Status of the NuMI Neutrino Beam at Fermilab

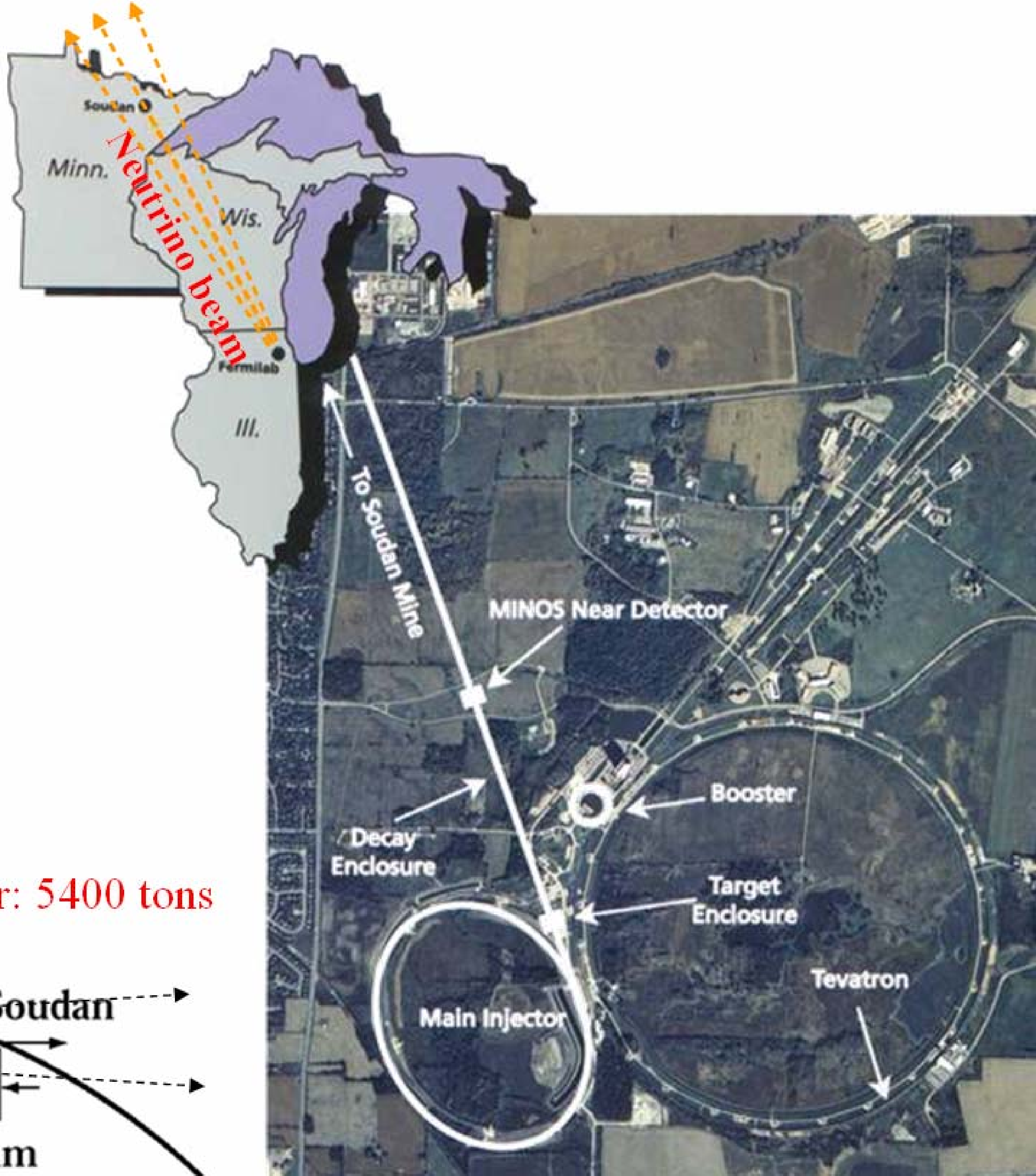
Robert Zwaska

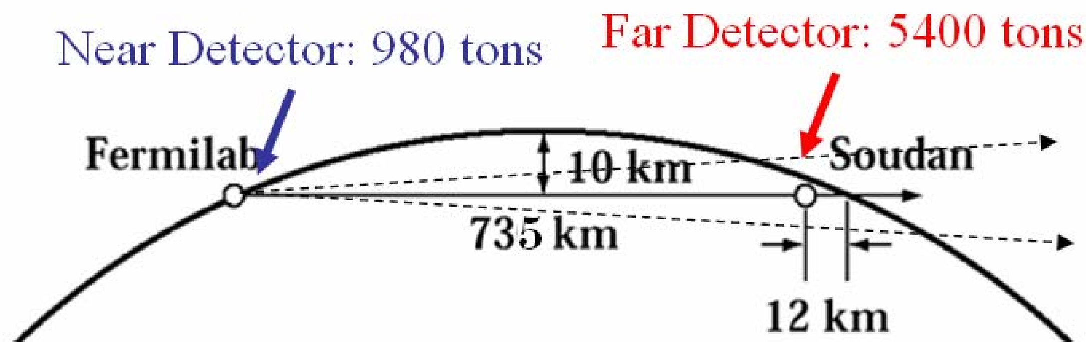
Fermilab

June 26, 2007

The NuMI Facility

- High-power neutrino beam for oscillation experiments
  - Beam tilted 3.3° down into the earth
- Neutrino beam travels to northern Minnesota
  - 735 km baseline
  - Intense source at Fermilab
  - Oscillated source in Minnesota
- Commissioned in 2004
- Operating since 2005

