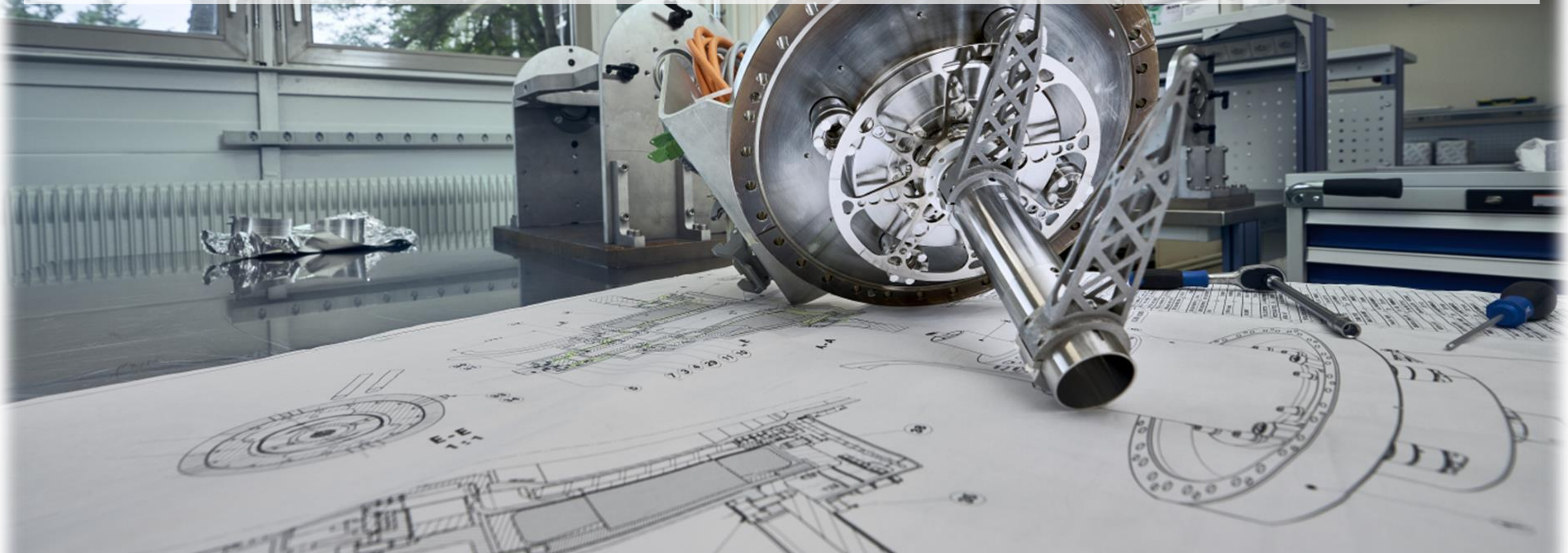
Beam secondary shower acquisition design for the CERN high accuracy wire scanner



PhD. thesis defense – 07/02/2019 – Universitat de Barcelona

Jose Luis Sirvent Blasco

Director: **Federico Roncarolo (CERN)**
Tutor: **Angel Dieguez Barrientos (UB)**

J.L. Sirvent
jsirvent@cern.ch

Objective of the thesis work:

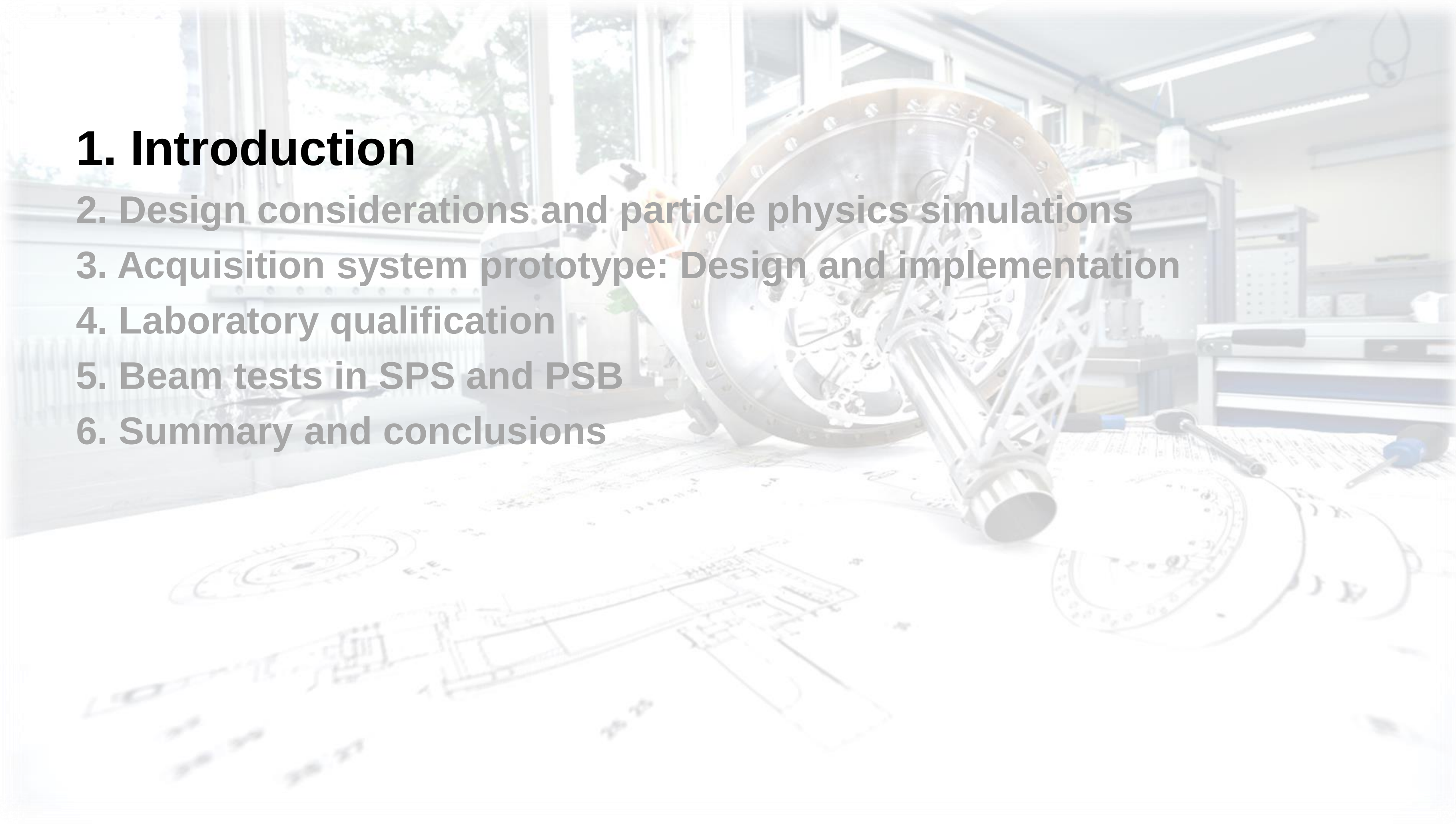
Research and develop HDR detector and acquisition systems for the secondary particles shower of the new Beam Wire Scanner (BWS) generation.

- Identify and study limiting factors of existing systems.
- Evaluation new detector techniques applied on BWS.
- Tests proof-of-concept prototypes.

Presentation Outline

1. Introduction
2. Design considerations and particle physics simulations
3. Acquisition system prototype: Design and implementation
4. Laboratory qualification
5. Beam tests in SPS and PSB
6. Summary and conclusions

Presentation Outline



1. **Introduction**
2. Design considerations and particle physics simulations
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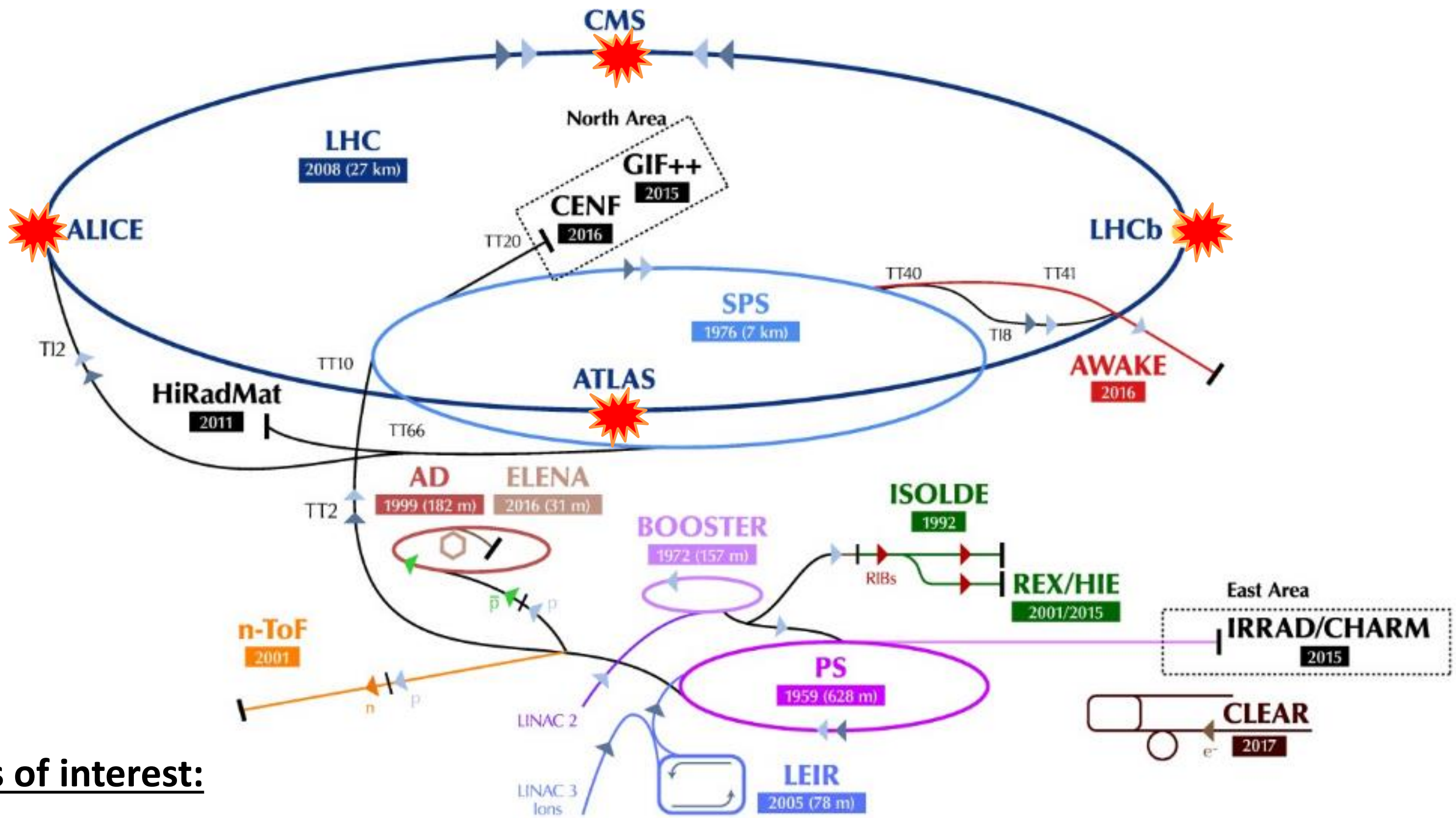
1. Introduction
1.1 CERN and its accelerator complex (Mission).

"Answer fundamental physics questions: What the universe is made of? How does it work?"



<u>Main fields of interest:</u>

Study collision products → Injector chain must deliver (monitor) high quality beams.

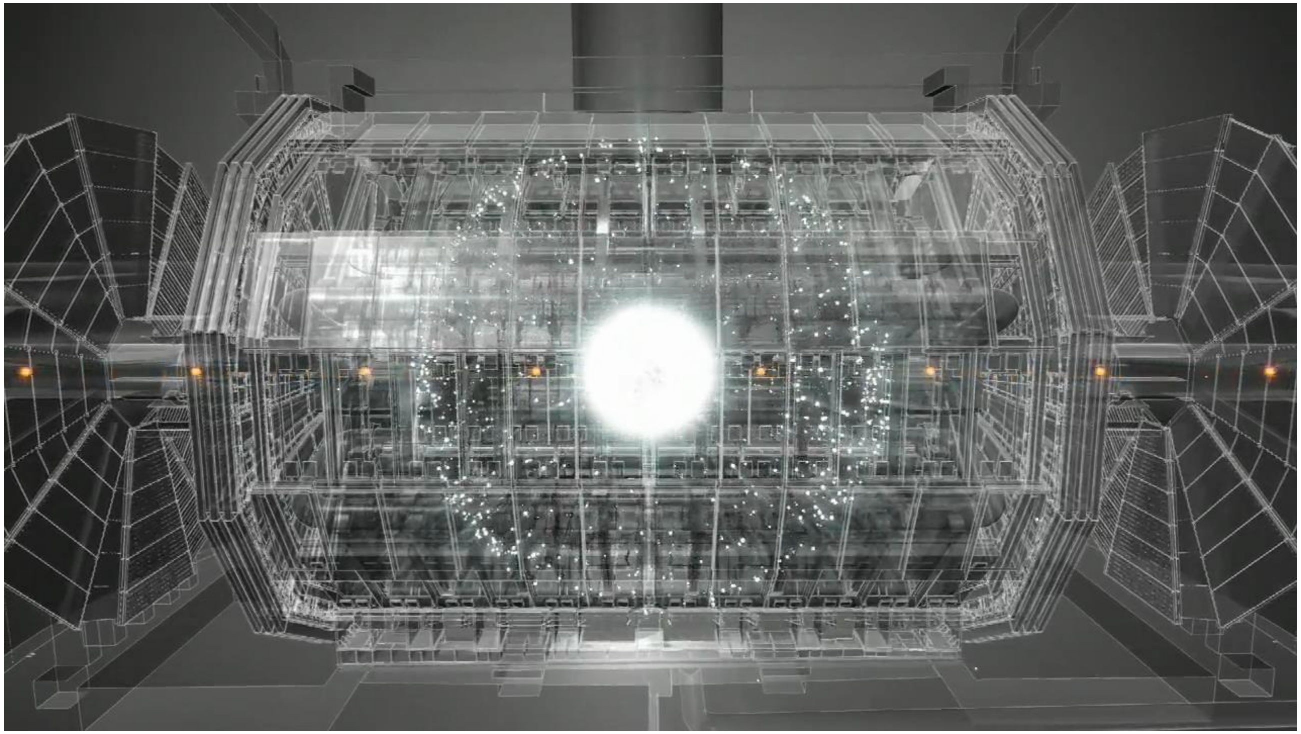
Other fields → Antimatter, Neutron Interactions, Radiation damage, Acceleration with proton driven plasma, Ion Beams research.

1. Introduction
1.1 CERN and its accelerator complex.

LHC Design:

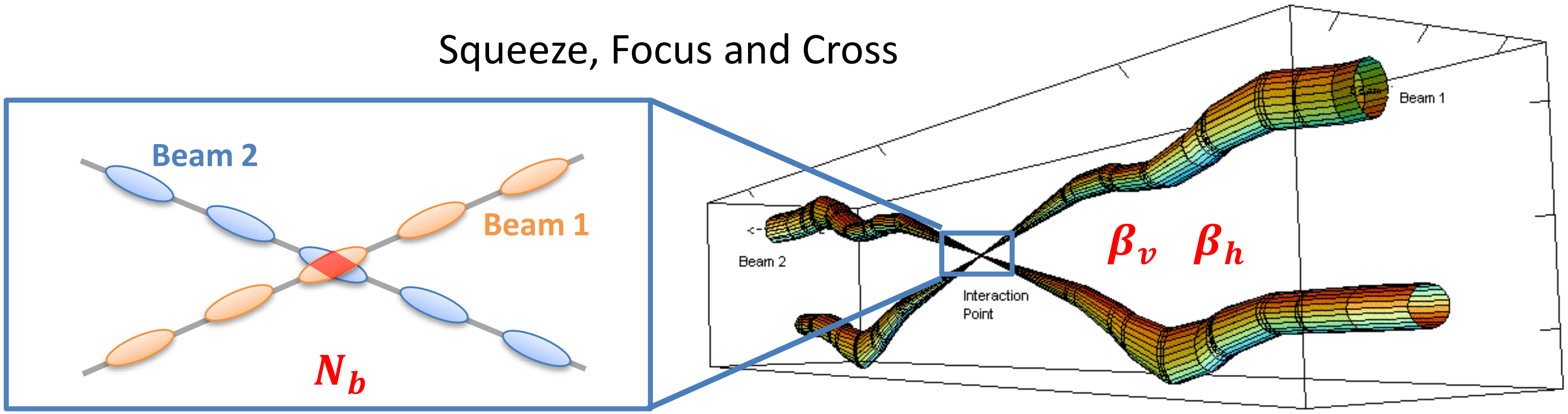
Bunches **2808** (*2556)
1.15e11 Protons
25ns Spacing
Beam Energy: **7 TeV** (*6.5TeV)
Collision Energy: **14 TeV** (*13TeV)

* Values reached before LS2
Re-start scheduled for **2021**

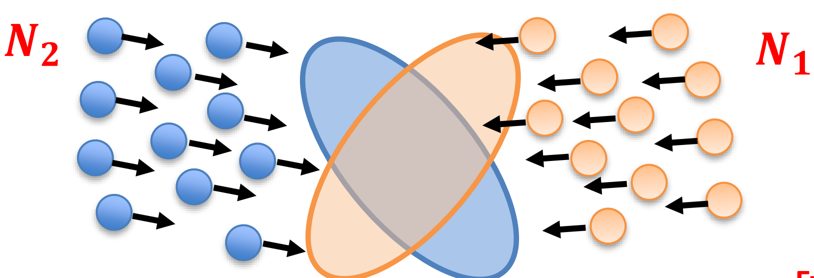


1. Introduction
1.1 What is required in a collision?

Squeeze, Focus and Cross



Relative beam sizes around IP1 (Atlas) in collision



$$\frac{dR}{dt} = \mathcal{L}\sigma_{int}$$

Luminosity (cm-2 s-1) → $\mathcal{L}$; Event Rate (events / sec) → $\frac{dR}{dt}$; Cross-Section (Probability) → σ_{int}

$$\mathcal{L} = f\,\frac{N_1 N_2 N_b}{4\sqrt{\epsilon_h \epsilon_v \beta_h \beta_v}}$$

Bunch population → $N_1 N_2$; Number of Bunches → N_b; Rev. Freq → f; Beam Emittance → $\epsilon_h \epsilon_v$; IP Optics → $\beta_h \beta_v$

Luminosity is the **figure of merit** of a collider. Linked to the **event production capability and** the **frequency** of those events.

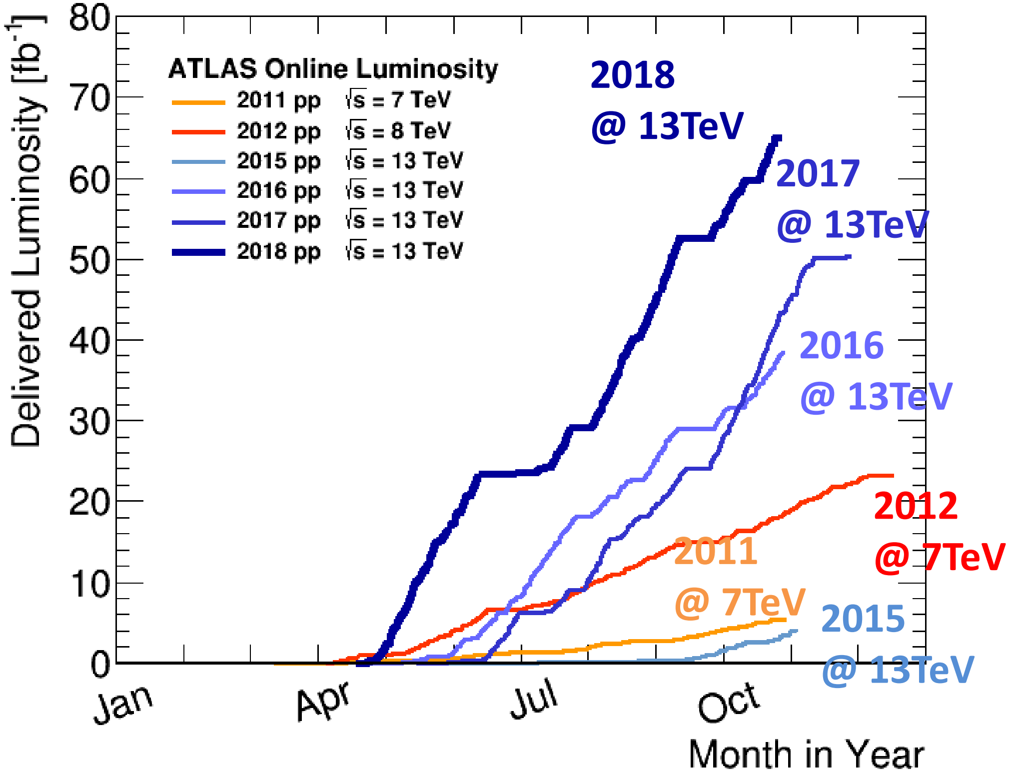
Emittance is a **key beam parameter** derived from the beam size and needs to be **monitored** in the full **injector chain**.

1. Introduction
1.1 What is Luminosity?

Integrated Luminosity used to represent the number of collisions recorded by experiments

$$\mathcal{L}_{int} = \int_0^T \mathcal{L}(t)\, dt$$

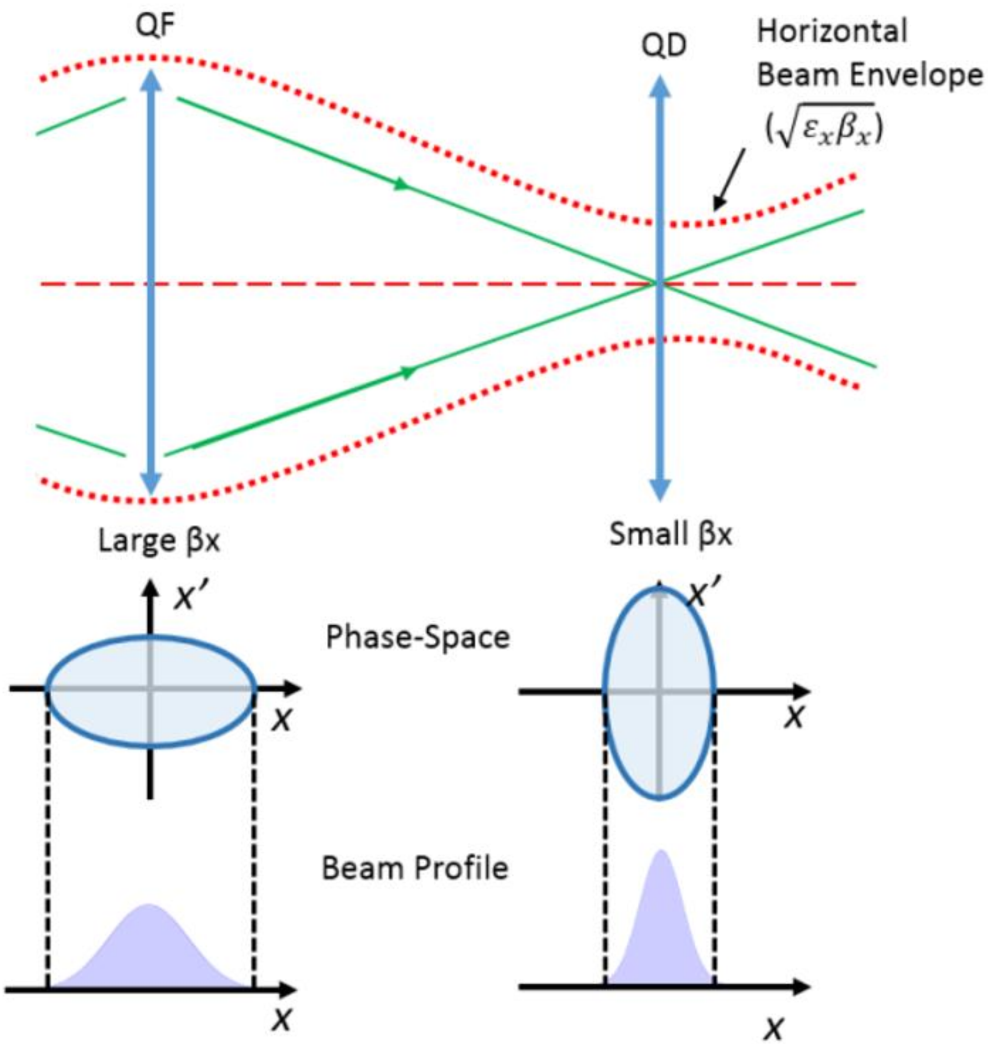
Units are inverse femto barns (fb^{-1})



All accelerator chain and machines operation aim to **maximize integrated luminosity**

To **maximise luminosity,** precise **emittance determination** is **essential**.

1. Introduction
1.1 Monitoring emittance from beam size



Beam Travels through FODO cells:

- Continuously focused and defocused
- Size "Sinusoidally modulated"

Transverse beam dynamics:

- Phase-Space distribution.
- Beam size (x) and Divergence (y)
- Area ~ Emittance = Constant

$$\epsilon^*_{x,y} = (\gamma_L \beta_r) \frac{\sigma^2_{x,y}}{\beta x, y}$$

Normalized Emittance

Relativistic functions

Beam size

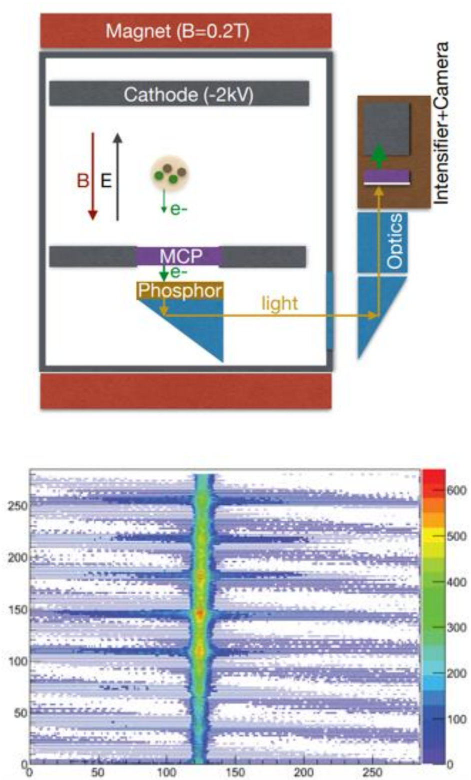
Accelerator Optics

1. Introduction
1.1 Beam profile monitoring devices at CERN

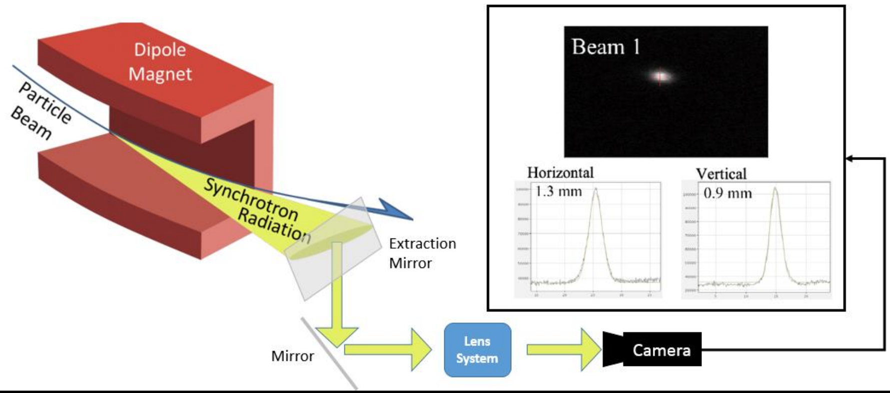
<u>Non Interceptive Monitors:</u>

- Non Destructive measurement techniques → Require calibration/correction factors.
- Limited spatial resolution (imaging device)
- Other Gas-Based Imaging techniques --> Fluorescence Monitors, Gas Jet…

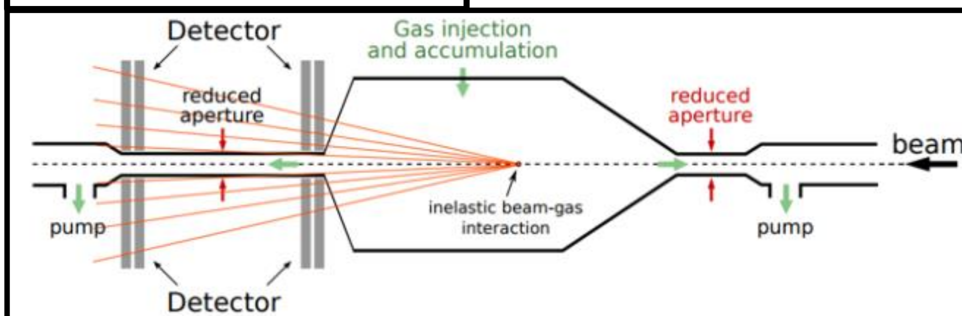
Beam Gas Ionization Monitor (BGI)



Synchrotron Light Monitors (BSRT)



Beam Gas Vertex Monitor (BGV)

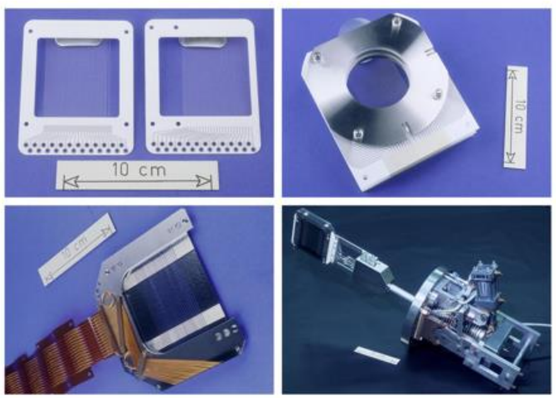


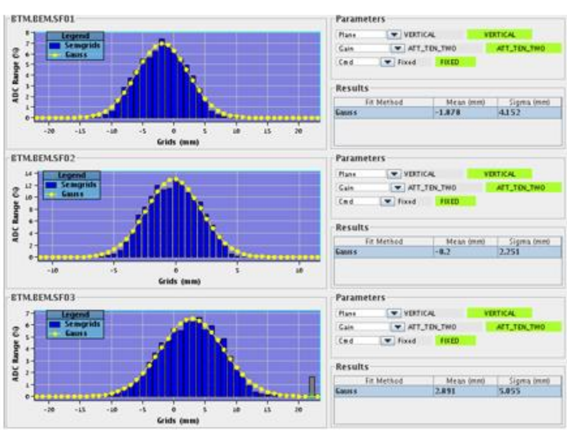
1. Introduction
1.1 Beam profile monitoring devices at CERN

Interceptive Monitors:

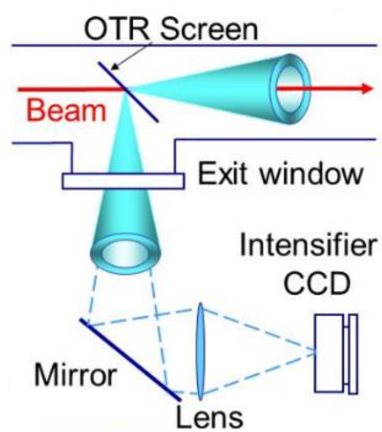
- Subject to beam induced damage (limited beam types), provide absolute beam size, higher precision/accuracy
- Degrade beam properties (emittance blow-up).

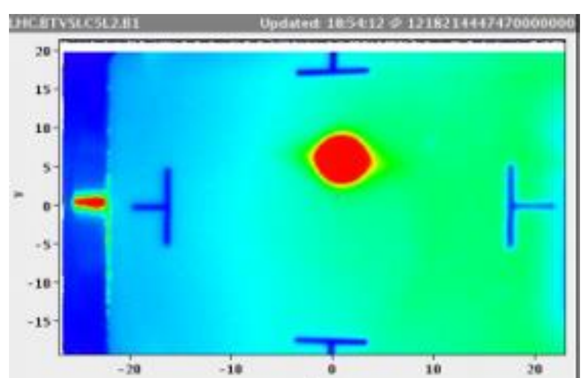
Secondary Emission Grids (SEM Grids)





Optical Transition Radiation Screens (OTR)

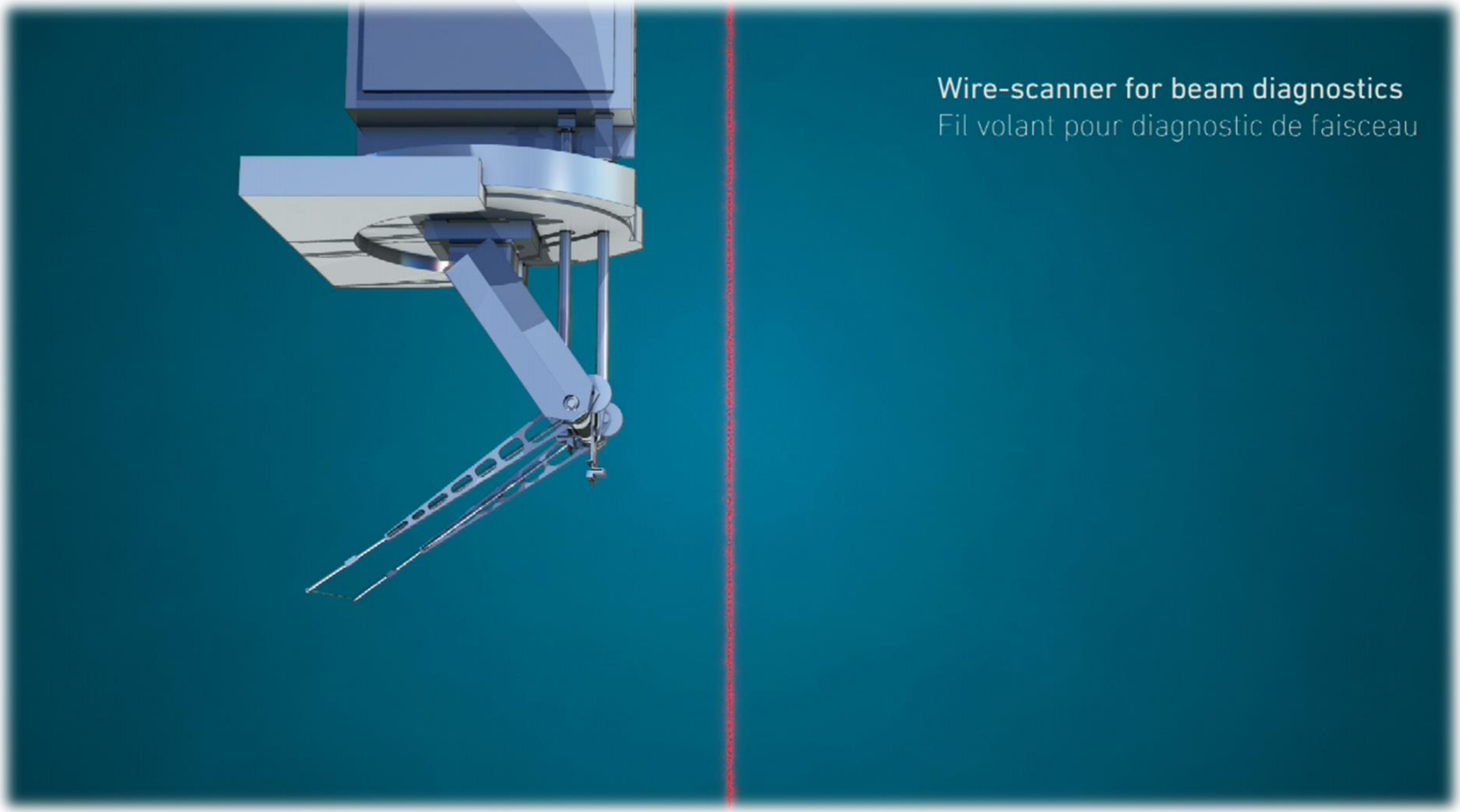




Beam Wire Scanners (BWS)

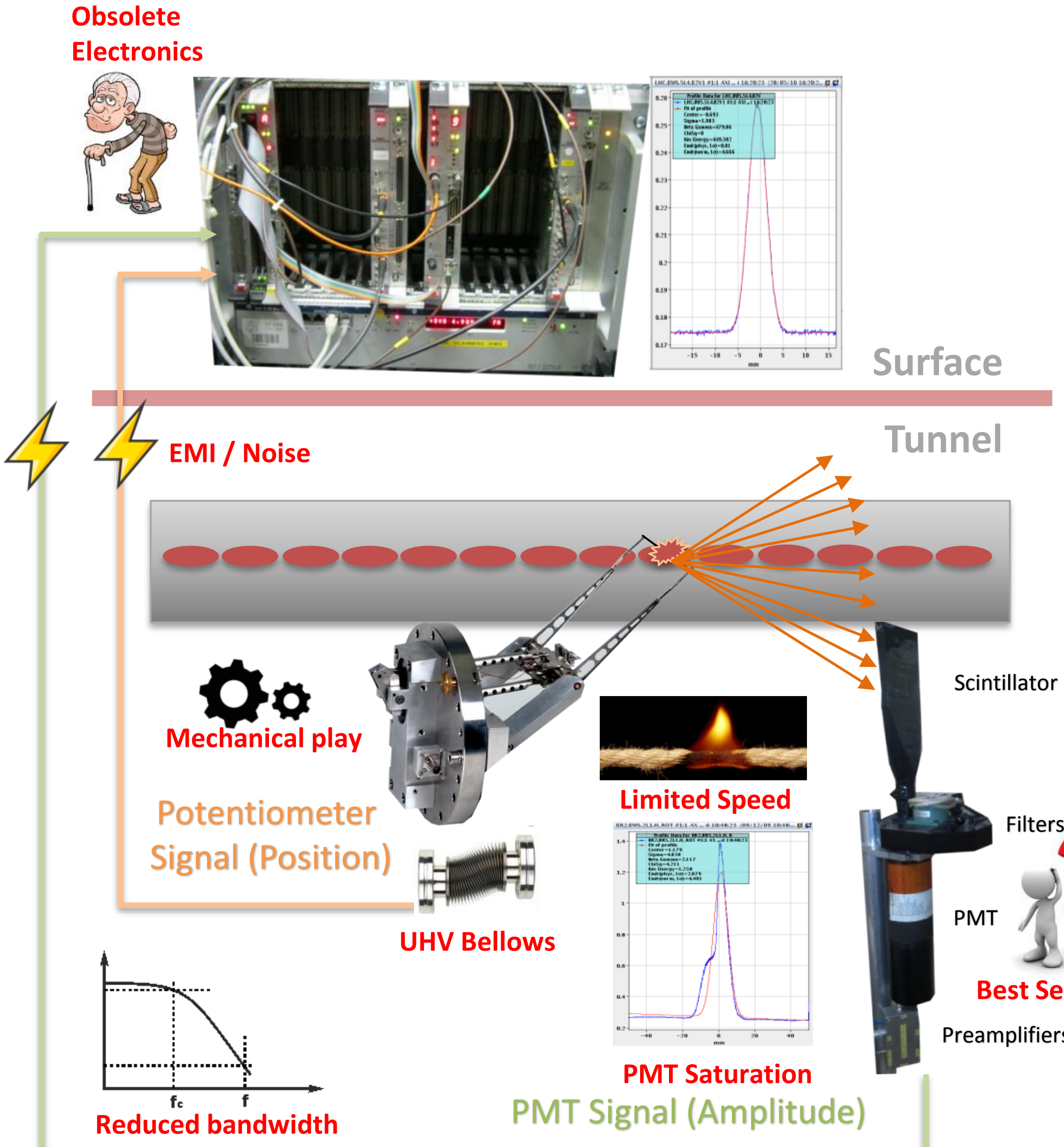
- Considered the most accurate system.
- Calibration device for other instruments.
- System present on the full accelerator chain.

1. Introduction
1.1 The beam wire scanner working principle



1. Introduction

1.3 Beam wire scanners at CERN: Upgrade Motivations



Mechanical Limitations:

- Limited Speed → Wire damage
- Mechanical play → Positon Uncertainty
- UHV Bellows Fatigue → Vacuum loss

Operational limitations:

- Setting point → Many measurements loss

Electronics limitations:

- Saturation Effect → Wrong measurements
- Limited Bandwidth → Bunch Pile-Up
- Noise Pick-up → Added X/Y uncertainty
- Obsolete Electronics → No longer produced

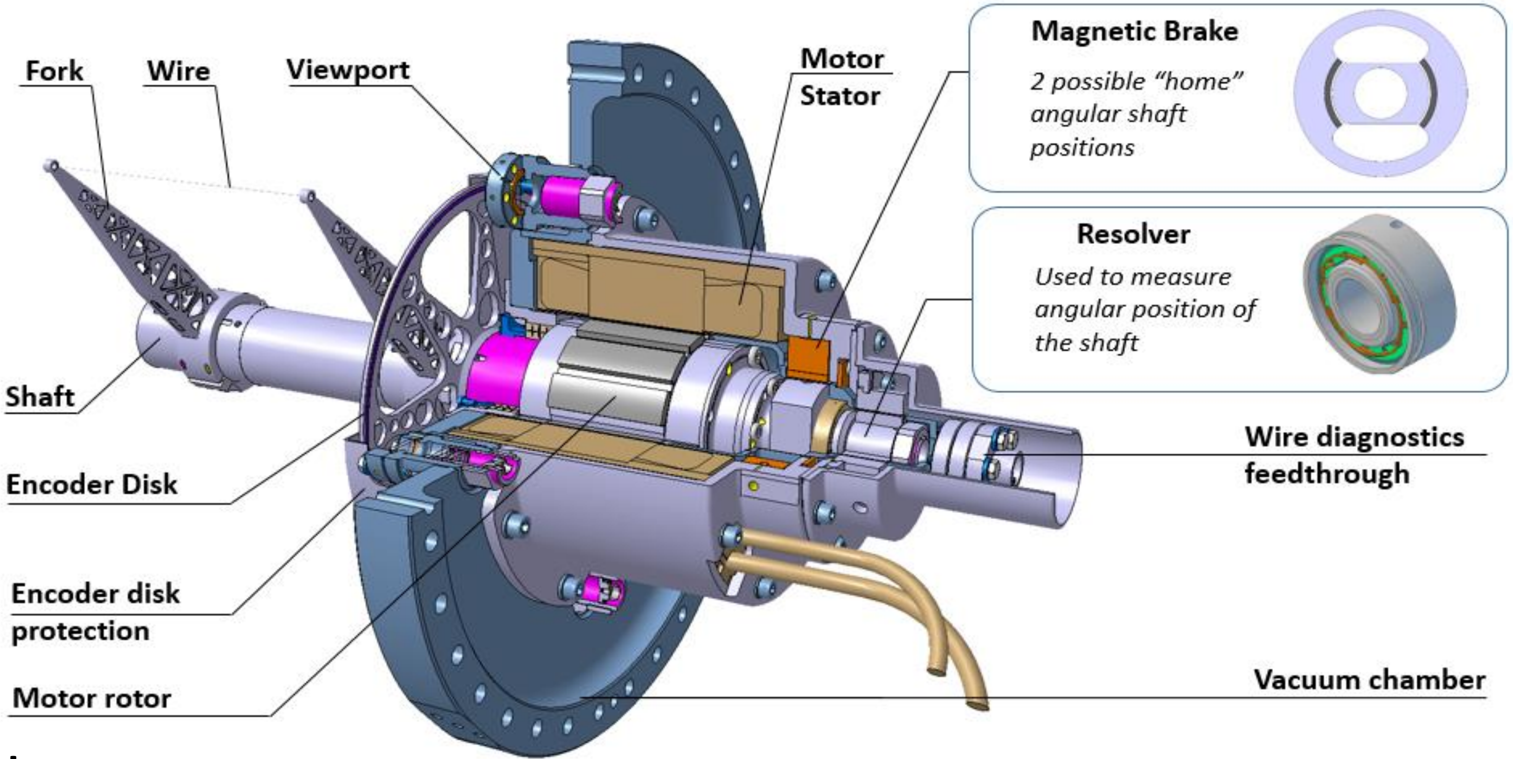
PhD. Thesis Motivations

LIU – BWS Specifications:

- Beam Emittance Precision: <5%
- Beam size precision: <2%

1. Introduction
1.4 BWS design for the LHC Injectors Upgrade

A high precision BWS device with a nominal scan speed of **20ms-1**



Features:

Forks → 3D printed metal, optimized for low vibrations and deformations.
Shaft → Shared shaft for all mobile components (in vacuum).
Encoder → Al. Metallic disk with laser engraved track (40um pitch).

