LINAC and BTF: looking at the future

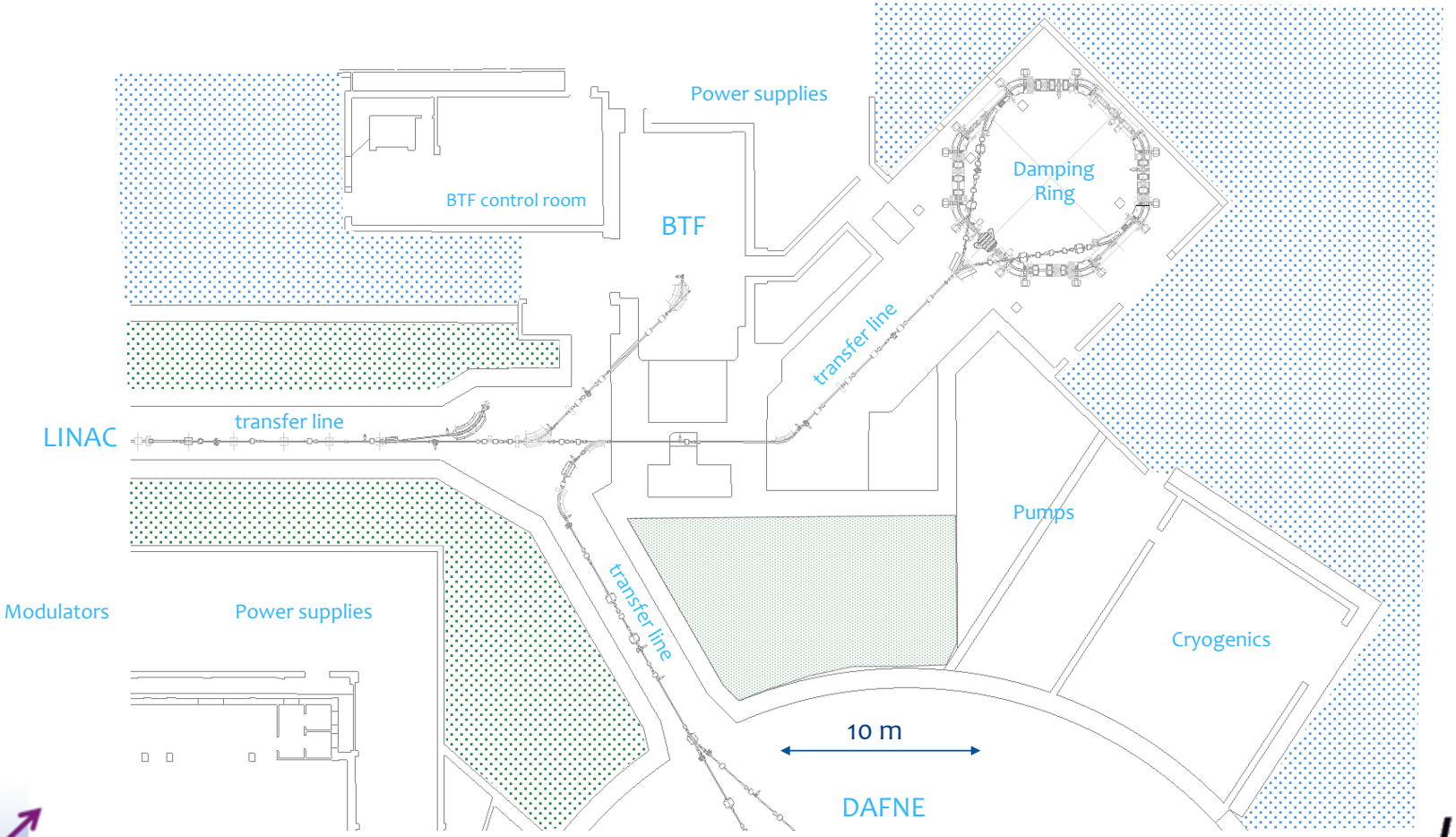
B. Buonomo, L. Foggetta and P. Valente
& the DAFNE linac technical staff

The question:

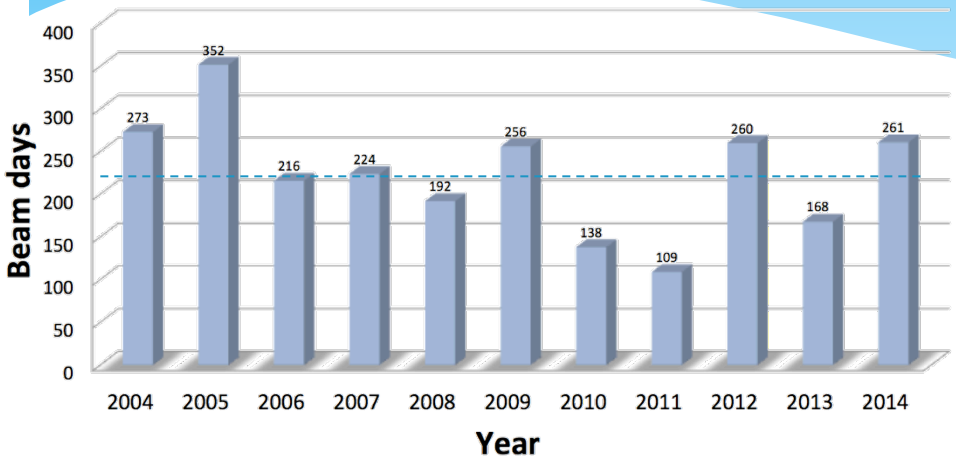
"Which developments or upgrades can be conceived using the DAFNE **linac + transfer lines + BTF** ?"

For each possible idea, one has to establish:

1. **Motivations**
2. The main lines of the **project**
3. A possible **planning** & an estimate of the **resources**
4. **Compatibility** and impact on other activities/infrastructures



Let's start from how the BTF has been used



- **11 years** of consolidated and steady running
- Average beam time: **220 days/year**
- Average shift : 8 days
- **70%** of the beam time in parasitic mode during DAFNE collider operations
- **30%** of foreign users

Users:

- Mainly detector testing from the **HEP** and **astro-particle** community

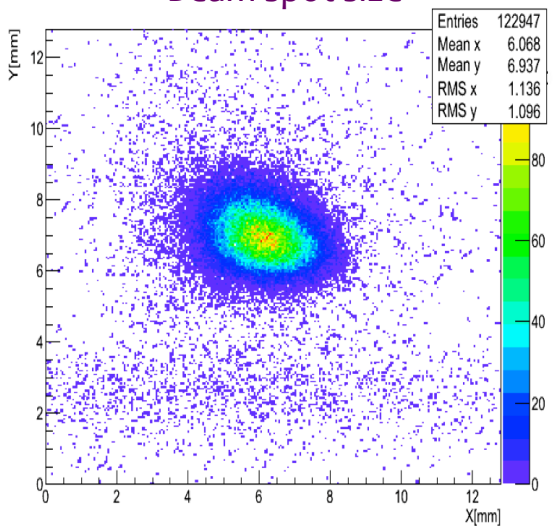
but also:

- High intensity tests and experiments:
  - RAP
  - AIRFLY, AMY
  - Channeling experiments
  - C-SPEED
  - Beam diagnostics (pepper-pot, diamonds)
  - Neutron and charged particles production

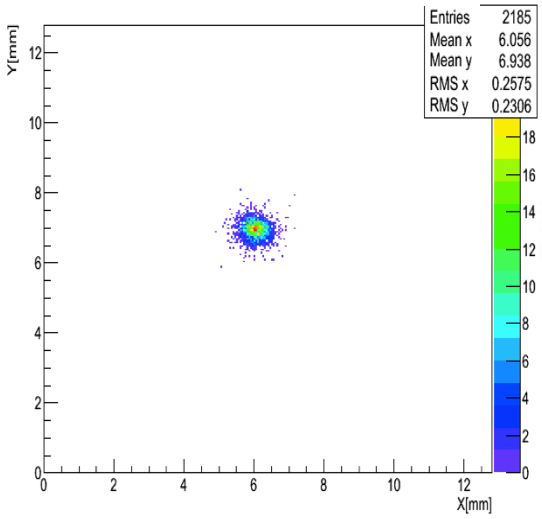
BTF beam

- Energy spread **Δp/p ~1%**
- Beam spot: **1 – 2 mm RMS**
- Divergence: **1 – 1.5 mrad**
  - Effect of multiple scattering in air has to be considered
  - Both size and divergence depend on the optics
- Beam position: **0.25 mm RMS**
- Pulse duration: **1.5 – 40 ns** (10 ns during DAFNE operations)

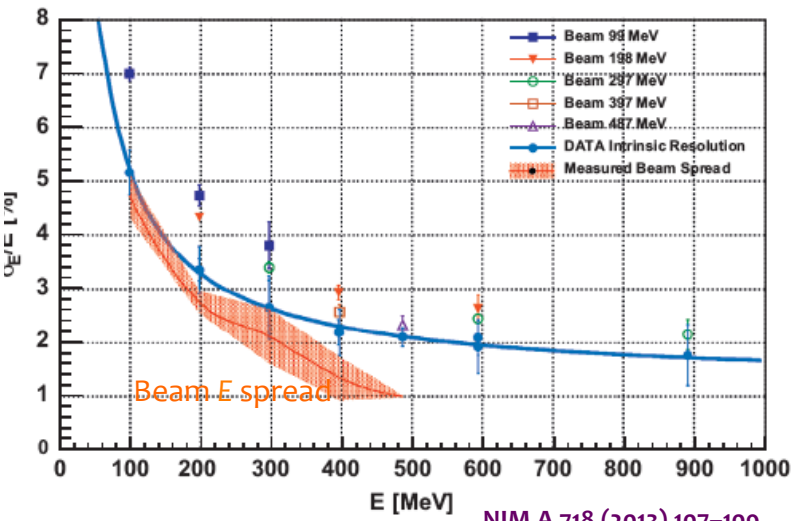
Beam spot size



Beam spot center



Measurement of the beam *E* spread



NIM A 718 (2013) 107–109

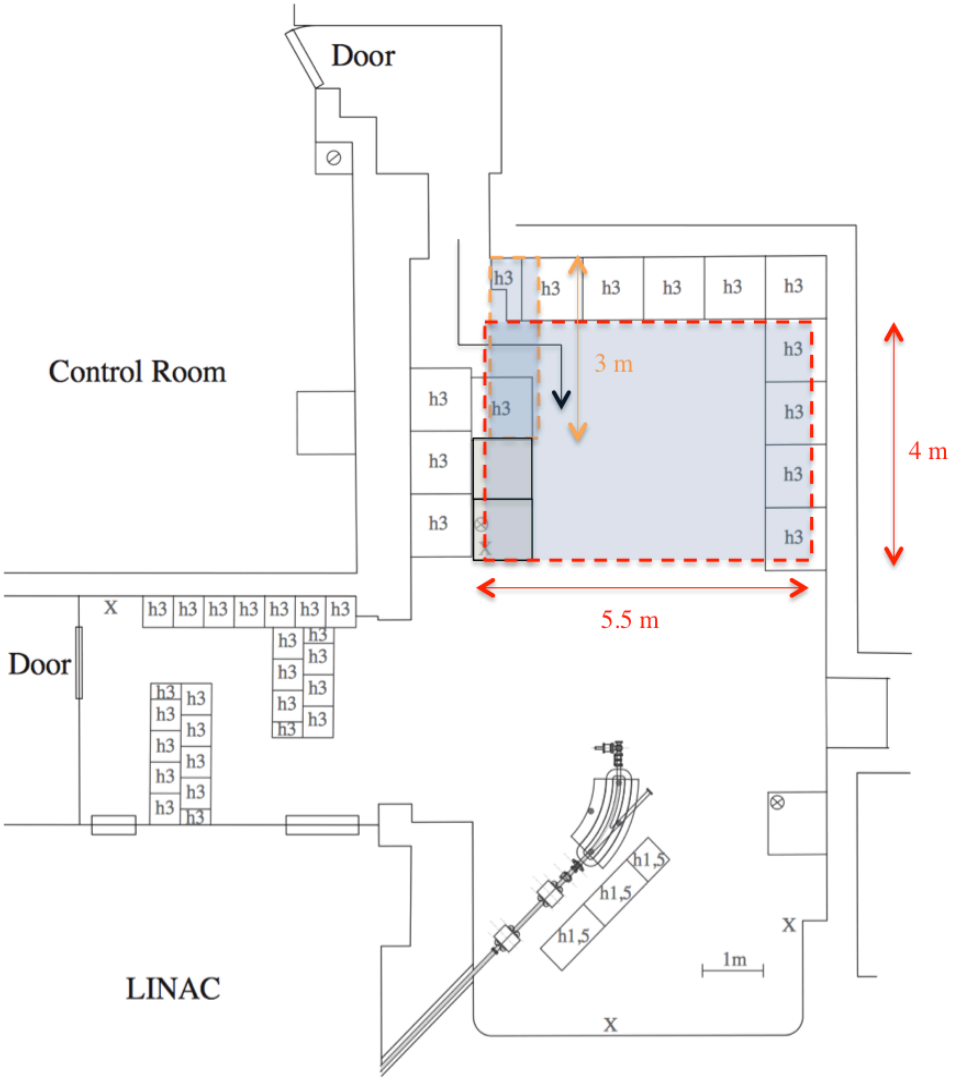
Improving the BTF shieldings

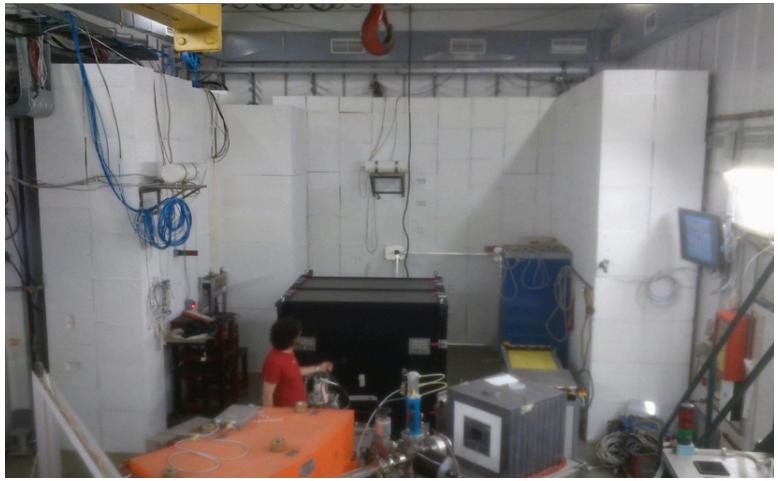
* Present authorization **for the BTF hall:**
  * average **3.125 10^{10} electrons/s** at 800 MeV
  * 5 nC/s = 10 mA × 10 ns × 50 Hz
  * Translates to **<10^{18} electrons/year**
* Calculated for 1 m of concrete + 15 cm of lead around scattering target
* 90% or more of the time running with target at very low intensity

