Study of (anti)deuteron production mechanism in proton-proton interactions

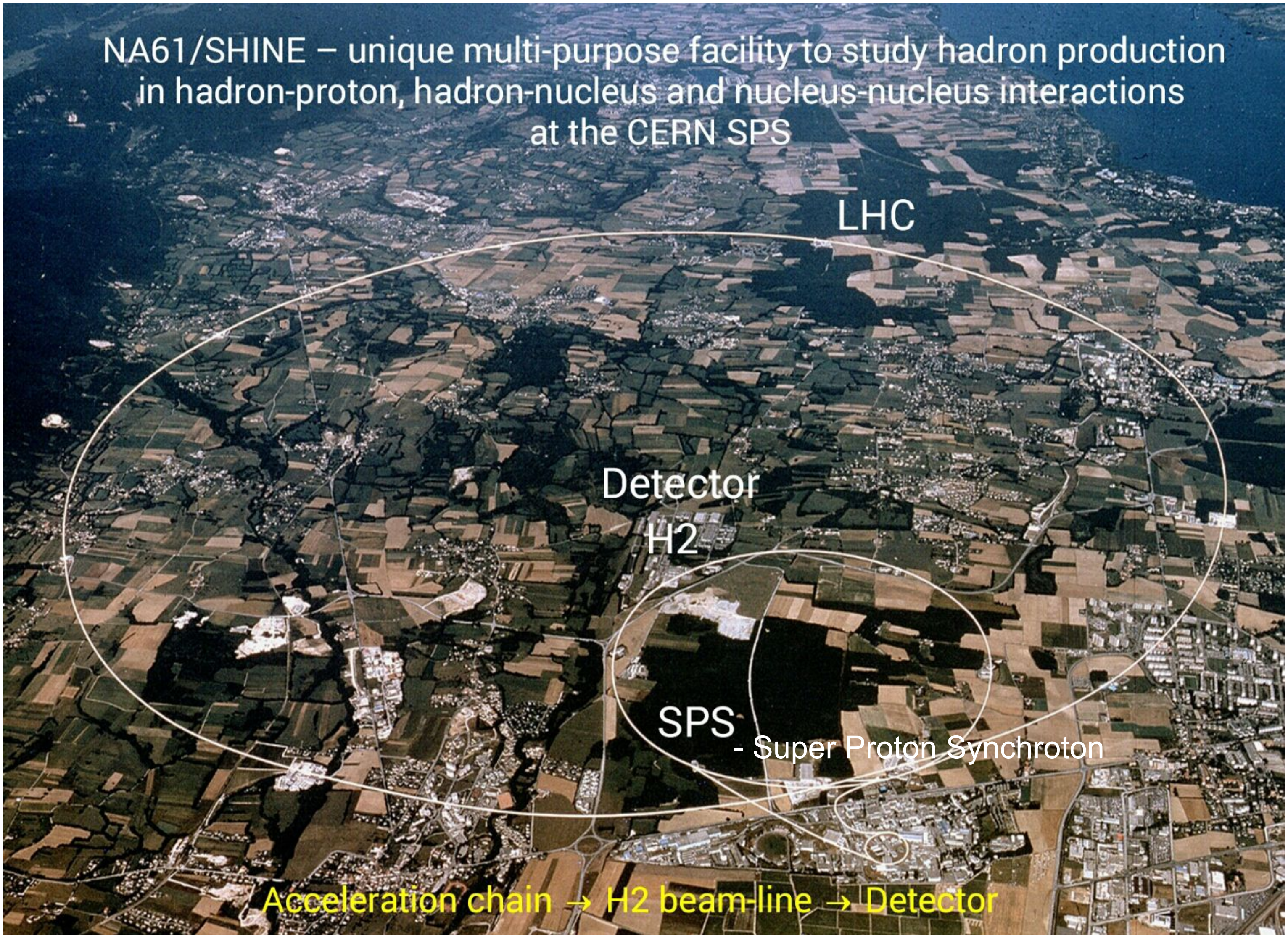
Anirvan Shukla

University of Hawaii at Manoa,
NA61/SHINE collaboration

2nd Cosmic-ray Antideuteron Workshop at UCLA
March 27-29, 2019

NA61/SHINE

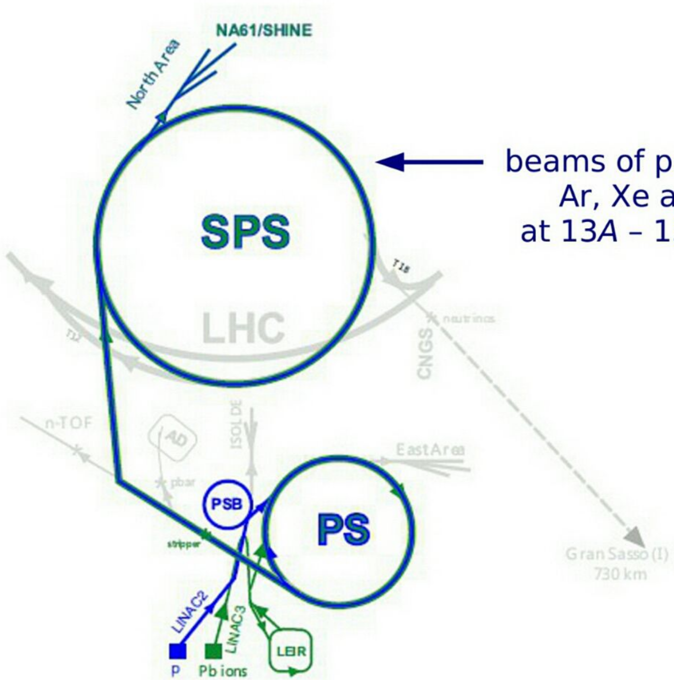
SPS **H**eavy **I**on and **N**eutrino **E**xperiment



NA61/SHINE broad physics program

- Heavy ion
  - Search for the QGP critical point.
  - Study the onset of QCD deconfinement.
- Cosmic ray
  - Hadron production measurements to improve air-shower model predictions
  - Study (anti)deuteron production mechanism, to better interpret results from AMS 02 and GAPS.
- Neutrino
  - Hadron production measurements to improve neutrino beam flux predictions.