This design is **5 times more precise** than operational PS/PSB scanners (9-10 Vs 50-70um) and **10 times less IN-OUT offset** (0.1 Vs 1-2 mm)

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1. Introduction
2. **Design considerations and particle physics simulations**
3. Acquisition system prototype: Design and implementation
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2. Design considerations and simulations
2.0 Pre-Design Studies

1. Dynamic range requirements per machine:

a) Characteristic **beams geometry** on measurement points.

b) **Secondaries** fluence **variation** with **energy** and **distance.**

2. Analysis of sources of error in beam profile determination:

a) Measurement **conditions** required for a **given** beam size **precision.**

3. Beam profile degradation in long coaxial lines:

a) Quantification of bunch by **bunch** beam **profiles uncertainty**

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2. Design considerations and simulations
2.1 Typical beam sizes and dynamics per machine

Estimate detector signal variation per machine (dynamic range) with different beam types:

Secondaries production proportional to bunch density:

- Beams characterized by: **Emittance (ϵ*), Bunch Intensity (Nb), Dispersion (dp/p)**
- Size calculation (σ) in monitors location: **Machine optics (β , D)**
- Size variation with energy ramp: **Relativistic factors (βr γL)**

- Estimations of boundaries for **Beam Size** and **Bunch density → Dynamics**

$$\sigma_h = \sqrt{\frac{\epsilon_h^* \beta_h}{\gamma_L \beta_r} + (D\frac{dp}{p})^2}, \qquad \sigma_v = \sqrt{\frac{\epsilon_v^* \beta_v}{\gamma_L \beta_r}}$$

Horizontal & Vertical Beam Size

$$HD_{Bunch} = \frac{N_b}{\sigma_h\sqrt{2\pi}} \quad , HV_{Bunch} = \frac{N_b}{\sigma_v\sqrt{2\pi}}$$

Horizontal & Vertical Bunch Densities

Beam profiles and Bunch densities for the CERN accelerators at the Beam Wire Scanners location

	σ_h [mm]		σ_v [mm]		HD Bunch [10^{11}/mm]		ΔHD Bunch	VD Bunch [10^{11}/mm]		ΔVD Bunch
Proton Synchrotron Booster (PSB)	1.57	13.5	1.2	9.0	0.01	16.82	1.6e3	0.01	26.43	2.6e3
Proton Synchrotron (PS)	0.8	13.0	0.5	8.8	0.01	8.53	8.5e2	0.01	16.54	1.6e3
Super Proton Synchrotron (SPS)	0.2	8.7	0.3	6.7	0.01	2.91	2.9e2	0.01	2.87	2.8e2
Large Hadron Collider (LHC)	0.16	1.19	0.22	1.79	0.031	4.752	1.5e2	0.022	3.403	1.5e2

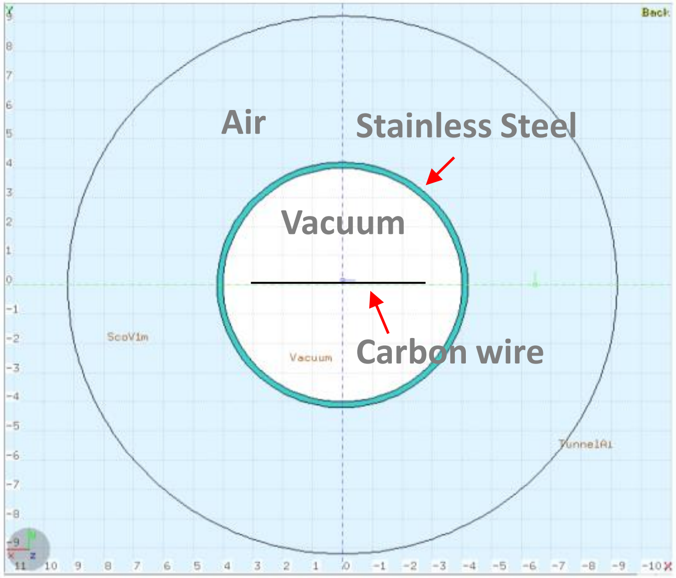
2. Design considerations and simulations
2.2 Simulations for BWS secondaries shower

Estimate detector signal variation (dynamic range) <u>with energy</u>:
How much energy would be deposited in an arbitrary detector? Does it vary with energy?

Finding an optimal detector location:
How the secondary shower is distributed around the beam pipe? Does it vary with energy?

Simulations for BWS in FLUKA:
- FLUKA is a Monte Carlo simulation tool for HEP
- Calculates particle transport, matter interactions, TID…
- Capable to handle complex geometries

Geometry and considerations for BWS Simulations:
- Beam pipe → Cylinder of stainless steel (as in accelerators)
- Beam pipe volume → "Filled" with Vacuum
- Tunnel volume → "Filled" with Air
- Carbon wire → Carbon cylinder of 30um diameter (2g/cm3)
- Beam → Pencil proton beam x=2.9mm (FWHM) y=30um (flat)

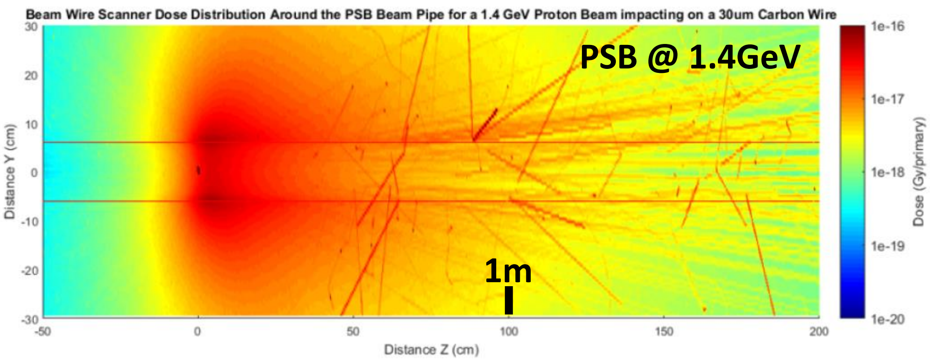


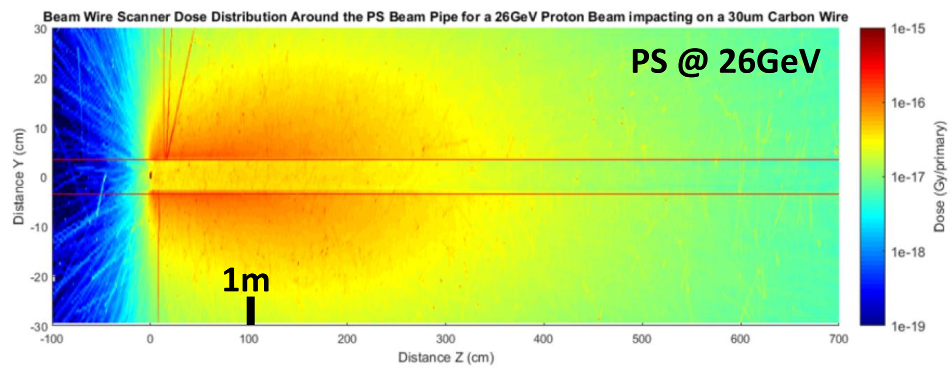
"The FLUKA Code: Developments and Challenges for High Energy and Medical Applications"
T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis,
Nuclear Data Sheets 120, 211-214 (2014)

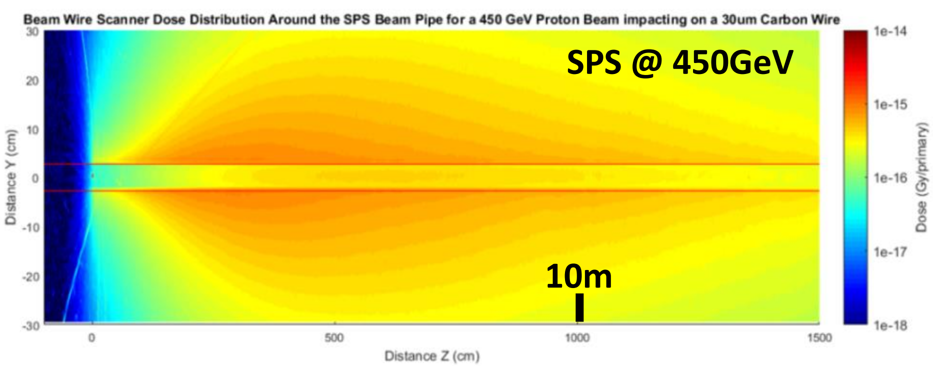
"FLUKA: a multi-particle transport code"
A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft,
CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

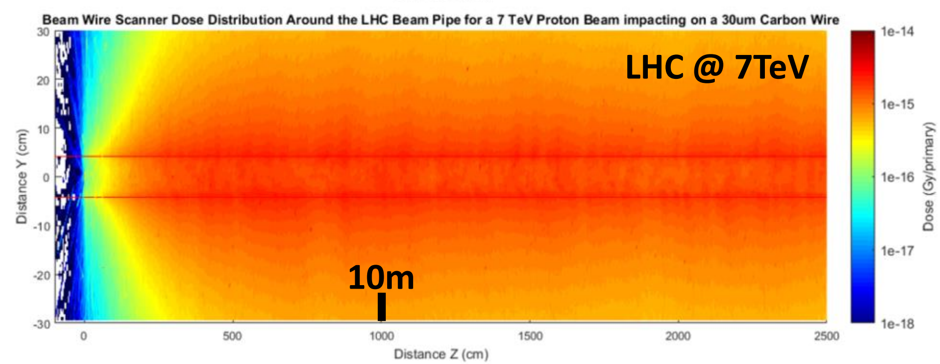
2. Design considerations and simulations
2.2 Simulations for BWS secondaries shower

Accelerator	Injection Energy	Extraction Energy	Beam Internal	Beam External	Pipe Material	Wire Diam.	Wire Material
PSB	50 MeV	1.4 GeV	120	123	Stainless Steel	30 µm	Carbon
PS	1.4 GeV	26 GeV	Elliptical 70 x 146 x 2				
SPS	26GeV	450 GeV	156 Elliptical 55 x 130.5 x 1.5	159			
LHC	450 GeV	7 TeV	80	84			



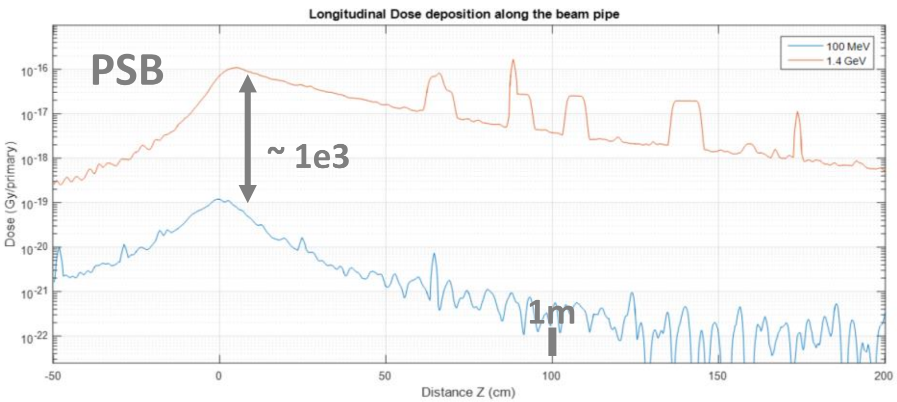




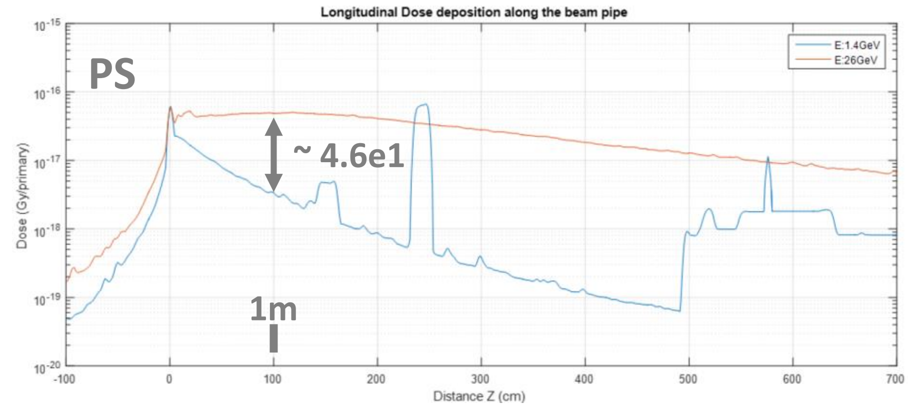


2. Design considerations and simulations
2.2 Simulations for BWS secondaries shower

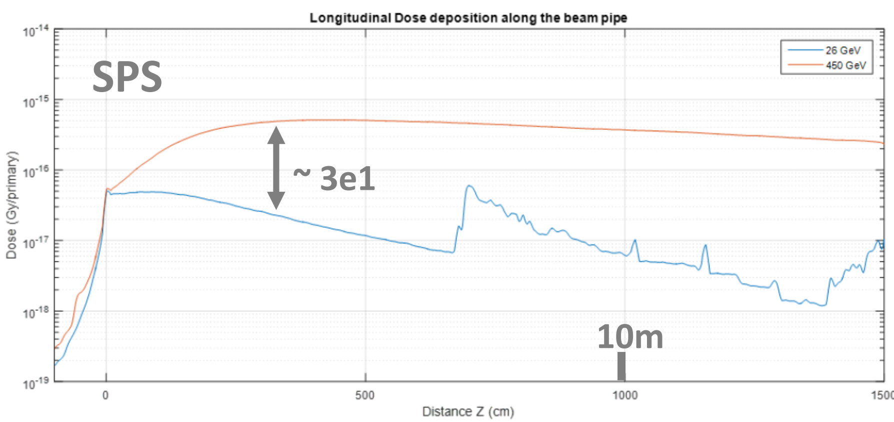
Injection Energy — Extraction Energy



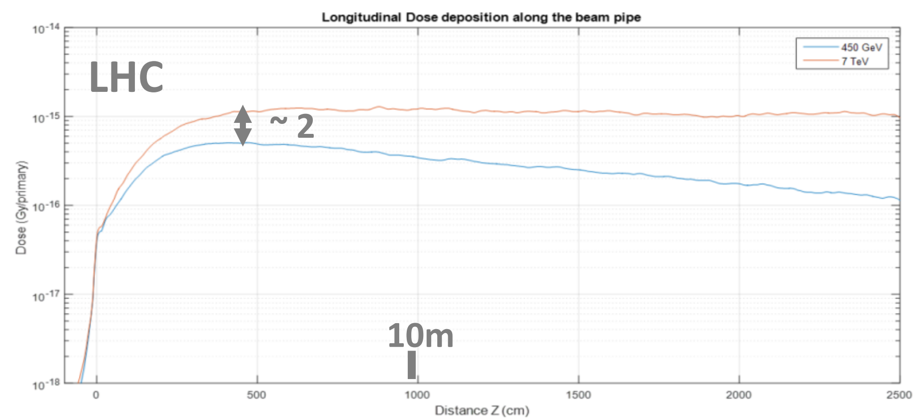
	Dose at 5cm (Gy/Primary)		Dose at 15cm (Gy/Primary)	
PSB	100MeV	1.4GeV	100MeV	1.4GeV
	8.46e-20	1.01e-16	1.49e-20	5.34e-17



	Dose at 10cm (Gy/Primary)		Dose at 1m (Gy/Primary)	
PS	1.4GeV	26GeV	1.4GeV	16GeV
	7.95e-17	1.70e-16	3.44e-18	1.60e-16



	Dose at 1m (Gy/Primary)		Dose at 3m (Gy/Primary)	
SPS	26GeV	450GeV	26GeV	450GeV
	1.82e-16	8.2e-16	5.18e-17	1.54e-15



	Dose at 3m (Gy/Primary)		Dose at 7m (Gy/Primary)	
LHC	450GeV	7TeV	450GeV	7TeV
	1.71e-15	3.32e-15	1.32e-15	3.43e-15

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2.0 Pre-Design Studies

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a) Quantification of bunch by **bunch** beam **profiles uncertainty**

2. Design considerations and simulations
2.3 Sources of error in beam profile determination

What influences the measurement precision?

1. **Number of points per sigma**
   (Scan speed, Rev.Freq, Beam Size): **PpS**

$$PpS = \frac{\sigma_{beam}}{V_{scan}} f_{rev}$$

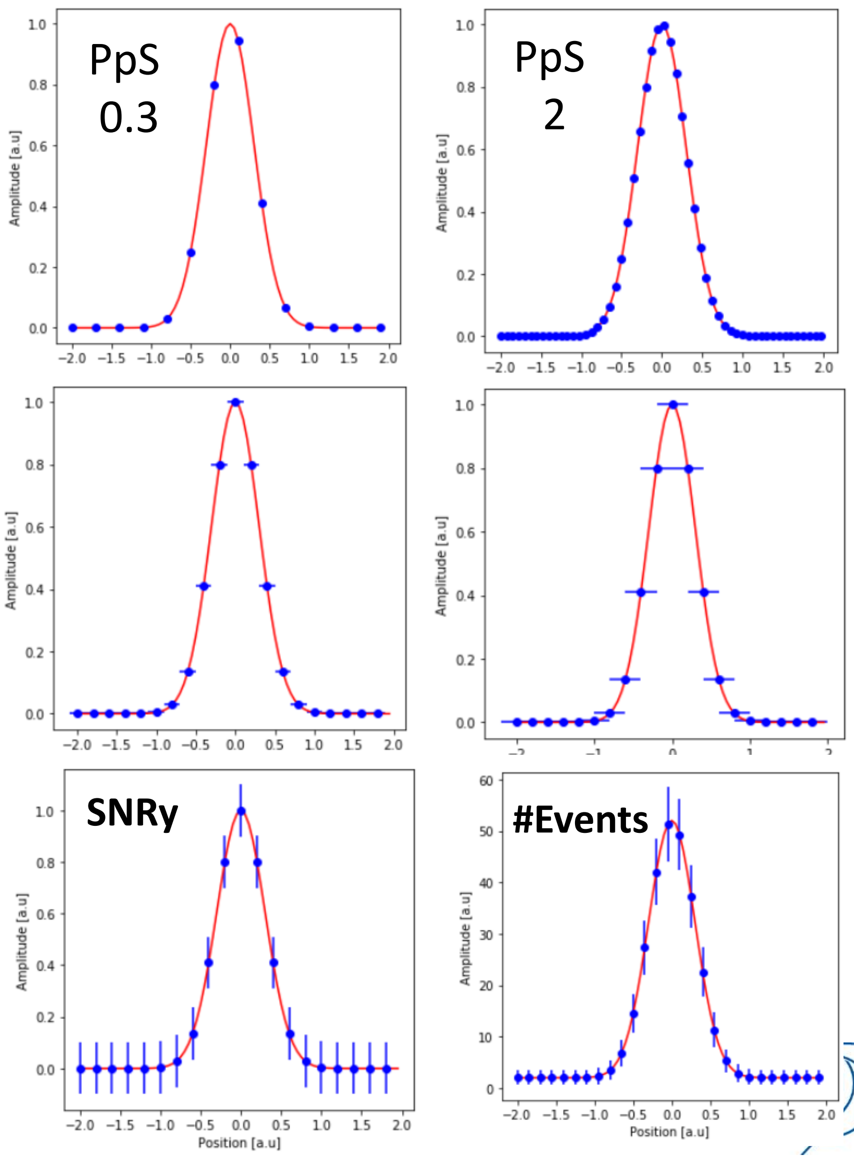
2. **Wire position incertitude**
   (and it´s relationship with Beam size): **SNRx**

$$SNR_x = \sigma_{beam}/\sigma_{pos}$$

3. **Amplitude incertitude:**
   a. Electrical pick-up Noise: **SNRy**
   b. Number of Events: **#Events**

$$SNR_y = \max(G(x))/\sigma_y$$

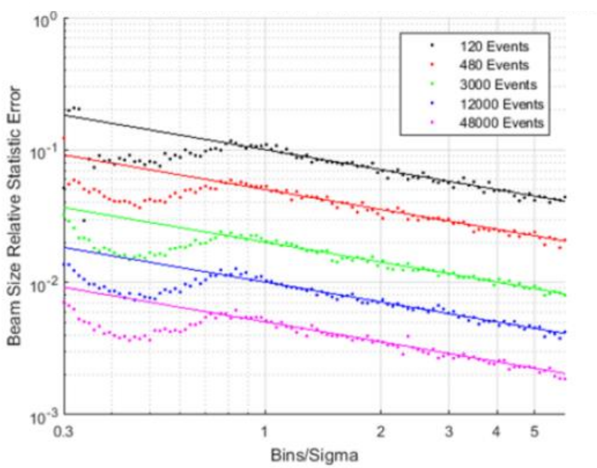
$$Inter. = \mu_{part} \mp 1/\sqrt{\mu_{part}}$$



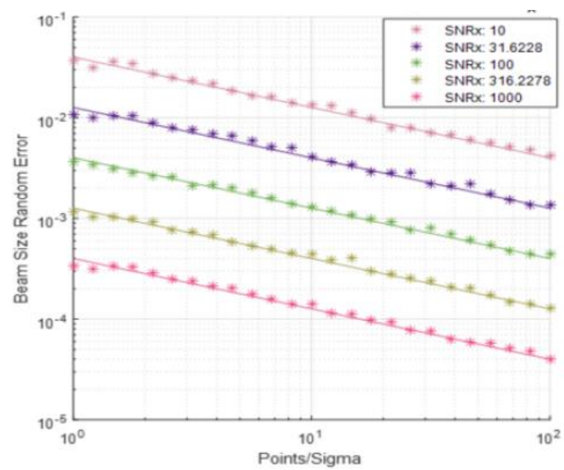
2. Design considerations and simulations
2.3 Sources of error in beam profile determination

Simulation Results:

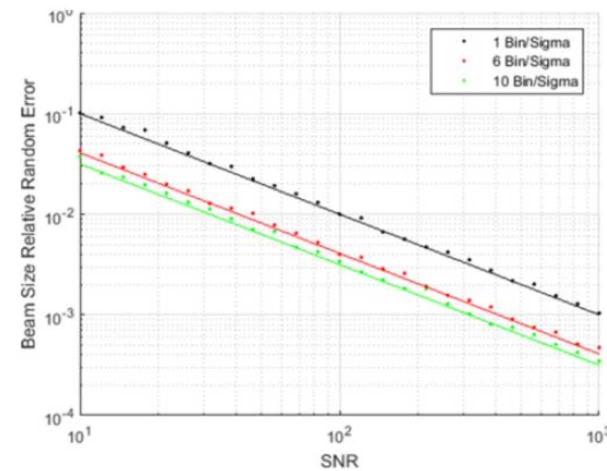
Error by **# of Events & PpS**



Error by **SNRx & PpS**



Error by **SNRy & PpS**



$$\epsilon(N_{\mathrm{TE}}, \mathrm{PpS}) = \frac{1{,}1}{\sqrt{N_{TE} PpS}}$$

$$\epsilon(\mathrm{SNR}_x, \mathrm{PpS}) = \frac{0{,}4}{\mathrm{SNR}_x \sqrt{PpS}}$$

$$\epsilon(\mathrm{SNR}_y, \mathrm{PpS}) = \frac{1}{\mathrm{SNR}_y \sqrt{PpS}}$$

$$\epsilon_{\mathrm{beamWidth}} = \sqrt{\epsilon^2_{\mathrm{NTE}} + \epsilon^2_{\mathrm{SNRx}} + \epsilon^2_{\mathrm{SNRy}}}$$

Conditions for LHC Beam (100um) error <1%?

Points per Sigma > 3, Position Precision < 4um, SNRy > 100, Number of Secondaries > 10000

2. Design considerations and simulations
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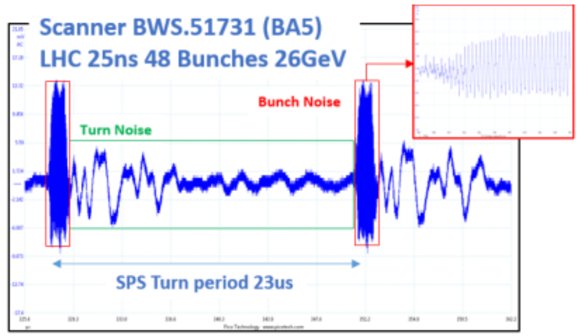
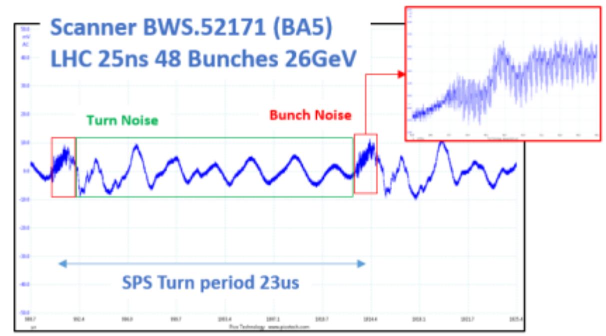
2. Design considerations and simulations
2.4 Implications of using long coax cables (CK50)

What happens when using long cables for high BW signal transmission? (100-250m)

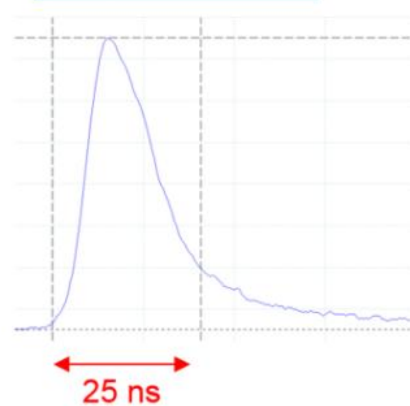
1. RF Noise pick-up:
- Beam Dependent
- Location Dependent
- Bunch synchronous
- Turn synchronous
- Falls within F. interest
- Difficult to model for all BWS





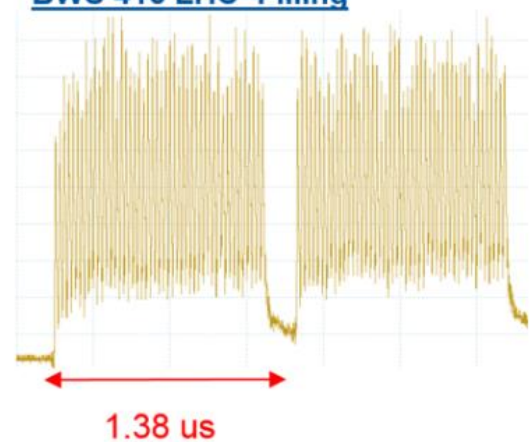
2. Pulse distortion (BW limit):
- Location dependent (Distance)
- Bunch cross-talk
- Bunch profiles compromised
- Impact **posible to model**

Linear BWS.51731.V



PMT **XP2203B** (FWHM 8ns)
TIA + Cable (~80m)
Fall time ~20ns

BWS 416 LHC Filling



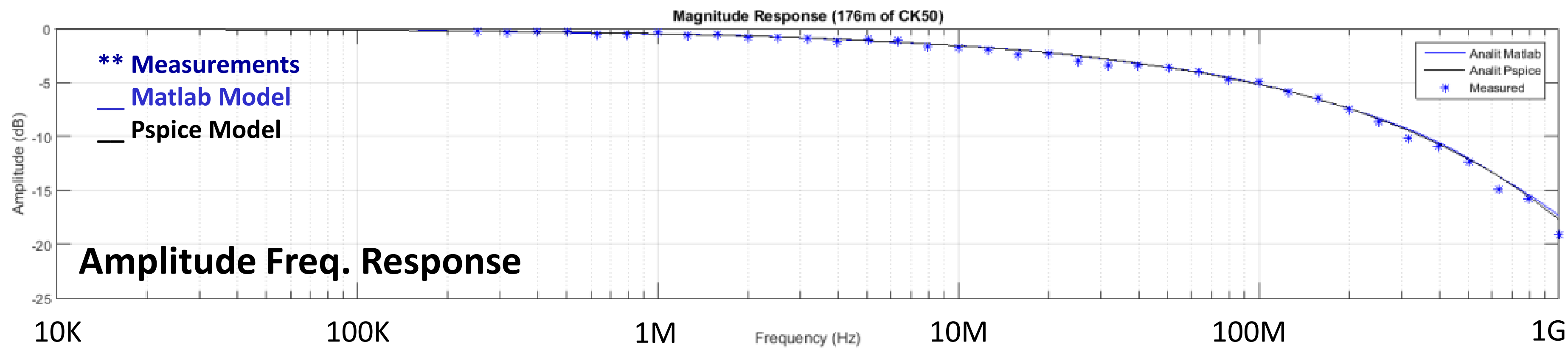
PMT **XP2203B** (FWHM 8ns)
TIA + Cable(190m)

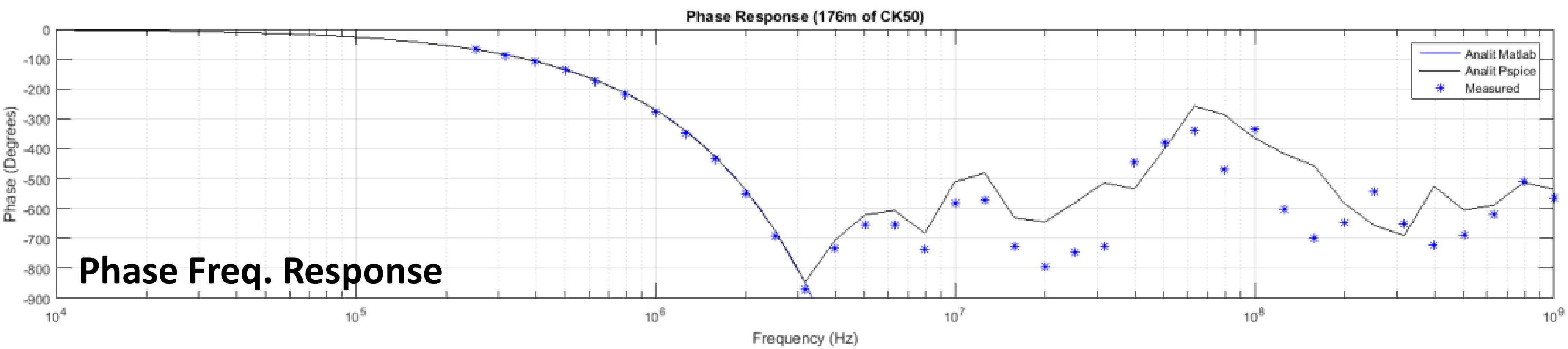
2. Design considerations and simulations
2.4 Implications of using long coax cables (CK50)

Analytical model evaluates pile-up impact in BbB profiles (Matlab & PSpice):

$$V_{out}(z,\omega) = V_{in} e^{-(\frac{1}{2}\frac{R_{ac}\sqrt{\omega}}{Z_0} + G_{ac}|\omega| Z_0) z} e^{-j\omega\sqrt{LC} z}$$

Skin Effect — Dielectric Loss — Delay



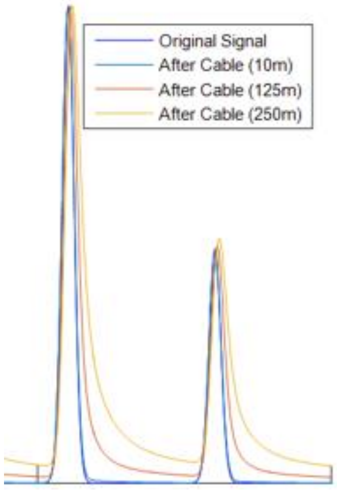


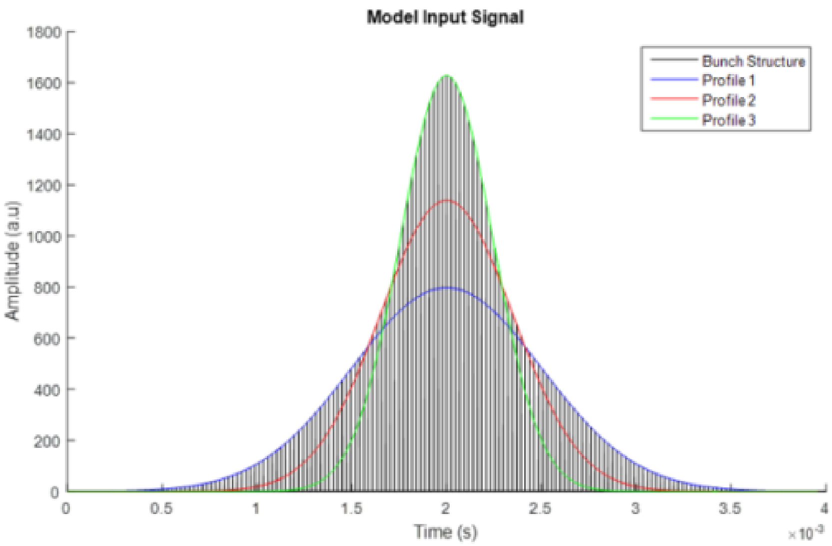
2. Design considerations and simulations
2.4 Implications of using long coax cables (CK50)

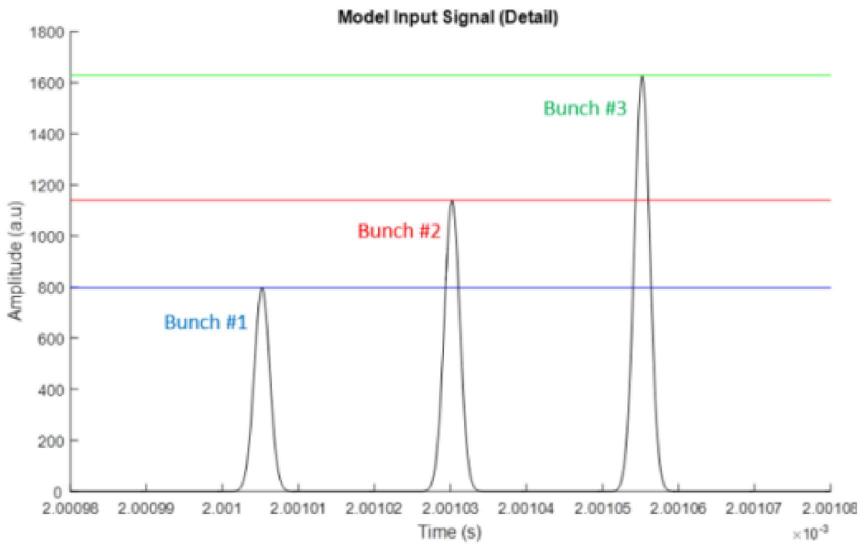
Analytical model evaluates pile-up impact in BbB profiles (Matlab & PSpice):

$$V_{out}(z,\omega) = V_{in} e^{-\left(\frac{1}{2}\frac{R_{ac}\sqrt{\omega}}{Z_0} + G_{ac}|\omega|Z_0\right)z} e^{-j\omega\sqrt{LC}z}$$

Skin Effect — Dielectric Loss — Delay



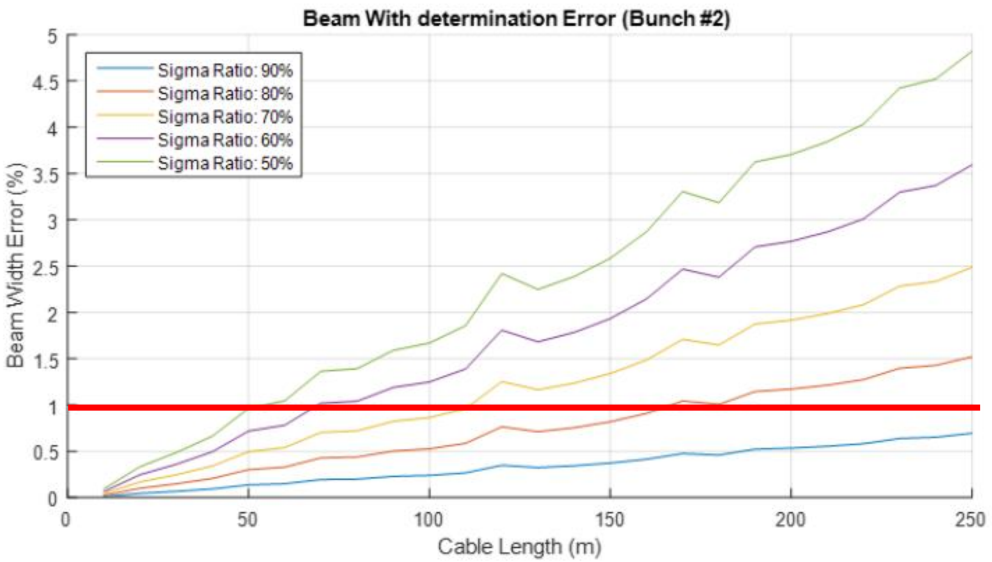




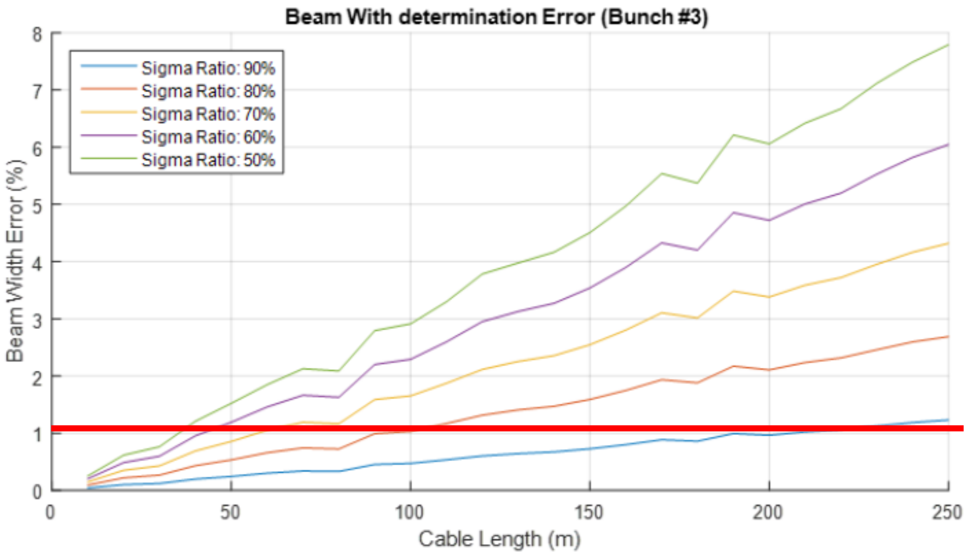
2. Design considerations and simulations
2.4 Implications of using long coax cables (CK50)

Simulation Results:

- **Pile-up leads easily to > 1% error**
- C. Length > 150m @ S.Ratio < 80 %
- Difficult to correct:
  - Unknown integration phase



- Error is cumulative in bunch sequence
  - See Bunch # 3
- Profile "Gaussianity" is degraded
  - Fit SSE increases with distance

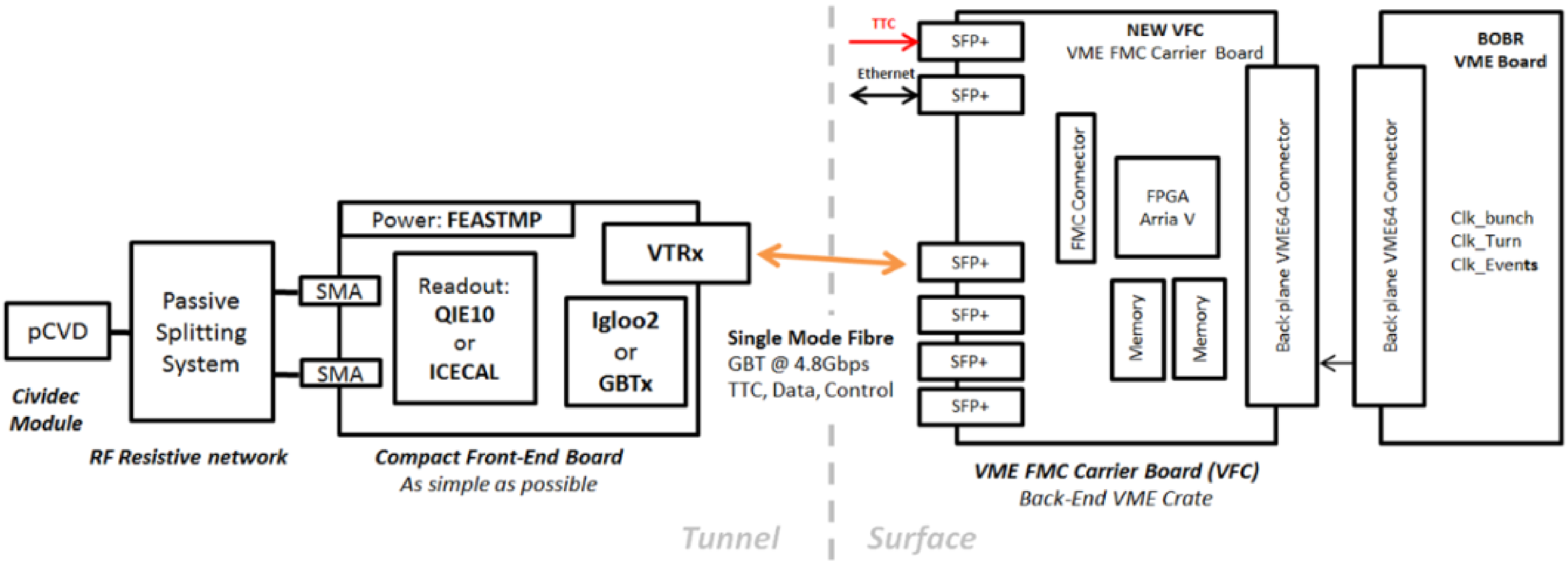


Long coax. cables need to be avoided if acquisition is based on synchronous bunch integrations.

