

# Stochastic Noise Extraction at COSY

Slow Extraction Workshop 2017, CERN, Nov 9<sup>th</sup>,- 11<sup>th</sup>,- 2016

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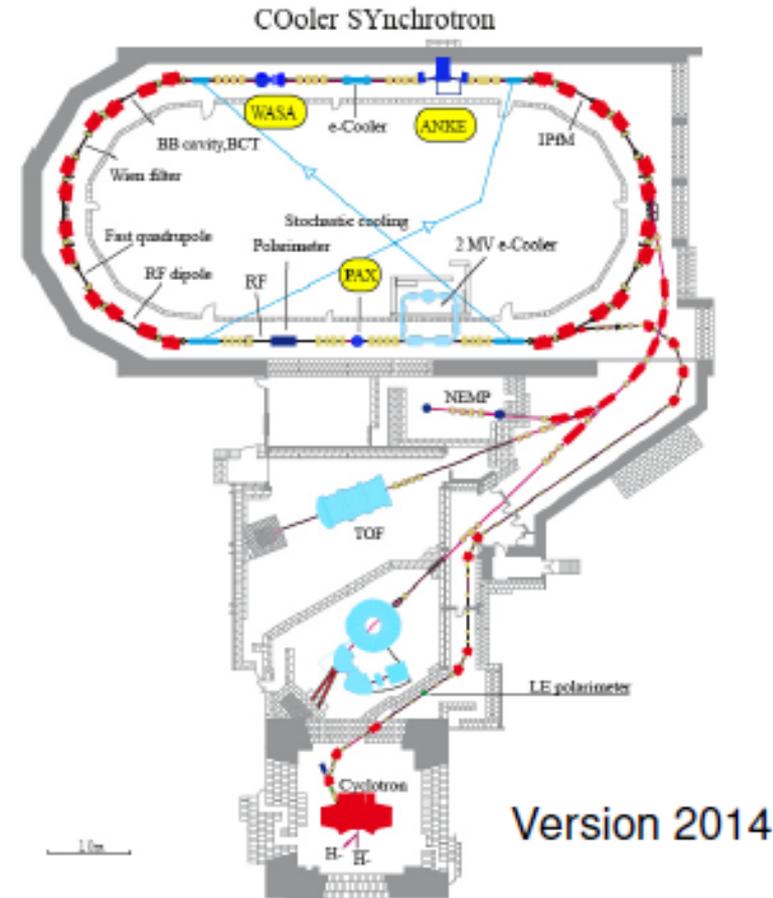
IKP4, COSY, Forschungszentrum Jülich

