CCC/SQUID beam current monitor at CERN p-bar rings

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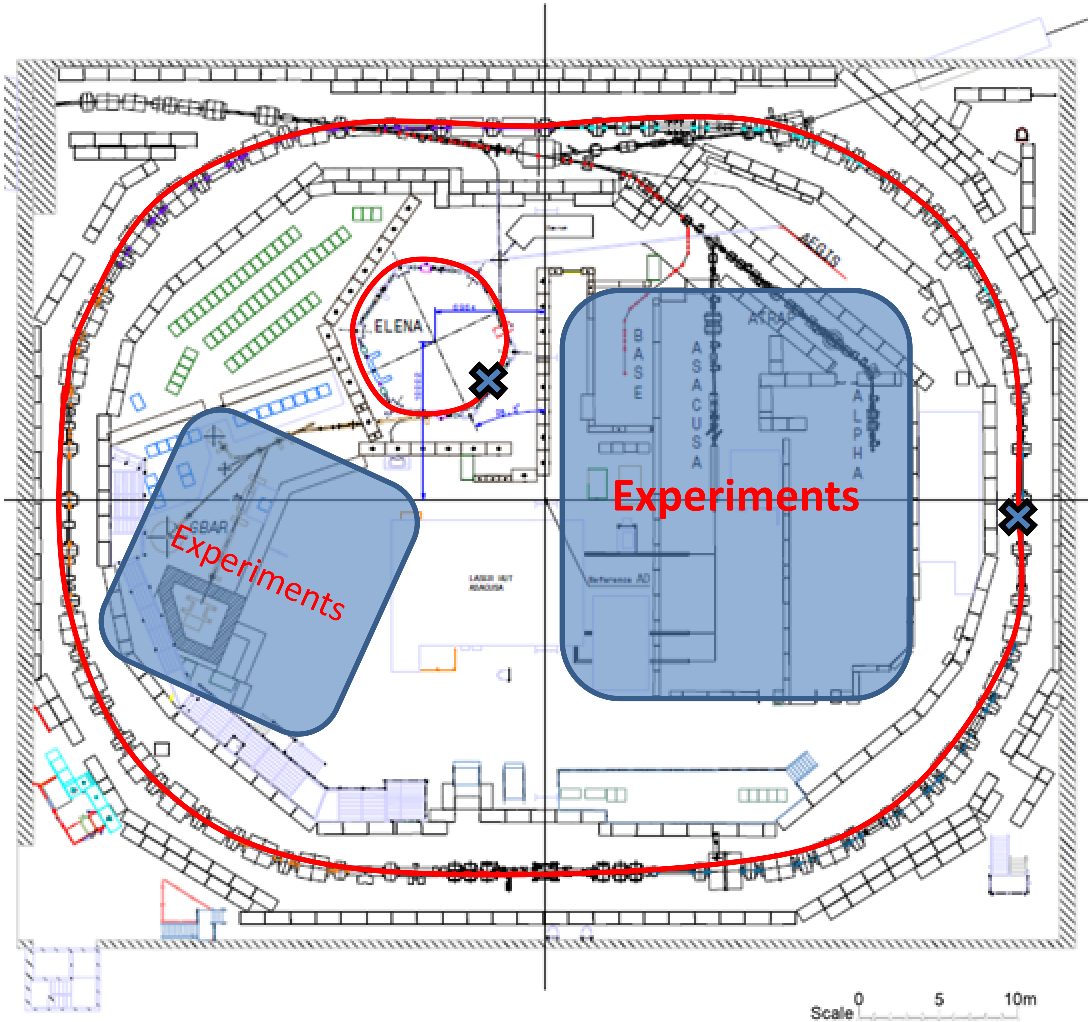
5th August 2013

