Horn R&D for 2002-2003

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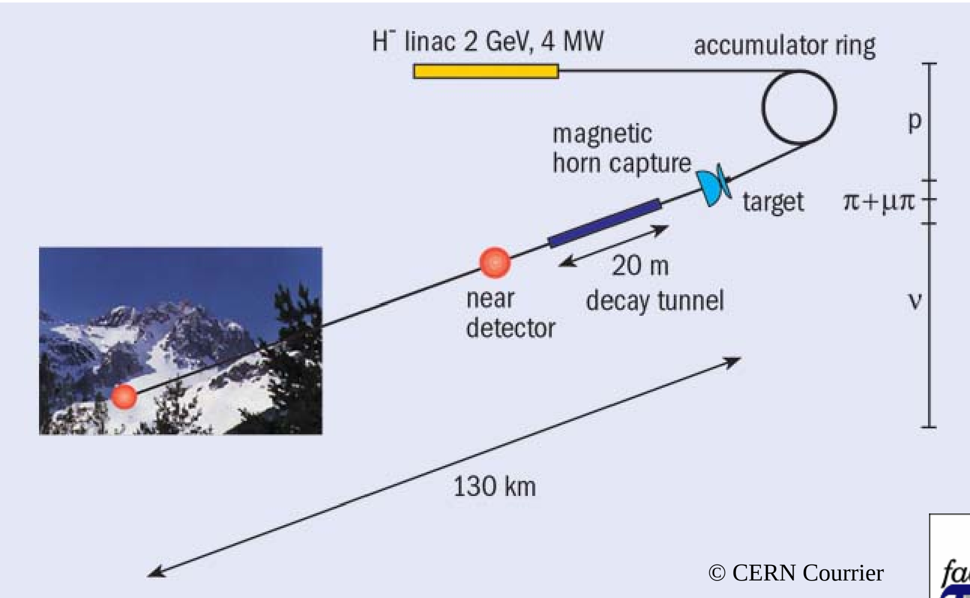
For the CERN Horn working group

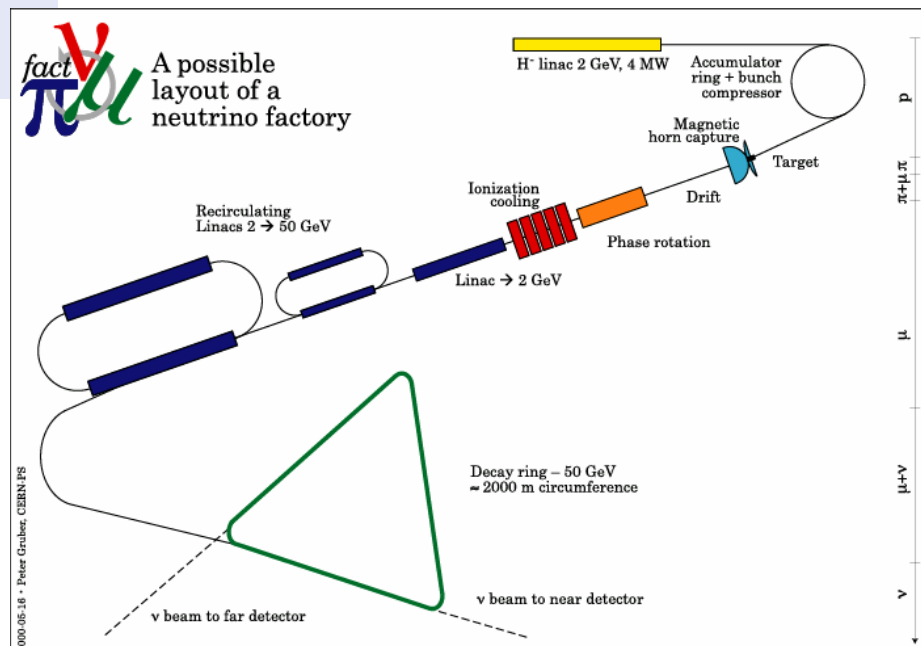
presented by

H. D. Haseroth

Nufact + SuperBeam



Different horn design&optimisation



Same technological issues:

- Lifetime estimation
- Target-horn integration

Horns available from the shelf

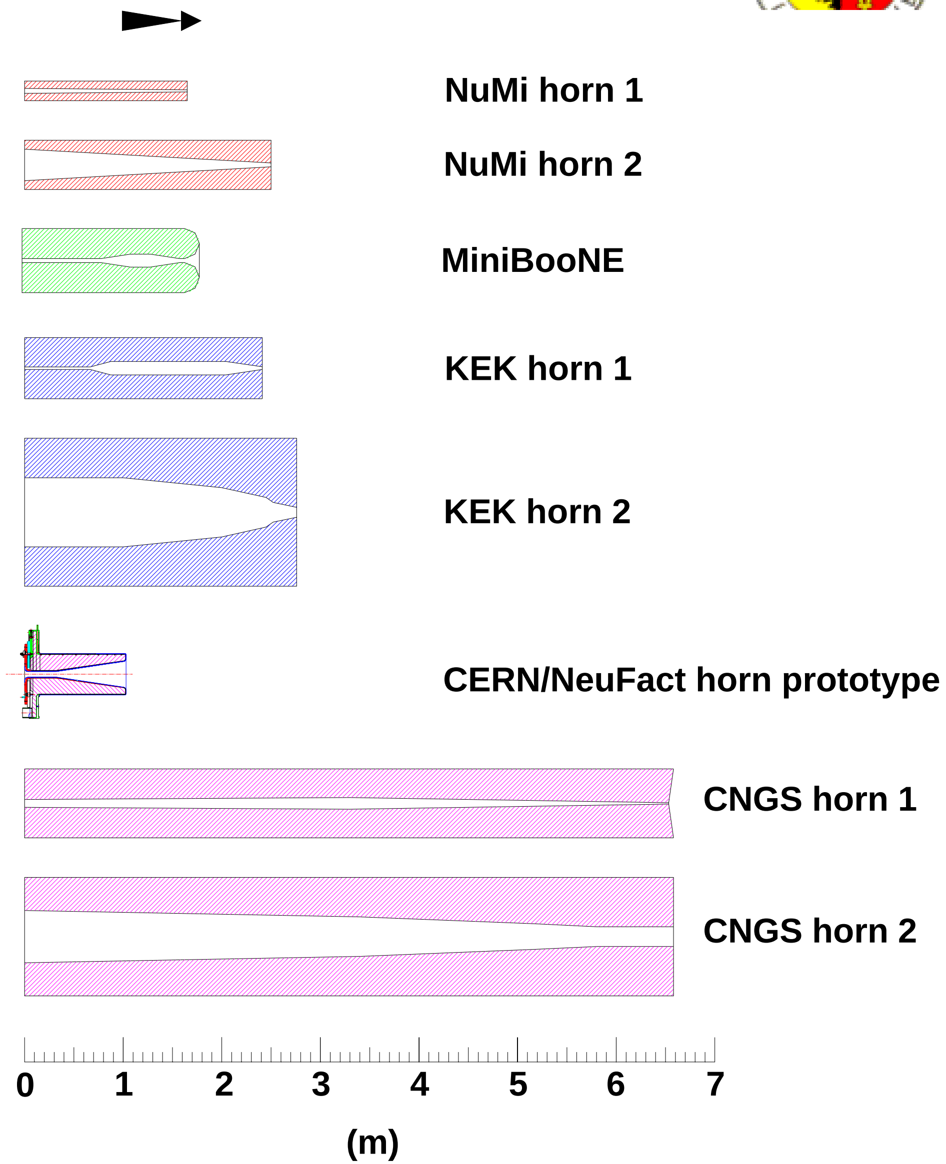
Numi: 200 kA, 0.5 Hz, 6M pulses
1 year

MinibooNe: 170 kA, 5 Hz, 11M pulses
1 year

K2K: 250 kA, 0.5 Hz, 11M pulses
1 year

Nufact: 300 kA, 50 Hz, 200 M pulses
6 weeks

CNGS: 150 kA, 2 pulse/6s, 42 M pulses
4 years

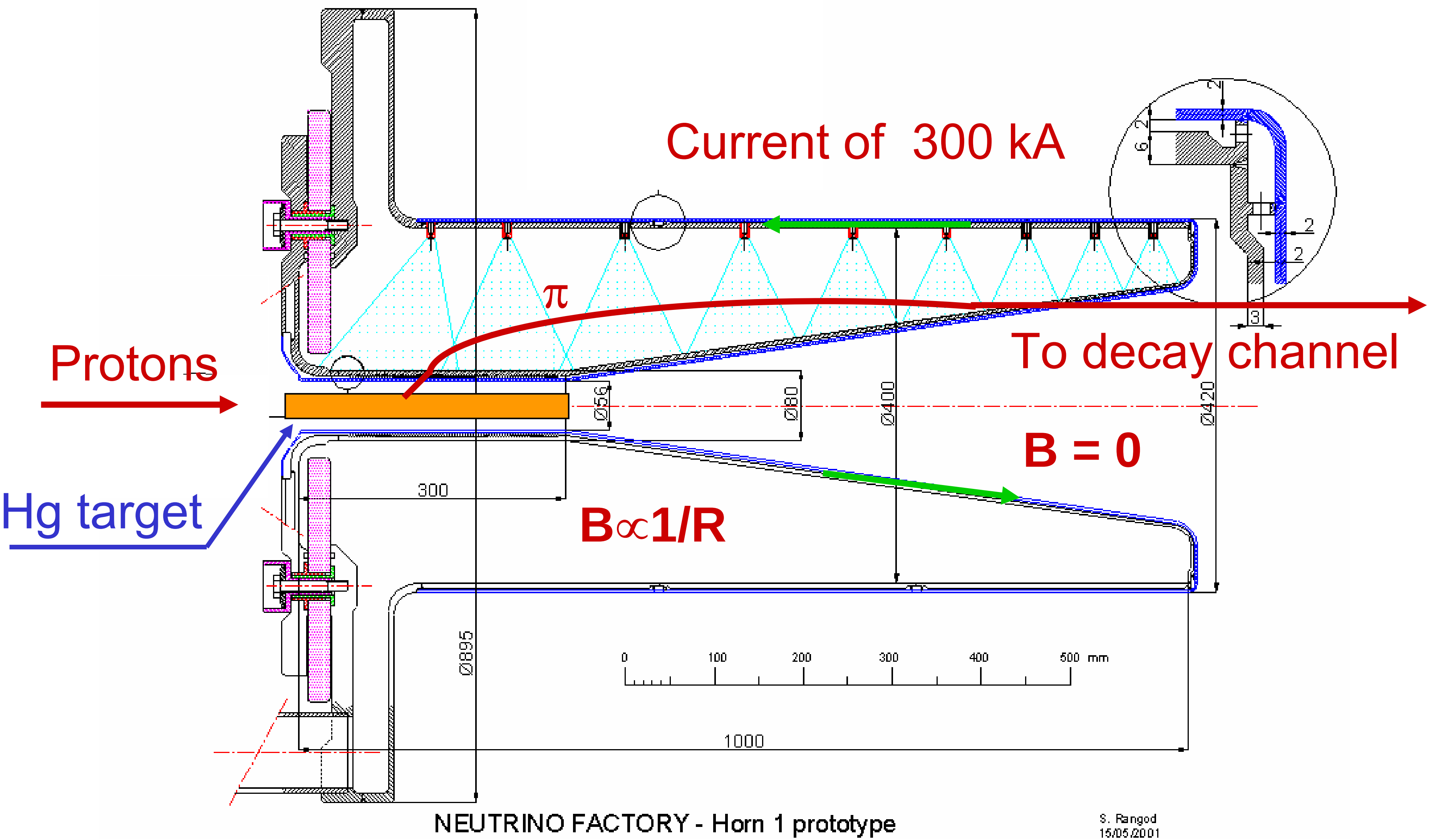


The challenge of low ν-energy

- The target is not point-like:
  - Normally 1-2 interaction lengths
    - Order 20-30 cm for heavy targets (Hg)
- Particle produced with large energy spread
  - Typical transverse momentum 250 MeV/c
  - Typical energy around 1 GeV (even less)
  - **Large divergence**
- In any case, from Van der Meer:
  - Max angle for a given momentum depends only on the square root of the current

$$\theta_{MAX} = \sqrt{\frac{\mu_0 I}{2\pi B\rho}}$$

Horn focusing system



Target inside or outside ?

