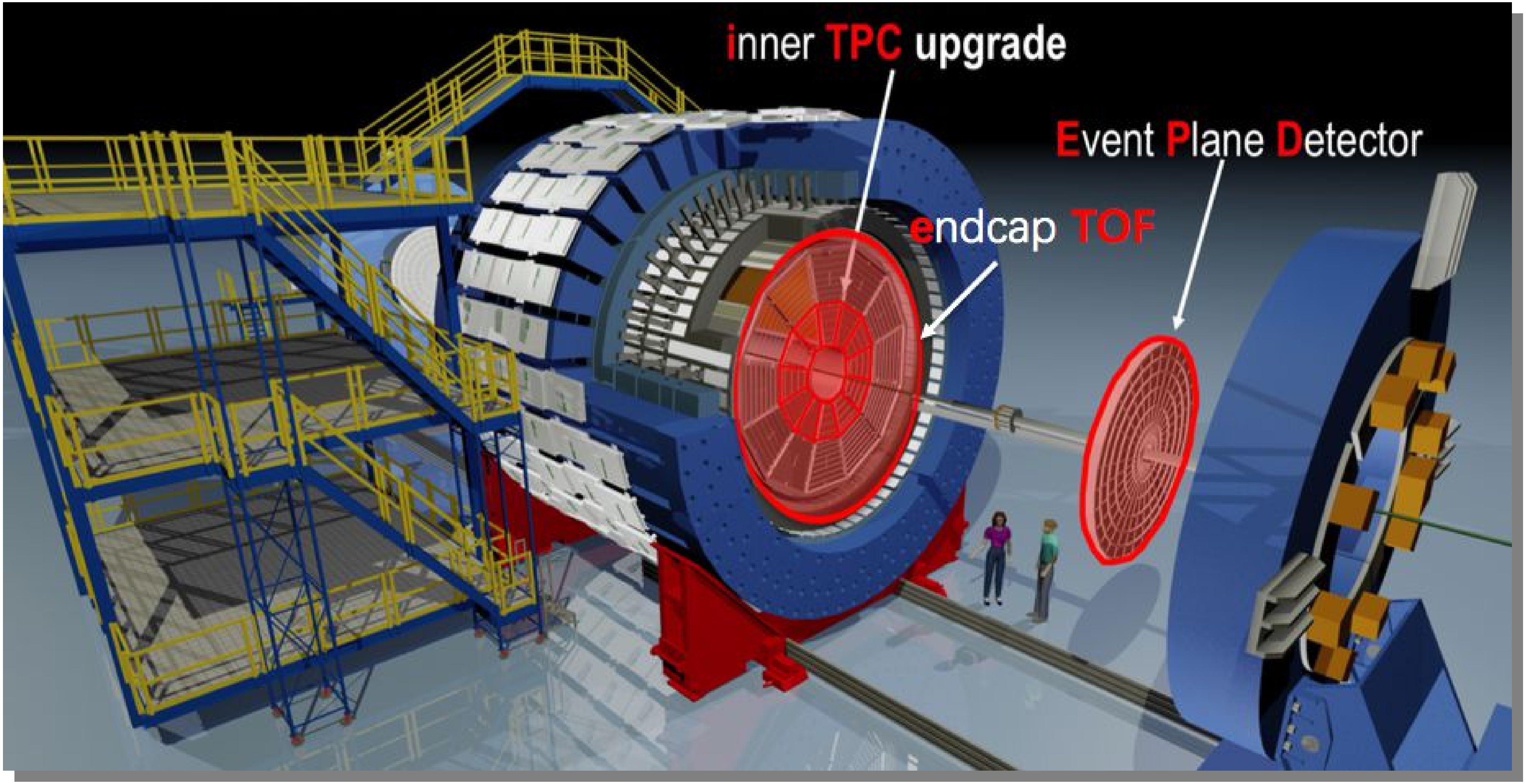
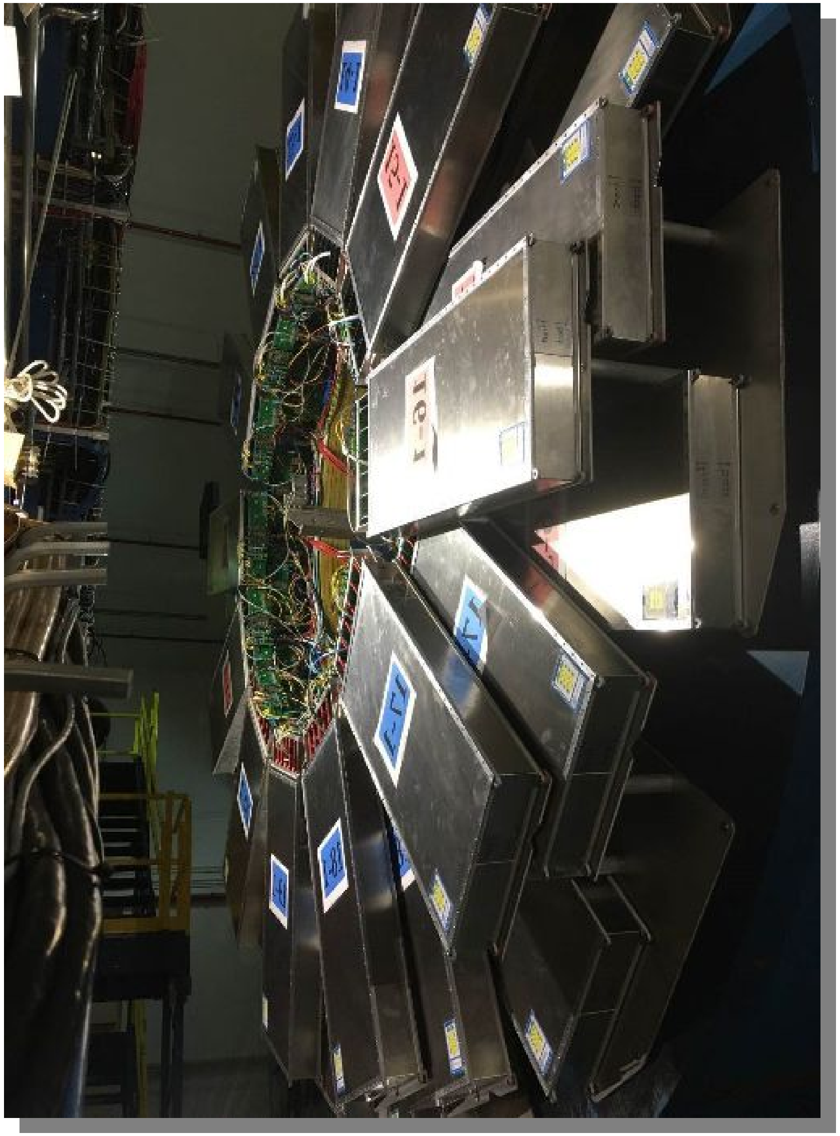
The End-cap Time-of-Flight Detector at STAR



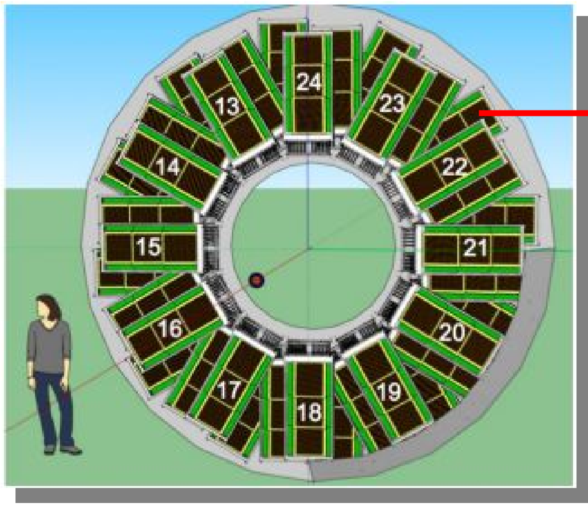
The End-cap Time-of-Flight Detector at STAR

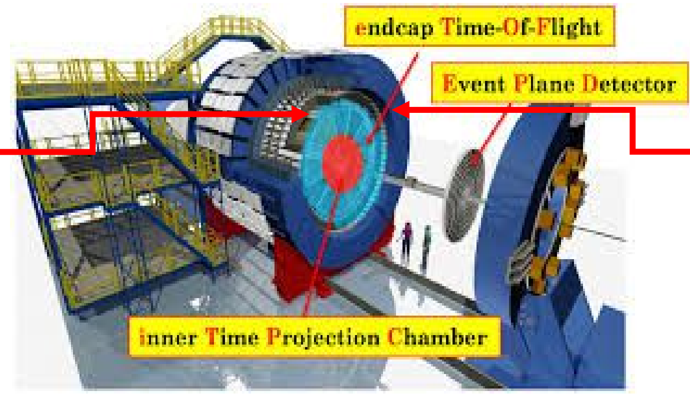
<u>Outline :</u>

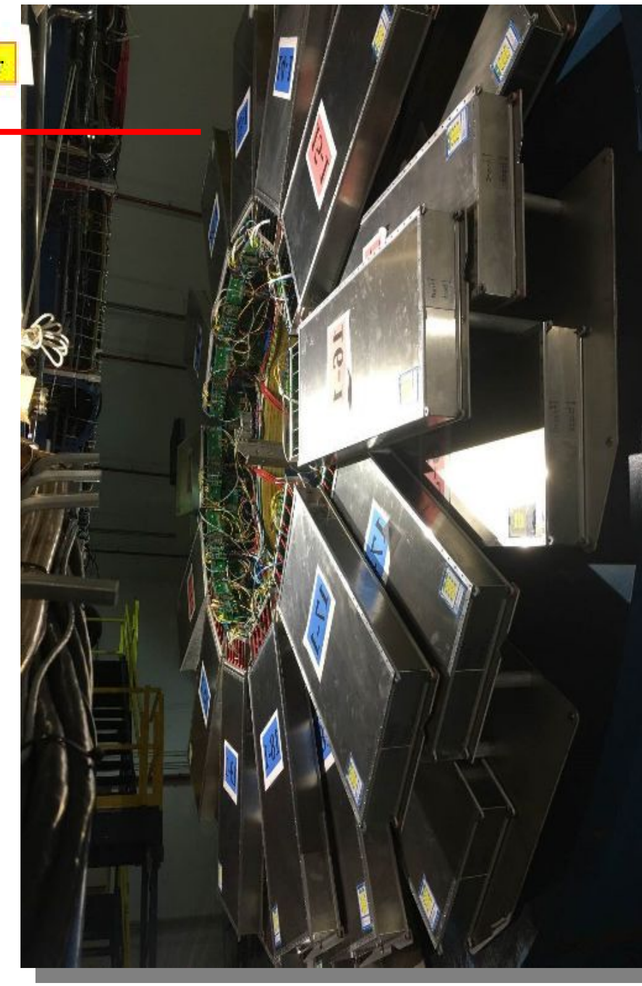
- The End-cap Time of Flight detector
- The purpose of EToF
- Overview of data sets with EToF
- EToF performance (FXT & Coll.)
- Physics with EToF: Proton fluctuations
- Physics with EToF: chemical potential
- Summary and outlook



The End-cap-Time-of-Flight detector







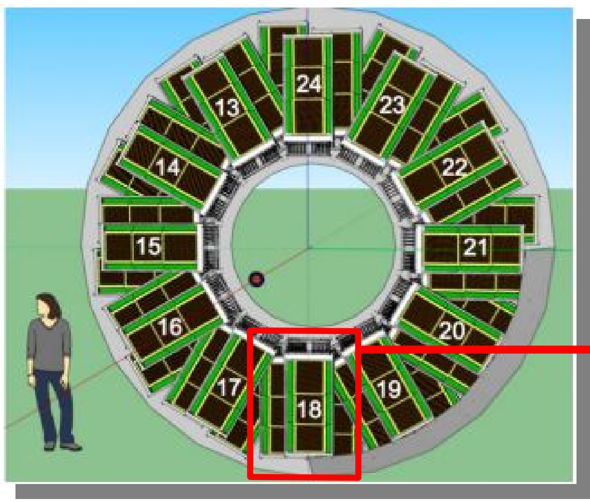
- 3 layers
- 12 sectors
- 36 modules
- 108 MRPC's
- 6912 channels

Installed in 2018
(STAR Forward Upgrade
& CBM: FAIR Phase 0)

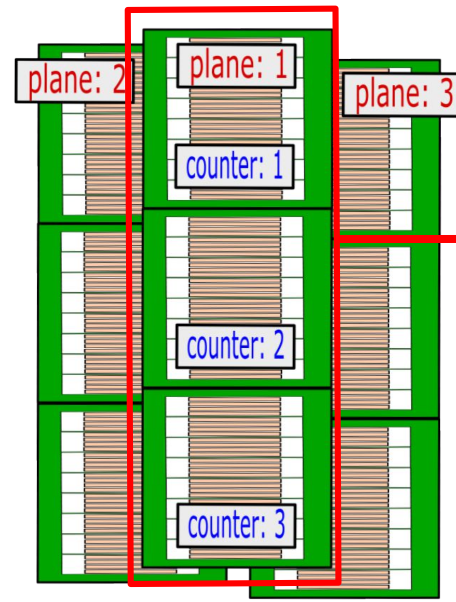
Operated from 2019 onward (BESII)

