LA-UR- 03-0902

Approved for public release; distribution is unlimited.

Title: Fiducial Mark Calibration

Author(s): Alexander Saunders

Submitted to: AccApp '03 Conference

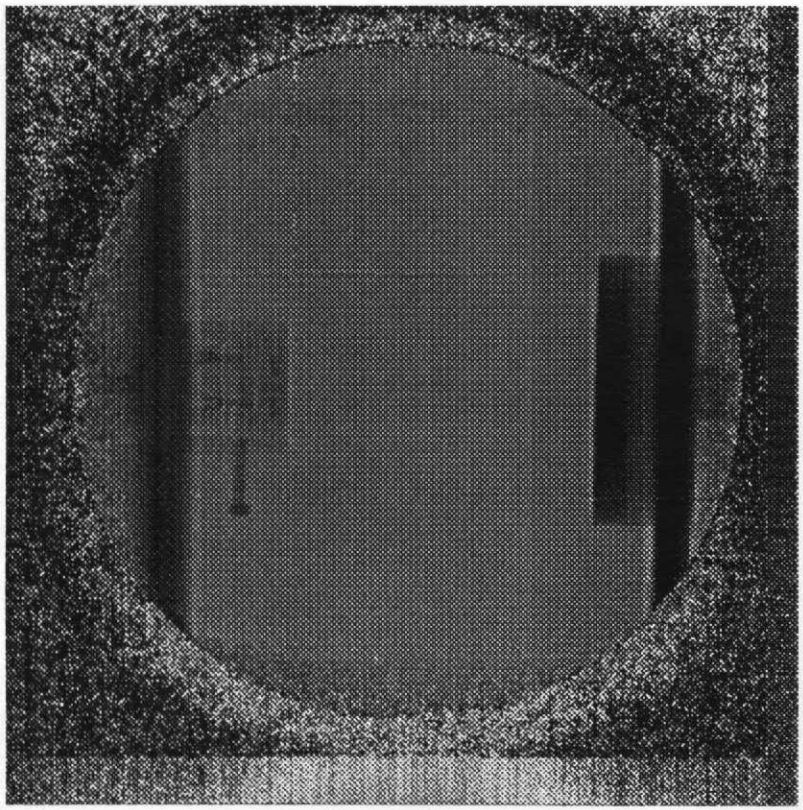
Los Alamos
NATIONAL LABORATORY

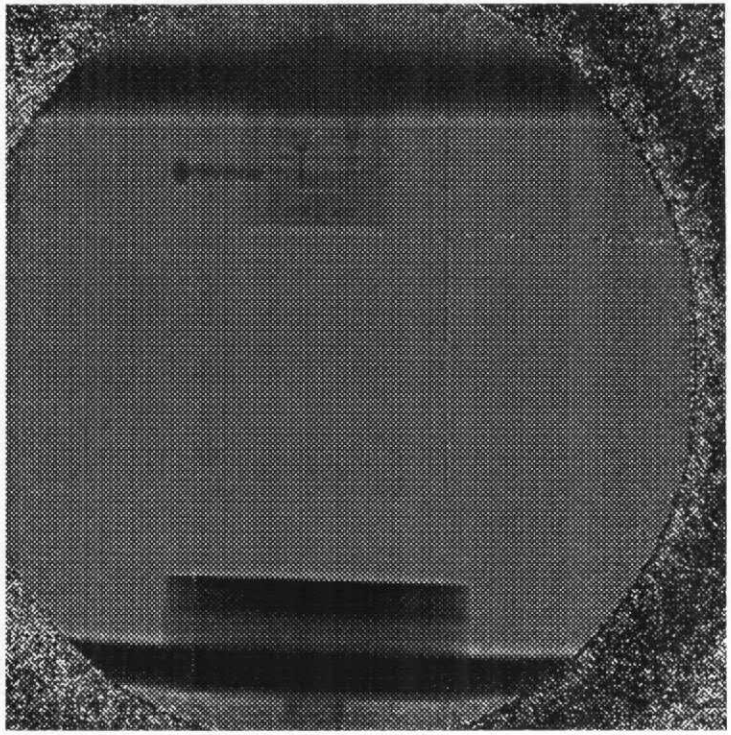
Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (8/00)

Fiducial Mark Calibration

- Aligns cameras to identical orientation, field of view and pixel size
- Removes pincushion, obliqueness distortion, and magnification
- Sets picture scale





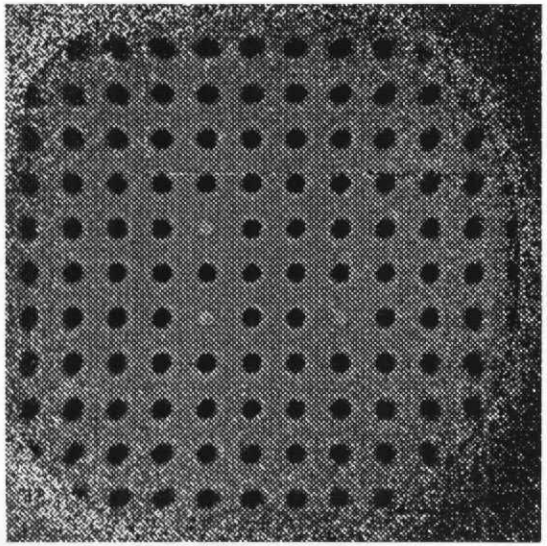
-22 22 -6 cm 6 cm

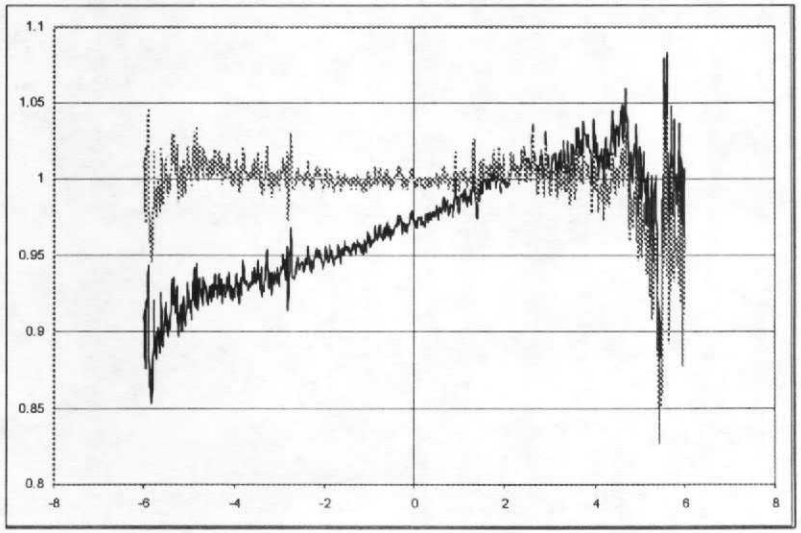
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Proton Beam Location and Flux

- Two methods: knowledge-based and measurement-based
- Knowledge based:
  - Fit polynomial to area of picture "known to be flat"
  - Divide pic by that polynomial
- Measurement based:
  - Proton toroid for flux; 4-chamber BPM for position
  - Normalize to flux, divide by shifted Gaussian for position





Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - ✓ Location
  - ✓ Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Areal Density Extraction

- Measured transmission depends on
  - Fixed scattering
  - Radiation length in object
  - Collimator cut angle
  - Nuclear scattering in object
  - Background scattering (Tile glow, protons)

$$t = \frac{\left[f_{Had} \bullet (1 - f_{MS})/(1 - f_{FS}) + f_{BG}\right]}{\left[1 + f_{BG}\right]}$$

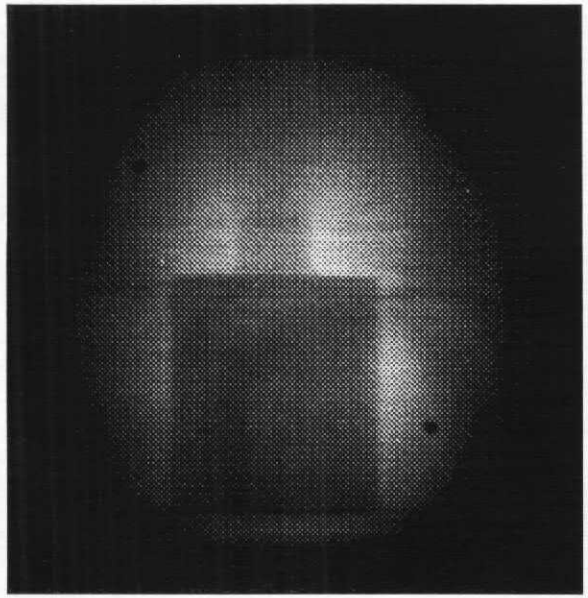
$$f_{Had} = e^{-\left(d/\lambda_H\right)}$$

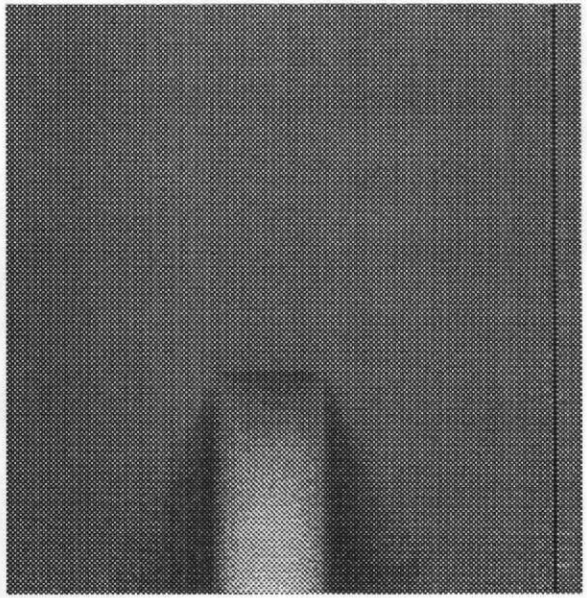
$$f_{MS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ \left(2\left(d/X_0 + R_f\right)\right)}$$

$$f_{FS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ R_f}$$

Proton Radiography Analysis Procedure

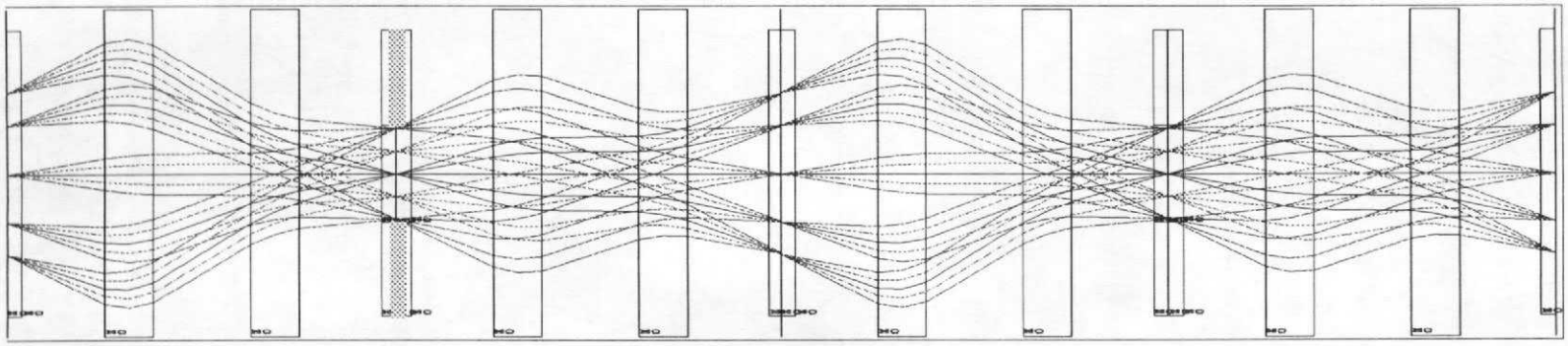
Alexander Saunders





- LANSCE Proton Radiography
- Effects to be Corrected
- Analysis Procedure
- Sample Results

Line C PRAD Apparatus



Object

Collimator 1
Typically 10 mr

Image
Station 1

Collimator 2

Image
Station 2

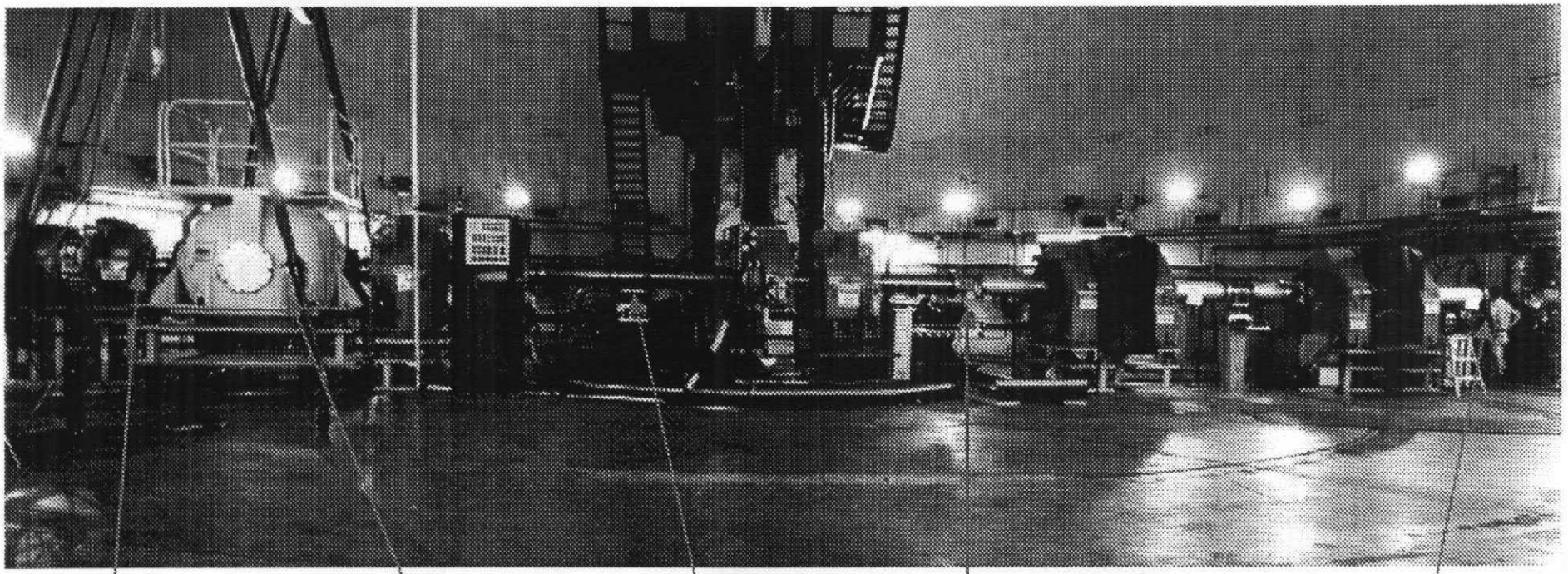
- Armored Windows
- Thin Windows
- LSO Scintillators
- Matching Lens
- Image Station 0: BPM, Calibration
- 800 MeV Protons
- Beam timing