Target INSIDE for low energy

- Max p_t more or less independent from the energy
  - p_t = 250 MeV/c

p_{tot}= 600 MeV/c

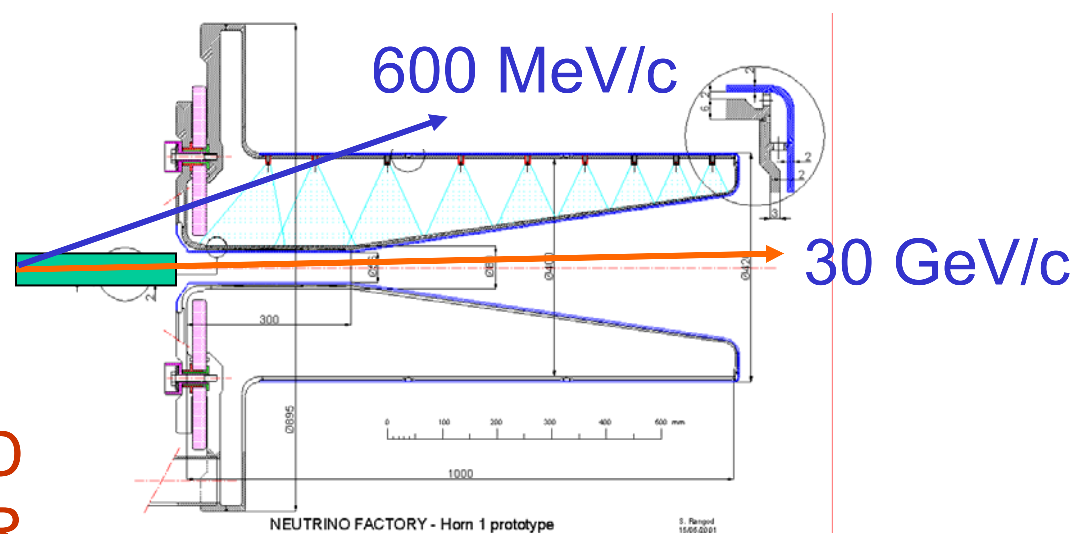
θ = 24º

R(z=30 cm)= 13 cm

p_{tot}= 30 GeV/c

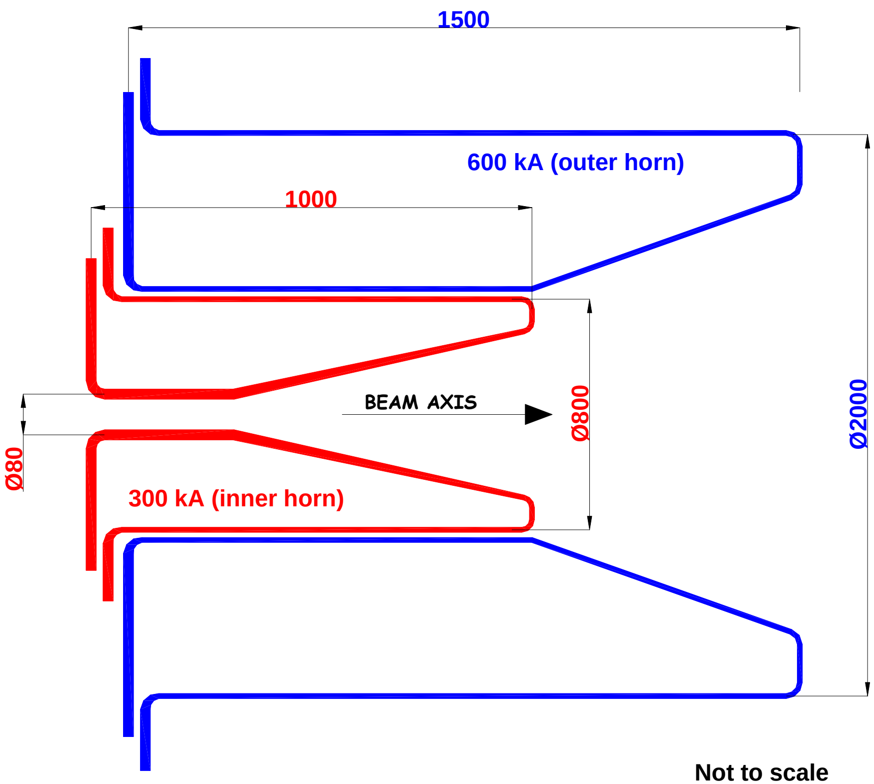
θ = 0.47º

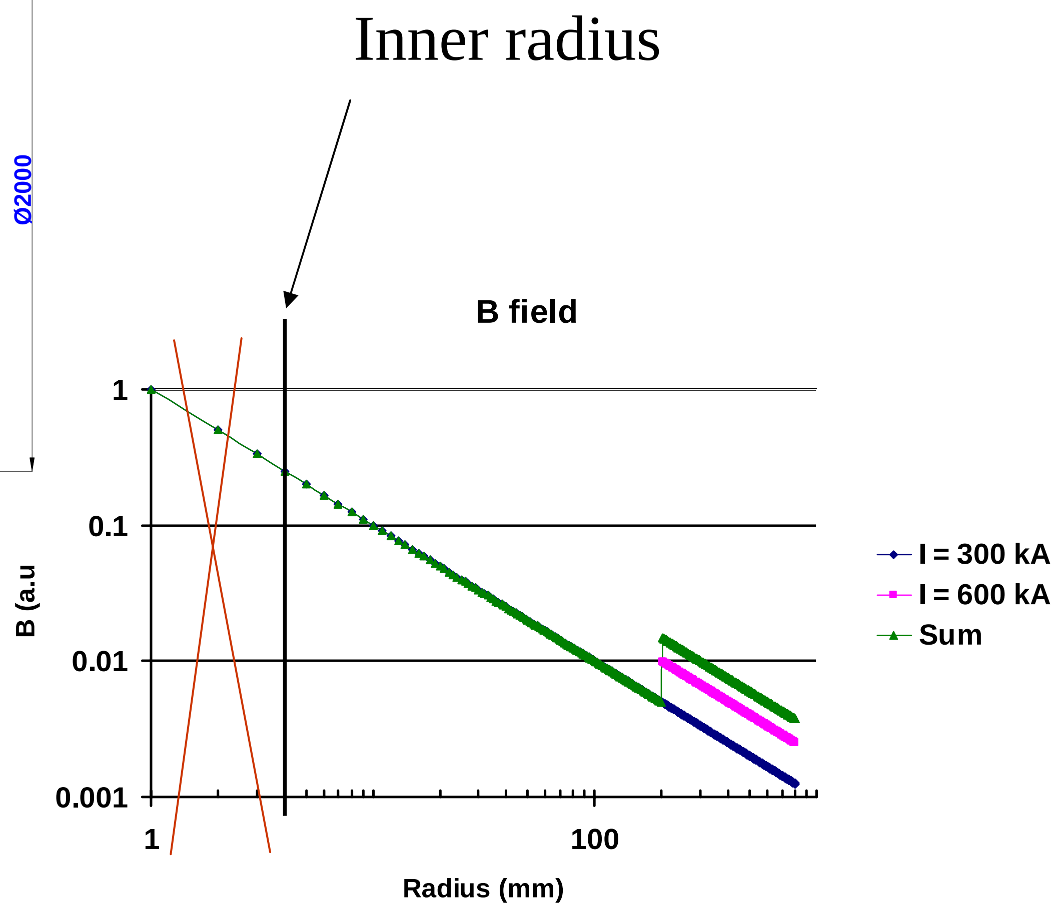
R(z=30 cm)= 0.25 cm



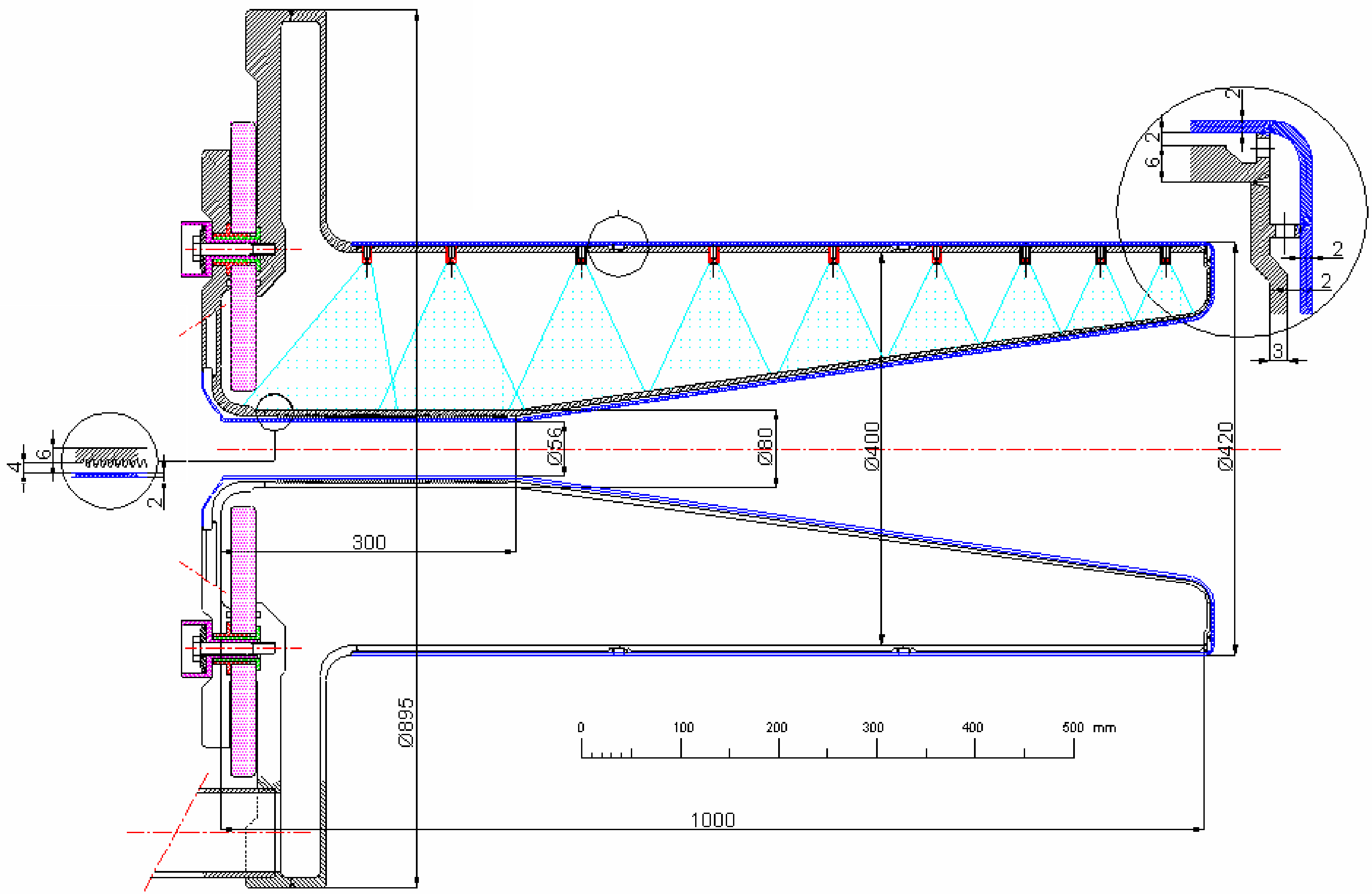
TARGET AND HORN R&D
HAVE TO GO TOGETHER

Double horn concept





Horn first prototype



NEUTRINO FACTORY - Horn 1 prototype

S. Rangod
15/05/2001

What we planned to do

- First "inner" horn 1:1 prototype
- Power supply for Test One:
  30 kA and 1 Hz, pulse 100 μs long
  - ✓ First mechanical measurements
  - ➢ Test of numerical results for vibration
  - ✓ Test of cooling system

done

- Test Two: 100 kA and 0.5 Hz
  – Testing during this week
- Last test: 300 kA and 50 Hz

Unknown schedule

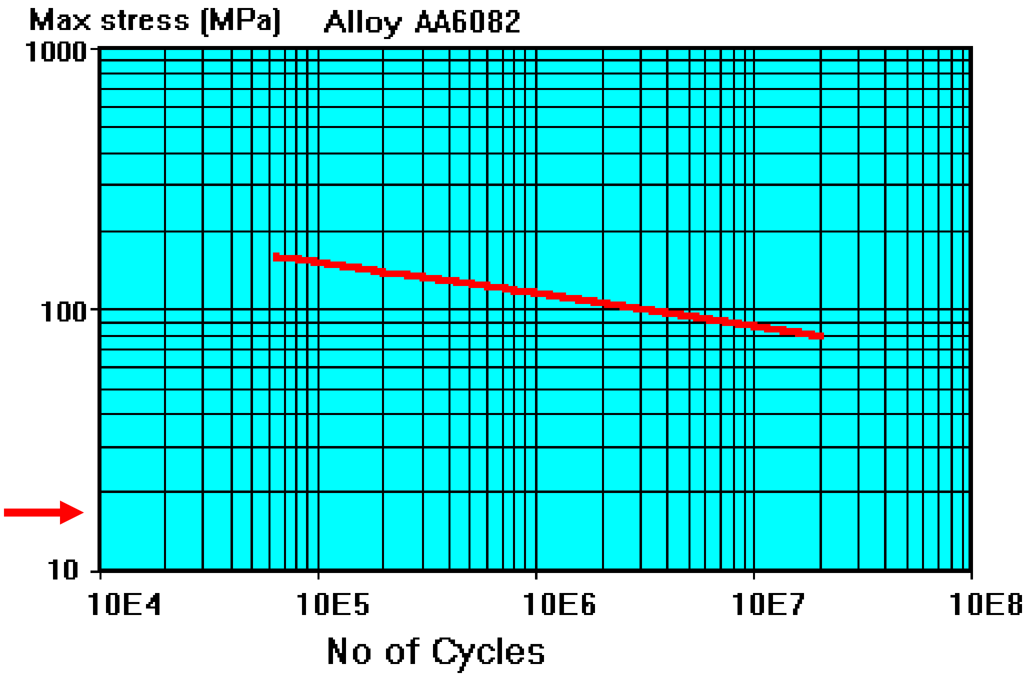
Goal: Horn Life-Time 6 weeks ($2*10^8$ pulses)

