High Intensity Neutrino Target

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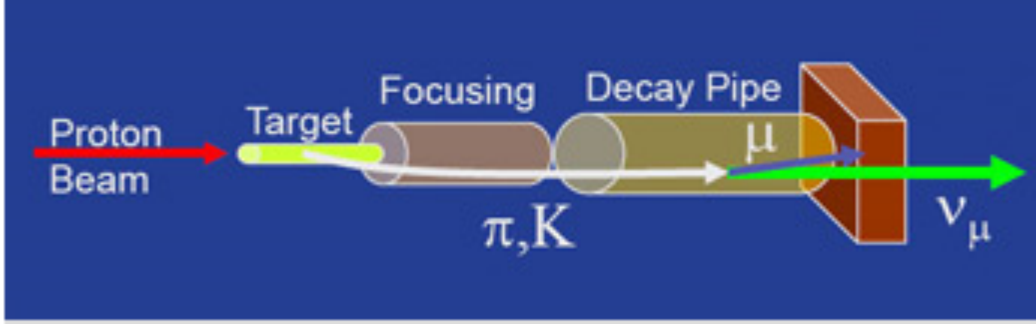
Ryan Schultz	Fermilab

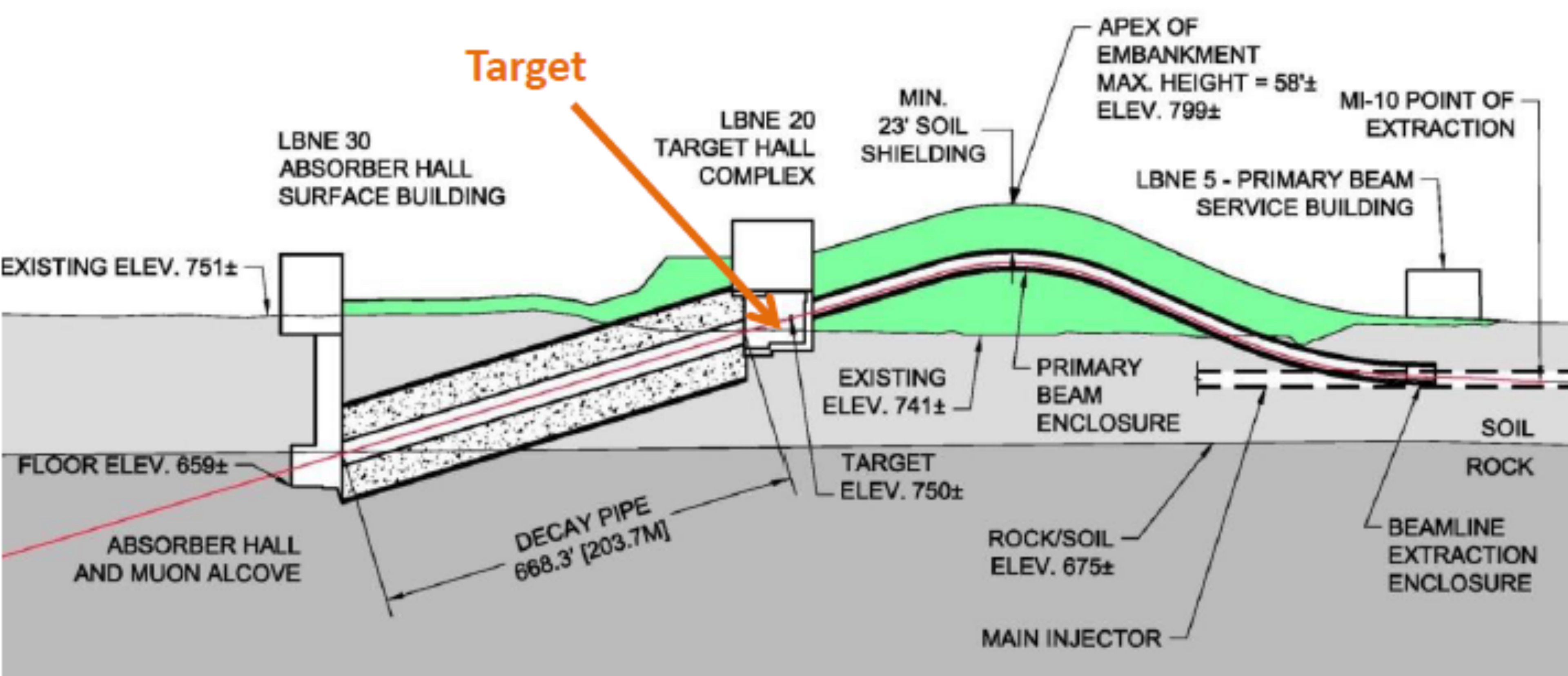
Charge

- Design a target for high intensity neutrino beam
  - 10^{14} protons/pulse
  - 200 Gev
  - Repetition Rate?
- Design a protection system for the target
  - Interlocks?
  - Other instrumentation?
- How do we monitor target status? Diagnose problems?
- Design neutron spallation target
  - 2 Gev, 5 MW

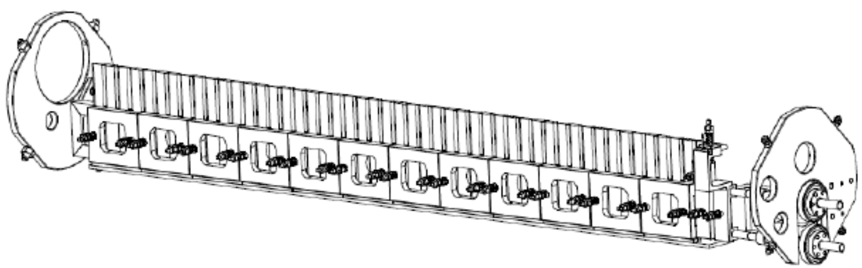
Background



Scientists create neutrinos by smashing protons into a target. The protons create short-lived particles called pions and kaons, which then decay into neutrinos and other particles. *Credit: Fermilab*