Presentation Outline

1. Introduction
2. Design considerations and particle physics simulations
3. **Acquisition system prototype: Design and implementation**
4. Laboratory qualification
5. Beam tests in SPS and PSB
6. Summary and conclusions

3. Acquisition System Prototype
3.1 General Architecture



Upgraded Secondaries acquisition system:

- HDR system (**1e6 required**) with no tuneable parameters.
- Acquisition near detector (**RH electronics**)
- Standard BE-BI Electronics
  - **GBT Link communication (optical data transfer)**
  - **Front-End – Back-End architecture (GEFE + VFC)**
- Bunch by bunch measurements:
  - **25 ns Integration with no dead time (40Mhz)**
  - **Bunch synchronous measurements**

Dynamic range coverage and readout:

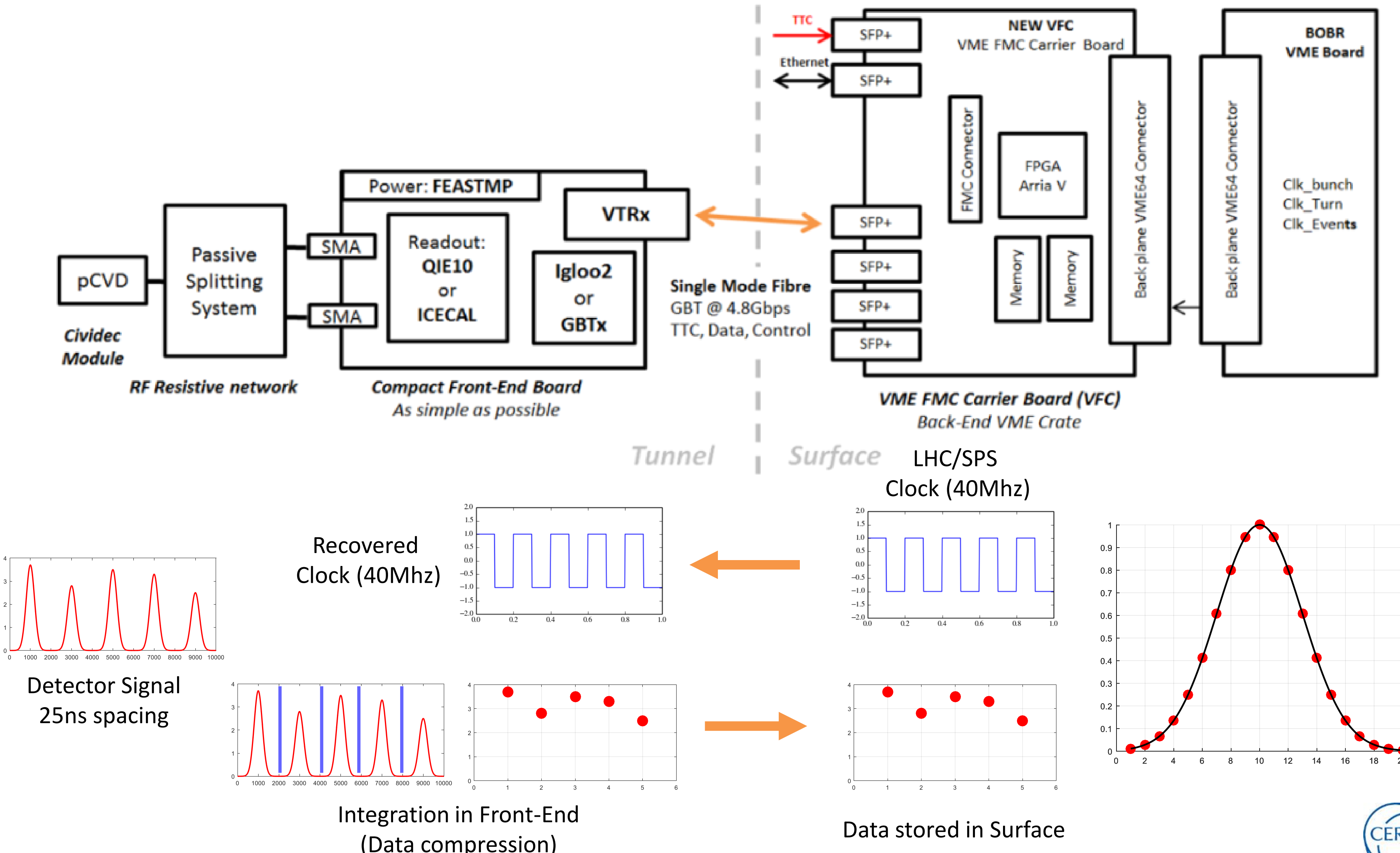
Strategy A: A **single** HDR detector + **logarithmic** acq.

Strategy B: A **Multi-channel** detector + **linear** acq.

RadHard Specs up to 1KGy
10 years of operation @ 100Gy/y

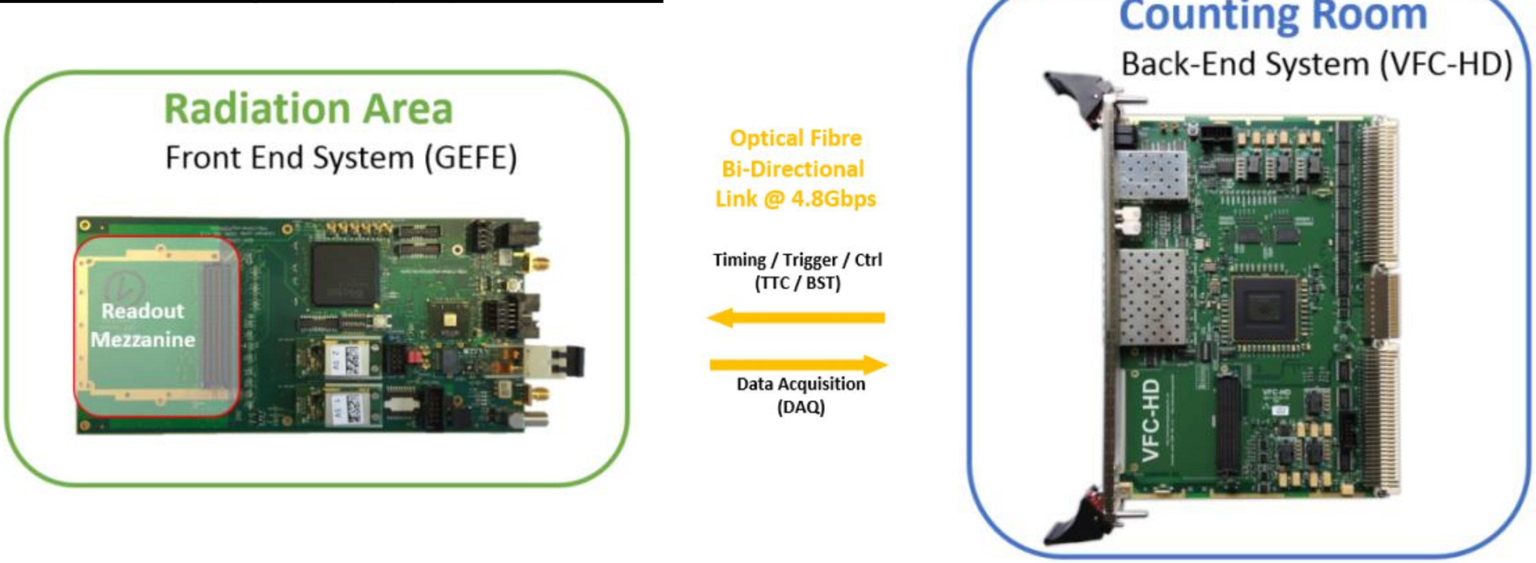
* Shielding required in PSB & PS

3. Acquisition System Prototype
3.1 General Architecture



3. Acquisition System Prototype
3.1 General Architecture

<u>The CERN´s BE-BI general purpose boards</u>



GBT-Based Expandable Front-End (GEFE):

- RadHard development used as Front-End in tunnel areas.
- GBT link chipset included: GBTx, VTRx.
- Supply by switching regulatros FEASTMP (RH).
- Radiation tolerance limited by FPGA up to 750Gy.

VME FMC Carrier Board (VFC):

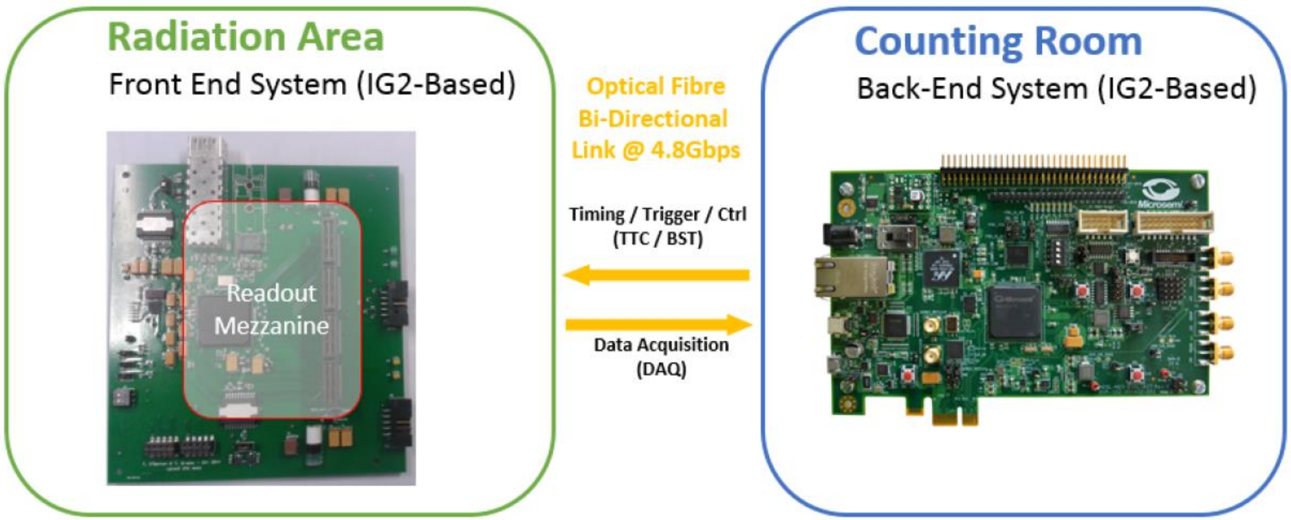
- FPGA-Based on ARRIA V GX.
- 6 SFP+ Slots (4 for user applications).
- FMC slot with VITA57 standard (mezzanines).
- 2 x DDR3 8Gb memories (14Gb data storage) .

Hardware unavailable during PhD.

Proof of concept prototype developed with custom infrastructure

3. Acquisition System Prototype
3.1 General Architecture

Custom infrastructure for the proof of concept prototype: Based on Flash-Based Igloo2 FPGAs



Front-End System:

- Based on CMS Igloo2 UMd Mezzanine Board (ngCCM)
- Connectivity through long HSMC connector
- Radiation Hard development specified for 200Gy
- 2 SFP+ slots (standard SFP+ and VTRx)
- Board intended as GBTx emulation device.

Back-End System:

- Based on Microsemi Igloo2 Dev. Kit.
- 512Mb LPDDR SDRAM.
- Gigabit Transceivers through SMA connectors.
- USB-UART Bridge.
- External clocking resources, GPIOS, switches.

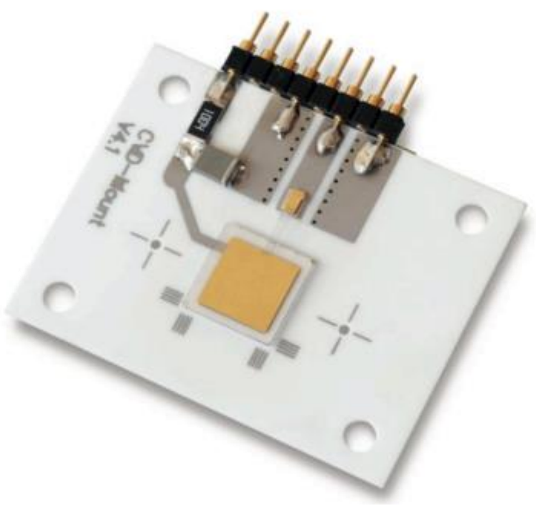
GBT Firmware for Igloo2 implemented in collaboration with CMS HCAL upgrade

3. Acquisition System Prototype
3.2 Detectors for secondary particles shower

Strategy A: **HDR with a single channel using pCVD diamond detector**

- Solid State Ionization Chamber 1cm2 (500um thickness):
- Already validated for Single particle detection (*) as well as for Intense beams (**)
- Many Know-How at CERN, RD42 collaboration, and already used in BE/BI-BL, Atlas BCM, CMS BCM…

Property	Si	Diamond	Advantage
Band gap [eV]	1.12	5.45	**Low $I_{leakage}$** (lower noise)
e- mobility [cm2/Vs]	1450	2200	**Faster Signal** (Better temporal resolution)
H mobility [cm2/Vs]	500	1600	
Dielectric constant	11.9	5.7	**Low Capacitance/noise**
Displacement E [eV]	13-20	43	**High Rad-hardness**
Ionization Energy for e-h[eV]	3.6	13	Smaller signal
Av. E-h per MIP per μm	89	36	
Charge Coll. Eff [%]	100	50 in pCVD 100 in sCVD	
Thermal conduct [W/cm K]	1.5	22	**No cooling**



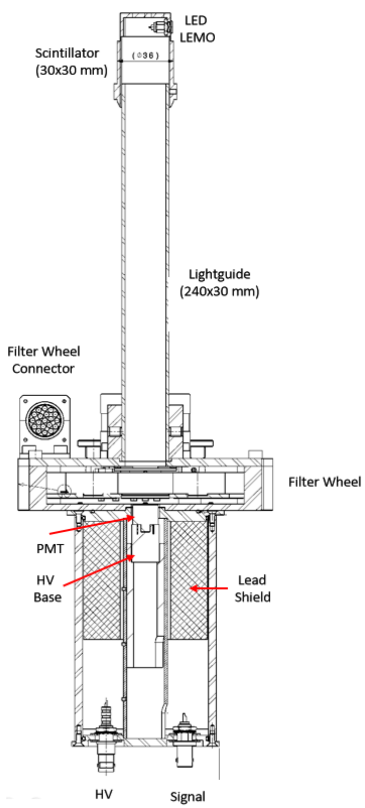
(*) B.Dehning, E. Effinger, H. Pernegger, D. Dobos, H. Frais-Kolbl, E.Griesmayer. **Test of a Diamond Detector using Unbunched Beam Halo Particles**. Feb.2010

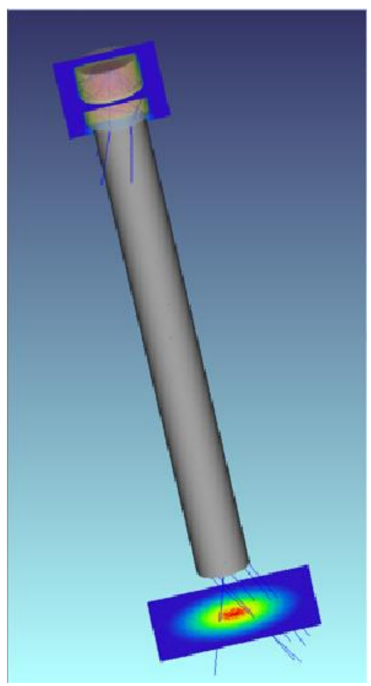
(**) J.L. Fernandez-Hernando. **Development of a Beam Condition Monitor system for the Experimental Areas of the LHC using CVD Diamond**. PhD. Thesis

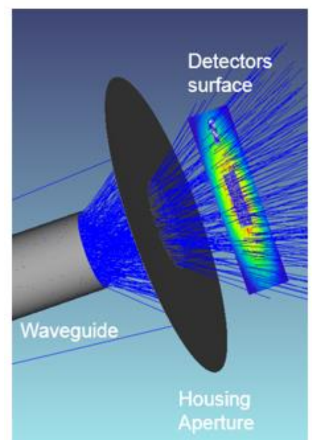
3. Acquisition System Prototype
3.2 Detectors for secondary particles shower

<u>Strategy B:</u> HDR with multiple channels using Scintillator and Photomultiplier tubes

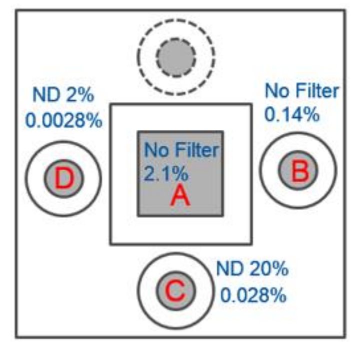
- Compatible PSB mechanics, PMT types R9880 (a = 0.5cm2) and MA R7600 (a = 0.8cm2)
- Simulations estimate photon distribution on detector plane: PhotoCathode area, ND Filters, location.
- Setup with 1e3-1e5 Gains. Each PMT 1ua - 1mA peak current pulse. Estimated Din. 1-1e6 MIPS.
- Filter wheel → dynamic channel selection after digitalization.

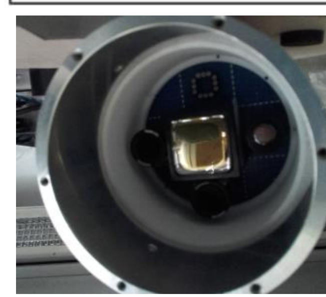






Optical Simulations

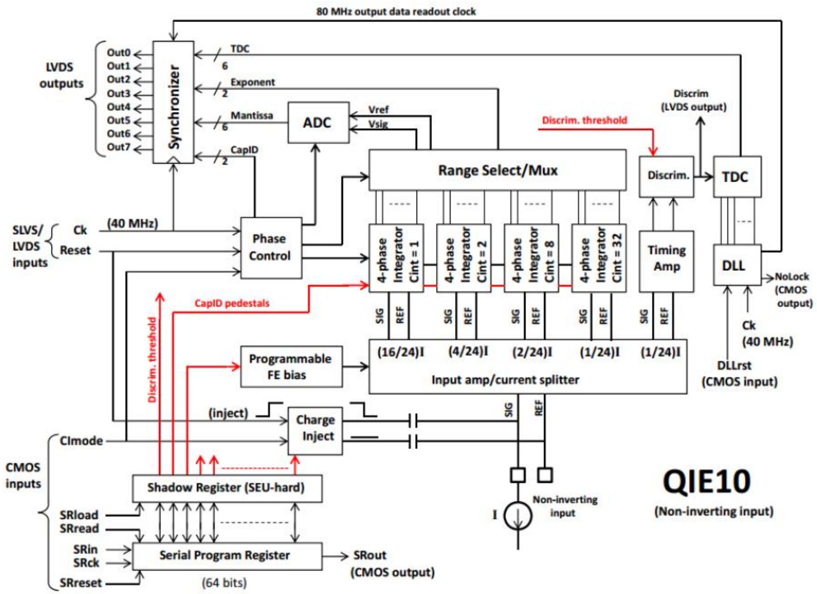




Detectors assembly

3. Acquisition System Prototype
3.3 Detector Readout ASICs under evaluation

Strategy A: QIE10 from CMS

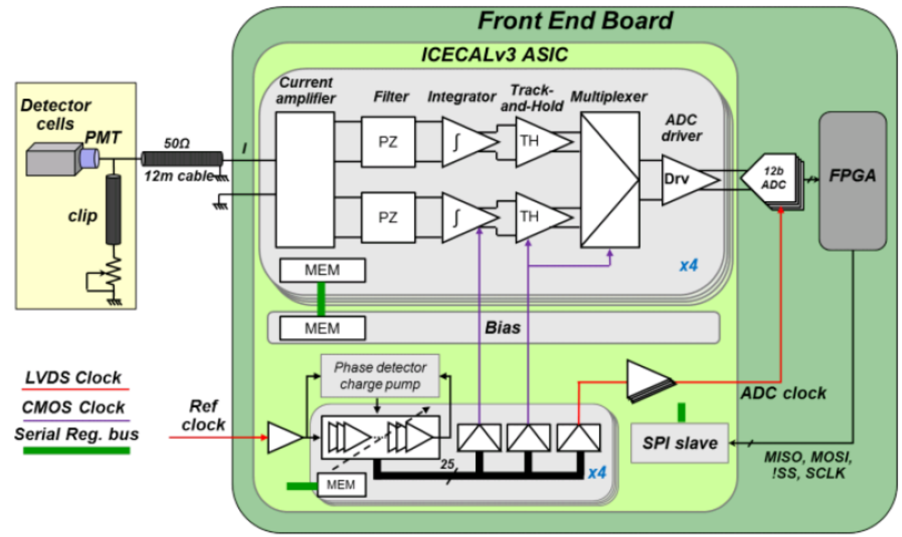


- **Functions:** 1 CH Integrator and Encoder
- **Dynamic Range:** 1e5 (3,2fC – 340pC)
- **Encoding:** Logarithmic with 8 bits.
- **Quantif. Error:** 1%
- **Technology:** AMS SiGe BiCMOS 0,35um
- **Rad. Hard:** 0,5KGy

Working principle:

- Current splitting by current mirror
- Automatic range switching and non linear ADC
- 16 sensitivity levels
- 4 interleaved integrator circuits (100ns)

Strategy B: ICECAL from LHCb



- **Functions:** 4 CH Integrator
- **Dynamic Range:** 1e3 (4fC – 16pC)
- **Encoding:** Linear, requires >= 12b ADC.
- **Quantif. Error:** << 1%
- **Technology:** AMS SiGe BiCMOS 0,35um
- **Rad. Hard: ~** 1-5 KGy (*E.Picatoste PhD.)

Working principle:

- Shaping input with Pole-Zero Filter
- Integrators + Track & Hold circuitry
- 2 interleaved integrator circuits (50ns)
- Clocking resources: PLL, delay lines…

3. Acquisition System Prototype
3.4 Prototype Implementation: HW → The Front-Ends

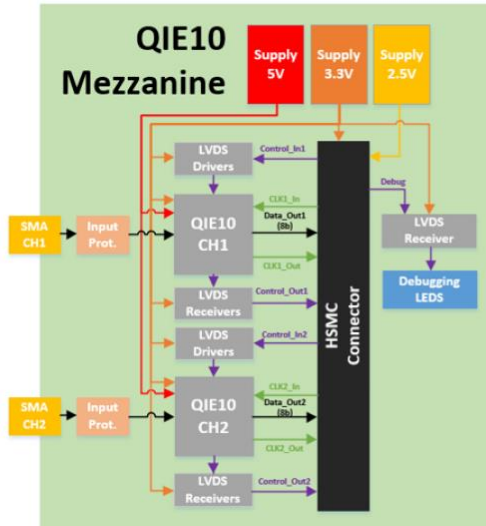
<u>Mezzanines for Igloo2 UMD:</u>

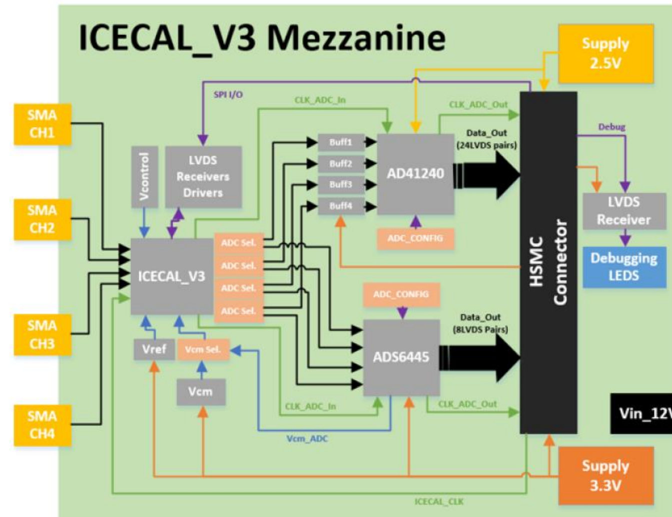
<u>QIE10 FE:</u>

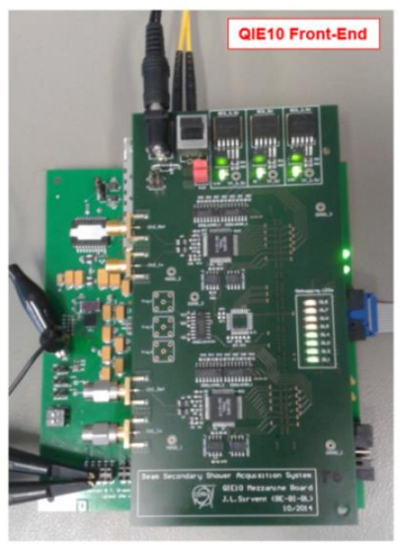
- Two QIE10 ASICs (2 ch)
- Digital data to HSMC LVDS DDR
  - 2 x 8 LVDS DDR @ 80Mbps
  - Data Stream → 1.28 Gbps
- LDO power supplies **1KGy**
- DDR LVDS Interfaces **0.7KGy**
- Debugging LEDS

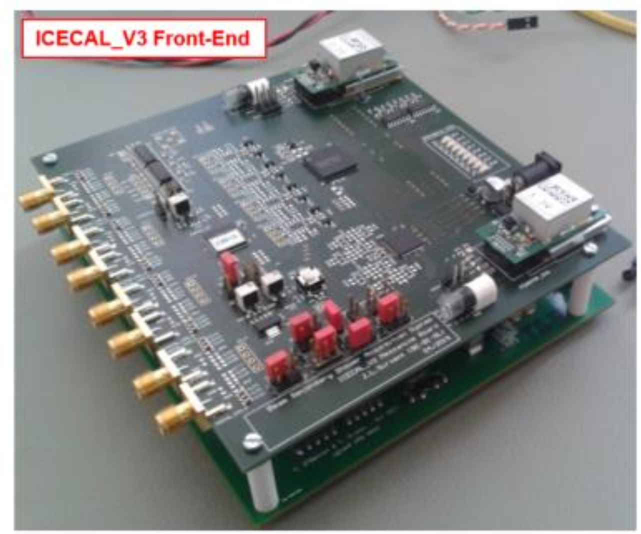
<u>ICECAL FE:</u>

- Single ICECAL ASIC (4ch)
- Two possible ADCs:
  - AD41240 (RH CERN) **100KGy**
    - 2 x 12 LVDS DDR @ 80Mbps
  - ADS6445 (COTS) **2.1KGy**
    - 4 x 2 LVDS DDR @ 320Mbps
  - Data Stream → 1.92 Gbps
- FEASTMP Power supplies **2MGy**
- Voltage bias & ref. **0.3-1KGy**
- DDR LVDS interfaces **0.7KGy**
- Debugging LEDS

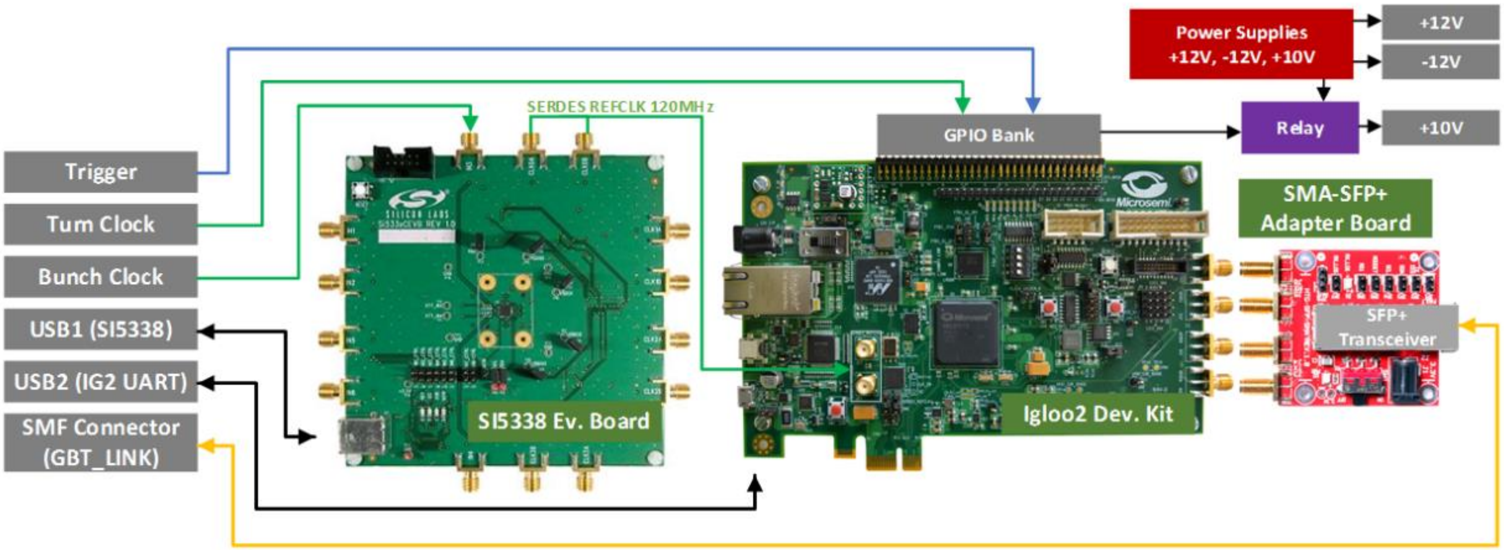








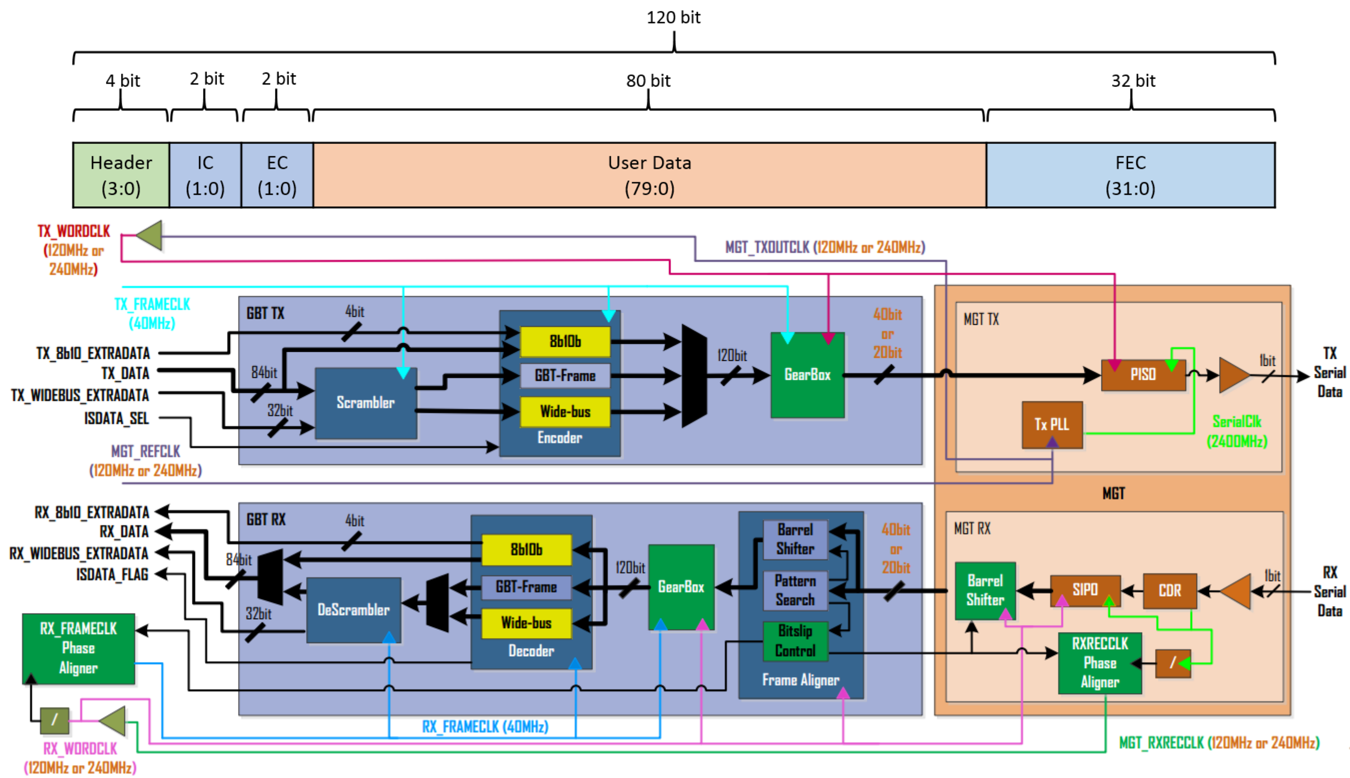
3. Acquisition System Prototype
3.4 Prototype Implementation: HW → The Back-End



3. Acquisition System Prototype

3.4 Prototype Implementation: FW → The GBT link

The CERN´S Rad-Hard and Bi-Directional Optical link



The GBT Frame:

- Protocol Bandwith → 4,8Gbps (120 bit @ 40Mhz)
- User Bandwidth → 3,2Gbps (80 bits @ 40Mhz)
- Robuts against SSE in VTRx → RS encoding with 32bit FEC
- DC Balanced data → Scrambler block
- Used for TTC, Slow control and data transmission.

Building Blocks:

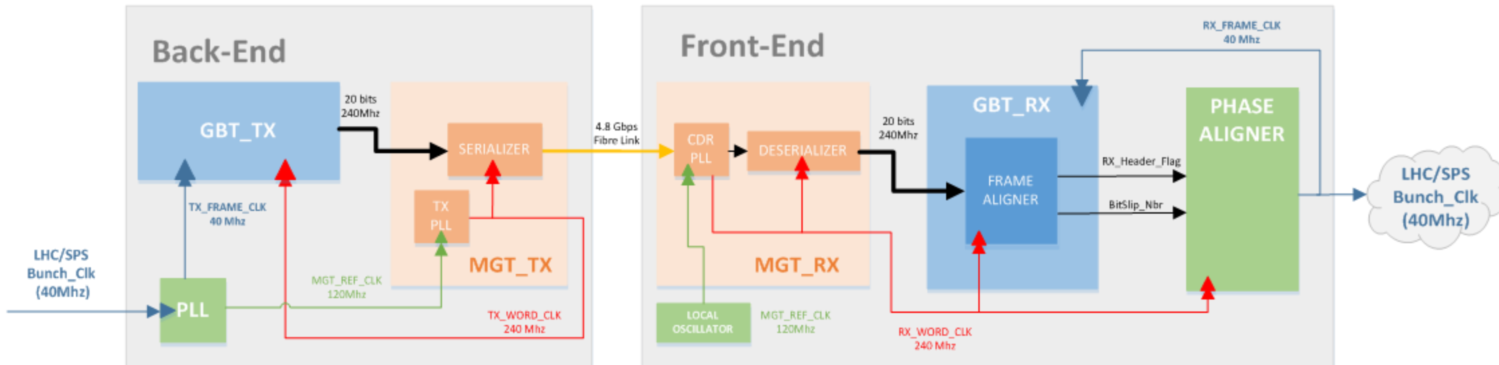
- Tunnel → RH Chipset (GBTx, VTRx, GBT-SCA)
- Surface → COTS (SFP+, FPGA)
  - Firmware → **GBT-FPGA** for Xilinx and Altera
- Prototype Emulates GBTx with a FPGAs Igloo2

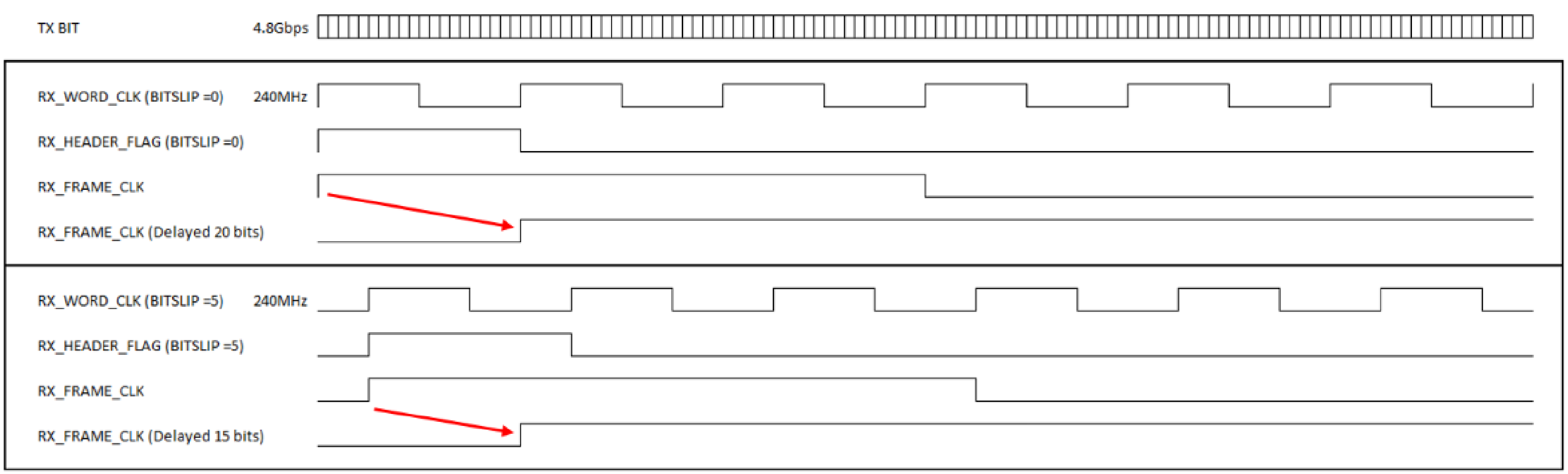
3. Acquisition System Prototype
3.4 Prototype Implementation: FW → The GBT link

Clock forwarding and recovery in FE:

From random clock phase (25ns) to only 1,4ns uncertainty

- FE ASICs need to synchronize with accelerators.
- SPS & LHC 40Mhz CLK propagated in GBT Link.
- Required deterministic clock latency and phase.
- B.CLK injected in BE, recovered and aligned in FE.
- FE CDR locks in bitstream, PLL follows in CDR with **header** reference.
- PLL uses programmable delay lines with 100ps delay steps (**bitslip**).





