Introduction of STAR detector

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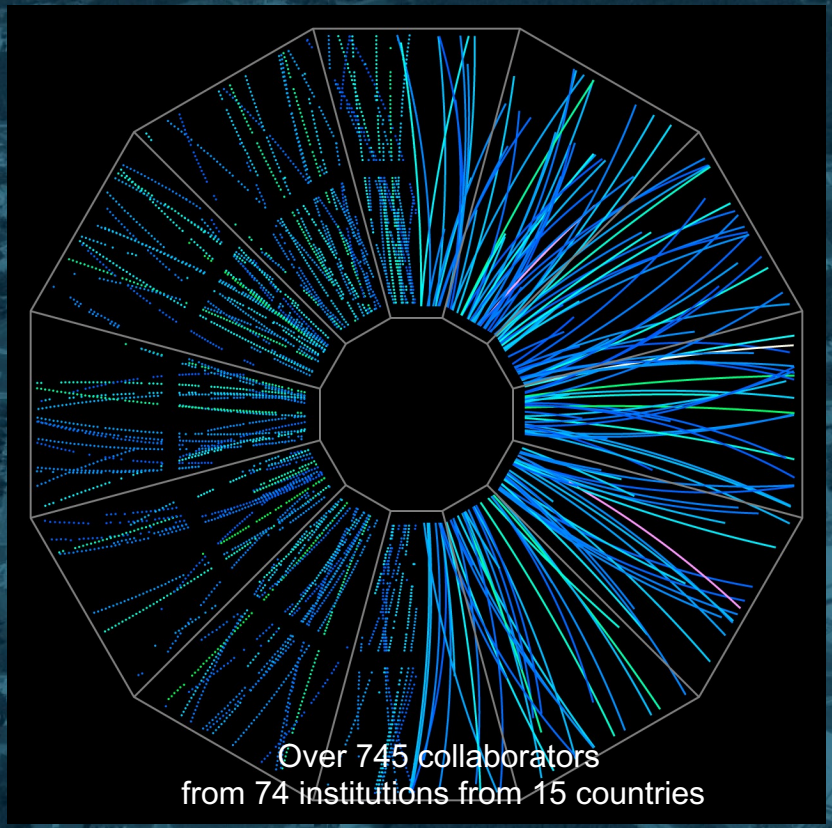
U.S. DEPARTMENT OF ENERGY



@BrookhavenLab

BNL part of NuSTEAM/NuPUMUS program

The unique advantage would be hands on experiences on hardware and software, data acquisition etc.

We would like to focus on the knowledge of detectors, hardwares, how scientists utilize the unique tools/detector hardware pieces to get interesting physics.

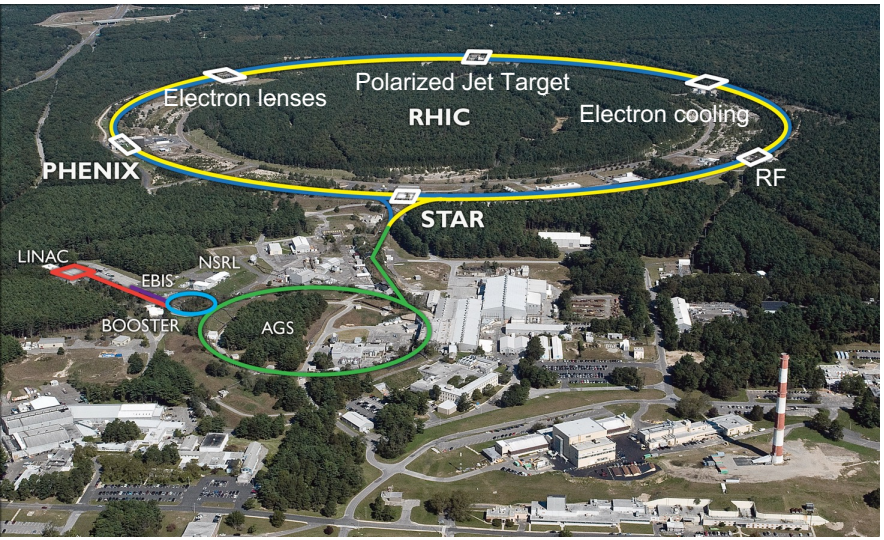
There are two parts: one focuses on STAR heavy ion program, the other on neutrino program.

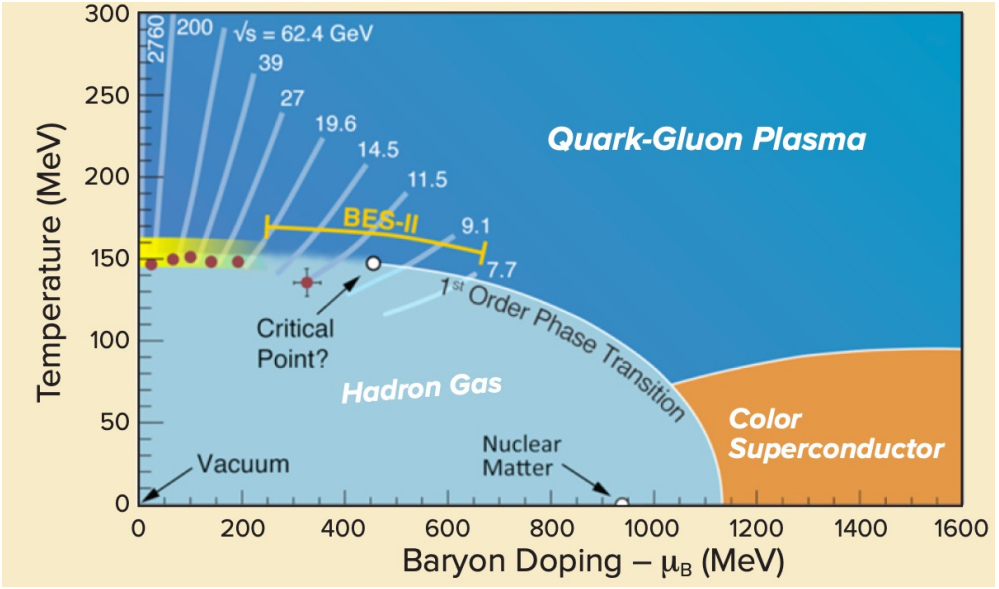
My lecture is an introduction of STAR program and detector

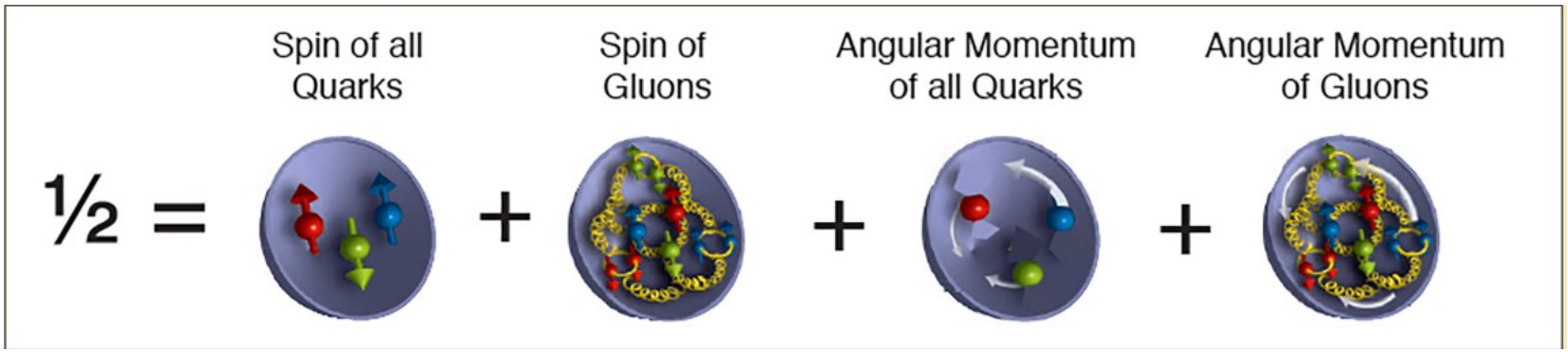
RHIC @ Brookhaven National Laboratory

23 years of RHIC operation

The mission of RHIC







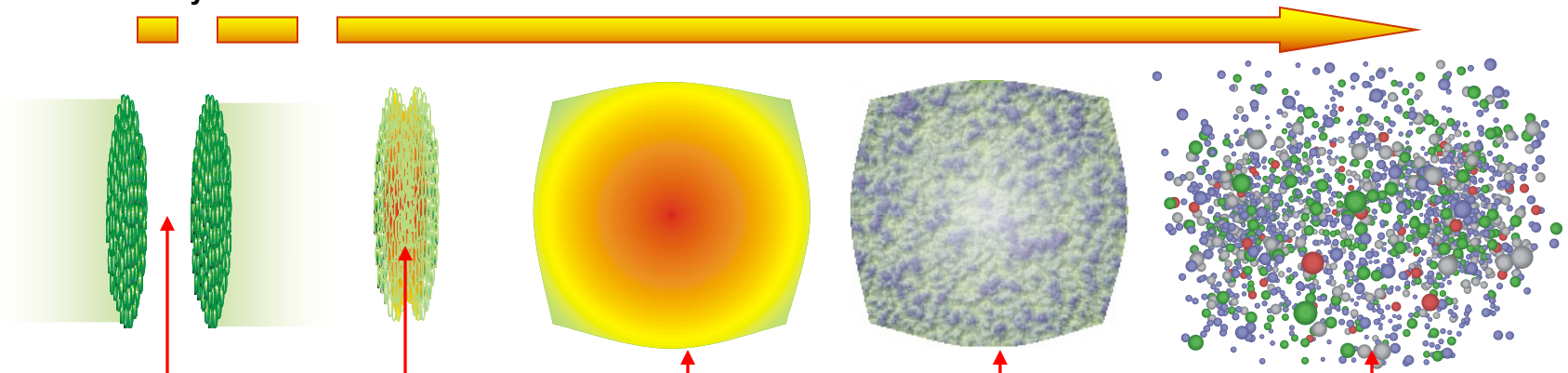
To probe the inner workings of the Quark-Gluon Plasma

To map the phase diagram of QCD

To study the spin puzzle of proton

Relativistic heavy ion collision

Courtesy of S. Bass



Initial state

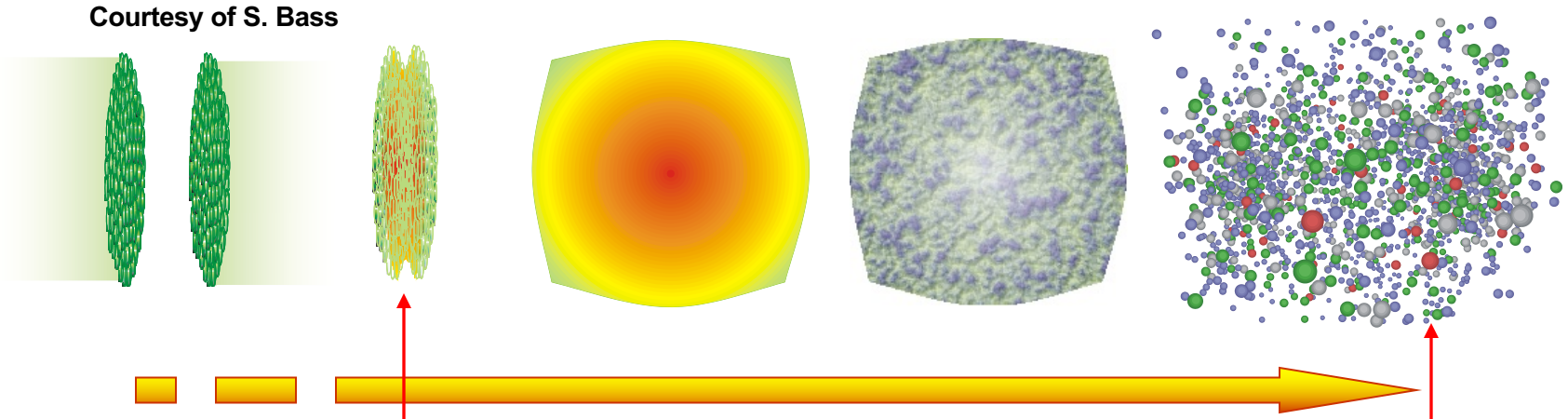
Collision

QGP

Hadronization

Freeze out:
Chemical and kinetic

Physics Goals at RHIC



Identify and study the properties of matter with partonic degrees of freedom.

