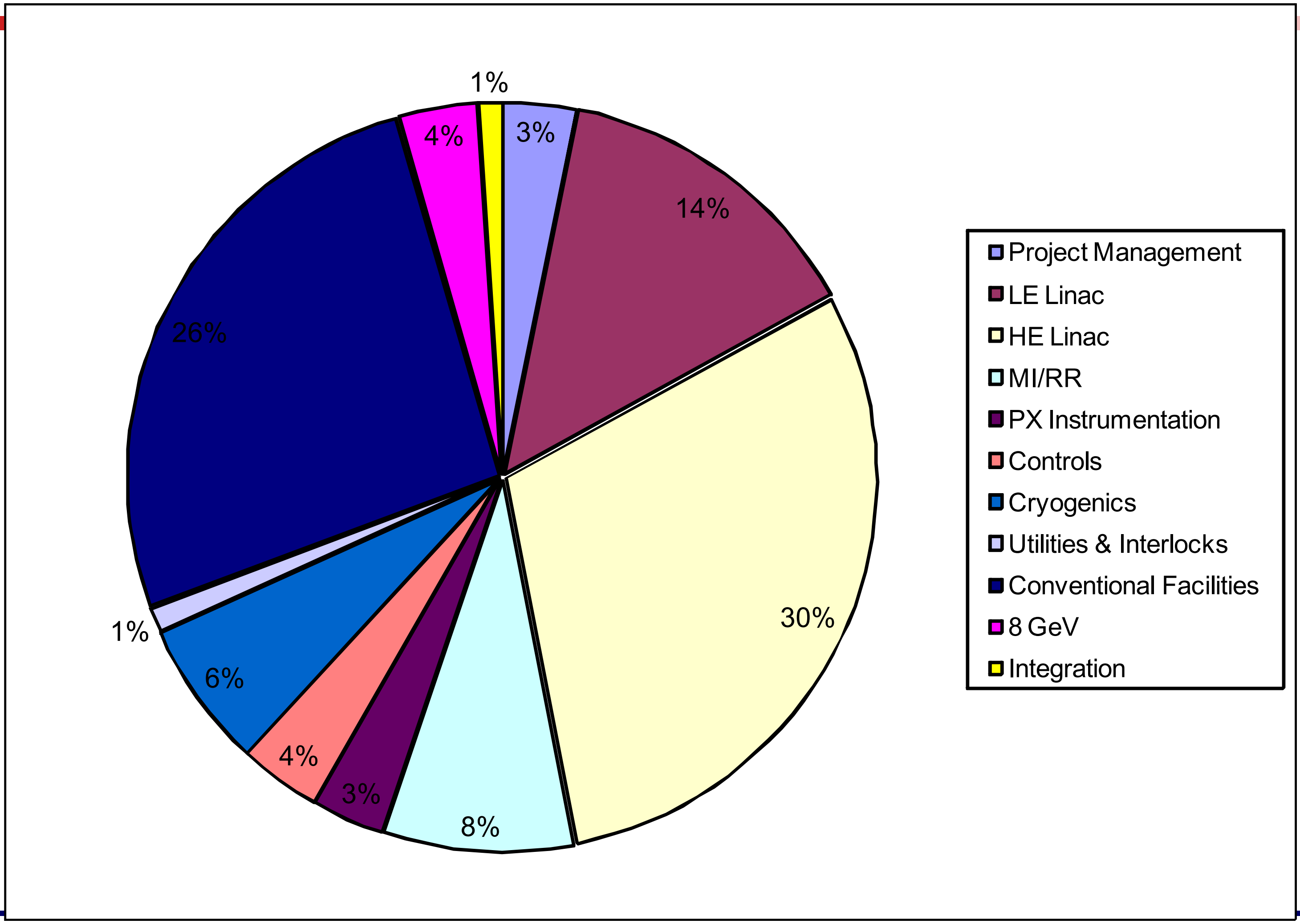
Project X systems and interfaces

Sergei Nagaitsev
Project X Director's Review
March 16, 2009

Facility scope

- An 8-GeV H- superconductive linac
  - LE: 325 MHz to 420 MeV
  - HE: 1.3 GHz to 8 GeV
- Beam line to transport to Recyler (incl. stripping injection)
- Modifications to Recycler (new injection, rf, transfer to MI)
- Modifications to Main Injector to support a single-turn extraction
- Conventional facilities
- Cryogenics
- Controls
- Instrumentation
- Project ends at extraction kicker from RR or MI

