Optimizing Time-of-Flight Calculations to Identify Particles in p+p and p+A Collisions with the STAR Detector

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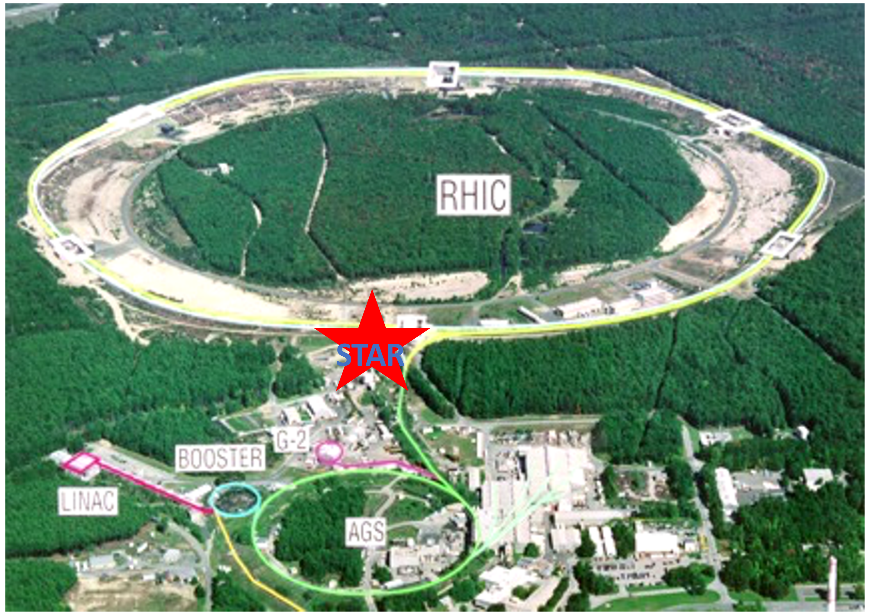
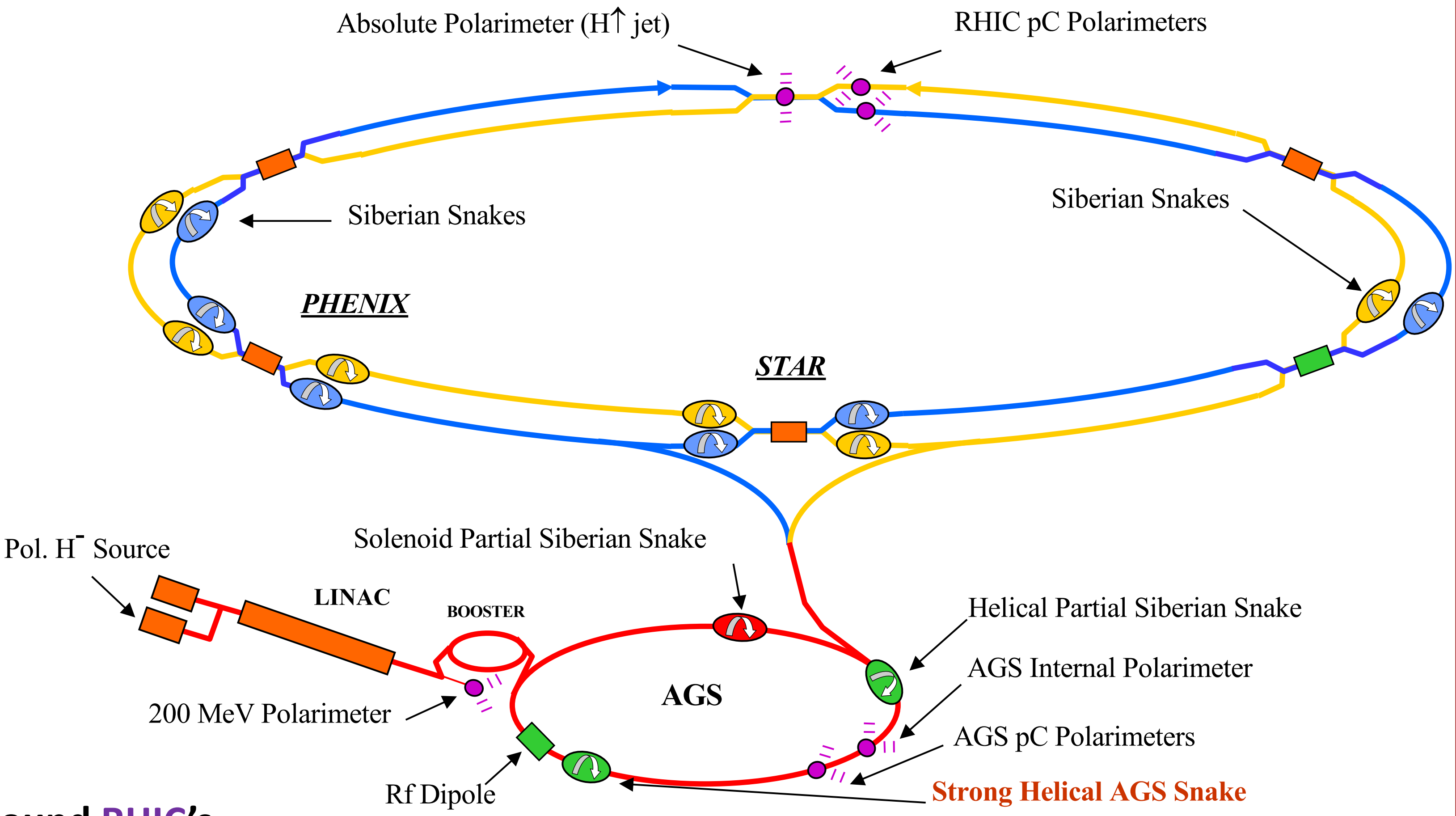
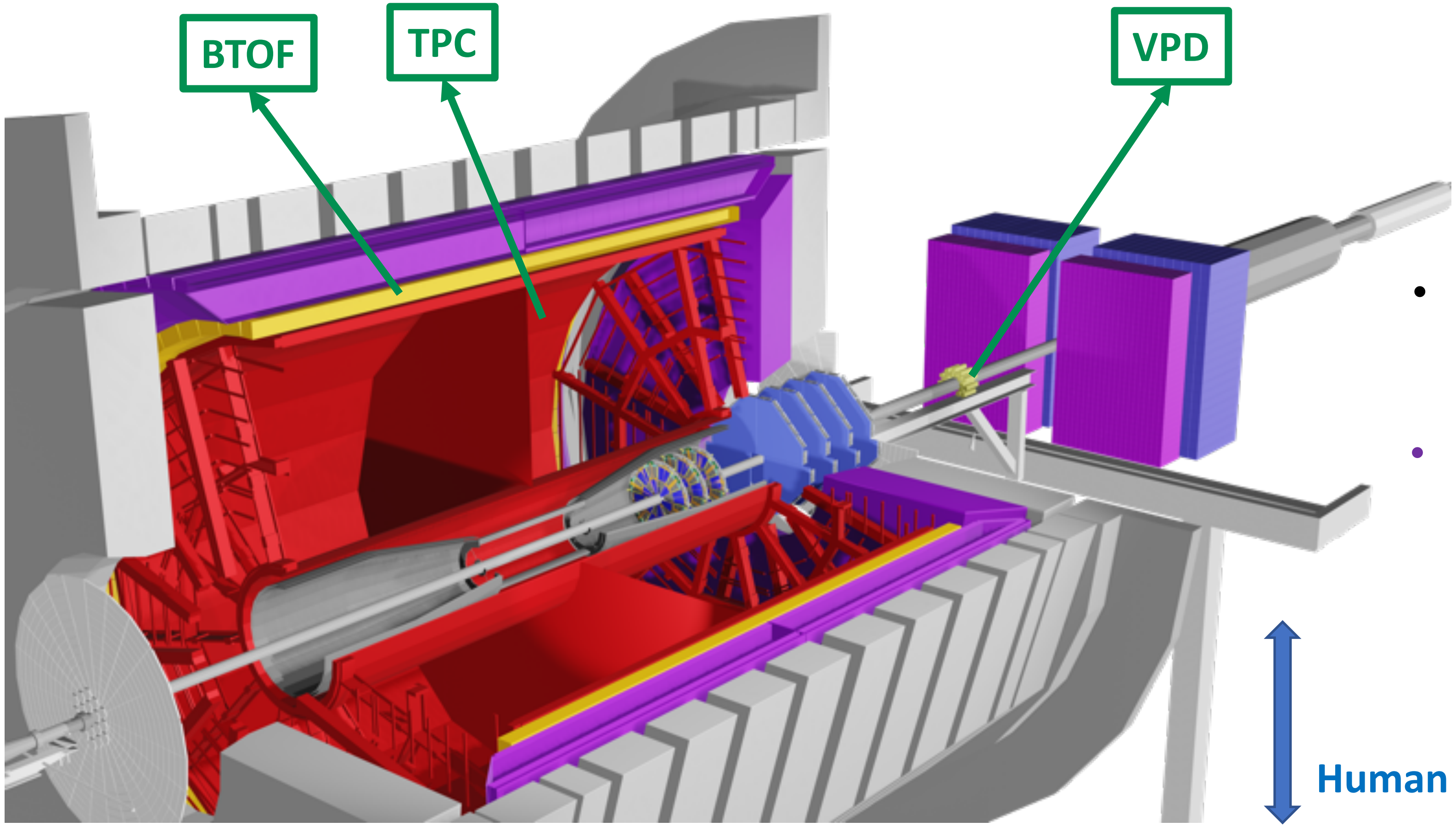
RHIC: Relativistic Heavy Ion Collider





