AN OVERVIEW OF THE CERN PS SLOW EXTRACTION AND THE RIPPLE COMPENSATION SYSTEMS

J. Kuczerowski, R. Steerenberg, R. Suykerbuyk

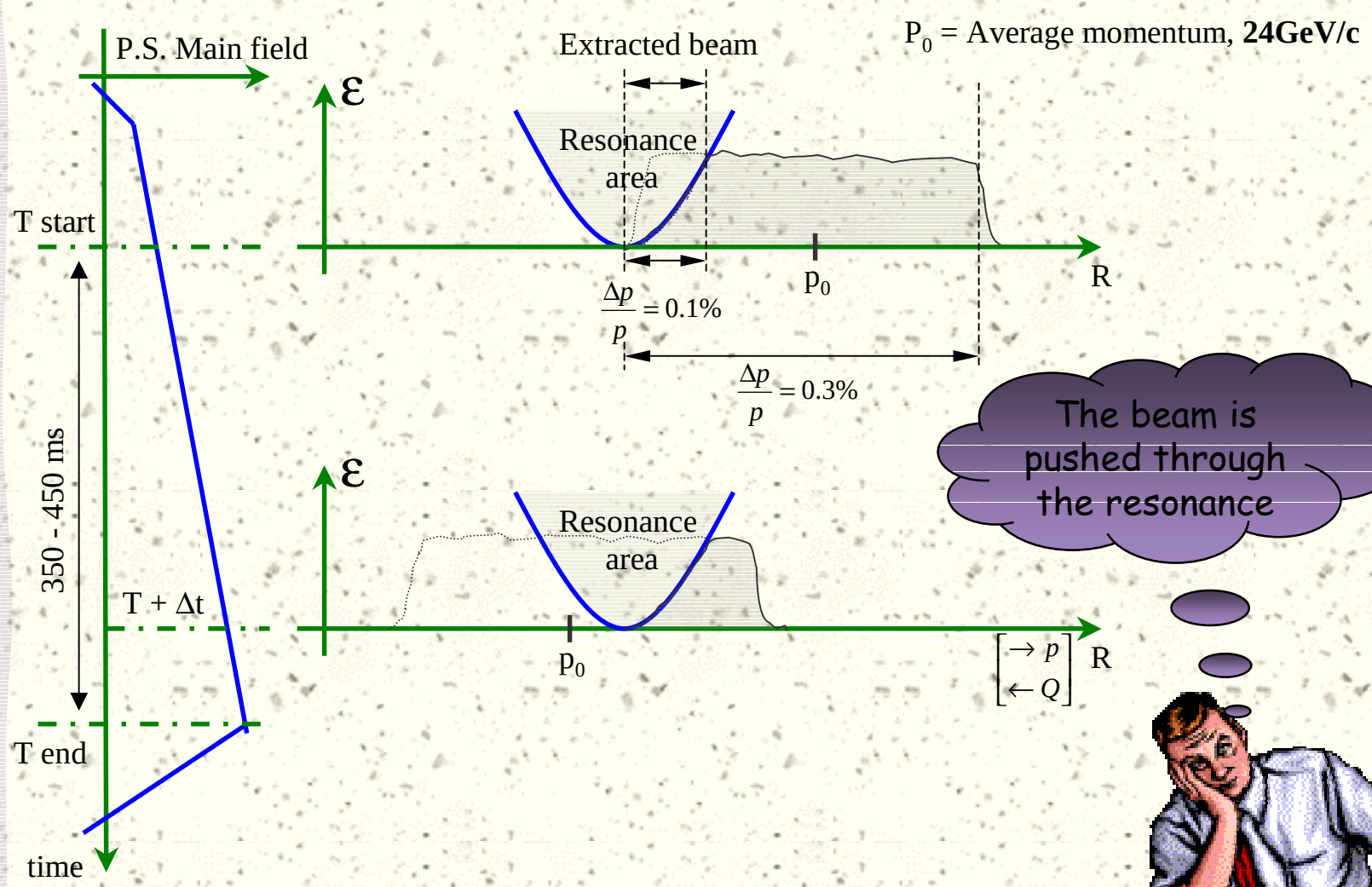
What will be covered:

- What beam is going where
- The CERN PS slow extraction
- The machine settings
  - Tune and Chromaticity
  - Bunch rotation
  - Bumps
  - Extraction septa
- Control and Diagnostics
- Ripple compensation (briefly)
  - Sources of ripple
  - Feed forward system using air quadrupoles
  - Channeling buckets
- Recent developments

What beam is going where

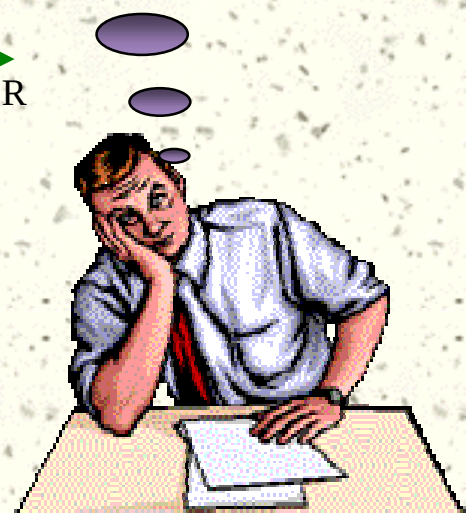
- The East Area beam:
  - Proton beam with an average momentum of 24 GeV/c
  - The total intensity ranges from $5*10^{10}$ to $4*10^{11}$
  - The spill length is 400ms to 450ms
  - Horizontal emittance $\varepsilon h = 0.5\ \pi\mu m$ (circulating beam)
  - Horizontal emittance $\varepsilon h = 0.1\ \pi\mu m$ (extracted beam)
  - Momentum spread $dp/p = 3 *10^{-3}$ (before extraction)
  - Momentum spread $dp/p = 1 *10^{-3}$ (extracted beam)
- The East Area clients:
  - 5 beam lines for 8 (9) areas in 1 building
    - 4 general purpose beam lines, behind two targets (LHC test beams)
    - 2 physics experiments until end 2002 run (DIRAC & HARP)
    - 2 (3) Irradiation facilities (LHC test beams)

