LHCb VELO RF Box Workshop 5-6 february 2015 (CERN): a summary

- Items covered
- Highlights
- What next ?

RF shield, RF box, ...

- We need a transparent box that protects the VELO without affecting the beams and with no material in the acceptance
- Challenges:
  - must be zero mass
  - must be electrically conducting
  - must not grossly increase the LHC impedance
  - must be mechanically stable
  - must not interfere with silicon sensors (mechanically, electrically)
  - must not cause beam-induced emission/desorption effects
  - must be safe (interlocks!)
  - must be movable
  - must accommodate silicon detector geometry (complex!)
  - must withstand heavy irradiation
  - must withstand temperature cycles (about -30 to 160 C)
  - etc...

All done !

- Pressed/deformed Al foils (300 um + 500 um) of very complex shape (corrugations, anticorrugations), welded together
- Coated detector side of foil with insulator (Torlon)
- Coated beam side with NEG, activated
- Connected to beam pipe with Au-coated 70 um thick CuBe wakefield suppressors, deformable
- Checked impedance with MAFIA/ABCI...
- Checked dynamic vacuum / multipacting effects with VASCO
- Performed extensive RF field measurements with wire-method
- Checked deformation versus differential pressure
- Measured overall shape
- etc...

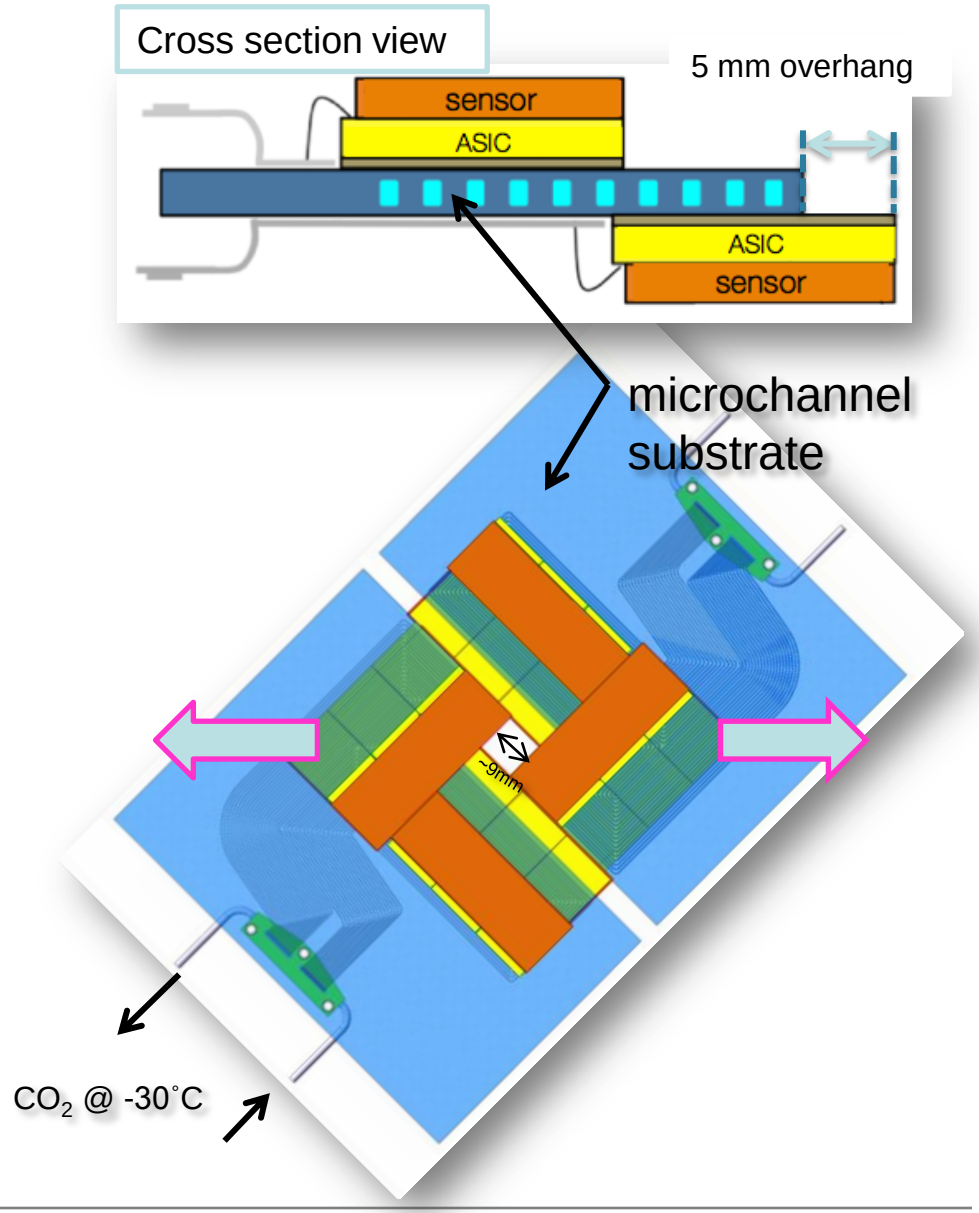
But it wasn't easy. It took several years from concept to final boxes.

LS2: LHCb upgrade

- PRECISION PHYSICS or DIE
- 10 x more physics data
- smaller aperture, closer to the beams
- different sensors, different geometry

Upgrade VELO modules: pixel sensors

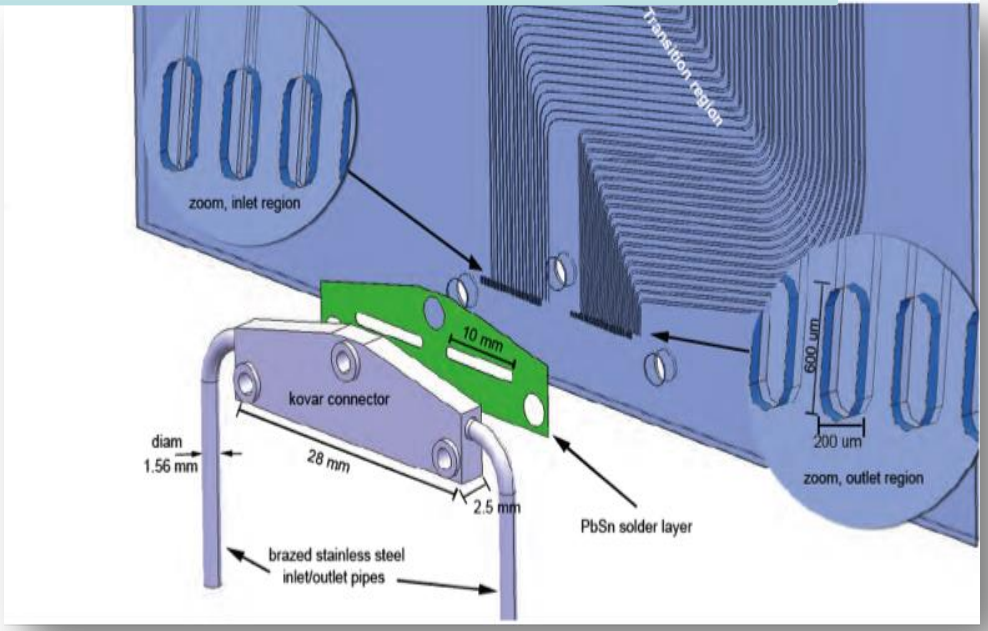
- Active silicon: the closest distance to LHC beam will be 5.1 mm (down from 8.2 mm).
- Very high ($8x10^{15} n_{eq}/cm^2$ for 50 fb^{-1}) & non-uniform radiation (~ $r^{-2.1}$)
- Huge data bandwidth: up to ~15 Gbit/s for central ASICs and 2.9 Tbit/s in total.
- Sensor temperature < -20˚C
- Total dissipation/module is ~26W.
  - ~2W/ASIC and ~2W on the innermost sensors.
  - Active cooling area ~ 24 cm^2
  - Power density: 1.1 W/cm^2
- Minimal material: cooling substrate is retracted 5 mm at the inner region.



