Workshop on Low Current, Low Energy Beam Diagnostics

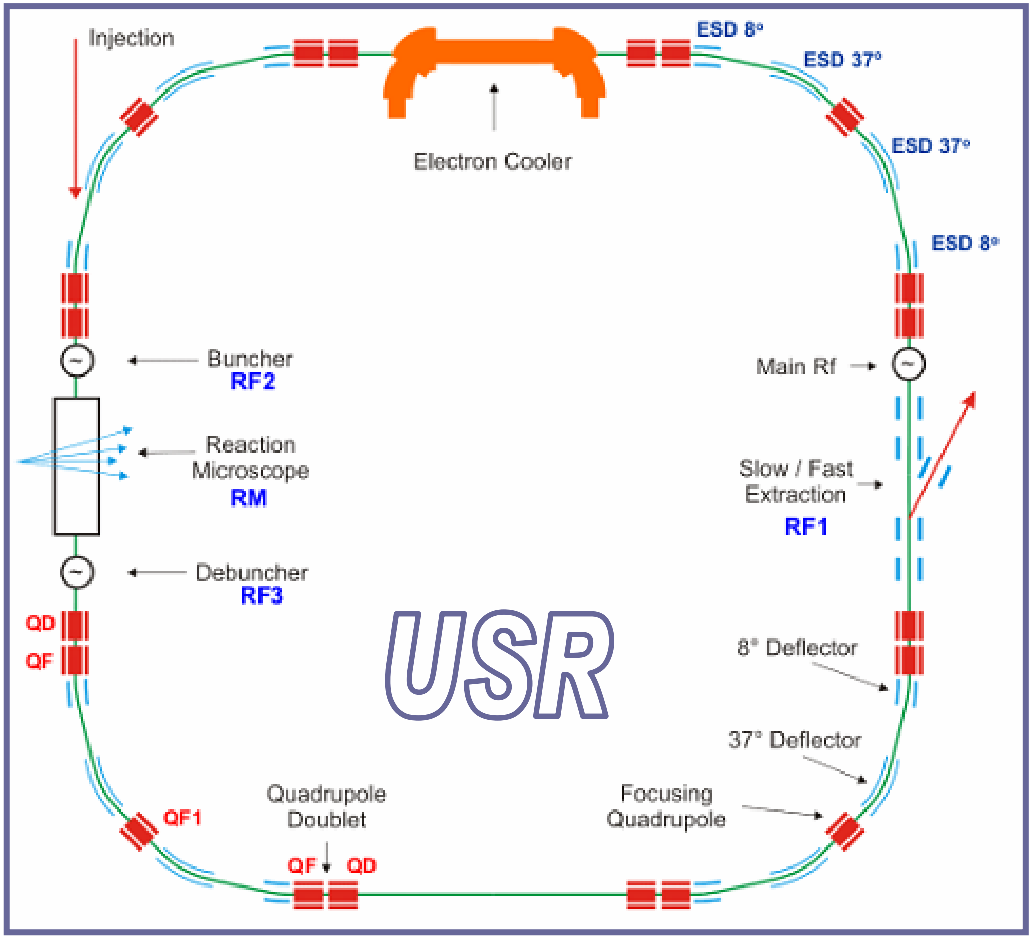
Diagnostics for USR

Janusz Harasimowicz

Hirschberg-Großsachsen, 25 Nov 2009

Janusz.Harasimowicz@quasar-group.org
www.quasar-group.org

Ultra-low Energy Storage Ring

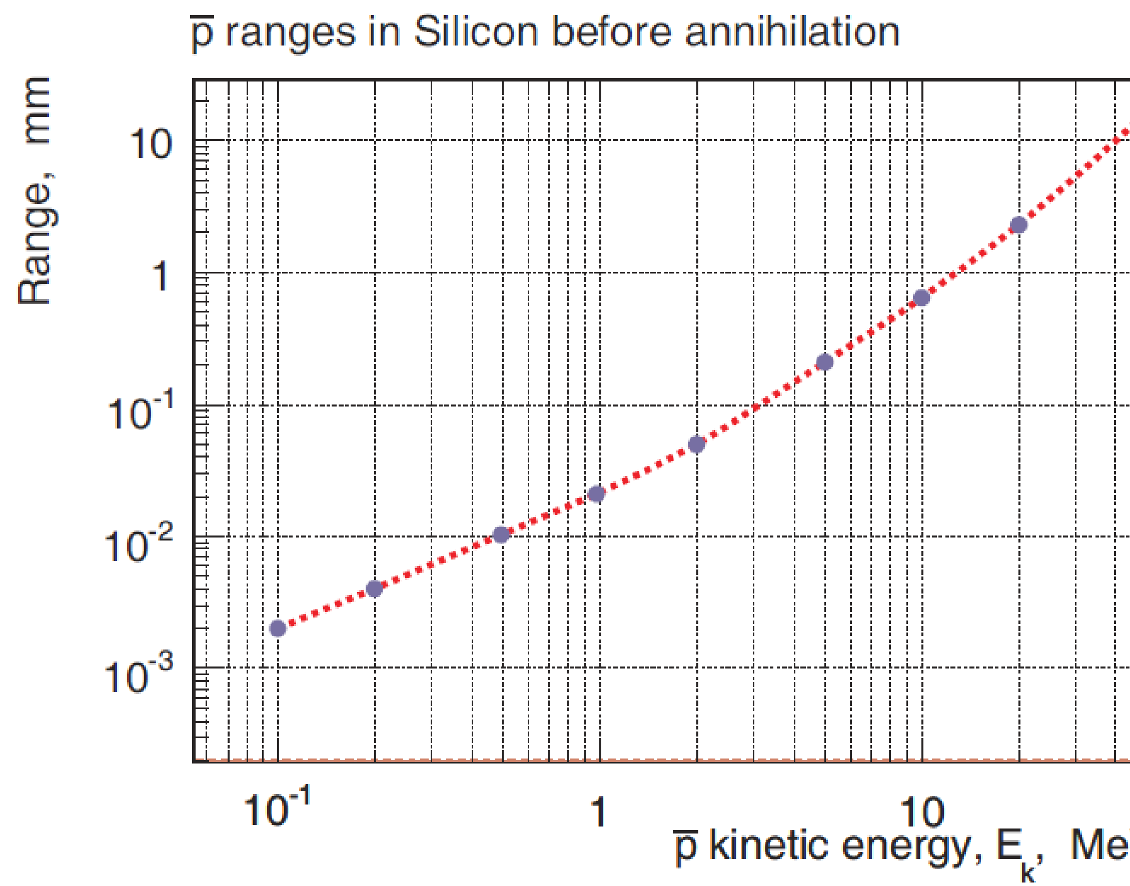


ANTIPROTONS

Energy	300 keV → 20 keV
Revolution frequency	178 kHz → 46 kHz
# of particles	~10^8 → ~10^7
Bunch length	1 ns – DC beam
Effective pbar rates for in-ring experiments	10^{10} pps – 10^{12} pps
Average rates of extracted pbars	$5 \cdot 10^5$ pps – 10^6 pps

Beam profile monitor

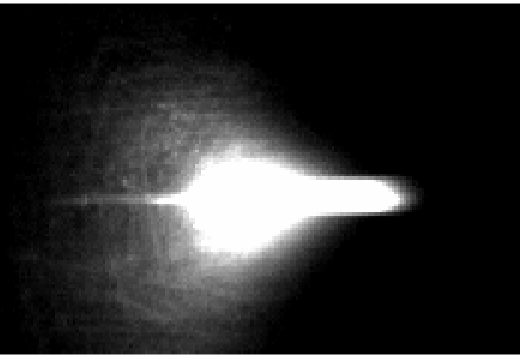
- Destructive beam profile measurements
- Detector type:
  - Scintillating screen?
  - Secondary electron emission monitor?
  - Silicon detector?
- Expected intensities:
  - Fast mode: ~10^7 particles in ~20 μs (~0.1 $\mu A_{p\text{-}p}$)
  - Slow mode: ~$5 \cdot 10^5$ pps (~0.1 pA_{DC})