First prototype ready

Material choices

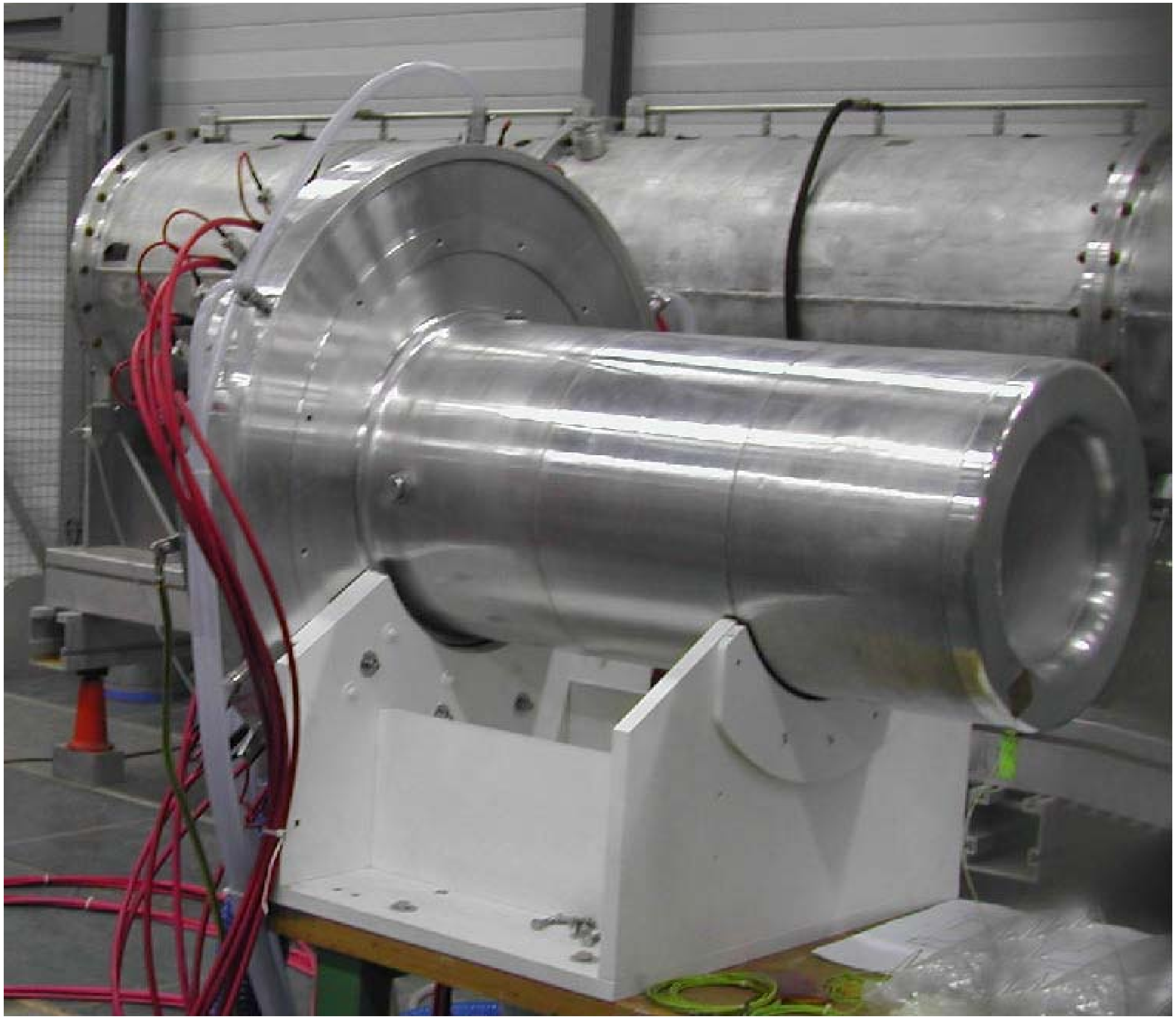
- **AA 6082-T6 / (AlMgSi1) is an acceptable compromise between the 4 main characteristics:**
  - Mechanical properties
  - Welding abilities
  - Electrical properties
  - Resistance to corrosion
  - Same for CNGS