Fluidic connector soldering

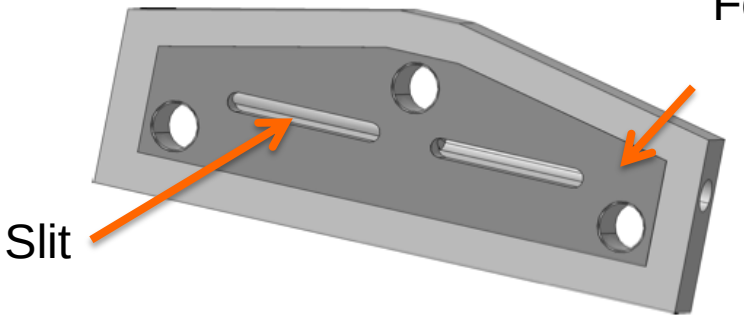
- Attachment of metal (Kovar) connector to the silicon substrate.
- Requirements:
  - No flux (prevent corrosive effects on long term and clogging effects)
  - Leak tight
  - No creep effect
  - Maximum force 130N @ 65 bars
- Reflow solder on vacuum
- Work in progress, solution is in common with NA62

Realistic design of the microchannels

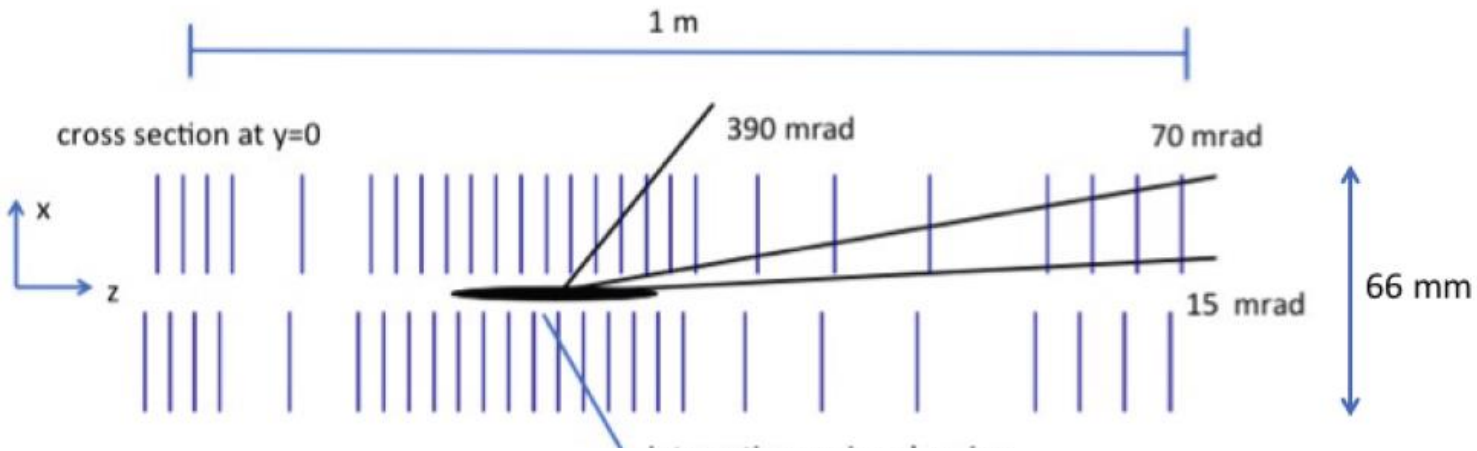


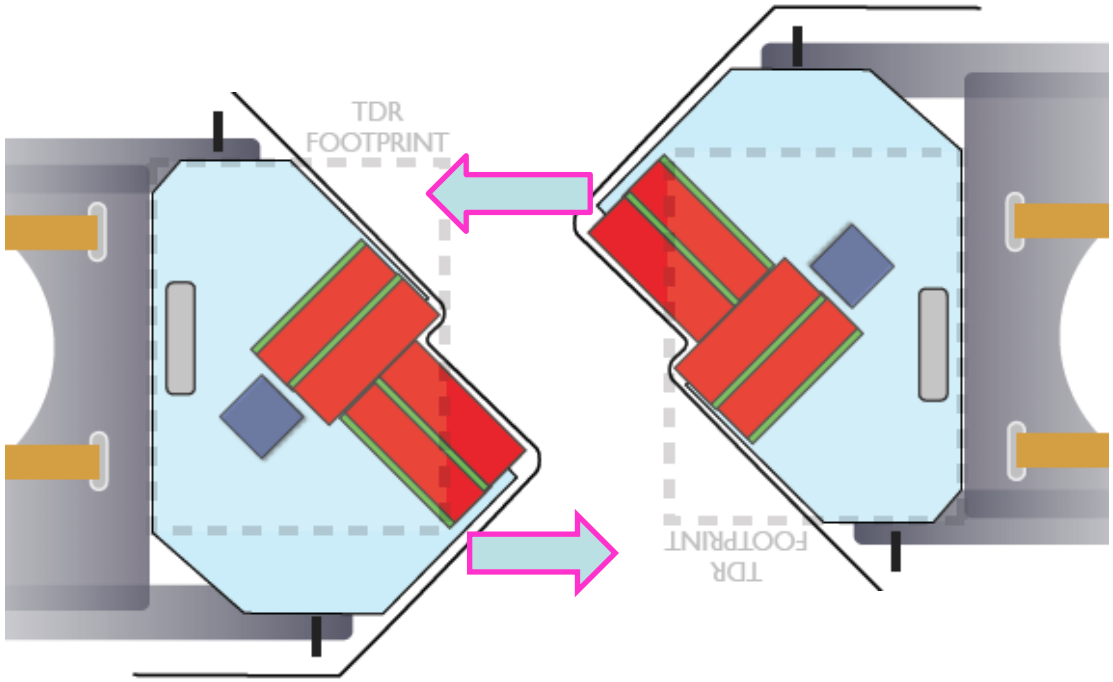
Connector bottom view

Solder Foil



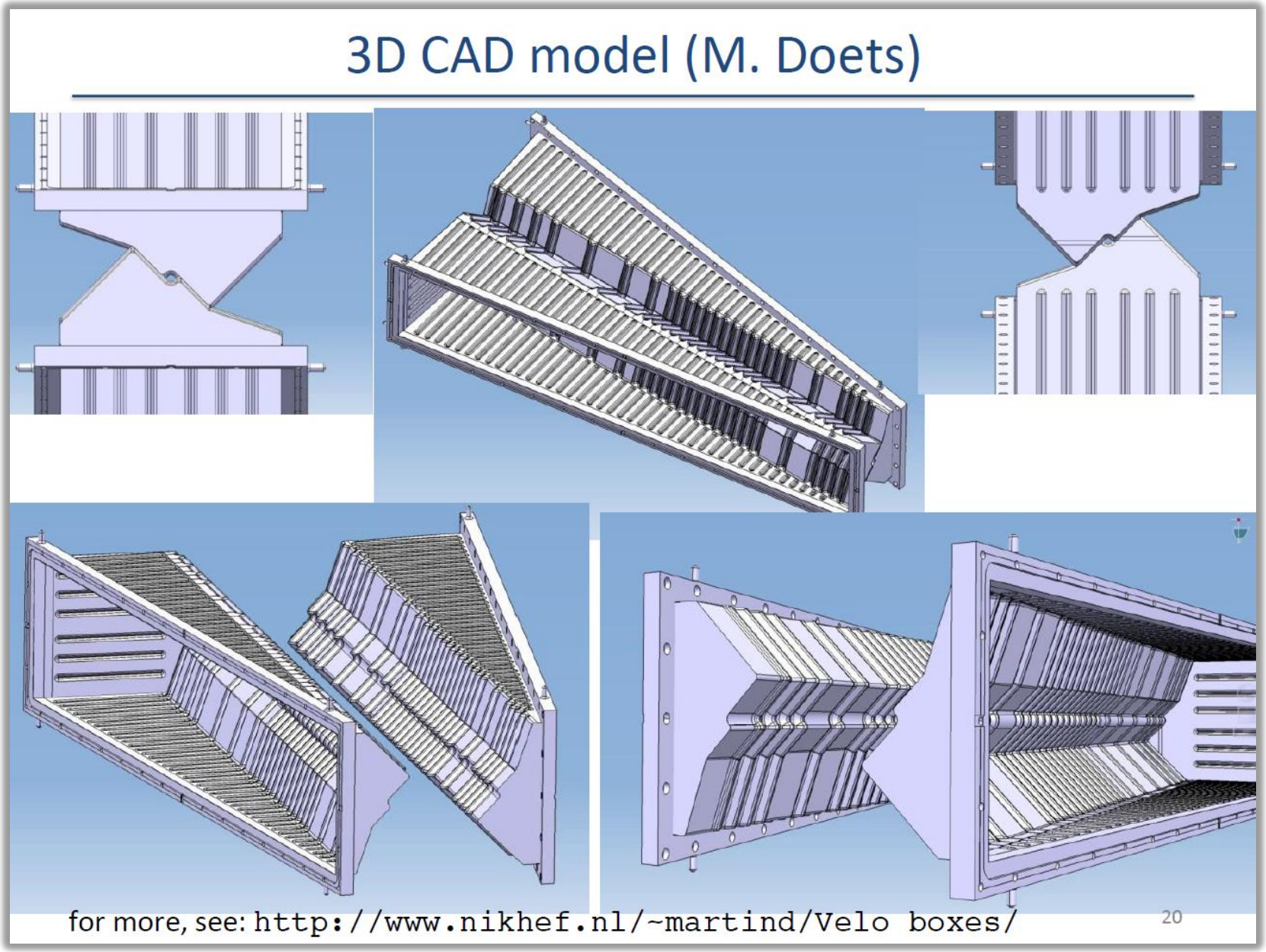
New layout of VELO (pixel)





Rotation by 45° of pixel modules was introduced to optimize for tolerances during insertion into RF box and for more useful "partial retractability" of detectors at run time (detector halves can be moved independently in horizontal direction)

New RF box shape "Mont-Blanc Over Lake Geneva"



Scope of the workshop

- Recapitulate all aspects related to the RF shield of the LHCb Vertex Locator (VELO), in particular machine interface aspects

  impedance, dynamic vacuum, operations...

  but also share experience on critical topics

- Discuss the status and progress of the RF shield R&D work in the context of the LHCb upgrade

  schedule!

