ASSUMPTIONS

(These can be adjusted off-line in

LINAC

0.2 → 3 GeV

200 MHZ (Variant: 1.5 → 3 GHz at

Aperture = 45 cm diameter

(Can be larger at small cos

FIRST RLA

3 → 12 GeV

200 MHZ (Variant: All at 400 MHz)

Arc Circumference : 400 m

No. of Recirculations : 4

SECOND RLA

12 → 50 GeV

200, 400, 500 MHZ

Arc : 1000 m

No. of Circulations : 4

MORE ASSUMPTIONS

E_{acc} = 15 MV/m (Active)

Linac Filling Factor = 0.5

U =

200 MHZ

$T_{operating}$ = 4.5

Q_0 = 5×10^9 $U \sim 1 \frac{KJoule}{m}$

400 MHZ

T_{op} = 2.5K

Q_0 = 2×10^9

See LHC Results at 400 MHZ

(A04, A09, A17) with lower performance, cavity A04 and cavity A17 reached already values close to $2 \cdot 10^9$. The niobium layer of this 3 cavities was stripped off, the coating was repeated and the cavities reached the design parameters with this second coating.

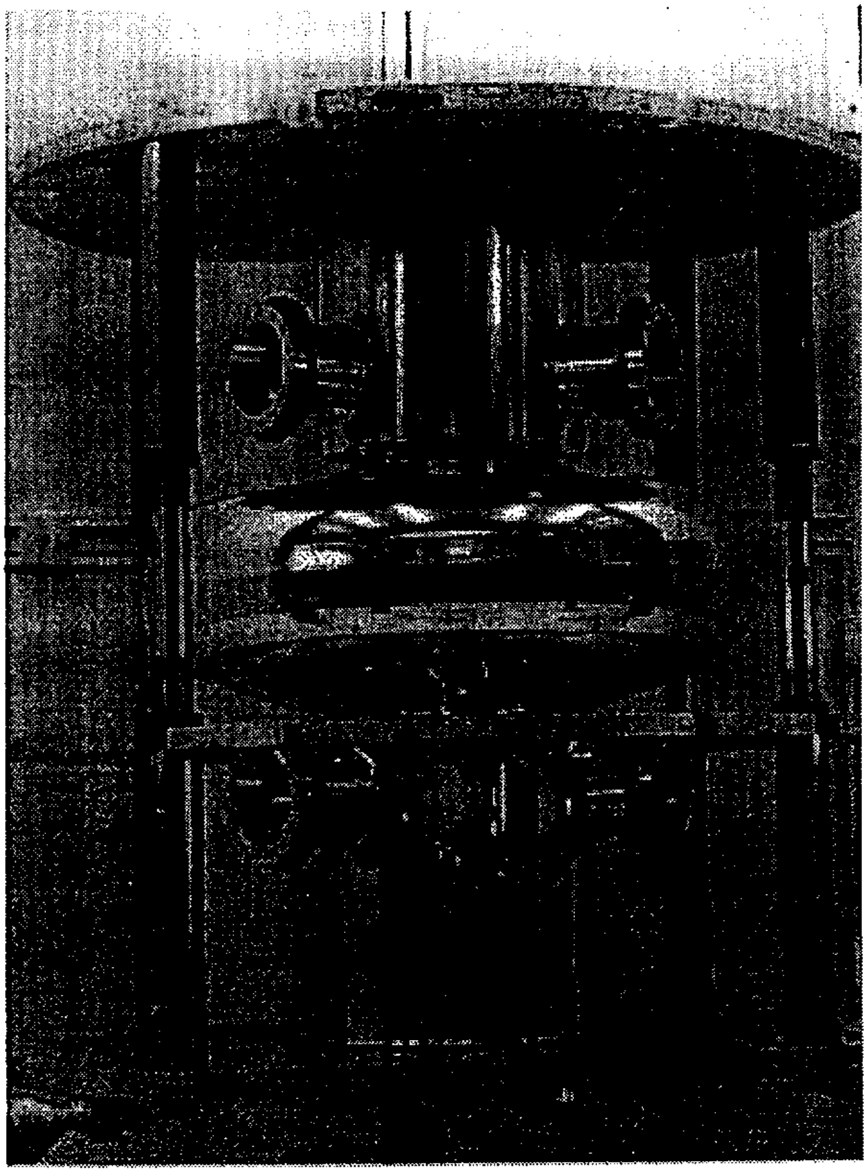


Figure 1: LHC 400 MHz copper cavity ready for magnetron sputtering of niobium. This technology was transfereed from CERN to ACCEL in the scope of the LEP 200 project