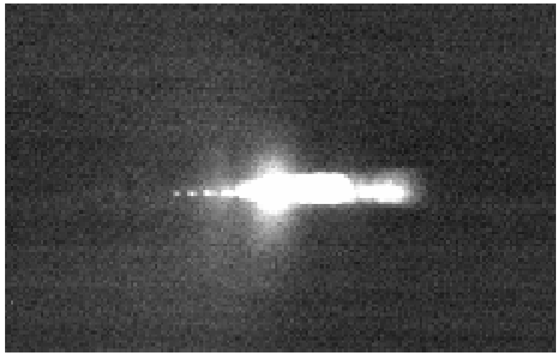
G. Macharashvili, Nuclear Physics Annual Report 2006, Forschungszentrum Jülich

Beam profile monitor

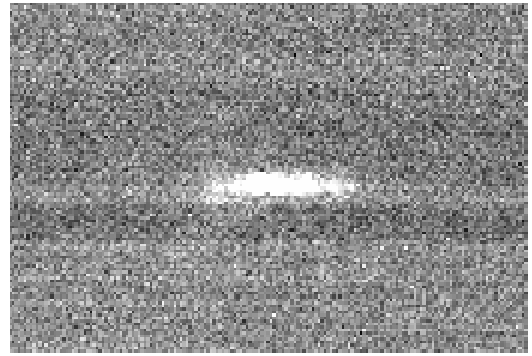
CsI(Tl): 200 keV protons



No attenuation: ~10 pA (1s)

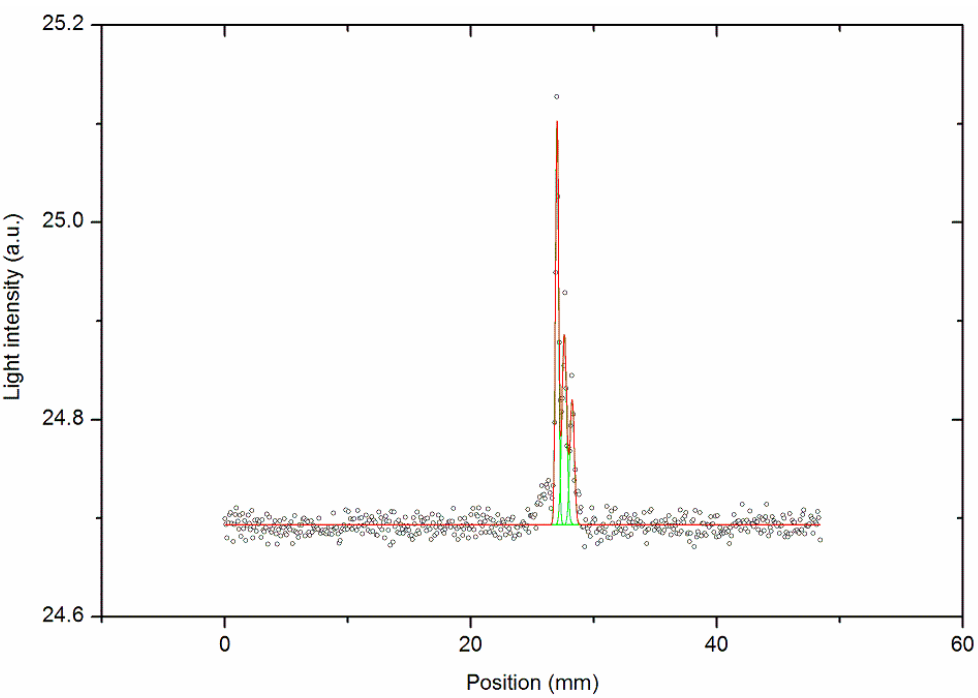


20x att.: ~500 fA (1s)



100x att.: ~100 fA (1s)

20x+100x att.: ~5 fA (20s)

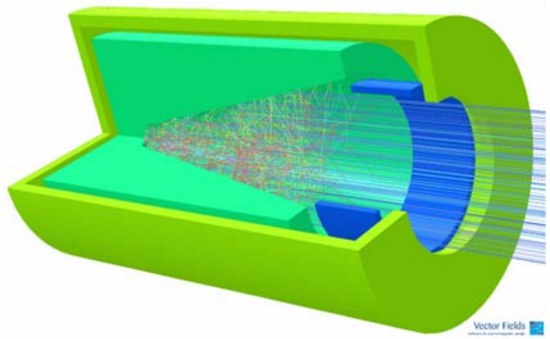


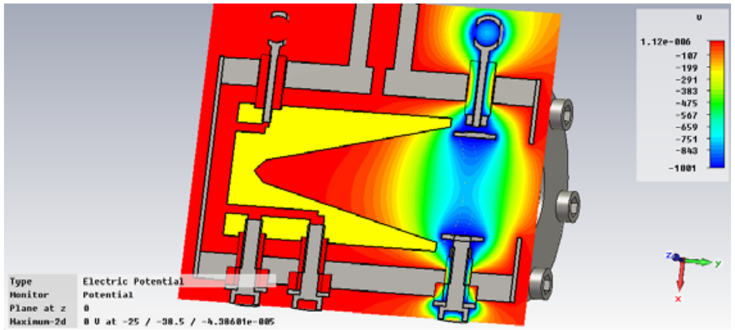
Tested screens: CsI(Tl), YAG(Ce) and SFOP with 200 keV and 50 keV protons.
Paper in preparation…

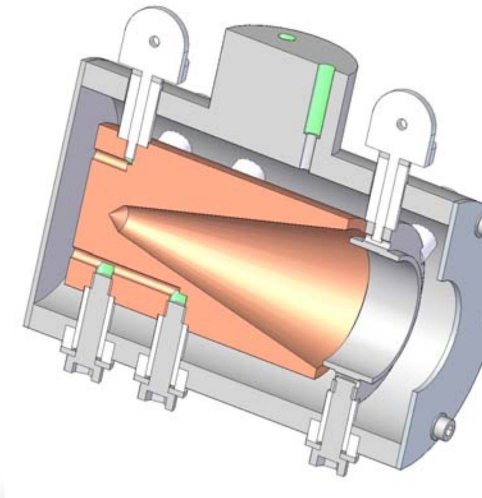
Acknowledgments:
Alfio Pappalardo
Luigi Cosentino
Paolo Finocchiaro
INFN-LNS

