



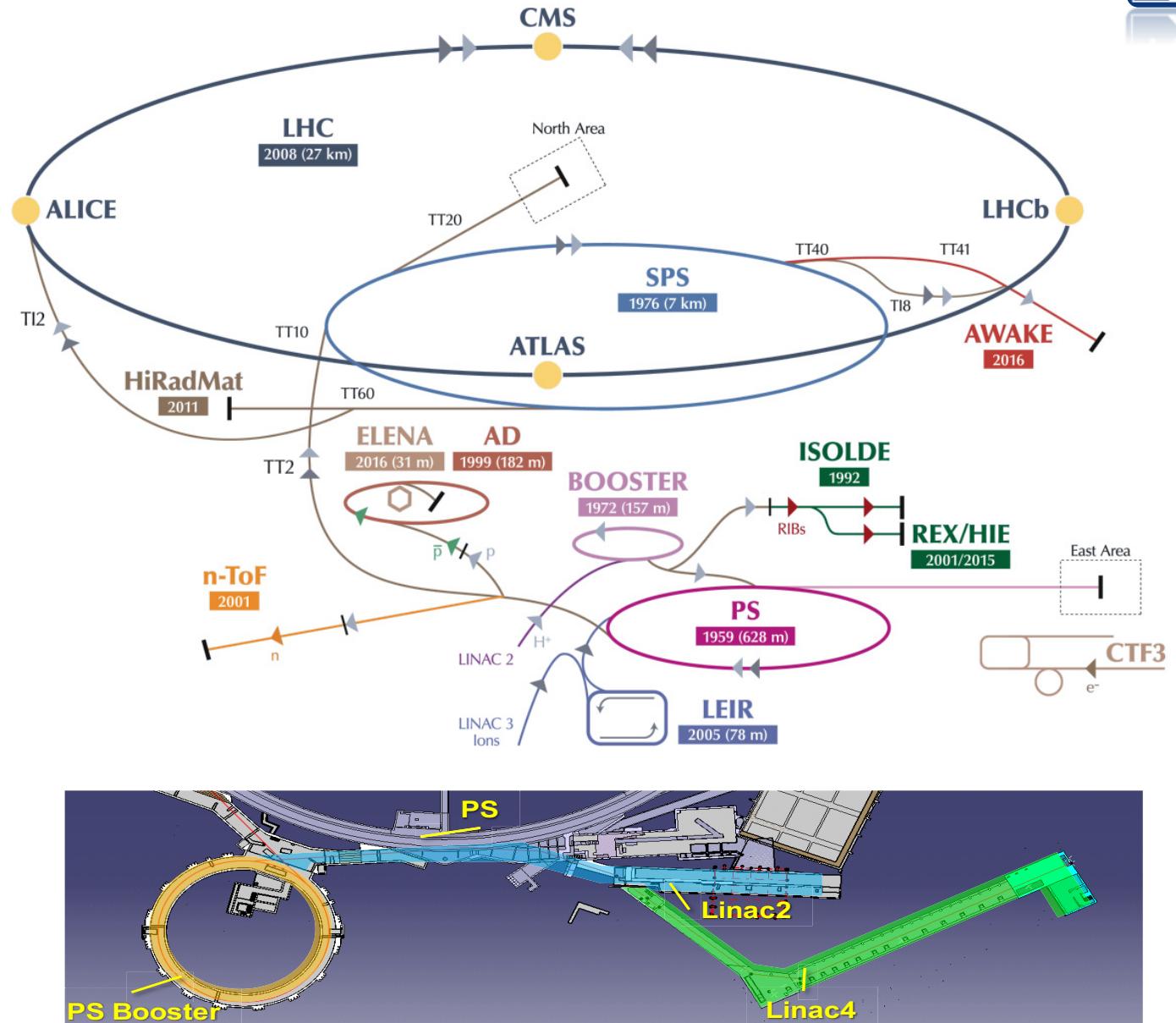
Experience with the construction and commissioning of Linac4

Jean-Baptiste Lallement for the Linac4 team



Linac4 : A new injector for the CERN proton complex

LINAC2	LINAC4
Protons	H ⁺
160 mA	40 mA
50 MeV	160 MeV
1 $\pi \cdot \text{mm} \cdot \text{mrad}$	0.4 $\pi \cdot \text{mm} \cdot \text{mrad}$
100 μsec , 1 Hz	400 μsec , 1 Hz
Since 1978	All new components
No longitudinal matching at injection	Fast chopping at 3 MeV Energy painting



The 3 MeV pre-injector



45 keV H- ion source – Cesiumated

Development and optimisation on-going in a test stand.

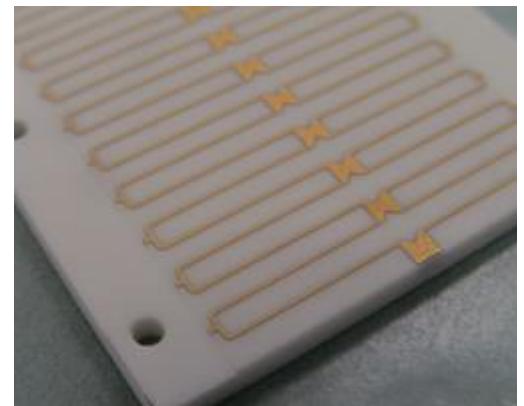
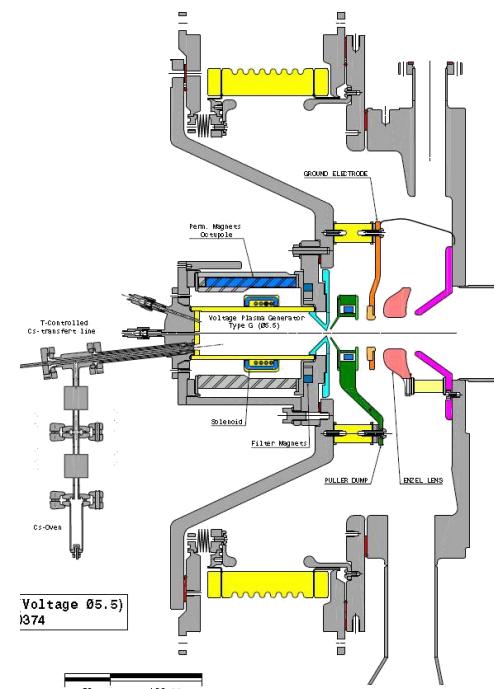
Delivering stably a 50 mA beam (35 mA within RFQ acceptance).