EToF : Hardware Schematics

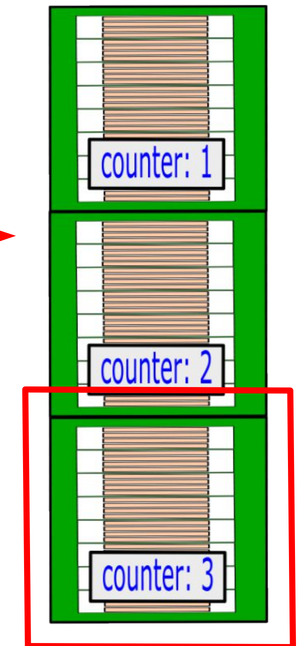
Full EToF wheel



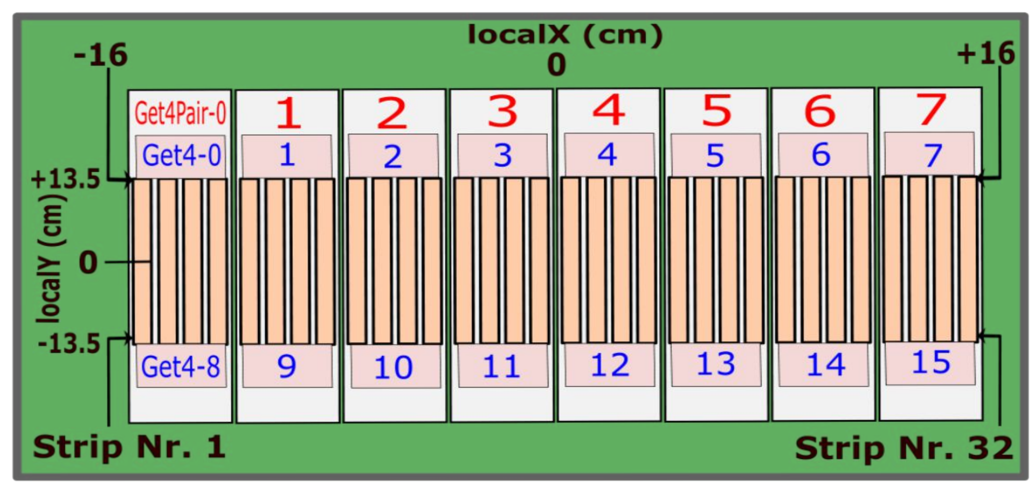
EToF sector



EToF module



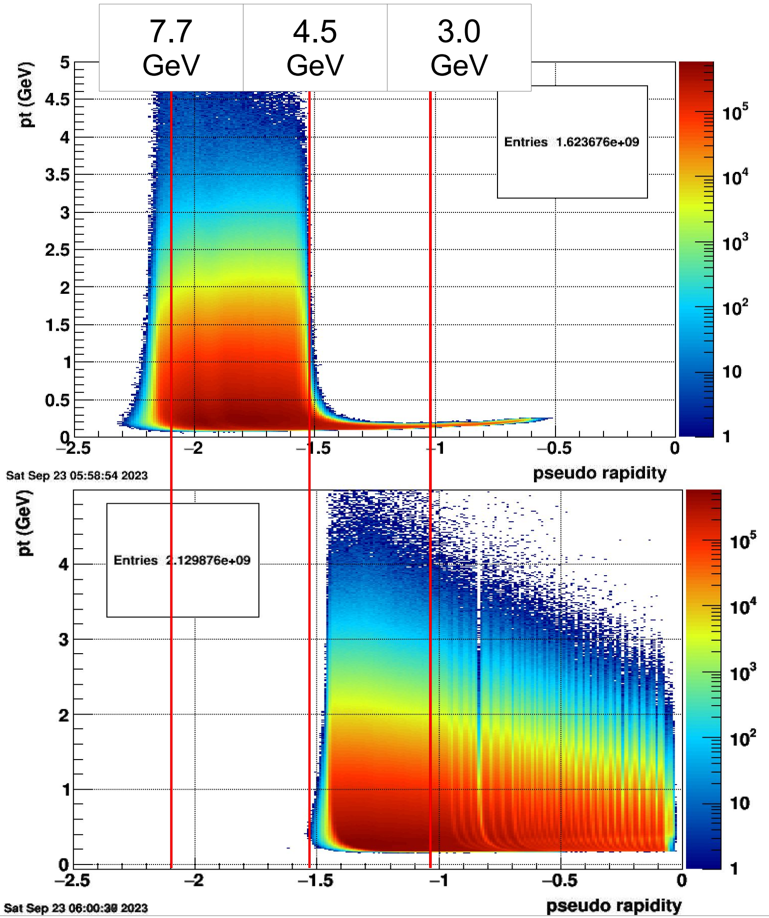
EToF counter



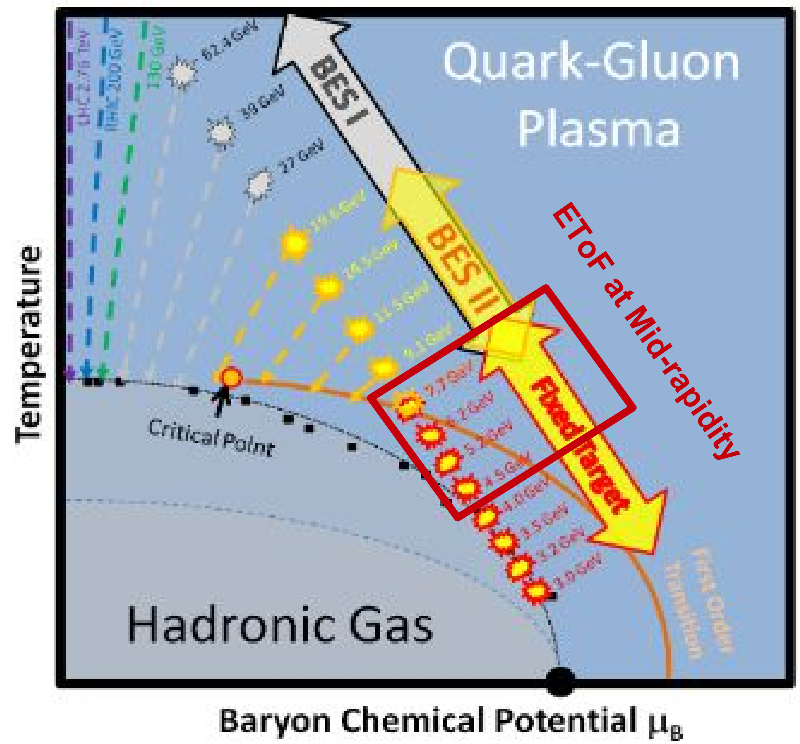
EToF consists of:

- **12 sectors** made of
- **3 modules** made of
- **3 counters** containing
- **8 Get4-pairs** reading out
- **32 strips**

Extension in Acceptance and μ_B with EToF



Acceptance at 4.5 GeV of EToF (top) and BToF (bottom)
Red lines : Mid rapidity at 3, 4.5 and 7.7 GeV



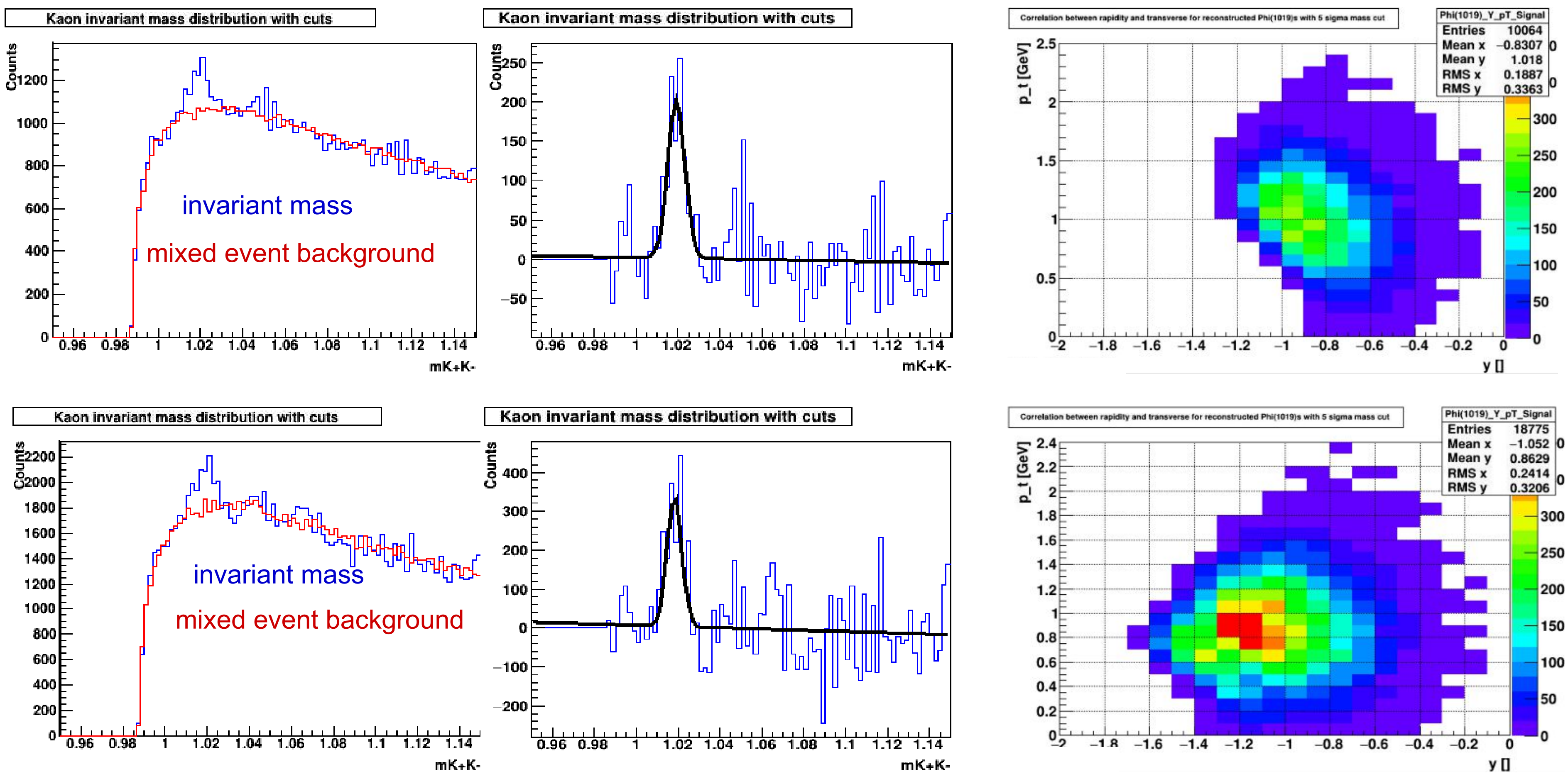
Phase diagram of strongly interacting matter with BES I & BES II energies

Nominal √s (GeV)	Chemical Potential μ_B (MeV)
3.2	697
3.5	666
3.9	632
4.5	589
5.2	541
6.2	487
7.2	443
7.7	420

Comparison to BToF at 7.7 GeV FXT

EToF only:

BToF only:



Phi invariant mass &
mixed event background

Fitted phi signal
(gauss + linear term)

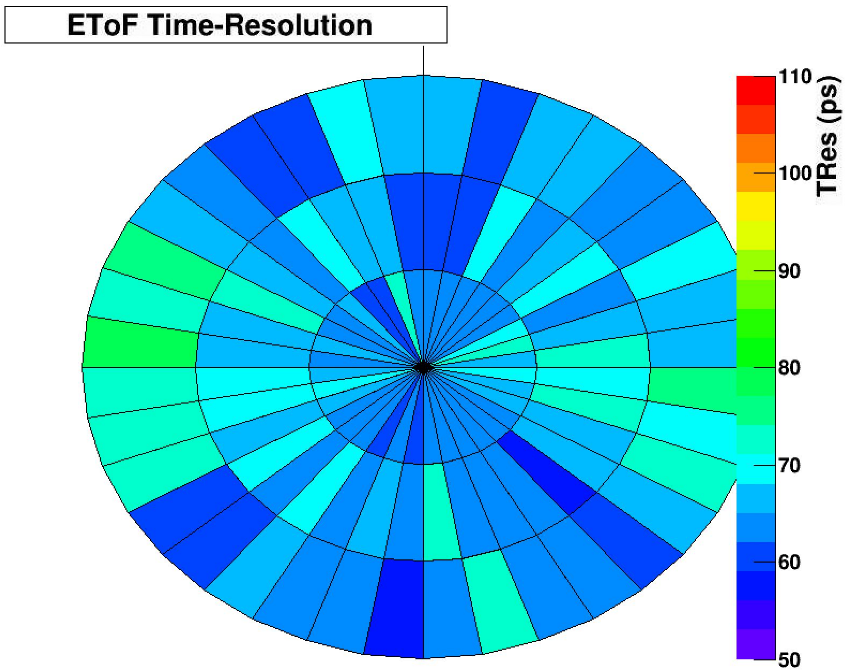
K+ K- pair acceptance for BToF only (top)
and EToF & BToF combined (bottom)

EToF Calibration Status Overview

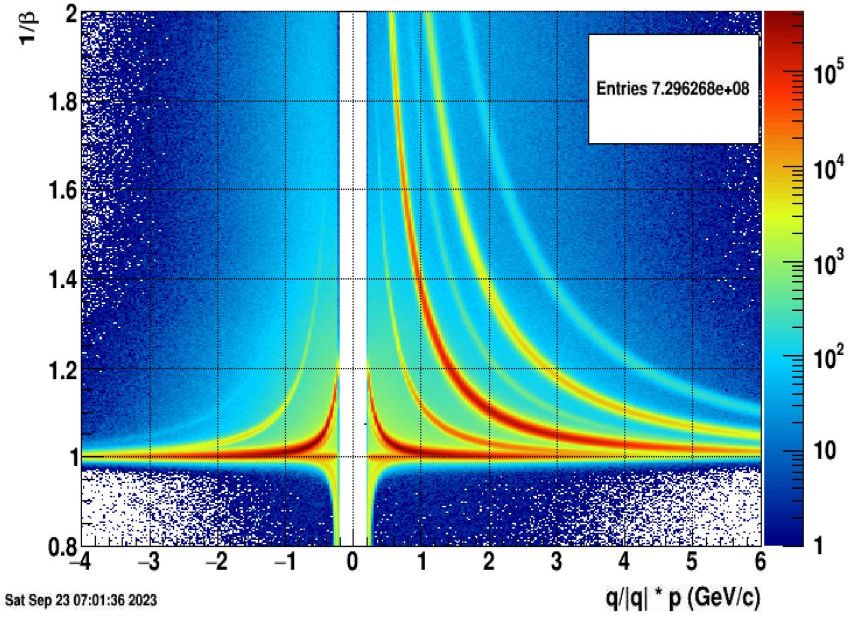
Energy (GeV) $\sqrt{s_{nn}}$	14.5	19.6	11.5	3.5	7.7	4.5	6.2	5.2	3.9	7.2	9.2	7.7	11.5	13.7	3.0	9.2
Year	2019		2020									2021				
Mode	Collider			Fixed Target							Collider		Fixed Target			
Status	flawed		produced									cal			wip	
Nr. of Events	320 M	580 M	230 M	100 M	100 M	100 M	100 M	100 M	100 M	320 M	160 M	100 M	50 M	50 M	2 B	50 M
Dmg	XX	XX								X	X	X	X	X	X	X

