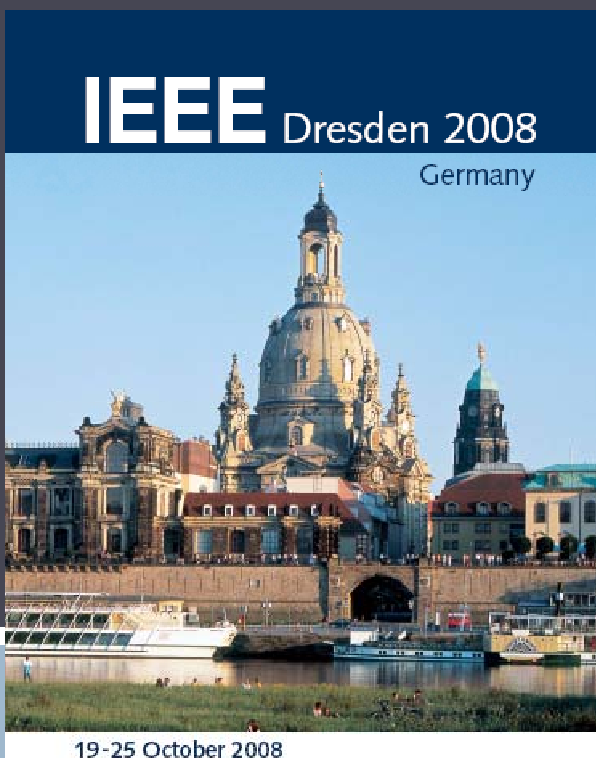
THE **MERIT** - HIGH INTENSITY LIQUID MERCURY TARGET EXPERIMENT AT THE CERN PS



Outline

- Introduction
- Experimental apparatus
- Analysis results

I. Efthymiopoulos, A. Fabich, F. Haug, M. Palm, J. Lettry, H. Pernegger, R.Steerenberg, A. Grudiev, *CERN*

H.G. Kirk, T. Tsang, *BNL - N.Mokhov, S.Striganov, FNAL*

A. Carroll, V.B. Graves, P. Spampinato, *ORNL - K.T. McDonald, Princeton Univ.*

J.R.J. Bennett*, O. Caretta, P. Loveridge, RAL - H. Park, SUNY at Stony Brook*

IEE-Nuclear Science Symposium
Dresden, October 23, 2008

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**.

- Basic physics process for generating neutrino beams:

$$p + A \rightarrow \pi^{\pm} X \xrightarrow{decay} \mu^{\pm} \nu_{\mu} (\overline{\nu}_{\mu})$$

Superbeams

$$p + A \rightarrow \pi^{\pm} X \xrightarrow{decay} \mu^{\pm} \nu_{\mu} (\overline{\nu}_{\mu}) \xrightarrow{decay} e^{\pm} \nu_{e} \overline{\nu}_{\mu} (\nu_{\mu} \overline{\nu}_{e})$$

Neutrino factory or muon collider

- For both cases the need of intense pion beams is required, emerging from high-intensity proton beams impinging on a target material
- Present experiments indicate that solid target systems (graphite, Be, Ta, etc.) cannot be reliably used for proton beam powers at the MMW scale
- The use of liquid targets (Hg or PbBi, etc.) in a free jet configuration is an interesting alternative. It avoids use of beam windows and offers the possibility of re-generation of the target volume at each pulse. 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, i.e. variable secondary particle flux vs time
- The **MERIT experiment** is designed to provide answers to both questions and validate the liquid target concept

The MERcury Intense Target Experiment

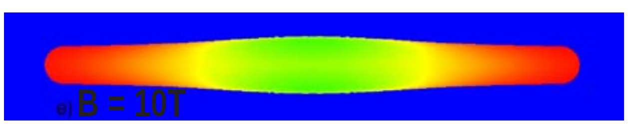
3 Scientific goals

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

0T

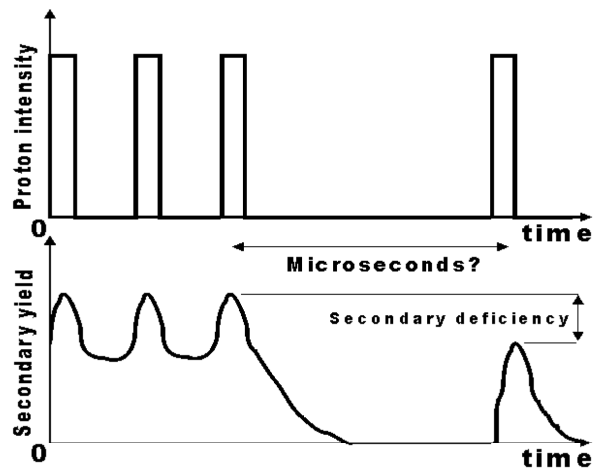
10T



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



I.Efthymiopoulos, CERN

The MERcury Intense Target Experiment

Key parameters of the experiment

- 14 and 24 GeV/c proton beam pulses from CERN 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; every beam pulse is a separate experiment.
  - ≈ 360 beam pulses in total
  - 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

