Status report on RHICf, FoCal, RANS test, etc.

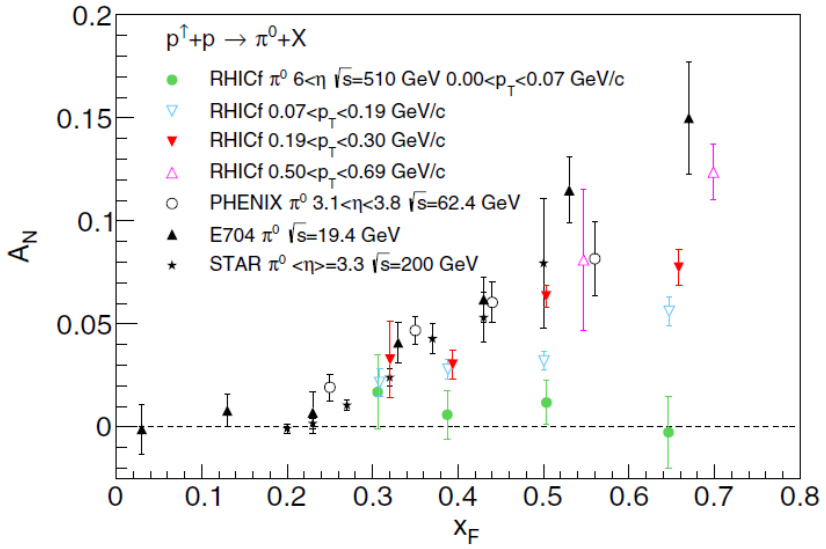
RBRC exp group meeting

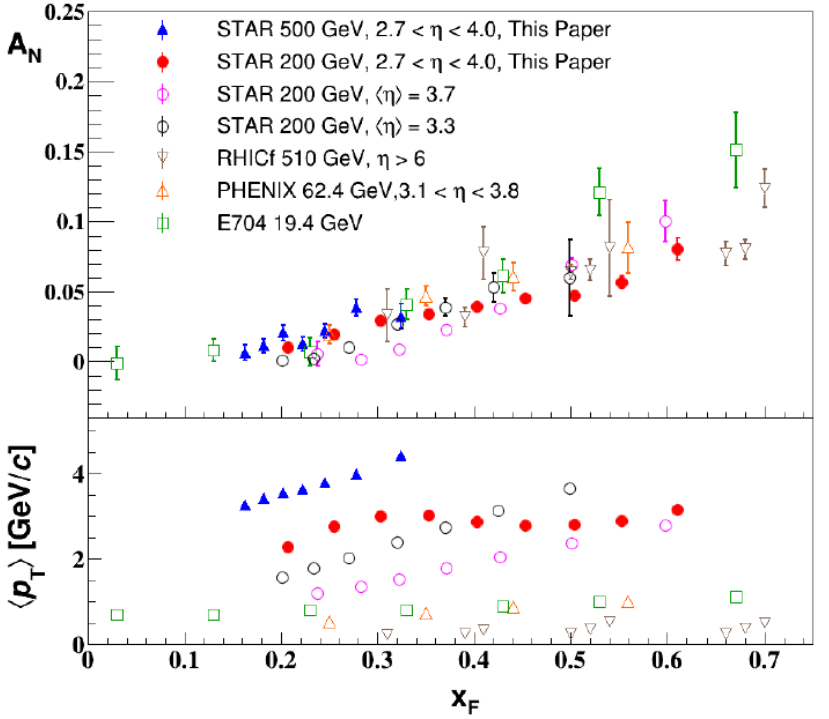
May 17, 2022

Yuji Goto

RHICf results

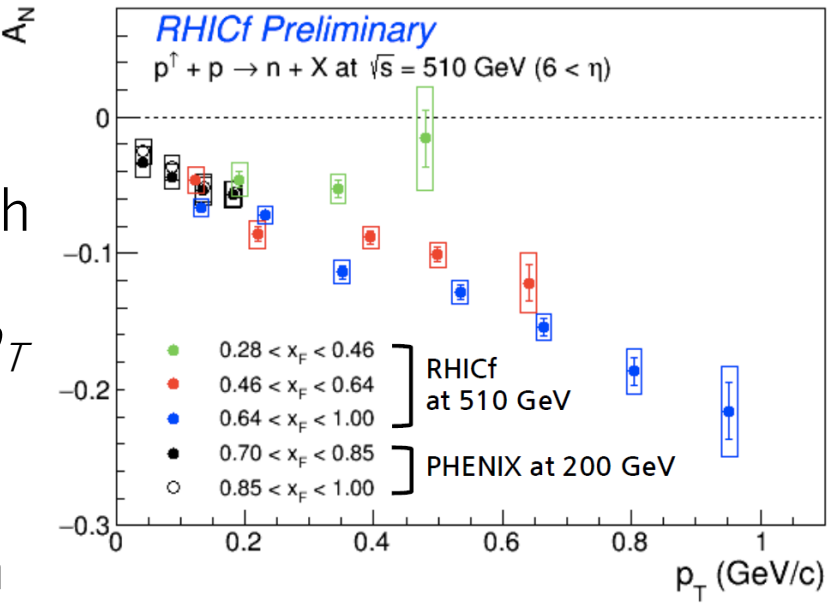
- π^0 asymmetry
  - Phys.Rev.Lett. 124 (2020) 252501
  - Comparison with high $p_T > 0.5$ GeV/c data of the past experiments
  - Nearly the same large asymmetry is reached at low $p_T < 0.2$ GeV/c
  - Contribution of other mechanisms, diffraction and resonance, may provide a hint to the mystery
- STAR comparison
  - Phys.Rev.D 103 (2021) 092009
  - $\sqrt{s}$ = 200 GeV & 500 GeV
  - Forward π^0, $2.7 < \eta < 4.0$
- Significant part of the (isolated) π^0 are from diffractive processes?

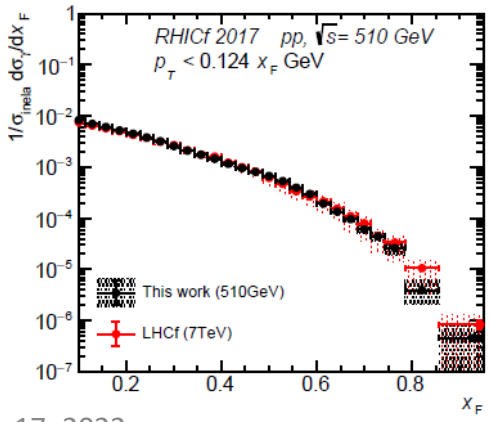


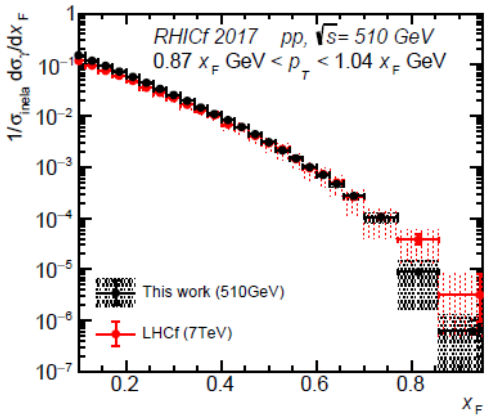


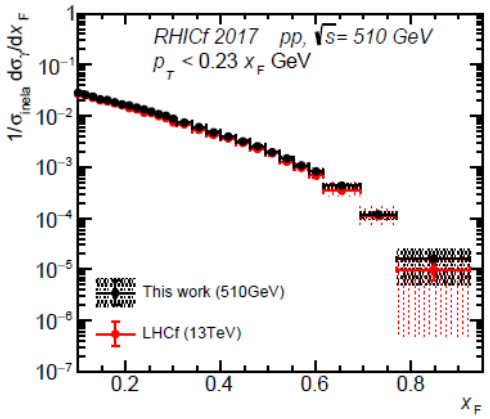
RHICf results

- Neutron asymmetry
  - Preliminary result
  - A_N increases in magnitude with p_T up to 1 GeV/c at high x_F
  - Clear x_F dependence at high p_T
- Photon spectrum
  - arXiv:2203.1541 [hep-ex]
  - Comparison with LHCf photon results
  - First confirmation of collision-energy scaling at zero degree photons



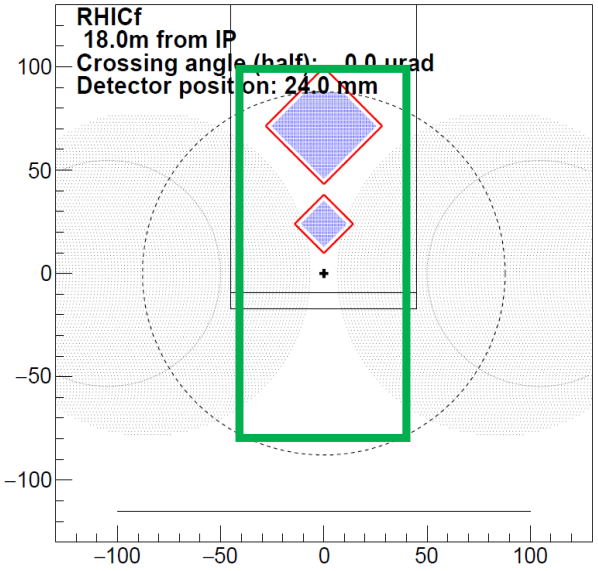






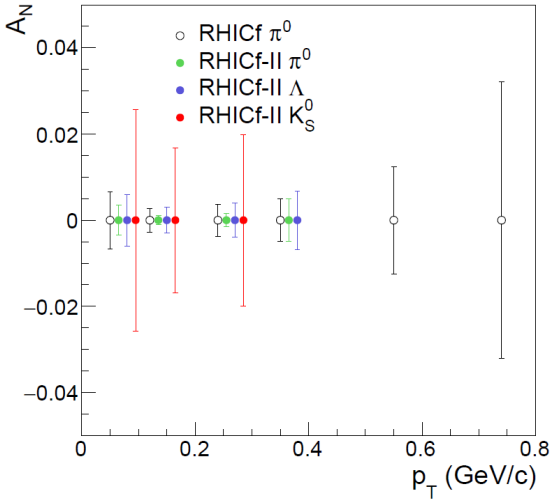
RHICf-II proposal

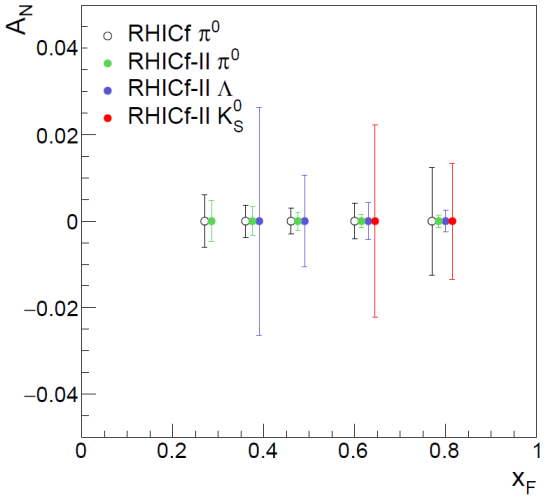
- We proposed a second run for RHICf in 2024 (RHICf-II)
- RHICf-II LoI was discussed by the PAC in 2020.9
  - Parasitic beam-time
- We're collaborating with ALICE-FoCal group to use the FoCal-E technology
  - 8cm x 18cm detector
  - Kakenhi-Kiban-A (2021-2024) + RIKEN budget
  - The detector have enough radiation hardness to work for a small β^* and normal luminosity



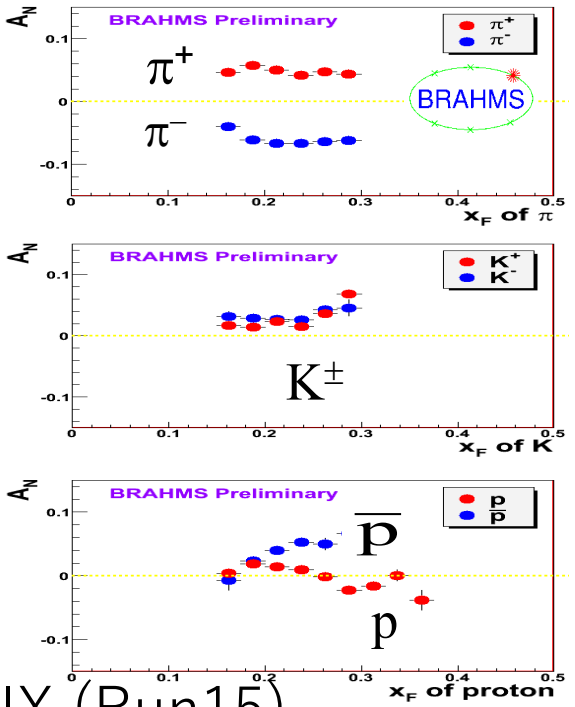
RHICf-II physics

- K^0_S & Λ asymmetry measurement
  - Expected statistical uncertainty of asymmetry measurements for π^0, K^0_S, and Λ compared to the RHICf (Run17) π^0 assuming the similar luminosity
  - BRAHMS comparison
  - To understand the forward hadron production mechanism





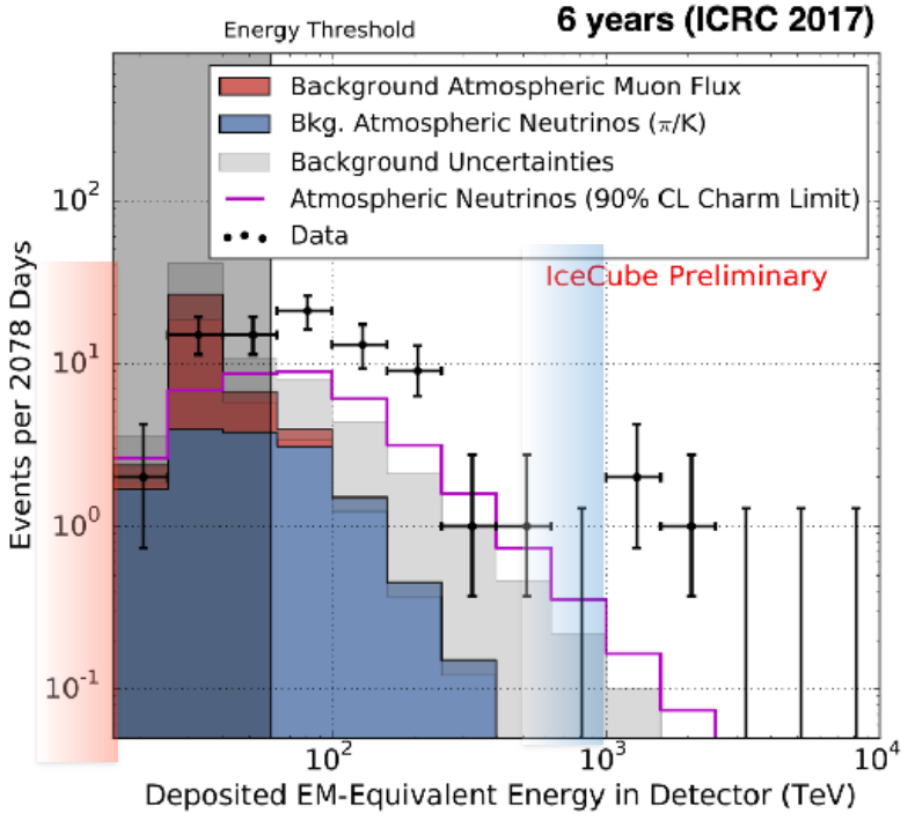
Forward identified particles at BRAHMS

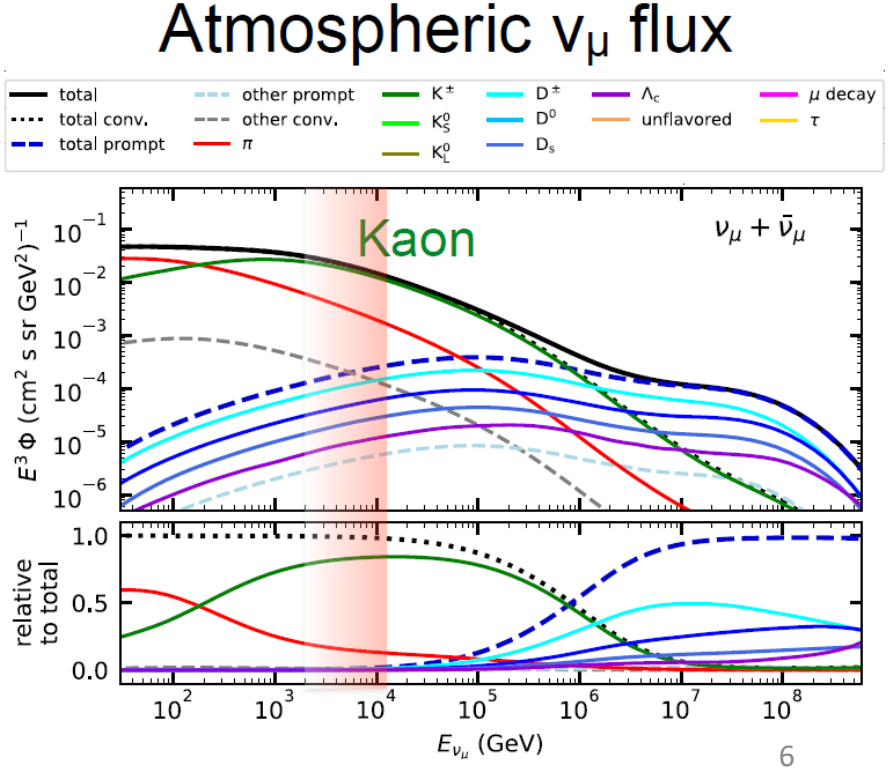


- Polarized-p + A
  - π^0 asymmetry
  - Neutron asymmetry measured at PHENIX (Run15)

