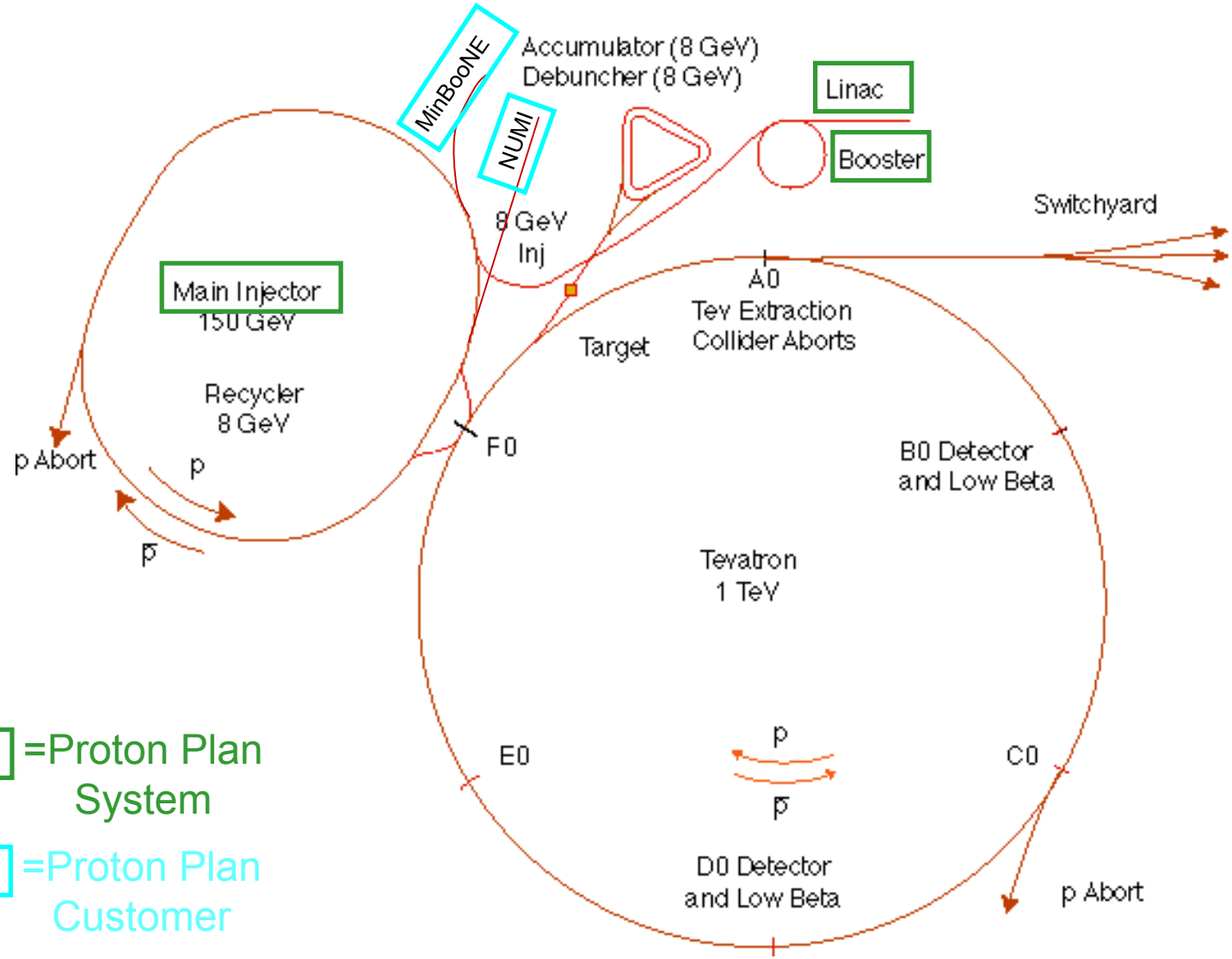
Proton Plan
Overview
Director's Review
August 2005

