Physics opportunities and status of eTOF at STAR

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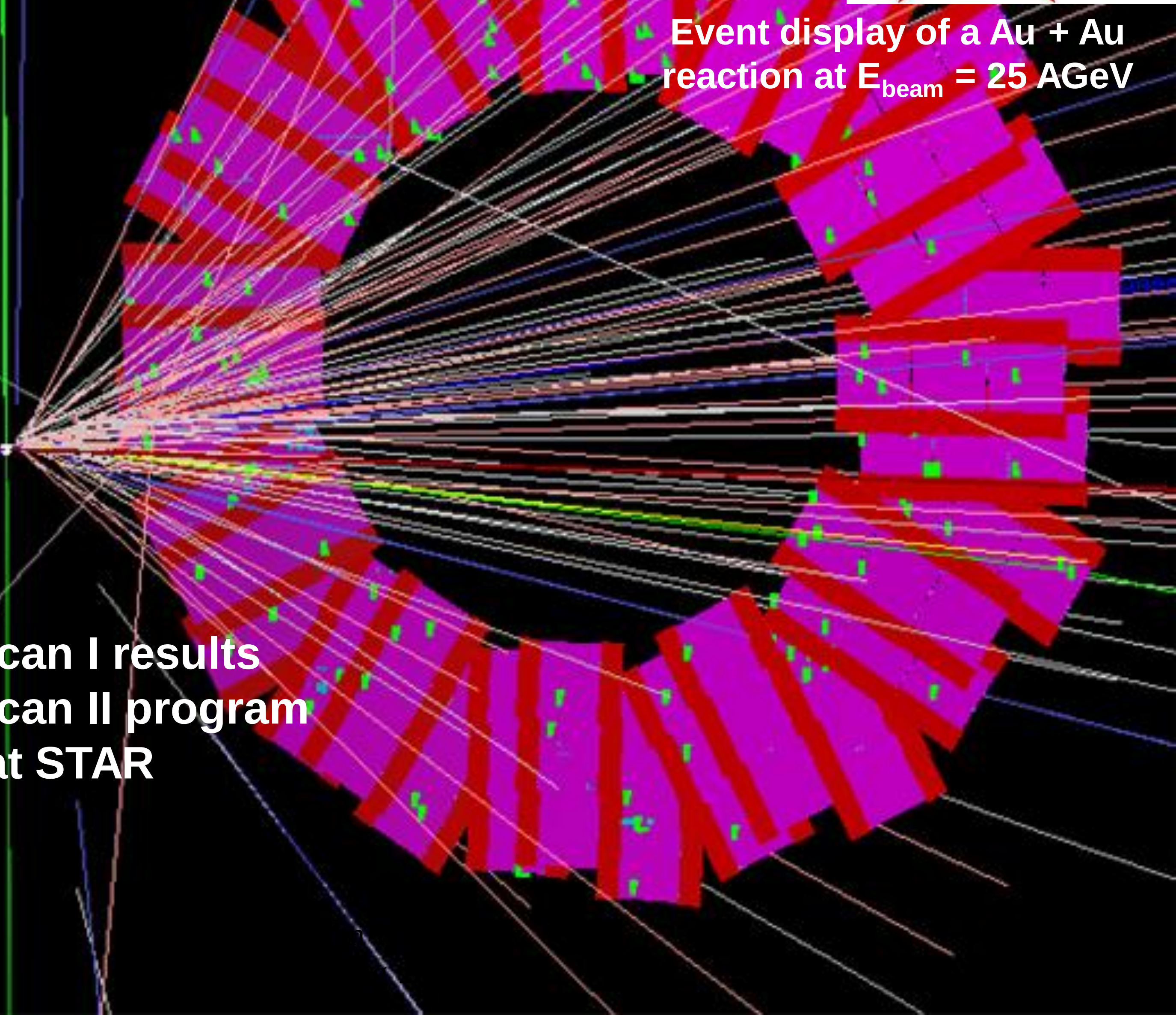


Event display of a Au + Au reaction at E_{beam} = 25 AGeV

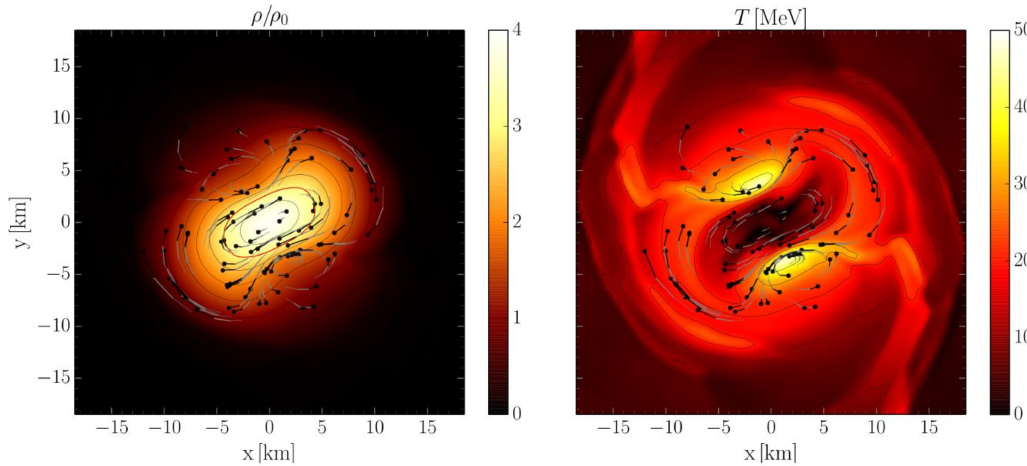
Outline

- Introduction
- Beam Energy Scan I results
- Beam Energy Scan II program
- eTOF upgrade at STAR
- Summary

Neutron star merger snd heavy ion collisions

GW170817

M. Hanauske et al., J. Phys.: Conf. Ser. 878 012031



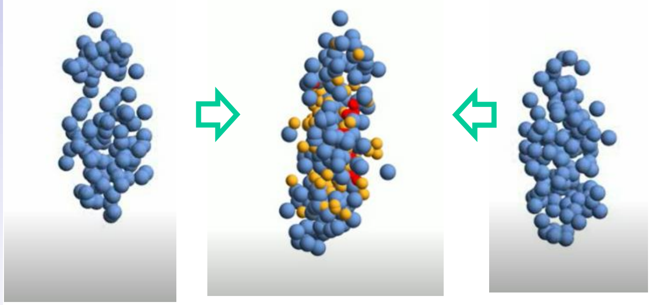
Neutron star merger

Temperature
T < 50 MeV

Density
$\rho < 2 - 6\ \rho_0$

Reaction time
(GW170817)
T ~ 10 ms

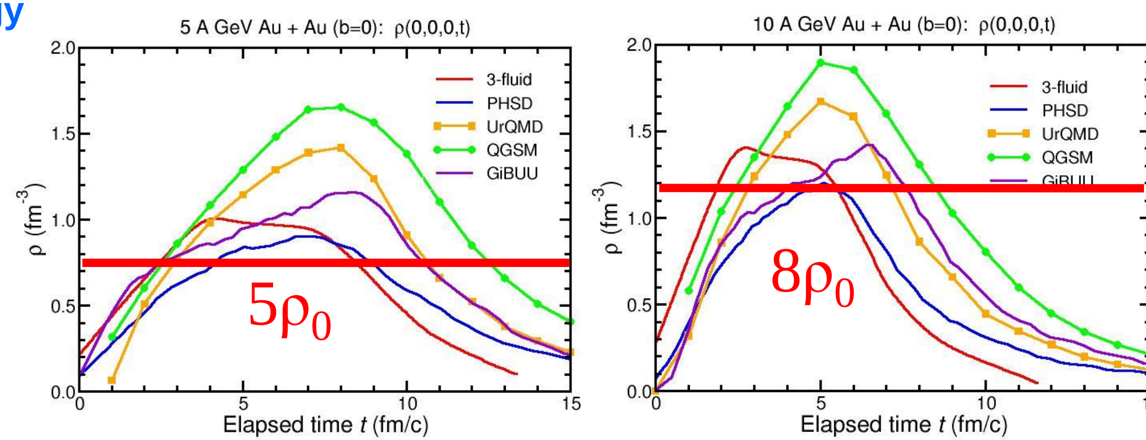
Heavy ion collisions at „low“ energy



Temperature, T < 120 MeV,

Density, $\rho < 8\rho_0$,

Reaction time $t \sim 10^{-23}$ s



I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

The QCD phase diagram

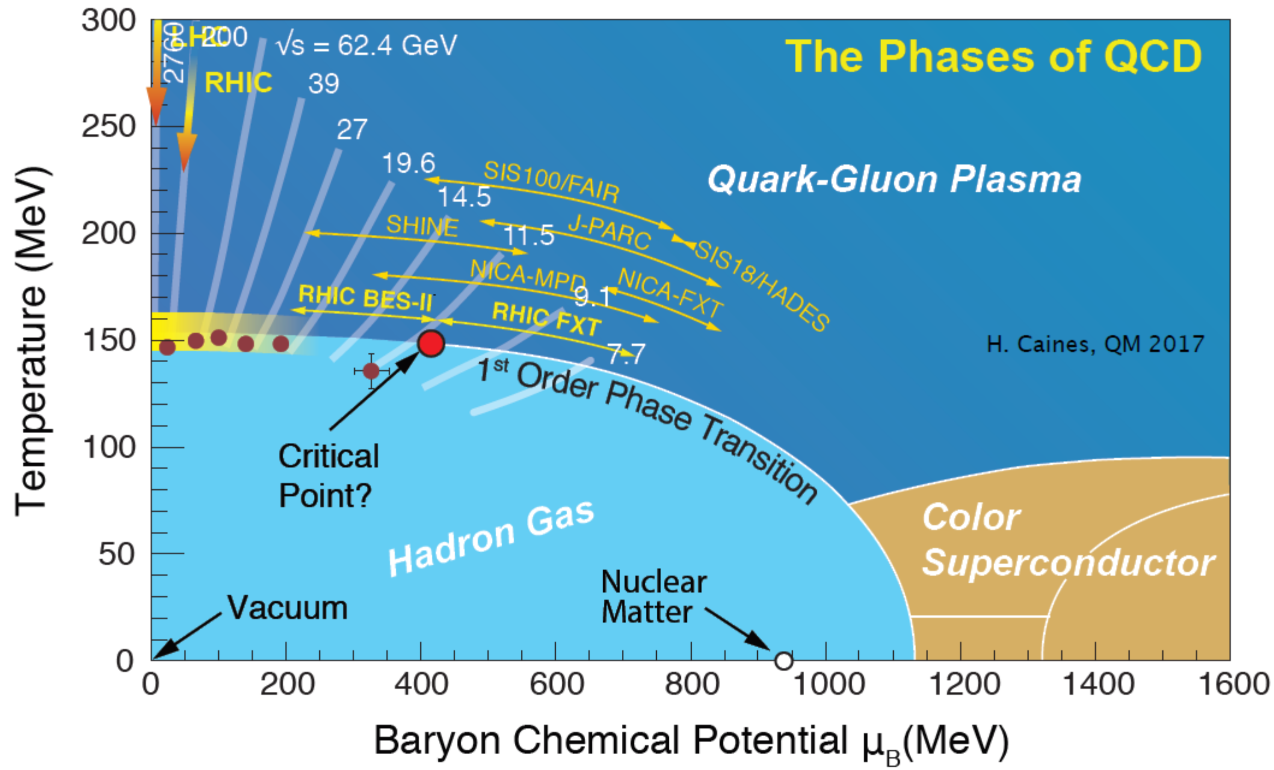
Observables for dense baryonic matter

Onset of deconfinement
- Strangeness enhancement
- NCQ scaling of elliptic flow
- High p_t suppression

1^{st} order phase transition
- Directed flow v_1
- Average transverse mass
- Volume and tilt angle of HBT

Critical point
- Higher moments
- Particle ratio fluctuation

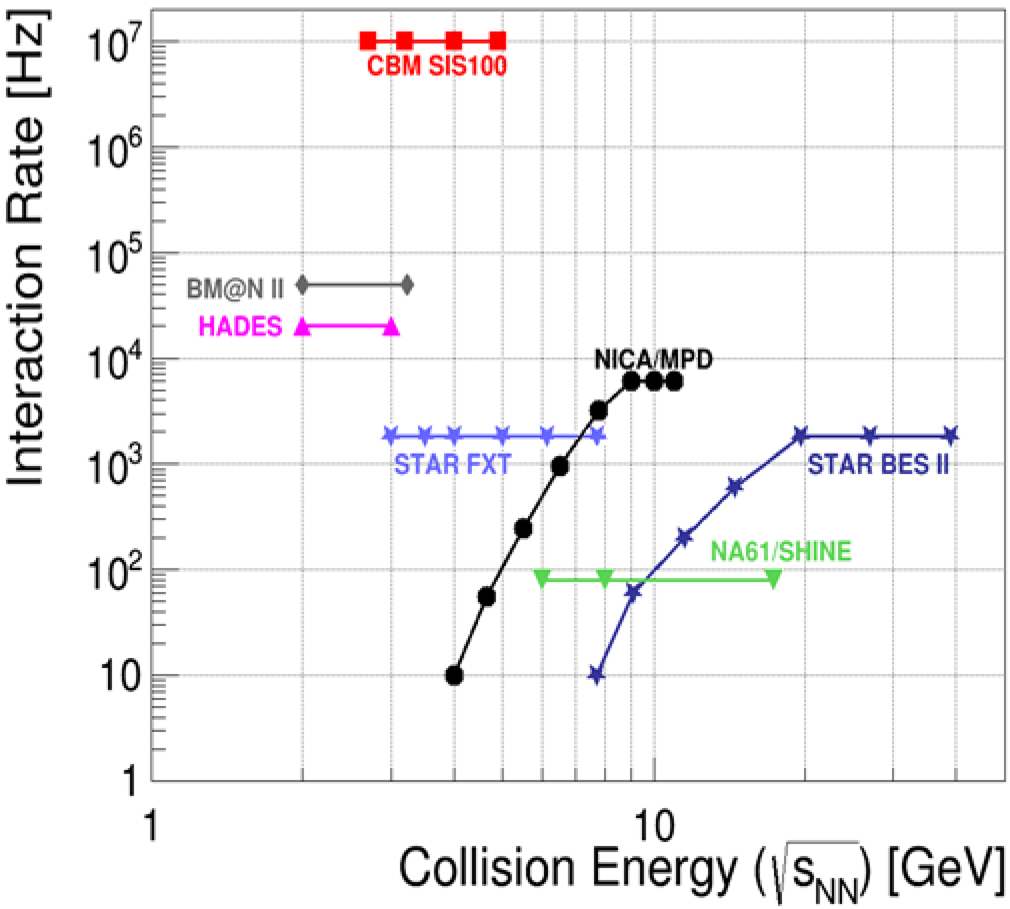
Equation of state (EoS)
- Particle yields/ratios
- Rapidity distribution of part.
- Flow (v_1 , v_2)