352.2 MHz RFQ

3 m long structure.

Designed and manufactured at CERN.

Reliable operation since 2013.



MEBT with fast beam chopper

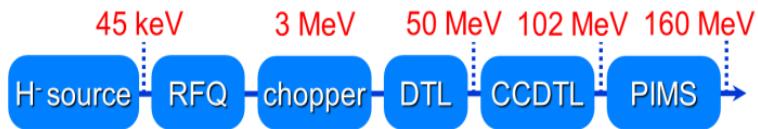
3.5 m long matching line from RFQ to DTL

Fast and efficient beam chopping due to the combination of:

Relatively low electric field applied between two plates.

Kick transferred in the real space by a defocusing quadrupole.

The accelerating structures



Drift Tube Linac – 3 - 50 MeV

PMQs in vacuum – FFDD focusing scheme

Designed for > 30 years reliable operation at 10% duty cycle

Adjust and Assemble philosophy:

Tight tolerance aluminium girder



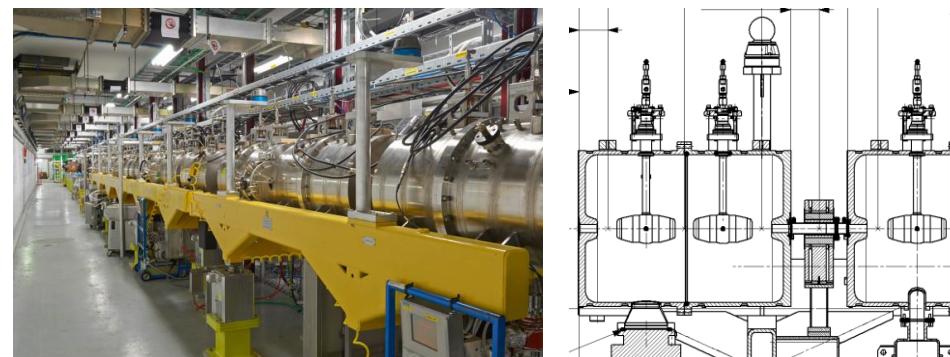
Cell-Coupled DTL – 50 - 102 MeV

Construction by BINP and VNIITF in Russia.

7 modules x 3 cavities x 3 gaps.

PMQs located in between cavities.

First-ever CCDTL on a working machine !



Π Mode Structure – 102 - 160 MeV

Collaboration with NCBJ and FZ-Jülich.

Discs and rings were tuned and electron-beam welded at CERN.

Long qualification period for series production:

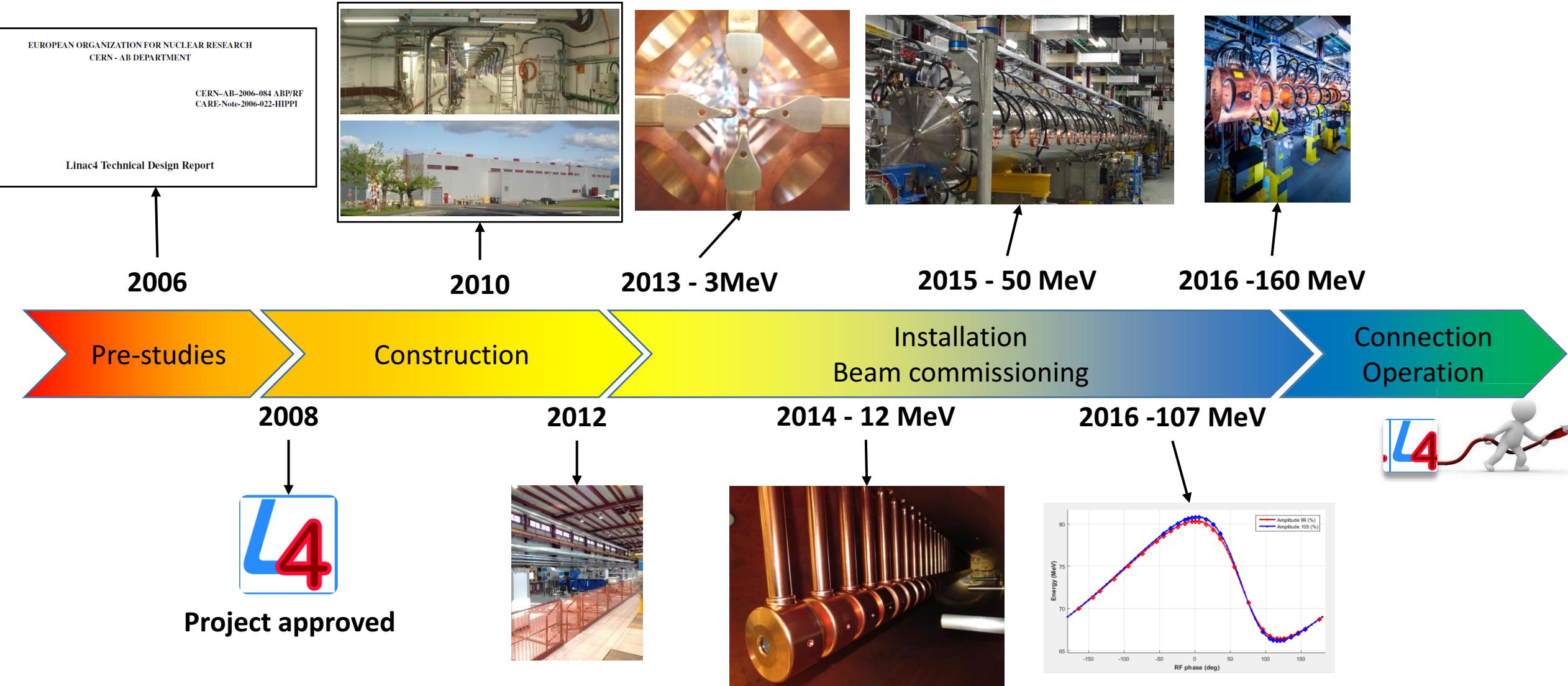
10-20 µm on 500 mm diameter pieces

First low-beta PIMS on an operational machine.