7 frames
1600^2 pixels

5 frames
1024^2 pixels
+ 9-frame
framing camera

LANSCE 800 MeV Proton Radiography

Proton Beam →

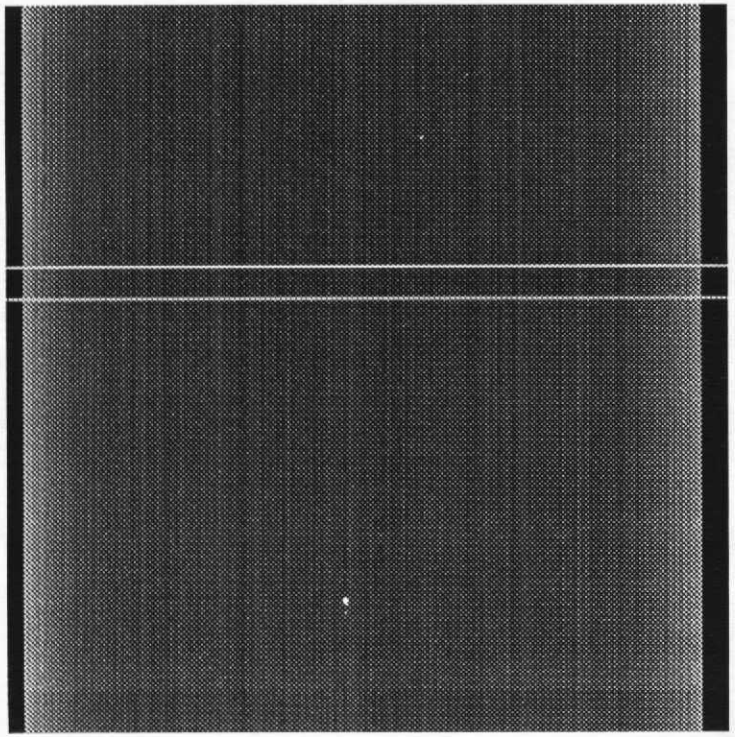


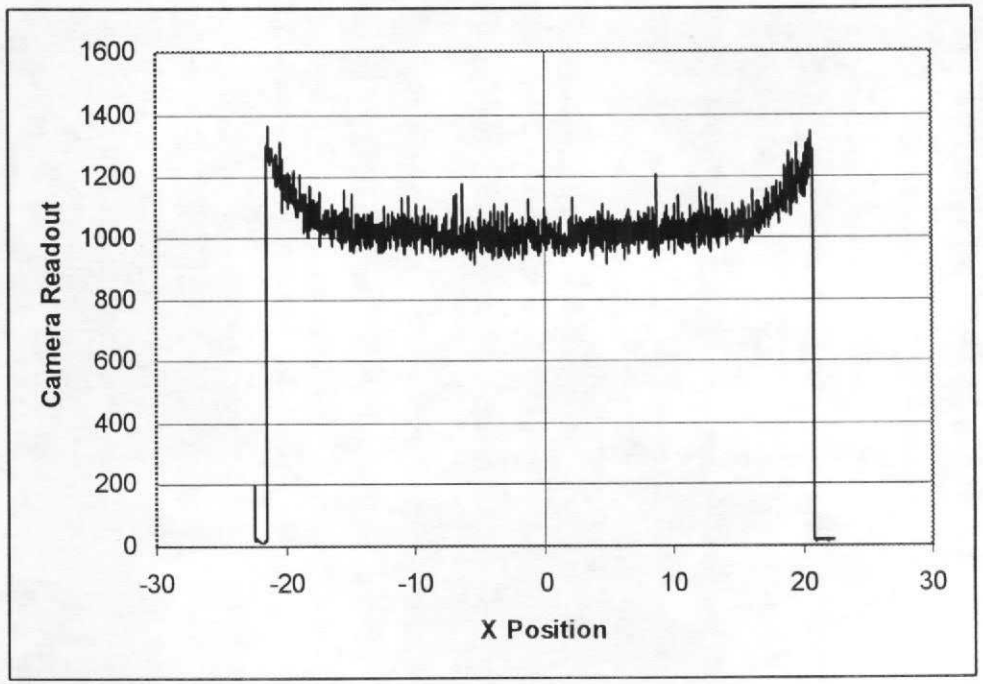
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Camera Dark Field

- Constant over hours to days
- <5% of camera signal
- Camera Temperature Dependent
- Typically Average 5 Pics





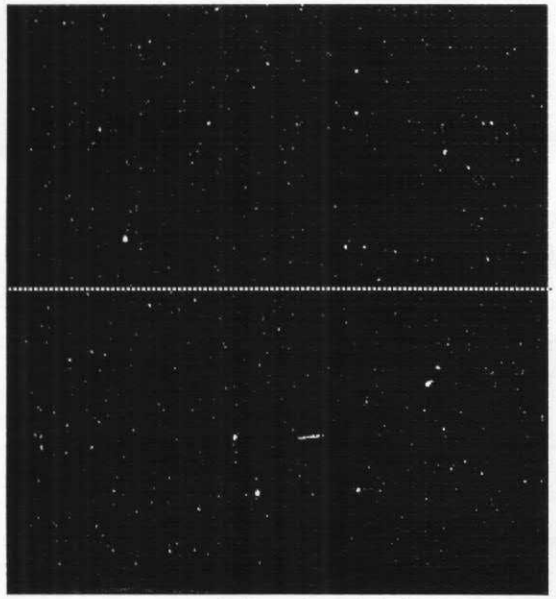
Effects to be Corrected

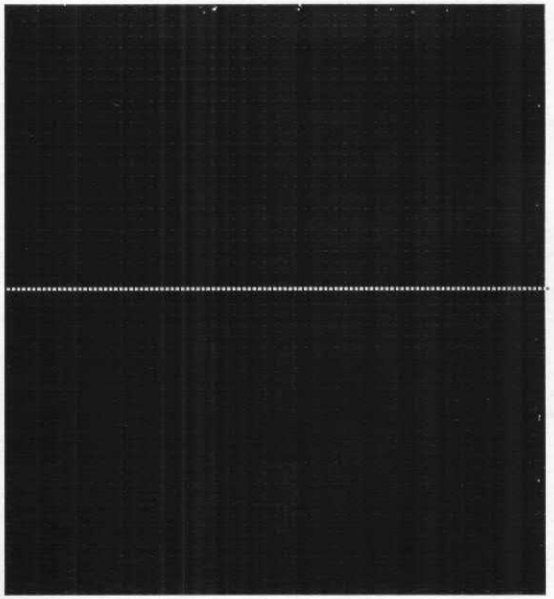
- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

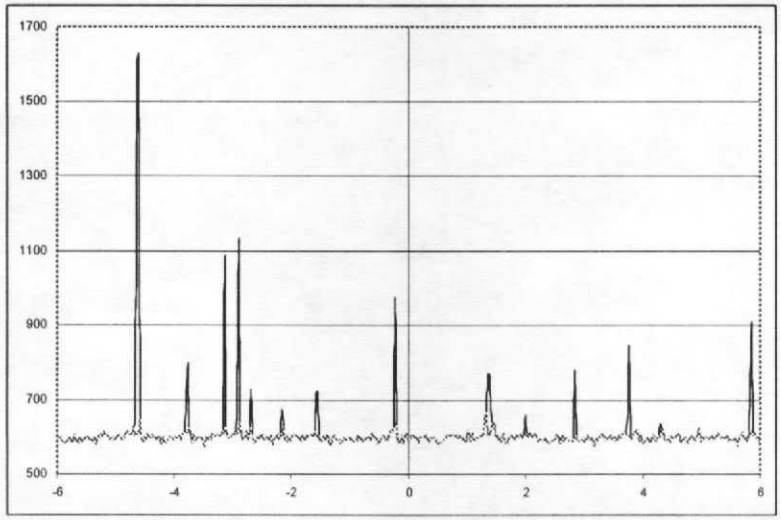
Star Correction

- Hadronic Interactions in Camera CCD
  - Large Local Energy Deposition
  - Shielding Necessary
- Correction:
  - Smooth data
  - Chop isolated outliers
  - Multiple passes
  - Correction is limited

Star Correction





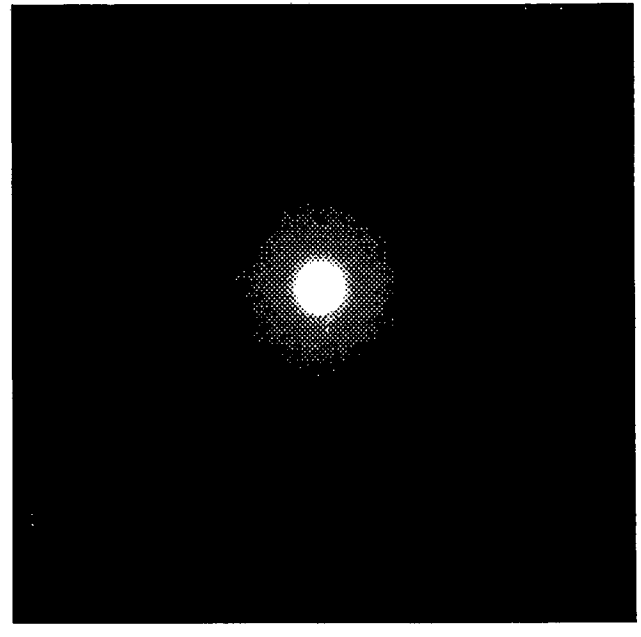


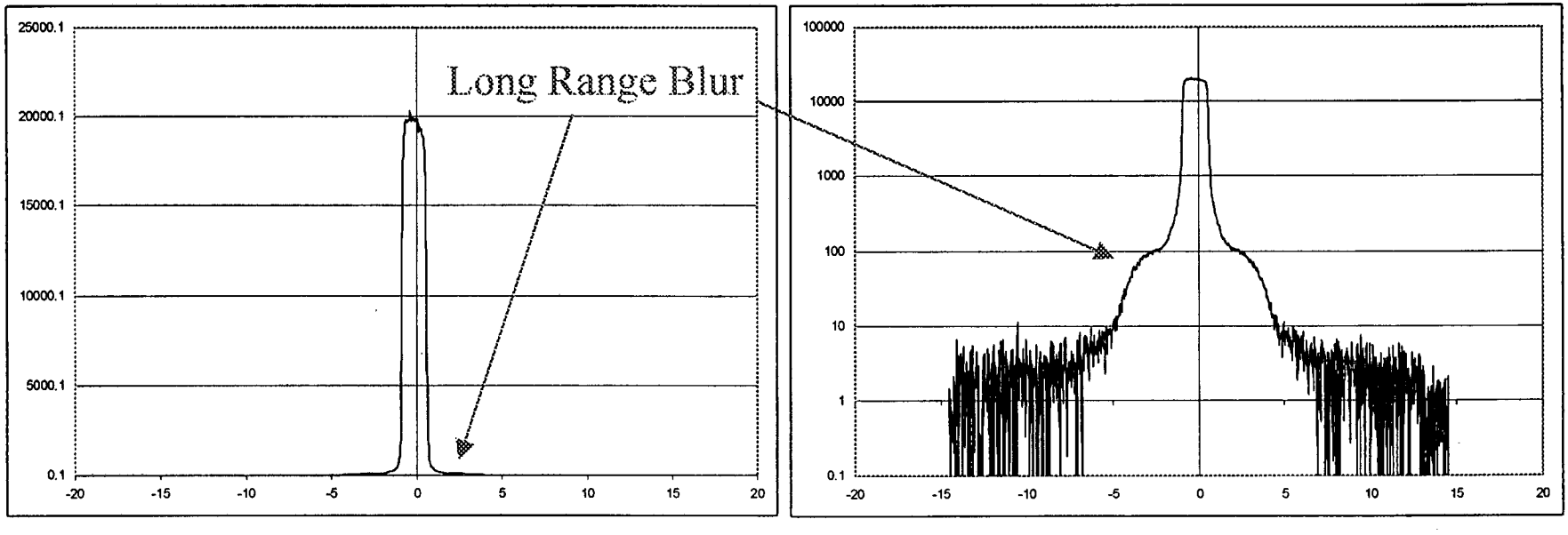
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Long Range Blur

- Optical Effect in Cameras
- Some (15%) light scatters widely
- Measure blur function, unfold from data



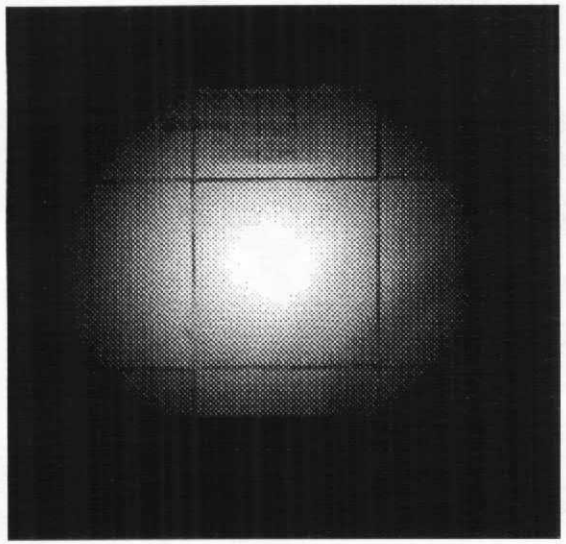


Effects to be Corrected

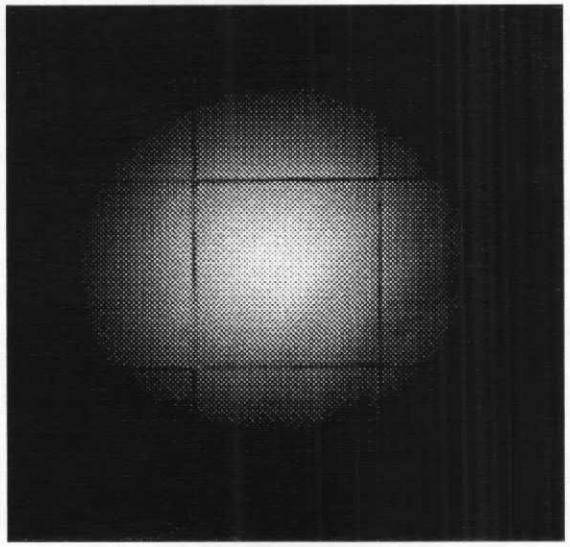
- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Beam Profile Flattening

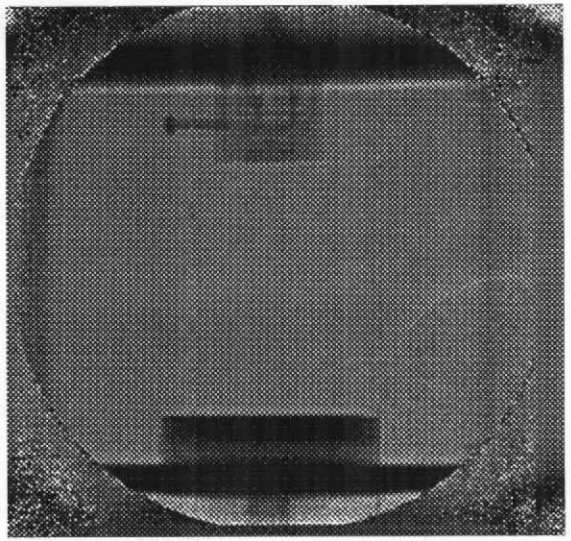
- Measure beam profile with no object in place
- Accounts for uneven beam and fixed pattern noise
- Result: "Flattened" picture



