Beamline measurement of a non-invasive BCM: its advantages and limits

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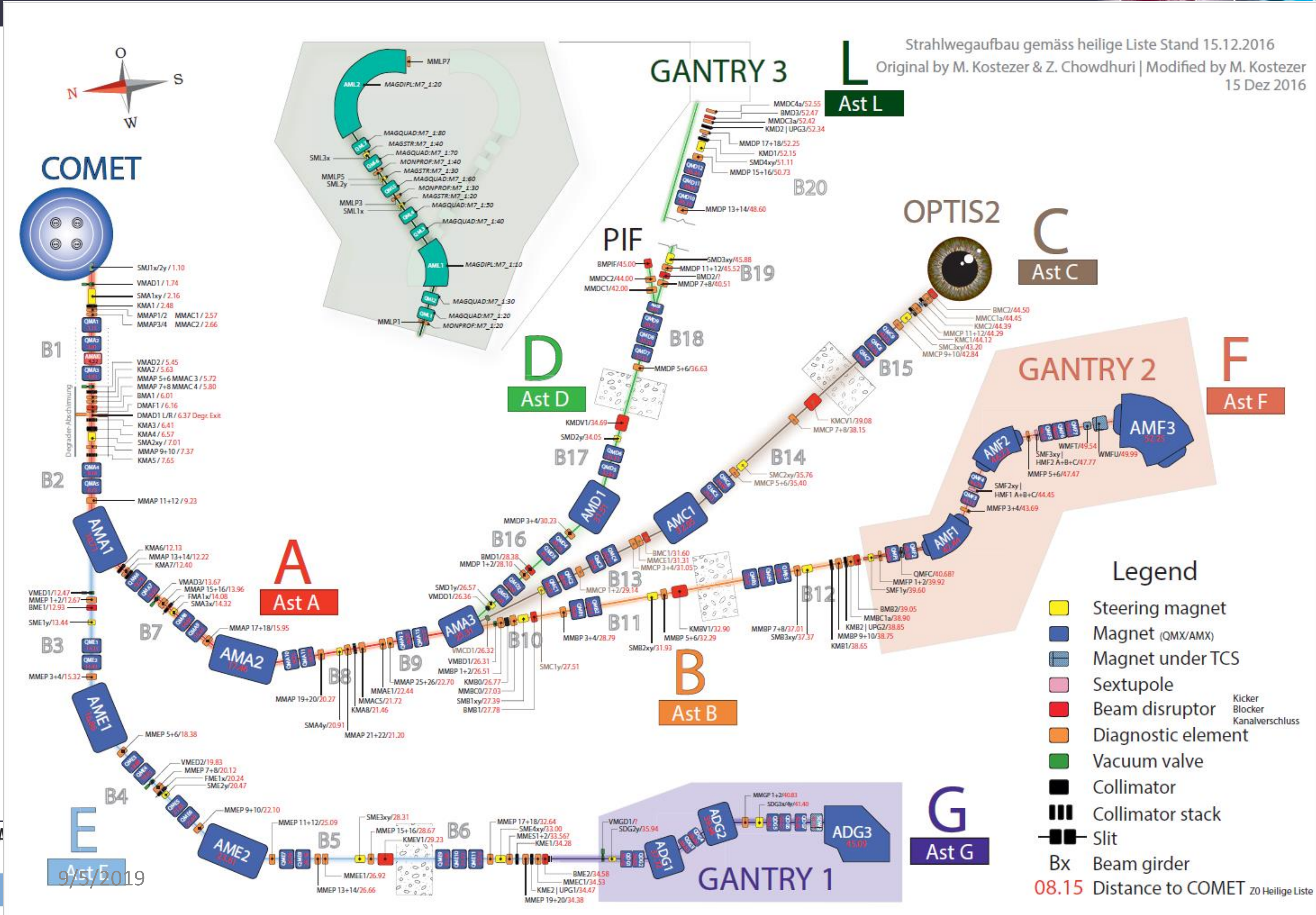
COMET


Strahlwegaufbau gemäss heilige Liste Stand 15.12.2016
Original by M. Kostezer & Z. Chowdhuri | Modified by M. Kostezer
15 Dez 2016
COMET
GANTRY 3
L
Ast L
PIF
OPTIS2
C
Ast C
D
Ast D
GANTRY 2
F
Ast F
A
Ast A
B
Ast B
E
Ast E
G
Ast G
GANTRY 1
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
B16
B17
B18
B19
B20
AMA1
AMA2
AMA3
AME1
AME2
AMC1
AMD1
AMF1
AMF2
AMF3
ADG1
ADG2
ADG3
Legend
Steering magnet
Magnet (QMX/AMX)
Magnet under TCS
Sextupole
Beam disruptor
Kicker
Blocker
Kanalverschluss
Diagnostic element
Vacuum valve
Collimator
Collimator stack
Slit
Bx Beam girder
08.15 Distance to COMET Z0 Heilige Liste

Specific Diagnostic needs

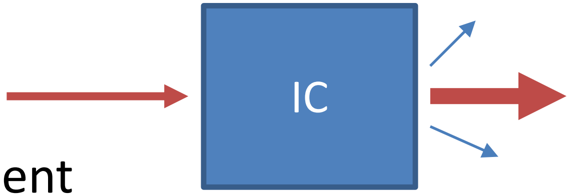
- Beam parameter of interest: Beam intensity (Most Important)
- Two different modes of operation: Diagnostics for commissioning/Diagnostics for Standard operation
- Diagnostics for Standard Operation [1]:
  - To control and improve accelerator operation (precise)
  - Diagnosis of unwanted errors and to trigger interlocks
  - High demands for accuracy
  - Minimum beam disturbing schemes
- Repetitive and stable beam: CW system (Closed loop system)
- Signals are treated typically in Frequency domain
- Beam current is a non- or slowly varying parameter
- High precision by averaging

