High-Power Targets for Muon Production

Low Emittance
Muon Collider Workshop

FNAL

June 11, 2009

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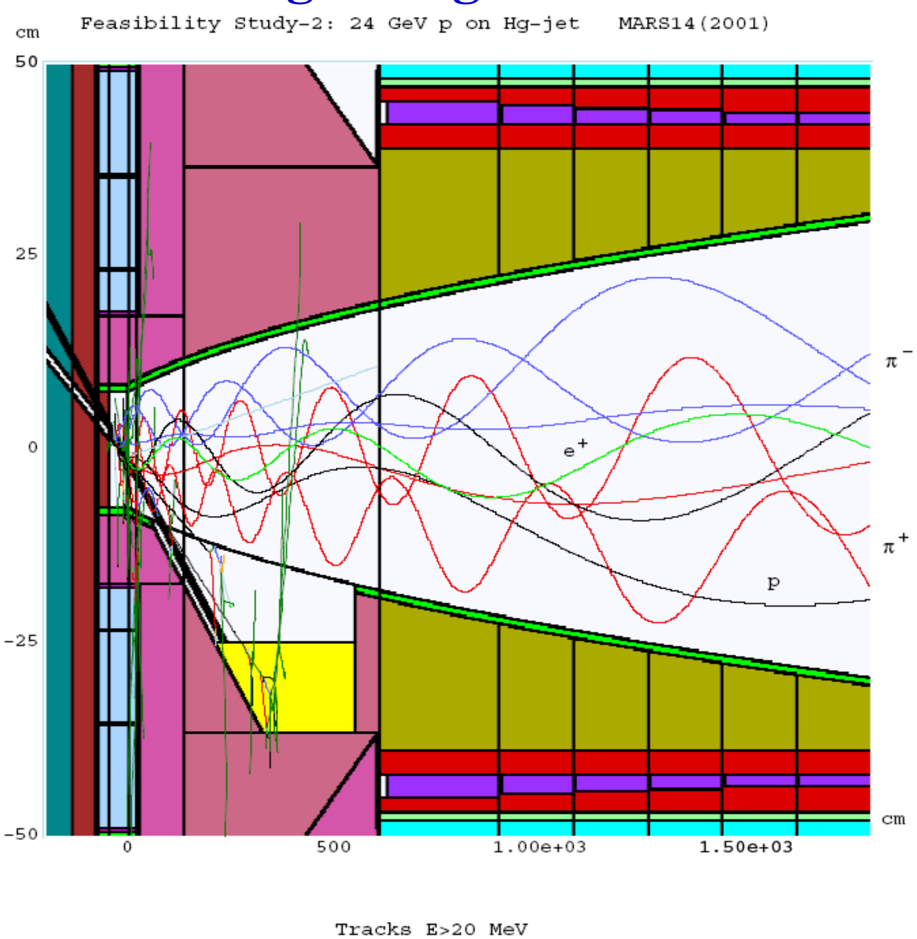
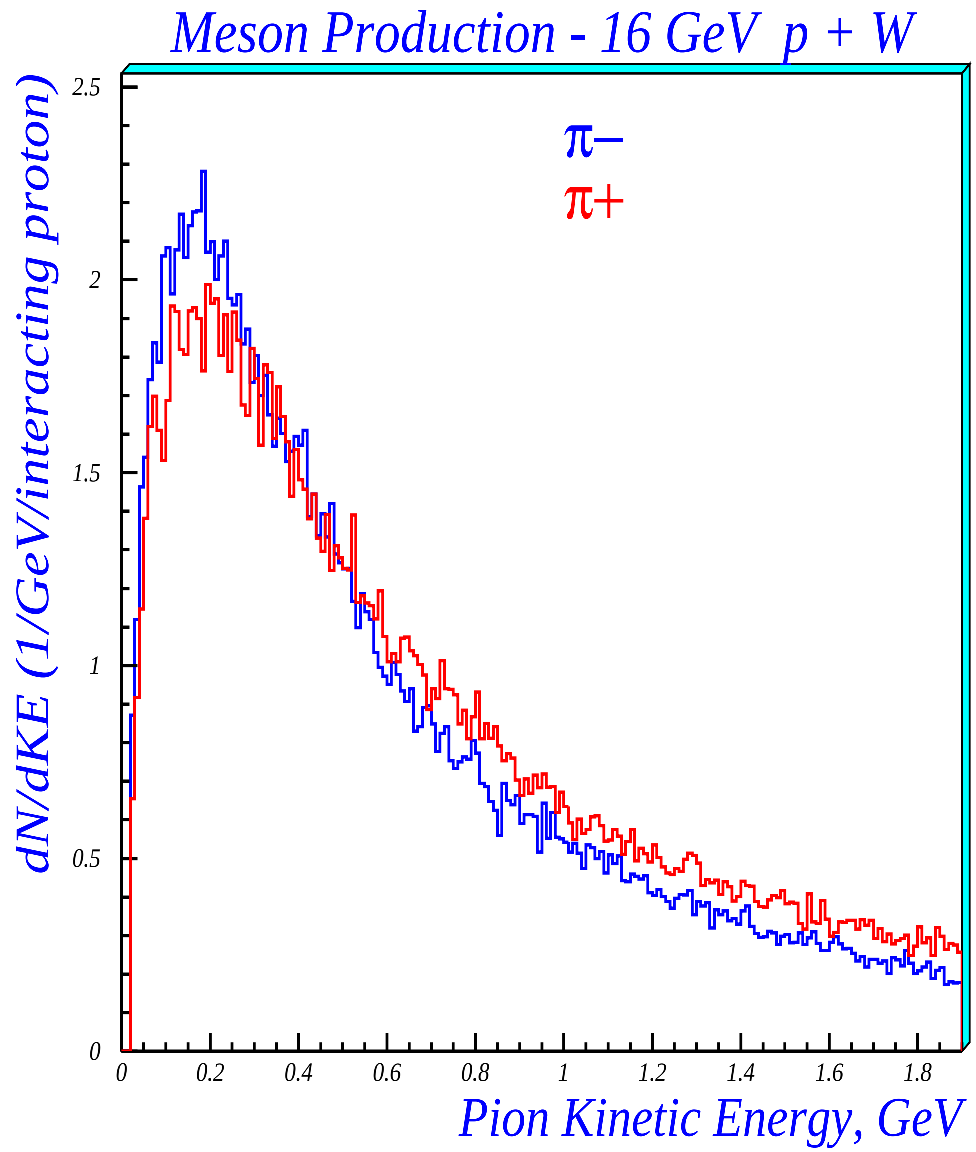
The Neutrino Factory Target Concept

Maximize Pion/Muon Production

- **Soft-pion Production**
- **High-Z materials**
- **High-Magnetic Field**





Palmer, PAC97

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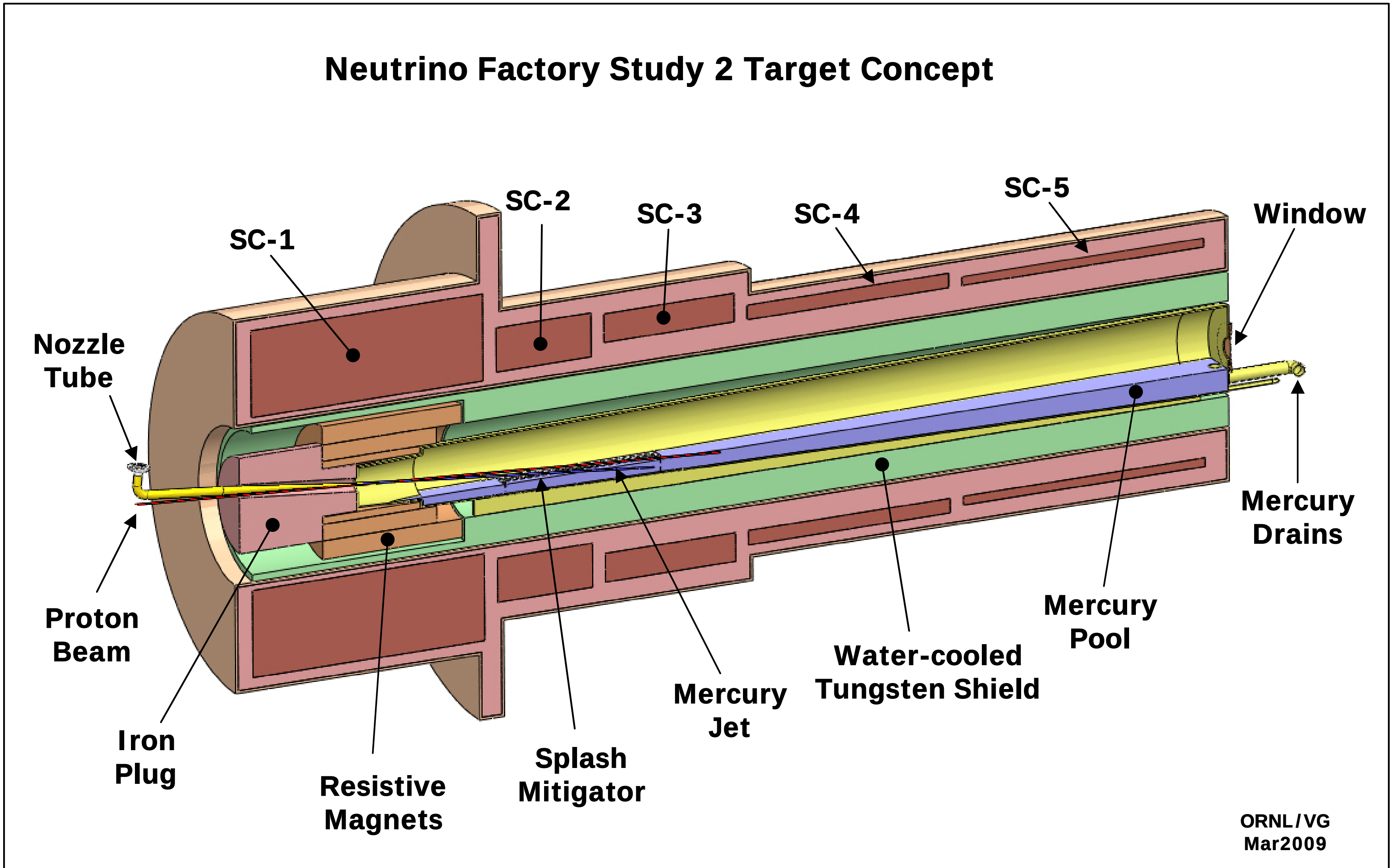
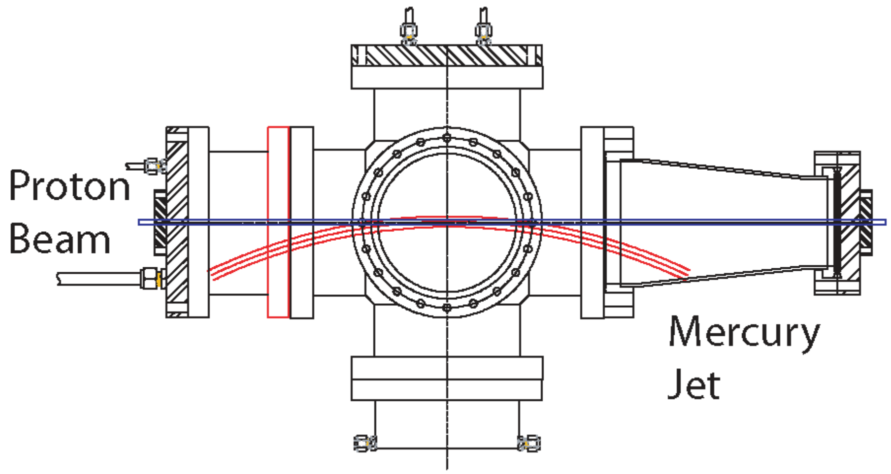
The Study 2 Target System



