Halo and Bunch Purity Monitoring
= Very High Dynamic Beam Profile Measurements;
Transversal and Longitudinal

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Outline

• Halo diagnostic:
  - What is Halo?
  - Halo Quantification

• Transversal Halo Measurements with:
  - IPM (Ionization Beam Profile Monitor)
  - LPM (Luminescence Beam Profile Monitor)
  - Laser
  - Wire Scanners and Scrapers (slow)
  - Optical Methods (fast)

• Longitudinal Halo
  - Bunch Purity
  - "Beam in Gap"
  - Coasting Beam

Monitors have not enough dynamic range.
Slides can be found after the last slide of talk
Outline

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What’s Halo?

...because of the beam distribution’s phase-space rotations, the observed halo in 1D oscillates, so that halo at different locations along the beam line is observable in differing degrees. 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 in the spatial projection. In most circumstances, the beam halo from simulation appears as an irreversible effect, when observed in the 2D phase-space distributions. Therefore, it is also important to search for another definition of halo in the 2D phase-space distributions....

...it became clear that even at this workshop (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....
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 and methods

Dynamic range > $10^5$

That’s not a halo, that’s a tail!
Dynamic range < $10^3$
Sources of halo are:
- space charge
- mismatch
- beam beam forces
- instabilities and resonances
- RF noise
- Scattering (inside beam, residual gas, macroparticles, photons, obstacles (stripping foil, screens), ...)
- nonlinear forces
- misalignments
- electron clouds
- etc.

What is Halo?

In storage synchrotrons, background due to halo can mask the rare physics processes and the experiment detectors are often the most radiation sensitive components in the accelerator. The beam loss threshold imposed by the most sensitive of the several experiments is often far below that imposed by activation of machine components.

A number of < 0.1‰ lost particles /bunch appears sometimes to be already critical (e.g. can cause harmful beam loss). We therefore require a beam monitor capable of measuring the transverse beam halo better than this. The required dynamic range is therefore of the order of $10^5$ or better.

Profile measurements are often questioned at the level of a few percent, the difficulty is easily seen in making halo measurements already at the level of $10^{-4}$ and beyond.
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**HALO QUANTIFICATION**

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

However, because of the beam’s phase-space rotations, the observed halo in 1D projections 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.

Used mainly in simulations

The excursions above the Gaussian level indicate a large halo.
• There is no clearly defined separation between the halo 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.
• A general characteristic of beam halo is the increased population of the outer part of the beam.
• Methods have been developed, and computationally studied, to characterize beam halo.

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

Note that a measurement always contains instrumental effects!!!! True for all methods!

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.

\[ k \equiv \frac{\langle (x-x_0)^4 \rangle}{\langle (x-x_0)^2 \rangle^2} - 2 \]

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.

 Might be not so well suited for us instrumental specialists.
HALO QUANTIFICATION

2) 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:

\[ f(x) = A \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right) \]

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 \( 1 \sigma \) gives a ratio of the tails to the core and, therefore, a quantitative measure of the halo present.

HALO QUANTIFICATION

3) Ratio of beam core to offset:
Fit the raw data to the function:

\[ f(x) = g(x) + l(x) \]

where

\[ g(x) = N \exp\left(-\frac{(x-x_0)^2}{2\sigma^2}\right) \]

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

\[ L = \int_{\text{detector}} l(x) \, dx \]

and

\[ G = \int_{\text{detector}} g(x) \, dx \]

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 \( L/G > 0 \).
Distribution of L/G values in the Fermilab Booster with and without the linac collimators. (Measured with an IPM)

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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, and the prime example is the wire scanner.
2. Devices that contribute to the diagnosis of machine conditions that cause halo formation, and an example would be a tune measurement system.
3. Devices that measure the effects of halo development, and an example would be the loss monitor system.

Halo Measurements

Transversal Halo Measurements

Transversal Halo Measurements with:
- Wire Scanners and Scrapers (slow)
- Optical Methods (fast)

For
- IPM (Ionization Beam Profile Monitor)
- LPM (Luminescence Beam Profile Monitor)
- Laser
see slides after the end.

Their dynamic range end at about $10^3$!
Wire Scanners and Scrapers

- Used around the world, focus here: Dynamic range and sensitivity
- Problems are well known: Emittance blow up, wire heating.
- Readout by Scintillators and/or SEM
- Huge dynamic range by:
  - Log-amplifier (PSR)
  - Wire + Scrapers (LEDA)
  - Scanning + counting (J-Lab, DESY, AGS)
  - Scraping with collimators (LEP)
  - Other methods

- **Real Halo Measurements**

Wire Scanners at LEDA
(Proton LINAC, SEM readout)

WS can move a 33-μm carbon mono filament and two halo scraper consisting of two graphite scraping devices (one for each side of the distribution).