Review of the BCM

Standard Beam Current Measurements:

- ionization chambers are the most commonly used detector type
- caveat: intercept beam → decrease the beam's quality by scattering

An alternative:



- a sensitive RF-based current monitor
- fully non-interceptive beam current measurement
- simple and robust system (KISS), good for safety purpose/applications

Challenge:

- For very low charge beams (bunch charge ~ 1.36e-17 C)
- Trade-off between bandwidth and sensitivity

Potential benefit:

- design a new beam position monitor system using the same technics

NOTE: Slide provided by Pierre André Duperrex

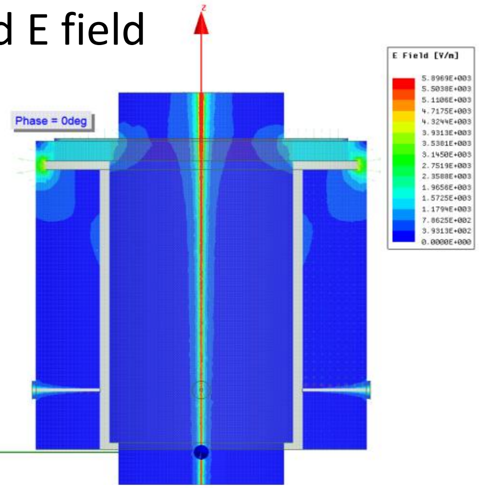
[2,3,4]

BPM types	Bunch/Beam size	Signal strength & quality	Mechanical realization
Linear-cut	Longer	smaller & deformations	complex
Button	comparable	smaller & deformations	simple
Stripline	short	larger & minor deformations	complex
Pill-box	very short	larger ; minuscule deformations	simple
Reentrant	very short	larger; minuscule deformations	simple
Resistive WCM	short	large with thermal noise	complex
Inductive WCM	short	better than linear-cut	complex

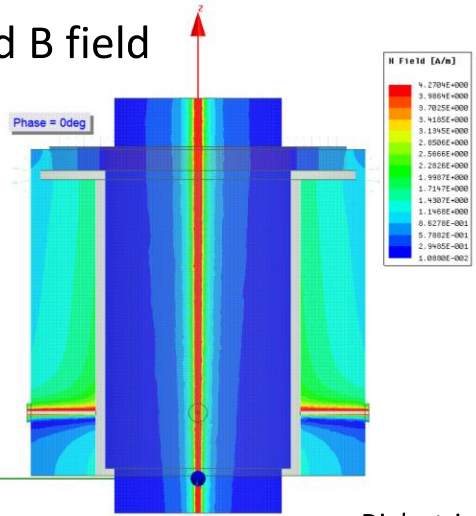
BPM types	Advantages	Bandwidth	PROSCAN
Linear-cut	highly linear and good position sensitivity	Broadband	No
Button	non-linear and good position sensitivity	Broadband	No
Stripline	directivity and better position sensitivity	Broadband	Yes (3)
Pill-box	extermely linear and highly position sensitive	Narrowban d	Yes (2)
Reentrant	extermely linear and highly position sensitive	Narrowban d	Yes (1)
Resistive WCM	linear and average position sensitivity	Broadband	No
Inductive WCM	linear and position sensitivity better than linear-cut	Broadband	No

Review of the BCM

Induced E field

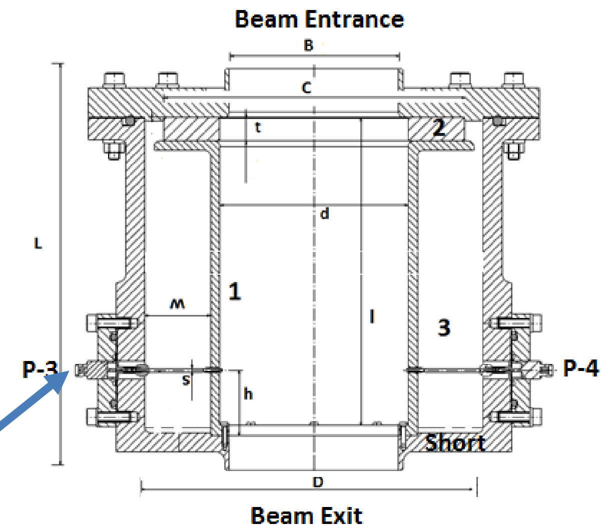


Induced B field



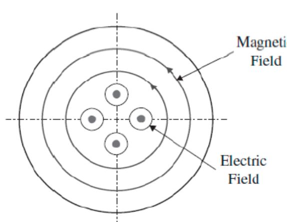
Matched to 2nd harmonic of the pulse repetition rate=72.85MHz

TM010



$$V_{out} = Q_{bunch}\omega_o \sqrt{\frac{(\frac{R}{Q_{unloaded}})Z_o}{Q_{ext}}} = 59.85nV$$

