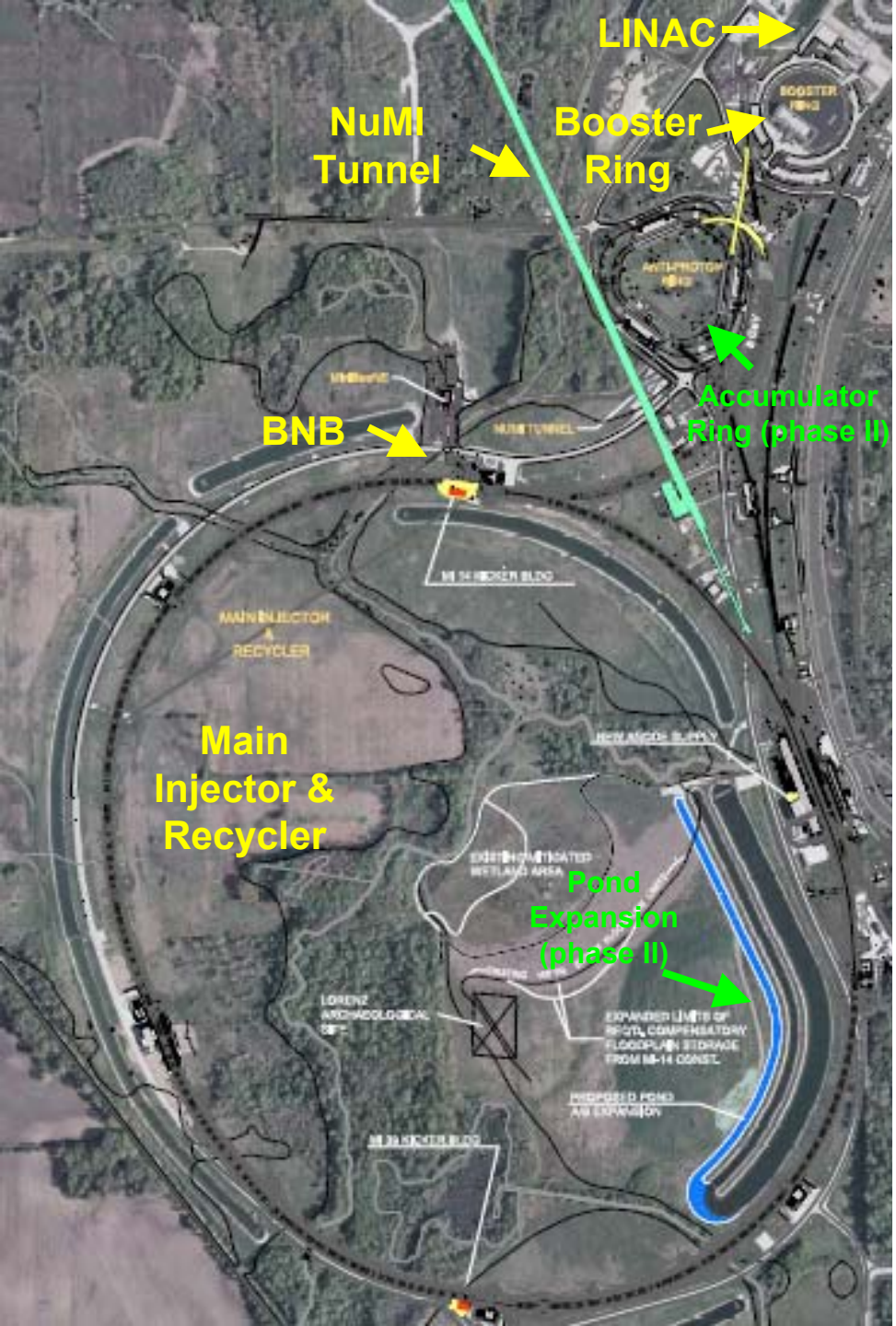


SNuMI:
Phase I & Phase II

Nancy Grossman

Phase I: $33.4M FY06$
(no contingency, no G&A)
41% contingency

Phase II: $53.7M FY06$
(no contingency, no G&A)

VERY conceptual cost and schedule for Phase II

Outline

(Proton Plan Phase II is SNuMI Phase I, continue proton plan effort)

- Proton Plan Phase II Overview
- Proton Plan Phase II Costs
- Proton Plan Phase II Schedule

(SNuMI is SNuMI Phase II, a bit more then continuing proton plan effort due to civil construction)

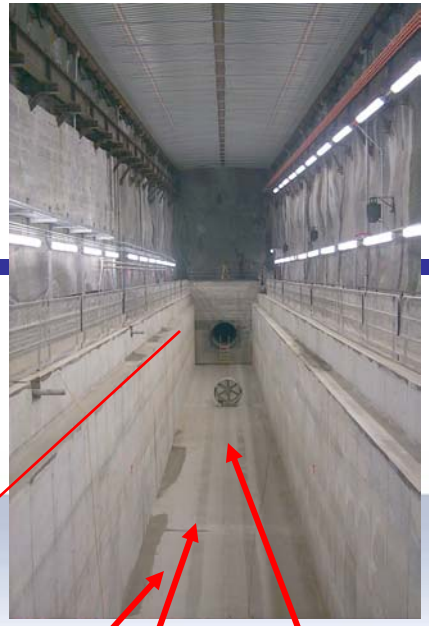
- SNuMI Overview
- SNuMI Costs
- SNuMI Schedule

