Status of GEM Trackers for Super Bigbite Spectrometer at JLab

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On behalf of the SBS Collaboration

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Outline

- GEM Trackers for Super Bigbite Spectrometer (SBS)
- Issues with large-area & light-weight GEM detectors
- APV25 readout electronics
The 12 GeV upgrade of CEBAF accelerator @ JLab

6 GeV CEBAF (< 2013)
Max Current: 200 \( \mu \)A
Max Energy: 0.8 - 5.7 GeV
Long. Polarization: 75-85%

12 GeV CEBAF
Max Current: 90 \( \mu \)A
Max Energy Hall A,B,C: 10.9 GeV
Max Energy Hall D: 12 GeV
Long. Polarization: 75-85%
Physics program in Hall A for the CEBAF 12 GeV era @ JLab

SBS physics program

- **GEP**: \(12 (\text{GeV/c})^2\)
- **GMN**: \(13.5 (\text{GeV/c})^2\)
- **GEN**: \(10 (\text{GeV/c})^2\)
- **SSA in nSIDIS**: 30,000 gain vs HERMES

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- **A1n/d2n** – gain ~ 20-30 compared with HMS/SHMS
- **TDIS** meson DIS
- **WACS-ALL**, full proposal, 100x gain in productivity
- **GENRP**, ready for full proposal, 10+x gain in productivity
- \(\text{pol } H(\gamma, p), H(\gamma, \pi^0 p)\)
- **PVDIS** – gain 10-15 compared with two HRSs
- A1p/d2p – gain ~20-30
- \(D(e,e'd) - A, T20\)
- J/Psi as gluon probe of QCD – well matched to BB/SBS
- \(A(e,e'p), A(e,e'\pi^+)\)

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**Neutron form factors, E12-09-016 and E12-09-019**

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**Proton form factors ratio, GEp(5) (E12-07-109)**

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**SIDIS experiment (conditionally approved)**

\[ e^+ + \text{He}^\uparrow \rightarrow e^' + \pi(K)\pm + X \]

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**Physics program in Hall A for the CEBAF 12 GeV era @ JLab**

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**10/13/2015**

**MPGD2015 Conference, Trieste Italy**
### Requirements for the Super Bigbite Spectrometer (SBS)

<table>
<thead>
<tr>
<th>Experiments</th>
<th>Luminosity (s·cm²)⁻¹</th>
<th>Tracking Area (cm²)</th>
<th>Angular (mrad)</th>
<th>Vertex (mm)</th>
<th>Momentum (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMn - GEn</td>
<td>up to $7 \cdot 10^{37}$</td>
<td>40x150 and 60x200</td>
<td>&lt; 1</td>
<td>&lt;2</td>
<td>0.5%</td>
</tr>
<tr>
<td>GEp(5)</td>
<td>up to $8 \cdot 10^{38}$</td>
<td>40x150, 60x200 and 80x300</td>
<td>&lt;0.7</td>
<td>~1</td>
<td>0.5%</td>
</tr>
<tr>
<td>SIDIS</td>
<td>up to $2 \cdot 10^{37}$</td>
<td>40x150 and 60x200</td>
<td>~0.5</td>
<td>~1</td>
<td>&lt;1%</td>
</tr>
</tbody>
</table>

**Most demanding**

Proton arm of the SBS in the Gep(5) configuration

- High rate
- Large area
- Spatial resolution < 100 microns

- Large luminosity
- Large acceptance
- Forward angles
- Re-configurable detectors
- Polarized Proton Target

High photon background up to 250 MHz/cm² and electron background 160 KHz/cm²

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**SBS GEM Trackers**

- **Front Tracker (FT): Track of the recoil protons**
  - 1st tracker: 6 GEM layers, active area of $150 \times 40 \text{ cm}^2$
  - Each layers: vertical stack of 3 GEM modules ($50 \times 40 \text{ cm}^2$)
  - Total production of 18 modules

- **Back Tracker (BT): Proton Polarimetry**
  - Polarization of the recoil protons
  - 2nd & 3rd Trackers: 10 layers, active area of $200 \times 60 \text{ cm}^2$
  - Each layer: vertical stack of 4 GEM modules ($60 \times 50 \text{ cm}^2$)
  - Total production of 40 ($+5$) modules
Assembly of the SBS Triple-GEM modules

