Alternatives to an e- lens for LHC halo cleaning

HS, 9-11-2012

Outline

Methods to remove beam Halo:

- **Collimation or Scraping** with movable obstacles
  → covered by S. Raedelli
- **E- lens …**
- **BBLR:** beam beam long range wire compensation: not really a tool to remove halo; rather to avoid halo formation; but can it be used to increase the drift speed of halo particles with different parameter settings?
- **Tune modulation**
  - principle
  - experiments at DESY (HERA)
  - application to the LHC:
    - options for a tune modulation up to 300 Hz modulation frequency and a modulation depth of dq = 10-5 … 10-4
    - resulting beta-beats and power converter requirements
- **AC dipole excitation or transverse feedback excitation**
  - principle
  - options to make the present LHC dipole remotely tuneable
- ~~Cooling (stochastic, electro-optical …) let's keep it simple~~

Halo diagnostics

- present limitations
- possibilities for new instruments

Conclusions

One email from Ralph on the BBLR

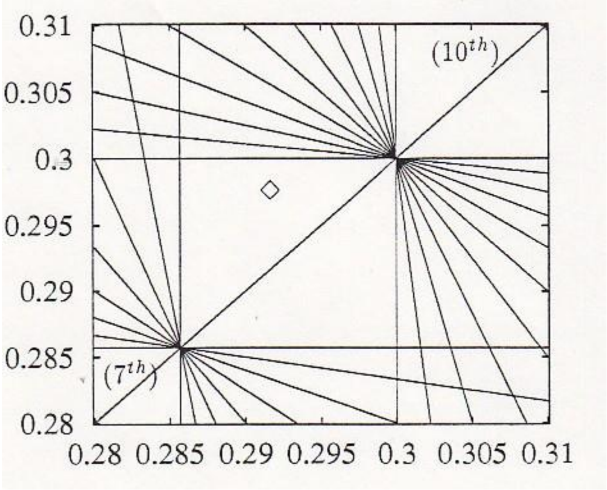
While primarily optimised to minimise the long-range tune foot-print and increase the dynamic aperture for nominal physics, the wire can be also used to create a defined edge in the dynamic aperture similar to long-range beam-beam effects with the difference that this can be done independent on the beam separation or whether the beams are actually colliding. Thus, this could be possibly used for single beams at injection. Details are in Tatiana's presentation and thesis.

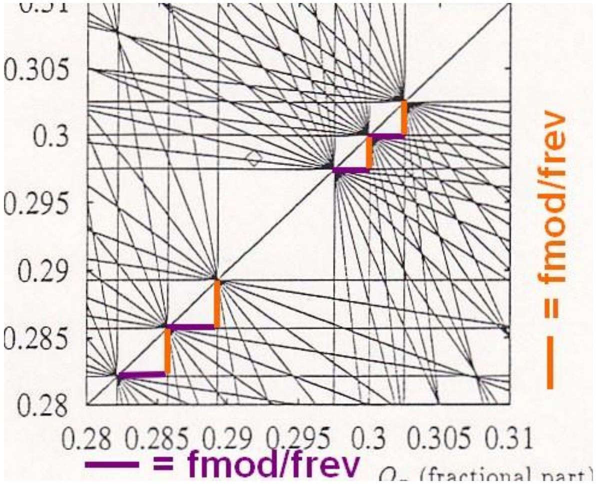
The full LR-BBC system is targeted to be installed between the D1 and TAN. However, the initial prototype targets to enhance the present TCTs collimators upstream of the IPs by embedding a wire a few hundred micrometre behind the W cleaning surface. This compromise was necessary for the feasibility of having two BBC being installed during or shortly after LS1.

For the time being, an ECR is under way concerning the installation of the required powering, rack and cabling infrastructure with the option of having a BBC upstream (at the TCT location) or downstream of IP1 and IP5. The asymmetric option of having e.g. the B1-BBC downstram of IP1 and the B2-BBC upstream of IP5 seems to be favoured as it would be more flexible/adapted to the present nominal optics. However, this would imply that the existing roman pots in Pt5 are being replaced by additional TCL collimators.
At the same time, mechanical prototype studies related to the wire integration, heat-load and impact an the regular collimator function are under way. We hope to have first results during the beginning of next year that would enable the design office to do the final wire-in-collimator-jaw integration.

Tune modulation

- Principle: Modulate H+V tunes at a fixed frequency in the range of
  a few 10 Hz to 500 Hz.
  The required modulation depth is low: dq= 10-5 to 10-4.
  This modulation creates «sidebands» in the lattice, i.e. also for all resonances of the lattice.
  → Choose modulation frequency such that halo particles are close to «sideband» resonances and get lost.





