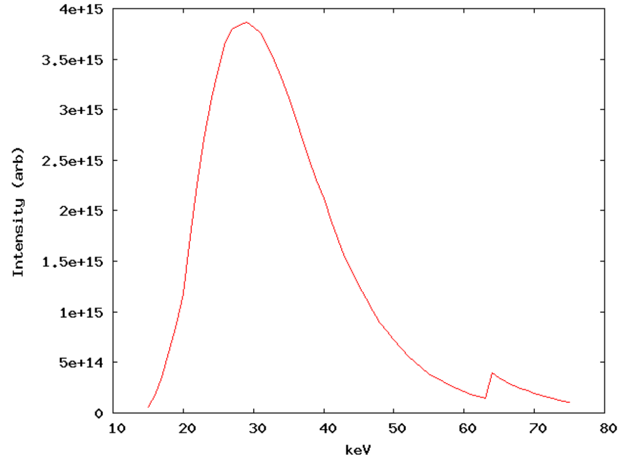




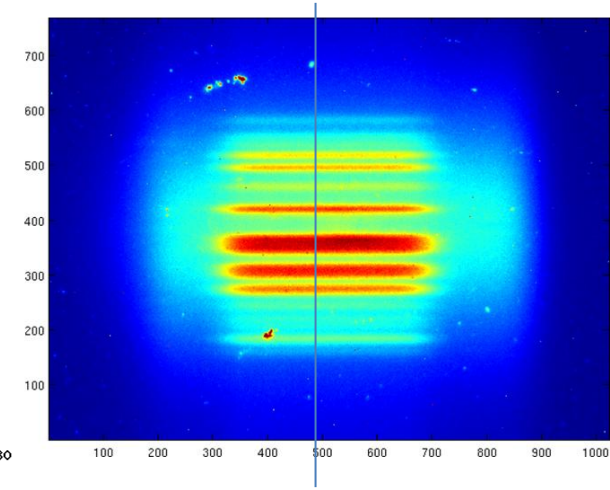



# XRM: Coded Aperture test at Diamond LS

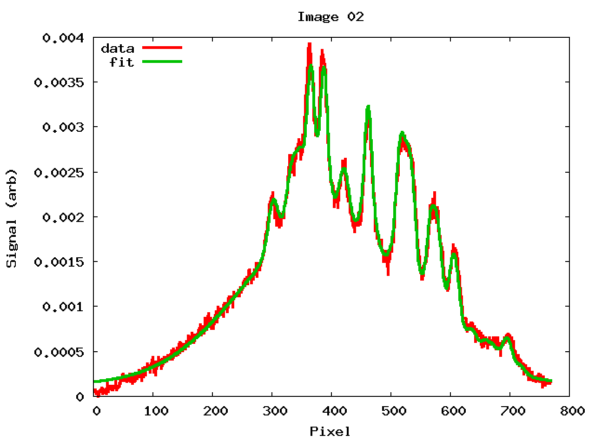
- Using spare high-energy optic (Au+Si) designed for SuperKEKB:
  - 10 µm x 59 URA
  - 18.2 µm Au mask on 625 µm Si substrate
- Detector:
  - 200 µm LuAG:Ce screen
  - 1024(H)x768(V) pixel camera
- **Not single-shot measurements, but sufficiently detailed data to use to provide input for modelling background due to coherentscattering effects (Rayleigh scattering)**
  - **Significant at high energies**



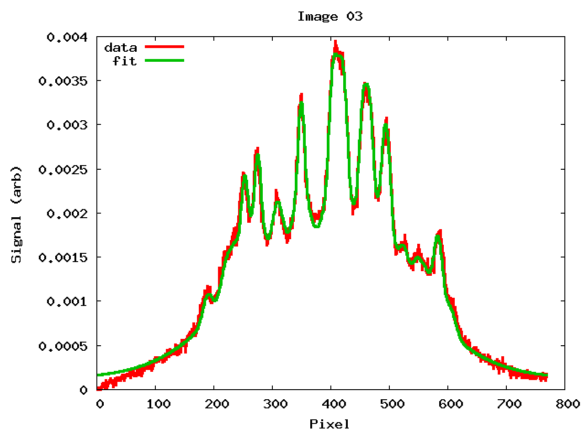

Modeled detected spectrum



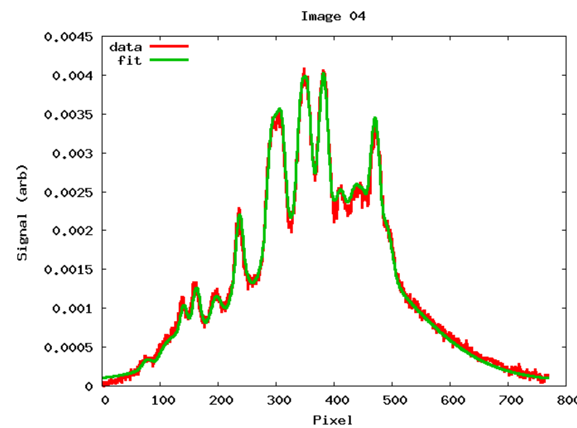
Data taken from single-pixel-width line near center




Best-fit:
--Beam size: 10.5 µm
--Mask position relative to beam: 166 µm




Best-fit:
--Beam size: 10.4 µm
--Mask position relative to beam: 5 µm

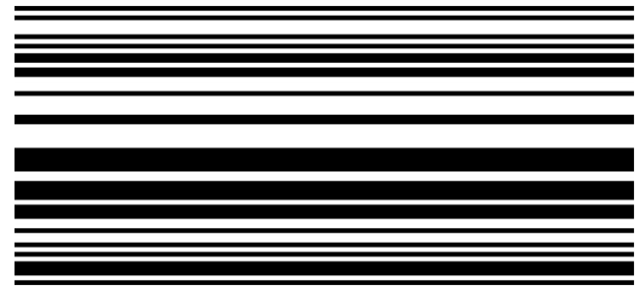



Best-fit:
--Beam size: 10.6 µm
--Mask position relative to beam: -126 µm

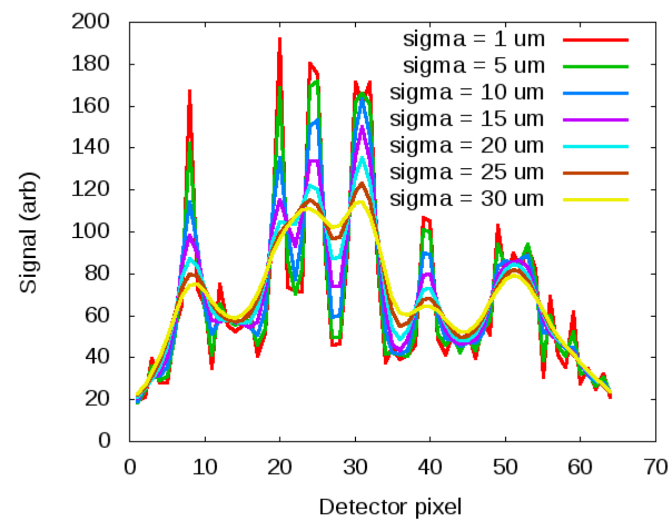
# XRM: SuperKEKB x-ray monitor

| Xray Source Bend Par. | S-LER (BS2FRP.1) | S-HER (BS2E.82) | Units |
|---|---|---|---|
| $\varepsilon_x$ | 3.20E-09 | 4.60E-09 | m |
| $\kappa$ | 0.27% | 0.24% | |
| $\varepsilon_y$ | 8.64E-12 | 1.10E-11 | m |
| $\beta_y$ | 50.0 | 11.5 | m |
| $\sigma_y$ | 20.8 | 11.3 | μm |
| Beam Energy | 4 | 7 | GeV |
| Effective length | 0.89 | 5.9 | m |
| Bend angle | 28.0 | 55.7 | mrad |
| ρ | 31.7 | 105.9 | m |
| Critical Energy | 4.4 | 7.1 | keV |

- Mask:
  - In-hand for Phase 1:
    - High-power, 59-element, 10 μm/element URA
    - 10 μm Au mask on 625 μm Si substrate
  - Under development:
    - 10 μm Au mask on 800 μm CVD diamond (monocrystalline) substrate
      - Substrates manufactured, samples given to NTT-AT to test masking method.
    - New pattern planned for improved resolution
- Detector:
  - Phase 1: 64-channel, 50 μm pitch
  - More channels desirable, for background subtraction and to accommodate beam deviations.



Uniformly Redundant Array (URA) for x-ray imaging to be used at SuperKEKB



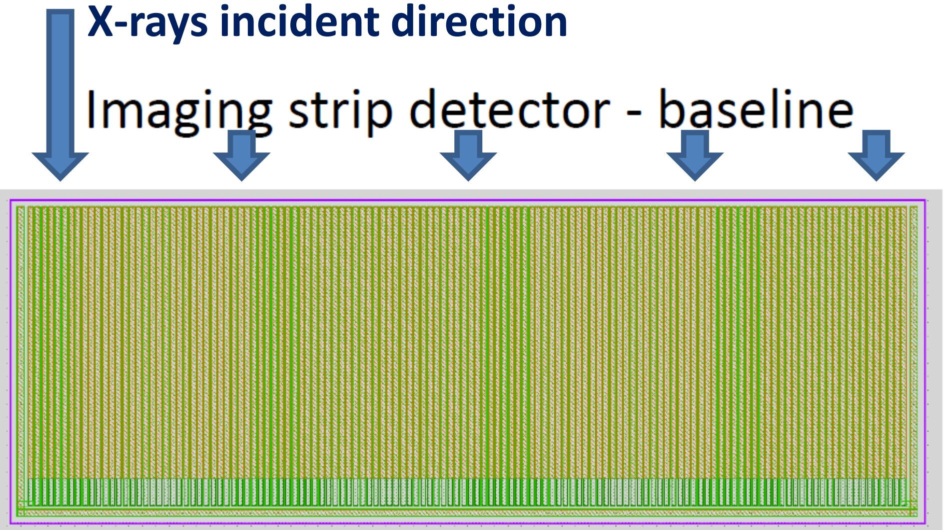

Simulated detector response for various beam sizes at SuperKEKB LER

# XRM: Detector

- Tests with Fermionics detector at Photon Factory and CesrTA showed that detection efficiency at high energies is very low
  - Active pixel depth is only 3.5 microns.
- Detector development needed for the future
  - Higher efficiency at hard x-ray spectrum seen at SuperKEKB
  - Fast response for being able to directly diagnose head-tail instabilities at SuperKEKB.
  - Active edge (Deep-pixel ) Si design being built in collaboration with SLAC:
    - Deep but narrow pixels: 2 mm deep, 50 um pitch, 128 pixels
    - Can stack 2 detectors for greater collection efficiency
  - Also making simple spectrometer using sideways-mounted detector with variable pixel widths

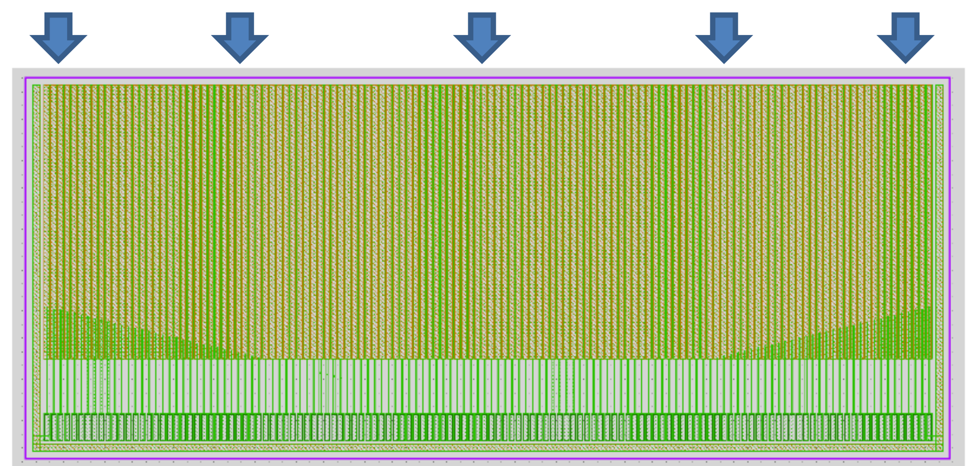
**X-rays incident direction**

Imaging strip detector - baseline



6.4mm imaging window: 128 x 50um wide strips

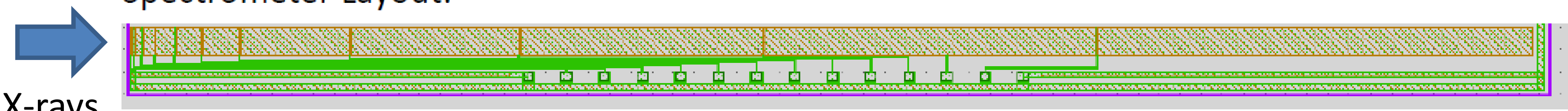
Imaging strip detector for stacking: extra room to daisy chain pads



J. Segal, C. Kenney (SLAC)

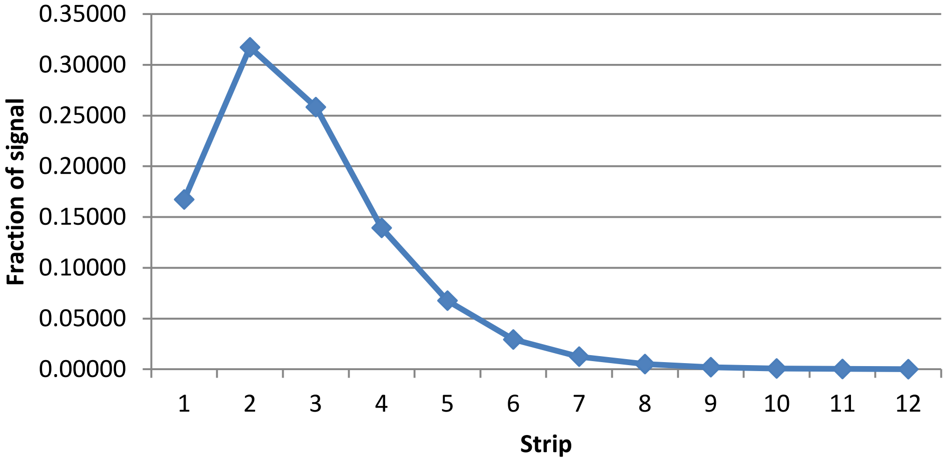
# XRM Spectrometer

Spectrometer Layout:

