4th Joint HiLumi LHC-LARP Annual Meeting, KEK, Japan.

Beam Instrumentation and Diagnostics for BBLR tests in LHC & commissioning in HL-LHC

Rhodri Jones
(CERN Beam Instrumentation Group)

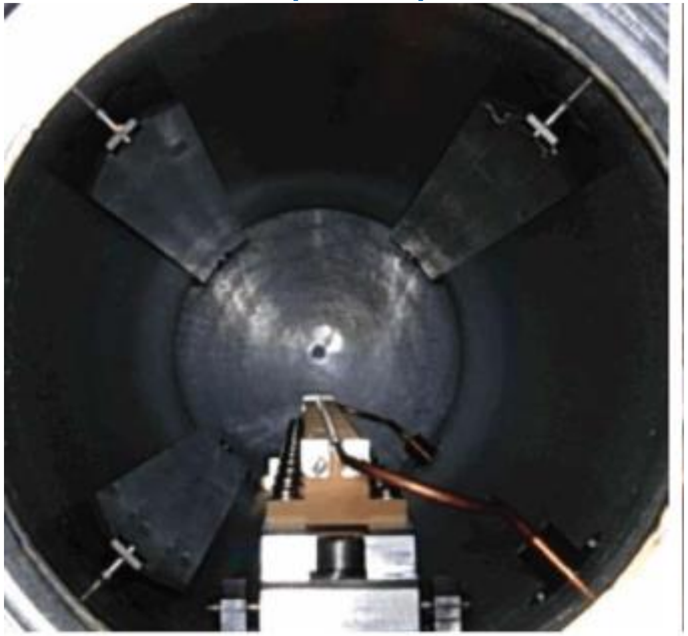
Outline

- Experience from the SPS
  - Measurements to see effect of wire on beam
- Long-range beam-beam in the LHC
  - Beam Instrumentation used in its understanding
- BI for testing BBLR wire-in-collimator prototype
- Techniques for Halo diagnostics

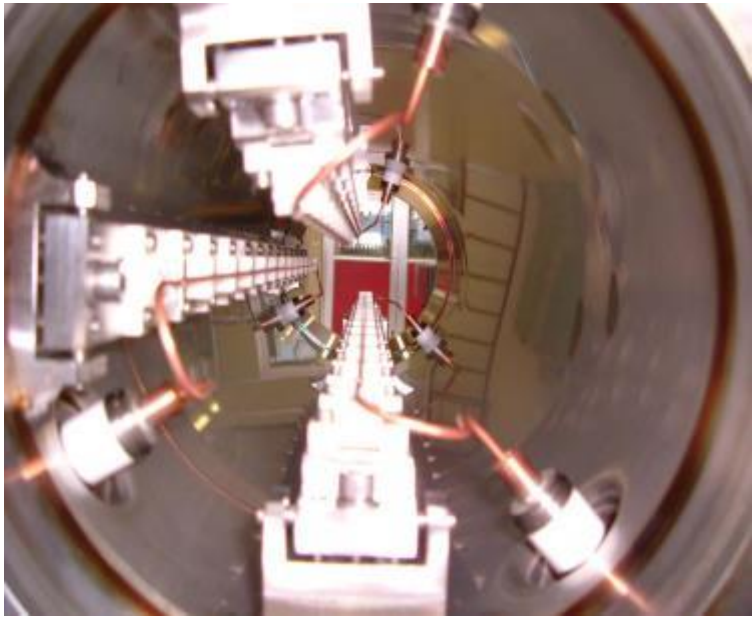
SPS Tests of BBLR Compensating Wires

- All slides courtesy of Frank Zimmerman
- Experimental program started over 10 years ago
  - After Jean-Pierre Koutchouk first proposed wires for LHC in 2000
  - Two 60-cm long, water cooled wires carrying up to 267 A
    - Equivalent to 60 LHC LR collisions (e.g., IP1 & 5)

1st (2002)



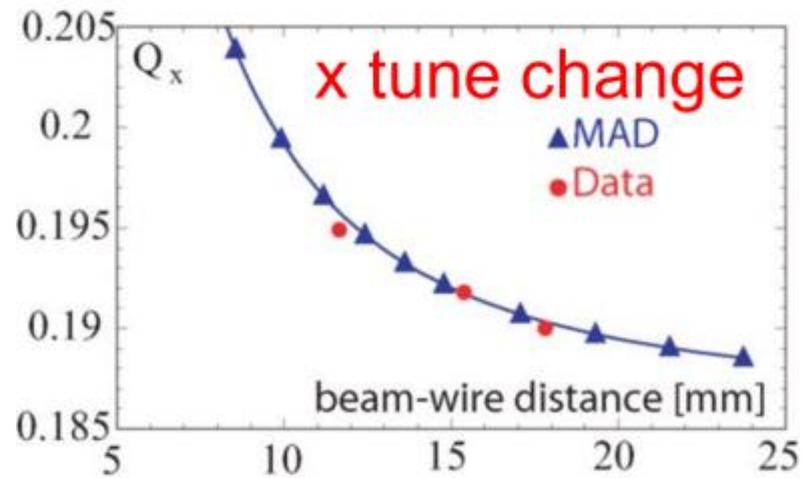
2nd (2004)

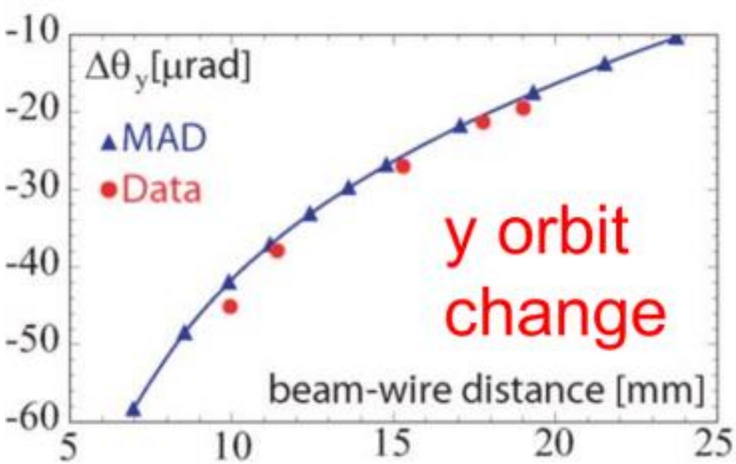


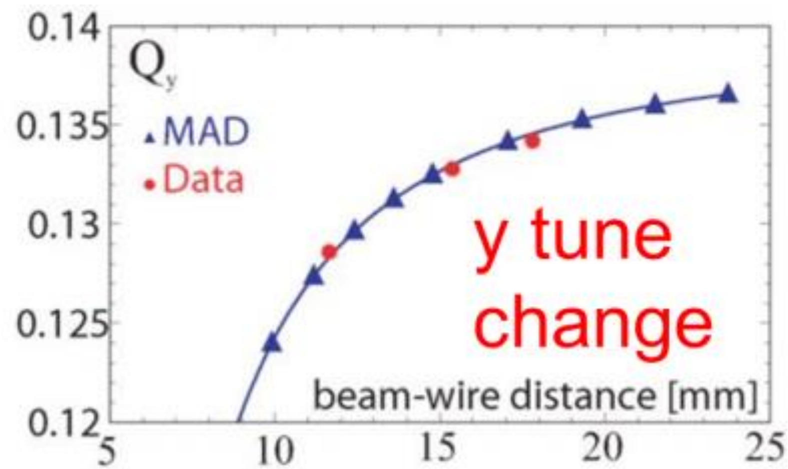
J.-P. Koutchouk, G. Burtin, J. Camas, J. Wenninger, U. Dorda, G. Sterbini, F. Zimmermann, et al

SPS BBLR - Orbit & Tune Change

- Measure effect of wire on beam & cross check with expected results from simulations
- Orbit with wire position
  - Need to measure both wire-beam position & orbit change
- Tune change with wire position



