VALIDATION OF THE MERIT MMW TARGET CONCEPT

Beam jet interaction @ MERIT
14 GeV/c beam, 12TP, 10T field

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The MERcury Intense Target Experiment

Outline

- Introduction
- Experimental apparatus
- Analysis results
- Conclusions – next steps

The MERcury Intense Target Experiment

Introduction

The MERIT experiment is a **proof-of-principle** test of a target system for a high power proton beam to be used as front-end for a **neutrino factory** or a **muon collider**

- In both cases the production of intense beams (ν_μ or μ) originates from high-intensity **proton beams** impinging in a **target material**

$$p + A \to \pi^{\pm} X$$

$$\pi^{\pm} \to \mu^{\pm} \nu_\mu (\overline{\nu_\mu})$$ Superbeams

$$\mu^{\pm} \to e^{\pm} \overline{\nu_\mu} \nu_e (\nu_\mu \overline{\nu_e})$$ Neutrino factory

$$\mu^{\pm}$$ Muon collider

- **Target system (targetry)** : target and capture system optimized to produce high neutrino or muon flux

Targetry - options:

- **Solid targets**:
  - **Static targets :** graphite (or carbon composite) water(or gas) cooled [CNGS, NuMI, T2K]
  - Present experiments indicate that solid target systems cannot be reliably used for proton beam powers at the multiMW scale
  - **Moving solid targets :** is an interesting variation, R&D ongoing
- **Liquid targets :**
  - **Vessel contained liquid :** is a possibility (SNS), however the use of beam windows is rather challenging for multiMW beams
  - **Free jet configuration :** past experiments at CERN & BNL produced encouraging results, proposed for Neutrino Factory Study-2

The MERcury Intense Target Experiment

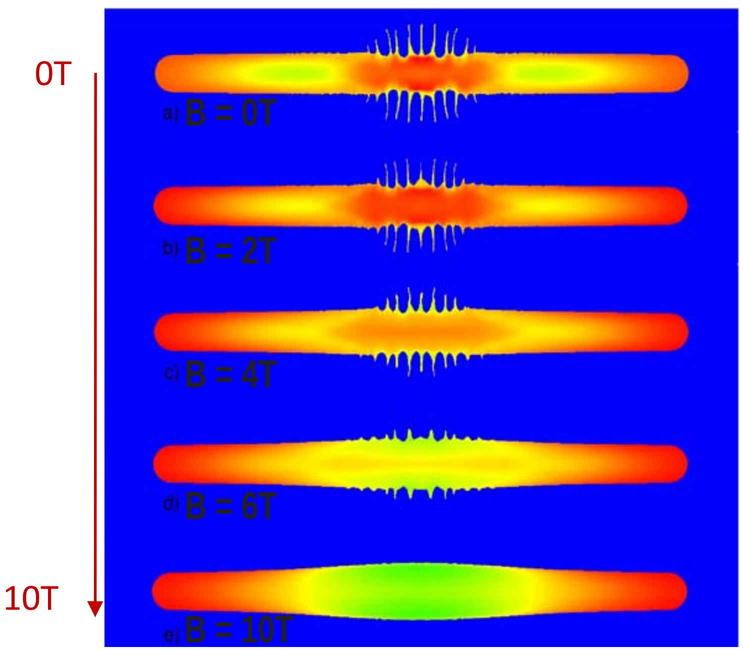
- **Liquid targets - free jet**
  - The use of liquid targets (Hg or PbBi, etc.) in a **free jet** configuration is very attractive as it avoids the use of beam windows and offers the possibility of re-generation of the target volume at each pulse.
  - However, there are important issues to clarify:
    - the stability of the liquid jet, in particular in the presence of a magnetic field required for the capture of the secondary particles
    - the formation of caviation due to the energy deposition in the target volume →inefficiencies in the secondary particle flux production

The **MERIT experiment [Hg-jet]** is designed to provide answers to both questions and therefore validate the liquid target concept

The MERcury Intense Target Experiment

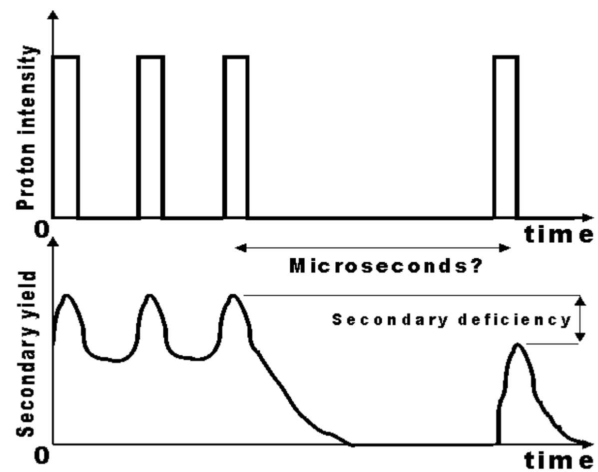
6 Scientific goals

1. Study the impact of an intense proton beam with a free mercury jet, at the presence of high magnetic field
   - e.g. MHD effects on a mercury jet
     - jet dispersal at t=100μs with magnetic field varying from 0-10 Tesla



R.Samulyak-BNL

2. Study the secondary particle yield and possible cavitation formation
   - Use the "**pump-probe**" method
     - Few high-intensity bunches – "**pump**" followed by other bunches – "probe" at variable delay
       - observe the secondary particle flux vs time
       - deficiencies could be a sign of cavitation formation



The MERcury Intense Target Experiment

Key parameters of the experiment

- 14 and 24 GeV/c proton beam pulses from CERN Proton Synchrotron (PS);
  - 1÷16 bunches/pulse, with variable spacing in between; up to 3.5×10^{12} protons/bunch
- Beam spot at the target σ_t ~1.2mm;
- Capture system: solenoid with 15T field surrounding the target
  - proton beam axis at 67mrad to magnet axis
- Target: free mercury jet of 1-cm Ø; velocity up to 20m/s
  - jet axis at 33mrad to magnet axis ; interaction region ~30cm (2 λ_{int})

- The experiment took data for three weeks in autumn 2007
  - ≈ 360 beam pulses in total; with each beam pulse “a separate experiment”
    - vary bunch intensity, bunch spacing, # of bunches
    - vary magnetic field strength
    - vary beam-jet alignment, beam spot size

- Data analysis ongoing – results obtained so far will be shown here

The MERcury Intense Target Experiment

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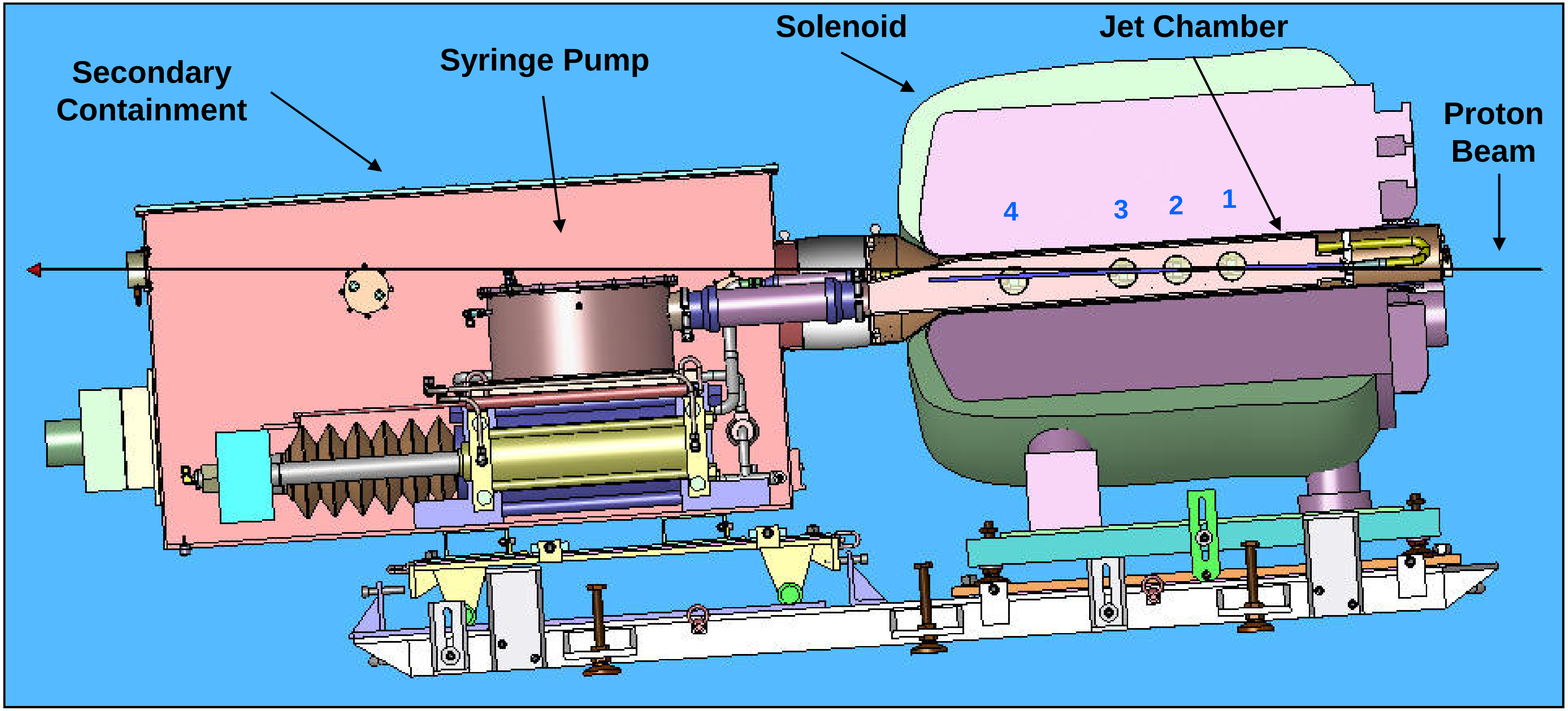
MERIT – Experimental setup

