Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Frascati Beam Test Facility: from experiment to test beam.

Luca Foggetta on the behalf of LNF LINAC&BTF groups

Beam Telescopes and Test Beams Workshop BTTB9
Online, Lecce, Italy
8-11/02/2021

Unione europea

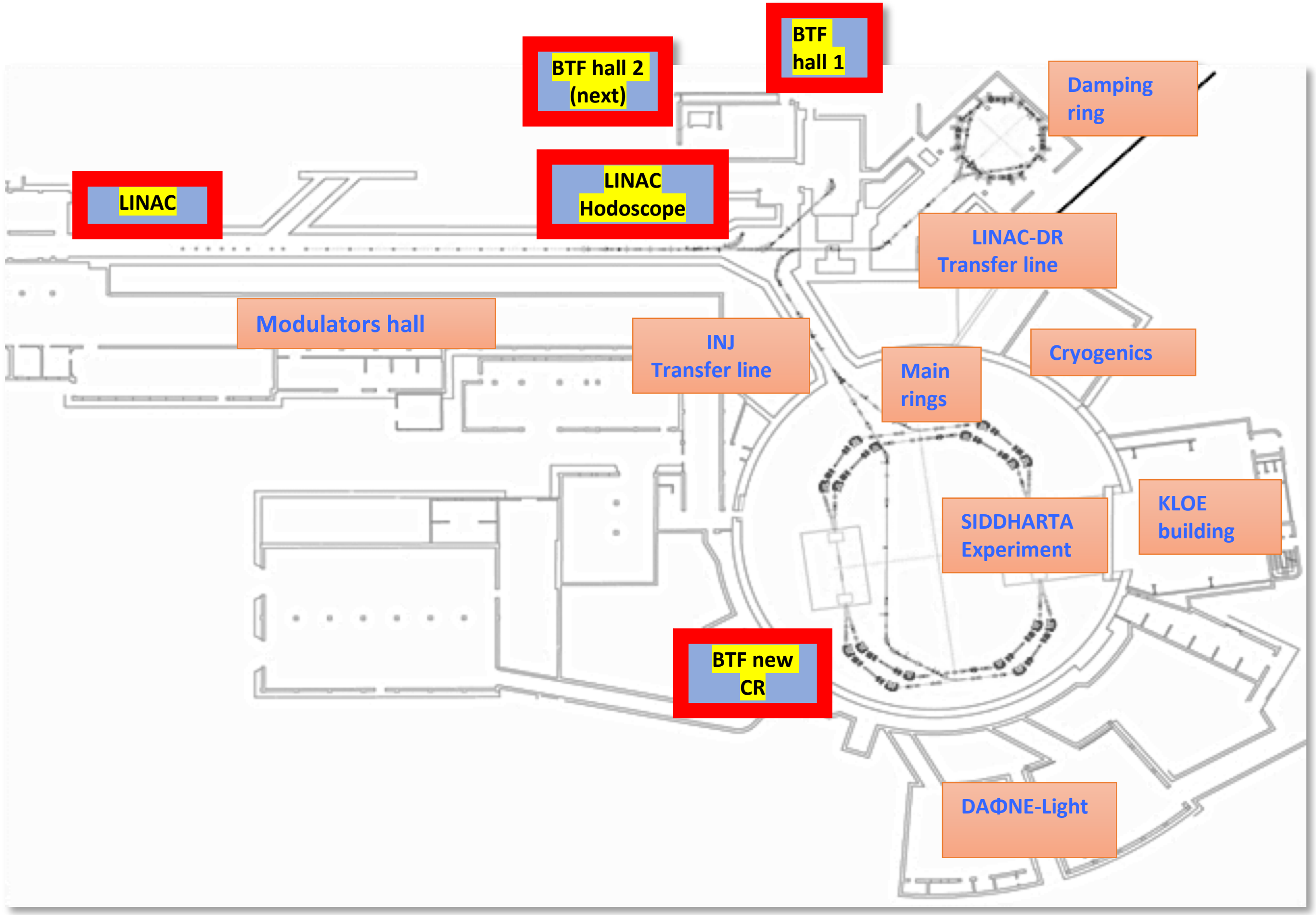
LNF – OVERVIEW

The BTF is part of the DAΦNE accelerator complex in LNF (Frascati, Italy):

- **it can extract and manipulate the high intensity LINAC e+/e- beam**

BTF is a facility:

- optimized for detector **calibration, long time experiment and testbeam**
- with the possibility of **DUT irradiation**
- with a **pulsed** electrons (or positrons) beam, in a definite range of parameters…
- With services at the user's disposable
  - DAQ data,
  - SLOW DCS data
  - Gas pipelines
  - HV
  - Networking
  - Detectors
  - Dedicated Staff

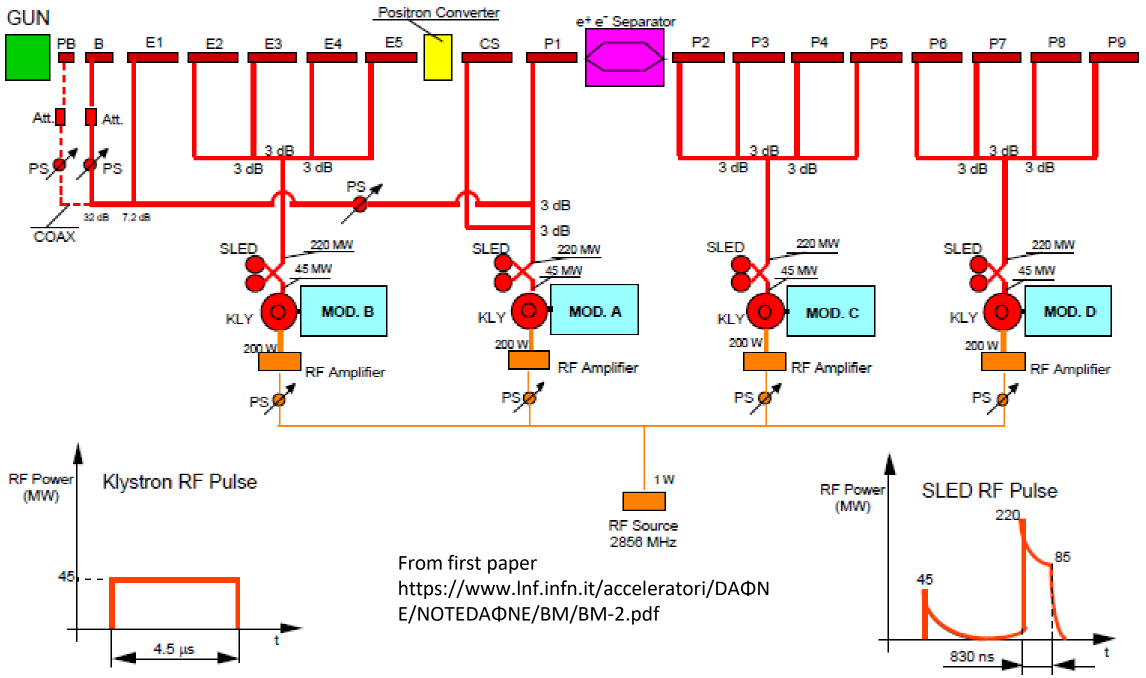


Detailed information and contacts

- Main web site: http://www.lnf.infn.it/acceleratori/btf
- Technical information and documentation: http://wiki.infn.it/strutture/lnf/da/btf/home
- Contact: btf@lists.lnf.infn.it
- Administration and access contact: btfsupport@lnf.infn.it

LNF – LINAC FACILITY

	Design	Operational
Accelerating structure	SLAC-type, CG, 2π/3	
RF source	4 x 45 MWp sled klystrons TH2128C	
Electron beam final energy	800 MeV	~780 MeV*
Positron beam final energy	550 MeV	~550 MeV*
RF frequency	2856 MHz	
Positron conversion energy	250 MeV	220 MeV
Beam pulse rep. rate	1 to 50 Hz	1 to 50 Hz
Beam macrobunch length	10 ns	1.4 to 320 ns (@0.01xcurrent)
Max Gun current (for positron production)	8 A	8 A
Beam spot on positron converter	1 mm	1 mm
norm. Emittance (mm. mrad)	1 (electron) 10 (positron)	< 1.5 <10
rms Energy spread	0.5% (electron) 1.0% (positron)	0.5% (electron) 1.0% (positron)
electron current on positron converter	5 A	5.2 A
Max output electron current	>150 mA	500 mA
Max output positron current	36 mA	85 mA



From first paper https://www.lnf.infn.it/acceleratori/DAΦNE/NOTEDAΦNE/BM/BM-2.pdf

- Electron and positron pulsed LINAC
- Commissioning: 24 years ago
- Used for DAΦNE inj, BTF in opportunistic way (but now hijacked for experiment also)
- Developed for few uptime hours/day at 10ns pulse length
  - **NOW capable of 24/7 continuous BTF in's for months**
  - **320ns beam macrobunch**

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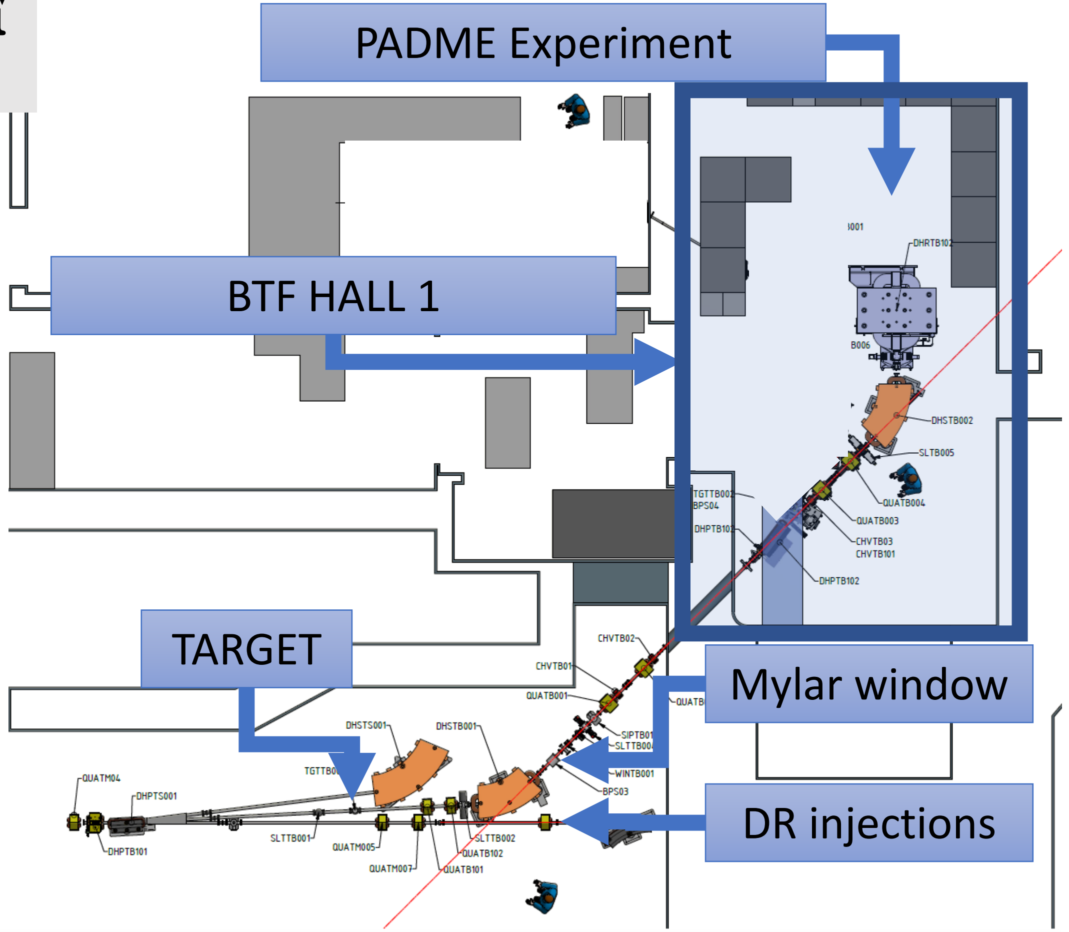
LNF – BEAM TEST FACILITY

Parameters	Parasitic		Dedicated	
	With Cu target	Without Cu target	With Cu target	Without Cu target
Particle	e^+ / e^- (User)	e^+ / e^- (DAΦNE status)	e^+ / e^- (User)	
Energy (MeV)	25–500	510	25–700 (e^-/e^+)	167–730 (e^-) 250–550 (e^+)
Best Energy Resolution at the experiment	0.5% at 500 MeV	0.5%/1%	0.5%	Energy dependant
Repetition rate (Hz)	Variable from 10 to 49 (DAΦNE status)		1–49 (User)	
Pulse length (ns)	10		1.5–320 (User)	
Intensity (particle/bunch)	$1–10^5$ (Energy dependence)	1 to 10^7 / 1.5 10^{10}	$1–10^5$ Energy dependence	1 to 3 10^{10}
Max int flux	3.125 10^{10} part./s			
Beam waist size(mm)	0.5–55 X / 0.35–25 Y (vacuum window dependent)			
Divergence (mrad)	Down to 0.5			

