# STAR forward upgrade: overview of sTGC and FCAL

Lijuan Ruan

BNL

Introduction

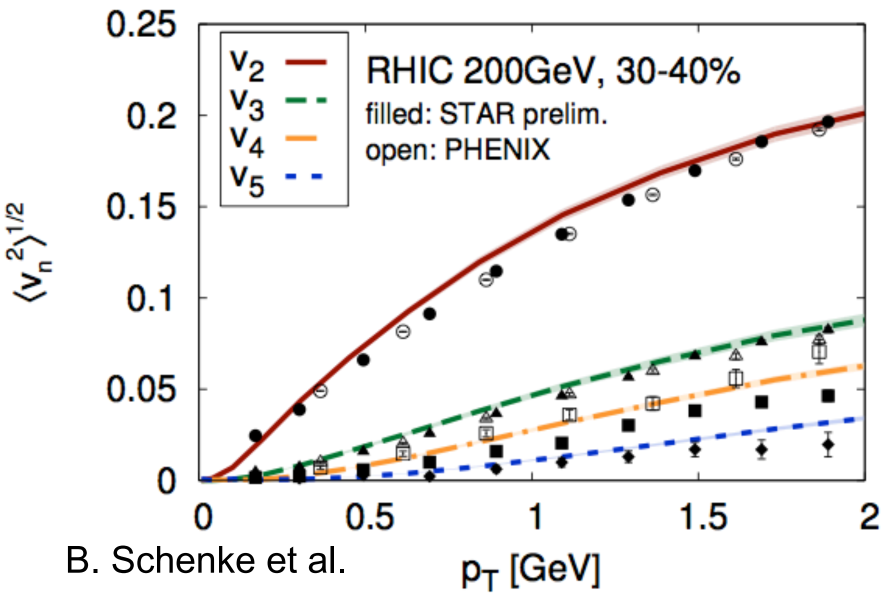
The current status

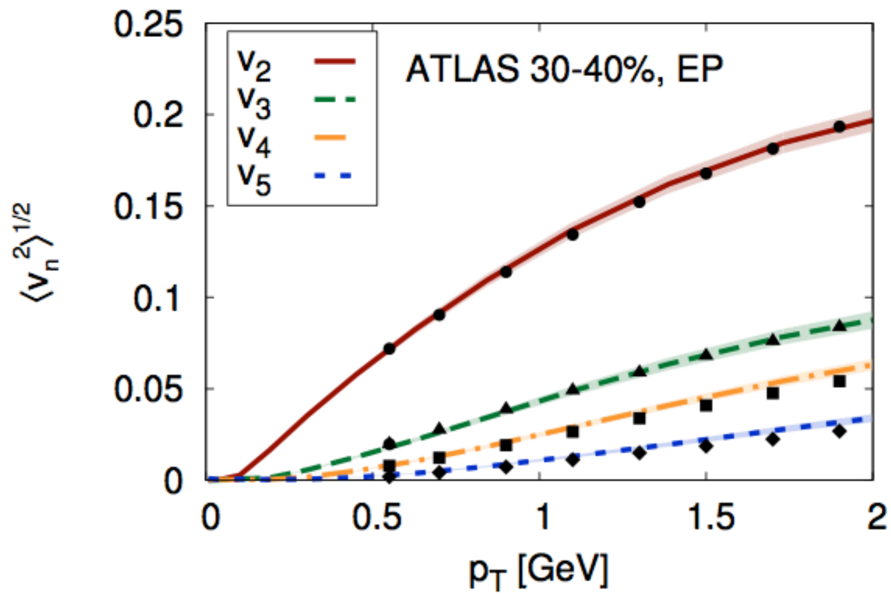
The future plan

Summary

Workshop on STAR Forward Tracking Detector Upgrade and Related Physics, May 7-8, 2019, SDU

# η/s constrained from flow observables




B. Schenke et al.

**IP Glasma initial condition, subnucleonic color charge fluctuations, 3+1D hydro evolution: η/s=0.12 (0.2) at 0.2 (2.76) TeV**

1. **Transverse fluctuation essential to reproduce data**

2. **How about longitudinal dynamics? How much do we understand it?**

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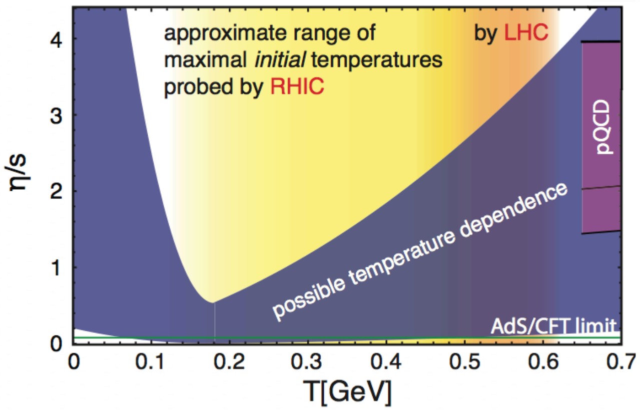
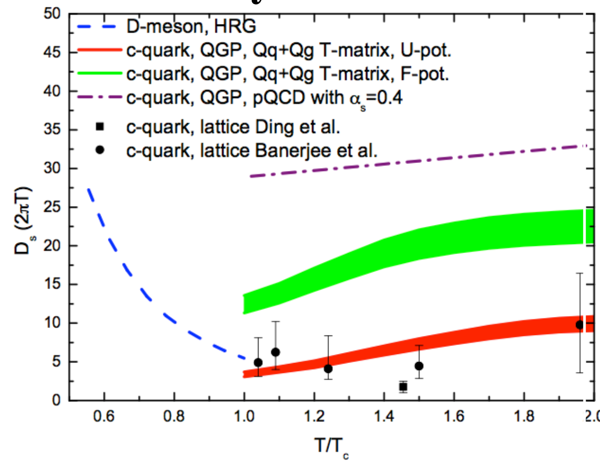
# Transport coefficients

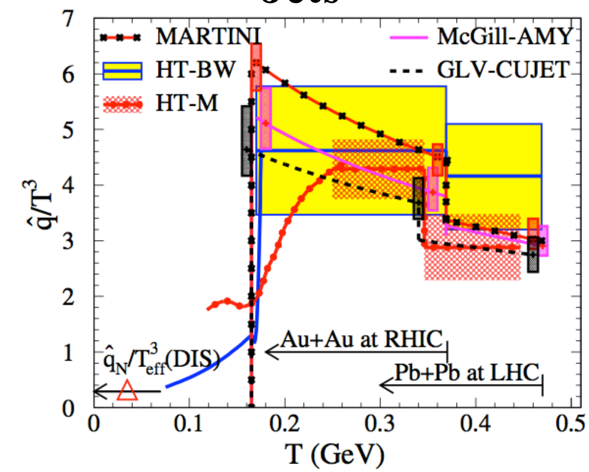
**Flow and particle correlation**




**Heavy flavor**




**Jets**




**Currently η/s and 3+1D hydro are essentially constrained by bulk measurements.**

**Utilizing 3+1D viscous hydro evolution and the heavy flavor measurements, one can constrain heavy flavor diffusion coefficient.**

**Utilizing 3+1D viscous hydro evolution and the jet related measurements, one can obtain jet transport coefficients (the average squared transverse momentum broadening per unit length and longitudinal energy loss coefficient with the latter constrained by heavy flavor).**

**Direct constraints on the temperature dependence of η/s from bulk observables are essential to understand heavy flavor and jet physics.**