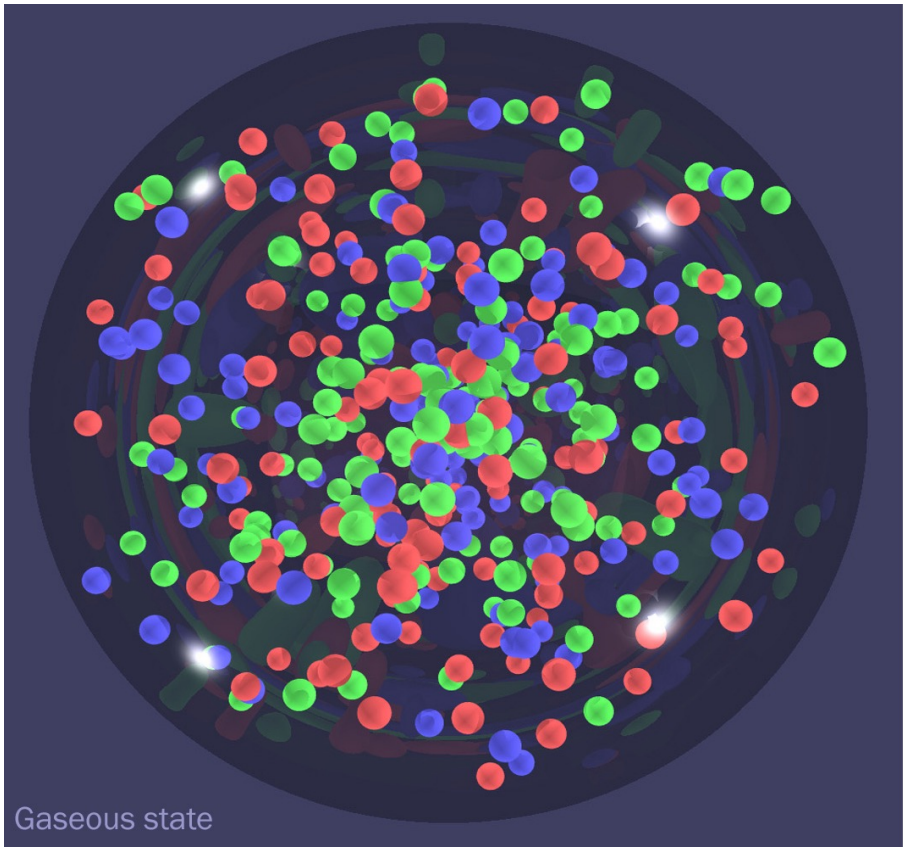
Penetrating probes

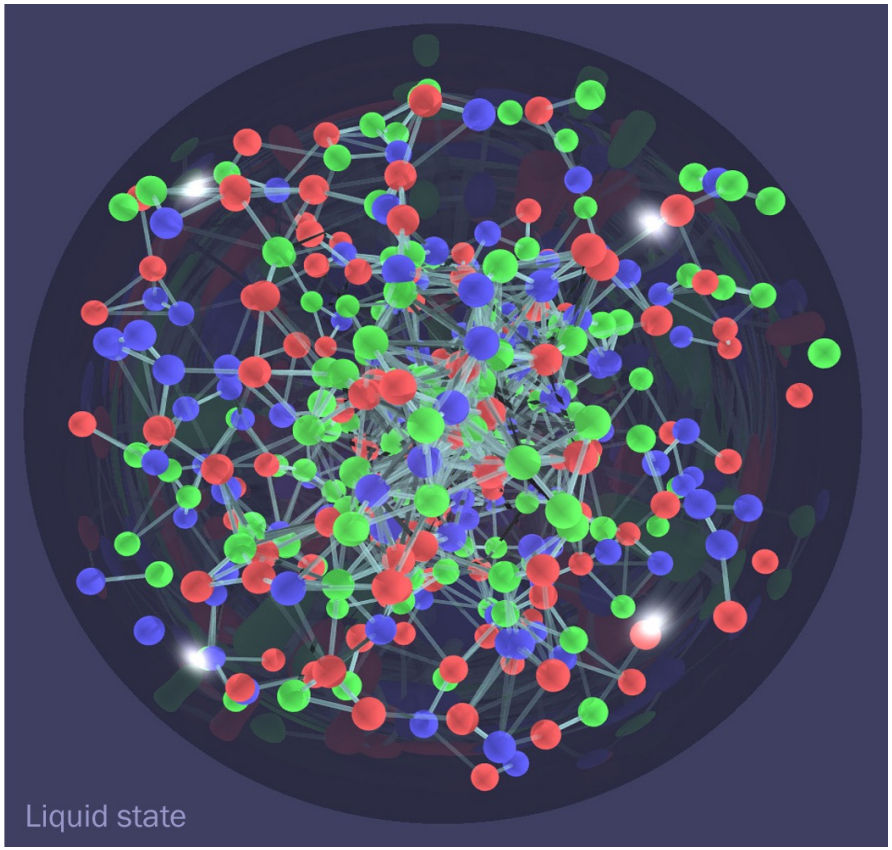
- "jets" and heavy flavor

Bulk probes

- v_2 → partonic collectivity
- spectra at low p_T, particle ratios.

Perfect Liquid discovery





In 2005, BNL announced a discovery of perfect liquid at RHIC

https://www.bnl.gov/newsroom/news.php?a=110303

How did we get there?

We need a good detector:

If possible, full-azimuthal coverage

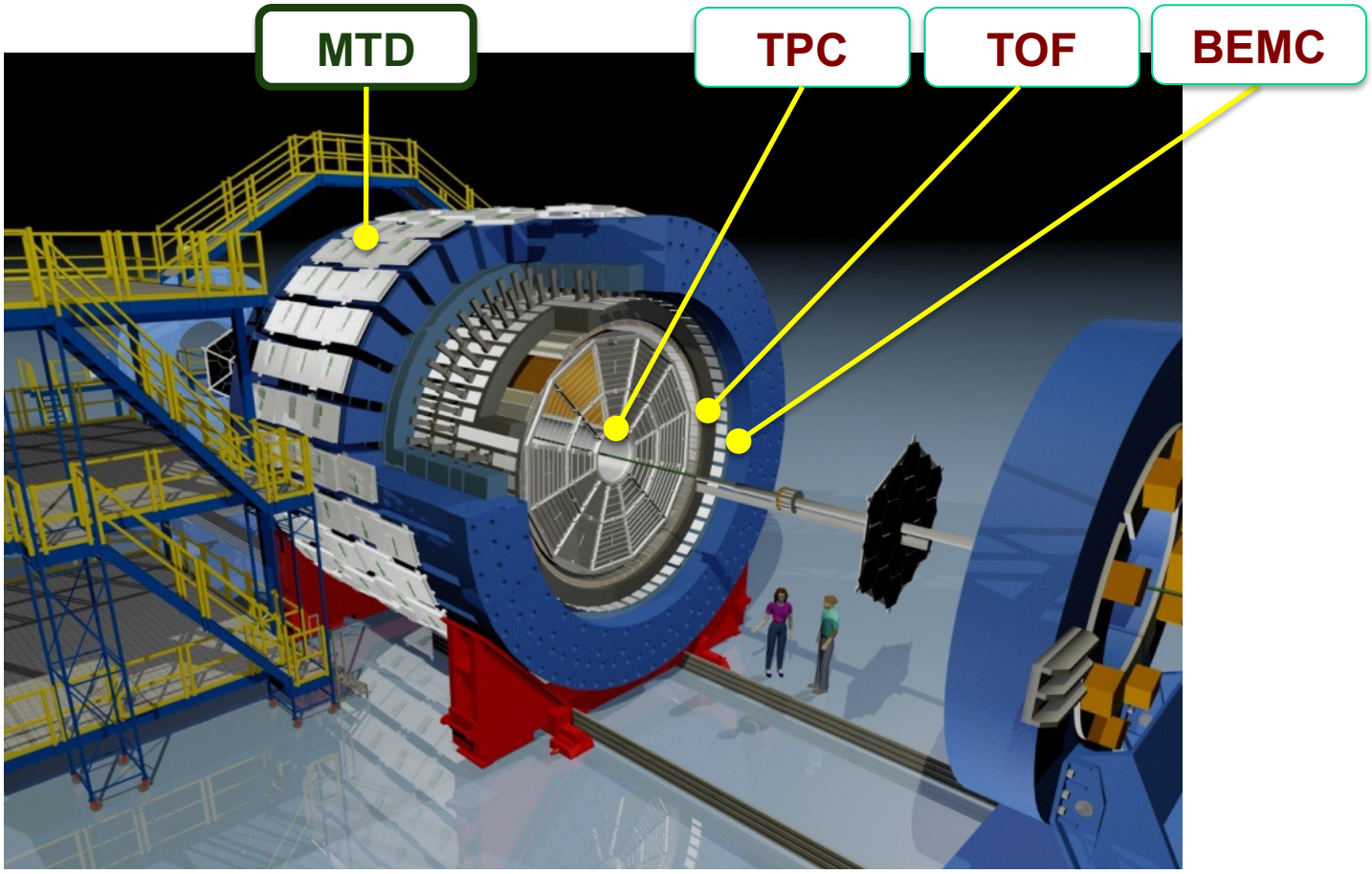
If possible, excellent particle identification capability over a broad kinematic region

If possible, wide rapidity coverage

If possible …

…

The STAR Detector

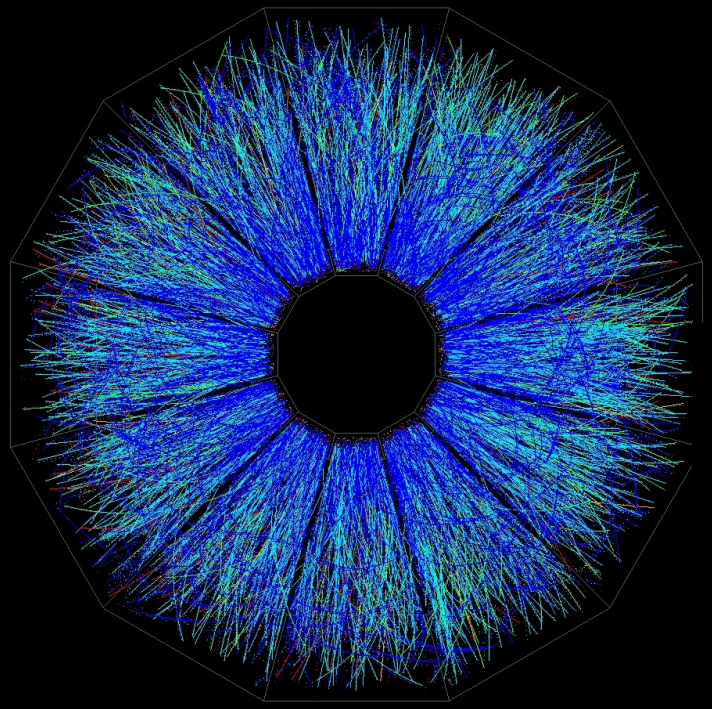


Solenoidal Tracker at RHIC (1200 tons)

Time Projection Chamber

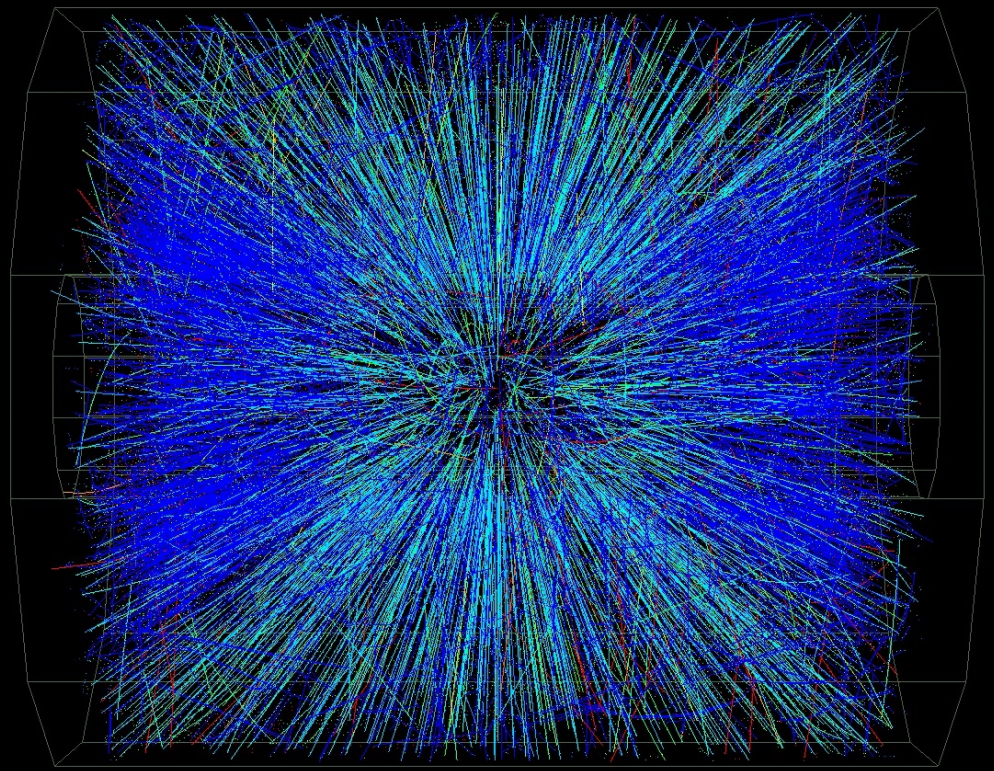
1. **Second largest device of its kind ever built**
2. **3D camera to take photos of the collisions**
3. **Measure ionization energy loss (dE/dx) and momentum**