The high-heat flux testing performed on the prototype scrapers revealed that the design can withstand the thermally induced fatigue loading. The peak heat flux that these scrapers have experienced in actual service is approximately 600 kW/cm².
To plot the complete beam distribution for each axis, the wire scanner and two scraper data sets must be joined. To accomplish this joining, several analysis tasks are performed on the wire and scraper data including:

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 (simple if on same fork)
5. Normalize data to beam current and beam position (true for all kind of halo measurements)!!!

Before scan: define safe scraper insertion limits (avoid too much heat load) by wire scan data. In SEM mode avoid thermal electron emission!

Procedure explained in:

**ANALYSIS OF DATA FROM THE LEDA WIRE SCANNER/HALO SCRAPER**


PAC2001
Wire Scanners

to 2: **Wire and scraper data are acquired with sufficient spatial overlap**
The first step in joining the scraper data to the wire scanner data is
determining where the data sets overlap. The overlap region consists of
wire scanner locations ranging from where the wire scanner signal-to-noise
ratio is greater than 2 to the maximum insertion location of the scraper.

to 3 and 4: **Differentiated scraper data are normalized to the wire beam core data and**
**Normalize data to axis**
Once the region of overlap has been determined, the scraper data must be
normalized to attach it to the wire scanner data. The scaling factor is the average
of wire scanner to halo scraper signal ratios at two of the three most-inboard points in the
overlap region (the most inboard point is excluded). Once scaled, the entire scraper data set is
thinned by keeping only every Nth scraper point and attached at the connecting points.
Measurements of wire to scraper distances were carried out in Lab. with an
uncertainty of 0.25 mm. This implies a positional attachment uncertainty of
0.25 mm. At this point, the resulting three distributions have been
combined into a single distribution with uniform step size.

**Wire Scanners and others**

to 5: **Normalize data to beam current and beam position**
Each data point has to be normalized to the measured beam current and
beam position for each measurement.

*Diagram showing plots of beam loss rates versus scraper position. The word movement
causes an artificial deviation in the measurement results.*
Wire Scanners at LEDA

Y-axis wire scan

Combined distribution in y.

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

Wire Scanners at PSR

linear amplification and $10^5$ dynamic range
$\Rightarrow$ 16-bit D/A converter

As an alternative solution is to process the integrated signal using a logarithmic amplifier. The log amplifier allows the use of standard 12-bit A/D converters.

A normal function shown in solid blue has been fit to the data (red x). 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.
Wire Scanners

Counting mode, bunch by bunch

Telescope Operation at the extracted beams (AGS)

Solid angle remains the same through scan
Narrow acceptance, reduces noise.
Telescope acceptance about $10^{-4}$ steradian.
Wire Scanners

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

Wire Scanners at Jefferson Lab

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

Figure 4. Beam Profile combining the 25cm 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 25cm wire data, the green points the 1mm wire data, the blue curve is the overall fit to the data and the red curve is the halo portion of the fit. The enthalpy is plotted with a log-scale and the beam 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.

**Saturation**

\[
\text{Position} \quad \text{normalized counts}
\]

\[
\begin{array}{c}
6 \sigma \\
4.1 \sigma \\
2.26 \sigma \\
\end{array}
\]

**Dynamic range:**

\[10^7\]

**Saturation effects**

**Rate:** [Counts/bunch] [Counts/s]

<table>
<thead>
<tr>
<th>Position</th>
<th>Center</th>
<th>1 σ</th>
<th>2 σ</th>
<th>...</th>
<th>Useful range</th>
<th>6 σ</th>
</tr>
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<tr>
<td>N⁺</td>
<td>1.484·10¹⁰</td>
<td>1.487</td>
<td>1.492·10¹⁰</td>
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<td></td>
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<td></td>
<td>8.968·10⁹</td>
<td>8.999</td>
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<td></td>
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<td>4.978·10⁶</td>
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<tr>
<td></td>
<td>2.28</td>
<td>2.2·10⁻⁵</td>
<td>2.361</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[N = n_{\text{bunch}} \cdot \int_{-\frac{\sigma}{2}}^{\frac{\sigma}{2}} \frac{1}{\sqrt{2 \pi \sigma_x}} \exp \left(-\frac{x^2}{2 \sigma_x^2}\right) \, dx\]