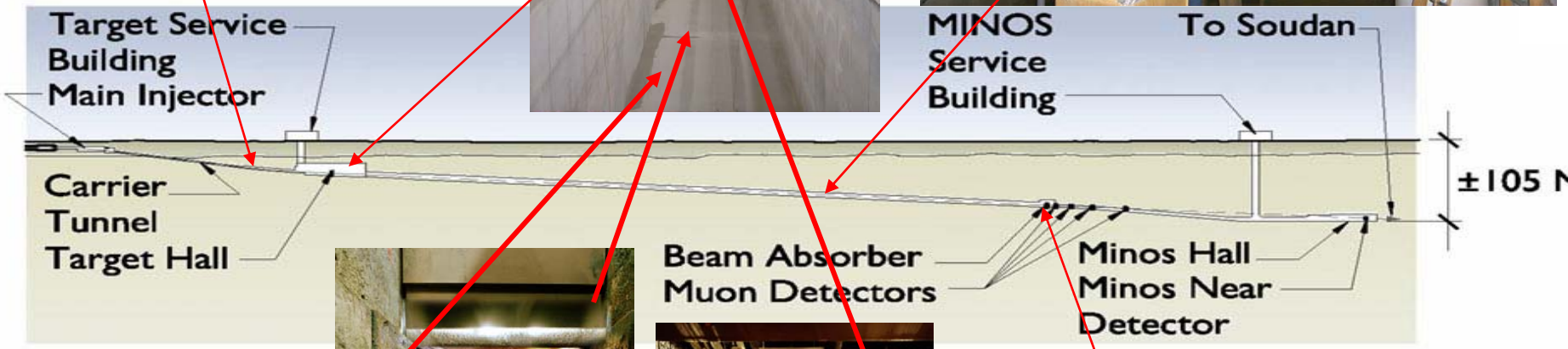
Motivations

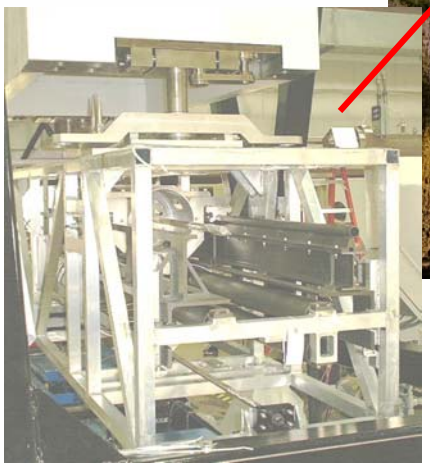
- Currently 3 major programs at Fermilab requesting high intensity proton beams
  - 120 GeV protons for anti-proton production
  - 120 GeV protons to NuMI (ν's at the Main Injector) for MINOS expt.
  - Booster Neutrino Beam (BNB) to MiniBoone (short baseline $\nu_\mu \rightarrow \nu_e$ search)
- The neutrino experimental program for the next decade
  - NOνA (long baseline $\nu_\mu \rightarrow \nu_e$ search)
  - MINERνA (Main Injector ν-A interactions)
- Superbeam upgrades to NuMI (SNuMI)
  - Plan of upgrades after the conclusion of the Collider program
  - Proton Plan phase II: Recycler as an 8 GeV proton pre-injector
  - SNuMI: momentum stacking in the Accumulator

The Accelerator Complex

- Main Injector is a rapid cycling accelerator at 120 GeV
- Booster batches injected into the Main Injector at 15 Hz
  - Main Injector is 7 times the circumference of the Booster
- Main Injector has to satisfy simultaneously the needs of the Collider program (anti-proton stacking and transfers to the Tevatron) and NuMI
  - Mixed-mode cycles: 1 slip-stacked batch to the antiproton source, 5 batches to NuMI
    - slip-stacking operational since end of 2004
  - NuMI-only cycles: 6 batches to NuMI
- Proton Plan
  - Current “campaign” to maximize protons to NuMI and MiniBoone during the Collider era
  - NuMI goal: implementation of slip-stacking over multi-batches



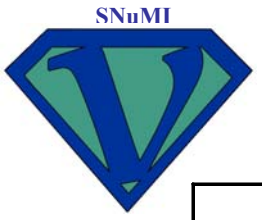




NuMI beam-line

Proton Plan phase II: 700 kW Recycler as an 8 GeV proton pre-injector

- After the Collider program concludes, we can use the Recycler as a proton pre-injector
  - **if we use the Recycler to accumulate protons from the Booster while MI is accelerating, we can save 0.4 s for each 6 Booster batches injected**
- Recycler momentum aperture is large enough to allow slip-stacking operation in Recycler, for up to 12 Booster batches injected
  - **6 batches are slipped with respect to the other 6 and, at the time they line up, they are extracted to MI in a single turn and there re-captured and accelerated**
  - **Main Injector will run at its design acceleration rate of 240 GeV/s (1.333 s cycle time)**
  - 4.3×10^{12} p/batch, 95% slip-stacking efficiency
  - 4.9×10^{13} ppp at 120 GeV every 1.333 s $\Rightarrow$ 700 kW



