ビームハロー測定について

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第102回ビームダイナミックスWGミーティング
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ERL開発棟会議室

Contents

1. 実験データの解析
2. シムレーション結果との比べ
3. HDR imagingのアプローチ

始めに

ビームハロー&をビームロース起こす理由:

1. Longitudinal bunch tail from cathode
2. Laser phase shift or movement
3. Laser pulse tail or train

Longitudinal halo

4. Misalignment of beam line elements(cavities, magnets)
5. Kicks from the input or HOM couplers
6. Kicks from the steering magnets(coils)

Transverse halo

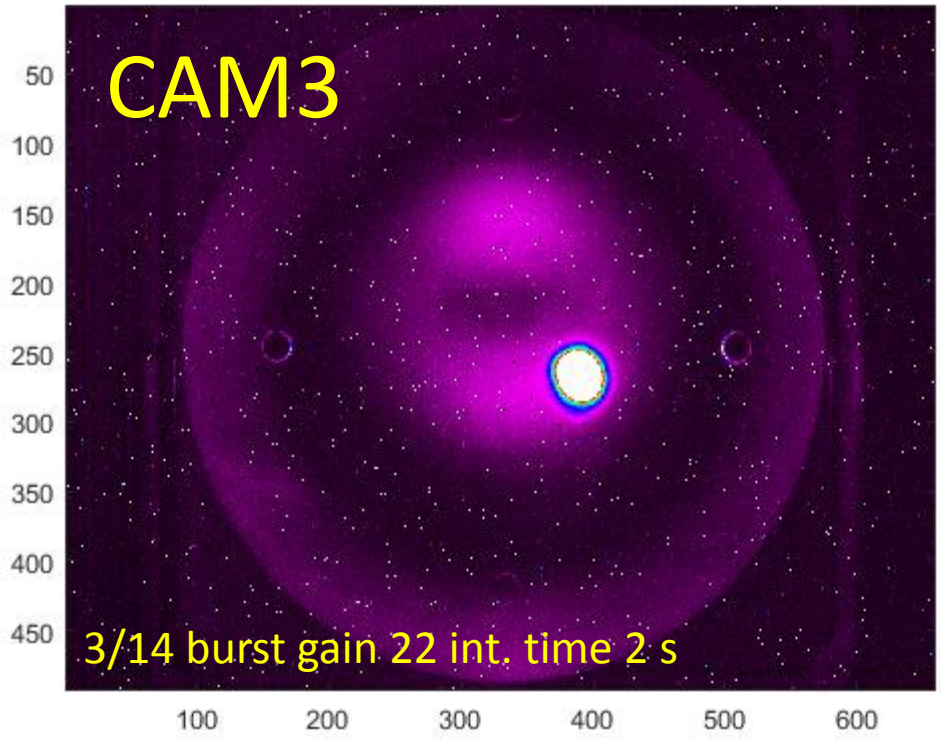
7. Space charge effect
8. Dispersion
9. Large betatron function
10. Large momentum deviation(spread)
11. Narrow(Small) aperture
12. Collimator insertion

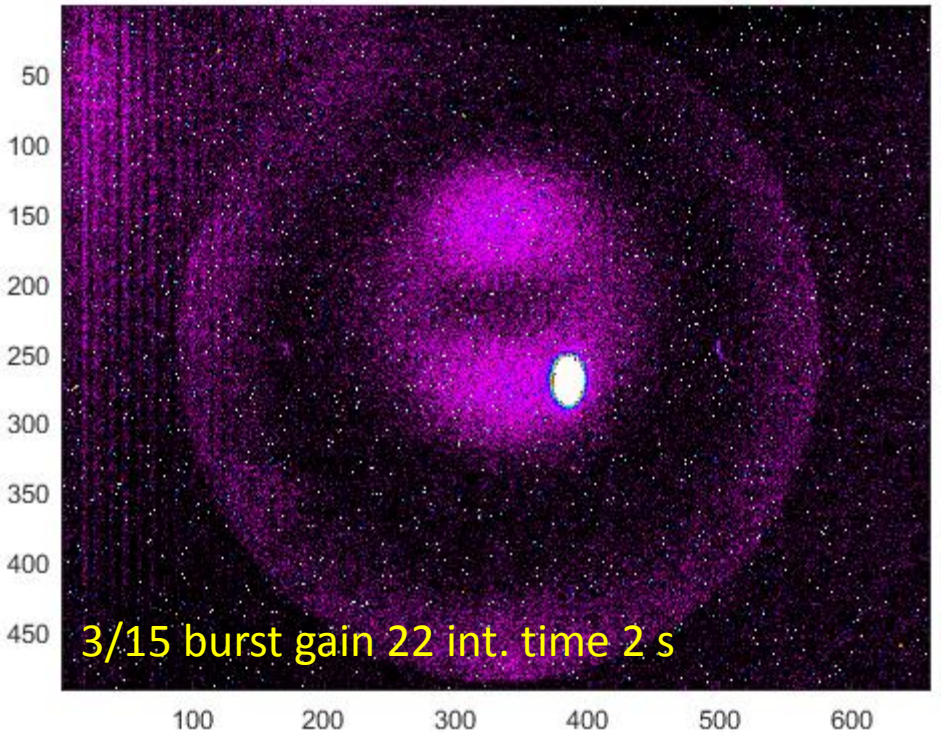
Loss reasons

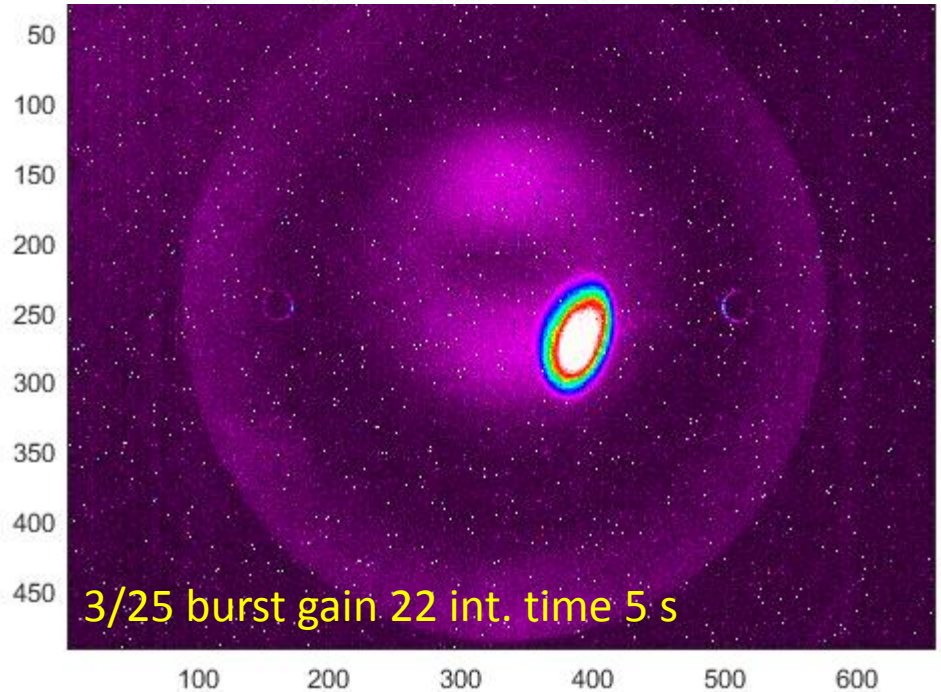
１．実験データの解析

ビーム状況の比べ

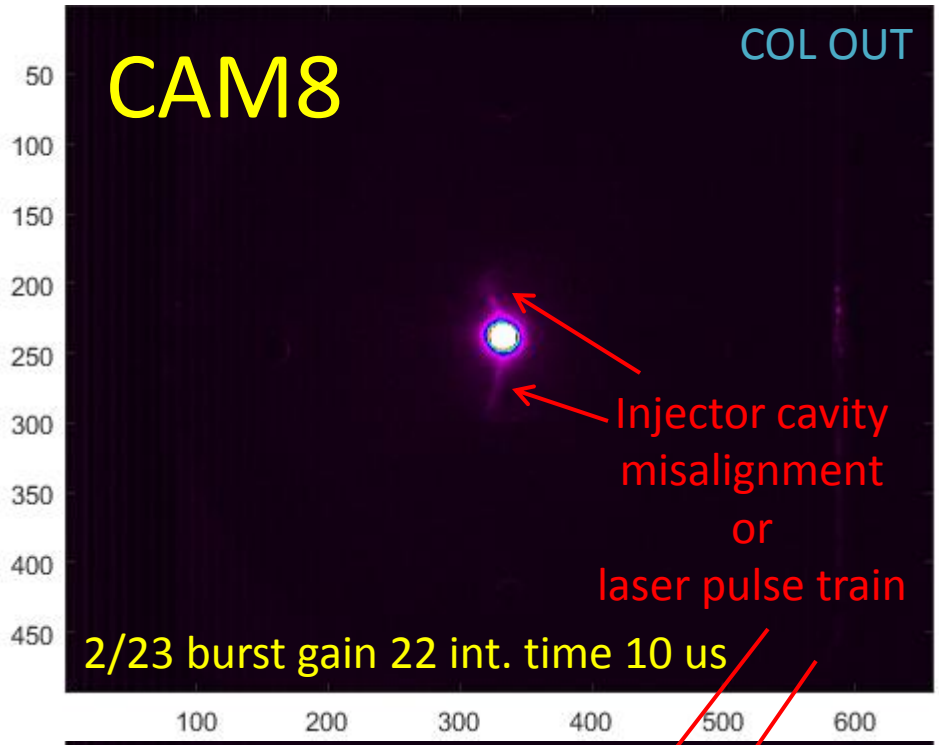
- 2/23
  - Burst mode
  - Integration time 10 usec
  - Macro pulse duration 1 usec
  - Macro pulse frequency 5 Hz
  - Repetition rate 1.3 GHz
  - Beam energy 2.9 — 20 MeV
  - Bunch charge 0.2 — 0.3 pC
  - Peak current 300 uA
  - Average current 1.5 nA
  - QE 1.57%
  - Injector cavity #1 phase = -80 deg.
  - Injector cavity #2-3 phase = -81 deg.
  - Main cavity #1 phase = -174 deg.
  - Main cavity #2 phase = -20 deg.
  - Buncher cavity phase = 174 deg.
- 3/2
  - Burst mode
  - Integration time 10 usec
  - Macro pulse duration 1 usec
  - Macro pulse frequency 5 Hz
  - Repetition rate 1.3 GHz
  - Beam energy 2.9 — 20 MeV
  - Bunch charge 0.2 — 0.3 pC
  - Peak current 300 uA
  - Average current 1.47 nA
  - QE 1.62%
  - Injector cavity #1 phase = -80 deg.
  - Injector cavity #2-3 phase = -81 deg.
  - Main cavity #1 phase = -174 deg.
  - Main cavity #2 phase = -20 deg.
  - Buncher cavity phase = 174 deg.
- 3/9
  - Long pulse mode
  - Integration time 2 msec
  - Macro pulse duration 1.5 msec
  - Macro pulse frequency 0.6 Hz
  - Average current 3 nA
  - 6 nC per pulse
  - Laser intensity 0.86 %
  - Repetition rate 1.3 GHz
  - Beam energy 20 MeV
  - QE 1.25%
  - Injector cavity #1 phase = -80 deg.
  - Injector cavity #2-3 phase = -81 deg.
  - Main cavity #1 phase = -174.5 deg.
  - Main cavity #2 phase = -21 deg.
  - Buncher cavity phase = 174 deg.
- 3/14
  - Burst mode
  - Integration time 2 sec
  - Macro pulse duration 1 usec
  - Macro pulse frequency 5 Hz
  - Repetition rate 162.5 MHz
  - Beam energy 2.9 — 20 MeV
  - Bunch charge 0.2 — 0.3 pC
  - Peak current 438 uA
  - Average current 2.12 nA
  - QE 1.38%
  - Injector cavity #1 phase = -80 deg.
  - Injector cavity #2-3 phase = -81 deg.
  - Main cavity #1 phase = - -165.5 deg.
  - Main cavity #2 phase = -12 deg.
  - Buncher cavity phase = 174 deg.
- 3/15
  - Burst mode
  - Integration time 2 sec
  - Macro pulse duration 1 usec
  - Macro pulse frequency 5 Hz
  - Repetition rate 162.5 MHz
  - Beam energy 2.9 — 20 MeV
  - Bunch charge 0.2 — 0.3 pC
  - Peak current 300 uA
  - Average current 1.47 nA
  - QE 2.58%
  - Injector cavity #1 phase = -80 deg.
  - Injector cavity #2-3 phase = -81 deg.
  - Main cavity #1 phase = -174.5 deg.
  - Main cavity #2 phase = -28 deg.
  - Buncher cavity phase = 174 deg.
- 3/25
  - Burst mode
  - Integration time 10 usec, 2 sec, 5sec
  - Macro pulse duration 1 usec
  - Macro pulse frequency 5 Hz
  - Average current 1.55 nA
  - Peak current 300 uA
  - Bunch charge 0.5 pC
  - Repetition rate 162.5 MHz
  - Beam energy 2.9-20 MeV
  - Injector cavity #1 phase = -80 deg.
  - Injector cavity #2-3 phase = -81 deg.
  - Main cavity #1 phase = -174.5 deg.
  - Main cavity #2 phase = -21 deg.
  - Buncher cavity phase = 175 deg.

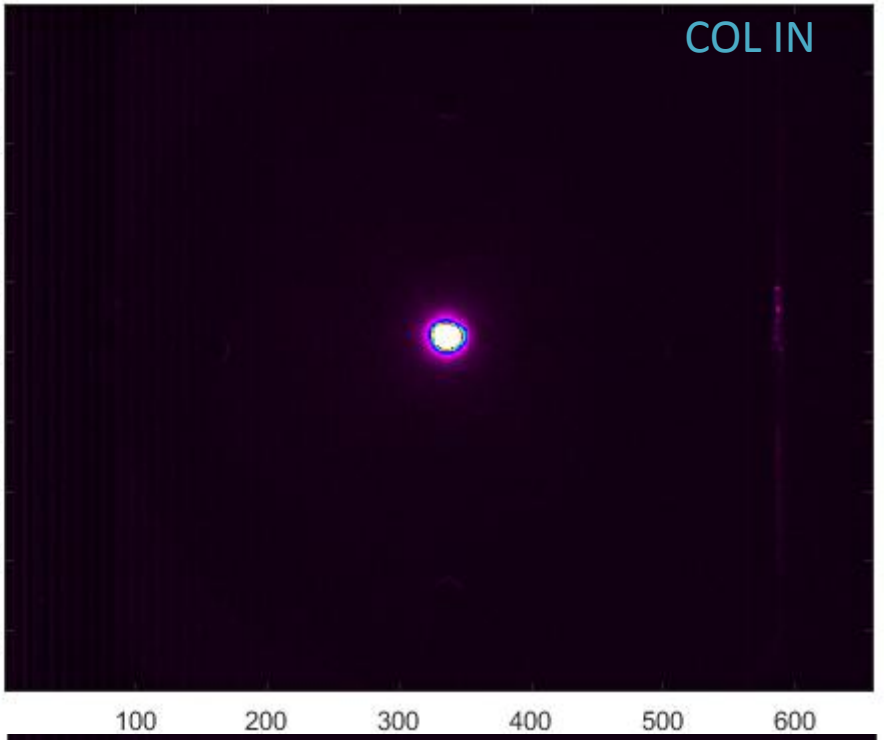


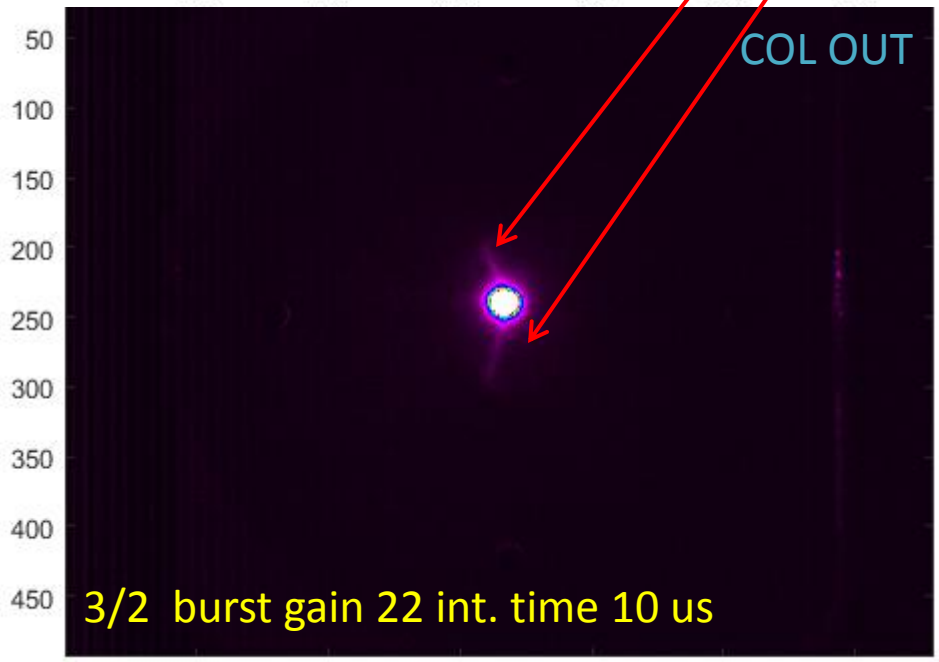




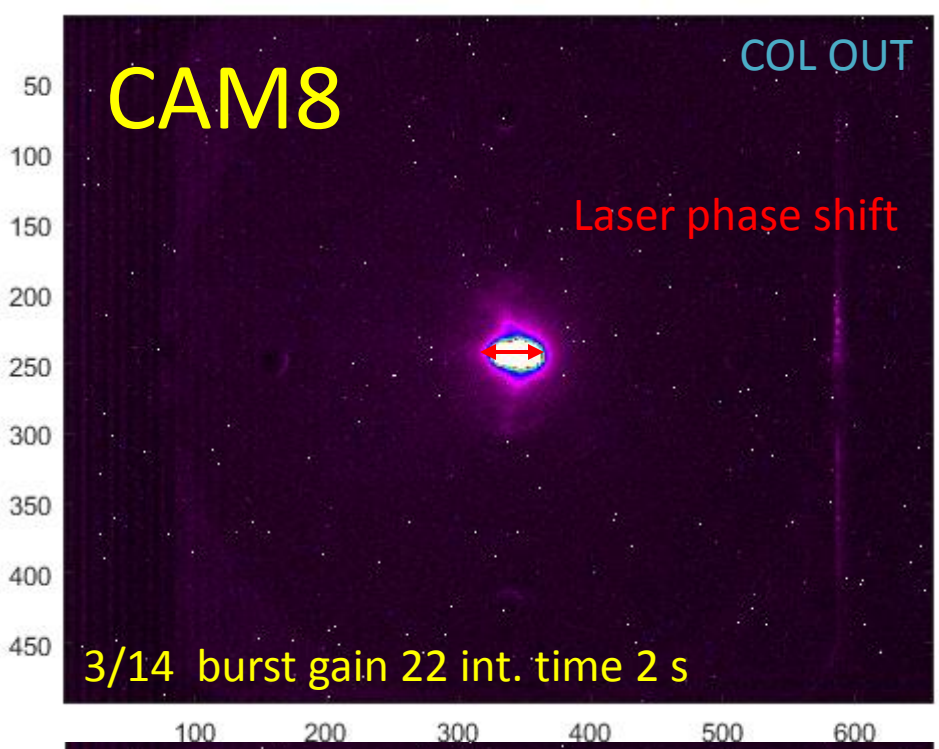
No tail from the cathode observed at CAM1, CAM2, CAM3!

