SBS software and tracking update

Eric Fuchey
University of Connecticut

Hall A collaboration meeting
Jefferson Lab, January 24-25, 2018
Overview

SBS Software Project:
- Overview;
- Milestones.

Tracking progress:
- Improvements and adjustments;
- Summary and next steps.

SBS Software progress:
- Digitization and analysis;
- HCal digitization;
- Summary and next steps.

Summary
Super BigBite spectrometer:
**one of the major new projects** for Hall A @ 12 GeV (with Moller and SoLID):
Medium solid angle spectrometer with a *modular* detector package behind a dipole magnet.
=> Many new subsystems with large nb of channels / events sizes (wrt Hall A standards)
Earliest run start: **2020, 189 (+27 cond.) running days approved**;
=> major occupation for Hall A collaboration for **many years**.

Physics programs:
- Form factors at *high* $Q^2$:
  * $G_M^n (L_D^2)$, $G_E^n (\text{pol. } ^3\text{He})$;
  * $G_E^p (L_H^2, \text{recoil pol})$;
  * $G_E^n (L_D^2, \text{recoil pol})$;
  (=> See John's slides);
- Semi-Inclusive DIS ($^3\text{He}$);
- Tagged $\pi$, $K$ DIS;
=> Major physics impact;
(Good opportunity for grad students, young postdocs to join)
=> *challenging measurements*: high luminosities, high detectors and DAQ rates;
**SBS Software Project:**

**SBS Software project overview**

* Major goal: "End-to-end" simulation: production of pseudodata + simulation of data sizes;
  * Both simulation and analysis framework need to be:
    → modular (ease configuration changes);
    → accessible (ease handling for new people);
    → flexible (ease inclusion of new configurations);
  * Also need:
    - Well defined IO formats and standards
    - Flexible database to accomodate both MC and data (SQL ?);
  * Requires significant coordination between working subgroups
    → 1 dedicated software meeting every 2 weeks
      (in addition to SBS weekly meeting).
    + About to migrate to e.g. Redmine for project management

* **Well defined responsibilities and milestones** (next slide)

**Strong requirement:**

*Online and offline analysis both need to be ready and tested, and pseudo-data sets have to be analyzed before data taking* (likely spring/fall 2020).

=> critical given high luminosities / high detectors and DAQ rates.

G4SBS simulation is up and running, and has already produced useful and compelling results (e.g. G\textsubscript{\textmu}E\textsubscript{R}R last summer *).

We have since then set our focus on its interface w/ analysis.

(* see my slides from Summer '17 Hall A/C collaboration Meeting)
SBS Software Project: 
SBS Software milestones

Rebaselined milestones, taken into account accelerator planning change, actual progress on software and manpower:

- **Nov 2016**: Software review
- **Jan 2017**: Start digitized simulation output (first focus on GEMs)
- **Apr 2017**: Decoder for all DAQ modules written
- **Jul 2017**: Each detector system in analyzer, experiment configurations, basic reconstruction algorithms
  => can analyze channel-level raw data at this point
- **Jun-Jul 2018**: Simulation interfaced to analysis; Have detector event displays, calibration scripts
- **Jul 2018**: Start simulated analysis for detector reconstruction
- **Jan 2019**: Begin simulated experimental analysis for core Form Factors (FF) experiments
- **Jun 2019**: Ready for beam for FF experiments, start simulated experimental analysis for SIDIS and TDIS

- **Spring 2020**: likely earliest start of neutron experiments
- **Spring 2021**: likely earliest start for Gep
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Summary
Reminder about GEM trackers:
Gas ionizing detectors
GEM readout by 400 µm strips

\[ \Rightarrow 40.96 \times 51.20 \text{ cm}^2 \text{ GEMs} = 1024 \times 1280 \text{ strips}; \]

The strips will be recorded by APV25 (128 strips/chip)
6 ADC samples of 25ns each are recorded for each strip
→ pulse shape;

Of course, 1 hit spreads on many strips \( \Rightarrow \) clustering
Tracking progress
Improvements and adjustments

GEM digitized strip by strip: use 6 ADC samples per strip;

Strip ADC calculation changed from deconvolution of first 3 samples to sum over the 6 samples;

Tuned digitization algorithm and database to match ADC spectrum and hit size with cosmic data;

(Plot credit: Danning Di, SBS weekly, 2017/11/15)
Tracking progress
Improvements and adjustments