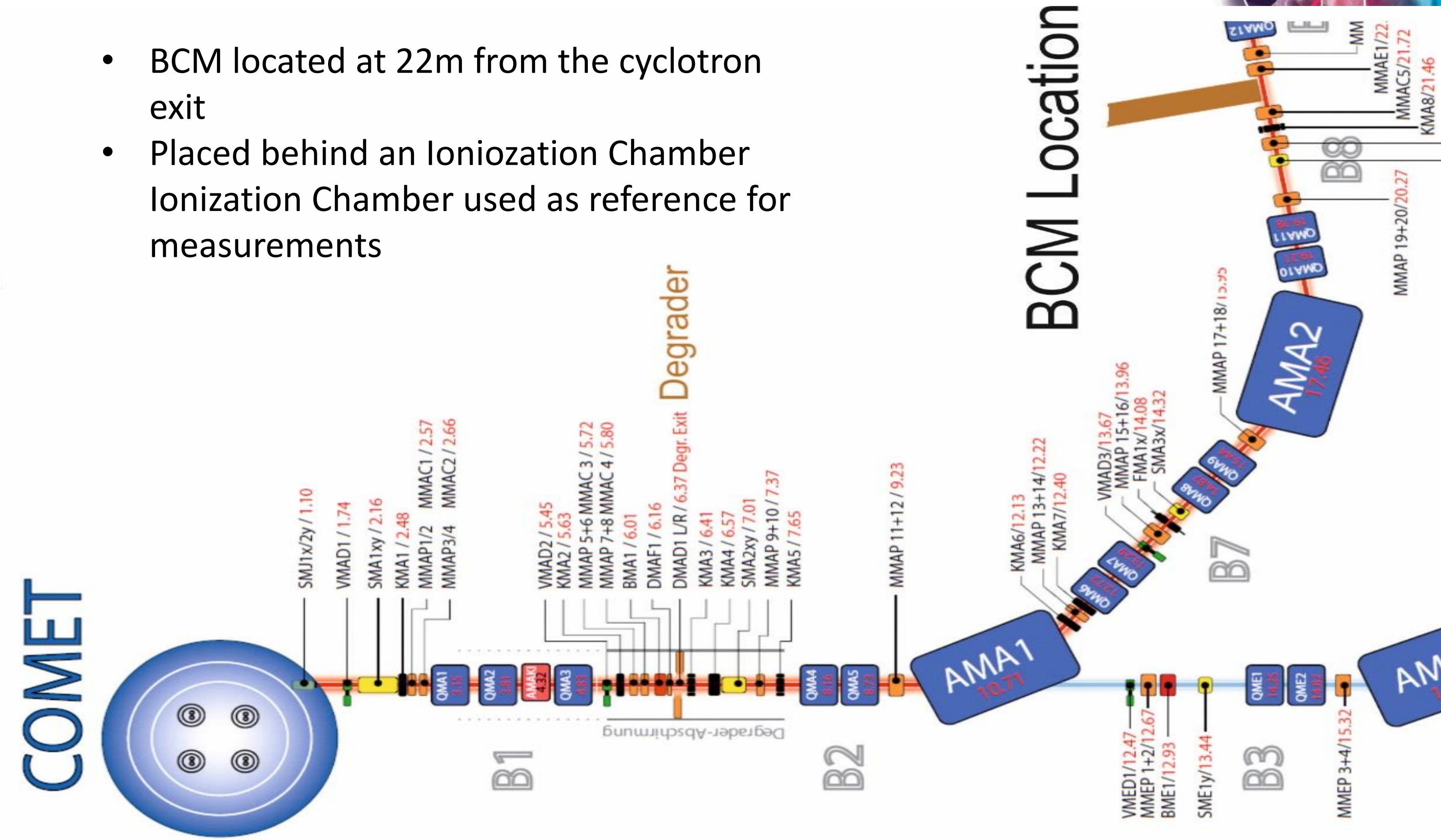
For 1nA at 145.7MHz



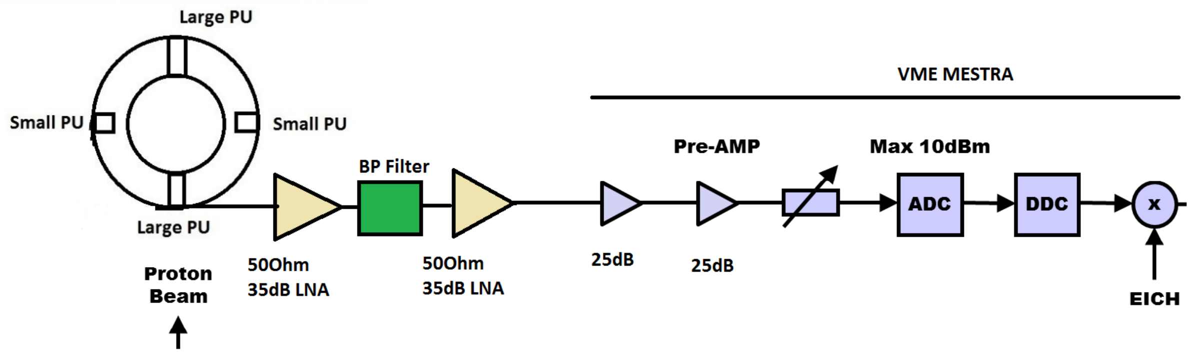
Dielectric-Filled Reentrant Cavity Resonator as a Low-Intensity Proton Beam Diagnostic, **Instruments** 2018, 2,24

PROSCAN Beamline

- BCM located at 22m from the cyclotron exit
- Placed behind an Ioniozation Chamber Ionization Chamber used as reference for measurements