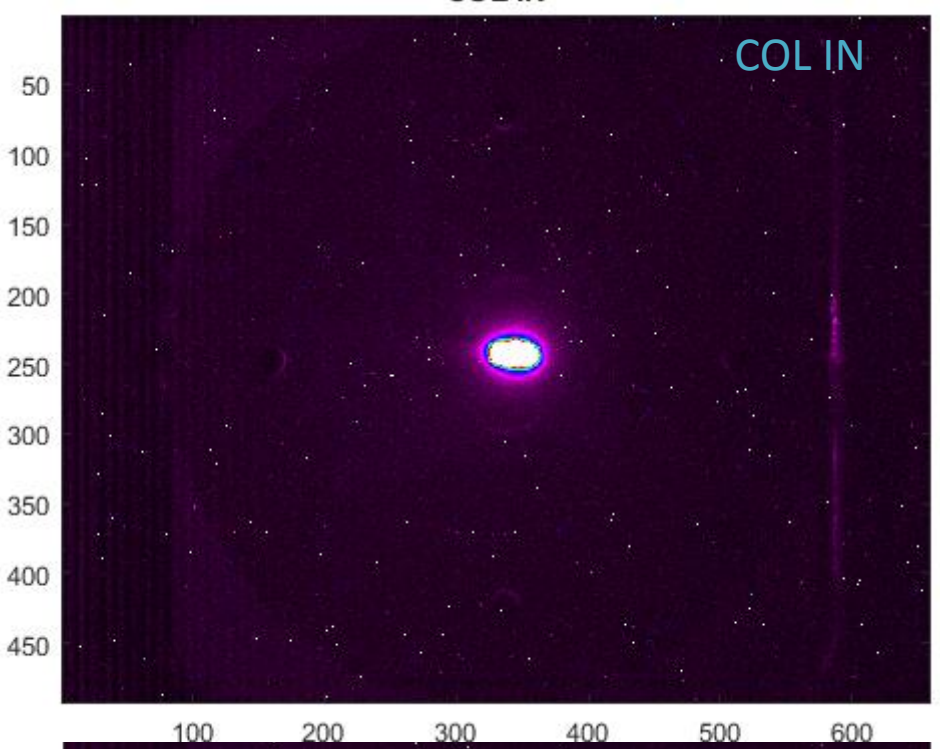

CAM8
COL OUT
Injector cavity
misalignment
or
laser pulse train
2/23 burst gain 22 int. time 10 us
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

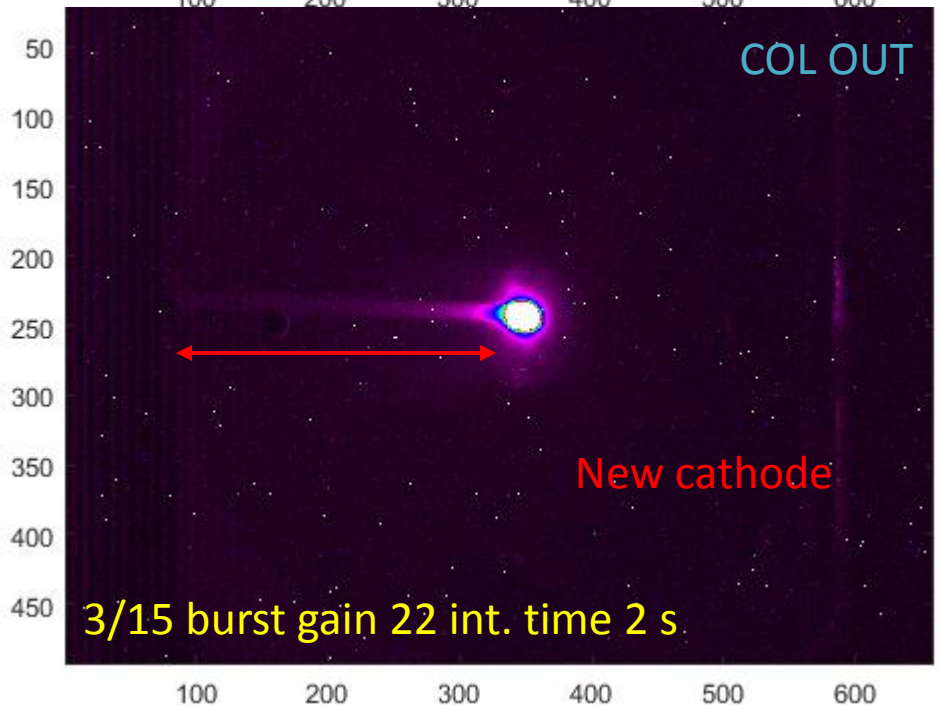

COL IN
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

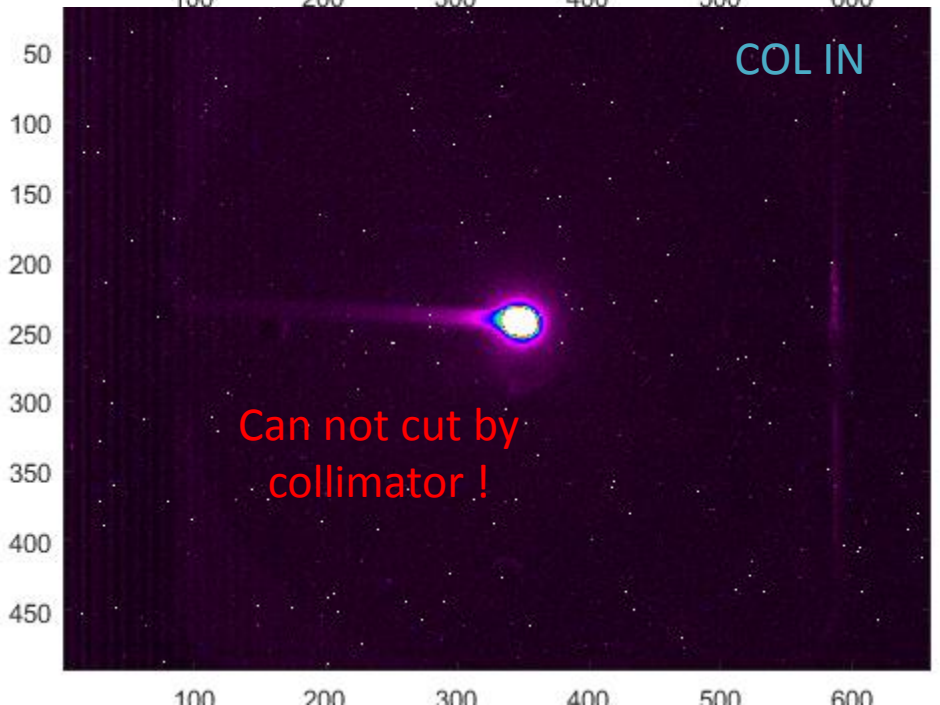

COL OUT
3/2 burst gain 22 int. time 10 us
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600

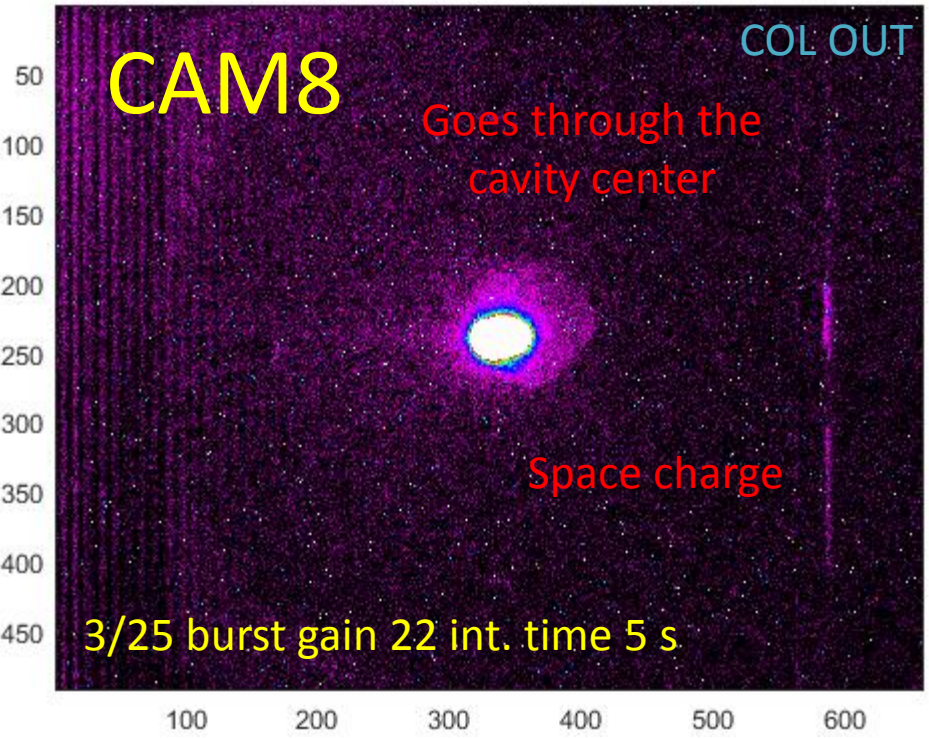

COL IN
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600


CAM8
COL OUT
Laser phase shift
3/14 burst gain 22 int. time 2 s


COL IN


COL OUT
New cathode
3/15 burst gain 22 int. time 2 s


COL IN
Can not cut by
collimator !


CAM8
COL OUT
Goes through the cavity center
Space charge
3/25 burst gain 22 int. time 5 s
50
100
150
200
250
300
350
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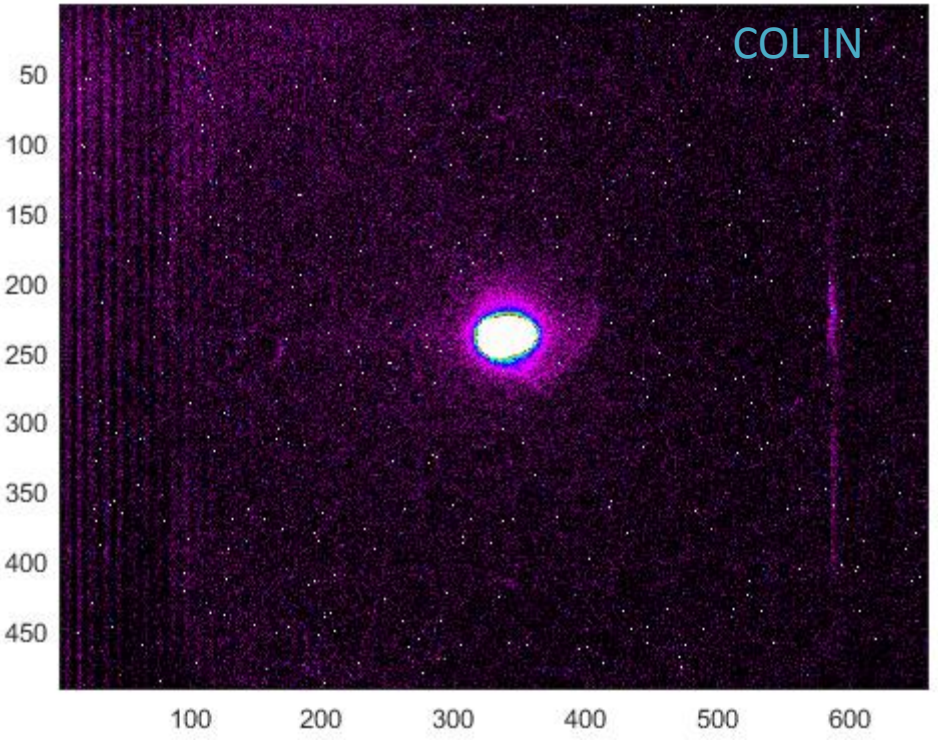
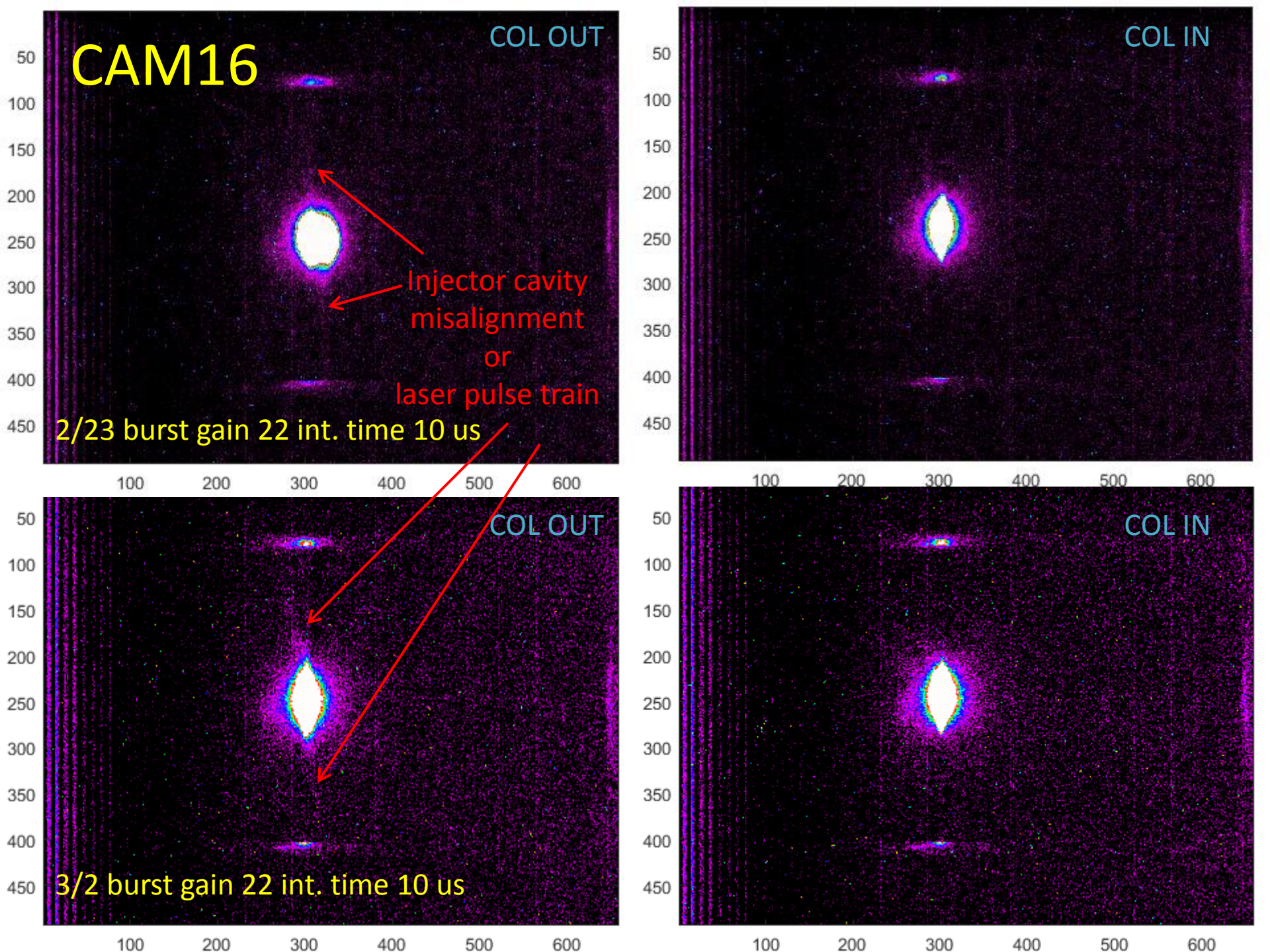
450
100
200
300
400
500
600


COL IN
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600


CAM16
COL OUT
COL IN
COL OUT
COL IN
Injector cavity
misalignment
or
laser pulse train
2/23 burst gain 22 int. time 10 us
3/2 burst gain 22 int. time 10 us
50
100
150
200
250
300
350
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450
100
200
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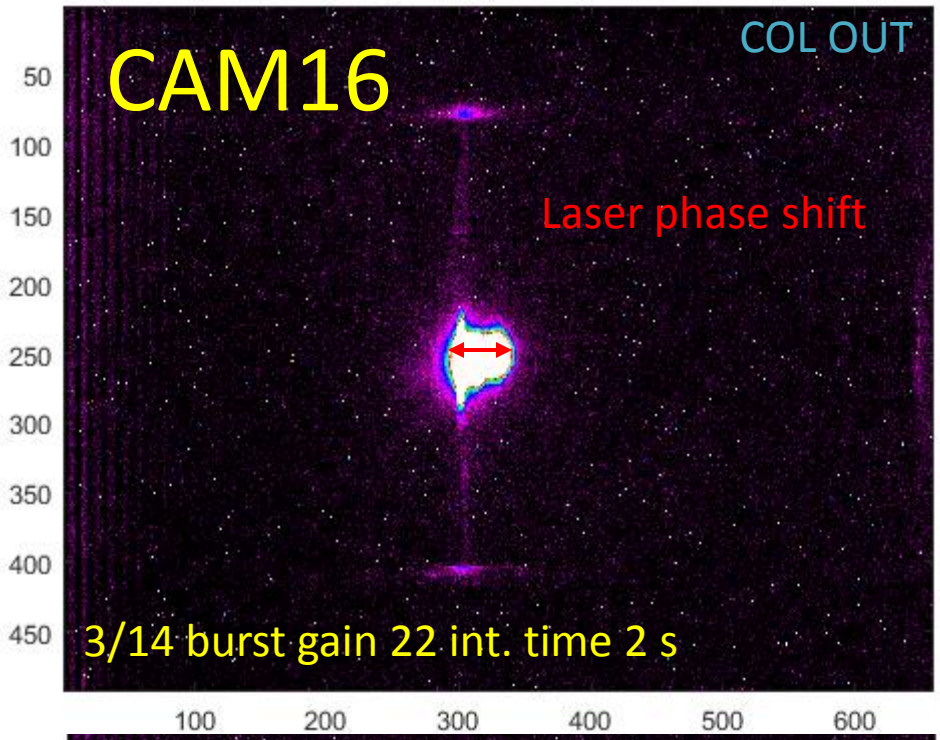
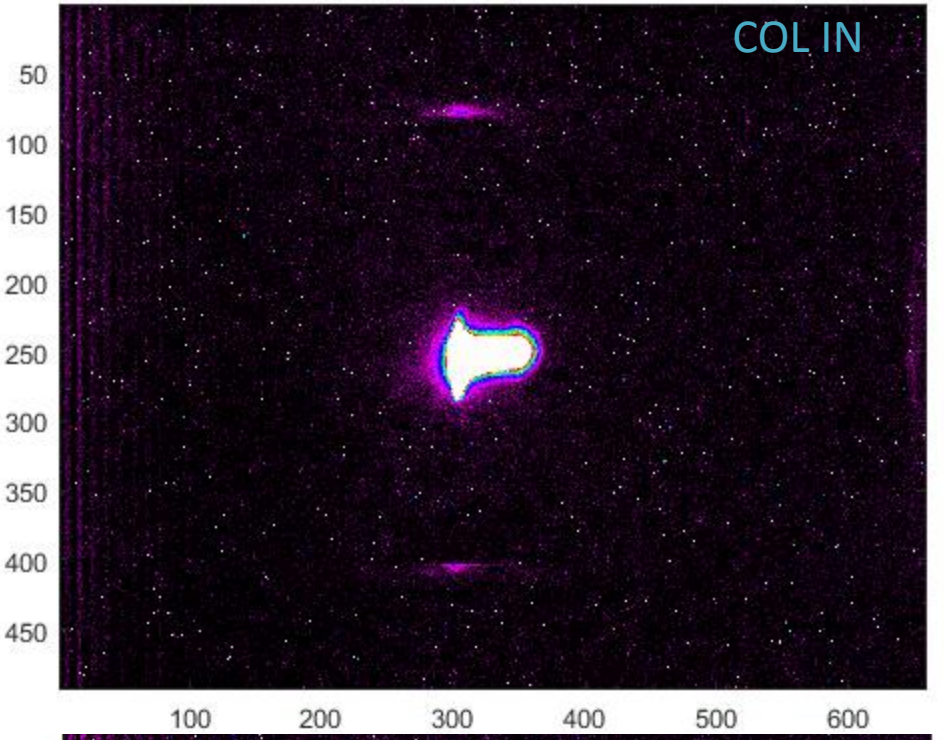
400
500
600