Added a 25 ns APV-trigger "jitter" to the strips timing, to translate that APV chip and trigger time are not in sync;

![Diagram showing APV clock and trigger time with 25 ns jitter]

Implemented pulse shape fitting to determine the timing for each strip;

(Plot credit: Danning Di, SBS weekly, 2017/11/15)
Last summer:

The full simulation → digitization → analysis → analyzed data (clusters, tracks) was functional

What has been done since then:

- Added subdivision of “GEMPlane” (called "module"), to *allow for transverse segmentation* of one plane within one tracker, in both digitization and Treesearch library (did not exist before)

- Tune digitization database and digitization code to have simulated digitized hits similar to cosmic data ;

- Implement pulse fitting on sampled ADC to extract timing, and integrate ADC (instead of deconvoluting it), in compliance with what will be done for the experiment;
TO-DO:

- Implement common mode (pedestal shift per APV) in digitization and common mode subtraction in Treesearch library; => This is necessary before we run digitization with background data.

- Improve cluster separation method: Add timing information to currently existing peak-valley-peak method ; => This is very important to analyze data with huge backgrounds.

- Cross talk removal in Treesearch library ;
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Summary
SBS Software progress: Digitization (in progress)

Purpose: Evaluate electronic response (ADC, TDC...) from G4SBS simulation output
First step to interface simulation with analysis

- **Input:** Geant4 File
  - TSBSGeant4File + g4sbs_tree
    - Unfolds Geant 4 file
- **Digitization library**
  - TSBSDBManager
    - Manages most databases
  - TSBSCherData
    - Internal data container
  - TSBSCher+TSBSSpec
    - Spectrometer and Detector classes
- **Database class structure**
  - (includes only Cherenkov so far)
  - db_generalinfo.dat
    - General library info
  - db_spec_name.dat
    - Geometry information (NB: of the PMT matrix)
  - db_ratedig.dat
    - Digitization parameters
  - db_run.dat
    - Run info
- **Output:** Digitized info / chan (ADC, TDC,...)
  - TSBSSimDecoder
    - Necessary to decode the digitized output
  - TSBSSimCherDigitization
    - Digitizes the Cherenkov data: Evaluate both TDC digital values, using the MC hit time and Npe, assuming the PMT pulse shape
  - TSBSSimEvent
    - Holds output data structure
SBS Software progress: Digitization (in progress)

Example of the GRINCH: Cherenkov detector readout by 510 PMTs (see Todd’s talk)
GRINCH PMTs will be readout by NINO cards => record TDC values for PMT rise time and fall time (pulse amp. goes resp. over/under NINO thr ; estimation of pulse amp. with Time-over threshold).

To evaluate the times $t_r$ and $t_f$ at which the pulse will go over/under the threshold, we have modeled a normalized pulse shape (left);
We calculate tables for a given threshold, over a wide span of amplitudes (right)

* Values plugged in the digitization library.
* Exponential extrapolation between 2 points to calculate $t_r$, $t_f$ for any given amplitude;
* Easy to redo these tables provided a new pulse shape function or threshold;
SBS Software progress:
Digitization (in progress)

Example of the GRINCH: Cherenkov detector readout by 510 PMTs (see Todd's talk)
GRINCH PMTs will be readout by NINO cards => record TDC values for PMT rise time and fall time (pulse amp. goes resp. over/under NINO thr; estimation of pulse amp. with Time-over threshold).

TDC times (relative to trigger time), NINO threshold: 3mV, Gain: $7 \times 10^6$

No background
**SBS Software progress:**

**Analysis steps after Digitization (in progress)**

 Example : **Data analysis steps for GRINCH** (under development) :

- **SBSSimDecoder** to attribute to each hit its corresponding crate/slot/channel number
  => **Exists for GEMs**, being written for Cherenkov detectors, does not exist yet for Scinti, ECals;
  + we consider pulling SimDecoder out of the digitization library.

- **SBS-offline: Data decoding** (build the elemental hits from the raw/digitized data) + **Processing** (e.g. for GRINCH : clustering, cluster association with tracks, etc) in relevant detector class:
  => **exists in principle for all subsystems**, but may need some rewriting depending on the subsystem
  => **operational for GEMs**, almost operational for cherenkovs, need to be worked out for Scinti, ECals.
SBS Software progress:
HCal digitization (in progress)

HCal digitization is a special case: it cannot be digitized directly with the existing g4sbs output (g4sbs HCal hits are integrated to 1 hit/chan/evt, which is too "rough" for FADC250).