Schematic layout



- The experiment was specially designed to avoid opening the primary container (Hg-wet volume) at CERN
  - 180deg bend in the Hg-delivery piping system upstream; likely cause of deterioration in the quality of the Hg-jet

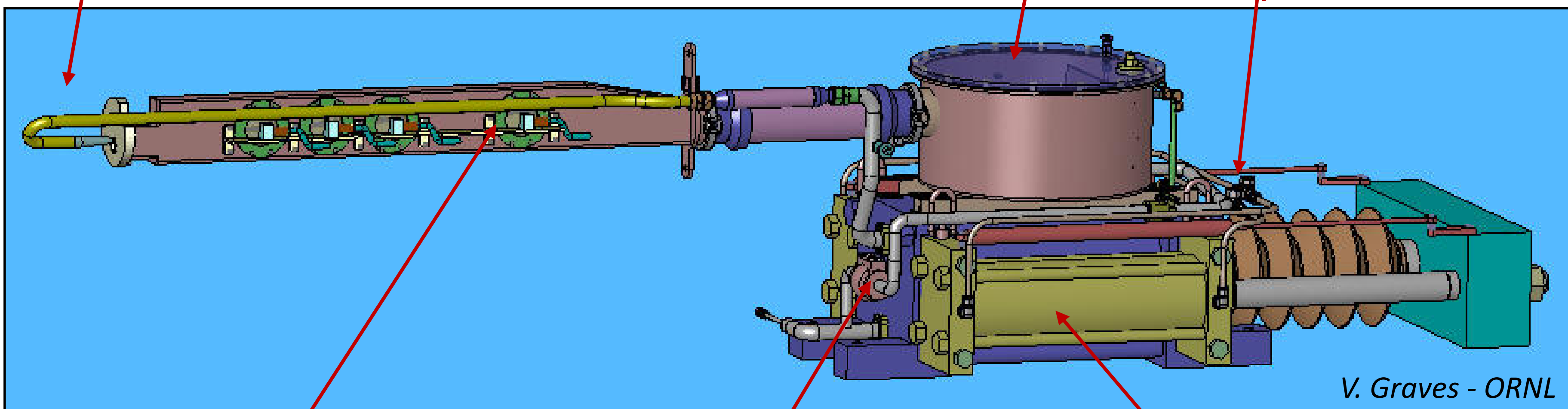
MERIT – Experimental setup

Hg-delivery system

1” pipe to transport mercury to nozzle at upstream end of primary vessel

Reservoir; collects the mercury returning at the end of the injection/jet

Local electronics ;
Hg-jet speed control



Optical diagnostics mounted on the outside of the primary vessel

Pressure monitor of Hg-supply pipe during pulsing

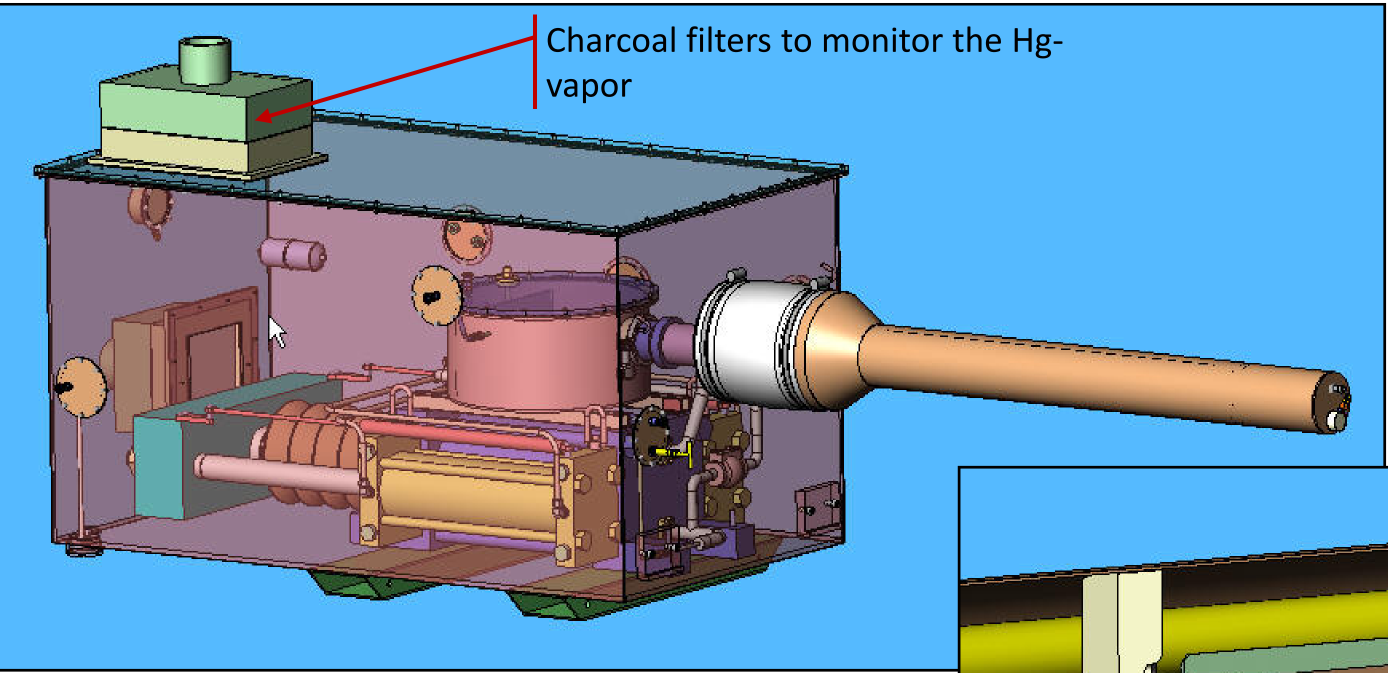
Syringe system; can produce a Hg-jet for 15s (~23lt)

System parameters:

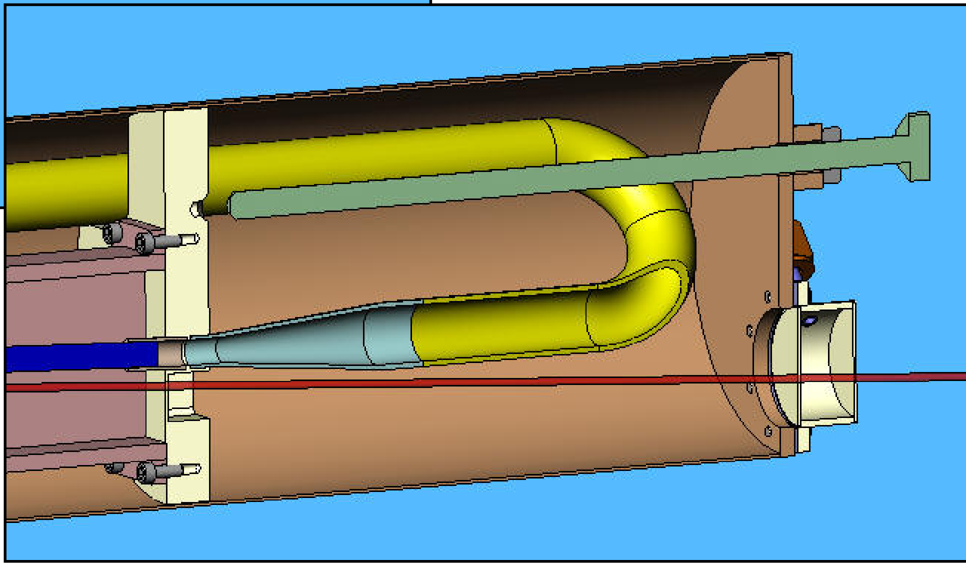
- Piston velocity : 3.0 cm/s
- Hg jet duration of 12s ;
- Drive cylinders: 15-cm diam, 45 lt/min, 2.1 MPa

