Beam Diagnostics for the Detection and Understanding of Beam Halo

Kay Wittenburg, DESY, MDI

Abstract
A general view that has been recently reached by different methods of halo diagnostics of high brightness hadron beams will be given....

And a request from our conveners:
1. "… what are really the demands from beam dynamics…"
2. "Please contribute something to the discussion session"

Kay.Wittenburg@desy.de

Outline

- Halo diagnostic:
  - **What is Halo?**
  - Halo Quantification
  - Halo Measurements
    - Some examples

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1) The demands from beam dynamics:
"The definition of halo is not important. What really matters is the source of halo"
7th ICFA Mini-Workshop on high intensity high brightness hadron beams; summary halo working group; 1999

What is Halo?

Sources of halo are:

- Space charge forces of the beam
- Mismatch of beam with accel. optics
- Beam beam forces
- Instabilities and resonances
- RF noise
- Scattering (inside beam, residual gas, macroparticles, photons, obstacles (stripping foil, screens etc.)
- Nonlinear forces, e.g. aberrations and nonlinearities of focusing elements
- Misalignments of accelerator components
- Electron clouds
- Beam energy tails from uncaptured particles
- Transverse-longitudinal coupling in the RF field
- etc.

What is Halo?

"It is very difficult to give a simple definition of the "halo". It could be a sole beam characteristic or a beam accelerator system characteristic linked to the potential losses it can produced. It could be defined by a number of particles (in the halo) or a size (of the halo). It could be described in the geometric space or in the phase-spaces… " N. Pichoff et al, IPAC14

…it became clear that even at this workshop (summary HALO 03) **a general definition of "Beam Halo" could not be given,** because of the **very different requirements** in different machines, and because of the **differing perspectives** of instrumentation specialists and accelerator physicists.

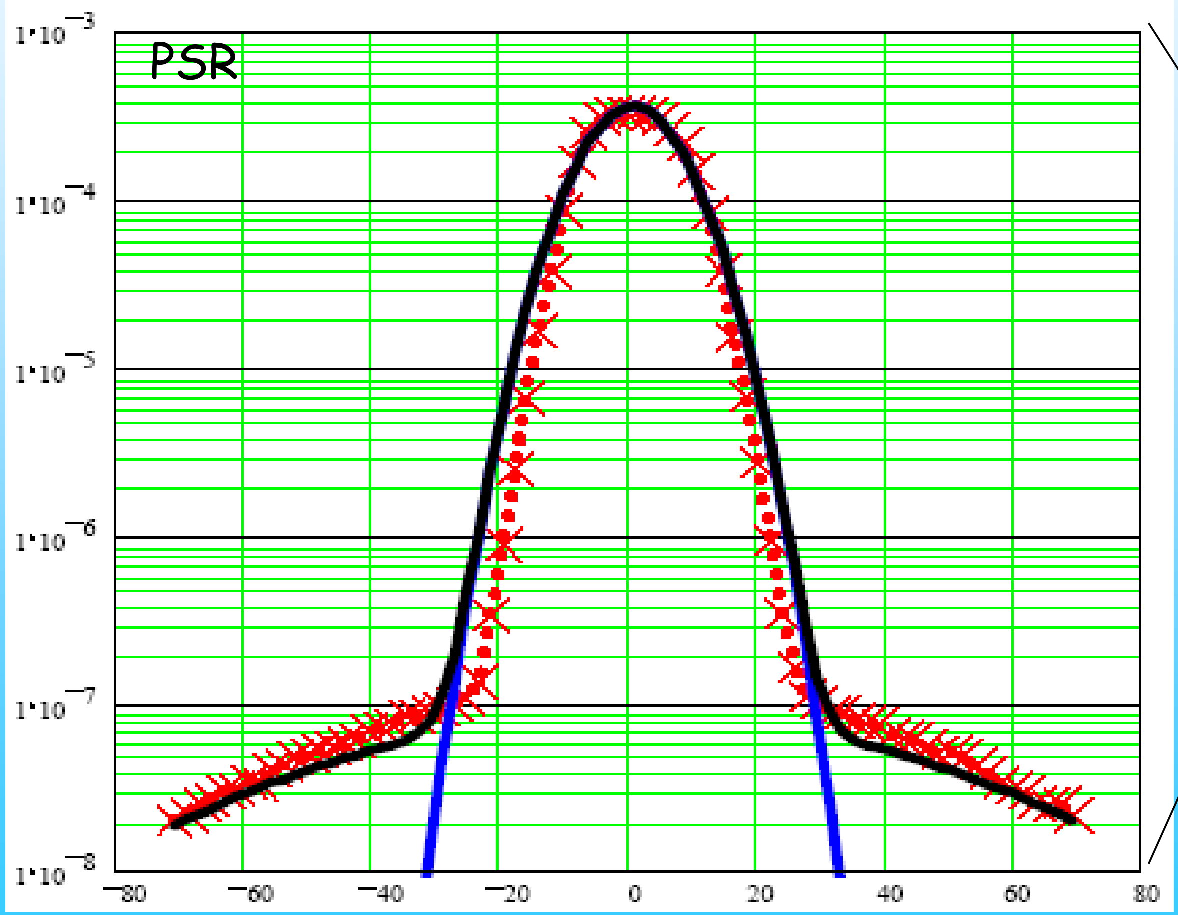
From the diagnostics point of view, one thing is certainly clear – by definition **halo is:**

- Low density and therefore
- Difficult to measure…

… it is bigger on the inside.; Dr. Who, 1963 - , BBC

What is Halo?

From the diagnostics point of view, one thing is certainly clear – by definition halo is low density and therefore difficult to measure…

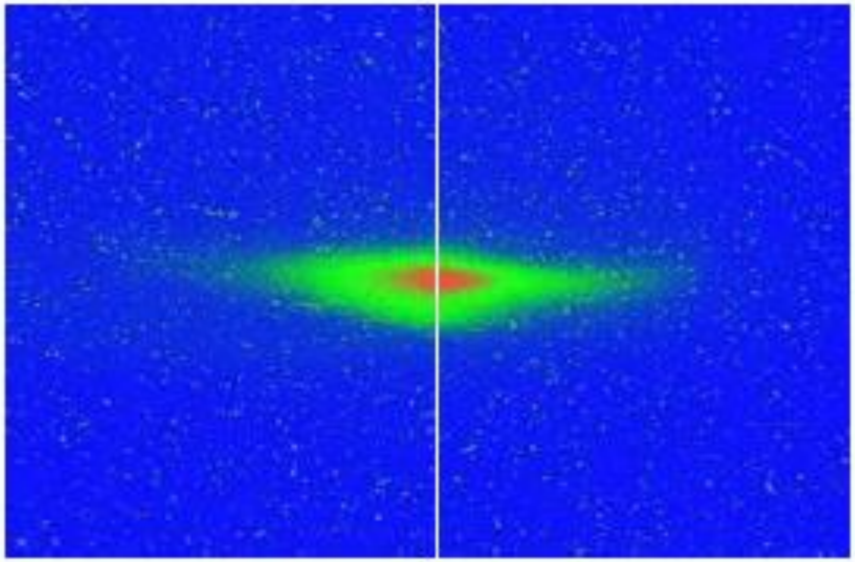


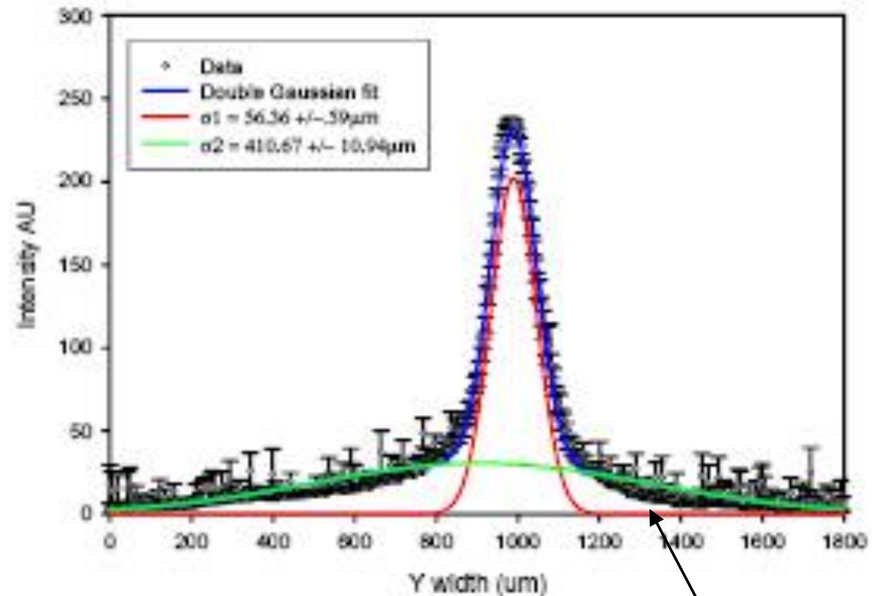
Halo measurements require **high dynamic range instruments**

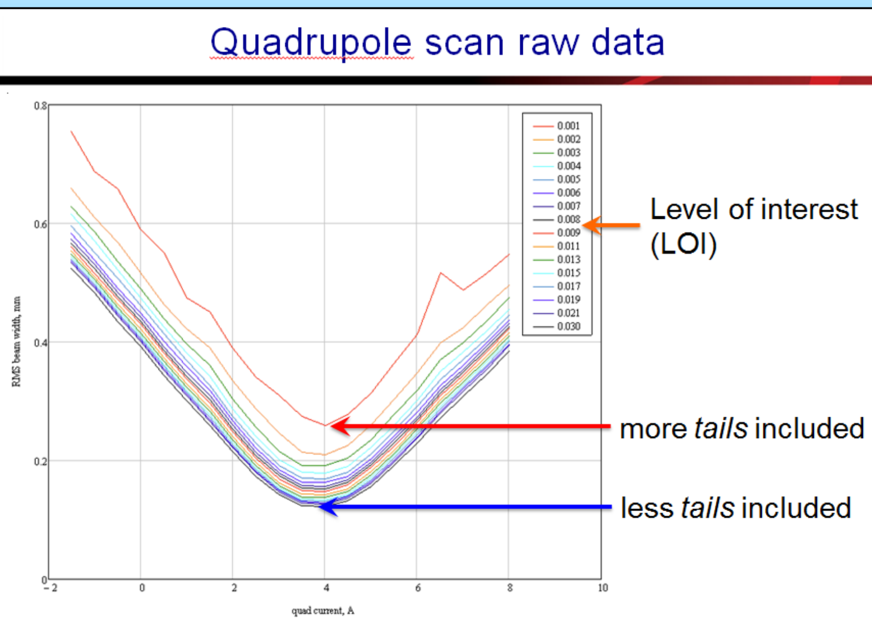
Dynamic range > 10^5

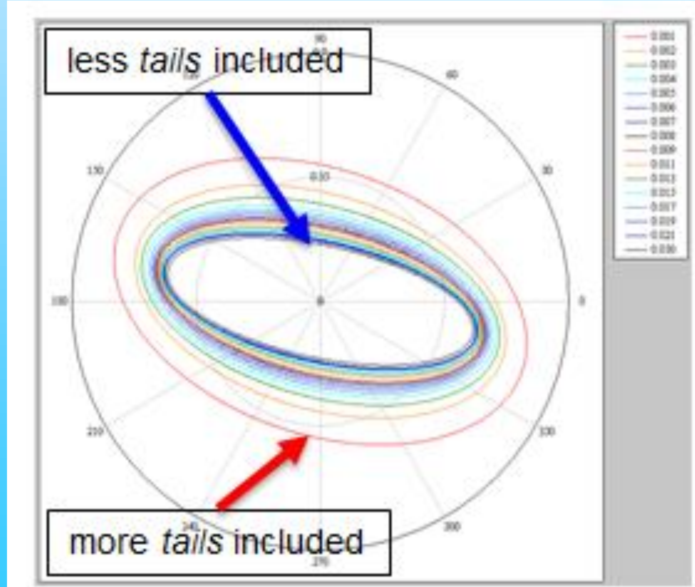
A. Browman, et al., PAC03

What is Halo?









That's not halo, that's a tail! Dynamic range $<10^3$

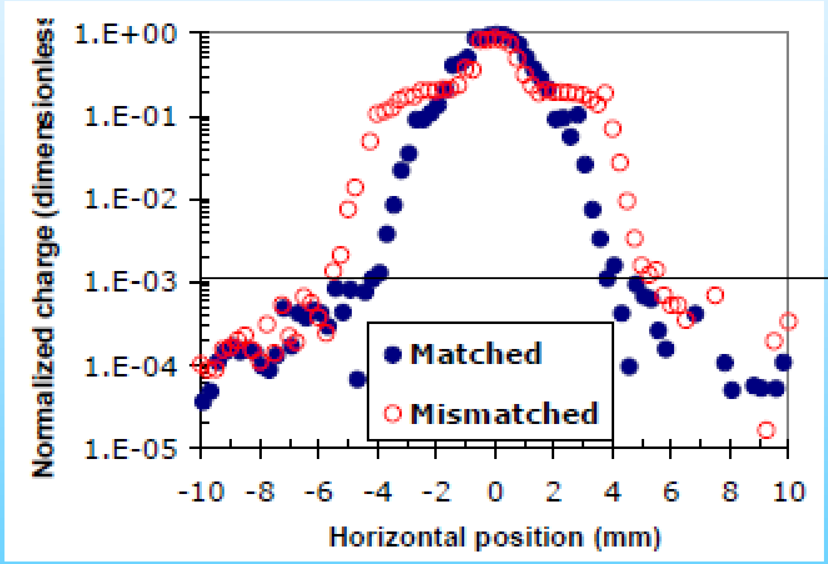
or ≤ 12 bit

What is Halo?

Emittance:

2) Contribution to discussion:
a) Emittance has nothing to do with Beam "Halo"

Mismatch:



Tails, **measured by profile monitors**

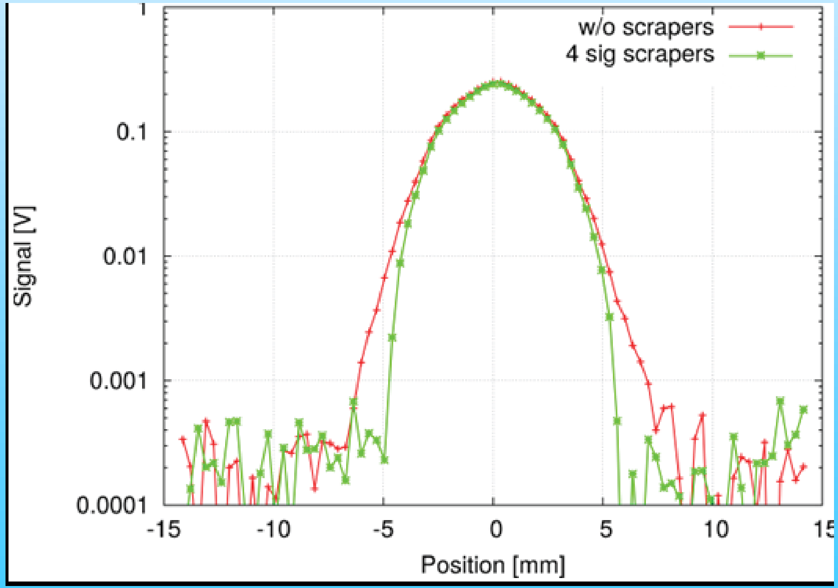
Halo, **measured by halo monitors**

T. P. Wangler, HALO03

2) Contribution to discussion:
b) Is "mismatch" a topic related to halo or to profiles?

What is Halo?

- **Unwanted!**
  "In the high power proton accelerator …, even small ratio of the beam loss such a **beam halo cause serious radiation dose**. … . The key issue to evaluate the high intensity **beam quality is the suppression of the transverse beam halo.**"



Scrape it away! (not so easy in circular machines)

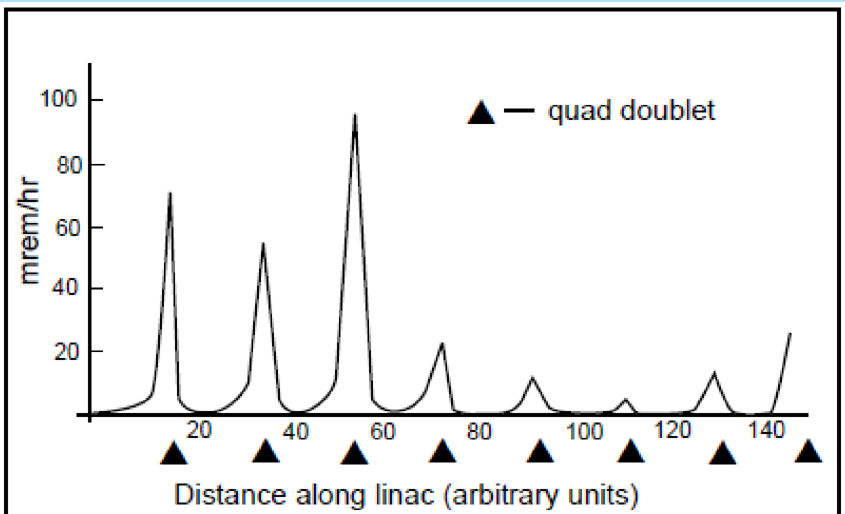
Scraped beam profile in the vertical direction.
Red lines are vertical beam profile without setting scrapers, green lines are beam profile with setting scrapers.

TRANSVERSE H- BEAM HALO SCRAPER SYSTEM IN THE J-PARC L3BT, K. Okabe et al, IPAC2014

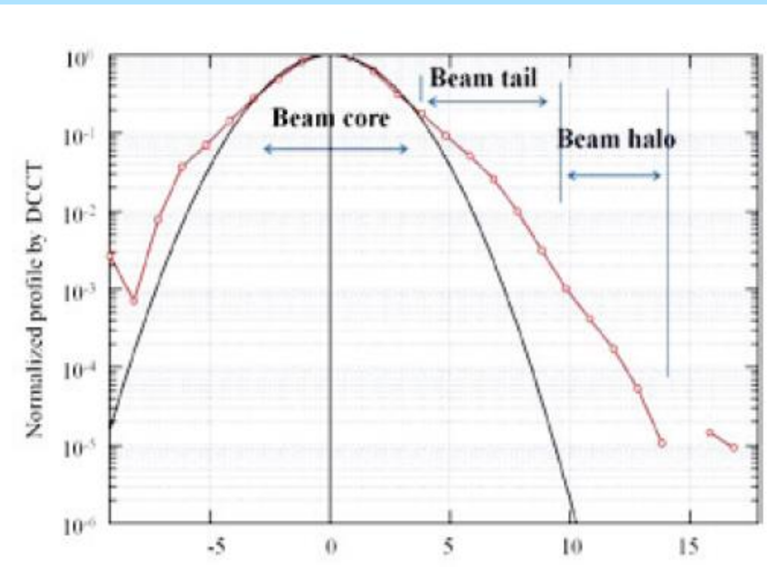
What is Halo?

- The hands-on limit has been found approximately between 0.1 to 1 W/m. (1 W/m corresponds to 1 GeV·nA/m).
- Assuming losses within 1/2 β-period ($L_\beta \approx 20$ m) and a beam-power of P_B (= 1 MW)
- $H_W \equiv 1\ \mathrm{W/m} * \frac{1}{2} L_\beta / P_B = 1\mathrm{W/m}*10\ \mathrm{m}/1\mathrm{MW} = 10^{-5}$ (>5σ)
- Constant loss of 10ppm of your full beam is enough to reach the activation limit! **<u>THAT'S HALO</u>**
- This formula defines if you need a Profile or Halo monitor

R.A. Hardekopf; Halo Workshop 1999



activation in the LANSCE tunnel after a long run period at near 1 MW beam power,



M. Yoshimoto, IPAC12

What is Halo?

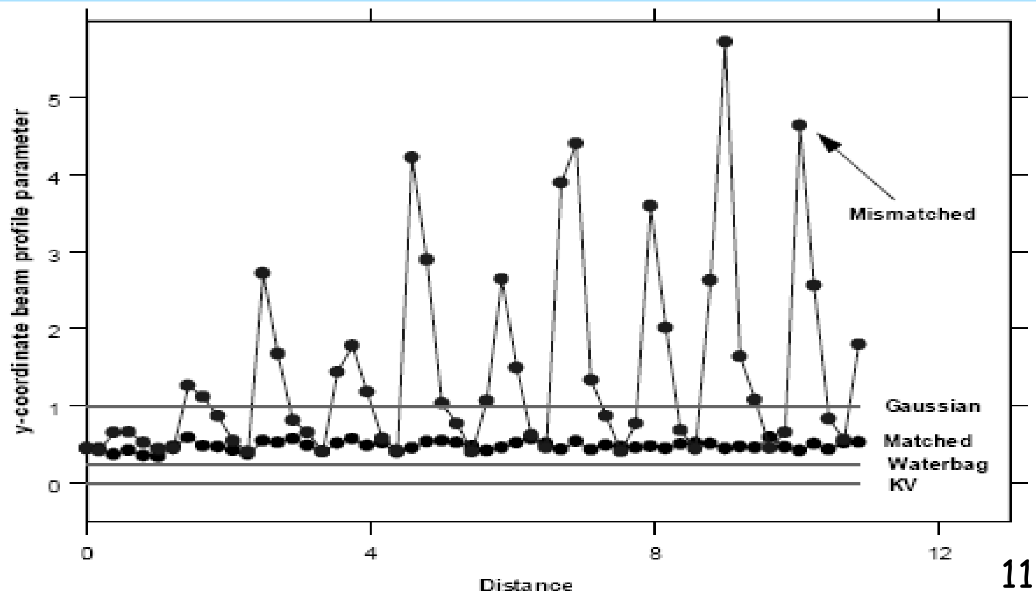
It is important to have a definition of halo in 1D spatial projection for which experimental measurements are easier to obtain.

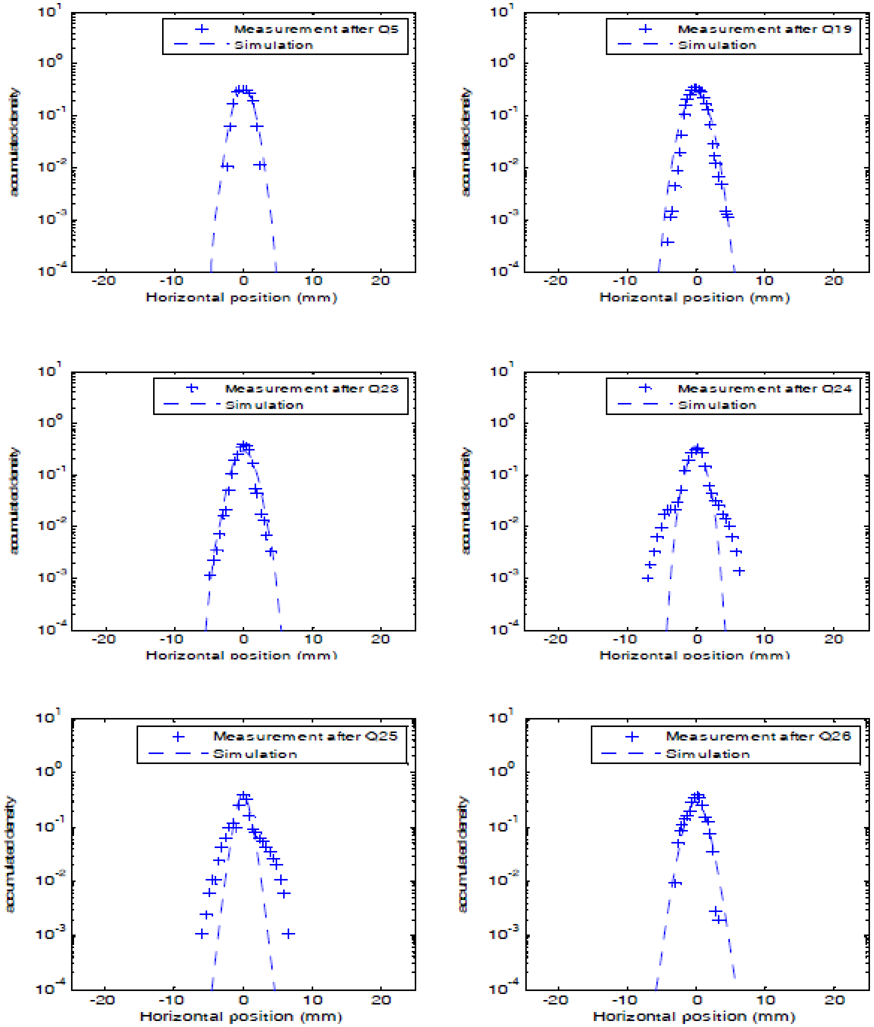
However, because of the beam's phase-space rotations, the observed halo in 1D projection oscillates. For example, at some locations the halo may project strongly along the **spatial coordinate** and only weakly along the **momentum coordinate**, while at others the reverse is true, and the halo can be hidden from the spatial projection. Therefore one should extend the 1D work to obtain a halo parameter suitable for description of beam halo in **whole phase space**. This lead naturally to the *kinematic invariants* and are the consequence of the linear forces and symplectic structure imposed by **Hamilton's equations**.*

*__Beam halo definitions based upon moments of the particle distribution__ C. K. Allen and T. P. Wangler Phys. Rev. ST Accel. Beams **5**, 124202 (2002)

Used mainly in simulations

"The excursions above the Gaussian level indicate a large halo."