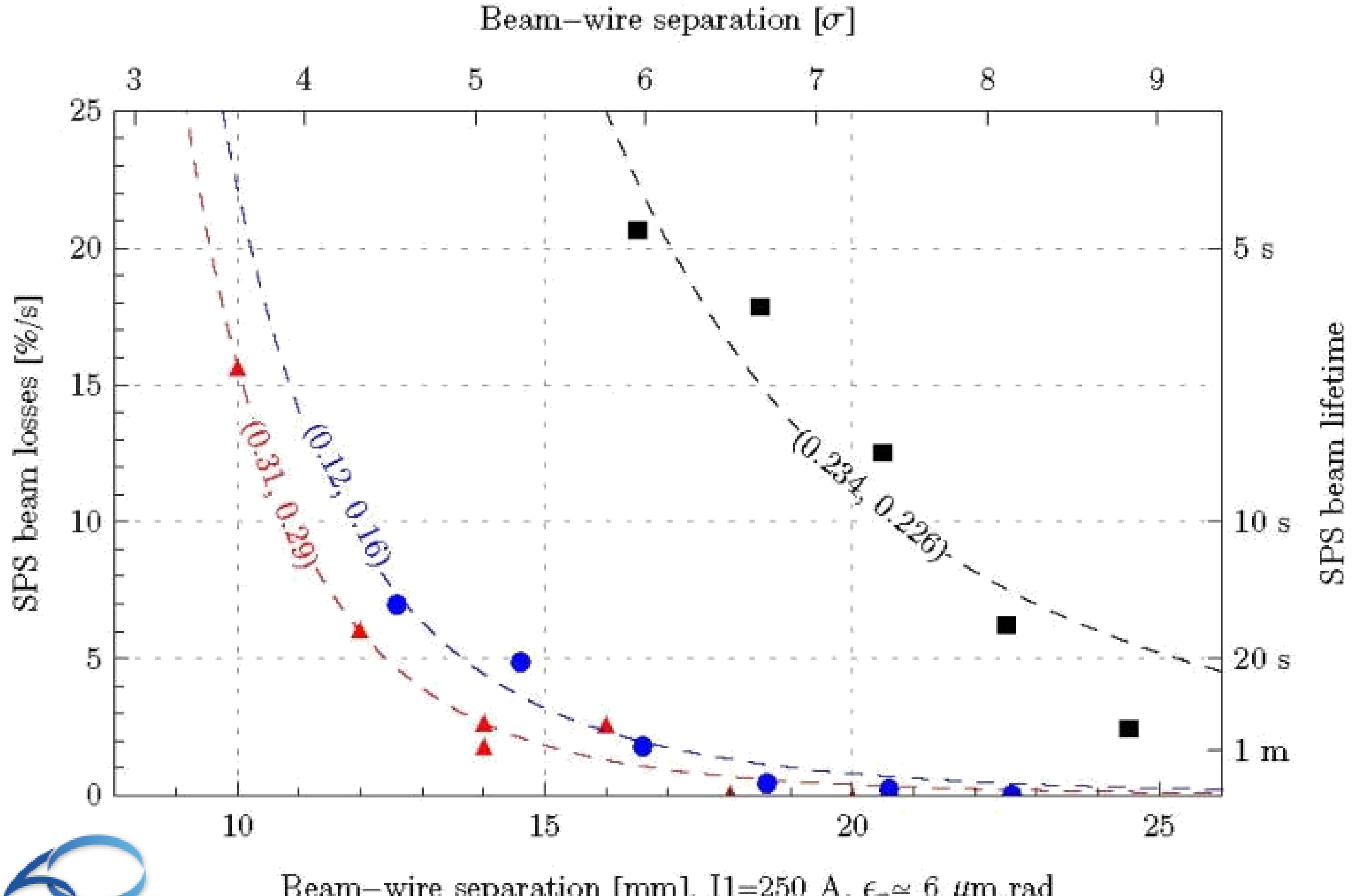




J. Wenninger

SPS BBLR – Lifetime v Wire Distance

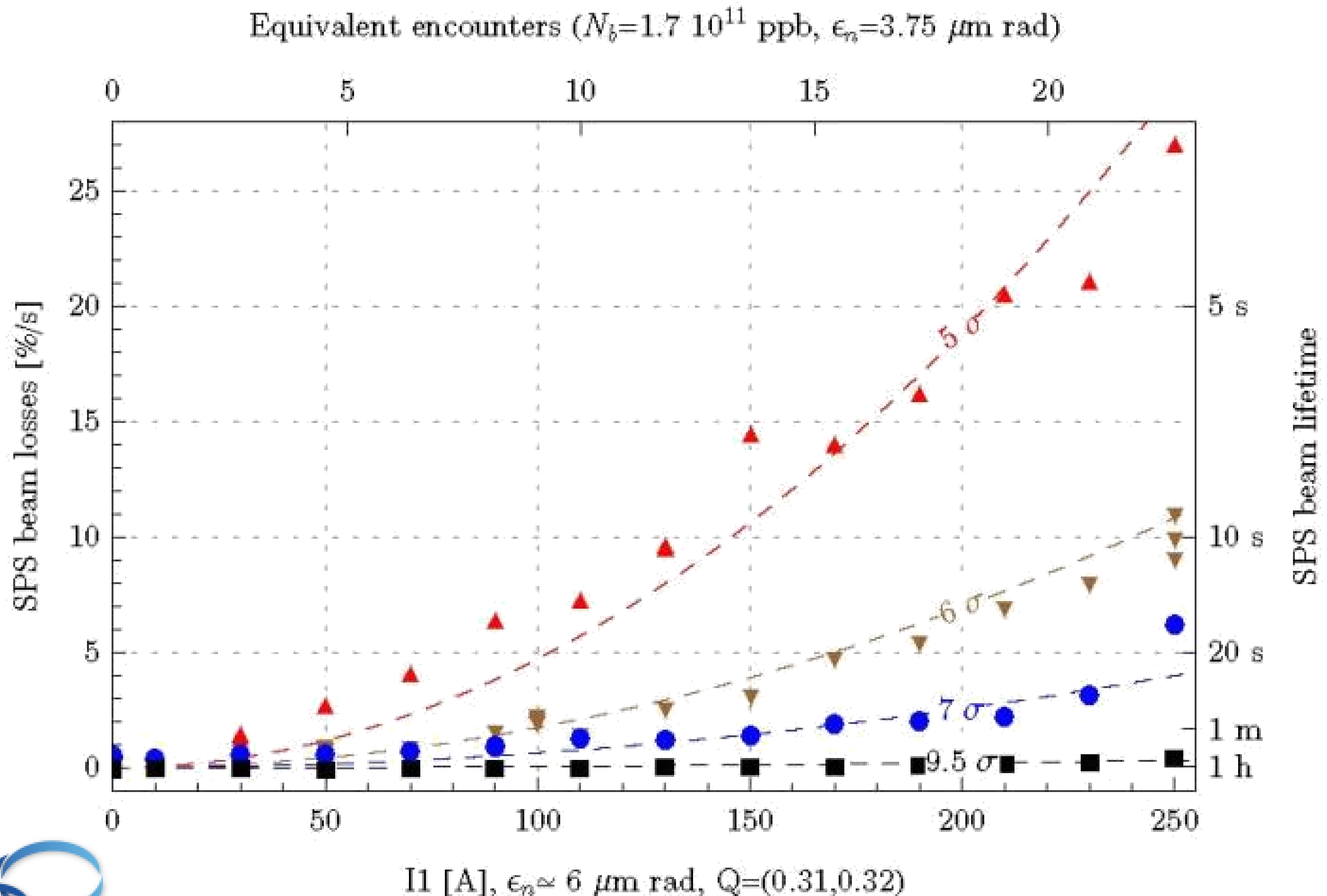
- Measurement of beam losses and beam to wire distance



G. Sterbini - @ 37GeV/c

SPS BBLR – Lifetime v Wire Current

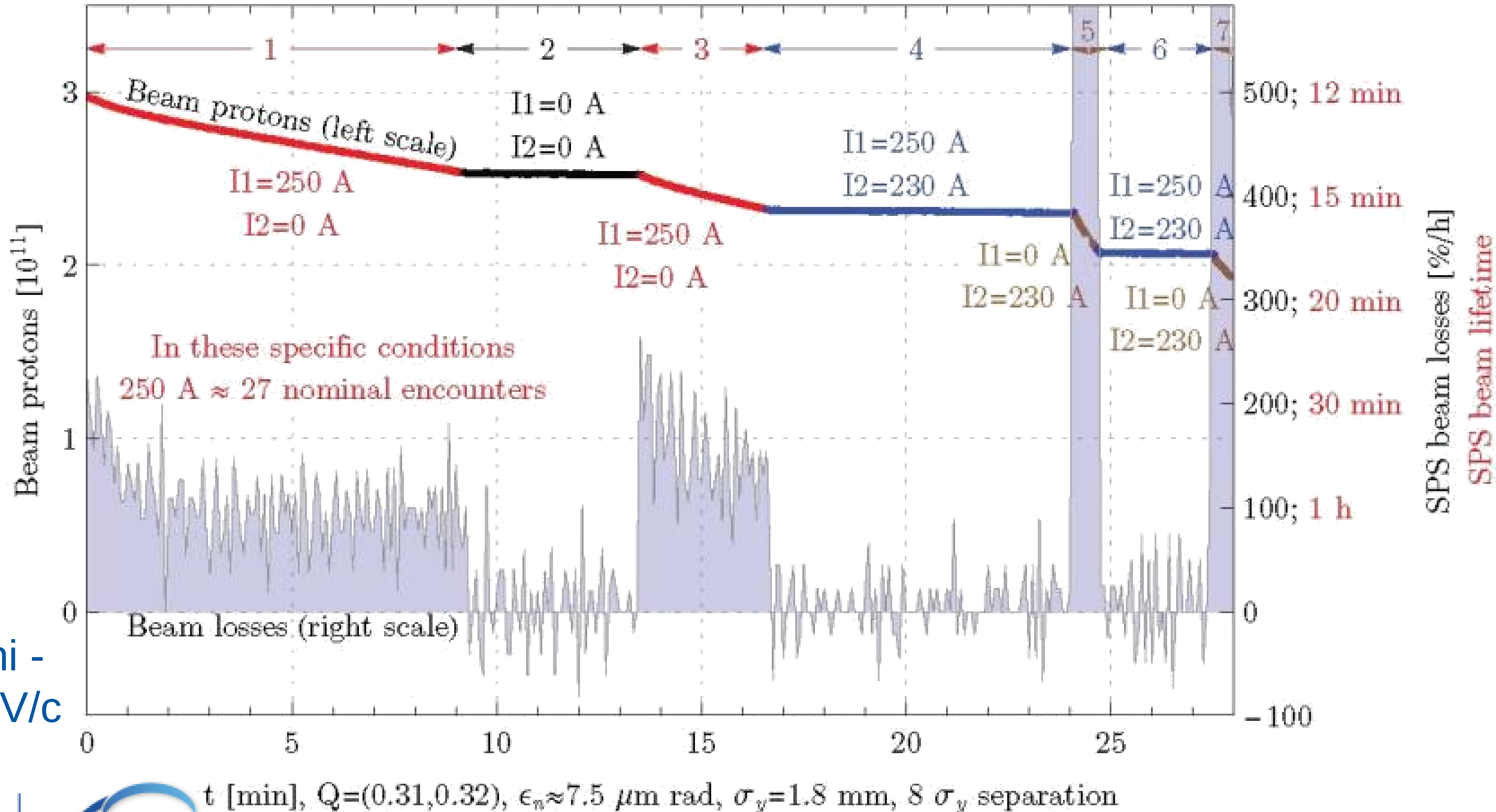
- Measurement of beam losses and beam to wire distance