- **The only machine in the world capable of colliding high-energy beams of polarized protons**
- **The beams travel in opposite directions around RHIC's 3.86 km two-lane racetrack**
- **Provides a tool to research and study the state of matter known as Quark-Gluon Plasma**
- **Enables us to explore the different properties of protons**

STAR: Solenoidal Tracker At RHIC

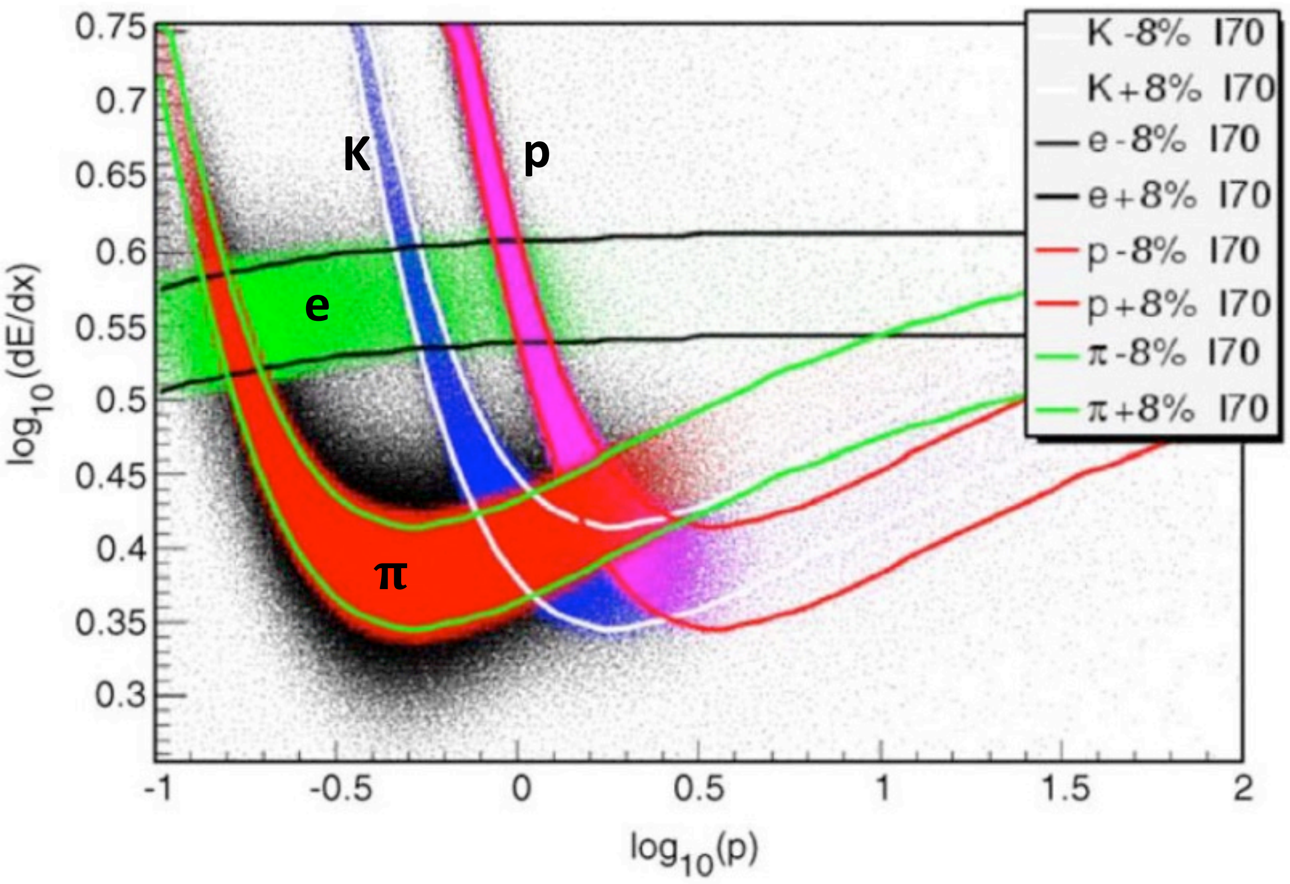


- STAR collaboration:
  - 14 counties
  - 68 institutes
  - 750 scientists and engineers
  - A broad range of research topics
- Particle identification is important for many STAR analyses
- STAR uses the following detectors for particle identification :
  - TPC: Time Projection Chamber
  - BTOF: Barrel Time-of-Flight
  - VPD: Vertex Position Detector