# Content

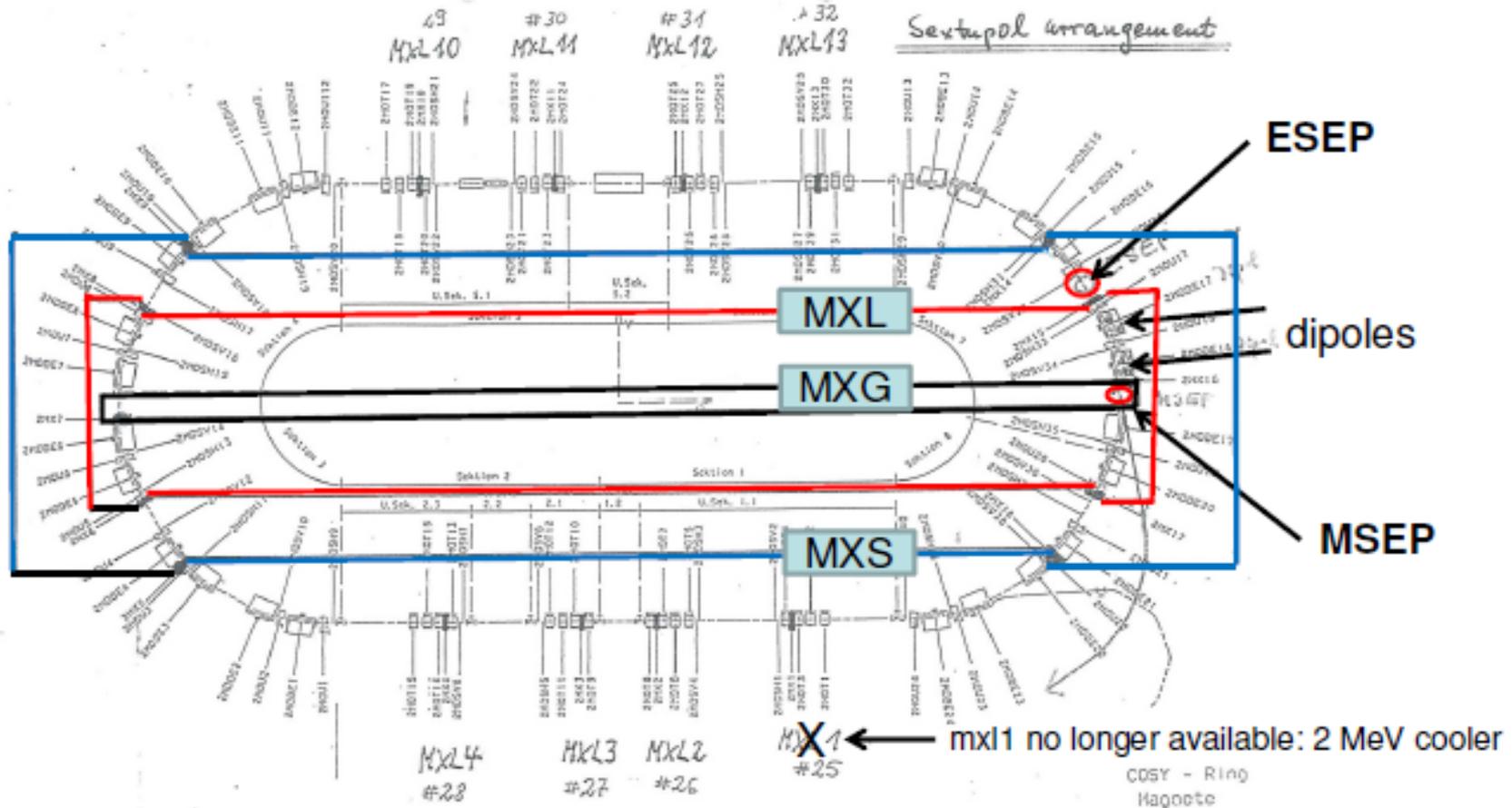
- Sketch of Extraction Development at COSY
- COSY Layout and Main Parameter
  - Extraction Layout and Components
- Extraction: Longitudinal Aspects
- Spill Time Structure (Example)
- Backup Slides Extraction: Transverse Aspects