Standard COMPASS triple-GEM

- Gain
- ~20
- ~20
- ~20
- ~8000

Assembly steps of the Front Tracker GEMs

- Module production fully established in INFN-Catania
- Electronics preliminary QA in Genoa
- Module integration and characterization in INFN-Sanità

Production rate: 2 modules in 3 months

- GEM Foils
  - HV curing and quality test
- Permagraph Frames
  - Visual Inspection
  - Ultrasound bath cleaning
- Stretching
- Gluing
- Clean room
  - Assembling gas lines
  - Put together (align on reference pins)
  - Glue Curing (~24 h)
  - Finalization (solder resistor, check HV)

Parts of the Back Trackers

Polarimeter GEM

- GEM foil with the visible contact of the HV sectors
- GEM foil in the Ns box for leakage current test
- GEM foil on the mechanical stretcher
- Support frame for GEM with 300 μm spacers inside the active area
- Frames on a custom holder for cleaning in Ultrasonic bath
- Two dimensional flexible readout board

Standard COMPASS 2D readout board

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SBS GEM modules

- Spatial resolution < 0.1 mm; high radiation tolerance
- Lightweight triple-GEM detectors (0.7% radiation length)
- Readout layer: 2D x/y strip ala COMPASS (0.4 mm pitch)
- APV25-based electronics with VME64x modules (total channels > 120K channels)

Production Status

Front Tracker GEMs

- 18 modules to be completed by mid 2017
- 8 modules already assembled with 4 tested
- One full layer integrated with APV25 cards @ JLab
- 4 layers expected by end 2016

Carbon fiber Holding frame
More compact and more rigid option
minimize thermal deformation
Production Status

Back Tracker GEMs

- 45 modules to be completed by mid 2017
- Production rate of 2 modules / month
- 19 modules successfully tested as of Oct. 2015

Holding frame:

- 4 modules: 2 modules sitting directly on the frame (bottom plane), other 2 modules on L-shape (top plane)
  - This minimizes dead area
  - And allow easy replacement of the modules and of the FE cards
- The holding frames are under production @ JLab
Performance in Test Beam

FT GEM modules high Intensity Proton beam in Julich COSY Test Beam (Oct. 2014)

• Study GEM response in high intensity proton beam (small spot ~ few cm²)
• Different dividers on different module
• Investigate HV and gas flow

• Efficiency slightly affected by the high beam intensity
• No noticeable effects from gas flow rate

2.8 GeV Proton Beam

4 x Large GEMs

Scintillator Pad-2

Black – low gain (m1)
Red – moderate gain (m2)
Green – normal gain (m3)
Blue – very low gain (m4)

Same HV, gas flow
1 - 16 V/h
Performance in Test Beam

BT GEM modules in Test Beam @ FNAL (Oct. 2013)

- Two SBS BT GEM prototypes tested at FTBF
- APV25-SRS electronic tested at trigger rate 400 Hz
- Data analysis for spatial resolution, gain efficiency, gain uniformity, timing of the APV25 signal ...
- FNAL test beam data reveals big issues (Gas flow, Quality of X/Y readout board etc)

Large GEM Test Beam Setup @ (FNAL) UVa & FIT

SRS + SRU Readout using DATE @ FTBF

- 64 APV’s read out by SRS
- Acquiring data from FECs with an SRU
- Current DAQ rate is ~150 Hz
- Using 6-9 25ns time slices for digitization
- Beam structure: 4s spills, 1min rep.time, 10 - 20 particles/spill
- Trigger: coincidence of 3 scintillators
Performances in test Beam

Hadron beam reconstruction

Charge sharing

Efficiency curve vs. HV

Gain uniformity

Spatial resolution


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GEM Trackers for Super Bigbite Spectrometer SBS

Issues with large-area & light-weight GEM detectors

APV25 readout electronics
Deformation of the readout board

Analysis of the APV25 signal timing from the FNAL Test Beam data

- We looked at the spatial distribution of the APV25 signal peak w.r.t. the trigger delay (arbitrary reference)
- Strong spatial non-uniformity of the signal timing → Induced charge signal collected later by the readout strips in the center of the detector than at the edges.
- Difference as high as 4 time bins (100 ns) between center and edges
- Excellent timing correlation of the signal in x-strips and y-strips → the readout electronics not the source

**Cause:** Deformation of the readout board due to over pressure caused by the gas flowing inside the detector
Deformation of the readout board