CAM16
COL OUT
Laser phase shift
3/14 burst gain 22 int. time 2 s
50
100
150
200
250
300
350
400
450
100
200
300
400
500
600


COL IN
50
100
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300
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400
450
100
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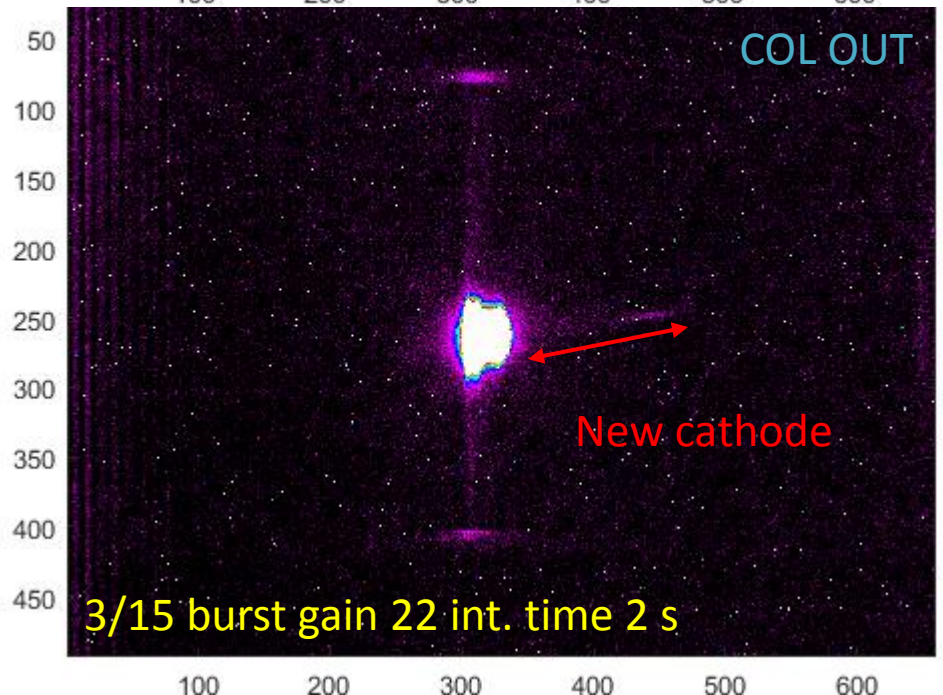
600


COL OUT
New cathode
3/15 burst gain 22 int. time 2 s
50
100
150
200
250
300
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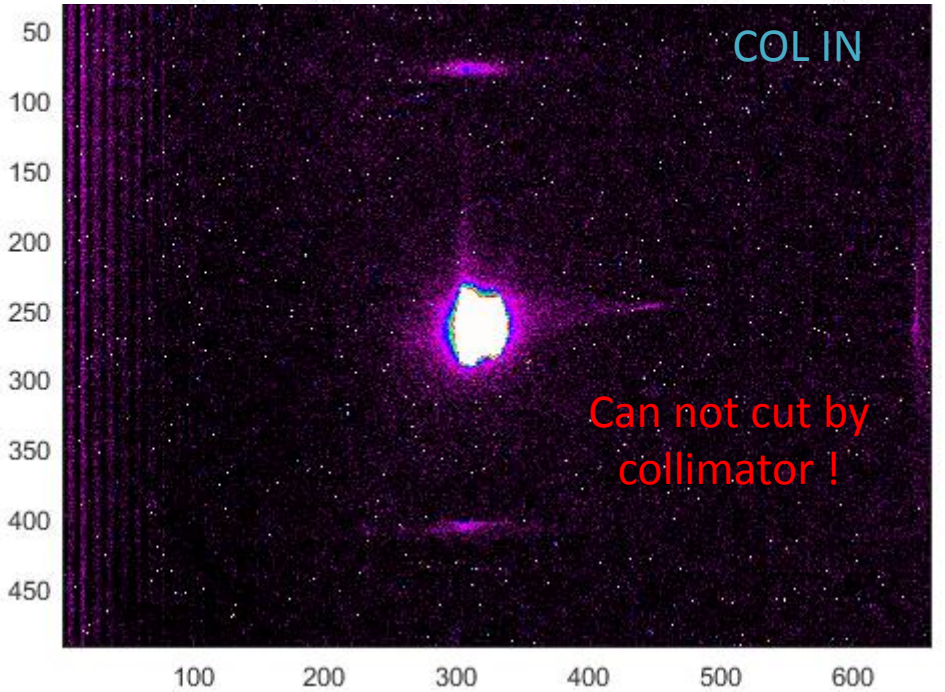
500
600


COL IN
Can not cut by collimator !
50
100
150
200
250
300
350
400
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200
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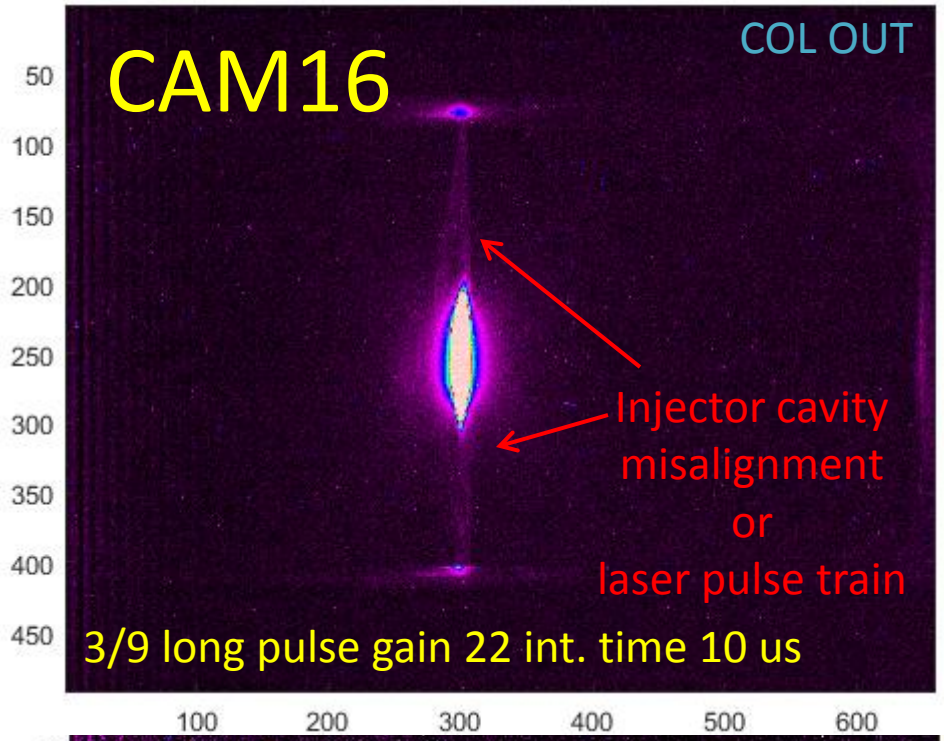
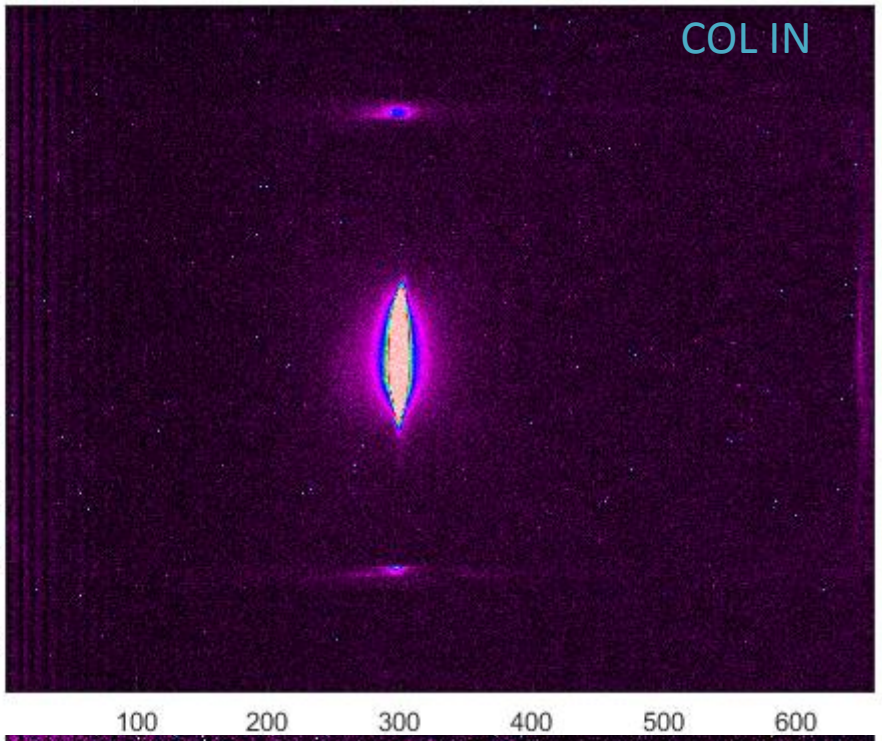
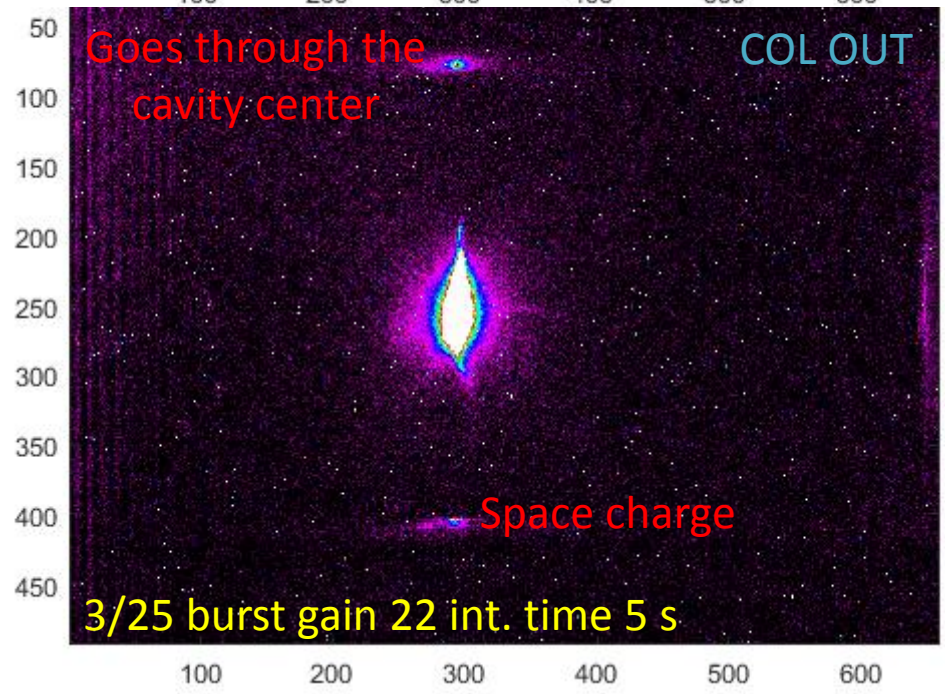
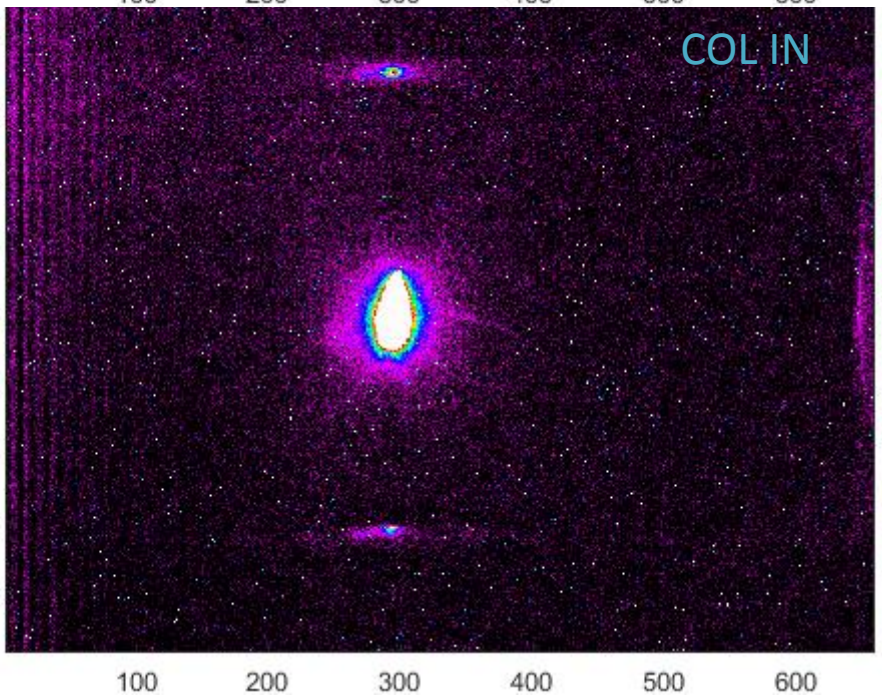
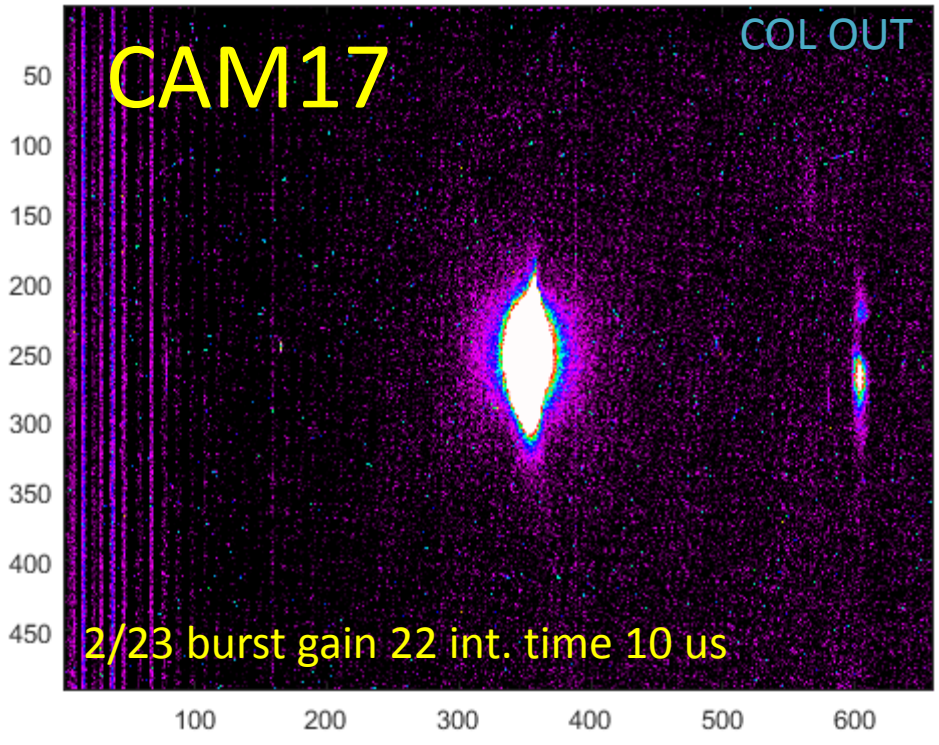
400
500
600


CAM16
COL OUT
Injector cavity
misalignment
or
laser pulse train
3/9 long pulse gain 22 int. time 10 us


COL IN


Goes through the
cavity center
COL OUT
Space charge
3/25 burst gain 22 int. time 5 s


COL IN


CAM17
COL OUT
2/23 burst gain 22 int. time 10 us
50
100
150
200
250
300
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100
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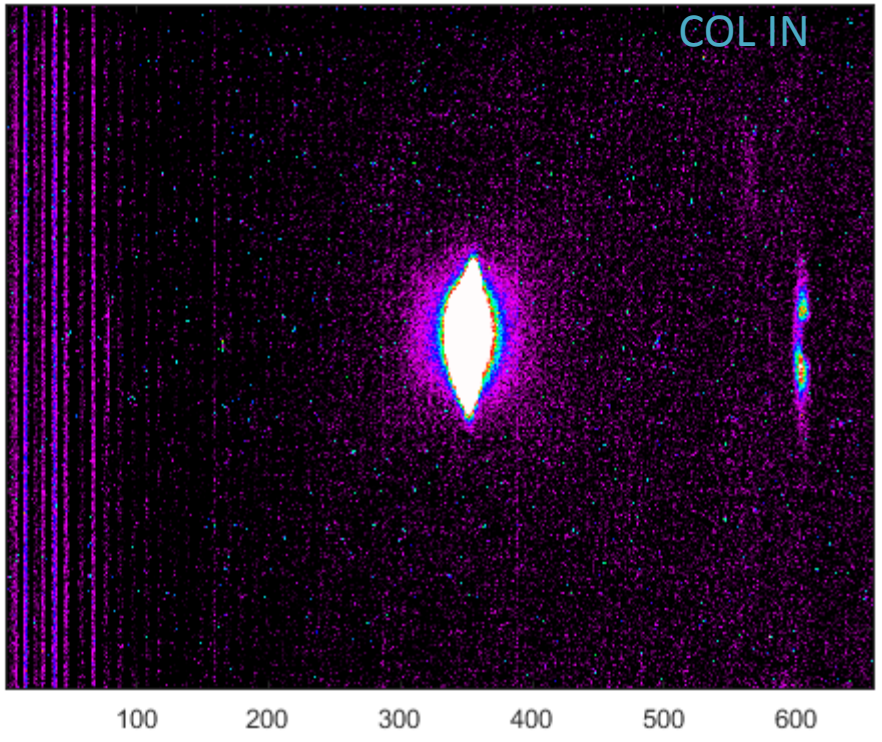
500
600