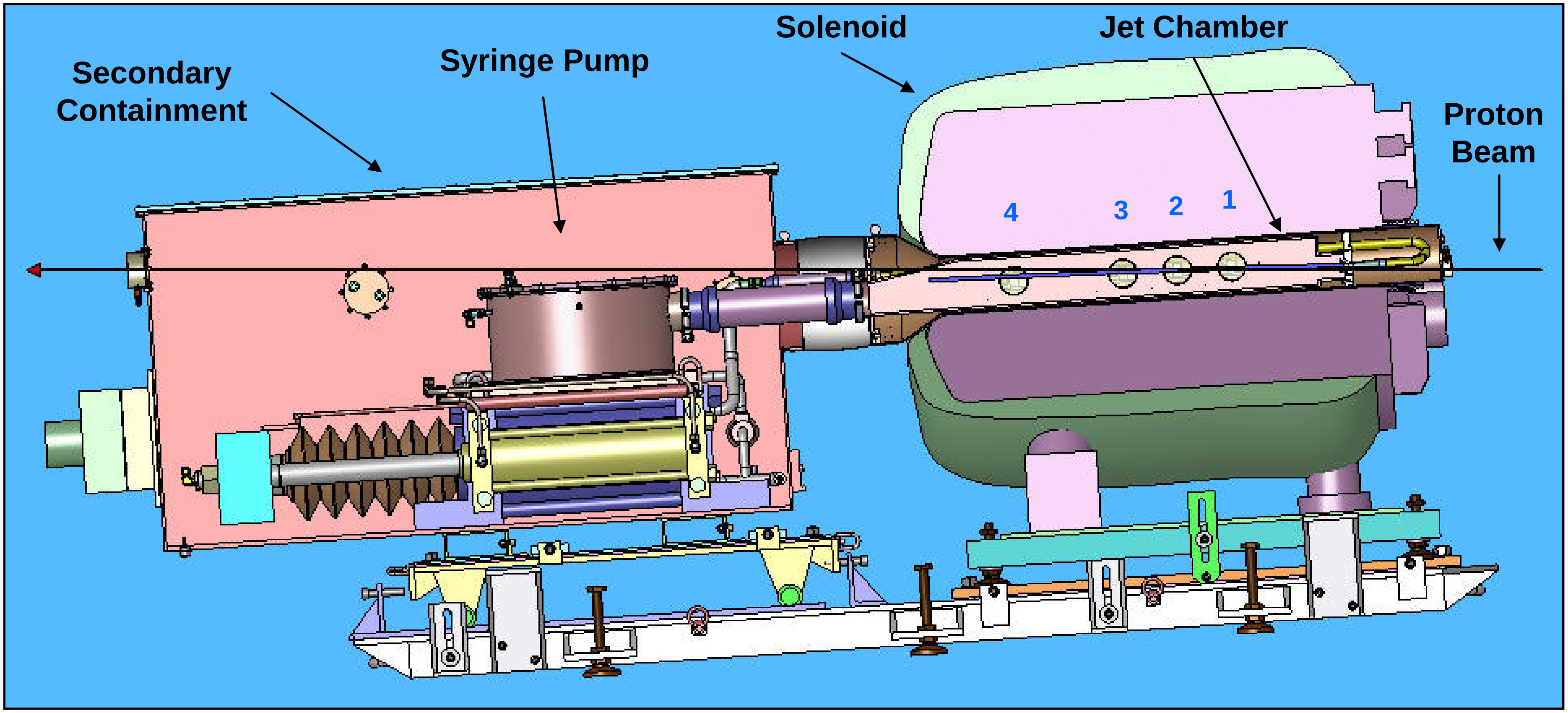
The MERcury Intense Target Experiment

Outline

- Introduction
- Experimental apparatus
- Analysis results

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

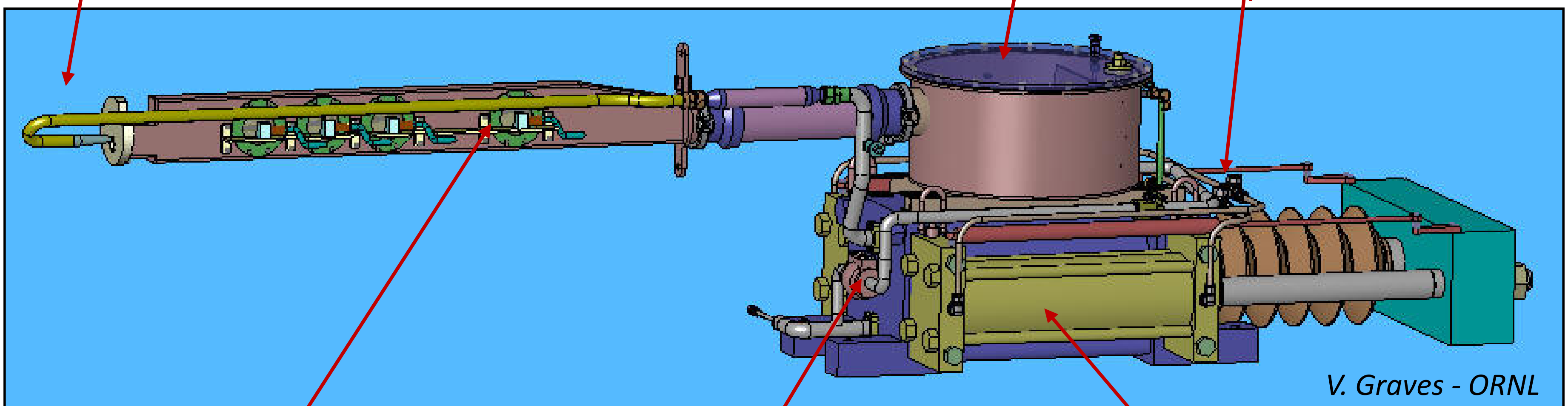
MERIT – Experimental setup

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

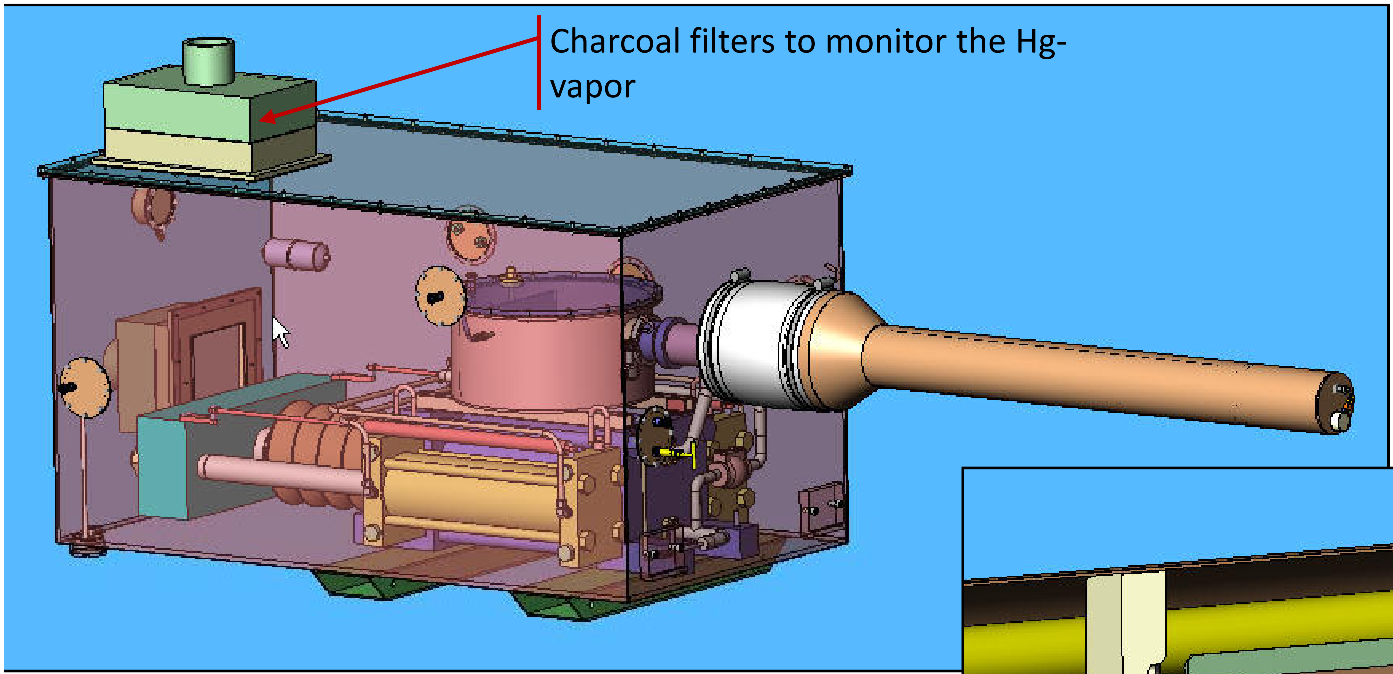
Syringe system; can produce a Hg-jet for 15s (~23lt)

System parameters:

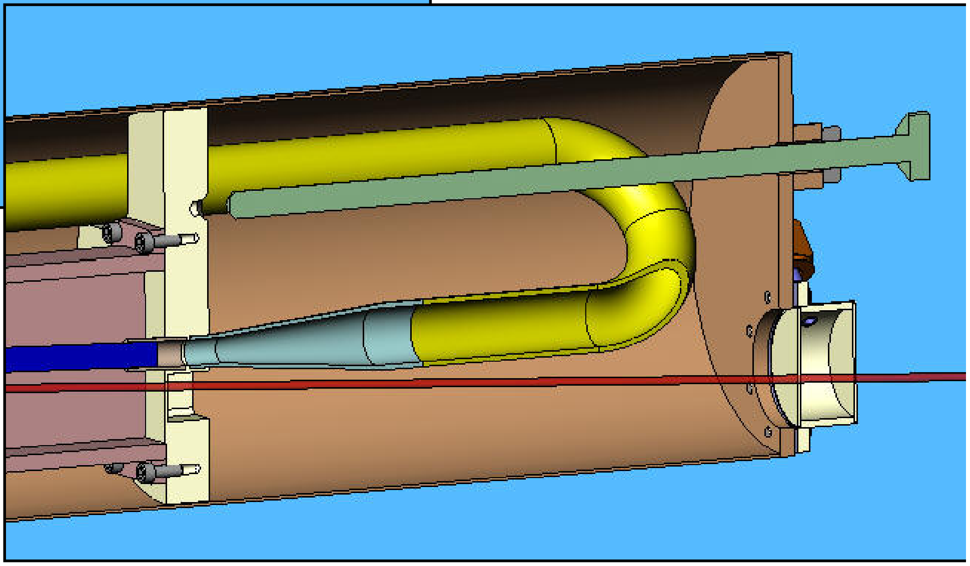
- Piston velocity : 3.0 cm/s
- Hg jet duration of 12s ;
- Drive cylinders: 15-cm diam, 45 lt/min, 2.1 MPa

MERIT – Experimental setup

Hg-delivery system



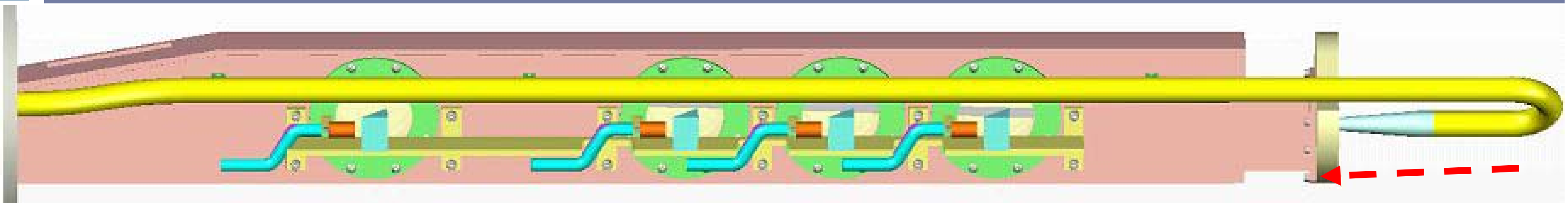
V. Graves - ORNL



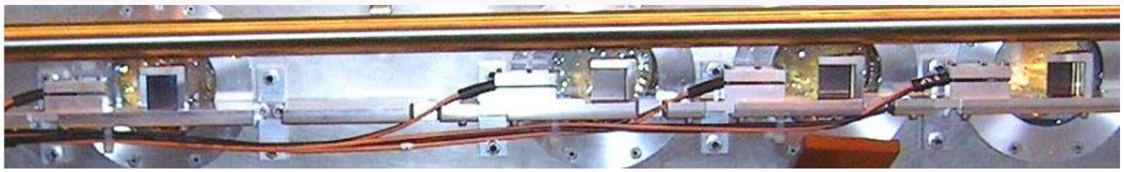
- Double container (primary and secondary) for safety requirements
- Upstream window; Ti6AlV4, double pressurized wall to detect failure

