

# Comparison of Different Bunch Charge Monitors used at the ARES Accelerator at DESY

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Saskatoon, 12<sup>th</sup> September 2023



HELMHOLTZ

12<sup>th</sup> INTERNATIONAL BEAM  
INSTRUMENTATION CONFERENCE

SASKATOON, CANADA  
September 10-14, 2023



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- Calibration

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- Mechanics and Electronics
- Calibration

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## 07 Summary

# 00 Motivation

# Motivation

- The ARES eFLASH (medical) experiment needs an **absolute**, non-destructive charge measurement
- ARES normally operates at lower charges compared to other DESY machines (30 fC - 200 pC)
- ARES is an R&D machine → install different types of charge monitors (increase dynamic range&resolution)

## Beam Charge Monitors at DESY

- Use in-house developed Charge Monitors (beginning in the 1980s)
  - i.e. E-XFEL, FLASH = 60 monitors (Toroid type)
  - Transport Lines in other machines
- No (non-destructive) absolute measurement with such a dynamic range needed so far
- Important: Transport efficiency

This talk only presents dedicated charge monitors.  
At the ARES accelerator there are also Cavity BPMs installed.

This Conference: Poster MOP019 by Bastian Lorbeer  
IBIC2022: Poster WEB14

# 01 ARES Overview



# The ARES Linac

## A dedicated accelerator R&D machine

**ARES goal:** Generate and characterize **ultrashort e- bunches (fs to sub-fs)** with **high stability** for applications related to **accelerator R&D** (advanced & compact longitudinal diagnostics and accelerating structures development, test of new accelerator components, machine learning, etc.), **medical applications studies** and beam time for **external R&D users**.

Parameter	Status
Charge	0.01 - 250 pC
Momentum	20 - 160 MeV/c
Bunch Length	≈ 20 fs (res. limited)
Rep Rate (Single Bunch)	10 Hz

Contact: [florian.burkart@desy.de](mailto:florian.burkart@desy.de)

<https://ares.desy.de/>

Courtesy: Willi Kuroпка

Experimental Areas 2&3

T-ICT (in vacuum)  
ICT (in air)

Toroid

X-Band PolariX TDS (2 Cavities)  
(not operational yet)

Bunch Compressor  
(not operational yet)

DaMon, Toroid

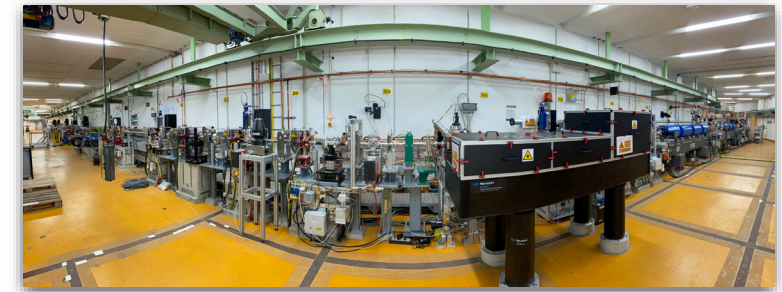
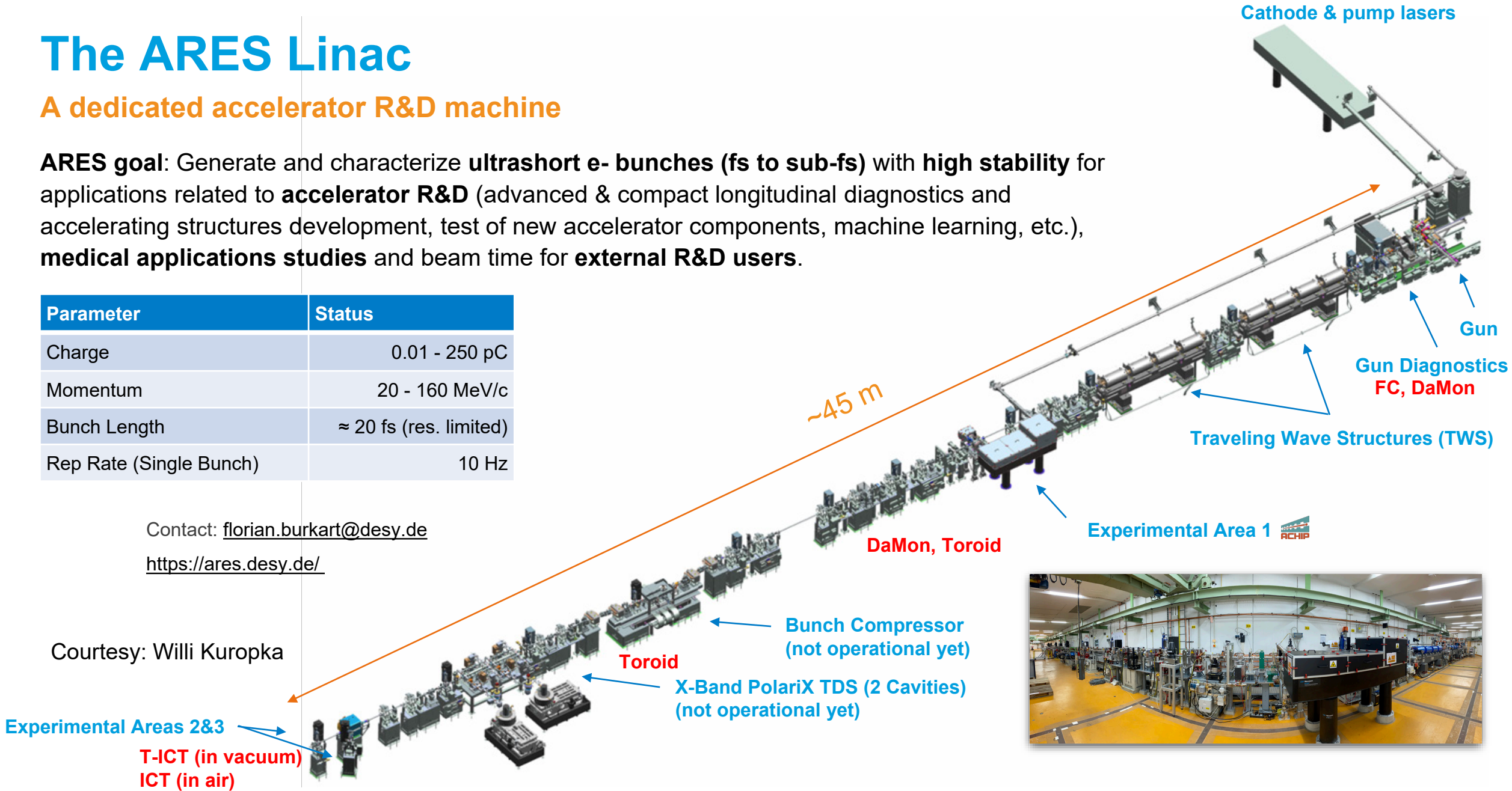
Experimental Area 1 

Traveling Wave Structures (TWS)

Gun Diagnostics  
FC, DaMon

Gun

Cathode & pump lasers

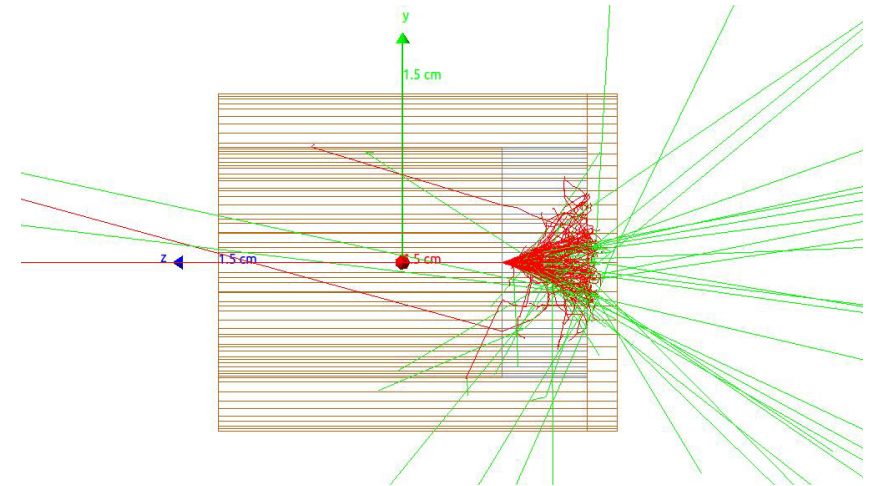
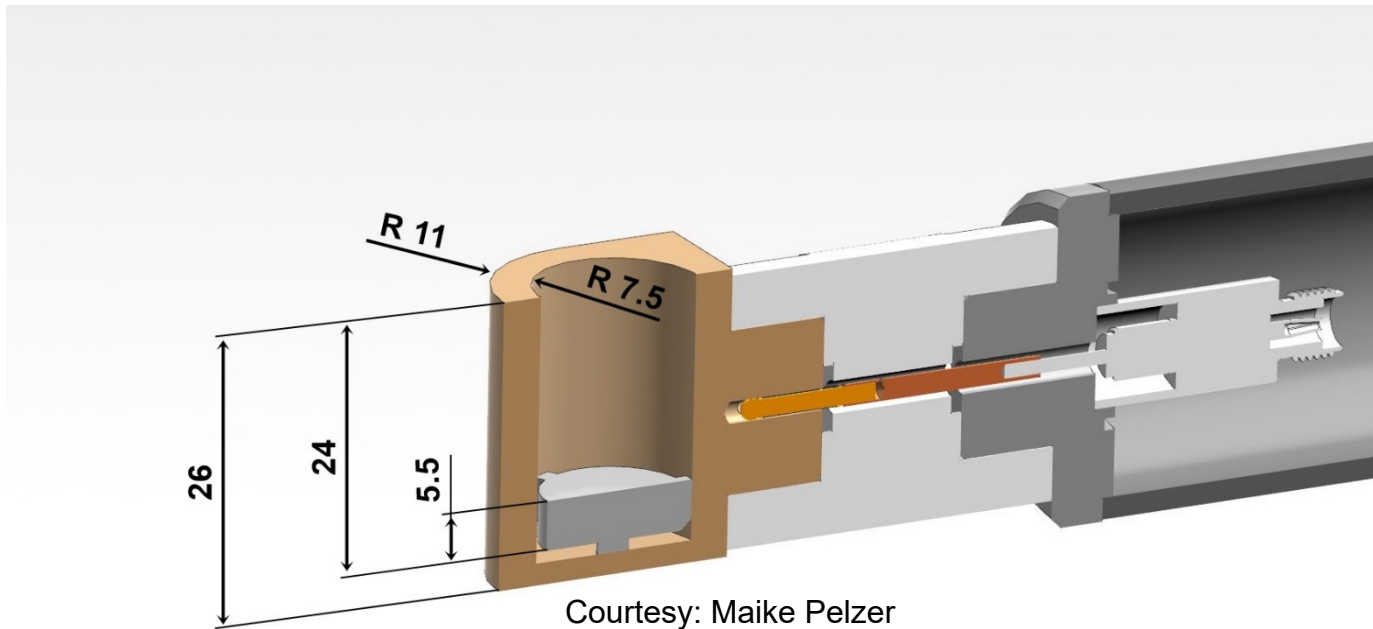


# 02 Faraday Cup (FC)

# Faraday Cup

## Simulation of new design for ARES

- Improvement of efficiency
- Optimized design with Cu cup + Al Inlay, 15 mm diameter, 24 mm depth simulated
- Found 0.6% of primary and secondary electrons escaping from the Faraday Cup at 5MeV
- Also different beam configurations and angles show very good results of <1% loss