COL IN
50
100
150
200
250
300
350
400
450
100
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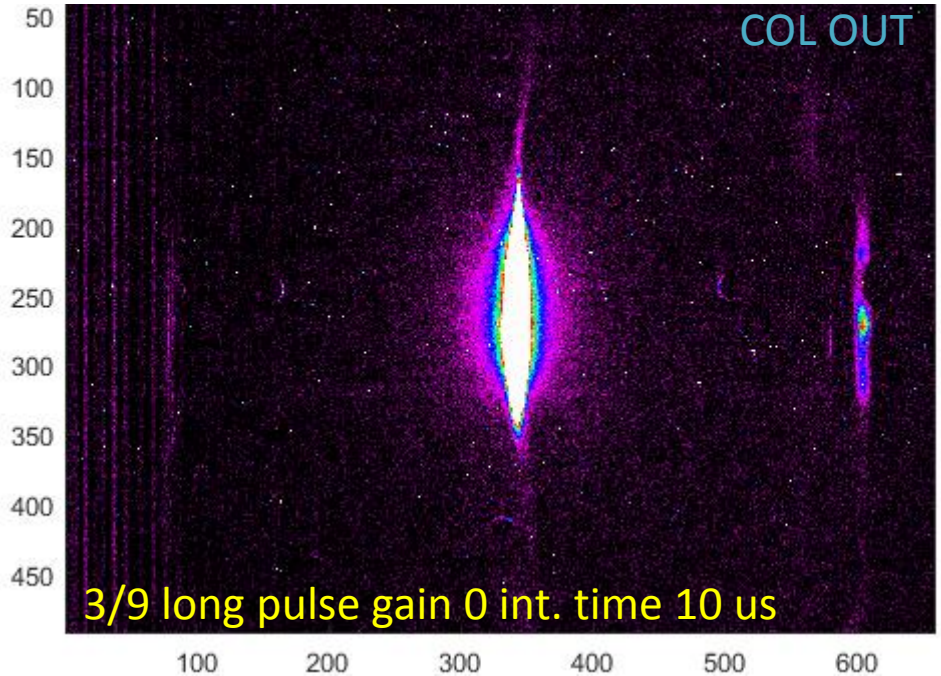
500
600


COL OUT
3/9 long pulse gain 0 int. time 10 us
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100
150
200
250
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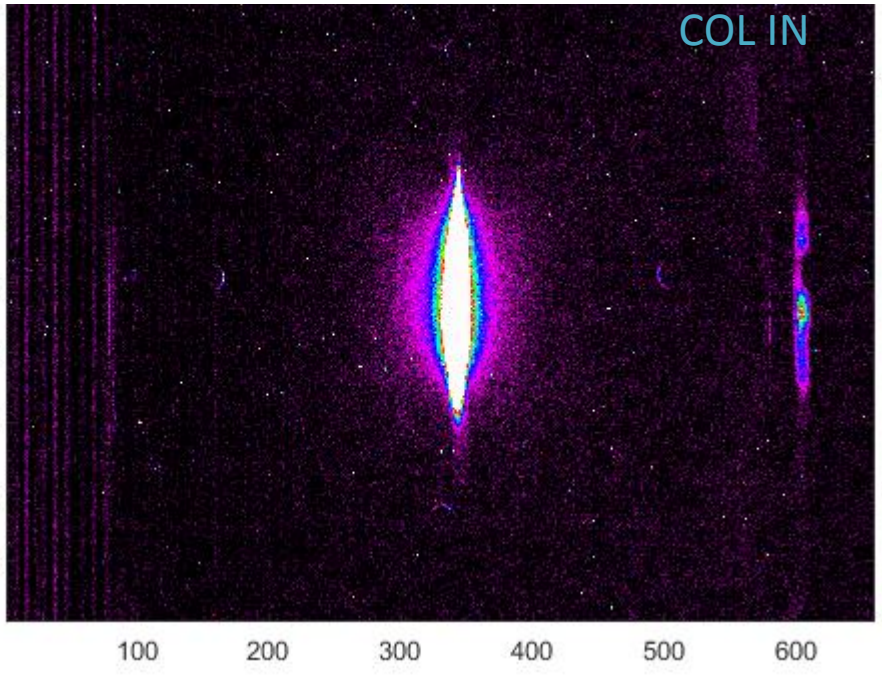
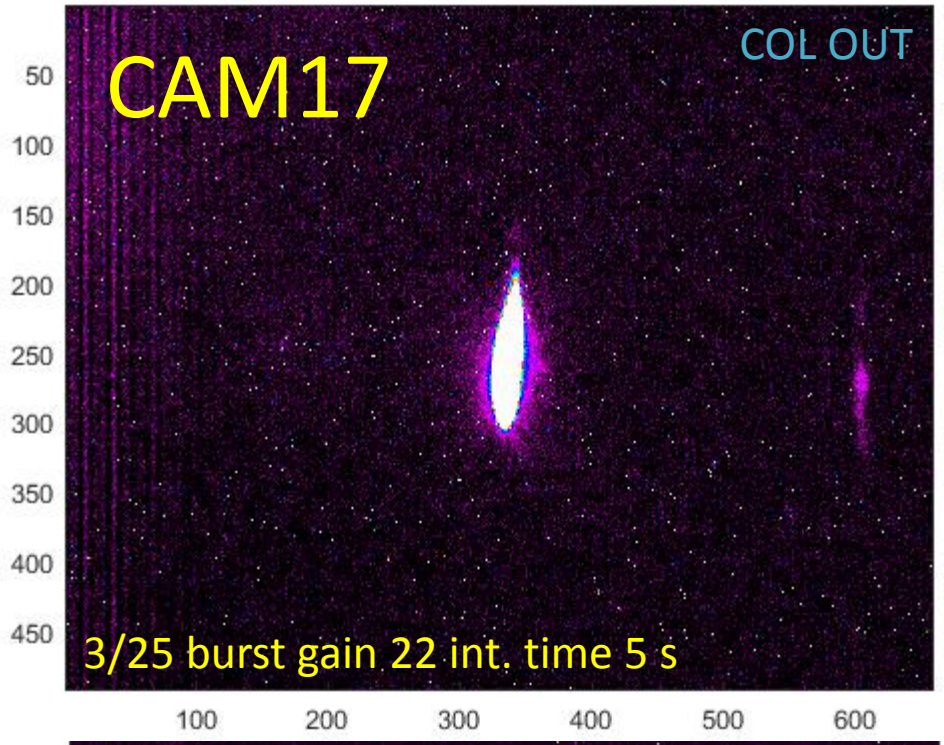
600


COL IN
100
150
200
250
300
350
400
450
100
200
300
400
500
600


CAM17
COL OUT
3/25 burst gain 22 int. time 5 s
50
100
150
200
250
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450
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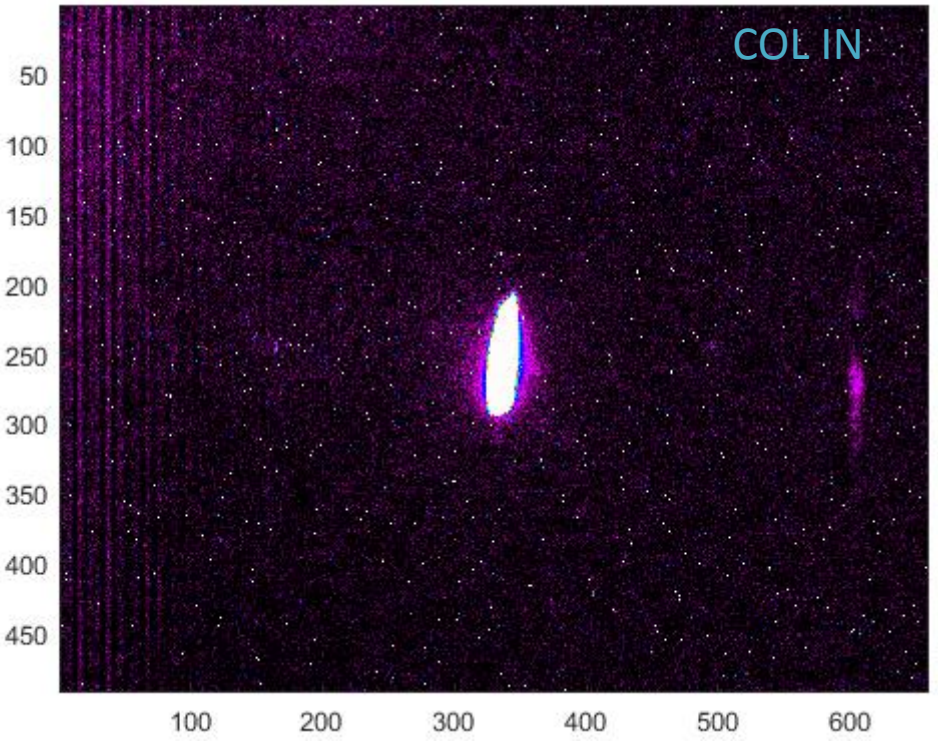
600


COL IN
50
100
150
200
250
300
350
400
450
100
200
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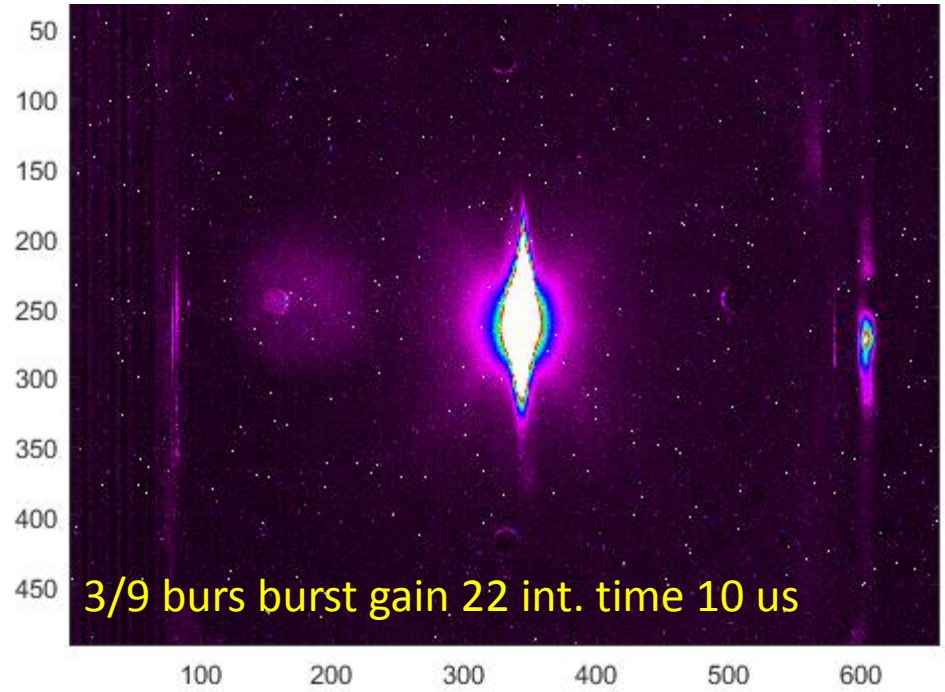
600


3/9 burs burst gain 22 int. time 10 us
50
100
150
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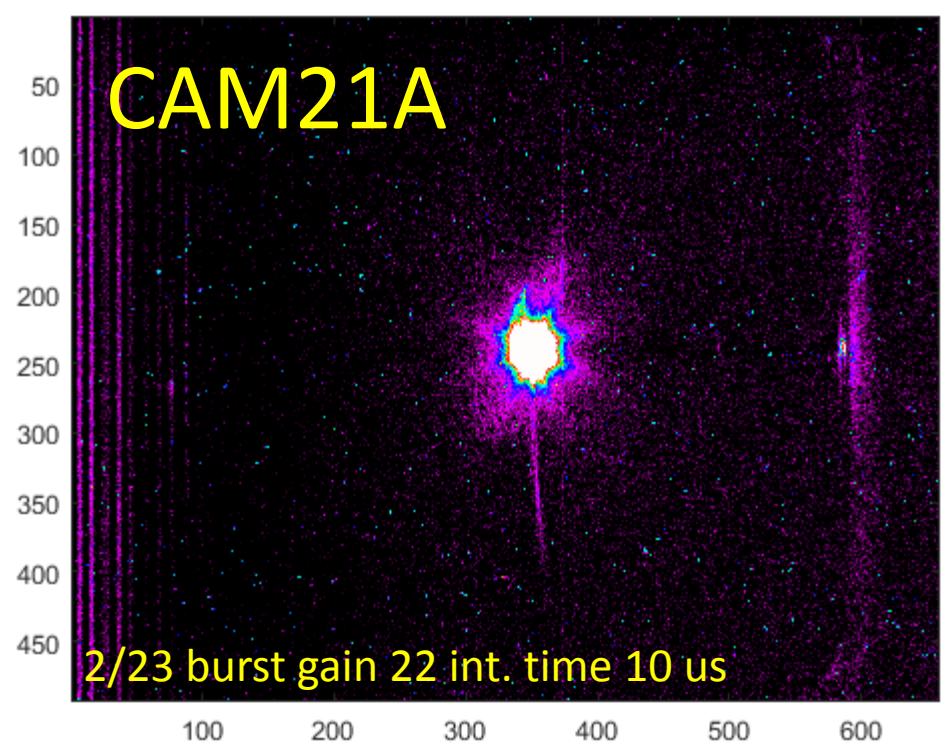
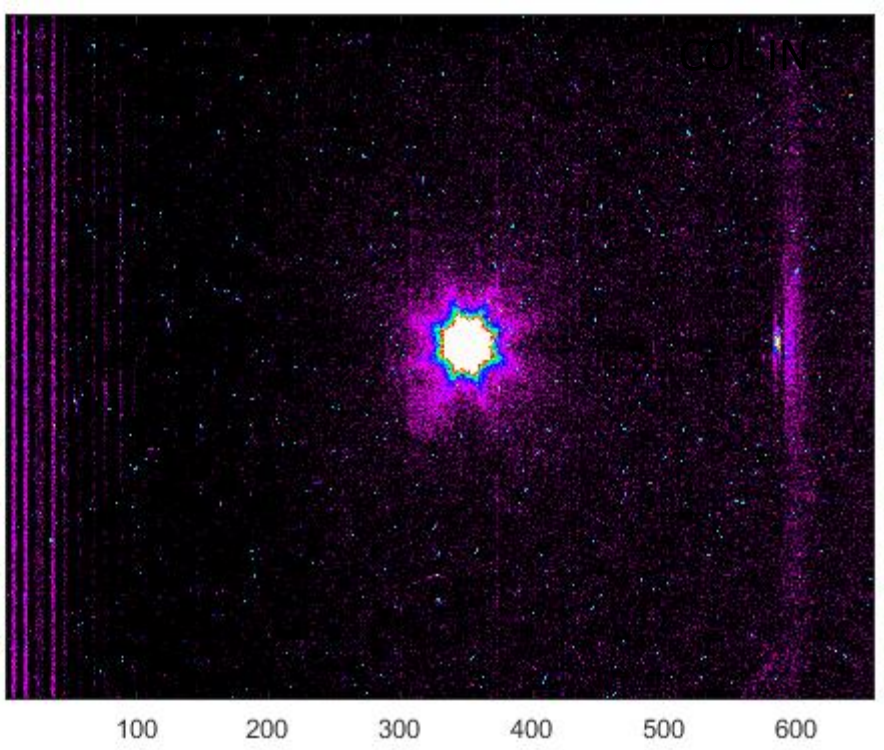
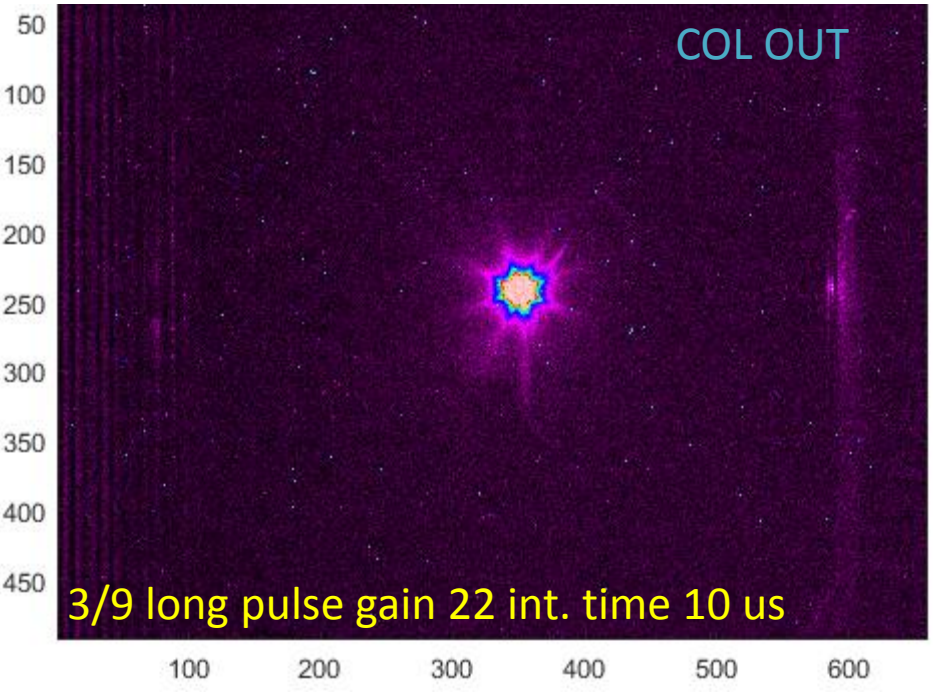
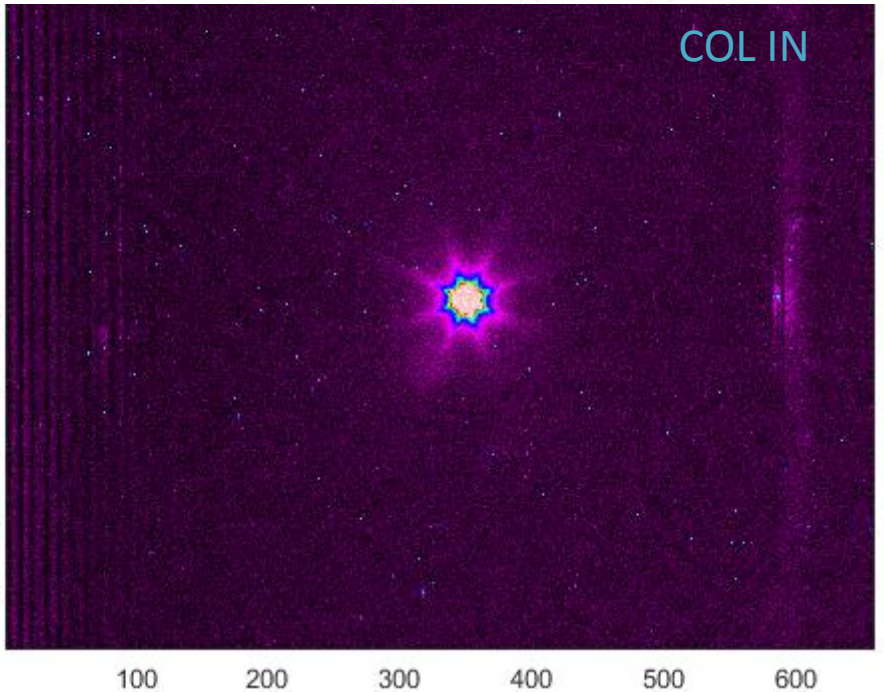
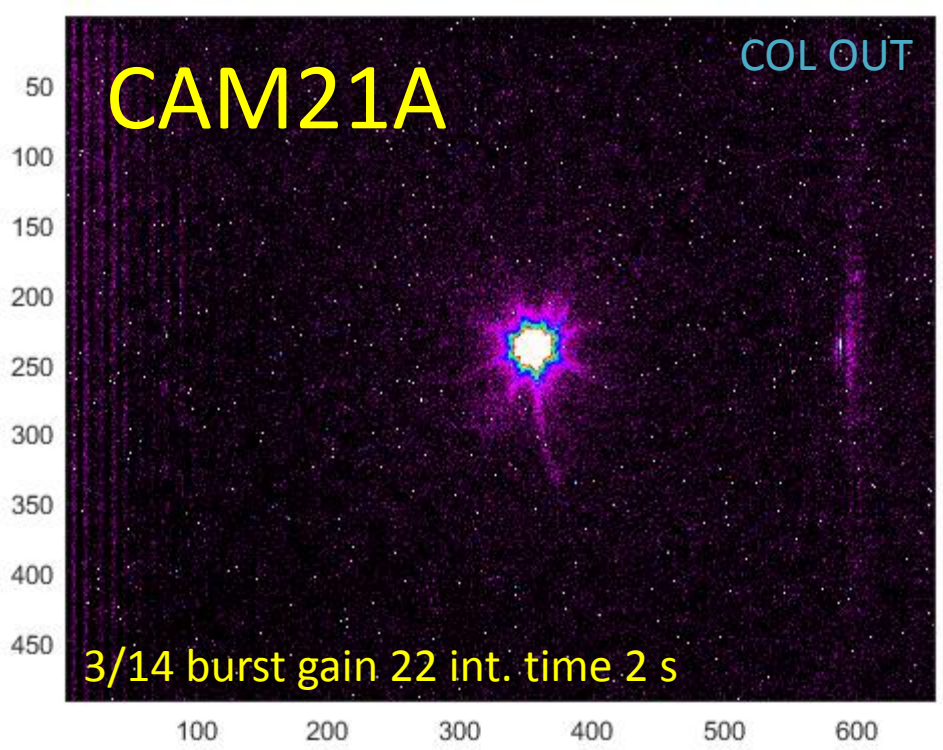

