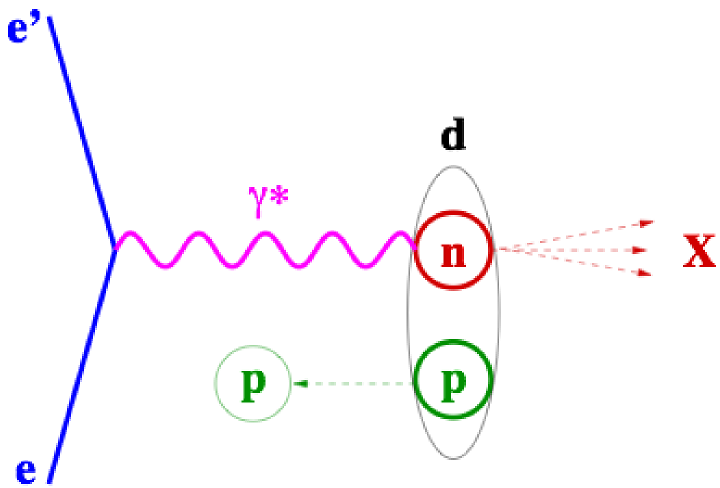
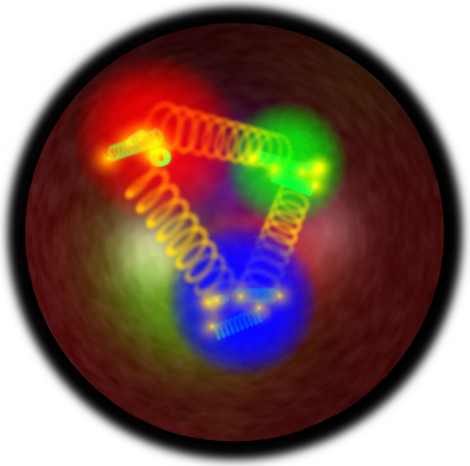
Status Report on BONuS12 Preparation

(E12-06-113, CLAS12 Run Group F)

M. Hattawy
Old Dominion University





DPWG, CLAS Collaboration Meeting, July 10-13, 2018

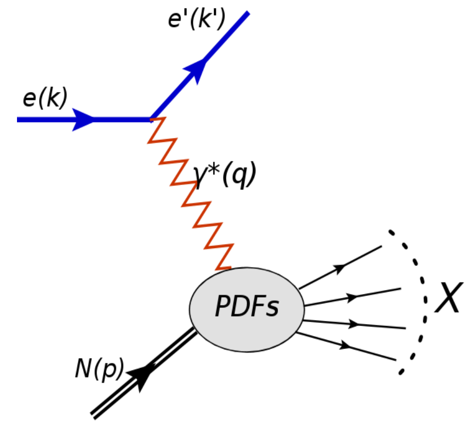
Outline

- BONuS12: The Structure of the Free Neutron at Large x-Bjorken.
- Experimental Setup and Recoil Detector.
- BONuS12 Subgroups.
- Updates on:
  - Detector Design.
  - Simulation and Tracking.
  - Prototyping and Testing.
  - Gas and Slow Controls.
  - CLAS12 Integration.
- Other Physics Topics Accessible with BONuS12
- Conclusions.

Nucleon Structure (1/2)

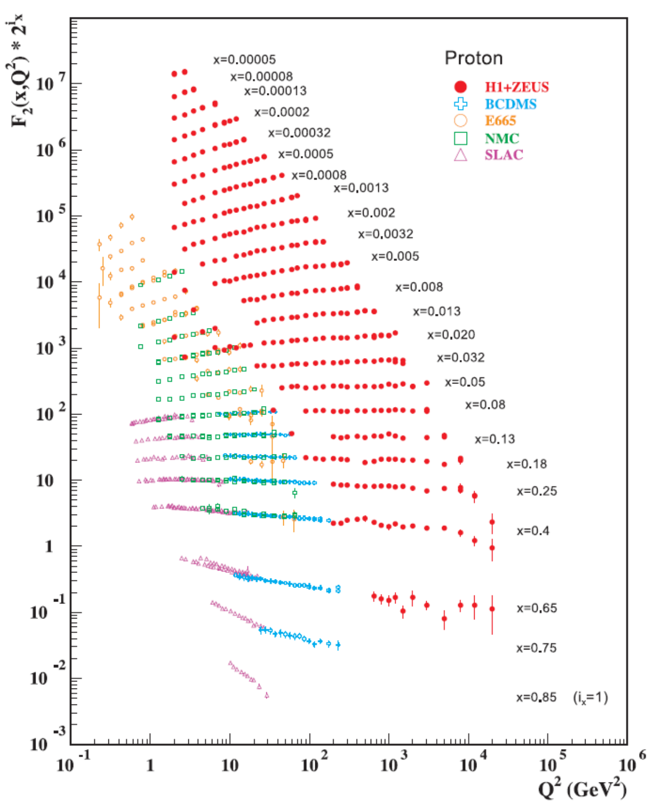
Parton Distribution Functions (PDFs)

→ Provide information on the partons longitudinal momentum distributions
→ Measurable via Deep Inelastic Scattering (DIS).



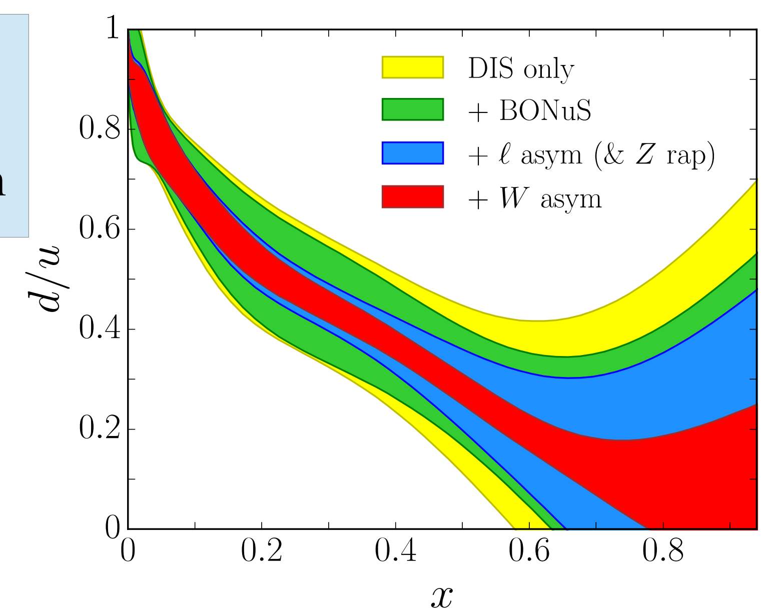
- For nucleons, the unpolarized DIS cross section is parametrized by two PDFs: $F_{1,2}(x)$, with $\mathcal{F}_1(x) = \frac{1}{2}\sum_q e_q^2 f_q(x)$ and $\mathcal{F}_2(x) = x\sum_q e_q^2 f_q(x)$

$$F_2^p(x) = x\sum_q e_q^2\,(q(x)+\bar{q}(x)) \approx x\left(\frac{4}{9}u(x)+\frac{1}{9}d(x)\right)$$



- J. Beringer et al. (Particle Data Group), Phys. Rev. D 86, 010001, page241, 2012.

DIS on proton provides strong constraints on the u quark distribution



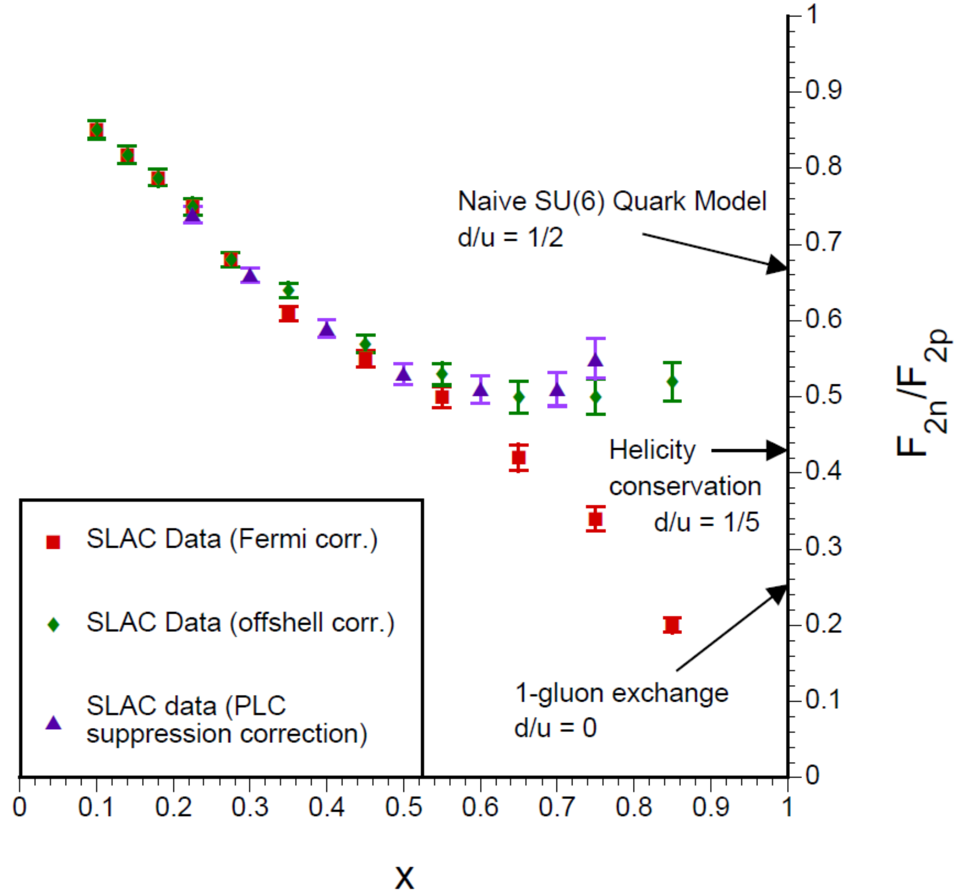
We need more precise determination of d quark distribution