Under calibration right now: 3 GeV FXT 21

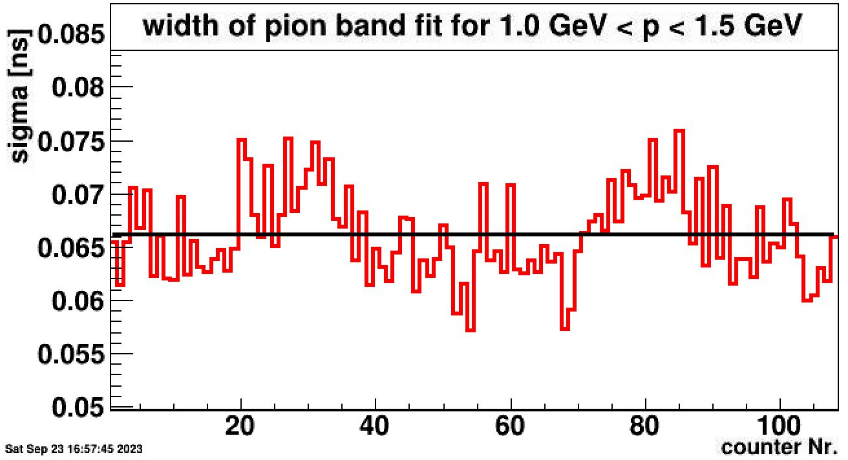
EToF Performance at 4.5 GeV FXT 2020

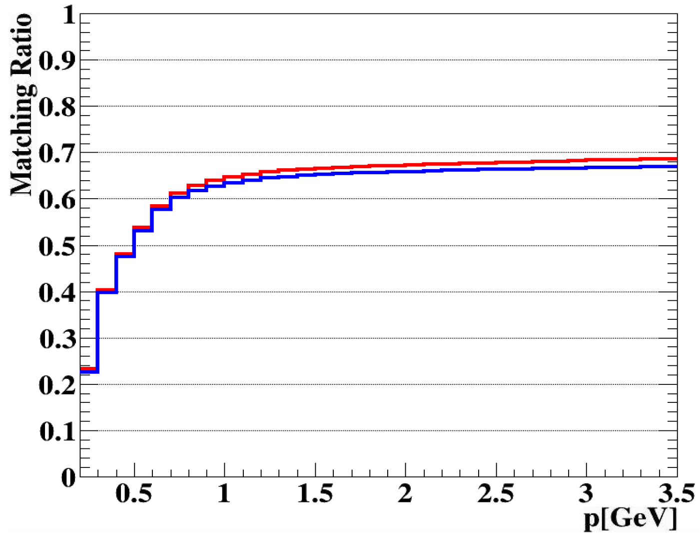


EToF-Time-Resolution at 3.5 GeV FXT 2020



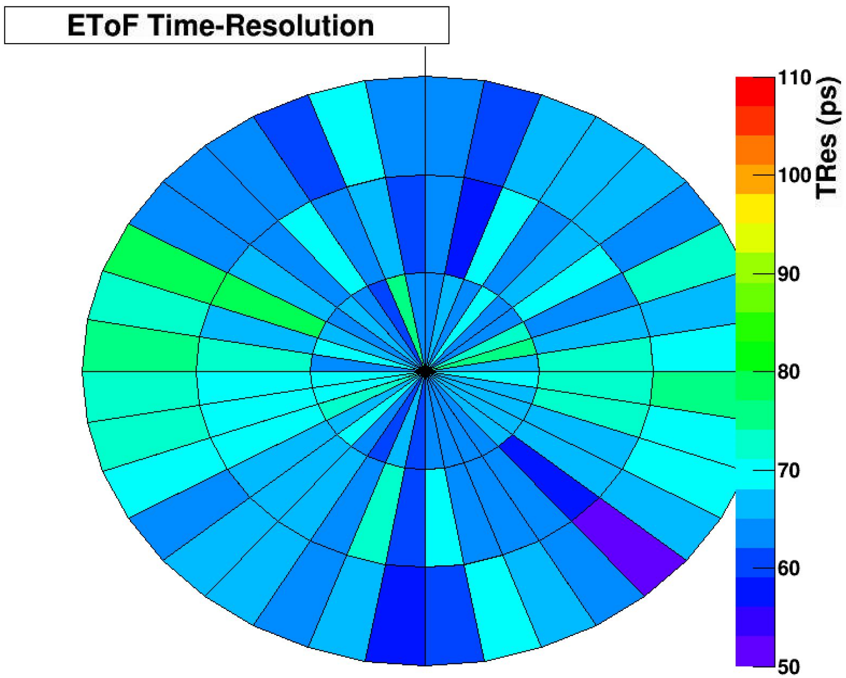
1 / β vs. momentum



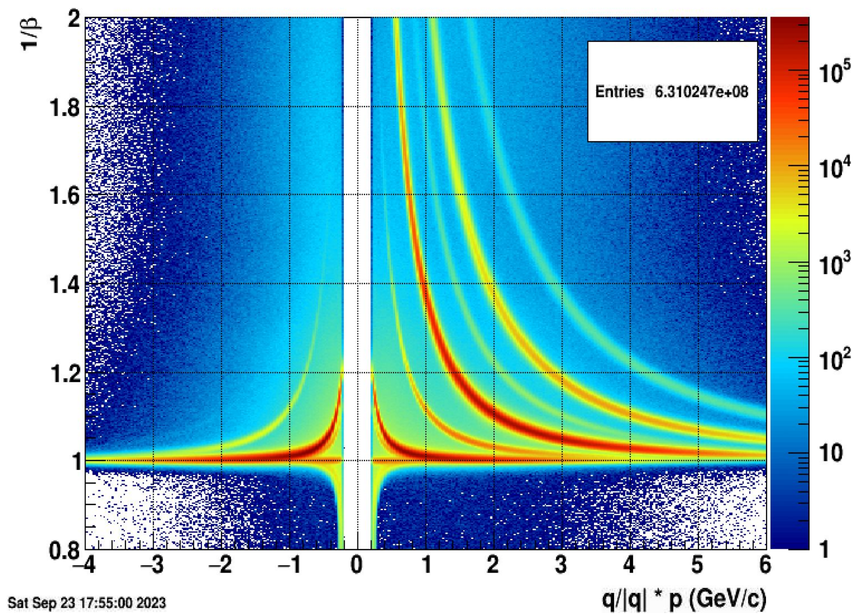


Matching Efficiency at 65% for p > 1GeV

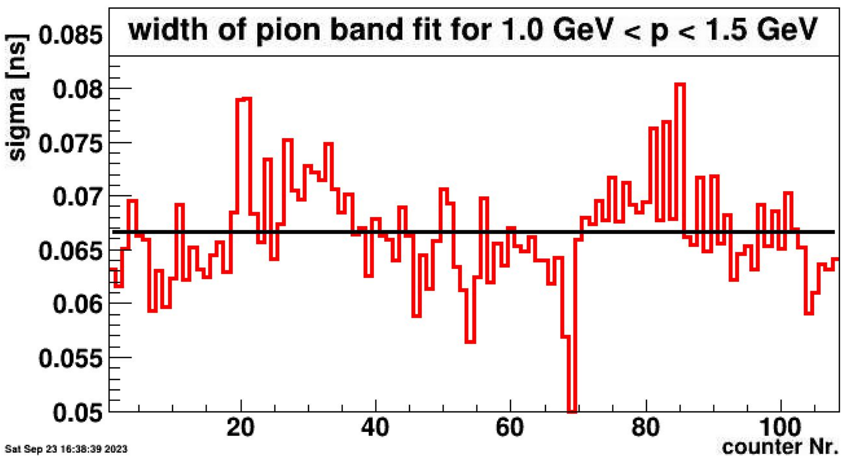
EToF Performance at 3.9 GeV FXT 2020

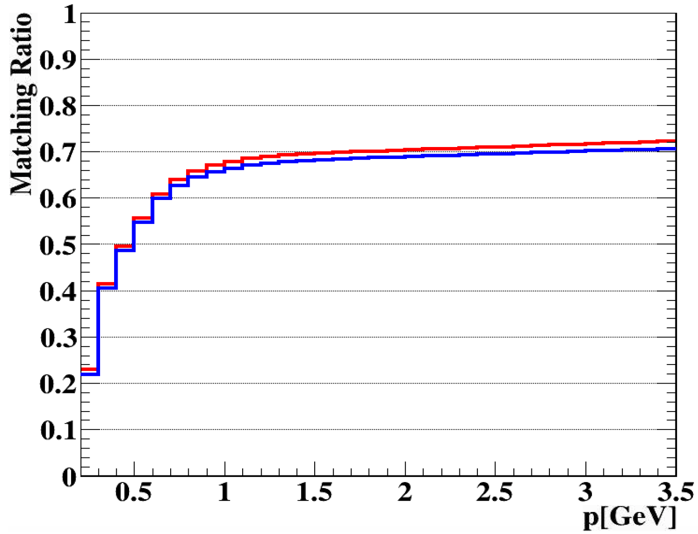


EToF-Time-Resolution at 3.5 GeV FXT 2020



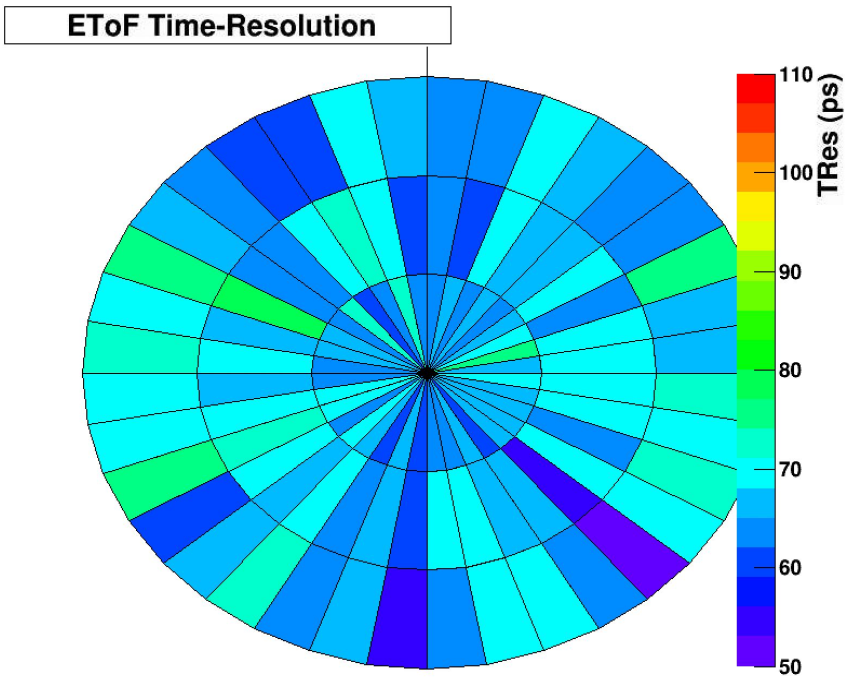
1 / β vs. momentum



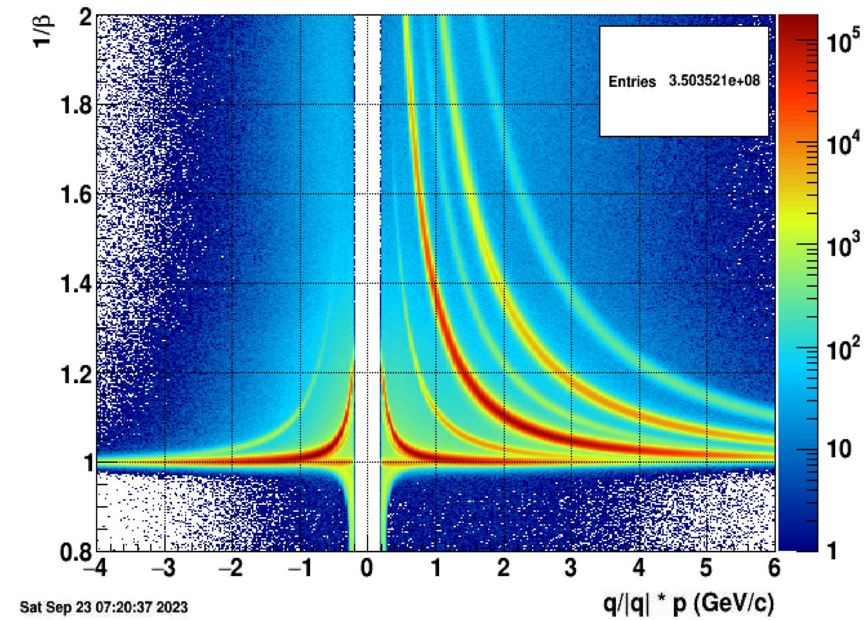


Matching Efficiency at 70% for p > 1GeV

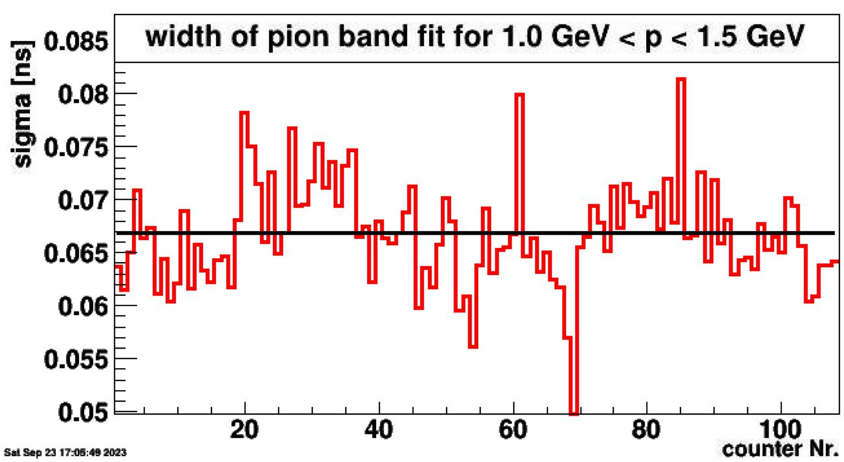
EToF Performance at 3.5 GeV FXT 2020

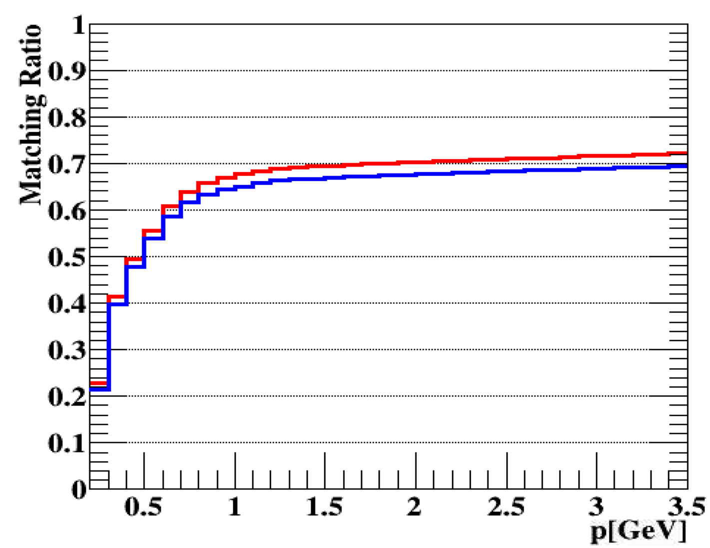


EToF-Time-Resolution at 3.5 GeV FXT 2020



$1 / \beta$ vs. momentum



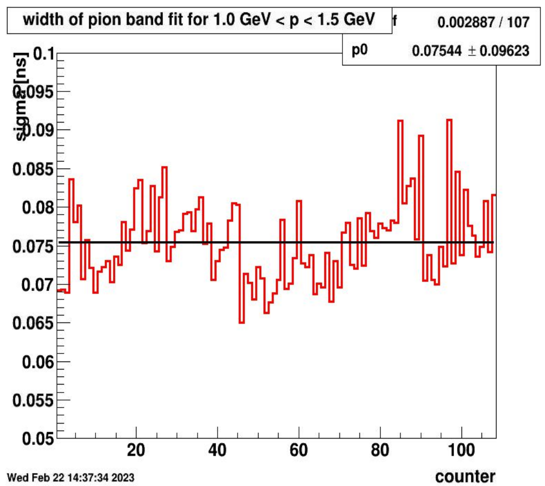


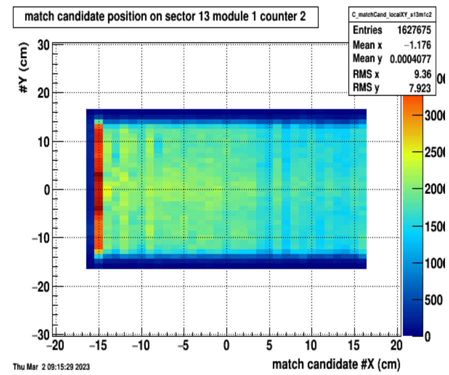
Matching Efficiency at 70% for p > 1GeV

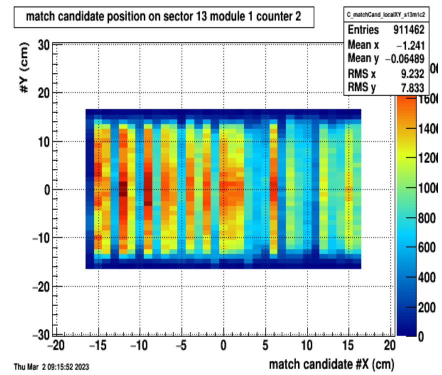
EToF Collider Performance at 9.2 GeV and 11.5 GeV

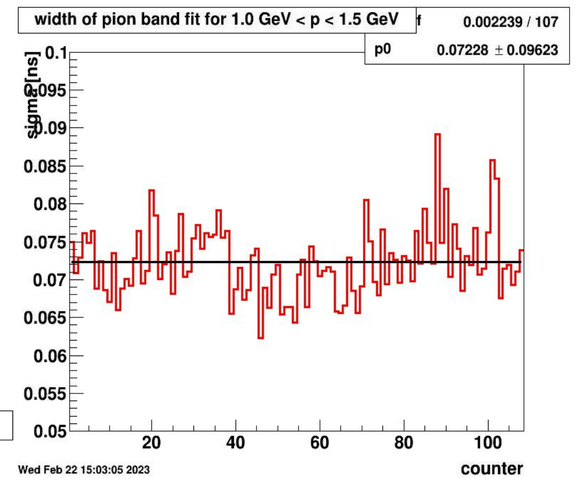
11.5 GeV Coll 2020 :
(undamaged)

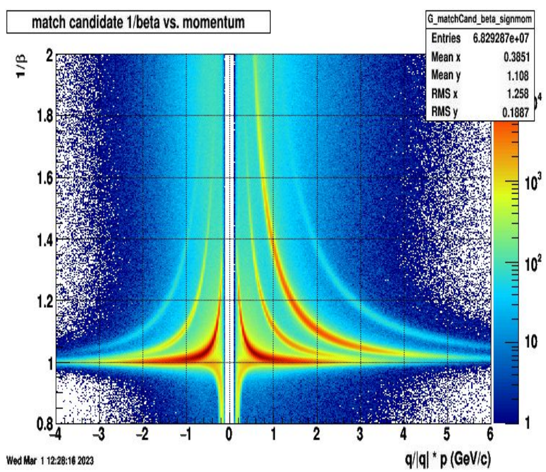