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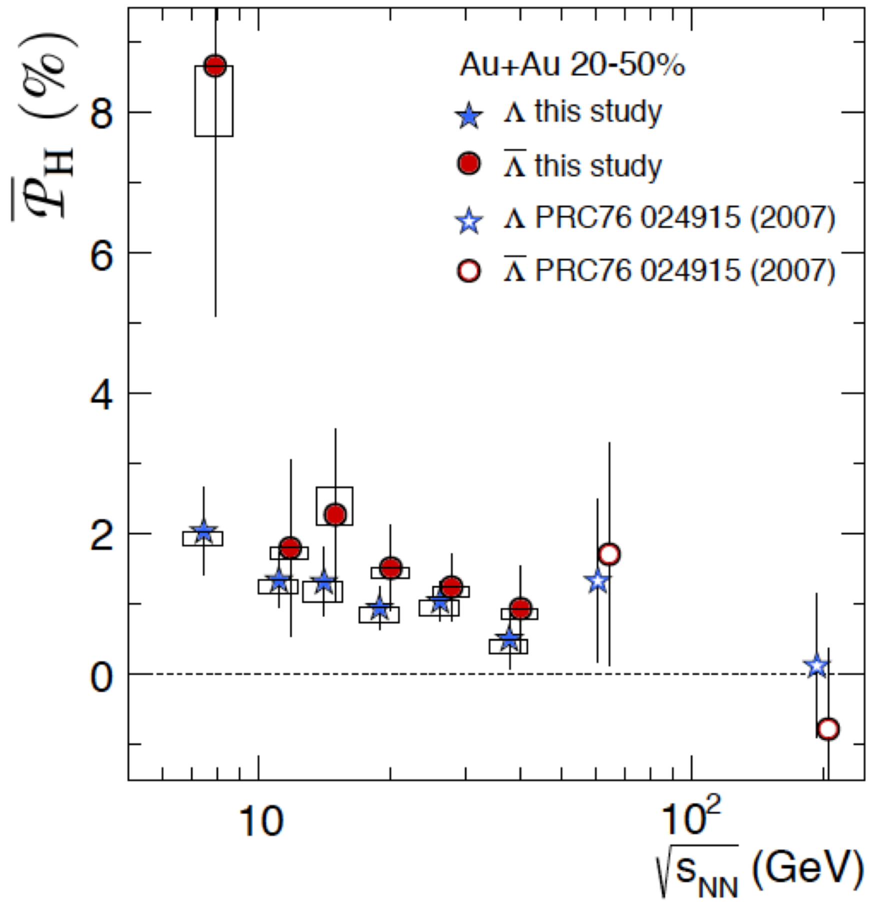
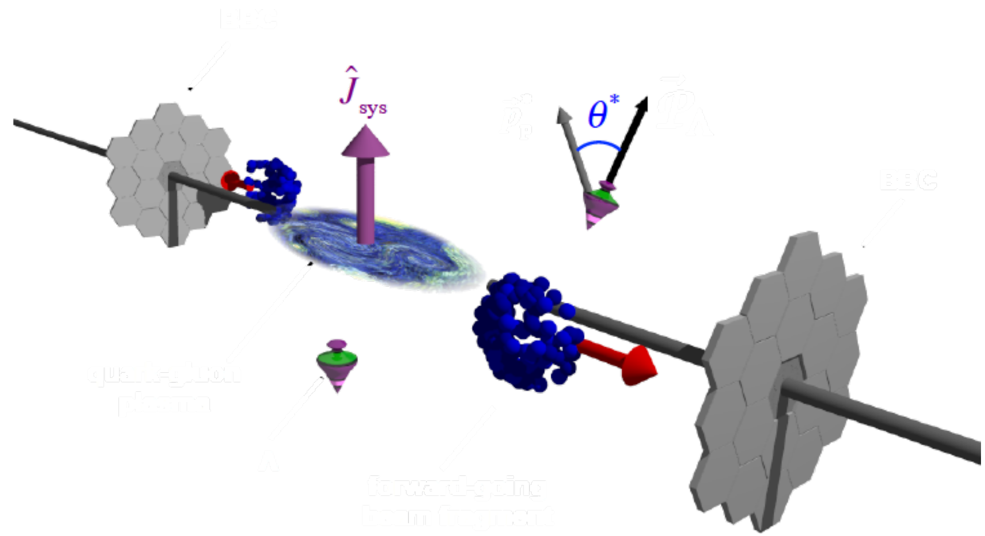
# Lambda global polarization



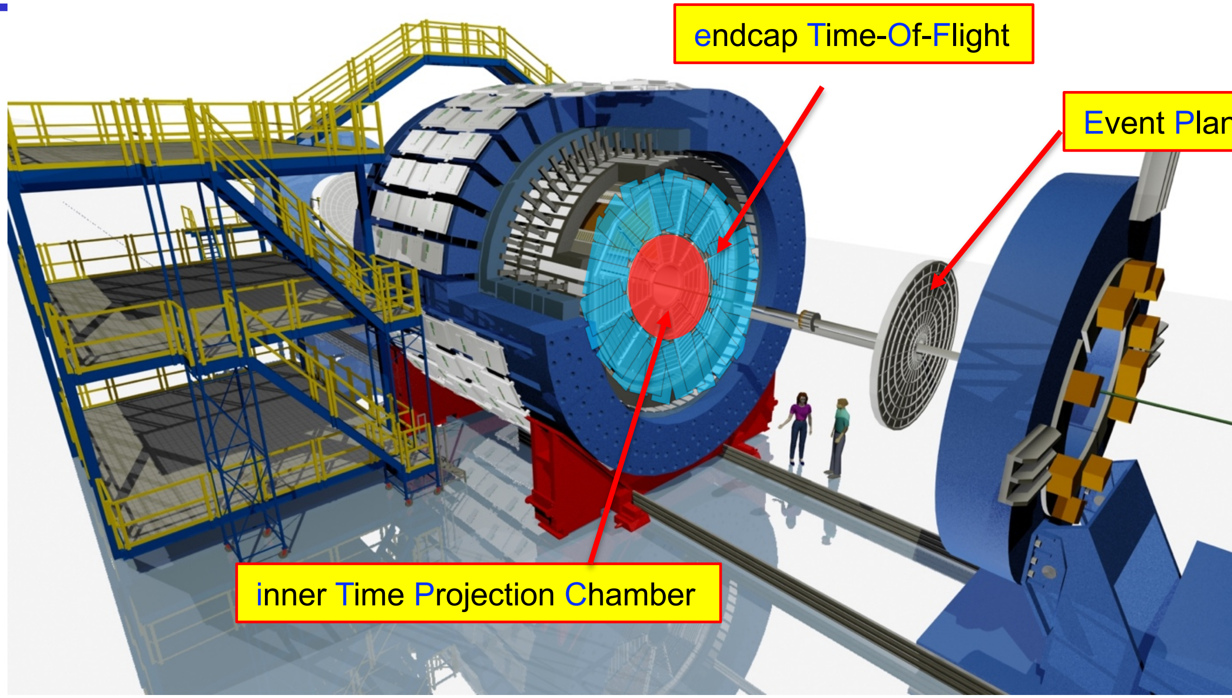




Nature **548** (2017) 62

Lambda and anti-Lambda polarized.

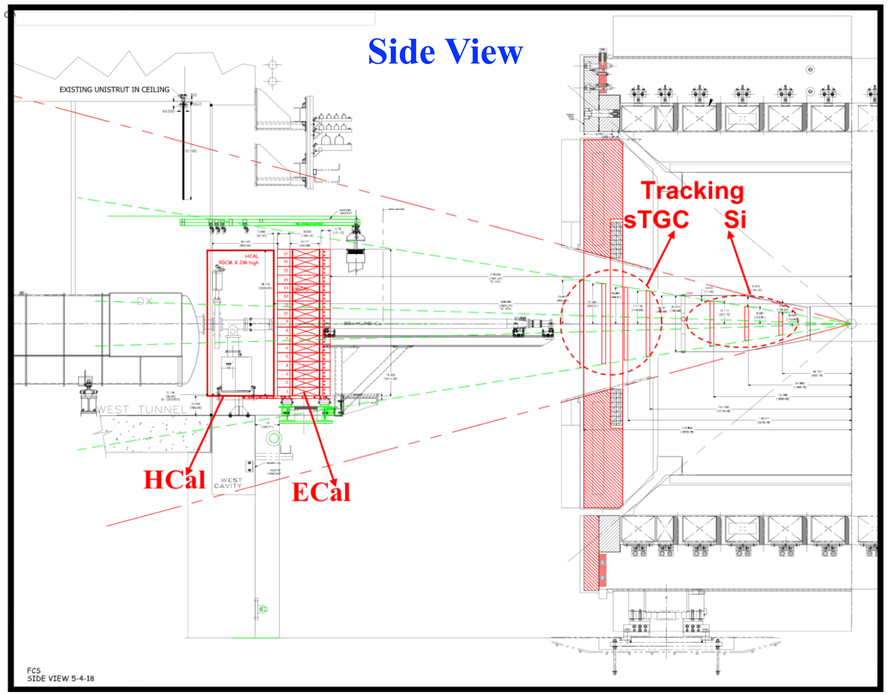
Most vortical system! What is the rapidity dependence?