Nucleon Structure (2/2)

- **What about Using Deuteron DIS to constrain the d quark distributions?**

$$\frac{F_{2n}}{F_{2p}} \approx \frac{1+4d/u}{4+d/u} \Rightarrow \frac{d}{u} \approx \frac{4F_{2n}/F_{2p}-1}{4-F_{2n}/F_{2p}}$$

$$F_{2n}/F_{2p} = F_{2d}/F_{2p} - 1$$



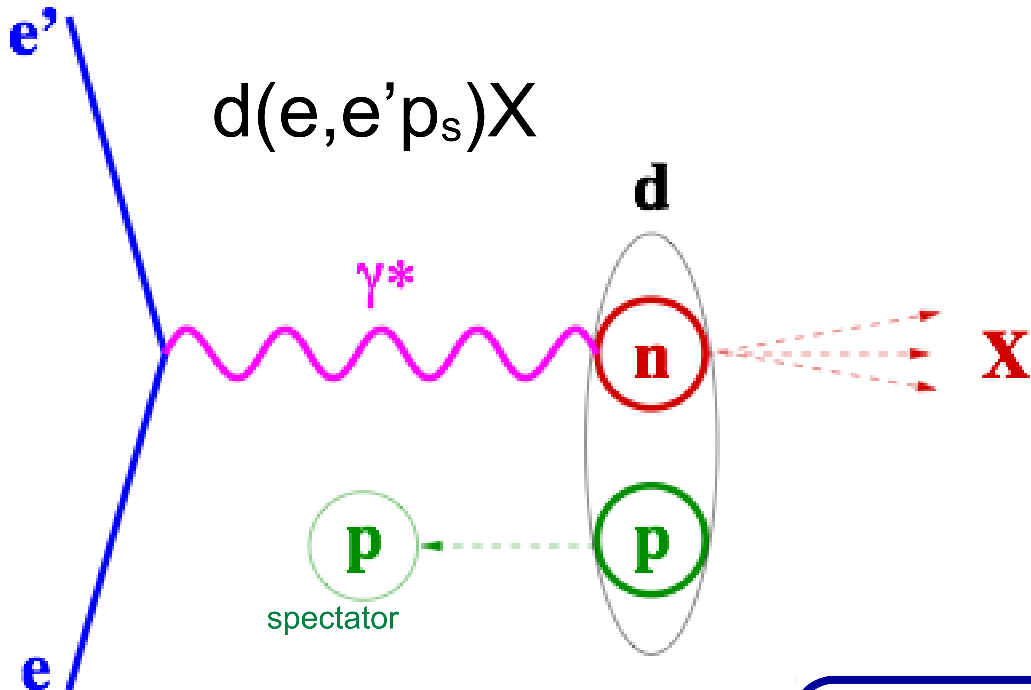
- L.W. Whitlow et al., Phys. Lett. B 282, 475 (1992)

- **Nuclear corrections led to ambiguities in the extracted F_{2n}.**

- **We need free neutron data, but ...**
  - Free neutrons decay in 15 minutes.
  - Radioactivity.
  - Difficulte to create dense target.

- **Alternative Solution:** Barely Off-shell Neutrons from Deuterons, Tritons and ^{3}He targets to minimize the nuclear model uncertainties associated with Fermi motion, off-shell effects (binding), structure modifications (EMC effect), ...

Minimizing Nuclear Uncertainties: "Spectator Tagging"



Initial hadronic state

$$p_N^\mu = (M_d - E_s, -\vec{p}_s)$$

$$E_p + E_n = M_d$$

$$E^* = M_d - \sqrt{M_s^2 + p_s^2}$$

$$M^{*2} = (M_d - E_s)^2 - \vec{p}_s^{\,2}$$

Final hadronic state

$$W^{*2} \approx M^{*2} - Q^2 + 2M\nu\,(2 - \alpha_s)$$

$$x^* = \frac{Q^2}{2p_N^\mu q^\mu} \approx \frac{Q^2}{2M\nu(2-\alpha_s)} = \frac{x}{2-\alpha_s}$$

$$\alpha_s = \frac{E_s - p_{s_{||}}}{M_s}$$

*** DIS region with:**

- $Q^2 > 1$ GeV$^2/c^2$
- $W^* > 2$ GeV
- $p_s > 70$ MeV$/c$
- $10° < \theta_{pq} < 170°$

How Good will be BONuS12 in Minimizing Nuclear Uncertainties?

Final State Interactions:

- Struck neutron interacts with the spectator p.
- Proton momentum is enhanced.
- FSIs are small at low p_s and large θ_{pq}.

Target Fragmentation:

- $e\ n \rightarrow e\ p\ X$ (where $n \rightarrow \pi^- p$) and

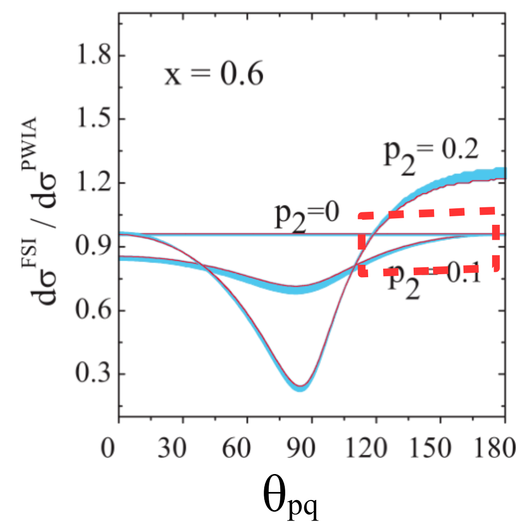
  $e\ p \rightarrow e\ p\ X$ (where $p \rightarrow \pi^0 p$).
- TF enhances the proton yield only at forward angles ($\cos\theta_{pq} > 0.6$).

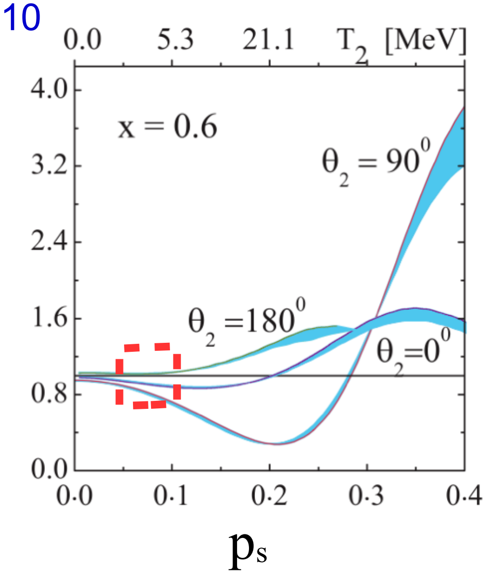
Off-Shell Corrections:

- Less than 2% in our region.

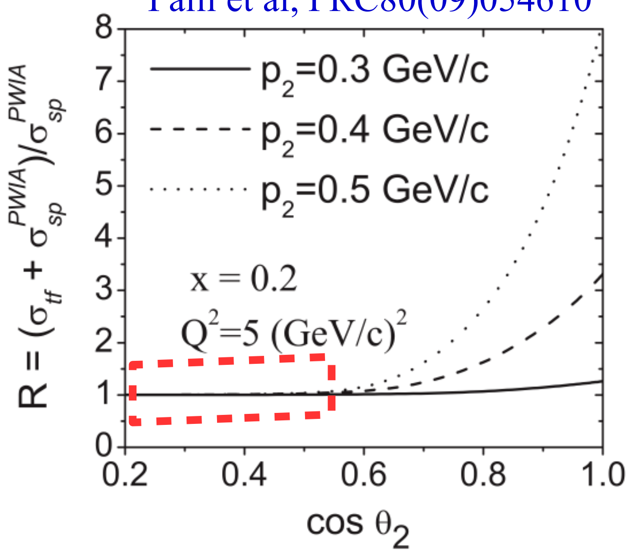
An Overall systematic uncertainities will be less than 6%

Palli et al, PRC80(09)054610

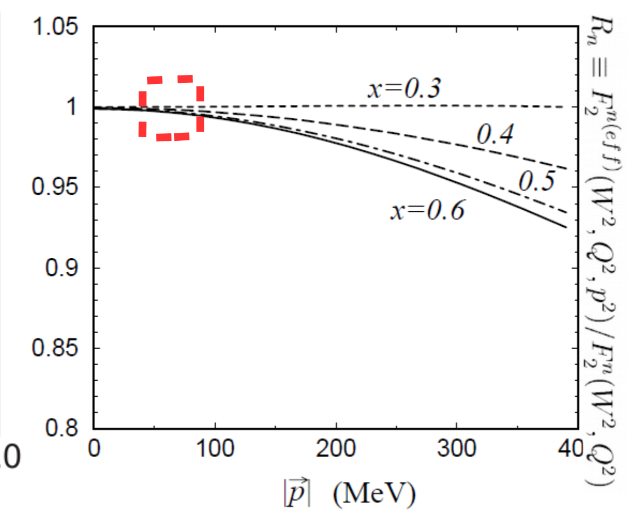




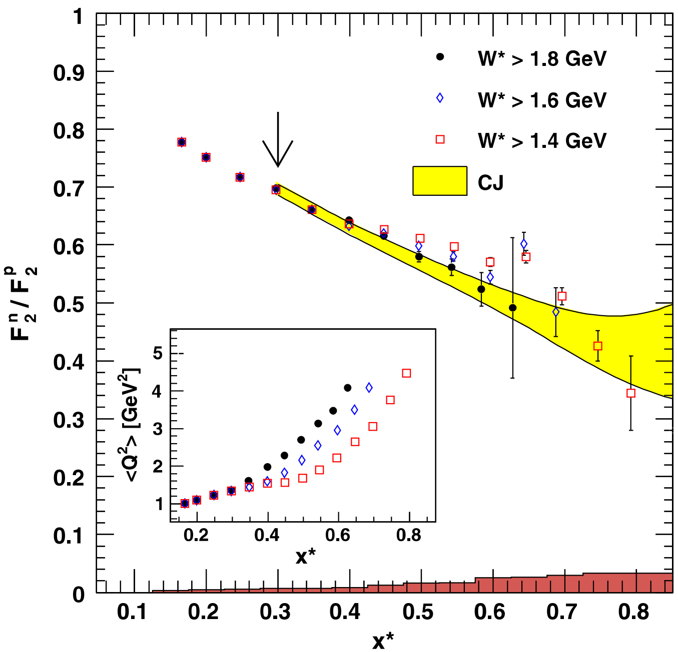
Palli et al, PRC80(09)054610



Melnitchoul et al, PRL B335,11(1994)