MERIT – Experimental setup

Optical diagnostics



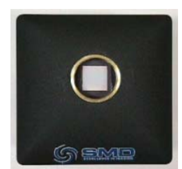
Proton beam



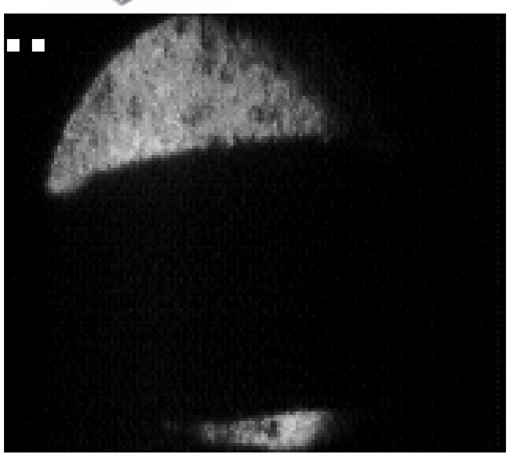
Viewport 4, Olympus
33 µs exposure; 160x140 pixels

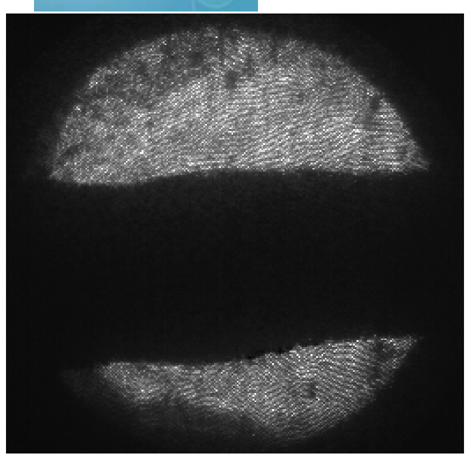
Viewport 3, FV Camera
6 µs exposure; 260x250 pixels

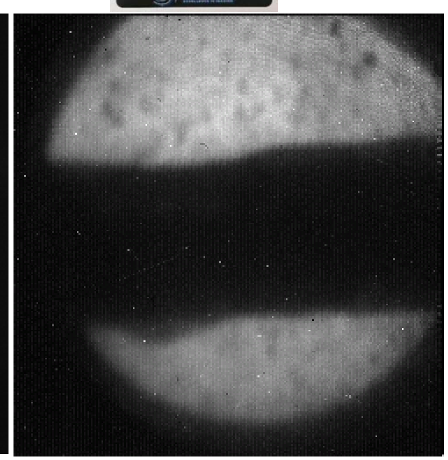
Viewport 2, SMD Camera
0.15 µs exposure; 245x252 pixels