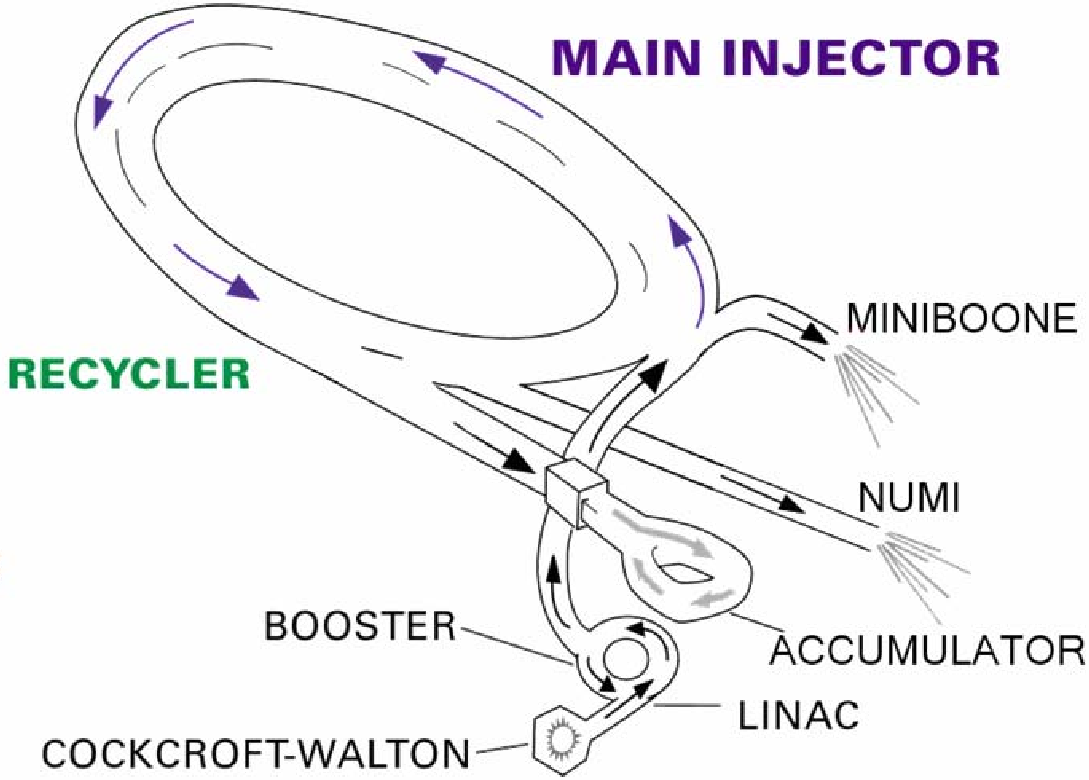




Protons as Raw Material

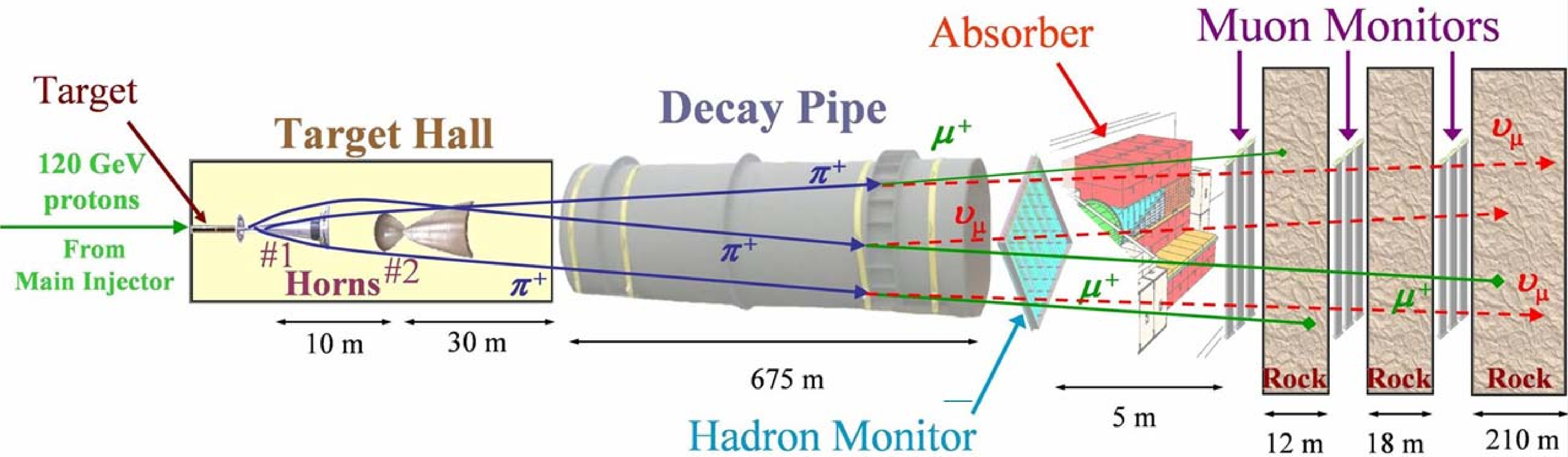
- 120 GeV protons from the Main Injector
  - Designed for as many as 4×10^{13} protons/pulse
  - 10 μs pulse every 1.9 s
  - 400 kW design power
- Shared proton capability
  - Antiproton Source
  - MiniBooNE beam
- Possibility to increase power in future
  - Redirect MiniBooNE protons
  - Re-use antiproton machines

FERMILAB'S PROTON COMPLEX



The NuMI Beam

"Neutrinos at the Main Injector"



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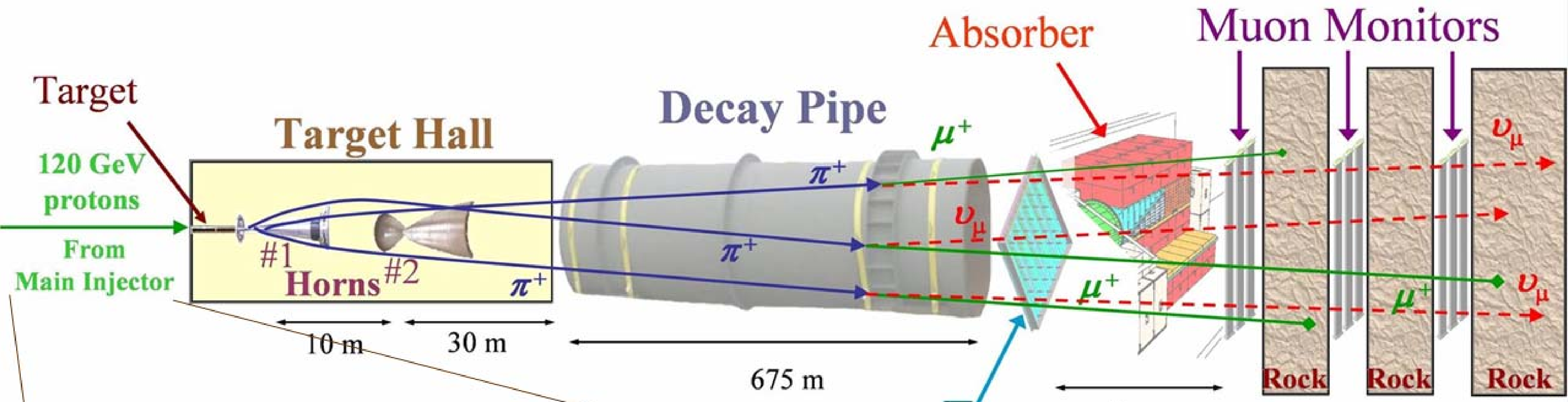
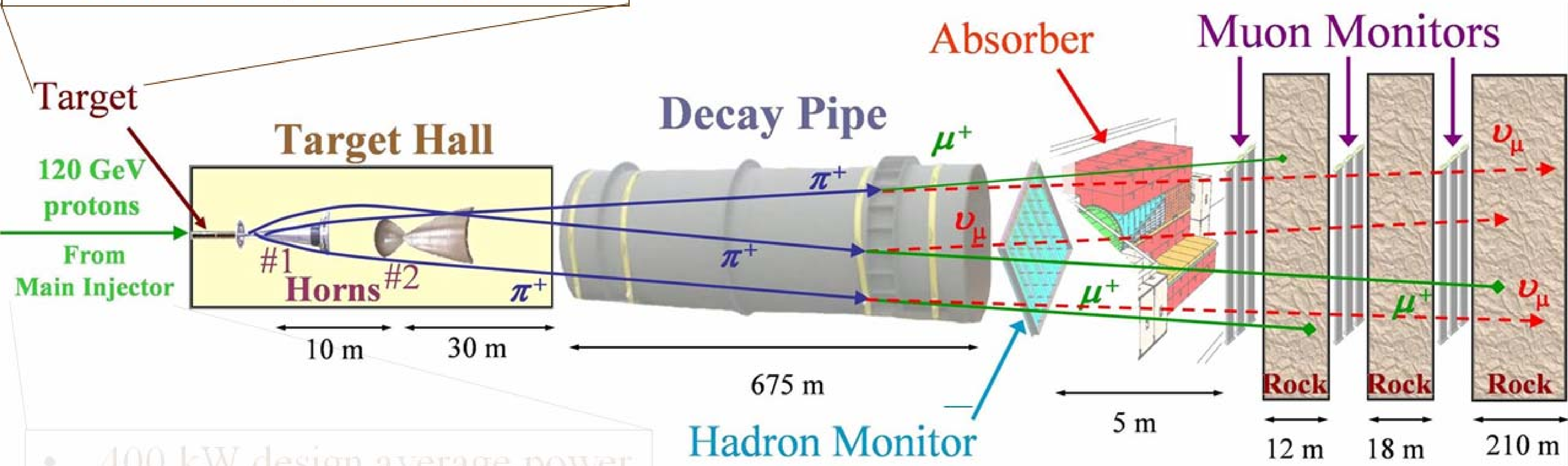


- 400 kW design average power
- $\sigma \sim 1$ mm

The NuMI Beam

"Neutrinos at the Main Injector"

- 2 interaction length, C target
- Produces π^+, K^+ mesons



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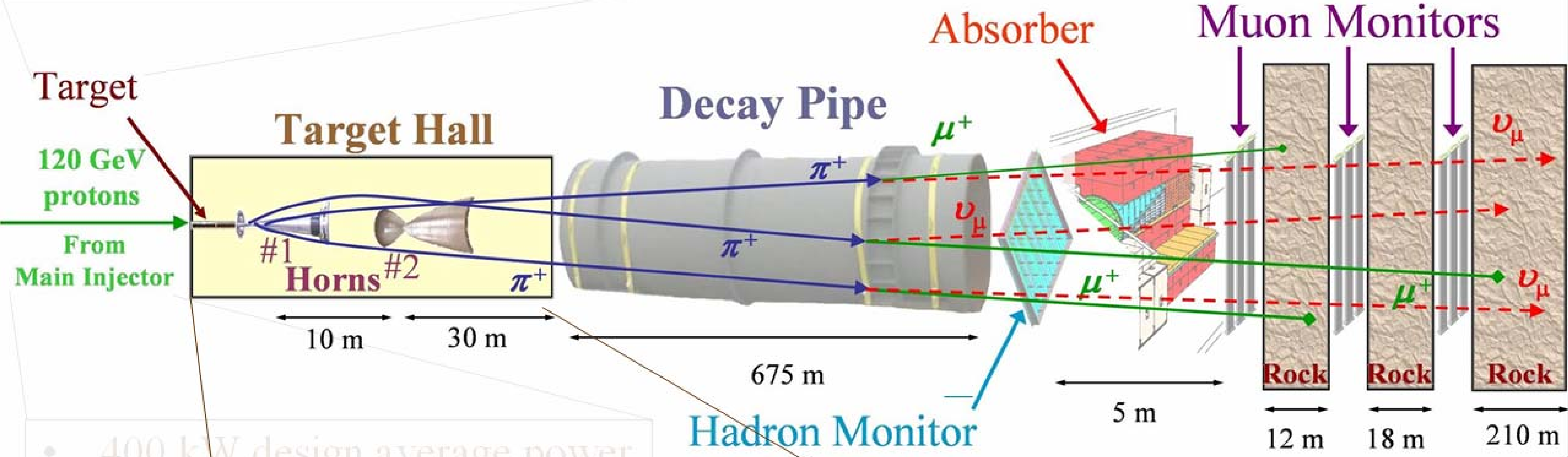