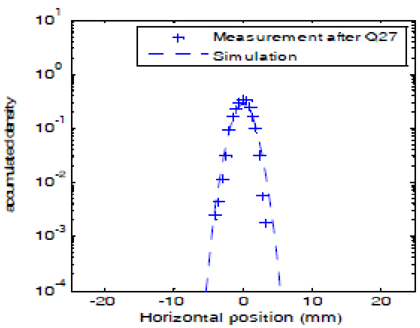




Simulation and (wire-Scanner) measurements at the beam transport line at the end of the IHEP RFQ.

Hongping Jiang et al, IPAC14

See also J. Qiang et al, PRST-AB 5, 2002



From the Figure 2 we can see in the most locations the simulations can properly reproduce the beam profiles, and there are a little halo particles in two locations. That means the beam in the phase space is not elliptic symmetry.

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  - **Halo Quantification**
  - Halo Measurements
    - Some examples

HALO QUANTIFICATION

- There is **no clearly defined separation** between the halo, tail and the main core of the beam. Consequently, there has been some difficulty identifying a suitable quantitative measure of the halo content of a beam in a model-independent way.
- **Methods have been developed, and computationally studied (by simulations), to characterize beam halo.**

1) **Kurtosis**
2) **Ratio of halo to core**
3) **Ratio of beam core to offset**
4) **The Gaussian area ratio method**

HALO QUANTIFICATION

1) Kurtosis

This method is based on analyzing the **fourth moment of the beam profile.** The kurtosis is a measure of **whether a data set is peaked or flat relative to a normal (Gaussian) distribution**.

$$k \equiv \frac{\left\langle (x - x_0)^4 \right\rangle}{\left\langle (x - x_0)^2 \right\rangle^2} - 2$$

Sensitive to tails!

Distributions with high kurtosis have sharp peaks near the mean that come down rapidly to heavy tails. An important feature of such quantifiers is that they are **model independent** and rely only on the characteristics of the beam distribution itself.

C. K. Allen and T. P.Wangler, PRST-AB Vol.5, 124202 (2002)

Might be not so well suited for us instrumental specialists.

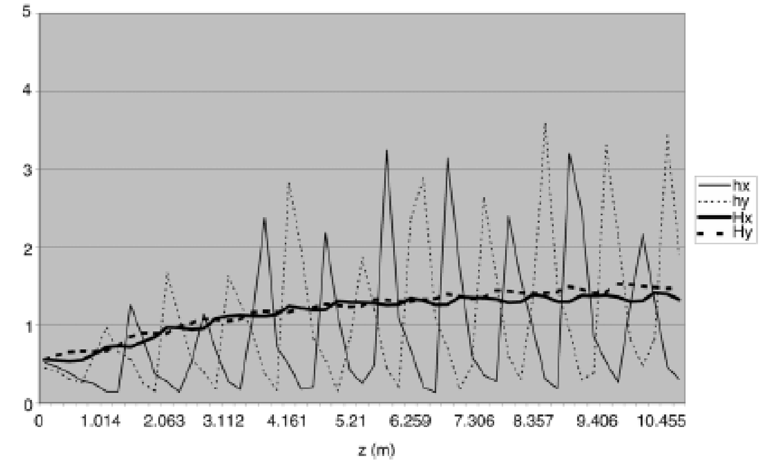
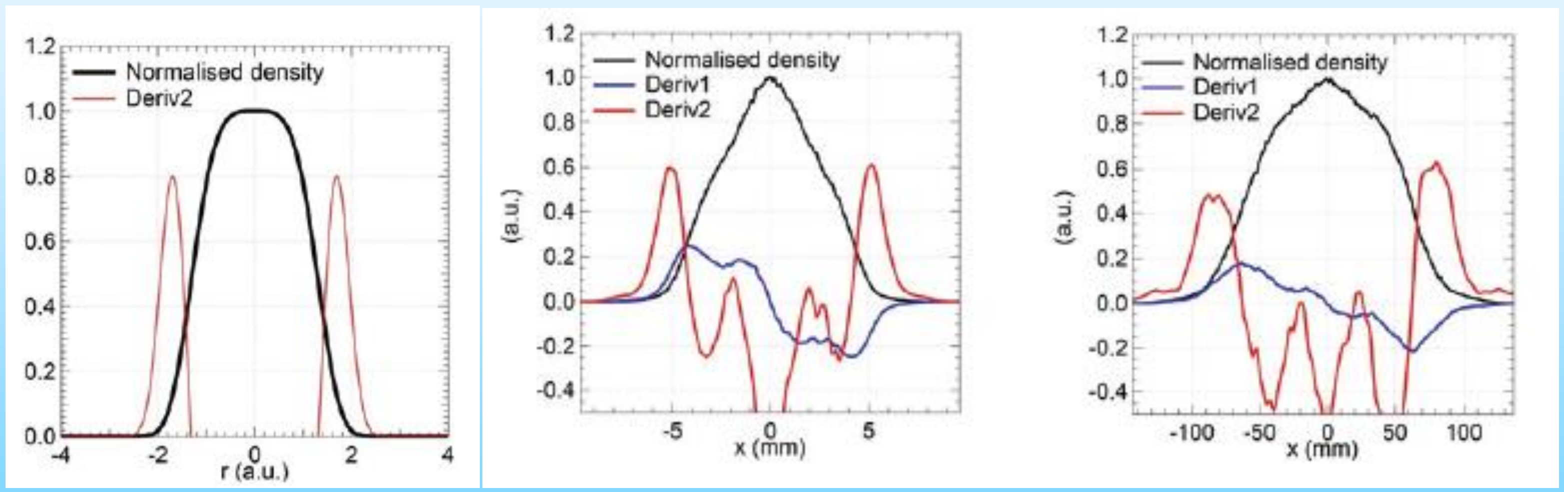


FIG. 2. rms envelopes and halo parameters for the quadrupole mismatch.

HALO QUANTIFICATION

2) Ratio of halo to core:

a) Define core-halo limit: The core-halo limit can be equivalently defined as **the location where there is the largest slope variation in the density profile**, i.e. where the density second derivative is maximum. A pure Gaussian profile with σ RMS has a halo starting from √3*σ, containing thus 8.3% particles of the beam.

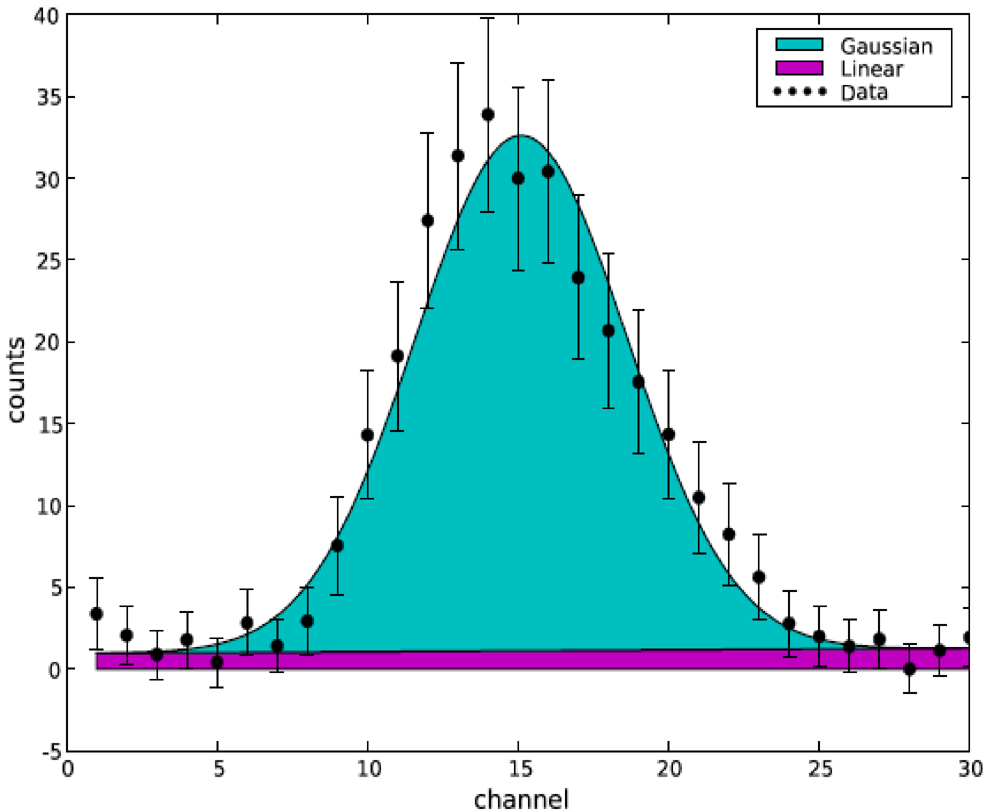


P.A.P. Nghiem et al, IPAC2014

Very sensitive to tails!

HALO QUANTIFICATION

3) Ratio of beam core to offset:



J. Amundson *et al.*, NIM A570 (2007)

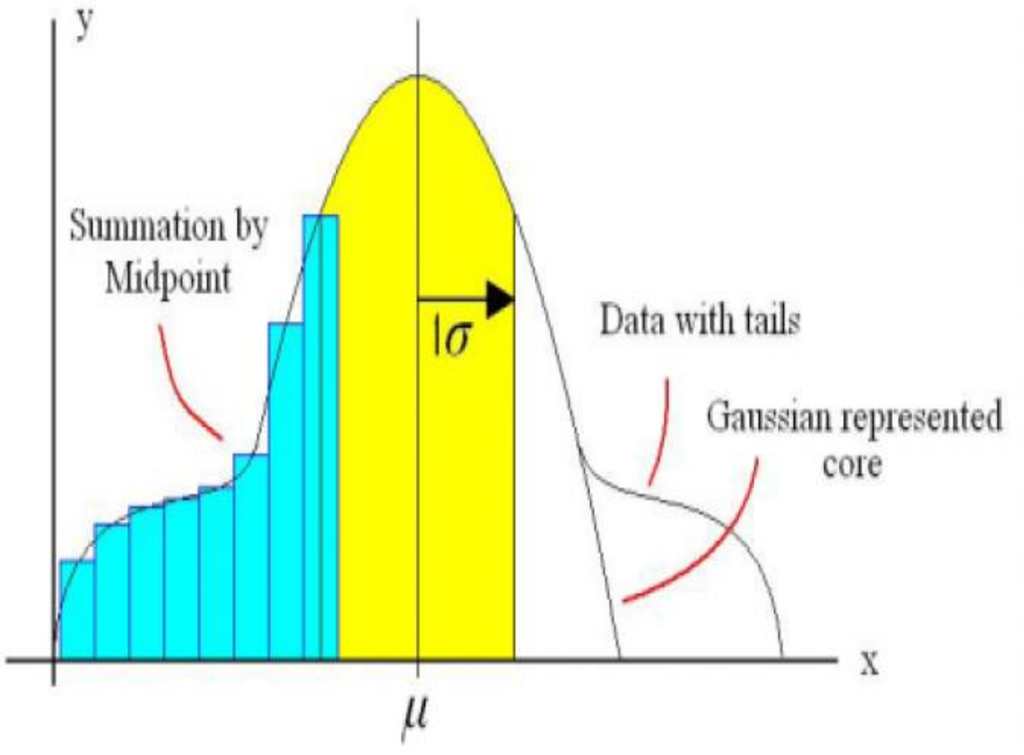
Fit the raw data to the function:
$f(x) = g(x) + l(x)$;
where
$g(x) = N \exp -(x - x_0)^2/(2\sigma^2)$
and
$l(x) = c_0 + c_1 x$
The two components of f(x) can be thought of as the Gaussian core g(x) and non-Gaussian tails l(x) of the beam distribution. Defining
$L = \int_{detector} l(x)dx$
and
$G = \int_{detector} g(x)dx$
we can now characterize the beam shape by the ratio L/G. A perfectly Gaussian beam will have L/G = 0, whereas a beam with halo will have L/G > 0.

Sensitive to tails and halo

HALO QUANTIFICATION

4) The Gaussian area ratio method:

Unlike the Kurtosis method, this method is not as sensitive to outlying particles but was found to be more useful for experimental data. The Gaussian area ratio method attempts to quantify the "non-Gaussian" component of the beam profile. After the data is filtered, it is fitted to a Gaussian of the form:



$f(x) = A \exp(-(x-x_0)2/(2\sigma^2))$

In order to represent the core, a Gaussian fit is performed on the top (90 percent) of the profile since most profiles greatly resemble Gaussian's in this region of the beam core. Dividing the total area by the area under the Gaussian outside **some σ** gives a ratio of the halo to the core and, therefore, a quantitative measure of the halo present.

D.A. Bartkoski *et al.*, EPAC2006

2. Gaussian representing the tail, residual=halo

HALO QUANTIFICATION

Halo characterization by one of the three quantities:
Kurtosis, PHS and PHP (**P**ercentage of **H**alo **S**ize and **P**ercentage of **H**alo **P**articles):

$$PHS = 100\frac{Halo\ size}{Total\ beam\ size}$$

$$PHP = 100\frac{Nb\ of\ Particles\ in\ the\ Halo}{Total\ Nb\ of\ particles}$$

Ref.: N. Pichoff et al, IPAC2014:
"*K* has less "physical" meaning but is more robust with a low number of particles. It is then very convenient in a design optimization process where low particle numbers are used. *PHS* and *PHP* have more physical meanings. Nevertheless, they are a more appropriate with a large number of particles. They are well suited to finalize and benchmark a design."

Note1: Tell the diagnostic specialists what you want to be measured! AND tell the beam dynamics what you have measured!
Note 2: Powerful simulations are useless if significant physical mechanisms are missing or if the beam input distribution is unrealistic.
Note 3: A measurement always contains instrumental effects!!!! => Good halo measurement need a resolution of << 10^{-2} of the beam size and a noise level of <10^{-5} of the beam peak.

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Halo Measurements

- The focus of the **accelerator physicists** is on designing and operating their machines to minimize this halo.

- The focus of the **collimation experts** is on cleanly and efficiently disposing of this halo as it appears, a consequence of the clean and efficient disposal being that useful diagnostic information is often lost, buried in the collimators.

- The focus of the **instrumentation specialists** is twofold;
  - ✓ to provide information useful to the accelerator physicists in their machine tuning efforts to avoid halo formation, and
  - ✓ to provide direct measurement of halo.

Definition of halo diagnostics: Classification into three categories.

1. Devices that directly measure halo and halo evolution. Examples are Wire Scanners and dedicated Halo Monitors.
2. Devices that contribute to the diagnosis of machine conditions that cause halo formation. An example would be a tune measurement system.
3. Devices that measure the effects of halo development. An example would be the loss monitor system.

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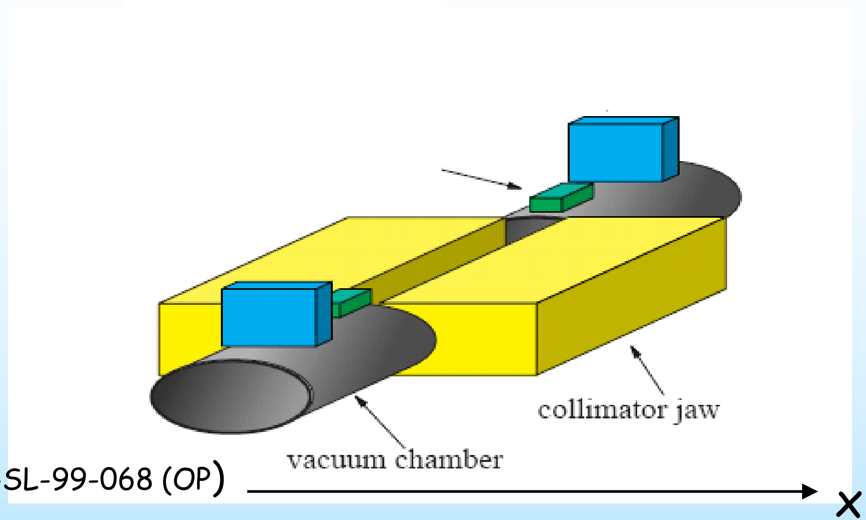
Halo scraping by collimators



CERN-SL-99-068 (OP)

In a synchrotron one jaw will scrape both sides of the beam distribution (β-oszillation)
=> meas. symmetric halo
Such a halo scan yields information about number of particles which oscillate with an amplitude larger than the position of the collimator = Halo Scraping

TRANSVERSE BEAM TAILS DUE TO INELASTIC SCATTERING
H. Burkhardt, I. Reichel, G. Roy, CERN-SL-99-068 (OP)

TRANSVERSE H- BEAM HALO SCRAPER SYSTEM IN THE J-PARC L3BT
K. Okabe et al., IPAC14

Figure 2: Picture of the new scraper head with the thin carbon foil. The carbon foil is mounted by the metal foil folder.

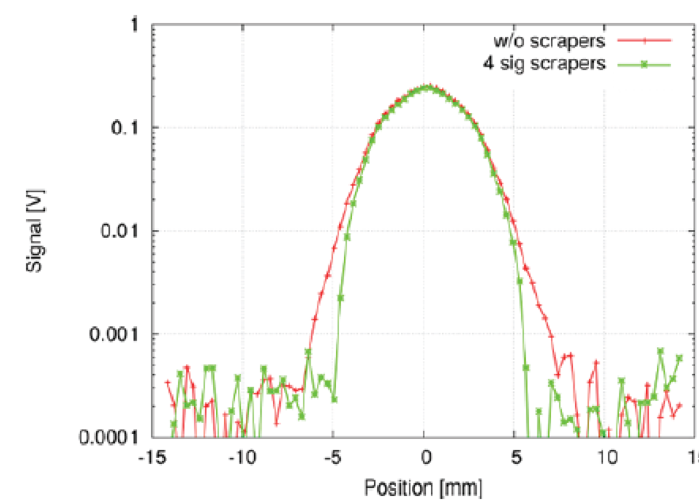
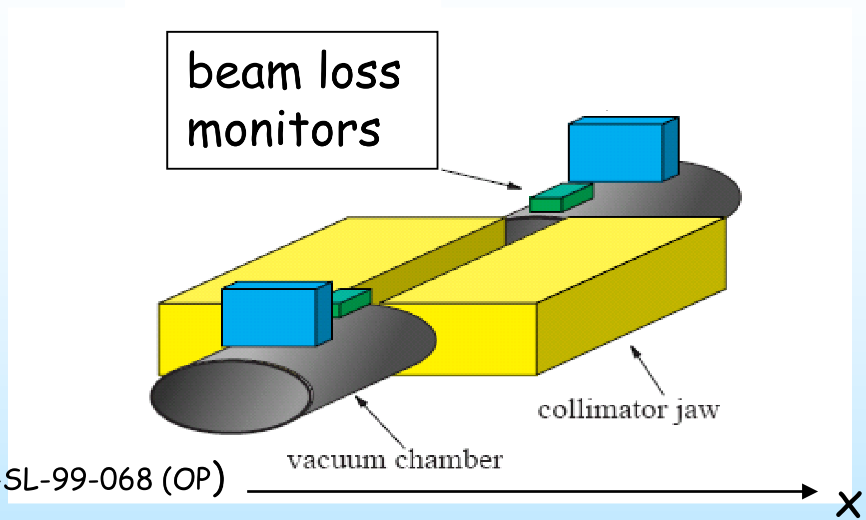


Figure 4: Scraped beam profile in the vertical direction. Red lines are vertical beam profile without setting scrapers, green lines are beam profile with setting scrapers.