The cavities have been tested at CERN at bath temperatures of 4.5 K and 2.5 K. The highest gradient achieved at 4.5 K was 10.5 MV/m with a quality factor of $1.2 \cdot 10^9$. At a bath temperature of 2.5 K the highest achieved gradient was even 14.5 MV/m with a quality factor Q_0 still above $2 \cdot 10^9$. The distribution of all achieved gradients and quality factors at this highest gradients for the two bath temperatures of 2.5 K and 4.5 K is shown in Fig. 3. On the average at 4.5 K a gradient of 9.2 ± 0.6 MV/m and at 2.5 K a gradient of

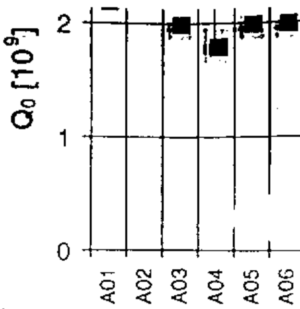


Figure 2: Distributio
of E_{acc} = 5 MV/m a
cavities reached Q_0 >
of niobium on copp
1-2 µm niobium lay
coating had to be rep

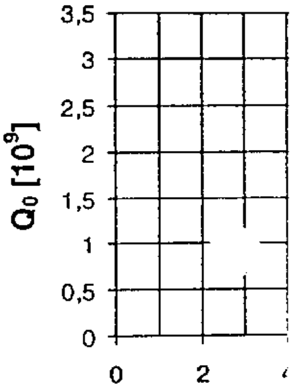
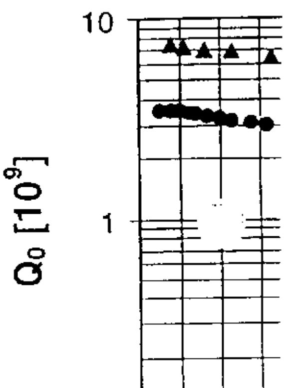
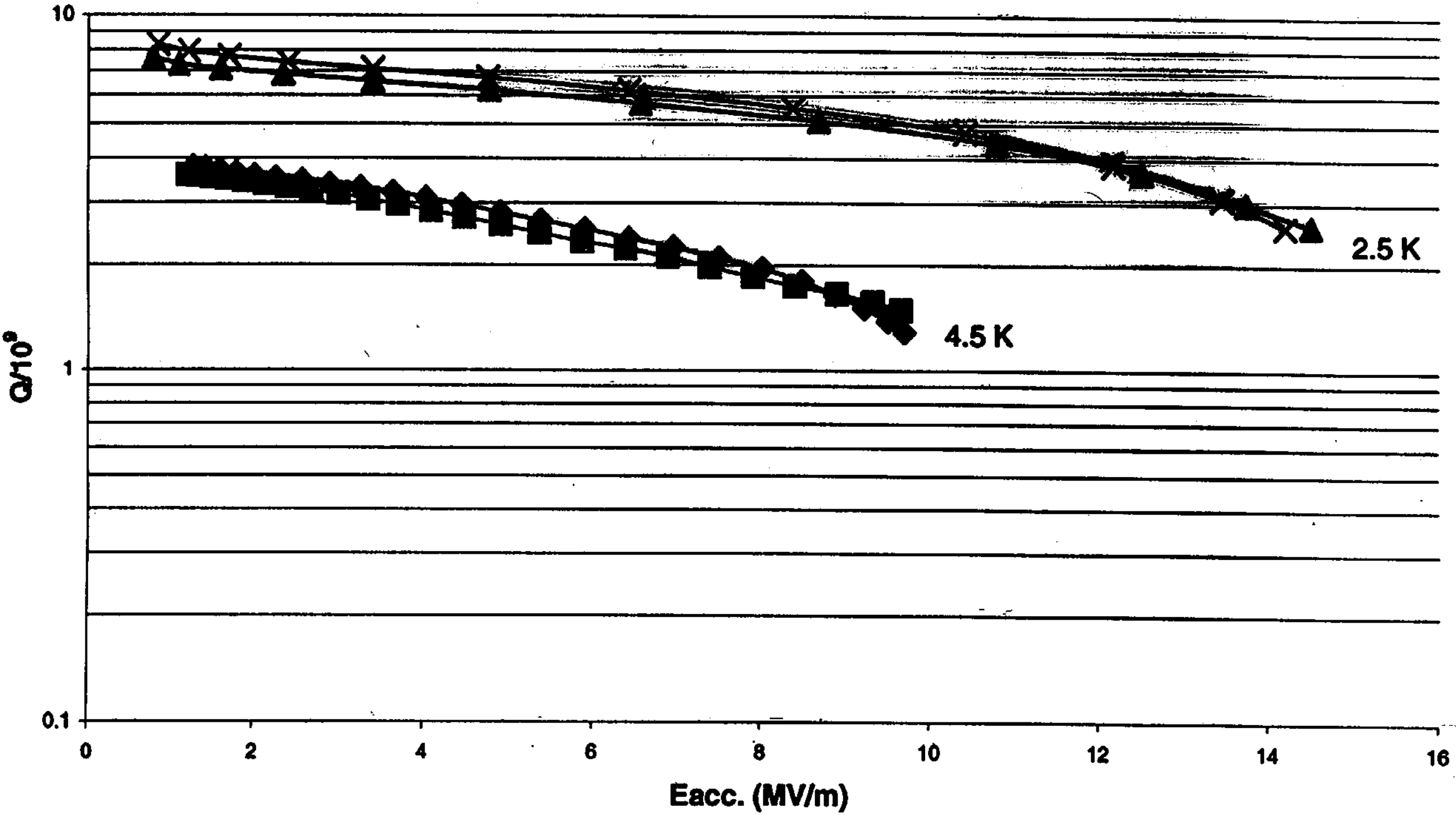