G. Sterbini - @ 37GeV/c

SPS BBLR - Compensation

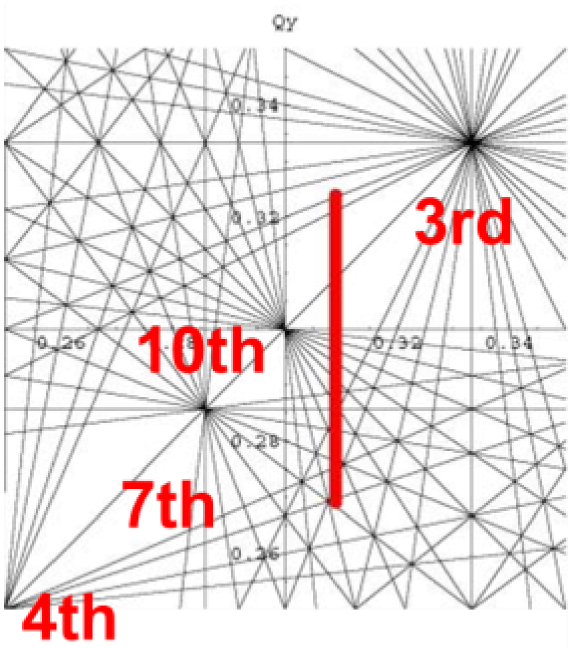
- Clearly demonstrated effect of one wire compensated by second wire



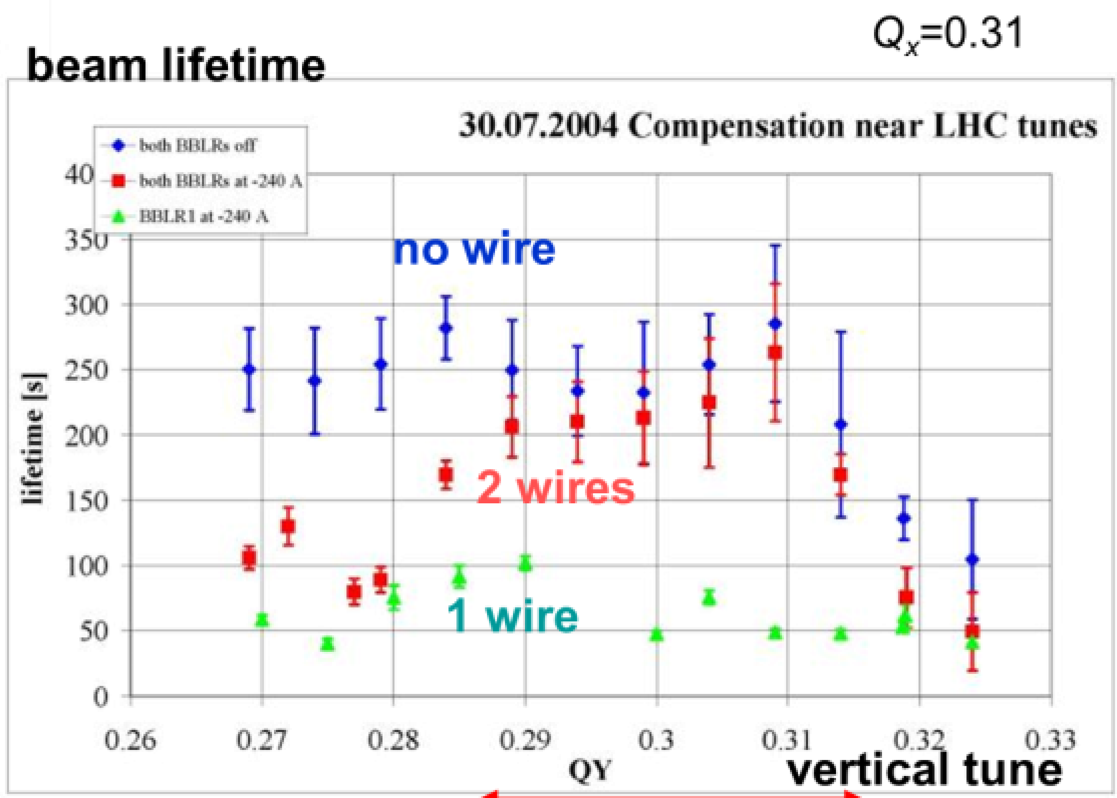
G. Sterbini - @ 120GeV/c

SPS BBLR - Compensation

- Tune scans coupled to lifetime measurements



@ 26GeV/c



what happens here?

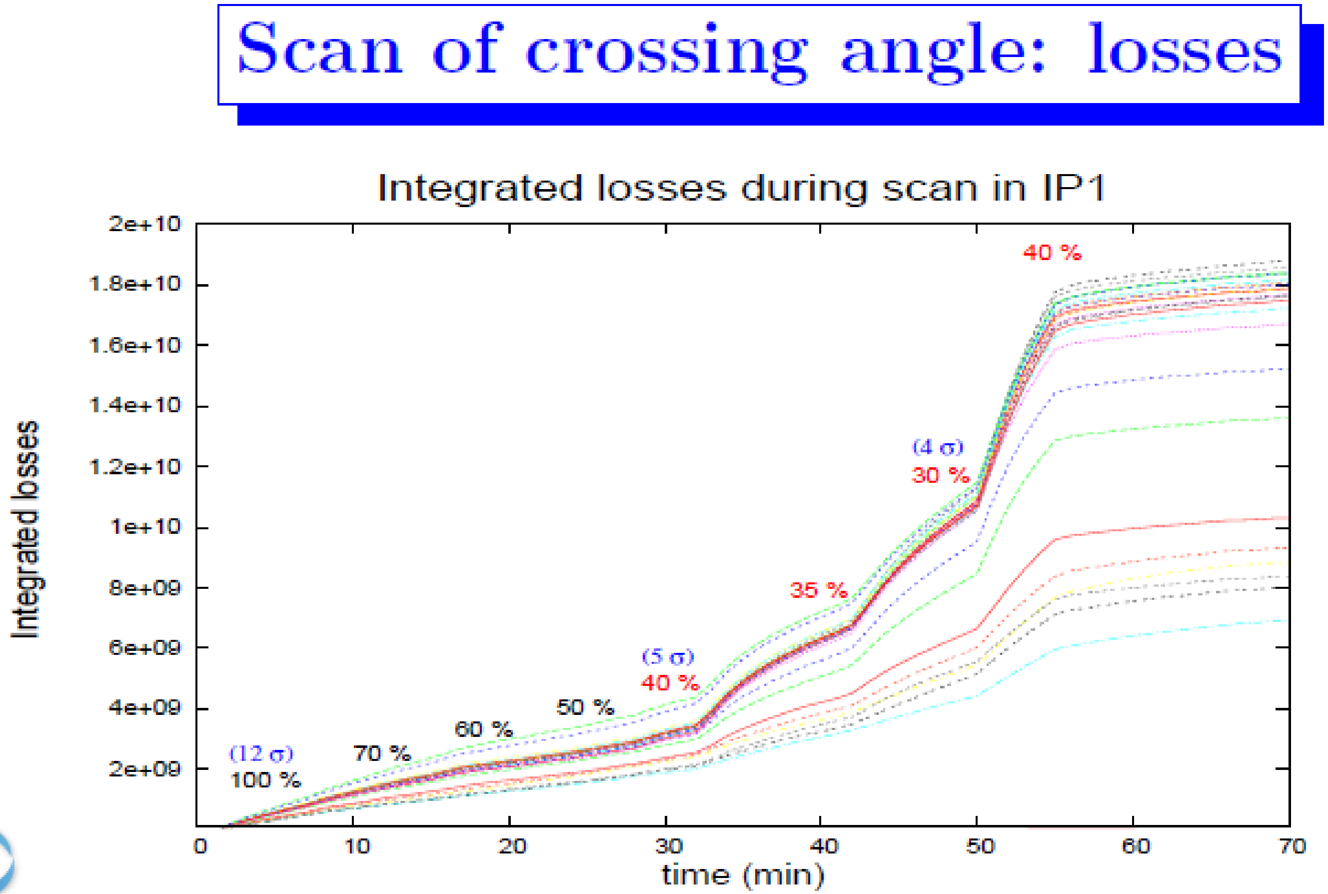
nearly perfect compensation

SPS BBLR Summary

- Over 10 years of wire excitation measurements performed in the SPS (F. Zimmerman et al.)
  - Compensation by second wire always improved the beam lifetime significantly over a large range of parameters
  - Proposal to revive the BBLR system to regain knowledge & make use of upgraded SPS diagnostics
- Main Beam Instrumentation systems used
  - Orbit
  - Tune
  - Chromaticity
  - Beam Loss (Lifetime)
  - Beam Intensity (Lifetime)
- Systems used but needing improvement
  - Diffusion rates through scraping & beam loss
  - Beam profile & emittance measurements

Long-Range Beam-Beam in the LHC

- Bunch by bunch intensity loss measurements as a function of crossing angle in IP1