Green=Gammas, Red = Electrons

Courtesy: Sergey Stokov, Gero Kube

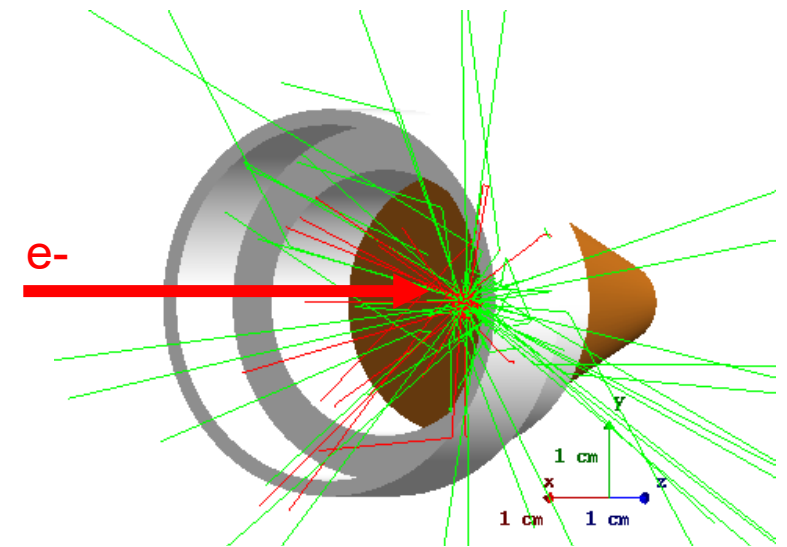
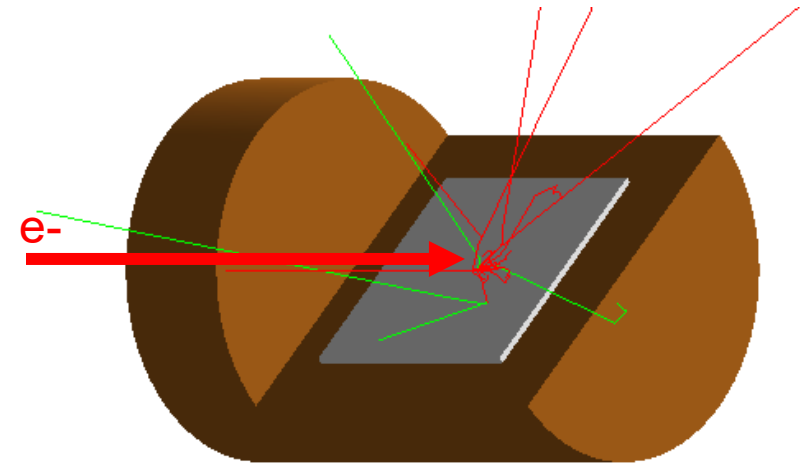


# Faraday Cup

## Simulations of former designs used at DESY

If you have other geometries...

- existing Faraday Cup variants at DESY
- Simulated for 5 MeV beam (ARES)
- Variants of materials (Copper - Aluminum combinations)
- Different geometries and angles of electron beam
- Between 4 - 22% of primary and secondary electrons escape from the Faraday Cup
- → **not sufficient for ARES**



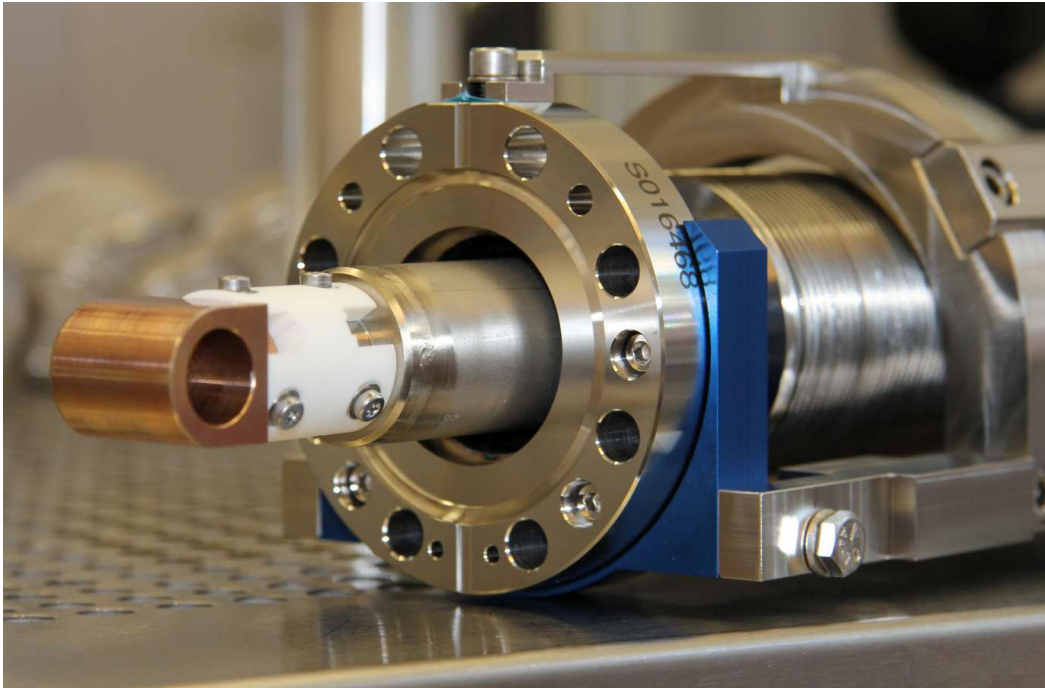
electrons  
gammas

Courtesy: Sergey Stokov, Gero Kube

# Faraday Cup

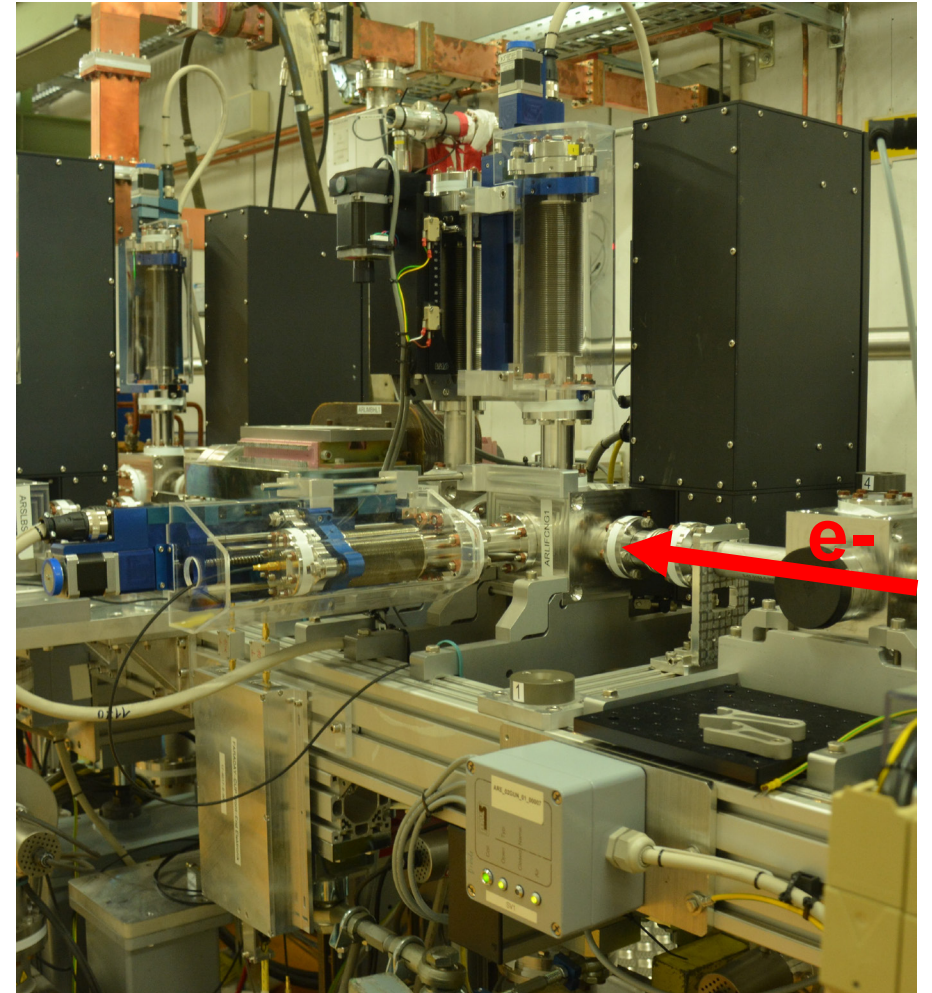
## Final design

- Faraday Cup mounted on a Mover
- Without cooling due to low repetition rate (10 Hz)
- Screen at same position to check beam size + position



Courtesy: Maike Pelzer (FC), Christian Wiebers (Mover), Juergen Kruse (Support)

Tunnel installation with Faraday Cup horizontal,  
Screen vertical



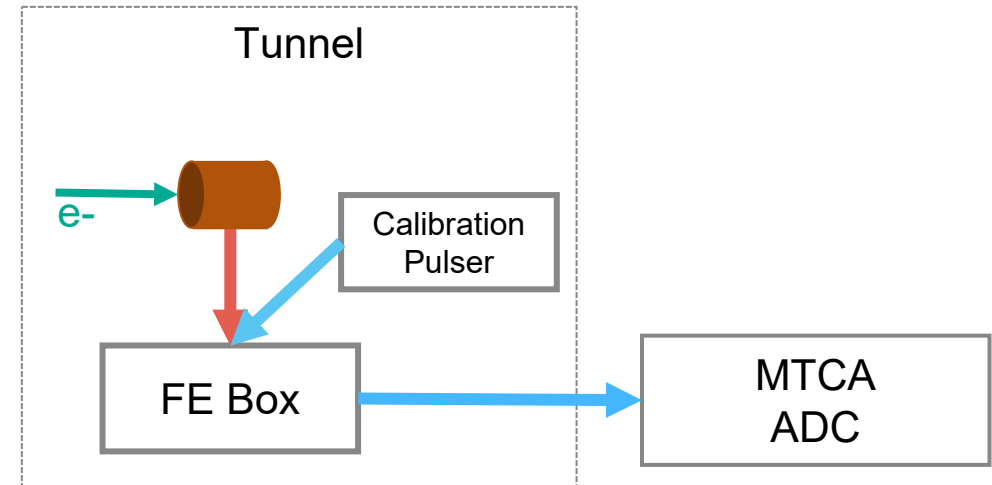
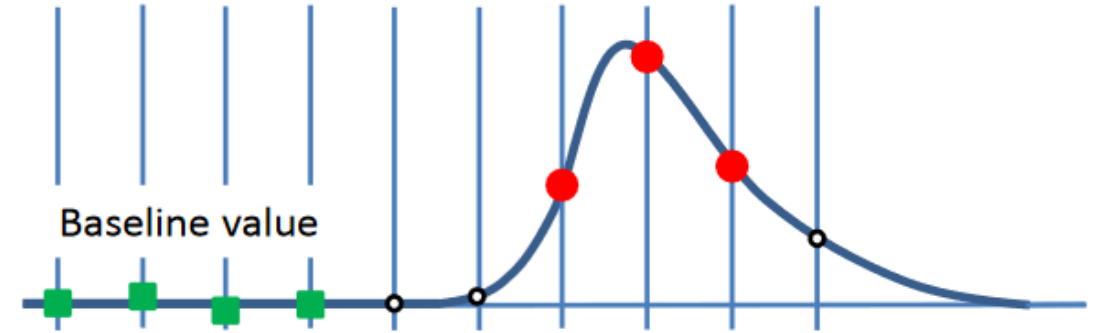
# Faraday Cup

