Development of High Resolution Radiotherapy Beam Characterization Technology Using Micropattern Gas Detection

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LDRD Proposal
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Proton Therapy for Cancer Treatment

Radiotherapy with a **proton beams** allows oncologists to design three-dimensional conformal cancer treatment plans that **minimize the healthy tissue damage**.

Fundamental nuclear physics: Bragg peak determines proton energy loss = dose to patient
- Enables higher precision, localized treatment
- Has fewer side effects due to reduced radiation outside the tumor region
- Nuclear physics technology to enable this includes simulation, acceleration, beam transport, **dose monitoring**.
- The nearby Hampton University Proton Therapy Center is one of the largest centers in the world, and provides most advanced, state-of-the-art beam delivery technologies.
Modulated Scanning

- Narrow proton beam is positioned laterally by scanning magnets for each energy layer
  - Dose delivered layer by layer **only to target area**
  - Beam shaping by
    - Scanning magnets in lateral direction
    - Active energy tuning in range
Proton Therapy for Cancer Treatment

>150,000 patients have been treated with particle therapy worldwide from 1954 to 2016.

Current average ~15,000 patients treated annually.

Proton Boom
Number of proton-beam therapy rooms world-wide

<table>
<thead>
<tr>
<th>Year</th>
<th>Rooms</th>
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<tbody>
<tr>
<td>2000</td>
<td>25</td>
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<tr>
<td>2005</td>
<td>50</td>
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<tr>
<td>2010</td>
<td>100</td>
</tr>
<tr>
<td>2015</td>
<td>175</td>
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Source: IBA
THE WALL STREET JOURNAL.

Tumor sites treated:
- **EYE & ORBIT**: Choroidal Melanoma, Retinoblastoma, Choroidal Metastases, Orbital Rhabdomyosarcoma, Localized Glied Carcinoma, Choroidal Hemangioma
- **ABDOMEN**: Pancreatic Tumors, Soft Tissue Sarcomas, Low Grade, Chordosarcoma, Chordomas
- **HEAD & NECK**: Locally Advanced Oropharynx, Locally Advanced Cervical Carcinoma, Soft Tissue Sarcomas, Recurrent or Unresectable, Misc. Unresectable or Recurrent Carcinomas
- **CHEST**: Non-Small Cell Lung Carcinoma, Early Stage, Metastatic Implantable, Breast Cancer, Soft Tissue Sarcomas
- **PELVIS**: Early Stage Prostate Carcinoma, Locally Advanced Prostate Carcinoma, Locally Advanced Cervical Carcinoma, Soft Tissue Sarcomas, Recurrent or Unresectable Pelvic Masses
Quality Assurance

✓ Most commonly done in homogeneous media
✓ Measurements
  ✓ ion chambers for absolute dose calibration
  ✓ profile measurements with film, array of chambers
Gas Electron Multiplier Detectors for Jefferson Lab Hall A Super Bigbite Spectrometer

GEM Detector:
- **UVA** & **INFN** production

GEM Electronics:
- **INFN** (Italy) production
- **UVA** testing and QA

**70 micron resolution**

**7 mm resolution**

IBA MatriXX ion chamber array, used for 2D beam characterization in proton and X-ray radiation therapy

Potentially excellent tool for (new) pencil beam scanning delivery – requires fast data acquisition
This Proposal: proton beam characterization GEM detection

• Develop 2D beam characterization detection technology based on Gas Electron Multiplier detection

• Construct prototype that
  — Bests the current industry standard spatial resolution (IBA MatriXX, for example) by ~an order of magnitude (Year 1 proposed)
  — Facilitates pencil beam delivery mapping (Year 2 proposed)
  — Can be calibrated for dosimetry

• Future applications beyond 2D beam characterization
  — Provide basis for proton CT development
  — Extend to X-ray radiation therapy (now have partnership in place for first medical linac measurements with Madison Accelerator)
Preliminary Data

• Transported small GEM detector from JLab nuclear physics experiment to HUPTI (with gas, DAQ, ….)
• Needed to establish voltage, thresholds, how to use in treatment room environment,…
• Very preliminary initial results look promising!

Beam profile measurements in 2D (left) and 1D (right) from proof-of-concept tests at HUPTI
This Proposal: Fast readout electronics (addressing review question)

- Develop fast electronic readout based on flash ADC
- Establish the proof of principle with commercial fADCs (e.g. V1742 modules)
  - Develop the interface between fast pre-amp and shaper chip interfaced with the V1742 module (Year 1 proposed)
  - Beam test with our 2D GEM beam profile prototype (~ few hundreds electronic channels) with the HUPTI proton beam (Year 1 & 2 proposed)
  - Demonstrate the viability of the system for the GEM-based 2D beam characterization detector
- Beyond the proof of concept
  - Develop a **low-cost** version of the fADC readout electronics for a multi-channel detectors application
  - Investigate options such as the DRS4 electronics for the low-cost, multi-channel fast electronics
  - Synergy with Nuclear Physics detector needs such as the development for GEM-based Transition Radiation Detector (GEM-TRD R&D) for EIC or other JLab experiments

CAEN V1742 flash ADC
This Proposal: Fast readout electronics

Characteristics of CAEN V1742 flash ADC

- 12 bit @ 5 GS/s, 1-unit wide 6U VME64 module
- Switched Capacitor technology based on the DRS4 chip (designed at Paul Scherrer Institute)
  - 1024 capacitor cells per channel (acquisition window of ~ 200 ns @ 5 GS/s)
- 5 GS/s, 2.5 GS/s, 1 GS/s, 750 MS/s software selectable sampling frequencies
- 32 analog input channels on MCX coaxial connectors
- 2 additional analog inputs (TR0 and TR1):
  - fast (low latency) trigger
  - digitizable for high resolution timing (up to 50 ps)
- 1 Vpp input dynamic range with programmable DC offset adjustment
- Dead-time due to conversion: 110 μs (analog inputs only), 181 μs (TR0, TR1 inputs)
- Trigger modes:
  - External on TRG-IN connector; common to all groups
  - Fast (Low Latency) on TR0 and TR1 connectors; common to couples of groups
  - Self-trigger, combinations of channels over-threshold in logic OR; common to couples of groups
- Memory buffer options: 128 events/ch; 1024 events/ch
- VME64 (VME64X compliant) and Optical Link communication interfaces
- Multi-board synchronization features
- 16 programmable LVDS I/Os
- Demo software tools, C and LabVIEW libraries

https://www.caen.it/products/v1742/

Pre-amplifier GAS-II as potential candidate

New interface board For GEM-TRD

- compatible with JLAB Flash-ADC 125MHz system
- Each board holds 10 preamplifiers, each preamplifier connects to 24 GEM strips resulting on a readout of 240 GEM strips per each readout board or X/Y coordinate.
- A pre-amplifier has 6AS-II ASIC chips (3 chips per each preamplifier card) and provides 2.6 mV/FC amplification. A preamplifier has a peaking time of 10 ns. It consumes 50 mWatt/channel and has a noise <0.3 fC. The dynamic range of preamplifiers (where it is linear) is about 200 fC.
- Covers up to 2.4 (32) μs of a drift time.