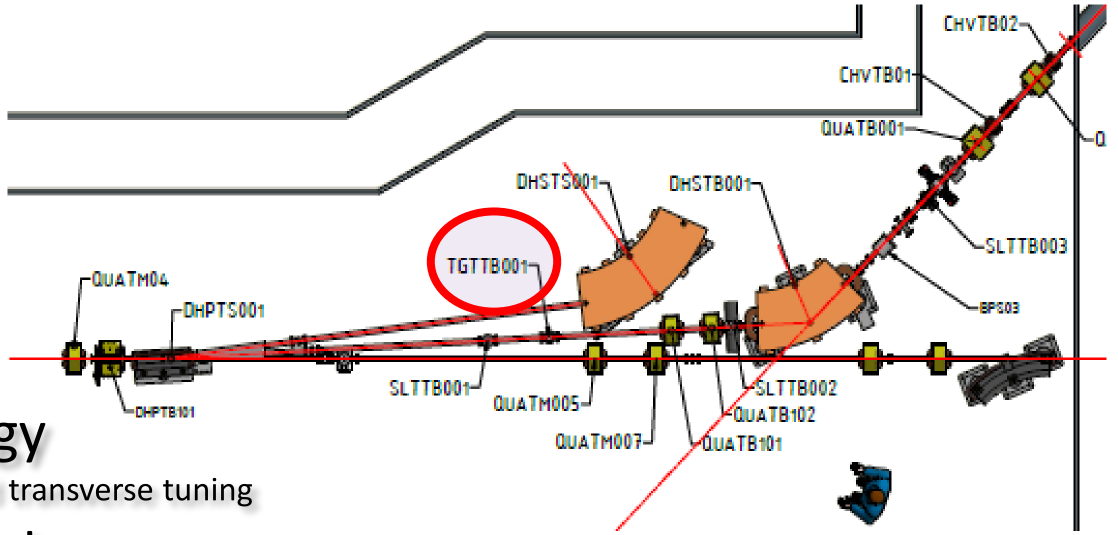


- Pulsed **electron** and **positron** beams (up to 49 pulses/second)
- Different ranges of parameters in the **two running modes**:
  - Dedicated (no collider operation, exclusive BTF users)
  - DAΦNE&BTF injections in sharing via pulsed magnet
    - Beam top parameters defined by DAΦNE injections

Average of 200 beam days/year, 25-30 experimental groups, 150-200 users

- Now BTF hall 1 setup for dark matter searches experiment **PADME**
- **PADME technical and scientific run in 2020– From July to December 2020**

BTF PRIMARY AND SECONDARY BEAMS

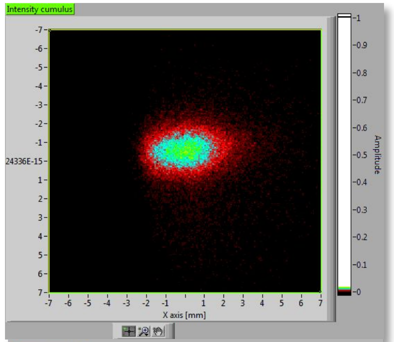


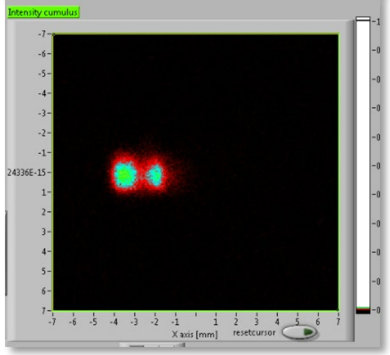
LINAC Conditioned Primary Beam

- Fixed energy
  - Steering and transverse tuning
- High current
  - from DAΦNE inj current
  - Easy tunable in 6 order of magnitude
  - Now down to single particle range

CU Target in the middle

- RUN time Tunable energy
  - All energies from $E_{primary}$ to ≈30 MeV
- RUN time Tunable multiplicity
  - From max(E) to single particle per shot
- Particle type decoupled from LINAC production



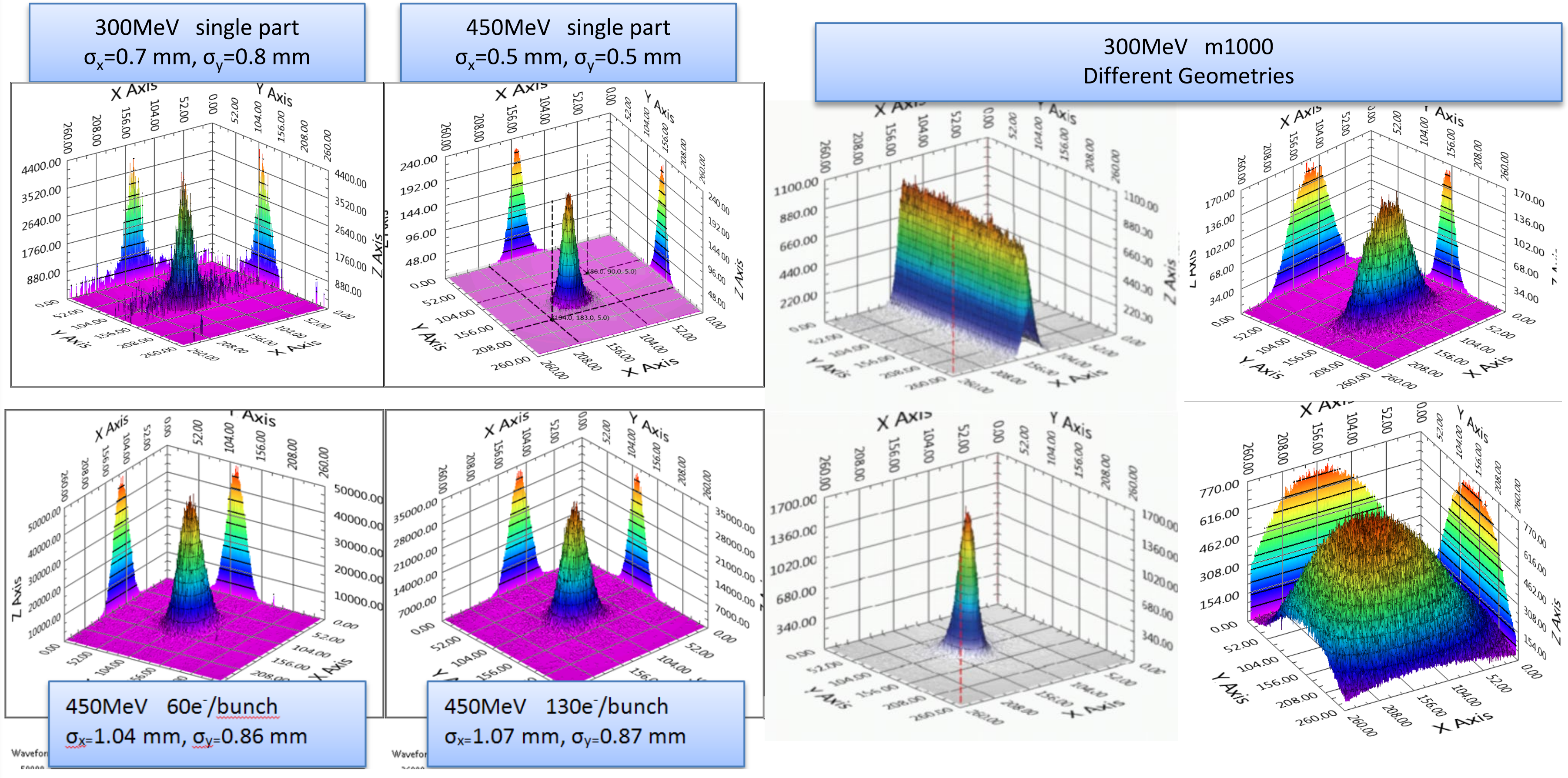


- Parameters setup via LINAC and BTF scrapers/magnets
- Final focus user dependant
- Runtime manageable

BTF "HIGH ENERGY" SECONDARY BEAMS - BTFEH1

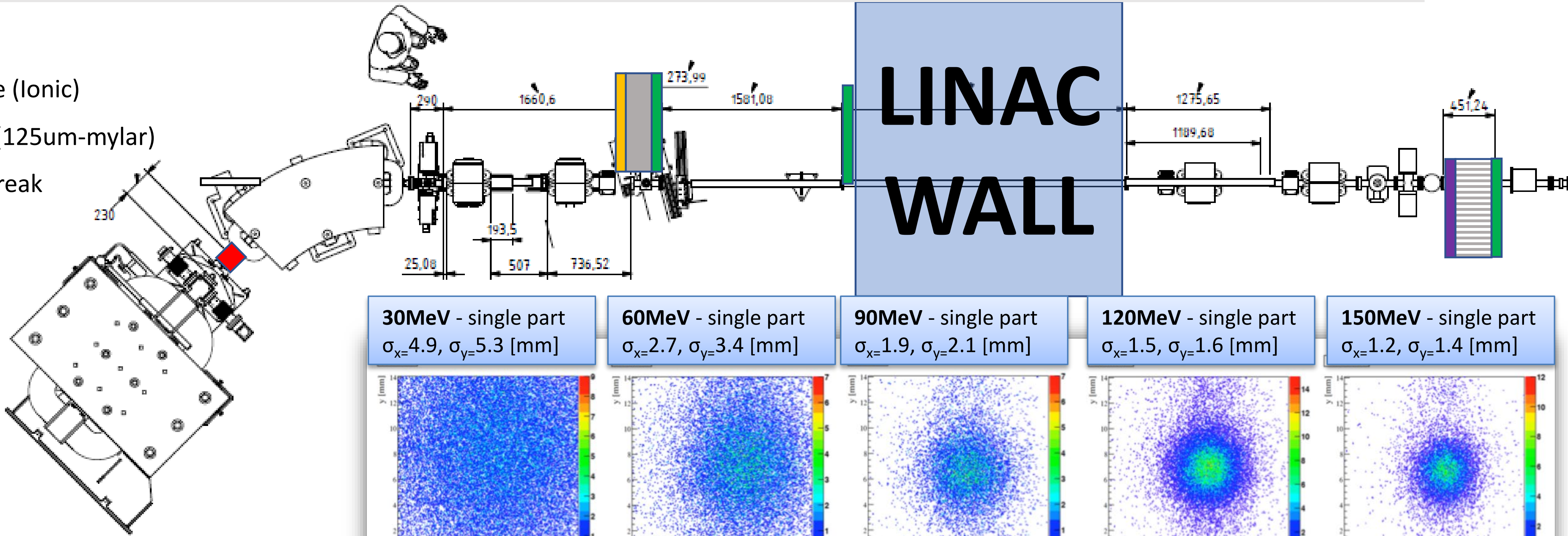
Secondary beams

- Mostly used in test beams (change energy and flux runtime)
- Limit to maximum multiplicity per bunch (energy dependent)
- Easy to develop
- High reproducibility
- Target decouples most of the LINAC instabilities



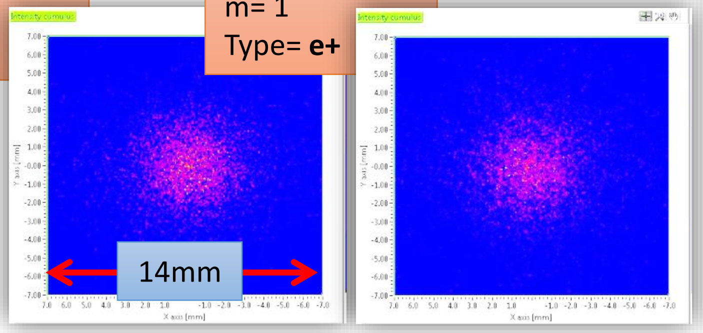
BTF "LOW ENERGY" SECONDARY BEAMS – BTFEH1

- Vacuum Service (Ionic)
- Vacuum Break (125um-mylar)
- OPT. Vacuum Break
- Manual Valves

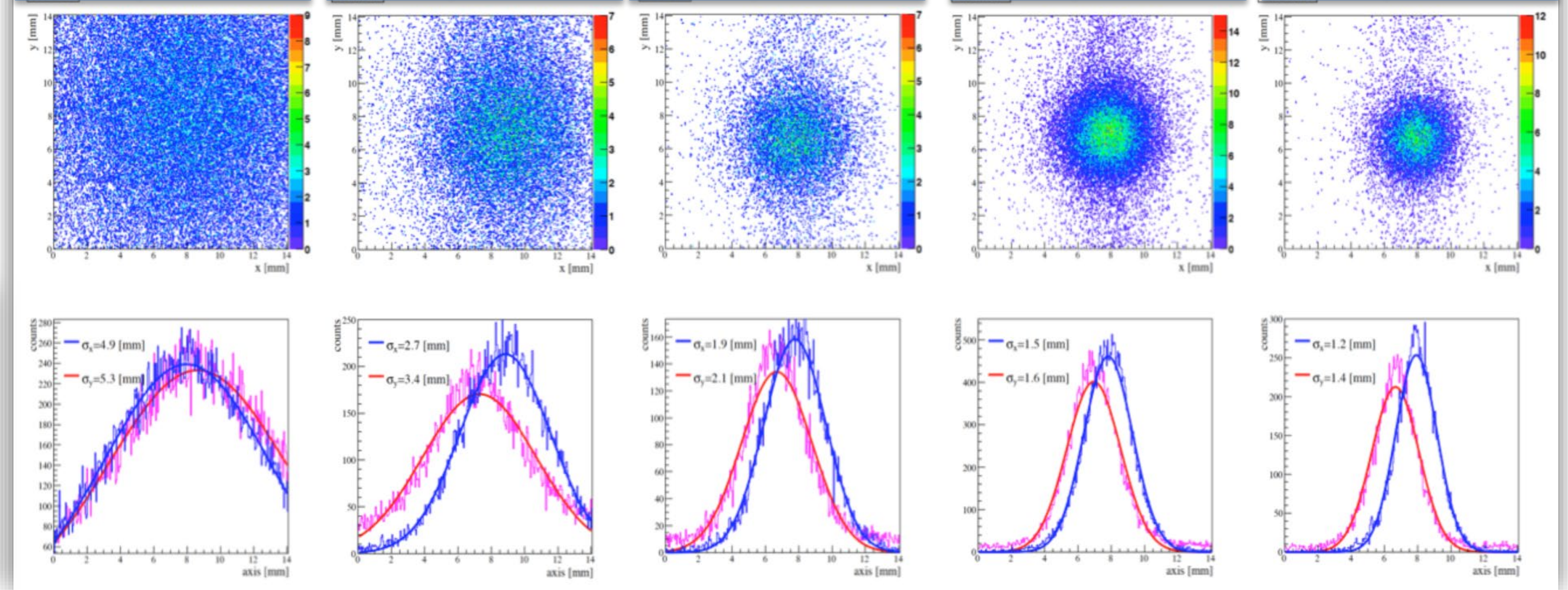


E= **100 MeV**
m= 1
Type= **e-**

E= **100 MeV**
m= 1
Type= **e+**



30MeV - single part	**60MeV** - single part	**90MeV** - single part	**120MeV** - single part	**150MeV** - single part
σ_{x}=4.9, σ_{y}=5.3 [mm]	σ_{x}=2.7, σ_{y}=3.4 [mm]	σ_{x}=1.9, σ_{y}=2.1 [mm]	σ_{x}=1.5, σ_{y}=1.6 [mm]	σ_{x}=1.2, σ_{y}=1.4 [mm]