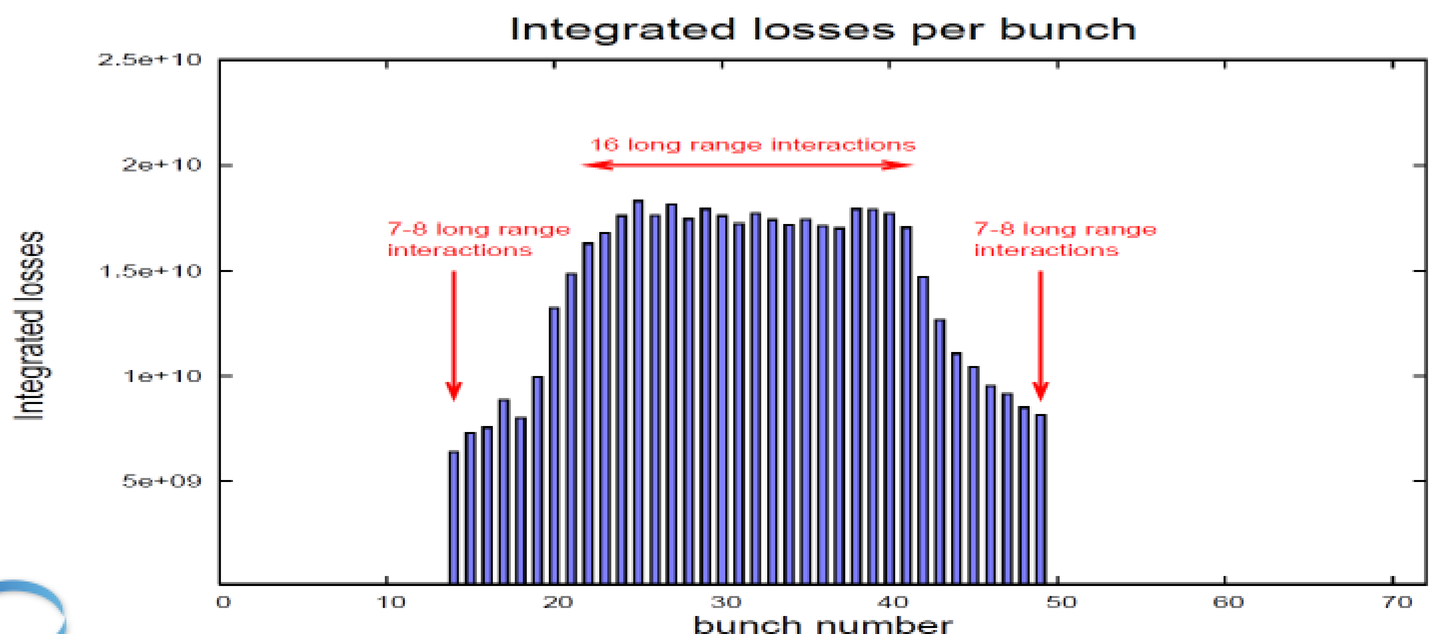


W. Herr
& the LHC
Beam-Beam
Studies Team

Long-Range Beam-Beam in the LHC

- Bunch by bunch intensity measurements
- Losses directly related to number of long range interactions
  - So-called ’PACMAN’ bunches have better life time

PACMAN effects



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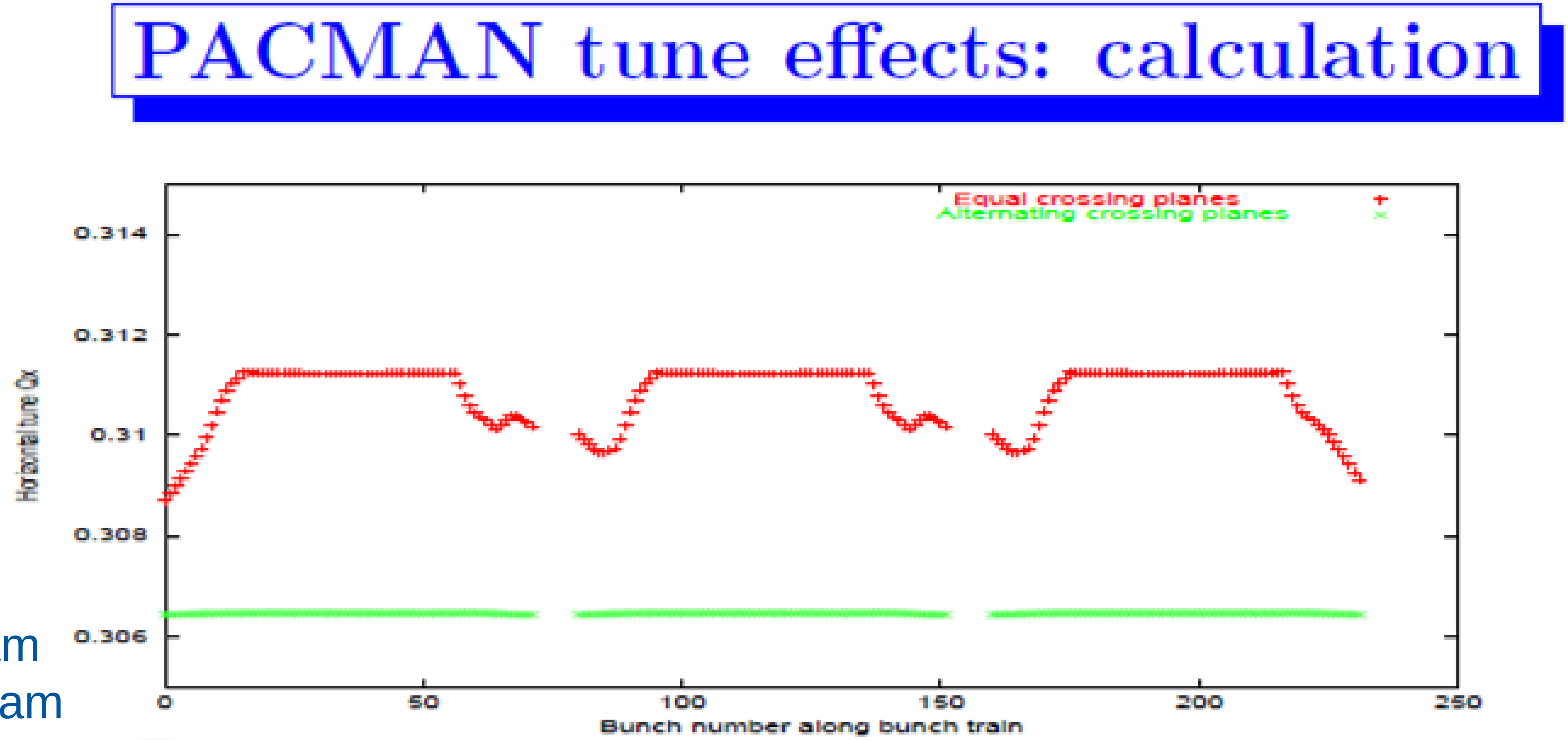
Long-Range Beam-Beam in the LHC

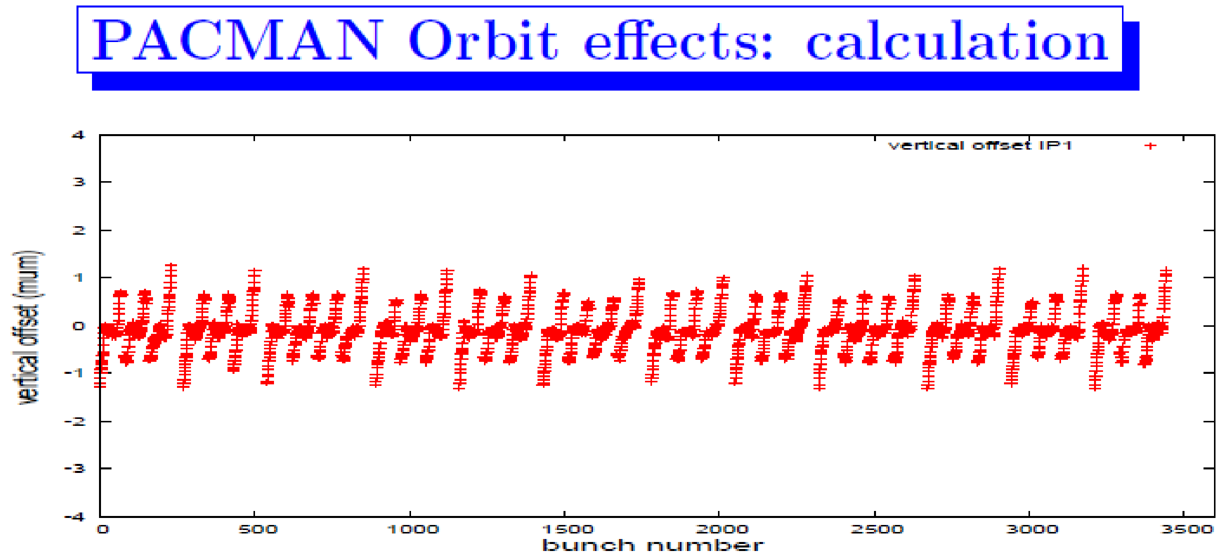
- No reliable measurement of bunch-by-bunch tune available during Run I

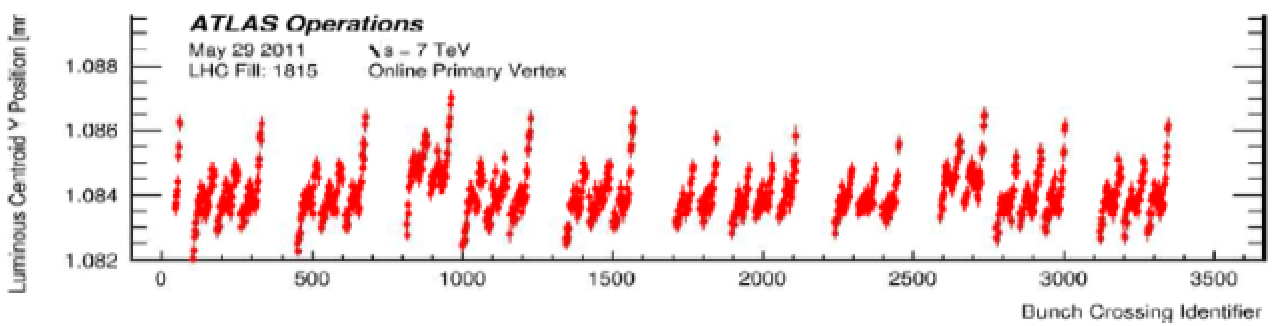


W. Herr & the LHC Beam-Beam Studies Team

Long-Range Beam-Beam in the LHC

- LHC BPM system unable to resolve orbit effects
  - Seen qualitatively in measured experimental vertex position





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Beam-Beam
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LHC Long-Range Summary

- Main Beam Instrumentation systems used
  - Beam Intensity (Lifetime)
  - Beam Loss (Lifetime)

- Systems used but needing improvement
  - Orbit
    - Bunch by bunch resolution
  - Tune
    - Bunch by bunch measurement

Testing the BBLR wire (wire-in-collimator design)

- First Steps
  - Repeat SPS measurements in the LHC
    - Wire effect on beam with comparison to simulations
    - Much of this can be performed at 450GeV
- Instrumentation required
  - Orbit
    - Can we make use of high sensitivity diode orbit system installed in tertiary collimators & some LSS BPMs?
  - Tune
    - Accurate measurements available when transverse damper off
    - Gating damper & tune simultaneously to measure bunch by bunch?