Divided by



Equals

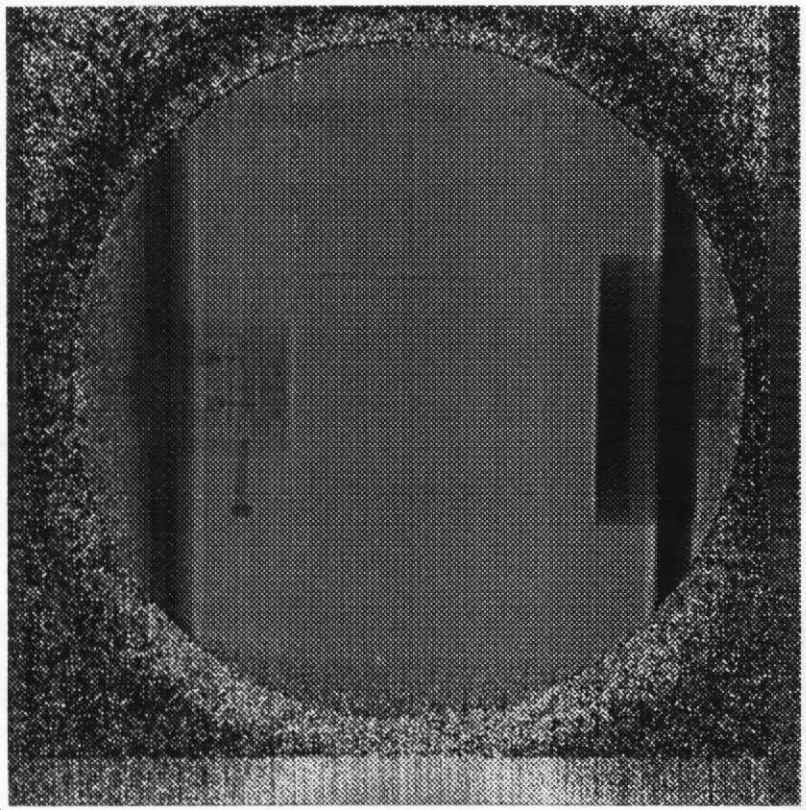


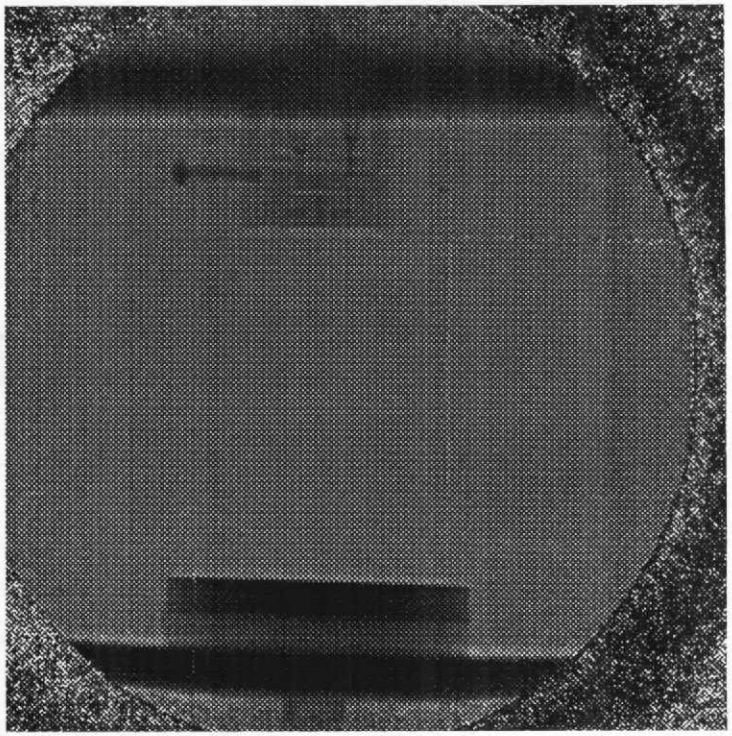
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - – Magnification
  - – Particle Background
  - – Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - – Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Fiducial Mark Calibration

- Aligns cameras to identical orientation, field of view and pixel size
- Removes pincushion, obliqueness distortion, and magnification
- Sets picture scale





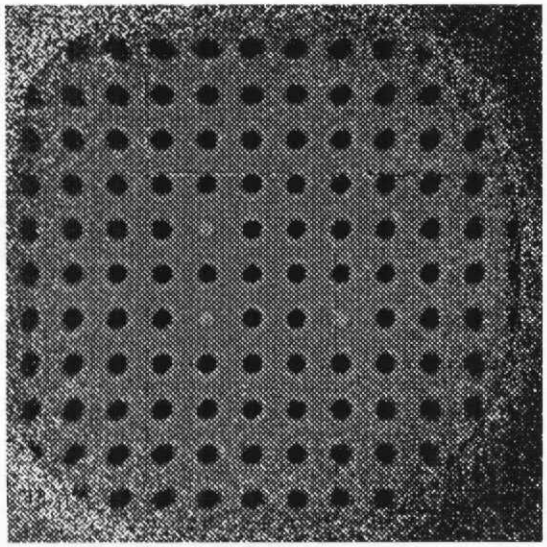
-22 22 -6 cm 6 cm

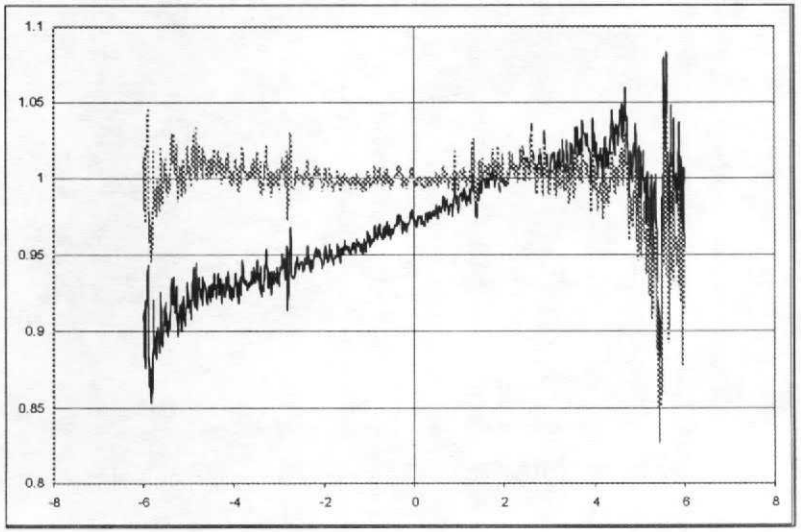
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Proton Beam Location and Flux

- Two methods: knowledge-based and measurement-based
- Knowledge based:
  - Fit polynomial to area of picture "known to be flat"
  - Divide pic by that polynomial
- Measurement based:
  - Proton toroid for flux; 4-chamber BPM for position
  - Normalize to flux, divide by shifted Gaussian for position





Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - ✓ Location
  - ✓ Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Areal Density Extraction

- Measured transmission depends on
  - Fixed scattering
  - Radiation length in object
  - Collimator cut angle
  - Nuclear scattering in object
  - Background scattering (Tile glow, protons)

$$t = \frac{\left[f_{Had} \bullet (1 - f_{MS})/(1 - f_{FS}) + f_{BG}\right]}{\left[1 + f_{BG}\right]}$$

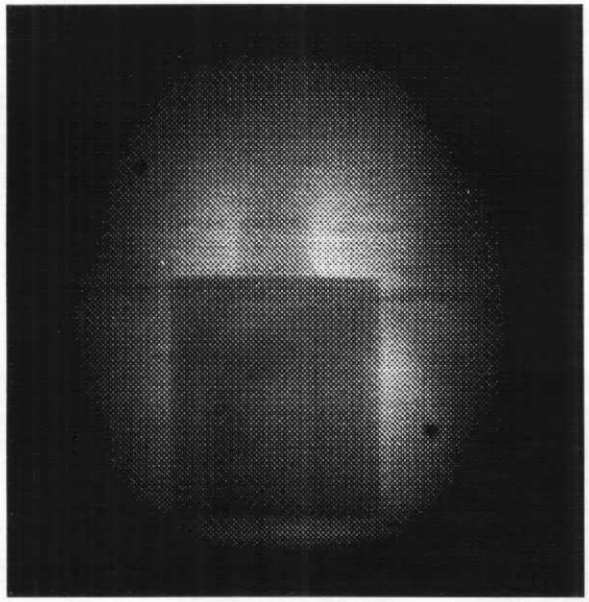
$$f_{Had} = e^{-\left(d/\lambda_H\right)}$$

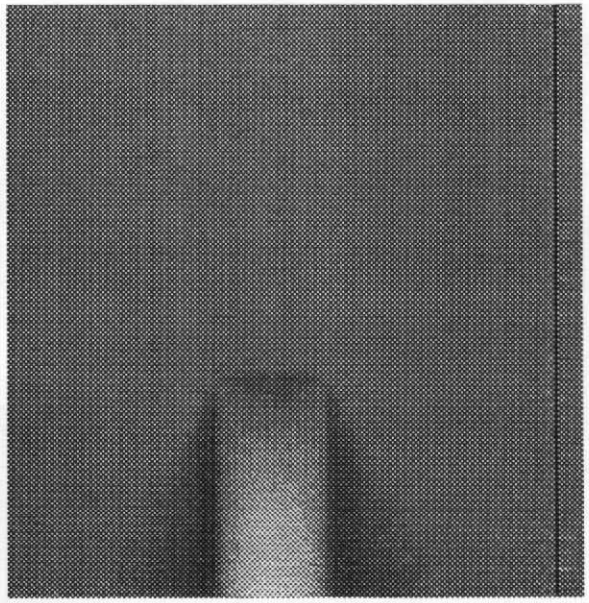
$$f_{MS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ \left(2\left(d/X_0 + R_f\right)\right)}$$

$$f_{FS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ R_f}$$

Proton Radiography Analysis Procedure

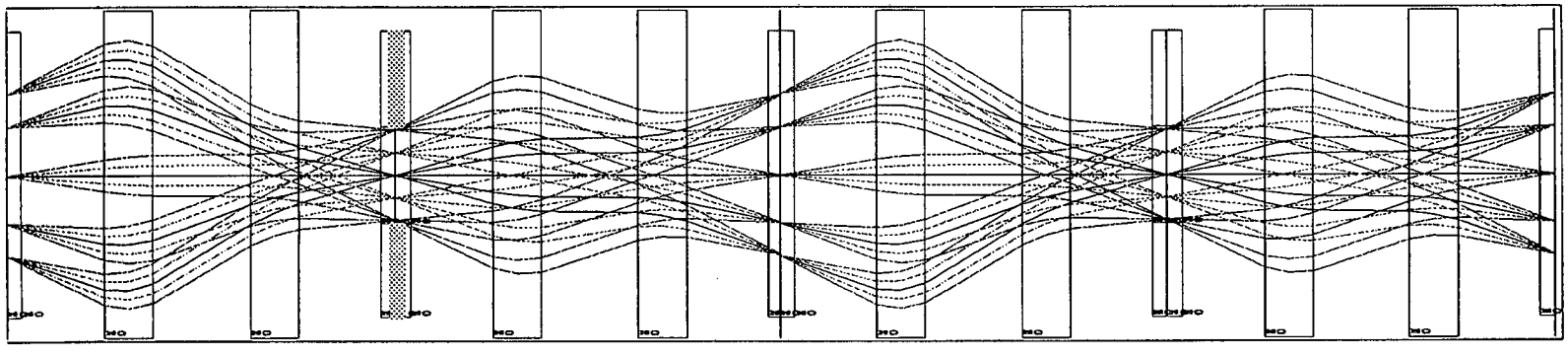
Alexander Saunders





- LANSCE Proton Radiography
- Effects to be Corrected
- Analysis Procedure
- Sample Results

Line C PRAD Apparatus



Object

Collimator 1
Typically 10 mr

Image
Station 1

Collimator 2

Image
Station 2

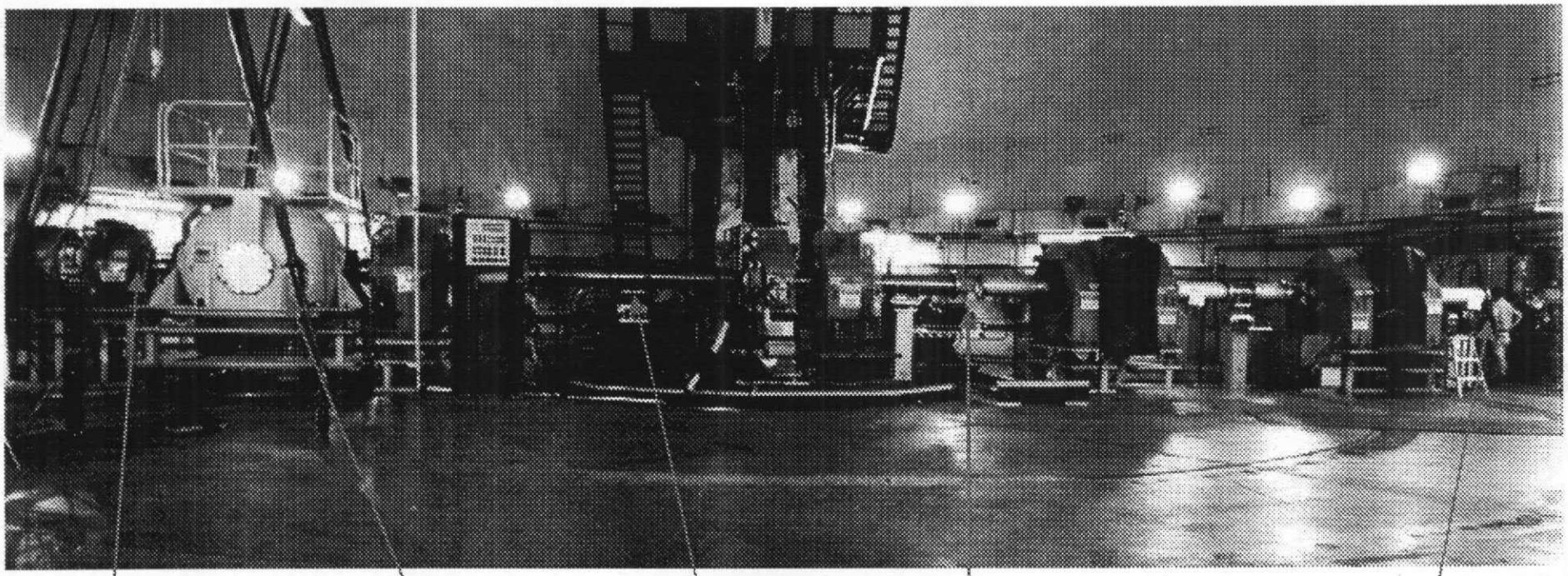
- Armored Windows
- Thin Windows
- LSO Scintillators
- Matching Lens
- Image Station 0: BPM, Calibration
- 800 MeV Protons
- Beam timing