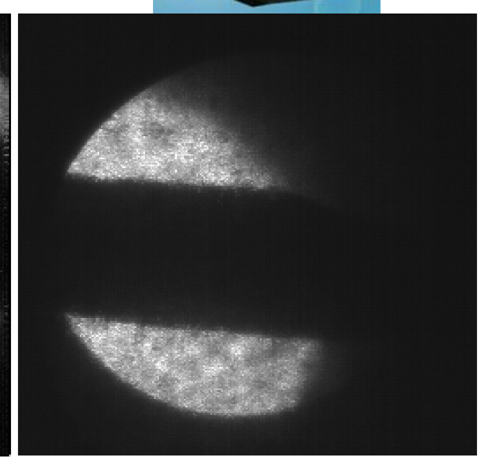


Viewport 1, FV Camera
6 µs exposure; 260x250 pixels







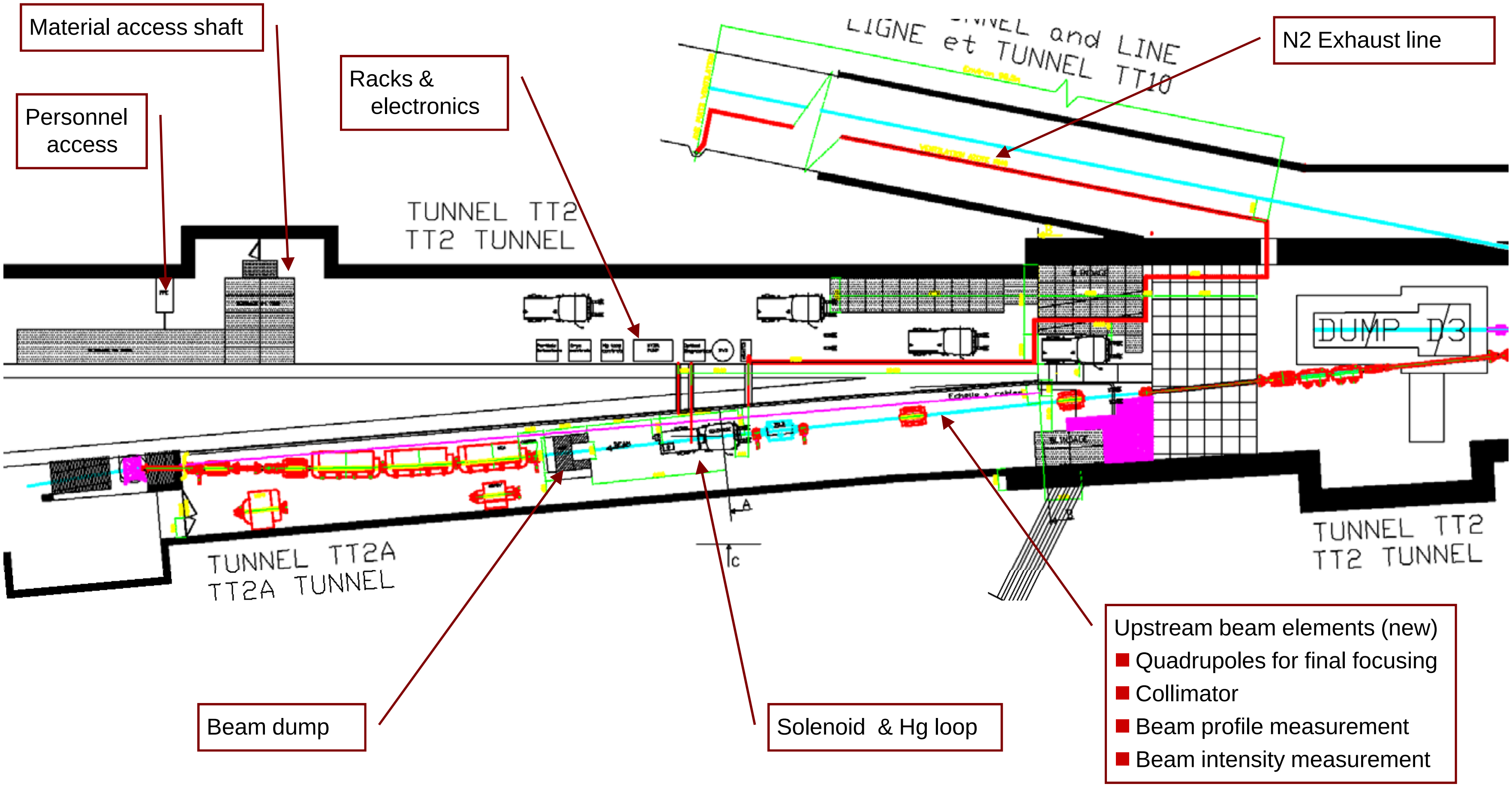


Nov. 11, 2007 Shot # 17020, 8 bunches, 6×10^{12} protons, 7 Tesla, 15 m/s jet

I.Efthymiopoulos, CERN

MERIT – Experimental setup

Experimental layout

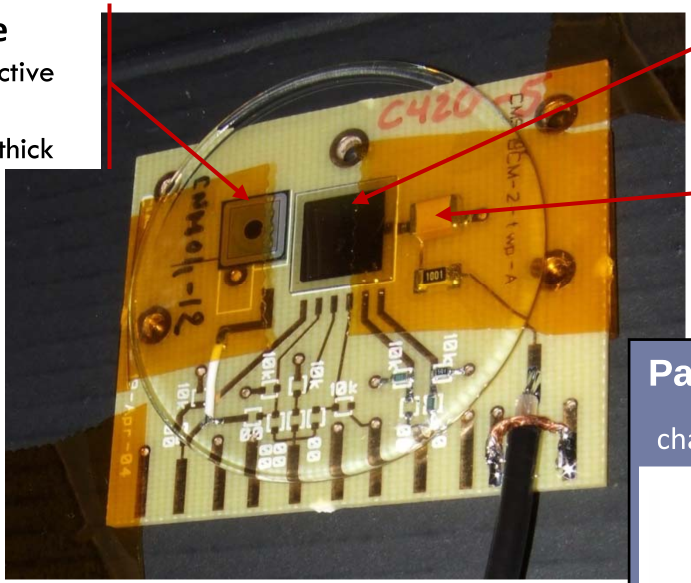


I.Efthymiopoulos, CERN

MERIT – Experimental setup

Particle flux detectors

pin diode
- $\sim 1\,cm^2$ active area
- 200 μm thick



pCVD diamond
- $7.5\times7.5\ mm^2$ active area
- 300 μm thick

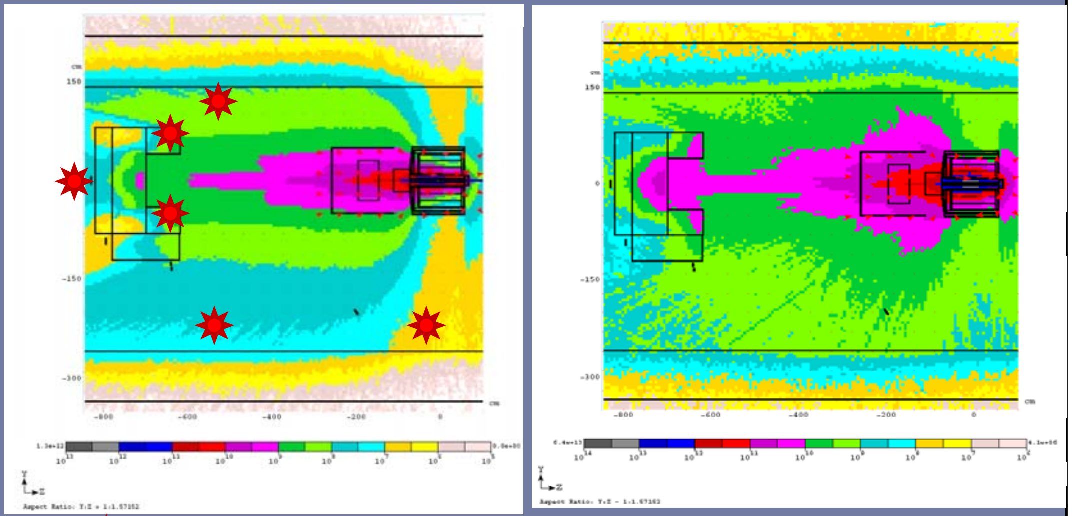
bypass capacitor 100nF/500V

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

I.Efthymiopoulos, CERN

MERIT – Experimental setup

Complete installation in the nTOF tunnel

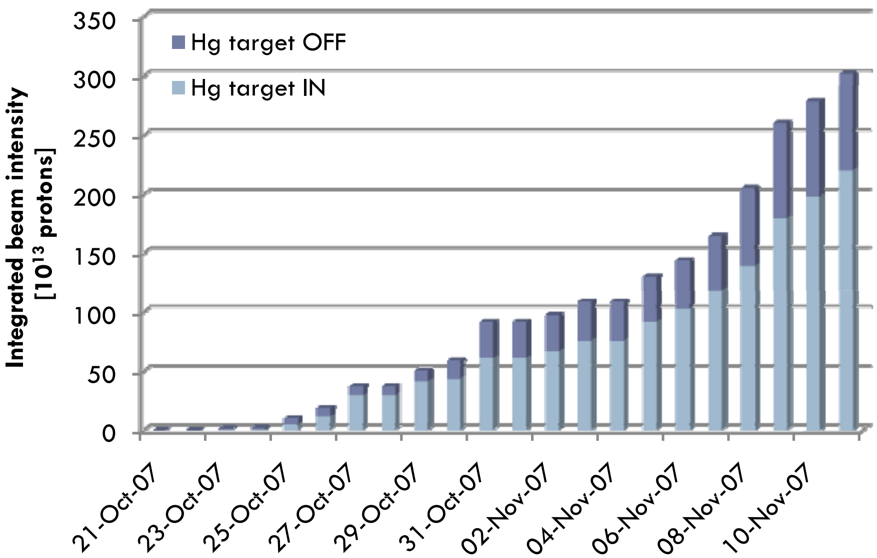
The MERcury Intense Target Experiment

Outline

- Introduction
- Experimental apparatus
- Analysis results

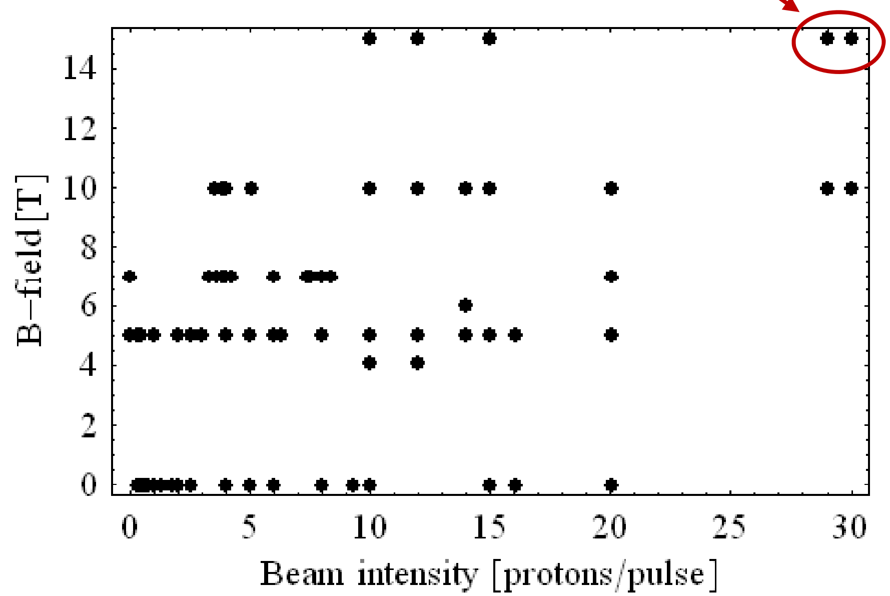
MERIT – Analysis results

Beam shots summary



30×10^{12} protons @ 24 GeV/c

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

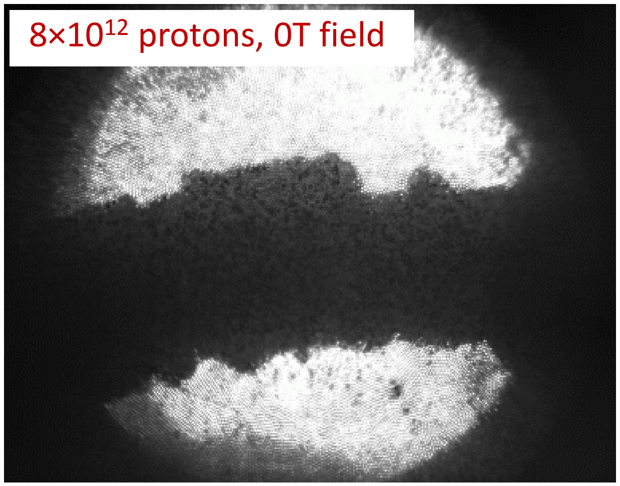


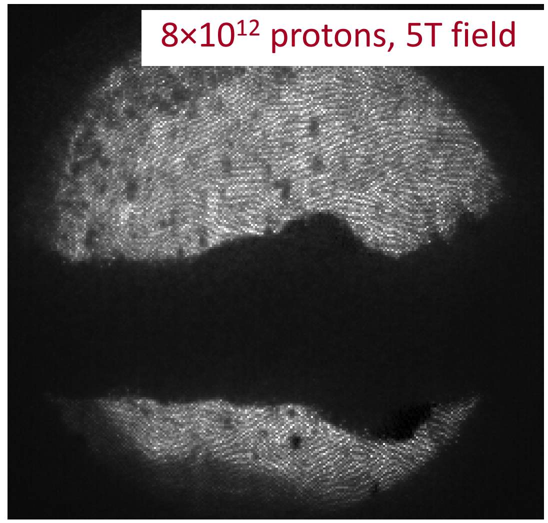
Beam *[GeV/c]*	Horiz. *[mm]*	Vert. *[mm]*	Spot *[mm2]*	Beam Density *[J/gr @ 30 TP]*
14	4.45	0.87	12.18	**80.4**
24	**2.94**	**0.66**	**6.13**	**160**