## Electronics and Calibration

- FC signal connected to front end with 15 MHz low pass filter and pre amp (tunnel)
- Read out with MTCA system (outside tunnel)
  - Struck ADC SIS8300-L2D, 16 bit, 125 MS/s
  - *Pulse-form-fit with 3-point sampling*

## Calibration

- Send electrical pulse to the FE electronic
- Corresponds to 1nC pulse
- Scaling the read out



# 03 Beam Charge Transformer (Toroid)

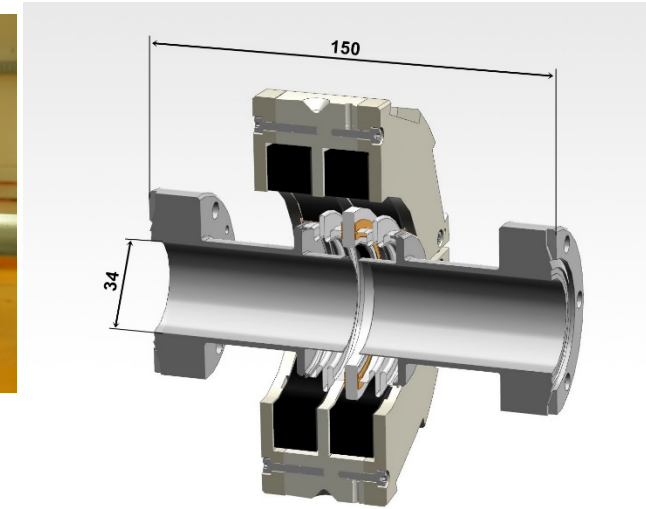
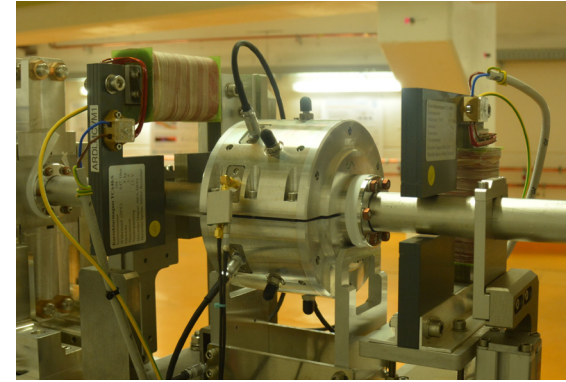
# Toroid

## Optimization of existing Beam Charge Transformers

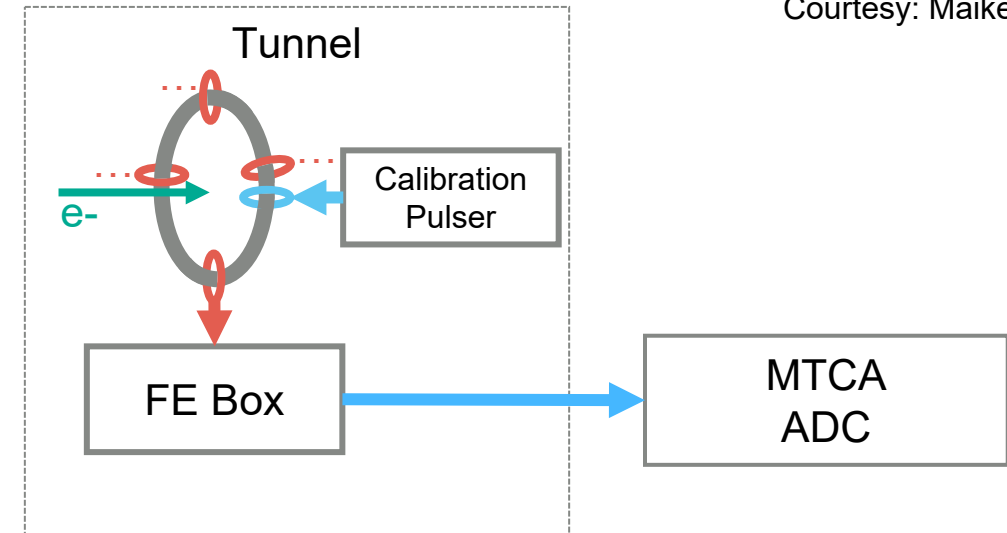
- E-XFEL and FLASH design (4.5 MHz bunch frequency)
- Ceramic gap with one or dual core, easy half-shell installation (i.e. service w/o opening vacuum)
- Four separate coils, one winding each, concatenated outside (red)
- Front end box with 15 MHz low pass filter and pre amp (tunnel)
- Read out with MTCA system (outside tunnel)
  - Struck ADC SIS8300-L2D, 16 bit, 125 MS/s
  - *Pulse-form-fit with 3-point sampling* (like at FC)

## Calibration

- Send electrical pulse to calibration winding (blue)
- Corresponds to 1nC pulse
- Scaling the read out



Courtesy: Maïke Pelzer



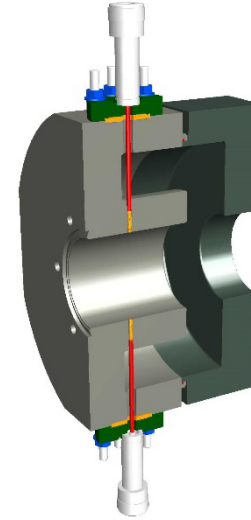


# 04 Dark Current Monitor (DaMon)

# Dark Current Monitor (DaMon)

Invented to measure dark current of accelerators with 1.3 GHz acceleration frequency

- Consists of stainless steel resonator  $TM_{010}$  mode at 1.3 GHz, loaded quality factor about 200, results in bandwidth of about 6 MHz and decay time 50 ns
- RF Front End Electronic (RFFE) with two channels:
  - dark current (DC) with local oscillator, down conversion and logarithmic detector
  - Charge (Q) with logarithmic detector
- Send to MTCA system with 16 bit ADC (Struck 8300-L2D)



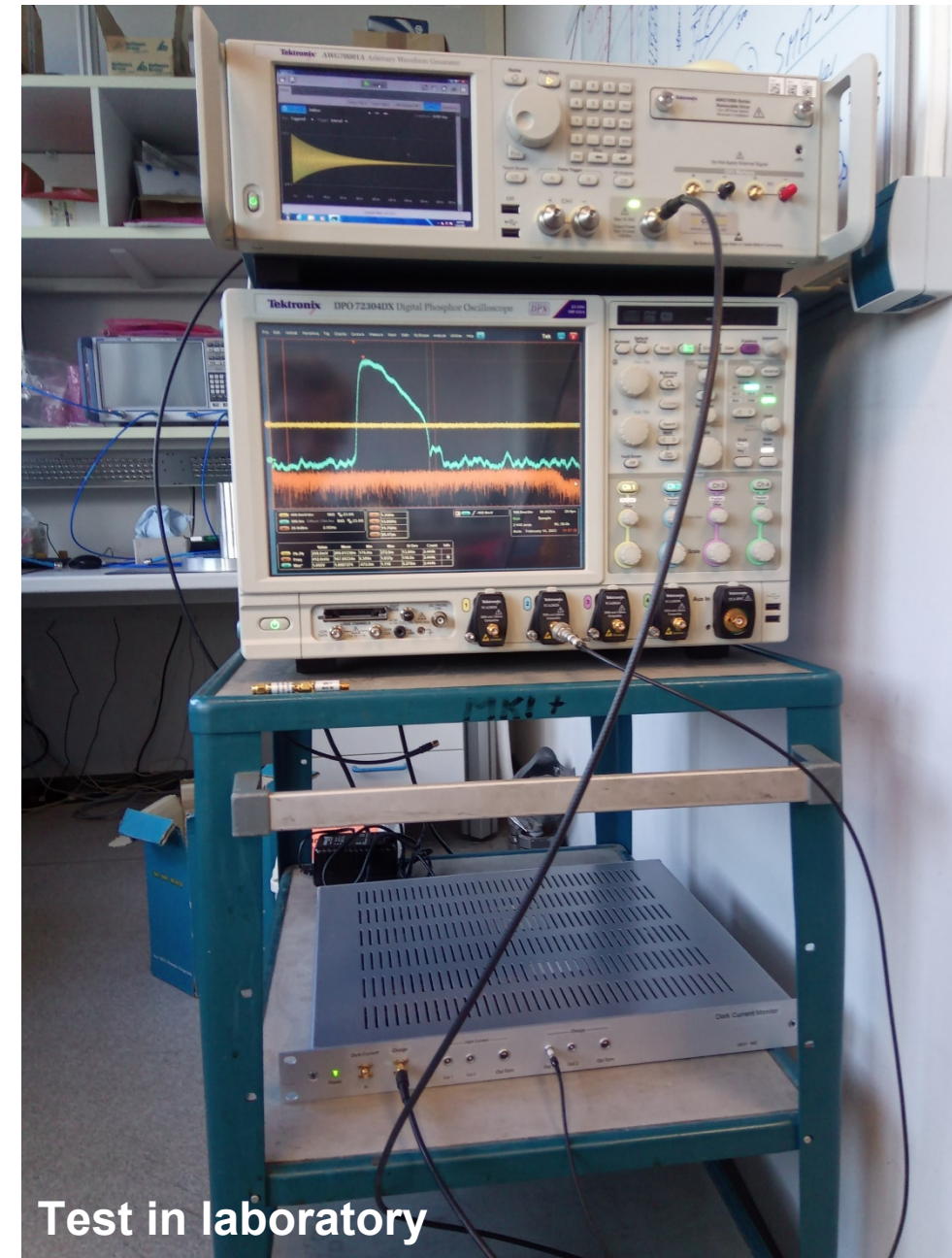
Refs: Lipka et al. DIPAC 2011 WEOC03 and IBIC 2013 WEPF25

# Dark Current Monitor (DaMon)

## Calibration

- For 3 GHz accelerator (ARES) both channels (DC and Q) are used for charge measurement: increase dynamic range
- Arbitrary Waveform generator (AWG) in laboratory simulates output of DaMon
- AWG as input for the RFFE at largest possible amplitude range
- Output of RFFE connected to ADC and monitors amplitude
- Results in an electronics response function look-up table
- Together with measured properties of each individual resonator (frequency, quality factors) and cable attenuation results in look-up table for each channel

Poster TUP037 by Dirk Lipka this afternoon



Test in laboratory



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Poster TUP037 by Dirk Lipka this afternoon