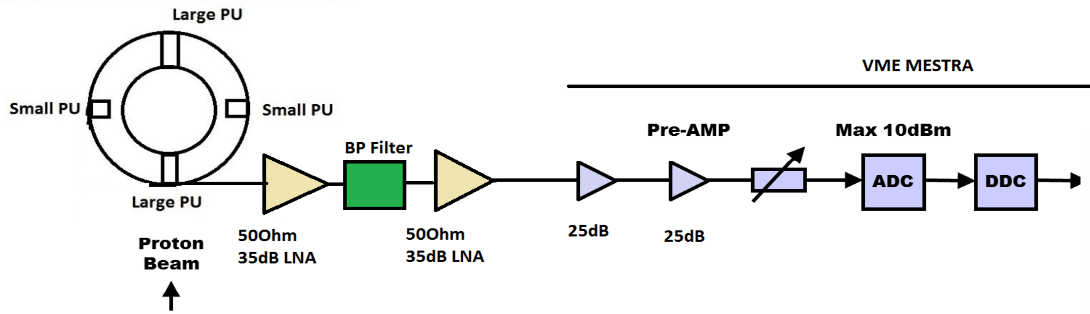
Measurement Chain



- 2*50Ohm LNA with a BP filter inbetween (center freq: 145.7MHz ; span=10MHz)
- Subsystems of VME MESTRA (PSI developed)
  - Preamplifier
  - Digitizer (ADC); ADC3110 : max. input power of 10dBm (2V peak-peak) 16bit resolution (0.0001V)
  - Digital Down Converter (DDC)
  - Current Calculations
- VME MESTRA converts RF signals to digital signals proportional to absolute beam current

Friss Formula

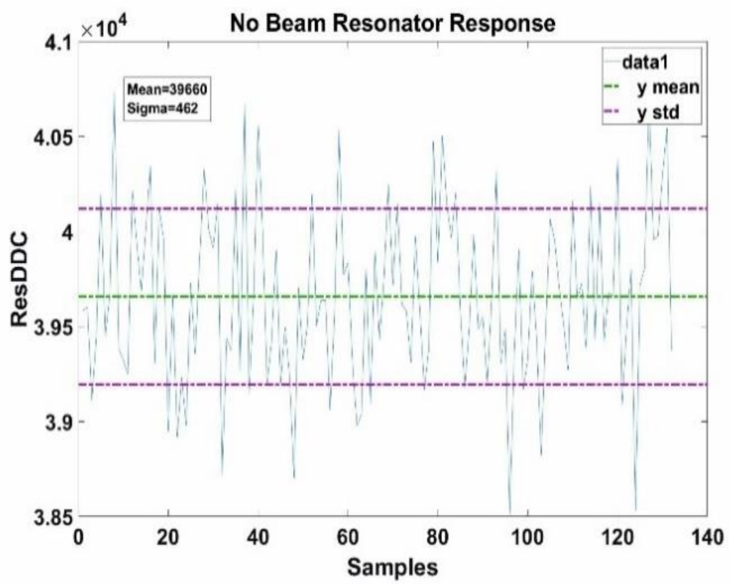
Measurement Chain: Power Budget



The typical power budget for the measurement system is:

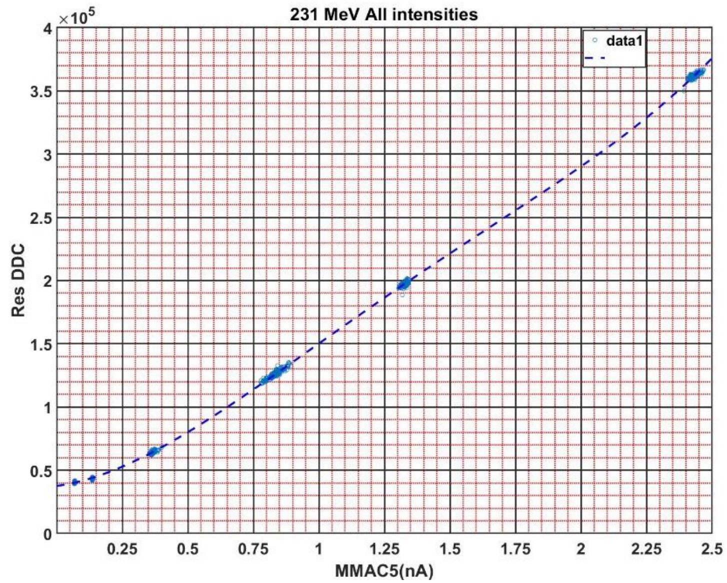
- Resonator at 1nA: -134dBm
- Local amplifiers: +70dB -64dBm
- Cellflex cable 150m: -3dB -67dBm
- 1st Amplifier: +25dB -42dBm
- 2nd Amplifier: +25dB -17dBm
  (0.089V peak to peak)