MERIT – Experimental setup

Hg-delivery system



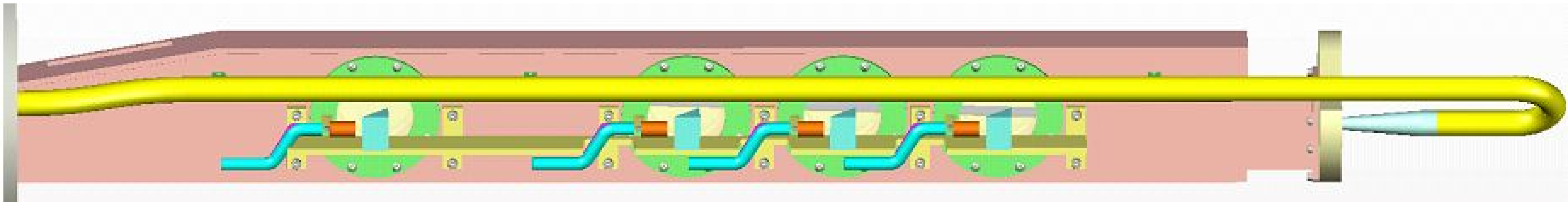
V. Graves - ORNL



- Double container (primary and secondary) for safety requirements
- Upstream window; Ti6AlV4, double pressurized wall to detect failure

MERIT – Experimental setup

Optical diagnostics

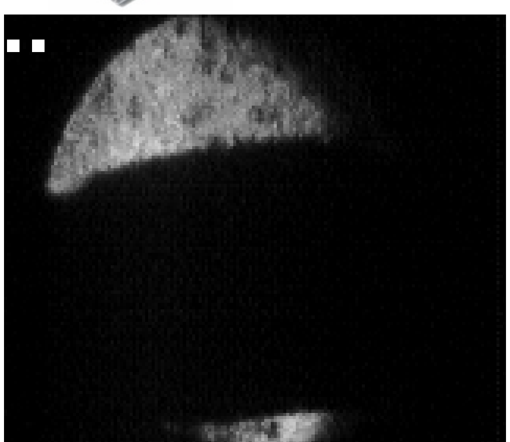


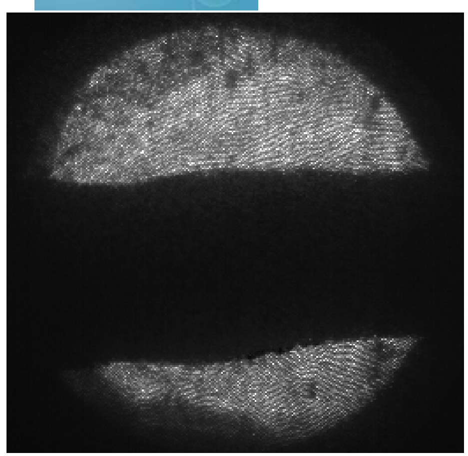
Viewport 4, Olympus
33 μs exposure; 160x140 pixels

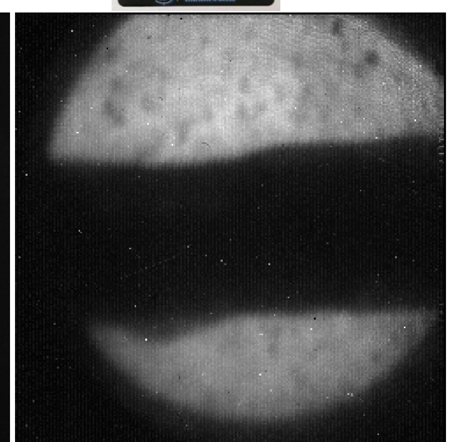
Viewport 3, FV Camera
6 μs exposure; 260x250 pixels

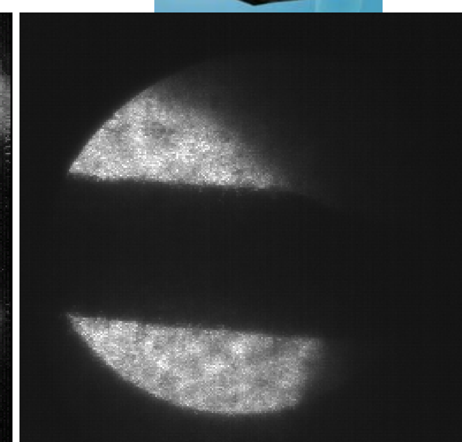
Viewport 2, SMD Camera
0.15 μs exposure; 245x252 pixels

