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Stochastic Extraction at COSY

Slow Extraction Workshop 2017, CERN, Nov 9th,- 11th,- 2016

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Content

- Sketch of Extraction Development at COSY
- COSY Layout and Main Parameter
  - Extraction Layout and Components
- Extraction: Longitudinal Aspects
- Spill Time Structure (Example)
- Backup Slides Extraction: Transverse Aspects

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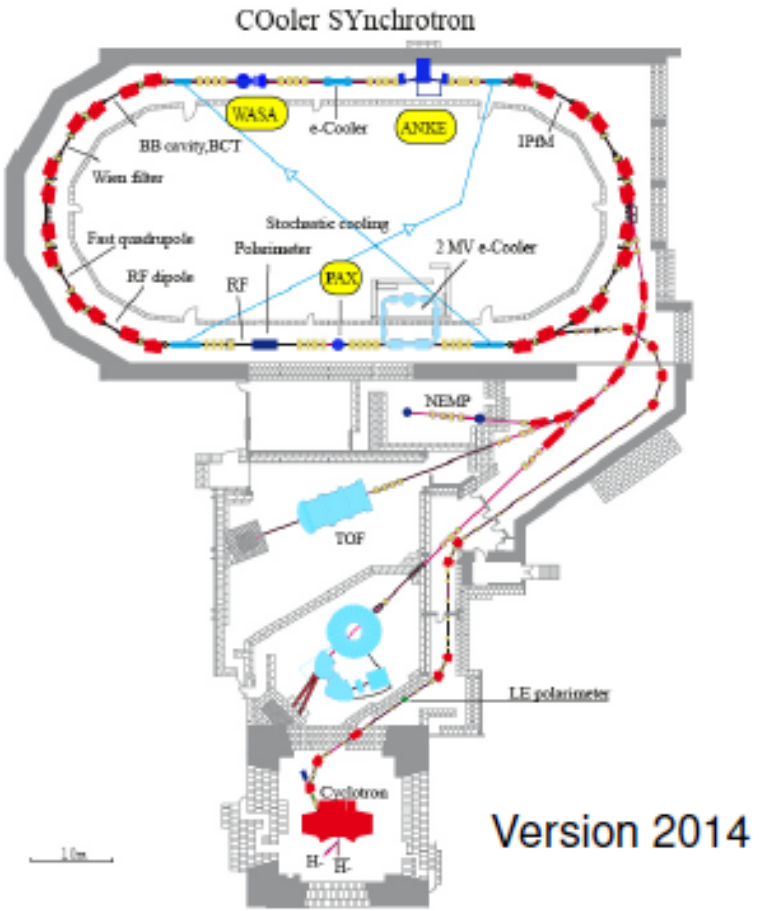
COSY Floorplan

- Circumference: 184
- Straight section: 40 m
  (telescopes with 2 π phase advance)
- Arc section 52 m
  (three cells, each
  QF-D-QD-D-D-QD-D-QF)
- Protons and deuterons momentum range 300 (540) MeV/c to 3300 MeV/c
- Polarized and unpolarized particles
- 100 keV electron cooler at injection and new 2 MeV cooler
- Stochastic cooling above 1.5 GeV/c
- Three extraction beam lines
- **Beam extraction in the whole momentum range**



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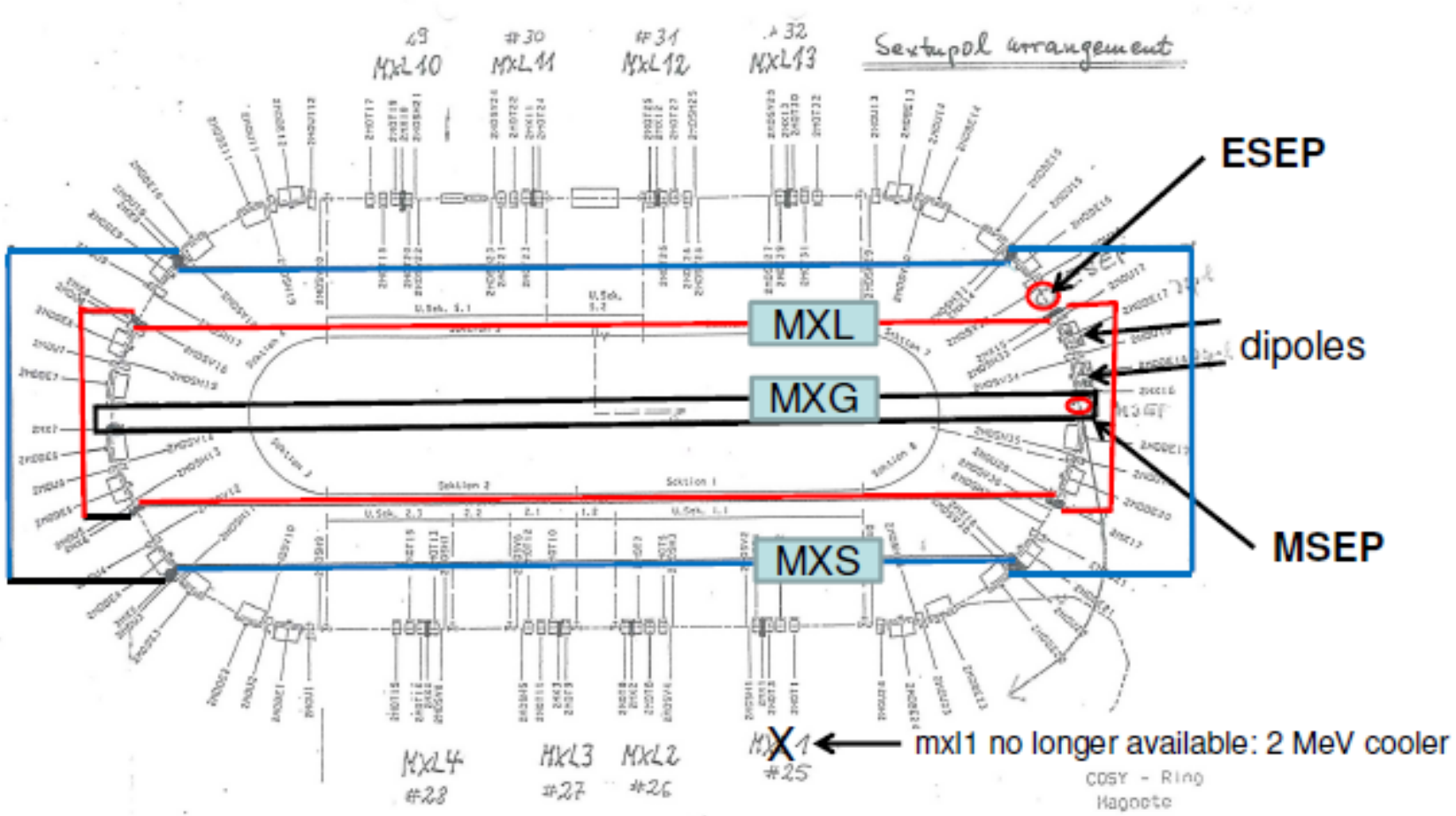
Sextupole Distribution