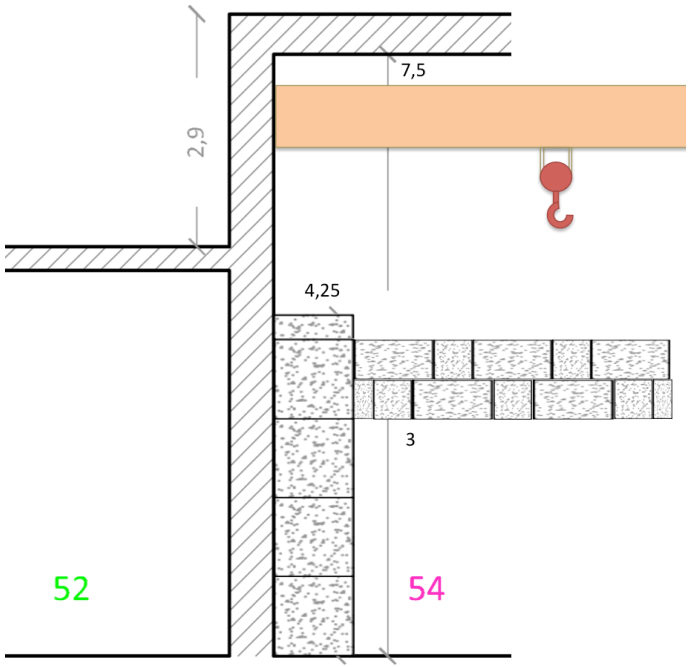
But:

* The neutron test source and some experiments require a long duty-cycle for high intensity (e.g. **PADME invisible**)

* To improve:
  * Add a concrete roof, at least in the "forward" area, same design of FLAME bunker
  * Add dedicated shielding for neutron (polyethylene sheets)


Door
Control Room
h3
3 m
4 m
5.5 m
Door
h3
h1,5
1m
LINAC




7,5
2,9
4,25
3
52
54

How to improve the BTF beam parameters

* The BTF line was originally designed to be used **only when not injecting** in the damping ring
* In 2004 the line has been separated from the transfer line to the damping ring
* Single linac pulses can be selected to be extracted to the BTF line by pulsed magnet **DHPTB101** or to the linac spectrometer (DHPTB101 + DHPST01)

The residual limitations when running with DAFNE come – of course – from the obvious fact that **the linac beam is the same**.

In particular it's not possible to change:

* **Particle species** (e^-/e^+) at full intensity (both can be selected, when showering on the target)
* **Maximum intensity** (it can be of course decreased, using the target)
* **Maximum energy** (it can be decreased, and generally it is, in the BTF line, using the target + selecting dipole)
* **Pulse length** is fixed (by the injection into the damping ring ≈10 ns)

BTF duty-cycle with DAFNE operations:

98% out of injection

20%-50% during injection

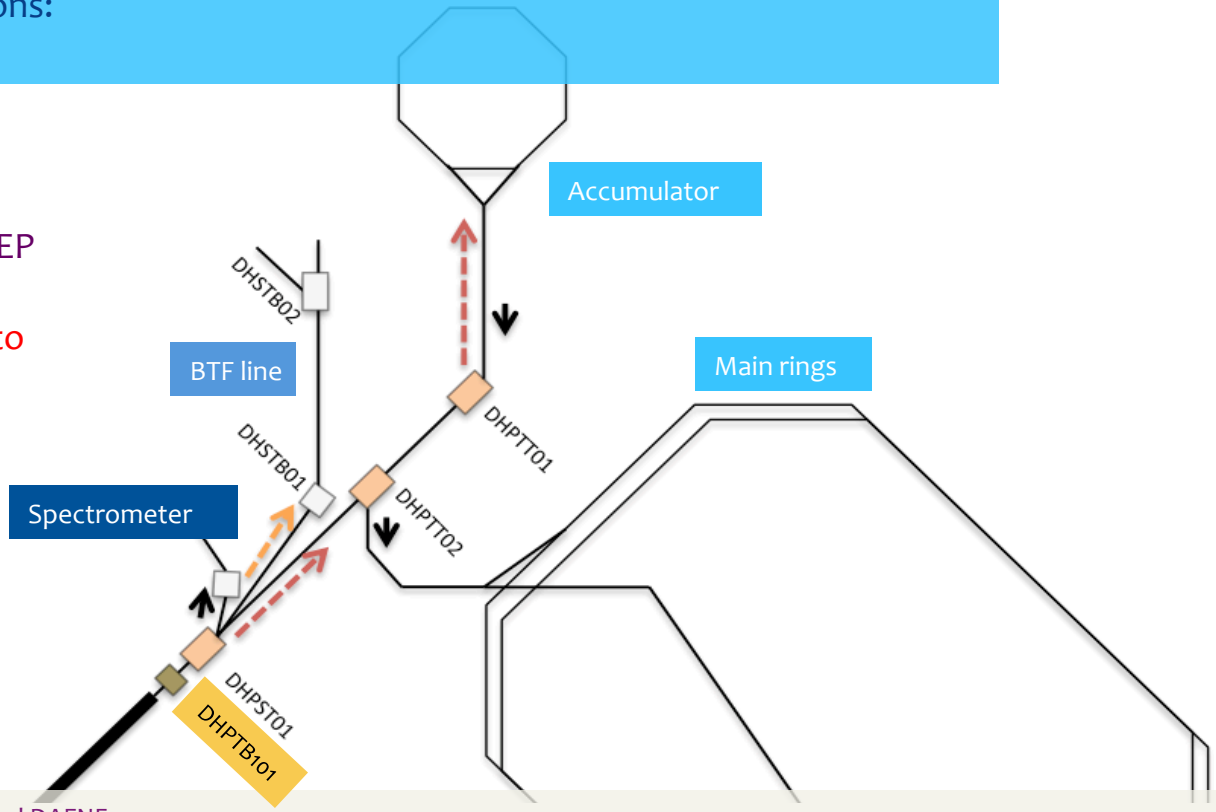
Switching time cannot be used

Generally only electrons phase used, not the positrons one

Very dependent on DAFNE running conditions:

- Lifetime, injection problems, etc.

- The linac has been operating at **25 Hz** during the last years
  - Enough for most use-cases of HEP detector testing
- After a major maintenance, has gone to **50 Hz** in 2014

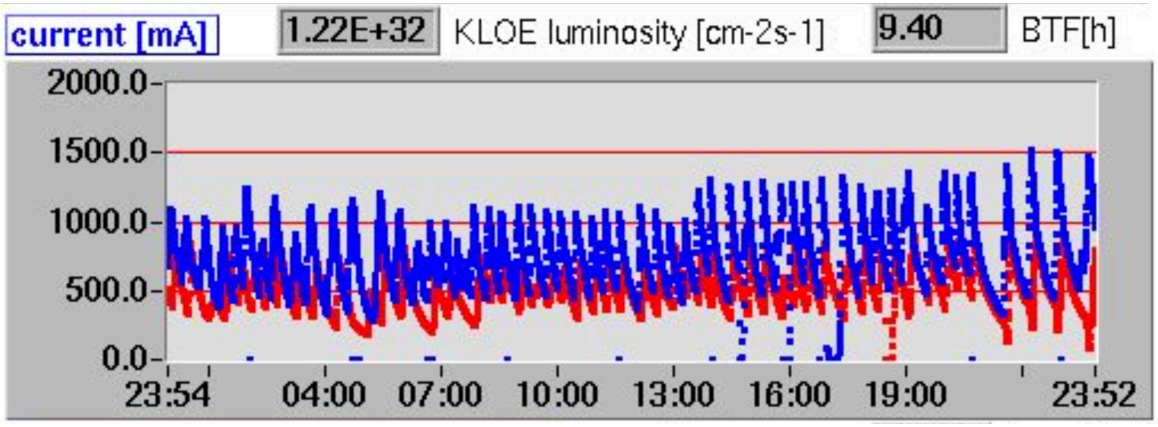


DAFNE phases of the complex LINAC, BTF and DAFNE:

- **LINAC** = 1 LINAC shot to the spectrometer line for energy measurement
- **LINAC+BTF** = LINAC shots are delivered with a selectable duty cycle to BTF from 1 to 24(49) pulses per second. The remaining are dumped at the end of the TL
- **GLOBAL** = LINAC shots are delivered with a variable duty cycle to BTF depending on the injection parameter in ACCUMULATOR
  - **NO INJECTION** => **selectable** from 1 to 24(49) pulse per second
  - **INJECTION** => the injection needs are DAFNE CR controlled. Typically an injection sequence pulses at **2Hz**, taking from 1 up to 10(19) LINAC bunches per sequence. In this configuration BTF delivers 22(46) down to **10 bunches/s**

BTF duty cycle

- Just a recent random day (Sunday, Nov. 9th)



- BTF live-time ≈ 40%
- Almost 60+60 injections

Doubling of BTF line

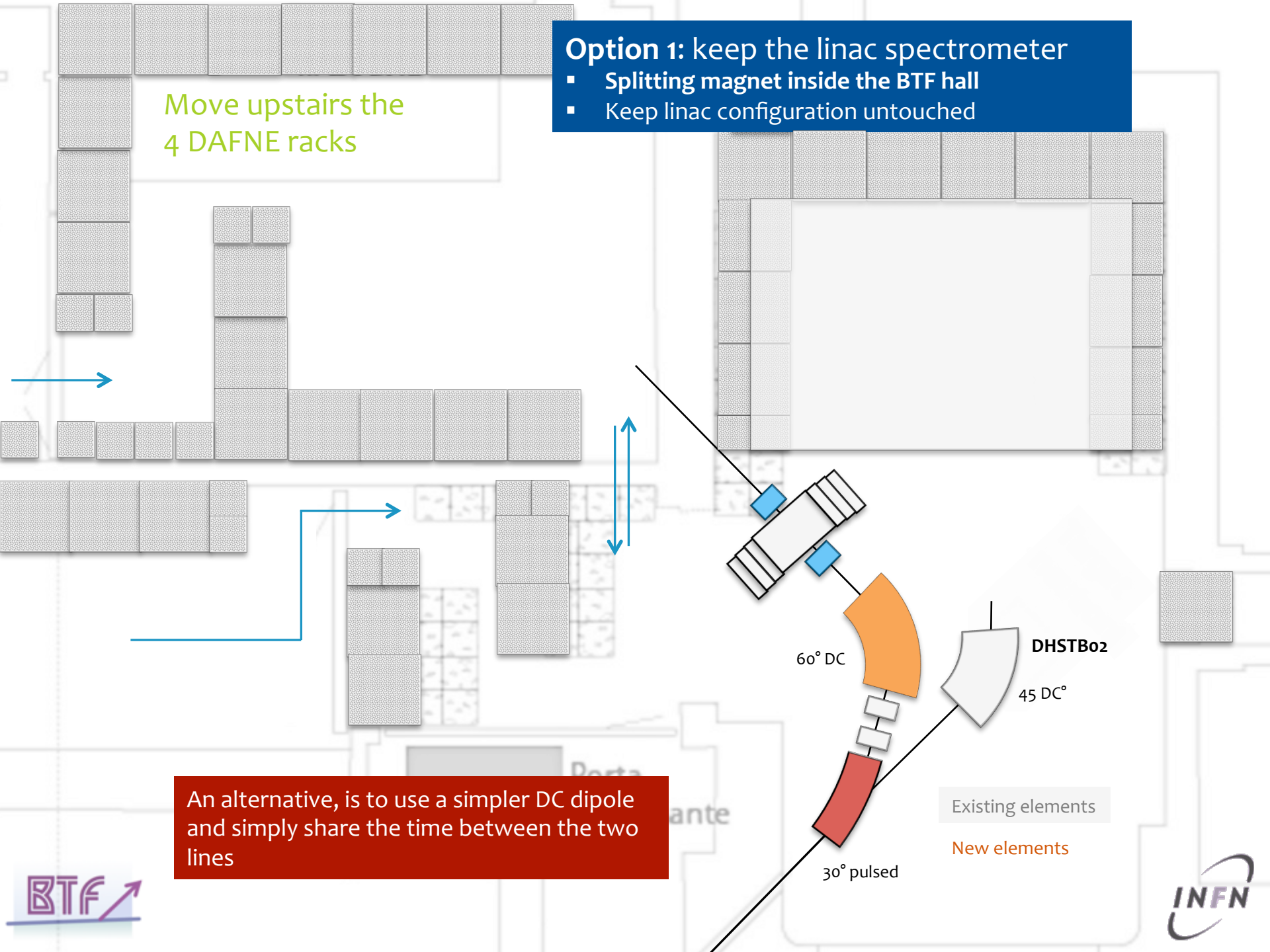
Beam-line doubling: main elements

* Move the control room upstairs
* Shield the present control room to be used as second experimental hall
* Move DAFNE control racks upstairs ("**vetrina**")
* In order to re-use the linac spectrometer line and dipole:
  * Measure beam energy in the the BTF line