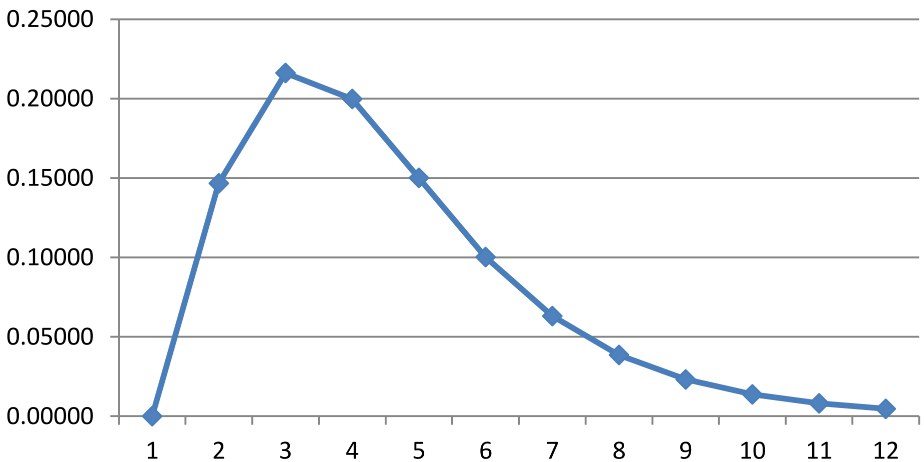


X-rays incident direction

**LER Spectrum in Spectrometer**




**HER Spectrum in Spectrometer**

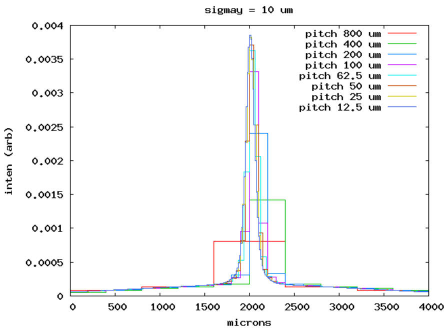


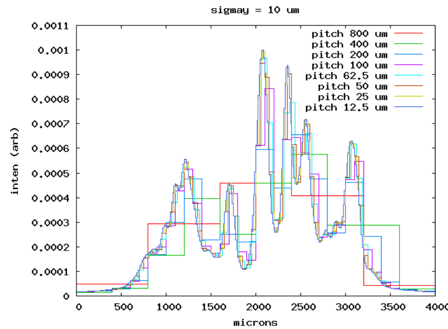

J. Segal, C. Kenney (SLAC)

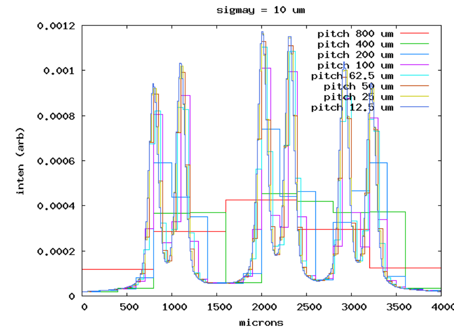
# XRM: statistical resolution

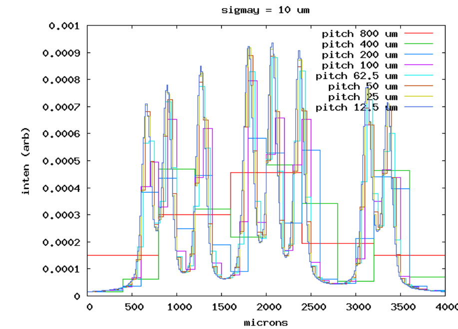
# Detected image simulations (LER):

| 35 um pinhole | 59x10 um URA mask | 13151 pattern | Modified Fibonacci pattern |
|---|---|---|---|

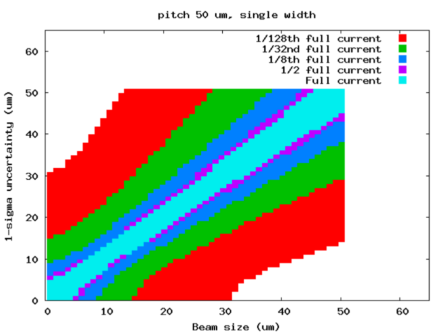


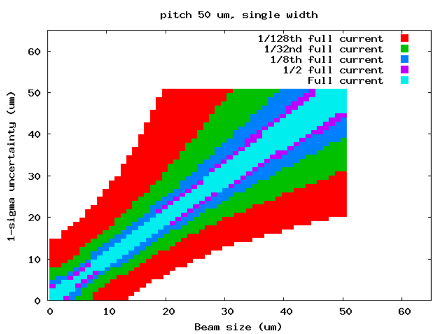



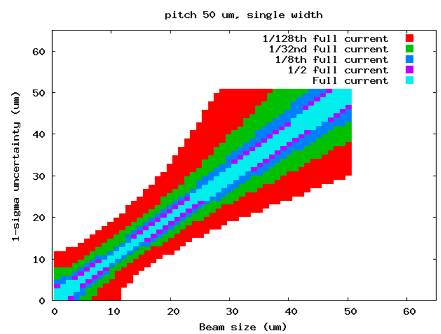



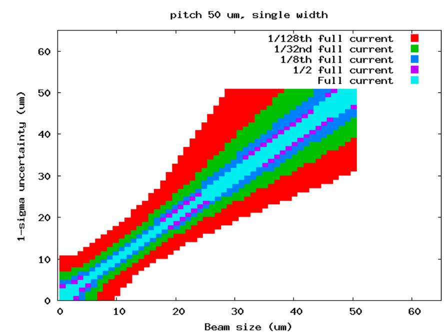




## Single-shot resolutions:



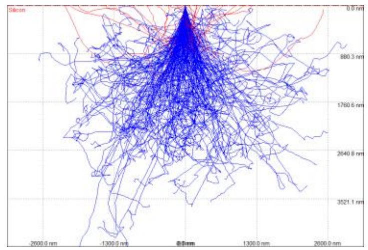




- Mask pattern:
  - URA mask better than single pinhole.
  - Other patterns found with even better resolution.
- Detector pitch:
  - For a range of mask types, most of the benefits are gained at 50 um. Below that, the only difference is at ~a few um, which we do not expect to see at SuperKEKB.
    - ➔Decision: Go with 50-um pitch, 128 pixels
  - If we need better single-shot resolution at low beam intensities, we should add detector layers to increase detected flux.

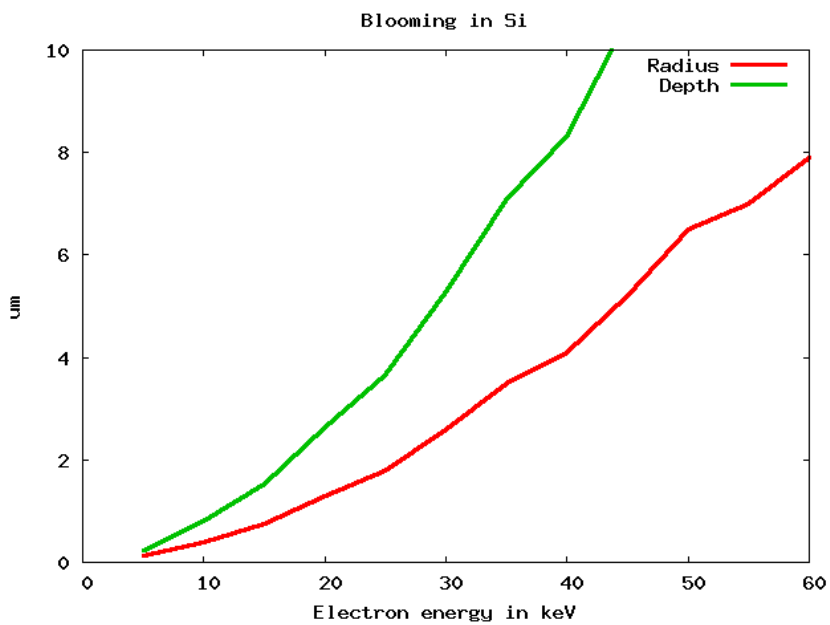
Blue: Single bunch, full current
Red: Single bunch, 1/128 current (optics correction mode)

# XRM: Detector resolution -- blooming

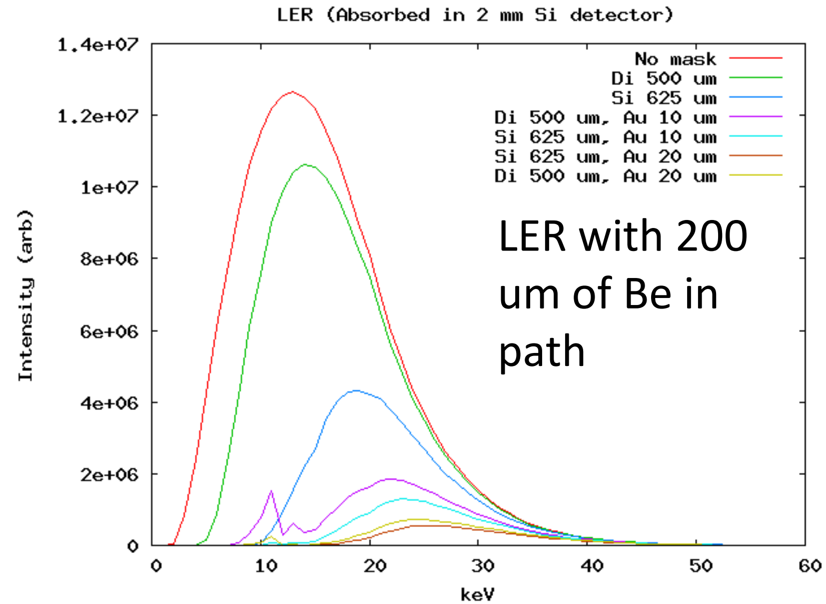
CASINO simulations of electron propagation in Si:

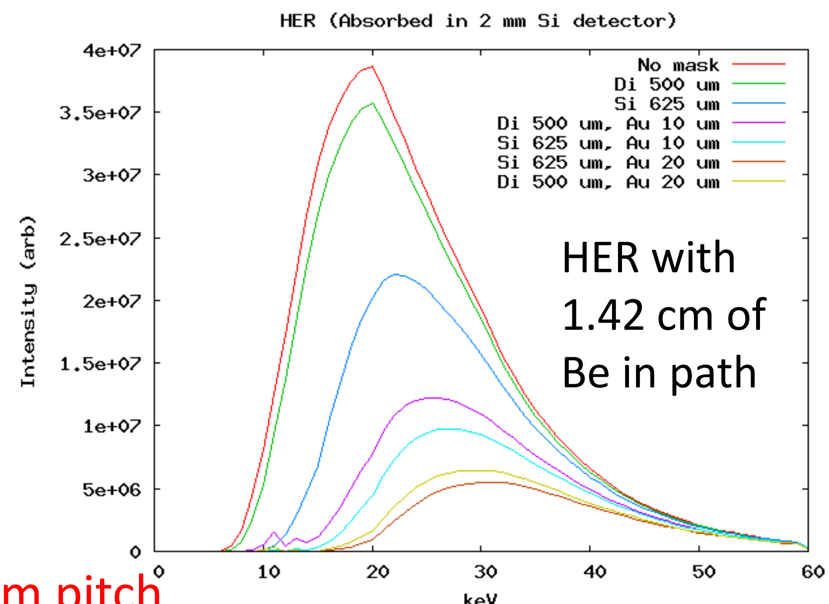


## Blooming vs energy




## Power absorbed in 2 mm-deep Si detector

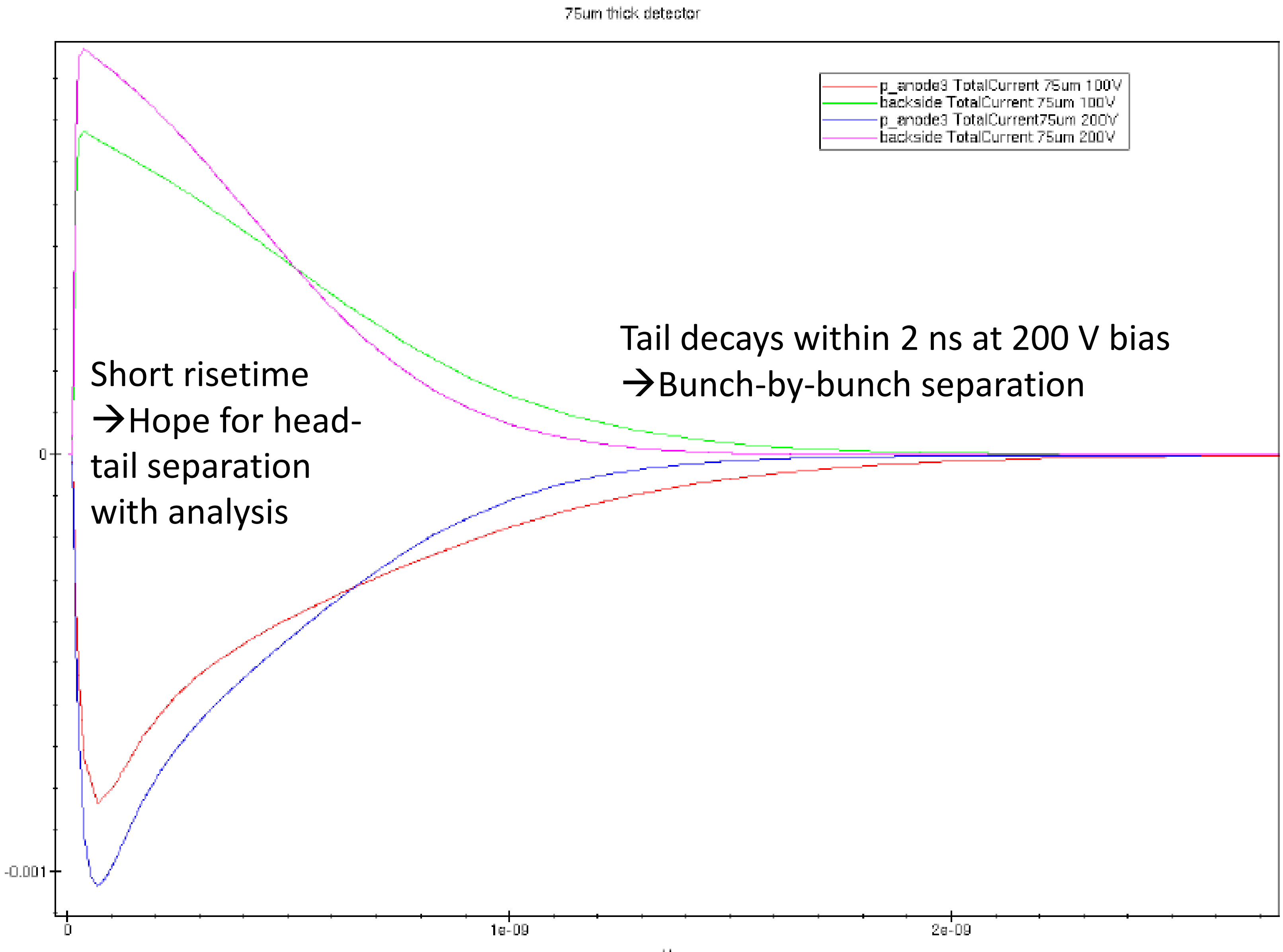



Blooming = ~2 um at 20 keV:  Looks OK w/50 um pitch

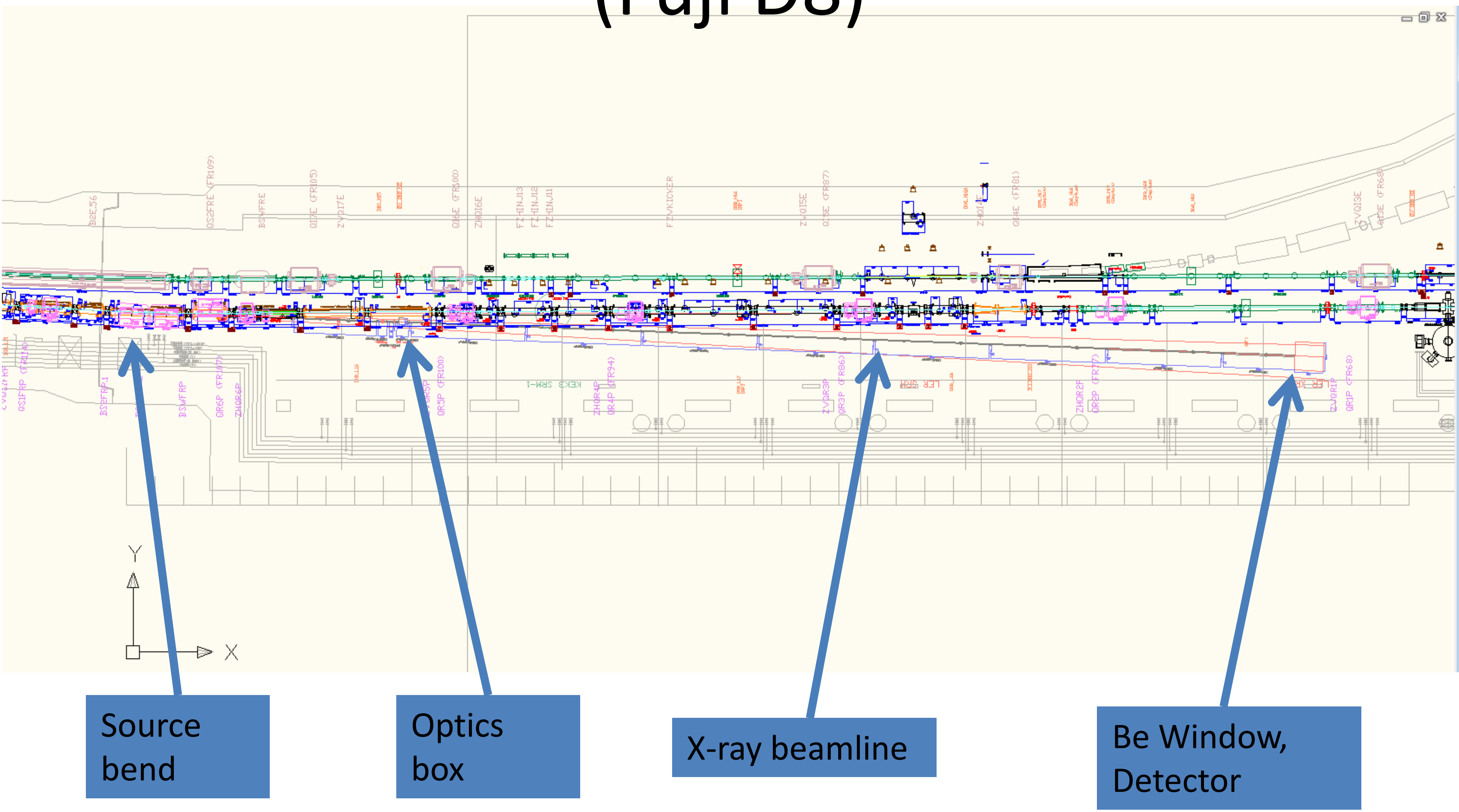
# XRM: Time resolution

## Contact Current vs. Time for 75um Thick Detector

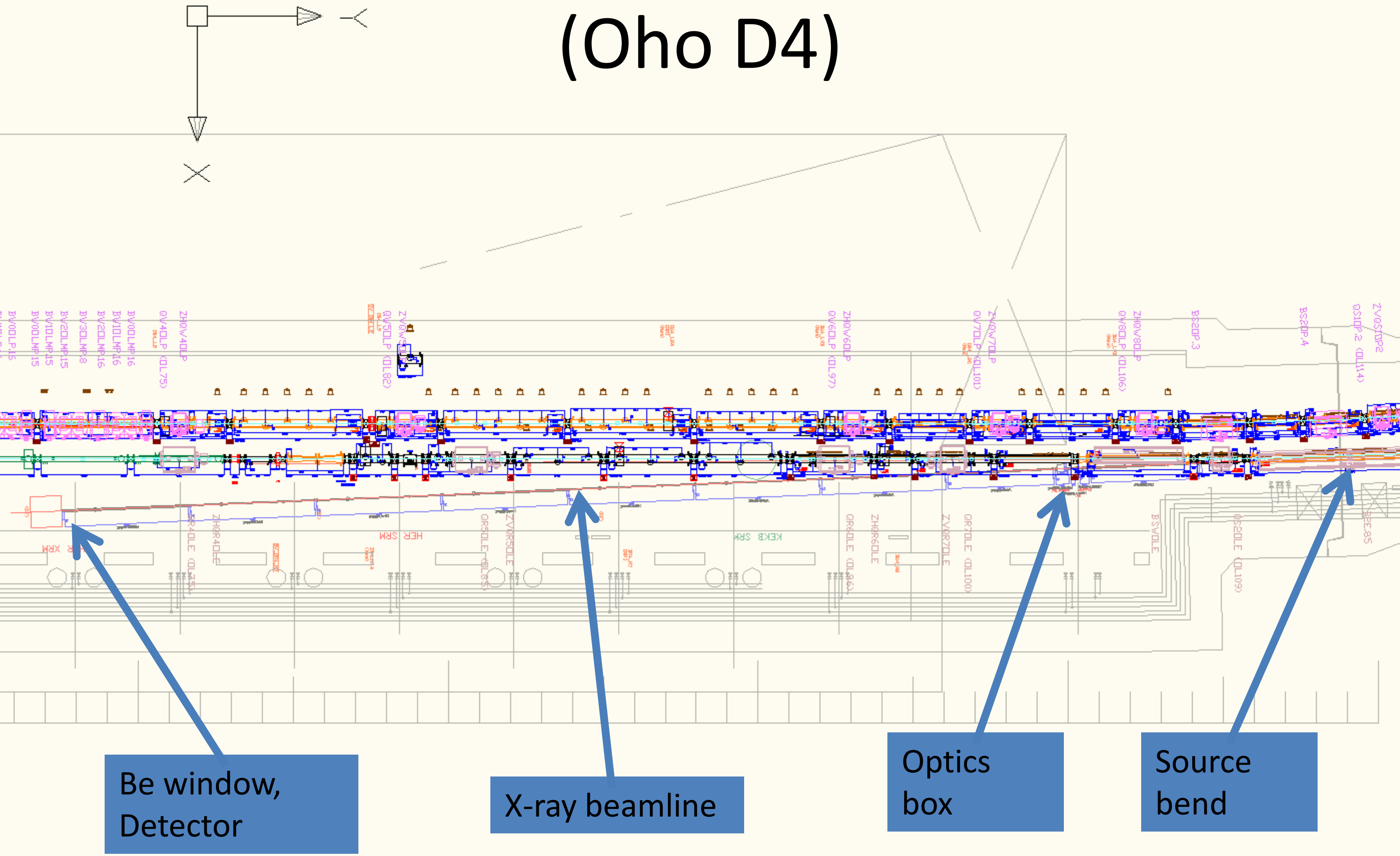



J. Segal (SLAC)

# XRM: LER X-ray beamline (Fuji D8)



# XRM: HER X-ray monitor beamline (Oho D4)



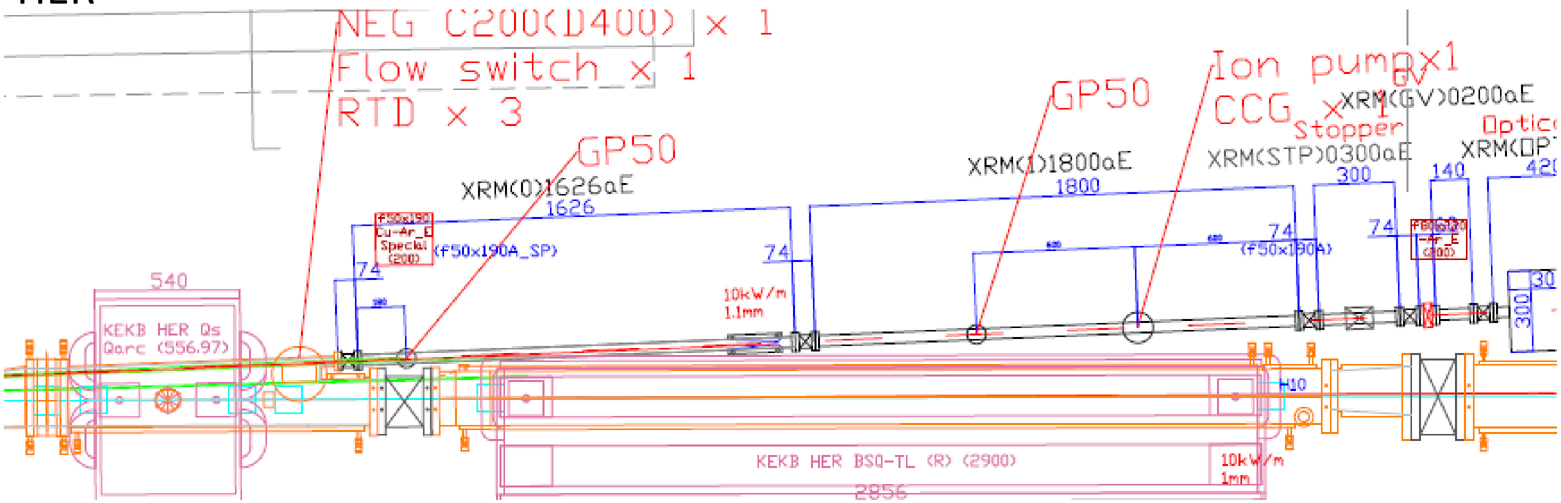
# XRM: Heat load on optics

| | CesrTA D Line | | SuperKEKB LER | SuperKEKB HER |
|---|---|---|---|---|
| E (GeV) | 5.3 | | 4 | 7 |
| $\rho$ (m) | 31.65 | | 31.74 | 106 |
| Critical energy (keV) | 10.3 | | 4.4 | 7.1 |
| Zero-degree Power Density (kW/mr^2/A) | 2.36 | | 0.56 | 2.8 |
| Linear Power Density (kW/mr/A) | 0.345 | | 0.112 | 0.313 |
| Distance from source to optics box (m) | 4.549 | | 9.39 | 10.27 |
| Aperture width (mm) | 2.38 | | 0.5 | 0.5 |
| Current (A) | 0.200 | 0.243 | 3.6 | 2.6 |
| Zero-degree Power Density (W/mm^2) | **23** | **28** | **23** | **69** |
| Linear Power Density (W/mm) | **15** | **18** | **43** | **79** |
| Total Linear Power over Aperture Width (W) | **36** | **43** | **21** | **40** |
| Burn test results | **Si mask OK**<br>**Dia. mask OK** | **Si mask NG**<br>**Dia mask OK** | | |

CesrTA burn test sets safe limits on incident power.
Need to filter out 2/3 of HER power before it hits optics.
Extra 1.4 cm of Be upstream of optics will work.

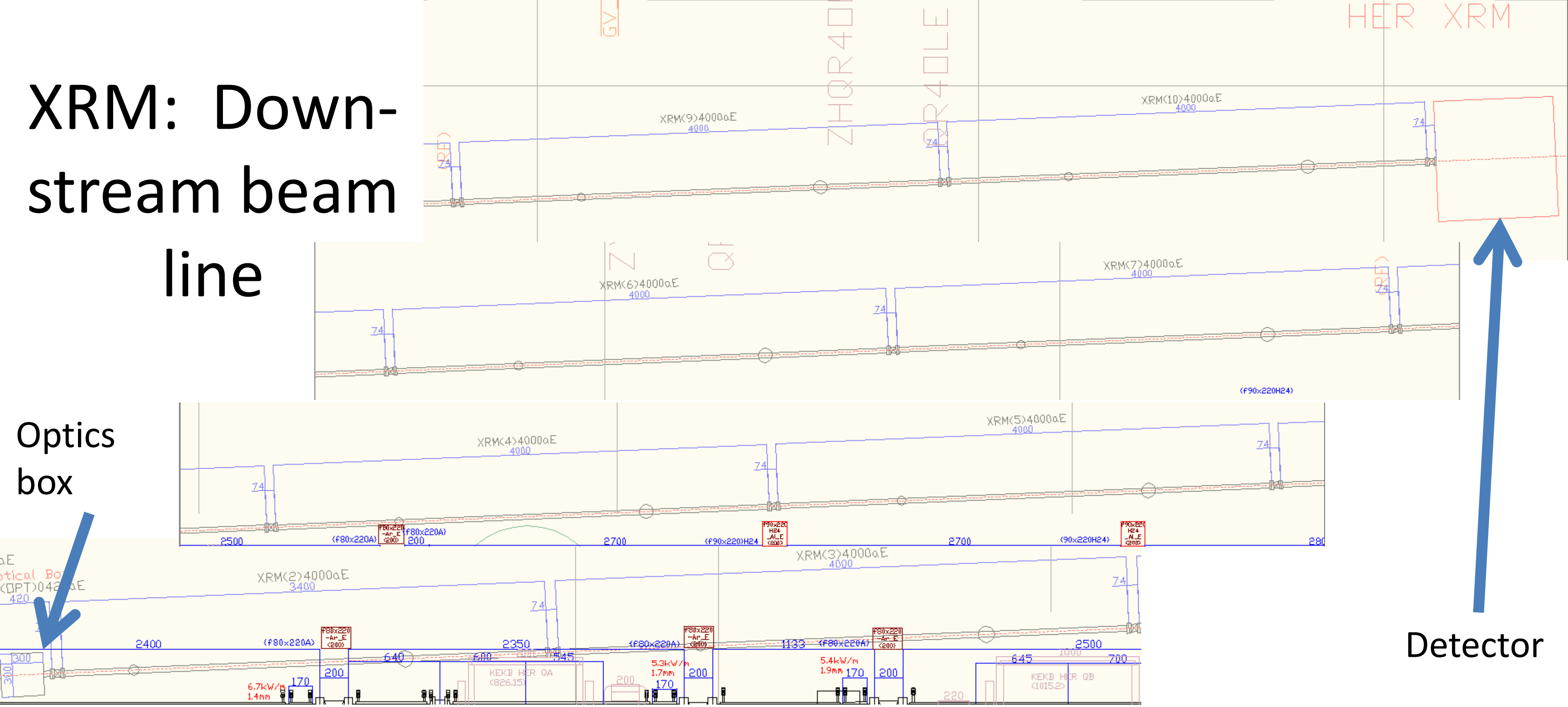
# XRM: Upstream beam line

HER




- 4-mm wide collimator located ~8(7) m from source point in HER(LER)
- Water-cooled Be filters
  - 2 cm total in HER
  - 1 mm total in LER
- Water cooled beam stopper
  - To protect gate valve
- Gate Valve
- Vacuum pumps upstream of gate valve:
  - 2 NEG pumps
  - 1 ion pump
  - Controlled by vacuum group (common with ring vacuum regardless of GV state)

