LHC Beam Size Measurement Review

Possible synchrotron light upgrades for HL-LHC

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Foreword

- There is no official upgrade plan for the BSRT
  - Modifications and improvements are for the moment financed by the exploitation budget
  - Run 3 will provide important lessons
- For the HL-LHC project a new synchrotron light extraction per beam will be designed and installed
  - The purpose of this new extraction is to accommodate the HALO monitor (aka coronagraph) and the streak cameras for monitoring the crabbing
  - The halo monitor is presently under development
  - The need of streak cameras is still under discussion

Content

- Present status and limitations
- Possible improvements for the imaging system
  - Mechanics
  - Optics
  - Acquisition
- Alternative measurements
  - Double slit interferometer
  - Pin-Hole camera
- Beam halo monitor
- New light extractions

BSRT Status and Limitations

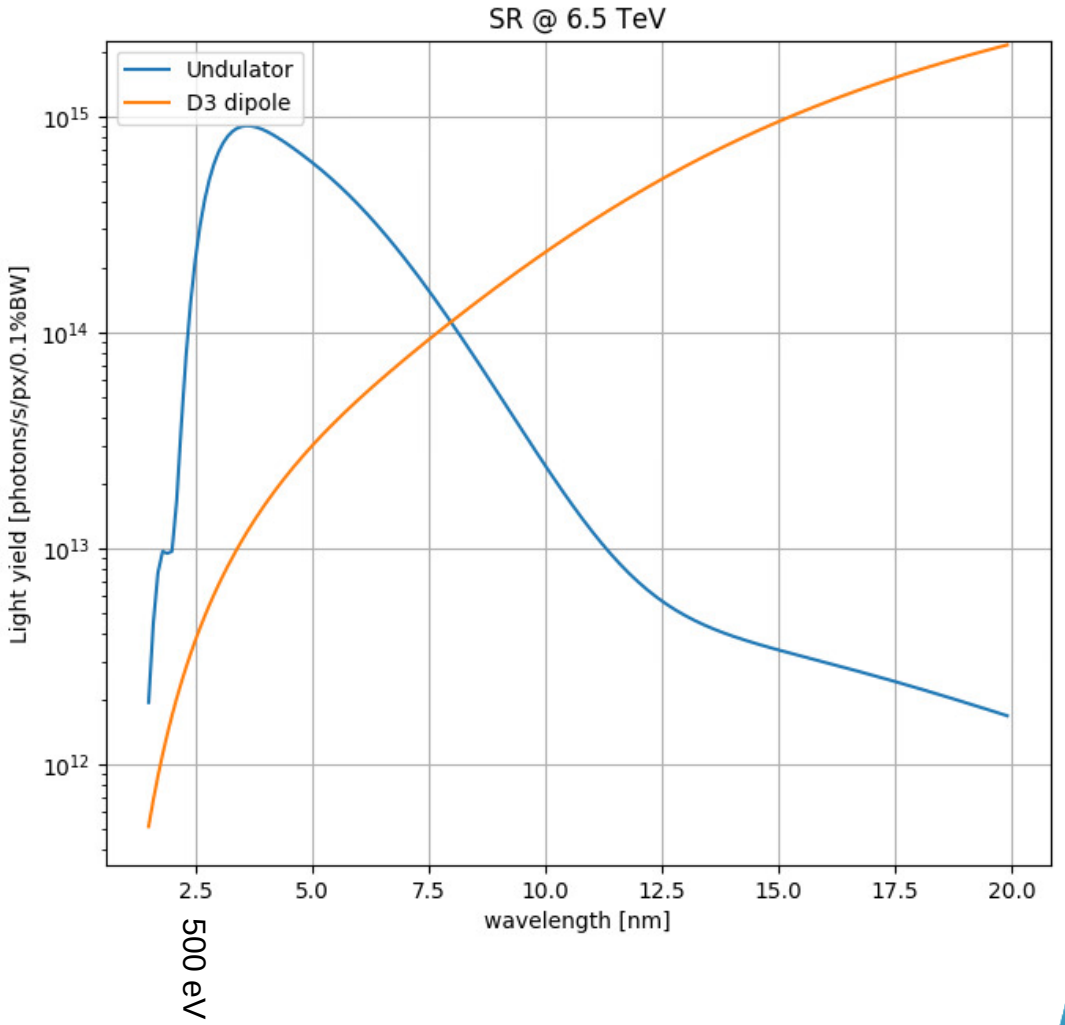
- Beam size derived from imaging of Synchrotron Radiation emitted in LSS4
  - Complex source: Undulator, D3-edge, D3-core, D3-edge on the other side, reflections, diffusion …
    - This together with diffraction limits the optical resolution
  - SR from D3 extend in the UV, Undulator even in X-Rays
    - Damage to the optical components
  - Acquisition relies on Image-Intensifiers for BbyB gating
    - Rapid wear of the photocathode, need to keep light low (reduce S/N) and slow the acquisition (long scans)