Option 1: keep the linac spectrometer

- **Splitting magnet inside the BTF hall**
- Keep linac configuration untouched

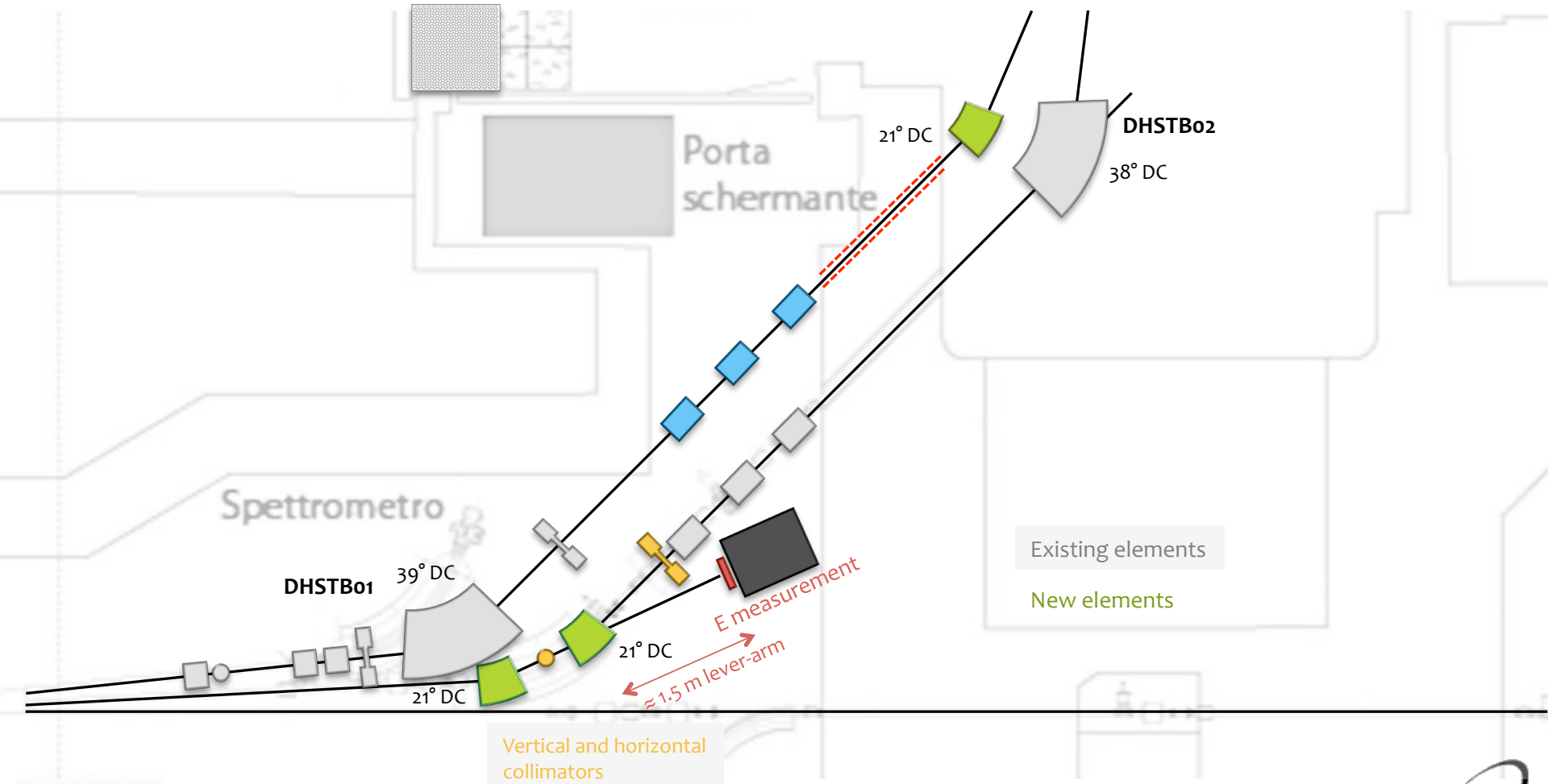
Move upstairs the
4 DAFNE racks



An alternative, is to use a simpler DC dipole and simply share the time between the two lines

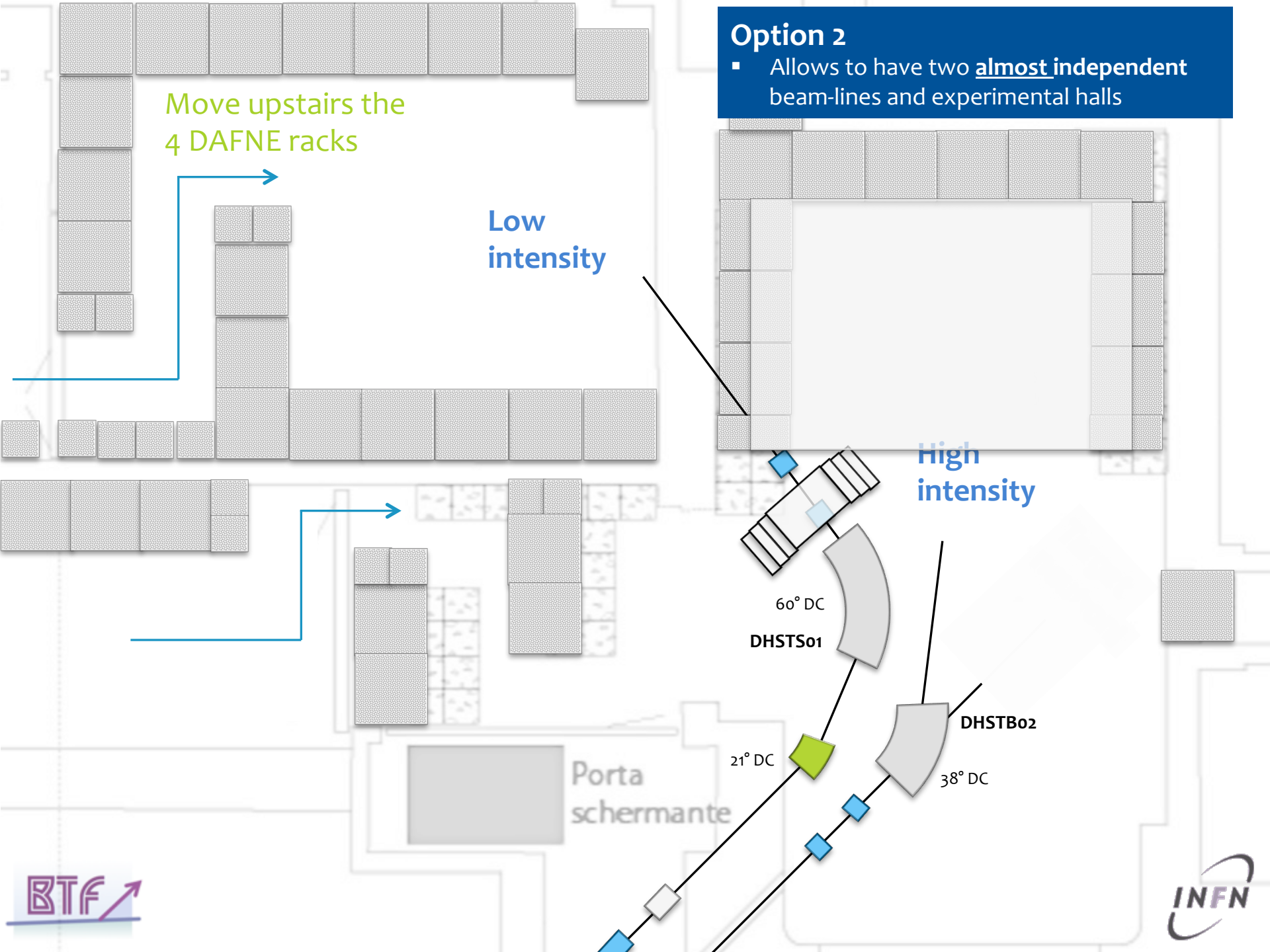
Option 2: move linac spectrometer

- **Use existing pulsed magnets**
- Move linac spectrometer on 3° line and re-design with a smaller magnet
- Move attenuating target and selector dipole on 6° line



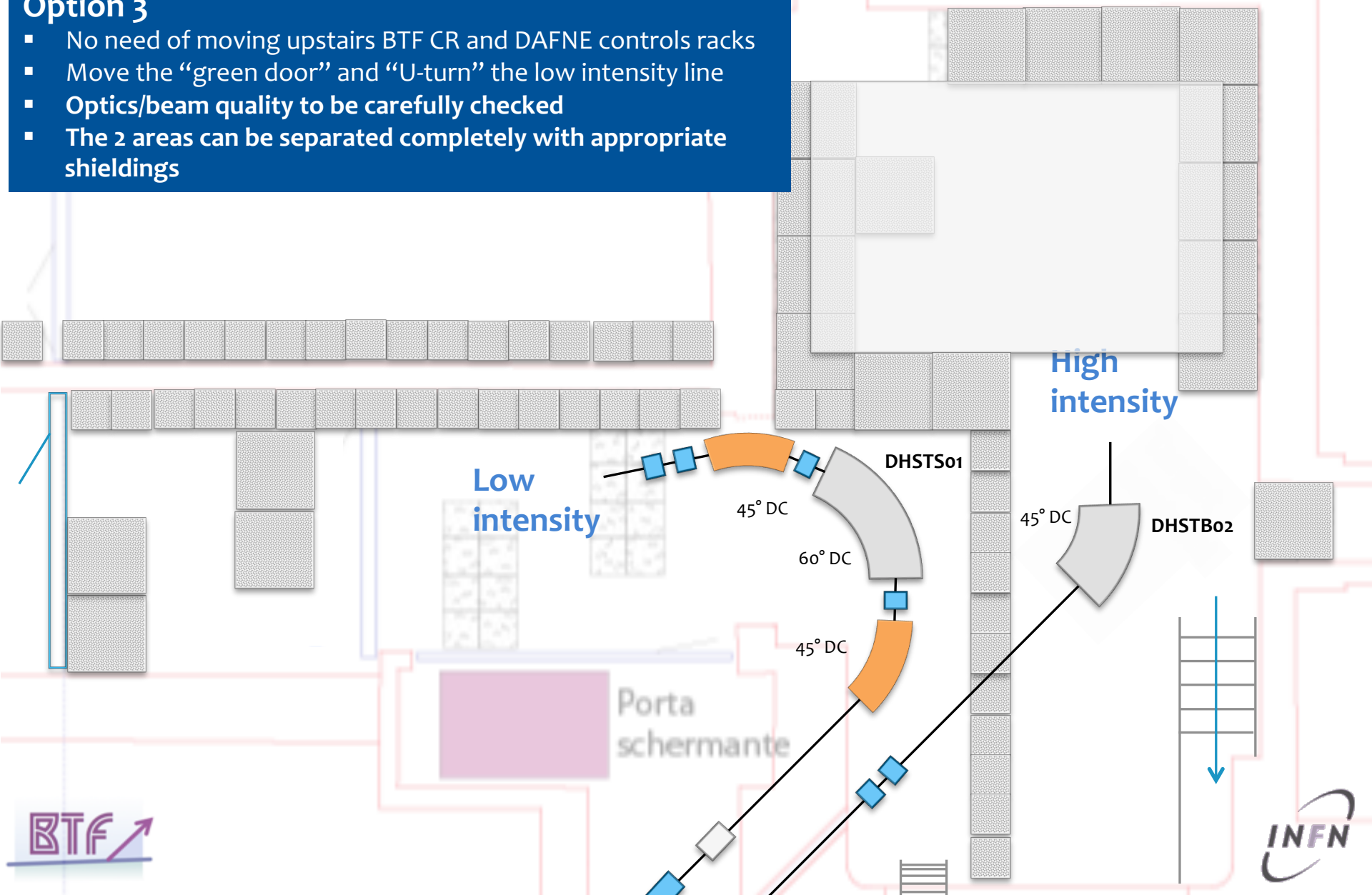
Option 2

- Allows to have two **almost independent** beam-lines and experimental halls



Option 3

- No need of moving upstairs BTF CR and DAFNE controls racks
- Move the "green door" and "U-turn" the low intensity line
- **Optics/beam quality to be carefully checked**
- **The 2 areas can be separated completely with appropriate shieldings**

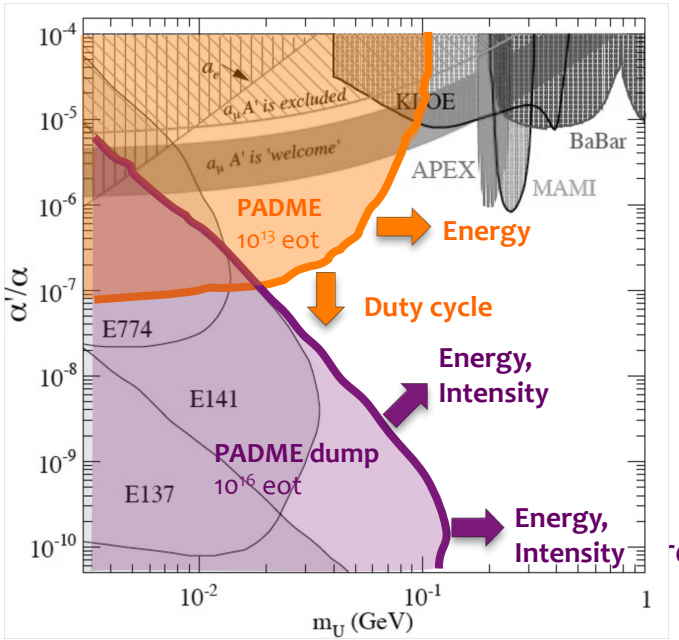


(In)compatibilities of splitted BTF lines

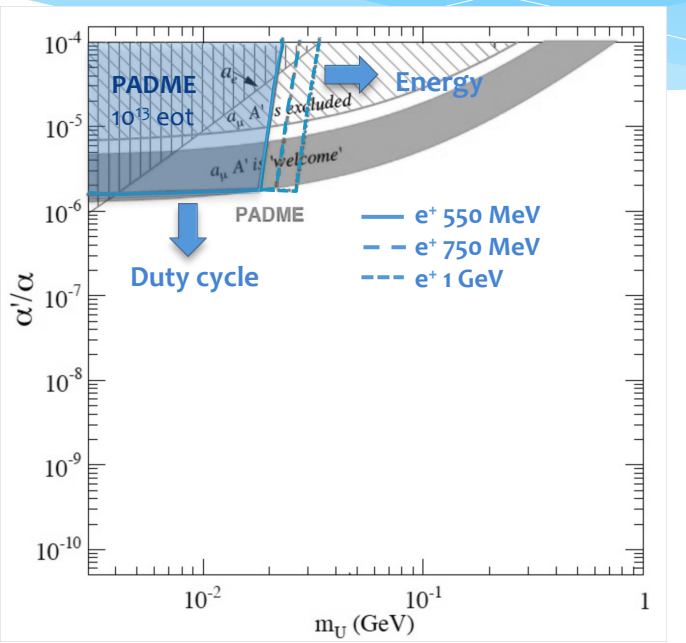
* **Option 1** produces two experimental halls, but when the beam will be on, none of the two zones will be accessible, due to the beam transport, regardless of the pulse selection
* In the case of **Option 2**, the low intensity area can be open, regardless of what happens in the high intensity one. The contrary is not valid: in order to access the high intensity, the beam should be stopped also for the low intensity one
* This configuration seems to be OK if a long-term experiment like PADME is installed and running in the high intensity, while the low intensity is used for "standard" test-beam activities.
* **Option 3** allows to create two completely independent experimental areas

