Project X: Cryogenic Segmentation Issues

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Outline

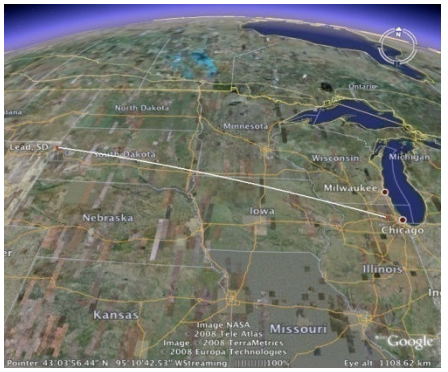
- Project X at Fermilab
- Current Design Options
- Key Functional Requirements and Design Issues
- Cryogenic segmentation
- Summary

Our websites: http://projectx.fnal.gov/

Project X at Fermilab

- A multi-MW Proton Source, Project X, is the linchpin of Fermilab's strategy for future development of the accelerator complex.
- Project X is designed to provide flexibility in evolving the Fermilab program in response to research results anticipated circa 2012.
  - Energy Frontier:

    Tevatron → ILC or Muon Collider
    - ➢ Technology alignment
    - ➢ Project X development retains ILC and MC as options for the Fermilab site

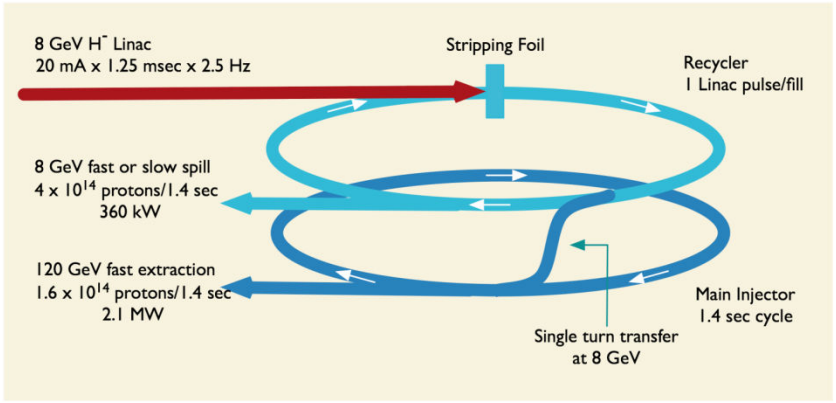


  - Intensity Frontier:

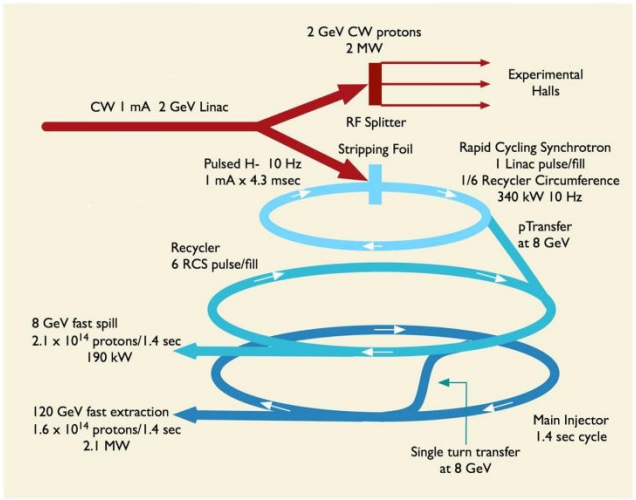
    NuMI→ NOνA→ LBNE/mu2e→ multi-MW Proton Source → NuFact
    - ➢ Continuously evolving world leading program in neutrino physics and other beyond the standard model phenomena

Current Design Options

- Initial Configuration I (IC-1)
  - 2 MW of beam power over the range 60 – 120 GeV;
  - ***Simultaneous with at least 150 kW of beam power at 8 GeV***;
  - Compatibility with future upgrades to 2-4 MW at 8 GeV.



- Initial Configuration 2 (IC-2)
  - 2 MW of beam power over the range 60 – 120 GeV;
  - ***Simultaneous with 2 MW beam power at 2 GeV;***
  - Compatibility with future upgrades to 2-4 MW at 8 GeV.