Acceleration chain → H2 beam-line → Detector

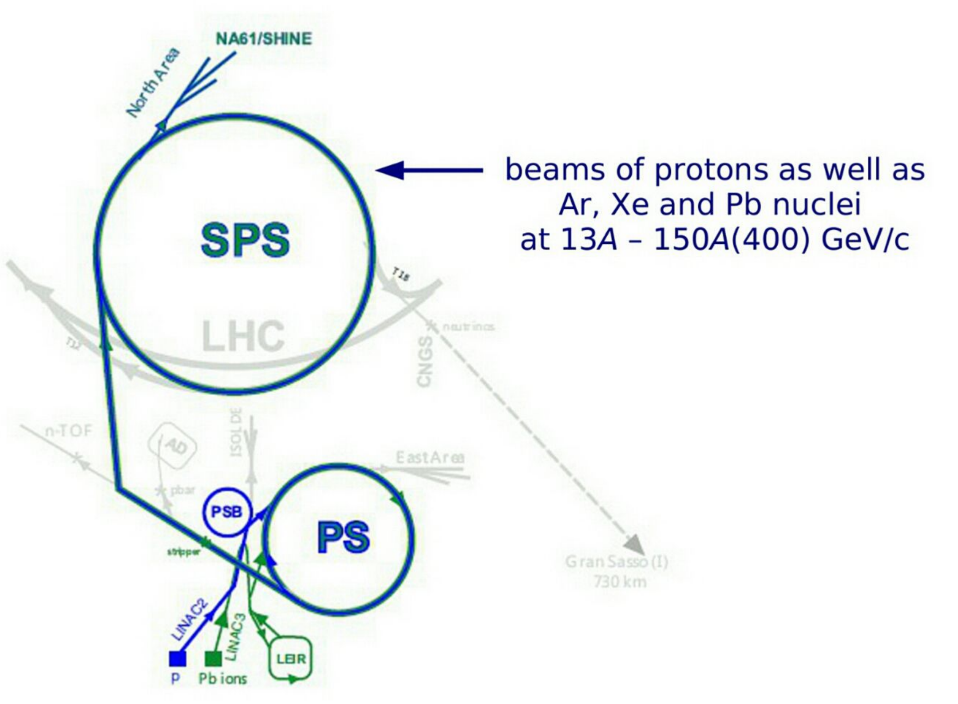


beams of protons as well as Ar, Xe and Pb nuclei at 13*A* – 150*A*(400) GeV/c

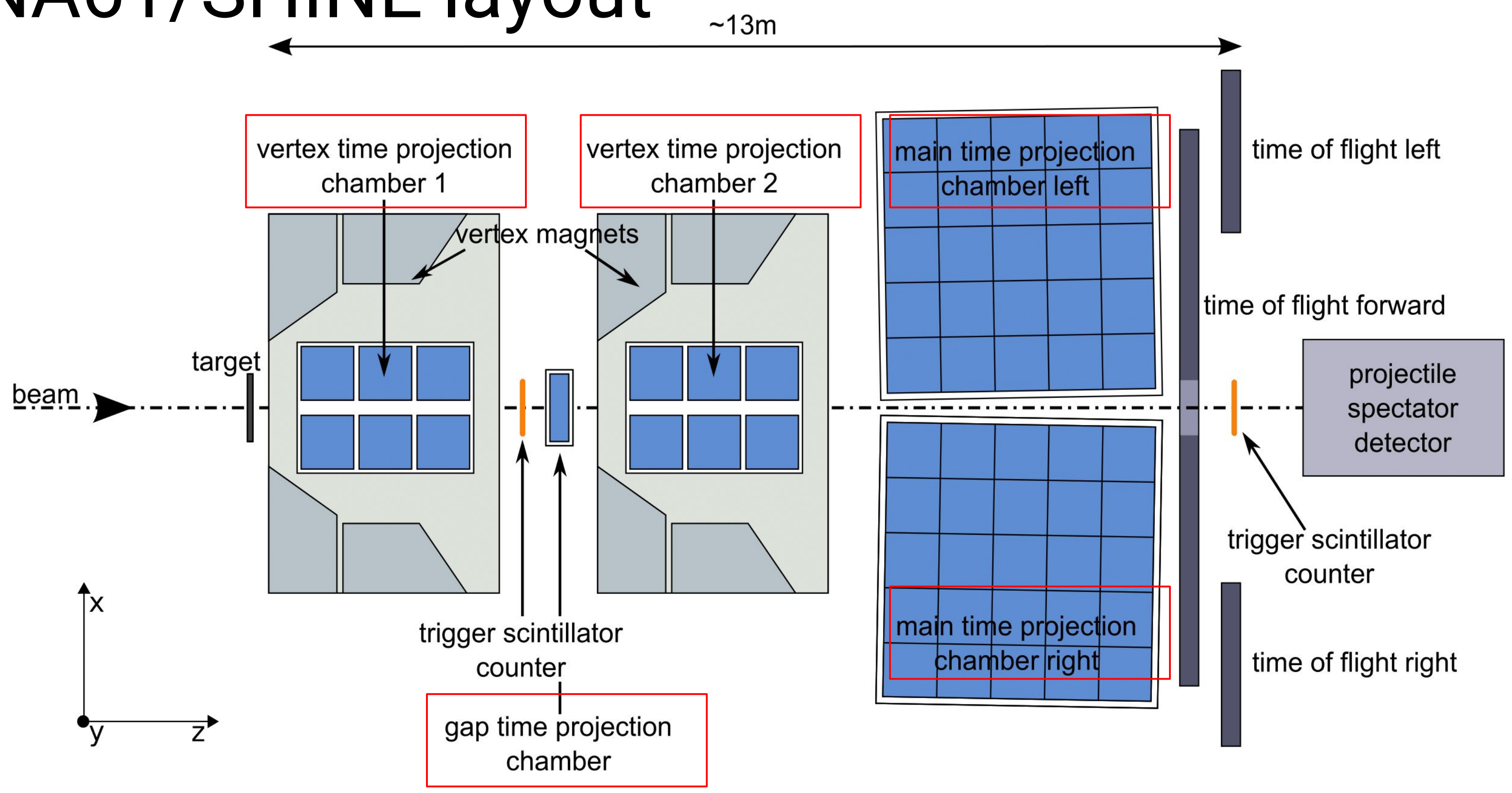
NA61/SHINE primary and secondary beams

- Primary beam of protons at 400 GeV/c is extracted from SPS.
- Primary beam interacts with Be target to produce secondary beam.
- Secondary beam is a mixture of $e^{\pm}$, $\mu^{\pm}$, $p^{\pm}$, $K^{\pm}$, $\pi^{\pm}$.
- Desired beam is selected via rigidity selection and Cerenkov Differential counter with Achromatic Ring focus (CEDAR).
- Details in [arxiv:1401.4699.](arxiv:1401.4699)