3. Acquisition System Prototype

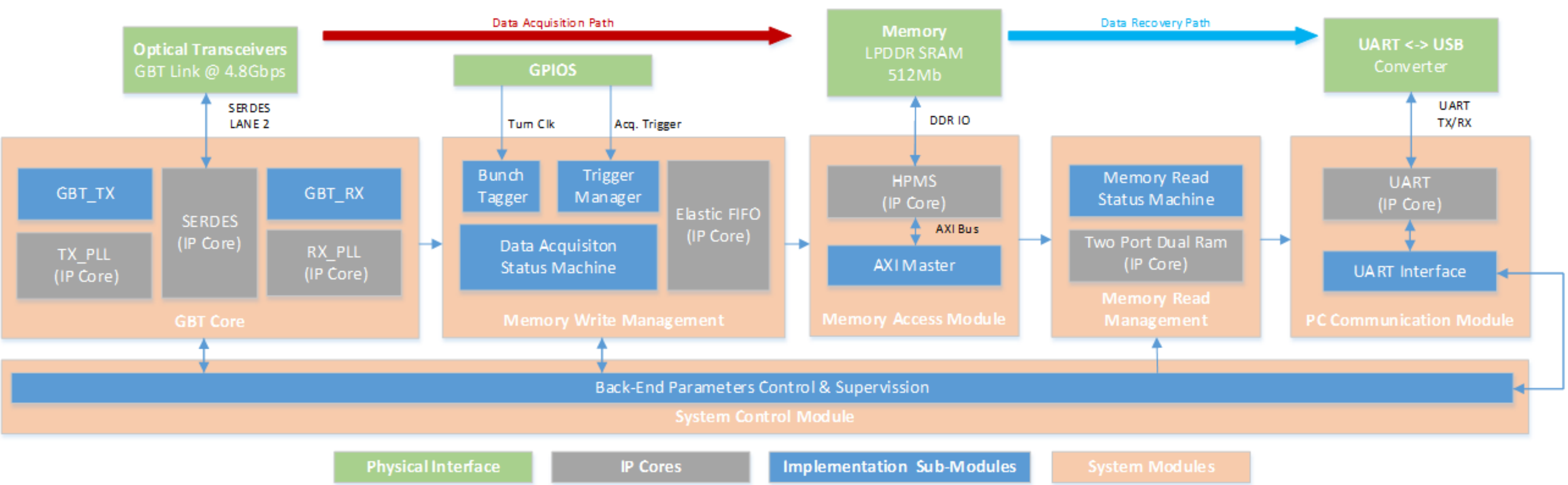
3.4 Prototype Implementation: FW → Back-End

Back-End Firmware features:

- Memory storage with 64b words:
  - Bunch ID + 51b GBT payload
  - Storage up to 200ms (4e6 words)
  - Several Acq. Modes.
- Memory Write-Read Interfaces:
  - Usage of HPMS IP core for LPDDR
  - Elastic FIFOs read-write
- GBT Core: LATOP version
  - Bunch tagging on surface
- System Control Module:
  - Controls BE workflow and status (User App)
  - Monitors for debugging

Identifiers (13 Bits)		Payload ICECAL_V3 (51 Bits)					
Turn_Ref (1Bit)	Bunch_Id (12 Bits)	UNUSED (2 Bits)	SubCh_ID (1 Bit)	ICE_CH3 (12 Bits)	ICE_CH2 (12 Bits)	ICE_CH1 (12 Bits)	ICE_CH0 (12 Bits)

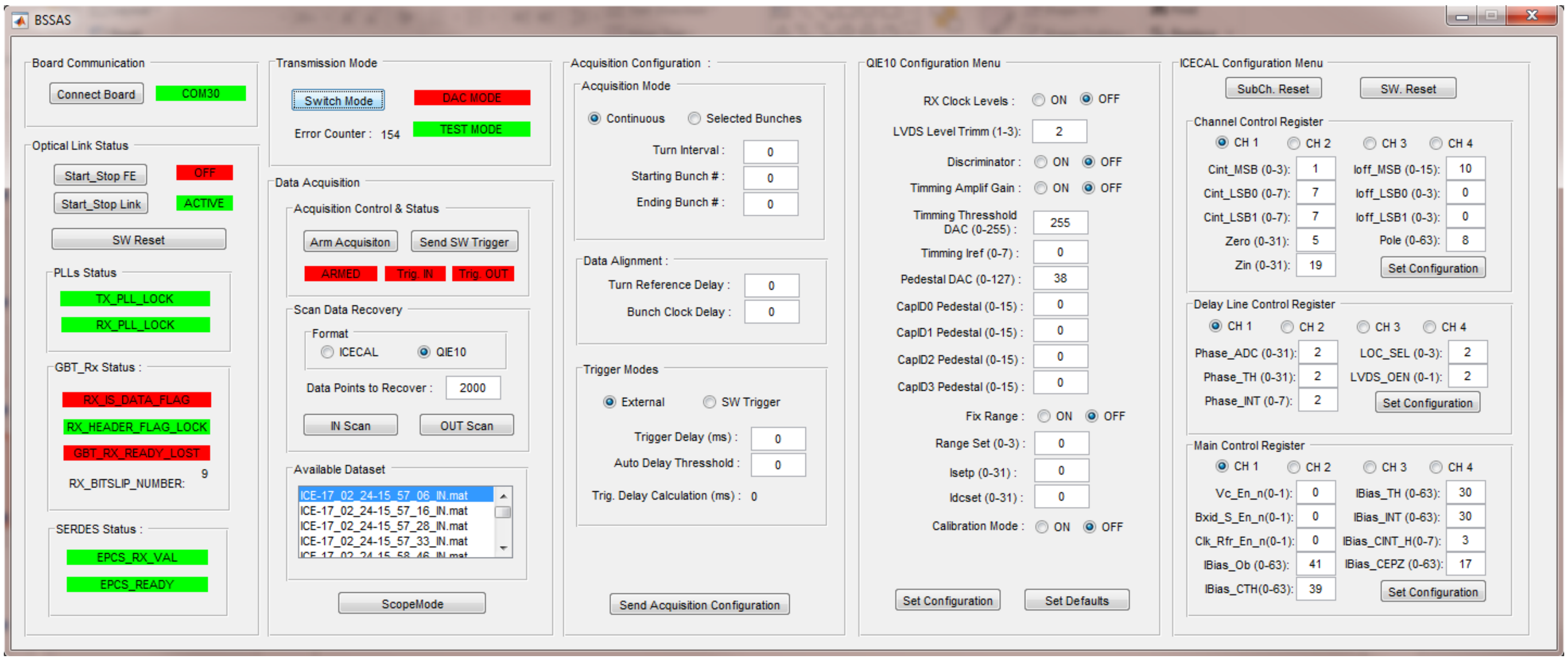
Identifiers (13 Bits)		Payload QIE10 (51 Bits)								
Turn_Ref (1Bit)	Bunch_Id (12 Bits)	UNUSED (15 Bits)	QIE_1 Discrim (1 Bit)	QIE_0 Discrim (1 Bit)	QIE_1 No_Lock (1 Bit)	QIE_0 No_Lock (1 Bit)	QIE_1 TTC (8 Bits)	QIE_1 DATA (8 Bits)	QIE_0 TTC (8 Bits)	QIE_0 DATA (8 Bits)



3. Acquisition System Prototype
3.4 Prototype Implementation: User Application

MATLAB® application with Communications toolbox (UART)

- Running on a local PC connected by USB to the Igloo2 Dev.Kit
- Controls acquisition, GBT link status, data recovery and Front-end configuration



GBT link:
Control and debugging
Start-Stop, reset

Acquisition control and data recovery:
Trigger type, FE type, data download,
Acq. Mode

QIE10 Registers:
Chips configuration,
CID offset, calib.

ICECAL Registers:
Ch. Reset, Gains, Pole-Zero,
Delay lines, Biasing

Presentation Outline

1. Introduction
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4. **Laboratory qualification**
5. Beam tests in SPS and PSB
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4. Laboratory qualification
4.1 pCVD Diamond detectors test with Alpha Source

Objectives:

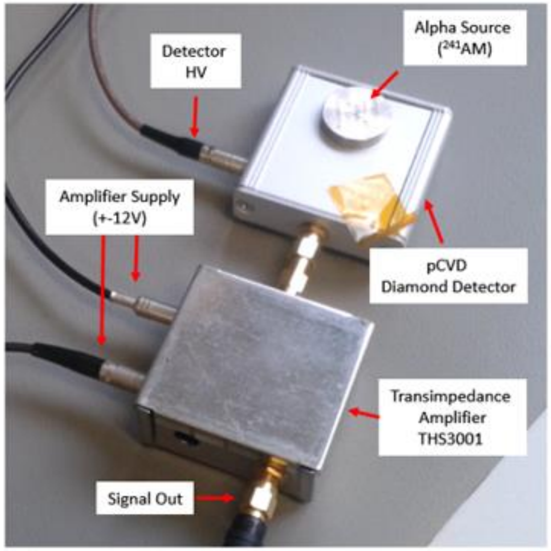
- Check TIA BW for 25ns structures
- Setup pre-installation check.

- Q_MIP → 1.4 - 1.6fC
  - 36e/um * 500um * 50 % CCD
  - Pions, Electrons >400 kEv
  - Protons >10MeV
  - Crossing particles

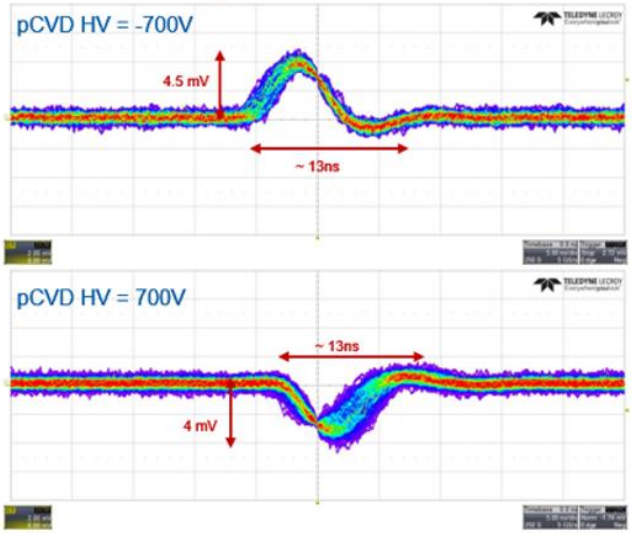
Outcome:

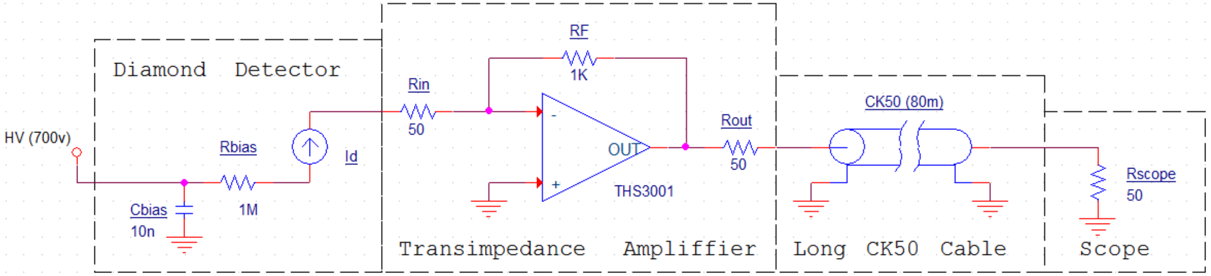
- Q_Alpha (241Am) → 90fC
  - Absorbed particles
  - Much more deposited E.

- TIA Recovery time < 13ns
- Setup Noise RMS < 1mv

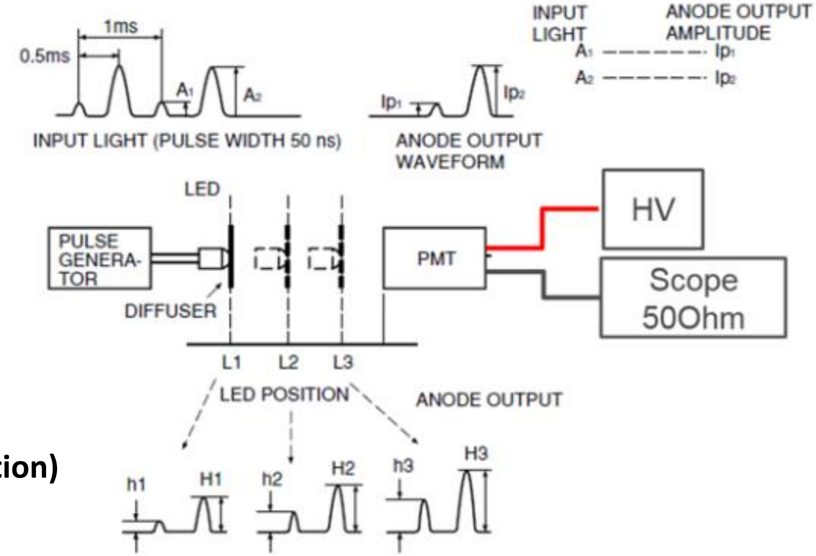


Transimpedance EDA-01716





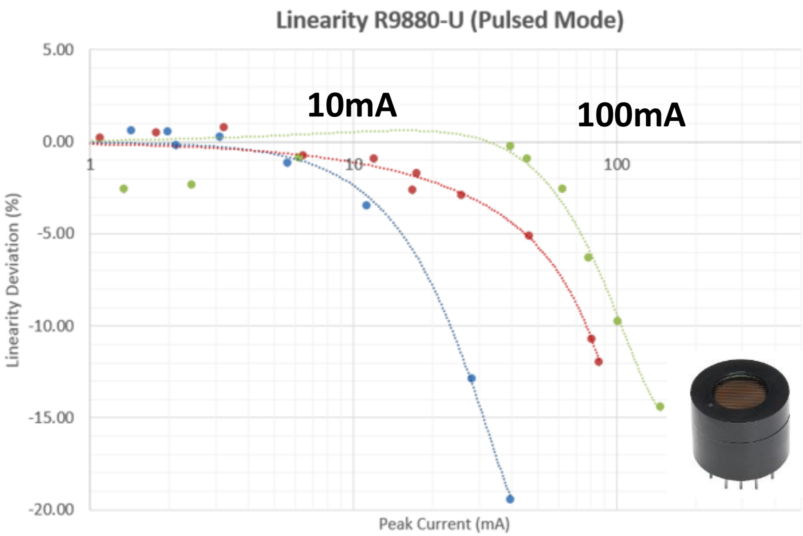
4. Laboratory qualification
4.2 Working point of M-PMT Detectors: Linearity



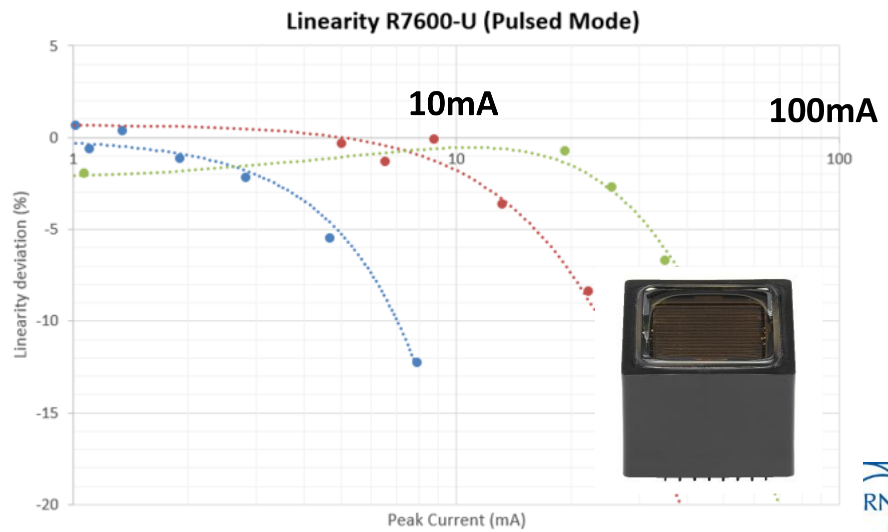
<u>Linearity study with double pulsed LED:</u>

- **Determination of Space-Charge limits.**
- Define linearity limits for diff. HV.
- Ensure proper operation during tests.
- Metal channel PMT **Type R9880**:
  500V < 10mA // 800V < 40mA // 1100V < 70mA
- Multi-Anode Metal Channel PMT **Type R7600 (4ch)**:
  400V < 8mA // 650V < 40mA // 900V < 100mA

Custom HV Bases to avoid PMT Saturation (Voltage re-distribution)



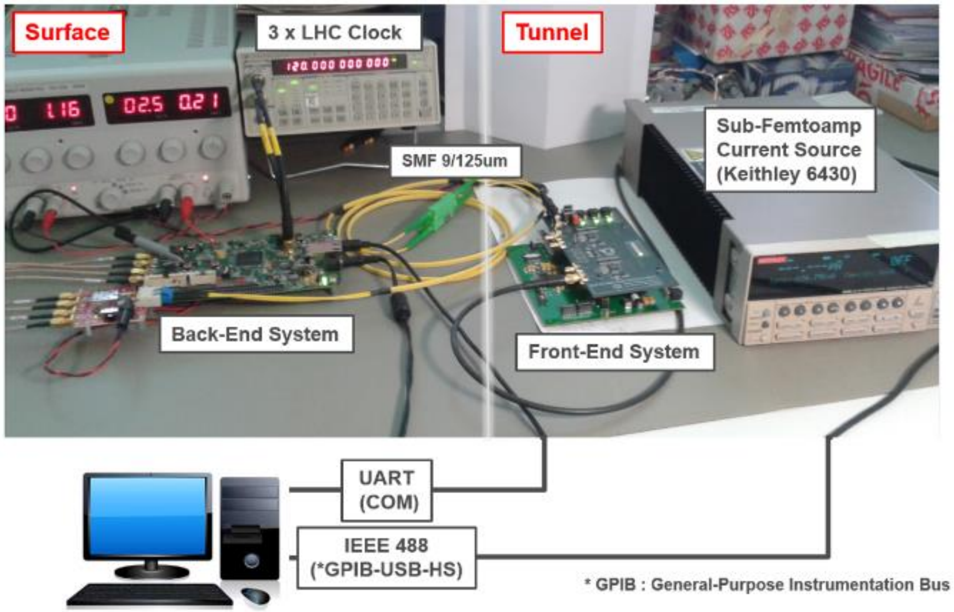
HV = 500V 800V 1100V



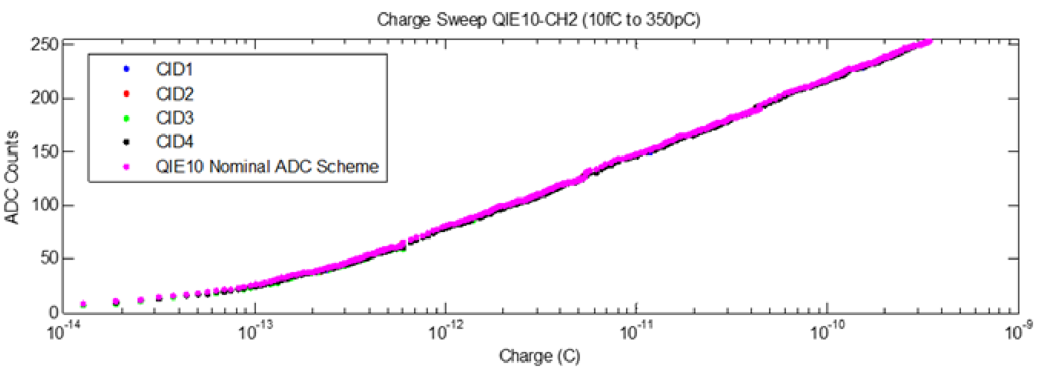
HV = 400V 650V 900V

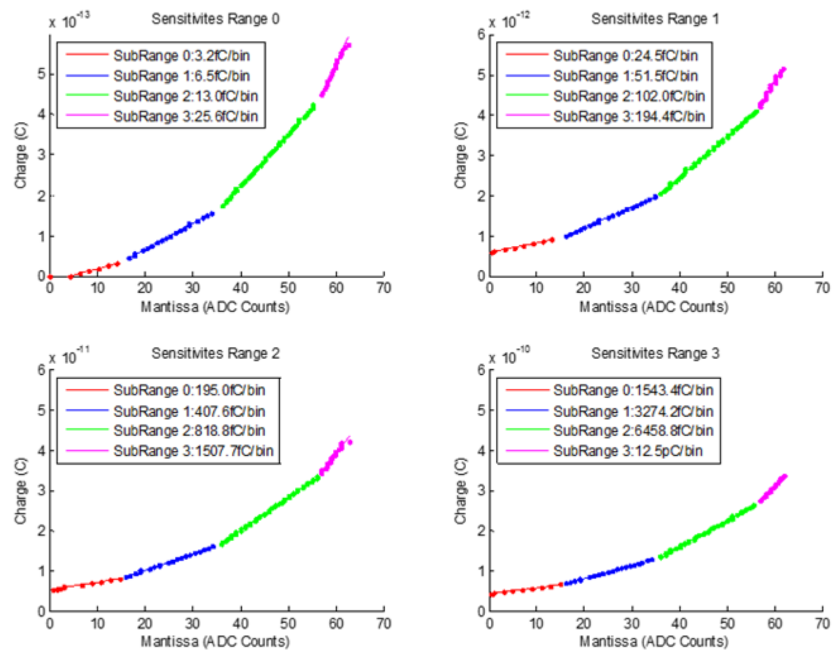
4. Laboratory qualification
4.3 Tests with QIE10 Front-End

Front-End QIE10: Lab Set-up for Linearity characterization



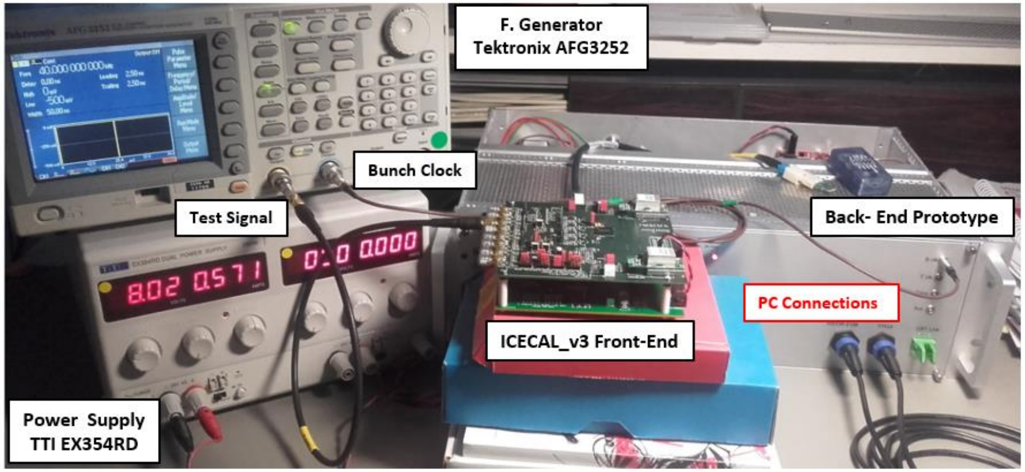
Automatized Setup:
- GPIB control of DC current source
- Pseudo-Logarithmic encoding
  - Automatic range selection (16 ranges)
- Boundaries ~ **3.2fC – 340pC**
- **1e5** Dynamic range per ASIC.
- ~ **1%** Non linearity (logarithmic)





4. Laboratory qualification
4.4 Tests with ICECAL_V3 Front-End

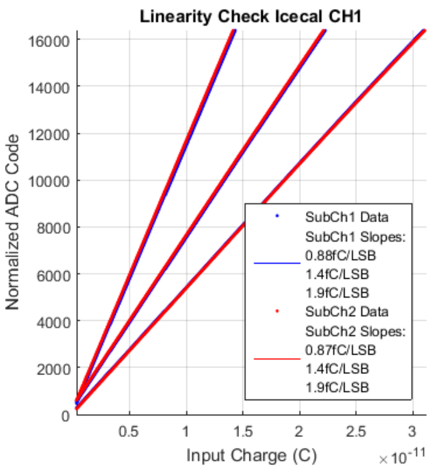
Front-End ICECAL_V3: Lab Set-up for Linearity characterization

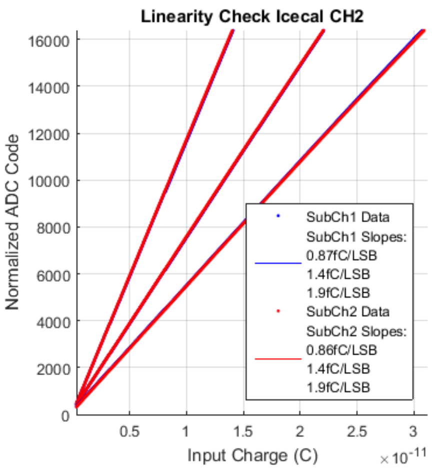


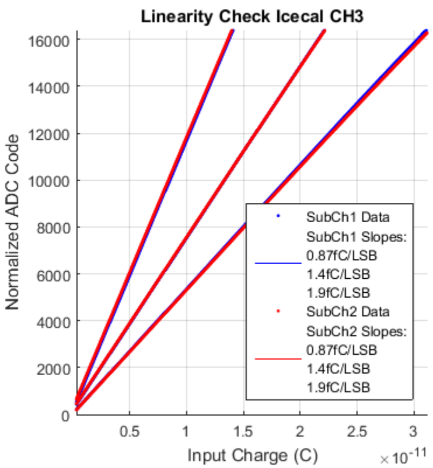
Automatized Setup:

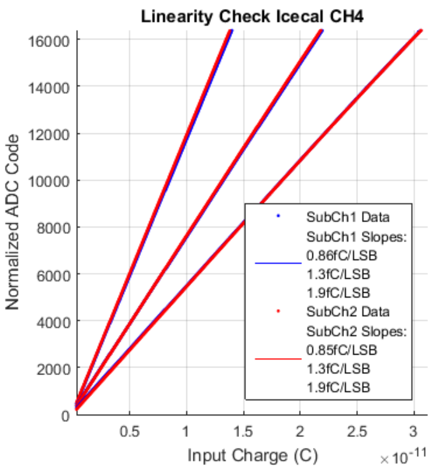
- AC Coupled ICECAL Inputs
- 50ns Pulses in synch. with B.Clock
- GPIB controls pulses amplitude

- Selectable slope
- Sensitivity ~**10.4fC (@ 0.8 fc / LSB)**
- Saturation ~**30.3pC (@ 1,9 fc / LSB)**
- **1.3e3** Dynamic range per channel.
- **< 1%** Non linearity





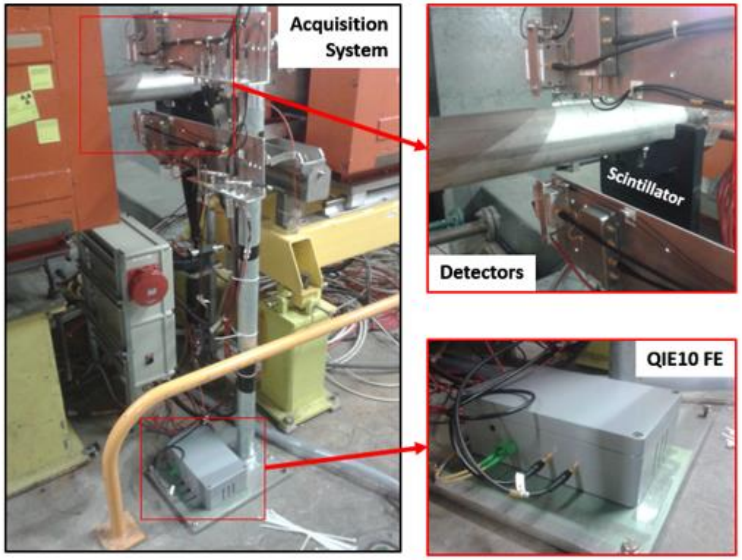


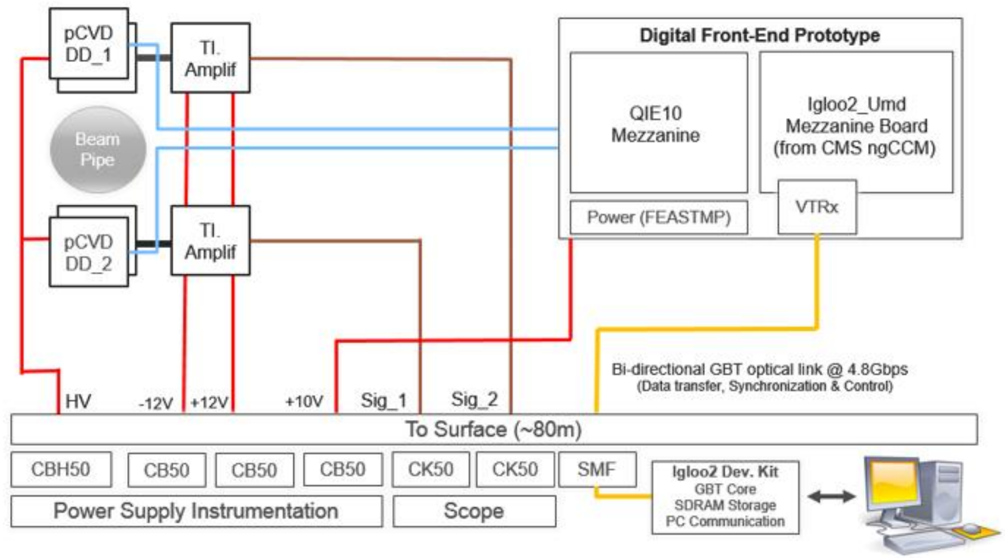


Presentation Outline

1. Introduction
2. Design considerations and particle physics simulations
3. Acquisition system prototype: Design and implementation
4. Laboratory qualification
5. **Beam tests in SPS and PSB**
6. Summary and conclusions

5. Beam Tests in SPS and PSB
5.1 Tests in SPS: Installation setup





Tests Objetives:

- Determine usability of diamond detectors for BWS
- Test QIE10 FE under operational conditions.
- Analyse improvements with local readout.
- Equipment for first LIU-BWS prototype
  - Comparative measurements with Op.
  - LIU-BWS performance with beam.

Locations:

- Close to linear BWS517 1ms-1
- Close to LIU-BWS prototype 20ms-1

Detectors:

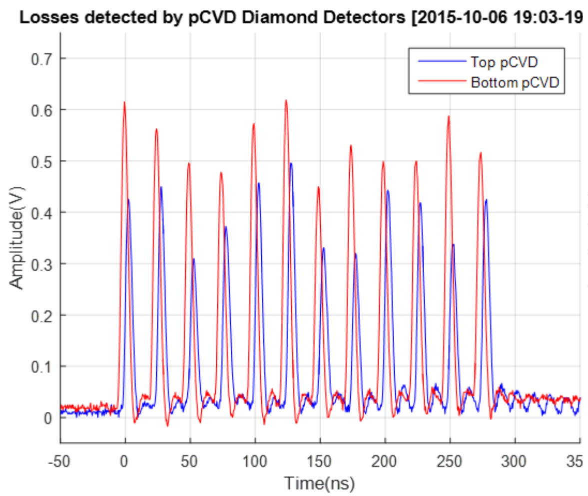
- 4 x pCVD Diamond detectors
- Operational Scintillator detectors

Readout:

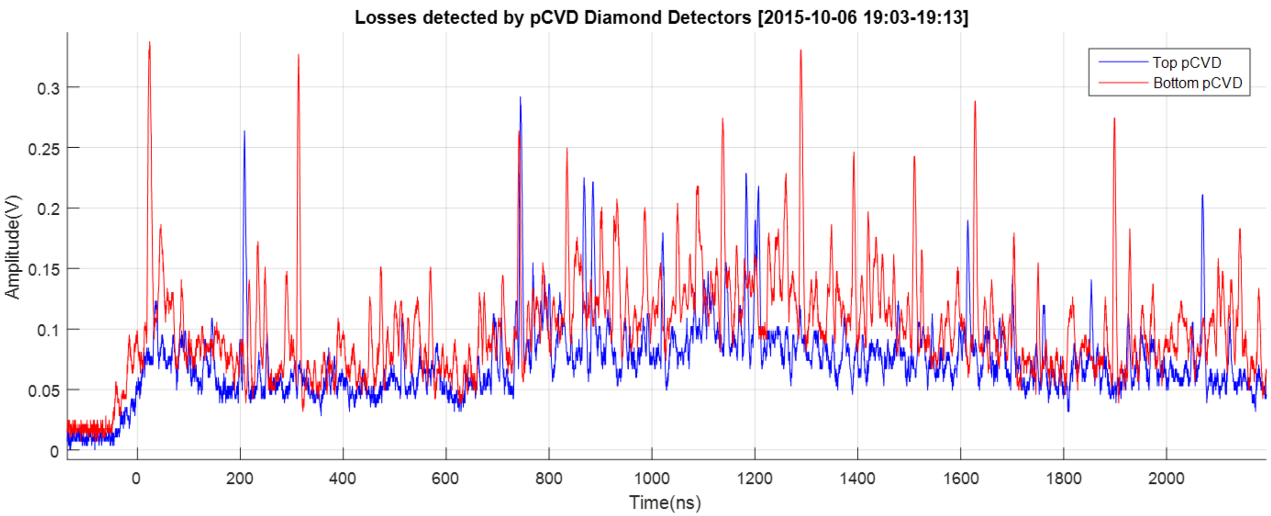
- QIE10 Front-End (2 detectors)
- Surface Scope at 80m (2 detectors)

5. Beam Tests in SPS and PSB
5.1 Tests in SPS: pCVD Diamond detectors

Raw traces recorded in surface scope (CK50 80m):



Random loses with 25ns Structures



Long Injection loses

Observations:

- Detector signal amplitude difference does **not keep proportionality.**
- Top & Bottom detectors do **not fully agree on loses structure** (see long injection loses)
- **Some** loses are **only detected in one** pCVD diamond detector.

First **clues of statistical effects** on low intensity losses

5. Beam Tests in SPS and PSB
5.1 Tests in SPS: pCVD Diamond detectors

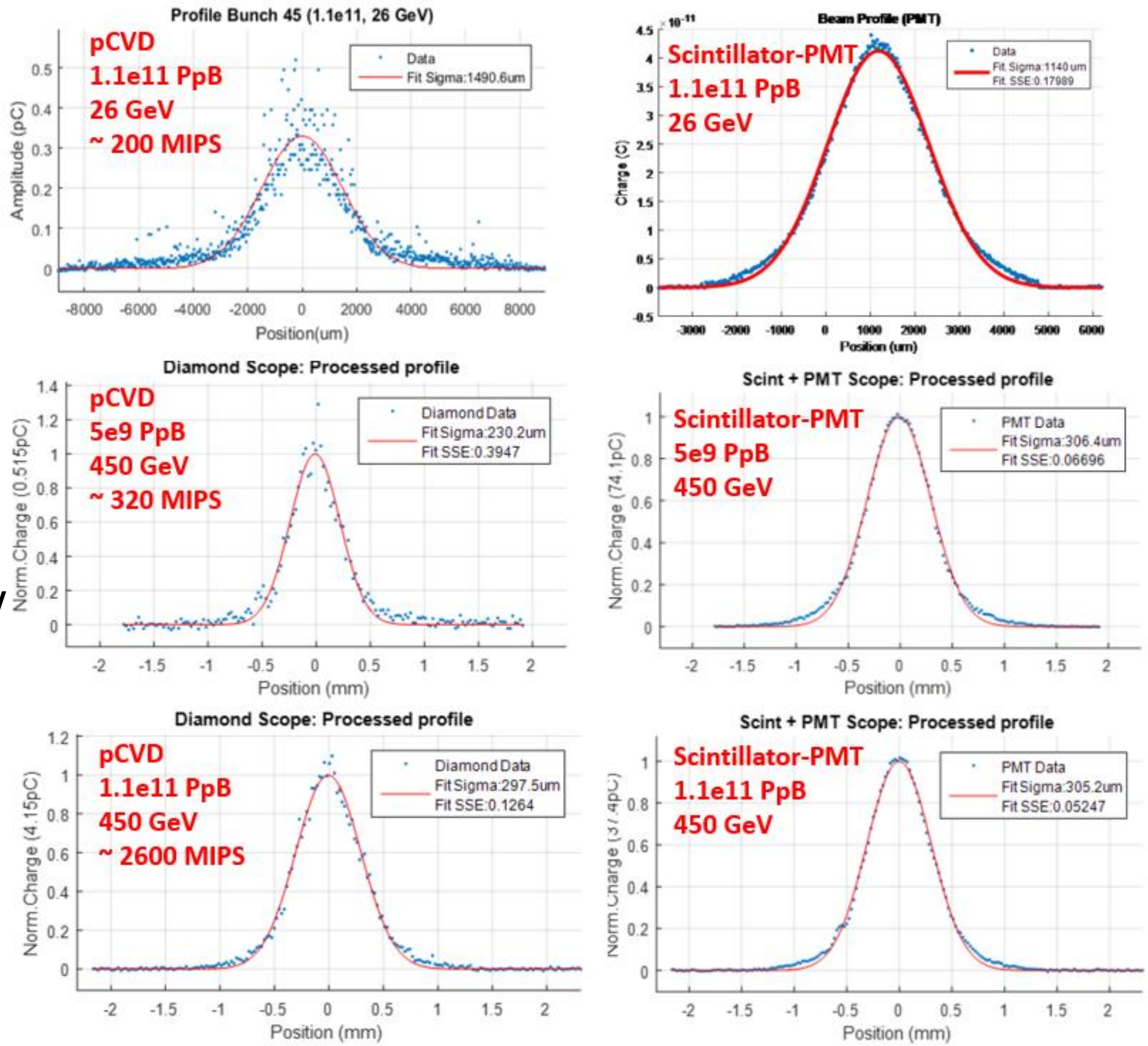
Initial tests with Linear BWS517 (1ms-1):

- Profiles with Scint (20x20cm)
- Profiles with pCVD (1x1cm)
- Different beam conditions:
  - Intensity & Energy

Outcome:

- **Better defined** profiles with **Scintillator**
- Very **small improvement combining** pCVDs
- pCVDs did **not detected 5e9 @ 26GeV**
- Only **comparable** results **1.1e11p @ 450GeV**

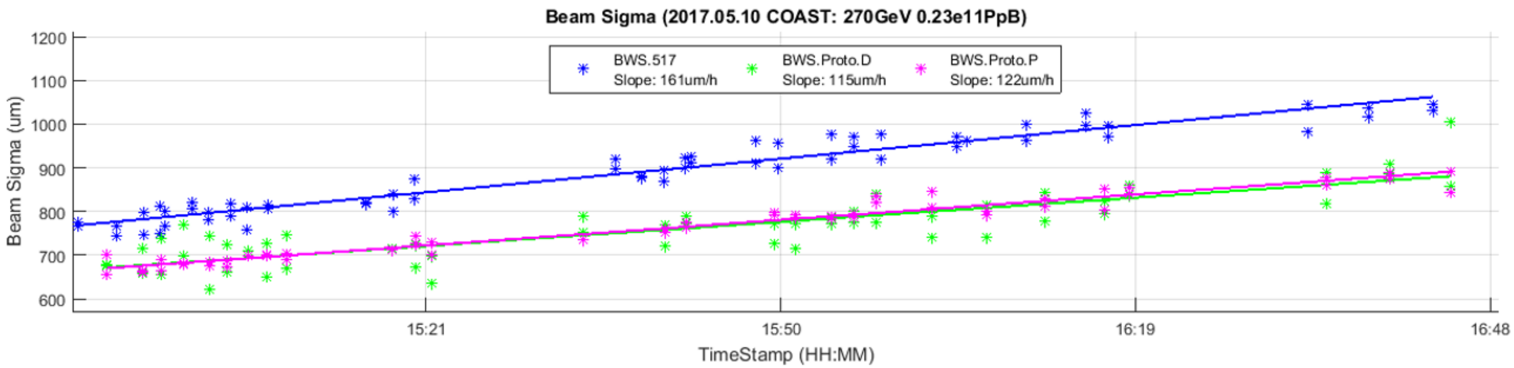
pCVD detectors seem to be **too small**, very **few particles cross their area** in each beam-wire interaction.

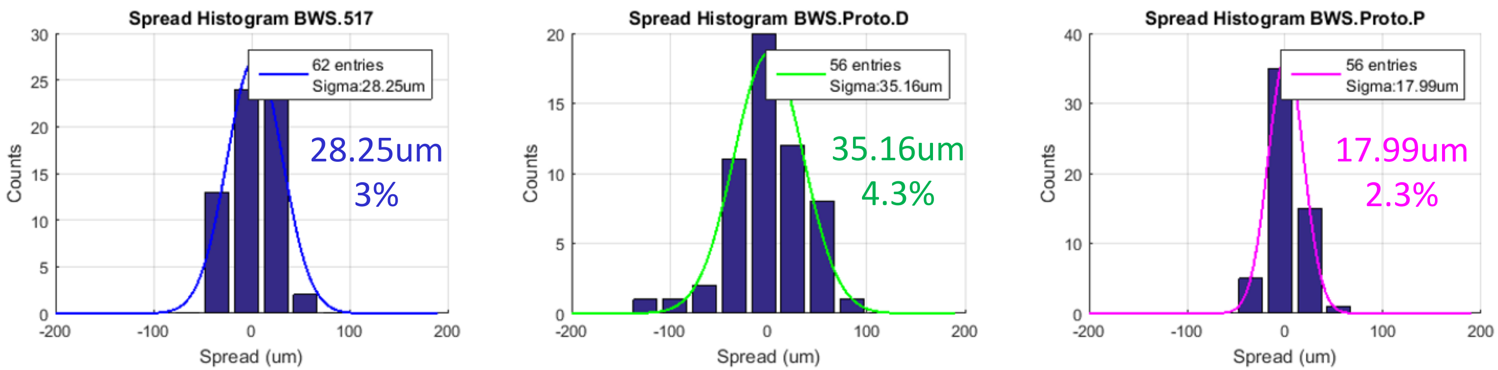


5. Beam Tests in SPS and PSB
5.1 Tests in SPS: pCVD Diamond detectors

How diamond detectors perform in a measurement campaign compared with scintillators?

- Test system displaced to LIU-BWS Prototype (5m away from BWS517 lin)
- Beam is a **COAST type 0.23e11 PpB @ 270GeV** circulating during hours → Emittance growth





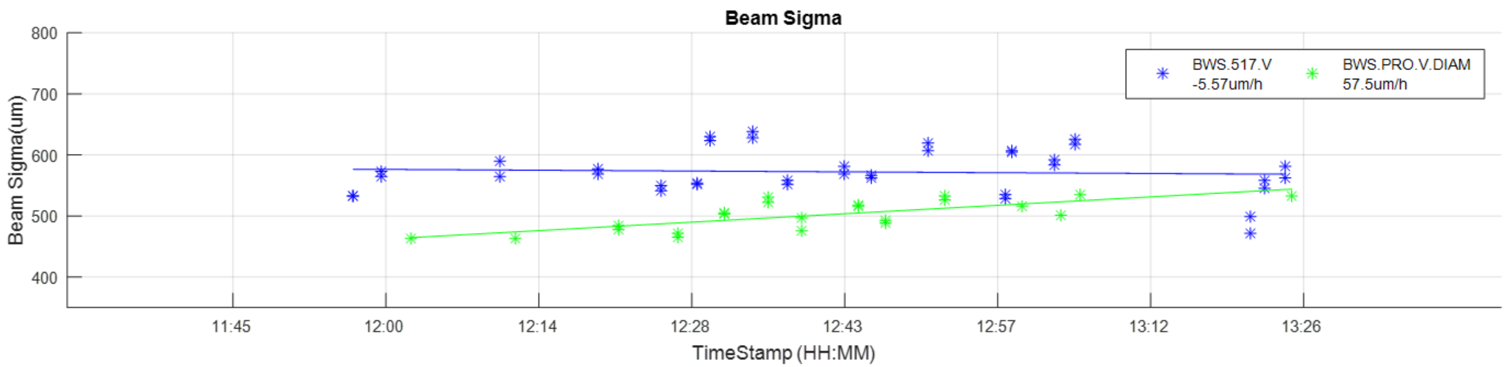
OP BWS517 Lin (1ms-1) 39 PpS
Scintillator 20x25x1cm

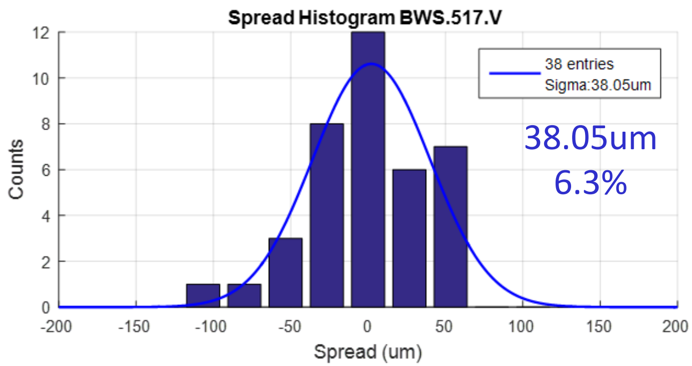
LIU-BWS Prototype (20ms-1) 1.7 PpS
pCVD Diamond 1x1cm
Scintillator 10x10x1cm

5. Beam Tests in SPS and PSB
5.1 Tests in SPS: pCVD Diamond detectors

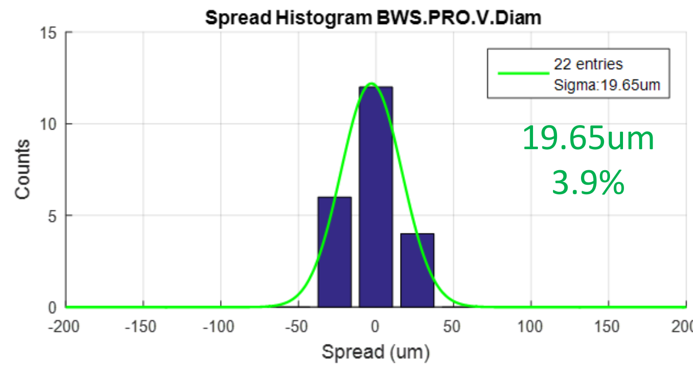
How diamond detectors perform in a measurement campaign compared with scintillators?