Strange states of matter
- Hypernuclei

Chiral symmetry restoration
- Di-lepton
- CME

Rate capability of HI experiments



STAR BES I: 2010 – 2017
7.7 GeV – 200 GeV

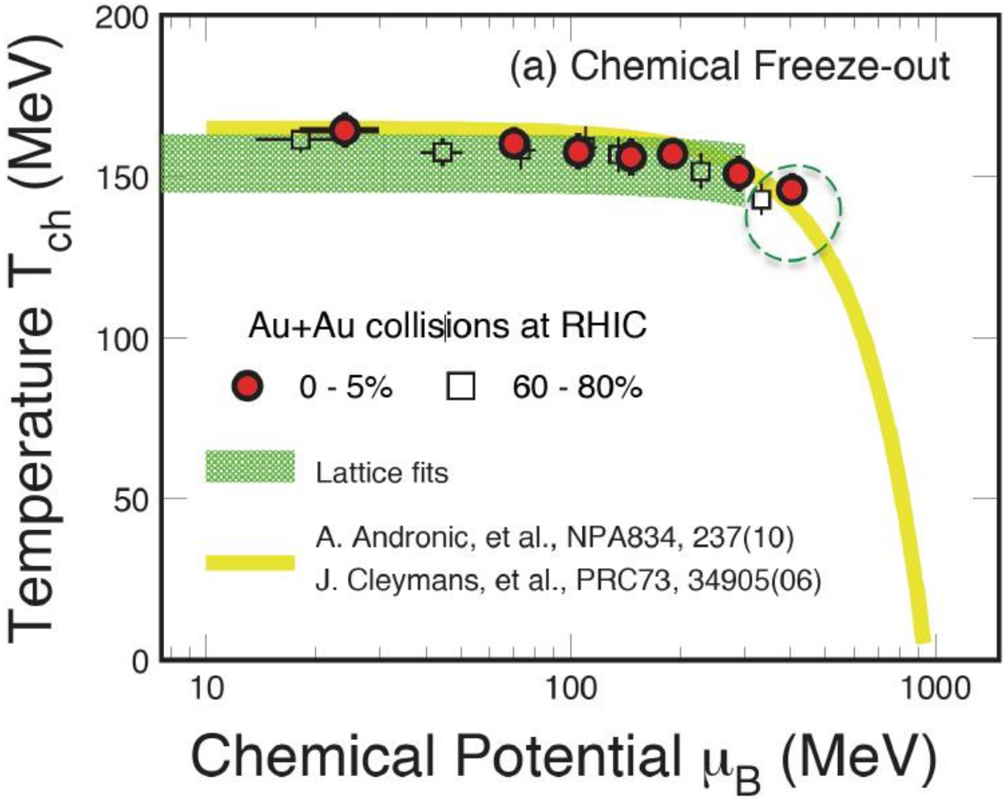
STAR BES II: 2019 – 2021
Collider: 7.7 GeV – 19.6 GeV
Fix Target: 3 GeV – 7.7 GeV

- At least 100 M Events for each energy required in order to do multi-differential measurement
- 2 days for each FT energy
- Data rate is limited by the DAQ

CBM: 2025 – ???
2.7 GeV – 4.5 GeV

BES I program

$\sqrt{s_{NN}}$ (GeV)	Events (10^6)	Year
200	350	2010
62.4	67	2010
54.4	**300**	**2017**
39	39	2010
27	70	2011
19.6	36	2011
14.5	20	2014
11.5	12	2010
7.7	4	2010



Statistical Hadronisation Model

P. Braun-Munzinger, J. Stachel, et al. Phys. Lett. B344(1995)43

Explored μ_B range: 20-420 MeV

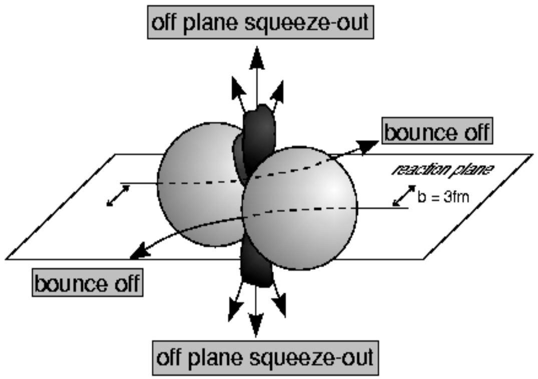
$$n_i(\mu,T) = \frac{N_i}{V} = -\frac{T}{V}\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2}\int \frac{p^2 dp}{e^{\frac{E_i-\mu_i}{T}} \pm 1}$$

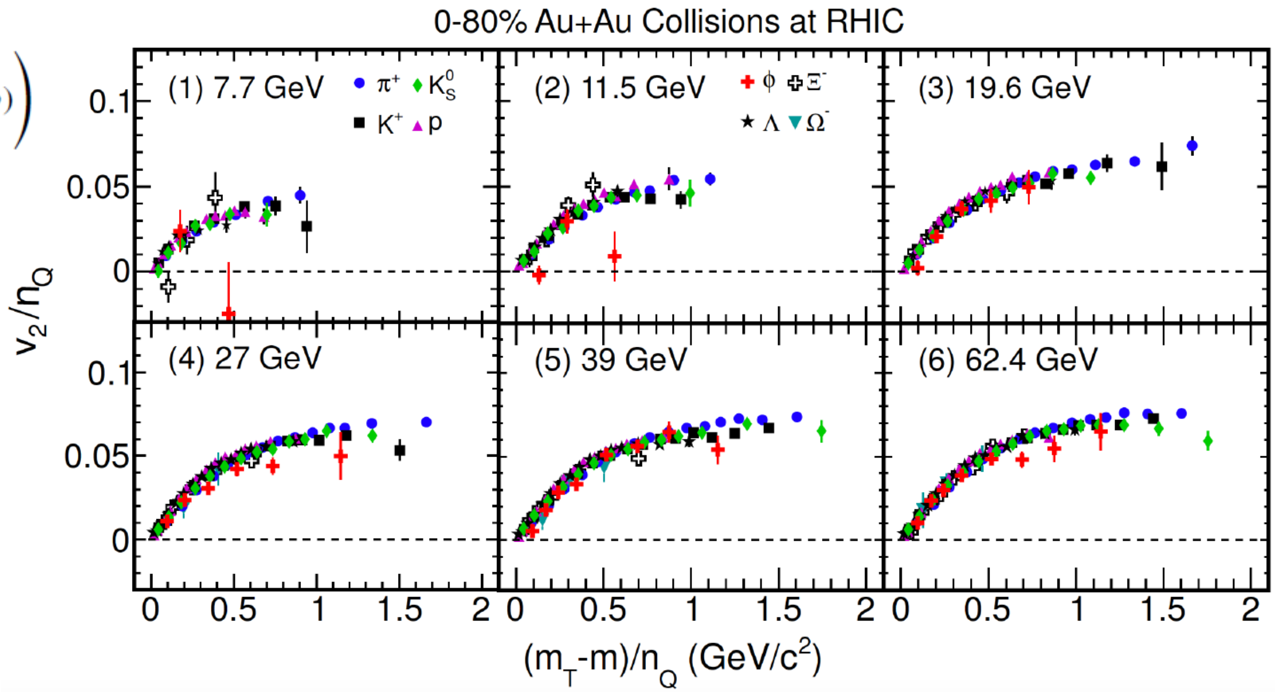
$$\mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_{3,i}$$

Onset of deconfinement NCQ scaling of elliptic flow

- Directed v_1 and elliptic v_2 flow is generated in the very early phase in the collision
- NCQ*-scaling indicates that collectivity is established on the partonic level
- ϕ v_2 deviates from NCQ-scaling below 19.6 GeV: Turn off QGP?
- ϕ meson has significantly lower collision cross section in hadronic matter

$$\frac{d^2N}{dy\,d\phi} = \frac{dN}{dy}\left(1 + \sum_{n=1}^{\infty} 2\, v_n(y)\cos(n\phi)\right)$$

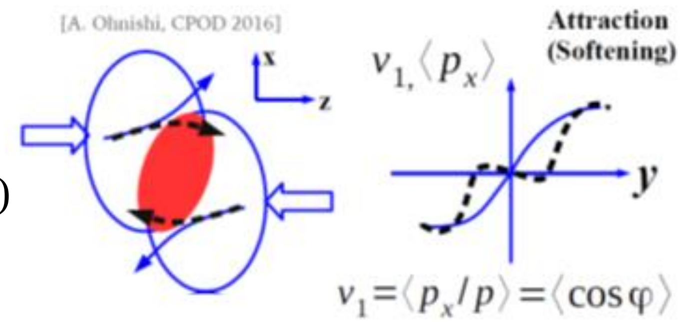


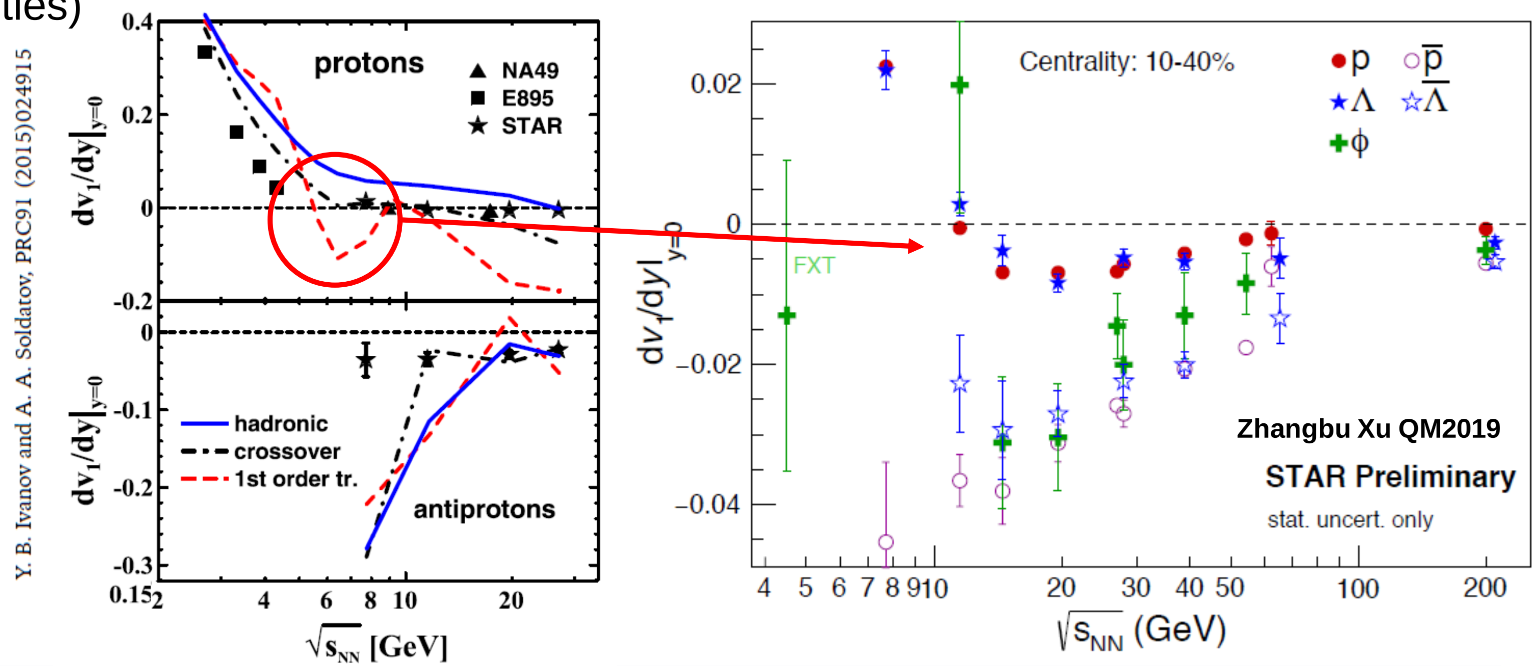


* Number of Constituent Quarks

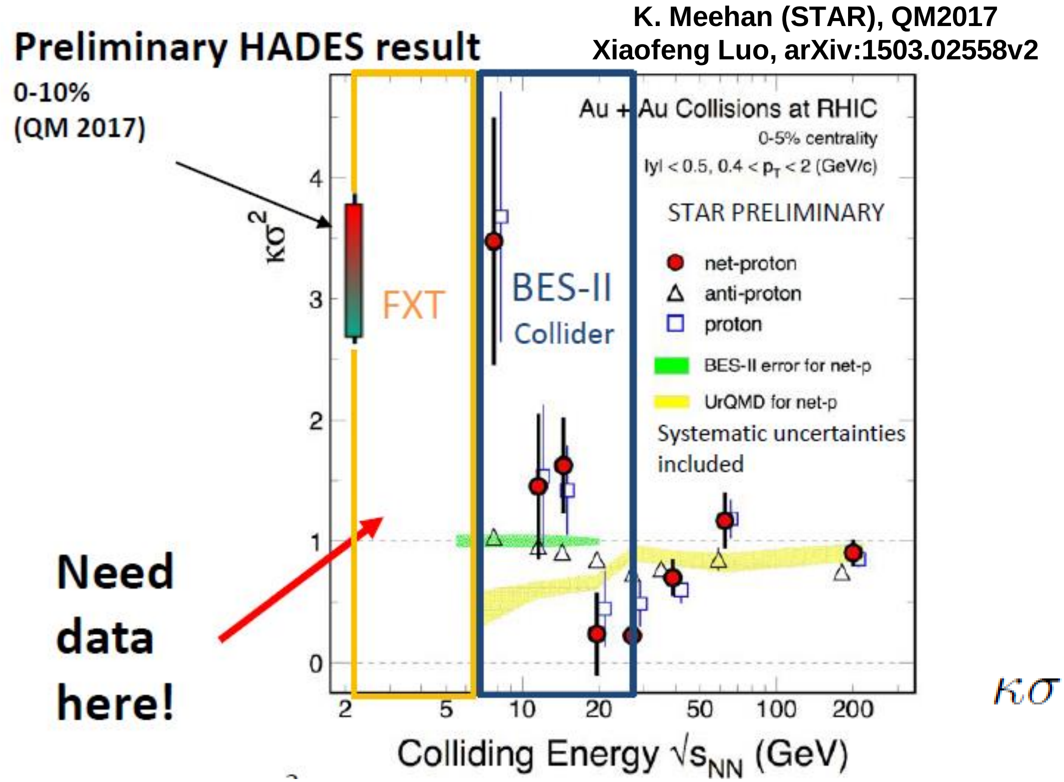
1st order phase transition
Directed flow

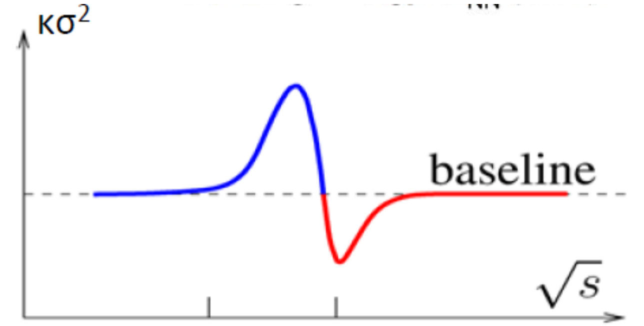
- Net baryons show hints of a minimum and double-sign change indicative of a softening equation of state
- A double-sign change is predicted by hydro. models
  H. Stöcker CPOD2007, Y. Nara et al., PRC 94 034906 (2016)
- STAR detector upgrade (reduction of systematic errors) and RHIC luminosity increase (reduction of statistical uncertainties)