Acceleration chain → H2 beam-line → Detector



NA61/SHINE layout

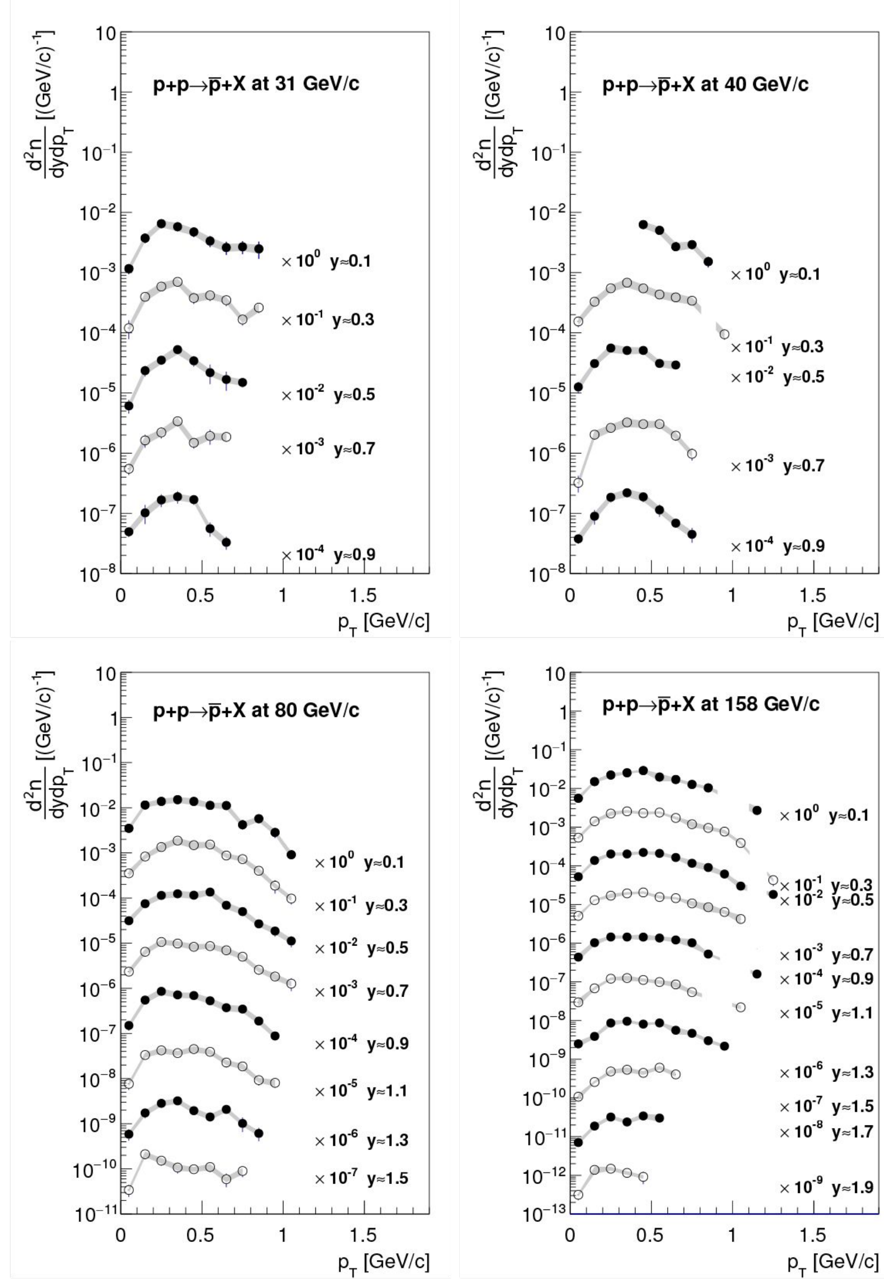


- Fixed-target, large acceptance spectrometer for charged particles.
- TPCs are main tracking detectors (measuring energy depositions along the track), and time-of-flight detectors also placed downstream.
- Liquid hydrogen target for proton-proton interactions.
- Good momentum resolution: $\sigma(p)/p^2 \approx 10^{-4}$ $(\mathrm{GeV}/c)^{-1}$
- Good energy resolution: $\sigma(dE/dx) = 4\%$

Previous results from NA49 and NA61

- NA61 p+p data sets from 2009 at beam momenta of 20, 31, 40, 80, and 158 GeV/c ($\sqrt{s}$= 6.3, 7.7, 8.8, 12.3 and 17.3 GeV, respectively) have already been analyzed.
    - dbar production threshold in p+p interactions is 15.9 GeV/c in the lab frame.
- Results from that analysis has already helped in interpretation of cosmic-ray anti-protons.
- Now looking at much larger new data sets from latest runs, which also make (anti)deuteron studies statistically feasible.
- p+p at 400 GeV/c is also available.

Run	Total p+p events at 158 GeV/c (millions)	After cuts (millions)
2009	4	1
2010	44	15.7
2011	14	4.3



From ***Aduszkiewicz, A., Ali, Y., Andronov, E. et al. Eur. Phys. J. C (2017) 77: 671.***