Max. allowed stress →

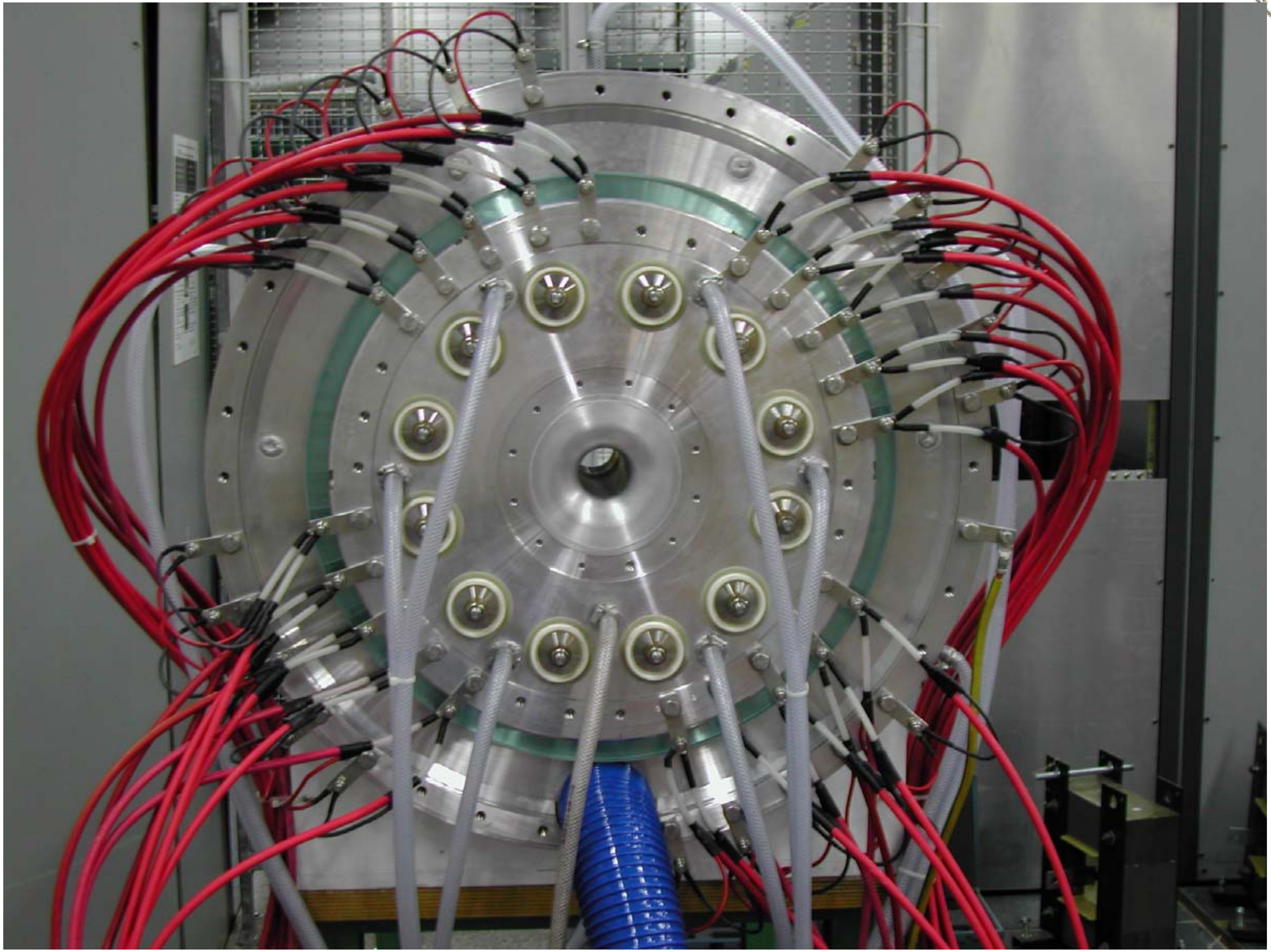


Not compatible with Mercury

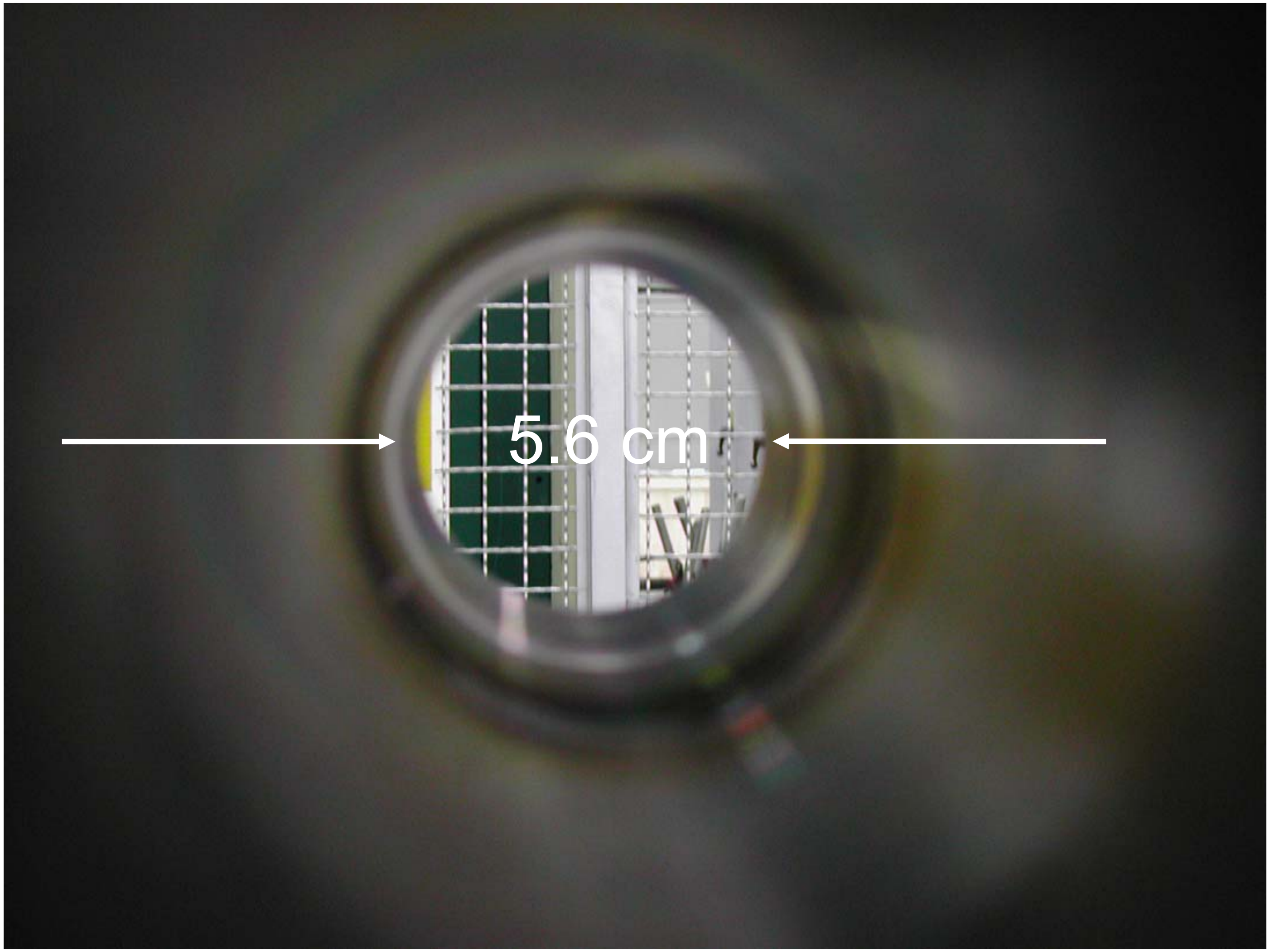
Horn prototype ready for tests



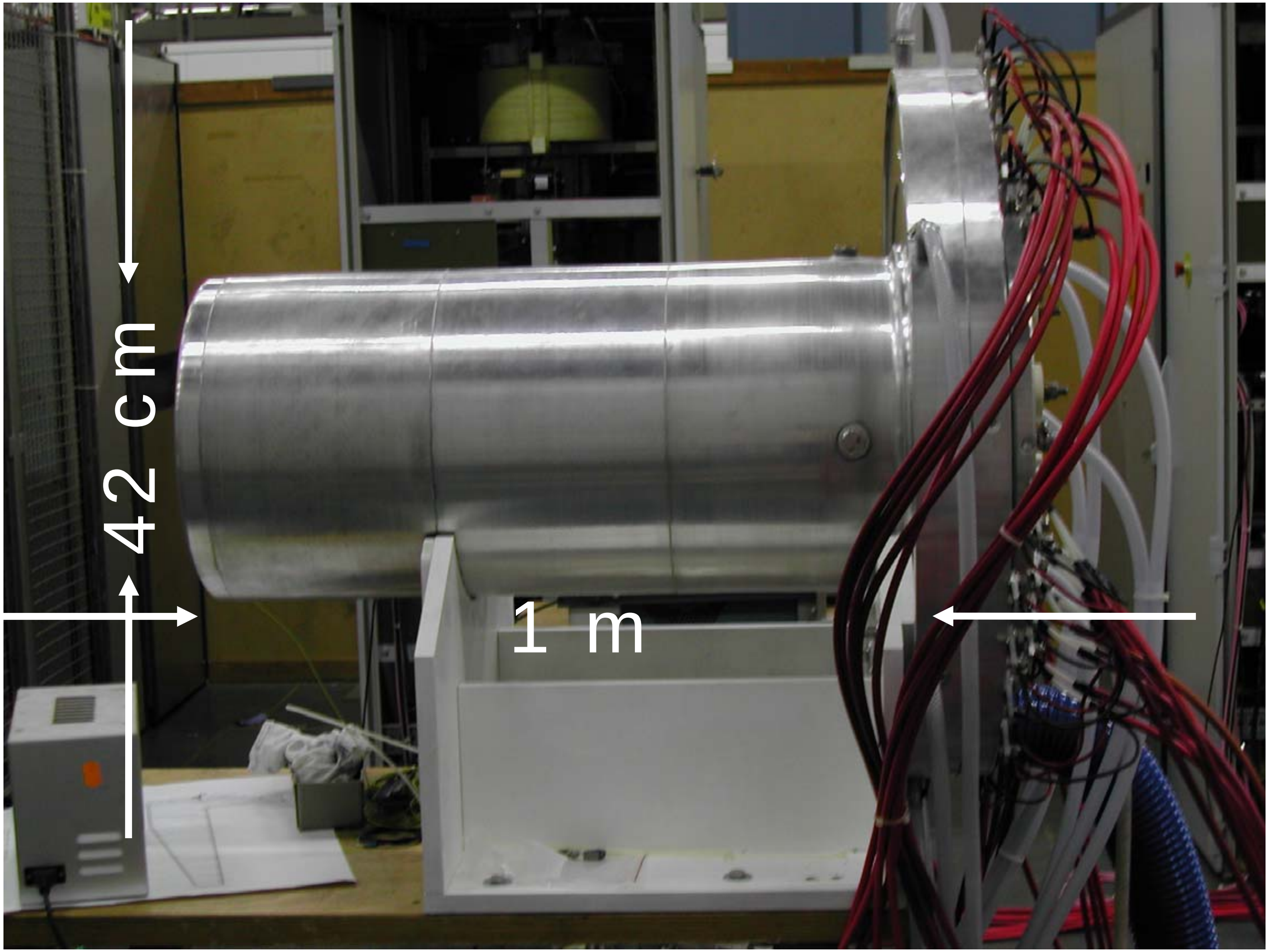
Electrical and water connections



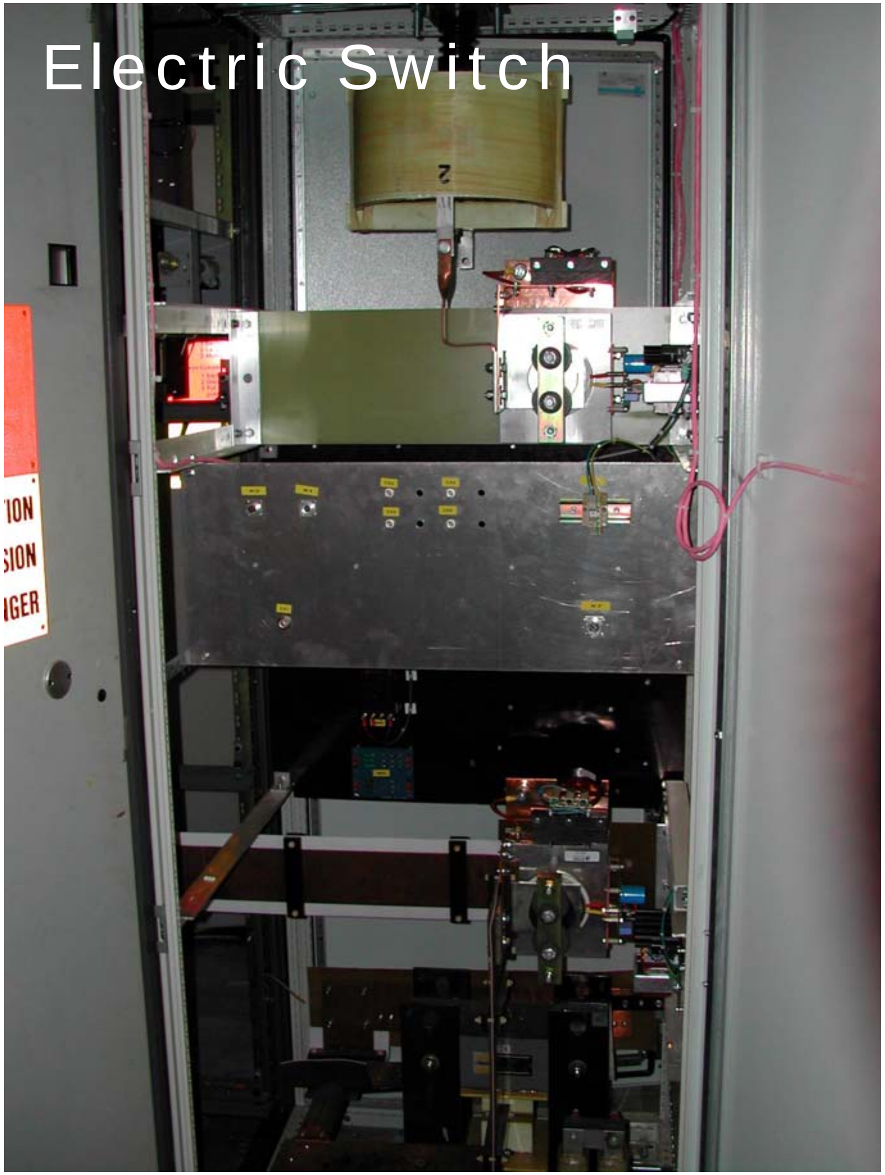
Inside the neck



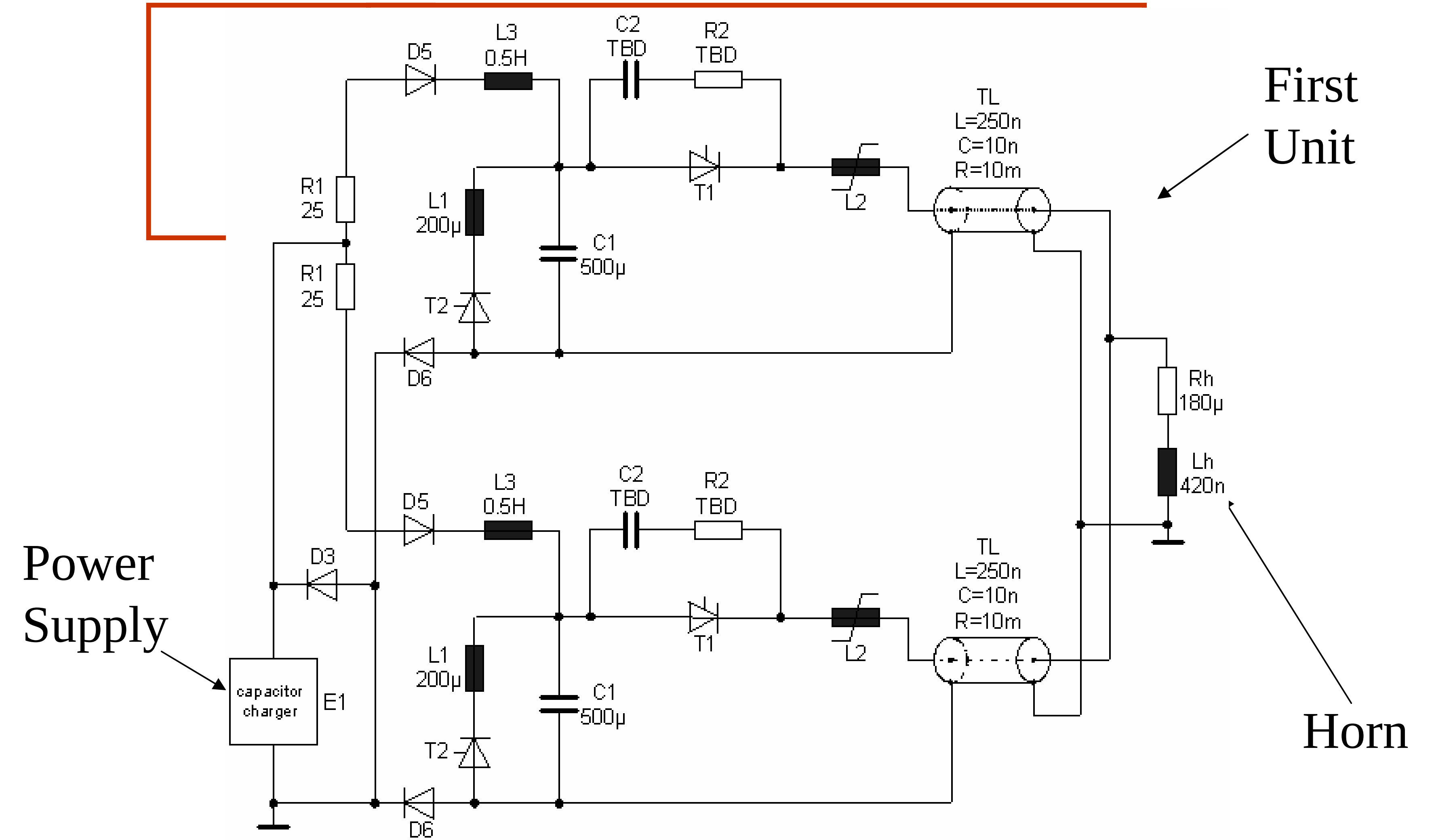
Lateral view



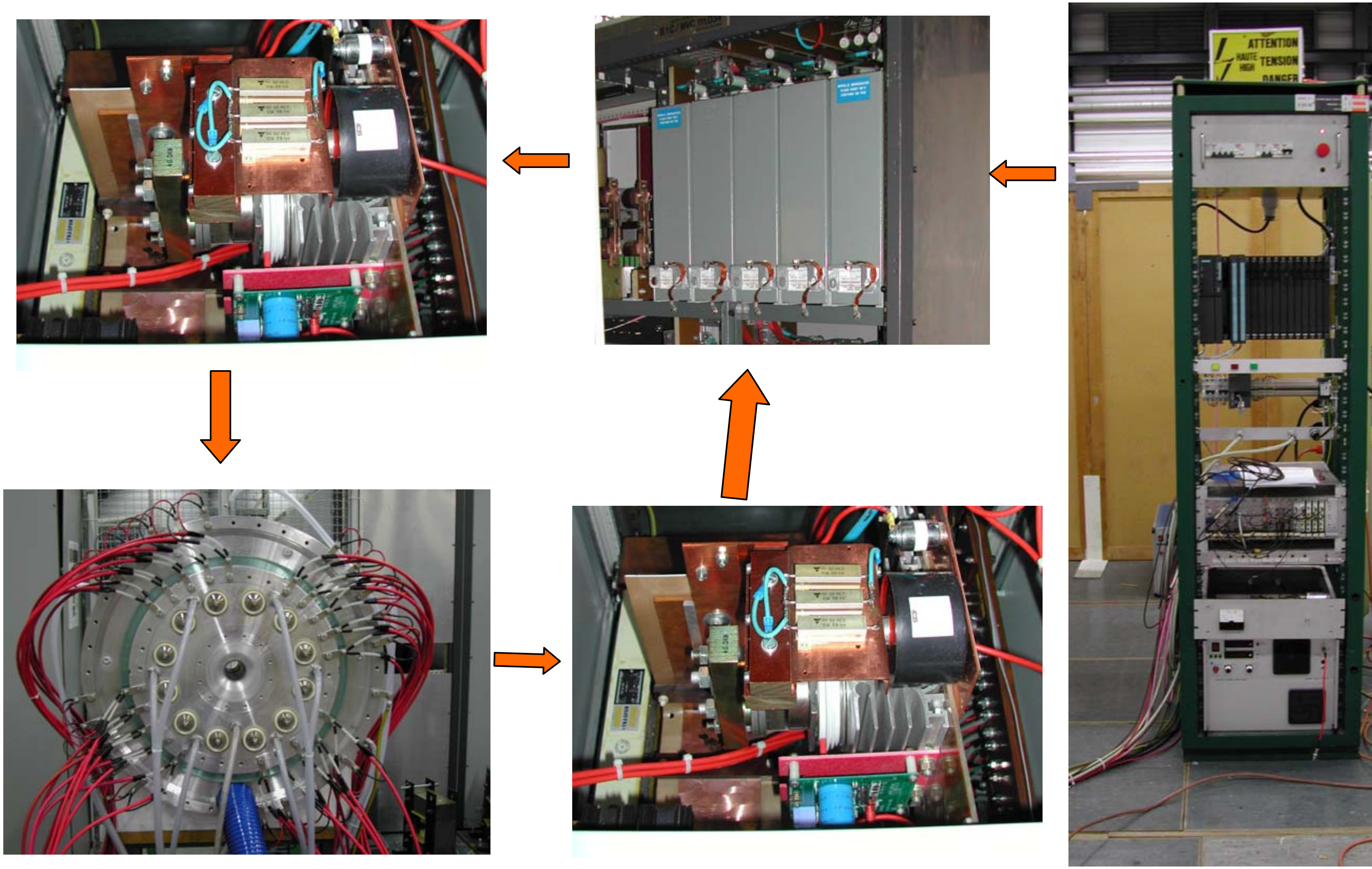
First discharger unit : 2 units in parallel



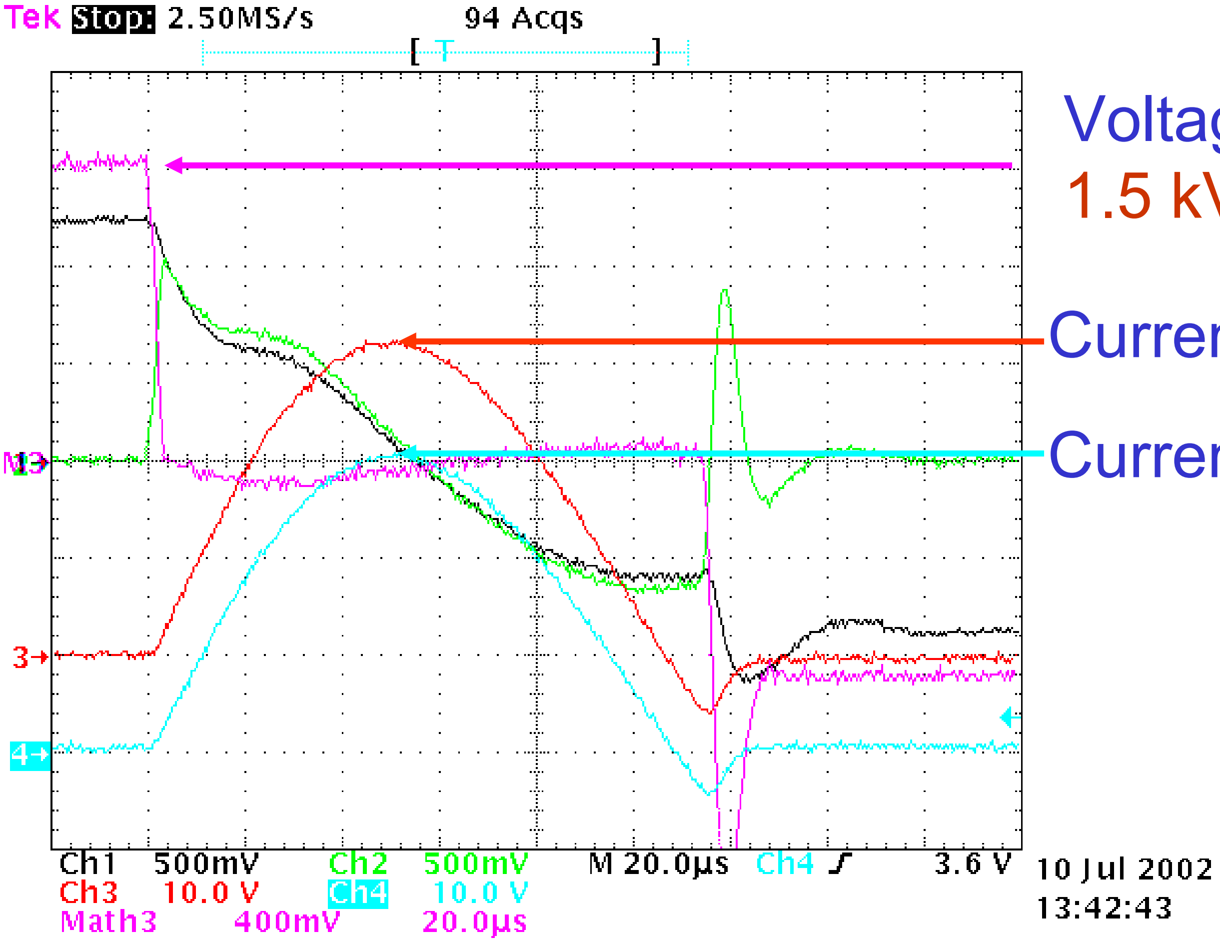
Power supply scheme



From scheme to reality



P.S. test on dummy load

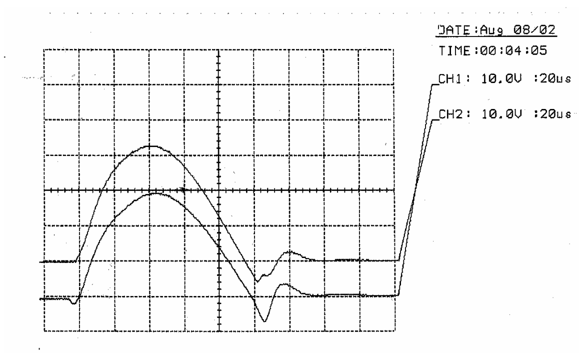


Voltage on horn/tyristor: 1.5 kV

Current first unit =16kA

Current second unit =15kA

Horn current



Channel 1: Voltage at anode of T_1 of first unit to ground (500V/div)

