Extracted electron and positron beams at LNF

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Paolo Valente – INFN Roma
on behalf of the BTF and PADME teams

Light Dark Matter @ Accelerators (LDMA)
24-28 May 2017 - La Biodola - Isola d'Elba (IT)

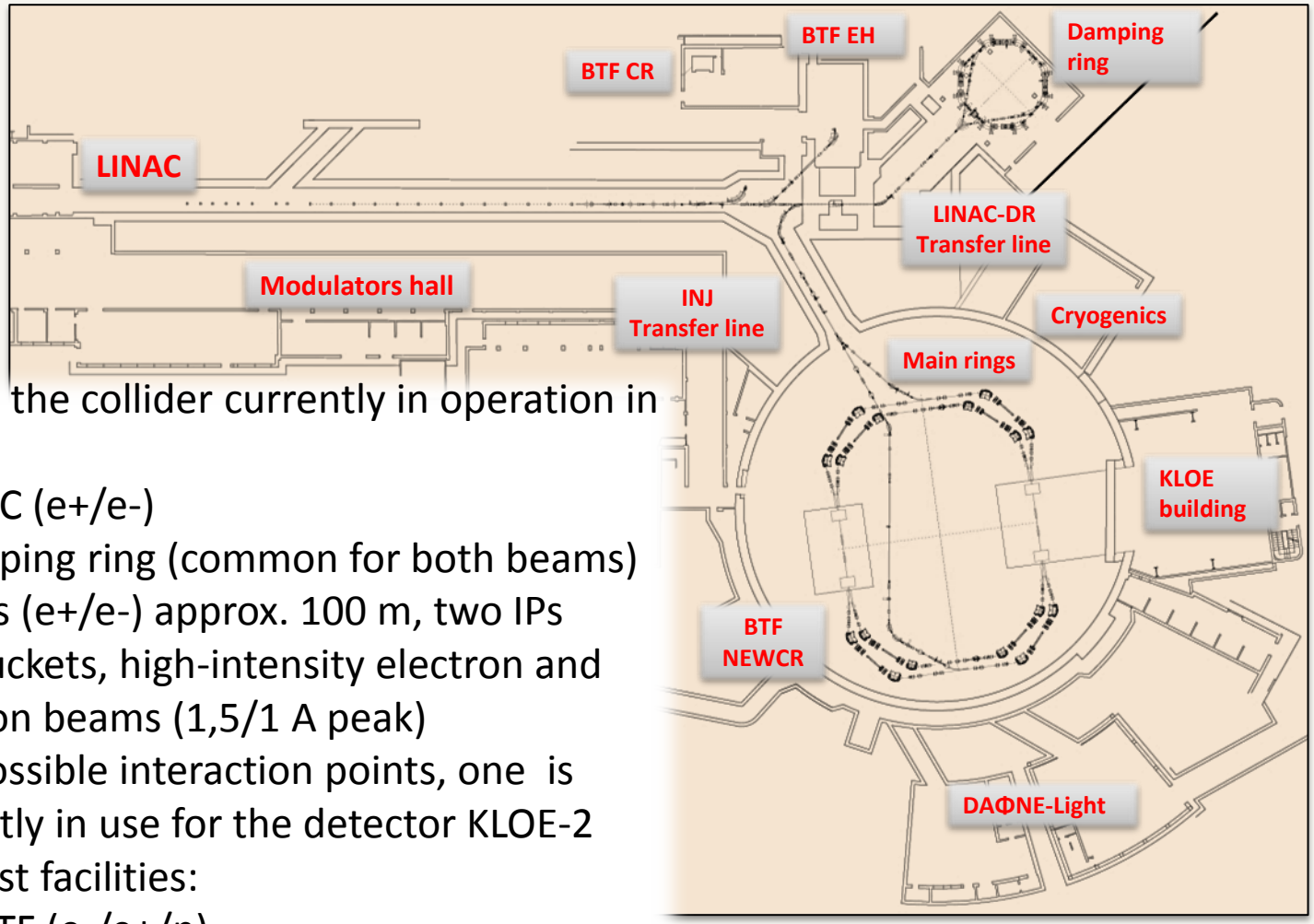
CUP I86D16000060005

Horizon 2020 G.A. 654168.

Ministero degli Affari Esteri e della Cooperazione Internazionale

The DAΦNE complex- LINAC

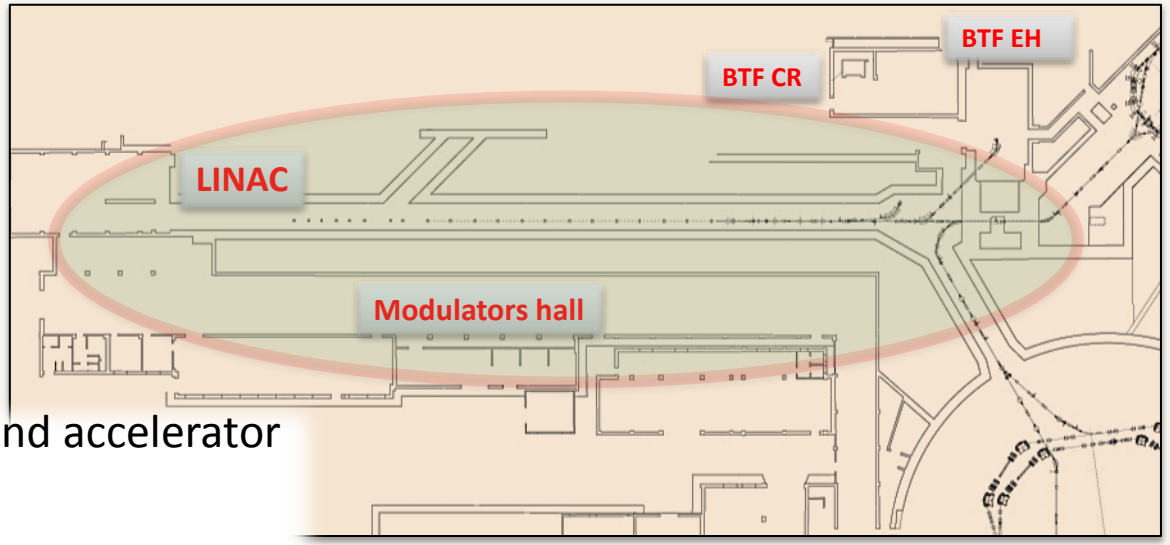
Laboratori Nazionali di Frascati (LNF)
Frascati (Rome, IT)



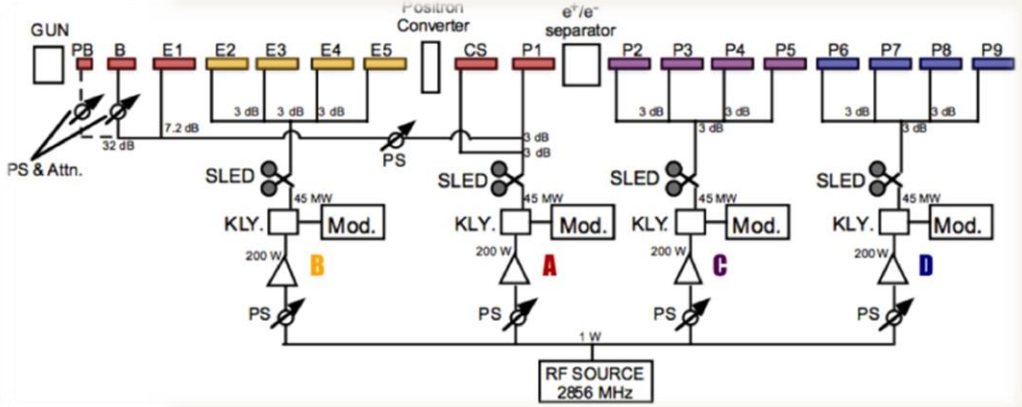
DAΦNE is the collider currently in operation in Frascati

- 1 LINAC (e+/e-)
- 1 Damping ring (common for both beams)
- 2 Rings (e+/e-) approx. 100 m, two IPs
- 120 buckets, high-intensity electron and positron beams (1,5/1 A peak)
- two possible interaction points, one is currently in use for the detector KLOE-2
- two test facilities:
  - BTF (e-/e+/n)
  - DAΦNE Light

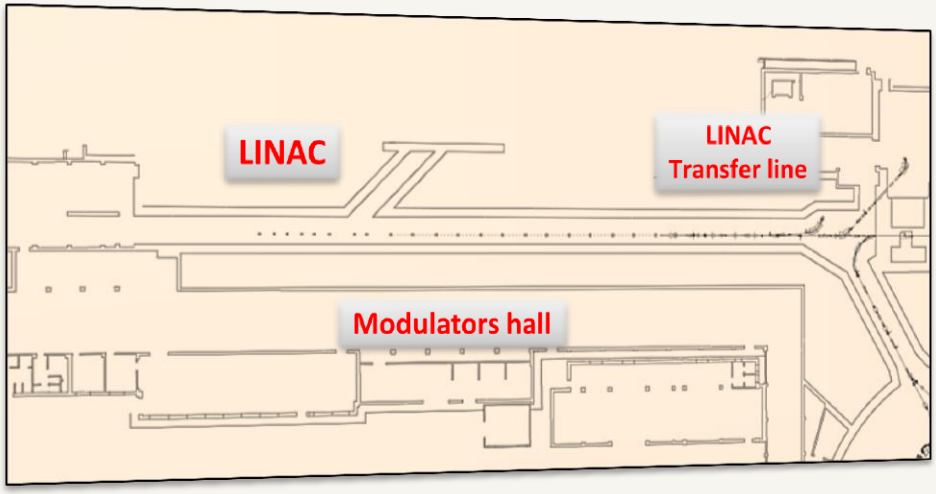
The DAΦNE complex - LINAC



- SLAC Type Traveling wave S-band accelerator (2.865 GHz)
- driven by
  - Traditional Cathode
  - 120KV electrostatic gun
  - four 45 MW klystrons
  - four SLED peak power doubling
  - 780MeV electron final energy
- **Pulsed** Machine
  - 10ns bunch envelope
  - repetition rate = 50 Hz.

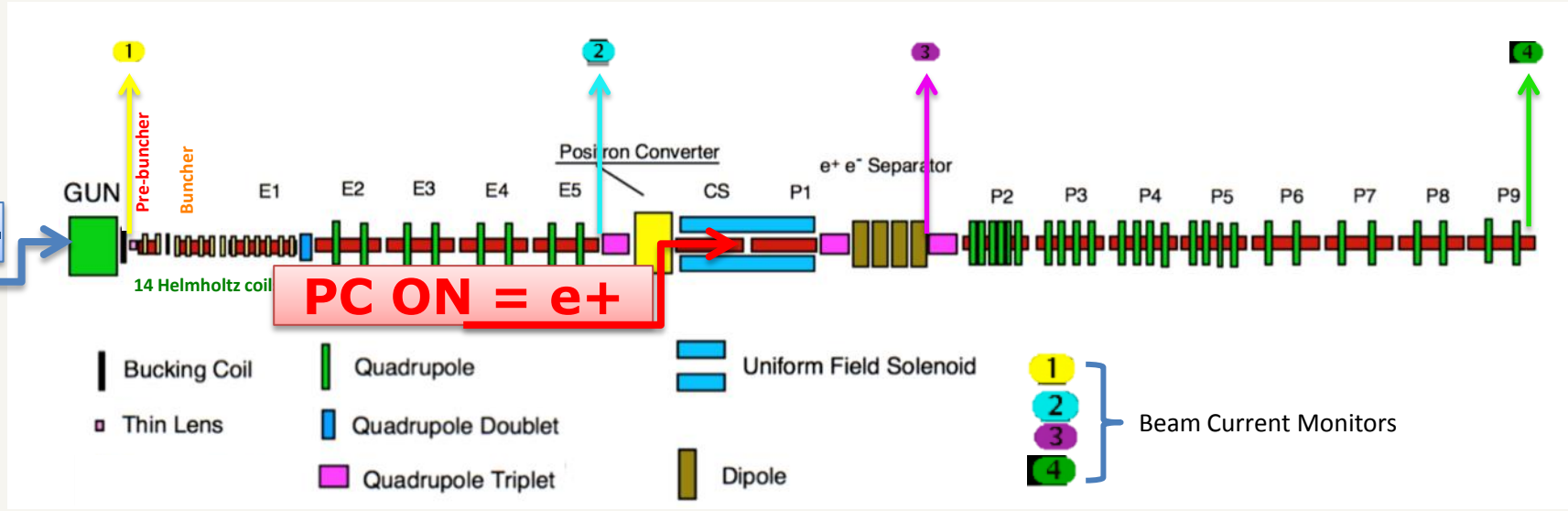


DAΦNE - LINAC



	Design	Operational (top)
Electron beam final energy	800 MeV	510 MeV (750)
Positron conversion energy	250 MeV	220 MeV
Positron beam final energy	550 MeV	510 MeV (535)
RF frequency	2856 MHz	
Accelerating structure	SLAC-type, CG, 2π/3	
RF Amplifiers	4 x 45 MW sledded klystrons TH2128C	
Beam pulse rep. rate	1 to 50 Hz	1 to 50 Hz
Beam macropulse length	10 nsec	1.4 ns to 250 ns
Gun current for positron	8 A	8 A
Beam spot on positron converter	1 mm	1 mm
Normalized Emittance (mm mrad)	1 (electron) 10 (positron)	1 (electron) 10 (positron)
RMS Energy spread	0.5% (electron) 1.0% (positron)	0.5% (electron) 1.0% (positron)
Output electron current (510MeV)	>150 mA	180 mA (>500)
Electron current on positron converter	5 A	5.2 A
Output positron current (510MeV)	36 mA	50 mA (>85)
Transport efficiency from capture section to linac end	90%	90%

DAΦNE LINAC - Layout



Electron Beam vs Positron one:

- Higher energy and current
- Less emittance (less transverse dimension at DUT)
- More degree of freedom in tuning
- ¼ operational power consumption less (life time components)
- Less total beam loss in transport

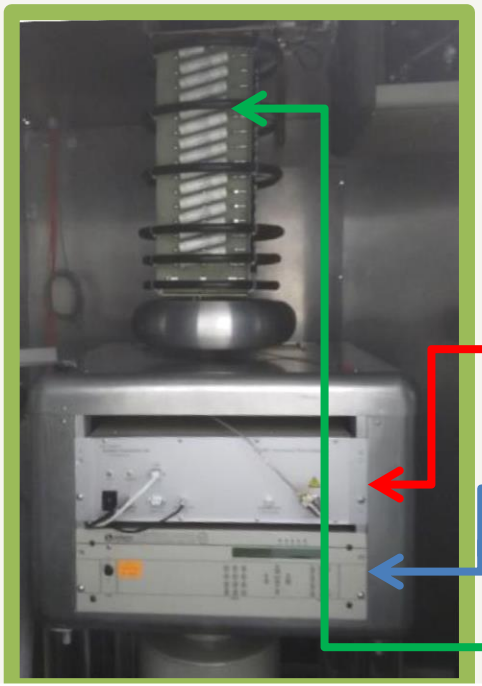
Positron Beam:

- Are positrons
- And 85mA of them (again to be improved)
- In these year, easily managed in transport
- Not too much used as primary in Beam Test
- Useful for DM research

DAΦNE LINAC – Electron GUN

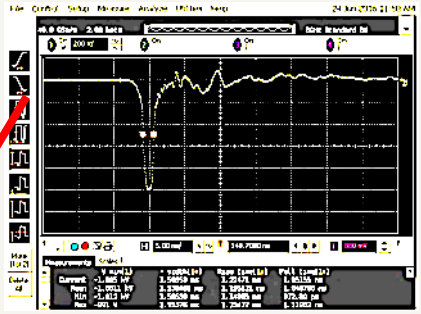
Giving the acceleration system doing the dirty job, focus on beam generation in time domain:

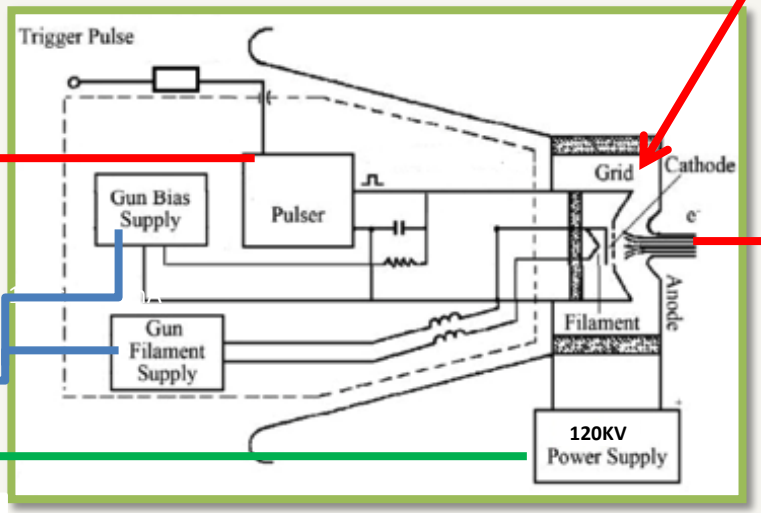
- Initial Beam Pulse Current and Length have to be conserved as more as possible
- Critical part of all the transport (order of 100keV) but all the beam is here
- Pulsed Machine, shots at 50 Hz, 10 ns typically
- In positron phase, gun releases 8A of current delivered to the positron converter!



