Workshop on

QCD Physics & Study of the QCD Phase Diagram and New-type Topologic Effect

Jul. 17 – 25, 2019, Weihai, China

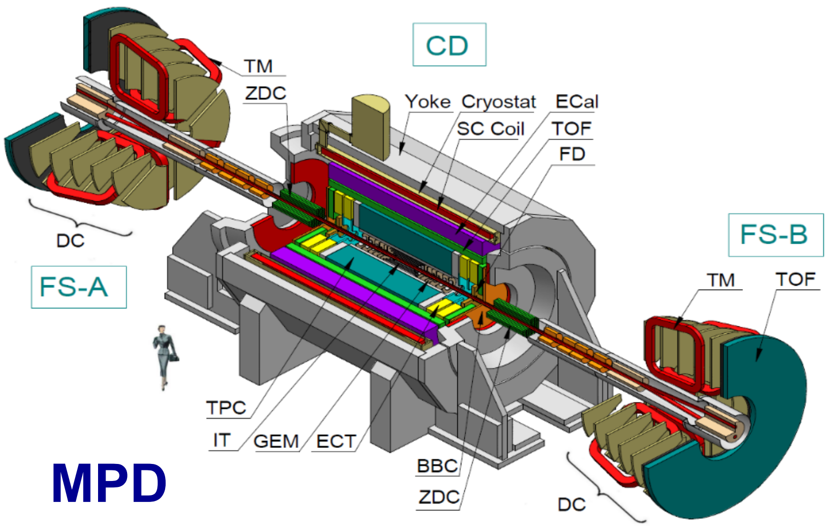
NICA-MPD ETOF: Physics Opportunities and Conceptual Design

Zebo Tang （唐泽波）

State Key Lab. of Particle Detection & Electronics

University of Science and Technology of China (USTC)

NICA Physics with MPD (and BM@N)



Physics goals:

- Onset of QGP
- 1^{st} order phase transition
- Search for critical end point
- Chiral phase transition

Systematic study of pp, pA and AA

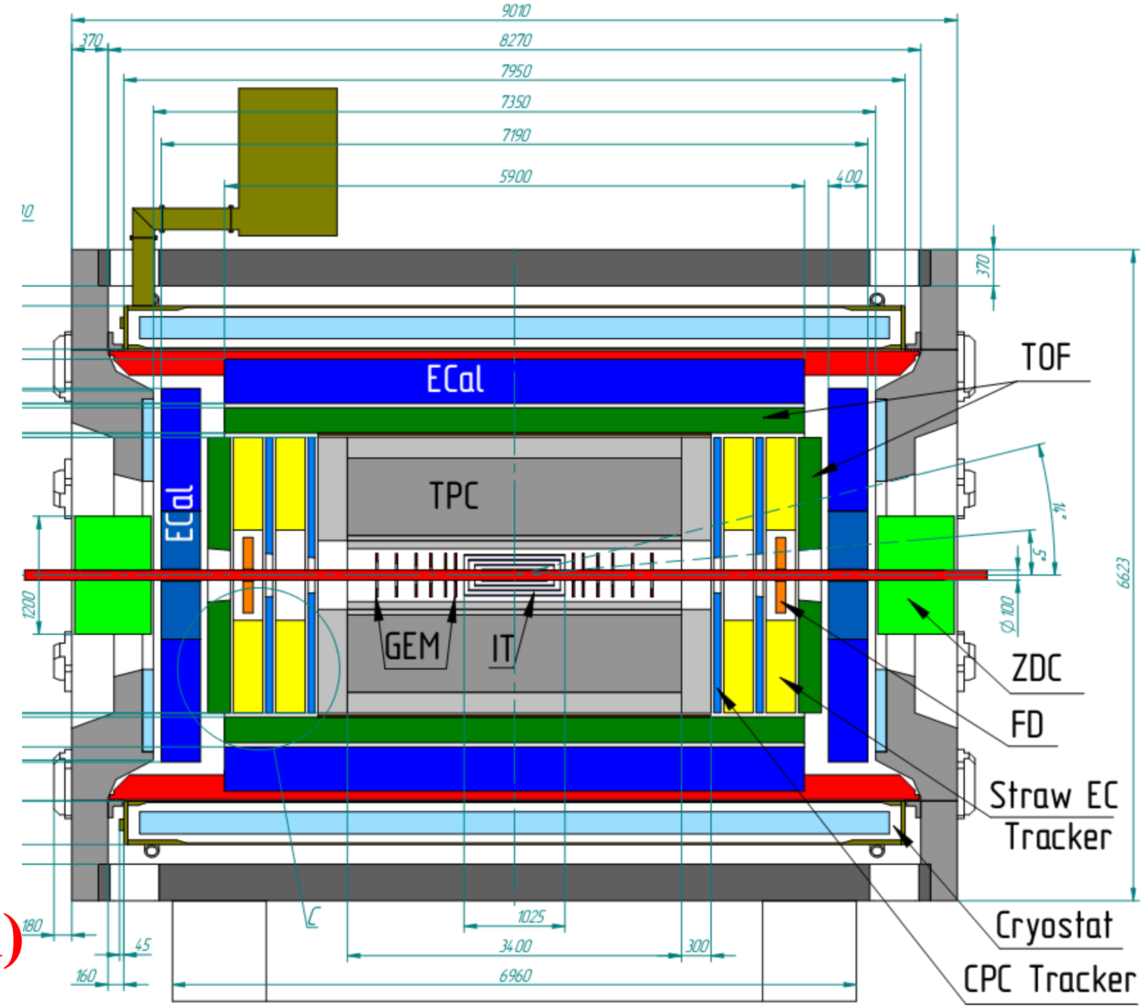
- **Bulk properties, EOS**
  - particle yields & spectra, femtoscopy, flow
- **Search for QCD Critical Point**
  - event-by-event fluctuations & correlations
- **Onset of phase transition:**
  - deconfinement (QGP thermal radiation)
  - in-medium modification of hadron properties: ρ, ω, ϕ → e+e- and continuum at m < 3 GeV/c^2
- **Enhanced strangeness production**
- **Chiral Magnetic (Vortical) effect**
  - Λ polarization
- **Strangeness in nuclear matter**
  - hypernuclei

Multi-Purpose Detector (MPD)

Stage 1: TPC, TOF, ECal, FHCal and FD

- 9 m long, 6m diameter
- Low material budget
- Good tracking and PID

- Tracking (TPC):
  $|\eta|<1.2$, 2π in azimuth
- PID (TOF, TPC, ECAL):
  π, K, p, d, t, …, e, γ
- Event characterization (FHCAL):
  centrality & event plane



Stage 2: IT and Endcaps (tracker, TOF, ECal)

TDR: *http://nica.jinr.ru/files/mpd_tdr.htm*

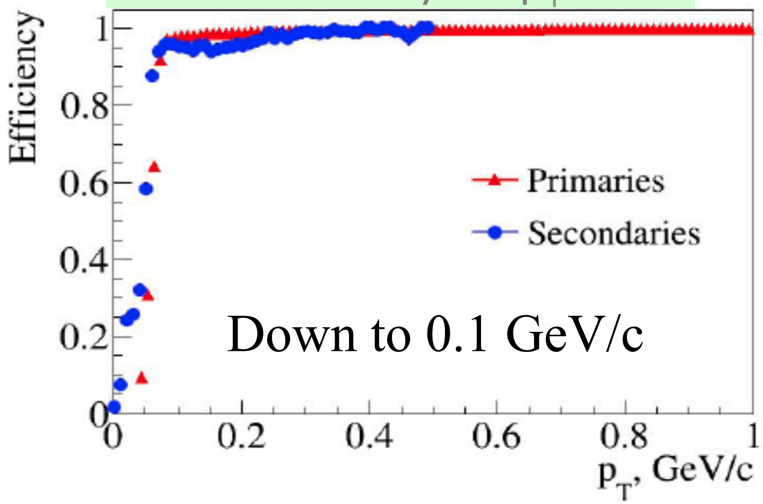
NICA Milestones

- **2018** – start of **BM@N** experiment
- **2018-2019** – **Booster** commissioning
- **2019** – **MPD** magnet commissioning
- **2019** – start of **MPD** detectors assembly
- **2020** – completion of civil constructions (**b. 17**)
- **2020** – **MPD** commissioning (**Stage I**)
- **2021** – **Collider** commissioning
- **2023** – **MPD** commissioning (**Stage II**)
- **2025 – SPD** commissioning (**Stage I**)

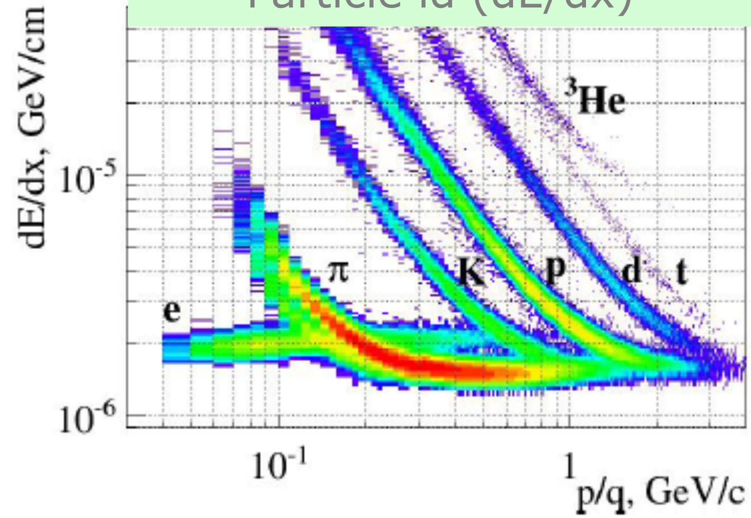
From Kekelize

MPD Performances at Barrel (Stage I)

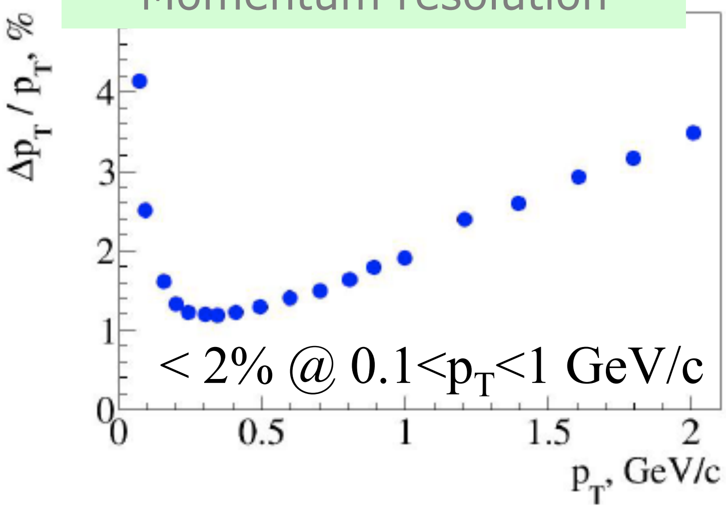
Efficiency vs p_T



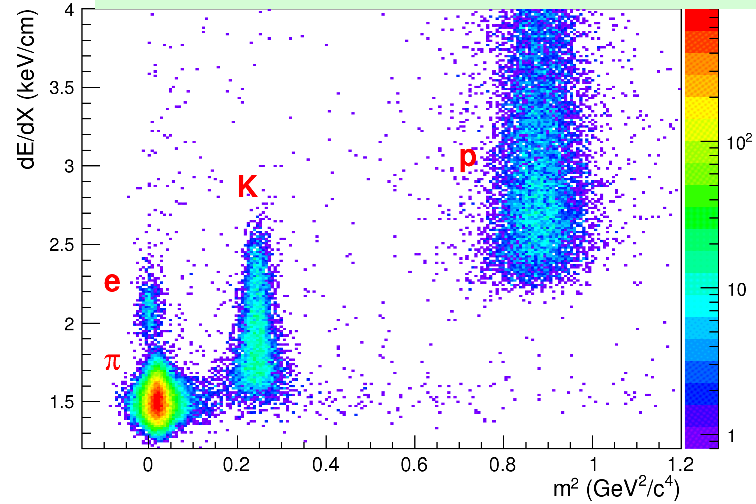
Particle id (dE/dx)



Momentum resolution



Particle id (dE/dx and ToF)



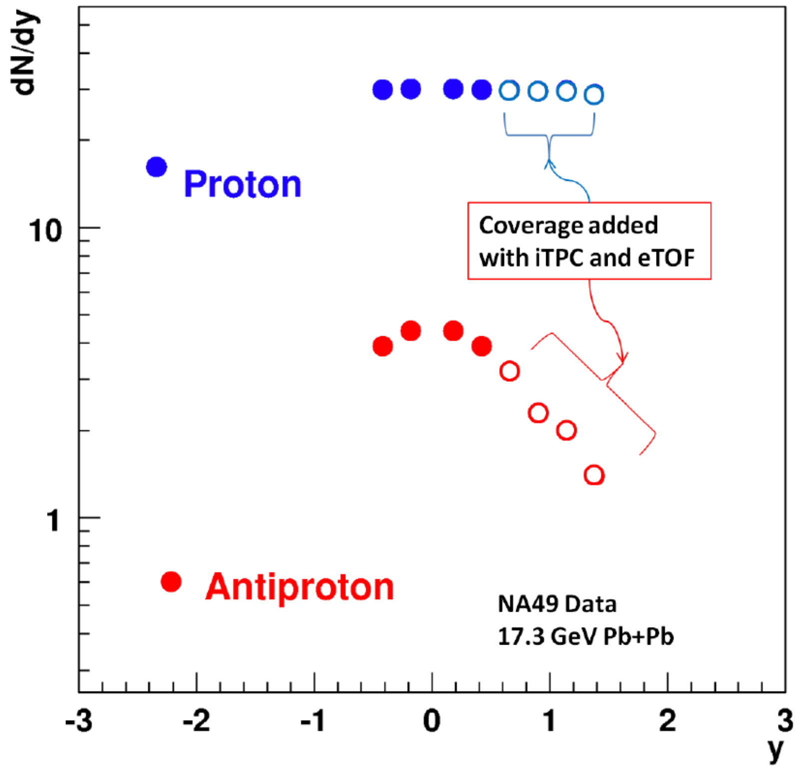
Benefits of Forward PID Detector

- Increase acceptance for identified particle measurements
  - Especially for 2,3-body decays