MXS: four sextupoles at one power supply
MXL: four sextupoles at one power supply
MXG: two sextupoles at one power supply

} Chromaticity correction only

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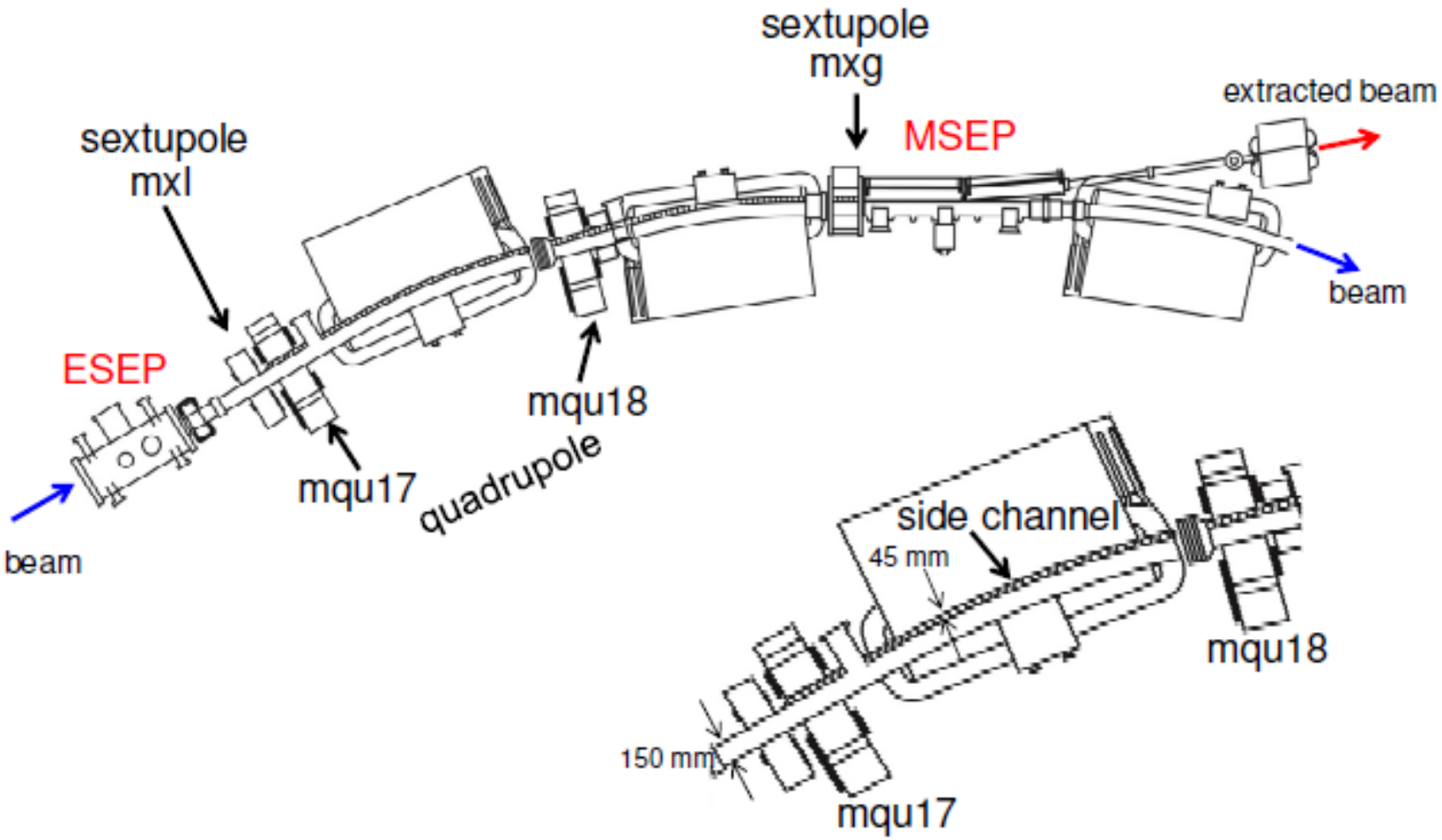
Arc Section and Extraction Elements