Current Designs



NOvA target. Beam passes through the graphite fins in upper part of the target

NuMI

MINOS

NuMI Target

long, thin, slides into horn without touching

NBI2006
September 6, 2006
NuMI Target Experience
Jim Hylen / FNAL
Page 2

Graphite Fin Core, 2 int. len.
(6.4 mm x 15 mm x 20 mm) x 47

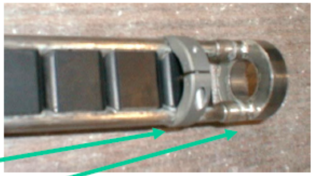
Water cooling tube also provides mech. support

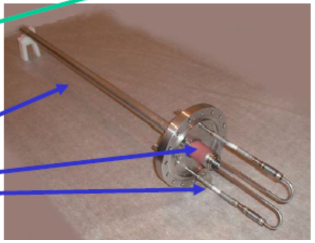
Anodized Al spacer (electrical insulation)

Water turn-around at end of target

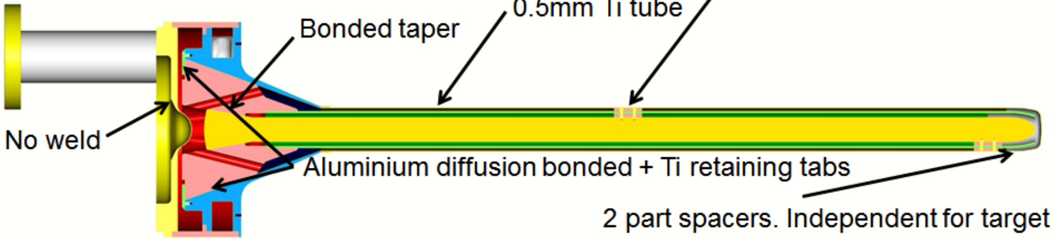
0.4 mm thick Aluminum vacuum/Helium tube