Operating Scenarios

NOvA
17 November 2006
Nancy Grossman

	Present operating conditions *	Proton Plan Multi-batch slip-stacking in MI *	Proton Plan phase II Multi-batch slip-stacking in Recycler	SNuMI Accumulator momentum stacking
Booster intensity (p/batch)	4.5×10^{12}	4.3×10^{12}	4.3×10^{12}	4.7×10^{12}
No. Booster batches to NuMI	5	9	12	18
MI cycle time (s)	2	2.2	1.333	1.333
MI intensity (ppp)	3.1×10^{13}	4.5×10^{13}	4.9×10^{13}	8.3×10^{13}
To NuMI (ppp)	2.25×10^{13}	3.7×10^{13}	4.9×10^{13}	8.3×10^{13}
NuMI beam power (kW)	210	320	700	1200
POT/yr to NuMI	2×10^{20}	3×10^{20}	6×10^{20}	10×10^{20}
MI protons/hr	5.5×10^{16}	7.3×10^{16}	1.3×10^{17}	2.2×10^{17}

* NuMI values are given for mixed-mode cycles

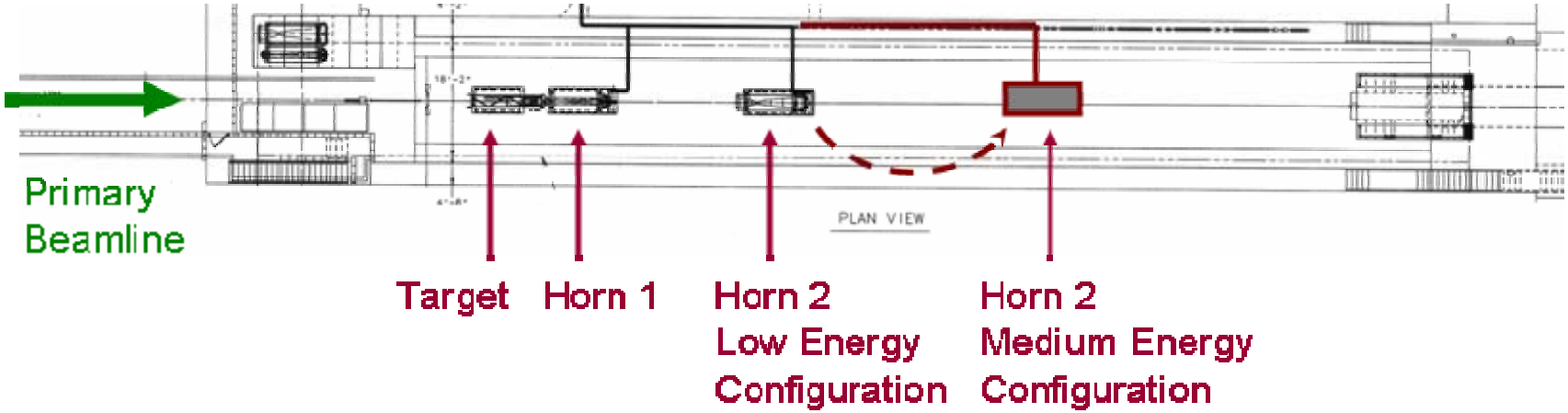
Proton Plan Phase II & SNuMI

Main Items PP Phase II: Accelerator Complex

- **Booster** has to run at 10.5 Hz average rate
  - **Proton Plan requires Booster to run at 9 Hz average rate**
- 2 additional RF cavities need to be installed in **Main Injector**
- **Recycler**
  - **Decommissioning of anti-proton specific devices**
  - **Installation of a new injection line directly from MI8 transfer line**
  - **Installation of a new extraction line from RR to MI together with a rework of the RR-30 straight section**
  - **Installation of a 53 MHz RF system**
  - **5 new kicker systems are required**
    - **Demanding specifications on injection kicker to inject 6 + 6 Booster batches**
    - **A "gap clearing" kicker to dispose cleanly of beam in the injection gap during injection of the second set of 6 Booster batches**
  - **2 additional MI building to house kicker power supplies (MI14 & MI39)**
  - **1 additional Anode Supply room at MI60 for the additional RF stations**

Main Items: NuMI neutrino line

- **NuMI** was designed for 4E13 ppp every 1.87 s (400 kW beam power)
  - **Cycle rate from 0.5 to 0.75 Hz** **X1.5**
  - **Per pulse intensity from 4.0E13 to 4.9E13** **X1.2**
  - **Beam power from 400 to 700 kW** **x1.75**
- **NOvA** requires Medium Energy Neutrino Configuration