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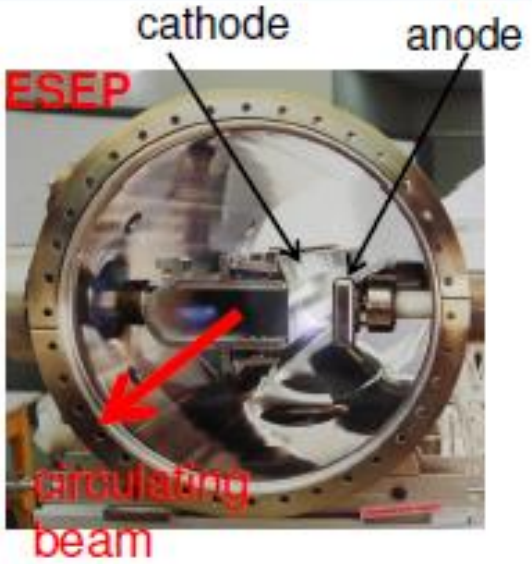
Main data ESEP and MSEP

ESEP

max. energy	2.5	GeV
max. momentum	3.3	GeV/c
deflection	3.5	mrad
max. voltage	200	kV
max. gradient	120	kV/cm
gap width	12 - 40	mm
radial position variation anode and cathode	± 20	mm
angle resp. to closed orbit	± 2	mrad
anode thickness	0.1	mm
length	1	m

max. field	1.1	T
length	2 x 1	m
deflection	2 x 5	degrees
max. current	2740	A
inner side	88	mm
outer side	120	mm
gap	32	mm



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Extraction Elements at COSY

MSEP

Second part:
disassembled

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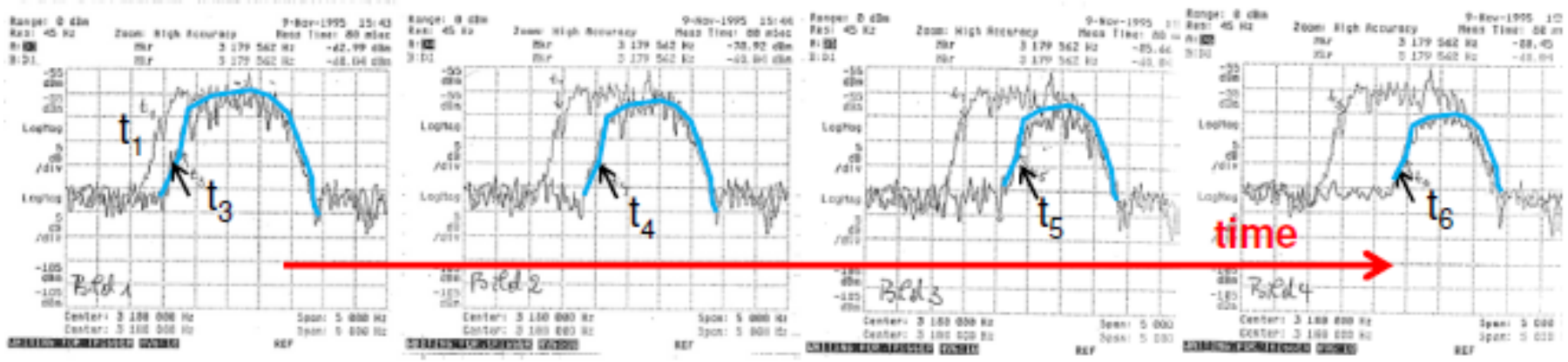
Conventional Extraction Method

- The beam is slowly swept across the resonance with constant speed by moving the tune.
- Circulating beam intensity distribution behaves like a ***rigid body***:
  Hard resonance edge for all particles!
- **For a constant spill the beam edge should never be repelled from the resonance! Otherwise ripple modulations.**

Longitudinal beam distributions during extraction of 800 MeV/c protons:



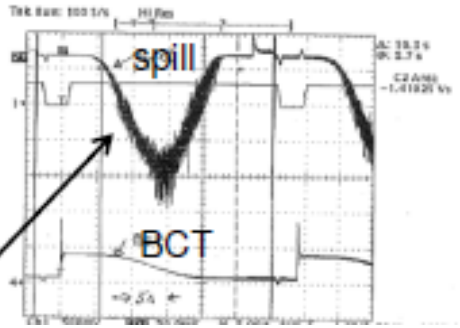
Linear tune ramp:

$$Q(t) = Q_S + \frac{dQ}{dt} \cdot (t - t_0)$$

$$\frac{dN}{dt} = \frac{dN}{dQ} \cdot \frac{dQ}{dt}$$

spill

tune distribution



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Stochastic Extraction with Band-Limited White Noise

- The main difference to the conventional extraction method is in the way the particles are driven to the third order resonance.
- The average tune of the beam and thus the lattice optics is **not** changed.
- Instead, the beam distribution is longitudinally heated by adding noise around a revolution harmonic.
- A diffusion in tune is created by a proper setting of the horizontal chromaticity to accelerate the particles into resonance.