Requirements from electron fixed target experiments for dark photon searches

Decays to lepton pairs



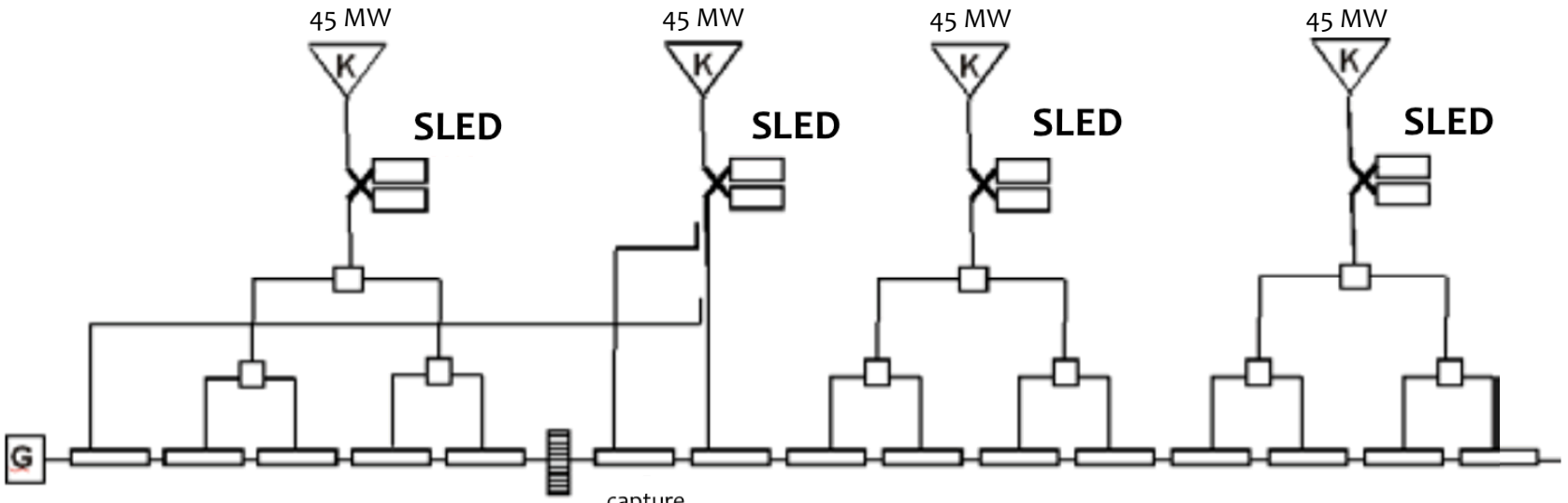
Decays to invisible



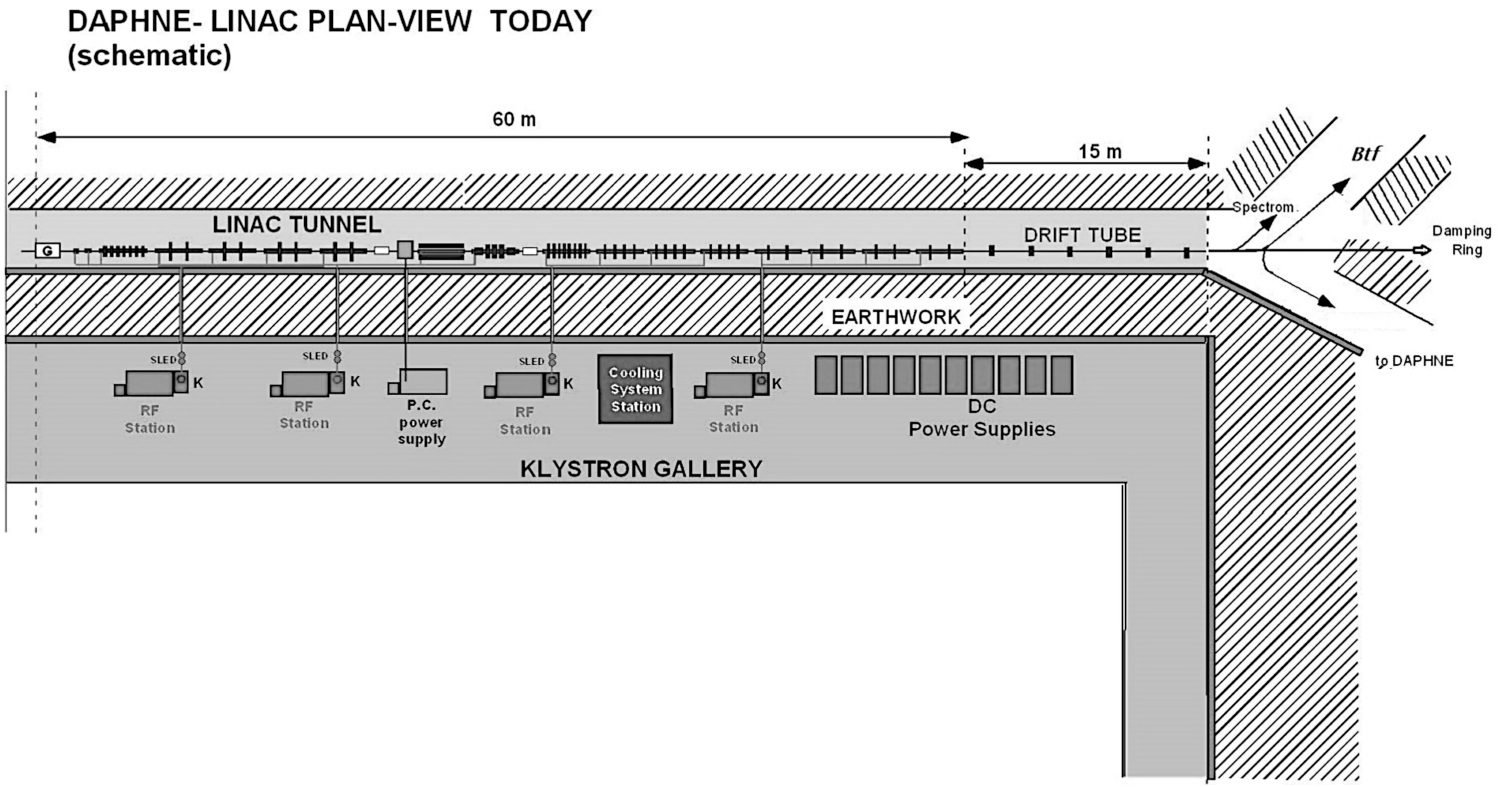
- Electron energy and intensity need to be pushed (even though exclusion plots are more complex) for **BDX @ LNF**
- **PADME invisible** requires longer pulses, with same current, in order to exploit the time resolution of the detector to increase the sensitivity

Energy upgrade of the linac

Current linac layout

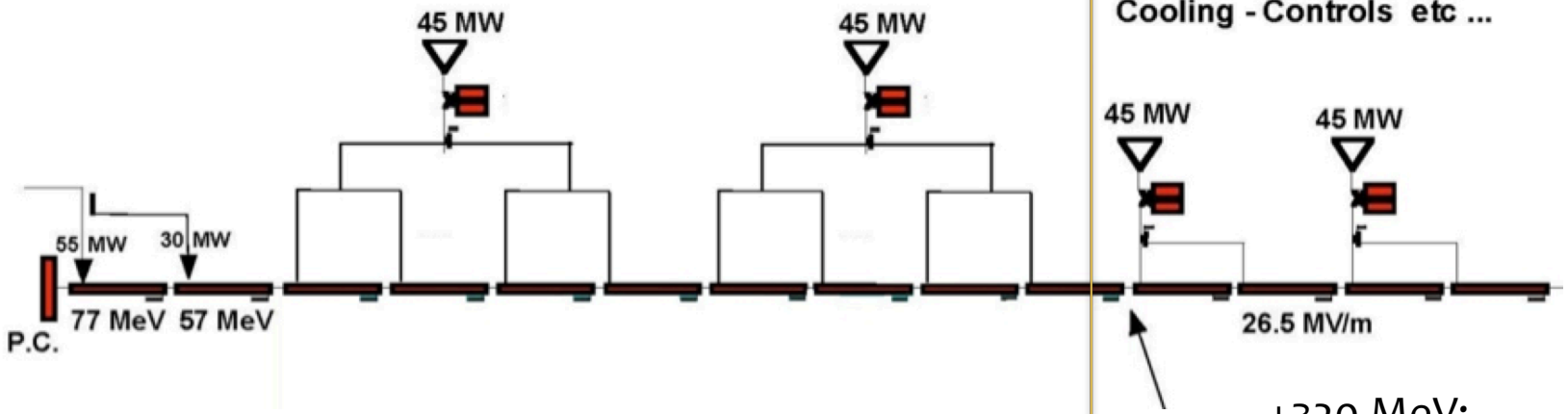


Proposal following the footprints of
R. Boni, http://arxiv.org/pdf/physics/0402081.pdf




15 m

Add 4 accelerating sections + 2 SLED-ed klystrons

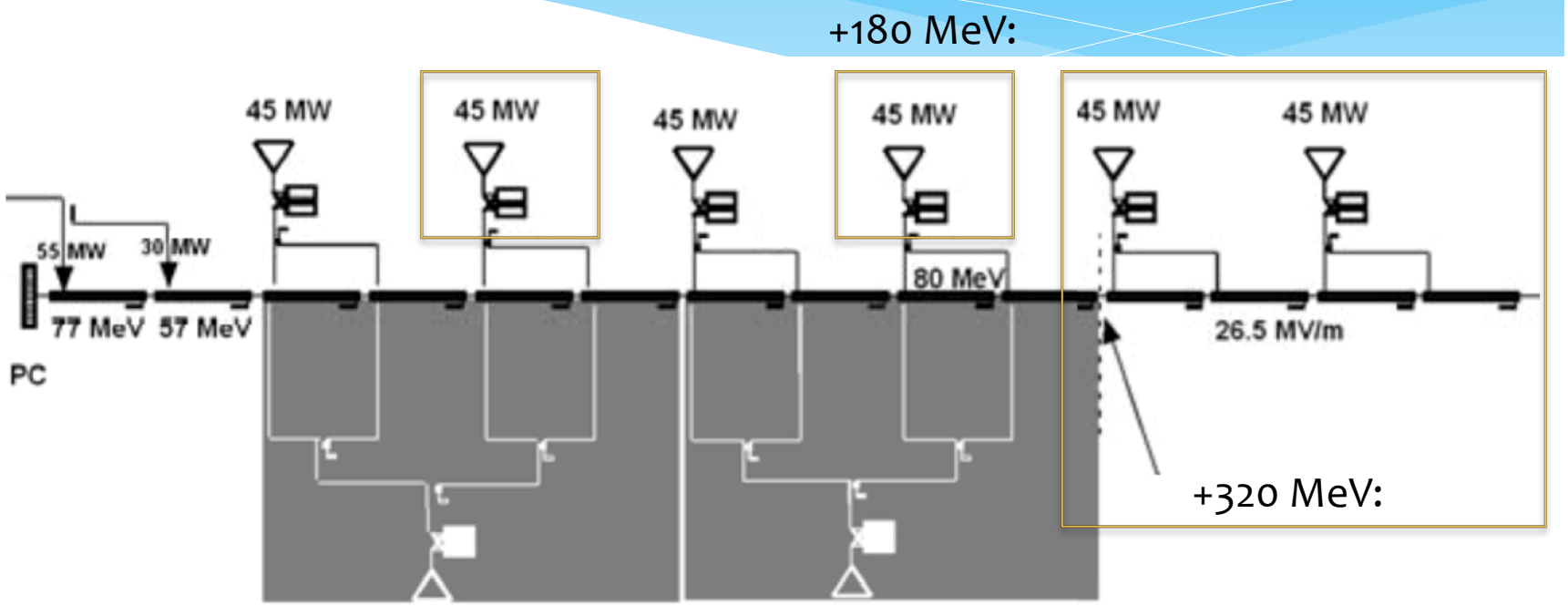


4 Acc. Sections
2 SLEDs
2 Power Stations
Waveguides + accessories
Vacuum - Diagn. - Magnetics - Cooling - Controls etc ...