Halo scraping by collimators



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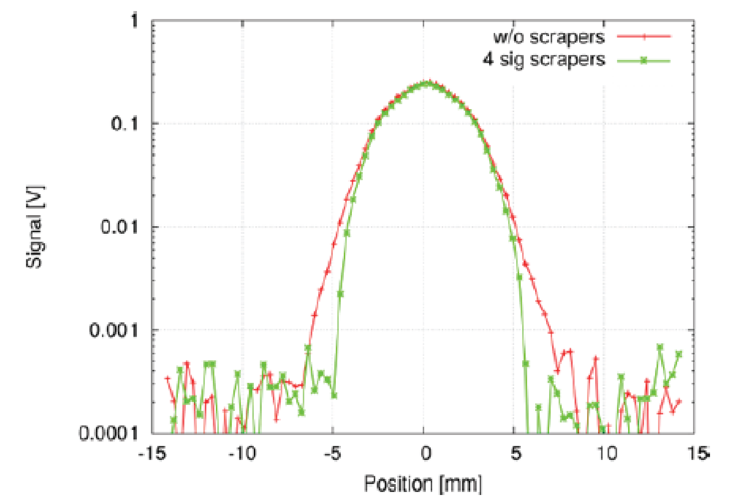

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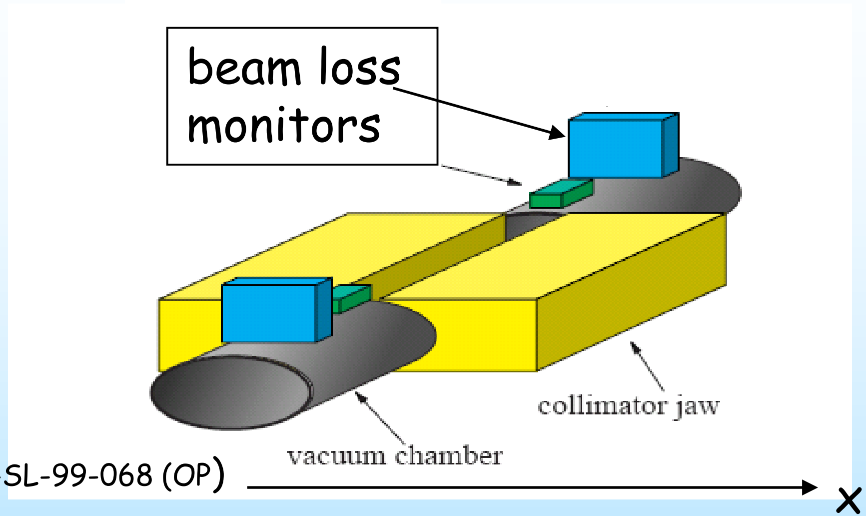

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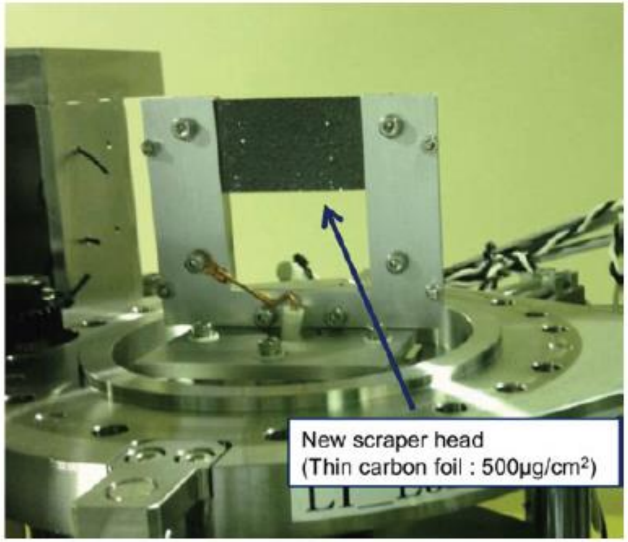

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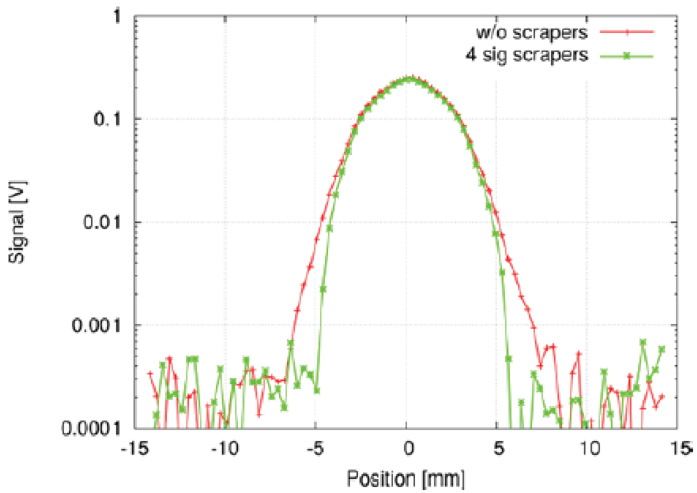

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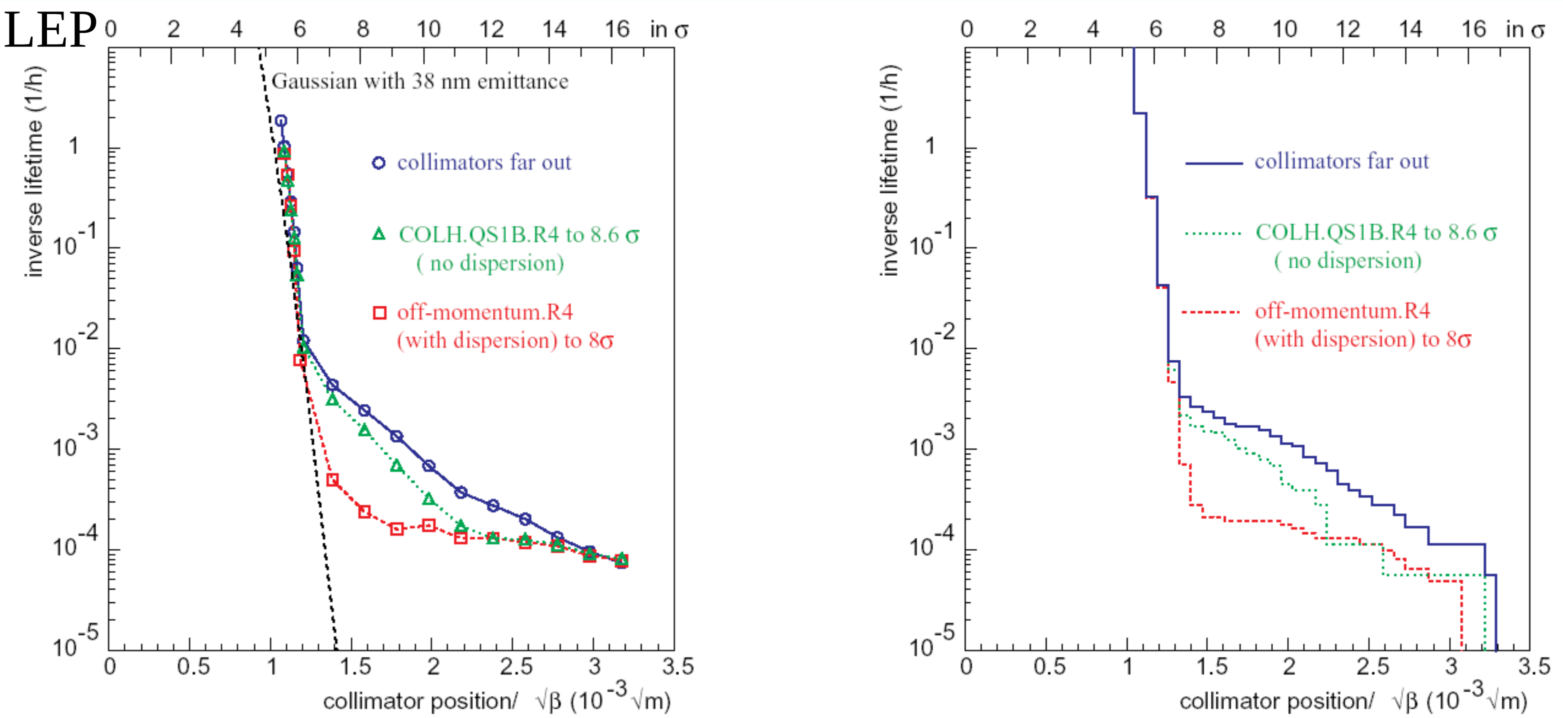
Halo Measurement = Scraping by collimators + BLM



Measurement (left) and simulation (right) of the horizontal beam tails for a beam energy of 80.5 GeV and for different collimator settings at LEP. The simulation is the result of tracking particles after Compton scattering on thermal photons (black body radiation of vacuum chamber).

Measurements were performed by moving one jaw of a collimator closer to the beam in steps. Beam current and beam size measurements were recorded for each collimator setting. The collimators were moved closer until significant lifetime reductions were observed. Lifetimes calculated from beam currents for these points were used to calibrate the loss monitors. This allows to give loss rates directly in terms of equivalent lifetimes

Halo scraping by collimators

Concept

The hollow electron beam collimator is a cylindrical, hollow, magnetically confined, possibly pulsed electron beam overlapping with the beam halo (Fig. 3). Electrons enclose the circulating beam. Halo particles are kicked transversely by the electromagnetic field of the electrons. If the hollow charge distribution is axially symmetric, the core of the circulating beam does not experience any electric or magnetic fields.

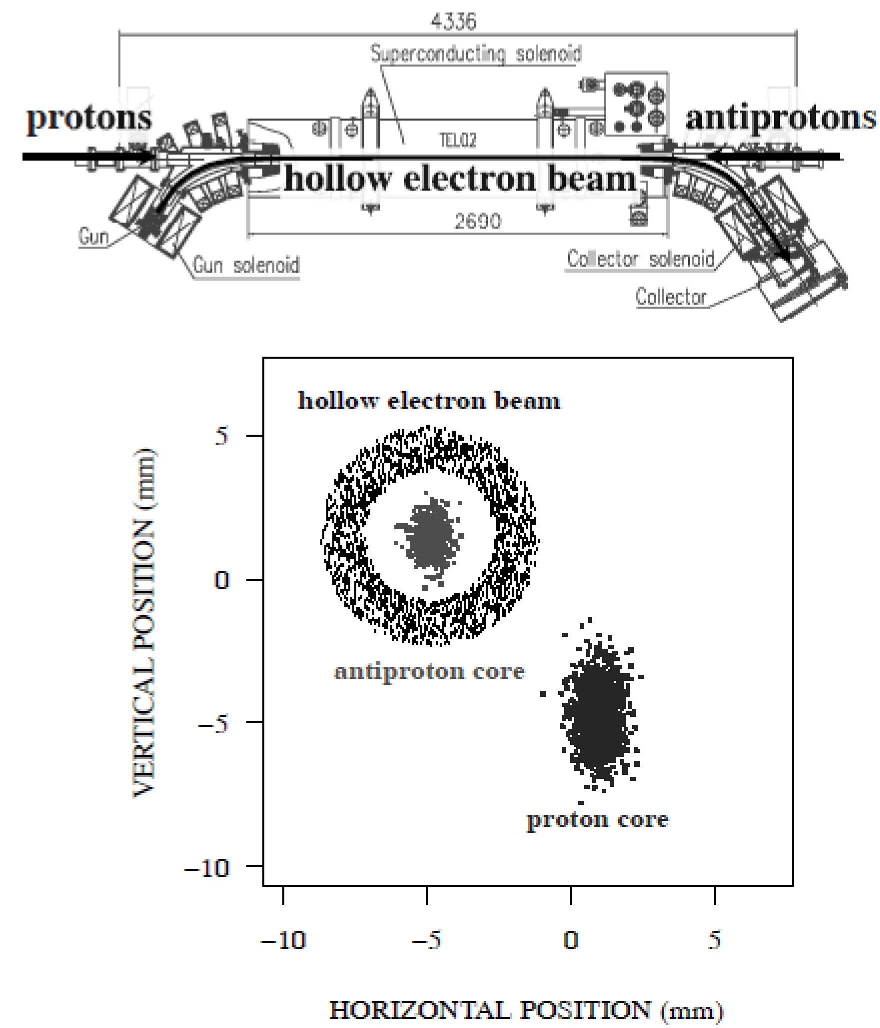
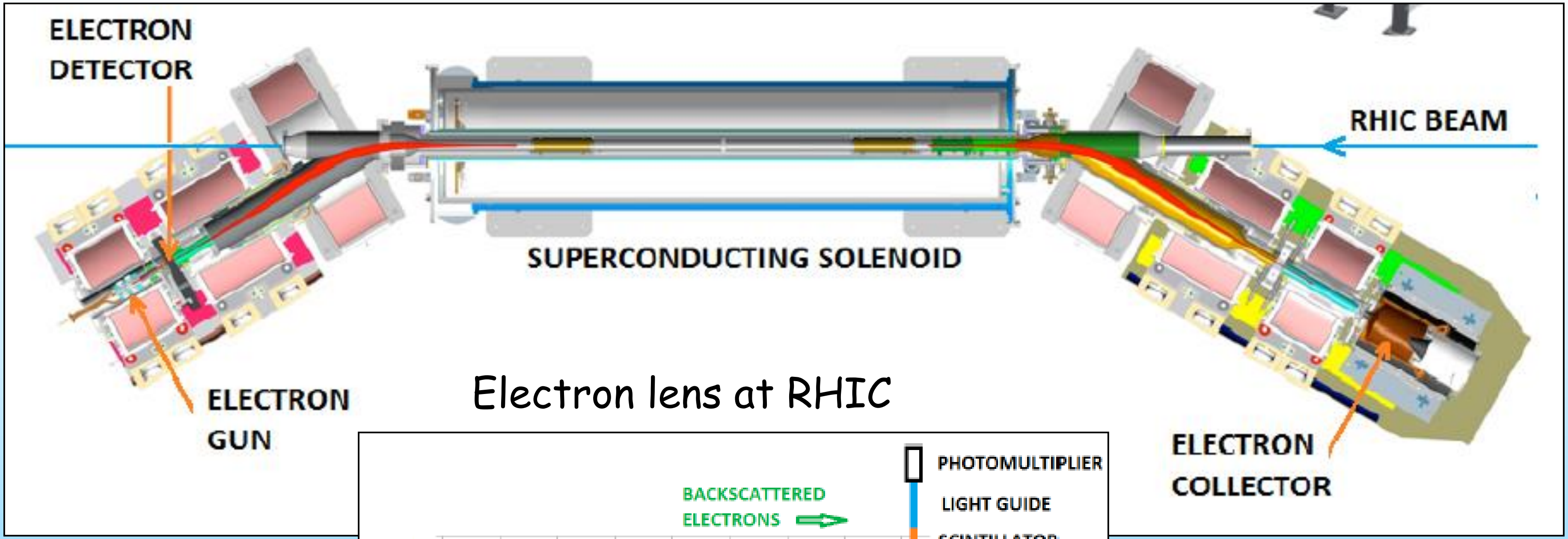


Figure 3: Schematic diagram of the beam layout in the Tevatron hollow electron beam collimator.

BEAM HALO DYNAMICS AND CONTROL WITH HOLLOW ELECTRON BEAMS G. Stancari et al. HB2012

Scattered electrons as possible probes for beam halo diagnostics



Electron lens at RHIC

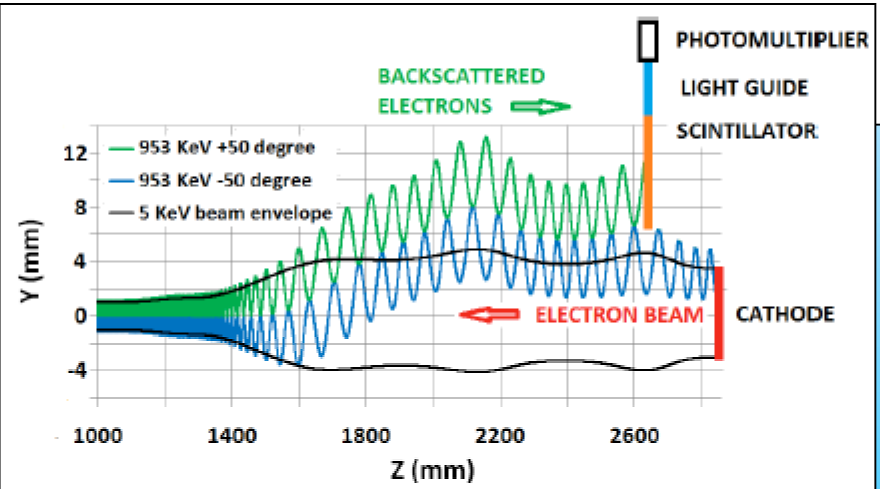


Figure 2: Schematic representation of the backscattered electron detector. Trajectories of two spiraling electrons were generated with an Opera simulation.

DESIGN OF A PROTON-ELECTRON BEAM OVERLAP MONITOR FOR THE NEW RHIC ELECTRON LENS BASED ON DETECTING ENERGETIC BACKSCATTERED ELECTRONS*
P. Thieberger etal, BIW2012

The main beam overlap diagnostic tool will make use of Electrons backscattered in close encounters with the relativistic protons.

Other sensitive, high dynamic halo monitors

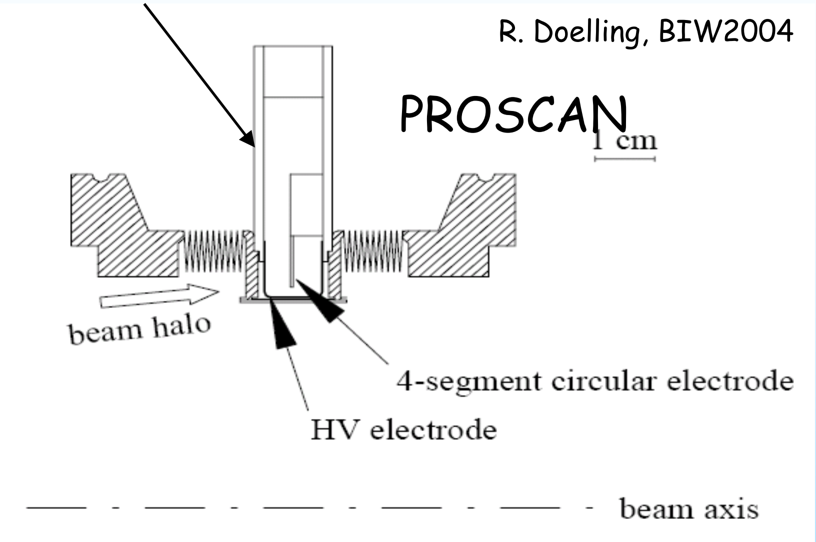
Suitable for minimizing losses

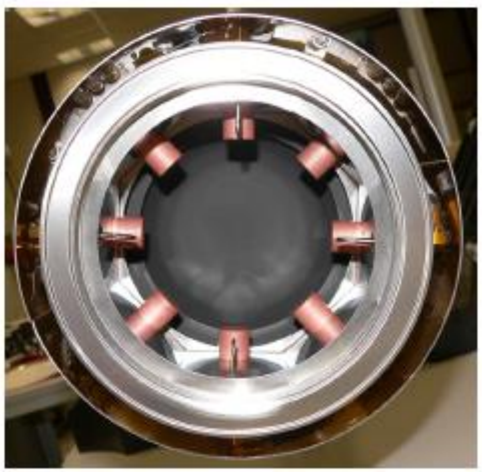
Direct measurement by inserting an intercepting monitor. **<u>No absolute calibration of halo!!! But gives the number of particles in halo, not the size.</u>** Calibration with current monitor required.

Ion chamber, SEM

R. Doelling, BIW2004

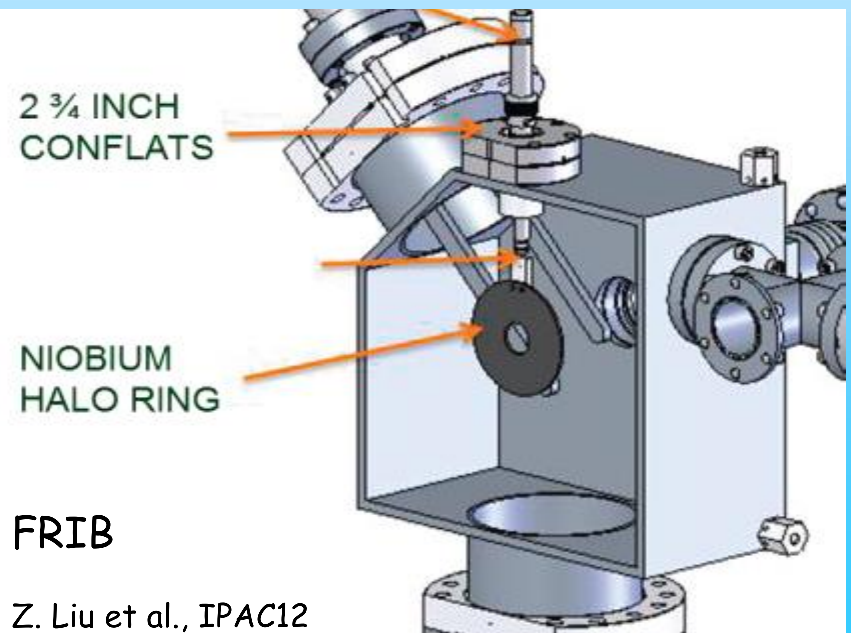
PROSCAN





A. Ignatenko et al., IPAC2012

Figure 1: View of the BHM from the dump. The BHM sensors are inside the caps. Four loops of the magnetic-coupled BPM are right in front of the BHM sensors.



FRIB

Z. Liu et al., IPAC12

Extended profile monitors; IPM

- J-Parc RCS: Idea to use additional MCP arrangement with lower resolution but high gain for halo observations.
- Upgrade in 2012, H. Harada, IPAC12

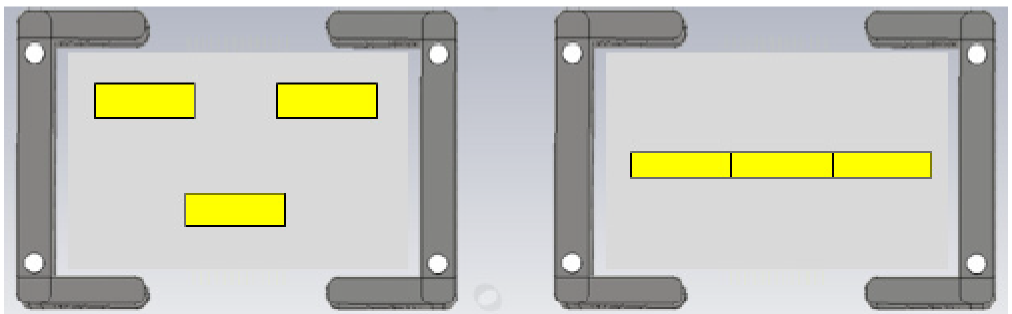
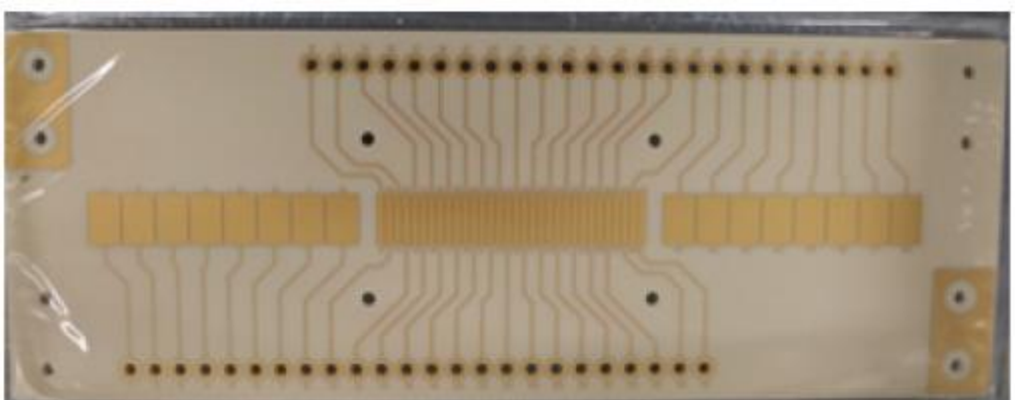
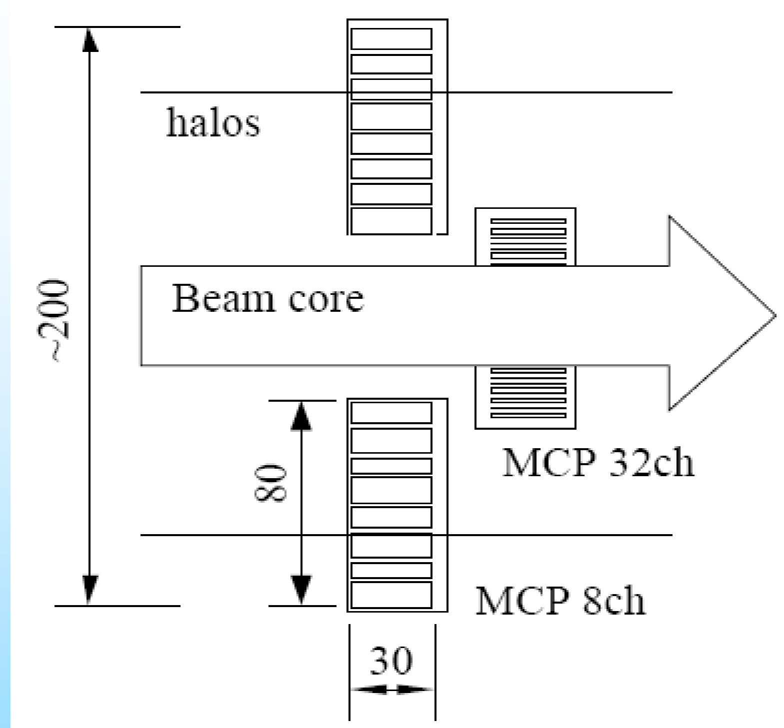


Figure 3: Old (left) and new (right) MCP structure and location. Yellow rectangles are MCPs.