Experiments at HERA-p

O.Bruening and F.Willeke

→ Experiments to understand and counteract emittance growth during stores

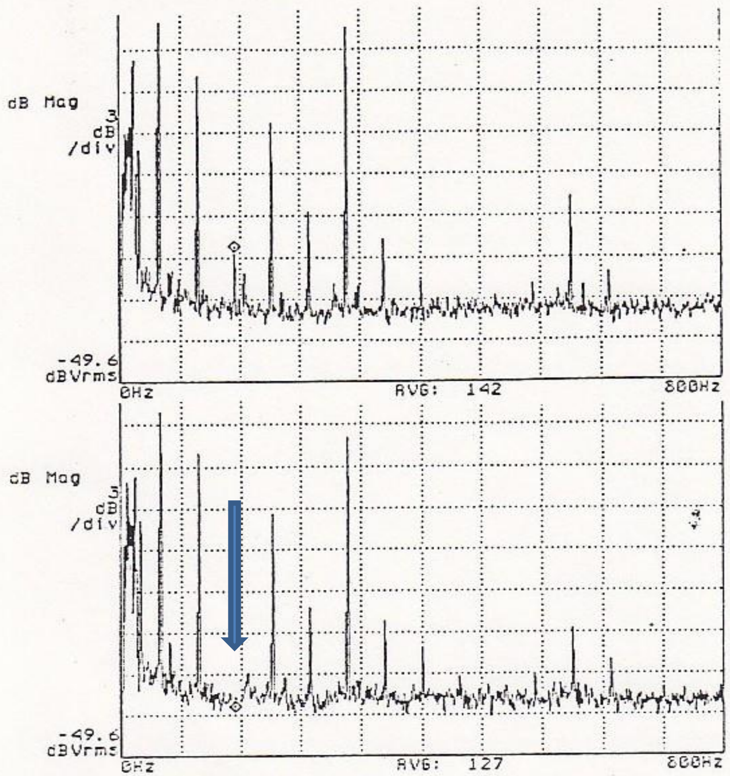


Figure 4: *The power spectrum of the proton loss rate.*
Top: The spectrum without an external tune modulation.
Bottom: The spectrum with a 150Hz tune modulation and $\triangle Q \sim 10^{-5}$

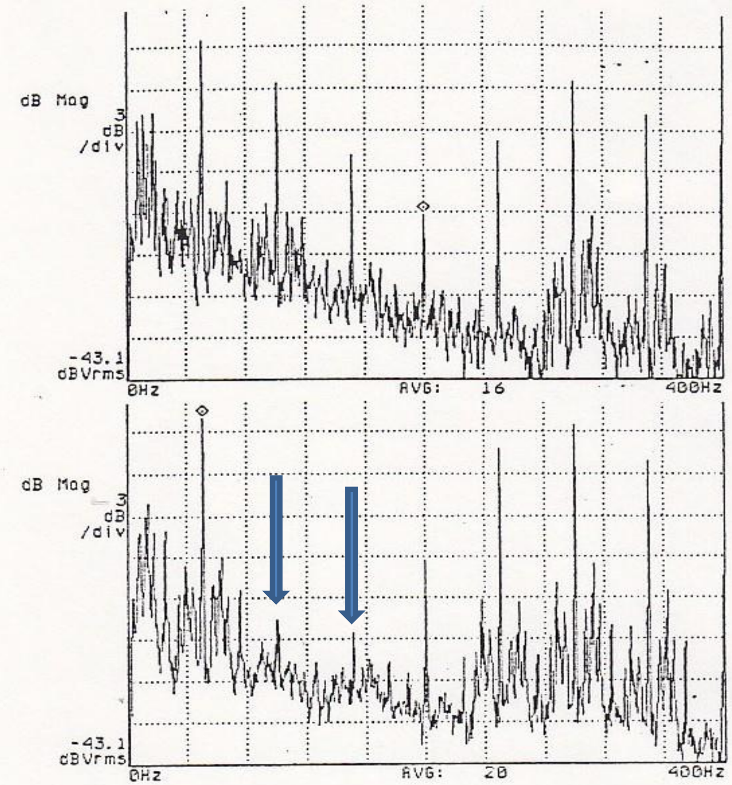
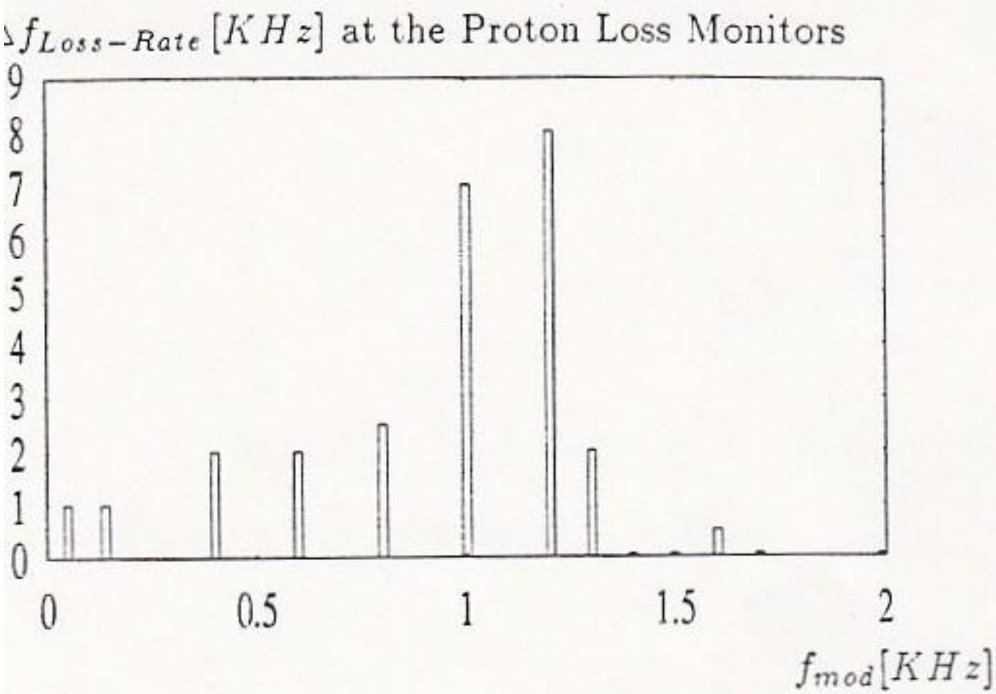


Figure 5: *The power spectrum of the proton loss rate.*
Top: The spectrum without an external tune modulation.
Bottom: The spectrum with a 50Hz tune modulation and $\triangle Q \sim 10^{-4}$.