+320 MeV:

Reach:
1070 MeV electrons
870 MeV positrons

Add 4 accelerating sections + 4 SLED-ed klystrons



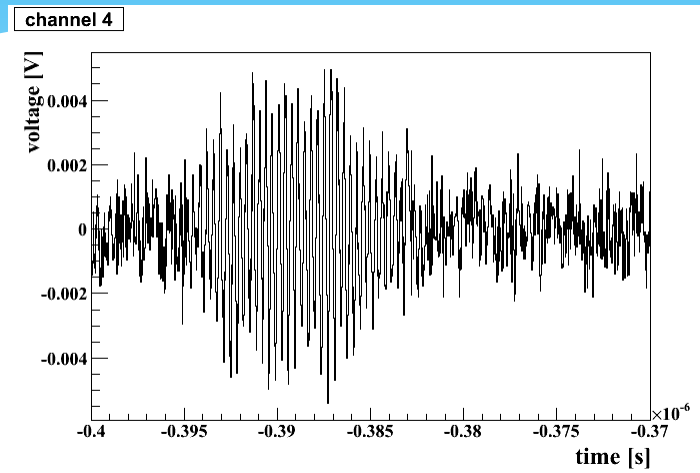
Reach:
1250 MeV electrons
1050 MeV positrons

ORIGINAL RF LAYOUT

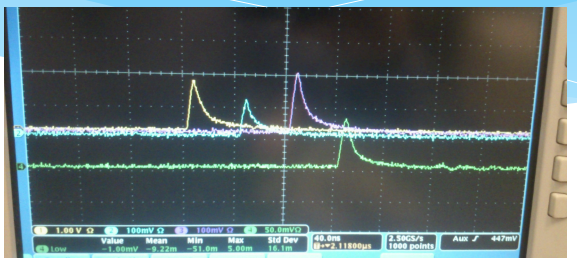
Add **two more SLED-ed klystrons** and split power only in two sections instead of four

Increasing the linac pulse charge and lenght

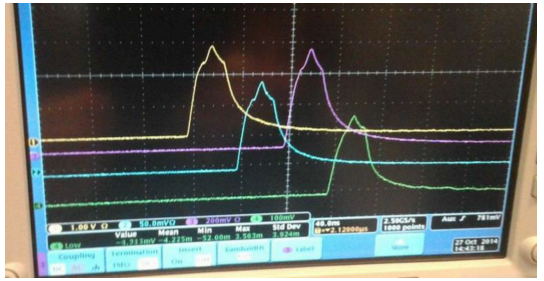
Bunch structure



10 ns ≈ 30 bunches with 350 ps spacing (2856 MHz)



10 ns

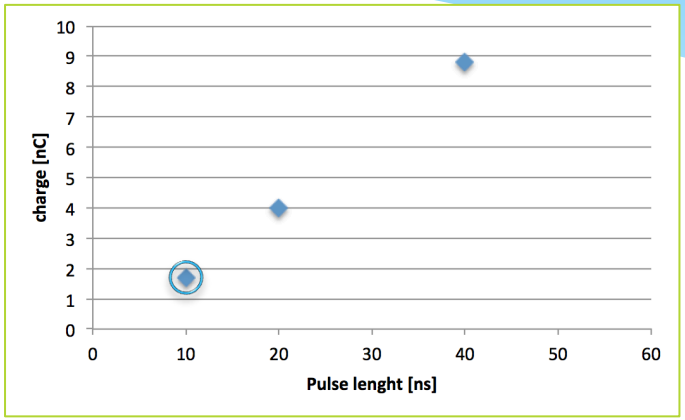


20 ns

40 ns

Current monitors

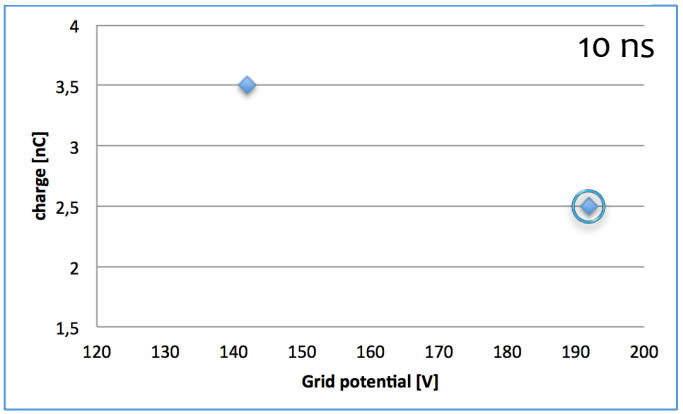
Bunch charge vs. length



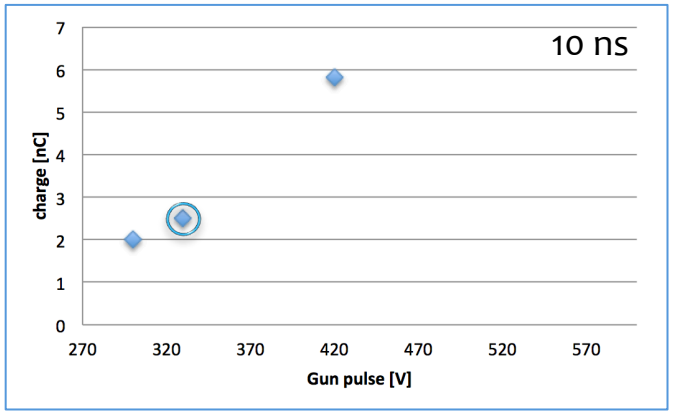
E = 725 MeV

×4 increasing pulse length

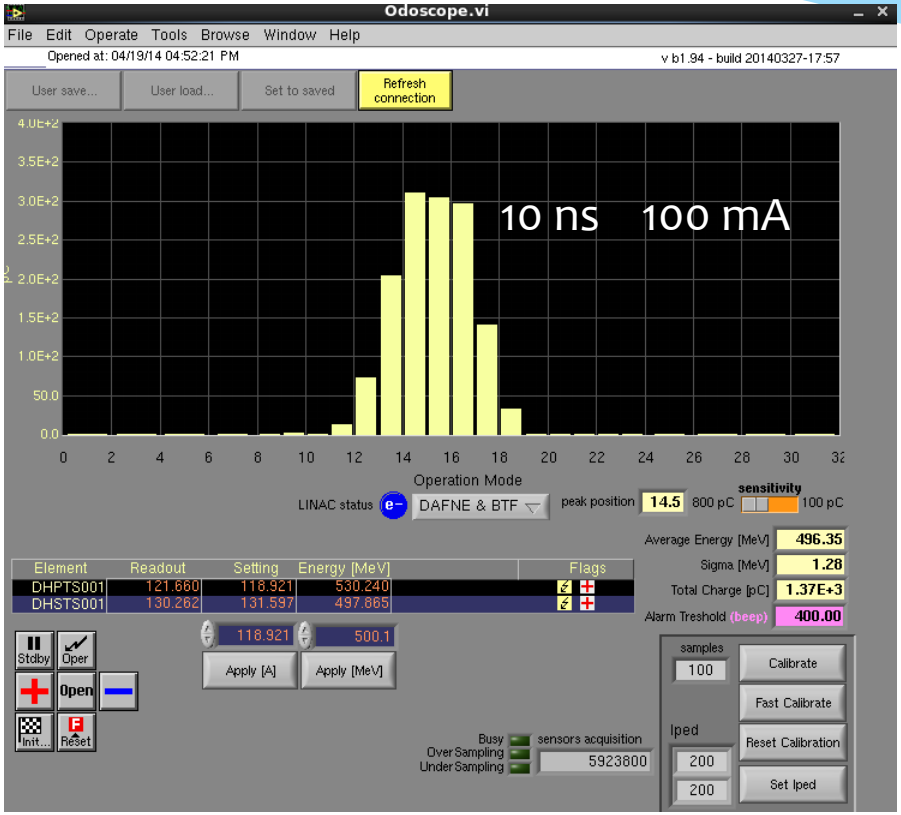
+30%
Decreasing grid stopping potential

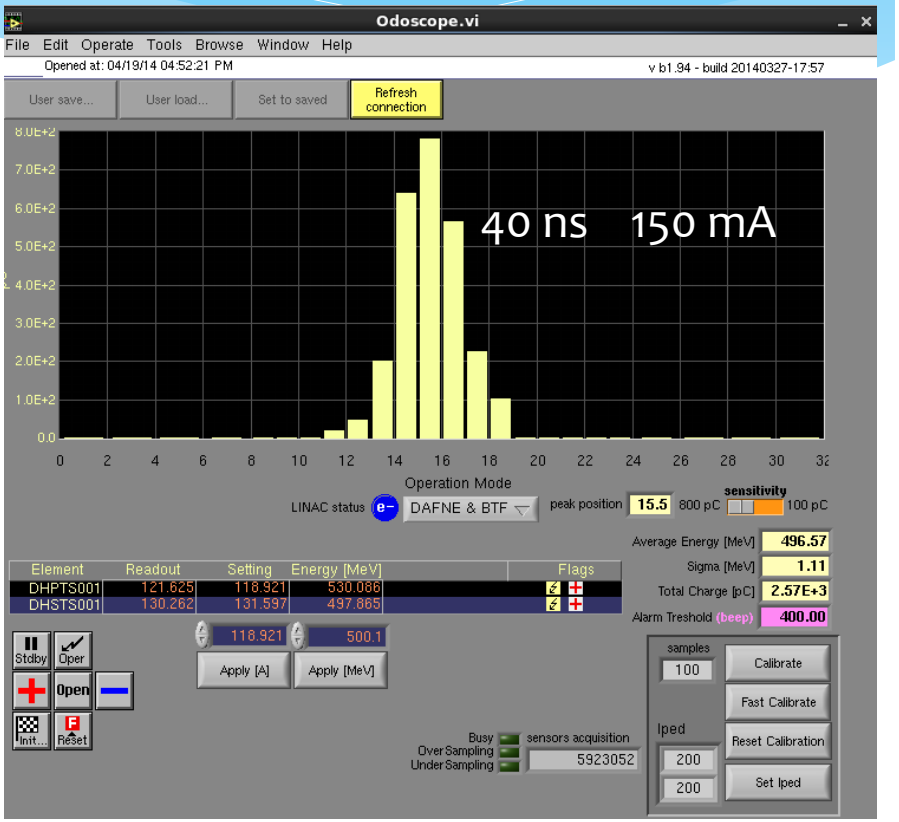


×3 - ×5
Increasing gun pulse height



Extending the pulse length: energy spread





Possible beam parameters for electron dump experiments

* **Measured maximum energy (2014) E=725 MeV**
* **Conservative value: Q=25 nC**
  * 8.5 nC ×3 gain using grid and gun pulse height
  * N_e = 1.6·10^{11} e/pulse× 49 pulse/s= **0.784·10^{13} e/s**
  * **P = 0.9 kW**
  * 0.784·10^{13} e/s × **3·10^{7} s** = 2.4·10^{20} eot
* **Further increase** by enlarging the pulse time width to **>100 ns**
  * Gun extraction **saturation** and **beam loading** effects to be checked
* **Full gain extrapolation: Q=50 nC**
  * Single factors well measured
  * But the combination of pulse height, length and grid voltage has to be tested
  * As a comparison, the design intensity **on positron converter** is 1.44·10^{13} e/s at 10 ns
    * Efficiency of the acceleration & transport has to be considered

The main limitation can come from radio-protection issues

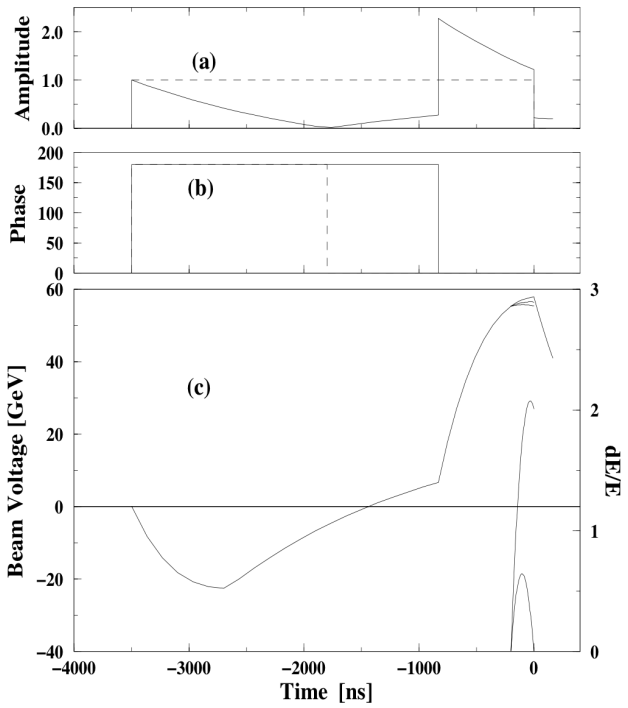
Extending the pulse length

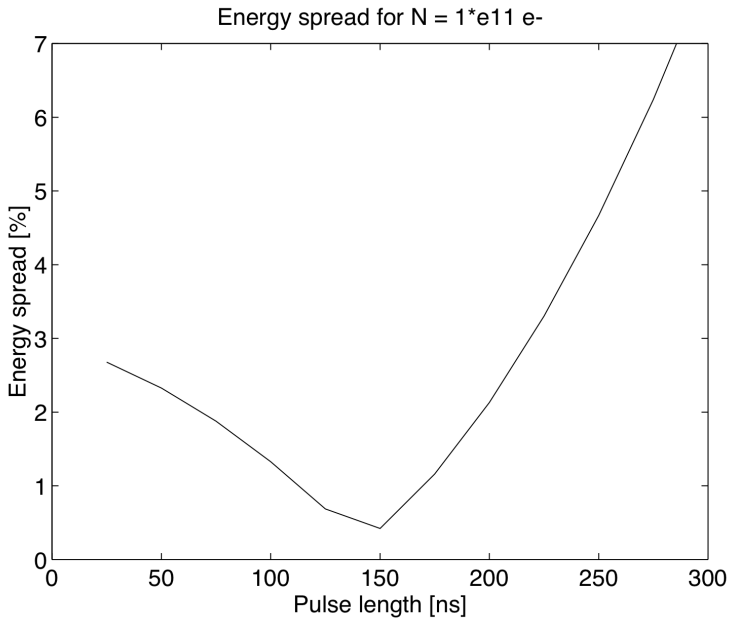
SLAC–PUB–7214
June 1996

Reducing Energy Spread for Long Bunch Train at SLAC*

F.-J. Decker, D. Farkas, L. Rinolfi[1], J. Truher
Stanford Linear Accelerator Center, Stanford CA 94309, USA

SLED





Extending the pulse length even more

SLAC–PUB–7214
June 1996

Reducing Energy Spread for Long Bunch Train at SLAC*

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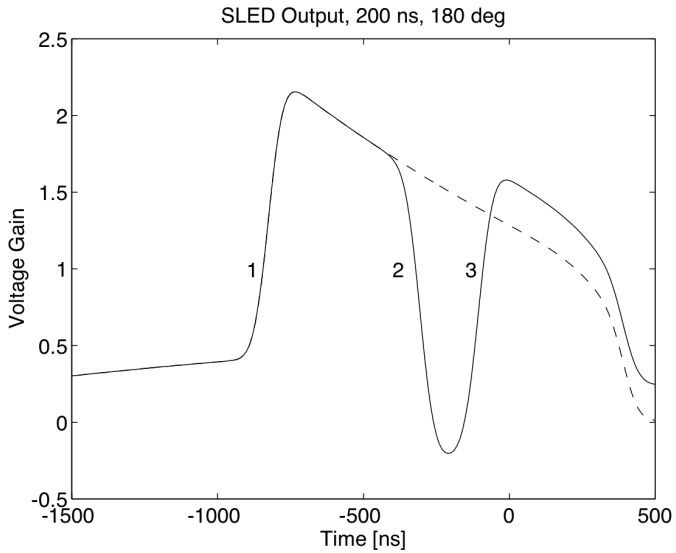