Measurement of the deformation of the readout board

- Setup of a test (see cartoon on the left) to measure the bending of the readout board (honeycomb support) with the Ar/CO₂ flow rate inside the chamber
- Measurement were taken at 4 location on the bottom side of the honeycomb support
- The measured deflection of 100 units is equivalent to 2.54 mm
- A gas flow = 10 units represent about 2 volumes (V) change / hour in the GEM chamber (V = 3.6 L)
Deformation of the readout board

**Measurement of the deformation of the readout board**

Bending of the readout at flow = 5

Bending of the readout at flow = 10

Bending of the readout at flow = 15

Gas flow: 10 units = 2 volumes (V) change / hour; Measured deflection: 100 units = 2.54 mm

- APV25 signal peak time bin measured with Sr90 source at different flow rates.
- Amplitude of the non-uniformity depend on the gas flow (more precisely built-up pressure in the chamber)
- Clear correlation between the time bin of signal peak and the deformation of the readout board
Deformation of the readout board

Solution: Compensate the deformation of the readout board with a bottom gas volume

- Adding the bottom gas window significantly reduce considerably the spatial non uniformity of the signal speak time bin at high gas flow rate
- In addition, we also slightly change the gas flow design of the chamber to reduce the pressure built-up inside the chamber

![Graph showing spatial non-uniformity comparison with and without bottom gas window]
Entrance gas window foil collapse

Problem

- High particle rate over a large area of the detector $\Rightarrow$ charging up of the Kapton foil $\Rightarrow$ Strong electrostatic attraction between gas window & drift cathode
- Strong distortion of the APV25 signal (timing and shape)

Initial proposed solution

- A simple initial fix was to add some spacers in the gas window region of the chamber
- We saw a improvement but not sure about long term stability of the fix in high rate condition
Entrance gas window foil collapse

Final proposed solution

- Use aluminized gas window foil and set it to the same potential as the drift cathode → Faraday cage like to prevent charges accumulation on the gas window as well as the top layer of the drift
- Tested with SBS-BT-GEM with x-ray source at high rate > 1 MHz /cm² equivalent MIP.
  - Without the HV on the gas window ⇒ foil collapse after a few hours of x-ray exposure
  - With the HV on, we did not observe any collapse after 5 days of almost continuous exposure
Outline

- GEM Trackers for Super Bigbite Spectrometer SBS
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- APV25 readout electronics
Readout electronics for SBS GEM Trackers

Main features:

- Use analog readout APV25 chips (> 100 k Channels)
- 2 actives components: APV25 Front end cards & VME64x module: Multi Purpose Digitizer (MPD)
- HDMI cables to transfer data between these two components
APV25 FE cards and Back planes

Different versions of the APV25 FE card produced

- v 4.10 with ZIF connectors for the FT Modules
- v 4.11 with Panasonic connectors for BT Modules

Different versions of the back planes

- 2 types for the Back Tracker GEMs: 5 and 12 slots
- 1 type for the Front Tracker GEM: long 5-slots

v 4.0
Front Tracker GEM

v 4.11
Back Tracker GEM (UVa)
Multi Purpose Digitizer (MPD) card

- VME64x board perform the digitization of analog signals from the FE cards and handle the slow control signals
- DDR2 (128 MB), 110 MHz system clock
- Compliant with JLab VME64x VITA 41 (VXS) standard
- 6 HDMI-A connectors for data and control signals
Long (23 m) HDMI cable effects on APV25 analog signal

- The large «binary» information (digital header) at the beginning of the analog signals of the APV introduce a large noise on the first (~20) channels of the frame
- Longer the cable larger the noise, higher the number of channel involved
- Belle (2012 JINST 7 C01082) proposed a 8-parameter FIR filter (12 m long cables) in firmware
- We added an off-line pedestal subtraction dependent on the digital header value (LUT suppression): very noisy channels largely recovered

Ideally must be a «delta»

Improved but not completely corrected
Summary

- The Hall A equipment for the 12 GeV Upgrade of the CEBAF at JLab is the Super Bigbite Spectrometer (SBS).
- The 3 tracking stations of the SBS are equipped with large area and light weight GEM detectors.
- The construction and commissioning of all 60 GEM chambers is ongoing at University of Virginia and at INFN Catania & Roma.
- The MPD system, an APV25-based readout electronics is developed at the University of Genoa to read out the GEM trackers.
- The MPD is compliant with the JLab VME64x VITA 41 (VXS) standard.