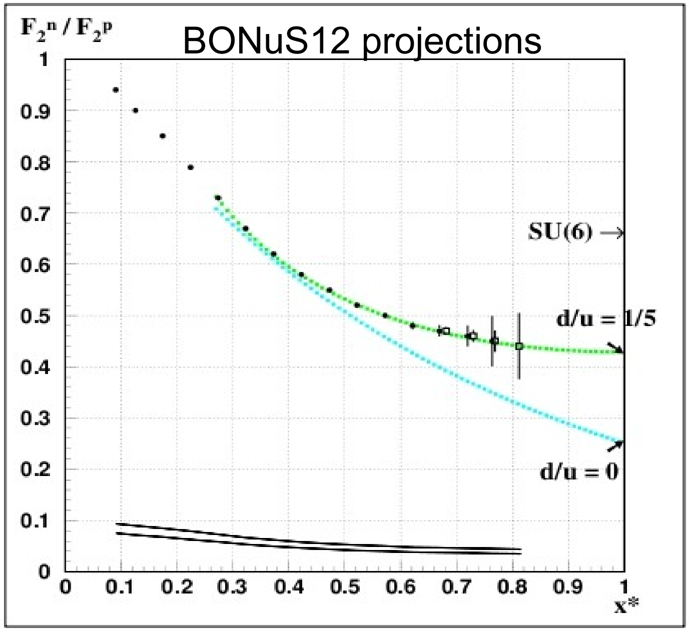


JLab Previous & planned measurements

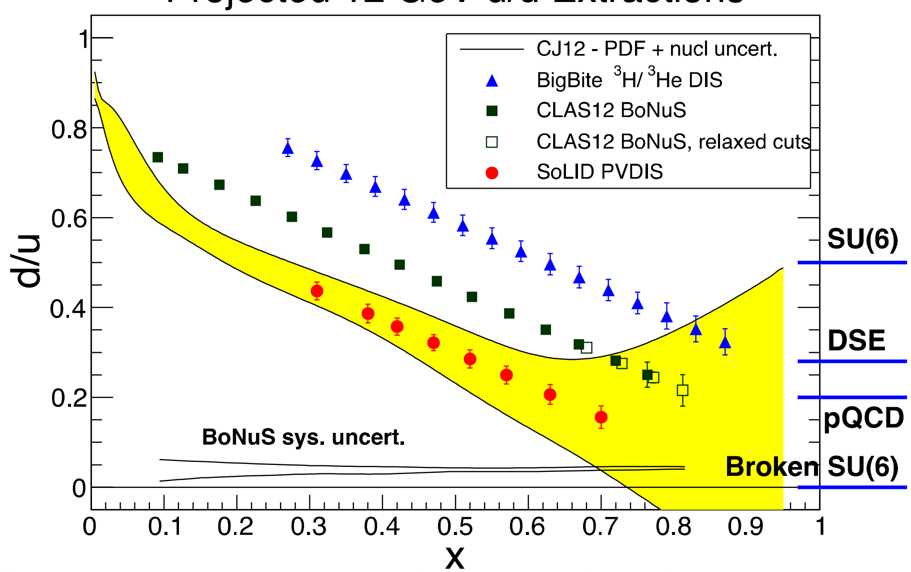


BONuS6

BONuS12



Projected 12 GeV d/u Extractions



ODU

BONuS12 Family

1. **Simulation,Tracking and Analysis Group**

   (S. Kuhn, J. Zhang, C. Ayerbe, G. Charles,N. Dzbenski, D. Payette, G. Dodge, M. Hattawy).

2. **Prototyping, Target, HV, DAQ and testing group**

   (S. Kuhn/S. Bültmann, J. Poudel, G. Dodge, N. Dzbenski, D. Payette, G. Charles, M. Hattawy, P. Pandey, I. Neththikumara)

3. **Detector Design group**

   (E. Christy, A. Nadeeshani, I. Albayrak, K. Griffioen, S. Bültmann, M. Hattawy, S. Kuhn, N. Kalantarians, H. Fenker, C. Wiggins, B. Miller, D. Kashy, C. Cuevas, M. Taylor, [N. Liyanage, K. Gnanvo, S. Covrig]);

4. **Gas and slow controls group**

   (C. Ayerbe [Gas System], N. Kalantarians [Slow Controls], K. Griffioen, N. Dzbenski, S. Bültmann, I. Niculescu, Y. Prok, W. Moore)

5. **CLAS12 Integration group**

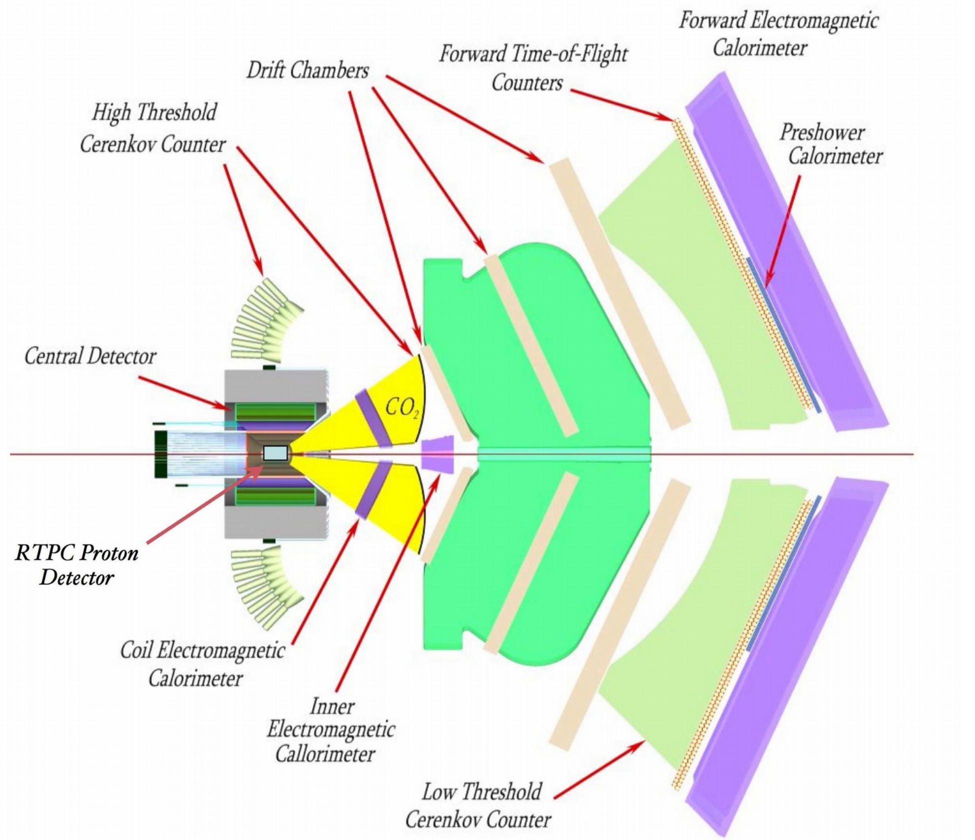
   (S. Kuhn, S. Bültmann, M. Hattawy, Bob Miller, Cyril Wiggins, S. Stepanyan, C. Cuevas)

ODU

BONuS12 Experimental Setup

$e^- D \rightarrow e^- p X$

11 GeV



- **Planned experimental setup:**
  - **CLAS12 Forward Detector:**
    - → Superconducting Torus magnet.
    - → 6 independent sectors:
      - → HTCC: identifying π^- (p >5.0 GeV/c).
      - → 3 regions of DCs: tracking charged particles.
      - → LTCC: π^- identification (p >3.0 GeV/c).
      - → FTOF Counters: identifying hadrons.
      - → PCAL and Ecs: detecting γ, e^- and n [5º,40º].
      - → FT : detecting γ, e^- [2.5º,4.5º]