7 frames
1600^2 pixels

5 frames
1024^2 pixels
+ 9-frame
framing camera

LANSCE 800 MeV Proton Radiography

Proton Beam →



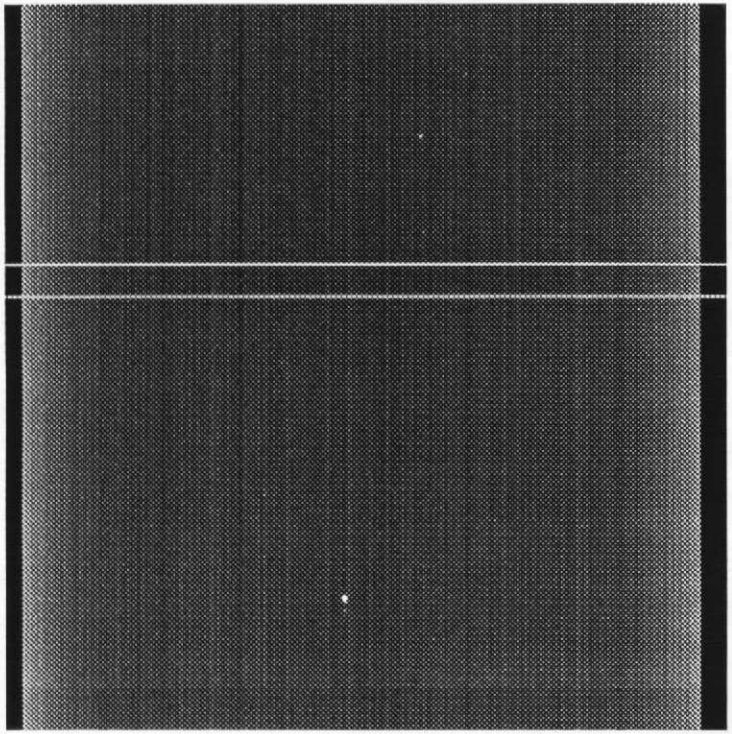
Proton Beam Line | Confinement vessel | Collimator 1 | Image Station 1 | Image Station 2

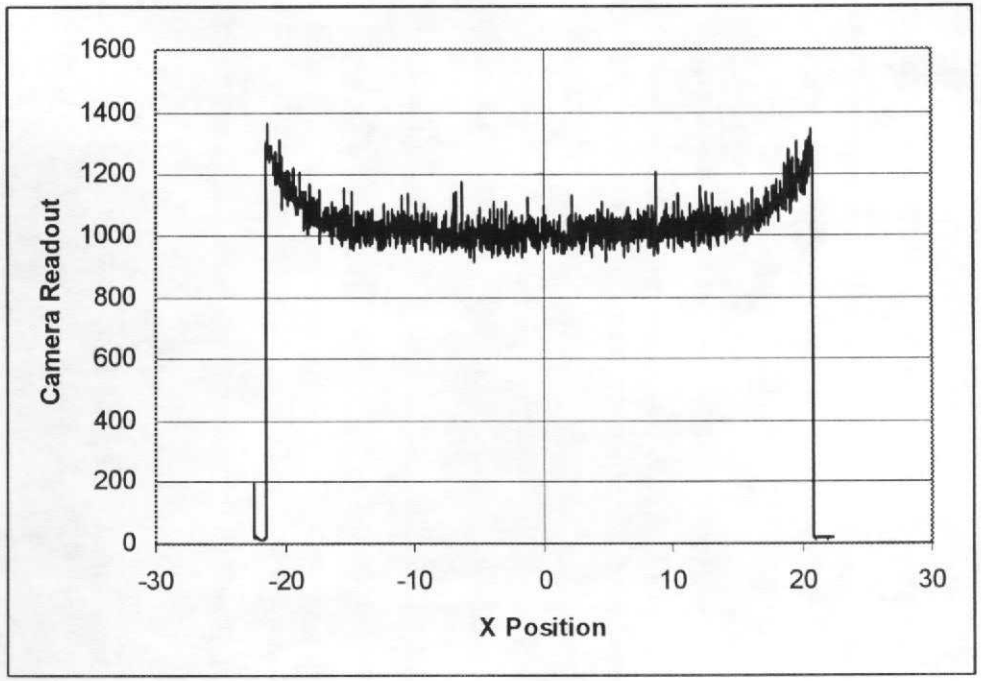
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Camera Dark Field

- Constant over hours to days
- <5% of camera signal
- Camera Temperature Dependent
- Typically Average 5 Pics





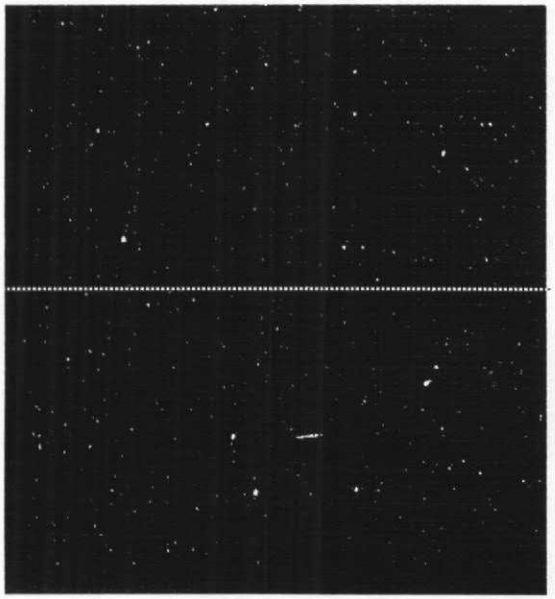
Effects to be Corrected

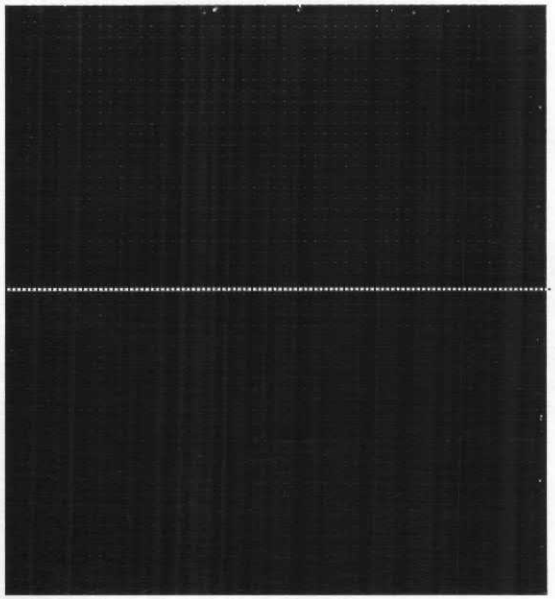
- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

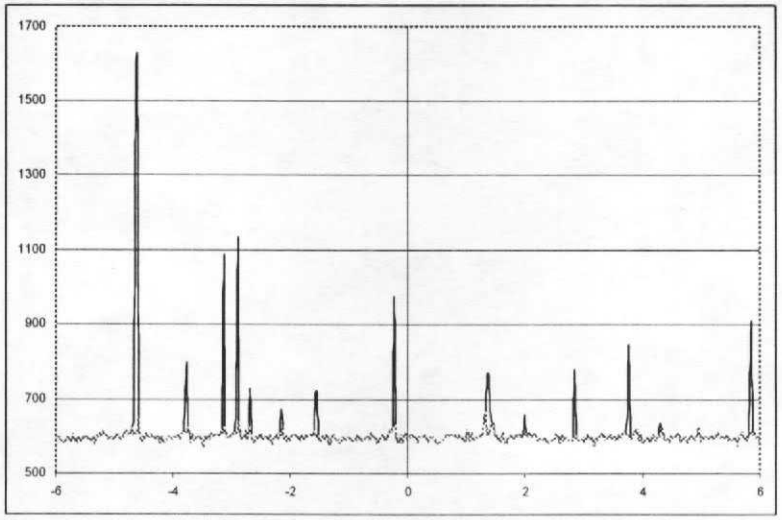
Star Correction

- Hadronic Interactions in Camera CCD
  - Large Local Energy Deposition
  - Shielding Necessary
- Correction:
  - Smooth data
  - Chop isolated outliers
  - Multiple passes
  - Correction is limited

Star Correction





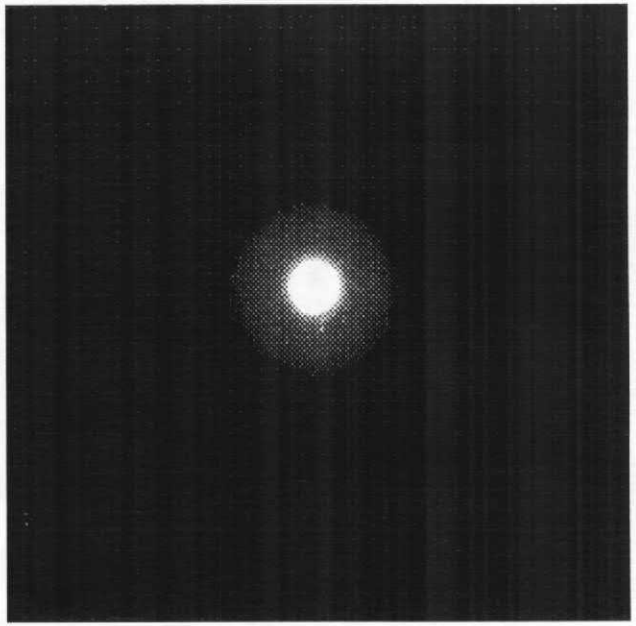


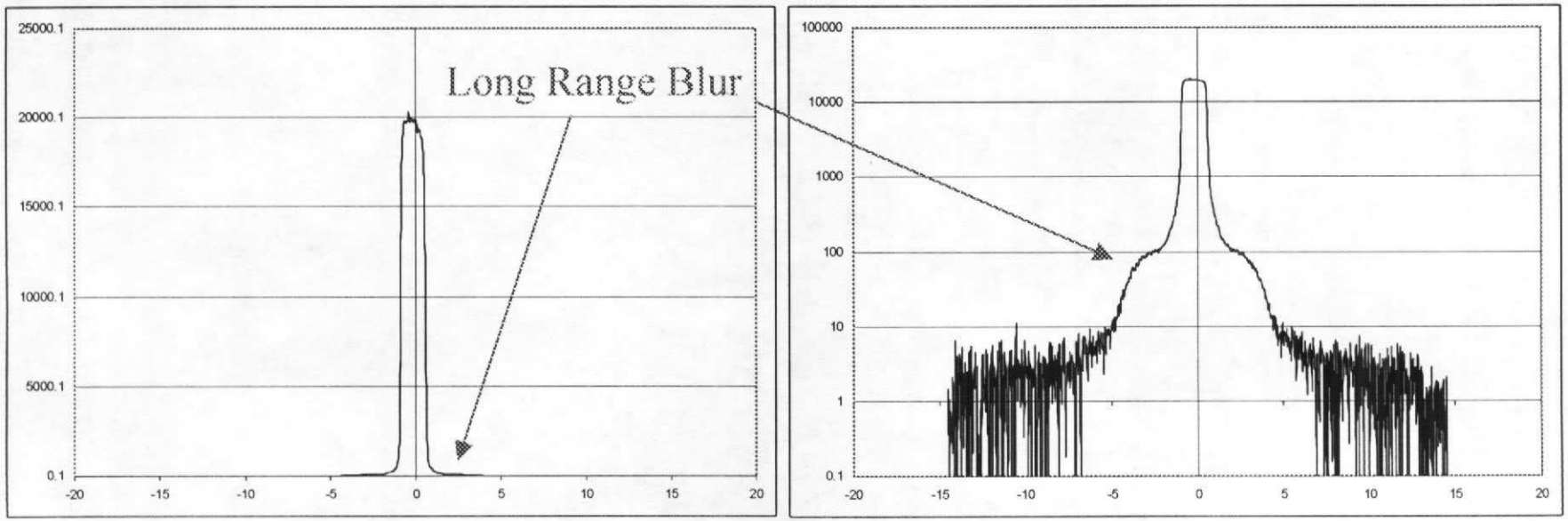
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Long Range Blur

- Optical Effect in Cameras
- Some (15%) light scatters widely
- Measure blur function, unfold from data



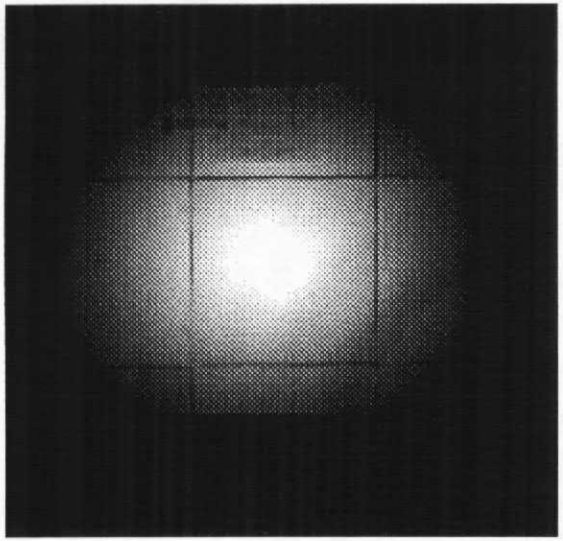


Effects to be Corrected

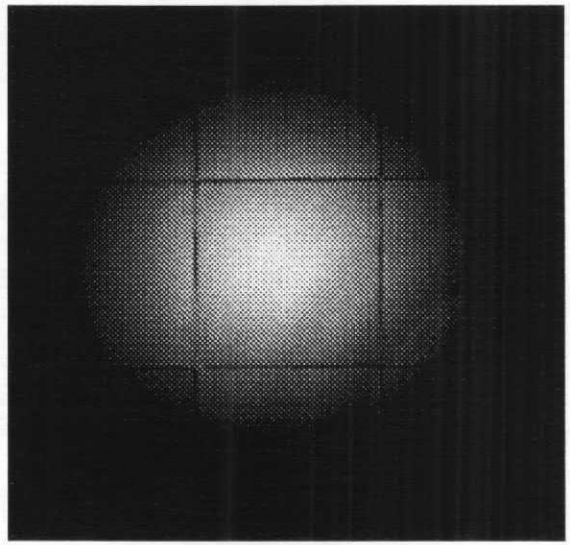
- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Beam Profile Flattening

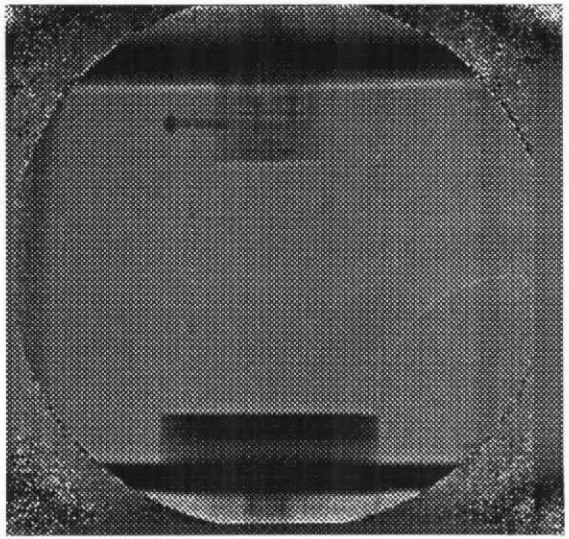
- Measure beam profile with no object in place
- Accounts for uneven beam and fixed pattern noise
- Result: "Flattened" picture



