R&D studies of a small-strip thin gap chamber as a STAR forward tracker

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STAR

BROOKHAVEN NATIONAL LABORATORY

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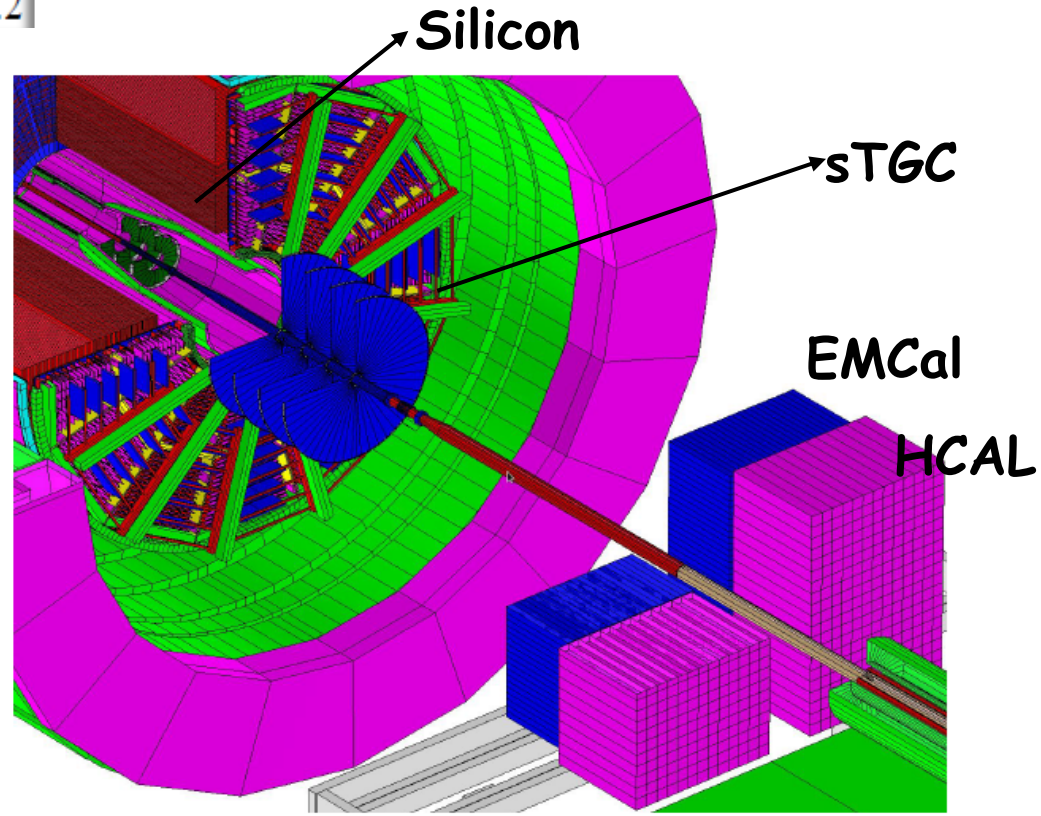
APS physics

Forward upgrade at STAR - fSTAR

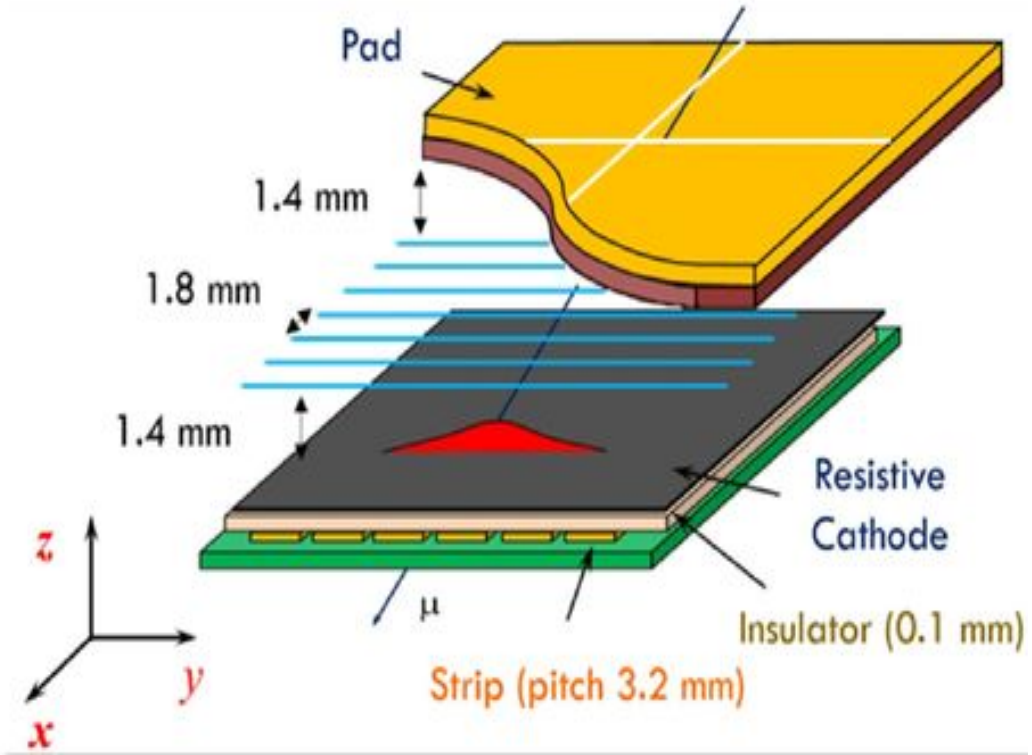
- Strongly endorsed by the BNL PAC

STAR presented a rich program for future operation after BES II that addresses many important and innovative topics in p+p, p+A and A+A physics. The most interesting of these is focused on forward physics that would be made possible by a forward upgrade covering rapidities up to 4.2

- Fulfill the RHIC physics program
  - Address key open questions in cold QCD
  - Study nuclear initial state and transport properties from heavy-ion collisions
- Lays ground work for the EIC
- West side of the STAR covering $2.5 < \eta < 4$
- p+p, p+A and A+A collisions in 2021/22 and in parallel with sPHENIX data taking