Viewport 1, FV Camera
6 μs exposure; 260x250 pixels







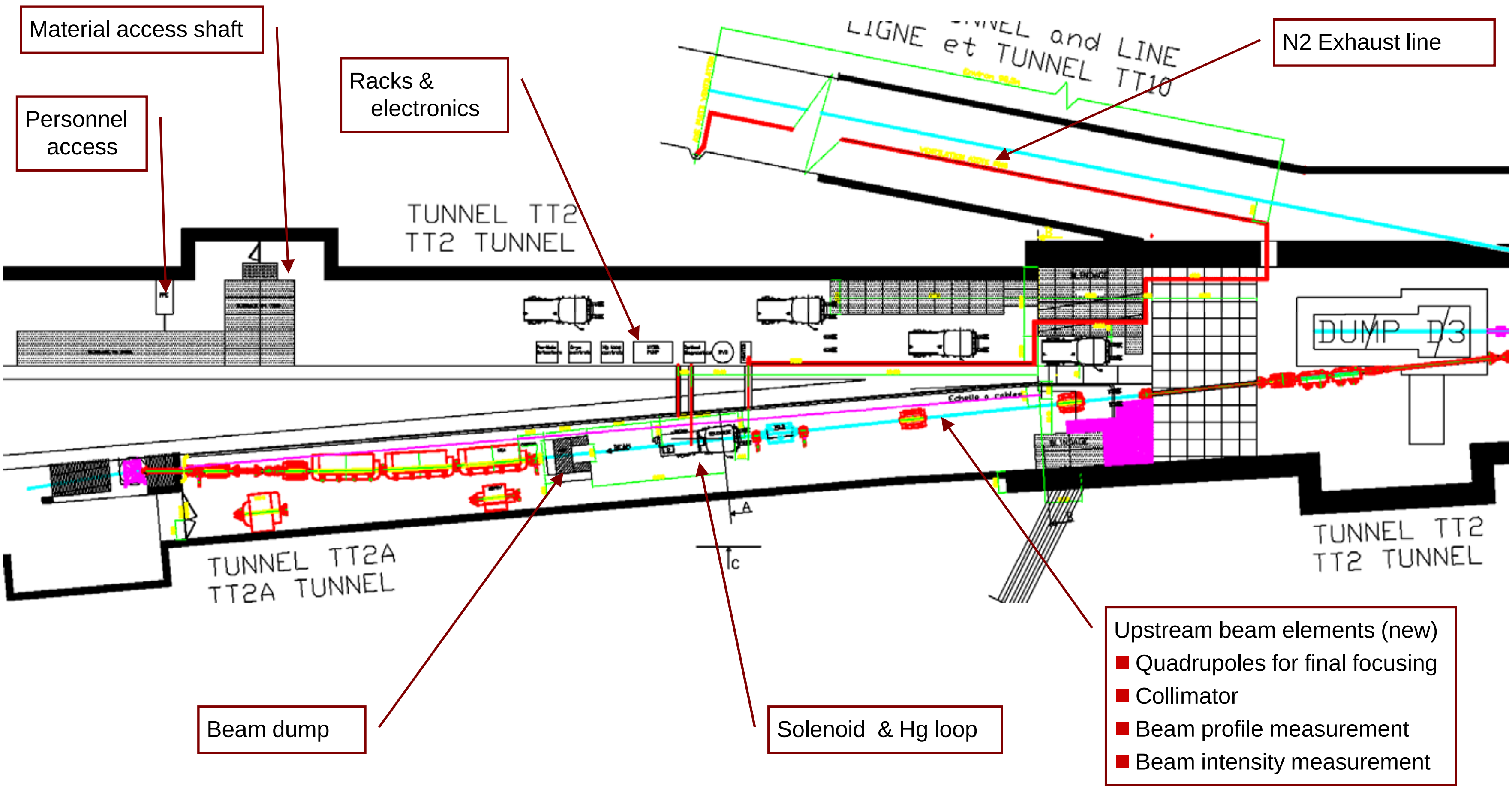


Nov. 11, 2007 Shot # 17020, 8 bunches, $6x10^{12}$ protons, 7 Tesla, 15 m/s jet

I.Efthymiopoulos, CERN

MERIT – Experimental setup

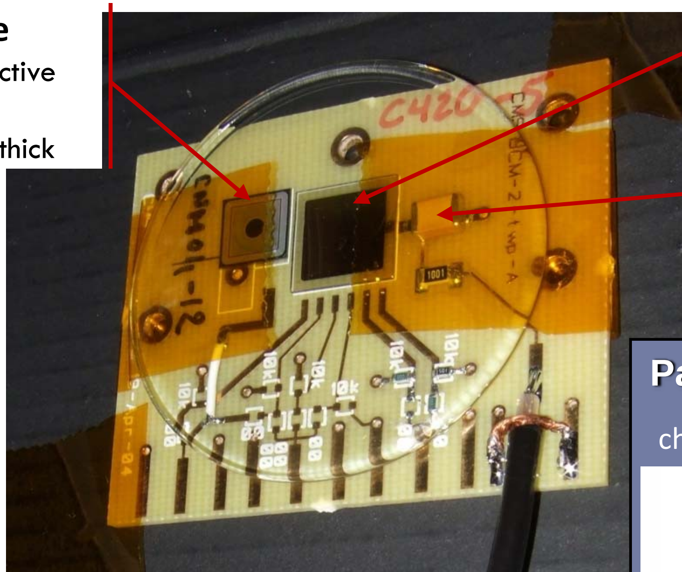
Experimental layout



MERIT – Experimental setup

14 Particle flux detectors

pin diode
- ~1cm^2 active area
- 200 μm thick



pCVD diamond
- 7.5×7.5 mm^2 active area
- 300 μm thick

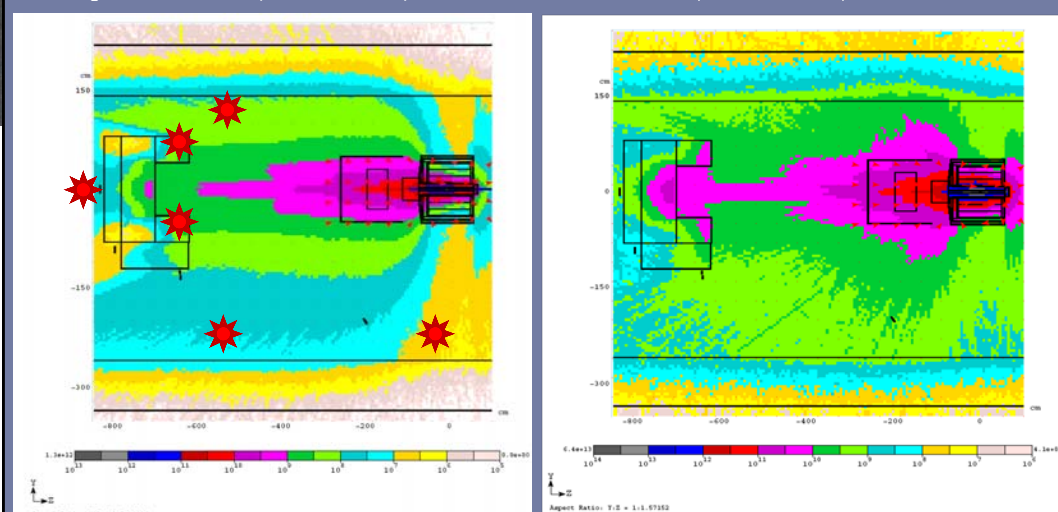
bypass capacitor 100nF/500V

ACEM detector

pCVD diamond & pin diode

Particle fluxes - 3×10^{13} protons (**MARS Simulation**)

charged hadrons (E>200 KeV) | neutrons (E>100 KeV)



particle detectors

S.Striganov - FNAL

MERIT – Experimental setup

Complete installation in the nTOF tunnel

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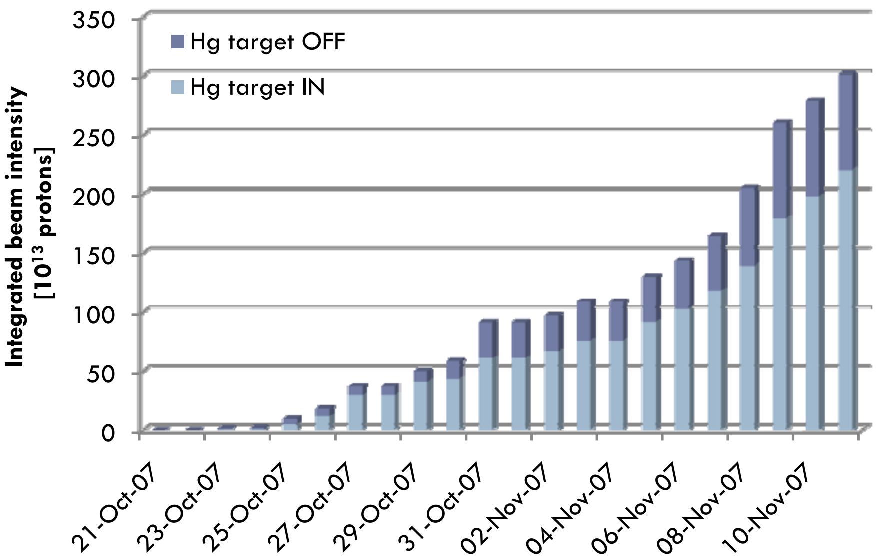
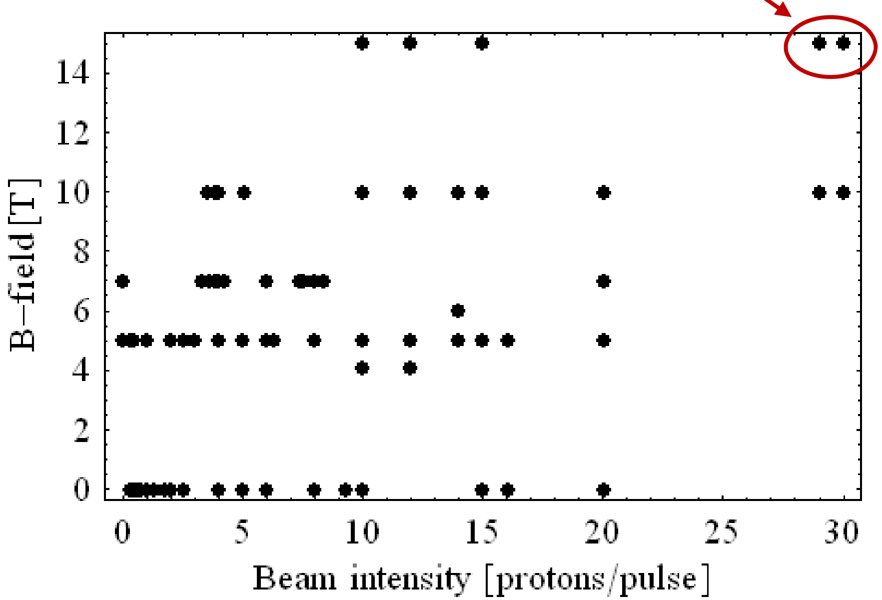
MERIT – Analysis results

Beam shots summary



30×10^{12} protons @ 24 GeV/c

- **115 kJ** of beam power
- a PS machine record !

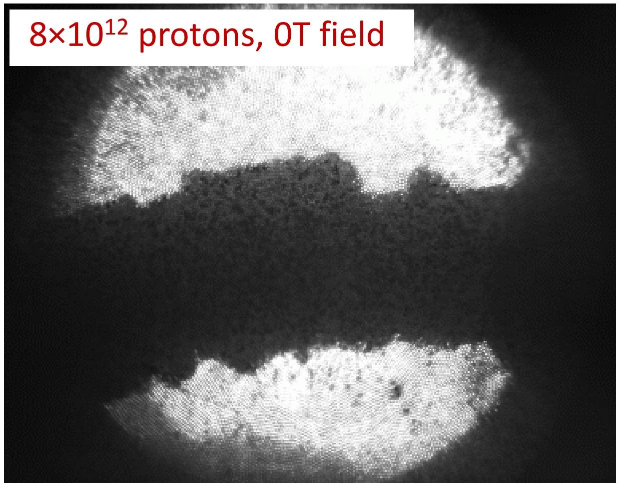


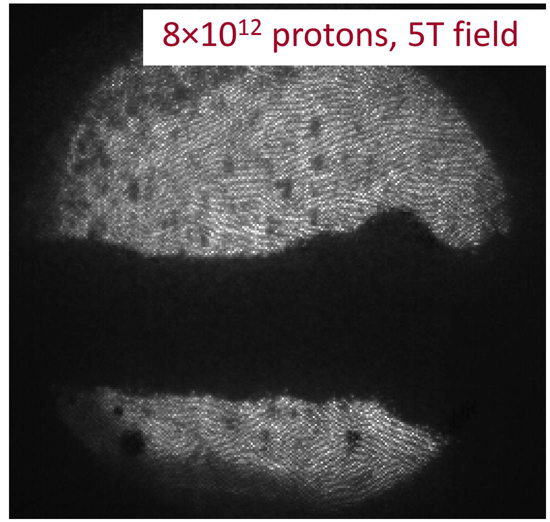
- Beam size and density for 30×10^{12} protons

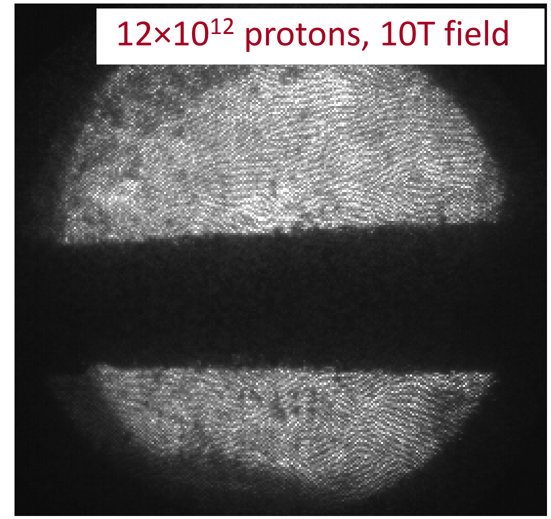
Beam [GeV/c]	Horiz. [mm]	Vert. [mm]	Spot [mm2]	Beam Density [J/gr @ 30 TP]
14	2.40	1.37	10.35	**94.5**
24	**1.74**	**1.04**	**5.72**	**171**