RHICf-II physics

- K^0_S & Λ spectrum measurement
  - Impact on air-shower development
    - Muon excess issue
  - Cosmic neutrino background
    - For accelerator neutrino physics, too (FASER, SND)





STAR Spin/Cold-QCD PWG

- 2022.1.26
- ZDC performance issue
  - 9 o'clock blue-beam Snake failure
  - Luminosity measurement
  - Local polarimeter performance
- Peoplepower issue
  - BNL peoplepower necessary for installation and safety
- DAQ requirement
- Available space
- List of tasks
  - Simulation tasks

Conclusion

- 2022.4.8: Decision by the STAR management
  - They cannot accept the RHICf-II proposal.
  - The main reason is the lack of human resources.
- 2022.4.22: NPP meeting
  - Last discussion to avoid losing the RHICf-II physics for understanding the forward hadron production mechanism
    - Diffractive process
    - Air-shower development & cosmic neutrino background
  - No way to cover the lack of human resources
    - Minimum two FTE necessary, mechanical engineer and technician who understand the complex system of STAR
    - No way to obtain them from outside

Conclusion

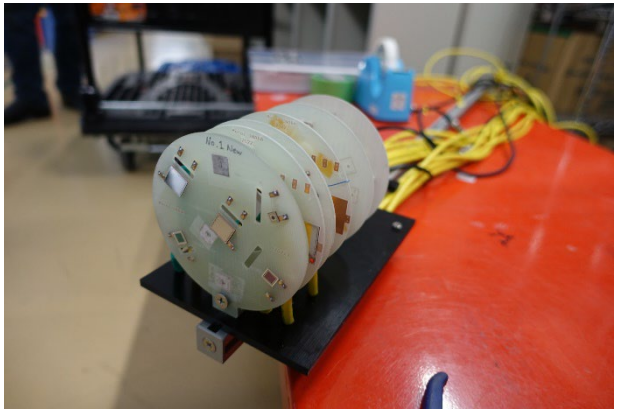
- RHICf-I data analysis will continue
  - Combined analysis with STAR detectors
    - Event type categorization
    - Diffraction + resonance tagging with STAR + RHICf
  - Joint meeting to be held in the near future

FoCal activities

- RANS irradiation test
- Temperature dependence test @ NWU
- CERN-PS test beam
- FoCal-E pad trigger and readout scheme

March 3 (Thu) - 4 (Fri)

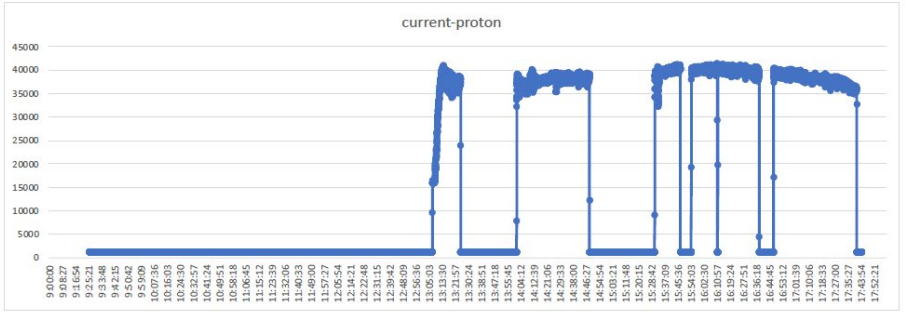
- RANS 7MeV proton beam up to 40 μA
  - Neutron irradiation from Be target

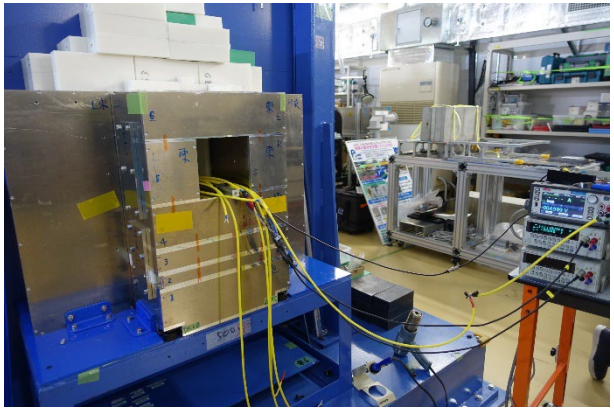


Proton beam current By S. Shimizu

3/Mar

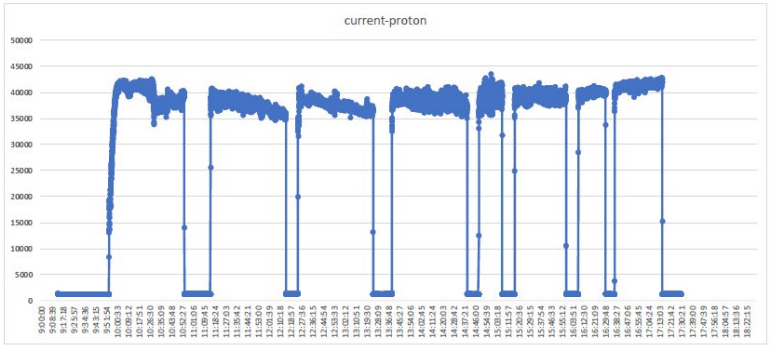
Mar. 3
2.98 hours
in total





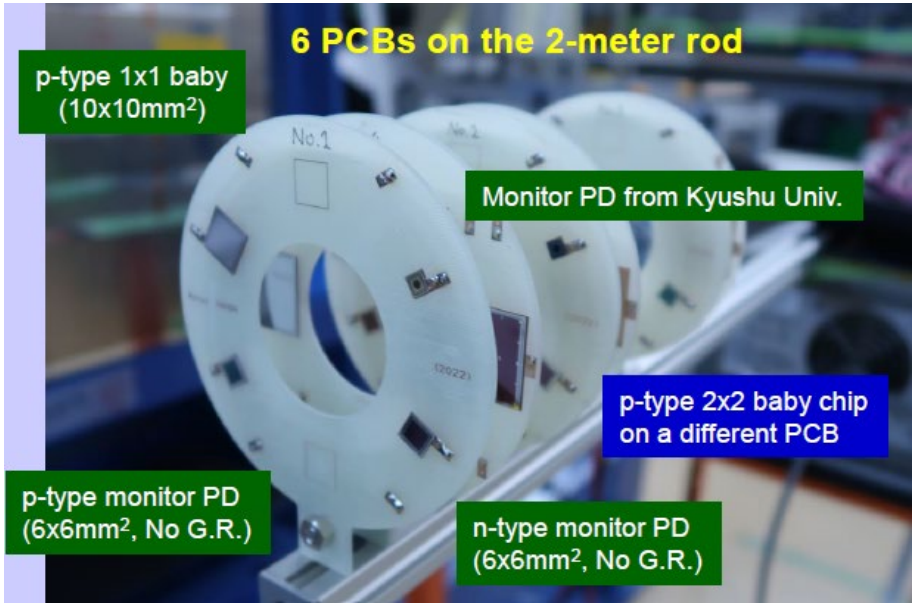
4/Mar

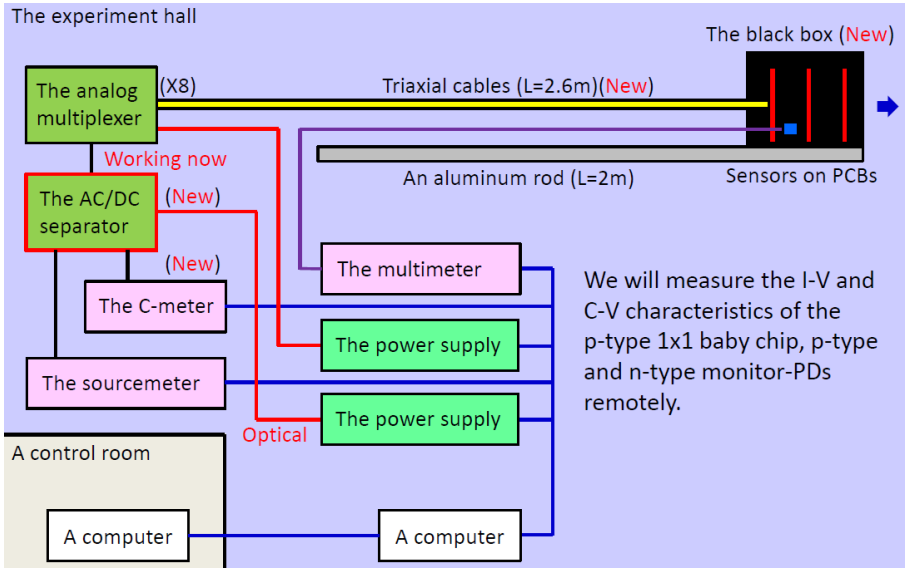
Mar. 4
5.99 hours
in total



March 3 (Thu) - 4 (Fri)

- Tested
  - FoCal-E pad
    - p-type 1x1 baby chip
    - p-type monitor PD
    - n-type monitor PD
    - P-type 2x2 baby chip
  - APD
    - by Yamazaki & Shimizu
  - sPHENIX-INTT cable
    - by Nakagawa
- Monitored by
  - Monitor PD
    - from Kyushu Univ.
  - Indium foil
  - Thermistor

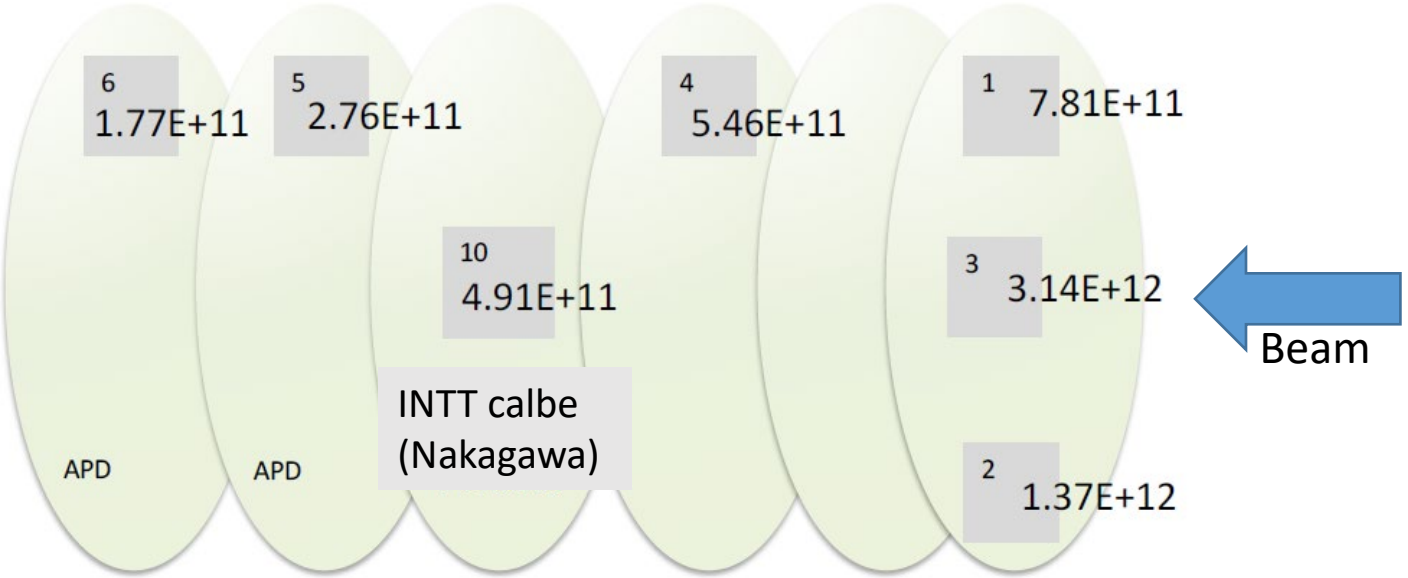




By M. Inaba

Neutron fluence analysis

- Estimation with Indium foil
  - by Shimizu-san
  - In Run1, 1092 s, 32.85μA average
  - 336 keV γ-ray measured by Ge detector



Status

- Residual radiation levels are still too high to take all out of the area.
- We have disassembled the setups and identify items with high radiation levels.
  - 4/8: board #4 60 cpm → took outside
    - Sent to NWU for the I-V measurement
  - 4/13: board #2 & #3, rod+box 80cpm → took outside
  - 4/28: board #5 & #6 70cpm → took outside
  - INTT micro-coax cable, APD, board #1 still in the area
    - To be checked again in this week
- Inaba-san is working on the analysis of the online measurement data and continuing I-V and C-V measurement

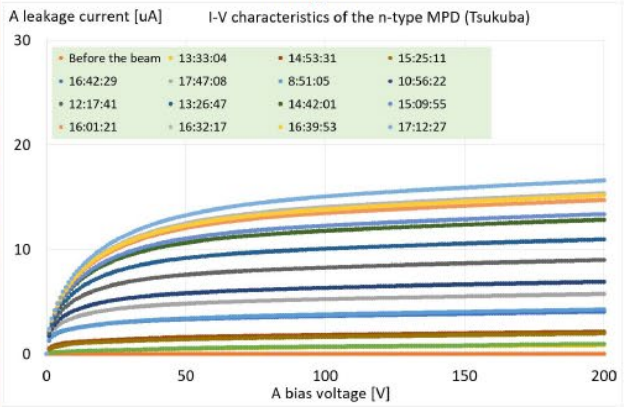
RANS irradiation test

March 3-4, 2022, RANS at RIKEN

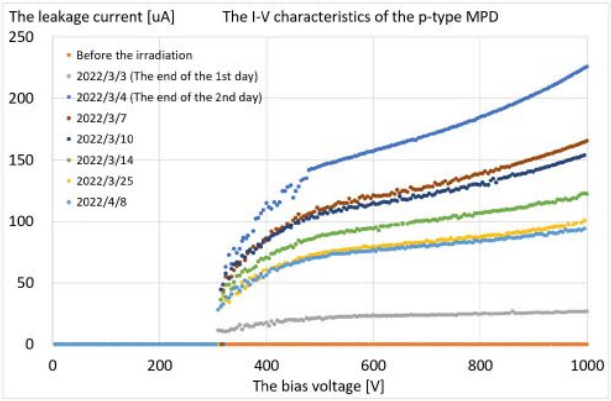
PCBs with sensors

- Monitor PD, baby chips were used
- irradiated ~10^{14} neutron /cm^2 in two days
- Future: IV, CV test, components irradiation test

n-type



p-type



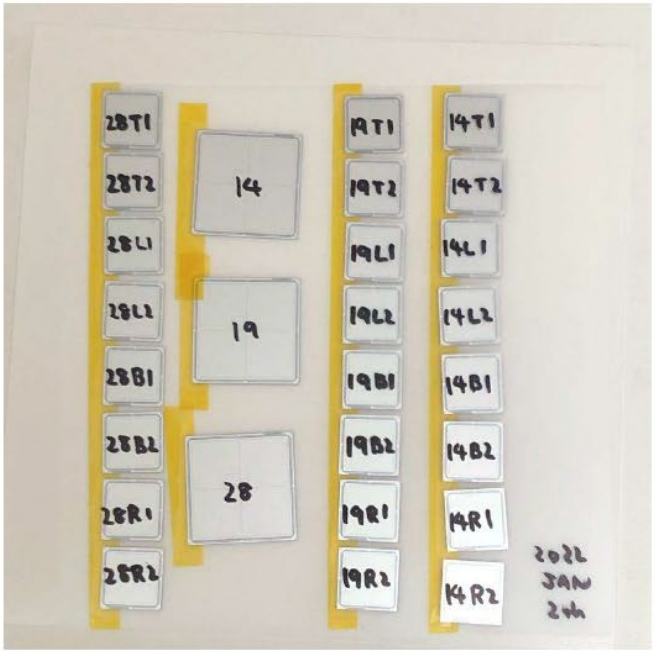
(M. Inaba)