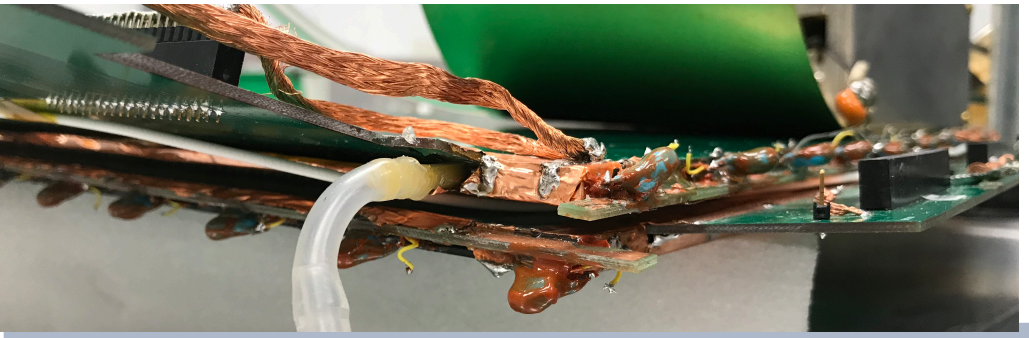
small-strip Thin Gap Chamber - sTGC

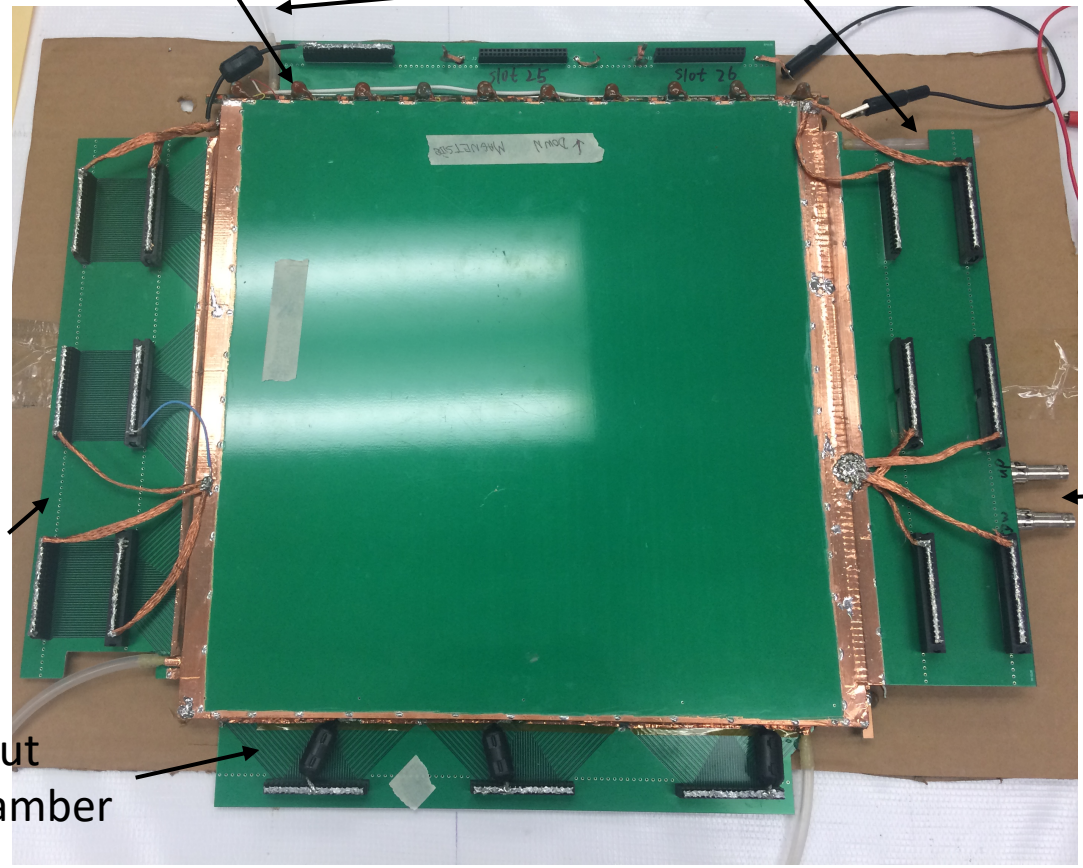


- Provides tracking and position resolution less than 100 µm, at high luminosity and background
- Anode (HV): 50 µm Gold plated tungsten wires held at a potential of ~2900 V
- Cathode(Ground): graphite-epoxy mixture with a typical surface resistivity of 100 to 200 kΩ/□ sprayed on G-10
- Readout: Small copper strips, perpendicular to anode wires, outside of cathode
- p+p & p+A: charge separation, photon suppression
- A+A: 0.2<pT<2 GeV/c with 20-30% resolution

sTGC Prototype

- Two chambers made at SDU-China
  - Each chamber 30 × 30 × 0.28 cm
  - Both are glued together with honeycomb structure in between
  - And perpendicular to the strips for 2D readout
  - Readout possible from strips and wires
  - 94 channels per chamber
- Leaks from the chambers are tested with pressure drop method, and found less than 10 cc/hr