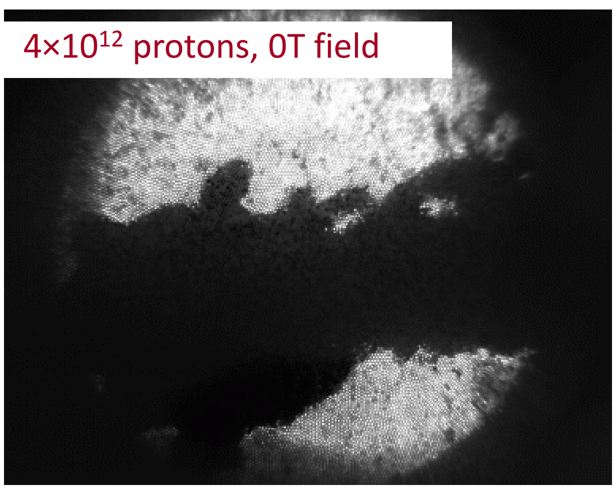
MERIT – Analysis results

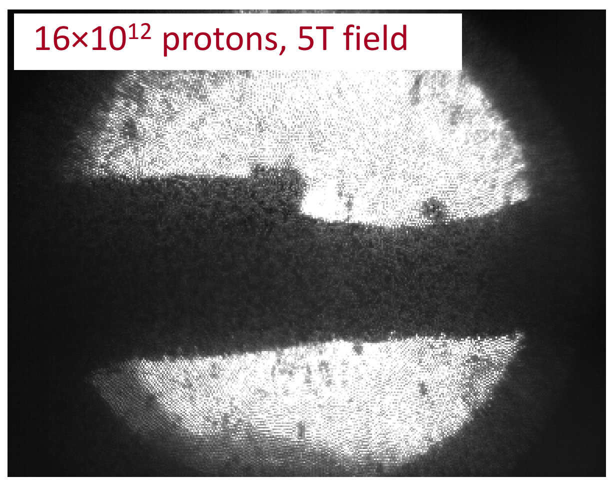
Beam-Hg-jet interaction examples – 14 GeV/c beam

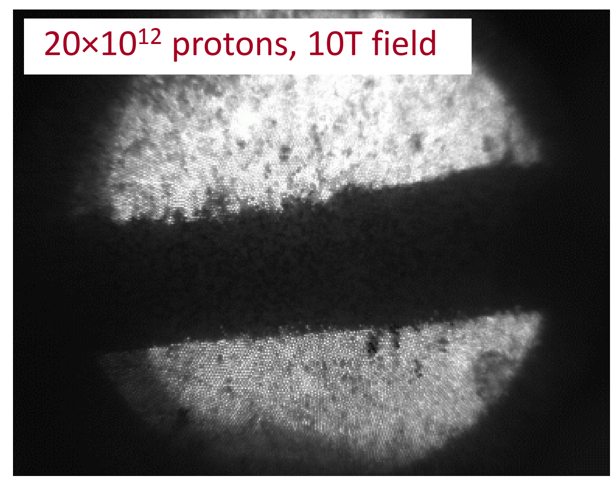

8×10^{12} protons, 0T field


8×10^{12} protons, 5T field


12×10^{12} protons, 10T field


4×10^{12} protons, 0T field

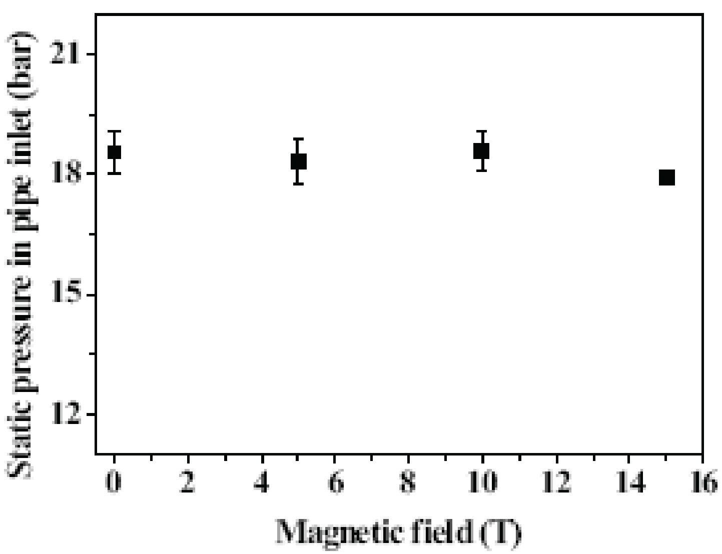

16×10^{12} protons, 5T field


20×10^{12} protons, 10T field

I.Efthymiopoulos, CERN

MERIT – Analysis results

Hg-jet properties without beam



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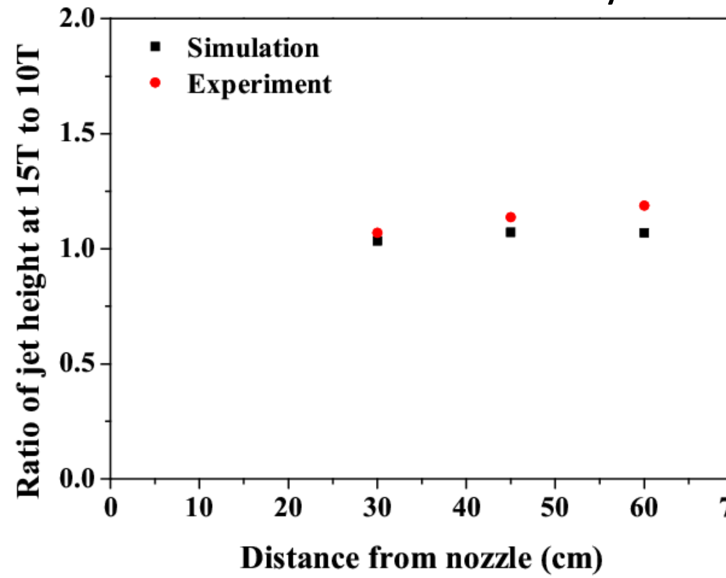
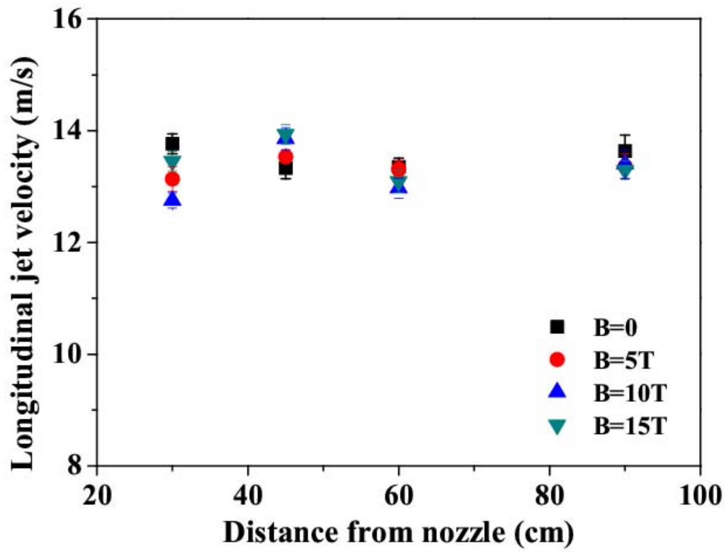
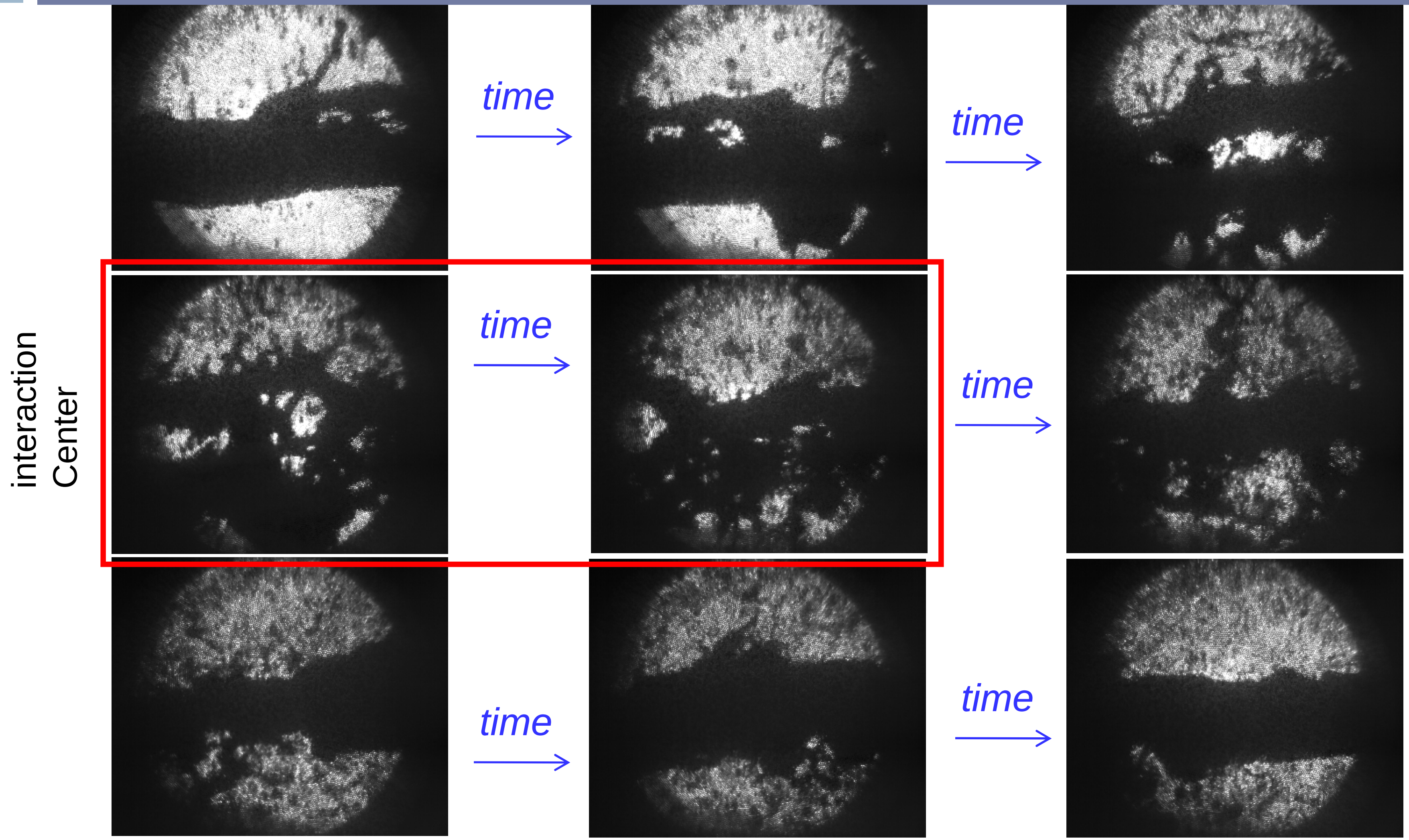