^{197}Au + ^{197}Au Collisions at RHIC



Central Event

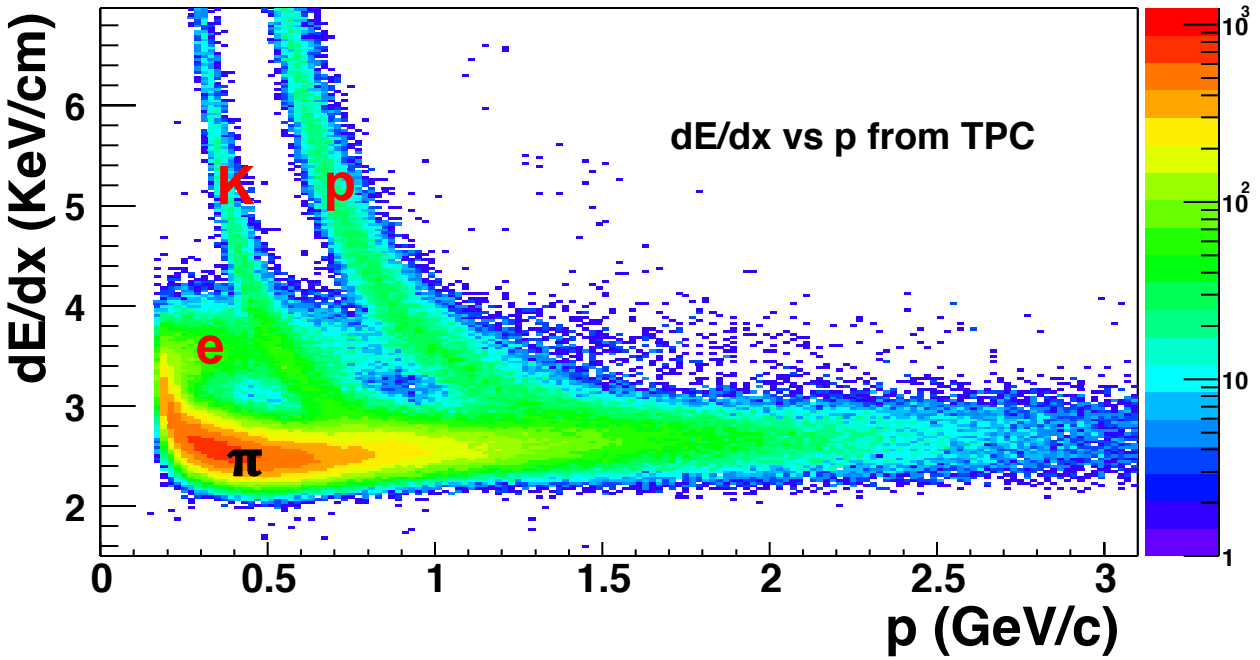
$E = m c^2$



STAR

(real-time Level 3)

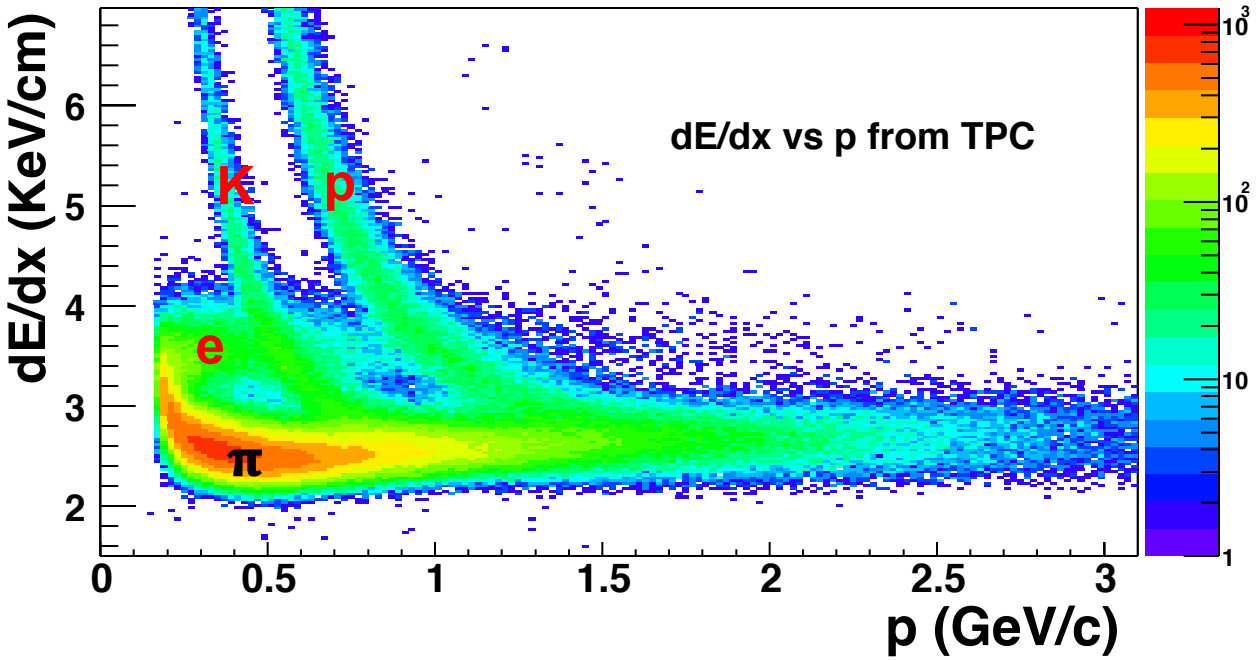
Particle identification



Electrons are difficult to find. Pion/kaon identification less than 1 GeV/c, proton identification less than 1.5 GeV/c

But that was enough for us to discover perfect liquid in 2005

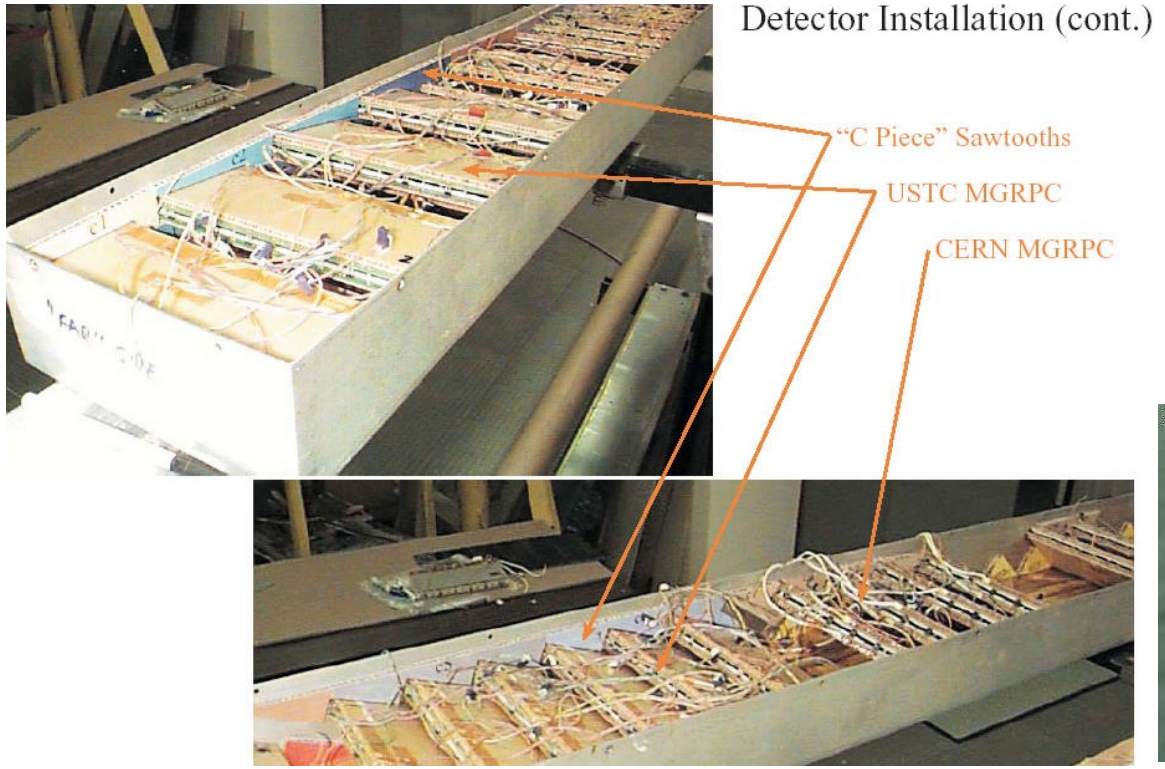
Extend particle identification

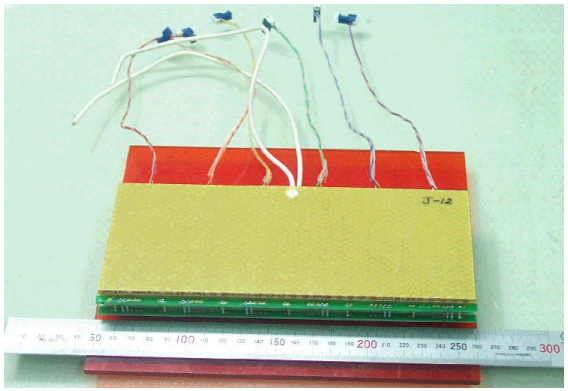


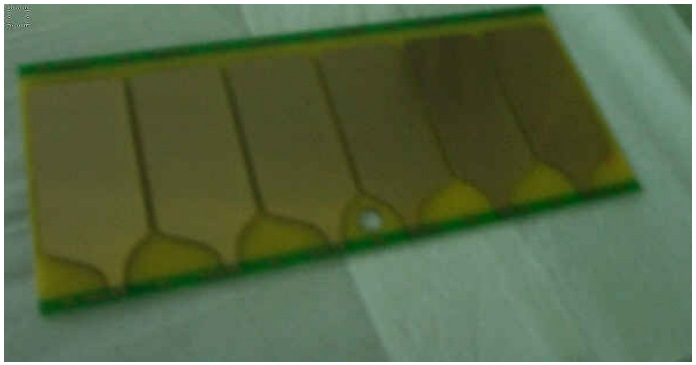
We would like to do more to probe detailed properties of the perfect liquid

Need new experimental tool to extend particle identification to higher momentum and separate electrons from hadrons

MRPC TOFr 2003





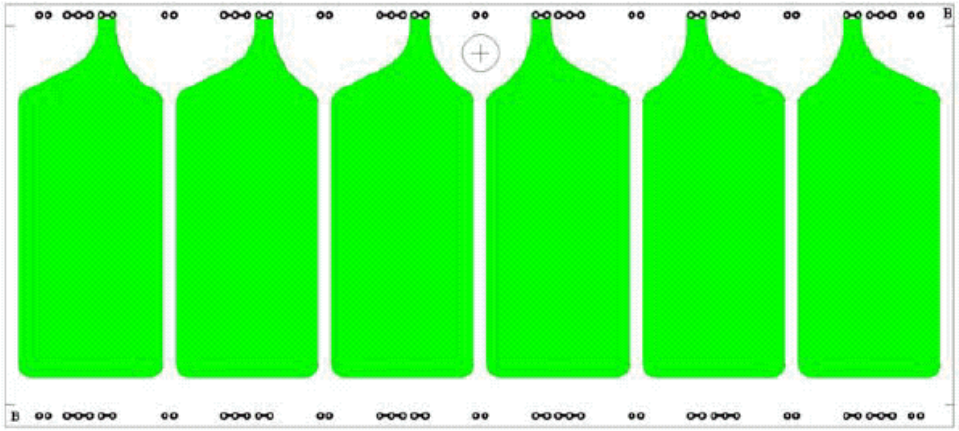


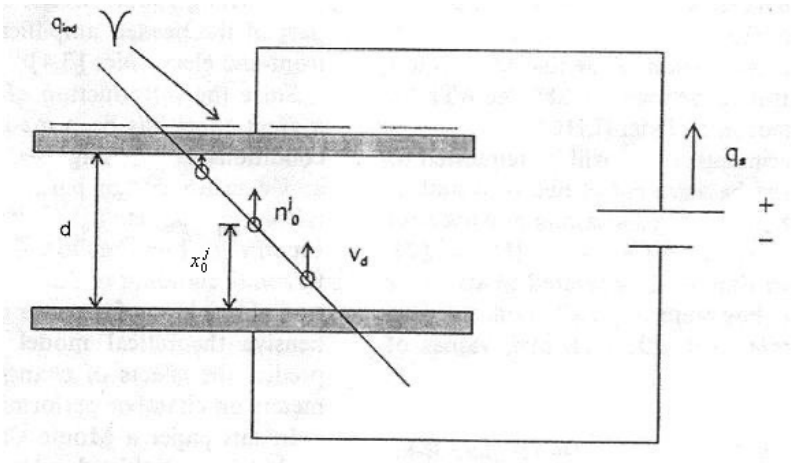
Multigap Resistive Plate Chamber (MRPC) Technology