[TUPLR047 – THPLR060 – S. Ramberger]

Linac4 from 2000's to 2020



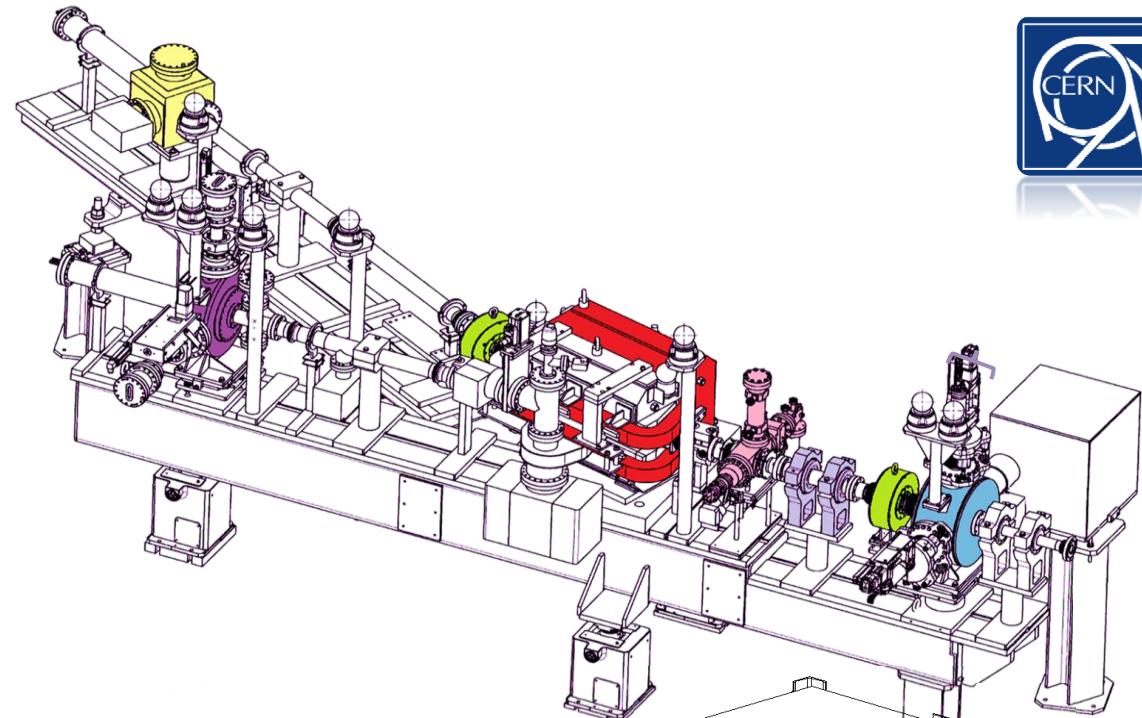
A staged commissioning

Low energy test bench at 3 and 12 MeV

Direct measurements

Transverse emittance with slit-grid

Energy – Energy spread with a spectrometer



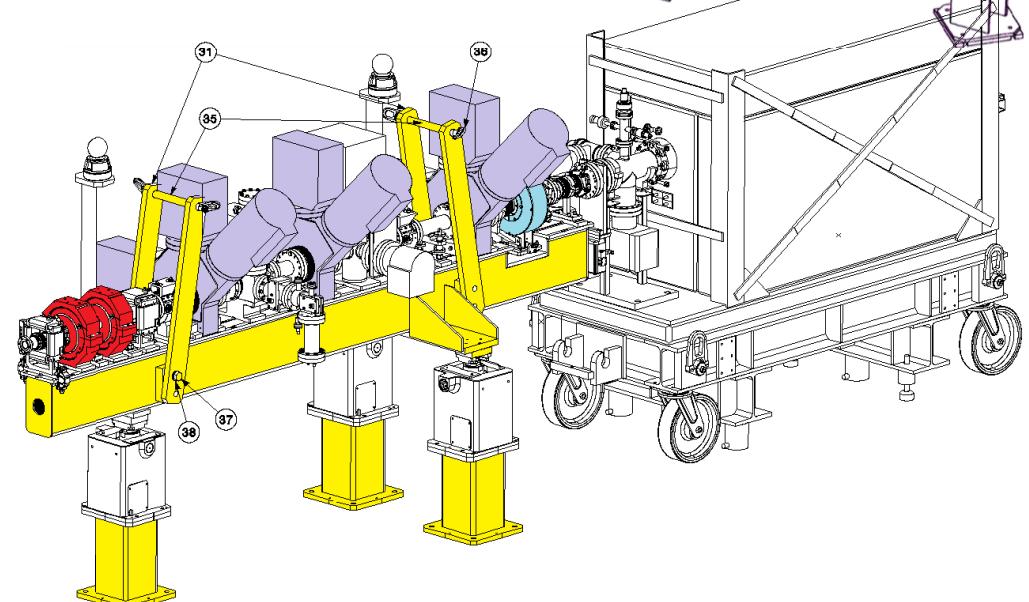
High energy test bench at 50 and 107 MeV