- Test system displaced to LIU-BWS Prototype (5m away from BWS517 lin)
- Beam is a **AWAKE type 1.1e11 PpB @ 400GeV** (Subject to shot by shot variations)





OP BWS517 Lin (1ms-1) 26 PpS
Scintillator 20x25x1cm

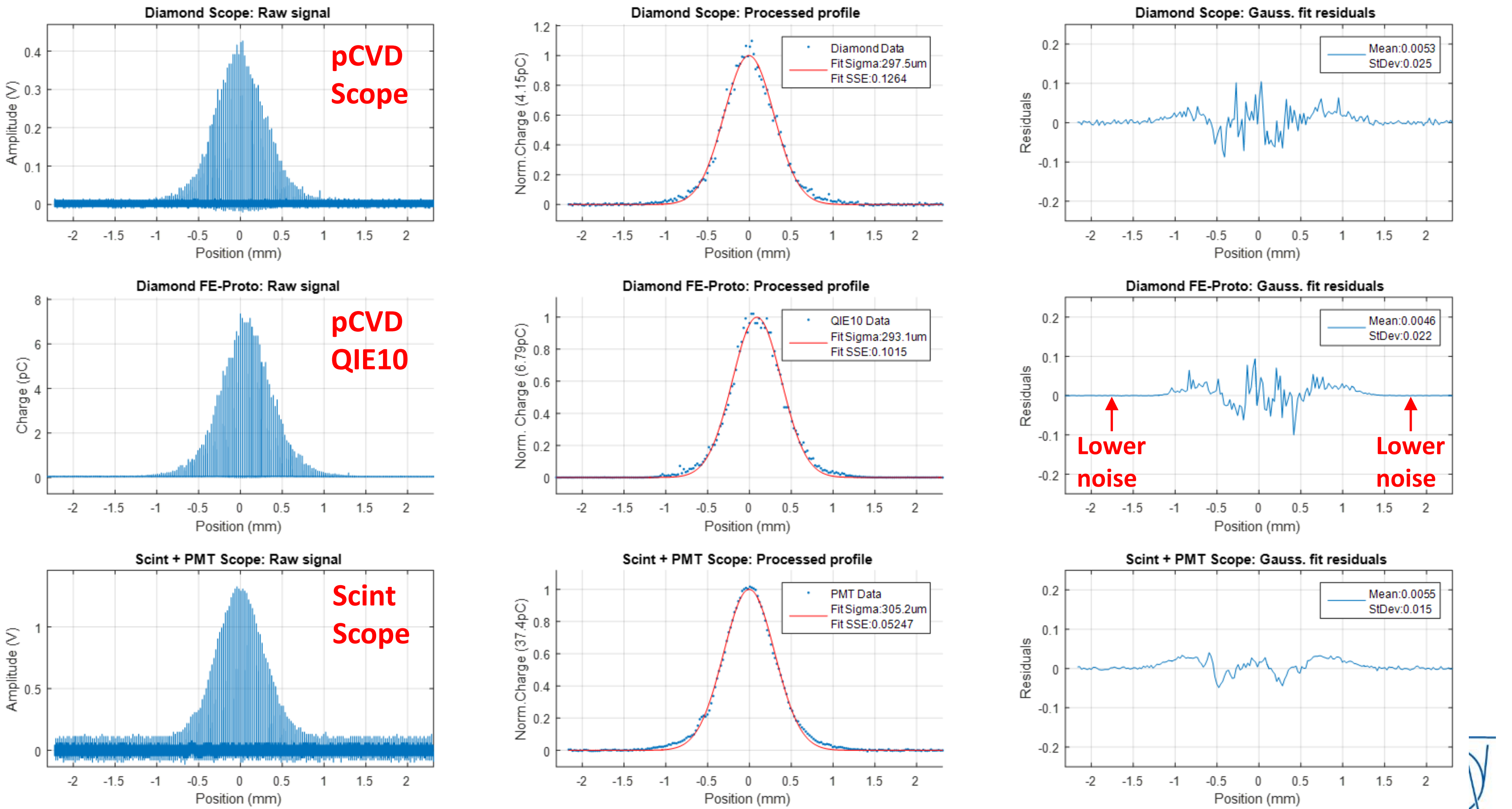


LIU-BWS Prototype (20ms-1) 1.08 PpS
pCVD Diamond 1x1cm

5. Beam Tests in SPS and PSB
5.1 Tests in SPS: HDR System with QIE10

<u>Operation of the QIE10 FE for pCVD Diamond detector readout:</u>

- Nominal SPS Beam 1.1e11 @ 450GeV (single bunch)
- Diamond dominated by amplitude statistics, but QIE10 showing lower noise levels



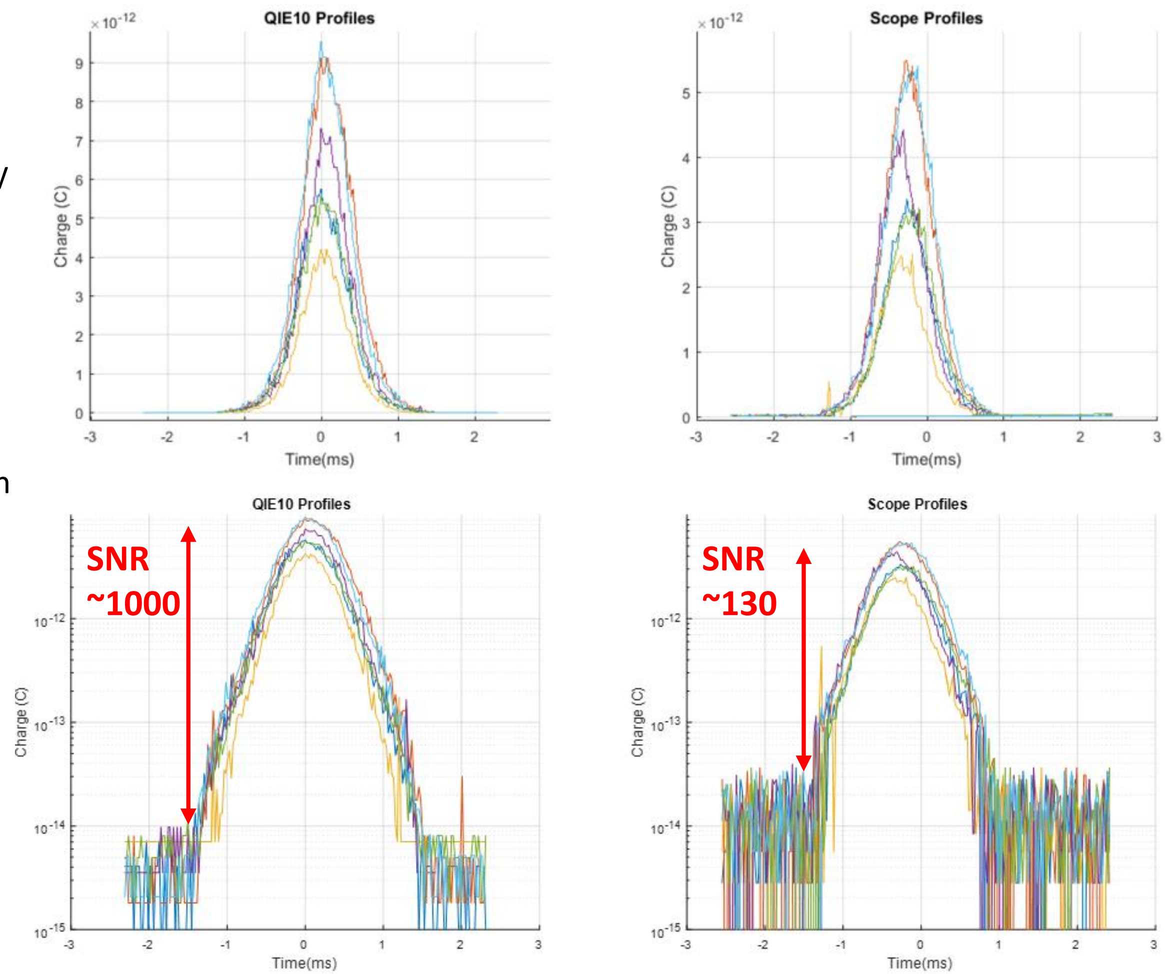
5. Beam Tests in SPS and PSB
5.1 Tests in SPS: HDR System with QIE10

Operation of the QIE10 FE for pCVD Diamond detector readout:

- Nominal SPS Beam 1.1e11 @ 450GeV (single bunch)
- Diamond dominated by amplitude statistics, but QIE10 showing lower noise levels

Outcome:

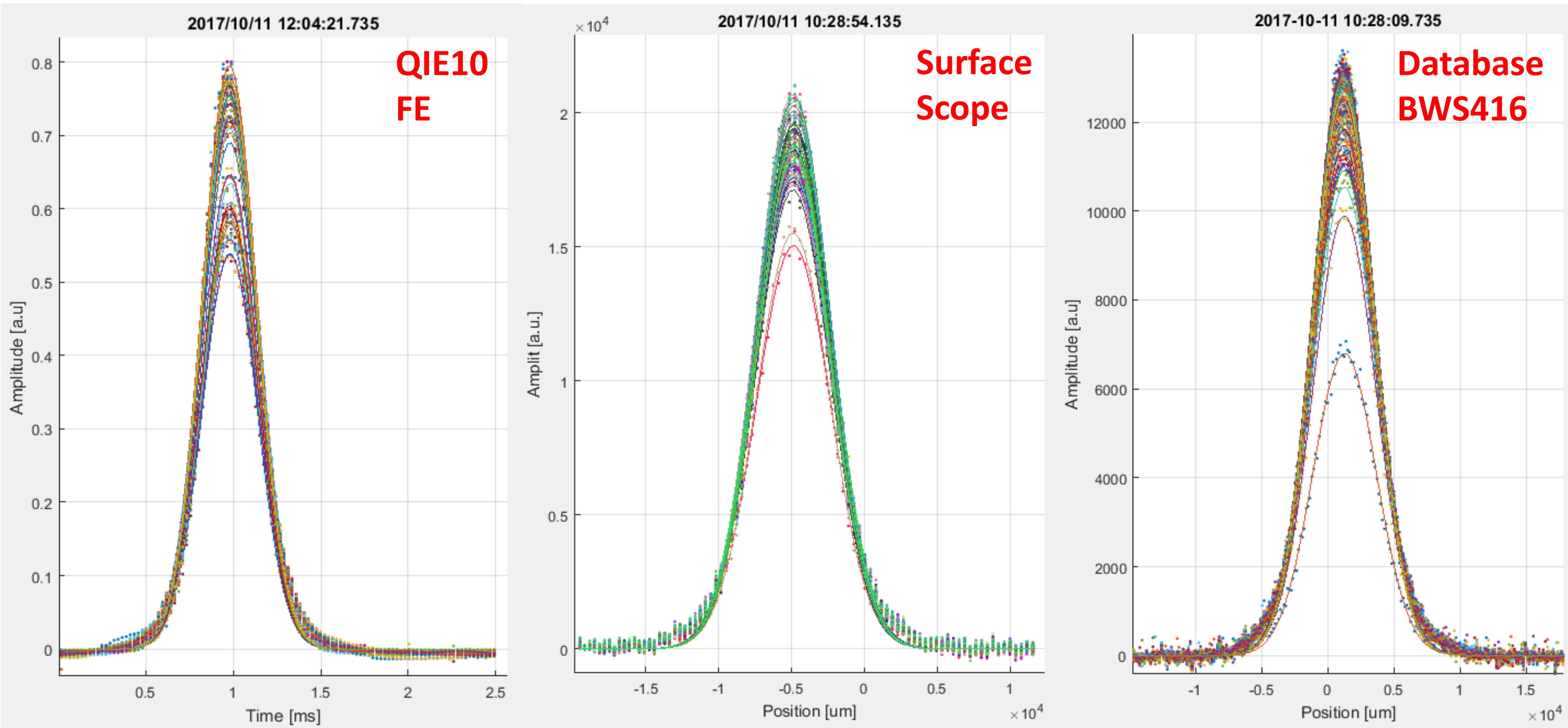
- Lower noise than in surface
  - pCVD TIA signals 20-400mV
- QIE10 Noise level ~ 3fC (2MIPs).
- No degradation in 1.5 years.
- pCVD Single conf. for all beams.
- QIE10 never saturated.
- FE Synchronization successful with no drift.
- ASIC exploited pCVD properties
- pCVD Coverage 6 - 0.2e6 MIPs



5. Beam Tests in SPS and PSB
5.1 Tests in SPS: HDR System with QIE10

Operation of the QIE10 FE for PMT readout (Comparison with Operational ACQ.Systems):

- Nominal SPS Beam STD/BCMS high intensity @ 450GeV (Multi-bunch structure 48b).



5. Beam Tests in SPS and PSB
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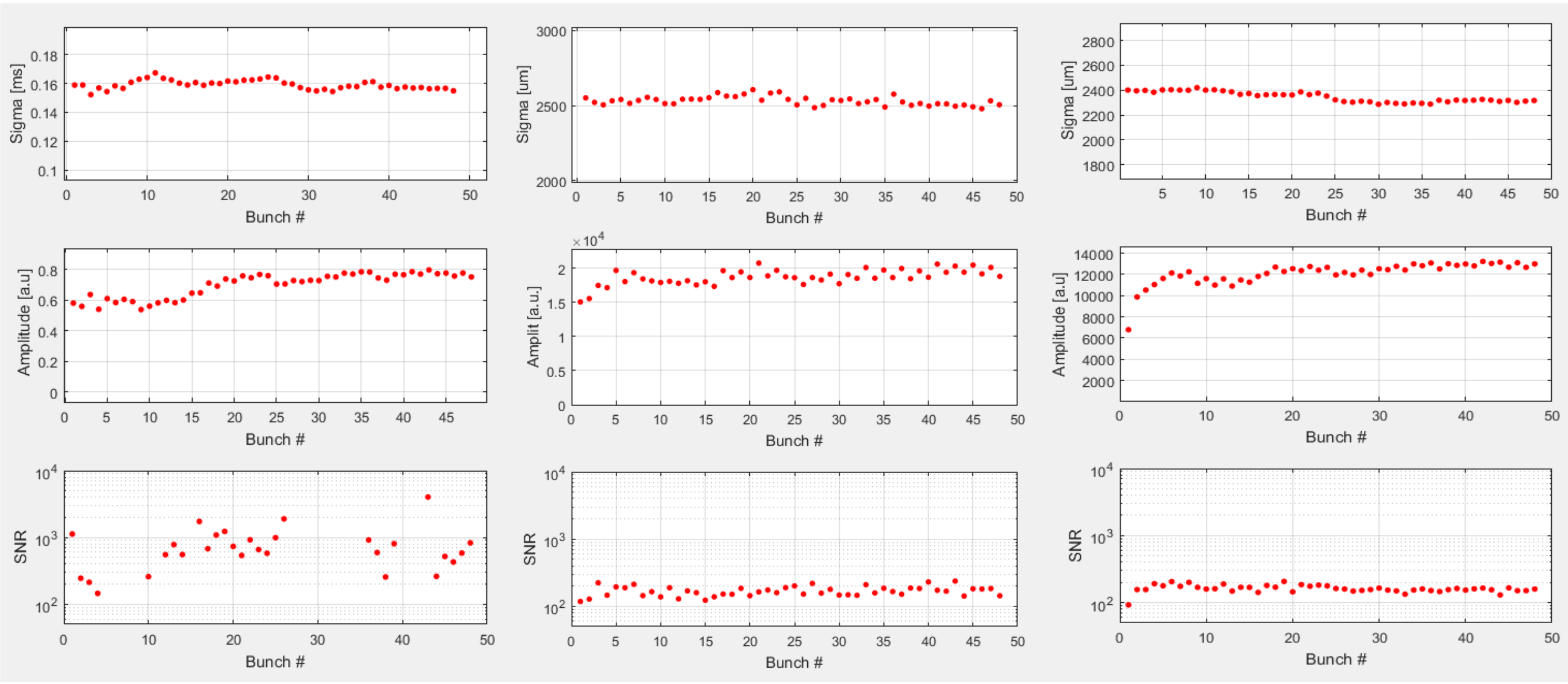
<u>Operation of the QIE10 FE for PMT readout (Comparison with Operational ACQ.Systems):</u>

- Nominal SPS Beam STD/BCMS high intensity @ 450GeV (Multi-bunch structure 48b).

QIE10 FE | **Surface Scope** | **Database BWS416**



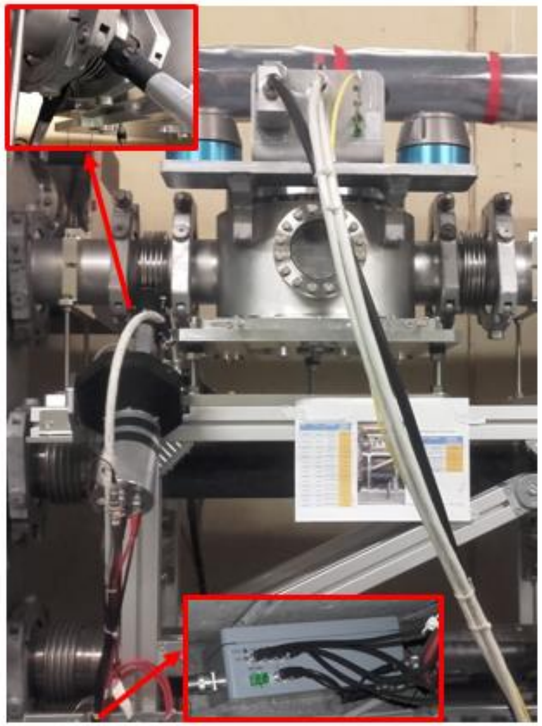
SNR ~ 150-1100

SNR ~ 150-200

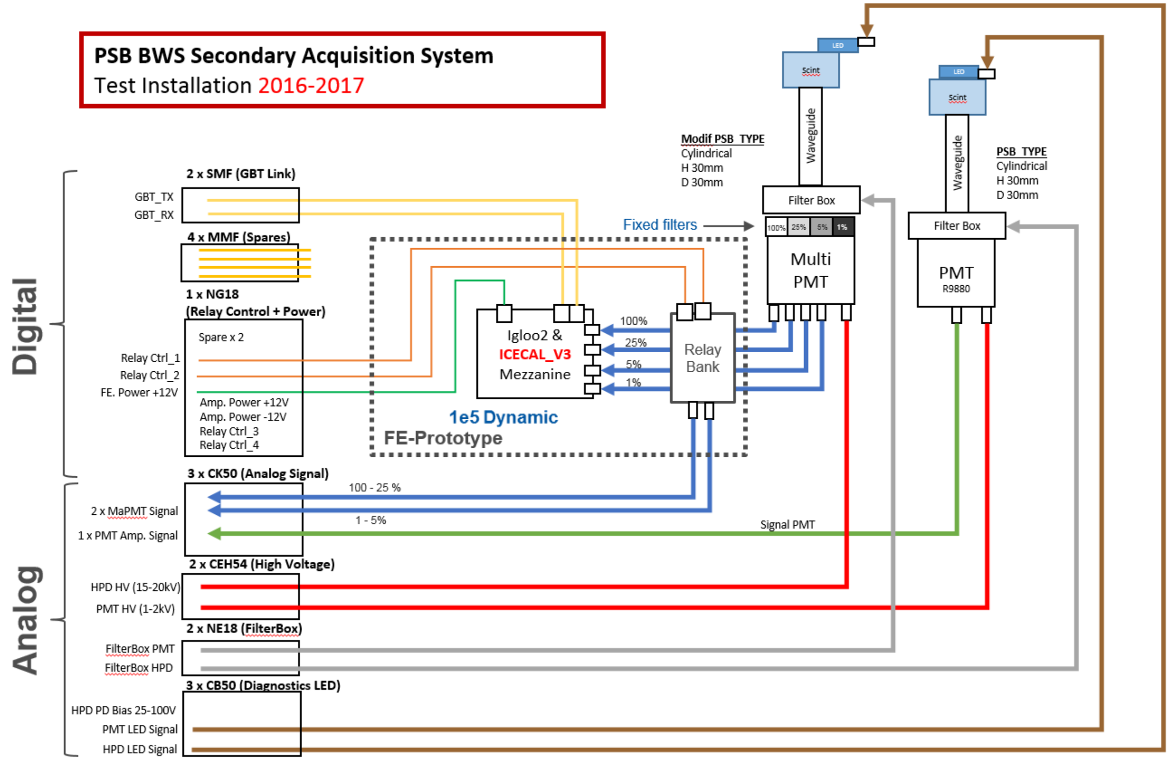
SNR ~ 150-200

5. Beam Tests in SPS and PSB
5.2 Tests in PSB: Installation setup

Detectors detail



ICECAL_V3 FE detail



Tests Objetives:

- Equip LIU-BWS prototype on PSB 4L1
- Check dynamic range coverage with M-PMT
- Test ICECAL FE under operational conditions

Detectors:

- Two detectors based on Scintillator + PMT
- 1 x Operational, 1 x M-PMT

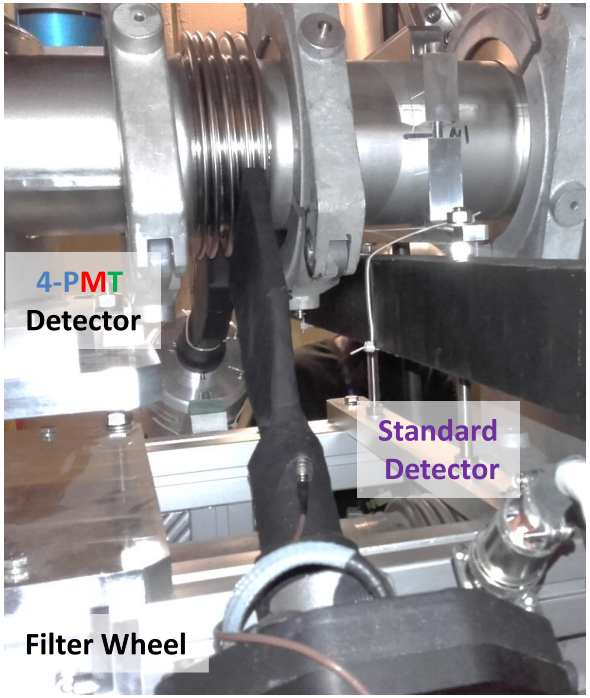
Readout:

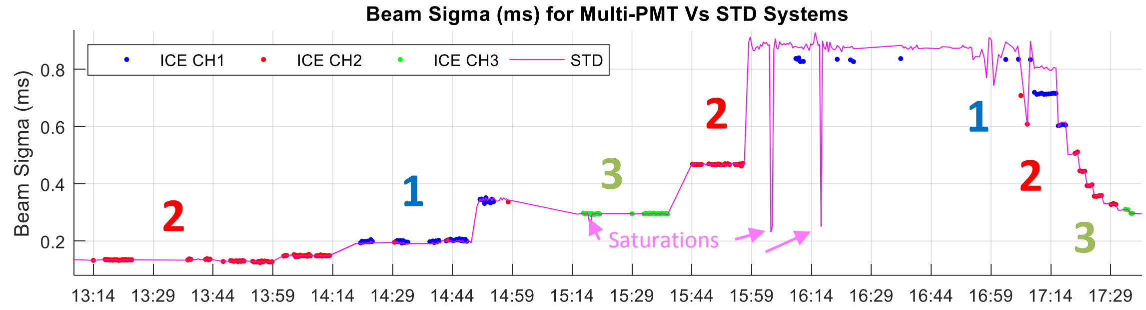
- ICECAL FE: M-PMT 4CH (Tunnel)
- Scope: 2CH M-PMT + 1 OP (Surface)

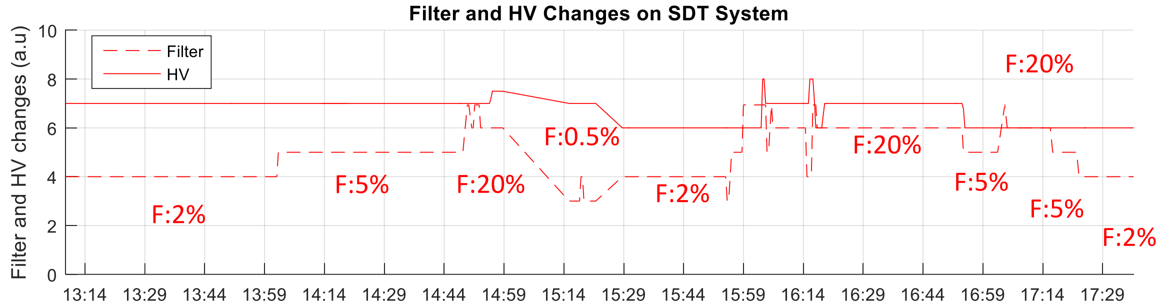
5. Beam Tests in SPS and PSB
5.2 Tests in PSB: HDR system with ICECAL

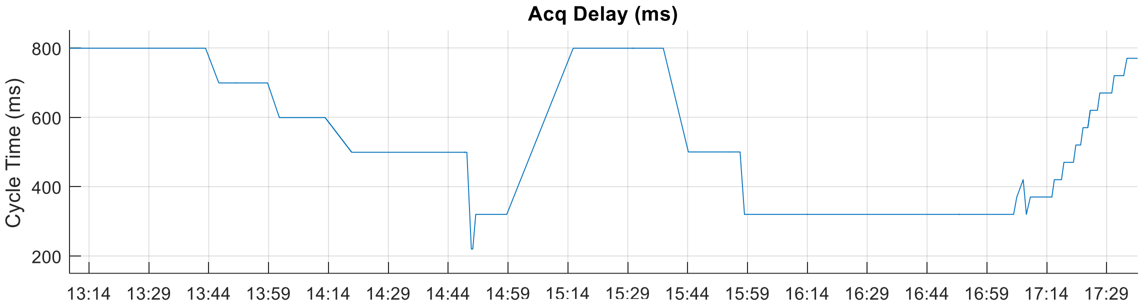
Measurements from: 2017/09/29

- Scanner: **LIU-BWS BR3.4L1**
- PSB Beams: **LHC25ns and ISOLDE**
- Δ Gaussian Amplit → **20 - 500**
- Shown Standard and 4-PMT detectors
- Single configuration in 4-PMT detector







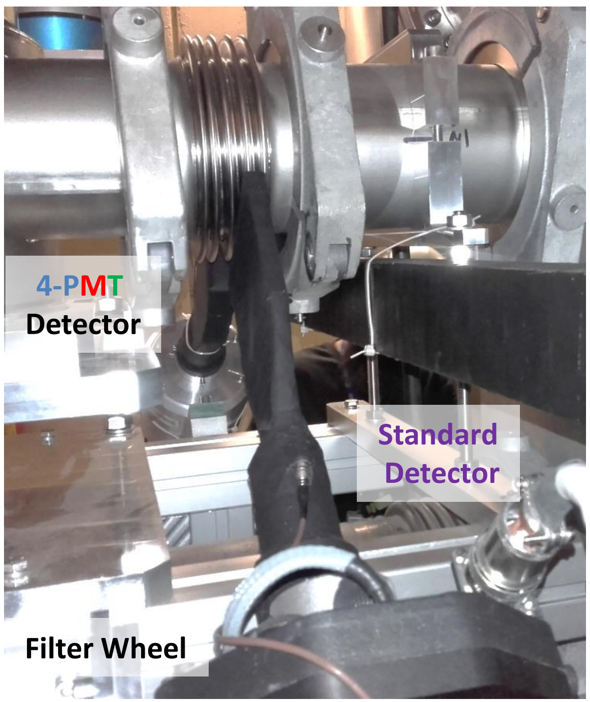


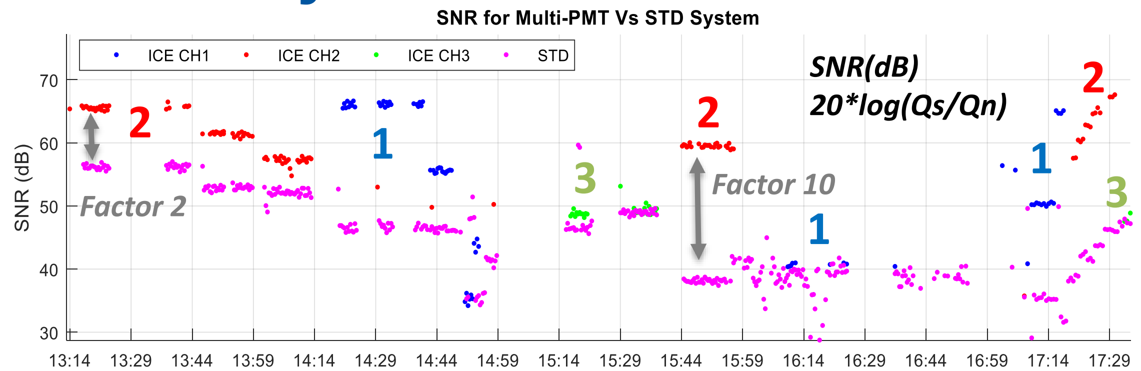
LHC25 CYCLE (144e10 p/b)	ISOLDE CYCLE (800e10p/b)

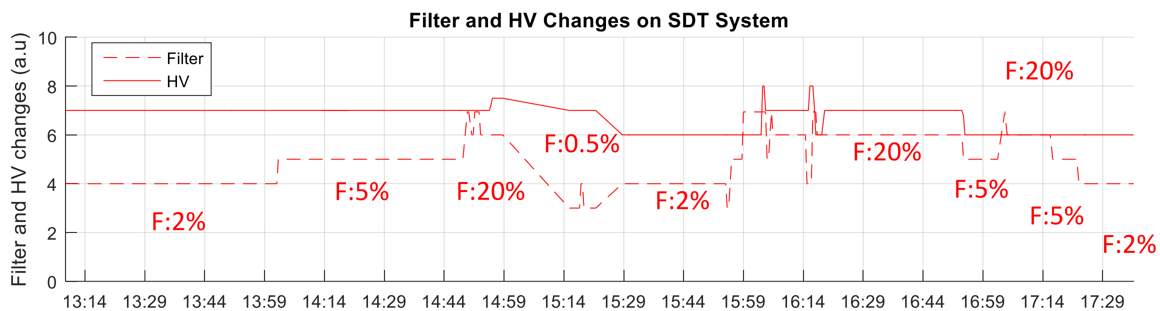
5. Beam Tests in SPS and PSB
5.2 Tests in PSB: HDR system with ICECAL

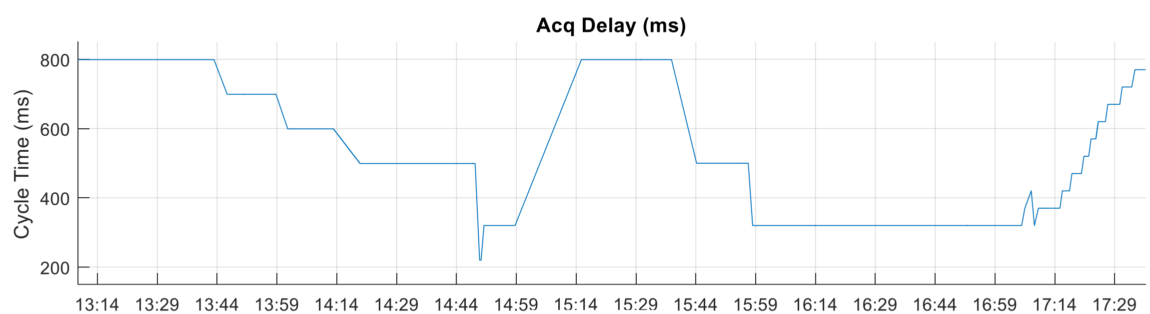
Measurements from: 2017/09/29

- Scanner: **LIU-BWS BR3.4L1**
- PSB Beams: **LHC25ns and ISOLDE**
- Δ Gaussian Amplit → **20 - 500**
- Shown **Standard** and **4-PMT** detectors
- Single configuration in **4-PMT** detector







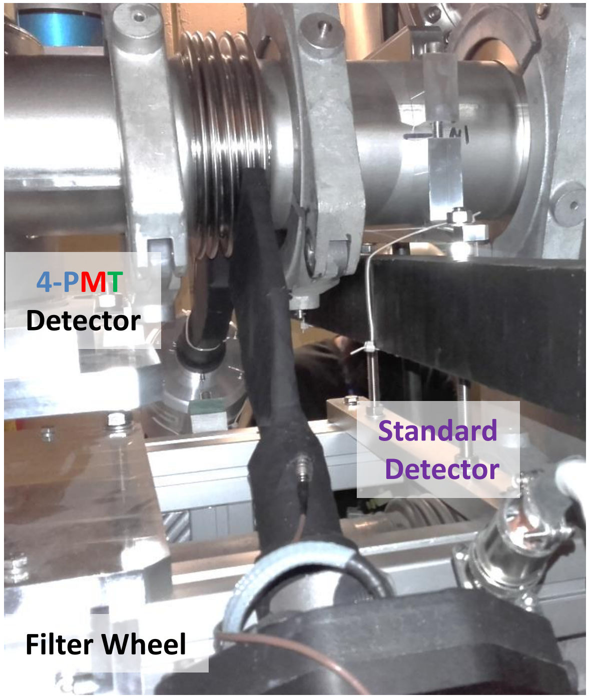


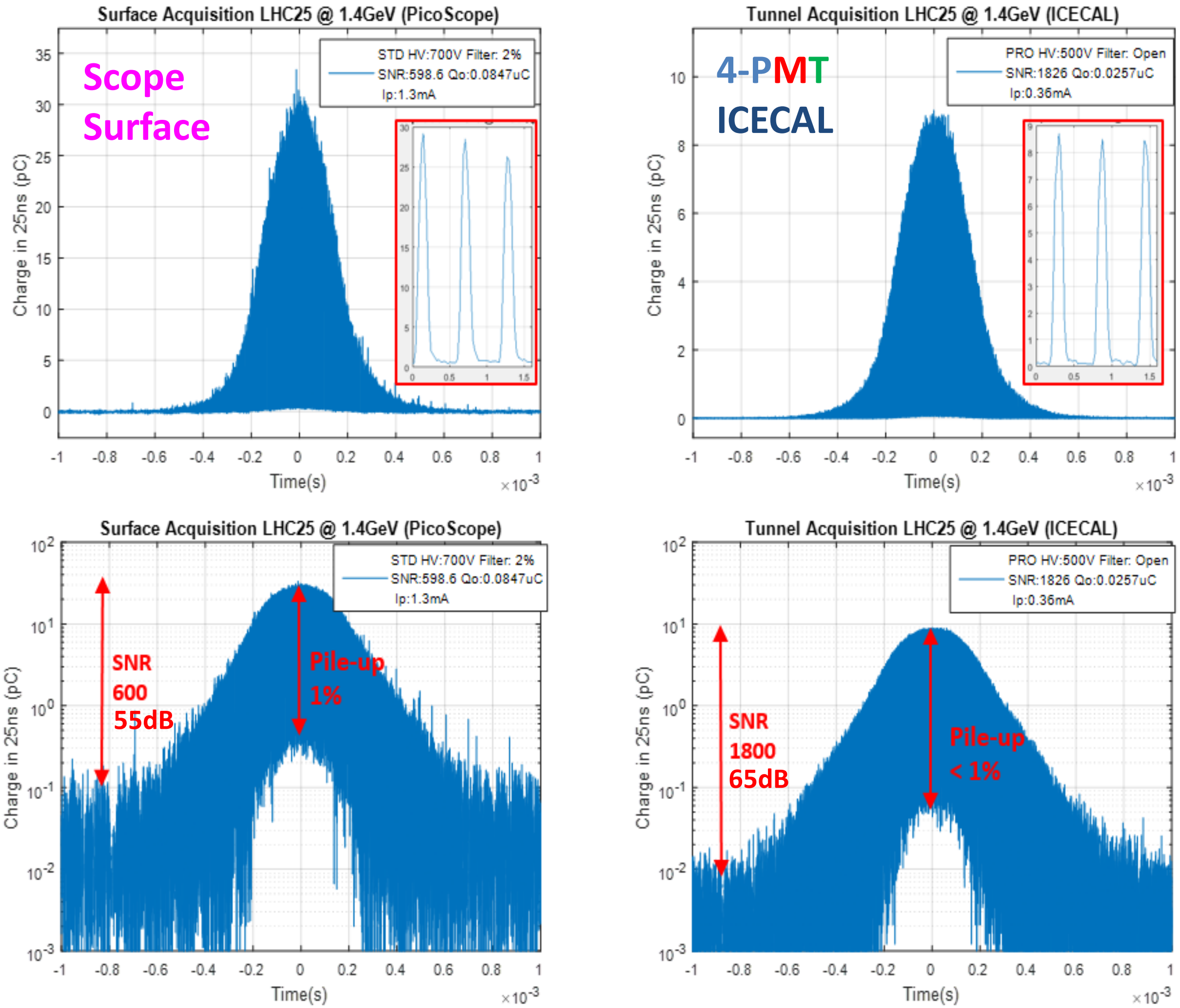
LHC25 CYCLE (144e10 p/b)	ISOLDE CYCLE (800e10p/b)

5. Beam Tests in SPS and PSB
5.2 Tests in PSB: HDR system with ICECAL

Measurements from: 2017/09/29

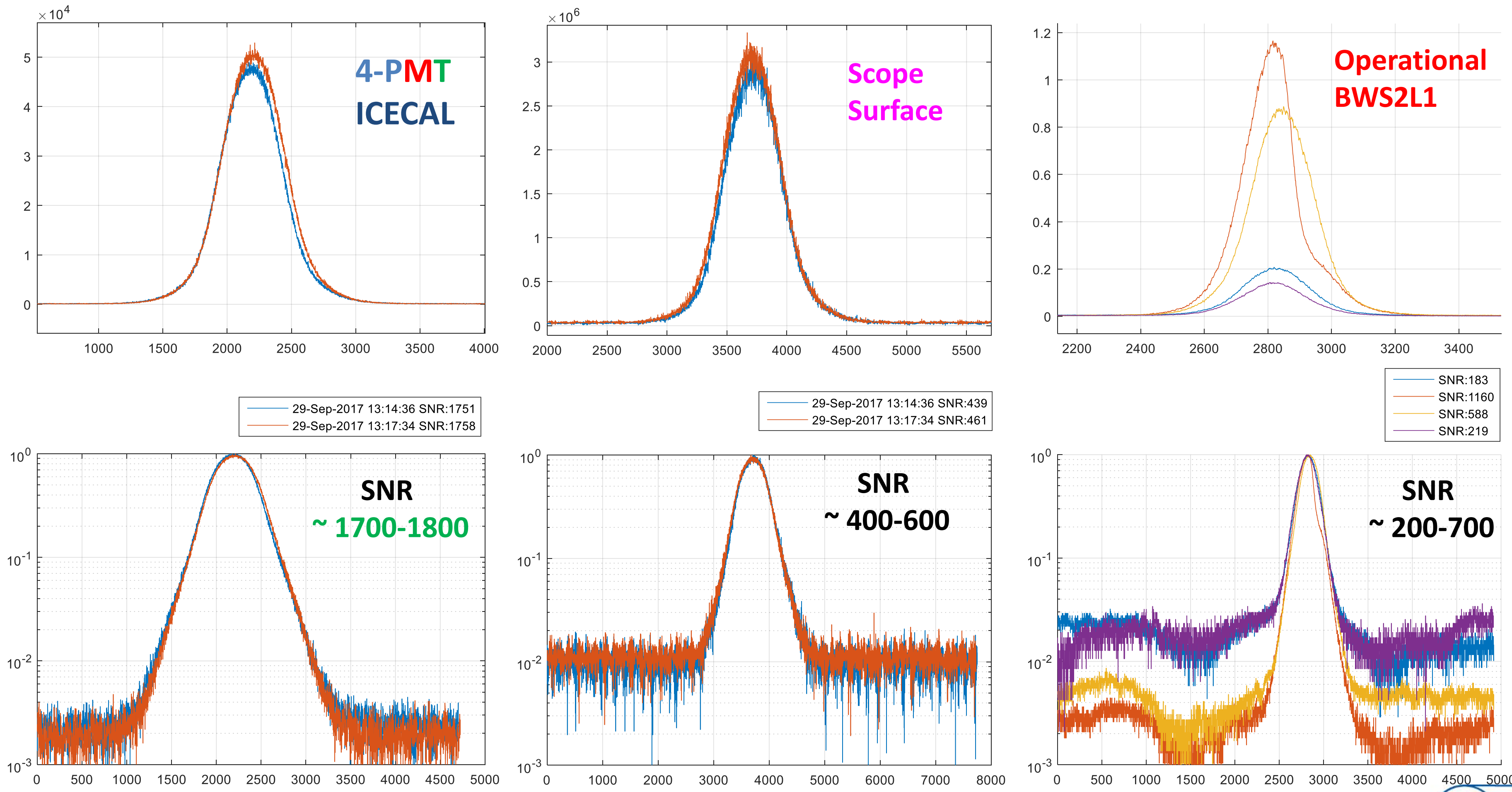
- Scanner: **LIU-BWS BR3.4L1**
- PSB Beams: **LHC25ns and ISOLDE**
- Δ Gaussian Amplit → **20 - 500**
- Shown **Standard** and **4-PMT** detectors
- Single configuration in **4-PMT** detector





5. Beam Tests in SPS and PSB
5.2 Tests in PSB: HDR system with ICECAL

Acquisition example of a Nominal LHC25ns beam @ 1.4GeV in PSB (Comparison with Operational Acq.Systems)



Presentation Outline

1. Introduction
2. Design considerations and particle physics simulations
3. Acquisition system prototype: Design and implementation
4. Laboratory qualification
5. Beam tests in SPS and PSB
6. **Summary and conclusions**

6. Summary and Conclusions

pCVD

First systematic **evaluation** of **pCVD Diamond detectors** for secondary shower **in BWS applications**.
Evaluation in **Energy and Intensity** → their available area (1cm2) is **too small** for SPS
- SPS Nominal beams @ **26GeV** → **100-200 MIPs** (impacts beam profile determination)
- SPS Nominal beams @ **450GeV** → **2000-5000 MIPs** (lower statistics, usable detectors for LHC)

Studies

Particle **physics models** for beam-matter interaction give **better insight** of the BWS **secondary rain**.
CK50 **cable model quantified bunch pile-up** for a given length (B. profile Err. > 1% in L>150m)
Analytical **equations** to calculate **measurement conditions** for a given measurement precision.