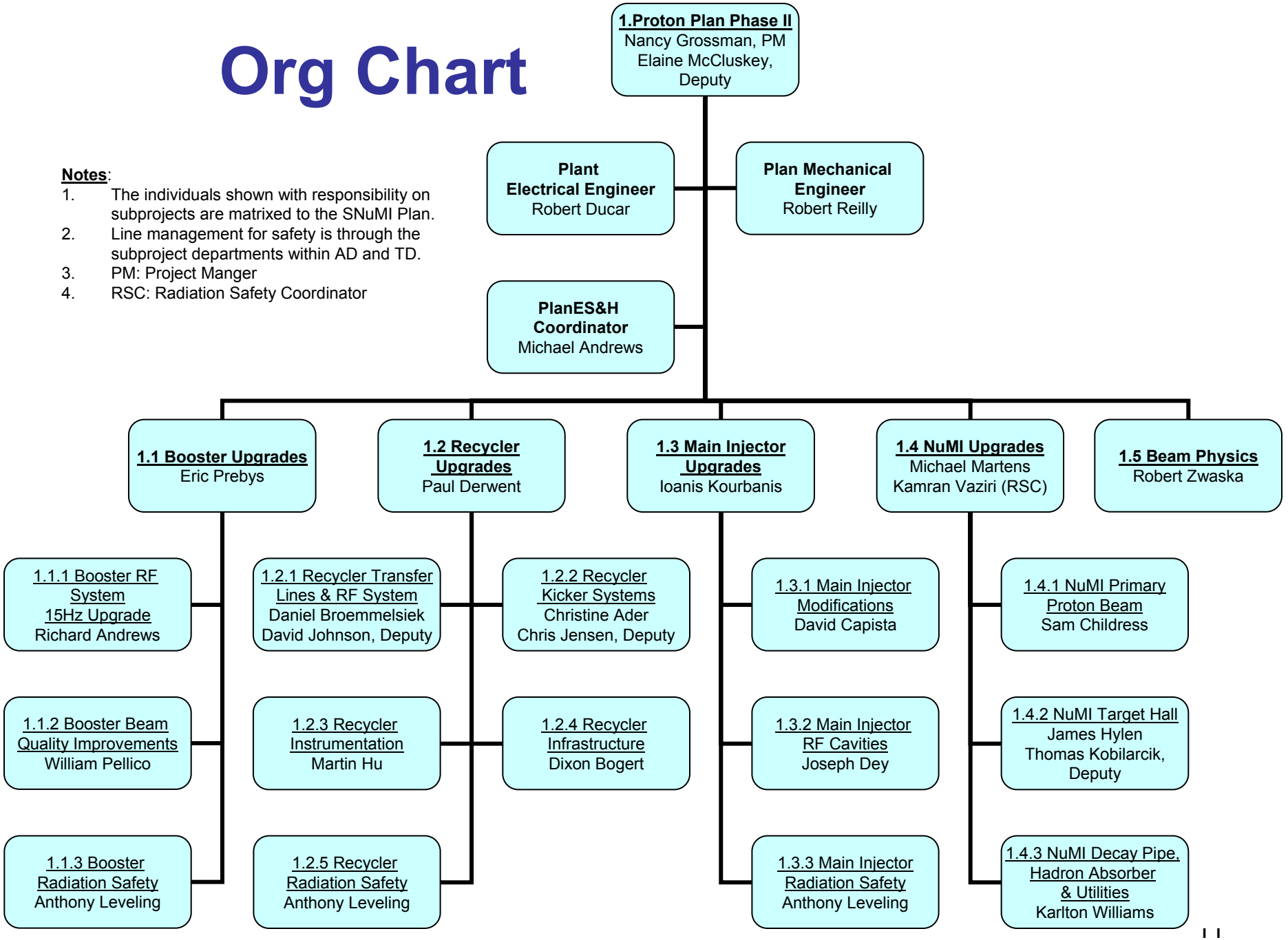


Proton Plan Phase II & SNuMI

Main Items: NuMI neutrino line

- **NuMI** upgrades
  - Capability for faster rep rate of the primary proton beamline
  - Cooling upgrade in the target chase
  - Horn 2 relocation to Medium Energy location and switch to Medium Energy target
  - New Horn 1 design (Horn2 ?) and implementation of stripline cooling
  - Work Cell upgrade and used radioactive components storage

Org Chart



Notes:

1. The individuals shown with responsibility on subprojects are matrixed to the SNuMI Plan.
2. Line management for safety is through the subproject departments within AD and TD.
3. PM: Project Manger
4. RSC: Radiation Safety Coordinator

PP Phase II Overall Costs

(costs with no G&A or contingency, FY06$K, physicist labor included)

WBS	Name	Cont %	Labor	M&S	Total	M&S/Labor
1	SNuMI	41%	$13,136	$20,307	$33,443	1.5
1.1	Booster Upgrades	30%	$139	$518	$657	3.7
1.2	Recycler Upgrades	36%	$4,540	$11,697	$16,236	2.6
1.3	Main Injector Upgrades	31%	$571	$1,091	$1,662	1.9
1.4	NuMI Upgrades	62%	$2,665	$6,101	$8,766	2.3
1.5	Beam Physics	37%	$463	$35	$498	0.1
1.6	Project Management	30%	$4,759	$865	$5,624	0.2