Van Graves, ORNL

AGS E951 Experiment at BNL

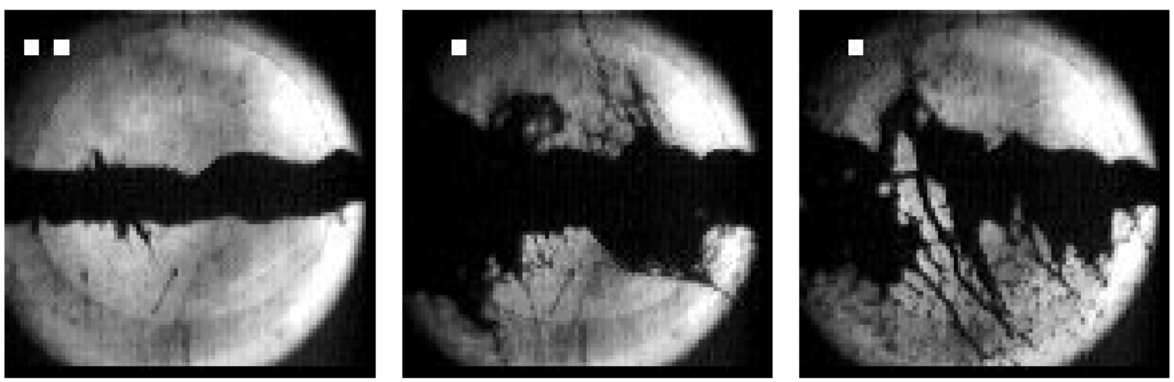


Features:

- 24 GeV, 4T*p* Proton Beam
- 1 cm, 2.5m/s Hg Jet
- No Magnetic Field

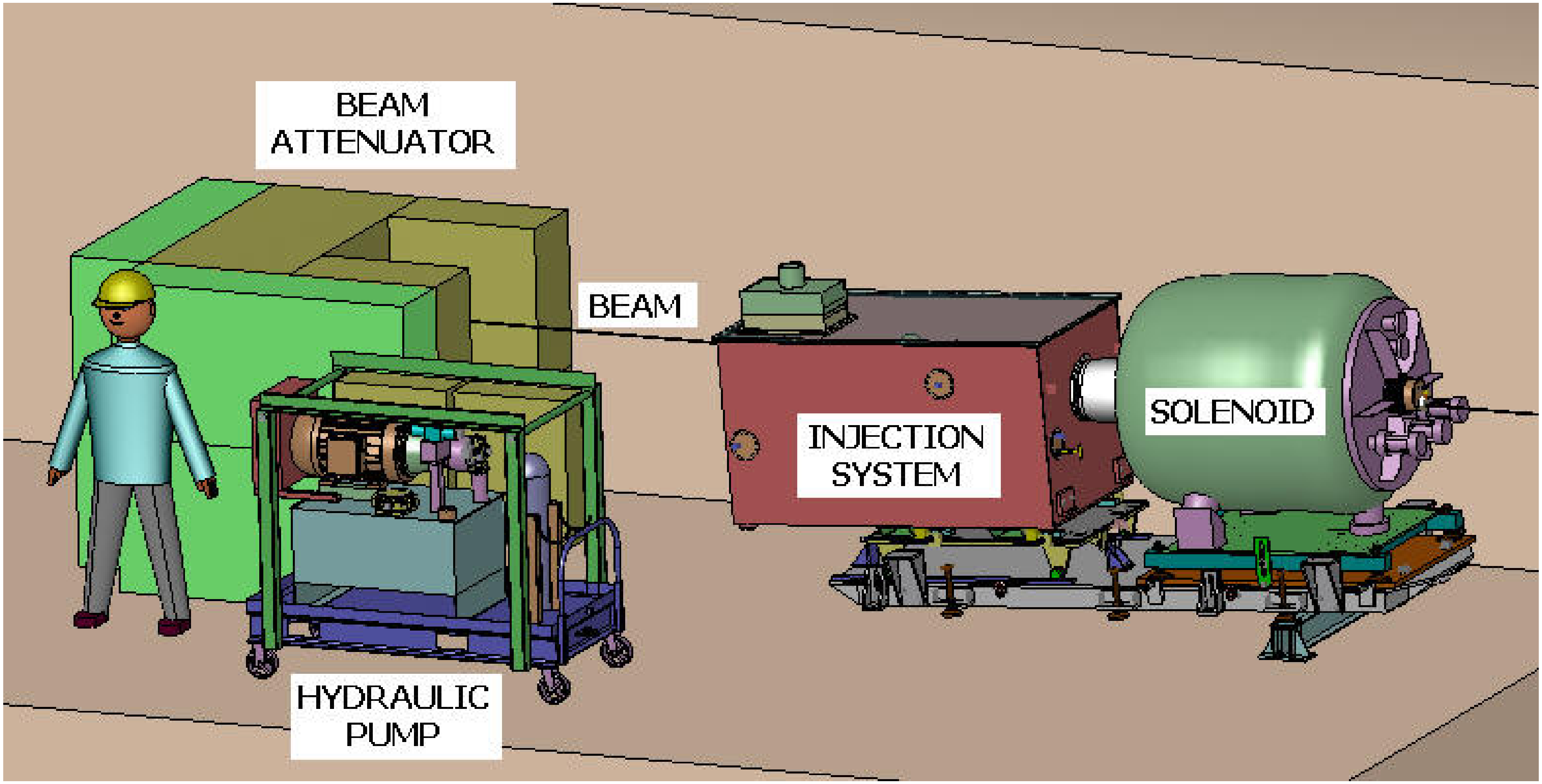
Key Results:

- Dispersal velocities ≤ 10m/s
- Dispersal Delay ≥ 40μs



Experiment ran April 2001

The MERIT Experiment



MERcury Intense Target

Experiment ran Oct./Nov. 2007

Scientific Goals of the CERN MERIT Experiment

- **Observe the effects of high-magnetic fields on:**
  - **The free Hg jet**
  - **The disruption of the Hg jet**
  - **The velocity of the ejected Hg**
- **Observe the influence of proton beam on the Hg jet**
  - **Vary the beam intensity**
  - **Vary the beam structure**
    - **Harmonic structure of the beam**
    - **Time delays for multiple extractions**

Demonstrate as a proof-of-principle the Neutrino Factory/Muon Collider Target Concept

Proton Beam Characteristics

- PS was run in a harmonic 4, 8, and 16 mode
- Fast extraction can accommodate entire 2.5 μs PS fill.
- Full single turn extraction at 24 GeV
- Partial/multiple extraction possible at 14 GeV
- First Beam on Target October 17 2007

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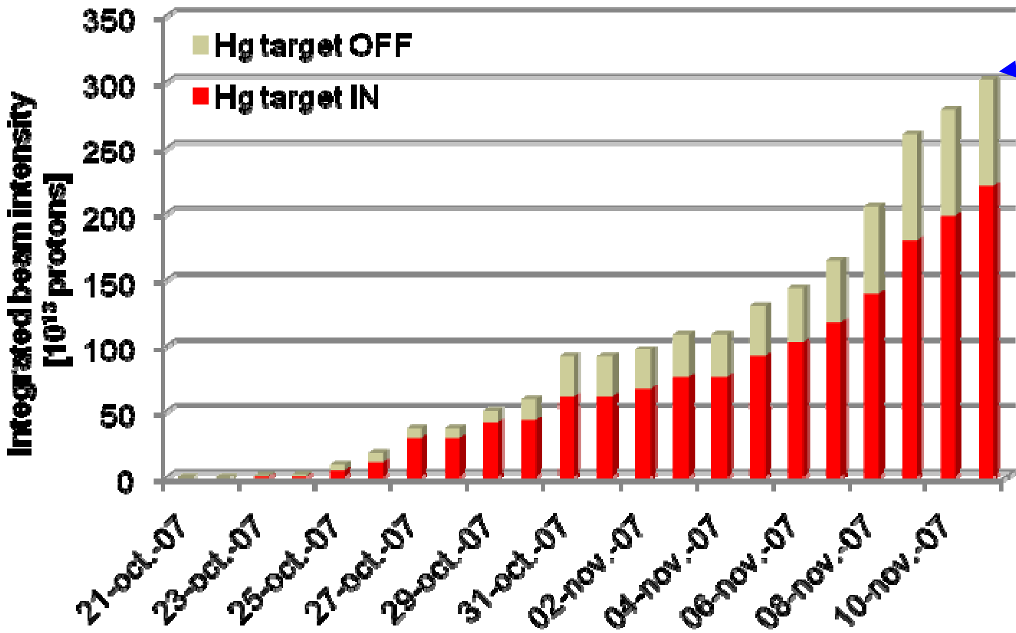
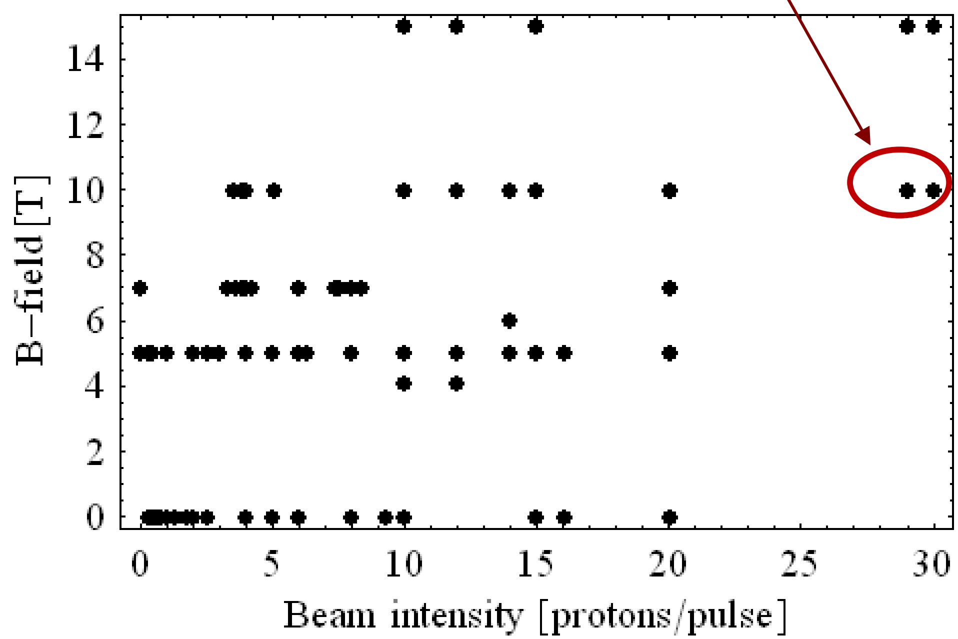
MERIT Beam Pulse Summary



MERIT was not to exceed 3 × 10^{15} protons on Hg to limit activation.