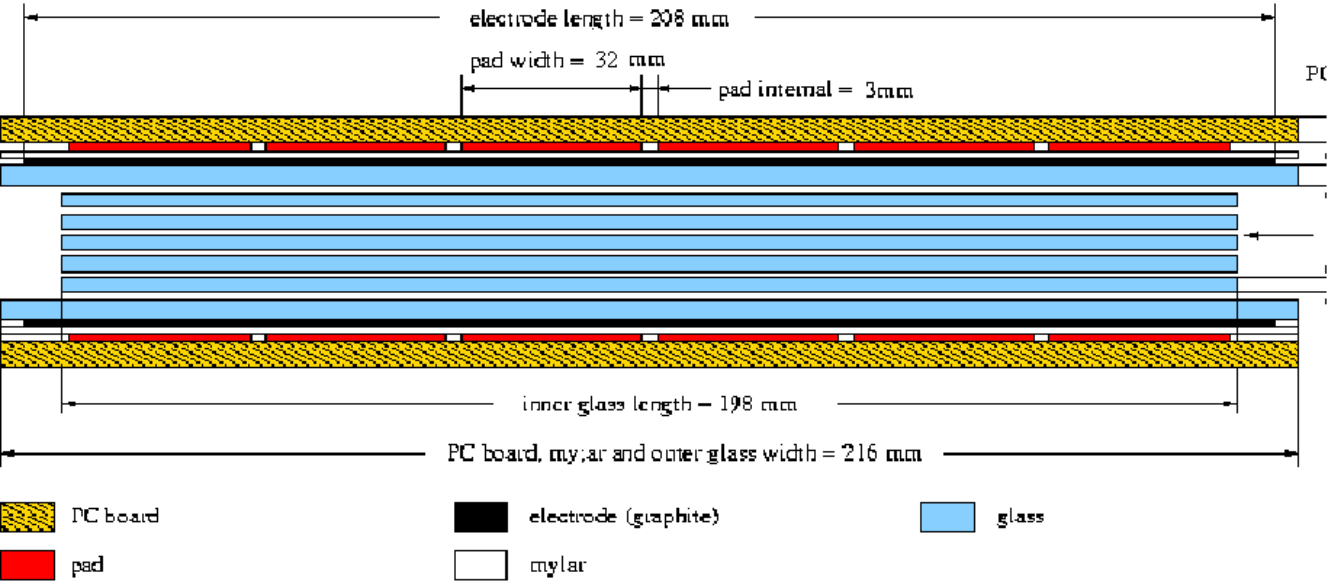
low cost, high timing resolution $<100 \times 10^{-12}$ second

A prototype tray (TOFr) was installed in 2002-2003

Structure of MRPC Module



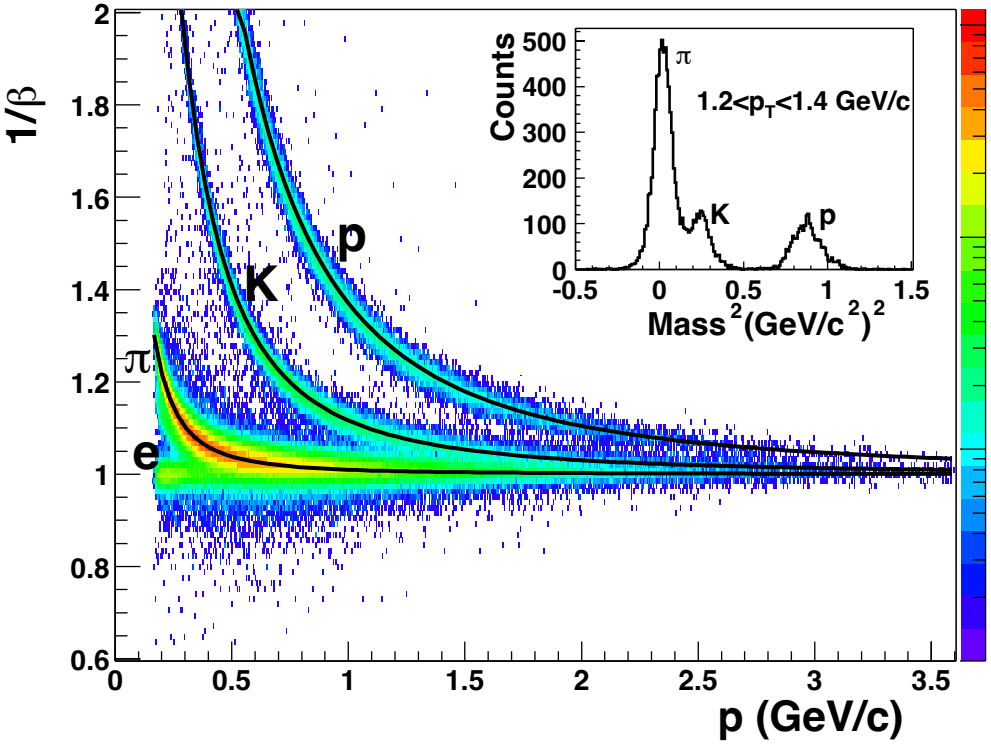




Read out pad size：3.15cm×6.3cm, gap：6×0.22mm

M. Abbrescia et al., Nucl. Instr. and Meth. A 398 (1997) 173-179
M. Abbrescia et al., Nucl. Instr. and Meth. A 431 (1999) 413-427

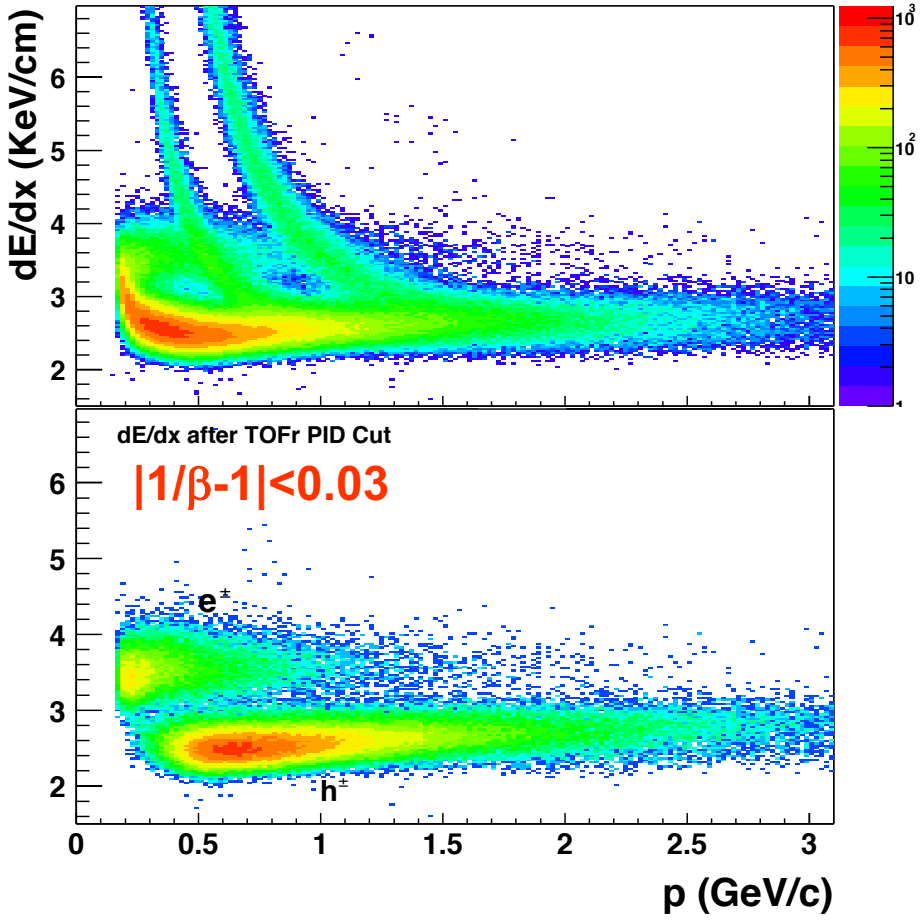
Particle identification from TOFr



STAR Collaboration, PLB616(2005)8

Curve: $$\frac{1}{\beta} = \sqrt{\frac{m^2}{p^2} + 1}$$

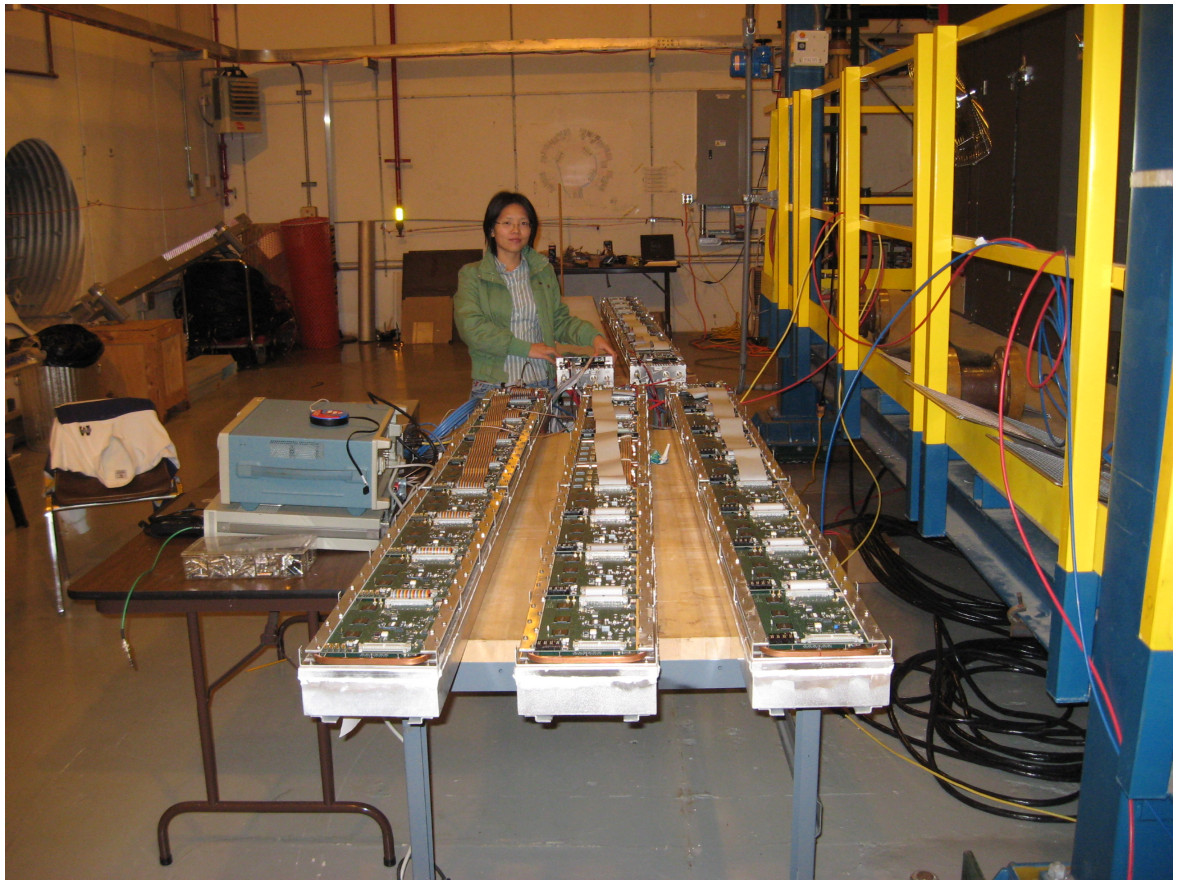
Electron identification



Clean electron samples!