SWITCHING TO LONGER PULSE PRIMARY BEAM

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BTF traditionally is tuned for any users request

PADME experiment has leading us to push forward functional limitation of LINAC-BTF
- Bunch length up to 300ns, pulse flatness in few percent
- Charge at users request (down to single particle, up to nominal one ~30kPoT/bunch) (sometimes also secondary TB)
- High beam stability (bunch charge, position, transverse dimension, transport…)
- Very very low background (externals, pipe internal, dark current included)

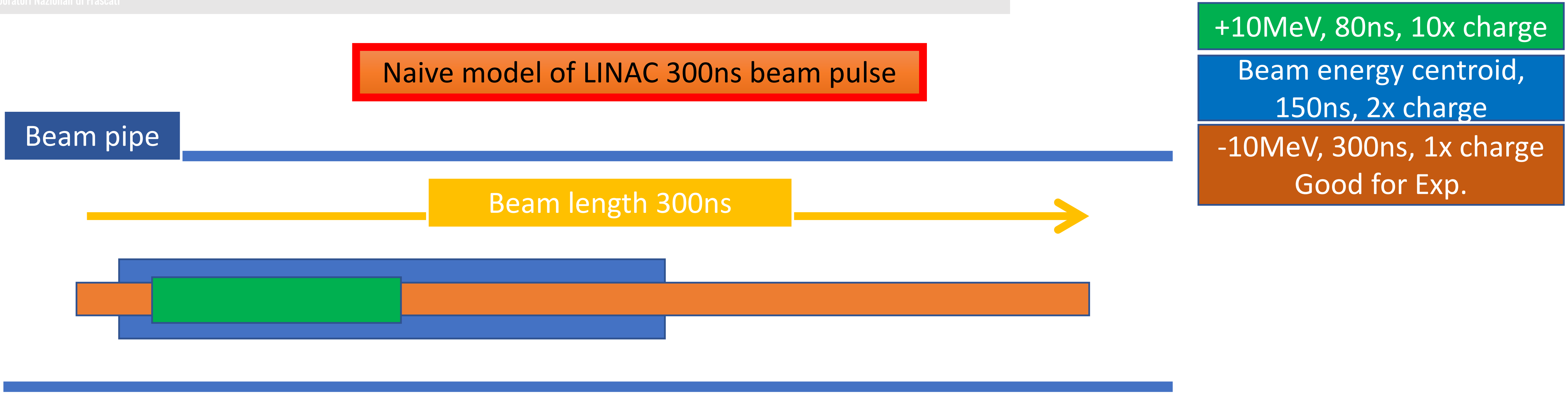
Trials in the past with secondary beam -> more background issues. Then we switch to primary one, so we manage:
- **Lowering two order of magnitude GUN emitted current**
  - Under the dynamic range for the most LINAC diagnostic, after positron converter (BCM, BPM, ICT)
  - Setup done at higher current, then increase GUN cathode control grid voltage (in linear range)

- **Reducing background** in BTF1 experimental hall and PADME (now **less than 230nS/h**, hit on PADME)
  - Increased stay-clear factor in BTFEH1 pipes, avoiding bottleneck
  - **Low beam loading** => Final beam energy spread around 5% (before BTF line selection)
  - Energy spread @ PADME target less than 1%

- **LINAC is in quasi-continuous mode** => Pulse time over 300ns => Beam length ~90m
  - The head of the pulse already converted in shower at the experiment, the tail yet to be born

LINAC BEAM – HODOSCOPE MEASUREMENT

Naive model of LINAC 300ns beam pulse



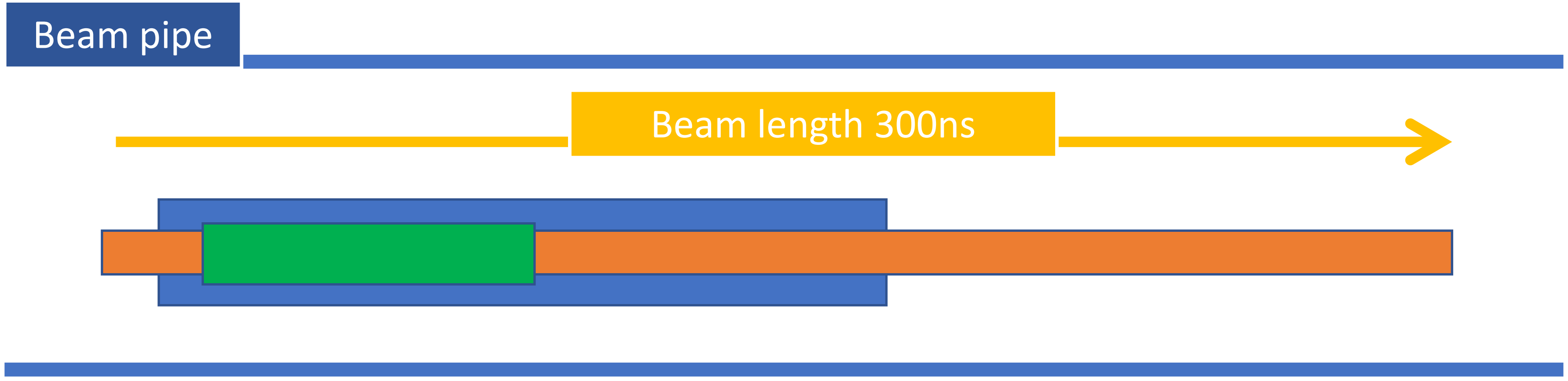
LINAC BEAM – HODOSCOPE MEASUREMENT

Naive model of LINAC 300ns beam pulse

+10MeV, 80ns, 10x charge

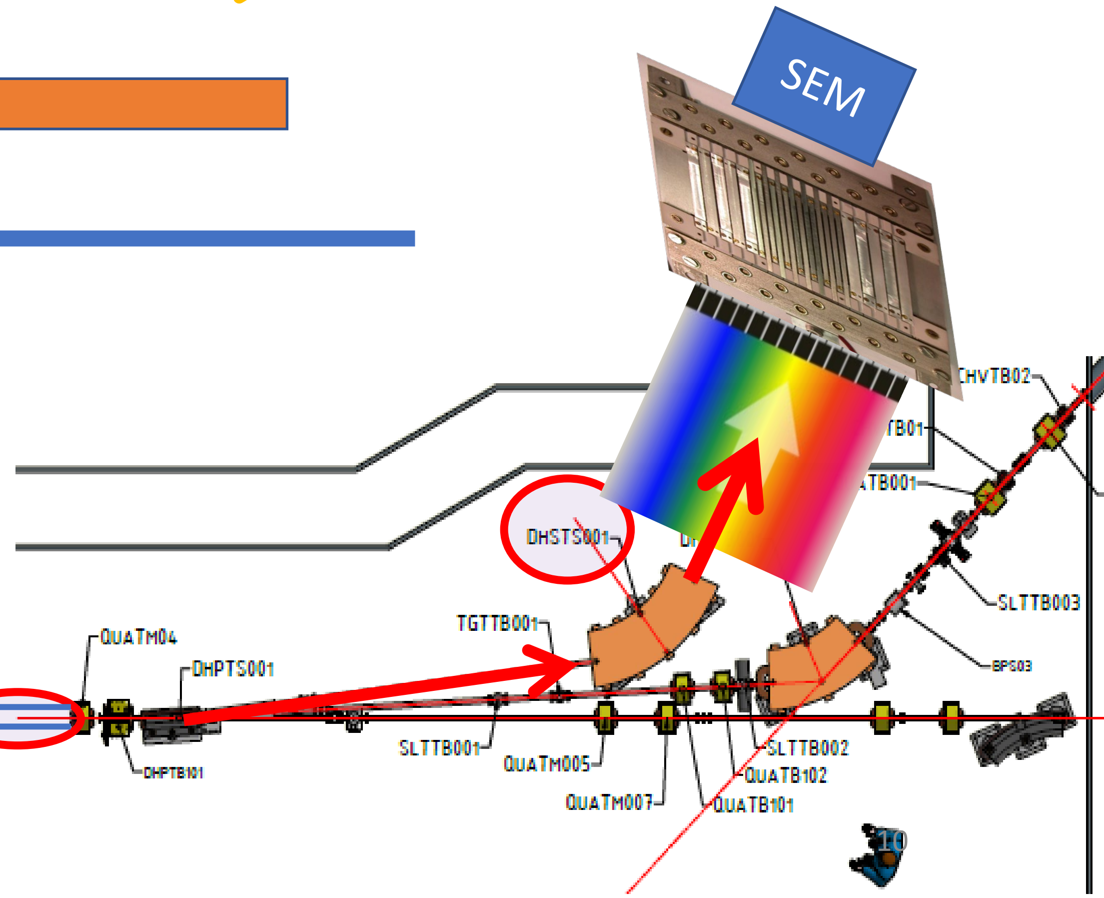
Beam energy centroid, 150ns, 2x charge

-10MeV, 300ns, 1x charge Good for Exp.

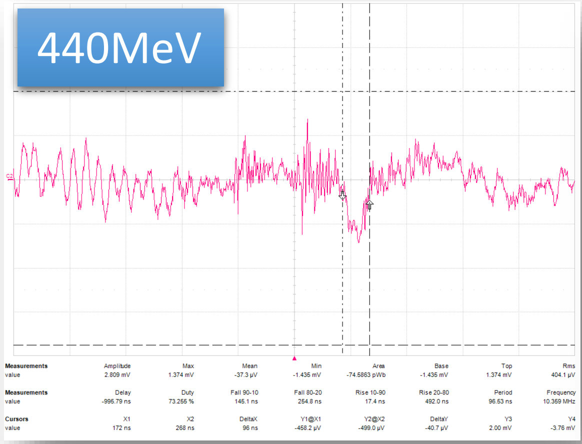


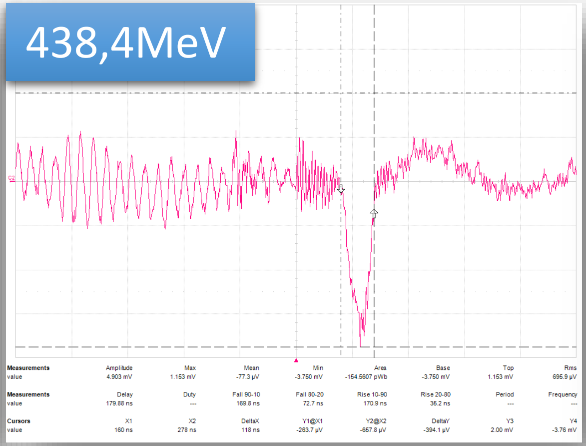
Hodoscope Seconday Emission strip Monitor (SEM)
used for LINAC pulse energy spread envelope and charge diagnostic:

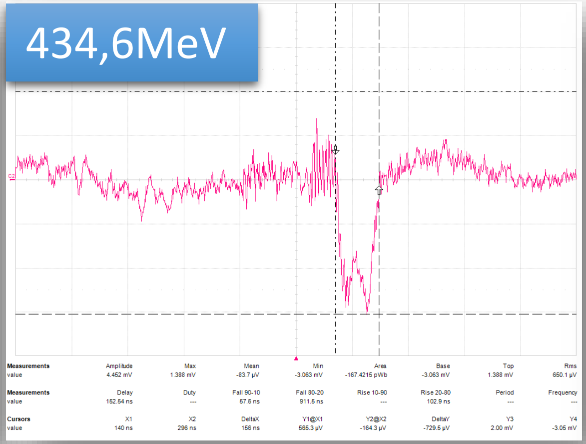
- **Downstream of <u>DHSTS001</u> 60° magnet (high dispersion)**
- Typically in charge readout (**QDC**)
- **Each strip senses a different beam energy bin**
  - **(~2MeV/strip at 432MeV energy)**
- Hodoscope time measurements with high band pass scope
  - Pulse delay
  - Pulse width
  - Pulse charge