- No significant reduction in the jet velocity with the magnetic field.
- No pressure increase for v = 15 m/s jet with magnetic field.
- Good agreement of the jet height increase with magnetic field and MHD simulation (R.Samulyak - 2008)

MERIT – Analysis results

Interaction example - 16×10^{12} protons, 5T, 14 GeV/c



- Note disruption of top of jet at early times, and of bottom at later times.
- "**Disruption length**" inferred from number of frames the disruption lasts.

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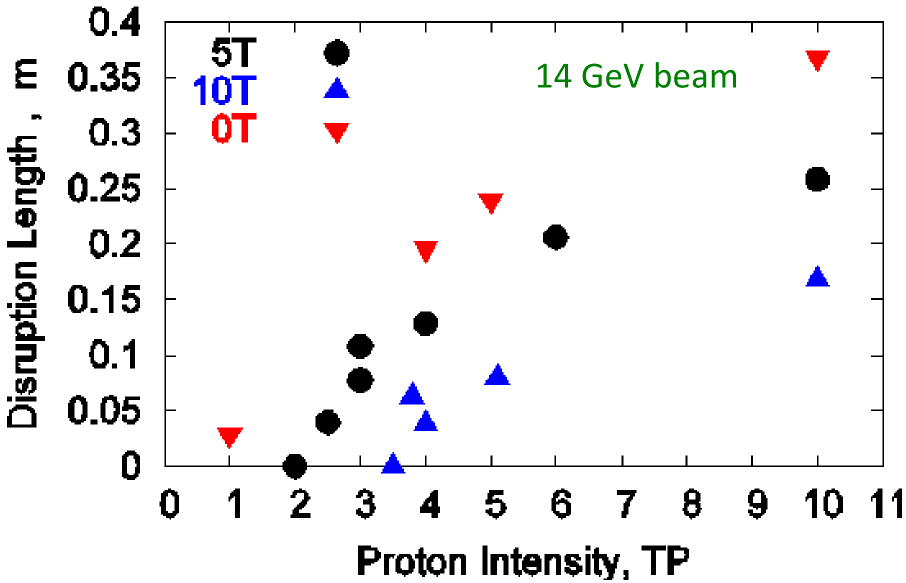
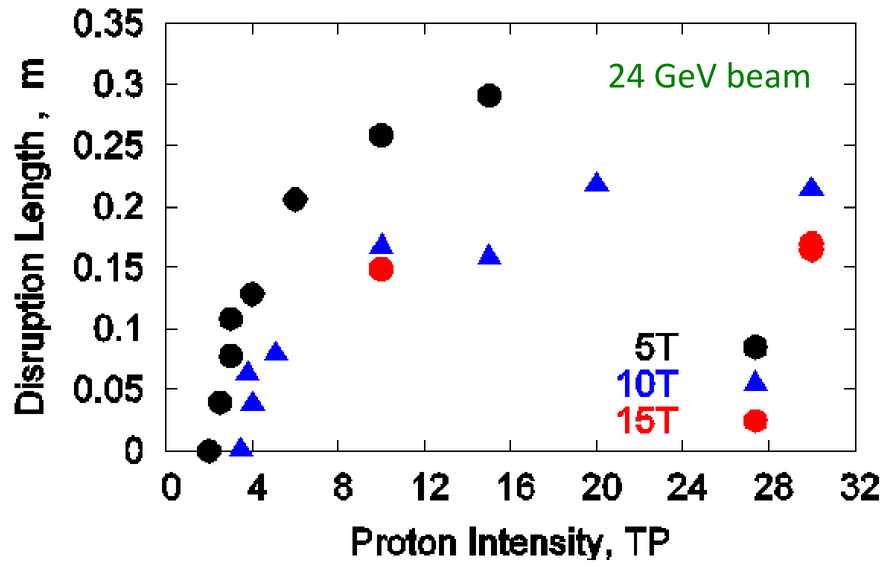
MERIT – Analysis results