Eric Prebys

History of Proton Plan

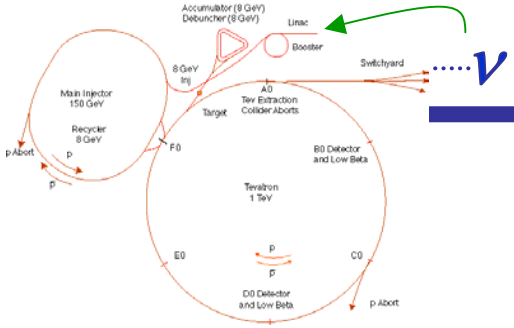
- 1993 – New injection bump magnets built for Booster
  - Jim Lackey is assured that Booster "will never be required to run at high repetition rates".
- 1995 – MINOS approved
  - Worries begin about consequences for proton source
  - Plans for shielding and rep. rate upgrades
- 1998 – MiniBooNE approved
  - Worries increase.
  - Shielding upgrade and reclassifications begin.
- 2001 – P. Kasper, "Getting Protons to NuMI (it's a worry)"
  - First quasi-official, quantitative, analysis proton economics, rate, and radiation issues
- 2002 – "Doug Michael Committee"
  - Preliminary report on proton delivery issues wrt to MiniBooNE and NuMI
  - E. Prebys hears term "Proton Economics" for first time.
- 10/26/2003 – Proton Team, "Report to the Fermilab Director" (BEAMS-DOC-1900)
  - Summary of proton demands and issues over next few years.
- 11/9/2004 – "The Proton Plan V1" (BEAMS-DOC-1441)
  - First version of Plan
  - First official, *realistic*, projection of proton delivery.
- 2005 – Project management structure formed
  - Refining plan
  - Building resource loaded project
  - Tracking cost, progress, and proton delivery

