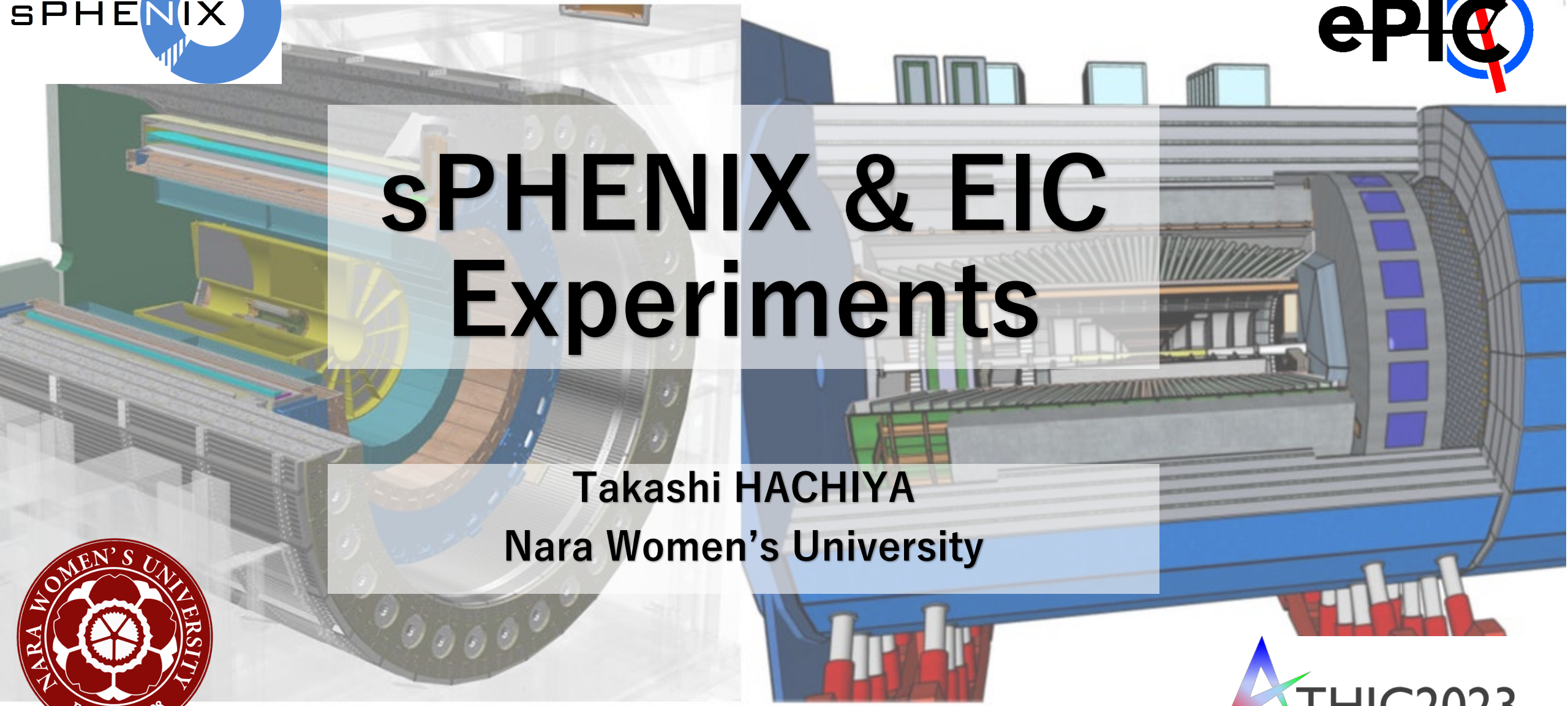


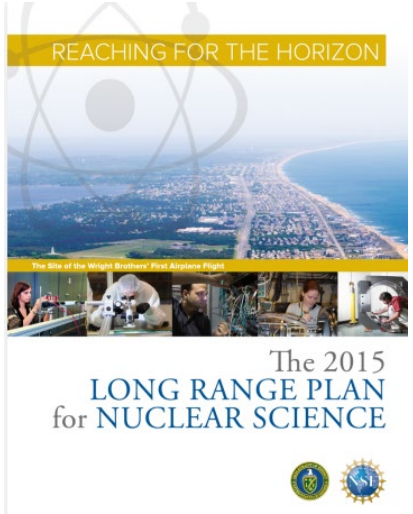
sPHENIX & EIC Experiments

Takashi HACHIYA
Nara Women's University

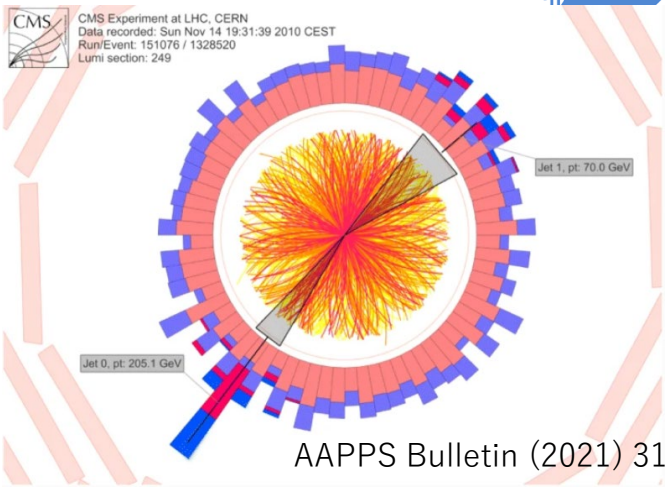
sPHENIX

- sPHENIX is a new QGP experiment at RHIC planed after the discovery of QGP at RHIC(2000~) and its deepening at LHC (2010~)

There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.**

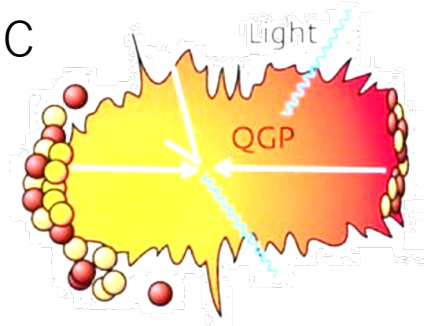


No away side jet



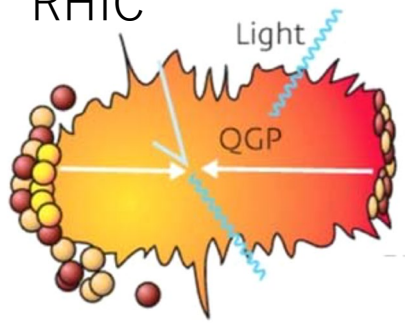
AAPPS Bulletin (2021) 31:12

LHC



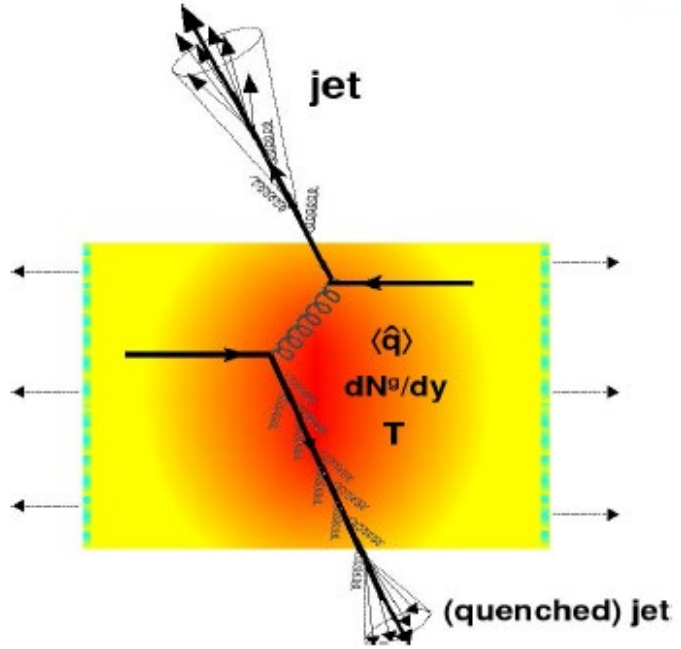
- **Comparison of RHIC and LHC** allows to study T and scale dependent QGP structure by measuring **jet modifications**
- **sPHENIX completes the QGP Physics mission at RHIC**

RHIC

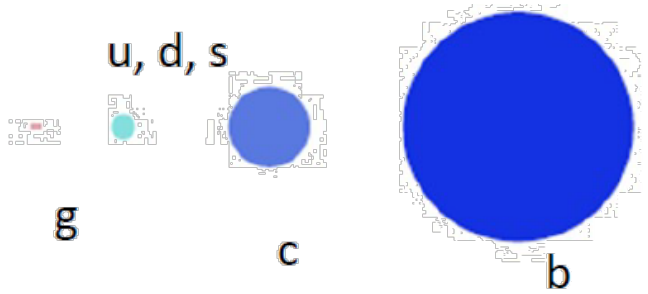


sPHENIX Physics Program

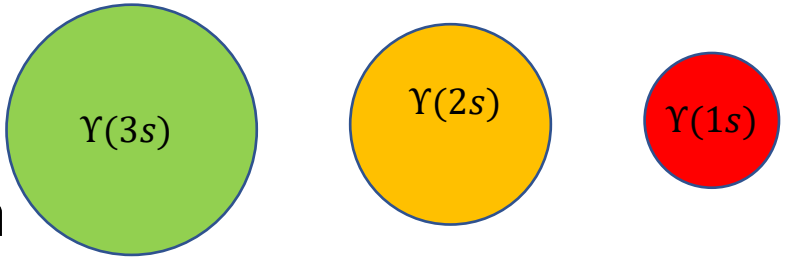
- **Energy loss by Jet**
  - Jet suppression
  - Jet shape modification and redistribution
  - Path length dependence



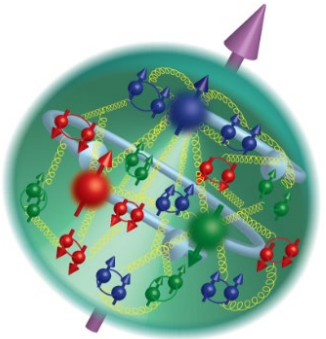
- **Flavor dependence**
  - Mass dependence



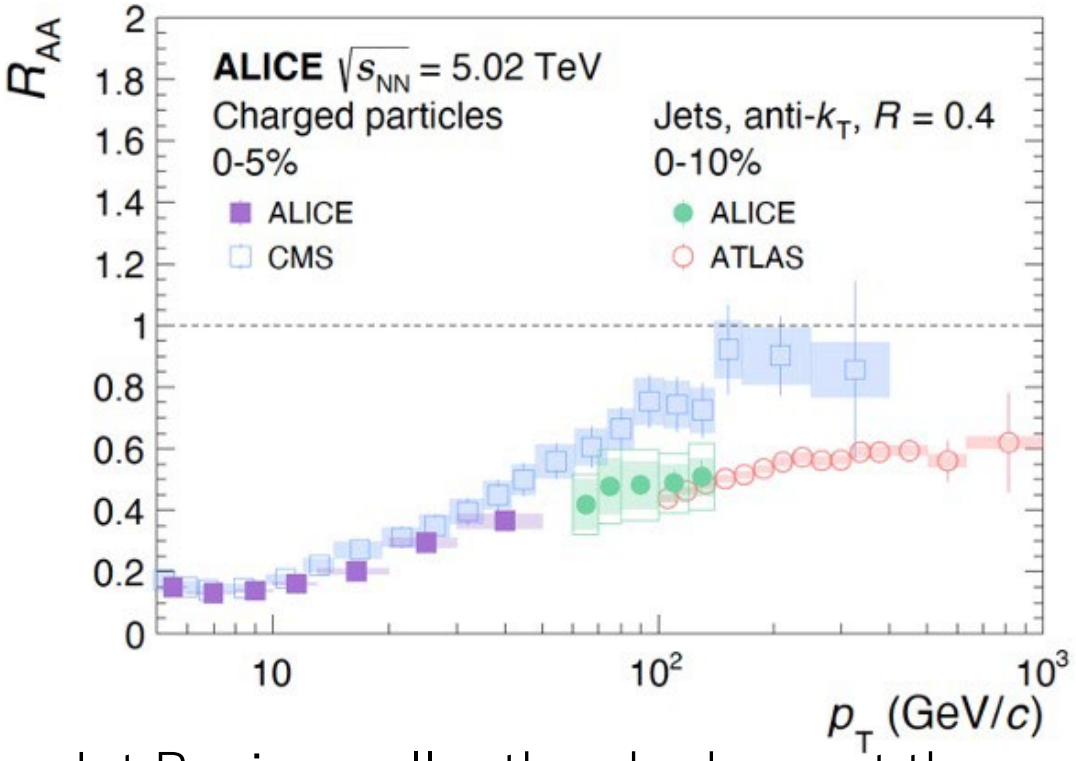
- **Upsilon** (1s, 2s, 3s) spectroscopy
  - Temperature (Scale) dependence of suppression