Synchrotron radiation in the EUV

Synchrotron radiation in the EUV range at 6.5 TeV for protons

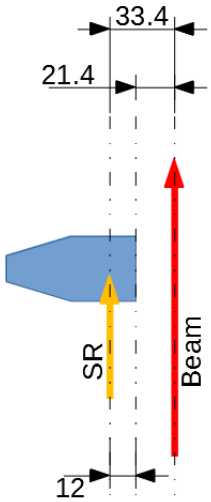
Undulator emission dominates at very short wavelengths

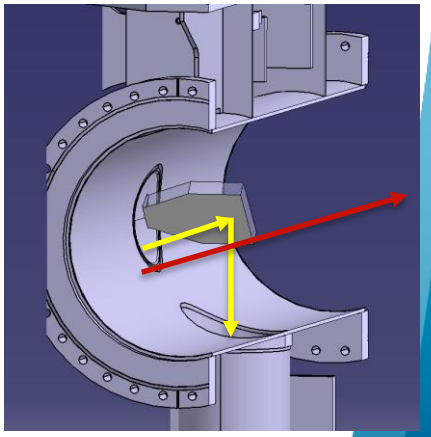
The absorption length of few nm photons is in the micrometer range



SR extraction

- SR is extracted using a multilayer dielectric mirror with fused silica substrate
  - Strict limitations on materials from RF coupling (heating)
  - Many layers needed to cover the visible and UV ranges (injection and FT), limited optical quality and prone to damage
- Mirror edge is fixed
  - Can not select “only core”





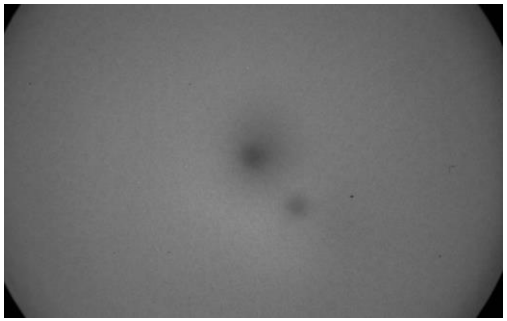
SR extraction improvements

- Ramp down undulators at high energy
- Separate extraction of UV and visible
  - Two mirrors (impedance?)
  - OR get rid of UV, gain of UV need to be studied
  - Better quality mirrors (flatness)
  - Less sensitive to heat deposition
- Implement a dynamic position for the mirror
  - Place the mirror closer to the beam as the energy increases (size shrinks)
  - Requires actuators similar to collimators
  - Allow to select only the core of D3 as source
- Add an X-Ray filter upstream of the mirror (Fused silica slab)
  - Reduce the damage to the components downstream

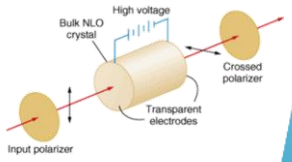
Optics

- Observed UV induced damage on: Viewport, UV-filters, Wedge splitter
- Cause of damage not fully understood, for the viewport and wedge, may be due to Fluorine presence in the enclosure (etching)
  - Replace all mirrors on the optical table (MgF coated)
  - Mask the synchrotron light to avoid UV on cables/mounts etc.
- UV-filters probably suffer from burns
  - Move filters to location where SR is defocused
- LSF larger than expected, not understood
  - More refined simulations
  - Investigate different optics solutions (focal lengths, Cassegrain, etc.)