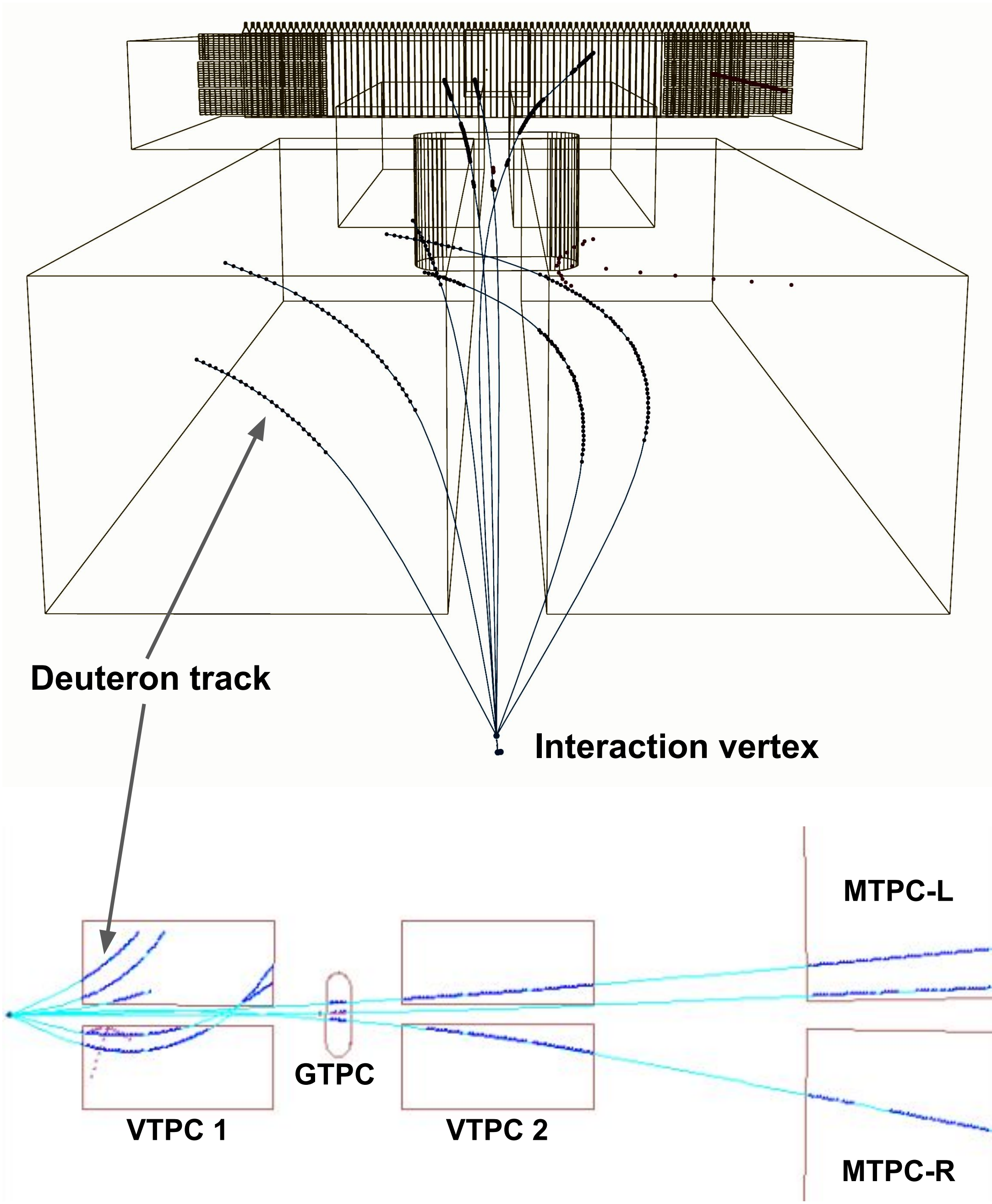
Deuteron analysis

Deuterons before anti-deuterons.

- Before analyzing data for dbar, we began by making sure we can identify protons and deuterons.
  - Easier to detect, as much more abundant

- NA61 has two methods for particle identification, based on:
  - energy loss in TPCs.
  - Time of flight.

