Cryogenic System Overview IC-2 v2

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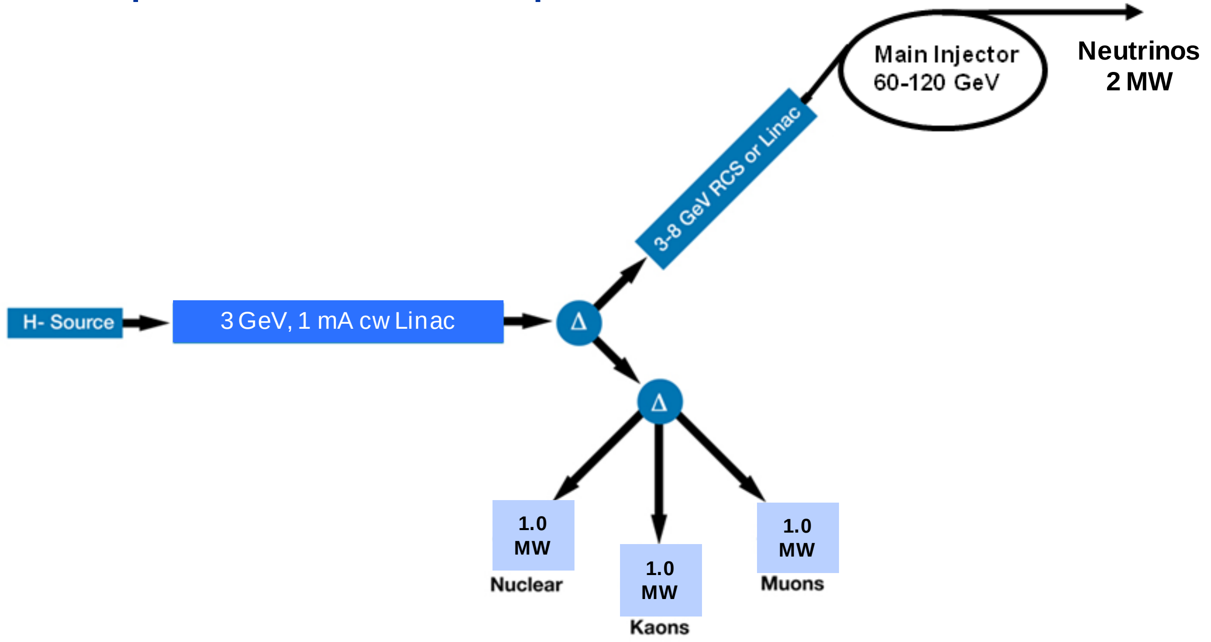
OUTLINE

- ICD-2 v2
- Cryogenic scope
- Functional requirements
- Assumptions and constraints
- Current configuration
- Heat load
- Cryogenic plant
- Summary

INITIAL CONFIGURATION DOCUMENT (ICD)

- Projects have to work within context of DoE order 413.3a Input to CD-0 “Approve Mission Need”, R&D and Conceptual Planning
- A solution is needed for the project cost estimate
- Current solution is described in ICD -2 v2: 3 GeV SC CW Linac with preferred option of 3-8 GeV pulsed Linac



SCOPE

- Cryogenic plant
- Cryogenic distribution system
- Ancillary systems
- Cryogenic testing infrastructure

FUNCTIONAL REQUIREMENTS

- IC-2 Cryogenic system supports operation of 3 GeV Linac in CW mode. Configuration for 3-8 GeV Linac is being finalized
- Maintain elliptical and spoke cavities, and magnets at a temperature below the lambda point under normal operation
- Provide shield and/or intercepts flow at multiple temperature levels
- Cool-down and fill (conversely empty and warm-up) the accelerator
- Efficiently support transient operating modes including RF on/RF off

FUNCTIONAL REQUIREMENTS (2)