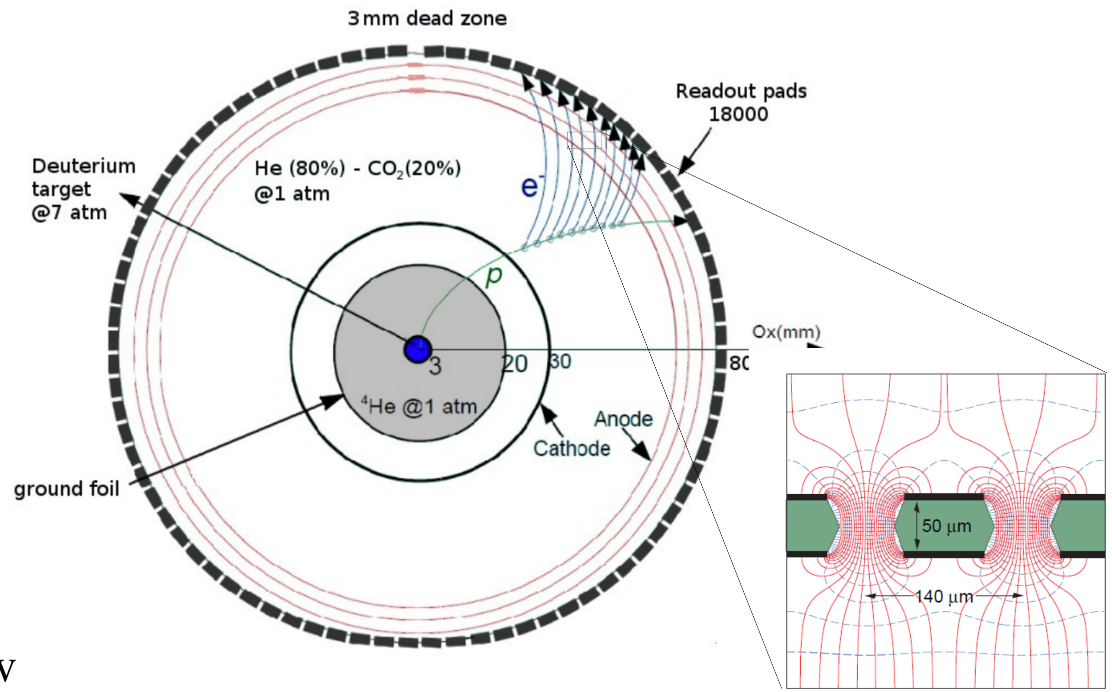
  - **Central Detector:**
    - **Target:** D gas @ 7.5 atm, 293 K
    - **BONuS12 RTPC:** Detects low energy spectator protons.
    - **Solenoid:** - Shields the detectors from Møller electrons.
      - Enables tracking in the RTPC.
    - **Additonal detectors to be used: CTOF, CND, and FMT**

35 days on D
5 days on H_2
with $L = 2 \cdot 10^{34}$ cm^{-2} sec^{-1}

BONuS12 RTPC

- Design:

- ♦ 100% azimuthal coverage
- ♦ 400 mm long , 160 mm Ø
- ♦ 50 µm target's Kapton wall
- ♦ 4 µm cathode foil @ 4.3 kV
- ♦ 40 mm drift region, uniform $|\vec{E}|$ = 500 V/cm, $|\vec{B}|$ = 5 T
- ♦ 3 GEMs layers, gain of 1000/layer
- ♦ 18000 readout elements (2.8 mm x 4 mm).



- Work principle:

Charged particle ionizes the gas atoms

→ Under EM field, released electrons follow their drift paths at a certain drift speed

→ Amplifications via the 3 GEM layers

→ Readout board, record electrons' charges (ADCs units) in time bins (TDCs units).

- Offline reconstruction:

ADCs $\xrightarrow{\text{Pads' gains } (G_i)}$ $\left\langle \frac{dE}{dX} \right\rangle = \frac{\sum_i \frac{ADC_i}{Gi}}{vtl}$

TDCs $\xrightarrow{\text{Drift speed and paths}}$ Reconstructing chains of hits $\xrightarrow{\text{Known } \vec{B}}$ p/q

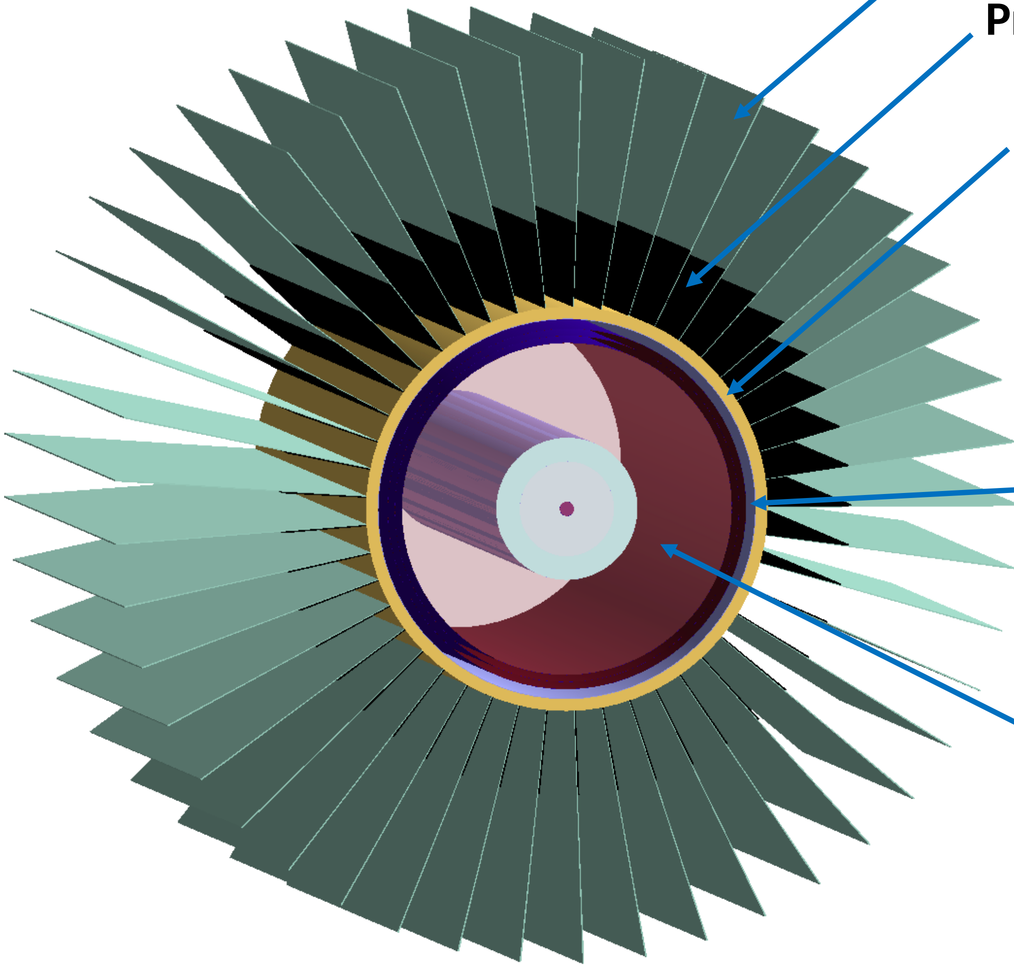
→ PID

ODU

GEMC Simulation of the BONuS12 RTPC (1/2)

Updated geometry, materials and hit process (using results from Garfield++ analysis) to include:

N. Dzbenski



45 Translation boards

Protection circuits

Electronics and spine support volume
Material type/density smeared throughout a cylinder to simulate the electronics and spine supports

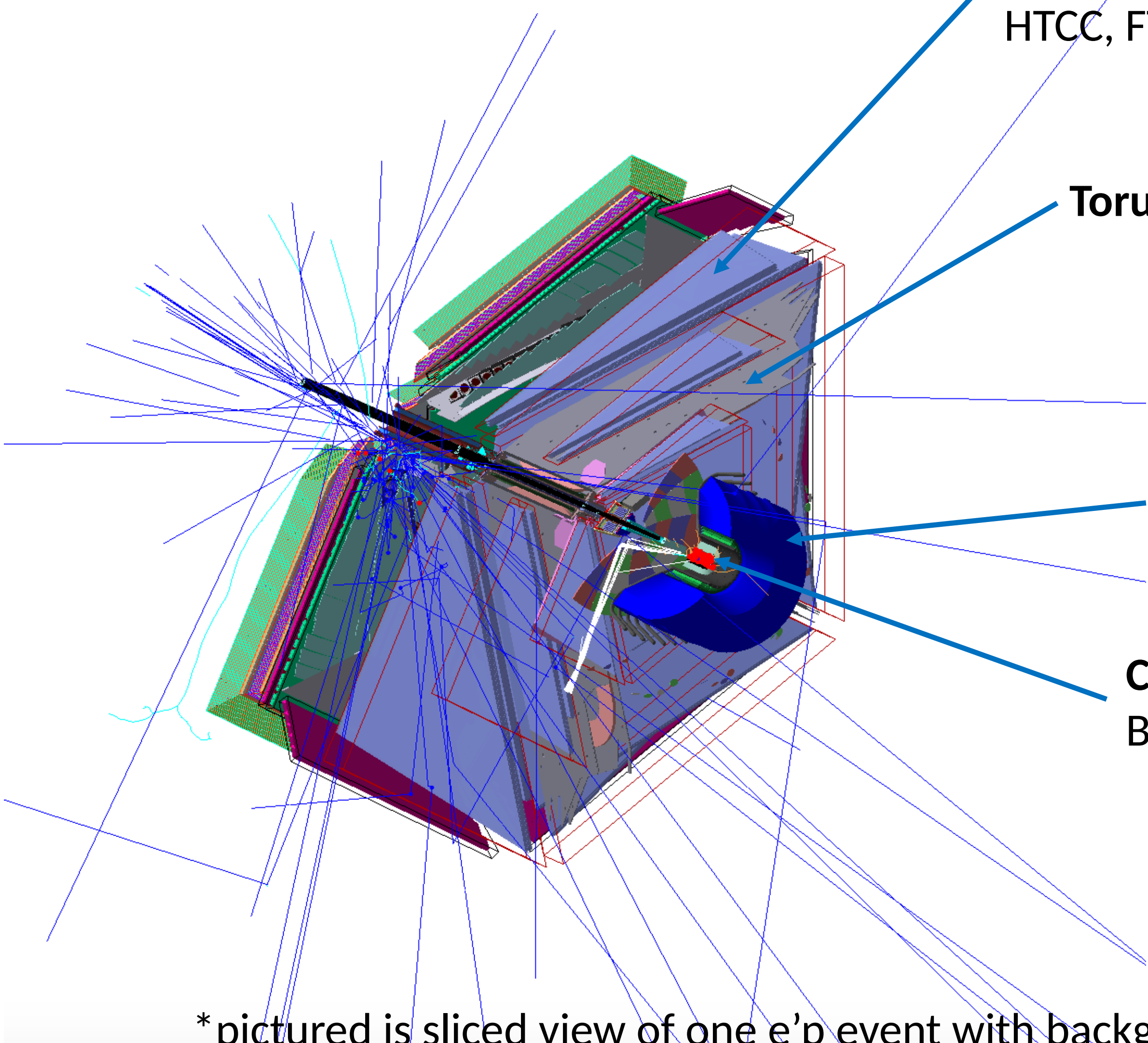
Readout pad board

Detector volume
Includes deuterium target, ground and cathode foils, sensitive gas region (currently 80:20 He:CO2), and 3 GEM layers