Cost distribution



Related programs

- HINS:
  - Bob Webber (APC)
  - Prototype a 30 MeV Linac operating at 325 MHz providing at least 20mA of beam with a 1 ms pulse length
- Superconducting RF Infrastructure
  - Kephart (Directorate), Mishra (TD/Dir), Nagaitsev (AD/Dir)
  - Project X related deliverables by 2013:
    - Develop 1 cryo-module/ month capability
    - Four β= 1 (2 Type3 & 2 Type4) and one β= 0.8 cryo-modules
    - NML RF unit test facility & CM test stand
    - System Integration test with beam (NML)
- ILC Americas
  - Cavities and processing: Mark Champion (TD)
  - Cryomodule design & assembly: Carter (TD)

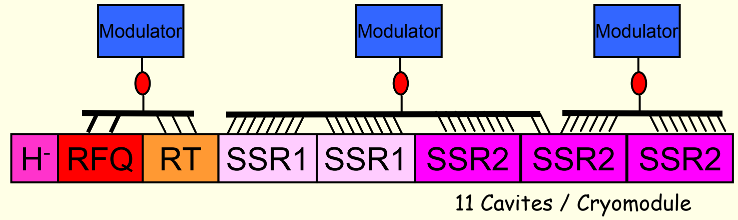
Project X

1000 kW 8GeV Linac

31 Klystrons (2 types)
453 SC Cavities
57 Cryomodules

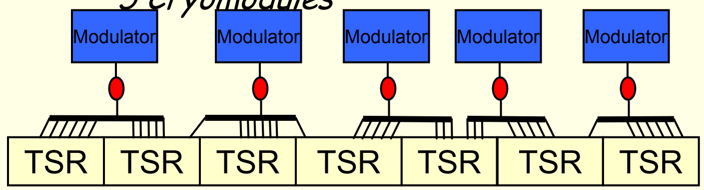
Front End Linac

325 MHz 0-10 MeV
1 Klystron (JPARC 2.5 MW)
RFQ + 18 RT Cavities



325 MHz 10-120 MeV
2 Klystrons (JPARC 2.5 MW)
51 Single Spoke Resonators
5 Cryomodules

325 MHz 0.12-0.42 GeV
5 Klystrons (JPARC 2.5 MW)
42 Triple Spoke Resonators
7 Cryomodules



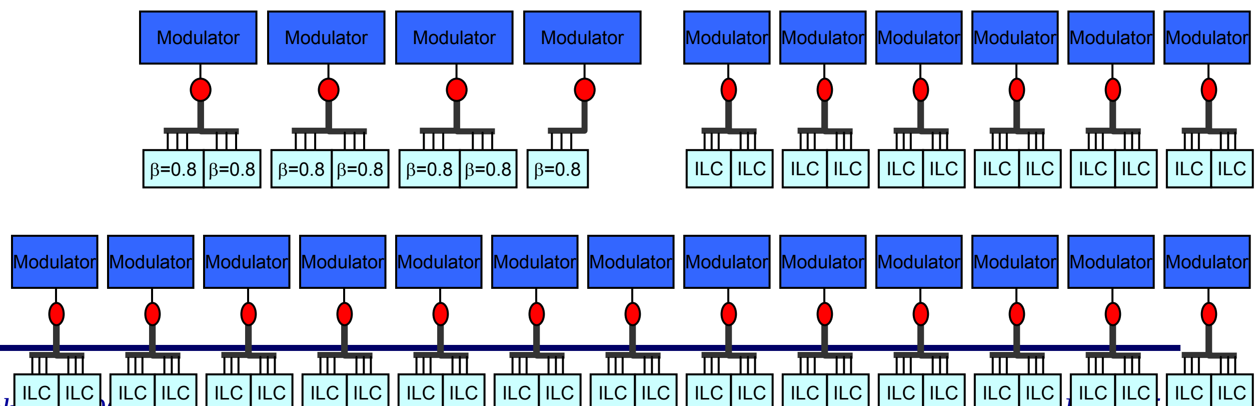
2.5 MW JPARC Klystron

Multi-Cavity Fanout
Phase and Amplitude Control

1300 MHz LINAC

1300 MHz 0.42-1.3 GeV
4 Klystrons (ILC 10 MW MBK)
56 Squeezed Cavities (β=0.81)
7 Cryomodules

1300 MHz 1.3-8.0 GeV
19 Klystrons (ILC 10 MW MBK)
304 ILC-identical Cavities
38 ILC-like Cryomodules



325 MHz Linac Requirements

- Serve as the low-energy front-end to the 1.3 GHz Linac section
- Deliver 1.25 msec pulses of 1.6E14 H- ions at 420 MeV at pulse rates up to 5 Hz