CAM21A
2/23 burst gain 22 int. time 10 us


COL IN


COL OUT
3/9 long pulse gain 22 int. time 10 us


COL IN


CAM21A
COL OUT
3/14 burst gain 22 int. time 2 s
50
100
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250
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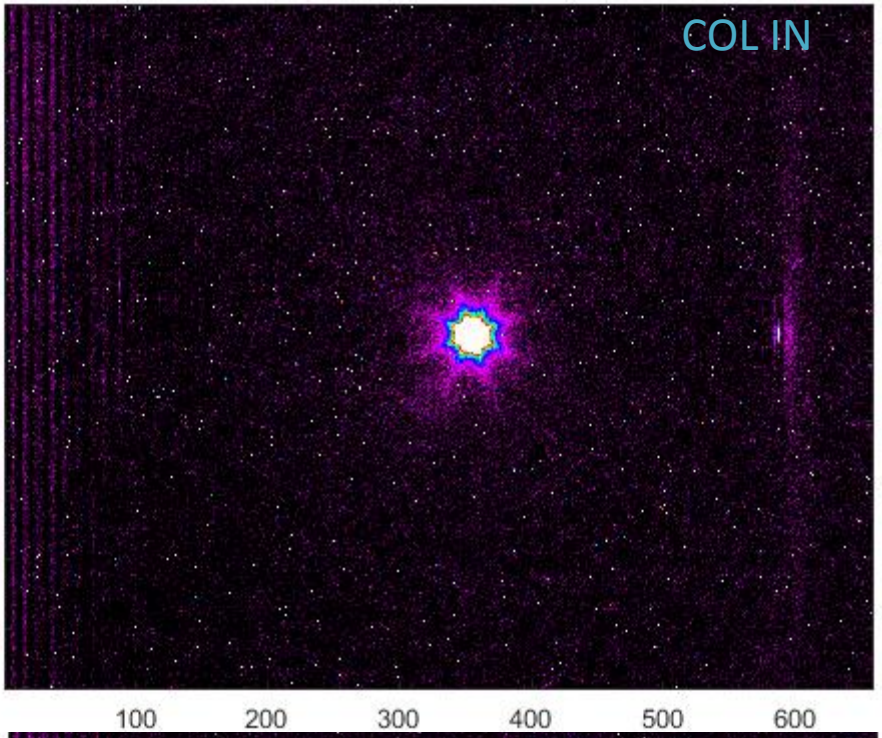
500
600


COL IN
50
100
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300
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100
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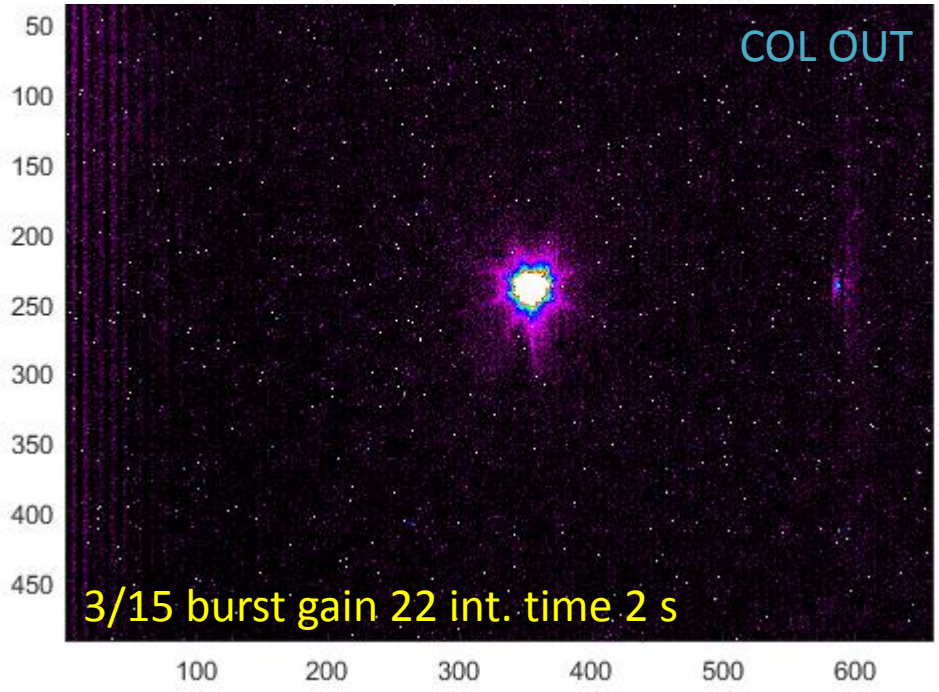
COL OUT
3/15 burst gain 22 int. time 2 s
50
100
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200
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300
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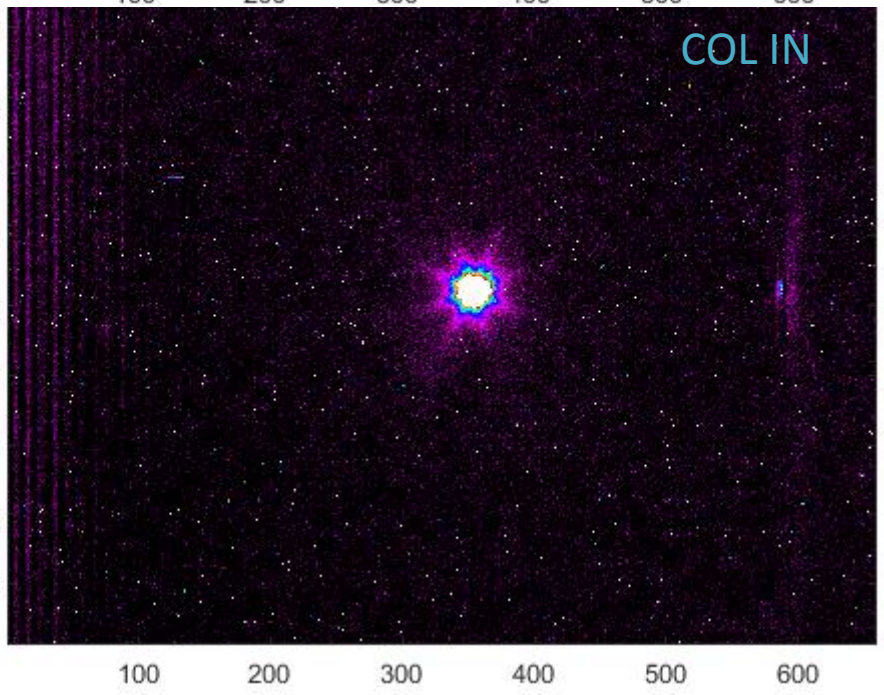
600


COL IN
50
100
150
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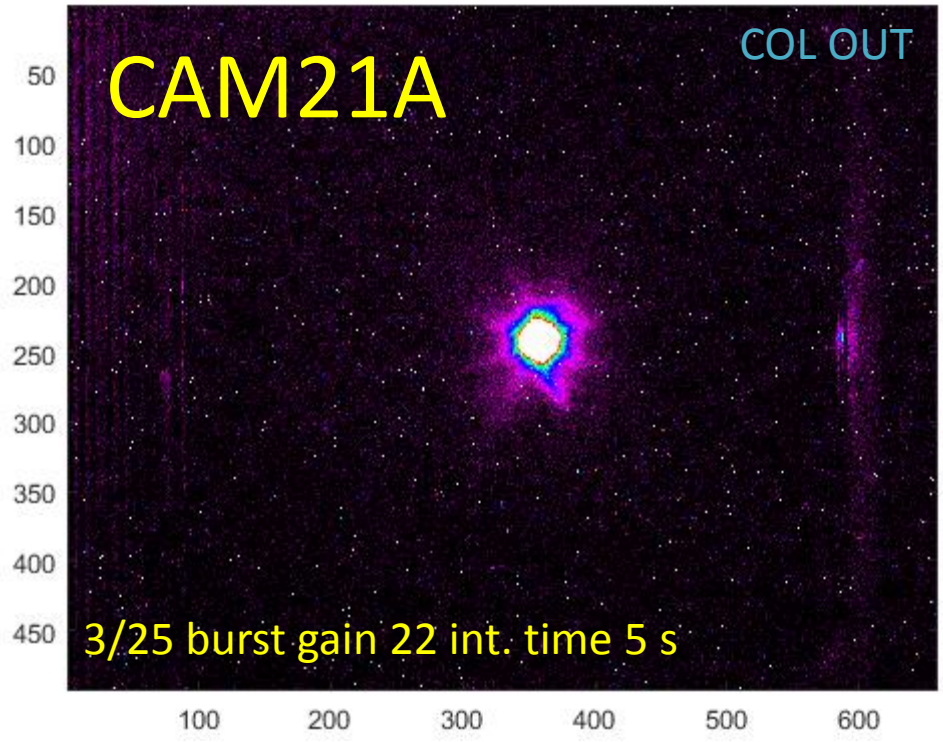
CAM21A
COL OUT
3/25 burst gain 22 int. time 5 s
50
100
150
200
250
300
350
400
450
100
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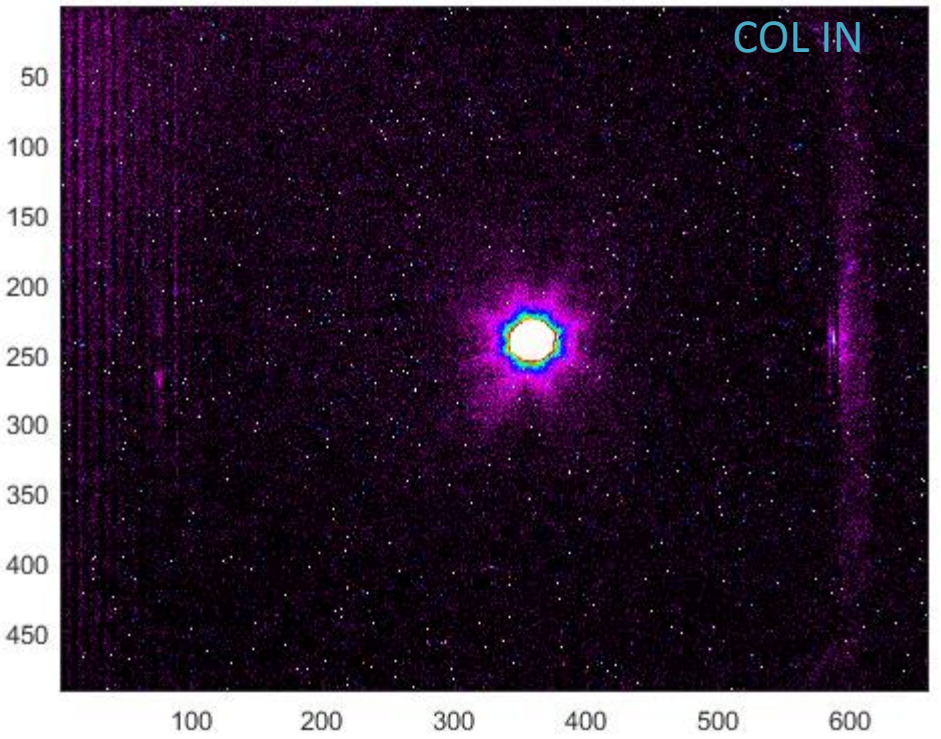
300
400
500
600


COL IN
50
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400
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100
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600

2. シムレーション結果との比べ

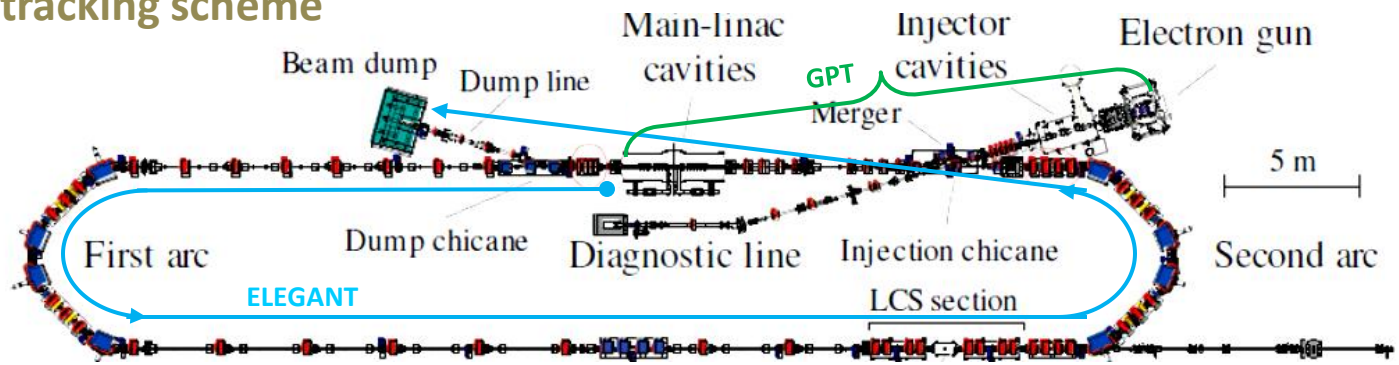
Beam halo simulation

Simulation workflow

- GPT tracking: from cathode to the main cavity exit (no SC)
- ELEGANT tracking: from the main cavity exit to the dump (LCS# optics, no SC##)
- 100 ps tail from the gun of the specific distribution was generated using GPT (General Particle Tracer*) routine, creating the longitudinal distribution by convolution of cathode response function with the Gaussian (core)
- The output tail distribution (at the exit of the main cavity) has about 40 ps length due to the acceleration in the main cavity
- Then obtained tail distribution tracked through the accelerator lattice** (from the main cavity exit to the dump) via ELEGANT tracking code***
- # LCS = Laser Compton Scattering installation
- ## SC = Space Charge effect

Simulation parameters	
Energy	2.9~20 MeV
Number of particles	5000
Repetition	1.3 GHz
Charge per bunch	0.5 pC
RMS bunch length	2.2 ps
RMS emittance	1 mm mrad
Tail length	40~100 ps

Tail tracking scheme

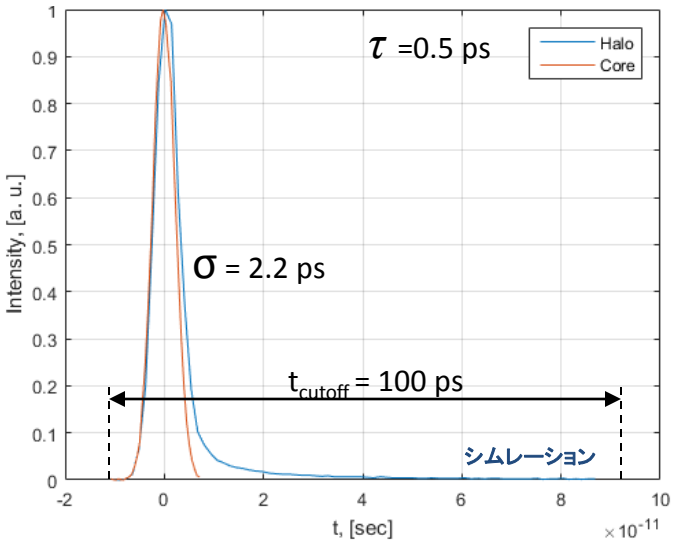


* GPT - A simulation tool for the design of accelerators and beam lines, http://www.pulsar.nl/gpt
** M. Shimada et al., "Optics measurement of cERL recirculation loop", 12th PASJ, 2015
*** M. Borland, "ELEGANT: A Flexible SDDS-Compliant Code for Accelerator Simulation", Advanced Photon Source LS-287, September (2000)

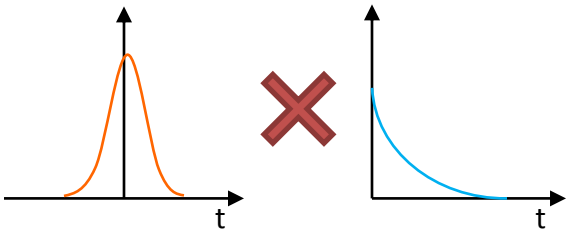
Longitudinal bunch tail from cathode

Construction of the initial distribution

Density function of temporal distribution



Laser pulse 2.2 ps × **Cathode response**



- To produce the time distribution with the tail for the computer simulation, the convolution of the temporal distribution (Gaussian distribution, σ = 2.2 ps) of the laser which is a basic distribution and cathode response function is made*
- Gau

$$I_g(\kappa) \propto \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

- Cathode response function:

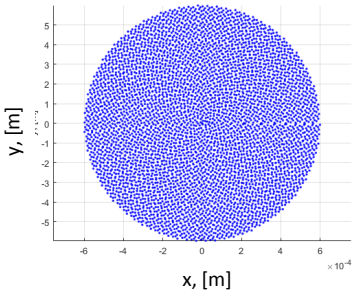
$$I_t(\kappa) \propto \frac{1}{\sqrt{\pi\kappa}} - \exp(\kappa)\mathrm{erfc}(\sqrt{\kappa})$$

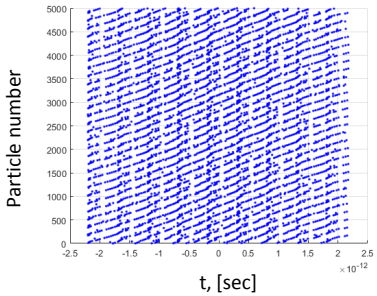
where $\kappa = t/\tau$ is a normalized time. Response function varies with the thickness of the active layer and with the excitation wavelength.