GEMC Simulation of the BONuS12 RTPC (2/2)

Currently implemented within GEMC tag 4a.2.3

N. Dzbenski



*pictured is sliced view of one e'p event with background in CLAS12 with the RTPC

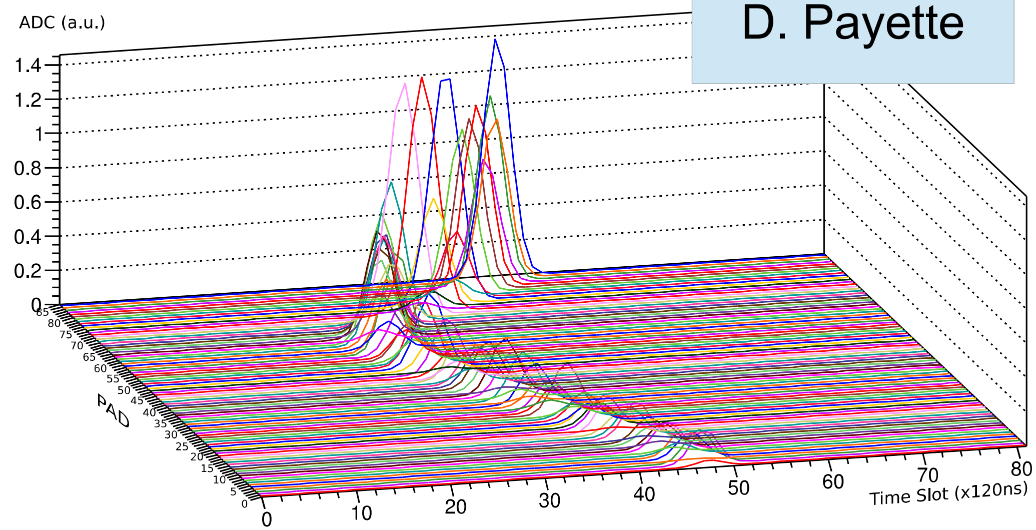
Updates on the Track Reconstruction

D. Payette

- Reconstructing the hit position:

$$r(t) = \frac{-\sqrt{a^2+4bt}+a+14b}{2b}$$

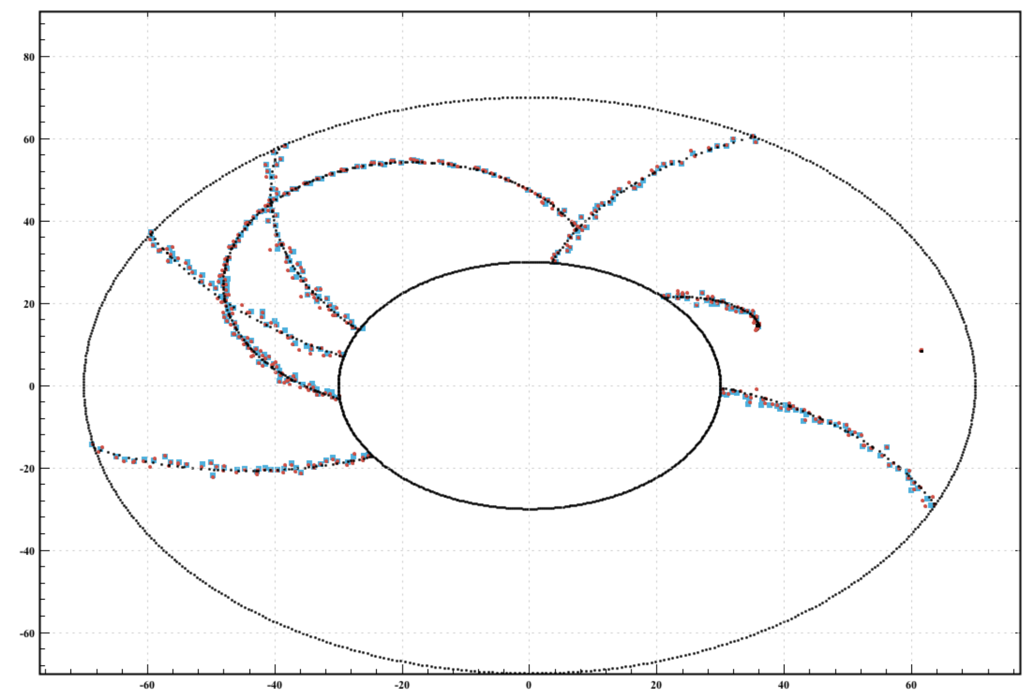
a and b parameters determined by a fit in Garfield++ based on the gas, and the electromagnetic field



- Track finder:

Input: Map which contains ADC for every 120 ns bin (time slice) for every hit pad over the whole time window (10000 ns).

Output: Map of Track IDs which contain, for each time slice, the pads which were sorted into that Track ID.



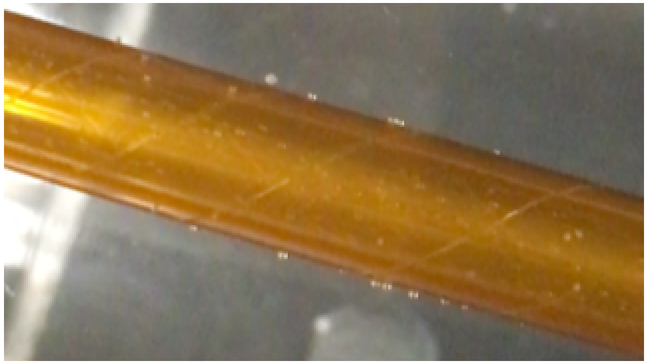
ODU

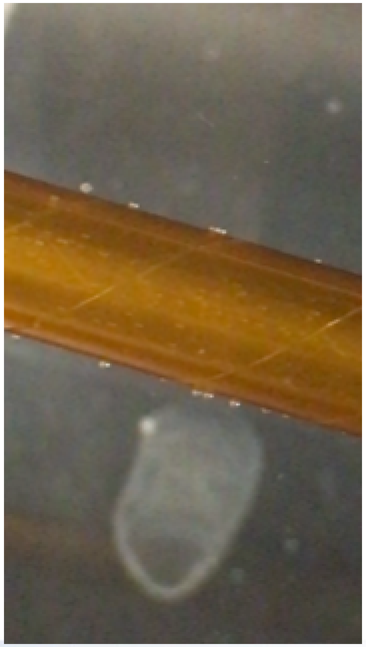
Target tube testing @ ODU

J. Poudel
I. Neththikumara

Testing of Kapton tube

- Leaking rate: < 0.07 atm/day (leak < 1%)
- Bursting limit: about 11 atm (> 150% of required pressure)
- Sagging and twisting: negligible under high pressure
- New Kapton tubes are arriving soon to perform next round of test.
- Alternative solutions:
  - 25 microns wall-thickness Aluminum tubes.
  - Aluminizing the kapton tubes.
  - Any suggestion?





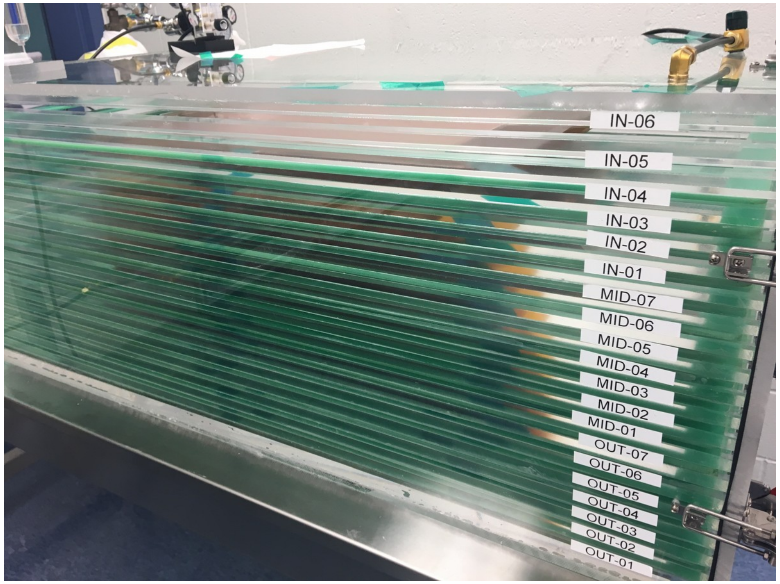
GEM foils testing @ ODU

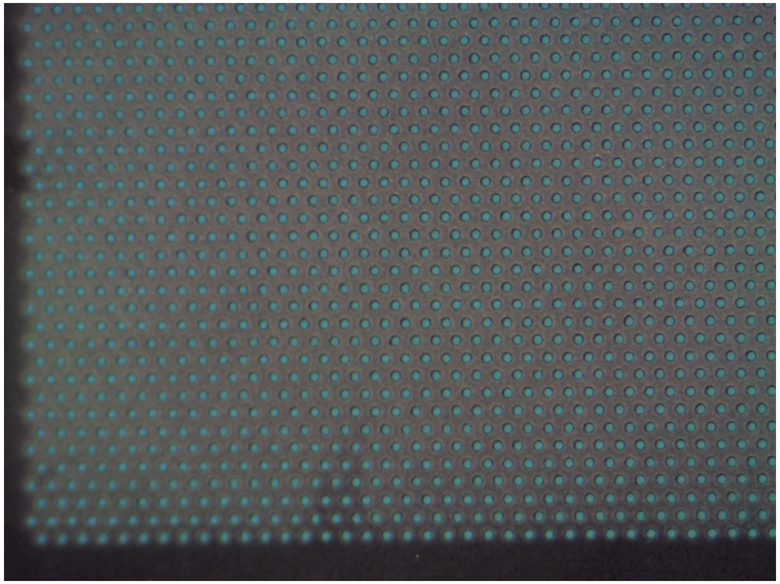
* 3 different GEM geometries associated with
  100% azimuthal coverage at the different radii.