System FW

Custom architecture with **GBT-FPGA** code in **Flash-Based FPGA** distributed **to CMS** ngCCM HCAL
LATOP GBT with **1.3ns uncertainty** in LHC/SPS 40Mhz **clock recovery and data**. No loss during ramp.

Prototypes

Two acquisition **strategies evaluated** based on 40Mhz Integrators
QIE10 FE with **no** apparent **degradation in 1.5y** of operation (noise ~3fC)
- Quantization error 1% not seen in measurements, amplitude dominated by pCVD statistics.

ICECAL FE tested with novel detector schema based on **M-PMT**
- Significant **step forward** in system **usability** with M-PMT system (no setting point):
- Redundancy and possibility to combine channels to enhance SNR

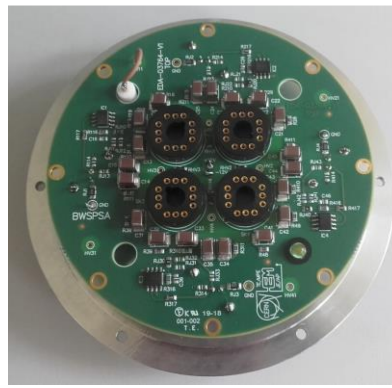
Both systems demonstrated a great **improvement in signal integrity, SNR** up to **10 times higher**

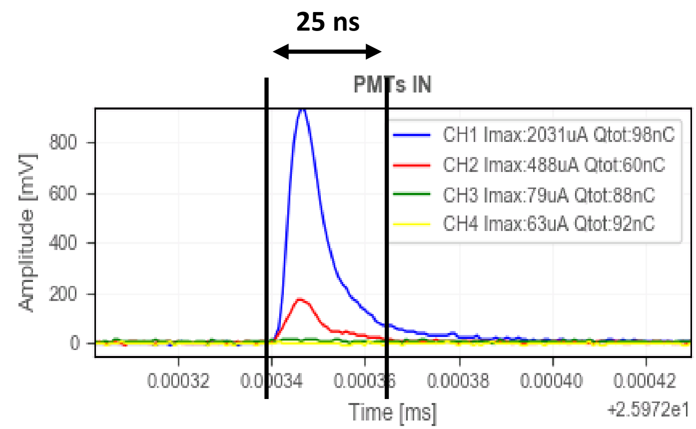
LIU-BWS Precision

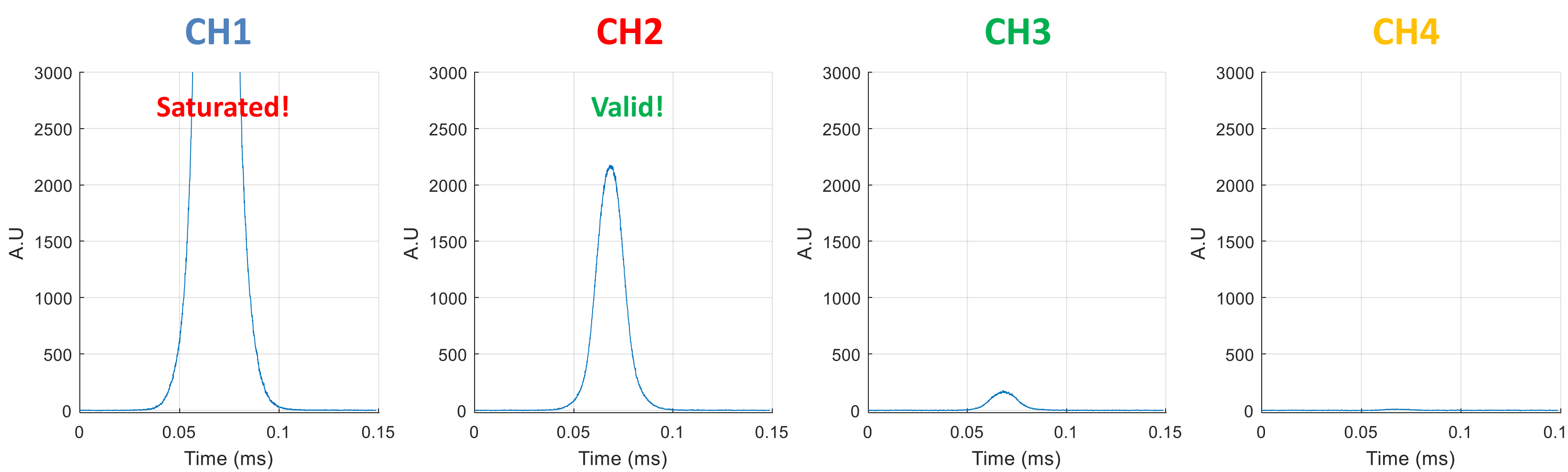
Mechanical performance of new prototype in beam tests
- SPS **AWAKE** (1e11PpB @ 400GeV) with Diamonds: Beam Size **4.2% Vs 6%**
- SPS **COAST** (0.23e11 PpB @ 200GeV) with PMT: Beam Size **2.3% Vs 3%**
- PSB Only improvement after **Scintillator exchange**: Beam Size **0.8% Vs 1.4%**

6. Summary and Conclusions

Multi-PMT detector adopted as baseline for the LIU-BWS upgrade

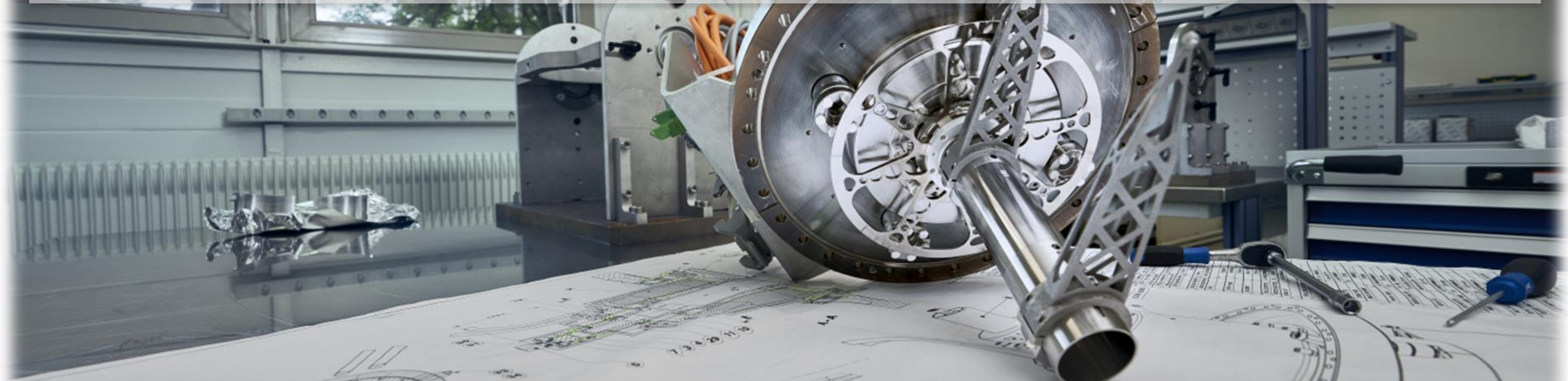






To everyone that supported me during all these years…

THANK YOU!!!



Beam secondary shower acquisition design for the CERN high accuracy wire scanner

Universitat de Barcelona

Jose Luis Sirvent Blasco

Director: **Federico Roncarolo (CERN)**
Tutor: **Angel Dieguez Barrientos (UB)**

2. Design considerations and simulations
2.5 Studies Outcome

1. Dynamic range coverage: Total = Beam dyn. * Sec. production

PSB: 1e6 (2,6e3 * 1e3), **CPS: 1e4** (8,5e2 * 4,6e1), **SPS: 1e4** (2,9e2 * 3e1), **LHC: 1e3** (1,5e2 * 2)

Required **1e6 dynamics** with minimum tunable parameters

2. Optimized detectors placement and estimation of energy deposited:

Calculated dose (Gy) per proton impacting the wire around beam pipe for diff. Energies.

Detectors placement: PSB < 50cm, CPS< 1m, SPS < 5m, LHC < 10m

3. Beam profile measurements precisión with BWS:

Highly dependent on measurement conditions (PpS, SNRx, SNRy, #Events…)

Analytical ecuations extracted to quantify precision and requirements per machine.

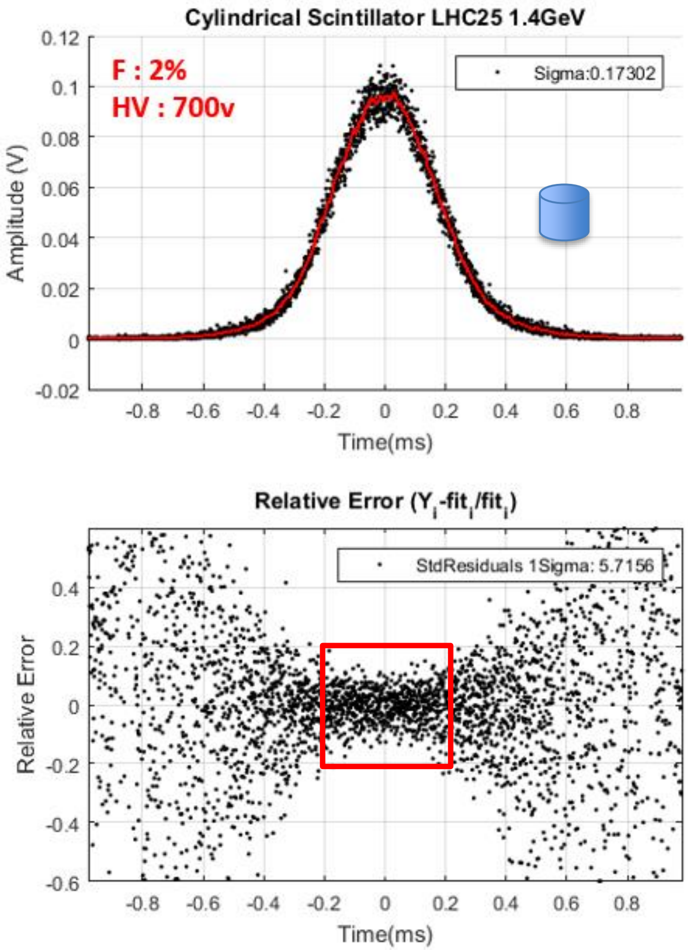
4. Long coaxial cable impact for PMT signal transmision:

Reliable cable model to estimate effect

Bunch pile-up → Bunch profile cross-talk

5. Beam Tests in SPS and PSB
5.2 Tests in PSB: Impact of Scintillator Geometry

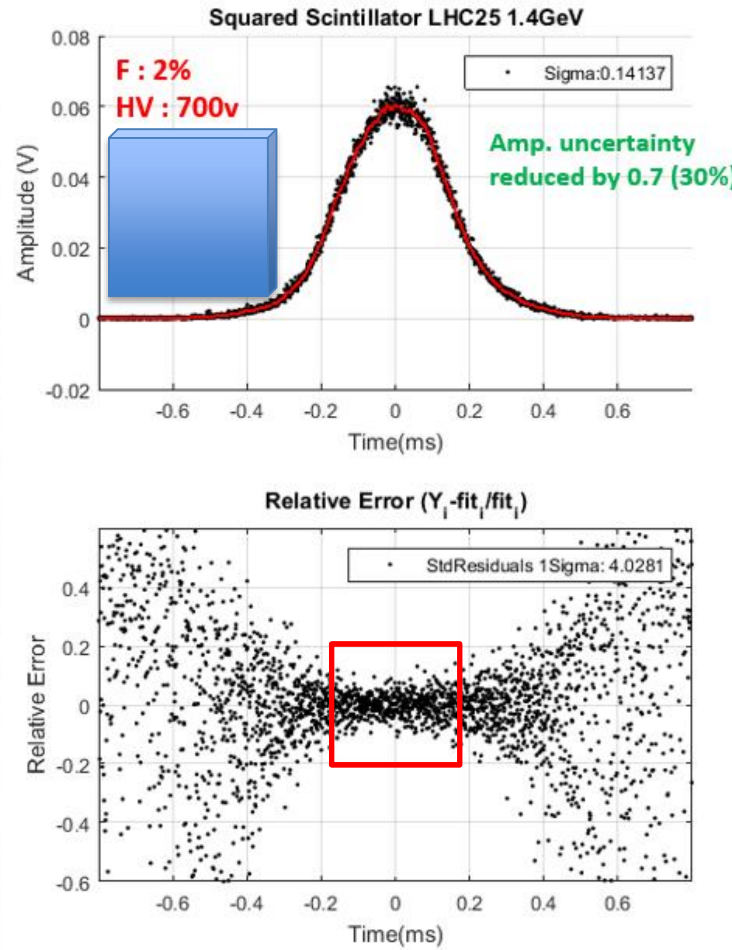
Scanner SN:64 (2017/06/28 MD2375)



Scintillator Cylindrical 30x30 mm

STD Residuals in ± 1xSigma **5.7%**

Scanner SN:65 (2017/09/29 MD2807)



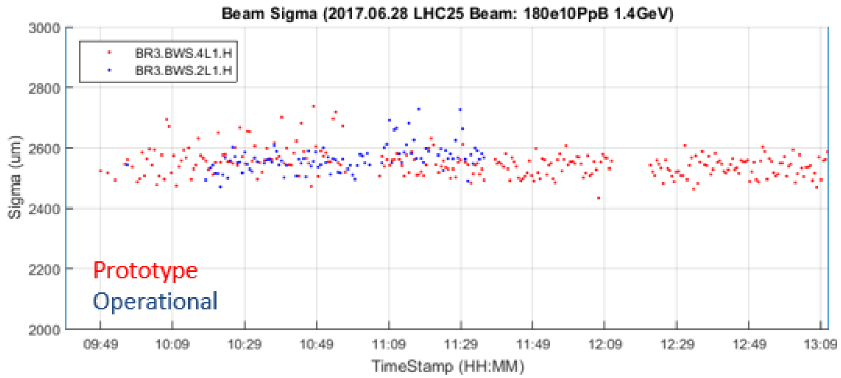
Scintillator Squared 100x100x10 mm

STD Residuals in ± 1xSigma **4.028%**

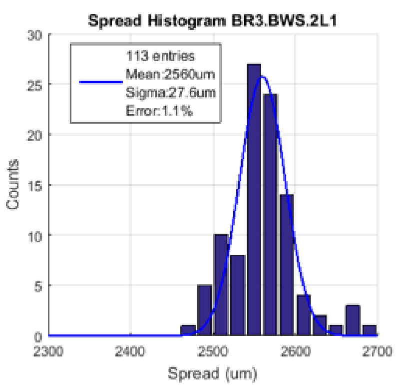
Why reduced uncertainty by **0.7** (particles x 2) **instead of** by **0.3** (particles x 10)? Rain geometry, photon transport…

5. Beam Tests in SPS and PSB
5.2 Tests in PSB: Impact of Scintillator Geometry

Scanner SN:64 (2017/06/28 MD2375)

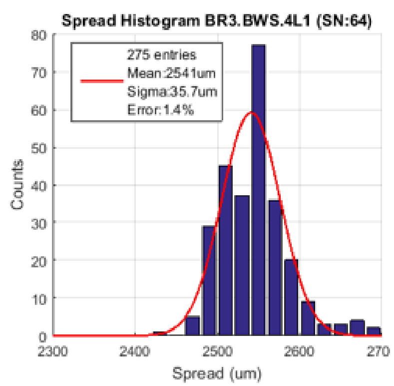


Operational



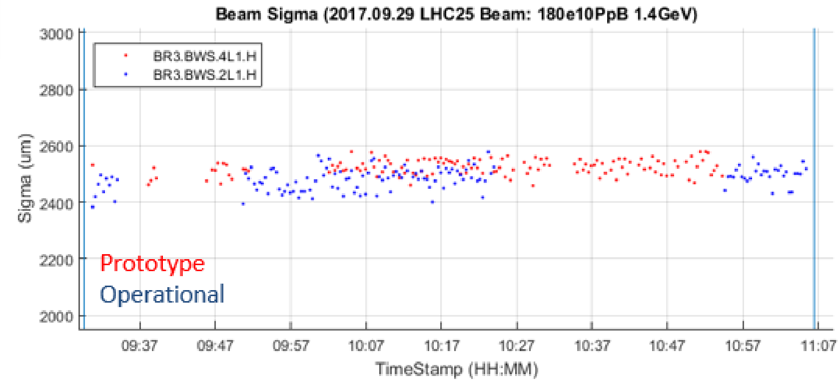
RMSe: 1.57%

Prototype

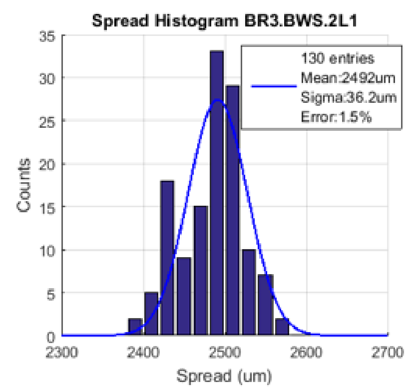


RMSe: 1.60%

Scanner SN:65 (2017/09/29 MD2807)



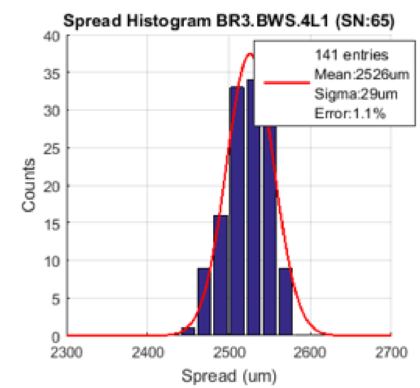
Operational



RMSe: 1.58%

1.4%

Prototype



RMSe: 1.07%

0.8%

Consistent beam conditions and acquisition systems configuration both campaigns.
Changed: BWS prototype control system and scintillator geometry

4. PSB Prototype Beam Tests

4.1 Results from 2017: Precision comparison with op BWS

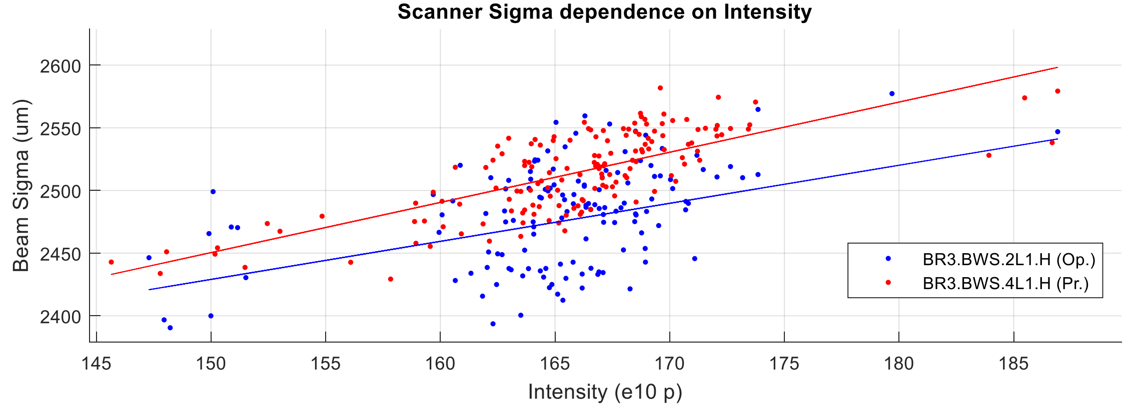
Shot by shot Intensity variations:

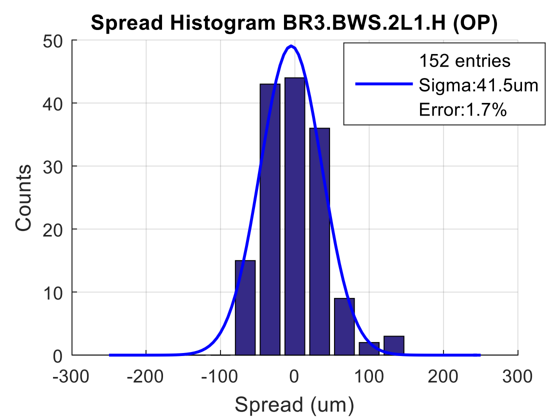
- Affects Beam profiles?
- Is there any correlation?
- Are measurements biased?

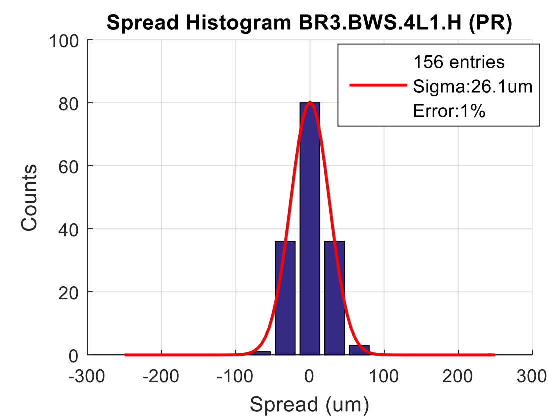
Correlation plot with a linear fit:

- PSB BR3 BCT → ΔI = 12%
- Higher intensity → Bigger beams
- Residuals analysis: fit – Data
- Bigger difference Op. Vs Proto.

Scanner SN:65 (2017/09/29 MD2807)







RMSe = 1.43%

RMSe = 0.88%

Other ASICs considered for the project

FE-Readout	Technology	Cum_Dose	Din_Range		Integ_ADC	Fs	Contact	Info
QIE10	350nm SiGe	400Gy -3KGy	3.1fC-320pC	1e5	Yes / 8bits	40Mhz	J.Mans (CMS)	Link
EasiRoc	350nm SiGe		160fC-320pC	2e3	No	---	S.Callier (Omega)	Link
Fatalic3	IBM 130nm CMOS		24fC-1000pC	4e4	No	40Mhz	N.Pillet (LCF)	Link
PACIFIC	IBM 130nm CMOS		750fC-30pC	40	Yes / 6bits			
IBMS ASIC		300Gy		1e3	No	40Mhz		Link
ICECAL2	SiGe BiCMOS 0.35um			4e3	No	40Mhz	E. Picatoste (UB)	Link
CALORIC	0.35 μm CMOS		4fC-10pC	2.5e3	Yes	3MHz		Link

40 Mhz Signal Integrators, No dead Time.
Dynamic range > 1e3
Radiation-Tolerant > 0.5- 1KGy

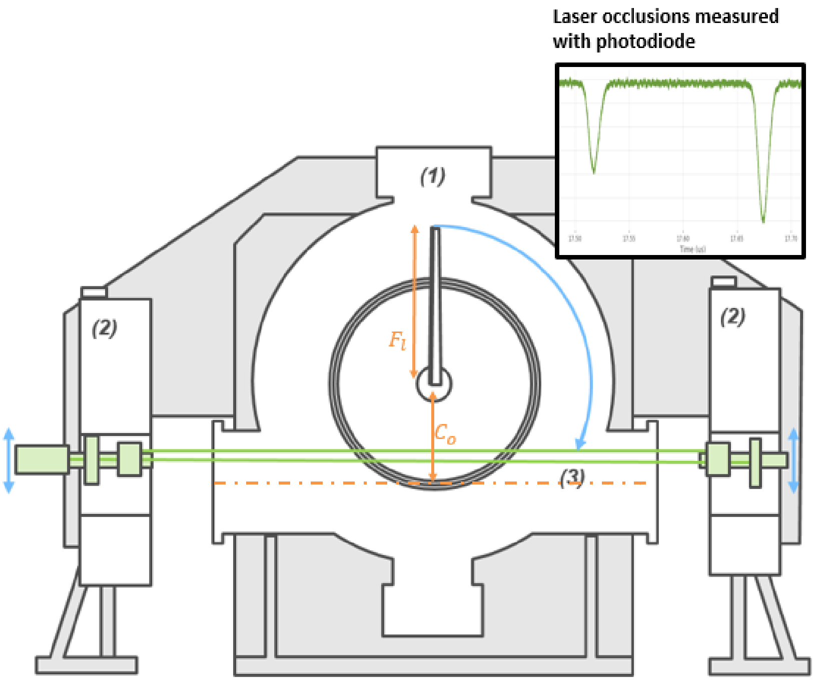
1. Introduction
1.5 Calibration and wire position incertitude

Why we calibrate the LIU-BWS?

- **Characterization** of angular-to-projected motion (compensation for BWS assembly tolerances).
- **Assessment** of wire determination incertitude under a controlled environment.
- **Test** different motion profiles to characterize/minimize vibrations on system or wire.

Projection based on Scanner Mechanics:

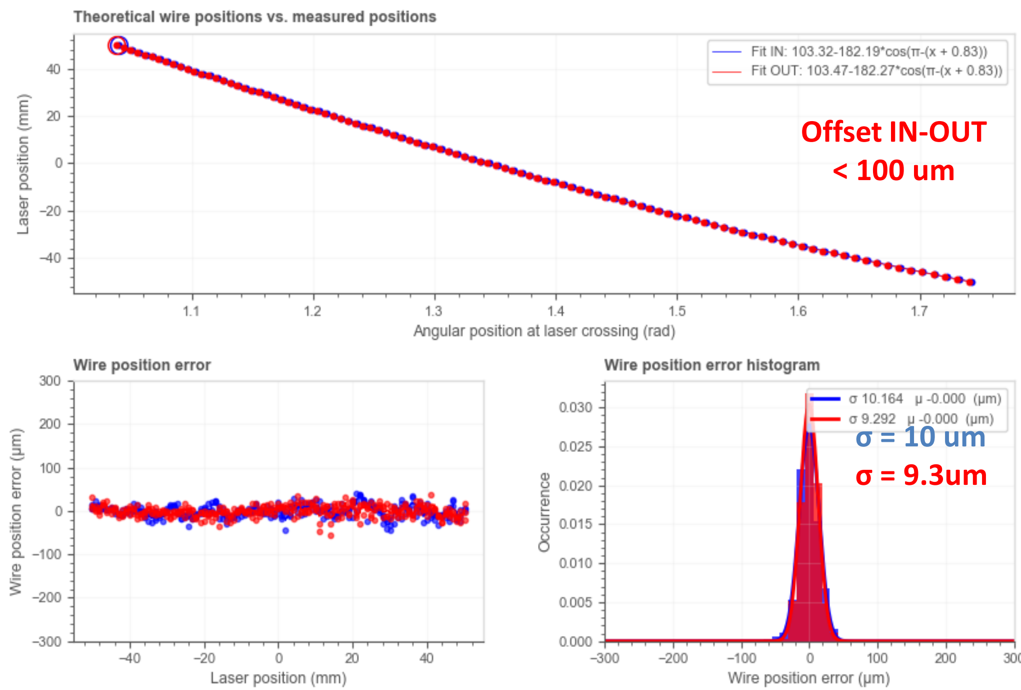
$$Y = C_o - F_l \cos(\pi - \alpha_{Sensor} + \theta)$$



Three parameters fit based on equation: C_o, F_l, θ

Extracted residuals to determine: Precision & Accuracy

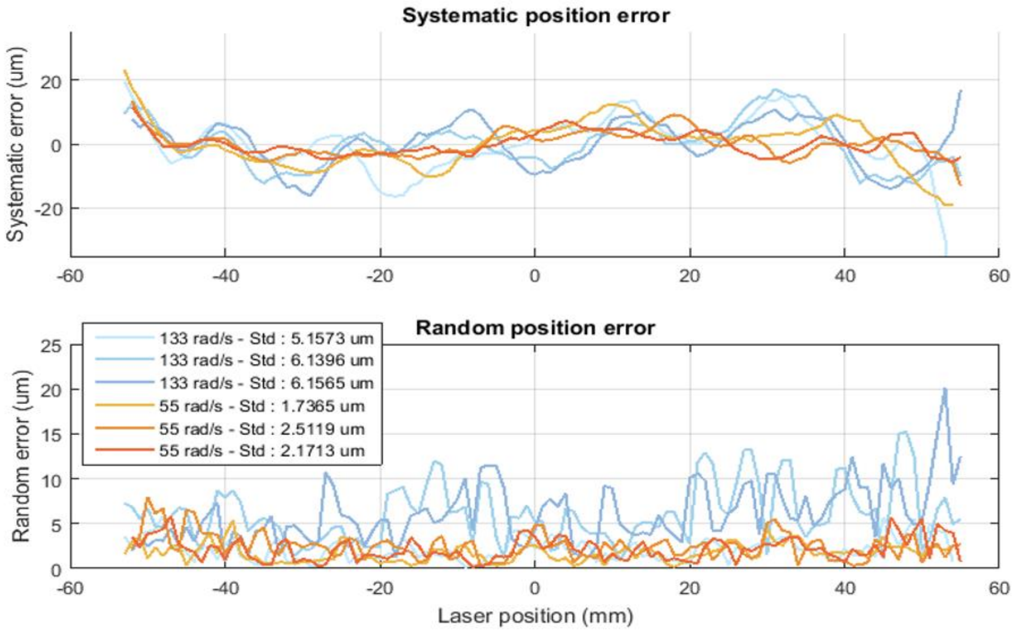
Accuracy: Systematic deviations , **Precision**: Random variations



This design is **5 times more precise** than operational PS/PSB scanners (9-10 Vs 50-70um) and **10 times less IN-OUT offset** (0.1 Vs 1-2 mm)

2. Calibration procedure and wire position incertitude

- Systematic oscillations at different speeds observed on fit residuals.
- Different spatial frequency but similar temporal frequency (1-2 kHz), suggest mechanical vibrations.



Operational fast BWS (PSB) show uncertainties **~100um**

Scanner performance on Cal. Bench:

Speed	8 m/s	20 m/s
Residuals Spread	5.5 um	11.5 um
Accuracy	10 um	
Precision	2.5 um	6 um

Extensive use during fatigue tests 2017:

- Total number of scans → **52900**
  - 20 ms-1 : 48700
  - 8 ms-1 : 4200
- Average Scans/day → 5000
- **Consistent behaviour and no degradation observed**

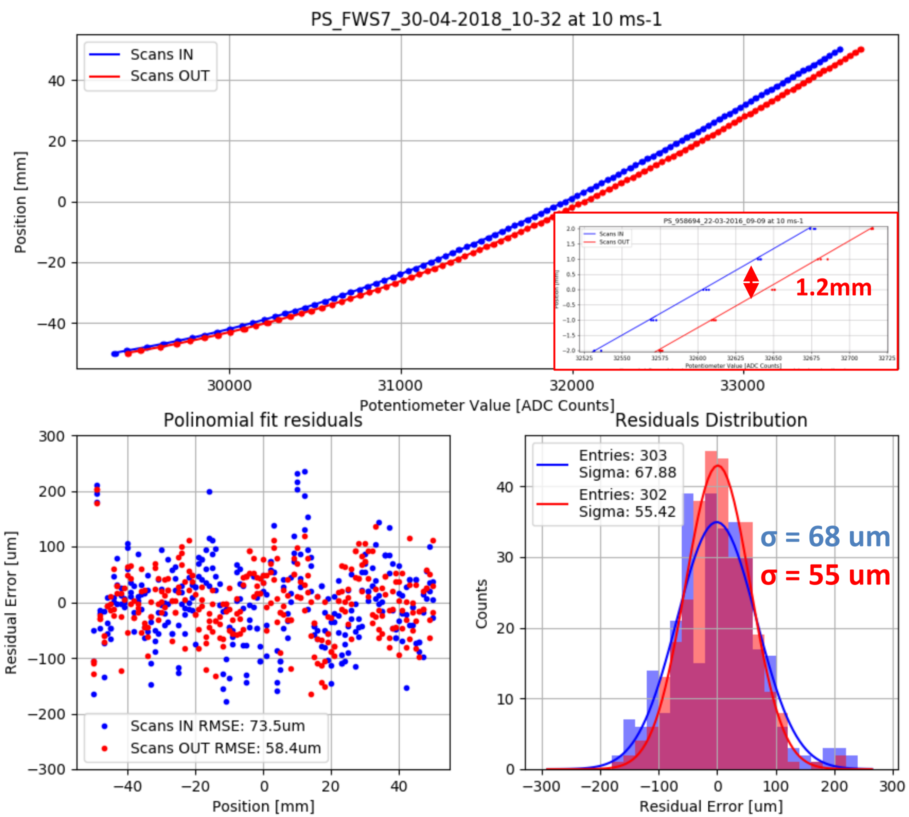
* J.L. Sirvent et al. Performance Assessment of pre-series fast beam wire scanner prototypes for the upgrade of the CERN LHC injector complex. 6th. International Beam Instrumentation Conference (IBIC2017). Grand Rapids, MI, USA.

1. Introduction
1.5 Calibration and wire position incertitude

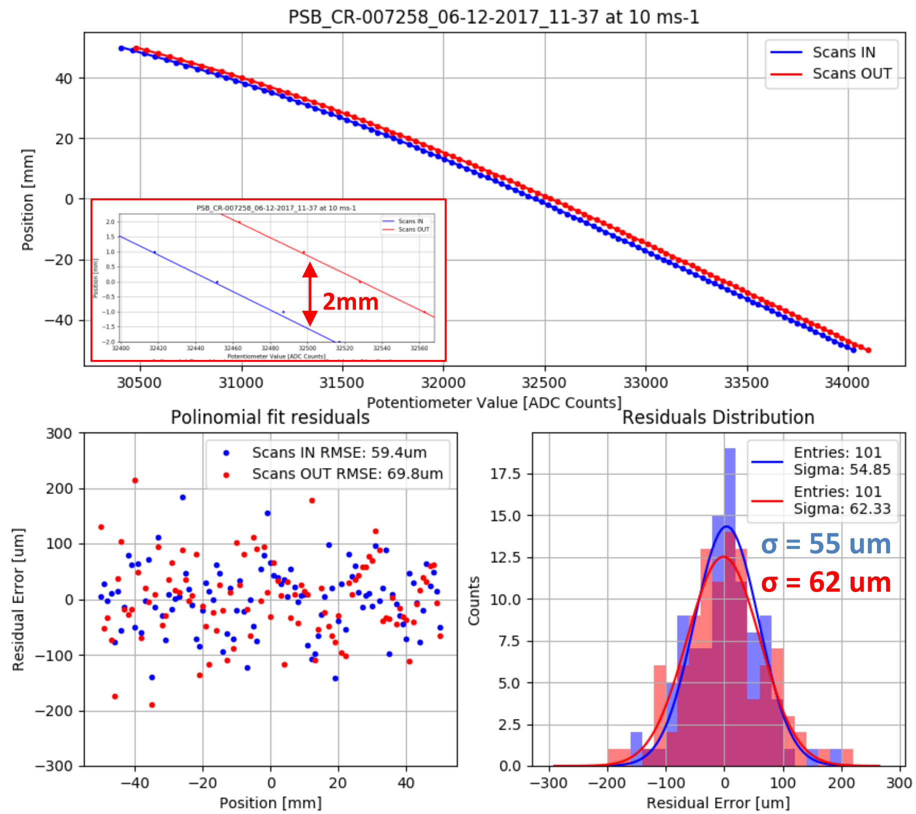
How LIU-BWS performance compares to operational CPS and PSB in calibrations?

- CPS and PSB BWS are calibrated with a similar setup
- Potentiometer Vs Position data fitted with 6-10 polynomial
- IN + OUT lookup tables generated (Mechanical play → Curves offset)

Calibration **CPS** BWS 30/04/2018



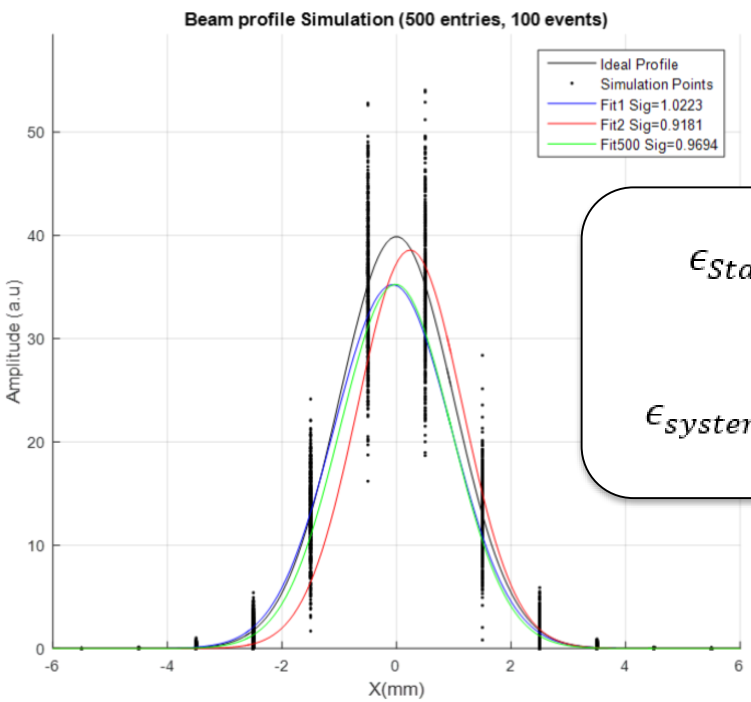
Calibration **PSB** BWS 06/12/2017



2. Design considerations and simulations
2.3 Sources of error in beam profile determination

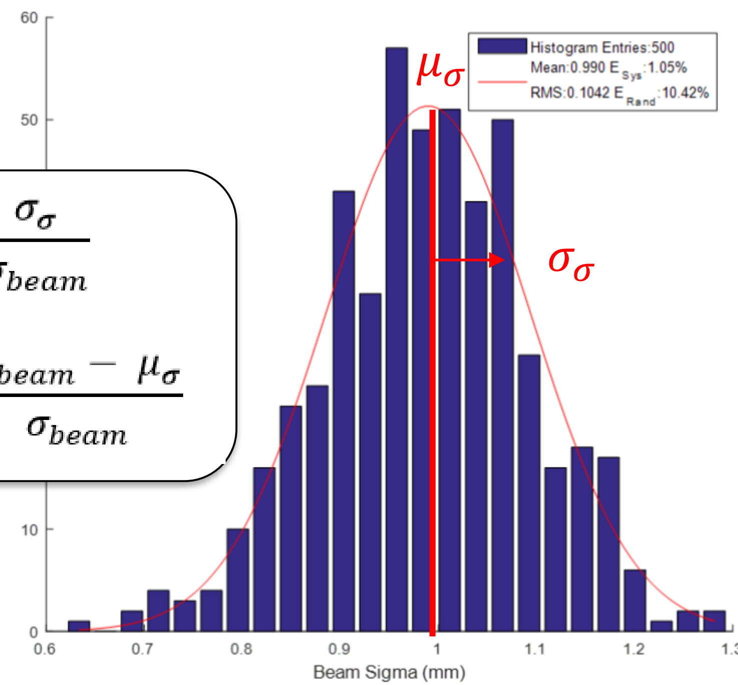
Simulation procedure:

1. Study independently impact of SNRx SNRy and #Events in function of PpS.
2. Set of 500 profiles with a given PpS and SNRx, SNRy or #Events.
3. Fit all profiles and histogram results.
4. Gaussian fit to results, extract $\boldsymbol{\sigma_\sigma}$ and $\boldsymbol{\mu_\sigma}$ to calculate $\boldsymbol{\epsilon_{systematic}}$ and $\boldsymbol{\epsilon_{statistic}}$



$$\epsilon_{Statistic} = \frac{\sigma_\sigma}{\sigma_{beam}}$$

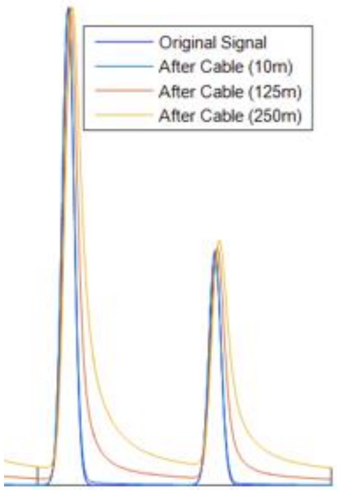
$$\epsilon_{systematic} = \frac{\sigma_{beam} - \mu_\sigma}{\sigma_{beam}}$$

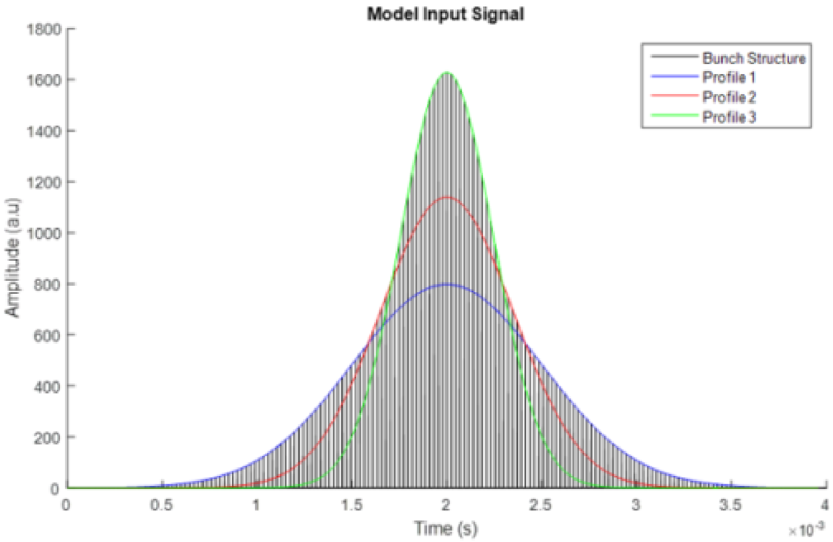


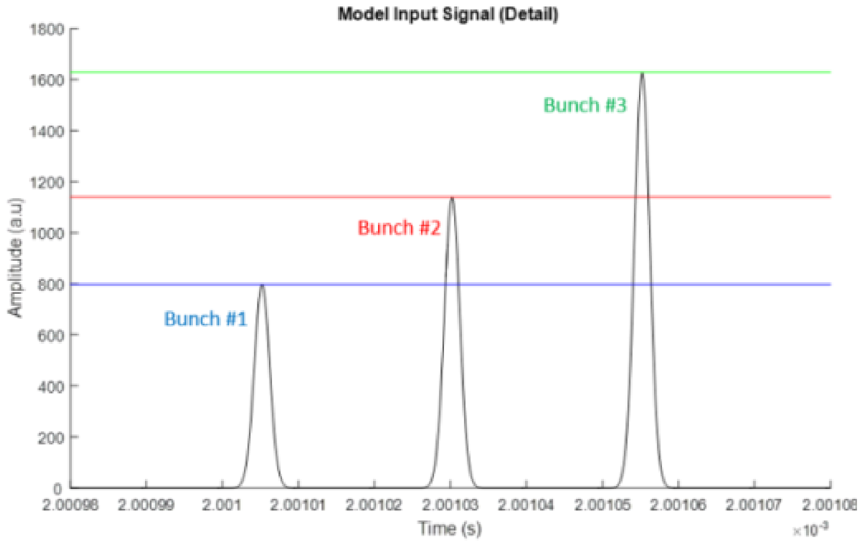
2. Design considerations and simulations
2.4 Implications of using long coax cables (CK50)

Simulation procedure:

1. Construction of beam scan with 3 bunches 2ns FWHM spaced by 25ns with different size.
2. Signal passed through CK50 model (arbitrary length).
3. Reconstruction of beam profiles by integrating 25ns around each bunch.
4. Evaluation of Beam size error → 100* (Expected – Measured) / Expected.
5. Variation of profile likehood and cable distance.