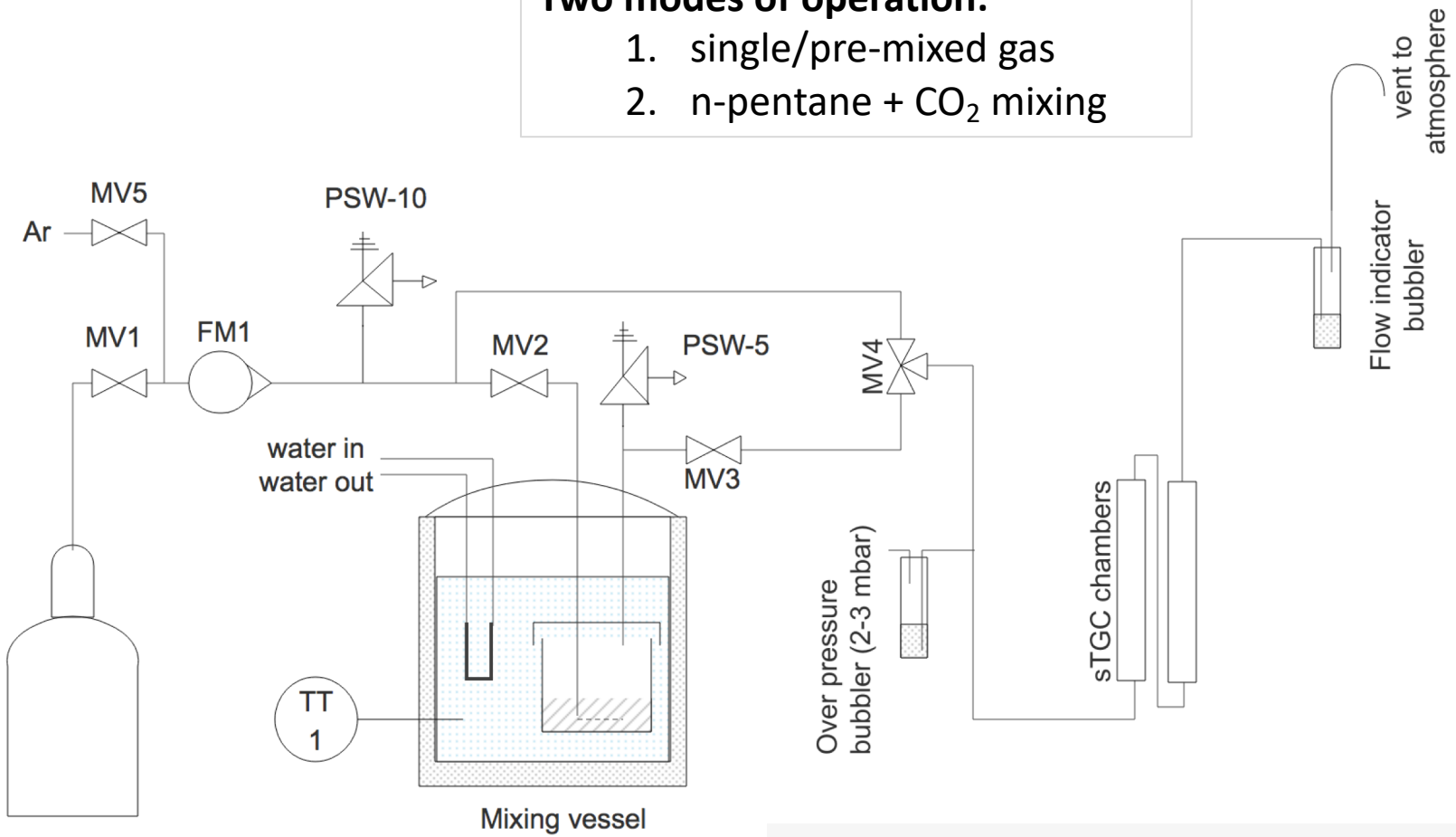




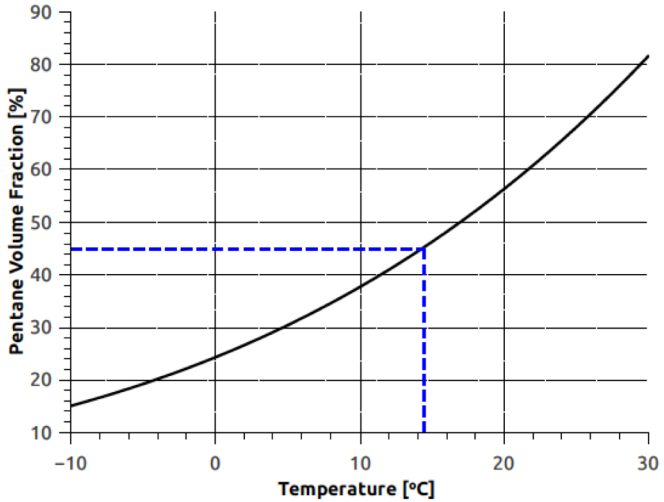
Gas system

Two modes of operation:

1. single/pre-mixed gas
2. n-pentane + CO_2 mixing

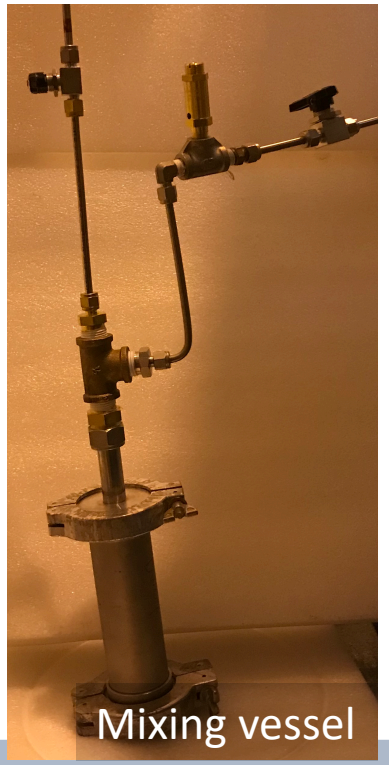


CO_2 or
pre-mixed gas



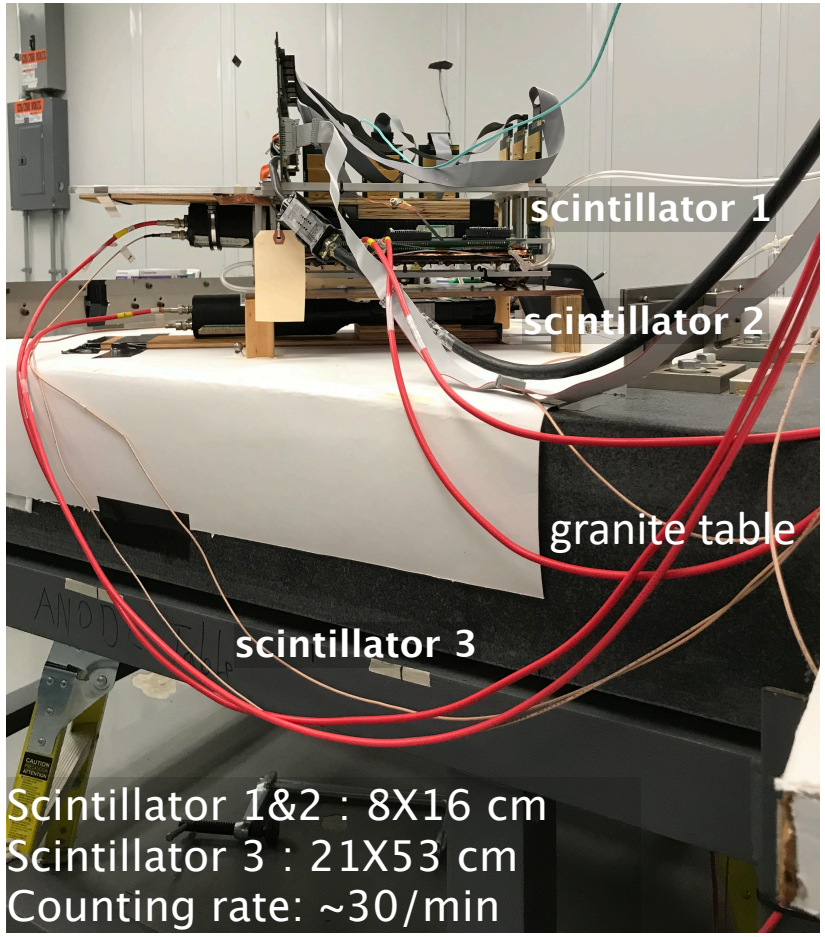
arXiv:1702.01240v3 [physics.ins-det]

