USPAS Case Study: Beam Halo

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What is a Beam Halo?

- There is no exact definition of a beam halo.
- It depends on the system and the definer.
- For this presentation, we will make several assumptions:
  - *The beam has a Gaussian shape.*
  - *It is a continuous beam in a storage ring.*
  - *The beam halo only includes particles beyond 4σ.*
  - *The beam halo is only in the transverse plane.*

How is a Beam Halo Formed?

- Particle processes
  - Collisions, gas scattering, (quasi) elastic and inelastic Bremsstrahlung, thermal photon, beam instabilities and resonances, etc.
- Optics related
  - Mismatch, coupling, dispersion, non-linearities (requires tracking for the "real" machine)
- Beam hitting RF surfaces
- Capture losses at the beginning of the ramp, RF noise, out-of-bucket losses, injection losses, and dump losses

Parameters that Define the Beam

- Several factors change the shape of the beam, and therefore the shape of the beam halo:
  - Magnetic/electric fields
  - Elements in the beam pipe
  - Beam instabilities
- Examples of beams defined by other parameters:

	LHC	HL-LHC	FCC-hh
Cms Energy [TeV]	14	14	100
Luminosity [$10^{34} cm^{-2} s^{-1}$]	1	5	5
Bunch Distance [ns]	25	25	25
Background Events/bx	27	135	170
Bunch Length [cm]	7.5	7.5	8

Energy Stored in a Beam Halo

- In a circular beam, the energy stored in the beam halo can be calculated using

$$E_h = E_b\left(1 - \int_{-4\sigma_x}^{4\sigma_x}\int_{-4\sigma_y}^{4\sigma_y} f(x,y)dxdy\right)$$

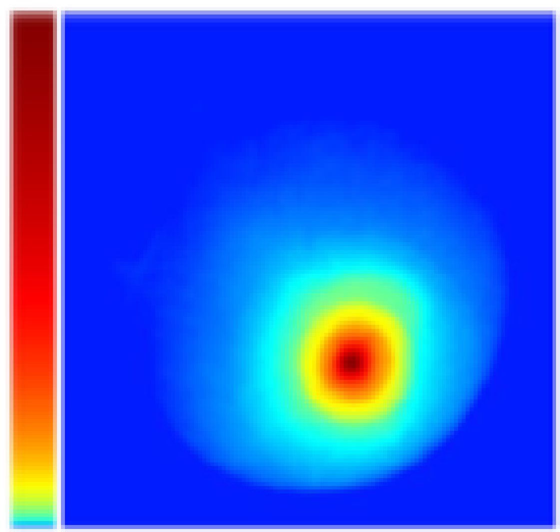
$$E_h = E_b(1.2668 \times 10^{-4})$$

$E_h = energy\ of\ the\ beam\ halo$
$E_b = energy\ of\ the\ total\ beam$
$f(x,y) = Gaussian\ function$

	LHC	HL-LHC	FCC	Tevatron
E_b [MJ]	360	678	8000	2
E_h [kJ]	45.6	85.9	1013	0.253

Motivation for Monitoring the Beam Halo

- To know the position of the beam.
- To measure the emittance, know the quality of the beam.
- To predict and prevent potential damage.



Methods to Monitor the Beam Halo

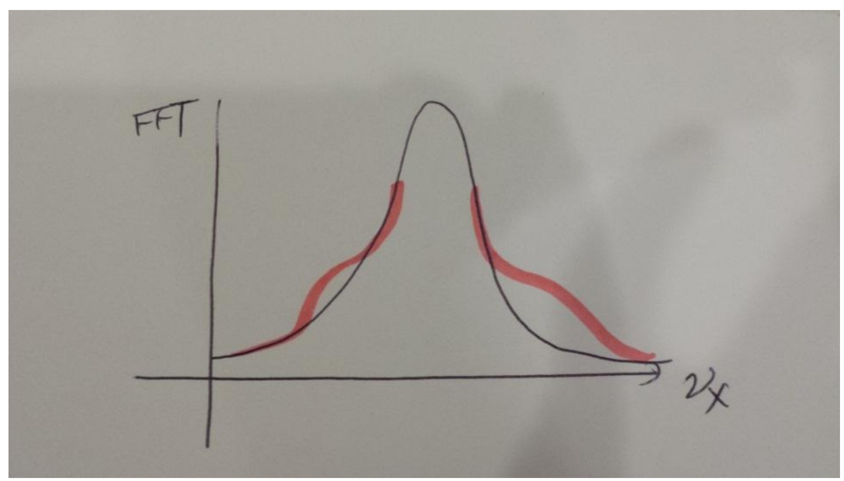
- Harps (wire scanners)
- Using secondary photons
  - Particles hit material, secondary photons are measured
- Aperture Monitors measure beam halo
  - Intercepts fraction of the beam near the aperture
    - Thermocouples