Faraday cup

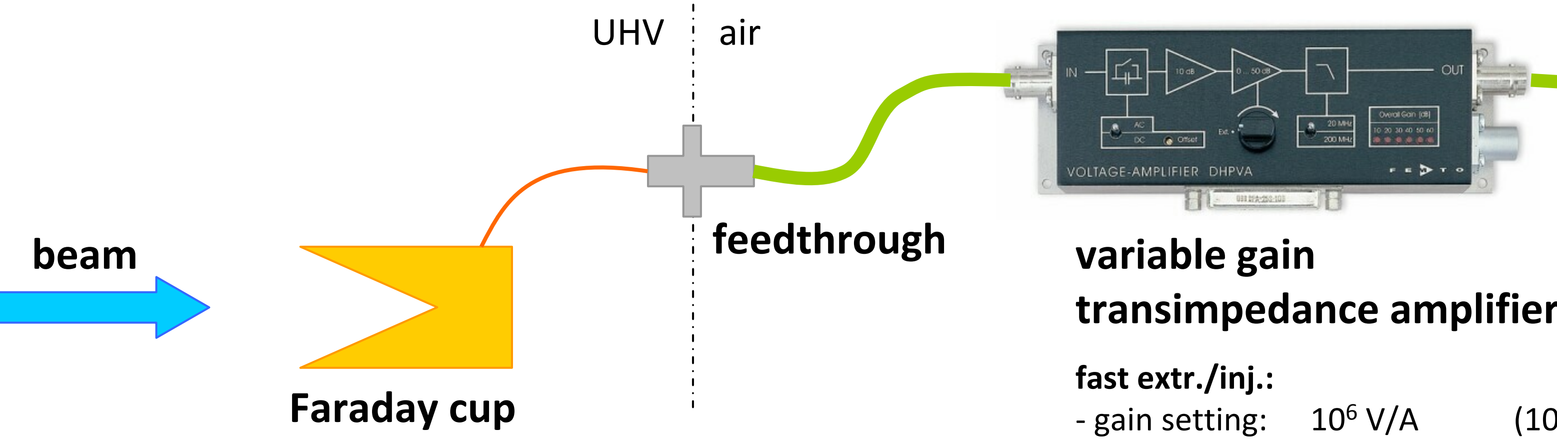
- Destructive beam current measurements
- Collection of secondary particles (total charge)
  - Secondary electrons
  - Annihilation: MeV-scale charged pions, recoil ions
- Expected intensities:
  - AC mode: ~0.1 $\mu A_{p\text{-}p}$
  - Quasi-DC mode: ~0.1 pA







Faraday cup



variable gain transimpedance amplifier

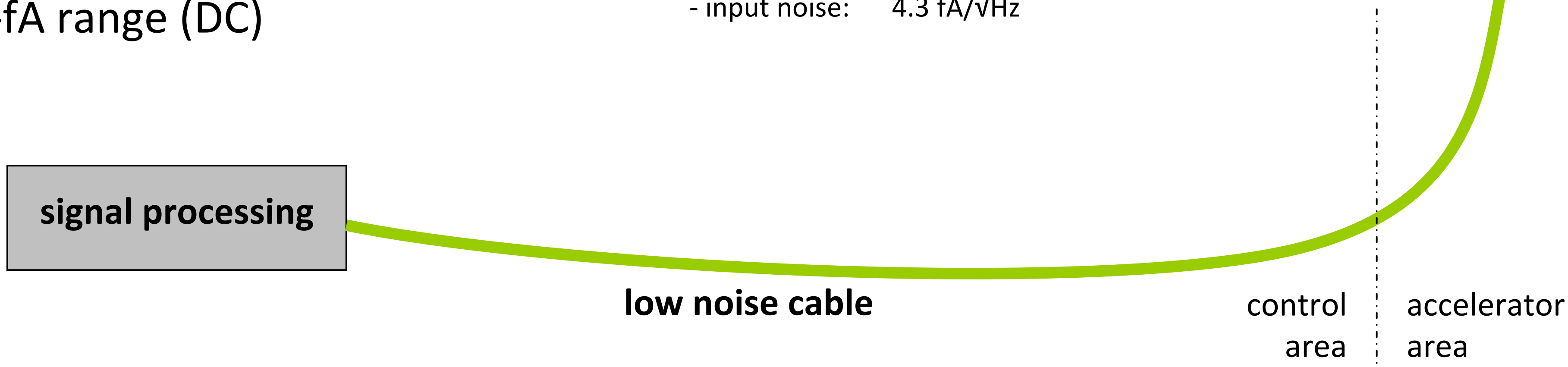
fast extr./inj.:

- gain setting:	10^6 V/A	(10^7 V/A)
- upper cut-off:	500 kHz	(400 kHz)
- rise/fall time:	0.7 µs	(0.9 µs)
- input noise:	1.8 pA/√Hz	(450 fA/√Hz)

slow extr.:

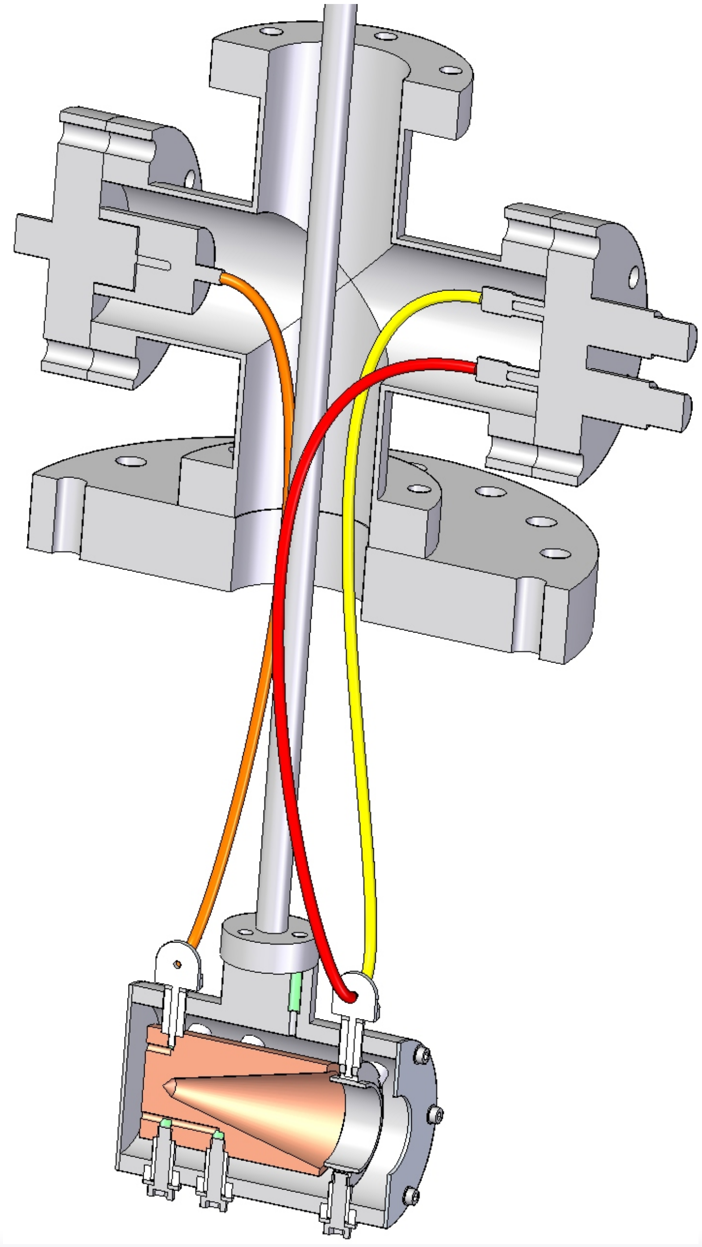
- gain setting:	10^{11} V/A
- upper cut-off:	1.2 kHz (10 Hz)
- rise/fall time:	300 µs
- input noise:	4.3 fA/√Hz

- Flexible system for both the fast and the slow extraction
- Easily upgradeable to the few-fA range (DC)



Faraday cup

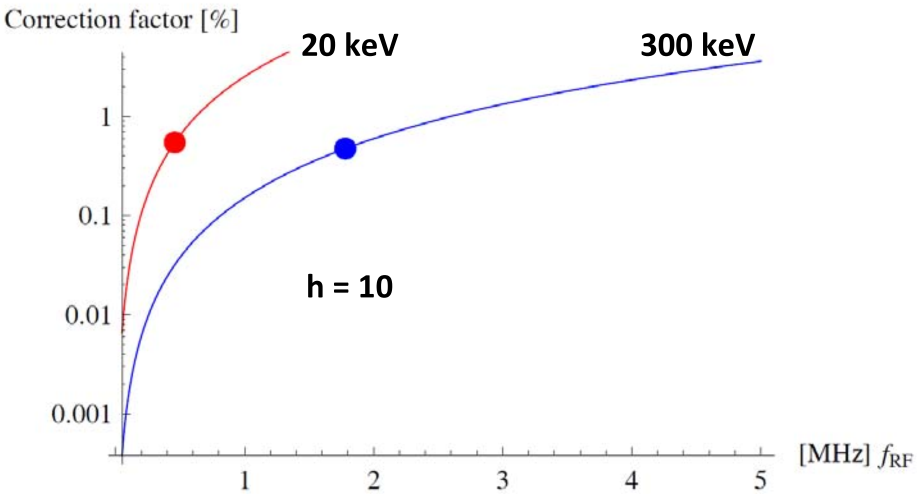
- DC and AC mode
- Current down to ~0.1 pA
- Low noise cables and connectors
- Movable device
- UHV system (10^{-11} mbar and ~250 ˚C baking)