GSI - Darmstadt

AD/ELENA: low-enery p-bar rings



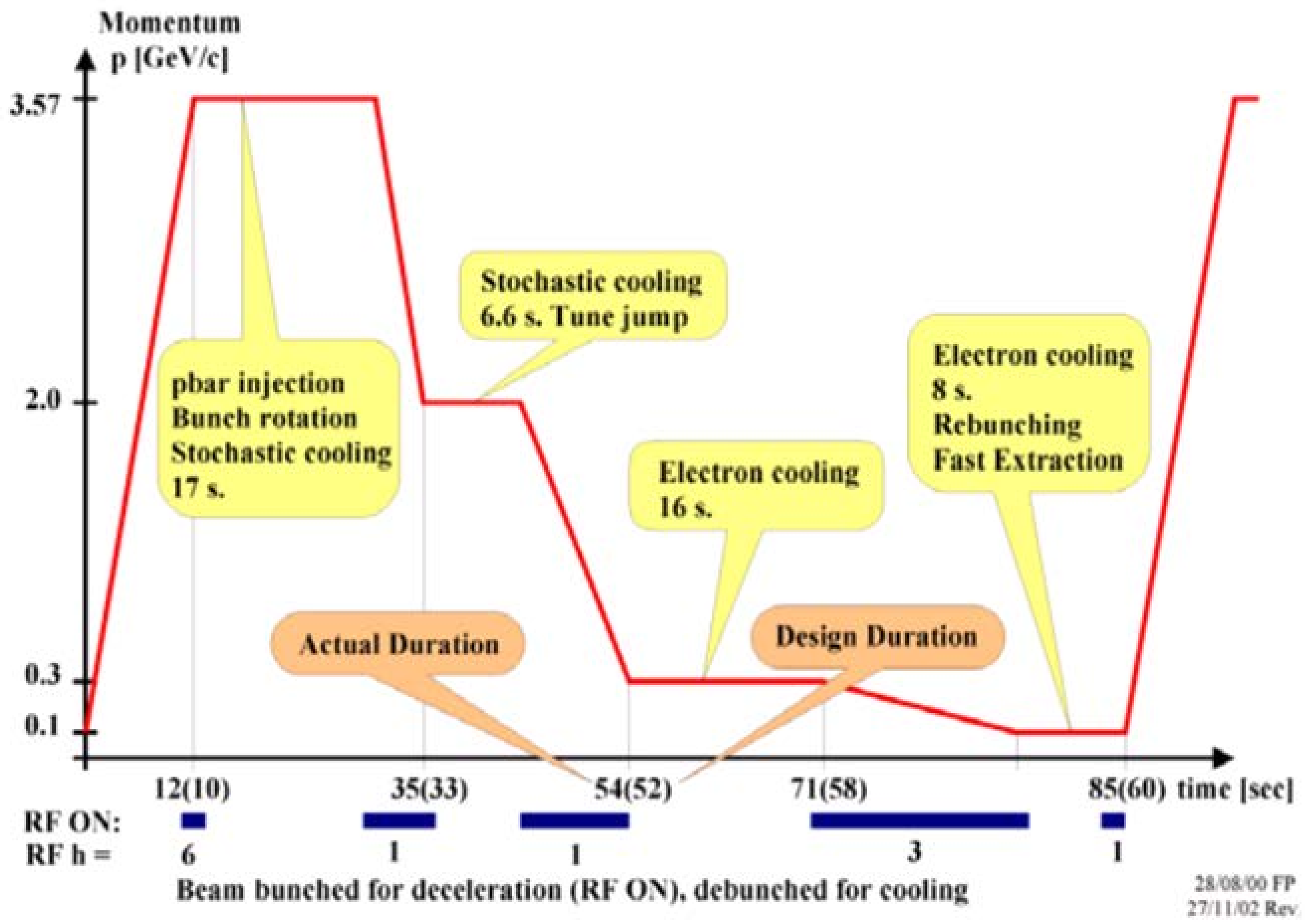
AD (commissioned 2000)

- Circumference: 182.5 m
- Aperture: 160 mm
- N particles: (5…1)x10^7
- Energy: (2753…5.3) MeV
- Momentum: (3.6…0.1) GeV/c

ELENA (forecast 2016)

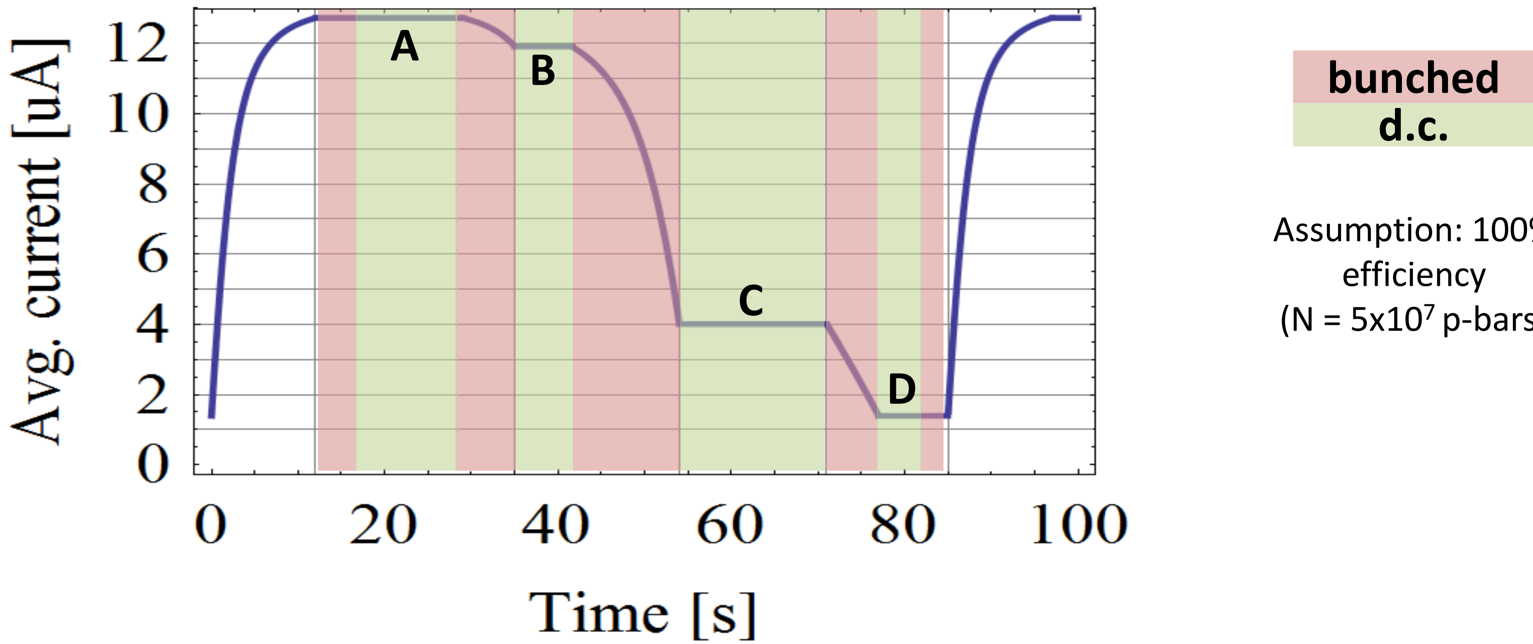
- Circumference: 30.4 m
- Aperture: 60 mm
- N particles: (3…1.8)x10^7
- Energy: (5.3…0.1) MeV
- Momentum: (100…13.7) MeV/c