- Provide transverse and longitudinal beam emittance and bunch parameters required to:
  - Match into the 1.3 GHz Linac
  - Avoid unacceptable beam losses at high energies
- Incorporate, into the 1.25 msec beam pulse, a 53 MHz structure to facilitate pseudo bunch-to-bucket transfer into the Recycler Ring and an 89 kHz structure to facilitate a 700 microsecond abort/extraction gap in the Recycler ring

325 MHz Linac Configuration per ICD

- Configuration is based on Proton Driver/HINS design and technologies
- 50 keV H- ion source
- 2.5 MeV RFQ
- 2.5 MeV Medium Energy Beam Transport (MEBT) including two re-buncher RF cavities and a 325 MHz beam chopper
- Sixteen copper crossbar-H cavities in room temperature section to 10 MeV
- Eighteen β=0.22 SC single-spoke resonator (SSR1) cavities to 30 MeV
- Thirty-three β =0.4 SC single-spoke resonator (SSR2) cavities to 120 MeV
- Forty-two β =0.6 SC triple-spoke resonator (TSR) cavities to 420 MeV
- SC solenoids provide transverse focusing from the RFQ through the SSR2 section
- SC quadrupoles provide transverse focusing starting in the TSR section.
- Eight Toshiba E3740A(Fermi) 2.5 MW klystrons driven by Fermilab bouncer-type pulse modulators provide the necessary RF power
- RF distribution system with fast ferrite vector modulators for amplitude and phase control of each individual

1.3 GHz Linac Requirements

- Deliver 1.25 msec pulses of 1.6E14 H- ions at 420 MeV at pulse rates up to 5 Hz
- Provide transverse and longitudinal beam emittance and bunch parameters required to:
  – Match into the 8-GeV beam transfer line
  – Avoid unacceptable beam losses at high energies