# 05 Turbo-ICT (Bergoz)

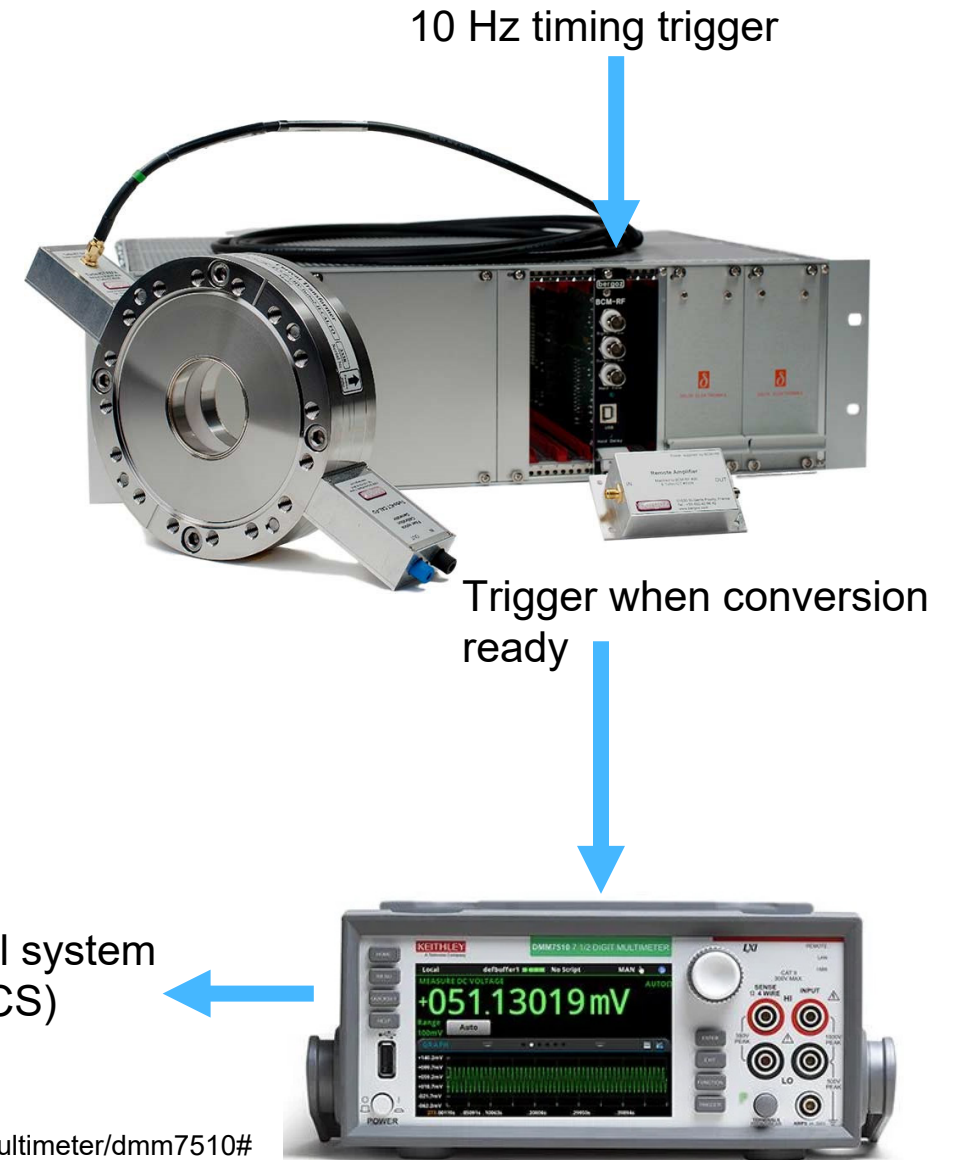


# Bergoz Turbo-ICT

## Integrating Current Transformer + Front end Filter (Bergoz)

### Turbo-ICT in vacuum

- BERGOZ Turbo-ICT and BCM-RF-E (outside tunnel, ~30m cable)
  - Use in Sample & Hold Mode
  - Range: 50 fC ... 300 pC
  - Noise: 10 fC rms or 1% of charge (whichever is higher)
- Connected to a KEITHLEY High Resolution DVM (DMM7510)
  - Resolution 1  $\mu$ V (at range 10 V)
  - Ethernet for control system read out
- Triggering
  - 10 Hz trigger from timing system
- Apply Look-up-Table in Software with data from Bergoz' calibration



<https://www.bergoz.com/products/turbo-ict/>  
<https://www.tek.com/de/products/keithley/digital-multimeter/dmm7510#>

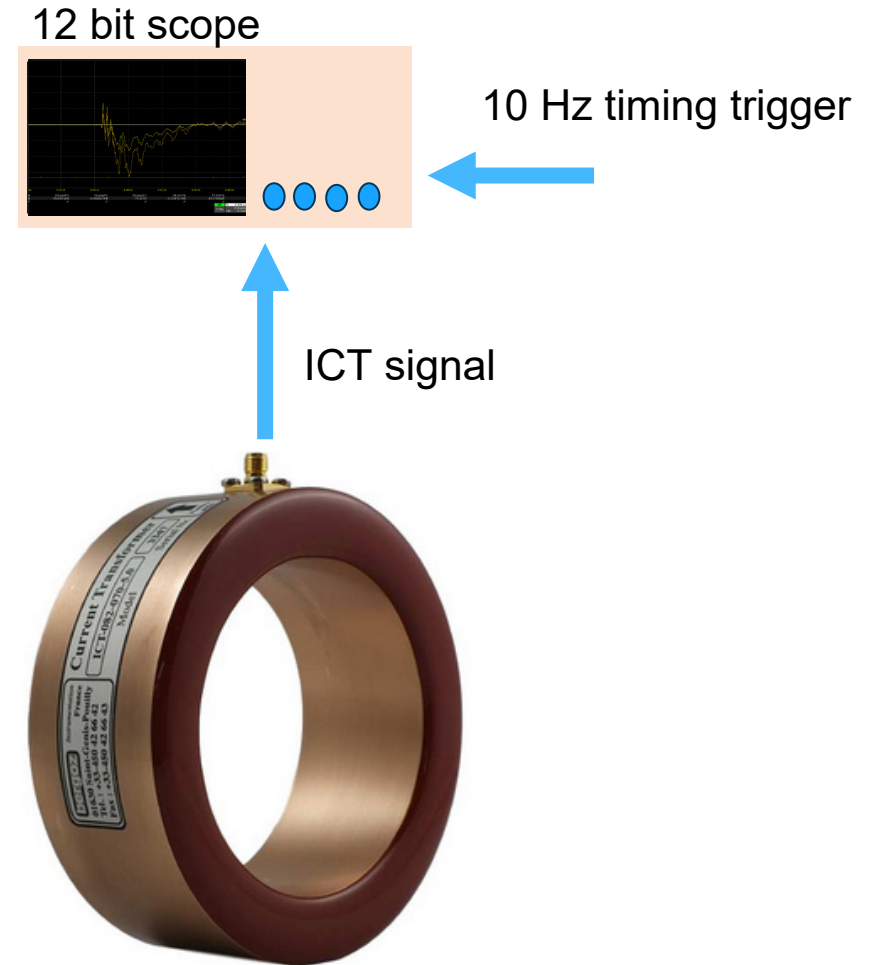
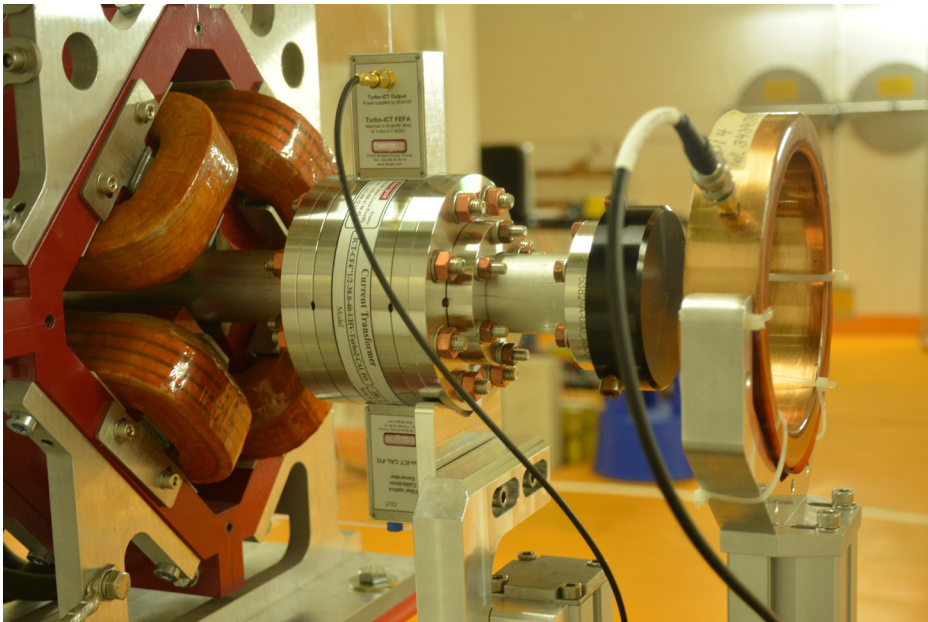
# 05 ICT (Bergoz)

# Bergoz ICT in air

## Improvised installation for testing purposes

### In-air ICT

- Placed after a window outside the end of beam pipe (~30 cm after T-ICT)
- Read-out, integration and scaling with 12 bit scope
- Can easily be moved to other DESY machines



<https://www.bergoz.com/products/ict/>

# 06 Measurements

# What has been measured?

- ARES at 10 Hz rep rate
- Charge Sweep from 0.1 – 153 pC
- ~100% Beam Transport (w/o Bunch Compressor and X-Band TDS)
- 500 values per charge from each monitor saved synchronously
  
- Output will be plots of ...
  - Linearity of each monitor compared to Faraday Cup (w/o uncompensated losses [0.6% simulation])
  - Resolution of each monitor

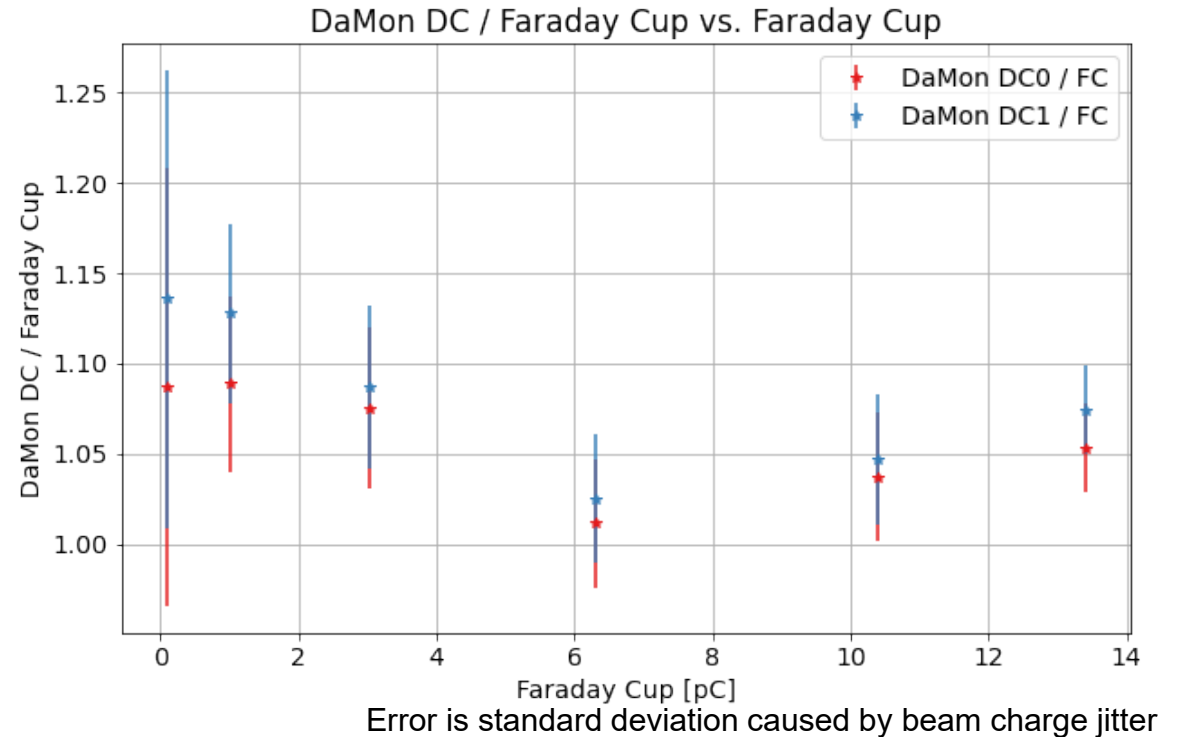
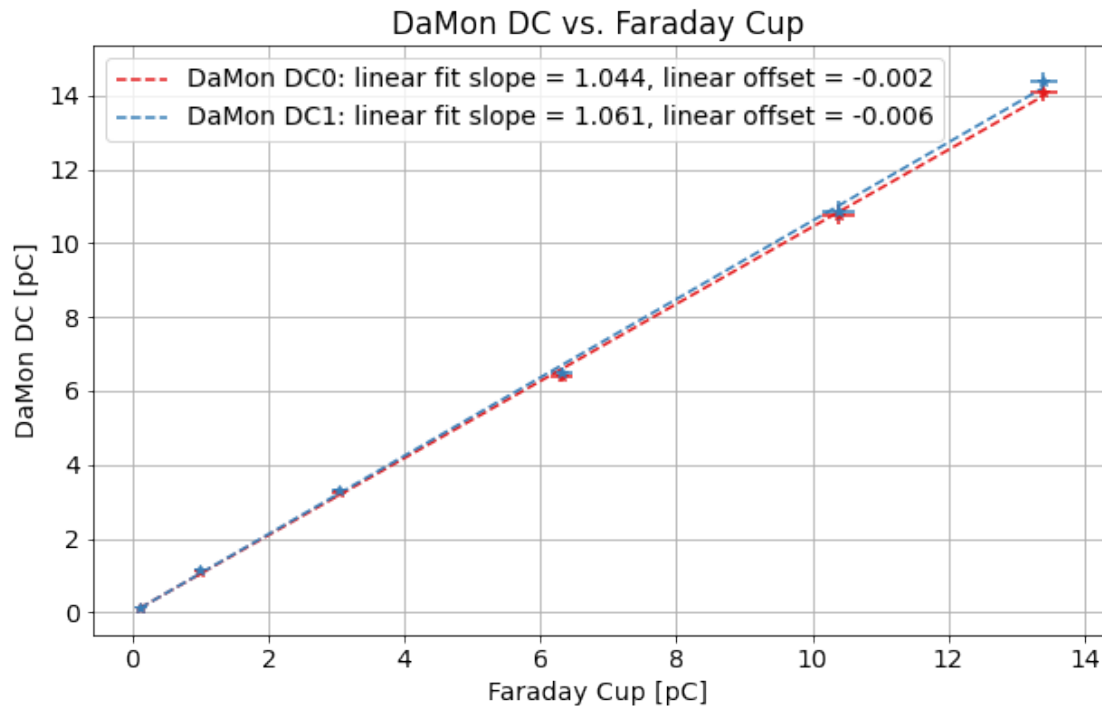