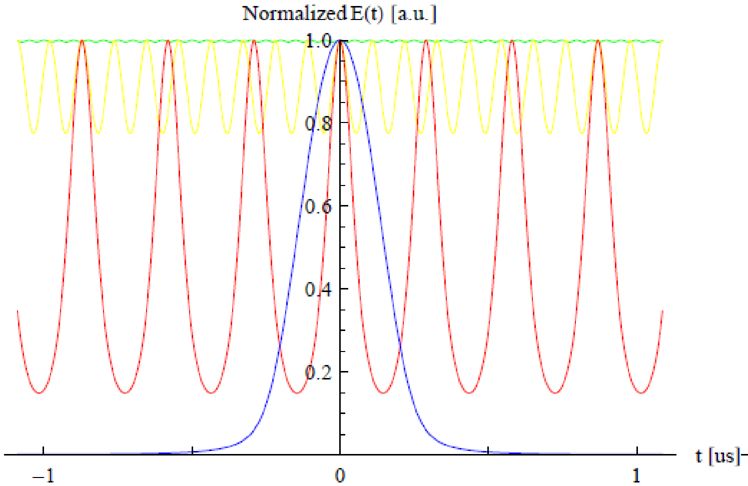
Low current BPMs

Low-β beams

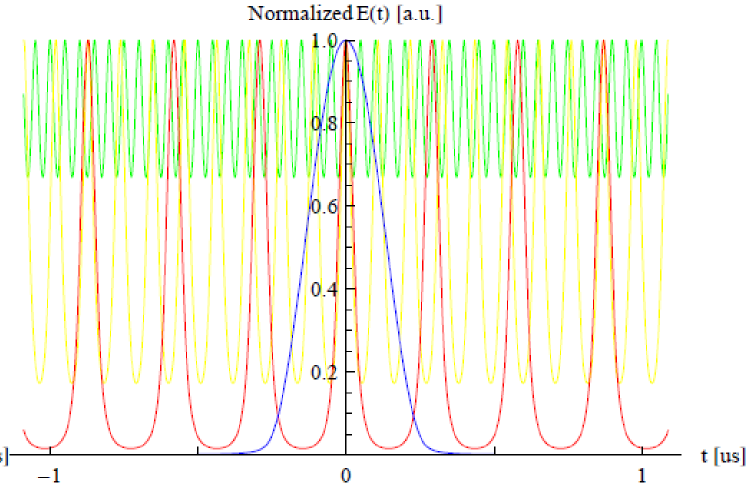
- USR: 300 keV to 20 keV
- Standard mode: h = 10
- Short-bunches: h = 436



See: J.Harasimowicz, DIPAC 2009



$Ø_{PU}$ = 250 mm



$Ø_{PU}$ = 100 mm

Signal for 20 keV pbars:

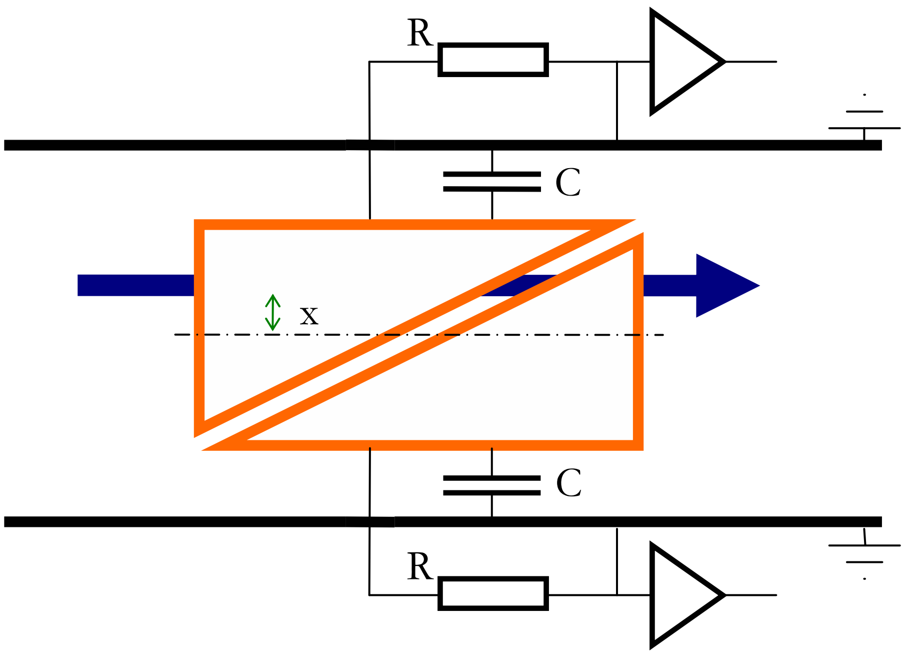
Blue: h = 10 (460 kHz)

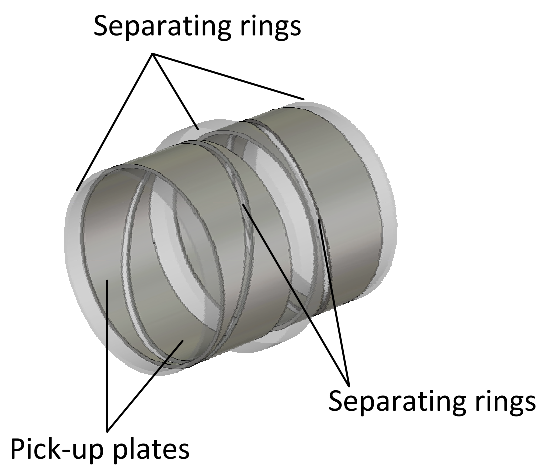
Red: h = 75 (3.5 MHz)

Yellow: h = 200 (9.2 MHz)

Green: h = 436 (20 MHz)