30 T*p* shot @ 24 GeV/c
- **115 kJ of beam power**
- **a PS machine record !**



1 T*p* = 10^{12} protons

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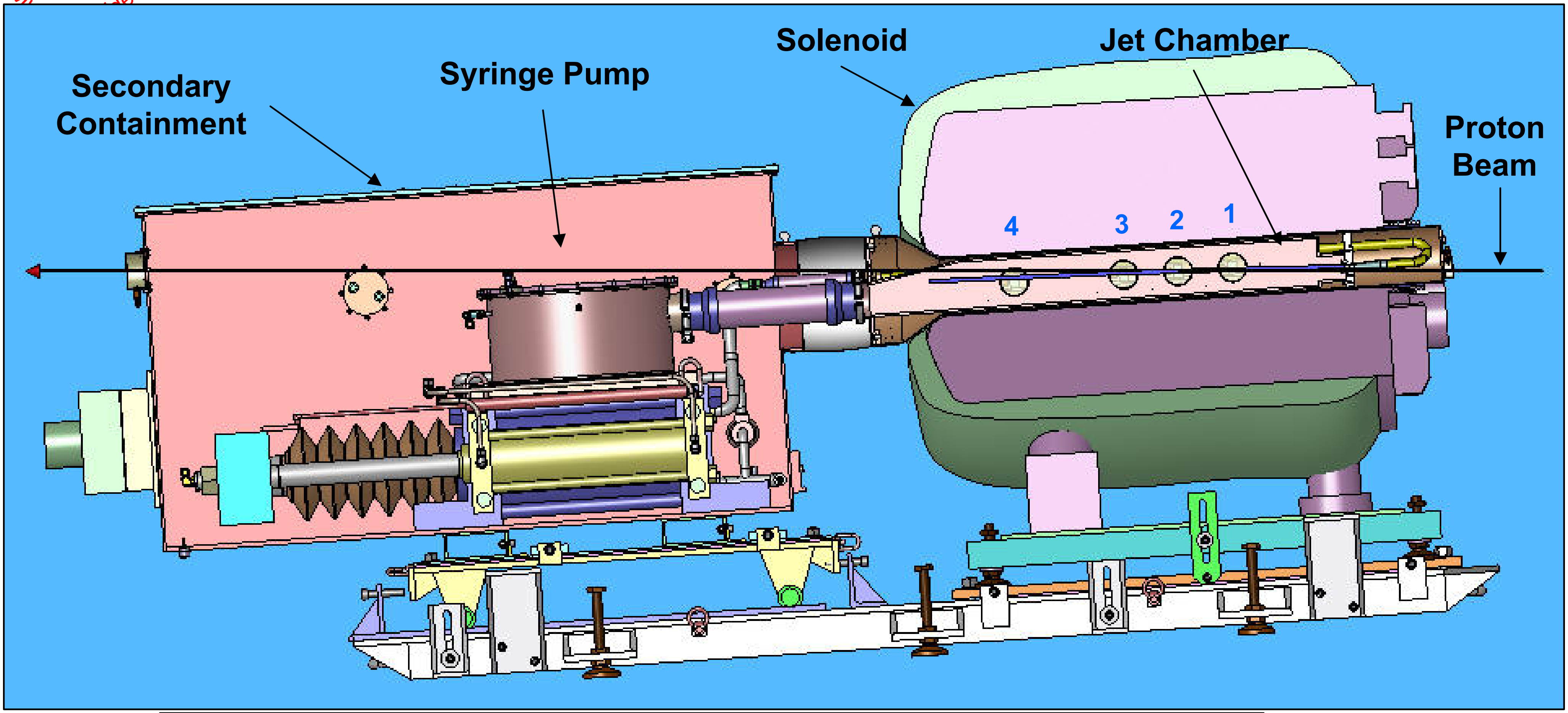
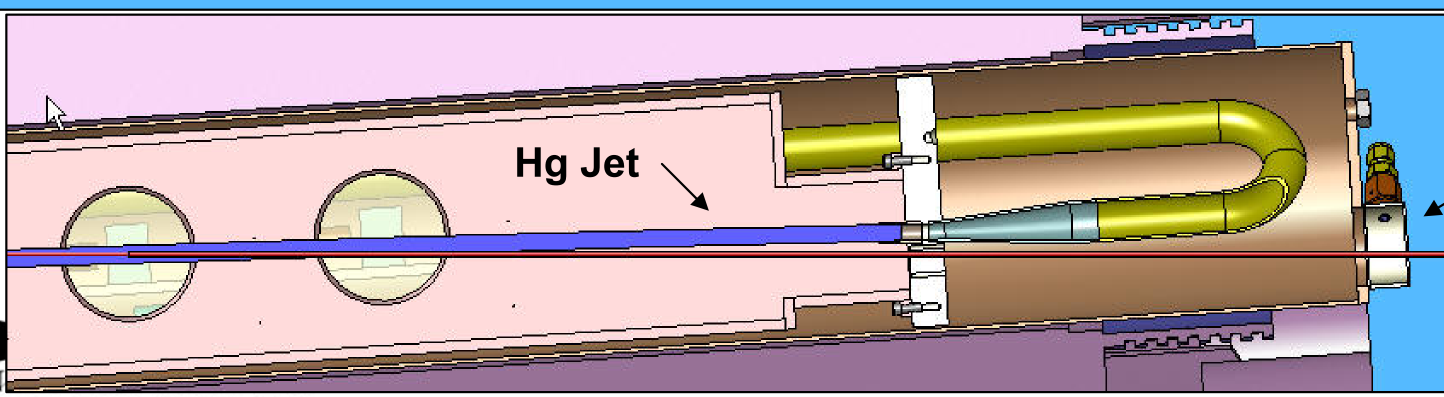
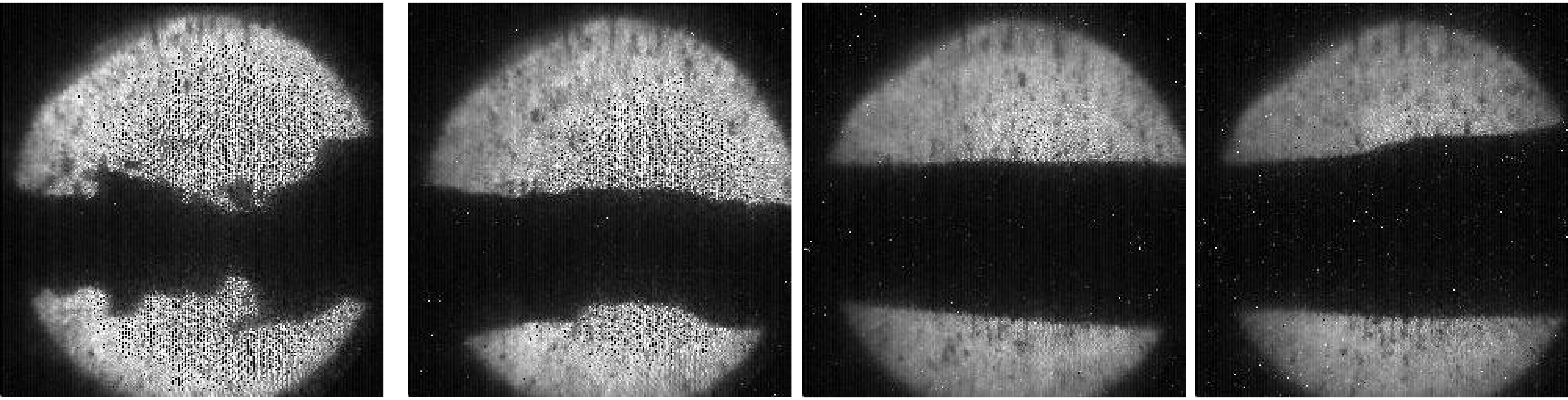
MERIT Experiment at CERN





Stabilization of Jet by High Magnet Field

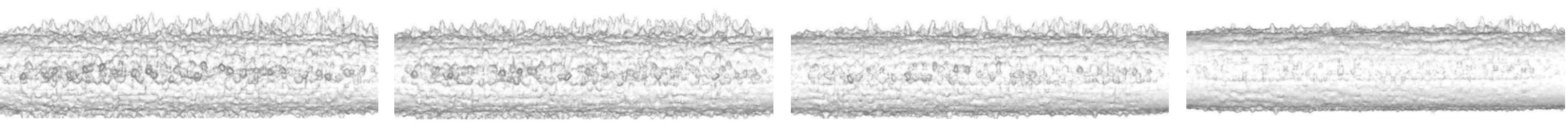


0T | 5 T | 10 T | 15 T

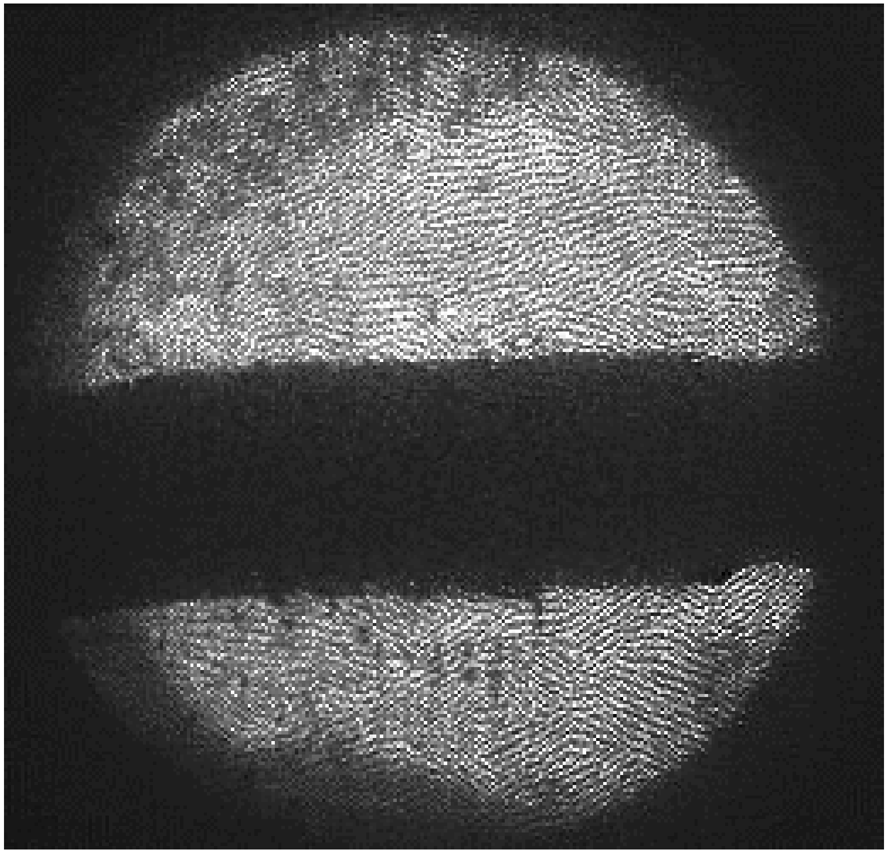
Jet velocities: 15 m/s

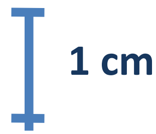
Substantial surface perturbations mitigated by high-magnetic field.