- **Cold QCD (p+p & p+A)**
  - Structure of nucleon and nuclei



Virtuality : Jet vs Hadron R_{AA} at LHC

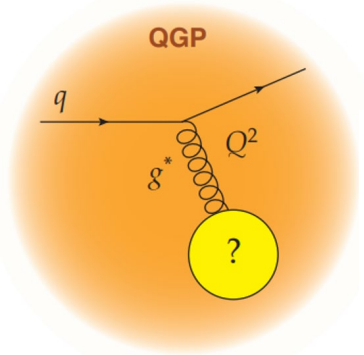


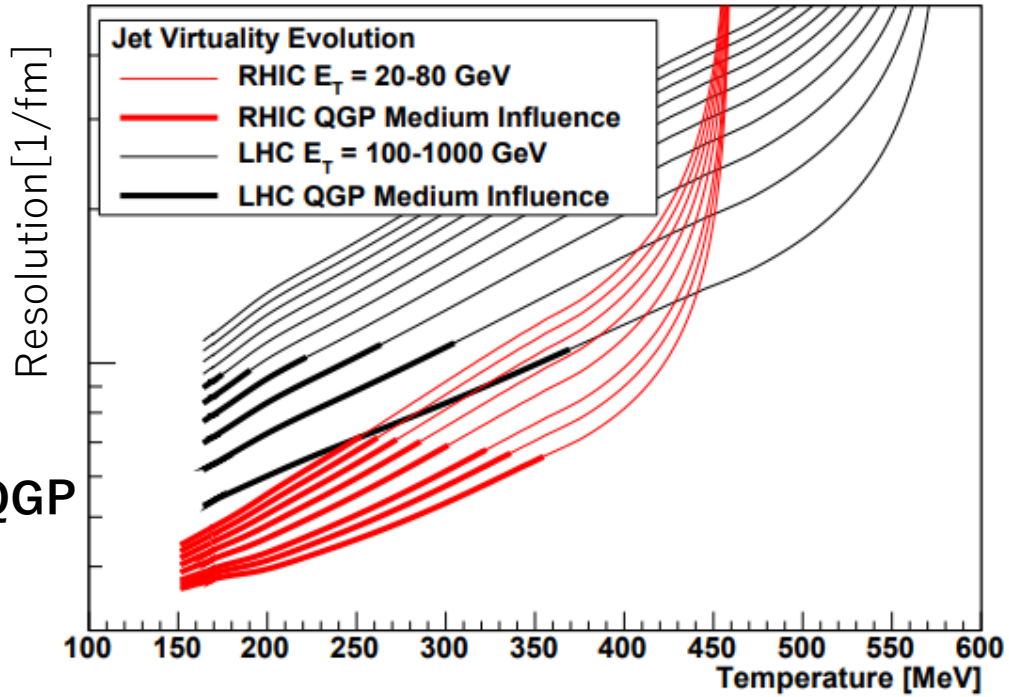
Jet and Hadron R_{AA} is increasing at higher p_T

- **Lower p_T is sensitive to energy loss in QGP**

Because the smaller BGs, sPHENIX accesses lower p_T Jet at RHIC

Virtuality = Resolution

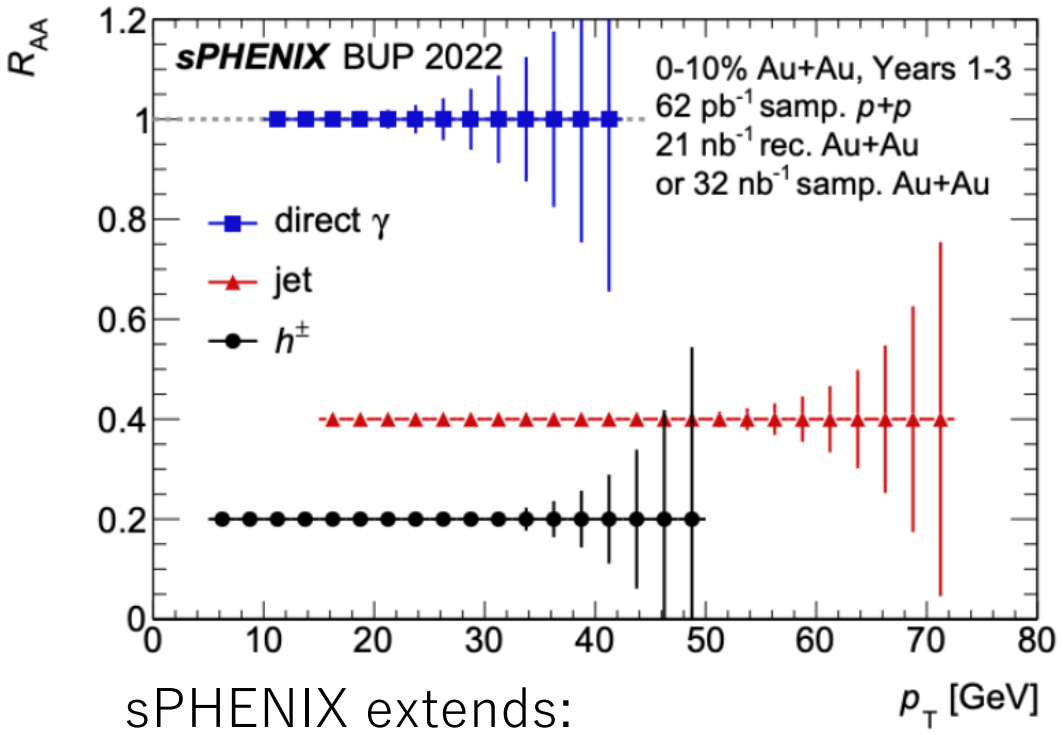




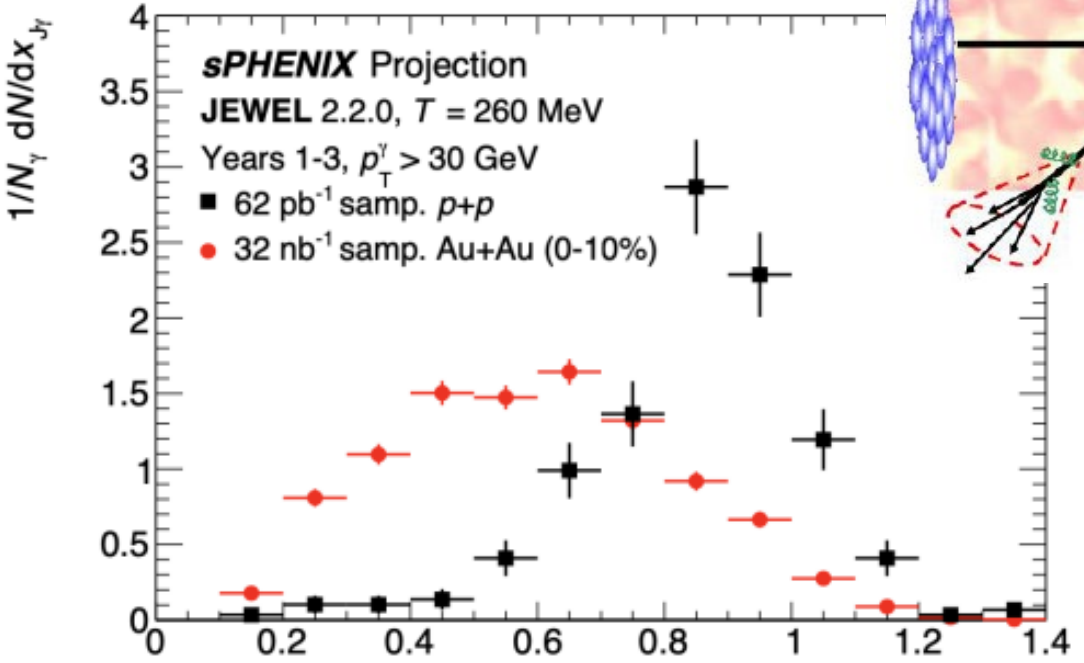
- Jet R_{AA} is smaller than hadrons at the same p_T range
  - The difference is described by the model with virtuality
- **sPHENIX access lower virtuality region**
  - **Virtuality scan is important to understand the energy loss in QGP**

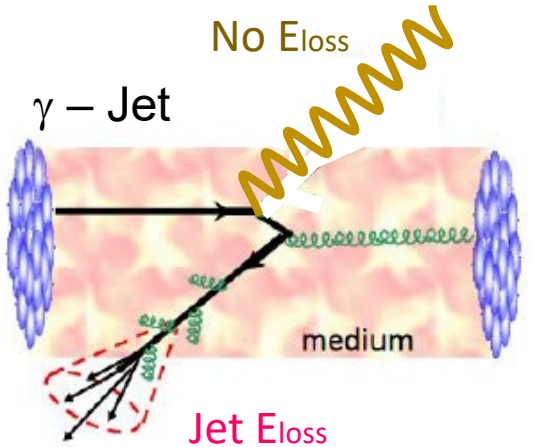
sPHENIX provides new insight of energy loss phenomena

Jets at sPHENIX



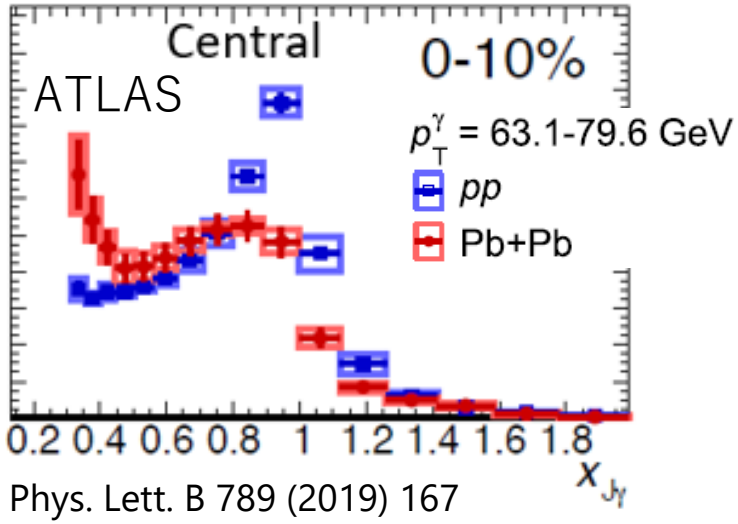
γ - Jet imbalance





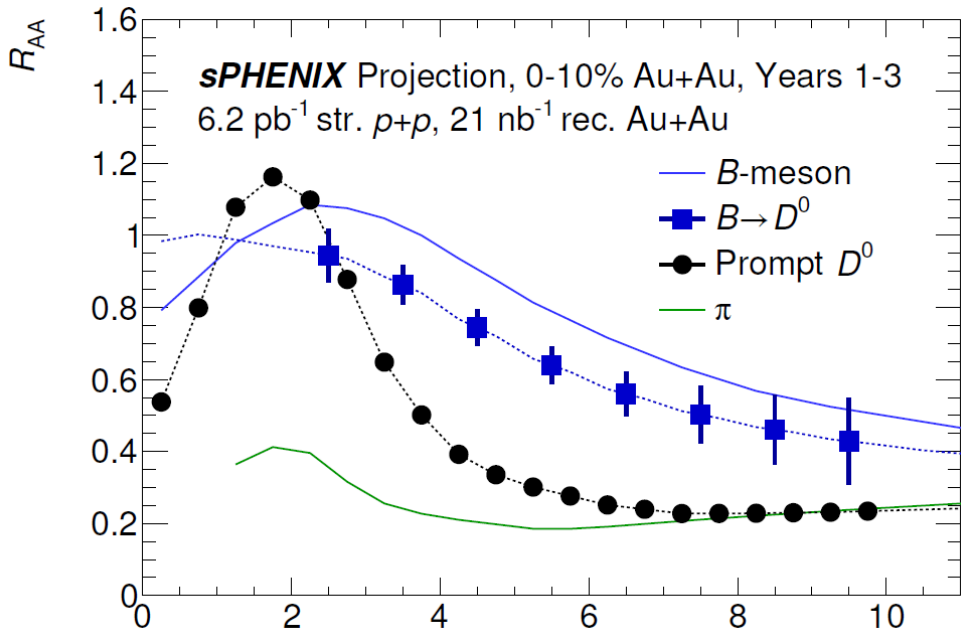
sPHENIX extends:

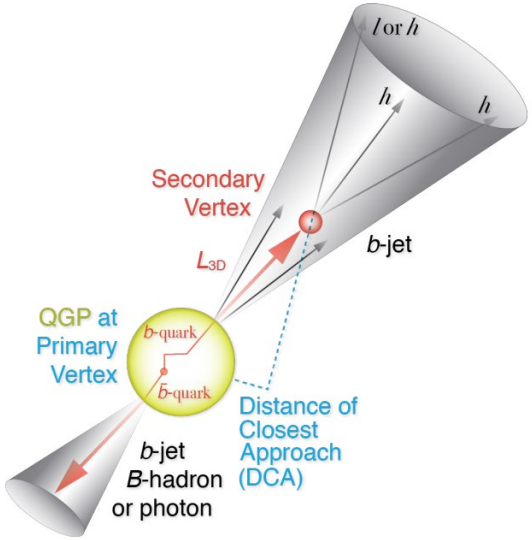
- Jet : p_T~70 GeV/c, Direct photons: ~ 40 GeV/c, hadrons: ~ 50 GeV/c,
- γ - Jet : Golden channel for studying energy loss in QGP
  - Self-calibrated probe, lower pT at RHIC
- Jet-v2, Jet substructure (R dependence), Jet grooming, etc
- kinematics overlap with LHC and lower p_T