# XRM: Down-stream beam line




- Optics box
  - Water-cooled copper heatsink plate, with two mounting spaces for optics
  - Optics (Au on diamond substrate):
    - 32 um slit
      - Simpler analysis possible, but photon statistics too low for single-shot measurements, esp. in optics correction mode (low current).
    - Coded aperture
      - For single-shot measurements
- Vacuum pumps:
  - 4 ion pumps
  - 1 NEG pump
  - Controlled by monitor group
- Screen monitor
- Extraction window
  - 200 um Be
- Detector (in air)

# XRM: Alignment

- Need to align x-ray beamlines to within ~0.1 mrad (4 mm over 40 m).
- Initial crude beam-line layout with laser leveler (V, H)
  - Mainly to make sure no obstacles remain in path
  - Serves to alert other groups as to where beam line will be
- Semi-final (pre-commissioning) mechanical alignment with help of magnet group (using laser tracker, etc.)
- Final mechanical alignment will require use of x-ray beam itself.
  - Upstream aperture determined by horizontal collimator position.
  - Can adjust positions of collimator, optics box, extraction window.
  - Screen monitor midway downstream of optics box to assist with beam-based alignment.
  - Detector mounted on movable (translational, rotational) stages, attached by flexible cables to readout electronics box.

# XRM: Heat load on detector

| | SuperKEKB LER | SuperKEKB HER | Filtered HER (to protect optics) |
|---|---|---|---|
| E (GeV) | 4 | 7 | |
| ρ (m) | 31.74 | 106 | |
| Critical energy (keV) | 4.4 | 7.1 | |
| Zero-degree Power Density (kW/mr^2/A) | 0.56 | 2.8 | |
| Linear Power Density (kW/mr/A) | 0.112 | 0.313 | |
| Distance from source to detector (m) | 40.70 | 42.55 | |
| Detector width (mm) | 0.1 | 0.1 | |
| Beam Current (A) | 3.6 | 2.6 | |
| Air path length (cm) | **10** | **10** | |
| Be window+filter thickness (cm) | **0.02** | **0.02** | **1.42** |
| Peak Power Density absorbed in detector (W/mm^2) | **0.7** | **2.8** | **1.0** |
| Linear Power Density absorbed in detector (W/mm) (Horizontal axis) | **6** | **13** | **5** |
| Integrated absorbed linear power over 0.1 mm detector width (W) | **0.6** | **1.3** | **0.5** |

Should design to be able to absorb a watt total, with peak power density of 2 W/mm^2
→Diamond heat sinks on detectors?

# XRM: Readout system

- High-speed readout electronics being developed by UH:
  - Custom digitizer ASICs (selectable by replacing daughtercard) for multi-turn measurements:
    - High-speed for bunch-slicing measurements of a few bunches
    - Slower speed for single-bunch measurements over whole train
    - Data transferred via raspberry-pi in tunnel
- Raw data sent to 64-CPU fitting/analysis computer in above-ground hut
- Fitting results sent to EPICS IOC in control building for beam tuning purposes

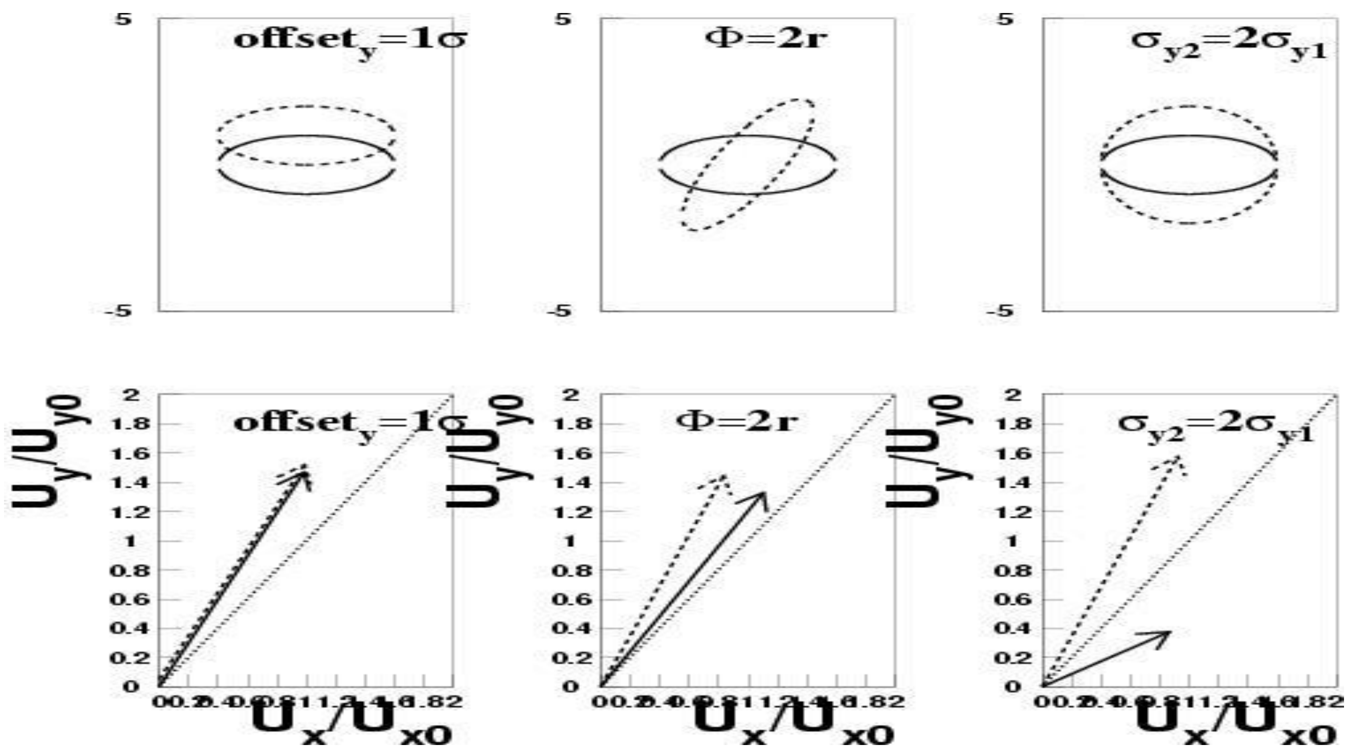
64-channel readout motherboard and digitizer daughter cards

# XRM: Schedule

- Now:
  - Downstream beam pipes in fabrication
  - Vacuum pumps purchased/acquired
  - High-energy detector in fabrication at SLAC
  - Design of beam stopper finalized
  - Design of upstream beam pipes (except for Be filters) finalized.
  - Design of Be filters and optics boxes/mounts under discussion with companies.
- March, April 2013:
  - Finalize designs of Be filters, Optics boxes/mounts, mask patterns
  - Rough layout of beam line
- From April 2014:
  - Fabrication of upstream components, optics boxes/mounts and masks
  - Imaging test of diamond mask prototype at CesrTA
  - Beam testing of readout system at ATF
  - Beam testing of high-energy detector at SLAC
- From September 2014, in preparation for Phase 1:
  - Installation and alignment of beamline vacuum components
  - Installation of detectors and 64-channel readout systems
- From Phase 1:
  - Beam-based alignment
  - Check-out, calibration, commissioning of x-ray monitor system for emittance tuning.

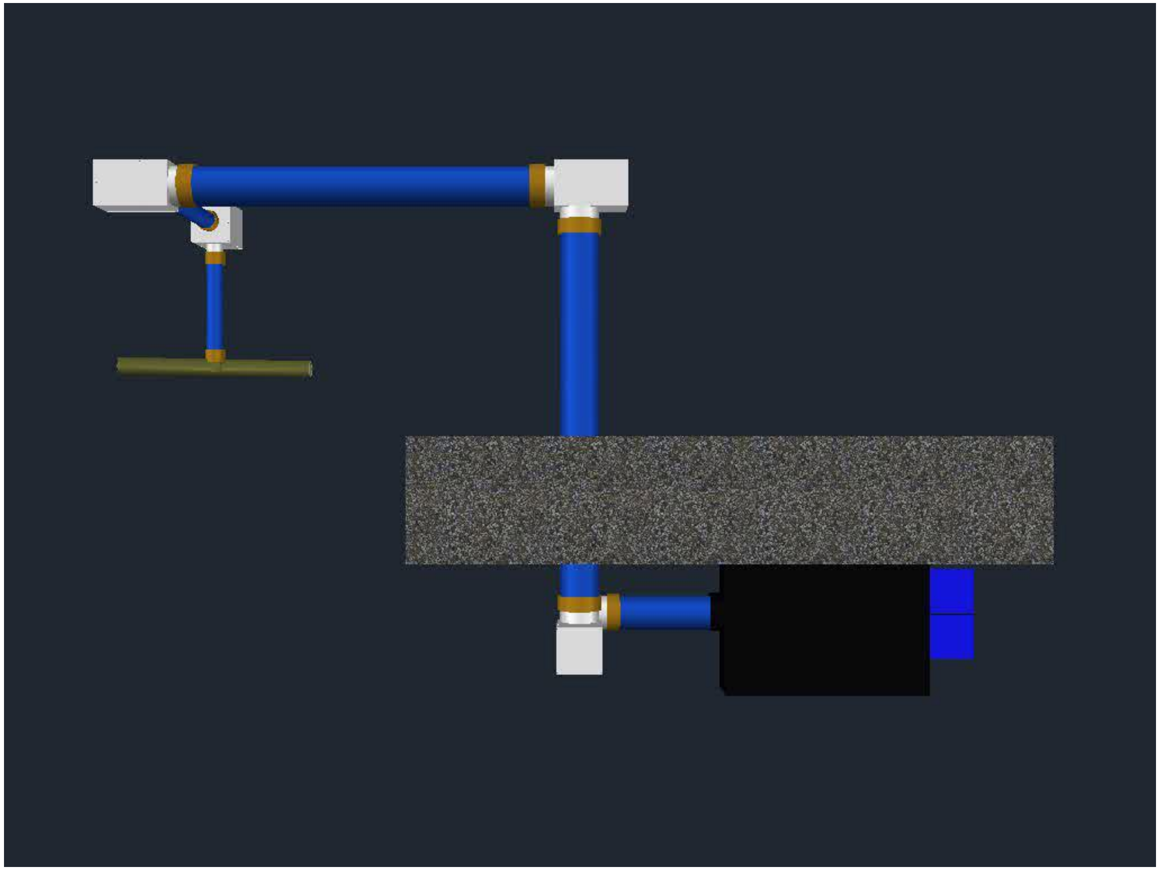
# LABM: Large Angle Beamstrahlung Monitor

- The radiation of the particles of one beam due to the bending force of the EM field of the other beam
- Beamstrahlung POLARIZATION at specific azimuthal points provides information about the beam-beam geometry.