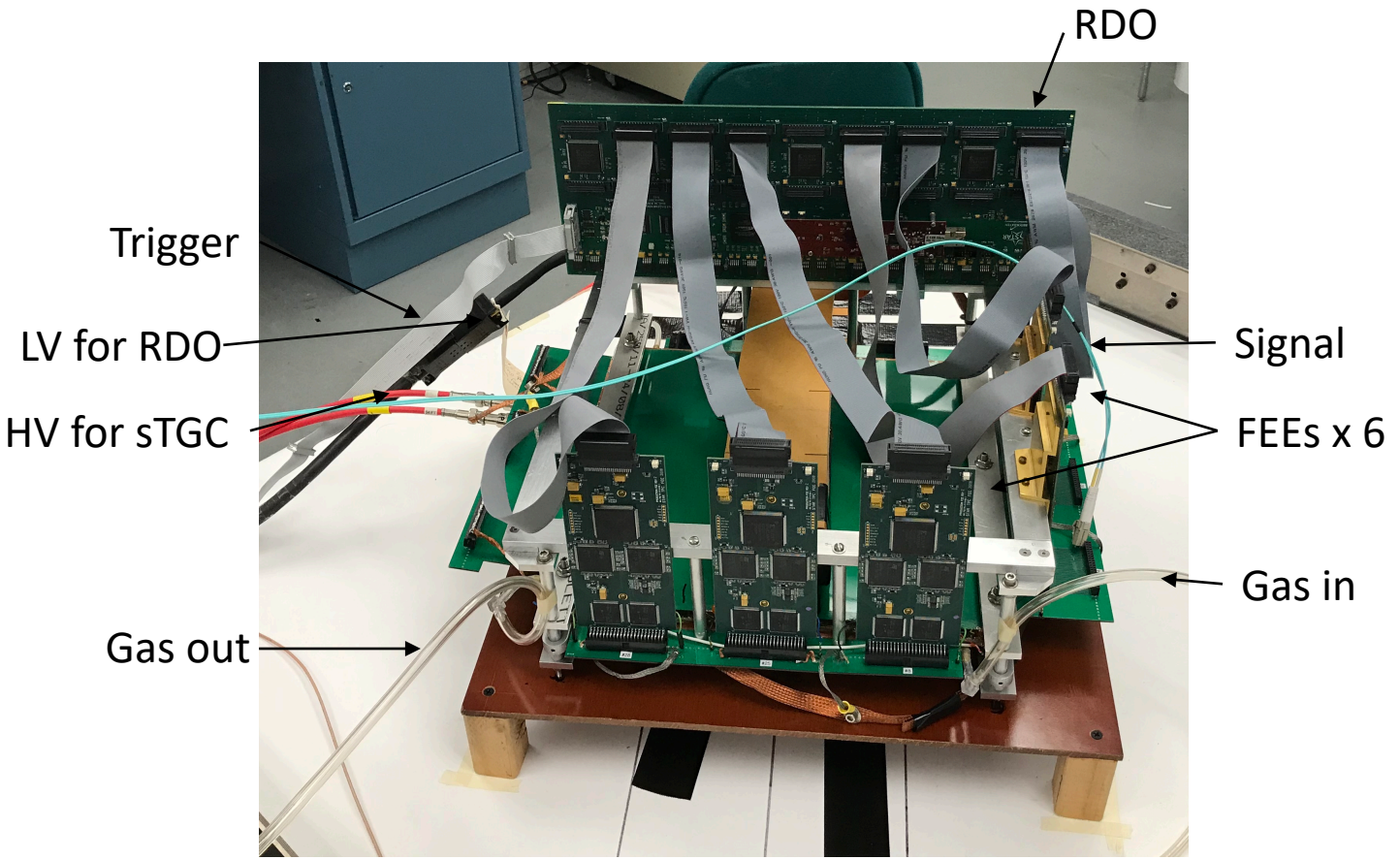
Mixing vessel is in insulated water bath, which is cooled by water chiller to maintain at the required temperature 17^0 C



Efficiency measurements

- Performance of the prototype was tested in the clean room with several gases including n-Pentane
- Triple coincidence from three scintillators are used for triggering on cosmic ray muons
- Existing TPC electronics was used for data acquisition