- Prepare the road for a successful fabrication, installation and exploitation of the upgrade VELO (with the new RF boxes!)

Agenda

Thu 5/2

14:00 **Introduction** — *Massimiliano FERRO-LUZZI* — *13-2-005, CERN* — 14:00 - 14:20

Current status of RF box design — *Wouter HULSBERGEN* — *13-2-005, CERN* — 14:20 - 15:20

15:00 **Box+WF suppressors impedance** — *Benoit SALVANT et al.* — *13-2-005, CERN* — 15:20 - 15:40

Coffee Break — *13-2-005, CERN* — 15:40 - 16:10

16:00 **Dynamic vacuum simulations** — *Christina YIN VALLGREN* — *13-2-005, CERN* — 16:10 - 16:30

Low SEY coatings — *Pedro COSTA PINTO* — *13-2-005, CERN* — 16:30 - 16:50

LHCb/VELO vacuum system: treatments & operational requirements — *Giuseppe BREGLIOZZI* — *13-2-005, CERN* — 16:50 - 17:10

cancelled

17:00

18:00

19:00 **Social dinner**

Fri 6/2

08:00

Foil thinning results — *Massimiliano FERRO-LUZZI* — *160-1-009, CERN* — 08:30 - 08:50

Box etching — *Lucia LAIN AMADOR* — *160-1-009, CERN* — 08:50 - 09:10

09:00 **Motion system safety & refurbishment** — *160-1-009, CERN* — 09:10 - 09:30

Coffee Break — *160-1-009, CERN* — 09:30 - 10:00

10:00 **Upgrade VELO cooling strategy** — *Malcolm JOHN* — *160-1-009, CERN* — 10:00 - 10:30

Schedule, milestones — *Paula COLLINS* — *160-1-009, CERN* — 10:30 - 10:50

Discussion on schedule, dates and format of reviews — *160-1-009, CERN* — 10:50 - 11:20

11:00

https://indico.cern.ch/event/367805/overview

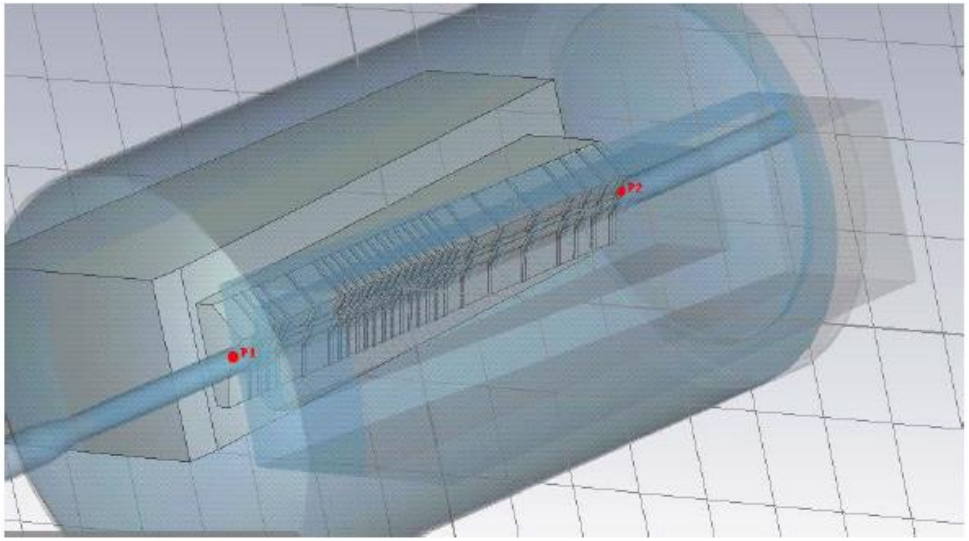
Highlights

- Impedance *et al*
- Dynamic vacuum
- Box frabrication and thinning

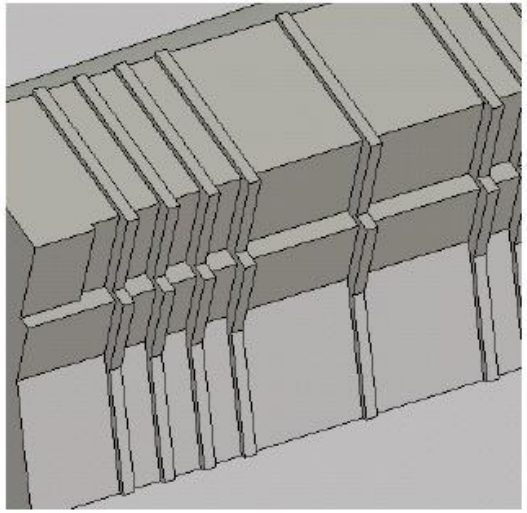
Simplifying the geometry further, to be able to keep the surrounding tank

- Simulation with full structure was crashing all the time
- We decided to redraw the full structure inside CST to avoid meshing issues (not a funny task!)
- Very coarse simplifications were therefore applied as a first step (to wakefield suppressor and blending of edges of the RF box)