Our Own Design for a Beam Halo Monitor

- Use BPM
  - Measure frequency spectrum dependence

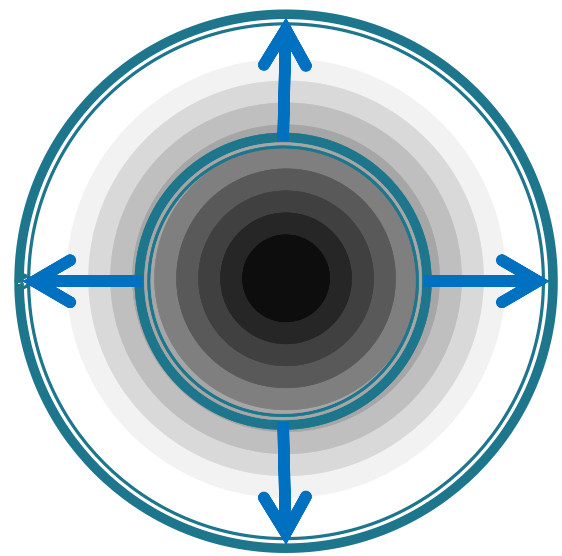
$$\bar{x}(t) = \int d\,J_x \rho(J_x) exp[2\pi i(v_{x0} + a_{xx}J_x)t]$$

$$\rightarrow \rho(J_x) = \int dt\,\bar{x}(t) exp[-2\pi i(v_{x0} + a_{xx}J_x)t]$$



Our Own Design for Beam Halo Monitoring

- Electric field pulls halo away from beam center without affecting beam
- Pull halo particles into separate path & clean out the bad particles