Channel 2: Voltage at cathode of T_1 of first unit to ground (500V/div)

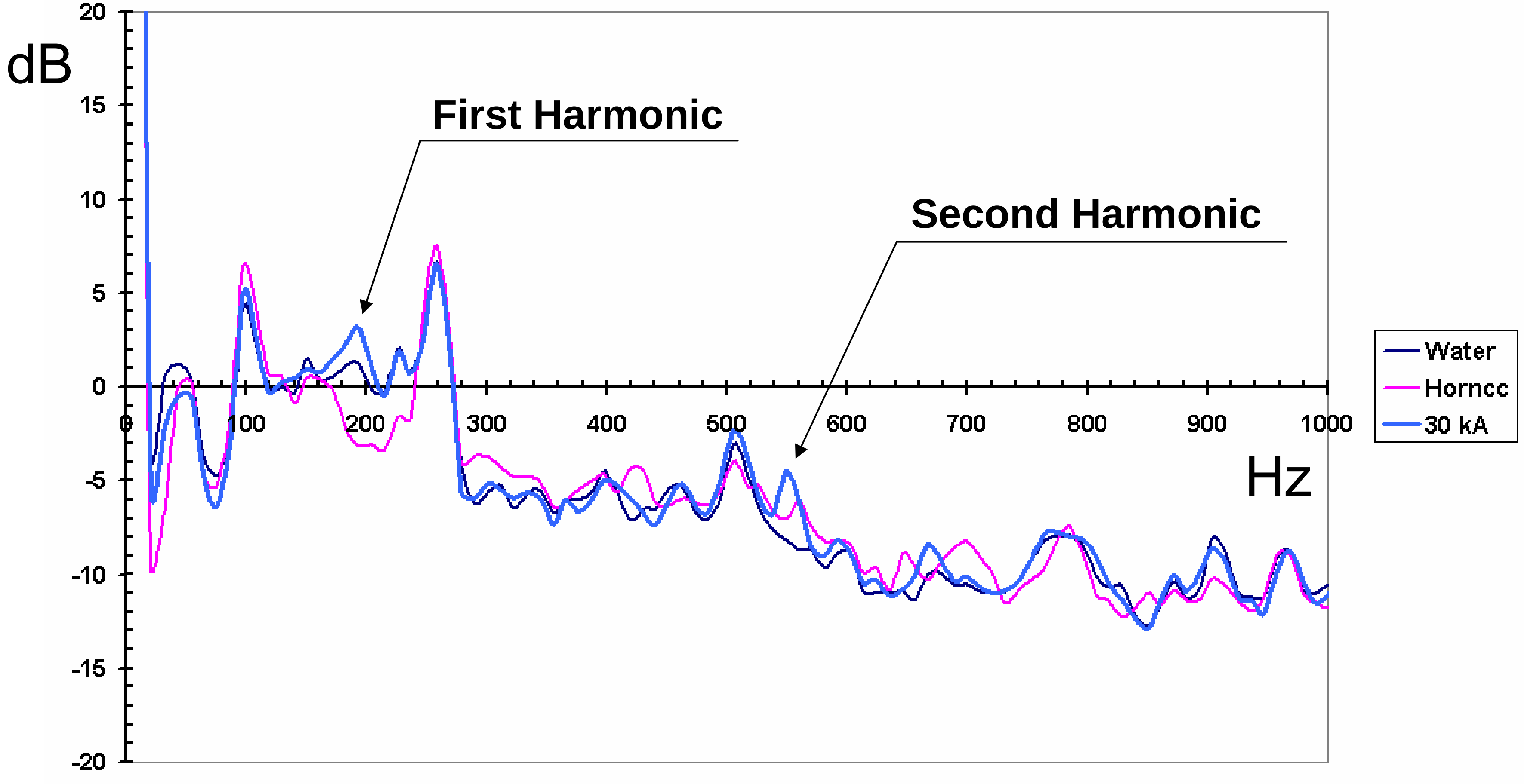
Channel 3: Pulse current of second unit measured with CT1 (5000A/div)

Channel 4: Pulse current of first unit measured with CT1 (5000A/div)

Math 3: Channel 1 – Channel 2, Voltage across T_1 (400V/div)

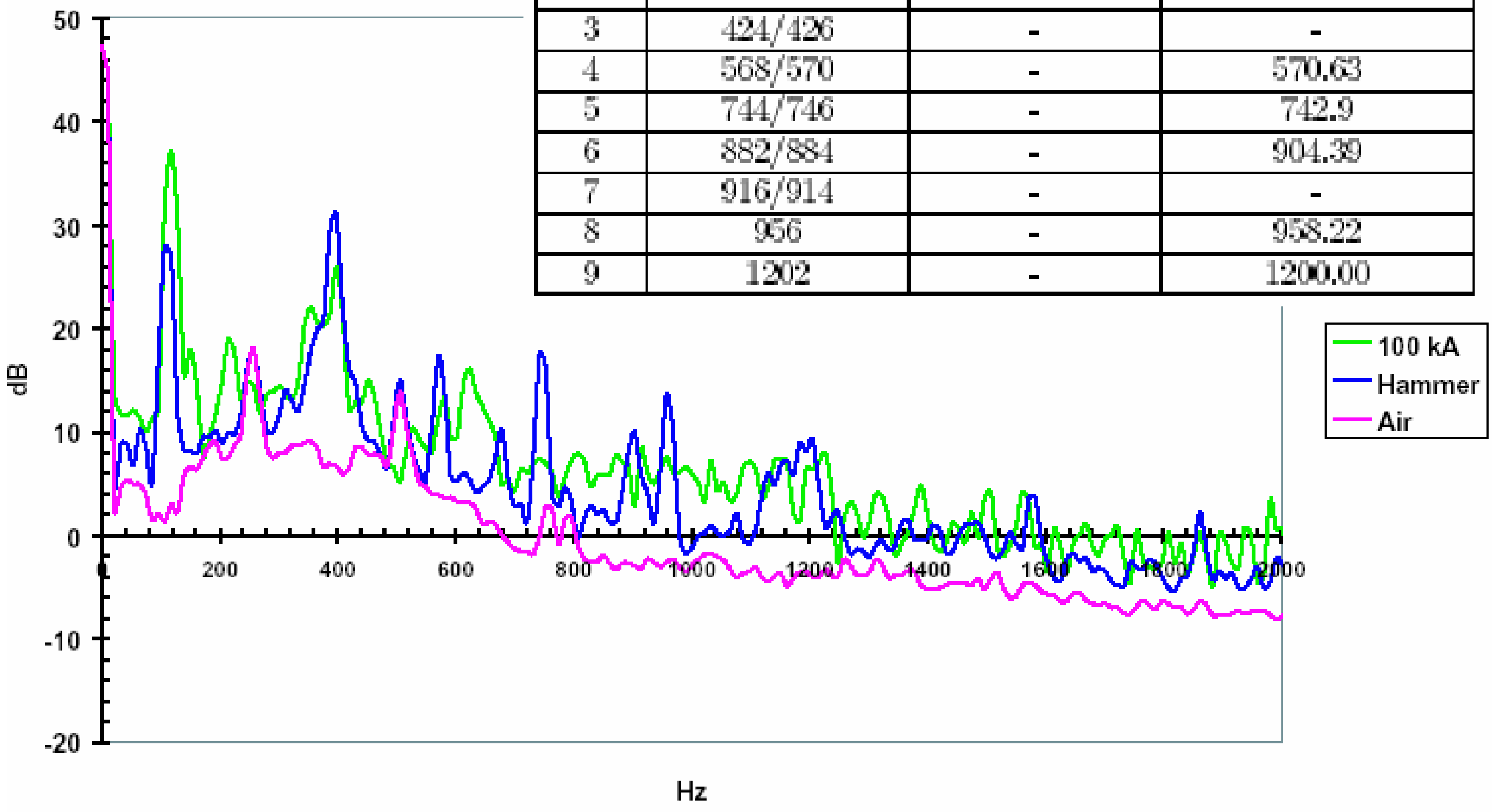
Acoustic frequency meas.

Horn eigenfrequencies from horn “sound”

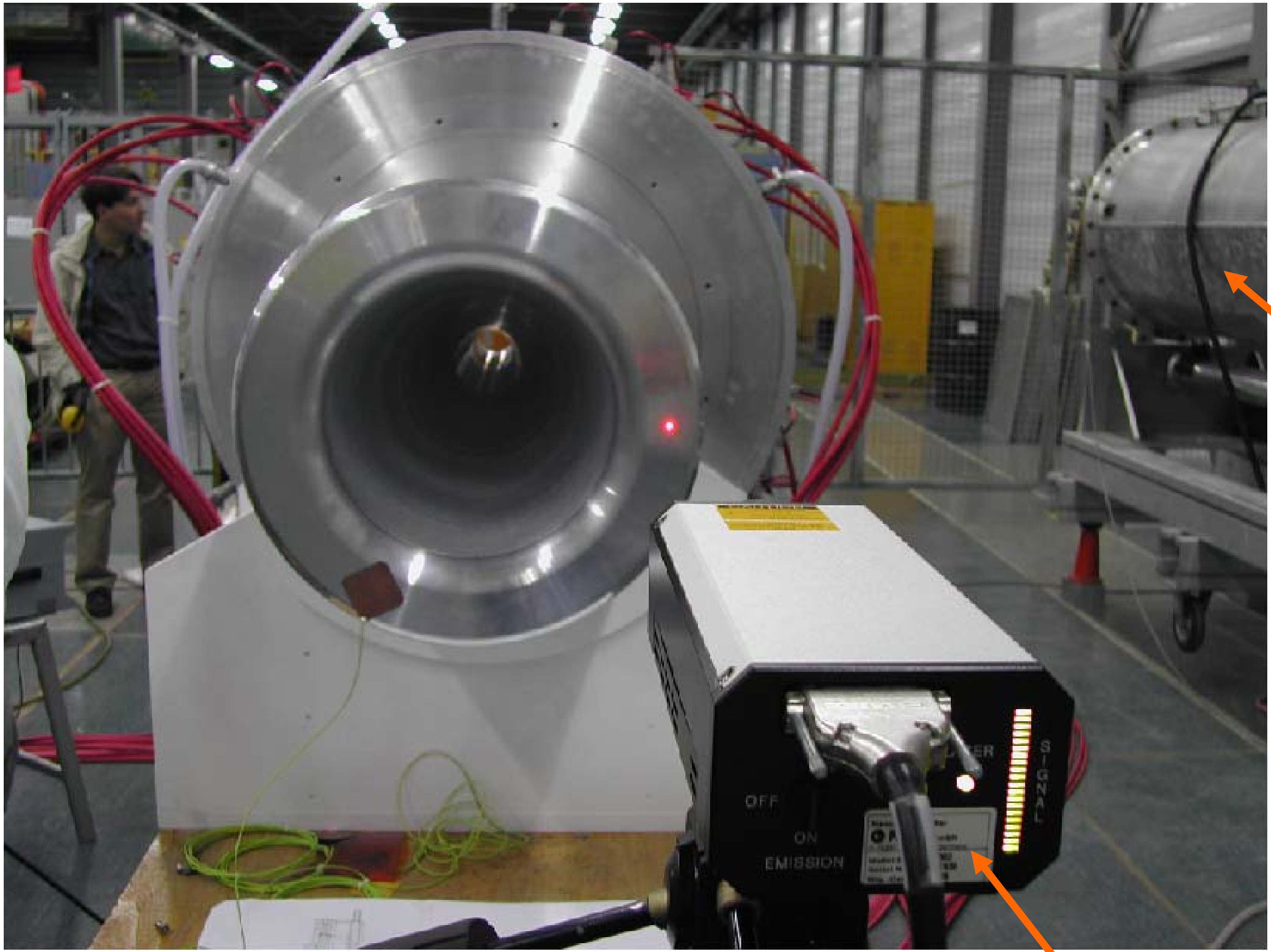


Method validation: CNGS

Mode	Meas. Ref. (Hz)	Calc. Ref. (Hz)	Meas. Microp. (Hz)
1	111	139	107.66
2	392	364	398.36
3	424/426	-	-
4	568/570	-	570.63
5	744/746	-	742.9
6	882/884	-	904.39
7	916/914	-	-
8	956	-	958.22
9	1202	-	1200.00



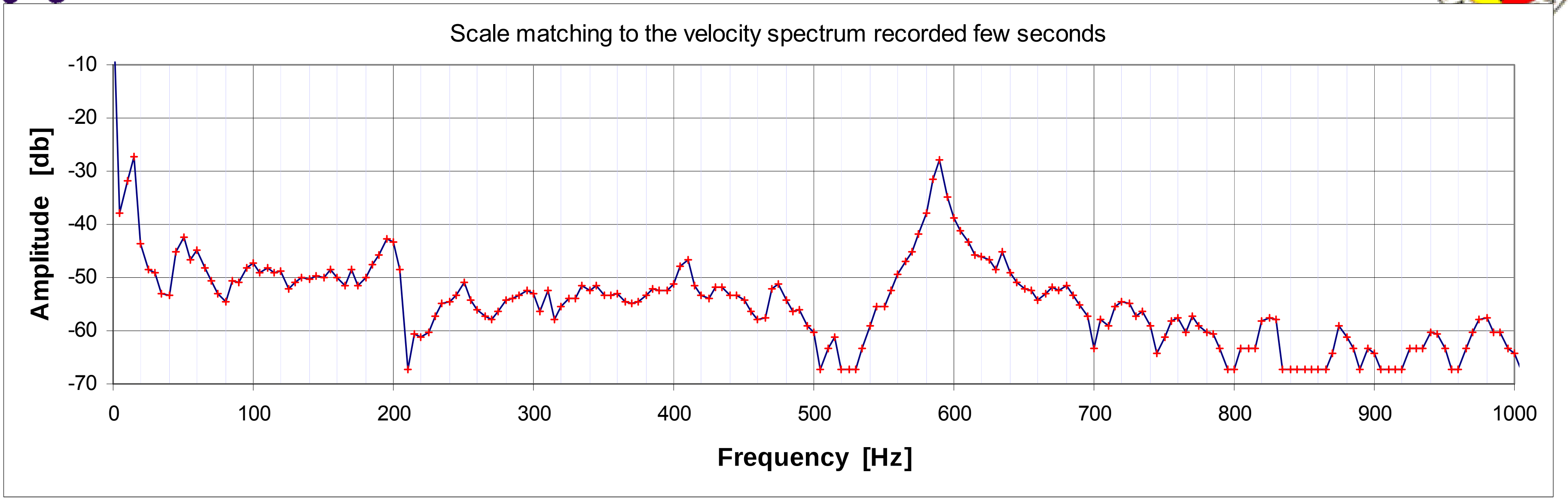
Laser Measurements (prel.)