# COSY Floorplan

- Circumference: 184
- Straight section: 40 m  
(telescopes with  $2\pi$  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**



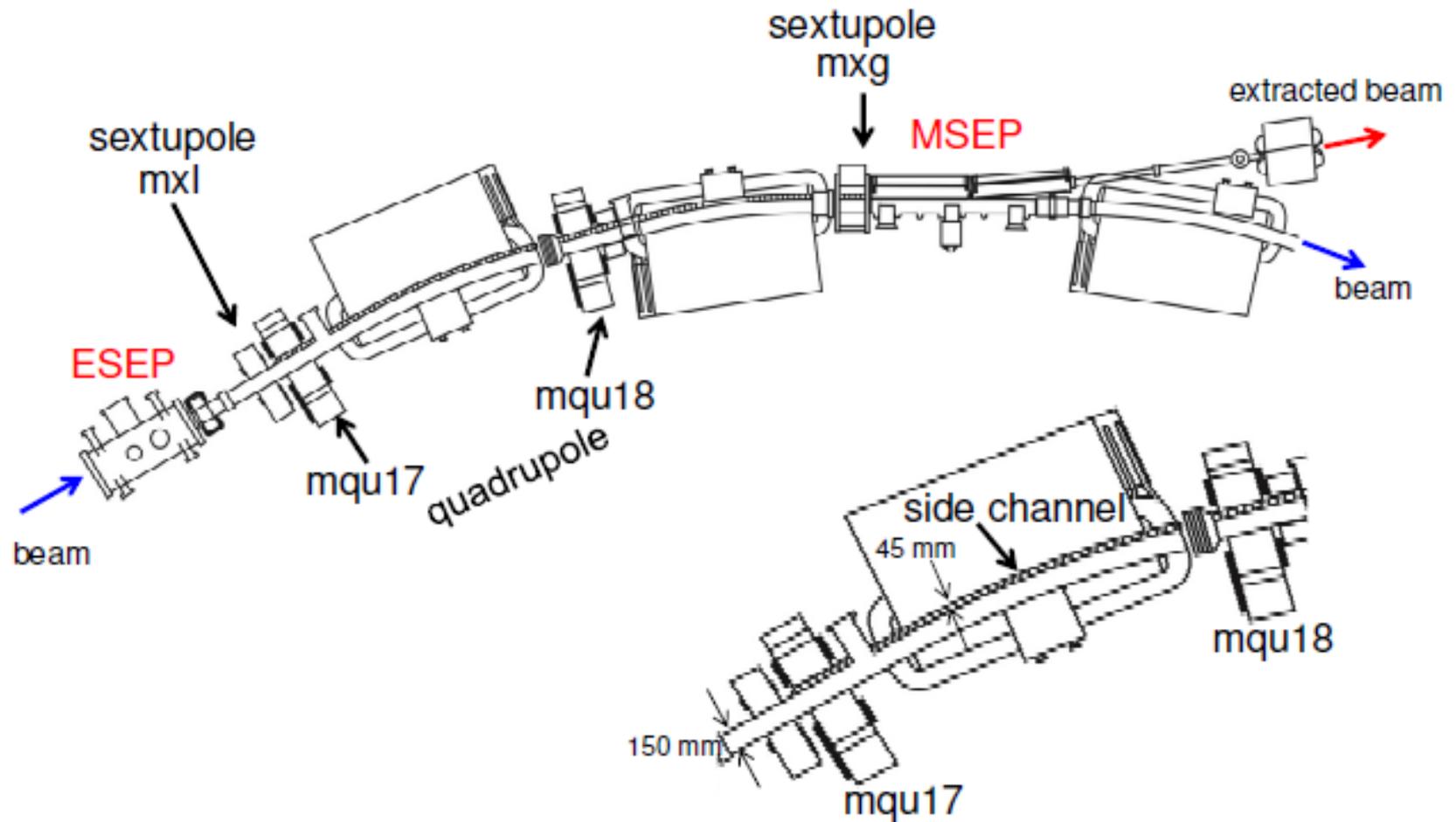
# Sextupole Distribution



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

} Chromaticity correction only

# Arc Section and Extraction Elements

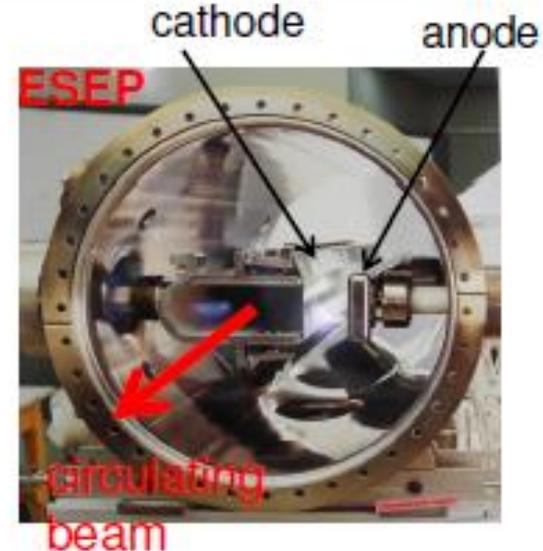


# Main data ESEP and MSEP

## 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 | $\pm 20$ | mm    |
| angle resp. to closed orbit                 | $\pm 2$  | 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      |