Testing the BBLR wire (wire-in-collimator design)

- Confirming Compensation
  - Filling scheme with sufficient number of bunches for long-range effect
  - Halo formation and diffusion rates
  - Lifetime as a function of crossing angle & wire powering/position
  - Bunch by bunch effects – e.g. PACMAN bunches with wire on & off
- Instrumentation required
  - Orbit
    - Accurate wire alignment with embedded BPMs & bunch by bunch resolution
  - Losses
    - Bunch by bunch – use of fast BCTs (to be upgraded) & diamond BLMs
  - Understanding the tune distribution
    - Ideas needed for experiments to be performed with unsafe beam at high energy
    - Schottky & BBQ for bunch to bunch measurements
  - **Halo – no instrumentation currently installed to measure this**
    - A direct observable to verify simulations & confirm understanding
    - Challenging for LHC/HL-LHC beam size
    - R&D starting with contributions proposed from SLAC (US) & KEK (Japan)

Halo Diagnostics for HL-LHC

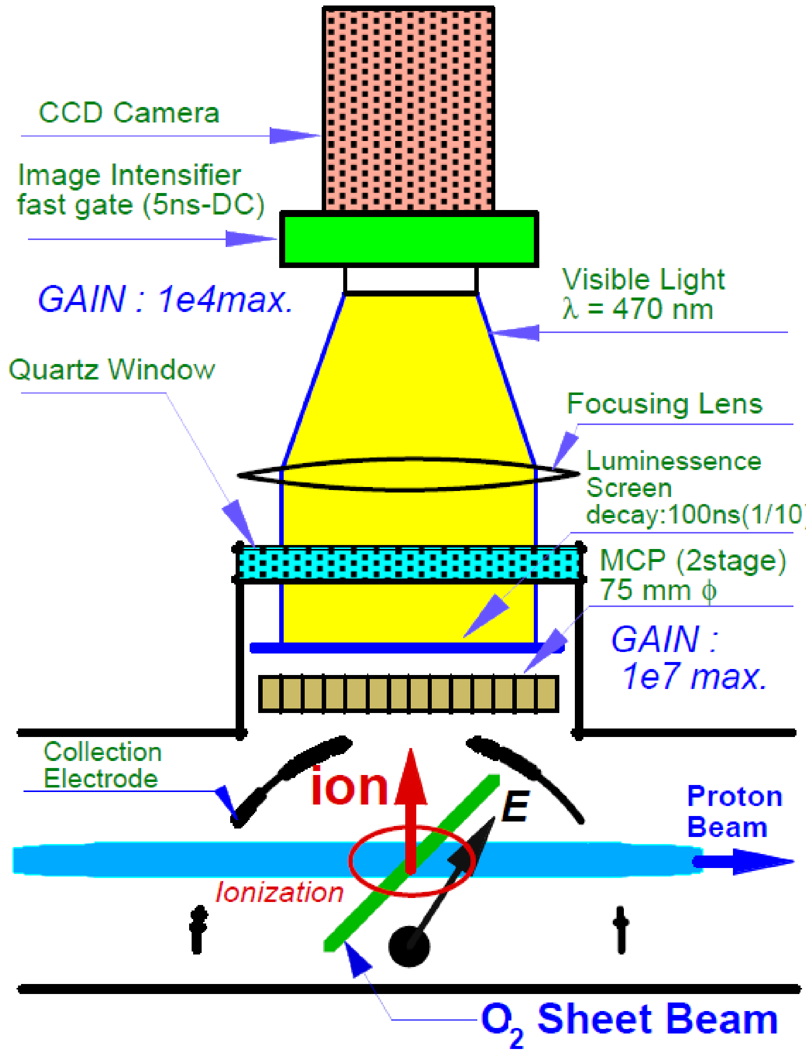
- Workshop organised at SLAC after the International Beam Instrumentation Conference (IBIC14)
  - Some 40 participants
  - Many presentations from interested parties
    - High power proton & electron machines
    - BNL, CERN, DESY, FNAL, JLAB, KEK, SLAC

- Observation techniques discussed
  - Invasive techniques
    - Not applicable for most LHC measurement scenarios
  - Non-invasive techniques
    - Using gas medium or electrons
    - Optical techniques using synchrotron radiation

Gas Jet Techniques

- Being developed by Univ. of Liverpool in collaboration with CERN for CLIC drive beam

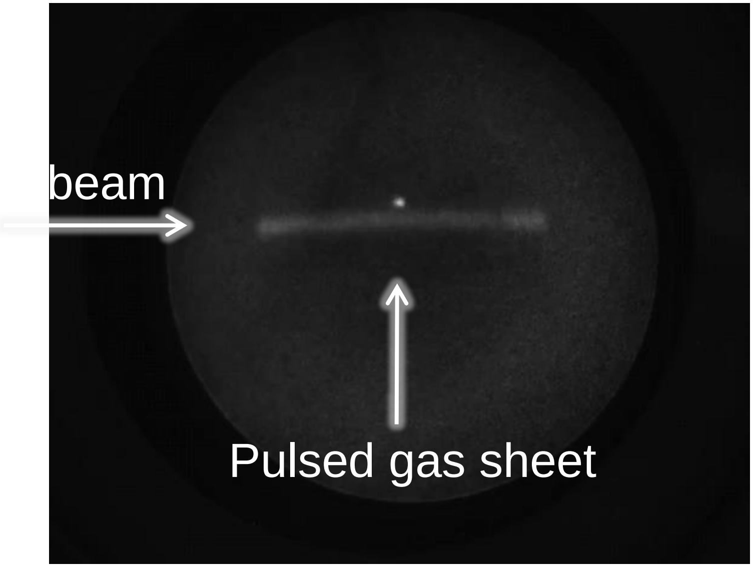
  (A. Jeff)
  - To measure beam profile non-invasively in high power machines
- Two options discussed:
  - Gas Sheet with ionisation profile monitor
    - Also developed by JPARC
  - Scanning gas jet



Gas Jet Techniques

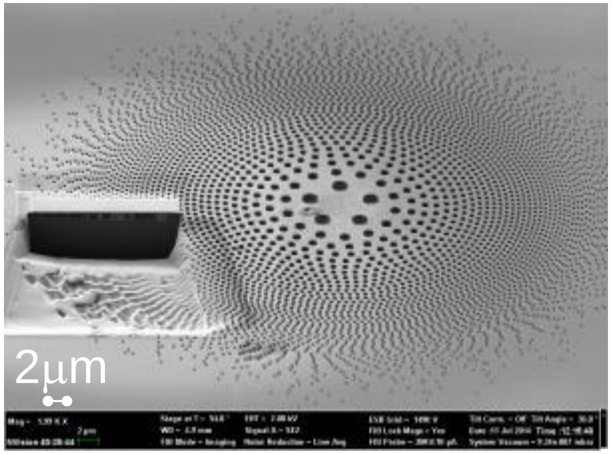
Gas sheet + IPM

- Profile - limited by space charge
- Halo - limited by beam rest-gas & core to halo distinction



Gas jet scanner

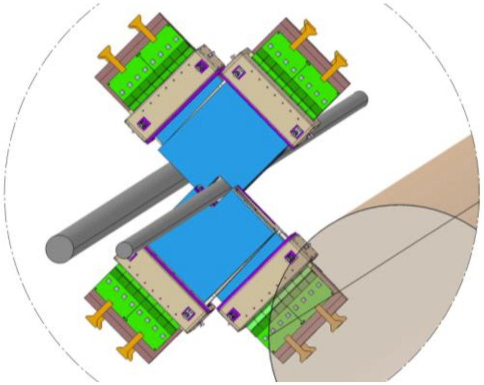
- Use of atomic sieve to focus neutral gas atoms (quantum interference through deBroglie wavelength)
- Space charge independent
- Scan faster/slower for core/halo