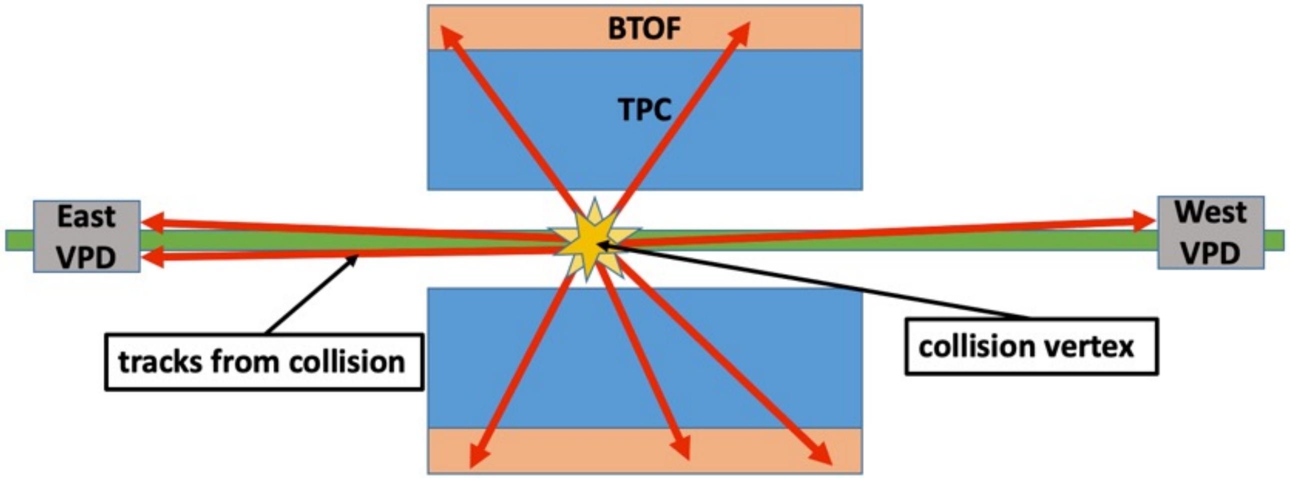
Human size compared to STAR

Particle Identification at STAR

- **STAR primarily relies on dE/dx information from the TPC for particle identification (PID):**
  - **This is powerful because it is available for every reconstructed track using the TPC**
- **In certain momentum ranges, dE/dx bands overlap and its PID power is reduced**
- **In the following slides, I will show work to optimize a PID tool that is complementary to dE/dx, and particularly where the dE/dx vs. p bands for different particle types are close or cross each other**



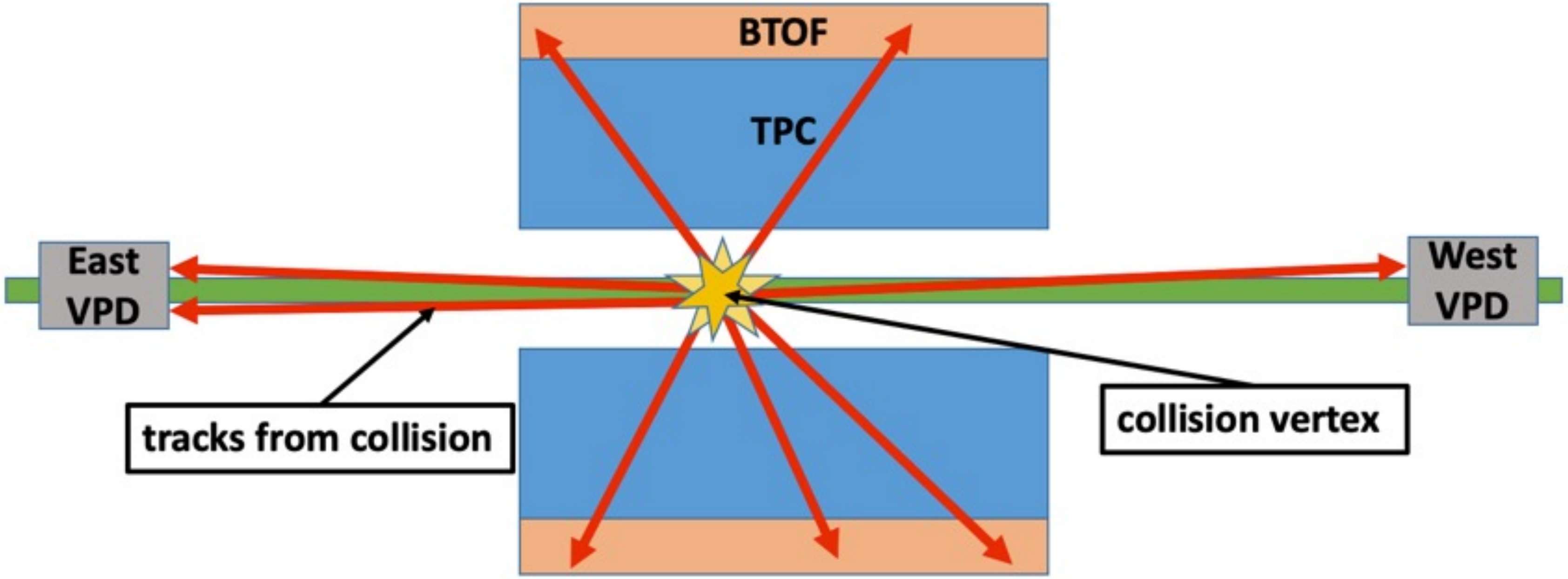
Time-of-Flight (TOF) System



- **The TOF system is used for direct identification of charged particles. The following quantities are needed to calculate the mass of a particle:**
    - **Flight time:** start time and stop time
    - **Path length:** obtained from the TPC
    - **Velocity:** obtained from the above two quantities
    - **Momentum:** obtained from the TPC

- **Two important inputs from TOF system:**
    - Event start time:
        - Usually measured using the VPD, but we explored an alternative way to determine the start time
    - Event stop time:
        - Measured using barrel time of flight (BTOF), also known as the stop-time detector

Start-less TOF



- **Originally developed for studying Au+Au collisions at low energies due to low VPD efficiency**
  - **It has never been used before to study collisions involving protons**