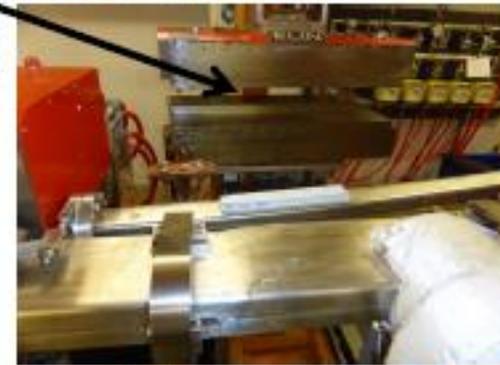


# Extraction Elements at COSY



MSEP

Second part:  
disassembled

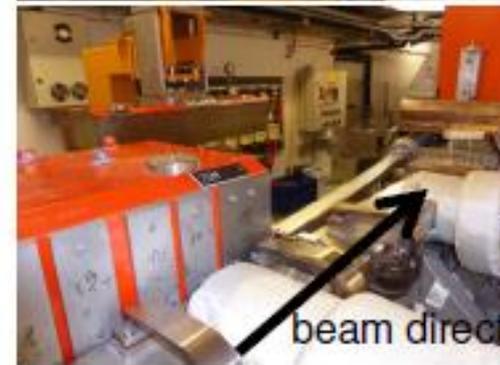


Xpole



ESEP

circulating  
beam

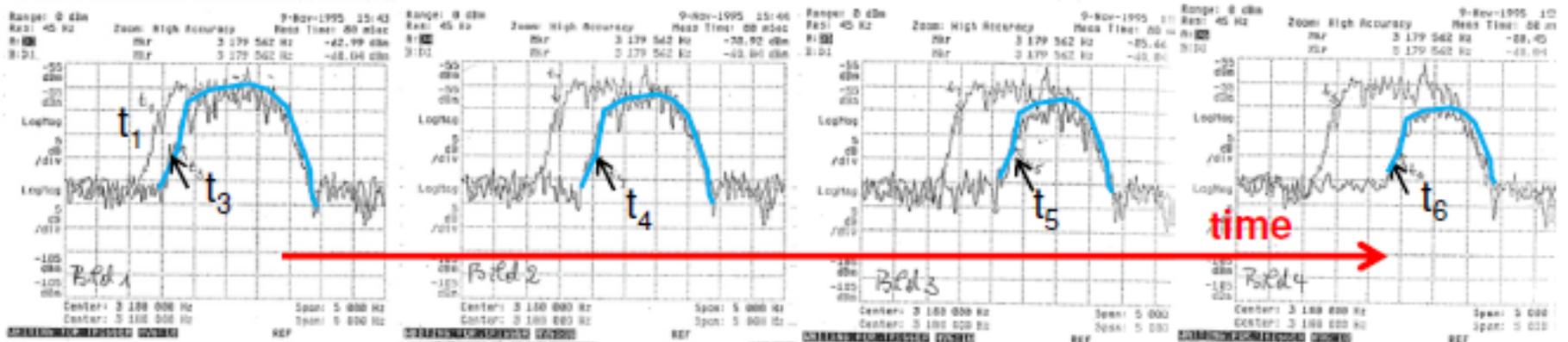


beam direction

# 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:



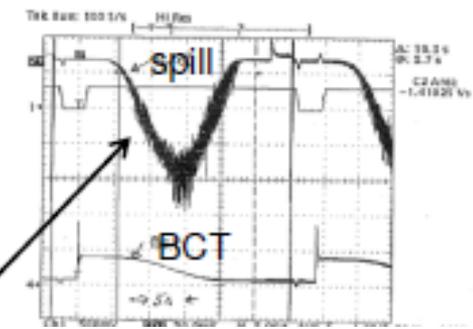
Linear tune ramp:

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

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

spill (pointing to  $\frac{dN}{dt}$ )

tune distribution (pointing to  $\frac{dN}{dQ}$ )



# 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

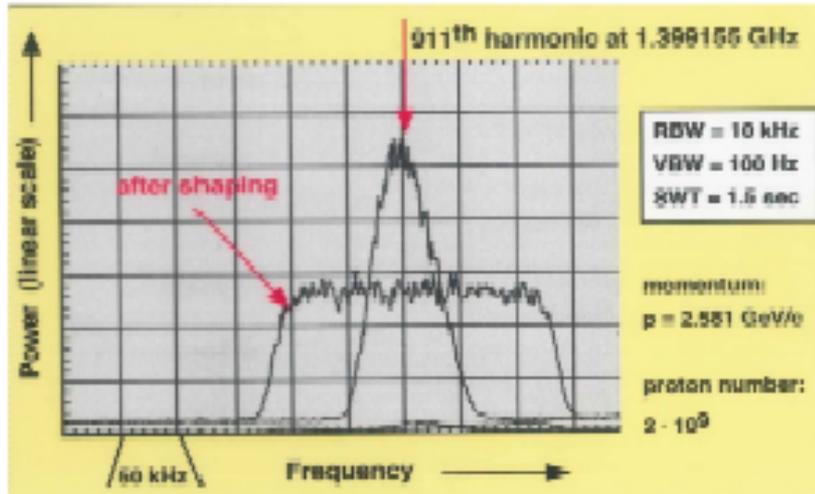
R. Cappi, W.E.K. Hardt and Ch.P. Steinbach, "Ultraslow Extraction with Good Duty Factor",  
11th International Conference on High-Energy Accelerators, Geneva, Switzerland, July 7–11, 1980

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

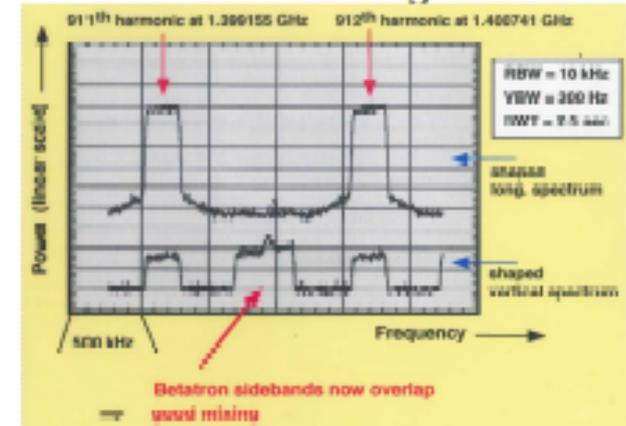
Michel Chanel, "LEAR Performances", Proc. of the LEAR Symposium, CERN, 15th May 1999,  
CERN/PS 99-040 (CA)