The CERN PS Slow Extraction



P_0 = Average momentum, **24GeV/c**

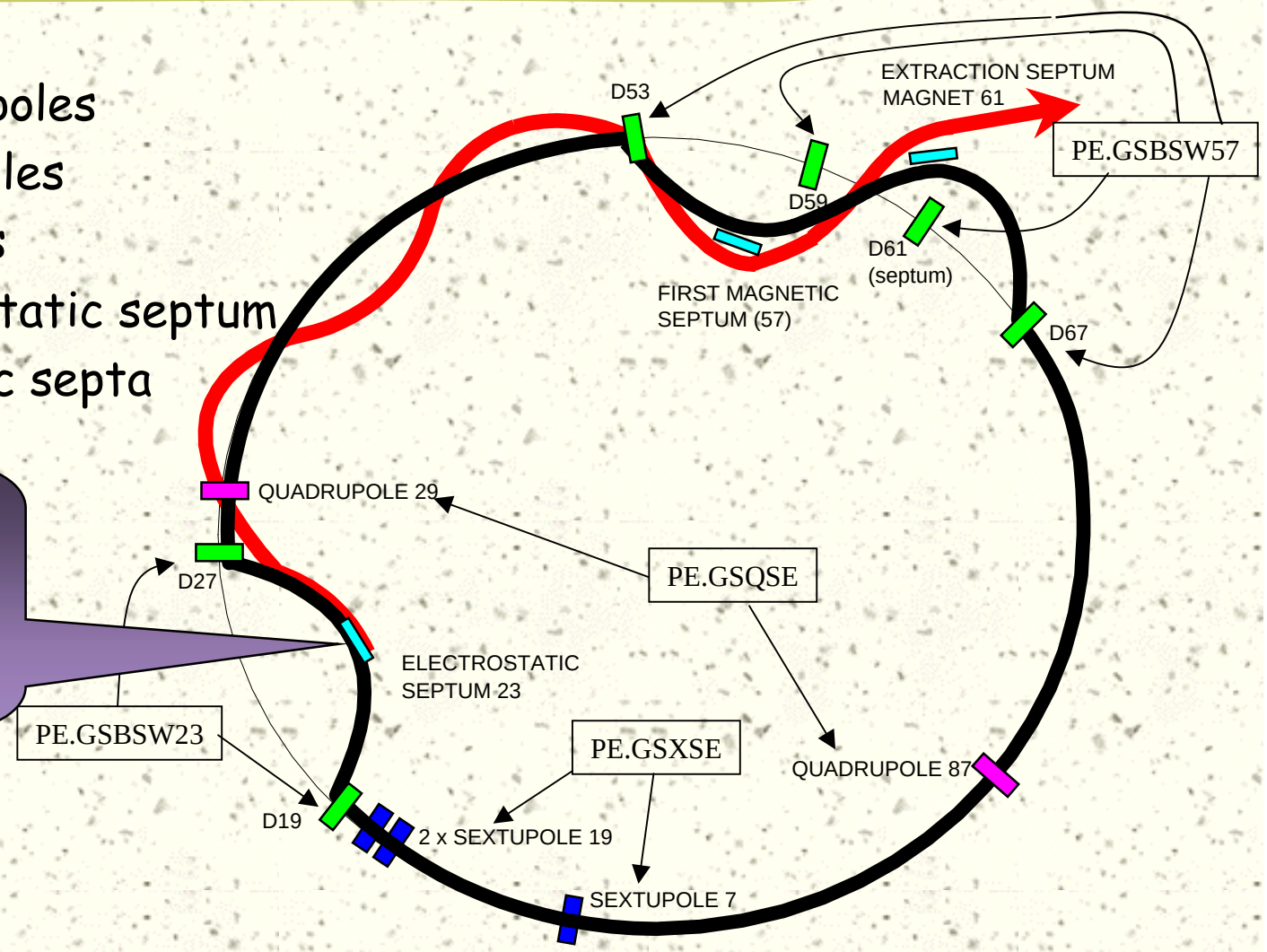
The beam is pushed through the resonance



The P.S. slow extraction lay-out

- 2 Quadrupoles
- 3 Sextupoles
- 2 Bumpers
- 1 Electrostatic septum
- 2 magnetic septa

On the inside of the machine to avoid damage due to synchrotron radiation during the period the PS was used as LEP pre-injector.



Some data on the 3 septa

- Electrostatic septum (thin septum)
  - 0.1 mm thick molybdenum foil stretched in a frame
  - Operating voltage 160 KV
  - Gap = 17 mm
- 1st Magnetic septum
  - 4 mm blade water cooled
  - Single turn coil pulsed up to 10 KA (0.7 T)
  - Gap = 25 mm
  - Contains wire chamber for measurements
- 2nd Magnetic septum (extraction septum)
  - Outside vacuum (thick blade)
  - Four turn coil pulsed up to 1600 A.