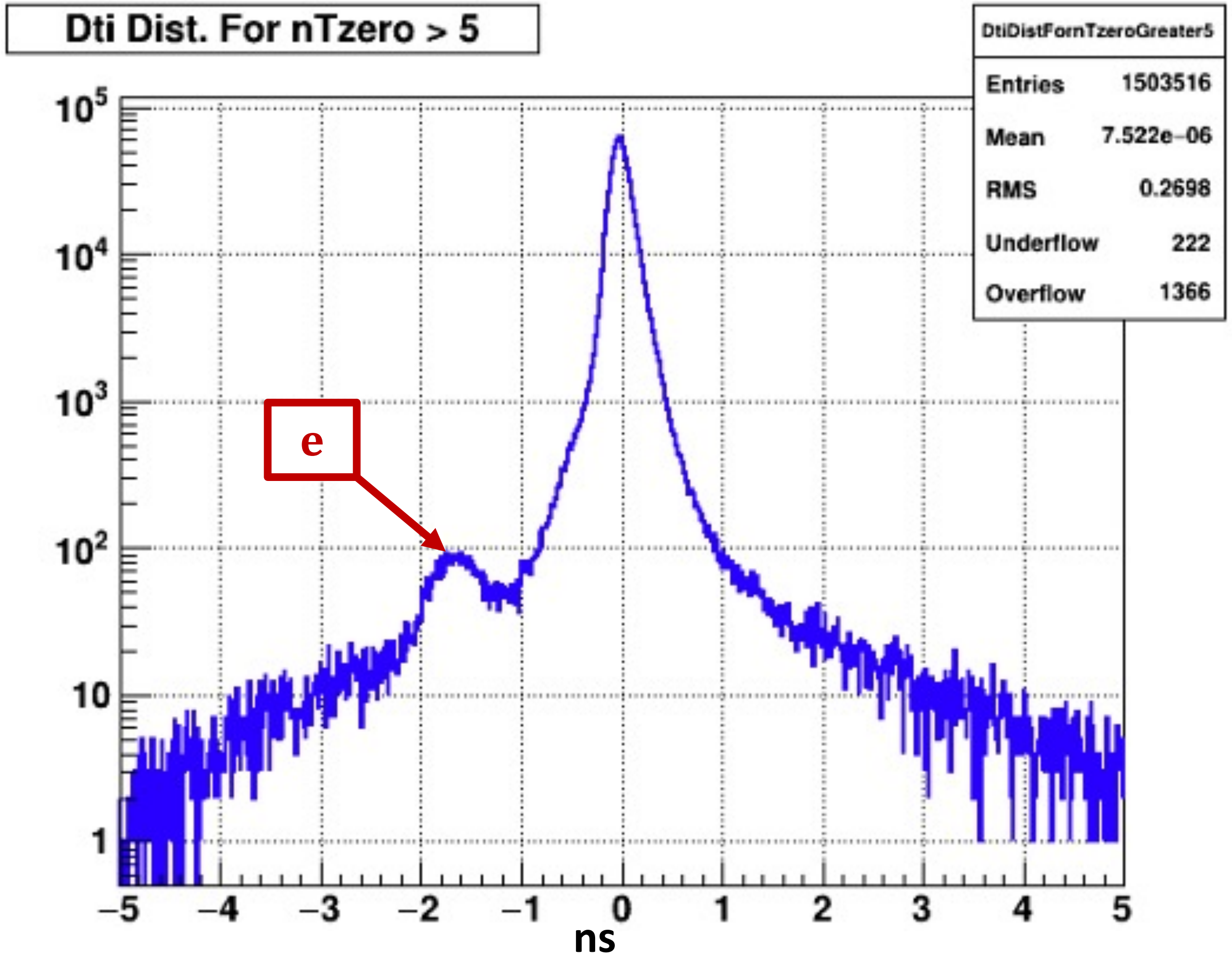
- **Start-less TOF uses:**
  - **BTOF to calculate stop time**
  - **Well-identified tracks with BTOF hits to calculate the start time**
    - **Low momentum pions end up providing the highest number of such tracks**
    - **The start time of a track is inferred based on the mass, momentum, and track length of the track**

Default Start-less TOF

- We investigated how the default start-less TOF algorithm works, which led to finding several issues

- The figure on the right illustrates one of the problems in the default start-less TOF algorithm, where the particle selection is allowing other particles to contaminate the pion sample used for start time calculations

- Due to time constraints, in the next slides, I will discuss only a couple of the problems we found