Divided by



Equals

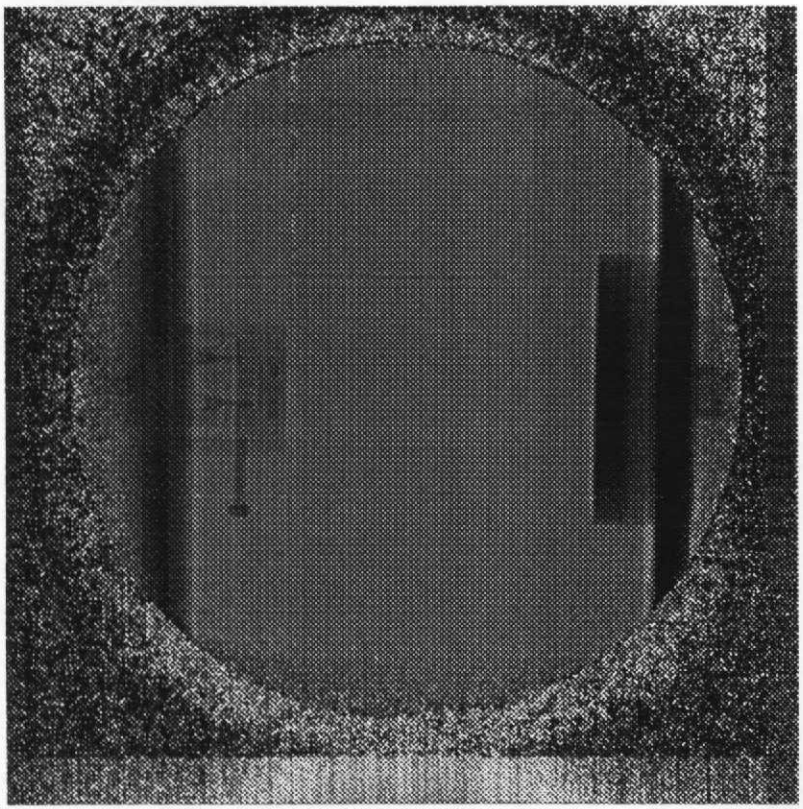


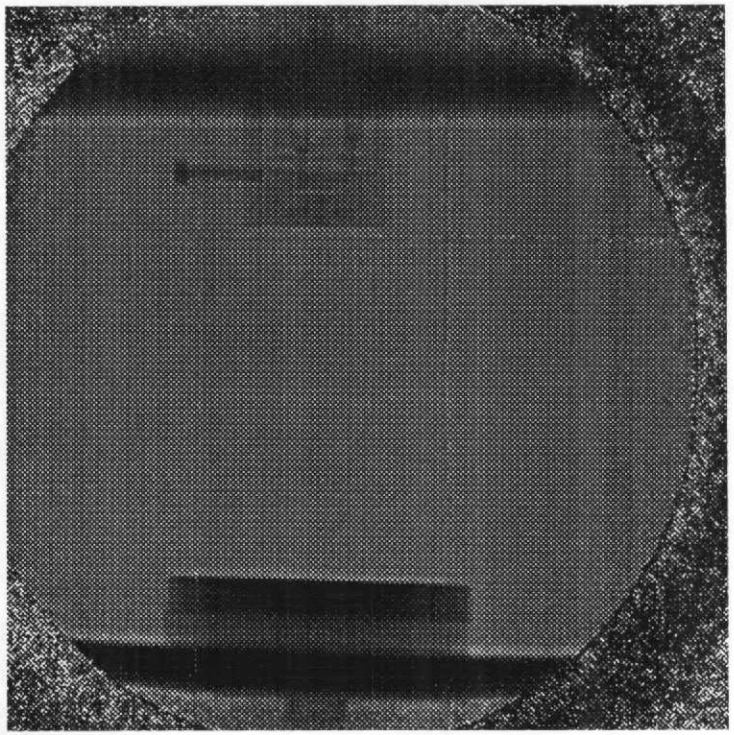
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - – Magnification
  - – Particle Background
  - – Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - – Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Fiducial Mark Calibration

- Aligns cameras to identical orientation, field of view and pixel size
- Removes pincushion, obliqueness distortion, and magnification
- Sets picture scale





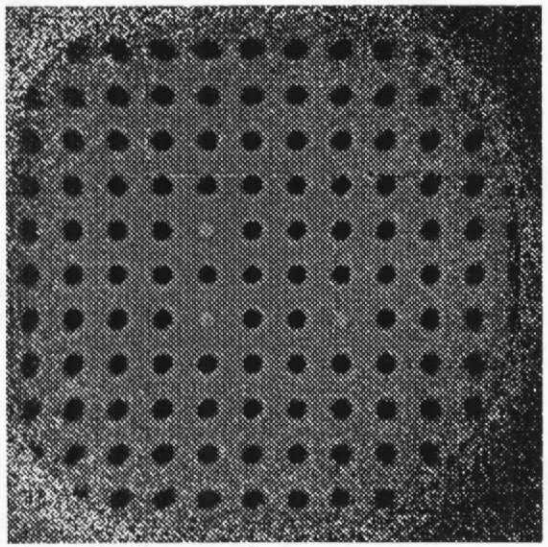
-22 22 -6 cm 6 cm

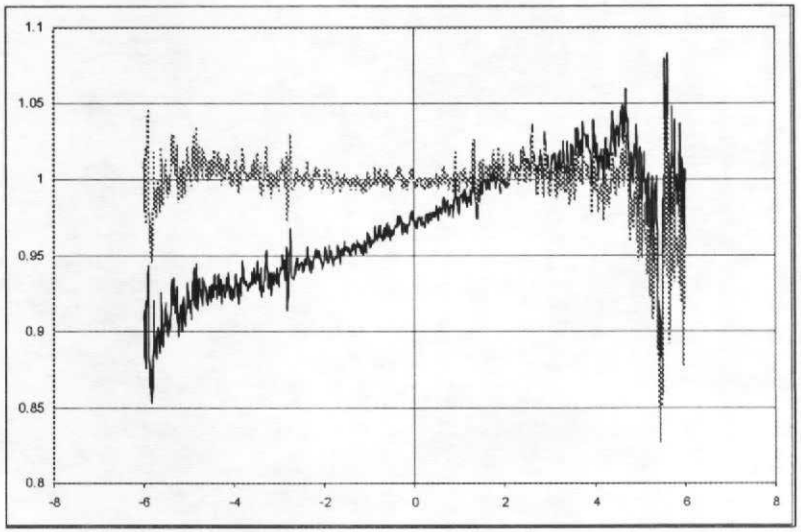
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Proton Beam Location and Flux

- Two methods: knowledge-based and measurement-based
- Knowledge based:
  - Fit polynomial to area of picture "known to be flat"
  - Divide pic by that polynomial
- Measurement based:
  - Proton toroid for flux; 4-chamber BPM for position
  - Normalize to flux, divide by shifted Gaussian for position





Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - ✓ Location
  - ✓ Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Areal Density Extraction

- Measured transmission depends on
  - Fixed scattering
  - Radiation length in object
  - Collimator cut angle
  - Nuclear scattering in object
  - Background scattering (Tile glow, protons)

$$t = \frac{\left[f_{Had} \bullet (1 - f_{MS})/(1 - f_{FS}) + f_{BG}\right]}{\left[1 + f_{BG}\right]}$$

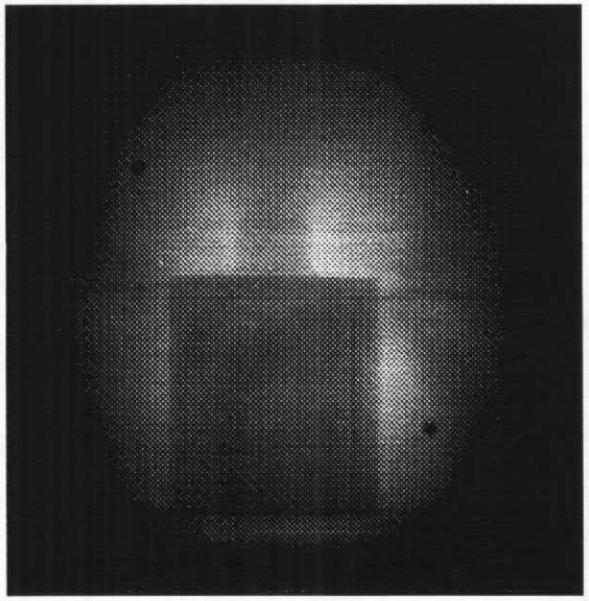
$$f_{Had} = e^{-\left(d/\lambda_H\right)}$$

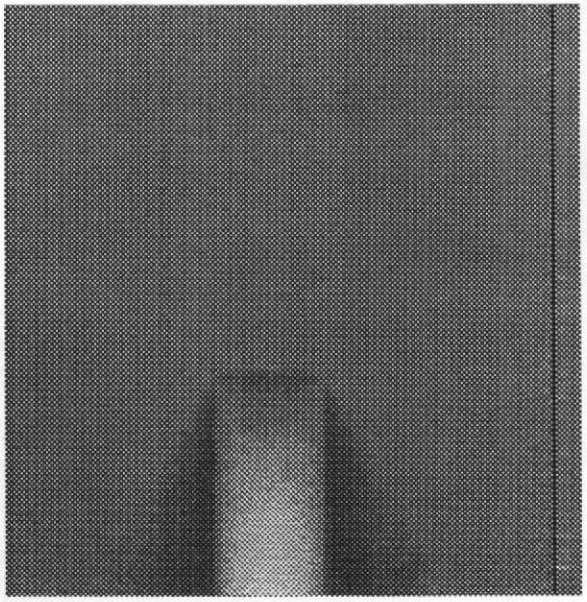
$$f_{MS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ \left(2\left(d/X_0 + R_f\right)\right)}$$

$$f_{FS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ R_f}$$

Proton Radiography Analysis Procedure

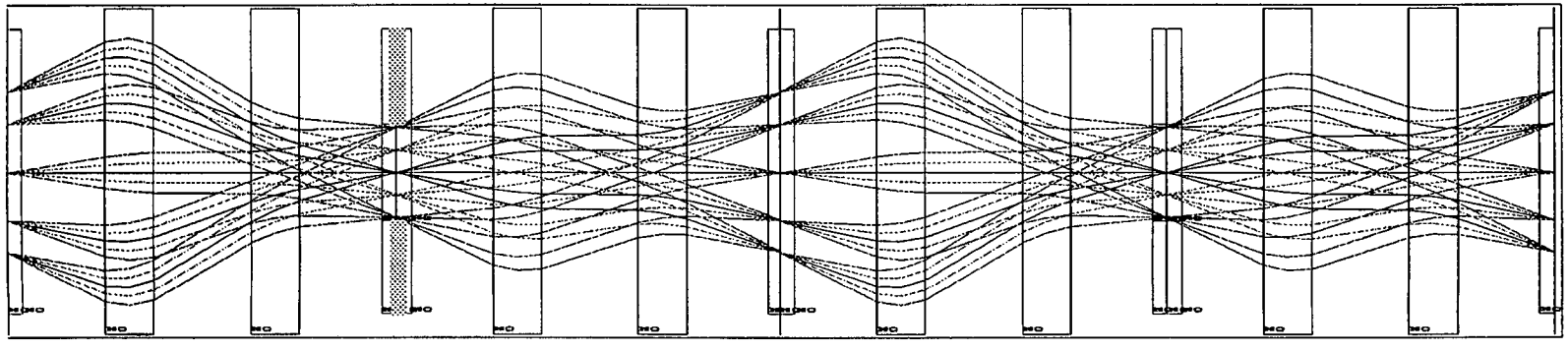
Alexander Saunders





- LANSCE Proton Radiography
- Effects to be Corrected
- Analysis Procedure
- Sample Results

Line C PRAD Apparatus



Object

Collimator 1
Typically 10 mr

Image
Station 1

Collimator 2

Image
Station 2

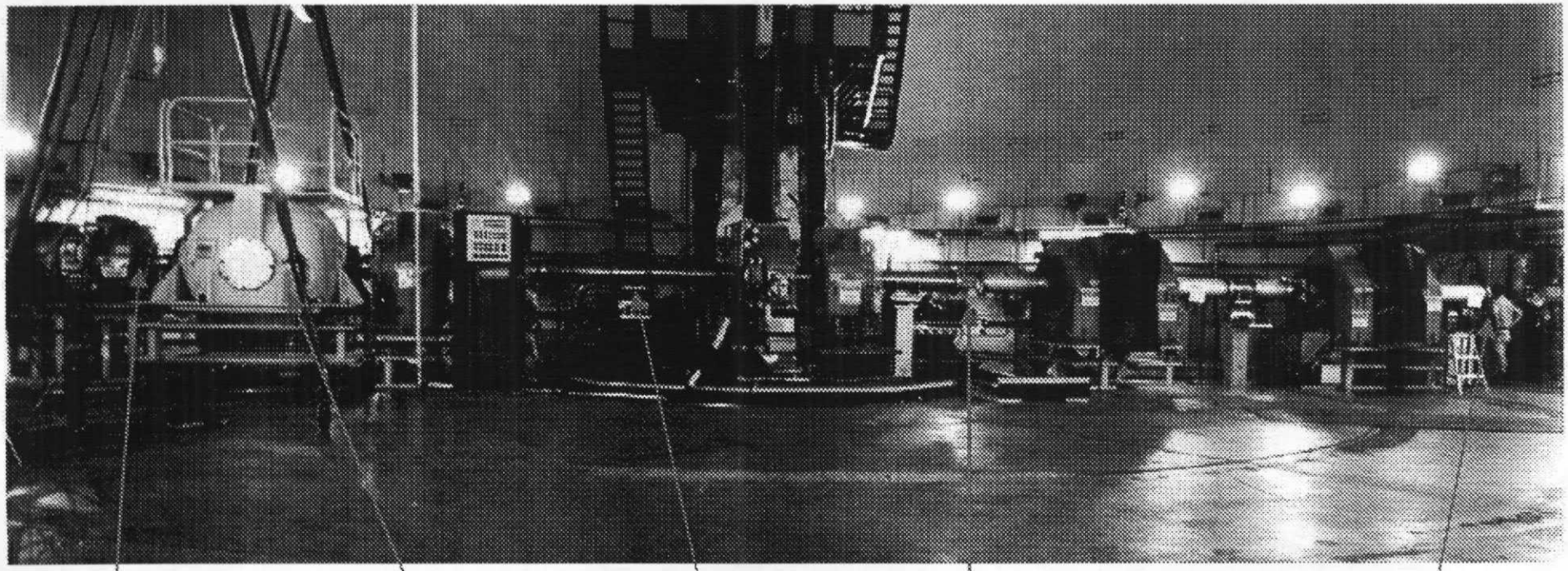
- Armored Windows
- Thin Windows
- LSO Scintillators
- Matching Lens
- Image Station 0: BPM, Calibration
- 800 MeV Protons
- Beam timing

7 frames
1600^2 pixels

5 frames
1024^2 pixels
+ 9-frame
framing camera

LANSCE 800 MeV Proton Radiography

Proton Beam →



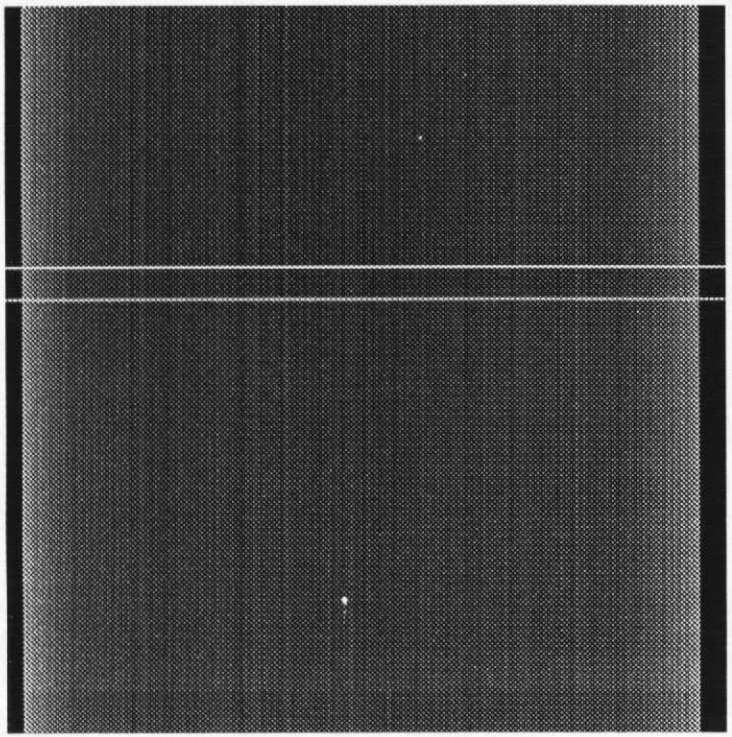
Proton Beam Line | Confinement vessel | Collimator 1 | Image Station 1 | Image Station 2