Simplified structure

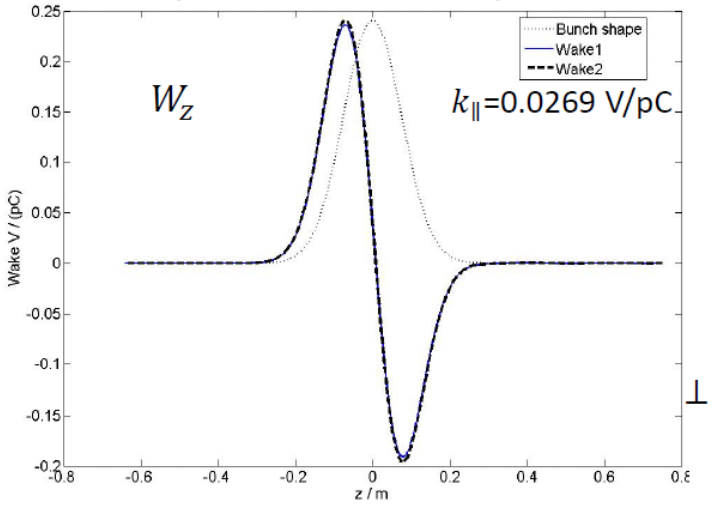


Detail of the RF box

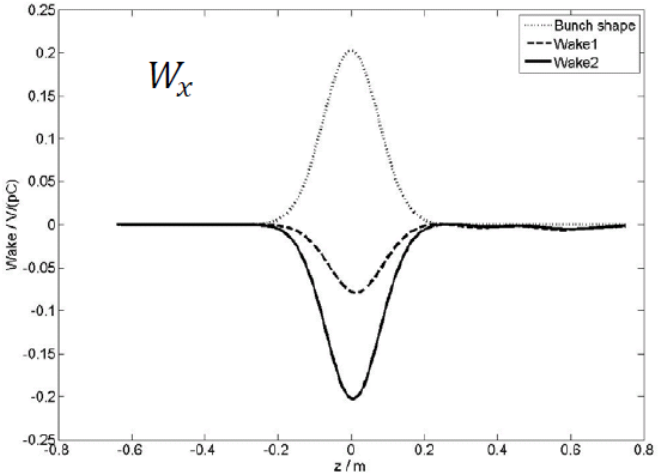


3D calculations with CST Microwave Studio 2015

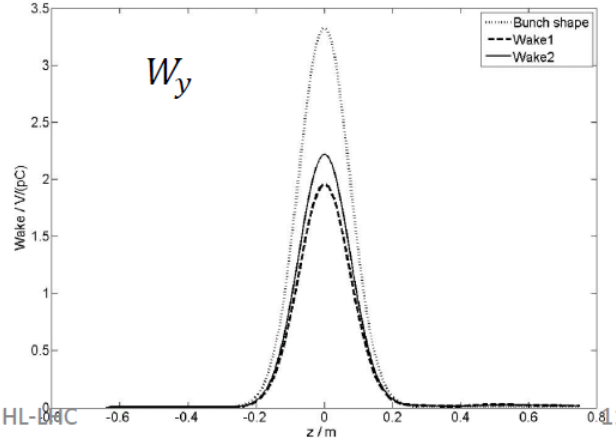
z-component of the wake potential



x-component of the wake potential



y-component of the wake potential

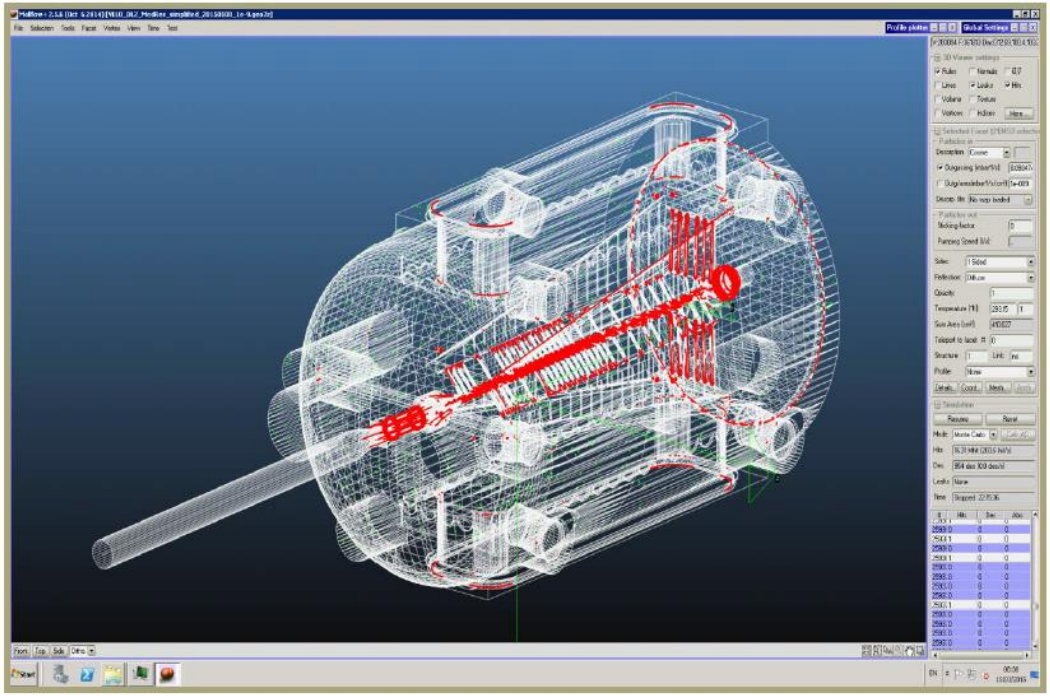


Wake 1 - for Mesh1 (95 805 540 cells)
Wake 2 - for Mesh2 (54 724 869 cells)

	Mesh1	Mesh2
$k_{\|\|}$(V/pC)	0.0269	0.0269
$k_{\perp x}$ (V/pC)	0.0547	0.1430
$k_{\perp y}$ (V/pC)	1.3807	1.5682

Christine Yin Vallgren

Molflow => Pumping speed/Pressure profile



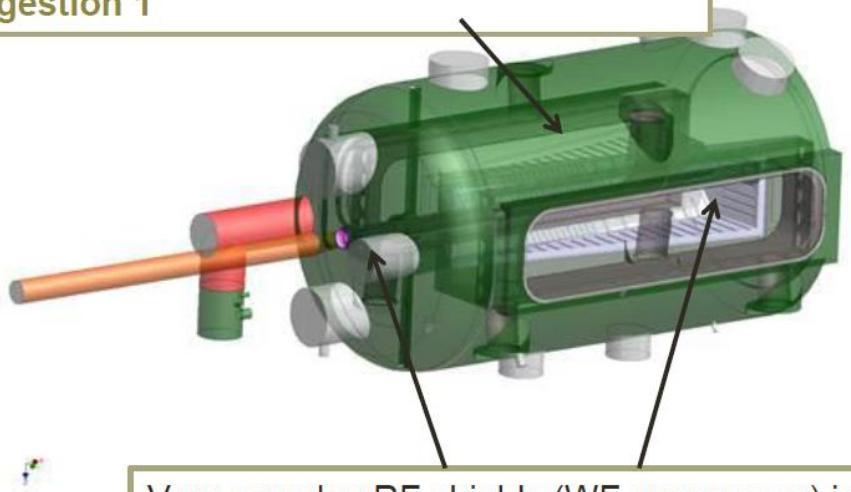
The original complex geometry can be used in Molflow, but:

- Large computational capacity / long computational time is needed.
- Better to use simplification of geometry…

Christine Yin Vallgren

Vacuum Limitation?

Molflow simulation gives: $C_{RF\ foil} \approx 1000$l/s
⇒ No conductance limitation with $S_{ion\ pump} = 180$l/s
⇒ $S_{effective}$ in the RF foil is only limited by $S_{ion\ pump}$.
⇒ **Suggestion 1**



Very complex RF shields (WF suppressor) is used to optimize the pumping speed in the RF foil?
For vacuum: the opening in the RF shields will not influence the pumping speed.
⇒ **Suggestion 2**

2015-02-05 LHCb VELO 19 VELO VACUUM – C. Yin Vallgren

Christine Yin Vallgren

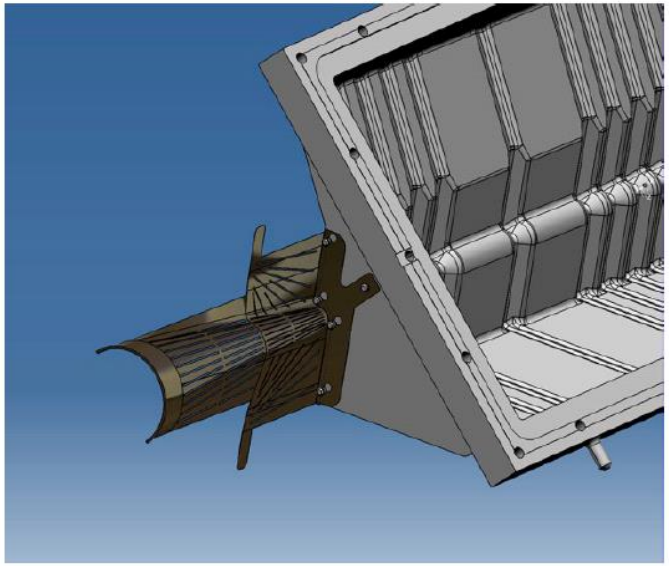
VASCO=> Critical current

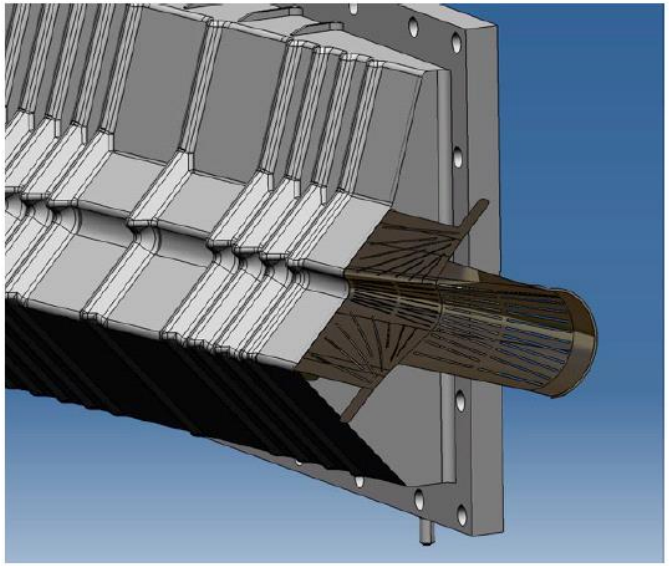
Material	Assumption	I_{crit} [A]	HL-LHC Status
Cu_baked	182l/s (H2) x 2 ion pumps	13.62	Stable
Cu_baked	500l/s (H2) x 2 ion pumps	14.08	Stable
Cu_baked	182l/s (H2) x 1 ion pumps	12.92	Stable
NEG_activ	182l/s (H2) x 2 ion pumps	>> I_{beam}	Stable
NEG_saturated	182l/s (H2) x 2 ion pumps	>> I_{beam}	Stable
Cu_baked	No ion pumps	<<< I_{beam}	Unstable!!

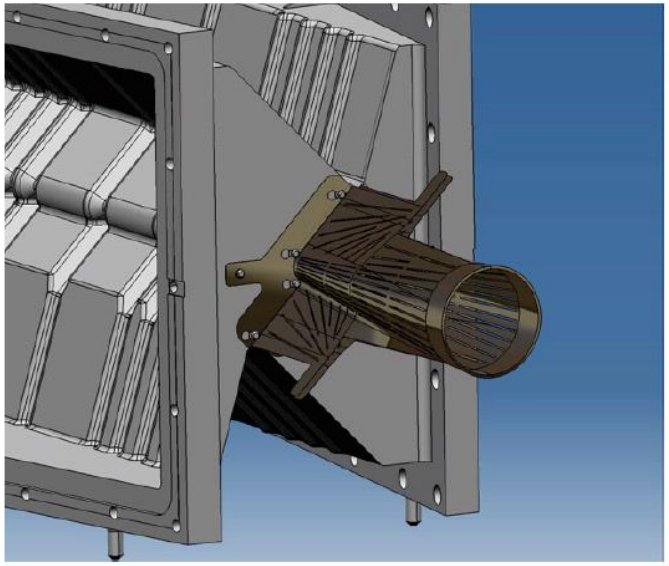
To be studied: NEG_saturated with no ion pumps.