1.3 GHz linac Configuration per ICD

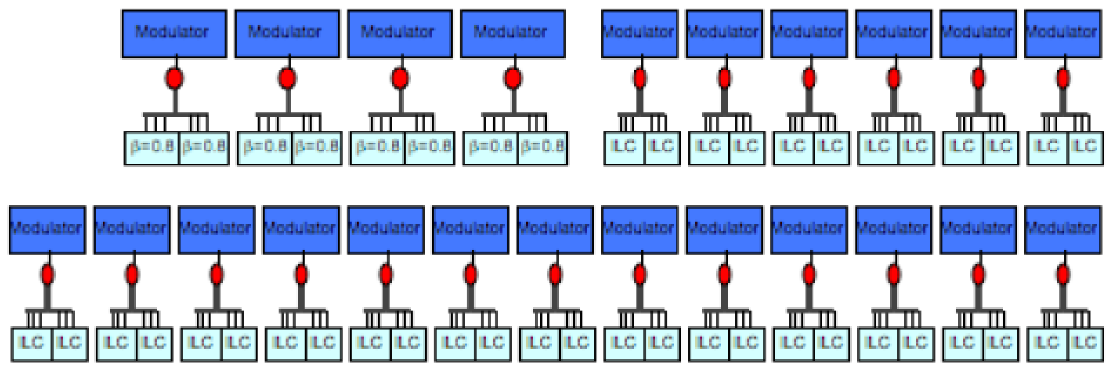
1300 MHz LINAC

1300 MHz 0.42-1.3 GeV

4 Klystrons (ILC 10 MW MBK)
64 Squeezed Cavities (β=0.81)
8 Cryomodules

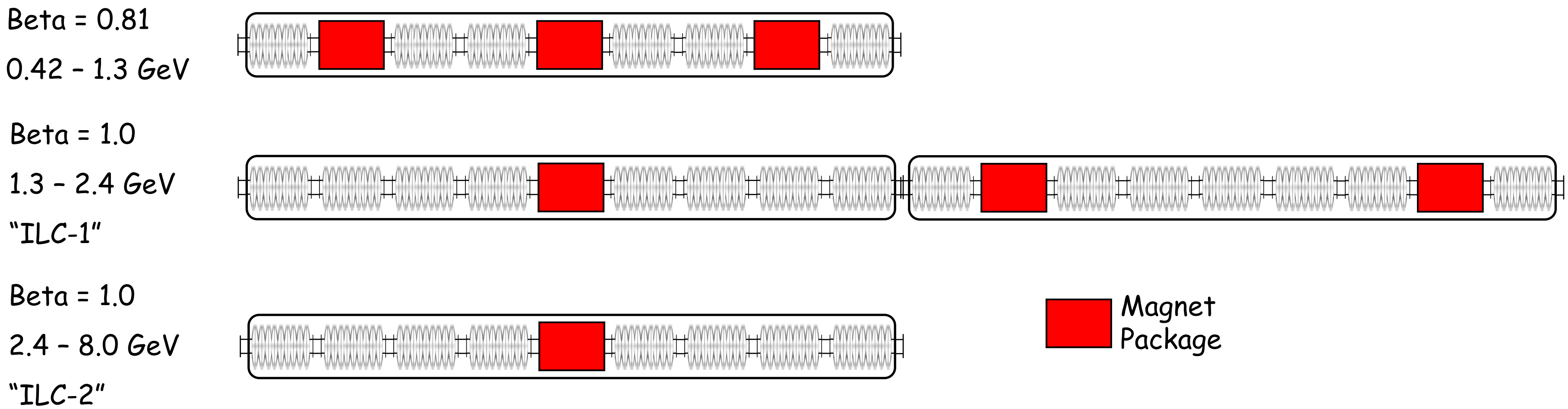
1300 MHz 1.3-8.0 GeV

19 Klystrons (ILC 10 MW MBK)
304 ILC-identical Cavities
38 ILC-like Cryomodules



- Primary Elements
  - Cavities and Cryomodules
  - RF Systems
- Interfaces to:
  - Controls, Vacuum Systems, Instrumentation, Cryogenics, Conventional Facilities

Project X — Primary elements



- Cryomodules
  - cavities, rf couplers, magnets, instrumentation, cold mass
- RF systems
  - modulators, klystrons, rf distribution (including vector modulators), LLRF controls, interlocks

Project X Transfer line (scope)

- Transfer Line
  - Magnets
  - Power supplies
  - Beam line vacuum
  - Beam line collimation
  - Energy Correction
  - Linac Primary Dump
- Recycler Injection
  - Magnets
  - Power supplies
  - Injection vacuum
  - Foil changer
  - Injection absorber

Recycler/MI

RR

- Accept the Linac beam and Inject into MI (bucket to bucket transfer) with good efficiency.
- Make the extra Linac cycles available for distribution at 8 GeV.

MI

- Accept beam from the RR in one turn.
- Provide 2MW of beam power from 60-120GeV by accelerating one Linac pulse of beam (1.6E14 protons).