# DaMon DC vs. Faraday Cup

Range 0.1 – 13 pC

	DaMon DC0	DaMon DC1
Linear fit slope	1.04	1.06
Linear fit offset	-0.002 pC	-0.006 pC

- Calibrated in the lab, not beam based
- Measure  $\sim <20$  pC only
- Error is standard deviation caused by beam charge jitter (relative plot)

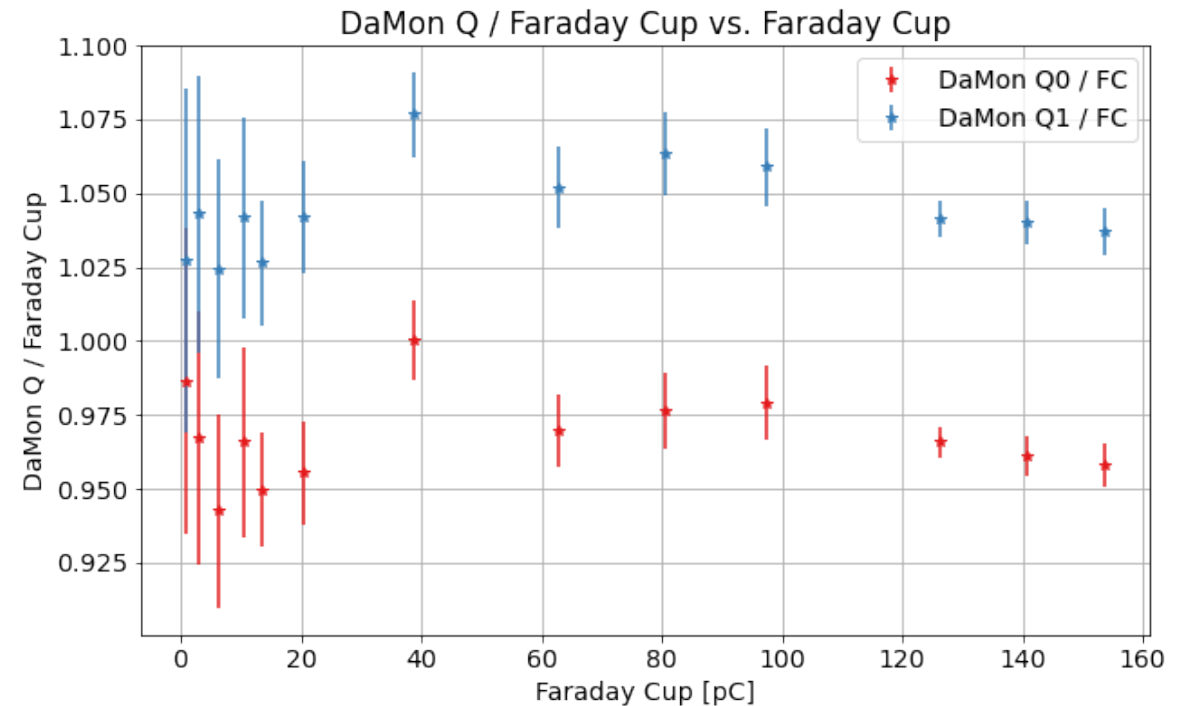
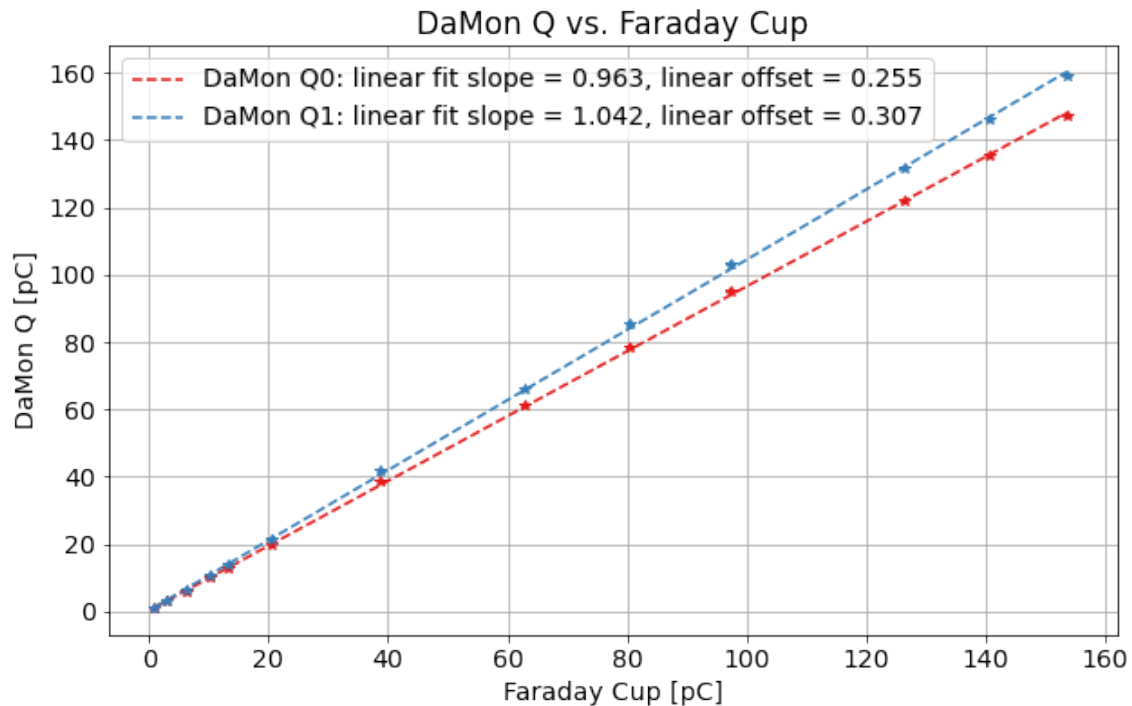


# DaMon Q vs. Faraday Cup

Range 1 – 153 pC

	DaMon Q0	DaMon Q1
Linear fit slope	0.96	1.04
Linear fit offset	0.26 pC	0.31 pC

- Calibrated in the lab, not beam based



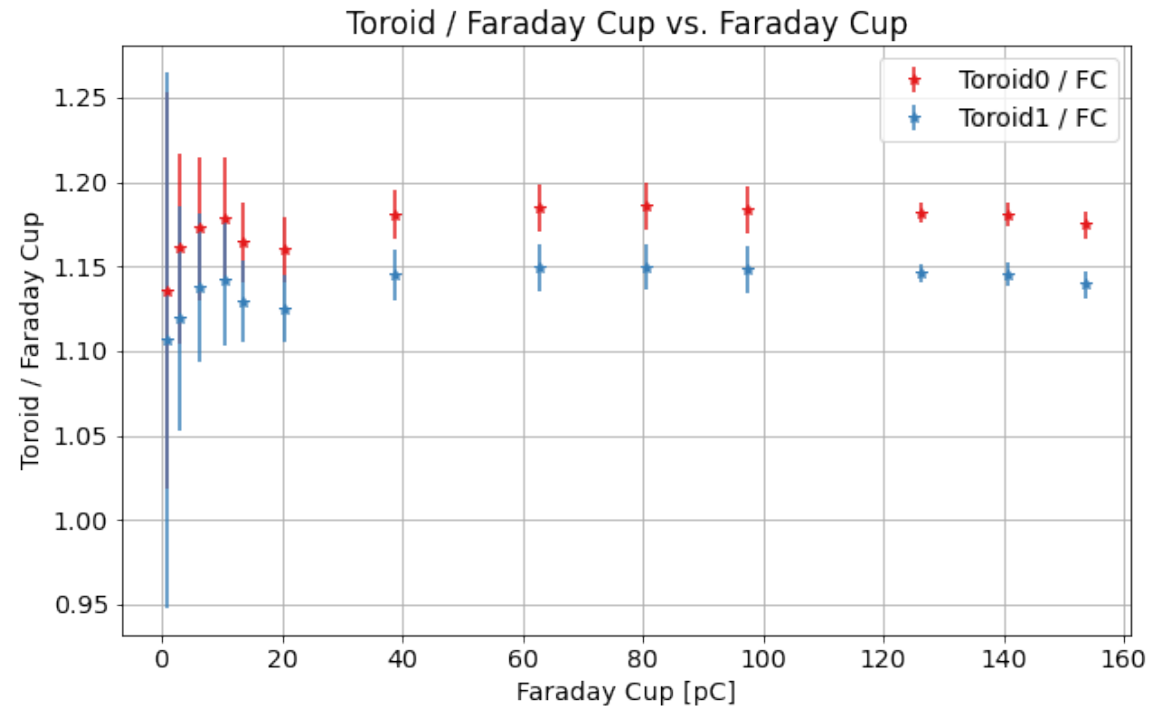
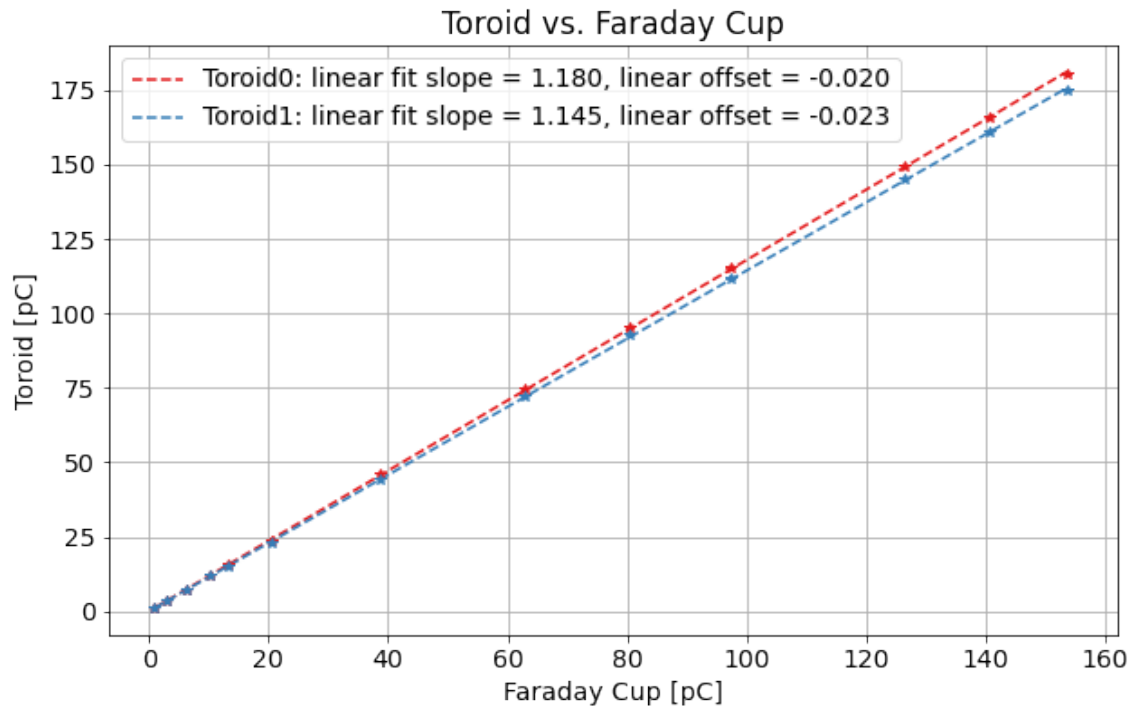
Error is standard deviation caused by beam charge jitter