The Fermilab Accelerator Complex

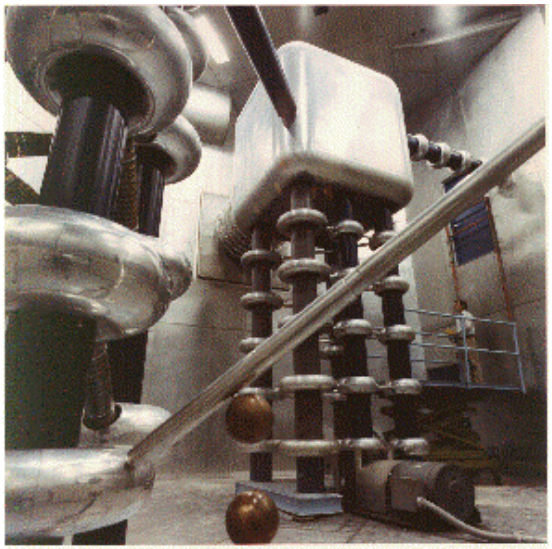


=Proton Plan System

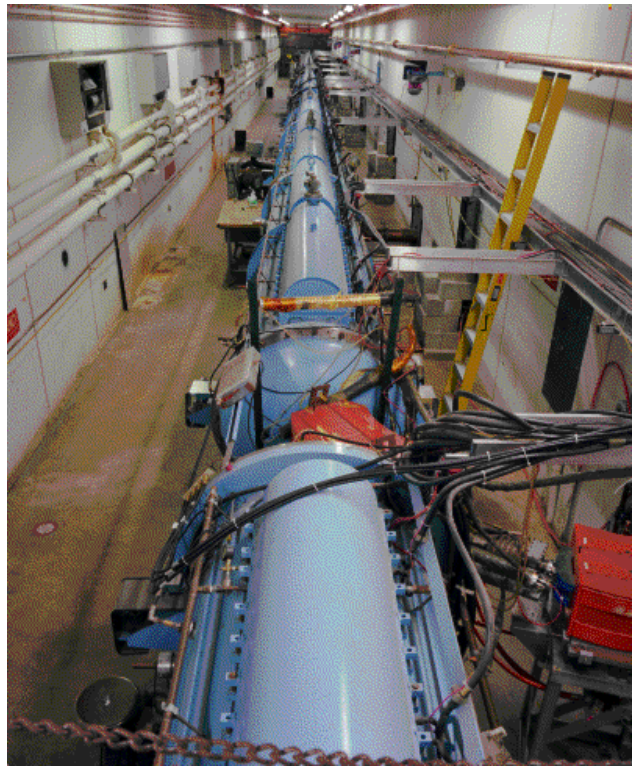
=Proton Plan Customer



Preac(cellerator) and Linac

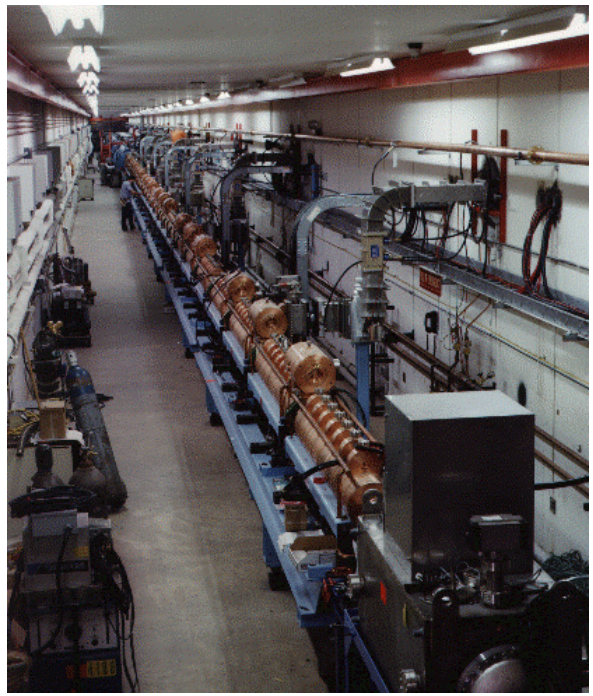


"Preac" - Coolest looking thing at Fermilab. Static Cockroft-Walton generator accelerates H- ions from 0 to 750 KeV. (Actually, there are two of these, H- and I-)



"Old linac"(LEL)- 200 MHz "Alvarez tubes" accelerate H- ions from 750 keV to 116 MeV

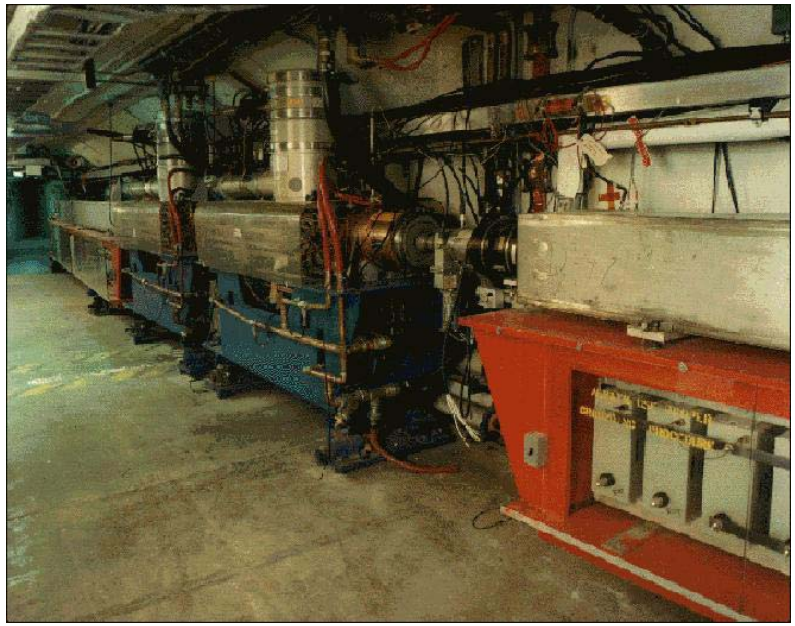
"New linac" (HEL)- 800 MHz "π cavities" accelerate H- ions from 116 MeV to 400 MeV



Preac/Linac can deliver about 45 mA of current for about 35 usec at a 15 Hz repetition rate.