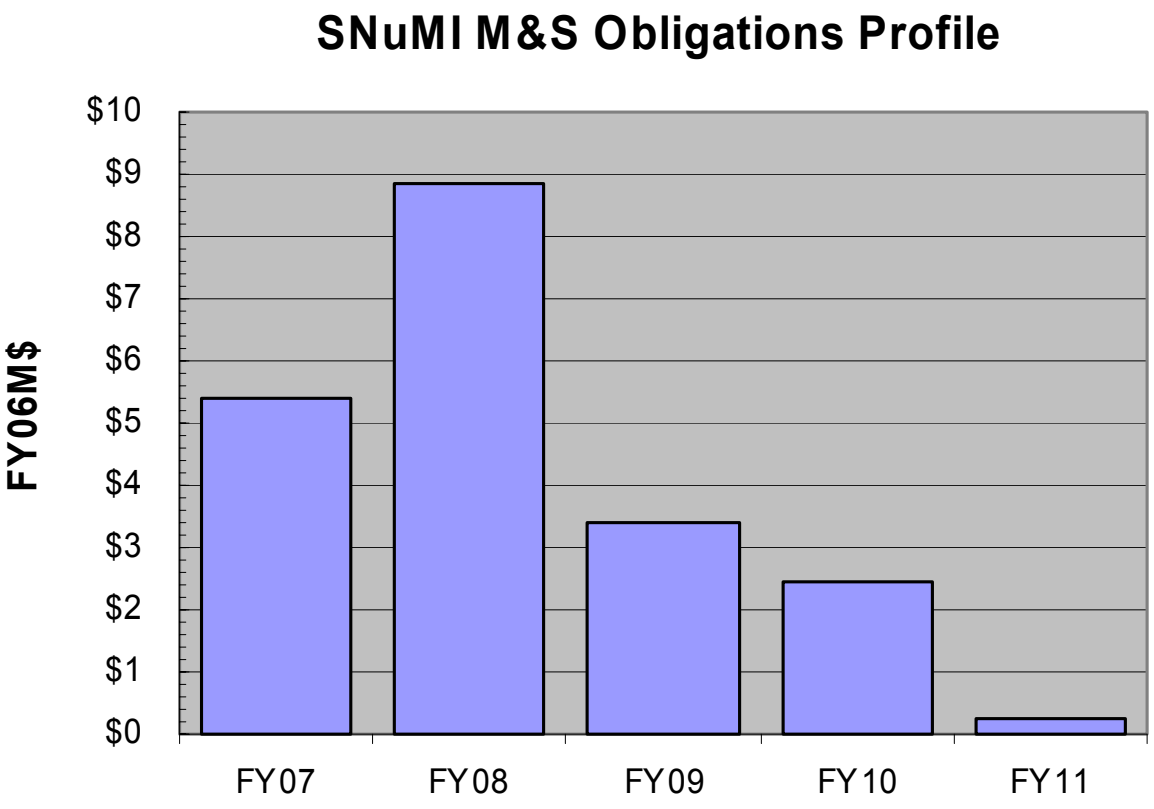
- Costs drivers are:
  - Recycler
    - Kicker systems: 24% of project cost
    - Recycler modifications: 11% of project cost
  - NuMI
    - Target Hall work: 21% of project cost
  - Project Management
    - 17% of project cost

(total 73% of plan costs)

PP Phase II M&S Obligations

(all FY06$, no G&A or contingency)

NOvA
17 November 2006
Nancy Grossman



No resource leveling has been applied yet

FY07: $5.4M
FY08: $8.8M
FY09: $3.4M
FY10: $2.5M
FY11: $0.2M
Total: $20.3M

Looks like we can delay ~$3.2M from FY07 to FY08.

PP Phase II Labor Needs

	Total FTE-yrs
AD Design/Drafter	18.3
AD Electrical Engineer	12.1
AD Electrical Tech	18.2
AD Mechanical Engineer	22.3
AD Mechanical Tech	27.8
AD Physicist	25.1
AD RF Engineer	1.6
AD RF Tech	2.8
TD Drafter	0.6
TD Electrical Engineer	2.9
TD Mechanical Engineer	3.8
TD Mechanical Tech	15.7
TD Physicist	1.1
Total	161.8