Digitizing HCAL PMT signal in G4SBS
Build up simulated PMT signal for N photo-electrons using model of single-photo-electron.

- Use a model of an ideal single photo electron pulse.
- Not as realistic, but no timing corrections need to be performed.
- Easier to work with a TSpline.

I found this model that Vahe when he was working on the Light Guide design.

I don’t know the details of exactly how he made this one.

It can either be fit to many single-pe or just used Polya statistics to make it.
SBS Software progress:
HCal digitization (in progress)

Early comparisons of HCal digitization with real cosmics
This is what a simulated signal looks like when built out of 309 photo-electrons

(Slide from Juan Carlos Cornejo, SBS soft/simu, 2017/12/13)
First attempt at timing with G4SBS (cosmic muon)

- Very basic timing by getting time of first bin above threshold.
- Need to do time-walk correction, and hope to get better timing with that.

(Slide from Juan Carlos Cornejo, SBS soft/simu, 2017/12/13)
SBS Software progress:  
Summary and next steps

What has been done:

- The digitization library has been set up and is now mostly functional for Cherenkov detectors.

- The analysis for the GRINCH detector is mostly rewritten; the full chain should be functional soon for this specific detector;

- The digitization process for HCal is being worked out on its own; the interface between digitized simulation and SBS-offline still needs to be written.

TO-DO:

- Add in the library the digitization for other subsystems: Scintillators (hodoscope, CDet), ECals (Gep ECal, BB Ecal), and work out their respective analysis chains;

- At some point, merge the digitization library with the GEM digitization library, and the TreeSearch to the SBS-offline;

- Refine the digitization: Pedestal noise, cross talk, properly manage background addition (pile-up), etc.
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Summary
Summary

* Milestones have been rebaselined, based on accelerator schedule, actual progress and manpower;

* There is still long way to go: *Everyone is welcome to join!*

* The GEM digitization and TreeSearch algorithm keep being improved; (thanks Danning)

* Main focus is now on digitization and analysis of subsystems; (myself + thanks Juan Carlos for HCal)

* In near future, will also focus on calibration scripts and event displays; for them to be ready this summer
Thank you for your attention!
# Software/simulation organization: responsibilities

## General purpose software

<table>
<thead>
<tr>
<th>Activity</th>
<th>Contact</th>
<th>Supporting groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzer development</td>
<td>O. Hansen</td>
<td>(JLab)</td>
</tr>
<tr>
<td>Front-end decoders</td>
<td>A. Camsonne</td>
<td>(JLab)</td>
</tr>
<tr>
<td>Event Reassembly</td>
<td></td>
<td>JLab DAQ group</td>
</tr>
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</table>

## SBS specific

<table>
<thead>
<tr>
<th>Activity</th>
<th>Contact</th>
<th>Supporting groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repository maintenance</td>
<td>S. Riordan</td>
<td>JLab</td>
</tr>
<tr>
<td>Simulation maintenance</td>
<td>A. Puckett</td>
<td>UConn</td>
</tr>
<tr>
<td>MPD decoding</td>
<td>S. Riordan</td>
<td>SBU, JLab, UVA, INFN</td>
</tr>
<tr>
<td>GEM Tracking</td>
<td>A. Puckett</td>
<td>INFN, JLab, UConn</td>
</tr>
<tr>
<td>HCal Analysis</td>
<td>G. Franklin</td>
<td>CMU</td>
</tr>
<tr>
<td>ECal analysis</td>
<td>A. Puckett</td>
<td>UConn</td>
</tr>
<tr>
<td>CDet analysis</td>
<td>P. Monoghan</td>
<td>CNU</td>
</tr>
<tr>
<td>GRINCH analysis</td>
<td>T. Averett</td>
<td>W&amp;M</td>
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<tr>
<td>BigBite analysis</td>
<td>S. Riordan</td>
<td>JLab</td>
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</table>