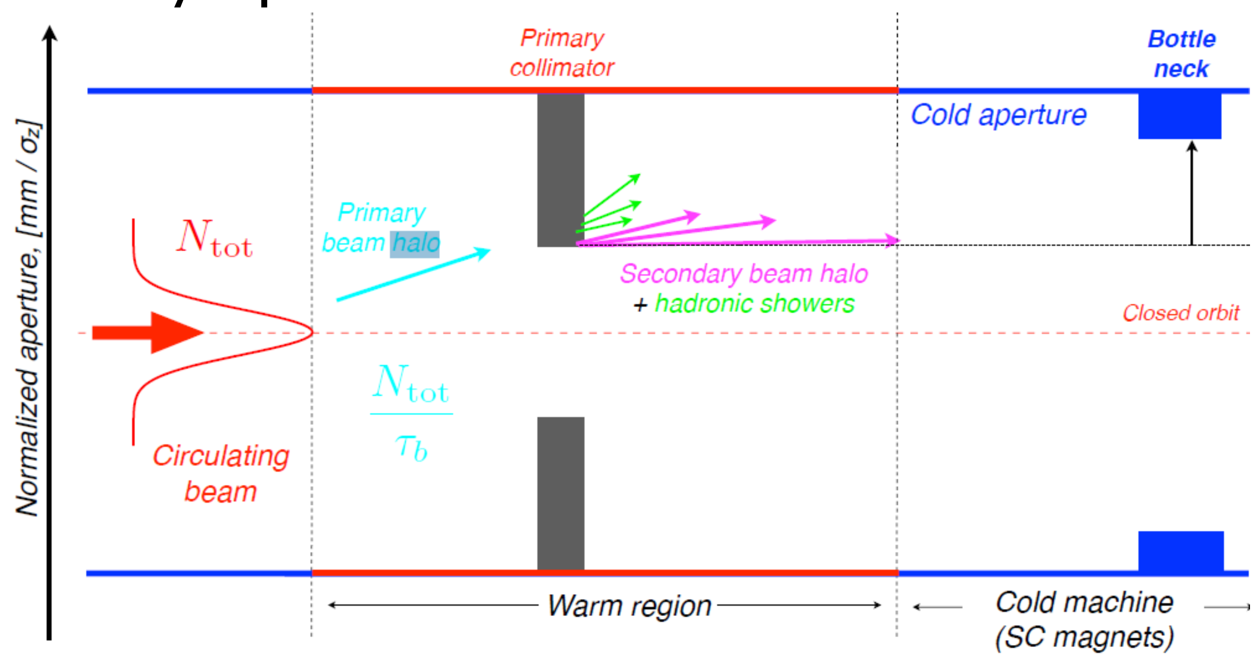


Motivation for Cleaning the Beam Halo

- Minimize the impact of halo losses
- Optimize the background in the experiments
- Handle the losses rather than losing the beam in an uncontrolled way
- Controlled and safe way to dispose of beam halo particles produced by unavoidable beam losses

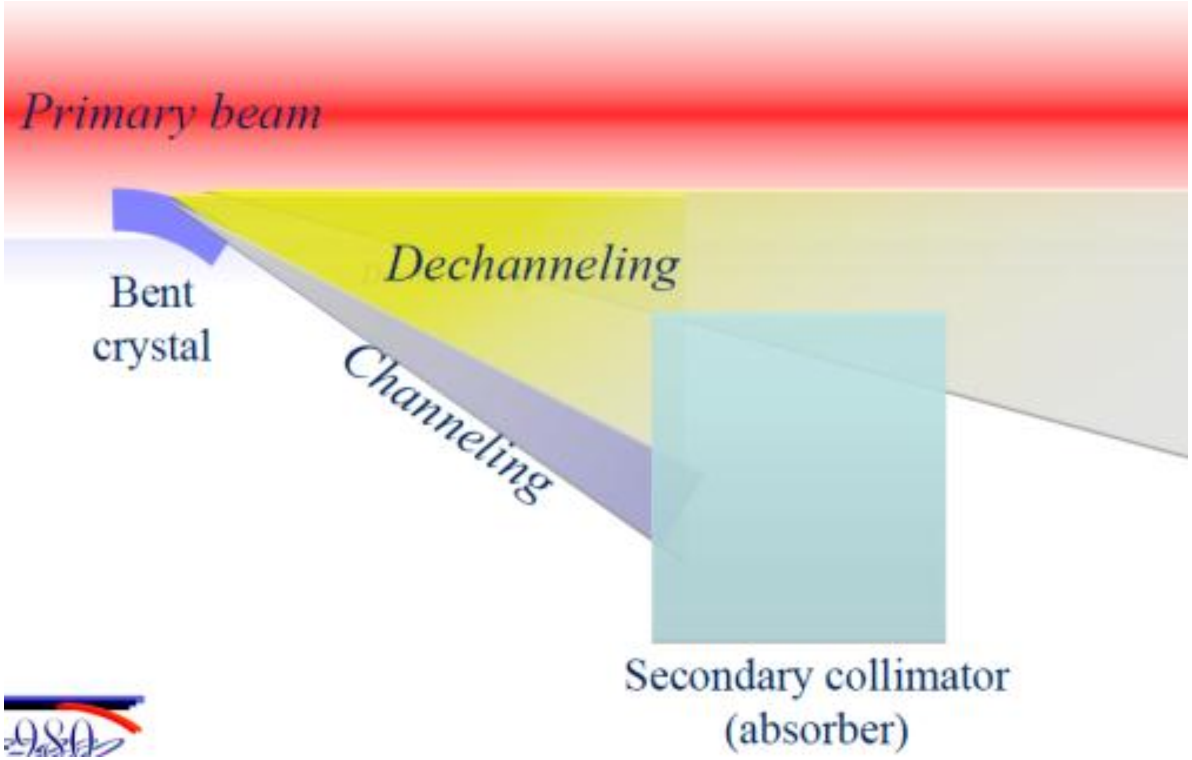
Methods to Clean the Beam Halo

- Single-stage collimator
- Multi-stage collimator
- Adjustable collimators
  - Automatic or by operator



Methods to Clean the Beam Halo

- Bending crystal collimators
  - Currently in R&D at CERN



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