9.2 GeV Coll 2020 :
(damaged)

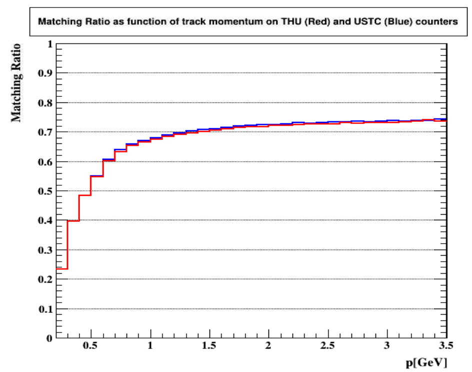


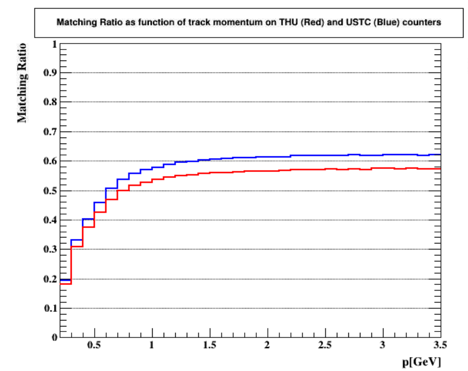


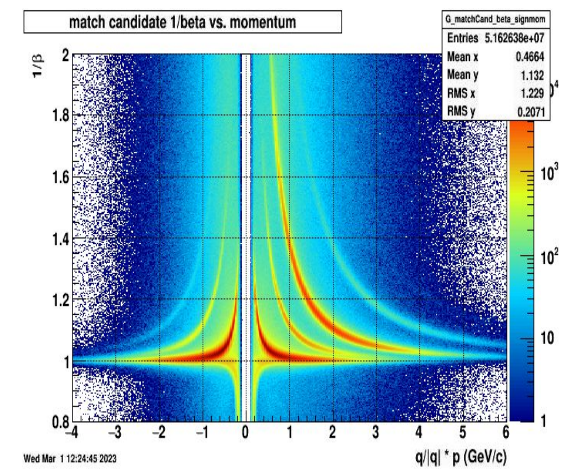












Front End Electronics Damaged during Run20!

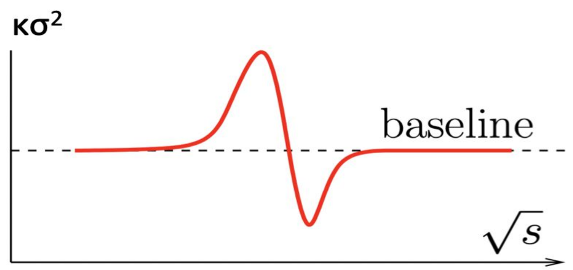
Time-Resolution unaffected

Drop in Matching-Ratio of about 15 %

Physics with EToF: Proton Fluctuations

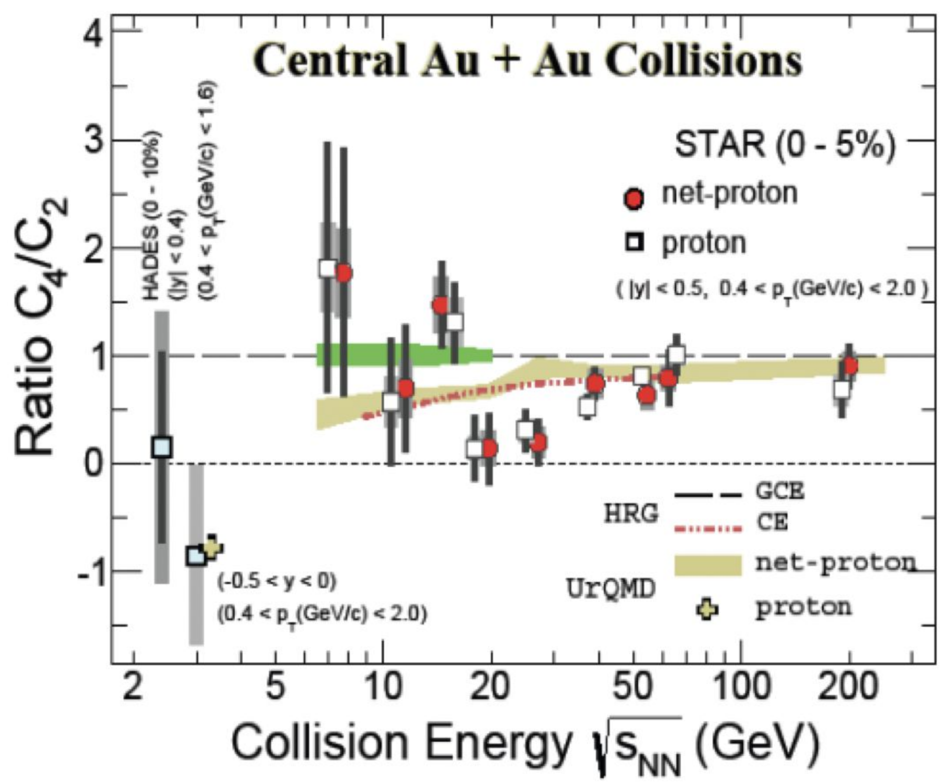
Is there a critical point in the phase diagram of strongly interacting matter ?

Higher order cumulants of proton fluctuations!



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

Predicted fluctuations of excess kurtosis (C_4/C_2) near critical point



STAR, Phys. Rev. Lett. 128, 202303 (2022) ; arXiv : 2209.11940.
Phys. Rev. Lett. 126, 092301 (2021); Phys. Rev. C 104, 024902 (2021)

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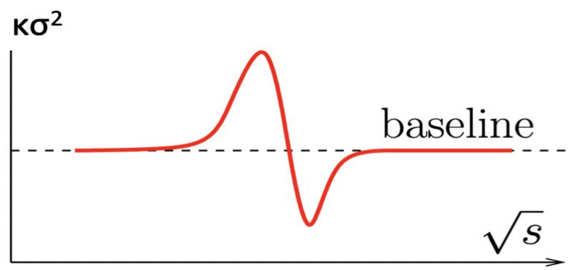
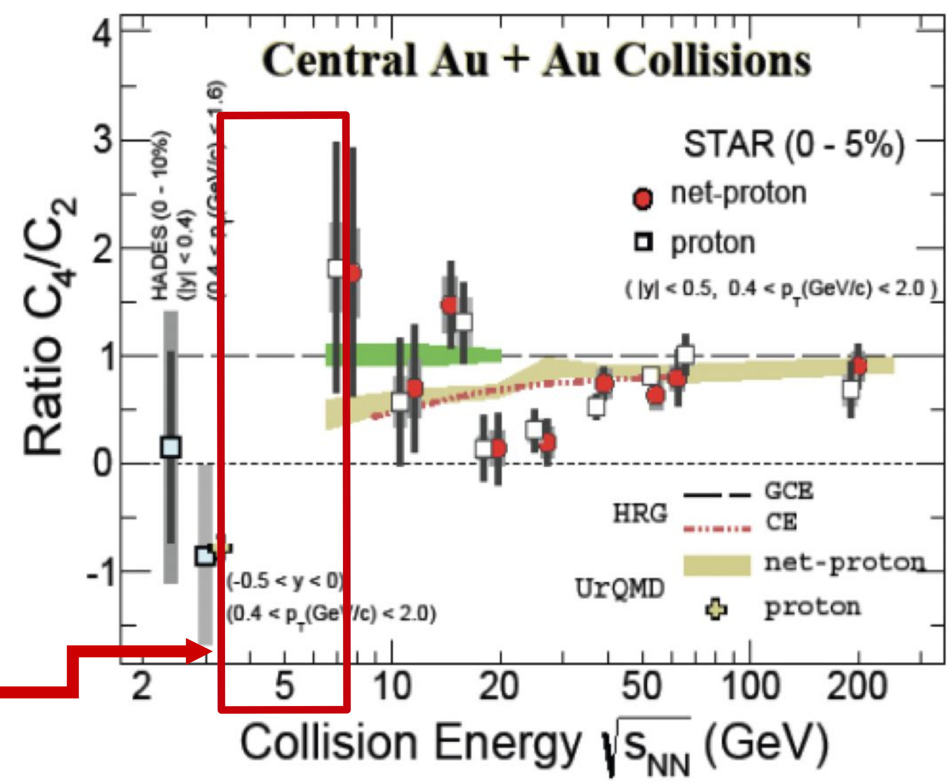


M. Stephanov. J. Physics G.: Nucl. Part. Phys. **38** (2011) 124147

Predicted fluctuations of excess kurtosis (C_4/C_2) near critical point

High statistics data sets with EToF bridging the gap from 3.5 GeV to 7.7 GeV now!!!