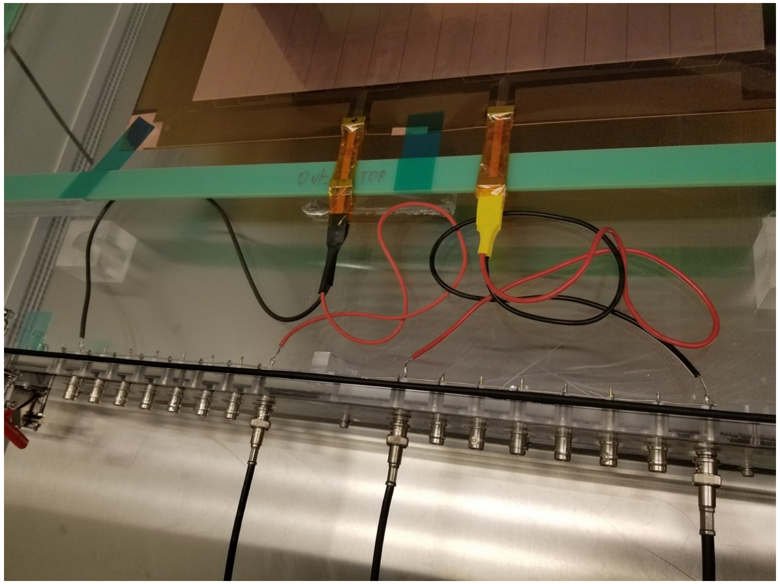
* GEM foils quality tests:
  - Optical scanning.
  - HV tests (500 V).

P. Pandey
D. Akers

* Foils are kept in dry N box from moisture.



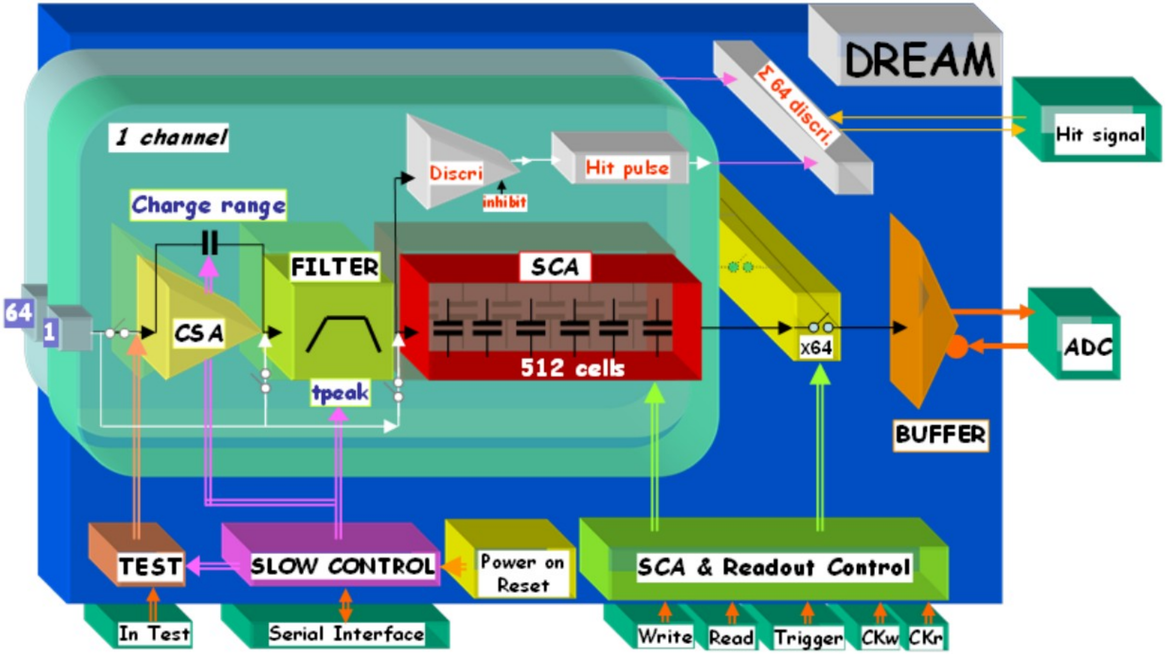




Updates on the DAQ testing @ ODU

DREAM electronics developed for the Micromegas of CLAS12

- 512 memory cells/channel
- read out selected cells after trigger
- Low noise
- Analogue multiplexed output
- Latency up to 16μs



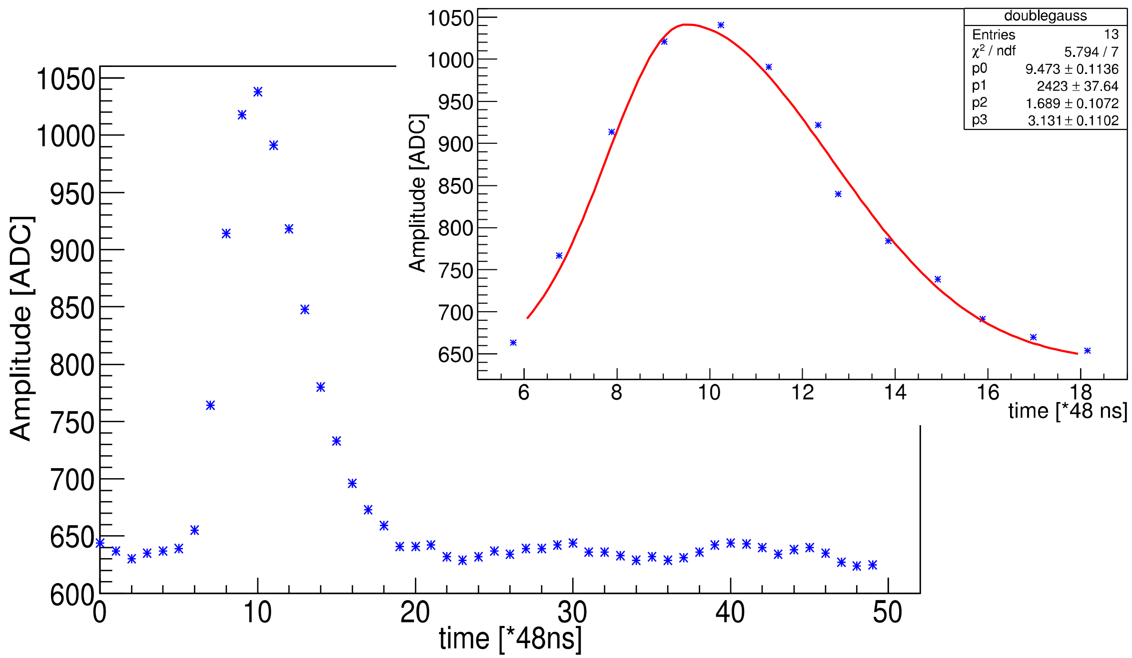
BONuS12 will use DREAM electronics

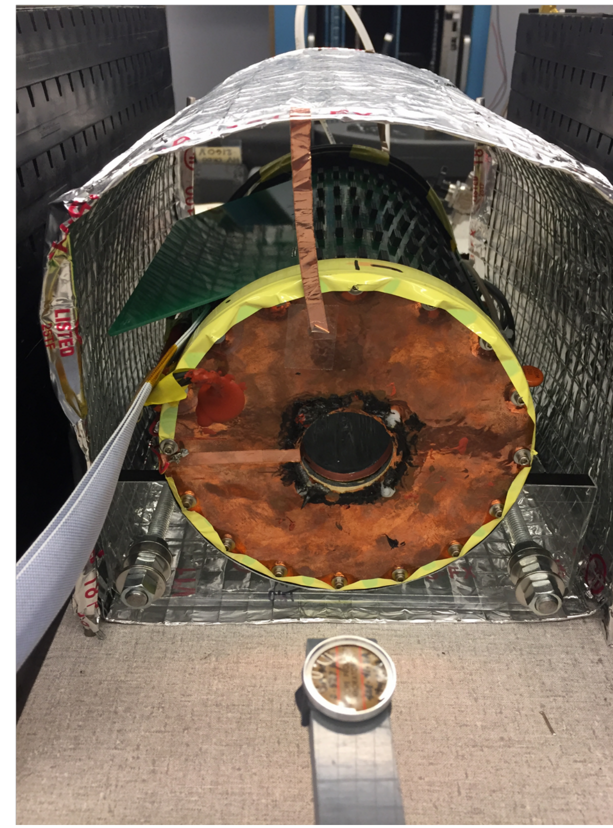
- Already available on site
- Fits BONuS12 needs
- Contract signed with Saclay (test bench + manpower)
- Need to update the firmware
- Test bench working at Old Dominion University
- BONuS12 will use available FEU and signal cables from barrel Micromegas
- Adaptation board to protect the electronics from over current