Figure 3: Highest gr
the highest gradient
4.5 K and 2.5 K i
cavities. The tests
preparation of the ca
ACCEL.



LHC CAVITIES PERFORMANCE



cavity A17 (see Fig. 2) a new Nb-cathode with an overall success rate d. Among the 3 cavities performance, cavity A04 dy values close to $2 \cdot 10^9$. ities was stripped off, the avities reached the design ting.

copper cavity ready for
m. This technology was

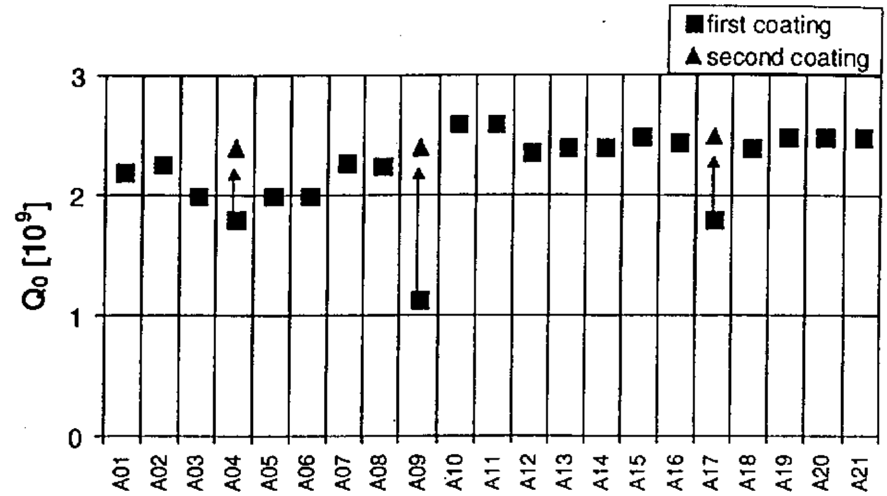


Figure 2: Distribution of cavity quality Q_0 at a gradient of E_{acc} = 5 MV/m and a bath temperature of 4.5 K. 18 cavities reached $Q_0 > 2 \cdot 10^9$ already after the first coating of niobium on copper. For the remaining 3 cavities the 1-2 µm niobium layer had to be stripped off, and the coating had to be repeated