S.Lee et al.
The 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, November 2003

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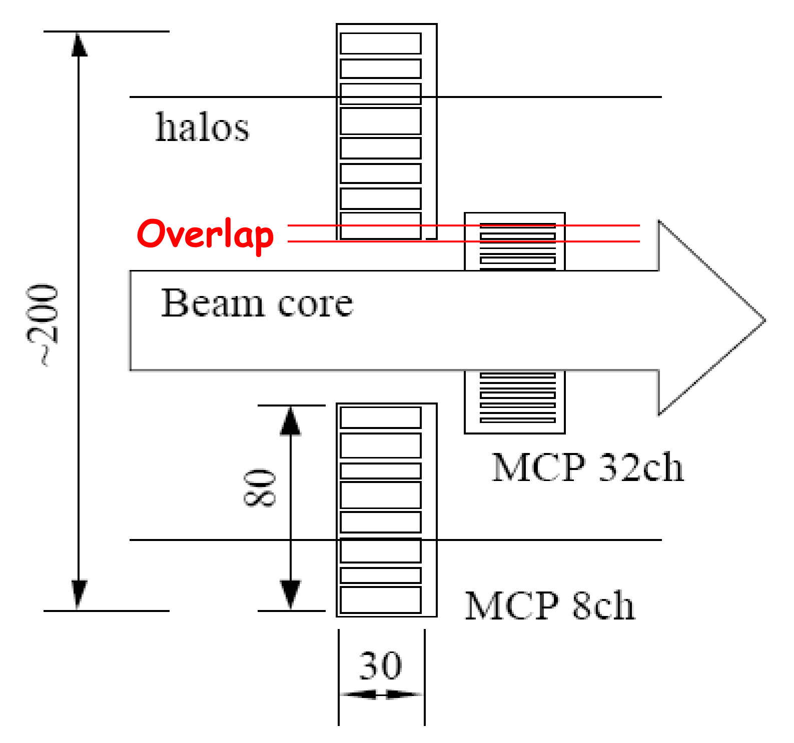
- J-Parc RCS: Idea to use additional MCP arrangement with lower resolution but high gain for halo observations.
- Upgrade in 2012, H. Harada, IPAC12



S.Lee et al.
The 14th Symposium on Accelerator Science and Technology, Tsukuba, Japan, November 2003

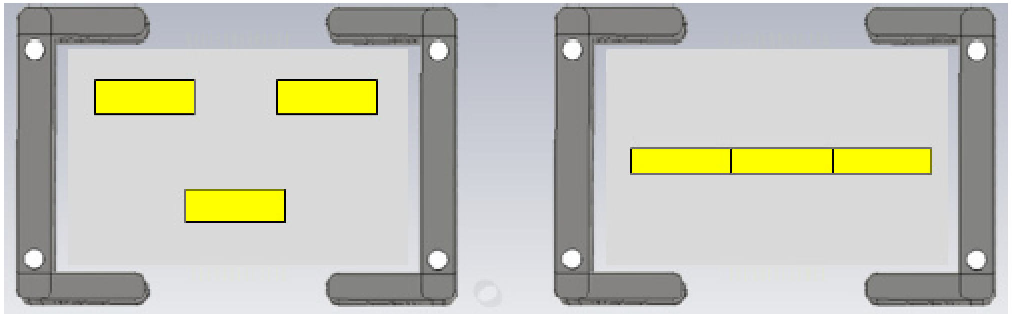
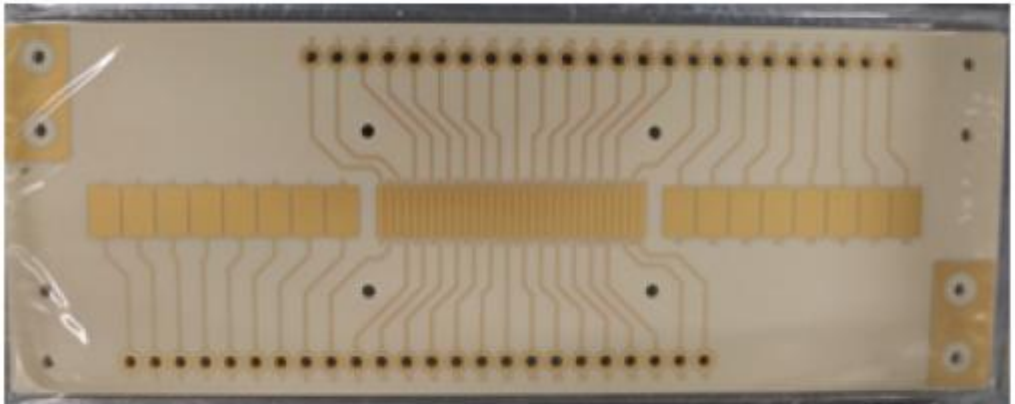
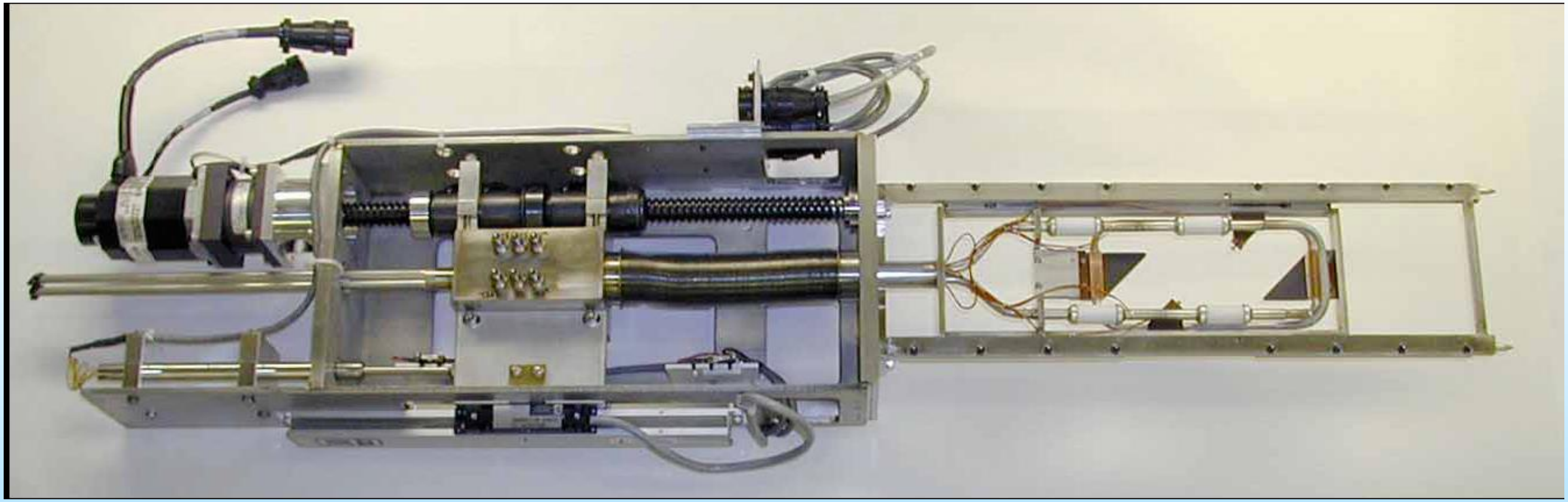


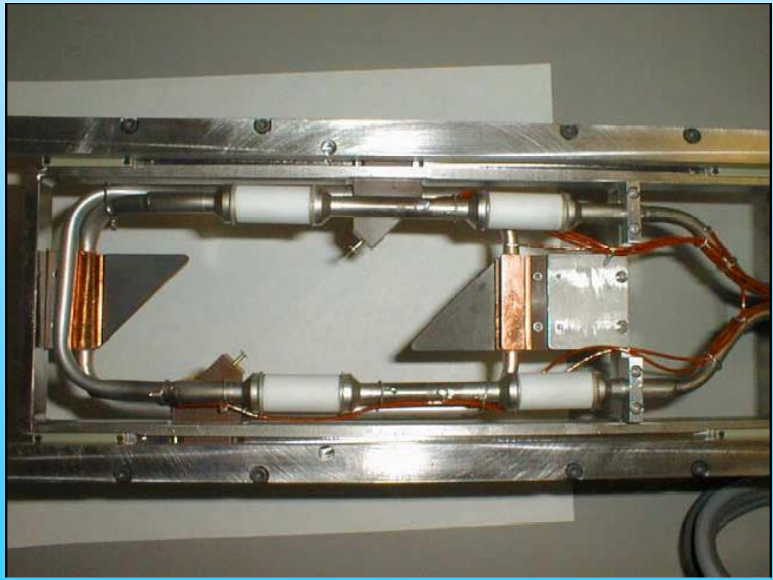
Figure 3: Old (left) and new (right) MCP structure and location. Yellow rectangles are MCPs.



Wire Scanners at LEDA
(Proton LINAC, SEM readout)



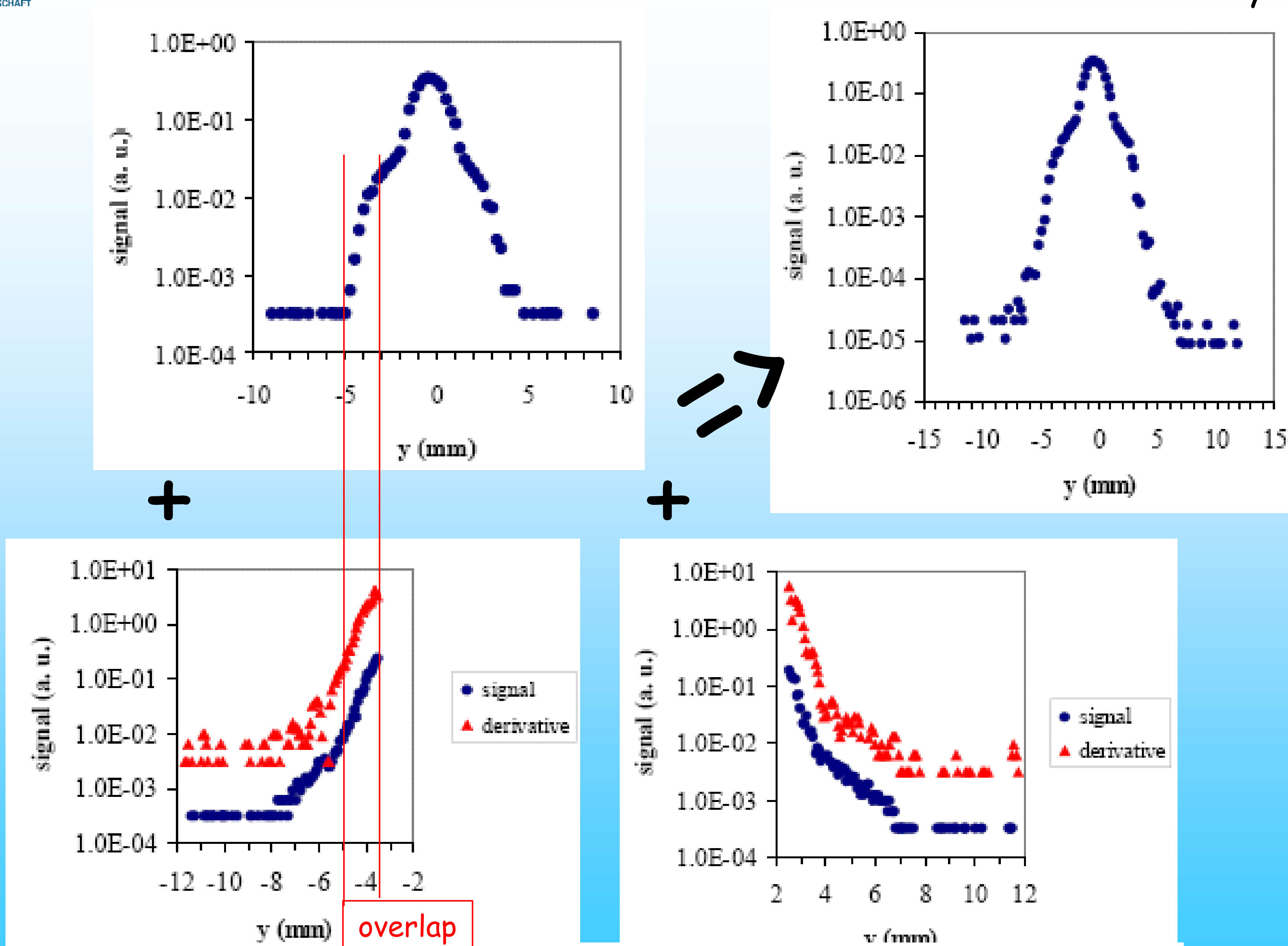
1.Scraper data are spatially differentiated and averaged,
2.Wire and scraper data are acquired with sufficient spatial overlap (where the wire scanner signal rises above the noise),
3.Differentiated scraper data are normalized to the wire beam core data,
4.Normalize data to axis
5.Normalize data to beam current and beam position (true for all kind of halo measurements)!!!!



J. F. O'Hara, et al, PAC2001

Y-axis wire scan

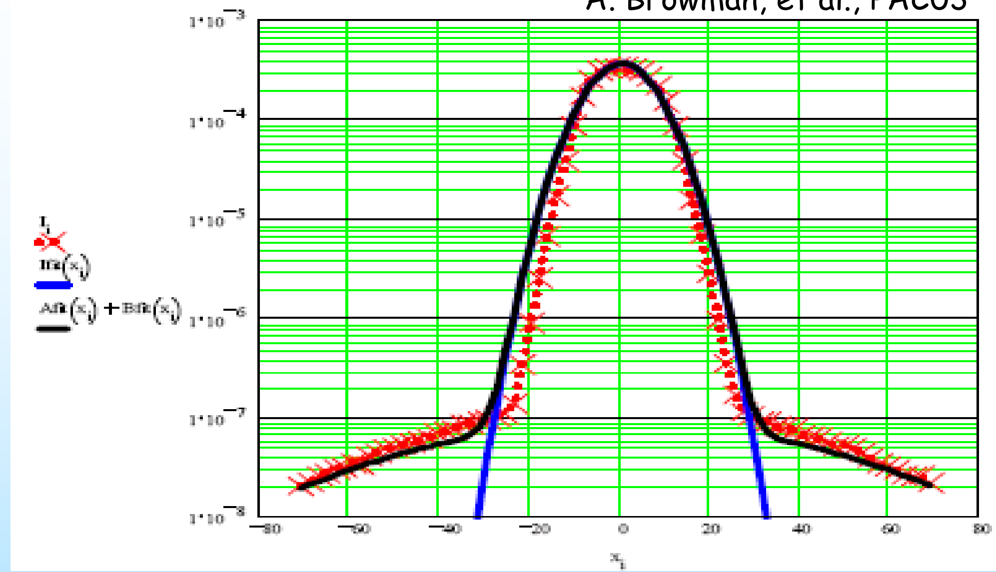
Combined distribution in y.



-Y and + Y scrape signal and derivative. The derivative has been multiplied by ten.

Wire Scanners, examples

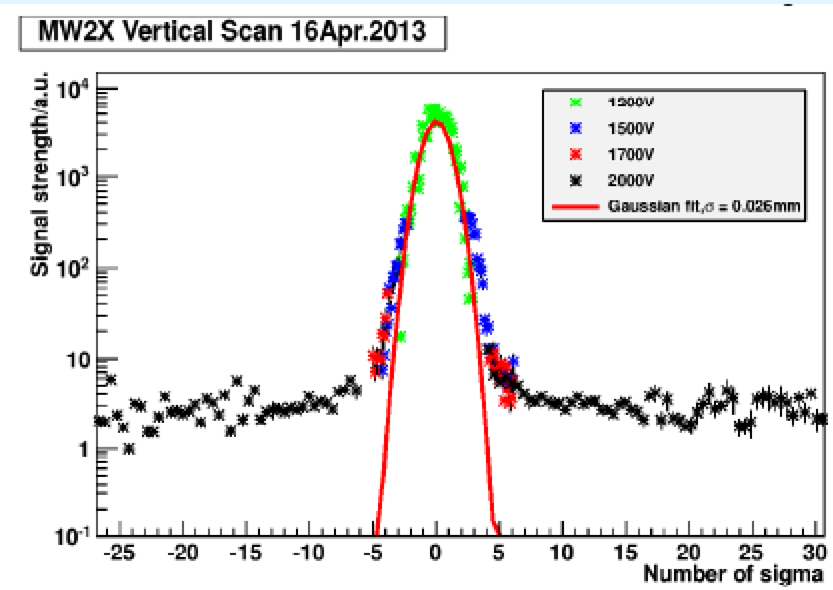
A. Browman, et al., PAC03

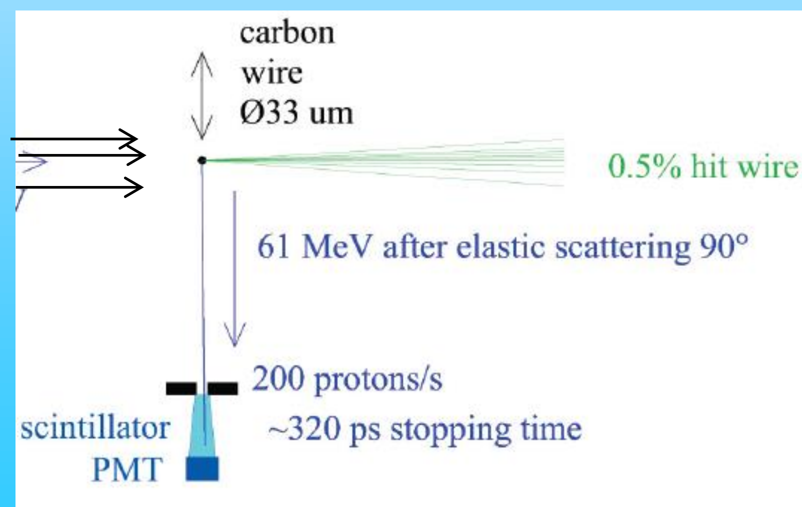


A normal function shown in solid blue has been fit to the data (red x's). A sum of two normal functions is shown in solid black. The x-axis is scaled as scanner position in mm's and the y-axis is log-amp input current in Amps.

linear amplification and 10^5 dynamic range
=> 16-bit ADC or log.-amps

Use of different PMT voltages.
ATF2, L.Lui et al., IPAC14

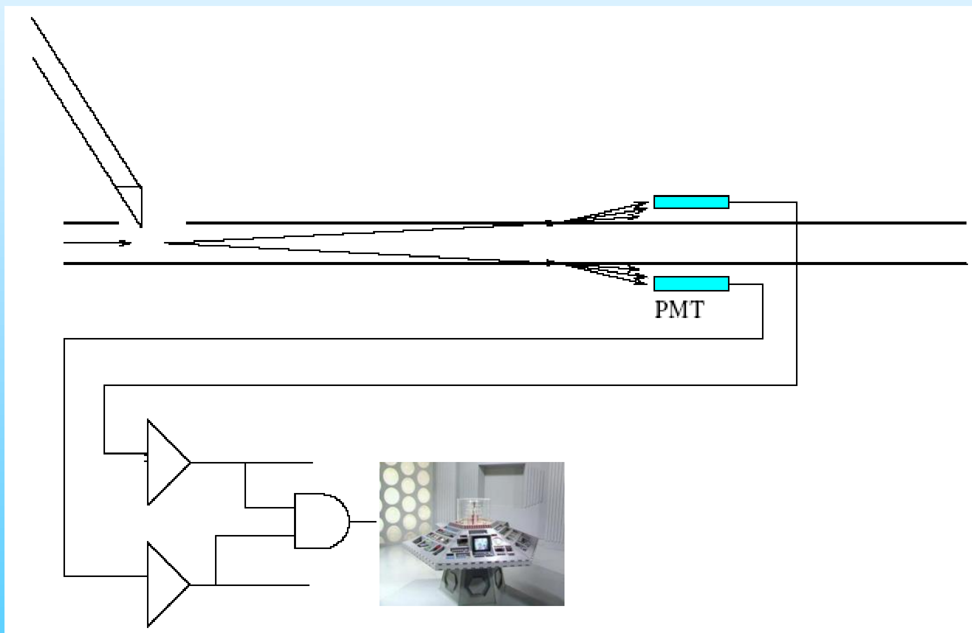




Wire scanners at low energy, 72 MeV:
Use of scattered protons.
Dynamic range ≈10^5
R. Dölling, Cyclotrons2013

Wire Scanners at Jefferson Lab

Huge dynamic range (10^8) by coincident counting:



Large Dynamic Range Beam Profile Measurements,
T. Freyberger, DIPAC05

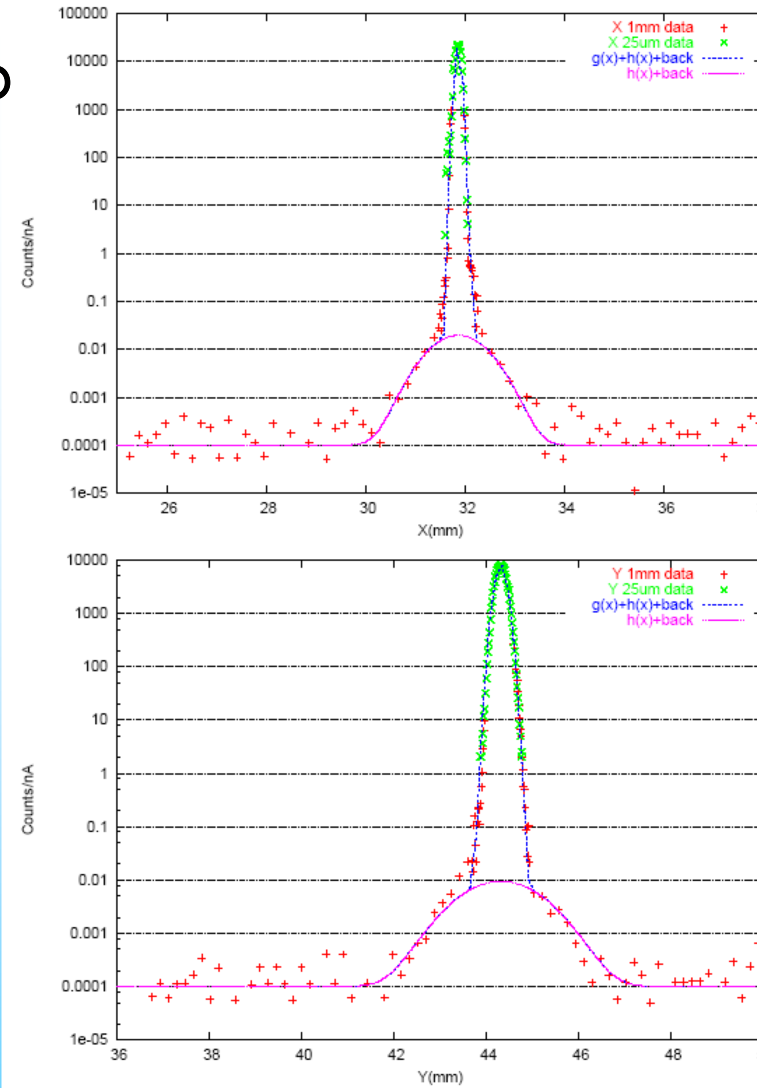
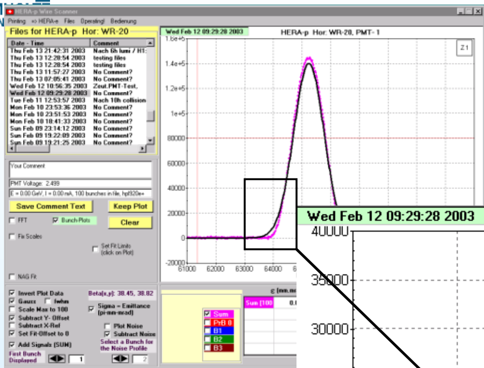


Figure 4: Beam Profile combining the 25μm and 1mm Fe wire data. The top(bottom) plot shows the X(Y) data and results of the fit to the data. The red points represent the 1mm wire data, the green points the 25μm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion of the fit. The ordinate is plotted with a log-scale and the count rate is normalized to the beam current.

