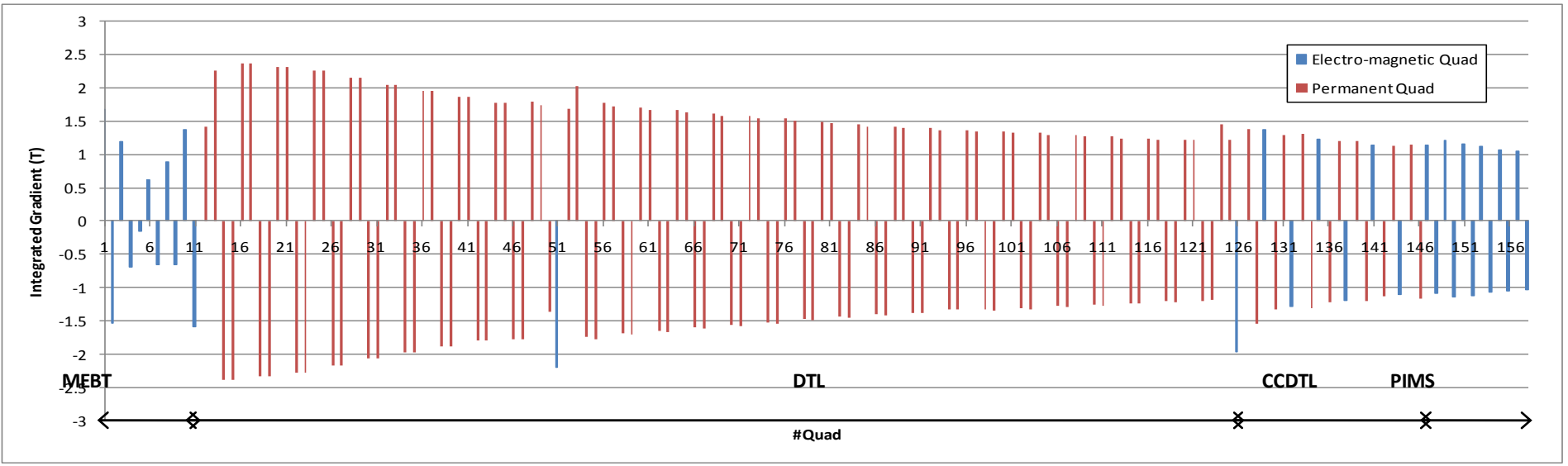
# Permanent magnet quadrupoles for the LINAC4 Drift Tube Linac design and procurement

# Permanent magnet quadrupoles for LINAC4

- Majority of focusing elements are permanent quadrupoles (136 PMQ and 31 EMQs in the linac).
- 3 families :
  - 45 mm long , 22/60 inner/outer diametre to be housed in drift tubes oftank1 + tank cover :43pieces
  - 80 mm long , 22/60 inner/outer diametre to be housed in drift tubes tank2and3 : 70 pieces
  - 100mm long 45/124 inner/outer diametre in CCDTL intertanks (outside beam pipe) : 14pieces




Integrated Gradient of the quadrupoles along linac4

# D.A. Swenson, E.D. Bush, Jr., R.F. Holsinger, J.J. Manca, N. Saito, and J.E. Stovall

Xth Int. Conference on High Energy Accelerators, USSR, 1977.
Project PIGMI.

Magnetic Material – Alnico, BaFe, and SmCo

G=6-11 kGs/cm

No pole tips. Harmonic #6 ~6 %,
#10 ~2 %, #14 ~0.2 %.

Stepped-pole geometry has been investigated to eliminate Harmonics #6 and #10
with the PANDIRA code by K.H. Halbach and R.F. Holsinger.