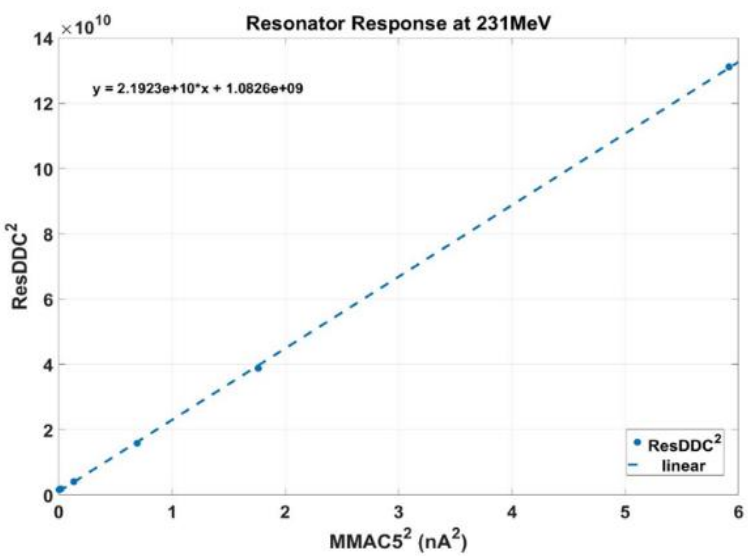
Noise Level



$$\text{ResDDC Counts} = \sqrt{I^2 + Q^2}$$

Resonator Vs MMAC5

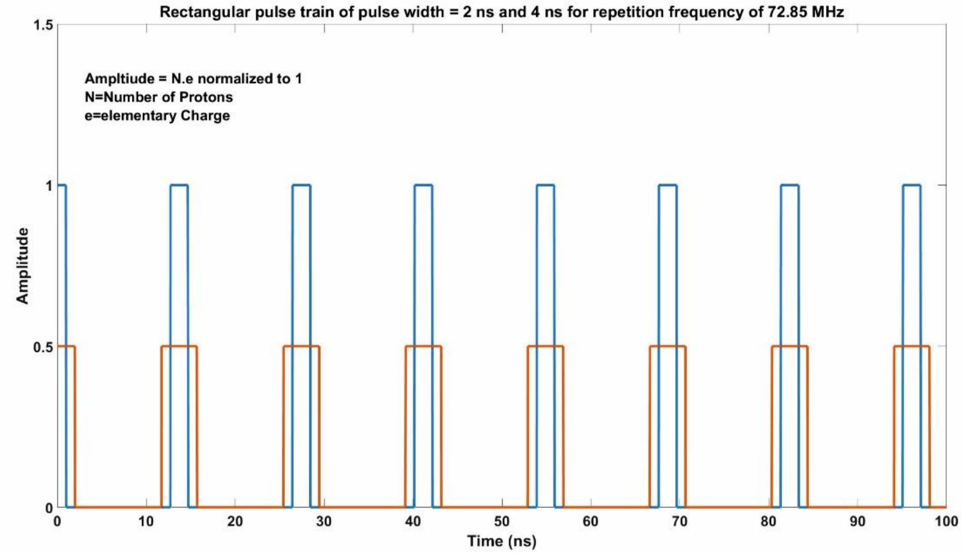




$$I_{ResDDC} = kI_{MMAC5}$$

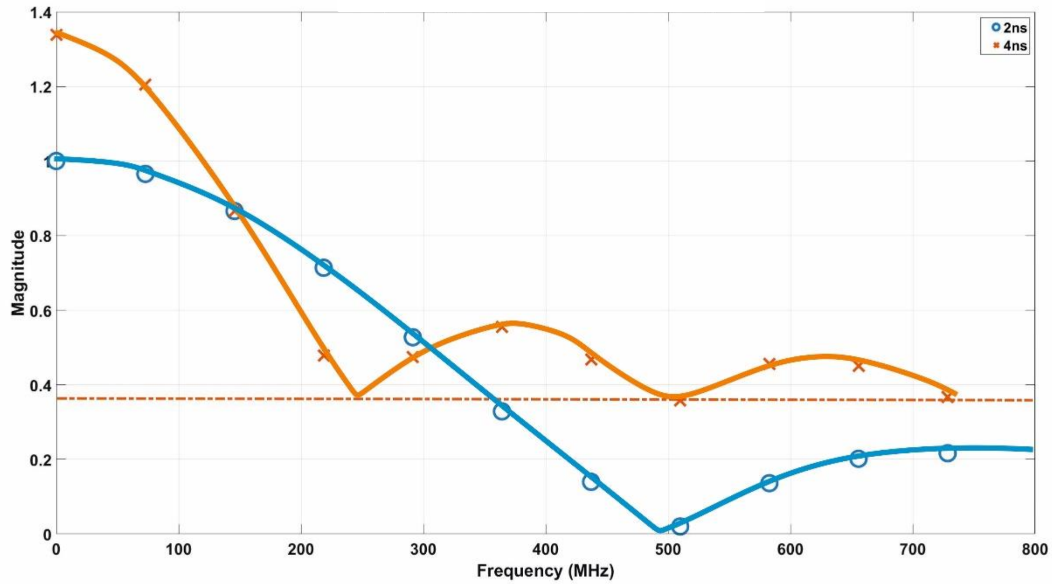
$$I_{ResDDC} = \sqrt{I_{ResNoise}^2 + k^2 I_{MMAC5}^2}$$