Results



igure 3: *Increase in the loss rate at the proton loss monitors for different modulation frequencies. For all modulation frequencies except for the 46.4Hz, the modulation depth was* $\triangle Q \sim 10^{-4}$.

Small feasibility study:

Tune modulation in LHC with warm quadrupoles (Oliver):

- Modulation of MQWA quad in IR7 (anti-symmetric for B1 and B2)
- delta k = 0.02%

→ Delta q = 10^-4

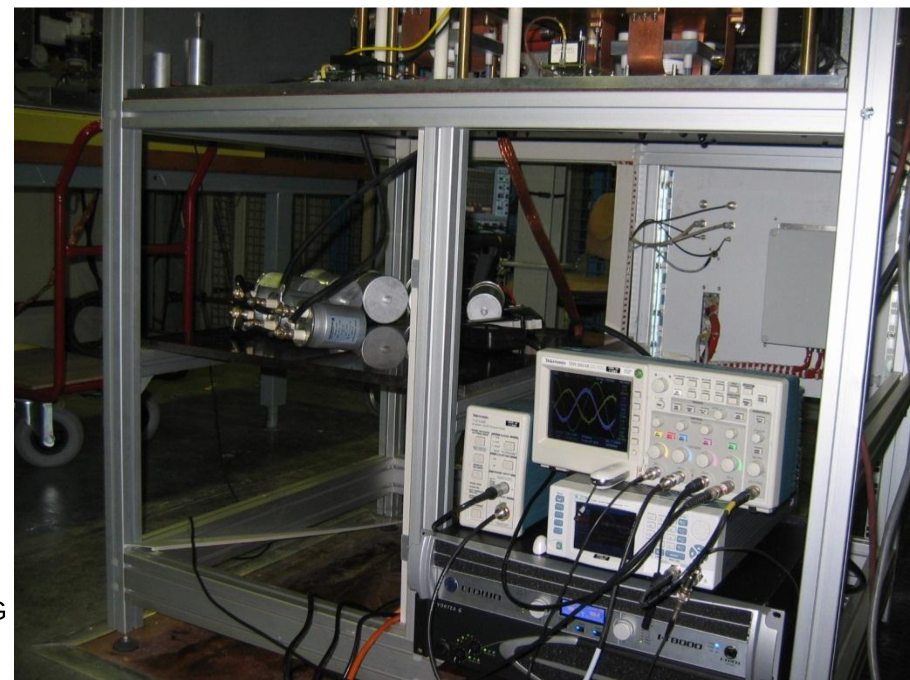
→ Beta-beat: 0.014% = negligible

Still needs to be done: Get inductance of magnet to check capability of PC for fmod up to 300 Hz?
Interference with QPS?

Almost the inverse: Excite large oscillations of halo particles

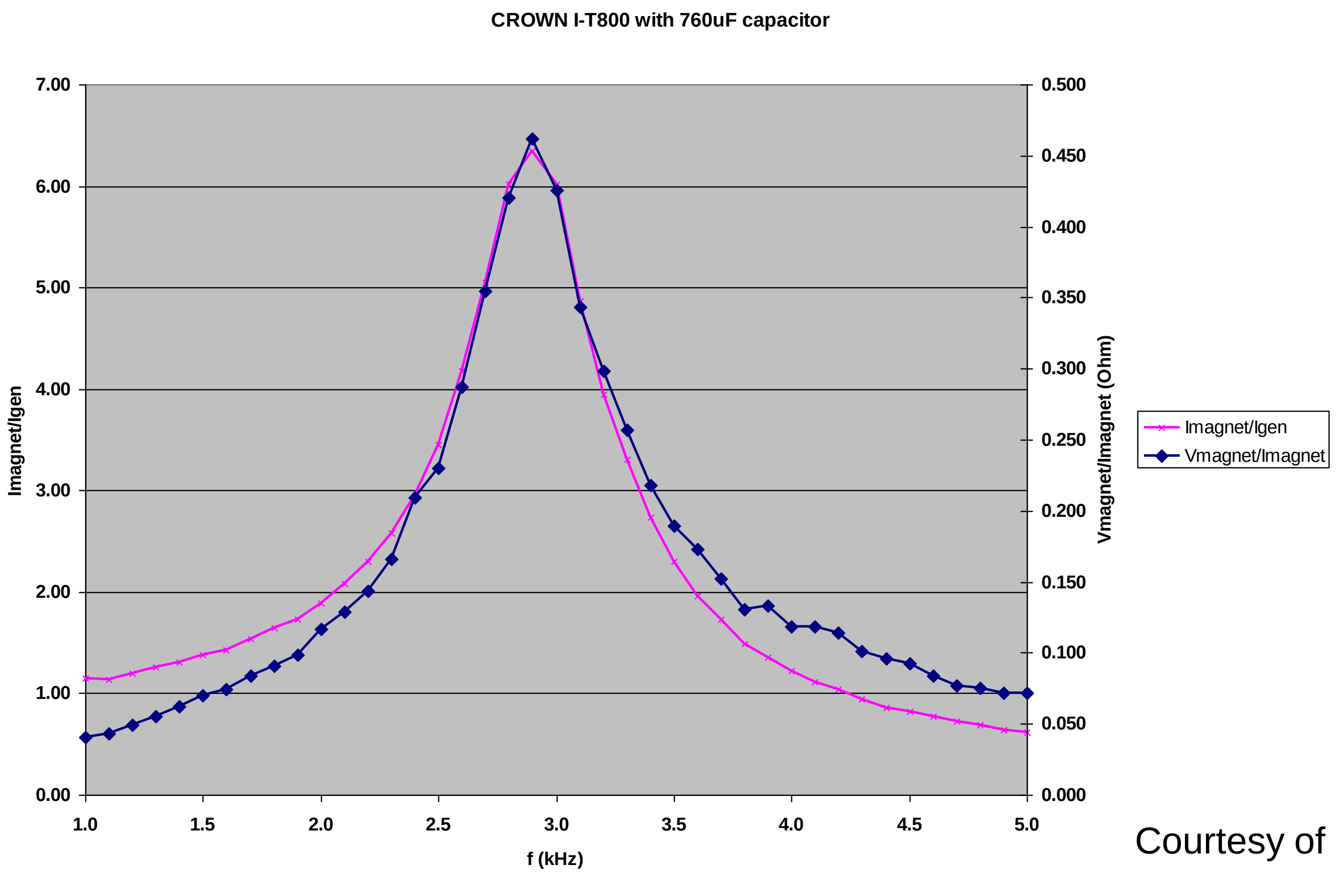
- Create large oscillation amplitudes with either ADT transverse damper or AC dipole
- Like previous method relies on favourable amplitude detuning
- Both tools probably strong enough; do not know if people want to tamper with ADT during stores?
- AC dipole does not need changes; requested excitation frequency well within range of the resonator.