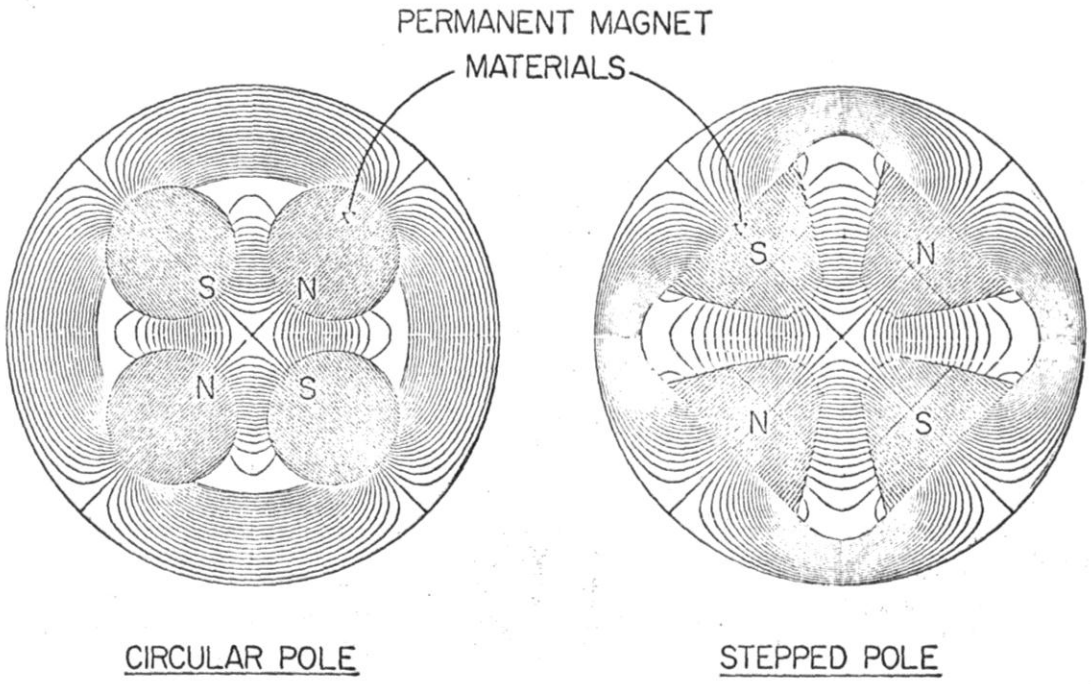



Fig. 5. Permanent magnet quadrupole lens geometries and calculated fields.

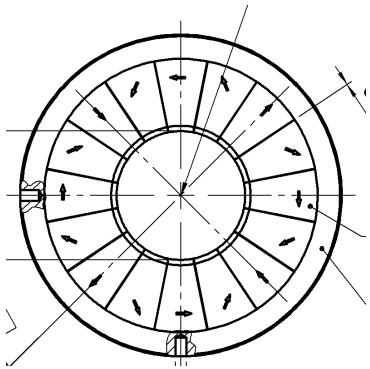
# Early prototypes

February 2006

I S T C

M H T Ц

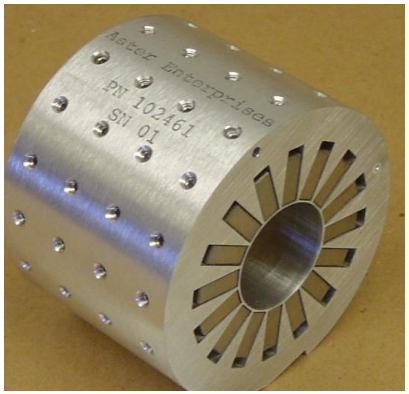
GL= 2.5 Tesla ; L=45 mm ; 30 pieces



May 2006

ASTER ENTERPRISES (USA)

GL = 4 Tesla ; L=45 mm ; 16 pieces




May 2006

ASTER ENTERPRISES (USA)