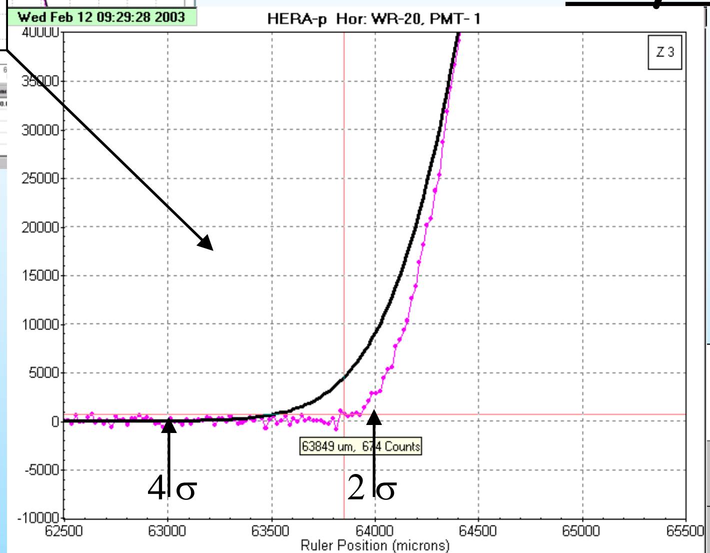
Wire Scanners at HERA

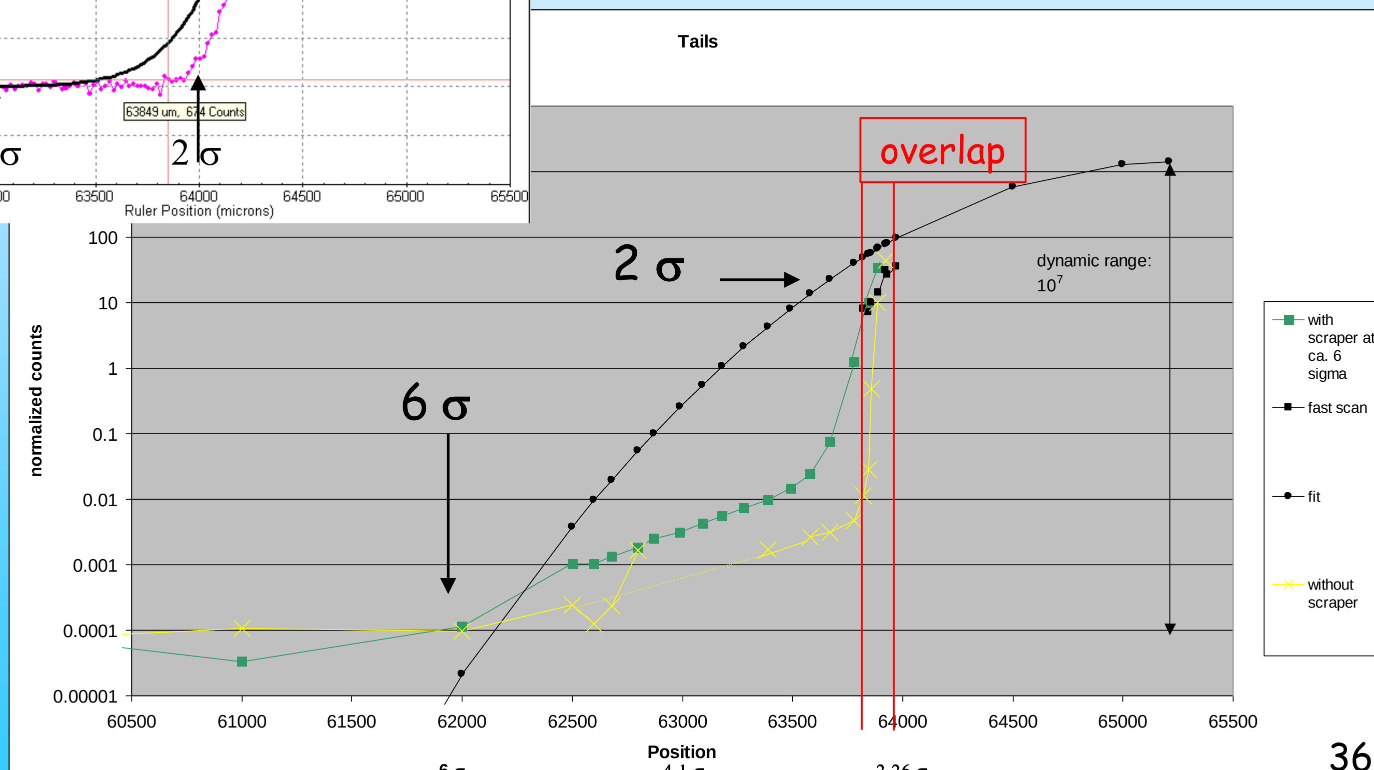


Fast scan
E=920 GeV/c
p-e$^+$ collisions

Huge dynamic range by scanning + counting
No scraping, single scintillator! (HERA):
Very clean beam conditions (no losses)
No halo,
even smaller than gaussian.

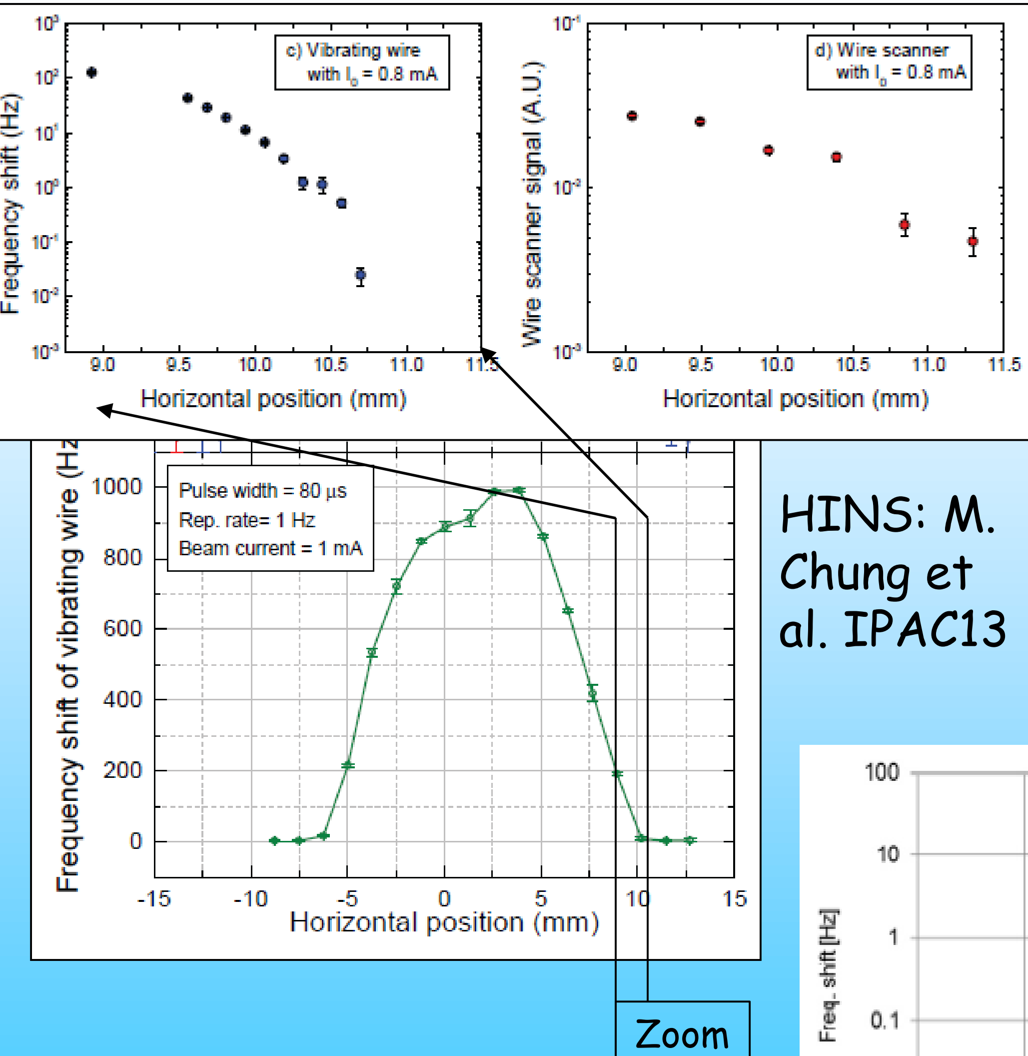
Dynamic range: 10^7





Beam Tail Measurements using Wire Scanners at DESY,
Halo Worshop 2003
S. Arutunian, et al.

Vibrating wire scanner



HINS: M. Chung et al. IPAC13

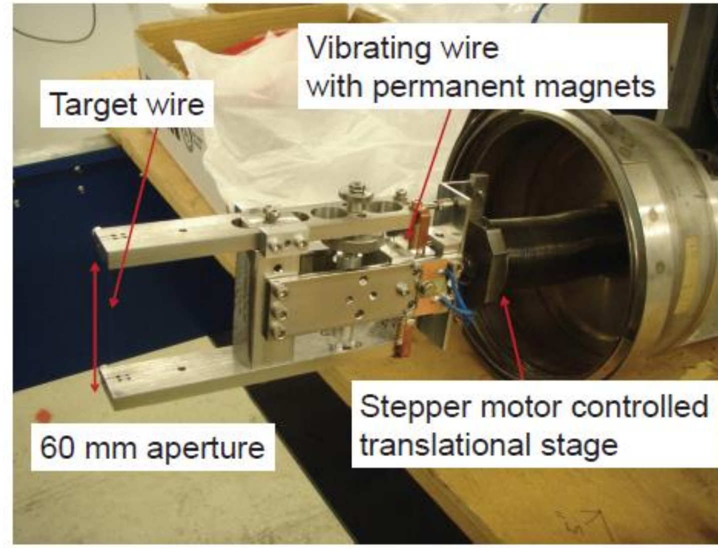
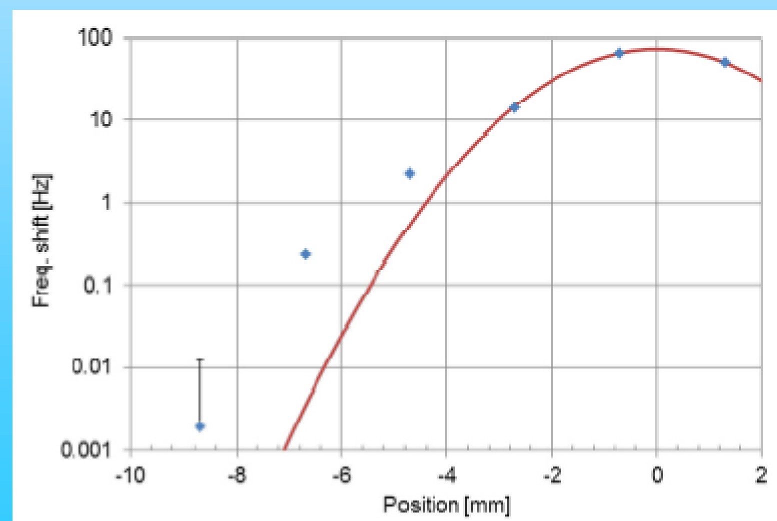
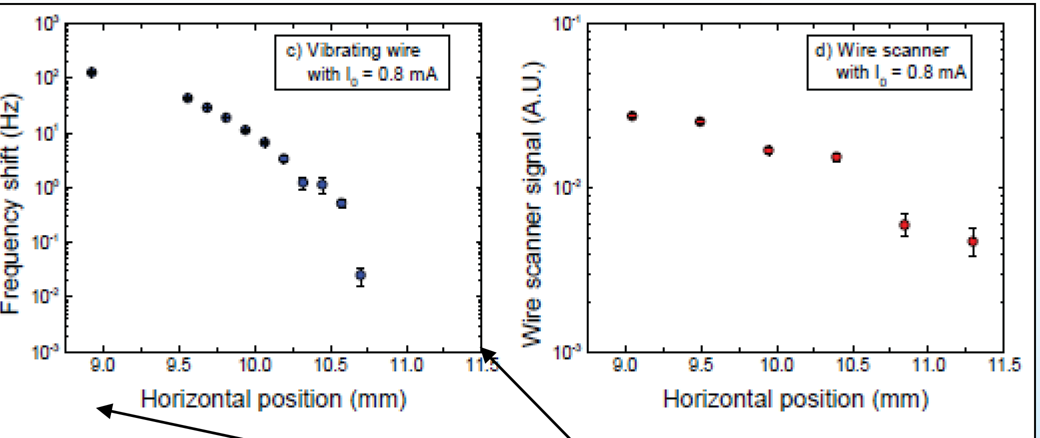


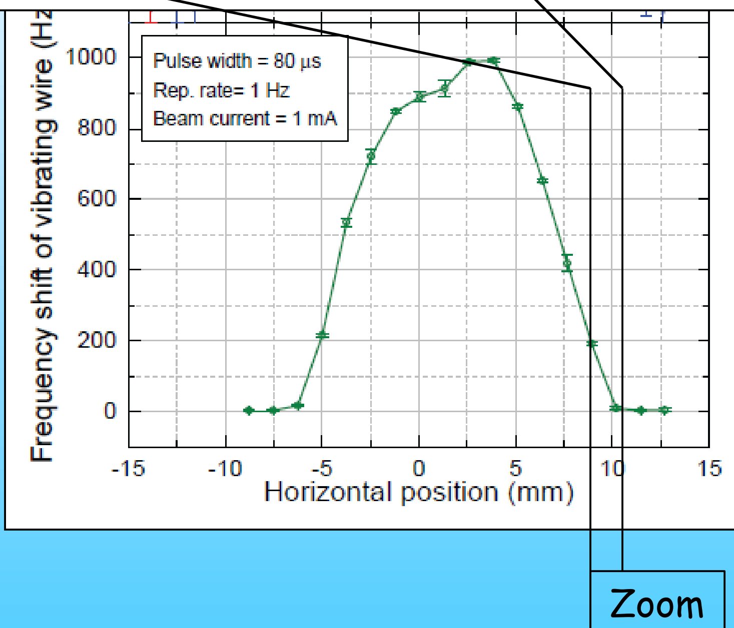
Figure 1: Picture of the large aperture vibrating wire monitor assembly.

J-PARC L3BT:
K. Okabe et al, IPAC13



Vibrating wire scanner





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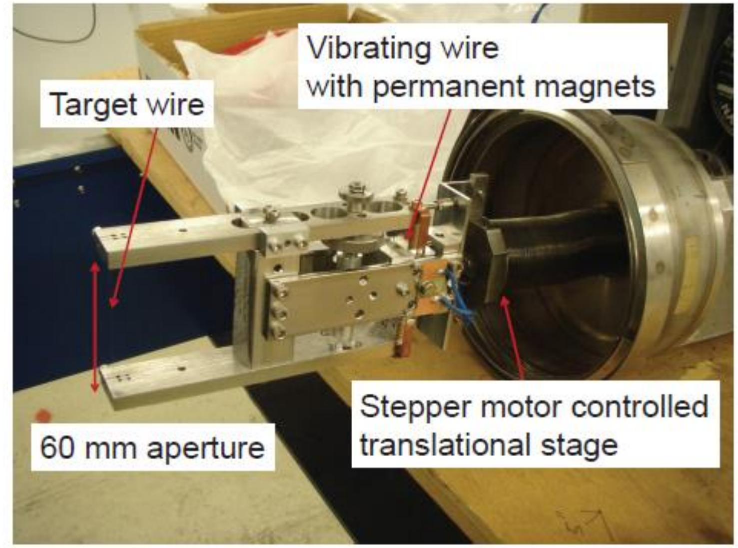

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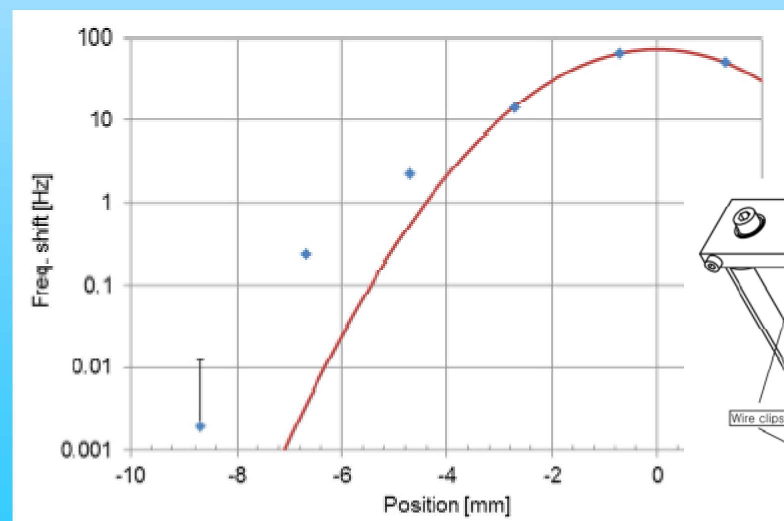
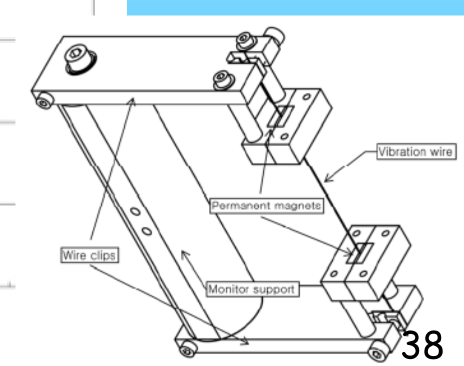




Optical Methods

Scanning devices might be very time consuming; sometimes one needs many minutes to measure the profile together with the halo with the required dynamic range.
Note that one always has to normalize the measurement to beam position and beam current!

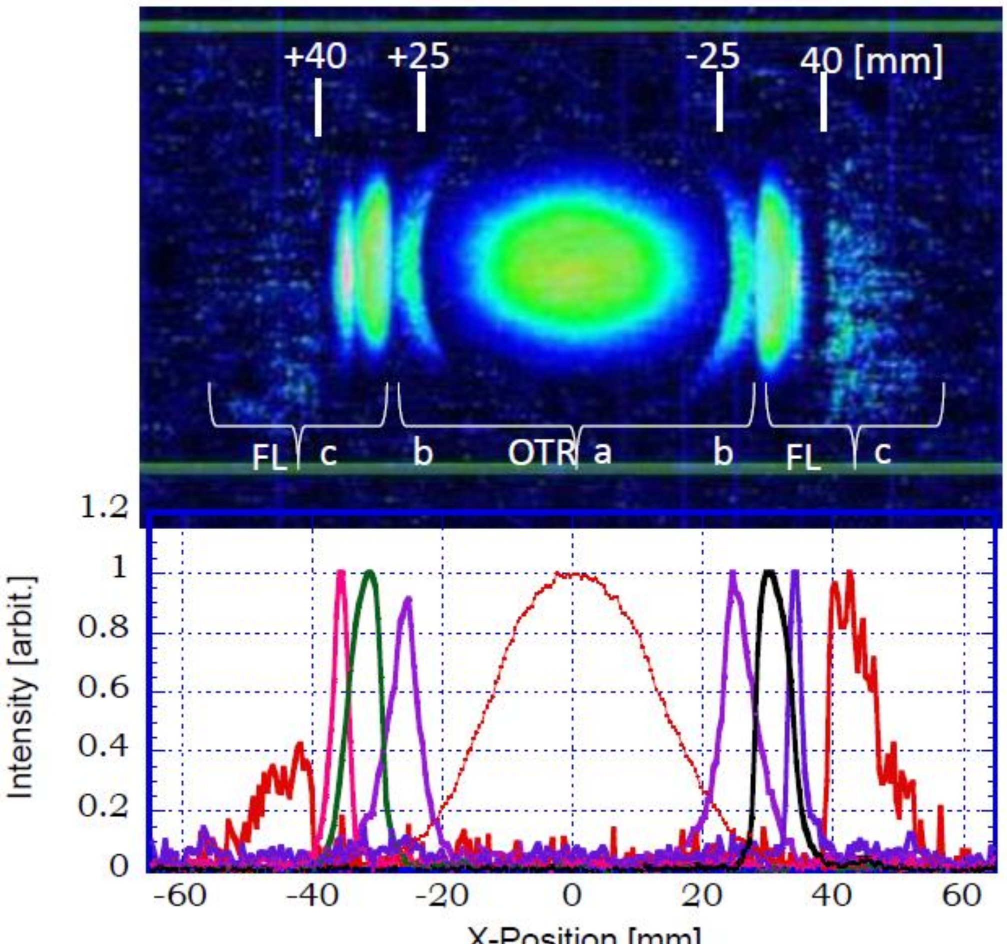
Optical methods can be (much) faster:

Optical Methods

Combination Measurement with OTR and Fluorescence

MULTI-SCREEN BEAM PROFILE MONITOR

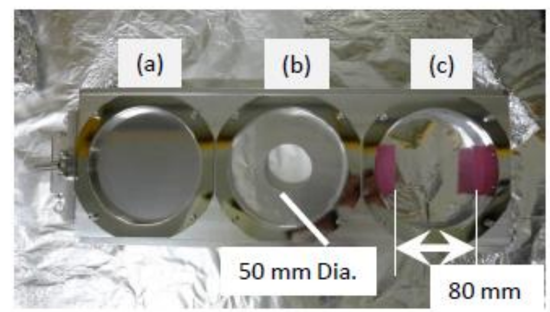
- Intensity : 9.6 e 12 proton /2bunch
- 2 bunches × 5 Shots (AVG)
- Image Intensifier Gate: 10 μs



Superimposed Profile Image

Horizontal Projection (Normalized)