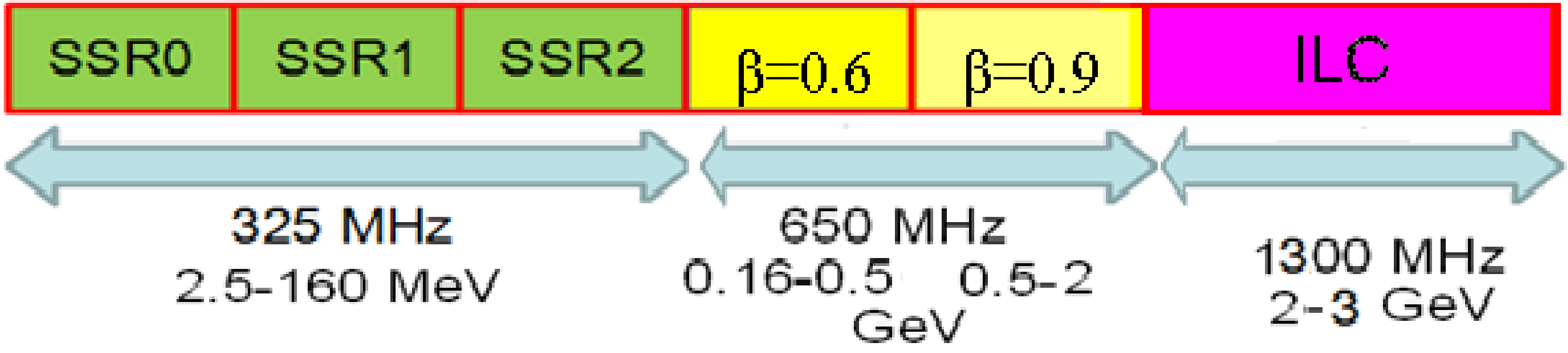
- Provide refrigeration for conductively cooled power leads. Liquefaction flow for power leads will not be required
- Allow cool-down and warm-up of limited-length strings for repair or exchange of superconducting accelerating components
- Protects superconducting RF (SRF) cavities from over pressurization beyond the component's MAWP during fault conditions

ASSUMPTIONS AND CONSTRAINTS

- Assumptions
  - Lowest MAWP of accelerating components is currently 2 bar warm
  - Low–β and medium–β cryomodules house J-T heat exchangers
  - Tevatron is decommissioned and its auxiliary equipment is available for use prior to the CD-3
- Constraints
  - For costing purposes, Linac segmentation remains the same as the original IC-2 layout (five cryogenic segments)

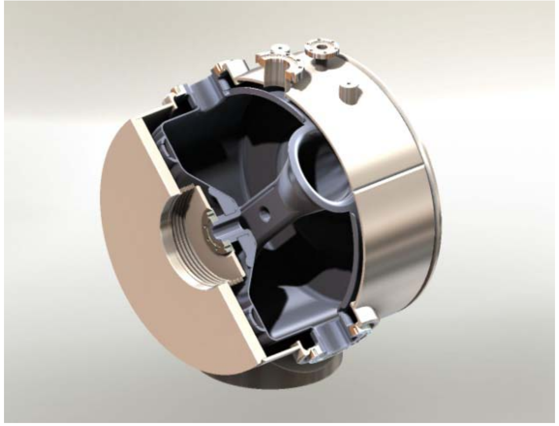
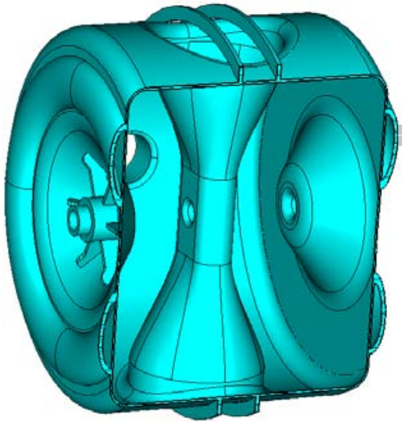
CURRENT CONFIGURATION

- 300+ cavities of three different frequencies (325 MHz, 650 MHz and 1300 MHz)
- 105 magnets with conductively cooled leads (solenoids, doublets and quads)
- 35 cryomodules (CM) of six different types