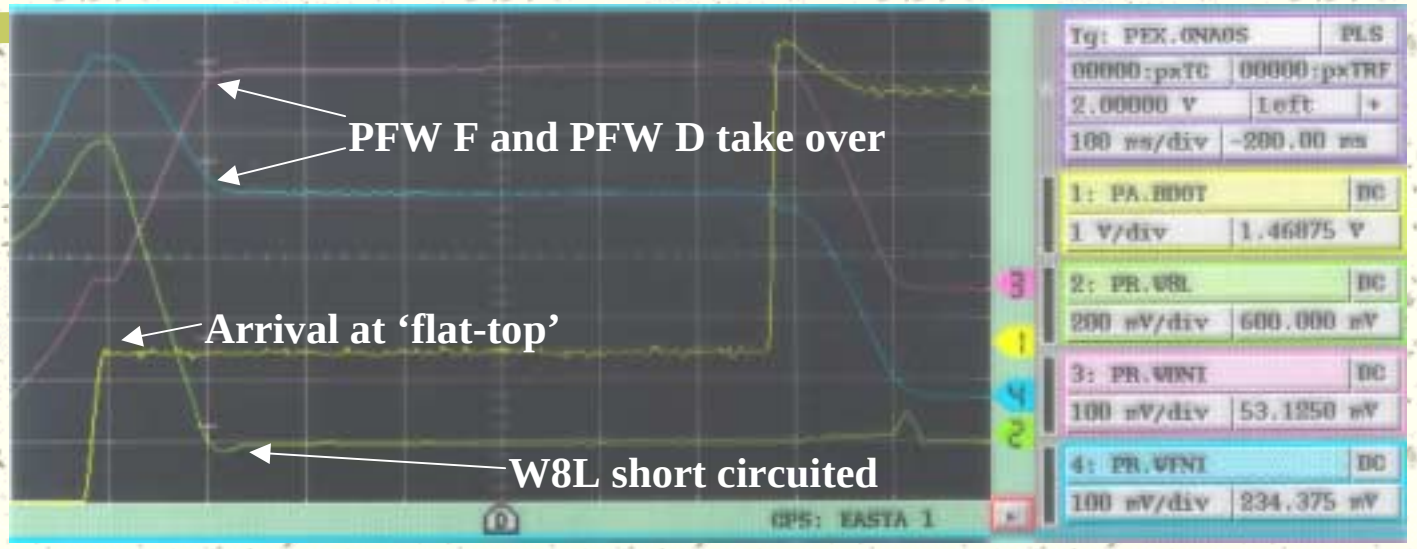
Preparation for Slow Extraction (1)

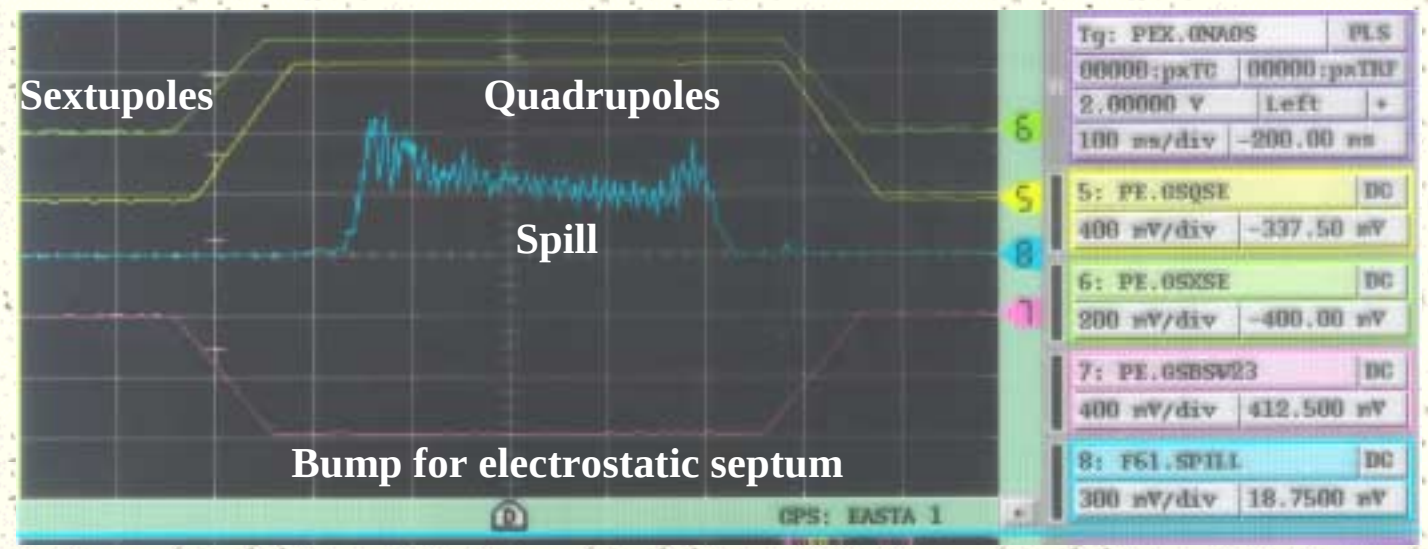
- The 8-loop goes to 0 A, Pole Face Winding D and F generate:
  - The correct horizontal tune: Qh = 6.2
  - The correct horizontal chromaticity $\xi h = -0.9$
- Switch on the slow extraction elements:
  - Quadrupoles
    - Add 0.13 to the horizontal tune to make Qh = 6.33
    - Increase β
    - Create low dispersion at electrostatic septum (SEH23)
    - Create big positive dispersion at 1st magnetic septum (SMH57)
  - Sextupoles
    - Add 0.4 to the horizontal chromaticity to make $\xi h = -0.5$
    - Control the 'stability triangle' size and the 'spiral pitch'
  - Bumps
    - To approach the beam towards the different septa
  - Septa
    - The electrostatic septum is always on
    - The two magnetic septa are only pulsed during extraction.