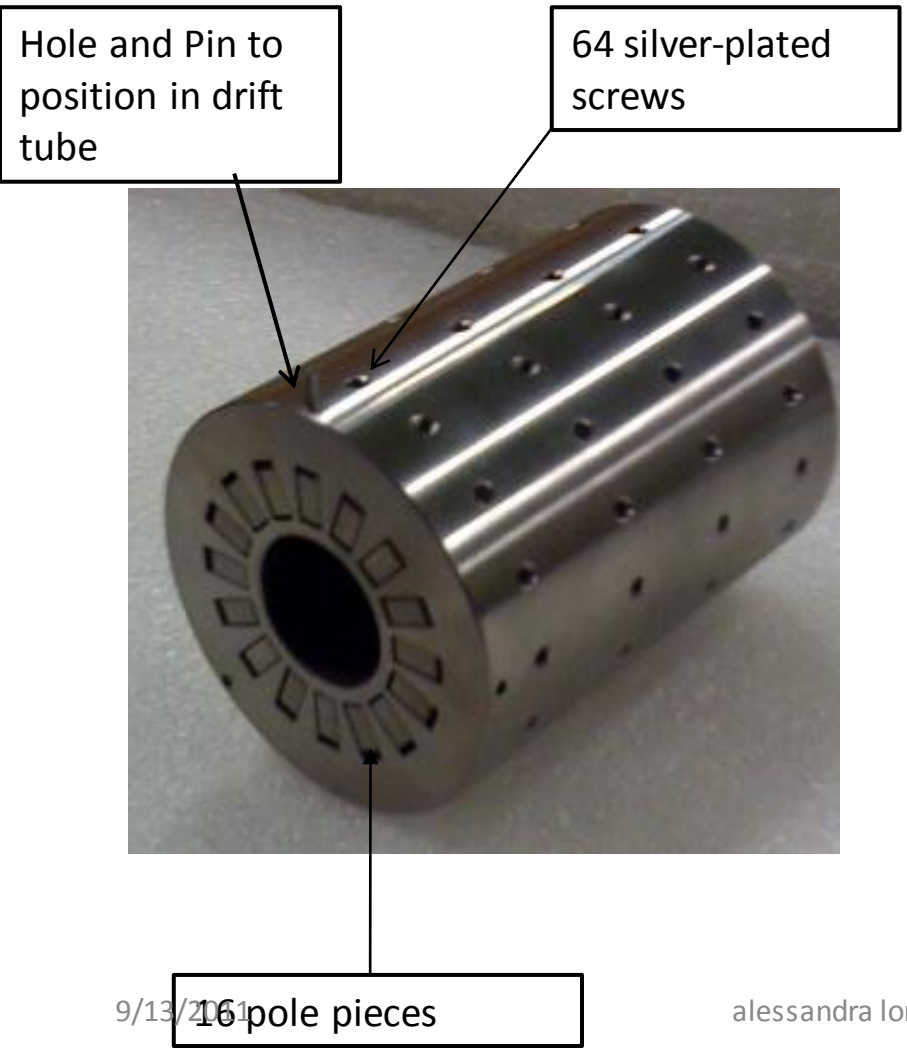
GL=2.5 Tesla ; L=45 mm ; 16 pieces

All prototypes were within the specs

All prototypes on time and on budget,

Choice was between field quality, strength, cost.

# PMQ for the drift tube Linac




- **One PMQ installed in each Drift Tube**
  - FFDD system
  - Max/Min integrated gradient= 2.4/1.2 T
  - Tolerance : ±0.5% on the field, 1mrad on the roll, harmonics <0.01 at 75%radius,
- **Magnet Material - Samarium Cobalt** ($Sm_2Co_{17}$)
  - PM material selected to minimize field strength loss due to neutron fluence.
- **Housing Material - Stainless Steel (**316LN)
  - Use in vacuum
  - Stable against corrosion (galvanic couple with copper)
  - Thermal expansion coefficient similar to copper
  - Low conductivity protects against accidental heating during the welding process
- **Installation in Drift tube**
  - Each PMQ will be positioned in the centre of the drift tube, oriented with a dowel pin and clamped in position by a spring washer
  - The drift tube will not have a full bore tube and the end-caps, located on the PMQ, will be welded to the body of the drift tube after positioning of the PMQ.