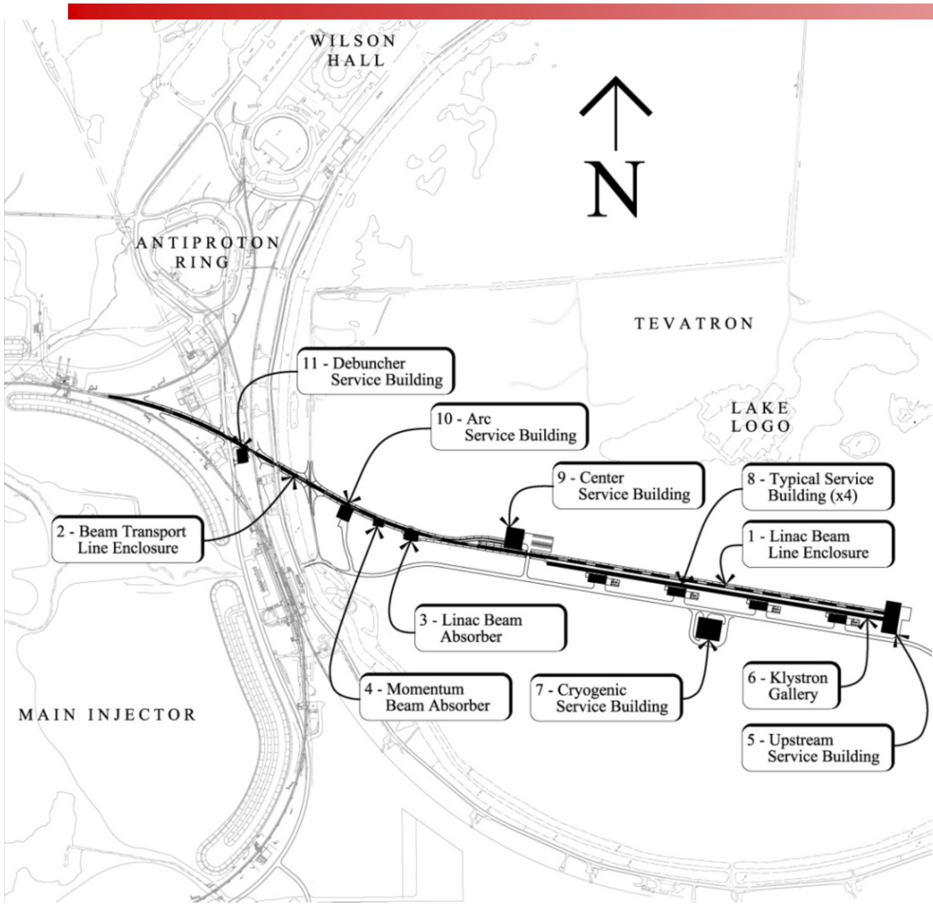
Recycler/MI

- What's included?
  - High-level RF systems for Recycler and MI
  - Beam pipe coating
  - Gamma-t jump system
  - Recycler modifications
  - Installation
  - RD&D program

Project X Conventional facilities

Siting is based on 2005 Proton Driver design

CF Scope



Item No.	Facility Name	Function	Contents
1	Linac Beam Line Enclosure	Below-grade enclosure for equipment/controls for linac H- accelerator components	H- source, RF cavities, magnets, beam instrumentation and utilities
2	Beam Transport Line Enclosure	Below-grade enclosure for H- beam transport from Linac Beam Line Enclosure to Main Injector	Beam transport magnets, momentum collimators and utilities
3	Linac Beam Absorber	Below-grade enclosure for equipment/controls for linac H- abort components	Concrete block and steel shielding and utilities for linac abort system
4	Momentum Beam Absorber	Below-grade enclosure for equipment/controls for momentum beam absorber components	Concrete block and steel shielding and utilities for momentum beam absorber components
5	Upstream Service Building	Building for personnel/equipment access for installation and operation of low-energy support equipement and tech space	Electrical equipment and controls, utility services and H- source support equipment
6	Klystron Gallery	Building for equipment for RF power generation	Klystrons, modulators, controls and utility dervices
7	Cryogenic Service Building	Building for equipment for helium refrigerator plant	Compressors and helium cold boxes
8	Typical Service Building	Building for LCW pumps, electrical services, power supplies and controls	Heat exchangers, pumps, electrical equipment, power supplies and controls
9	Center Service Building	Building for personnel/equipment access for installation of linac	Crane bay, hatch and staging area
10	Arc Service Building	Building and enclosure for correction power supplies and controls	Power supplies and controls
11	Debuncher Service Building	Building and enclosure for debuncher RF modulator and klystron magnet power supplies and controls	Klystron modulator, power supplies and controls

CF scope

<u>Underground Elements</u>

- **Linac Beam Line Enclosure** ~ 2200 ft long
- **Beam Transport Line Enclosure** ~ 3000 ft long
- **Linac Beam Absorber (**2.1 MW?? beam power)
- **Injection Line Beam Absorber** (10-100kW?? beam power)

<u>Above Grade Buildings</u>

- **Upstream Service Building** connected to Klystron Gallery
- **Klystron Gallery** ~ 2200 ft long
- **Cryogenic Service Building** for the superconducting linac
- **Pump Service Building** for LCW pumps, heat exchangers
- **Center Service Building** for access to beamline enclosures
- **Arc Service Building** (corrector power supplies, beam instrumentation)
- **Debuncher Service Building** (klystron, modulator, magnet power supplies/controls)

<u>Utilities</u>

- **HV Electrical Power** from MSS 5.3 MW?? – backfed from KRS
    - Conventional Power, Machine Power, Cryogenic Power – separate feeders
- **CHW & CHWR - Chilled Water** from CUB for 2.1 MW?? heat rejection
- **ICW - Industrial Cooling Water** from C-0 Corridor for fire protection
- **DWS - Domestic Water** from C-0 Corridor for facilities
- **Sanitary Sewer** from C-0 Corridor for facilities
- **Site Work and Infrastructure** (new roads, parking lots, wetland mitigation, etc.)