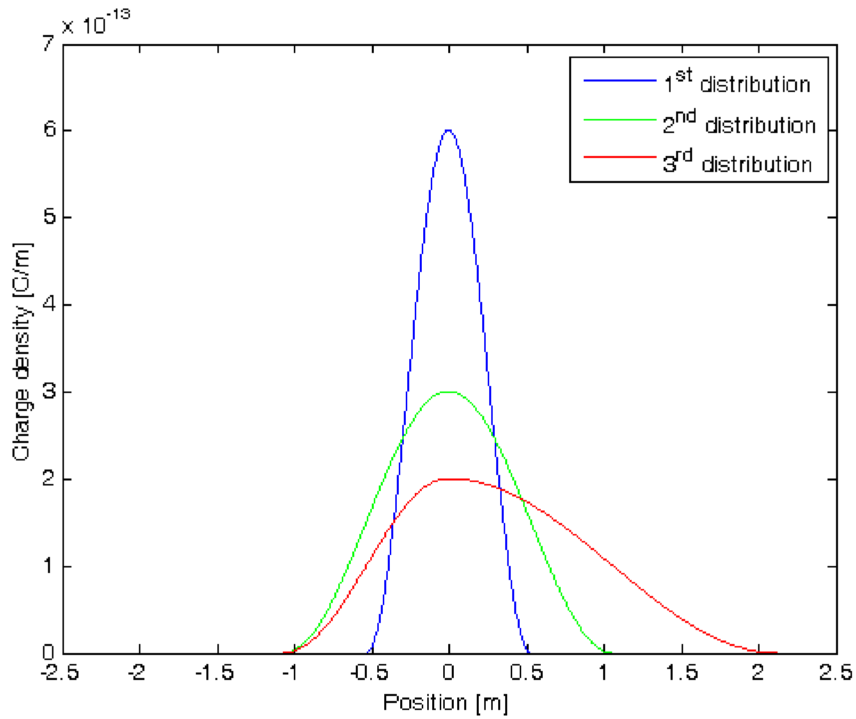
Capacitive PU

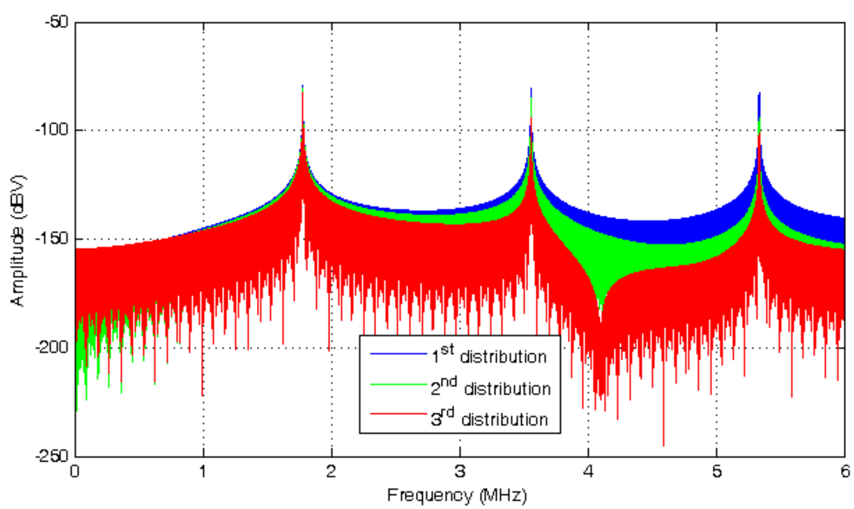


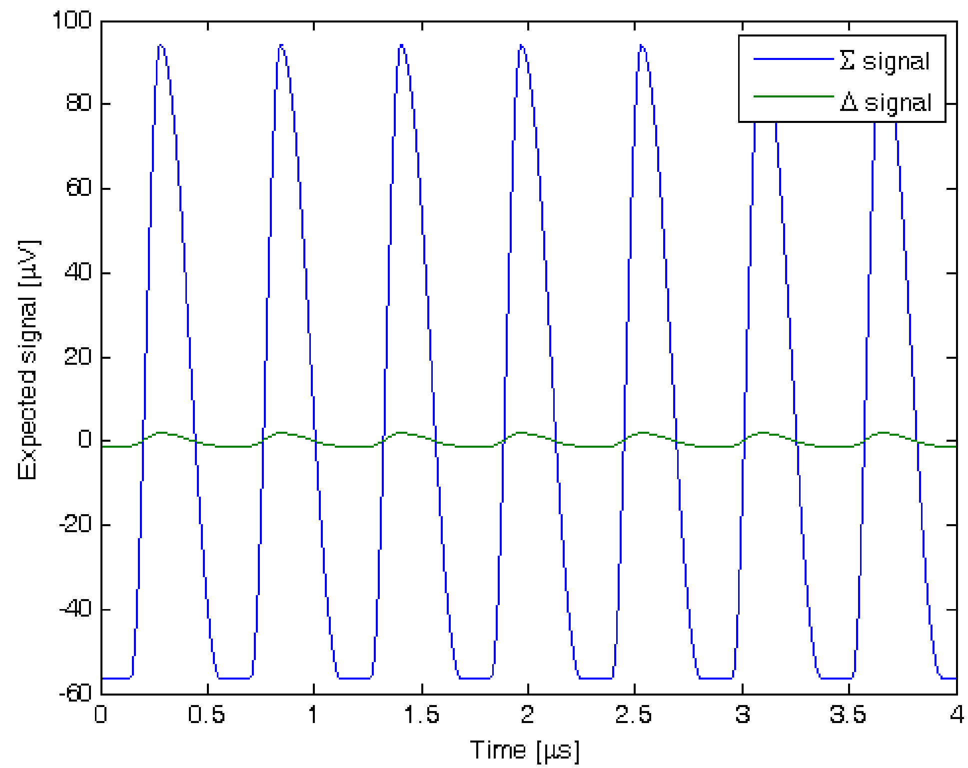


- Harmonic mode h = 10:
  - No. pbars/bunch: ~$2 \cdot 10^6$
  - Bunch length: ~1 m
  - $f_{RF}^{300\ keV}$ = ~1.8 MHz
  - $f_{RF}^{20\ keV}$ = ~460 kHz
- High input impedance
- Expected signal
  - ΣU: ~150 $\mu V_{p\text{-}p}$
  - ΔU (1 mm): ~3 $\mu V_{p\text{-}p}$

