

# A Forward Rapidity Upgrade at

STAR 🖈



第十八届全国中高能核物理大会, 2019年6月21日-25日, 长沙

## Outline



### **STAR Detector Upgrades**









Successful, <u>on-time & under budget</u> completion of the iTPC upgrade

#### SDU iTPC local group





2019 Event Display : Au+Au 19.6 GeV Full tracking with all iTPC sectors



### **Event Plane Detector**

#### Replaces Beam-Beam Counter (BBC)

- ✓ Improved triggering capabilities
- ✓ Improves background rejection

#### $\text{Coverage}: 2.1 < |\eta| < 5.1$

#### Greatly improves event plane resolution

- ✓ Especially  $1^{st}$  order event plane
- ✓ Crucial for achieving BES II physics goals

Smooth installation (completed in 2018), commissioning, and operation

Already used for physics analysis of 2018 data



STAR Note 666 https://drupal.star.bnl.gov/STAR/starnotes/public/sno666

- ✓ Each (East, West) wheel:
- ✓ 16 tile "rows" at given radius
- ✓ 24 tiles per row (except 12 for innermost)
- ✓ 372 tiles x 2 = 744 tiles in total

### **Event Plane Performance**

#### 1<sup>st</sup> order Event Plane Resolution

→ Significant improvement across all centrality



#### Added coverage from EPD

ightarrow Allows measurement of  $v_1$  over ~10 units of  $\eta!$ 



## **Endcap Time-of-Flight Detector**

#### Full eTOF installation : completed Nov 22, 2018



Inside face of east pole-tip, partially installed



Fully installed and cabled

## **Endcap Time-of-Flight Detector**



### STAR Physics Program after Beam Energy Scan II

 ✓ STAR Upgrades for BES II → provide <u>unique</u> opportunities at midrapidity in high energy A+A, p+A, and p+p



#### The STAR mid-rapidity pp, pA, AA physics program beyond BES-II :

https://drupal.star.bnl.gov/STAR/starnotes/public/sno669

## Forward Rapidity Physics at STAR

- ✓ Unique program addressing several fundamental questions in QCD
- Essential to RHIC cold & hot QCD physics mission + fully realize scientific promise of future Electron Ion Collider



### STAR Forward Detectors: FTS + FCS



Silicon + small-Strip Thin Gap Chambers (sTGC)





## STAR Forward Upgrade Status

#### https://drupal.star.bnl.gov/STAR/system/files/ForwardUpgrade.Nov\_.2018.Review\_o.docx

#### Associate Laboratory Director's Review

Reviewed on 19<sup>th</sup>, November 2018 :

- Physics requirements
- Cost & Schedule for each subsystem
- Readout & Triggering
- Plan for integration and in-situ testing

Positive Feedback & Recommendations

<u>"Good progress has been made on an intriguing concept for a cold-QCD</u> program to run in the near future in the forward direction at STAR"

#### NSF proposal submitted Jan 2019

- Funding for Forward Calorimeter systems
- Received very positive feedback
- Awaiting final response fully expect funding

#### The STAR Forward Calorimeter System and Forward Tracking System



Proposal November 2018

Final Report ALD's review : https://drupal.star.bnl.gov/STAR/system/files/STAR%20forward%20upgrade%20review%20Final%20Report.pdf

### **Organizational Structure**



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## **Forward Tracking System**

|                        | Requirement                   | Motivation      |
|------------------------|-------------------------------|-----------------|
| Momentum<br>Resolution | < 30%                         | A+A goals       |
| Tracking Efficiency    | > 80% @ 100<br>tracks / event | A+A goals       |
| Charge Separation      | _                             | p+p / p+A goals |

Silicon mini-strip disks -- 3 layers

- Location from interaction point : z = 90, 140, 187 cm
- ✓ Build on and utilize STAR experience of successful Intermediate Silicon Tracker (IST) detector

small-strip Thin Gap Chamber -- 4 layers

- Location from interaction point : z = 270, 300, 330, 360 cm
- ✓ Significant reduction in cost
- Build on and utilize SDU experience of successful inner Time Projection Chamber (iTPC) detector

https://drupal.star.bnl.gov/STAR/starnotes/public/sno648

## **Forward Tracking System**



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## Forward Silicon Tracker (FST) Current Status



## Forward sTGC Tracker (FTT) Current Status

- ✓ 30 cm x 30 cm prototype delivered to BNL in January 2019
- Module tested in test-stand using cosmic rays + scintillator pads for trigger
- Connected to STAR Data Acquisition system first test data being analyzed now
- ✓ Installed in STAR on Jun. 5, 2019