- **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.*

# Longitudinal Beam Shaping

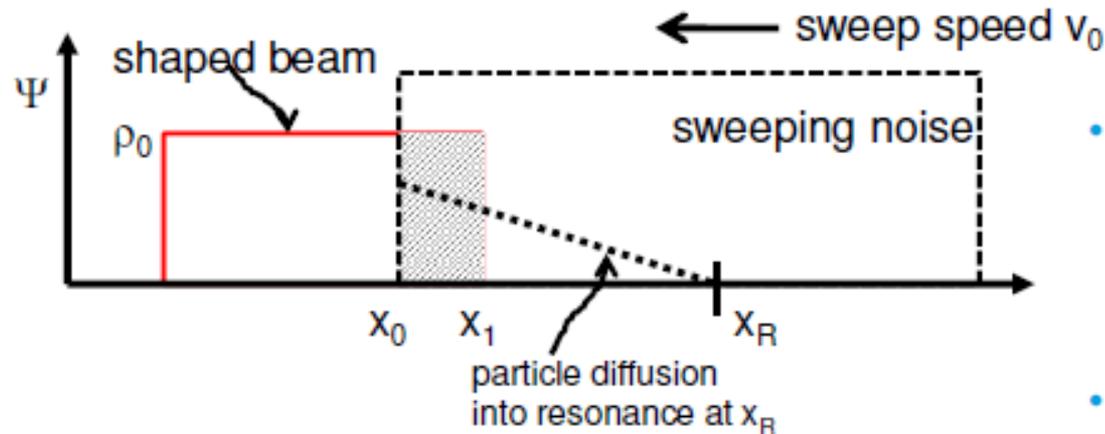


observed with PU  
of stochastic cooling in band I



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

# 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:

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

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

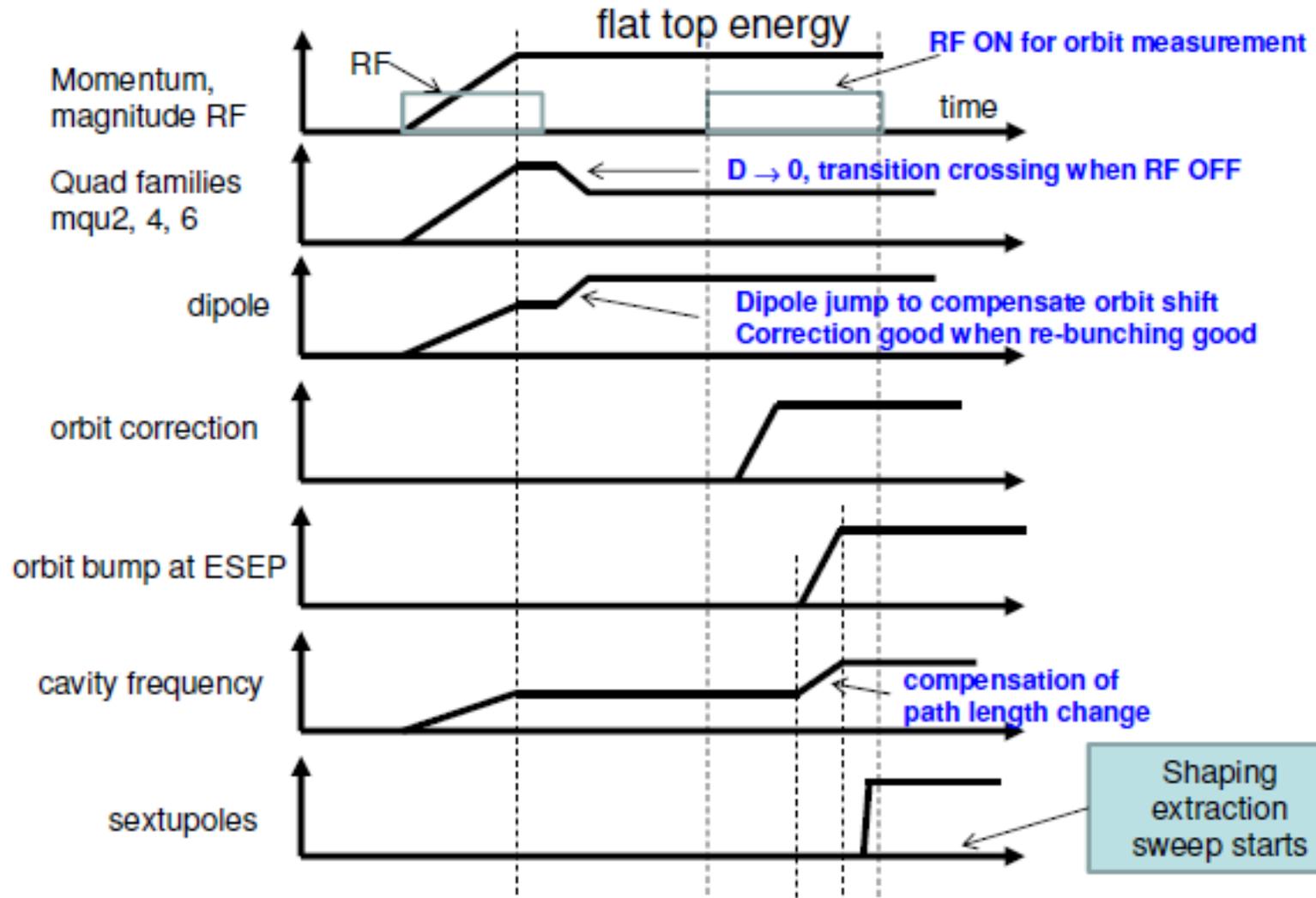
$$\Phi_{ex}(t) = \Phi(x_R, t) = -D \cdot \frac{\partial}{\partial x} \Psi(x_R, t) \quad \text{and yields the constant flux} \quad \Phi_{ex}(t) = \Phi_0$$