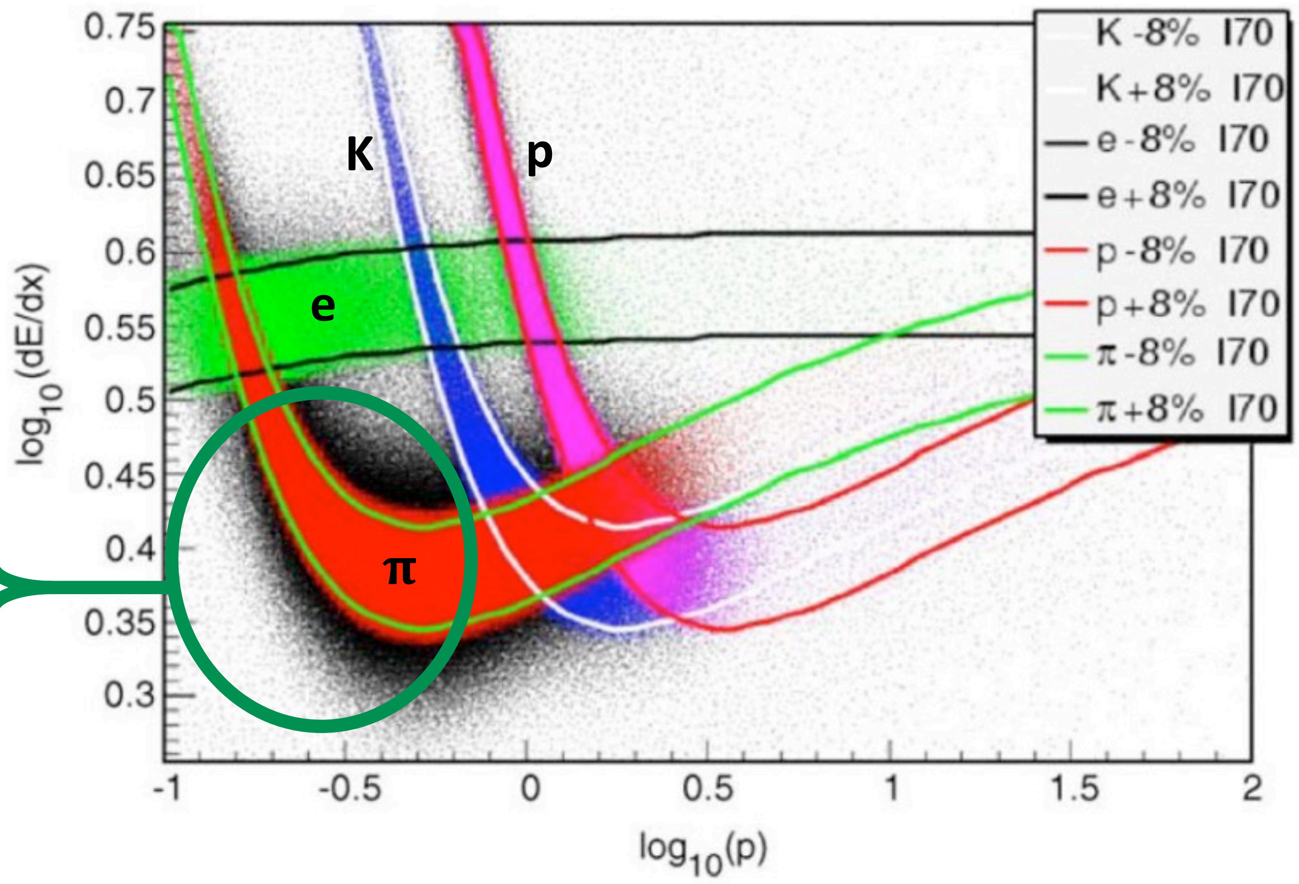


Difference between the start time of one accepted "high-purity" pion and the average start time of the remaining "high-purity" pions

Selecting Pions With High Purity Using dE/dx

- **Default start-less TOF high purity pion selection cuts:**
  - **0.2 < p < 0.6 GeV/c**
  - **|N_σ(pi)| < 2.0 , where N_σ is the dE/dx for a given particle in normalized units**

- **Optimized start-less TOF high purity pion selection cuts:**
  - **0.2 < p < 0.7 GeV/c**
  - **|N_σ(pi)| < 2.0**
  - **$N_\sigma(e)$ < -3.0 and $N_\sigma(K)$ < -3.0**
  - **Track cuts to have good quality tracks:**
    - **nHitsFit > 20**
    - **nHitsFit/nHitsPoss > 0.51**
    - **nHitsdEdx > 0.5 * nHitsFit**
  - **Avoid tracks tangent to BTOF trays:**
    - **p_T > 0.18 GeV/c**
  - **Vertex pointing accuracy to reduce contamination from secondary particles and decays in flight:**
    - **2 cm global DCA cut**



A Conceptional Problem With The Default Outlier Rejection

- **The outlier rejection algorithm prunes through the candidate pions to remove ones with anomalous start time w.r.t. the remaining pions:**
  - **But the result depends on the order of the candidate pions**

Consider the following hit times:

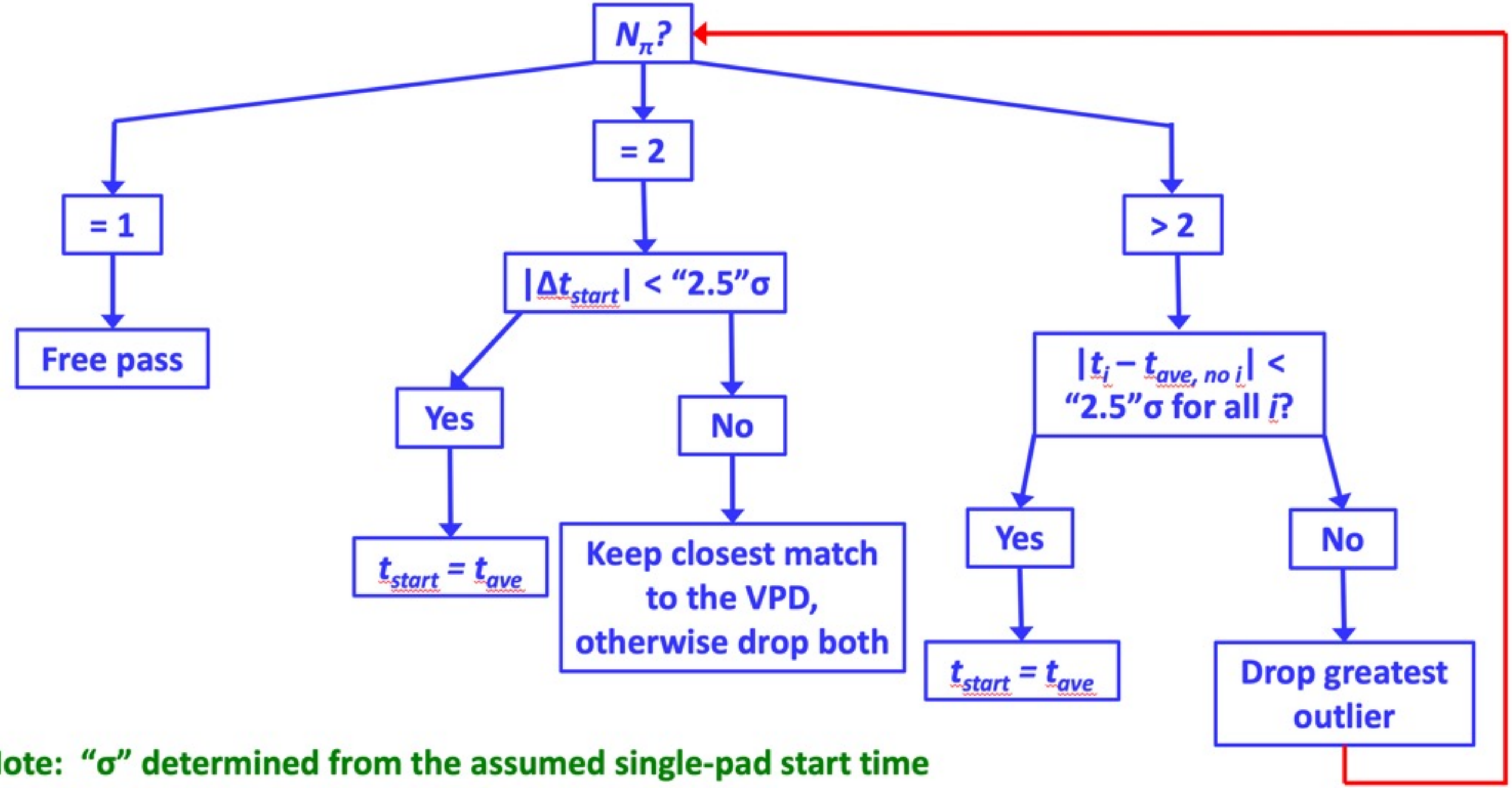
- **4.8 ns, 5.0 ns, 5.2 ns, and 21 ns**

- **From the above time values, it is expected that 21 ns seconds would be the hit with the outlier time value and the time average to be 5 ns**

Example:

Order	t_ave	Tot Prob
x,y,21,4.8	4.8	1/12
5.2,21,y,z	4.9	1/12
21,x,y,z	5	5/12
5.0,21,x,y	5	
x,y,21,5.0	5	
4.8,21,x,y	5.1	1/12
x,y,21,5.2	5.2	1/12
x,y,z,21	21	1/4 !!!!

Improved BTof Outlier Rejection Algorithm



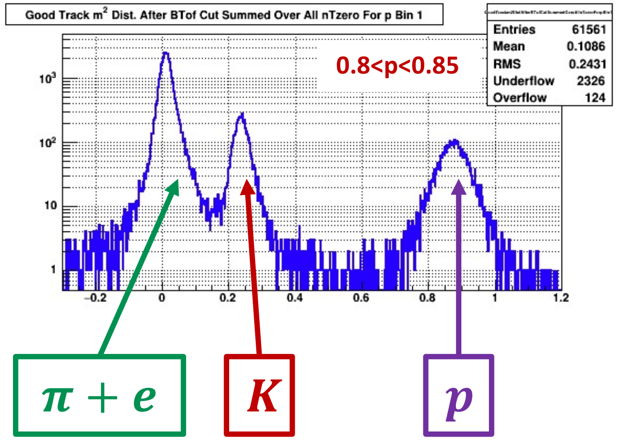
Note: "σ" determined from the assumed single-pad start time resolution and the number of pads in the calculation

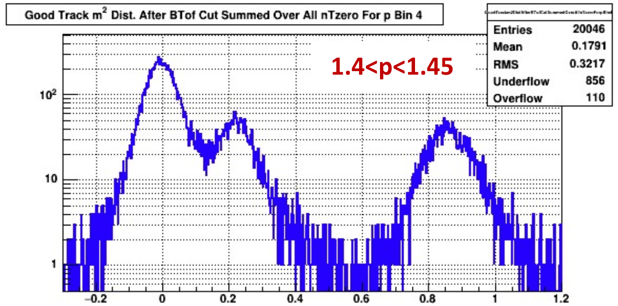
mass^2 Distributions Before and After Optimizing Start-less TOF