S. van der Meer, "Stochastic Extraction, a Low-Ripple Version of Resonant Extraction", CERN/PS/AA 78-6

R. Cappi, W.E.K. Hardt and Ch.P. Steinbach, "Ultraslow Extraction with Good Duty Factor", 11th International Conference on High-Energy Accelerators, Geneva, Switzerland, July 7–11, 1980

The LEAR team, "Performance of LEAR", IEEE Transactions on Nuclear Science, Vol. NS-32. No. 5, October 1985

Michel Chanel, "LEAR Performances", Proc. of the LEAR Symposium, CERN, 15th May 1999, CERN/PS 99-040 (CA)

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- ***Step 1:***
  - Beam Momentum Distribution Shaping
    - *Gaussian beam → Uniform beam distribution*

- ***Step 2:***
  - Uniform noise is applied **that always covers the resonance.**
  - The carrier frequency is slowly moved towards the shaped beam distribution.
    - *Particles diffuse into the resonance and are extracted.*

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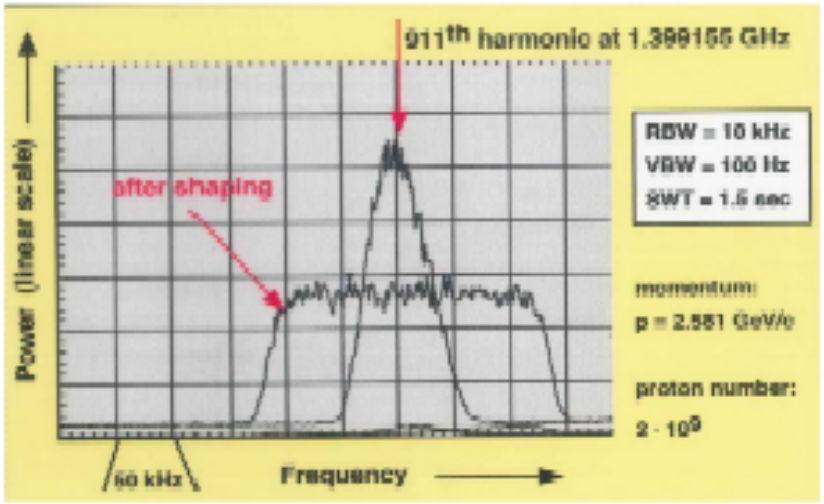
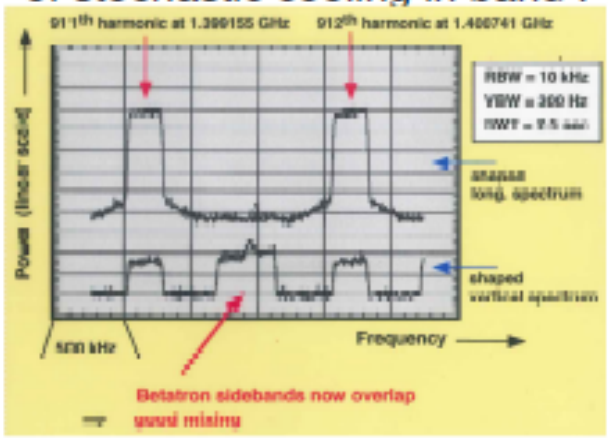
Longitudinal Beam Shaping



observed with PU
of stochastic cooling in band I



- Rectangular shaped noise with width W = 1 kHz applied to the 4th revolution harmonic
- Longitudinal momentum distribution rectangular ⇒ transverse sidebands rectangular
- Shaping time 1 s
- Width of 4th harmonic without noise 340 Hz
- The resulting width of the revolution harmonic 911 agrees with $W = 911 \cdot \frac{1kHz}{4} = 228Hz$
- Necessary voltage: U_{rms} = 77 V, noise power into 50 Ω: 120 W, spectral noise density: S = 120 mW/Hz

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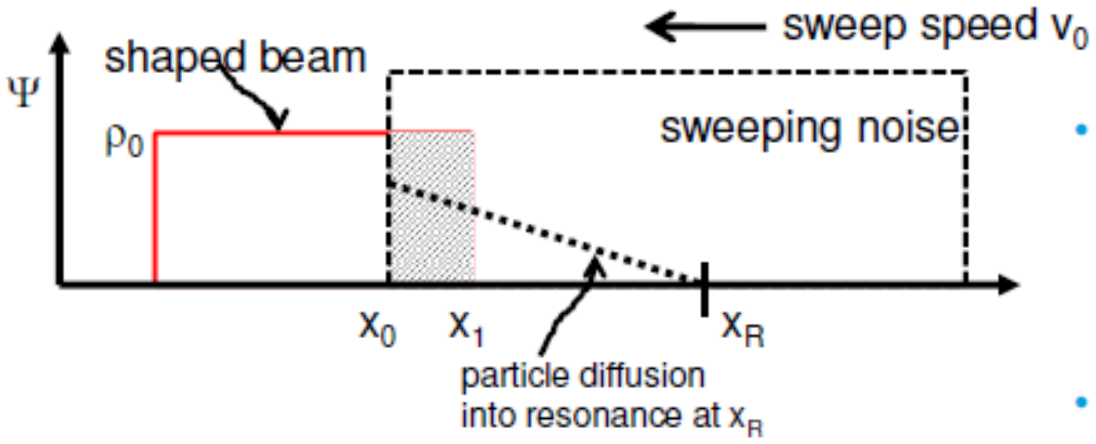
Beam Extraction with swept Noise