AC Dipole Test Stand in building 867



Test at f=2.9 kHz (close to f1)

- C = 760μF (3*120μF + 4*100μF) Q(measured)=6.35 Rp(measured)=0.462 Ohm



Courtesy of Matthieu Cattin

Making the AC-dipole center frequency tuneable?

- Variable capacitors and inductors. Contact: Peter Oddo (BNL):
  - Variable capacitors: C in series with switch. Effective C depends on switch’s duty cycle.
  - Variable inductors (1): make a core saturate, therefore losing its inductance, a certain percentage of time, with the help of an auxiliary DC winding. This is ON/OFF control as with the capacitor.
  - Variable inductors (2): with an auxiliary winding carrying a DC current, go to a certain point in the core’s B-H curve. Incremental inductance can be controlled in this way.

Halo Diagnostics

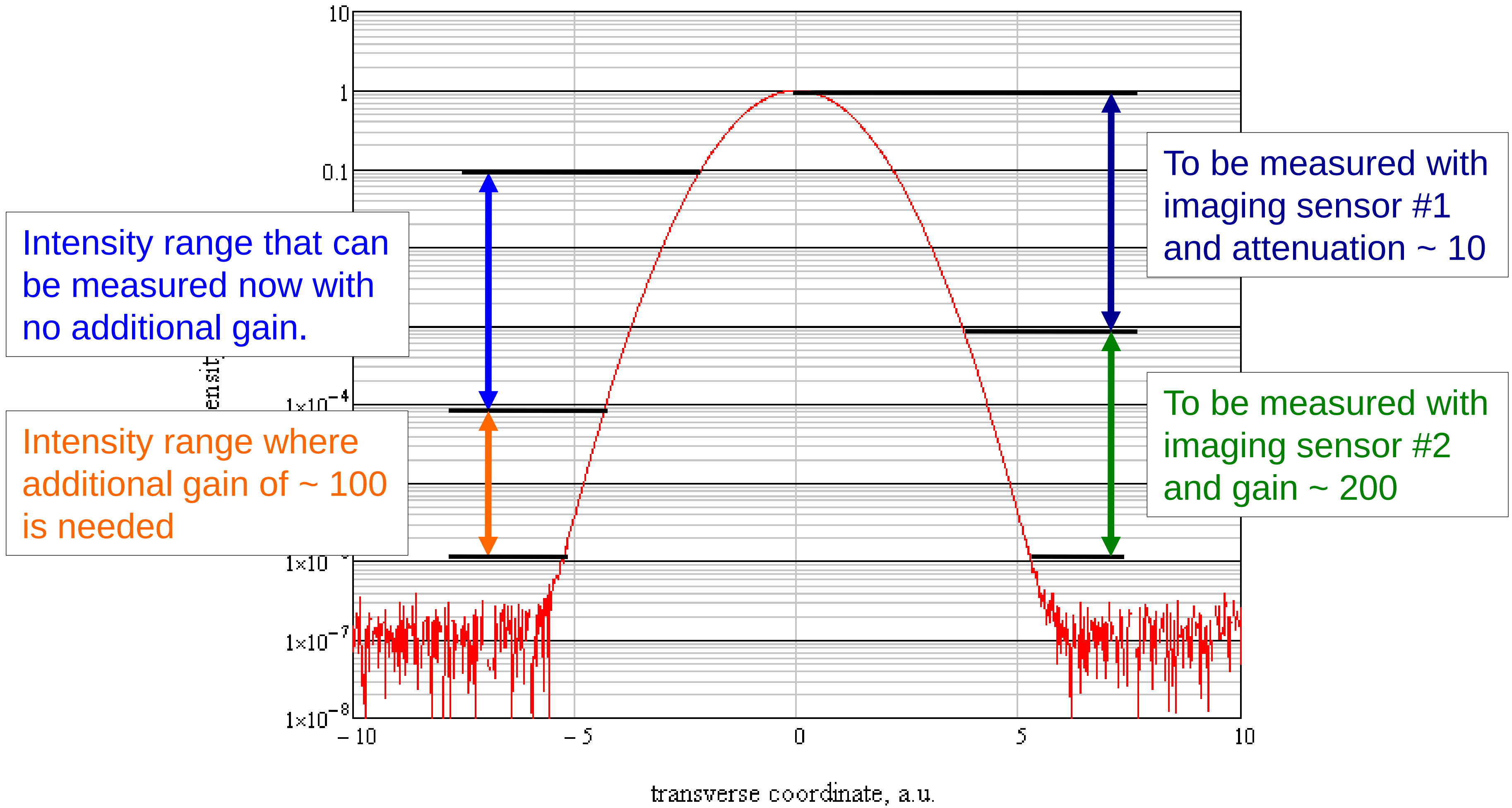
- Objectives:
  1) measure transverse beam density (2D) with a typical dynamic range of 10-6
  - time resolution: integrate over all bunches, measurement time less than a minute
  2) measure loss rates at a movable aperture limit (or wire) with a time resolution better than one revolution;
  → measure beam loss spectra
- What do we have in the LHC:
  - all 2 D profile monitors with a dynamic range of 10-3 to 10-4
  - loss monitors (Ionization chambers, SEM monitors, diamonds) and a project to position the wire scanners to a fixed known position