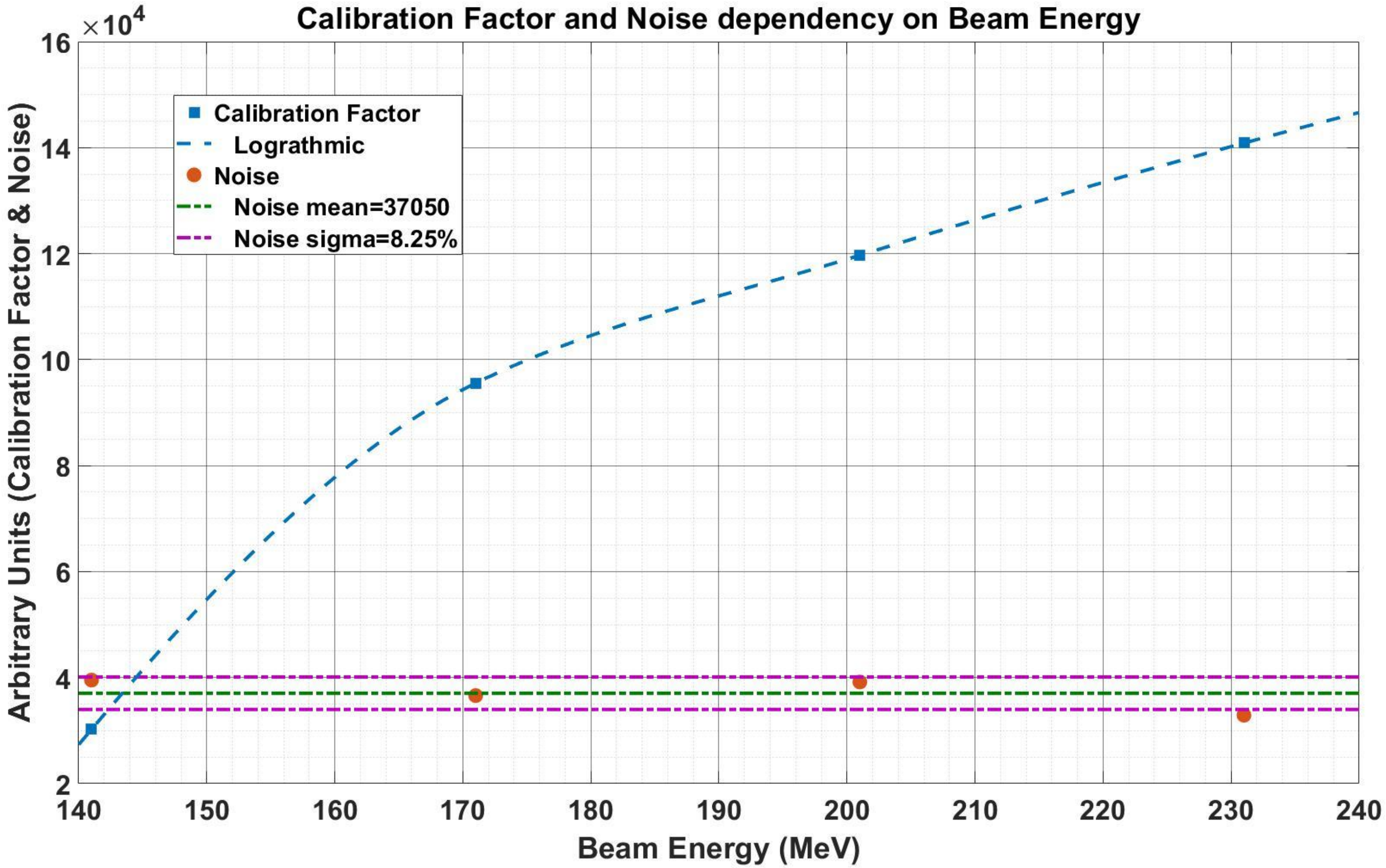
Uncertainty in noise arises from uncertainty of MMAC5 (15-20% measurement uncertainty)



$$X_n = \frac{A\Delta}{T}\mathrm{sinc}(n\Delta / T)$$

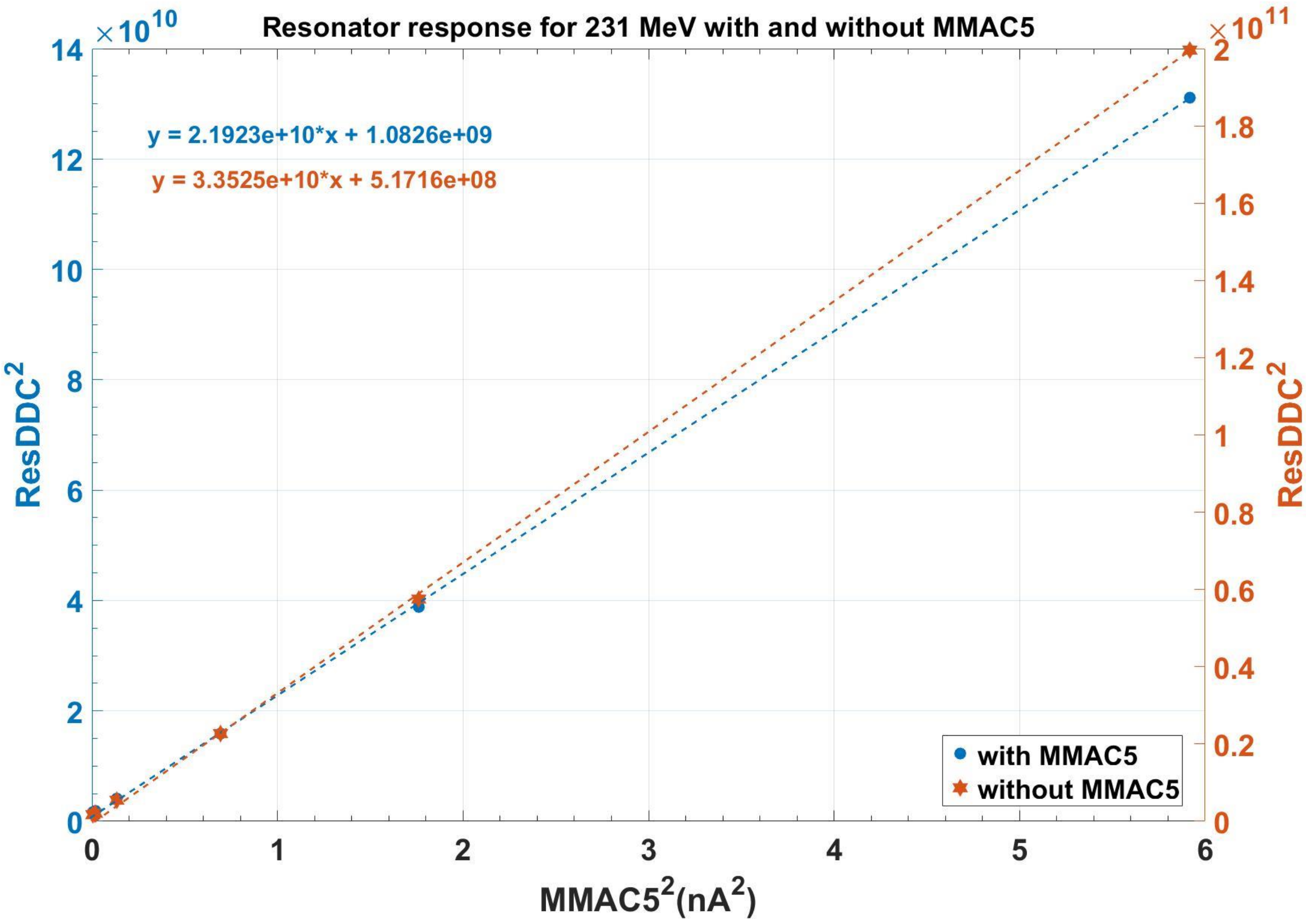
For lower beam energies, energy spread is higher beyond degrader. Hence, pulse length increases thus decreasing the 2nd harmonic component of the beam current.