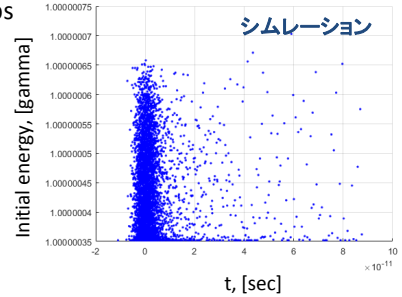
- τ is the tail characterization time** (<1 for cERL). τ = 0.5 ps used in this simulation.
- Convolution:

$$t_{cutoff}\left(I_g * I_t\right)(t) = \int I_g(s) I_t(t-s) ds$$

Initial distribution at cathode (beer can)

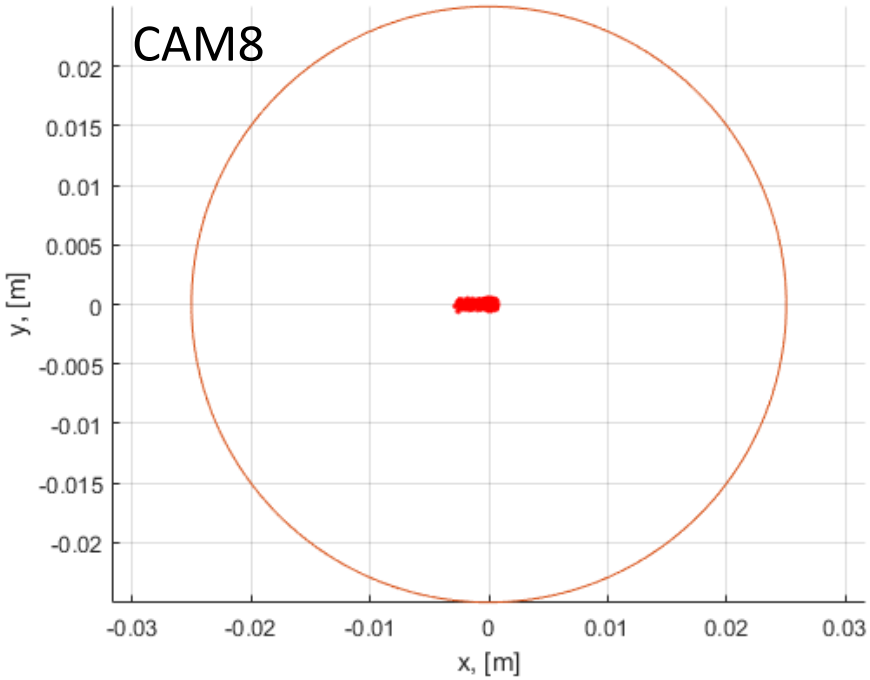






* I.V. Bazarov , et al., "Thermal emittance and response time measurements of negative electron affinity photocathodes", J. Appl. Phys. 103, 054901 (2008)

** S. Matsuba et al., "Initial Emittance and Temporal Response Measurement for GaAs Based Photocathodes", IPAC'12, New Orleans, (2012)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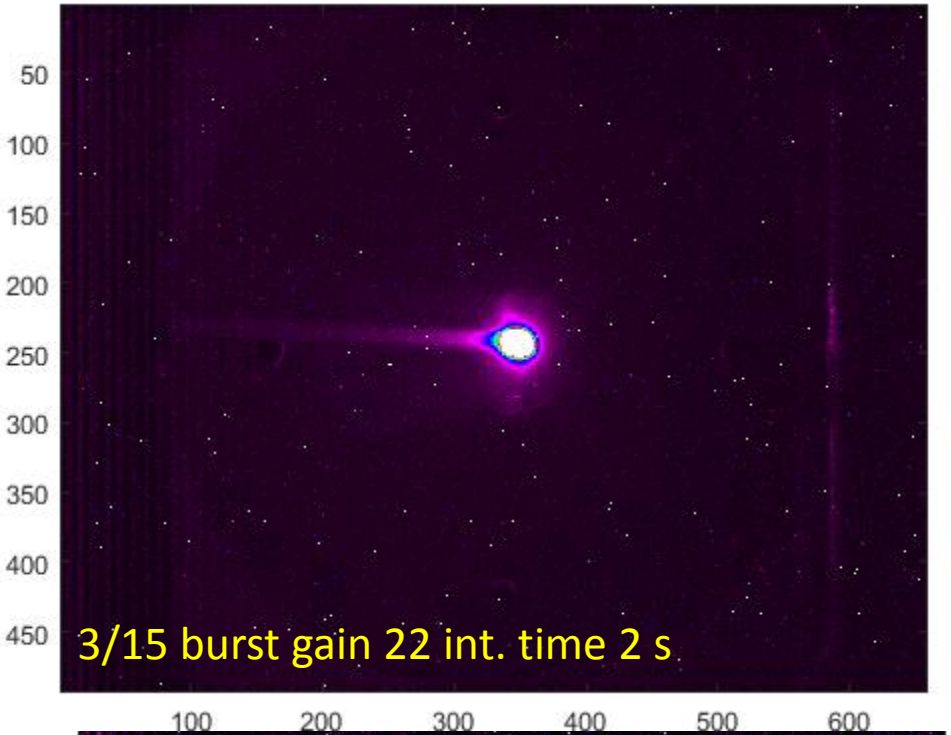
-0.01
-0.015
-0.02
y, [m]
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
x, [m]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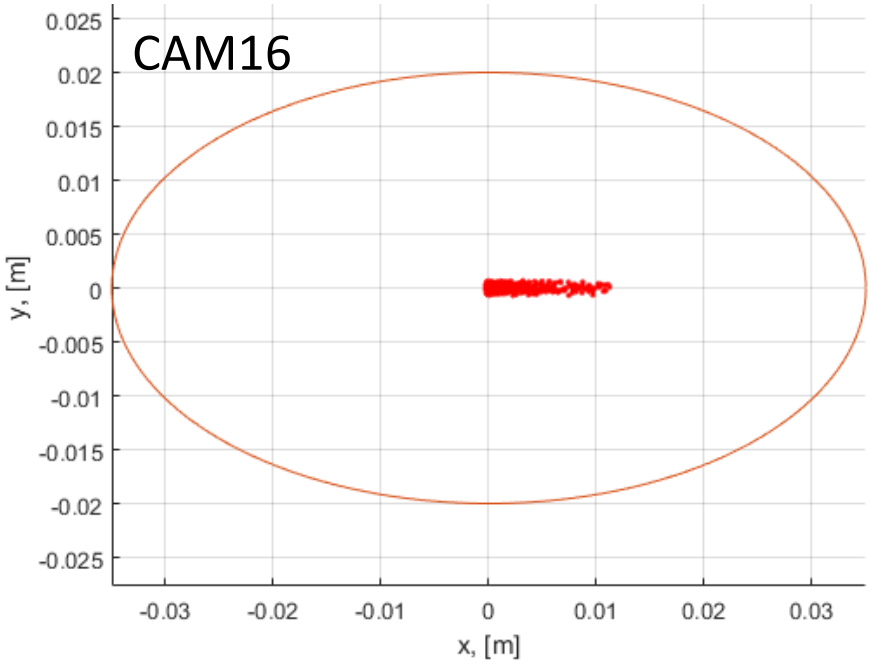
3/15 burst gain 22 int. time 2 s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0.01
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-0.01
-0.015
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-0.025
y, [m]
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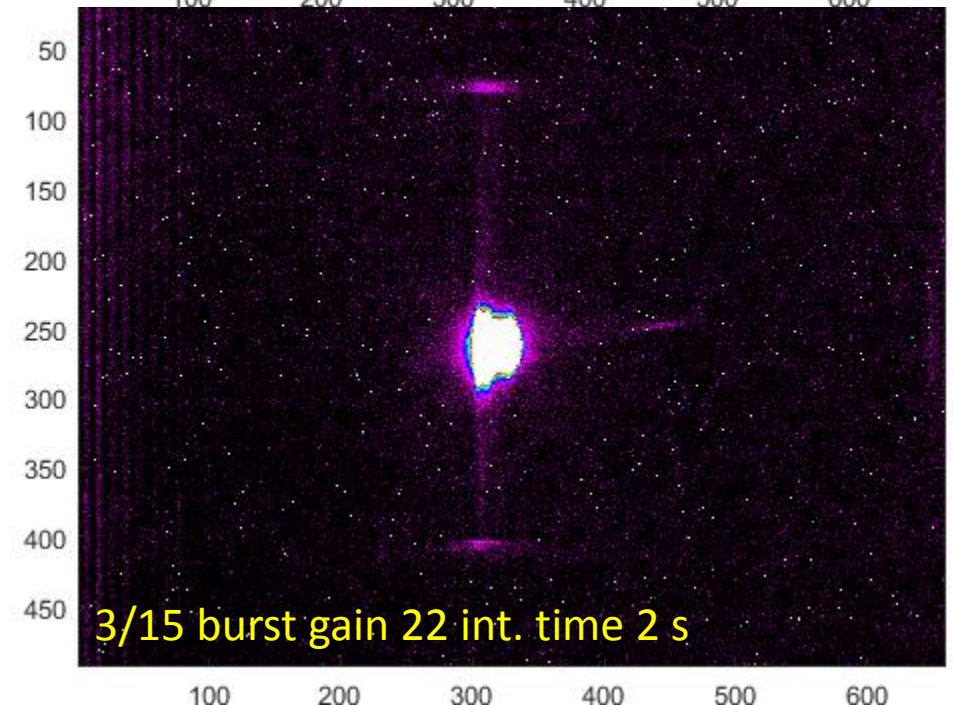
-0.02
-0.01
0
0.01
0.02
0.03
x, [m]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300
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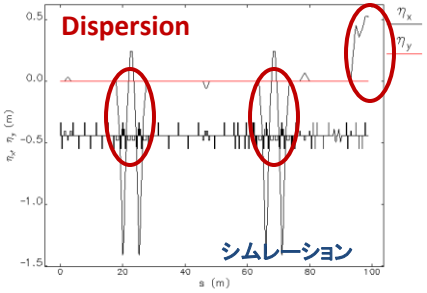
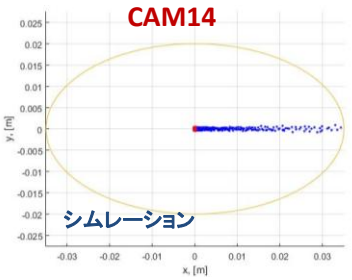
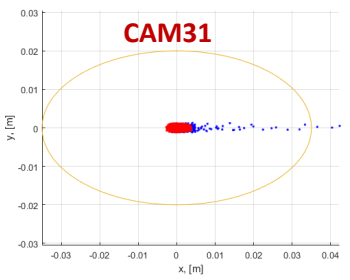
400
450
100
200
300
400
500
600
3/15 burst gain 22 int. time 2 s

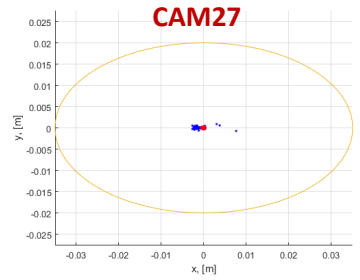
Beam halo impact on the beam loss

Beam loss points and lost current summary

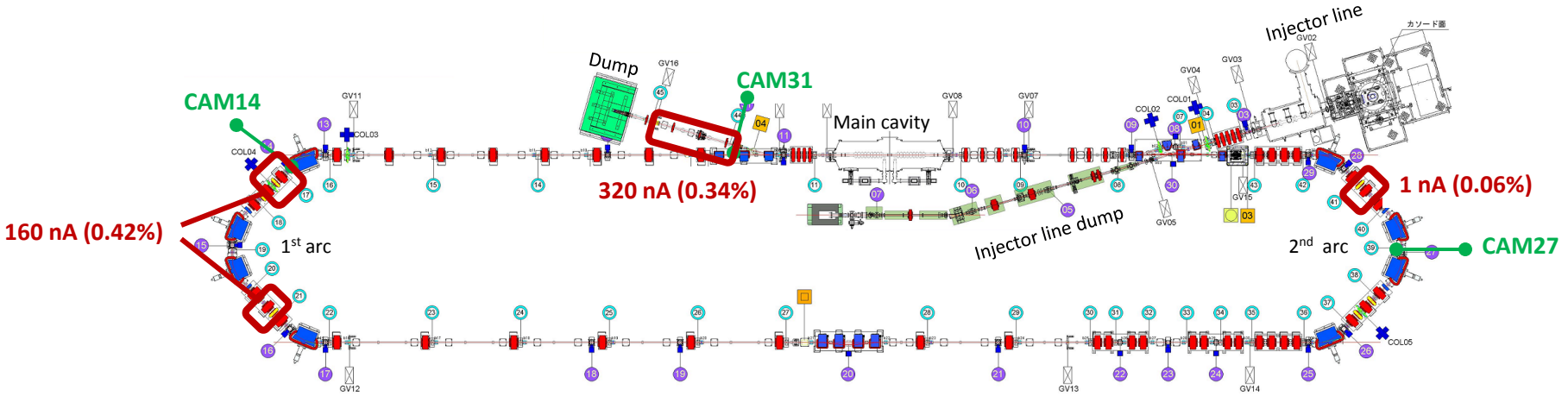








- ✓ **Red dots** – core particles
- ✓ **Blue dots** – halo particles

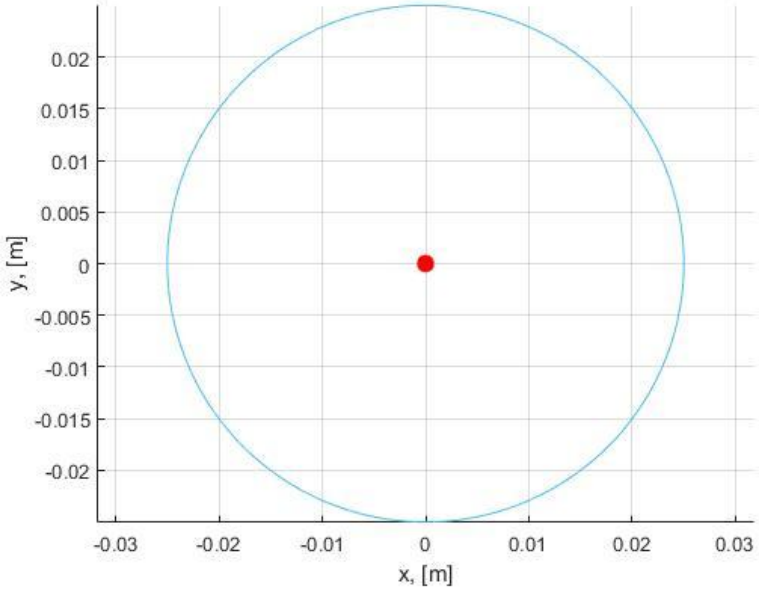


- No losses in the injector line were found
- Low energy tail assumed to impact into the beam losses at the points of the beam line with non zero dispersion

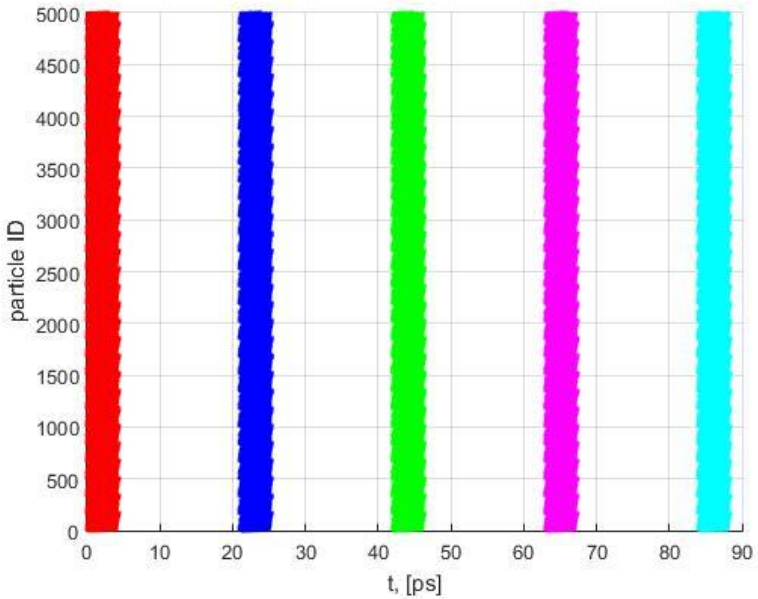
Laser phase shift or movement

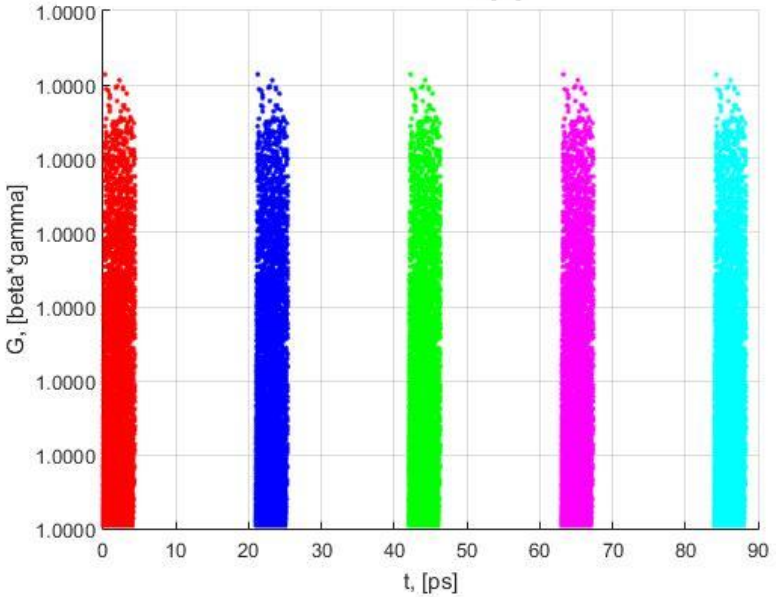
（+10, +20, +30, +40 deg.）

Transverse XY

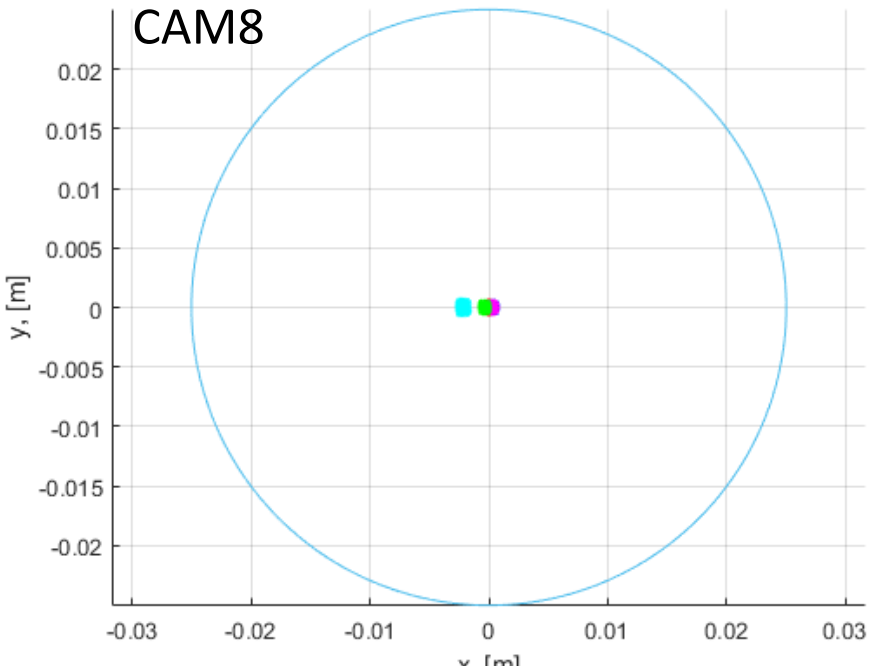


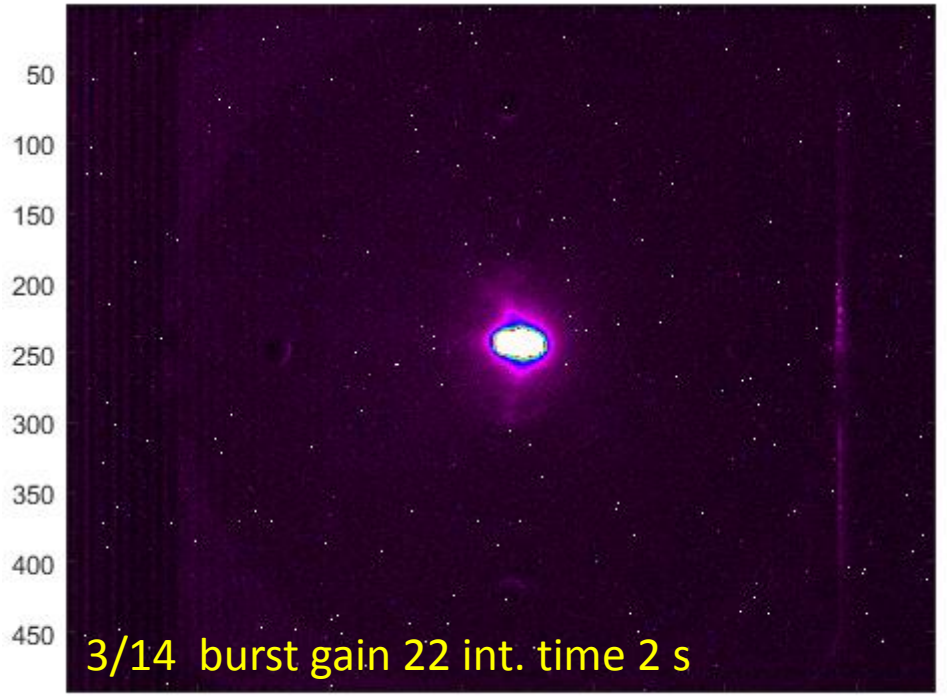
Temporal (z=0)