# STAR Detector




| iTPC upgrade | EPD upgrade | eTOF upgrade |
|---|---|---|
| **Continuous pad rows<br>Replace all inner TPC sectors** | **Replace Beam Beam Counter** | **Add CBM TOF modules and electronics (FAIR Phase 0)** |
| **$\|\eta\|<1.5$** | **$2.1<\|\eta\|<5.1$** | **$-1.6<\eta<-1.1$** |
| $p_T$ >60 MeV/c | Better trigger & b/g reduction | Extend forward PID capability |
| Better dE/dx resolution<br>Better momentum resolution | Greatly improved Event Plane info (esp. 1st-order EP) | Allows higher energy range of Fixed Target program |
| **Fully operational in 2019** | **Fully operational in 2018** | **Operational in 2019** |

# STAR forward upgrade for 2.5 < η < 4




Calorimetry:
Electromagnetic and Hadronic

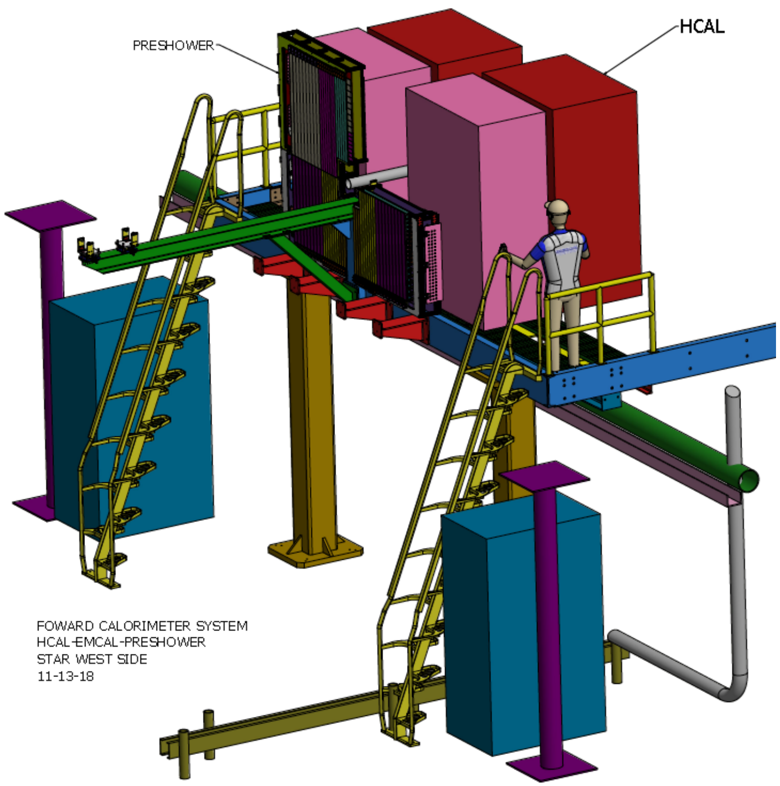
Tracking:
Silicon detectors and
small-strip Thin Gap Chambers (sTGC)

pp, pA and AA data taking in FY2021/22 and parallel with sPHENIX data taking period

**AA physics at 200 GeV for 2023-2025:**
**Constrain 3D hydro evolution**
**Temperature dependent η/s**
**Rapidity dependent vorticity**

**Successful cost and schedule review on Nov 19, 2018, BNL**

# ECal & HCal




**Location:** 7 m from the IP on the "FMS platform"

**Readout:** SiPMs

- Used in Trigger
- Split in 2 movable halves inside and outside of ring
- Slightly projective

**ECal:**

reuse PHENIX PbSC calorimeter with new readout on front phase → 1496 channels

- ➢ Secured one Sector (2592 towers) PbSc towers: 5.52 x 5.52 x 33 cm3 (18 $X_0$)
  66 sampling cells with 1.5 mm Pb,
  4 mm SC & Wavelength shifting fibers

**HCal:**

- Fe/Sc (20mm/3 mm) sandwich.
- 520 readout channels
- Lateral tower size 10 x 10 cm2, ~ 4.5 l
  - ➢ in close collaboration with EIC R&D

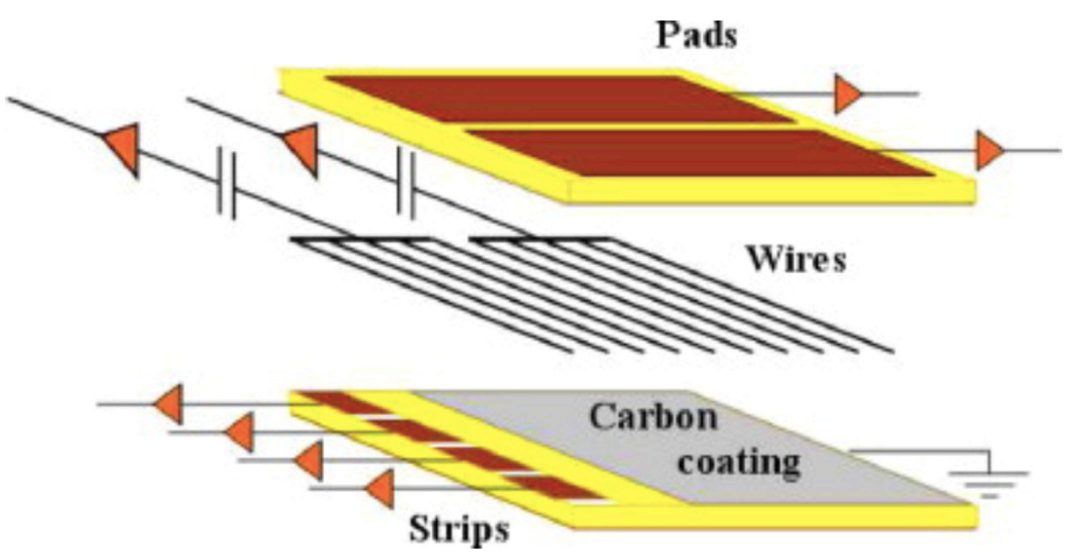
**Preshower**

- Reuse 2 of the existing planes from the FMS-pre-shower operated in 2015 & 2017
- SC-slats with SiPM readout

# The sTGC

We propose to use 4 double-sided small-strip Thin Gap Chamber (sTGC) disks in addition to 3 silicon disks to provide tracking for charged particles, for the cold QCD and peripheral heavy ion physics program.
For the sTGC, the size will be 60 cm ✖ 60 cm. Four double-sided sTGC will form a disk.
The readout strip size is 2.7 mm ✖ 15 cm. We planned to use the old Time Projection Chamber (TPX) electronics. We will have 15000 readout channels in total.

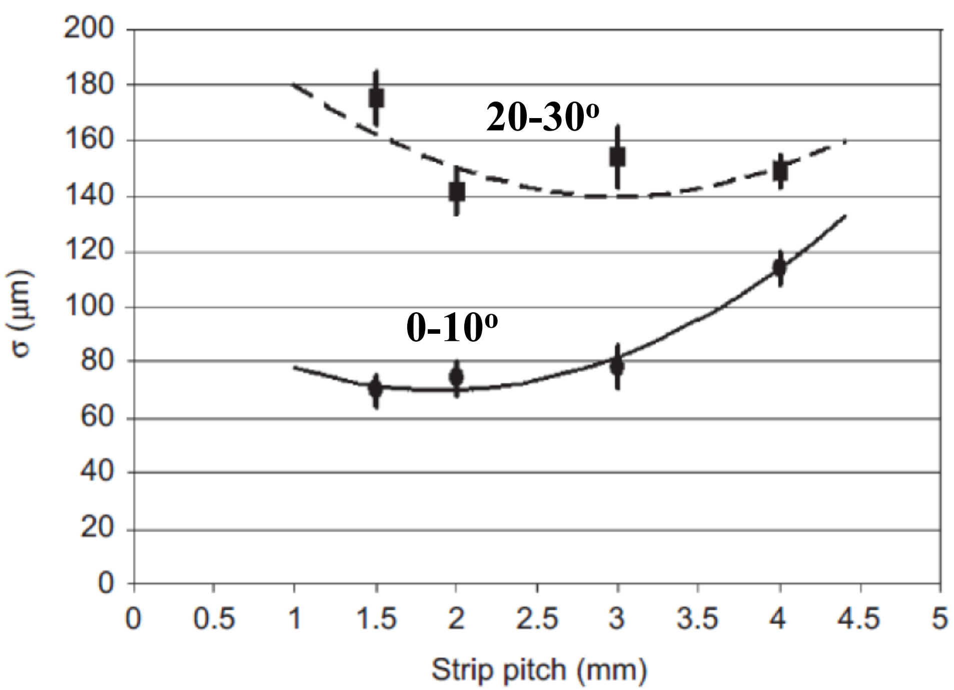
The sTGC module is much smaller than ATLAS sTGC.
All the PCB boards can be fabricated in China.

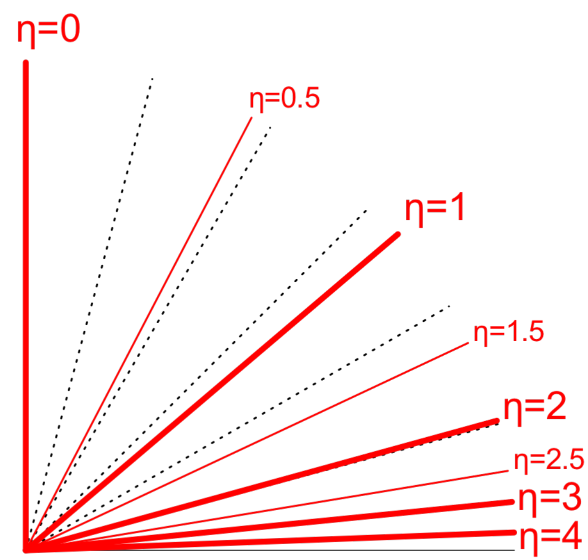


# Position resolution

Forward upgrade is for the η region 2.5-4. Most of particles will hit the detector within 10 degree of being perpendicular. The position resolution will be better than 100 μm.