Multi-screen



T. Mitsuhashi et al.
Halo diagnostic workshop, 2014, SLAC

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J-PARC
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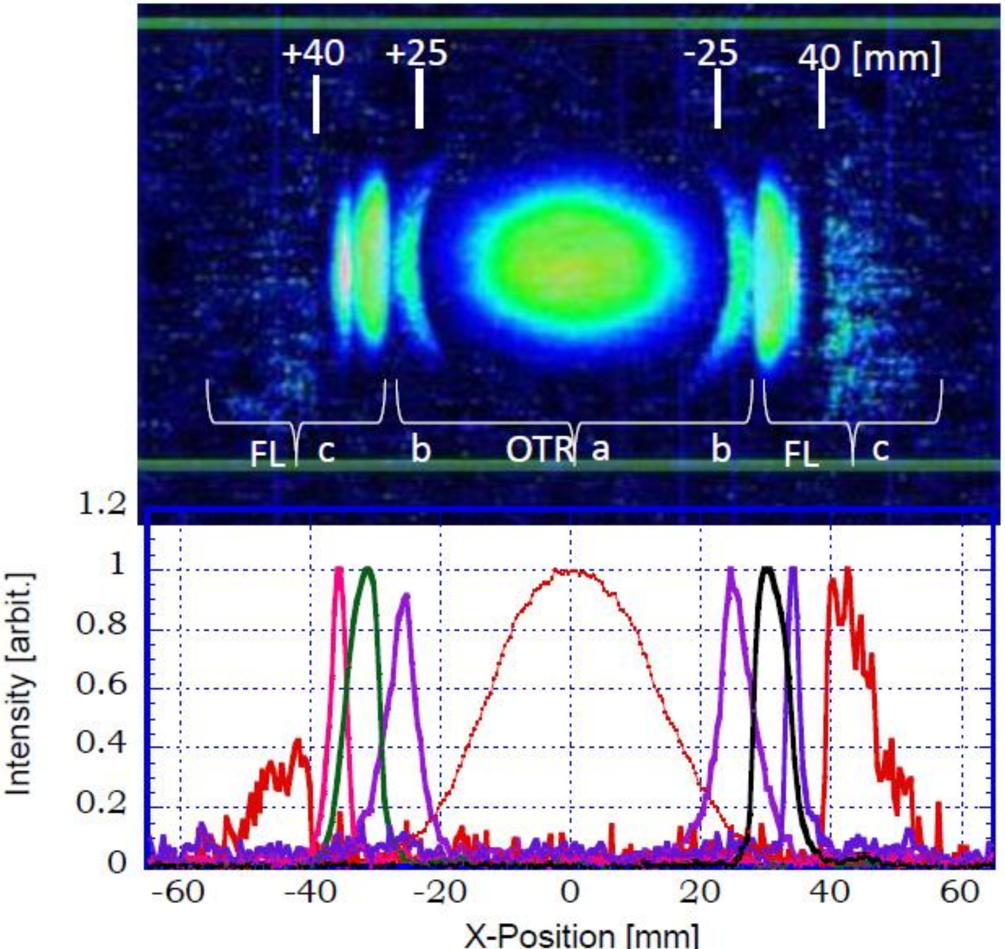
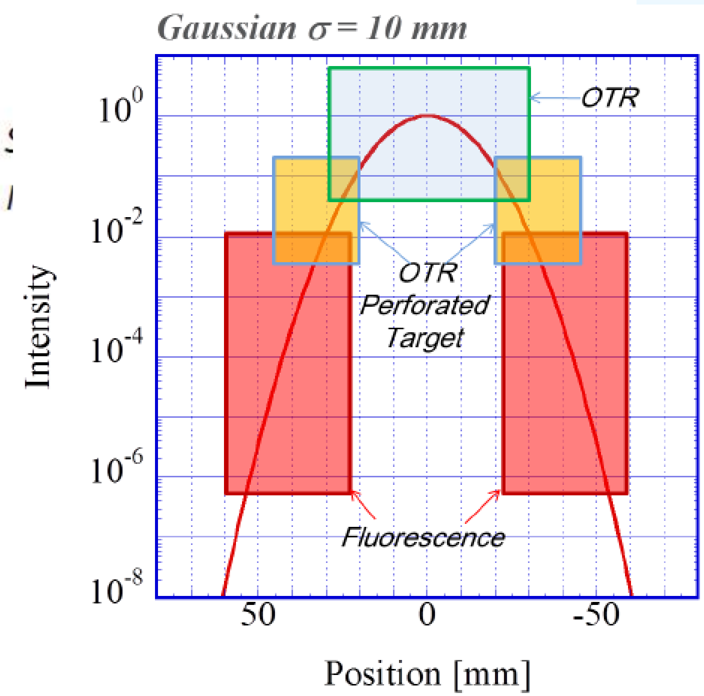


Horizontal Projection (Normalized)



T. Mitsuhashi et al.
Halo diagnostic workshop, 2014, SLAC

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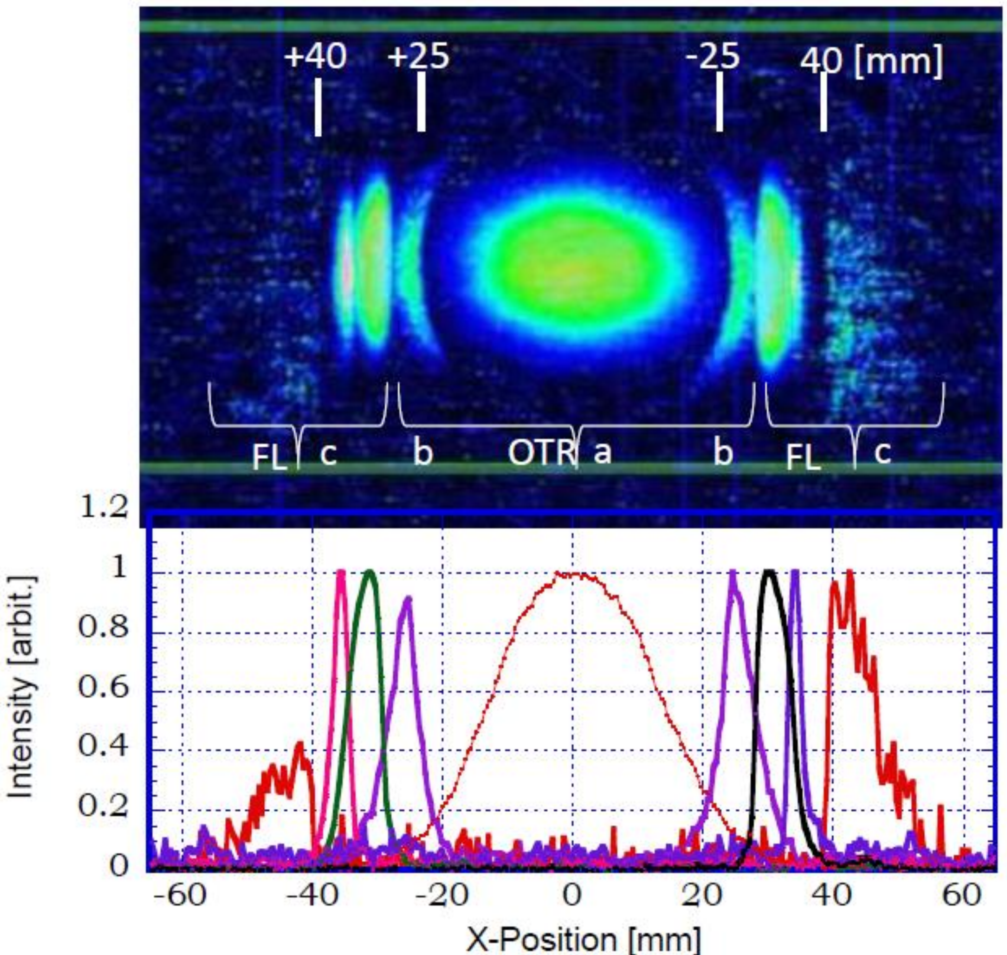

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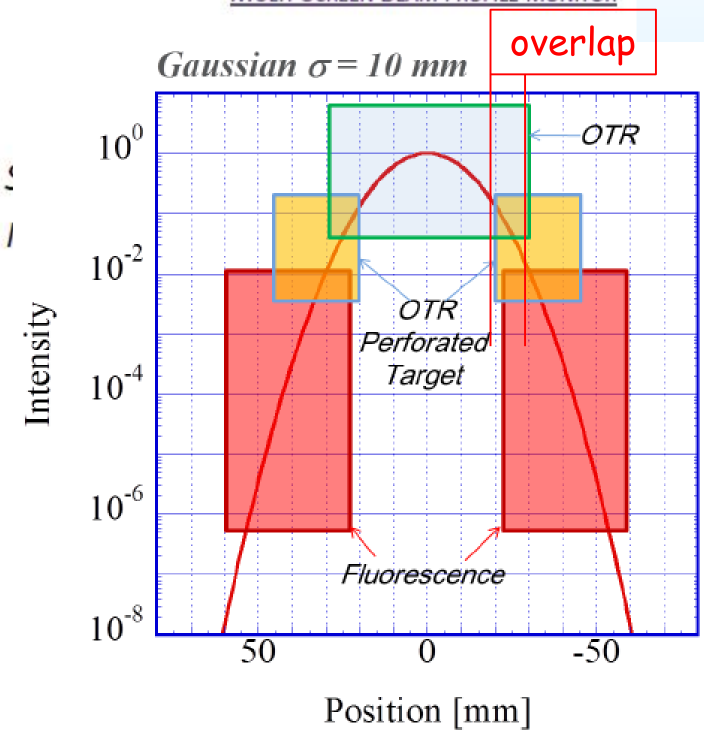
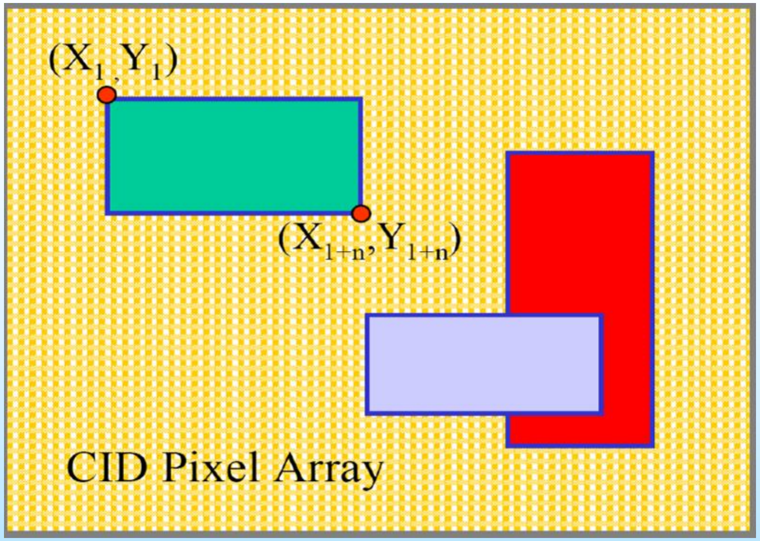
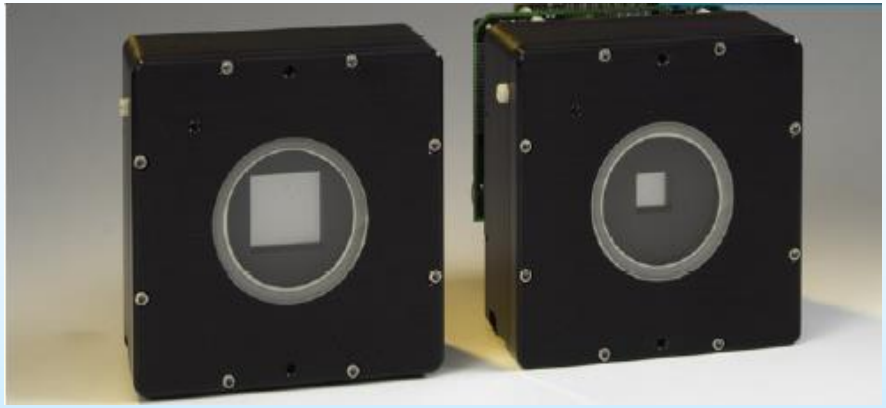


T. Mitsuhashi et al.
Halo diagnostic workshop, 2014, SLAC

CID Camera

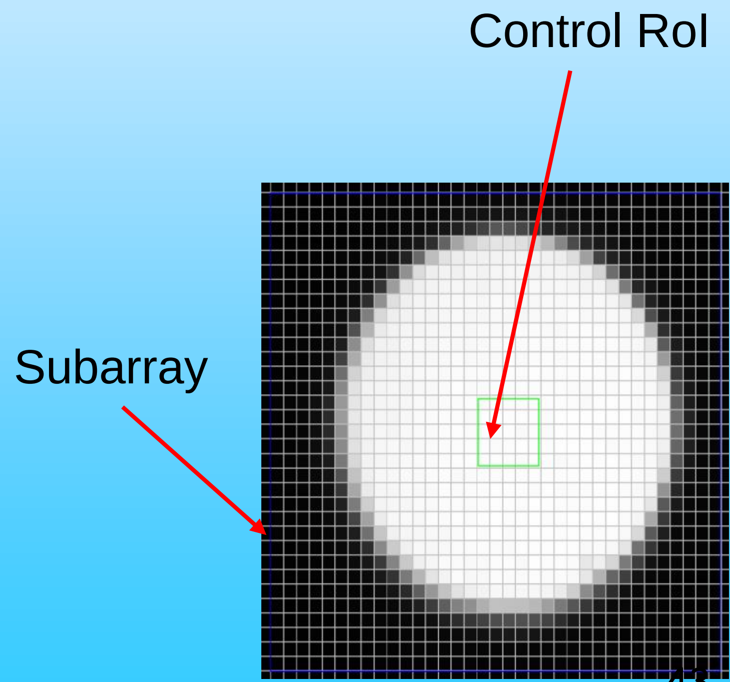




Commercial available

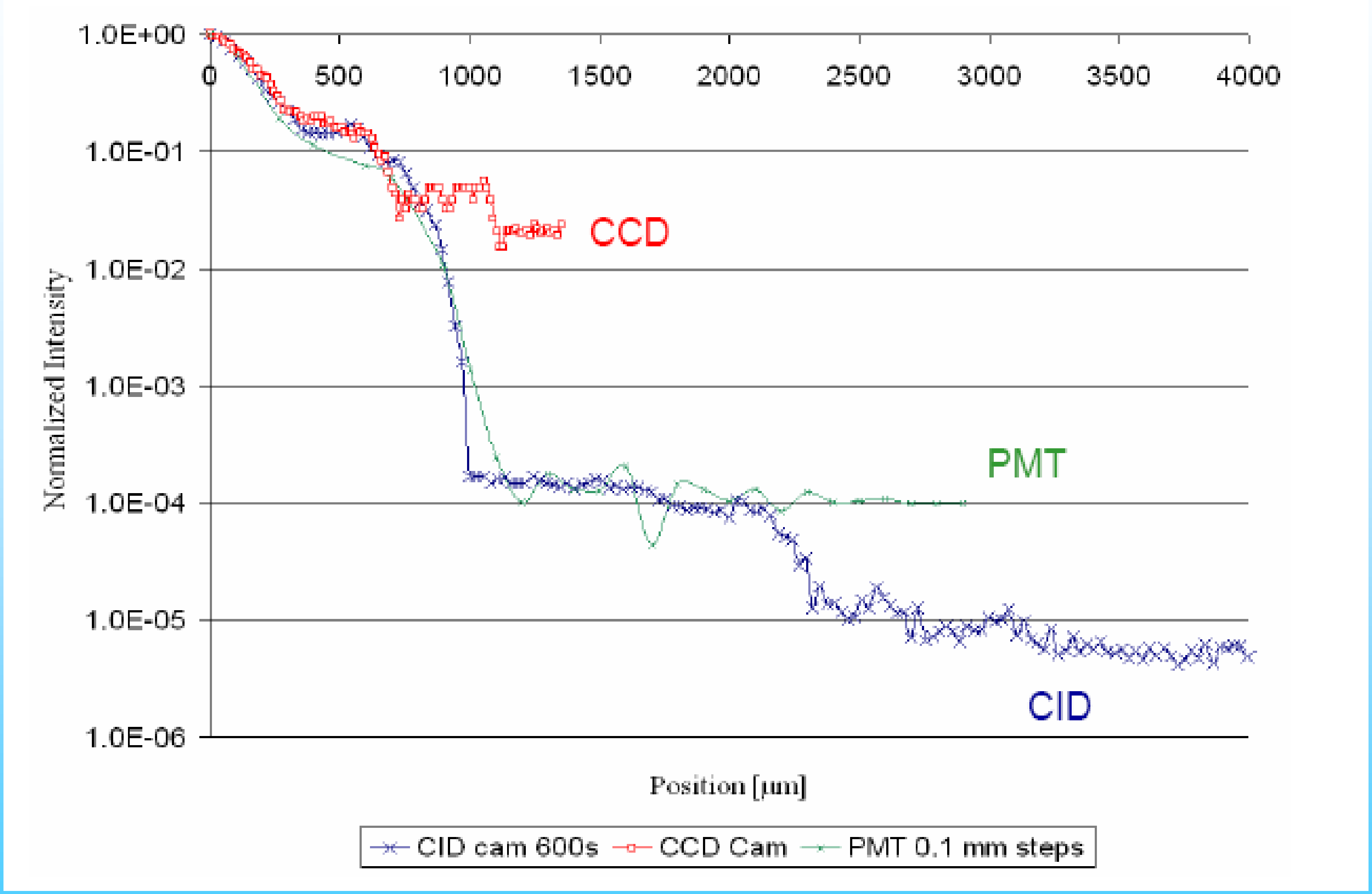
http://www.thermo.com/eThermo/CMA/PDFs/Product/productPDF_26754.pdf

Each pixel on the CID array is individually addressable and allows for random access non-destructive pixel readout. The *random access integration* (RAI) mode **automatically adjusts the integration time from pixel to pixel based upon the real-time observation of photon flux** using CID random accessibility and non-destructive readout. With this RAI mode a **dynamic range (~10^6)** can be achieved.



C.P. Welsch et al., CLIC Note 657, 2006

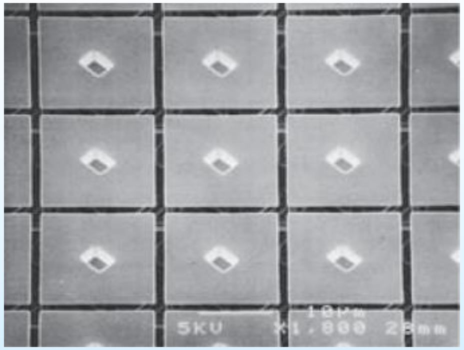
CID Camera

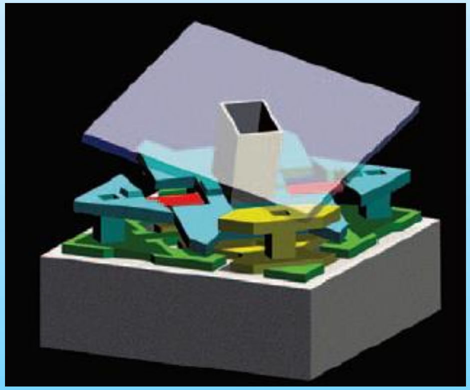


C.P. Welsch et al, EPAC06

Micro Mirror Array

- 1024 x 768 pixels (XGA)
- USB Interface
- high-speed port 64-bit @ 120 MHz for data transfer
- up to 9.600 full array mirror patterns / sec (7.6 Gbs)
- 16 μm in size
- +/- 10° of rotation
- Switch of 15 μs physically, 2 μs optically





The first applications were in digital projection equipment, which has now expanded into digital cinema projectors, with sometimes **more than two million micro mirrors per chip switching at frequencies of up to 5 kHz**. Recently MMAs are finding applications in the large telecommunications market as optical multiplexers and cross-connect switches.

T. Lefevre, BIW08

Micro Mirror Array

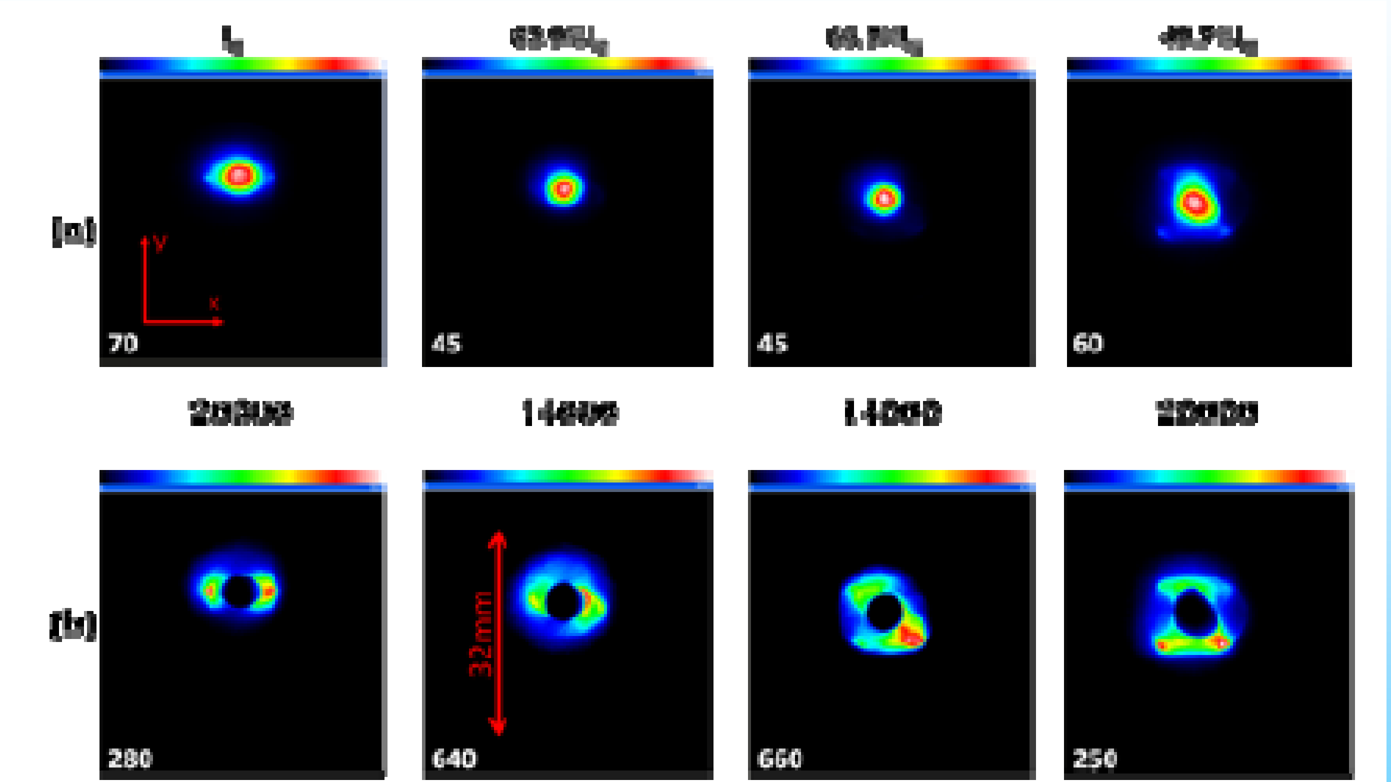
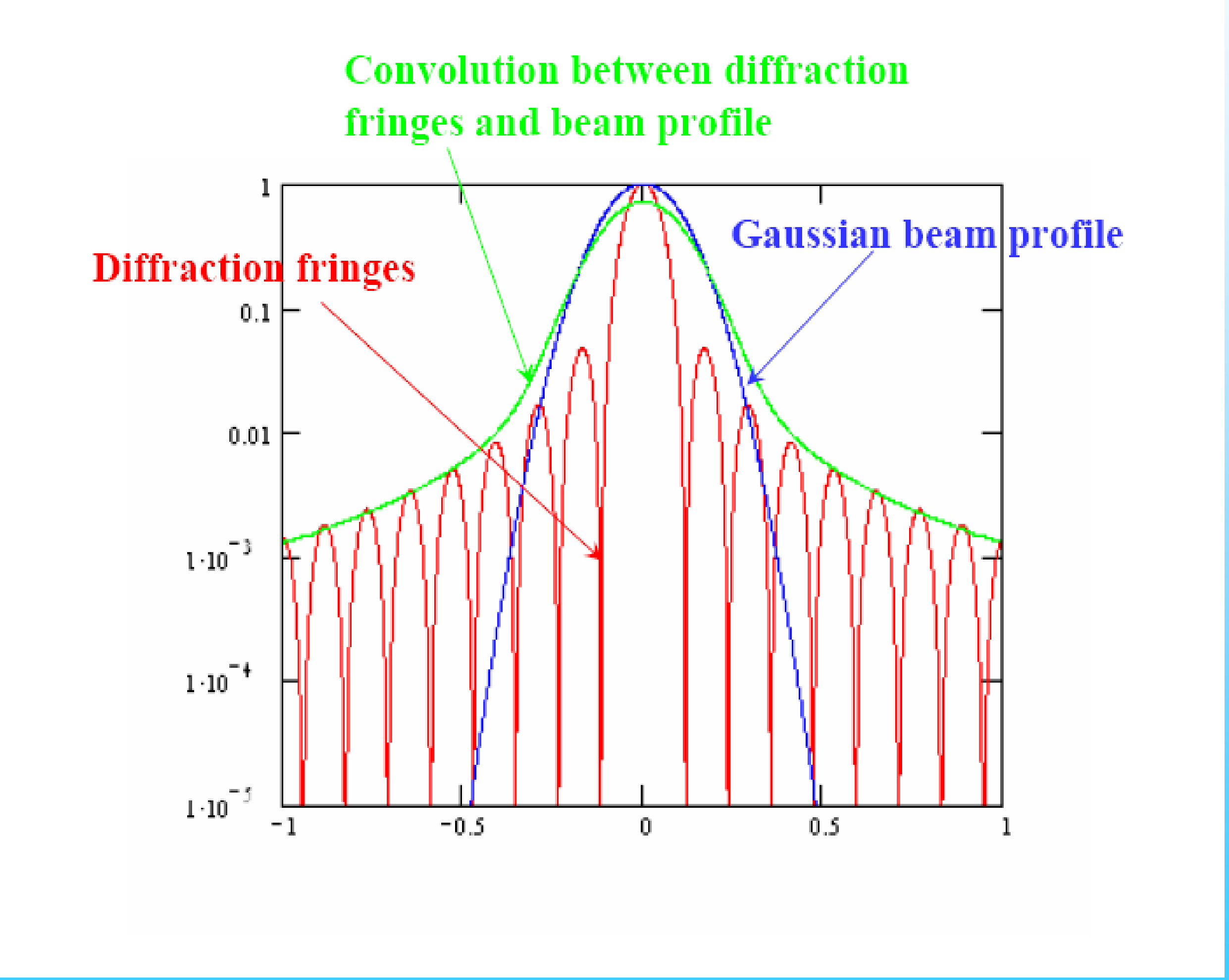


Figure 2: Beam (a) and halo (b) images with quadrupole current variation[5].