CNGS horn

Laser vibrometer

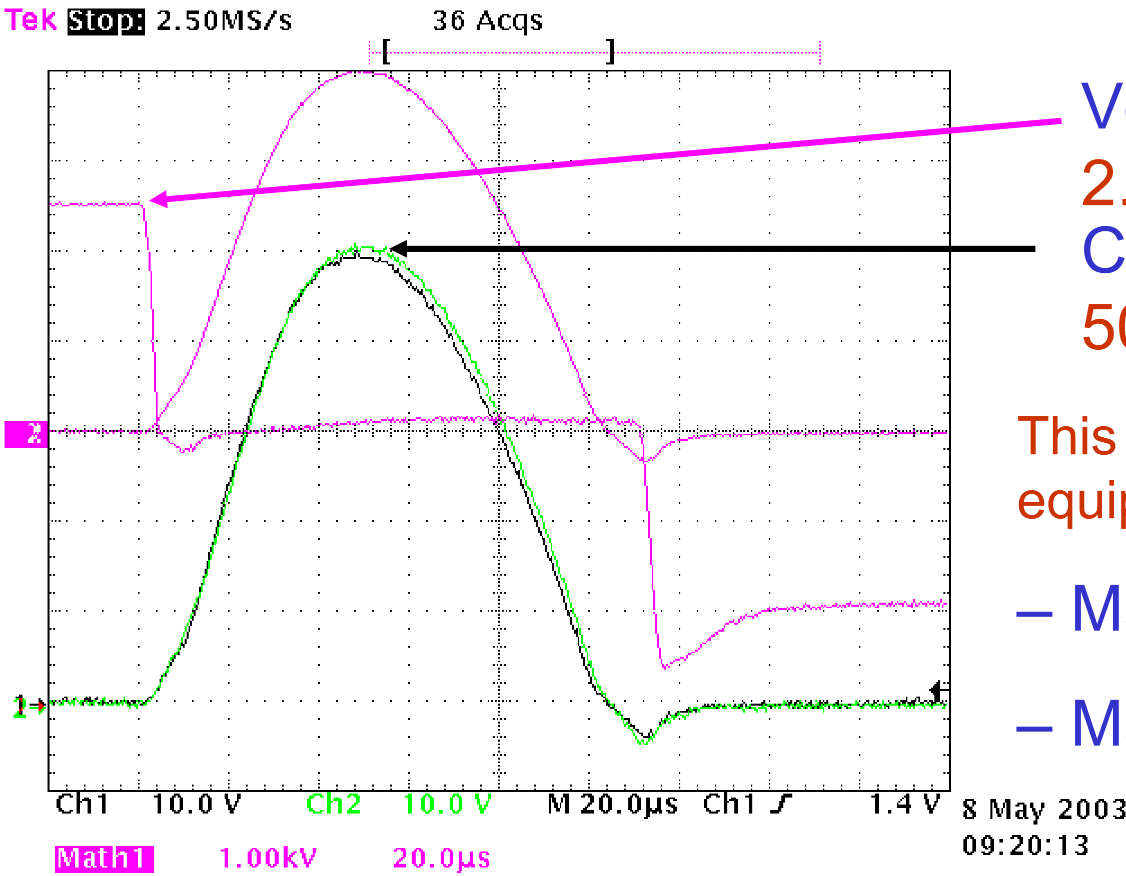
Preliminary vibration meas.



New campaigns of measurements with laser vibrometer and microphone with new power supply.

Any suggestions how to measure a surface that you cannot touch and with water flowing, the INNER conductor ?

Next step: 100 kA – 0.5 Hz



Voltage on horn/thyristor: 2.5 kV

Current first/second unit 50 kA

This is the Limit for the existing equipment:

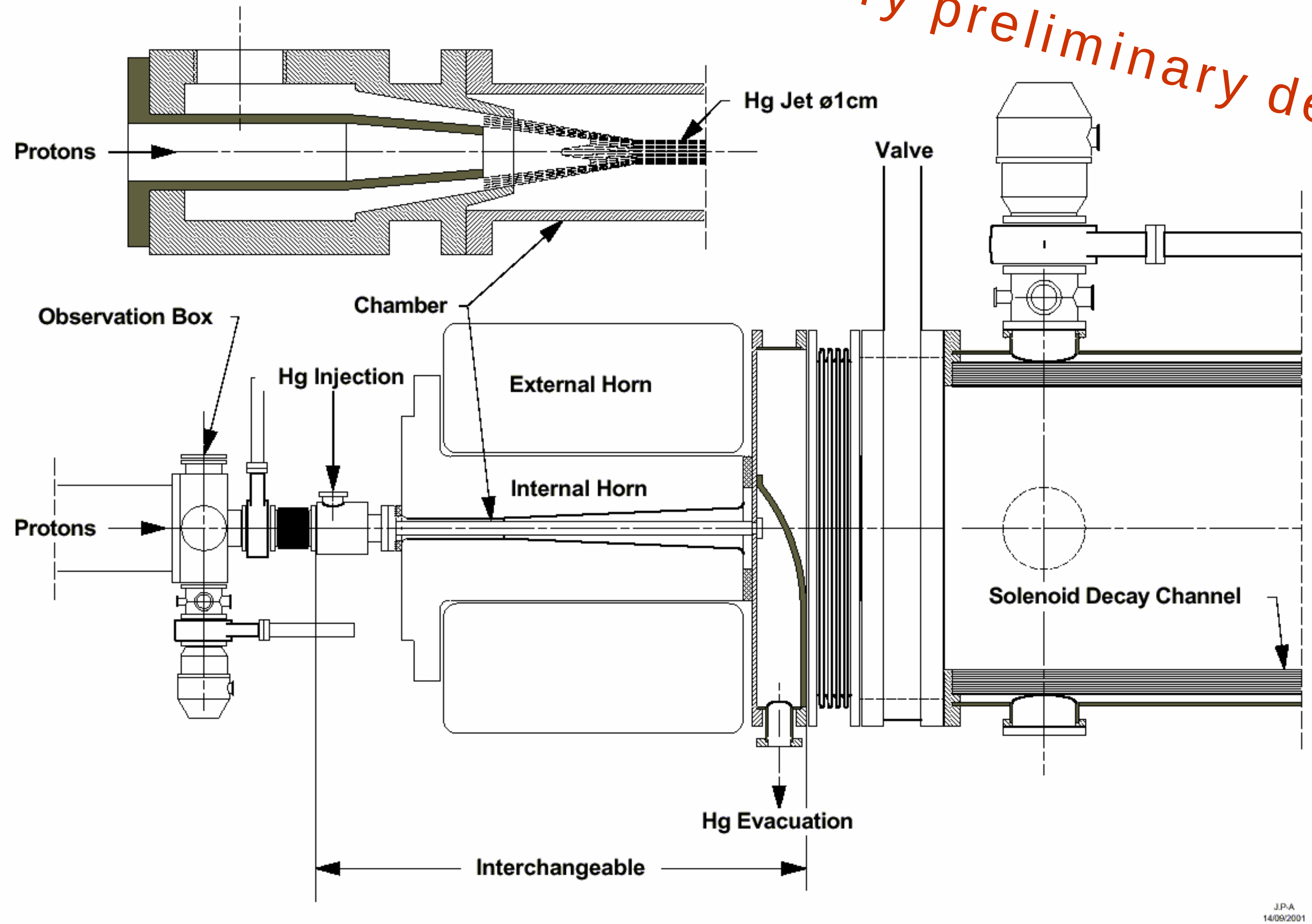
– Max voltage on thyristor

– Max rep rate for resistors

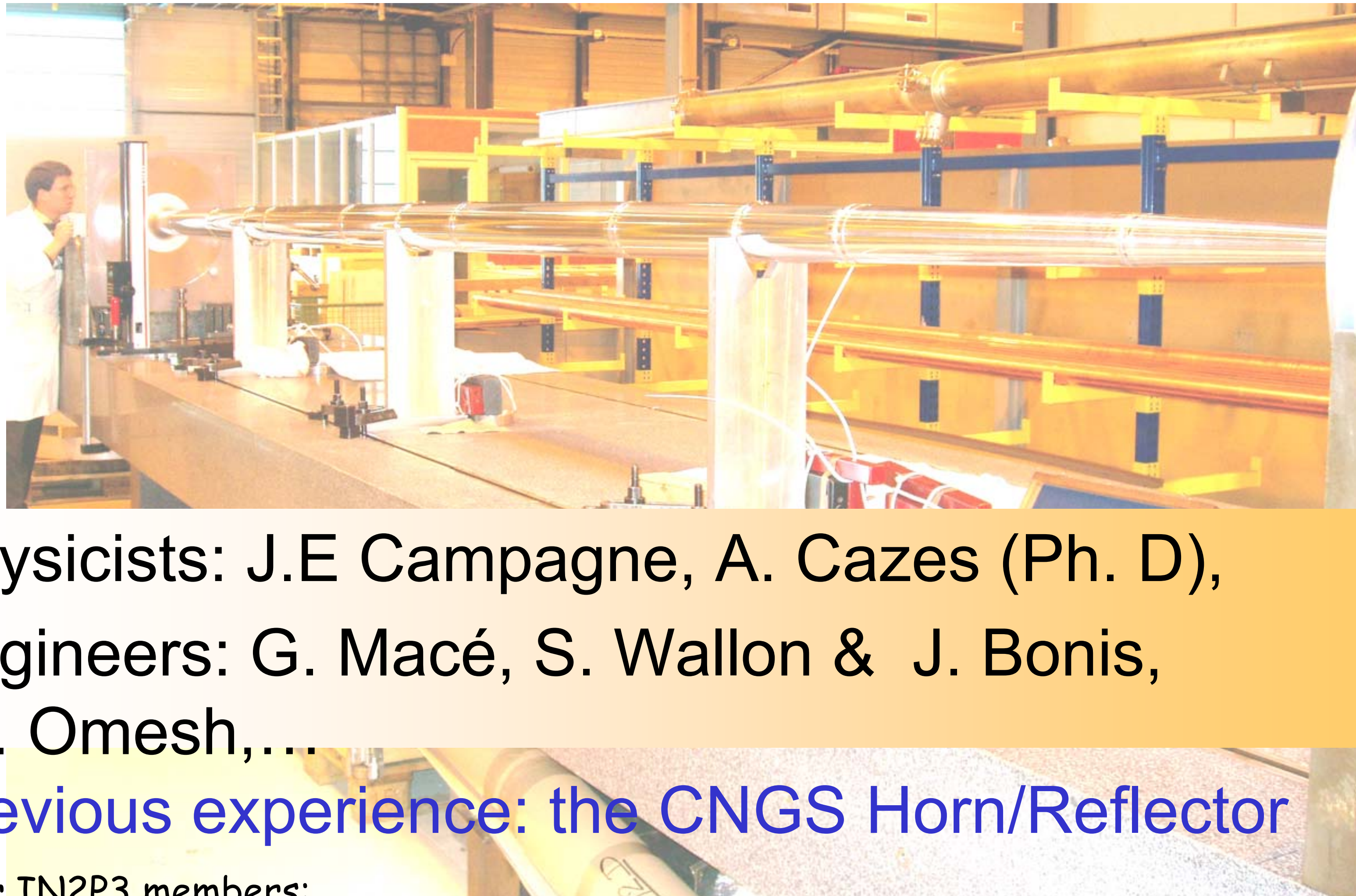
Ch1:	Current of unit one measured with current transformer. (10kA/div)
Ch2:	Current of unit two measured with current transformer. (10kA/div)
M1:	Voltage across thyristor. (1kV/div)
M2:	Sum of both currents. (25kA/div)

Target and Horn integration

Very preliminary design



LAL Horn R&D



- Physicists: J.E Campagne, A. Cazes (Ph. D),
- Engineers: G. Macé, S. Wallon & J. Bonis, M. Omesh,…
- Previous experience: the CNGS Horn/Reflector