The sTGC module will be produced at Shandong University (SDU). Funds are available now.
FEEs and electronics boards are available and free.
Power supplies, cables, DAQ, gas and mechanical instrumentation will be provided by BNL.



# Key Performance Requirements

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**Charged sign separation for cold QCD physics**

**Momentum resolution 20-30% for peripheral heavy ion physics**

| Detector | pp and pA | AA |
|---|---|---|
| **ECal** | ~10%/√E | ~20%/√E |
| **HCal** | ~50%/√E+10% | --- |
| **Tracking** | charge separation<br>photon suppression | $0.2<p_T<2$ GeV/c with 20-30% $1/p_T$ |

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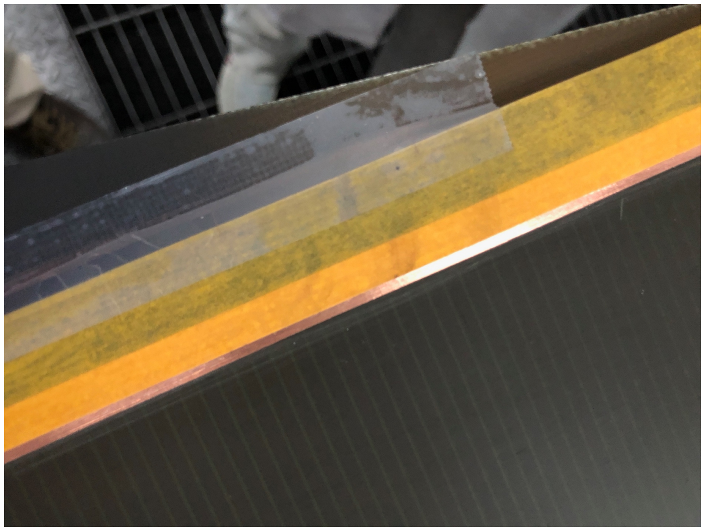
# Prototype building procedure

1. Carbon coating and polishing
2. Wire winding
3. Upper PCB bonding
4. X-ray leakage current scan
5. Two chambers combination
6. Performance testing

SDU has established a procedure to build and test an sTGC module for STAR.
The same group has completed the iTPC module production timely.

A different group in the same department at SDU is building ATLAS sTGC modules.