MHD simulations (R. Samulyak):



Viewport 3: Disruption Analysis





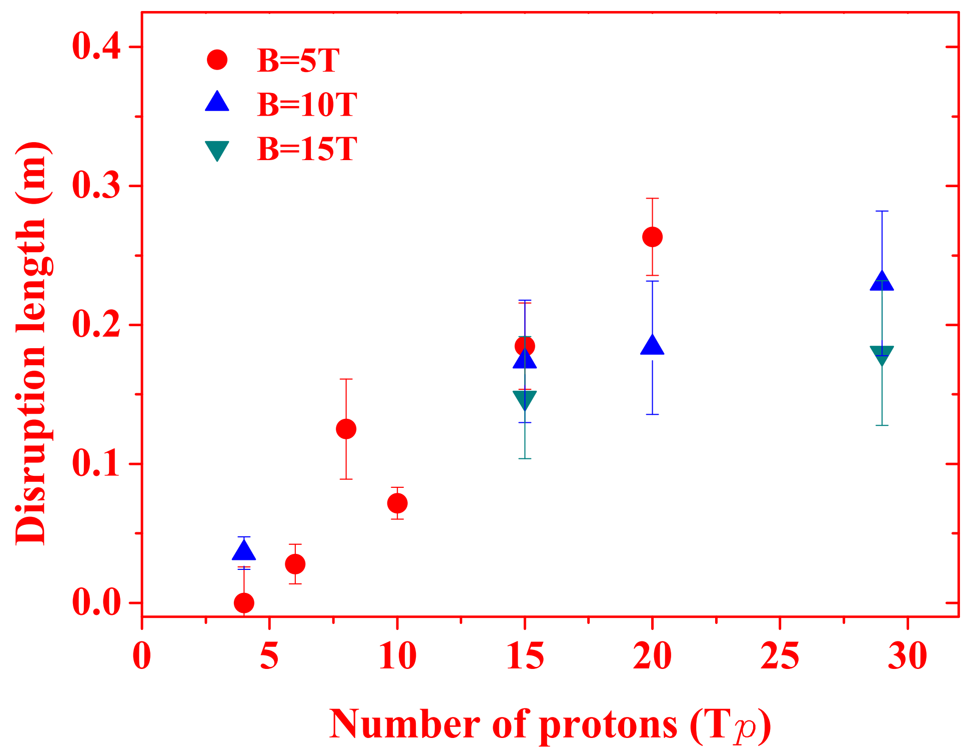
Shot 16014
- 14 GeV
- 12×10^{12} protons/pulse
- B-field 10 T
- 500μs/frame

Disruption Length =16.5cm

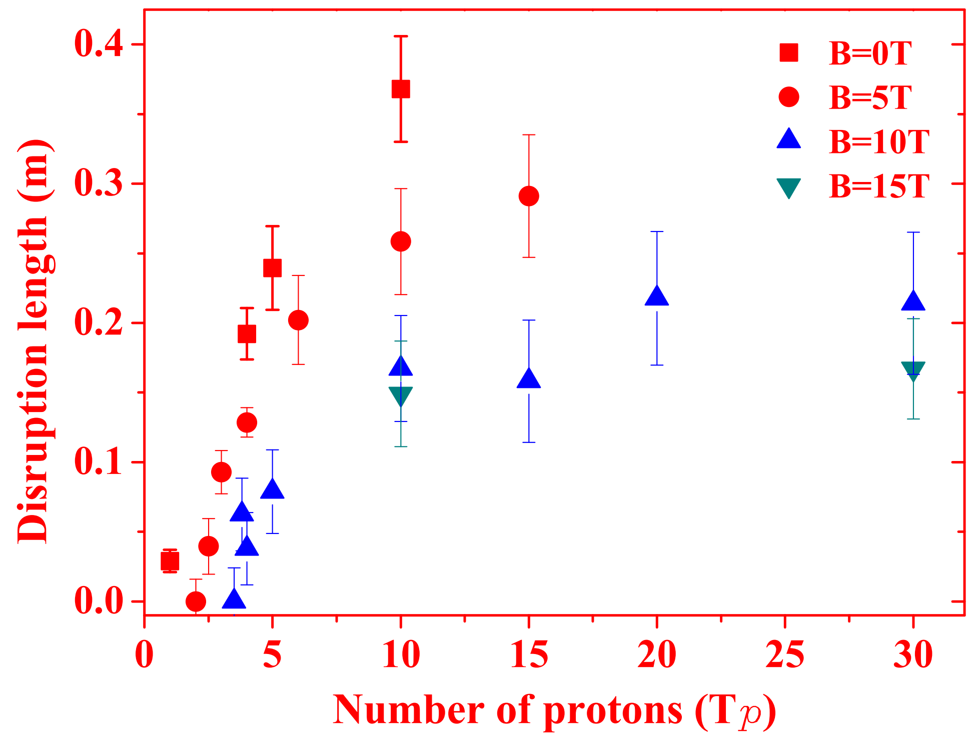
View of Jet/Proton interaction aftermath

Disruption Analysis

14 GeV



24 GeV



Disruption lengths reduced with higher magnetic fields

Disruption thresholds increased with higher magnetic fields

Disruption lengths less than 2 interactions lengths (28cm)

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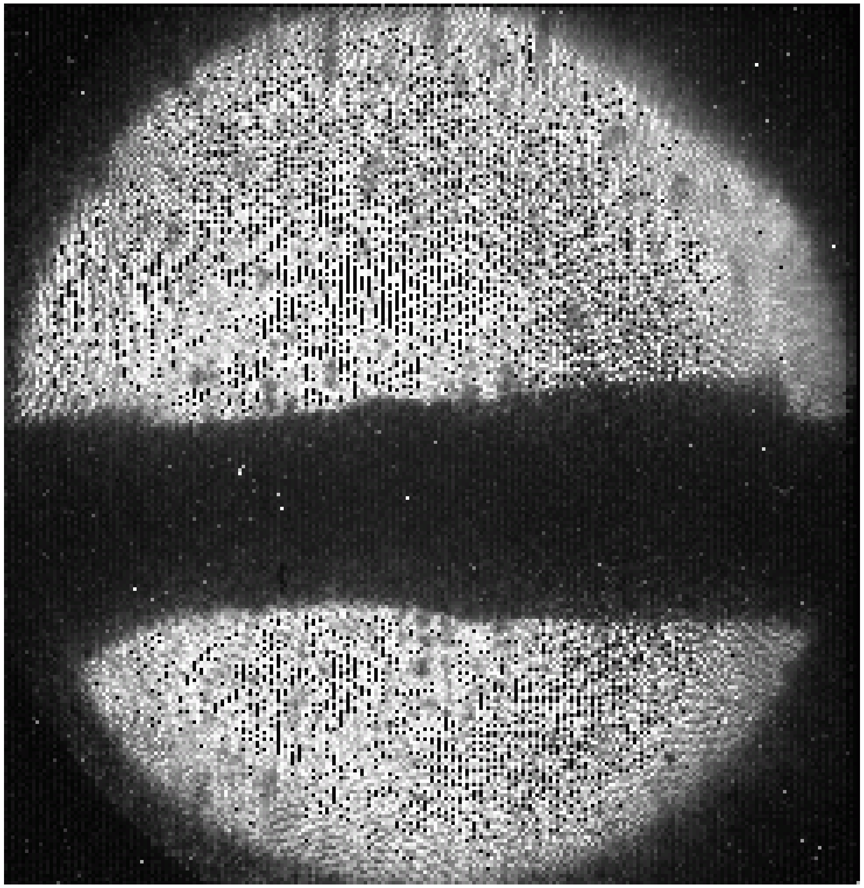
Viewport 2: Velocity Analysis