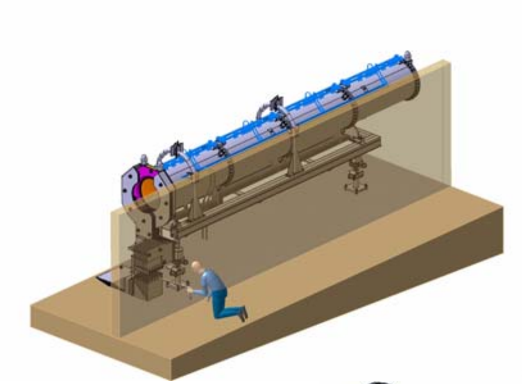
Other IN2P3 members:
J. Dumarchez (LPNHE), D. Autiero (IPNL), S.Katsanevas(IN2P3-adm)

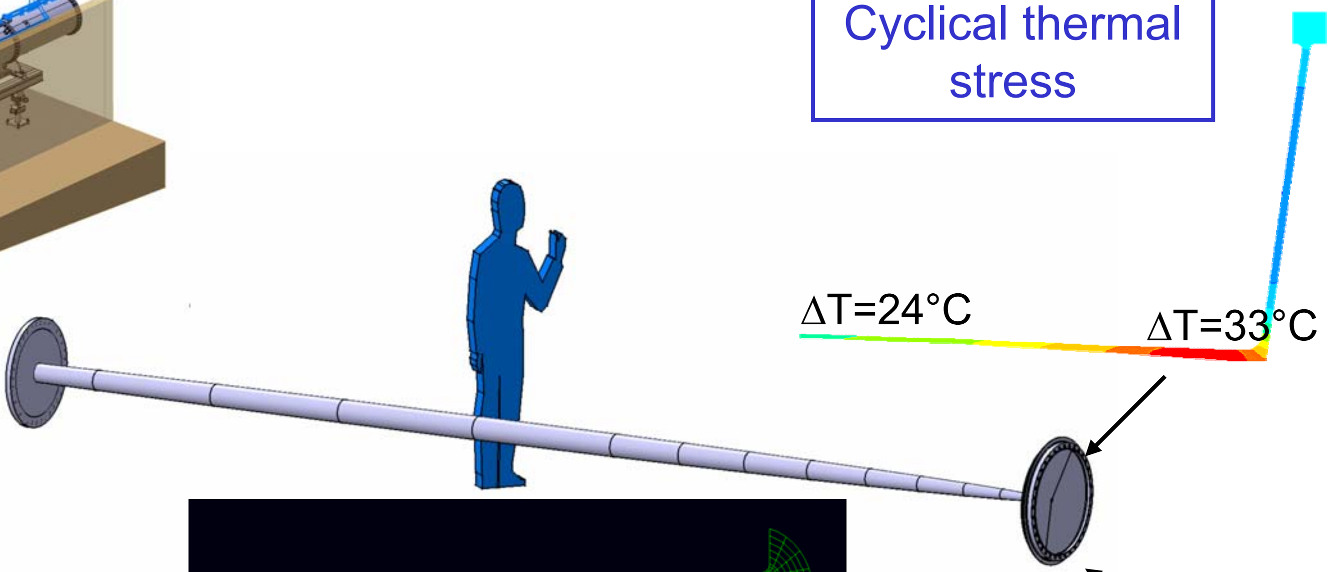
Competence examples for CNGS

Installation/Replacement

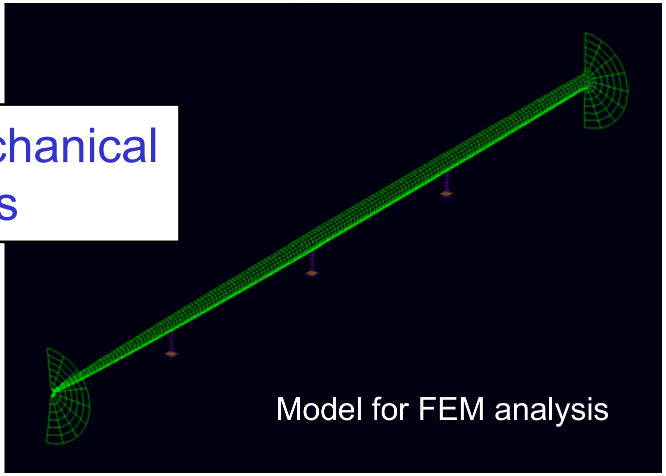
Thermal study

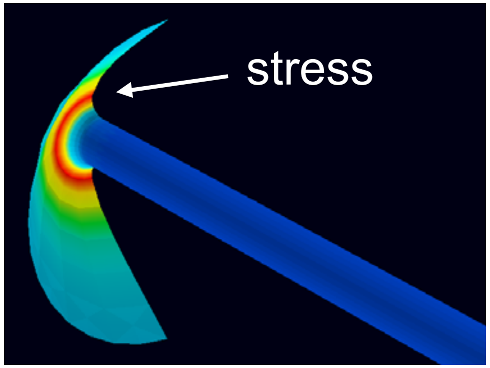
Cyclical thermal stress





Cyclical mechanical stress





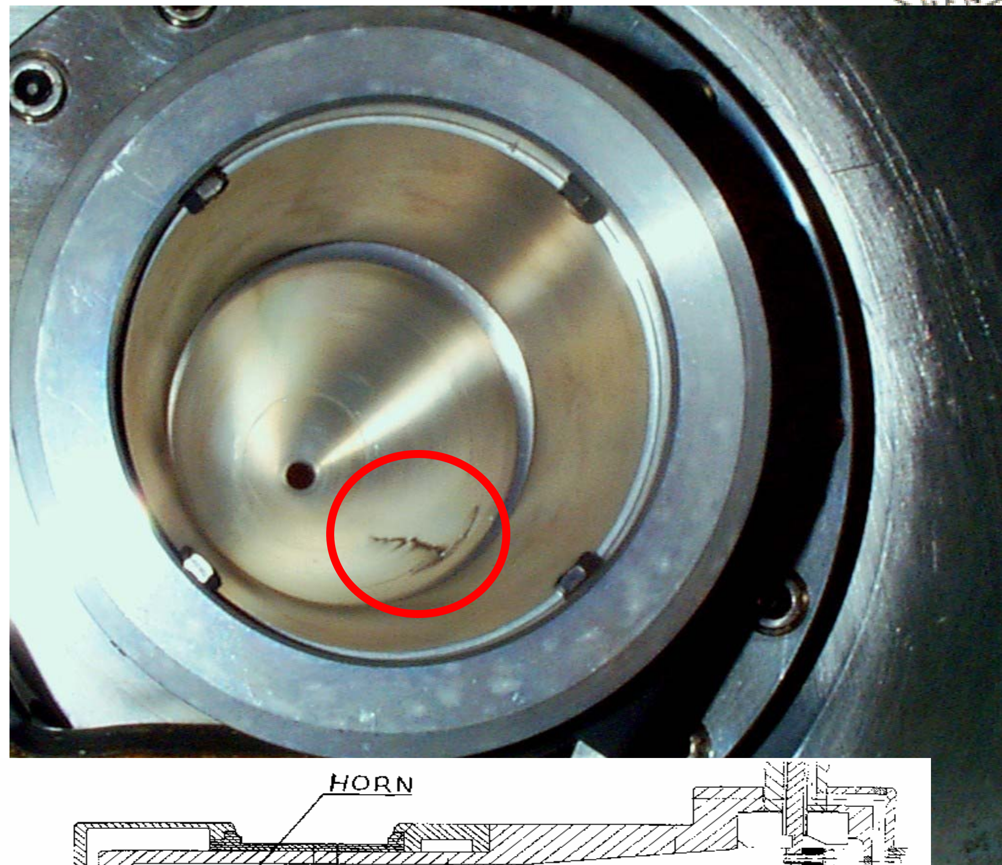
Conclusions

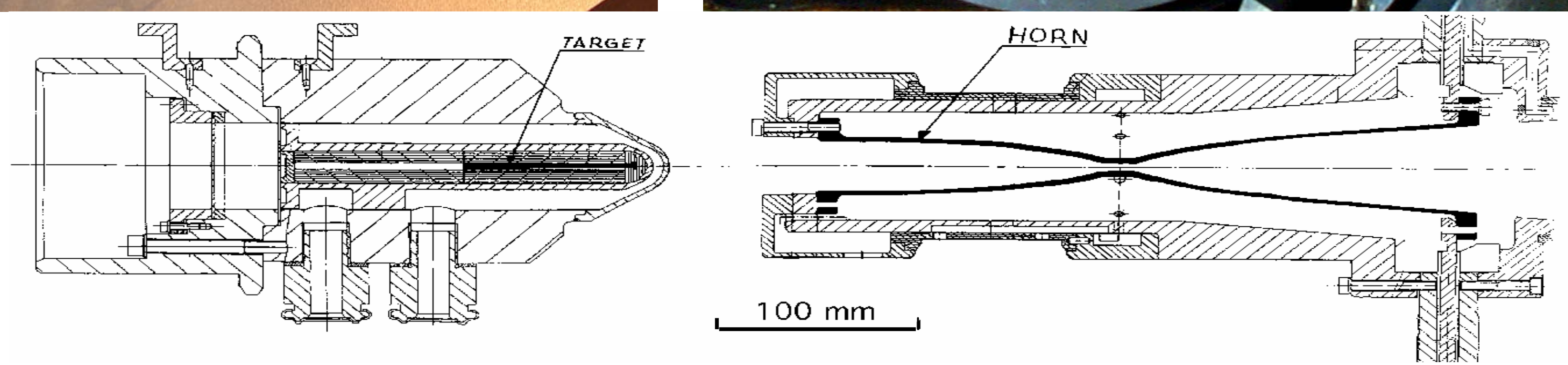
- Results of last year for horn+power supply
  - Construction and test at 30 kA – 1 Hz – 100 μs
  - First evaluation of horn eigenfrequencies
- Horn CERN program for this year:
  - Measurement with new power supply
  - "Working point" with CNGS power supply
- New friends in the game, LAL draft program:
  - Secondary particles collection simulation
  - Electrical power supply studies
  - Mechanical Simulation
  - Thermal Simulation

Horn life-time precise estimation

Horn failures ...When? Why?

AD horn (see Microcosm)
300 kA, 0.5 Hz, 1M pulses





Reasons for horn failure

- Fatigue limit
  - ✓ Resonances between current and horn eigenfreq.
  - – stress due to electro-magnetic forces
  - – Max pressure: $\approx$14 MPa (140 kg/cm^2)

- Thermal stresses
  - ✓ Joule losses: 39 kW
  - – particle energy deposition (still to be evaluated)

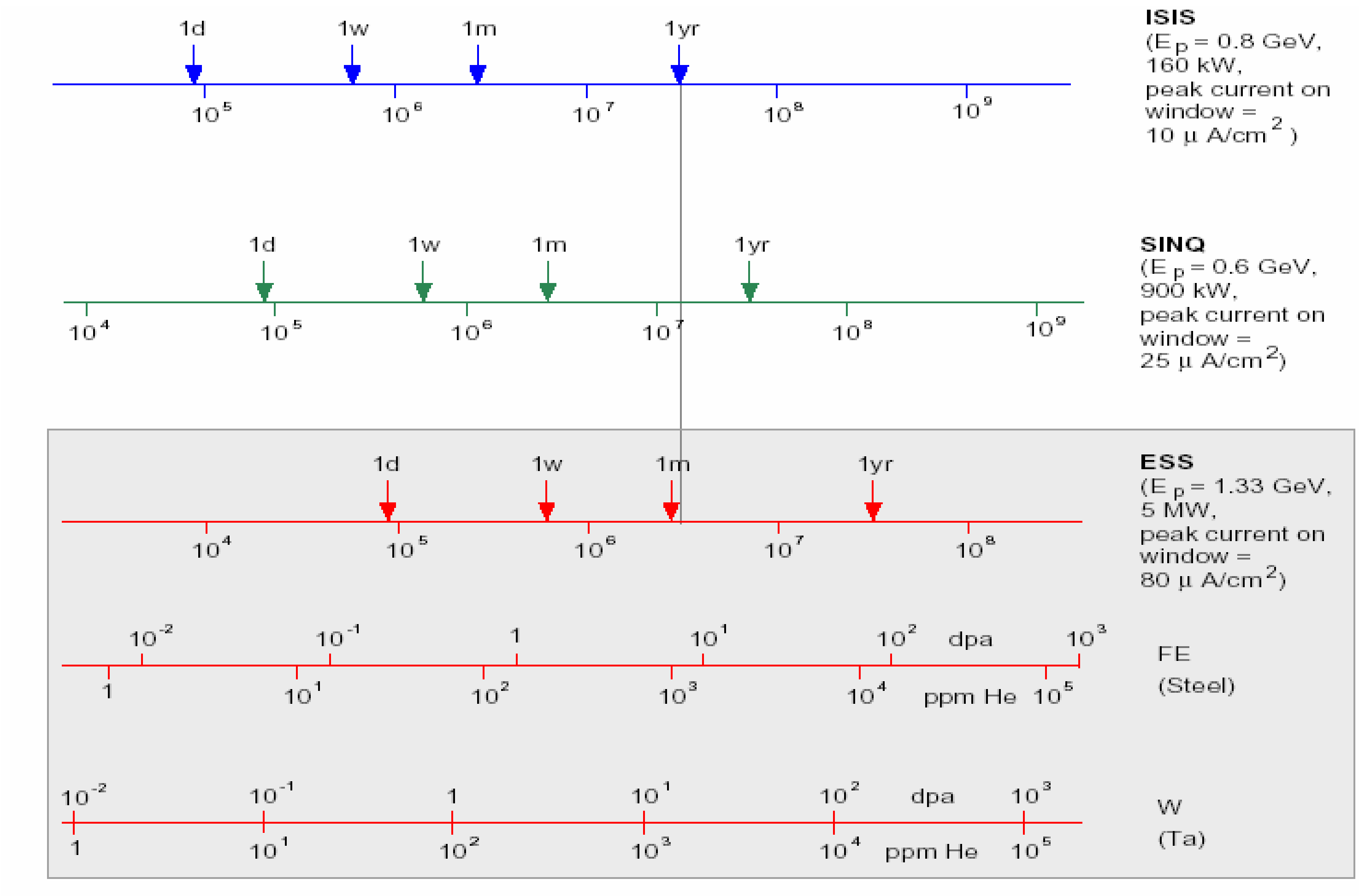
- Neutron irradiation
  - – Swelling
  - – Mechanical properties variation