Cryogenics: Scope

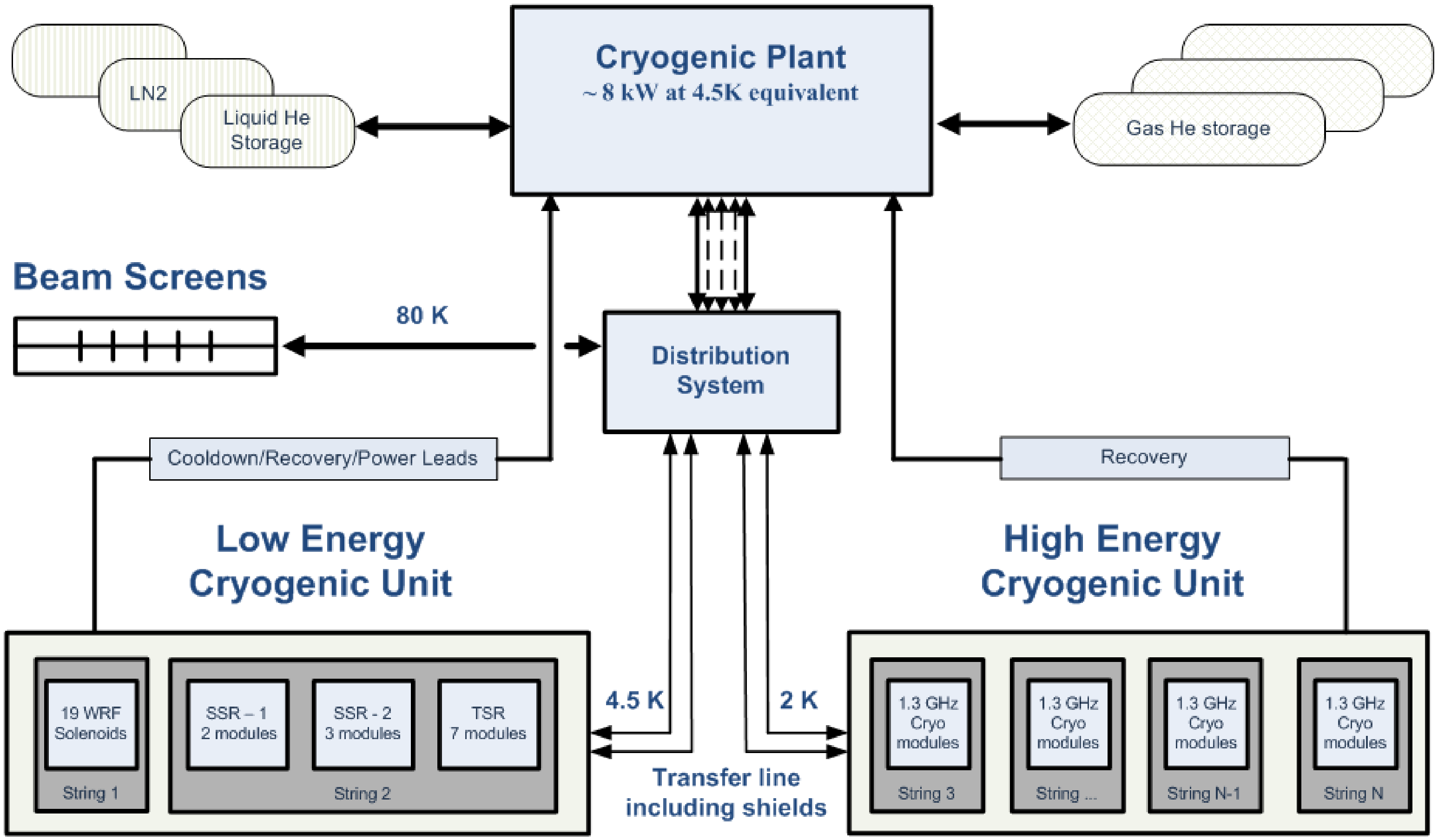
- **Cryogenic Plant** – compressors, helium refrigerators, oil removal, gas management, internal purifiers, nitrogen exchanger, valve boxes, plant controls, etc.
- **Cryogenic Distribution System** – feed boxes, bayonet boxes, feed caps, end caps, cryogenic transfer lines, headers, over pressure protection devices, cryogenic load instrumentation, etc.
- **Ancillary Systems** – gas and liquid storage, recovery compressors, cooling towers, dryers, purification system, etc.
- **Cryomodule Test Stand** - CMTB Feed Cap and End Cap, HTS cryogenic infrastructure
  - With primary interfaces to Civil, Controls and Linac SRF components