Ceramic electrical isolation





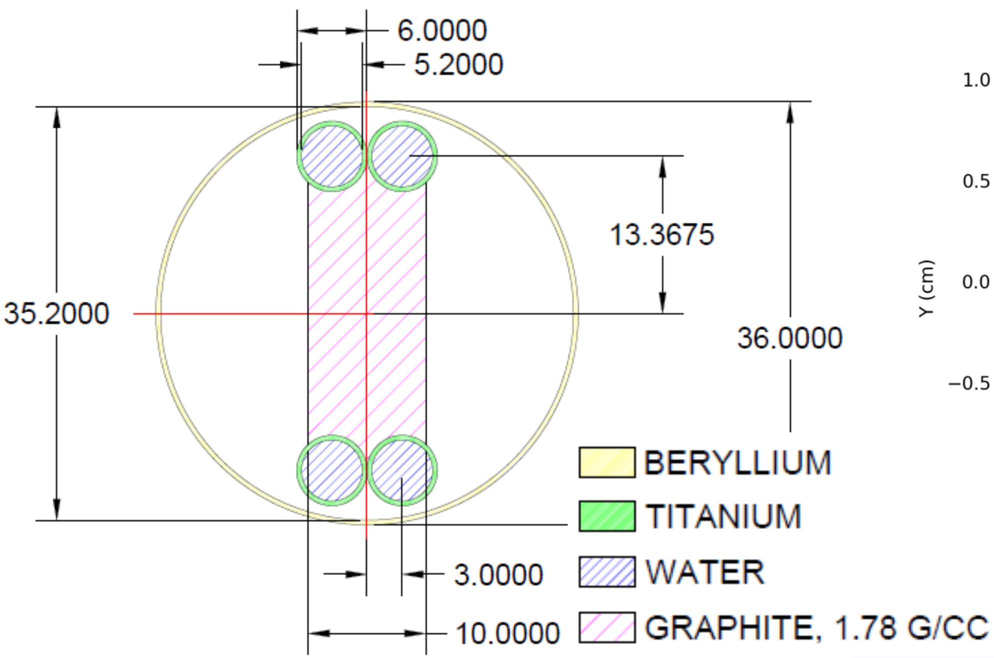
Mk 2 (RAL manufacture)