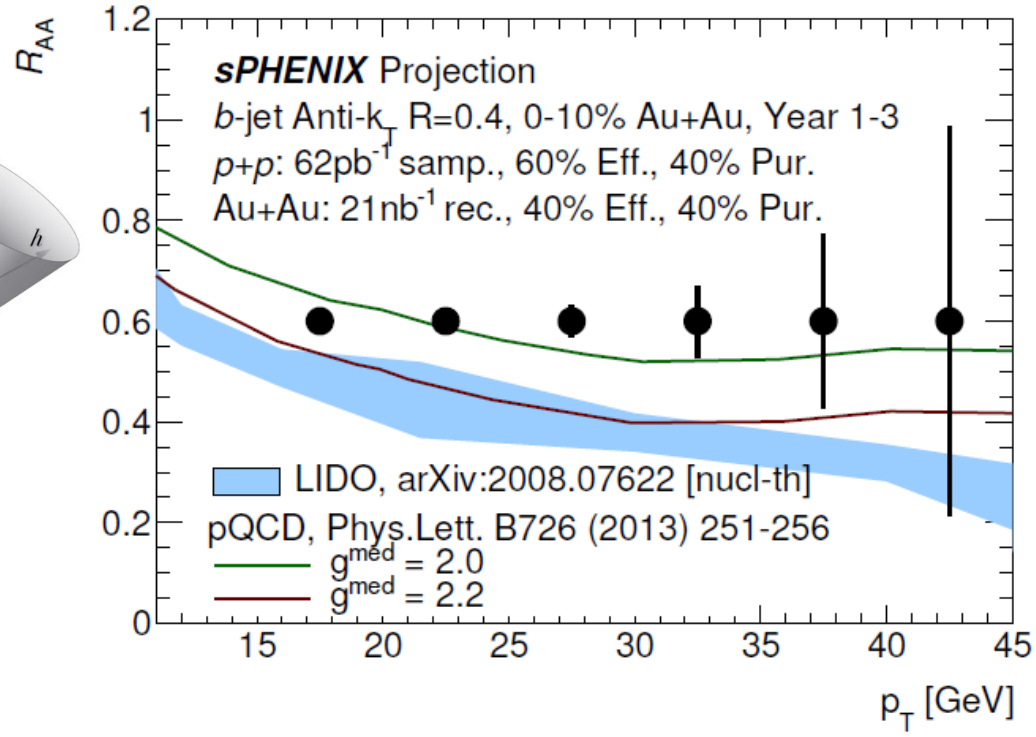


Phys. Lett. B 789 (2019) 167

Heavy Flavors and HF-Jets

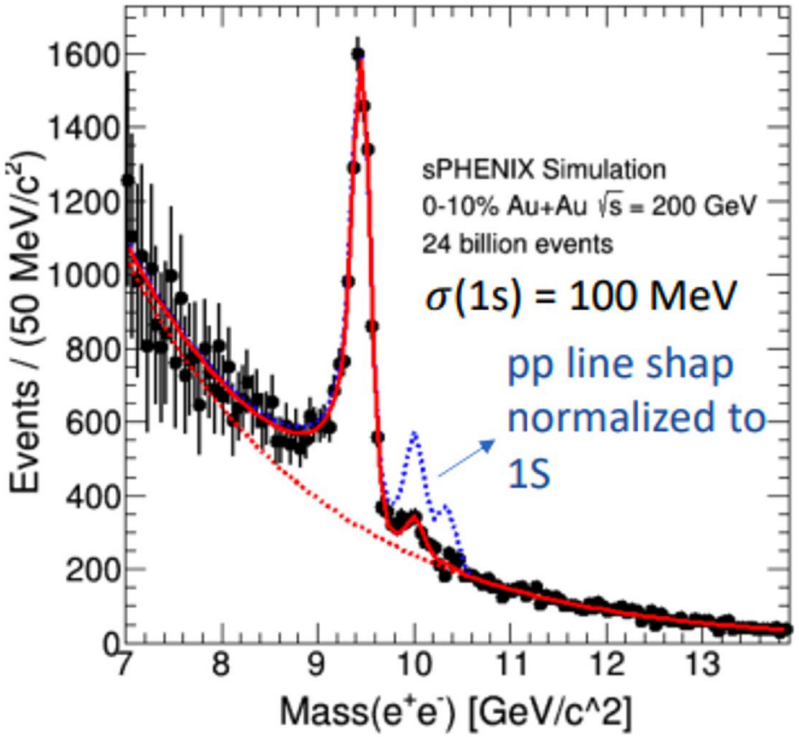


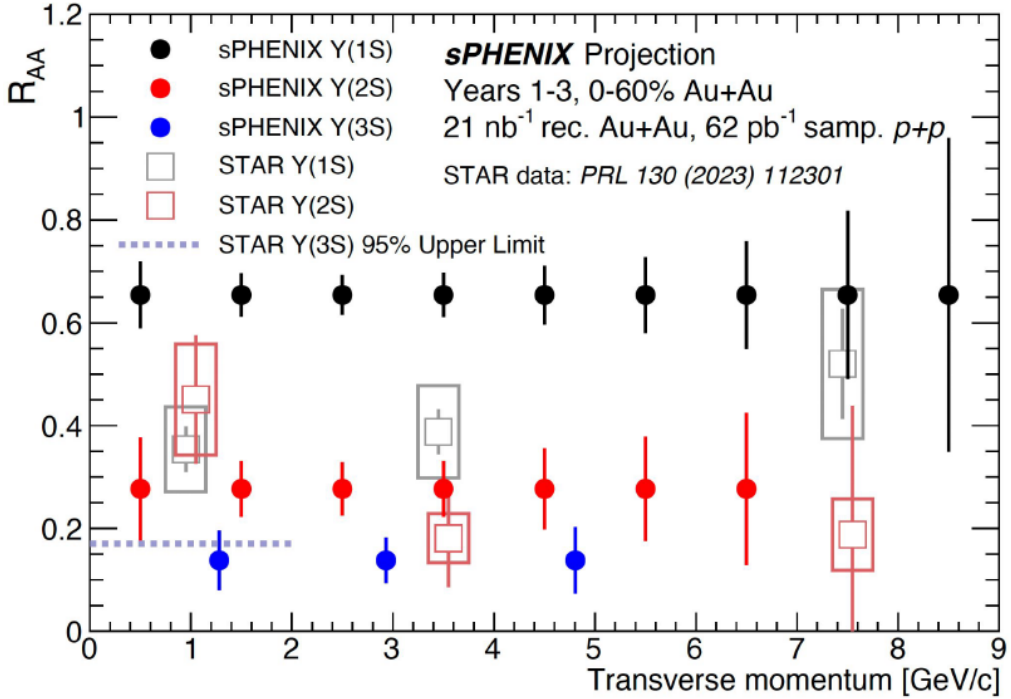




- Study radiative and collisional energy loss w/ broad p_T range
- First b-tagged jets at RHIC
  - Jet + displaced vertex

Upsilon spectroscopy





- Separate three Upsilon states (1s, 2s, 3s)
  - Υ(3s) is quantified if suppression is less
- Study centrality and p_T dependence
- RHIC is more clean than LHC
  - No regeneration of Upsilon at RHIC

Run plan for three years

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

Commissioning and 1st physics Au + Au 200 GeV

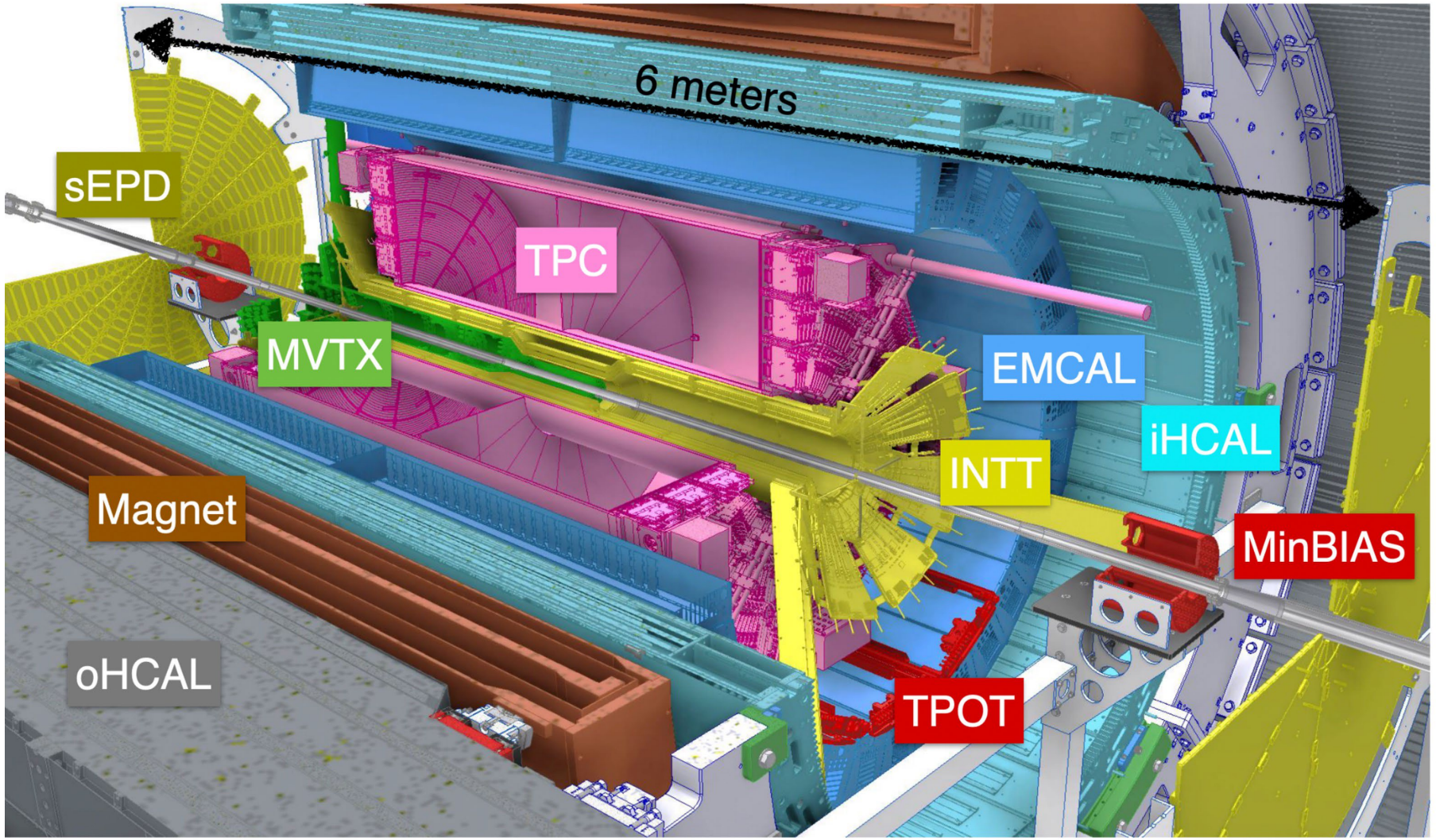
Reference p + p and p + A

Cold QCD/small systems

High statistics Au + Au

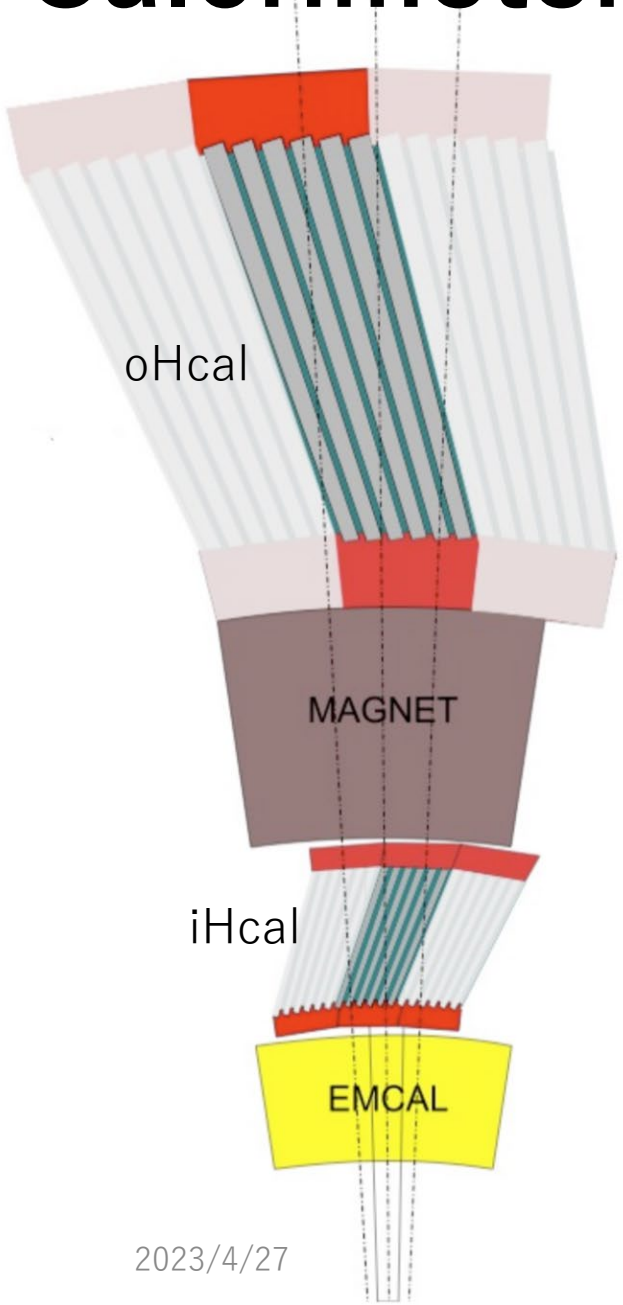
sPHENIX data taking will start in a few weeks

sPHENIX Detector



- Large acceptance
  - $|\eta| < 1.1$
  - full azimuth
- HCAL + EMCAL + Tracking system allows full-jet measurement
- 15kHz DAQ and streaming readout for tracking