G. Bonvicini

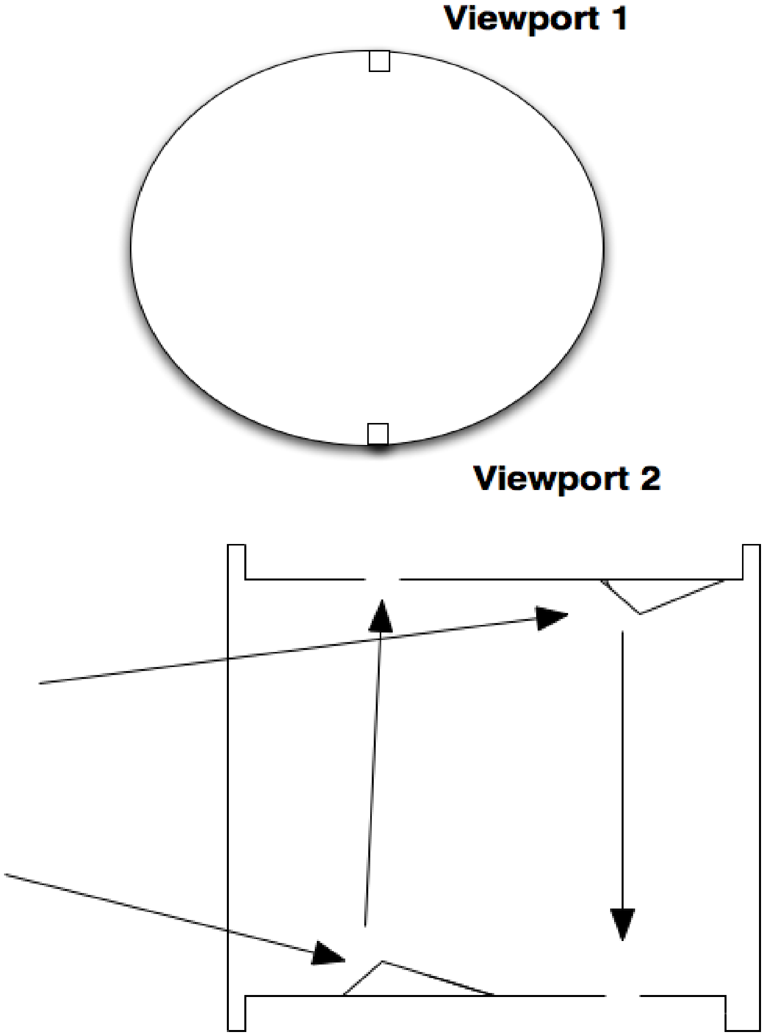
# LABM: Detector concept - I



Light is extracted out
the Beam Pipe (brown)
By a Vacuum mirror.
The light is then
Transported through an
Optical Channel (blue
Pipes, gray elbows) to
An Optics Box (black)
Where light is divided
In two polarizations and
4 spectral bands

# LABM: Detector Concept - II

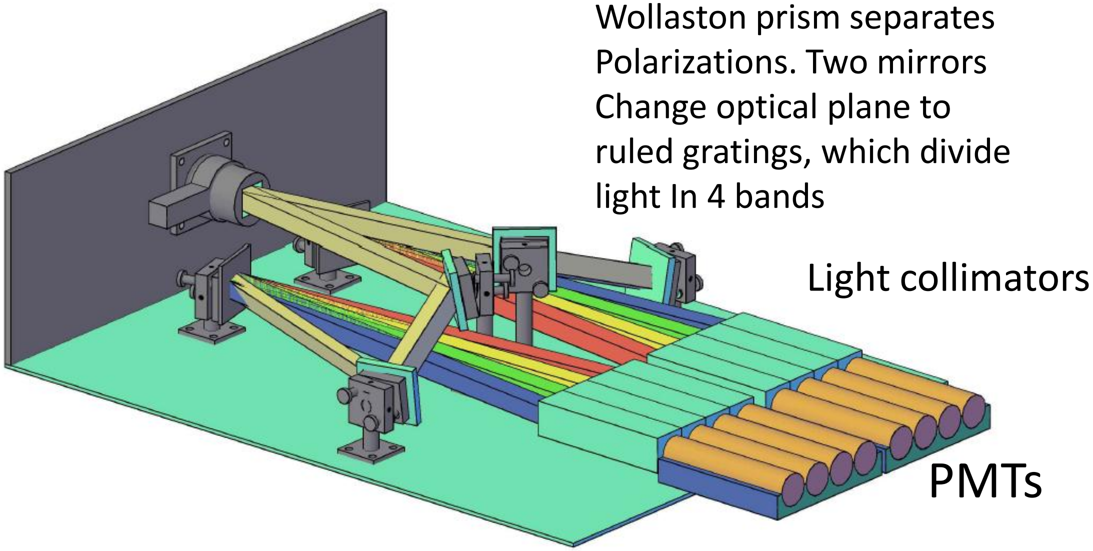
- Two view ports per beam to control systematics - 4 Optical Channels
- Each view port light is split into two polarizations, 4 bands - 8 PMTs or SiPMTs per Channel, 32 channels total
- Each Optics Box has two optical tables, each table counting one Optical Channel - 2 Optics Boxes



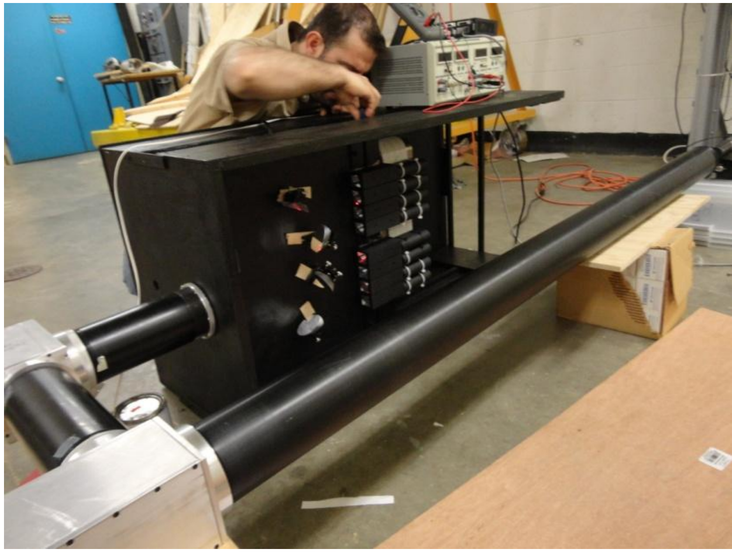

G. Bonvicini

# LABM: Optics box and optical path

Optics Box Concept (one of two Optical Tables shown)




Prototype optics box



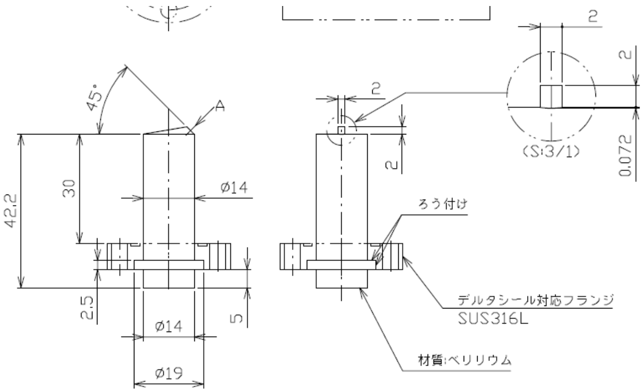
Changing just the grating allows observation of 2 different bands (300-600 or 450-900 nm)

PMT mounts inside optics box

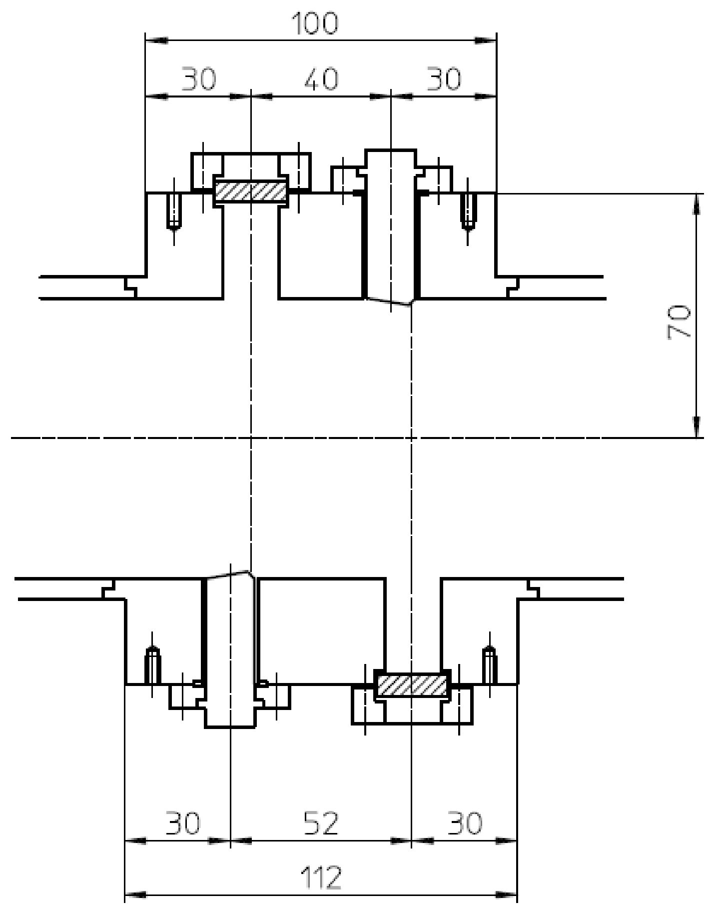
Movable mirror

G. Bonvicini

# LABM: Be mirror and extraction holes



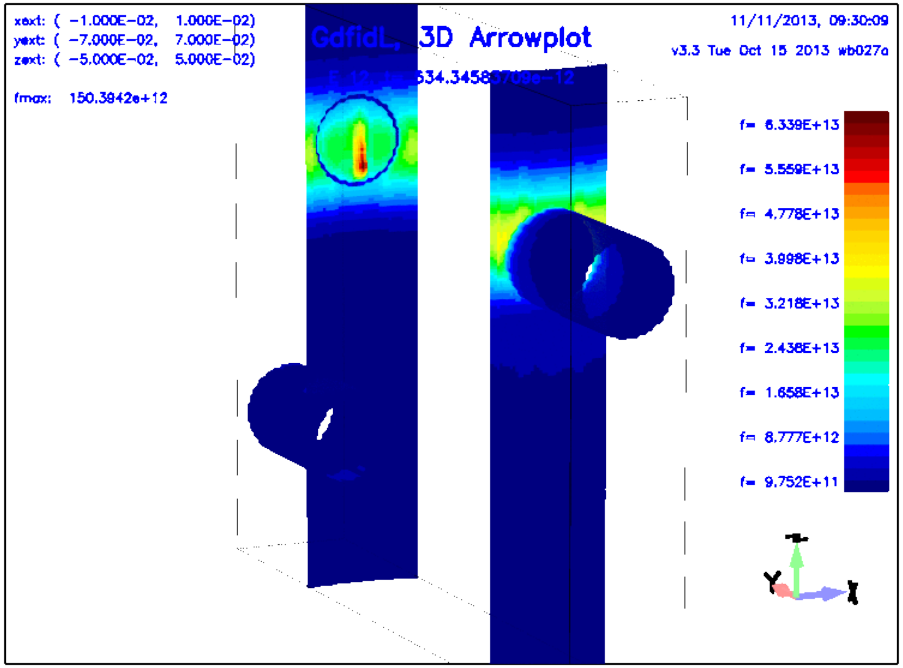


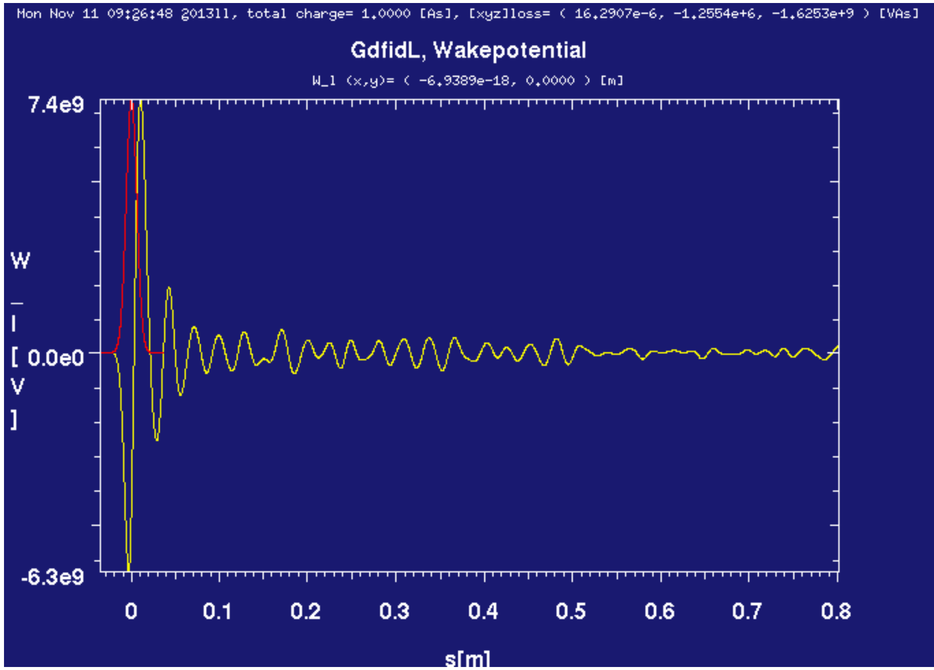



- RF fingers around mirror stem not shown

Original design

# LABM: HOM losses




- Loss factor: 1.6e-3 V/pC
- →84 W
  - Extraction holes: 40 W each
  - Mirrors: 2.5 W each
    - If no RF fingers, 40 W each in trapped modes
- Note: mirrors also receive incident Beamstrahlung power of ~2 W

# LABM: Extraction chamber

- Extraction holes:
  - Diameter 16 mm -> 8 mm
    - Cuts HOM losses due to extraction hole to a few Watts
  - Center of extraction hole shifted 1 mm to better align with optical axis
    - Beam reflected at ~10 mrad
  - Extraction hole depth reduced to minimize excessive collimation risk