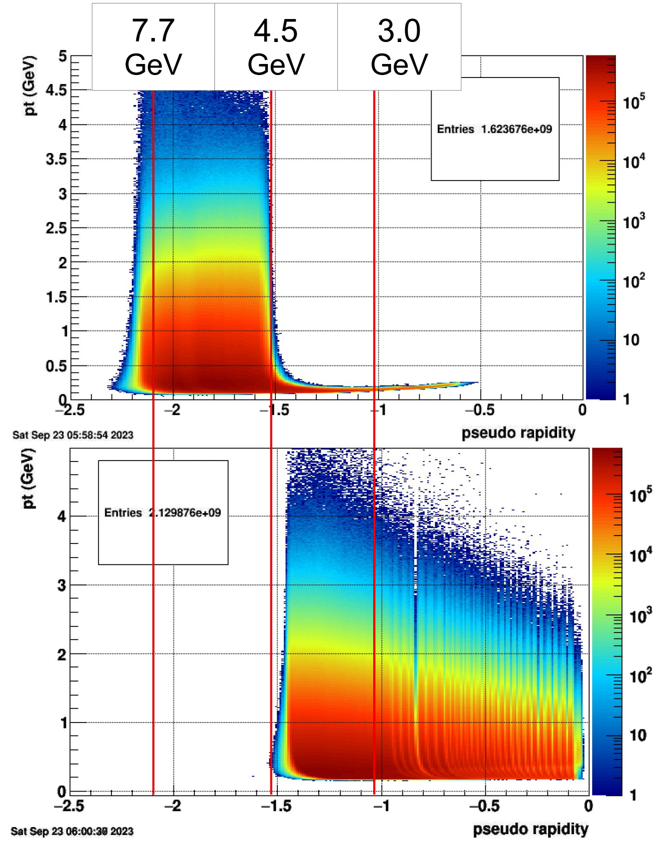


STAR, Phys. Rev. Lett. 128, 202303 (2022) ; arXiv : 2209.11940.
Phys. Rev. Lett. 126, 092301 (2021); Phys. Rev. C 104, 024902 (2021)

Net Proton Fluctuation Analysis: Requirements

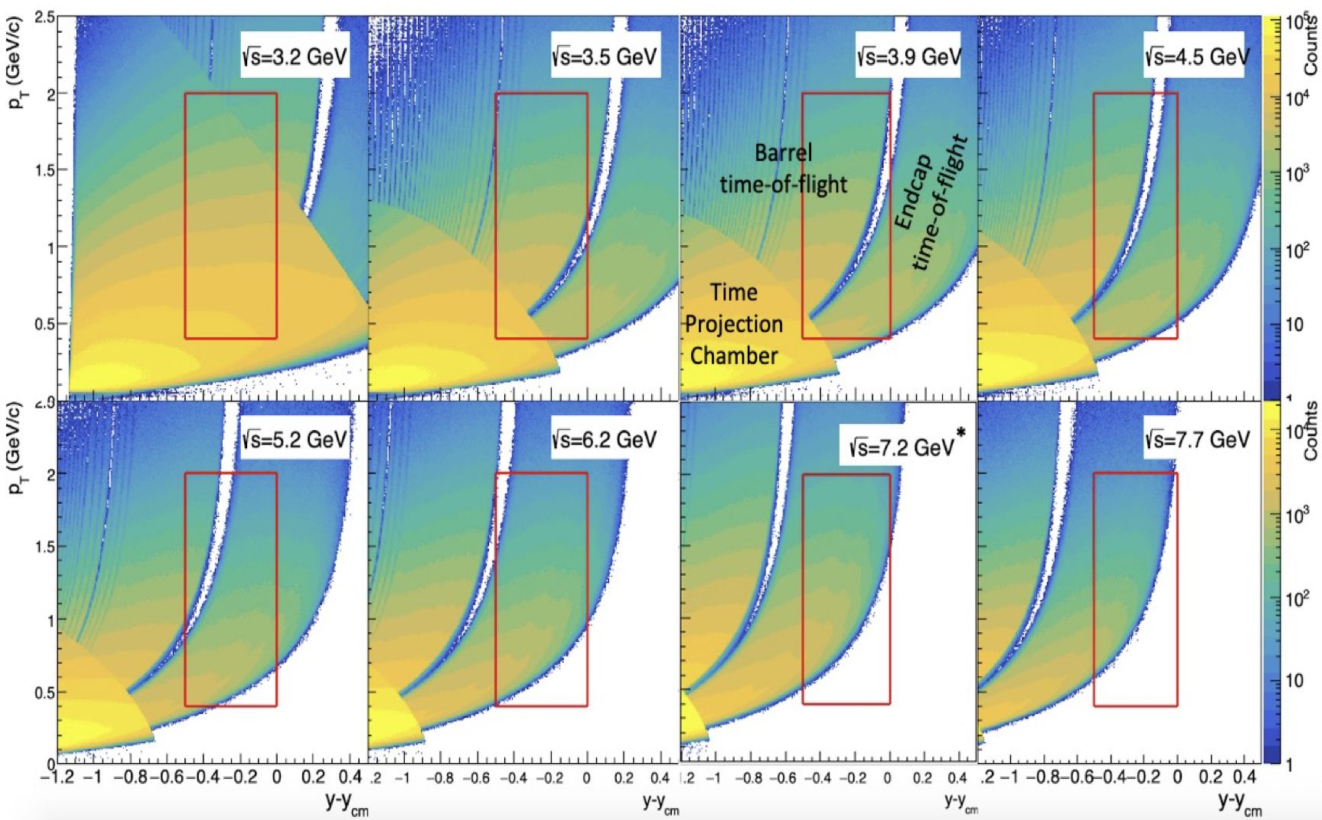
The requirements of the proton fluctuation analysis include:

- Purity > 90%
- Fixed acceptance
- Efficiency known event by event
- ...



Acceptance at 4.5 GeV of EToF (top) and BToF (bottom)
Red lines : Mid rapidity at 3, 4.5 and 7.7 GeV

Proton fluctuations acceptance with $-0.5<y-y_{CM}<0$ analysis window in red



*7.2 GeV acceptance map comes from 6.2 GeV, shifted to the appropriate rapidity

Challenges: Front-End-Electronics dropouts

Get4's can “drop out” during data taking and have to resynchronize with the system

↓

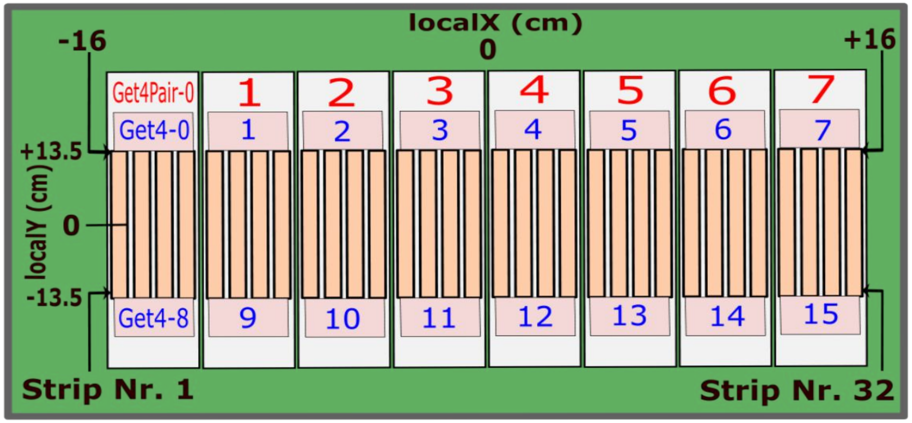
During resynchronization the recorded data is “incomplete”

↓

Which Get4 is resynchronizing at what time is monitored

↓

For any given event and Get4 a status flag is set in the event header



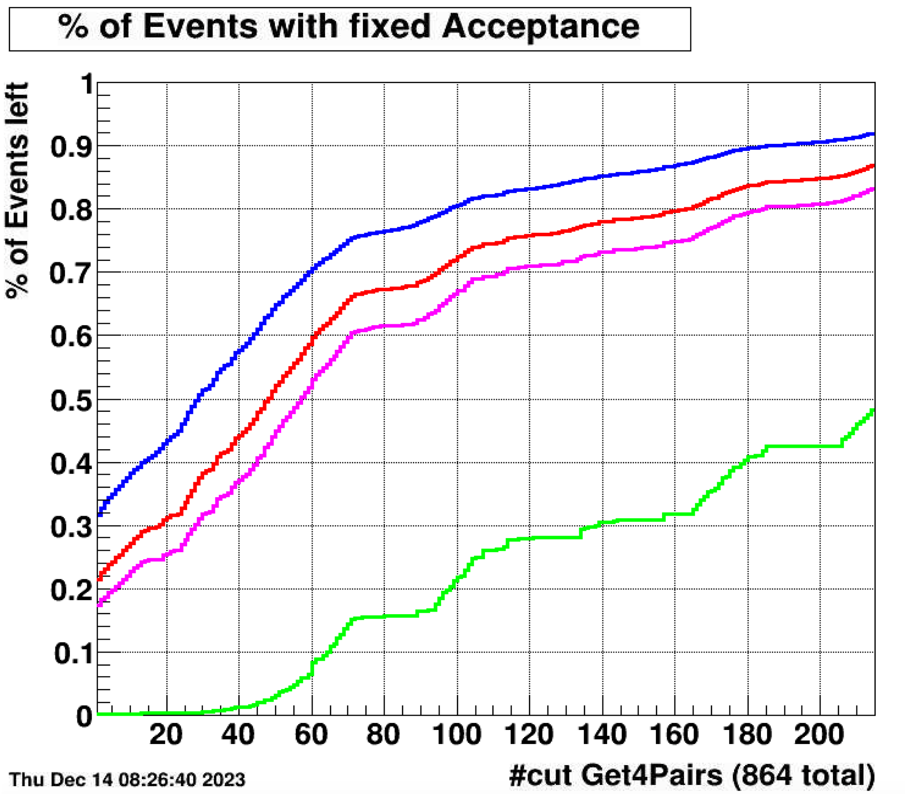
Consequences of electronic drop-outs:

- Efficiency for Get4's with “bad-flag” in any given event significantly lower
- EToF acceptance fluctuating on event-by-event basis

Electronics Dropouts Solution: Event Mask

Possible solutions:

- Ignore Get4's with flag (→ fluctuating acceptance but known efficiency)
- Correct for the loss in efficiency
- Mask out most unstable Get4's and create “stable subset”, ignoring events with bad flags



Number of masked Get4Pairs (864 in total, 8 for each counter)
vs.
Fraction of events with fixed acceptance

Only events with at least one EToF-Hit and at least one intersection taken into account!

Blue:
Intersection on Ge4 required to discard an event

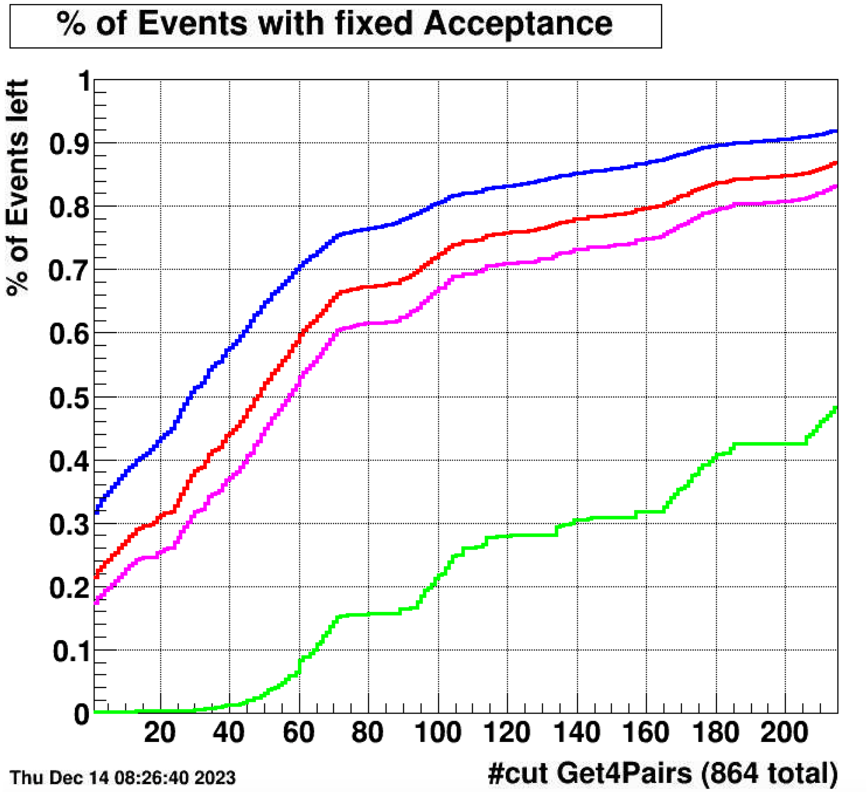
Red:
Intersection on Get4 or half of neighboring Get4's required

Magenta:
Intersection on Get4 or neighboring Get4's required

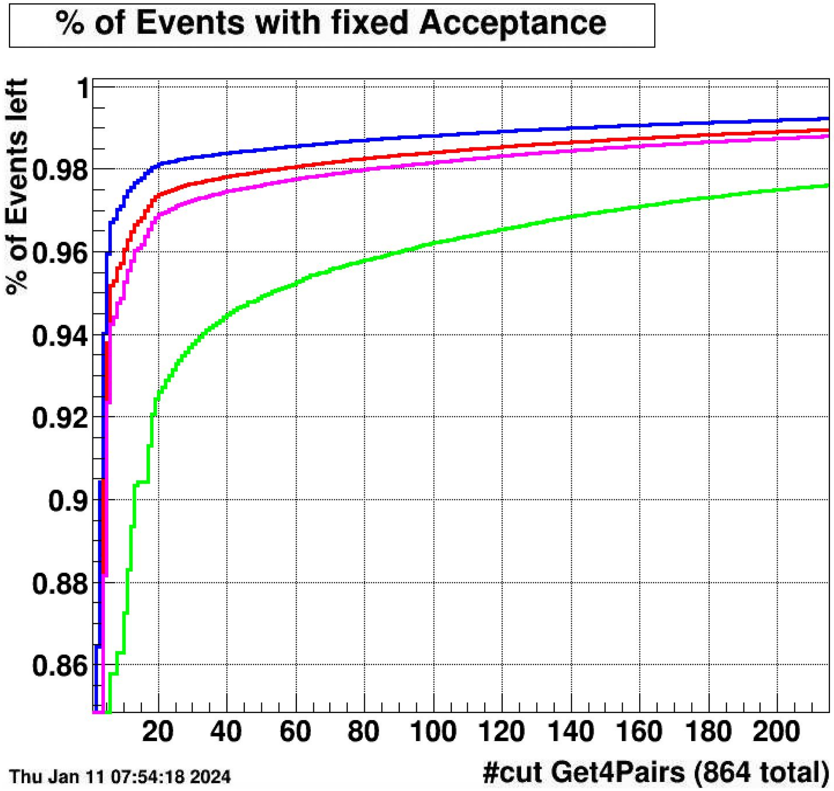
Green:
No intersection required

Saving Statistics : Single-Sided Matches

Most drop outs are single-sided (~ 95%)



Hit reconstruction feasible with single-sided read-out (as for BToF)



Number of masked Get4Pairs (864 in total, 8 for each counter)
vs.
Fraction of events with fixed acceptance

Fluctuations reduced by an order of magnitude!!