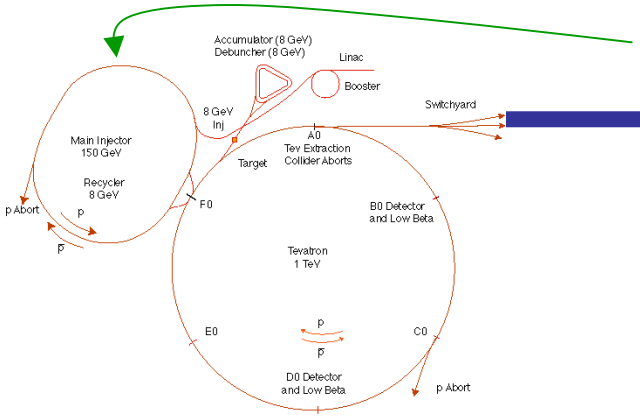
Booster

- 400 MeV Linac H- beam is injected into booster over several (up to 15) "turns". The ion beam allows one to (negative) beam on top of existing (positive) beam.
- The main magnets of the Booster form a 15 Hz offset resonant circuit , so the Booster field is continuously "ramping", whether there is beam in the machine or not. Ramped elements limit the average rep rate to somewhat lower.
- From the Booster, beam can be directed to
  - The Main Injector
  - MiniBooNE (switch occurs in the MI-8 transfer line).
  - The Radiation Damage Facility (RDF) – actually, this is the old main ring transfer line.
  - A dump.



- One full booster "batch" sets a fundamental unit of protons throughout the accelerator complex (max 5E12).
- This is divided amongst 84 53 MHz RF buckets, which sets another fundamental sub-unit (max 6E10).

Main Injector



- The Main Injector can accept 8 GeV protons OR antiprotons from
  - Booster
  - The anti-proton accumulator
  - The Recycler (which shares the same tunnel)
- It can accelerate protons to 120 GeV (in a minimum of 1.4 s) and deliver them to
  - The antiproton production target.
  - The fixed target area.
  - The NUMI beamline.
- It can accelerate protons OR antiprotons to 150 GeV and inject them into the Tevatron.
- The Main Injector can also accept 150 GeV antiprotons from the Tevatron and *decelerate* them to 8 GeV for transfer to the Recycler.

- The Main Injector is exactly 7 times the circumference of the Booster. Allowing one empty "slot" for switching, it can hold six booster batches, in the absence of exotic stacking schemes (slip stacking, RF barrier).

Proton Plan Charge

- Develop a plan for a set of upgrades and operational improvements to maximize proton delivery to:
  - NuMI beamline (120 GeV from MI)
  - Booster Neutrino Beam (BNB) (8 GeV from Booster)
- Goal: complete the upgrades over the next 3 years, and operate through 2015 or beyond
  - This plan precedes the Proton Driver replacement of the existing Proton Source (Linac+Booster).
- Develop the budget and timeline for these improvements
- Estimate projected proton delivery (PoT) to both beam lines

Plan Strategy

- **Increase the proton delivery from the Booster (to both NuMI and BNB)**
  - Increase acceptance by improving orbit control, beam quality, etc
  - Increase maximum average Booster repetition rate
- **Increase the beam intensity in the Main Injector for NuMI**
  - Main Injector multi-batch operation
    - 5 single batches to NuMI
    - ->9 slip stacked batches to NuMI
  - Identify and ameliorate loss and rep. rate issuess
  - Might require RF improvements.
- **Improve operational reliability and stability**
  - Alleviate 7835 Problem
  - Linac quad supplies and Low Level RF
  - Booster RF?

Limits to Proton Intensity

- Total proton rate from Proton Source (Linac+Booster):
  - Booster batch size
    - Typical ~5E12 protons/batch
  - Booster repetition rate
    - 15 Hz instantaneous
    - Currently 7.5Hz average (limited by injection bump and RF cooling)
  - Beam loss
    - Damage and/or activation of Booster components
    - Above ground radiation
- Total protons accelerated in Main Injector:
  - Maximum main injector load
    - Six "slots" for booster batches (3E13)
    - Up to ~11 with slip stacking (5.5E13)
    - RF stability limitations (under study)
  - Cycle time:
    - 1.4s + loading time (1/15s per booster batch)