- Enlarge η coverage/gap for correlation studies

- Unique physics opportunities at forward-rapidity

Forward is Different



Proton: flat rapidity distribution

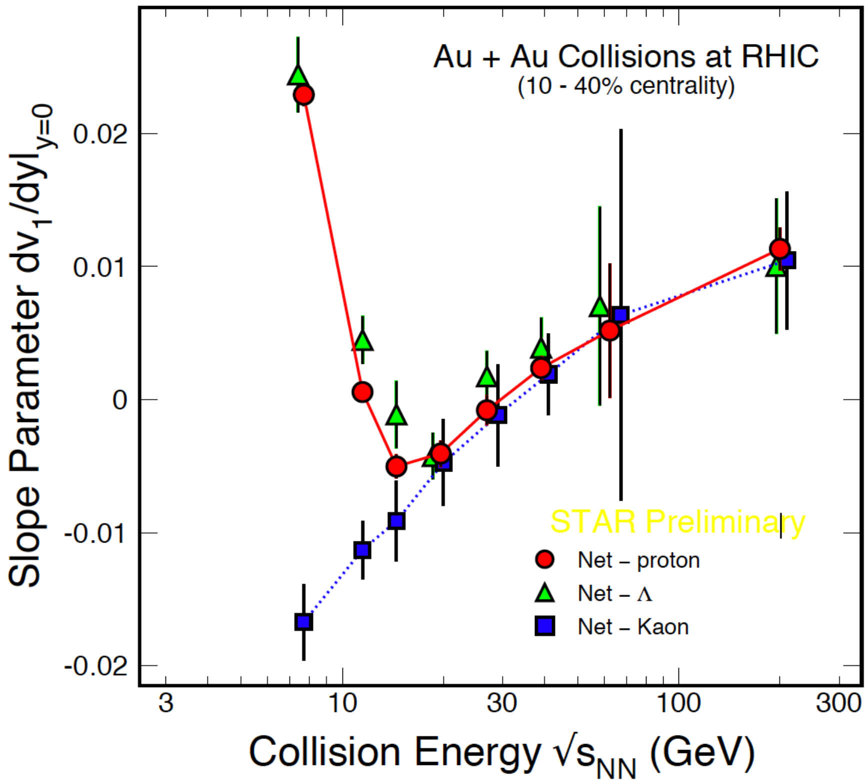
Anti-proton: decreasing rapidly

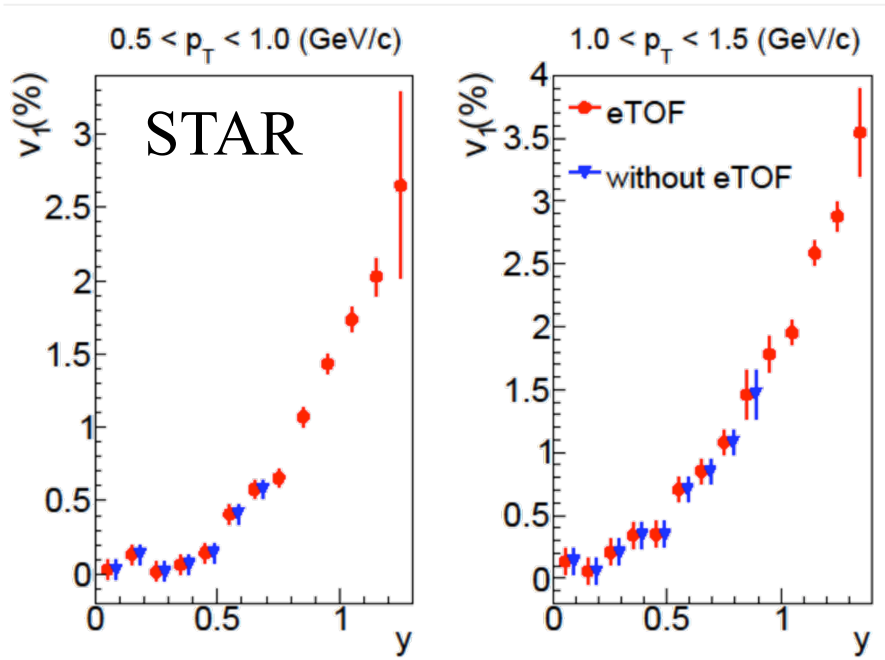
μ_B increases with rapidity

~50 MeV from mid- to forward

- Explore different μ_B at different rapidity
- Possible mixture of different phases at forward rapidity due to non-uniform compression *M. Gyulassy and L. P. Csernai, NPA460,723(1986)*

Energy Dependent Directed Flow



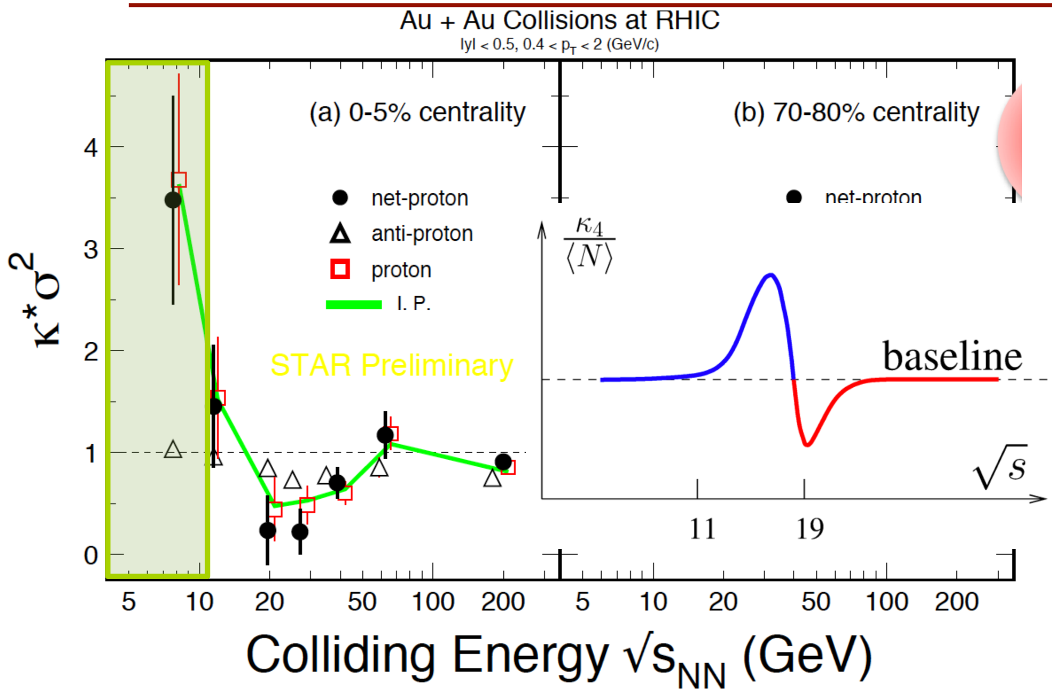


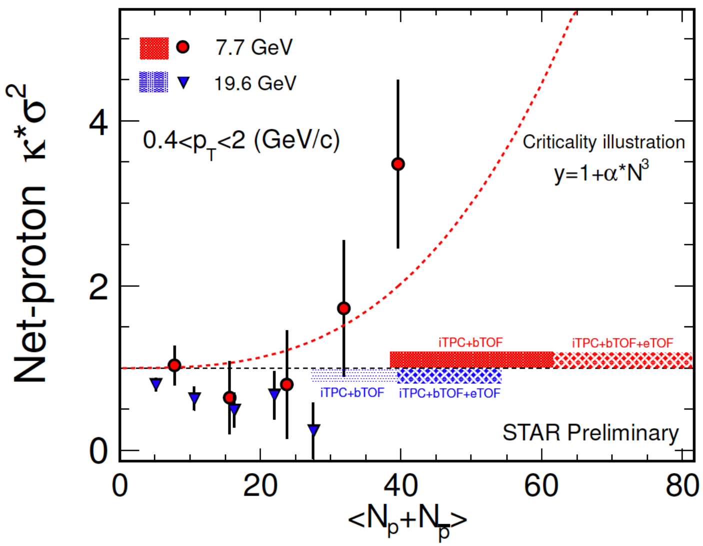
- v_1 slope of identified particles
- Closely related to EOS
- Non-monotonic dependence for net-baryons

Forward PID detectors:

Significantly extend the rapidity coverage of v_1 measurement

Critical Point Search





- Higher moments of conserved quantities is a unique tool for critical point search
- Need higher precision and lower beam energy

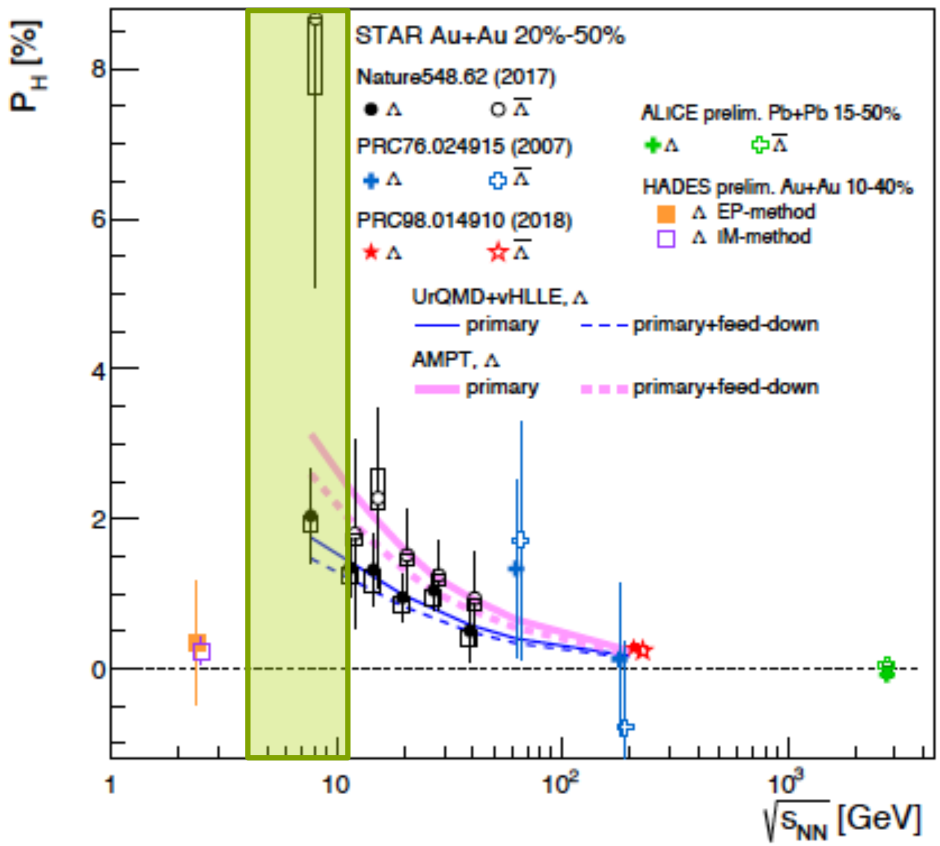
Forward PID detectors:

Enhance fluctuation signal for net-proton, net-kaon etc.

Provides cleaner and more significant indication of critical behavior

Energy Dependence of Λ Polarization

Plot from Takafumi Niida



MPD sqrt(s_{NN}) = 4-11 GeV

Significant global polarization observed at RHIC BES-I

Clear increase trend with decreasing energy

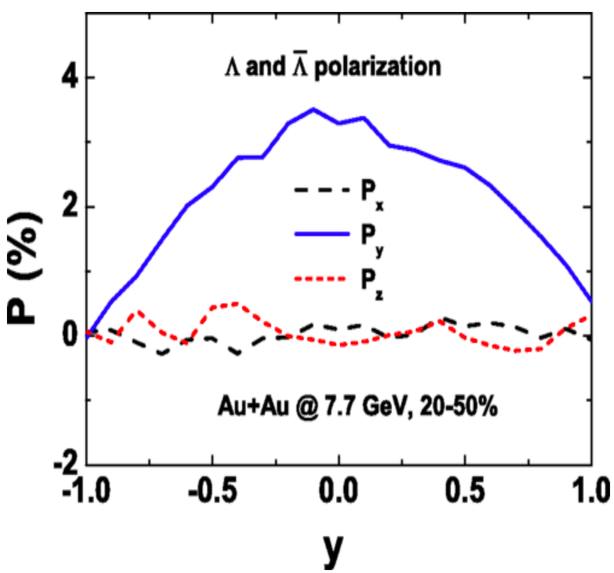
HADES results consistent with zero

Large polarization at NICA top energy

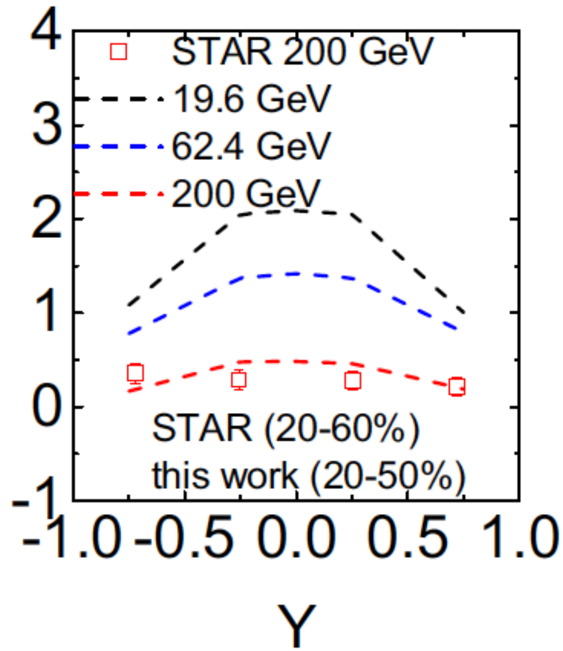
Turning off at NICA energies?