- Red – gaussian (settdist (“beam”, “g”, center=0, sigma=2.2e-12, tcutoff=1, 1))
- Blue – gaussian (settdist (“beam”, “g”, center=21e-12, sigma=2.2e-12, tcutoff=1, 1))
- Green - gaussian (settdist (“beam”, “g”, center=42e-12, sigma=2.2e-12, tcutoff=1, 1))
- Magenta - gaussian (settdist (“beam”, “g”, center=63e-12, sigma=2.2e-12, tcutoff=1, 1))
- Cyan - gaussian (settdist (“beam”, “g”, center=84e-12, sigma=2.2e-12, tcutoff=1, 1))


CAM8
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
y, [m]
-0.03
-0.02
-0.01
0
0.01
0.02
0.03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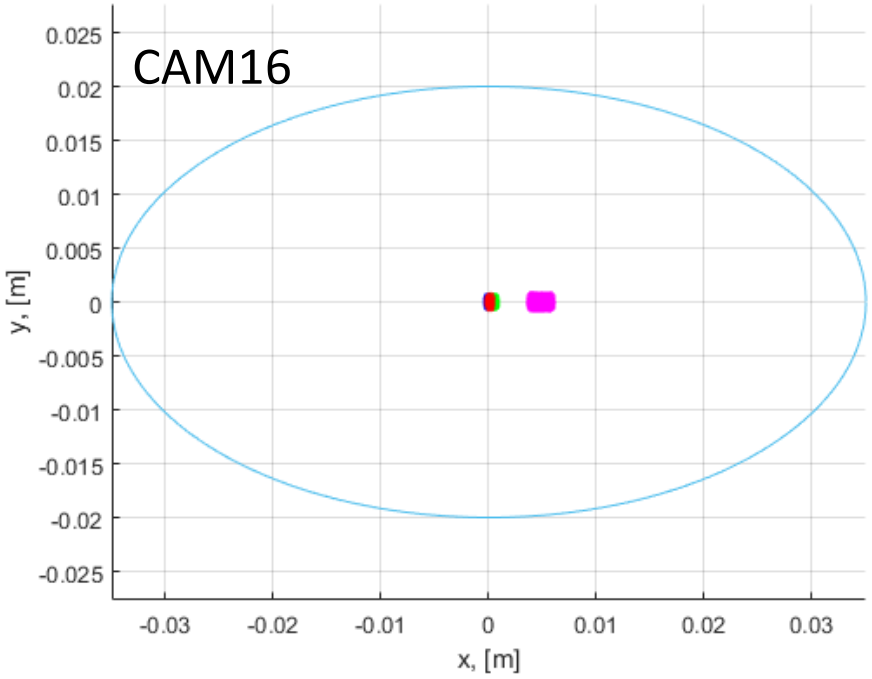
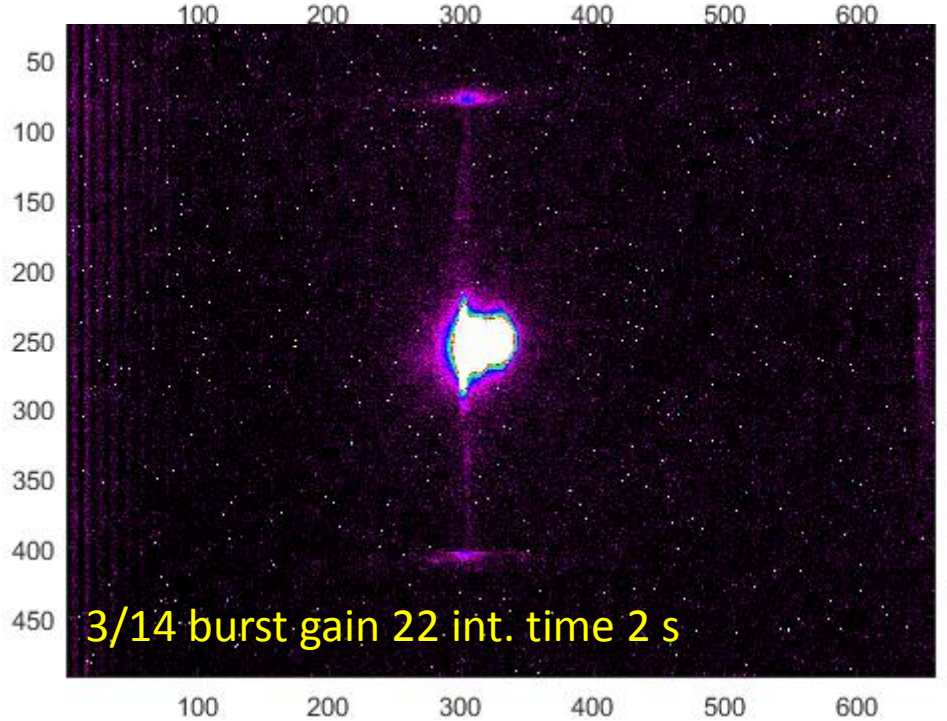
350
400
450
3/14 burst gain 22 int. time 2 s


CAM16
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
y, [m]
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
x, [m]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300
350
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100
200
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400
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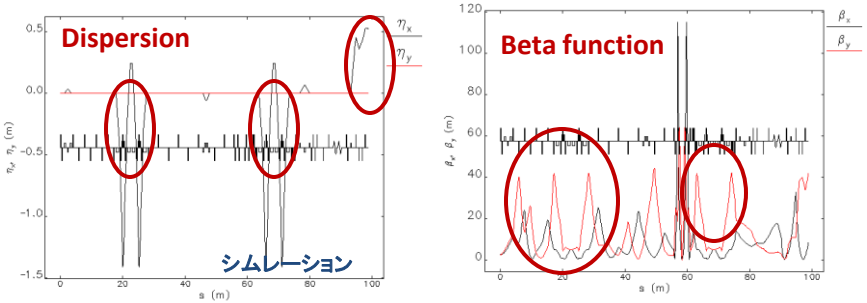
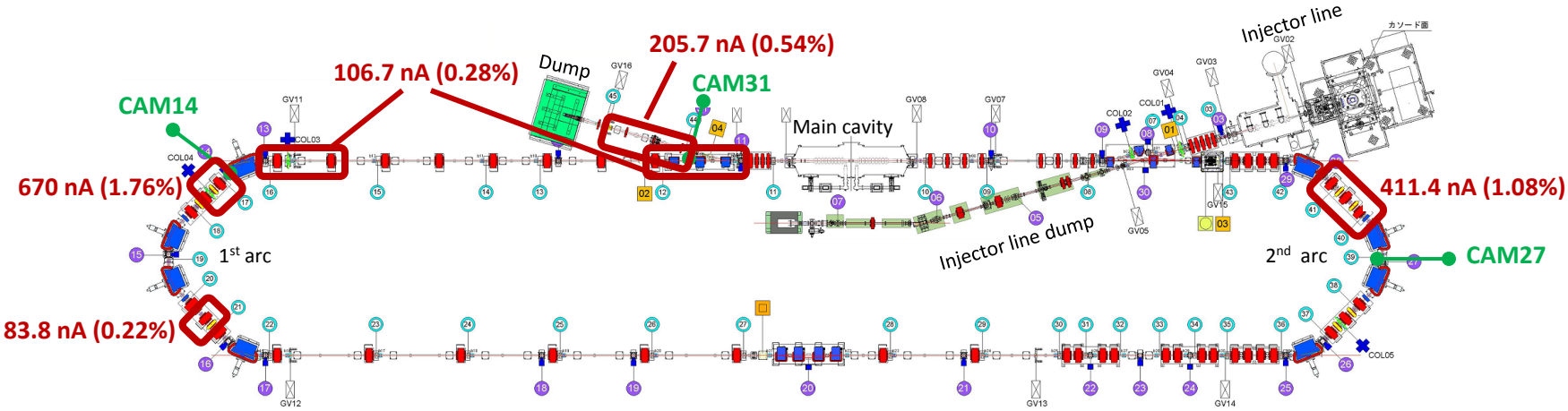
600
3/14 burst gain 22 int. time 2 s

Laser phase shift impact on the beam loss

Beam loss points and lost current summary

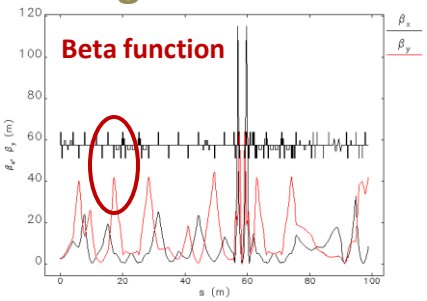


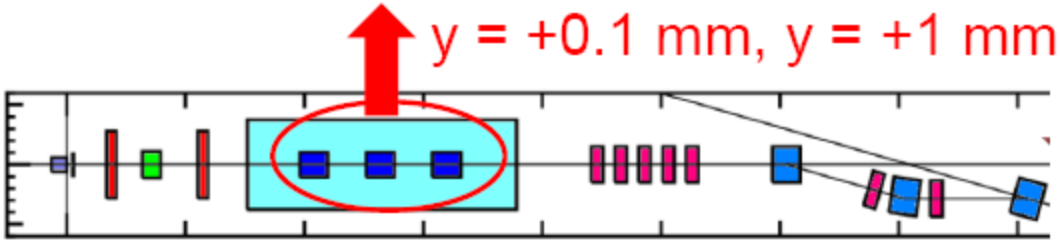


- No losses in the injector line were found
- Low energy tail assumed to impact into the beam losses at the points of the beam line with non zero dispersion

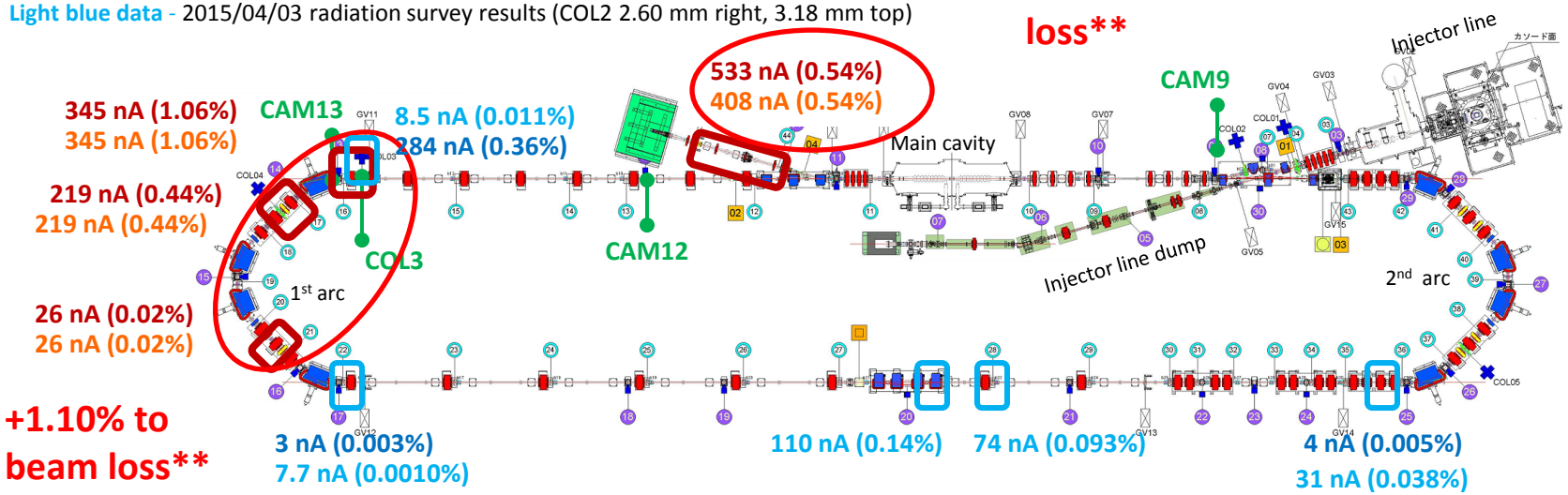
Misalignment of beam line elements impact on the beam loss

Misalignment simulation result





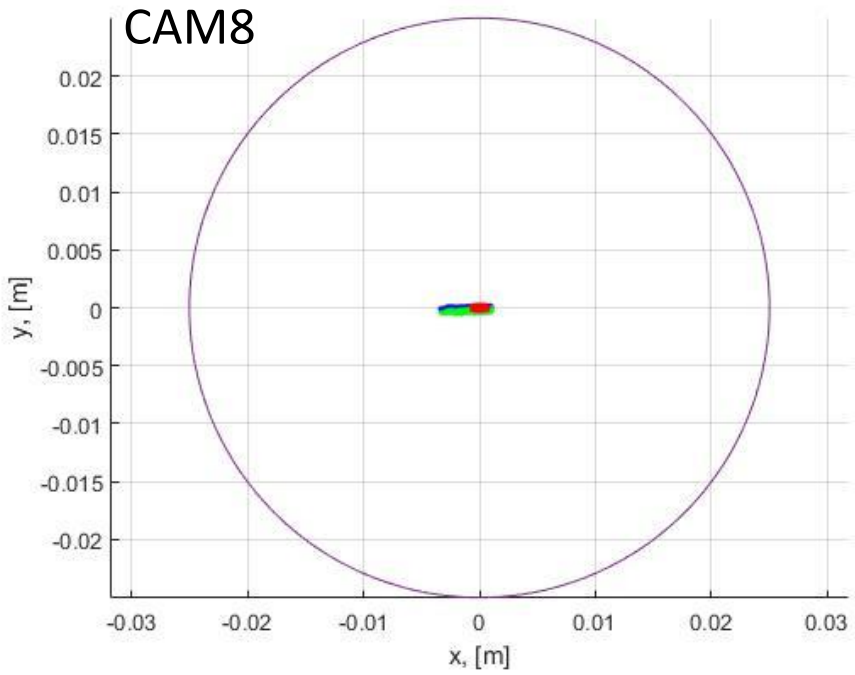
- ✓ **Dark red data** - simulation results tail + 1 mm misalignment
- ✓ **Orange data** - simulation results tail + 0.1 mm misalignment
- ✓ **Dark blue data** - 2015/04/02 radiation survey results* (COL2 2.65 mm right)
- ✓ **Light blue data** - 2015/04/03 radiation survey results (COL2 2.60 mm right, 3.18 mm top)



- Tail coming from beam line elements misalignment assumed to impact into the beam loss at the points of the beam line with large betatron function (e.g. straight section before the 1st arc)

* H. Matsumura et al., "Various Radiation Measurements to Estimate the Beam Loss", (in Japanese), KEK, cERL Construction Meeting, April (2015)

** Comparing with common halo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0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
y, [m]
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
x, [m]


50
100
150
200
250
300
350
400
450
100
200
300
400
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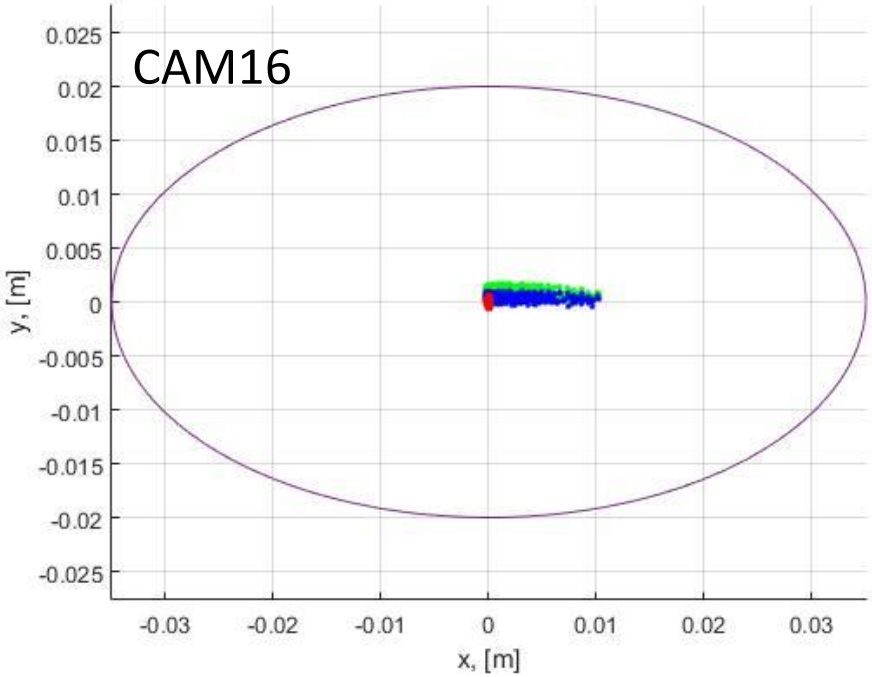
600
2/23 burst gain 22 int. time 10 us


CAM16
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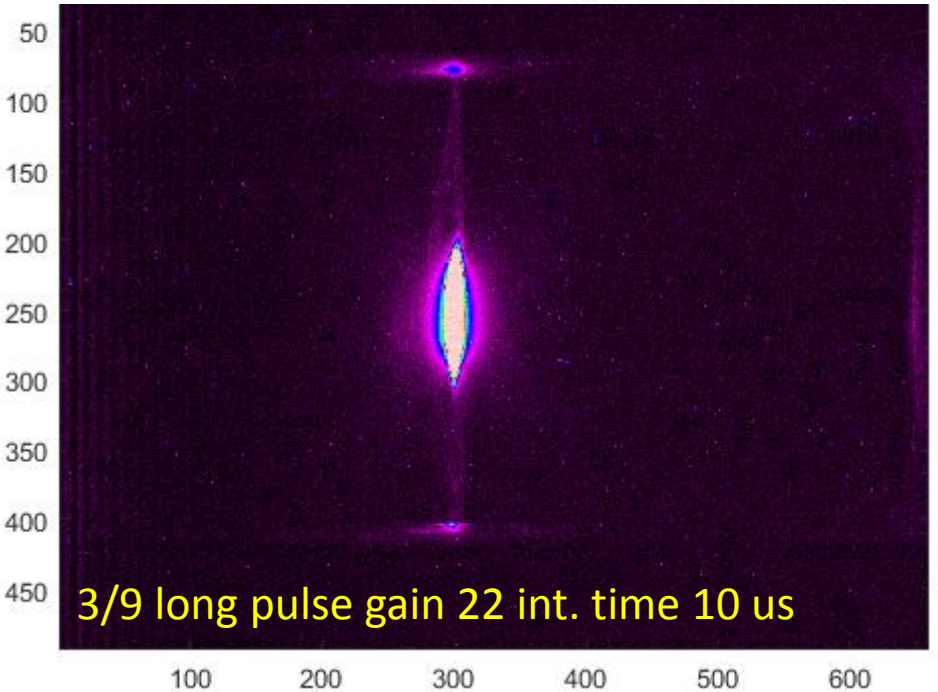
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
y, [m]
-0.03
-0.02
-0.01
0
0.01
0.02
0.03
x, [m]