Operational Limit

Goals of Plan

- 120 GeV (NuMI)
  - Accelerate 5-6E13 protons per 2.2s cycle
  - This alone is within demonstrated performance of the Booster (at least in terms of total protons):
    - 7.5Hz adequate
    - Total proton rate ~OK
  - Most of the necessary work is in Main Injector
- 8 GeV (BNB)
  - No concrete goal
  - Assume ~2e20 p/year to maintain 8 GeV neutrino program
  - Requires ~50% increase in total protons
  - Requires Booster to go to ~9Hz
- Future
  - Pave the way for increased beam throughput needed by Stage II

Context: Staged Approach to Neutrino Program

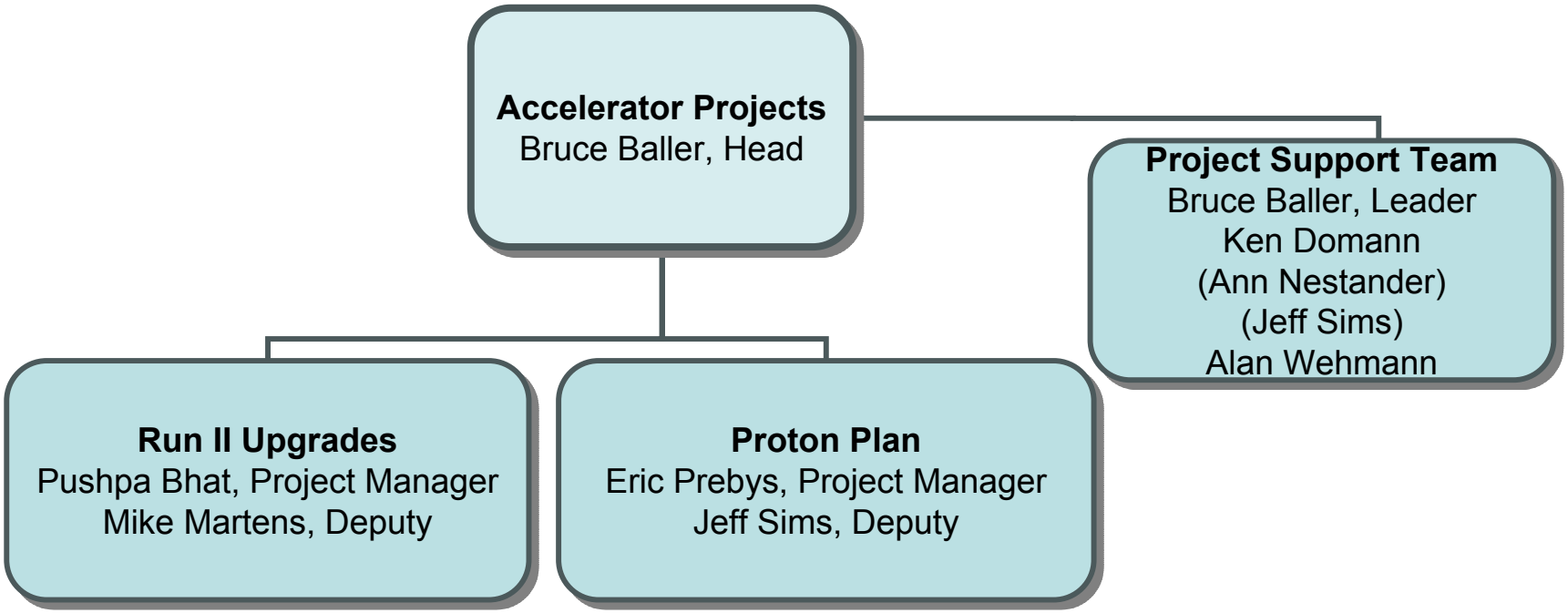
This Plan

- Stage 0 (now):
  - Goal: deliver 2.5E13 protons per 2 second MI cycle to NuMI (~2E20 p/yr)
  - Deliver 1-2E20 protons per year to Booster Neutrino Beam (currently MiniBooNE)
- Stage 1 (~2007):
  - A combination of Main Injector RF improvements and operational loading initiatives will increase the NuMI intensity to ~5E13 protons per 2.2 second cycle (~3E20 p/yr)
  - It is hoped we can continue to operate BNB at the 2E20 p/yr level during this period.
- Stage 2 (post-collider):
  - Proton to NuMI will immediately increase by 20%
  - Consider (for example) using the Recycler as a preloader to the Main Injector and reducing the Main Injector cycle time
  - The exact scope and potential of these improvements are under study (WBS 1.5)
- Stage 3 (proton driver)
  - Main Injector must accommodate 1.5E14 protons every 1.5 seconds
  - NuMI beamline and target must also be compatible with these intensities.

Plan Concept

- Similar to the Run II plan:
  - Not a "project" in the traditional sense
  - A set of improvements and operational initiatives
  - Doesn't cover everything that's happening (try to avoid "shopping list")
  - Assume that department budgets will remain more or less constant, so this plan may free up some resources within departments as well.
- Criteria for being "in the plan" (one of the following):
  - Critical to the success of planned slip stacked operation to NuMI.
  - Expensive (>$200K).
  - Involves significant coordination between departments.
- Minimum R&D component
  - Not a "cash cow"
  - Answer specific questions
  - Maintain a few key backup options
  - Important to maintain R&D within departments
    - Might move into the plan with a CR if anything comes to fruition