Calorimeter

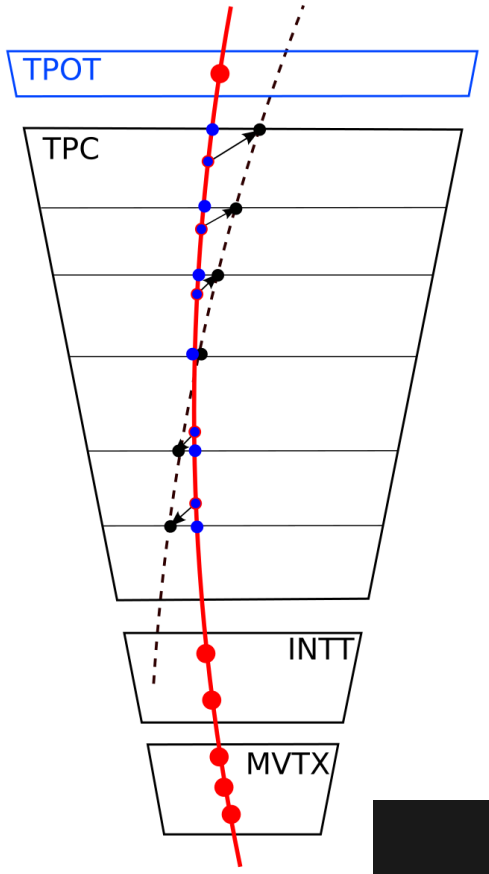


- Outer + Inner HCal (3.8 & 0.25 λ_0)
  - First hadronic calorimeter @ RHIC
  - Steel (Al) absorber + Scintillator tiles
  - Size : 0.1 & 0.1 in ϕ and η
  - Hadron : $\Delta E/E \sim 14\% + 65\%/\sqrt{E}$
- EMCal (18 X_0)
  - Tungsten + Sci-fiber sampling calorimeter
  - Size : 0.025 & 0.025 in ϕ and η
  - EM: $\Delta E/E \sim 5\% + 16\%/\sqrt{E}$

oHCal and iHCal

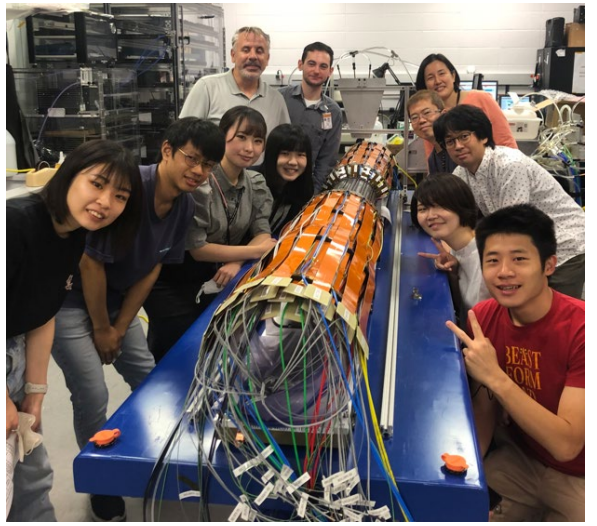
EMCal

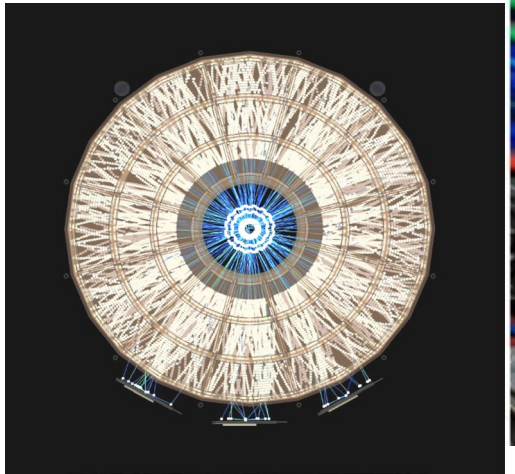
Tracking



- TPC (20<R<78cm)
  - Momentum w/ $\Delta p/p$ ~1% at 5 GeV/c
  - Gateless - continues readout
  - TPOT (TPC Outer Tracker)
    - Correct for TPC space-charge distortions
- INTT (2 layer Si-Strip w/ 6<R<12cm)
  - Good timing resolution to resolve event pile-up
- MVTX (3 layer MAPS PIXEL w/ 2~4cm)
  - ALICE ITS2 technology
  - Fine pitch (27 x 29 um) for displaced vertex
- Tracking system use streaming readout

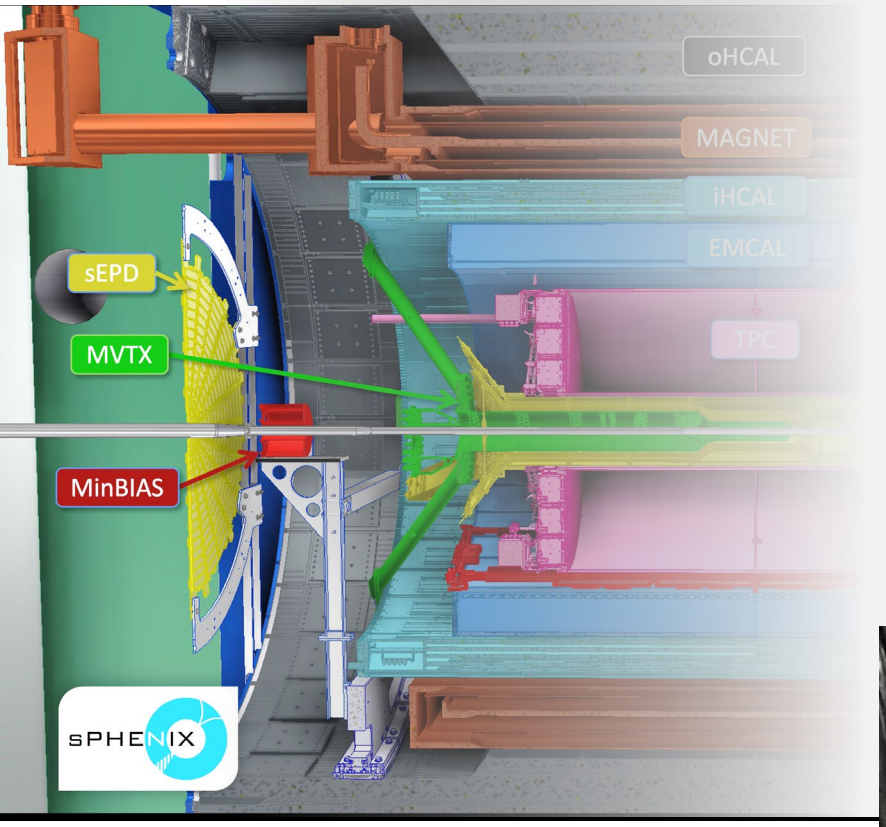
INTT assembly completed !





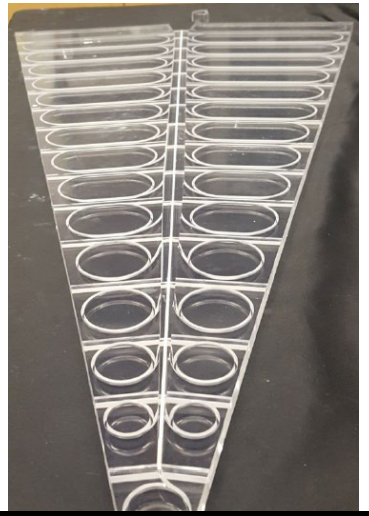
TPC+TPOT+INTT+MVTX installed by March 2023

Global Detectors MBD and sEPD



- MBD η: 3.5-4.6
  - Reuse PHENIX BBC
  - Provide min. bias and event characterization
- sEPD η: 2.0-4.9
  - Event plane at outside of mid-rapidity
  - Scintillator + fiber : similar to the STAR EPD
- ZDC

MBD installed at Apr. 2023



sEPD will be installed

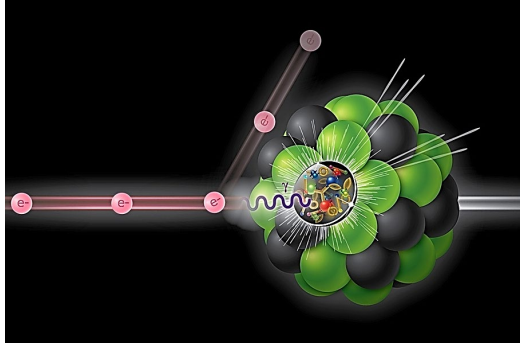
sPHENIX summary

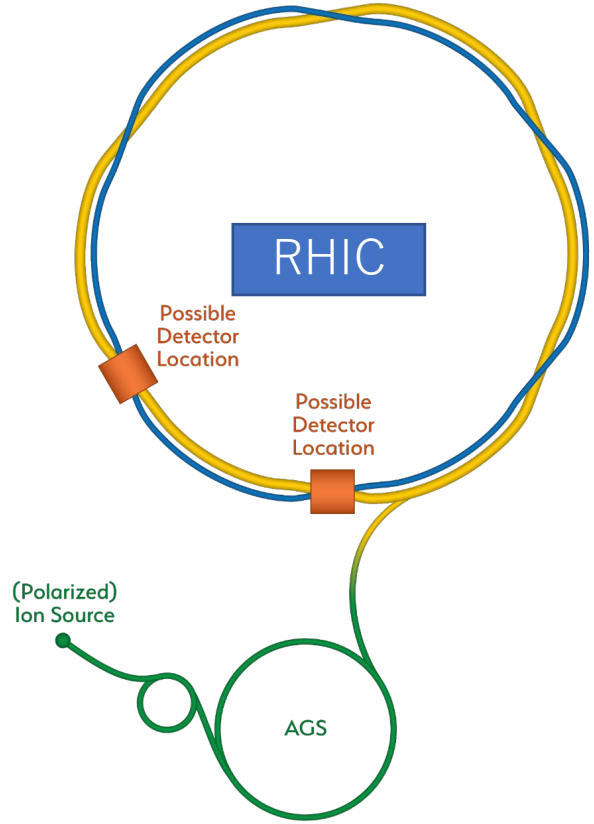
- sPHENIX is new detector to complete the QGP missions at RHIC
  - Measure Jet, HF, Upsilons
- sPHENIX construction is completed and under final adjustment

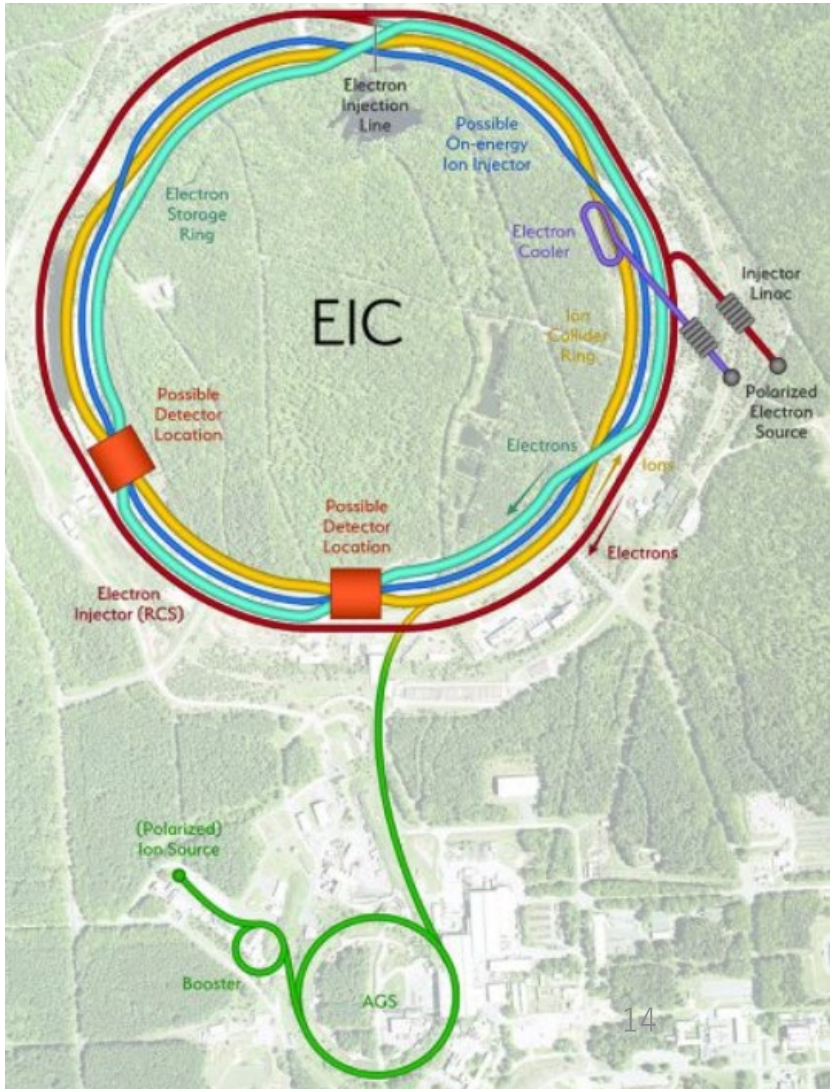
Apr. 27 2023

Electron Ion Collider

- RHIC mission is completed in 2025 and RHIC is modified to a new Electron-Ion-Collider.