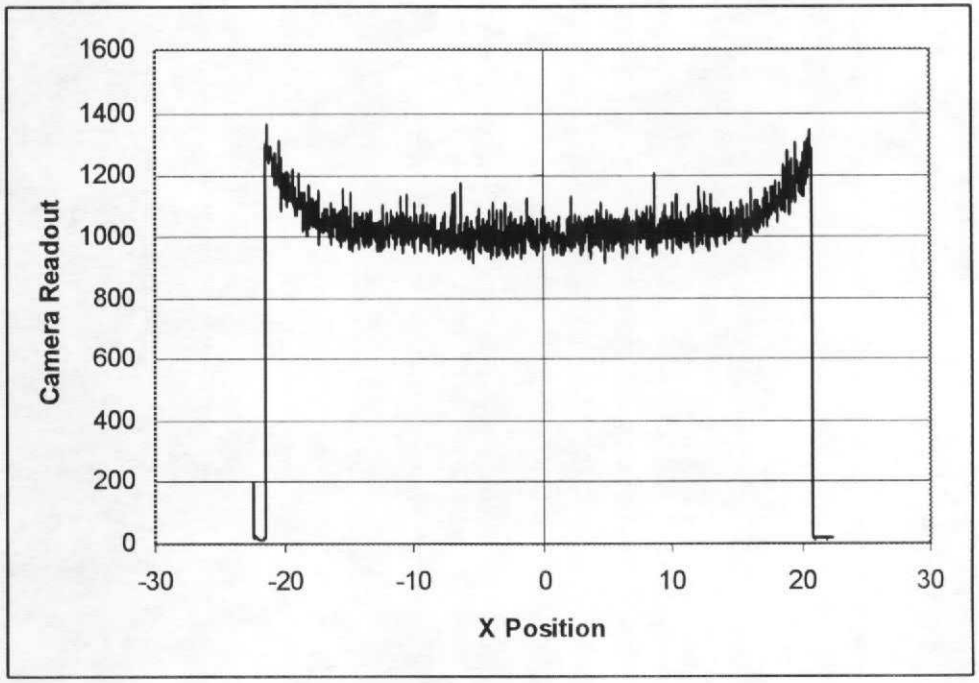
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Camera Dark Field

- Constant over hours to days
- <5% of camera signal
- Camera Temperature Dependent
- Typically Average 5 Pics





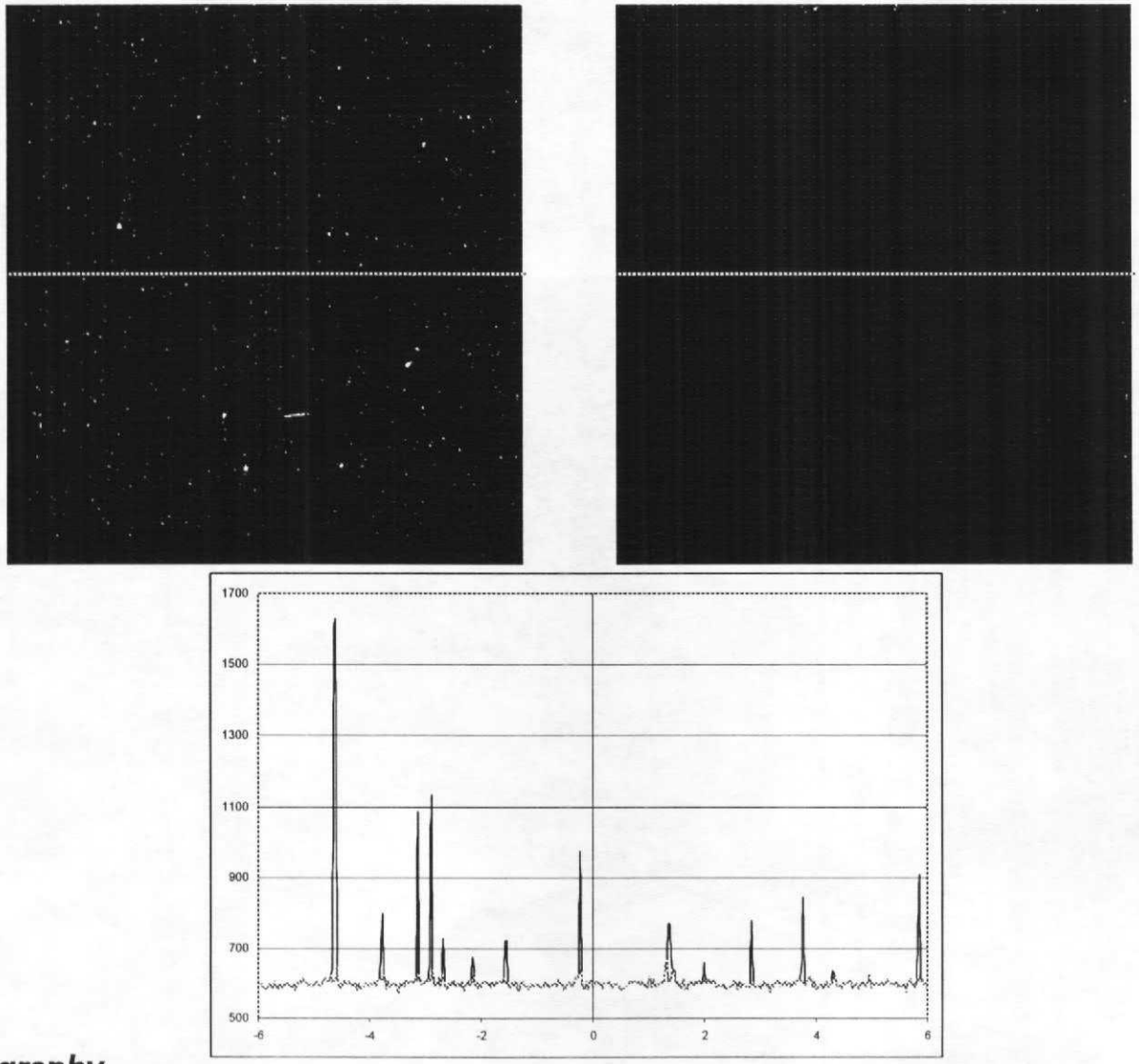
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Star Correction

- Hadronic Interactions in Camera CCD
  - Large Local Energy Deposition
  - Shielding Necessary
- Correction:
  - Smooth data
  - Chop isolated outliers
  - Multiple passes
  - Correction is limited

Star Correction

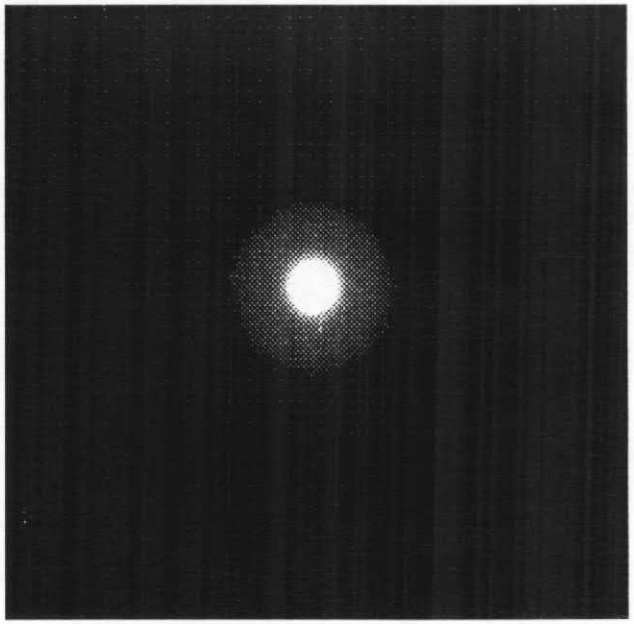


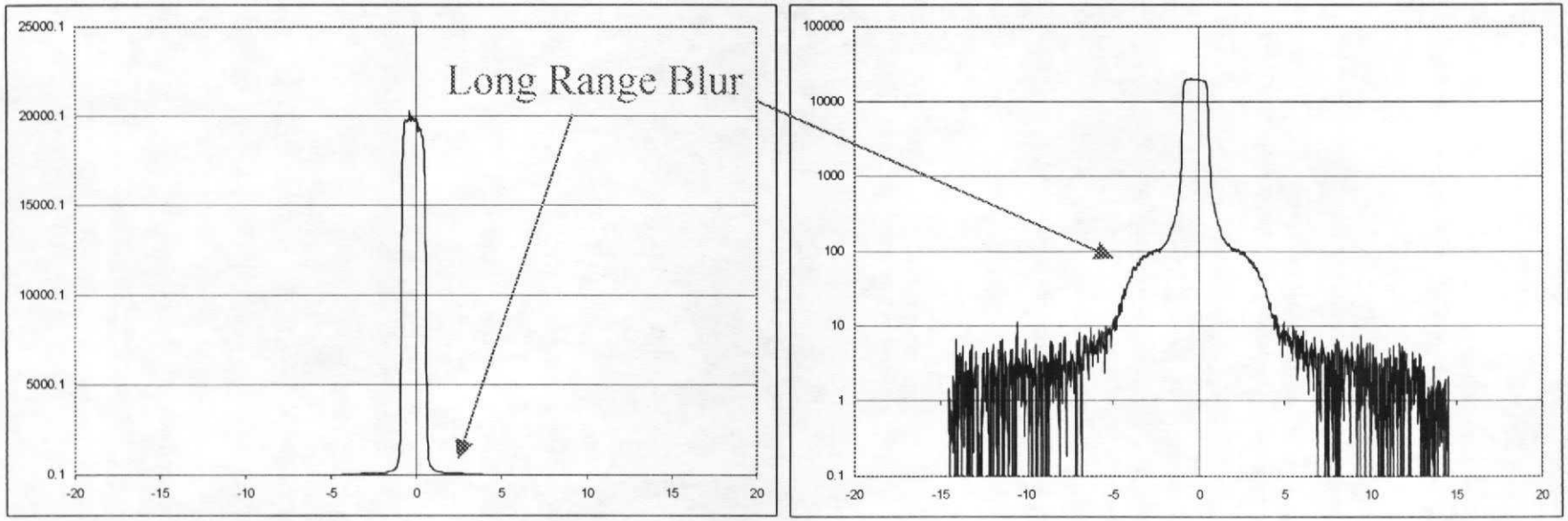
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Long Range Blur

- Optical Effect in Cameras
- Some (15%) light scatters widely
- Measure blur function, unfold from data



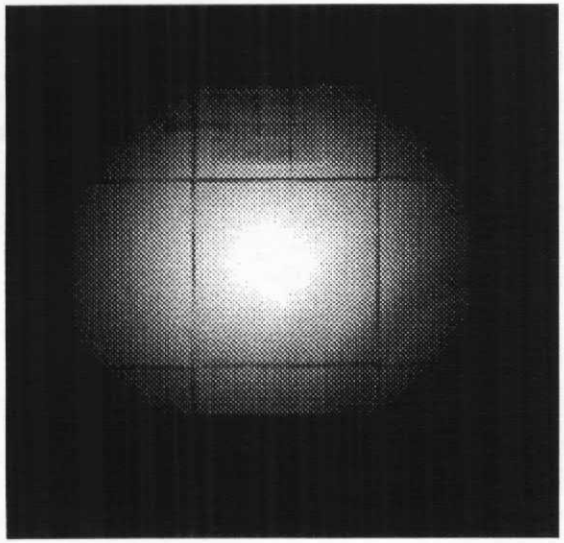


Effects to be Corrected

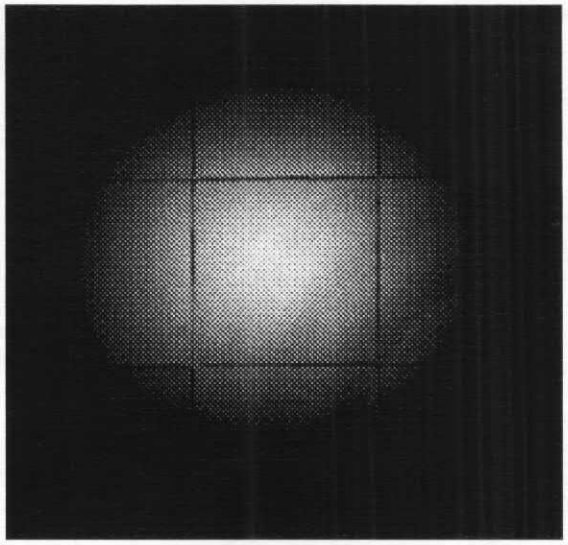
- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Beam Profile Flattening

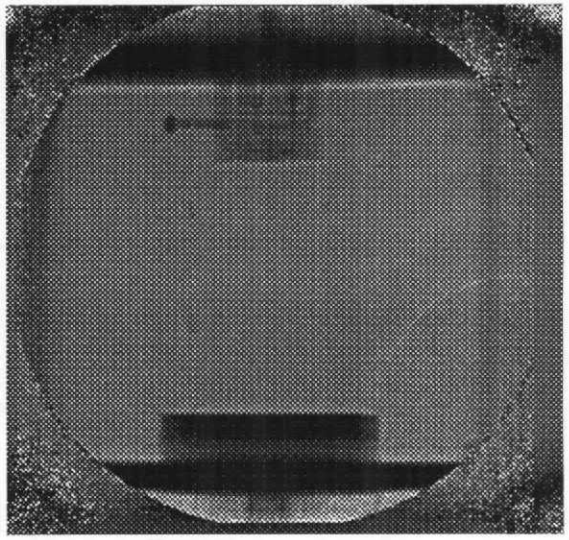
- Measure beam profile with no object in place
- Accounts for uneven beam and fixed pattern noise
- Result: "Flattened" picture