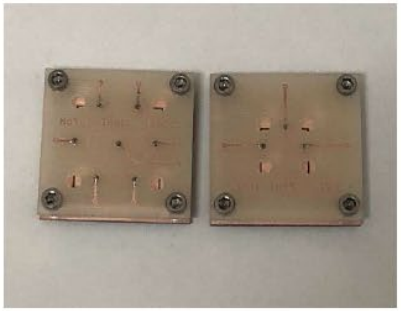
Slide by T. Chujo

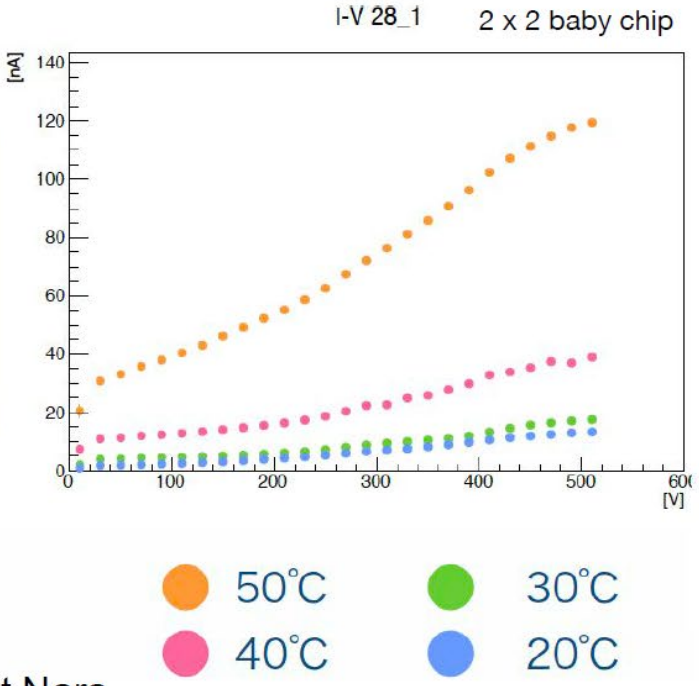
What we have learned

- Neutron fluence was 10 times higher than expected by some miscalculations. The distance dependence from the target was smaller than expected.
  - Good to be able to confirm by simulation calculation
- It would be good to create a system using MPD as an online monitor of irradiation doses.
  - It would be good to collaborate with RANS to develop such a system, which can be offered to other users.
- Since the indium foil irradiation measurement is performed under high radiation dose, it is necessary to devise a way to mount and dismount the foil in a short period of time.
  - The amount of irradiation (time) and the number of sheets at a time should be considered, taking into account the measurement time with the Ge detector.
- Online measurements provided very useful data. We hope to succeed next time with the measurements we were not able to make this time.

Temp. dep. of I/V for p-type sensor







- I/V curves for 2x2 and 1x1 babies have been measured at Nara Women's Univ. before the irradiation.
- Initial measurements after irradiation was done (April, 2022)

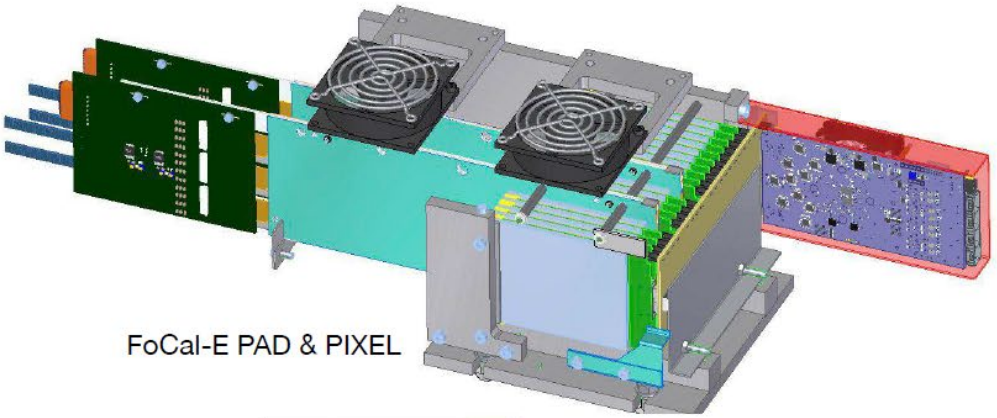
(M. Hata, T. Hachiya, M. Shimomura)

Slide by T. Chujo

FoCal PS/ SPS test beam in 2022

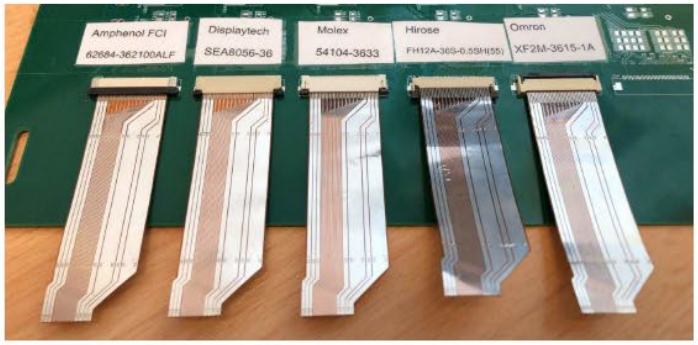
- **June @ PS (dedicated for PAD (HCal))**
- **September @ SPS (all subsystems**
- **November @ SPS (all subsystems)**

FoCal-E
- 18 single pad, and 2 pixel layers
- PAD: HGCROC for PAD w/ aggregator board and O^2 (FLP and CRU) system
- PIXEL: under repair of damaged half-layers. Another option is old prototype (mTower with 8 ALPIDEs)

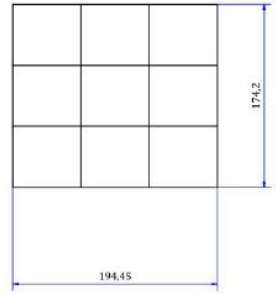


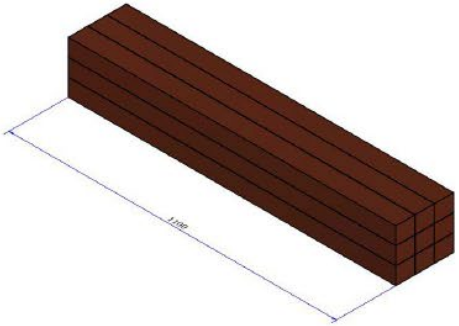
FoCal-E PAD & PIXEL

FoCal-H
- 9 modules, 3x3 construction underway
- Each module: 6.5 x 6.5 x 110 cm^3



PIXEL





FoCal-H

Slide by T. Chujo

FoCal-E pad trigger and readout scheme discussion

Possible trigger scheme (just an idea)

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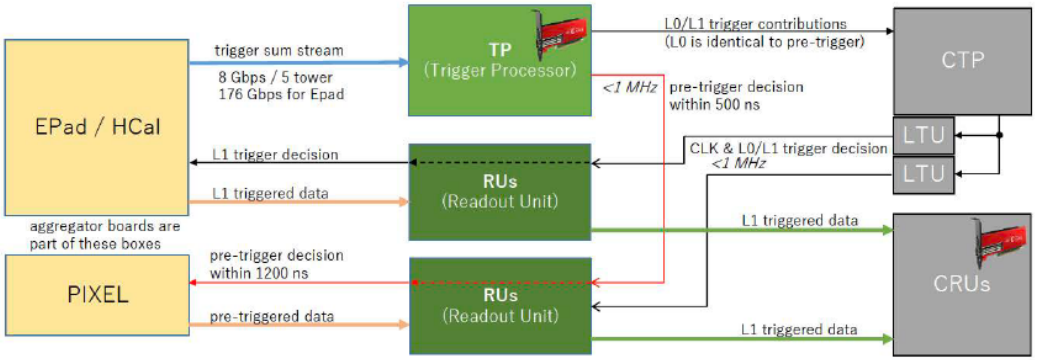
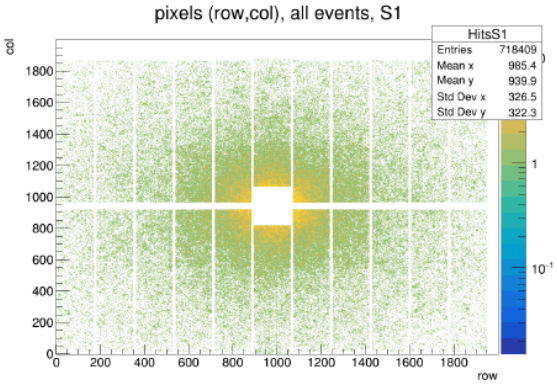
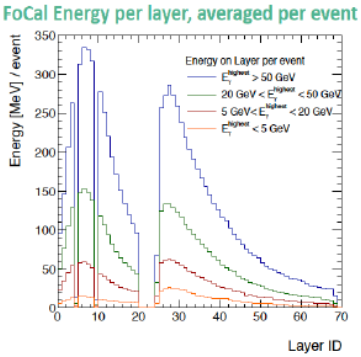


- **RUs** for EPad/HCal ··· forward L1 trigger decisions to detector, receive data, and forward it to CRUs
  - so simple thus it acts as just media converter
- **RUs** for PIXEL ··· forward pre-trigger to detector, buffer pre-triggered data, ship it to CRU if it is confirmed by L1 trigger of CTP
  - quite some complication similar to ITS (pre-trigger merging, tagging, etc)
- **RUs** functions and present aggregator functions can be merged (location is question)
- **TP** ··· large scale FPGA together with trigger stream aggregation custom hardware
  - collect 2x1.28 Gbps streams from each or selected HGCROCs)

(K. Oyama, R. Guernane, I. Arsene)





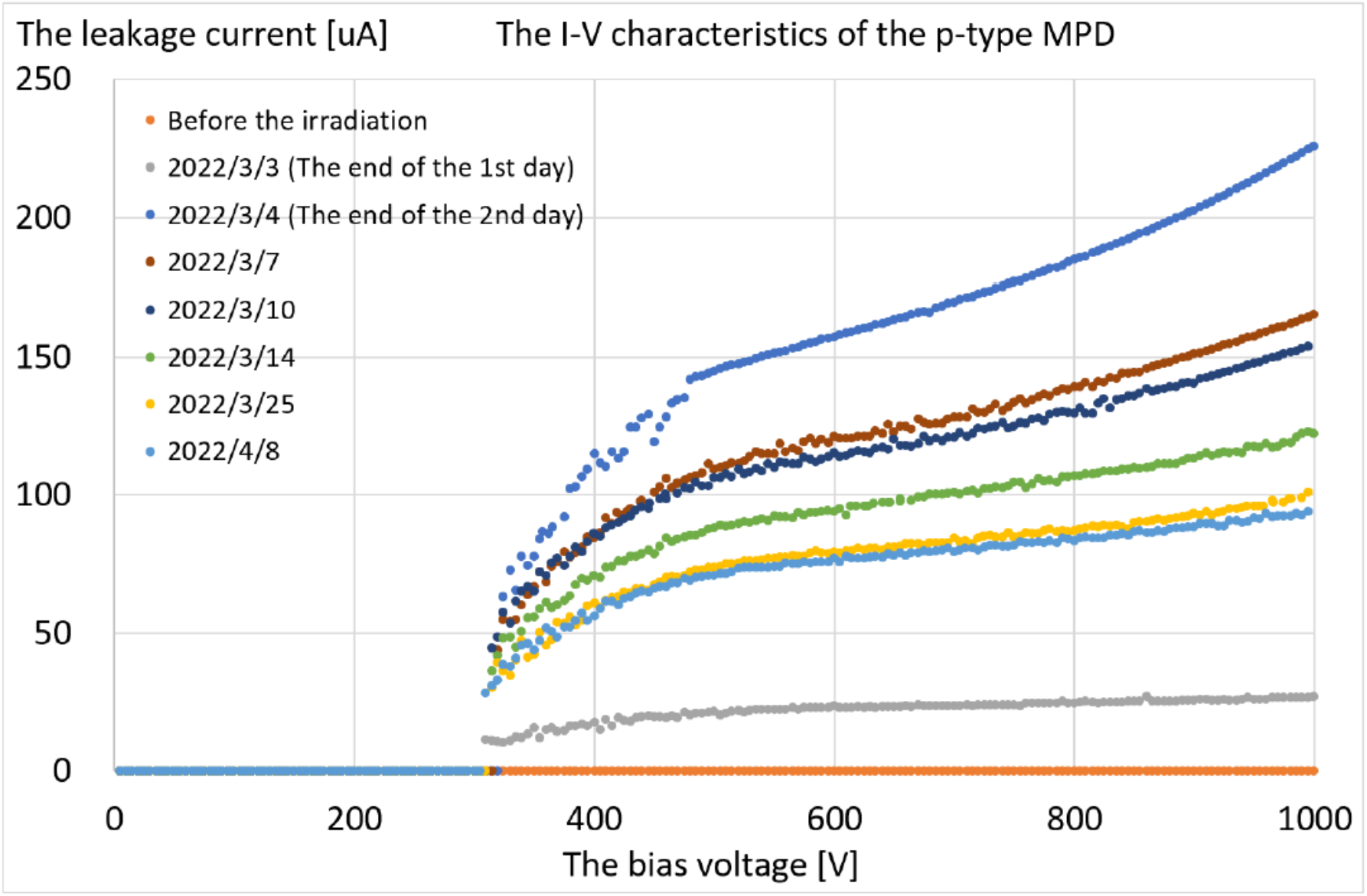
(S. Shimizu)

- Started Bi-weekly meeting on trigger using FoCal-E pad data.
- Skimming simulations for trigger simulation, and trigger studies are ongoing.