- Band-limited white noise permanently covering the resonance is swept over the beam with speed v_0.
- Diffusion equation with diffusion coefficient D

In the vicinity of the resonance:

$$\Psi_0(x) \approx -\frac{v_0 \cdot \rho_0}{D}(x - x_R) \qquad \Rightarrow \quad \Psi_0(x_R) = 0$$

- The number of particles that are extracted per sec is given by

$$\Phi_{ex}(t) = \Phi(x_R, t) = -D \cdot \frac{\partial}{\partial x}\Psi(x_R, t)$$ and yields the **constant flux** $\Phi_{ex}(t) = \Phi_0$

W. Hardt, "Remarks on Stochastic Extraction", PS/DL/Note 78-5

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Choice and Control of Extraction Parameters

- **Many parameters must be controlled and adjusted:**
  - Sextupole strength (emittance should be known)
  - Angle of separatrix at ESEP (little program)
  - Chromaticity (can be measured)
  - Hardt condition (can be checked at wire chamber after MSEP, optimum if beam position does not vary during extraction)
  - Momentum spread (can be measured)
  - Orbit bump (can be measured, choice of amplitude depends on sextupole strength and thus spiral step)
  - Angle kick in ESEP and deflection in MSEP
  - Tune and beam shaping prior to extraction (shaping can be tuned so that spill becomes flat, no “initial” peak)
  - Extraction noise (width and center frequency, no “initial” peak)
  - Power adjustment
- Parameters are not independent from each other
  - Parameters are tuned to optimum extraction efficiency (> 80 %)

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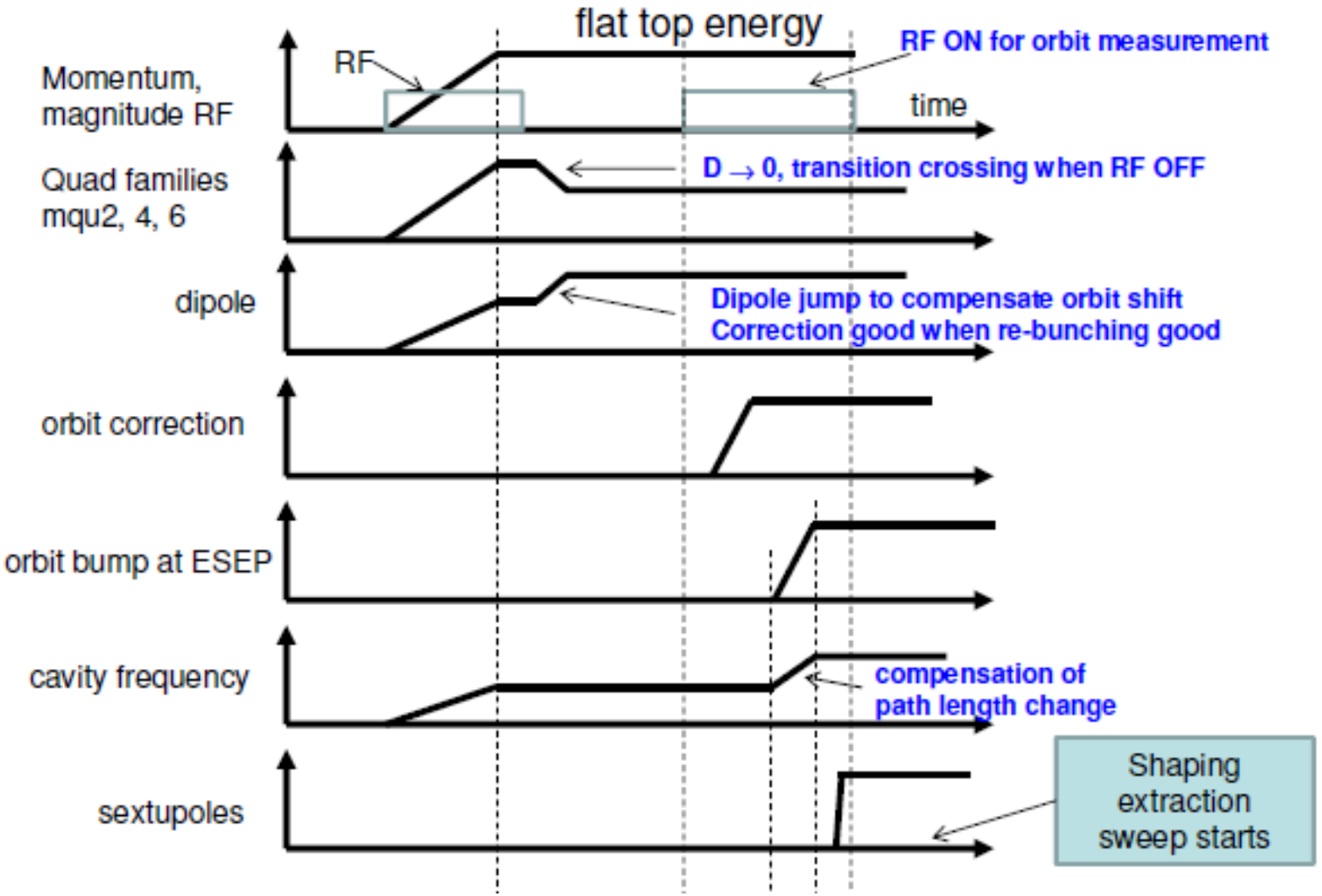
Ramp Procedure for Beam Extraction