Rapidity Dependence of Polarization

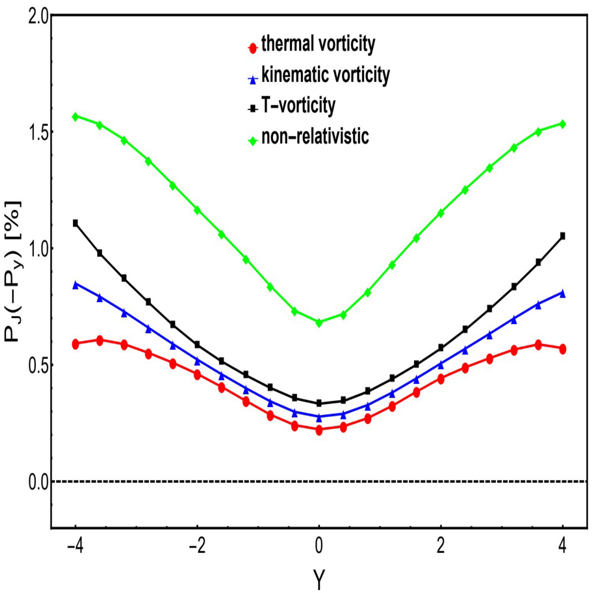
Measurement of rapidity dependence helps to disentangle models



Y. Sun and C. Ko, PRC96, 034906 (2017)

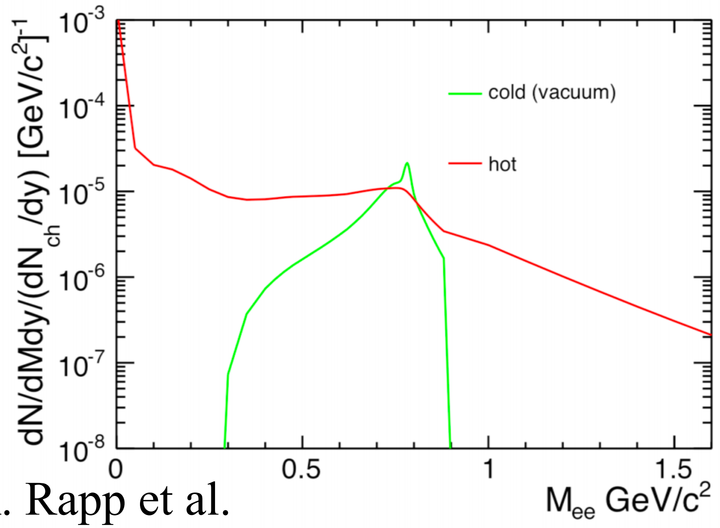


D. Wei, W. Deng, X. Huang, PRC99, 014905 (2019)

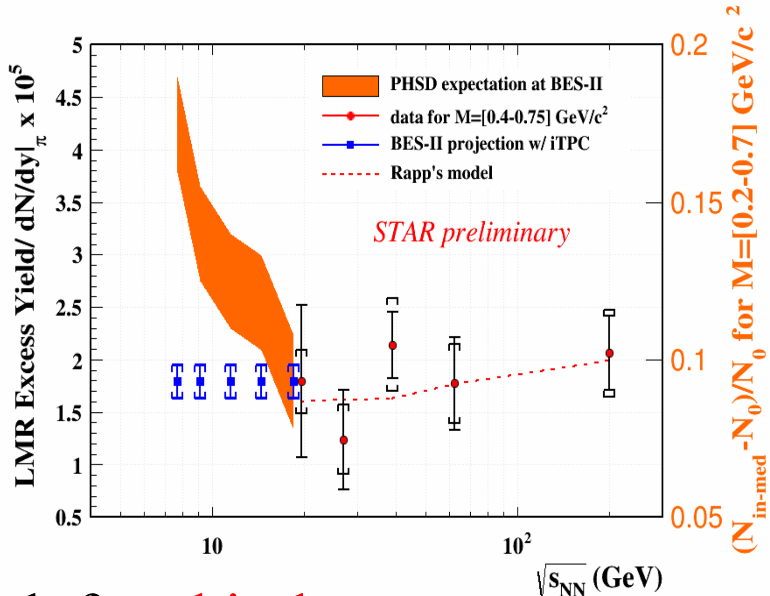


H. Wu, L. Pang, X. Huang, Q. Wang, arXiv:1906.09385 and private communication

Dilepton Measurement at Forward

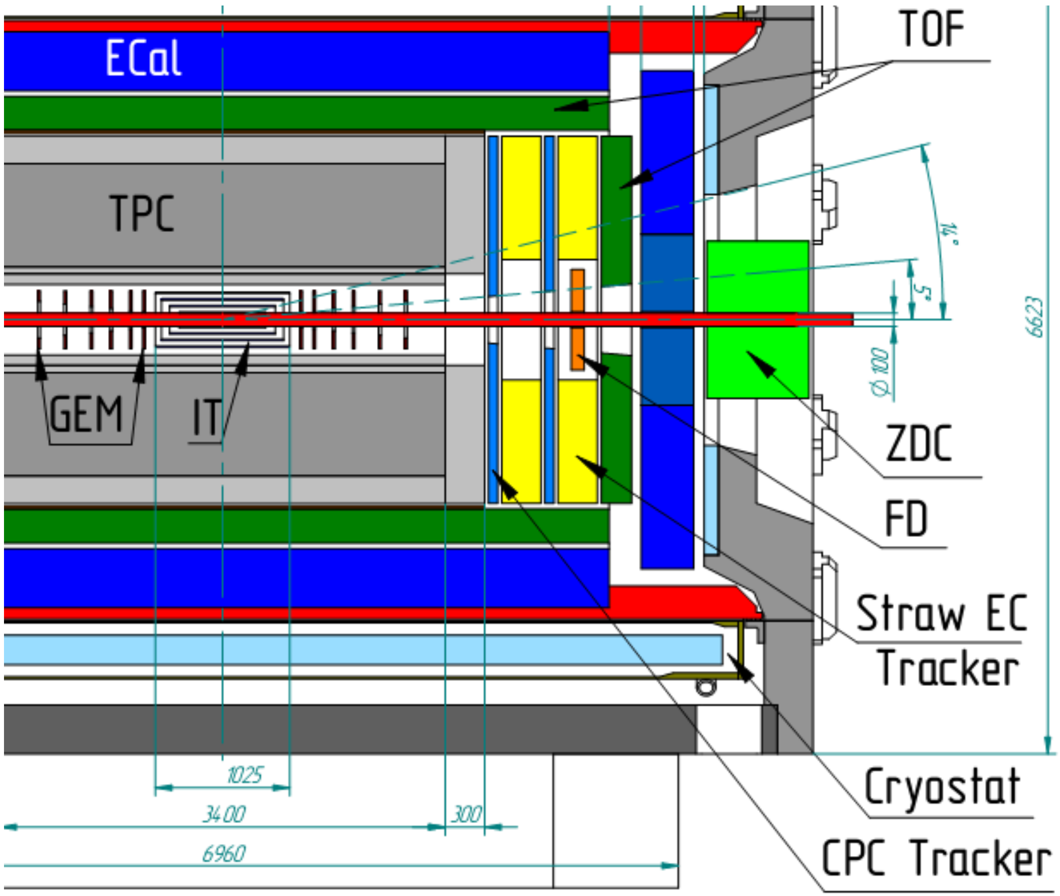


R. Rapp et al.



- In-medium modification of ρ: search for chiral symmetry restoration
- Low-mass-range (LMR) dilepton yields depend on temperature, lifetime and baryon-density
- Forward measurements provides for independent observable to study the baryon-density dependence

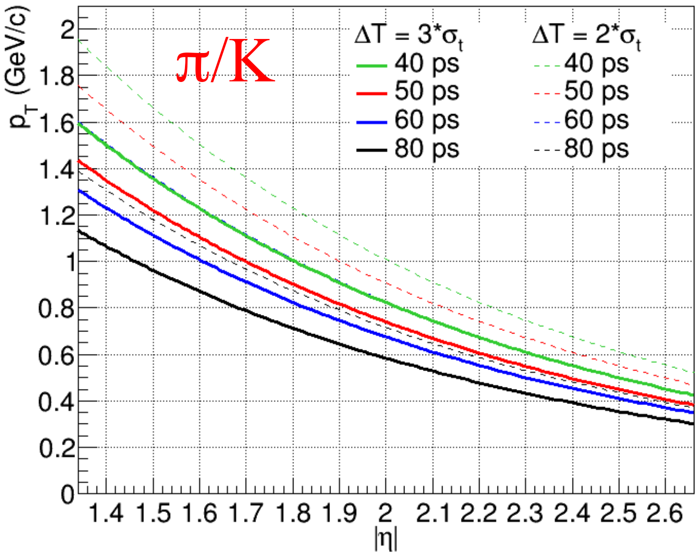
Challenges of Forward PID Detector

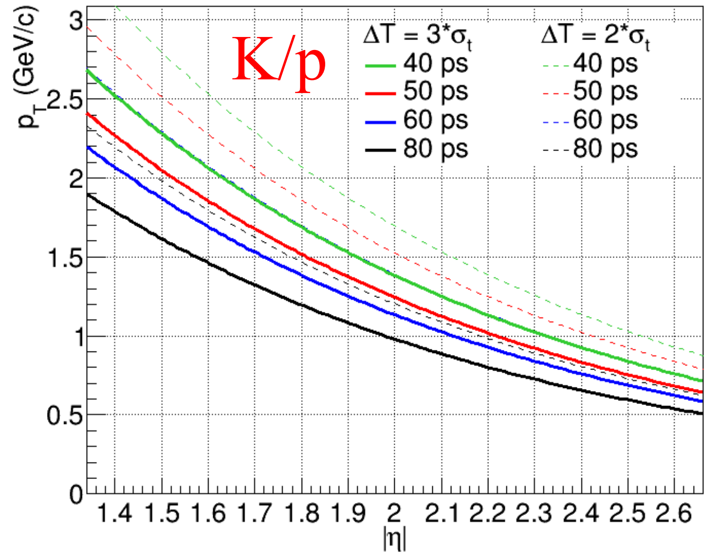


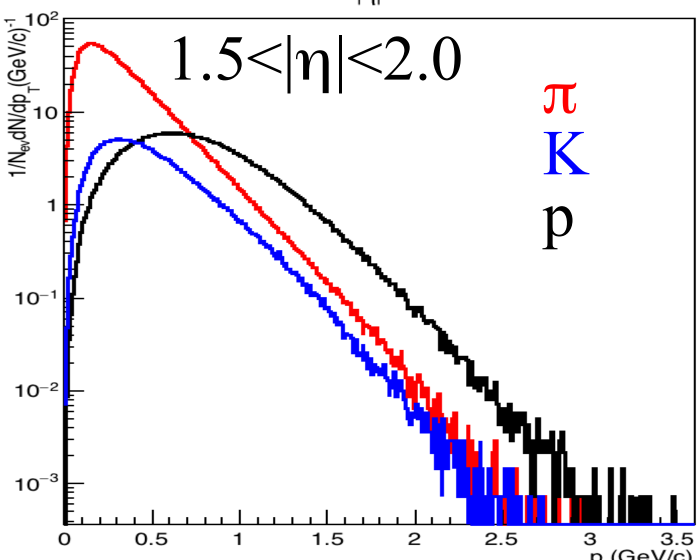
- dE/dx measurement getting worse at forward
- p getting larger at forward (at same p_T)
- eTOF is crucial

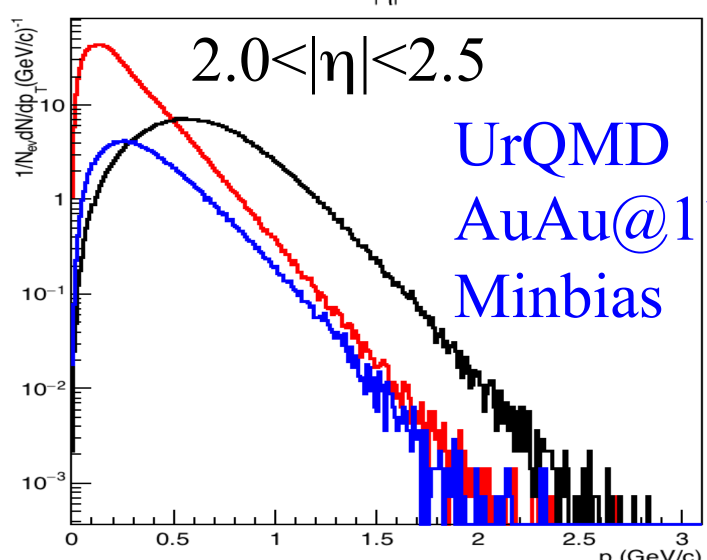
  Better resolution needed

Challenge of eTOF









UrQMD
AuAu@11GeV
Minbias

Requirement of eTOF

High timing resolution eTOF system: 40-50 ps?