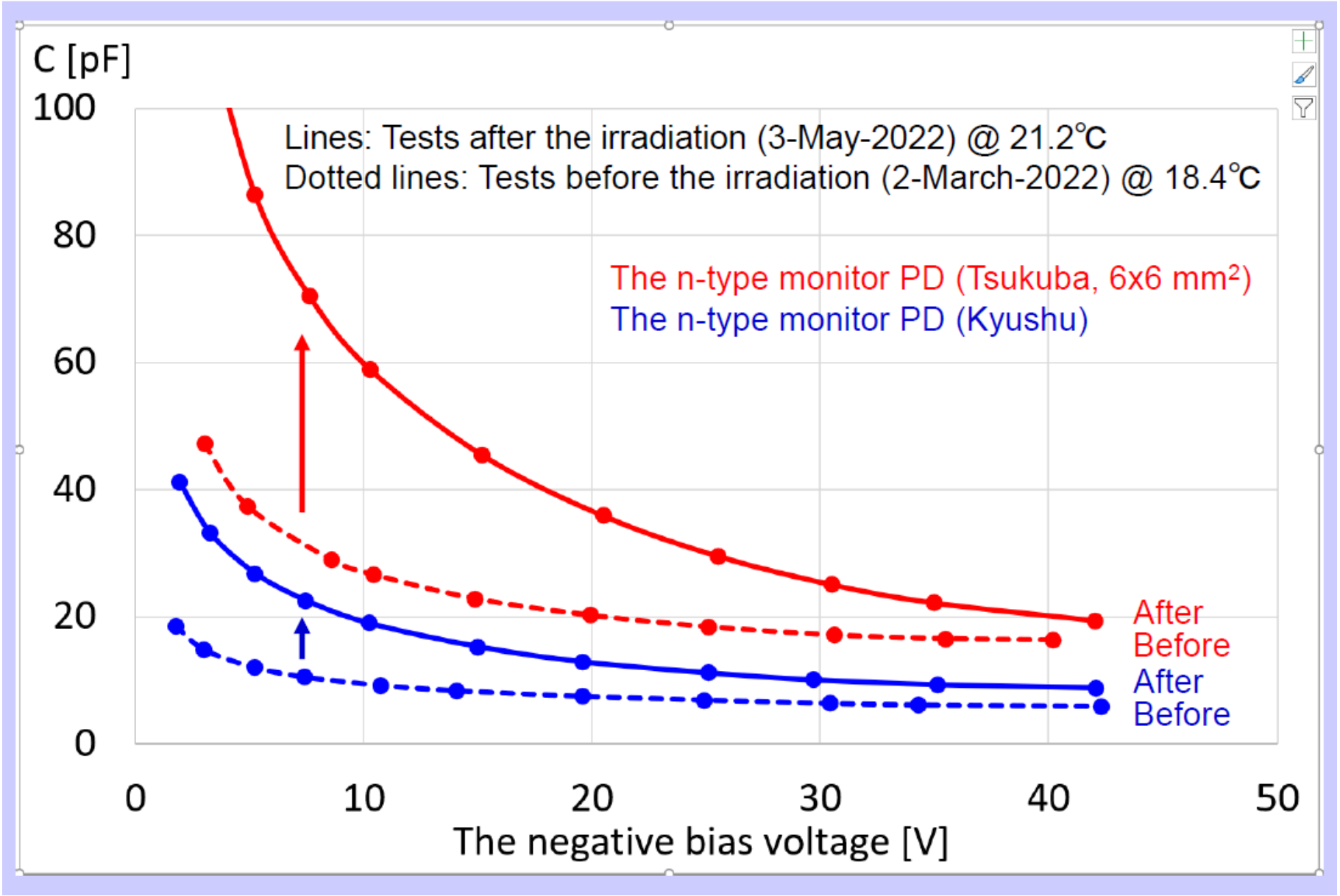
Slide by T. Chujo

Backup Slides

The p-type monitor PD (Tsukuba)



The C-V characteristics of n-type monitor PDs



Discussion

- 2022.4.8: Decision by the STAR management
  - They cannot accept the RHICf-II proposal.
  - The main reason is the lack or human resources.
- 2022.4.22: NPP meeting
  - Any way to change this situation?
  - To avoid losing the RHICf-II physics for understanding the forward hadron production mechanism
    - Diffractive process
    - Air-shower development & cosmic neutrino background

- RHICf-I data analysis will continue
  - Combined analysis with STAR detectors
    - Event type categorization
    - Diffraction + resonance tagging with STAR + RHICf

Status

- Residual radiation levels are still too high to take anything out of the area.
- We have been able to disassemble some of the setups and identify areas with high radiation levels.
  - Substrate
- Expect to be able to take out the ones that are low enough next week.
- Setups are being stored together in the area and online measurements are continuing.
- Inaba-san is working on the analysis of the online measurement data.

Collision system & Polarization	Science goals & objects	Measurement time, luminosity or number of events	Trigger rate / DAQ requirement
p+p Radial polarization	High-p_T π^0, K^0_S, Λ SSA	1 pb^{-1}, a few hours with 200 Hz rare trigger	200 Hz rare trigger for high-p_T π^0, K^0_S, Λ with no-prescale & high efficiency
p+p Vertical polarization	K^0_S, Λ Spectrum	10^8 events, about a week with 200 Hz shower trigger (with prescale)	200 Hz shower trigger (with prescale)
p+A Radial polarization	High-p_T π^0 SSA nuclear dependence	Similar to p+p Radial polarization	200 Hz rare trigger for high-p_T π^0 with no-prescale
p+A Vertical polarization	Photon, π^0, neutron Spectrum	< 10^8 events, < 1 week with 200 Hz shower trigger (with prescale)	200 Hz shower trigger (with prescale)

ZDC performance issue

- Luminosity measurement
  - No effect found in 2017 Vernier scan data
    - Can we understand this?
  - Calibration by Vernier scans if necessary
- Polarization measurement
  - Especially, problematic blue-beam snake failure requires a stable measurement
  - How stable we can monitor & evaluate polarization of the blue beam?
    - With shifted threshold energy of ZDC by our detector
  - We're studying the effect of additional material in front of the ZDC, or W+ZDC by simulation.
  - We'll consider to study it with existing data in 2022.

Peoplepower issue

- BNL's peoplepower necessary for installation and safety
  - We will do everything we can to support this.
- Hardware design and fabrication to be done by the RHICf-II collaboration
  - Remote manipulator in front of the ZDC
  - Other materials and supplies
- Participation in the STAR shift from 2023

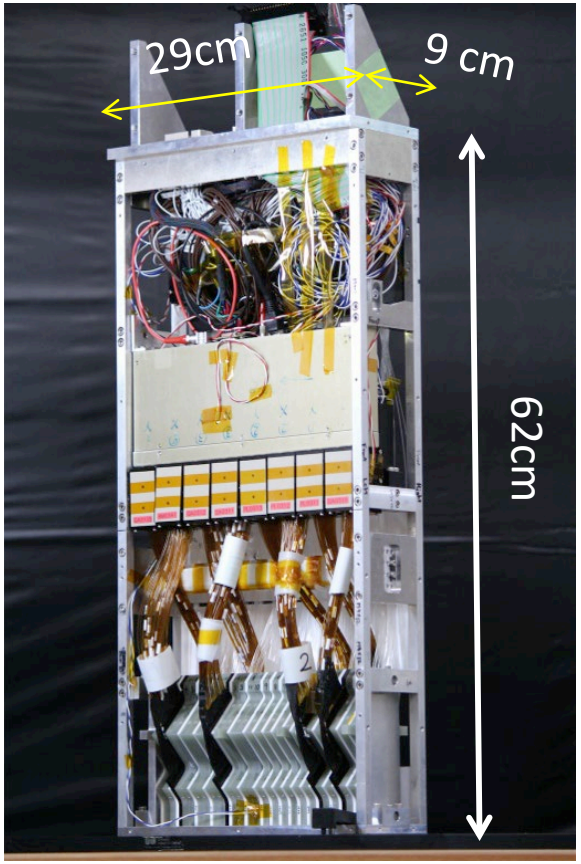
- New collaborators in the US
  - Stony Brook Univ, Kansas Univ
- Other new collaborators
  - Sejong Univ

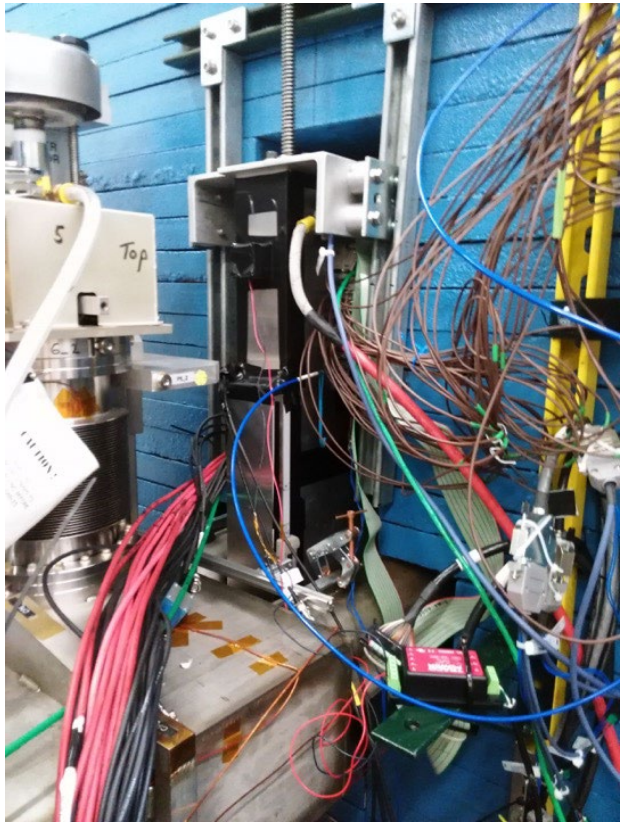
DAQ requirement

- STAR data recording with 200 Hz RHICf trigger
  - 10% TPC data recording if possible
  - Remaining 90% without TPC but all other STAR data recording for combined analysis of RHICf + STAR
- Standalone RHICf-II DAQ with independent data stream
  - Event correspondence between STAR DAQ & RHICf-II DAQ with event number sharing
  - Established in 2017 run

Available space

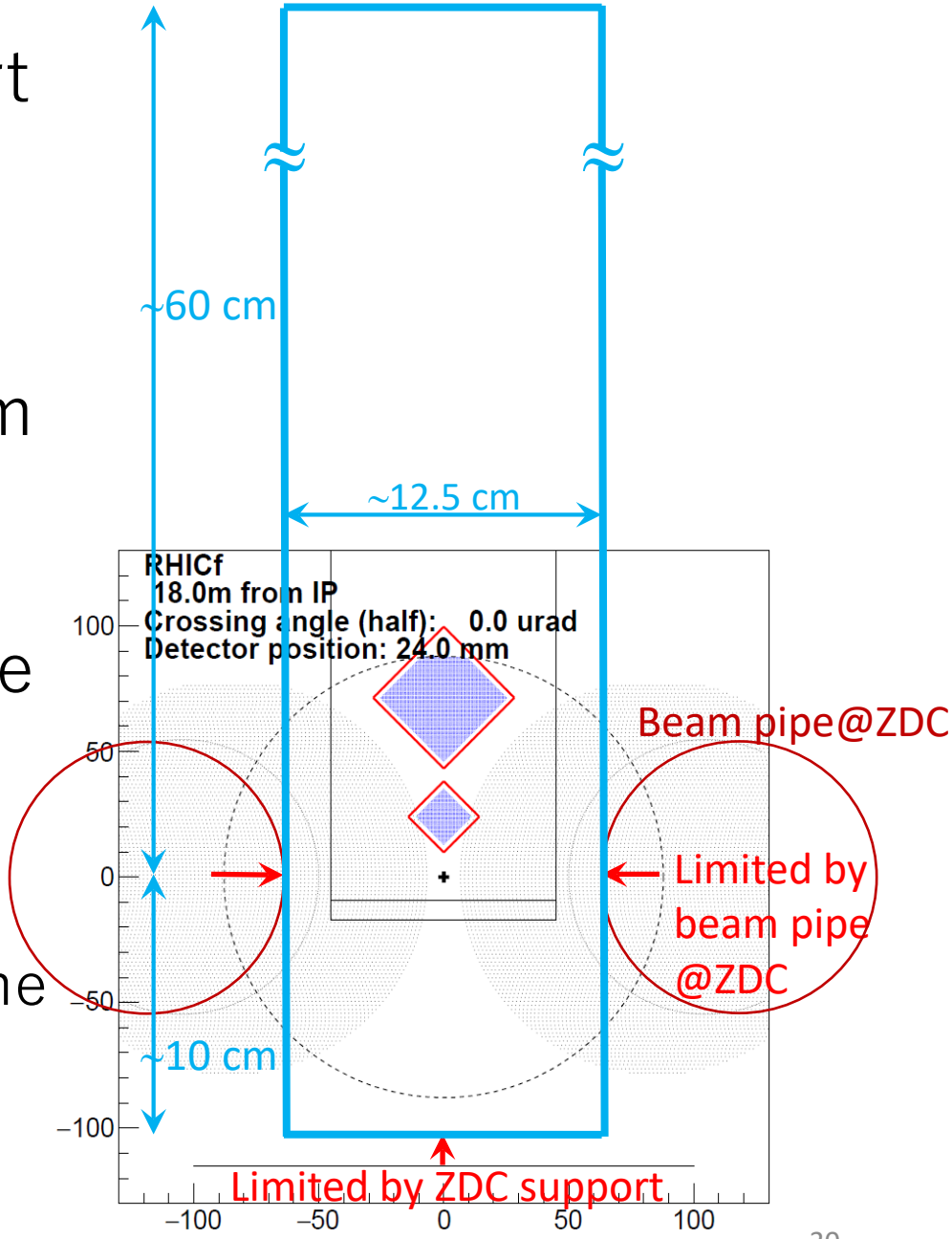
- We installed RHICf calorimeter (LHCf Arm-1 calorimeter) in 2017.
  - W:9cm x H:62cm x D: 29cm
    - by removing the top structure as shown in the right picture