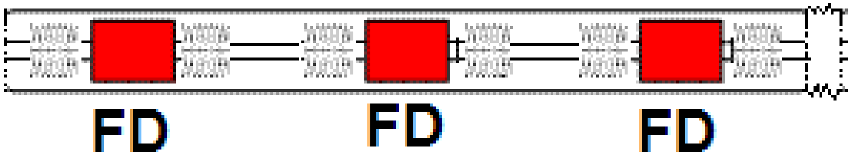
325 MHz SECTION

- Low-energy 325 MHZ linac (2.5-160 MeV)
- 3 families of single-spoke resonators
- 88 cavities and 68 magnets
- Single SSR0 CM that contains 26 cavities and 26 solenoids
- Two SSR1 CM with 9 cavities and 9 solenoids per CM
- Four SSR2 CM with 11 cavities and 6 solenoids per CM

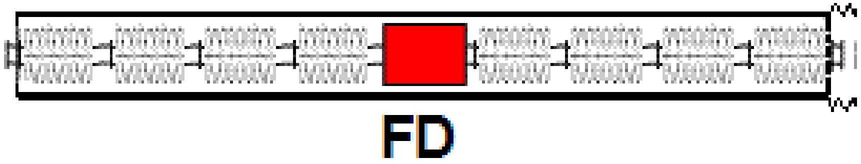

650 MHz LOW–β SECTION

- 5-cell elliptical cavity
- 42 cavities
- 21 magnets
- 6 cavities and 3 doublets per cryomodule
- 7 cryomodules



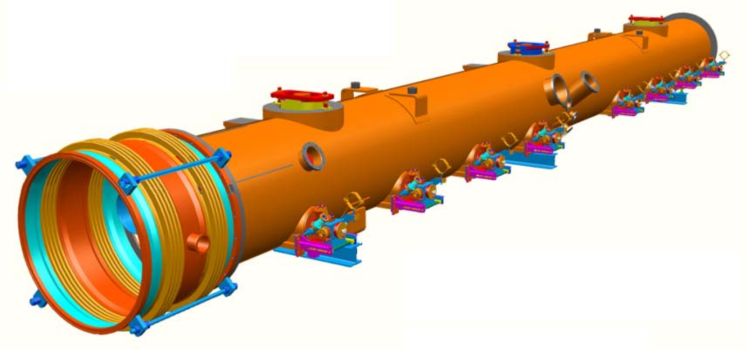
650 MHz HIGH–β SECTION

- 5-cell elliptical cavity
- 96 cavities
- 12 doublets
- 8 cavities and 1 doublet per CM
- 12 cryomodules
- Two segments – 6 cryomodules each



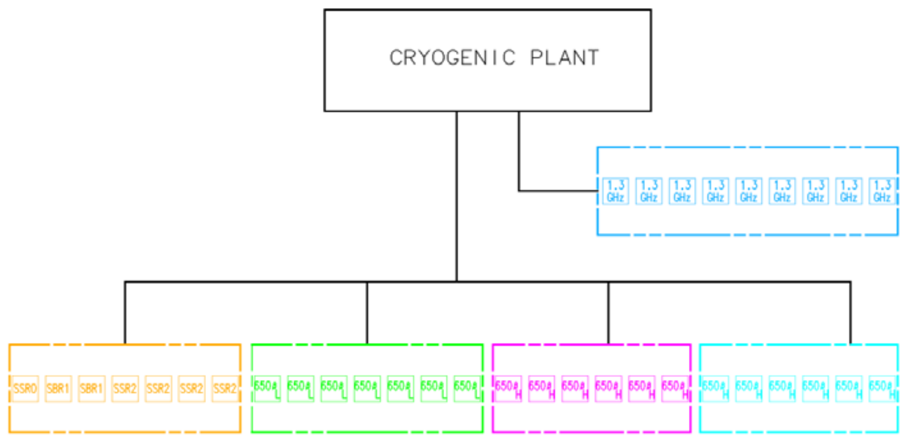
1.3 GHz SECTION

- 9-cell TESLA cavity
- 72 cavities
- 9 magnets
- TESLA style cryomodule (8 cavities and 1 quad per CM)
- 9 cryomodules



CRYOGENIC DISTRIBUTION

- For costing purposes, cryomodules are divided in two units – Upstream and Downstream
- Upstream unit contains four segments
- Downstream unit contains a single segment
- Units are fed by refrigerators in parallel



UPSTREAM UNIT

- Segments are fed in parallel
- Within a segment, cryomodules are fed in series – TESLA like
- Four segments:

  #1 – 7 CM (1 x SSR0, 2 x SSR1 and 4 x SSR2)