Electron GUN Deck

Typical setup = HV fast pulse to invert grid potential on cathode





DAΦNE LINAC gun

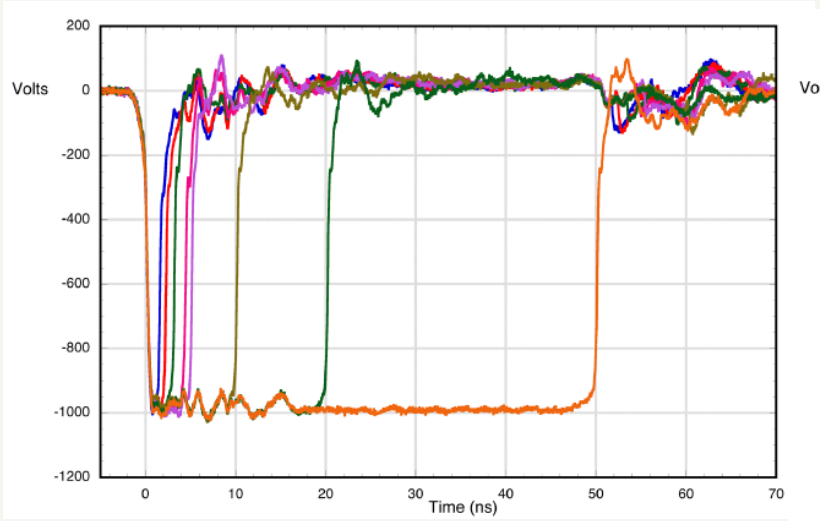
DAΦNE LINAC – GUN PULSER

Kentech PG1000 Nanosecond Pulser

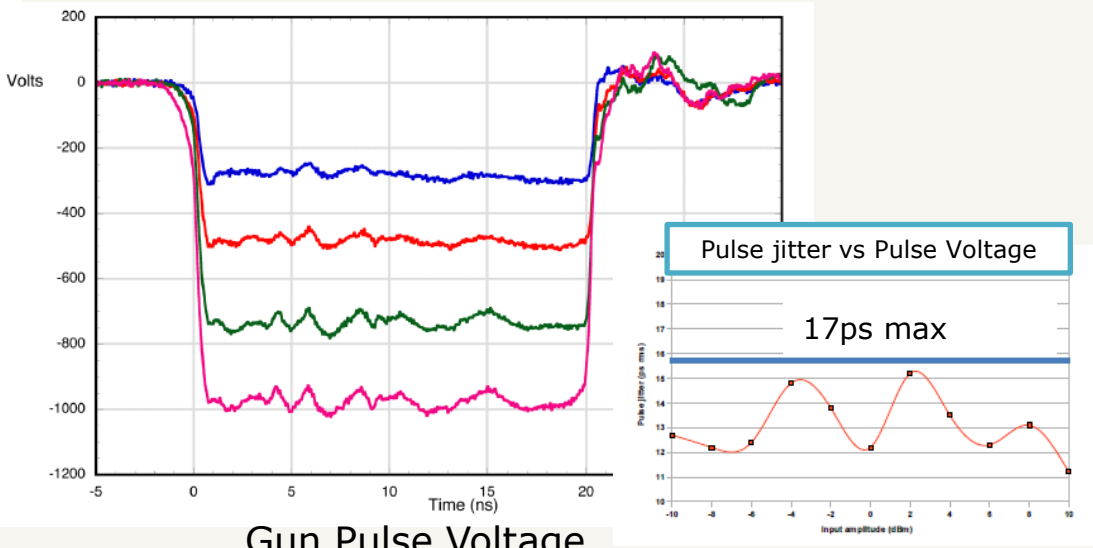
Polarity = Negative, AC coupled
Amplitude = -300 to -1000 [V]
Pulse shape = Rectangular

Flatness = ±10%
Post pulse noise = ±10%
Max Rep Rate = 50Hz

Pulse Range [ns]	1.5 -> 45	45 -> 5000
RMS Pulse jitter [ps]	<20	<500
Rise time [ns]	<1	<1
Fall time [ns]	1.5	8

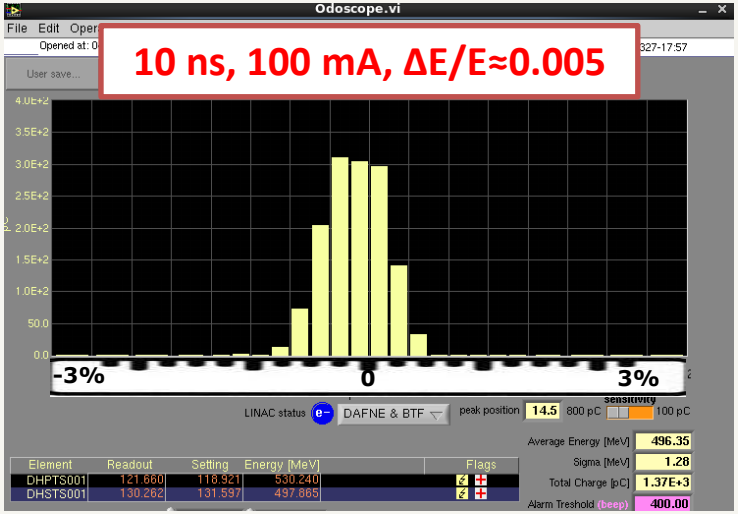


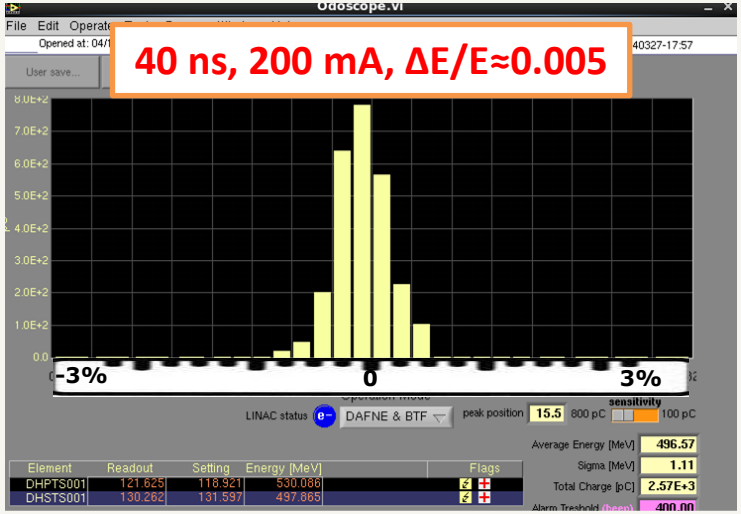
Gun Pulse Lenght

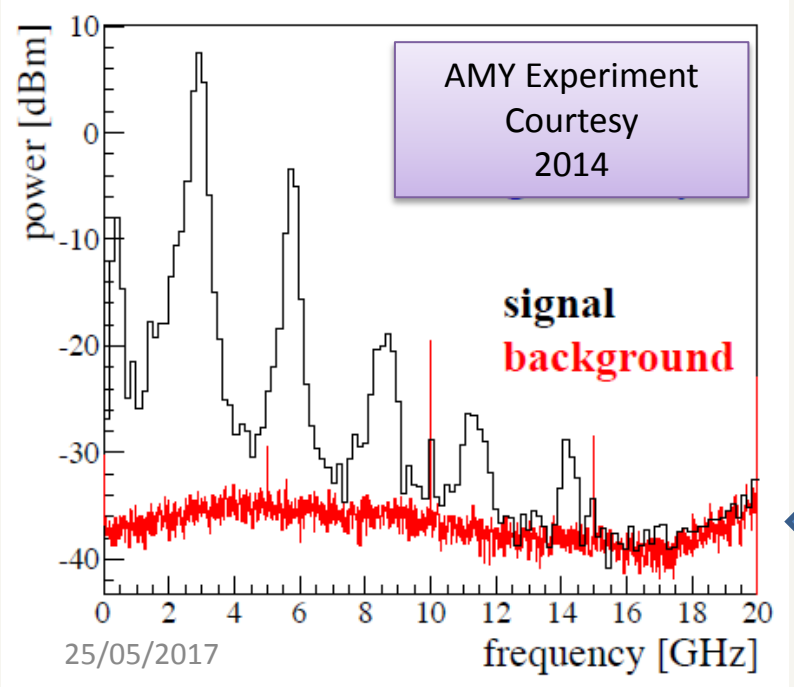


Gun Pulse Voltage

DAΦNE LINAC – Typical Beam

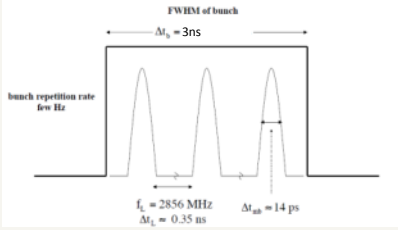






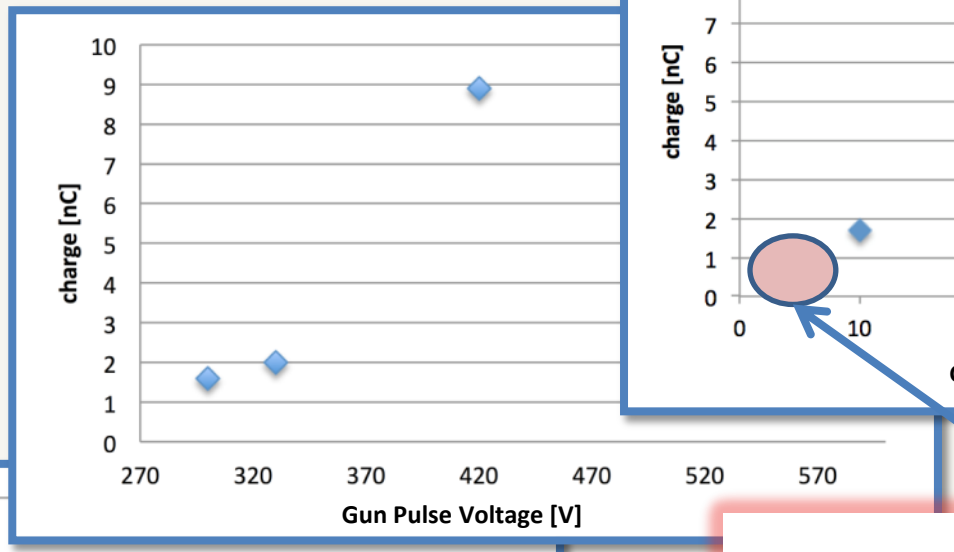
- During parasitic operation, pulse duration is fixed at **10 ns** for the injection into the damping ring
- Bunched structure at **2856 MHz** is visible with a good enough timing resolution
- Typical charge: 2 nC for e^-, 0.5 for e^+
- Fixed Energy = 510MeV for both of e-/e+

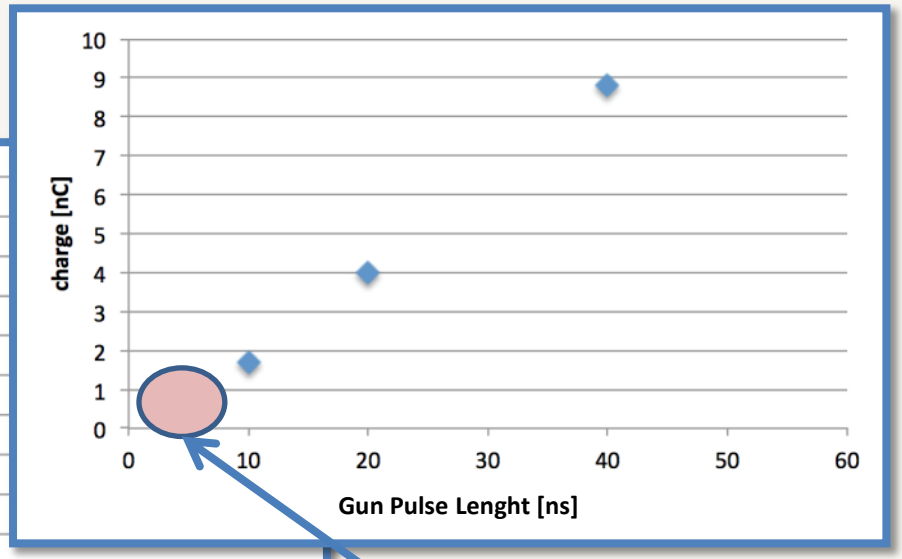
3ns,1nC LINAC Electron beam on antenna

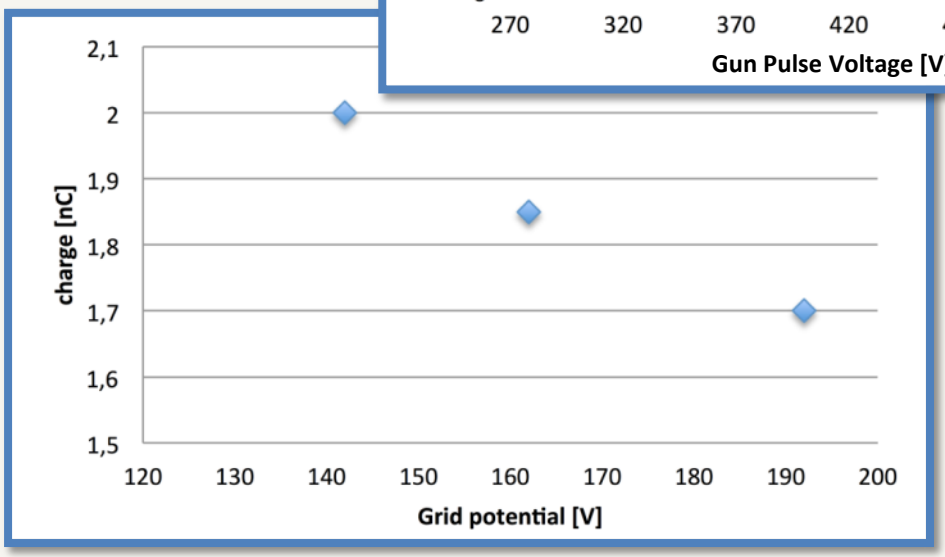


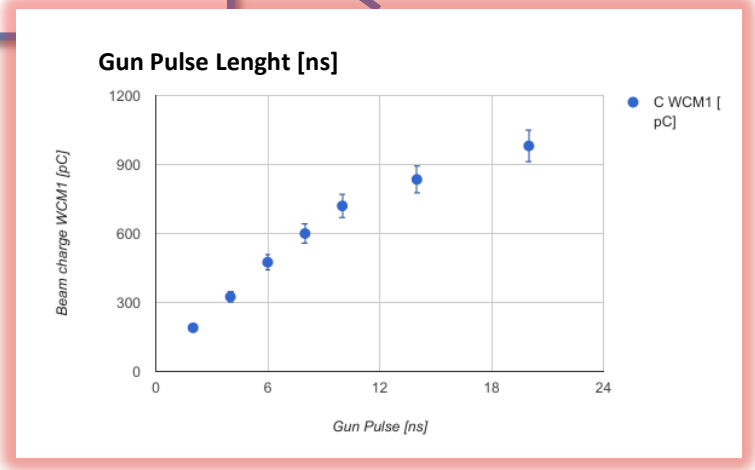
DAΦNE LINAC –Beam workouts

- Old gun pulser: from 1.5ns to 40ns
- Trials in Gun Pulse length, Gun Pulse voltages
- Beam Particle = Electrons
- E = 725 MeV
- ΔE/E < 0.005