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

# 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 %)

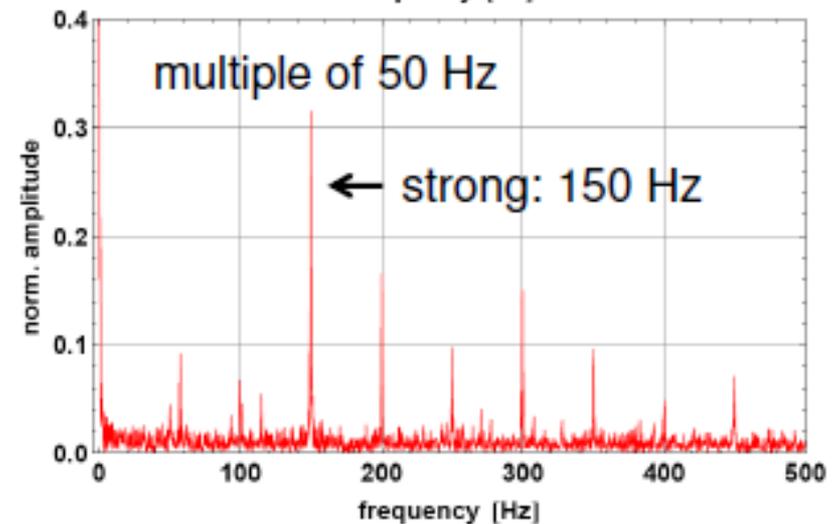
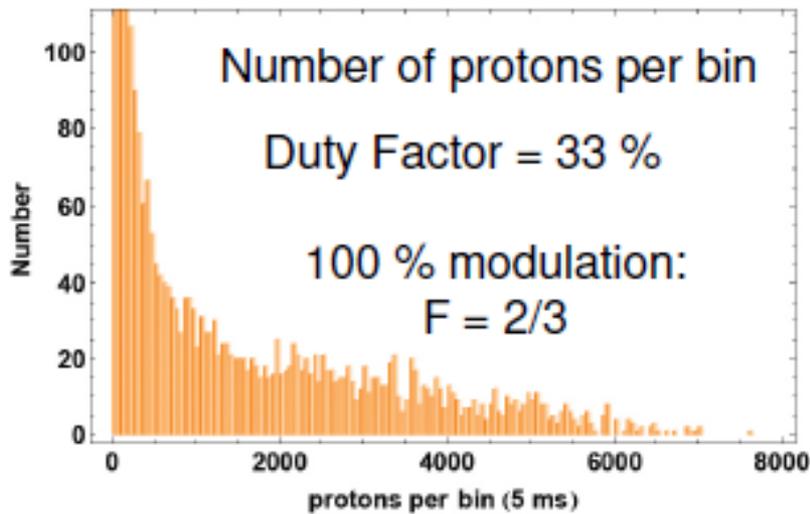
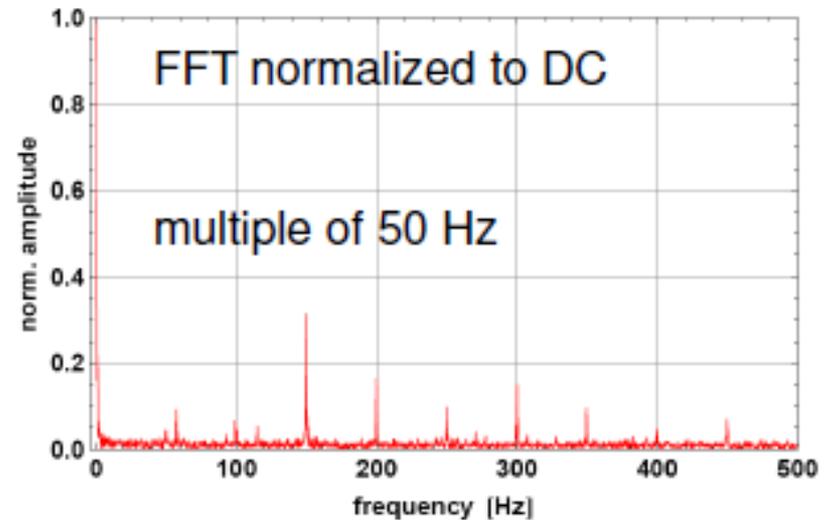
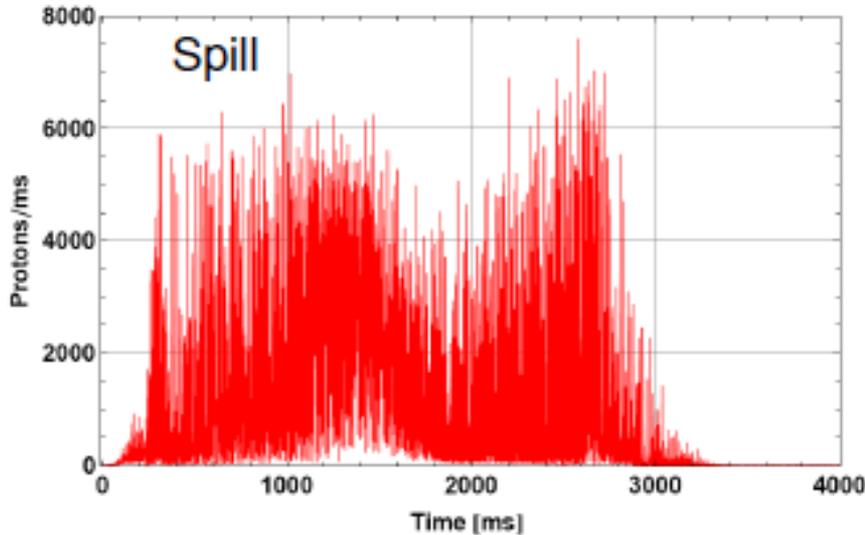
# Ramp Procedure for Beam Extraction