Critical Point - fluctuations of conserved quantities





M. Stephanov. J. Physics G.: Nucl. Part. Phys. ***38*** (2011) 124147

$$\delta N = N - \langle N \rangle$$

$$C_2 = \langle (\delta N)^2 \rangle ,$$

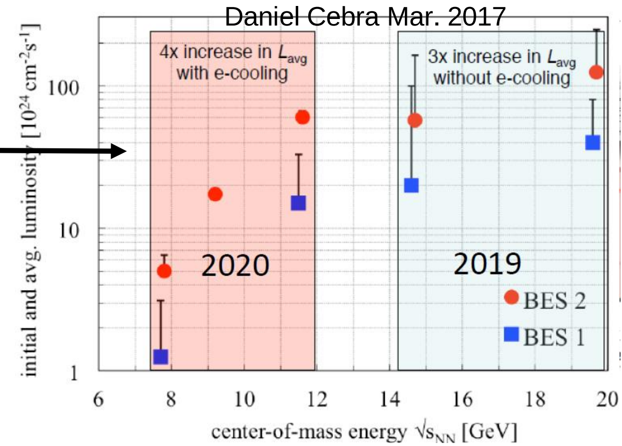
$$C_4 = \langle (\delta N)^4 \rangle - 3 \langle (\delta N)^2 \rangle^2$$

$$\kappa\sigma^2 = \frac{C_4}{C_2} ; C_4 \propto \xi^7 ; \kappa\sigma^2 = \frac{\chi^{(4)}}{\chi^{(2)}/T^2}$$

- Event-by-event fluctuations of conserved quantities (net-charge, net-baryon, net-strangeness)
- Moments of net-particle multiplicity distributions can be related to susceptibilities of conserved charges calculated on the lattice [P. Alba et al., Phys. Rev. C 92, 064910 (2015)]
- A no non-monotonic behavior in net-proton kurtosis times the variance observed
- Large (mainly) statistical uncertainties – need more statistics and data at lower energies

BES II program

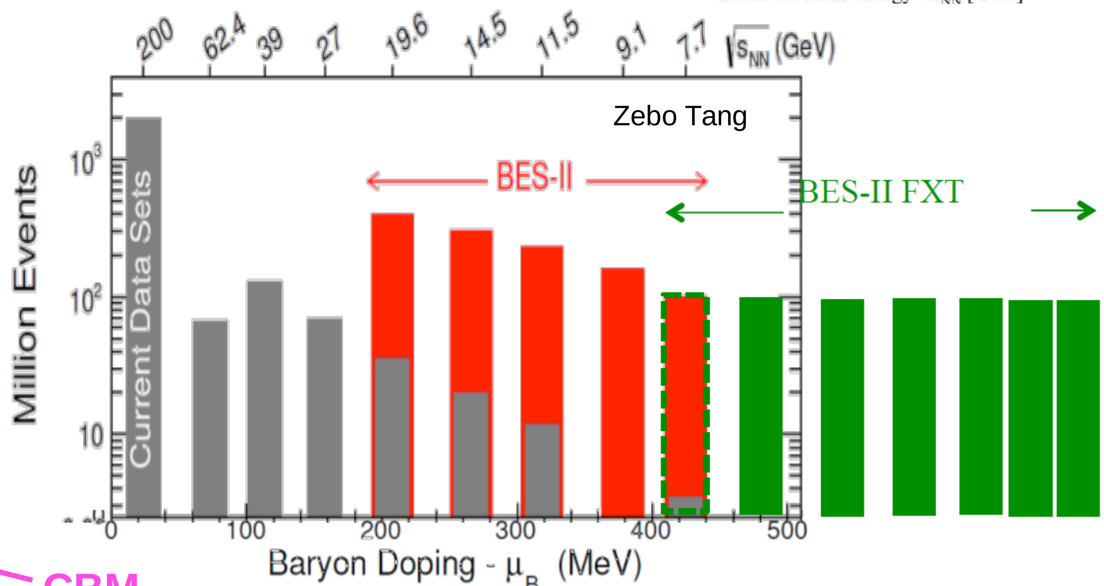
- Most BES I measurements limited by statistics and large systematic uncertainties
- BES II will significantly improve statistics (electron cooling and upgraded detector)
- Fix target program will extend μ_B coverage to about 720 MeV
- CBM covers a big part of BES II fix target but with much higher statistics => investigation of rare probes



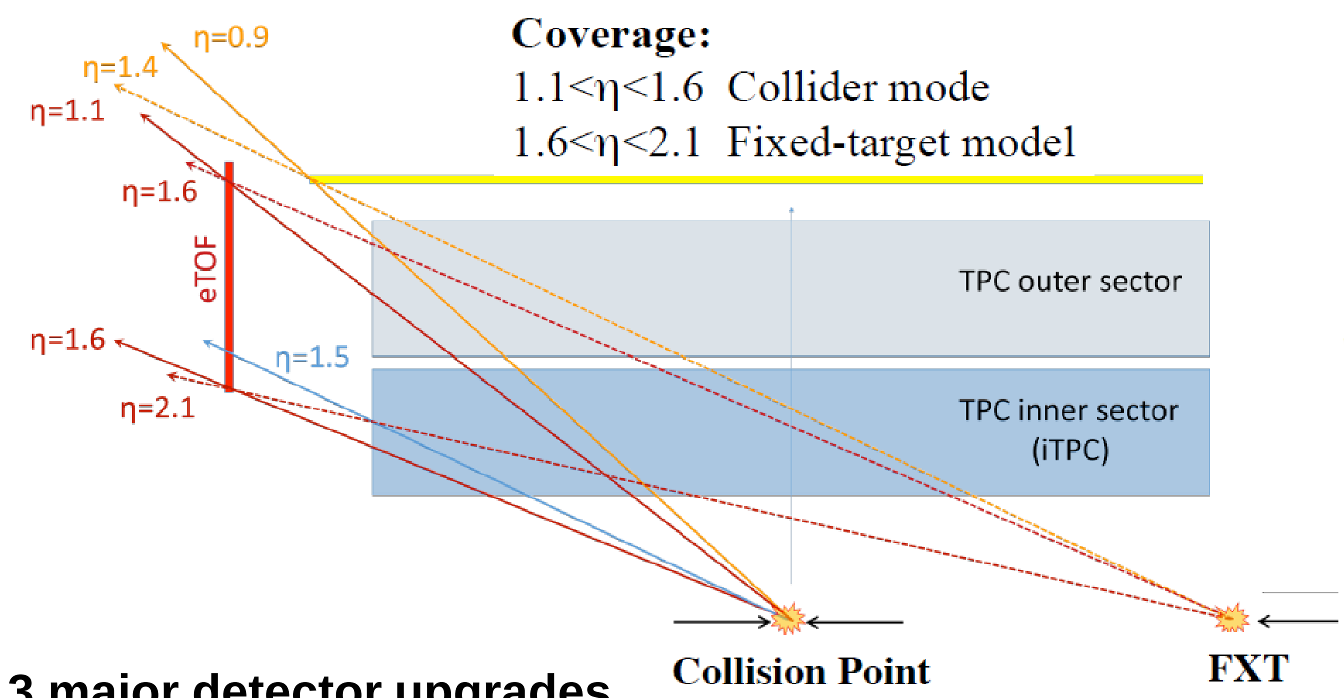
Collider Energy	Fixed-Target Energy	Single beam AGeV	Center-of-mass Rapidity	μ_B (MeV)
62.4	7.7	30.3	2.10	420
39	6.2	18.6	1.87	487
27	5.2	12.6	1.68	541
19.6	4.5	8.9	1.52	589
14.5	3.9	6.3	1.37	633
11.5	3.5	4.8	1.25	666
9.1	3.2	3.6	1.13	699
7.7	3.0	2.9	1.05	721

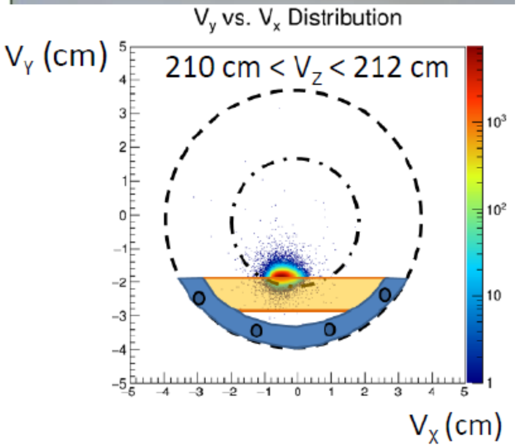
CBM

2019
2020



eTOF acceptance in collider and fixed target mode





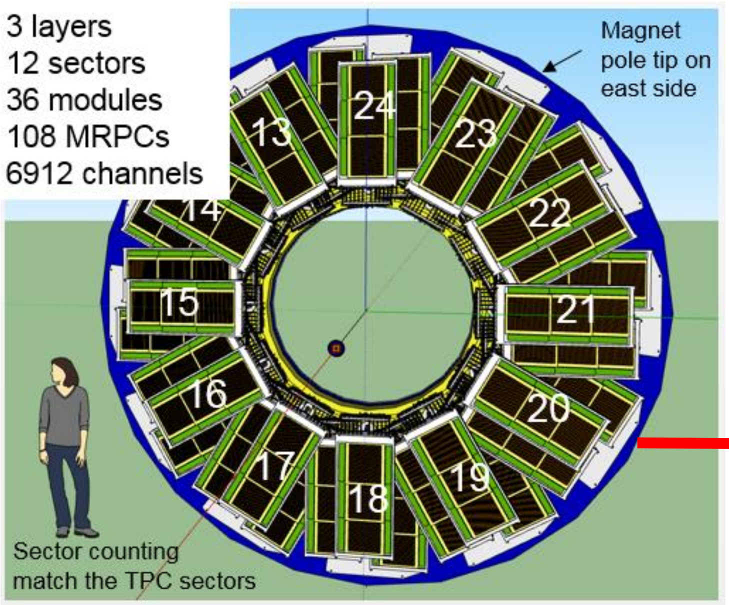
3 major detector upgrades

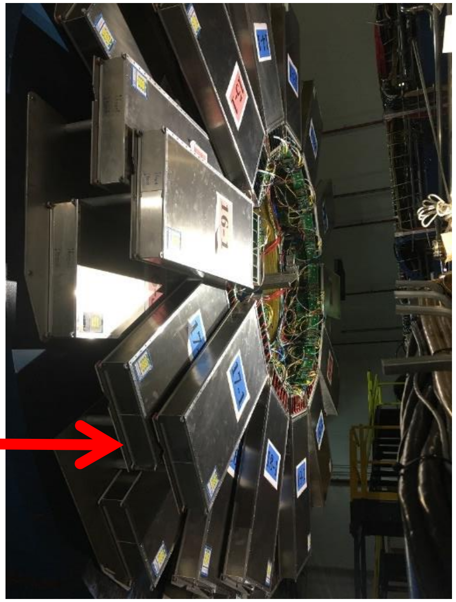
iTPC upgrade	EPD upgrade	eTOF upgrade
Continuous pad rows Replace all inner TPC sectors	**Replace Beam Beam Counter**	**Add CBM TOF modules and electronics (FAIR Phase 0)**
|η|<1.5 (was 1.0)	**2.1<|η|<5.1**	**-1.6<η<-1.1**
p_T >60 MeV/c (was 150MeV/c)	Better trigger & b/g reduction	Extend forward PID capability
Better dE/dx resolution Better momentum resolution	Greatly improved Event Plane info (esp. 1st-order EP)	Allows higher energy range of Fixed Target program
Fully operational in 2019	**Fully operational in 2018**	**Fully operational in 2019**

FAIR Phase 0 – eTOF@STAR

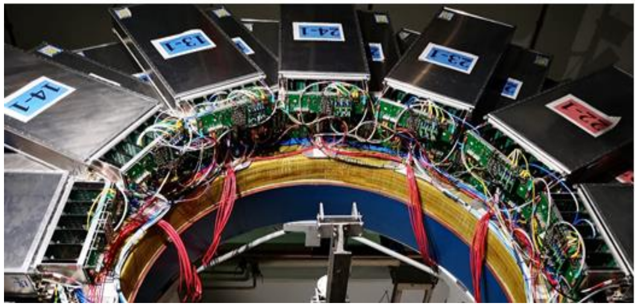
What is the eTOF project arXiv:1609.05102v

- eTOF project is a joint project between CBM and STAR
- eTOF project is part of the BESII detector upgrade at STAR
- It comprises the installation, commissioning and operation of CBM TOF modules positioned at the east pole tip of the STAR apparatus during the BESII campaign and physics analysis of data obtained with eTOF
- CBM institutions involved: CCNU, GSI, TSU, TUD, UHD, USTC (PL Ingo Deppner)