AD Cycle



Momentum
p [GeV/c]
3.57
2.0
0.3
0.1
pbar injection
Bunch rotation
Stochastic cooling
17 s.
Stochastic cooling
6.6 s. Tune jump
Electron cooling
16 s.
Electron cooling
8 s.
Rebunching
Fast Extraction
Actual Duration
Design Duration
12(10)
35(33)
54(52)
71(58)
85(60) time [sec]
RF ON:
RF h =
6
1
1
3
1
Beam bunched for deceleration (RF ON), debunched for cooling
28/08/00 FP
27/11/02 Rev.

AD beam structure



Assumption: 100% efficiency
(N = 5×10^7 p-bars)

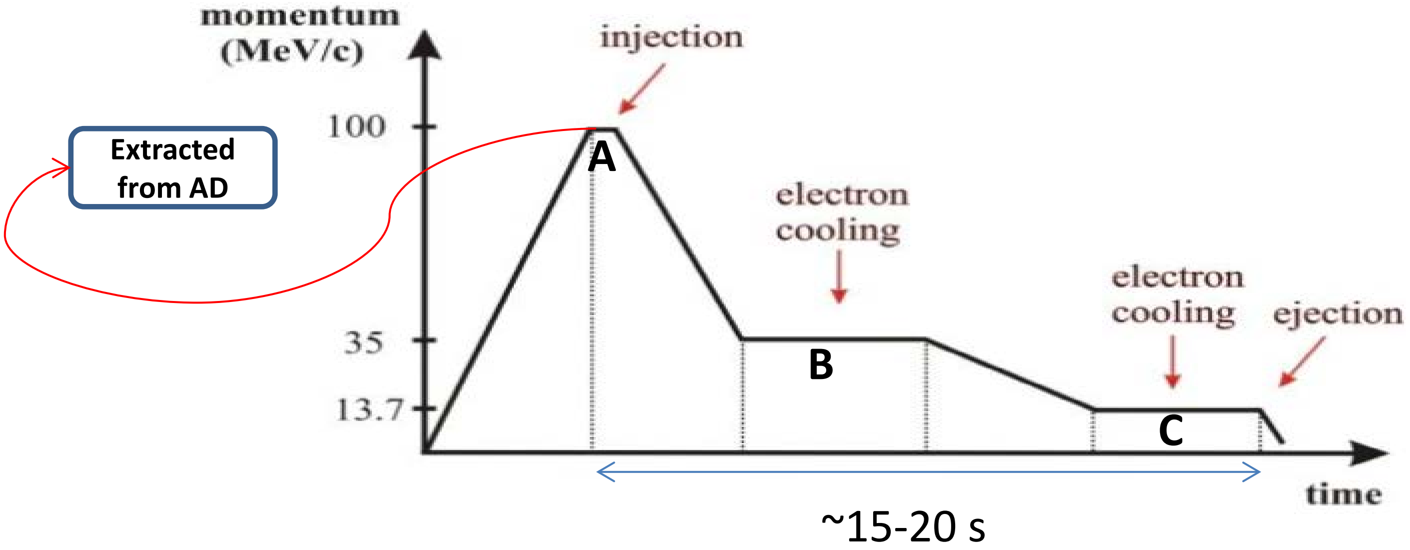
Flat-Top phases	A	B	C	D
β	**0.97**	**0.91**	**0.30**	**0.11**
f_{rev} [MHz]	1.6	1.5	0.50	0.17
Momentum [GeV/C]	3.57	2.0	0.3	0.1
Average current [µA]	12	11	4	1.3 - 0.3
Peak current [µA]	74	140	41	150
Bunch length [ns]	172	136	104	> 110

Ideal case ($N=5 \times 10^7$): 1.3 µA
Worst case ($N=1 \times 10^7$): 0.3 µA

Resolution (1%): 3 nA

Dynamic range: 54 dB

ELENA cycle



Flat-Top phases	A	B	C
Beta	**0.11**	**0.04**	**0.01**
Revolution [MHz]	1.1	0.4	0.1
Momentum [GeV/C]	100	35	13.7
Average current [μA]	5.2	1.9	0.3
Peak current [μA]	-	-	15.3
Bunch length [ns]	-	-	300