# Toroid vs. Faraday Cup

Range 1 – 153 pC

	Toroid0	Toroid1
Linear fit slope	1.18	1.15
Linear fit offset	-0.02 pC	-0.02 pC

- Calibrated with 1nC pulse
- Calibration scheme seems to be not matched as expected  
→ under investigation
- ... but linear



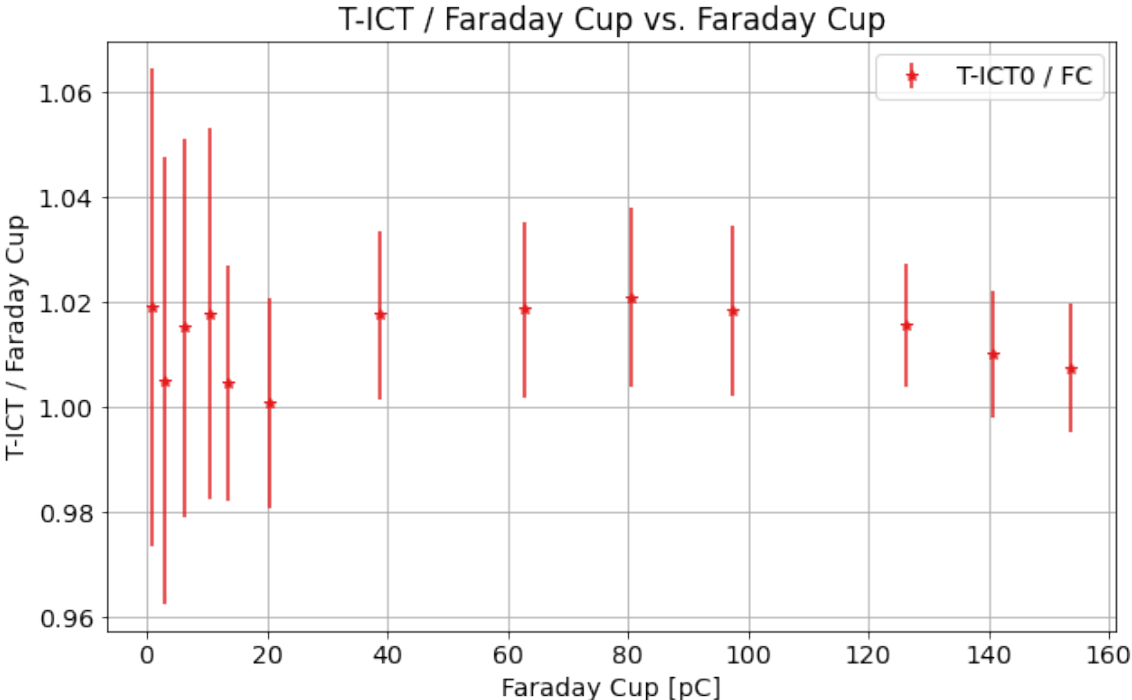
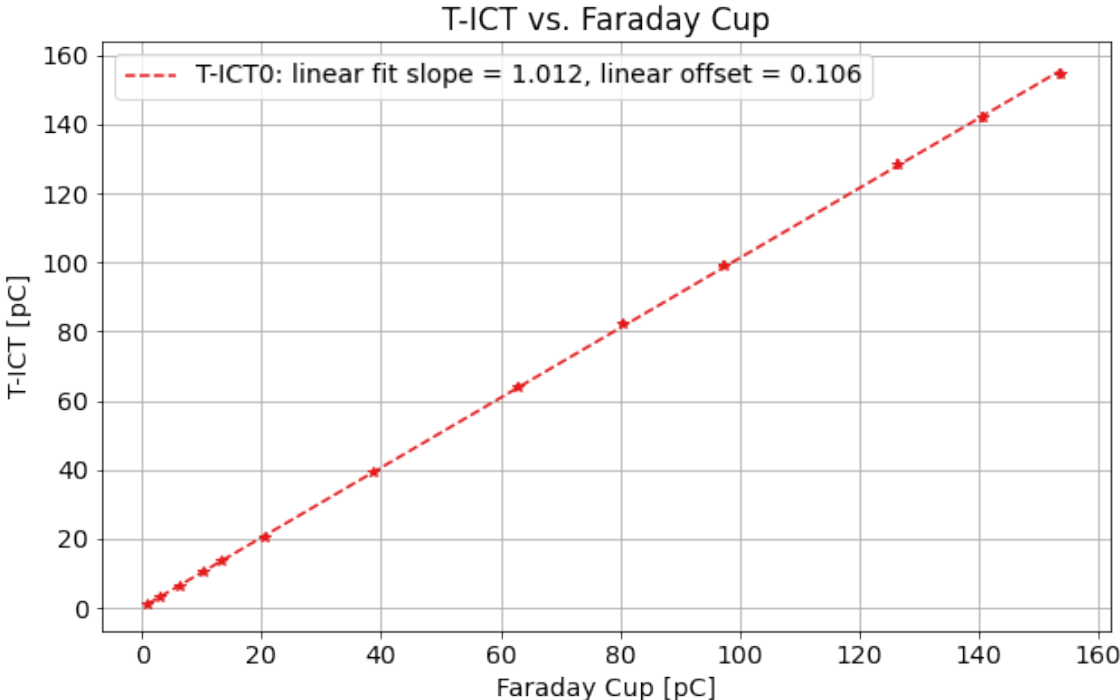
Error is standard deviation caused by beam charge jitter

# Bergoz Turbo ICT vs. Faraday Cup

Range 1 – 153 pC

	T-ICT
Linear fit slope	1.012
Linear fit offset	0.11 pC

- Calibrated at Bergoz
- Implemented look up table



Error is standard deviation caused by beam charge jitter

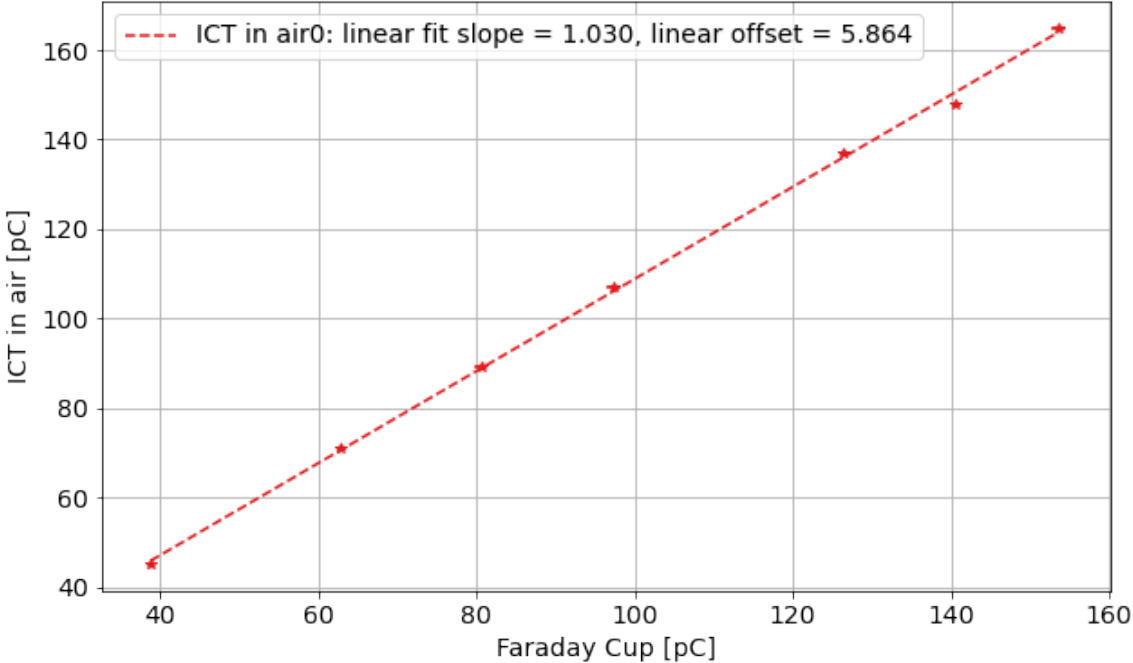
# Bergoz ICT in Air vs. Faraday Cup

Range 30 – 153 pC

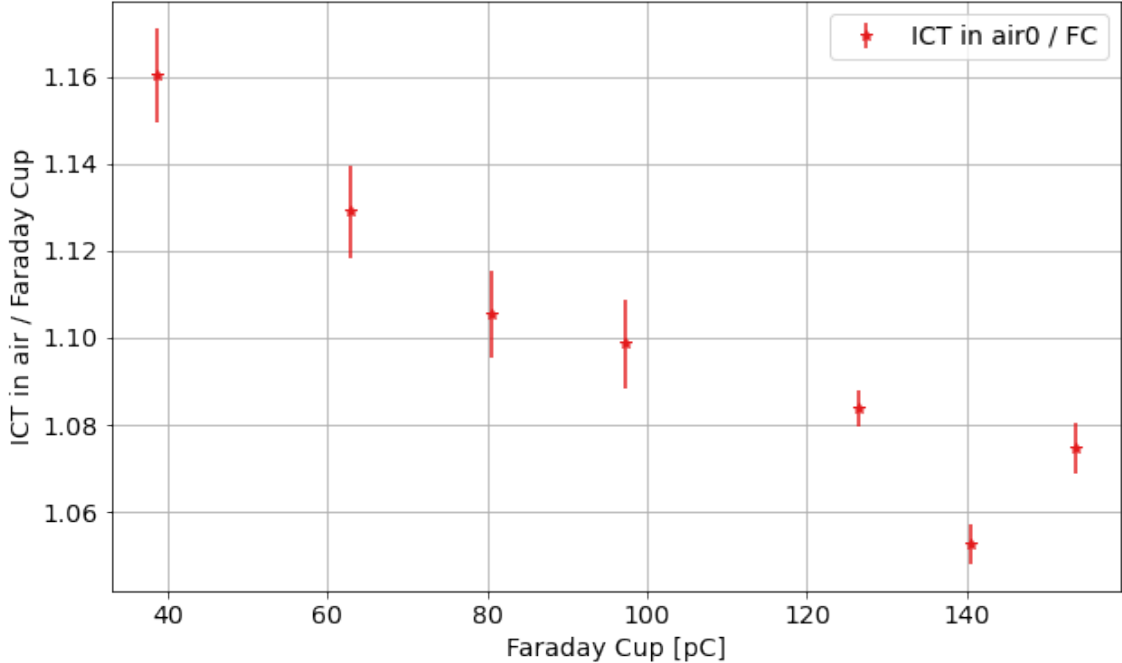
	ICT
Linear fit slope	1.03
Linear fit offset	5.9 pC