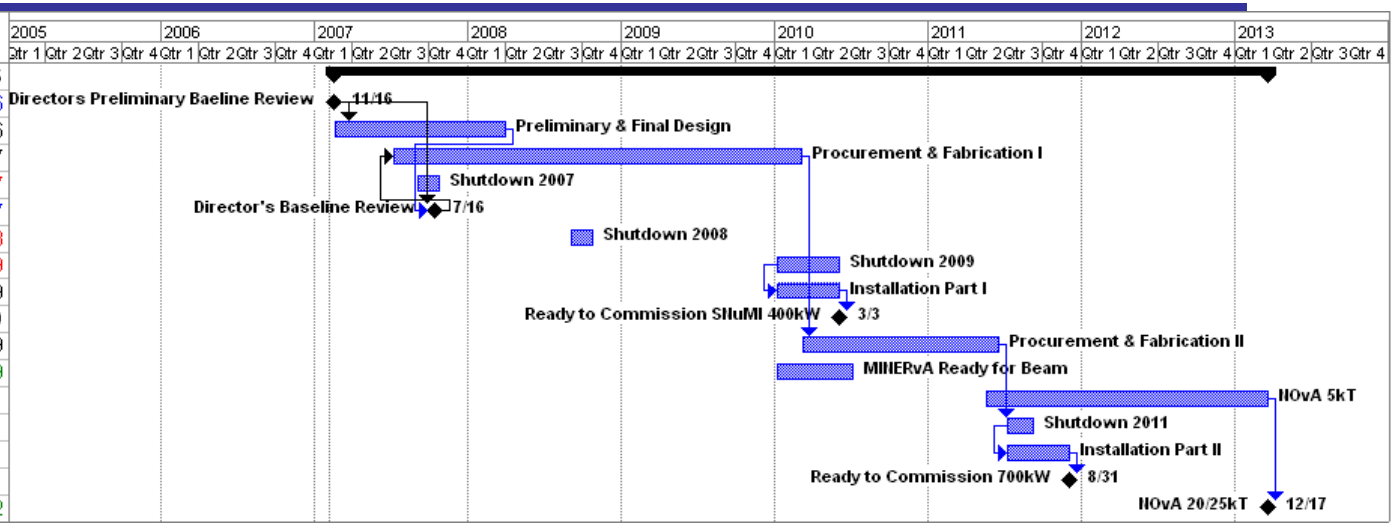
Main concerns:

- AD Mechanical Engineering
- AD Mechanical Tech
- TD Mechanical Tech
- AD Designer/Drafter

- Need to know if this resource amount is achievable in AD and TD
  - Can contract out MT work
- Project is 3.5 - 4.5 years long
  - NuMI portion 1 year longer then accelerator portion

PP Phase II Timeline

Task Name	Start
SNuMI Phase I (Campaign)	**11/16/06**
Directors Preliminary Baeline Review	11/16/06
Preliminary & Final Design	11/16/06
Procurement & Fabrication I	4/5/07
Shutdown 2007	6/1/07
Director's Baseline Review	7/16/07
Shutdown 2008	6/2/08
Shutdown 2009	10/5/09
Installation Part I	10/5/09
Ready to Commission SNuMI 400kW	**3/3/10**
Procurement & Fabrication II	12/4/09
MINERvA Ready for Beam	10/5/09
NOvA 5kT	2/15/11
Shutdown 2011	4/4/11
Installation Part II	4/4/11
Ready to Commission 700kW	**8/31/11**
NOvA 20/25kT	12/17/12



- 2007 shutdown: Civil penetrations for buildings completed
- Fall 2009 shutdown: accelerator phase II work installed/completed
  - Starts Oct. 1 and ends March 19 (5.6 month shutdown)
- Spring 2010: Start up and commission recycler (400kW)
- 1 year of running with NuMI LE target for MINERvA
- Spring 2011 shutdown: complete NuMI Target Hall work for 700kW
- May 2011: Start up and commission recycler (700kW)
- Early 2011: NOvA 5kT detector ready

Proton Plan Phase II & SNuMI

PP Phase II Critical Path

- Critical path through the Recycler injection and gap clearing kickers (as expected) until Fall 2009 shutdown
  - Some pulser parts don't arrive until late September 2009
- Horn 1 & module installation on the critical path for the 2011 shutdown

Now on to SNuMI rough costs and schedule…..

(note SNuMI is very conceptual, we need people to work on this to get it past the conceptual point…)

Motivation for SNuMI

- PP Phase II: uses slip stacking of multiple Booster batches in the Recycler and increased repetition rate in the MI -> 700KW.
  - Slip stacking at 8 GeV reduces peak intensity requirement in the Booster.
  - Results in a smaller required aperture for the Booster.
  - Beam intensity in Recycler & MI increased only 10% above Proton Plan
- Can't further increase the number of batches stacked into the Recycler
  - Too much longitudinal emittance dilution
- Not practical to further decrease the cycle time of the accelerator complex
  - Need additional power supplies, building extensions & RF system in MI
  - NuMI would also need power supplies, possibly magnets, more space…
  - Very large cost to upgrade the electrical infrastructure for this
- SNuMI: Momentum stacking in the accumulator & box car stacking in Recycler)
  - No longer need Accumulator for anti-protons
    - **Can be used to achieve the beam power of 1.2 MW (SNuMI).**
  - Much smaller emittance dilution than slip stacking
  - Intensity in the Recycler and MI is increased by 70%.