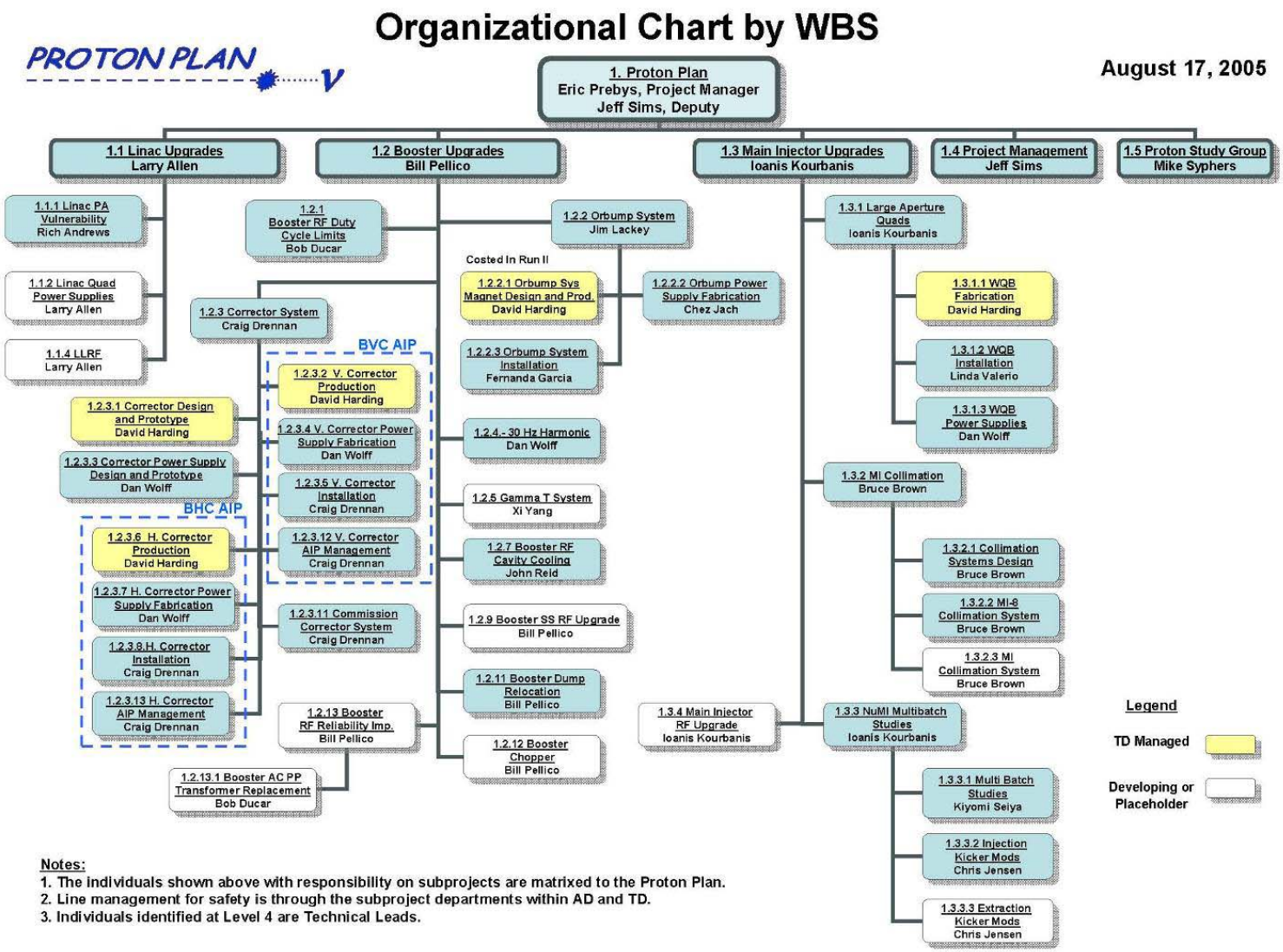
AD Project Management



Project Support Team provides help on:

- Maintaining Resource Loaded Schedule (MS Project)- Domann
- Accounting Support with Cobra Interface - Nestander
- General Project Management Support– Sims
- Web Support - Wehmann

Project Organization



Selection Process for "Plan" Projects

- Initial:
  - Series of meetings with representatives of Proton Source (Linac+Booster) and Main Injector Departments
  - Worked to identify candidate projects, as well as approximate costs and timelines
- Continuing:
  - Have begun open weekly meetings
  - Discussions of priorities
  - Working to resolve remaining questions.
  - Refine costs and schedules

Major Changes Since version 1

- Descoped:
  - Instrumentation projects
    - Moved under department budgets
  - Booster alignment
    - Moved to ordinary Booster operation
  - Booster Cavity #20
    - Limited success of cavity #19 and manpower concerns
- Reduced:
  - Linac quad power supplies
    - Went from replacement to refurbishment
  - Main Injector RF
    - Likely no major upgrade needed
- Added:
  - Linac LLRF upgrade
  - Significantly increased ORBUMP project
  - Booster Dump relocation