# Graphite spraying



Copper pads are partially covered before spraying

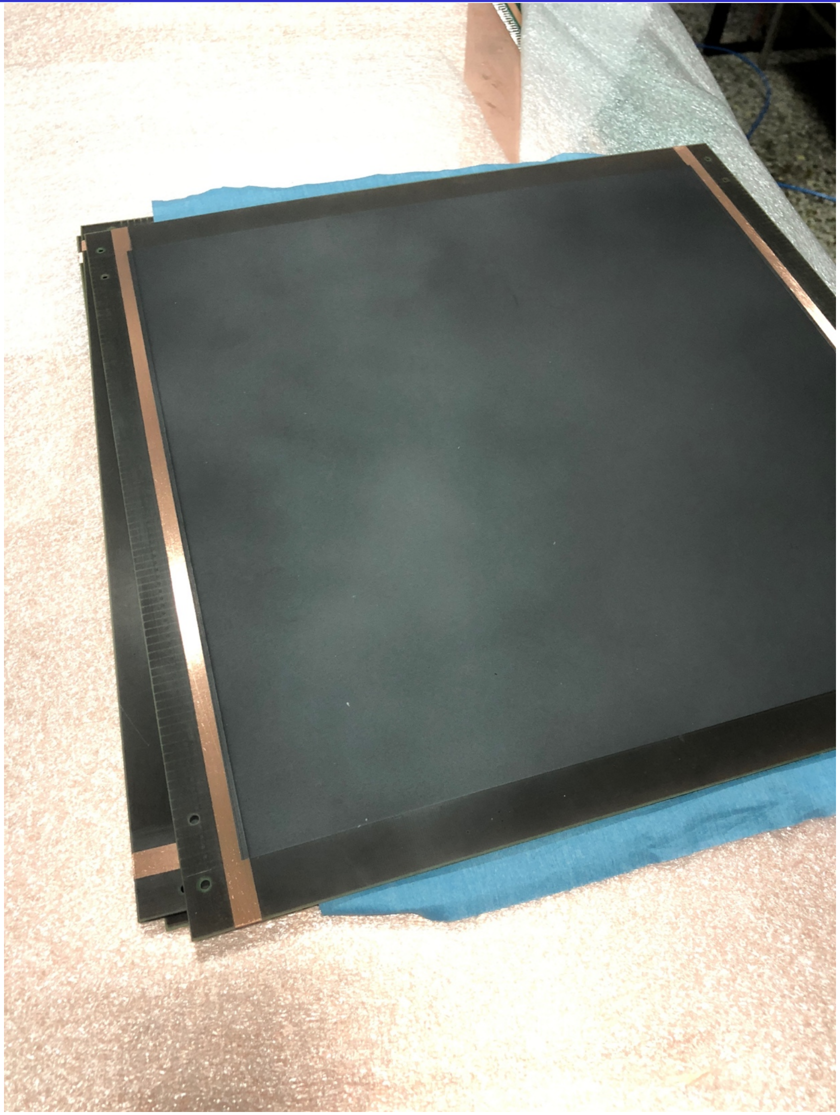
Graphite sprayer

Handle four PCBs together

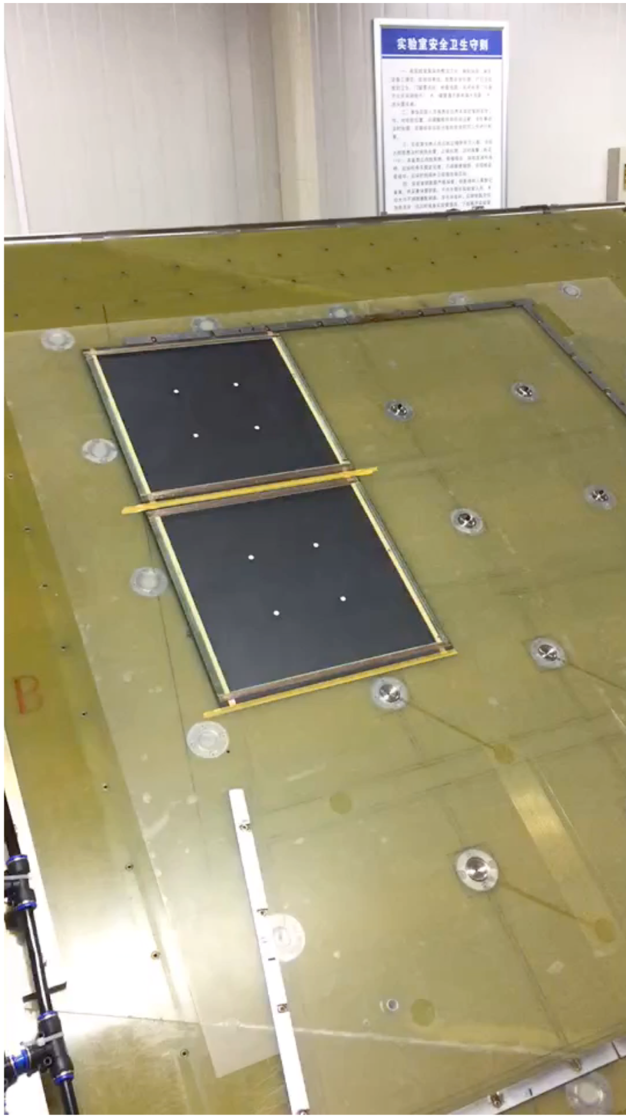
# Surface polishing

Polish to surface resistance：
200kΩ/2.5cm2

Measure -> Polish -> Measure ……



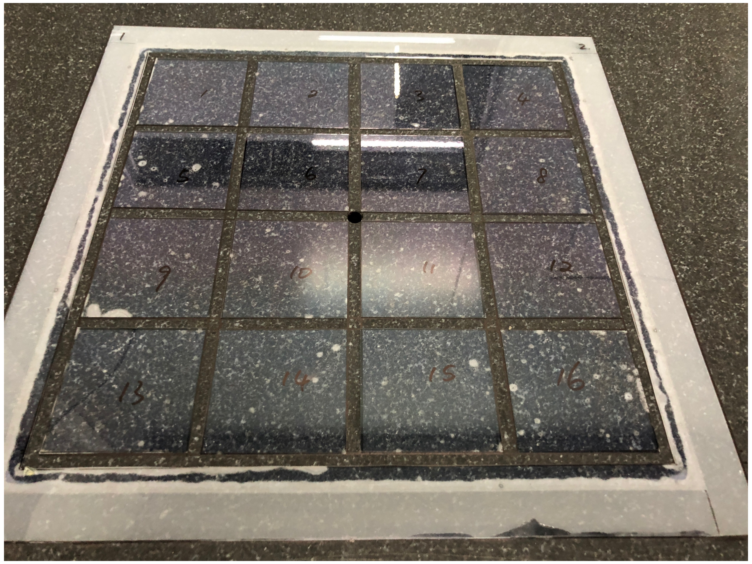
# Wire winding



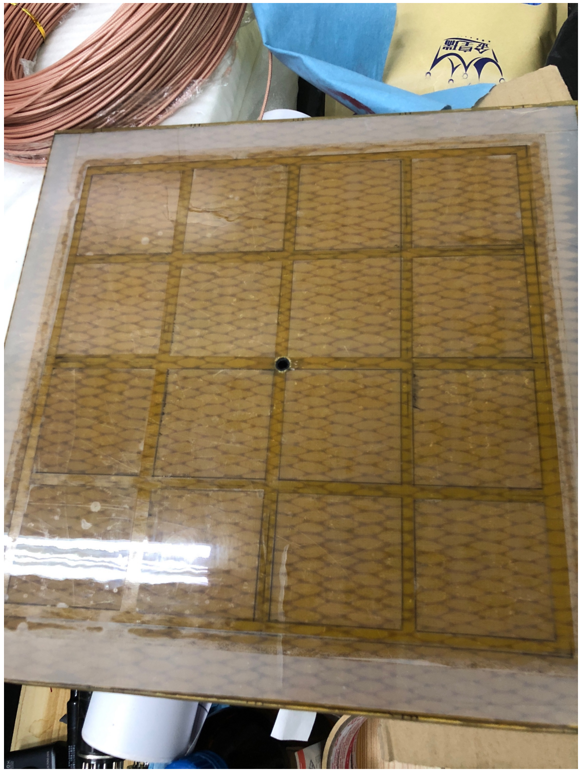
- ✓ Wires lay on the side wire mounts when winding
- ✓ Wire tension and pitch are kept by the winding machine
- ✓ Wires are soldered on the wire mounts after winding

# Combine the upper and lower half

Vacuum pumping frame on granite table



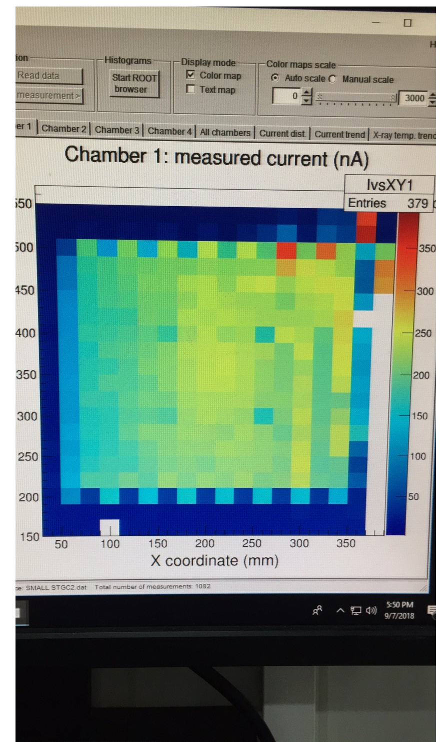
Use vacuum pump to keep the flatness of the sTGC PCBs



Vacuum pumping frame on honey comb

# X-ray radiation test

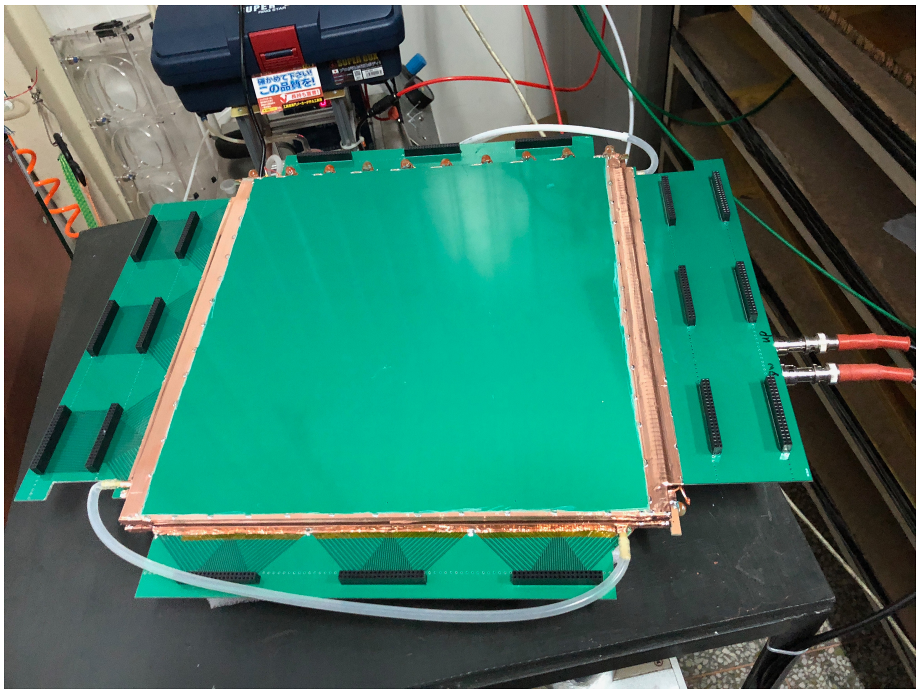
- ✓ 2D X-ray scan platform from local ATLAS group
- ✓ Step by step scan (2cm step)
- ✓ Tracking the leakage current

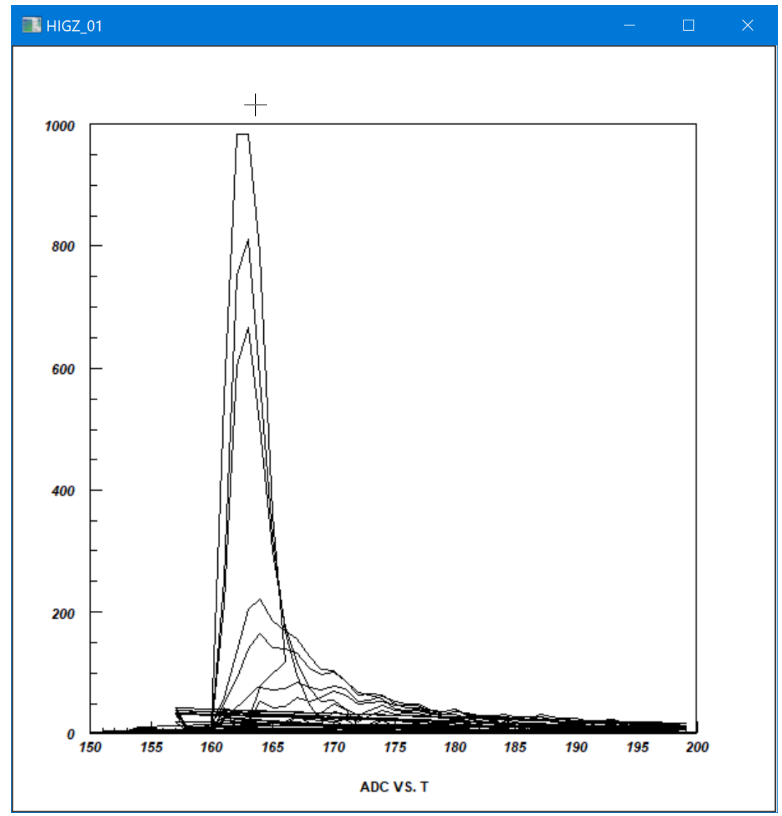



Based on the previous sTGC experience, seen from the leakage current distribution, the flatness is about 50 micros.
Meet ATLAS sTGC flatness requirement.