## Experimental analysis

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<thead>
<tr>
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</thead>
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<tr>
<td>GMn</td>
<td>B. Quinn (CMU)</td>
<td>Bigbite, HCal</td>
</tr>
<tr>
<td>GEn</td>
<td>S. Riordan (SBU)</td>
<td>Bigbite, HCal, 3He target</td>
</tr>
<tr>
<td>GEp</td>
<td>E. Cisbani (INFN)</td>
<td>ECal, CDet, SBS w/ FT, FPPs GEM trackers</td>
</tr>
<tr>
<td>SIDIS</td>
<td>A. Puckett (UConn)</td>
<td>Bigbite, SBS w/ GEM trackers and RICH</td>
</tr>
<tr>
<td>TDIS</td>
<td>D. Dutta (SBU)</td>
<td>SBS e – w/ GEM trackers and RICH, LAC, RTPC</td>
</tr>
</tbody>
</table>
Tracking progress

Improvements and adjustments

Detector modelling $\Rightarrow$ Current BigBite Tracker layout
(digitization+analysis)

- Add “module” concept in both digitization and Treereach library so that “plane” collect hits decoded from “modules” and function as a tracking plane
- Save “moduleID” in each hit for later 2D track matching
- New database format

(Slide from Danning, SBS weekly, 2017/11/15)
Tracking progress
Improvements and adjustments

Detector modelling =>
(digitization+analysis)

Old BigBite Tracker layout

Plane_1  Plane_2  Plane_3  Plane_4
Tracker_1  Tracker_2  Tracker_3

Hall A tracker had no subdivision, the "GEMplane" function as a detector and tracking plane

- Track A reconstructed
- Track B lost
Tracking progress
Improvements and adjustments

Reconstructed hits after layout change

- INFN Plane size: (3x50cm)x40cm
- Edge of modules can be seen due to lost strips at the edge of module

(Plot credit: Danning, SBS weekly, 2017/11/15)
To evaluate the times $t_r$ and $t_f$ at which the pulse will go over/under the threshold, we need to know the pulse shape and its amplitude (see below);

The goal is to retrieve the GRINCH PMT timing characteristics (right panel), which has required the convolution of a exponentially decreasing function $t/\tau^2 \exp(-t/\tau)$ with a gaussian.

Another issue is the normalization of this pulse, to evaluate at which moment it will cross the threshold.

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**GRINCH PMT pulse shape**

To evaluate the times $t_r$ and $t_f$ at which the pulse will go over/under the threshold, we need to know the pulse shape and its amplitude (see below);

The goal is to retrieve the GRINCH PMT timing characteristics (right panel), which has required the convolution of a exponentially decreasing function $t/\tau^2 \exp(-t/\tau)$ with a gaussian.

Another issue is the normalization of this pulse, to evaluate at which moment it will cross the threshold.
GRINCH PMT pulse normalization

The pulse integral contains $N_{pe} G_{PMT}$ electrons, or $N_{pe} G_{PMT} q_e$ coulombs.
Hence, the pulse function shall be an intensity function $I(t)$, which just needs to be multiplied by the readout impedance $\Omega_{RO}$ to obtain a voltage function $V(t)$.

PS: yes, my scale is in ns, and I have taken this into account in the normalization. I get a similar pulse height if I use scale in seconds (instead of ns).

If this is normalization is correct, then it means the threshold should be lower (2-3 mV).

If this is normalization is correct, then it means the threshold should be lower (2-3 mV).
Option 1 for digitizing HCAL PMT Signal in G4SBS

- Build up simulated PMT signal for N photo-electrons using model of single-photo-electron.
- Use scope images for single photo-electrons (Vahe took this using scintillator and one PMT).
- Can be more realistic since at single-pe pulses look very jagged
- Has 5 ps resolution.
- Need to be start time corrected.

(Slide from Juan Carlos, SBS soft/simu, 2017/12/13)
Early comparisons of Option 2 and real cosmics

- I am benchmarking using Option 2 (since it proved to be easier to work with) to simulate real cosmic data on a single HCAL module.
  
- Vertical module with two trigger scintillators above and below.
  - Positioned so that muons do not go through Wavelength Shifter

- Used similar setup in G4SBS and used gun to generate 4GeV muons.

- Took only muons that passed through similar region defined by trigger scintillators.

(Slide from Juan Carlos, SBS soft/simu, 2017/12/13)
SBS Software progress: HCal digitization

 Cosmic data timing (using NINO and Leading Edge)

Here is an example from Cosmic data (Left to graphs are using NINO, Right two graphs are using a leading edge discriminator)

(Slide from Juan Carlos, SBS soft/simu, 2017/12/13)