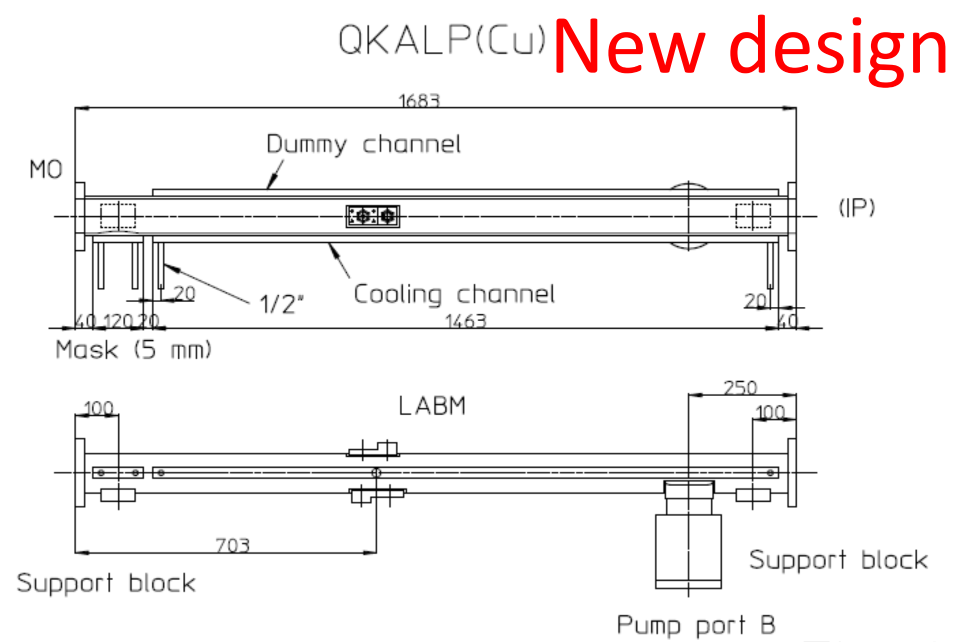



Fig. 1

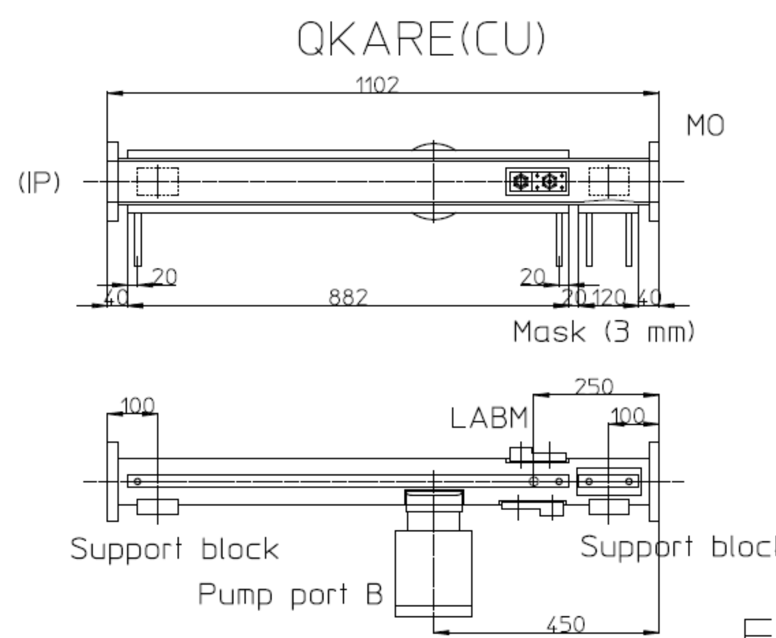
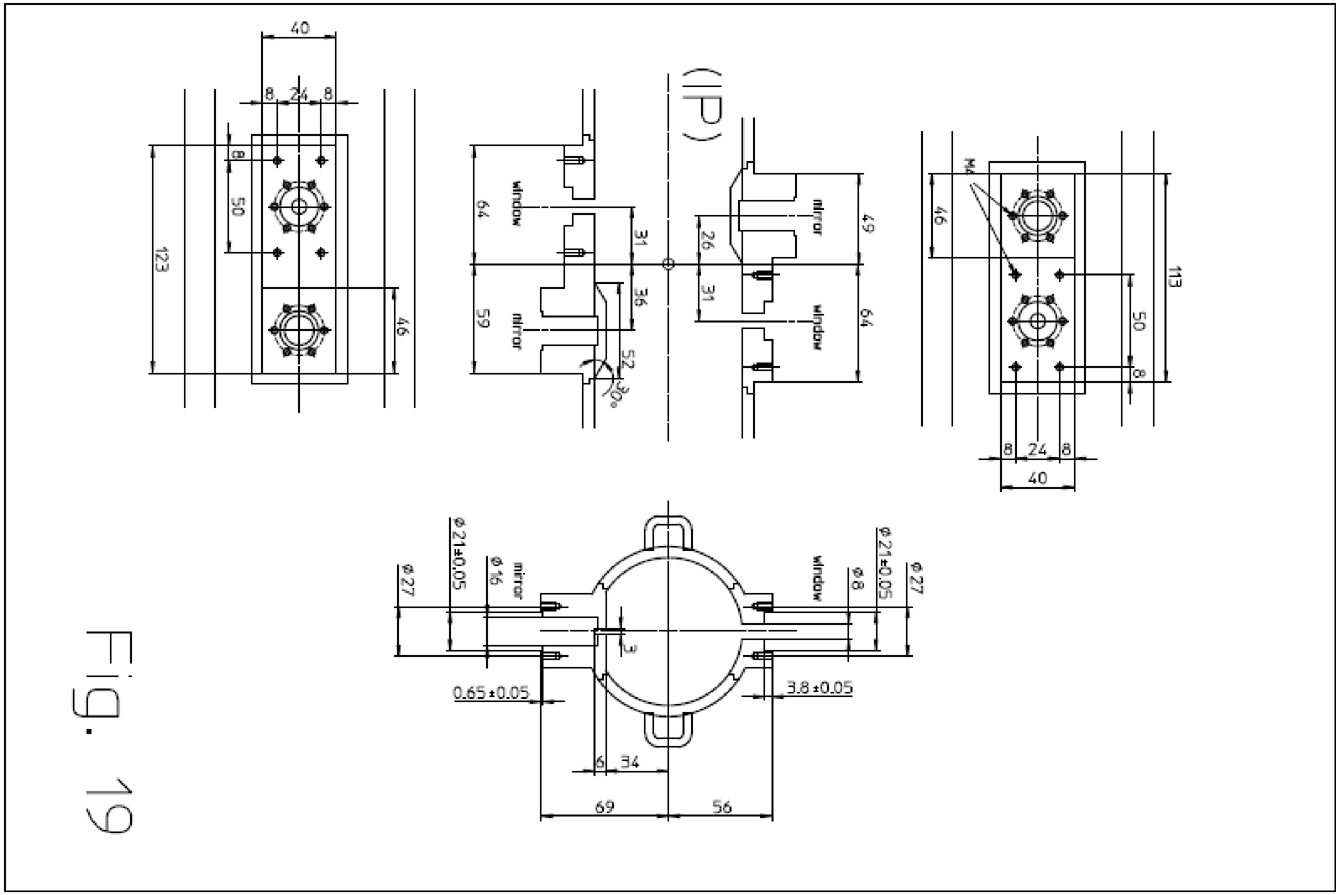


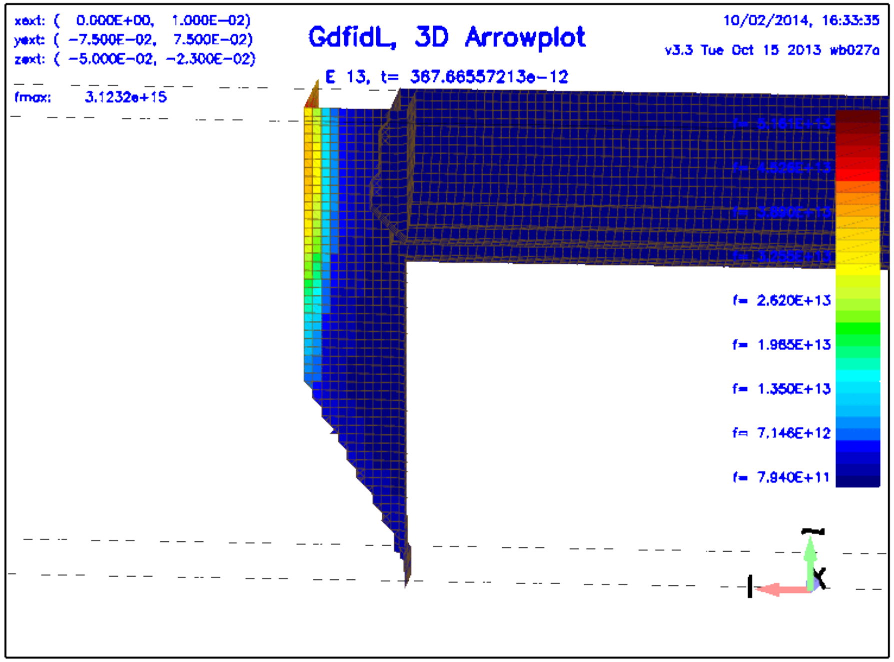

Fig. 4

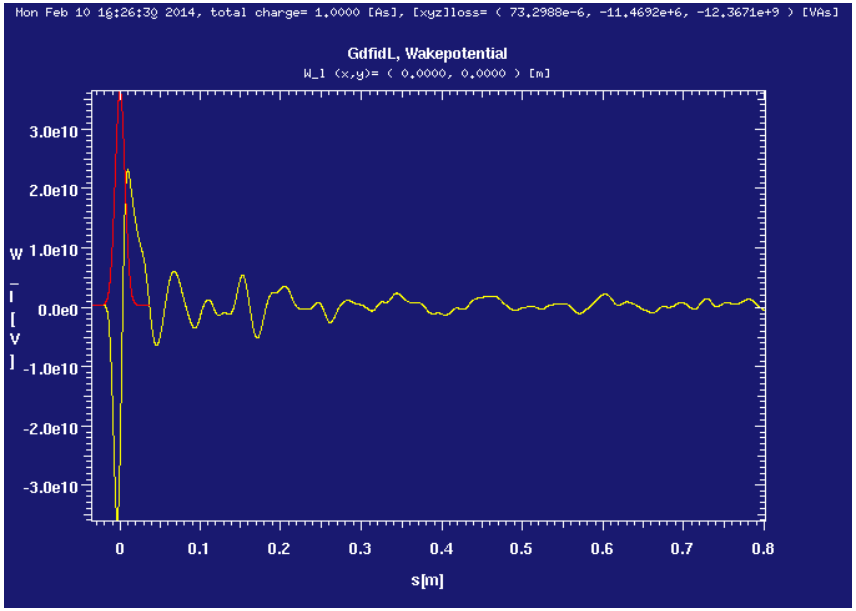
# LABM: Extraction chamber

- Mirror shield:
  - 6 mm-high around mirror, with 30-degree leading and trailing edges
  - Mirror sits in 3-mm wide slot
  - Mirror is 2-mm wide
  - View of IP unobstructed
  - Reflections from side of slot should be at large enough angle to be eliminable by downstream collimation



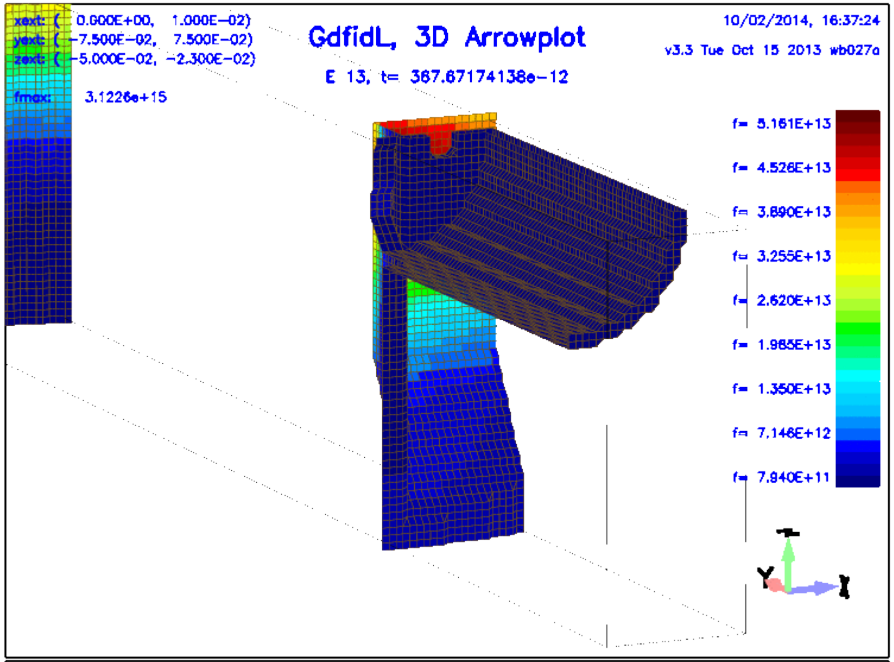
# LABM: Extraction chamber Shield ramp, no RF contacts

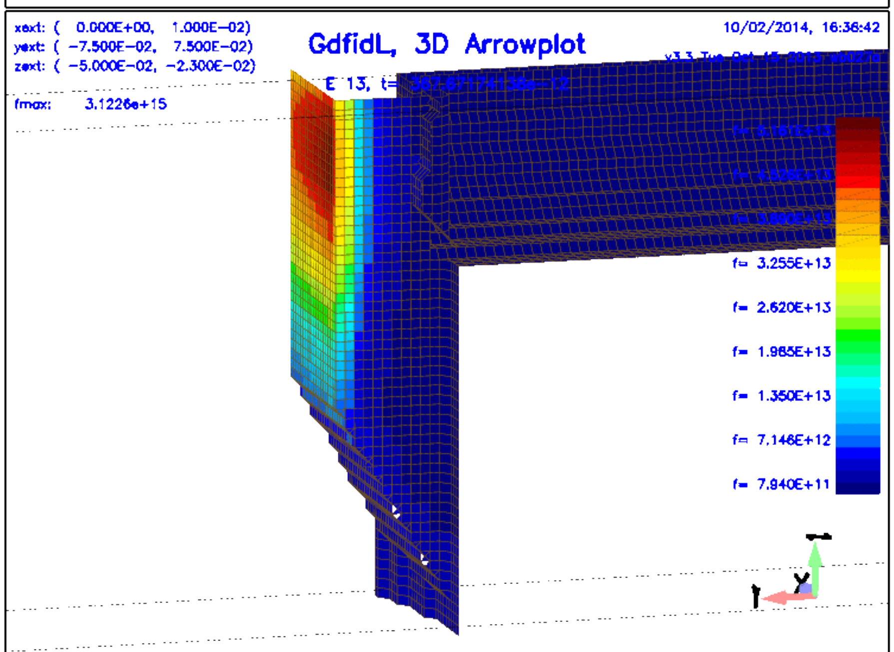


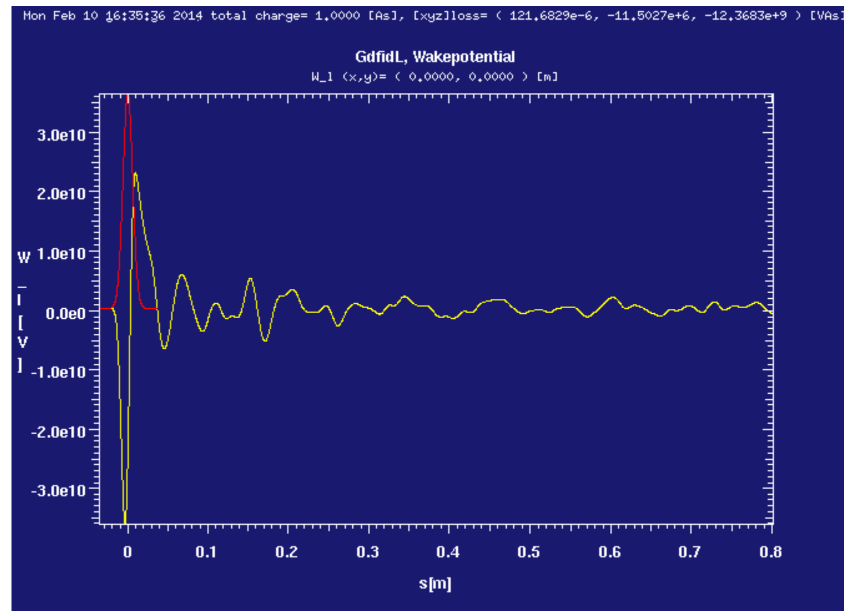

- Loss factor: 12.3e-3 V/pC
- →645 W
  - But very little field leakage into mirror area, even without RF contact between mirror and shielding ramp