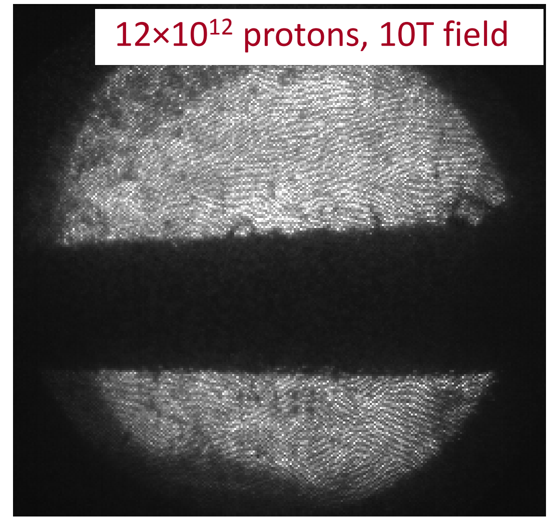
I.Efthymiopoulos, CERN

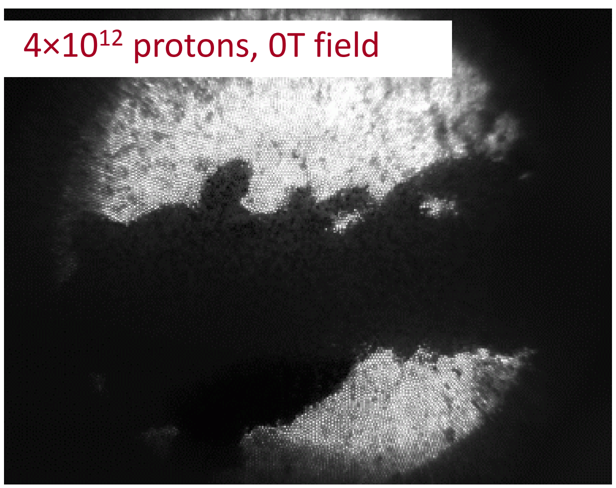
MERIT – Analysis results

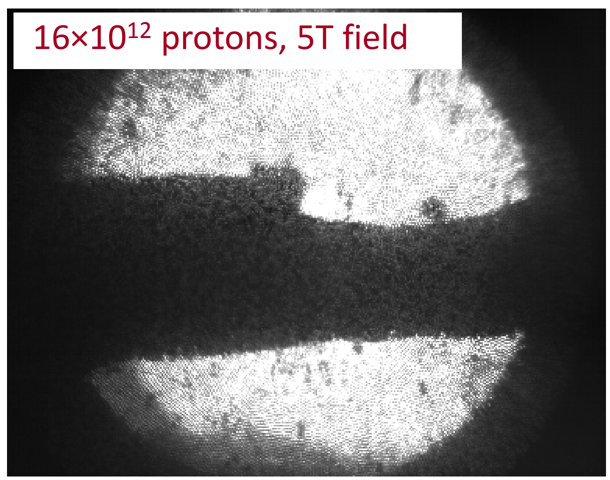
Beam-Hg-jet interaction examples – 14 GeV/c beam