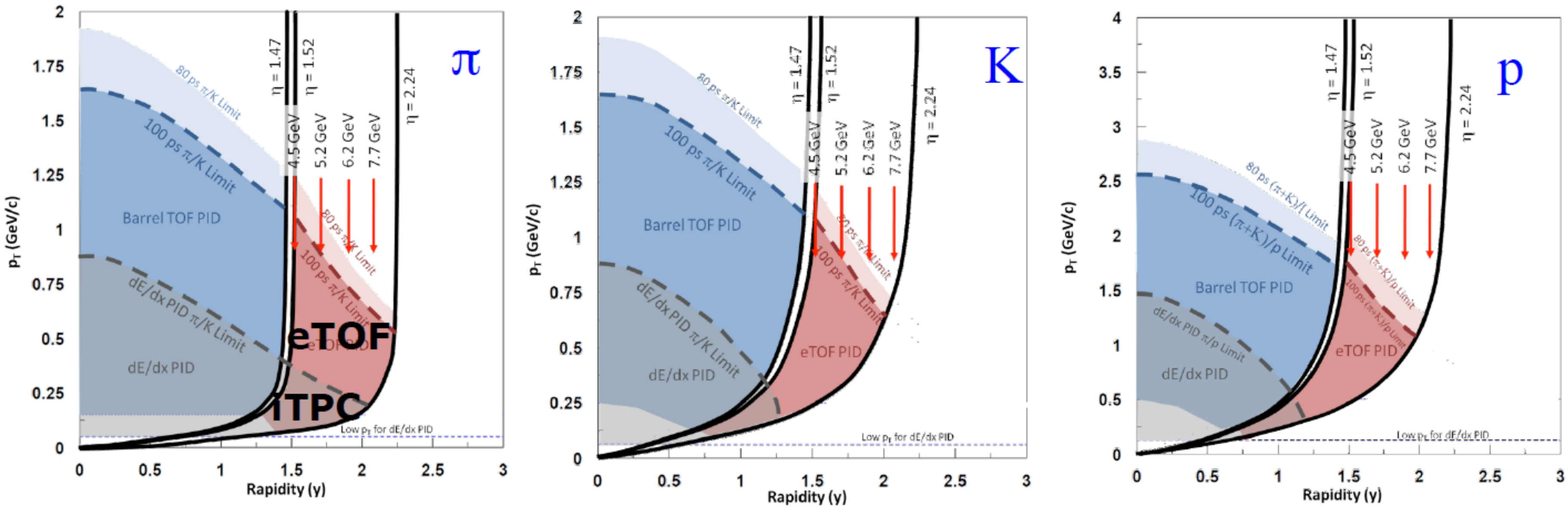




Full installation in Nov. 2018

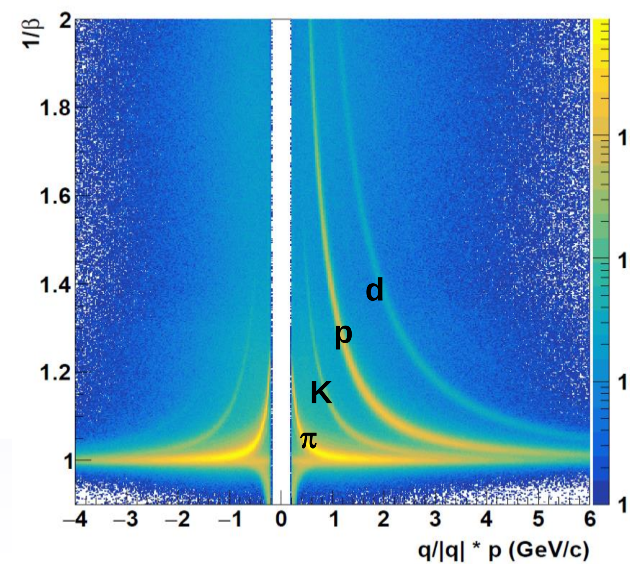


Acceptance in fixed target mode



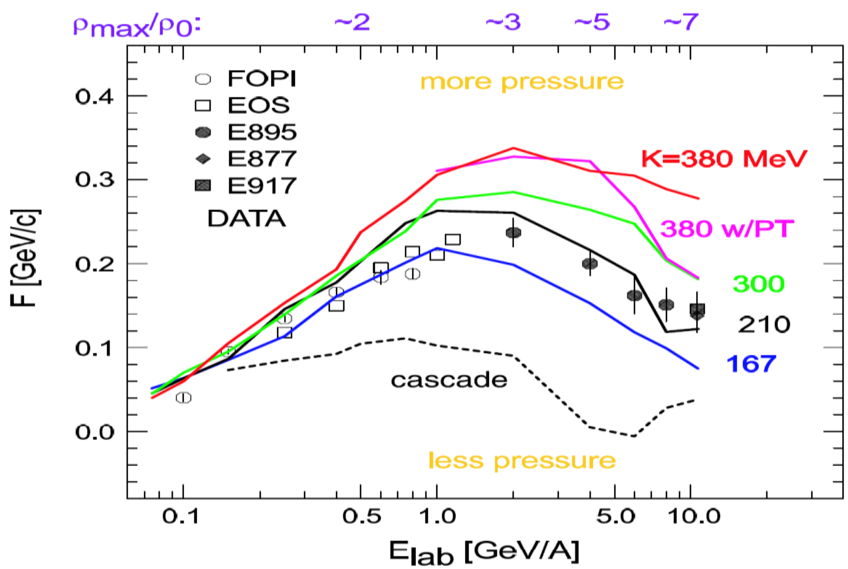
- eTOF is essential for fix target program for $\sqrt{s}$ > 4.5 GeV
- It covers mid-rapidity region for higher $\sqrt{s}$ energies
- π/K separation up to 2.5 GeV/c (current status)

iTPC + eTOF: 1.52 < η < 2.24

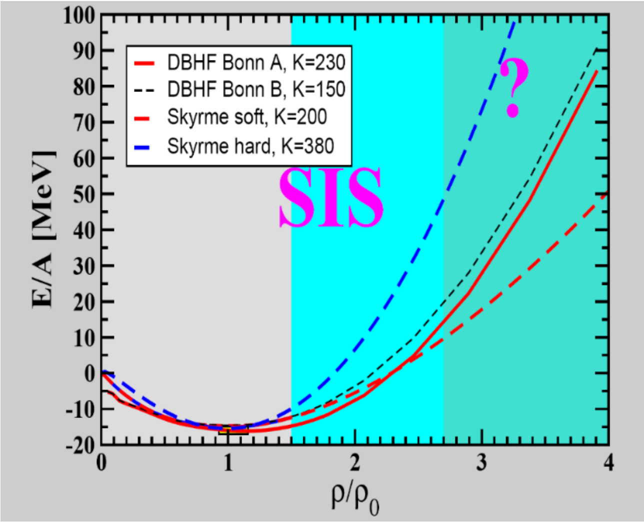


Equation of state

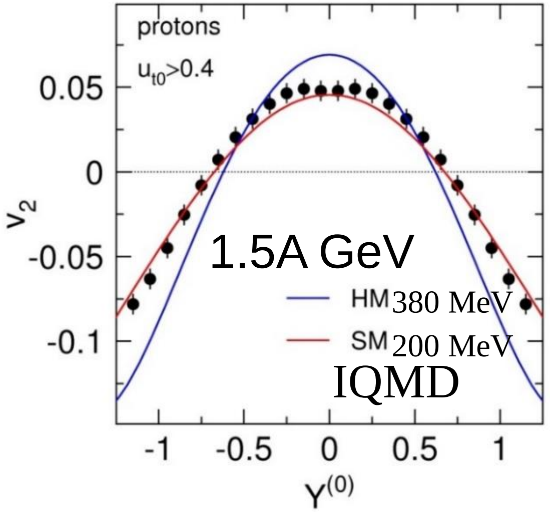
P. Danielewicz, R. Lacey, W.G. Lynch,
nucl-th/0112006 (2001), Science 298 (2002) 1592



C. Fuchs, Prog. Part. Nucl. Phys. 56 (2006) 1



W. Reisdorf et al.,Nucl. Phys. A 876 (2012) 1

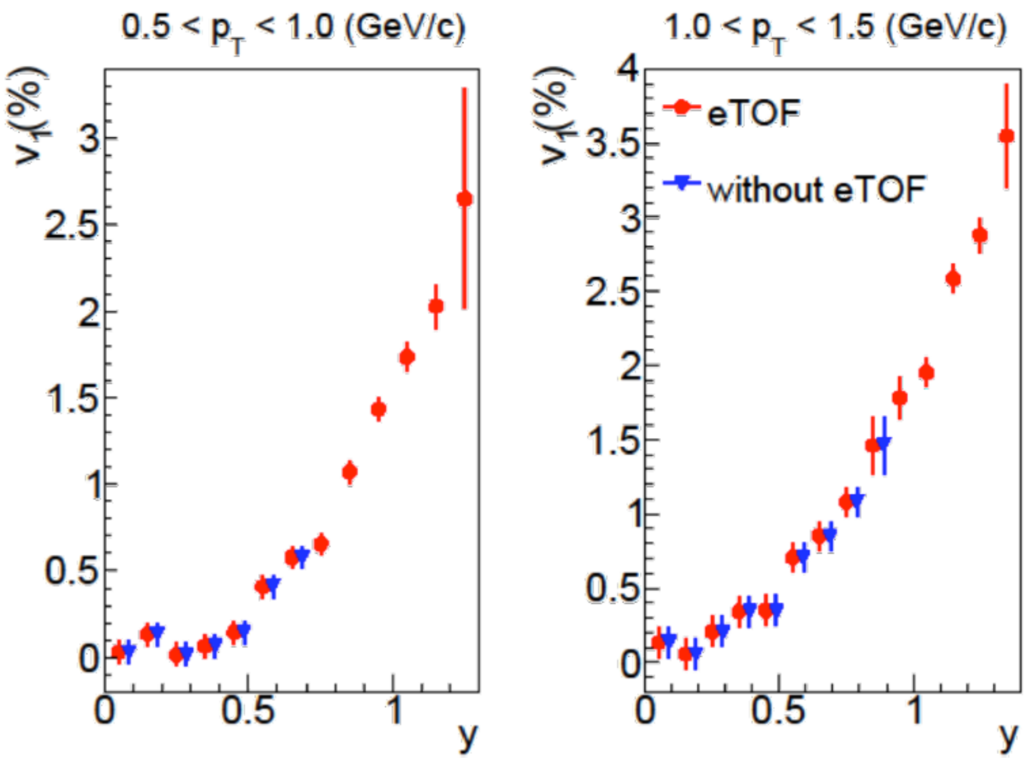


- At SIS18 energies (subthreshold kaons, flow) favor a soft EoS
- At higher energy no consistency yet
- Size of available data sample: ~ 10^6 events
- Soft EOS does not to allow for a neutron star with 2 $M_\odot$
- Proton collective flow measurements can be improved with BES II

Directed flow

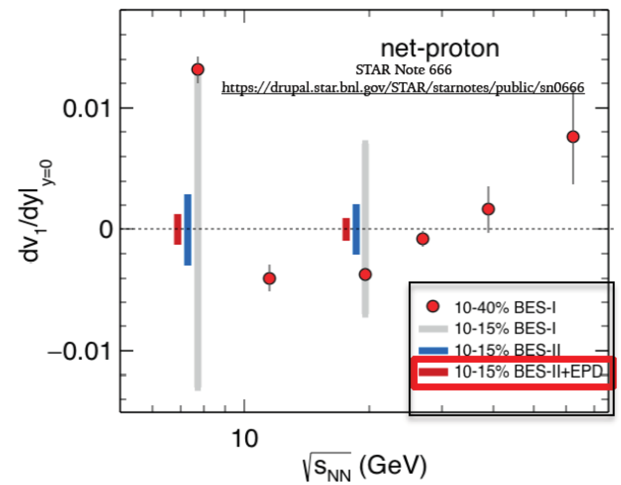
arXiv:1609.05102v

UrQMD events at 19.6 GeV



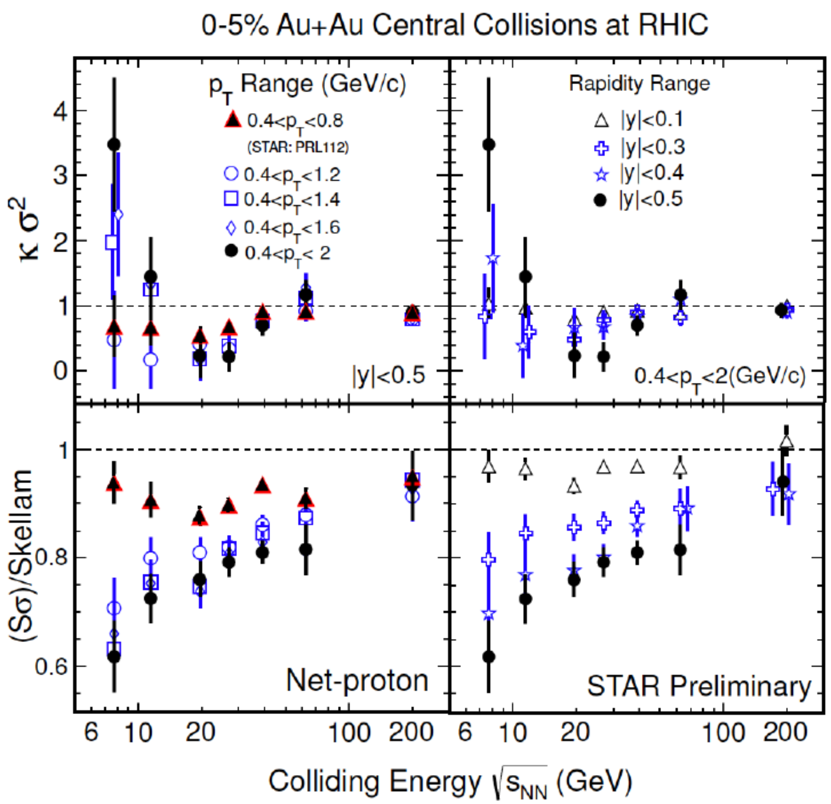
EPD upgrade

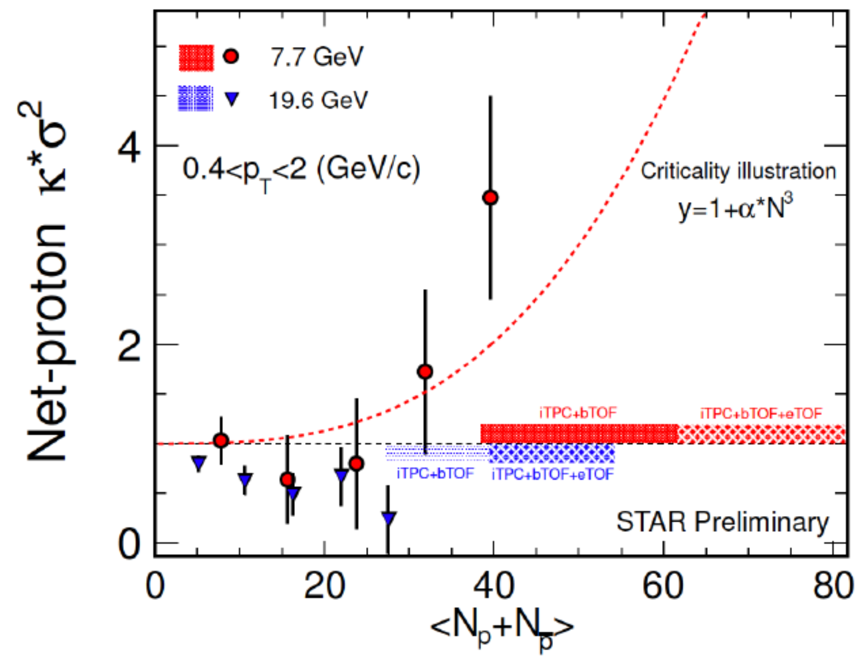
significantly better event plane resolution than BBC



- eTOF can significantly extend the rapidity coverage
- EoS softening would occur at different energies for forward rapidities