#### Prototype in STAR Clean Room



#### On the Mounting Structure





## sTGC at SDU Current Status

Garfield Simulation on different gas options

- ✓ R&D started from Mar. 2018
  - ✓ 30cmx30cm prototype finished in Oct. 2018
  - ✓ Full-size 6ocmx6ocm prototype in R&D
  - Final designation is in preparing







## **Forward Calorimeter System**

**EMCal** 

HCal

#### **FCS Requirements**

| Detector | pp and pA   | AA      |
|----------|-------------|---------|
| ECal     | ~10%/√E     | ~20%/√E |
| HCal     | ~50%/√E+10% |         |

Electromagnetic Calorimeter
 Use PHENIX PbSc
 New readout SiPM/APD

Hadronic Calorimeter
 Sampling iron-scintillator
 Uses same readout as EMC

R&D in support of EIC

- $\rightarrow$  HCal development
- $\rightarrow$  All readout electronics
- → Balance Cost & performance

#### Large scale test run at Fermilab:

16 Ch HCal, 16 Ch EMCal, DAQ etc. delivered to Fermilab in Apr.2019

#### All test completed as planned

ECAL energy resolution measured ~ 10% /  $\sqrt{E}$  - meets requirement

HCAL energy resolution measured ~ 75% /  $\sqrt{E}$  + 7%

Work on modified light collection to improve resolution

✓ Promising results

✓ (ongoing development, but does not effect design)

## RHIC Run Plan 2019-2025

### Beam Energy Scan II (2019-2021):

- ✓ Low energy (7.7, 9.1, 11.5, 14.5, 19.6GeV) Au+Au runs
- ✓ Fixed Target runs at (3.0, 3.9, 4.5, 5.2, 6.2, 7.7 GeV)
- ✓ Search for signs of critical phenomena and chiral phase transition

#### Forward spin run (2022): fall 2021

- ✓ 500GeV p+p, enhanced by forward upgrades at STAR
- $\checkmark$  Spin physics measurement complementary to EIC

### Run with sPHENIX (2023-2025):

- ✓ Top energy 200GeV Au+Au, p+Au and p+p
- $\checkmark$  Precision measurement of fully resolved jets and Upsilon states
- Precision measurement of in-medium rho modification and QGP thermal dilepton

## RHIC Run Plan 2019-2025

| Beam Energy (7  | 2019 | 28 cryo-weeks with STAR  |
|---|------|--|
| <ul> <li>✓ Fixed Target ru</li> <li>✓ Search for sigr</li> </ul>                    | 2020 | Au+Au at 3.5, 3.9, 4.5, 5.2, 6.2, 7.7 GeV (FXT)                |
| Forward spin ı  | 2021 | 20 cryo-weeks with STAR<br>Au+Au at 7.7 / 9.1 GeV              |
| <ul> <li>✓ 500GeV p+p, e</li> <li>✓ Spin physics m</li> </ul>                       | 2022 | 16 cryo-weeks with STAR (forward)<br>p+p at 500 GeV            |
| Run with sPH<br>✓ Top energy 20<br>✓ Precision meas<br>✓ Precision meas<br>dilepton | 2023 | 24 cryo-weeks with sPHENIX and STAR<br>Au+Au at 200 GeV        |
|   | 2024 | 24 cryo-weeks with sPHENIX and STAR<br>p+p and p+Au at 200 GeV |
| uncpton   | 2025 | 24 cryo-weeks with sPHENIX and STAR<br>Au+Au at 200 GeV        |