# Prototype performance

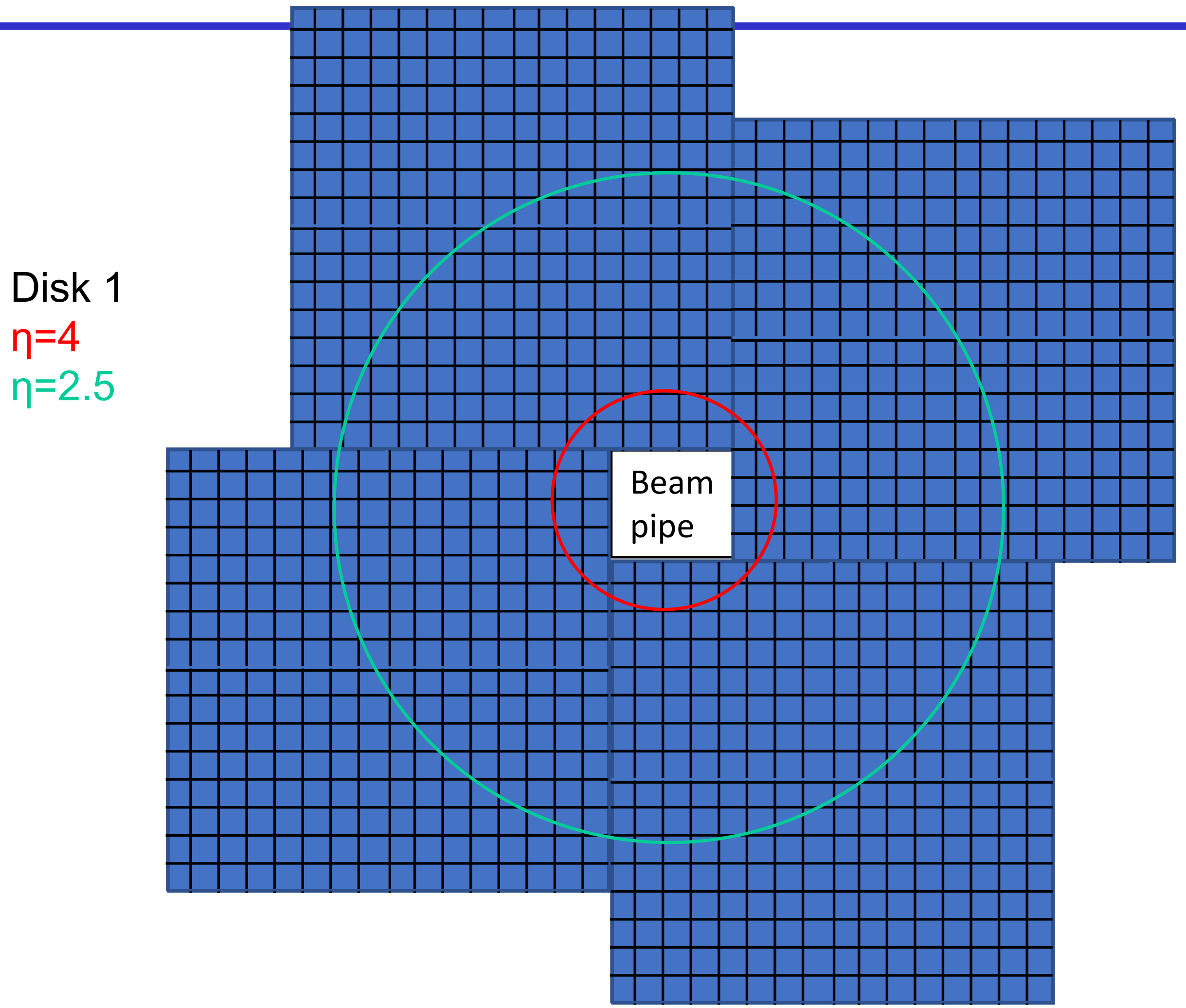
The SDU built a prototype of 30 cm ✖ 30 cm with TPX electronics readout last summer. Results are very promising.





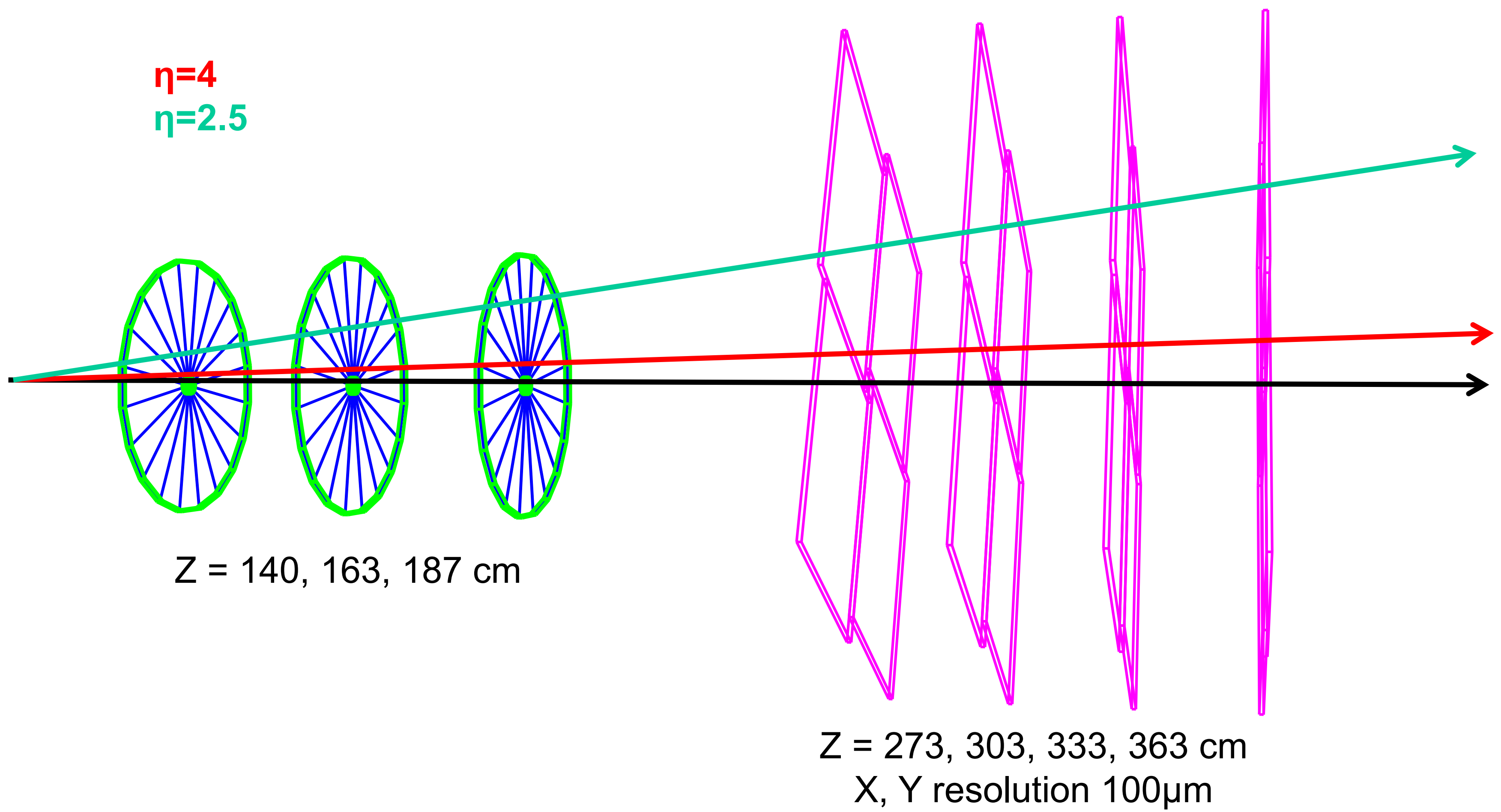

The module was shipped to BNL in January 2019 and will be installed at STAR in May. The sTGC prototype will take data together with the PreShower, forward ECAL and HCAL prototype in Run 2019.

# sTGC disk in simulation




Geometry: 4 identical quadrants arranged around beam-pipe cut out.

# sTGC geometry



# Simulation goal

Physics: cold QCD and heavy ion collisions.
Heavy ion collisions at forward rapidity:

- Lambda global polarization (signal is large is peripheral collisions)
- PT dependent charged particle vn

Need to be able to provide tracking in peripheral collisions (e.g. 40-50% centrality)

Study the strip length dependence (30 cm versus 15 cm)
Simulate occupancy, efficiency v.s. eta and centrality

Conclusion: our current tracking detector configuration meets the requirement!

The devil is in the detail.  See Zhenyu Chen, Isaac, and Daniel's talks.

# Cost

Module production: 1.5 million RMB, ~ 220 k USD equivalent, available at Shandong University

Electronics FEEs and RDOs: available

LV Power supplies, cables, and daq (based on Tonko's estimation): $36k including 30% contingency

HV power supplies, distribution and gas system: $41k including 30% contingency

Mechanical integration and water cooling (based on Rahul's estimation): $65k including 30% contingency

Total to BNL (M&S): $142k

No major cost component.