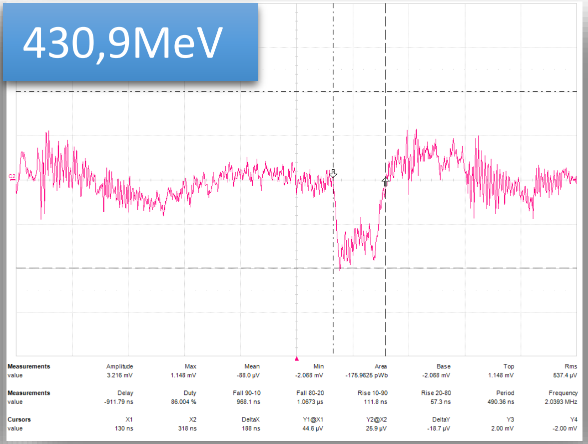


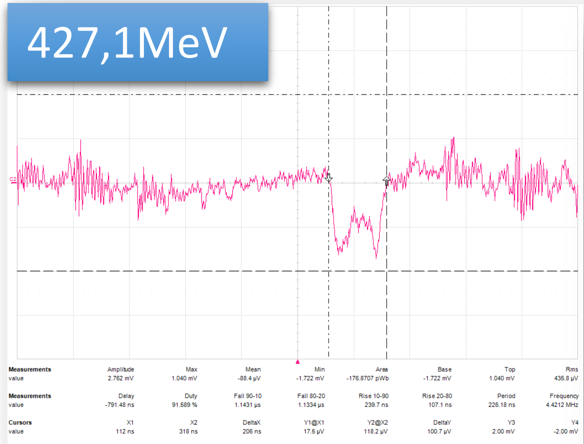
LINAC BEAM – PRIMARY LONG PULSE

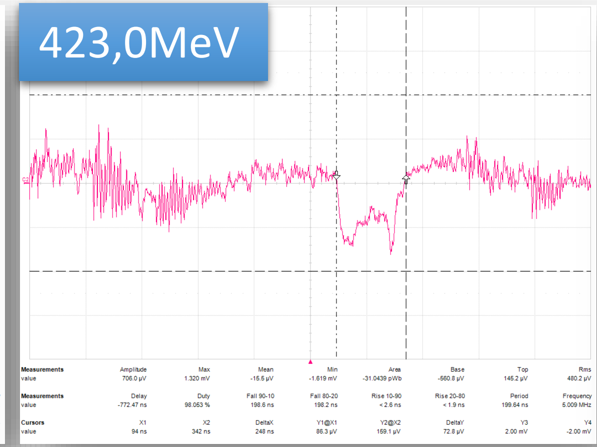


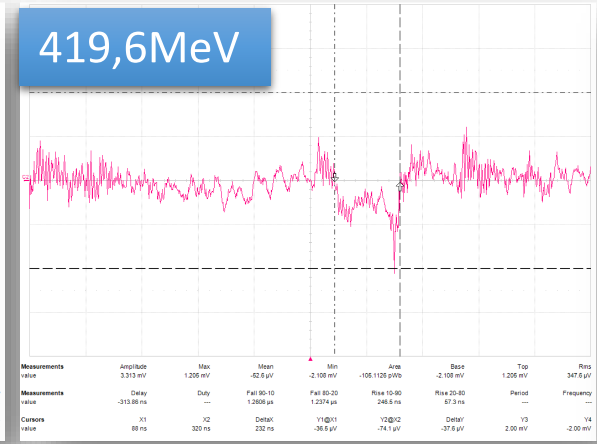


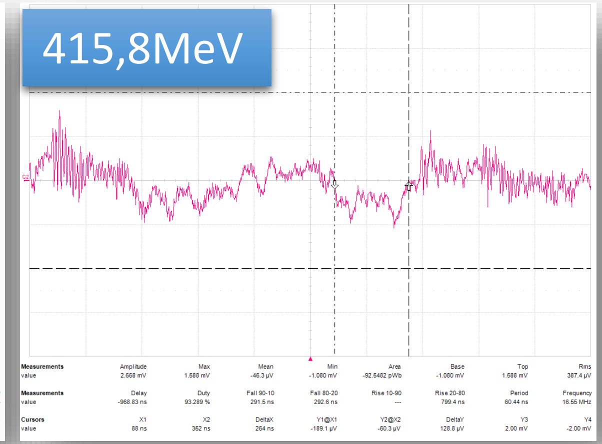












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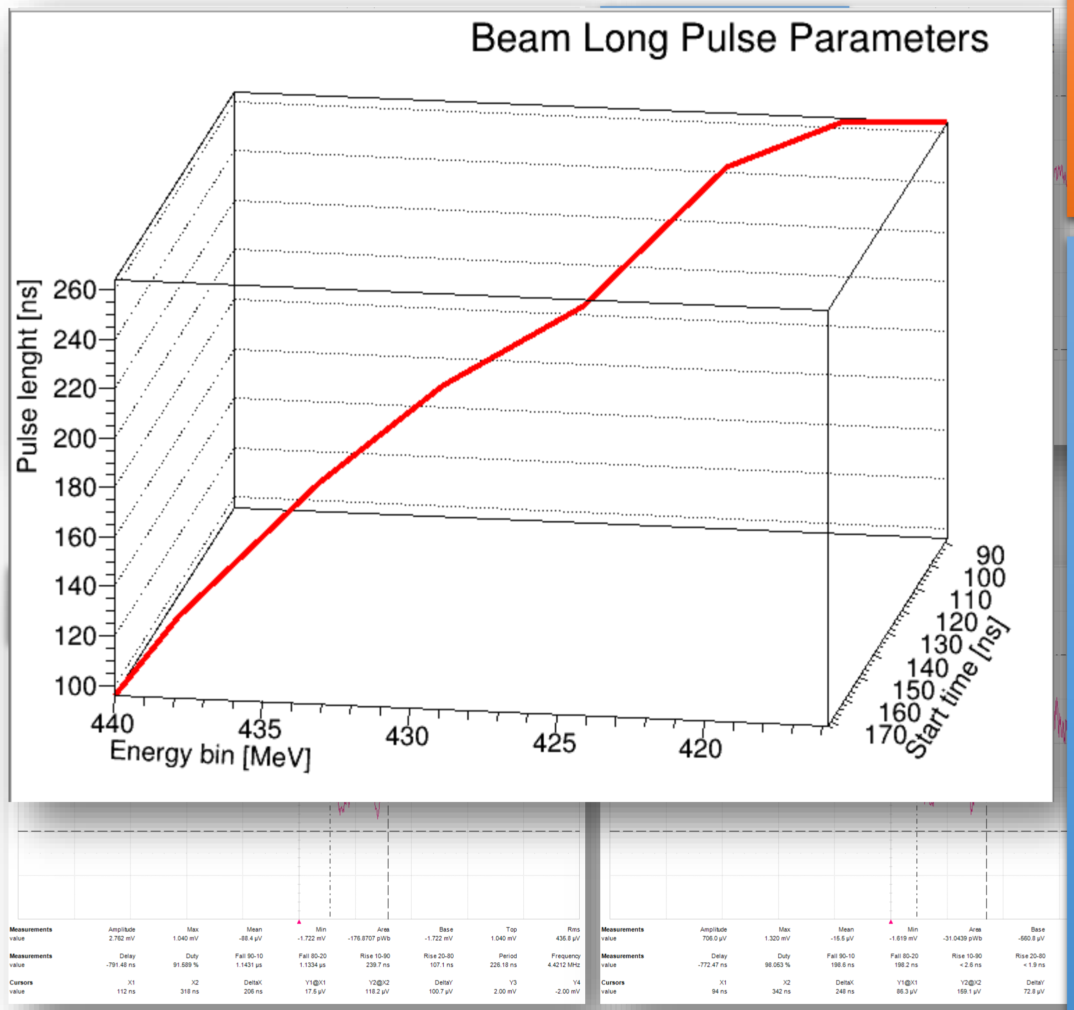
LINAC BEAM - HODOSCOPE



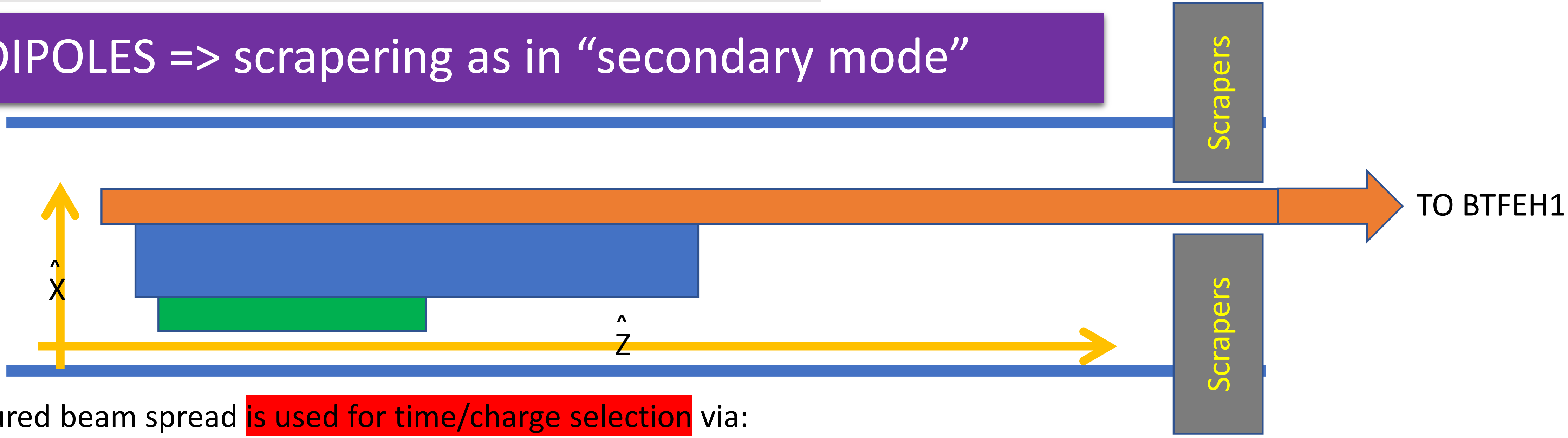
- Starting from end point energy, a monotonic increase on all the parameter (flux, energy bin, pulse width)
- A tool for selecting wide energy spread beams downstream scrapers and spectrometer

Beam structure strongly dependent on:

- Gun time advance in respect to the best injection point (as in DAΦNE mode, 10ns as DIRAC δ, -200ns)
- GUN control grid and HV
- LINAC RF main frequency then prebuncher&buncher power/phases
- Modulator phase, obviously, for the beam energy centroid
- Modulator reciprocal timing

BTF BEAM - SELECTION

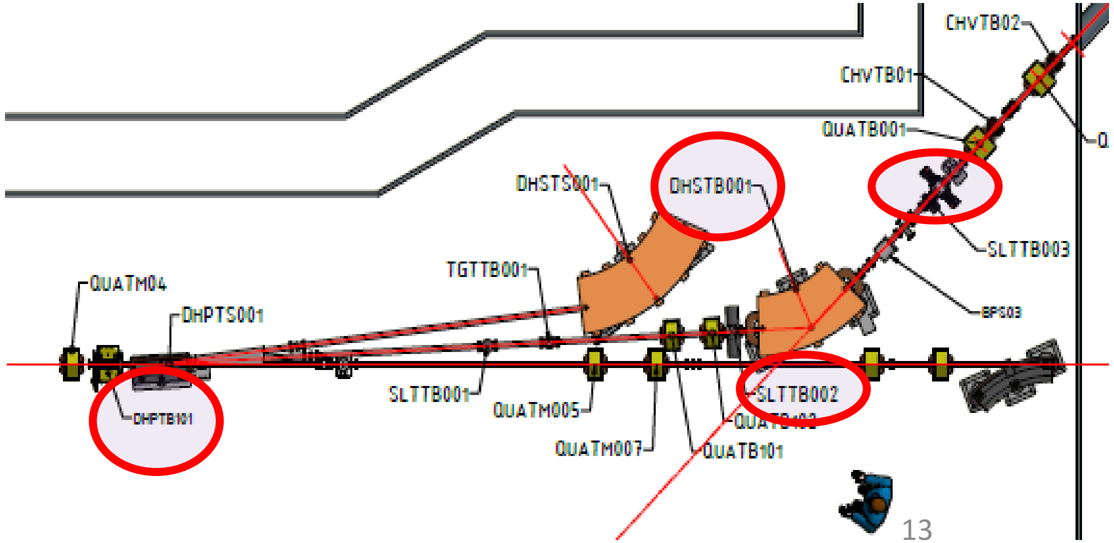
After DIPOLES => scrapering as in “secondary mode”