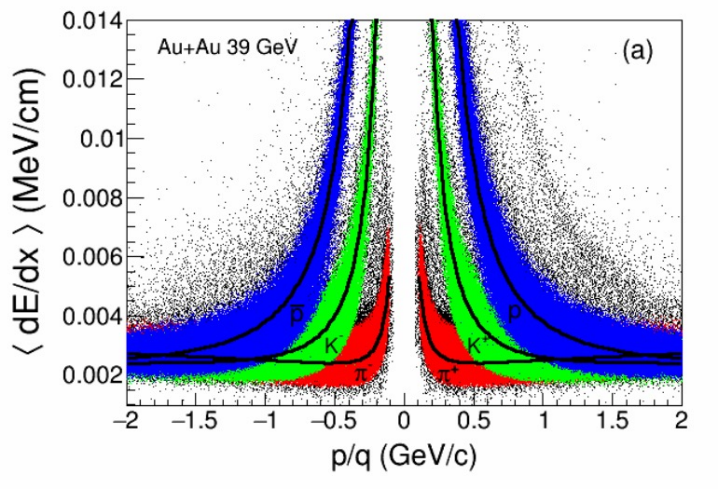
STAR Collaboration, PRL94(2005)062301

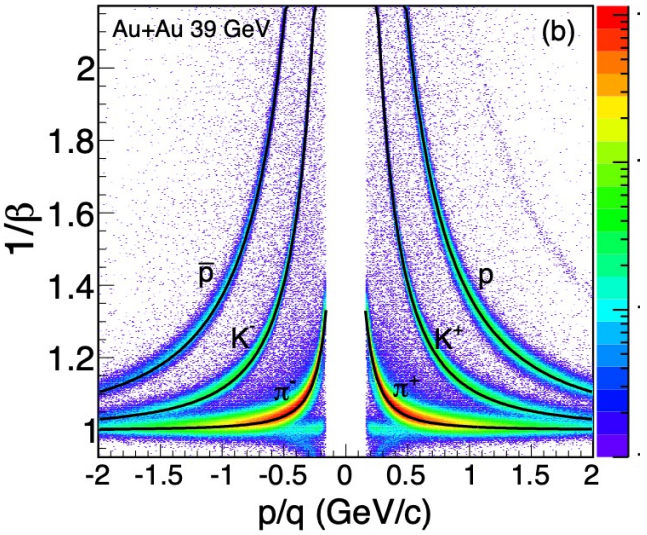
Time of Flight Detector upgrade

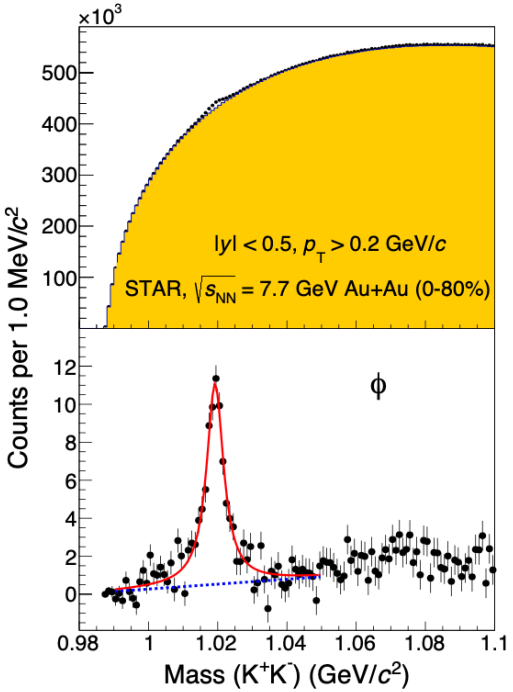


US-China Collaboration, 120 units in total:
2008: 4%; 2009: 72%; 2010: 100%

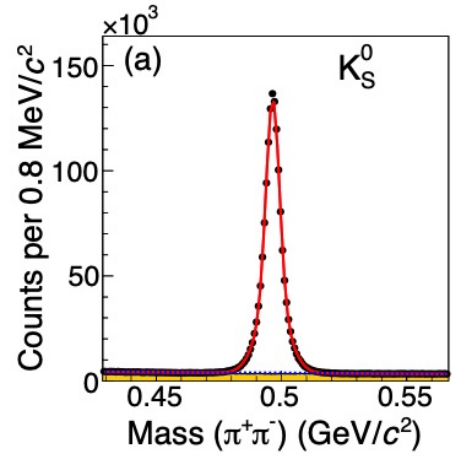
Beautiful particle identification at STAR

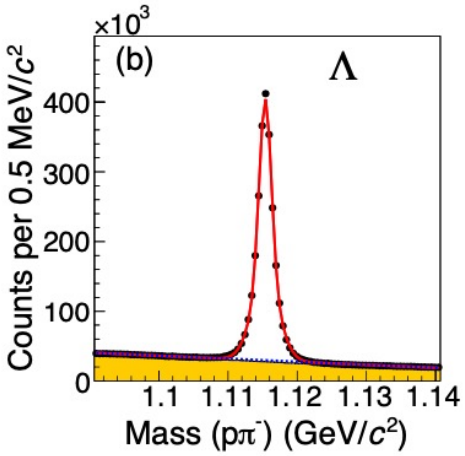


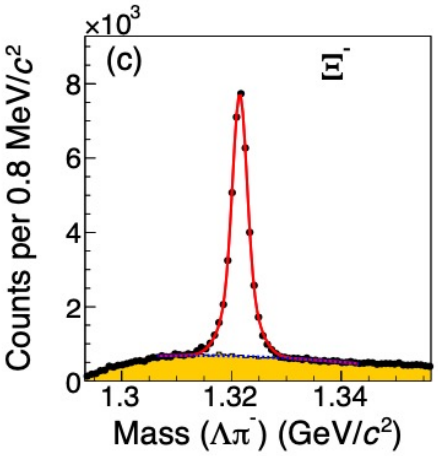


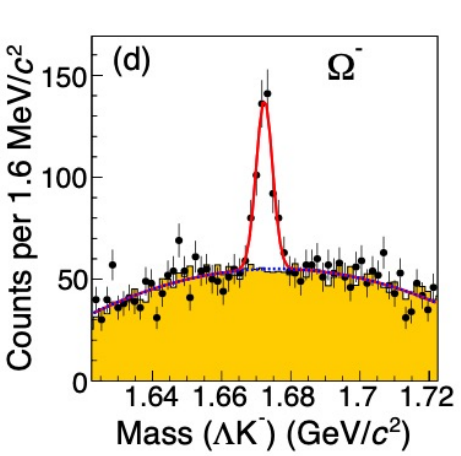


STAR, $\sqrt{s_{NN}}$ = 7.7 GeV Au+Au (0-80%), |y|<0.5





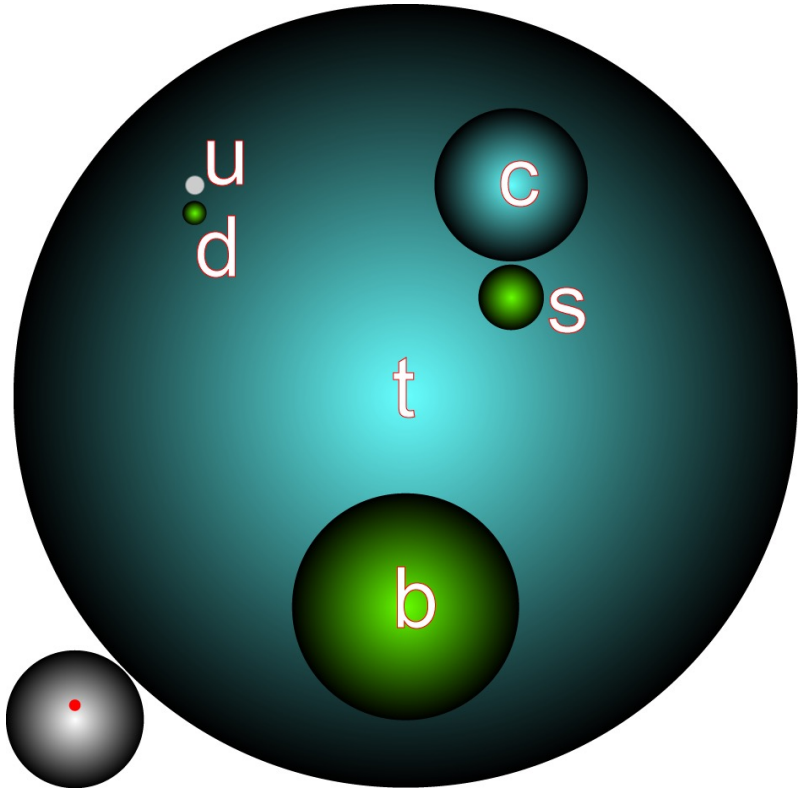




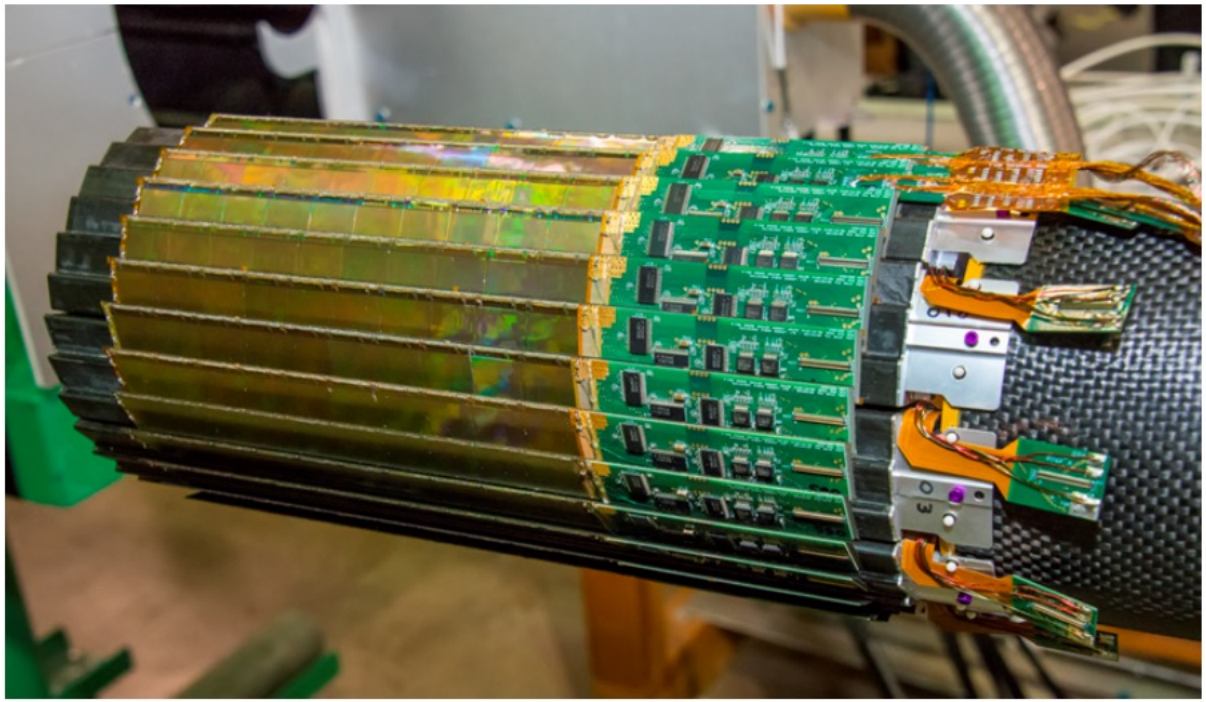
We still would like to do more

Those particles are all light-flavor particles. We would like to use heavy flavor particles to probe medium properties further.

How do we do that?



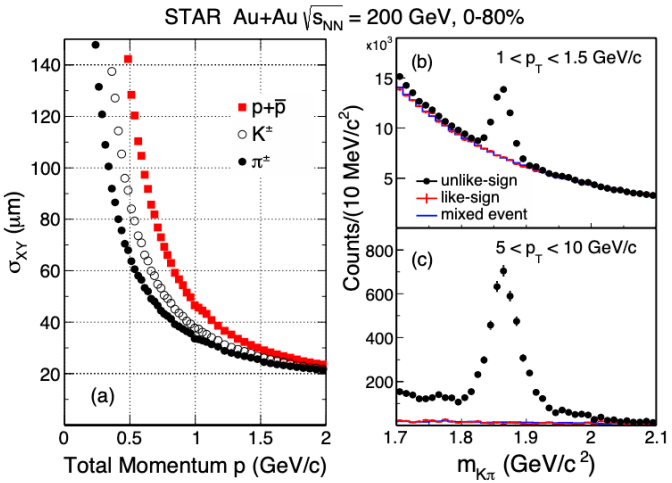
HFT and MTD

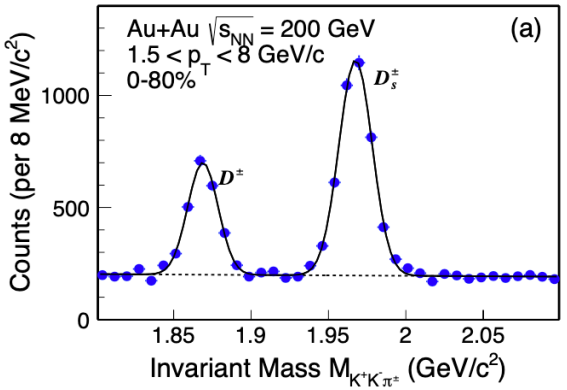


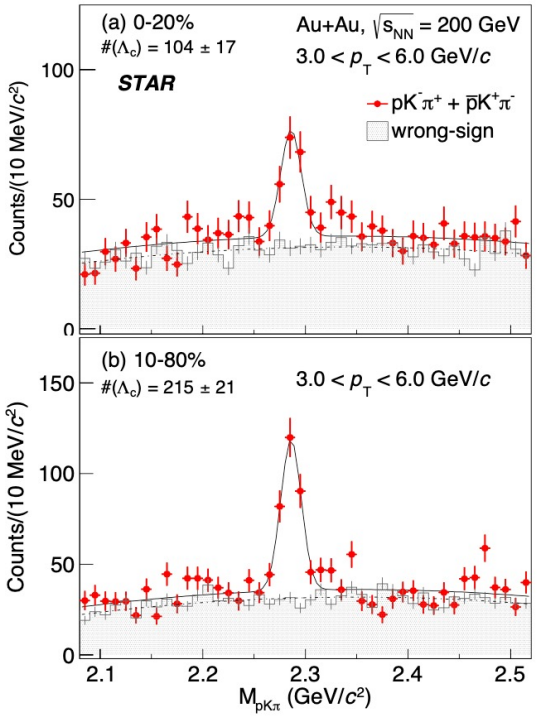
PiXeL detector for STAR Heavy Flavor Tracker, first application of start-of-the-art thin Monolithic Active Pixel Sensors (MAPS) technology in a collider.
https://arxiv.org/pdf/1710.02176.pdf