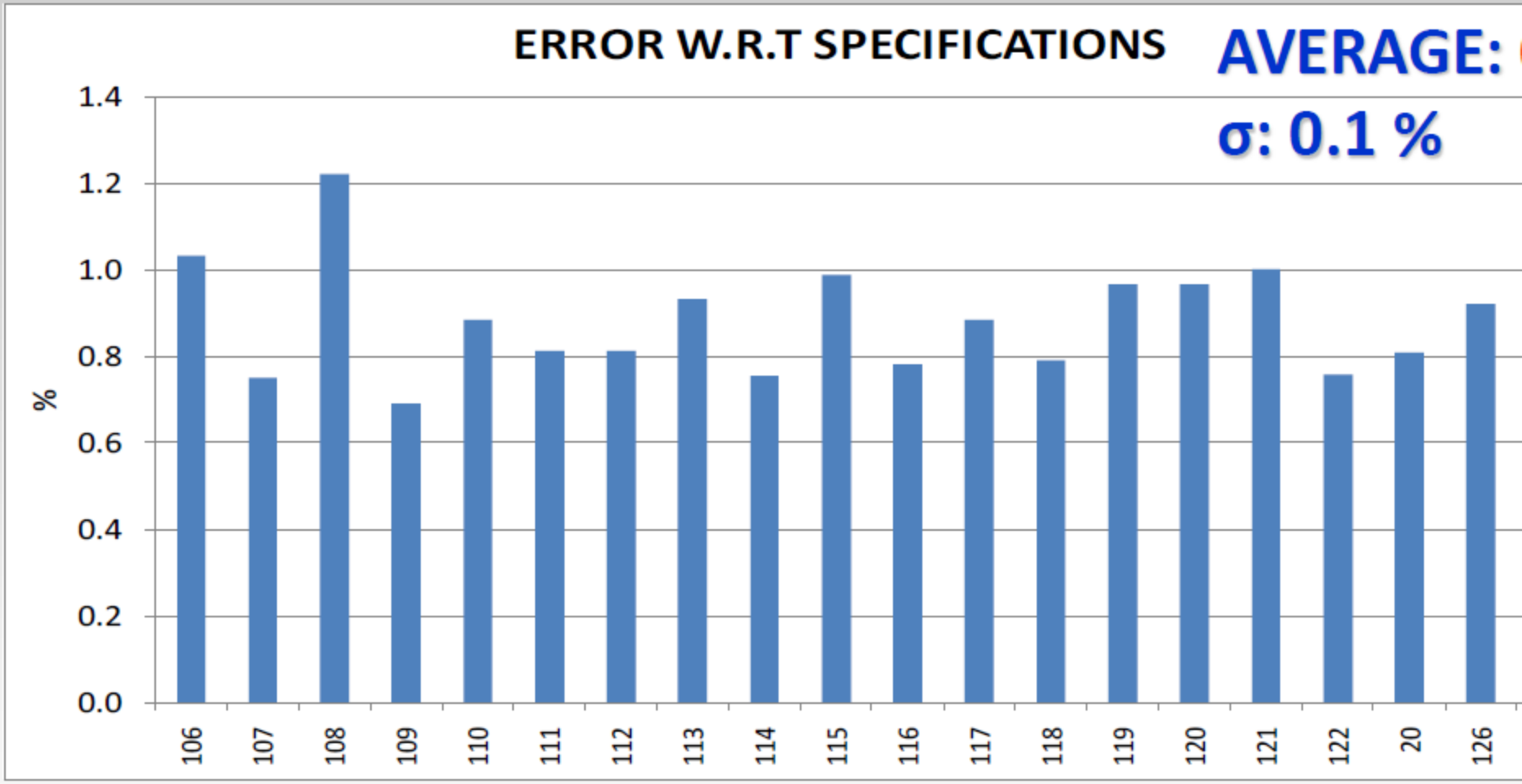
# Critical specifications

| | **Specs for the PMQ** |
|---|---|
| | **Family 2 : PMQ for DTL tank2 and 3** |
| | Number of pieces : 70 |
| | Integrated gradient (Max) : 2.0 Tesla |
| | Integrated gradient (min) : 1.2 Tesla |
| Mechanical tolerances, verified by EN/MME (A. Cherif) | Mechanical Length : 80 mm |
| | Inner diameter : 22 mm |
| | Outer diameter : 60 mm |
| Magnetic tolerances , verified by TE/MSC (M. Buzio, G. Golluccio,F. Mateos) | Gradient integral error (rms) -+ 0.5 % |
| | Magnetic versus geometric axis: < 0.1 mm |
| | Harmonic content at 7.5 mm radius: Bn/B2 for n=3,4,...10 : < 0.01 |
| | Yaw/pitch: 2 mrad |
| | Roll: 1 mrad |
| | |
| | Machining tolerances ISO 2768-mK unless indicated in SPLACDTD00009 |
| Vacuum tolerances verified by TE/VSC G. Vandoni, I. Weavers. | Outgassing rate per magnet below $4 \cdot 10^{-6}$mbar l $s^{-1}$ |
| | |

# 45 mm

- Procurement of quadrupoles started January 2009 with ASTER (USA).
- 39 quadrupoles for tank1 drift tubes in house, last batch arrived Jan 2011
- Lesson learned
  - Galvanic couple copper-Aluminium : use 316 LN for holder material
  - Specify the vacuum requirement in terms of outgassing
  - Cross calibrate magnetic measurements