Preparation for Slow Extraction (2)

- Put the beam on the right orbit using an offset in the radial loop.
- Perform a bunch rotation (jump to and from the unstable phase)
- Switch off the RF voltage at maximum dp/p.
- Let the beam de-bunch
- The slope on the magnetic field of the main magnets will push the beam through the resonance.
- Particles with large betatron amplitude will be extracted.

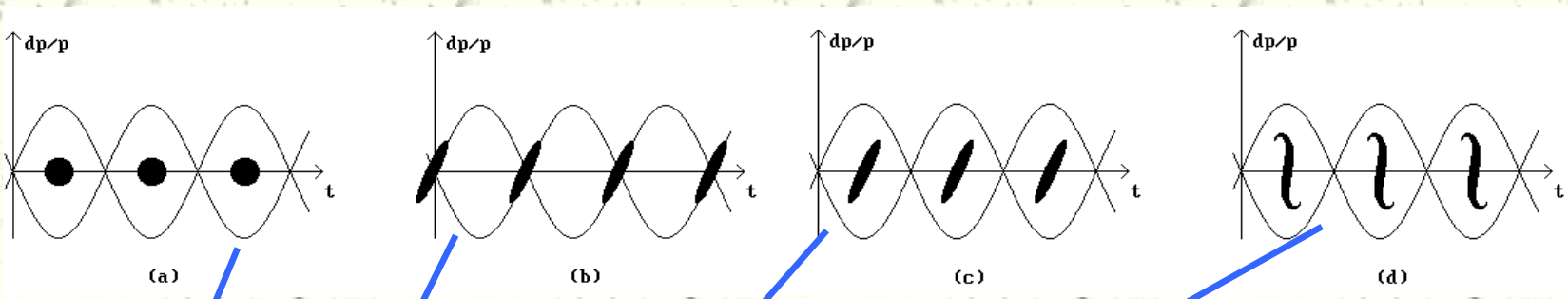
Magnetic preparation





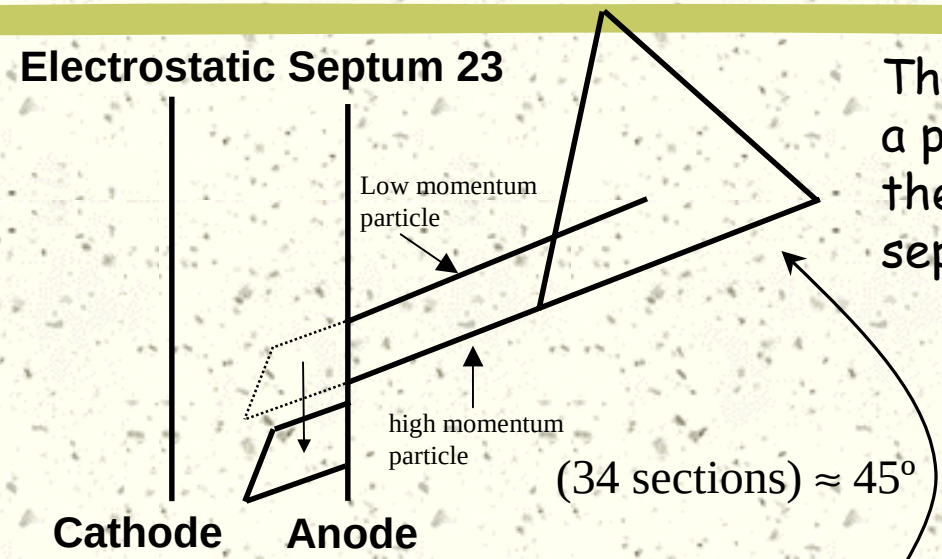
RF preparation (bunch rotation)

Schematically:

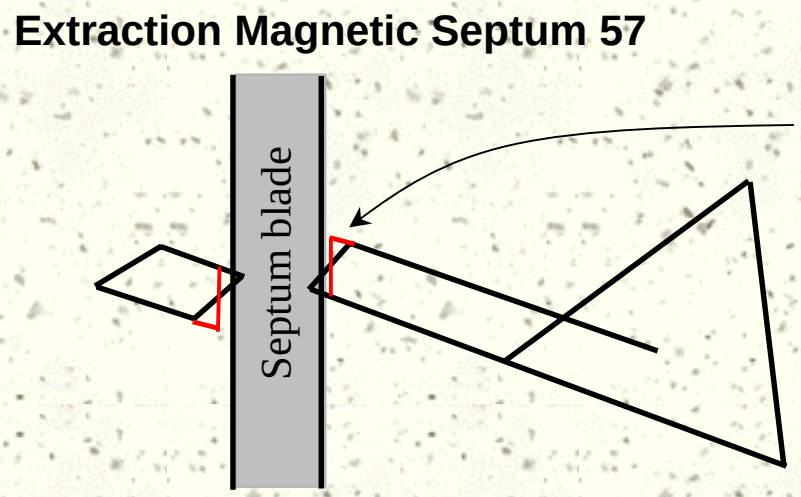


Real life:

Optics and Septa, source of losses



The electrostatic septum kicks a part of the beam and creates the space for the 1st magnetic septum.