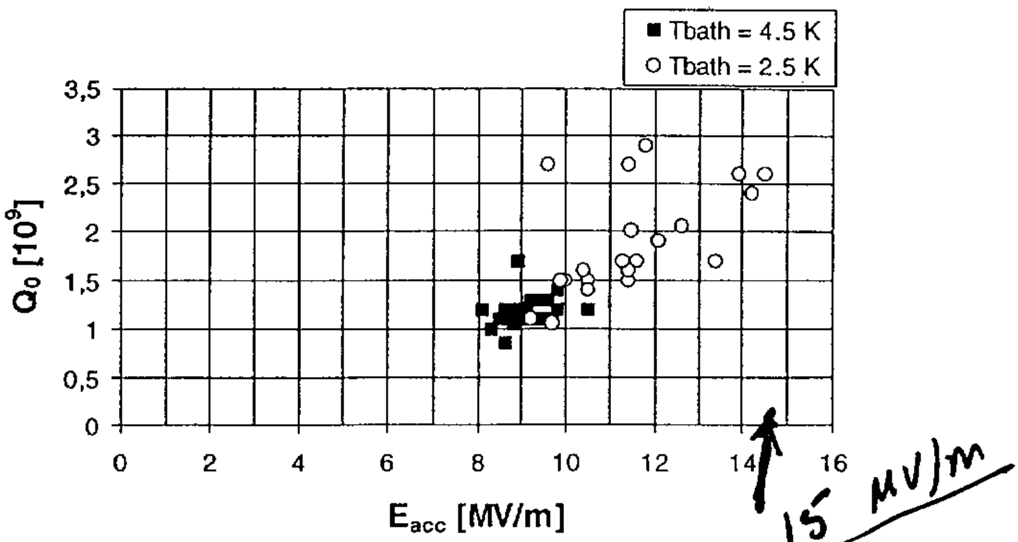


Figure 3: Highest gradients E_{acc} and quality factors Q_0 at the highest gradients achieved at bath temperatures of 4.5 K and 2.5 K in the LHC 400 MHz single cell cavities. The tests were carried out at CERN. The preparation of the cavities prior vertical test was done at

ALGORITHMS

e.g. RLA I : 3 → 12 GeV

- Linac Active Length =

$$\frac{(E_{final} - E_{initial})}{\text{No. of Recirculations} \times \text{Gradient}}$$

L = 150 m (active)

Real estate Length = 300 m

- Total Voltage Installed
  Gradient X Length
  = 2.25 GV
  ~~(In the~~ Less than LEP ≈ 1/2.

Beam Power

- Average Beam Power =
  Bunch Charge × No. of Bunches × Rep R
  × [Final Energy − Initial Energy)

  = 54 KW

- RF on time for beam =
  No. of Recirculations × $\frac{\text{arc Circumfe}}{c}$