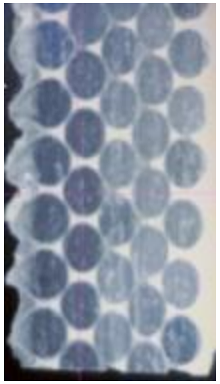


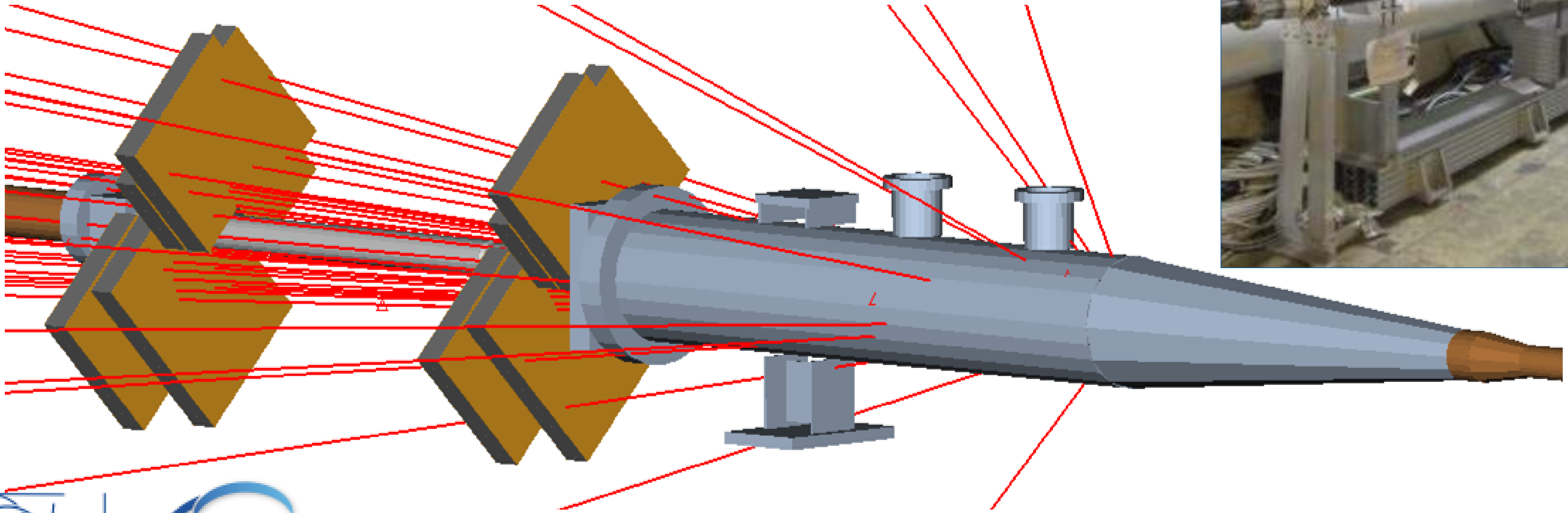
- Gas jet scanner very interesting as possible alternative to fast wire-scanner for HL-LHC
  - Could provide halo measurement if pencil beam clean enough
  - Could also be interesting to measure profile of hollow e-lens beam

Use of the Beam Gas Vertex Detector

- Collaboration with LHCb, EPFL & Aachen
- No experience with trying to measure the halo at 4-6 sigma
- Need to deconvolve with tail of vertex resolution
- Beam-gas rate will be orders of magnitude smaller at this radial distance
  - Aim at 100Hz beam-gas per nominal bunch.
  - Sampling 0.1% at tail of bunch $\Rightarrow$ 0.1 Hz / bunch

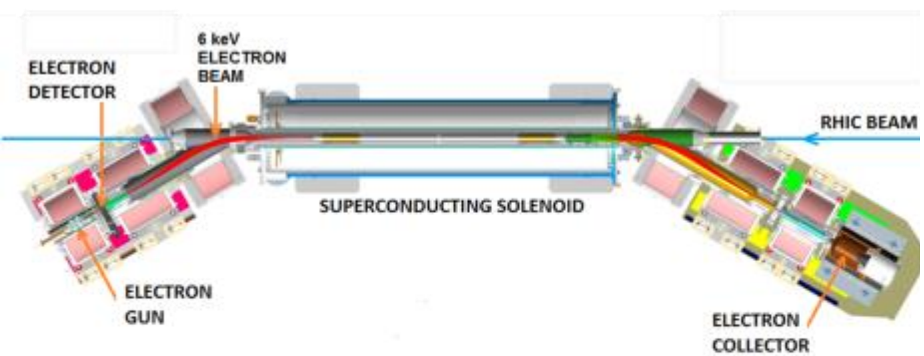


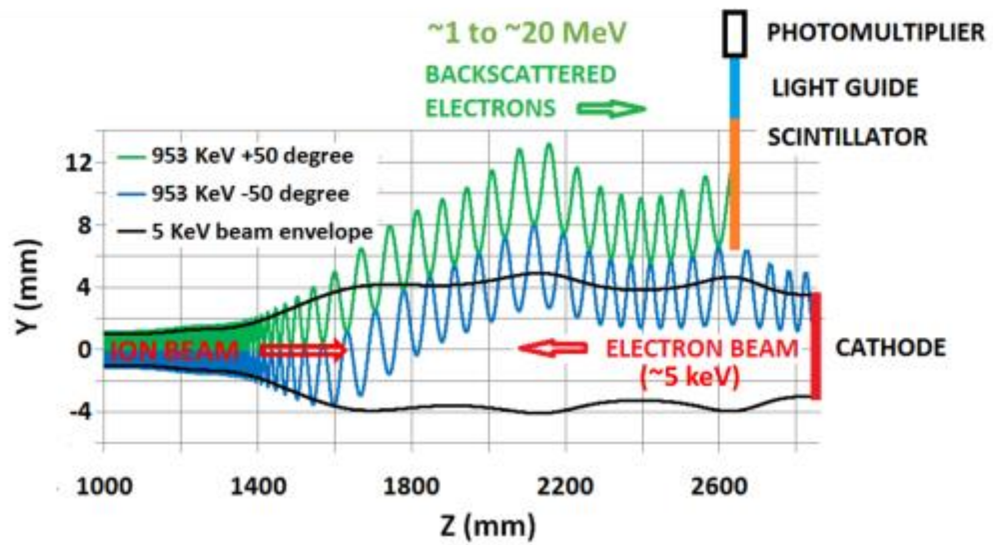




Use of Scattered Electrons

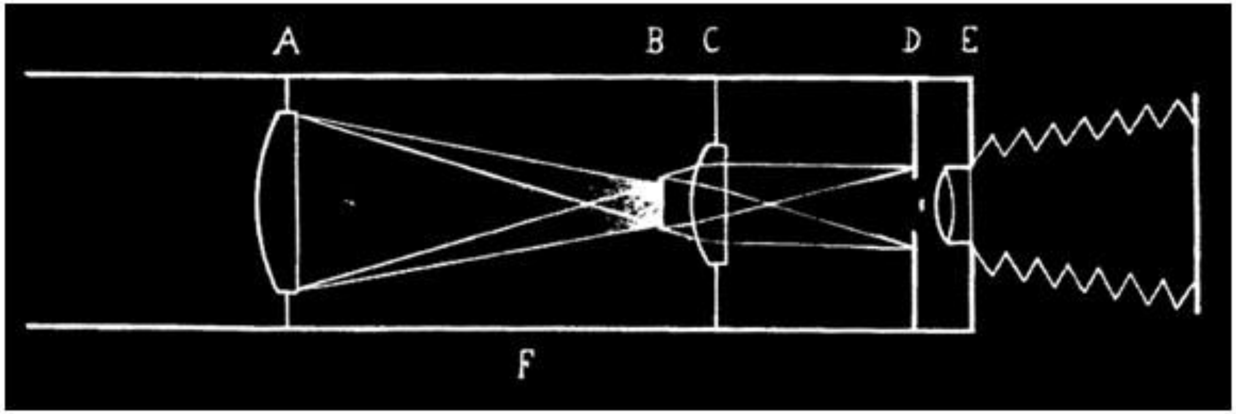
- Successful commissioning of electron back-scattering with gold and ^{3}He beams in RHIC (P. Thieberger)
- In combination with hollow electron lens could be ideal halo probe – BUT:
  - Residual gas electrons backscattered by the intense beam core
  - Electrons backscattered when hollow beam crosses proton beam





Optical Techniques using Synchrotron Radiation

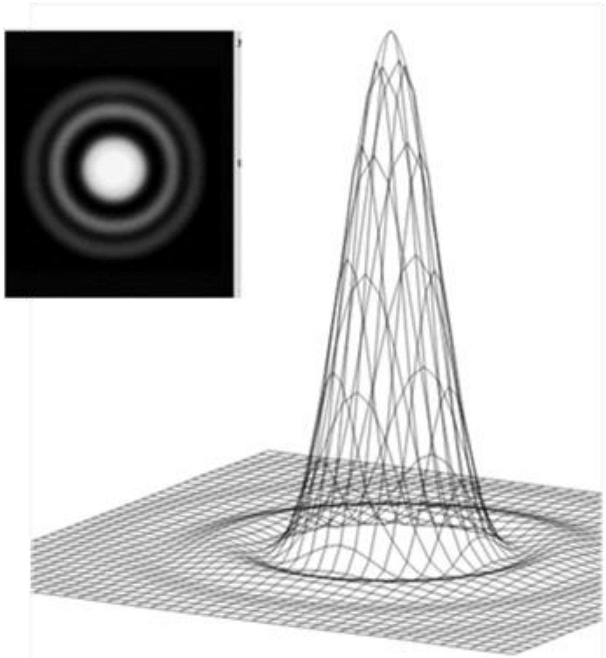
- Two methods presented
  - Amplitude Apodiser (P. Evtushenko, JLAB)
  - Coronagraph (T. Mitsuhashi, KEK)
- Synergy with direct exoplanet detection
  - S. Thomas (NASA, Ames)
  - Contrast required ~10^{10} for Earth-like planets