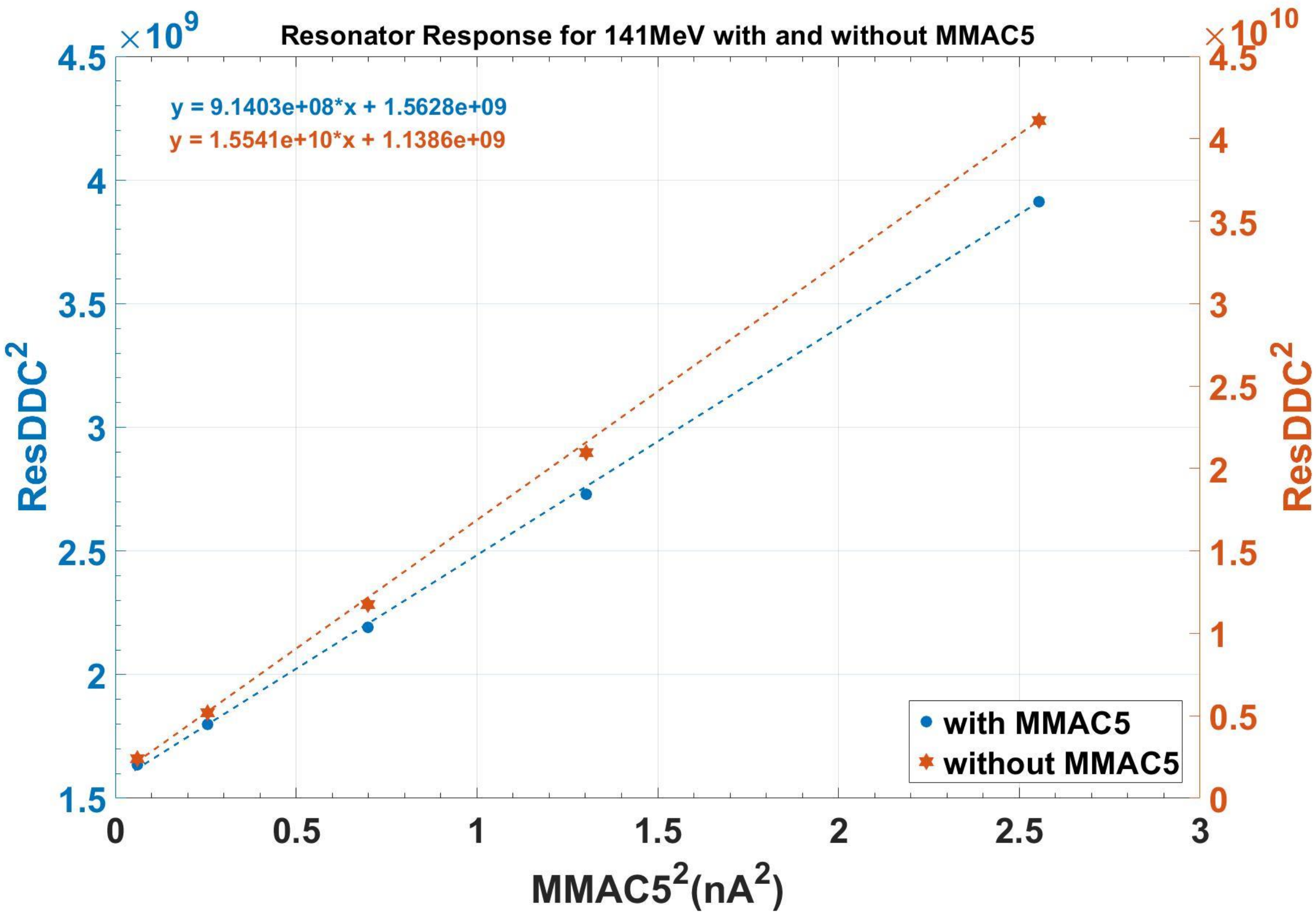


Calibration Factor and Noise dependency on Beam Energy
×10^4
16
14
12
10
8
6
4
2
Arbitrary Units (Calibration Factor & Noise)
Calibration Factor
Lograthmic
Noise
Noise mean=37050
Noise sigma=8.25%
140
150
160
170
180
190
200
210
220
230
240
Beam Energy (MeV)