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Spill Structure (Example)

- Proton momentum 796 MeV/c
- Spill duration app. 4 s
- Hodoscope signals measured with time interval analyzer HP 5372 A
- Bin width 1 ms, 4096 bins

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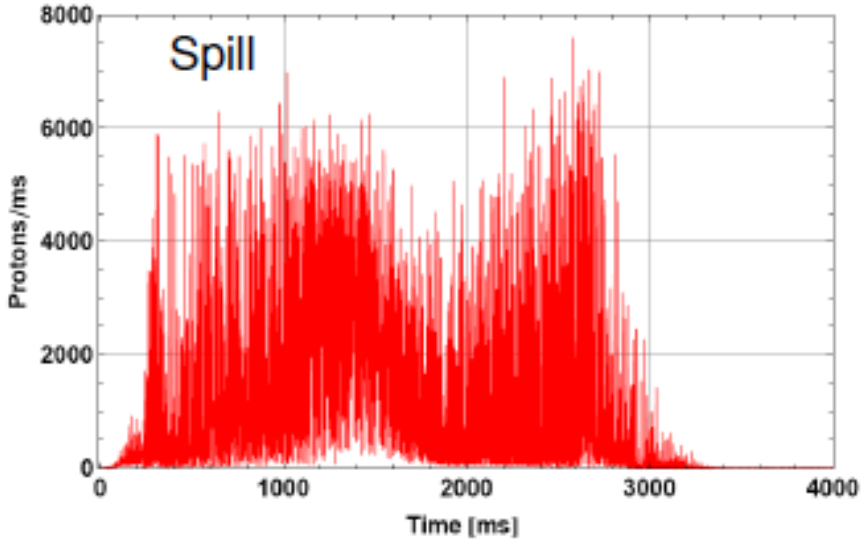
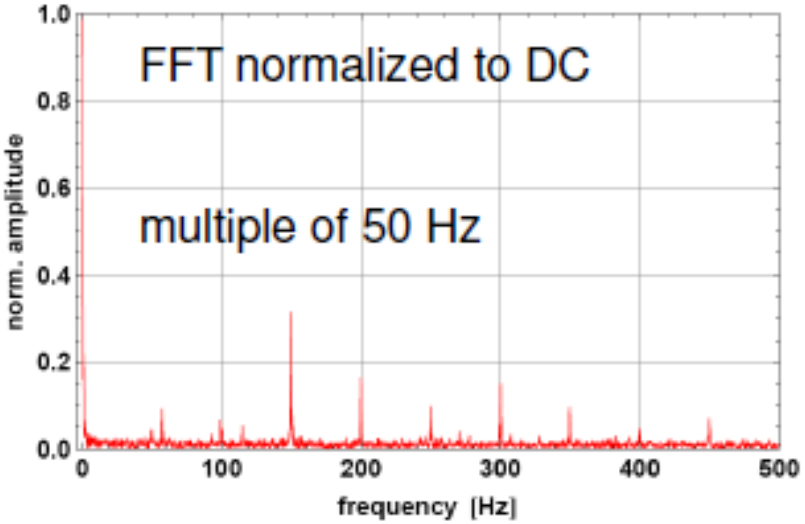
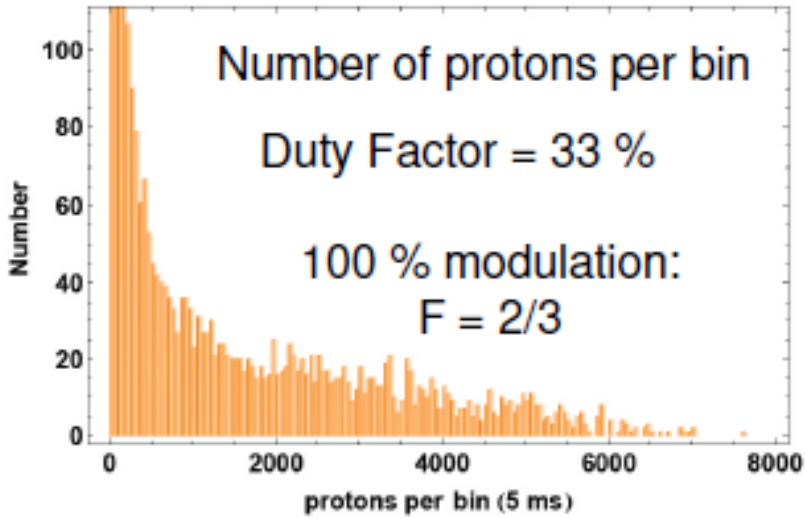
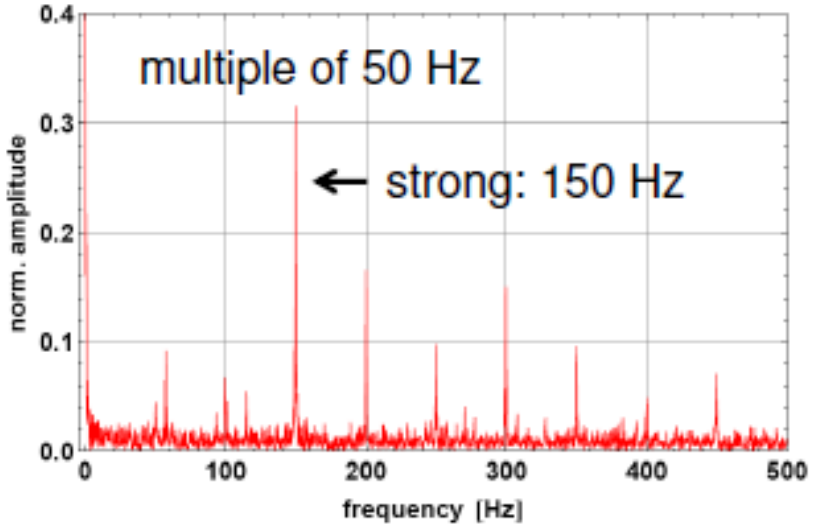
Conventional Extraction