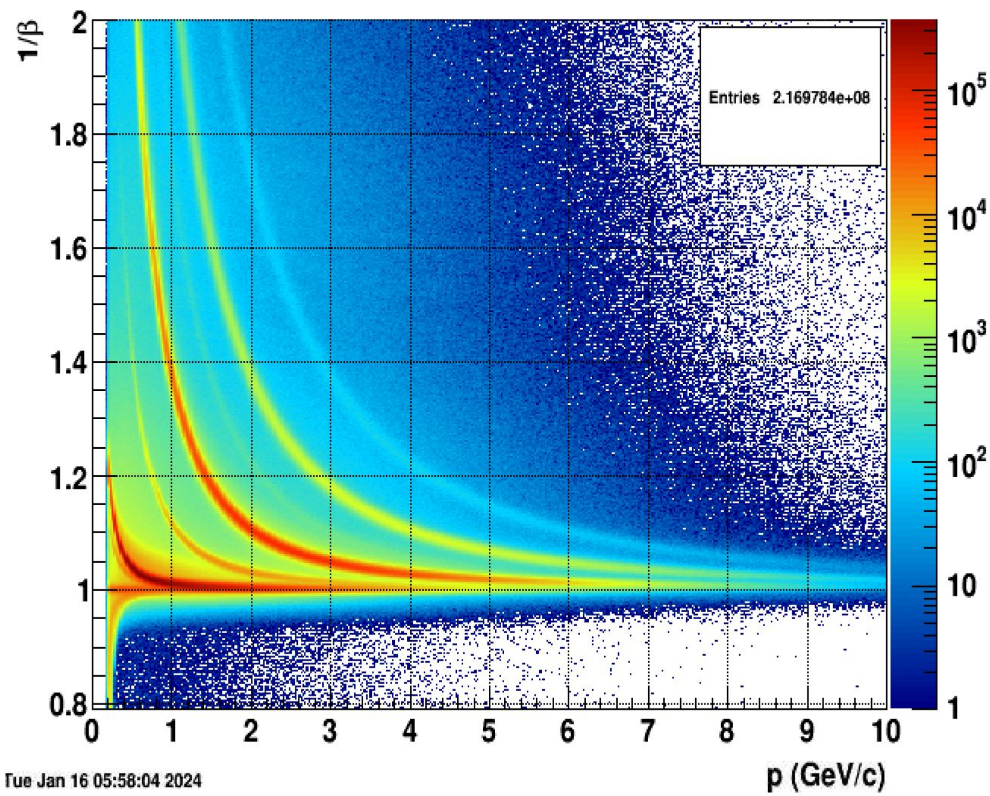
Single-Sided Matches

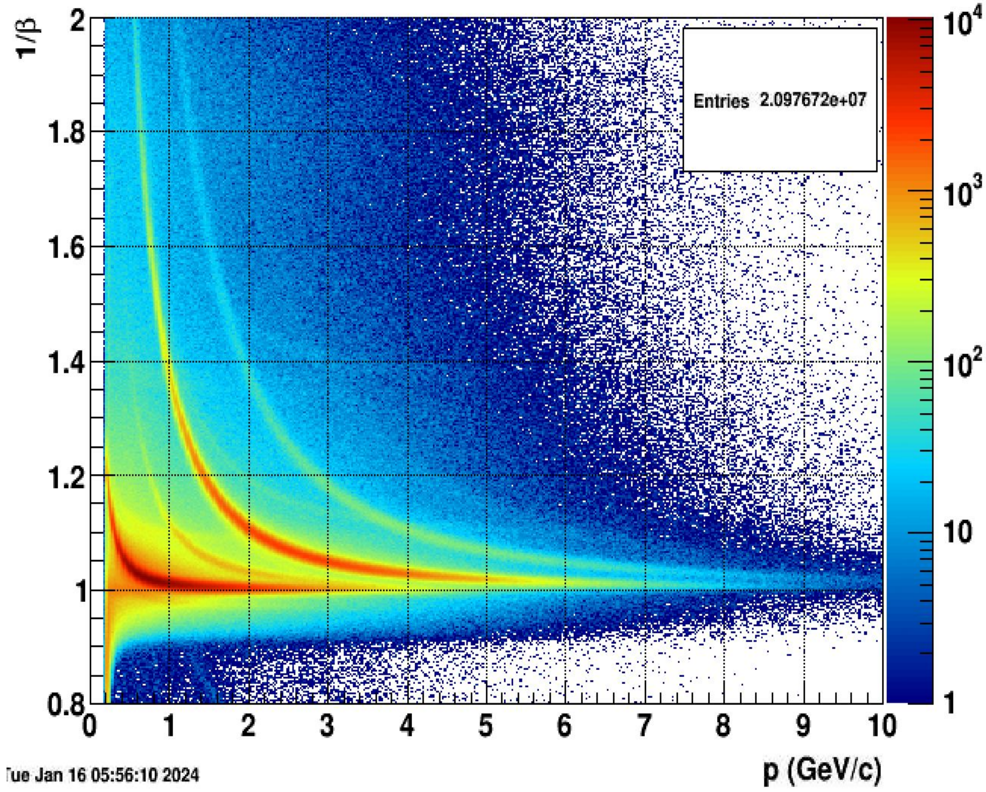
Workflow for double sided matches :

- Create hit from 2 digis -> time and local y known
- Find track intersection in vicinity and create match
- Sort out ambiguities
- Merge hits matched to the same track

Workflow for single sided Matches :

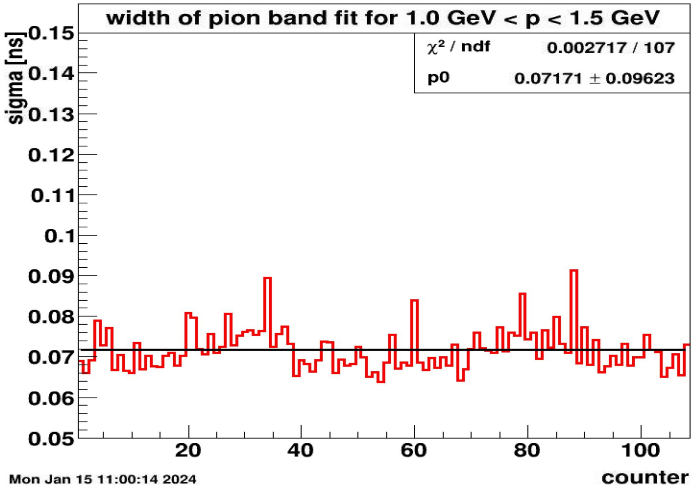
- Create hit from single digi at arbitrary local y
- Find intersection close in local x and create match
- Use local y info from track to correct the hit time
- Sort out ambiguities and merge multi-hits





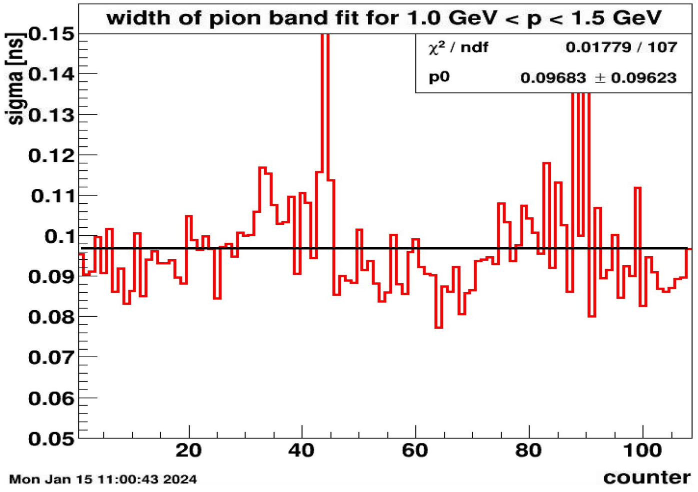
1/ β vs. momentum for double-sided Matches (left) and single-sided Matches (right)

Single-Sided Matches: Performance

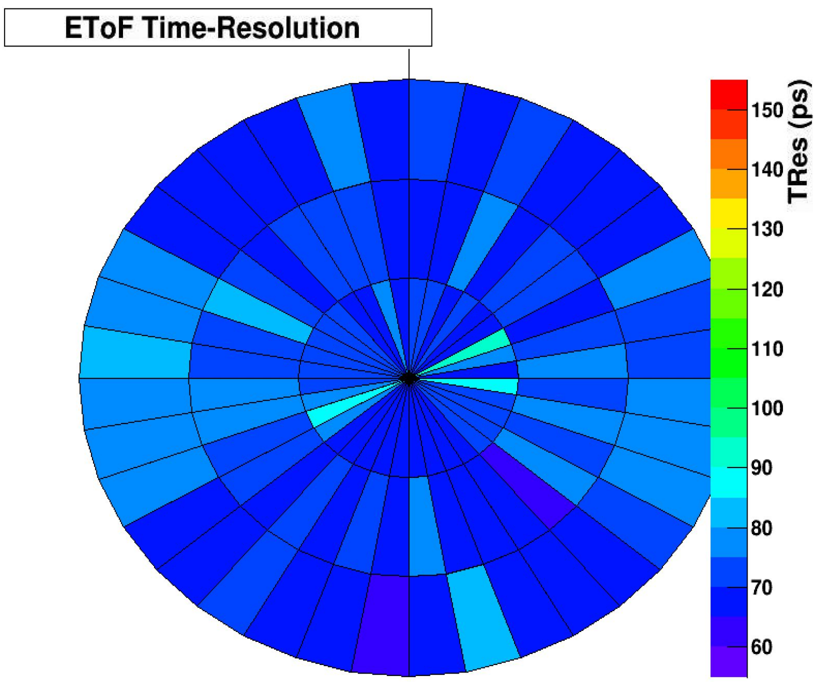


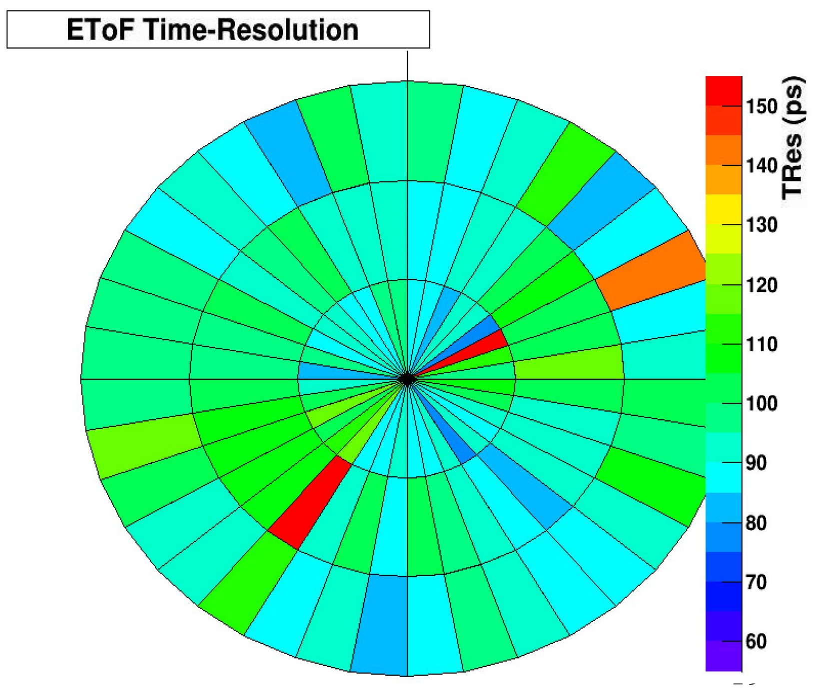
Single-Sided Matches:

- 25ps worse time resolution
- 10% more matches
- Reduced acceptance fluct.



Time-Resolution for double-sided Matches (left) and single-sided Matches (right)





The different Types of Matches

(different) treatment of different match cases not yet clear !!