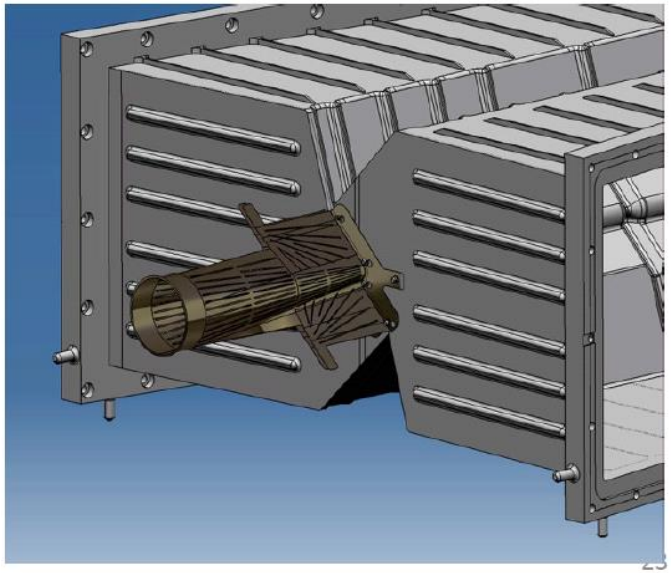
Box manufacturing

Wouter Hulsbergen et al









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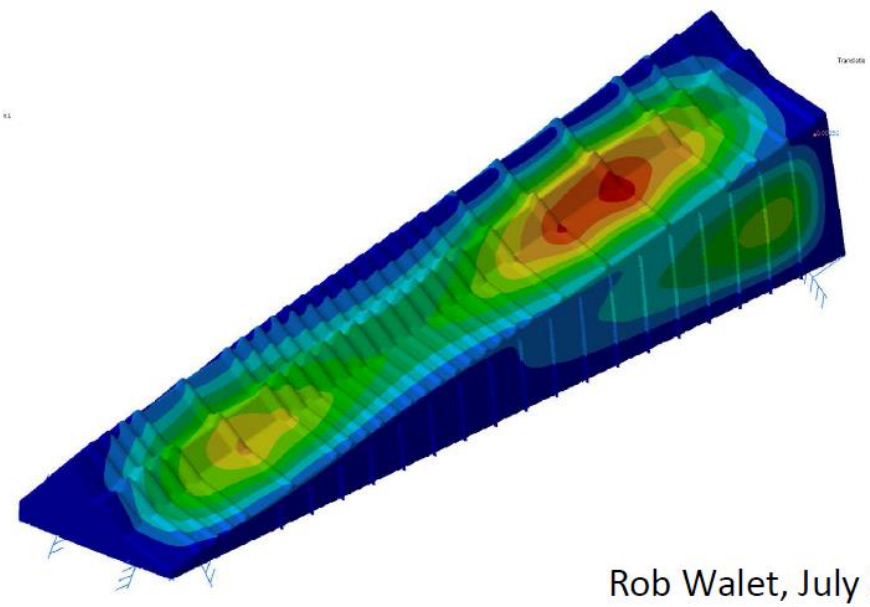
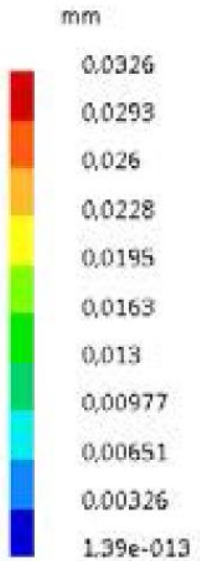
Stiffness

- in worst case foil sees Δp = +/-10mbar (by-pass SV421 opens)
- FEM analysis shows that deformations remain within ~33 mu for 250 mu thick foil: well within tolerances



Rob Walet, July 2014

displacement for 10mbar



- note: most of foil will be thicker than 250 mu; only 40 mm side section near beam needs to be <=250 foil

21

Box manufacturing

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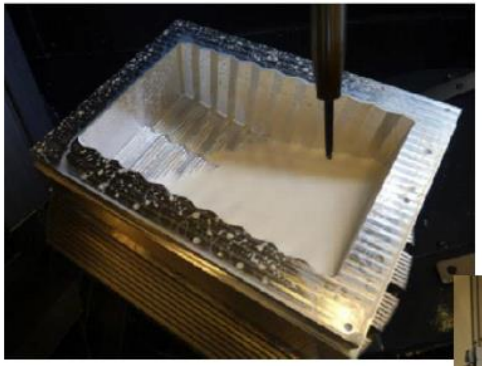
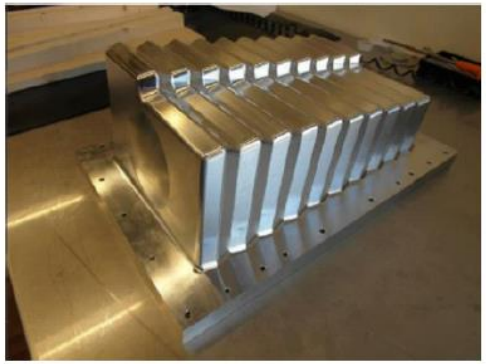
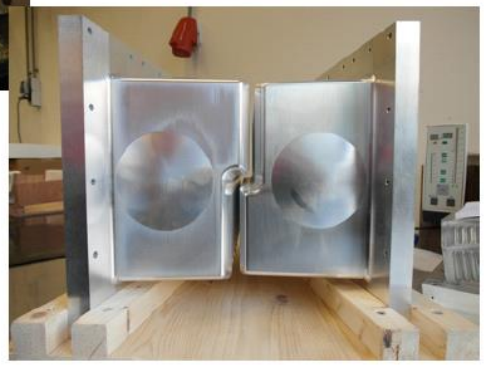
VU-MF boxes (2011)

- photo impression







http://www.nikhef.nl/pub/departments/mt/projects/lhcb-vertex/production/UpgradeRFbox/index.html

- in general, great success …
  → demonstrate milling technique for box production
- some important lessons learned: see next slides

31

Box manufacturing

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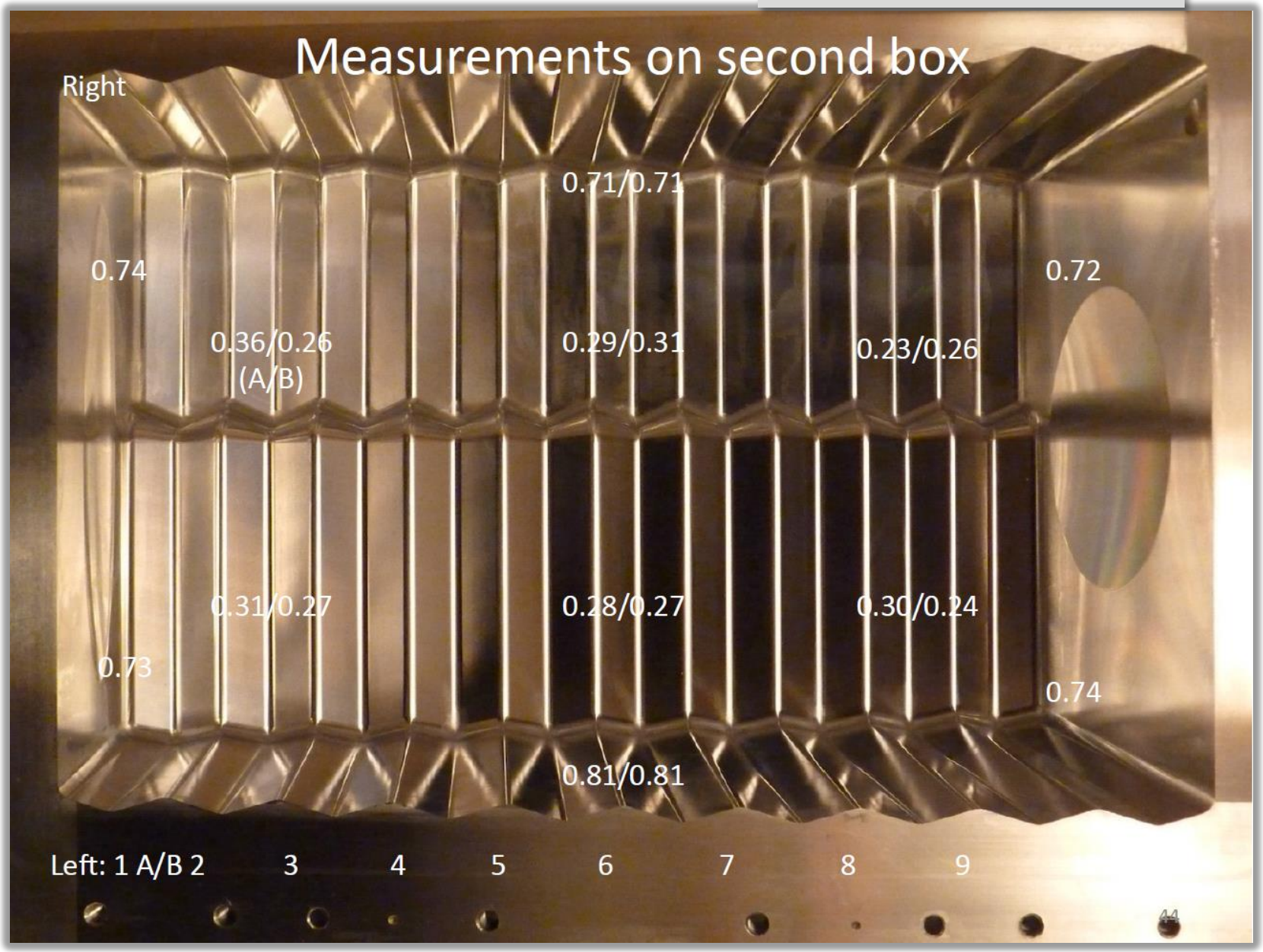

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Nikhef boxes (2014 – 2016)

- Final box is ~110cm long: need big machine
- DMF260 5-axis milling machine at Nikhef since 2012

"DMF 260 linear:
With a swivel milling head (B-axis) and an integrated NC rotary table."