UMER: BEAM HALO MEASUREMENTS USING ADAPTIVE MASKING METHODS AND PROPOSED HALO EXPERIMENT
H. Zhang et al., HB2012

Optical halo measurements

Directional optical radiation (e.g. Synchrotron radiation or OTR) with small opening angles (≈ $1/\gamma$) suffer from diffraction limits:



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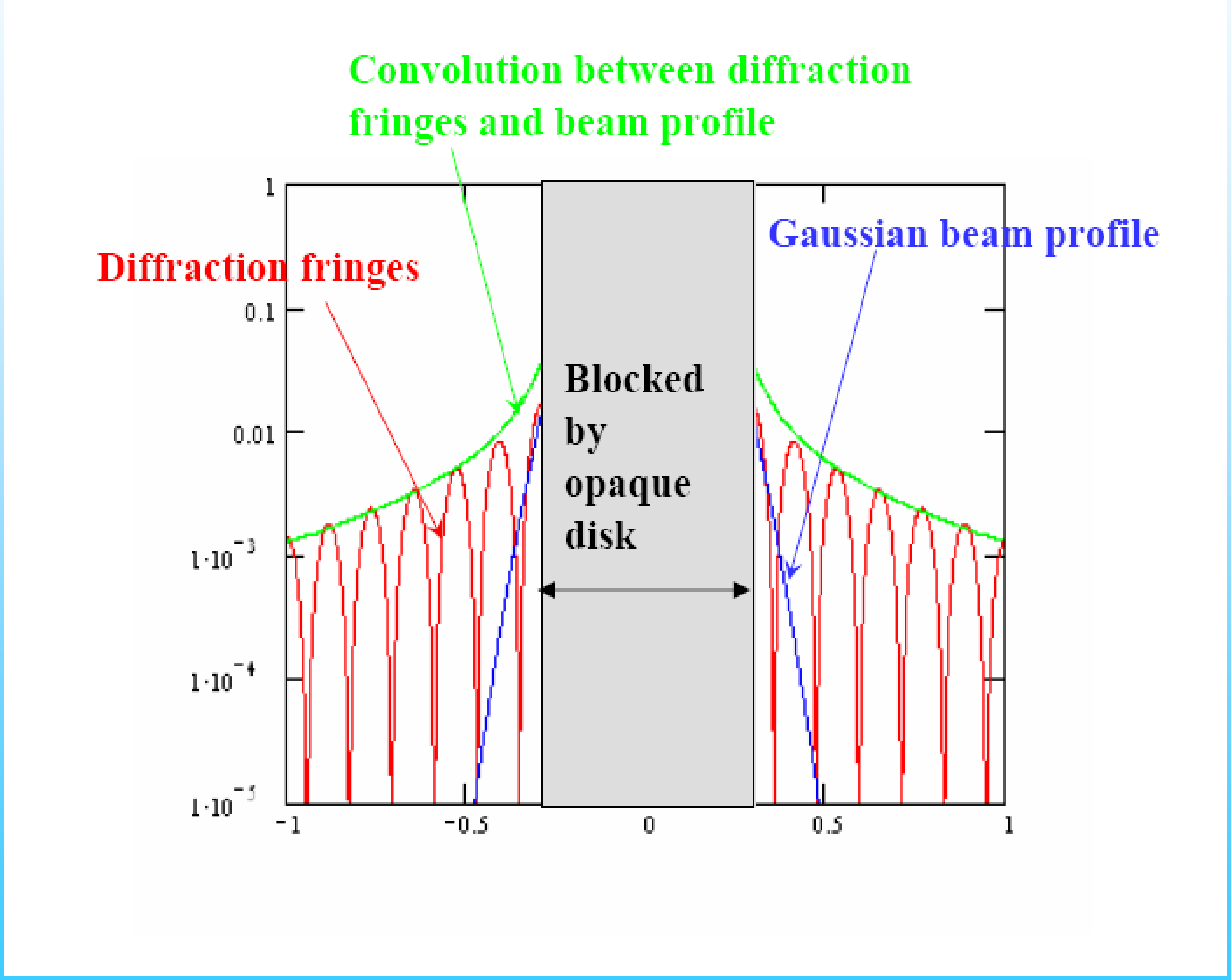

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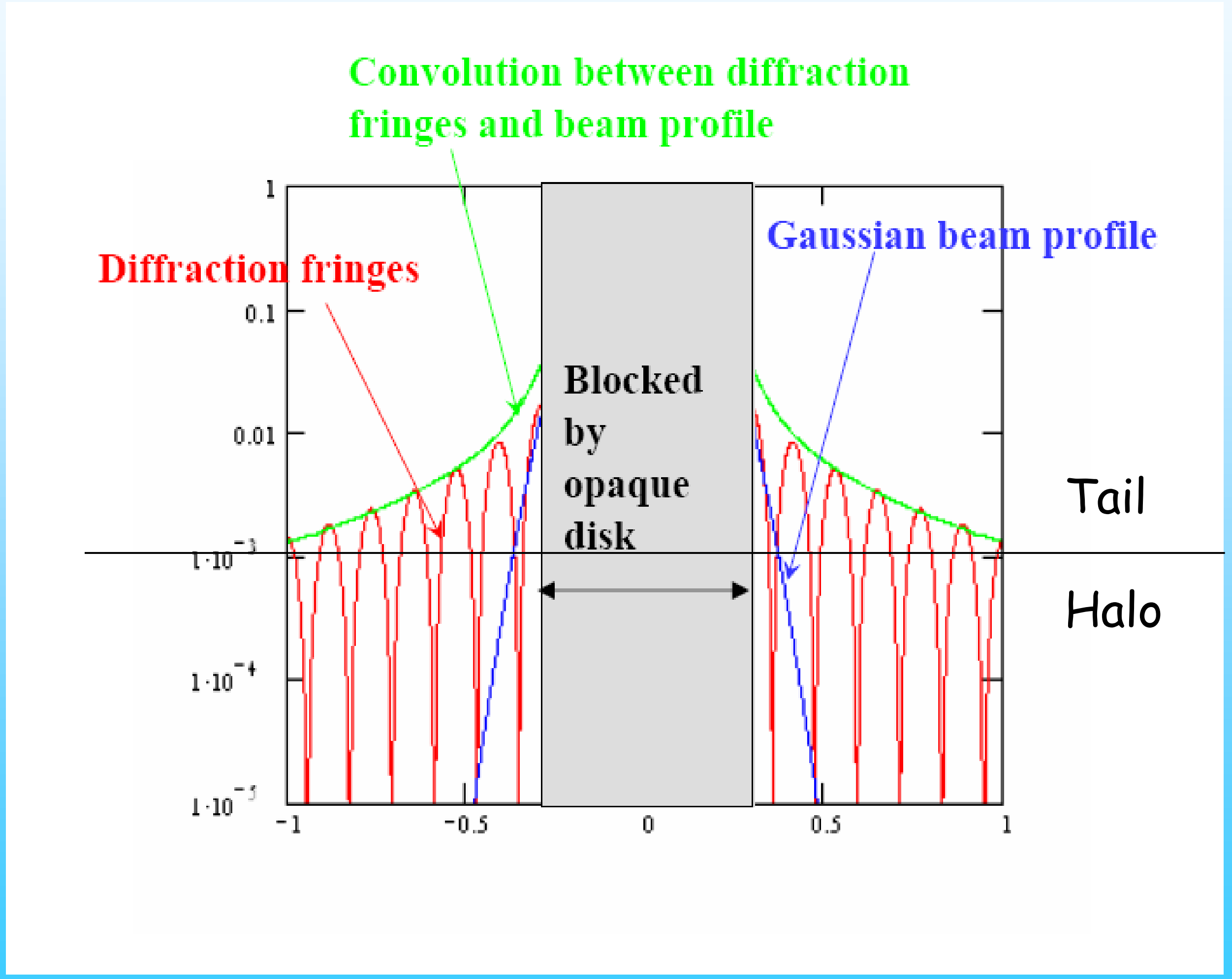
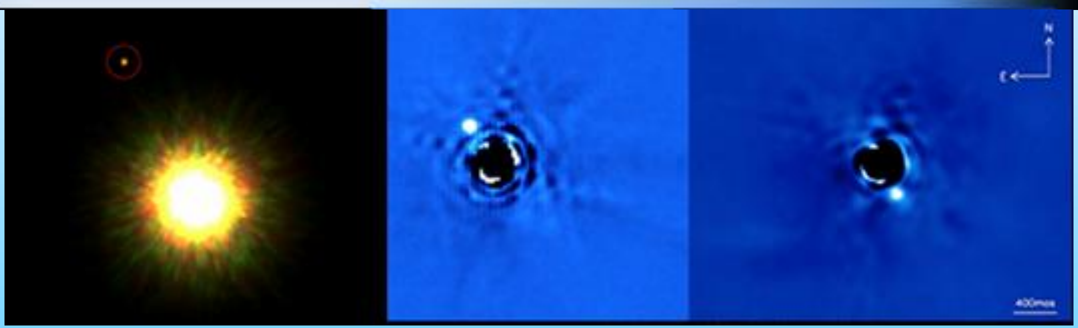


Is there another Earth out there?

High Contrast Imaging

Like searching for a firefly next to a lighthouse in San Francisco from Boston
=> Very faint and small in comparison



Limitations:

- Diffraction from the parent star
- Passives and active aberrations in the system
- Amplitude errors and Talbot effect

Solutions:

- Diffraction: Coronagraphs
- Aberrations: Active and adaptive optics

High-Contrast Imaging and the Direct Detection of Exoplanets,
Sandrine Thomas, Ruslan Belikov, and many collaborators,
Halo Diagnostic Workshop 2014, SLAC

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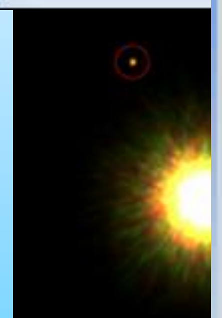

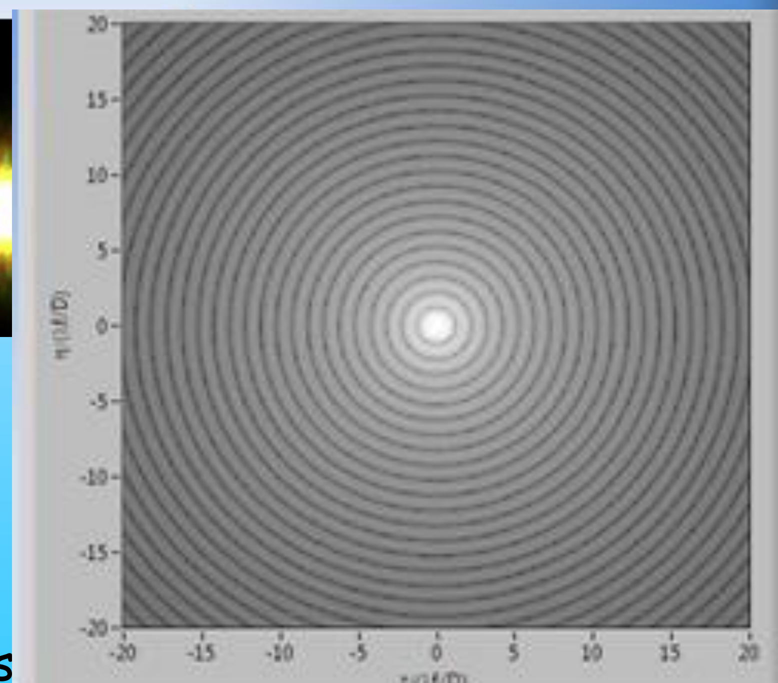

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Direct

, and

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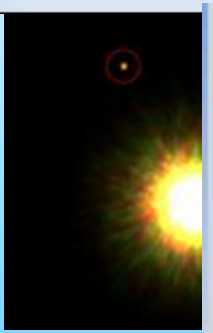

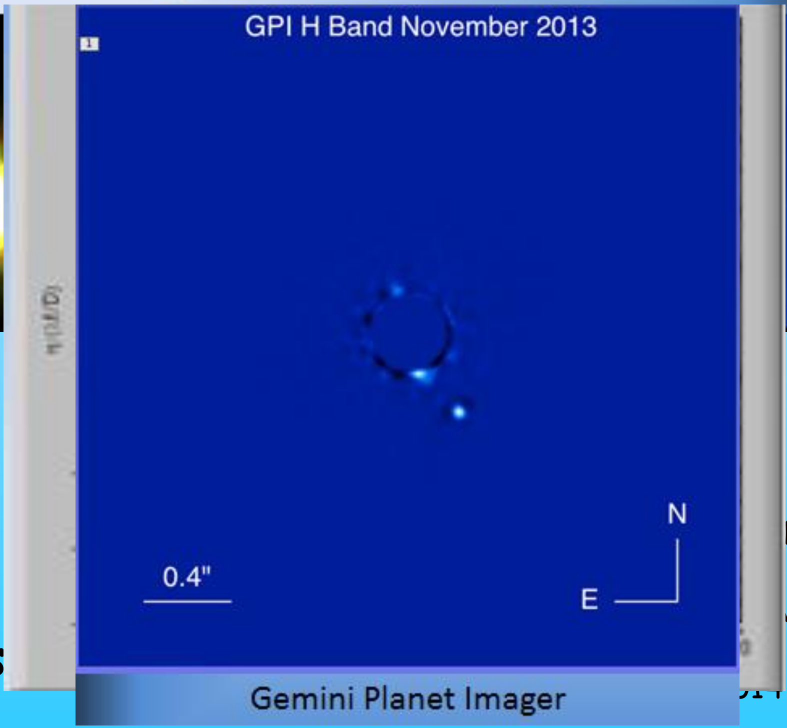

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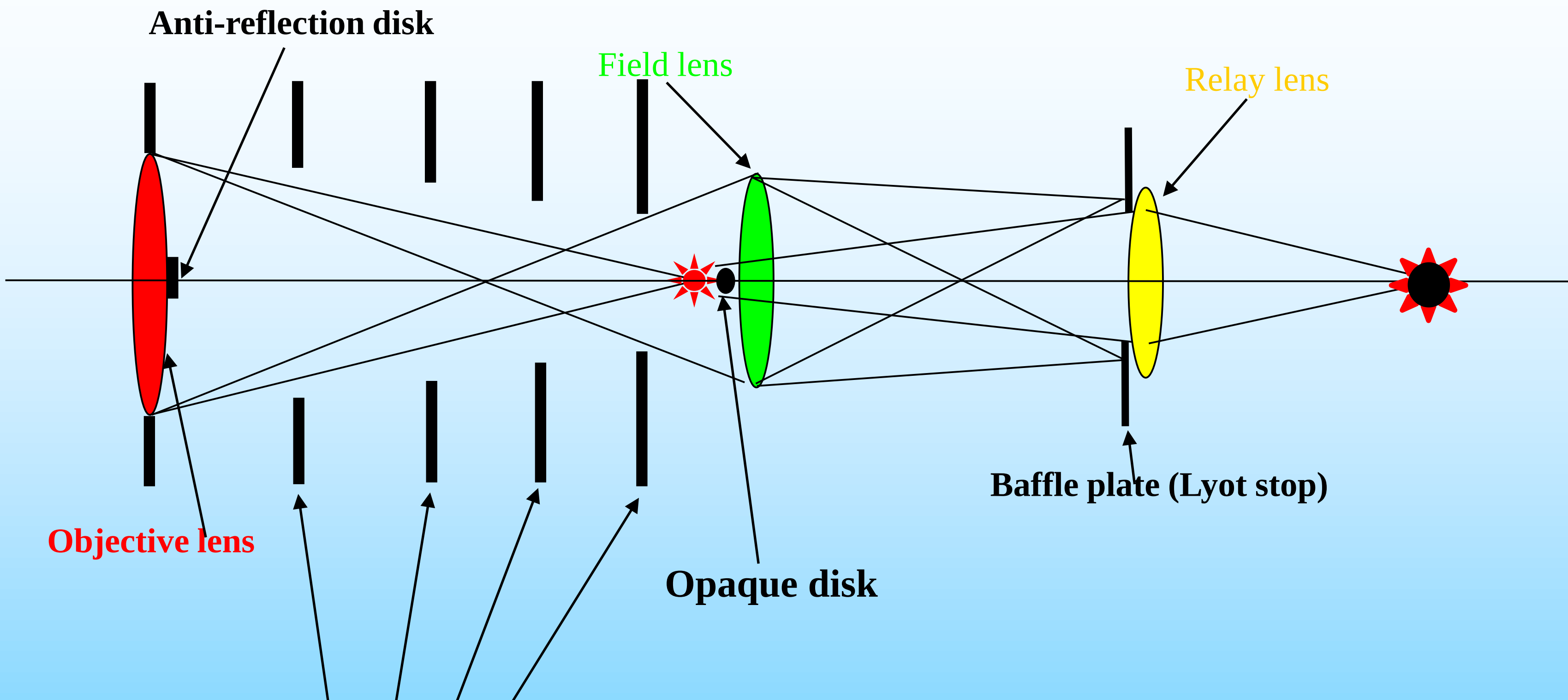
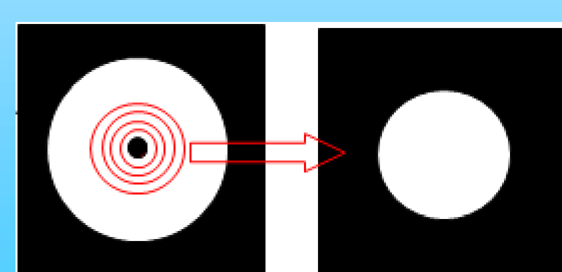
Direct

, and

, SLAC

Optical system of Lyot's coronagraph





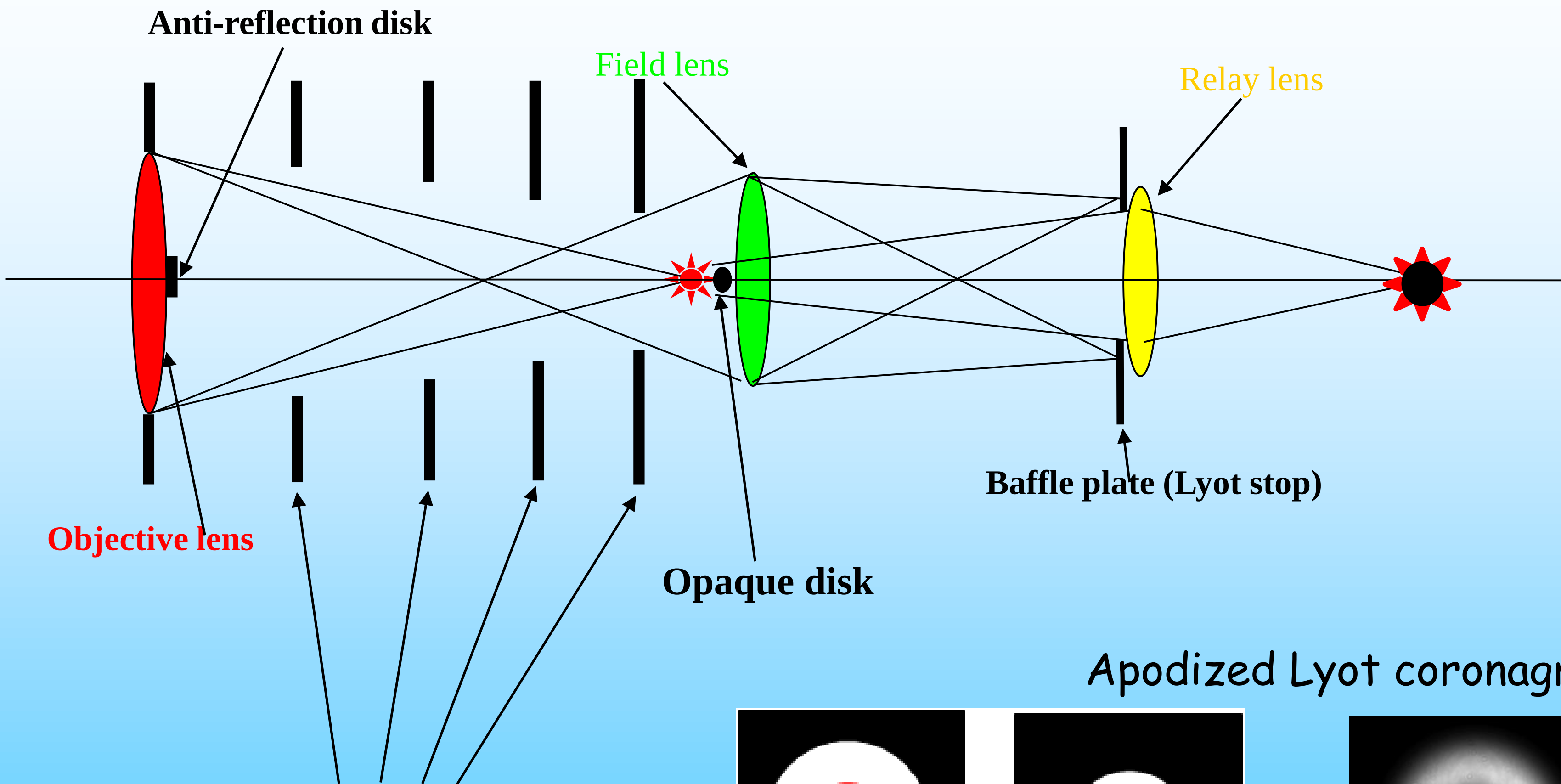
Blocking diffraction fringe by Lyot stop

T. Mitsuhashi, DIPAC2005 and
Halo Diagnostic Workshop 2014, *SLAC*

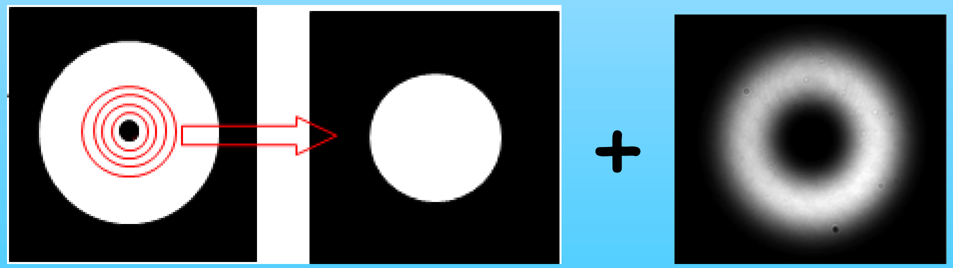
A STUDY OF THE SOLAR CORONA AND PROMINENCES WITHOUT ECLIPSES

(*George Darwin Lecture, delivered by M. Bernard Lyot, Assoc.R.A.S., on* 1939 *May* 12)