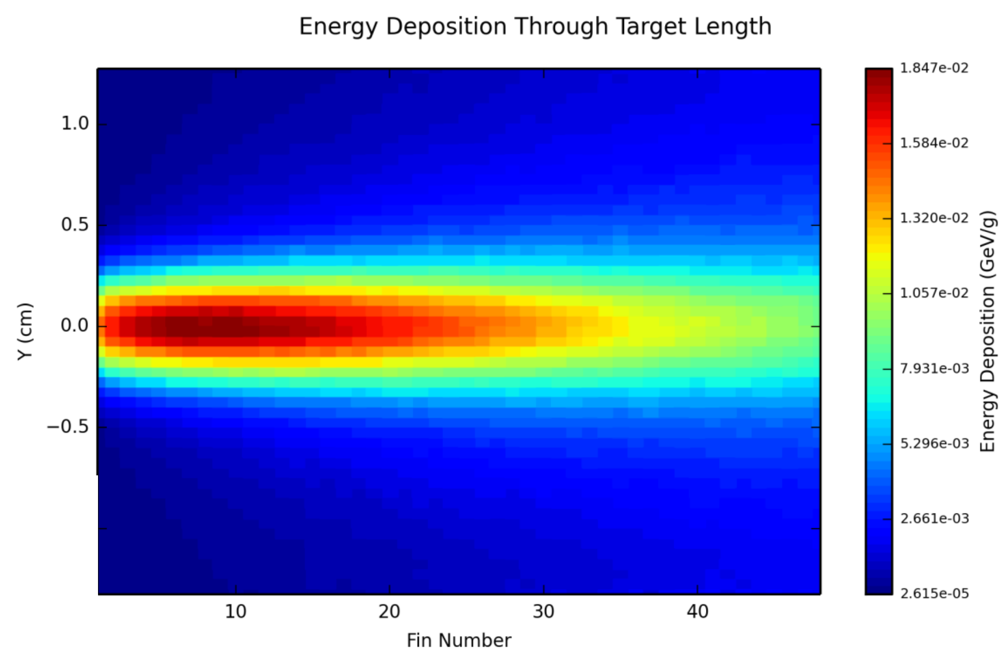


T2K

Current Designs

- 1.2 MW LBNF target uses 2 water paths
  - compared to 1 path for NuMI/NoVA
- 3-4 paths may be necessary for greater power
- Heat removal is a limiting factor





Specifications

- Beam Parameters
  - 10^{14} protons/bunch
  - 200 GeV
  - *Proton Beam size: 1-2mm dia.
  - *Bunch time: 1 micro second
  - *1.6 MW at 0.5 Hz.
    - Pulse rate to be defined by maximum target temperature
  - *Target length: 1.5 meters

* Estimated or calculated value

Quote

- "The hardest single part of building a software system is deciding precisely what to build. No other part of the conceptual work is as difficult as establishing the detailed technical requirements … No other part of the work so cripples the resulting system if done wrong. No other part is as difficult to rectify later."

-- Fred Brooks, *The Mythical Man-Month*

Considerations

- Target material: Carbon-Carbon, Moly-Graphite, Graphite, Plasma.
- Body Shape: (cylindrical, ~~finned outer profile~~)
- Size:
  - Long enough to absorb all of the proton beam.
  - Short enough to not prevent the release of Pions.
- Beam size: 1-2mm diameter
- Cooling media: (chilled water or He)
- Risks (short term and long term damage to target)
- Helium at leading face of target, (prevent/reduce corrosion)
- Windows: Primary beam and Target

3 possible approaches:

1. **Conventionally designed target (long life)**
2. **Don't worry about target damage**
3. **Have a target that can't be damaged**