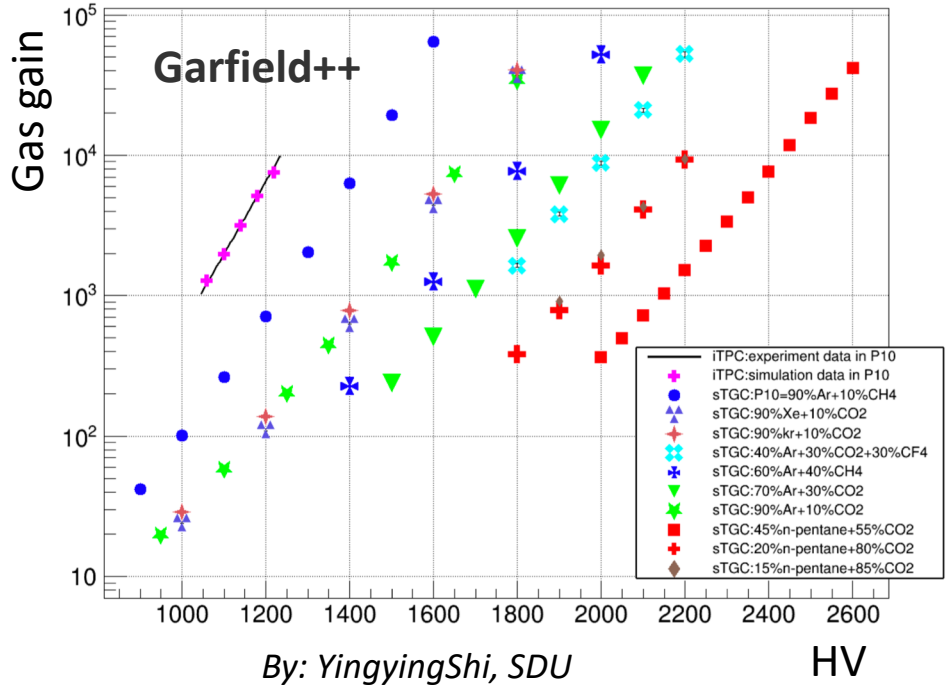




Gas options

- sTGC uses n-pentane + CO_2 (45+55)% to operate in high gain ~10^7
- n-pentane is flammable and liquid below 96^0 F (36^0 C)
  - Very difficult to operate
- Trying different gases:
  - C10 -> Ar 90% + CO_2 10%
  - P8.5 -> Ar 91.5% + CH_4 8.5%
  - i-Butane(C_4H_{10}) + Ar (30+70)%
  - n-pentane(C_5H_{12}) + CO_2 (45+55)%
  - …

Gas	Density, mg cm^{-3}	E_x eV	E_I eV	W_I eV	$dE/dx\|_{\min}$ keV cm^{-1}	N_P cm^{-1}	N_T cm^{-1}
He	0.179	19.8	24.6	41.3	0.32	3.5	8
Ne	0.839	16.7	21.6	37	1.45	13	40
Ar	1.66	11.6	15.7	26	2.53	25	97
Xe	5.495	8.4	12.1	22	6.87	41	312
CH_4	0.667	8.8	12.6	30	1.61	28	54
C_2H_6	1.26	8.2	11.5	26	2.91	48	112
iC_4H_{10}	2.49	6.5	10.6	26	5.67	90	220
CO_2	1.84	7.0	13.8	34	3.35	35	100
CF_4	3.78	10.0	16.0	54	6.38	63	120



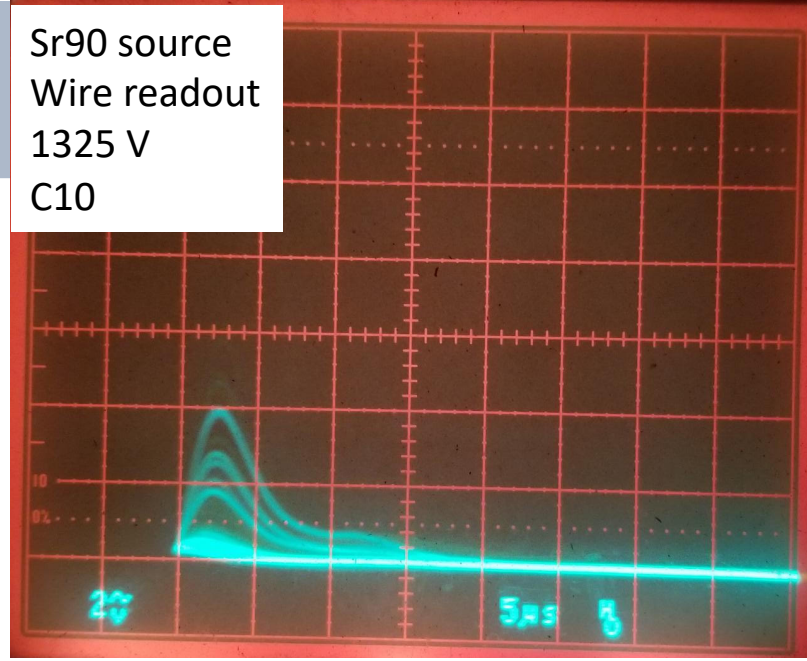
By: YingyingShi, SDU

Gas options

Gas	Signal at wire readout		Operation
	Low HV (V)	High HV (V)/ Trip limit	
C10 -> Ar+CO_2 (90%+10%)	1250	1600	Stable
P8.5 -> Ar+CH_4 (91.5%+8.5%)	1400	1600	Not stable
i-Butane(C_4H_{10}) + Ar (30+70)%	1500	1800	Not stable
n-pentane(C_5H_{12}) + CO_2 (45+55)%	2200	2800+	Stable

- Sr90 source is used
- Signal from wire and strips are recorded
- Low HV: Signal at least 10 times greater than the noise level
- More gas mixtures are being tested

Sr90 source
Wire readout
1325 V
C10



Sr90 source
Strip readout
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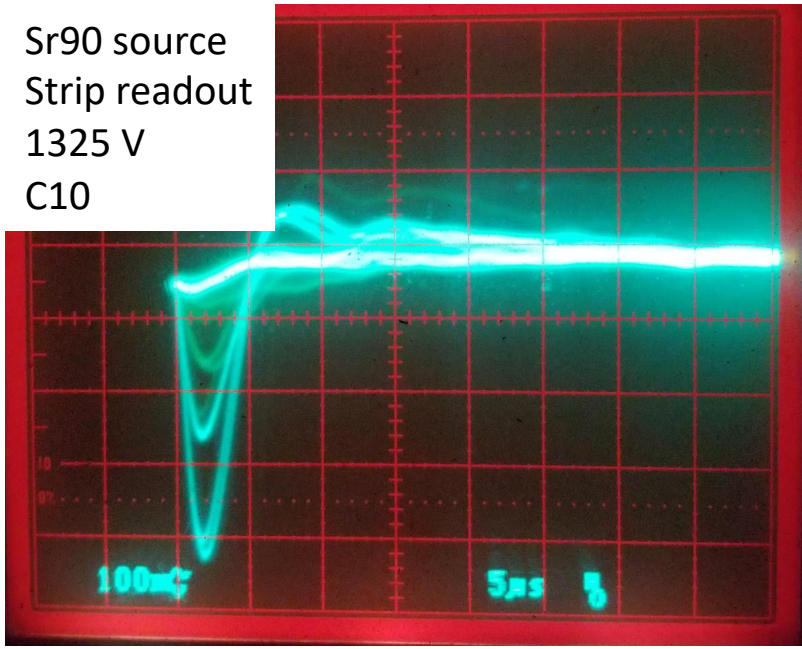
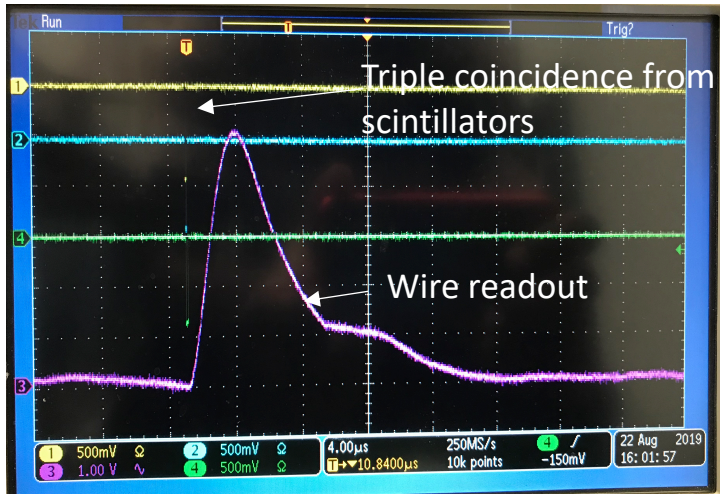