240 ns with <0.5% energy spread achieved at SLAC for E-154 experiment

Add two more 180° phase inversions

Adapted from:

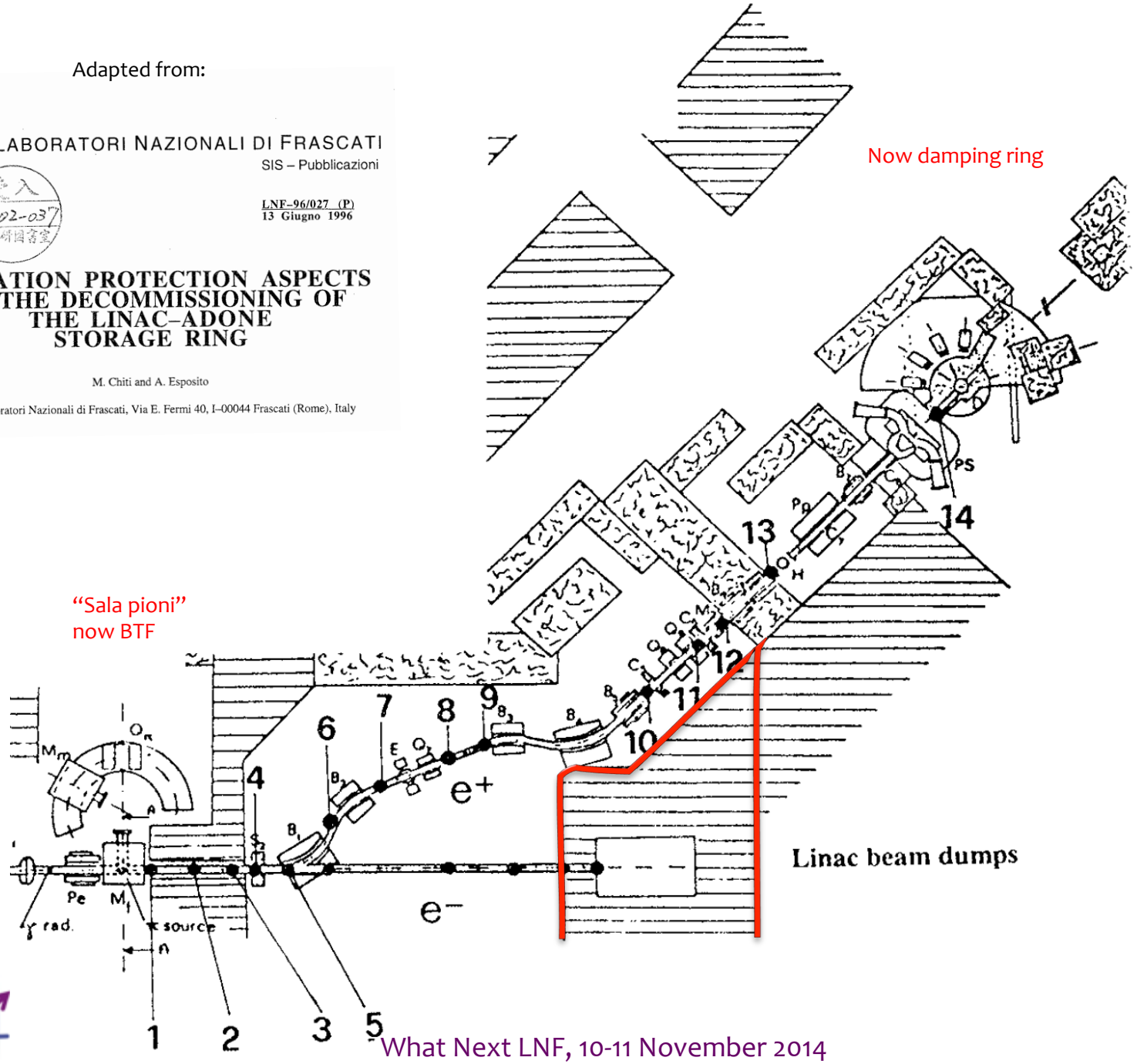
LABORATORI NAZIONALI DI FRASCATI
SIS – Pubblicazioni

LNF-96/027 (P)
13 Giugno 1996

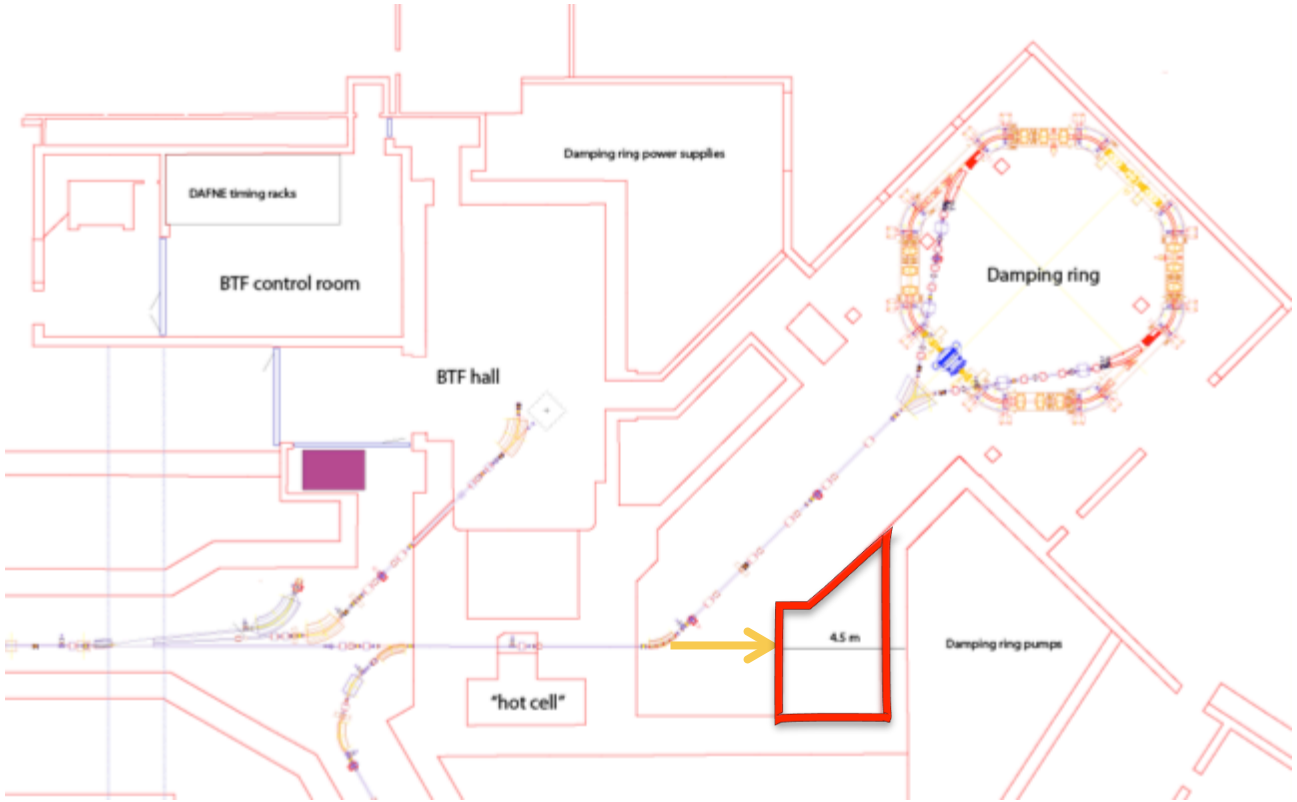
RADIATION PROTECTION ASPECTS OF THE DECOMMISSIONING OF THE LINAC–ADONE STORAGE RING

M. Chiti and A. Esposito

INFN-Laboratori Nazionali di Frascati, Via E. Fermi 40, I–00044 Frascati (Rome), Italy



Use existing ADONE linac dump



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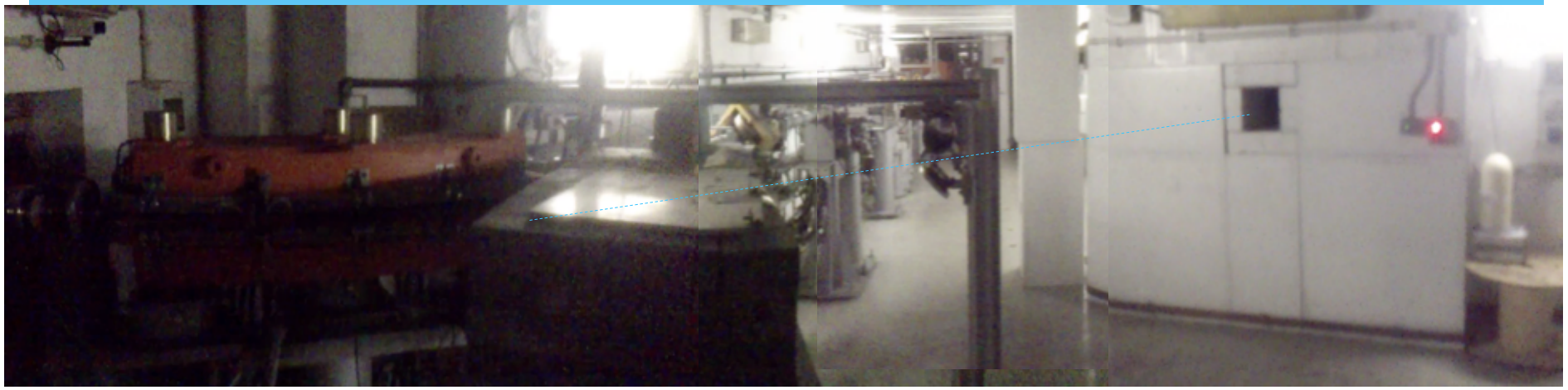
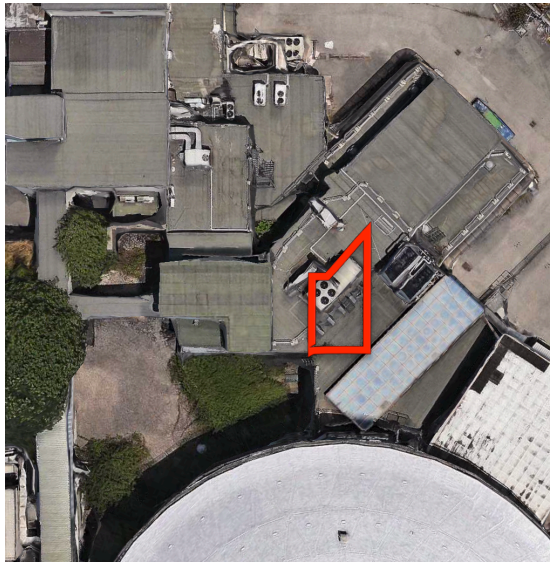


25×25×50 cm³ surrounded by concrete
20x50(+10)x40 cm³ surrounded by lead



DHPTT01

Pumps

Pumps

Pumps

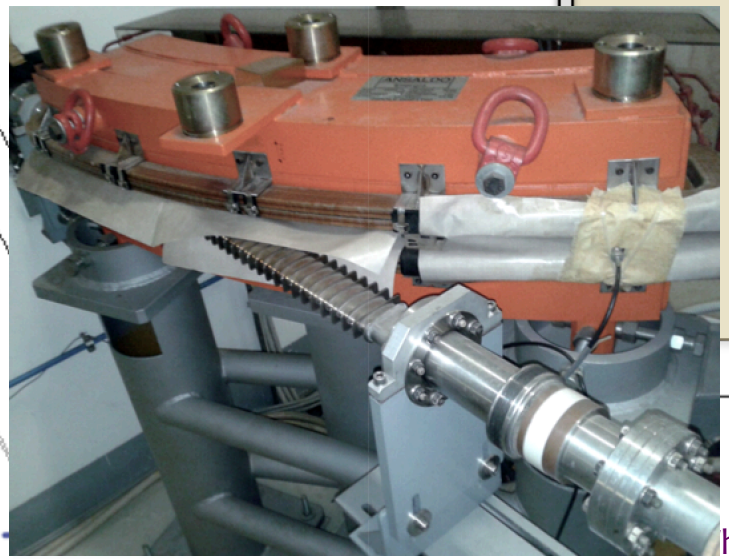
Racks

Racks

Option A:

- A new **thin vacuum chamber** for DHPTT01 with a double exit
- Exactly the same design of the one of DHPTT02