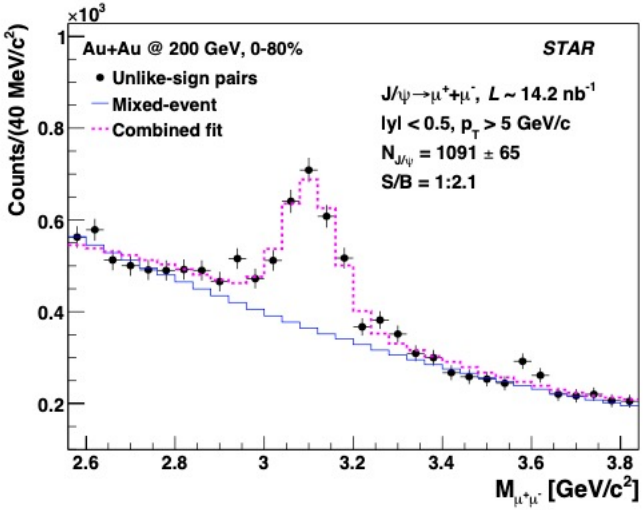
Heavy Flavor Tracker in Runs 2014-2016: open heavy flavor (Flemming Videbaek's lecture on July 5)

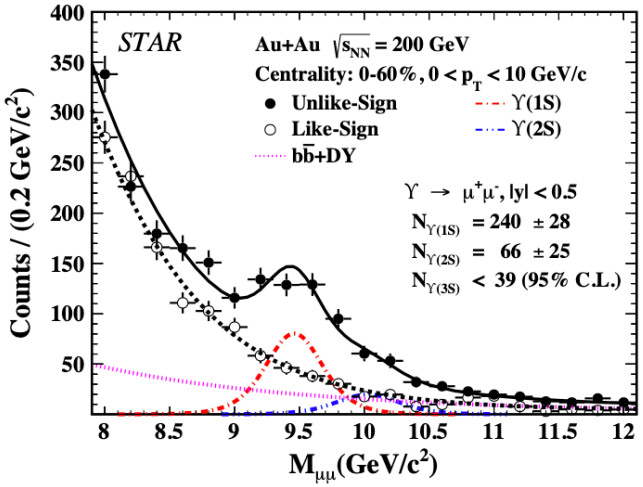
What did HFT and MTD bring to STAR?



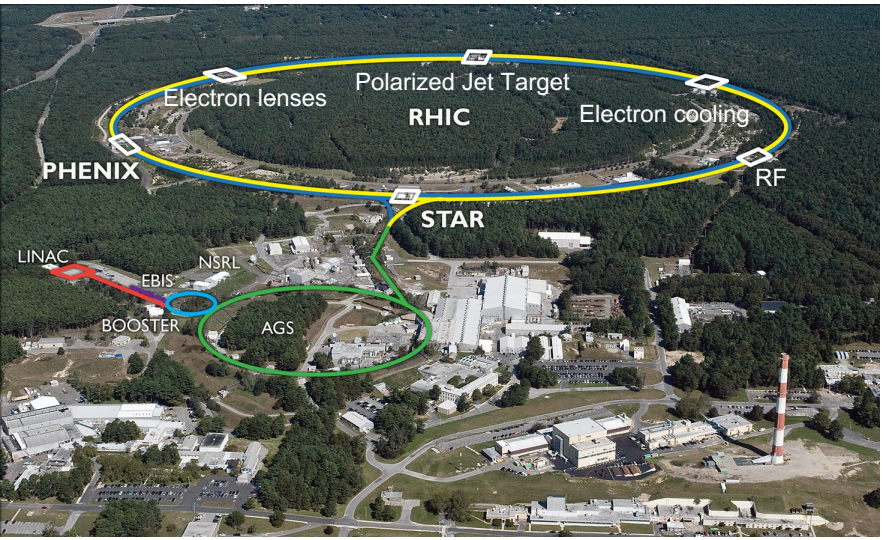


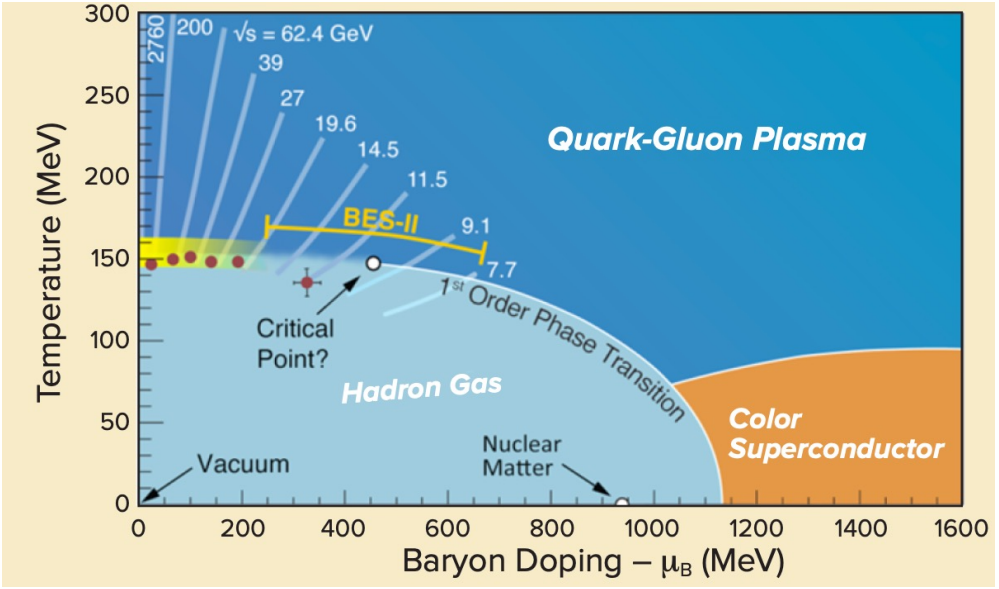


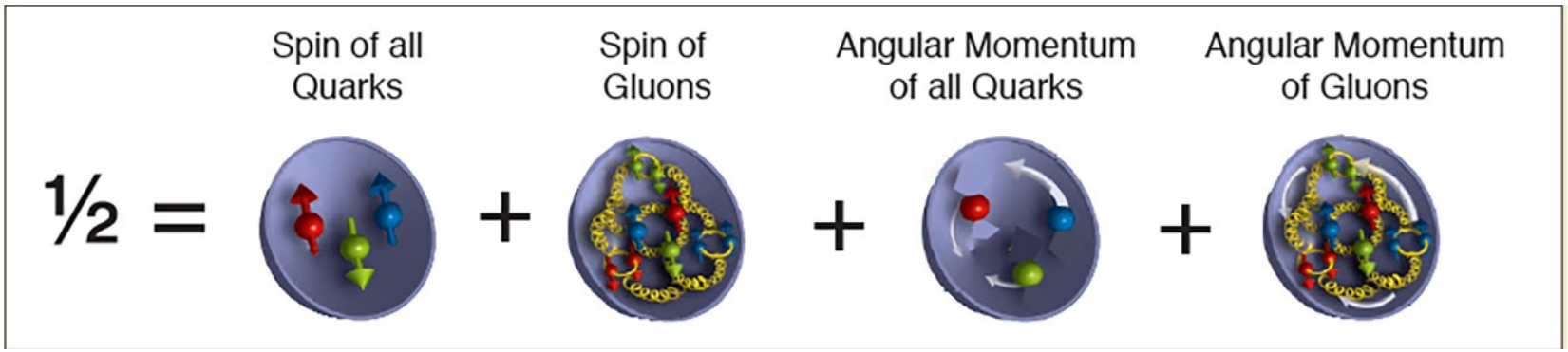




The mission of RHIC







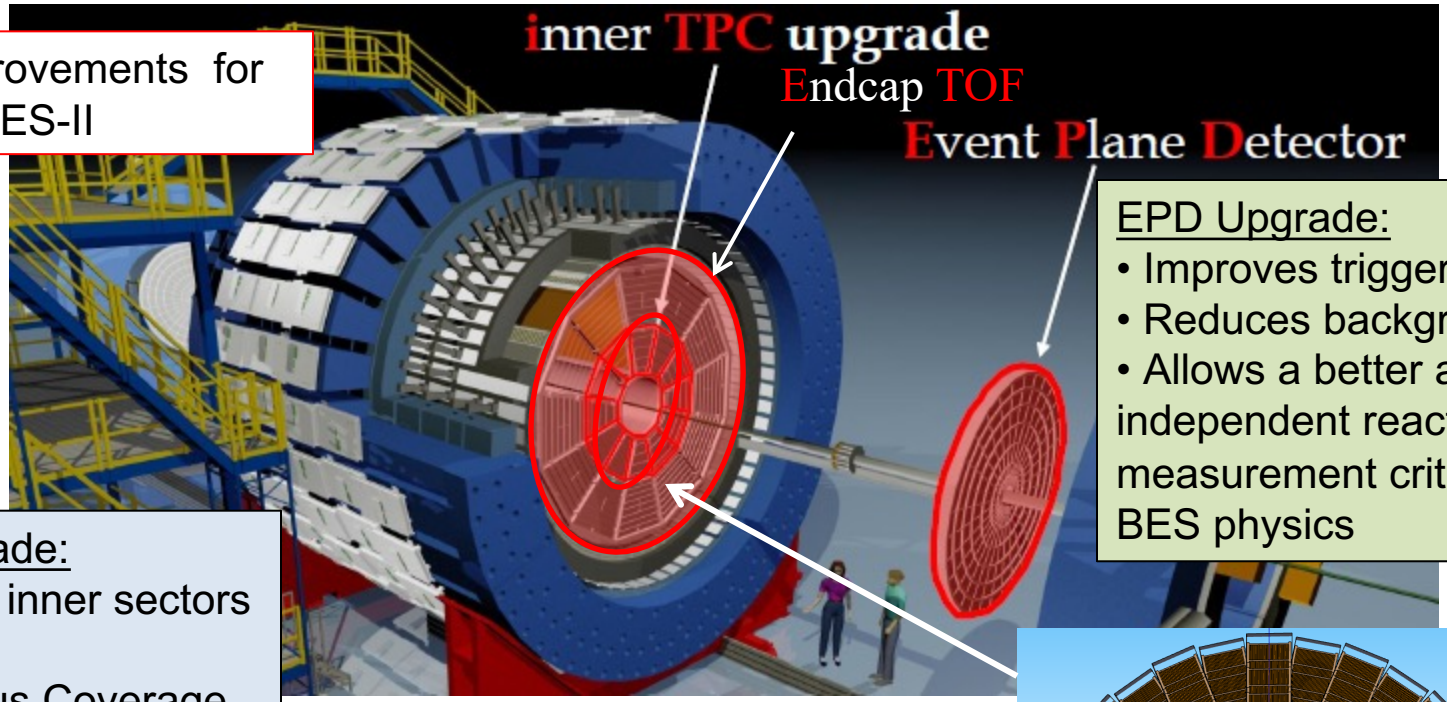
To probe the inner workings of the Quark-Gluon Plasma

To map the phase diagram of QCD

To study the spin puzzle of proton

STAR detector at BES-II

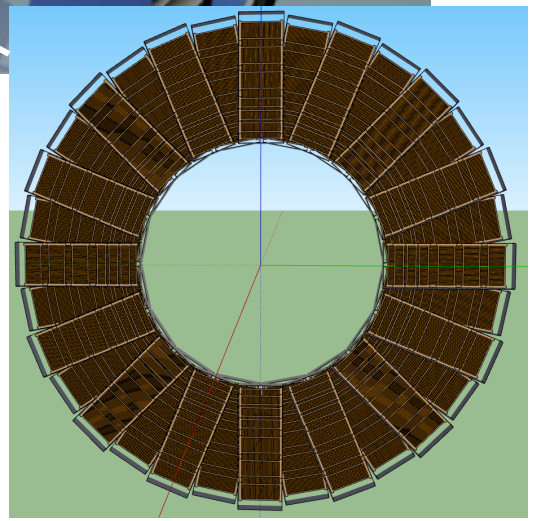
Major improvements for BES-II



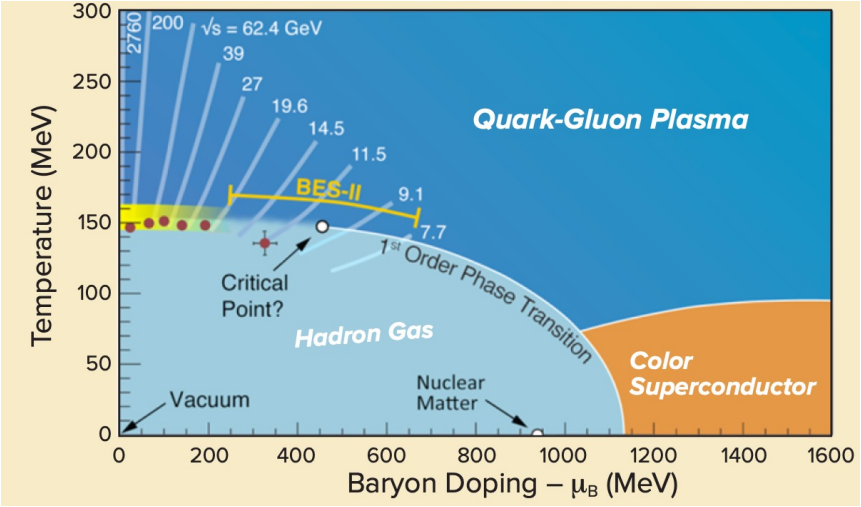
EPD Upgrade:
- Improves trigger
- Reduces background
- Allows a better and independent reaction plane measurement critical to BES physics