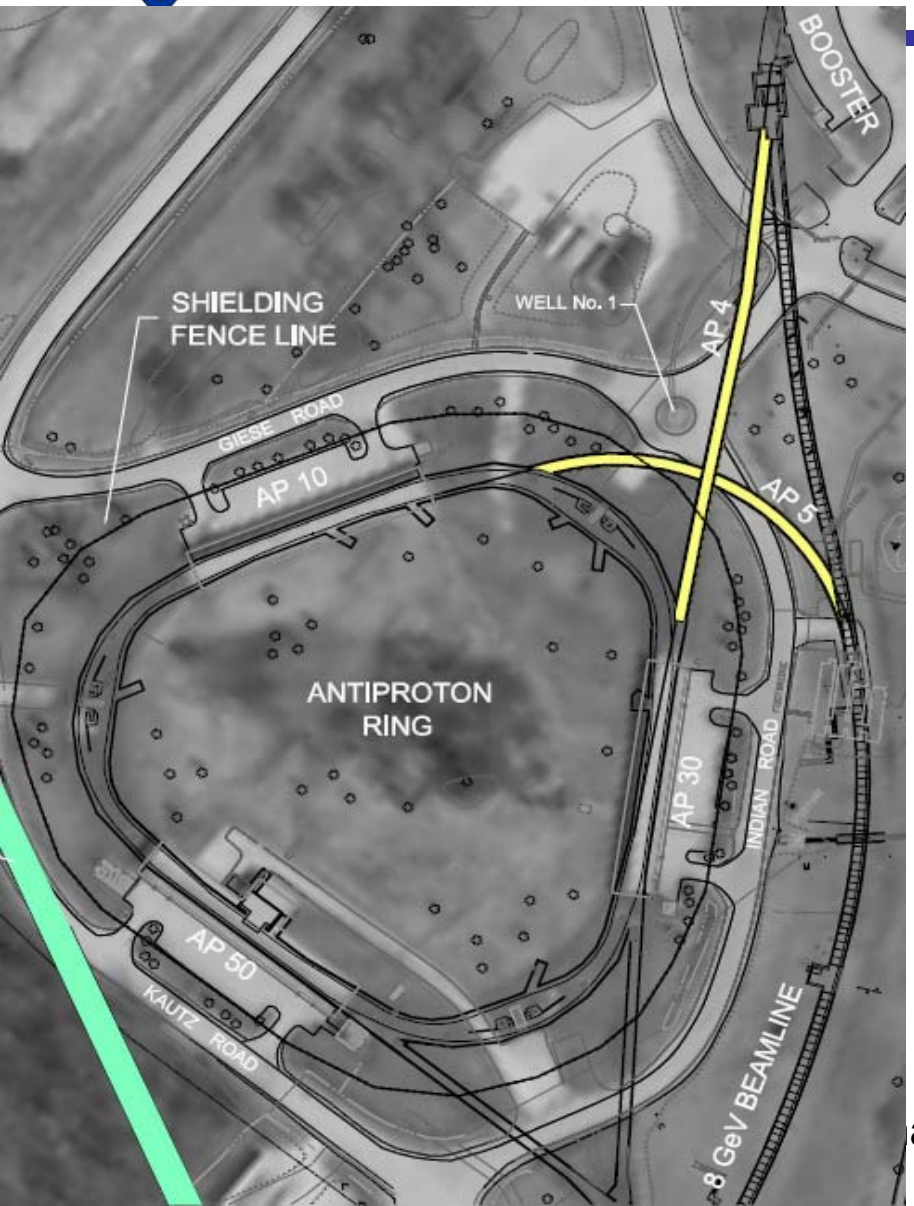
Proton Plan Phase II & SNuMI

SNuMI Overview

Use the Accumulator in the Anti-proton Source as a proton ring (D. McGinnis):

- After acceleration in the Booster, beam transferred to the Accumulator
- Accumulator was designed for momentum stacking
  - Momentum stack 3 Booster batches (4.7×10^{12} p/batch) every 200 ms
  - No need to cog in the Booster when injecting into the Accumulator
  - Longitudinal emittance dilution of ~ 20% instead of ~ 80% as in slip-stacking
- Box Car stack in the Recycler
  - Load in a new Accumulator batch every 200 ms
  - Place 6 Accumulator batches sequentially around the Recycler
- Load the Main Injector in a single turn
- 8.3×10^{13} ppp in MI every 1.333 s $\Rightarrow$ 1.2 MW

Accumulator Ring, AP4 & AP5 Lines



- Accumulator Ring:
  - Decommission and set up for proton momentum stacking
  - 3 booster batches per stacking cycle
    - 3 * 4.7E12 = 1.4E13
  - New 53MHz RF system
  - Re-bunch the entire stacked beam at h=12 in the Accumulator (new 7.5 MHz RF system)
  - 0.2 sec between extractions
  - Beam intensity at extraction: 1.4E13 protons
  - 6 batches extracted to the recycler
- Build injection line from Booster: AP4
- Build extraction line to 8 GeV Line: AP5
- Radiation fence around Accumulator

SNuMI: Overview of Scope

- Booster: 15Hz operation, need to visit Booster throughput
- Add Accumulator ring to momentum stack Booster Batches
  - Civil construction of building injection and extraction lines
  - Design/build/install the beamline elements
  - 53 MHz RF system
  - 7.5 MHz RF system
- Recycler: 2 additional 53 MHz RF cavities, 7.5MHz RF system
- Main Injector: Upgrade RF system using 2 power tubes
  - Possible additional cooling pond needed for this (minor floodplain mitigation)
- NuMI: Water cooling of target pile, new target and horns

(Red items are the big ticket items)

SNuMI: Very Preliminary Cost Overview

(no G&A or contingency, FY06K$, physicist labor included)