p + Au

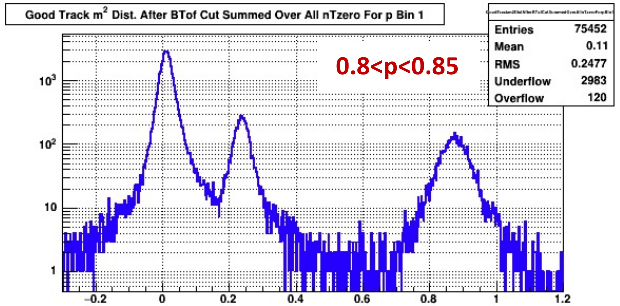
Default Start-Less TOF

p + p

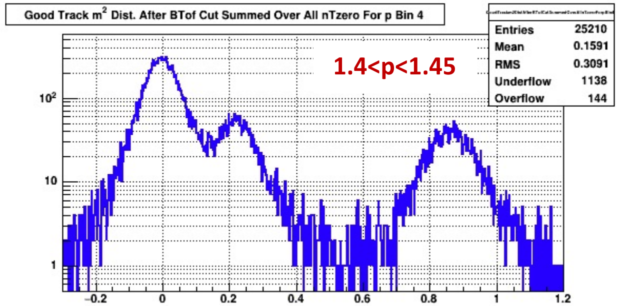




mass^2

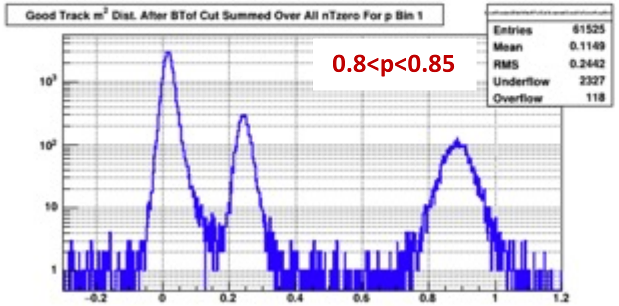


mass^2

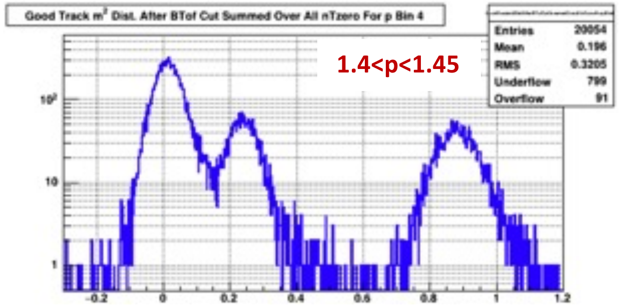


mass^2

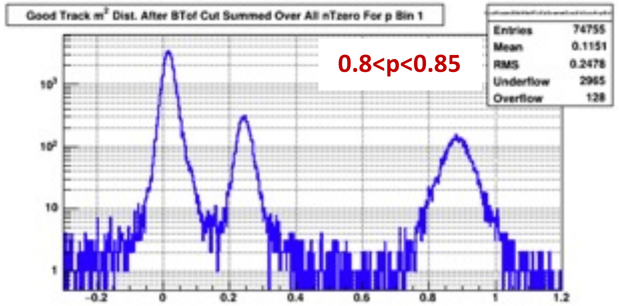
Optimized Start-Less TOF



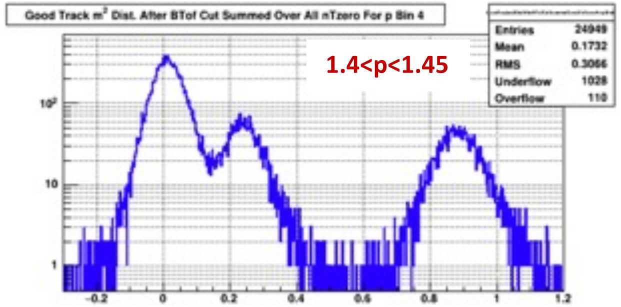
mass^2



mass^2



mass^2



mass^2

- **15-20% improvement in resolution**
- **1-2% increase in signal yield**

Conclusions

- **I have shown that the new algorithms for start-less TOF lead to significantly improved resolution and a modest increase in efficiency, which will enhance STAR's particle identification capability in p+p and p+A systems**

- **Colleagues in the STAR Cold QCD group are now using the revised start-less TOF routines in their analyses of p+p data from 2015 and 2017**

- **Heavy ion colleagues have expressed interest in the improved start-less TOF algorithms for analysis of low-energy Au+Au collision data from 2019, 2020, and 2021**

- **Efforts are ongoing to incorporate these improvements into the official STAR library**

Back up

Energy Loss (dE/dx) Time Correction

- **The pion momentum used for start-time calculation is the momentum at the collision point, but:**
  - The particle loses energy and slows down as it passes through material
  - This leads to a measured TOF that is longer than the calculated TOF for a pion of momentum p

- **Based on the geometry of STAR we introduced a simple and effective dE/dx correction to the start time calculation of candidate pions used for the determination of start time for a given event**
  - This dE/dx correction includes an empirically tuned fudge factor (FF)
  - Depends on the configuration of STAR for a given run
  - When dE/dx correction is included, we obtain a better BTOF time resolution and a higher number of candidate pions for start time calculations