Projects for Halo Monitoring (1)

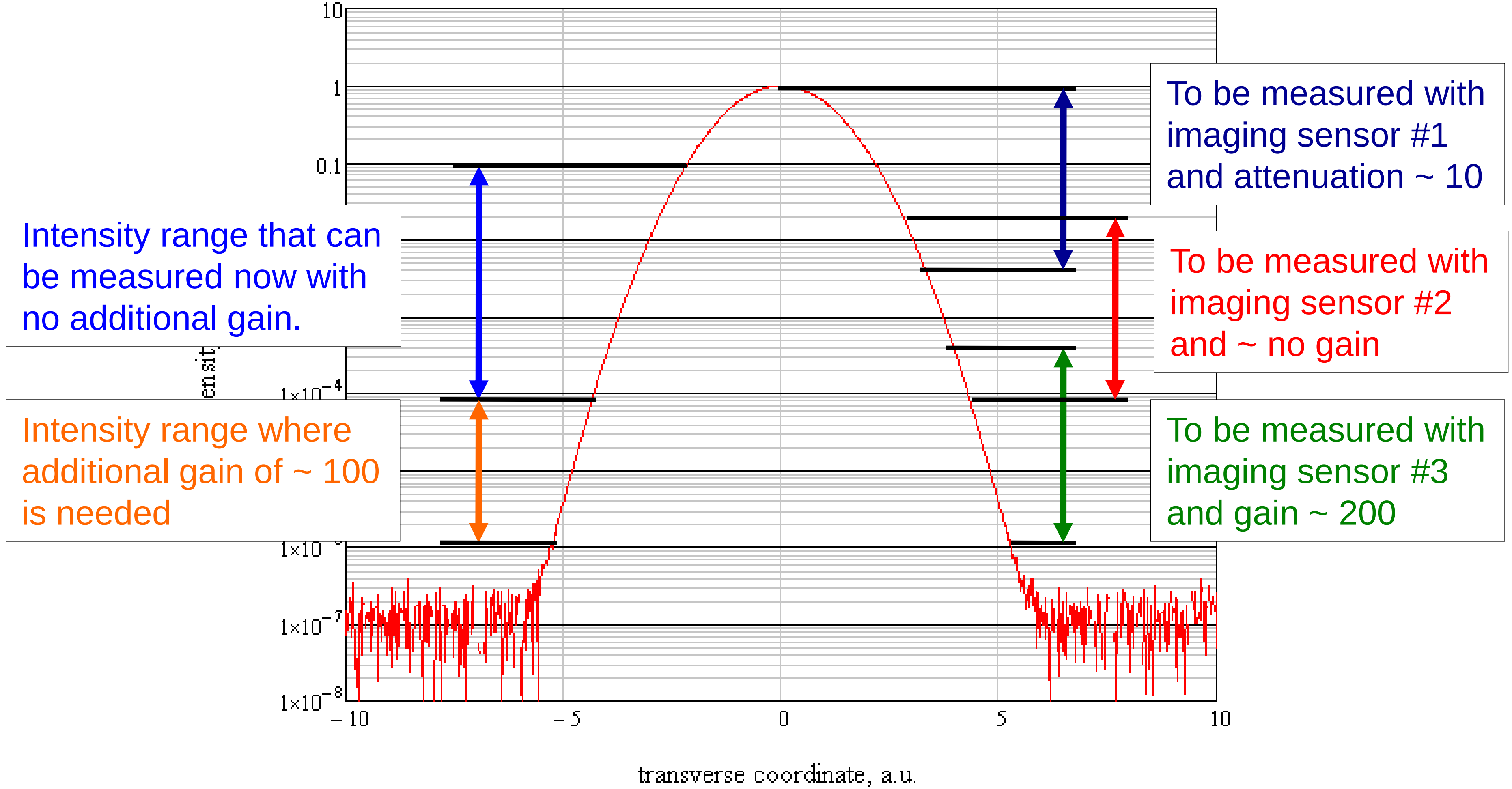
1. The two following slides are taken from Pavel Evtushenko et al. (JLAB); S&T review 2012
   - basic idea: light produced by the particle beam (wiggler, bend...) gets imaged in parallel onto 2 or 3 cameras with different gains. Recombination of the camera images into one high dynamic range picture.