Signal estimation



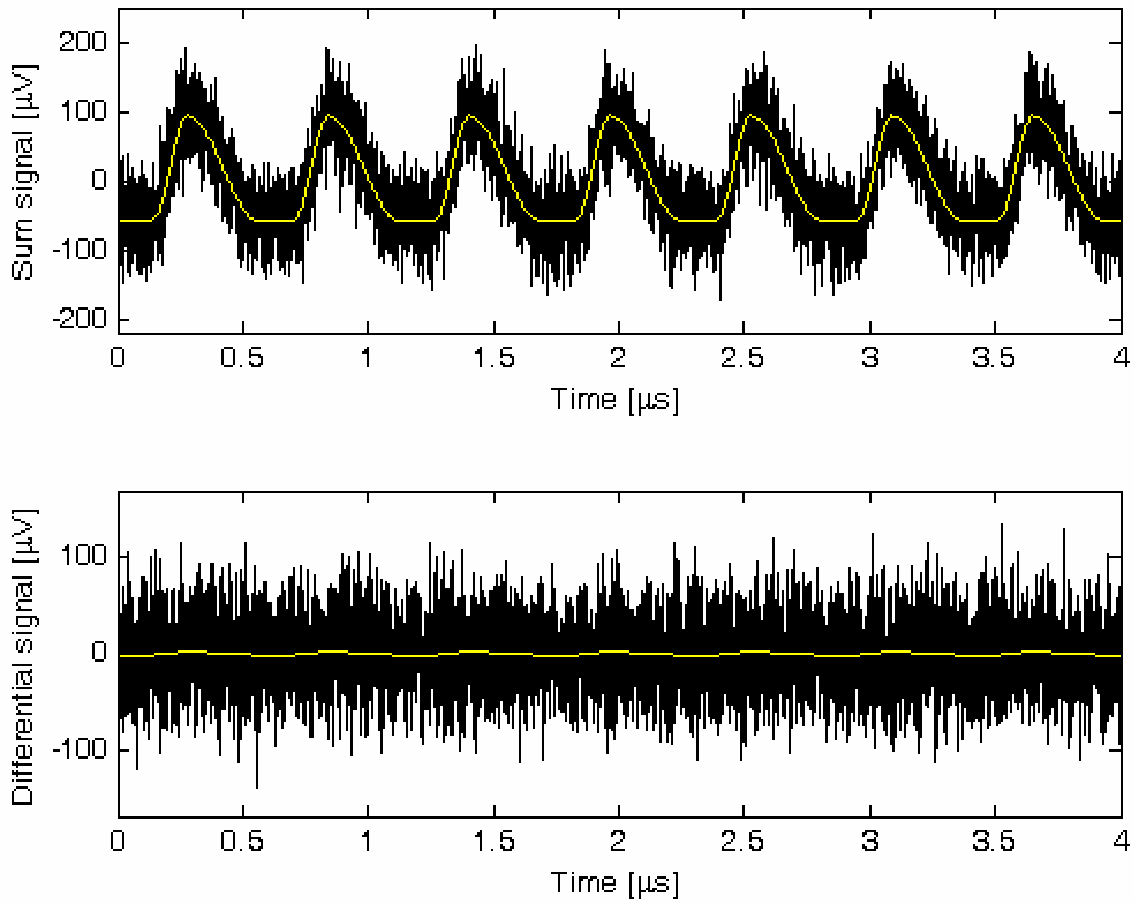




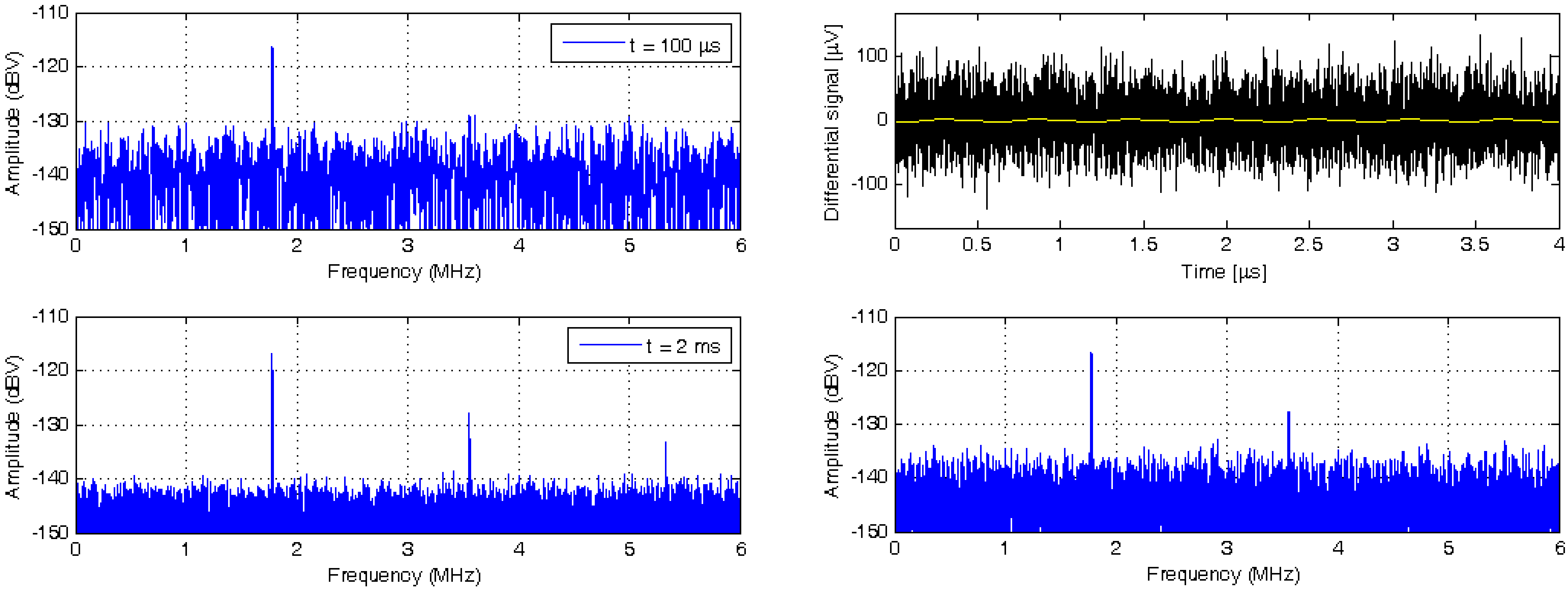
- ΣU: ~150 $\mu V_{p\text{-}p}$
- ΔU (1 mm): ~3 $\mu V_{p\text{-}p}$

Noise

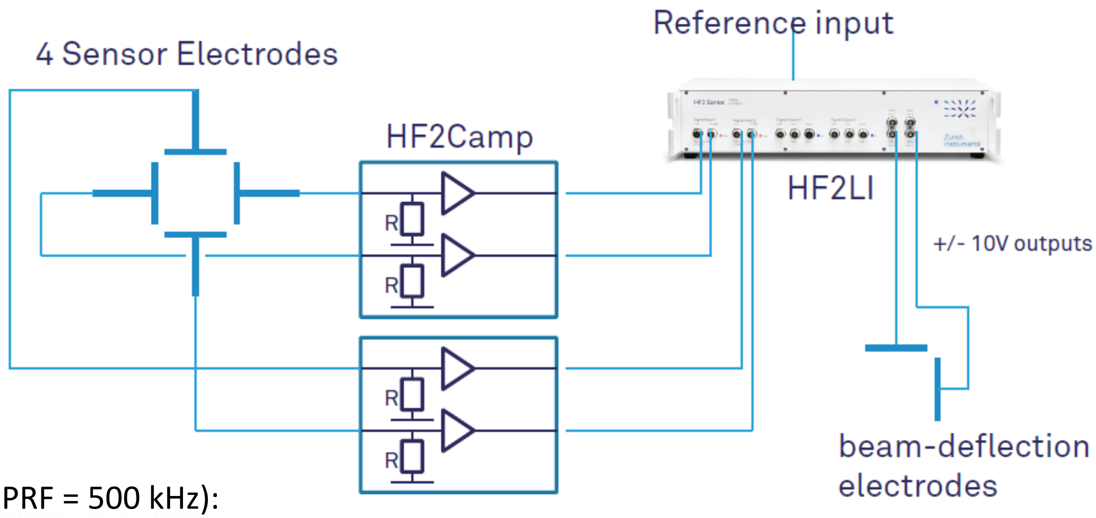
- Preamplifier noise: 0.5 nV/√Hz (4.7 nV/√Hz)
- Assumed noise: 30 μV_{rms}



Expected spectra



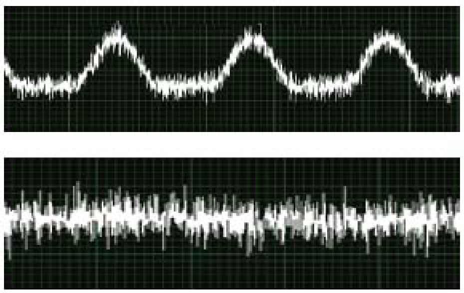
Lock-in amplifier



Zurich Instruments

Acknowledgments:
Flavio Heer
Zurich Instruments

Simulated signal (PRF = 500 kHz):

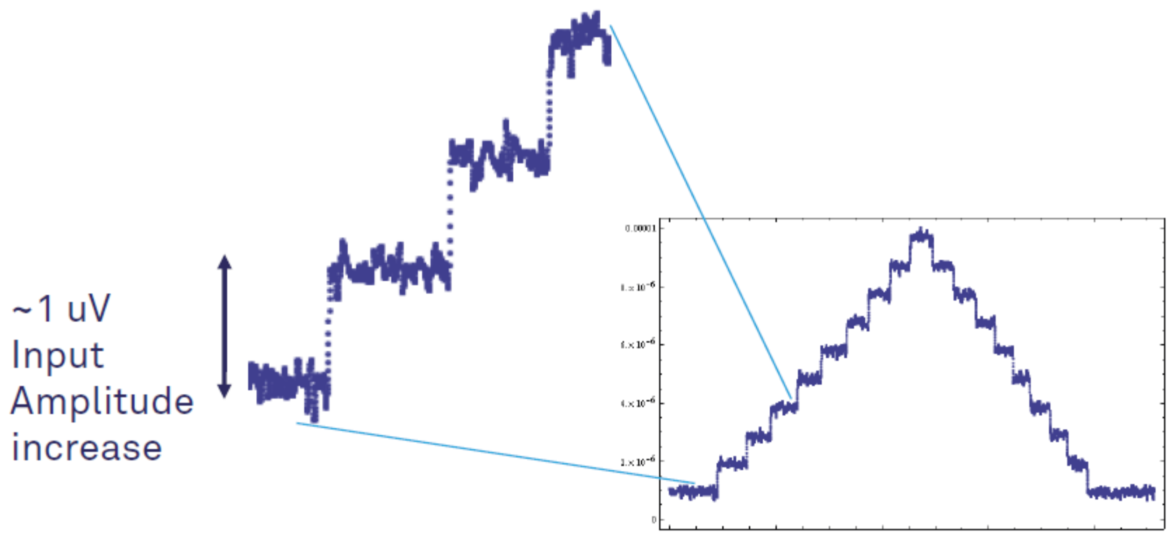


Preamplifier:

- bandwidth:	DC – 100 MHz
- input noise:	6 nV/√Hz
- output gain:	20 dB

Lock-in amplifier:

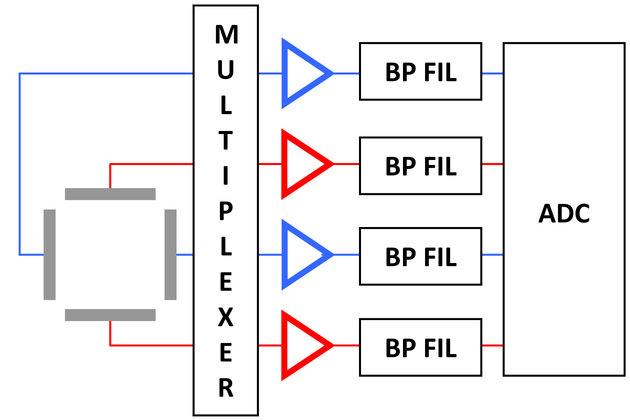
- bandwidth:	1 μHz – 50 MHz
- input noise:	5 nV/√Hz
- dynamic reserve:	>120 dB
- input AC range:	±1 mV to ±1.5 V
- A/D conversion:	14 bit, 210 MS/s



Input amplitude was varied from 1uV to 10 uV and back to 1uV in 1uV steps. Total recording is around 20 seconds.

Digital processing

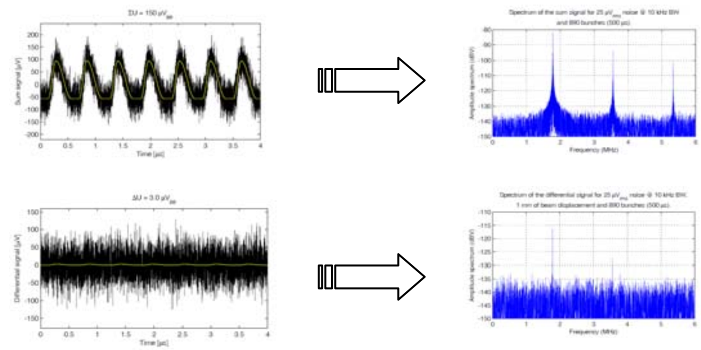
ΣU = ~150 µV
ΔU = ~1.5 µV = 10^{-2} ΣU (δx = 0.5 mm)



Gain 20 dB:
ΣU = 1.5 mV
ΔU = 15 µV

Gain 46 dB:
ΣU = 30 mV
ΔU = 300 µV

Gain 60 dB:
ΣU = 150 mV
ΔU = 15 mV



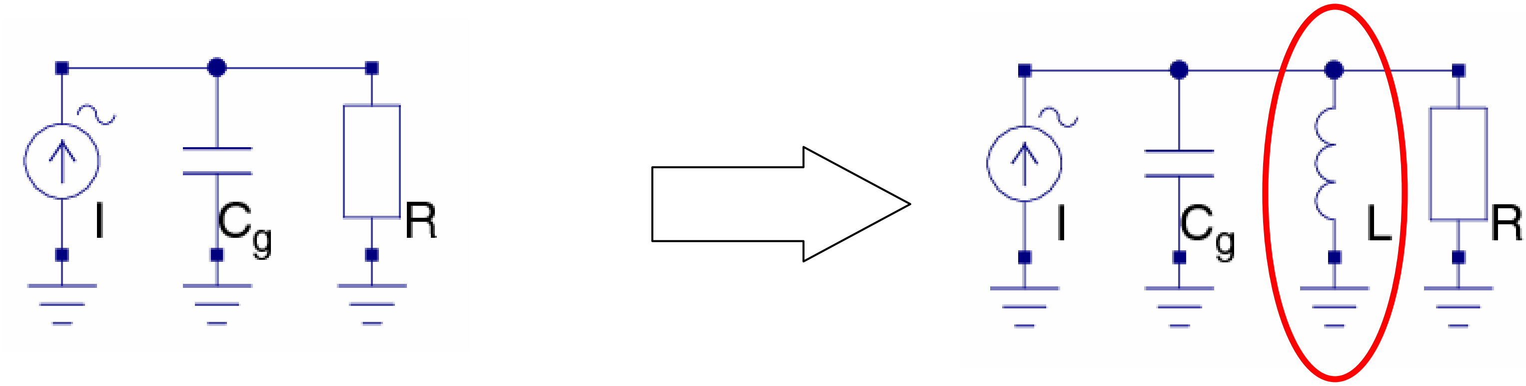
ADC resolution vs. input range:

50 mV:
- 10-bit: ~50 µV
- 12-bit: ~13 µV
- 14-bit: ~3 µV

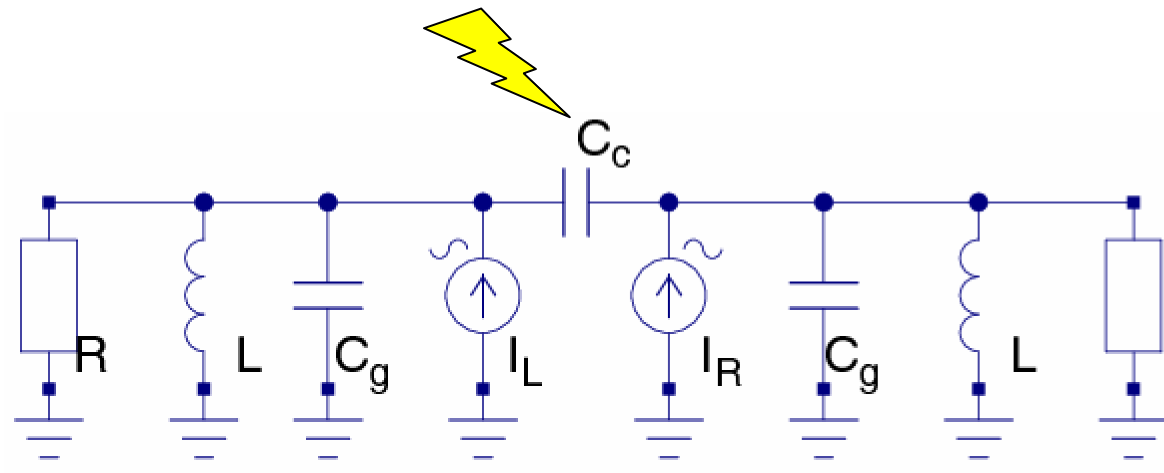
200 mV:
- 10-bit: ~200 µV
- 12-bit: ~50 µV
- 14-bit: ~12 µV