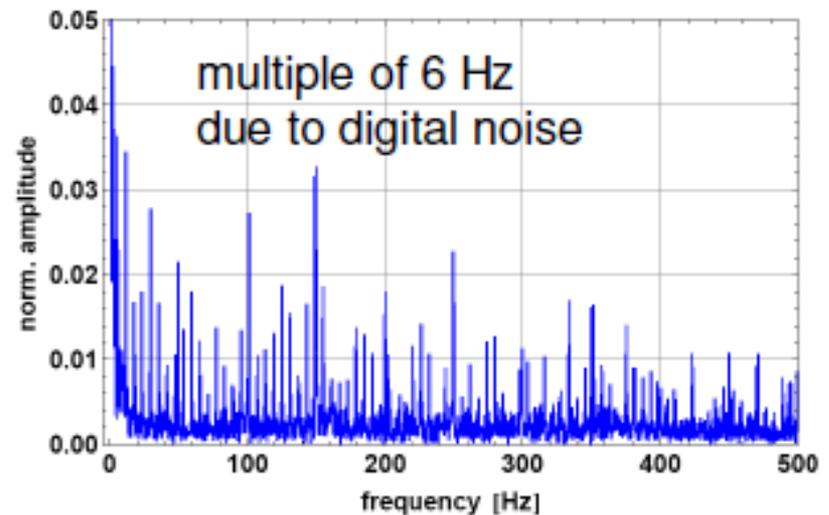
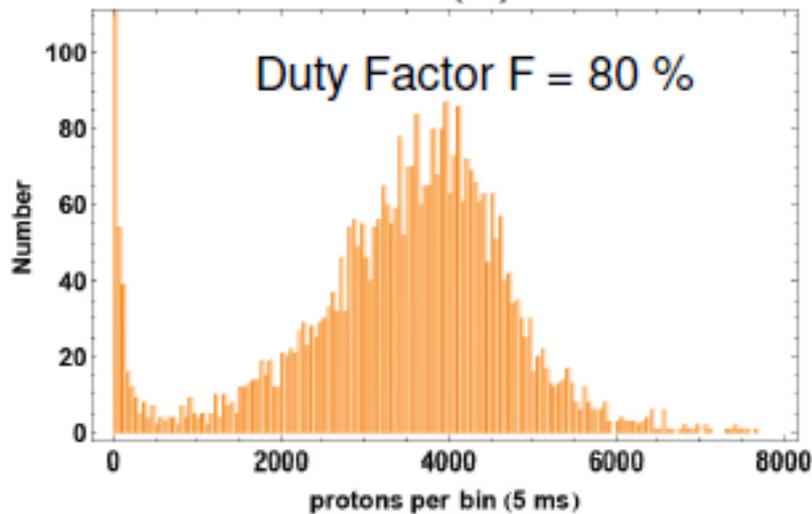
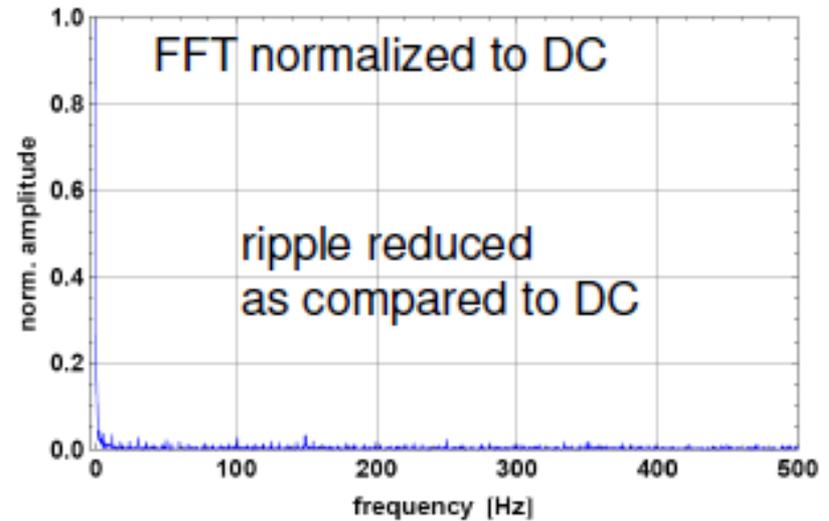
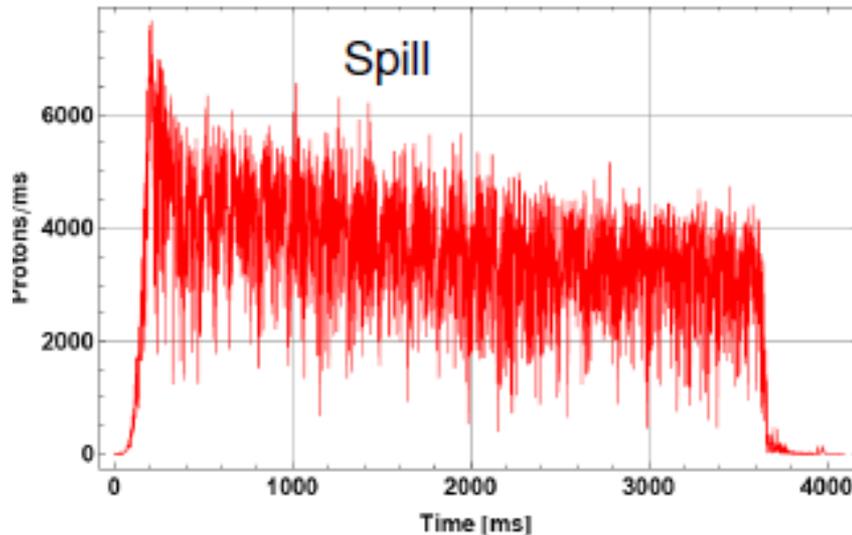
# Spill Structure (Example)