  = 5.93 μsec

- RF on for beam Duty Factor (d,

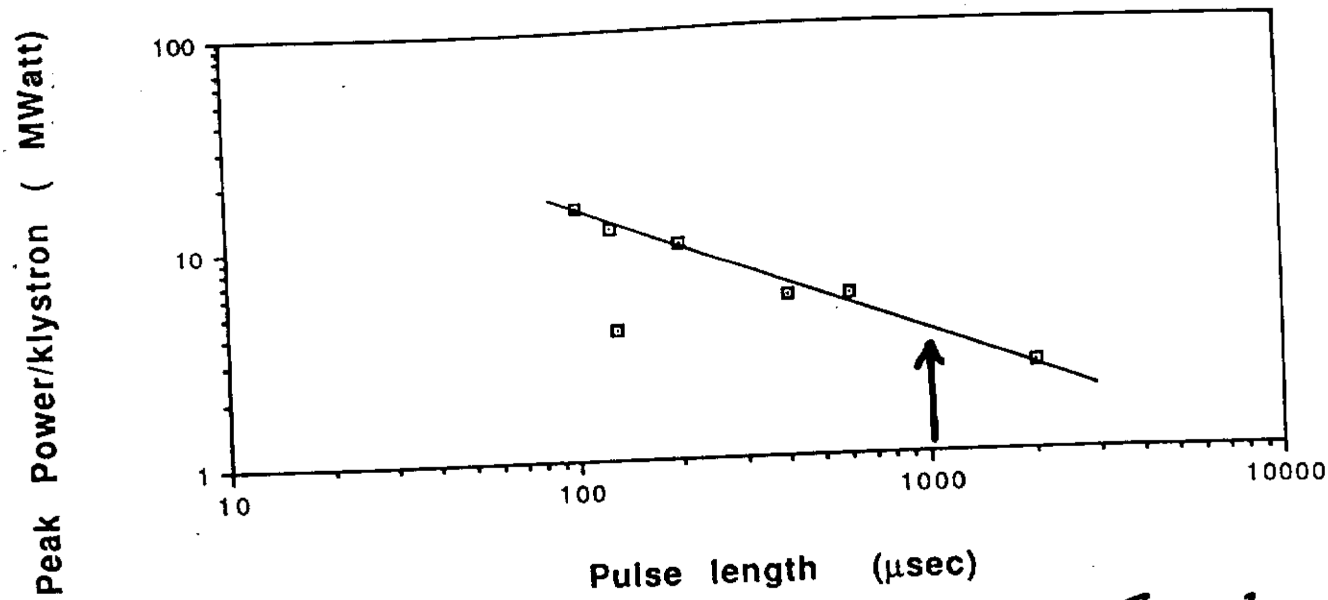
  = RF on time × Rep Rate

  = 8.9×10^{-5}

- Peak Beam Power

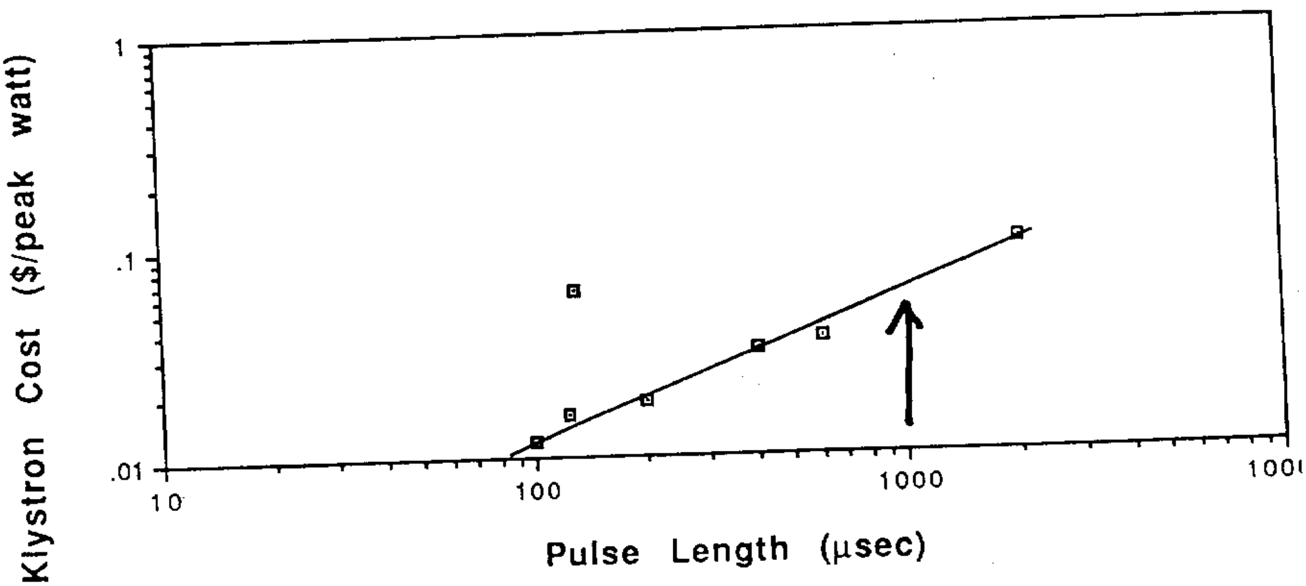
  = $\frac{\text{Average Beam Power}}{d}$ = 607 MW

Peak Power of klystrons (MWatts) dep...