Acquisition

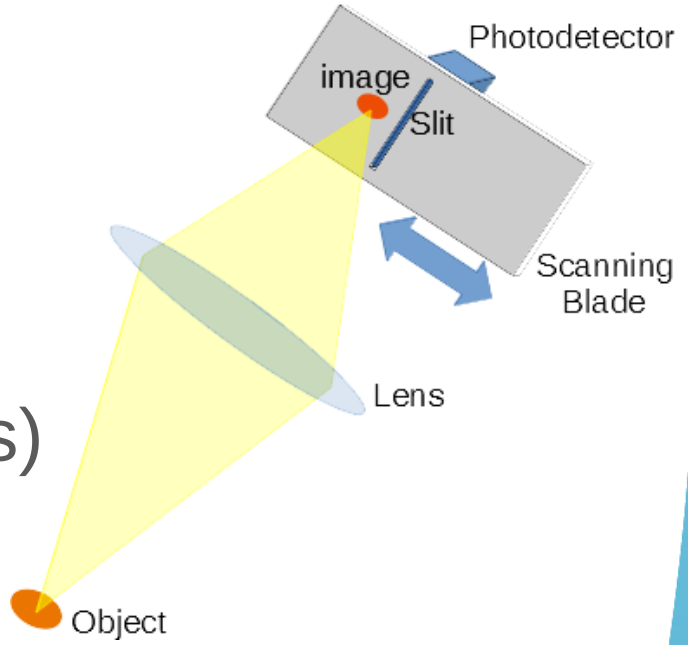


- Lifetime of cameras ~ 1-2 Year
  - Compatible with operation
    - Image quality and acquisition rates degraded to maximize lifetime
  - Need to formalize purchasing (Japan) if regular procurement needed (~30kCHF/intensifier)
  - Need to develop remote check/calibration system
    - Allow to spot problems early and apply corrections
- Alternatives
  - Pockels cells shutter
    - Limited extinction ratio, image quality, wavelength
  - Slit scanner
    - Sample profiles instead of image

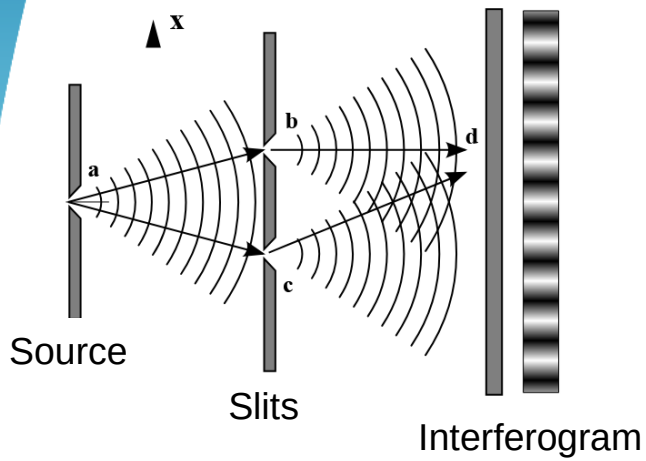


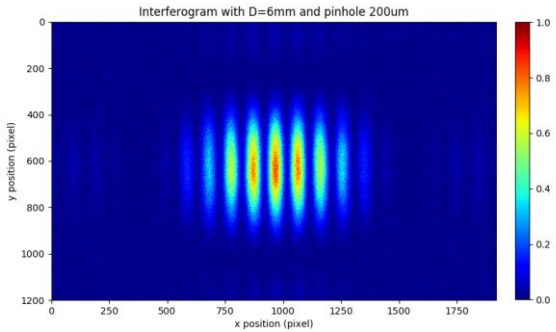
Slit scanner

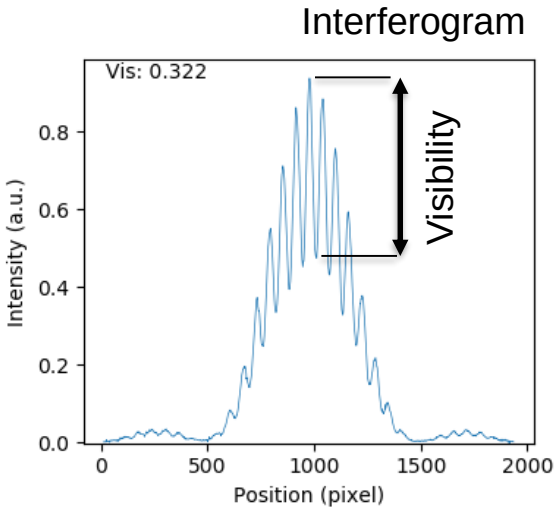
- Photodetector signal vs. slit position → beam profile
- Use fast photodetector to disentangle the different bunches (600MHz digitizer)
- Scan can be very fast (seconds)
- Mechanical device (wear and tear), rotating slit?
- Small slit width (50-100 um)