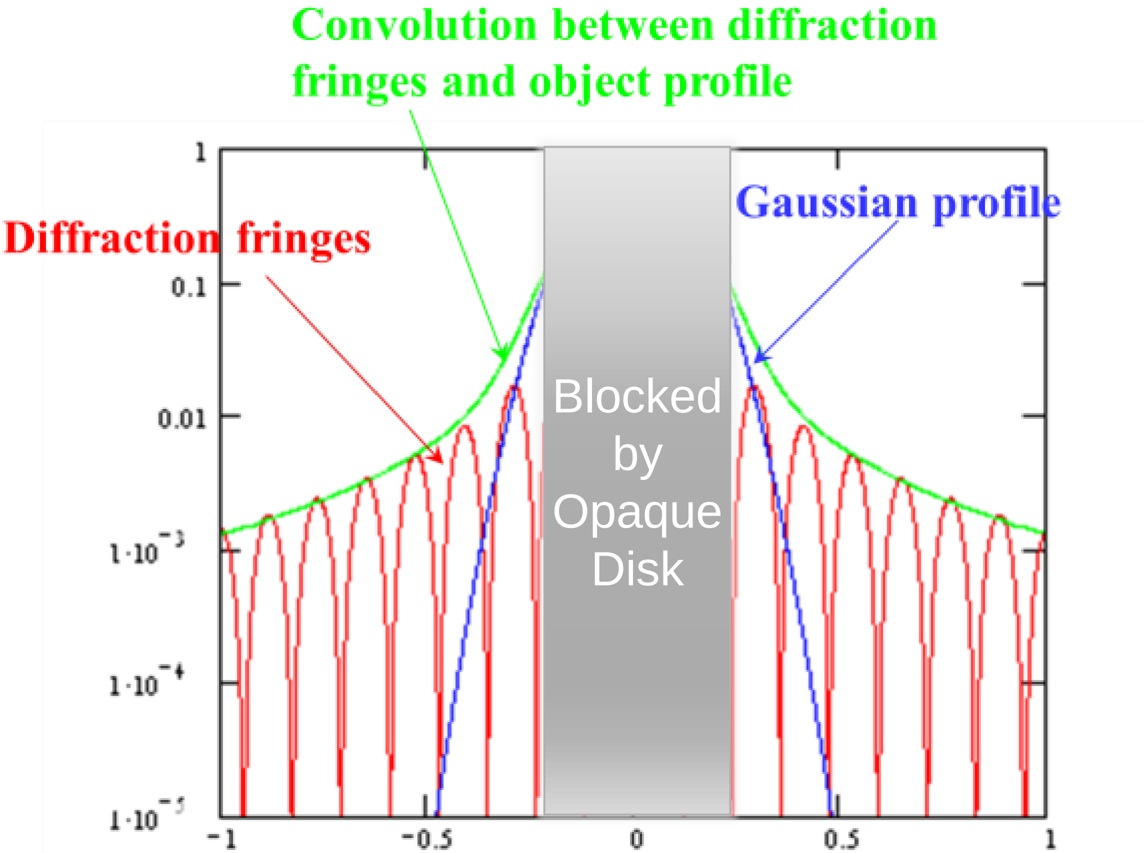


Lyot's Solar Coronagraph, 1936

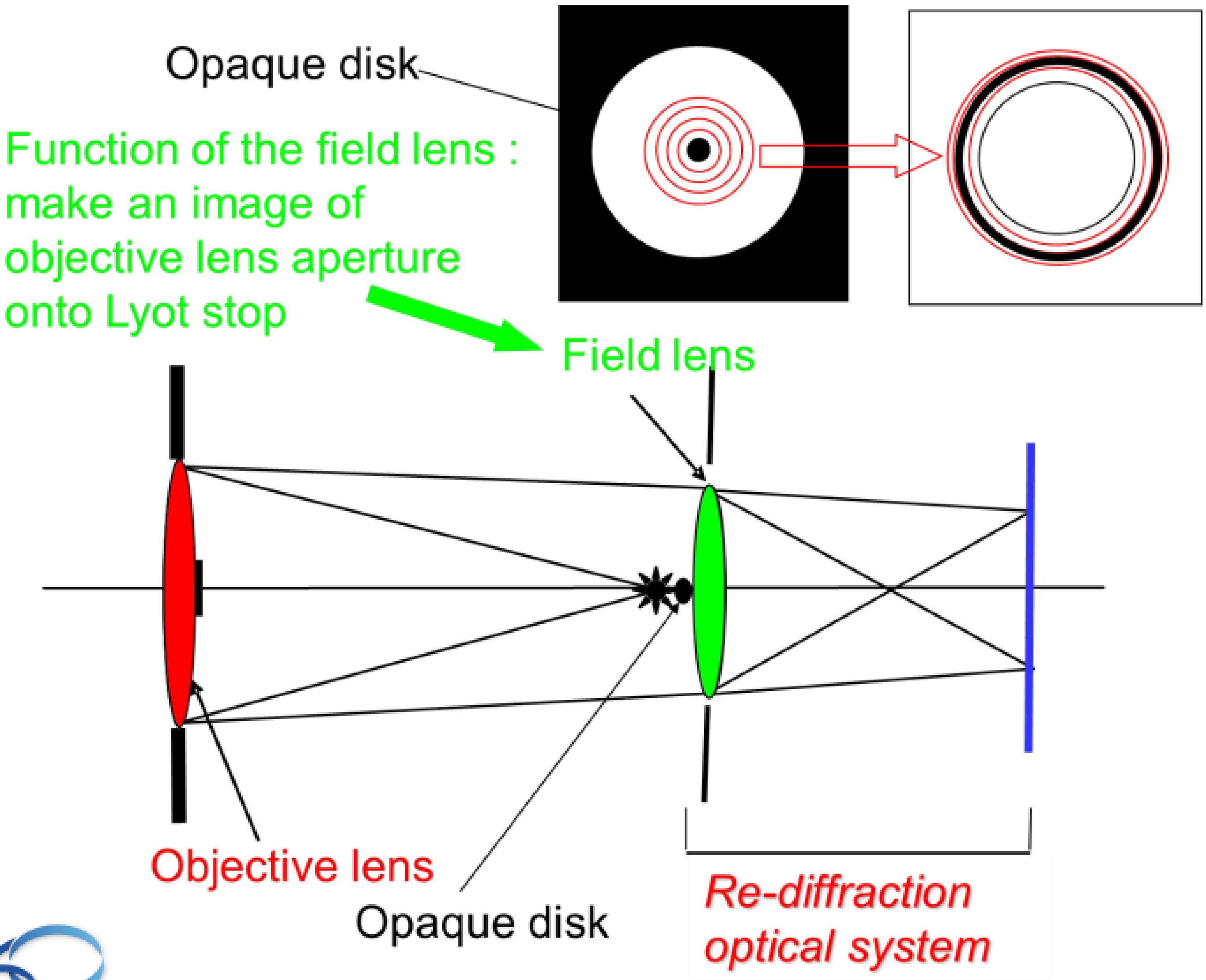
Coronagraph for Halo Diagnostics

- Diffraction creates fringes surrounding central beam image
- Intensity of fringes in range of 10^{-2} - 10^{-3} of peak intensity
- Masks observation of weak corona at 10^{-5} -10^{-6}
  - Need a way to reduce effect of diffraction fringes