- High timing resolution eTOF detector (MRPC)

  <~ 30 ps? (intrinsic)

- High timing resolution electronics

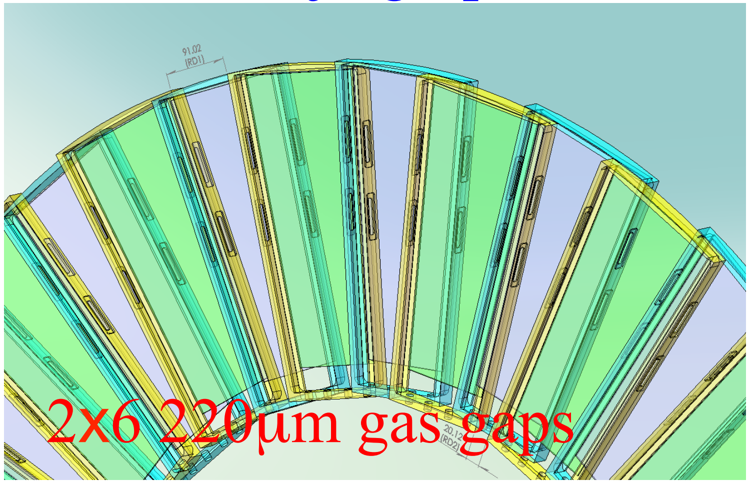
  10-15 ps

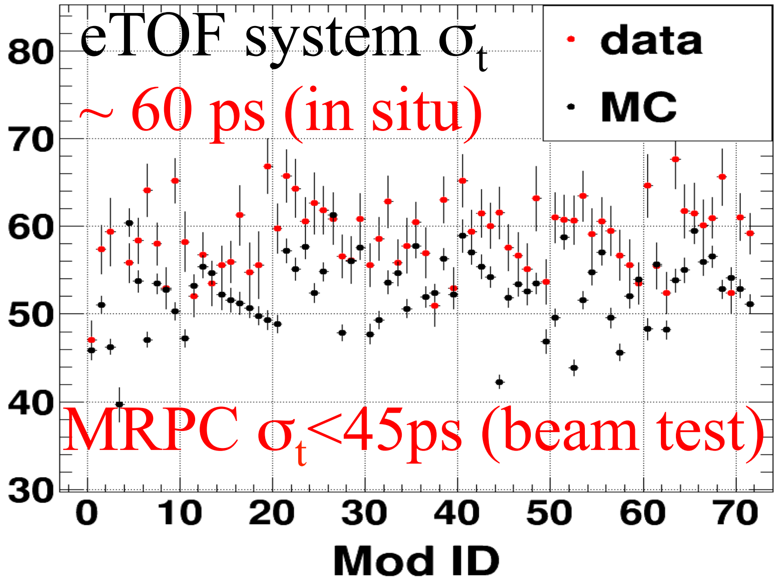
- High timing resolution T0 with low material budget

  <~30 ps?

High Timing Resolution MRPC

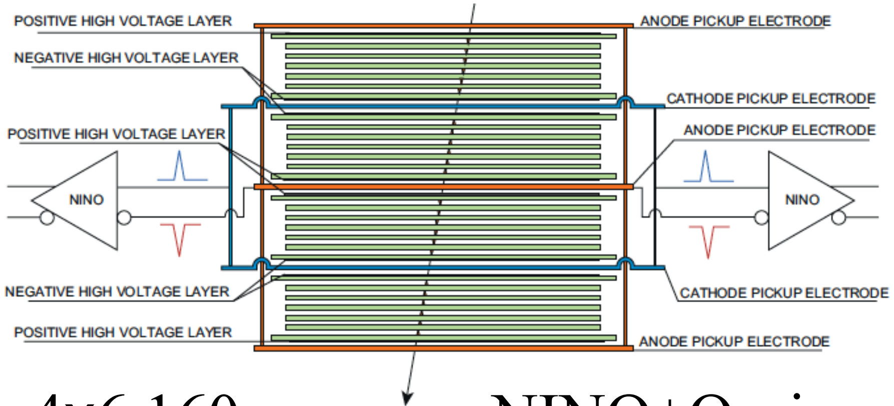
eTOF of Beijing Spectrometer



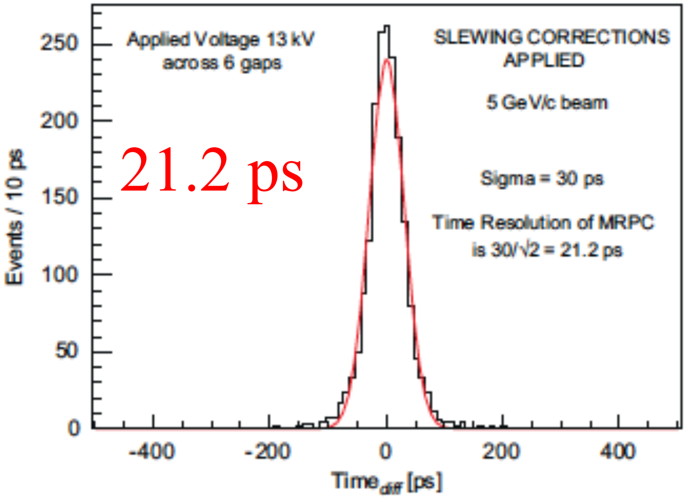


24-gaps MRPC

Shaohui An et. al, NIMA594, 39 (2008)



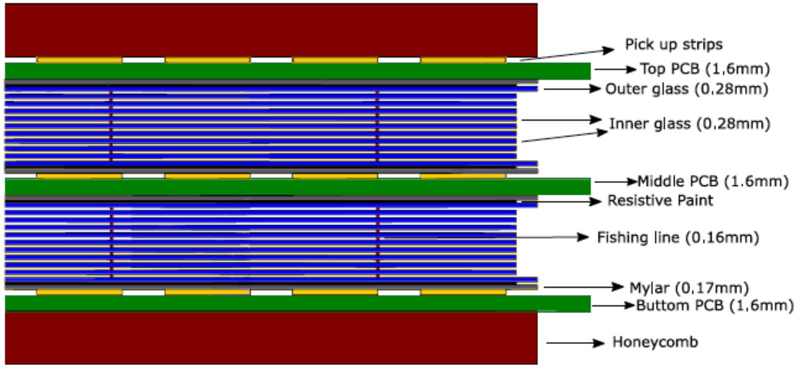
4x6 160μm gaps, NINO+Osci.



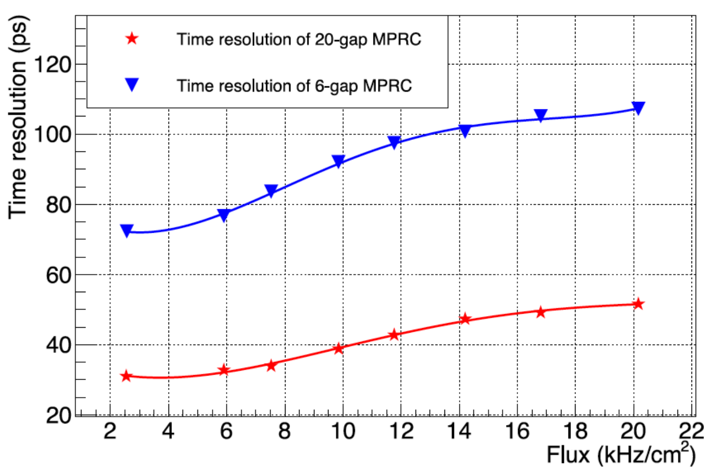
Recent Developments

20-gaps MRPC with thin glass

Z. Liu et. al, NIMA908, 383 (2018)

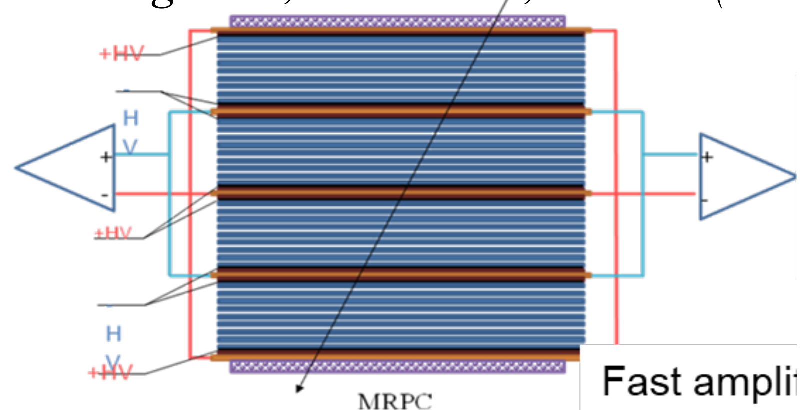


2x10 160μm-gaps, NINO+WaveCatcher

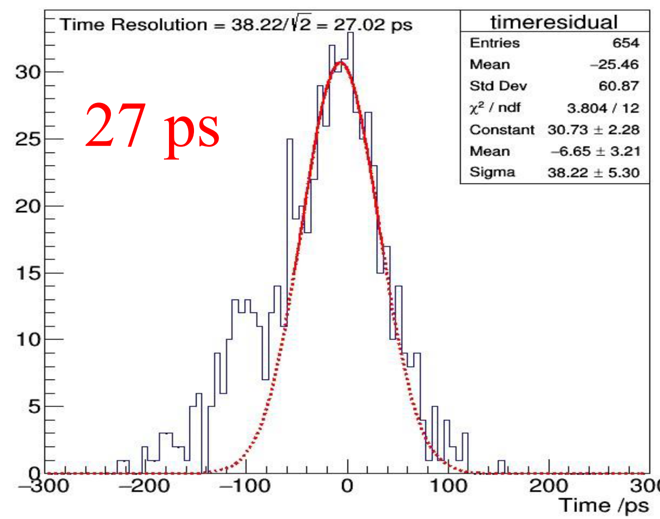


32-gaps MRPC

Y. Wang et. al, JINST1406, C06015 (2019)



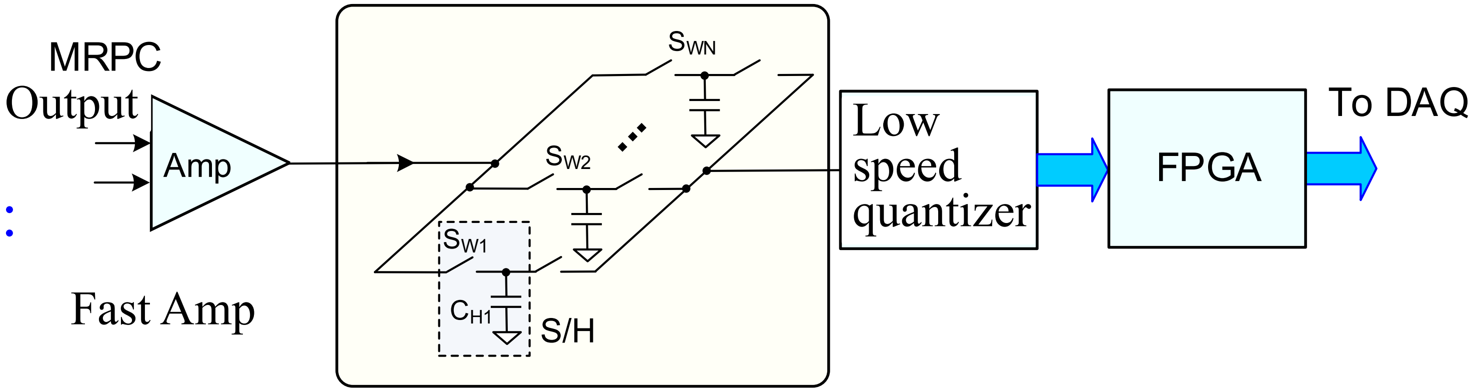
4x8 104μm-gaps, Amp.s+DT5742



High Timing Resolution Electronics

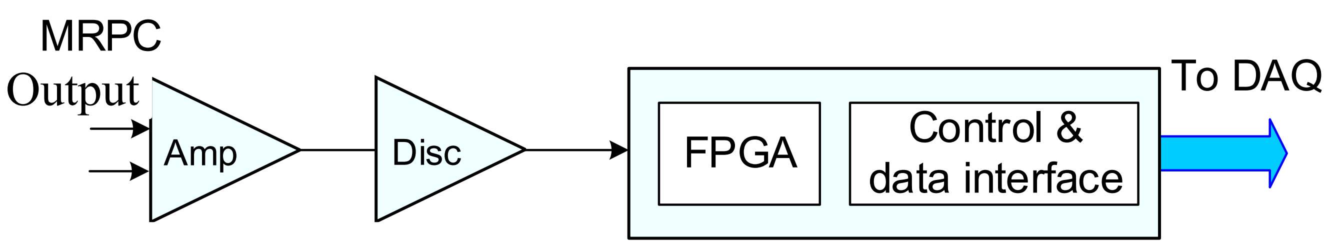
Lei Zhao from USTC

Option 1:



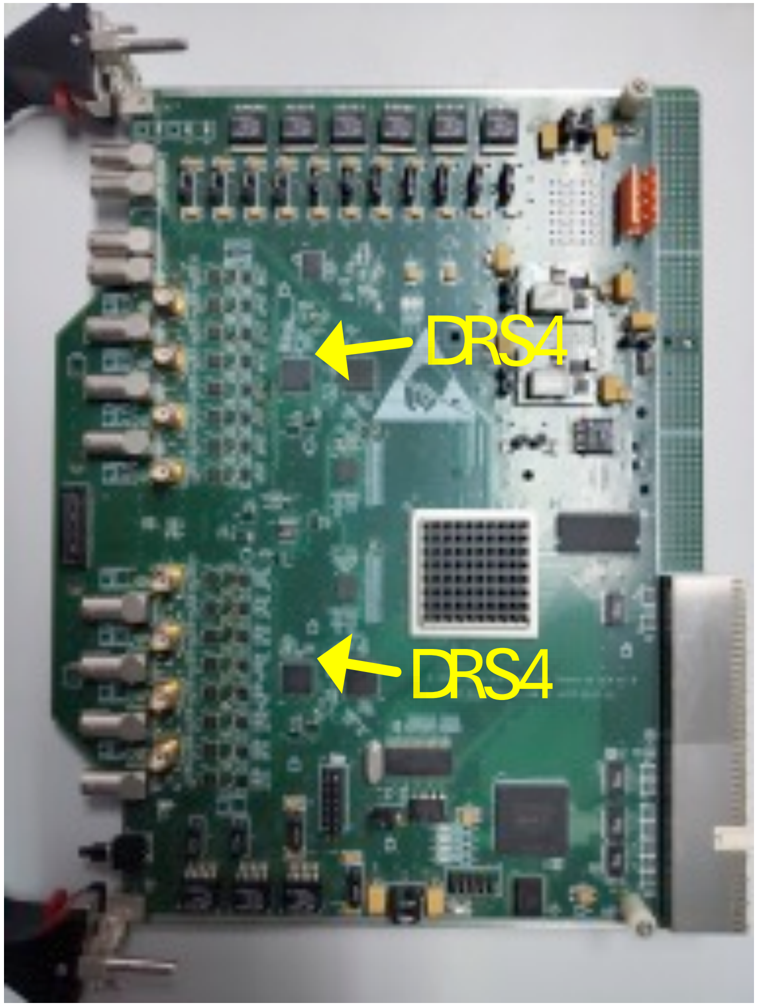
SCA: Switched Capacitor Array

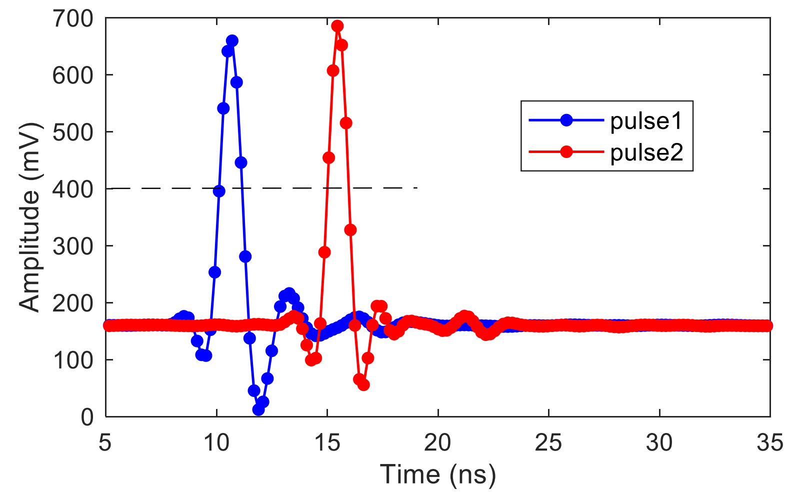
Option 2:

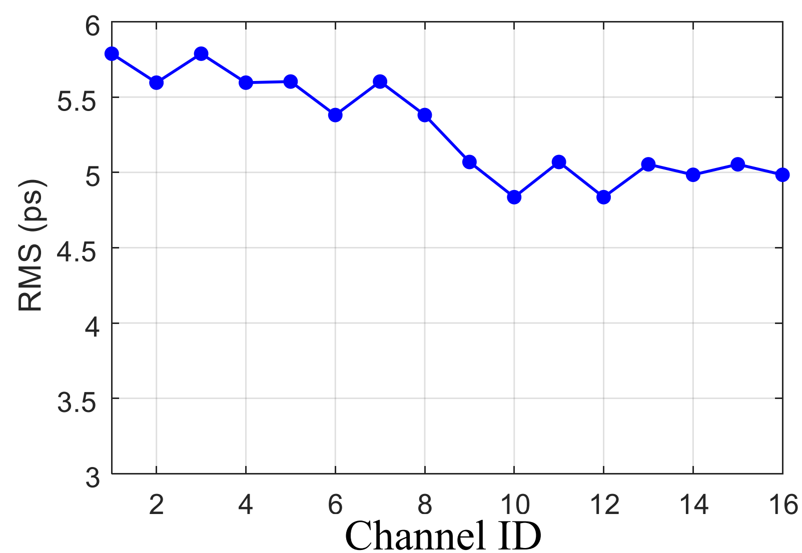


FPGA TDC (10ps achieved)

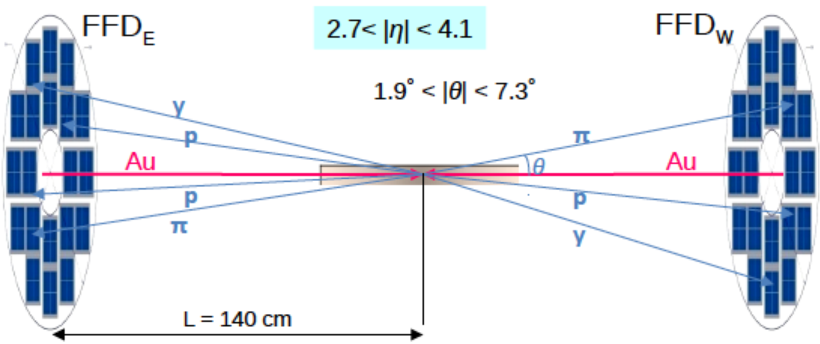
Digitizer Based on DRS4

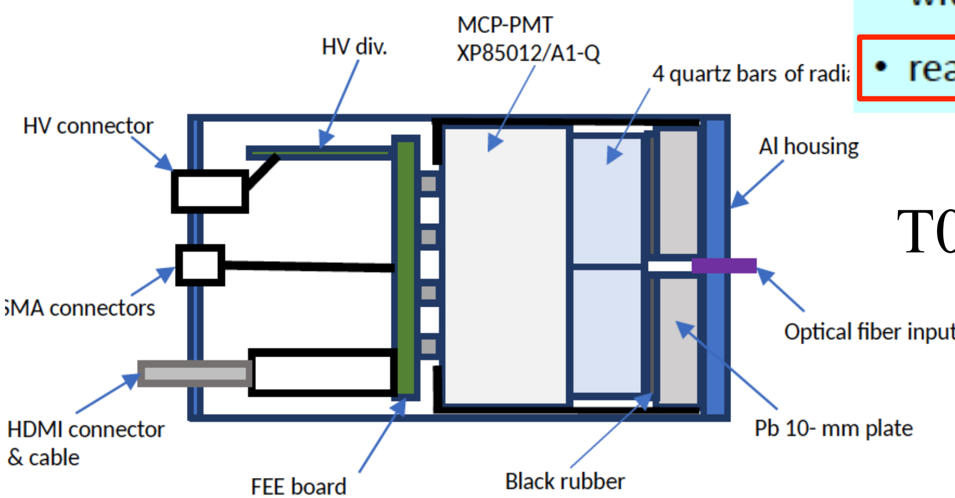






Forward Fast Detector (FFD) Detector





10 mm Lead converter
15 mm quartz radiator
Readout by MCP-PMTs

Trigger, vertex and T0

Detect photons and charged particles

- Time resolution of FFD module itself - 21.5 ps
- with readout by E.B. DRS4 digitizer - 24 ps
- with readout by digitizer CAEN mod.N6742 - 34 ps
- real chain with readout by TDC72VHL - 44 ps

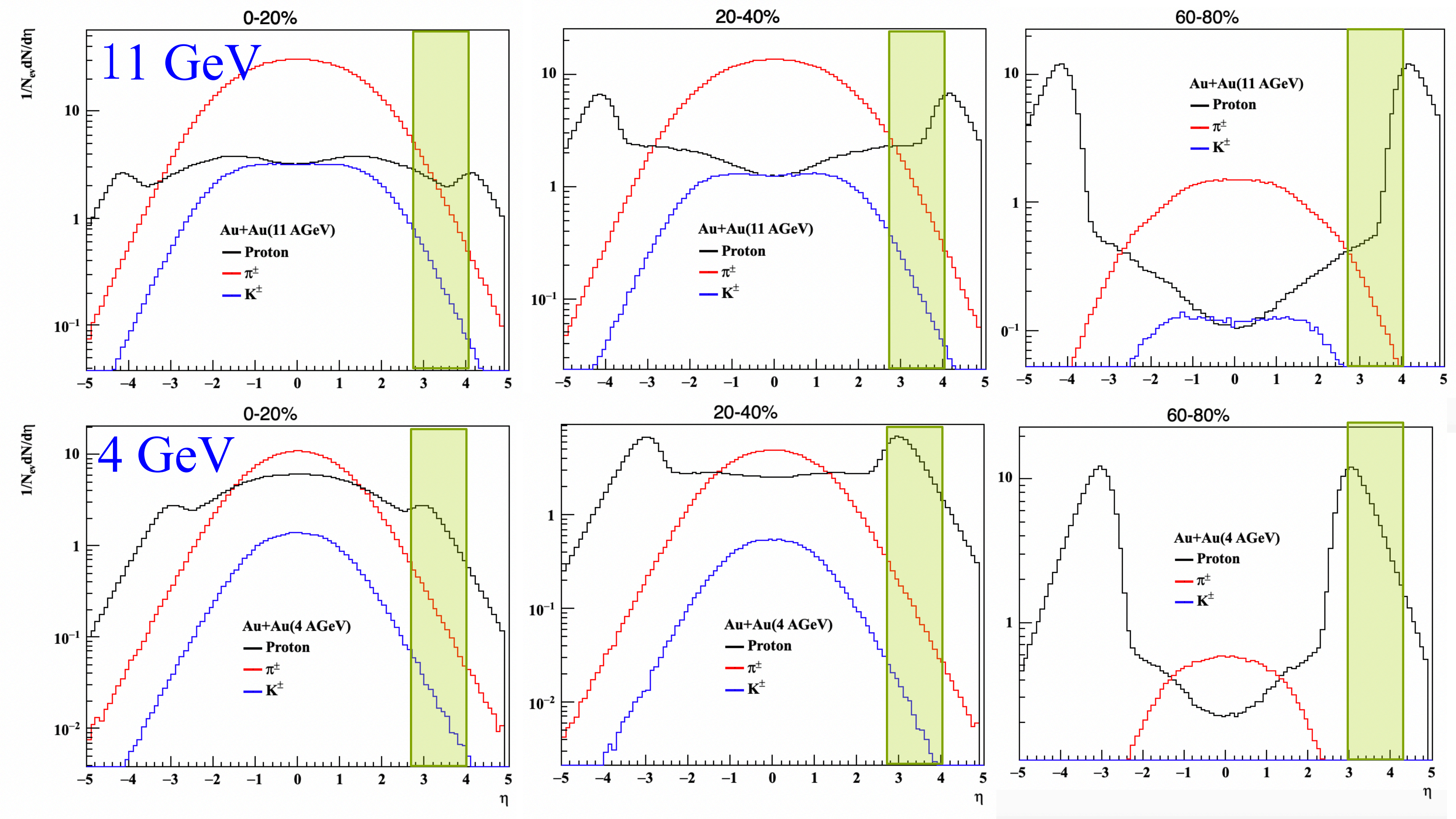
T0 resolution improved by sqrt(1/N)