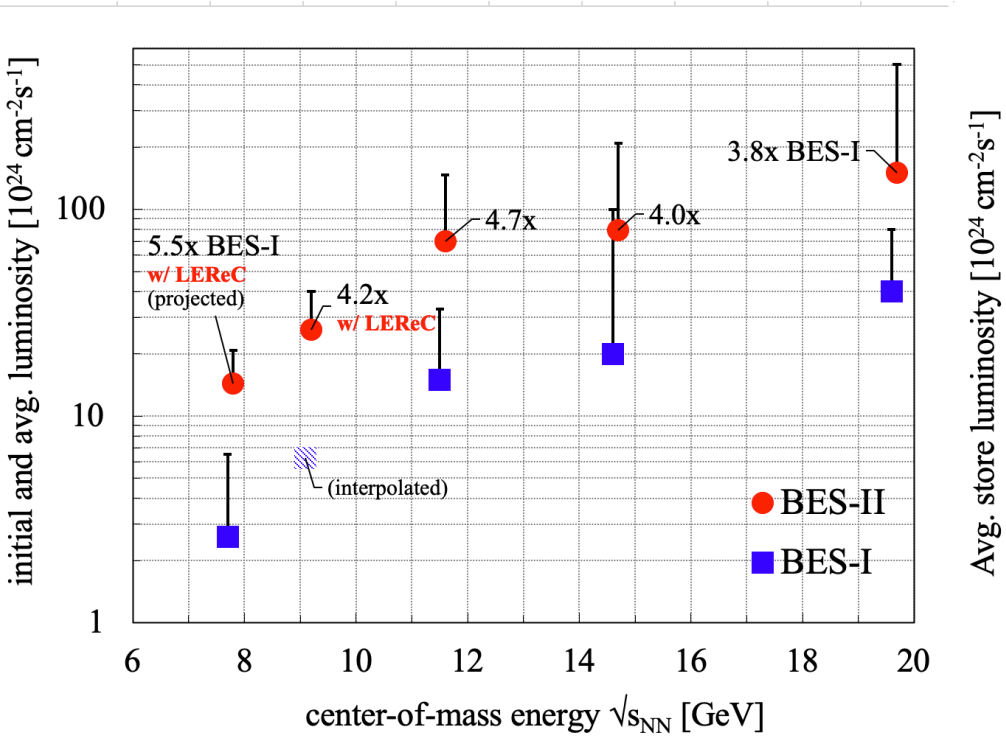
iTPC Upgrade:
- Replaced inner sectors of the TPC
- Continuous Coverage
- Improves dE/dx
- Extends η coverage from 1.0 to 1.5
- Lowers p_T cut from 125 MeV/c to 60 MeV/c

EndCap TOF Upgrade:
- Rapidity coverage is critical
- PID at η = 1 to 1.5
- Improves the fixed target program
- Provided by CBM-FAIR



Beam Energy Scan II in 2019-2021



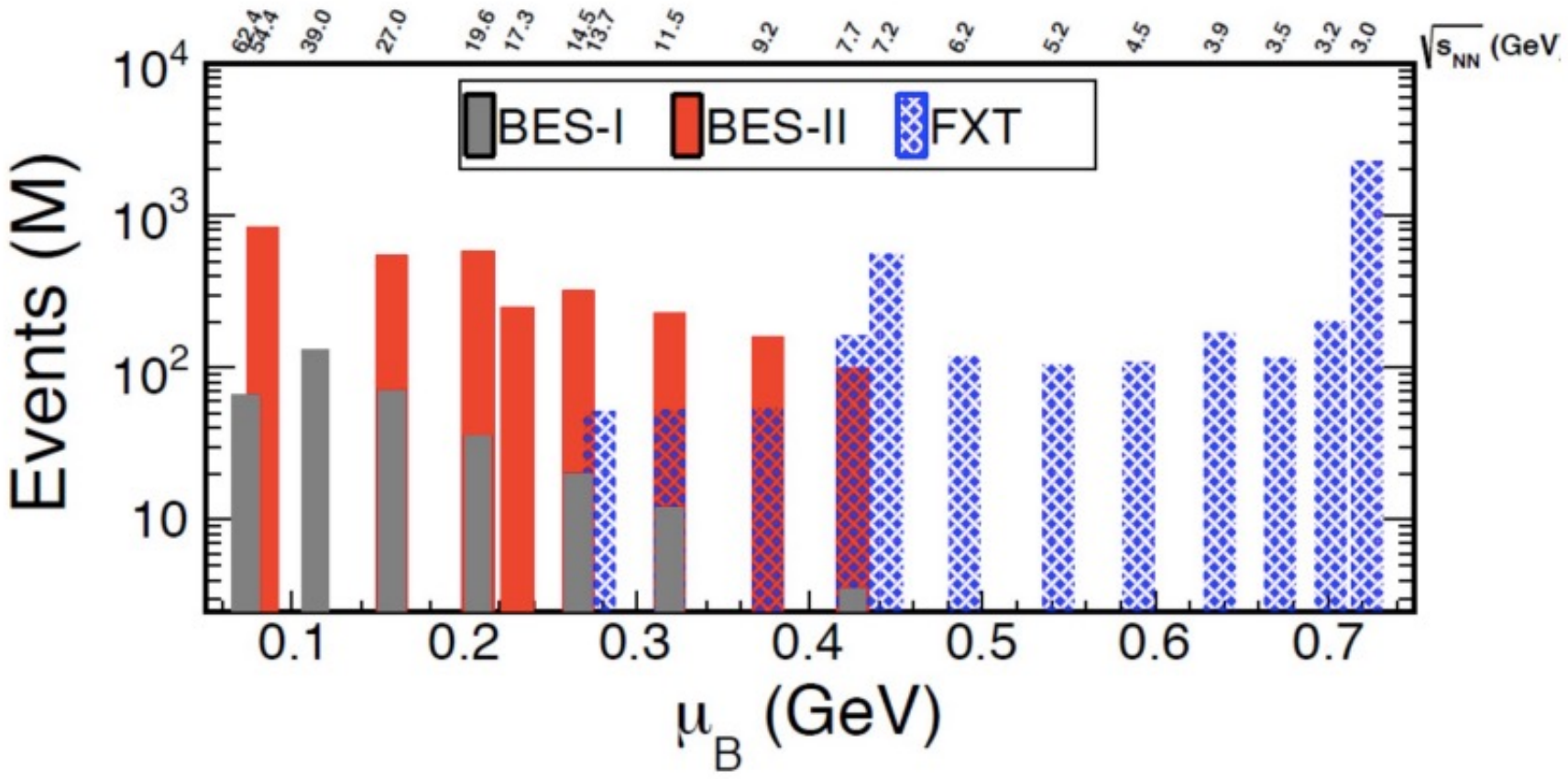


RHIC is unique to map the phase diagram of QCD:

Beam energy scan II: collision energies 7.7, 9.1, 11.5, 14.5, 19.6 GeV and many fixed-target energies

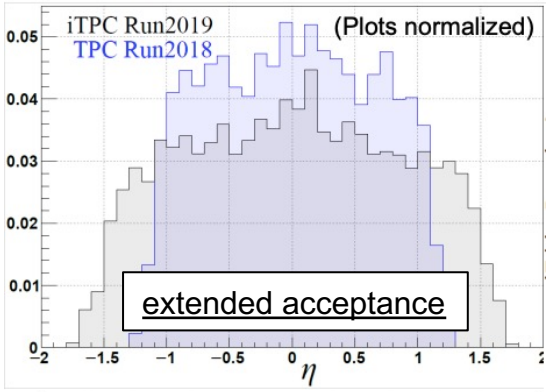
In 2021, collected the last collider data set at 7.7 GeV, completed the BES-II program.

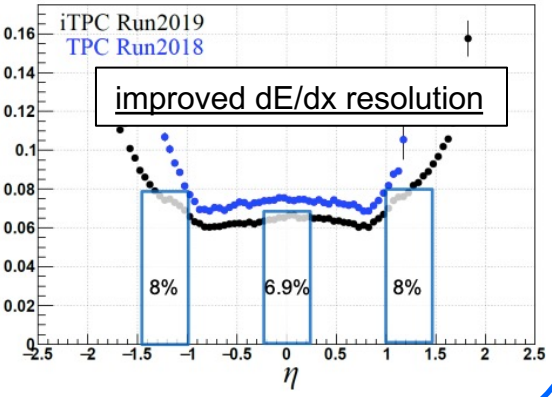
BES-II datasets



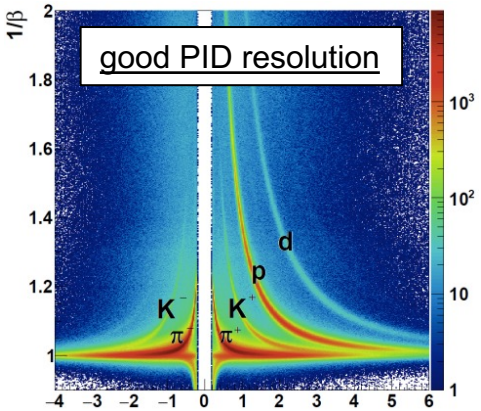
Detector performance

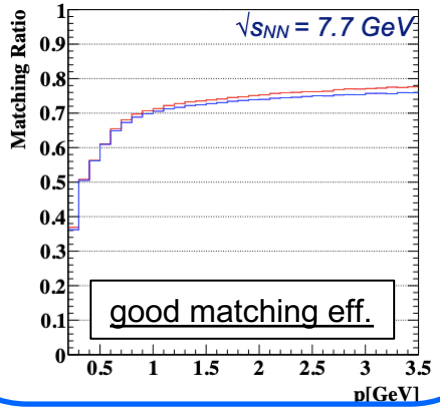
iTPC (2019+)



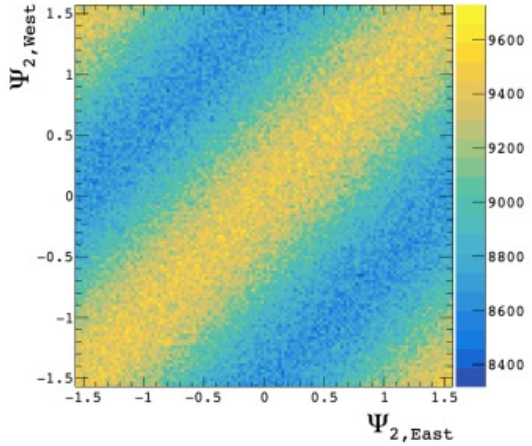


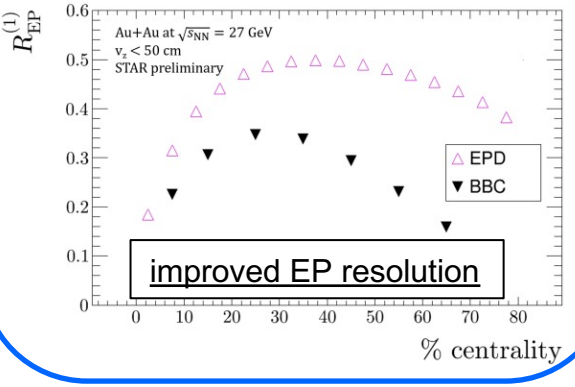
eTOF (2019+)