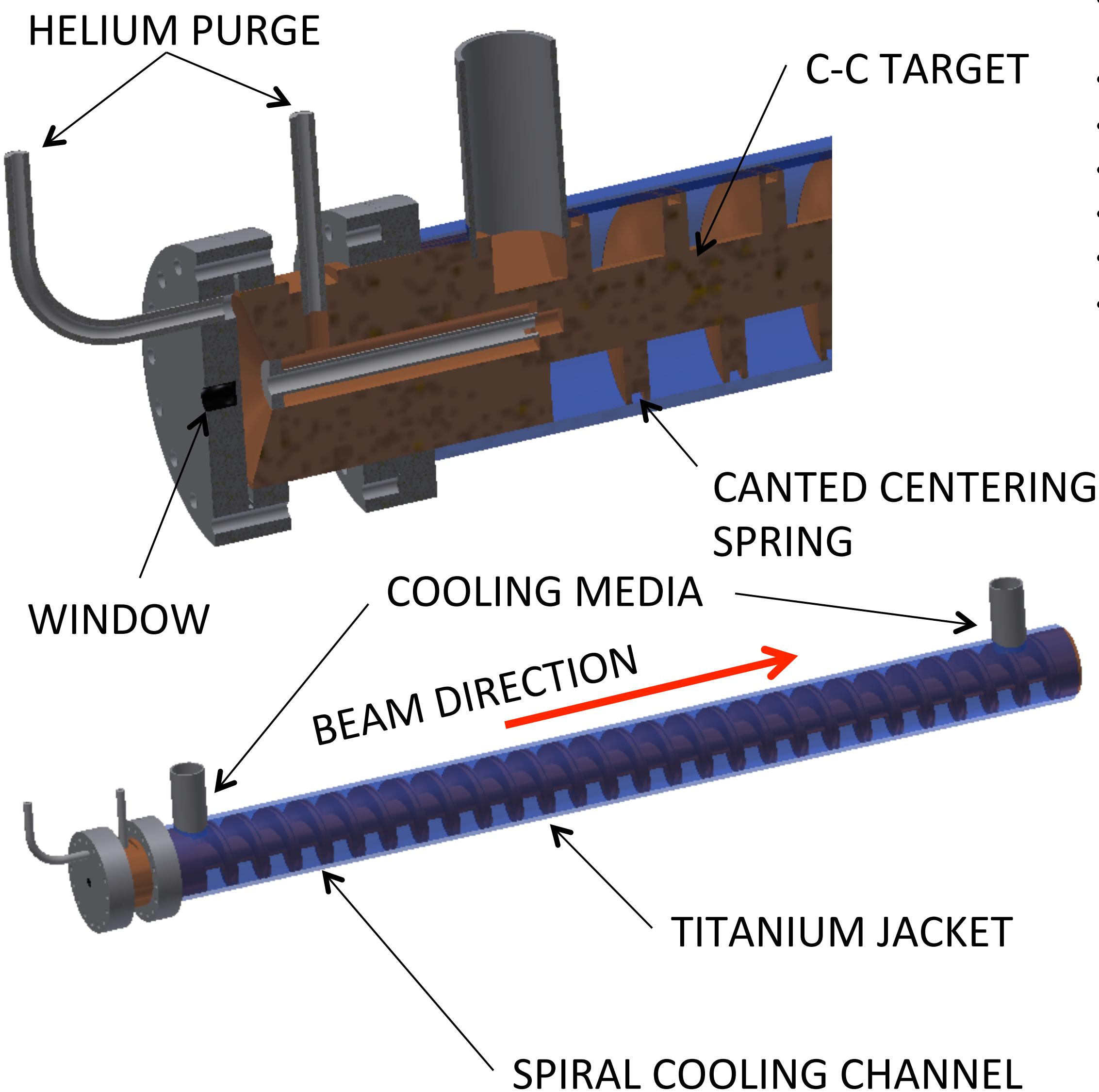
Material Requirements

- Maximize **Thermal Conductivity** (λ) to maintain geometrical stability under steady-state losses (**TSI**)
- Minimize **CTE** (α) to increase resistance to thermal shock and maintain geometrical stability (**TRI** and **TSI**)
- Maximize **Melting/Degradation Temperature** (**Tm**) to withstand high temperatures reached in case of beam impacts (**TRI**)
- Maximize **Specific Heat** (**cp**) to lower Temperature increase during impacts (**TRI**)
- Maximize **Mechanical Strength** (**RM**) (particularly ***strain to failure***) to improve thermal shock resistance (**TRI**)
- Balance **Density** (ρ) and atomic number (**Z**) to limit peak energy deposition while maintaining adequate cleaning/ interaction efficiency (**TRI** and **TSI**)
- Minimize **Radiation-induced Damage** to improve component lifetime under long term particle irradiation

Material	Beryllium	Carbon-Carbon	Graphite	Molybdenum Graphite	Copper-Diamond	Glidcop ®	Molybdenum	Tungsten Alloy (IT180)
ρ [g/cm^3]	1.84	1.65	1.9	2.50	5.4	8.90	10.22	18
Z	4	6	6	~6.5	~11.4	~29	42	~70.8
X_0 [cm]	35	26	19	17	4.8	1.4	0.96	0.35
c_p [Jkg^{-1}K^{-1}]	1925	780	760	750	420	391	251	150
$\bar{\alpha}$ [10^{-6} K^{-1}]	18.4	4.1	5.5	5.0	7.8	20.5	5.3	6.8
$\bar{\lambda}$ [Wm^{-1}K^{-1}]	216	167	70	547	490	365	138	90.5
T_m [°C]	1273	3650	3650	2589	~1083	1083	2623	~1400
$\bar{E}$ [GPa]	303	62.5	12	44	220	130	330	360
R_M [MPa]	*370*	87	*30*	*80*	70	365	660	*660*
ΔT_q [K]	0.36	1.2	1.7	2.1	15.1	60.1	144	745
TRI [–]	790	1237	1101	634	6.8	5.3	6.4	0.5
TSI [-]	17.1	44.6	10.1	69.4	9.9	0.8	0.7	0.1
γ [MSm^{-1}]	23.3	~0.14	~0.07	~1÷18	~12.6	53.8	19.2	8.6