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- Pulsed focusing horns
- Toroidal magnetic field
- Parabolic inner conductor profile
- Focuses meson momentum band

The NuMI Beam

“Neutrinos at the Main Injector”

- 2 m diameter
- Roughly decay length for 10 GeV π^+
- Evacuated & cooled

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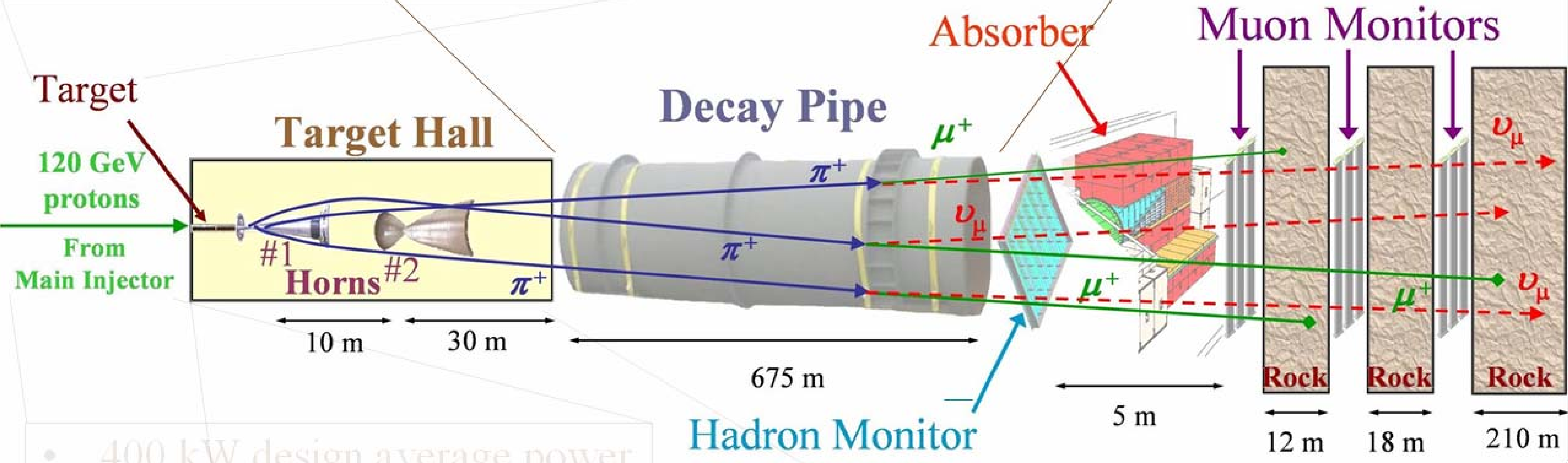

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The NuMI Beam

"Neutrinos at the Main Injector"

- Absorbs 160 kW of protons and other hadrons
- Allows high-energy muons to penetrate

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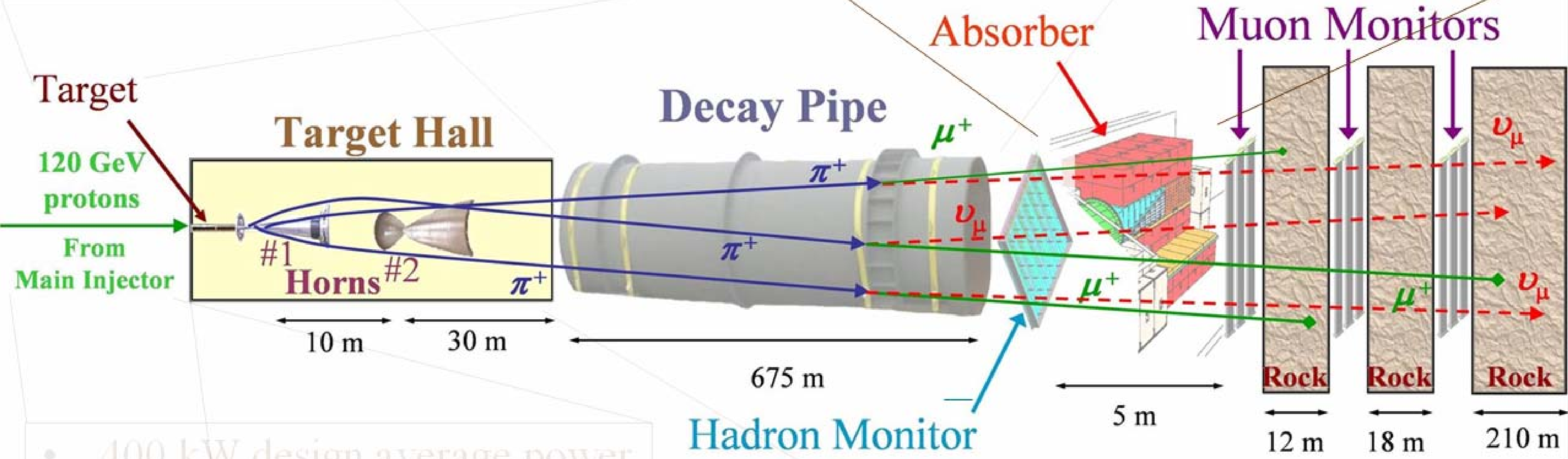

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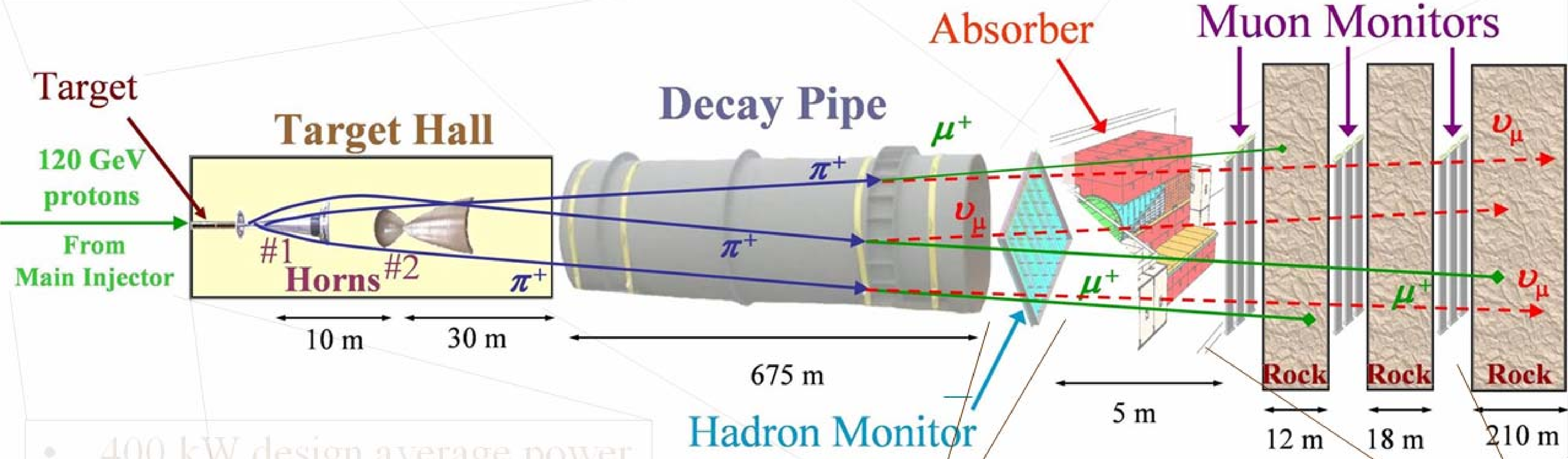

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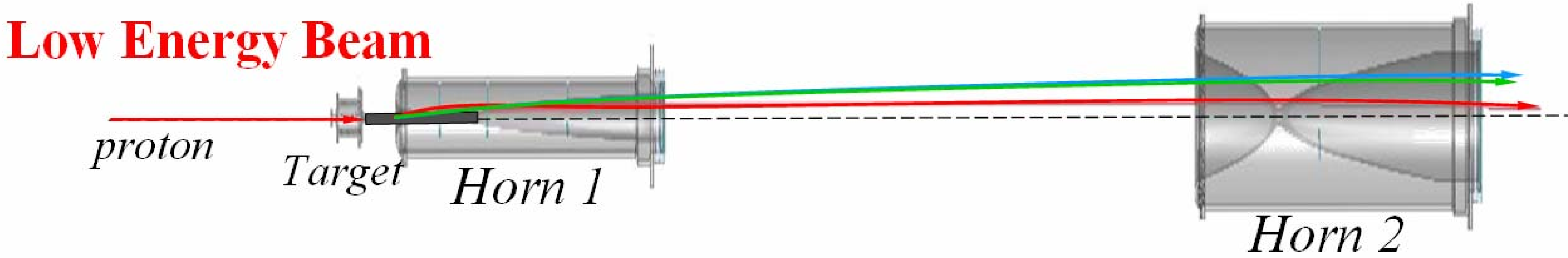
- Measure hadron & muon fluxes
- Arrays measure distributions