Main Parameters

•Radius of the waist	40 mm
•Peak current	300 kA
•Repetition rate	50 Hz
•Pulse length	93 μs
•Voltage on the horn	4200 V
•rms current in the horn	14.5 kA
•Power dissipation (by current)	39 kW
•Skin depth	1.25 mm

•Total length	1030 mm
•Outer diameter	420 mm
•Max diameter (electrical connection flange)	895 mm
•Free waist aperture	56 mm
•Waist outer diameter	80 mm
•Average waist wall thickness	6 mm
•Double skin thickness	2 mm

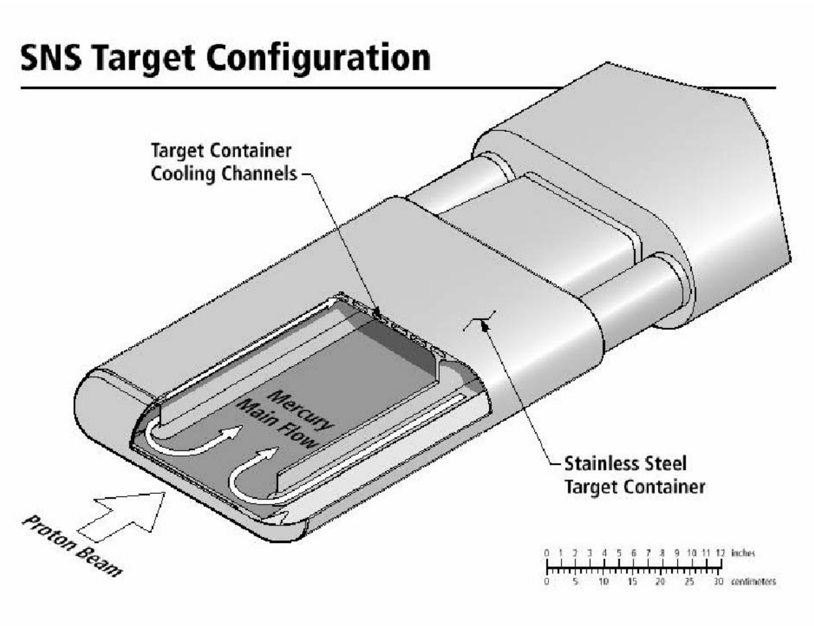
DPA for spallation sources

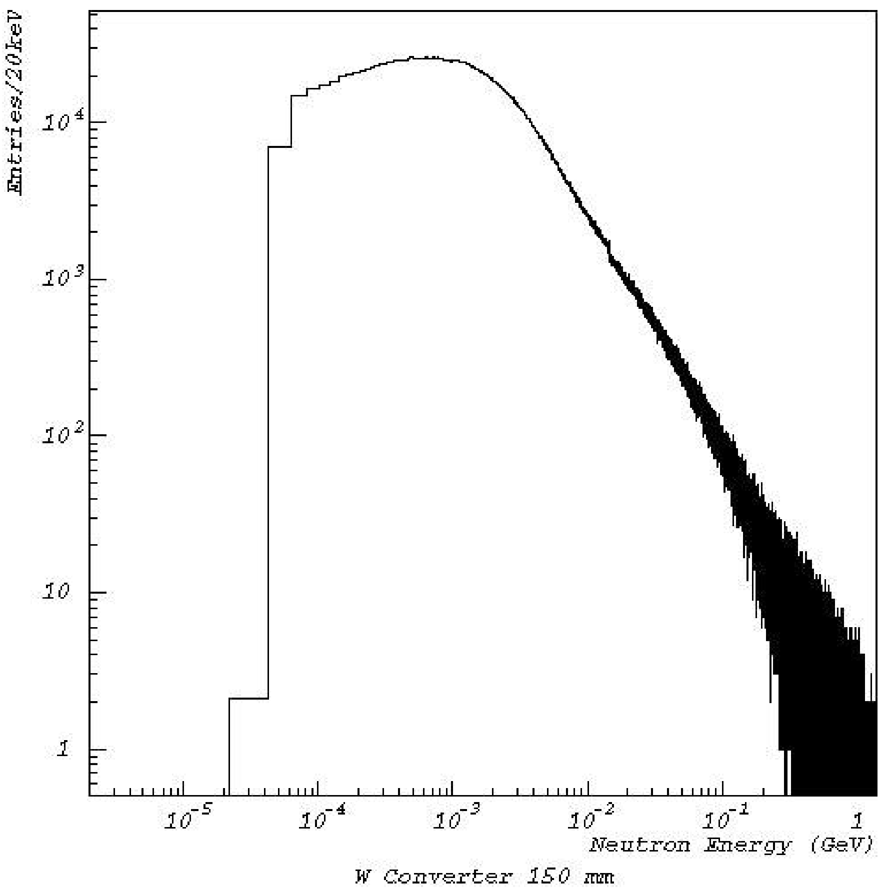


Neutron damage

Typical neutron spectrum

Hg target as SNS target





Same for our case

DPA: Displacements per atom

$$DPA = 0.4 \frac{T_{dam}(MeV - barn)}{T_d^a(MeV)} \Phi\left(\frac{n}{cm^2 s}\right) t(s) = \sigma_{damage} \Phi t$$

T_{dam} : damage energy cross section

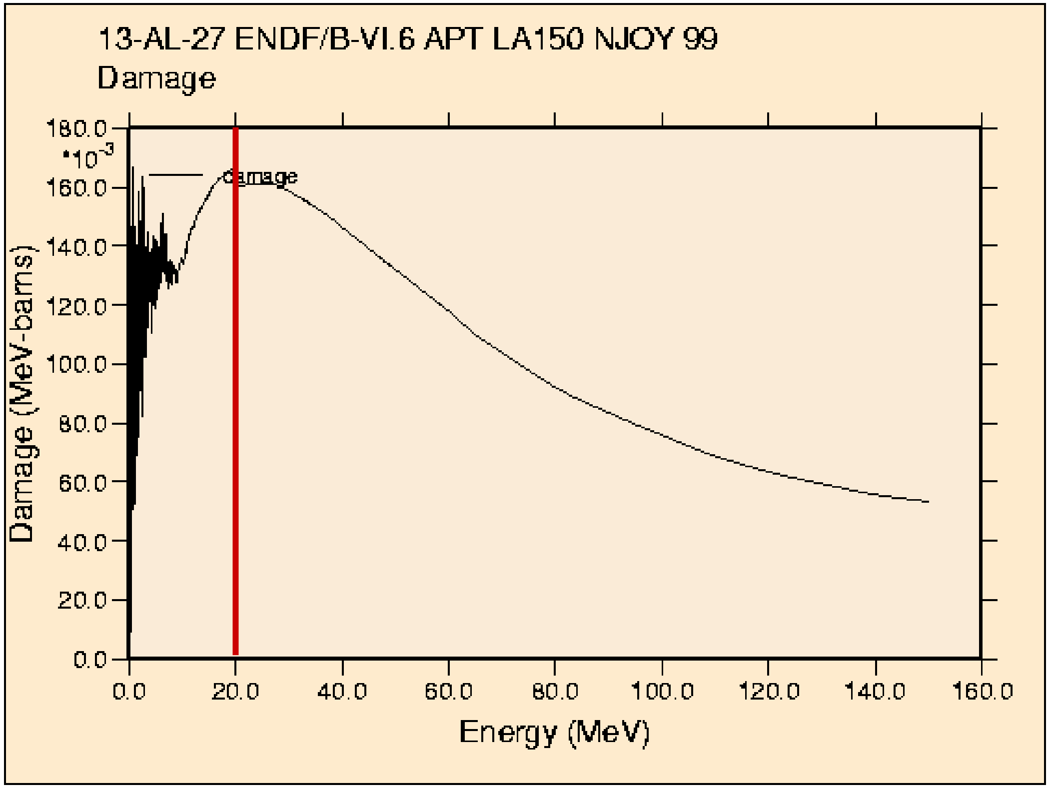
$\rightarrow$ Total available energy to cause displacement

$T^a{}_d$: effective threshold displacement energy

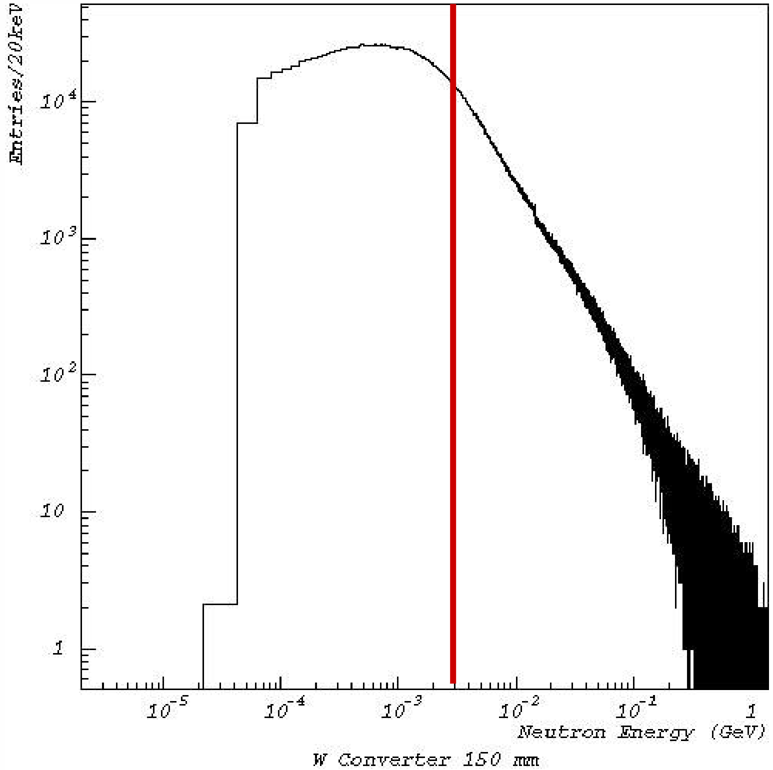
$\rightarrow$ Energy required to displace an atom (Al = 27 eV)

Neutron damage

Damage cross section



Neutron spectrum



GeV

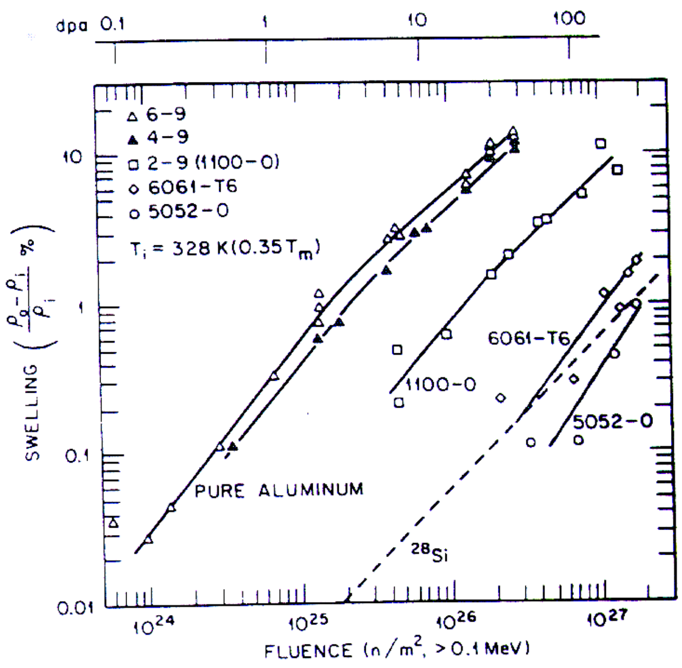
Large neutron fraction & damage cross section is high

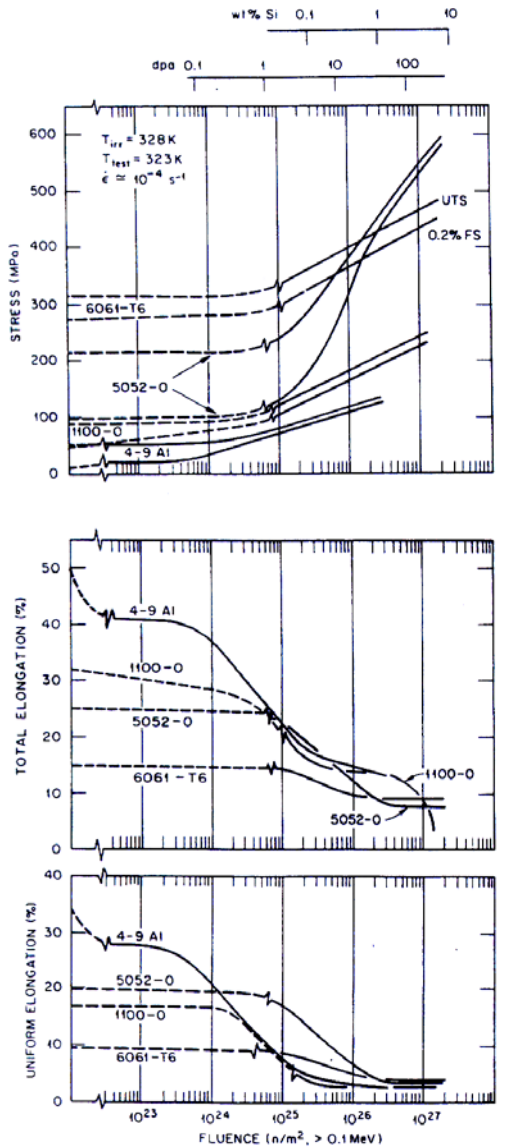
→Same damage from neutrons as SNS target container

Ductility variation and swelling

Neutron flux from Hg
typical of a
Neutron Spallation Source
(ESS, SNS)

Approx 10^{26} n/m^2





Material development

- Mechanical tests of Aluminum-Alloys before and after irradiation
  - Variation of the mechanical parameters
  - CERN is not equipped for such measurements
    - Isolde as irradiation facility but somewhere else for tests

- Define material as a wall between Aluminum and Hg
  - Highly “active” environment:
    - Mercury splashing around
    - Minimum thickness but high mechanical resistance (Ti-Alloys? Stainless Steel? See ESS, SNS target)

Energy deposition in the conductors