  #2 – 7 x 650 Low-β cryomodules

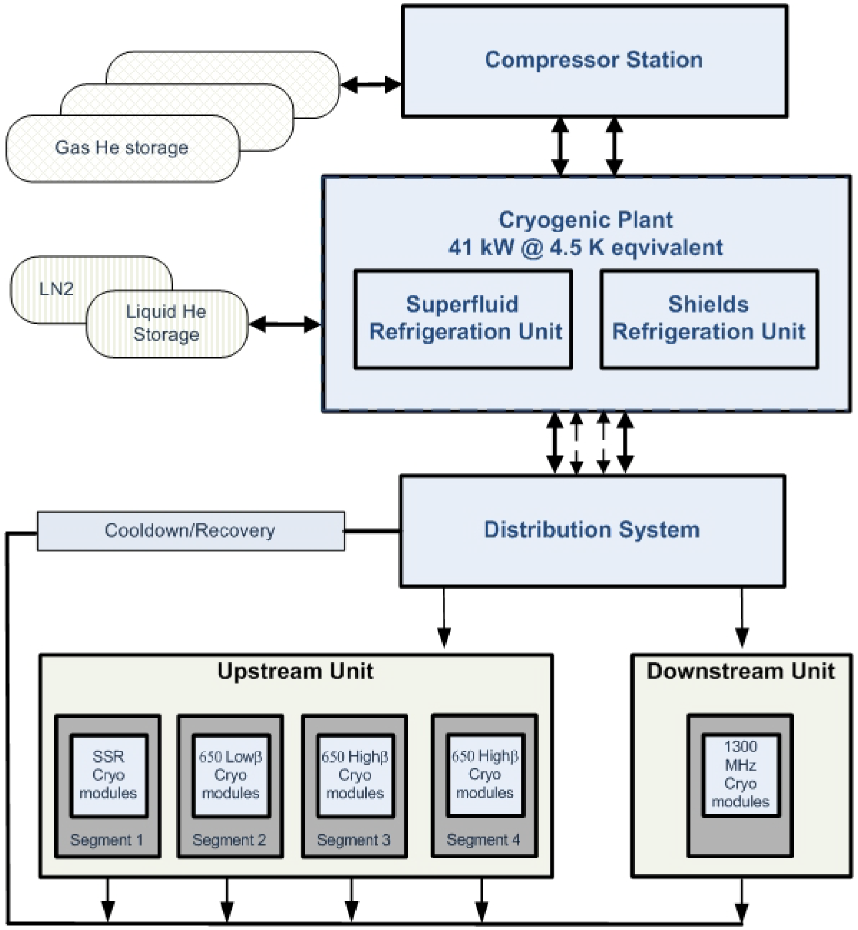
  #3 – 6 x 650 High-β cryomodules

  #4 – 6 x 650 High-β cryomodules
- Each segment is connected to a transfer line that runs from a refrigerator along the upstream unit

DOWNSTREAM UNIT

- 9 TESLA style cryomodules
- Revising and resizing the TESLA cryogenic concept for CW operation
- Saturated He II cooled cavities
- Helium gas thermal shield @ 5 - 8 K
- Helium gas thermal shield @ 40 - 80 K
- Low pressure heat exchanger is located at or near the refrigerator