Variable Energy Neutrino Beam



Pions with

p_T=300 MeV/c and

p=5 GeV/c

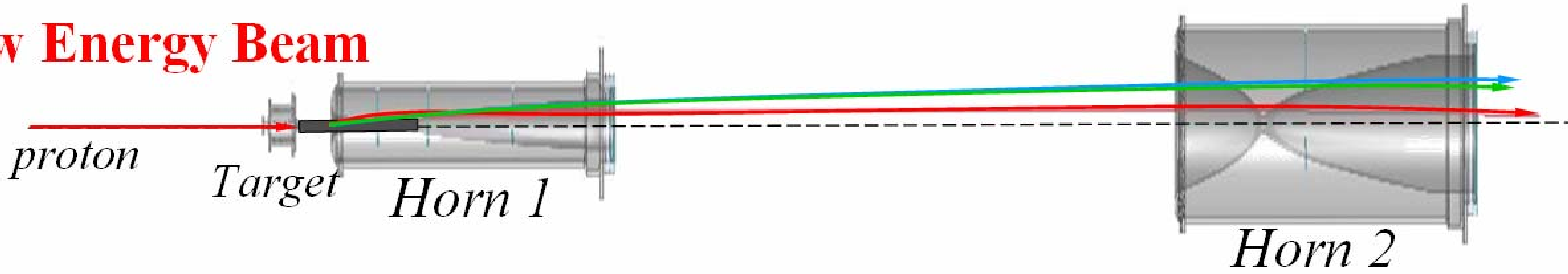
p=10 GeV/c

p=20 GeV/c

figure courtesy Ž. Pavlović

Variable Energy Neutrino Beam

Low Energy Beam



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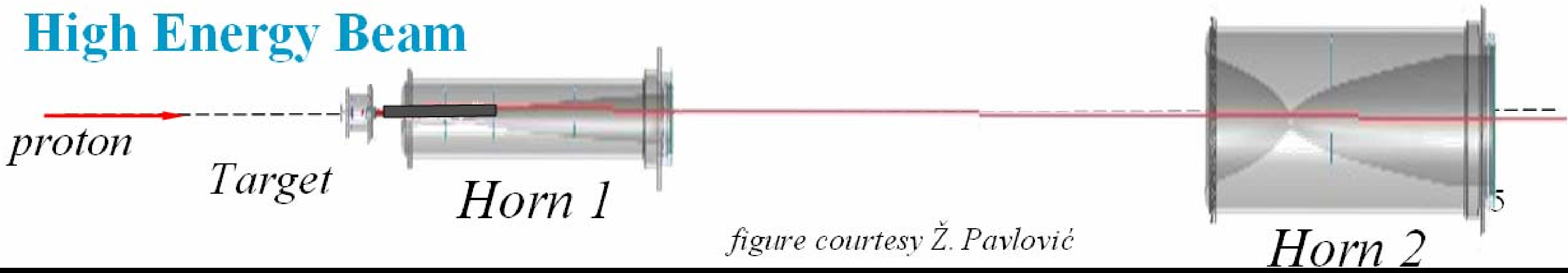

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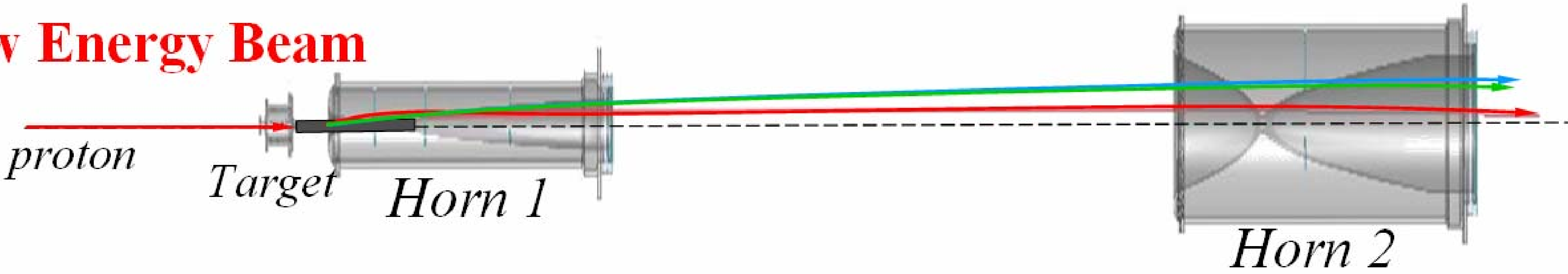

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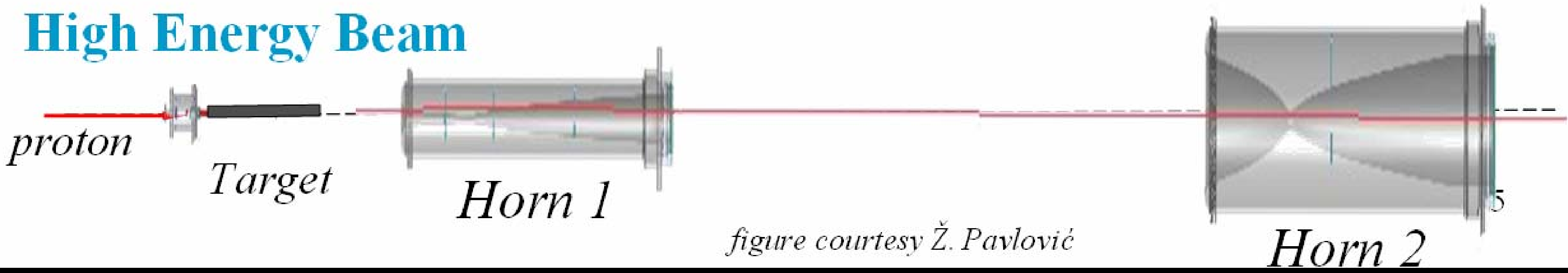
Vary ν beam energy by sliding the target in/out of the 1st horn

High Energy Beam



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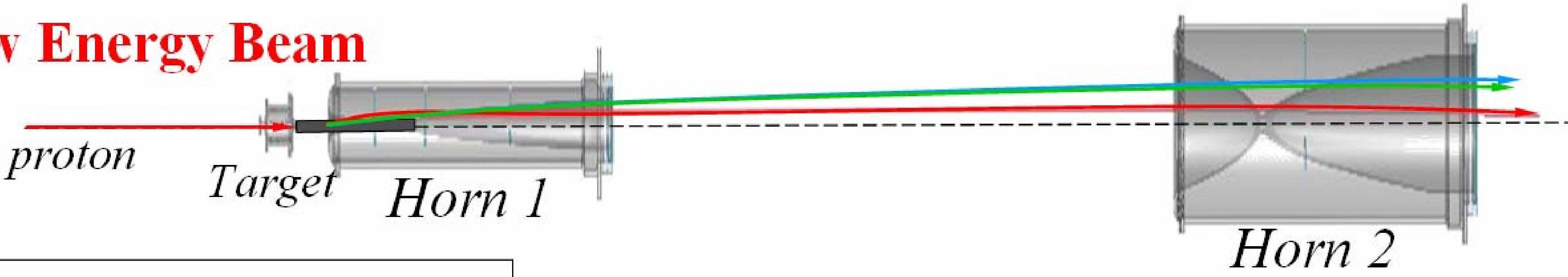