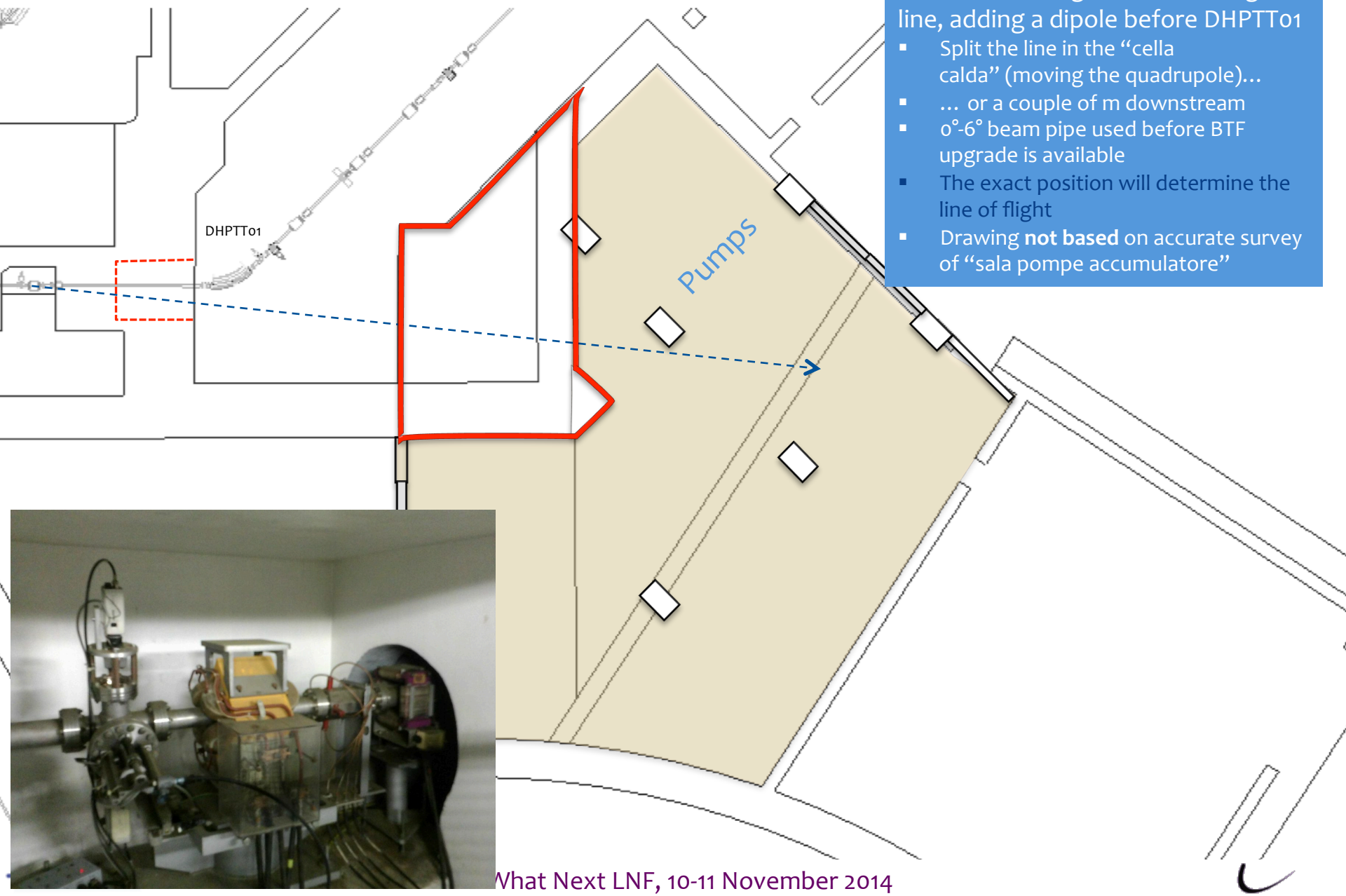
DHPTT01



Option B:

Go at a small angle wrt the straigh line, adding a dipole before DHPTT01

- Split the line in the "cella calda" (moving the quadrupole)…
- … or a couple of m downstream
- 0°-6° beam pipe used before BTF upgrade is available
- The exact position will determine the line of flight
- Drawing **not based** on accurate survey of "sala pompe accumulatore"

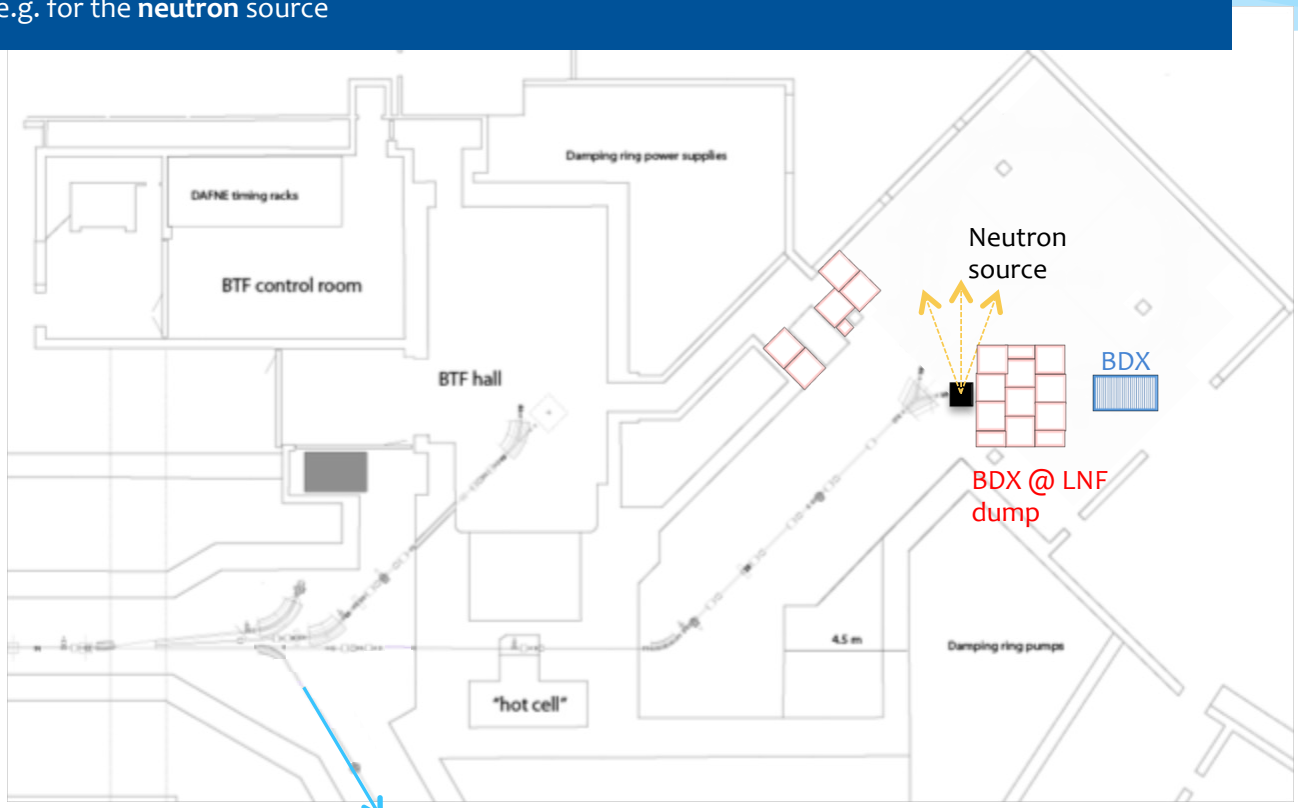


Sala pompe accumulatore

A radical approach

In case DAFNE collider is shut-down, the damping ring may be not necessary any more

* What about the gamma factory? The linac pulse can be shortened to **≈1.5 ns**
* Put the dump at some point of the transfer line, or on one of the two branches after the splitter magnet of the damping ring
* Dismount the ring and use the room as experimental hall
  * e.g. for the **neutron** source



Electron beam only, e.g. to the gamma factory

(In)compatibilities of dump experiments

* Long pulses are **not compatible** with the injection in the damping ring
  * Short pulses are also needed in order to inject electrons inside DAFNE for the gamma factory
  * In case of DAFNE collider, duty-cycle is greatly reduced by the alternative electron/positron modes of the linac
  * A time sharing with the injection/operations of the collider is probably more efficient if one splits one year, for example in two halves

* "Normal" test-beam activities in BTF and electron beam-dump at maximum energy and intensity **can** probably **live together**, but the intensity on the BTF copper target has to be reduced, e.g. with a tungsten collimator
* A longer pulse time distribution can be also annoying for detector testing:
  * A **fast trigger** detector can help the test-beam activities when going to longer pulses

* A more ambitious solution for BTF operation with longer linac pulses: an **RF kicker** to select single micro-bunches
  * **Few ps pulses**
  * Reduced charge on attenuating target (a factor 30 at 10 ns)
  * Much better background expected

What if…

* If DAFNE collider is completely dismissed, what can be done in the main rings hall?
* Several beam lines, sharing the 50 Hz from the linac:
  * One or more for electron fixed target, with and without dump
  * Micro-divergence beam
  * Photon tagging
  * Irradiation

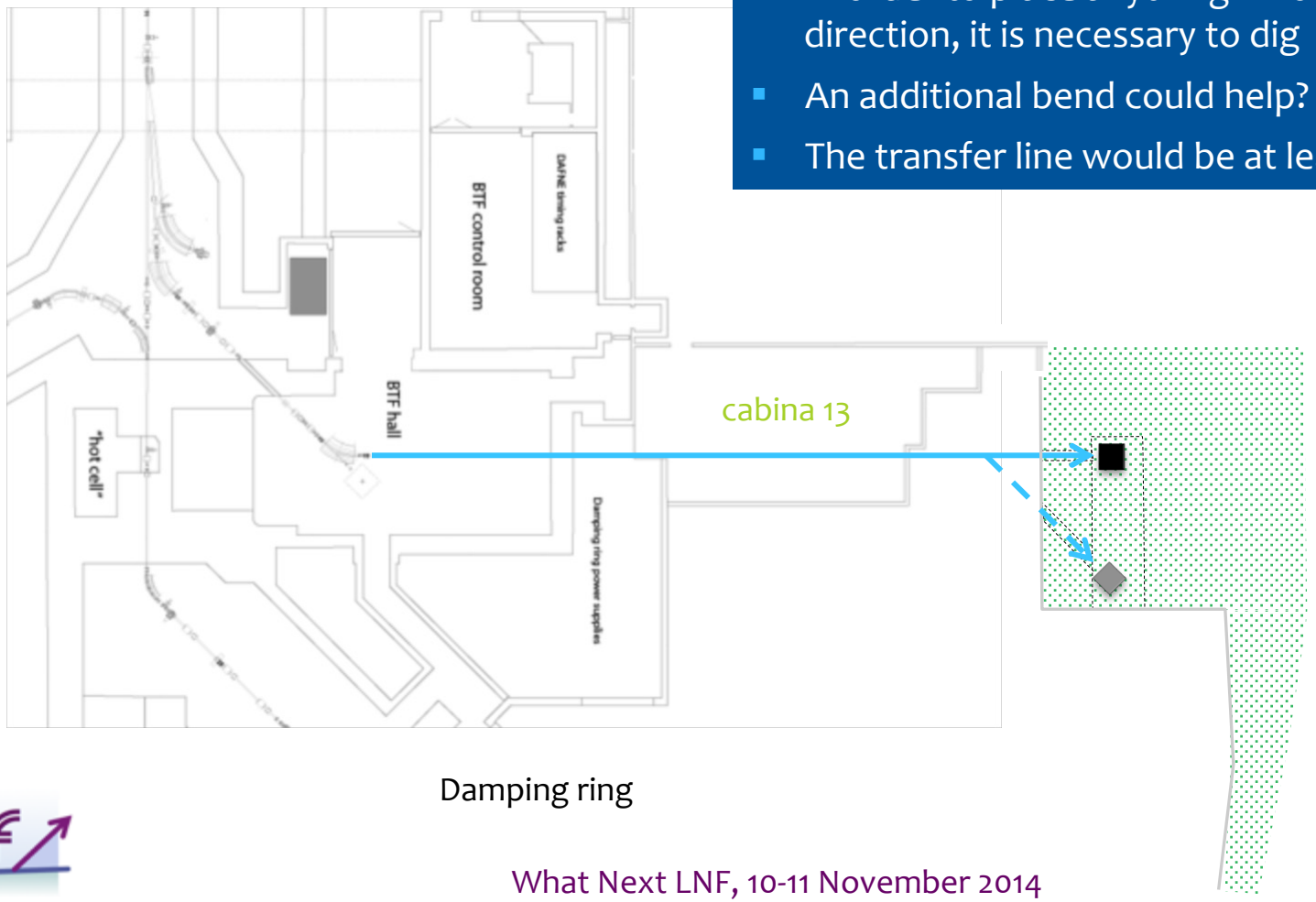
Another possible location for beam-dump

Another possible location for beam-dump

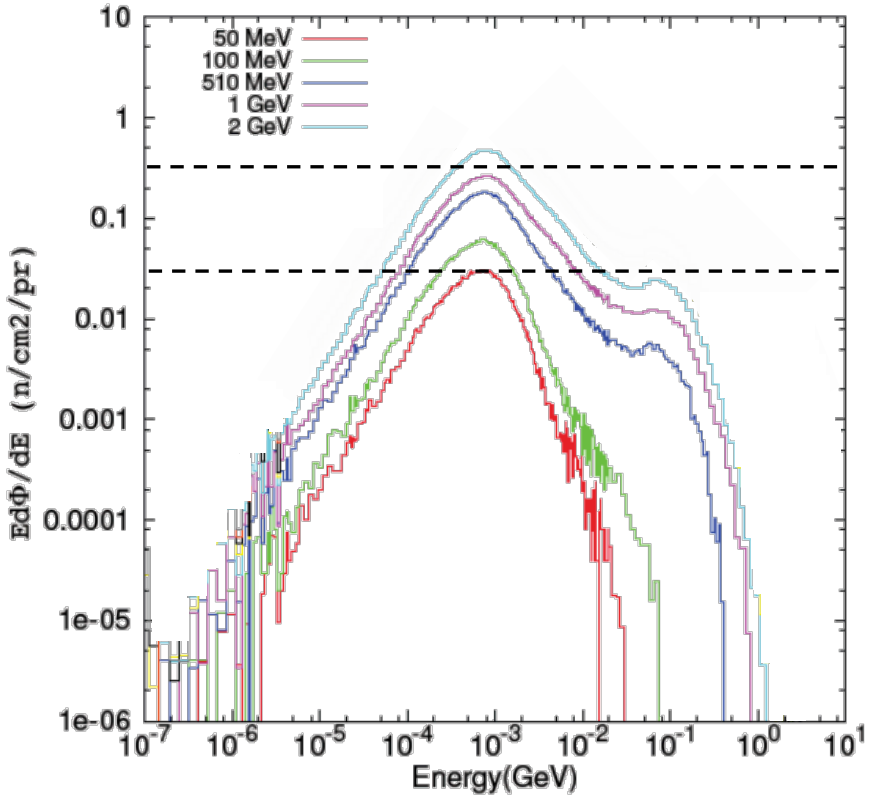
- Interesting area along the ideal line of flight of the beam outside the BTF hall
- Could be interesting for a **neutron target station**
- The space at 90° in the DR fence could be used by experimental apparata