Influence of MMAC5

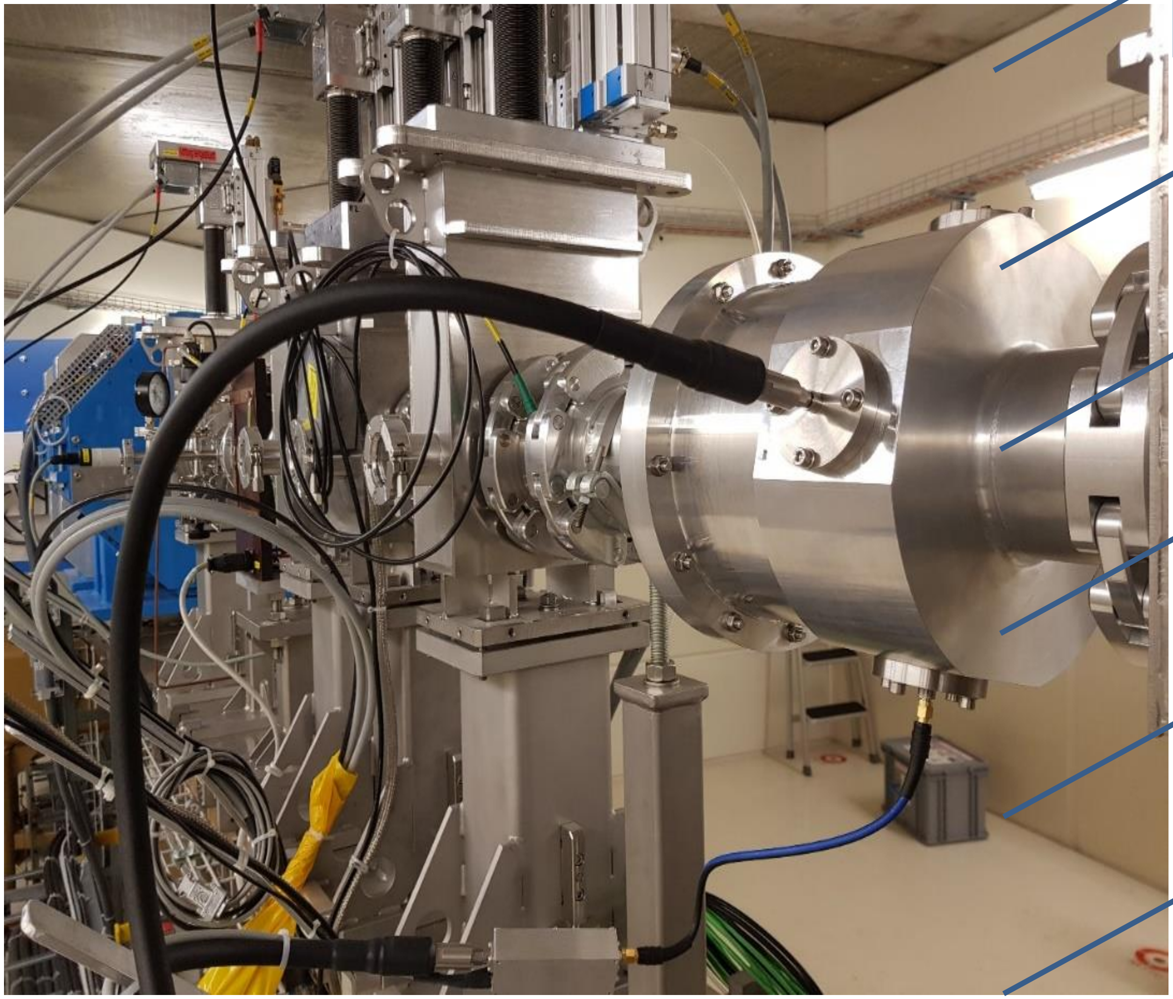


Influence of MMAC5



- For higher beam energy (200-230MeV), the influence of IC is minor
- As for lower beam energies, IC influence is detrimental affecting signal sensitivity
- IC has a huge measurement uncertainty (15-20%)
- Beam measurements without IC in beamline recommended

Summary



TM010 resonance

Energy spread affects signal level

60pA at 230MeV; 500pA at 140MeV

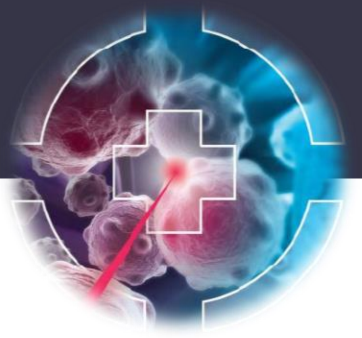
Few 100ms integration time

No activation unlike in IC

NO IC in Beamline

References

1. G.Kube, CAS on Beam Diagnostics, ``Specific diagnostic needs for different machines``, 2008.
2. J.C. Denard, CAS on Beam Diagnostics, ``Beam Current Monitors``, 2008
3. P.Forck, P.Kowina; D. Liakin, CAS on Beam Diagnostics, ``Beam Position Monitors``, 2008
4. Q. Luo; B.G. Sun; Z.R. Zhou; Q.K. Jia, ``Design and Cold test of Reentrant Cavity for HIs``, Proceedings of PAC2011



Thank You

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Questions???

Potential Benefits

TM110