   → in principle "easy", but no assessment of spurious light (stray light, reflections)….similar problem in LHC

Large Dynamic Range imaging (2)

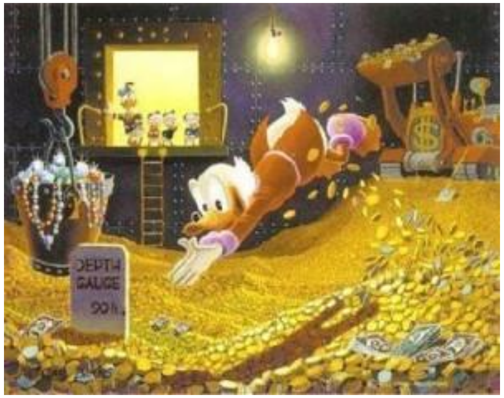


Large Dynamic Range imaging (3)



Projects for Halo Monitoring(2)

The best way to cover a large dynamic range is by counting:



2. Photon Counting Techniques
   - experience at LHC with abort gap monitor (Avalanche Photodiode Detector: APD)
   - can imagine an APD array of 20 x 20 APDs pointing at a beam image of 10 x 10 sigma
   - measurement times for 10-6 dynamic range (a few seconds to 1 minute)
   - light source:

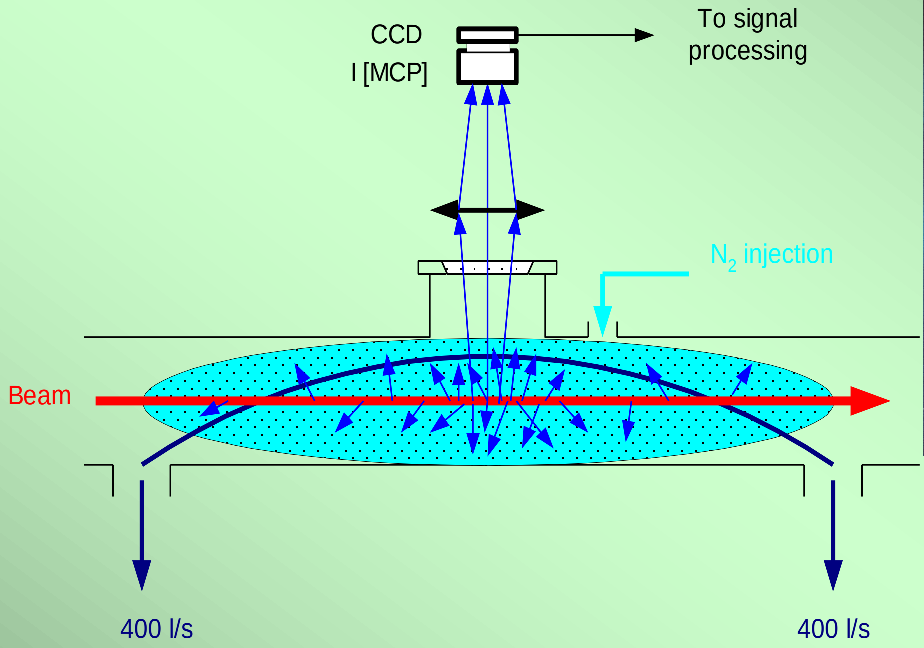
     again the BSRT: expect again problems with stray light

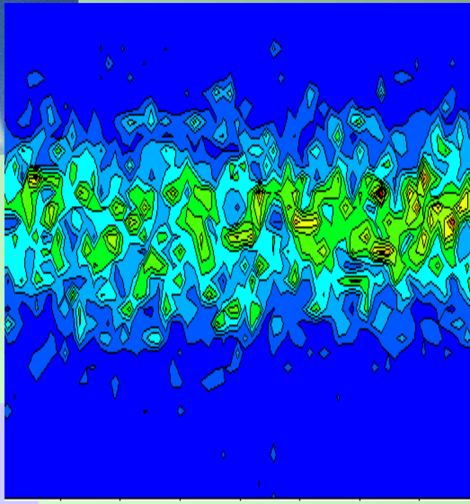
     or use luminescence monitor (probably with a small pressure bump); Nitrogen luminescence delivers a narrow spectral line; light can be heavily filtered: almost no background

   but: only gives projections (2 x 1D)

   Great R&D project....