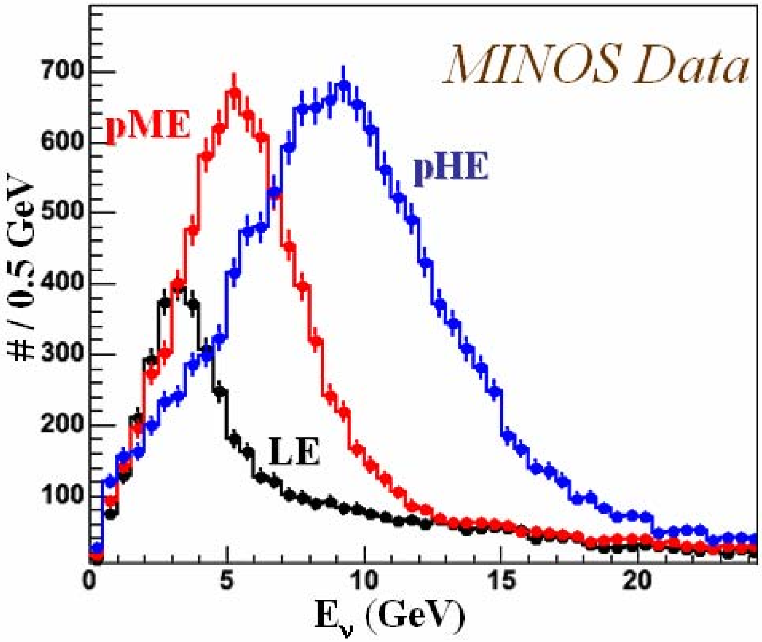

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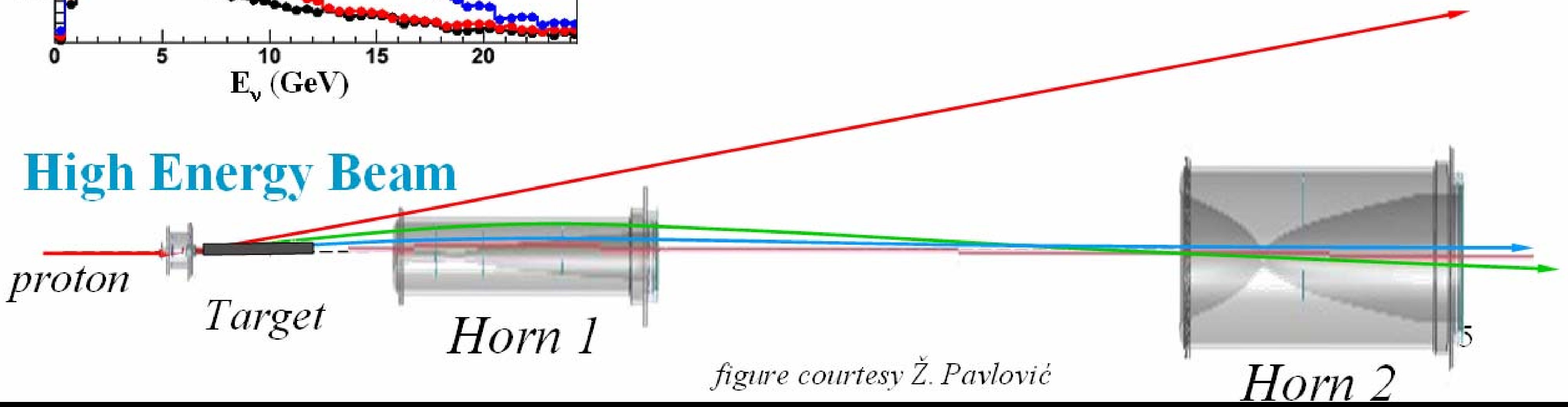

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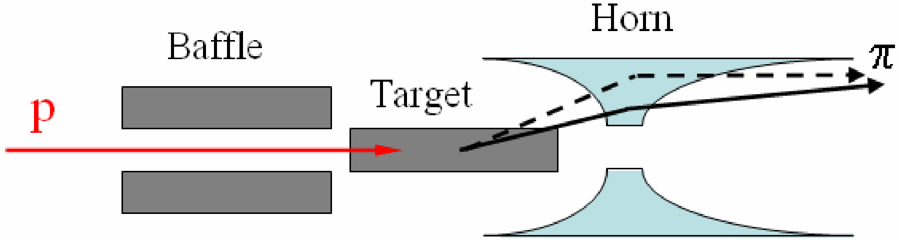
Achieving a Precision ν Spectrum

- Component placement affects the ν beam
  - Beam monitors detect changes in muon & hadron beams
  - Variation measured spill-to-spill
- Beam based alignment for all major components

- Horn 1 displacements affect pion focusing



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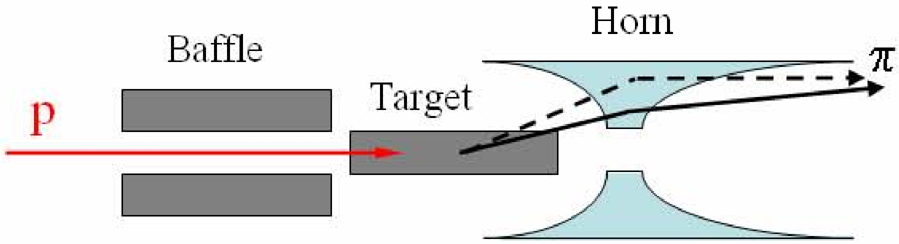

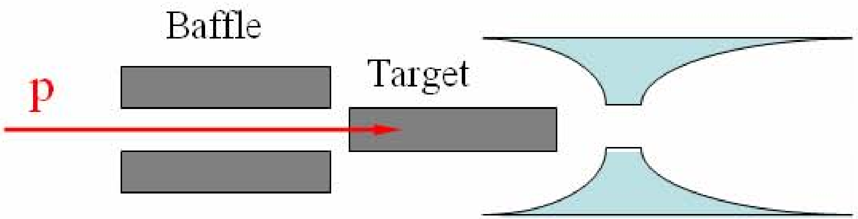

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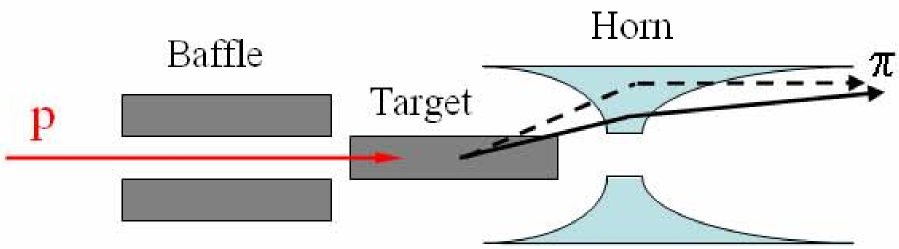

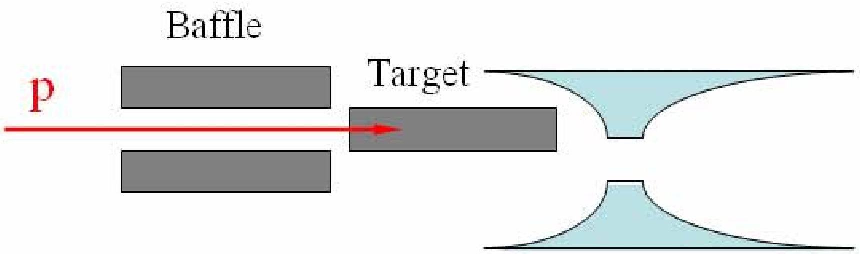

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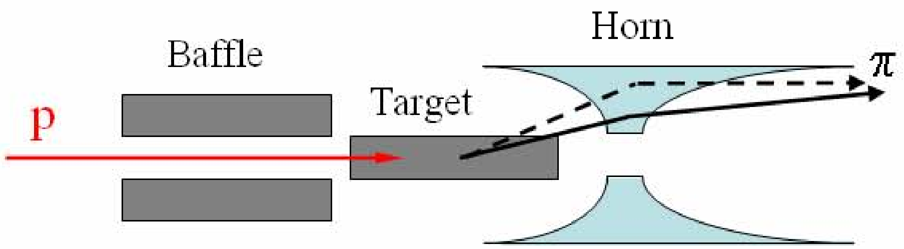