  - Improved Booster Notcher

Elements of the Plan

- Linac (1.1)
  - (1.1) PA Vulnerability
    - Benefit: Reliability, avoid catastrophic down time
    - Complete: 2007
    - Cost: $3.6M (Esc. M&S+SWF w/o contingency)
      - 7835 spares + Thales tube test facility
  - (1.2) Linac Quad Power Supplies [reliability, stability]
    - Reliability, stability
    - 2008
    - $414K
  - (1.4) Low Energy Linac Low Level RF [stability]
    - Stability, 5-10% more integrated beam
    - 2007
    - $680K

Elements of the Plan (cont'd)

- Booster (1.2)
  - (1.2.1) Determine Rep Rate and Reliability
    - Reliability, stability
      - Insure Booster can go to 9Hz
    - 2005
    - $35K
  - (1.2.2) ORBUMP/400 MeV [Reliability, Rep Rate, Beam Loss]
    - Reliability, rep. rate, beam loss
      - Rep. rate 7.5->15Hz
      - Potentially 40% more beam within radiation limits
    - 2005
    - $322K
      - (actual magnets paid for by Run II under "reliability")
  - (1.2.3) Corrector System
    - Beam Loss
      - Potentially 50% more beam
    - 2007
    - $4.6M
  - (1.2.4) 30 Hz harmonic
    - Beam loss, Batch size
      - Evaluating potential, decision point ~1/06
    - ~2007
    - $1.7M

Elements of the Plan (cont'd)