Minimum design current equal to worst case in AD

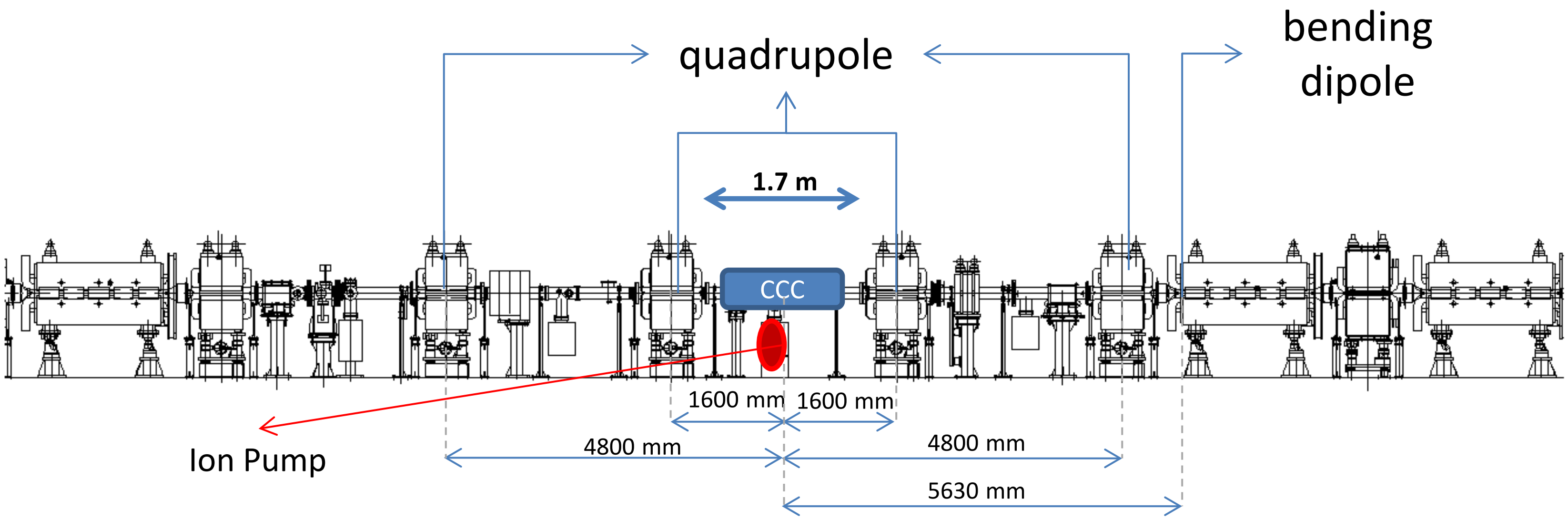
Motivation for CCC/SQUID

Existing beam current diagnostics at AD

- DCCT:
  - Insufficient resolution for the low current (low β,N) regime.
- Fast BCTs:
  - Limited to bunched beam phases.
- L-Schottky (from ultra-low noise BCT):
  - Bunched: time resolution of 20 ms; error of 10%
  - Un-bunched: time resolution of 200 ms; error > 10%
  - Complex calibration process

A more precise measurement (1% ↔ 3nA ☺) of average beam current (bunched and DC) is needed!

AD: magnetic environment



Field from beam current:

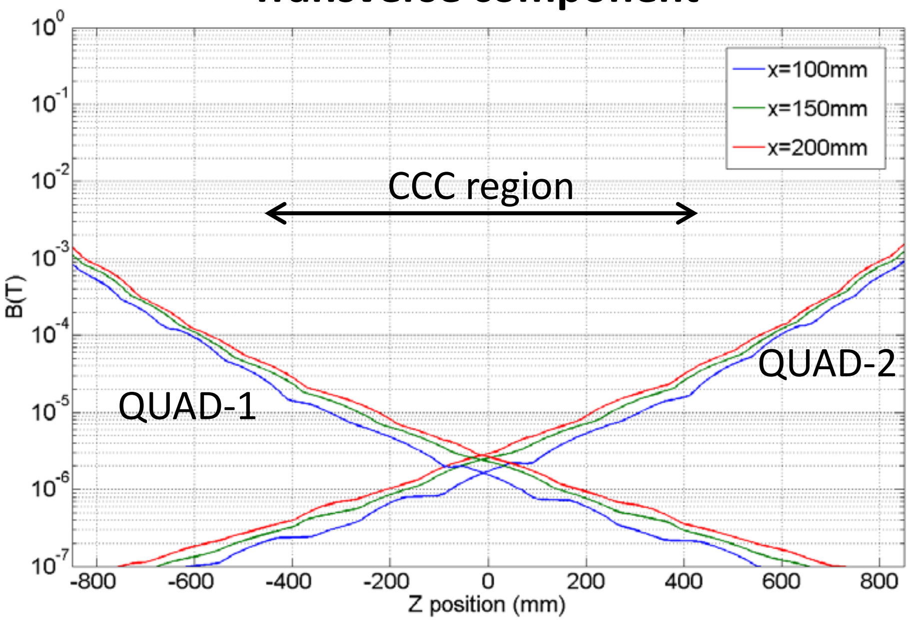
- Aperture: 170 mm
- Distance: 154 mm
- Current: 12 … 0.3 µA
- B_θ field: 15.6 … 0.39 pT

Assuming:

- Infinitely straight current
- Calculated at mid-point between r_{inner} and r_{outer} of a CCC with dimensions proportional to that of GSI (r_{inner}=69mm and r_{inner}=112mm)