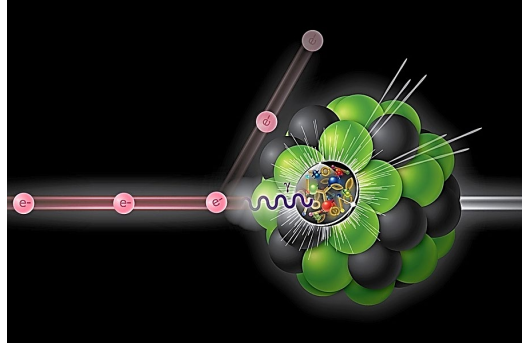


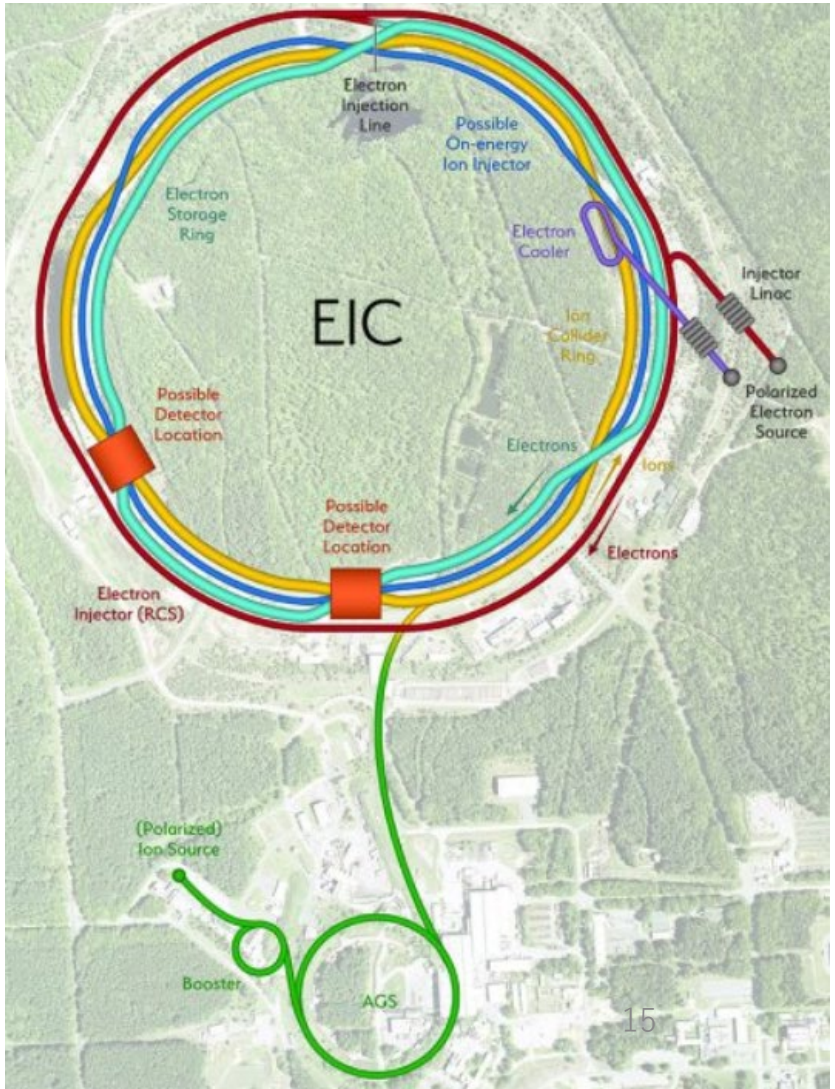
Electron Ion Collider

- RHIC mission is completed in 2025 and RHIC is modified to a new Electron-Ion-Collider.

- **World first polarized electron + Ion collider**
- EIC Design Parameters
  - High luminosity : $10^{33\text{-}34}$ $cm^{-2}sec^{-1}$
    - a factor of ~1000 higher than HERA
  - Broad range of energies : 28 – 140 GeV
  - Polarized beam : electron, proton, He
  - Ion beam : p - Uranium

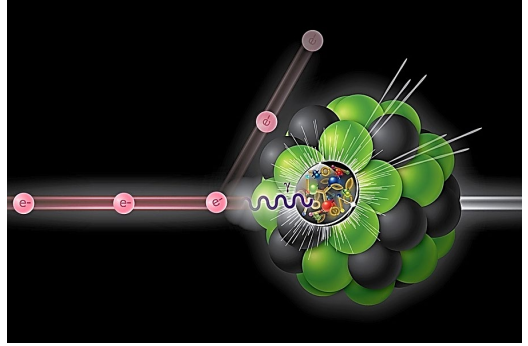
- EIC w/ high luminosity and polarization address fundamental questions



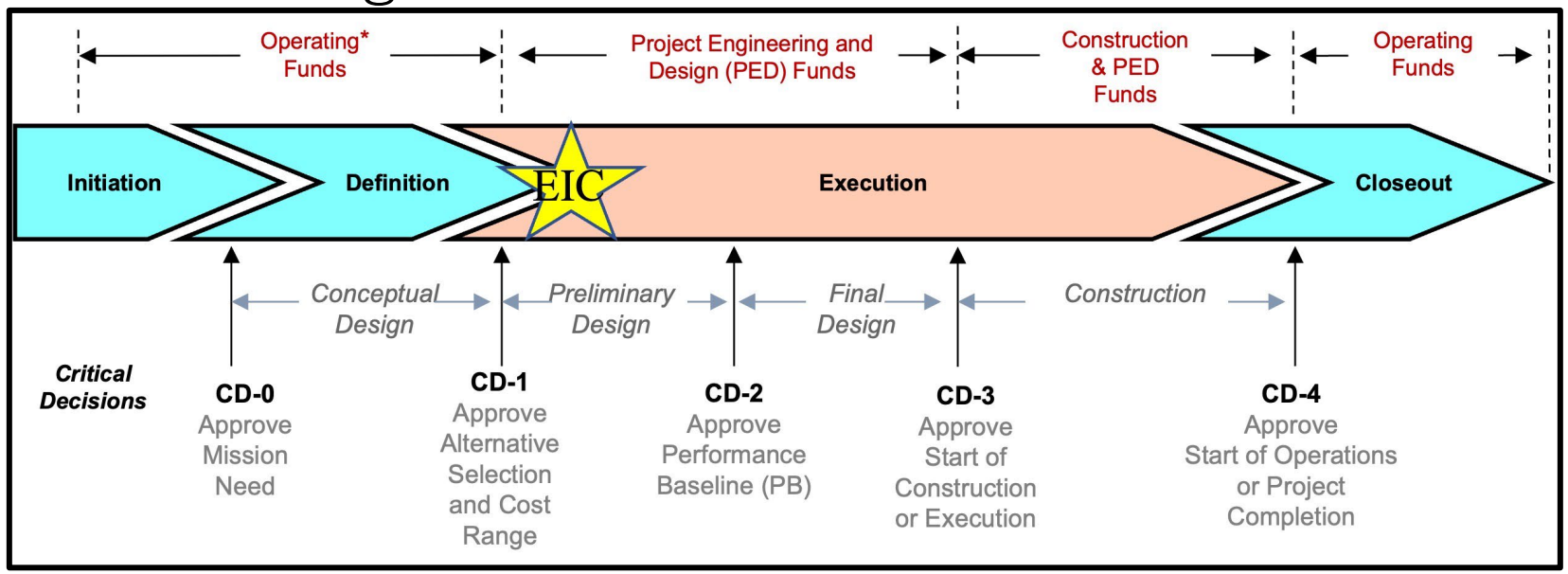


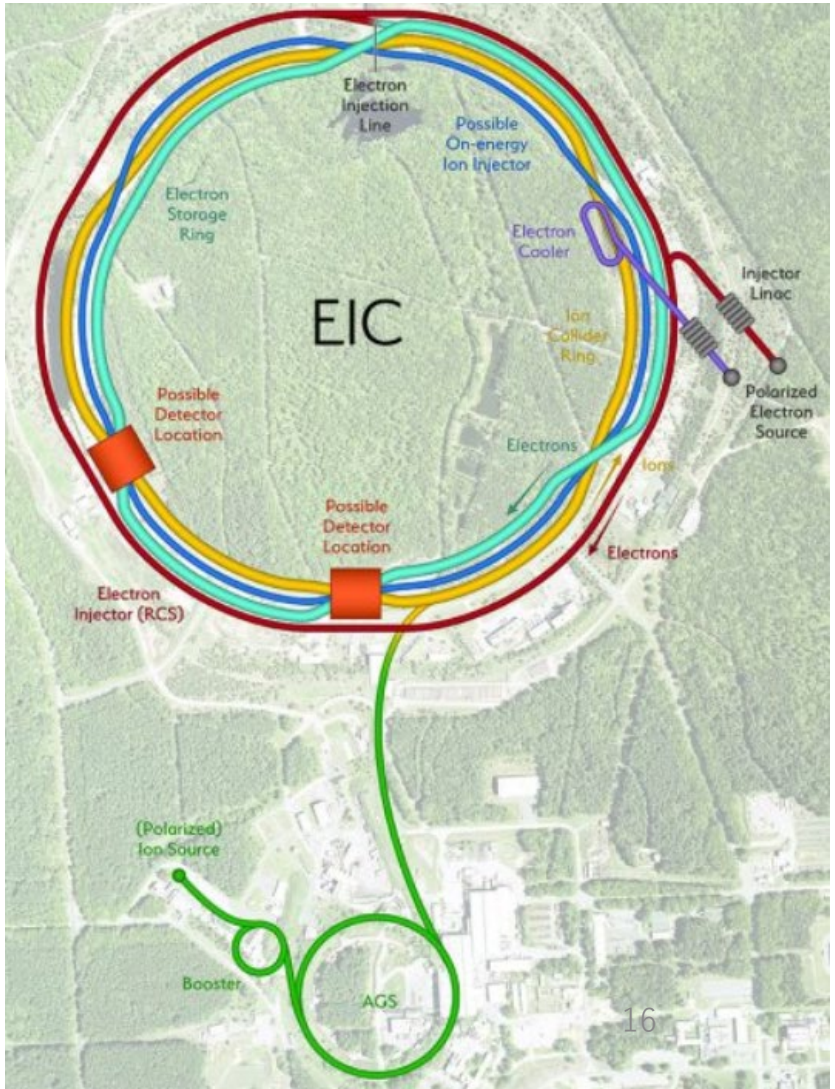
Electron Ion Collider

- World first polarized electron + Ion collider



- EIC Design Parameters





2020 CD0 + BNL selected as EIC site
2021 CD1 approved
2025 EIC construction is expected to start
2032 CD-4A start of operation expected

Electron-Ion Collider

- Understanding the dynamics of **quarks and gluons** is the primary goal in high energy nuclear physics

Slide from A. Deshpande in EIC asia meeting

- Heavy-Ion-Collision
  - Unique to study the dynamics in extreme condition
- **Electron-Ion-Collision**
  - Precise to study the internal structure of proton by **a sharp knife**

Study of internal structure of a watermelon:

A-A (RHIC/LHC)

1) Violent collision of melons

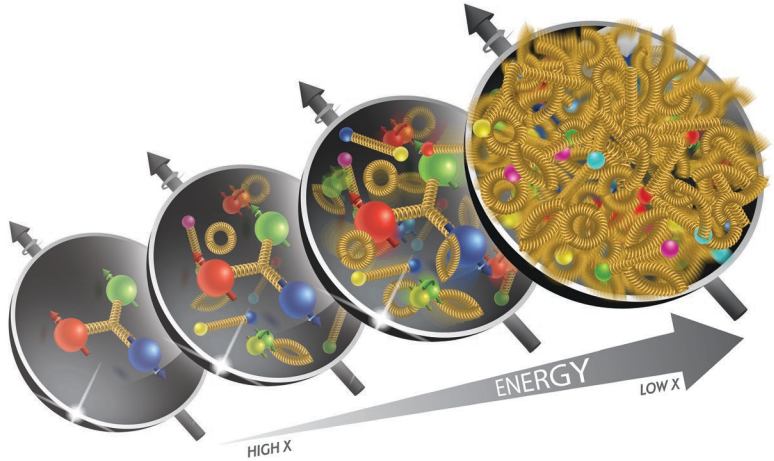
2) Cutting the watermelon with a knife

Violent DIS e-A (EIC)

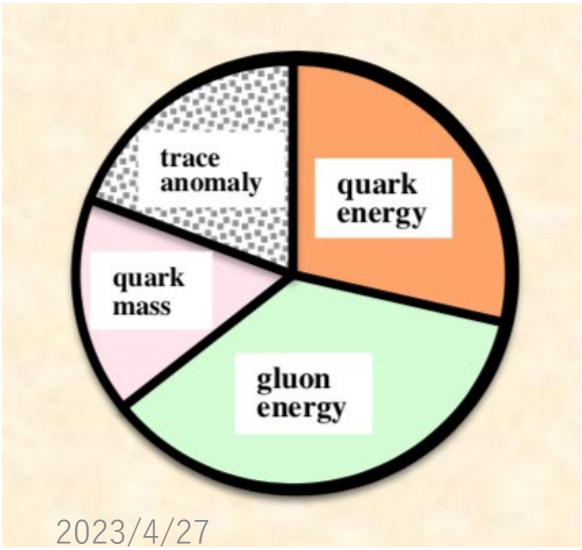
In HIC physics, the precision is improved by high statistics, EIC can achieve even more precise measurements by sharpening the probe and high statistics.