Optical system of Lyot's coronagraph



Apodized Lyot coronagraph



Blocking diffraction fringe by Lyot stop Apodizer

T. Mitsuhashi, DIPAC2005 and
Halo Diagnostic Workshop 2014, SLAC

A STUDY OF THE SOLAR CORONA AND PROMINENCES WITHOUT ECLIPSES

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Apodizer: Remove Airy disks caused by diffraction around an intensity peak, improving the focus

Observation of beam halo at the Photon Factory, KEK

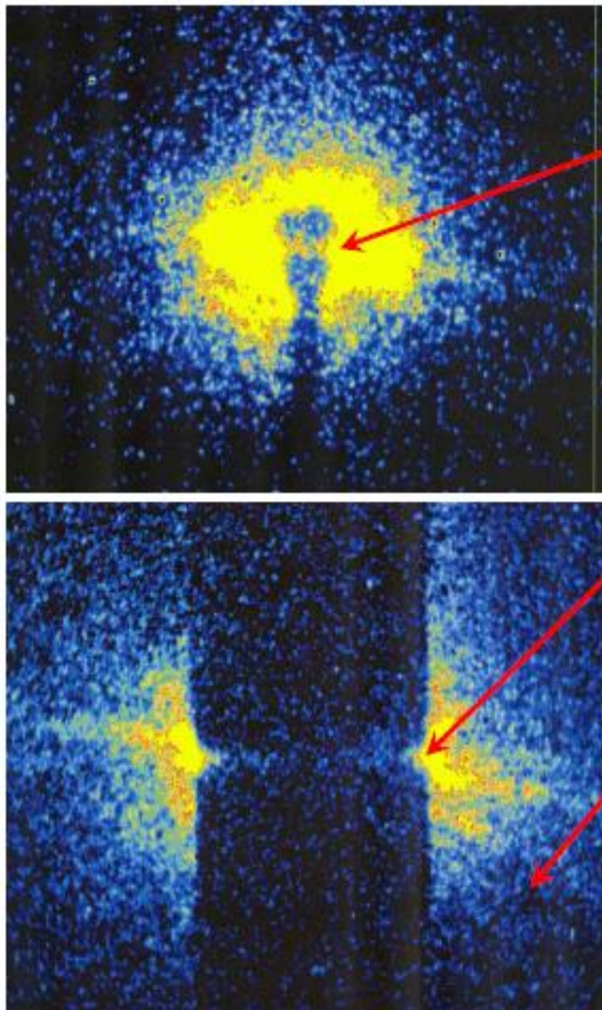
A background level of $6 \cdot 10^{-7}$ and a spatial resolution of 50 μm was achieved

Single bunch
65.8mA

Exposure time
of CCD : 3msec

Far tail

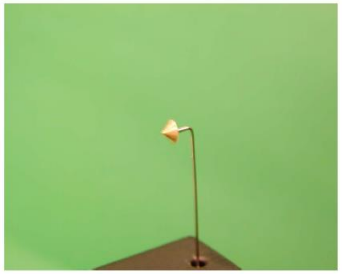
Exposure
time of CCD :
100msec



Intensity
in here :
2.05×10^{-4}
of peak
intensity

2.55×10^{-6}

Background
leavel : about
6×10^{-7}



Zoom up of opaque disk.

Shape is cone and top-angle is 45°

Finally

Contribution to the discussion session:

Finally

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- "The definition of halo is not important. What really matters is the source of halo"

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  What about the halo simulations?

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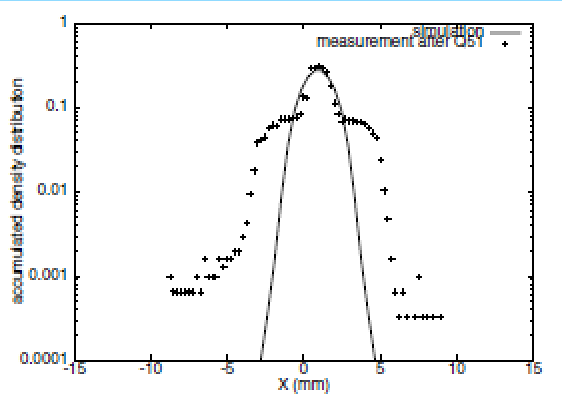
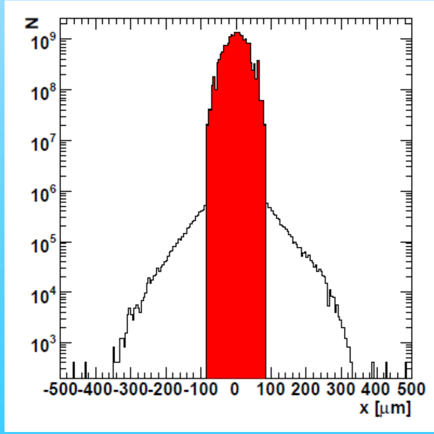
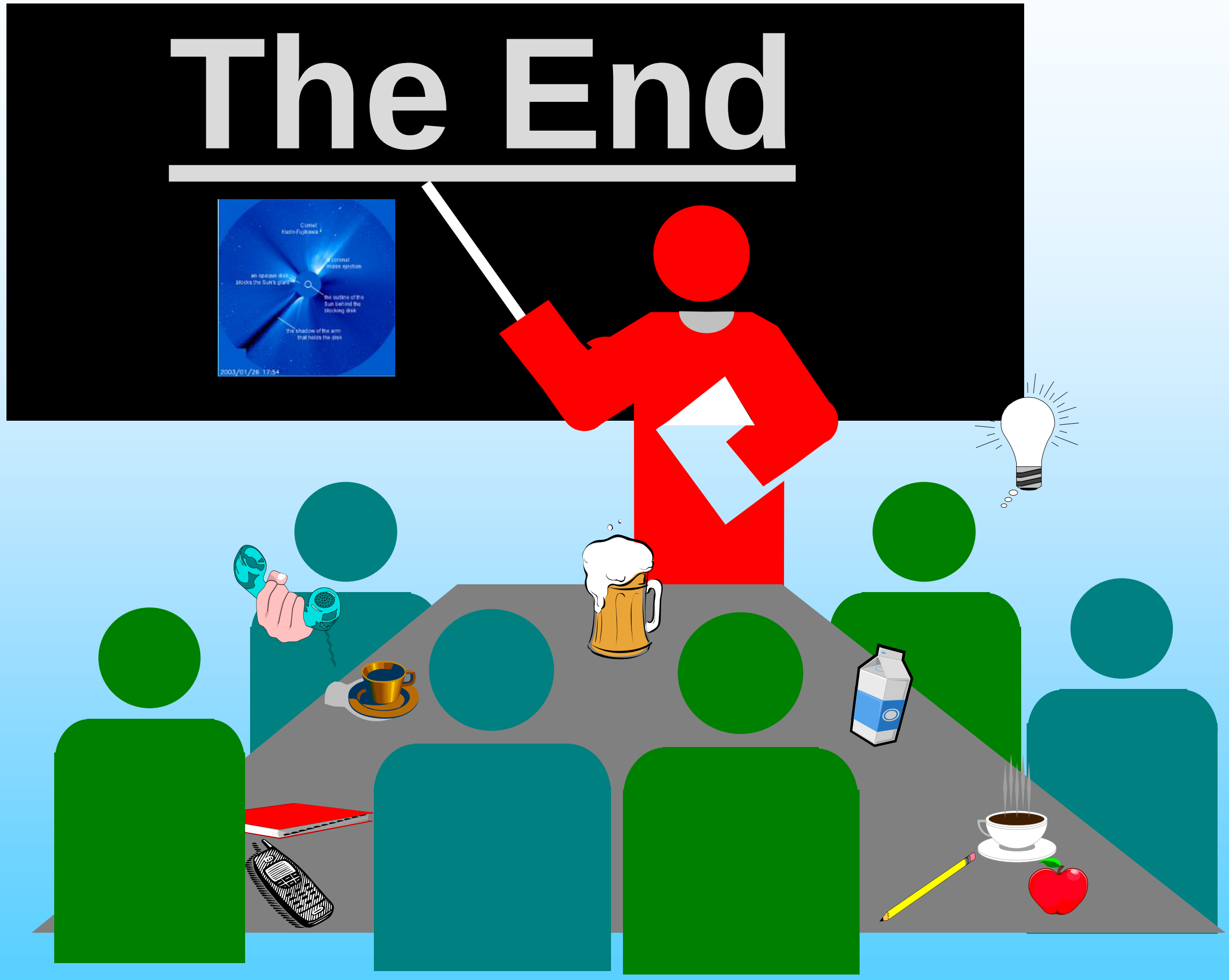
What about the halo simulations?

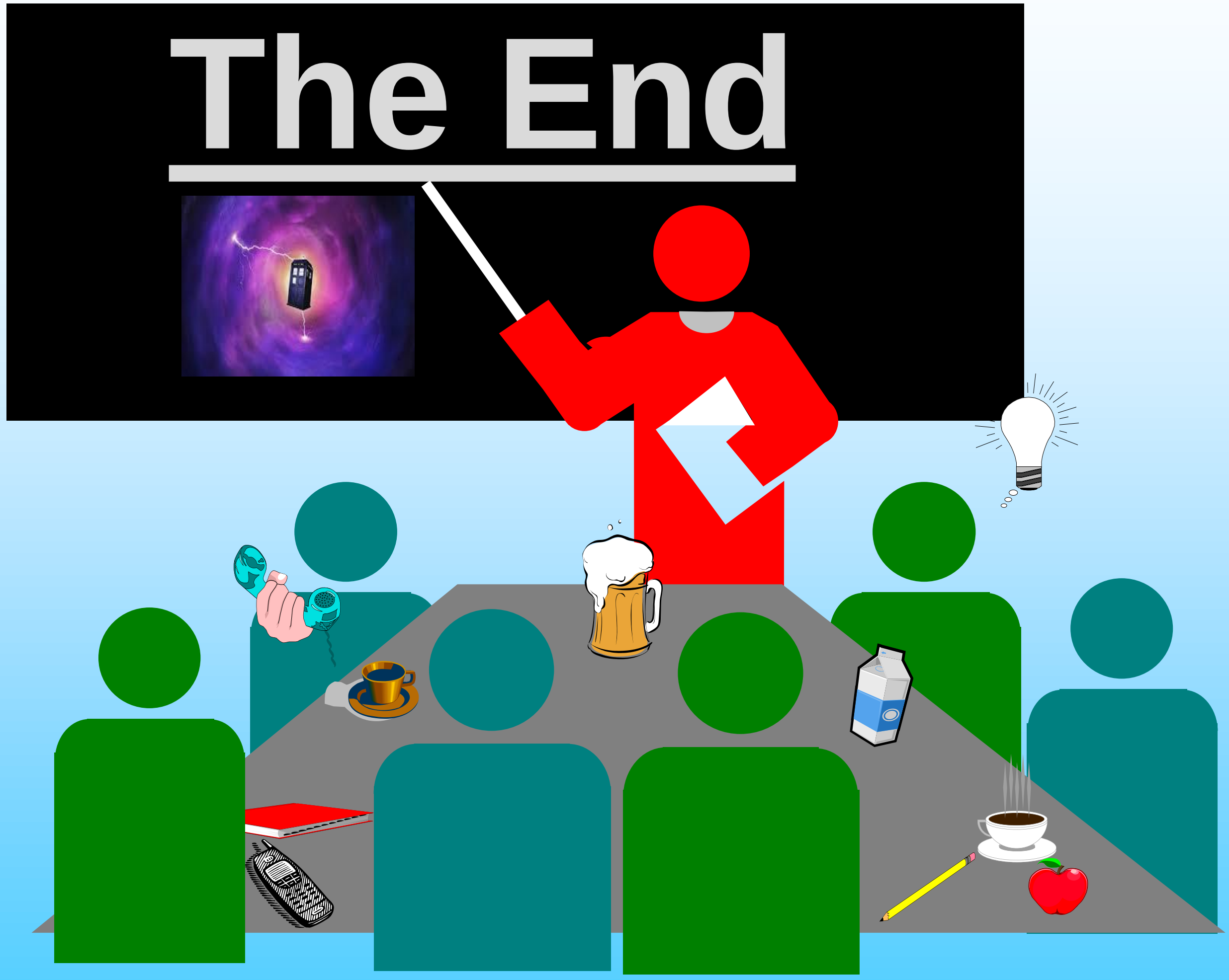


J. Qiang, et al., Macroparticle simulation studies of a proton beam halo experiment, *Phys. Rev. ST Accel. Beams,* **5** (2002)

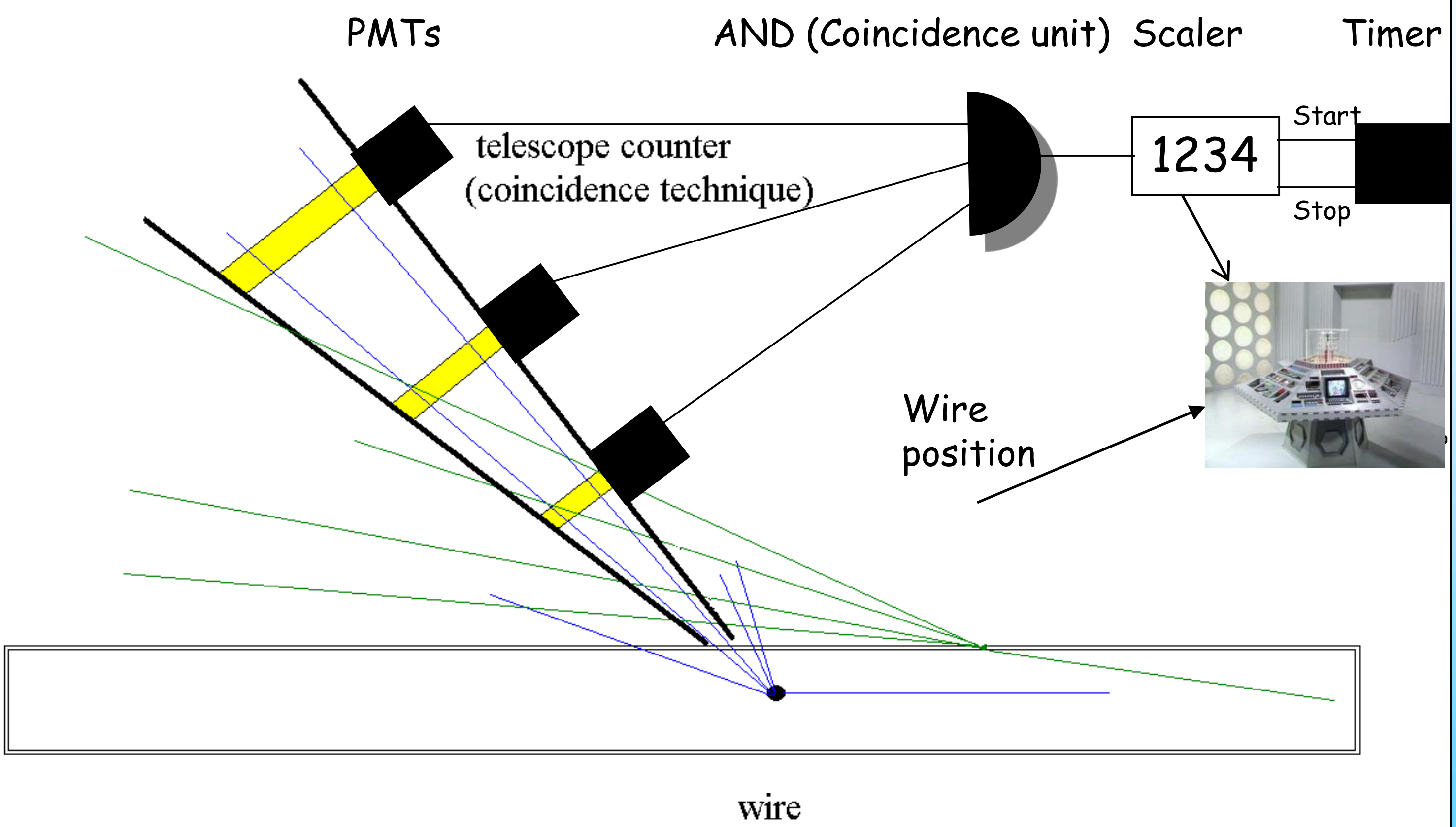


H. Burkhardt et al., HALO AND TAIL GENERATION COMPUTER MODEL AND STUDIES FOR LINEAR COLLIDERS, EUROTeV-Report-2008-076


The End


The End

Wire Scanners



Normalize counts to time interval!
Reduced background from dark counts and beam losses

Optical Methods;
X-Ray Synchrotron Radiation

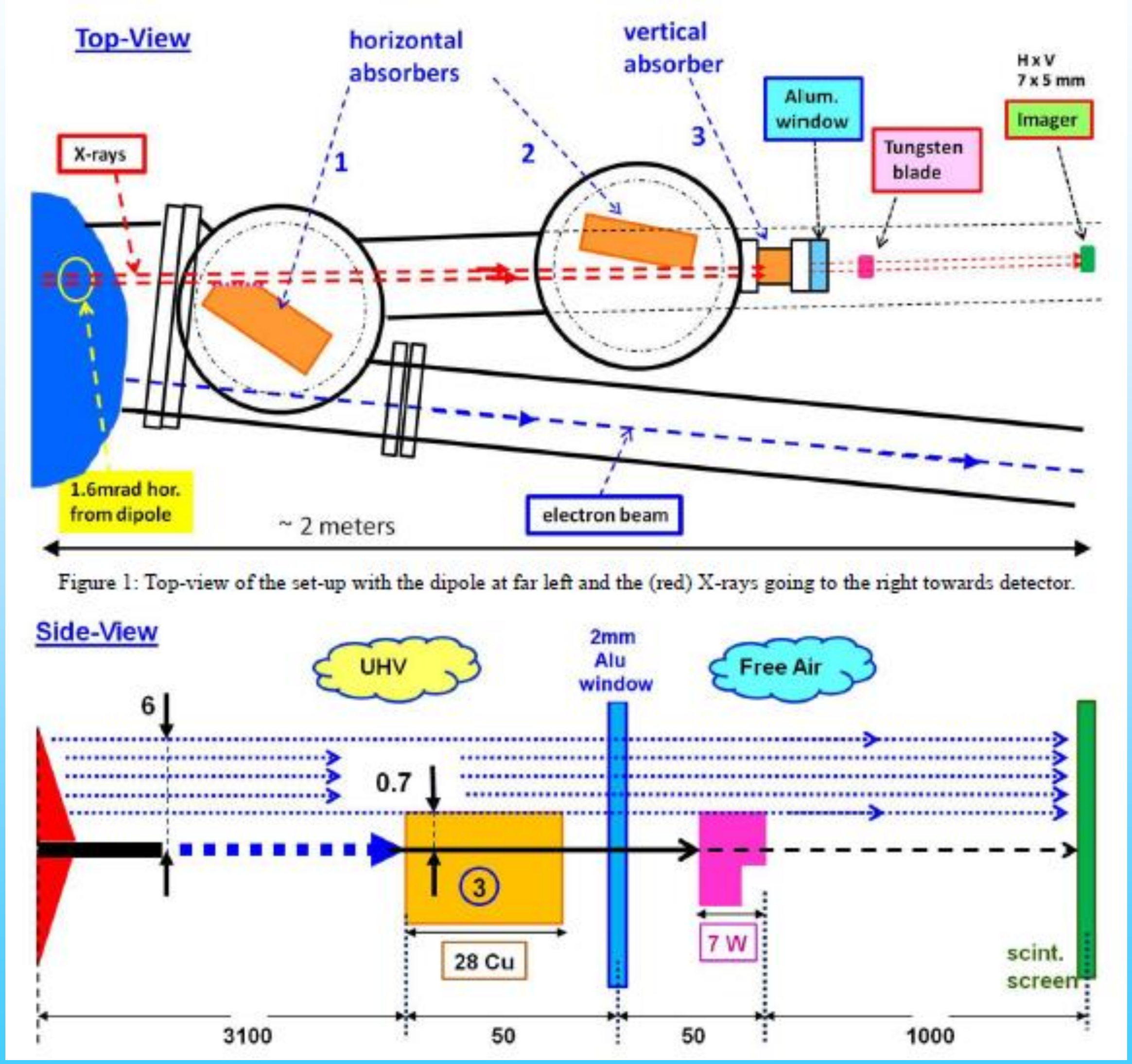
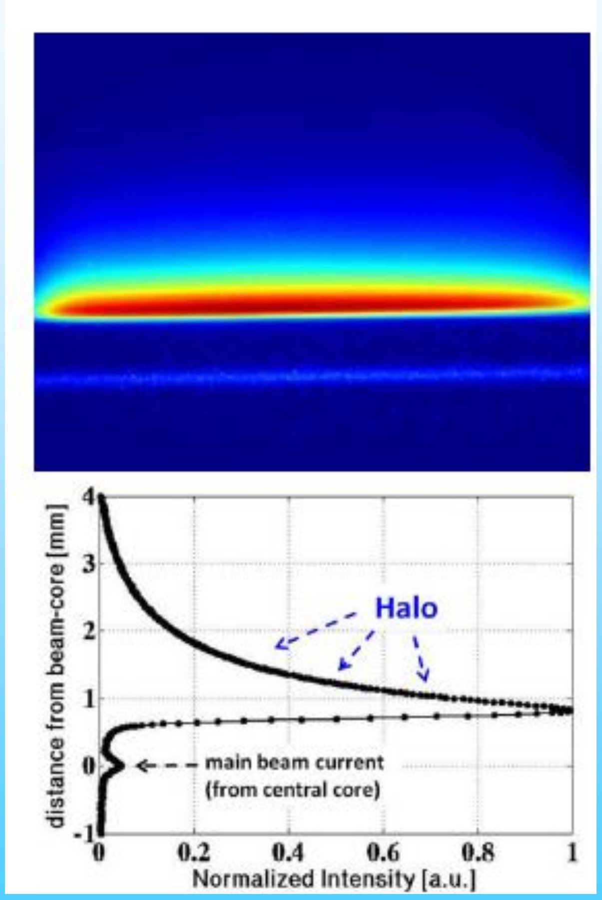


Figure 1: Top-view of the set-up with the dipole at far left and the (red) X-rays going to the right towards detector.

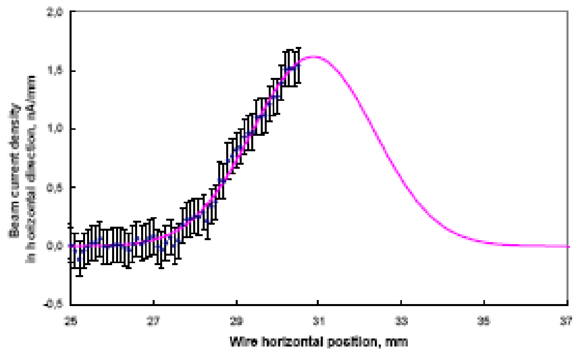


NON-DESTRUCTIVE VERTICAL HALO MONITOR ON THE ESRF'S 6GeV ELECTRON BEAM

B.K. Scheidt, IBIC2014

Vibrating wire scanner

VWS mounted on the vacuum below with 1 μm step motor feed



Scan of the electron beam at the Injector of Yerevan Synchrotron with an average current of about 10 nA (after collimation) and an electron energy of 50 MeV