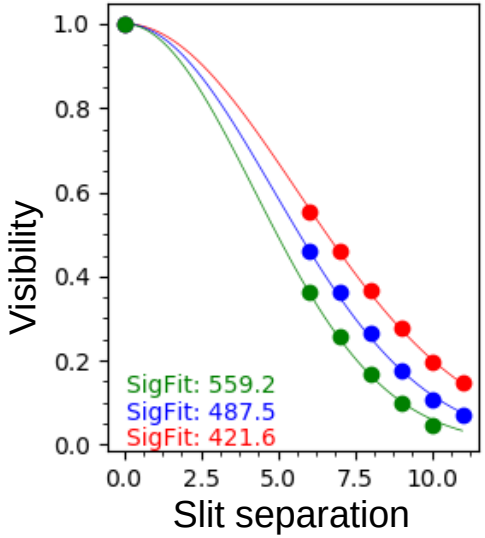


Double slit interferometer



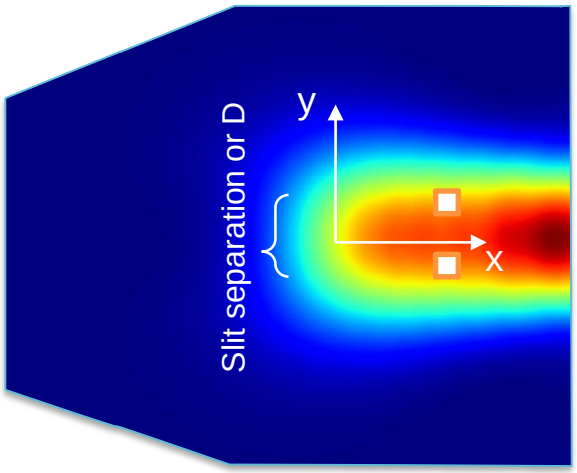


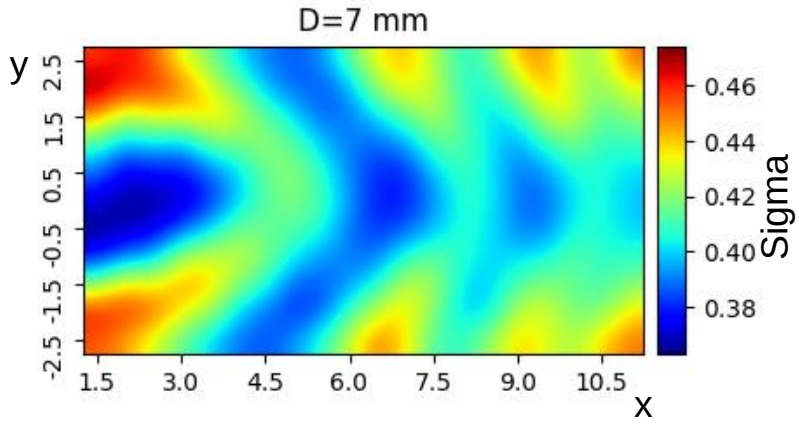




- VCZ: Visibility vs. Slit separation == Fourier transform of source distribution
- In principle can provide absolute size of the light source
- Used in most electron machines

BSRI tests

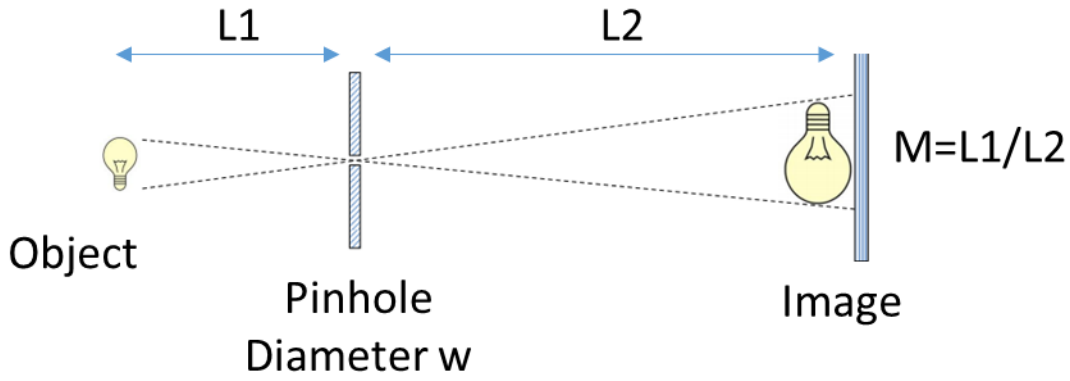




- Several tests in Run 2 on B1
- Unexpected results
  - Estimated size depends on slits position
    - Should only depend on slit distance
- Investigations ongoing (new PhD just starting)
- B1 test system will be improved in LS2