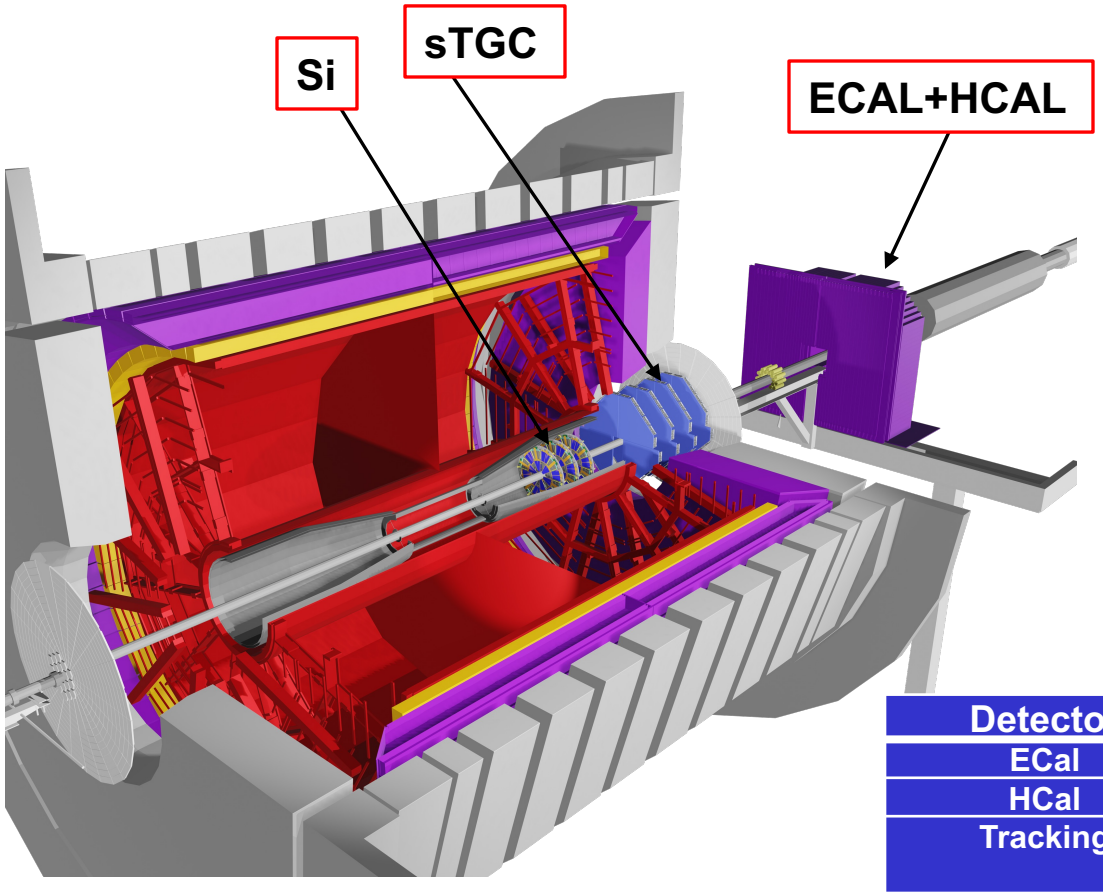


EPD (2018+)





STAR forward upgrades for 2022-2025



At 2.5<η<4

- Jets
- PID (π^0, γ, e, Λ)
- charged particle momentum resolution 20-30% at $0.2<p_T<2$ GeV/c
- event-plane reconstruction and trigger capability

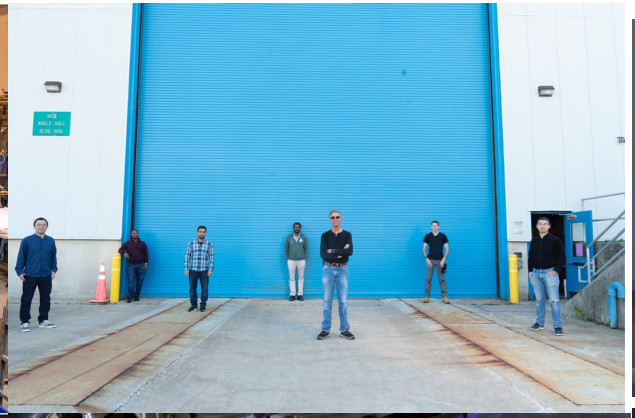
Detector	pp and pA	AA
ECal	~10%/√E	~20%/√E
HCal	~50%/√E+10%	---
Tracking	charge separation photon suppression	$0.2<p_T<2$ GeV/c with 20-30% $1/p_T$

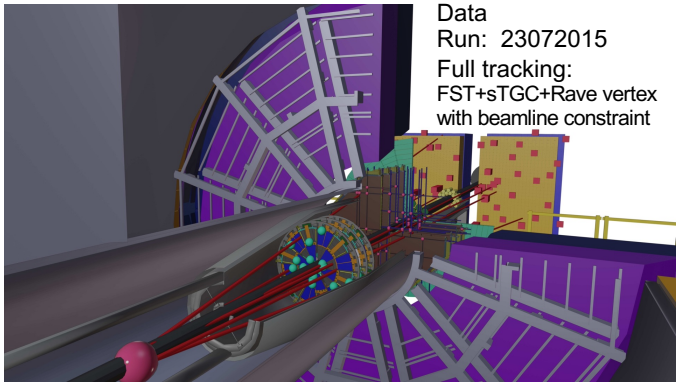
To probe the inner workings of the Quark-Gluon Plasma

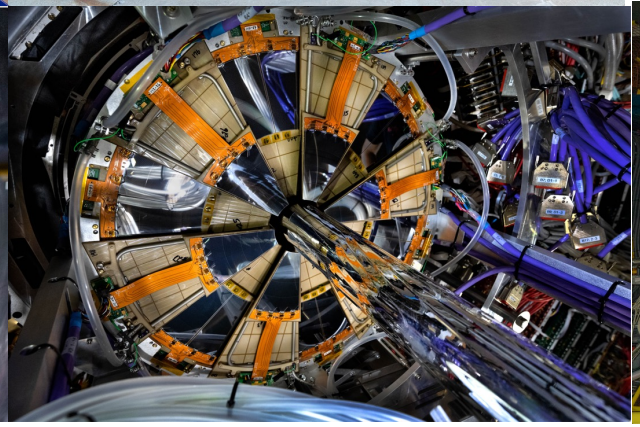
To study the spin puzzle of proton

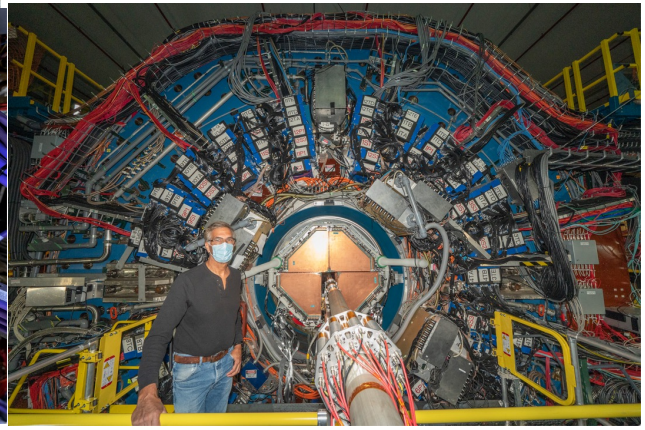
sTGC: Prashanth Shanmuganathan's lecture on July 6

STAR forward upgrades









FCS **FST** **sTGC**

FCS: successfully commissioned during Run-21
FST and sTGC: installed at STAR in August and October, 2021 respectively.

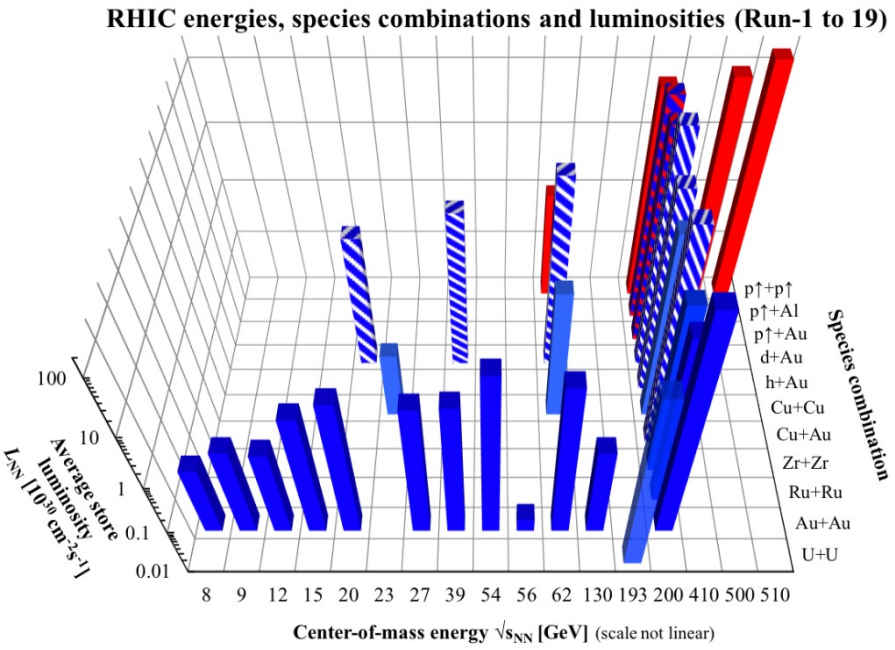
Enormous efforts to make forward upgrades on schedule during pandemic

Successful first operation of the forward upgrades and BES-II upgrades in pp

It is an amazing journey

Evolution of the STAR Detector

major upgrades over the last twenty years to improve particle identification and vertex reconstruction, and is still evolving with an extension to forward rapidity as of today. pioneered in using new technologies: MRPC, MAPS, GEM and siPM.
Estimate 35M(initial) +75M(upgrades)$.



Detector	primary functions	DOE+(in-kind)	year
TPC+Trigger	$\|\eta\|$ <1 Tracking		1999-
Barrel EMC	$\|\eta\|$ <1 jets/γ/π^0/e		2004-
FTPC	forward tracking	(Germany)	2002-2012
L3	Online Display	(Germany)	2000-2012
SVT/SSD	V0/charm	(France)	2004-2007
PMD	forward photons	(India)	2003-2011
EEMC	1< η <2 jets/π^0/e	(NSF)	2005-
Roman Pots	diffractive		2009-
TOF	PID	(China)	2009-
FMS/Preshower	2.5< η <4.2	(Russia)	2008-2017
DAQ1000	x10 DAQ rate		2008-
HLT	Online Tracking	(China/Germany)	2012-
FGT	1< η <2 $W^{\pm}$		2012-2013
GMT	TPC calibration		2012-
HFT/SSD	open charm	(France/UIC)	2014-2016
MTD	muon ID	(China/India)	2014-
EPD	event plane	(China)	2018-
RHICf	η >5 π^0	(Japan)	2017
iTPC	$\|\eta\|$ <1.5 Tracking	(China)	2019-
eTOF	-2< η <-1 PID	(Germany/China)	2019-
FCS	2.5< η <4 calorimeter	(NSF)	2021-
FTS	2.5< η <4 Tracking	(NCKU/SDU)	2021-

Zhangbu Xu, STAR Collaboration meeting, September 2020

STAR is a discovery machine

RHIC Scientists Serve Up “Perfect” Liquid
https://www.bnl.gov/newsroom/news.php?a=110303

Exotic Antimatter Detected at Relativistic Heavy Ion Collider
https://www.bnl.gov/newsroom/news.php?a=111075

RHIC Physicists Nab New Record for Heaviest Antimatter
https://www.bnl.gov/newsroom/news.php?a=111259

Physicists Measure Force that Makes Antimatter Stick Together
https://www.bnl.gov/newsroom/news.php?a=111786

‘Perfect Liquid’ Quark-Gluon Plasma is the Most Vortical Fluid
https://www.bnl.gov/newsroom/news.php?a=112068

‘Strange’ Glimpse into Neutron Stars and Symmetry Violation
https://www.bnl.gov/newsroom/news.php?a=116983

Collisions of Light Produce Matter/Antimatter from Pure Energy
https://www.bnl.gov/newsroom/news.php?a=119023

…

The journey continues …

Additional lectures

Anti-alpha discovery: Aihong Tang on July 7

EIC: Alexander Jentsch on July 5

Data acquisition: Jeff Landgraf on July 12

You will hear neutrino related lectures on July 10-11 and July 13

Most importantly, we hope you enjoy the program.

https://indico.bnl.gov/event/19789/

The format

A teacher will give a lecture and some homework

You are expected to work on your homework in the afternoon

Feel free to send out questions to teachers by email

There will also be tours to labs and experiments

On July 14, we ask each student to give a 15 mins presentation on what they learn and what they are interested in.

Today's homework

- Read this following publications
- https://drupal.star.bnl.gov/STAR/publications/star-detector-overview
- https://drupal.star.bnl.gov/STAR/publications/star-time-projection-chamber-unique-tool-studying-high-multiplicity-events-rhic
- https://drupal.star.bnl.gov/STAR/publications/star-maps-based-pixel-detector-0
- Next: tour to STAR labs (Tim Camarda) after lunch

A few logistics

Food Truck Hours: 11 am - 1 pm

Onsite courtesy shuttle: 8:00 am – 9:45 pm, 631-344-2714, Mon-Fri

Shopping shuttle: Wednesday 5-8:30 pm; Saturday morning, schedule details:

https://www.bnl.gov/staffservices/shuttleservices.php