Indirect measurements

Transverse emittance with 3 profile monitors

Longitudinal emittance with bunch shape monitor

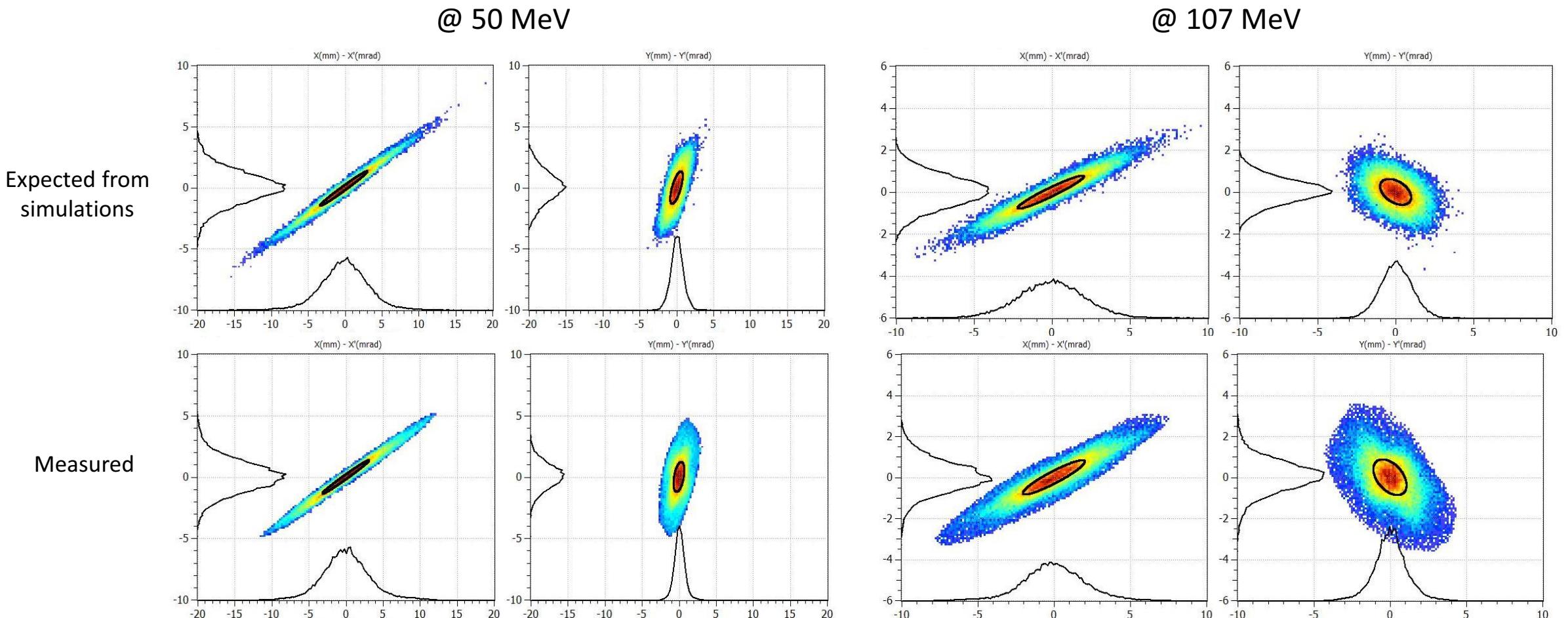
Energy with Time of Flight



Permanent measurement line in the transfer line for 160 MeV

Transverse emittance: Close to our expectations

Transverse emittances were indirectly measured with: The “**Forward method**” and the “**Hybrid Tomographic method**”
Both based on: The 3 profiles method – Including the space charge forces with multi-particle simulation codes.



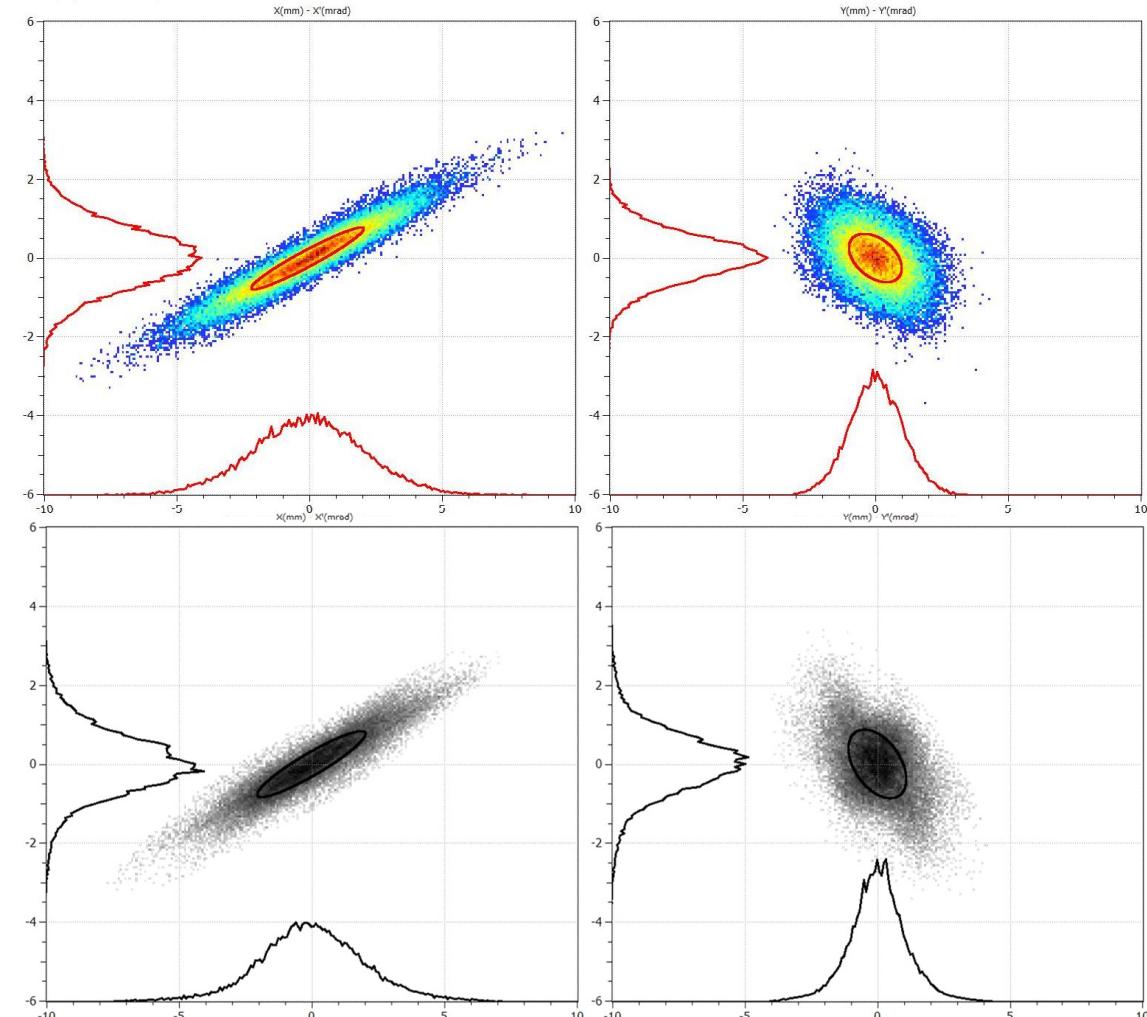
Transverse emittance: Close to our expectations

Transverse emittances were reconstructed with 2 techniques: The “**Forward method**” and the “**Hybrid Tomographic method**”
Both based on: The 3 profiles method – Including the space charge forces with multi-particle simulation codes.