Optimum situation obtained by changing the dispersion coefficients at SES23 and SMH57. This is done using the 2 quadrupoles.

Dispersion at 23 small and positive
Dispersion at 57 Big and positive.

How the Slow extraction is controlled

- There is no feed back system for the PS slow extraction in order to control or shape the spill.
- All adjustments are made manually using a few software applications written by the operators.
  - Tune, chromaticity and bump amplitude control
  - Radial position control
- Different measurement devices are available to measure the properties of the circulating beam
  - Bunch shape measurement (dp/p, bunch length, ….)
  - Wire scanners (horizontal vertical emittance)
  - Horizontal and vertical tune measurement
  - Orbit / trajectory measurement
- The beam steering in the transfer lines is done using scintellator screens.

The spill control application

Slow Extraction 61

File Option Control PFW Timing Help

se61 EASTA Apr 3 07:33:44

Values At Time :	REQUIRED PARAMETERS						RESULTING PARAMETERS			
	Bumps [mm]		PFWs		Quad. & Sext.					
	X23	X57	Qho	Xiho	DQh	DXih	Qh	Qv	Xih	Xiv
C 990	-46.001	-17.000	6.213	-1.398	0.145	0.503	6.358	6.198	-0.895	-1.180
C 1380	-46.002	-17.391	6.207	-1.398	0.145	0.503	6.352	6.205	-0.895	-1.202
Variations	-0.002	-1.003	-0.015	0.000	-0.000	0.000				
	[mm s-1]		[s-1]		[s-1]					

No message

Kmeta - CPS.USER.EASTC -

PA.RPOSSE

Enable Enable

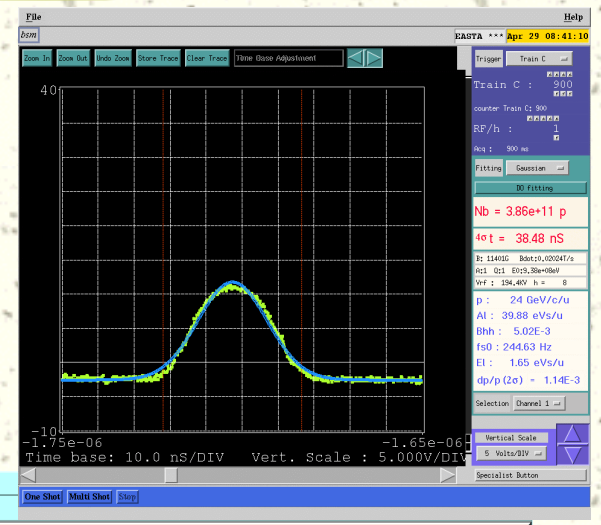
Ampl: Ref 4.00 MM; Init 4.60 MM; 4.60 MM

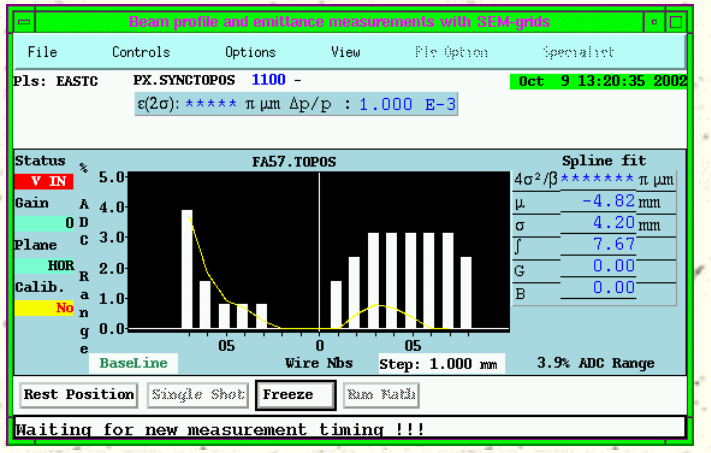
Start: Ref 850.00 C; Init 850.00 C; 850.00 C

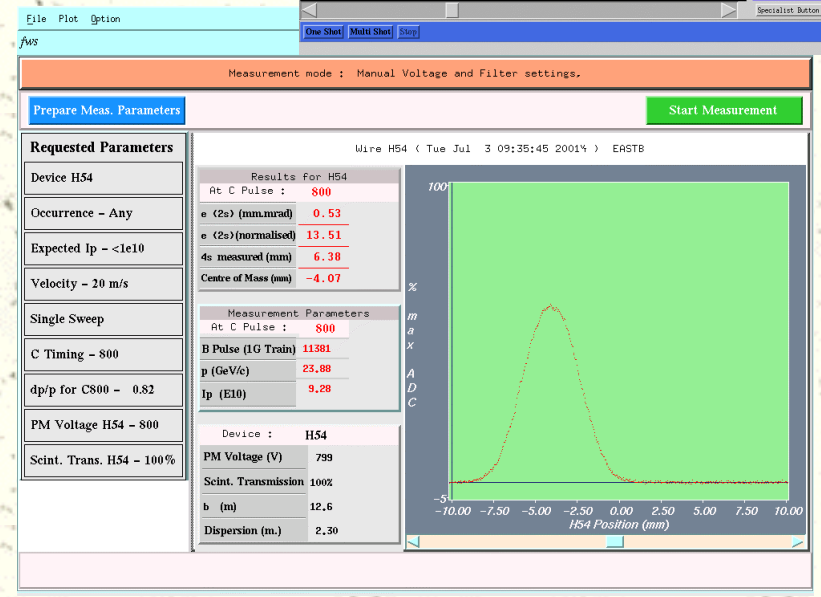
Rise: Ref 10.00 ms; Init 10.00 ms; 10.00 ms