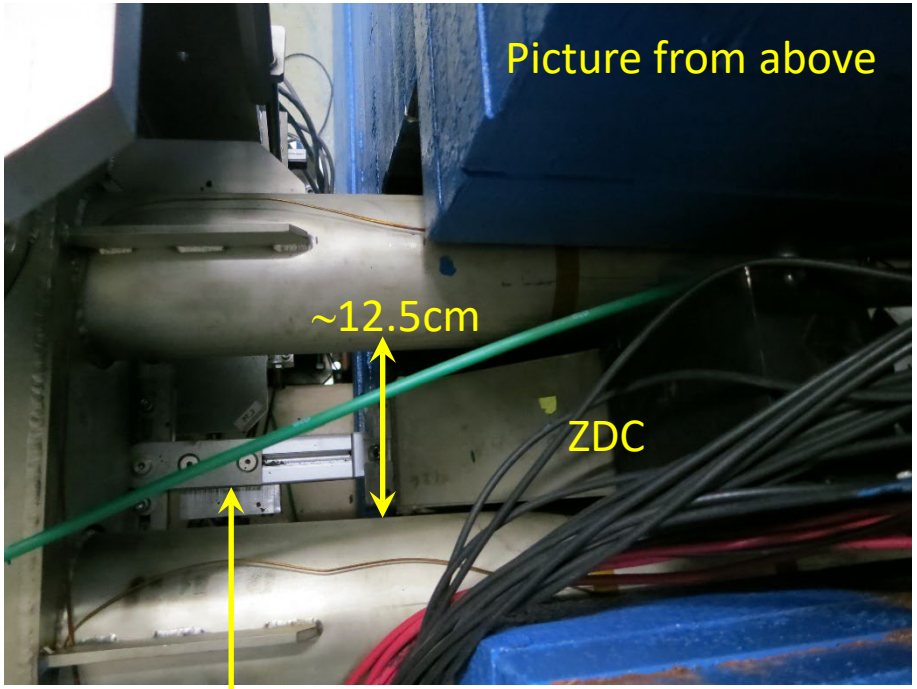


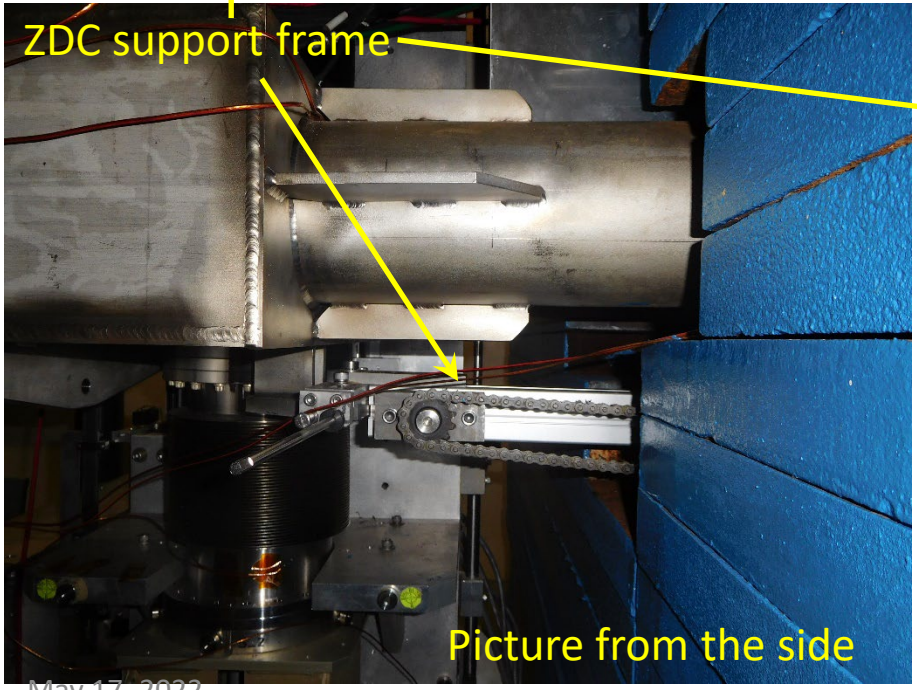


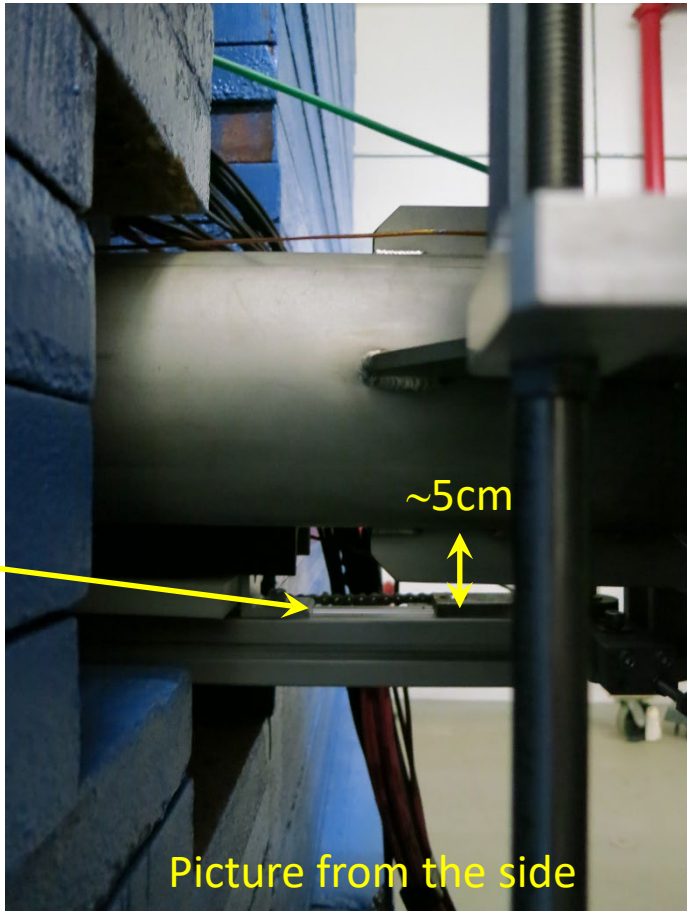
Available space

- There is a ZDC support frame under the detector.
- Due to this limitation, there is only about 5cm space below the beam pipe.
- The space between the beam pipes is about 12.5cm in front of the ZDC.
  - (9.5 cm at the exit of the vacuum section)




Picture from above
~12.5cm
ZDC

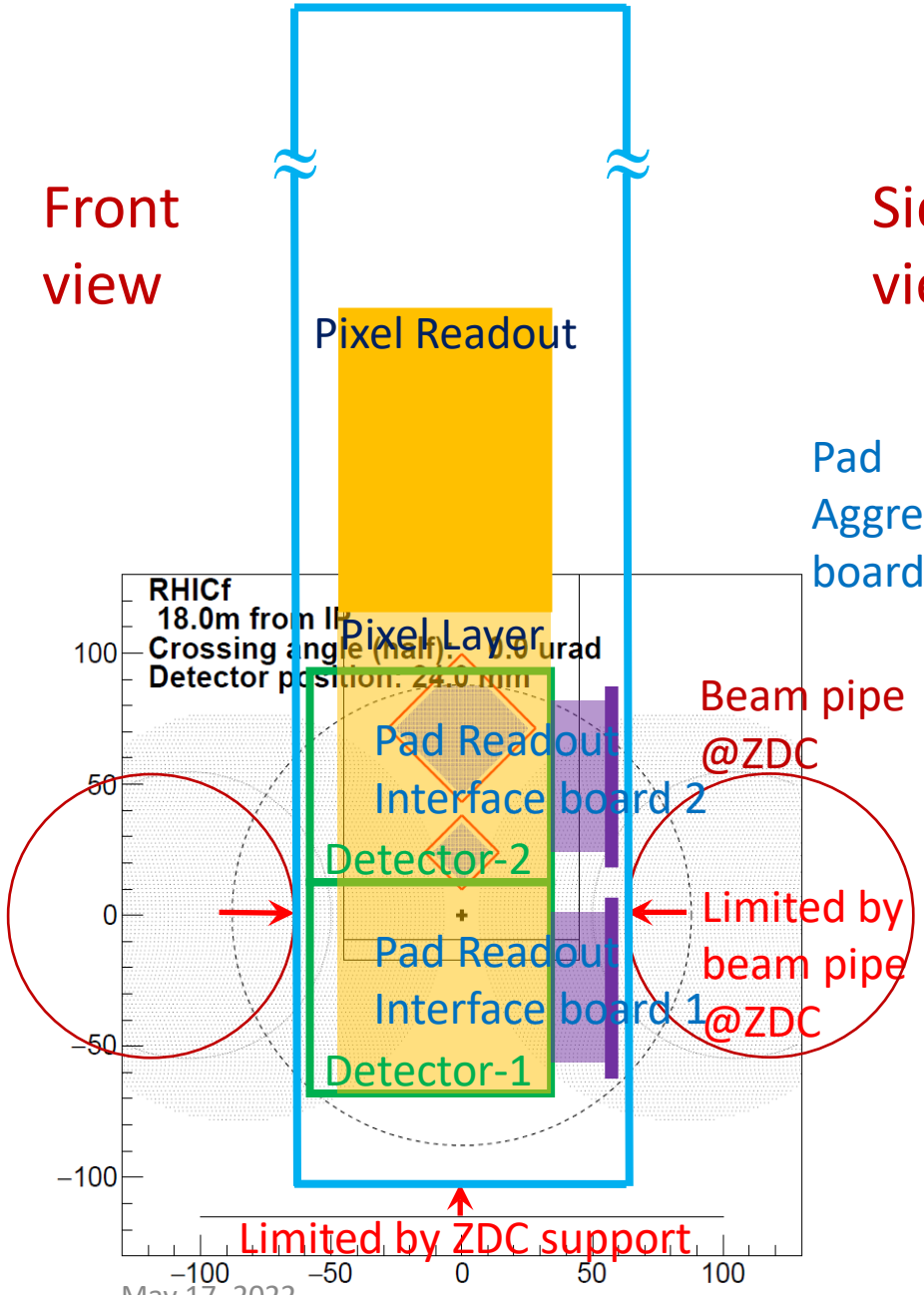

ZDC support frame
Picture from the side

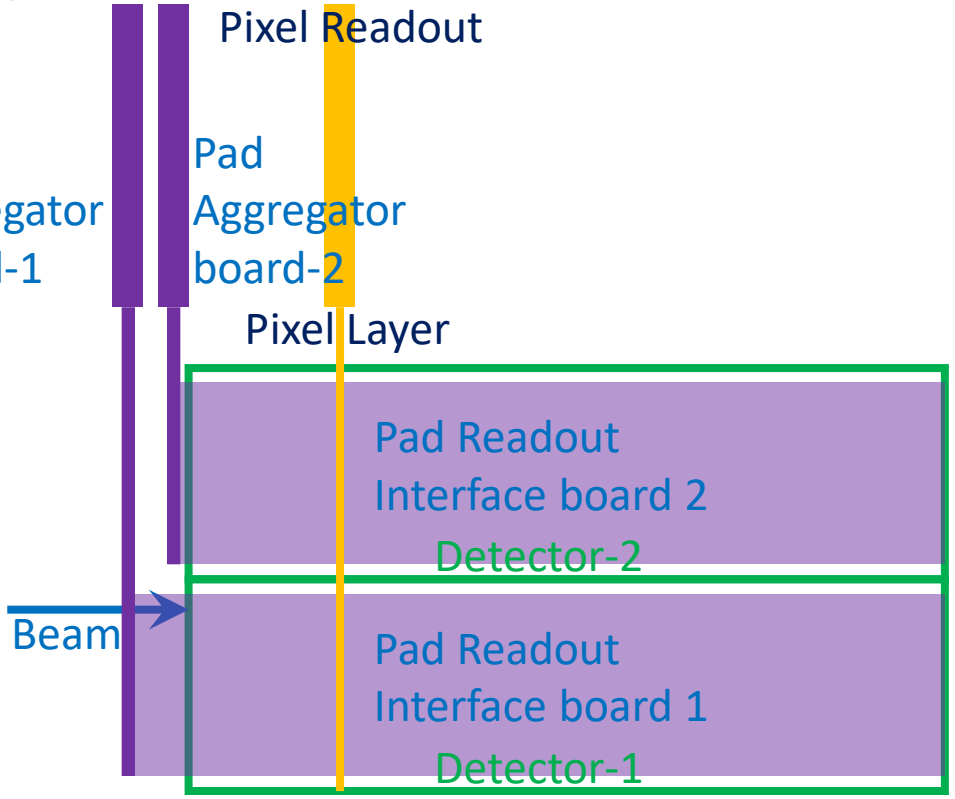

~5cm
Picture from the side

Configuration 1

Front view

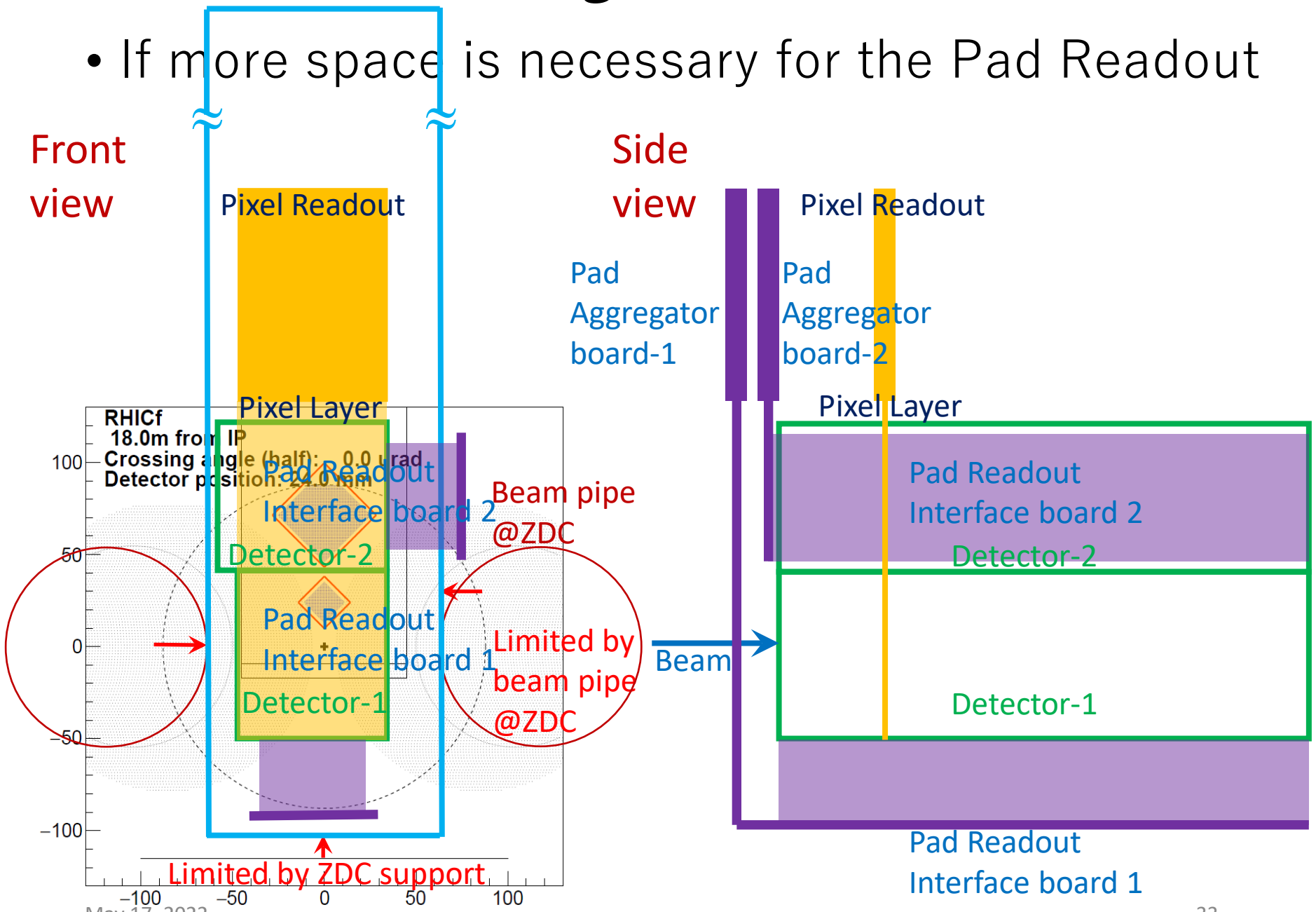
Side view





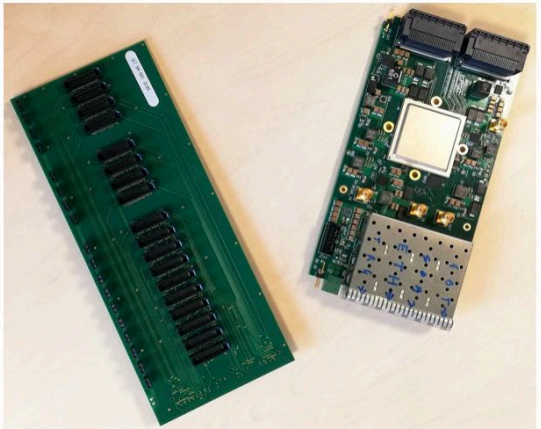
Configuration 2

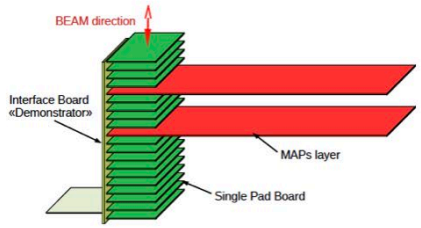
- If more space is necessary for the Pad Readout



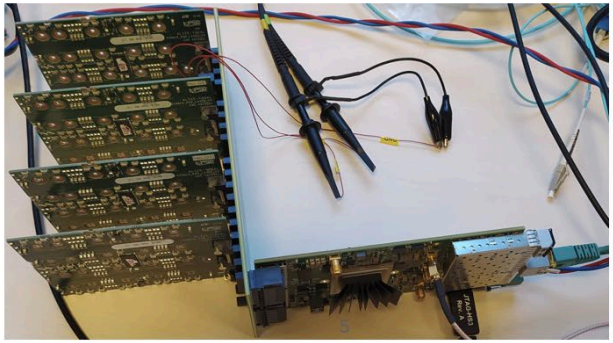
Aggregator and interface boards for 2022

- For SPS test beam in 2022, PCB v2, aggregator and interface board have been produced and largely programmed
- Logic tests are ongoing
- Built-up of cosmic test bench in progress
  - Grenoble group is preparing the firmware and online monitoring software