Pin-hole camera

- Hard radiation from undulator could be used in a pin-hole camera
- Little contribution from diffraction (short λ)
- Well defined source, no depth of field LSF → PSF



End of D3

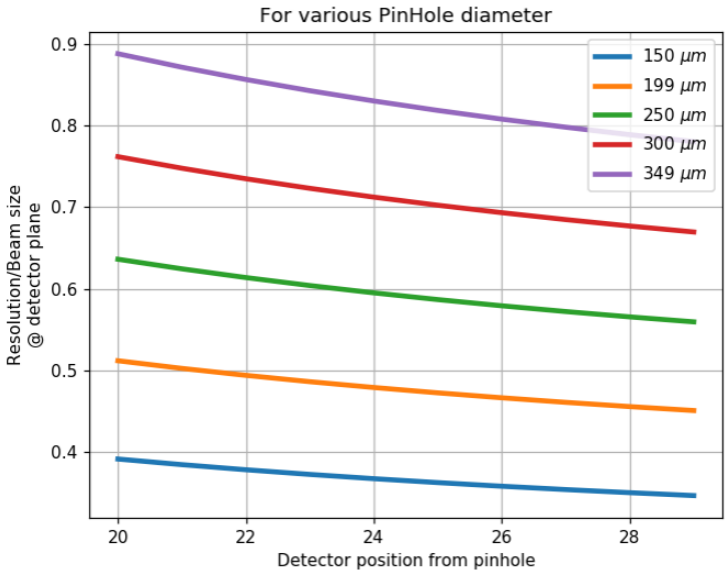
Downstream of BSRTM

Pin-hole resolution

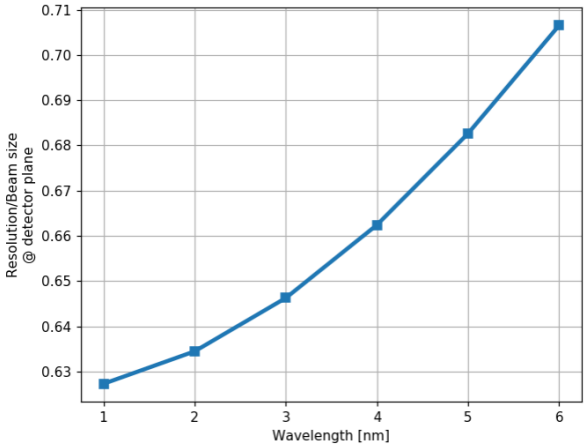
$$(\sigma_{image})^2 = (M \cdot \sigma_{source})^2 + (\sigma_{blur})^2 + (\sigma_{diffraction})^2$$

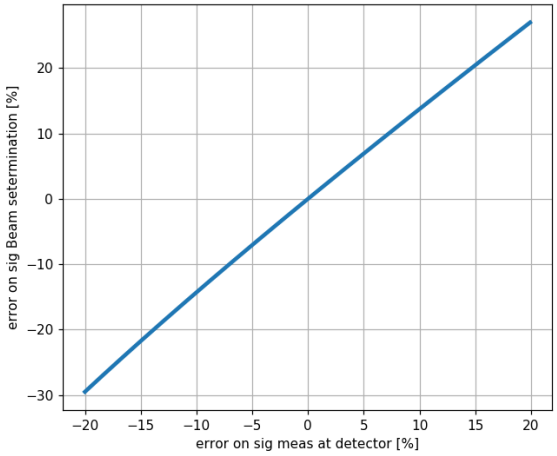
$$\sigma_{blur} = \frac{w}{\sqrt{2\pi}} \frac{(L_1 + L_2)}{L_1} \qquad \sigma_{diffraction} = \frac{\sqrt{12}}{4\pi} \frac{\lambda L_2}{w}$$

$$\varepsilon_\sigma = \frac{\partial \sigma}{\partial \sigma_M} \varepsilon_M = \frac{1}{\sqrt{1 - \frac{1}{1 + \frac{\sigma^2}{PSF^2}}}} \varepsilon_M$$