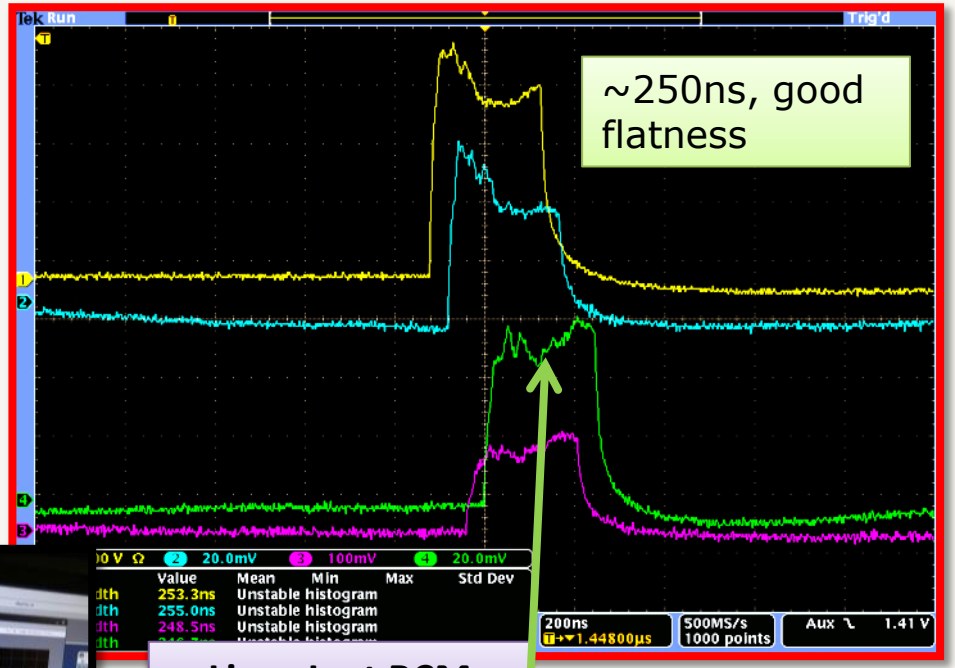




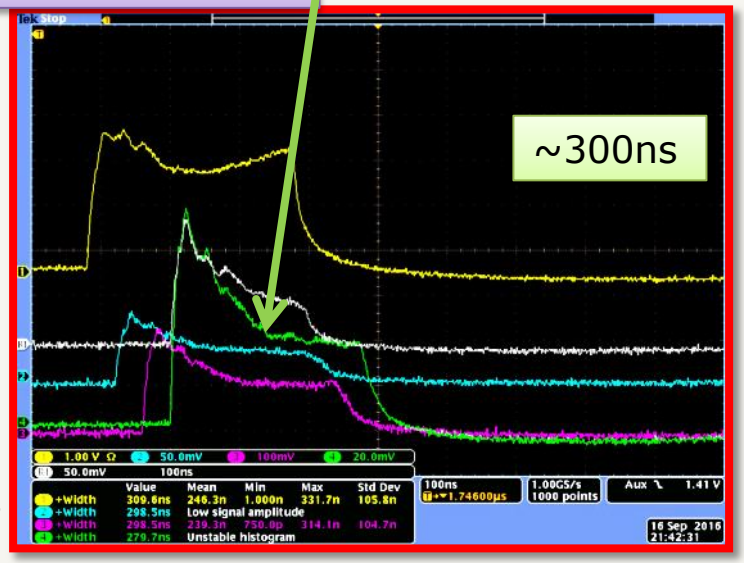


DAΦNE LINAC – New Beam

- New gun pulser: from 1.5ns to 5µs
- Trials in Gun Pulse length, Gun Pulse voltages plus acting on GUN and Modulator trigger timing
  - Beam Particle = Electrons
  - E = 558 MeV
  - ΔE/E = 0.015
  - Charge = 2nC
  - Beam at LINAC exit >250ns!
  - To be optimized further



Linac Last BCM

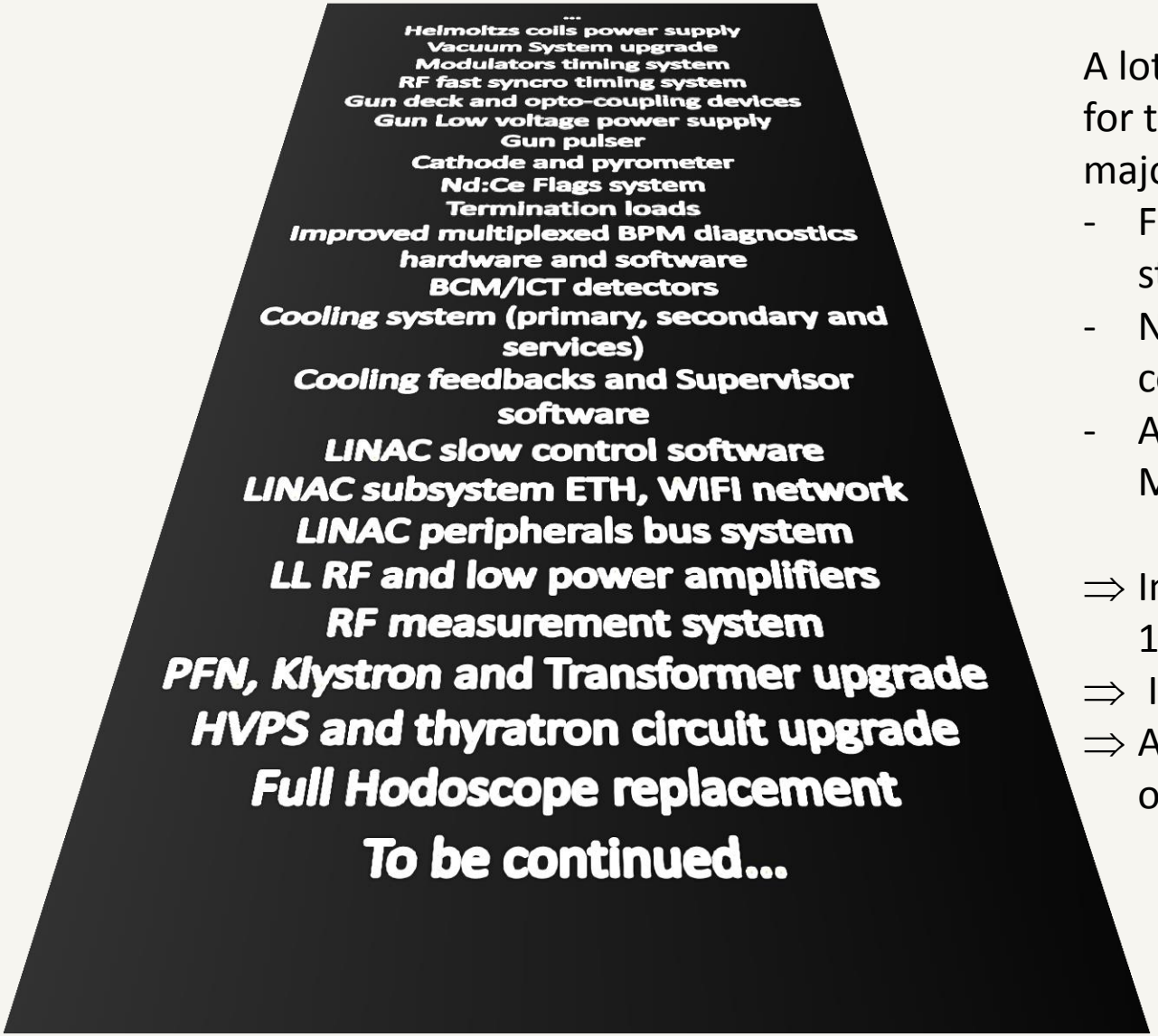


DAΦNE LINAC – Future

A long (too much long) four years ago in LINAC modulator hall, not too much far away….

(music by yourself, in honor of PADME exp.)

DAΦNE LINAC – Future



A lot of work has been done, but for the next upgrade the planned major improvements are:

- Full replacement with solid state HVPS for the PFN
- New embedded modulator control system
- Add a new Modulator+Kly+SLED

⇒ Increase energy beam up to 1GeV electron

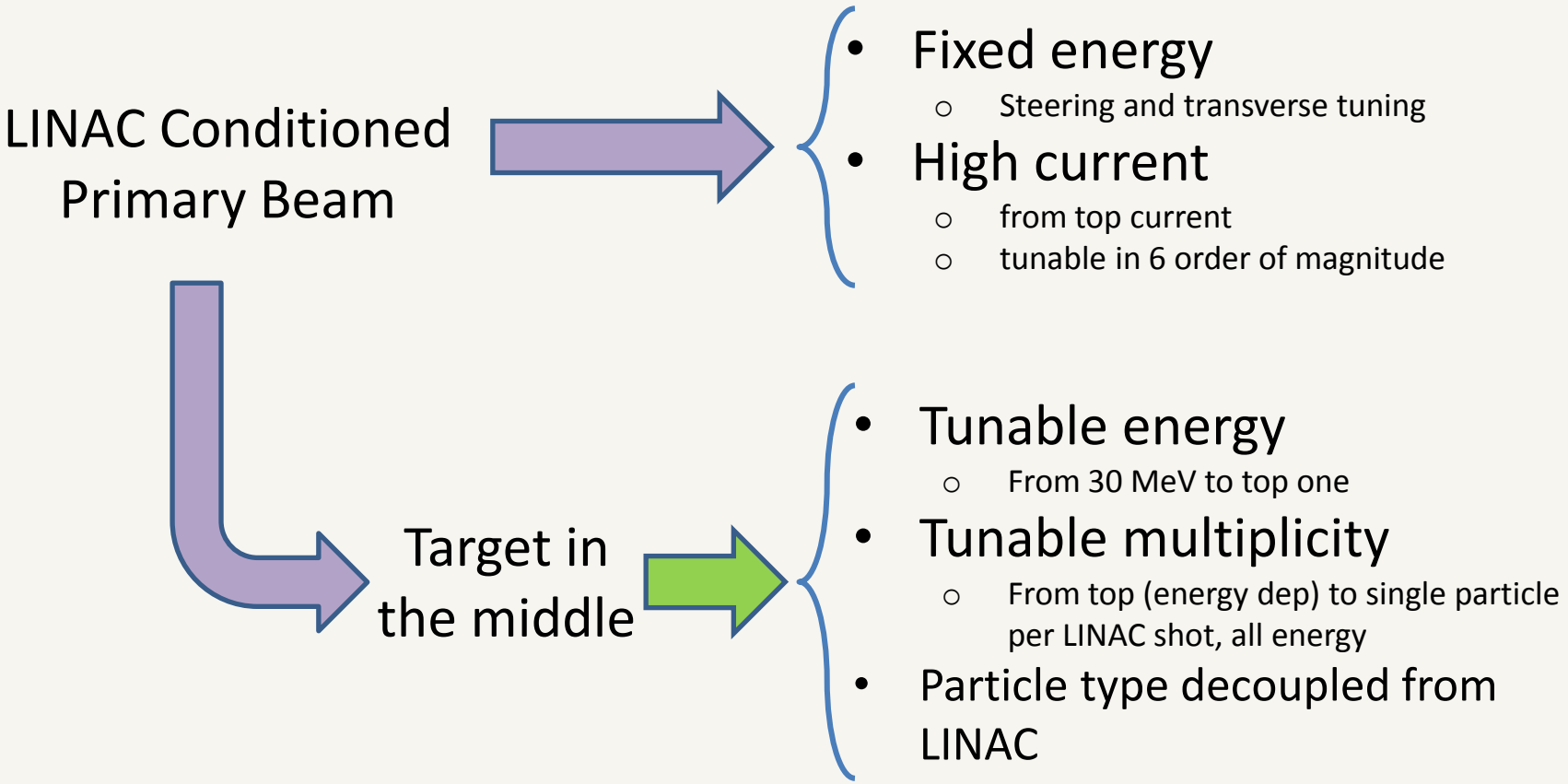
⇒ Improve stability operation

⇒ Add more 10 years to a very old machine (20 years old)

DAΦNE LINAC Primary Beam

Why discussing about it?
Down the end of LINAC, Beam Test Facility!

Two different types of experiments:

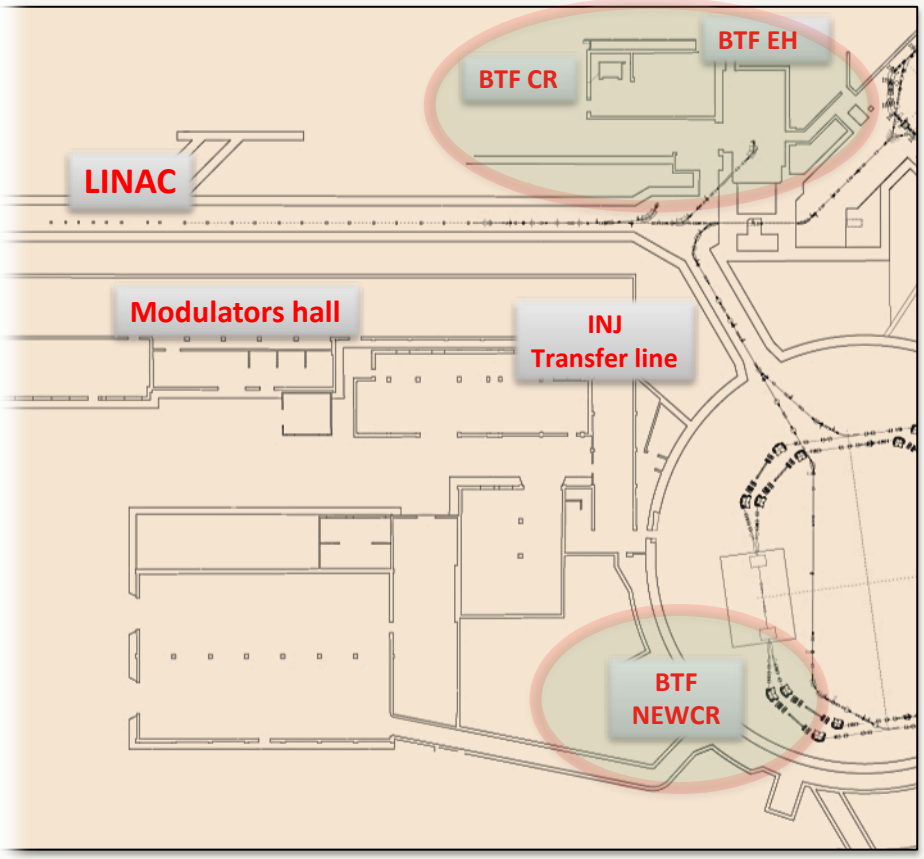


The DAΦNE complex - BTF

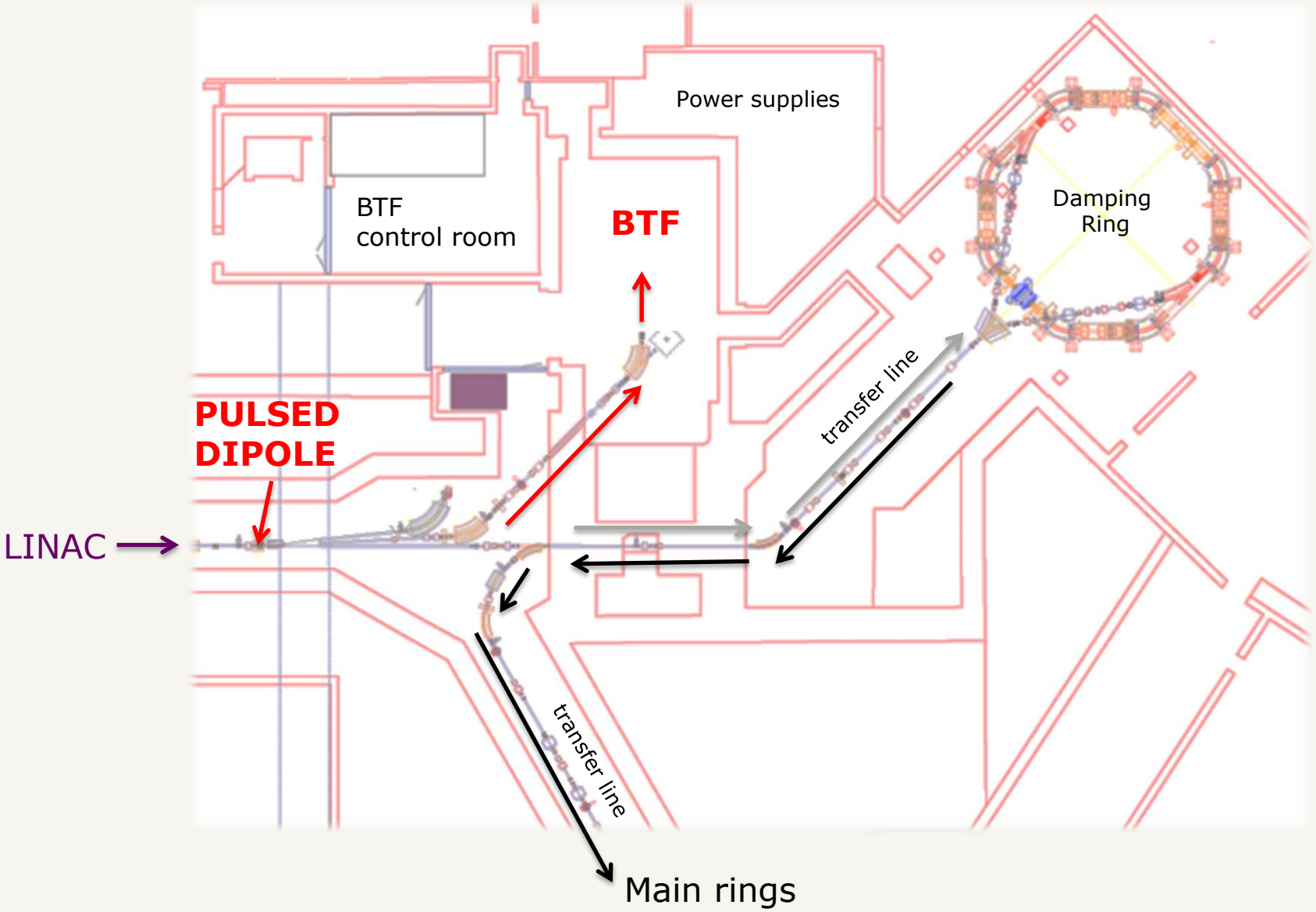
The BTF (Beam Test Facility) is composed of:

- a transfer line
  - driven by a pulsed magnet
  - can steers primary electrons or positrons coming from LINAC,
  - or create secondary beams from electromagnetic shower
  - Whose electrons or positrons are selected in energy, multiplicity and transverse dimensions

- a 100 m^2 experimental hall,
  - With a good availability of services and detectors
  - Open to external users
  - Hardly booked!