"Large work area with 1,100 mm traverse path in the Y-axis,
a B-axis with 18,000 rpm and a tool magazine with 60 pockets. "

DMF 260 *linear*: A large work area with a 1,100 mm traverse path in the Y-axis, a B-axis with 18,000 rpm and a tool magazine with 60 pockets.

- reasonably certain that RF box fits, but some restrictions to degrees of freedom

53

Box manufacturing

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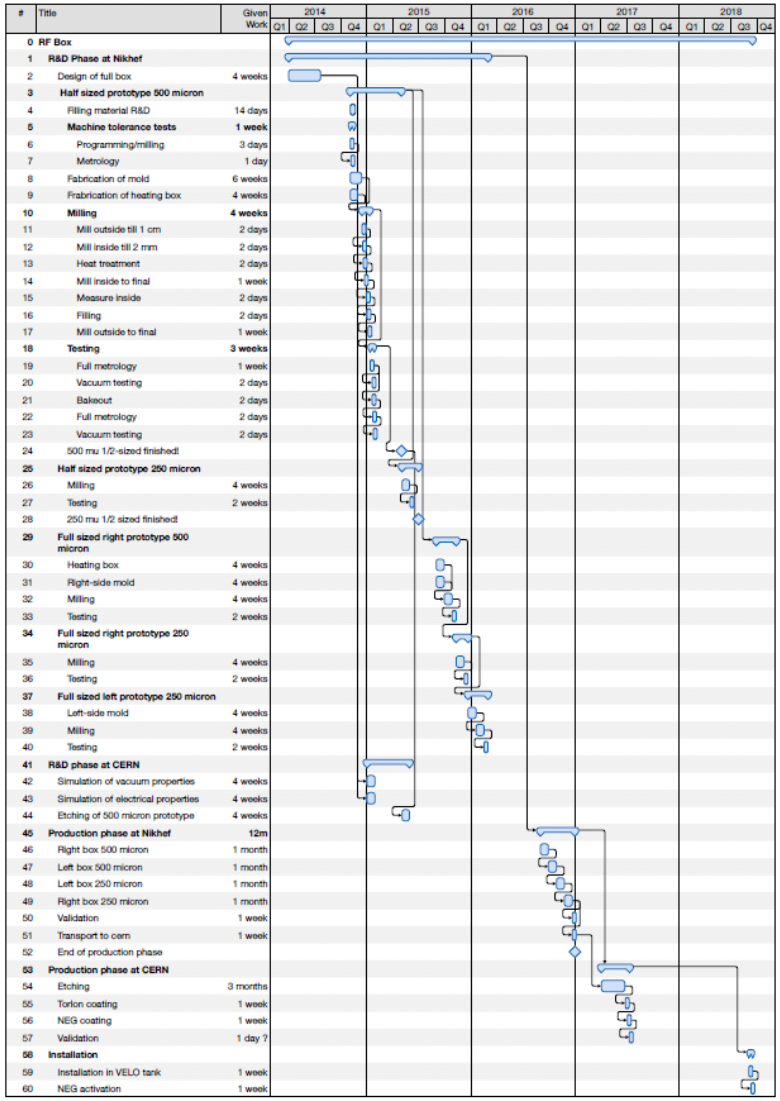
Time line



#	Title	Given Work
0	**RF Box**	
1	**R&D Phase at Nikhef**	
2	Design of full box	4 weeks
3	**Half sized prototype 500 micron**	
4	Filling material R&D	14 days
5	**Machine tolerance tests**	**1 week**
6	Programming/milling	3 days
7	Metrology	1 day
8	Fabrication of mold	6 weeks
9	Frabrication of heating box	4 weeks
10	**Milling**	**4 weeks**
11	Mill outside till 1 cm	2 days
12	Mill inside till 2 mm	2 days
13	Heat treatment	2 days
14	Mill inside to final	1 week
15	Measure inside	2 days
16	Filling	2 days
17	Mill outside to final	1 week
18	**Testing**	**3 weeks**
19	Full metrology	1 week
20	Vacuum testing	2 days
21	Bakeout	2 days
22	Full metrology	2 days
23	Vacuum testing	2 days
24	500 mu 1/2-sized finished!	
25	**Half sized prototype 250 micron**	
26	Milling	4 weeks
27	Testing	2 weeks
28	250 mu 1/2 sized finished!	
29	**Full sized right prototype 500 micron**	
30	Heating box	4 weeks
31	Right-side mold	4 weeks
32	Milling	4 weeks
33	Testing	2 weeks
34	**Full sized right prototype 250 micron**	
35	Milling	4 weeks
36	Testing	2 weeks
37	**Full sized left prototype 250 micron**	
38	Left-side mold	4 weeks
39	Milling	4 weeks
40	Testing	2 weeks
41	**R&D phase at CERN**	
42	Simulation of vacuum properties	4 weeks
43	Simulation of electrical properties	4 weeks
44	Etching of 500 micron prototype	4 weeks
45	**Production phase at Nikhef**	**12m**
46	Right box 500 micron	1 month
47	Left box 500 micron	1 month
48	Left box 250 micron	1 month
49	Right box 250 micron	1 month
50	Validation	1 week
51	Transport to cern	1 week
52	End of production phase	
53	**Production phase at CERN**	
54	Etching	3 months
55	Torlon coating	1 week
56	NEG coating	1 week
57	Validation	1 day ?
58	**Installation**	
59	Installation in VELO tank	1 week
60	NEG activation	1 week

- Q1: half-sized box, 500 mu thick
- Q2: half-sized box, 250 mu thick
- Q3: full-sized 500 mu
- Q4: full-sized 250 mu

- 2016Q2-2017Q2: production

- 2018: installation

- still need to plan reviews

56

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R&D on fixing leaks

Two methods foreseen:

1. repair with Al, e.g. with laser welding
   - good for 'macroscopic leaks'
   - experts at VDL (Dutch company) and TU Delft did not succeed to far (see next slides)

2. paint with Torlon!
   - applied to 'VELO-side' for electrical insulation
   - basically applied with a brush, then hardened by heating for several hours at ~200 degrees C
   - side-effect: very effective to fix small leaks

64

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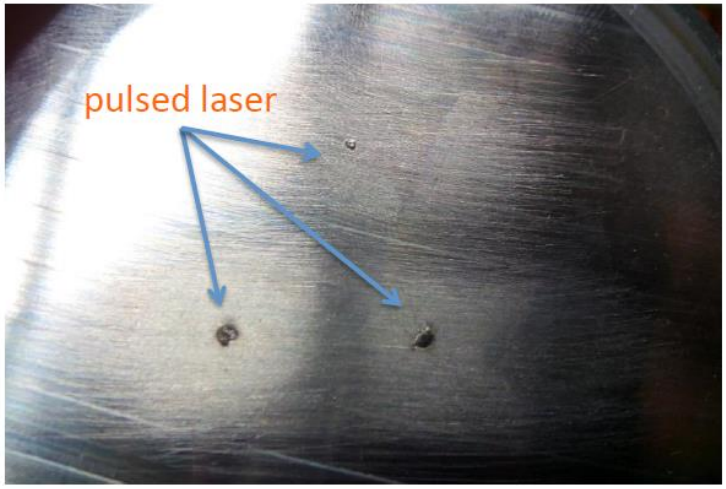
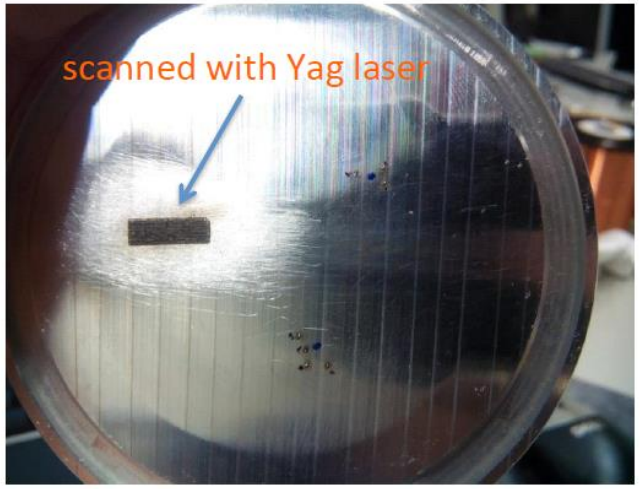
VDL (II)

- try 2a: short single pulse without adding material
  - Alu melts, but holes not closed; surface no longer flat and looses contact with Cu heater below
- try 2b: same, but now added small 'dot' of 99.5% Alu
  - obtain good melt, but added Alu falls through the 0.1 mm holes!