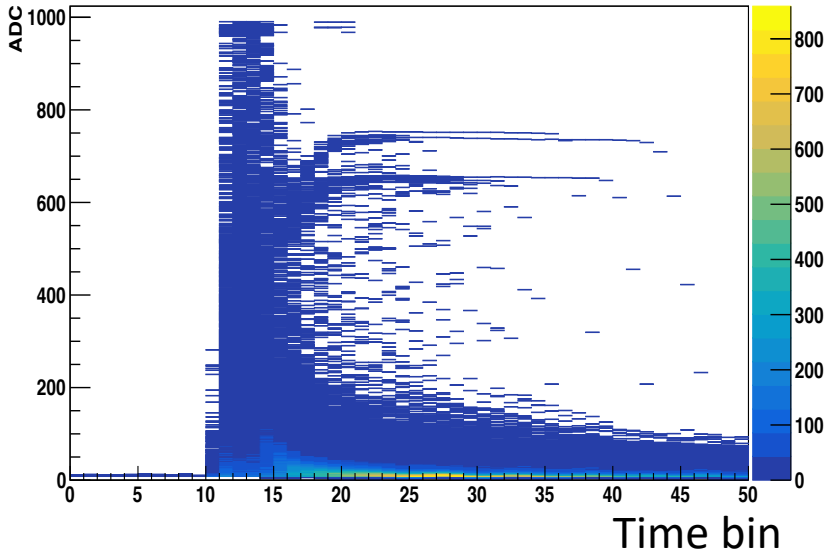
Note: amp inverts the signal

Wire and strip signals

Scope trace of trigged cosmic muon from wires

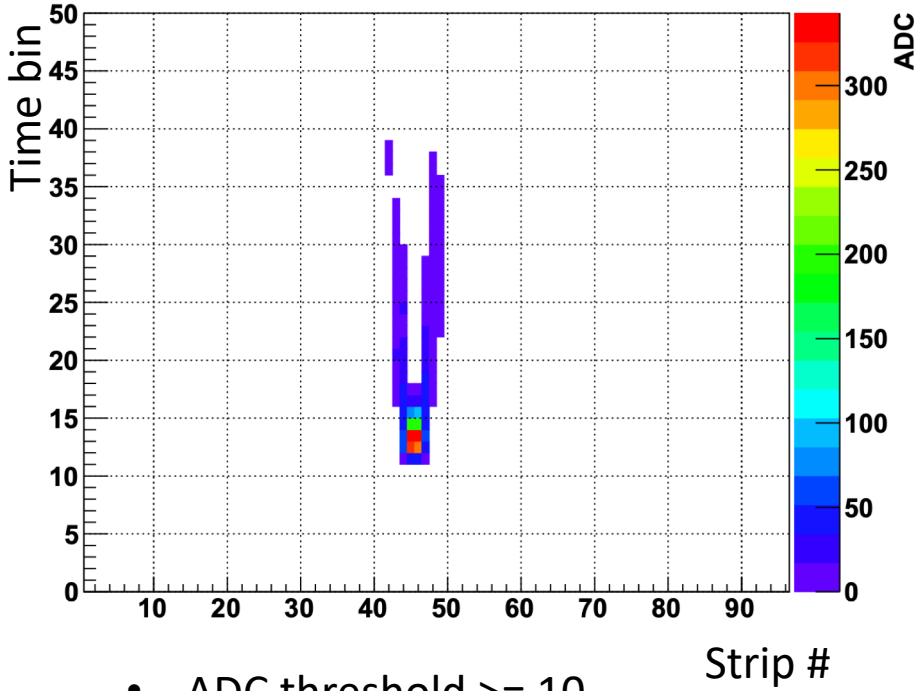


ADC vs. arrival time of 5000 cosmic muons



- One time bin = 107 ns (1 RHIC clock)
- Most of the muons are in between 10 and 15 time bin
- There is an after pulse seen from the data
- More investigation is ongoing

Signal from a single cosmic ray



- ADC threshold >= 10
- Number of strip>= 4
- Number of time bins >= 4

- Detailed cluster studies are ongoing

Efficiency

C10 gas efficiency

Total triggered events:

$$\frac{top\ \ layer\ respond}{Total\ Events} = 1\%$$

$$\frac{bottom\ layer\ respond}{Total\ Events} = 1.8\%$$

$$\frac{at\ least\ one\ layer\ respond}{Total\ Events} = 2.7\%$$

Self trigger:

$$\frac{two\ layer\ respond}{bottom\ layer\ respond} = \ 7.3\%$$

$$\frac{two\ layer\ respond}{top\ layer\ respond} = 13.0\%$$

n-pentane + CO_2 efficiency

Total triggered events:

$$\frac{top\ \ layer\ respond}{Total\ Events} = 98.3\%$$

$$\frac{bottom\ layer\ respond}{Total\ Events} = 98.8\%$$

$$\frac{at\ least\ one\ layer\ respond}{Total\ Events} = 99.8\%$$

Self trigger:

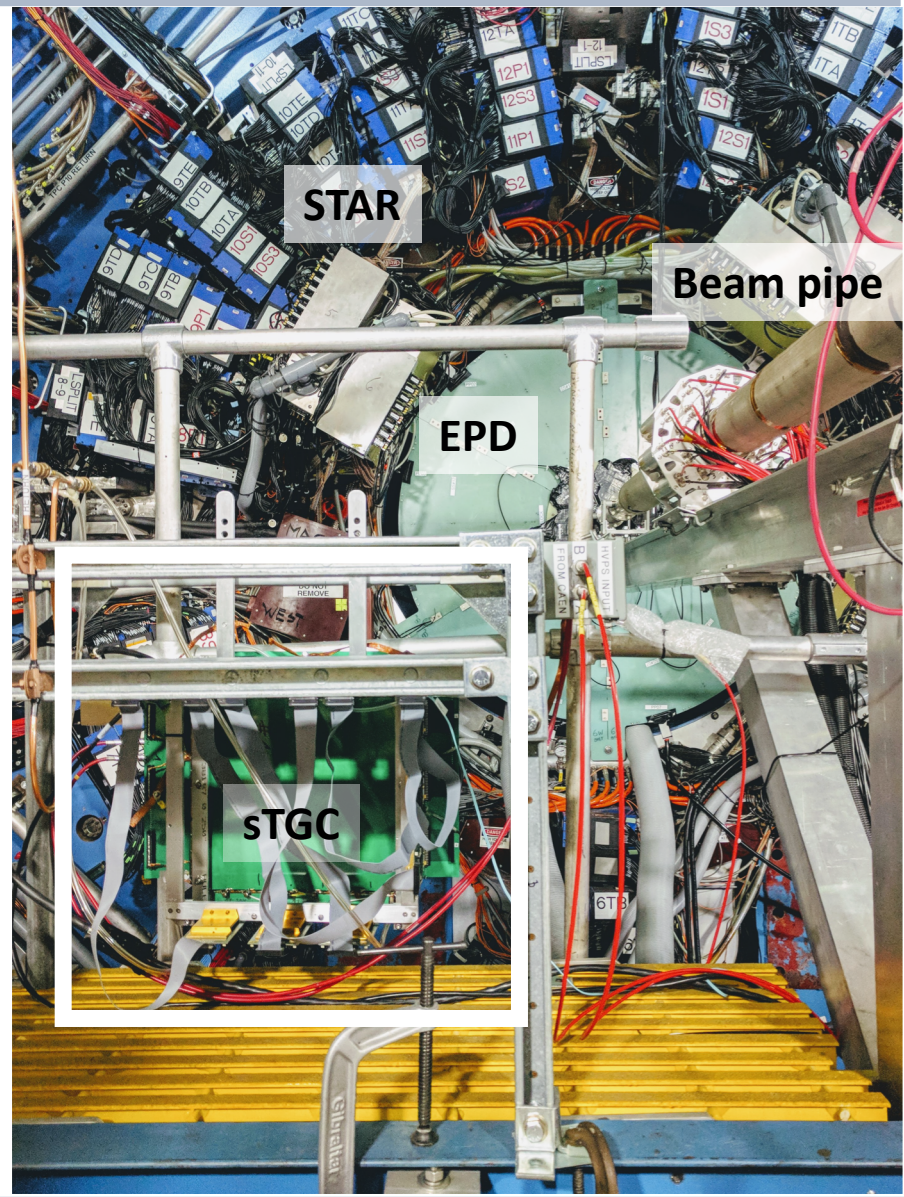
$$\frac{two\ layer\ respond}{bottom\ layer\ respond} = 98.5\%$$

$$\frac{two\ layer\ respond}{top\ layer\ respond} = 99.0\%$$

Efficiency is found to be independent of temperature change (17 ± 2^0 C) (and flow rate)

RHIC – Run 19 operation

- Prototype was mounted on the west plat form of STAR, in front of HCAL, EMCAL and pre-shower
- Electronics and DAQ were integrated to STAR
- Used pre-mixed C10 gas
  - Other gases were not possible with safety requirement at that time
- Collected data with Au+Au 200 GeV collisions
  - Data is being analyzed