Expected from
simulations

@ 107 MeV

Measured



[TH2A02 – T. Hofmann]

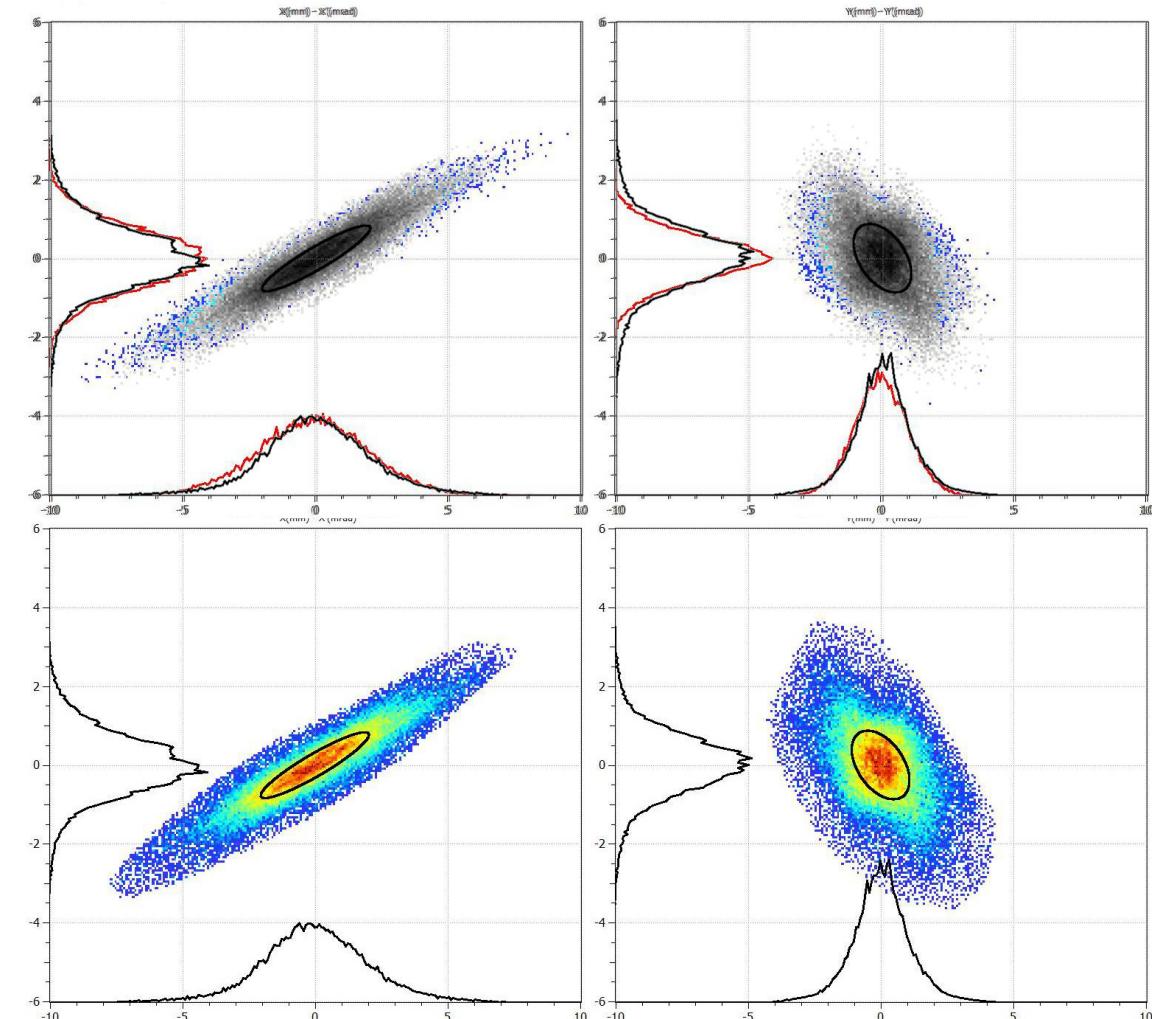
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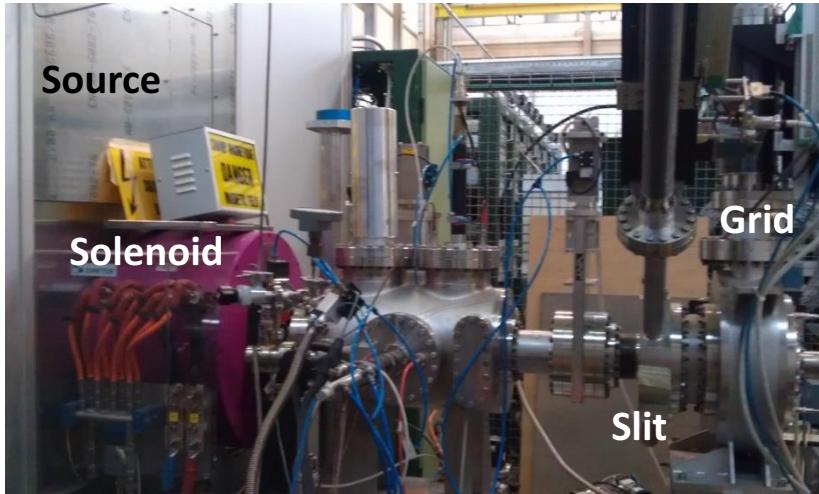
Measured



[TH2A02 – T. Hofmann]

Why such a good agreement ?