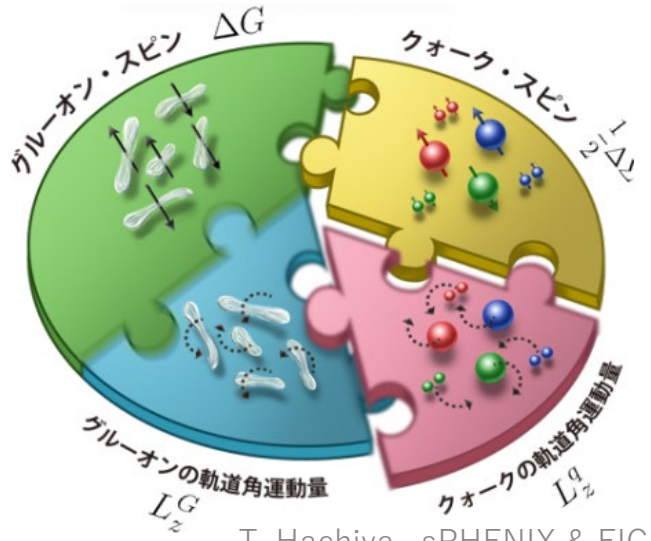
EIC Physics

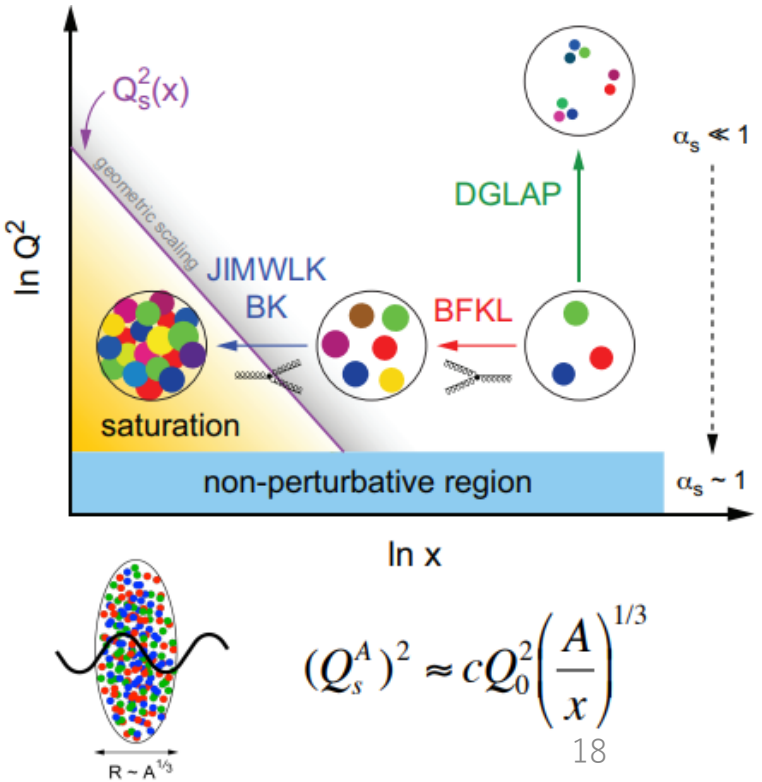
- How proton and nuclei emerge from quarks and gluons
  - Proton is simplest object but not well known



- Questions in EIC
  - 3D structure of proton and ions
  - Origin of proton mass and spin.
  - High-density gluon field (saturation) in small-x

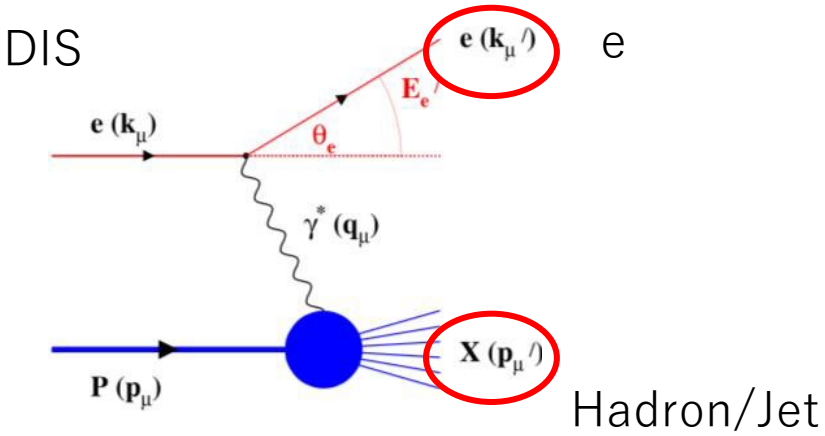


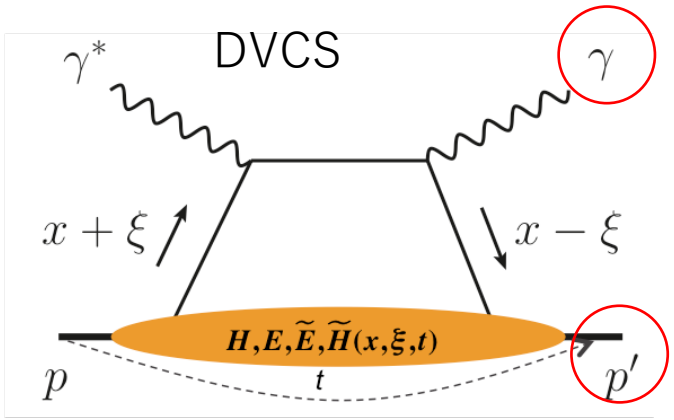


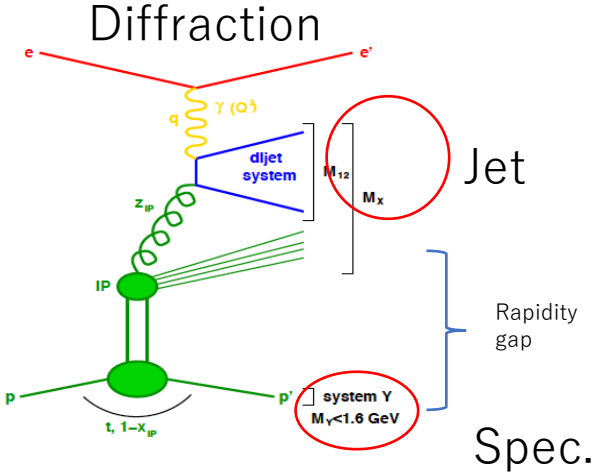


EIC project experiment

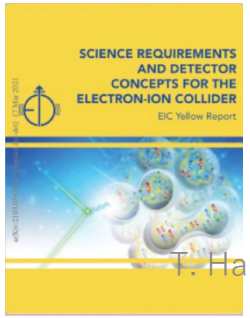
EIC measures both inclusive and exclusive processes from DIS, DVCS and Diffraction

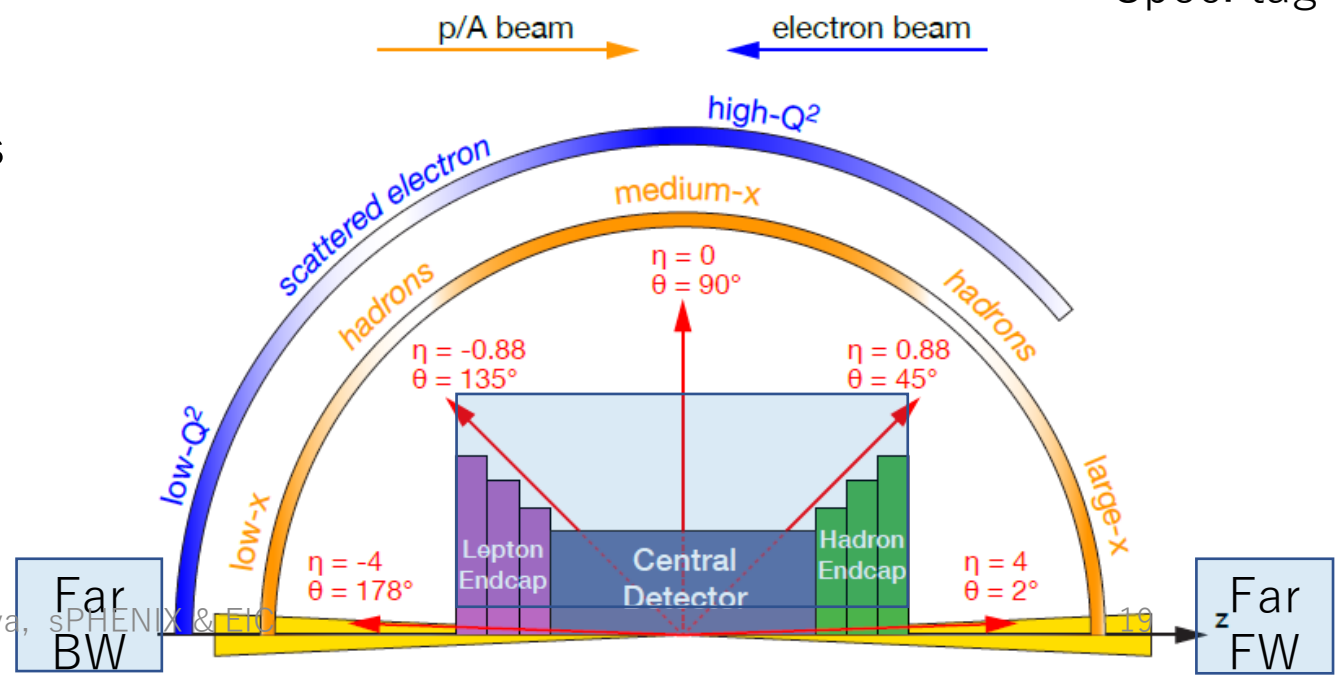






- General-purpose detector is necessary
  - Wide coverage in both electrons and hadrons
    - Scattered e ： Q^2 for BW(low) – FW (high)
    - Hadrons ： x for BW(low) - FW (high)
  - e / hadron ID
  - Far FW & Far BW detectors
  - Requirements are summarized in EIC YR (2021)