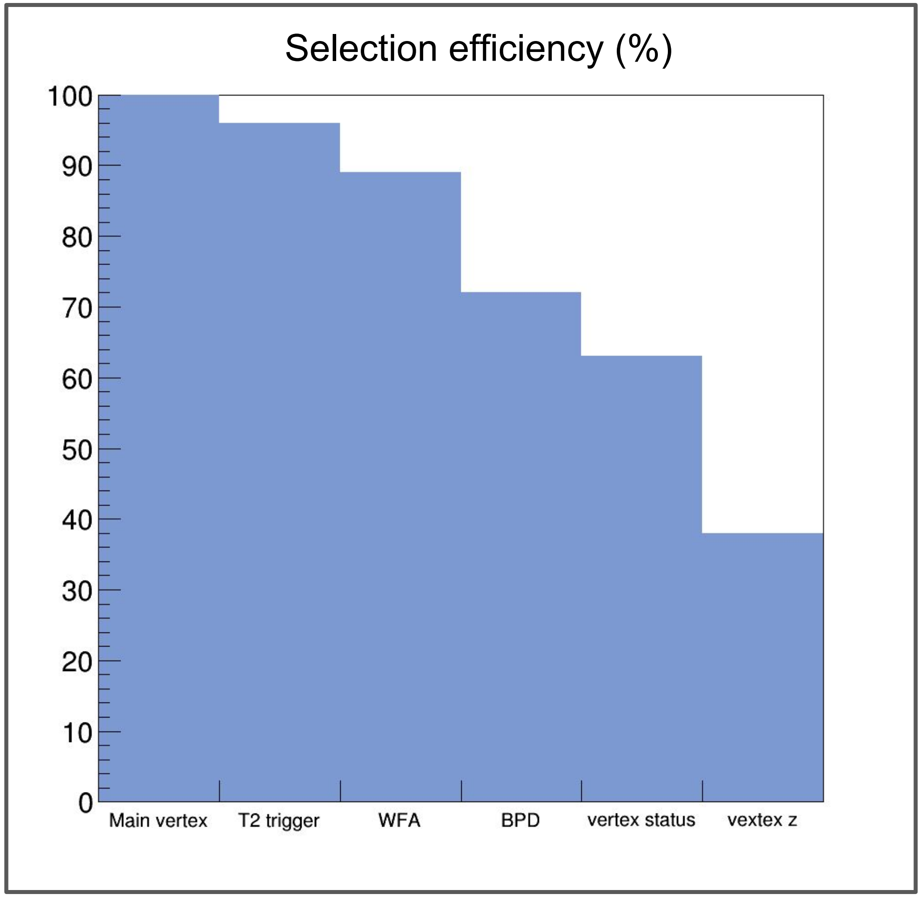
- Reconstruction:
  - Yellow dots - Detector hits
  - Red lines - Tracks originating from primary interaction vertex.