Key Cryogenic System Functional Requirements

IC-1

- *Support operation Pulsed Linac (5Hz rep rate)*
  - 40 TESLA style cryomodules (β = 0.81 and β = 1)
  - 2 x SSR*-1 cryomodules
  - 3 x SSR-2 cryomodules
  - 7 x TSR** cryomodules
  - 19 SC solenoids
  - Elliptical cavities at 2.0 K
  - Spoke resonators below 4.5K

IC-2

- *Support operation CW Linac*
  - 20 TESLA style cryomodules (β = 0.81 and β = 1)
  - 4 x SSR-0 cryomodules
  - 2 x SSR-1 cryomodules
  - 3 x SSR-2 cryomodules
  - 8 x TSR cryomodules
  - Elliptical cavities and Spoke resonators at 1.8 K

- *Allow cool-down and warm-up of limited-length strings for repair or exchange of superconducting accelerating components*
- *Protects superconducting RF cavities from over pressurization beyond the component's MAWP during fault conditions*

*– Single Spoke Resonator (SSR), ** – Triple Spoke Resonator (TSR)

Key Design Issues

- Cryogenic Distribution and Segmentation
- System Operating Parameters
- Heat Loads

Cryogenic Segmentation

- There is no “one-size-fits-all” answer to cryogenic and vacuum segmentation
- Use of segmentation varies from machine to machine
  - Wide range of machine designs & sizes
    - ILC – ~30 km linac, most cryomodules ~ identical
    - CEBAF -- 20 cryomodules in each linac, each CM removable
    - FRIB – ~ 300 m linac, at least 2 separate cryomodule designs
- Iterative Process:
  - Make choices, look at design implications, change as required

Levels of Segmentation

- Vent lines at intermediate locations for relief valves
  - Long strings of RF cavity helium vessels with low maximum allowable pressures or long 5 K shield pipes may require intermediate venting between end boxes
- Insulating vacuum breaks, internal lines continue through
  - Insulating vacuum break divides the leak check volume into smaller segments and limits the extent of a loss of vacuum incident
- Insulating vacuum break and separation valves
  - Permits warm-up and intervention in a section by letting up insulating vacuum with insulated buffer sections on each end, but no bypass. All flow is stopped but most of machine remains “floating” cold. May also expedite phased installation.
- Insulating vacuum break, bayonet disconnection or double-valve isolation with cold bypass line
  - Permits warm-up and intervention in a section while actively refrigerating the rest of the cold system. Expedites phased installation.

Factors to Consider

- Composition of Components
- Heat Loads
- Safety & Venting
- Reliability & Availability
- Technical Risk
- Cost
- Warm Space Requirements (beam optics)
- Commissioning and Upgrade Scenarios
- History
- Technology Demonstration & Other External Factors

Composition of Cryogenic Components

- Unlike ILC and XFEL, Project X will consist of a variety of cryomodule designs
  - IC-1 (Pulsed Linac)
    - SSR-1,SSR-2,TSR at 4.5 K
    - TESLA (β=1 and β=0.81) at ~ 2.0 K
  - IC-2 (CW Linac)
    - SSR-0,SSR-1,SSR-2,TSR, TESLA (β=1 and β=0.81) at ~ 1.8 K
- Cryomodules will be provided by different sources and arrive at different times
- Segmentation should allow for phased installation and commissioning

Heat Loads (Impact of CW Operation)

- IC-2 (β=1 and β=0.81) cryomodules will have to be modified from standard TESLA design

- Significantly higher dynamic heat load in CW operation will exceed design capacity of the Helium Gas Return Pipe for large numbers of cryomodules in series
  - This implies finer segmentation in IC-2 than in IC-1 for these cryomodules

Safety & Venting

- Segmentation must be sufficiently fine to allow safe venting of process piping, cryostat vacuum and beam tube vacuum under worst case accident scenarios

- This factor will be the same for both IC-1 and IC-2

Reliability & Availability

- Finer segmentation yields additional interconnect boxes, transfer lines and bayonets
  - Static heat leak due to bayonets may not be well understood and may benefit from additional R&D
- Vacuum space should be finely divided to allow efficient leak testing
  - Searching for leaks can have significant impacts on schedule and availability
- Additional complicated devices may result in lower overall reliability
- – historical data is mixed on this point
- By contrast, ability to quickly warm up and repair small sections of components may well lead to overall better availability
- Increased probability for ODH event

Technical Risk

- Segmentation should take into account that those components containing items of higher technical risk are more apt to require warm up and repair
- For Project X
  - TESLA (β=1) in pulsed mode have lower risk due to FLASH history and testing
  - SSR and TSR have moderate technical risk
  - TESLA (β=1 and β=0.81) in CW mode have high technical risk due mainly to new power coupler design