# Schedule

Milestones:
Aug 2019, sTGC R&D completed (build another two 60 cm✖60 cm modules)
Sep 2019, sTGC mass production readiness review
Oct 2019 to Oct 2020, mass production of 32+8 (spare) sTGCs
May 2021, Last batch of sTGCs installed at STAR
Schedule float: 6 months

SDU made a detail assessment for the production time:

| # | Step | Duration(hour) |
|---|---|---|
| 1 | Material inspection/cleaning | 14 |
| 2 | PPPCB masking tape pasting | 2 |
| 3 | Graphite mixing/spraying/polishing | 8 |
| 4 | Half-chamber production, HV burn-in | 48 |
| 5 | wire winding, soldering, washing | 24 |
| 6 | Two half combination | 24 |
| 7 | Air tap installation and sealing | 48 |
| 8 | Gas leak inspection and repairing | 4 |
| 9 | Flow in CO2 HV burn-in | 12 |
| 10 | Flow in CO2+N.P X-ray test | 24 |
| 11 | CO2 washing residual N.P. | 12 |

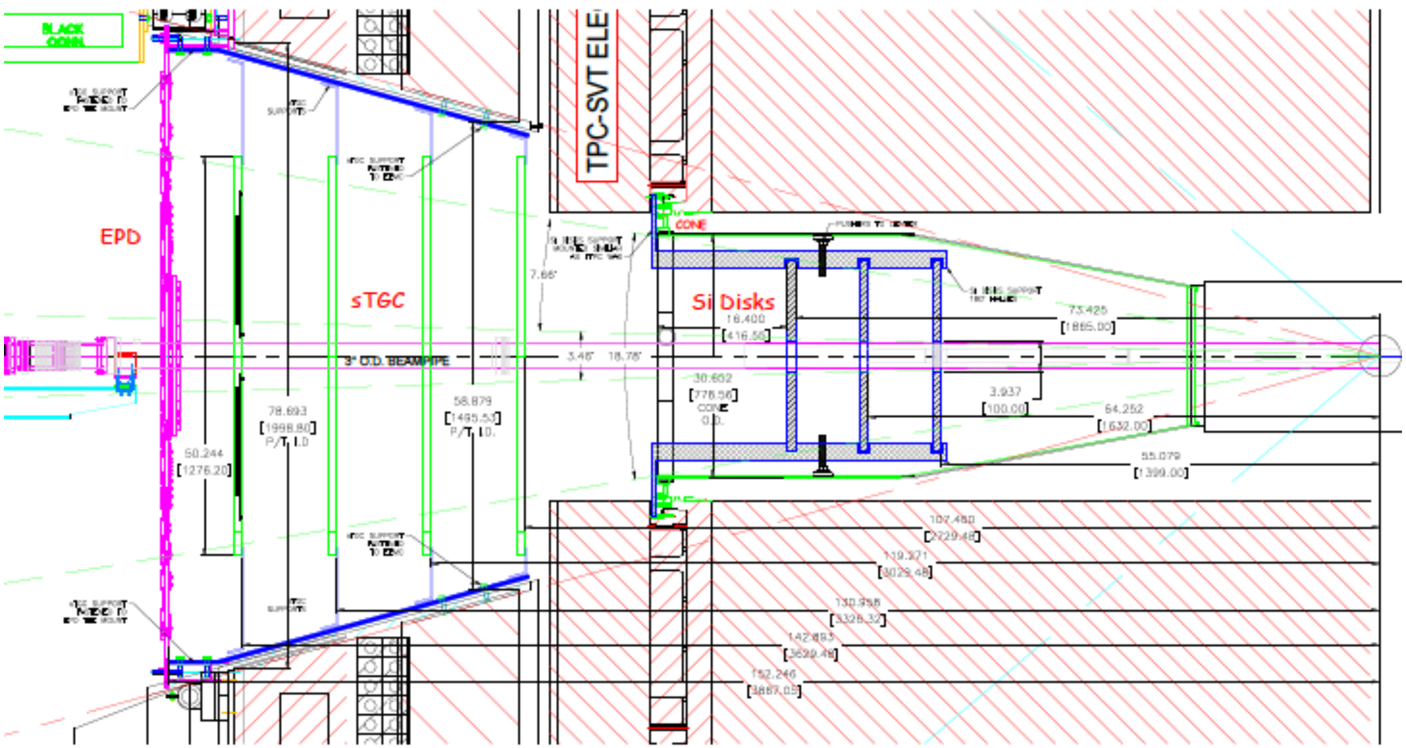
**About 9 days per chamber, including preparation and testing.**

In addition, the ALTAS sTGC production project will end in Aug-Sep, 2019.
If using their technicians, SDU can finish the project in 4-6 months after mass production is started

# Highest Risk Areas

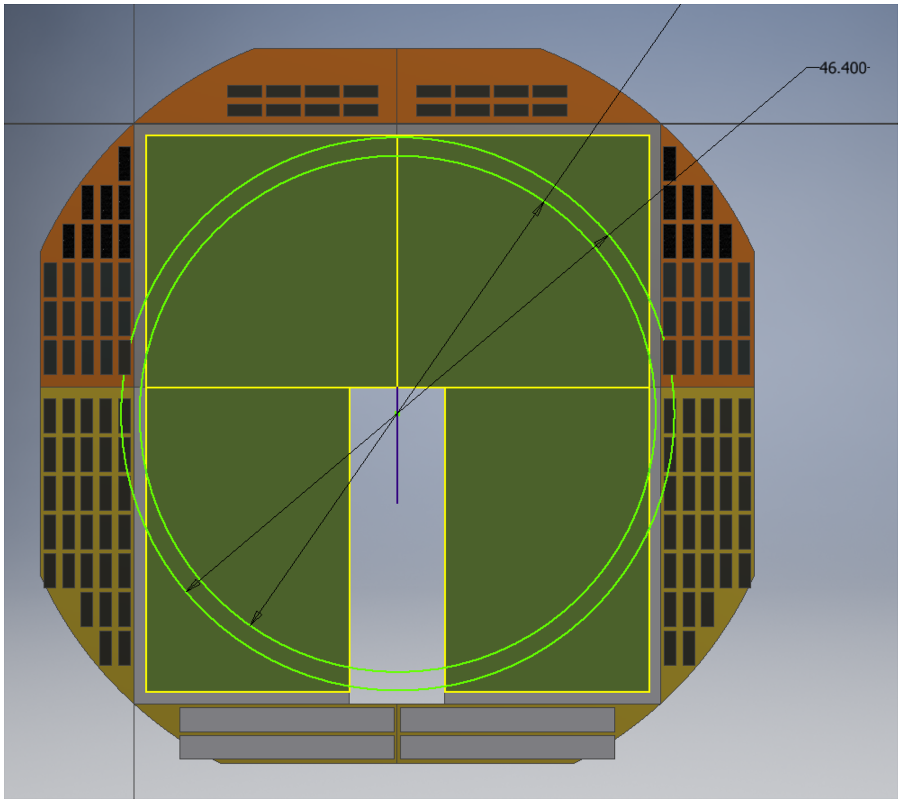
In the sTGC project, mechanical integration and cooling is a highest risk area compared to others.

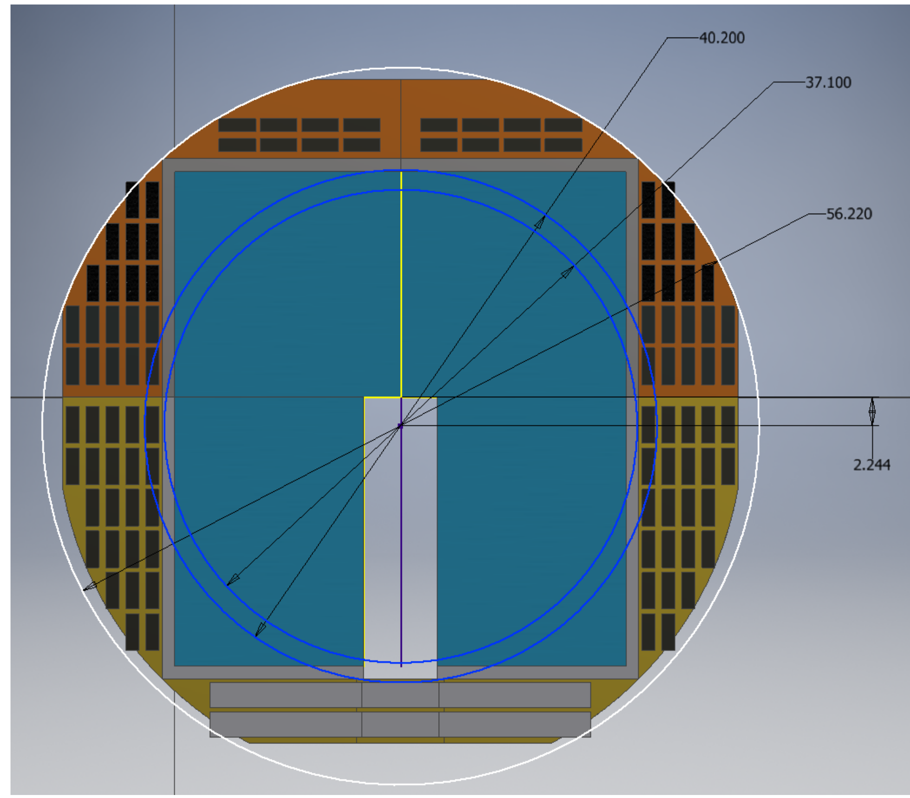
The 4 sTGC disks will be placed at z = 273, 303, 333 and 363 cm, inside the cone of the pole tip and endcap EMC. With the limited space for the high-density electronics readout, water cooling will be needed.