15 Tp 14GeV Proton Beam

Solenoid Field at 5T

Beam 5016, Hg 15m/s, 100μs/frame, Total 1.6ms

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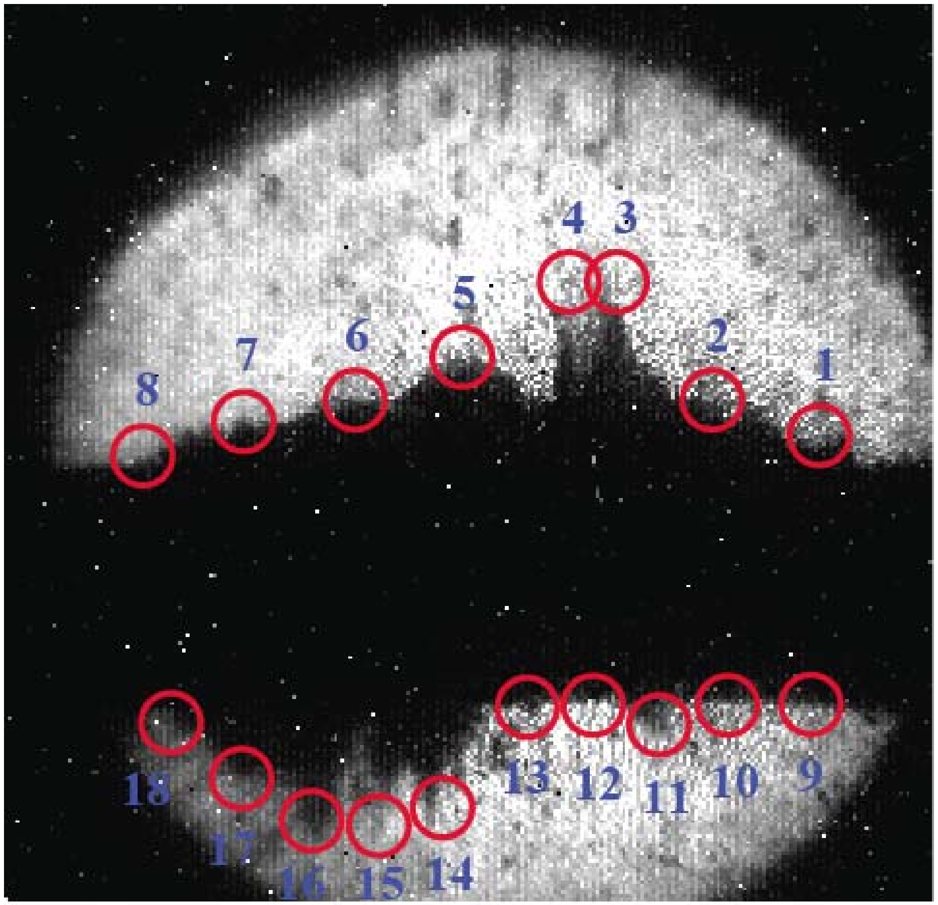
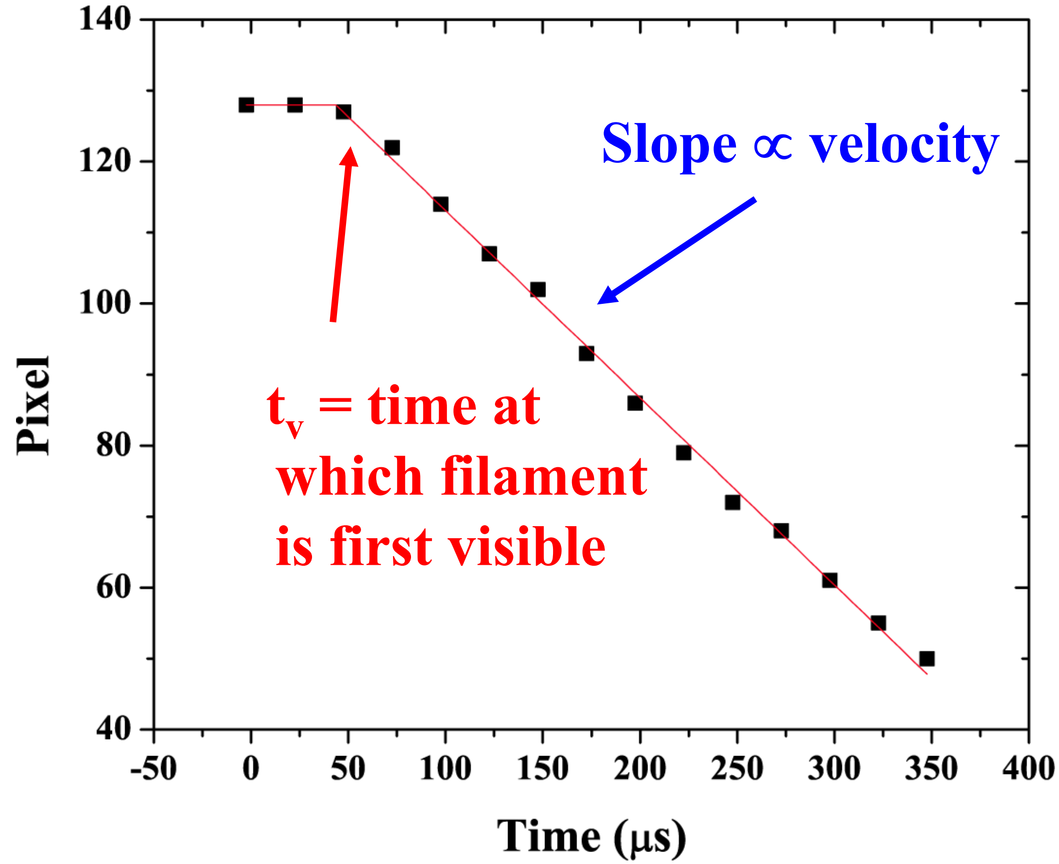
Ejection Velocity Analysis





Study velocity of filaments of ejected mercury using the highest speed camera, at viewport 2, at frame periods of 25, 100 or 500 μs

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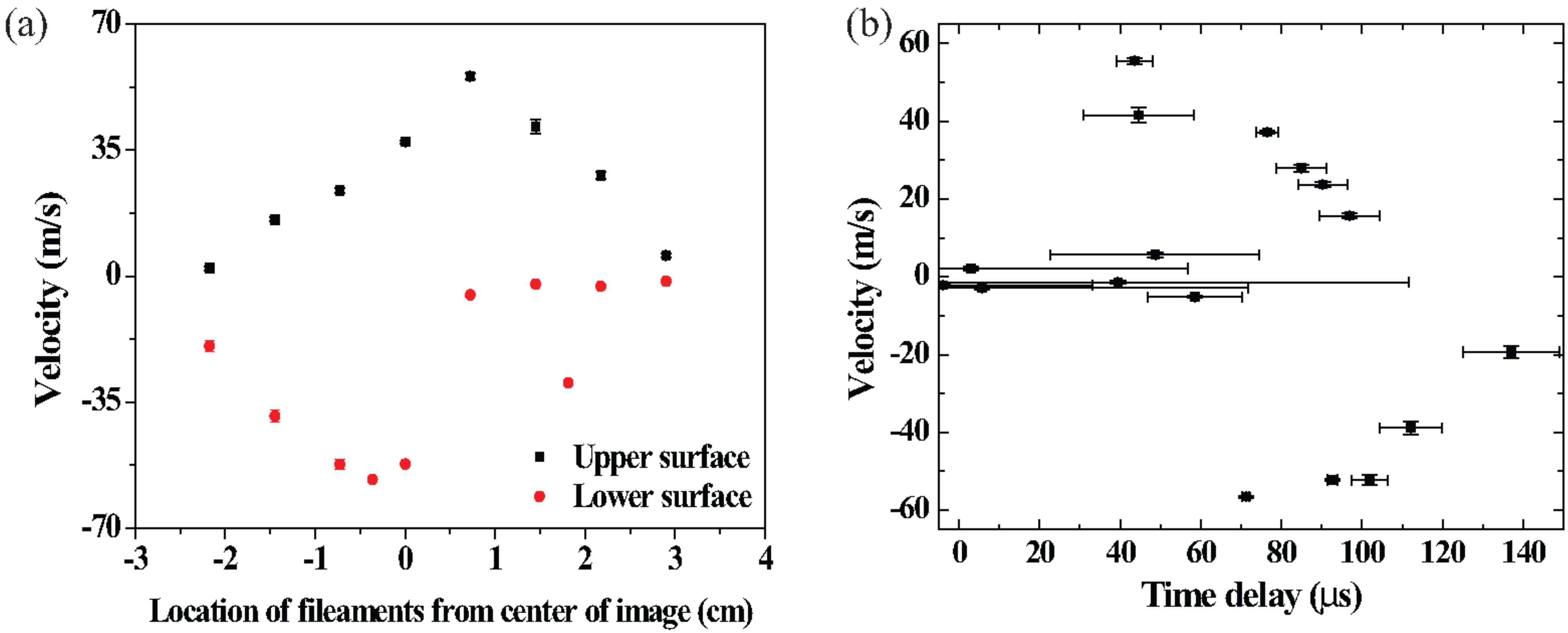
Ejection Velocity Analysis II



Shot 11019: 24-GeV, 10-T*p* Beam, 10-T Field, 25μs/frame:

Peak Velocity—60m/s Time delay ≥ 40μs (agrees with E-951)

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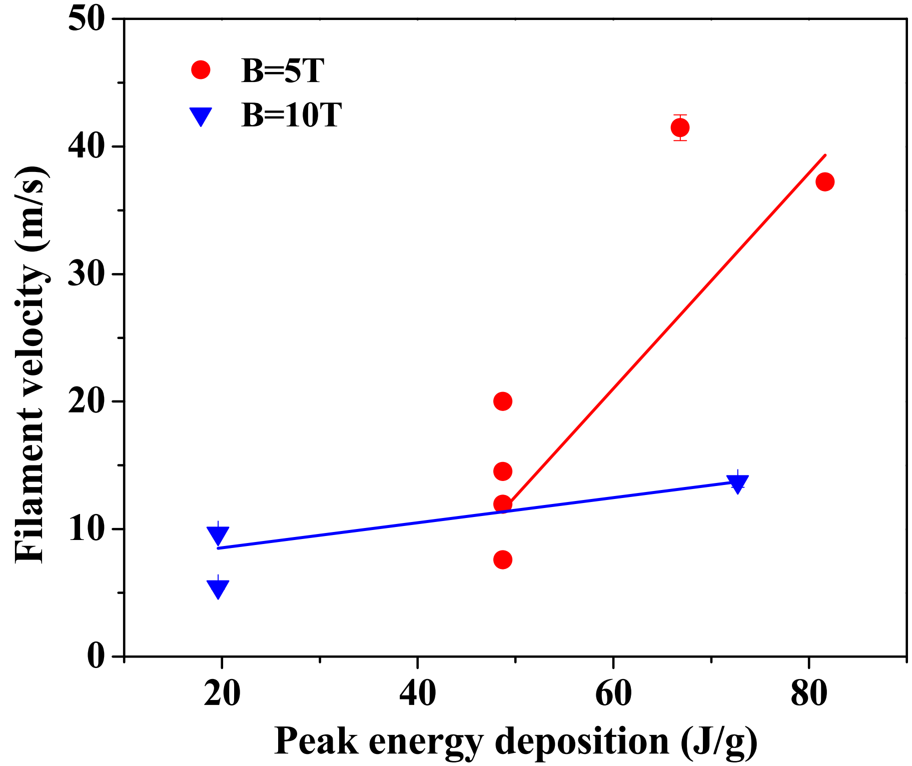
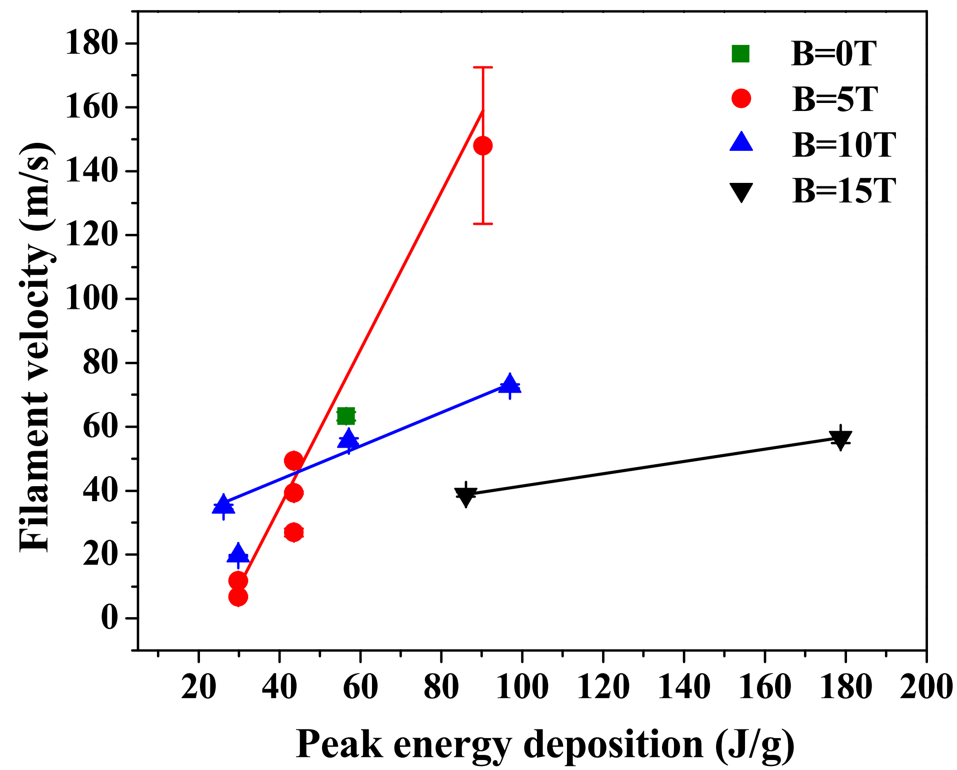
Peak Velocities