Cryogenic Loads

- **Low Energy Linac**
  - Superconducting Solenoids and Spoke Cavities
  - Components are cooled by two-phase helium
- **High Energy Linac**
  - Superconducting Quads and Elliptical Cavities
  - Components are cooled by superfluid helium
- **Transfer Line**
  - Beam pipe is cooled by a cryogenic fluid
- **Test equipment**

Cryo Scheme

Project X



Control system:
high level requirements

- Pulsed machine – 5 Hz
  - some users may operate at 15 Hz (e.g. Mu2e)
- Potentially different characteristics and disposition of each pulse
- Pulse to pulse feedback for required stability
- Scale roughly comparable to the current complex:
  - ~350K device properties
  - ~500 front-ends
  - ~100 central services
  - ~200 consoles
  - Archive ~50K devices; ~10 GB/day

Project X Control System Scope

- Control System Infrastructure
  - Software frameworks – front-ends, services, applications
  - Core services – alarms, data acquisition, archiving, database, etc.
  - Network infrastructure – central and remote switches and cabling
- Timing System
  - Central timing generator
  - Signal distribution
  - Receiver modules for front-end hardware
- Machine Protection System
  - Input modules
  - Network
  - Central concentration
  - Not including detectors

Project X Control System Scope

- Technical subsystems
  - Vacuum
  - LCW
  - Motion Control
  - Tunnel cryogenics
  - High level power supply control
- Application software
  - Technical subsystems
  - Utility applications
  - Machine applications
- Not included here:
  - Instrumentation controls
  - RF controls

Instrumentation

- Detailed requirements and specifications for beam instrumentation systems have NOT yet been established.
  - Requirements to be derived from beam dynamics and operations aspects (intensity ranges, resolution, precision, operating modes, etc.)
  - Define monitor technologies
  - Exact location / layout / space / # of beam detector components.
    Space limitations: Optics / diagnostics balance (beam quality vs. diagn.)

System Scope

Beam Instrumentation and Diagnostics Systems

- Measure and characterize beam parameters (beam intensity, orbit, profiles/emittance, phase/timing, halo, etc.) for
  - Machine commissioning
  - Performance evaluation and improvements under various machine conditions, operating modes and a range(?) of beam parameters.
  - Detection and analysis of faults and error sources.
- Provide detection systems (BLMs, current monitors) for a fast Machine Protection System (MPS).
- Instrumentation hard-, firm- and software includes
  - EM and optical detection systems and control elements
  - Read-out, analysis and calibration systems
  - Infrastructure, cabling, timing and clock systems, DAQ interface
- Many beam instruments are distributed systems