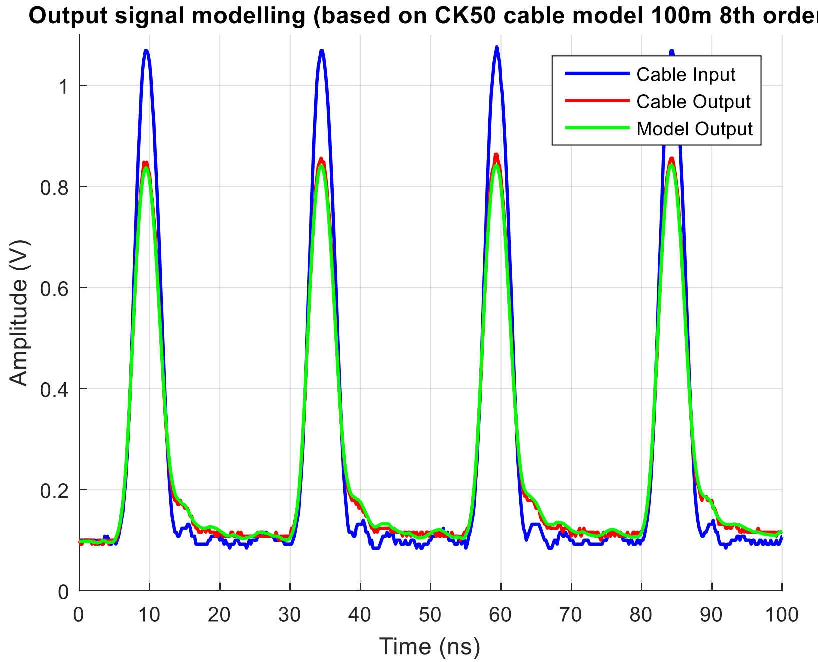


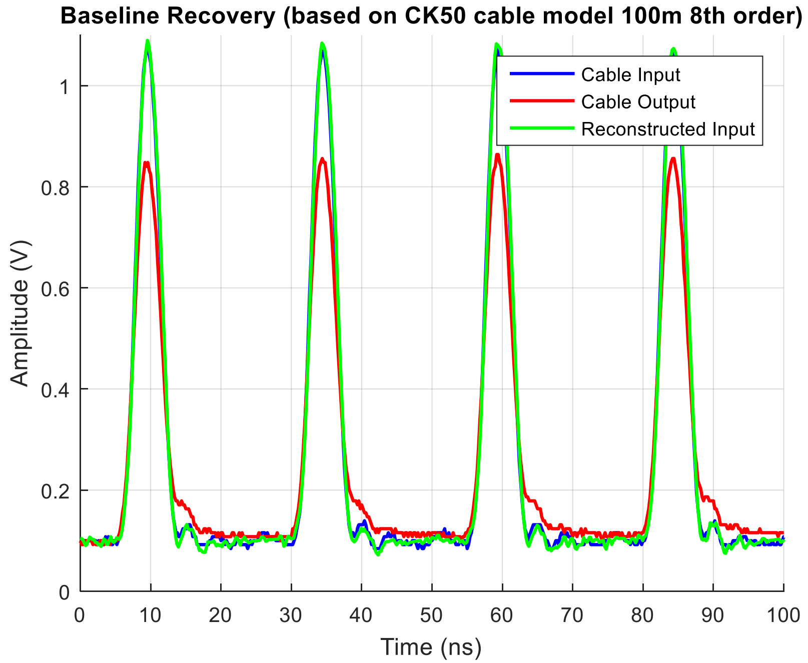


5. Activity 2: Sneak peek

5.1 Tests on 867/R-V16 (CK50 cable length: 100m)

- Pulses train 4ns FWHM, 25ns separation
- Fs 5GSPS
- Extra 100m CK50 ordered for 200m tests

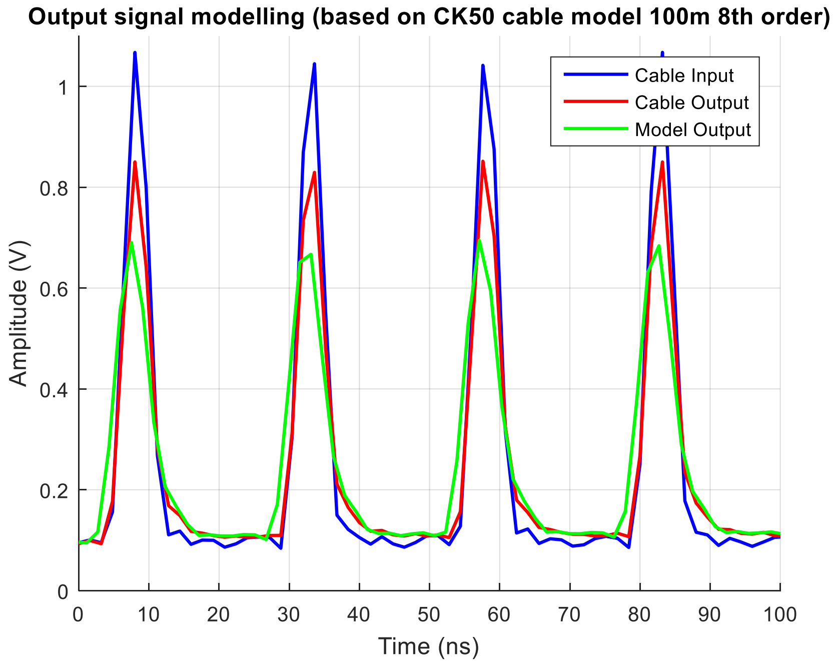


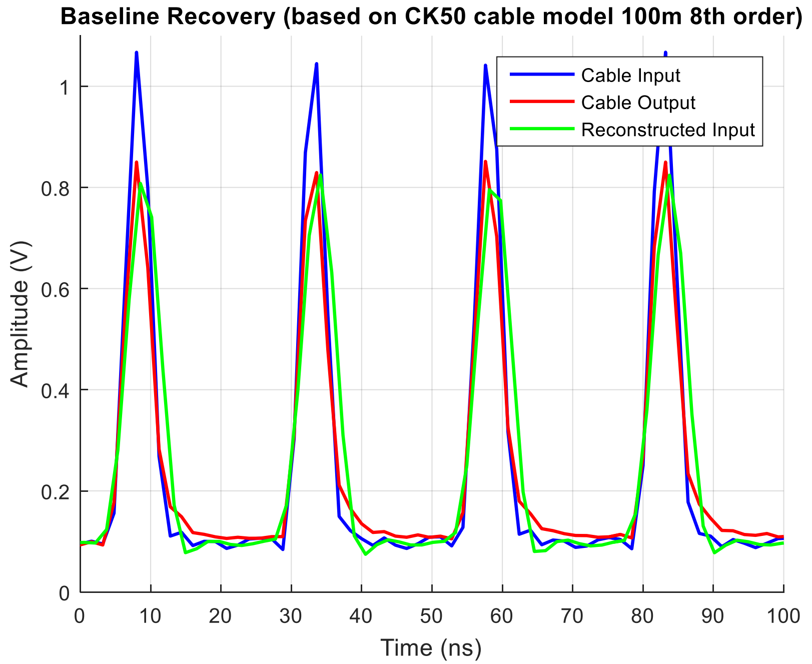


5. Activity 2: Sneak peek

5.1 Tests on 867/R-V16 (CK50 cable length: 100m)

- Pulses train 4ns FWHM, 25ns separation
- Fs 5GSPS → Down-sampled 625MSPS
- Extra 100m CK50 ordered for 200m tests





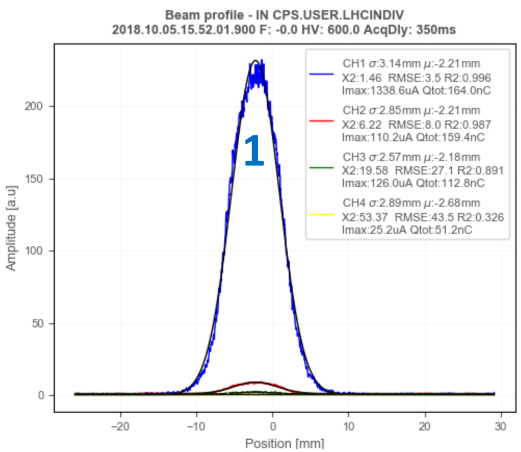
4. Results from tests with beam

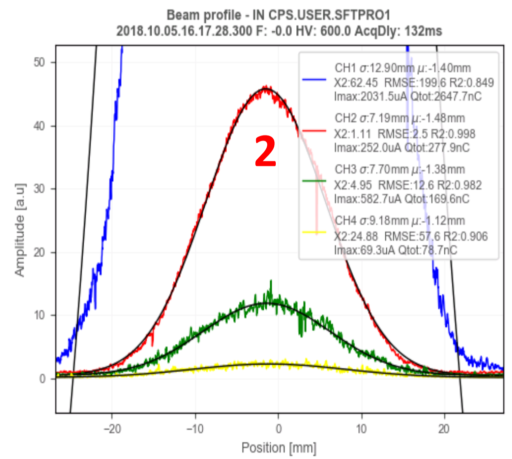
4.1 Coverage of Injectors dynamics: PS

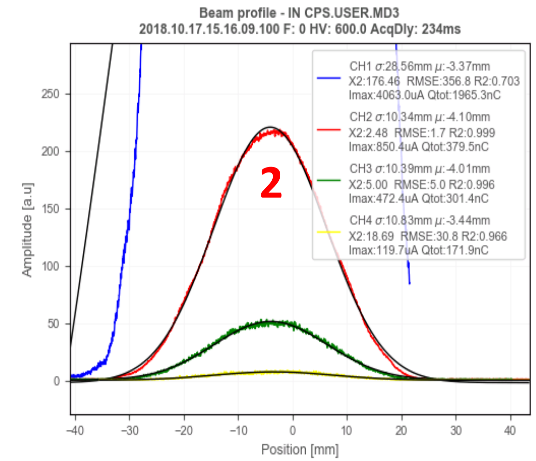
Proton Synchrotron: Single working point at all measurements **HV @ 600V**

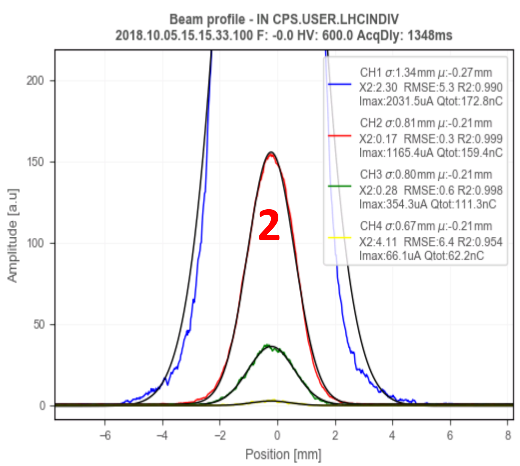
LHCINDIV 1 Bunch x **4e10 PpB** | **SFTPRO1** 8 Bunch x **200e10 PpB** | **TOF** 1 Bunch x **810e10 PpB**

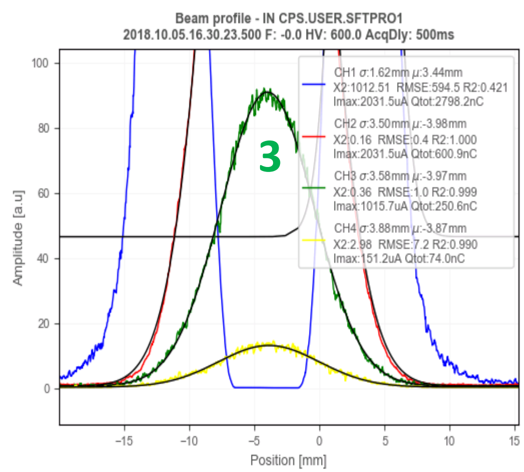
Flat_Bottom | Flat_Top

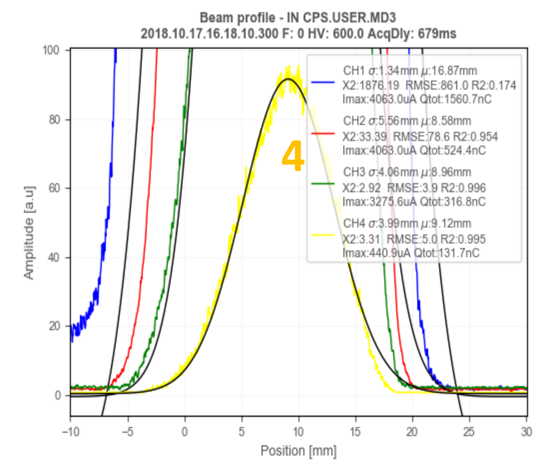








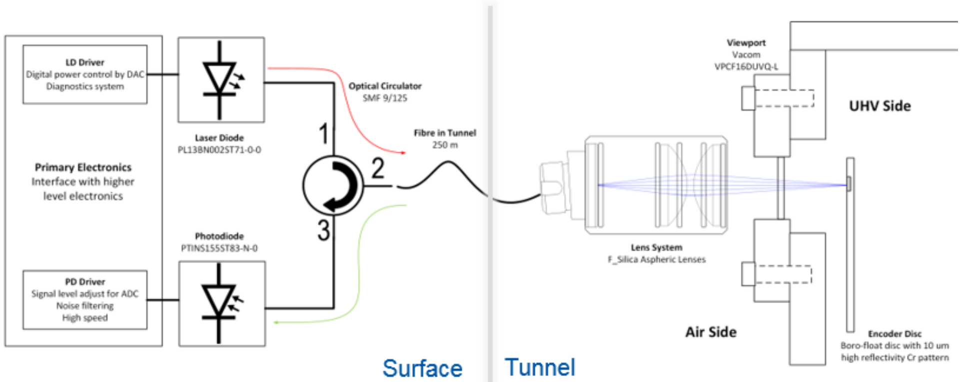


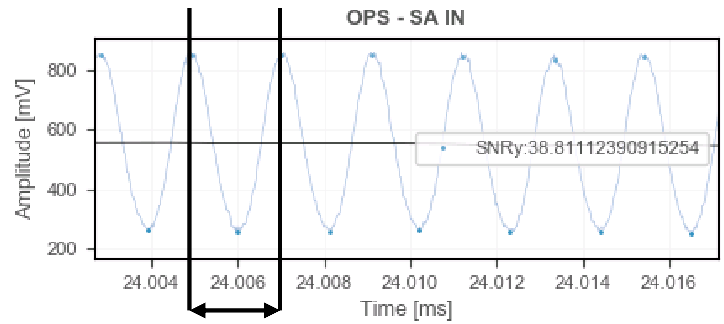


LIU Beam wire scanners architecture and design
Details on the BWS Optical position sensor

1. Passive optical position sensor:

- Rad-Tol Incremental fibre optic encoder system
- Typically sinusoidal signal <1MHz



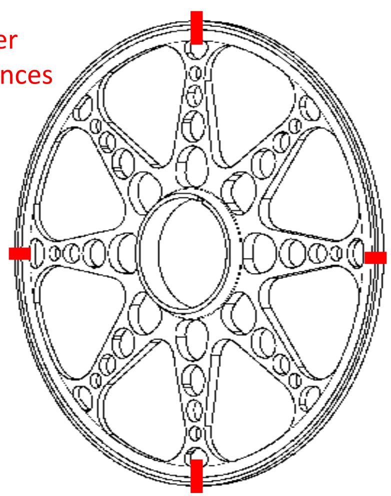


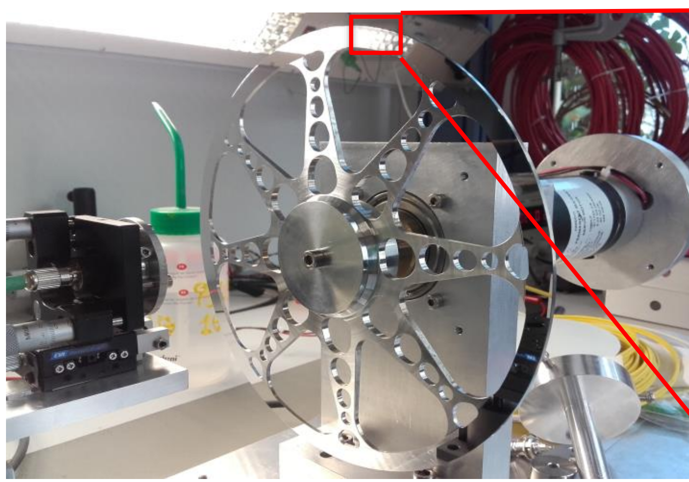
2.8 us
~400KHz

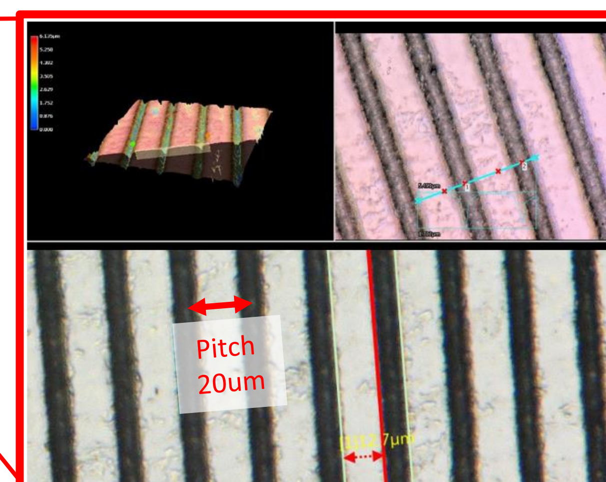
Digitalization Requirements:
2 CH 10-12 Bits 40MSPS ADC
DC Coupling

Thorough R&D program for disk production during 2017-2018:

- Aluminium type, surface treatment, slits engagement process….

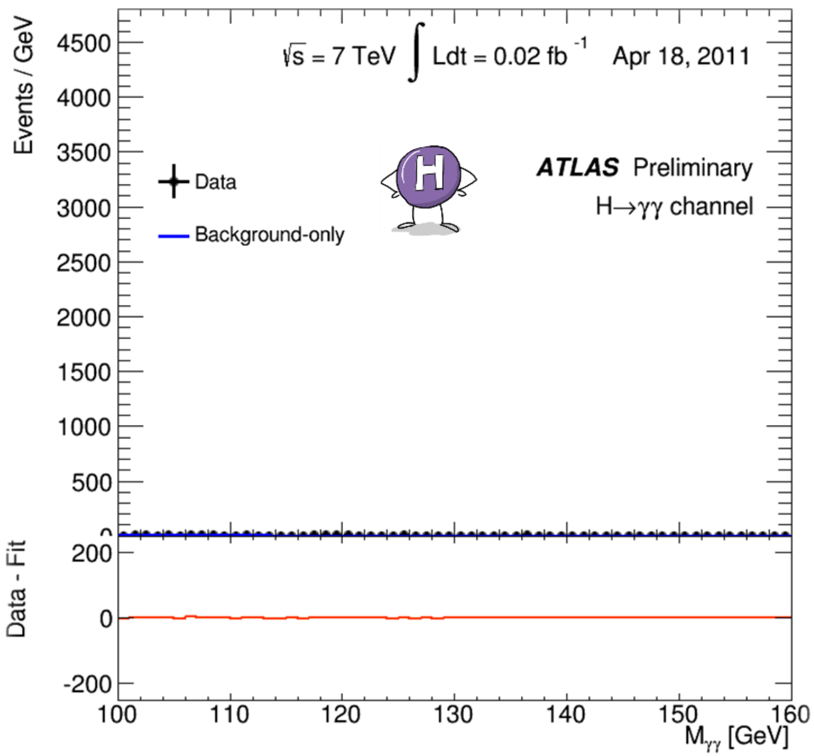




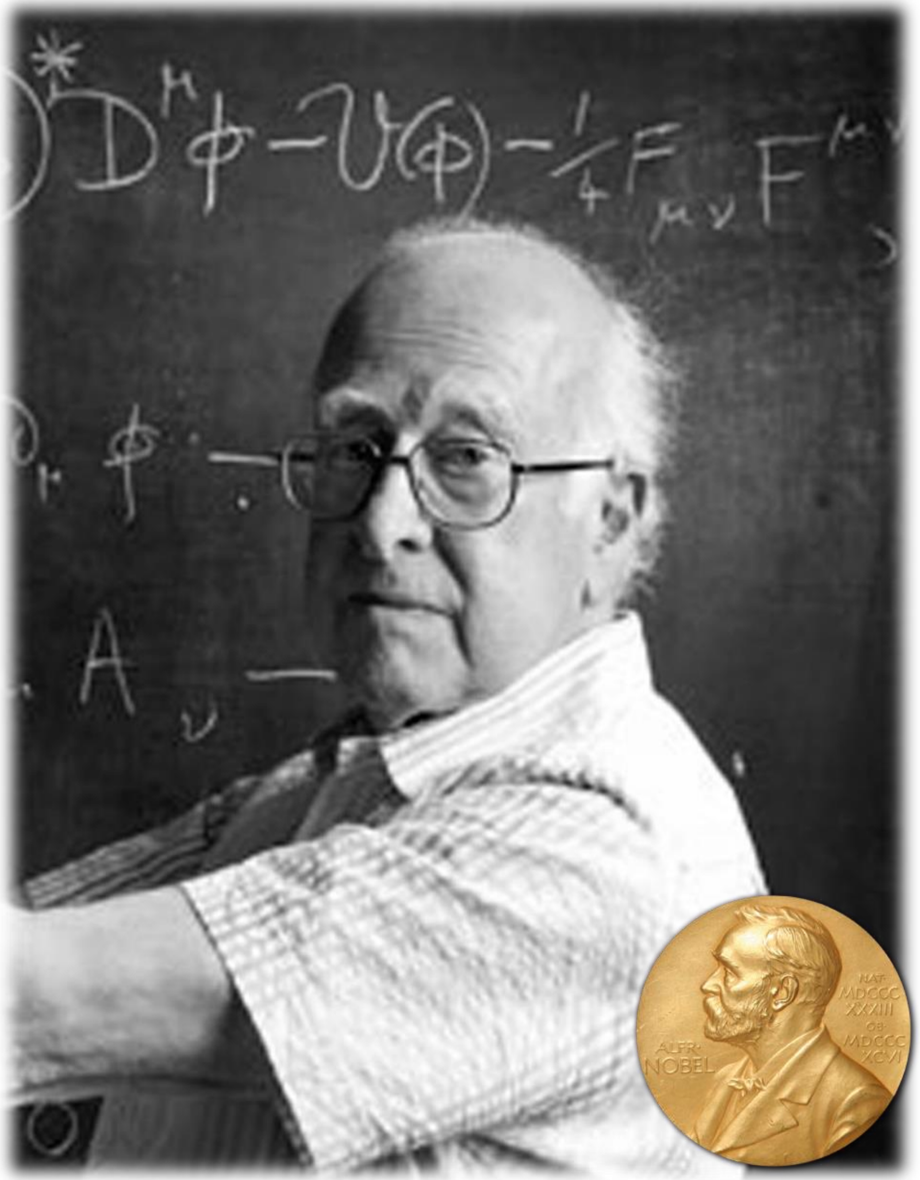


1. Introduction
1.2 Why luminosity is so important?

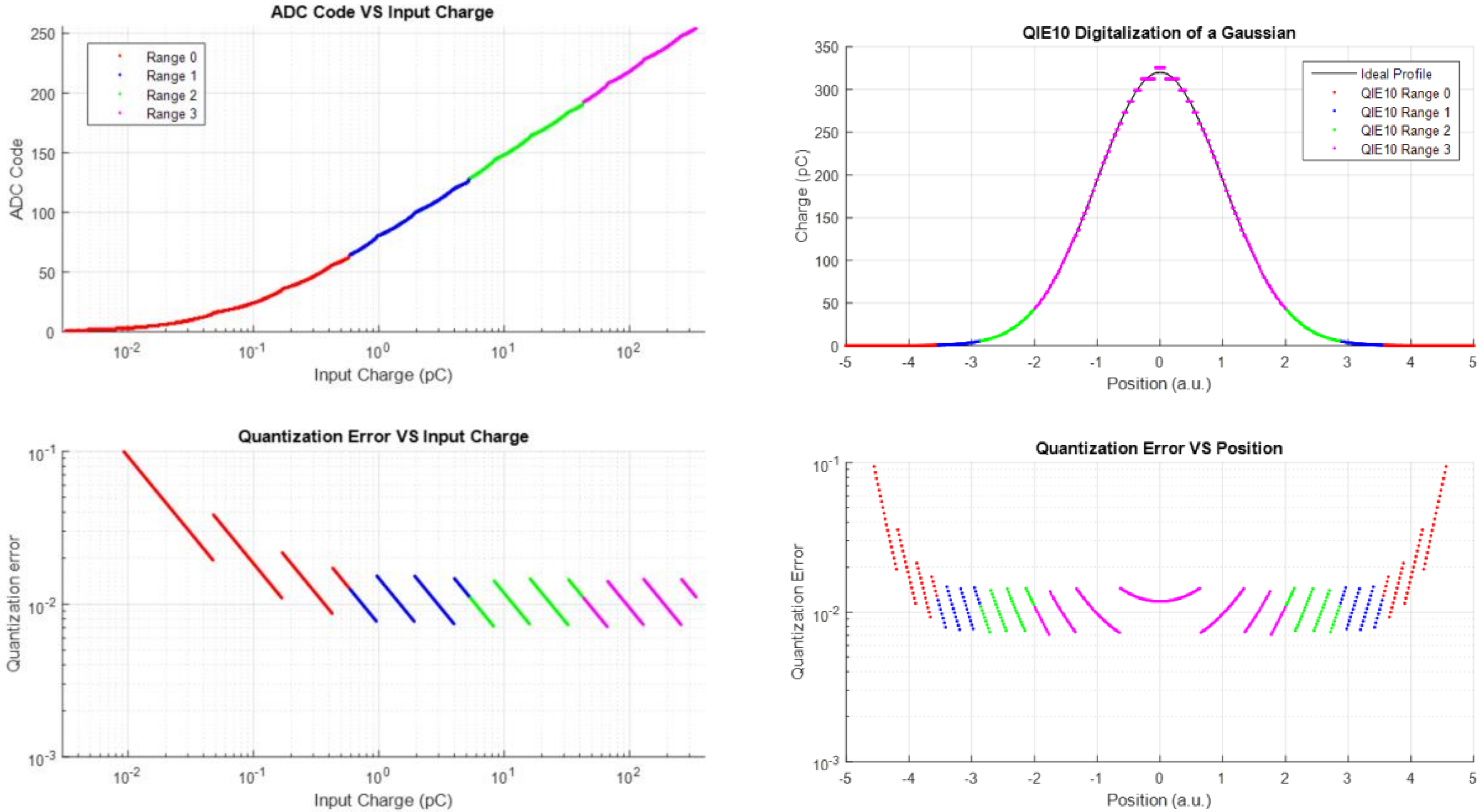
A high luminosity enhances the statistics for the observation of rare events, i.e. new particle type discovery



New particle detected by Atlas in the mas region around 125GeV
Higgs boson!!

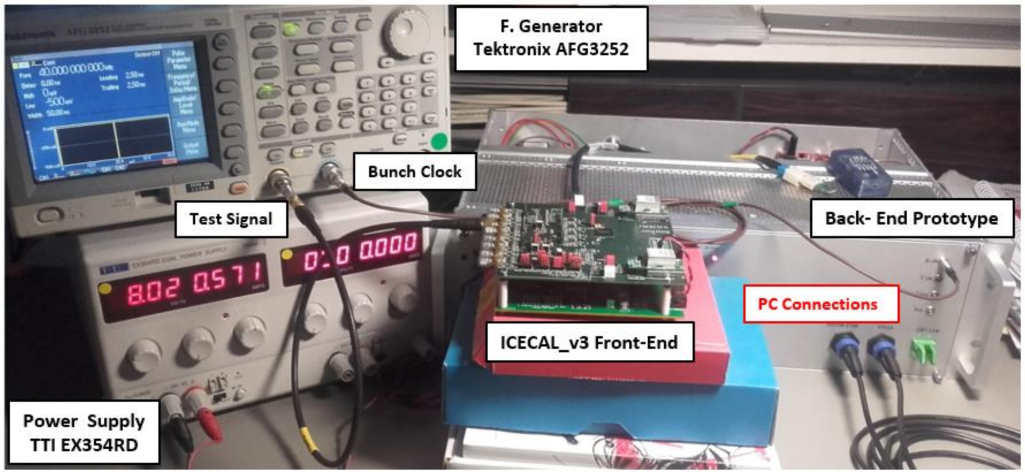


QIE10 Logarithmic digitalization schema



4. Laboratory qualification
4.2 Tests with ICECAL_V3 Front-End

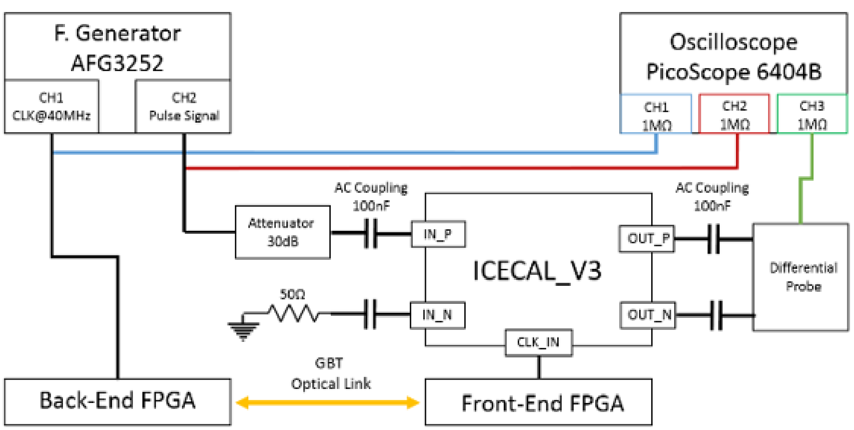
Front-End ICECAL_V3: Lab Set-up for Linearity characterization

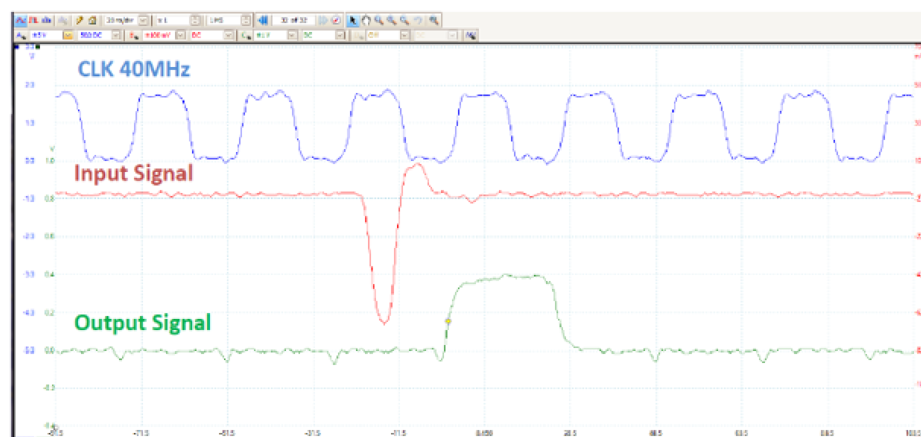


Automatized Setup:

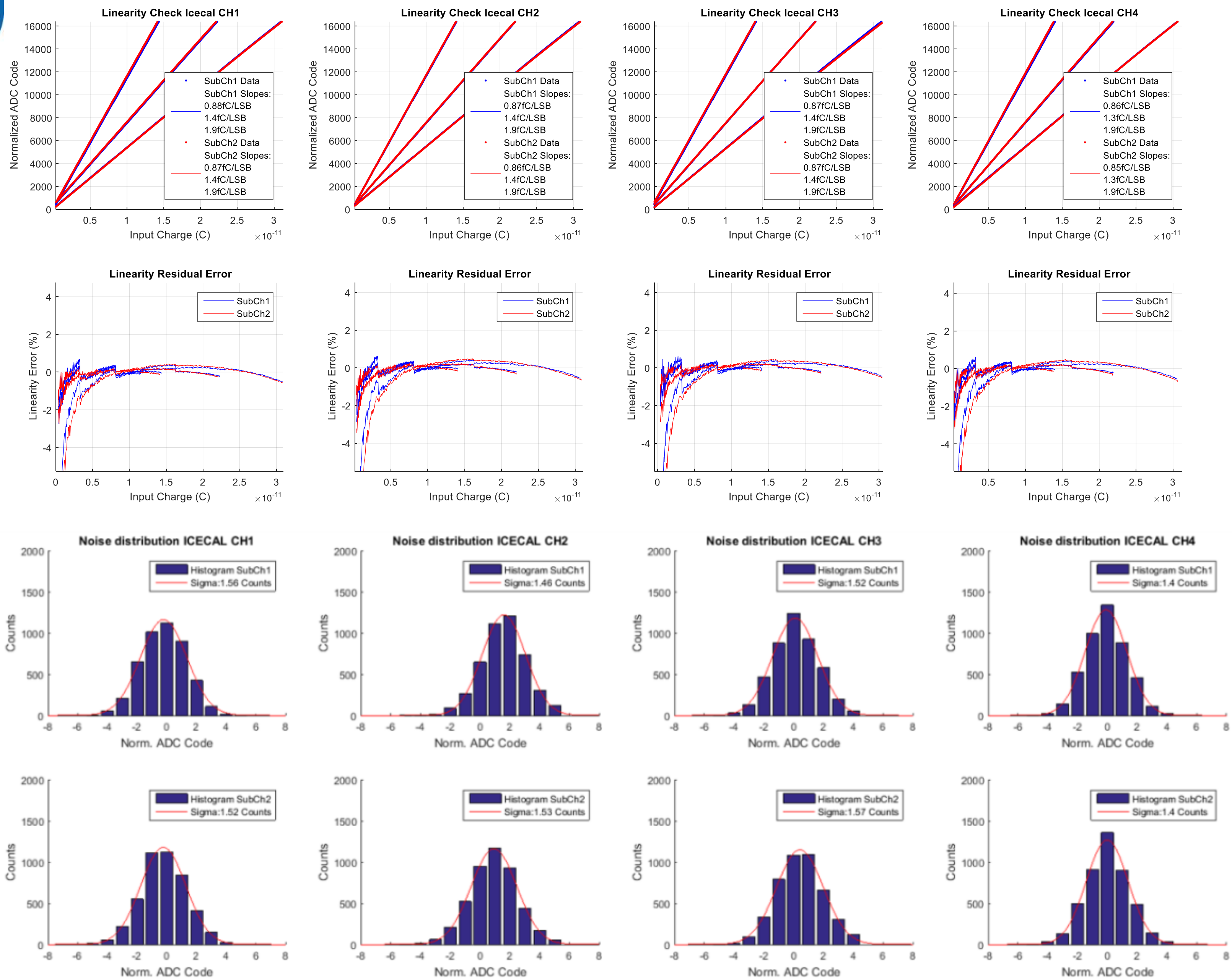
- AC Coupled ICECAL Inputs
- 50ns Pulses in synch. with B.Clock
- GPIB controls pulses amplitude

- B.Clock propagated trough GBT link

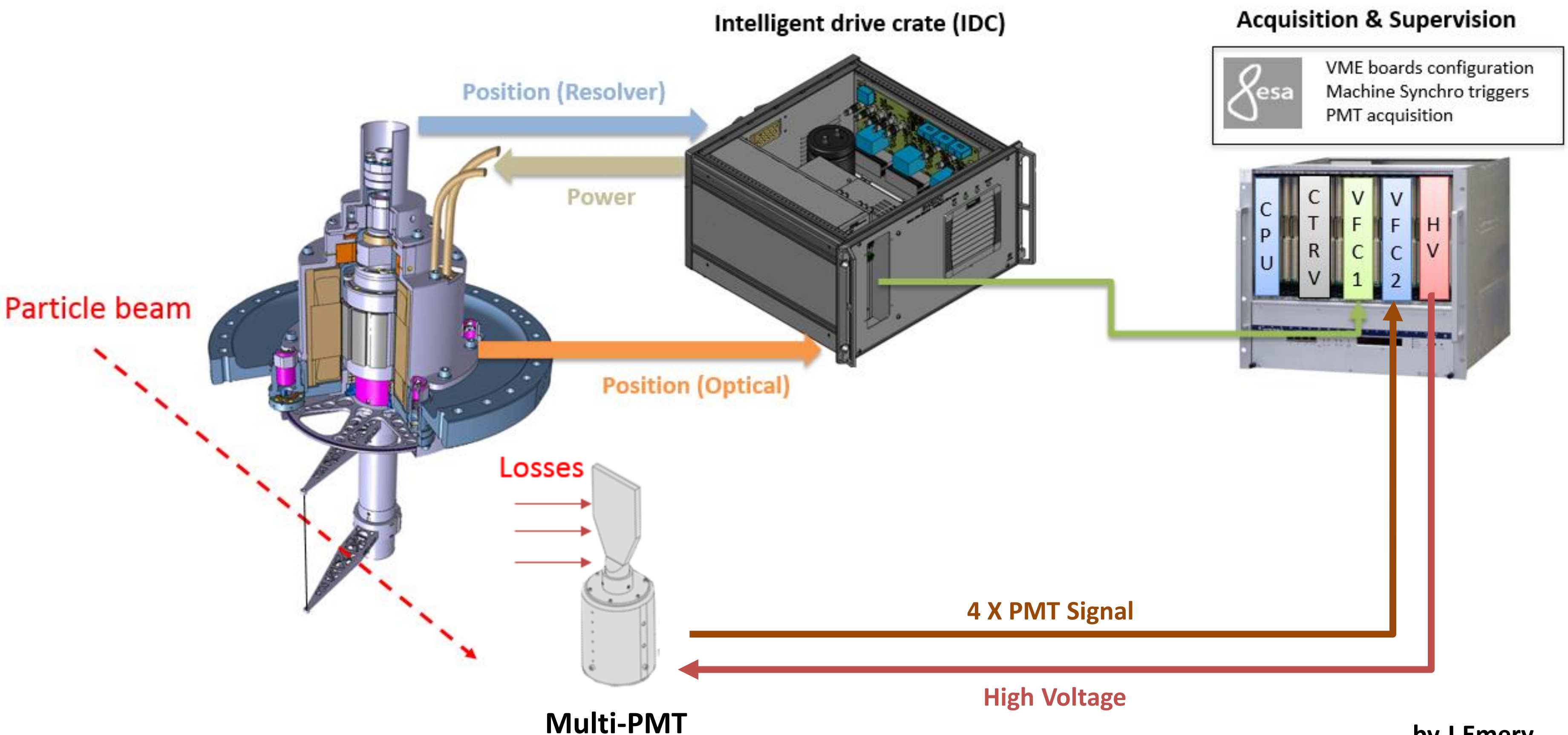




LAB Tests with ICECAL FE



1. LIU Beam wire scanners architecture and design
1.2 Control and acquisition electronics



by J.Emery

Final Configuration for all systems shown adobe:

Current Test Configuration in PSB → Motion Control Alpha (Pre-Series), OPS+PMT Acquisition (Scope-based)

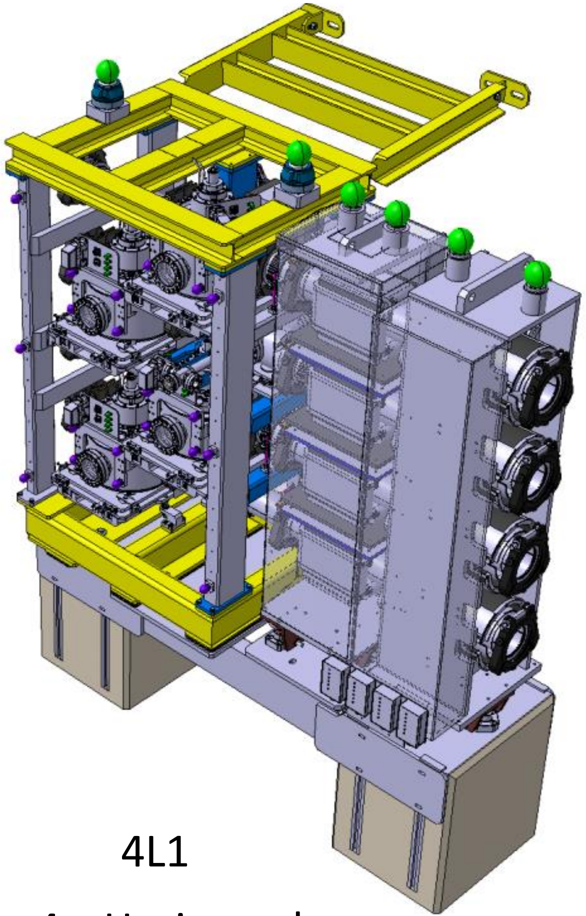
Current Test Configuration in PS → Motion Control (IDC), OPS+PMT Acquisition (Scope-based, soon VME + FESA)