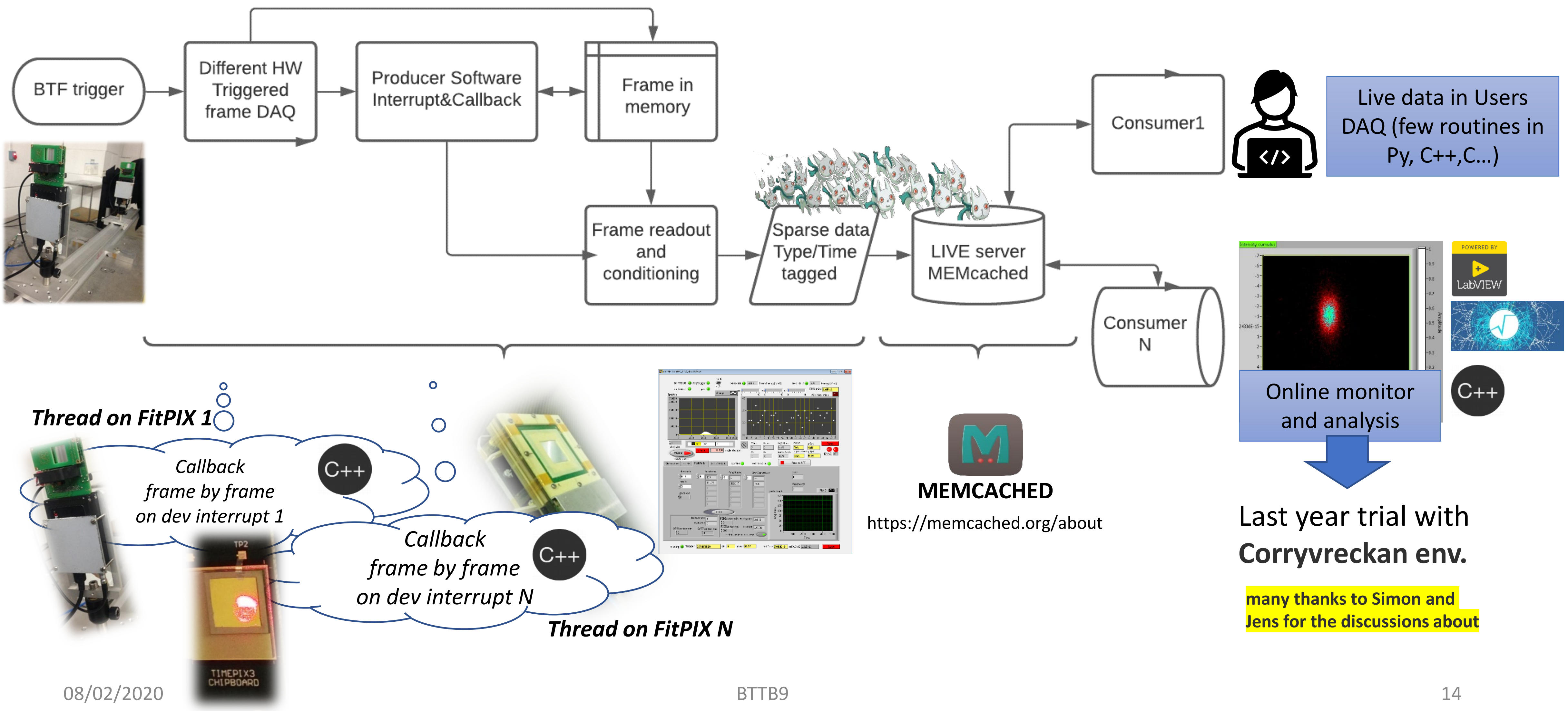
The structured beam spread is used for time/charge selection via:

- Injection angle in BTF channel
- Horizontals scrapering , get final energy spread

- Charge control via LINAC current is great(down to single particle multiplicity !!!!) **-> no needs of target**
- SLTB004 scrapering downstream enhances final beam spread (< 1%)
  - Limited use of downstream scrapers => lower BTFEH1 background and beam side effects
- **Reduced coupling of final focus from injected beam** (transverse shape are huge compared to SLTB003-004 scraper pin hole)



DIAGNOSTICS SOFTWARE LAYOUT



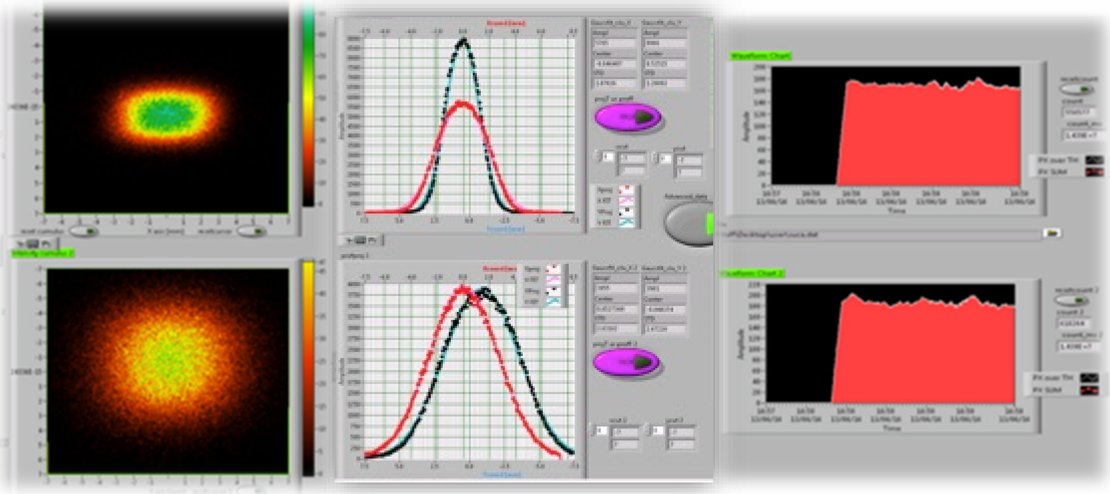
Last year trial with **Corryvreckan env.**

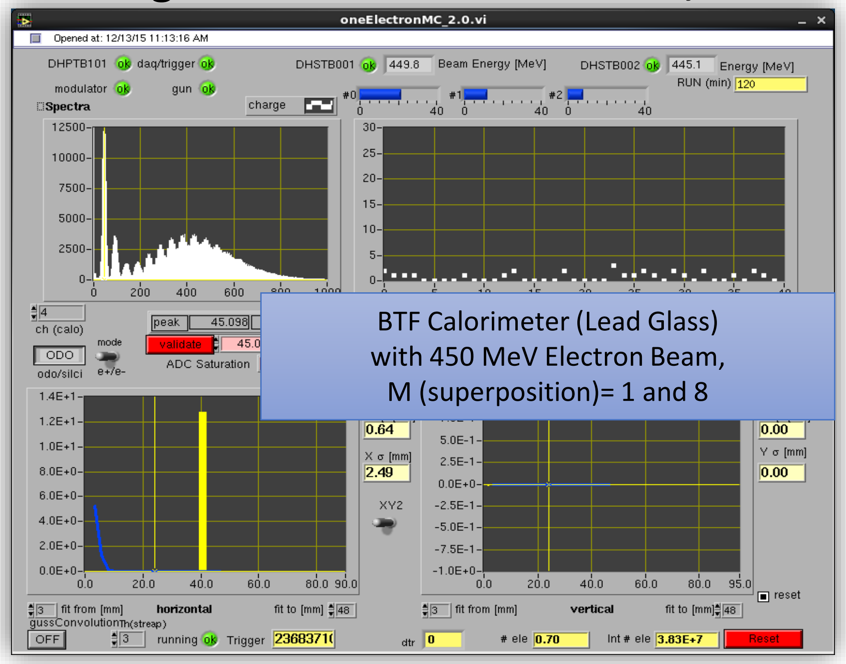
many thanks to Simon and Jens for the discussions about

DIAGNOSTICS: SECONDARY BEAM

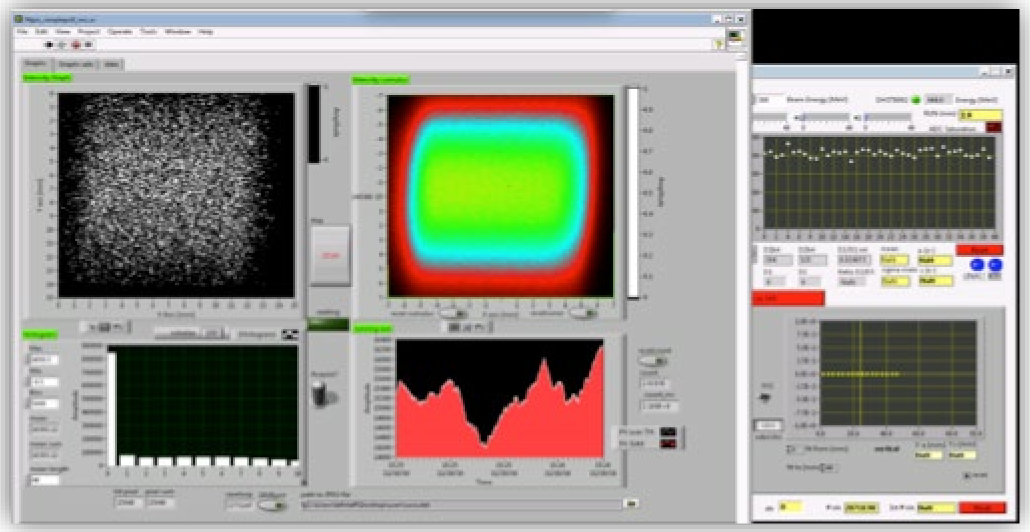
Typical secondary beam diagnostics (some of)

- **ADVACAM FITPIX/TIMEPIX detectors**
  - 256×256 pixels, 55 μm pitch, 14×14 mm^2 active area
  - 300 μm thickness sensor
  - Three FitPIX devices **operational**
- **LEAD GLASS Calorimeter: higher beam (charge*energy)**
- **BGO segmented Calorimeter: next, lower**





BTF Calorimeter (Lead Glass) with 450 MeV Electron Beam, M (superposition)= 1 and 8



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DIAGNOSTICS: PRIMARY BEAM

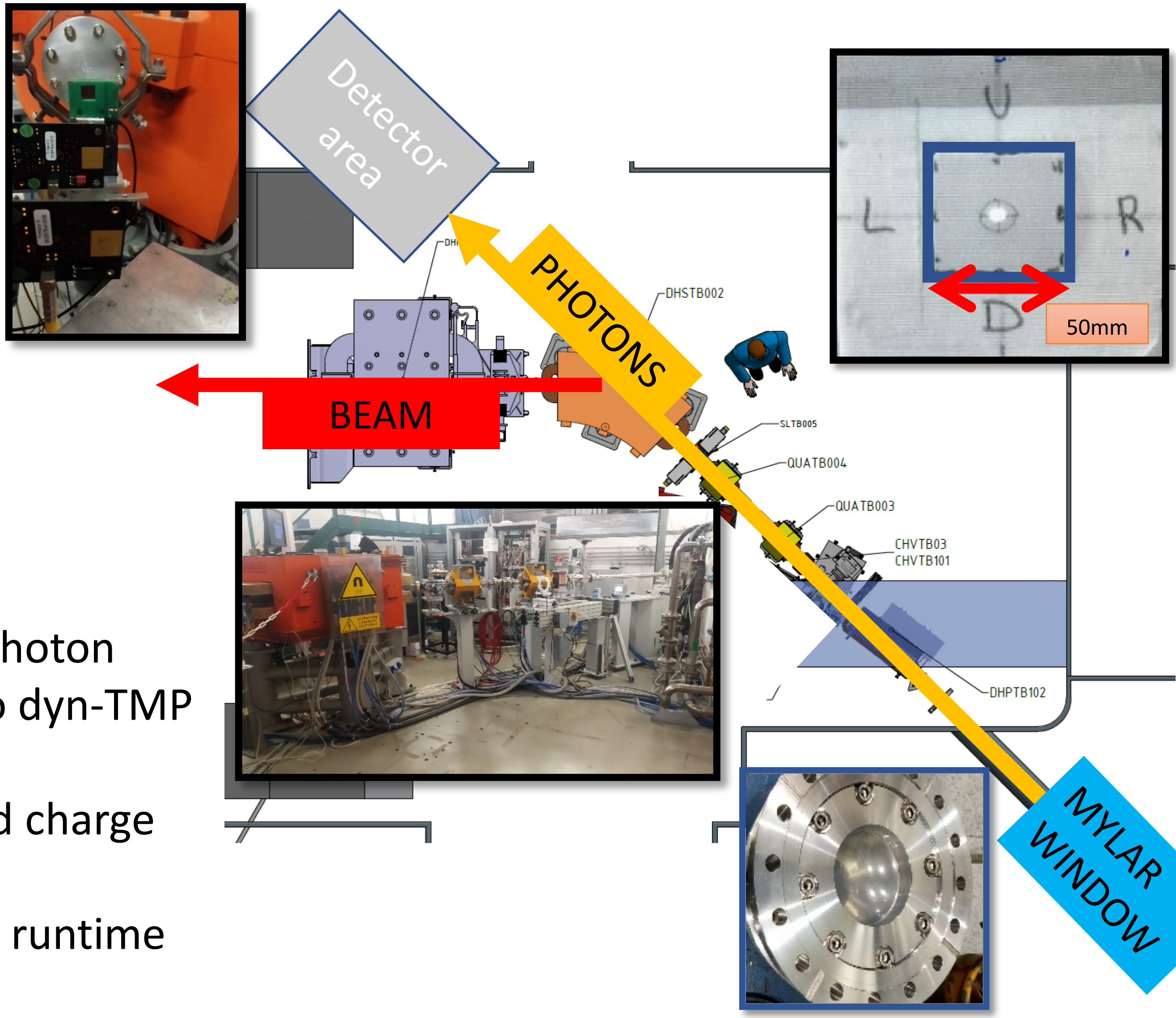
Primary beam diagnostics (some of)

Direct measurement
(test beam particles, destructive)

- Bergoz Integrating Current Transformer
    - (ICT-122-070-05:1)
    - Flags and fast cam