Cost

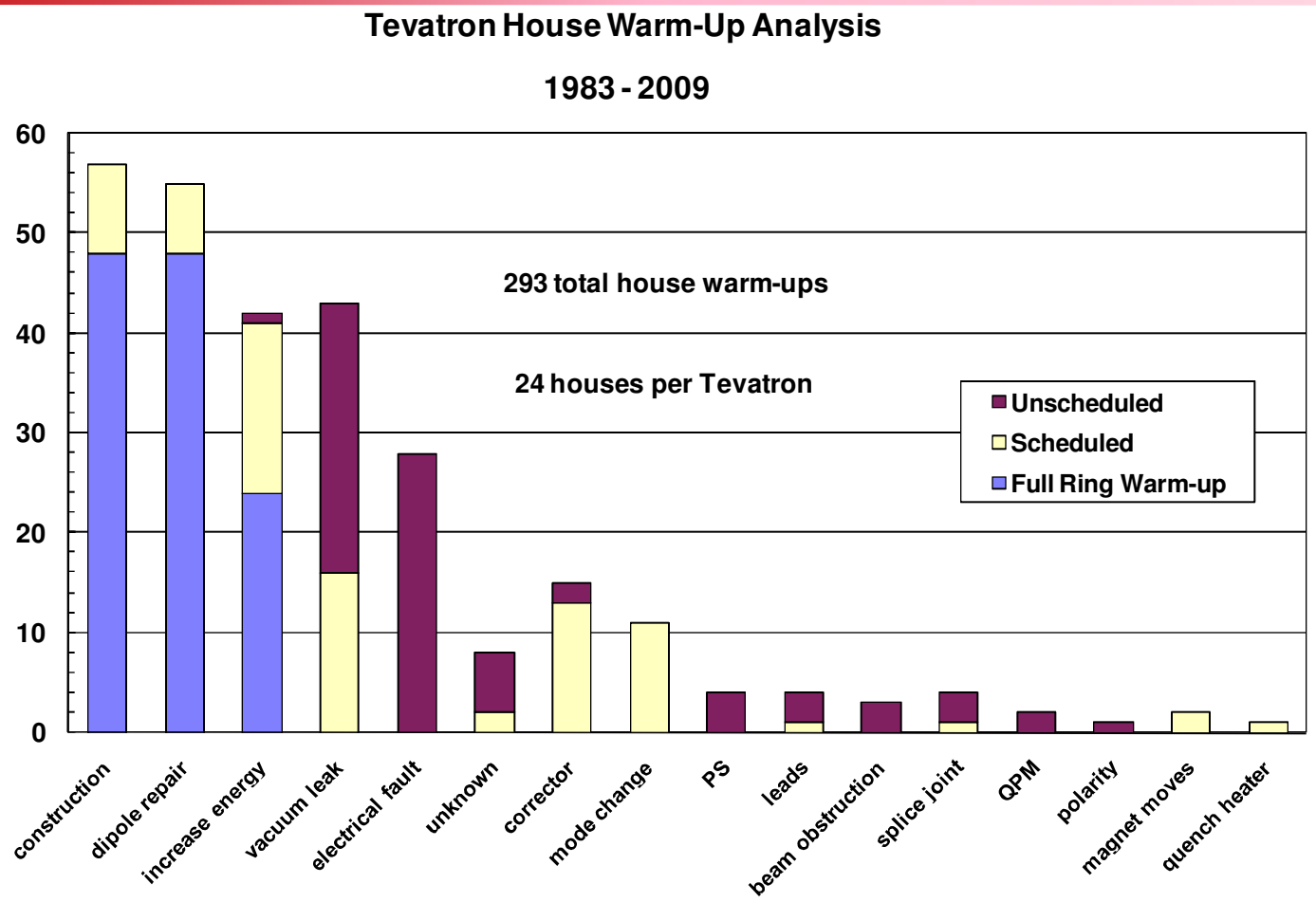
- Finer segmentation clearly adds costs
  - design, construction, installation and maintenance of interconnect boxes, transfer lines, vacuum barriers and bayonets
- Parallel cryogenic transfer line (although accelerator components become less complicated)
- Added tunnel length (1-3 m per isolation)
- Added tunnel diameter or alcoves (to accommodate transfer line and U-tube pulling)

Tevatron Segmentation

- Driven by warm iron magnet design
  - Limited distance cryogens could be distributed
- Positive cryogenic isolation (U-tubes)
- Cold seal connection between components

Cryostat Vacuum	**31 m**
Cryogenic	250 m
Beam Tube	250 m

History


Tevatron House Warm-Up Analysis
1983 - 2009
293 total house warm-ups
24 houses per Tevatron
Unscheduled
Scheduled
Full Ring Warm-up
60
50
40
30
20
10
0
construction
dipole repair
increase energy
vacuum leak
electrical fault
unknown
corrector
mode change
PS
leads
beam obstruction
splice joint
QPM
polarity
magnet moves
quench heater

Project X Technology Demonstration

- One goal of Project X is to develop and demonstrate technologies for future linear colliders
- This is best seen in the ILC cryomodules in IC-1
- It is thus sensible to segment these modules consistent with the ILC baseline, yielding less segmentation

Next Steps

- Choose segmentation options for both IC-1 and IC-2 cases – *Soon*
- Based on these choices, develop conceptual layouts, boxes, piping sizes, check safety calculations and estimate costs
- Alter choices as required based on this more detailed information

Summary

- Cryogenic & vacuum segmentation is an early first design choice
- There is no single correct choice
- Segmentation will vary from machine to machine
- Factors influencing the Project X segmentation will differ in significance than those for other machines like CEBAF and ILC
- Segmentation design is iterative
- No choice made yet for Project X but it appears clear the IC-2 will be more finely segmented than IC-1