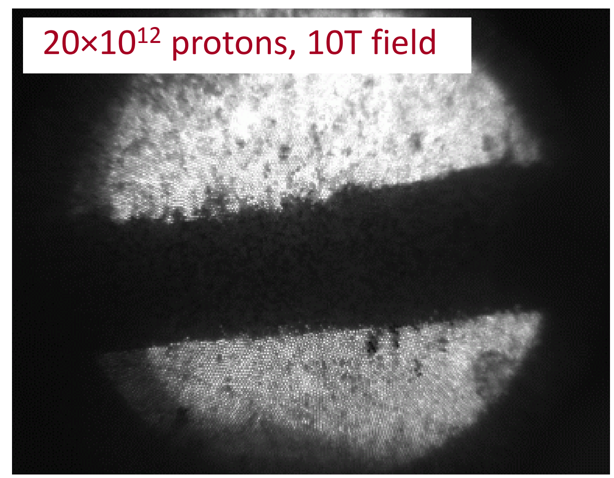

8×10^{12} protons, 0T field


8×10^{12} protons, 5T field


12×10^{12} protons, 10T field


4×10^{12} protons, 0T field

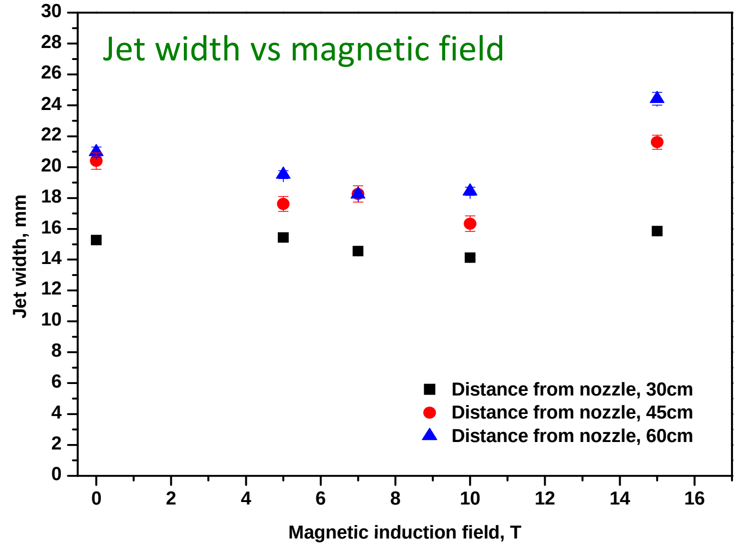

16×10^{12} protons, 5T field

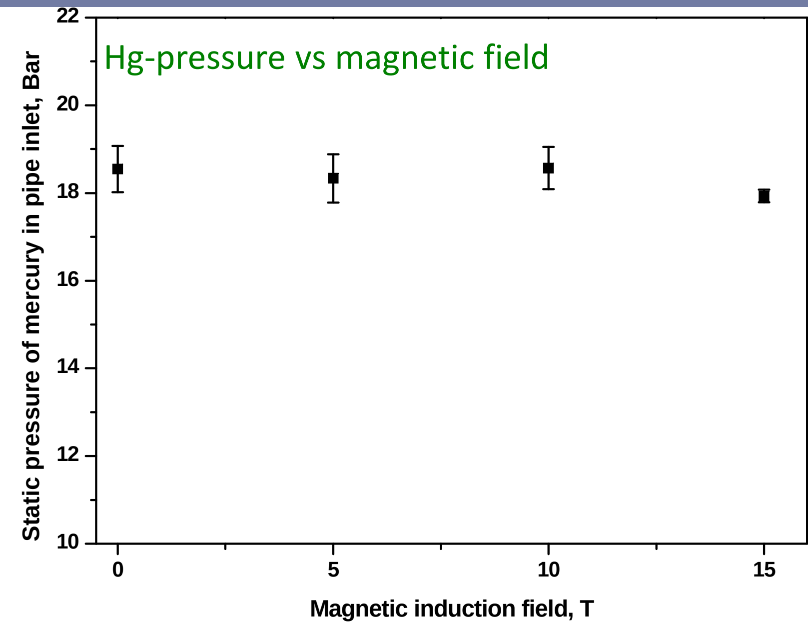

20×10^{12} protons, 10T field

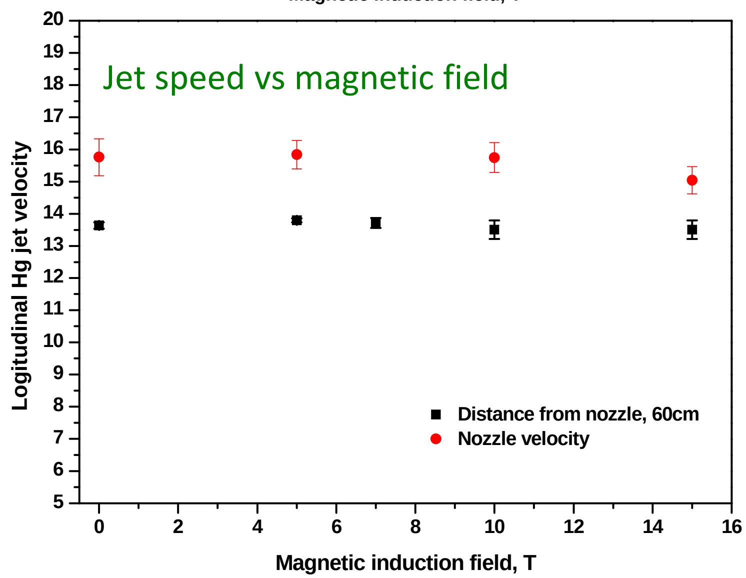
I.Efthymiopoulos, CERN

MERIT – Analysis results

16 Hg-jet properties without beam





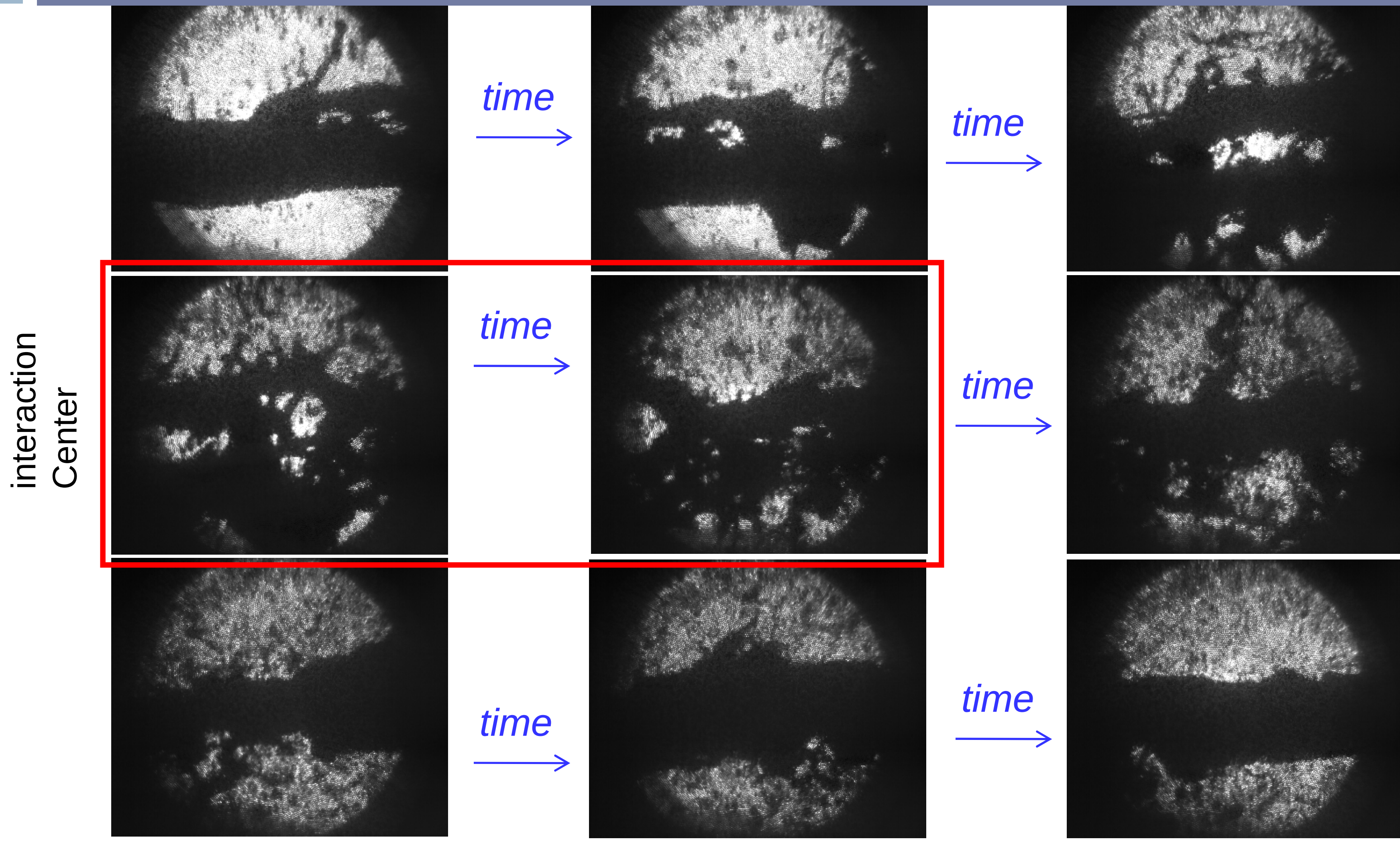


- Jet velocity not noticeably reduced on entering magnetic field.
- Pressure needed for v = 15 m/s does not increase with magnetic field.
- Vertical height of jet not affected by magnetic field – but the height is ≈ double the nozzle diameter.

I.Efthymiopoulos, CERN

MERIT – Analysis results

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

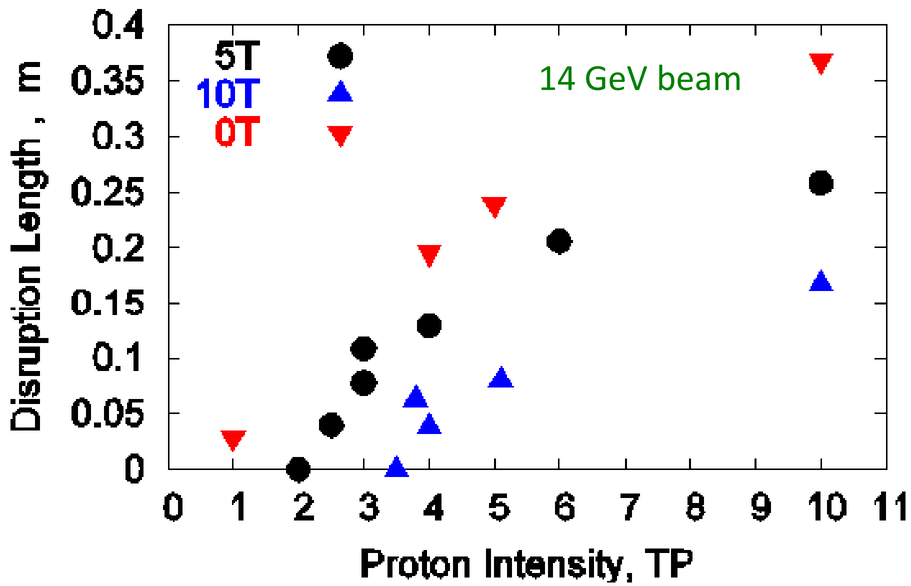


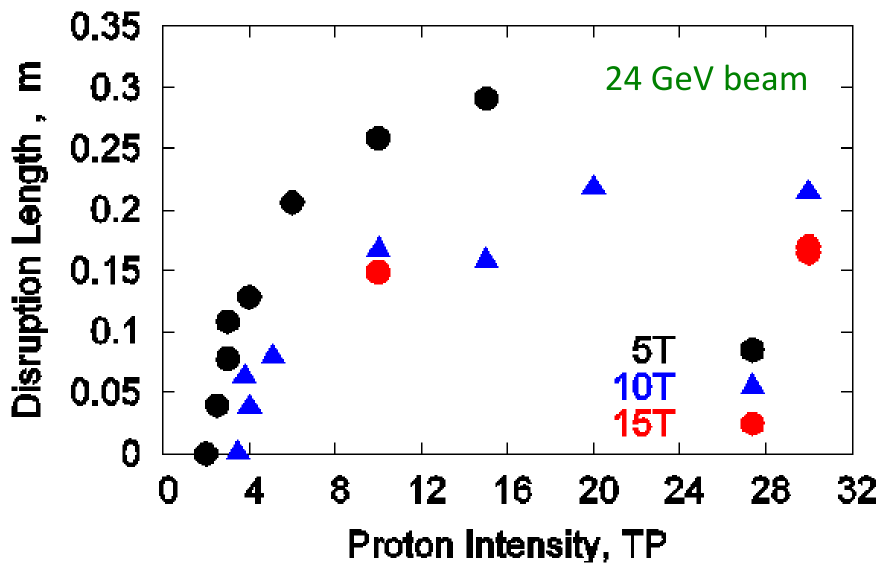
- Note disruption of top of jet at early times, and of bottom at later times.
- "Disruption length" inferred from number of frames the disruption lasts.