Indirect measurement
(secondary photons, run quality monitor)

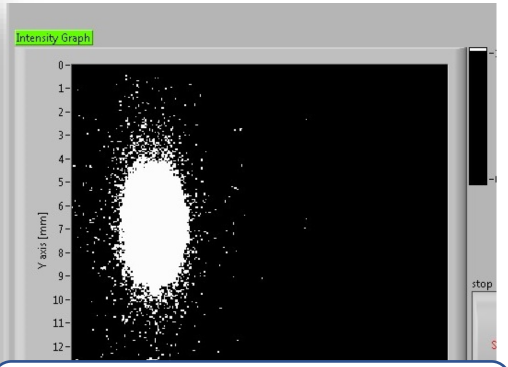
- Beam steered to experiment
- Lead Glass Calo and FITPix get Bremssthralung photon from mylar window (decoupler for static-ionic to dyn-TMP vacuum)
- Energy collected is less 0,001 of the total steered charge (12m away)
- Used to calculate delivered charge, beam lenght runtime
- Higher measurement errors (10%)



BTF BEAM – PRIMARY MEASUREMENT

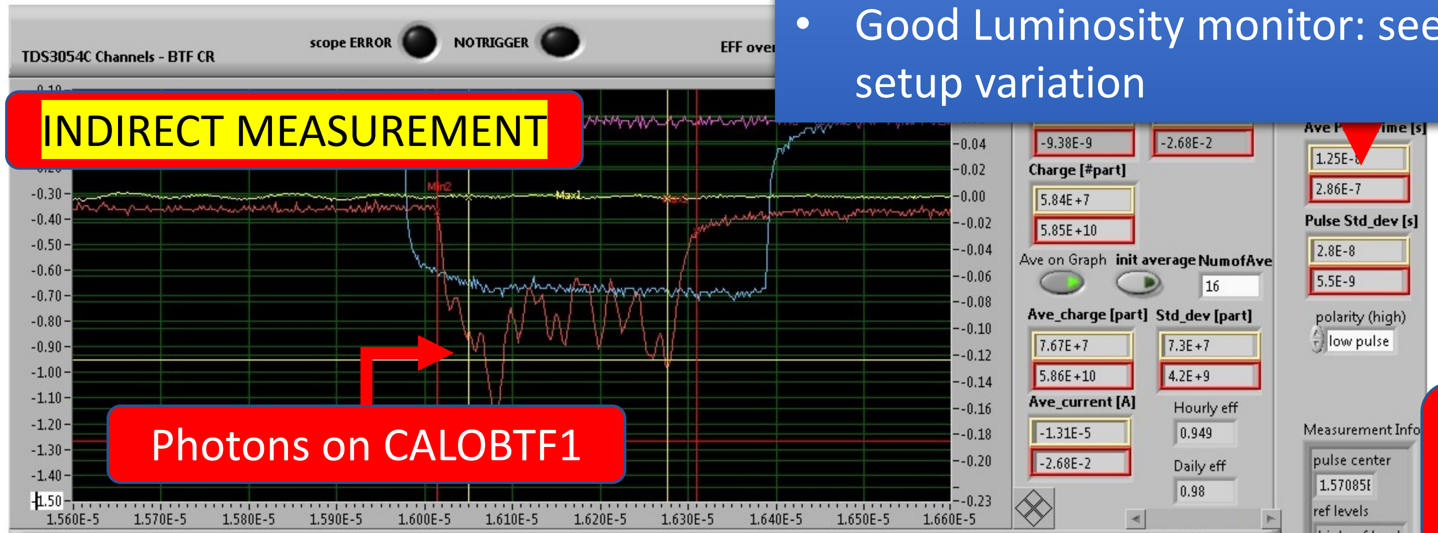
DIRECT MEASUREMENT

Positrons on CALOBTF1



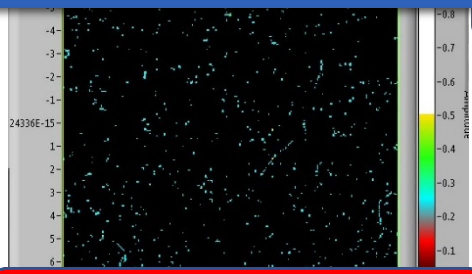
Direct positrons in FitPIX

- Good agreement in time evaluation
- An indirect calibration for photons measurements
- Good Luminosity monitor: seems robust to beam setup variation

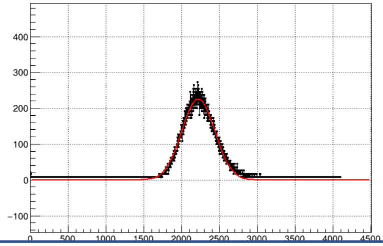


INDIRECT MEASUREMENT

Photons on CALOBTF1



Photons conversion on adsorber, deltas… in FitPIX



CALOBTF1 – Indirect measurement
1000 bunched 30kPoT
photons charge distribution
10% resolution

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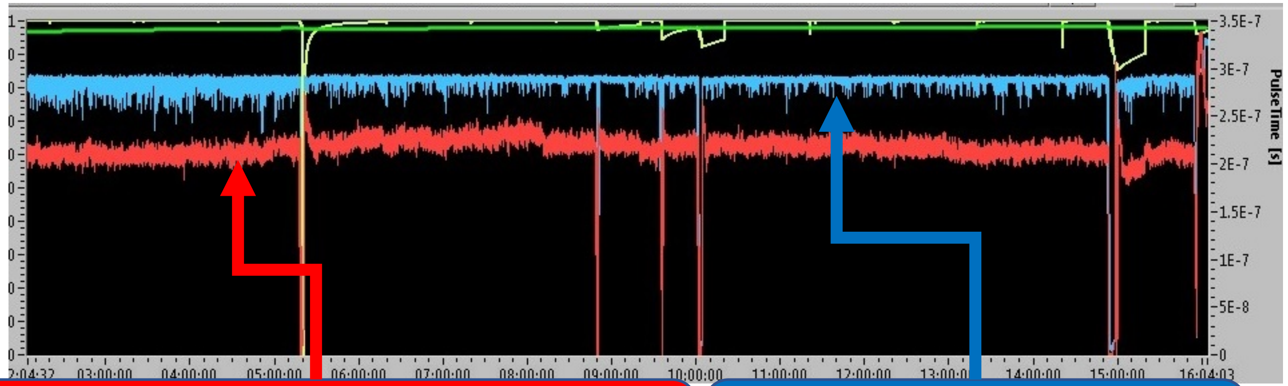
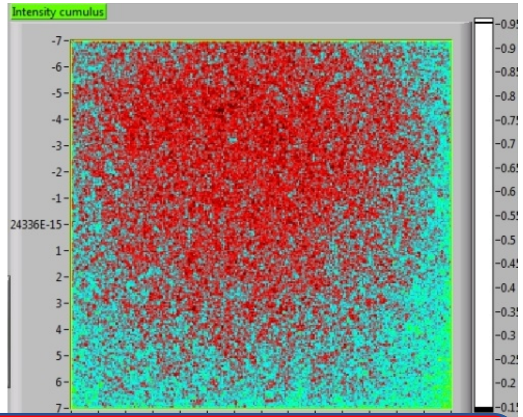
BTF BEAM – 320NS PULSE TRIALS

Positrons on CALOBTF1

Extending longitudinal line acceptance with GUN improved timing:

- 15/10/20 trials on 320ns, 32kPoT/bunch
- Measure on BTFDAQ in direct and Bremss photons
- Coherent measure with PADME SAC DAQ
- Flatness to be improved (no much time on it)
- Very good result for a LINAC intended for 10ns pulse!!!





Daily trends photons stripchart on CALOBTF1

Daily trends pulse width

Cumulative plot of photons conversion at FitPIX (red < cyan, Mylar image)

BTF BEAM – PRIMARY BEAMS

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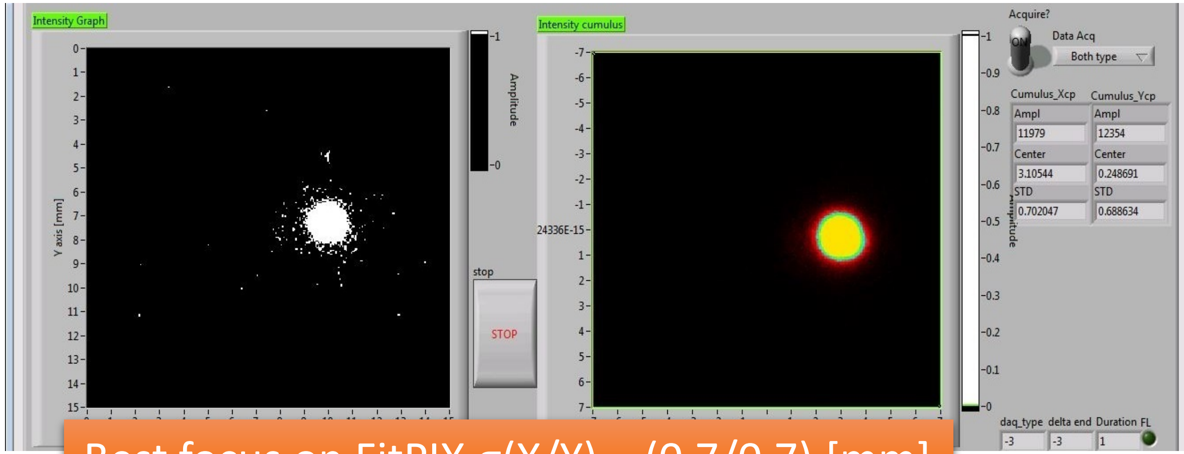
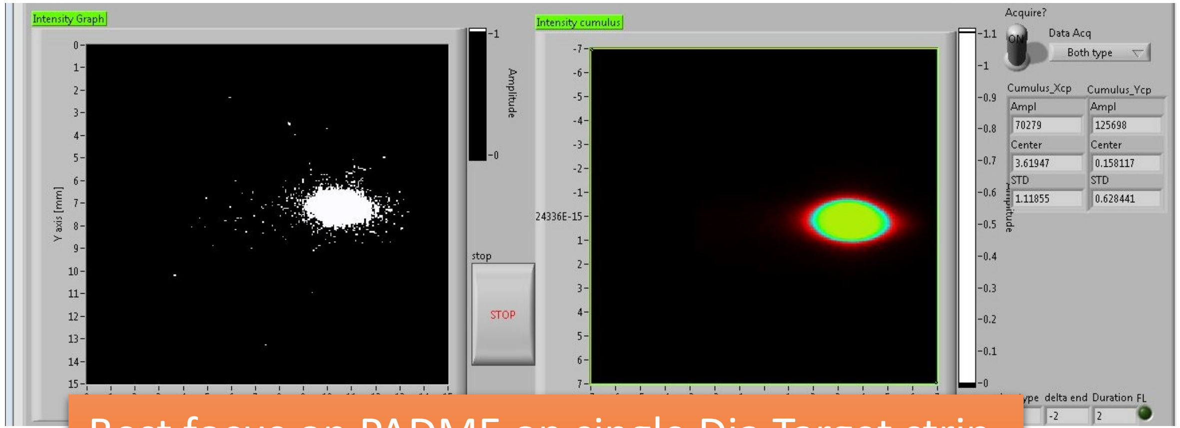


Best focus on FitPIX σ(X/Y) = (0,7/0,7) [mm]

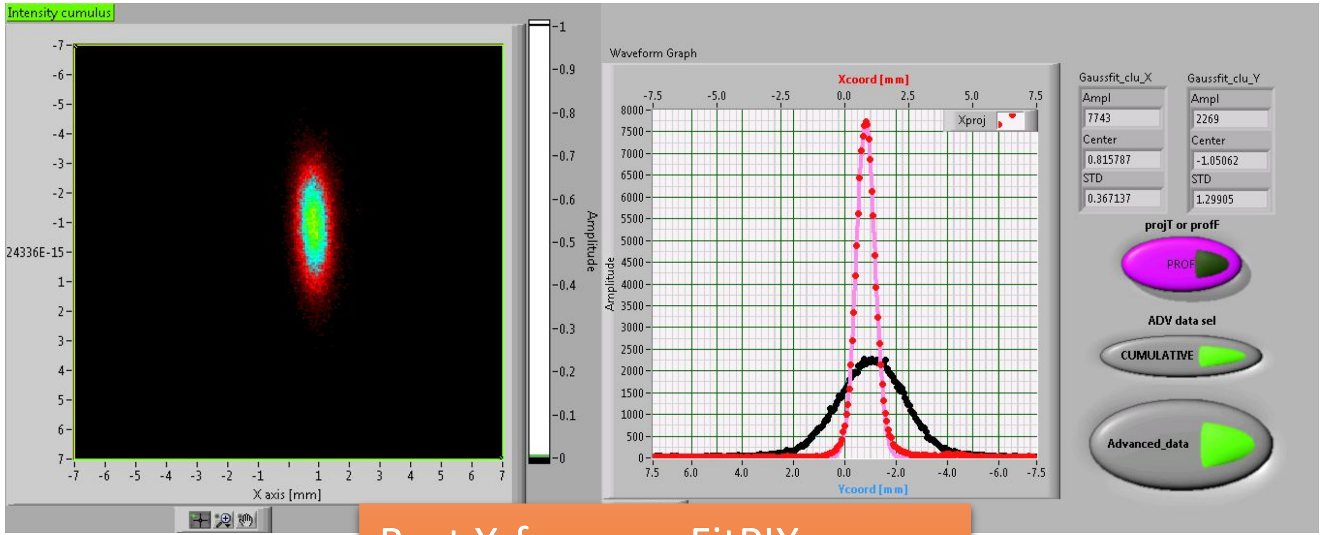


Best focus on PADME on single Dia Target strip

- High divergence and flux
- σ(X/Y) = (1,1/0,6) [mm]