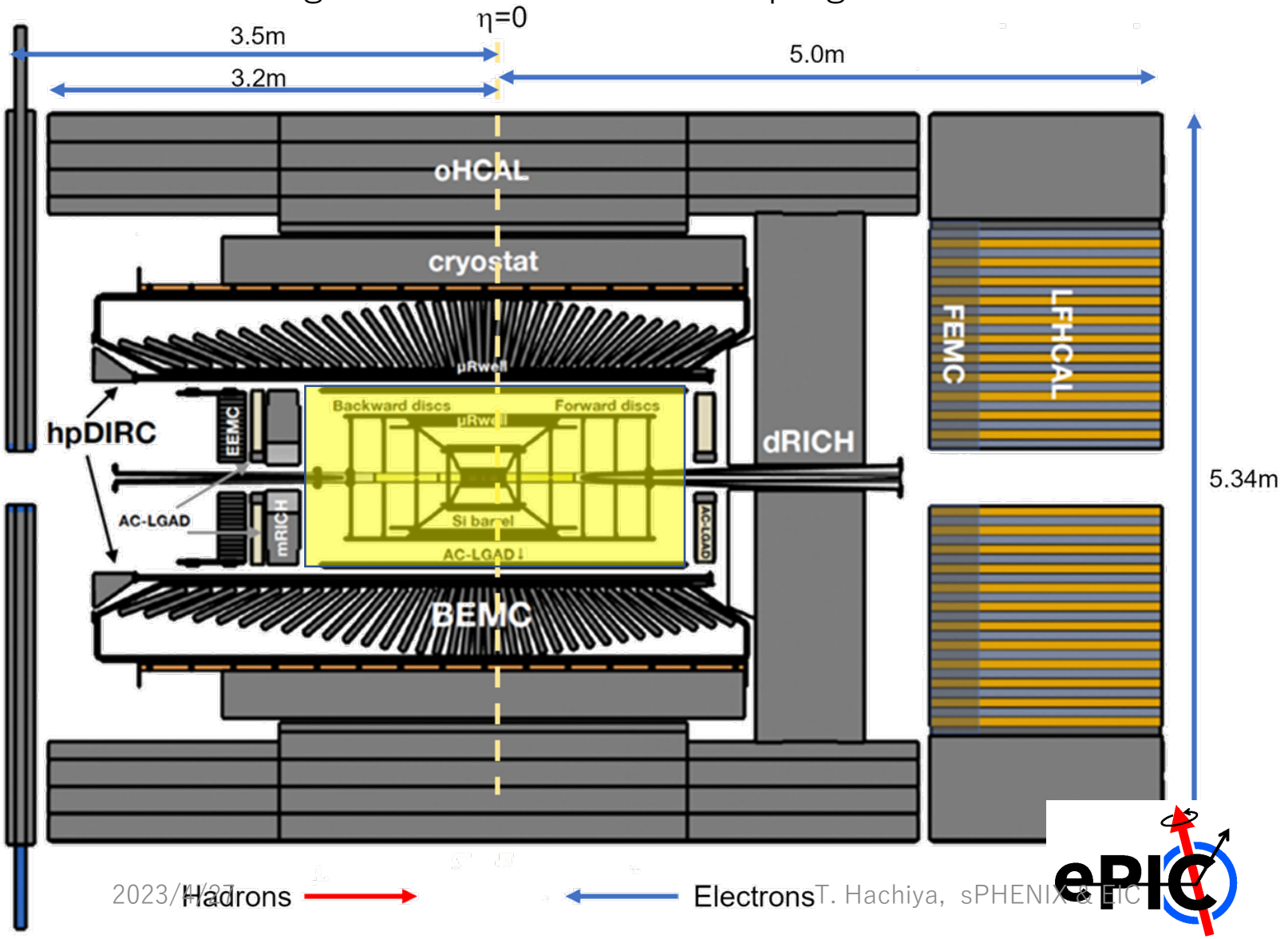




ePIC Central Detector (current)

ePIC collaboration is formed in 2022

Detailed design and detector R&D is in progress

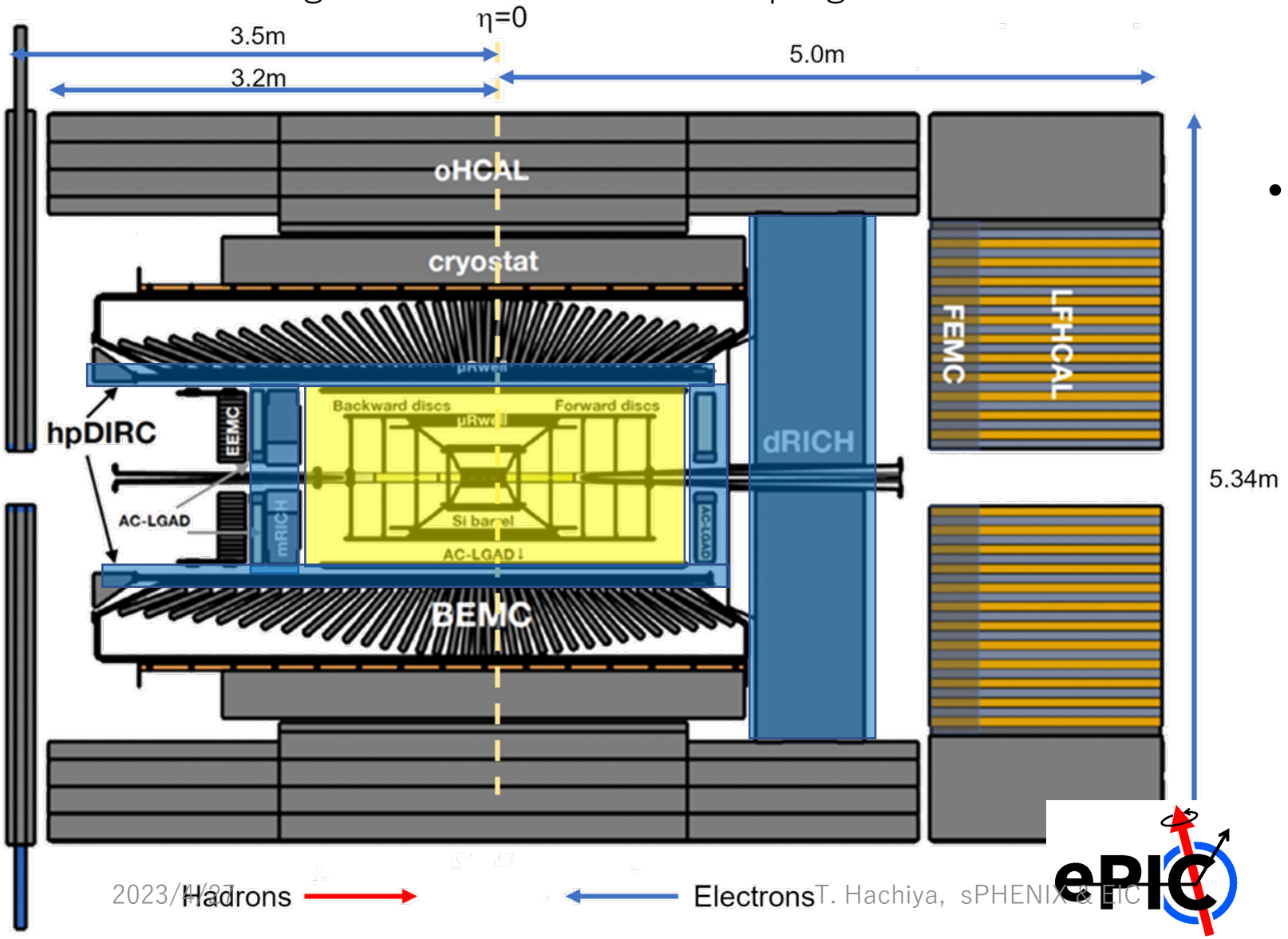


- Coverage : 2π, |y|<4
- Inner Tracker
  - New 1.7T solenoid
  - Si MAPS
  - MPGD(uRWELL/uMegas)

ePIC Central Detector (current)

ePIC collaboration is formed in 2022

Detailed design and detector R&D is in progress

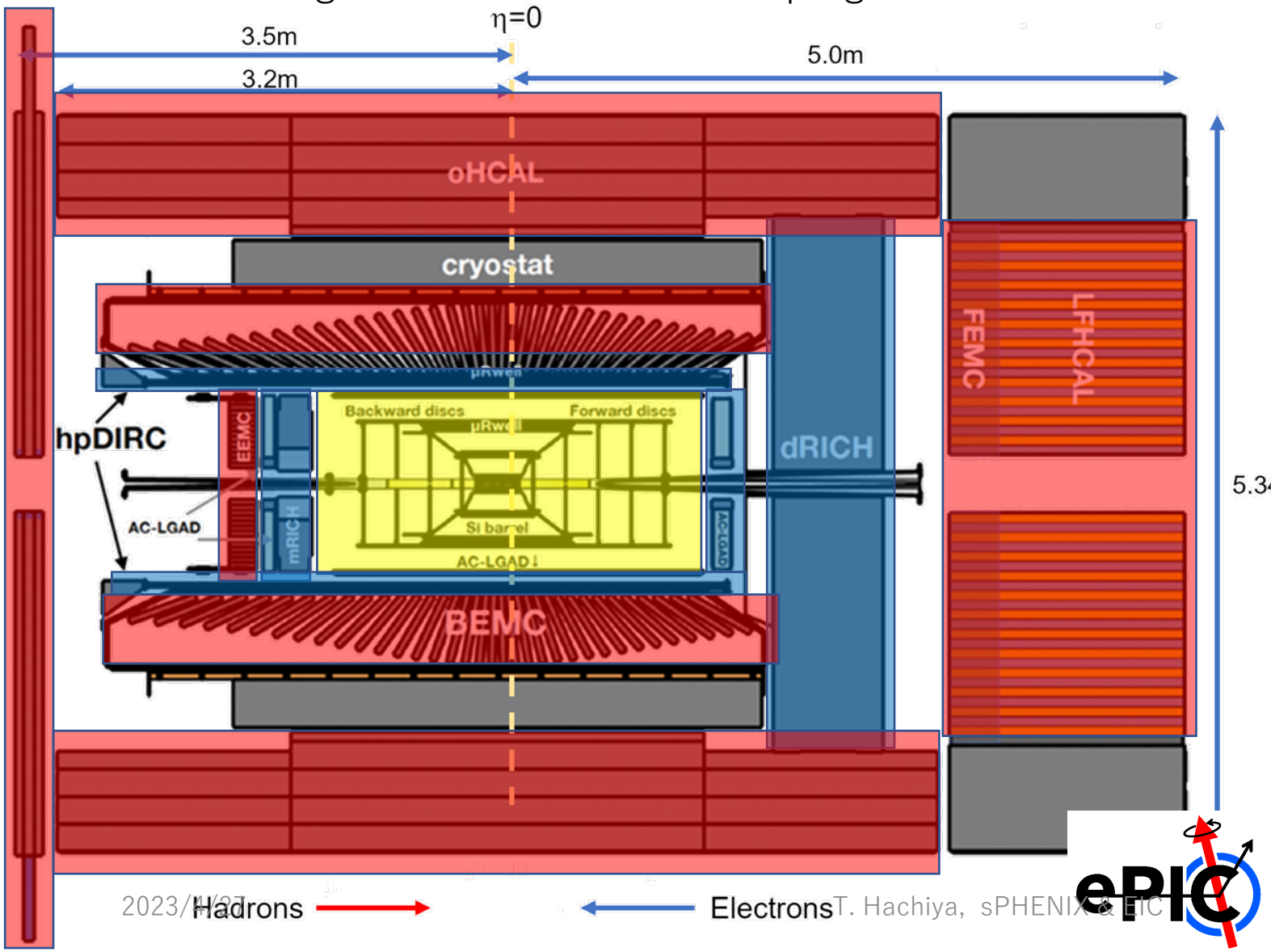


- Coverage : 2π, |y|<4
- Inner Tracker
  - New 1.7T solenoid
  - Si MAPS
  - MPGD(uRWELL/uMegas)
- PID
  - hpDIRC (cent)
  - mRICH/pfRICH (BW)
  - dRICH (FW)
  - Si-TOF (AC-LGAD ~30ps)

ePIC Central Detector (current)

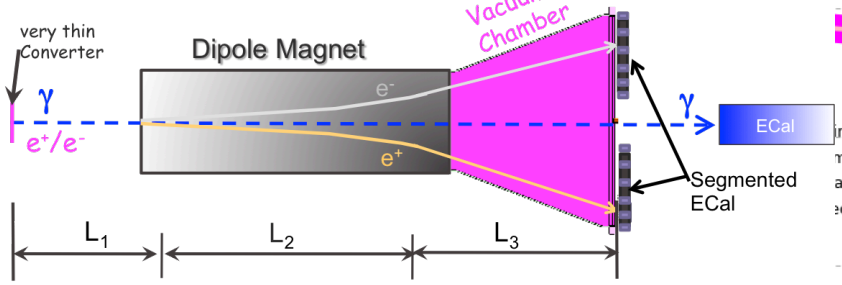
ePIC collaboration is formed in 2022

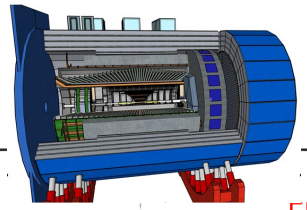
Detailed design and detector R&D is in progress