L1=12.9, w=250 um, L2=20.75

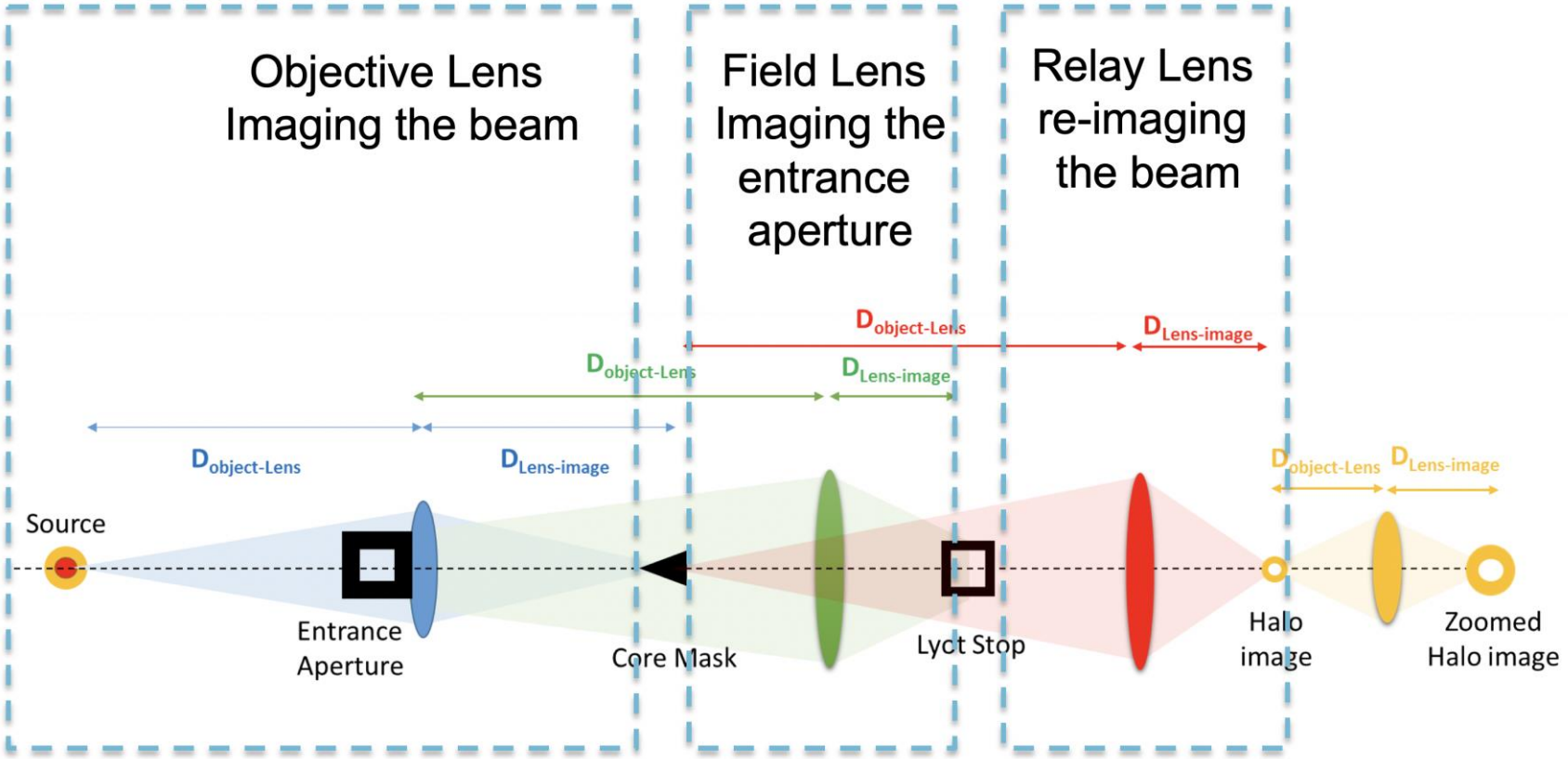


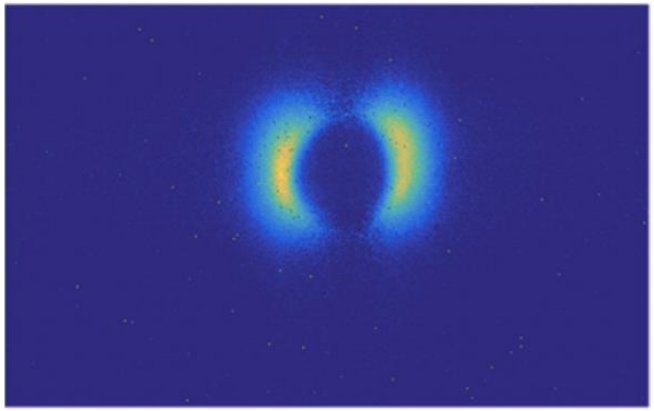


M=1.6

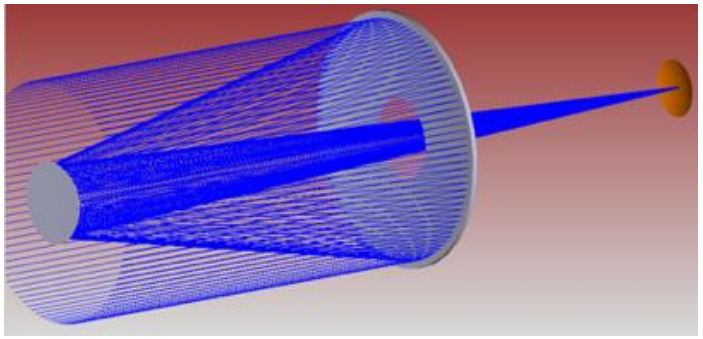
For λ=2.5nm
Blur= 260um
Diff= 57um

Beam Halo monitor



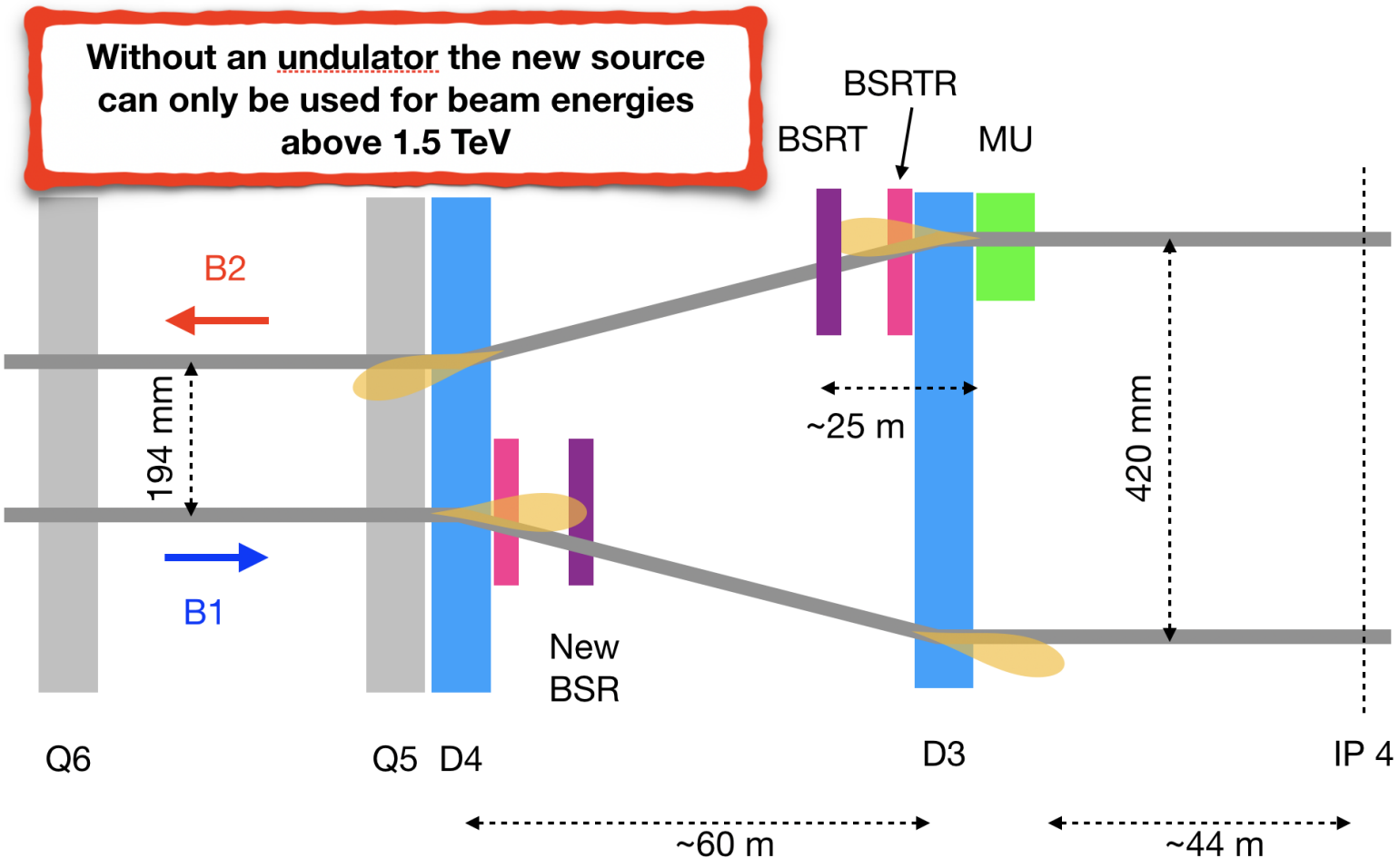


BSRH



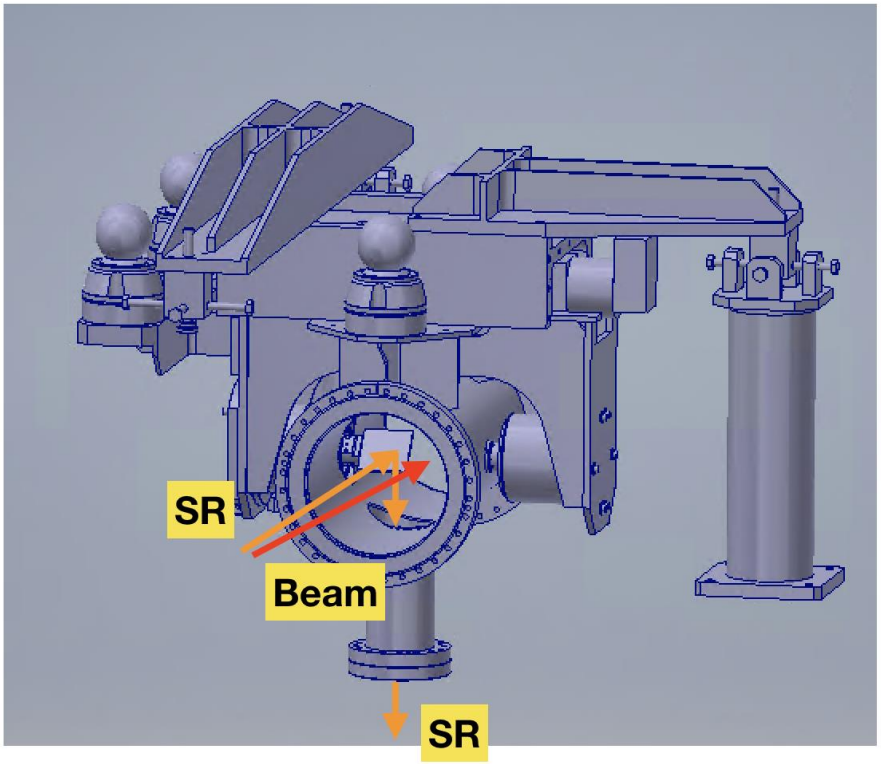
- 1st prototype in 2016 tested on B2, built using parts from KEK, contrast of 1E-3