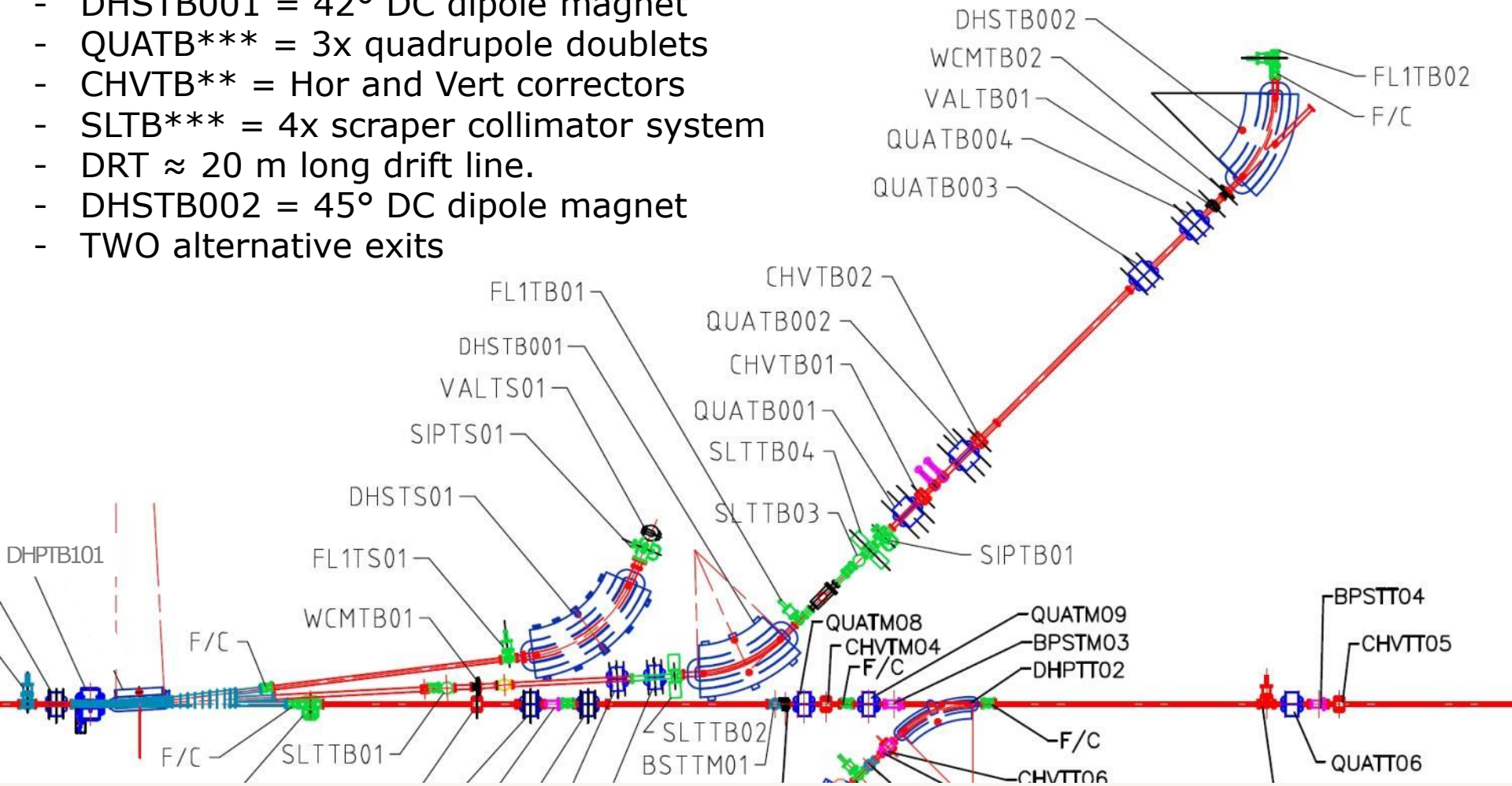


DAΦNE– BTF Injection



BTF Layout - Transport

- DHPTB101 = 3° pulsed dipole
- DHSTB001 = 42° DC dipole magnet
- QUATB*** = 3x quadrupole doublets
- CHVTB** = Hor and Vert correctors
- SLTB*** = 4x scraper collimator system
- DRT ≈ 20 m long drift line.
- DHSTB002 = 45° DC dipole magnet
- TWO alternative exits



BTF Layout - Transport

- DHPTB101 = 3° pulsed dipole
- DHSTB001 = 42° DC dipole magnet
- QUATB*** = 3x quadrupole doublets
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- SLTB*** = 4x scraper collimator system
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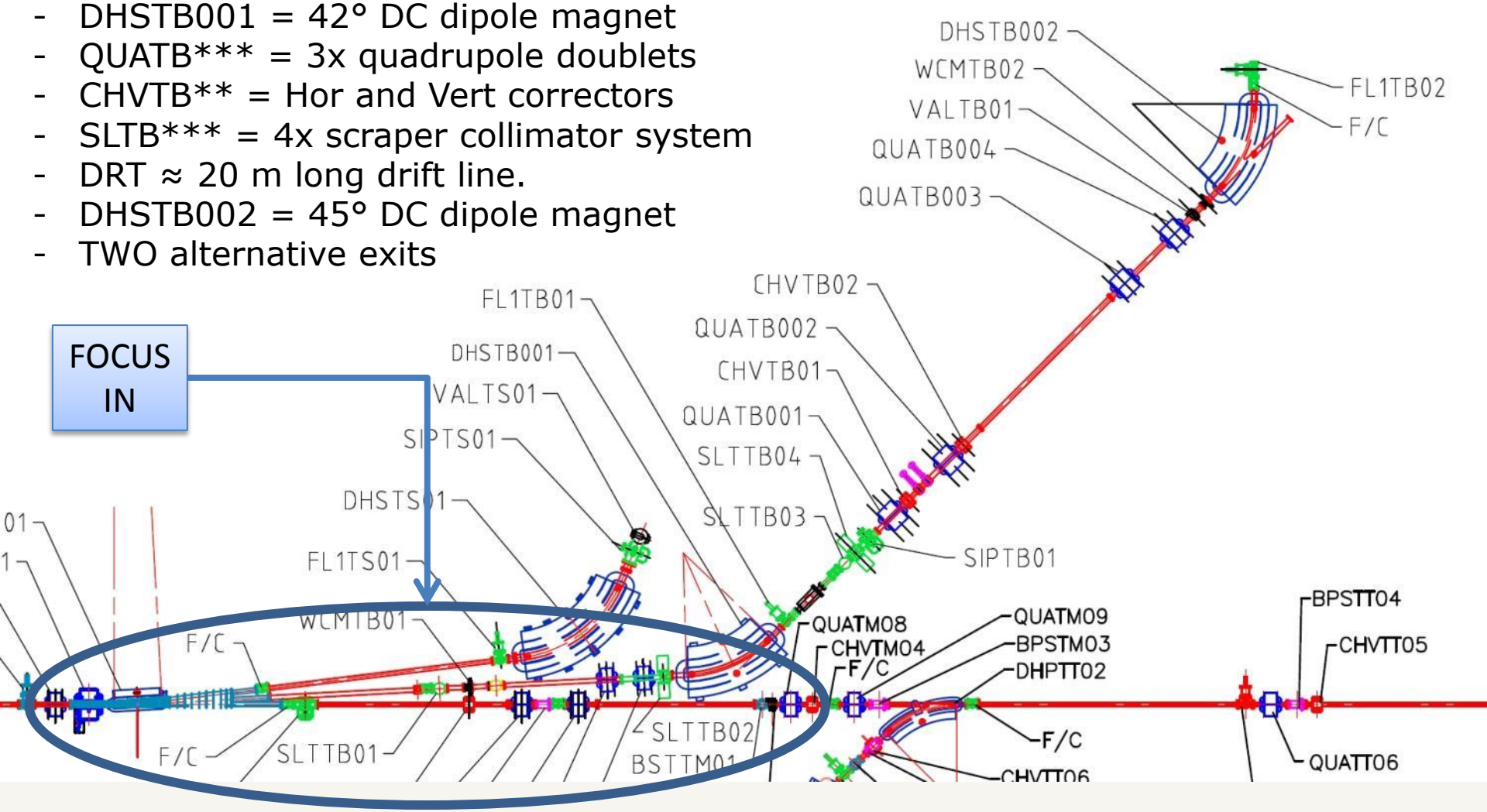
- DHSTB002 = 45° DC dipole magnet
- TWO alternative exits



BTF Layout – Primary Beam

- Fixed Energy! (Straigth forward from the LINAC)
- Multiplicity (current) selection! (Scrapers)
- Spot transverse dimensions (Scrapers, Quad for final focus)
- Matching angle and position in the DUT (Dipoles and Correctors)
- Maximum allowed intensity ≈ 3*10^10 prim/sec in ExpHall

Normal way of thinking

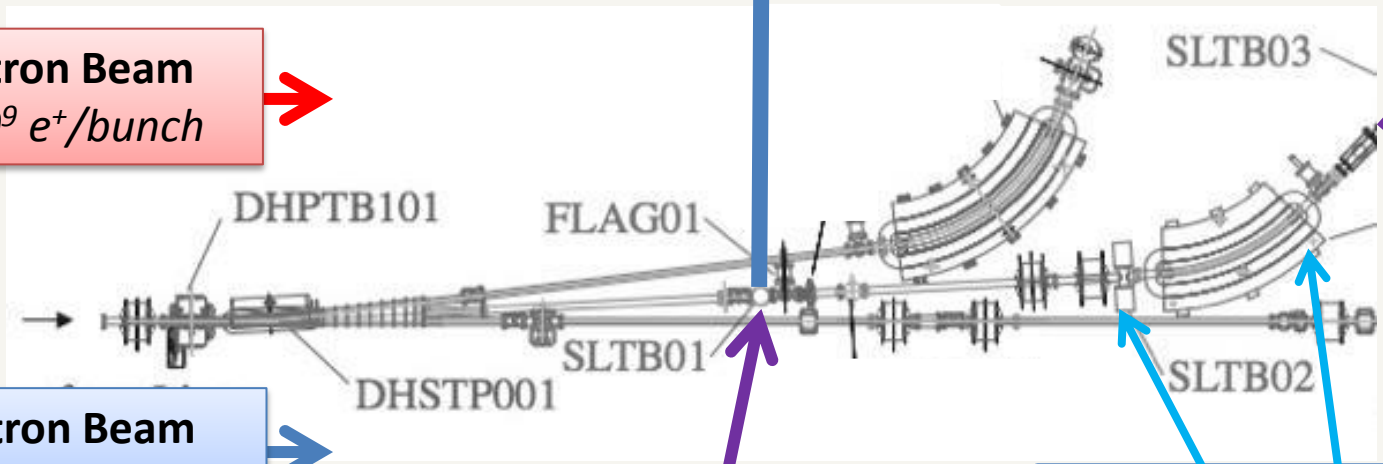
PRIMARY

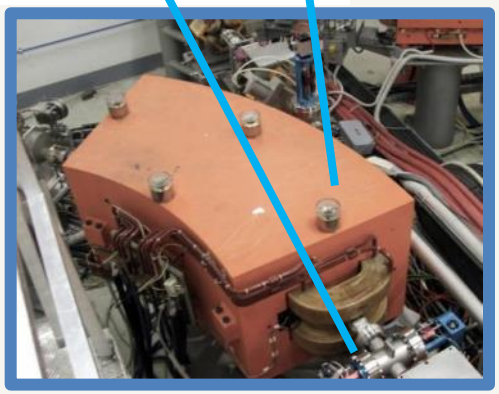
PRIM conditioned

TO BTF EH

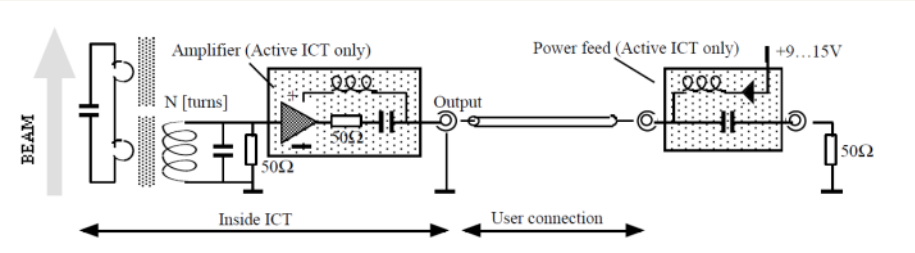
Positron Beam
6×10⁹ e⁺/bunch

Electron Beam
3×10¹⁰ e⁻/bunch



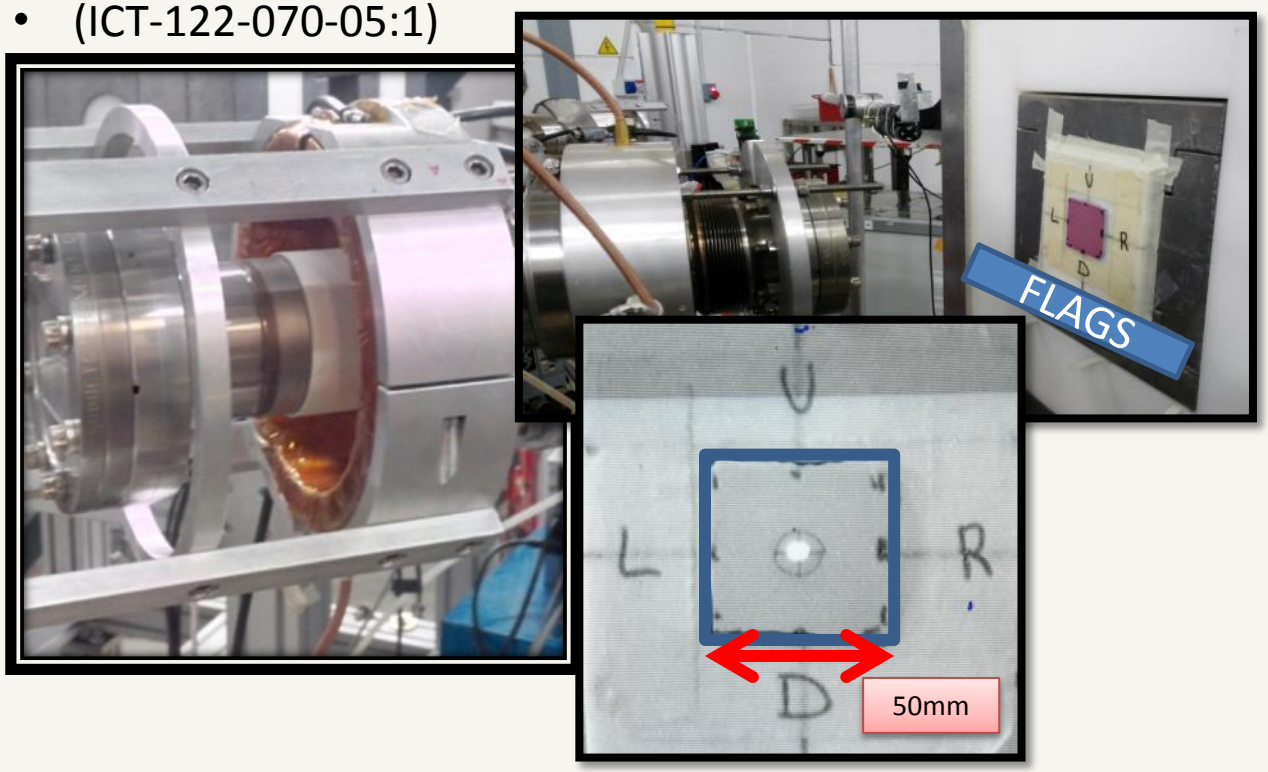


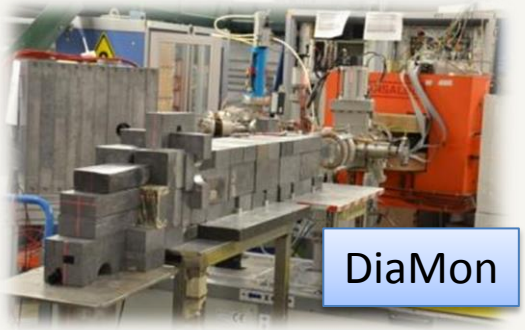
BTF Layout – Primary Beam Diagnostics & Experiments