Material budget is large

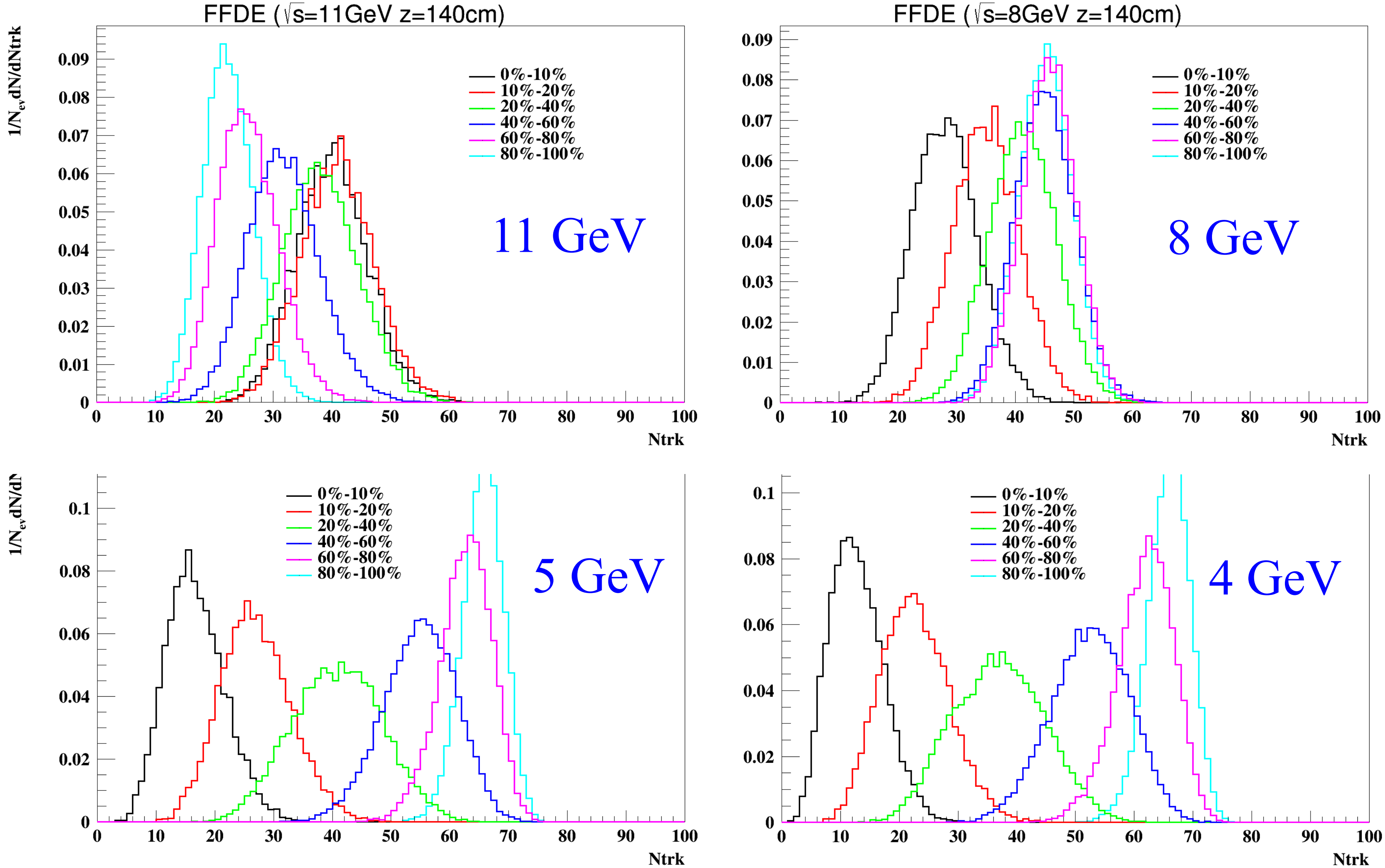
Problem for forward detectors

Low-material T0 Detector

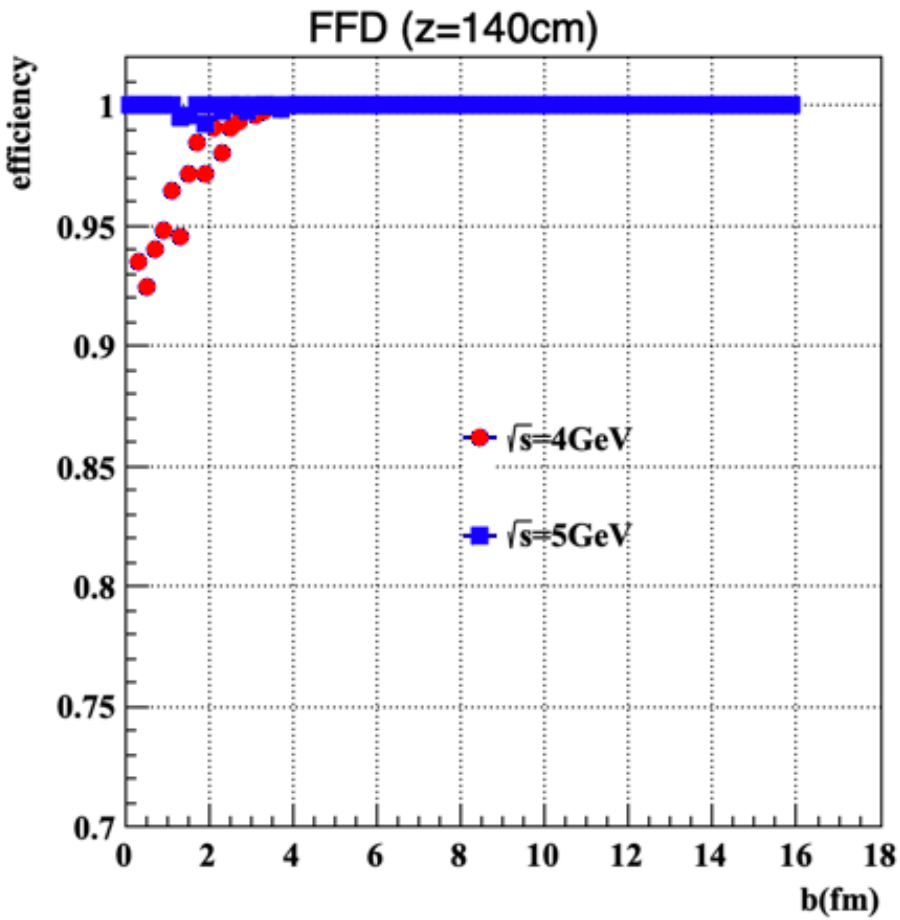
Detect only charged particle (mainly proton) in forward region?



Multiplicity on T0 Detector

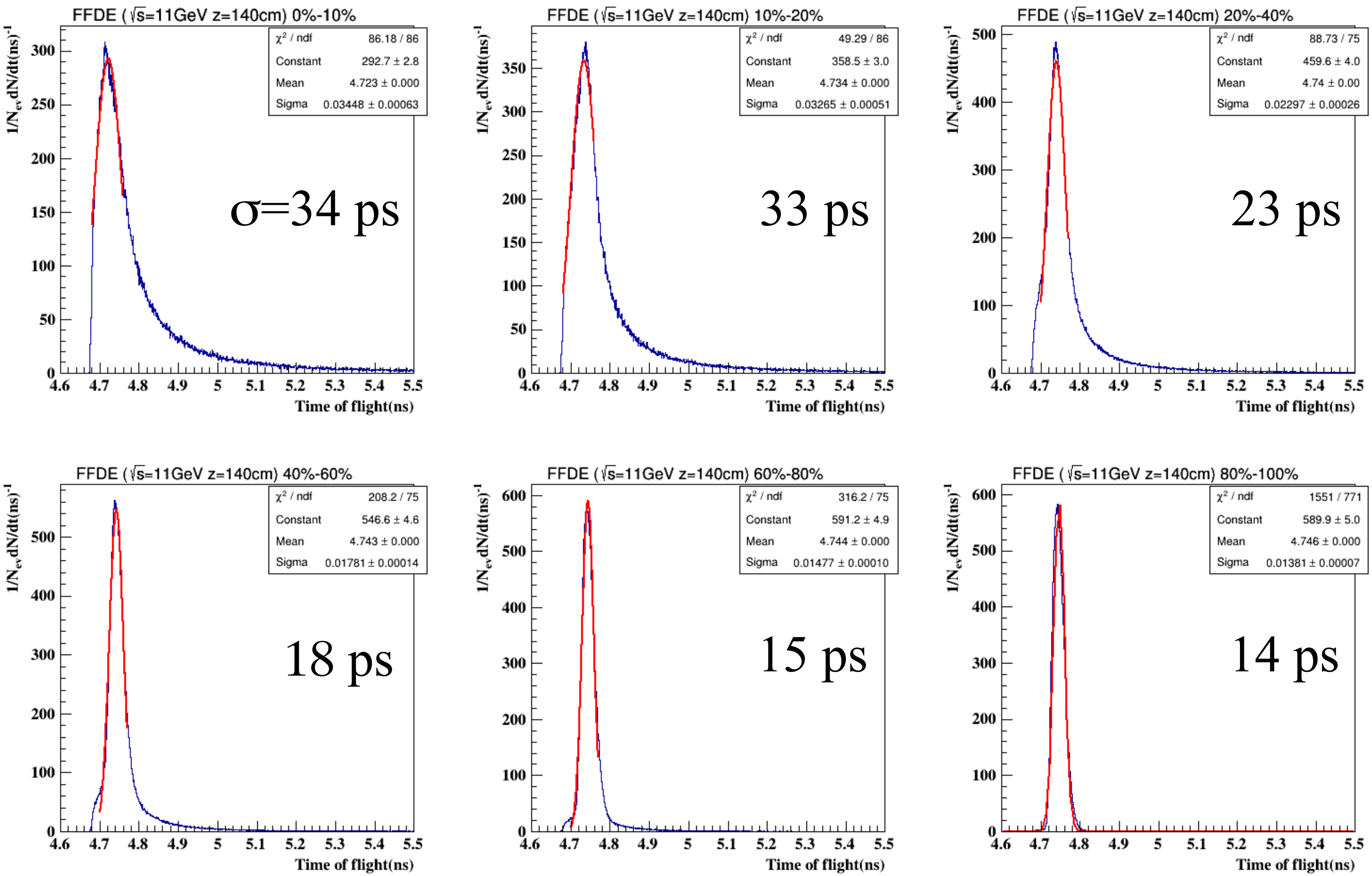


Trigger Efficiency

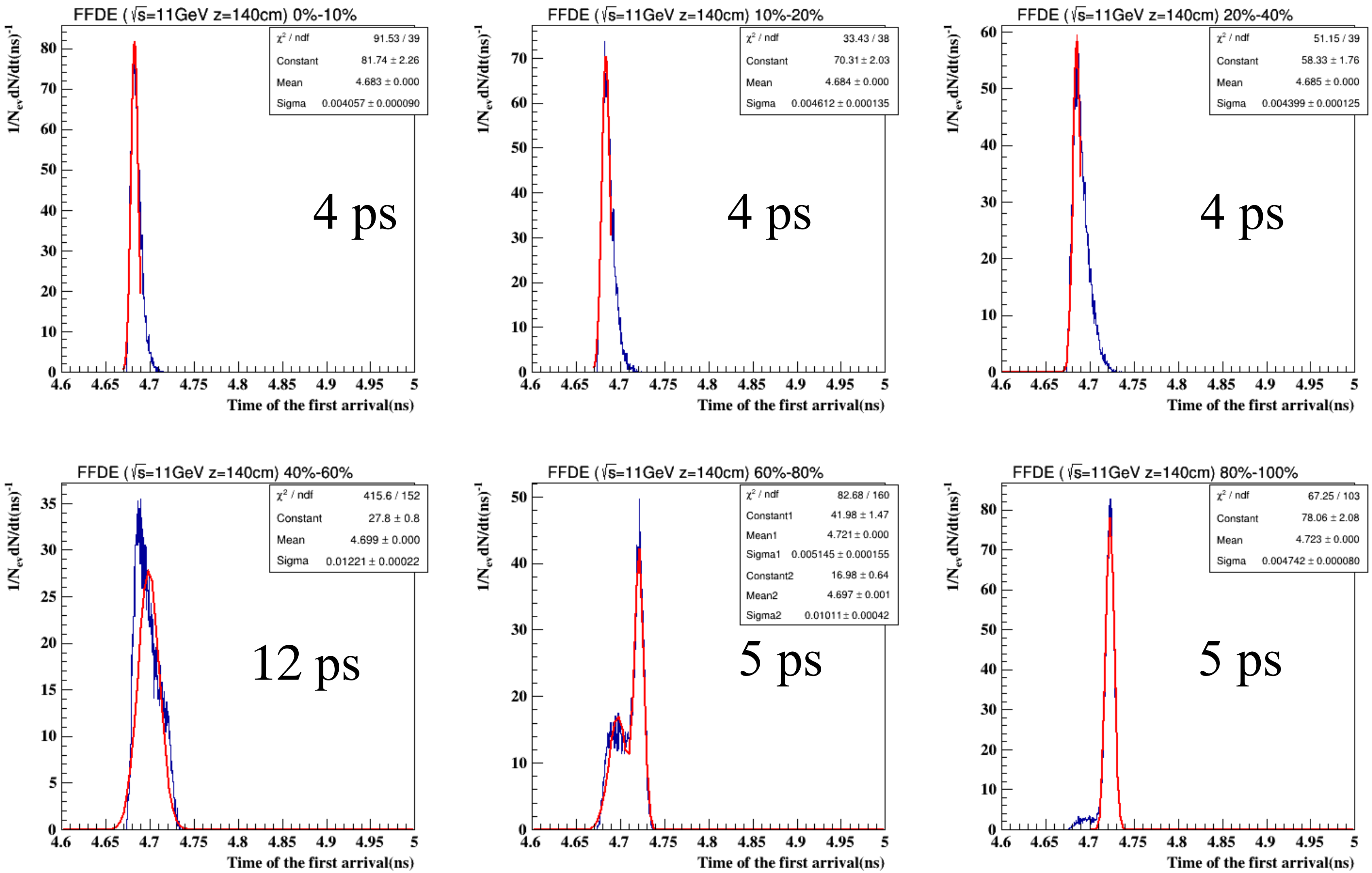


- Requires coincidence of the detectors at east and west
- Assuming 50% detection acceptance and efficiency
- 100% trigger efficiency except in central collisions at sqrt(s_{NN})=4 GeV