- Performance limited by diffraction on core mask
- Redesign of optics ongoing, replace objective lens with Cassegrain telescope
- Magnification of first stage increased to 0.5
  - Will reduce diffraction of core mask
- Target contrast of 1E-5

New SR extraction line



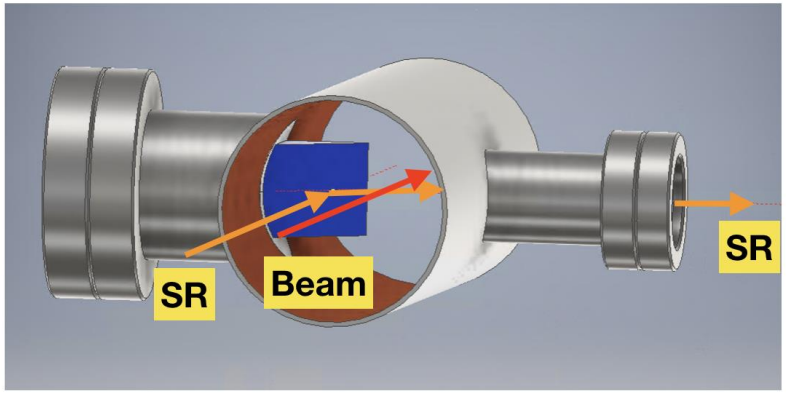
New SR extraction tank

LHC BSRTM



Suffers from dust and debris falling on viewport

New SPS BSRTM design



Conclusions

- No major upgrade plan for the BSRT
- HL-LHC will profit from the continuous improvements of the system during LS2 and Run 3
- Interferometer proceeding well, will be made operational during Run 3
- Pin-hole camera could be interesting, but many technical difficulties to implement (impedance)
- New SR extraction lines offer flexibility to reshuffle/optimize the different instruments