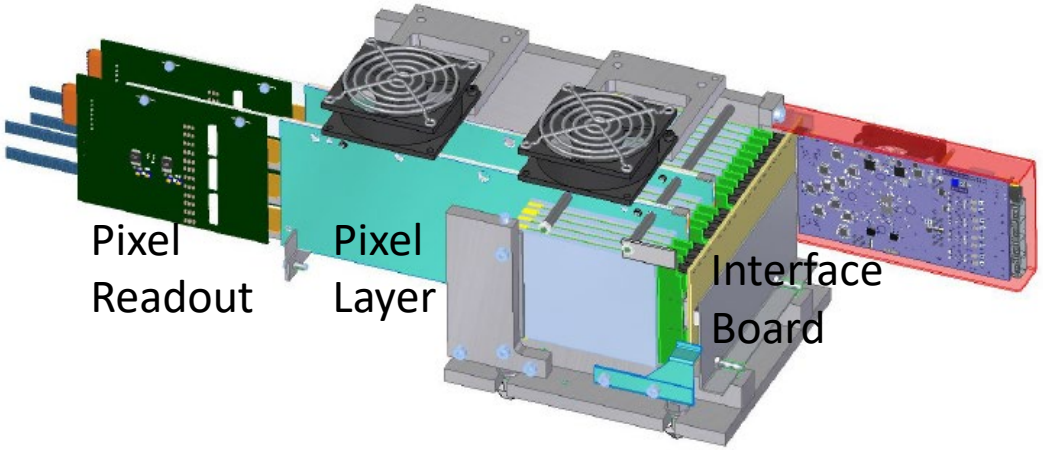


(Olivier Bourrion, Damien Tourres, Fatah Rarbi, Rachid Guernane and Grenoble LPSC CAD team)



(Grenoble)

2022 SPS test beam setup

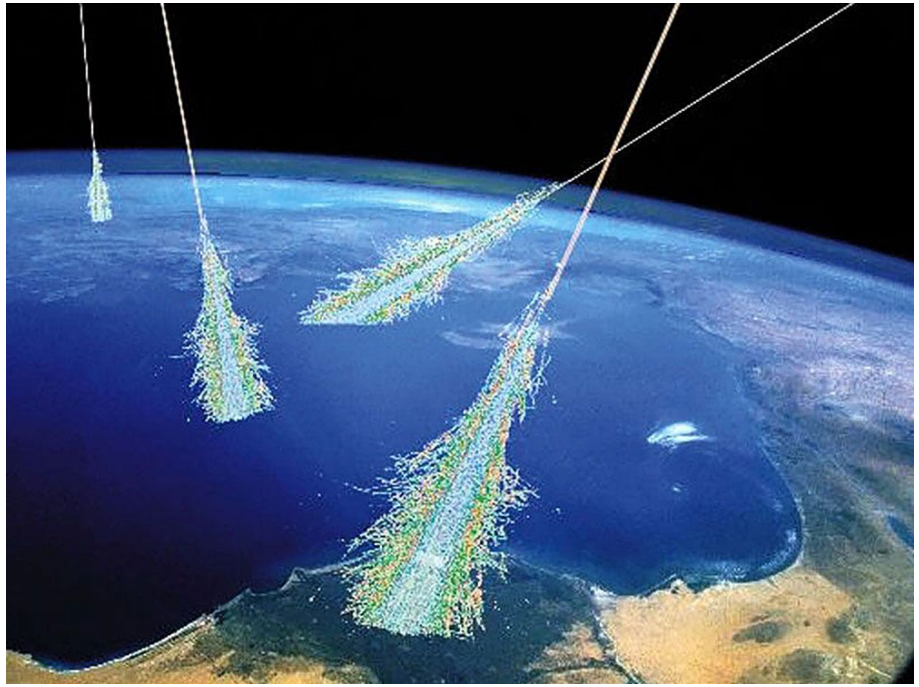


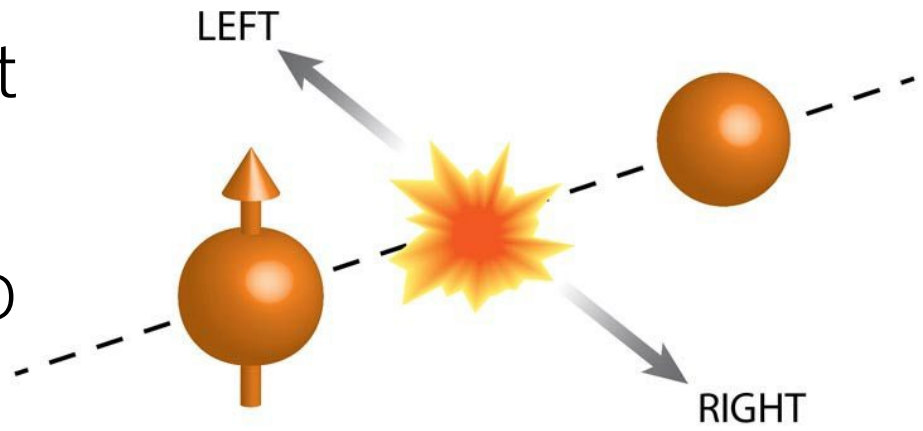
List of tasks

- Simulation tasks
  - ZDC + W simulation for luminosity measurement and polarimetry performance with shifted threshold energy of ZDC
  - $\Lambda \rightarrow n + 2\gamma$ background simulation for reconstruction and resolution
  - Detector configuration and trigger scheme
  - Minho Kim is working on the simulation studies
- Blue beam snake failure
  - 2022 data analysis
  - Hope someone can participate in 2022 data analysis
- Timeline for the RHICf-II calorimeter construction
  - ALICE-FoCal-E prototype beam test at CERN-SPS in 2022 (September & November)
  - ALICE-FoCal-E prototype will be used as the first module of the RHICf-II calorimeter and commissioned at RHIC in 2023
  - The second module will be constructed in 2022-2023

Physics at RHICf & RHICf-II

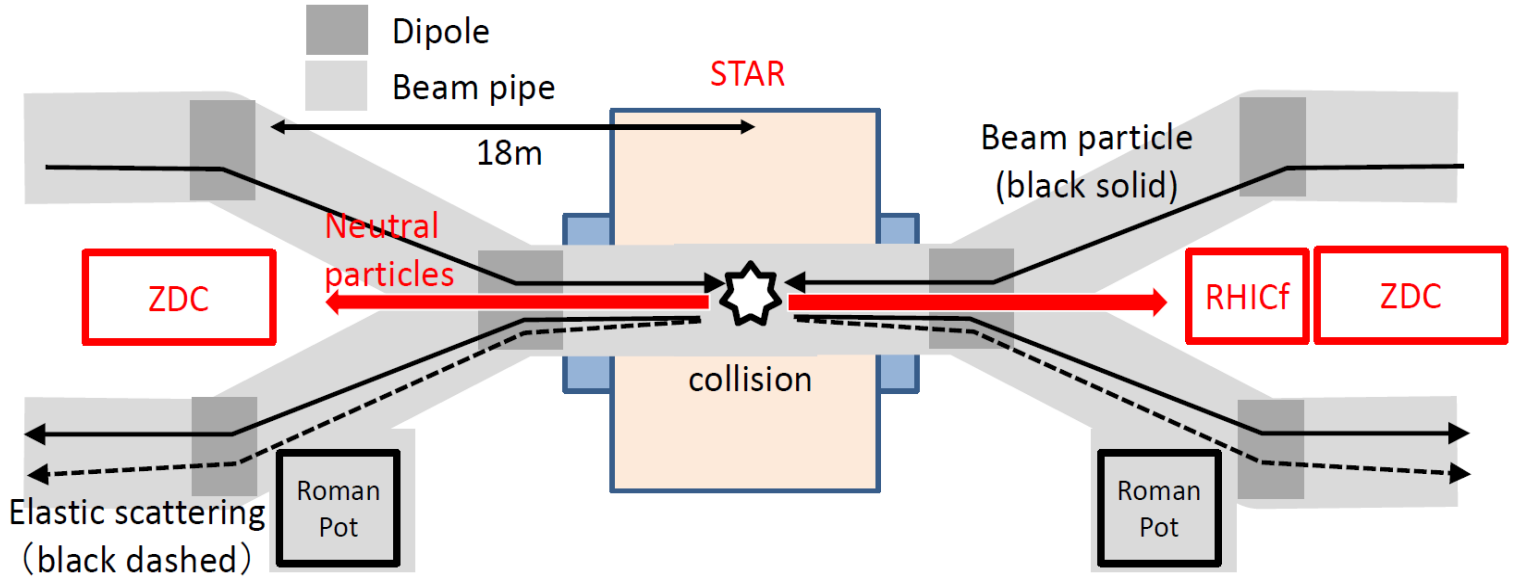
- Measurements of neutral particle production at zero degree with RHIC polarized proton collisions
- Cosmic-ray study
  - Cross section measurement to understand ultra-high energy cosmic rays
- Asymmetry measurement
  - To understand the hadronic collision mechanism based on QCD



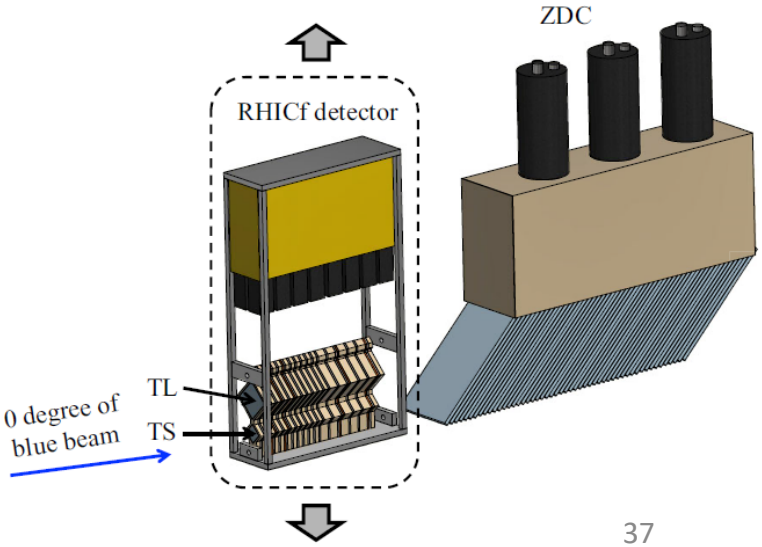


RHICf at STAR in 2017

- EM calorimeter (RHICf detector) installed in front of the Zero-Degree Calorimeter (ZDC) of the STAR experiment

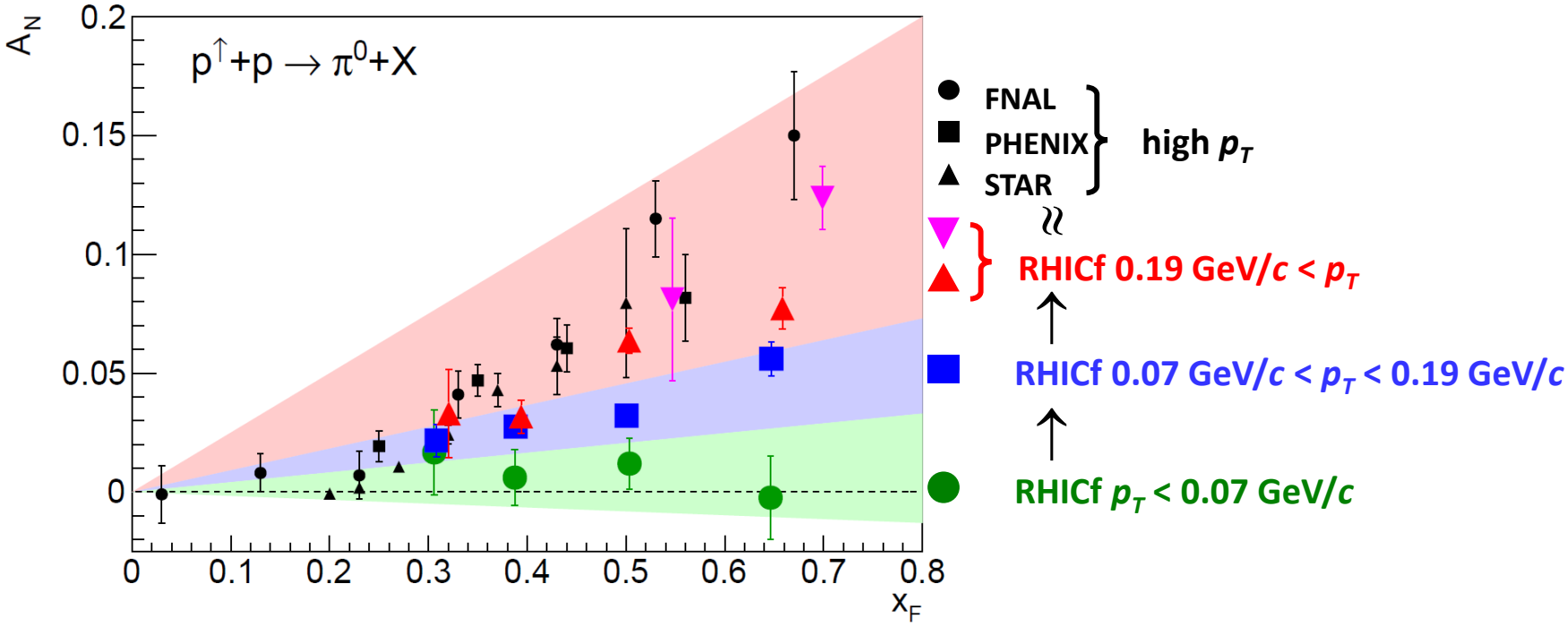


- Two position-sensitive sampling calorimeters
  - TS (small tower): 20mm x 20mm
  - TL (large tower): 40mm x 40mm
  - Tungsten absorber (44 X_0, 1.6 λ_{int})
  - 16 GSO sampling layers
  - 4 XY pairs of GSO-bar position layers



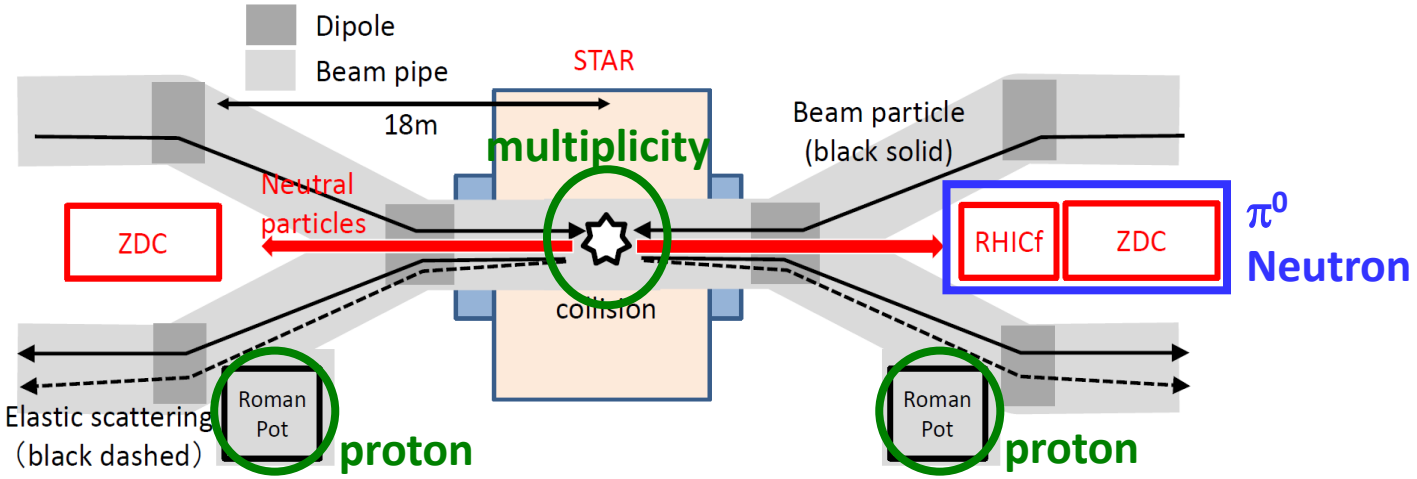
RHICf at STAR in 2017

- π^0 asymmetry
  - Phys. Rev. Lett. 124, 252501 (2020)
  - Comparison with high $p_T > 0.5$ GeV/c data of the past experiments
  - Nearly the same large asymmetry is reached at low $p_T < 0.2$ GeV/c
  - Contribution of other mechanisms, diffraction and resonance, may provide a hint to the mystery