- Calibrated at Bergoz
- Read out with 12 bit scope
- Values <30 pC not measurable in the current scheme (cable ...)
- not fully trustworthy due to improvised read out → Ongoing work

ICT in air vs. Faraday Cup



ICT in air / Faraday Cup vs. Faraday Cup



Error is standard deviation caused by beam charge jitter



# Resolution Measurement

## Use standard deviation (rms) to calculate resolution

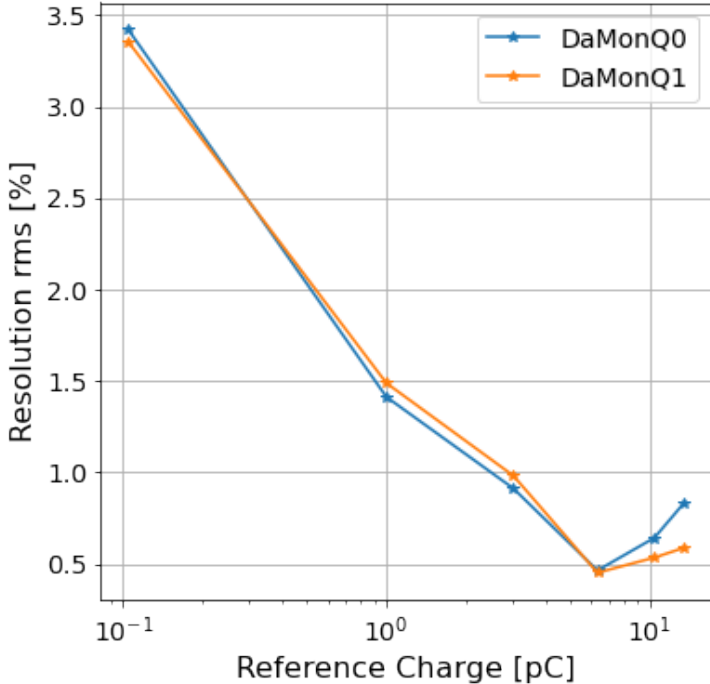
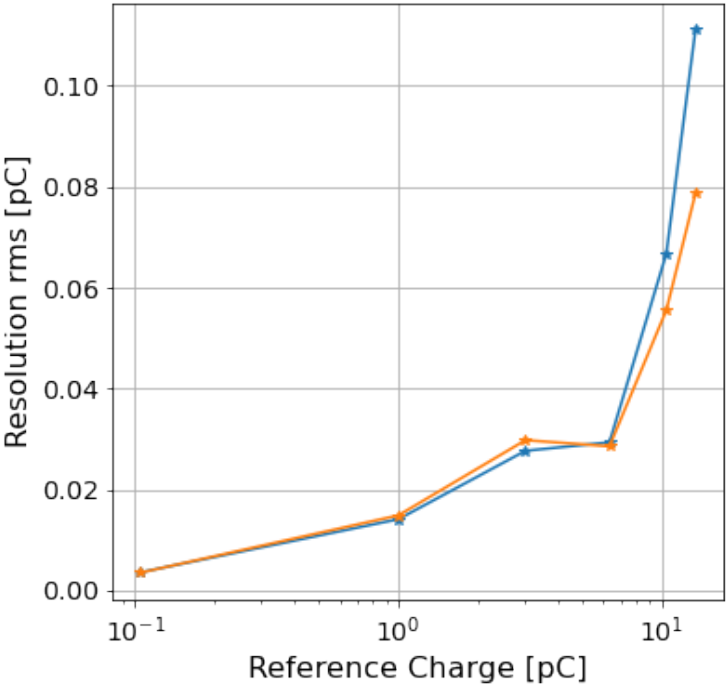
- Take all non-destructive charge monitors synchronously per charge step as reference value
- Compare monitor under test to the reference value
- Independent from machine optics
  
- We included Cavity BPM charge channel data to enhance the reference value
  
- Details of this procedure:
  - „Resolution Studies at Beam Position Monitors at the FLASH Facility at DESY“, N.Baboi, BIW2006

# Resolution of DaMon DC Channel

Charge range from 0.1 – 13 pC

100 fC – 13 pC	DaMonDC0	DaMonDC1
Resolution [fC]	4 – 111	4 – 90
Resolution [%]	3.4 – 0.83	3.36 – 0.59

- DaMon DC Channels limited to <20 pC
- Very good at <10 pC

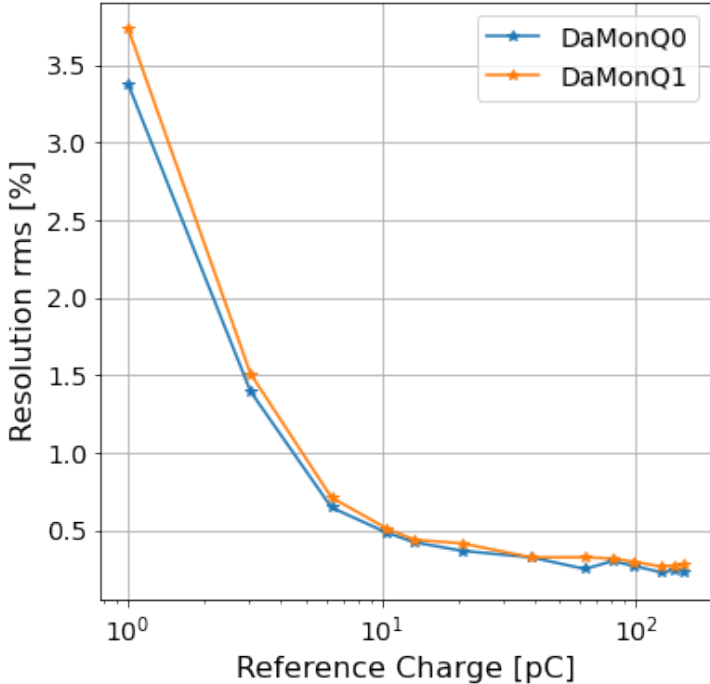
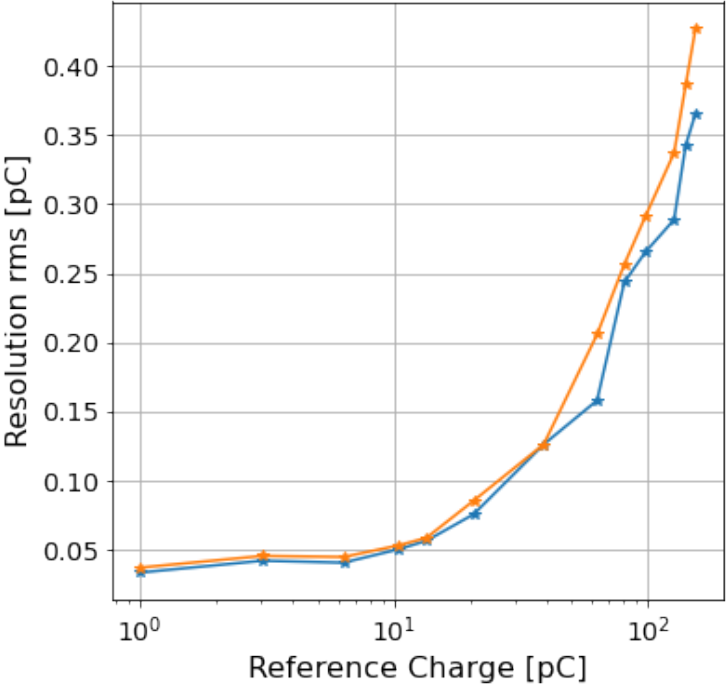


# Resolution of DaMon Q Channel

Charge range from 1 – 153 pC

1 pC – 153 pC	DaMonQ0	DaMonQ1
Resolution [fC]	34 – 366	37 – 427
Resolution [%]	3.38 – 0.24	3.74 – 0.28

- For high charges resolution converges to <0.3%

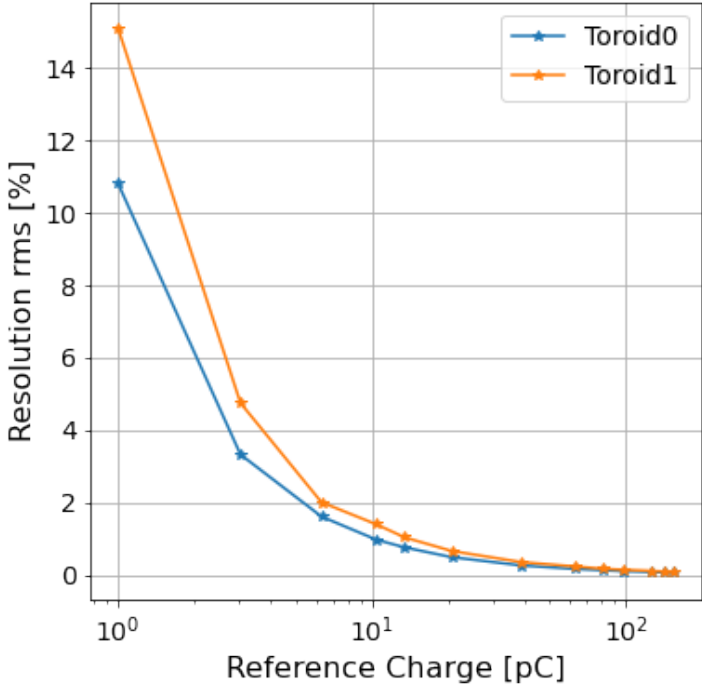
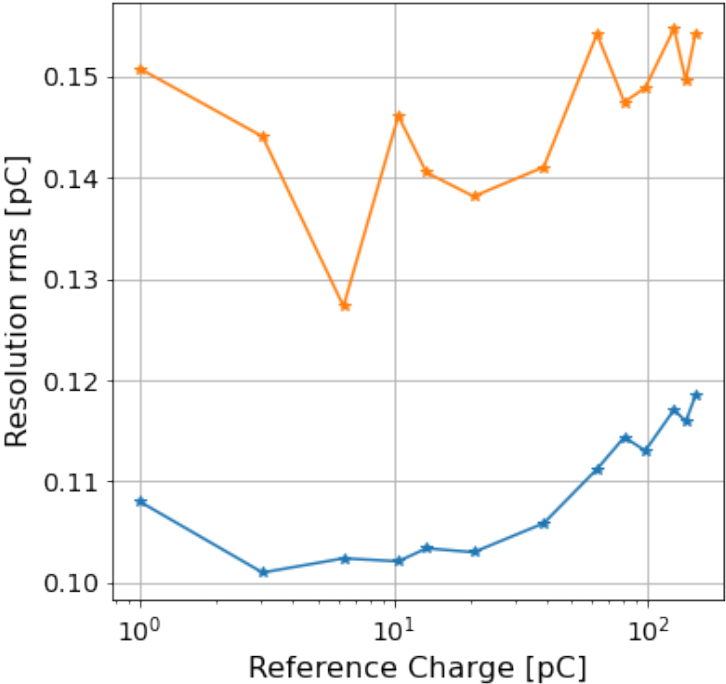