The Lyot Coronagraph



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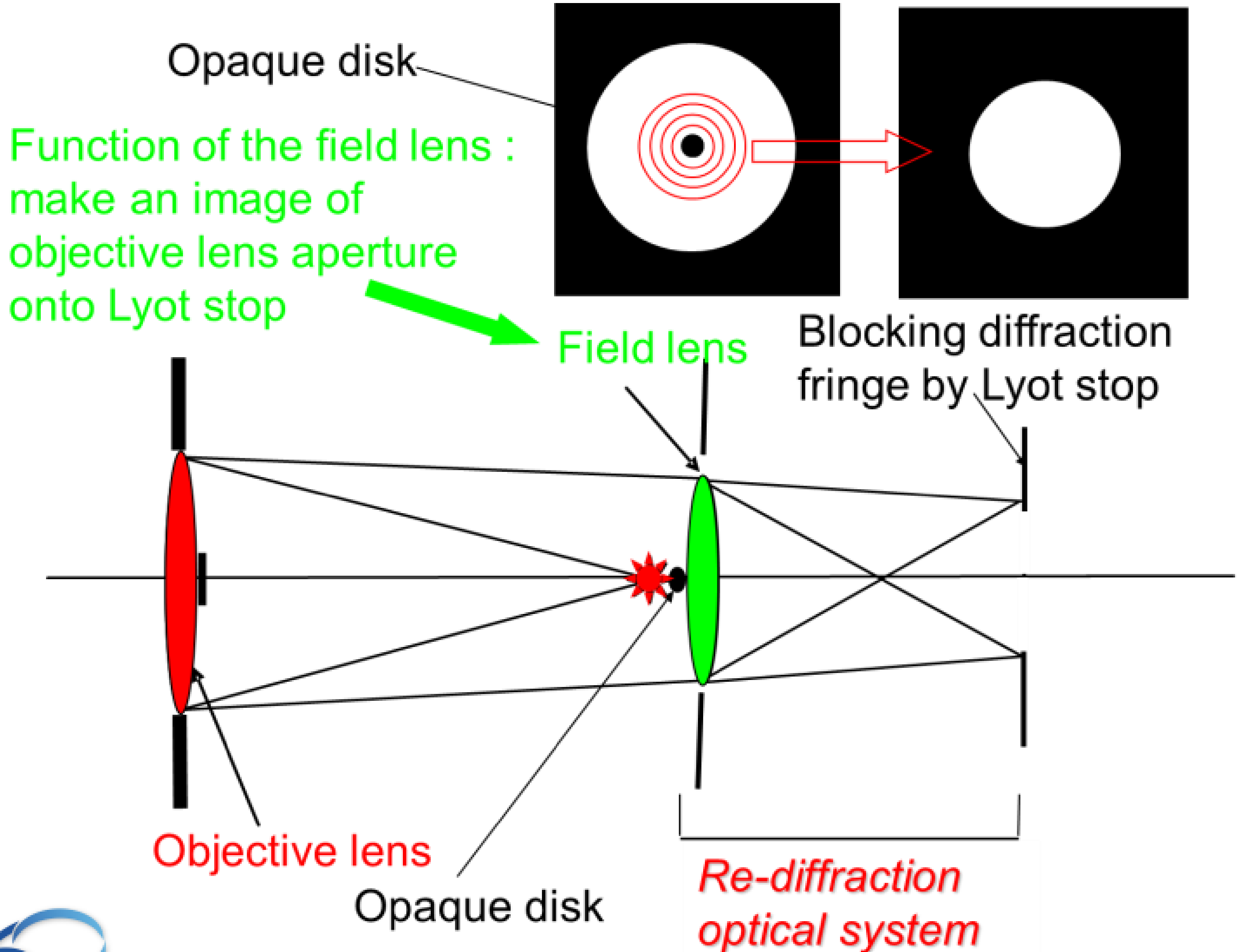
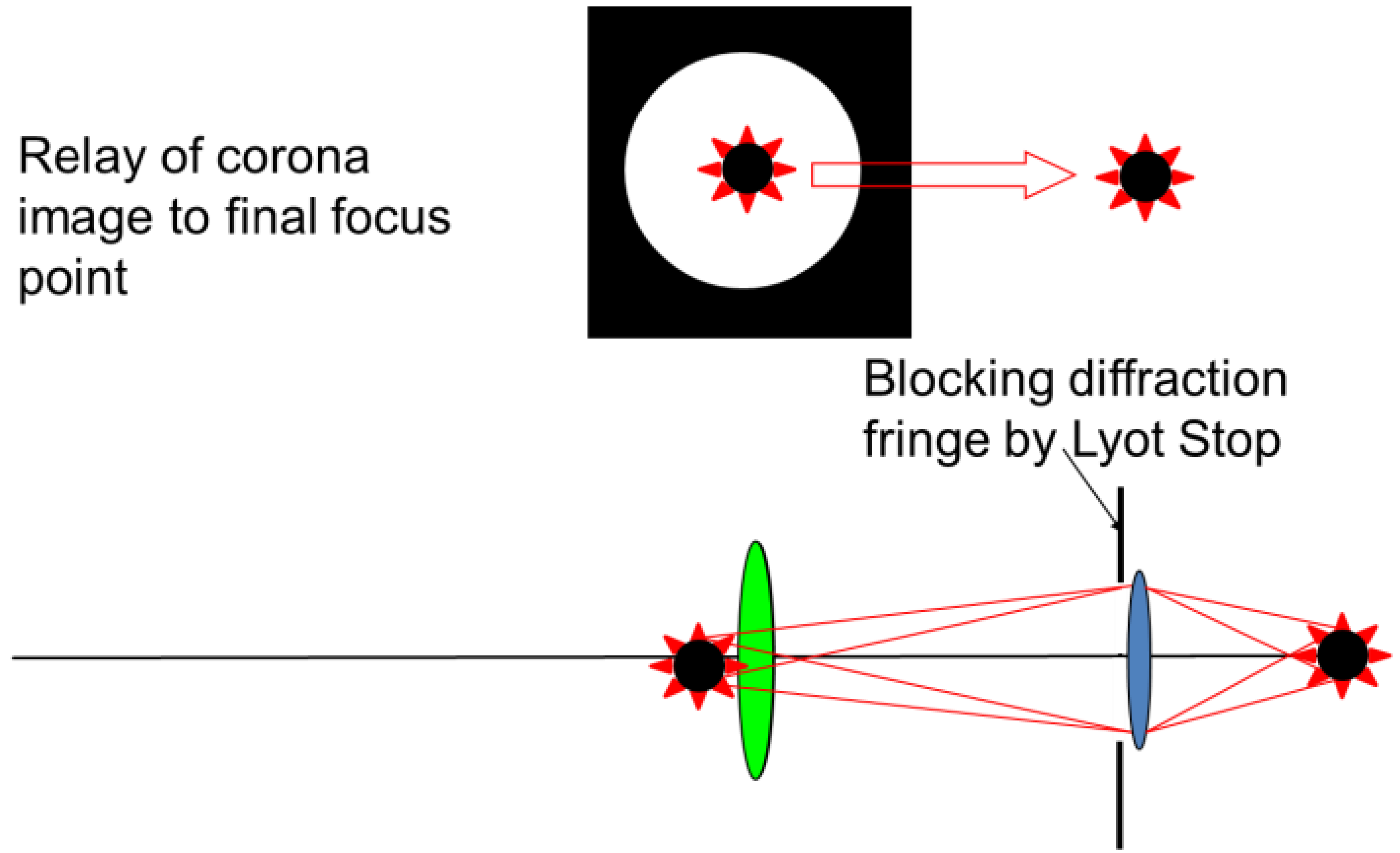
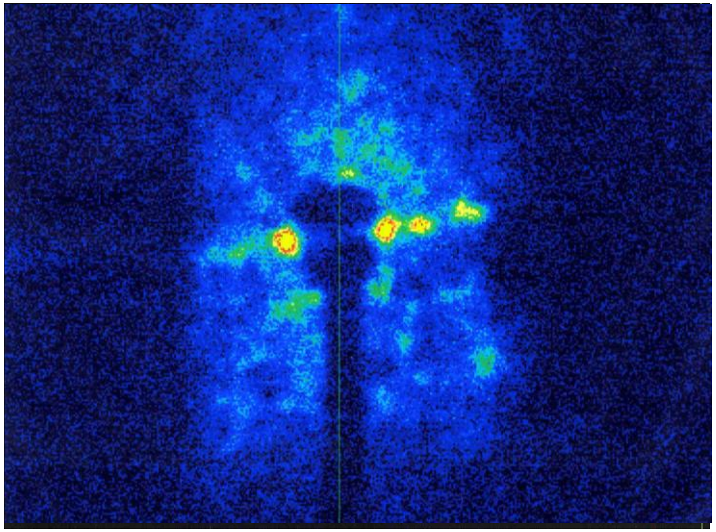


The Lyot Coronagraph



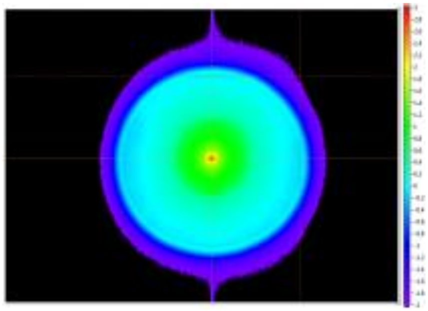
Coronagraph for Halo Diagnostics

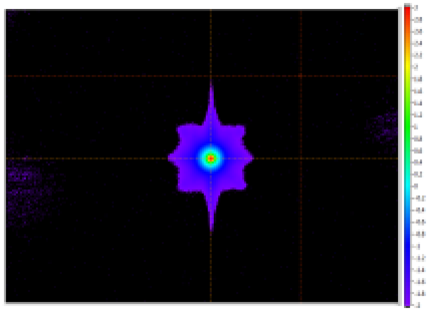
- Demonstrated at KEK Photon Factory
  - Achieved ratio for background to peak intensity of $6x10^{-7}$
  - Spatial resolution is about 50μm
  - Main challenge – avoid noise introduced by Mie Scattering from imperfections or dust on the objective lens
- Preliminary estimation for LHC
  - Reduction of background from diffraction to 10^{-6} in region of interest seems possible .
  - Halo image in 1mm to few mm surrounding of beam core with 0.1-0.2mm spatial resolution
- Collaboration with KEK proposed to produce technical specifications for LHC coronagraph

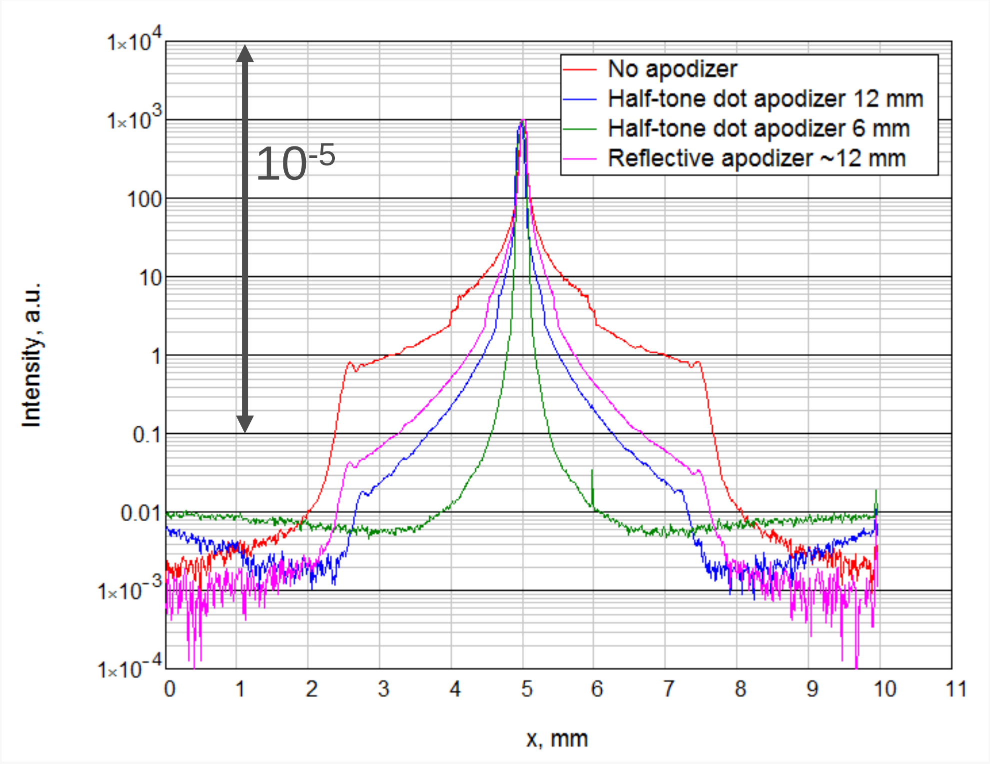


Amplitude Apodiser for Halo Diagnostics

- Convolution of Point Spread Function (PSF) of Gaussian apodizers with 2D Gaussian distribution
- Criterion – deviations from Gaussian must be small (%)
- Combine with high dynamic range camera system
- Collaboration with SLAC proposed to investigate this technique







Summary

- Two Step approach for BBLR Tests
  1. Check understanding of wire effect on beam
  2. Confirm compensation
- Instrumentation
  - Benefit from upgrades to many systems post LS1
    - Orbit, Tune (Schottky, BBQ), Fast BCTs & Diamond BLMs
    - All give indirect measurements of wire effect/compensation
  - Main missing diagnostics
    - Halo monitoring for direct observation of diffusion
      - **Collaboration proposed with SLAC & KEK to develop this further**
    - Chromaticity at top energy with nominal beams
      - Hope to make schottky system fully operational for Run II
- Workshop involving WP2 & WP13 mid 2015 to brainstorm on observation techniques for confirming BBLR simulations with beam