## **Looking Forward**

#### Measurements planned for 2021+ with the STAR forward upgrade

| √s (GeV)                      | Delivered             | Scientific Goals  | Observable                                    | Required           |
|-------------------------------|-----------------------|---|---|--------------------|
|                               | Luminosity            |   |   | Upgrade            |
| p <sup>↑</sup> p @ 200        | 300 pb <sup>-1</sup>  | Subprocess driving the large $A_N$ at high $x_F$ and $\eta$ | $A_N$ for charged hadrons and                 | Forward instrum.   |
|                               | 8 weeks               |   | flavor enhanced jets                          | ECal+HCal+Tracking |
| p^Au @                        | 1.8 pb <sup>-1</sup>  | What is the nature of the initial state and hadronization   | $R_{pAu}$ direct photons and DY               |                    |
| 200                           | 8 weeks               | in nuclear collisions                                       |   | Forward instrum.   |
|                               |                       |   |   | ECal+HCal+Tracking |
|                               |                       | Clear signatures for Saturation                             | Dihadrons, $\gamma$ -jet, h-jet,              |                    |
|                               |                       |   | diffraction                                   |                    |
| p^Al @                        | 12.6 pb <sup>-1</sup> | A-dependence of nPDF,                                       | $R_{pAl}$ : direct photons and DY             | Forward instrum.   |
| 200                           | 8 weeks               |   |   | ECal+HCal+Tracking |
|                               |                       | A-dependence for Saturation                                 | Dihadrons, $\gamma$ -jet, h-jet,              |                    |
|                               |                       |   | diffraction                                   |                    |
| p <sup>↑</sup> p @ 510        | 1.1 fb <sup>-1</sup>  | TMDs at low and high <i>x</i>                               | $A_{UT}$ for Collins observables, i.e.        | Forward instrum.   |
|                               | 10 weeks              |   | hadron in jet modulations at $\eta >$         | ECal+HCal+Tracking |
|                               |                       |   | 1   |                    |
| $\vec{p} \cdot \vec{p} @ 510$ | 1.1 fb <sup>-1</sup>  | $\Delta g(x)$ at small x                                    | $A_{LL}$ for jets, di-jets, h/ $\gamma$ -jets | Forward instrum.   |
|                               | 10 weeks              |   | at $\eta > 1$                                 | ECal+HCal          |

- ✓ Addresses important topics in hot and cold QCD:
- ✓ Transverse polarization effects in the proton : Twist-3 and TMDs
- ✓ Transversity, Collins, and Interference fragmentation functions
- ✓ Access  $\Delta G$  through dijets with p+p at  $\sqrt{s}$  = 500 GeV
- ✓ Probe initial state with p+A collisions

## Looking Forward

Future A+A Measurements with the STAR forward upgrade

| Physics<br>Measurements             |                                      | Longitudinal de-correlation             |                   | Mixed flow                              |                 | Event<br>Shape                         |
|-------------------------------------|--------------------------------------|---|-------------------|---|-----------------|--|
| Detectors                           | Acceptance                           | $C_n(\Delta \eta)$ $r_n(\eta_a,\eta_b)$ | η/s(T),<br>ζ/s(T) | Harmonics<br><i>C<sub>m,n,m+n</sub></i> | Ridge           | and<br>Jet-<br>studies                 |
| Forward<br>Calorimeter<br>(FCS)     | $2.5 < \eta < 4$ (photons, hadrons)  | One of these                            |                   | One of these<br>detectors<br>necessary  | Good<br>to have | One of<br>these<br>detectors<br>needed |
| Forward<br>Tracking System<br>(FTS) | $2.5 < \eta < 4$ (charged particles) | necessary                               | Important         |   | Important       |  |

- ✓ Addresses important topics in hot QCD:
- ✓ Ridge in p+p, p+A, and A+A
- ✓ Correlation measurements in hot and dense nuclear matter
- ✓ Precision measurements of long range correlations
- ✓ Temperature dependence of the viscosity through flow measurements at  $\eta$  ~4

## Current plan in 2019

### **Forward Calorimeter System**

10-20 hours of Au+Au 200 GeV collisions

- ✓ Test readout of calorimeters at ~ 10kHz rate
- ✓ Finish commissioning of DEP (digitizer/trigger) boards with this data
- ✓ Look at MIPS use for calibration etc.

### **Forward Tracking System**

Silicon Detectors

- ✓ Complete the design of detector module in June 2019
- ✓ Build the first complete prototype module in Summer/Fall 2019
- ✓ Fully test the prototype module in Fall/Winter 2019

sTGC Detectors

- ✓ Test in STAR DAQ with C10 (90% argon + 10% CO2)
- Test performance with various gas mixtures at Shandong University in full size (60cm x 60 cm) prototypes

## Summary

#### **Crucial Upgrades for Beam Energy Scan II:**

- ✓ Inner TPC : Successful, on-time & under budget completion, excellent performance
- Event Plane Detector : Excellent uniformity + delivered expected improvement in the eventplane resolution
- ✓ Endcap Time of Flight : Fully installed, commissioning and data taking are ongoing 2019

Upgrades provide <u>unique</u> opportunities at mid-rapidity in high energy A+A, p+A, and p+p

#### STAR Forward Rapidity Upgrade:

#### Essential to RHIC cold & hot QCD physics mission & to realize scientific promise of future EIC

- ✓ Forward Tracking System : Silicon + small-strip Thin Gap Chambers
  - -- sTGC prototype delivered by SDU and being tested at BNL
  - -- Silicon design and R&D at UIC + SDU + NCKU
- ✓ Forward Calorimetry System : EMCal + HCal
  - -- Large scale prototype testing at Fermilab

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