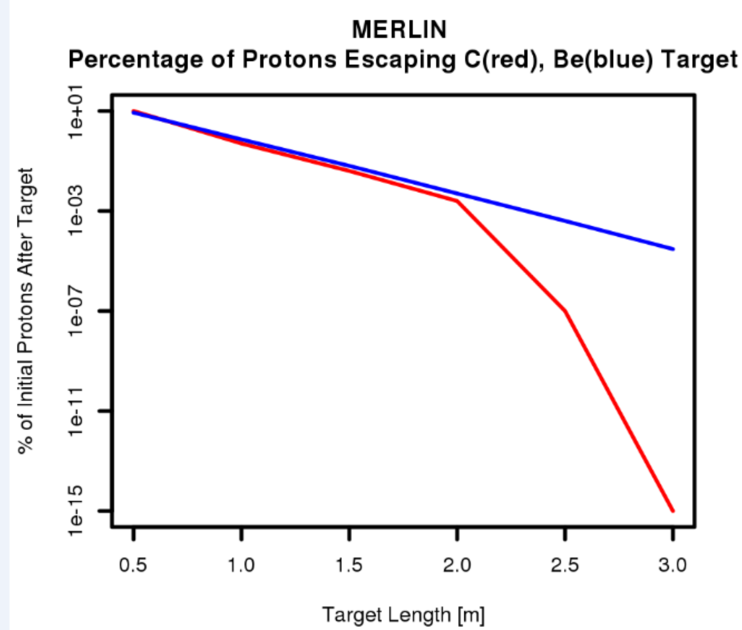
A. Bertarelli

Proposed Design



- The CNGS target was 2m long, checked the code and got the following estimates:
- Target length | % of incident protons escaping target
- 0.5m 10%
- 1m 0.5%
- 1.5m 0.04%
- 2m 0.025%
- 2.5m 0.0001%

200 GeV protons escaping targets using MERLIN.png



Risks to Target System

- Primary Risks
  - Damage to target assembly
    - » Positioning beam
    - » Excessive Power applied to target
    - » Overheating of target
    - » Deformation of target
    - » Corrosion of target
    - » Alignment of target
  - Damage to other system components