1000 mV:
- 10-bit: ~1 mV
- 12-bit: ~250 µV
- 14-bit: ~60 µV

Resonant capacitive PU



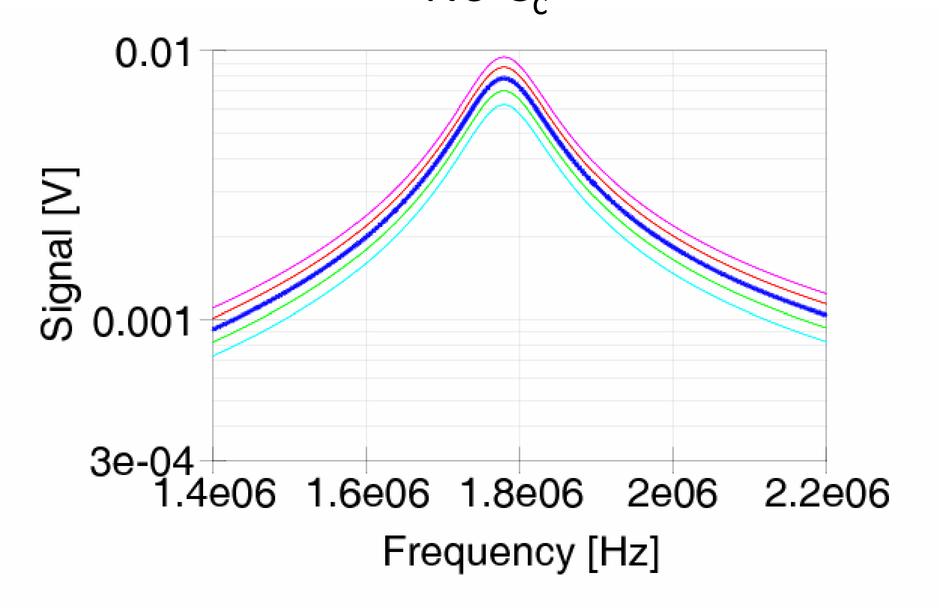
But...



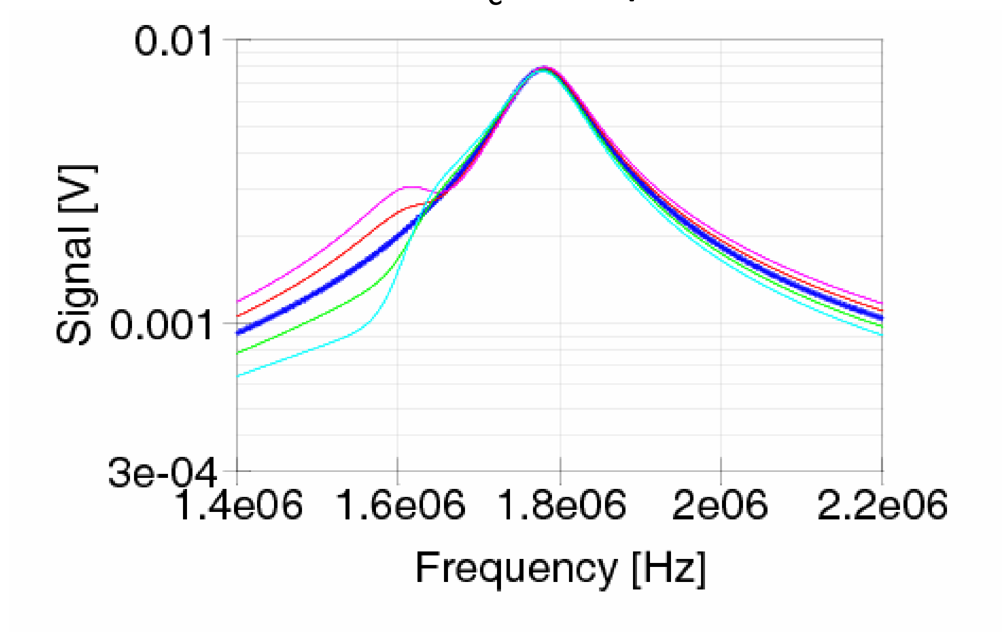
Coupling capacitance

I_p = 500 nA, R = 1 MΩ, C_g = 100 pF, L = 80 µH, R_L = 50 Ω

No C_c



C_c = 10 pF



ΔU(0.1 mm, 1.78 MHz) = 16 µV

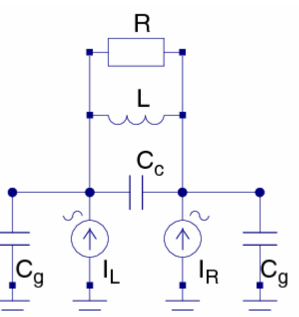
Increases with the increasing Q-factor

ΔU(0.1 mm, 1.78 MHz) = 4 µV

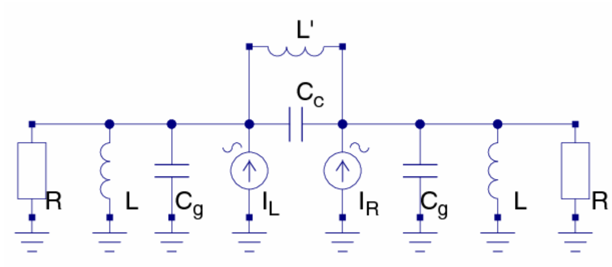
Does not improve considerably with the Q-factor

Capacitive PU

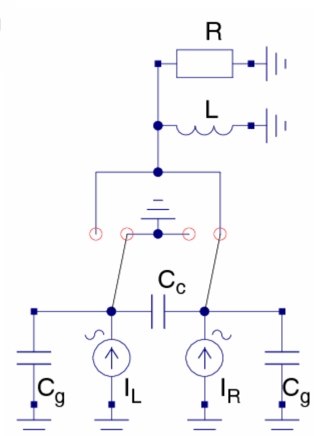
- Narrowband signal processing + averaging (closed orbit)
- Additional coil to improve S/N ratio?
  - Plates decoupling
  - High Q-factor



Single coil?

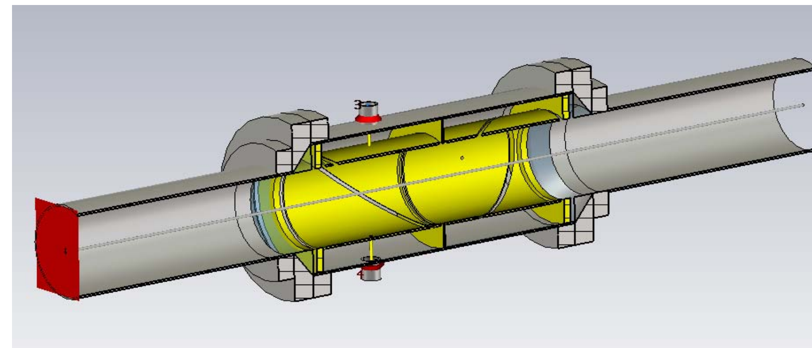


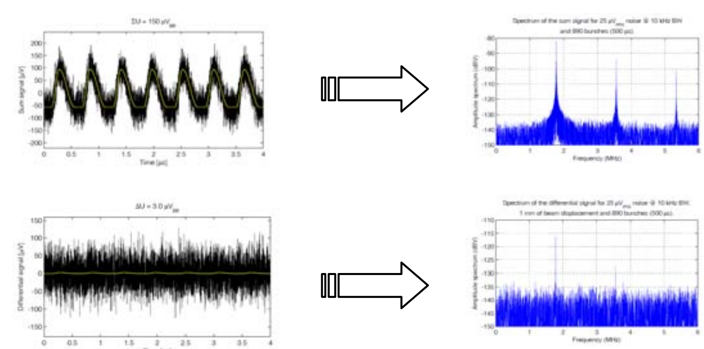
Compensating coil?



Switch?

See the talk by
Felix Laux





Summary

- **Scintillating screen**
  - Low number of particles (~$5 \cdot 10^5$ pps)
  - Large beam spread (~20 mm^2 – ~100 mm^2)
  - Low energy (20 keV)
- **Faraday cup**
  - Low current (~0.1 pA) measurements under UHV
- **Capacitive pick-up**
  - Low differential signal (~1 µV for ~1 mm)
- **Gas curtain monitor**
  - See the next talk by **Massimiliano Putignano**