↓

Match-Flag provides precise information on match type (and assumable quality)

Match-Flag scheme:

Match-Flag = A + B + C

A = 100 → single-hit single-track
A = 200 → multi-hit single-track
A = 300 → single-hit multi-track
A = 400 → multi-hit multi-track

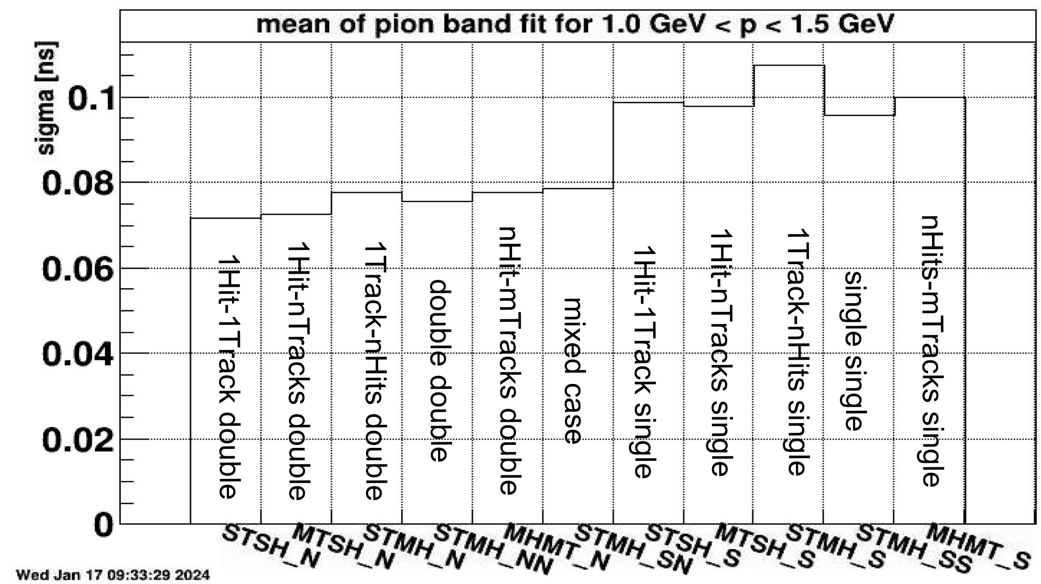
B = 10 → single double sided match
B = 20 → single single sided match
B = 30 → multiple double sided matches
B = 40 → multiple single sided matches
B = 50 → mixture of both

C = 0 → is not an overlap hit
C = 1 → is an overlap hit

Example :

Match-Flag = 421

- 400 → multi-hit multi-track match
- + 20 → single-sided match cluster-size = 1
- + 1 → is Overlap hit

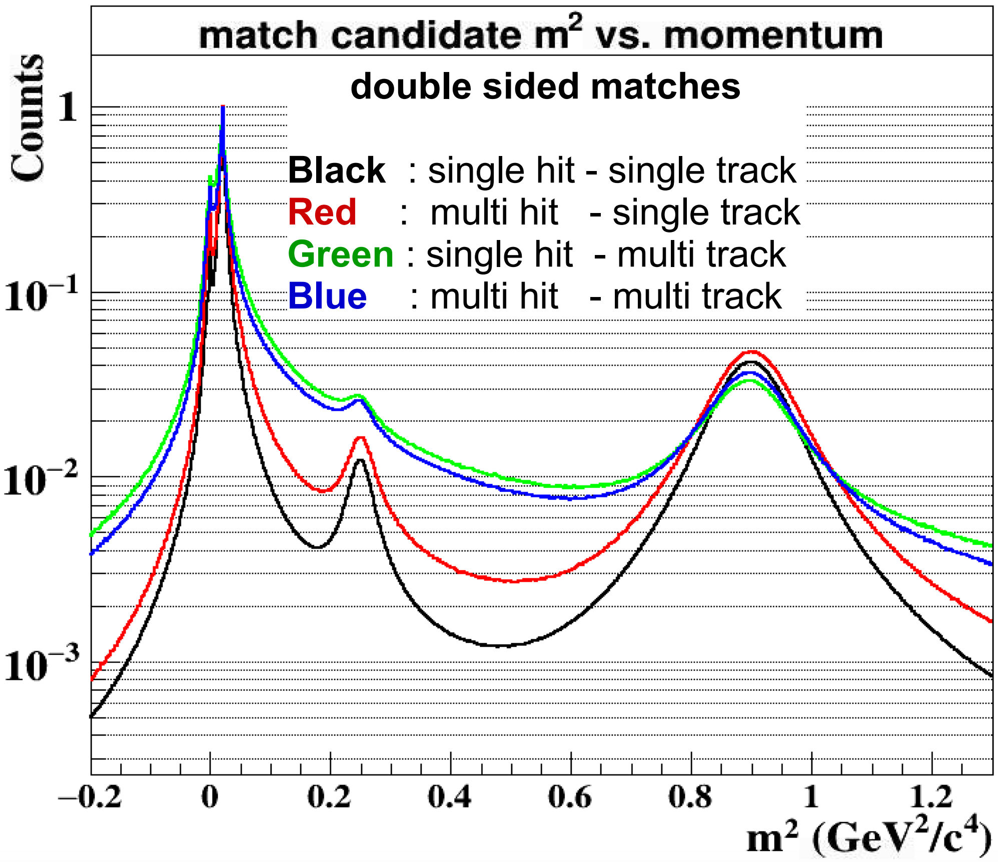


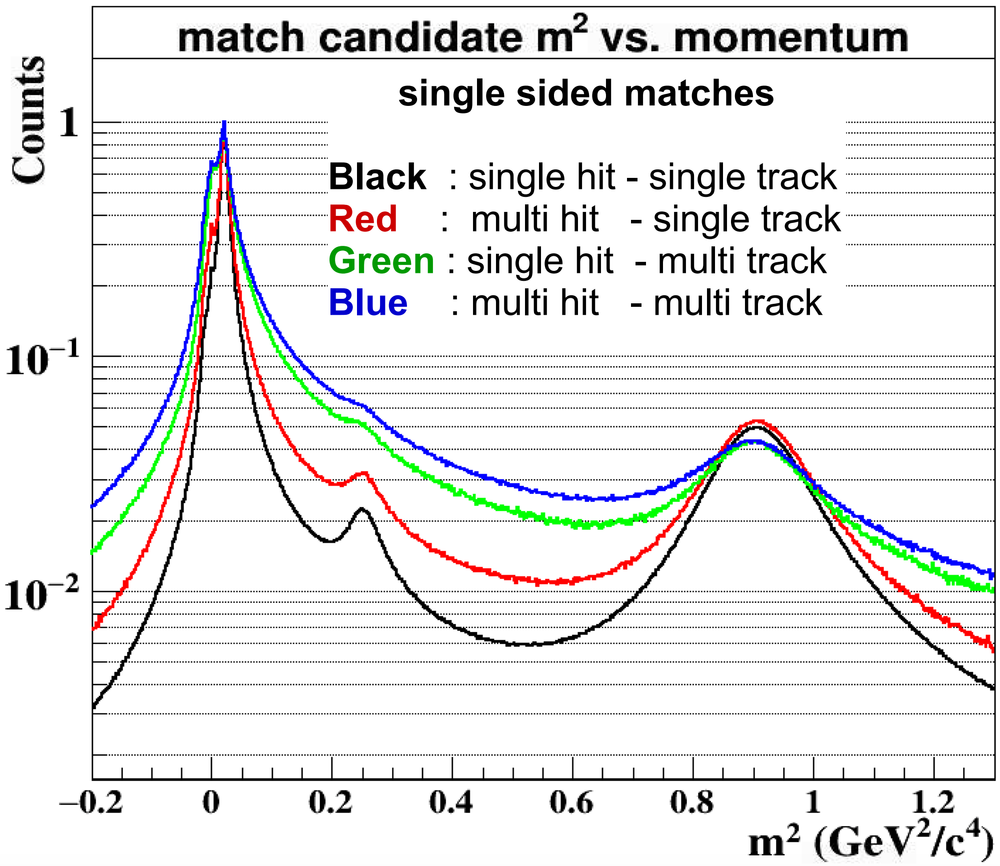
Time resolution of different match cases

Multiplicity Interval	1Hit 1Track	1Hit nTracks	1Track nHits	nHits mTracks
0-25%	89%	0.4%	9.9%	0.0004 %
25-50%	74%	0.8%	24.6%	0.3%
50-75%	65%	1.8%	31.5%	1.6%
75-100%	56%	3.7%	29.9%	9.6%

Fraction of match cases given for 4 multiplicity intervals

Match Cases





m^2-spectra for different match cases for double sided (left) and single sided matches (right)

Signal to background ratio decreasing for more complex match cases !!

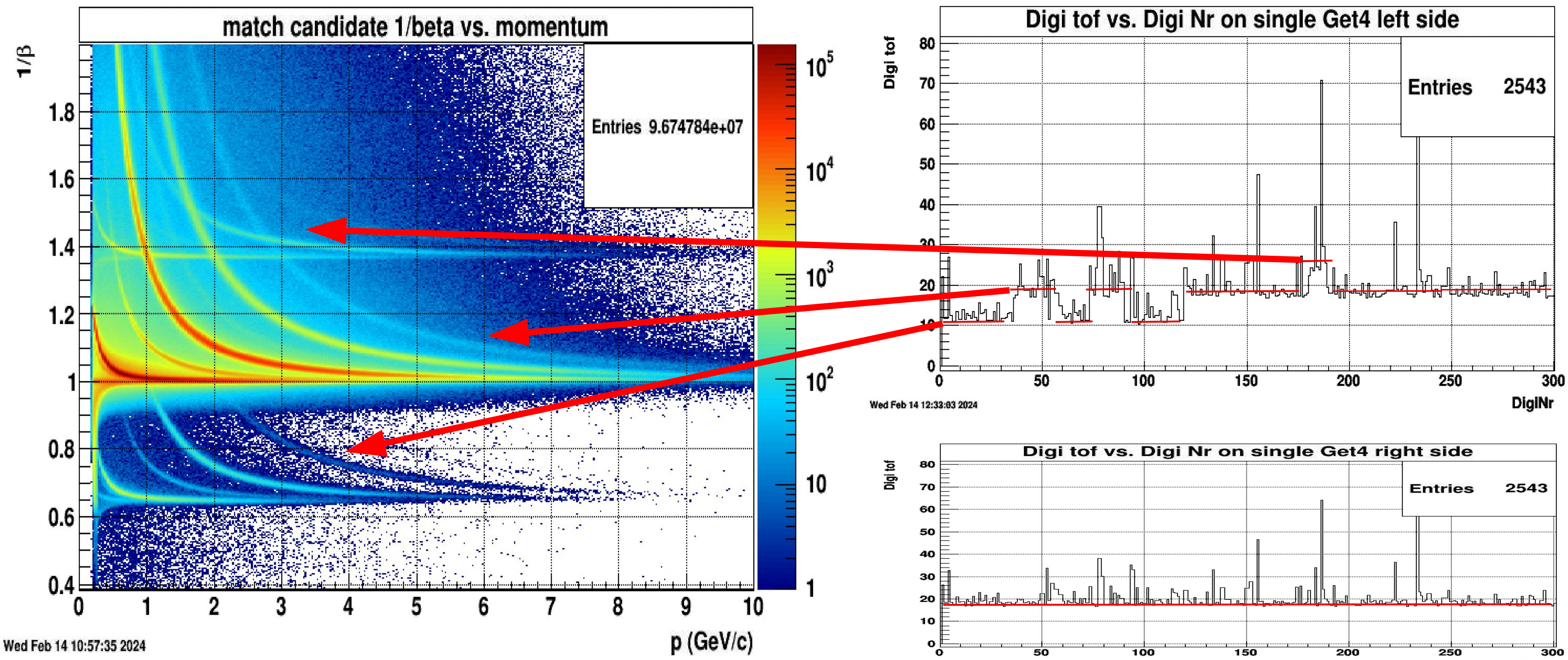
Estimated Proton-Purity on average still above 90% for single sided matches

Challenges: Clock Jumps

Get4s can miss a clock cycle (Hits too early) or count one too much (late Hits)

↓

Sidebands with fixed time offset of 6.25ns in PID spectra

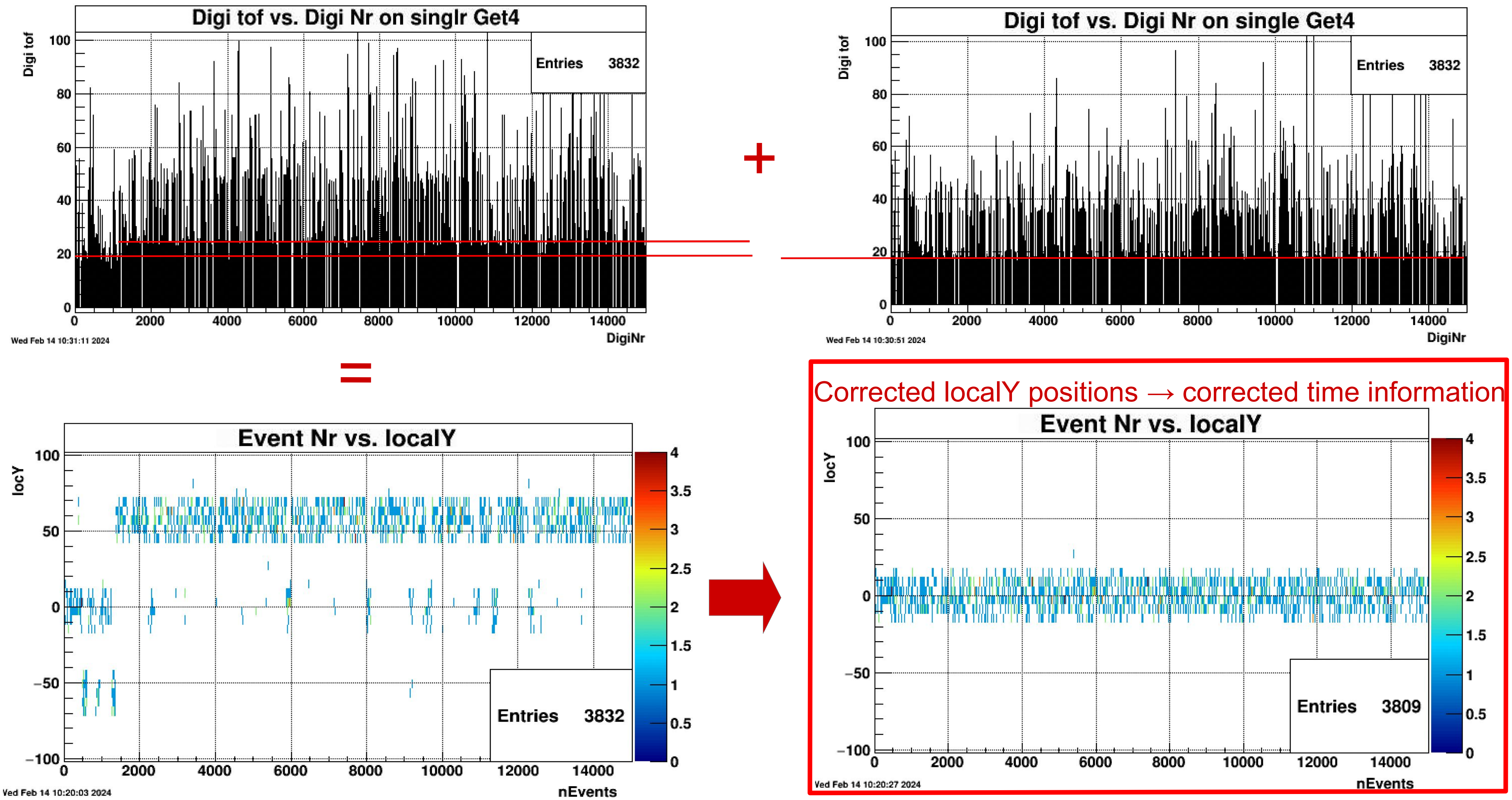


1/beta spectrum with clock jumps in both directions

Digi tof (= Digi time – starttime) vs Digi Nr. On jumping Get4 (top) and its non-jumping partner (bottom)

Consequences if ignored : Acceptance holes, fluctuating on the timescale of several events!!!