The diagnostics before extraction

- Bunch shape measurement,
- Fast wire scanners,
- Tune measurement,
- Secondary emission wires
- Closed orbit display
- Naos oscilloscopes







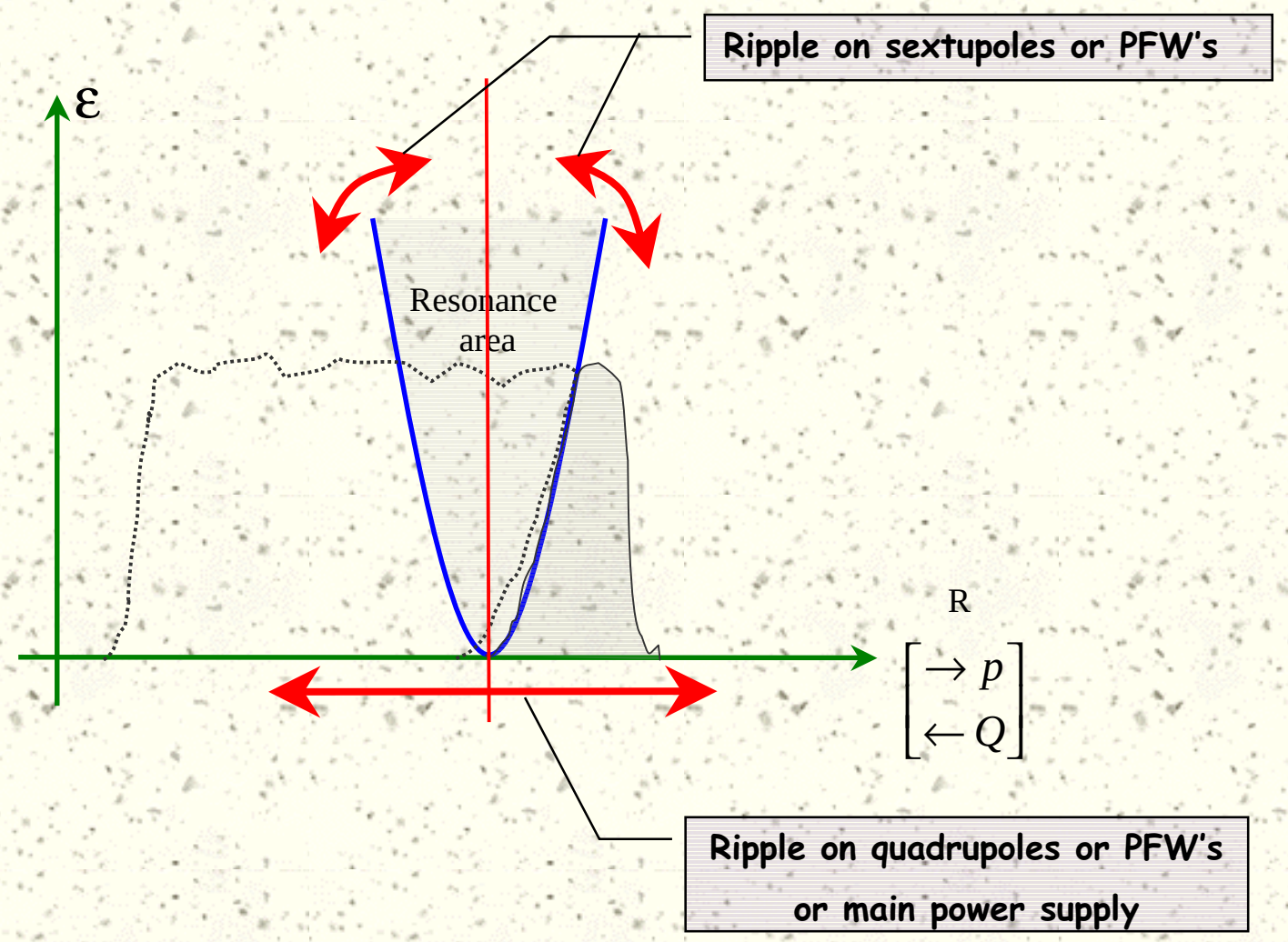
The diagnostics after extraction

- The beam spill intensity is measured using secondary emission chambers and photo multipliers.
- This provides an integrated value, but also the spill shape as a function of time.
- Scintellator screens
- The 'Centroid' beam position detector (only in combination with a target)

Sources of ripple on the spill

- Two basic frequencies are involved:
  - 49 Hz (and its harmonics)
    - from the Main Power Supply
    - The MPS is a motor generator set
    - During 'flat top' motor decelerates slightly (frequency and phase are not constant)
  - 50 Hz (and its harmonics)
    - Pole face winding power supplies
    - Quadrupole power supplies
    - Sextupole power supplies