I.Efthymiopoulos, CERN

MERIT – Analysis results

Disruption length vs beam intensity

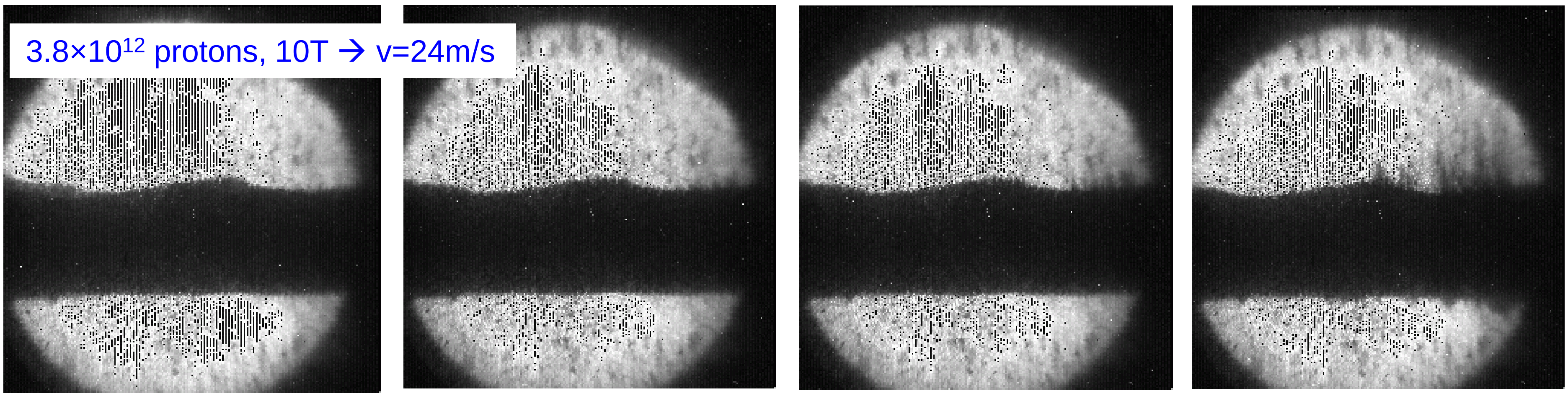




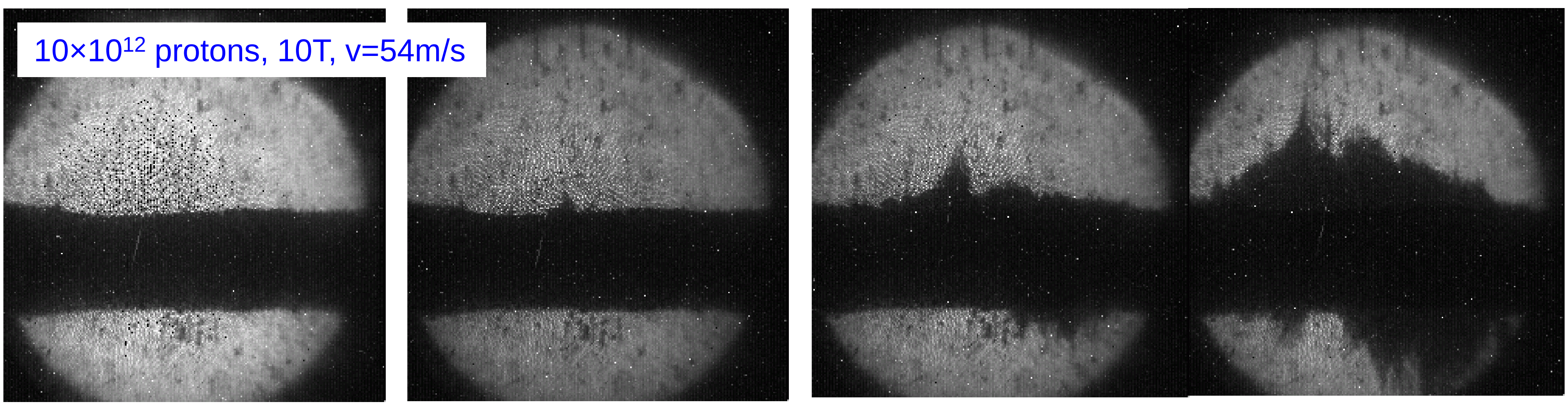
- Disruption length is never longer than length of overlap of beam and jet.
- Maximum disruption length same at 14 and 25 GeV/c.
- Disruption length smaller at higher magnetic field.
- Disruption threshold increases at higher magnetic field.

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*

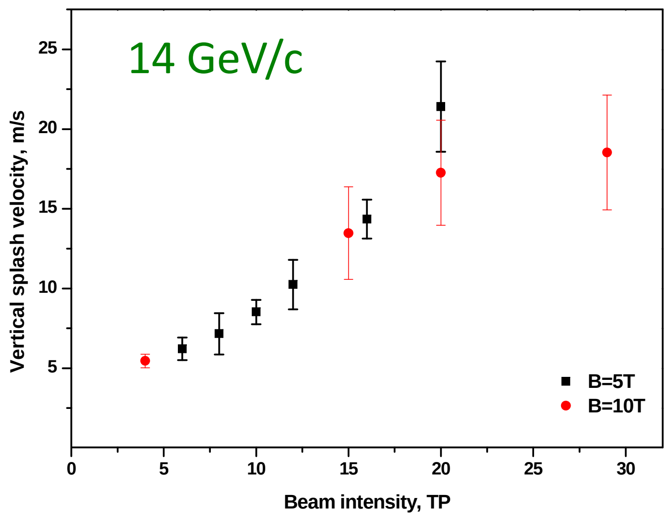


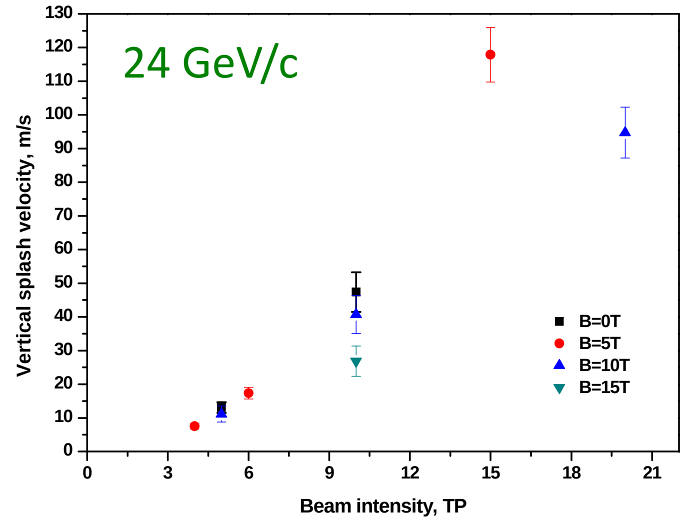
t = 0 *t = 0.075 ms* *t = 0.175 ms* *t = 0.375 ms*

I.Efthymiopoulos, CERN

MERIT – Analysis results

Jet Breakup Velocity Measurements

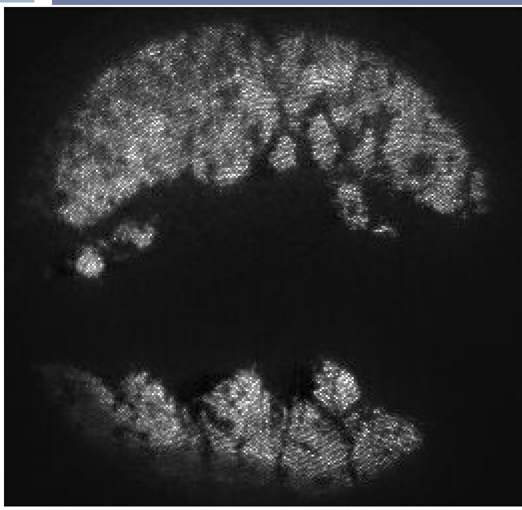




- Beam spot area at 24 GeV/c is (14/24) of that at 14 GeV/c.
- Beam intensity = energy/cm^2 is $(24/14)^2 \approx 3$ times greater at 24 than at 14 GeV/c.
- Measurements are consistent with model that breakup velocity$\propto$beam intensity.