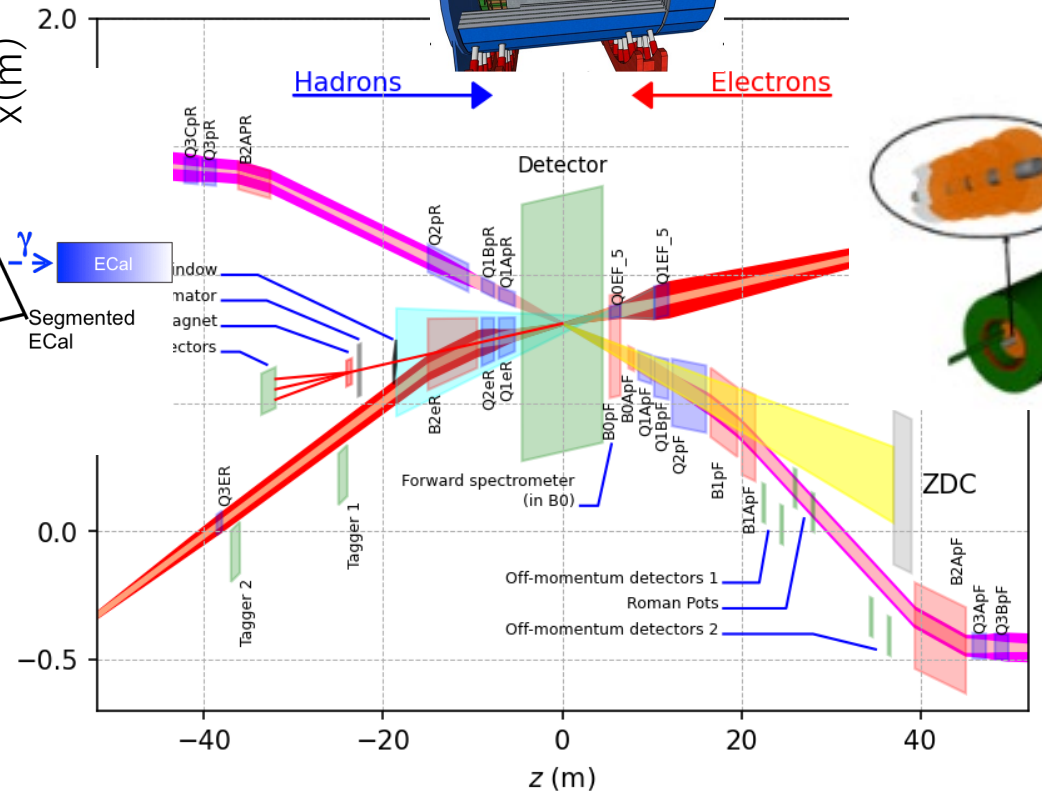


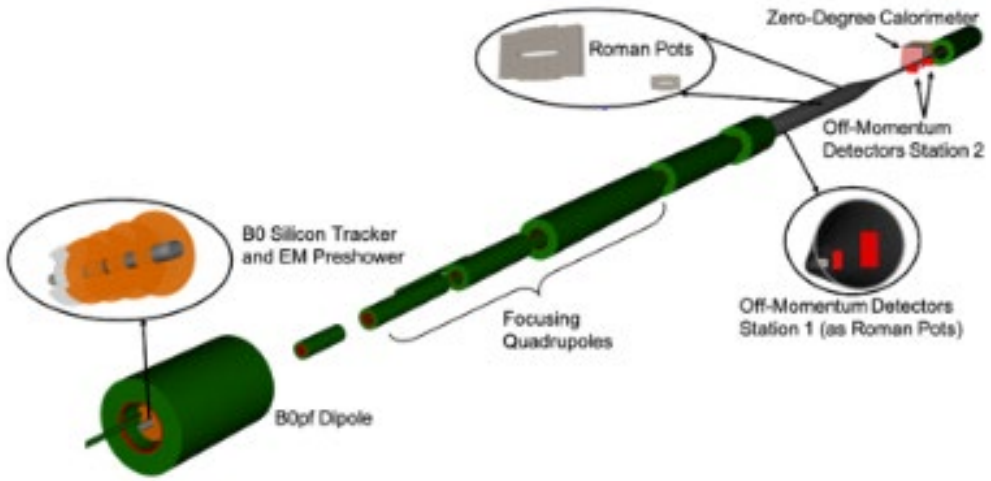
- Coverage : 2π, |y|<4
- Inner Tracker
  - New 1.7T solenoid
  - Si MAPS
  - MPGD(uRWELL/uMegas)
- PID
  - hpDIRC (cent)
  - mRICH/pfRICH (BW)
  - dRICH (FW)
  - Si-TOF (AC-LGAD ~30ps)
- Calorimeters
  - SciGlass/Imaging Barrel EMCAL
  - OuterHCAL (from sPHENIX)
  - Fine-segmented EMCAL+ HCAL in forward
  - PWO EMCAL + HCAL in backward

ePIC FW & BW detector (current design)





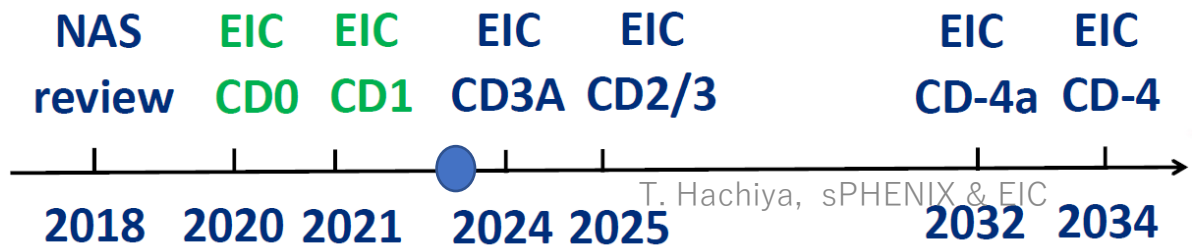




Far-Backward
- Luminosity monitor by $\boldsymbol{\gamma}$ from $\boldsymbol{e + p \rightarrow e\gamma p}$
- Low-Q^2 tagging

Far-Forward
- B0 Si tracker and EMCal for tracking + neutral particles
- Off-Momentum detector for charged particles from fissions and decays
- Roman Pots for charged particles
- Zero Degree Calorimeter for neutral particles

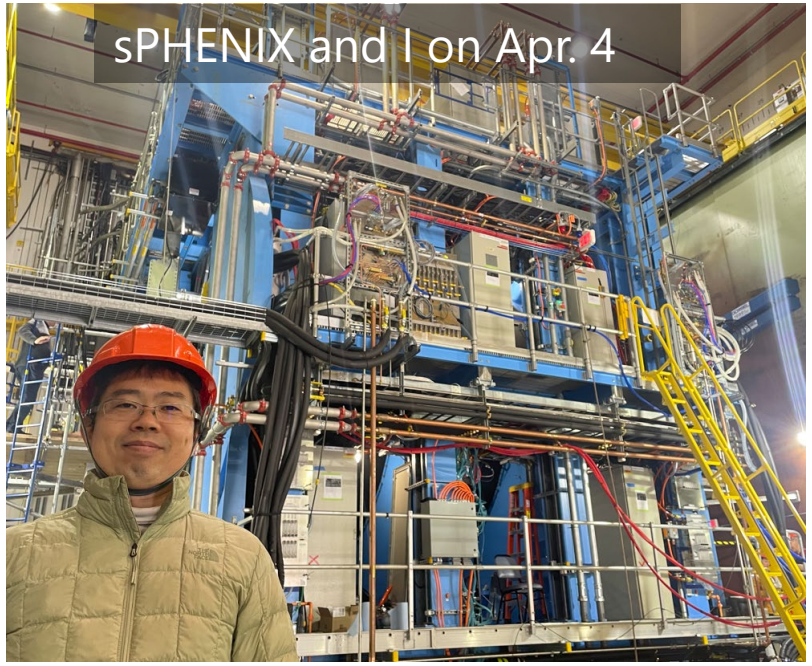
Detailed design and detector R&D is in progress for TDR

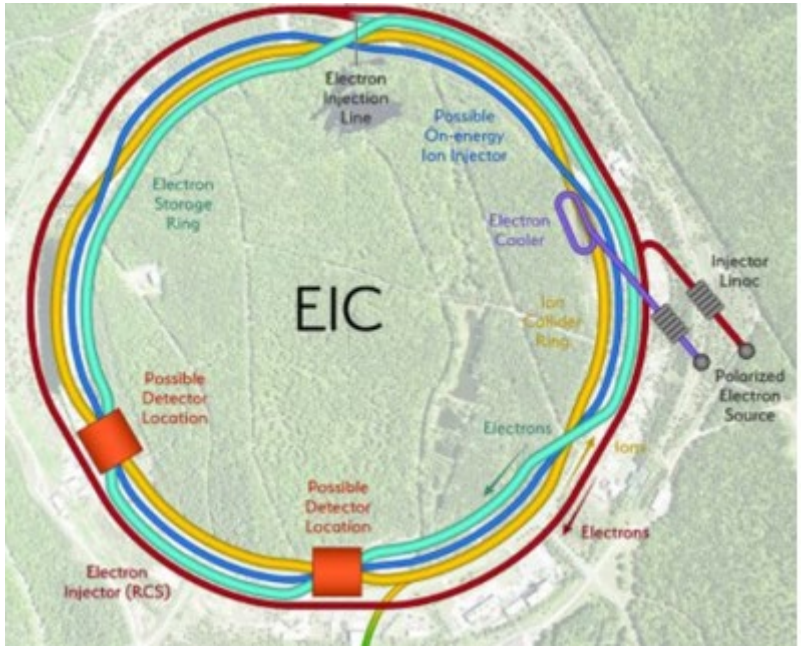


Summary

- sPHENIX complete QGP physics mission at RHIC
- Provide key insight of QGP
  - Precise jet, jet imbalance and sub-structure with gamma-jets
  - First b–tagged jet at RHIC
  - Upsilon three state suppressions
- sPHENIX data taking starts in a few weeks

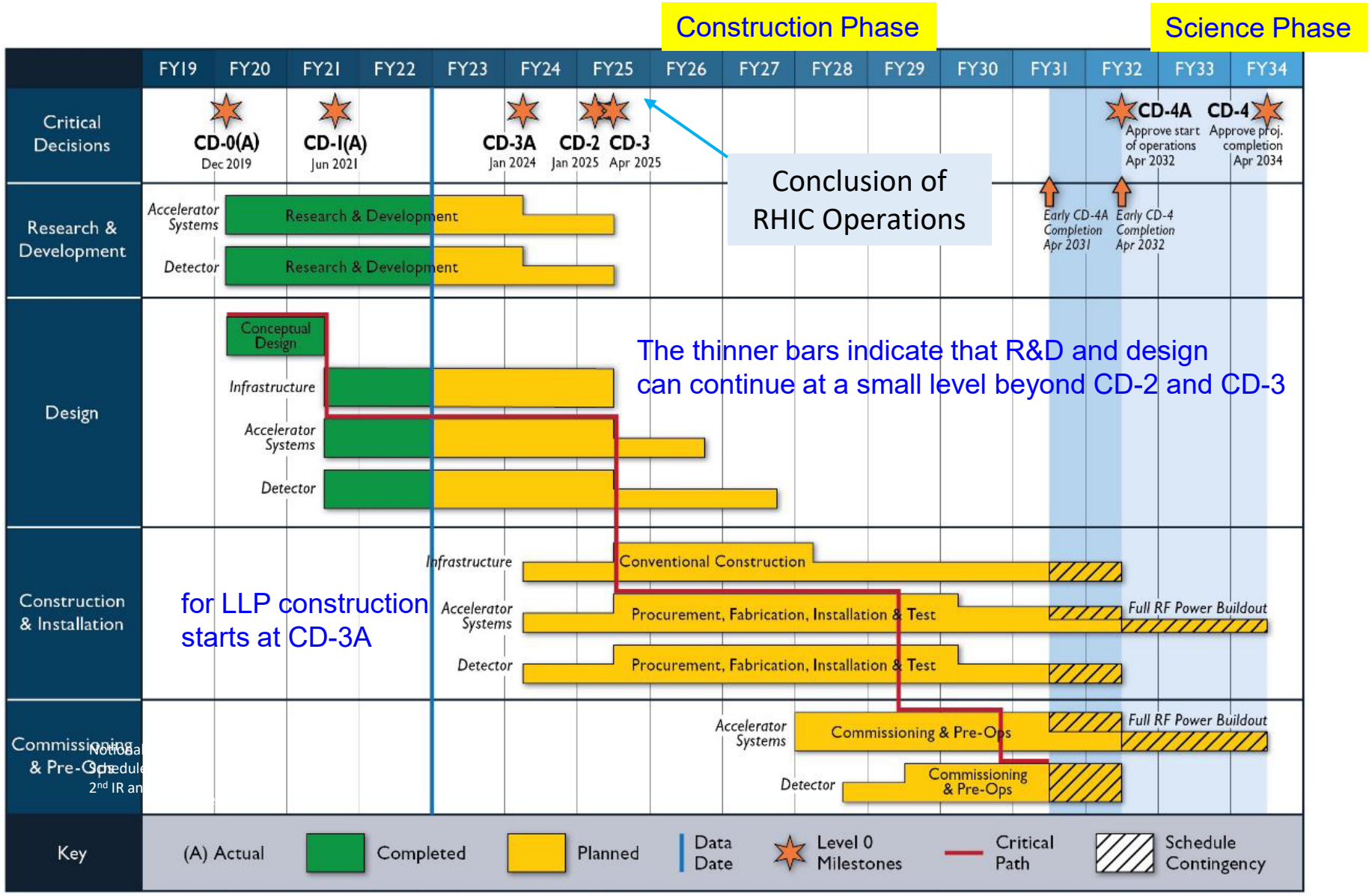
- EIC is a future QCD collider to address fundamental questions on NP.
  - ePIC detector design is in progress
  - Moving to the EIC construction in 2025 and data taking in 2032





backup

EIC Reference Schedule



Option beyond 3 years data taking

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2026	$p^{\uparrow}p^{\uparrow}$	200	28	15.5	1.0 pb^{-1} [10 kHz] 80 pb^{-1} [100%-*str*]	80 pb^{-1}
–	O+O	200	–	2	18 nb^{-1} 37 nb^{-1} [100%-*str*]	37 nb^{-1}
–	Ar+Ar	200	–	2	6 nb^{-1} 12 nb^{-1} [100%-*str*]	12 nb^{-1}
2027	Au+Au	200	28	24.5	30 nb^{-1} [100%-*str* / DeMux]	30 nb^{-1}