WBS	Task Name	M&S Cost	Labor	Total
1	SNuMI Phase II	$31,428	$22,240	$53,668
1.1	Booster	$0	$0	$0
1.2	Recycler	$1,500	$1,500	$3,000
1.3	Main Injector	$6,979	$2,200	$9,179
1.4	NuMI	$4,800	$4,800	$9,600
1.5	Beam Physics	$100	$500	$600
1.6	Accumlulator	$5,835	$5,840	$11,675
1.7	Civil (covered in breakout talk)	$11,214	$0	$11,214
1.8	Radiation Safety	$0	$500	$500
1.9	Project Management	$1,000	$6,900	$7,900

- Cost Drivers (77%):
  - Accumulator work @ $11.7M (22%)
  - Civil work @ $11.2M (21%)
    - Includes 20% overhead, others don't
  - NuMI Upgrades @ $9.6M (18%)
  - Followed by MI RF $9.2M (16%)
- Estimate 270 man-year (FTE) effort (~5.5 years), avg. 50 FTEs/year
- (Proton Plan Phase II ($P^3$2?) was ~40 FTE's/yr: 90FTE's per year total…)

Proton Plan Phase II & SNuMI

PP Phase II & SNuMI : Schedule Overview

Fall 2009: 5.6 month shutdown to complete all accelerator upgrades for 700kW

- Commission the Recycler at 400kW (no higher due to NuMI low energy target in place)
- Best time to do SNuMI connection work (4-5 months)

Early 2011: 2 Month shutdown to complete installation in NuMI Target Hall for 700kW beam;

- Gradually implement slip-stacking over multi-batches up to 700 kW beam power
- Fall back time to do SNuMI connection work (4-5 months)

Mid to late 2011: run steadily at 700kW

Sometime in 2012: 4-5 month shutdown for installation of SNuMI lines (AP4, AP5) and accelerator & NuMI upgrades for SNuMI

- Start momentum stacking in Accumulator, increasing beam power to 1.2MW

Late 2012: NOvA 10/25kT detector ready

Mid to late 2013: run steadily at 1.2MW

SNuMI Needs in FY07

- M&S: less then $225K
  - MI RF, Civil construction A&E work
- Labor
  - Can't support all SNuMI work with same people working on P^{3}2
    - Need more manpower this year for this effort
    - **Has been a struggle to get engineering time for PP phase II**
  - October 2009 is not that far away and there is much to do for P^{3}2 and SNuMI
  - Require a significant R&D effort in the next few years In order to make the correct choices to plan for Phase II upgrades
- Team to work on SNuMI (now): (all at 20-50% level of effort)
  - Team Leader
  - RF Engineer
  - Beam Line designer (need beam lattice ASAP to proceed with civil design concepts)

SNuMI: Campaign or Project: MIE or Line Item

- Campaign: don't need to get CD-0 or do formal DOE Reviews
  - SNuMI is very similar to PP phase II in that it is upgrades to the accelerator complex and NuMI
  - Complete SNuMI: early 2012
- Project: need to follow DOE Order 413.3 Critical Decision matrix, (CD's)
  - Major Item of Equipment (MIE):
    - **CD-0 mid 2007 (doable?)**
    - **CD-2 (baseline) to get real R&D money (non-conceptual)**
    - **CD-3 (allows procurement)**
    - **Can do combined CD-2/3a to get a few important procurements started early in early 2009**
    - **Complete: mid 2012**
  - Due to Civil work may need to approach as a Line Item
    - **Need CD-2 approval in April, 1.5 years before need construction money**
    - **Earliest we could get CD-2 approval would be April 2008**
    - **Implies CD-2 DOE Baseline Review in January 2008 & construction money in FY2010**
    - **Complete: late 2012**

Recent Director's Review of SNuMI I & II (PP Phase II & SNuMI)

- Review went very well
  - People worked very hard for this review and it showed

- 43 Recommendations, many quite technical and quite good

  Proton Plan Phase II:
  - Need to work with the lab to get FY07 guidance soon
  - Need to work with lab management on an achievable funding profile
  - Resources are a concern, and we need to work with lab management (AD and TD mostly) on this issue for near term and long term
  - Need to keep up the impressive rate of progress

  SNuMI:
  - Need a team to work on the best concepts to achieve >1MW

- Many comments that are also technically useful and we need to address them

Summary

- PP Phase II: M&S: $20M; Labor: $13M Total: $33M
- SNuMI: Cost of roughly M&S: $31M; Labor: $22M Total: $54M
- Proton Plan Phase II: Schedule aggressive, but achievable
  - Commissioning Recycler with 400kW beam spring 2010
  - Commissioning for 700kW beam spring 2011
  - NOvA 5 kT detector scheduled to be ready early 2011
- Phase II: Schedule: could be ready by 2012, depending on the level of resource overlap with people working on phase I
  - Schedule depends critically on getting significant manpower for this effort this FY (and continuing to get significant manpower)
  - Project Line Item: ready 12/12
  - NOvA 20/25 kT detector scheduled to be ready 12/12

SNuMI: A world class neutrino facility for the next decade

Neutrino beams power