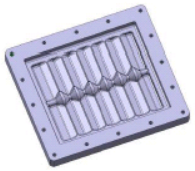
- also tried with pulsed Yag laser, but similar results

70

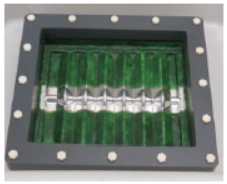
Box thinning

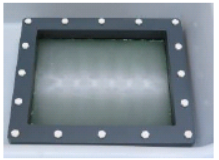
Lucia Amador

Chemical thinning procedure:

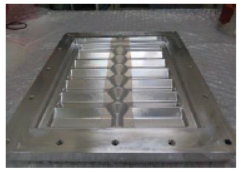


Sample → (Sample weighing) → Degreasing → (Sample weighing) → Flange assembling and Masking





Etching with NaOH 5M → Rinsing with deionised water → Removal of the mask



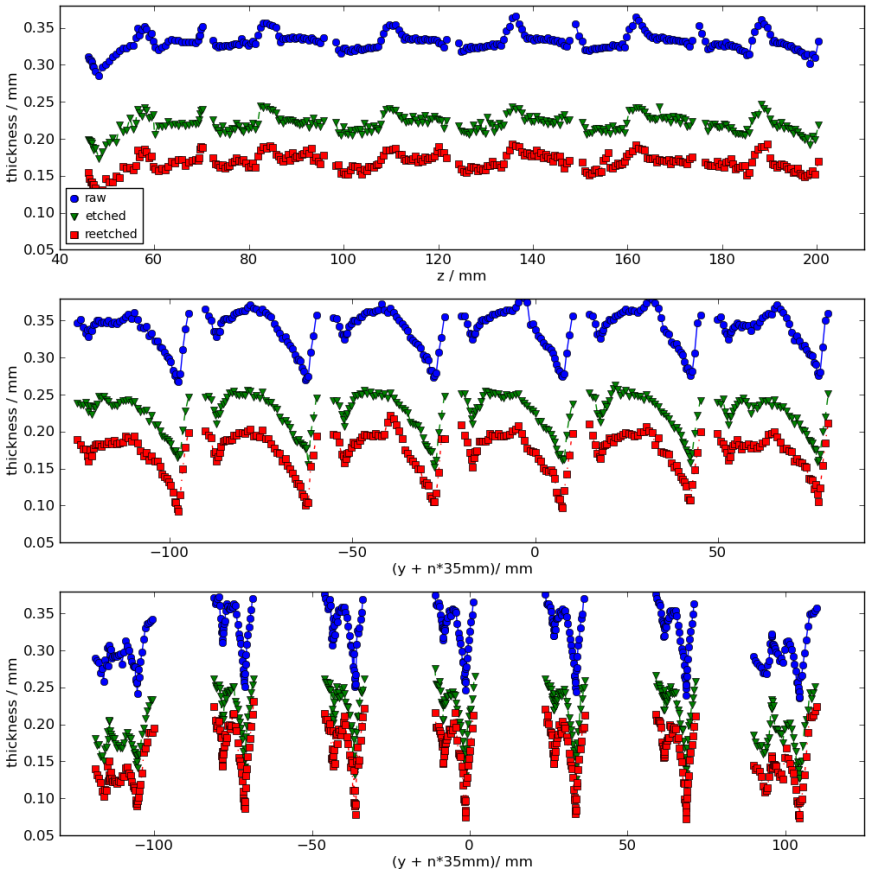
Removal of the mask → (Sample weighing) → Control removed thickness

Etching with NaOH 5M → Taking sample of the bath after etching (0.5 L (NaOH 5M +Al)) → Analysis of the content of Al with ICP → Control removed thickness

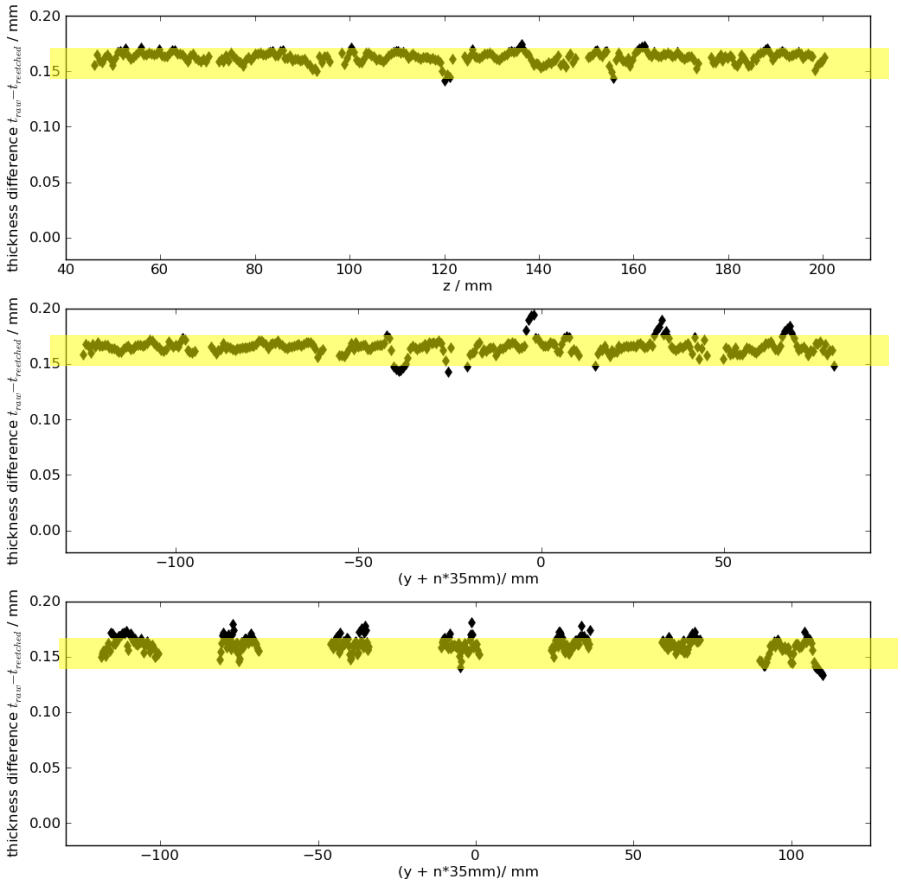
Control removed thickness → Local thickness Metrology

Box thinning

thickness



thickness difference "raw - reetched"



yellow bands ~30um width

NB: here, 3 successive etchings

Box thinning

Lucia Amador

What we have learnt

- From the chemical etching process
  - Process is very sensitive to the temperature of the etching bath. The temperature should be always controlled during the etching.
  - Etching is not sensitive to the surface shape (uniform removed thickness).
- How to mask / unmask areas that must not be thinned
  - Make several coatings with Abdecklack Nr.1. Mask shows very good results: No residues, no plastic deformation and easy to remove if thicker enough.

How to control the average removed thickness

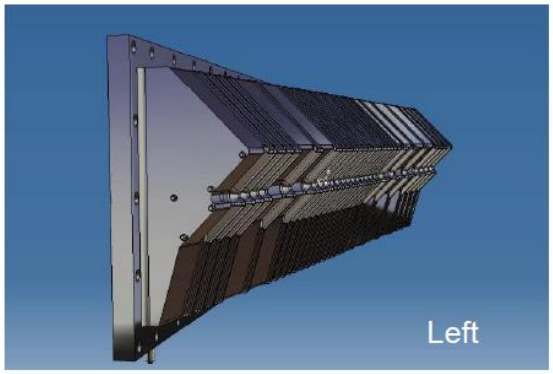
- By weighing or measuring the aluminium concentration of the bath. Good correlation with metrology results.

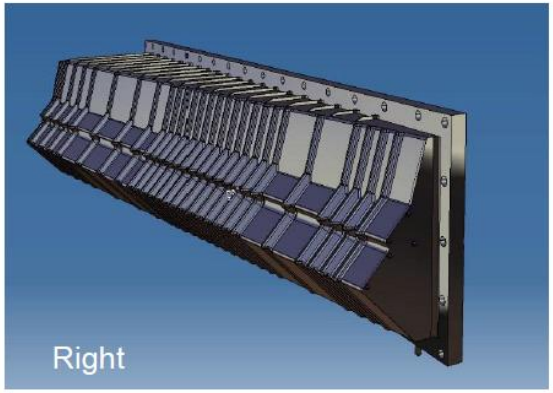
Lucia Amador

What we do not know

- Possible impact of larger dimensions
  - Difficult handling of the piece.
    (degreasing, painting and etching)
  - Weight control more difficult.
  - ICP control not affected.
  - Local increase of temperature
  - Different chemistry for rinsing.
    - Step of acidic rinsing due to big surface
- Working proposal

  Make a trial in a real size mock-up.