Critical point



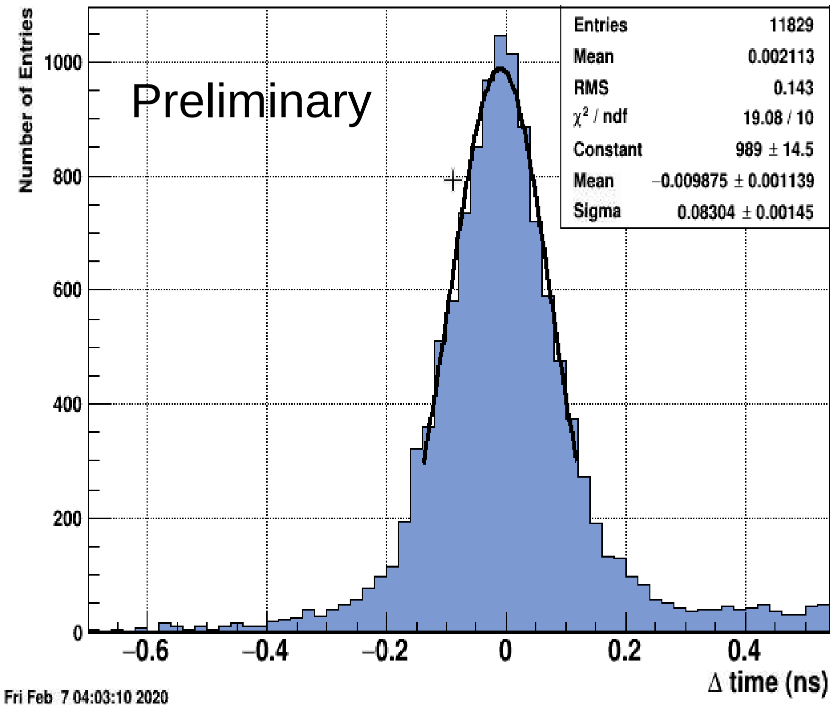


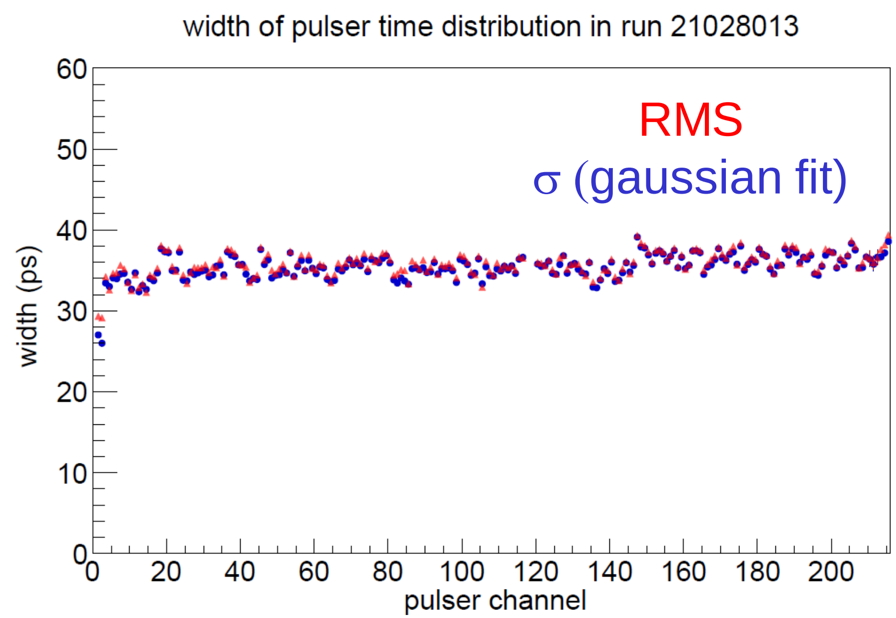
- 7.7 GeV is the lowest realistic collider energy
- Critical Point studies need results below 7.7 GeV
- FXT program provides control measurements for critical point and onset of deconfinement
- FXT span the region between the current SIS program and the RHIC BES program

eTOF performance

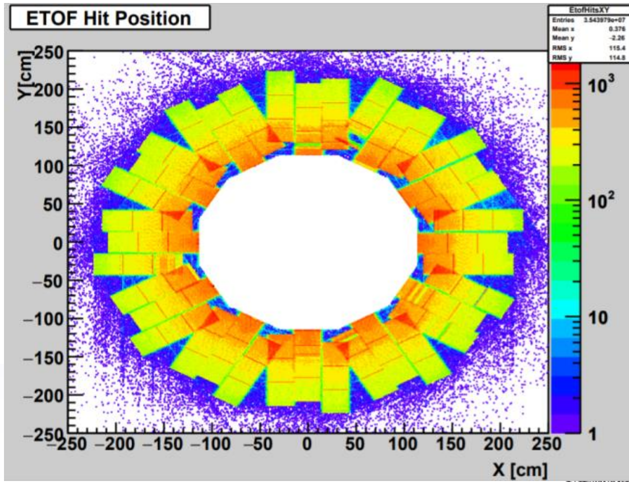
CBM ToF

System time resolution





- System synchronization on the level of 35 ps
- System time resolution measured with fast pions
- System time resolution in the order of 85 ps



Summary

- BES-I results hint at critical behavior and maybe a 1st order phase transition
- most measurement were limited by statistics and with large systematic uncertainties
- BES II with increased statistics (electron cooling) and upgraded detectors
- The FXT program will allow to extend the BES-II down to $\sqrt{s_{NN}}$ =3.0 GeV
- Flow measurement as an indication on pressure and in-medium effects
- eTOF upgrade (in combination with iTPC) opens the PID capability toward higher rapidity's and facilitates FXT program at higher energies up to $\sqrt{s_{NN}}$ = 7.7 GeV
- eTOF upgrade successful (time resolution about 80 ps)
- Many more interesting observable like HBT, high-p_T suppression, di-leptons, (sub threshold produced) multi-strange hyperons, hypernuclei,…

Thank you for your attention

Contributing CBM institutions:

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USTC Hefei,
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Großgeräte
der physikalischen
Grundlagenforschung

FAIR — Facility for Antiproton and Ion
Research in Europe

Phase 0
Research Program

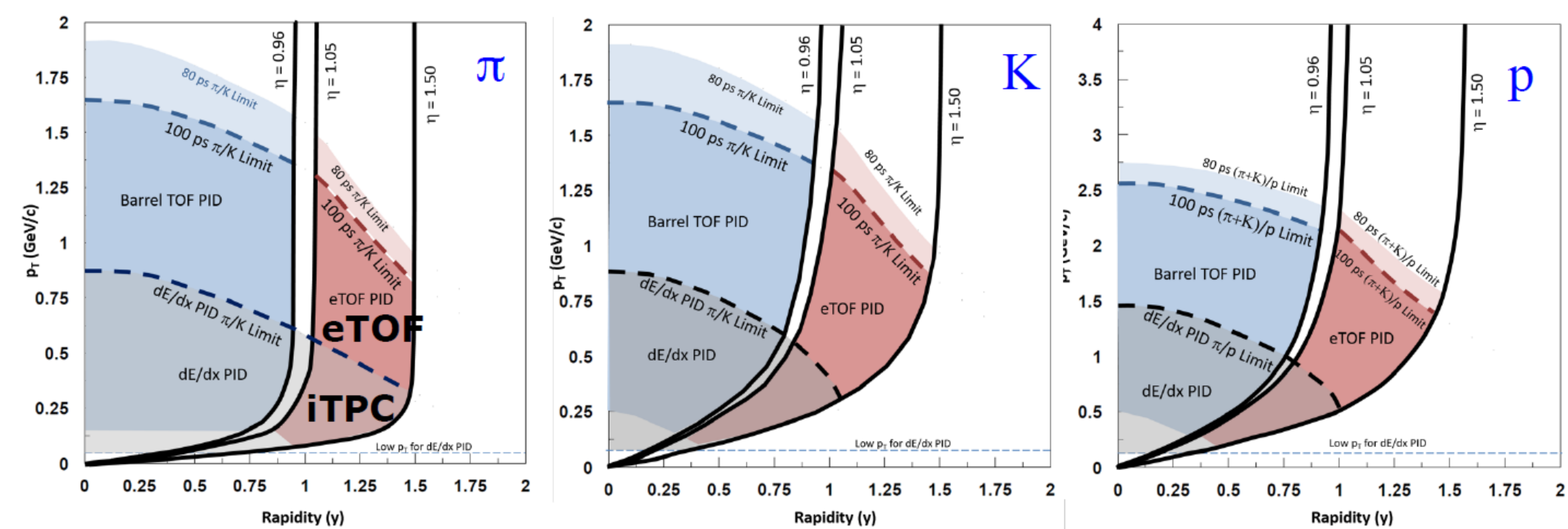
Backup Slides

BES II program

Daniel Cebra

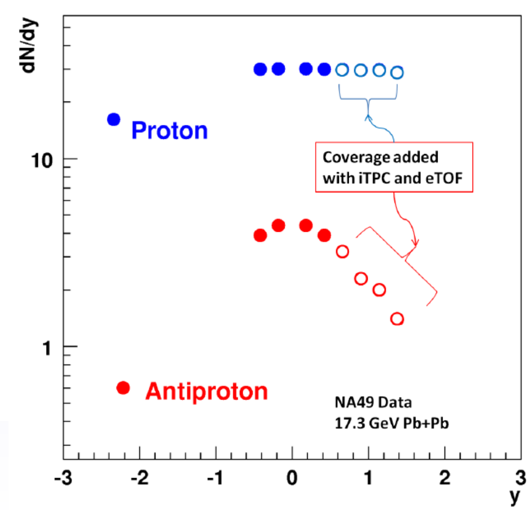
	Observables	7.7	9.1	11.5	14.5	19.6
	Collision Energies (GeV):	**7.7**	**9.1**	**11.5**	**14.5**	**19.6**
	Chemical Potential (MeV):	**420**	**370**	**315**	**260**	**205**
	Observables	Millions of Events Needed				
QGP	R_{CP} up to p_T 4.5 GeV	NA	NA	160	92	22
QGP	Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400
QGP	Local Parity Violation (CME)	50	50	50	50	50
1st P.T.	Directed Flow studies (v_1)	50	75	100	100	200
1st P.T.	asHBT (proton-proton)	35	40	50	65	80
C.P.	net-proton kurtosis ($\kappa\sigma^2$)	80	100	120	200	400
EM Probes	Dileptons	100	160	230	300	400
	Number of Events	**100**	**160**	**230**	**300**	**400**
	Weeks of Beams	**12**	**9.5**	**5.0**	**5.5**	**4.5**

Acceptance in collider mode



- Extends rapidity range -> allows a change in μ_B
- Complementary to iTPC upgrade -> improve PID in forward rapidity
- Improves yield of protons -> better kurtosis

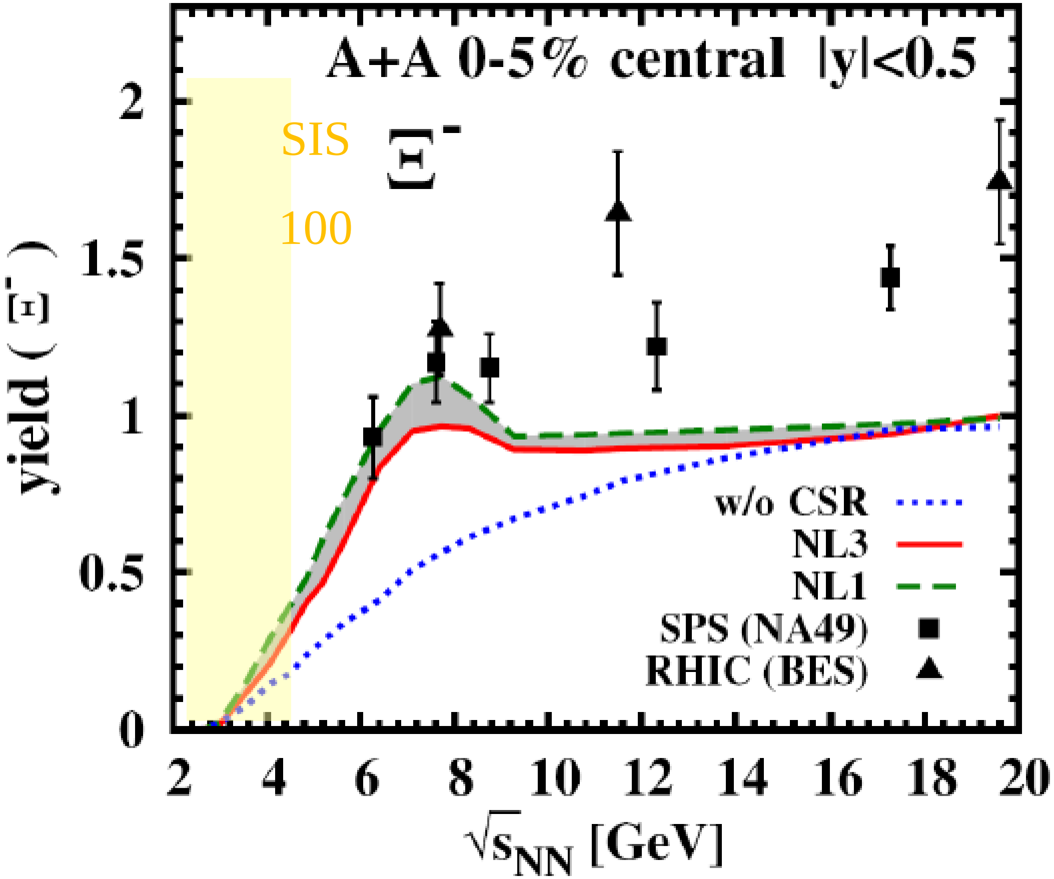
iTPC + eTOF: 1.05 < η < 1.50



Multi-strange hyperons

PHSD interpretation of Ξ^- - production

A. Palmese et al. Phys.Rev. C94 (2016) no.4, 044912



- Predicted sensitivities of production yields:
- strong dependence on Chiral Symmetry Restoration (CSR)
- Measurable dependence on Equation of State (NL1, NL3)
- Ξ^- production threshold in pp $\sqrt{s}$ = 3,247 GeV

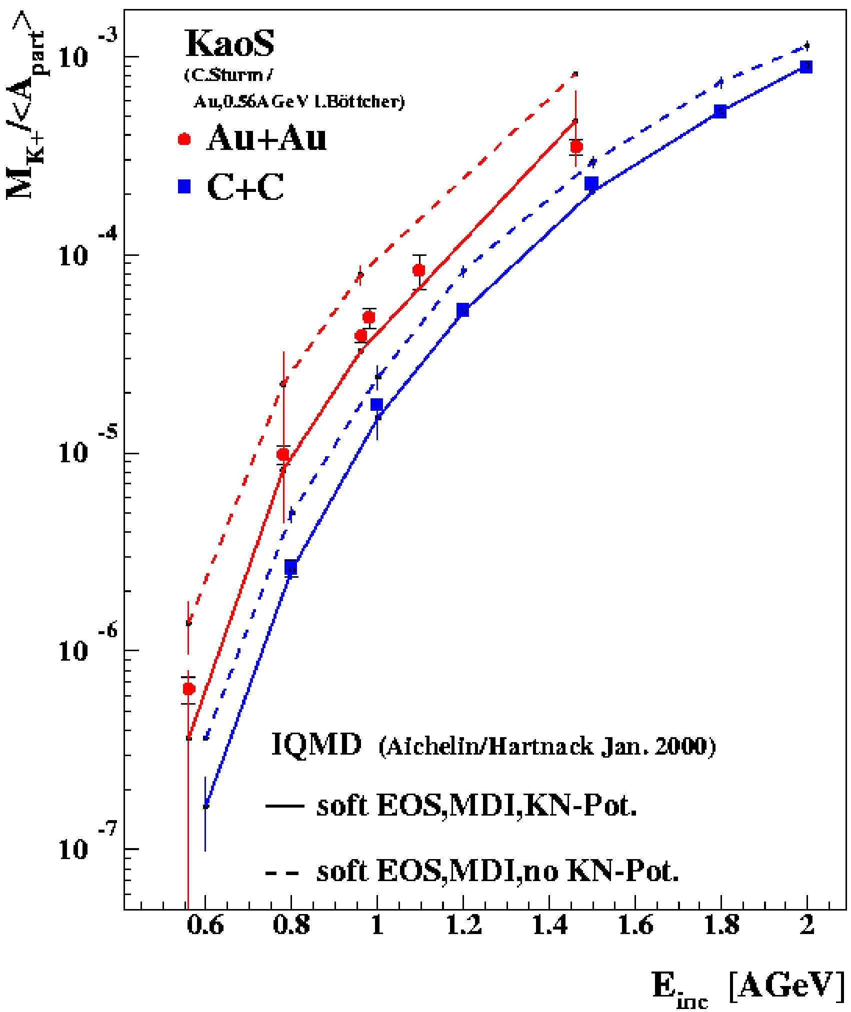
$$pp \rightarrow K^+K^+\Xi^-p$$

Alternative explanation (URQMD): Tuned resonance parameter

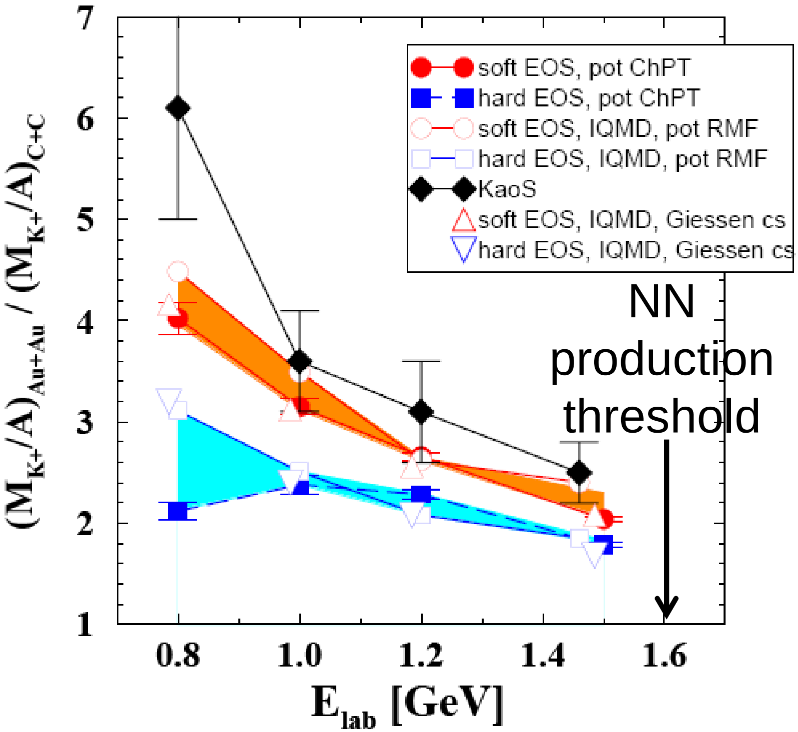
J. Steinheimer, M. Bleicher, J.Phys. G43 (2016), 015104