50
100
150
200
250
300
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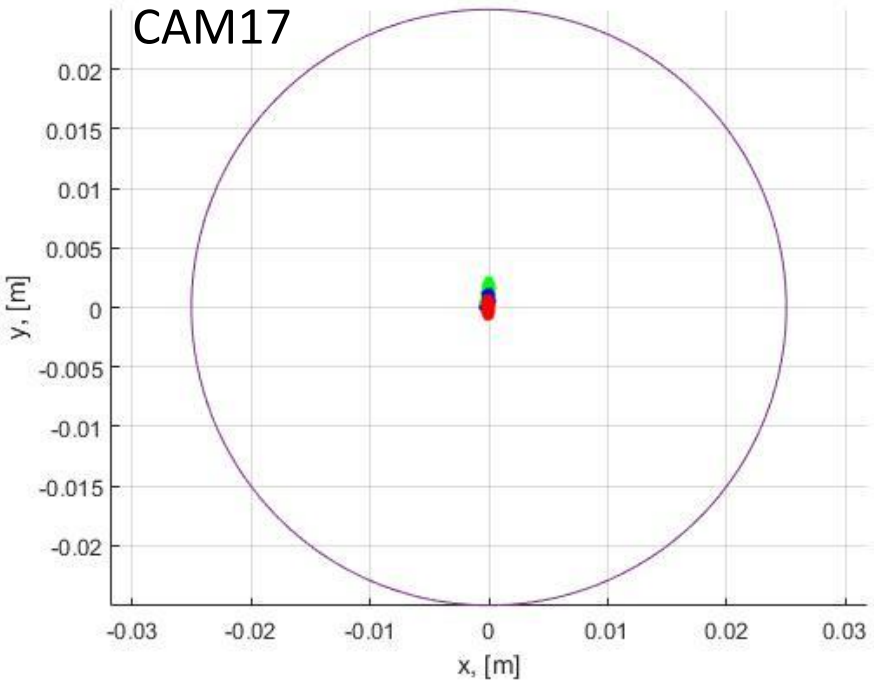
450
100
200
300
400
500
600
3/9 long pulse gain 22 int. time 10 us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y, [m]
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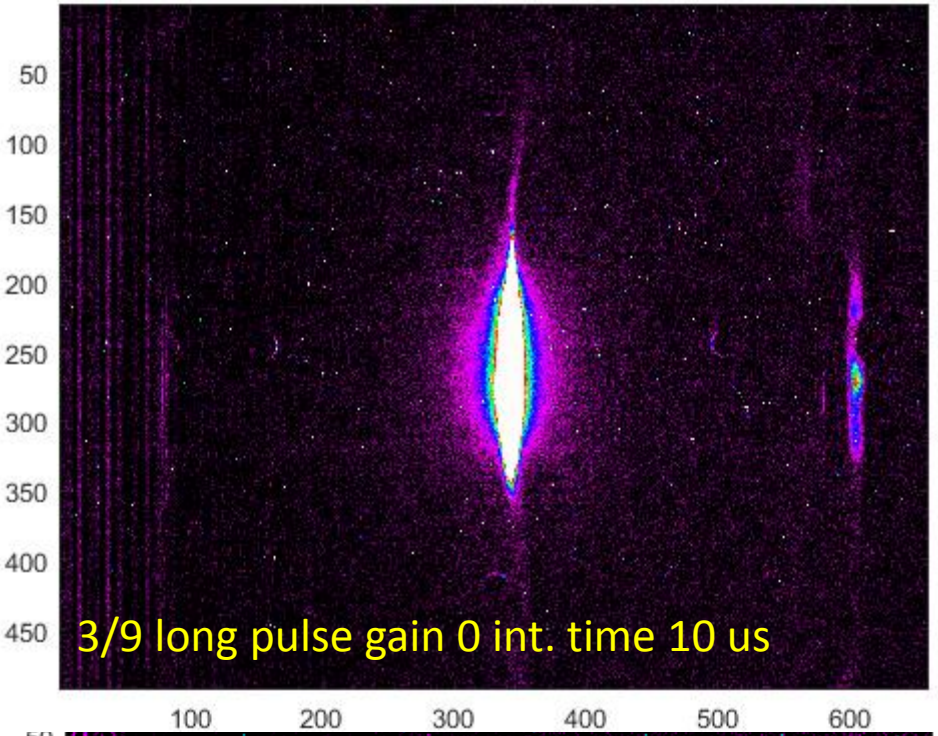
-0.01
0
0.01
0.02
0.03
x, [m]


50
100
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300
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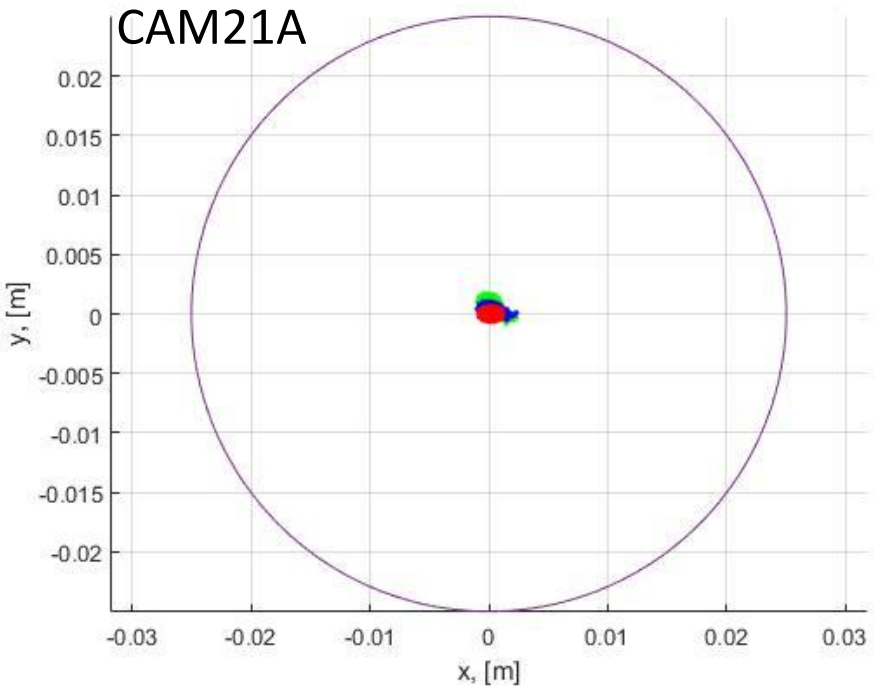
600
3/9 long pulse gain 0 int. time 10 us


CAM21A
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y, [m]
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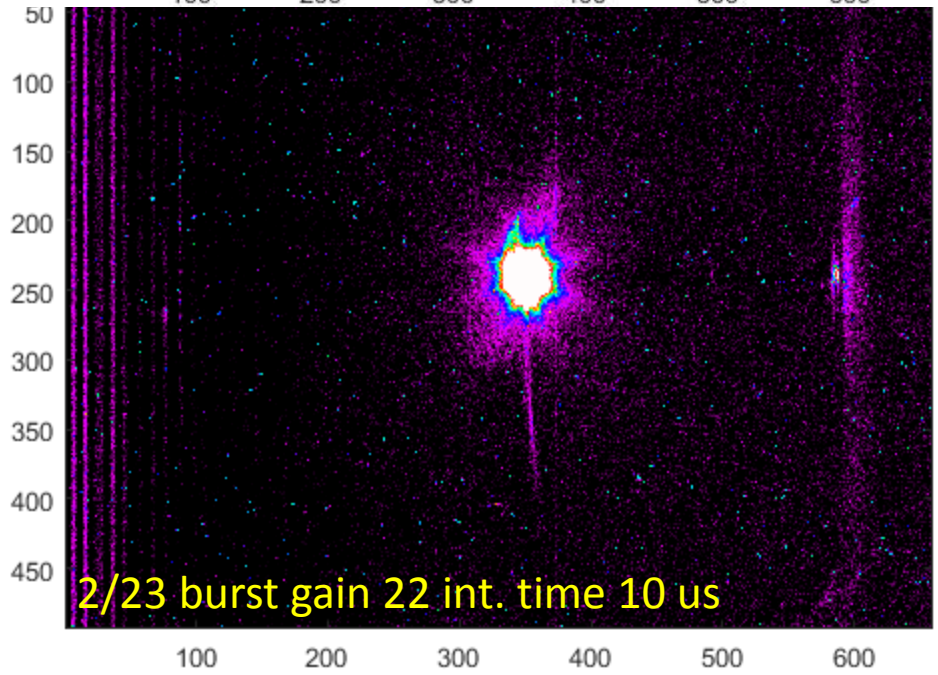
0
0.01
0.02
0.03
x, [m]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2/23 burst gain 22 int. time 10 us

3. HDR imagingアプローチ

HDR imagingアプローチについて

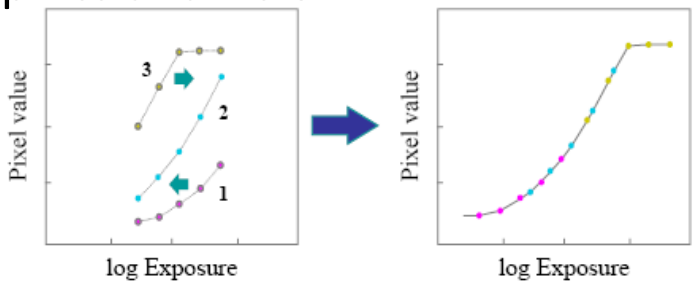
Idea: (from the field of professional photography) to combine pixels from different exposures directly into a final composite

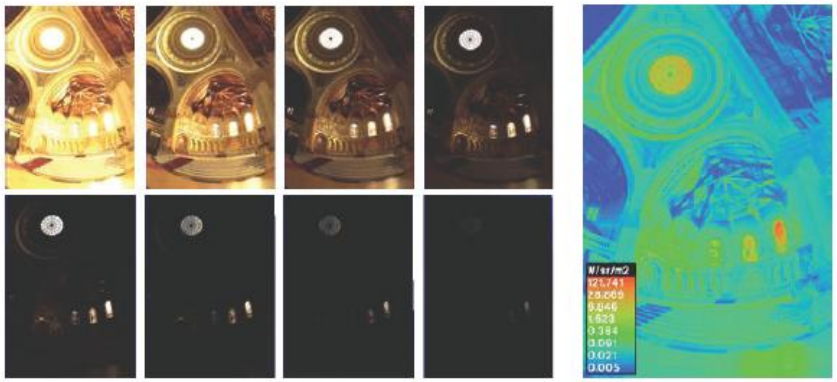
Merit: HDR images have much larger dynamic ranges than traditional images' 256 levels. In addition, they correspond linearly to physical irradiance values of the scene. Hence, they are useful for many graphics and vision applications.

Steps of processing:

1. Estimate the radiometric response function from the aligned images.
2. Estimate a radiance map by selecting blending pixels from different
3. Tone map the resulting HDR image back into a displayable gamut.

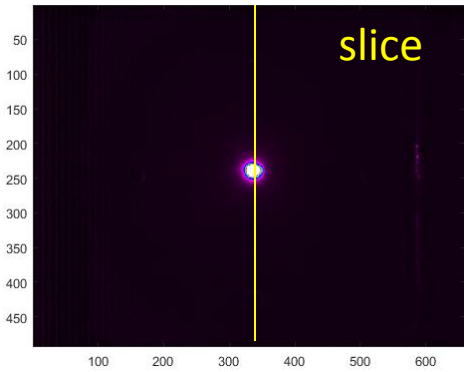
Needs only for RGB images





HDR imagingの計算について

The whole project is implemented in Matlab. The flow of the program is as following:



1. **Load an image set with different exposures**

   (12 screen captures with different gain values)

2. **Prepare a down-sampling of the image set**

   slice one column (493 pixels), because

   $$N(P-1) > (Z_{max} - Z_{min})$$

   where N is number of pixels, P is number of photographs, Z_{max} and Z_{min} maximum and minimum pixel values

3. **Prepare a weighting function**

   $$w(z) = \begin{cases} z - Z_{min} & \text{for } z \leq \frac{1}{2}(Z_{min} + Z_{max}) \\ Z_{max} - z & \text{for } z > \frac{1}{2}(Z_{min} + Z_{max}) \end{cases}$$

   Since pixel values are more reliable in the middle of their range, they also add a weighting (hat) function w(k) that decays to zero at both ends of the pixel value range

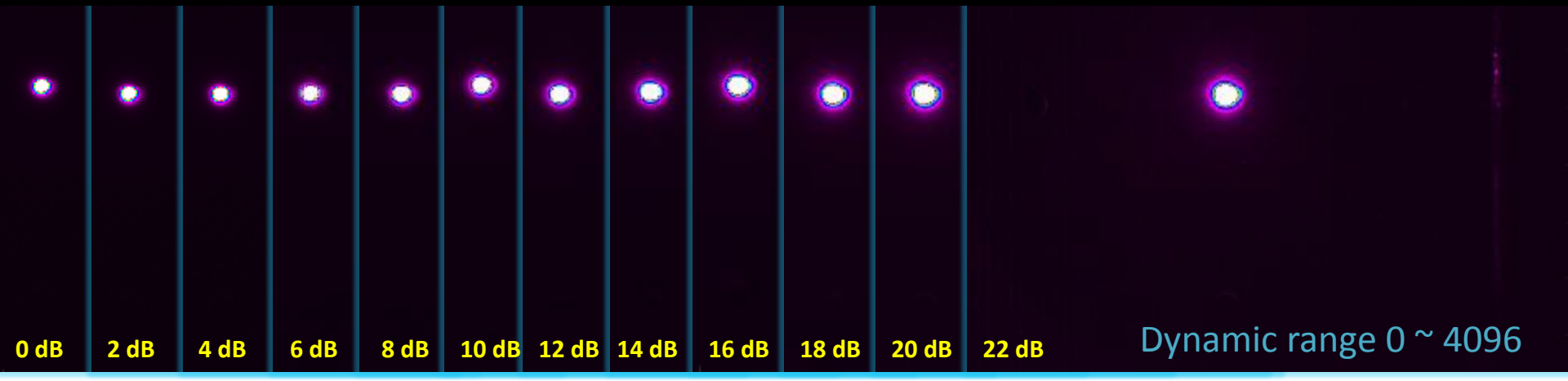
4. **Rum *gsolve.m*** to get the camera's response curve(function)

5. **Run *hdrDebevec.m*** to reconstruct the HDR image

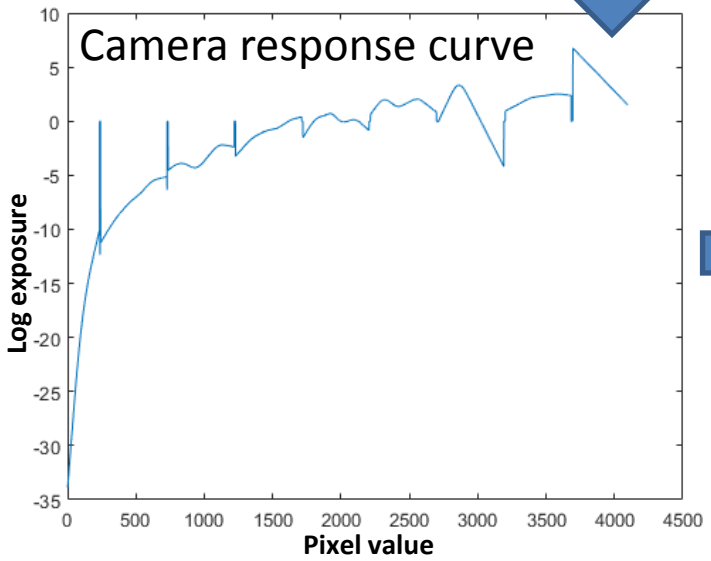
$$\ln E_i = \frac{\sum_{j=1}^{P} w(Z_{ij})(g(Z_{ij}) - \ln \Delta t_j)}{\sum_{j=1}^{P} w(Z_{ij})}$$

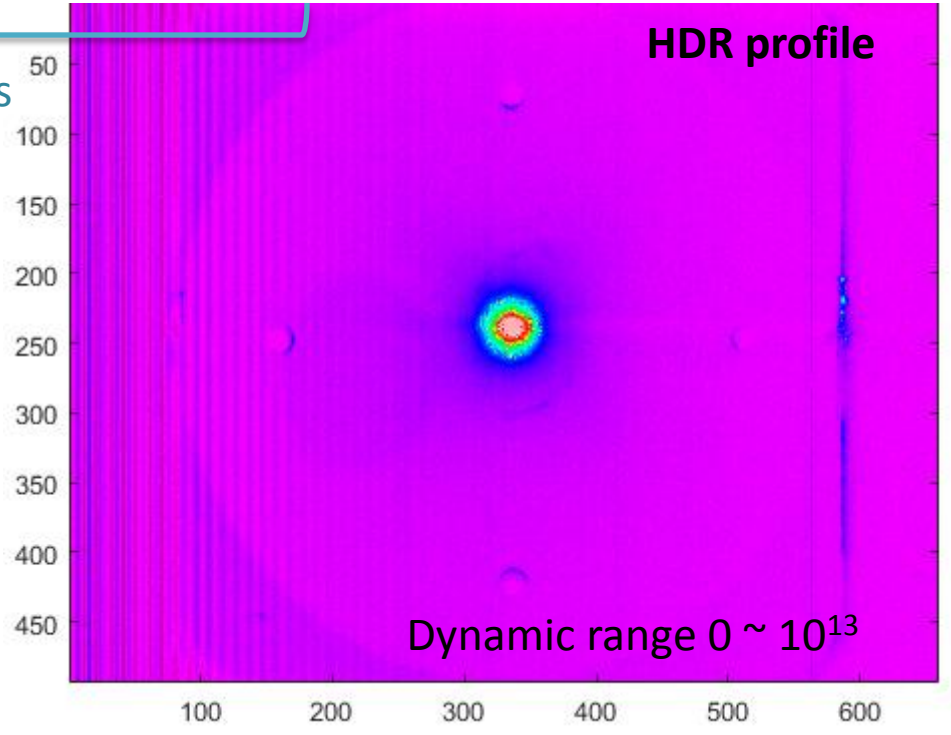
where ln E_i is the logarithm of irradiance, Z_{ij} is a i,j pixel's value, g is the camera's response function, and Δt_j is the exposure of image number j

Example: 2/23@CAM8, COL in



Set of 12 images with different exposures





まとめ

Beam halo & beam loss reasons	Observation	Simulation	Solution
Longitudinal bunch tail from cathode			
Laser phase shift or movement			
Laser pulse tail or train			
Misalignment of beam line elements			
Kicks from the input or HOM couplers			
Kicks from the steering magnets			
Space charge effect			
Dispersion			
Large betatron function			
Large momentum deviation			
Narrow aperture			
Collimator insertion