- Booster (cont'd)
  - (1.2.5) Gamma-t system
    - Beam loss, batch size
      - Evaluating potential along with 30 Hz
    - 2007
      - System already exists
      - Install new magnets along with new corrector system
      - $326K
  - (1.2.7) Drift tube cooling
    - Rep rate
      - Necessary to go beyond 7.5 Hz
    - 2005
    - $9K
  - (1.2.11) Booster dump relocation
    - beam loss
      - Potentially 7% increase in beam
    - 2005
    - $320K
  - (1.2.12) Booster chopper
    - Beam loss
      - ~2% more beam
    - 2006
    - $237K
  - (1.2.13) Booster RF improvements
    - Reliability, stability
      - ~5% more integrated beam to NuMI
    - Now->2007
    - $516K place holder, but might go to $6M for solid state upgrade

Elements of Plan (cont'd)

- Main Injector (1.3)
  - (1.3.1) Large Aperture Quads
    - Slip stacking
      - Eliminates prohibitive losses
    - 2005 -> 2006
    - $1.4M
  - (1.3.2) Collimation and Loss Mitigation
    - Slip stacking
      - Eliminates prohibitive losses
    - 2005->??
    - $1.0M
      - MI-8 well scopes
      - Rest place holder
      - Relies on BLM system from Run II
  - (1.3.3) Multibatch Operation
    - NuMI operation, slip stacking
    - 2005->2007
    - $493K
      - Studies (SWF) + kicker modifications
  - (1.3.4) Main Injector RF
    - Slip stacking
    - 2005->2007
    - SWF for studies, might escalate if improvement needed
- Management (1.4)
  - 2005->2008
  - $1.3M (SWF)
- Stage 2 Planning (1.5)
  - 2005->??
  - $11K (SWF)

Short Term Projects

- (1.1.1) Linac PA reliability
  - Initial work of committee more or less complete
  - Initiating next phase
- (1.2.2) ORBUMP/ORBUMP PS/ 400 MeV Line
  - On track for 2005 shutdown
- (1.2.11) Booster Dump Relocation
  - On track for 2005 shutdown
- (1.3.1) Main Injector Large Aperture Quads
  - Partial installation in 2005 shutdown
- (1.3.2.1.2) MI-8 Collimation System
  - On track for 2005 shutdown

*For historical reasons, the ORBUMP magnets are still funded out of Run II, but the detailed schedule and everything else is handled out of the Proton Plan.

Major Long Term Projects

- Reasonably well scoped:
  - (1.2.3) Booster Corrector System
    - Most involved single project in the plan
    - Scheduled for installation in 2007
  - (1.3.3) NuMI Multibatch Operation
    - Mostly operational initiatives
    - Plan in place for slip stacking
  - (1.3.4) Main Injector RF
    - Great progress in understanding limitations of existing system
    - Drastically reduced upgrade scope

Major Long Term Projects (cont'd)

- Need More Work
  - (1.1.3) Quad Power Supplies
    - Reduced scope from replacement to refurbishment
    - Working on detailed plan
  - (1.1.4) Linac LLRF Upgrade
    - No detailed plan
    - Cost and schedule based on High Energy Linac experience
  - (1.2.4) Booster 30 Hz Harmonic
    - Work continues on prototype
    - Project decision 1/06
  - (1.2.5) Gamma-t system
    - Studies ongoing
    - Will remove existing magnets during corrector upgrade
    - If needed, will build new magnets (decision coupled with 1.2.4)

Needs most work

  - (1.2.9/1.2.13) Booster RF Upgrade/Replacement
    - Scope increasing after reduction of MI RF upgrade
    - Largest financial uncertainty in the plan
  - (1.3.2) Main Injector Collimation (besides MI-8)
    - Ultimately will rely on BLM system (being installed as part of Run II)
    - If in-ring collimation is warranted, the design is complicated by the lack of dispersive straight sections

Design Handbook

- At least for the near term, we will dynamically maintain the Design Handbook, along with everything else about the plan at

`http://www-accel-proj.fnal.gov/internal/Proton_Plan/index.html`

What are we baselining?

- In a perfect world, this plan would have started ten years ago.
- Because this plan involves ongoing activities, it has evolved and will continue to evolve
- There will never be a "right" time to get a perfect snapshot of these activities
- We hope to
  - Baseline the projects which are well scopes
  - Baseline the total cost profile of the plan
  - Get feedback on the philosophy and cost scale of the placeholder items