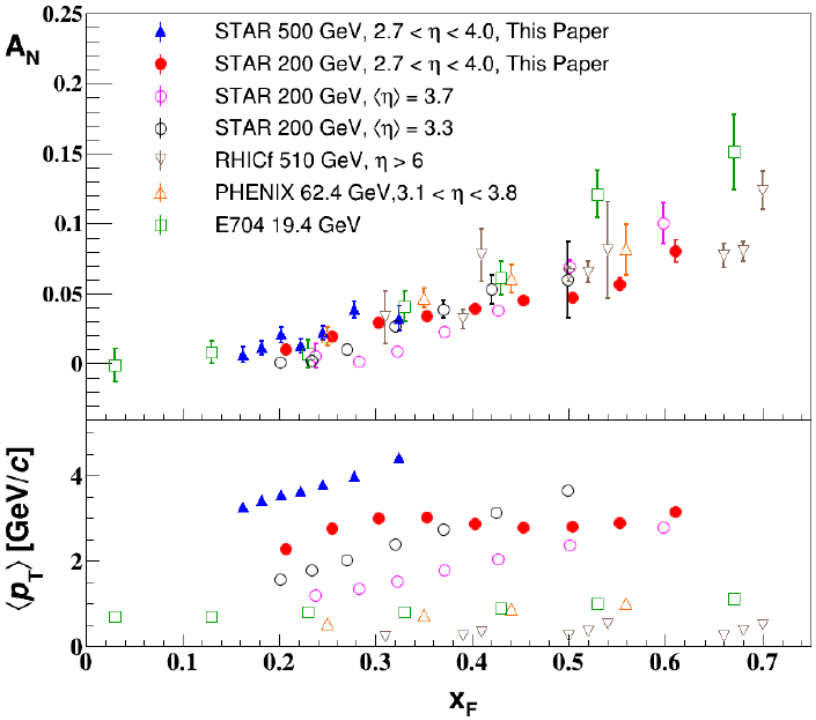
RHICf at STAR in 2017

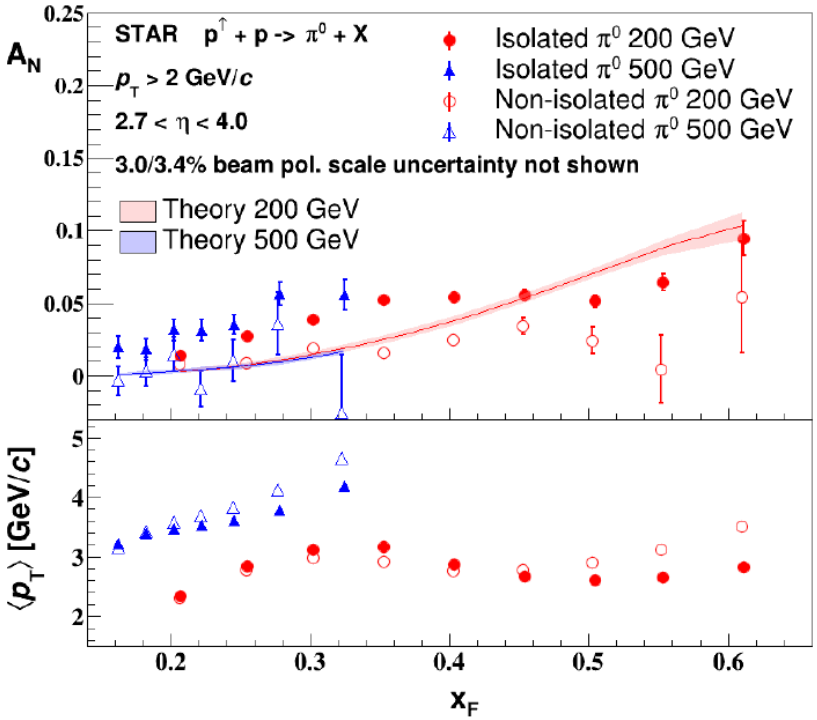
- Other analyses ongoing
  - π^0 & neutron cross section analysis
  - Neutron asymmetry (RHICf + ZDC)
  - Combined analysis with STAR detectors
    - Event type categorization
    - Diffraction + resonance tagging with STAR + RHICf combined data analysis
    - Event type, multiplicity (FMS) dependence of cross section & asymmetry to be obtained



New STAR results

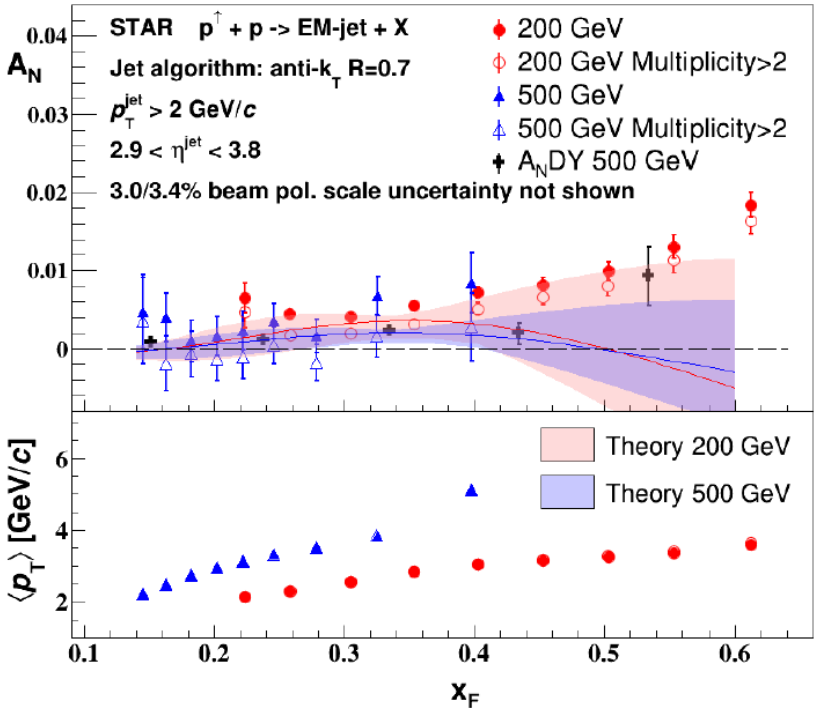
- Phys.Rev.D 103 (2021) 092009
  - $\sqrt{s}$ = 200 GeV & 500 GeV
  - Forward π^0, $2.7 < \eta < 4.0$
  - Asymmetries for the isolated π^0 are larger than these for the non-isolated π^0
  - Possible explanation is that a significant part of the isolated π^0 are from diffractive processes

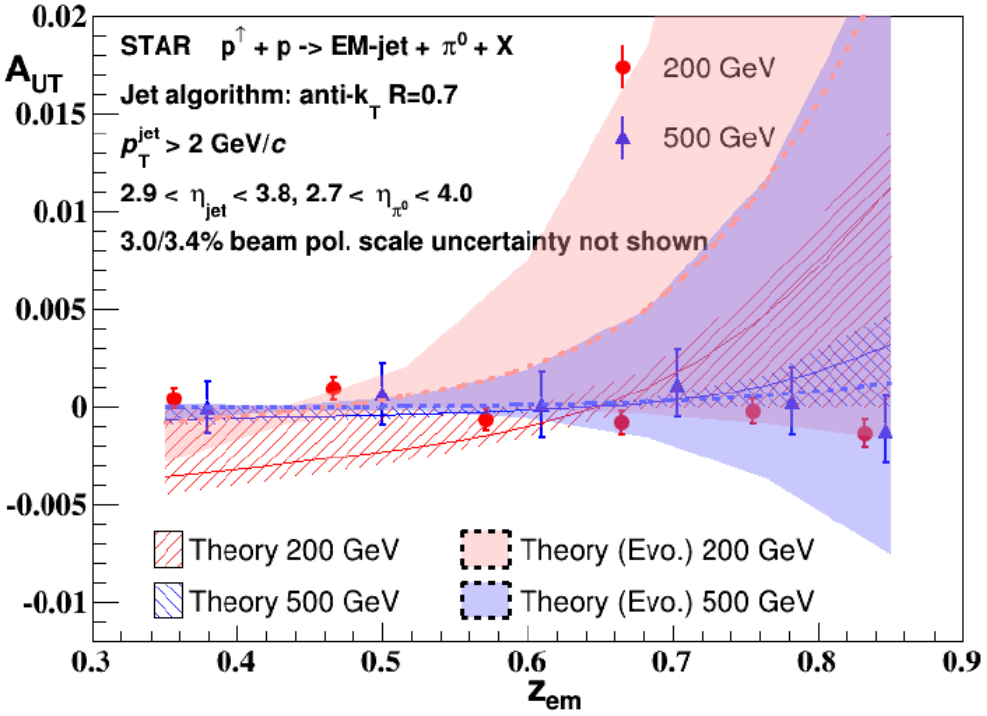




New STAR results

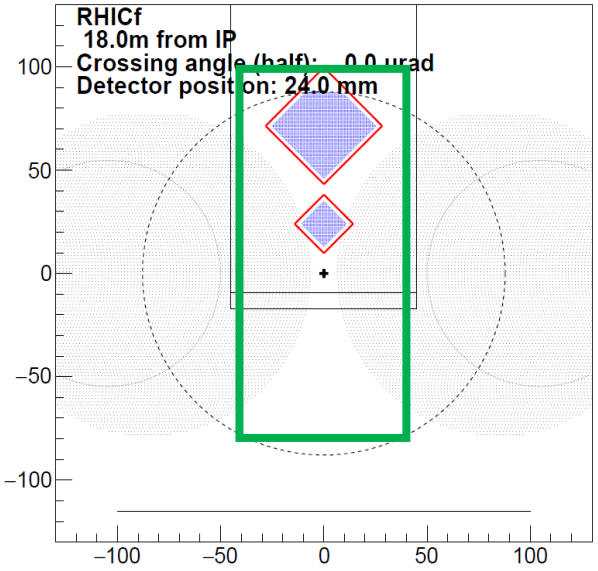
- Phys.Rev.D 103 (2021) 092009
  - Small EM-jet asymmetry, consistent with AnDY result
  - $z_{em} = E_{\pi 0} / E_{jet}$
  - Hadron in jet Collins asymmetries small
    - Cancellation of the Collins effect of the u/d quark?





RHICf-II proposal

- We have proposed a second run for RHICf in 2024 (RHICf-II)
- RHICf-II LoI was discussed by the PAC in 2020.9
  - Parasitic beam-time
- We're collaborating with ALICE-FoCal group to use the FoCal-E technology
  - 8cm x 18cm detector
  - Kakenhi-Kiban-A (2021-2024) + RIKEN budget
  - The detector have enough radiation hardness to work for a small β^* and normal luminosity



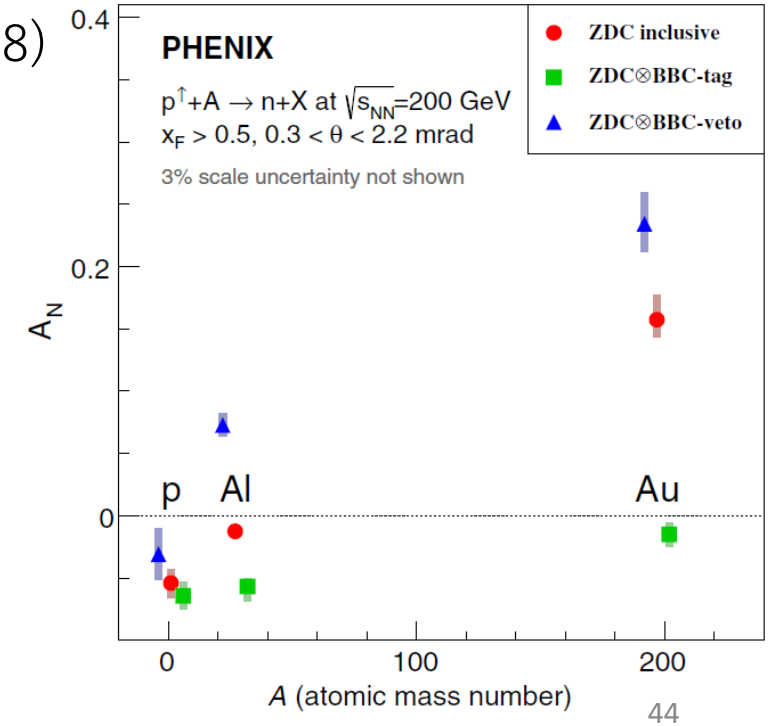
RHICf-II Collaboration

- Y. Goto, I. Nakagawa, R. Seidl (RIKEN)
- B. Hong, M.H. Kim (Korea Univ.)
- K. Tanida (JAEA)
- T. Chujo (Tsukuba Univ.) ← New
- Y. Itow, H. Menjo (Nagoya Univ.)
- T. Sako (ICRR, Univ. of Tokyo)
- K. Kasahara (Shibaura Tech.)
- O. Adriani, L. Bonechi, R. D'Alessandro (INFN Firenze)
- A. Tricomi (INFN Catania)

- New collaborators expected or under discussion from:
  - Sejong Univ.
  - Univ. of Kansas
  - Nara Women's Univ. and EIC Japan group
- Cooperation from FoCal collaboration
  - ORNL

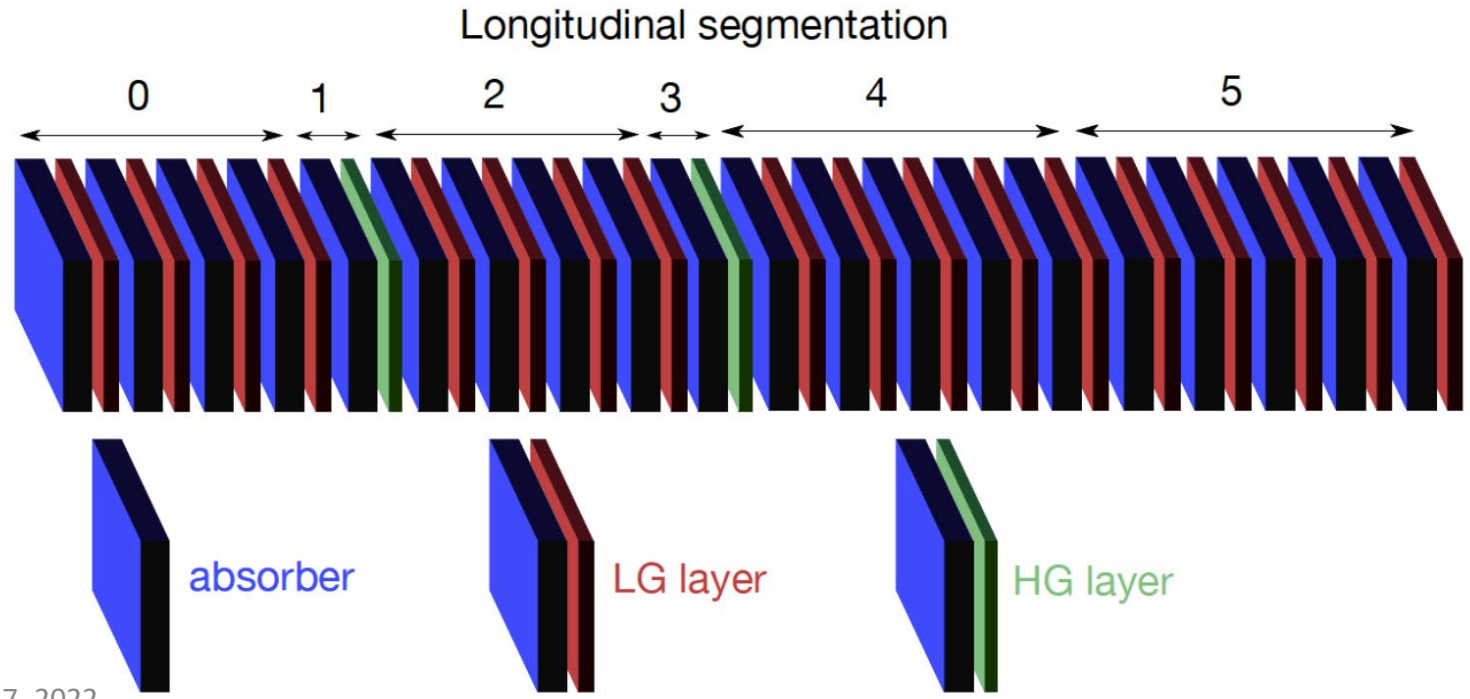
New topics at RHICf-II

- K^0_S and Λ measurement
  - Spectrum and cross section
  - Asymmetry
- A-dependence of the π^0 asymmetry
  - Correlation between asymmetries of forward neutron and π^0
  - Strong A-dependence of the neutron asymmetry measured at PHENIX in Run 15
    - Phys. Rev. Lett. 120, 022001 (2018)
    - UPC vs hadronic component