- 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

# Conventional Extraction



# Stochastic Extraction



# 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

# Present COSY operation scheme

1. 50 % dedicated to studies for edm storage ring experiment
  - mainly internal to the COSY ring
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  - detector tests for FAIR (Extracted beams)
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| beam time schedule, 2017 2 <sup>nd</sup> half |                            |    |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
|---|----------------------------|----|-------------------|------------------------|-----------------------------|----|---------------------------|------------------------|--------------------------|---------------------------|--------------|-----------------|----------------|
|   | July                       |    |                   |                        |                             |    | August                    |                        |                          |                           |              |                 | September      |
| Week  | 27                         | 28 | 29                | 30                     | 31                          | 01 | 02                        | 03                     | 04                       | 05                        | 06           | 07              | 08             |
| Monday  | MD                         | MD | MD / INT (D008.3) | Beam Instrum. (A007.2) | Beam Optic studies (A005.3) | MD | stochastic cooling (A001) | MD                     | Tb cross sections (D010) | HBS (A010.1)              | HBS (A010.3) | MD              | FAIR PANDA MVD |
| Tuesday                                       | MD                         | MD |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
| Wednesday                                     | MD                         | MD |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
| Thursday                                      | MD                         | MD |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
| Friday  | MD                         | MD |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
| Saturday                                      | MD                         | MD |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
| Sunday  | MD                         | MD |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
|   | unpolarized protons        |    |                   |                        |                             |    |                           |                        |                          |                           |              | Local Decisions |                |
| October                                       |                            |    |                   |                        |                             |    |                           |                        |                          |                           |              |                 |                |
| Week  | 40                         | 41 | 42                | 43                     | 44                          | 45 | 46                        | 47                     | 48                       | 49                        | 50           | 51              | 52             |
| Monday  | Holiday                    | MD | MD                | MD                     | FAIR CBM (D004.2)           | MD | JEDI Wienfilter (E005)    | JEDI Wienfilter (E005) | slow extraction (A12)    | JEDI Polarimeter (E002.3) | CBAC         | MD              | MD             |
| Tuesday                                       | MD                         | MD | MD                | MD                     |                             |    |                           |                        |                          |                           |              |                 |                |
| Wednesday                                     | MD                         | MD | MD                | MD                     |                             |    |                           |                        |                          |                           |              |                 |                |
| Thursday                                      | COSY tunnel limited access | MD | MD                | MD                     |                             |    |                           |                        |                          |                           |              |                 |                |
| Friday  | MD                         | MD | MD                | MD                     |                             |    |                           |                        |                          |                           |              |                 |                |
| Saturday                                      | MD                         | MD | MD                | MD                     |                             |    |                           |                        |                          |                           |              |                 |                |
| Sunday  | MD                         | MD | MD                | MD                     |                             |    |                           |                        |                          |                           |              |                 |                |

# 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