Test bench @ ODU

Using EG6 RTPC and Dream electronics

J. Poudel
I. Neththikumara



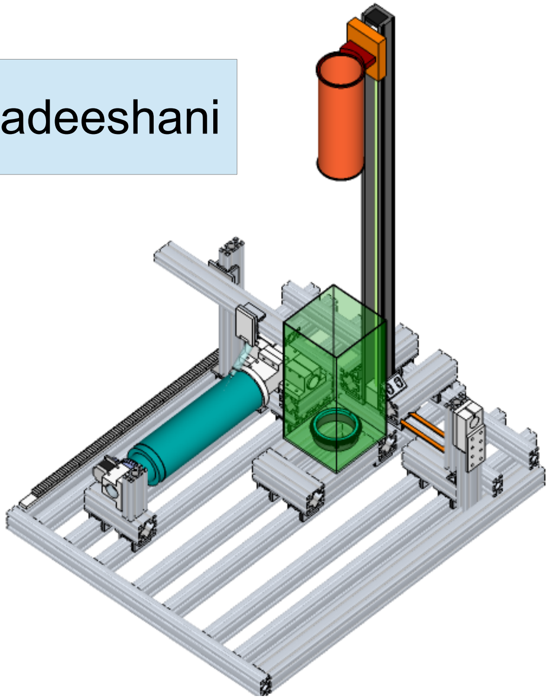


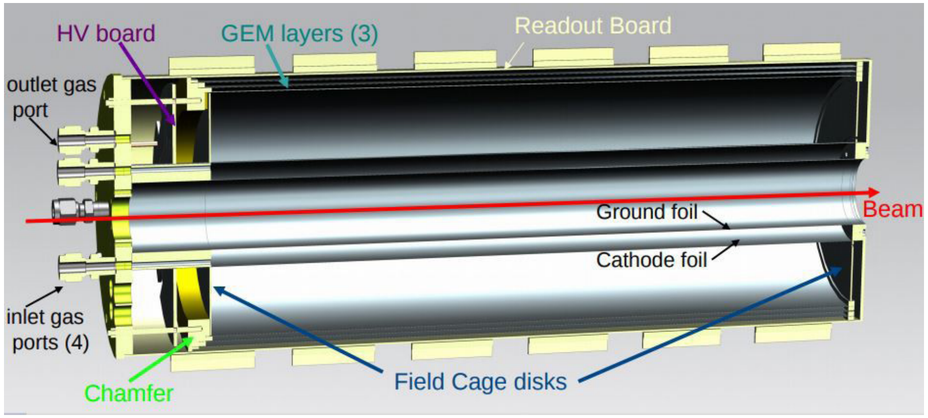
- Using radioactive source.
- Adaption boards to protect the electronics from over current.
- Signal spread ≈ 600 μns
- Low noise, S/N ratio > 50

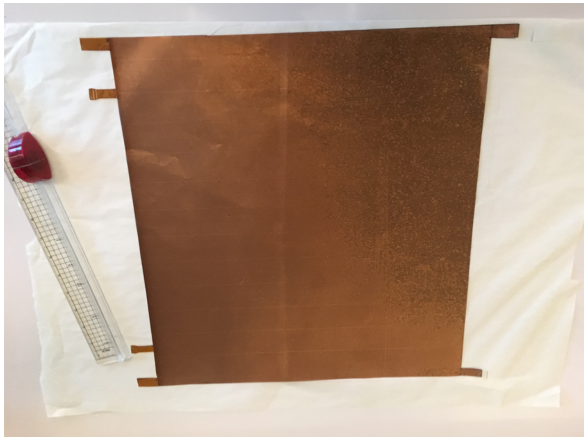
Detector assembly and construction @ HU

- Step by step, optimum detector assembly procedure is being determined.
- GEM foil wrapping station constructed, procedure tested successfully.
- Cathode foil assembly construction procedure tested and an optimum procedure was determined.
- Detector assembly tools are under construction.
- Readout board wrapping procedure and mechanical tests are being performed.
- Construction of the full detector is underway.

A. Nadeeshani

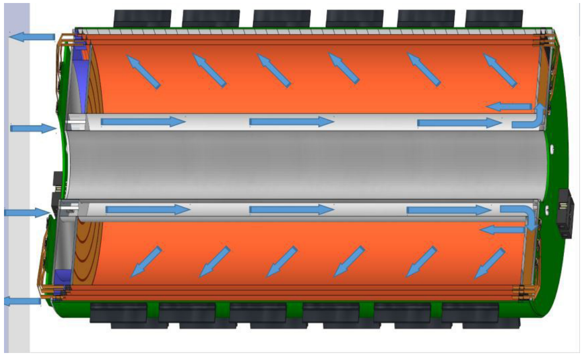






Updates on the Drift Gas System

Requirements: 0.2 L/min and uniform flow

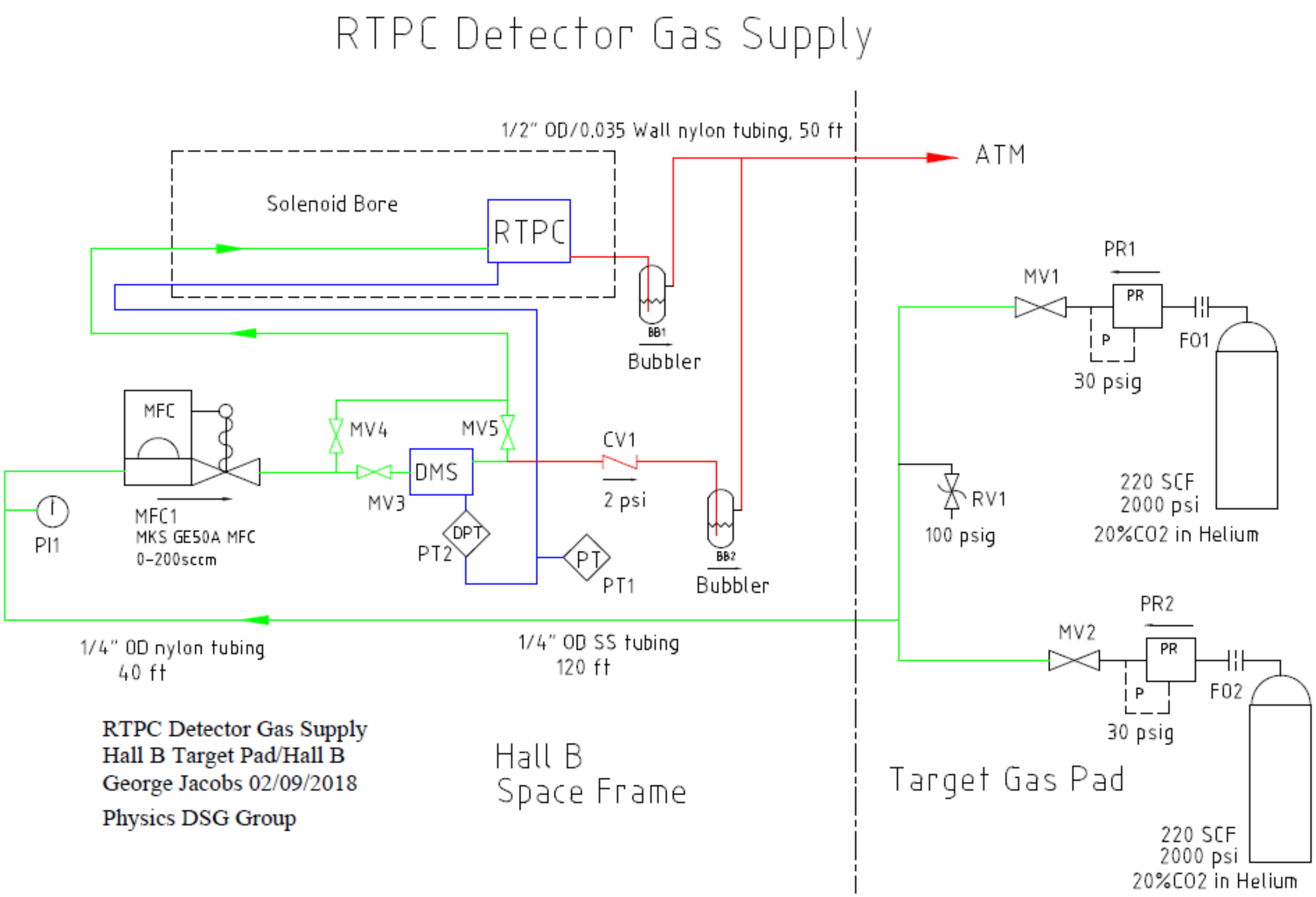


- Gas System set up at William & Mary (K. Griffioen, C. Ayerbe).

- Have EPICS framework on Raspberry Pi.