AD: magnetic environment

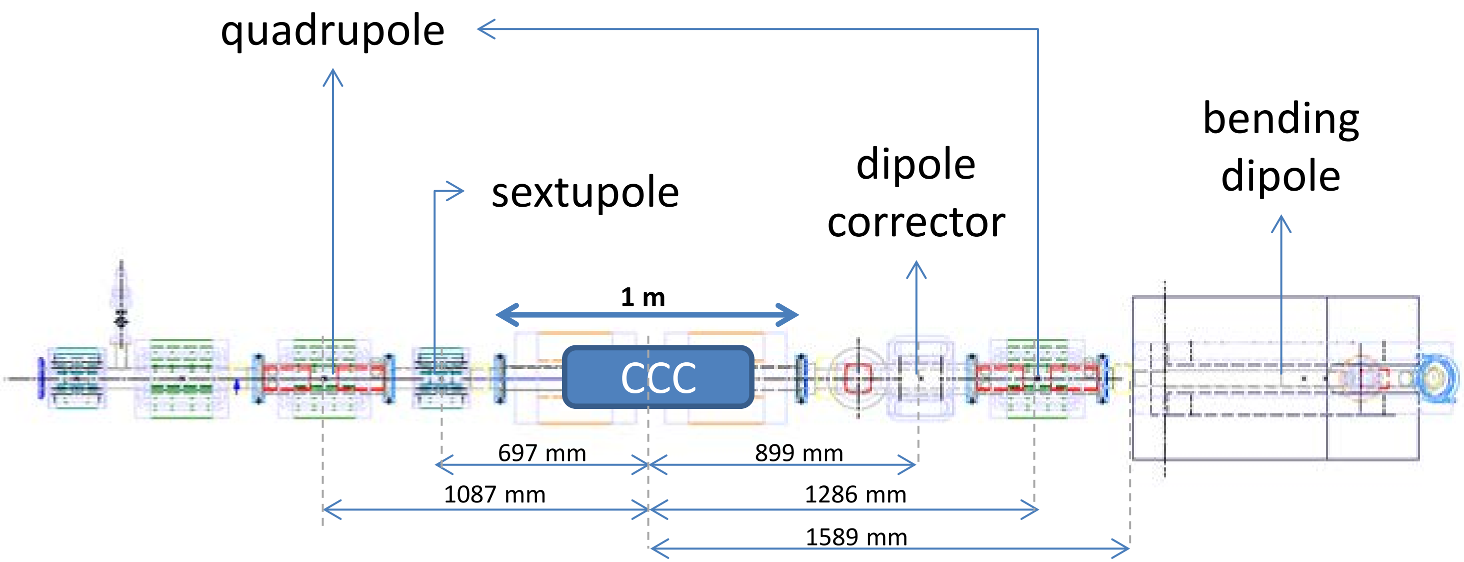
Transverse component



- Only 2 closest quadrupoles were considered
- Maximum magnet current was considered
- Field obtained in XZ plane at Y=0
- Long. component of quadrupole fields is zero in XZ (this should remain small in other longitudinal planes)

$|z|<300\text{ mm} \rightarrow |B_{trans}|<20\ \mu T$

ELENA: magnetic environment



Field from beam current:

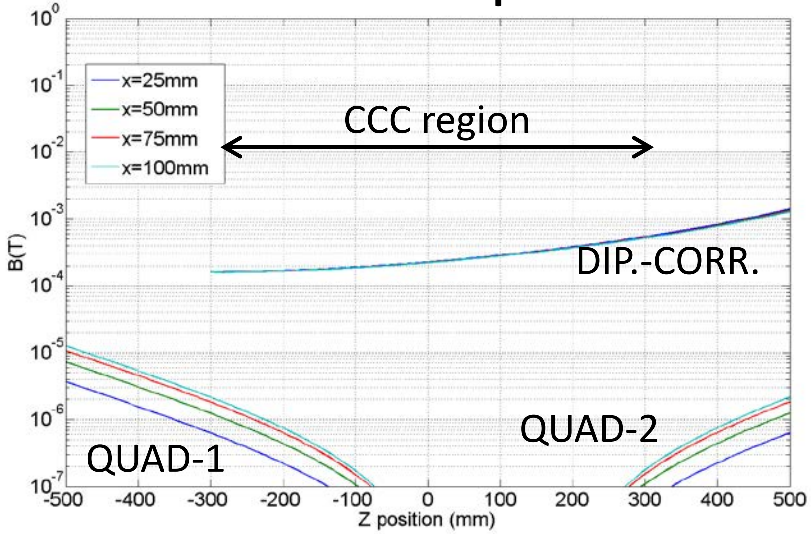
- Aperture: 60 mm
- Distance: 54 mm
- Current: 5.2 … 0.3 µA
- B_θ field: 19.2 … 1.05 pT

Assuming:

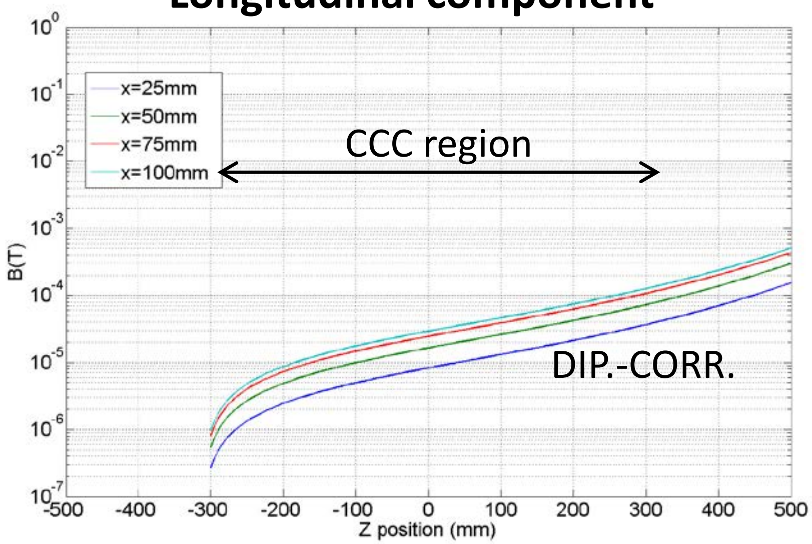
- Infinitely straight current
- Calculated at mid-point between r_{inner} and r_{outer} of a CCC with dimensions proportional to that of GSI (r_{inner}=69mm and r_{inner}=112mm)