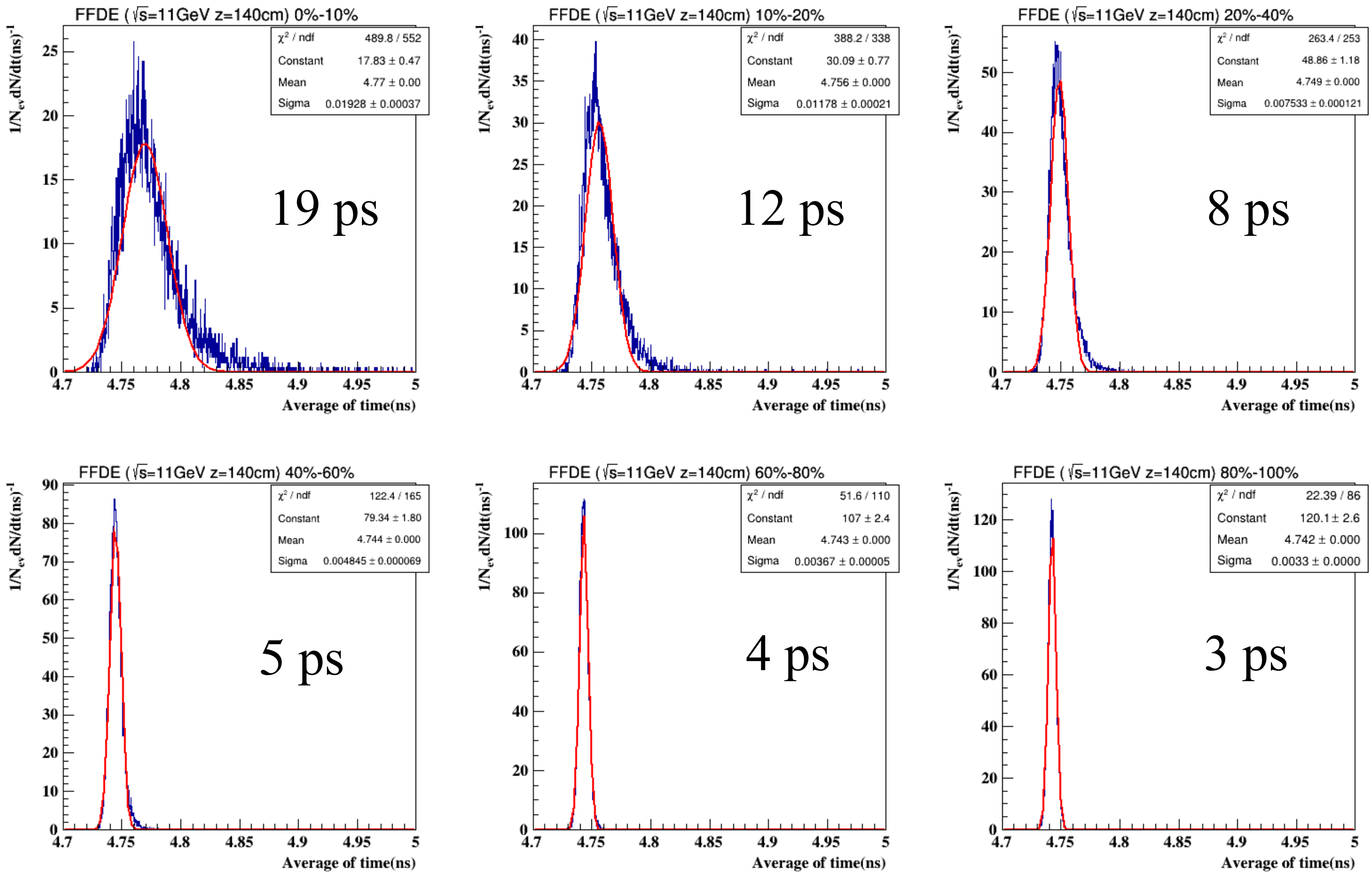
Time-of-Flight Distribution



Time Distribution of the First Arrival

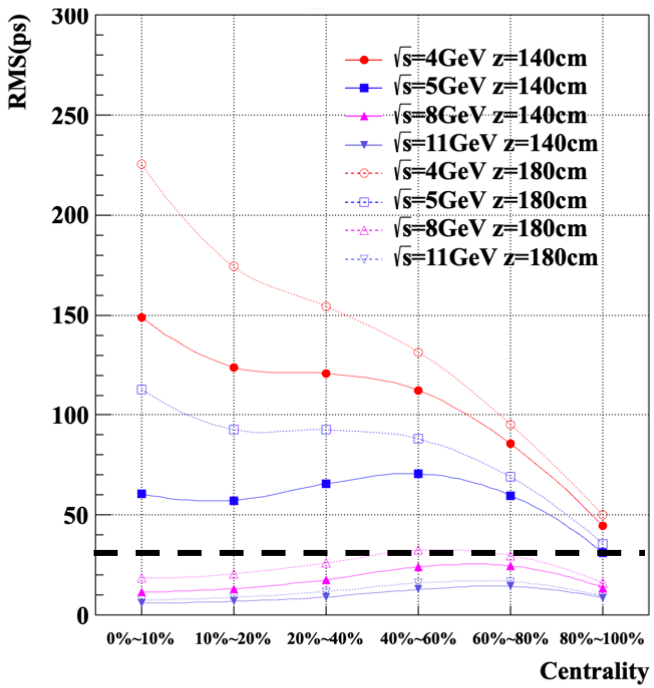


Distribution of Average Time

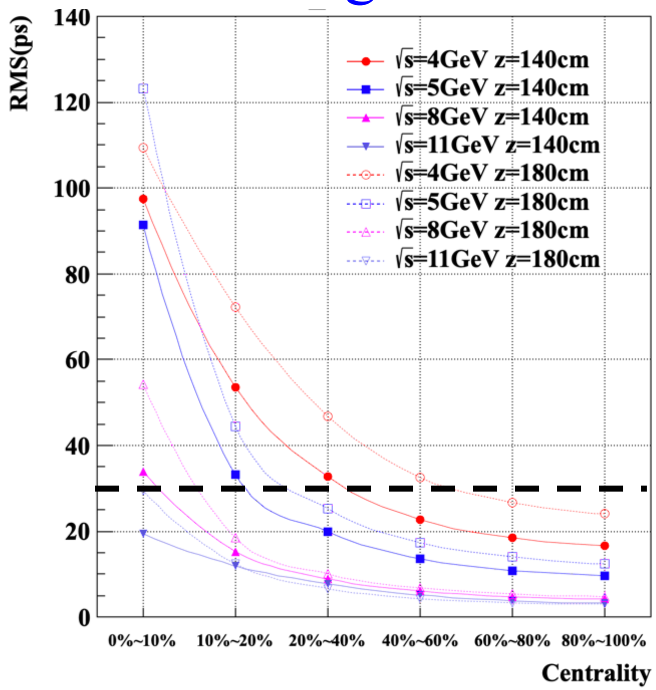


Intrinsic Timing Resolution

First arrival

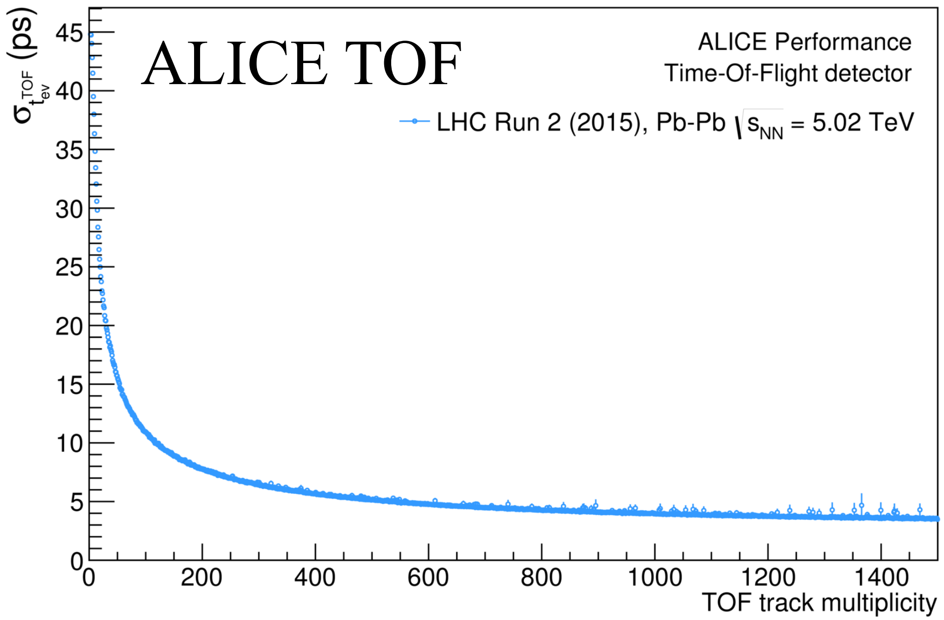


Average



- <30 ps in most of the cases
- Problem in central collisions at low energy
  Mixture of produced particle and transported particles
  Requirement at low energy is lower

T0 from TOF Itself



ALI-PERF-143047

With 2 or more tracks, T0 can be obtained directly from TOF itself

ALICE TOF can obtain:

- < 30 ps with 10 tracks
- < 10 ps with 150 tracks
- < 5 ps with 600 tracks

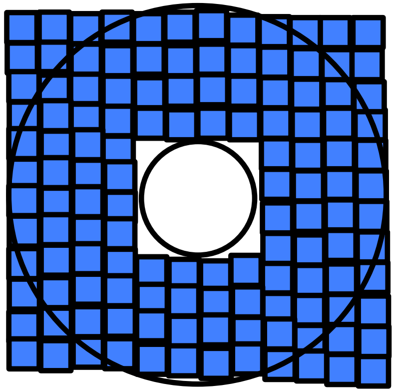
T0 from bTOF (+ eTOF)

Complementary to T0 detector

Especially for (semi-)central collisions

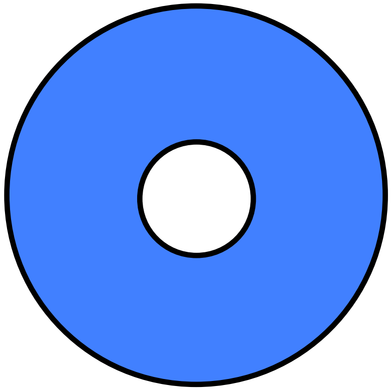
Technical Options for T0 Detector

- Plastic scintillator + MCP-PMT
- Plastic scintillator + SiPM



128 x 2

- Low Gain Avalanche Detector (LGAD)



Is Plastic Scintillator Fast Enough?

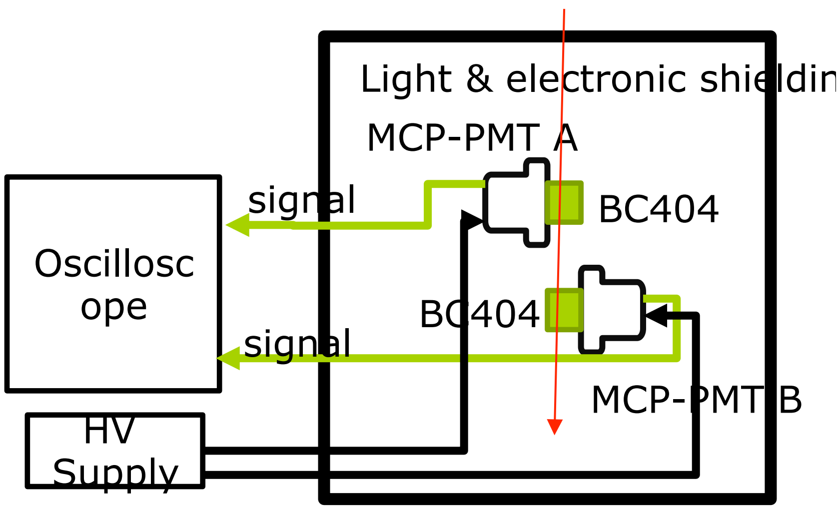
Properties	BC-400	BC-404	BC-408	BC-412	BC-416
Light Output, % Anthracene	65	68	64	60	38
Rise Time, ns	0.9	0.7	0.9	1.0	—
Decay Time, ns	2.4	1.8	2.1	3.3	4.0
Pulse Width, FWHM, ns	2.7	2.2	~2.5	4.2	5.3
Light Attenuation Length, cm*	160	140	210	210	210
Wavelength of Max. Emission, nm	423	408	425	434	434
No. of H Atoms per cm^3, ($x10^{22}$)	5.23	5.21	5.23	5.23	5.25
No. of C Atoms per cm^3, ($x10^{22}$)	4.74	4.74	4.74	4.74	4.73
Ratio H:C Atoms	1.103	1.100	1.104	1.104	1.110
No. of Electrons per cm^3, ($x10^{23}$)	3.37	3.37	3.37	3.37	3.37
Principal uses/applications	general purpose	fast counting	TOF counters, large area	large area	large area economy

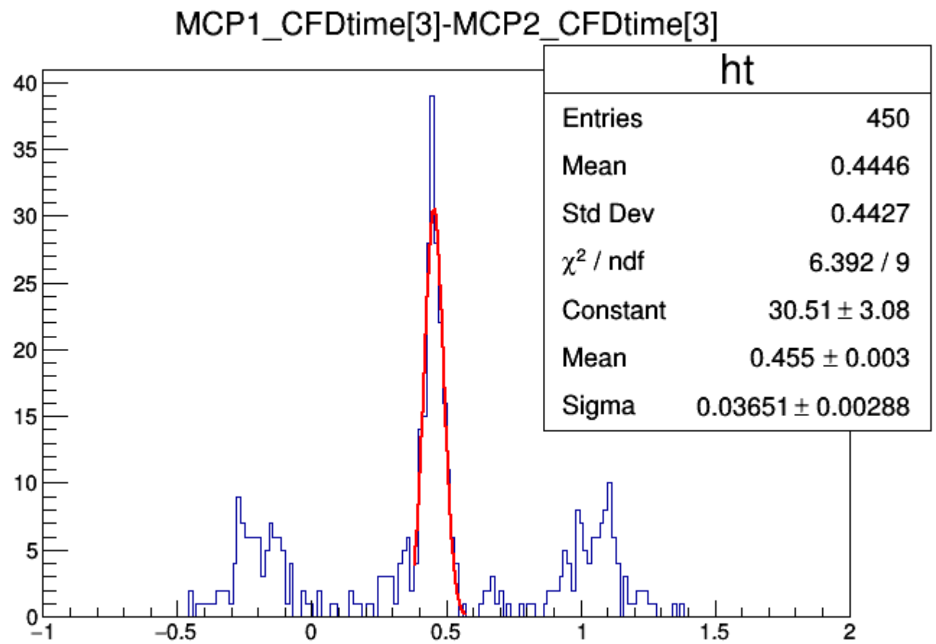
*The typical 1/e attenuation length of a 1 x 20 x 200 cm cast sheet with edges polished as measured with a bialkali photomultiplier tube coupled to one end

Cosmic Ray Test Results

Plastic Scintillator: BC404, 5mm x 5mm x 5mm

MCP-PMT: Hamamatsu R3809U





σ=36/sqrt(2) = 26 ps

Amplitude ~ 600 p.e.