3 GeV LINAC SIMPLIFIED CRYOGENIC LAYOUT

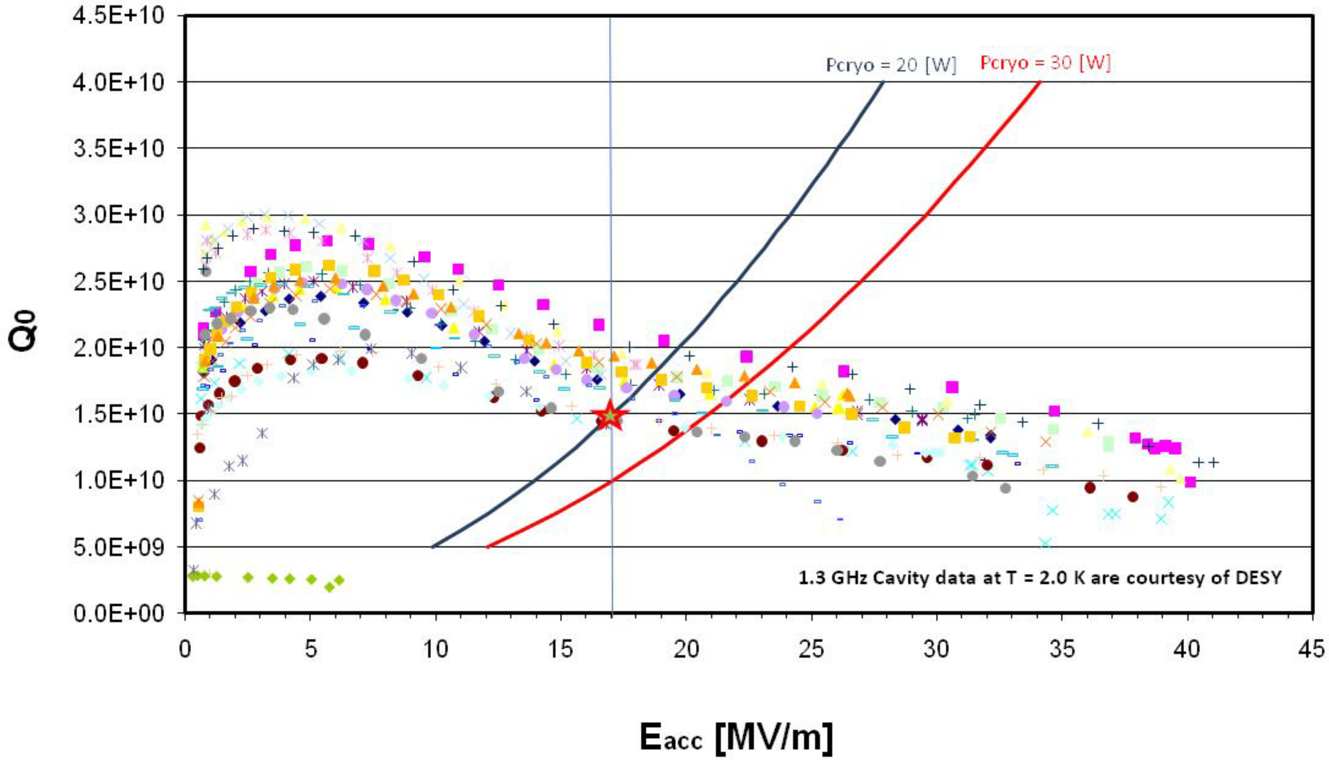


HEAT LOAD

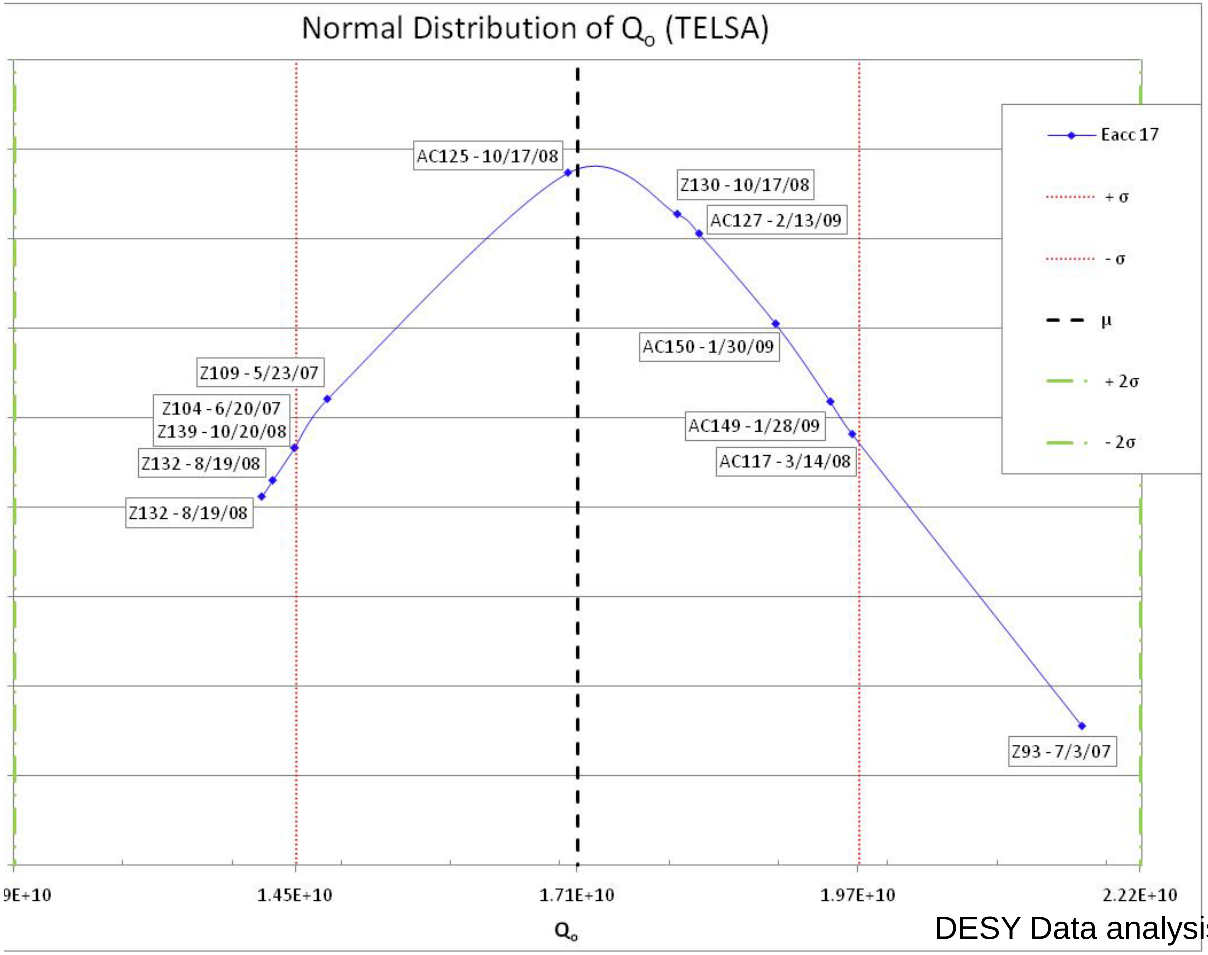
- CW mode:

  RF dynamic heat load is dominant

- $P_{RF} \sim 1/ Q_0$
- $Q_0 (T) \sim G/R_s$



HEAT LOAD (2)



DESY Data analysis by A. Dalesandro

HEAT LOAD (3)

- The quality factor of superconducting bulk niobium cavities has a mild degradation between *Bp* = 20–90 mT

$$Rs_0(T)*\left[1+\gamma(T)*\left(\frac{Bp}{Bc}\right)\right]$$

Frequency, MHz	Bpeak/Eacc, [mT/(MV/m)]
1,300	4.26
650 High-β	3.76
650 Low-β	2.26

- Need to better understand γ(T)

HEAT LOAD (5)

- Current assumptions $\gamma(T)=1$ (~ 30% effect)

Frequency, MHz	Q_0
325	1.0e10
650 Low-β	1.5e10
650 High-β	2.0e10
1,300	1.5e10

- A preliminary heat load estimate has been performed. For the design study, an additional 50% margin is applied to the estimated heat loads to ensure the system could meet all operational requirements. With this factor, the total 4.5 K equivalent design capacity for the entire linac is approximately 41 kW

CRYOPLANT

- Cryogenic plant capacity
  - 41 kW @ 4.5 K equivalent
- The physical size of a plant of this capacity is too large to house in a single cold box. As a result, two cold boxes are envisioned; one to support the superfluid loads and one to support the thermal shield loads.
- A wide range of possible cryogenic plant design solutions that satisfy all requirements and constraints for Project X will be studied further
- Combining effective use of the existing Fermilab infrastructure with commercially available components requires further study. The final solution will be based on a cycle with either cold compression alone or utilizing a hybrid approach (both cold and ambient temperature compression).

SUMMARY

- A solution for the purpose of a Pre CD-0 project cost estimate was developed

- The IC-2 configuration is technically feasible

- It supports operation of the 3 GeV SC Linac operating in CW mode. The next iteration will benefit from refining of the project constraints and assumptions

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