14 GeV



24 GeV



Ejection velocities are suppressed by magnetic field

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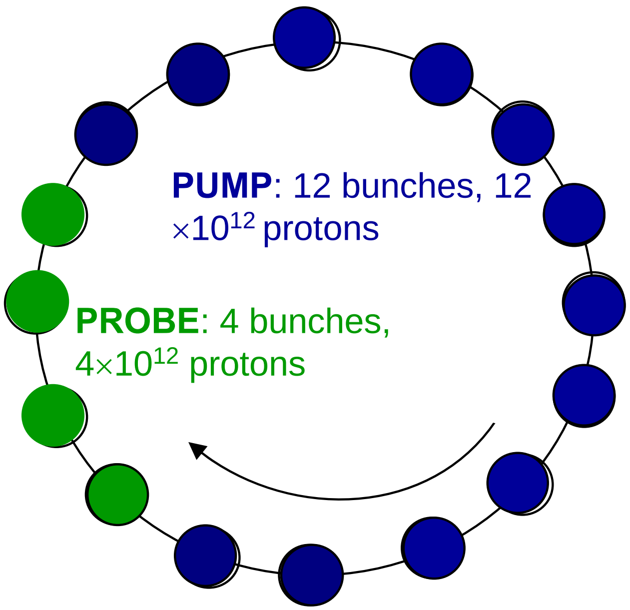
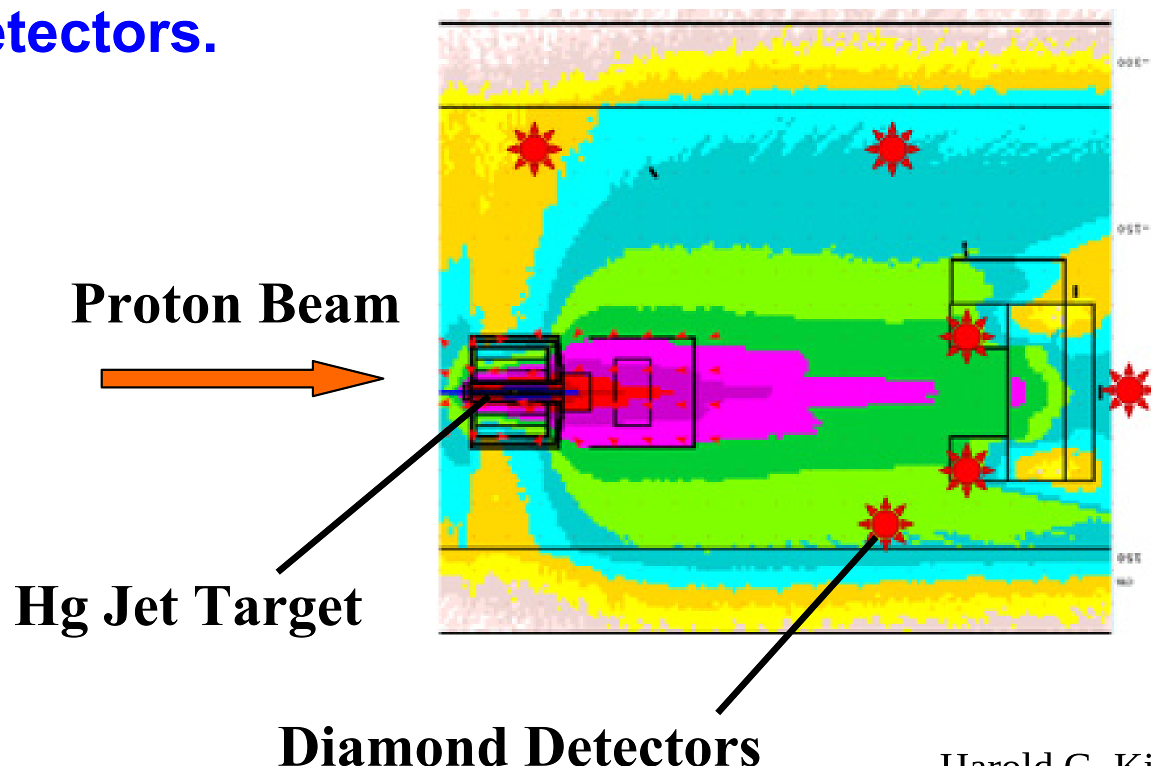
Pump-Probe Studies

- Test pion production by trailing bunches after disruption of the mercury jet due to earlier bunches
- At 14 GeV, the CERN PS can extract several bunches during one turn (pump), and then the remaining bunches at a later time (probe).
- Pion production was monitored for both target-in and target-out events by a set of diamond diode detectors.





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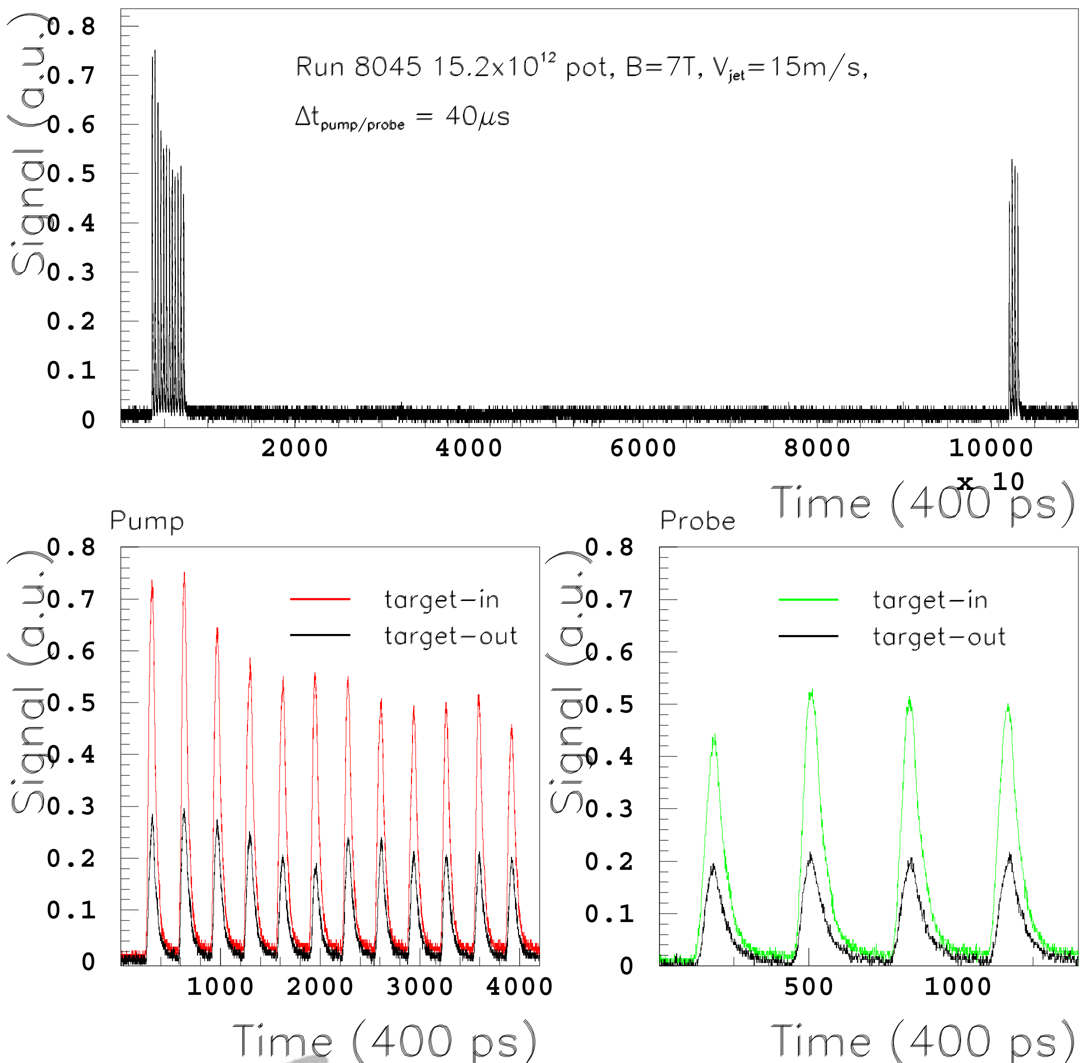
The Diamond Detector Reponses

pCVD Diamond, beam-right 20deg, PS in h=16



These detectors showed effects of rapid depletion of the charge stored on the detector electrodes, followed by a slow RC recovery of the charge/voltage.