Can be Better

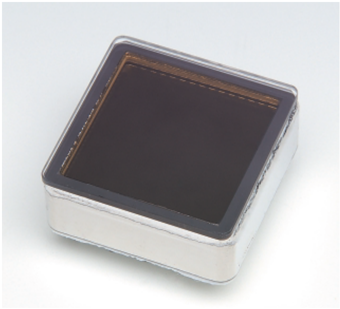
	BC-418	BC-420	BC-422	BC404
Scintillation Properties				
Light Output, %Anthracene	67	64	55	68
Rise Time, ns	0.5	0.5	0.35	0.7
Decay Time (ns)	1.4	1.5	1.6	1.8
Pulse Width, FWHM, ns	1.2	1.3	1.3	2.2
Wavelength of Max. Emission, nm	391	391	370	408
Light Attenuation Length, cm*	NA**	140	NA**	140
Bulk Light Attenuation Length, cm	100	110	8	160
Atomic Composition				
No. H Atoms per cc ($\times 10^{22}$)	5.21	5.21	5.19	5.21
No. C Atoms per cc ($\times 10^{22}$)	4.74	4.74	4.71	4.74
Ratio H:C Atoms	1.100	1.100	1.102	1.100
No. of Electrons per cc ($\times 10^{23}$)	3.37	3.37	3.34	3.37

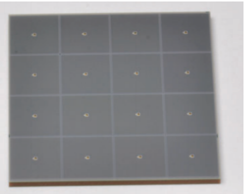
BC422Q

	Weight % Benzophenone					
	None*	**0.5**	**1.0**	**2.0**	**3.0**	**5.0**
Scintillation Properties						
Light Output, %Anthracene	55	19	11	5	4	3
Rise Time, ps	350	110	105	100	100	100
Decay Time (ns)	1.6	0.7	0.7	0.7	0.7	0.7
Pulse Width, FWHM, ps	1300	360	290	260	240	220
*BC-422						

Inquiring

MCP-PMT and SiPM





Hamamatsu
R10754-07-M16
27.6mm x 27.6mm
(23mm x 23 mm)

4 tubes on hand

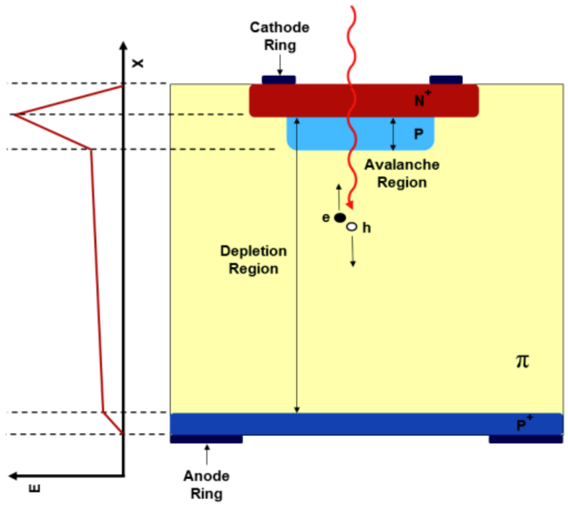
Photonis
XP85012
59mm x 59mm
(53mm x 53 mm)

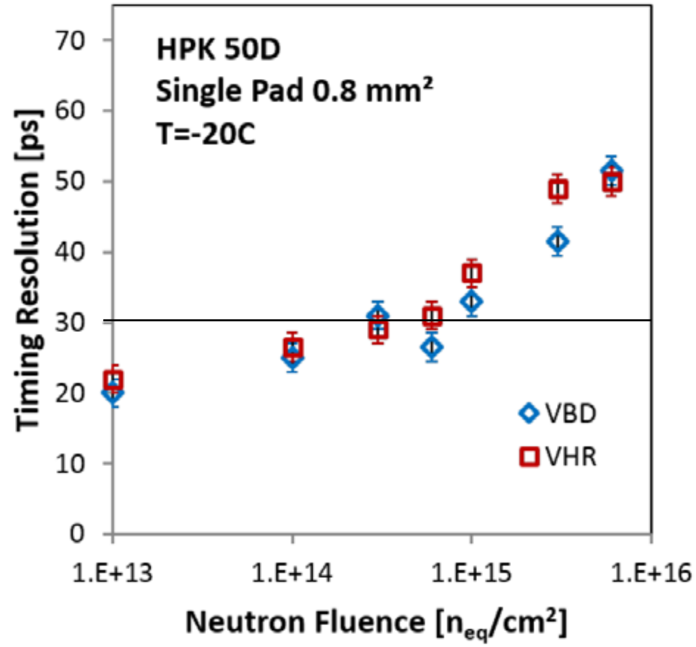
Inquiring

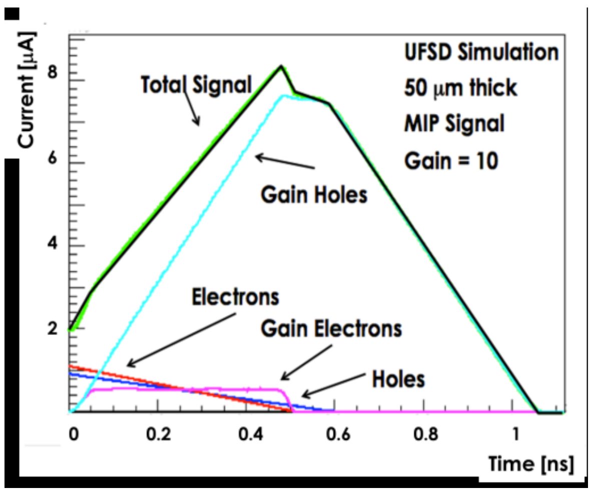
Hamamatsu
S14161-6050HS-04
25mm x 25mm

Inquiring

Low Gain Avalanche Detectors (LGAD)







ATLAS High-Granularity Timing Detector

Very active R&D at USTC, IHEP etc recently

Summary

- Plenty of physics opportunities with forward PID detector at NICA-MPD
- eTOF is a good choice of forward PID detector
- Excellent timing resolution is required for eTOF system
- High timing resolution MRPC + fast electronics looks promising
- Low-material T0 detector may also needed to replace current FFD, R&D planed

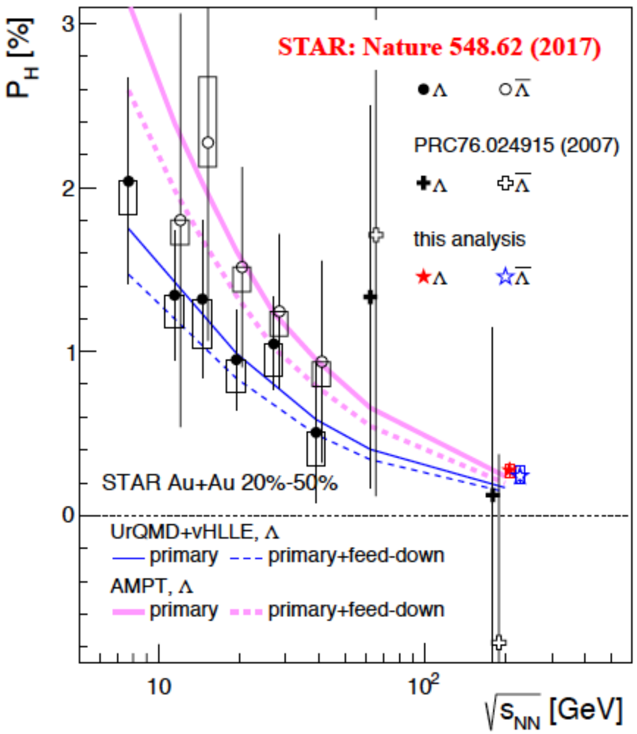
Thanks!

NICA-MPD Physics Working Groups

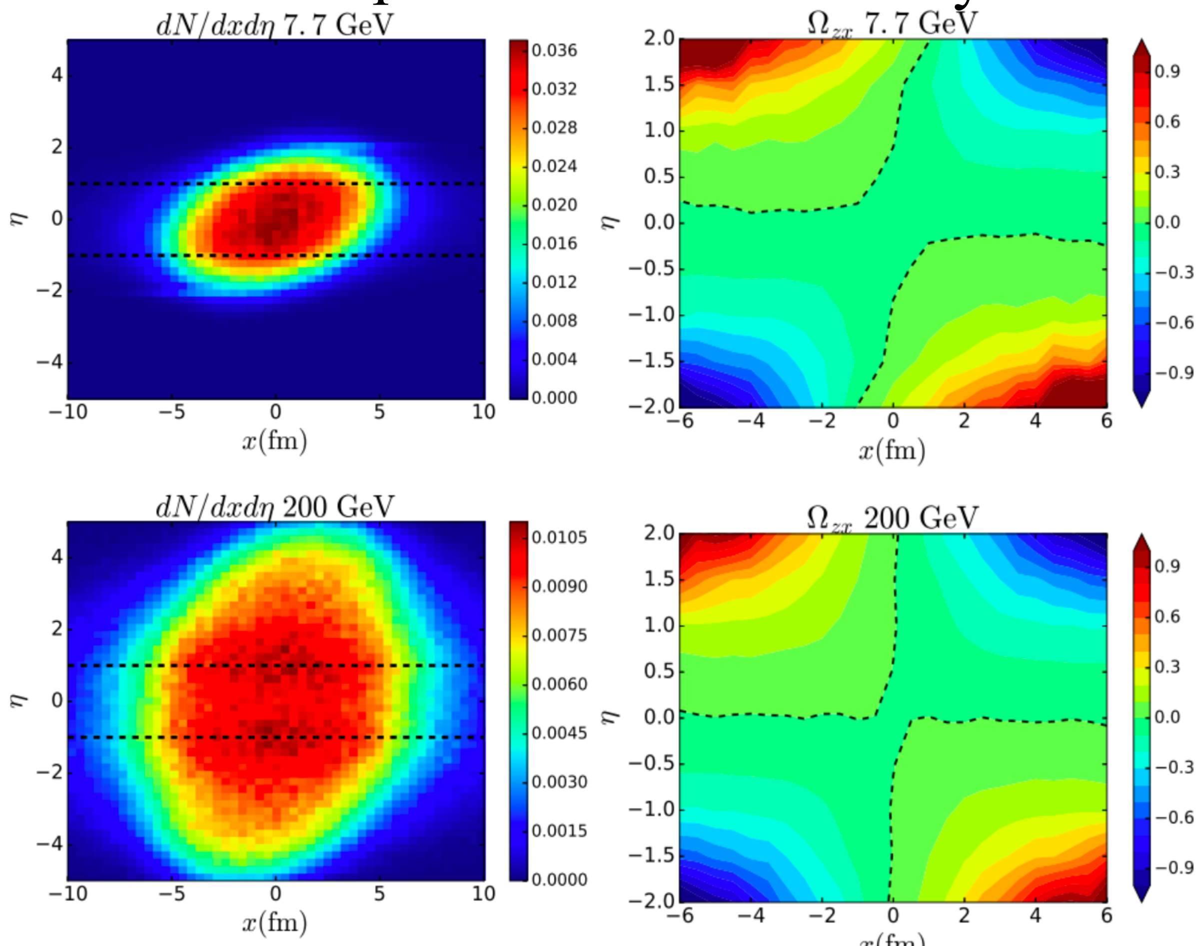
- PWG1 - "Global Observables"
  - Grigory Feofilov from SPSU, St. Petersburg
  - Alexander Ivashkin from INR RAS, Moscow
- PWG2 - "Spectra of light flavor and hypernuclei”
  - Vadim Kolesnikov from JINR
  - Xainglei Zhu from Tsinghua University, Beijing
- PWG3 - "Correlations and Fluctuations"
  - Konstantin Mikhaylov from NRC "Kurchatov Institute" - ITEP, Moscow, and JINR
  - Arkadiy Taranenko from MEPhI, Moscow
- PWG4 - "Electromagnetic Probes"
  - Victor Riabov from PNPI, Gatchina
  - Chi Yang from Shandong University, Qingdao
- PWG5 - "Heavy Flavor"
  - Wangmei Zha from USTC, Hefei
  - Alexander Zinchenko from JINR

Lambda Polarization at Forward

Change of rapidity affect the global polarization



Λ freeze-out position × Vorticity



Significant energy dependence observed and explained

H. Li, L. Pang, Q. Wang and X. Xia, PRC96, 0549082 (2017)