Sources of ripple schematically

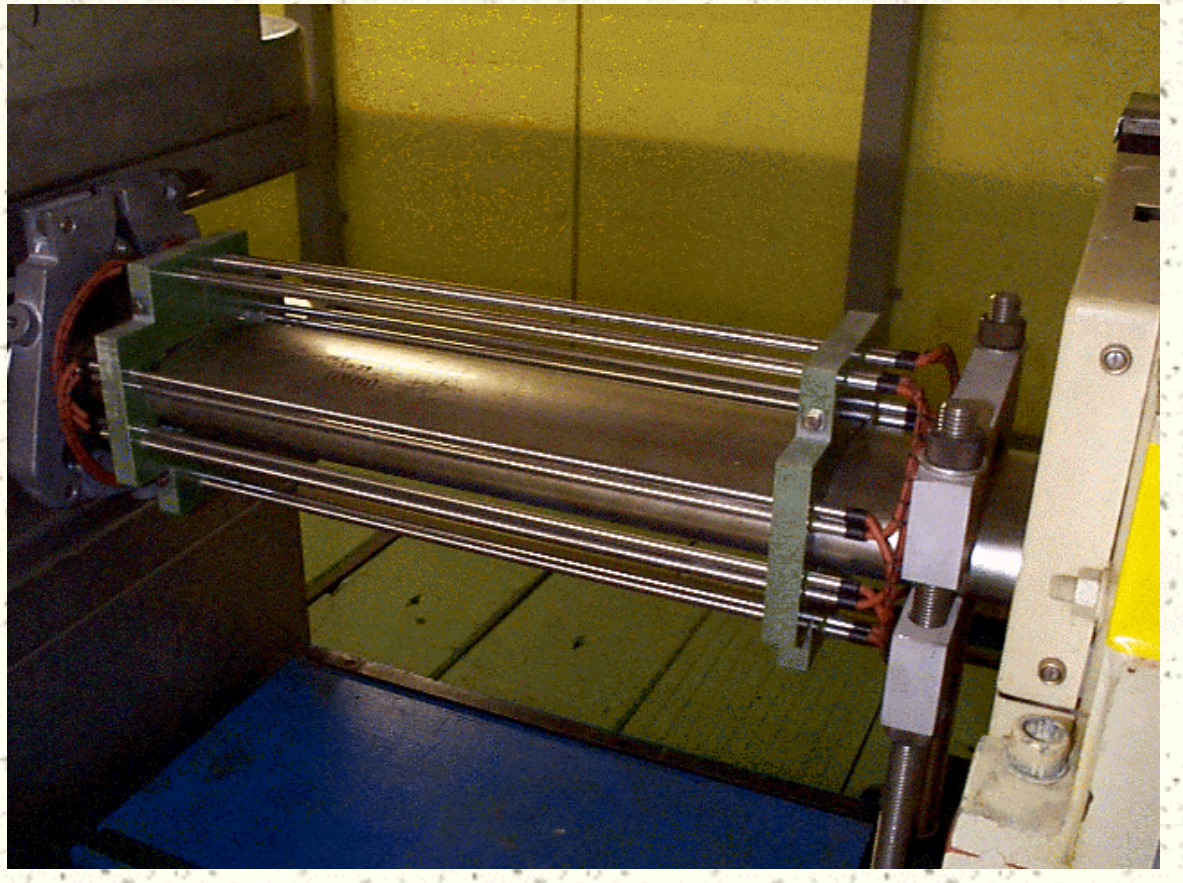


Feed forward

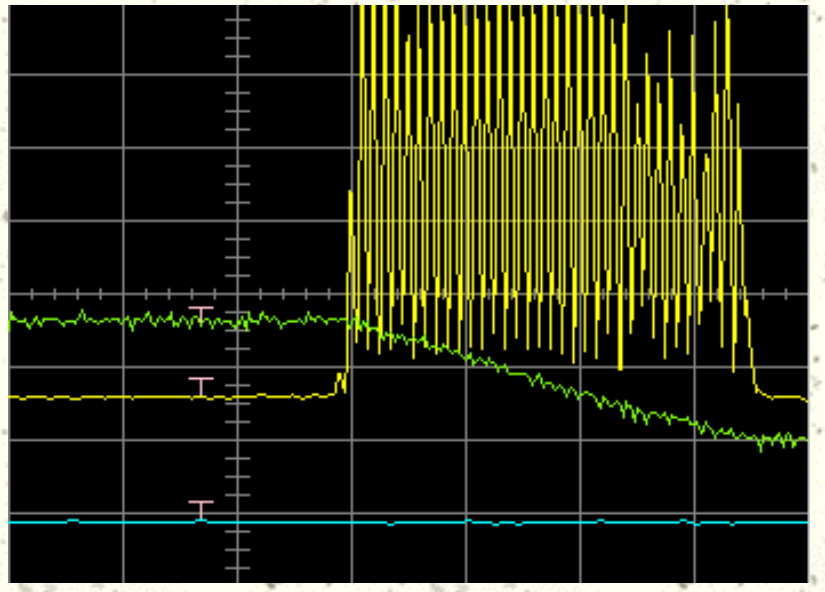
- Modulate the betatron tune using air quadrupoles.
- The spill measurement contains all the information on the frequency components responsible for the ripple.
- A LabView application acquires the spill signal, calculates the frequency components and their amplitude and generates a function that is programmed into a function generator.
- The function generator drives an amplifier which is connected to the air quadrupole.