Bergoz Integrating Current Transformer

- (ICT-122-070-05:1)





BTF Layout – Secondary Beam

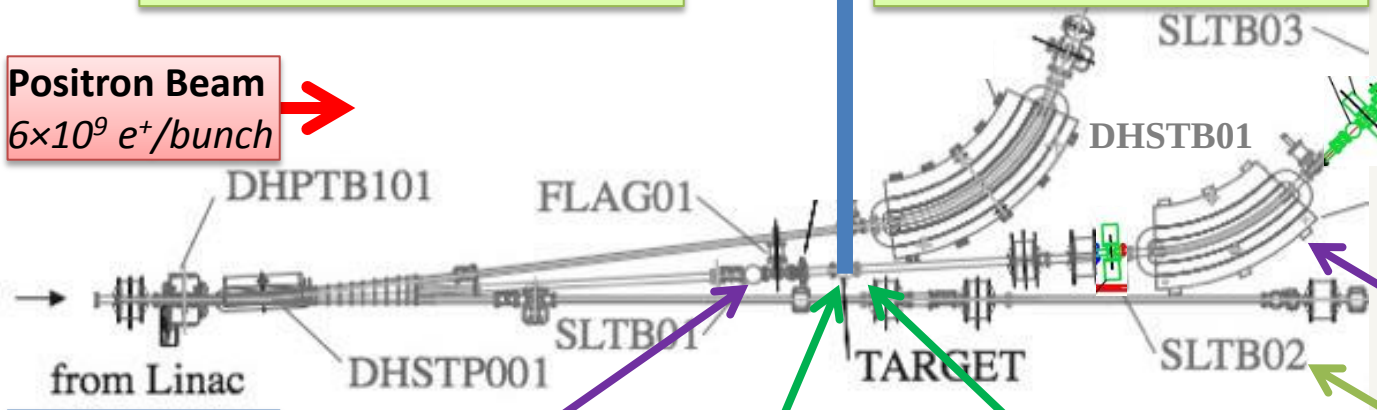
PRIMARY

SECONDARY

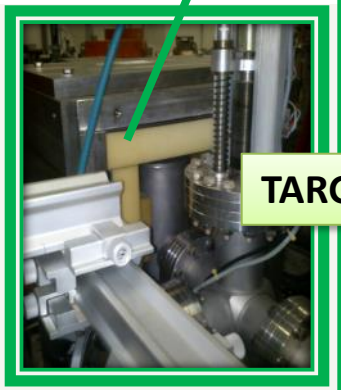
TO BTF

Positron Beam
6×10⁹ e⁺/bunch

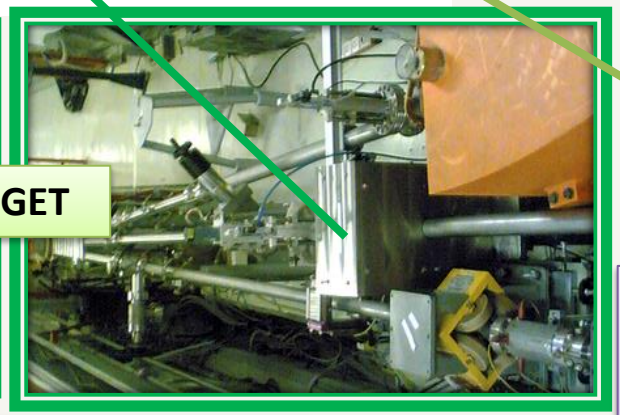
Electron Beam
3×10¹⁰ e⁻/bunch

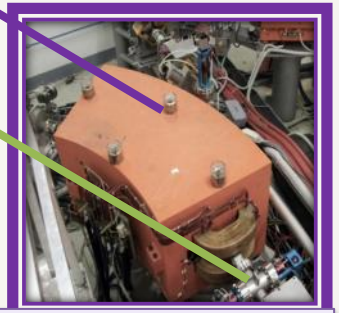


- 4x single-axes SCRAPERS
- LINAC Energy is different to BTF energy
- TARGET!!!!



TARGET





DHSTB001+Scrapers
- Selects energy
- Select multiplicity
- Steers

ENERGY selector device!

- Copper target in the middle
- **ENERGY** and its spread selection! (Scrapers,Dipoles)
- **MULTIPLICITY** selection! (Scrapers,Dipoles)
- Transverse Scrapers, Quad, Dipoles
- Dipoles and Correctors to match angle and position in the DUT

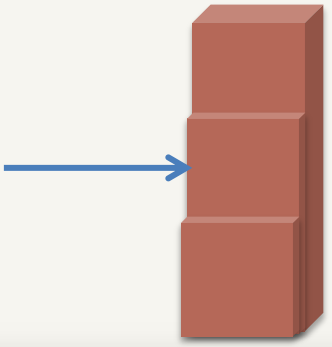
BTF BEAM - Targets

LINAC positron converter

- Target: tungsten (Z=74)-rhenium(Z=75), L=2 x_0
- Positrons by pairs production
- Active capture via flux concentrator, jointly with DC solenoid magnets, generate a strong magnetic field (5 T peak) necessary for the positron capture.

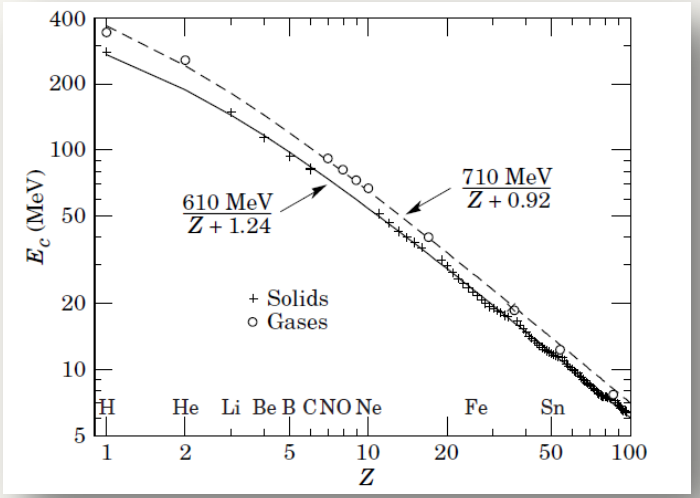
BTF target

- Copper (Z=29) variable depth (1.7, 2 or 2.3 radiation lengths)
- Positrons by pairs production
- Passive Capture (scrapers and divergence (QUADTB10X)
- Selection in energy with (DHSTB001) and scrapers



B. Rossi model of e.m. shower

$$w(E_o, \alpha, E) = \frac{1}{E_o} \frac{\left[\ln\left(\frac{E_o}{E}\right)\right]^{\frac{\alpha}{\ln 2}-1}}{\Gamma\left(\frac{\alpha}{\ln 2}\right)}$$

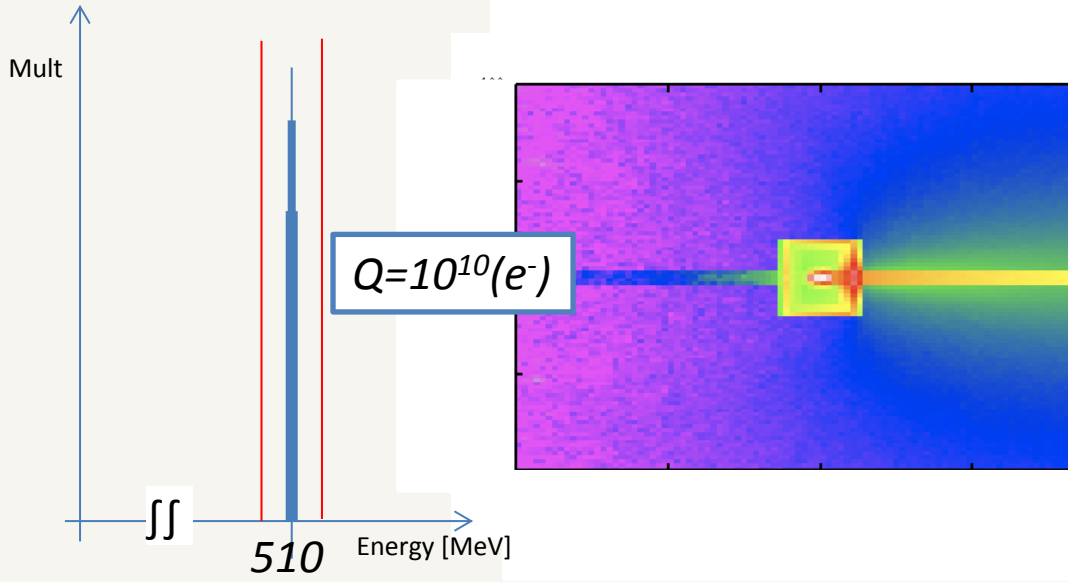


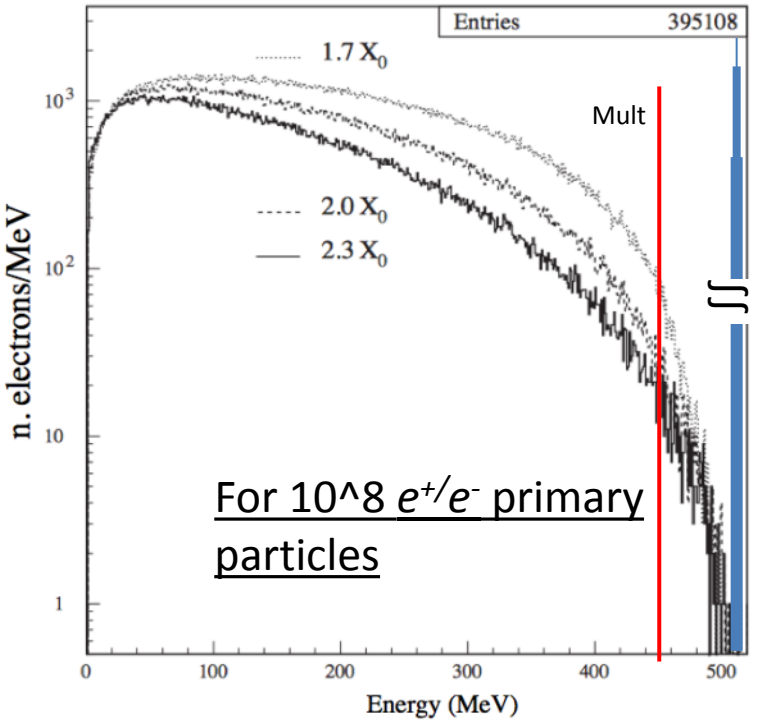
- Copper critical energy ≈ **19 MeV** (≈ **46 MeV** for W/Re)
- Not so far from the less energetic BTF tuned beam (30MeV)

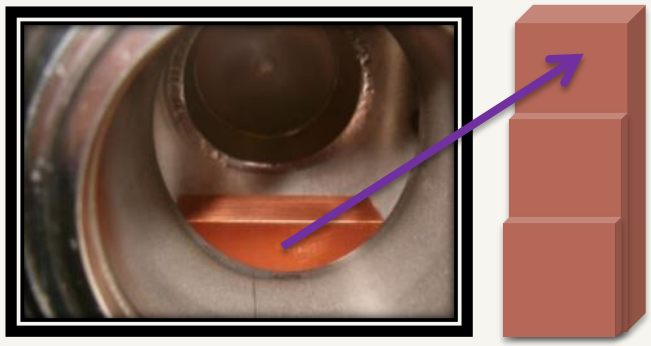
BTF LAYOUT - Secondary Beam

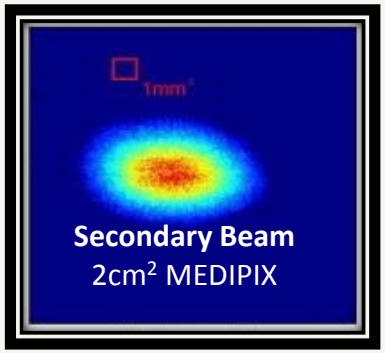
3-selectable thickness Copper Showering TARGET

- 1.7, 2.0 or 2.3 radiation lengths





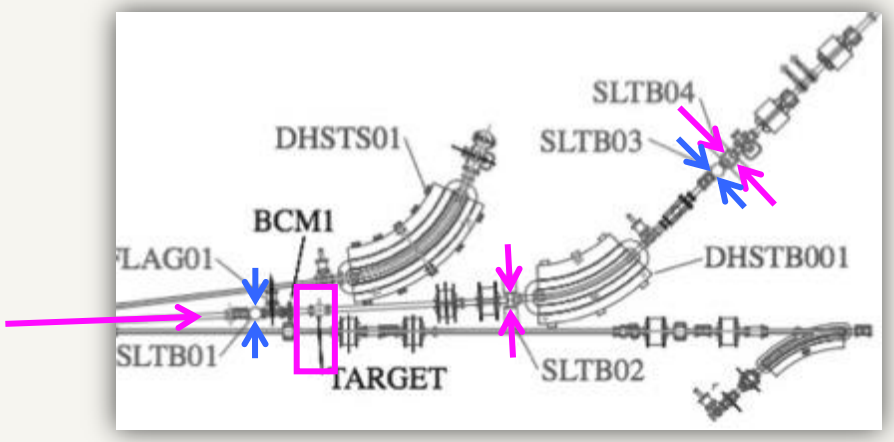


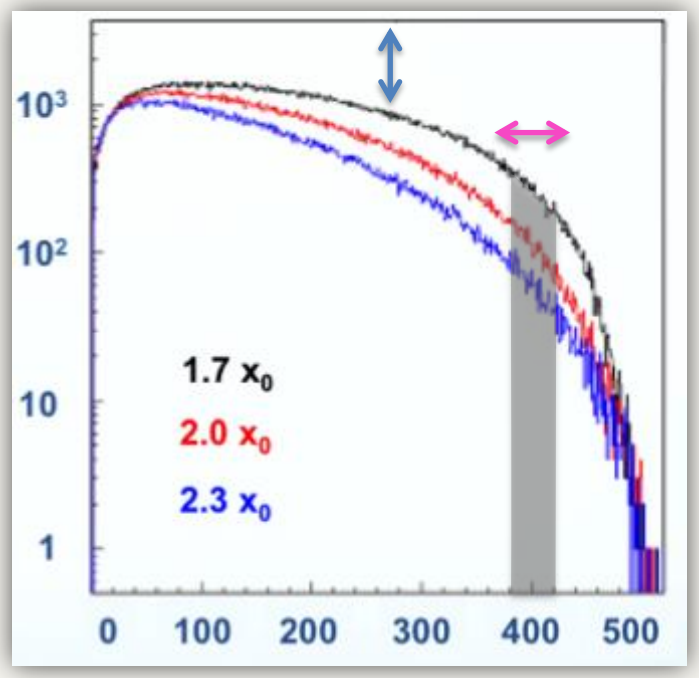


BTF BEAM - Intensity tuning

Adjustment of the number of particles can be achieved:

- Without changing the momentum resolution:
  - **Modulating** the LINAC **current** [not possible in 'parasitic mode', very rough]
    - Act on transport optics or modulators power/phase
  - Choosing another **target depth** [step change but reproducible] –> **Secondary beam**
  - Closing/Opening the **down-stream vertical collimators** [fine but small range]
  - Closing/Opening the **up-stream vertical collimators**
- Also changing the momentum resolution:
  - Closing/Opening the **horizontal collimators**





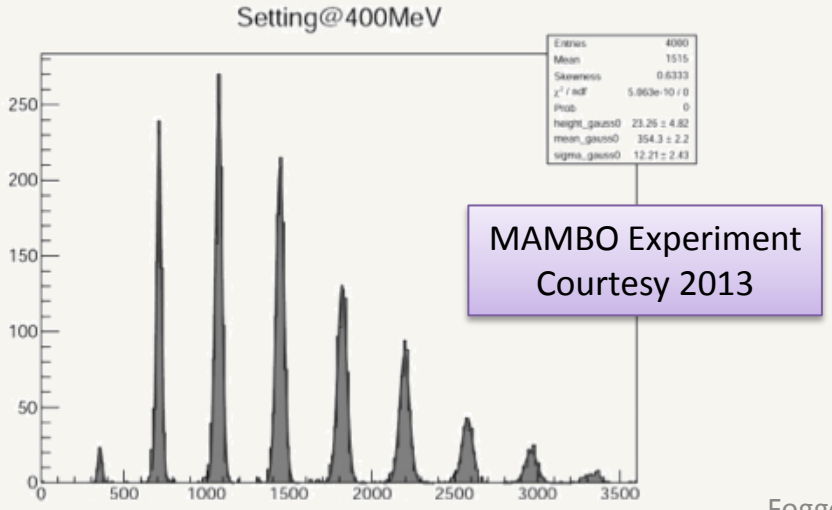
BTF BEAM - Intensity tuning

Secondary beam, single particle

- The primary beam is attenuated by the copper target
- Starting from primary beam energy down to 30 MeV
- **Multiplicity as Poissonian distribution with a given average multiplicity is selectable**
- Selectable positrons or electrons , independently from LINAC phase

Secondary beam, intermediate intensity

- The primary beam is attenuated by the copper target
- Starting from primary beam energy down to 30 MeV
- ***Ranging from ten to hundred thousand particles per bunch***
- ***Selecting at least 10MeV energy lower than the primary one***
- ***Multiplicity is directly related to the secondary energy spectrum accepted by the line***
- Selectable positrons or electrons , independently from LINAC phase



→ thus allowing a very fine tuning of the beam intensity and energy

BTF Layout – Secondary Beam Parameters

Energy [MeV]	Max mult e- per bunch [#, 10^3]	Max mult e- with DAFNE[#/s, 10^3]	Max mult e- only BTF (e- mode) [#/s, 10^3]	Max mult e+	Transverse Dimensions * [mm]
450	5	50	250	To be filled, factor 1/10 less	1
350	30	300	1500		2
300	60	600	3000		2,5
200	80	800	4000		3
150	100	1000	5000		4
100	40	400	2000		5
50	2	20	100		8

- For nominal LINAC current (180mA)
- Average bunch/s = 10 (not counting e+ LINAC mode, normal timing in DAΦNE injections)
- Conservative values, strongly dependant on DAΦNE requirements
- Not consider: machine uptime/vacation...

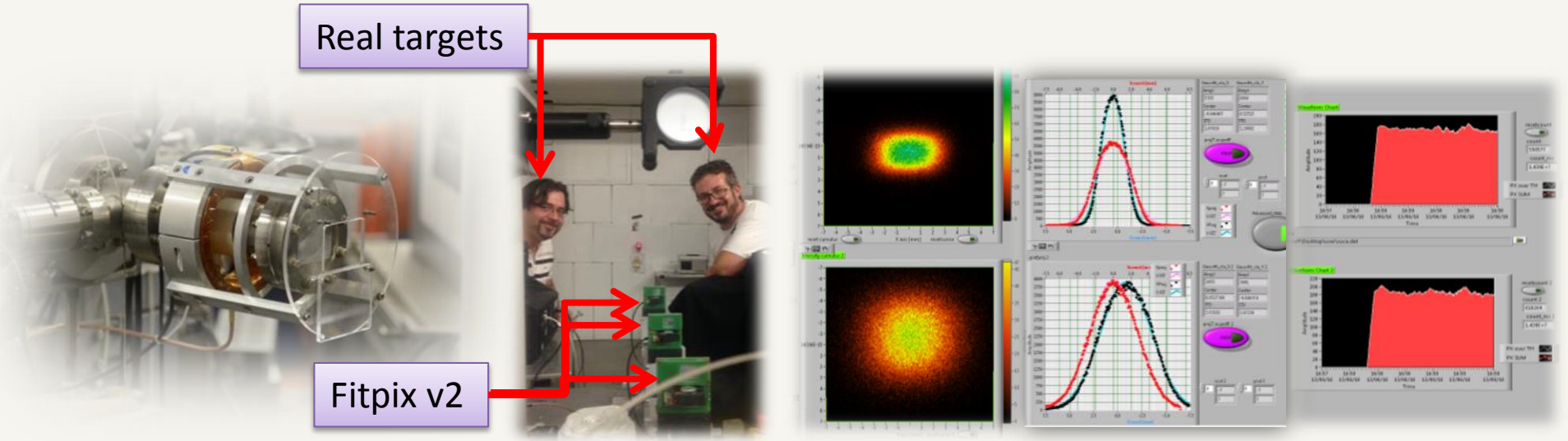
* Best transverse Dimensions (at 400 mm from Be-window exit) for a round gaussian beam

BTF Layout – Secondary Beam Parameters

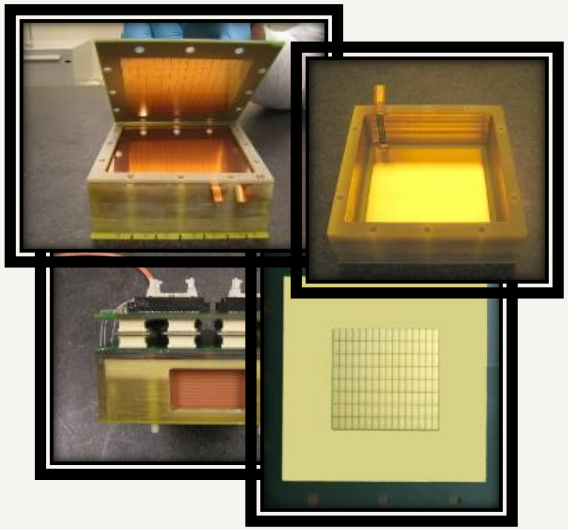
Energy [MeV]	Best Transverse Dimensions round beam (σ both plane) [mm]	Multiplicity
500	0,45	1
400	0,6	1
300	0,8	1
200	1,2	1
100	1,8	1
50	3,1	1
30	4,9	1

* Best transverse dimensions (at 200 mm from Be-window exit) for a round gaussian beam +-10%

BTF BEAM – Runtime diagnostics (few)

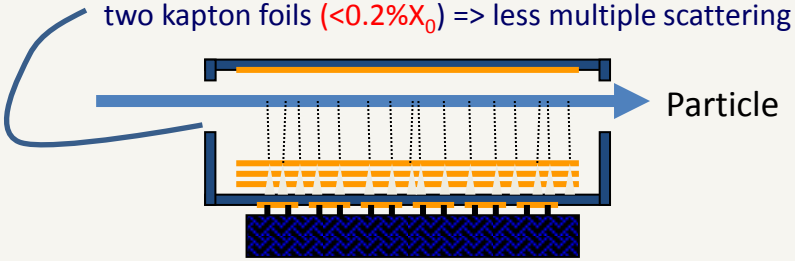


- **ADVACAM FITPIX detectors**
  - 256×256 pixels, 55 μm pitch, 300 μm thickness sensor
  - 14×14 mm^2 active area
- Three FitPIX devices **ready**, **readout integrated** in MEMcached based BTF control system
  - >> 50 frames/s achieved



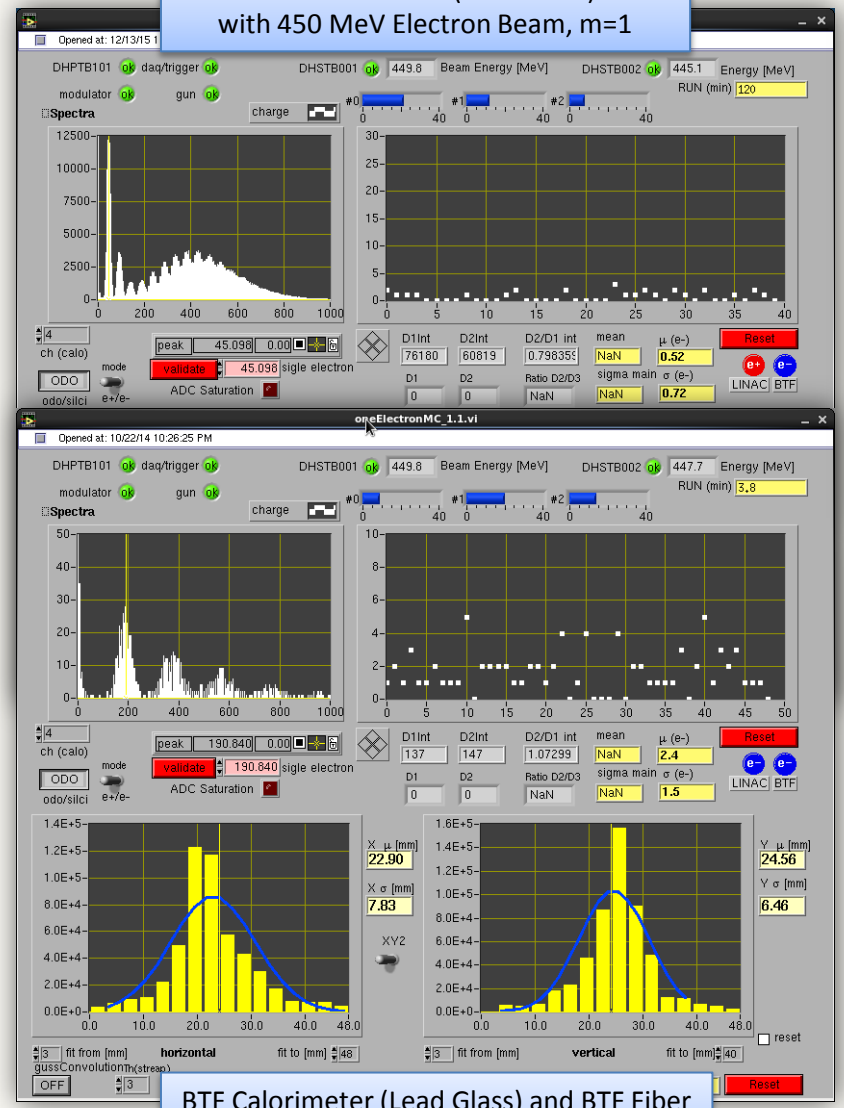
BTF GEM

Triple GEM structure
AIDA

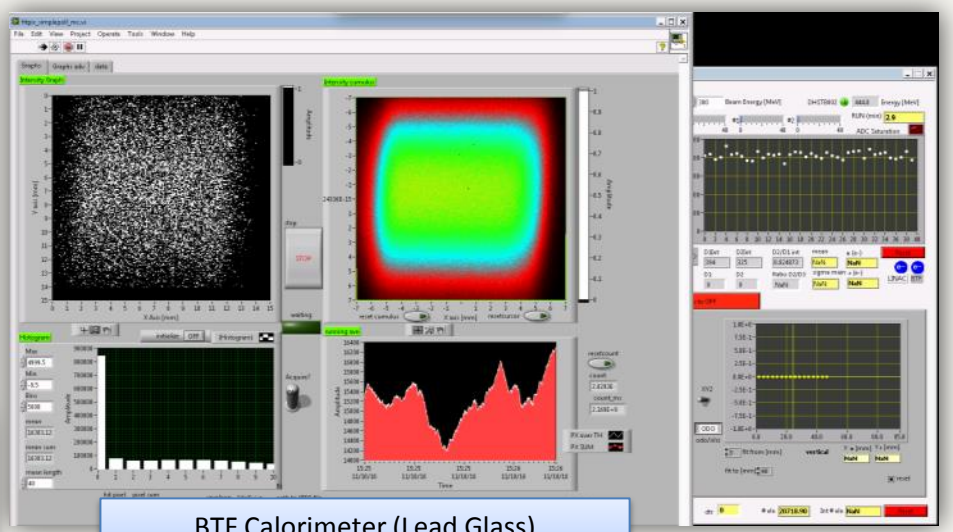


BTF BEAM – Runtime diagnostics (few)

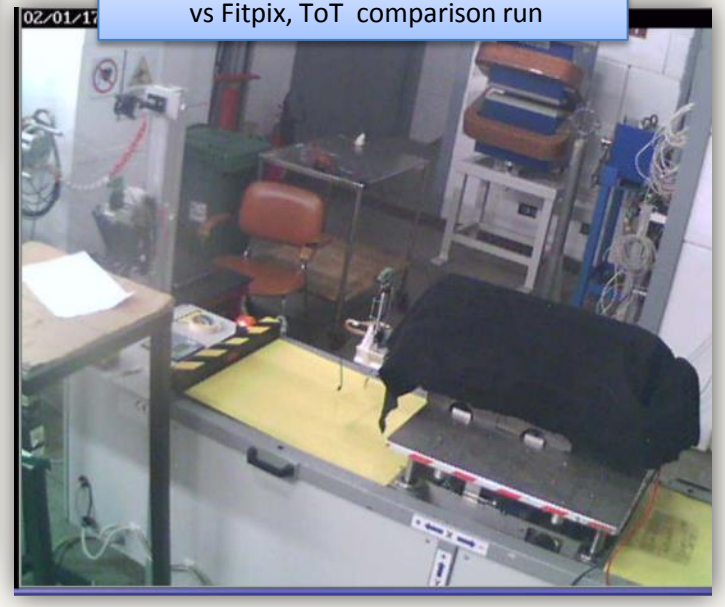
BTF Calorimeter (Lead Glass)
with 450 MeV Electron Beam, m=1

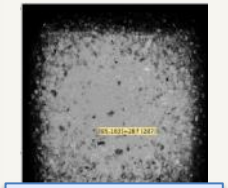


BTF Calorimeter (Lead Glass) and BTF Fiber Hodoscope with Electron Beam, m=1



BTF Calorimeter (Lead Glass)
vs Fitpix, ToT comparison run

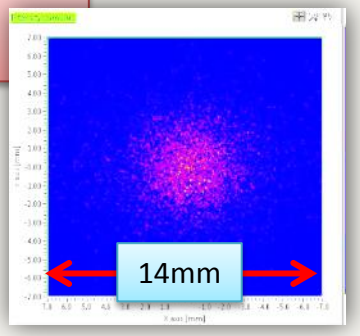




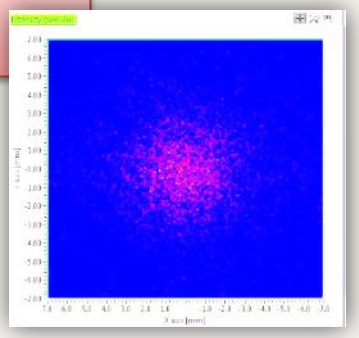
The next One?