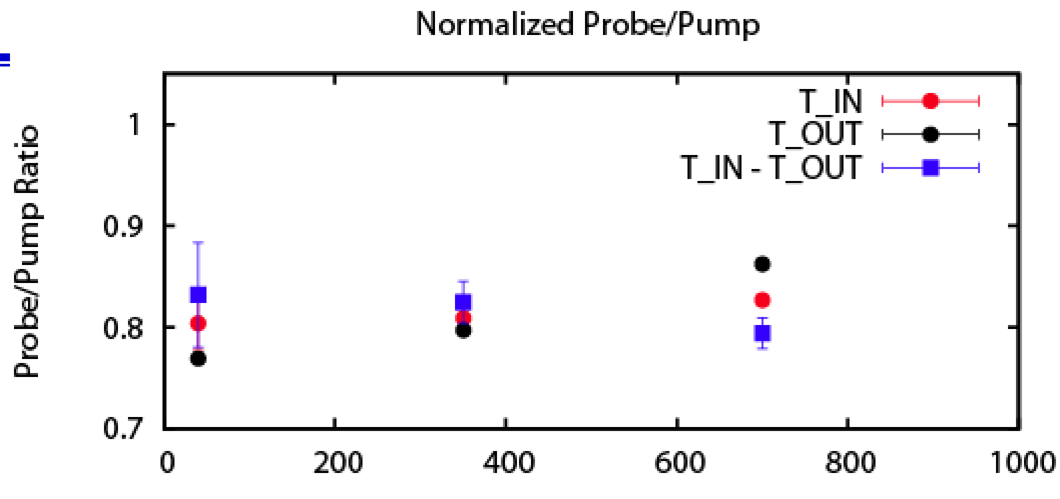
The beam-current transformer data was used to correct for fluctuations in the number of protons per bunch.

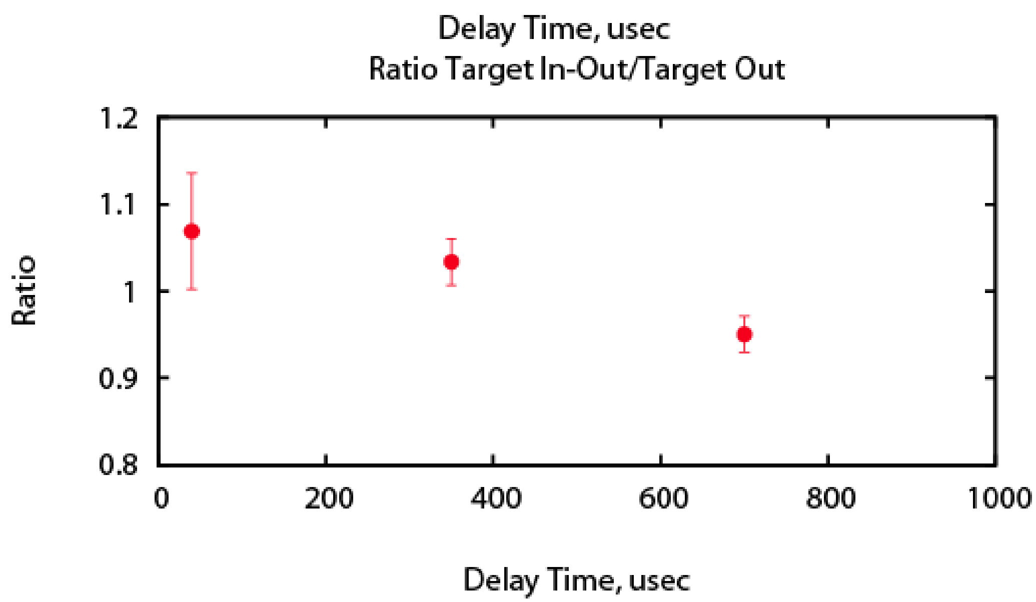
Pump followed by 40μs Probe delay

Pump-Probe Data Analysis

- Both target-in and target-out data showed smaller signals, relative to the pump bunches, for probe bunches delayed by 40, 350 and 700 μs.
- We therefore report a corrected probe/pump ratio:

$$\text{Ratio} = \frac{\dfrac{\text{Probe}_{\text{target in}} - \text{Probe}_{\text{target out}}}{\text{Pump}_{\text{target in}} - \text{Pump}_{\text{target out}}}}{\dfrac{\text{Probe}_{\text{target out}}}{\text{Pump}_{\text{target out}}}}$$





Results are consistent with no loss of pion production for bunch delays of 40 and 350 μs, and a 5% loss (2.5-σ effect) of pion production for bunches delayed by 700 μs.

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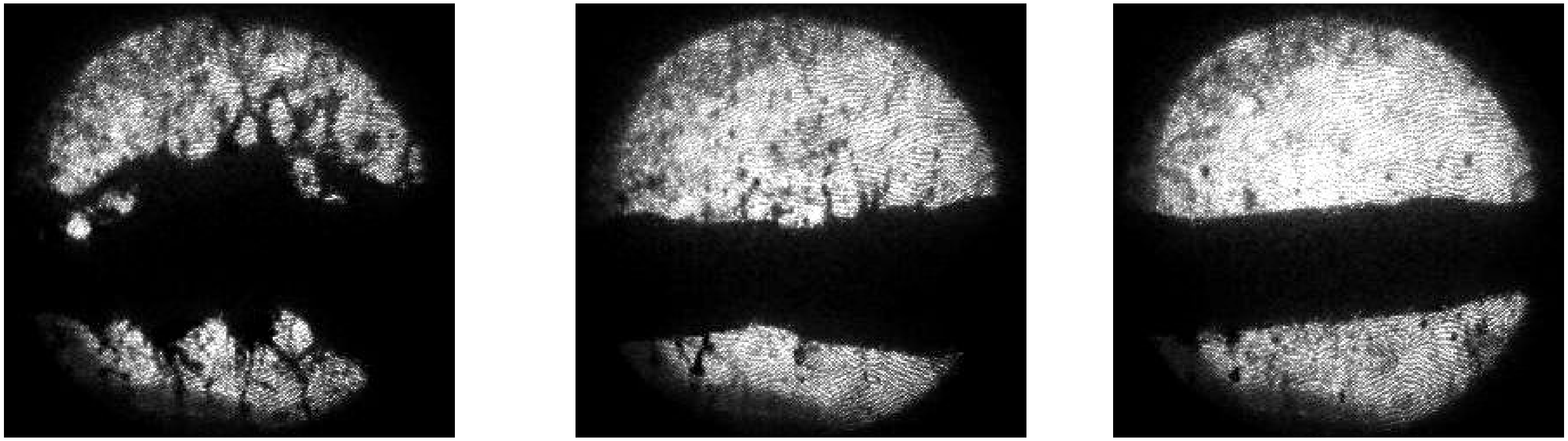
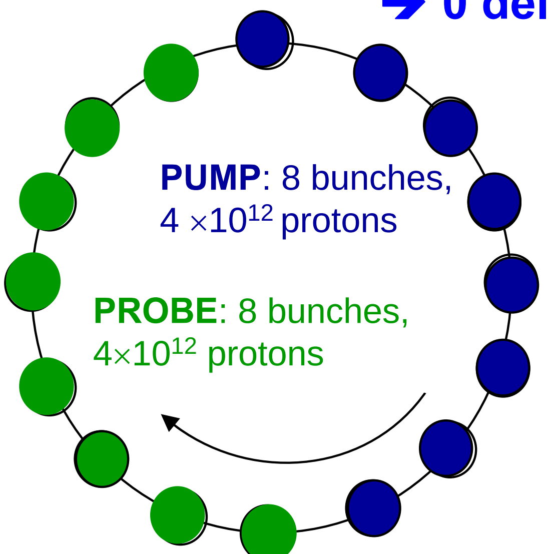
Study with 4 T*p* + 4 T*p* at 14 GeV, 10 T



Single-turn extraction
➔ 0 delay, 8 T*p*

4-T*p* probe extracted on subsequent turn
➔ 3.2 μs delay

4-T*p* probe extracted after 2nd full turn
➔ 5.8 μs Delay



Threshold of disruption is > 4 T*p* at 14 Gev, 10 T.

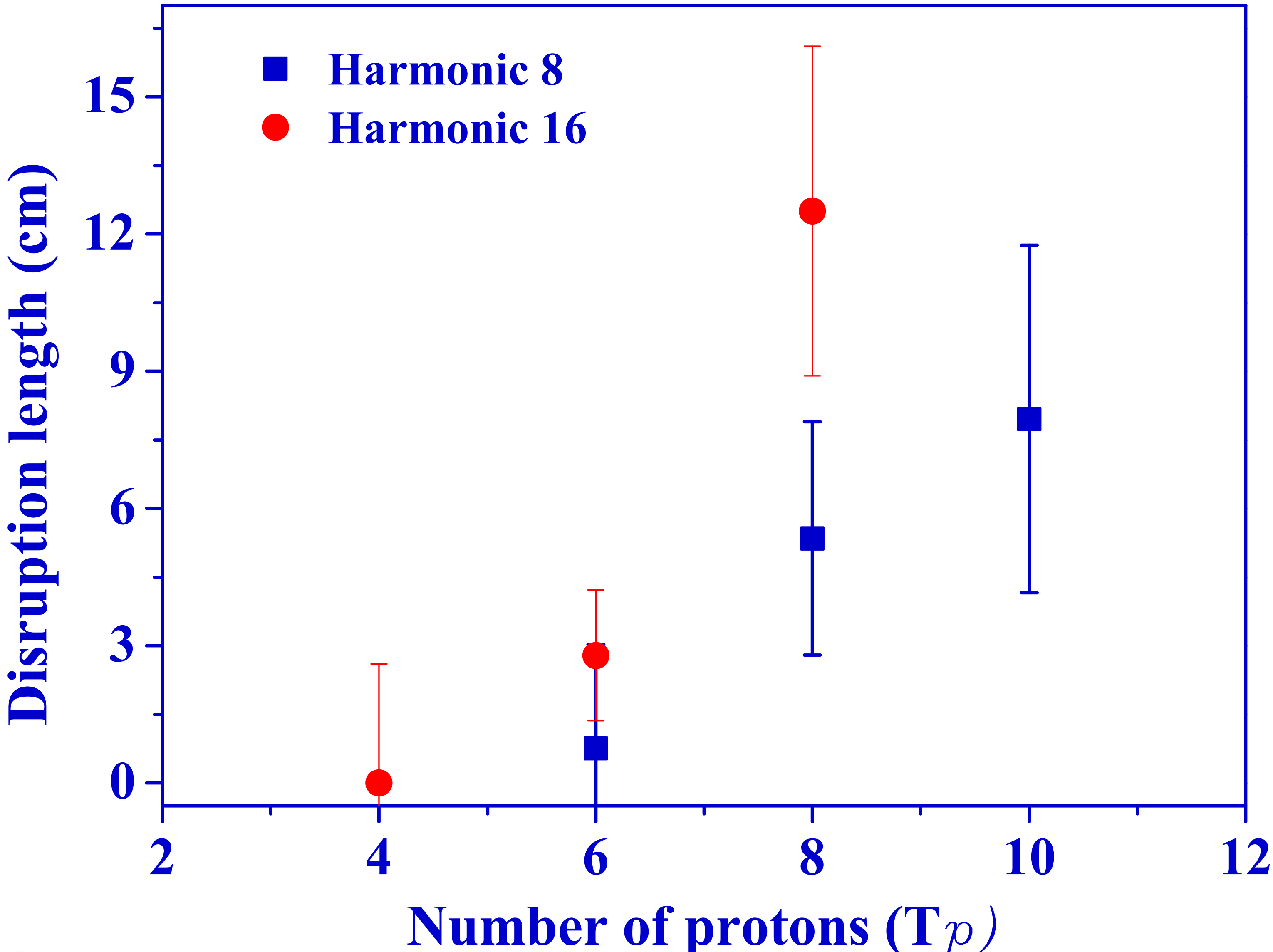
⇒Target supports a 14-GeV, 4-T*p* beam at 172 kHz rep rate without disruption.