# LABM: Extraction chamber




Shield ramp,
with RF contacts (posts) to ground mirror to underside of shield

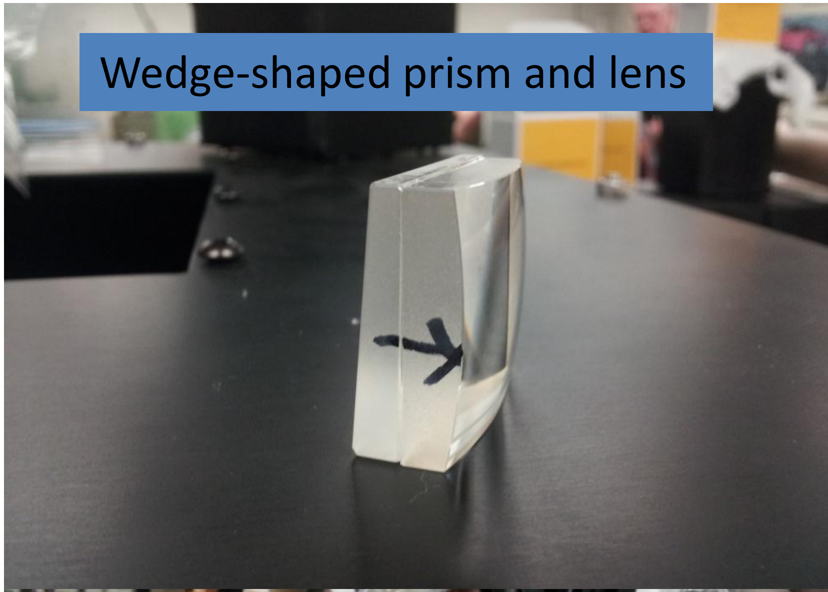


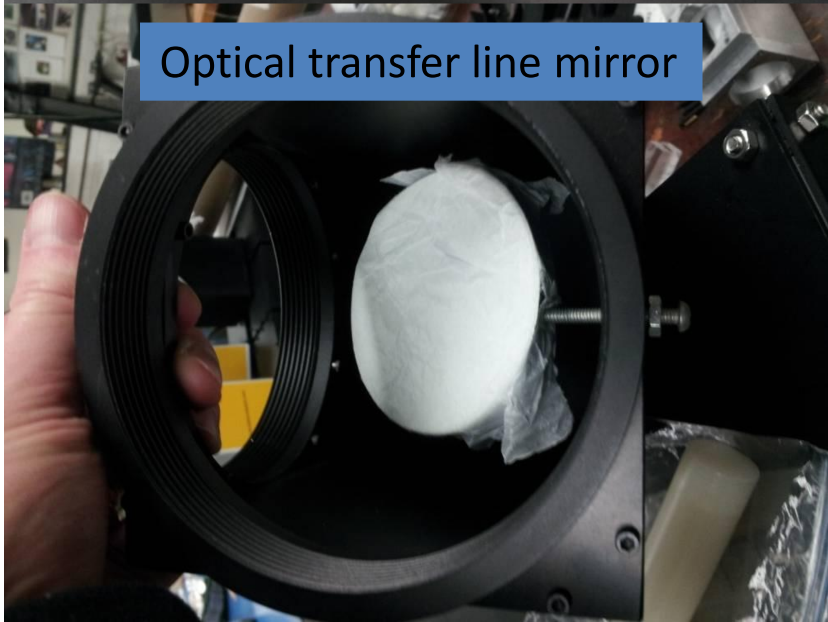

Essentially unchanged
→Go with no RF contacts

# LABM: Schedule

- Wayne State:
  - Optics boxes have been redesigned and fabricated
  - Optical components calibrated
  - Part of optical transfer lines fabricated
  - Readout electronics for Phase 1 systematic checks designed and in preparation
  - Final read-out system for Phase 2 operation being designed
  - Prior to Phase 1:
    - Install optical transfer lines, optical tables, Phase 1 electronics
  - From Phase 1:
    - Initial commissioning and systematic checks
    - NOTE: If possible, would like to try collisions without QCS
      - Low-luminosity, but zero background
  - From Phase 2:
    - Re-commissioning after re-configuration of IR, wth final electronics
    - Final commissioning for physics running

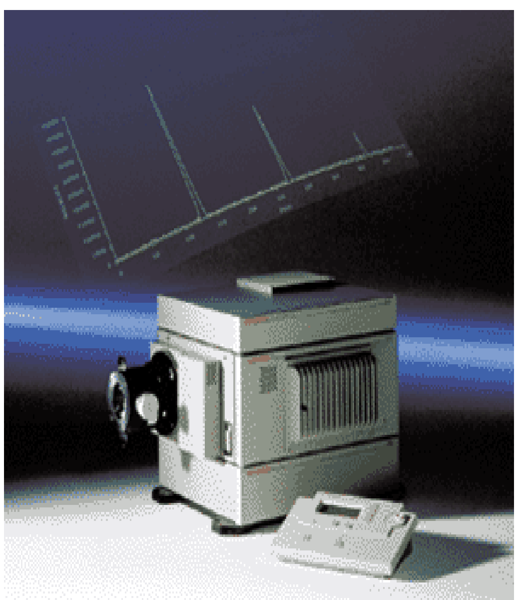
- KEK:
  - Mirrors in fabrication
  - Extraction chamber design finalized, to be ordered in April 2014 (vacuum group)
  - Racks purchased for LABM use
  - Installation of vacuum components by start of Phase 1.



# DR SRM: Components

- Extraction mirror, transport line, streak camera, gated camera and optical elements: ready
- Extraction mirror chamber : prepared by vacuum group
- Painting of SRM hut will be done this month.
  - Matte black interior
- Set-up inside the hut will start soon.
- Installation of extraction mirror and transport line depends on the progress of other groups.



# DR SRM: Hut

DR SRM hut

# Loss Monitor：MR

- Ready for re-cabling and installation.
  - Re-use detectors (ion chamber and PIN PD) from KEKB.
  - We use the same read-out system as KEKB
    - Satisfies specifications for SuperKEKB.
  - Extra read-out modules for IC and PD channels have been produced.
  - New ADC modules (18K14 DIGITEX) developed and produced.
    - Old ones no longer being manufactured.

# Loss Monitor : DR

- Almost all components are ready
  - Detectors: Reuse linac ion chambers
  - Electronics
    - Integrator (gain of read-out is changed from MR read-out.)→ready
    - ADC, digital I/O: ready
    - I/O divider, H.V. filter, H.V. divider: order in FY2014
  - H.V.: ready
  - Cables, Plate: ready
- Installation starts in April.

# Summary

- At SuperKEKB Phase 1 turn-on (non-collision):
  - SRM & XRM:
    - Alignment, commissioning and beam size measurements
  - LABM commissioning and background studies
    - Initial systematics checks.
    - No final-focus quadrupole, so no SR background.
    - If it is possible to collide in that condition, would provide a valuable, background-free systematic check.
- At DR turn-on, DR SRM commissioning
  - DR BLM to be used for tuning
- After Belle II completion, Beamstrahlung monitor commissioning begins in earnest.
  - Eventually aim to provide feedback for luminosity tuning.

# Spares

# XRM: Single-shot resolution estimation

- Want to know, what is chance that a beam of a certain size is misfit as one of a different size?
- Tend to be photon statistics limited. (Thus coded aperture.)
- So:
  - Calculate simulated detector images for beams of different sizes
  - "Fit" images pairwise against each other:
    - One image represents true beam size, one the measured beam size
    - Calculate $\chi^2/\nu$ residuals differences between images:

*N* = # pixels/channels
*n* = # fit parameters (=1, normalization)
$S_i$ = expected number of photons in channel *i*

$$\frac{\chi^2}{\upsilon} = \frac{1}{N-n-1}\sum_{i=1}^{N}\frac{[s_i' - s_i]^2}{\sigma_i^2},$$

    - Weighting function for channel i:

$$\sigma_i = \sqrt{s_i}\,.$$

  - Value of $\chi^2/\nu$ that corresponds to a confidence interval of 68% is chosen to represent the 1-s confidence interval

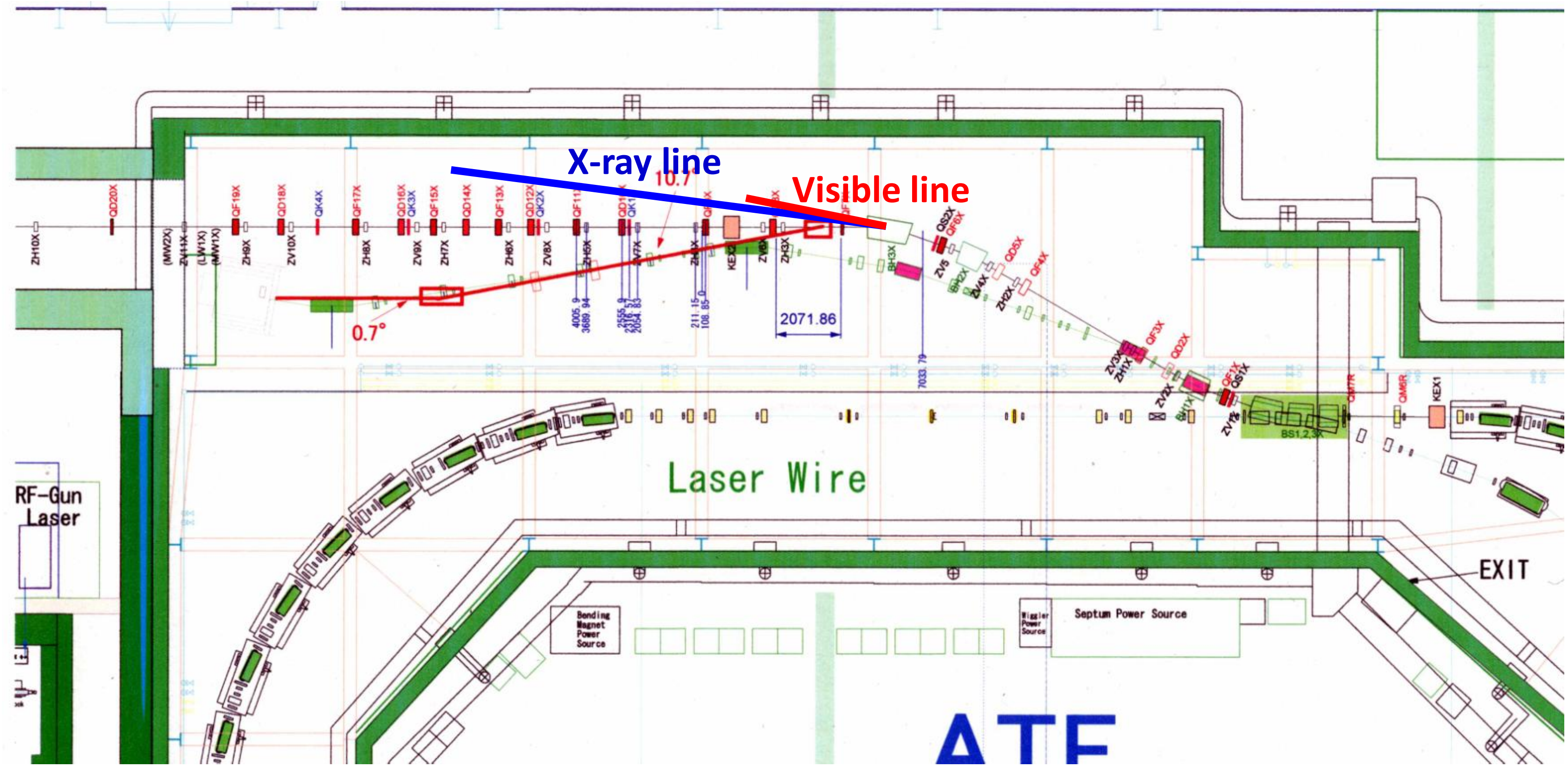
# XRM: Summary

- Source bends upstream of SRM source bends
  - LER bend is reused KEKB LER bend magnet (at half strength)
  - HER uses same current arc bend magnet
  - Some modifications to magnets downstream of source point have been requested of magnet group, to accommodate x-ray extraction line.
- $\sigma_y$: Coded Aperture Mask
  - Single-shot (single-bunch, single turn) resolution expected to be sufficient.
  - Single-shot mode probably be needed for low-emittance tuning, based on experience at CesrTA.
- $\sigma_x$: Possible, if single-shot measurements are needed
  - SRM should work for this in slow integration mode
- Being developed in collaboration with Cornell U., U. Hawaii and SLAC
  - Testing different components at CesrTA and ATF2
- Development work continuing on detector and readout

# XRM:Tests at ATF2 beam line

**Location**

**Source of SR: BH3X**

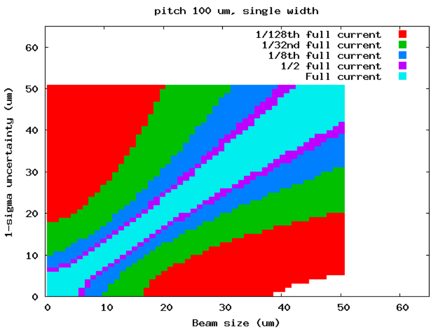



T. Mitsuhashi

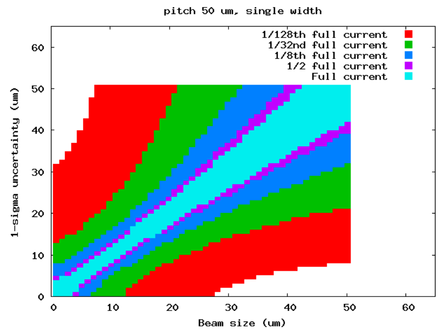
# HER, 59x10 um URA mask

## Single width detectors:

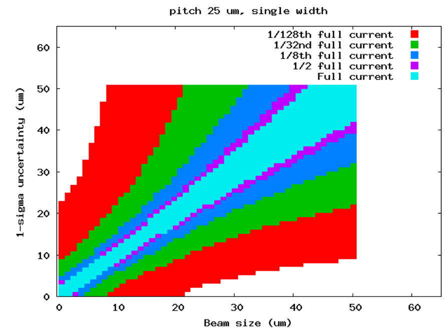
### 100 um pixels



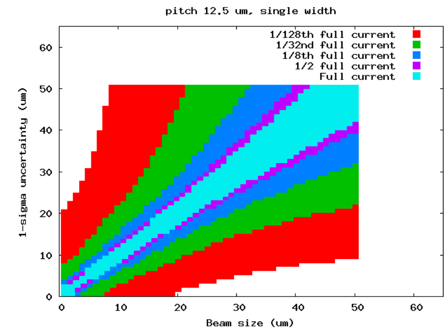

### 50 um pixels




### 25 um pixels



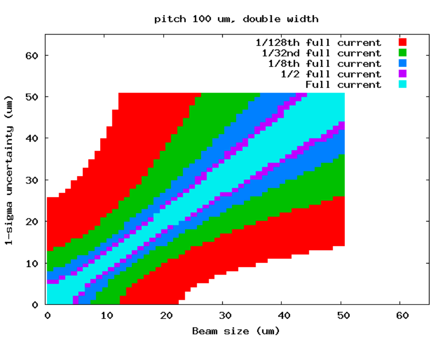

### 12.5 um pixels



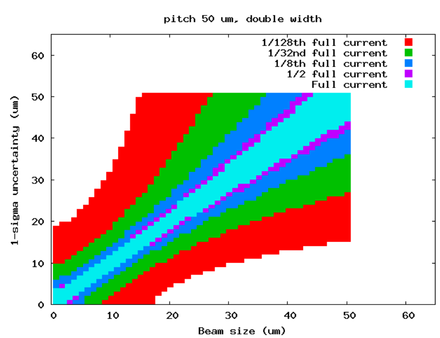

(taking root of sum of squares of sigmas)