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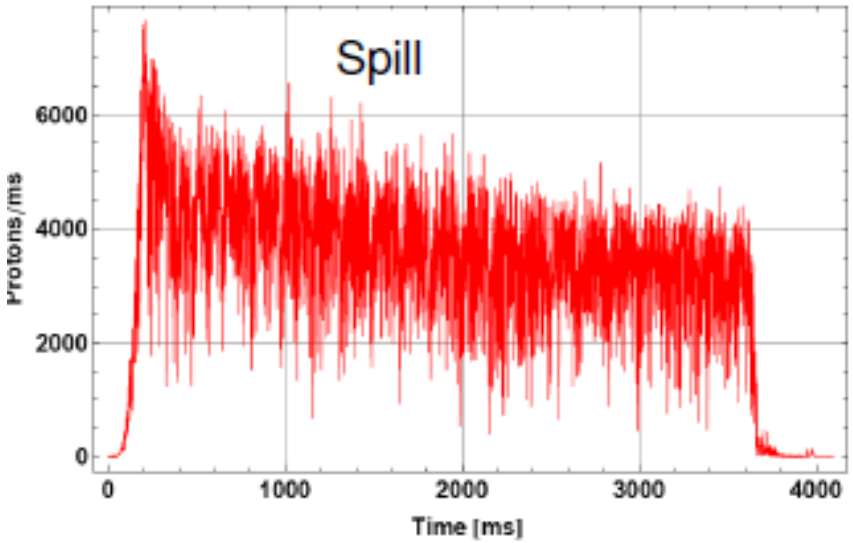
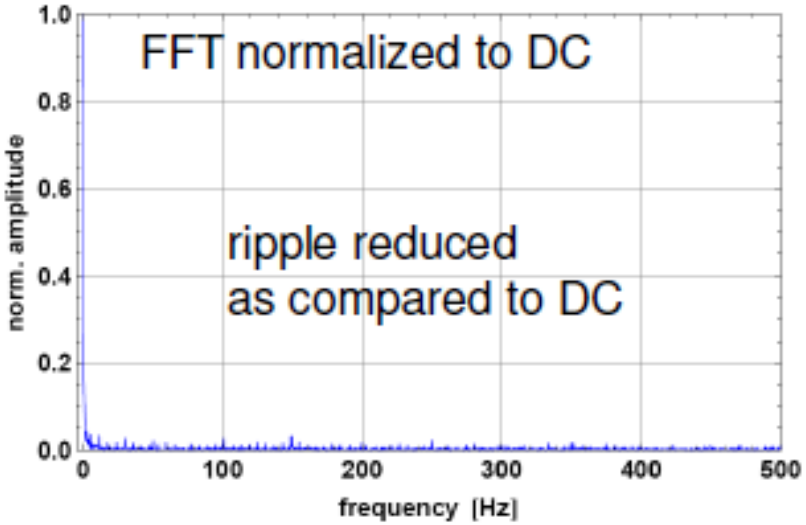
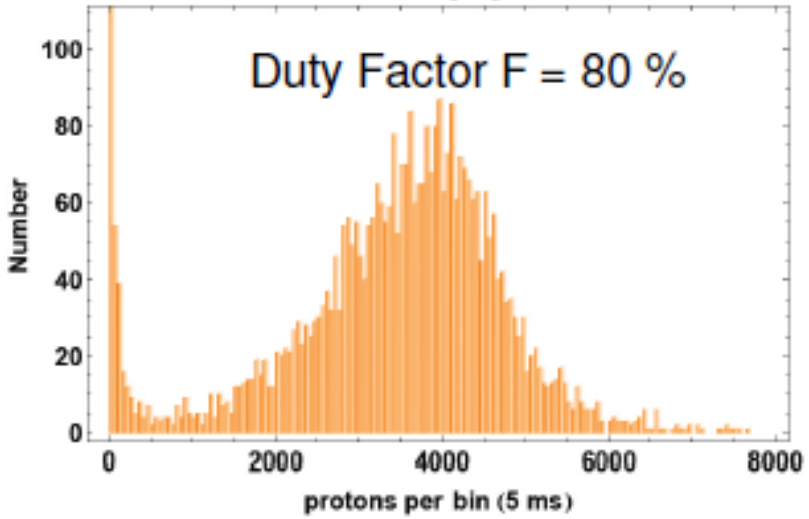
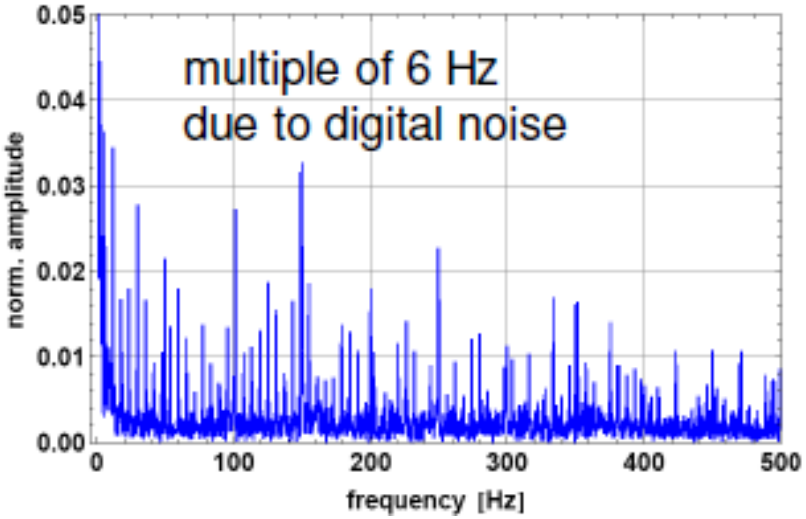
Stochastic Extraction