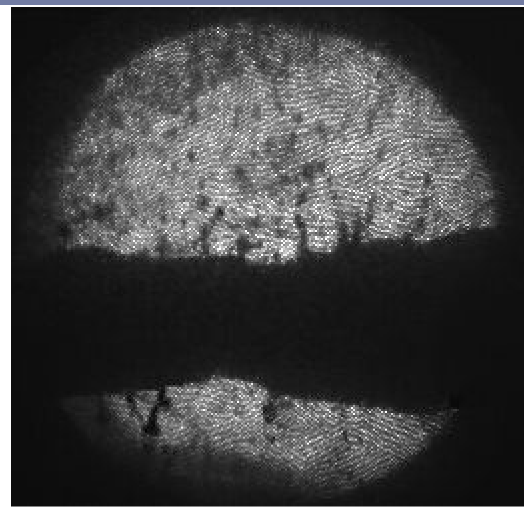
MERIT – Analysis results

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



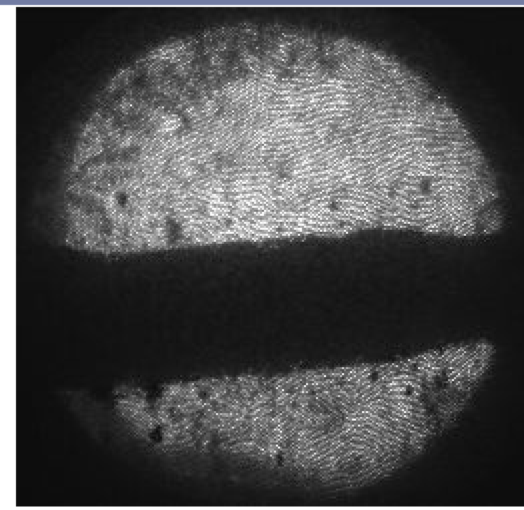
Δt = 0s

- single-turn extraction



Δt = 3.2 μs

- “probe extracted in subsequent turn



Δt = 5.8 μs

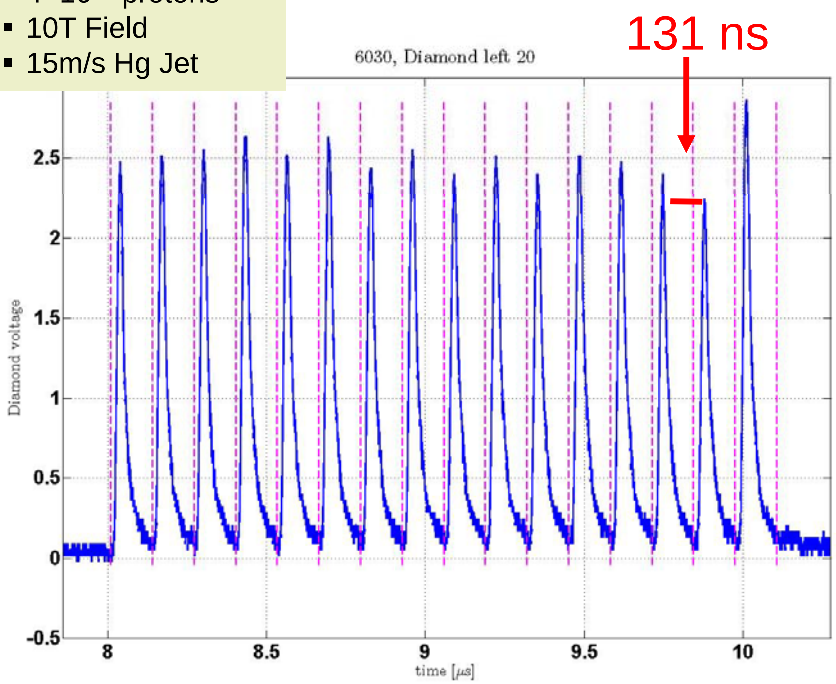
- “probe extracted after 2^{nd} full turn

- **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.*

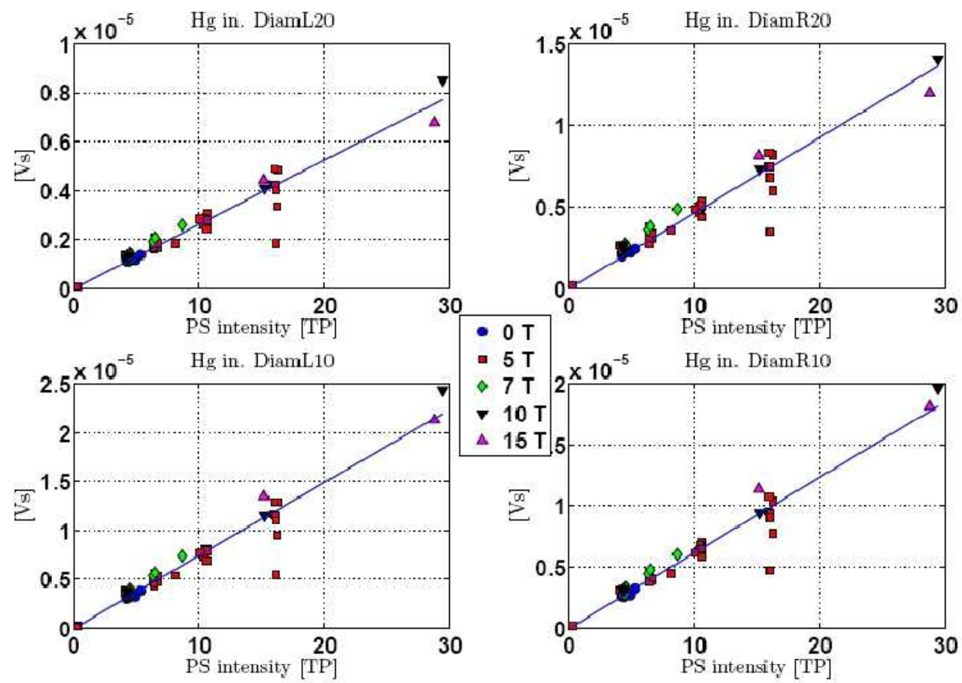
MERIT – Analysis results

Particle detector data – pCVD diamond detector response

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



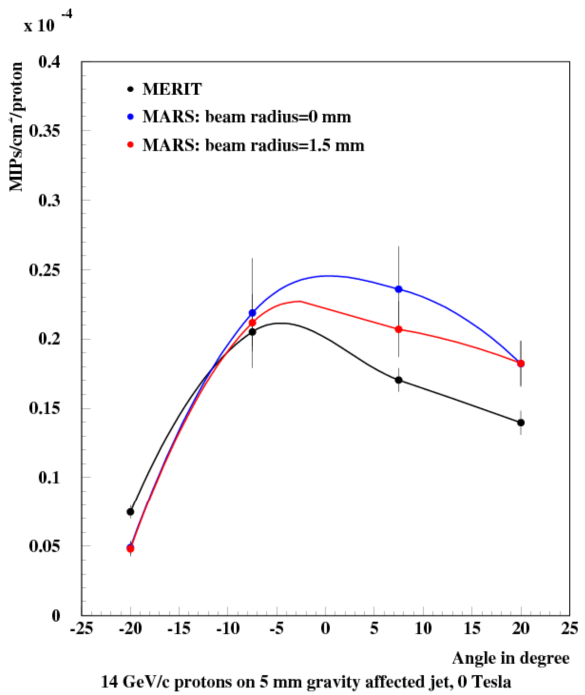
❑ Response linearity

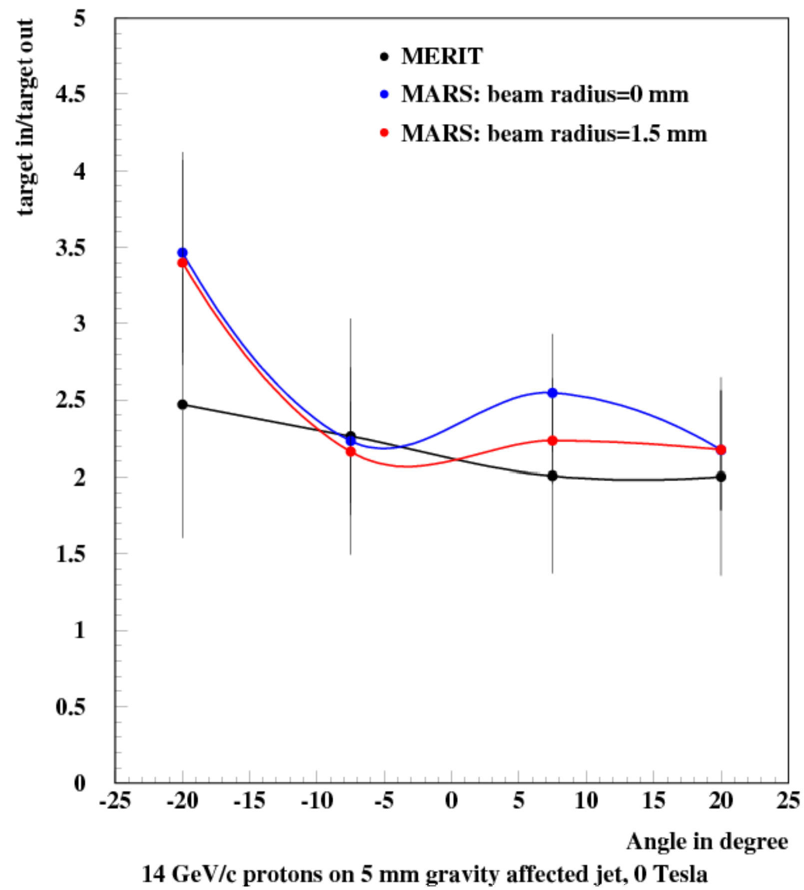


- ❑ Good performance
- ❑ Able to identify individual bunches event at the highest intensities
- ❑ Data analysis ongoing…

MERIT – Analysis results

Particle detector - flux measurement





- Good agreement with MC simulation
- Further analysis ongoing…

Summary

Spare slides