Divided by



Equals

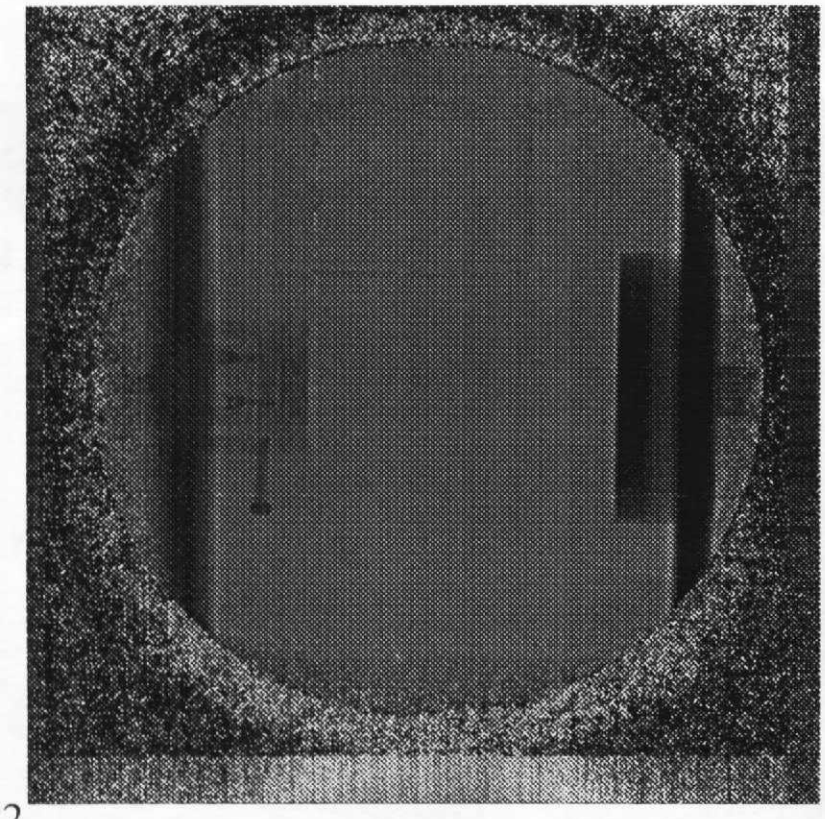


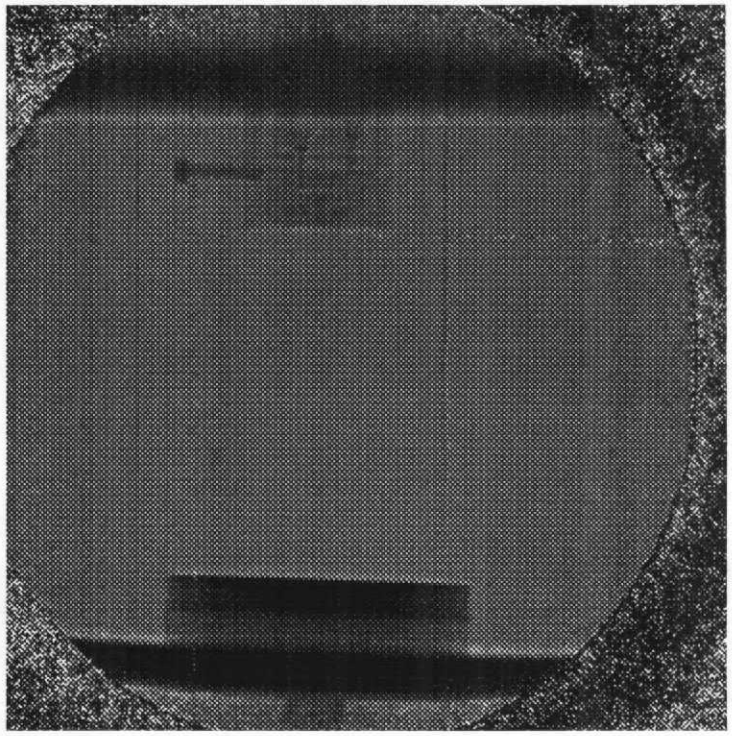
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - – Magnification
  - – Particle Background
  - – Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - – Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Fiducial Mark Calibration

- Aligns cameras to identical orientation, field of view and pixel size
- Removes pincushion, obliqueness distortion, and magnification
- Sets picture scale





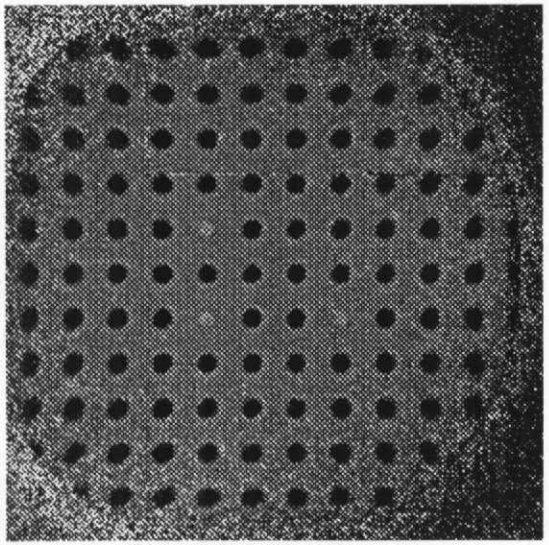
-22 22 -6 cm 6 cm

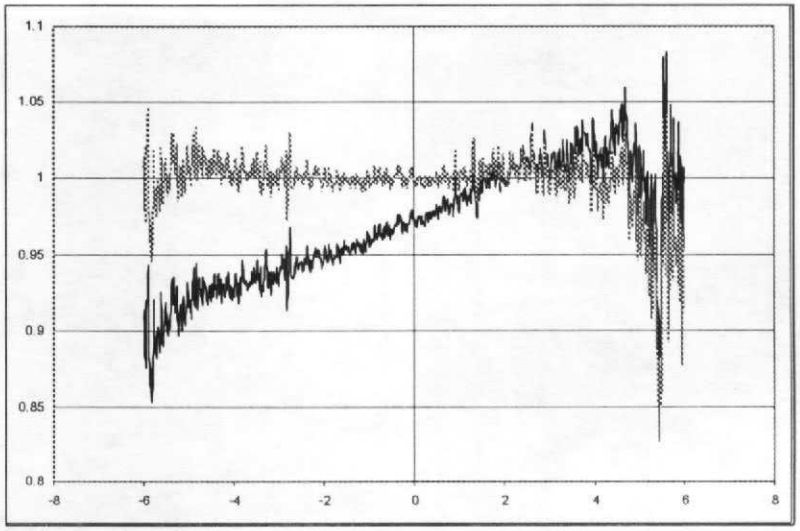
Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Proton Beam Location and Flux

- Two methods: knowledge-based and measurement-based
- Knowledge based:
  - Fit polynomial to area of picture "known to be flat"
  - Divide pic by that polynomial
- Measurement based:
  - Proton toroid for flux; 4-chamber BPM for position
  - Normalize to flux, divide by shifted Gaussian for position





Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - ✓ Location
  - ✓ Flux
- Magnetic Lens
  - ✓ Magnification
  - – Particle Background
  - ✓ Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - ✓ Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry

Areal Density Extraction

- Measured transmission depends on
  - Fixed scattering
  - Radiation length in object
  - Collimator cut angle
  - Nuclear scattering in object
  - Background scattering (Tile glow, protons)

$$t = \frac{\left[f_{Had} \bullet (1 - f_{MS})/(1 - f_{FS}) + f_{BG}\right]}{\left[1 + f_{BG}\right]}$$

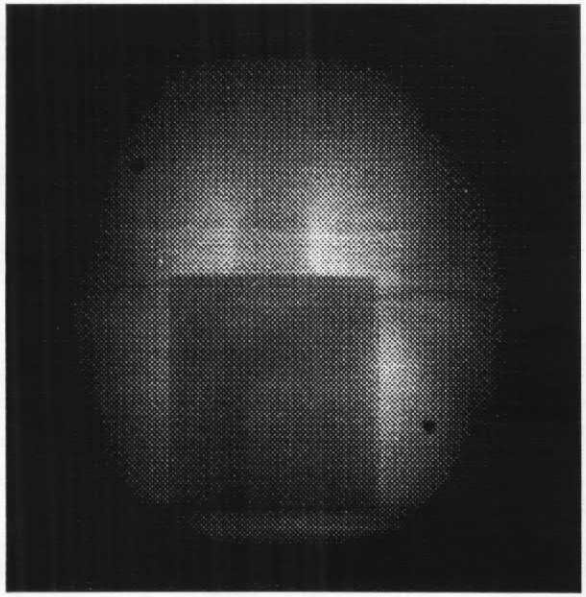
$$f_{Had} = e^{-\left(d/\lambda_H\right)}$$

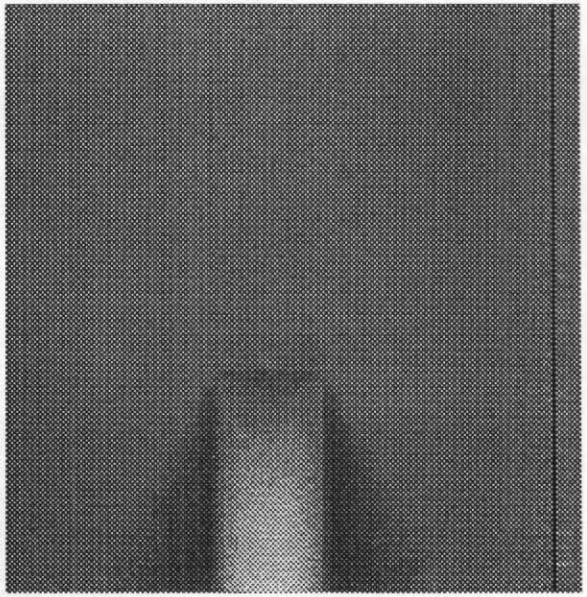
$$f_{MS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ \left(2\left(d/X_0 + R_f\right)\right)}$$

$$f_{FS} = e^{-\left(\frac{p\beta\theta_C}{14.1}\right)^2 \Big/ R_f}$$

Proton Radiography Analysis Procedure

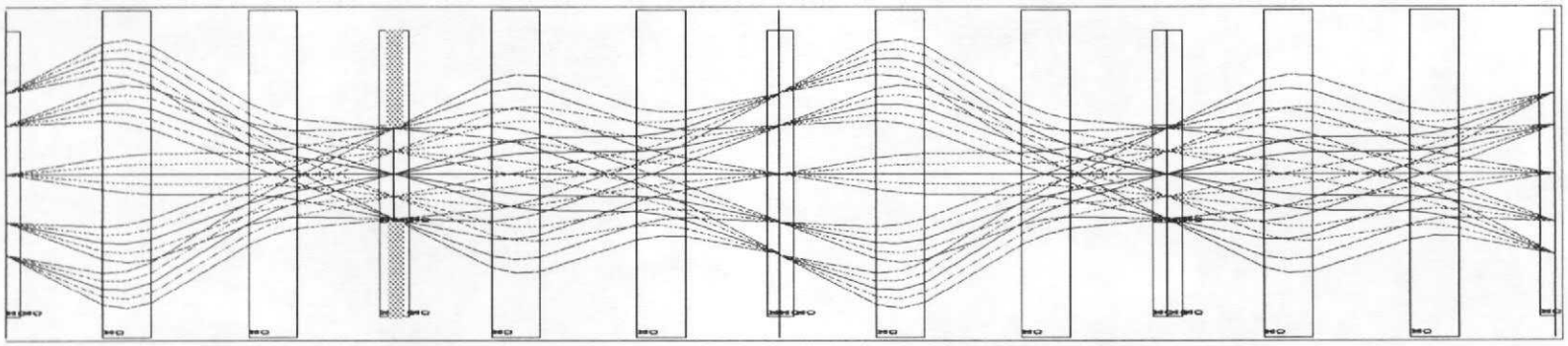
Alexander Saunders





- LANSCE Proton Radiography
- Effects to be Corrected
- Analysis Procedure
- Sample Results

Line C PRAD Apparatus



Object

Collimator 1
Typically 10 mr

Image
Station 1

Collimator 2

Image
Station 2

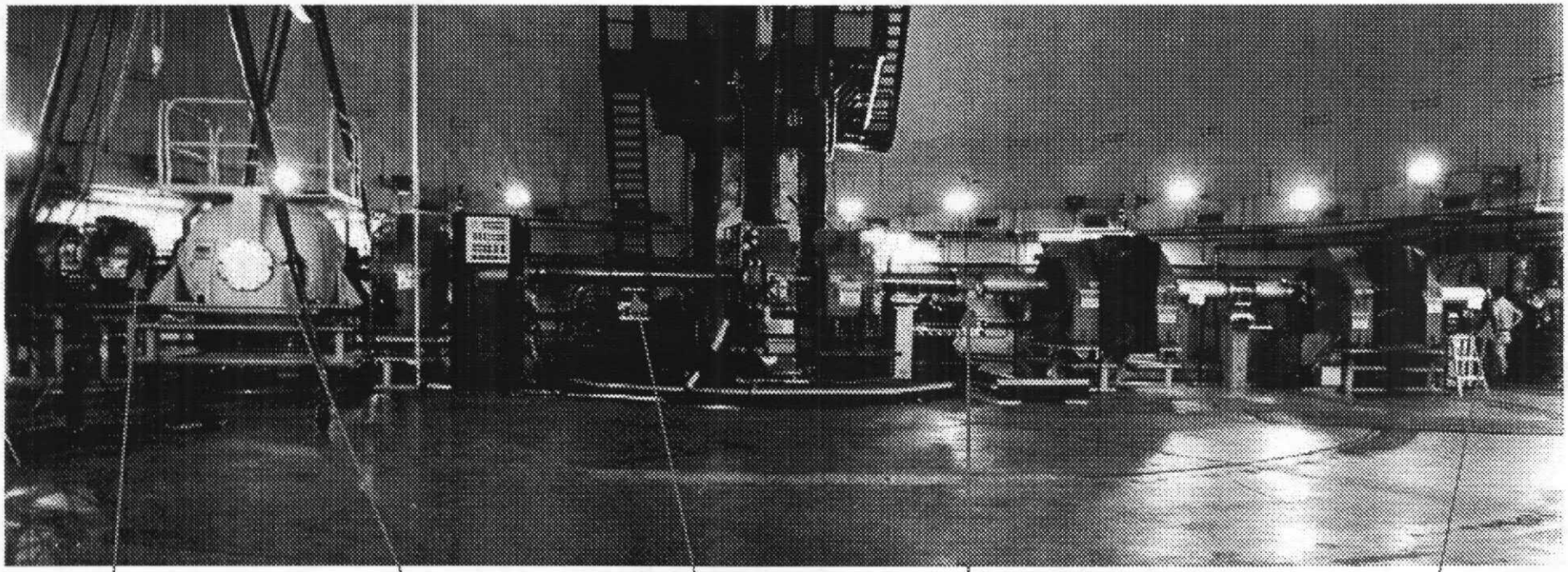
- Armored Windows
- Thin Windows
- LSO Scintillators
- Matching Lens
- Image Station 0: BPM, Calibration
- 800 MeV Protons
- Beam timing

7 frames
1600^2 pixels

5 frames
1024^2 pixels
+ 9-frame
framing camera

LANSCE 800 MeV Proton Radiography

Proton Beam →



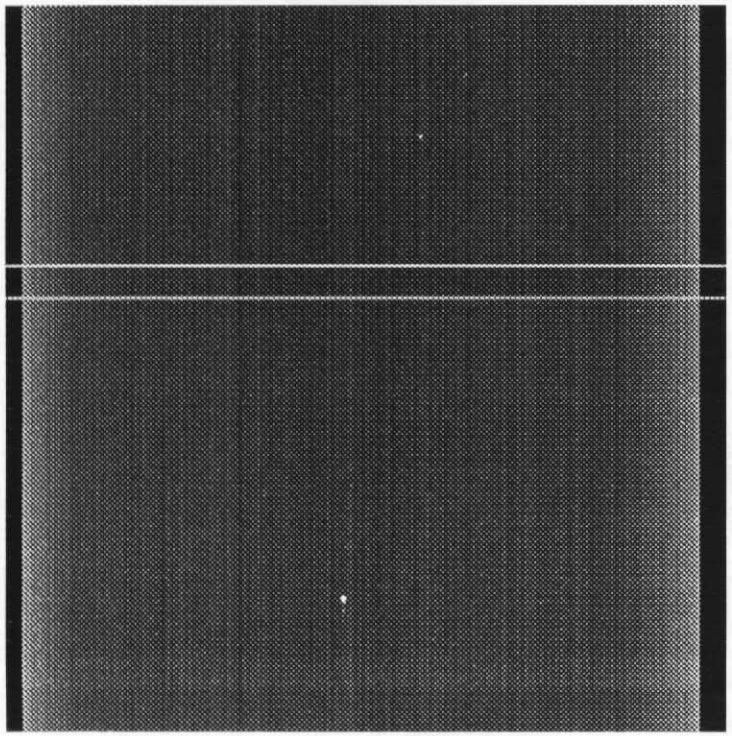
Proton Beam Line | Confinement vessel | Collimator 1 | Image Station 1 | Image Station 2