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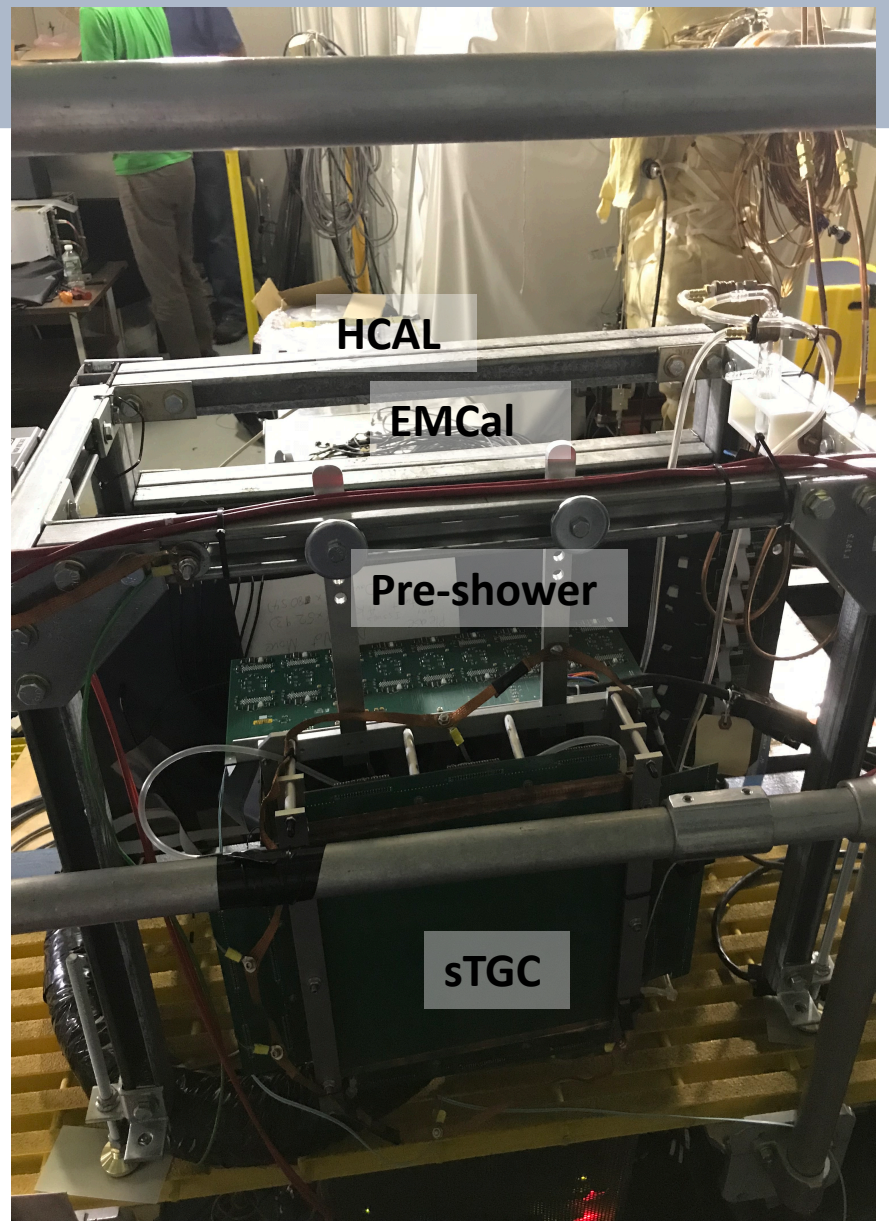
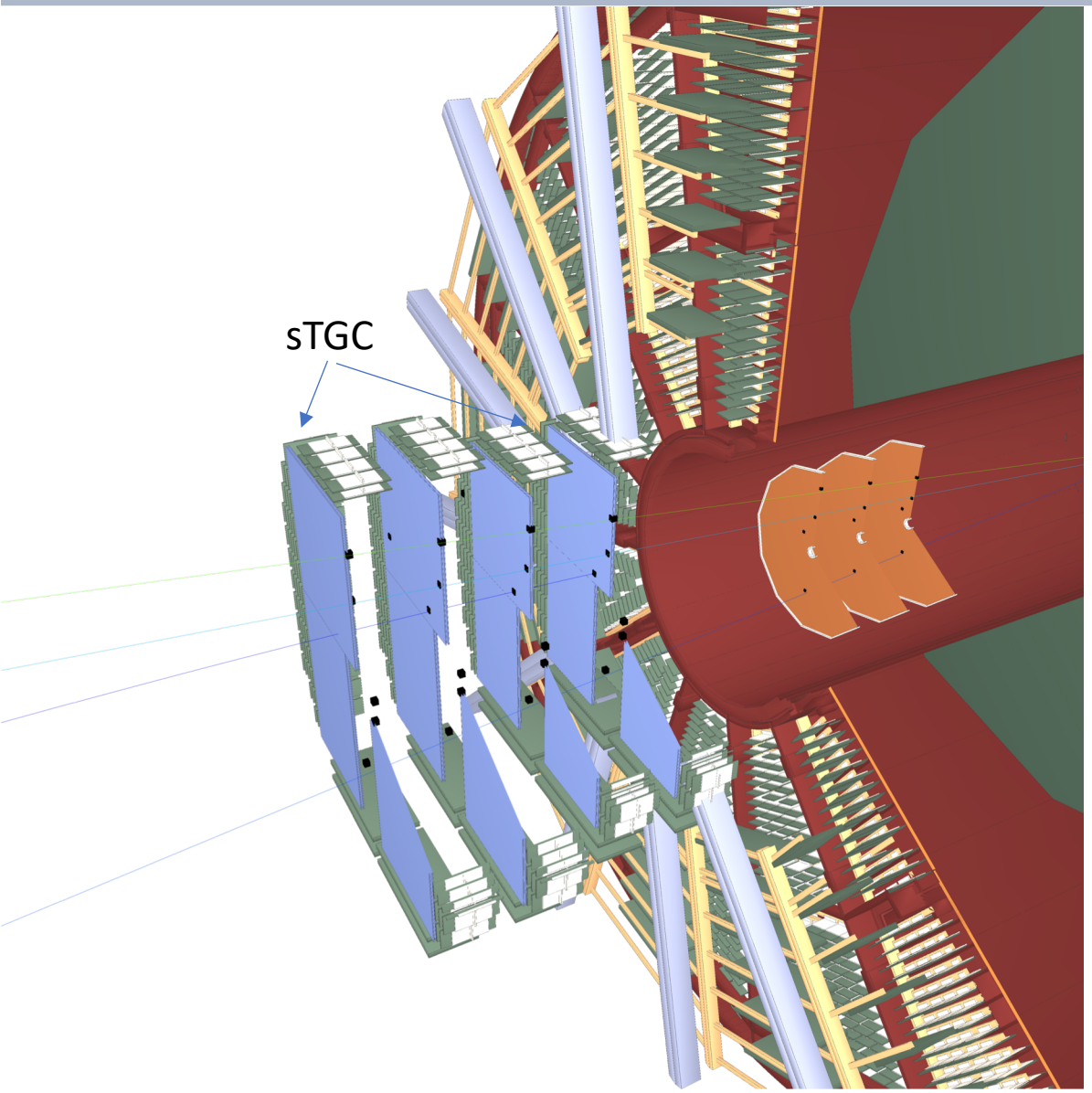


Summary and Outlook

- Forward upgrade at STAR enables to address **key open questions** in both spin and heavy-ion physics, and provides **ground work for the EIC**
- Requirements for the upgrade can be met with the sTGC, without significant loss of performance compare to **all silicon tracking**
  - Provides position resolution better than 100 µm, charge discrimination, photon suppression and pT measurements in forward rapidity
- n-Pentane + CO2 mixtures shows better than 98% efficiency
  - We couldn't get similar efficiency from the other gases that we tried
  - More gas mixtures are being studied
  - Position resolution studies is being conducted at Shandong university
- Prototype was integrated to STAR during RHIC run 19 and tested with C-10 gas
- For the next RHIC run 2020:
  - 60X60 cm prototype will be integrated to STAR
  - A new n-pentane and CO_2 gas mixing system is being developed and tested

Proposed final arrangement



- 4 sTGC layers: at 273, 303, 333 and 363 cm from IP
- Each layer double sided
  - Provide (diagonal) x-y coordinates
- Position resolution: less than 100 µm
- location inside Magnet pole tip opening
  - inhomogeneous magnetic field
- Readout: VMM electronics from ATLAS
  - 24000 channels