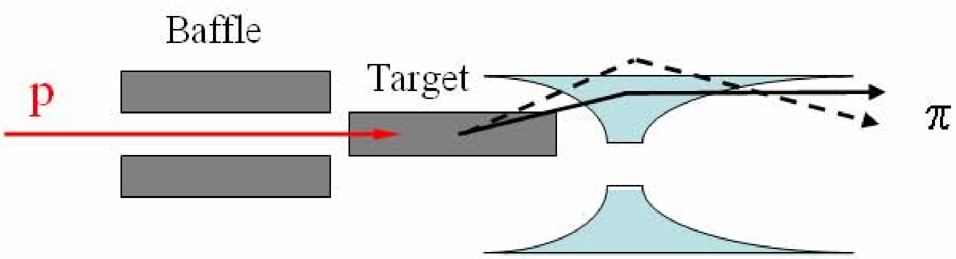

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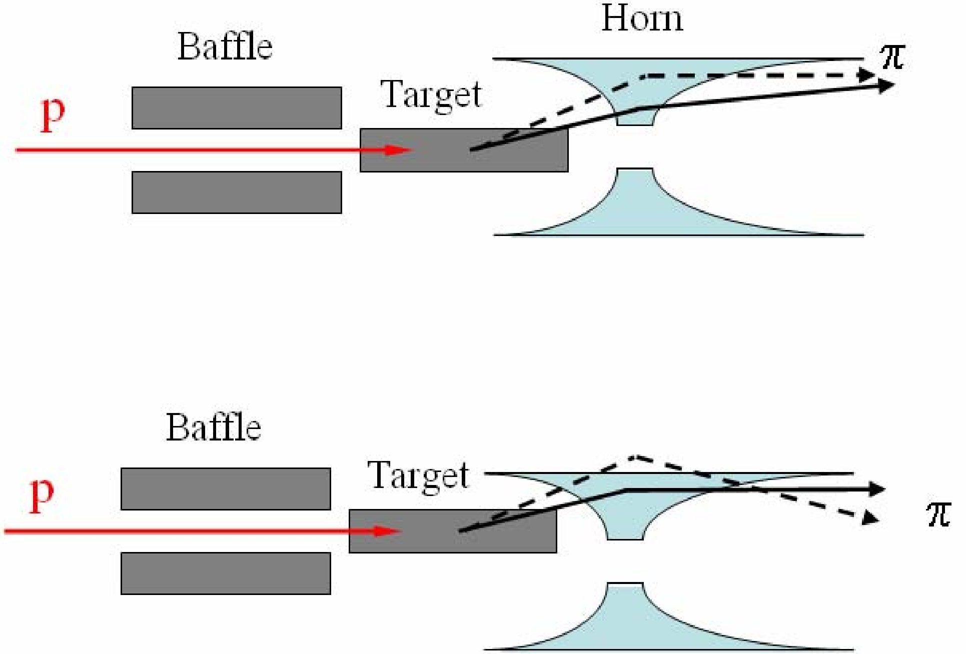
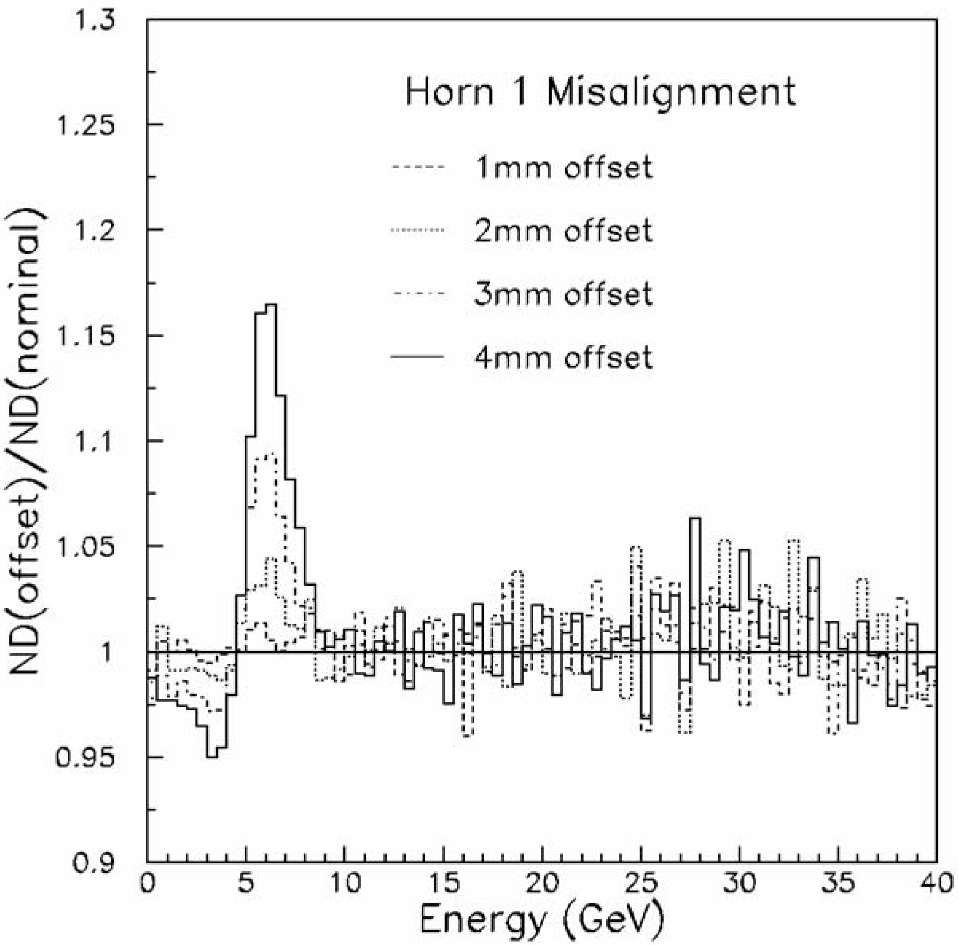
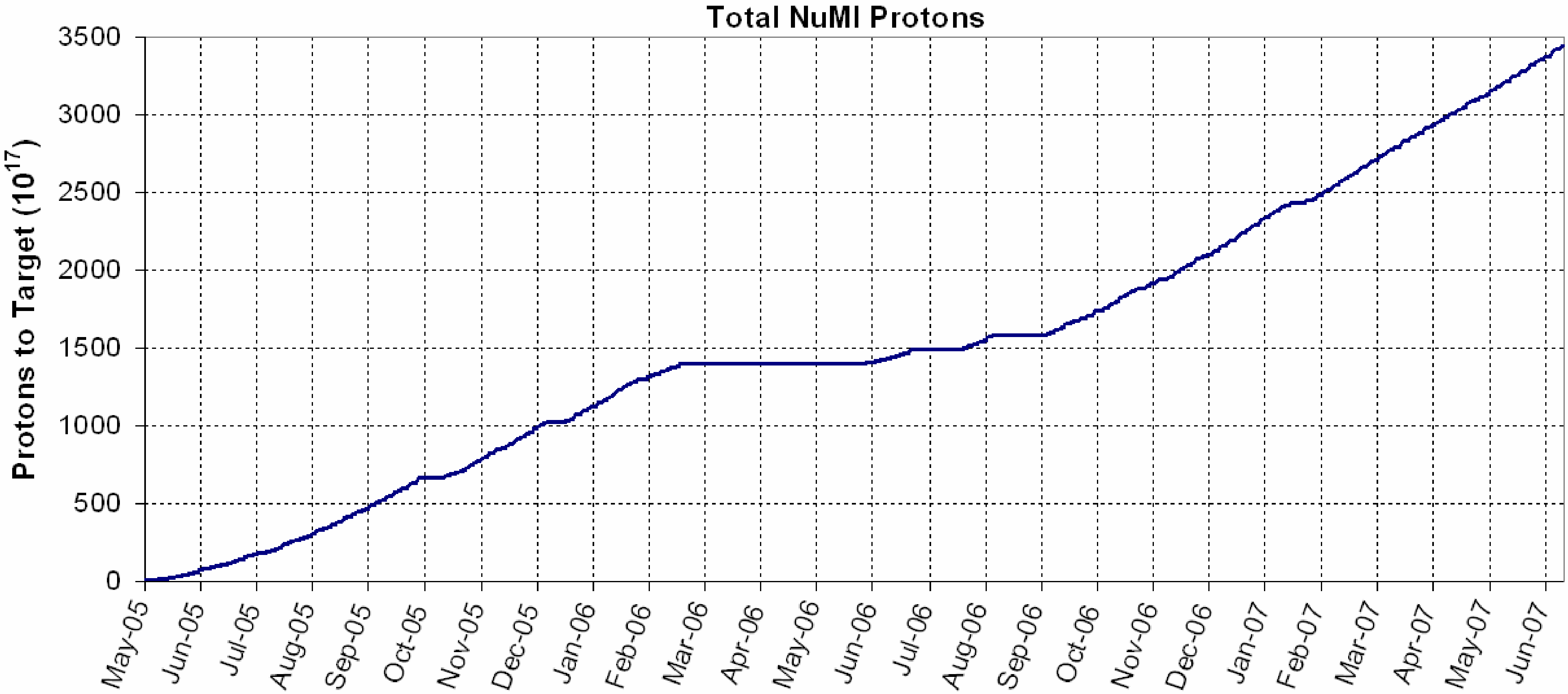




Beam Performance

- Typical beam powers of 180 kW
  - Higher beam powers of ~ 270 kW without antiproton production
- Downtimes due to:
  - Planned shutdowns
  - Component failures
  - Accelerator downtime