Another possible location for beam-dump

- In order to place anything in forward direction, it is necessary to dig
- An additional bend could help?
- The transfer line would be at least **25 m** long



Neutron source



Electrons on W target

- **of magnitude in the neutron yield**
- Of course the high-energy neutron tail is absent at 50 MeV
- At 725 MeV and full linac power: 10^{13} e/s
  - to be compared e.g. with nELBE, $N=6\cdot10^{15}$ e/s

- **Swanson estimate**
  - **$9.3\cdot10^{10}\ Z^{(0.73\pm0.05)}$ n/s kW^{-1}**
  - **$2.15\cdot10^{12}$ n/s kW^{-1}** for tungsten

- n@BTF optimized target: **$2.75\cdot10^{12}$ n/s kW^{-1}**
- Increasing pulse height and length, we can increase 50× (from 40 W to ~1 kW)

A 50 MeV linac? (linac-ino)

* Original proposal by linac team
* Based on the fact that the neutron photo-production at 50 MeV is only an order of magnitude less wrt 500 MeV: **0,02 n/primary**
* **Can give an interesting neutron source**
* Very interesting for **low-energy detector testing**, especially for astro-particles: **1–50 MeV** range
* Needed parts:
  * Gun system (cathode, HV, pulser)
  * Focussing + velocity bunching system
  * 1 standard SLAC 3 m accelerating section
  * Modulator + klystron
* Possible location: radio-protection bunker

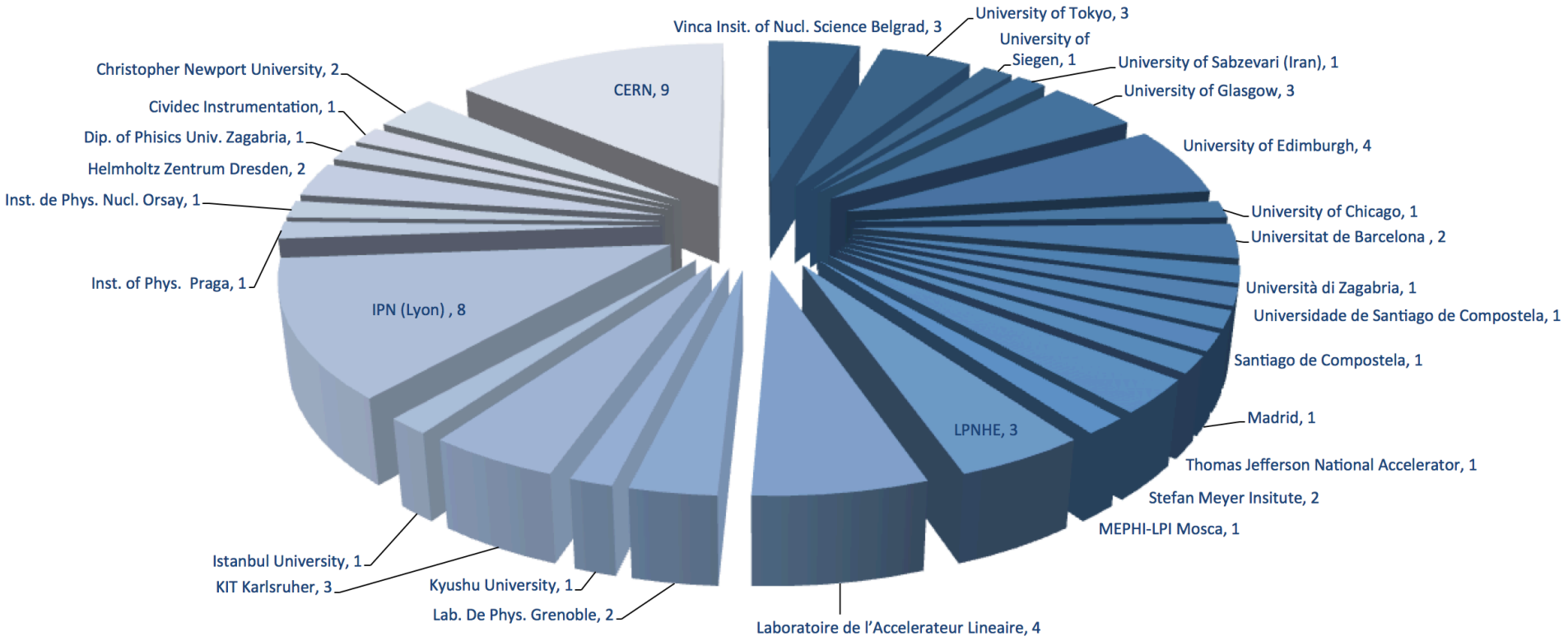
* Possible to stage the construction:
  * Modulator design and building
  * RF testing station (adding a klystron)
  * Gun system (many spare parts available)
  * Accelerating section available
  * Vacuum and cooling system

Would be very useful for **gaining know-how** and for the **R&D** on all sub-systems

Spare slides

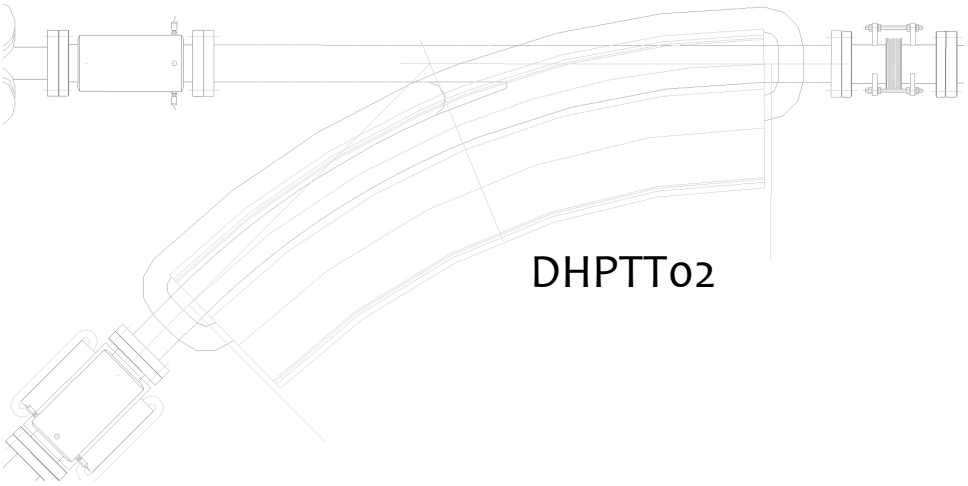
"Let's take another look at the plans, shall we?"

Foreign institutions users

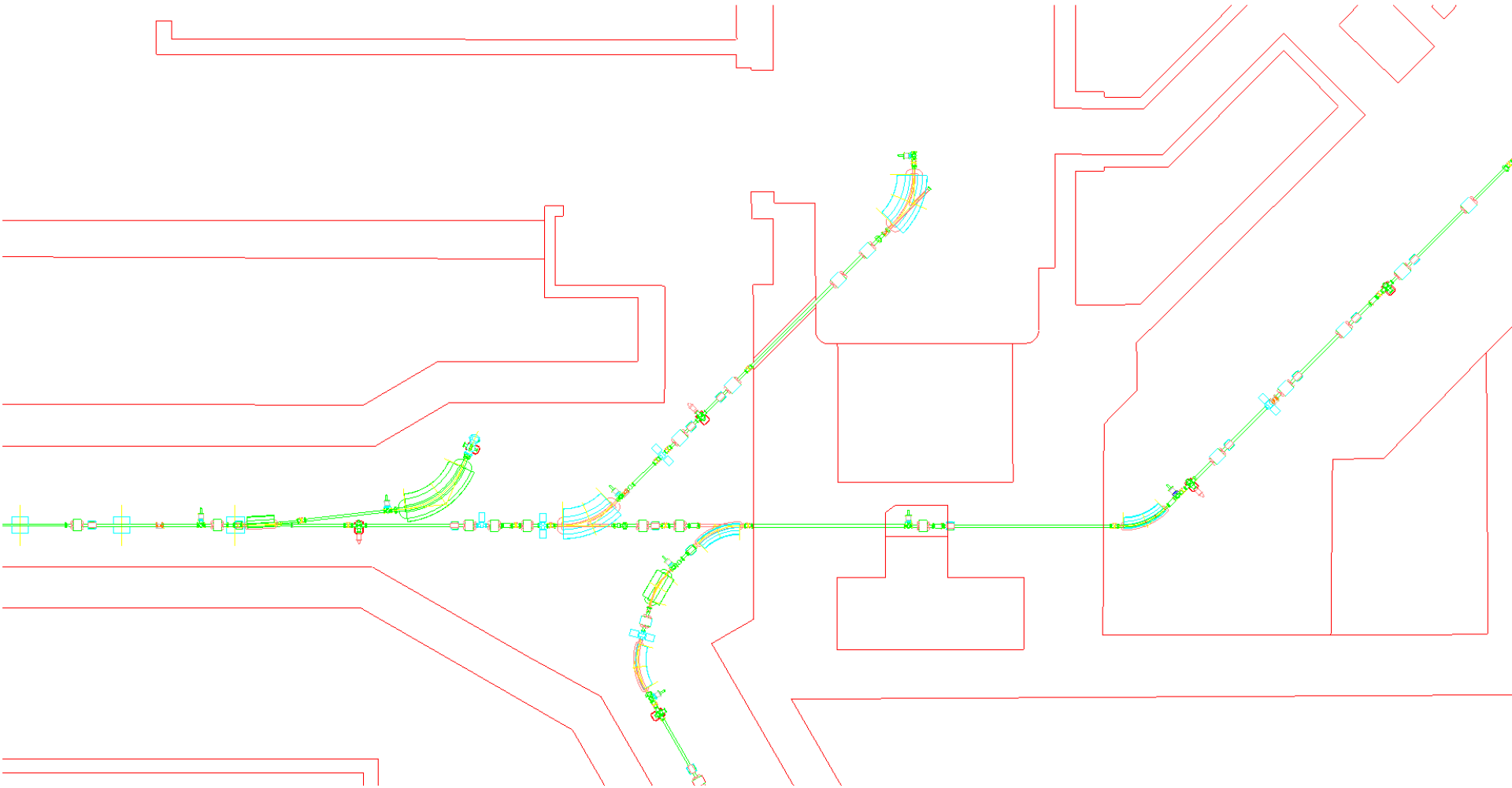


BTF users, coming from foreign institutions (multiple shifts counted once), during the **last 3 years**

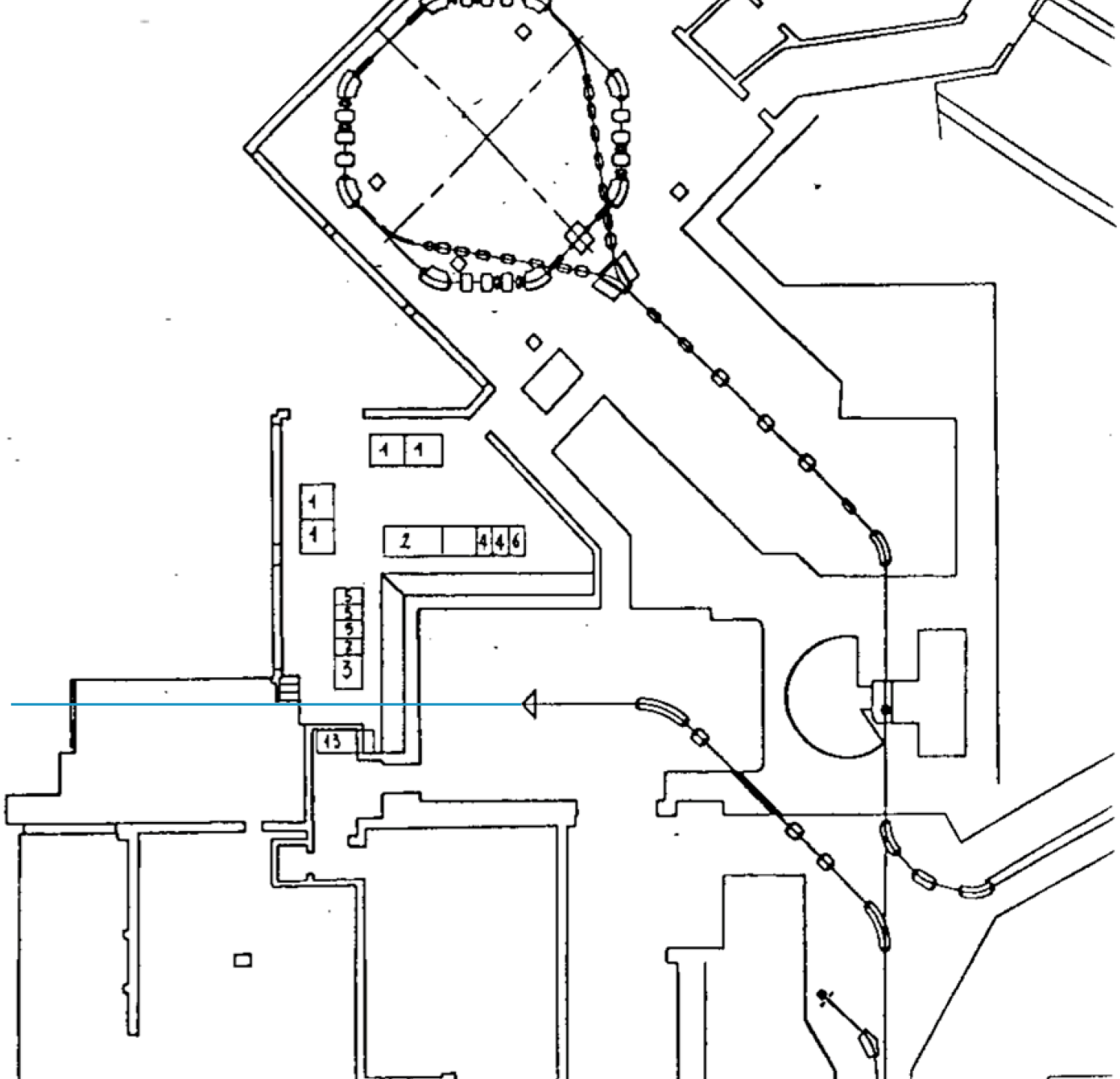
DHPTT01



DHPTT02




STOP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