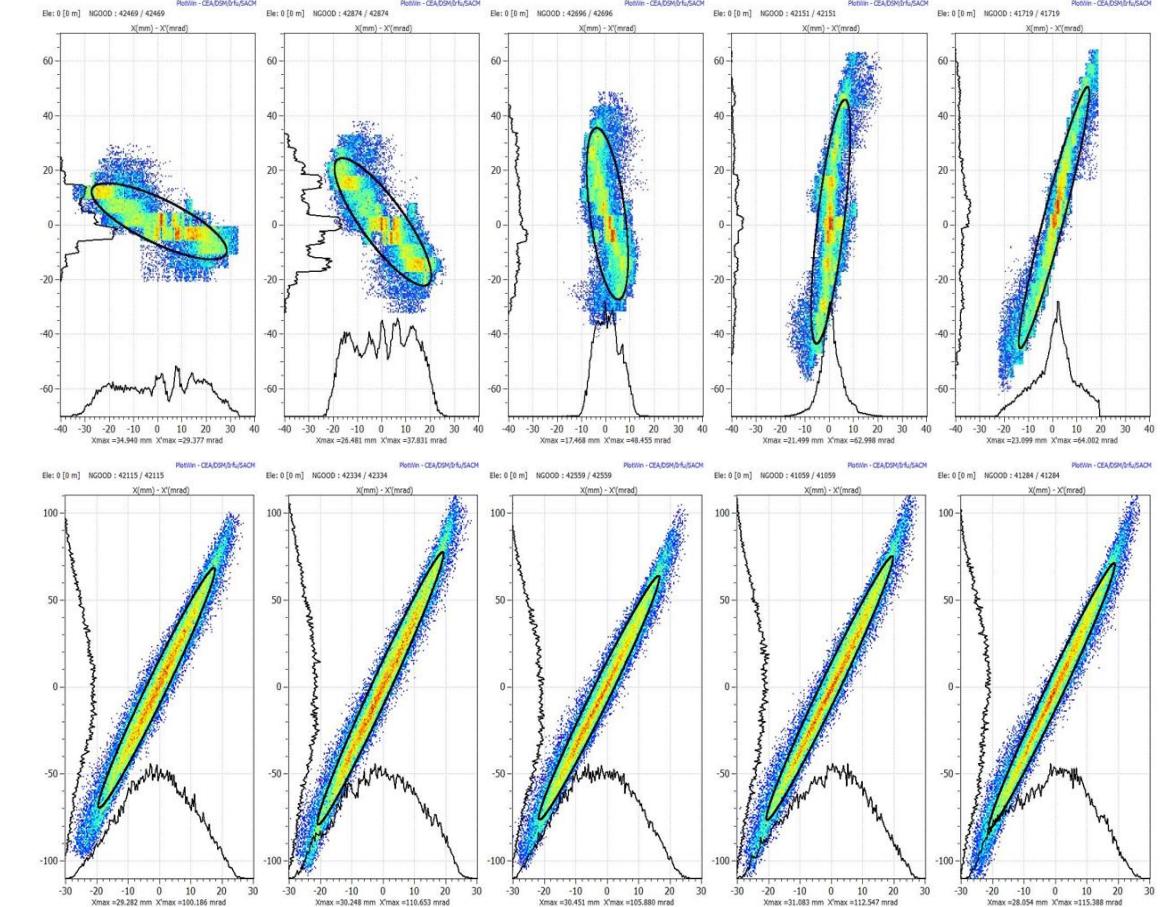
Extensive measurements of the emittance out of the source at 45 keV !



Measurements
varying solenoidal
field

Back-trace to the
source output

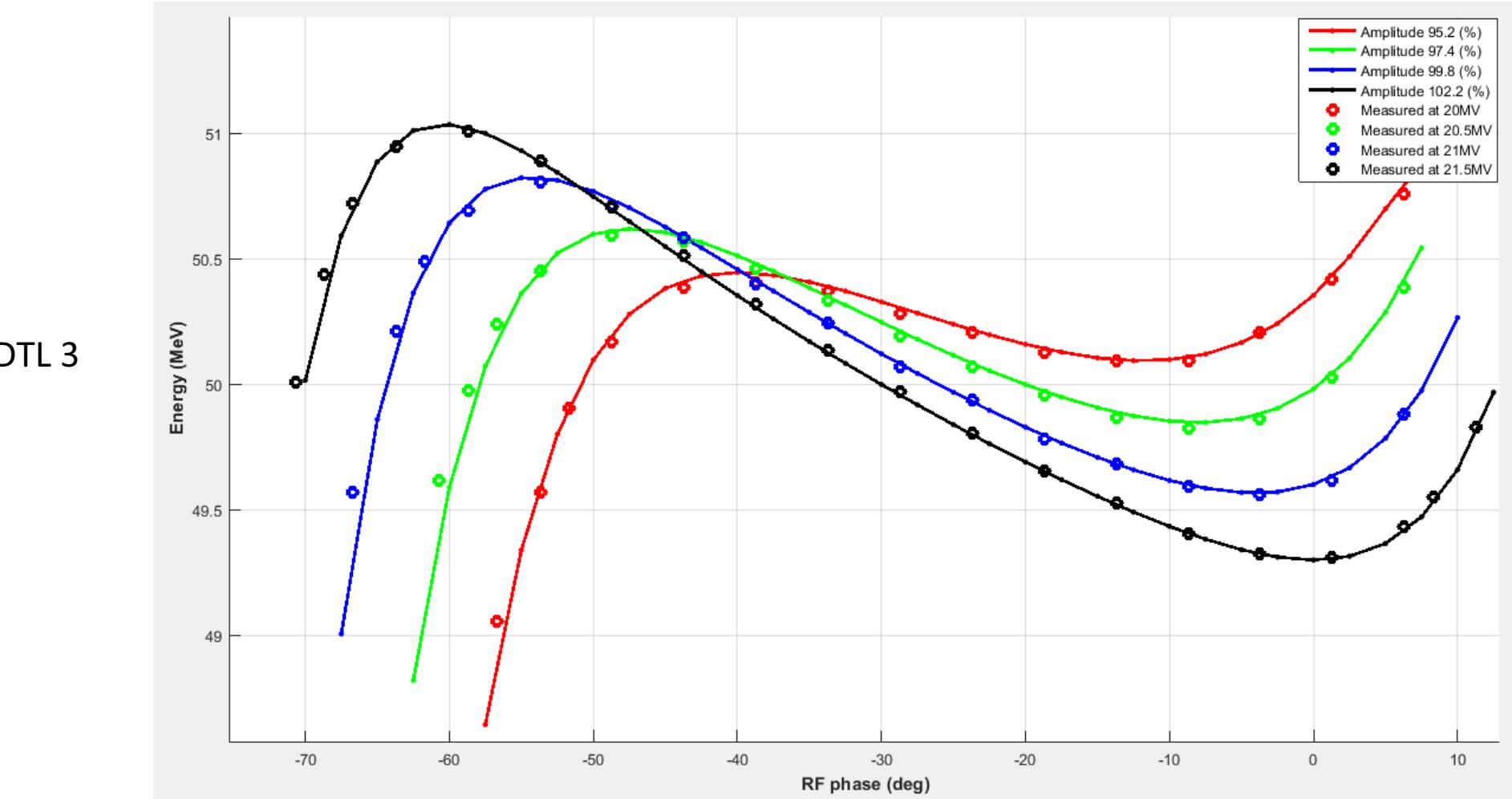
We have an empirical input beam distribution that very well represents the dynamics in the LEBT and the rest of the accelerator !