Disruption length vs beam intensity

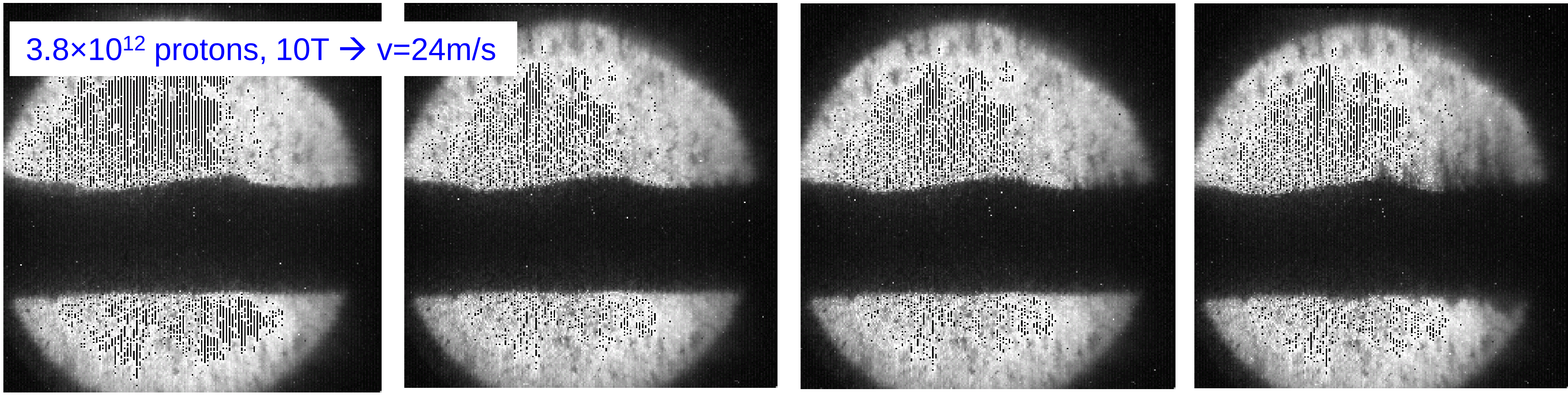




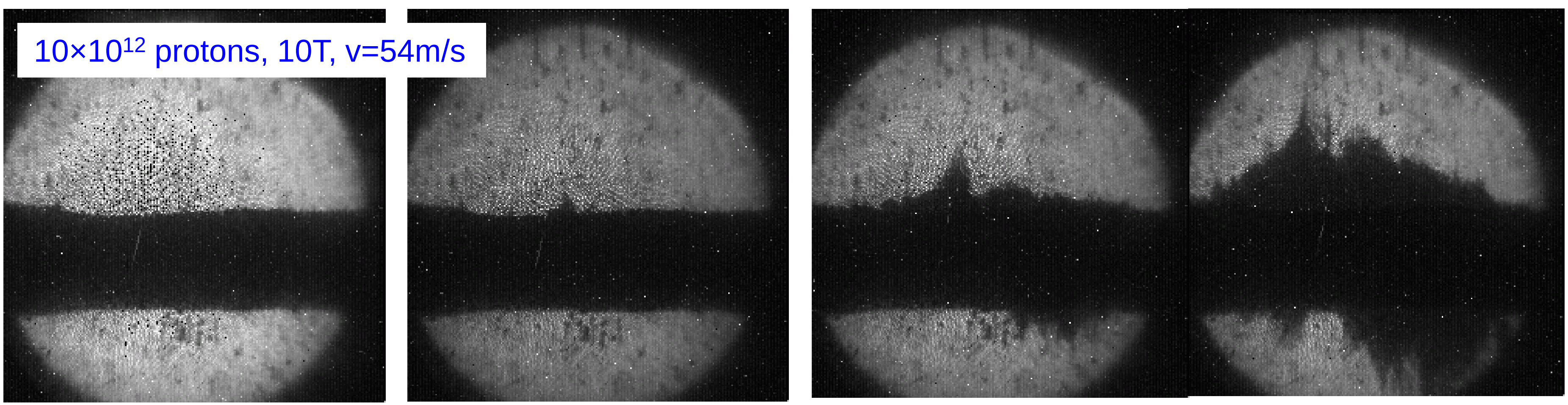
- Disruption length is always smaller than the beam-jet overlap distance (~30cm)
- Maximum disruption length is the same at 14 and 24 GeV/c
  - **~30cm** corresponds to **67Hz** repetition rate, which for a **24 GeV/c** beam of **30 × 10^{12} protons**, equivalent to **115kJ** corresponds to a total beam power of **7.7MW**
- The disruption length decreases with increasing magnetic field
- The disruption threshold increases with increasing magnetic field.

MERIT – Analysis results

Jet Breakup Velocity Observed at Port 2 with Fast Camera



t = 0 | *t = 0.150 ms* | *t = 0.175 ms* | *t = 0.375 ms*



t = 0 | *t = 0.075 ms* | *t = 0.175 ms* | *t = 0.375 ms*

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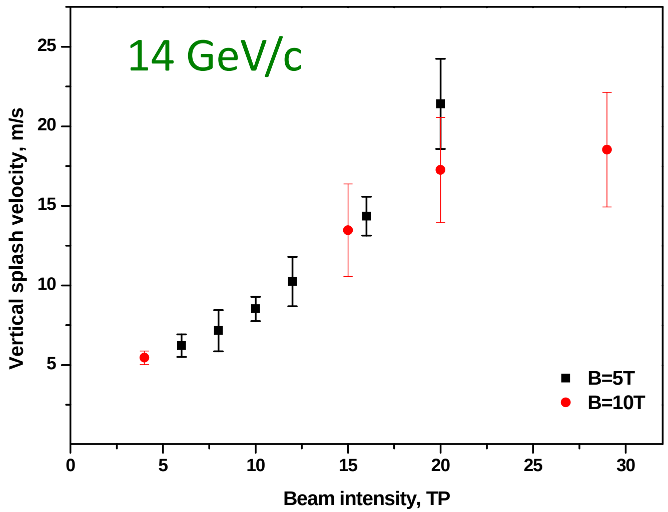
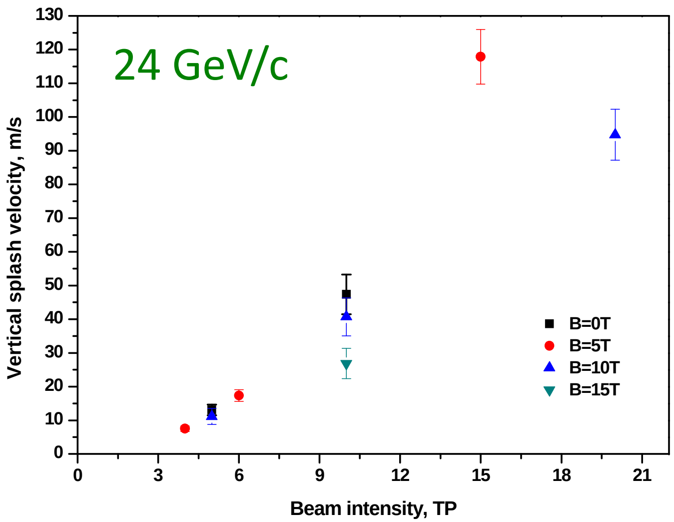
MERIT – Analysis results

Jet Breakup Velocity Measurements

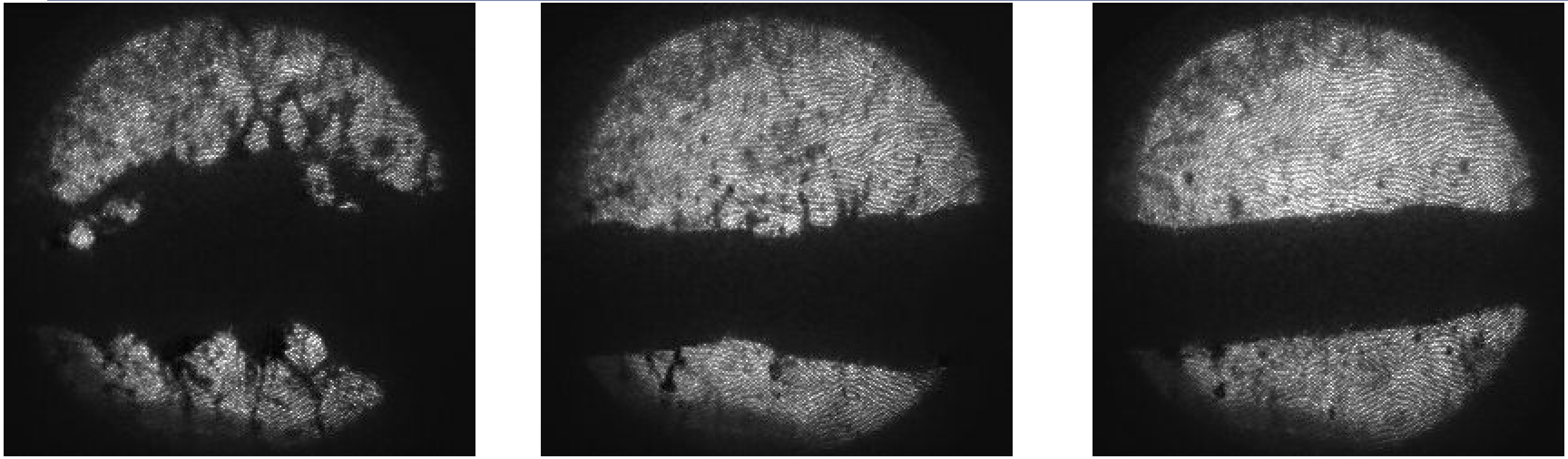




- Beam spot area at 24 GeV/c is (14/24) of that at 14 GeV/c.
- Beam intensity = energy/cm^2 is $(24/14)^2 \approx 3$ times greater at 24 than at 14 GeV/c.
- Measurements are consistent with model that breakup velocity$\propto$beam intensity.

MERIT – Analysis results

Pump-Probe study: 4 ×10^{12} p. – "pump" + 4 ×10^{12} p. – "probe" at 14 GeV/c



$\Delta t_{(pump\text{-}probe)}$ = 0s
↳ single-turn extraction

$\Delta t_{(pump\text{-}probe)}$ = 3.2 μs
↳ "probe" extracted in subsequent turn

$\Delta t_{(pump\text{-}probe)}$ = 5.8 μs
↳ "probe" extracted after 2nd full turn

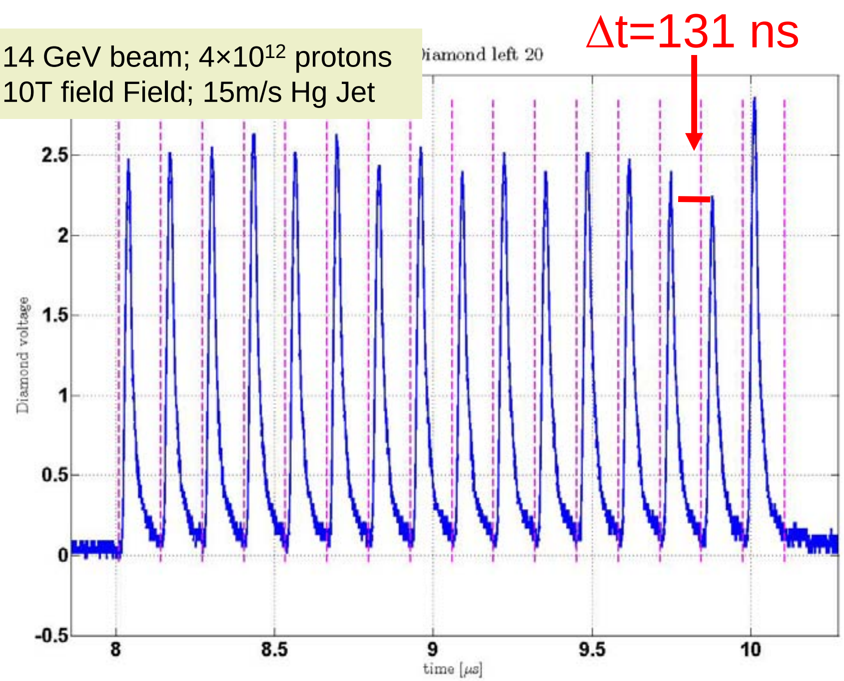
- **Target supports 14-GeV/c, 4×10^{12} protons beam at 172 kHz rep rate without disruption.**
- ***Preliminary*** *analysis of studies at 14 GeV/c with 15×10^{12} protons-pump and 5×10^{12} protons-probe with delays of 2-700 μs indicate little change in secondary particle production by probe.*
  - *Initial breakup of jet does not reduce particle production immediately.*
  - *May be able to use bunch trains of several-hundred μs length.*