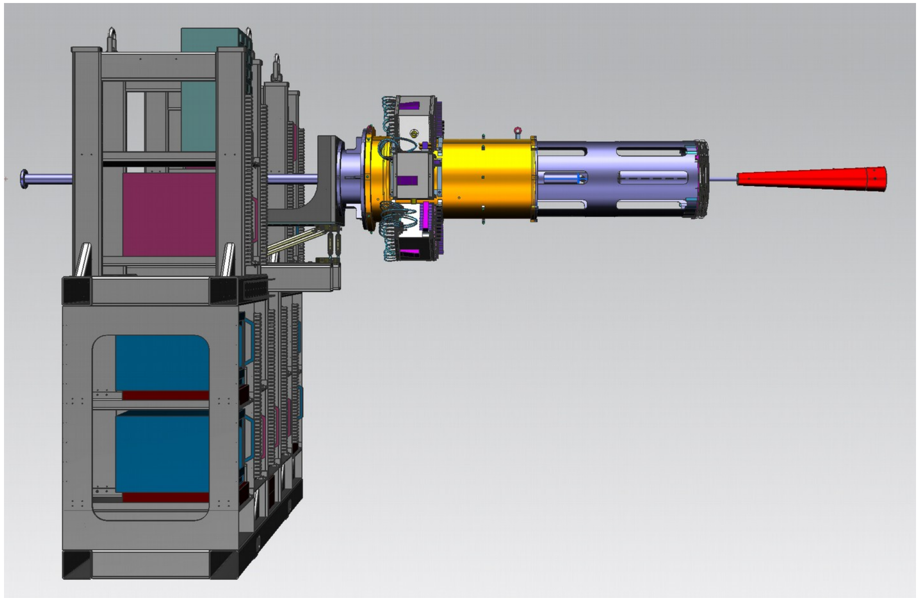
- Will soon test slow controls with BONuS6 controller: MKS 146.

- The system will have a controller, pressure sensors, and temperature Sensors.



Plan for the BONuS12 Integration in CLAS2

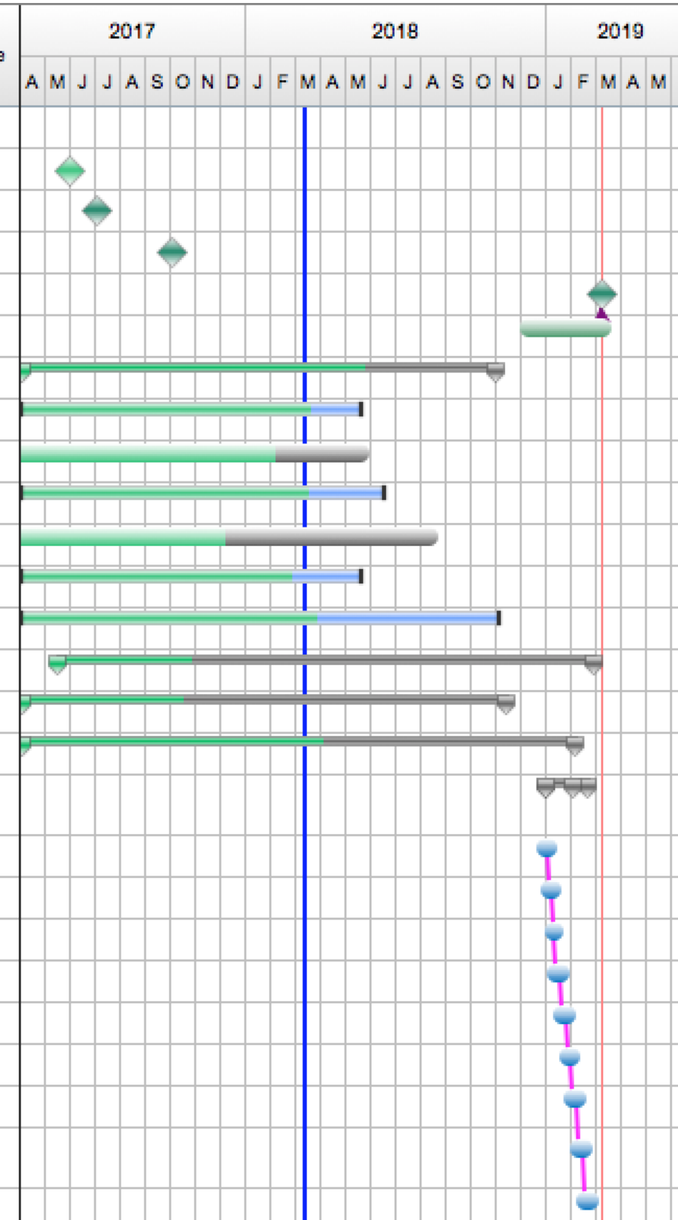
Installation prodecures:



- Remove upstream beamline
- Retract MVT/SiVT cart, bring to EEL
- Separate MM assembly from SiVT
- Store SiVT
- Disconnect all MM-DREAM cables at MM and remove MM, store Barrel MM safely
- Install upstream MM electronics barrel, RTPC holder and beam pipe on cart
- Install RTPC + target, attach all plumbing, readout boards, electrical connections, cables to DREAM FEUs
- Fiducialize RTPC position relative to alignment targets
- Install outer shell/Forward MM Vtx holder
- Install and cable up Forward MM Vtx counters
- Insert cart back into CLAS12 CD and align
- Replace beam line, align and pump down.

Time Schedule

	Activity Name	Resources Assigned	Duration (Weeks)	Start Date	% Done	Finish Date
1	Milestones					
2	Readiness Review		0.0	5/31/17	100%	5/31/17
3	Schedule Request		0.0	7/3/17	0%	7/3/17
4	Schedule Released by JLab		0.0	10/2/17	0%	10/2/17
5	All BONuS Equipment Ready to Install		0.0	3/8/19	0%	3/8/19
6	Float		13.0	12/10/18	0%	3/8/19
7	Detailed Design		**83.0**	**4/3/17**	**72%**	**11/2/18**
8	RTPC...		**59.0**	**4/3/17**	**86%**	**5/18/18**
13	Target	M. Zarecky, ODU, R. Miller	59.0	4/3/17	75%	5/18/18
14	Ancillary Systems...		**63.0**	**4/3/17**	**79%**	**6/15/18**
18	Slow Controls	VCU, VUU, W. Moore	71.0	4/3/17	50%	8/10/18
19	Electronics...		**59.0**	**4/3/17**	**80%**	**5/18/18**
23	Integration...		**83.0**	**4/3/17**	**62%**	**11/2/18**
29	Construction...		**94.0**	**5/15/17**	**25%**	**3/1/19**
47	Data Acquisition...		**85.0**	**4/3/17**	**33%**	**11/16/18**
55	Data Analysis Software...		**97.0**	**4/3/17**	**54%**	**2/8/19**
71	Installation in Hall (Arbitrary start point; after end of previous experiment and Hall ready)		**7.8** 5.0	**1/1/19** 1/1/19	**0%** 0%	**2/22/19** 2/4/19
72	Remove MVT/SVT cart and bring to EEL		0.8	1/1/19	0%	1/4/19
73	Separate MVT from SVT, store SVT		0.6	1/7/19	0%	1/9/19
74	Disconnect all MVT cables from FEUs, secure		0.4	1/10/19	0%	1/11/19
75	Remove FMVT, remove BMVT and store		1.0	1/14/19	0%	1/18/19
76	Mechanically install all RTPC components and		1.0	1/21/19	0%	1/25/19
77	Install and test all cables, HV, gas lines		1.0	1/28/19	0%	2/1/19
78	Transport to Hall B, fiducialize, insert and align		1.0	2/4/19	0%	2/8/19
79	Integrate into CLAS12 DAQ, ancillary systems, beam line		1.0	2/11/19	0%	2/15/19
80	Cosmic tests		1.0	2/18/19	0%	2/22/19



Commissioning

- Commissioning without beam
  - Test run with ^{90}Sr source
  - Cosmic test run on bench (before installation)
  - Cosmic test run with CTOF (no solenoid field)
    - Check operation, alignment, acceptance/efficiency
  - Cosmic test run with CTOF (solenoid on)
    - Check track reconstruction, efficiency, resolution
- Commissioning with beam (2.2 GeV)
  - Low current (20 nA), 1 atm target (“empty)
    - Check backgrounds, noise
  - Low current, full (7.5 atm H) target
    - Check occupancies, data rates, dead channels
  - Full current (200 nA), 7.5 atm H target (1 PAC day)
    - p(e,e’p) and p(e,e’p $\pi^+\pi^-$) reactions to calibrate alignment, tracking parameters, resolution and gain/efficiency of RTPC
  - 7.5 atm D target (1 PAC day)
    - d(e,e’pπ^- p_S) to further calibrate RTPC and determine acceptance, efficiency, track reconstruction, and particle ID

Other Physics Topics Accessible with BONuS12

The neutron PDF measurements is at the heart of the physics that will be achieved by successfully analyzing BONuS12 dataset, while a whole list of physics topics will be explored from this future golden data:

- Neutron Elastic Scattering
  - Access to neutron form factors.
- Coherent DVCS off D
  - Access to new GPDs, H_3 , with relationships to dueteron charge form factors.
- Coherent DVMP off D
  - π^0 , φ, ω and ρ mesons.
- Semi-inclusive reaction p(e,e`p)X
  - Study the π^0 cloud of the proton.
- D(e, e`pp$_S$)X
  - Study the π^- cloud of the neutron.

- More Physics:
  - DVCS off bound nucleons.
  - DVMP off bound nucleons.
  - The role of the final state interaction in hadronization and medium modified fragmentation functions.
  - The medium modification of the transverse momentum dependent parton distributions.
  - ... and more

Conclusions

◊ After the successful running of **BONuS6**, **BONuS12** continues to explore the higher x_B region of the neutron PDFs measurements in addition to many physics topics to be explored using this future golden dataset.

◊ We are applying all the lessons learned from **BONuS6** and **EG6 RTPCs** in constructing a next generation RTPC.

◊ Promising Individual testing for the subparts of the BONuS12 RTPC.

◊ **Future perespectives**:

→ The **first BONuS12 RTPC** will be ready by **Sep 2018**.
→ A **second BONuS12 RTPC** will be delivered by **March 2019**.
→ The installation of the detector in HallB is expected by **Nov 2019**.
→ The **experiment** will be taking data by the **spring of 2020**.