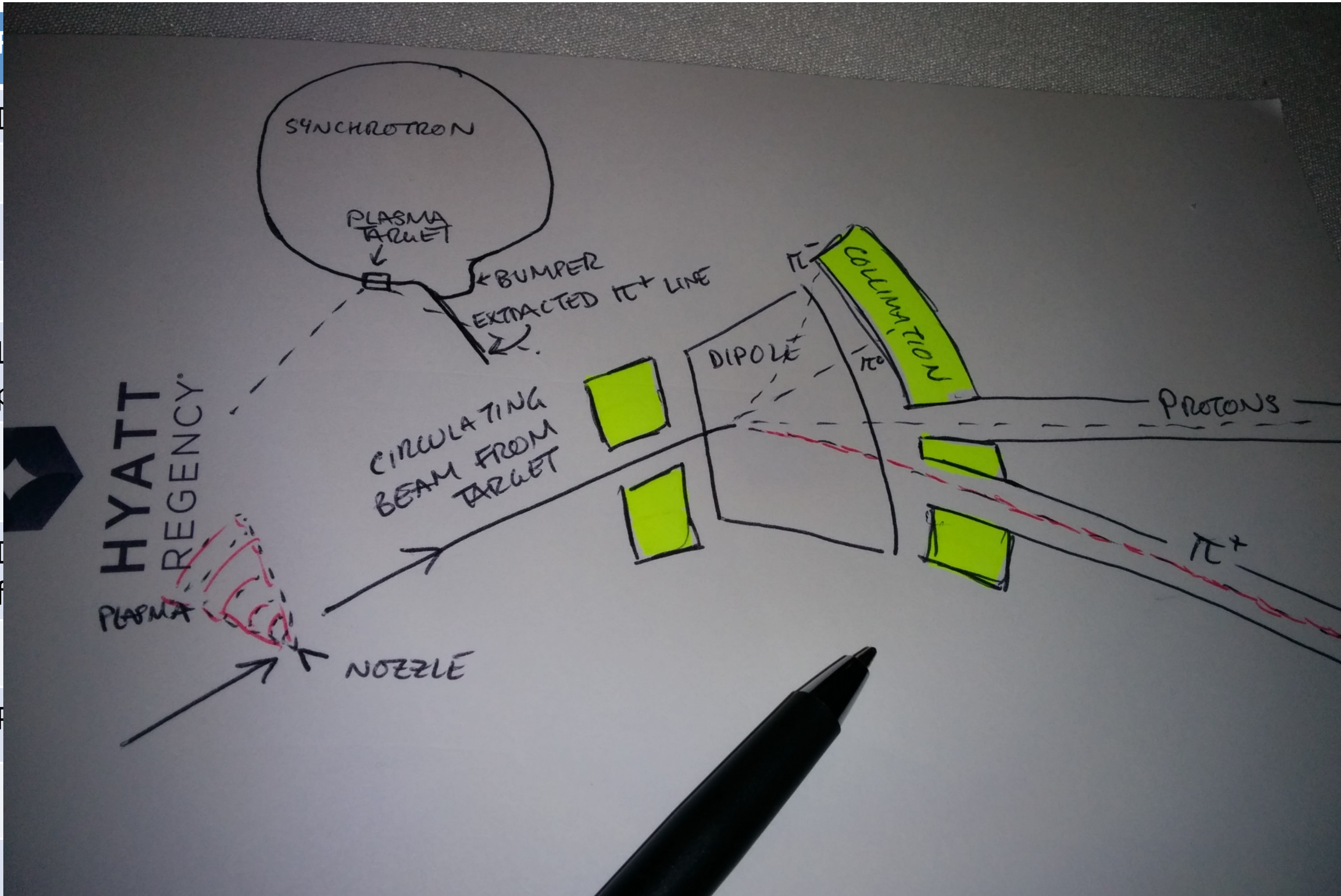
Interlocks and Monitoring

- All listed items would include warning and alarm limits. Alarm limits in accelerator would prevent pulsing target
  - Accelerator Status
    - BPM, BLM
    - Beam current, Pulse Rate, Pulse length
    - Target station and absorber readiness
    - Power supply status
    - Heat Removal: flow, pressure, temperature
    - Collimator temperatures
    - Automatic beam steering
  - Target Station status
    - Target imaging system
    - Neutrino "near" detector
    - Negative Pion detector (or other secondary particles)
    - Heat Removal: flow, pressure, temperature
    - Acoustic monitoring
    - Helium loss

…and many more.

Target that isn't damaged

Plasma Target MPS



Neutron Spallation Target

- Design neutron spallation target
  - 2 Gev, 5 MW
  - Examples: SNS & Oak Ridge use Hg targets, ESS uses tungsten
- Differences come from the target themselves
  - Material, higher Z for larger neutron production
  - Shielding for neutrons
- Possible additional safety measures for higher power
  - Beam rastering
- Essentially the same MPS as neutrino target

References

- All of our Professors – Thanks!
- And a few other references below

XIII International Workshop on Neutrino Factories, Super beams and Beta beams (NUFACT11) IOP Publishing
Journal of Physics: Conference Series **408** (2013) 012007 doi:10.1088/1742-6596/408/1/012007

LBNE 1.2MW Target

NBI 2014
Presented by Brian Hartsell

THO2A01 Proceedings of HB2010, Morschach, Switzerland

DESIGN OF THE T2K TARGET FOR A 0.75-MW PROTON BEAM*

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Drinks?