Setting the RF cavities: ToF

Most of the RF cavities settings are found with Time of Flight:

A total of 17 Beam position monitors from 12 to 160 MeV (for 22 cavities).



The ToF is sufficiently precise to allow setting each RF cavity to:

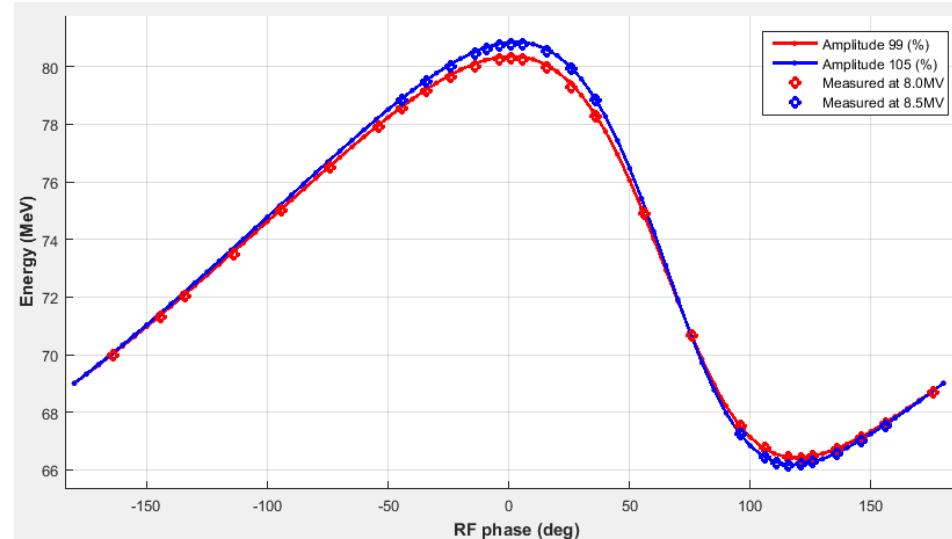
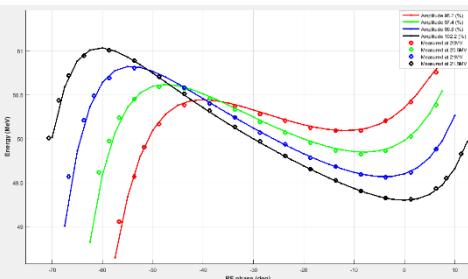
$\pm 0.5\%$ in amplitude
 $\pm 0.5^\circ$ for the phase

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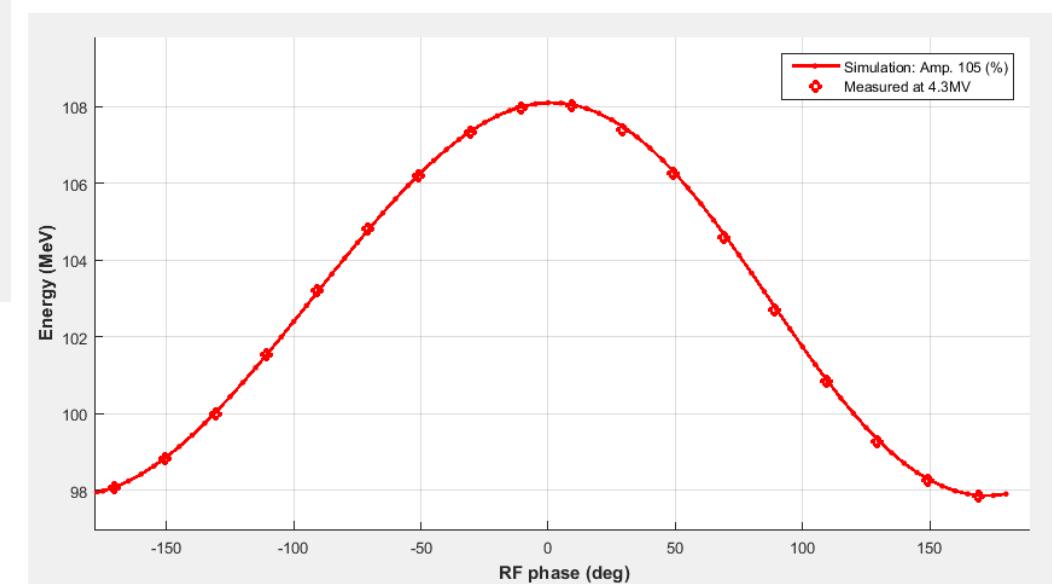
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DTL tank 3