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Present COSY operation scheme

1. 50 % dedicated to studies for edm storage ring experiment
   - mainly internal to the COSY ring
   - extraction of polarized beam

2. 50 % FAIR related studies
   - detector tests for FAIR (Extracted beams)
   - tests of equipment for HESR@FAIR and machine studies

Close to 50 % extracted beam operation

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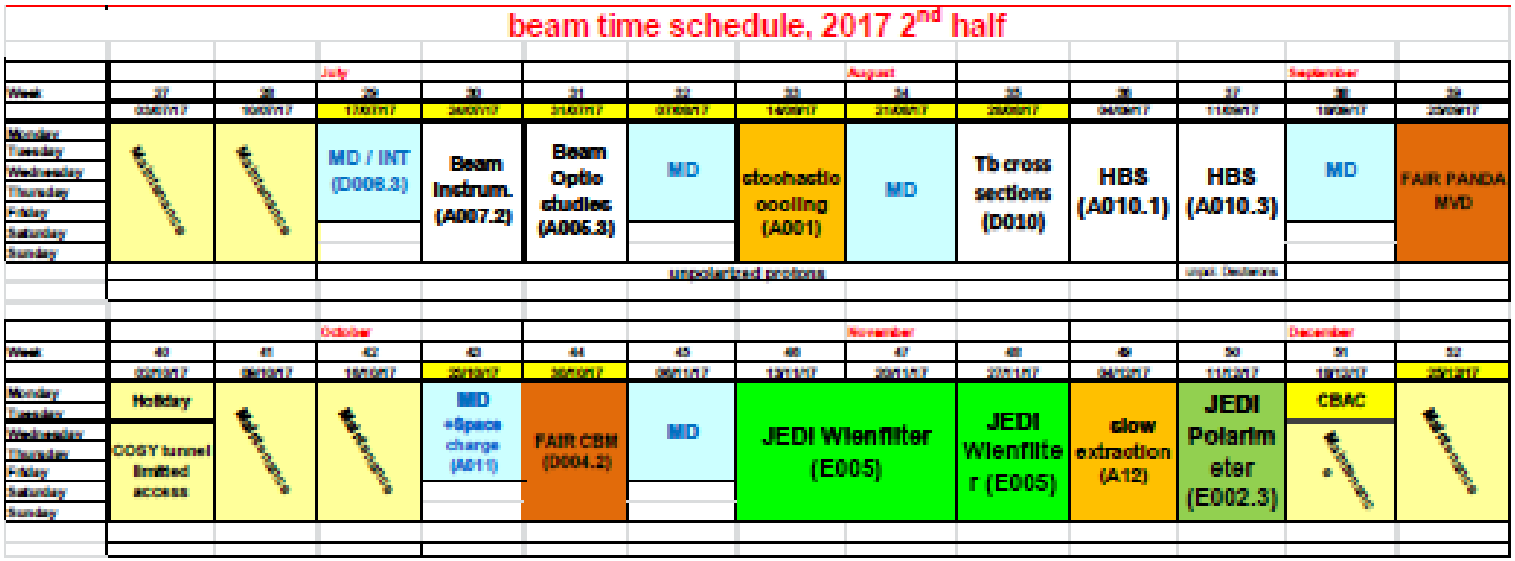

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Summary

- Stochastic extraction at COSY in the whole energy range
- Spill durations of a few seconds upto several minutes
  (1 h spill duration has been done)
- Extraction efficiency larger than 80 %
- Extraction of polarized beams

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