Kaon production at SIS 18

C.Sturm et al. (KaoS), PRL 86 (2001) 39



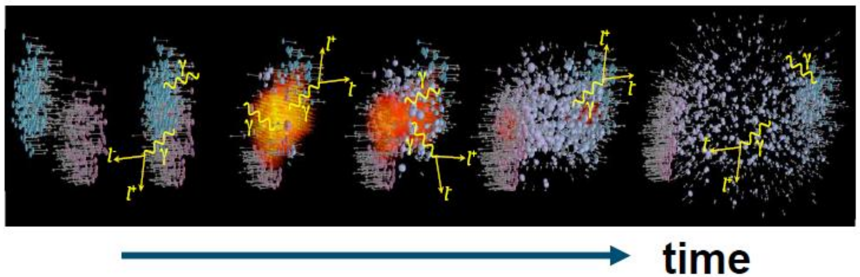
C. Fuchs et al., PRL 86 (2001) 1974



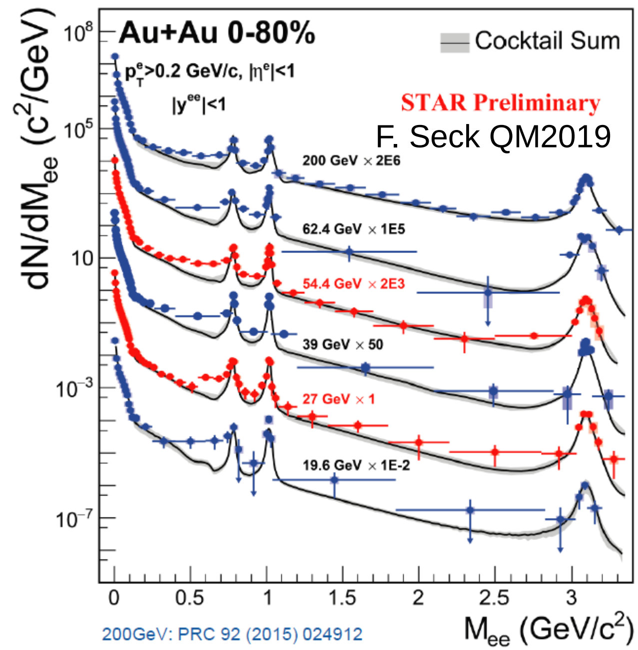
- Strong sensitivity to Equation Of State due to multistep production (formation of nucleon resonances)

=> soft EOS (K=200 MeV)

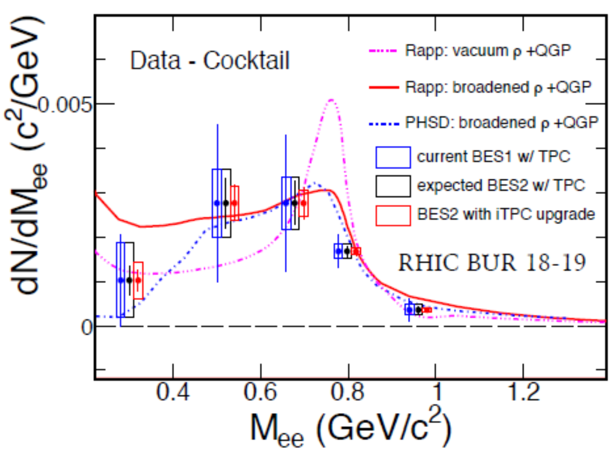
Chiral symmetry restoration Di-leptones

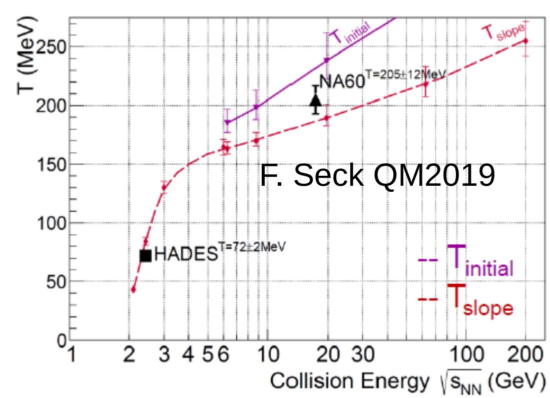


- Dilepton measurement can provide
  - Temperature of fireball
  - Lifetime of fireball
  - Chiral symmetry restoration
  - hint to first order phase transition
- Not enough statistics for meaningful measurements below 19.6 GeV



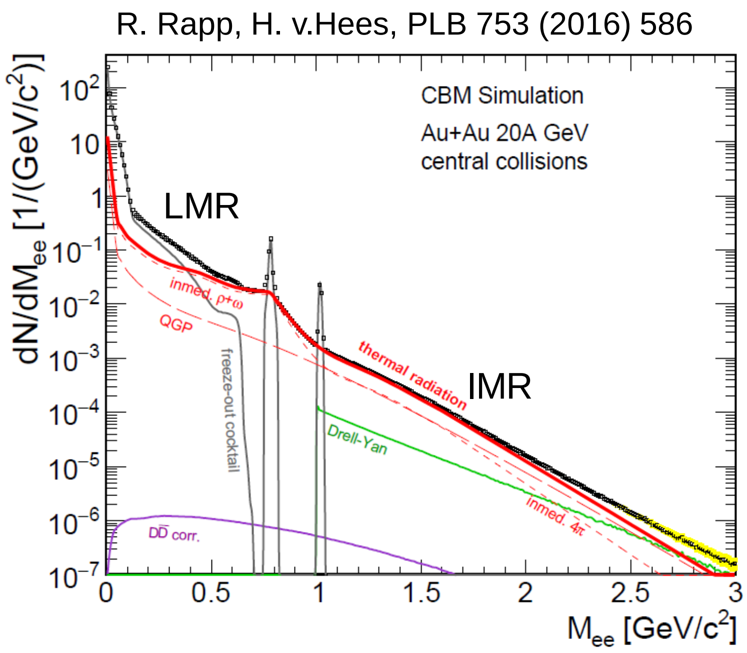
200GeV: PRC 92 (2015) 024912
19.6 GeV: PLB 750 (2015) 64
62.4 & 39 GeV: arXiv:1810.10159 [nucl-ex]

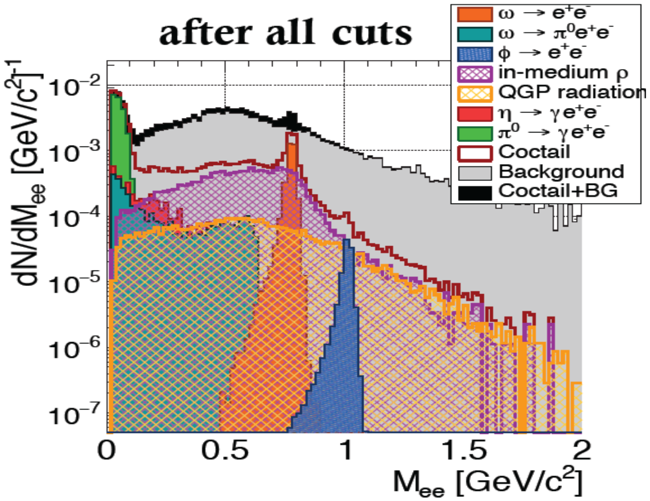




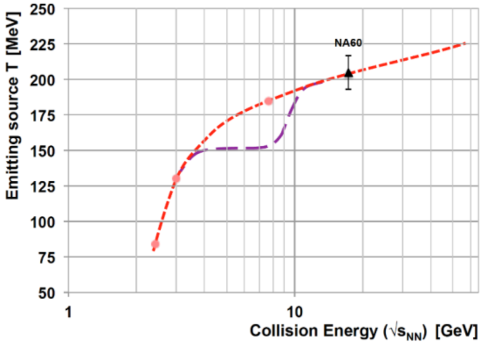
R. Rapp, H. van Hees: PLB 753 (2016) 586
FS *et al.*: EPJ A 52 (2016) 131
NA60: Chiral 2010, AIP Conf.Proc. 1322 (2010) 1

Di-leptons as probe of dense matter



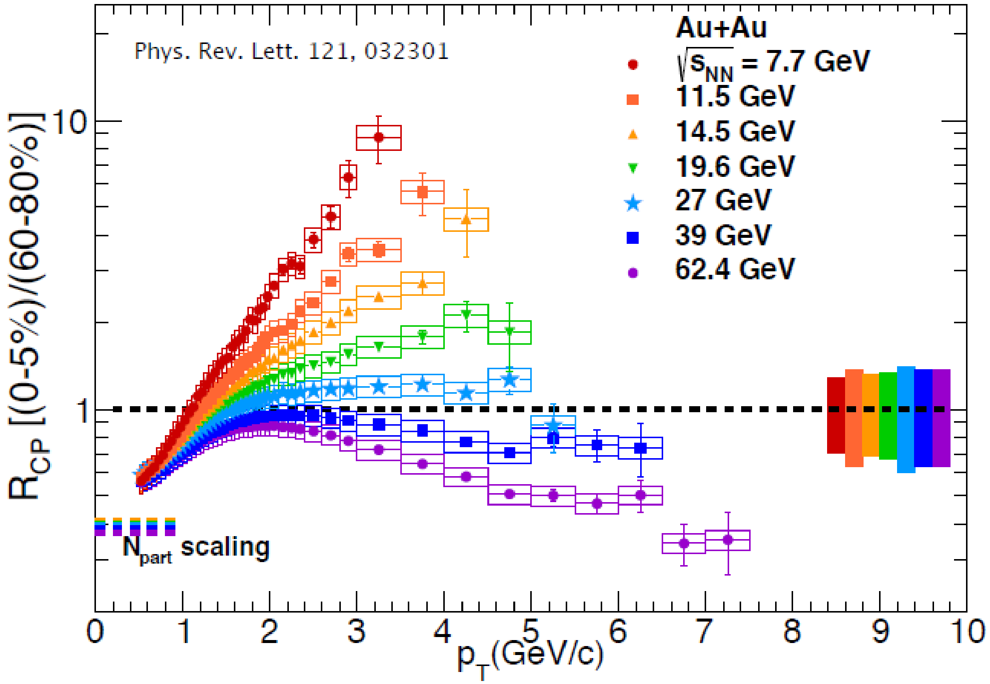


- 1M Au+Au (b=0 fm), 8 AGeV
- IMR: S/B > 1/100
- Statistical accuracy of 10% requires ~1 week of CBM beamtime at 100 kHz IR



LMR: ρ – chiral symmetry restoration
fireball space – time extension
IMR: access to fireball temperature
ρ-a_1 chiral mixing

Onset of deconfinement nuclear modification factor

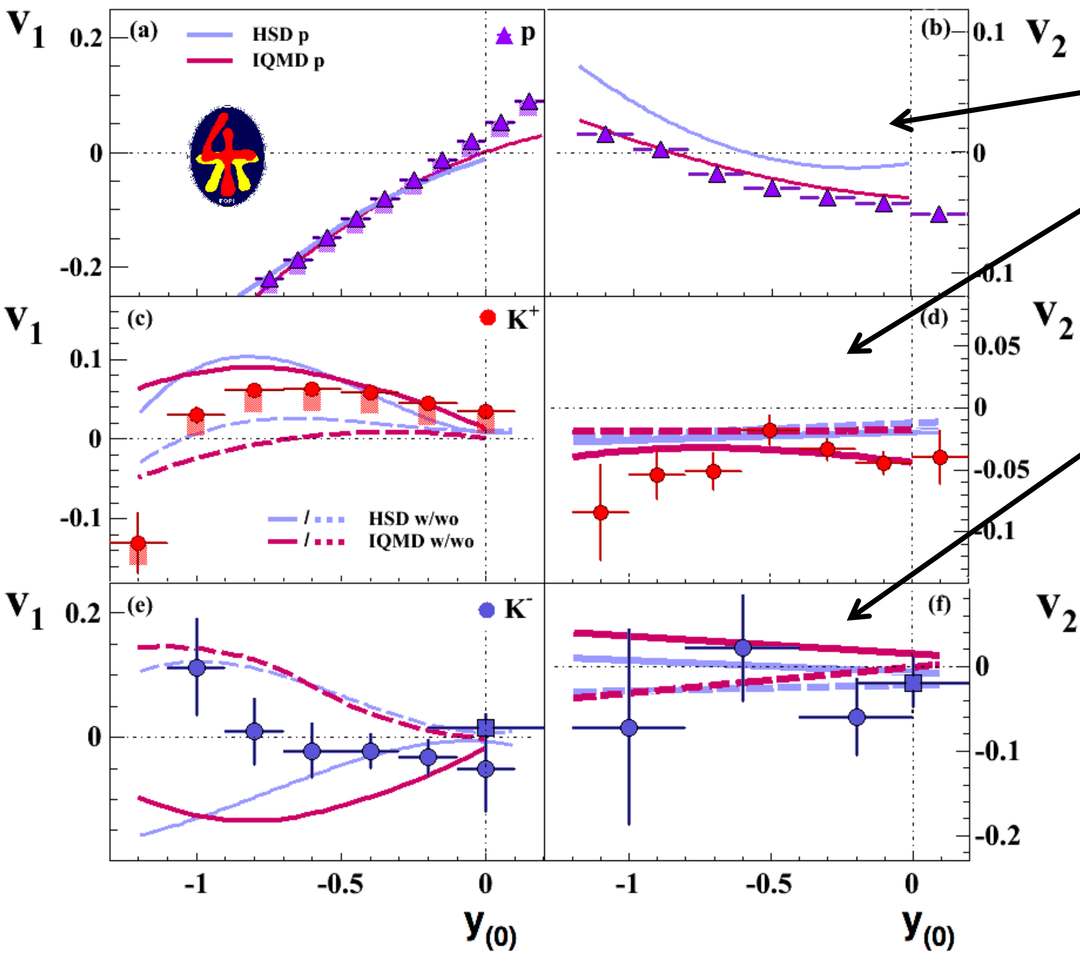


- nuclear modification factor R_{CP}
  - smooth transition from suppression to enhancement
  - $R_{CP} > 1$ does not mean automatically absence of QGP
  - Cronin-like enhancement competes with the suppression effect