Proton Beam Bunch Structure

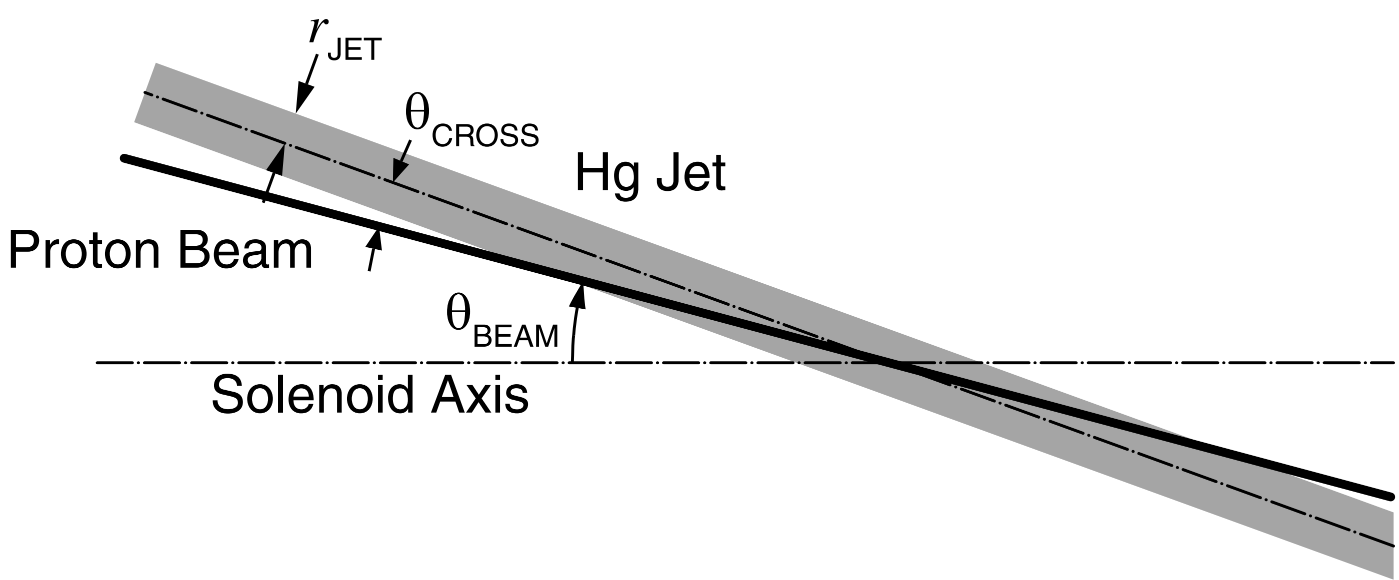
Magnetic field at 7T

Proton Beam at 14GeV

Less disruption with more particles per micro-bunches



MARS15 Study of the Hg Jet Target Geometry

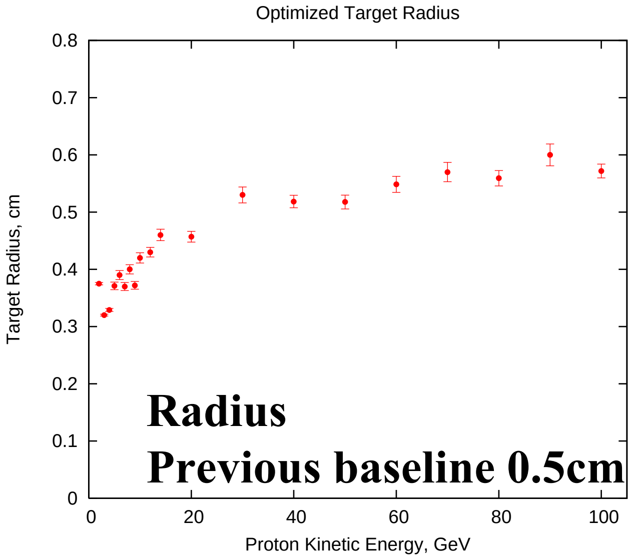


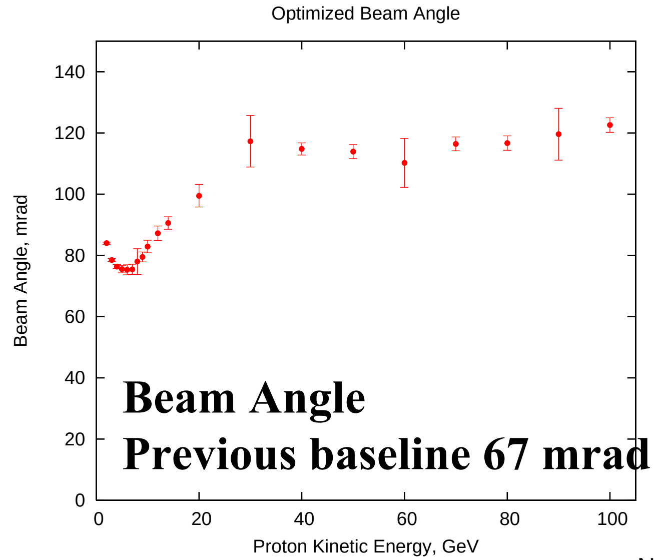
Previous results: Radius 5mm, θ_{beam} =67mrad

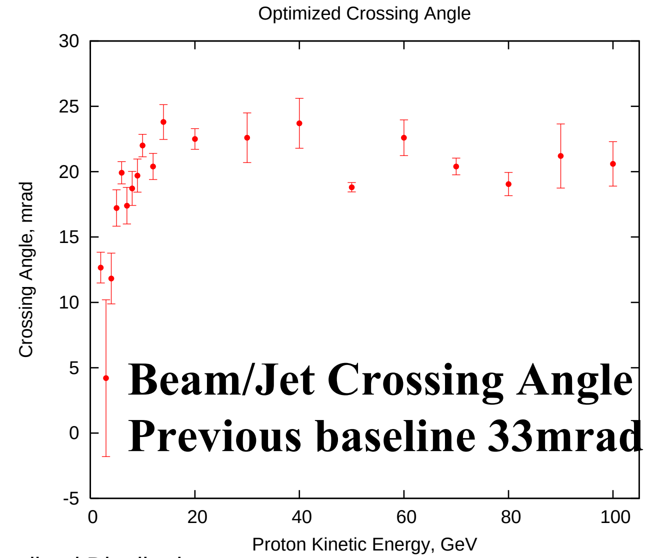
$\Theta_{crossing}$ = 33mrad

Optimized Meson Production

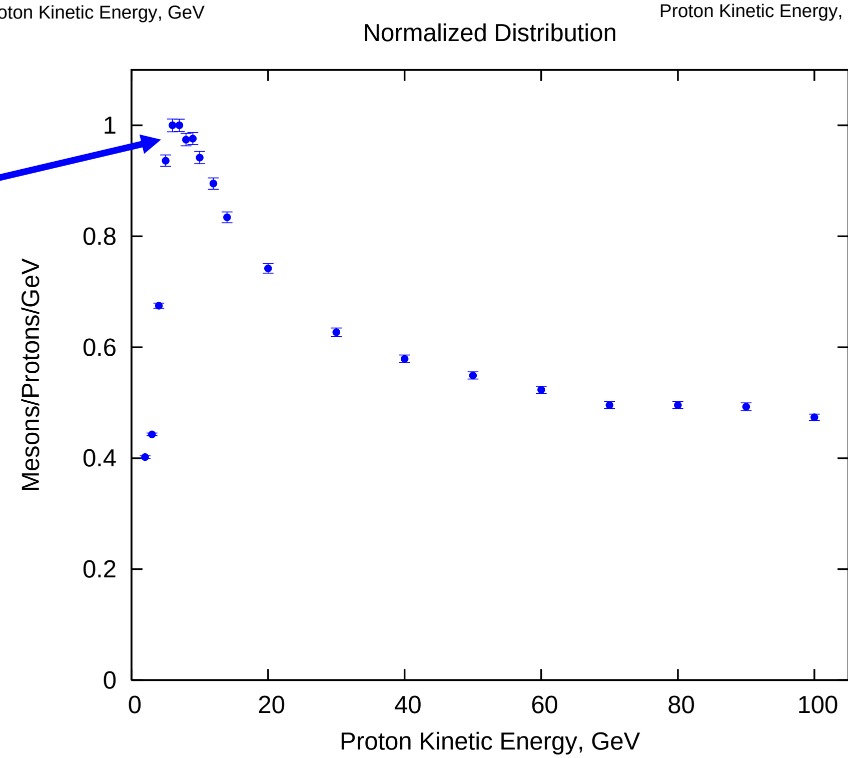
X. Ding, UCLA







Production of soft pions is most efficient for a Hg target at E_p ~ 6-8 GeV,



Confirmation of low-energy dropoff by FLUKA highly desirable.

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Summary

MERIT experimental results

- **Jet surface instabilities reduced by high-magnetic fields**
- **Proton beam induced Hg jet disruption confined to jet/beam overlap region**
  - **20 m/s operations allows for 70Hz operations**
  - **115kJ pulse containment demonstrated**

  → **8 MW operations demonstrated**
- **Hg jet disruption mitigated by magnetic field**
- **Hg ejection velocities reduced by magnetic field**
- **Pion production remains viable upto 350μs after previous beam impact**
- **170kHz operations possible for sub-disruption threshold beam intensities**
- **Hg jet disruptions influence by proton beam micro-structure**

MARS15 simulations indicate maximal meson production effieciences at incoming proton beam energies of 6-8 GeV

Future Work

Follow-up: Engineering study of a mercury loop + 20-T capture magnet, begun in ν Factory Study 2, in the context of the International Design Study for a Neutrino Factory.

- **Splash mitigation in the mercury beam dump.**
- **Possible drain of mercury out upstream end of magnets.**
- **Downstream beam window.**
- **Water-cooled tungsten-carbide shield of superconducting magnets.**
- **High-TC fabrication of the superconducting magnets.**
- **Improved nozzle for delivery of Hg jet**