CCDTL module4

PIMS cavity 1



Increasing β & Decreasing number of gaps per cavity

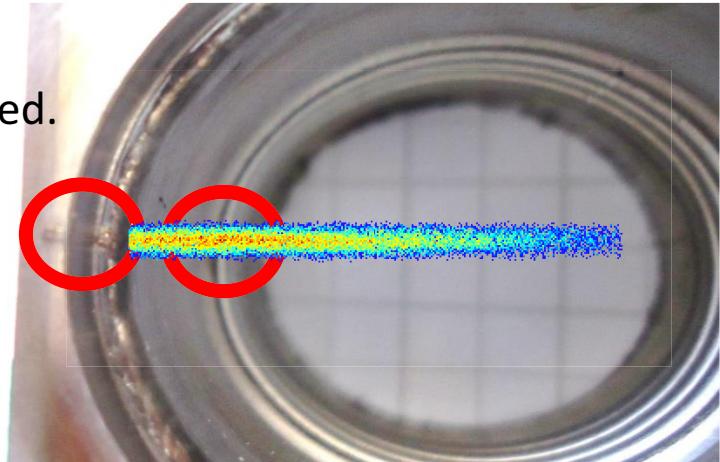
Sometimes we missed the drop-zone

1st Lesson learnt: A 10 mA – 3 MeV beam can drill a hole in the vacuum chamber

A misalignment at RFQ/MEBT combined with an unlucky quadrupoles settings.

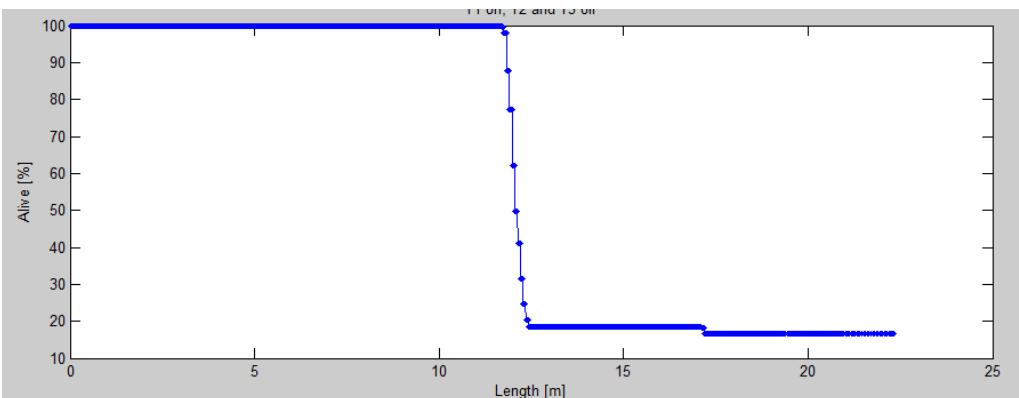
All bellows with inner diameter smaller than the beam pipe were progressively replaced.

Restarted beam after 2 weeks...



2nd Lesson learnt: Simulation tools are good guide dogs

Starting the 50 MeV commissioning stage -> Low transmission



Given the hot-point at DTL3 entrance and thanks to beam dynamics simulations, we understood that last DTL2 PMQ and first DTL3 PMQ were accidentally inverted.

Beam restarted after 3 days...

Almost to the finish line

Nominal	As of Today
H ⁻	H ⁻
40 mA peak current	25 mA
160 MeV	107 MeV (160 soon)
0.4 π.mm.mrad	0.35 π.mm.mrad
400 μsec, 1 Hz	600 μsec, 1 Hz
Fast chopping at 3 MeV Energy painting	100% - 10 ns To be done in 2019

Machine installation is completed

All equipment tested/validated

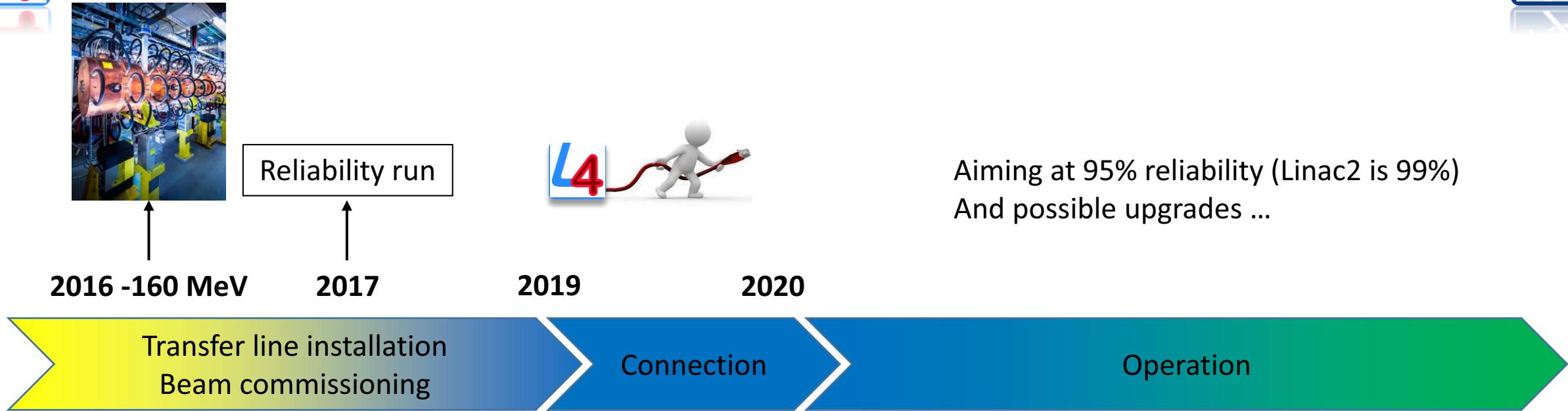
Commissioning went pretty smoothly up to now

Very good agreement between our machine model and the measurements.

We reap the fruit of the successful collaboration between the different group involved since many years on the Linac4 project.



Linac4 from 2016 to 20??



- The source development and the low energy beam characterization will continue**

A dedicated test stand will bring us a better understanding of the dynamics in this crucial part of the machine on which the linac overall performances depends.



Thank you !