MERIT – Analysis results

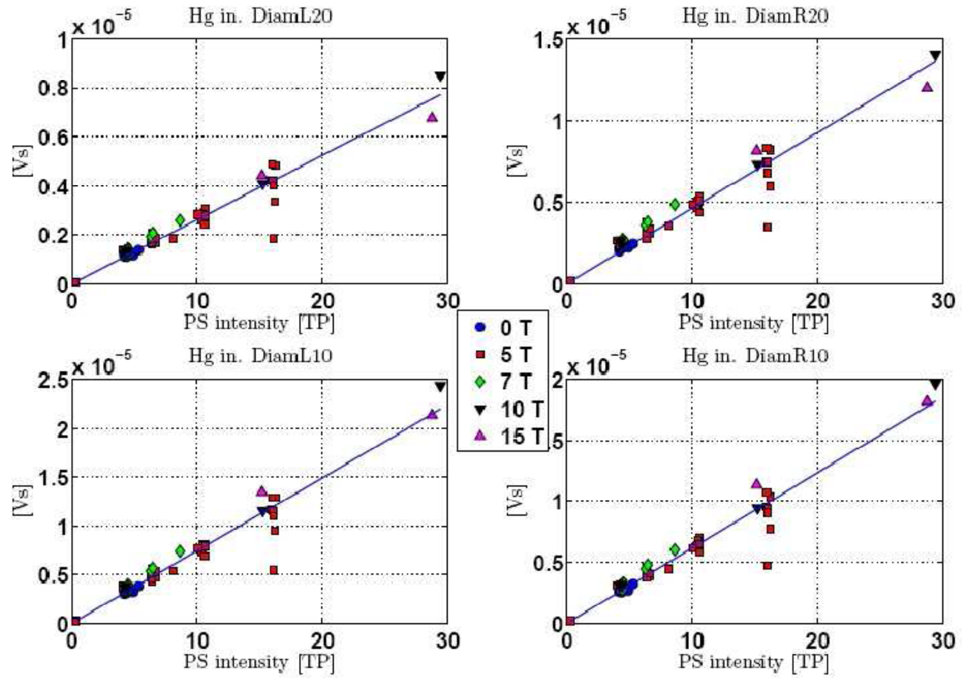
Particle detector data – pCVD diamond detector response

- Detector signal for multi-bunch beam pulse

- ▪ 14 GeV beam; 4×10^{12} protons
- ▪ 10T field Field; 15m/s Hg Jet



- Response linearity



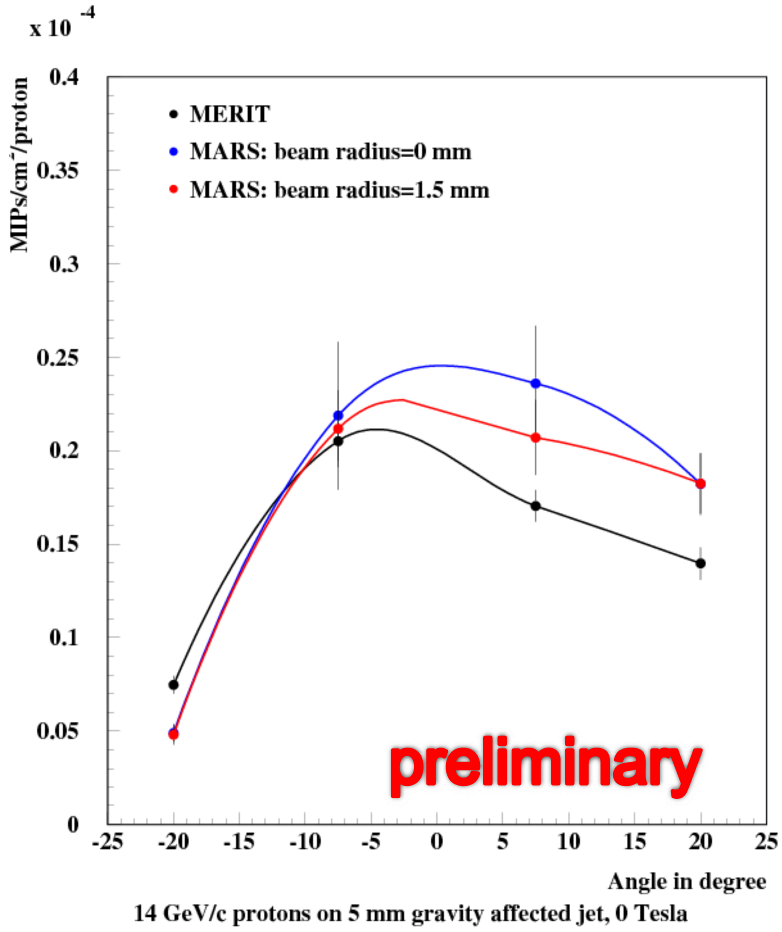
- Able to identify individual bunches event at the highest intensities

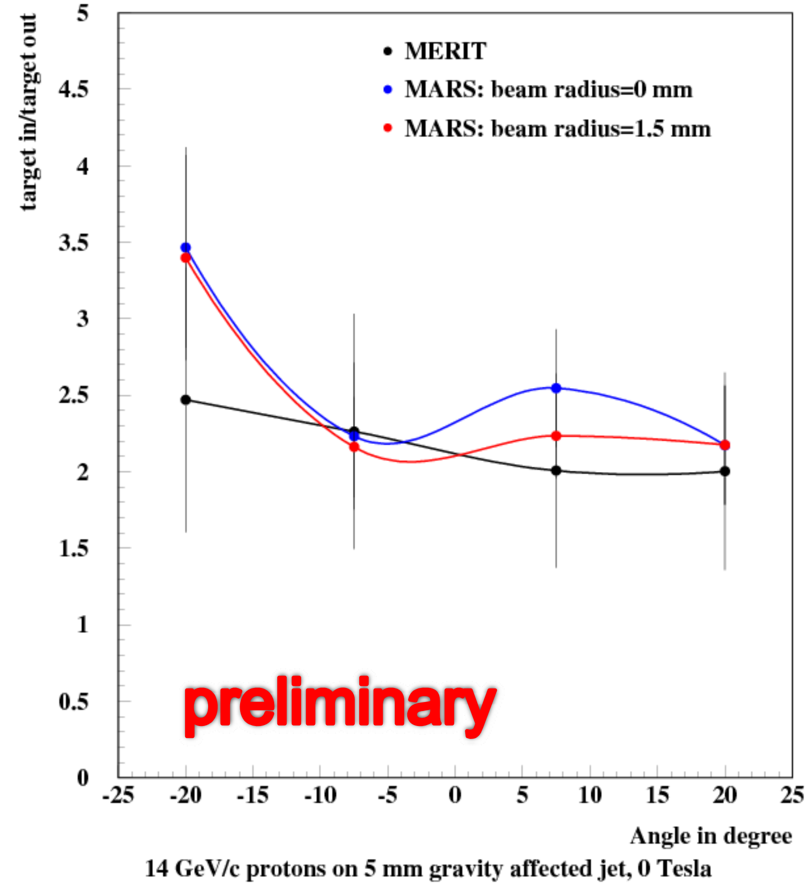
- Data analysis ongoing…

MERIT – Analysis results

Particle detector - flux measurement

- Comparison with MARS simulation





Conclusions

- The MERIT experiment took beam as scheduled for three weeks in autumn 2007 at CERN PS. All systems performed well, the run with beam was smooth and the whole scientific program was completed

- The primary objective to conduct a successful and safe experiment at CERN was amply fulfilled

- Important results validating the liquid metal target concept are coming out as the analysis progresses

- The MERIT experiment represents a big step forward in the targetry R&D for high power systems

Next steps

Post-MERIT Targetry R&D

- Discussions ongoing to define the future R&D program. Two workshops held so far:
  - http://www.physics.princeton.edu/~bridges/targetworkshop2/
  - http://www.physics.ox.ac.uk/users/peachk/HPT/

- Areas for further studies identified so far:
  - Hg-jet quality and handling
    - induced corrosion in the primary container? - traces in the MERIT primary container?
    - nozzle design for improved jet quality
    - Improved optical diagnostics system to observe the jet in both planes {H, V} and comparison with simulations
  - Study of system aspects, e.g. Hg jet and beam dump

- Repeating MERIT with improved conditions would be an important milestone (possibly coupled with a capture & beam dump system) once the physics case is established and an adequate experimental area at CERN or elsewhere is found