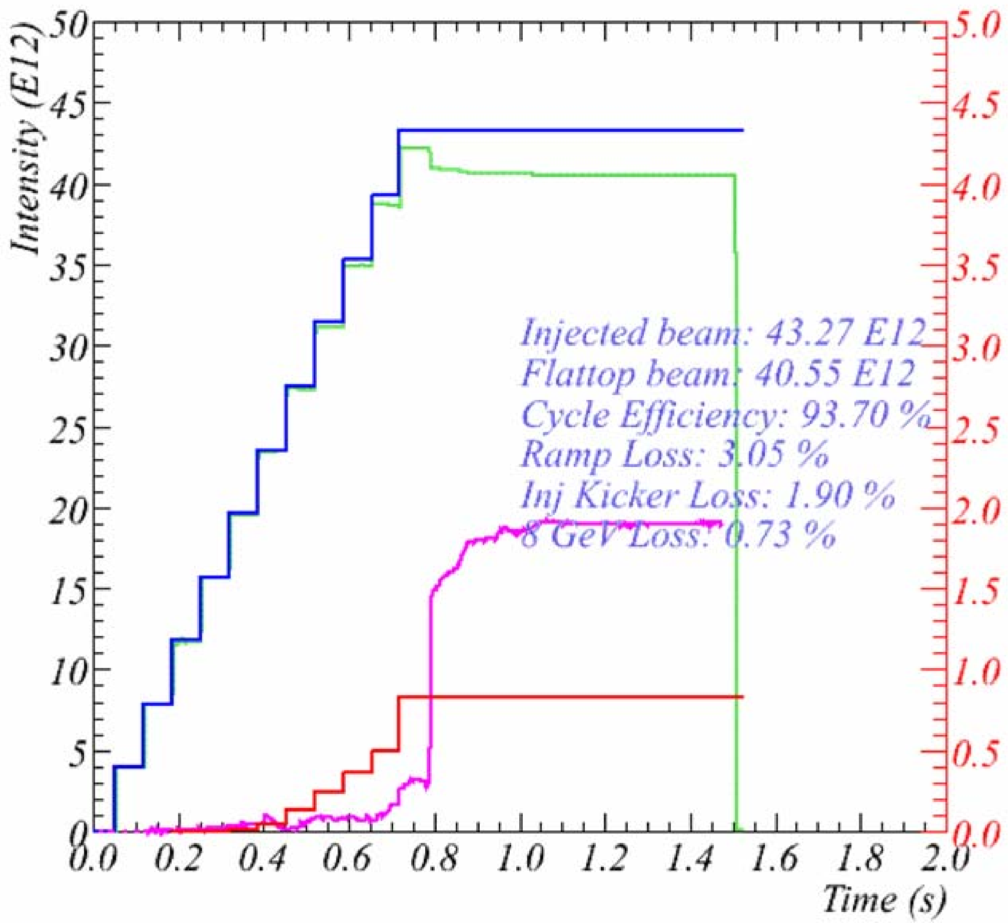


Reliability

- Major points of failures are the secondary beam components
  - Target
    - First had a water leak repaired, then motion failed
    - Now on second target
  - Horns
    - Each has had repairs
- Significant impact upon delivered number of protons
- Inventory of spares in progress
- Repair capability invented, now being augmented

New Beam Records

- 11 batch slip stacking produces > 4 x10^{13} protons
  - Exceeds target design intensity
  - Changing to a larger spot size
- Beam power has reached 325 kW
  - Plan to be able to exceed 400 kW for short periods of time
- Expect to integrate ≥ 50% more protons in 2008
  - Requires improvement in loss control in MI and reliability in NuMI



Users

- MINOS – Main Injector Neutrino Oscillation Search
  - Primary user – built concurrently with NuMI
  - 10s of millions of neutrino events
  - Producing world-competitive measurements
  - 10s of millions if neutrinos
- MINERνA experiment starting construction
  - Sited in MINOS Fermilab hall

- NOνA experiment proposed and in planning
  - New detector in northern Minnesota
  - Includes beam upgrades to 700 kW

Conclusion

- The NuMI beam has been in operation over 2 years
  - Beam power is below design, but consistent with expectations
  - Continuing to see improvement via Proton Plan
- Reliability improved for high-power components
  - Had been a significant cost in beam throughput
- Precision beam information used for experiments
  - Car in design and measurement of beam components
  - Verification through monitoring
  - Checked with millions of neutrinos by MINOS

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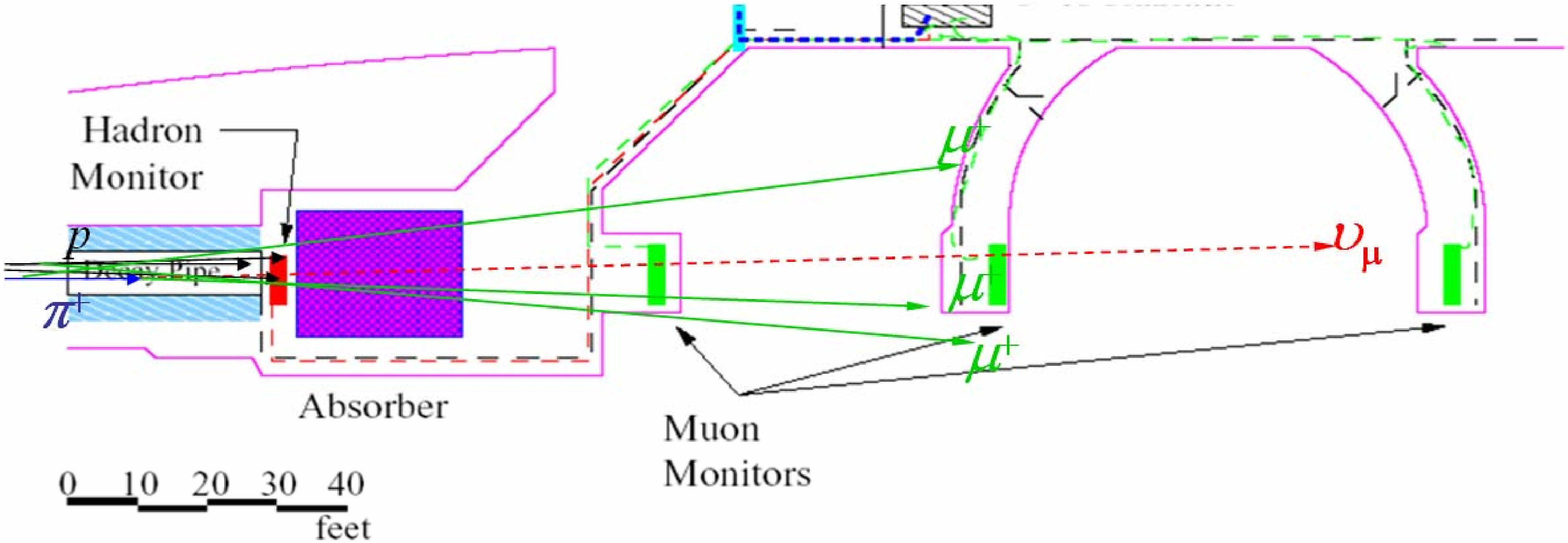
Secondary Beam Monitoring

- Spill-to-spill measurements of the Neutrino beam (faster than Near Detector)



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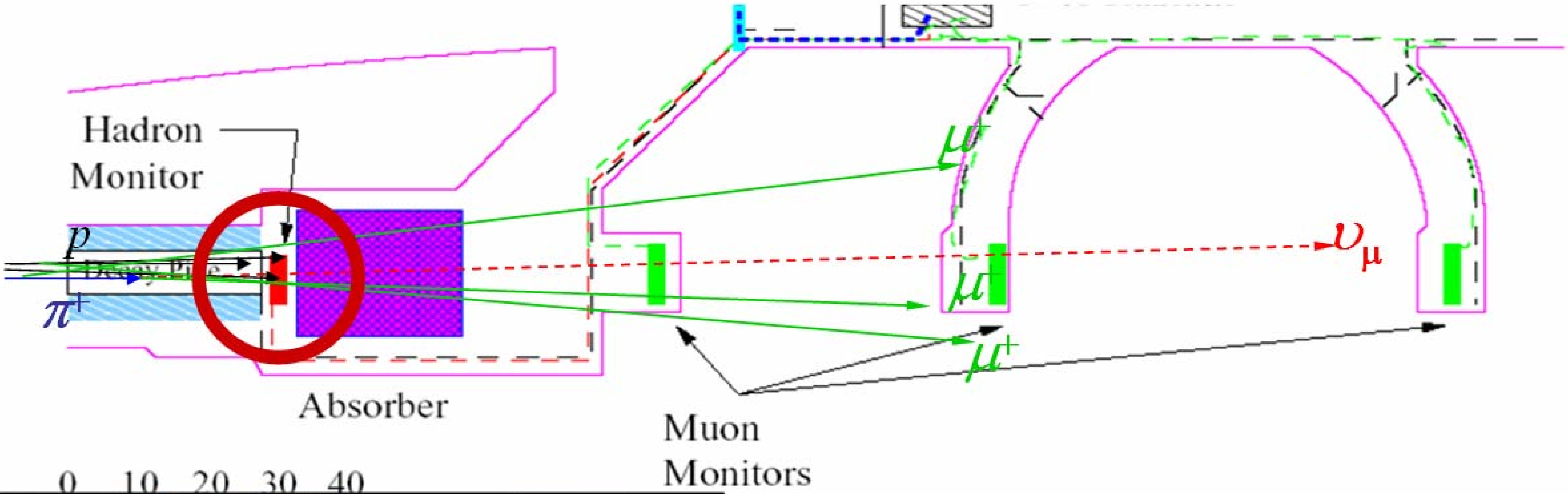