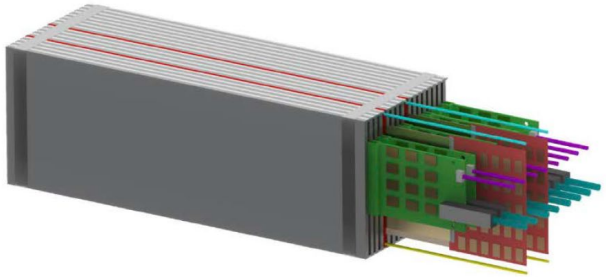
ALICE FoCal-E

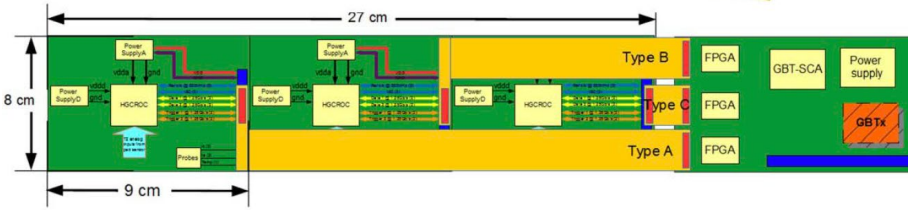
- Led by Tsukuba Univ. group
- Tungsten absorber
- Low granularity (LG) silicon pad for energy measurement
  - σ_E / E = 25% / √E (GeV) ⊕ 2% for photon energy resolution (simulation)
- High granularity (HG) silicon pixel (CMOS-MAPS) for accurate position measurement



ALICE FoCal-E for RHICf-II

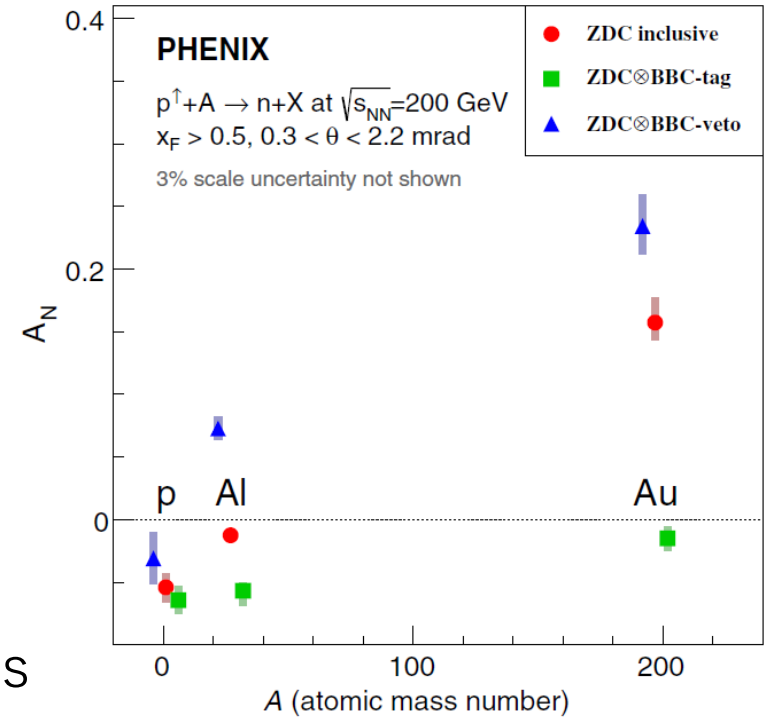
- Space restriction at RHICf
- Pad layer
  - Lead by Tsukuba Univ. group
  - Readout electronics based on HGCROC ASIC (CMS) working with Grenoble group leading the development
- Pixel layer
  - Lead by European group
- Trigger
  - Rare trigger for asymmetry measurement
  - Shower trigger for cross section measurement
- DAQ
  - Standalone ALICE DAQ
  - Event correspondence with STAR DAQ





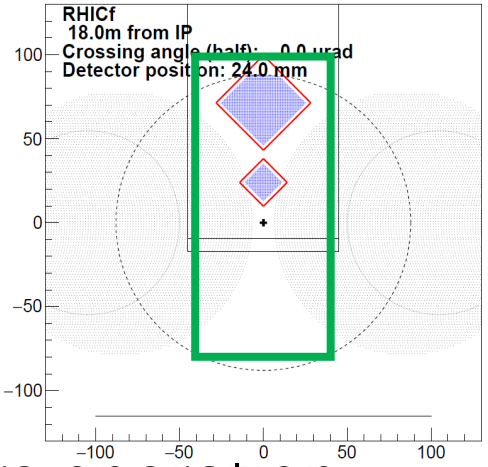
New topics at RHICf-II

- p + A collisions
  - Measurement of nuclear effect (p+A / p+p)
- Strong A-dependence of the neutron asymmetry
  - Measured at PHENIX in Run 15
  - Phys. Rev. Lett. 120, 022001 (2018)
  - UPC vs hadronic component
- A-dependence of the π^0 asymmetry
  - Correlation between asymmetries of forward neutron and π^0
- p + Oxygen collision
  - Ideal condition for cosmic-ray interaction studies measuring π^0, neutron, photon, K^0_S

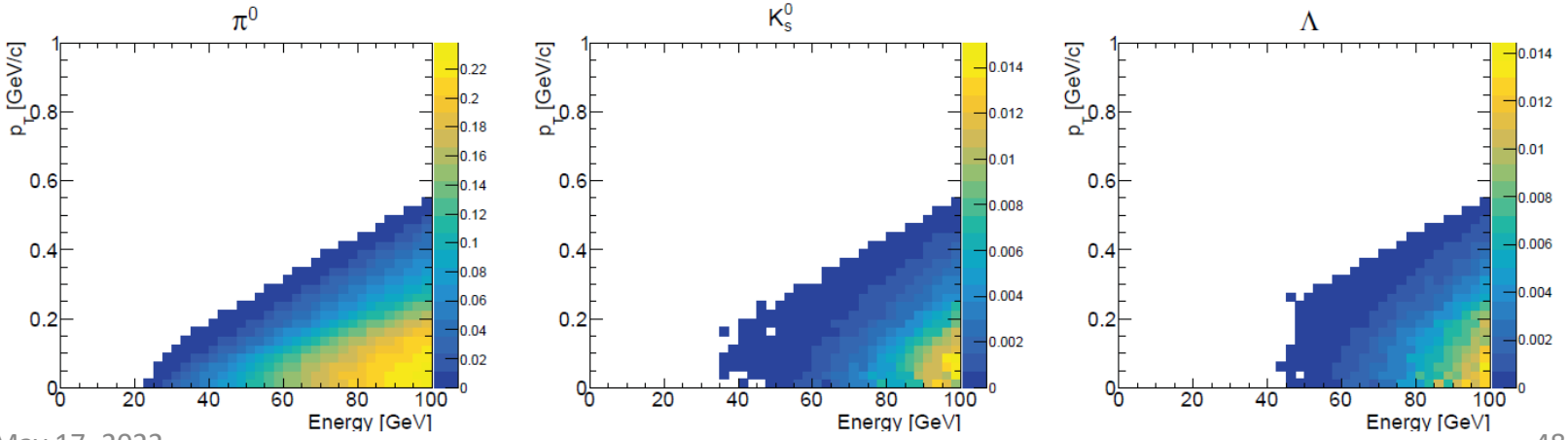


New topics at RHICf-II

- Large acceptance detector
  - 8cm x 18cm
  - For more particles: K^0_S and Λ

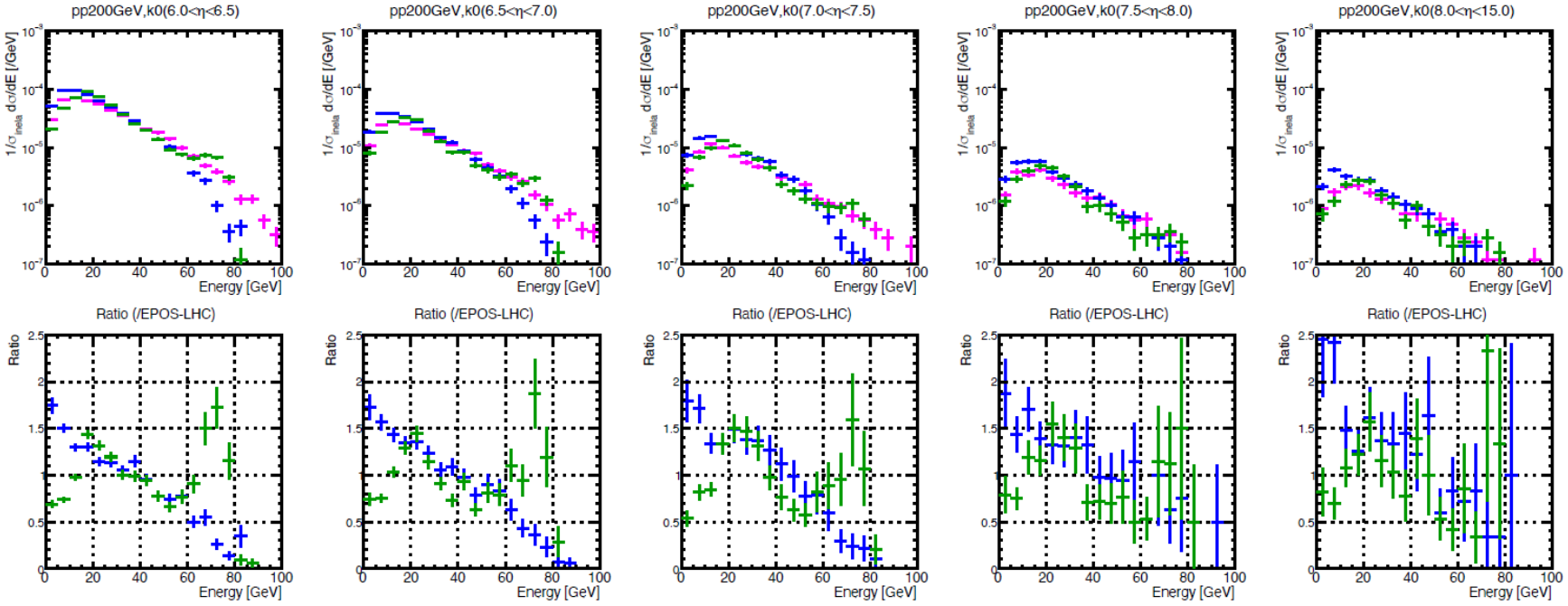


- $K^0_S \rightarrow 2\pi^0 \rightarrow 4\gamma$ (B.R. 30.7%)
  - 0.2 K^0_S /sec = 10^4 K^0_Ss in 14 hours operation
- $\Lambda \rightarrow n + \pi^0 \rightarrow n + 2\gamma$ (B.R. 35.9%)
  - 12 Λ /sec = 10^5 Λs in 2.5 hours operation
- Geometric acceptance of π^0, K^0_S and Λ

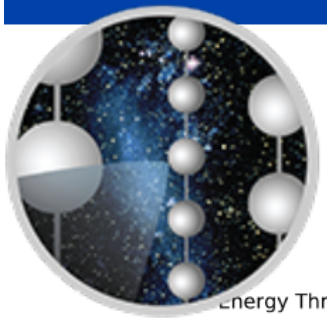


New topics at RHICf-II

- K^0_S for studying impact on the high-energy atmospheric neutrino flux
  - Differences in p+p collisions at 200 GeV between models: EPOSLHC (magenta), QGSJET II-4 (blue), SIBYLL 2.3 (green)

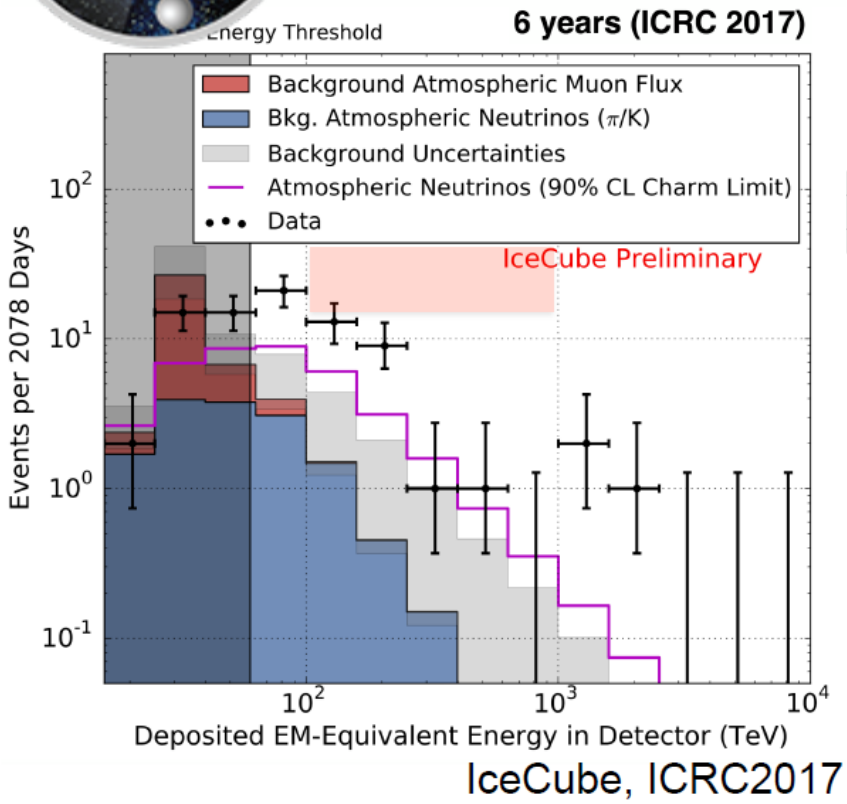


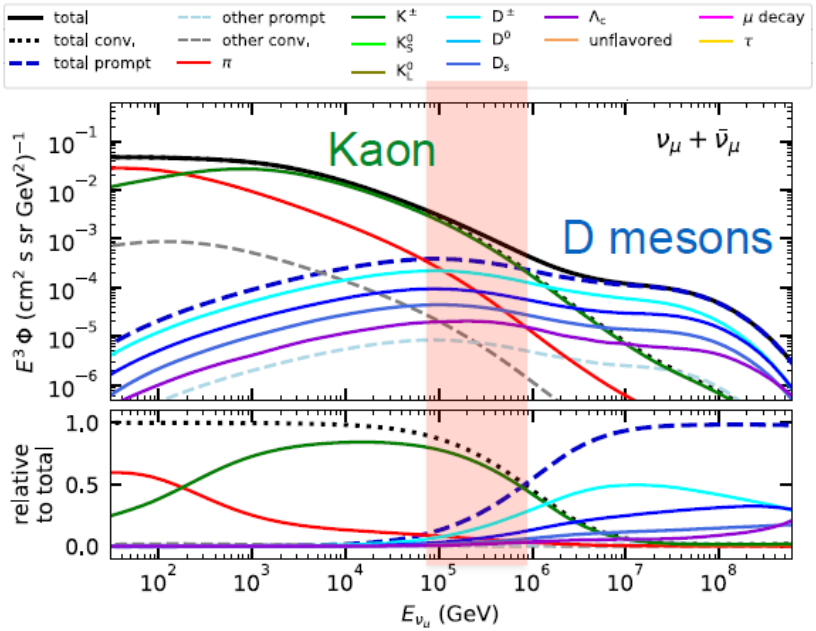
Kaons in atm. ν productions



IceCube detected astronomical neutrinos.
Better understanding of background
(Atmospheric neutrinos) is required.

Slide by
H. Menjo





New topics at RHICf-II

- Asymmetry measurement of K^0_S and Λ
  - Expected statistical uncertainty of asymmetry measurements for π^0, K^0_S, and Λ compared to the RHICf (Run 17) π^0
  - Assuming the similar luminosity