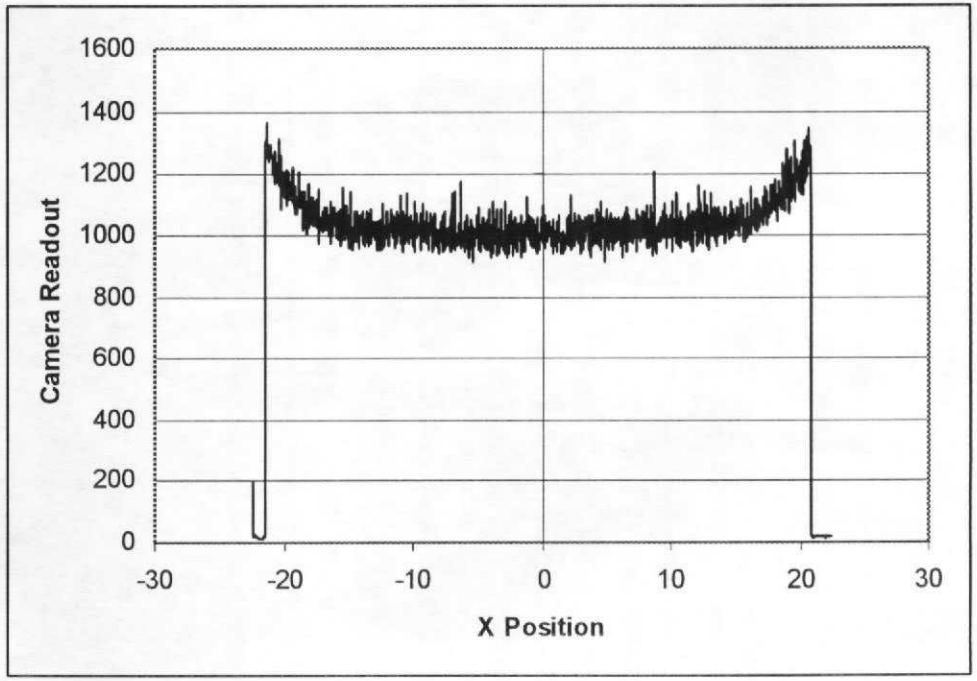
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Camera Dark Field

- Constant over hours to days
- <5% of camera signal
- Camera Temperature Dependent
- Typically Average 5 Pics





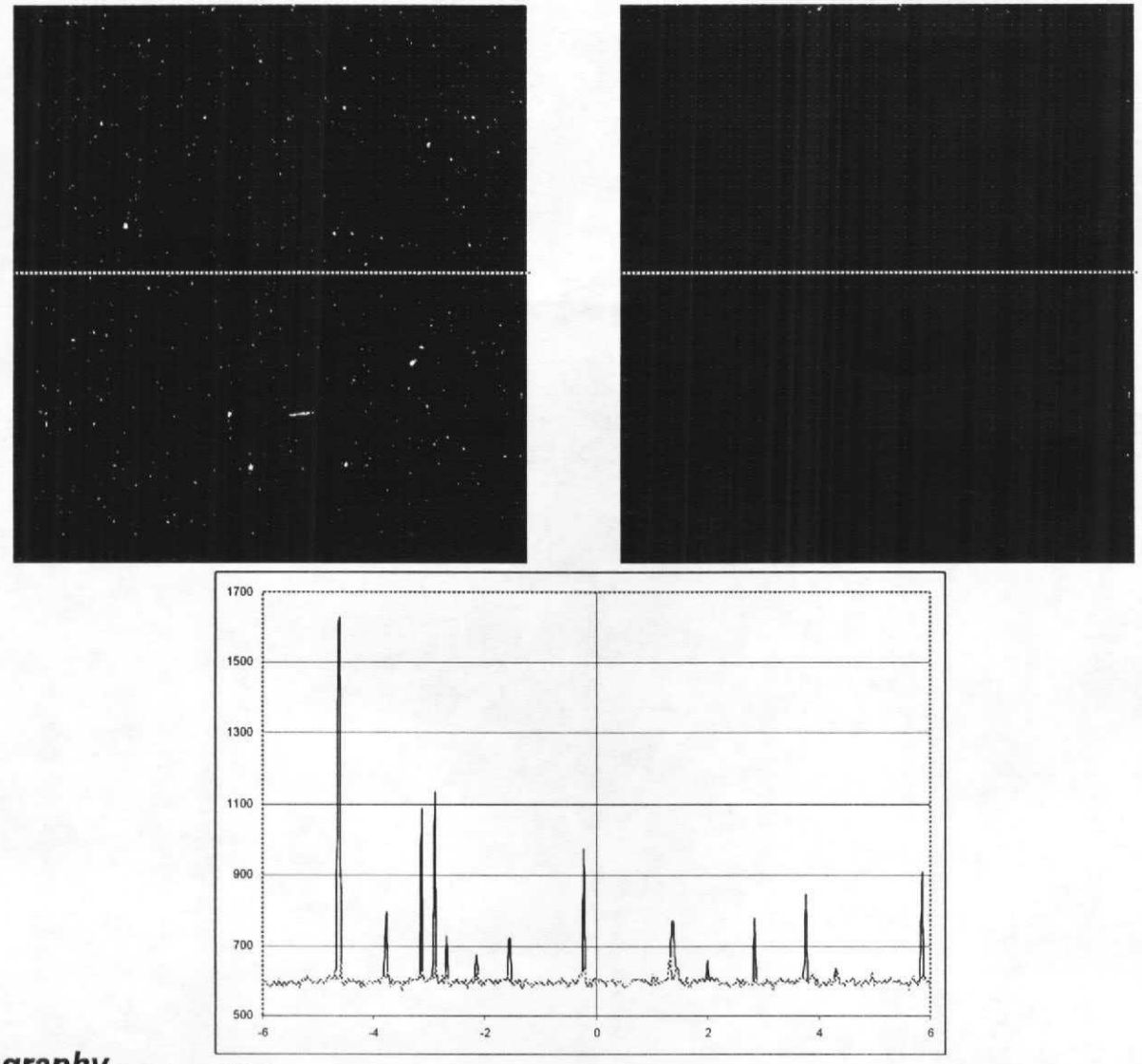
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Star Correction

- Hadronic Interactions in Camera CCD
  - Large Local Energy Deposition
  - Shielding Necessary
- Correction:
  - Smooth data
  - Chop isolated outliers
  - Multiple passes
  - Correction is limited

Star Correction

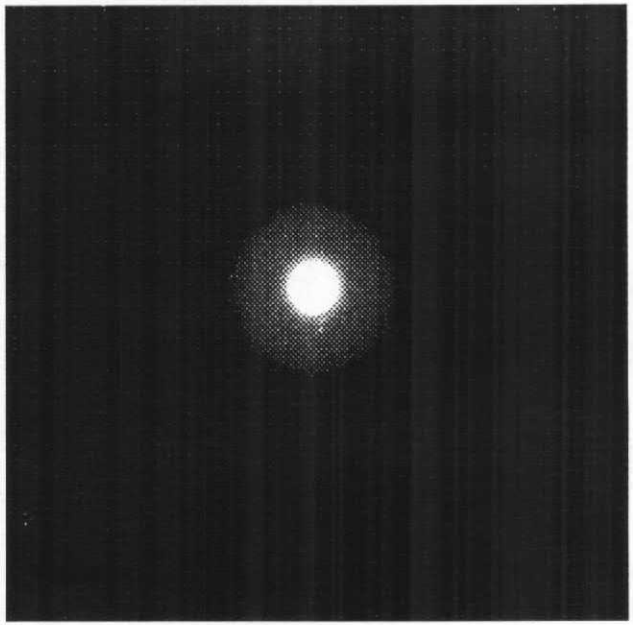


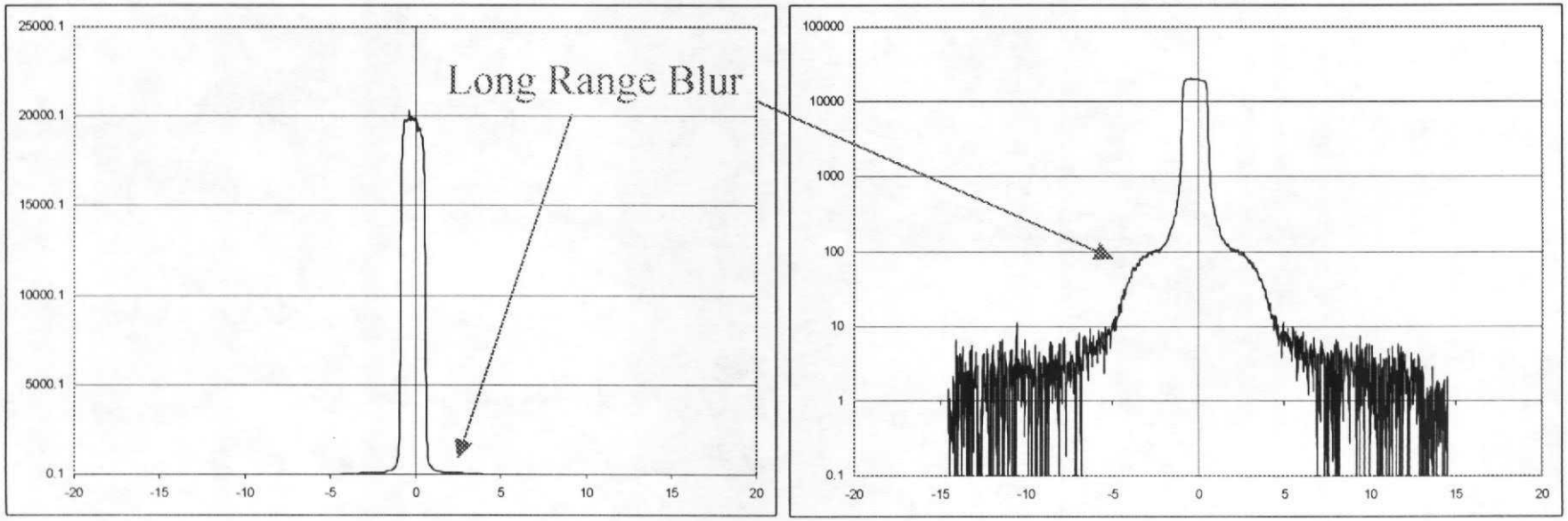
Effects to be Corrected

- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Long Range Blur

- Optical Effect in Cameras
- Some (15%) light scatters widely
- Measure blur function, unfold from data



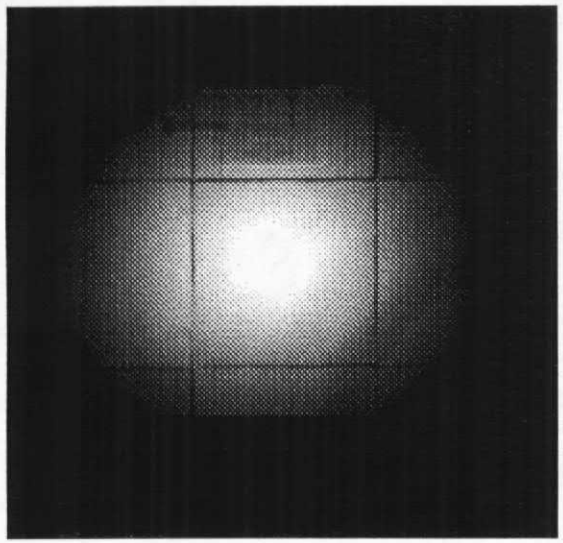


Effects to be Corrected

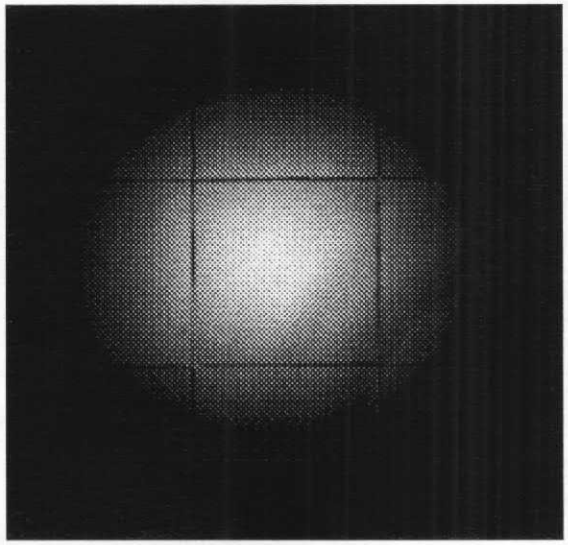
- Proton Beam
  - Beam Profile
  - Location
  - Flux
- Magnetic Lens
  - Magnification
  - Particle Background
  - Distortion
- Optical/Camera
  - ✓ Dark Field
  - Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - Orientation/Alignment
- Areal Density from Transmission
  - Collimator Angle Cut
  - Fixed Scattering
  - Background Signal
- Volume Density from Areal
  - Cylindrical Symmetry

Beam Profile Flattening

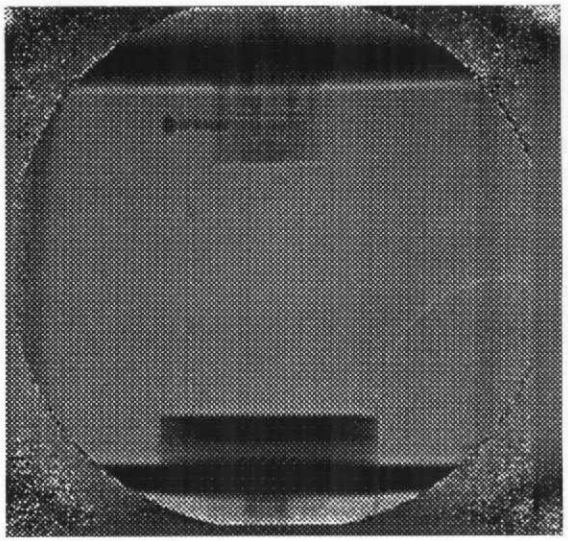
- Measure beam profile with no object in place
- Accounts for uneven beam and fixed pattern noise
- Result: "Flattened" picture



Divided by



Equals



Effects to be Corrected

- Proton Beam
  - ✓ Beam Profile
  - – Location
  - – Flux
- Magnetic Lens
  - – Magnification
  - – Particle Background
  - – Distortion
- Optical/Camera
  - ✓ Dark Field
  - ✓ Fixed pattern Noise
  - ✓ Long Range Blur
  - ✓ Stars
  - – Orientation/Alignment
- Areal Density from Transmission
  - – Collimator Angle Cut
  - – Fixed Scattering
  - – Background Signal
- Volume Density from Areal
  - – Cylindrical Symmetry