ELENA: magnetic environment

Transverse component



Longitudinal component



- Only closest quadrupoles and dipole corrector simulations are available
- Maximum magnetic field was considered
- Field obtained in XZ plane at Y=0
- In XZ-plane long. component of quadrupole field is zero (this should remain small in other longitudinal planes)

$|z|<300$ mm → $|B_{trans}|<50$ μT

Measurements in AD hall *

- Field sources:
  - geomagnetic field
  - DC and AC currents: power lines, busbars …
  - remnant magnetization in steel components (typical in welded/cold worked parts)
  - electrical machinery (motors, pumps …)

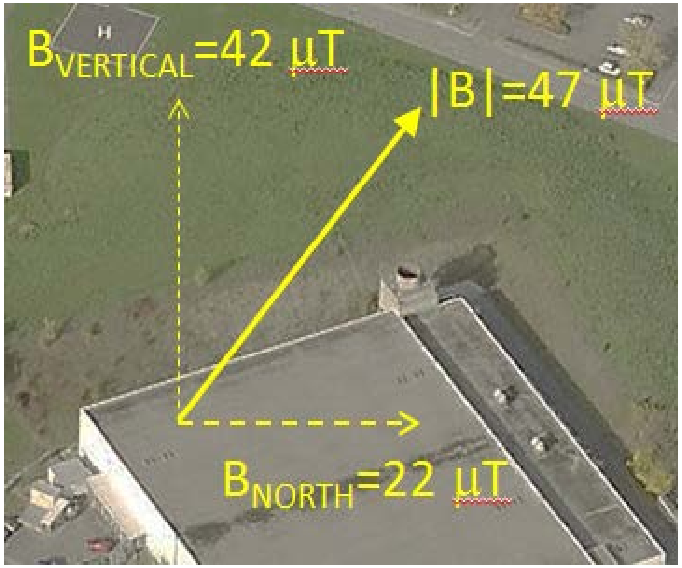
- Steel structures (scaffolding, rebars in concrete etc.) may both shield or amplify locally the field ($\mu_0 \approx 200$) according to the geometry, material properties, magnetic history … prediction of stray field map is very hard !

- Measurements done with a 3D fluxgate teslameter (1-1000 μT).

- Future measurements near CCC locations will be done.

* Courtesy of Marco Buzio (CERN)

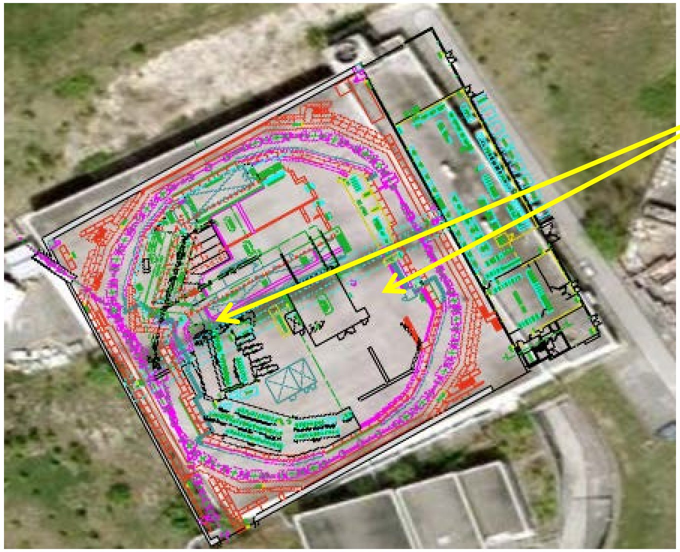
Measurements in AD hall *



* Courtesy of Marco Buzio (CERN)

Earth's magnetic field:

- Daily and yearly change < 1%



Measurements inside AD hall:

- General field levels:
  $B_{VERTICAL} \lesssim 35\ \mu T$ $B_{HORIZONTAL} \lesssim 30\ \mu T$
- Field at concrete shielding blocks:
  $|B| \lesssim 10\ \mu T$
- Scaffolding structure behind kicker spools:
  150 µT (70 µT @ 0.2 m)

Specification Summary

CCC/SQUID specifications	AD	ELENA
Aperture	160 mm	60 mm
Average current	0.3 … 12 µA	0.4 … 5 µA
Dynamic range	54 dB	~50 dB (??)
Bunch length	~100 ns (shortest)	~300 ns
Measurement bandwidth	dc … 1kHz	dc … 1kHz
Background magnetic field	< 20 … 50 µT	

- System should provide a measurement every 1ms, so B.W.= 1 kHz
- Measurements will provide a more precise view of the magnetic background
- Estimation of shielding factors:
  - $B_{out} = 50\ \mu T$
  - $B_{in} = 1\% \cdot B_{beam}$
  - $B_{in} = A \cdot B_{out}$

Transverse Atten.	AD/ELENA
Max. current	- 170 dB !!
Min. current	- 200 dB !!