N = protons intersecting wire area  
\(\sigma = \) beam width (0.527 mm)  
d' = wire diameter (7 mm)  
NBunch = 2.8 * 10¹⁰ protons  
Bunch Rate R₈ = 10.4 MHz  
limits the max count rate

**Signal efficiency of \(\varepsilon = 10^{-7}\)**

Eff = N · \(\varepsilon\),  
Signal Rate S = Eff · R₈
Scraping by collimators

In a synchrotron one jaw will scrape both sides of the beam distribution (β-oscillation) \Rightarrow measure symmetric halo
Such a tail scan yields information about particles which oscillate with an amplitude larger than the position of the collimator

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.
Other sensitive, high dynamic halo monitors

- Direct measurement by inserting monitor or by an intercepting monitor

But a normalization to the beam core has still to be done (like in scraping measurement.)

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 mA (after collimation) and an electron energy of 60 MeV

6σ 1: frequency, 2: beam current, 3: position, 4: PMT rates
Vibrating wire scanner

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Optical methods

Light generation by SR, OTR, Phosphor screens, ...

Very fast compared with scanning methods

- Large dynamic range readout
  - CID camera
  - Micro Mirror Array
- Halo measurements with coronagraph

CID Camera

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 ($\sim 10^6$) can be achieved.

Comparison

![Comparison Graph]

Optical methods

![Optical Methods Chart]

SPECTRACAM XDR: High resolution scientific imaging camera system using Charge Injection Device capable of extremely high dynamic range and random pixel addressing.
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.
(1) Acquire profile
(2) Define core
(3) Generate mask
(4) Re-Measure

**Micro Mirror Array**

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

**Optical methods**

Convolution between diffraction fringes and beam profile
A coronagraph is a telescopic attachment designed specifically to block out the direct light from a star, so that nearby objects can be resolved without burning out the telescope’s optics. Most coronagraphs are intended to view the corona of the Sun. The coronagraph was introduced in 1930 by the astronomer Bernard Lyot.

The simplest possible coronagraph is a simple lens or pinhole camera behind an appropriately aligned occulting disk that blocks direct sunlight. During a solar eclipse, the Moon acts as an occulting disk and any camera in the eclipse path may be operated as a coronagraph until the eclipse is over.

http://en.wikipedia.org/wiki/Coronagraph
When using OTR or SR (narrow cone) the diffraction fringes makes tail surrounding from the central beam image. Intensity of diffraction tail is in the range of $10^{-2} - 10^{-3}$ of the peak intensity. The diffraction tail disturb an observation of week object surrounding from bright central beam.

Following pictures from a talk:
BEAM HALO OBSERVATION BY CORONAGRAPH. T. Mitsuhashi, DIPAC 2005
Photon Factory storage ring

Lyot's brilliant idea for the coronagraph is to remove this diffraction fringe by a mask, and relay the hidden weak image by a third lens onto the final observation plane.

The Lyot stop effectively remove the diffracted light halo that surrounds the target, giving higher contrast improvement.

The first lens (objective lens) makes a real image of the object (beam image) on to a blocking opaque disk.
Halo measurements with coronagraph

Lyot’s brilliant idea for the coronagraph is to remove this diffraction fringe by a mask, and relay the hidden weak image by a third lens onto the final observation plane.

The Lyot stop effectively remove the diffracted light halo that surrounds the target, giving higher contrast improvement.

Then the re-diffracted light makes another diffraction fringe around the geometrical image of the objective lens aperture in the focal plane of the field lens. The Lyot stop removes this diffraction fringe by a mask, and relay the image by a third lens onto the final observation plane.
Halo measurements with coronagraph

**Expected dynamic range:** $10^6 - 10^7$

**Zoom up of opaque disk:** Shape is cone and top-angle is $45^\circ$

**Beam profile**

**Beam tail**

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**Halo measurements with coronagraph**

**Observation for the more outside**

- **Single bunch 65.8mA**
  - Exposure time of CCD: 3msec
  - Intensity in here: $2.05 \times 10^{-4}$ of peak intensity

- **Far tail**
  - Exposure time of CCD: 100msec
  - Background level: about $6 \times 10^{-3}$
Halo measurements with coronagraph

Background sources
1. Scattering by defects on the lens surface (inside) such as scratches and digs.
2. Scattering from the optical components (mirrors) near by coronagraph.
3. Reflections in inside wall of the coronagraph. Cover the inside wall with a flock paper (light trapping material).
4. Scattering from dust in air. Use the coronagraph in clean room.

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

LIMITATIONS
- OTR light intensity was not intense enough to explore further the halo distribution (CTF3).
- The masking technique must follow the beam position and halo size to avoid the saturation of the camera.