Different final focus trials maintaining:

- Background level
- Lower use of scrapers
- Low sensibility on LINAC fluctuations



Best X-focus on FitPIX

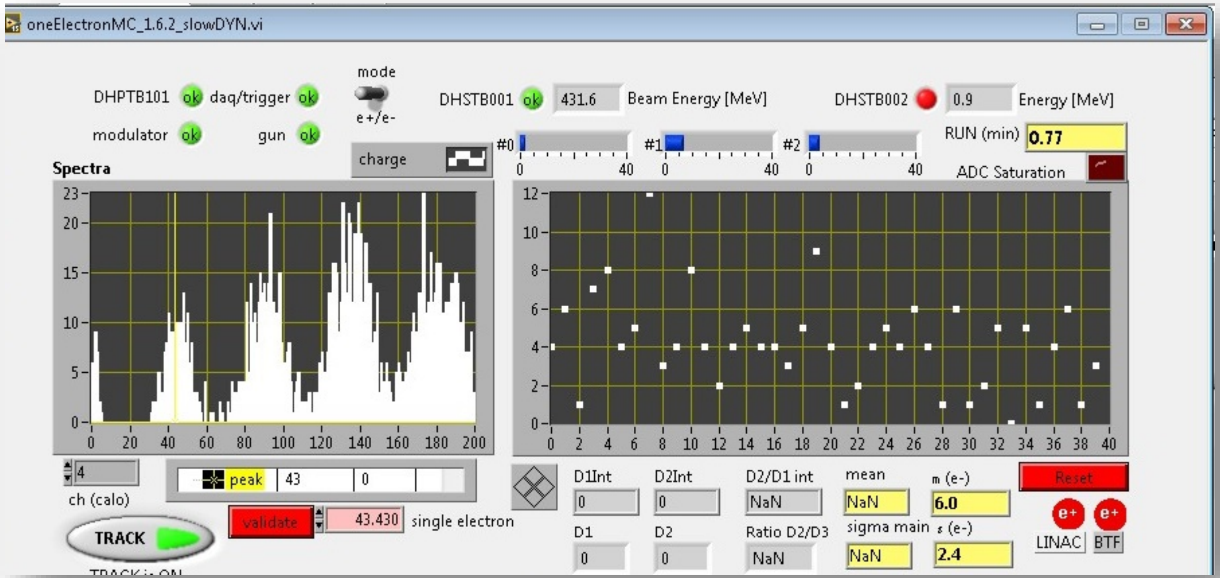
- σ(X/Y) = (1,3/0,36) [mm]
- Pulse time = 250ns
- Single particle

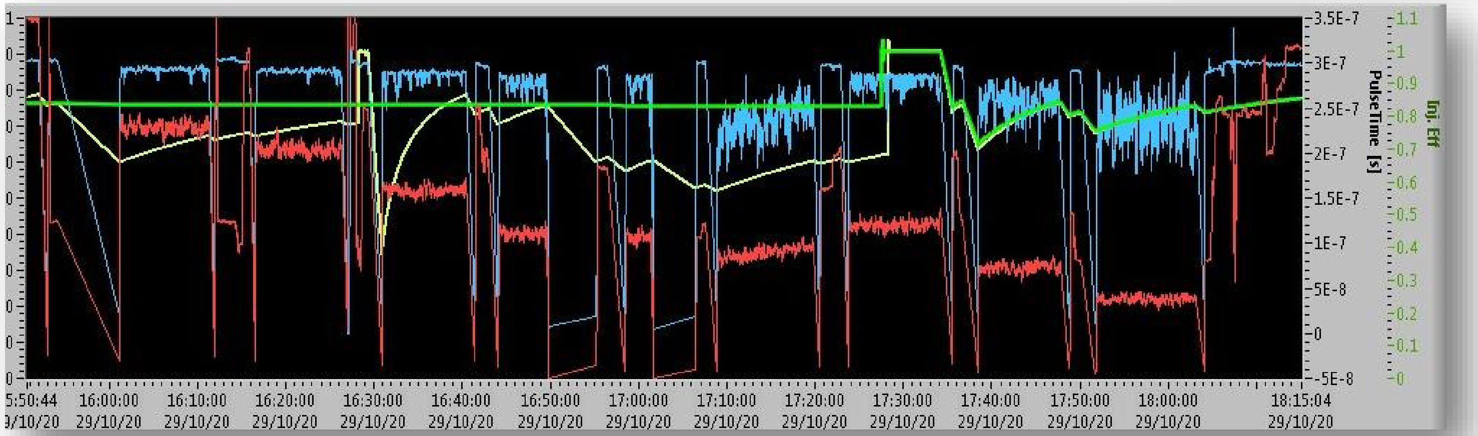
BTF BEAM – PRIMARY SINGLE PARTICLE

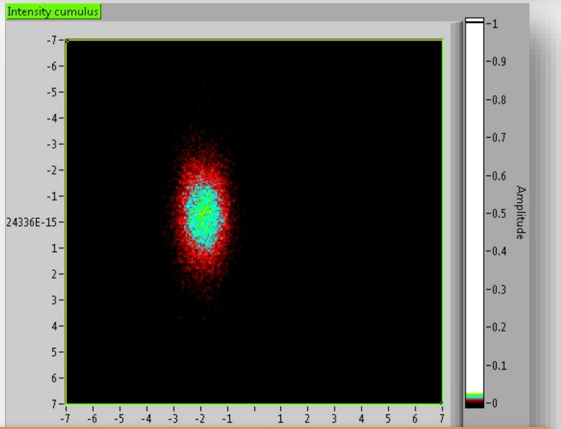
A tough feature gained is the delivery of a single particle beam by only means of GUN grid control:

- Scrapers setpoint unchanged from nominal position
- Apart GUN grid, LINAC set not changed
- Beam pulse width conserved (distortion on flatness)
- Linear control
- Standard transport unchanged

AGAIN another very good result for a LINAC intended for high charge, 10ns pulse!!!







Standard transport

BTF BEAM
100 MEV IRRAD


ERAD @ BTF

Lucia Sabbatini, Bruno Buonomo

INFN TEAM :Bruno Buonomo, Luca Foggetta, Claudio Di Giulio, Domenico Di Giovenale, Fabio Cardelli

REGIONE LAZIO

eRAD
Test di resistenza alle radiazioni per componenti aerospaziali

IMT
Ingegneria Marketing Tecnologia

INFN

asi
Agenzia Spaziale Italiana

REGIONAL FUND

AIMS:
The general aim of the project is the use of electron sources, available at the INFN-LNF to measure the behavior and resistance of electronic components intended to be subjected to radiation in the aerospace environment.

The values and results acquired with these measurements will be compared with homologous measurements performed with photons in order to define comparative resistance thresholds and related indicators.

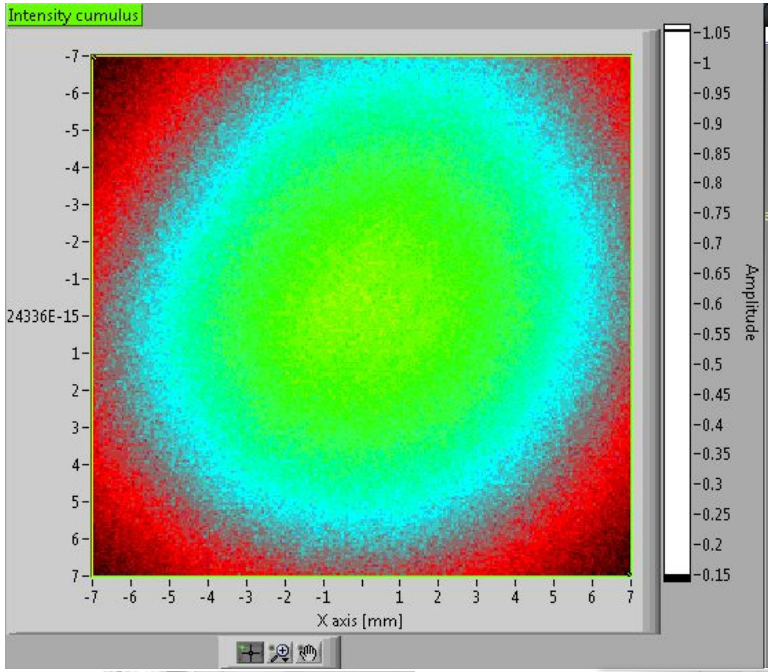
Started 11/06/2020 Duration 2 years

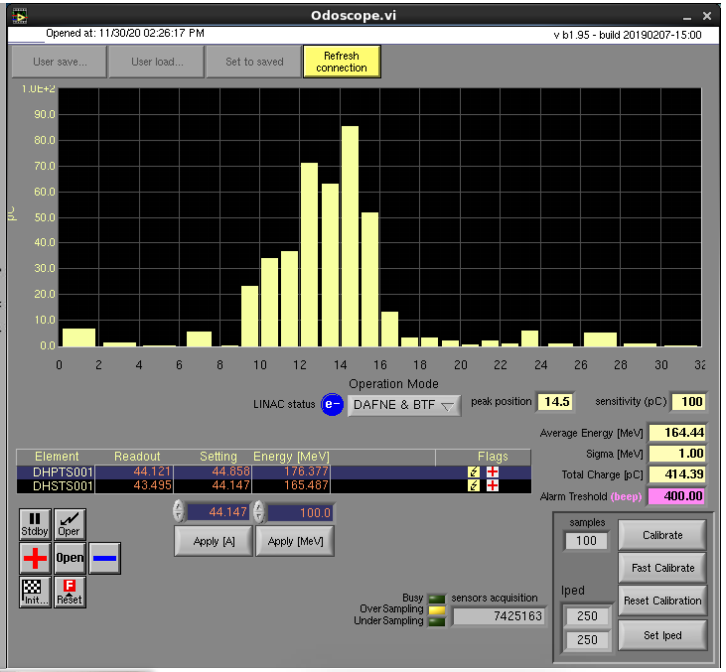
Beam time request ~ 3 months high intensity beam @ BTF

LINAC Measurements time request ~1 month

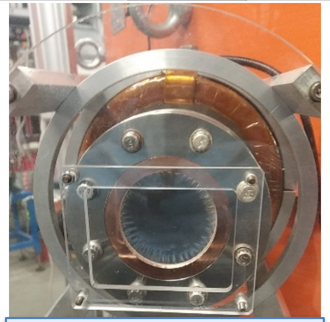
BTF BEAM
100 MEV DEVELOPMENT

BTF for SPACE related RAD hardness test
- Goal to achieve 100MeV primary beam
- 20->100ns beam pulse time
- Shot over 10^6 -> 10^10 electron per bunch
- Narrow energy spread
- Broad X/Y dimensions (~cm^2)
- Overall tolerance on 10%





First trials on DEC-2020:
- 164 MeV achived
- 20ns pulse time
- Test on lower charge due to FitPIX saturation (but well under charge limits)
- Counter phased modulators
- Energy spread less than 1%



25µm Ti Vacuum window break

DIAGNOSTICS LATEST

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KATHERINE = Ethernet Embedded Readout Interface for Timepix3

- RJ45 plug – 1Gbit interface
    - No needs of standalone PC
- Easy included in BTF virtual machine environment
- Test Beam with native software
- Actually trials on BTF DAQ
- Debugging a BTF solution for compact and portable tracker

FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

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IEAP
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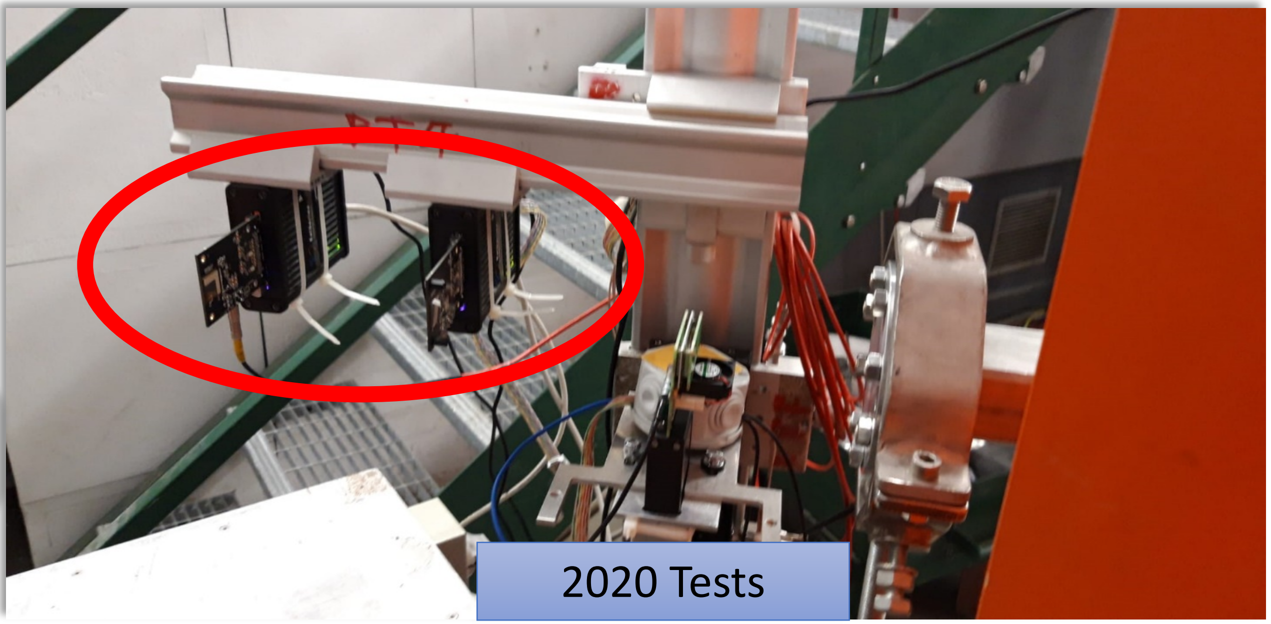
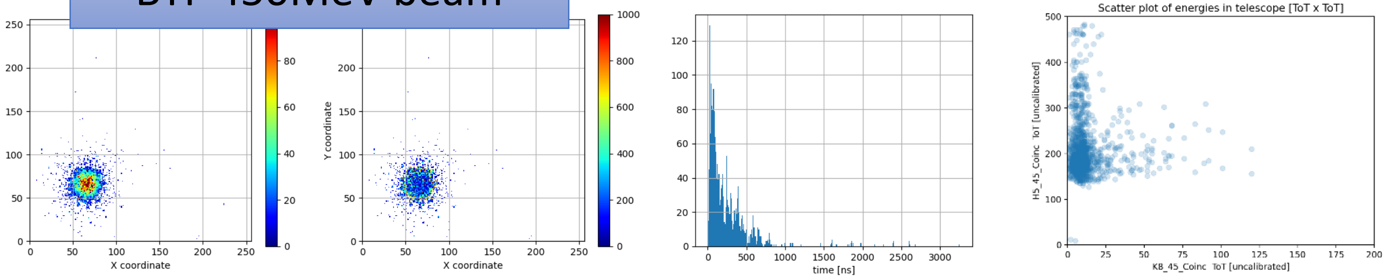
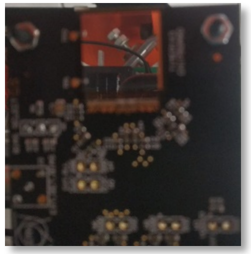
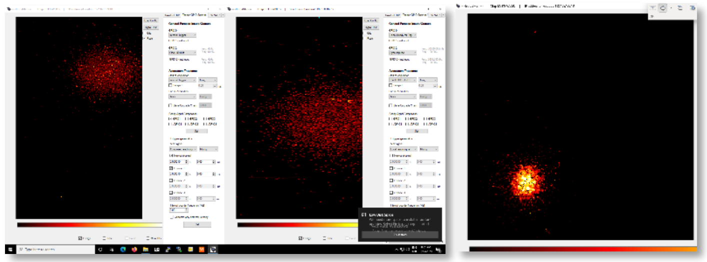


BTF 450MeV beam







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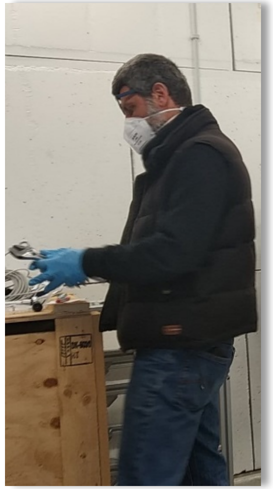
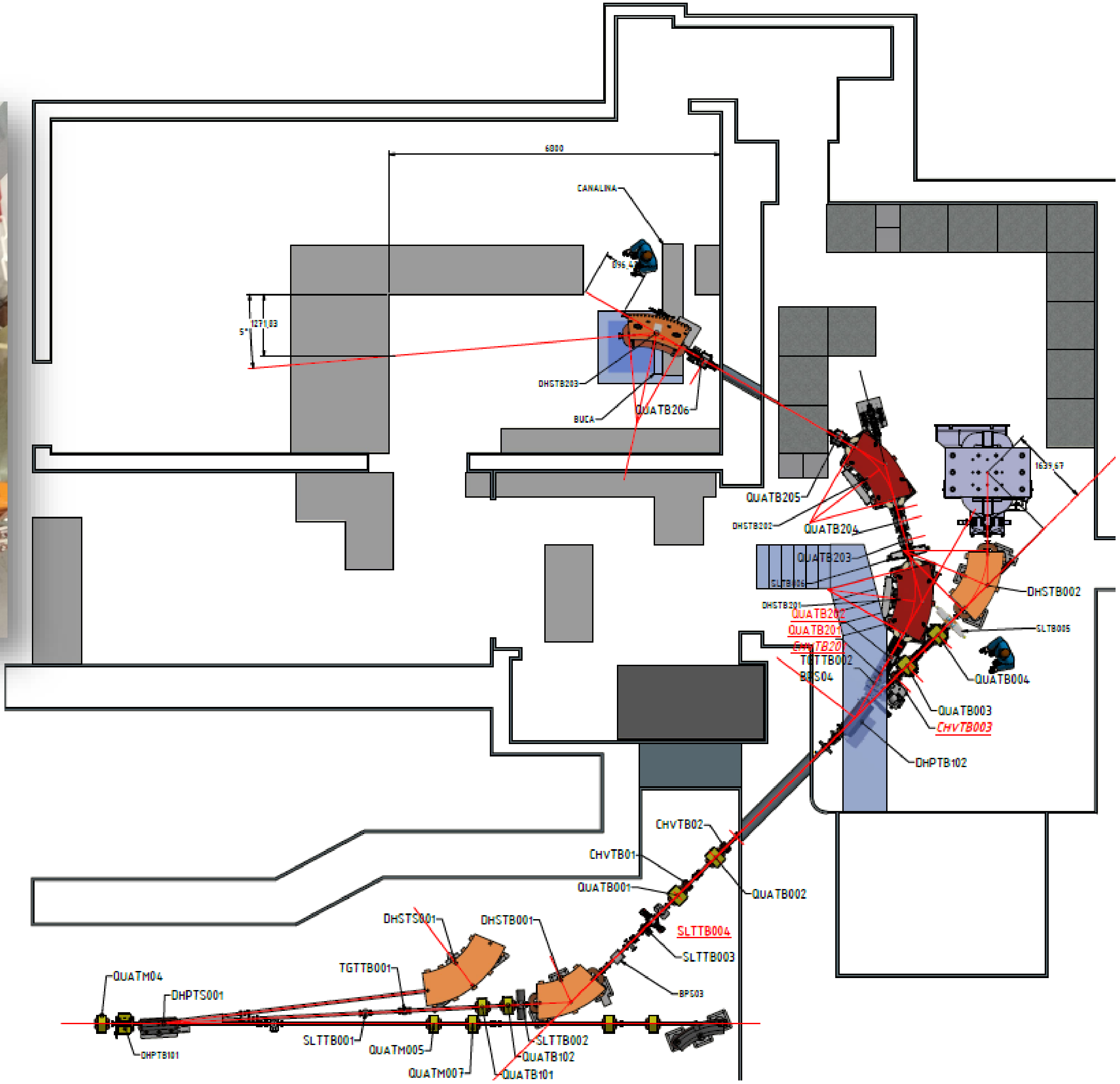
BTF - UPGRADE



Ready to start mounting a 2nd line

Exp. Halls have been just prepared to receive tons of iron
Again, hard months of work will be on the horizon. Maybe we will have some to present on next BTTB!
Thank you for your attention!!!



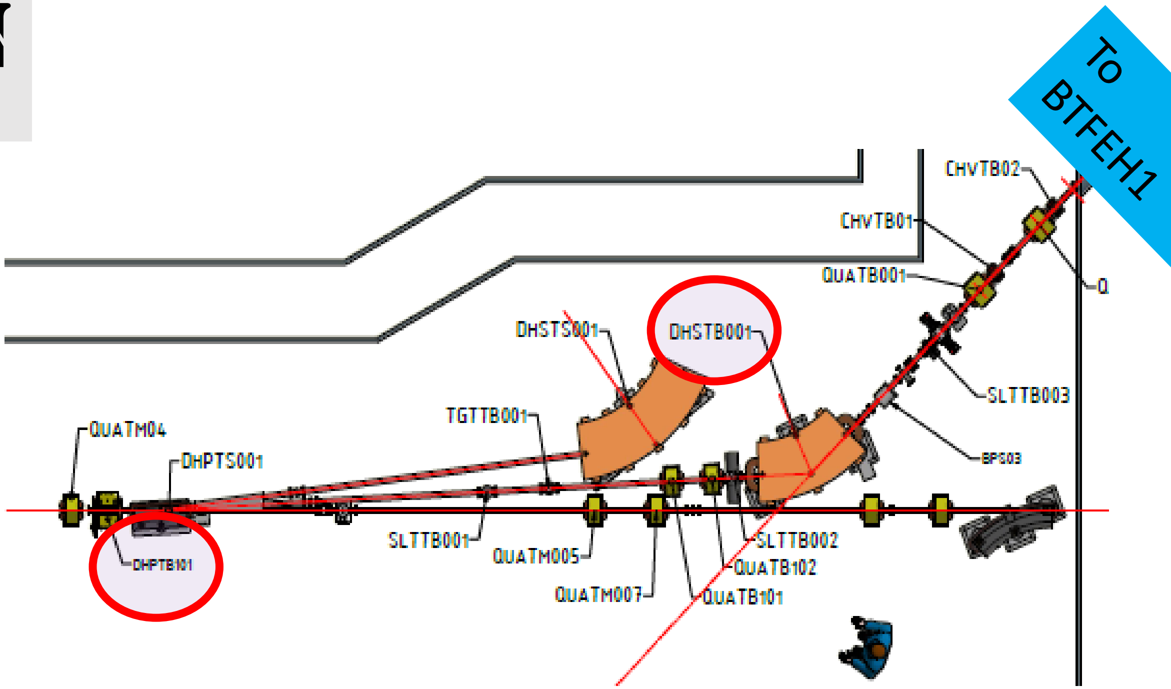
SPARE slides

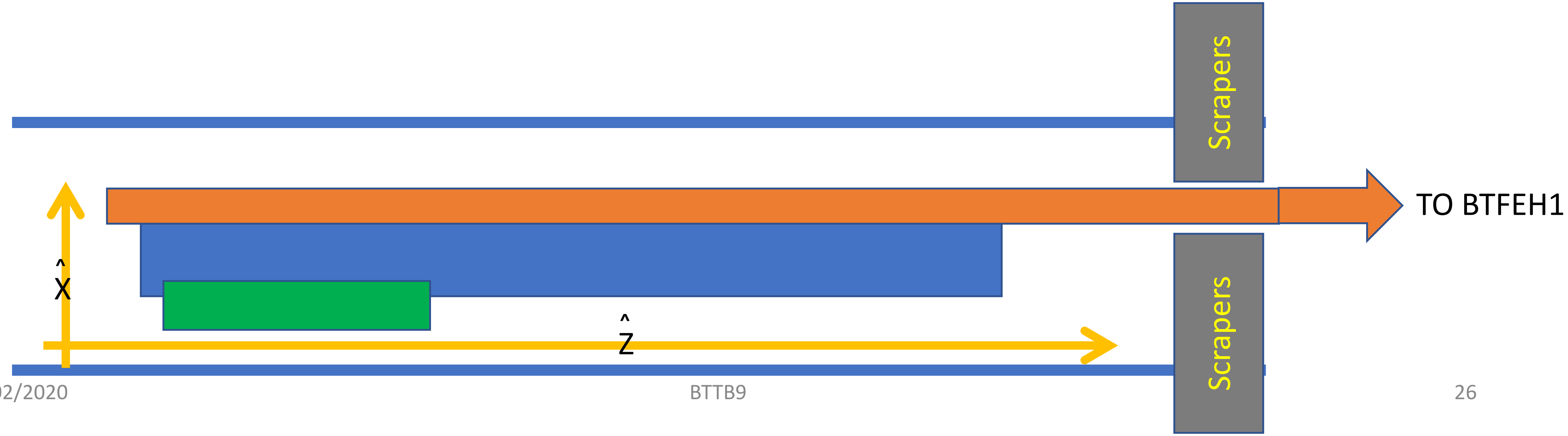
BTF BEAM - SELECTION

These way of beam structure leads to:

- DHPTB001 - DHSTB001 act as second beam pulse flattening tool (removes head-tail peaks)
- DHSTB001 sector magnet => -X sees more focusing for higher energy
    - Treat this beam as secondary beam (as BTF usually do)

- Mylar window is a good Bremsstrahlung radiator for an online monitor





BTF BEAM – NEW DIAGNOSTICS SETUP

Fast BTF beam diagnostics

- CALOBTF1 (PbWO – NA62 like)
- Timepix detectors (65k Pixel TPX,TPX3 detector, ~2cm^2)
- Located downstream the straight pipe in the DHSTB002 dipole
- Adsorber in the middle (0.3mm Al window, 0.7 Si detectors)

Direct measurement (positrons, PADME delivered beam):

- Stop injections to PADME
- DHSTB002 switch off
- Injection in the straight DHSTB002 channel

Indirect mesurement (secondary photons, run quality monitor)

- Beam steered to PADME
- CALOBTF1 and FITPix **get Bremssthralung photon from mylar window**
- Energy collected is less 0,001 of the total steered charge (12m away)
- Used to calculate delivered PoT, beam lenght runtime
- Higher measurement errors (10%)