Project Plan

2013

- Write and present proposal, including spending profile.

2014

- Develop and manufacture experimental setup.
- Characterize CCC and SQUID devices.
- Design acquisition chain, controls and cabling.
- Integration in AD machine (design scaling for ELENA?).

2015

- Installation in the AD machine and beam tests.

Points for discussion (1)

Magnetic shielding:

- Agreement of simulations with measurements.
- SC materials used: Nb, Pb (can lower B_c be a problem?).
- Manufacturing issues of the CCC.
- Asymmetry of the CCC in longitudinal direction.

Magnetic coupling:

- Material for the magnetic core.
- What kind of noise is dominating in the core (Barkhausen?).
- SC wiring and coupling to SQUID.

Points for discussion (2)

SQUID:

- Can Jena Uni. supply SQUID + electronics?

Cryogenic:

- Possible support/collaboration on cryostat design.
- Heat load and He consumption.
- Cryostat design (insolation layers; feedthroughs).

Operation of the device:

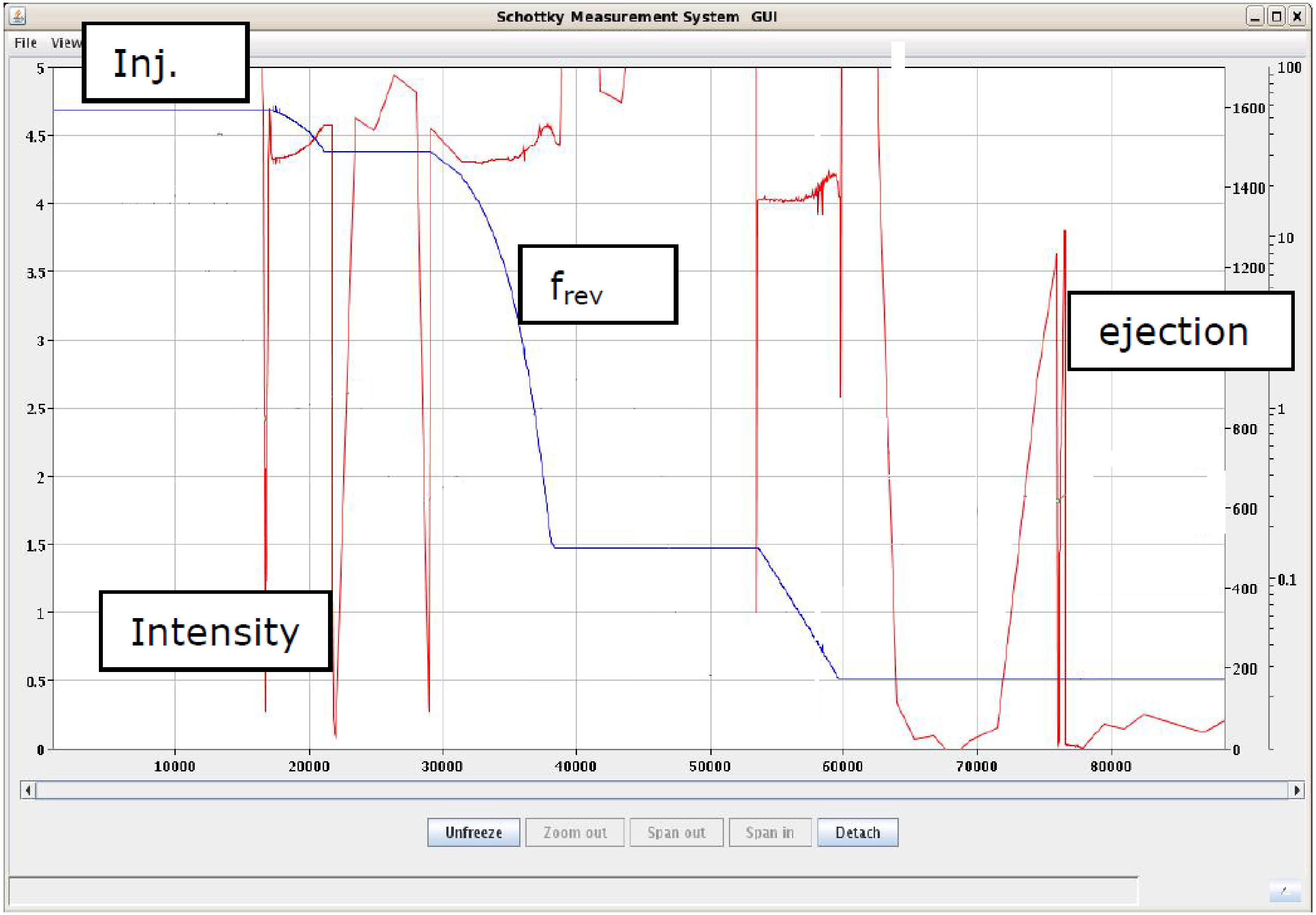
- Effect of mechanical vibrations.
- System stability.
- Calibration procedure.
- Possibility to be used by non-expert operator.