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  - **Bunch Purity:** Time-Correlated Single Photon Counting (TCSPC)
  - “Beam in Gap”
  - Coasting Beam
Measurement of the sometimes special fill pattern of synchrotron light sources (rings) is important for the time-resolved experiments. The adjacent buckets must not have any stored particles or, in reality, as few as possible. A method with very good time resolution (< 1 ns for a 500 MHz RF-System) and high dynamic range (more than six orders of magnitude) is necessary.

Mechanism of losing electrons
1) Quantum lifetime. An electron is lost from a bucket by emitting a photon having a momentum larger than bucket height $\eta_{RF}$ and can be captured by the backward buckets.
2) Lifetime determined by the vacuum pressure. Electrons lose energy by collisions with residual gas molecules in the vacuum chamber.
3) Touschek effect. Electrons in a bunch execute betatron oscillation with transverse momenta. When two electrons are scattered elastically (Moller scattering), the transverse momenta can be transferred to longitudinal ones.
4) Injection errors (energy, timing). At top-up a source of impurity growth on the both time sides of the main rf buckets.

A typical measurement is a time-correlated single photon counting method (TCSPC):

TCSPC

PETRA II setup: “The parasitic bunch measurement is achieved by an avalanche-photo diode (APD) detecting scattered X-rays from a 1 mm thick graphite foil. It is located in the PETRA beaml ine 31.3 m downstream of a dipole used as x-ray source. The detector signals are amplified close to the diode by a fast amplifier. “

The detector must be carefully shielded against stray light.
The arrival time of single photons emitted by the electron bunches passing through a particular dipole in the storage ring is measured. The photon arrival time is measured relative to a clock pulse which is synchronized to the bunch revolution frequency via the storage ring RF system.

The amplified signal is analyzed using a time-to-digital-converter (TDC) and a multichannel-analyzer (MCA). To reduce the influence of the so-called “walk” and to reduce the background due to electronic noise the amplified detector signal is filtered by a constant-fraction-discriminator (CFD).

TCSPC

The TDC-board offers 4096 channels with minimum width below 40 ps and can work at count rates up to 3 MHz (300 ns recovery time). To measure a histogram not affected by recovery-time and pile-up effects, the detector count rate should be limited to below 1.5% of the sync rate.

Bunch distance = 10 MHz, count rate = 10 kHz, expected dynamic range: $10^7$ => time to resolve $1/10^7 = 100$ sec, with better statistic => $1000$ s = 16 min!!!
Improvements:

1) Better TDC: The HydraHarp 400 ps event timer & TCSPC. The system features a time resolution down to 1 ps. A common sync input for all channels permits to use the system for TCSPC in forward start-stop mode at stable excitation sources up to 150 MHz.

2) Use of MCP-PMT for better detector timing

http://www.picoquant.com/_instrumentation.htm
APD: The average over many events is shown (smooth curve) as well as two single-photon events to show an indication of the noise level. Scale: 50 mV (upper) 100 mV (lower) and 5 ns/div.

typ. dark count rate 20-500 c/s


Pile up:

The number of electrons is nearly the same in the bunches of the train, but the measurement shows a decreasing number in the first bunches, down to a minimum value, followed by a flat top for the rest of the bunches. This effect is due to a too high count rate of 4.5 \times 10^6 \text{ counts/s}. At this rate, a photon arrives every 220 ns on average: this is comparable to the dead time of the PicoHarp 300 (95 ns). As a result the probability of a photon from one of the first pulses to be detected is significantly larger than for the rest of the train.
Instrumental effects:

**MCP-PMT after pulses**

**Spring-8:**
Huge dynamic range with fast optical light shutters (Pockels cells), selecting only one bucket. Measuring time: 500 s for satellites.
Main peak is suppressed by $10^{-5}$ due to shutter efficiency.

$=>$ Dynamic range $\approx 10^{10}$

**Growth of bunch impurity during top up at Spring-8:**
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Beam in Gap
Proton storage rings

If beam (AC or DC) in gap, extraction kicker ramp will spray beam \( \Rightarrow \) will result in:
- Quenches (SC-magnets)
- activation
- spikes in experiments
- equipment damage
- ...

Beam in Gap (hadrons) due to:
- Injection errors (timing)
- debunching
- diffusion
- RF noise/glitches
- ...

Temporal Loss Distribution by Synchrotron Radiation
Successful test at ALS for LHC with gated MCP/PMT (AC beam).
More tests at TEVATRON with MCP-PMT in counting mode (more sensitive, DC beam).