The Air Quadrupole

- There are 2 air quadrupoles installed in the PS machine



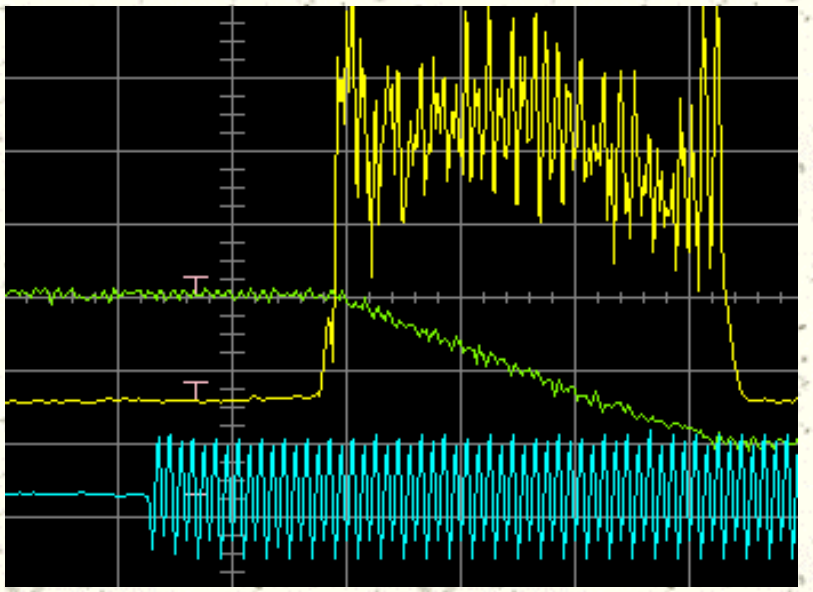
Ripple compensation measured



Ripple compensation

50Hz off

49Hz off

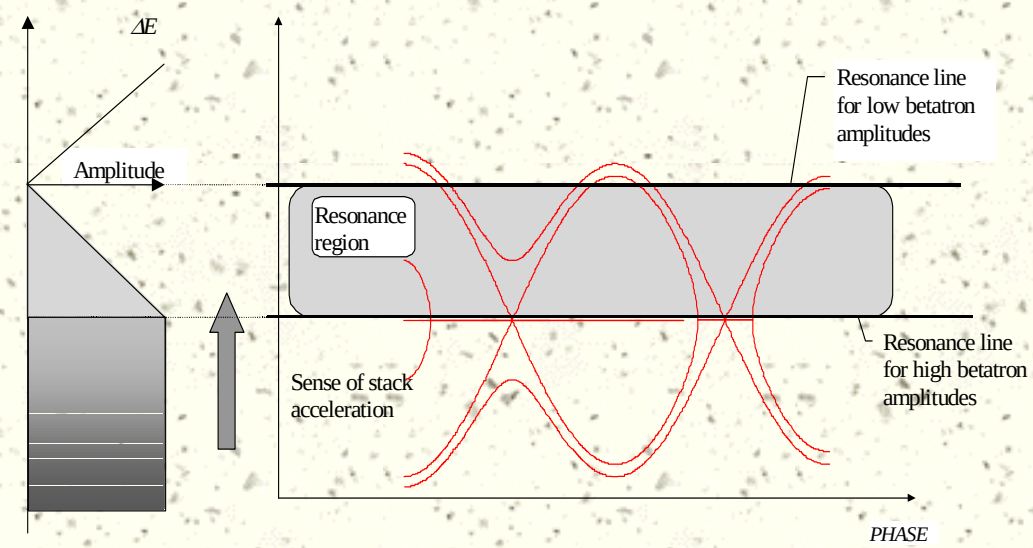


Ripple compensation

50Hz on

49Hz off

Empty Bucket Channeling



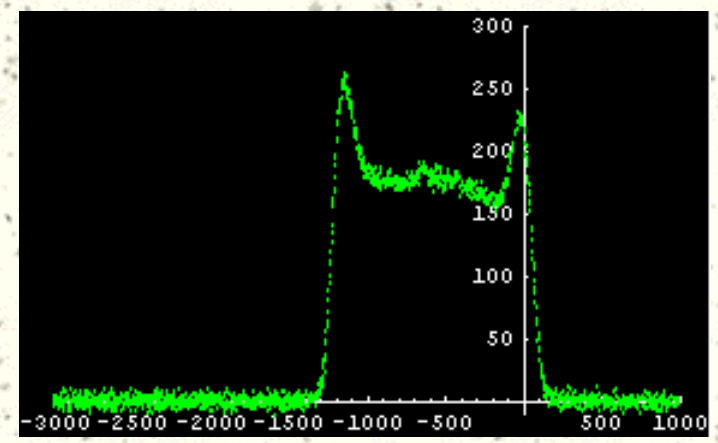
- Has been tested successfully in the PS machine using the 200 Mhz fixed frequency cavities.
- The cavities have a very narrow bandwidth and are adjusted for other purposes.
- This is the reason why bucket channeling is not operational for the PS machine.

Recent developments

- Dual operation on the slow extraction cycle
  - High intensity ($4*10^{12}$) bunch ejected to nTOF facility
  - Low intensity ($2*10^{11}$ – $4*10^{11}$) bunch slowly extracted
  - More sensitive to instabilities due to different behavior
  - Extra RF gymnastics for multiple bunch rotations
- Slow extraction at 20 GeV/c (instead of 24GeV/c)
  - Longer beam spills possible (up to 700 ms)
  - Larger physical beam size, more losses at extraction
  - Beam passes slower through the resonance, so more sensitive to ripple.
- Fast extraction using the 3rd order resonance.
  - Needed for special test in irradiation facility
  - Kick the beam on the separatrix using a fast kicker
  - Beam will eject in 3 turns.

Some references

- Beam optics at resonant extraction septa
  - C. Steinbach, CERN/PS 92-22 (OP)
- The new slow extraction system of the CERN PS
  - C. Steinbach, H. Stucki, M. Thivent, CERN/PS 93-28 (OP)
- Empty bucket channeling
  - R. Cappi, C. Steinbach, PAC 1981
  - M. Cresenti, CERN/PS 97-68 (DI)

Questions or Remarks ?
Thank you for your attention

The slow extraction animated