Luminescence Profile Monitor

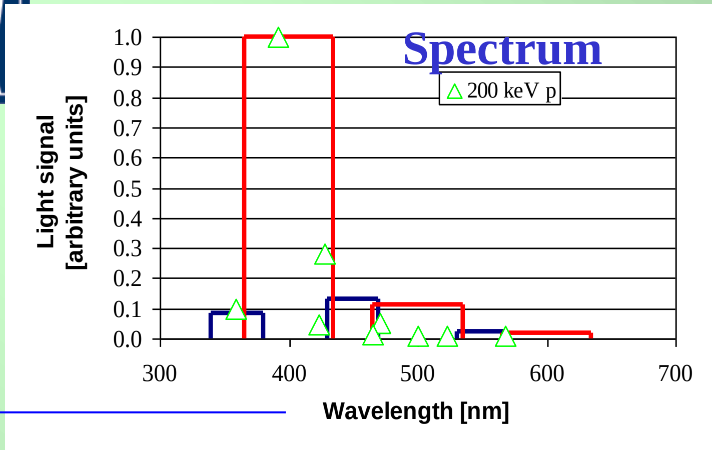


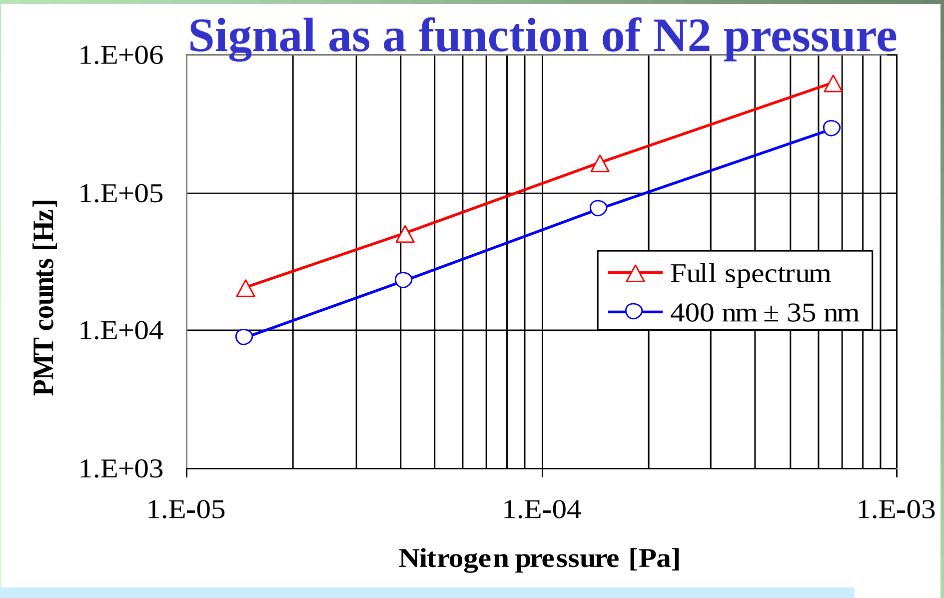


PRINCIPLE **Uses the light emitted by gas molecules when they return to their ground state after having been excited by the beam:**

Nitrogen is a good candidate: **high cross-section,**
low decay time,
well pumped
emits towards lower end of the visible spectrum

Luminescence





At 7 10^{-5} Pa (5 10^{-7} torr), the photon production corresponds to the N_2^+ spectrum: ~ 60% of the light is within the bandwidth of a 400nm ± 35nm filter.

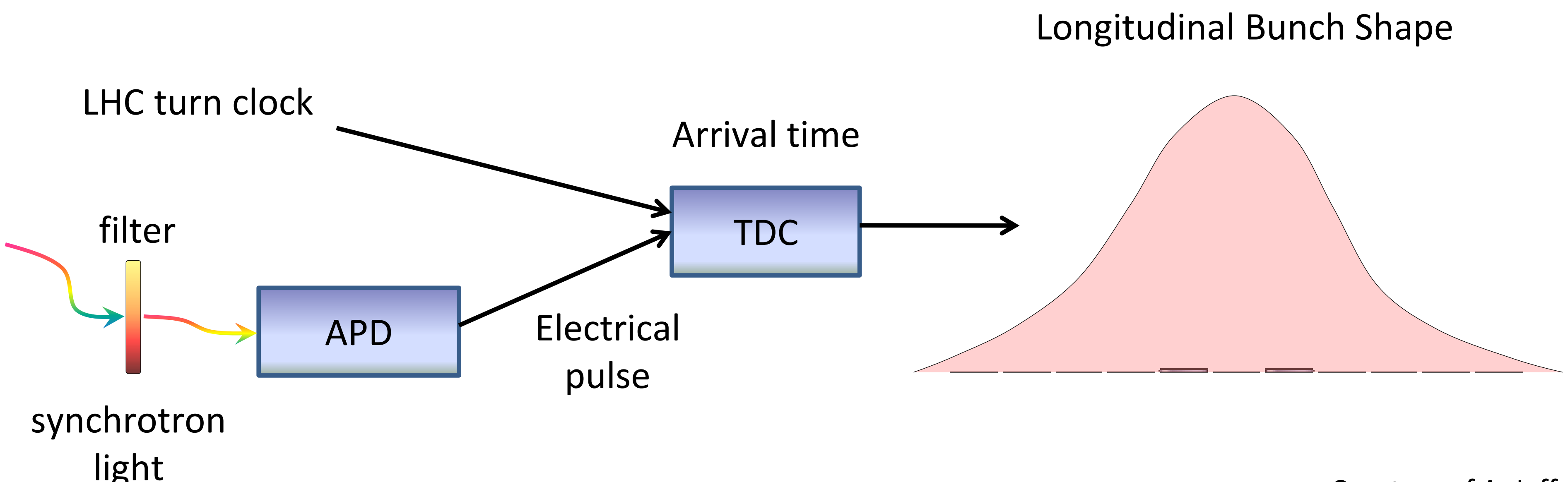
- The light production is linear with pressure: single step process with short decay time ➔ suitable for profile measurements.
- The pressure can be used to increase the dynamic range of the detector.