# Resolution of Toroid

Charge range from 1 – 153 pC

1 pC – 153 pC	Toroid0 (dual core)	Toroid1 (single core)
Resolution [fC]	108 – 119	151 – 154
Resolution [%]	10.8 – 0.08	15.08 – 0.1

- For high charges resolution converges to 0.1%

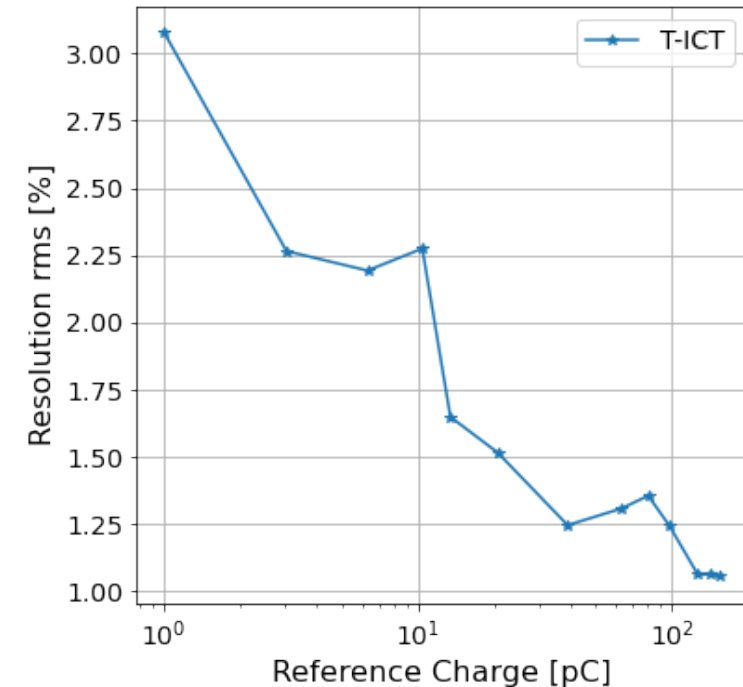
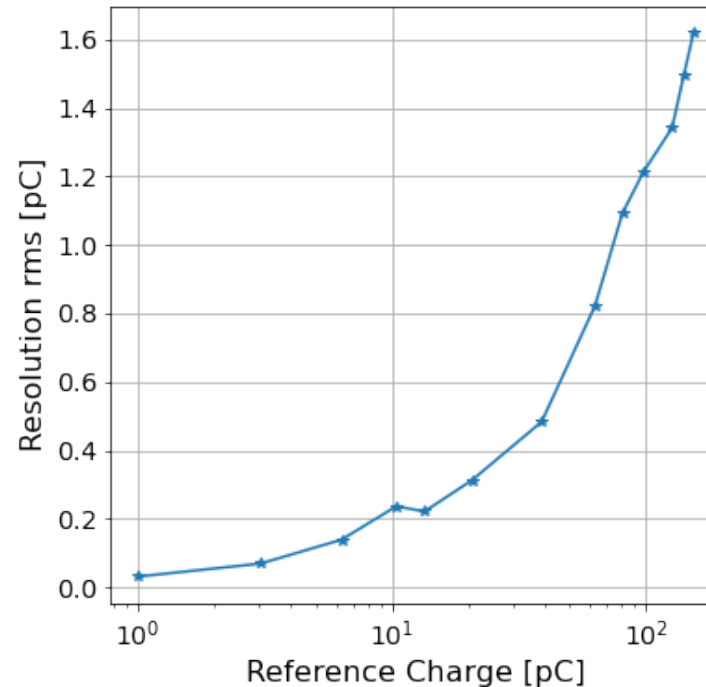


# Resolution of T-ICT

Charge range from 1 – 153 pC

- For high charges resolution converges to ~1%
- Resolution value larger due to extended cable (~30m) (expected 10 fC @5m cable)

1 pC – 153 pC	T-ICT
Resolution [fC]	31 – 1621
Resolution [%]	3.08 – 1.06

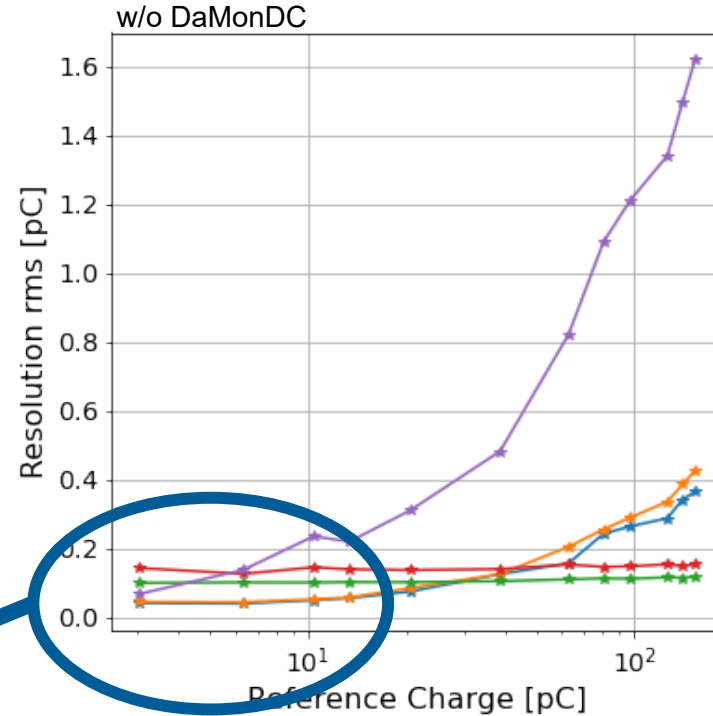
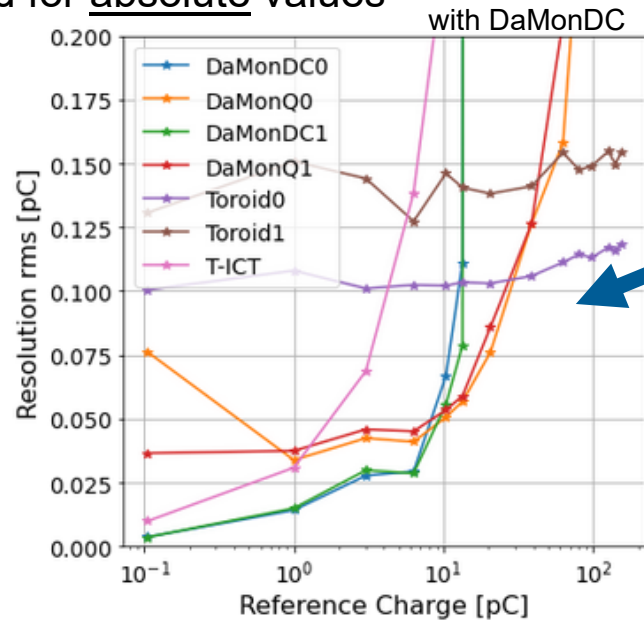




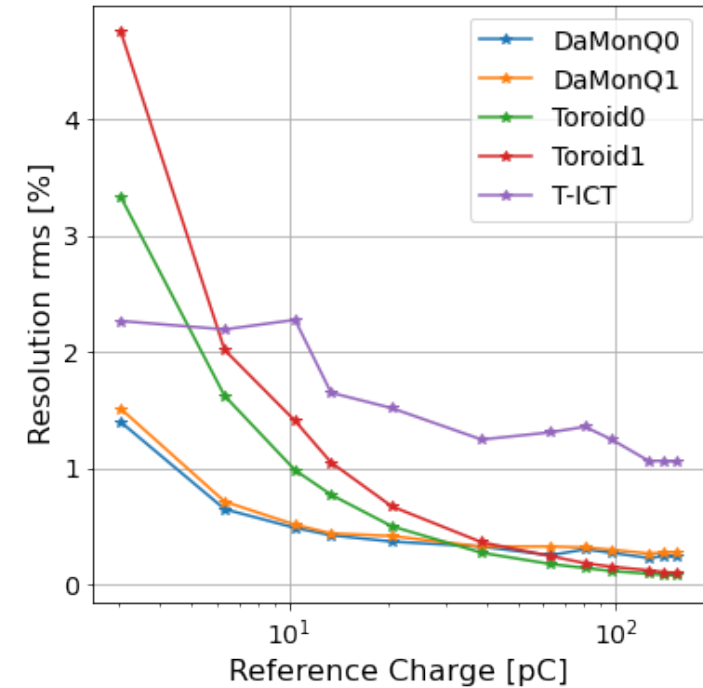
# Compare Resolution

If we want to do a ranking ...

- DaMonDC:  $\leq 6$  pC
- DaMonQ: 6 – 60 pC
- Toroids:  $>60$  pC Toroids best resolution
- T-ICT:
  - also good for  $<1$  pC
  - used for absolute values



Legend colors differs!



# 07 Summary

# Summary

## Linearities and Resolutions of all monitors @ARES

	DaMon DC	DaMon Q	Toroid	T-ICT	ICT
Measurement range [pC]	0.1 to 13	1 to 153	1 to 153	1 to 153	38 to 153
Linear fit Slope	1.04 1.06	0.96 1.04	1.18 1.15	1.01	1.03
Linear fit Offset [pC]	-0.002 -0.006	0.26 0.31	-0.02 -0.02	0.11	5.9
Resolution rel. (min/max charge)	3.4% to 0.8% 3.3% to 0.6%	3.4% to 0.2% 3.7% to 0.3%	10.8% to 0.1% (Dual core) 15.1% to 0.1% (Single core)	3.1% to 1.1%	not accessible
Use for	Resolution $\leq 6$ pC	Resolution 6 – 60 pC	Resolution $>60$ pC	Absolute measurement	<i>take-away-ref</i>

- ICT measurement not to be taken as face value yet

# Summary

- Four different types of charge monitors, 1 destructive, 4 non-destructive installed in ARES
- New simulated Faraday Cup design, catches >99% of charged particles
- DaMons show very good results compared to Faraday Cup
- Toroids show 15-18% linear slope deviation, but linear with good resolution at higher charges
- T-ICT also shows very good agreement with Faraday Cup → absolute measurement
  
- Except ICT all monitors are used for machine operation
- Outlook: improve ICT read out and Toroid calibration

# Thank you



12<sup>th</sup> INTERNATIONAL BEAM  
INSTRUMENTATION CONFERENCE  
SASKATOON, CANADA  
September 10-14, 2023



**Many people contributed to development, installation, commissioning and measurements**

**From the ARES team**

Florian Burkhart, Willi Kuroпка, Hannes Dinter, Frank Mayet, Max Kellermeier, Sonja Jaster-Merz

**From Diagnostics Group (MDI)**

Maike Pelzer, Jürgen Kruse, Norbert Wentowski, Zlatan Pizarov, Klaus Knaack, Artem Novokshonov, Jörg Neugebauer, Sergey Stokov, Christian Wiebers, Bastian Lorbeer, Hans-Thomas Duhme, Igor Krouptchenkov, Jorgen Lund-Nielsen<sup>†</sup>

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