## Double width detectors (twice the photon flux):

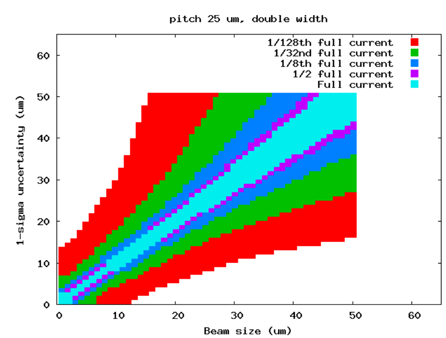
### 100 um pixels



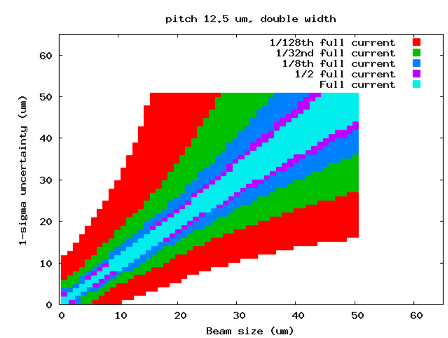

### 50 um pixels




### 25 um pixels



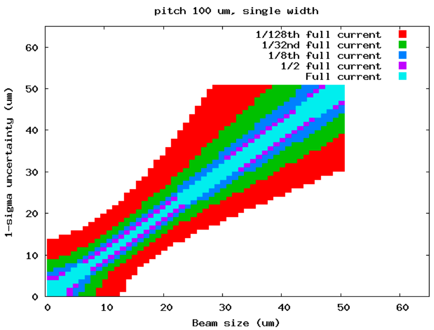

### 12.5 um pixels



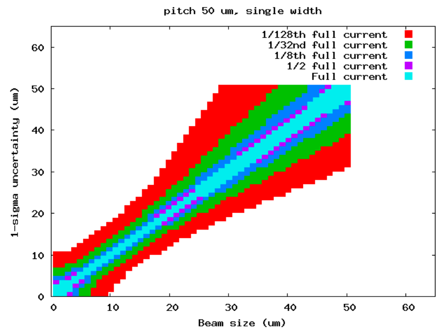
# LER, modified fibonacci pattern

## Single width detectors:

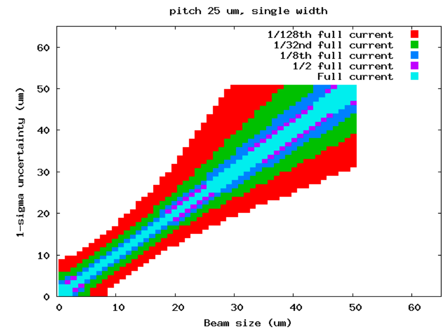
### 100 um pixels



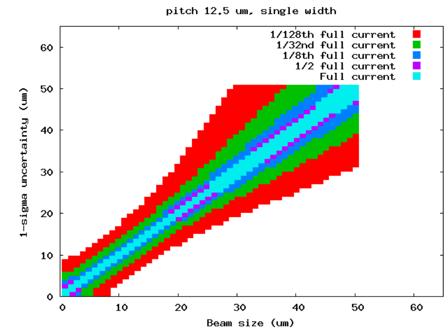

### 50 um pixels




### 25 um pixels

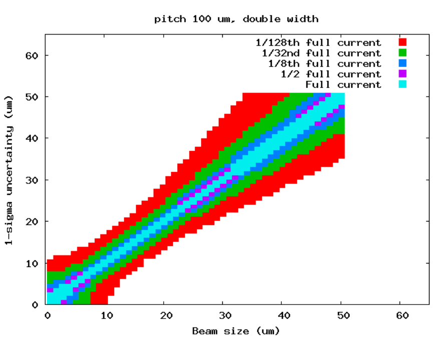



### 12.5 um pixels

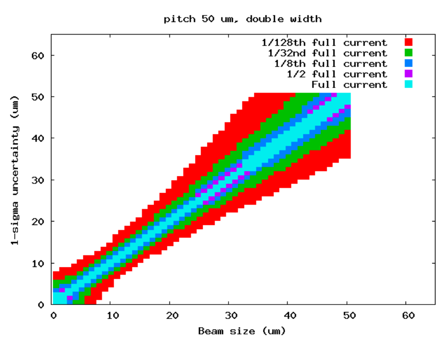



## Double width detectors (twice the photon flux):

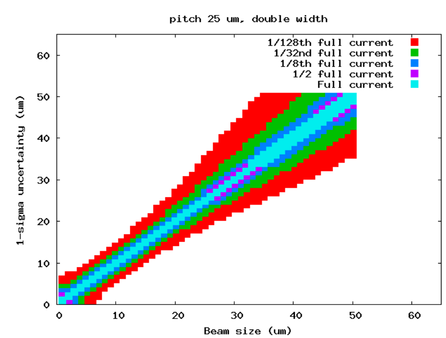
### 100 um pixels



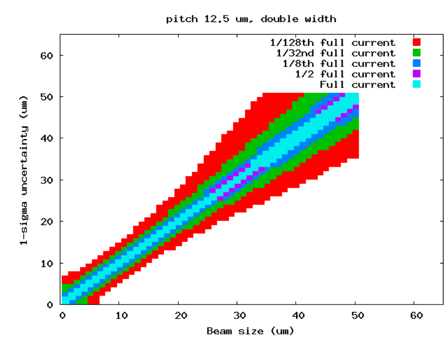

### 50 um pixels




### 25 um pixels




### 12.5 um pixels



# Simulation parameters

- Both rings:
  - 20 um Au on 500 um CVD diamond optics element
  - 200 um Be extraction window, 10 cm air
  - 2 mm deep x 75 um wide Si detector pixels
    - Vertical size ranges from 12.5 um to 800 um microns/pixel.
    - Total vertical area = 4000 um.
  - Simulate single-wafer detector seeing range of beam currents from full current down to 1/128 current (around the level that will be used for machine optics tuning).
- LER:
  - At full current (3.6 A over 2500 bunches), expect per 25 um high pixel:
    - Hole regions: 3967 photons/turn/bunch
    - Gold regions: 32 photons/turn/bunch
  - Patterns tested:
    - 35 um "pinhole" (slit) = size which gives minimum PSF at detector plane
    - 59x10 um URA mask
    - "13151 pattern": 6 35-um pinholes with varying spacings between them
    - "modified fibonacci pattern": 8 35-um pinholes with varying spacings between them
- HER:
  - Additional 2 cm be filter placed upstream of optics element
  - At full current (2.6 A over 2500 bunches), expect per 25 um high pixel:
    - Hole regions: 1655 photons/turn/bunch
    - Gold regions: 104 photons/turn/bunch
  - Pattern tested:
    - 59x10 um URA mask

# Single-shot resolution estimation

- Want to know, what is chance that a beam of a certain size is misfit as one of a different size?
- Tend to be photon statistics limited.
- So:
  - Calculate simulated detector images for beams of different sizes
  - "Fit" images pair-wise against each other:
    - One image represents true beam size, one the measured beam size
    - Calculate $\chi^2/\nu$ residuals differences between images:

*N* = # pixels/channels
*n* = # fit parameters (=0 here)
$S_i$ = expected number of photons in channel *i*

$$\frac{\chi^2}{\upsilon} = \frac{1}{N-n-1}\sum_{i=1}^{N}\frac{[s_i' - s_i]^2}{\sigma_i^2},$$

    - Weighting function for channel i:

$$\sigma_i = \sqrt{s_i}.$$

  - Draw contours at $\chi^2/\nu$ =1 to represent ~50% confidence intervals.

# Modified approach:

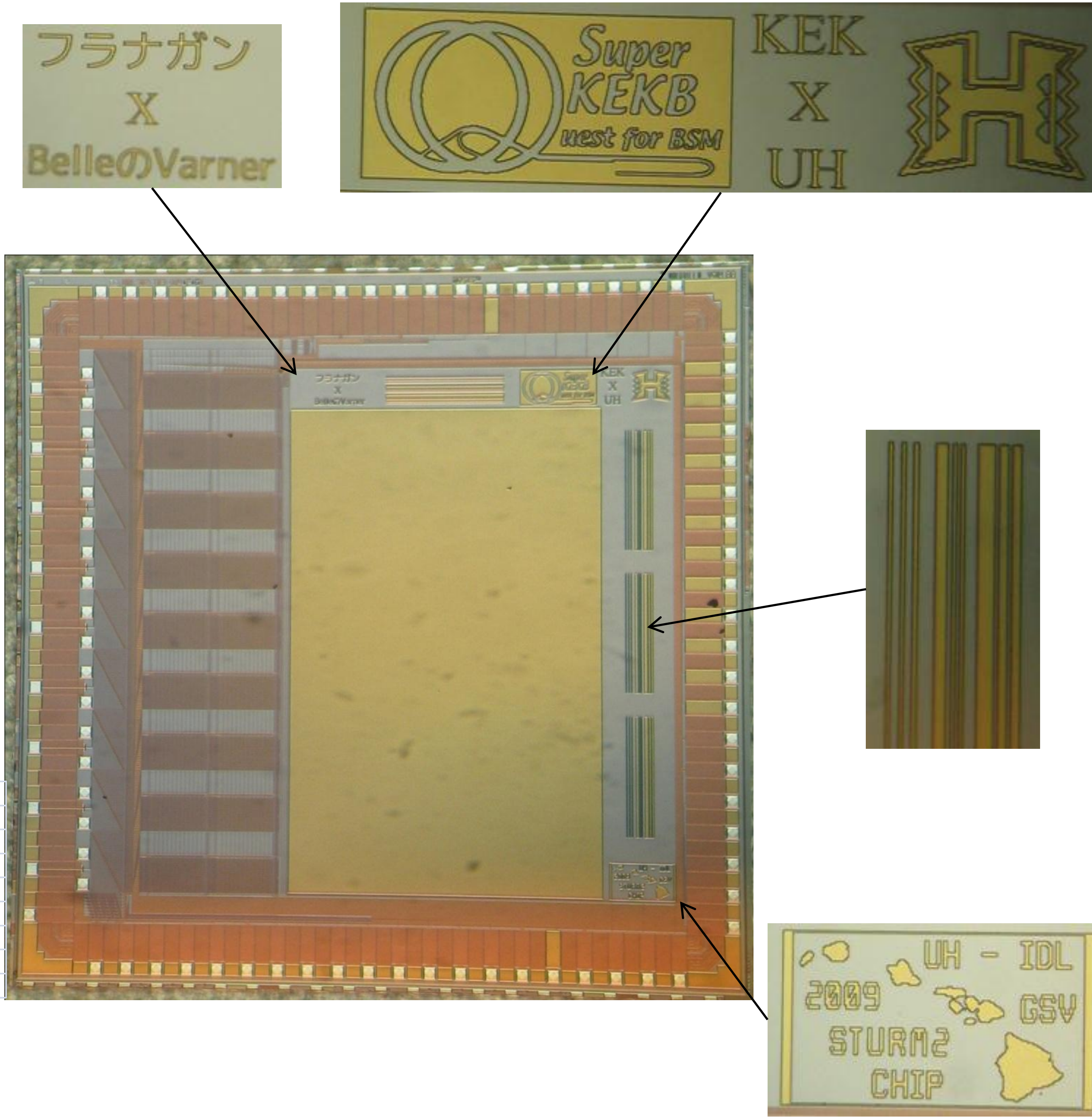
- Draw contours at chisq = 80, instead of chisq/dof = 1
  - This corresponds to chisq/dof = 1 for 50-um pixels
    - There are 80 50-um pixels in 4000 um simulated detector
  - Should cancel out change in degrees of freedom due to change in pitch

# XRM: Digitizer

# STURM2 ASIC

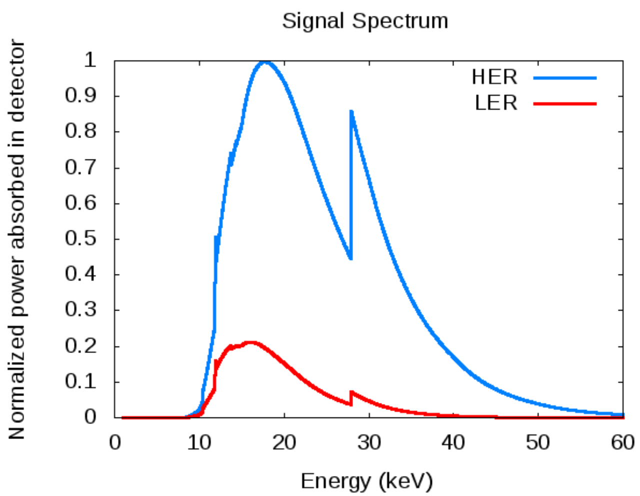
STURM ASIC for high-speed readout (G. Varner).
Ver. 1 tested at KEK PF, March 2009.
Ver. 2 fabricated.
Ver. 2 specs:

| | |
|---|---|
| 8 | channels/STURM sampling |
| 1 | monitor channel |
| 4 | TSA sample buffers |
| 8 | samples/TSA buffer (32x channel) |
| 288 | Wilkinson conversion cells |
| 1-200 | GSa/s effective (5ps - 1ns Tstep) |
| 1 | word (RAM) sample readout |
| 1+n*0.02 | us to read n samples |
| 100 | kHz sustained readout (orbit) |



# XRM: SuperKEKB estimated single-shot resolutions (SuperKEKB full current)

- Red points: using 64-pixel detector of same type as at CesrTA (Fermionics)
- Green points: using detector with improved photon detection efficiency at higher x-ray energies (being developed)




Detected spectrum (Fermionics detector)