BASED ON 1992 Klystron Survey

\$/peak RF Watt for klystrons is determined from the following graph derived from klystron catalog information:



$$LCrf := 0.708 \cdot \log\left[\frac{trf}{10^{-6}}\right] - 3.335$$

Log of cost

$$Crf := 10^{LCrf}$$

Cost of Peak power (\$/watt)

Peak Beam Power per meter

$= 4\ MW$

$\approx$ Coupler Capability

Total RF Pulse Length

- Loaded Q to match to beam =

$$\frac{\text{Gradient}^2}{\left(\frac{R}{Q}\right)\ \frac{\text{Peak Beam Power}}{L}}$$

$= 3.3 \times 10^5 \Rightarrow$ Bandwidth $= 600\ Hz$

- RF Fill time

$$= 2\ln(2) \times \frac{Q_L}{\omega} \qquad \omega = 2\pi f_{rf}$$

$= 0.37\ ms \gg$ Beam time

$\Rightarrow$ Size of Klystron

$P_{Klystron} = 6.6\ MW$ (See curve)

Peak Beam Power per meter

= 4 MW

≈ Coupler Capability

<u>Total RF Pulse Length</u>

- Loaded Q to match to beam =

$$\frac{\text{Gradient}^2}{\left(\frac{R}{Q}\right)\ \frac{\text{Peak Beam Power}}{L}}$$

$= 3.3 \times 10^5 \Rightarrow$ Bandwidth $= 600\,Hz$

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$\Rightarrow$ size of Klystron

$P_{Klystron} = 6.6\ MW$ (see curve)

REFRIGERATION

- RF ON DUTY FACTOR =

  Rep Rate x (RF ON TIME + FILL TIME + ~DECAY)

  $= 7.6 \times 10^{-3}$

- Dynamic Heat Load =

  $$\frac{\text{Gradient}^2 \times \text{Active Length} \times \text{RF Duty}}{\left(\frac{R}{Q}\right) \cdot Q_0}$$

  = 310 watt

  small

- Static Heat Leak

  = 5 w/m x Active Length x 2

  = 1.5 KW

- HoM power : small

Total Cryogenic Heat Load

$\approx 310 + 1500 + 150$

Distribution

$\approx$ 2 KW

AC POWER

- Ave. RF Power =

Total Peak RF Power X Rep Rate X
Total RF ON TIME

= 3.4 MW

- AC Power For RF = 3.4 MW/Klystron Eff. (.65)
- AC Power For Refrigerator =

$$\frac{\text{Total Cryo Power}}{\text{Carnot Efficiency} \times \text{Technical Eff.}}$$

= 600 KW

Total AC Power = 5.8 MW.

	Active Length (m)	Klystron Power (MW)	No. of Klystrons	Pulse Length (μs)	Band Width Hz	REF RIGERATOR (KW)	(MW)	CAP COST %
LINAC	187	5.2	96	550*	400*	2.6	7.3	24
RLA 1	150	6.6	92	370	600	1.8	5.8	21
RLA 2	633	8	135	870	254	9.4	25	55
	LINAC	RF				FRIG		

* Loaded Q to Match = 3.4×10^4

Chosen Q_L = 5×10^5

Fill Slowly to Reduce Peak Power Cost (LINAC)

IF NOT, LINAC 24% → **> 50%**

ALL IN %

	STRUCTURE	RF	FRIG	Σ	VARIANTS
LINAC	8	14	1	24	→ 17 Make 1.5 → 3 GeV @ 400 MHz
RLA 1	6.5	14	<1	21	→ 11 RLA 1 @ 400 MHz
RLA 2	24	27	4	55	→ 31 RLA 2 @ 400 MHz ↓ 27 @ 500 MHz 25 @ 5 Recirculations

R + D (General)

- Development of RF Structures and RF Sources is a long lead time item

ADVICE:

ADDRESS THIS WORK EARLY

- Although there is considerable SRF experience at
  350, 500, now 400 MHz

THERE IS ZERO EXPERIENCE AT

E_{acc} = 15 MV/m <u>and</u>

Pulsed <u>and</u> 200 MHz.

R+D (con't)

- At low frequency (~200 MHz) Nb/Cu becomes attractive
  - Nb material cost saving
  - Thick copper against Lorentz Force Detuning
  - RF Performance improves with low Frequency

RECOMMENDATIONS

- Look into Spinning half-cells at 200 MH
  → 100 MHZ
- Conduct experiments on Pulsed RF with SC Cavities at Various Frequencies
- Develop higher power couplers + windows   Linac 2.7 MW coupler
  RLA1 4MW, RLA2 = 1.7 MW

  (useful for both NRF, SRF)
- Can we make Cavity compact?