Studies with Single-Photon Avalanche Detectors for LHC are ongoing.
Coasting beam
Hadron beams, rings

DC current (upper) and total bunch current (lower)

**Tevatron:** 980 GeV protons and antiprotons lose about 9 eV/turn due to the SR. For uncaptured beam particles, this energy loss is not being replenished by the rf system, so they slowly spiral radially inward and die on the collimators, which determine the tightest aperture in the Tevatron during collisions. The typical time for an uncaptured particle to reach the collimator is about 20 minutes. The total uncaptured beam intensity is a product of the rate at which particles leak out of the main bunches and the time required for them to leave the machine.


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Coasting beam
Measured by temporal beam loss distribution

**HERA-B:** Wire scanners + Counters + TDC (only in beam tails)

Uncertainty due to meas. in halo!

Detection efficiency > 50%
Note the increased rate in the Bunch gaps (=coasting beam)

Coasting beam and bunch impurity

Another method: Fast wall current monitor
**Coasting beam**

CDF (FNAL): "normal" losses + Counter + variable Trigger delay

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} not mentioned: Abort Gap Cleaning by Kickers (fast or resonant) Electron lens
Summary

Transversal Halo

- Wire scanners still "state of the art" instruments for very high dynamic range up to $10^8$ or more.
- SR with CID and coronagraph has potential to more dynamic range.
- IPM and LPM sufficient for profiles but background and instrumental issues limit use for halo.
- Laser work well for H- beams.

Longitudinal Halo

- Bunch purity measurements with $>10^{10}$ dynamic range
- Beam in Gap: SR limited to high energy beam
- Wire scanners are very sensitive but applicable in trans. halo only

Introduction

What is Halo

HALO ESTIMATES AND SIMULATIONS FOR LINEAR COLLIDERS, H. Badertscher et al, EUROTeV-Report-2007-064, CLIC Note-714
Halo Diagnostics Summary, P. Cameron, K. Wittenburg, Haloid
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Halo Measurements with Ionization Profile Monitors (IPM)
Modern IPMs use strong magnet field $B_g$ and high voltage ($E_{ext} \leq 100$ kV/m) to overcome space charge distortion! However typical strength of the electric field is about 250kV/m around the beam.

\[ \sigma = 1.393 \text{ mm} B \ 20\% \]
\[ \sigma = 0.777 \text{ mm} B \ 100\% \]

Ionization Profile Monitor

Emphasis on
1. Development of a proper electromagnetic guiding system design (transversal and longitudinal) for sub-mm resolution.
2. New MCP calibration scheme with EPG (Electron Generator Plate (Burle Inc.) or tungsten filaments.
3) Improved optical design done with the ZEMAX Program (CERN)

- IMP still overestimates beam size
- Resolution not better than 100 μm
- Many Profiles show tails (artifacts?)
- Dynamic range did not exceed $10^3$

The Fig displays the absolute difference between the beam size measured by the IPM and the expected value at the IPM location derived from the Wire scanner measurements.
Dynamic range did not exceed $10^3$.

- CERN: Results of scraping vertically 1% of the distribution of a beam of $2.6 \times 10^{12}$ protons as seen by the IPM.

- J-Parc RCS: Idea to use additional MCP arrangement with lower resolution but high gain for halo observations.

Luminescence Profile Monitor (LPM)
Luminescence Profile Monitor

- Gas Jet needed in most cases (H₂ or N₂)
- Sensitive multi anode PMT needed, therefore limited resolution (10⁻⁸ mbar).
- PEFP (Proton Engineering Frontier Project) use CCD camera at 4 ⋅ 10⁻⁵ mbar
- Insensitive to electric and magnetic fields (space charge of beam, ext. fields)
- Limited dynamic range due to tails, high background and week signal
- COSY used shield against stray particles and light

Luminescence Profile Monitor

I.P.H.I: We have to carry on additional experiments in order to understand more accurately the observed beam profiles. Huge background from several secondary processes. Try to discriminate background from real profile by Doppler shift of Balmer series.

Example: Ion source 100 keV, 100 mA protons
P. Assiot et al. (Orsay/Saclay)

Profiles from different gases

=> Instrumental effects make it useless for Halo determination.
Laser Profile Monitor

- Used for ions at SNS and J-PARC (beside electron beams (Compton))
  - H+ beam photo neutralization
  - Collecting electrons
- SNS:
  - Profiles down to $3\sigma$, dynamic range $\geq 10^3$

Laser Profile Monitor

- Halo Issue: Mechanical drift and vibration (SNS)
  - Compensation scheme foreseen, main frequencies up to 10 Hz