Project X Instrum. interfaces

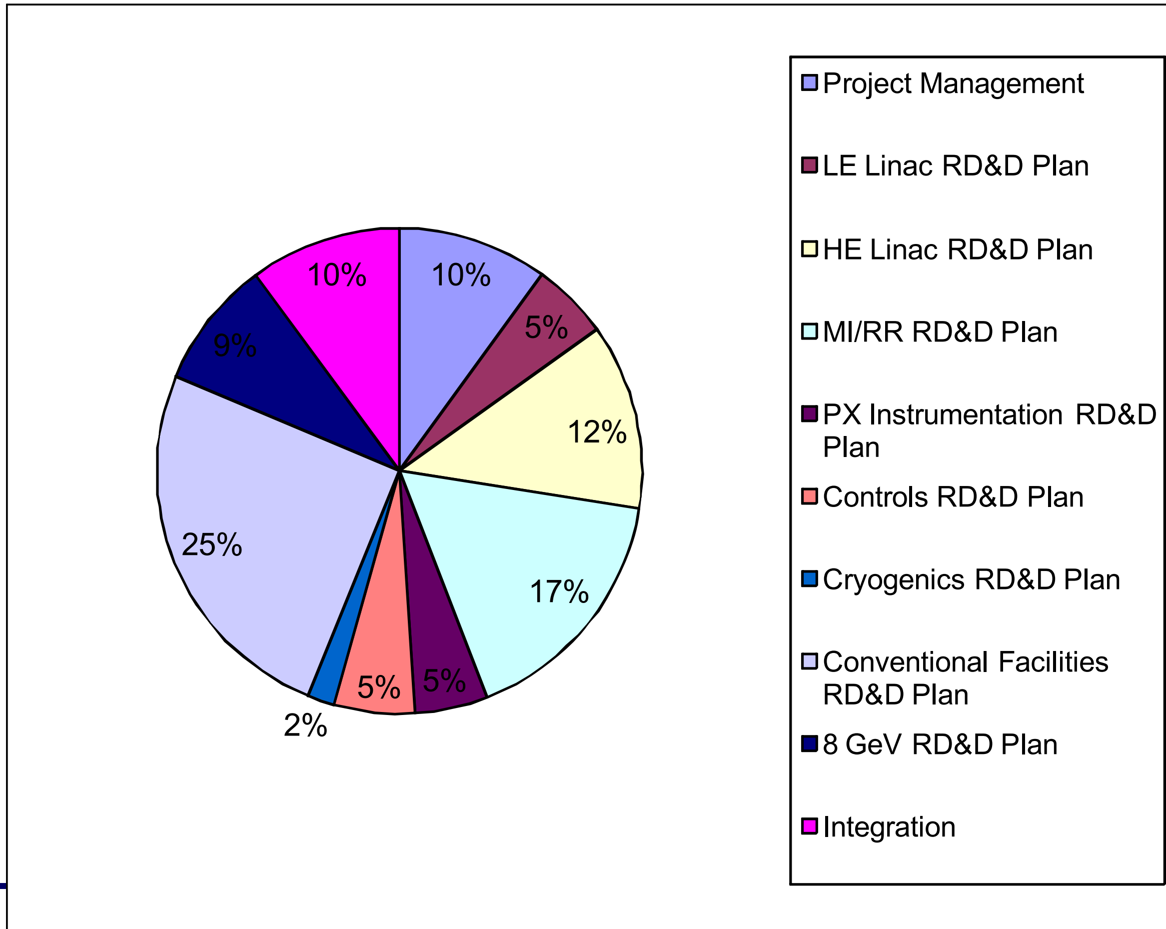
- Beam instrumentation systems primary interfaces with
  - The vacuum system on the detector (pickup) side.
  - The controls system on the read-out system end for DAQ, controls, and trigger events.
  - The LLRF system to supply low-jitter clock signals (for ADCs).
  - …and is linked to beam dynamics and operational requirements!
- Practical beam tests of mission critical diagnostic systems is mandatory. This instrumentation RD&D will be tested at
  - HINS: Proton and H^- diagnostics, e.g. BPMs, beam intensity monitors, beam profile monitors (wire-scanners, slit-multiwire), laser-based diagnostics, long. bunch profile, BLMs, etc.
  - NML: Diagnostics at ß≈1, BPMs for the cryomodule.
  - MI: Electron cloud diagnostics, e-beam scanner (profile monitor).
  - Other beam facilities, e.g. Fermilab Linac, SNS Linac.

Project X Areas of technical risk

- Started to identify areas of technical risk but did not rank it (yet) on a consistent basis
- Preliminary list of “moderate & high” technical risk areas:
  - LE linac: beam availability, chopper, SSR2 and TSR cryomodules
  - HE linac: 0.81 cryomodules, couplers
  - Linac RF systems: field regulation of multiple cavities powered by a single rf source, resonant control of spoke cavities
  - BTL: beam losses, 8-GeV stripping (efficiency, foil lifetime)
  - RR/MI: beam stability and losses, electron cloud instability
  - CF: no technical risks; identified cost and schedule risks
- Created a bottom-up RD&D plan to address these risks.
  - No show-stoppers!
  - RD&D costs FY09-12 are included in the cost range estimate
- HINS and NML are important test areas for risk mitigation

Project X R&D cost distribution

Found in projx-doc-149



Summary

- The Initial Configuration Design represents a complete, well defined, scope
  - each system's leader understands the scope and interfaces;
- The preliminary estimate is a complete representation of the ICD
- Each system has provided bottom-up preliminary cost from CD0 to CD4
- Risks were identified but not formally ranked
  - the RD&D plan was created to address these risks