Flow and in-medium modification

V.Zinyuk et al. (FOPI), PRC 90 (2014) 025210

Ni+Ni at 1.91 AGeV, σ = 1.5 b



Protons

Kaons (K^+)

Potentials with linear density dependence at $r=r_0$:

$U_{HSD}(K^+)$	20 MeV
$U_{IQMD}(K^+)$	40 MeV

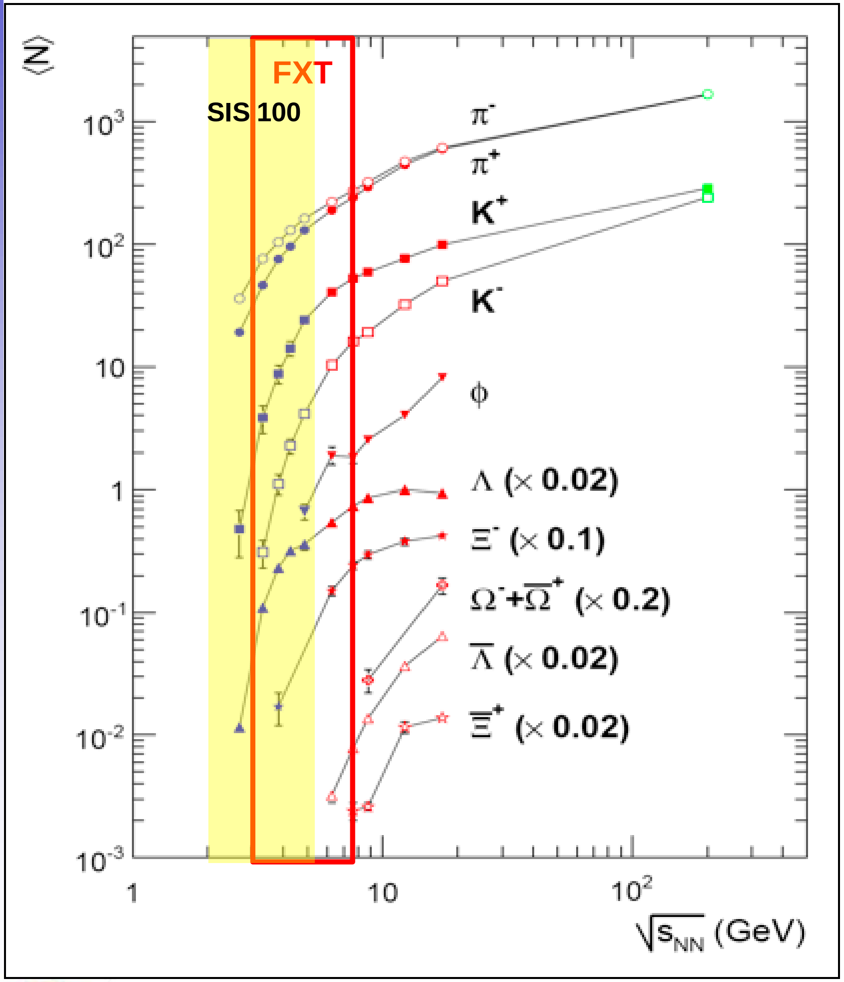
Antikaons (K^-)

$U_{HSD}(K^-)$	-50 MeV
$U_{IQMD}(K^-)$	-90 MeV

- Transport model calculations need to be refined,
- Exp. data need to be extended, much more statistics needed for K^-.

Hyperons in FXT

C. Blume, J. Phys. G31, S57 (2005)



Strange and charmed particle production thresholds in pp - collisions

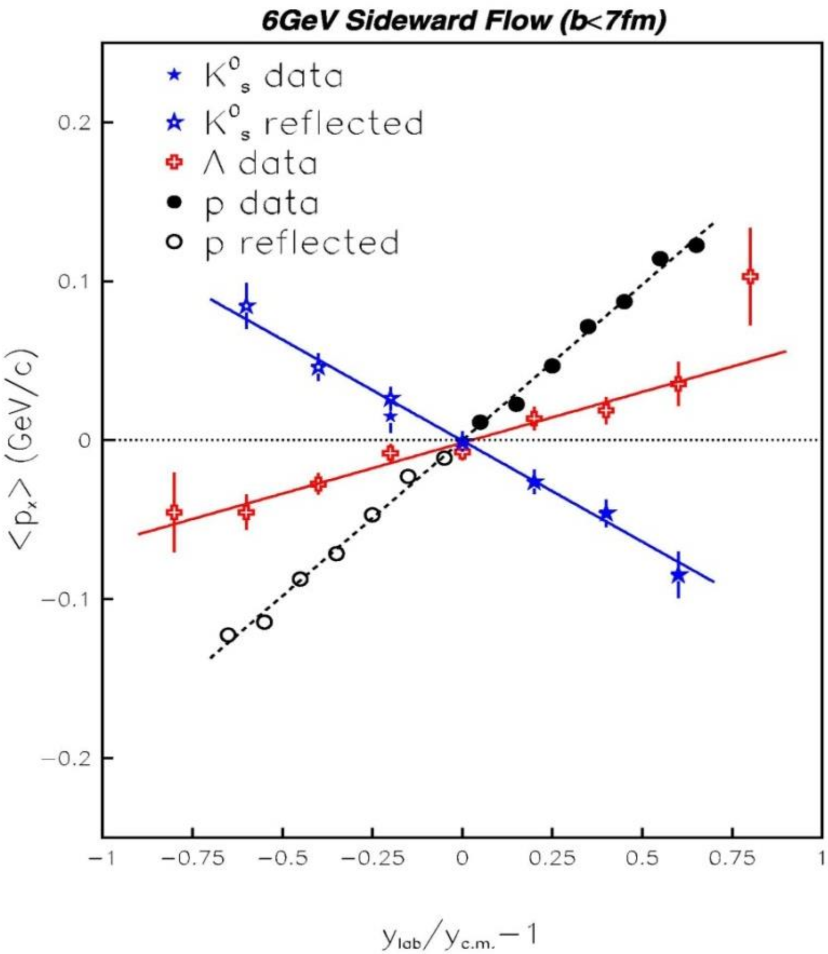
reaction	$\sqrt{s}$ (GeV)	T_{lab}(GeV)
$pp \rightarrow K^+\Lambda p$	2.548	1.6
$pp \rightarrow K^+K^-pp$	2.864	2.5
$pp \rightarrow K^+K^+\Xi^-p$	3.247	3.7
$pp \rightarrow K^+K^+K^+\Omega^-n$	4.092	7.0
$pp \rightarrow \Lambda\bar{\Lambda}pp$	4.108	7.1
$pp \rightarrow \Xi^-\bar{\Xi}^+pp$	4.520	9.0
$pp \rightarrow \Omega^-\bar{\Omega}^+pp$	5.222	12.7
$pp \rightarrow J/\Psi\, pp$	4.973	12.2

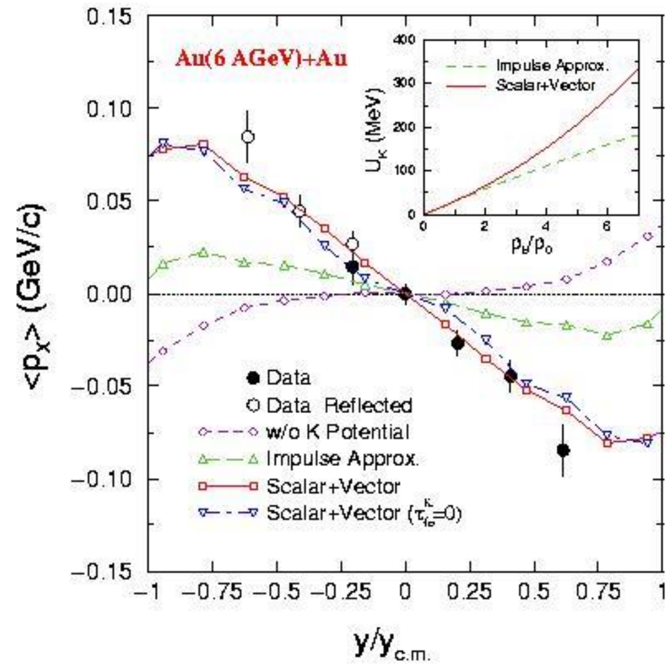
- Yield of sub-threshold produced hyperons is sensitive to the medium density (multi step processes)
- In the FXT energy regime very few data available

AGS K^0-flow

Data: P. Chung et al. (E895), PRL85, 940 (2000)

Theo: S. Pal et al., Phys.Rev.C62:061903, (2000)





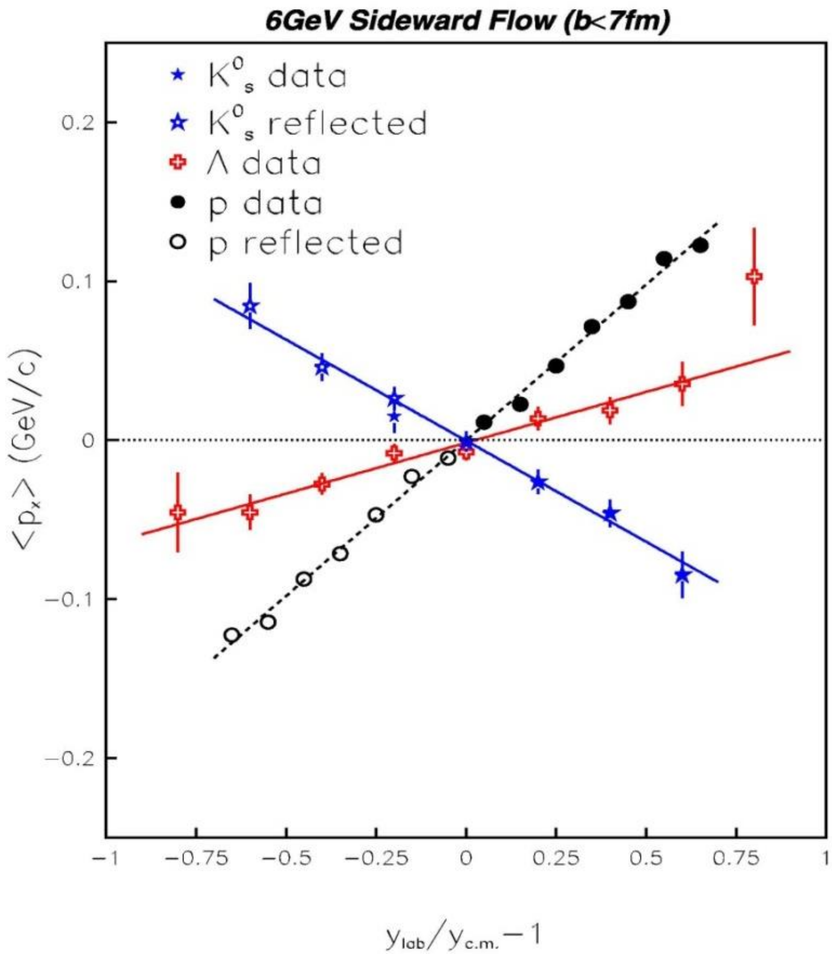
Kaon flow as barometer in HI collisions?

Calibrate probe by systematic measurements

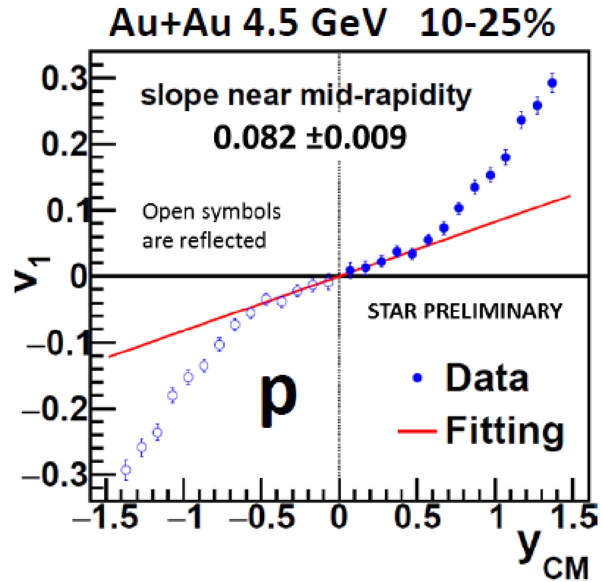
- centrality
- system size
- incident energy

AGS K^0-flow

Data: P. Chung et al. (E895), PRL85, 940 (2000)

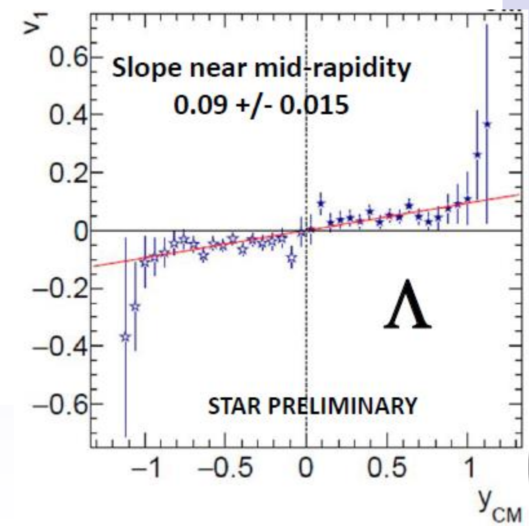


K. Meehan (STAR), QM2017



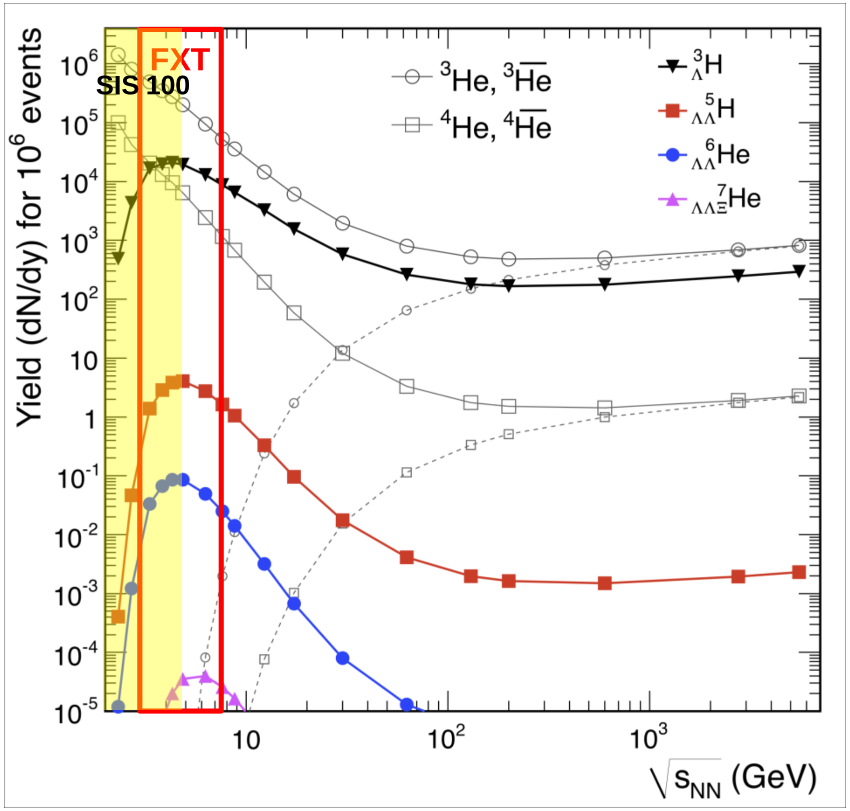
E895 *trend*:
Λ/p flow ratio at
4.5 GeV ➔ 0.2