Backup Slides

AD beam parameters

	inj – 3.57	3.57 (FT)	3.57 (cap.)	2.0 (deb.)	2.0 (FT)	2.0 (cap)	0.3 (deb)	0.3 (FT)	0.3 (cap)	0.1 (deb)	0.1 (FT)				0.1 – ejection	
Revolution freq. [kHz]		1589.48			1487.70			500.46					174.16			
Revolution period [ns]		629.14			672.18			1998.18					5742.01			
Bunch length [ns]	100...400	d.c.	172	420	d.c.	136	859	d.c.	104	370	d.c.	110	110	d.c	110	110
Bunch spacing [ns]																
Harmonic	1	-	1	1	-	1	1	-	3	3	-	1	6		1	6
Total intensity [pbar]		5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	5.0E+07	1.0E+07	1.0E+07	1.0E+07
Bunch intensity [pbar]		-	5.0E+07	5.0E+07	-	5.0E+07	5.0E+07	-	1.7E+07	1.7E+07	-	5.0E+07	8.3E+06	-	1.0E+07	1.7E+06
Average current [uA]		12			11			4			1.3				0.3	
Bunch (gauss 4σ) peak current [uA]			74.2	45.6	-	140.8	22.3	-	40.9	17.3	-	174.1	29.0	-	34.8	5.8
Bunching factor (gauss 4σ)			6.2	4.1	-	12.8	5.6	-	10.2	13.3	-	133.9	22.3	-	26.8	19.3

L-Schottky current measurement



Magnetic field at magnets

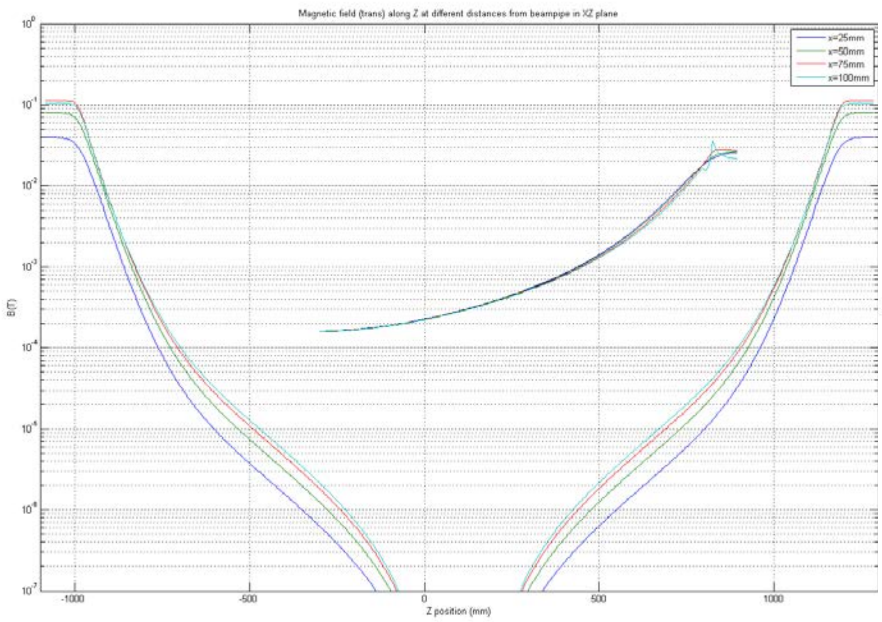
Fields at pole (ELENA):

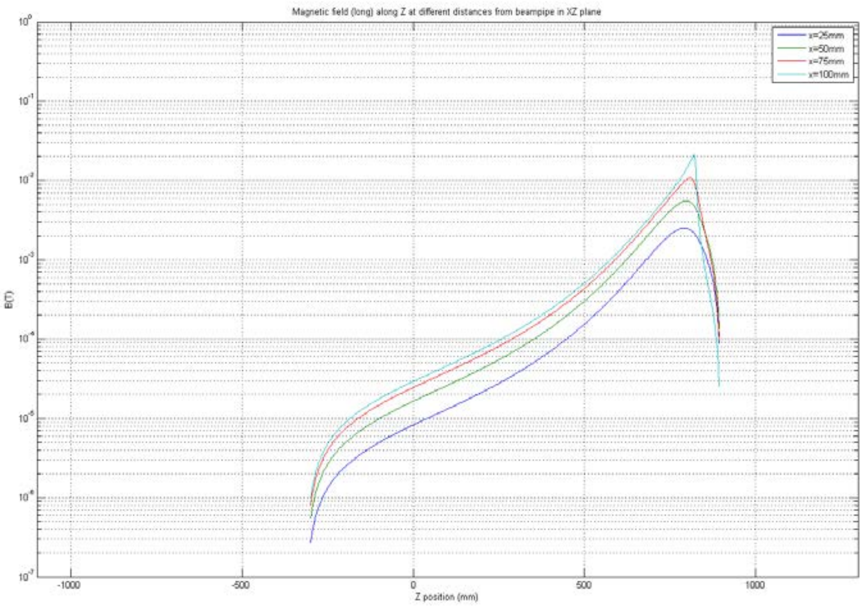
- Bending dipole: 0.36 T
- Quadrupole: 0.064 T
- Sextupole: 0.0134 T
- Dipole corrector: 0.04 T

Fields at pole (AD):

- Bending dipole: 0. T
- Quadrupole: 0.7 T

ELENA magnetic field





AD magnetic field