3. LIU-BWS on PSB
3.3 Integration studies and schedule

Integration and ECR status

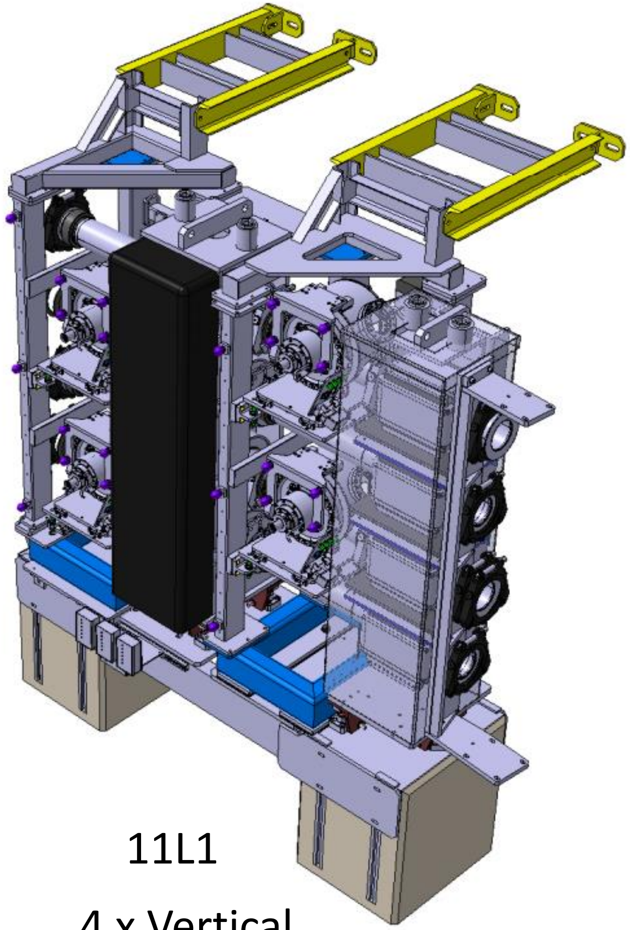
ECR approved: https://edms.cern.ch/document/1962159/0.1

Approval Accepted status - BIRTWISTLE Thomas William - 2018-08-06, 15:53



4L1

4 x Horizontal



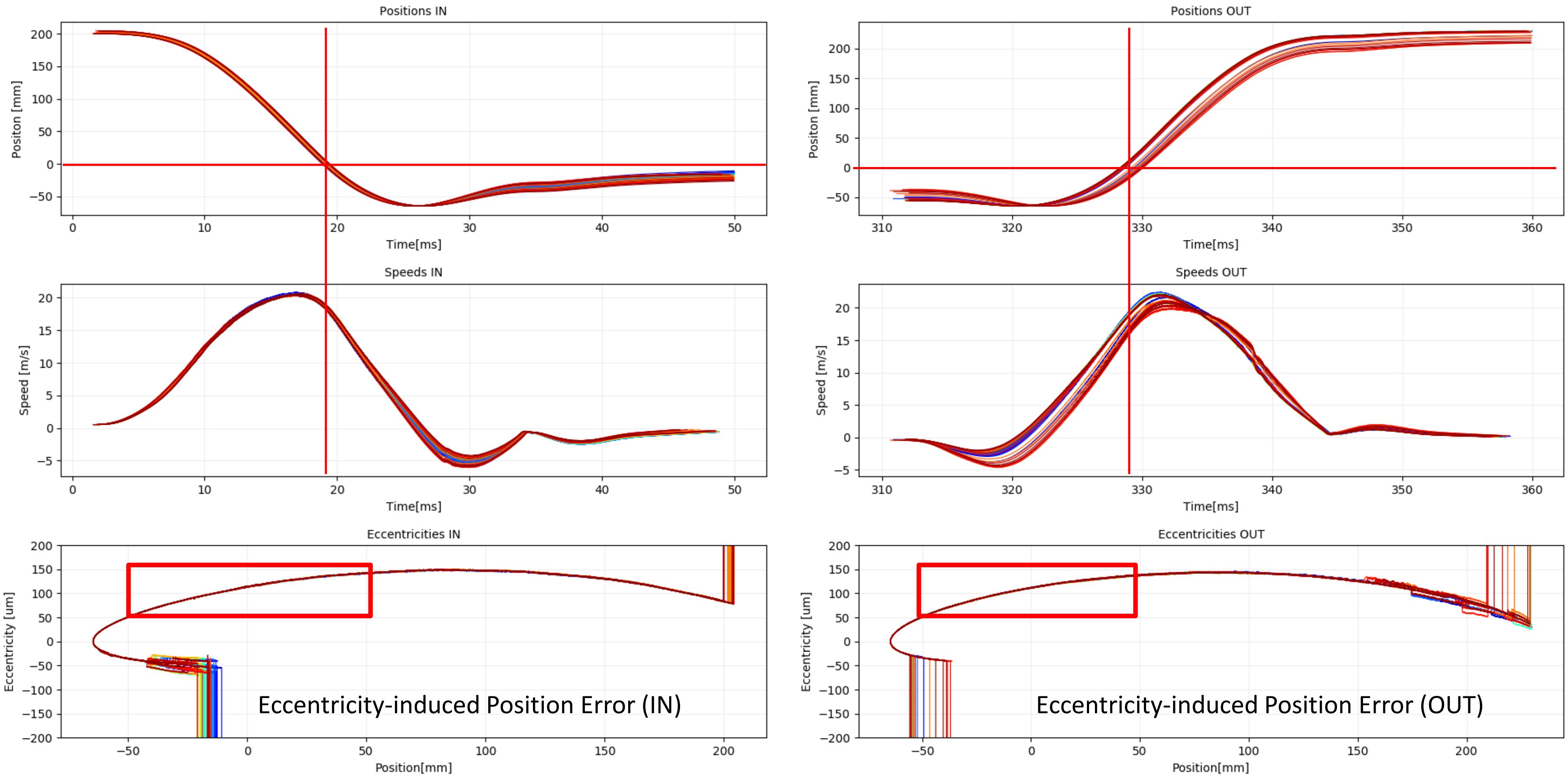
11L1

4 x Vertical

by D.Gudkov

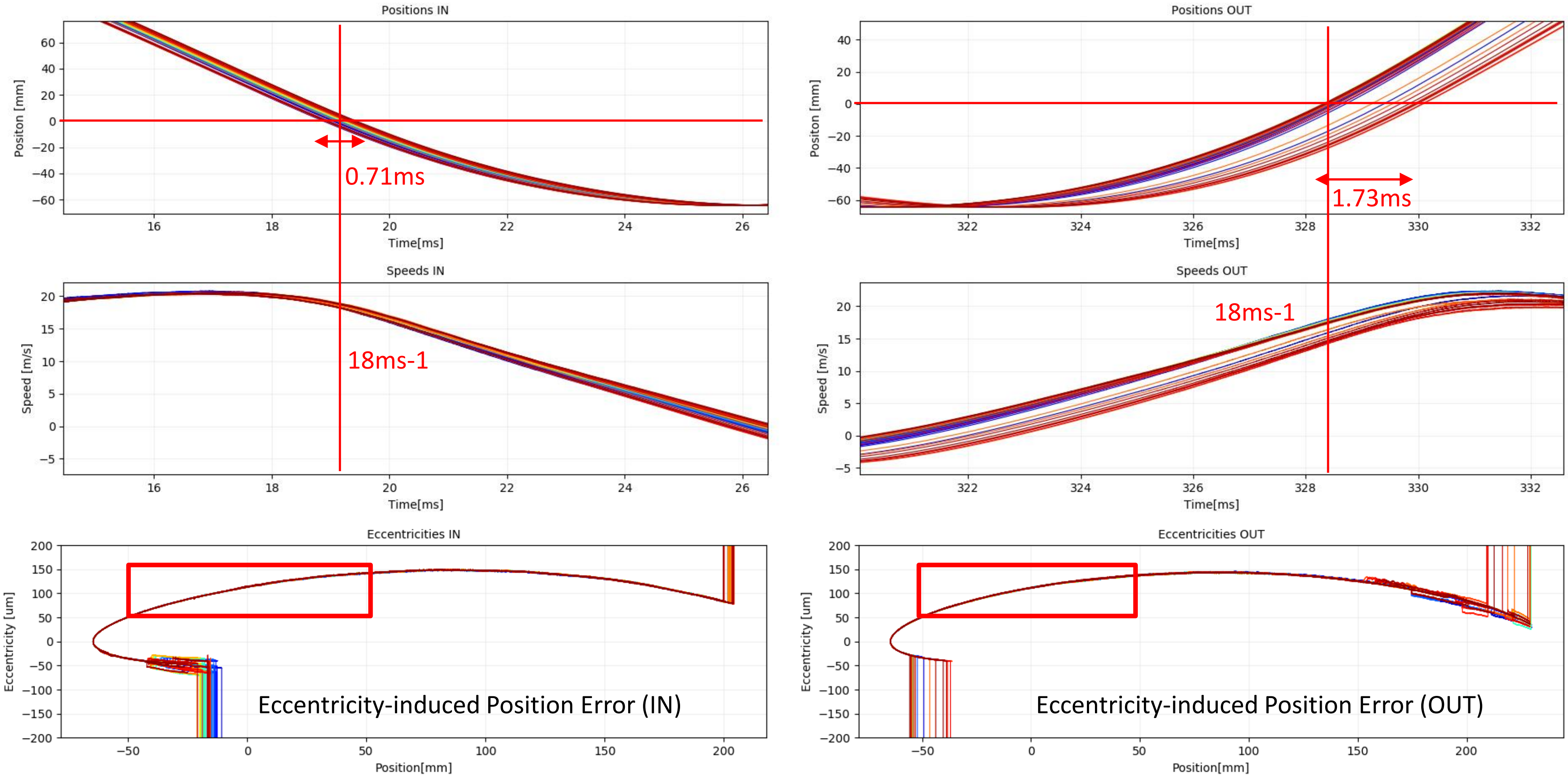
4. PSB Prototype Beam Tests
4.2 Results from 2018: Metallic disk motion

Projection position by using calibration curve (PSB_PXBWSRA005_CR000001 2018_02_23__11_17)



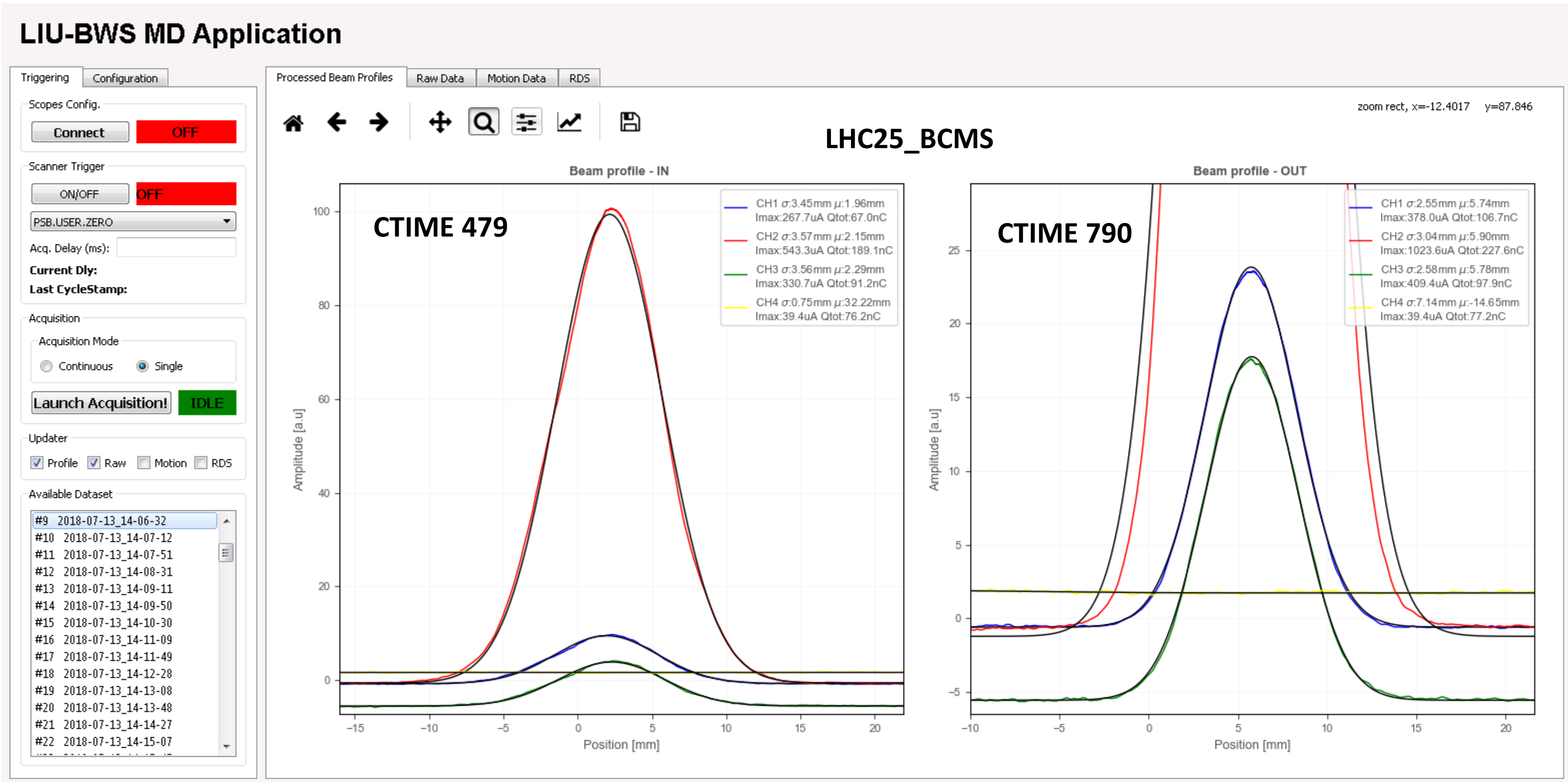
4. PSB Prototype Beam Tests
4.2 Results from 2018: Metallic disk motion

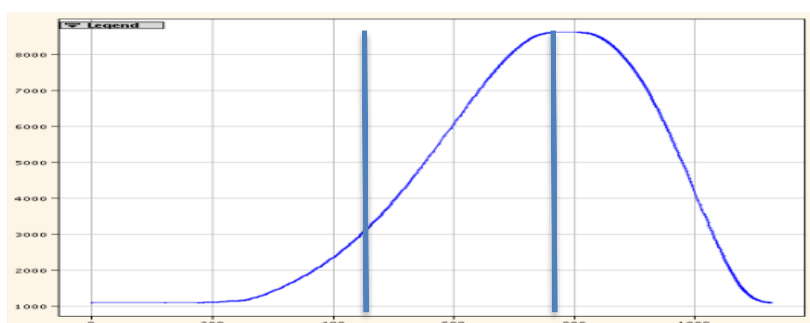
Projection position by using calibration curve (PSB_PXBWSRA005_CR000001 2018_02_23__11_17)



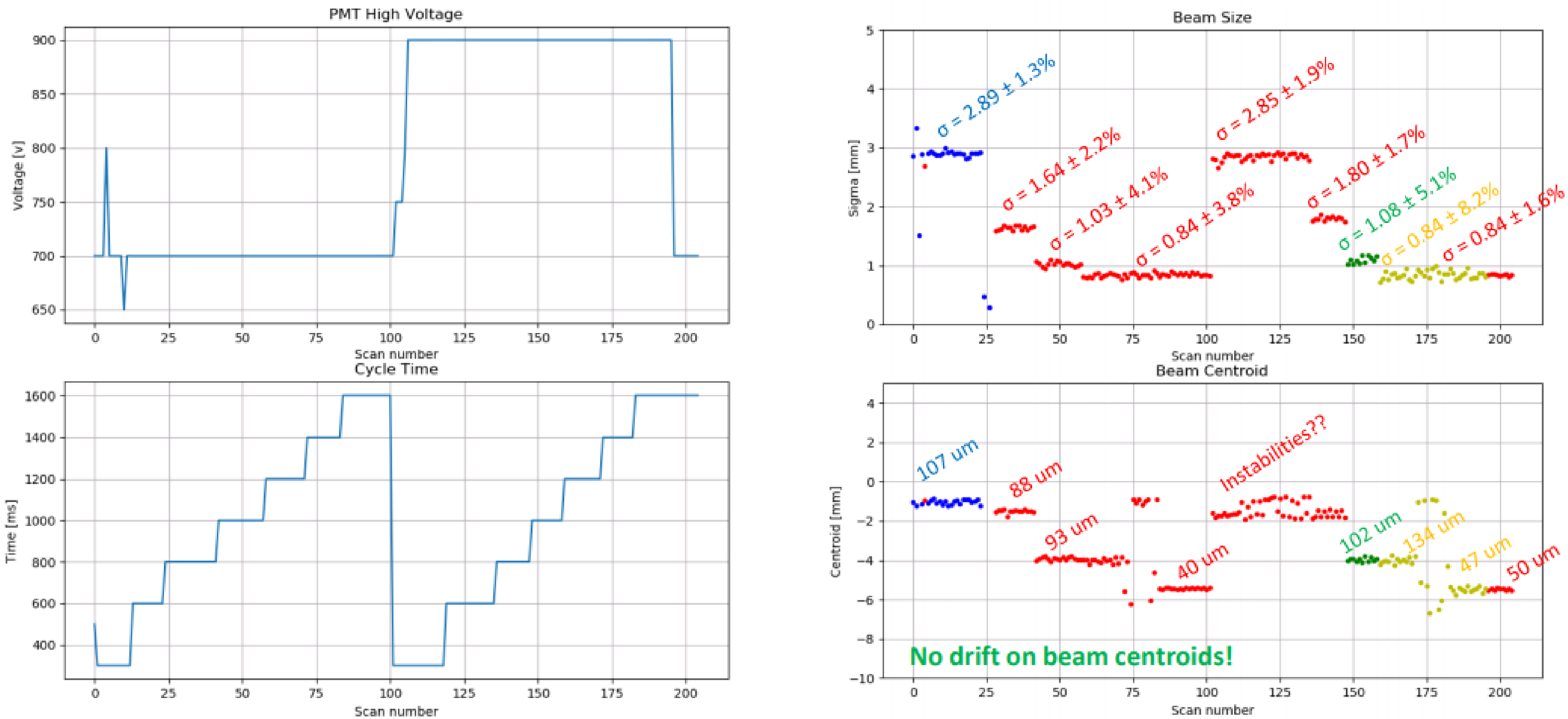
4. PSB Prototype Beam Tests

4.2 Results from 2018: Metallic disk motion





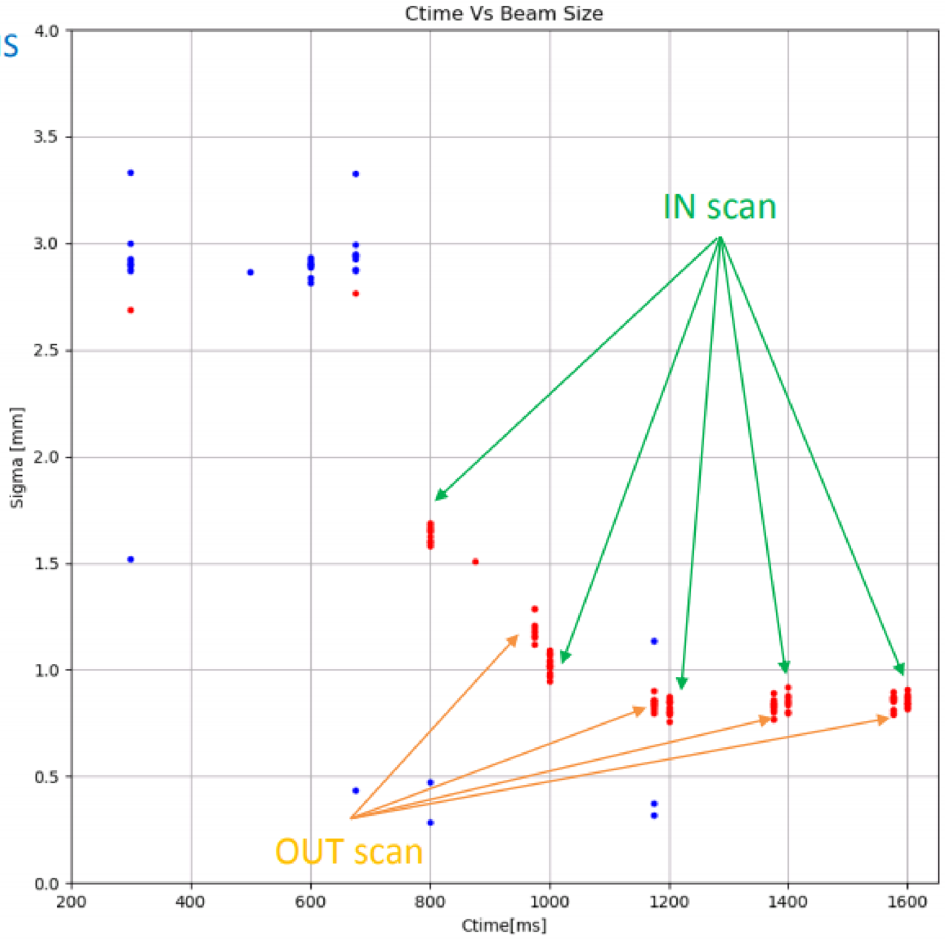
5. Sneak peek to some CPS BWS results
5.2 Preliminary results: 2018/06/11 LHC_INDIV



WARNING!!
Preliminary data (Still under analysis)

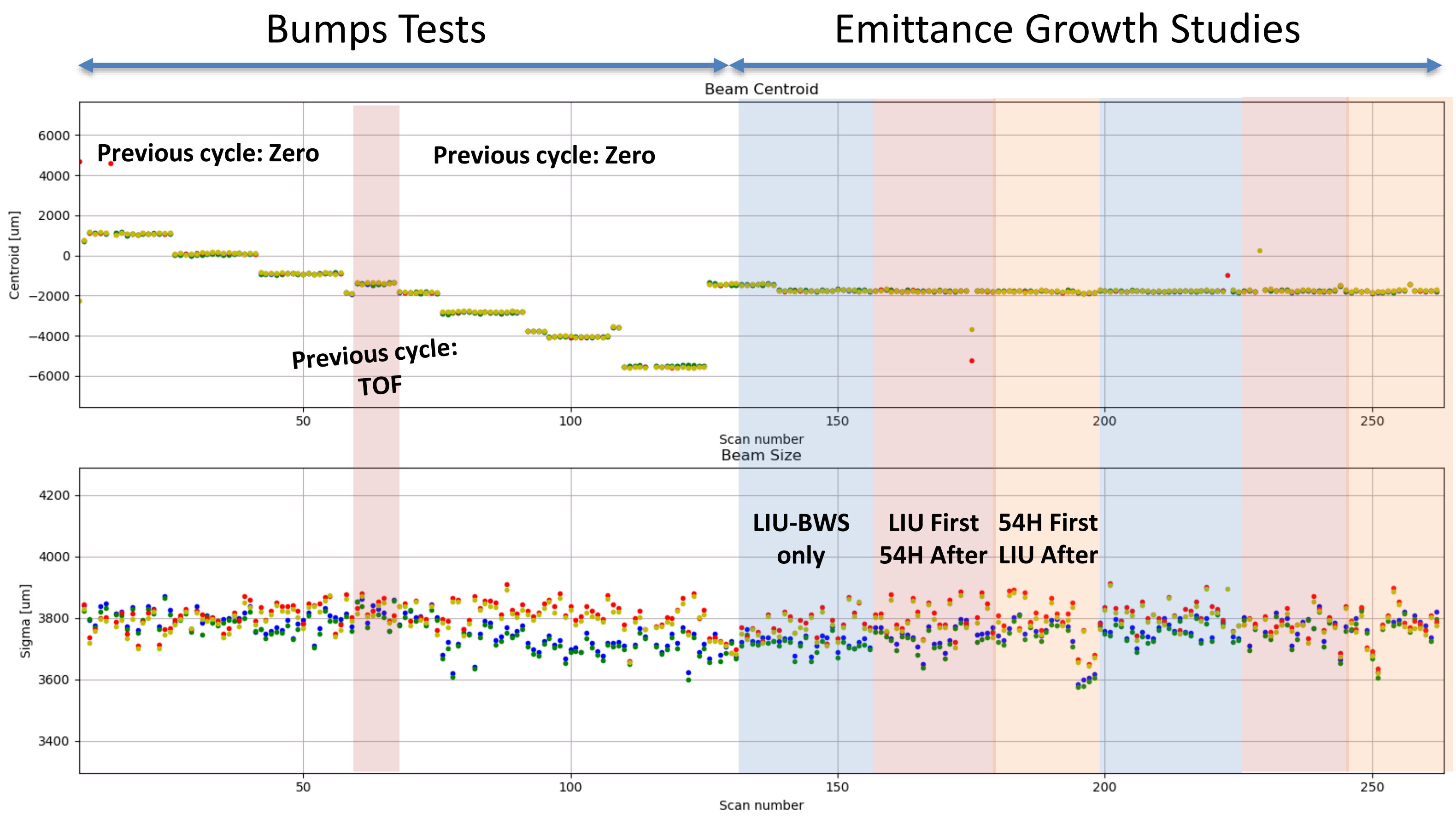
5. Sneak peek to some CPS BWS results
5.2 Preliminary results: 2018/06/11 LHC_INDIV

IN + OUT SCANS
0-101 @ 700V



5. Sneak peek to some CPS BWS results

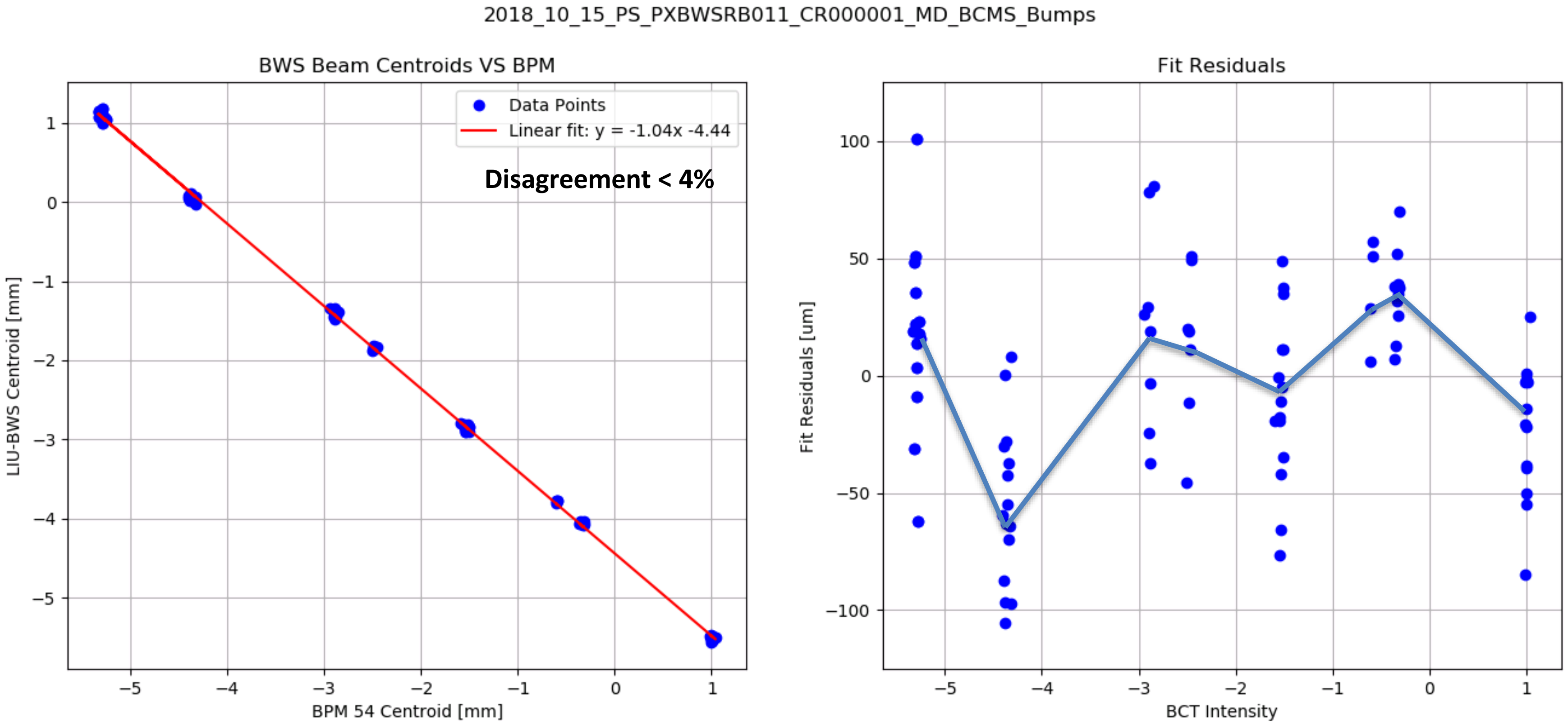
5.2 Preliminary results: 2018/10/15 LHC25_BCMS Bumps



WARNING!!
Preliminary data (Still under analysis)

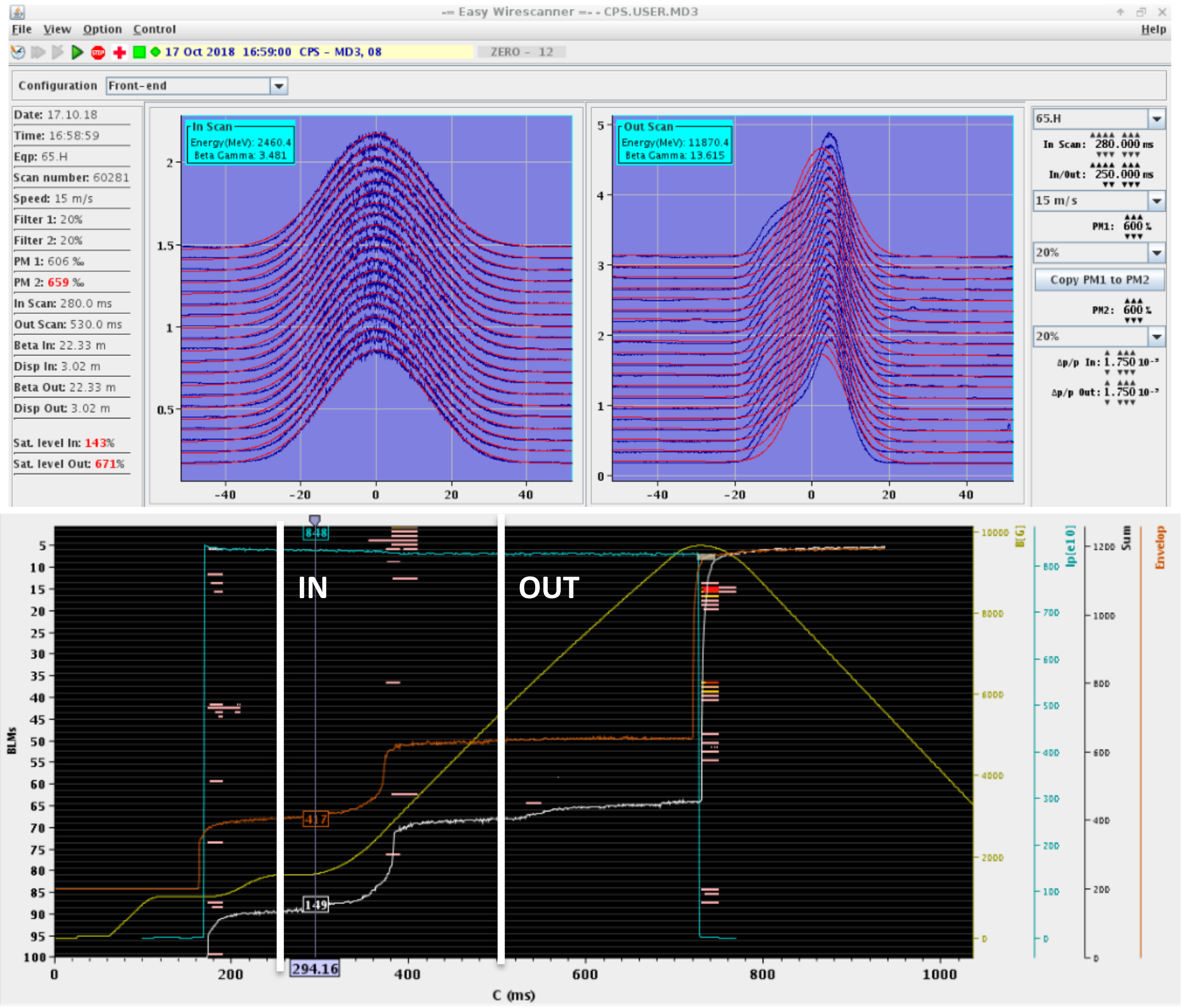
5. Sneak peek to some CPS BWS results

5.2 Preliminary results: 2018/10/15 LHC25_BCMS Bumps



WARNING!!
Preliminary data (Still under analysis)

5. Sneak peek to some CPS BWS results
5.2 TOF Beam



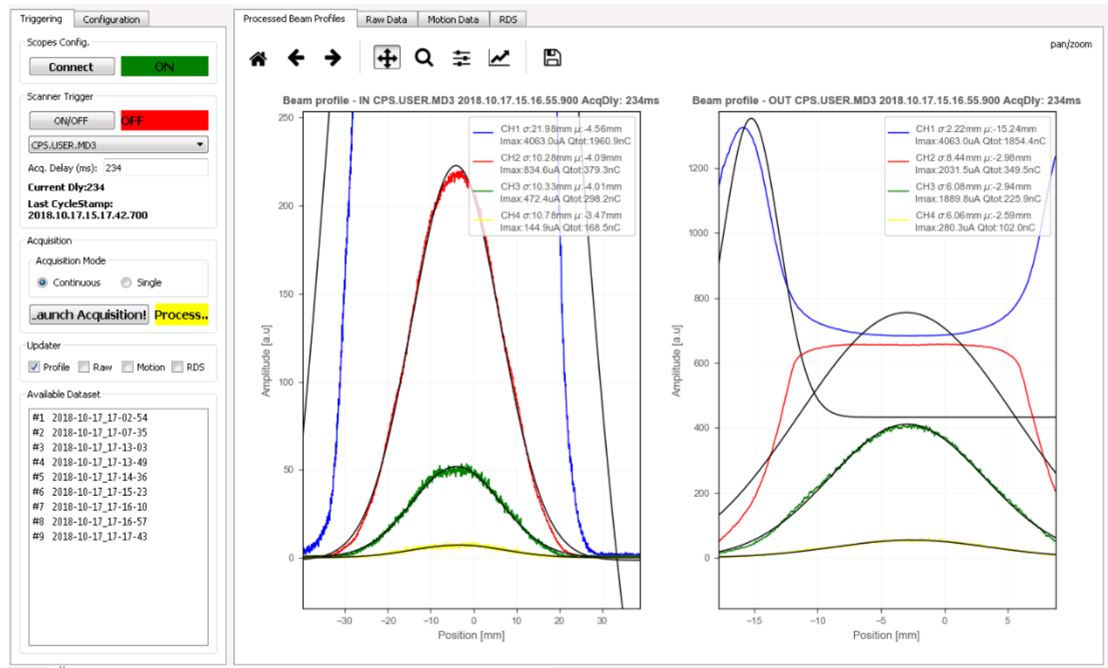
5. Sneak peek to some CPS BWS results

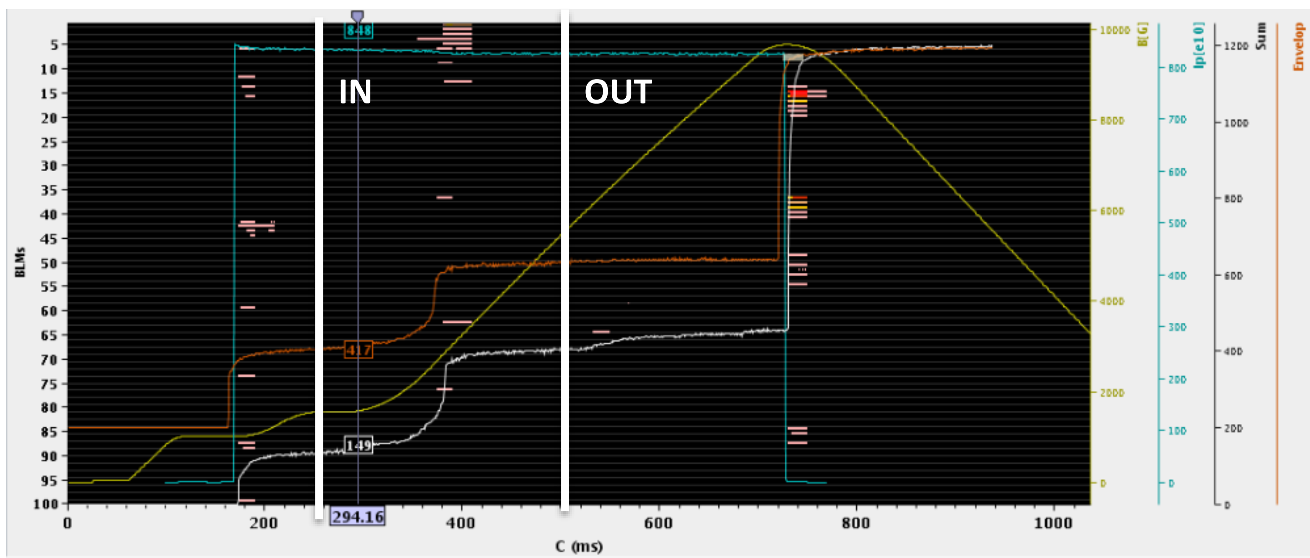
5.2 TOF Beam

Signal amplitude increase ~ 10

From CTIME 250ms → 500ms

Useful data from IN+OUT



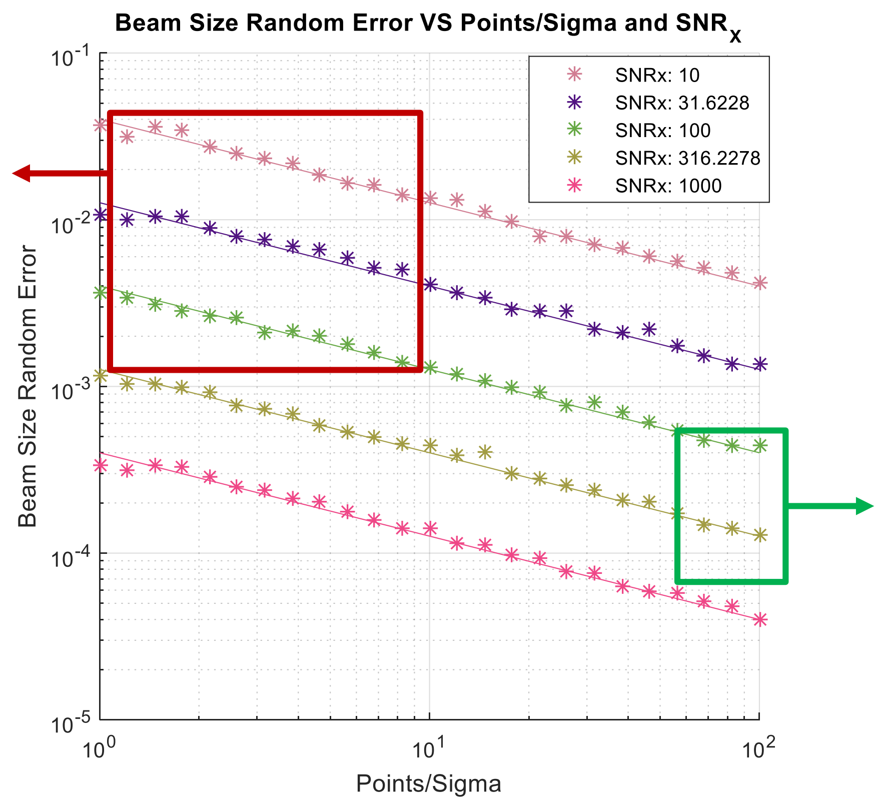


3. Position Incertitude VS Beam Sigma Incertitude

3.1 Numerical Simulations: Results

$$\epsilon_{Statistic}(SNR_x, PpS) = \frac{0.4}{SNR_x \sqrt{PpS}}$$

$$SNR_x = \frac{\sigma_{beam}}{\sigma_x}$$



Typical Examples:

Machine	Beam Size	PpS @ 20ms-1	Uncertitude	SNRx	Rand Err
PSB	1.5 - 9 mm	46 - 281	11 um	136 - 820	< 0.1 %
SPS	0.2 – 5 mm	0.4 - 10	11 um	18 - 454	> 4 % - 0.1 %

Position Incertitude VS Beam Sigma Incertitude

Numerical Simulations: Outcome and conclusions

Requirements for Rand Err < 1% on SPS @ 20ms-1:

$$\epsilon_{Statistic}(SNR_x, PpS) = \frac{0.4}{SNR_x \sqrt{PpS}} \qquad SNR_x = \frac{\sigma_{beam}}{\sigma_x}$$

Sigma 200 um

PpS = 0.4, SNRx needs to be >63

Pos Incertitude required better than 3 um

Sigma 5000 um

PpS = 10, SNRx needs to be >13

Pos Incertitude required better than 380 um

Comments

Specifications:

- Bernd´s Document → Position measurement accuracy of the order of 1 µm

Conclusions:

- For PSB beams: System is within specifications in terms of beam size error (< 0.1%).
- For SPS beams: For small beams, accuracy needs to be improved or speed reduced.
  - Analitical approx diverges for PpS < 1 maybe intertitude > 3 um can be alowed for small beams.

To everyone that supported me during all these years…

THANK YOU!!!