What next

Impedance et al.

- Just starting. Preliminary tests were done. Structure is very difficult to handle, mesh problems. Coarse simplifications needed. Large amount of work to redraw and simplify.
- Olga needs a short model version to be able to calculate with CST MW. Model should have a few corrugations and the connections to the same WF suppressors. => NIKHEF: make available
- Olga/Benoît: Preliminary results indicate potential nuisance of a "large" longitudinal impedance. To be confirmed and impact assessed.
  - Calculations of the wake potentials on-axis for 3D original model with sufficient accuracy and off-axis for approximate models and for original model for different mesh sets.
  - Might be reduced by reducing depths of corrugations ? It was not clear whether that is possible at all (mechanical limits). If possible, impact on VELO performance should be studied (LHCb MonteCarlo).
- Benoît: Evaluate local power loss in Al foil as function of distance to beam (assuming box moves to beam by mistake). From that, evaluate thermal impact on foil (LHCb) => evaluate validity of current foil protection strategy (BCM)
- Benoît's proposal: look into 2012 VELO temperature data (Eddy Jans) and make use of 2015 insertions to try to predict what could happen to the new foil.

dynamic vacuum and low-SEY coatings

- RF box design is OK (performs better than current one!)
  - suggestions made and will be considered
- For specification of leak-tightness, the key conditions are when beam vacuum is under 1atm ultrapure neon and the detector under ambient air. Lack of knowledge about SEY of NEG exposed to air at low pressures:
  - Mauro Taborelli's group will try to make measurements of the SEY of activated NEG exposed 10-100s at 1e-8 mbar and then see what happens for longer times
  - Based on this, one could properly define what leak rate is acceptable for the RF box (during detector installation, neon/air)
  - If the SEY results come out much worse than for CO saturation, it was suggested one could pre-saturate with CO. (to be investigated)
- Low SEY: carbon could be an option for the VELO, but more properties need to be established (like ion desorption yield)
- Vacuum group would like LHCb to define what dynamic vacuum pressure is acceptable for the experiment. => needs beam-gas MC simulation (LHCb)

Box manufacturing & thinning

Etching:

- Leonel Ferreira's team could make good use of toy boxes for testing (handling issues, tooling).
- NIKHEF will deliver a 500um half size box soon (Q2 ?) after it has been tested (leaks, deltaP, metrology). Box can be tested for etching developments.
- Full-size 500um proto will come in 2nd half of 2015. Could also be shipped for real size etching tests
- The three CERN samples are at NIKHEF for further testing, in particular the DeltaP cycling.

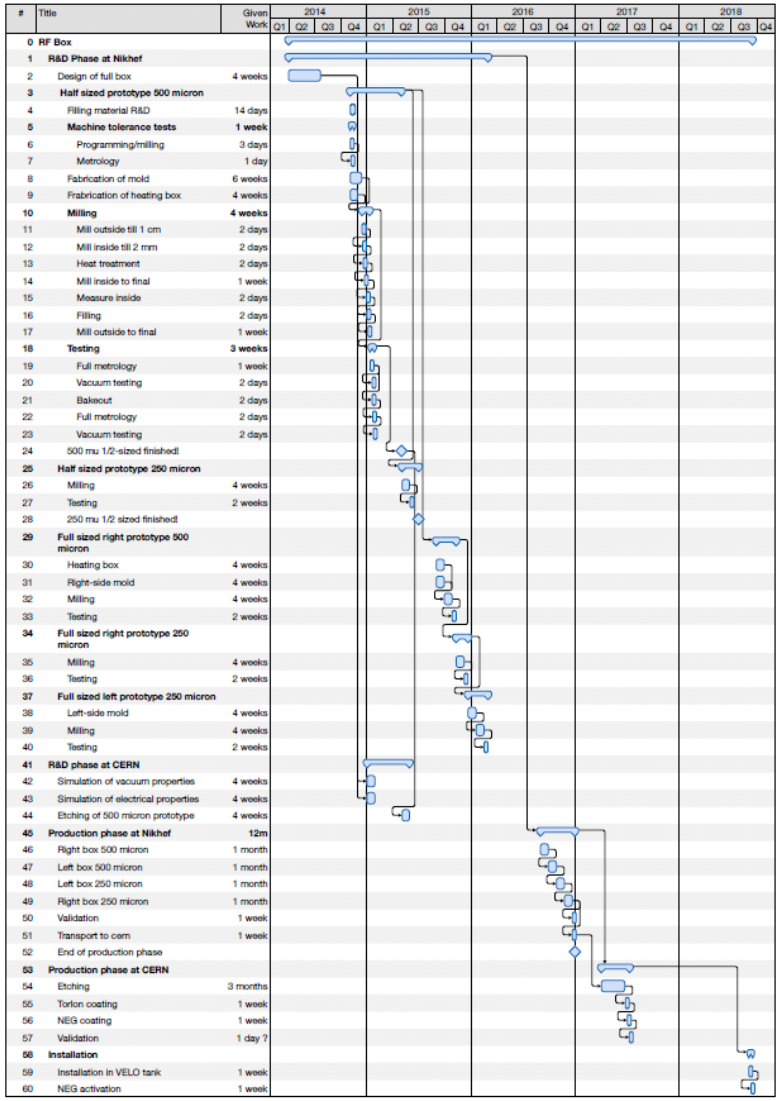
Material choice:

- Floriane Leaux: for such critical application (machining in all direction, low thickness, vacuum…) advises to use wrought products with a fine grain size (<50 um) and isotropic microstructure (3D forged blanks). Can be ordered via CERN
- NIKHEF: define what blocks we want, get price quotation

Box manufacturing schedule

Wouter Hulsbergen et al

Time line



#	Title	Given Work
0	**RF Box**	
1	**R&D Phase at Nikhef**	
2	Design of full box	4 weeks
3	**Half sized prototype 500 micron**	
4	Filling material R&D	14 days
5	**Machine tolerance tests**	**1 week**
6	Programming/milling	3 days
7	Metrology	1 day
8	Fabrication of mold	6 weeks
9	Frabrication of heating box	4 weeks
10	**Milling**	**4 weeks**
11	Mill outside till 1 cm	2 days
12	Mill inside till 2 mm	2 days
13	Heat treatment	2 days
14	Mill inside to final	1 week
15	Measure inside	2 days
16	Filling	2 days
17	Mill outside to final	1 week
18	**Testing**	**3 weeks**
19	Full metrology	1 week
20	Vacuum testing	2 days
21	Bakeout	2 days
22	Full metrology	2 days
23	Vacuum testing	2 days
24	500 mu 1/2-sized finished!	
25	**Half sized prototype 250 micron**	
26	Milling	4 weeks
27	Testing	2 weeks
28	250 mu 1/2 sized finished!	
29	**Full sized right prototype 500 micron**	
30	Heating box	4 weeks
31	Right-side mold	4 weeks
32	Milling	4 weeks
33	Testing	2 weeks
34	**Full sized right prototype 250 micron**	
35	Milling	4 weeks
36	Testing	2 weeks
37	**Full sized left prototype 250 micron**	
38	Left-side mold	4 weeks
39	Milling	4 weeks
40	Testing	2 weeks
41	**R&D phase at CERN**	
42	Simulation of vacuum properties	4 weeks
43	Simulation of electrical properties	4 weeks
44	Etching of 500 micron prototype	4 weeks
45	**Production phase at Nikhef**	**12m**
46	Right box 500 micron	1 month
47	Left box 500 micron	1 month
48	Left box 250 micron	1 month
49	Right box 250 micron	1 month
50	Validation	1 week
51	Transport to cern	1 week
52	End of production phase	
53	**Production phase at CERN**	
54	Etching	3 months
55	Torlon coating	1 week
56	NEG coating	1 week
57	Validation	1 day ?
58	**Installation**	
59	Installation in VELO tank	1 week
60	NEG activation	1 week

- Q1: half-sized box, 500 mu thick
- Q2: half-sized box, 250 mu thick
- Q3: full-sized 500 mu
- Q4: full-sized 250 mu

- 2016Q2-2017Q2: production

- 2018: installation

- still need to plan reviews

56

RF box milestones

- **February 2015:** RF box and cooling workshop
- **Q4 2015:** RF box EDR (date to be decided)
- **May 2016**: Decision on etching
- **September 2016**: RF foil PRR (Official LHCC)
- **October 2016:** RF box production
- **October 2017:** RF box etching (if used)
- **Q1-Q3 2018**: low-SEY coating
- **Q1-Q3 2018:** integration of system control
- **October 2018:** RF box installation, leak testing, bakeout