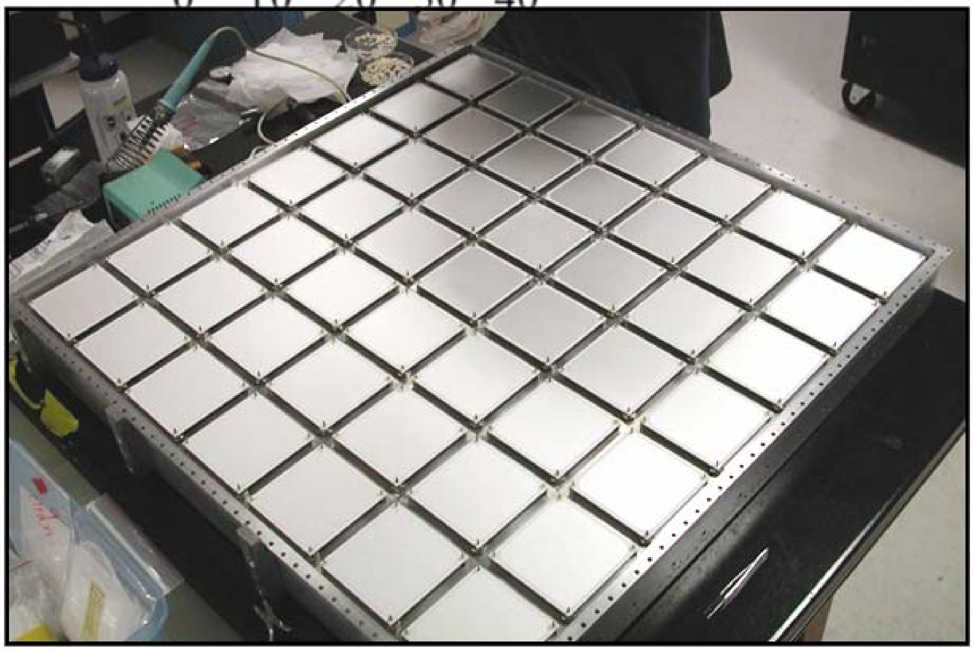

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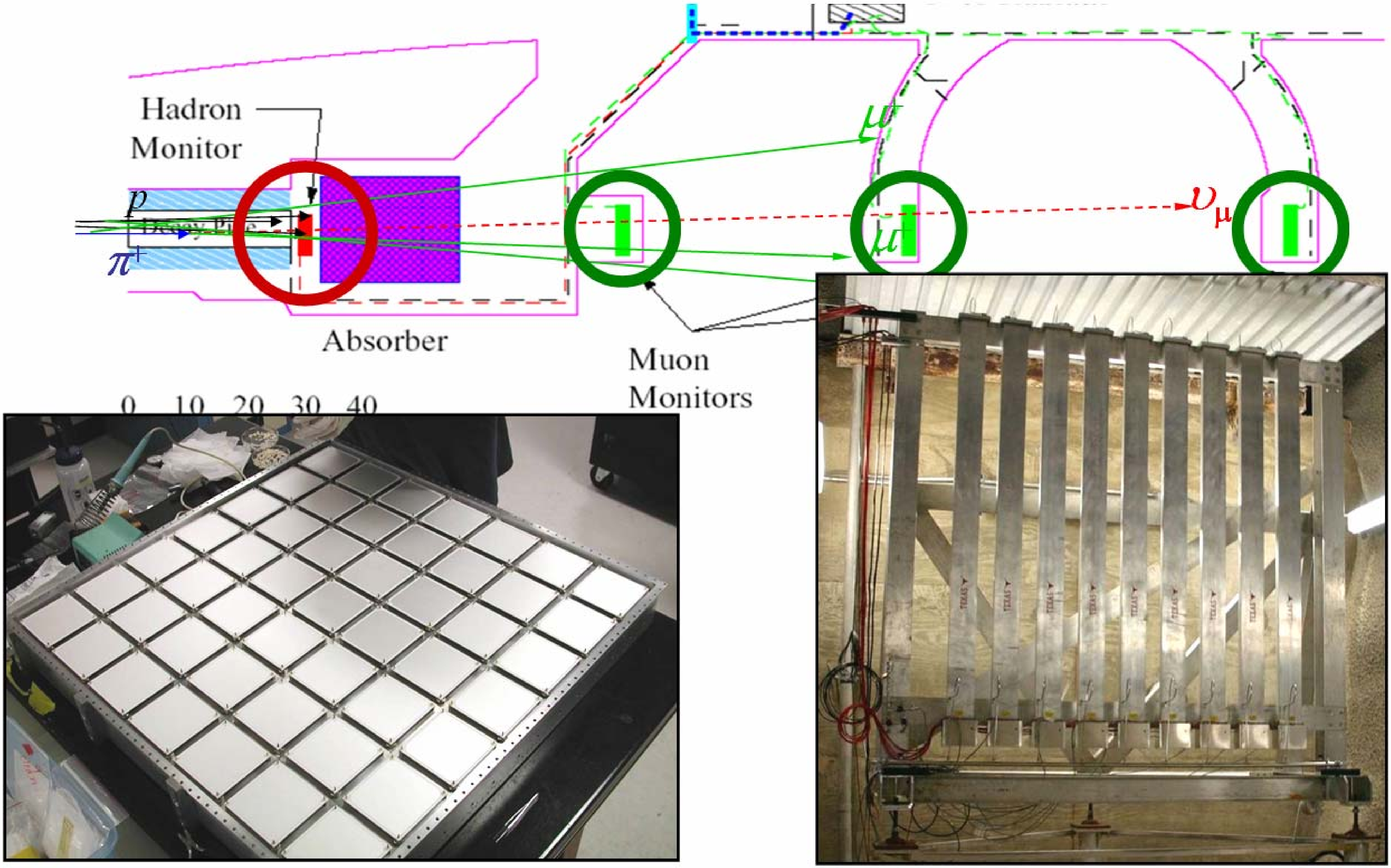
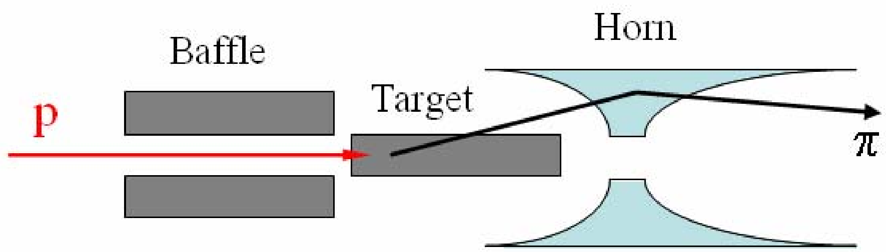
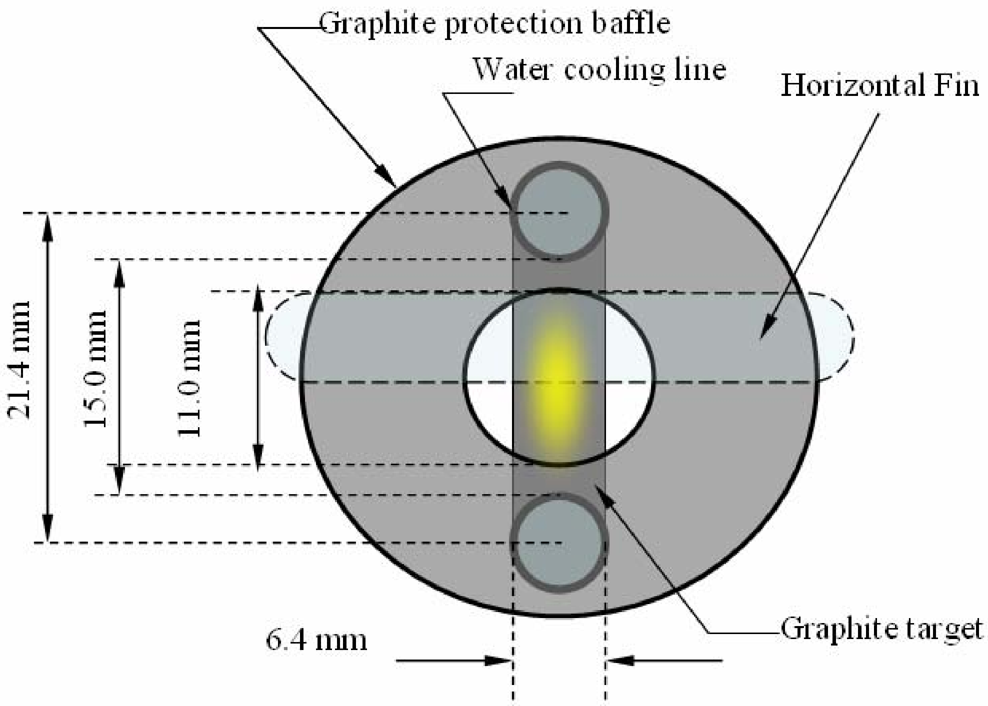


Beam-Based Alignment

- Proton beam scanned horizontally across target and protection baffle
    - Also used to locate horns
- Hadron Monitor and the Muon Monitors used to find the edges





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  - Measured small (~1.2 mm) offset of target relative to primary beam instrumentation.