# GdL

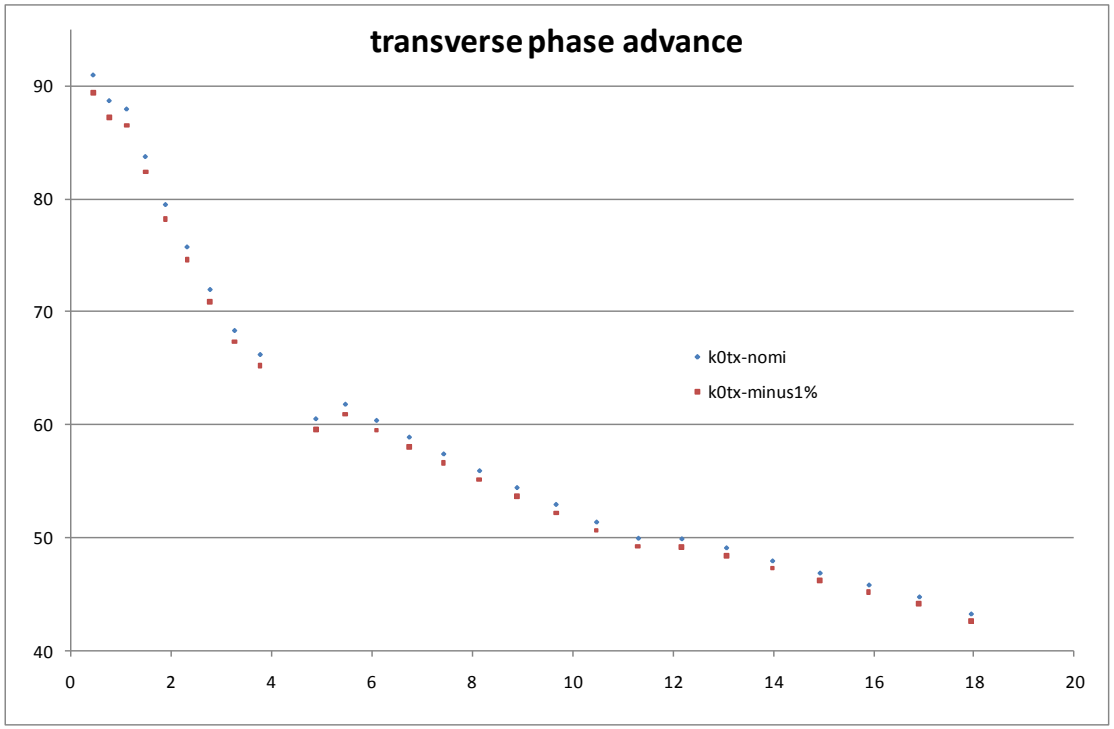



-The integrated measured gradient is systematically 0.88 % lower than the specified values
-the GdL measured by the coil after the latest calibration (reference = PMQ 121) agrees with t
within the uncertainties of the 2 systems (0.2 % SSW and 0.3 % Rotating coil @ 1 σ)
-There are no systematic discrepancies between rotating coil and SSW

# Why -1% is ok.

- It is a bias on all quadrupoles, not a scatter.
- It decreases the transverse phase advance everywhere but it stays smooth and the ratio with the longitudinal has the same behaviour
- Beam can be re-matched from the MEBT
- Increase of the envelope 20-50microns, rms emitt. increase (+0.5%).

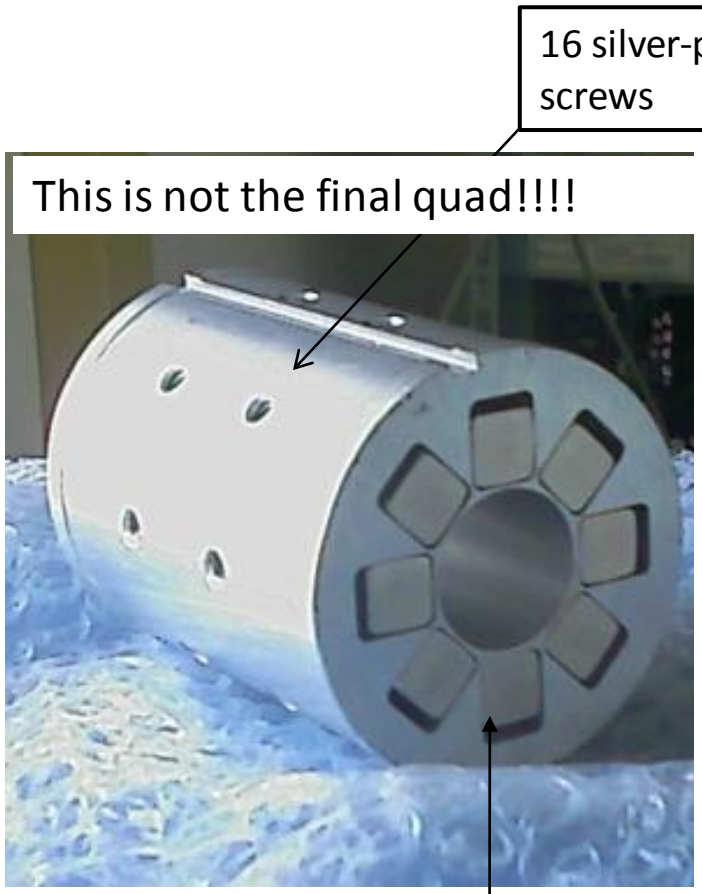
# Choice of phase advance



# 80 mm long

- 2 prototyping campaigns
  - Jan 2010 :to validate potential new companies (VS, Elytt) : Elytt magnetic design validated; tolerances ok, vacuum not ok due to bad shimming material choice.
  - July 2010 : to test 316LN and Titanium. Machining of 316LN doesn't create a problem (screws are silver-plated to avoid galling); Titanium ok but too expensive.

# 80 mm long PMQs

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# To be procured

- 72 “long” quadrupoles : to be produced by Elytt.
  - Sep 2011 : 16 quads (tank3)
  - Oct 2011 : 15 quads (tank3)
  - Nov 2011 : 23 quads (tank2)
  - Jan 2012 : 18 quads (tank2)
- 4 “short” quadrupoles : retune existing ones
  - Sometimes in 2012 when the intertanks are assembled
- Spares : 10 “short” + 20 “long” : schedule tbd