The pressure increase is negligible in the SPS:

5% for 6 10^{-5} Pa (5 10^{-7} torr) over 3 m

Maximising the Available Data - Example

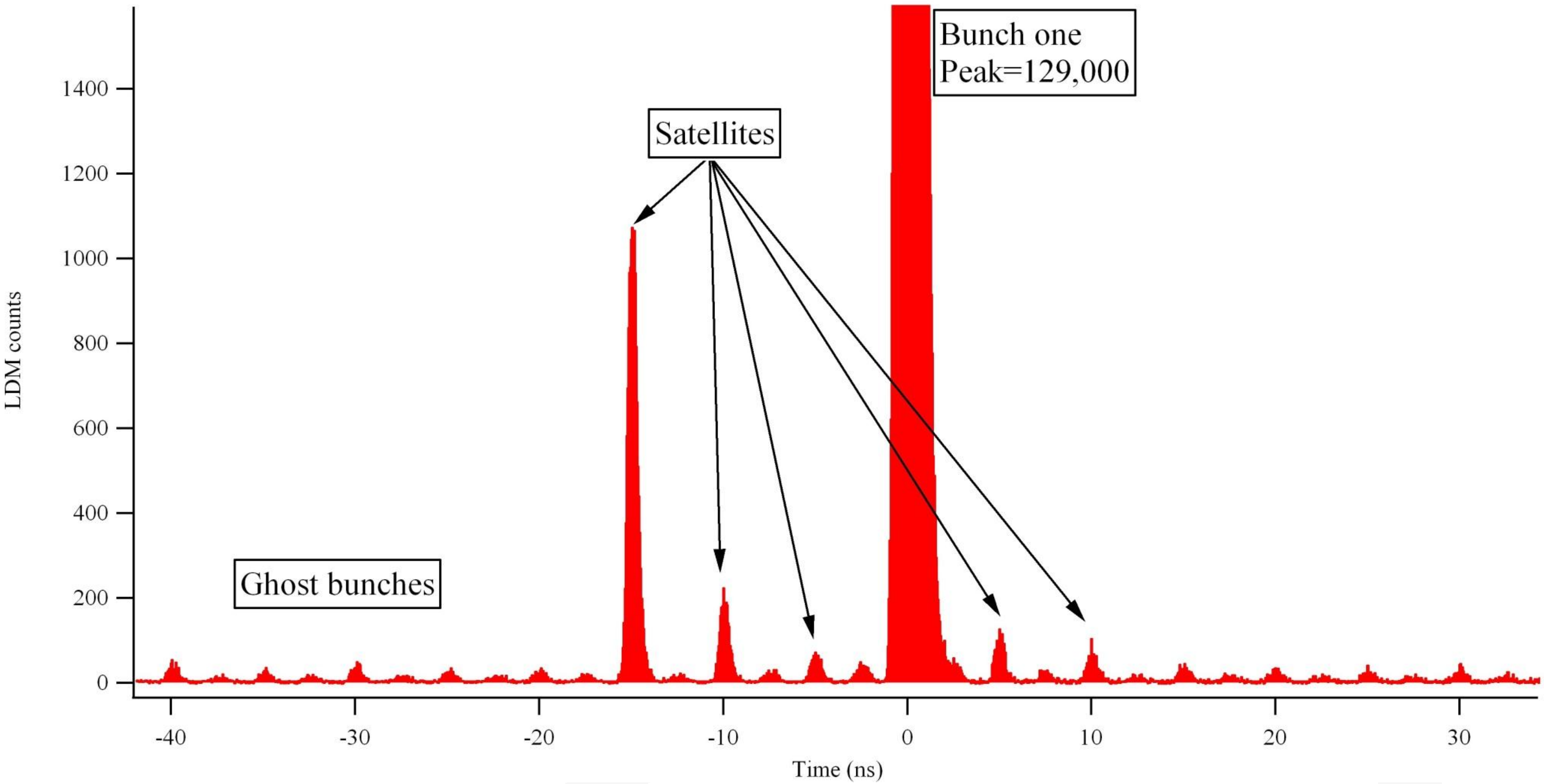
- **LHC Longitudinal Density Monitor**
  - Aims:
    - Profile of the whole LHC ring with 50ps resolution
    - High dynamic range for ghost charge measurement
  - Method:
    - Single photon counting with Synchrotron light
      - Avalanche photodiode detector
      - 50ps resolution TDC



Courtesy of A. Jeff

LDM Results

- **Results**
  - Able to profile the whole ring within a matter of minutes
  - Critical input for accurate luminosity calibration of the experiments



Conclusions

- Halo cleaning will most likely be part of the standard operational procedures for LHC luminosity production
  hence:
  - must be simple and fast
  - should not involve much additional equipment
- Experiments must be performed as soon as possible in order to quantify the cleaning efficiency and operational “ease” of the various methods. There is already equipment readily available to do significant experiments.
- High priority should be given on the design and construction of a “Halo Monitor”; ideas exist; possible collaboration with US-LARP
- Prepare functional specification for tune modulation and corresponding modulating circuits/quench protection
- More preparation by simulations during LS1, in particular assessment on different possibilities to scrape halo in physical dimensions or in tune space.