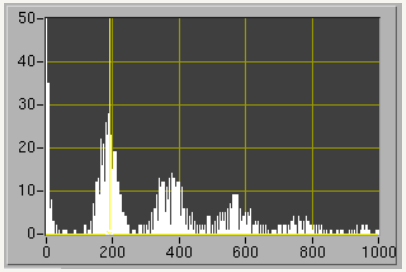
BTF BEAM – Energy tuning (e-,e+)

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



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





No significative difference from positron to electron secondary beam parameters

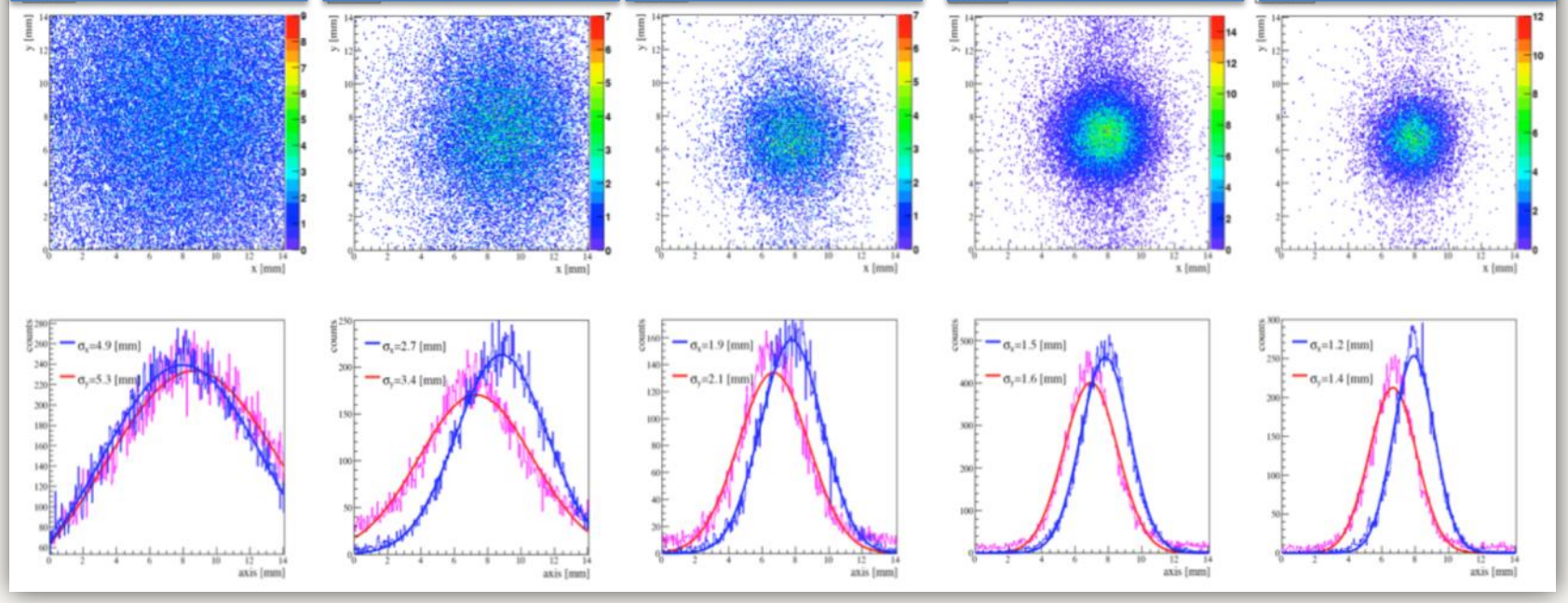
30MeV - single part
$\sigma_{x=}$4.9, $\sigma_{y=}$5.3 [mm]

60MeV - single part
$\sigma_{x=}$2.7, $\sigma_{y=}$3.4 [mm]

90MeV - single part
$\sigma_{x=}$1.9, $\sigma_{y=}$2.1 [mm]

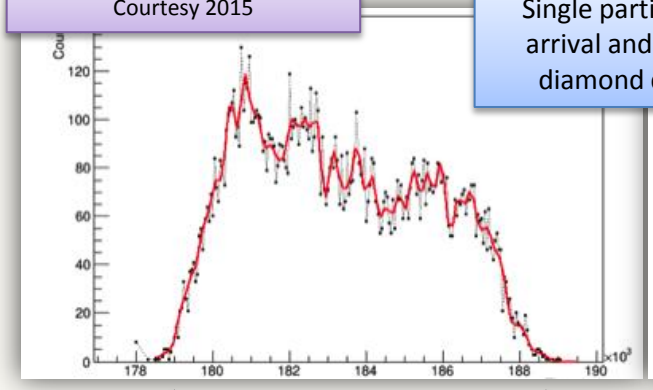
120MeV - single part
$\sigma_{x=}$1.5, $\sigma_{y=}$1.6 [mm]

150MeV - single part
$\sigma_{x=}$1.2, $\sigma_{y=}$1.4 [mm]



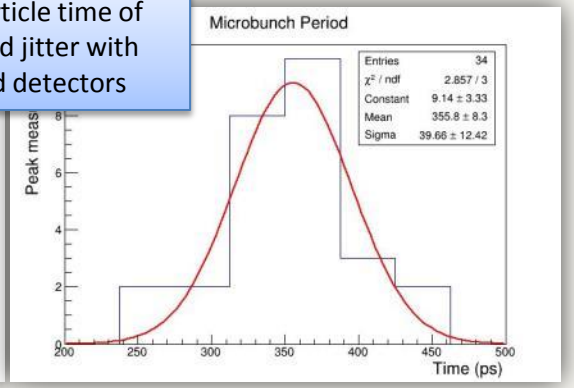
BTF BEAM – Other features

TOF Diamond Experiment
Courtesy 2015



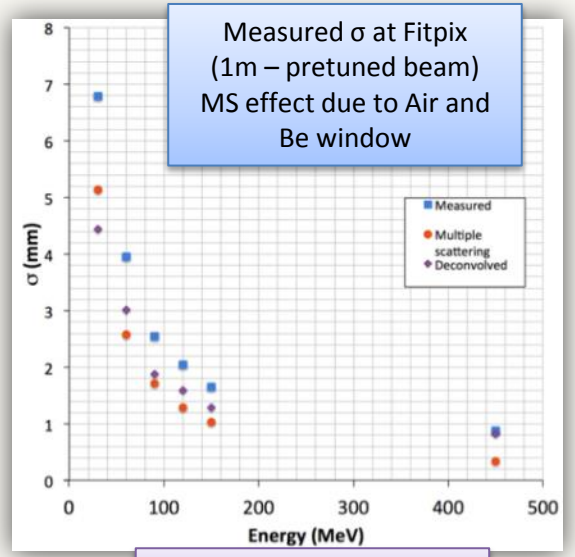
10 ns

Single particle time of arrival and jitter with diamond detectors



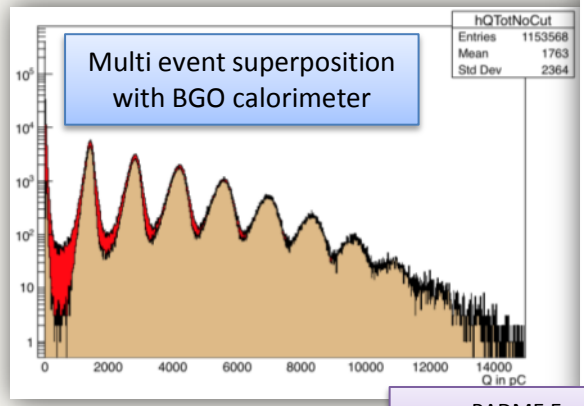
300 ps

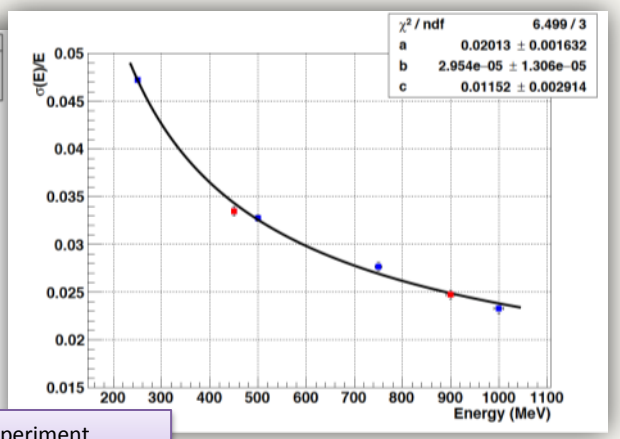
Measured σ at Fitpix
(1m – pretuned beam)
MS effect due to Air and
Be window



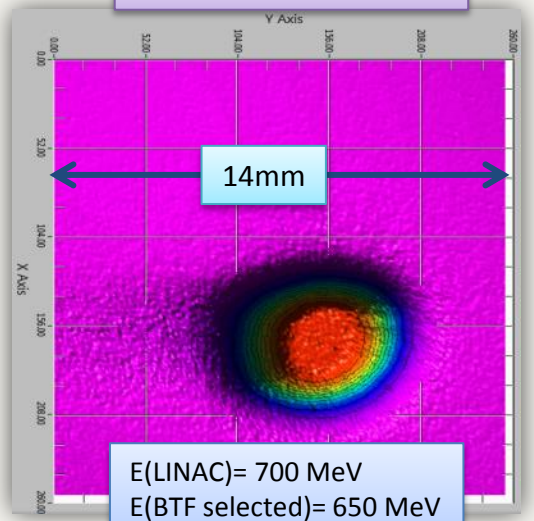
Our Courtesy 2014

Multi event superposition
with BGO calorimeter





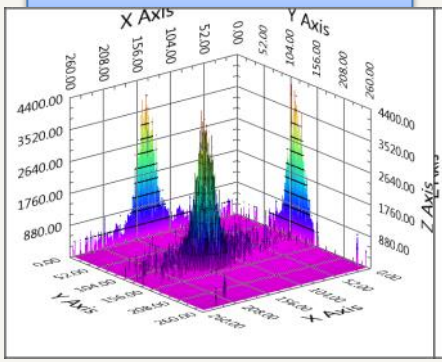
PADME Experiment
Courtesy 2017



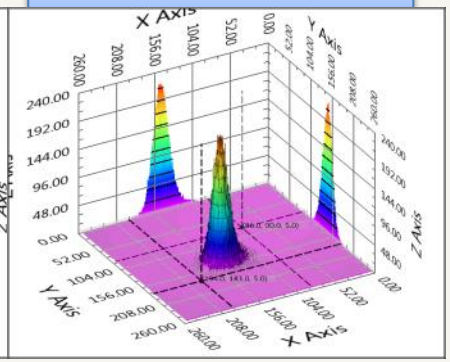
E(LINAC)= 700 MeV
E(BTF selected)= 650 MeV
Type= e-

BTF BEAM
Multiplicity and transverse tuning

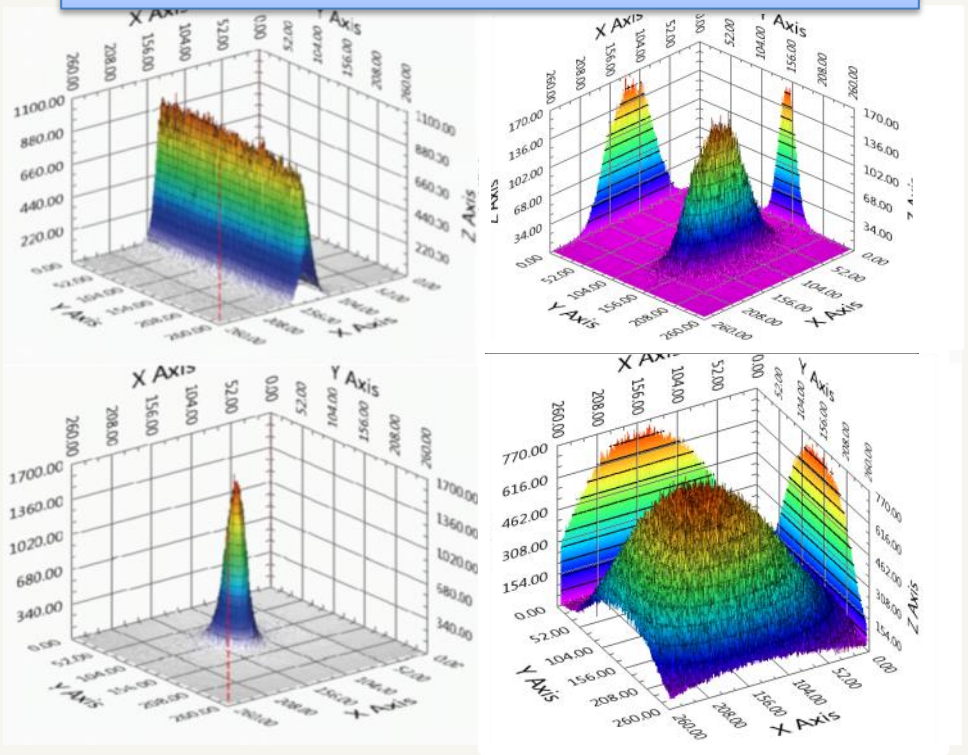
300MeV single part
σ_x=0.7 mm, σ_y=0.8 mm