Clock Jumps



Single sided clock jumps can be identified by the shift in localY position it comes along with!

→ **Jumped Hits can be identified and corrected!**

Clock Jumps

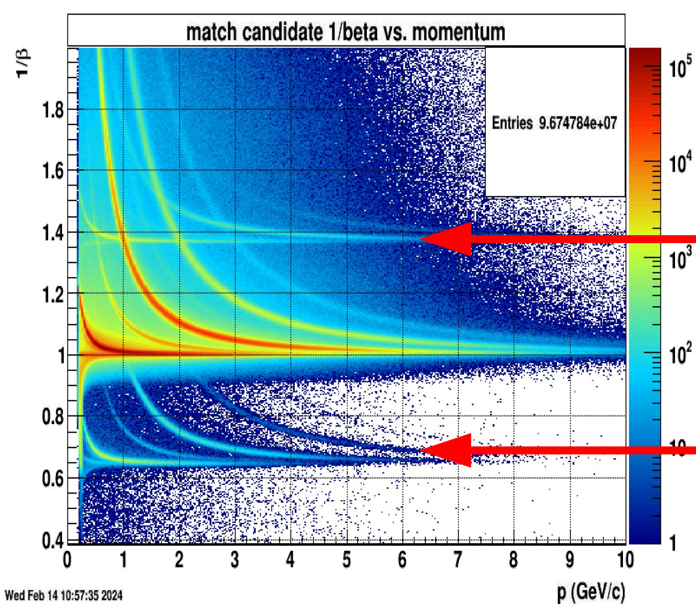
<u>Challenge to correct for those jumps on the fly:</u>

Which of the Get4s did jump and in which direction (too early or too late) ???

To determine the jump direction of a Get4 a couple of Hits are needed (easier for too early Hits)

On average only one hit on a Get4 in about 10 events

This latency in determining the Get4 state results in hits being shifted in the wrong direction

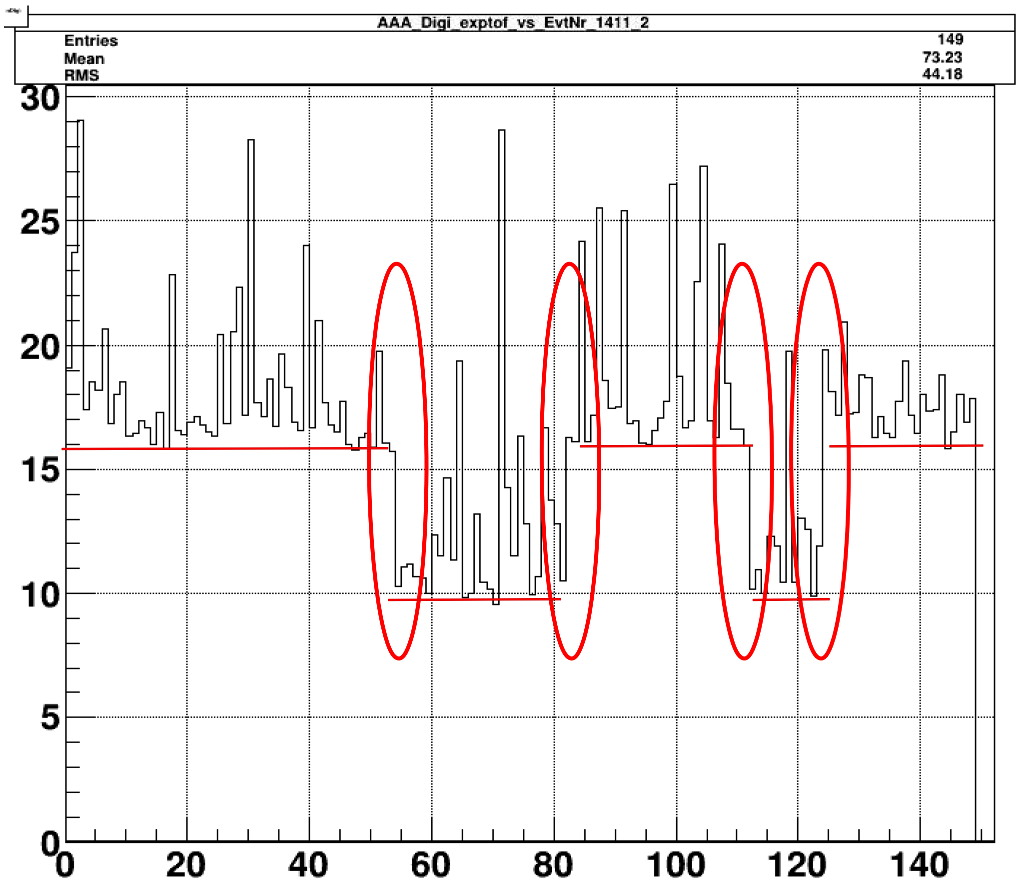


Hits correctly identified as jumped

...

but shifted in the wrong direction

Clock Jumps Solution: Use full Time Information



Measured time - start time of consecutive digis on a single Get4

On the fly correction insufficient

↓

New strategy:

1. Use full Get4 time spectrum from already produced data to identify state jumps
2. Collect the information on Get4 state for each period in db-table
3. “calibrate” jumps out in second production

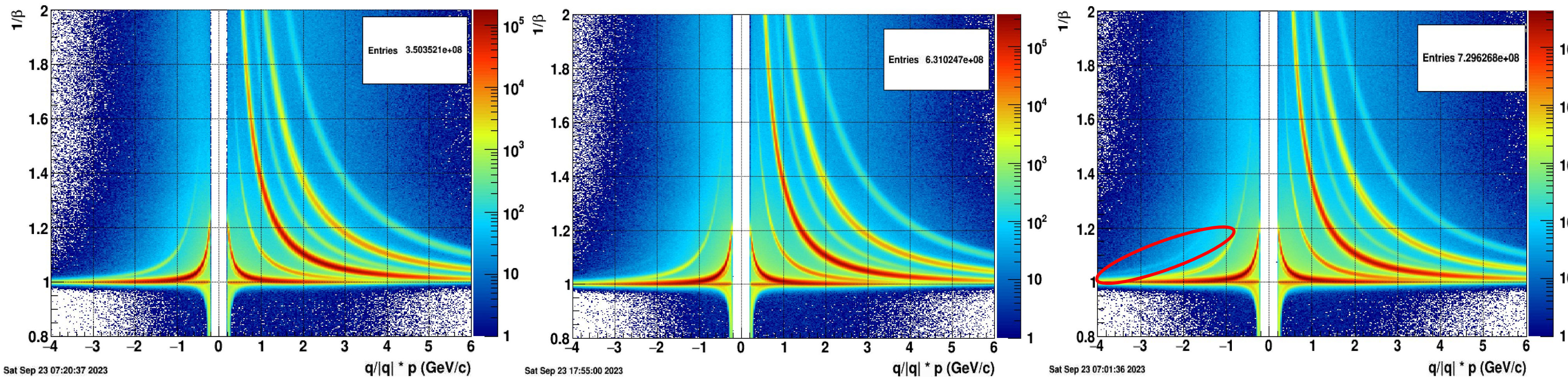
Pro:

- full time info available for correction

Cons:

- High resource consumption

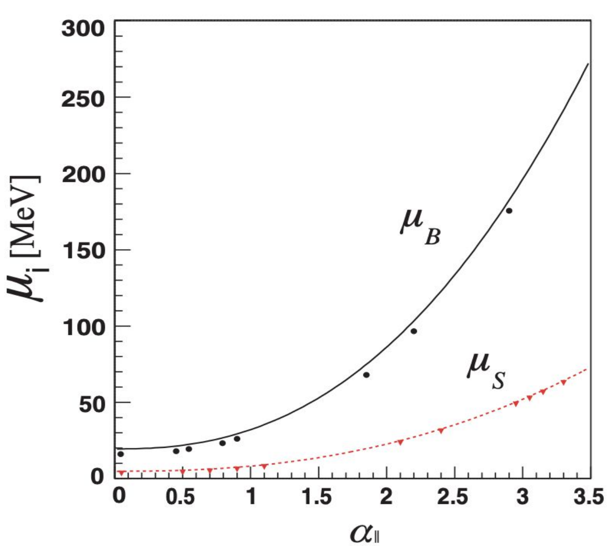
Physics with EToF: baryon chemical Potential



3.5 GeV 3.9 GeV 4.5 GeV

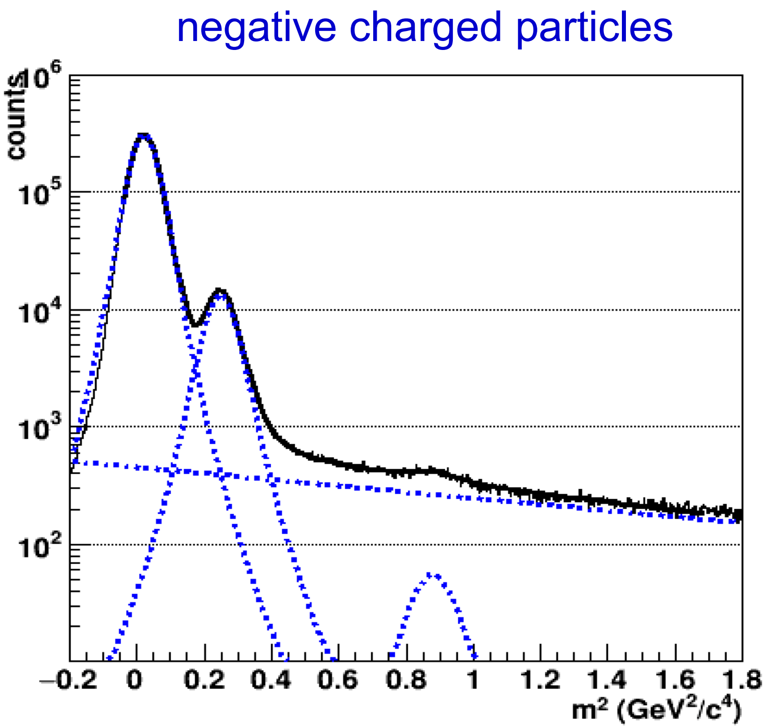
Antiprotons matter! → $\bar{p}$ / p provides a good proxy for μ_B :

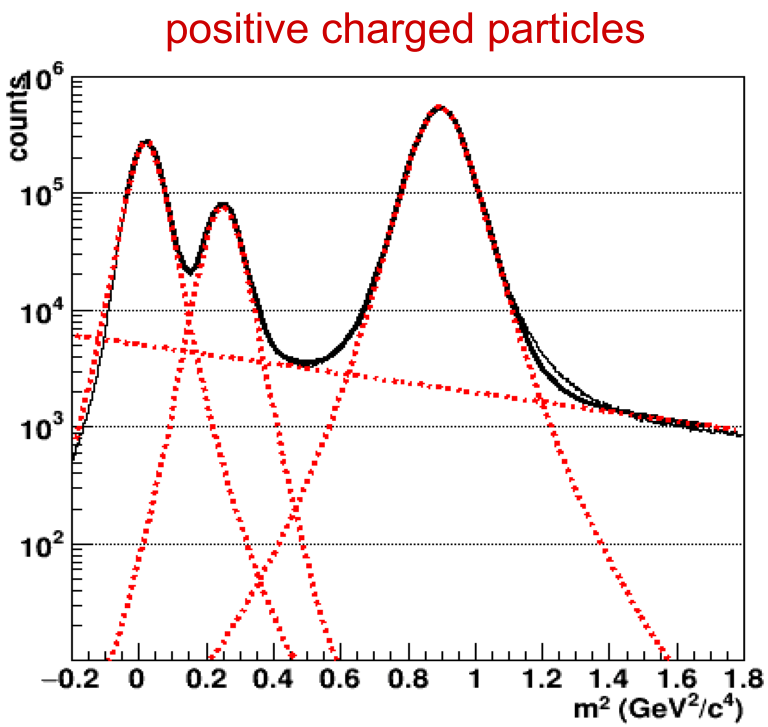
$$\frac{p}{\bar{p}} \simeq \exp(2\beta\mu_B).$$



Black line : μ_B from full fit with decays
Black dots : fit by antiproton/proton ratio only
Red line: μ_s from full fit with decays
Red dots: fit by K^+/K^- ratio only
Data: 200GeV AuAu taken by BRAHMS

EToF : m^2 spectra at 4.5 GeV





<u>Pid by EToF only</u>

Pions,Kaons,Protons :
- Student_t func.

Background:
- exponential

Centrality :
- 0-5% most central

Momentum range :
- 2.25-2.5 GeV

Assumed temperature:
- 160MeV

First estimate : $\mu_B \approx 689.6$ MeV (literature : $\mu_B \approx 589$ MeV)

Overestimation maybe due to :

- Background description insufficient
- Feed down from decays not taken into account
- Coalescence of protons into deuterons not taken into account

Summary and Outlook

Plenty of data featuring EToF available

- All FXT 2020 data sets are calibrated (7 energies from 3.5GeV to 7.7 GeV)
- 3 Collider data sets including the overlap energy at 7.7GeV are calibrated
- Large 3.0 GeV FXT 2021 data set (2B events!) calibration close to final
- Final clock jump corrected productions coming soon!

Physics analysis using EToF ongoing

- Proton fluctuation analysis making good progress
- Hypernuclei reconstruction benefiting from inclusion of EToF information
- Investigation of baryon chemical potential prioritized after production

Thank you for your attention!