# Mechanical integration

- Each double module need 30 FEEs and 1 RDO. The length of ribbon cable from FEE to RDO need to be less than 75 cm. No enough space for FEEs and RDOs!!!




12 kinds of wire chambers for construction, too complicated!!!

Solution: use ALTAS electronics. 1 board has 8 VMM chips for 512 channels. So we just need 32 boards in total for the full system. The size of the board is 27.3 *7.6 cm2. Cost: 150 k USD in total.

# EH&S Concerns

For sTGC, we use gas mixture: 45% n-pentane and 55% co2
n-pentane is flammable.
Gas flow rate: less than 400 ccm.

HV: 3000 volts

We had two official safety reviews at BNL for the prototype, not approved yet.

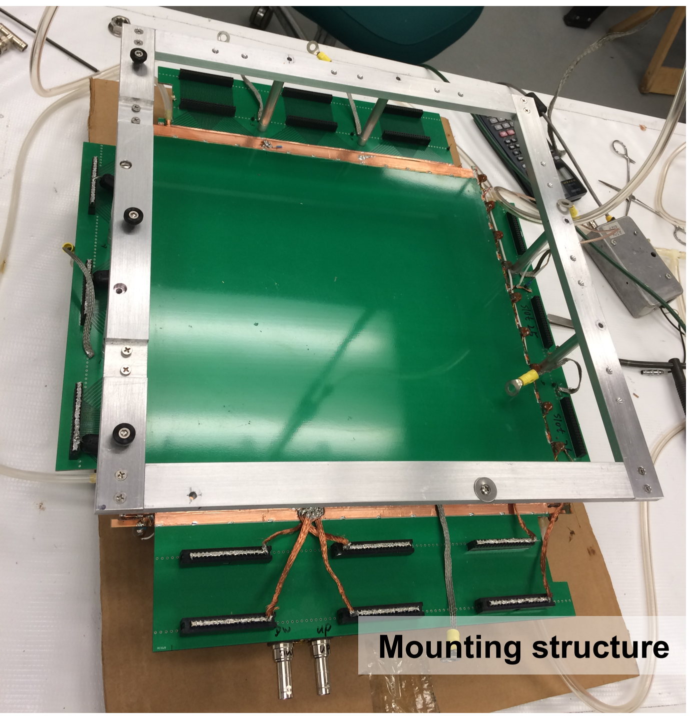
Still work with them.

At the same time, we tested the prototype at BNL using C10, P10, etc.
We can see reasonable signals with C10 but we do not know efficiency or position resolution.

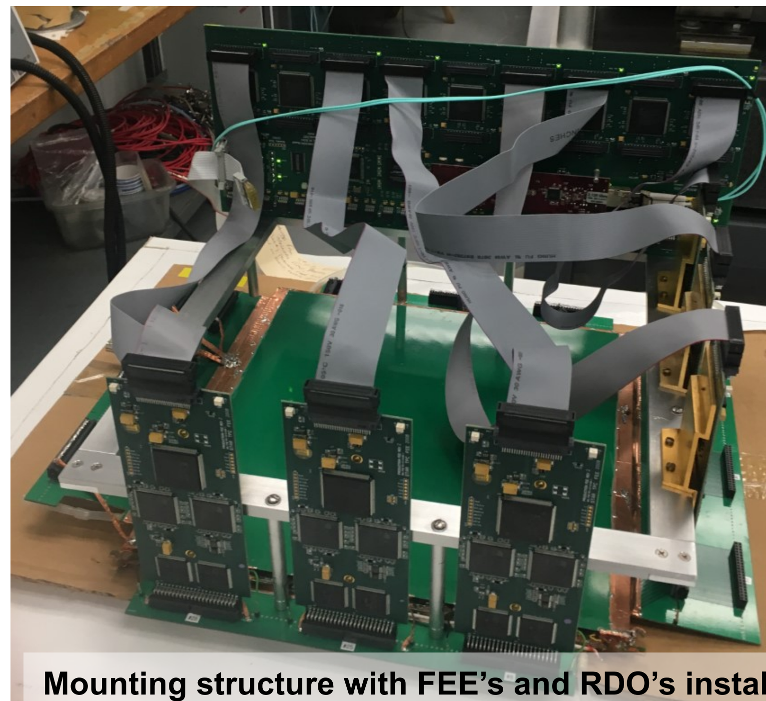
So my proposal to SDU team: test sTGC with different gas mixtures if possible, for example, C10 to check signal amplitudes, efficiency and position resolution.

# Mounting Structure and test set up at BNL

- Built by Bill Struble
- Hold 6 TPX FEE's and a RDO board
- Will be placed in front of FCS and Pre-shower



Mounting structure

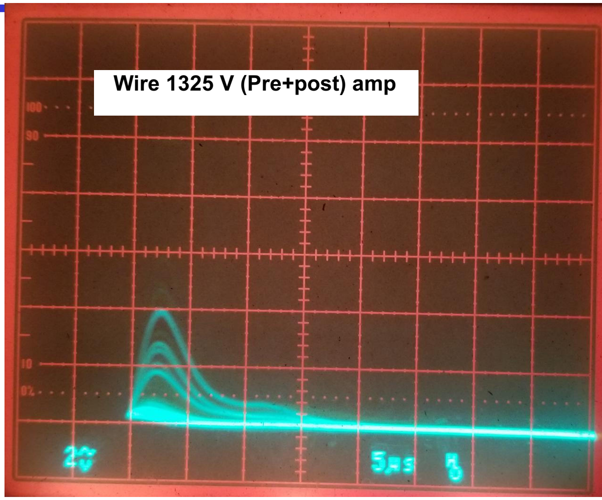


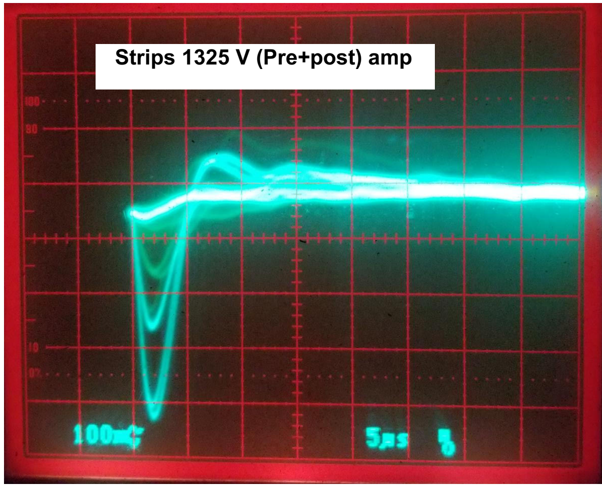
Mounting structure with FEE's and RDO's installed

- Cosmic ray test set up is completed. Will do the efficiency study.

# C-10 Test

- Ar 90 % and $CO_2$ 10%
- C-10 flown overnight
- Wire readout with Sr90:
  - 1250 V -> ~ 70 mV
  - 1300 V -> ~100 mV
  - 1350 V -> ~ 200 mV
  - 1400 V -> ~250 mV
  - 1450 V -> ~500 mV
  - 1500 V -> ~800 mV
  - 1550 V -> pre-amp saturates
  - 1600 V -> tripped
- Noise level is about 20 mV
- Pre-amp gain ~10, pre+post amp gain ~140
- Kept overnight at 1450 V -> Stable




***Note: pre-amp inverts the signal***

# Conclusion

There is a team on board for the sTGC detector. The team has been successful to deliver the STAR upgrade projects timely: TOF (2008-2010), MTD (2011-2014), and iTPC (2016-2018).

The 3 silicon disks + 4 sTGC disks will provide the forward tracking, and meet the requirement of the cold QCD and heavy ion physics.

Path forward:
At BNL
1. Install the prototype sTGC at STAR at the end of May and take data with beam collisions using C10 gas and TPC electronics.
2. Test ATLAS electronics at lab (Steve Valentino) and then test it with the prototype detector at summer shut down.
3. Work with safety committee to get the n-pentane/co2 gas system approved in the clean room for the summer shut down test
4. Get funds 150 k USD for ATLAS electronics

For SDU
1. Get electronics mechanical drawing so that we can pass the sTGC and electronics information to Rahul for integration, need to know the cooling option (air vs. water).
2. Once the dimension is finalized, we can start procurement.
3. For the 4 sTGCs of 60*60 cm2, test them with sTGC electronics and with different gas mixtures so that we know whether absolutely we need n-pentane or we have an alternative

# Backup

# i-Butane Test

- Ar 70% + $C_4H_{10}$ 30%
- Flown for about 40 min
- Strip readout:
  - Noise 20 mV
  - 1500 V -> ~ 40-60 mV
  - 1600 V -> ~100-150 mV
  - 1700 V -> ~200-300 mV and trip
  - 1800 V -> ~400 -600 mV and trip fast