STAR FXT:
Λ/p flow ratio at
4.5 GeV ➔ 1.1



Hypernuclei in FXT

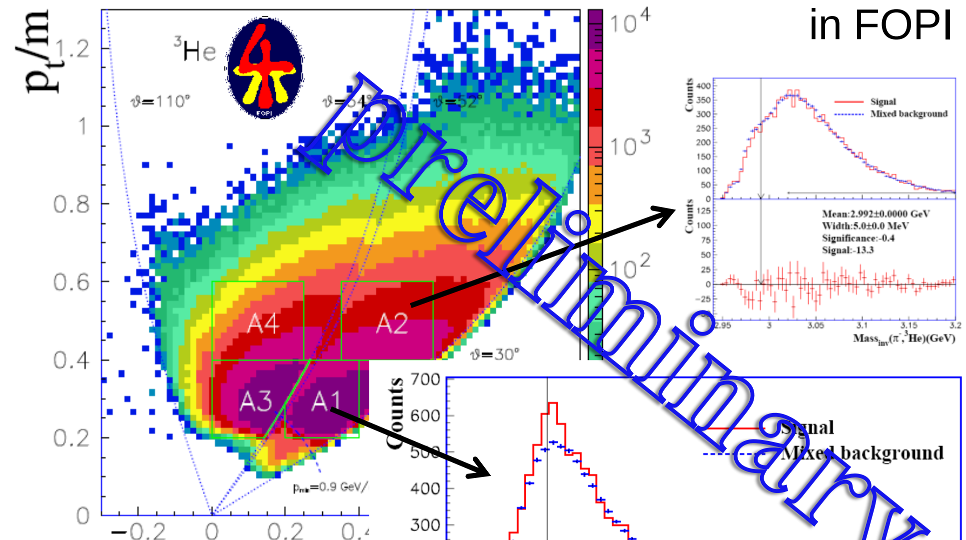
A. Andronic, P. Braun-Munzinger, J. Stachel, and H. Stocker, Phys. Lett. B697, 203 (2011), arXiv:1010.2995 [nucl-th]

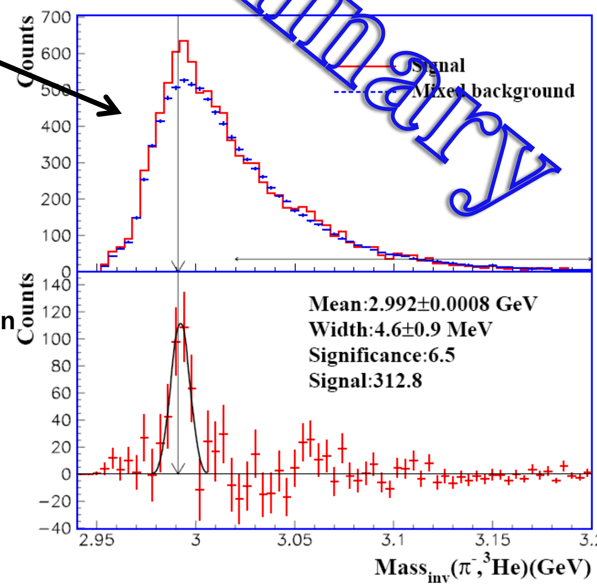


- Thermal model predicts a maximal yield at FXT energies

Hypertriton production in Ni + Ni at 2 AGeV

in FOPI





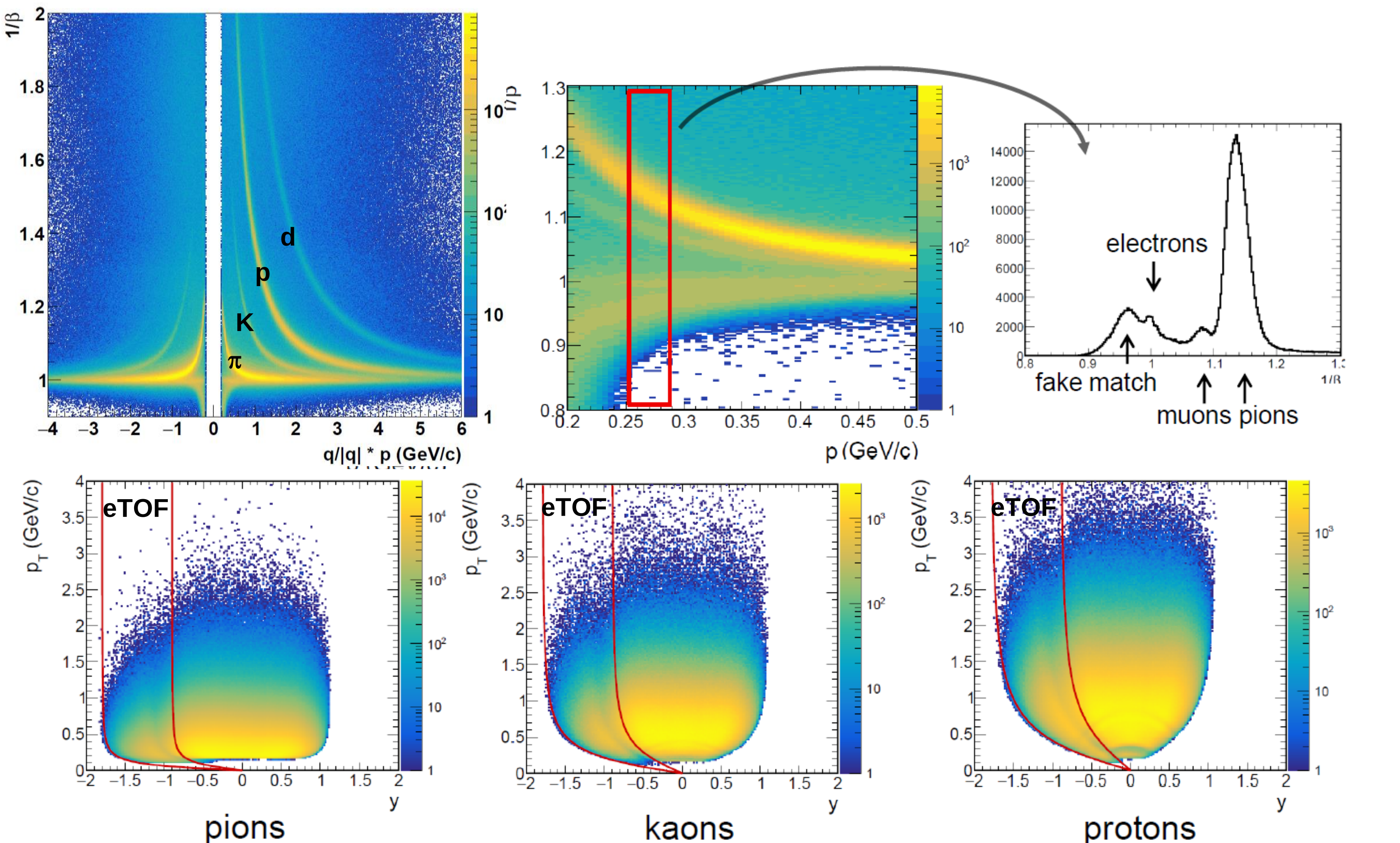
50 M events,

$\sigma_{triggered} = 0.5 \cdot \Sigma_{reaction}$

312 candidates

Y.P. Zhang, PhD thesis, Heidelberg

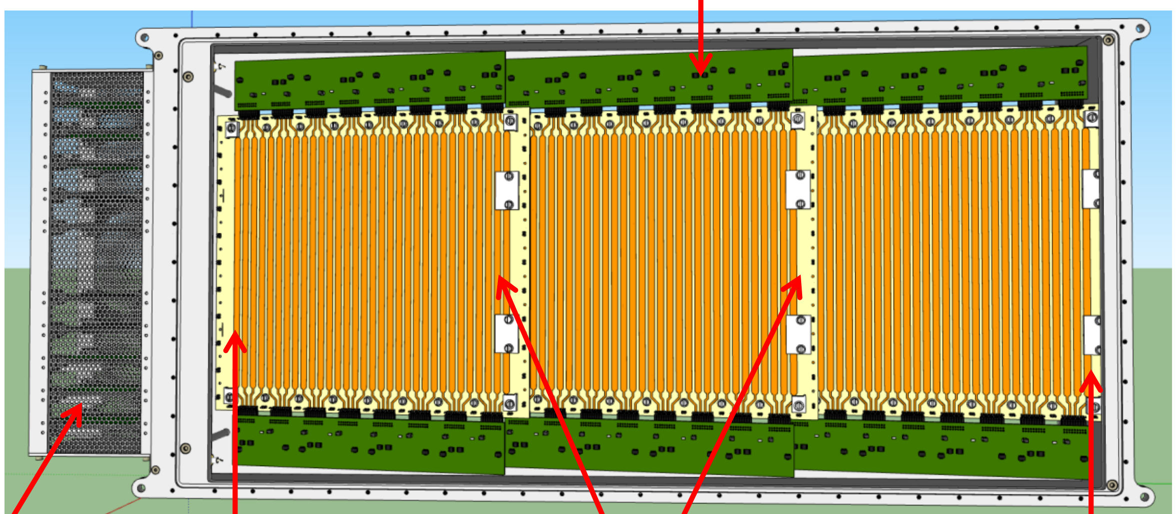
Particle identification and phase space coverage

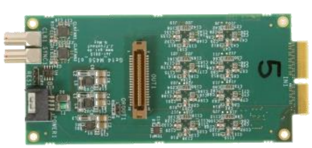


eTOF module

- 3 MRPCs (MRPC3a/b) – tilted by ≈7°
- 32 strips/MRPC with a pitch of 1 cm
- 27 cm strip length
- Active area about 92 cm x 27 cm
- 192 read out channels

Preamplifier PADI boards





TDC GET4 boards

Strip 1

overlapping strips

Strip 96

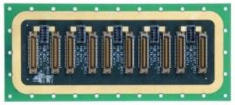
33

Readout chain

Readout chain (data driven)

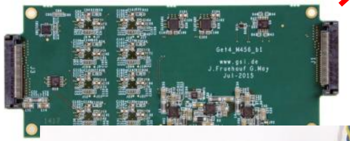
- PADIX: Preamplifier board 32 ch

- Feed through PCB

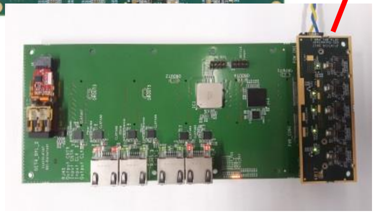


  On board are temperature, pressure and humidity sensors

- TDC board 32 ch.
  (8 GET4 chips)

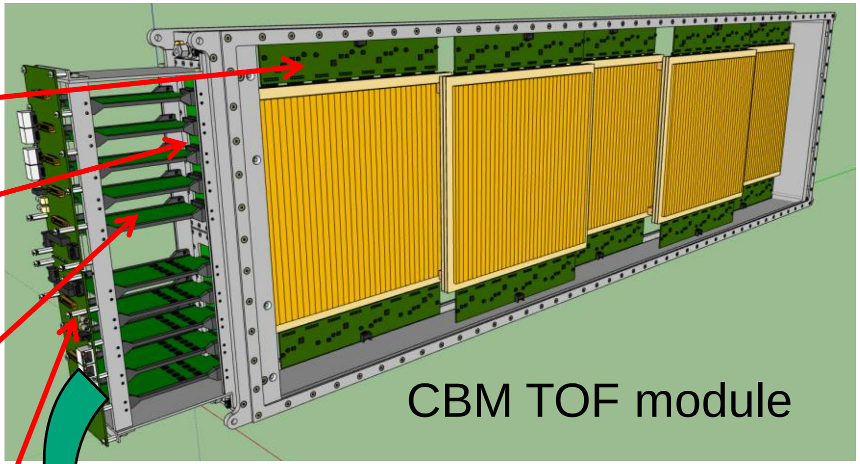


- Backplane with GBTx chip
  (SCA chip for slow control)

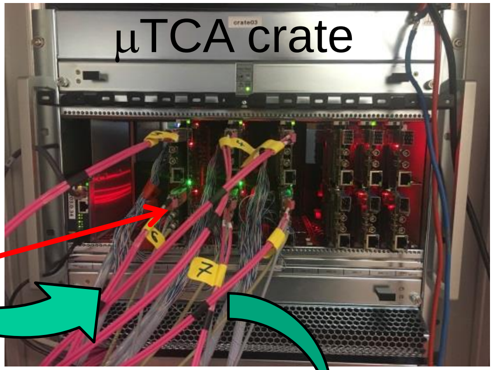


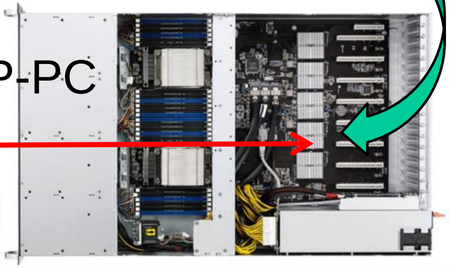
- AFCK: FPGA board
  (AMC FMC Carrier with Kintex)

- FLIB: FPGA PCI express card



Optic fiber
20 m





Optic fiber
100 m

Benefits

Benefit for STAR:

- providing critical TOF coverage for BES II

  - PID extension to y = 1.2 in collider mode

  - access to energies from 4.5 to 7.7 GeV in the fixed target program

Benefit for CBM:

- providing a large-scale integration test of the CBM TOF system, including PID and calibration of the detectors (hardware and software)
- preparation for day one experiment at SIS 100

Benefit for CBM-TOF group members:

- participation in the analysis of the physics data provided by the CBM TOF detectors, including authorship of any publications from this data.

eTOF timeline

✓ December 2015	submit the physics proposal to GSI and BNL for approval
✓ Summer 2016	shipping a real size module to BNL and installing it on the east side pole of STAR
✓ Feb. 2017	1st system integration test with one module by participating in the Run17 beam time in STAR
✓ Fall 2017	shipping and installation of one sector
✓ Feb. 2018	2nd system integration test with one sector by participating in the Run18 beam time in STAR
✓ Sep. - Oct. 2018	shipping all 36 modules including infrastructure (gas system, LV-, HV-power supply) to BNL
✓ Oct. - Nov. 2018	Installation and commissioning
✓ Feb. 2019	Start of the BES II campaign
➢ Summer 2021	Decommissioning and shipping of all modules including infrastructure to FAIR