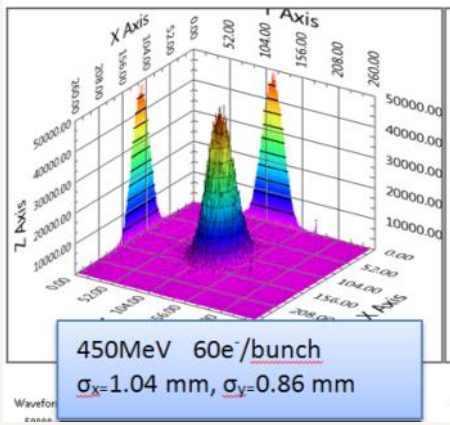


450MeV single part
σ_x=0.5 mm, σ_y=0.5 mm

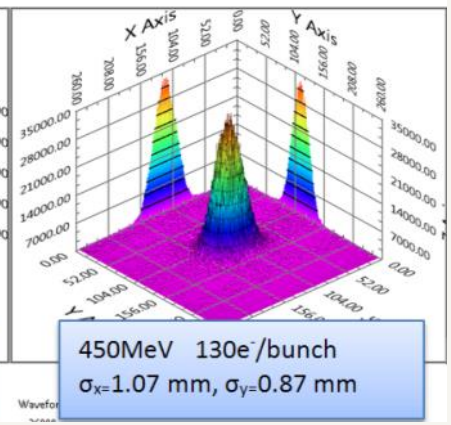


300MeV m1000
Different Geometries



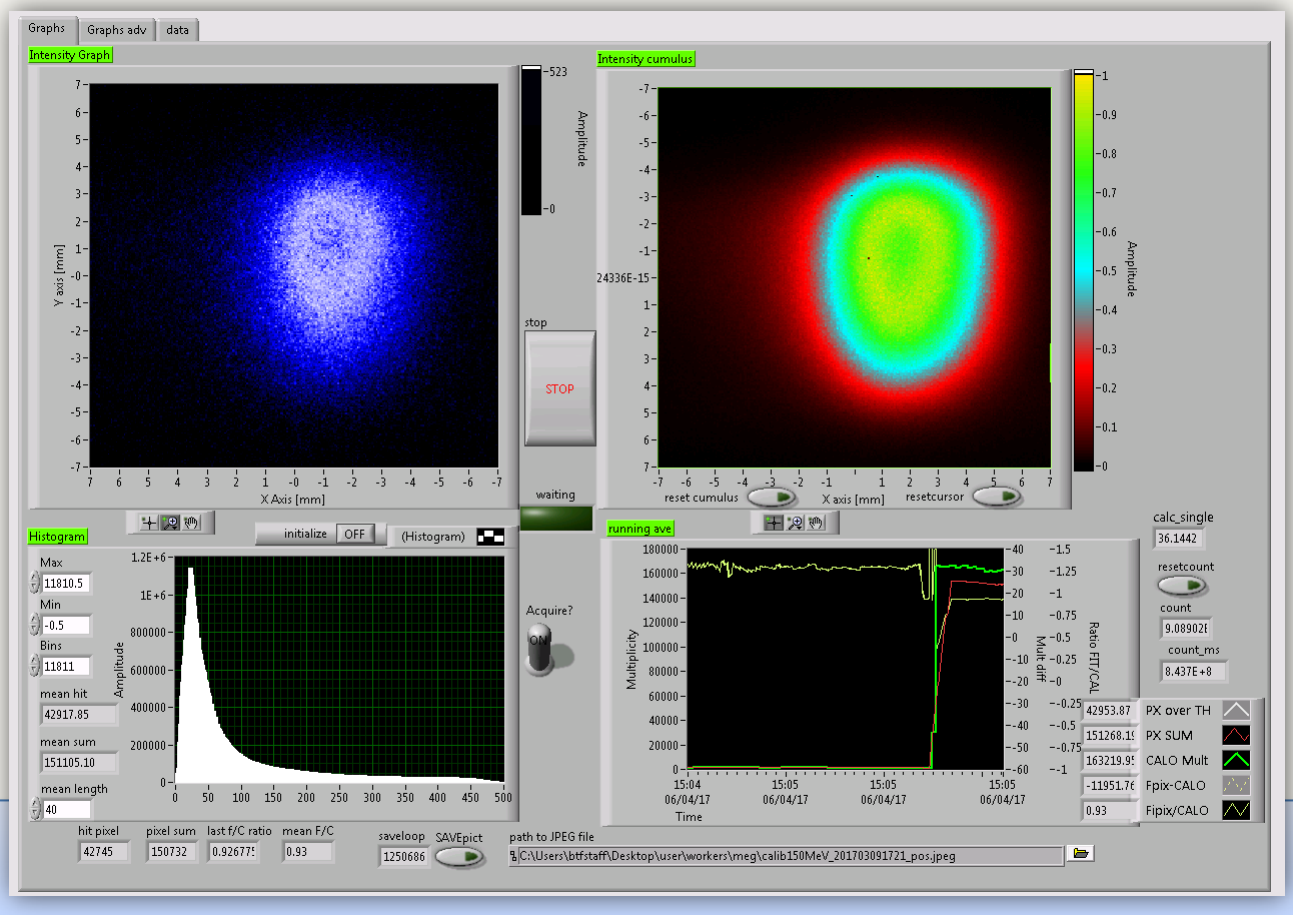


450MeV 60e⁻/bunch
σ_x=1.04 mm, σ_y=0.86 mm



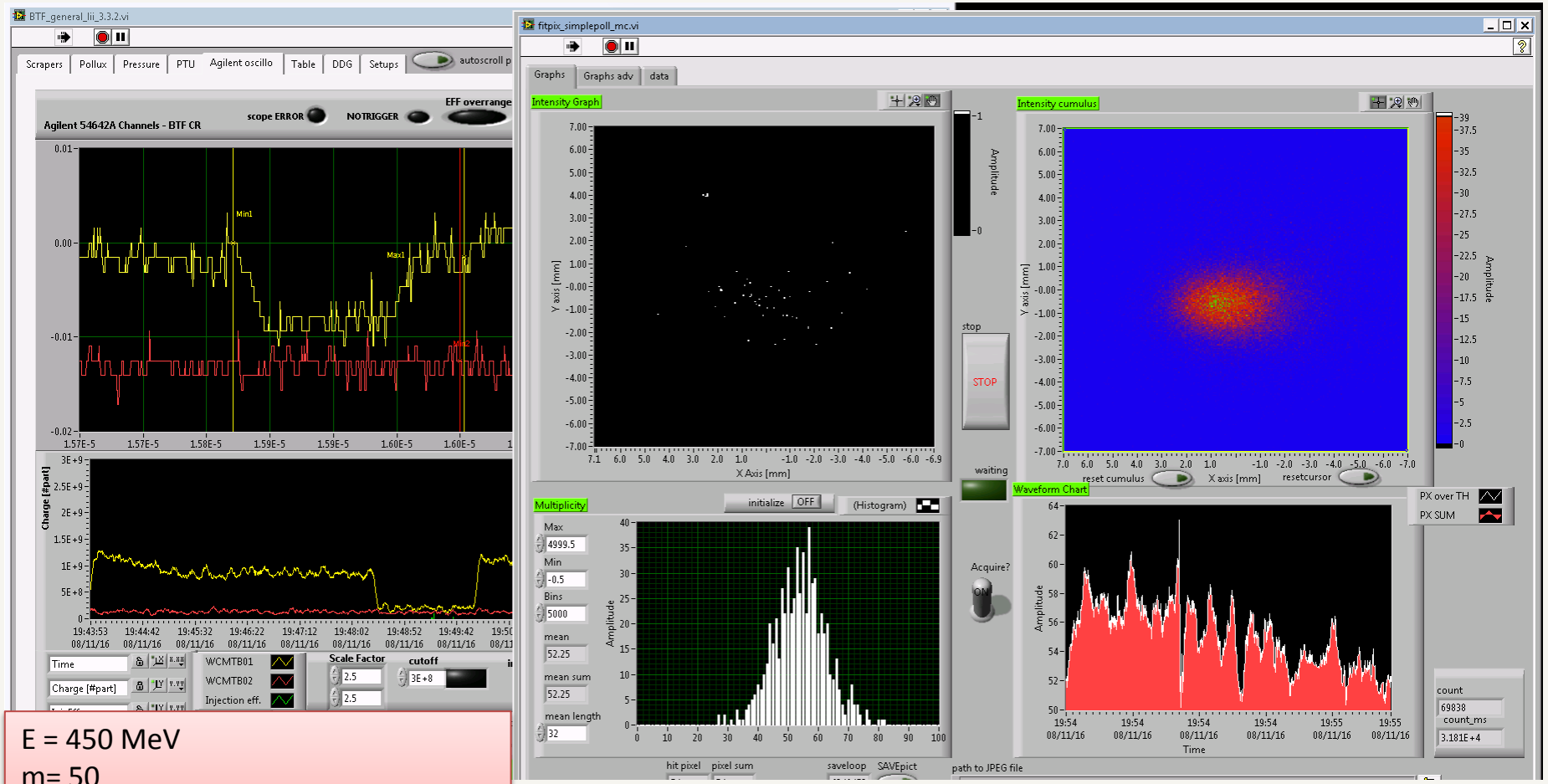
450MeV 130e⁻/bunch
σ_x=1.07 mm, σ_y=0.87 mm

BTF BEAM – Pushing harder…



E= 150 MeV
m= 160k
Fitpix, special configuration in ToT to count pileupped pixels

BTF BEAM – Pulse length tuning



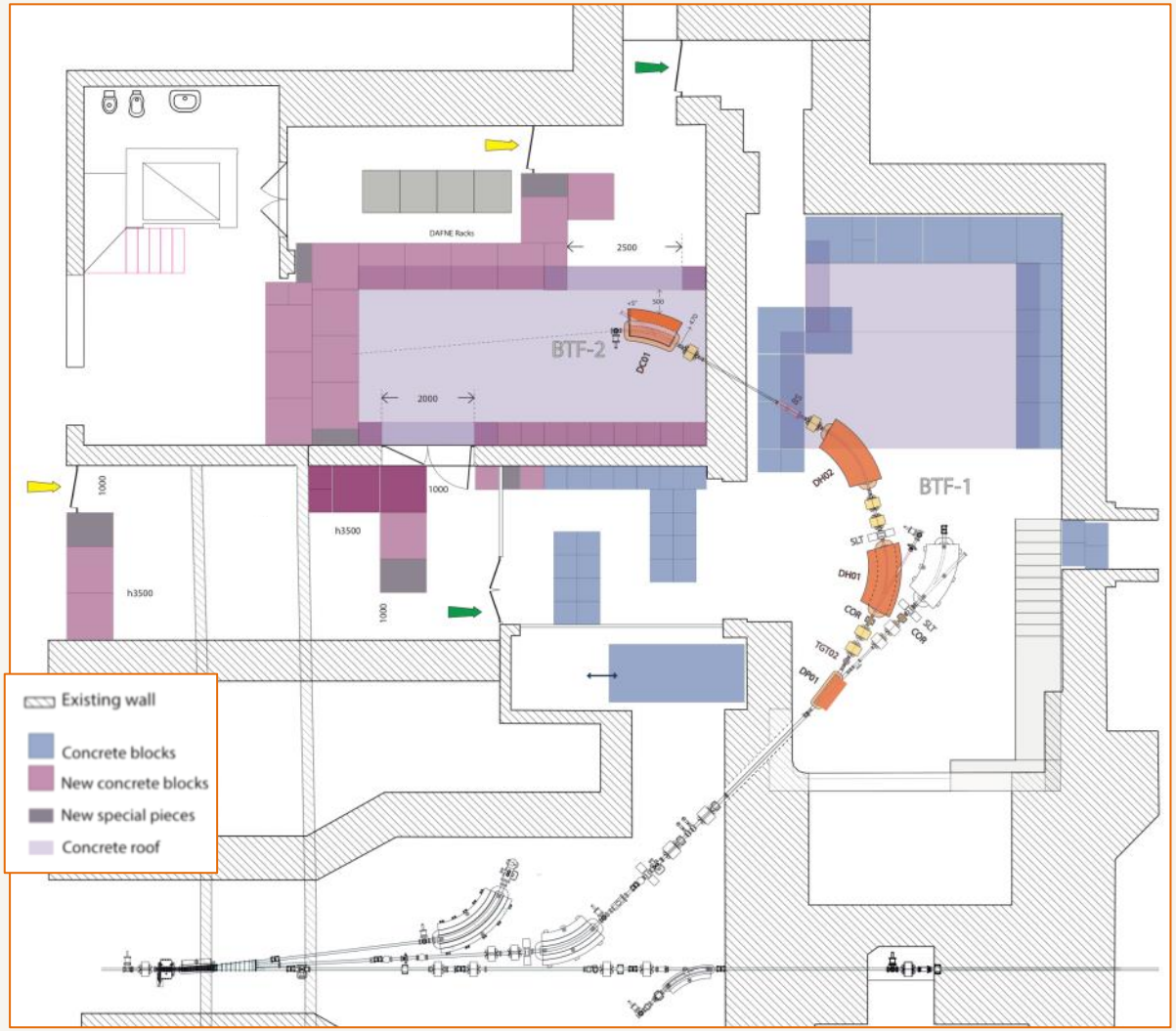
E = 450 MeV
m= 50
Type= e+
Pulse length= 150ns!

- Significant **characterization** and **optimization** work still to be done:
- 2017: at least 1 week (**2 weeks** would be better) with **fully dedicated LINAC** + PADME target + beam tracker + background detectors

BTF - Future

Details fixed:

- Increase top energy up to 1/0.7GeV (e-/e+)
- 100ms Pulsed magnet to steer in one of the two lines
- 3 more dipoles and doublets
- More strict beam acceptance
- Modify stairs to get **larger access** space from the front of new hall
- Preserve DAΦNE racks in order to have **no interference with DAΦNE next runs**
- Enlarged (top) side access for **better use of the area** and at the same time **improve protection of racks area**
- Additional labyrinth in place of sliding shielded door on the (bottom) side of new hall for **simpler and faster civil engineering**
- Correctors added for **better beam control**



BTF upgrade team

Bruno Buonomo, Claudio Di Giulio, Luca Foggetta, Bruno Bolli, Sergio Cantarella, Oreste Cerafogli, DnAdolfo Esposito, Oscar Frasciello, Andrea Ghigo, Simona Incremona, Franco Iungo, Stefano Lauciani, Roberto Mascio, Stefano Martelli, Luigi Pellegrino, Lucia Sabbatini, Claudio Sanelli, Franco Sardone, Giancarlo Sensolini, Ruggero Ricci, Ugo Rotundo, Angelo Stella - LNF

Paolo Valente – INFN Roma – Project Manager

Thanks!

Some remarks:

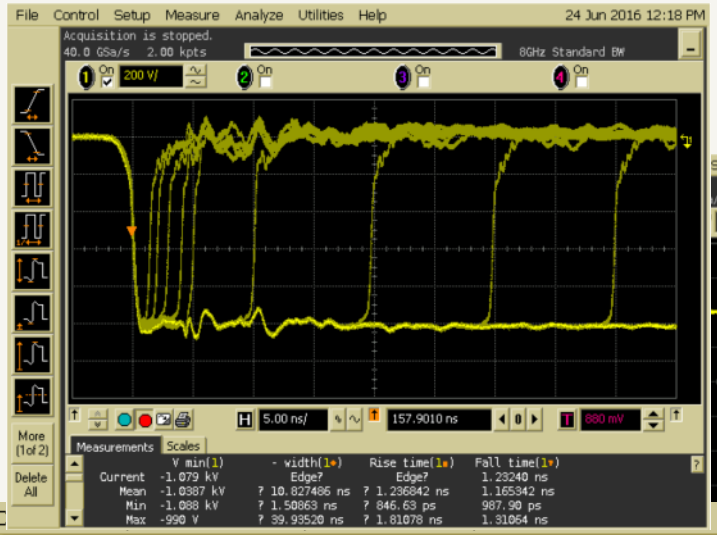
- BTF Welcome page
  - http://www.lnf.infn.it/acceleratori/btf/
- Booking for BTF time slot (Minimum One week)
  - http://www.lnf.infn.it/acceleratori/btf/call2017.html
  - http://www.lnf.infn.it/acceleratori/btf/request.html

- BTF Scheduled Time DB (starting from 2006)
  - http://www.lnf.infn.it/acceleratori/btf/php/schedule.php?year=2017&acc=1

- BTF Wiki pages
  - http://wiki.infn.it/strutture/lnf/da/btf/home

Looking forward to see you in!

BTF TEAM:
BRUNO BUONOMO
CLAUDIO DI GIULIO
LUCA FOGGETTA
PAOLO VALENTE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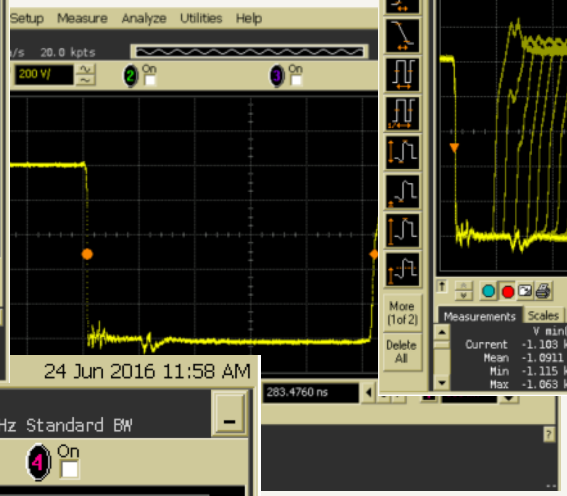
24 Jun 2016 12:18 PM
Acquisition is stopped.
40.0 GSa/s 2.00 kpts
8GHz Standard BW
200 V/
5.00 ns/
157.9010 ns
880 mV
Measurements
Scales
V min(1) - width(1) Rise time(1) Fall time(1)
Current -1.079 kV Edge? Edge? 1.23240 ns
Mean -1.0387 kV ? 10.827486 ns ? 1.236842 ns 1.165342 ns
Min -1.088 kV ? 1.50863 ns ? 846.63 ps 987.90 ps
Max -990 V ? 39.93520 ns ? 1.81078 ns 1.31064 ns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200 V/
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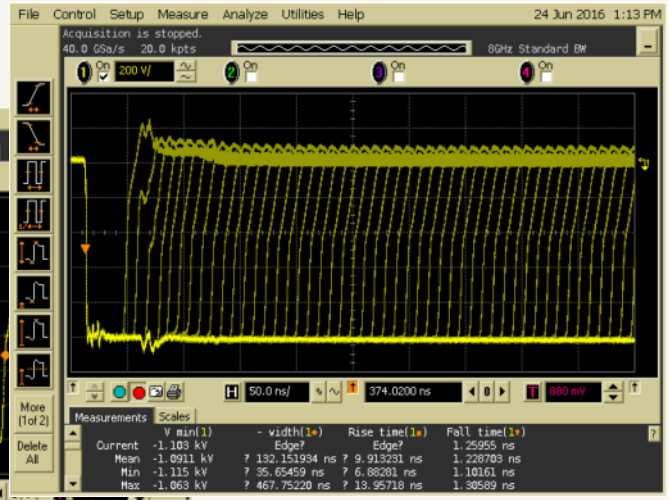
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8GHz Standard BW
200 V/
50.0 ns/
374.0200 ns
880 mV
Measurements
Scales
V min(1) - width(1) Rise time(1) Fall time(1)
Current -1.103 kV Edge? Edge? 1.25955 ns
Mean -1.0911 kV ? 132.151934 ns ? 9.913231 ns 1.228703 ns
Min -1.115 kV ? 35.65459 ns ? 6.88281 ns 1.10161 ns
Max -1.063 kV ? 467.75220 ns ? 13.95718 ns 1.30589 ns


File C
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Measurements
Scales
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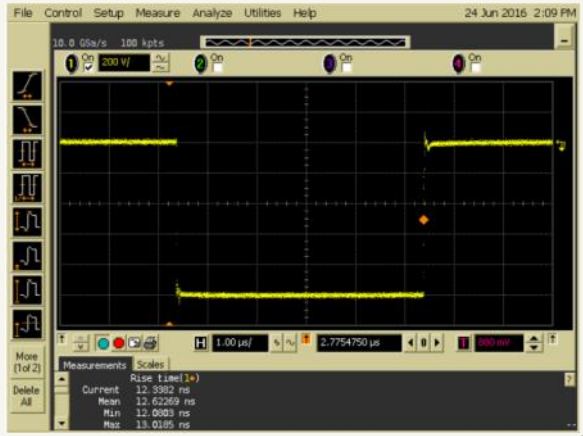
Current -1.005 kV 1.50953 ns 1.21471 ns 1.05155 ns
Mean -1.0011 kV 1.530401 ns 1.195121 ns 1.040780 ns
Min -1.012 kV 1.50538 ns 1.14865 ns 972.80 ps
Max -991 V 1.55376 ns 1.23477 ns 1.11902 ns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24 Jun 2016 2:09 PM
200 V/
1.00 µs/
Measurements
Scales


FRONTE