Top view

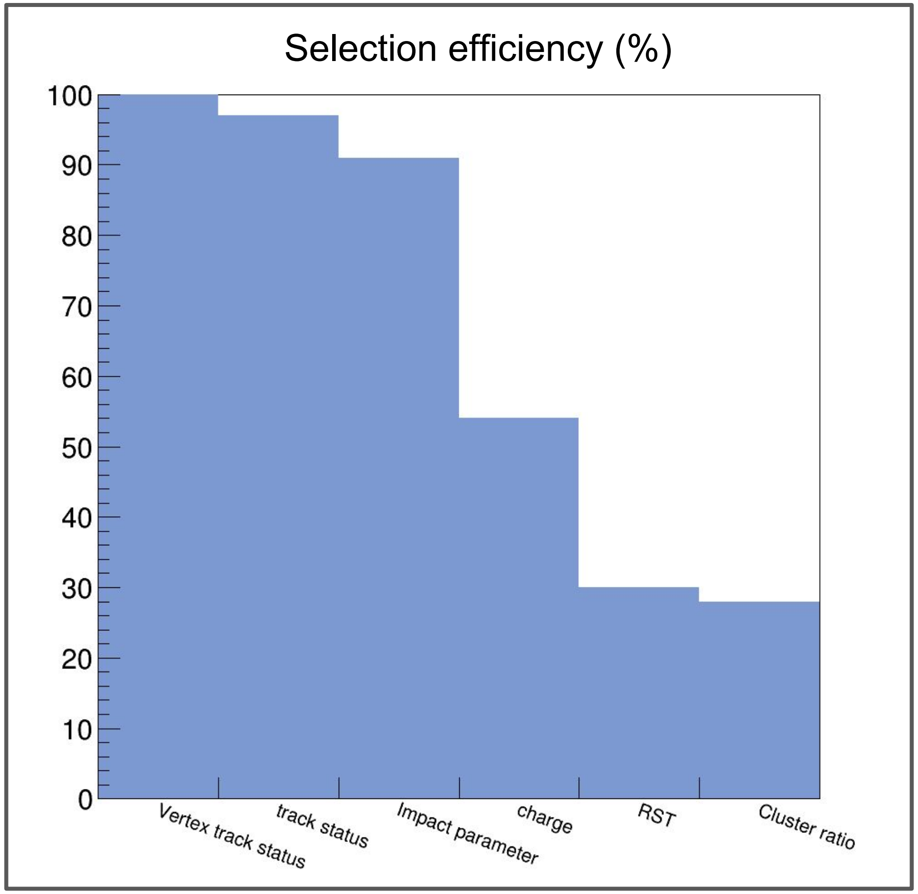
Event selection

- Interaction trigger
- No pile-up of events.
- Good beam particle trajectory.
- At least one reconstructed track fitted to the interaction vertex.
- Interaction vertex is reconstructed within the target region
- We were able to retain ~35% of total recorded events.



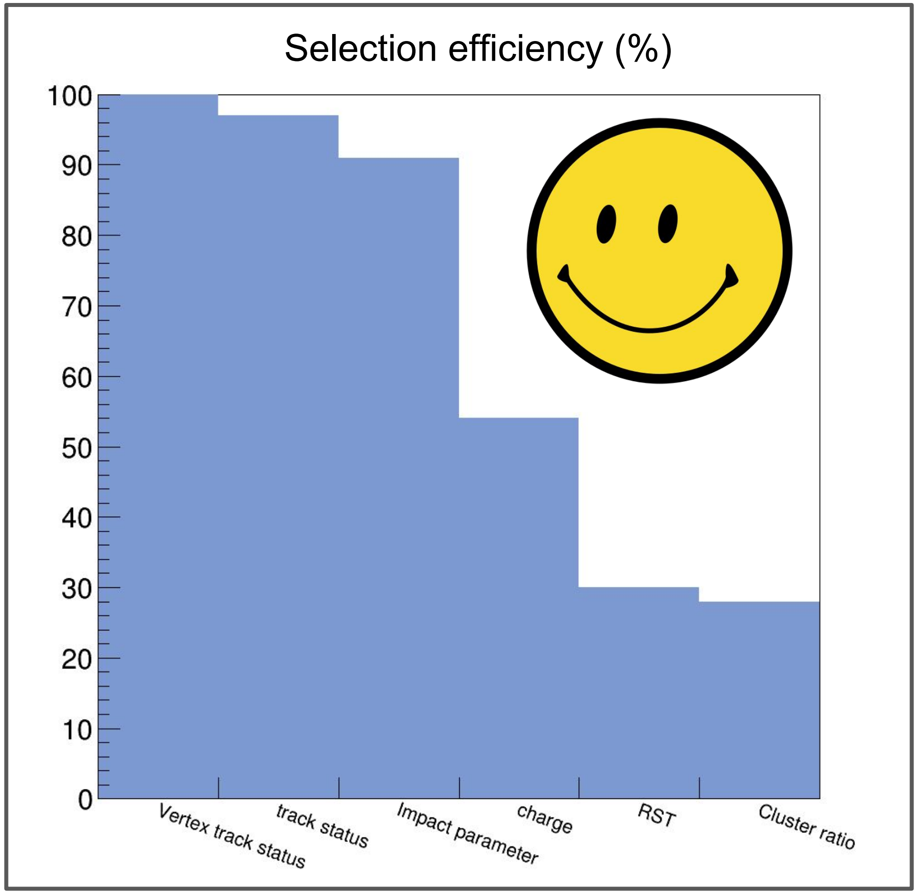
Track selection

- We start with events that have at least one well-reconstructed track coming from the p-p interaction.
- Tracks with low χ^2.
- Track momentum < 100 GeV/c.
- Energy deposition < 5 MIPs.
- Optimized criteria to retain low-momentum tracks.

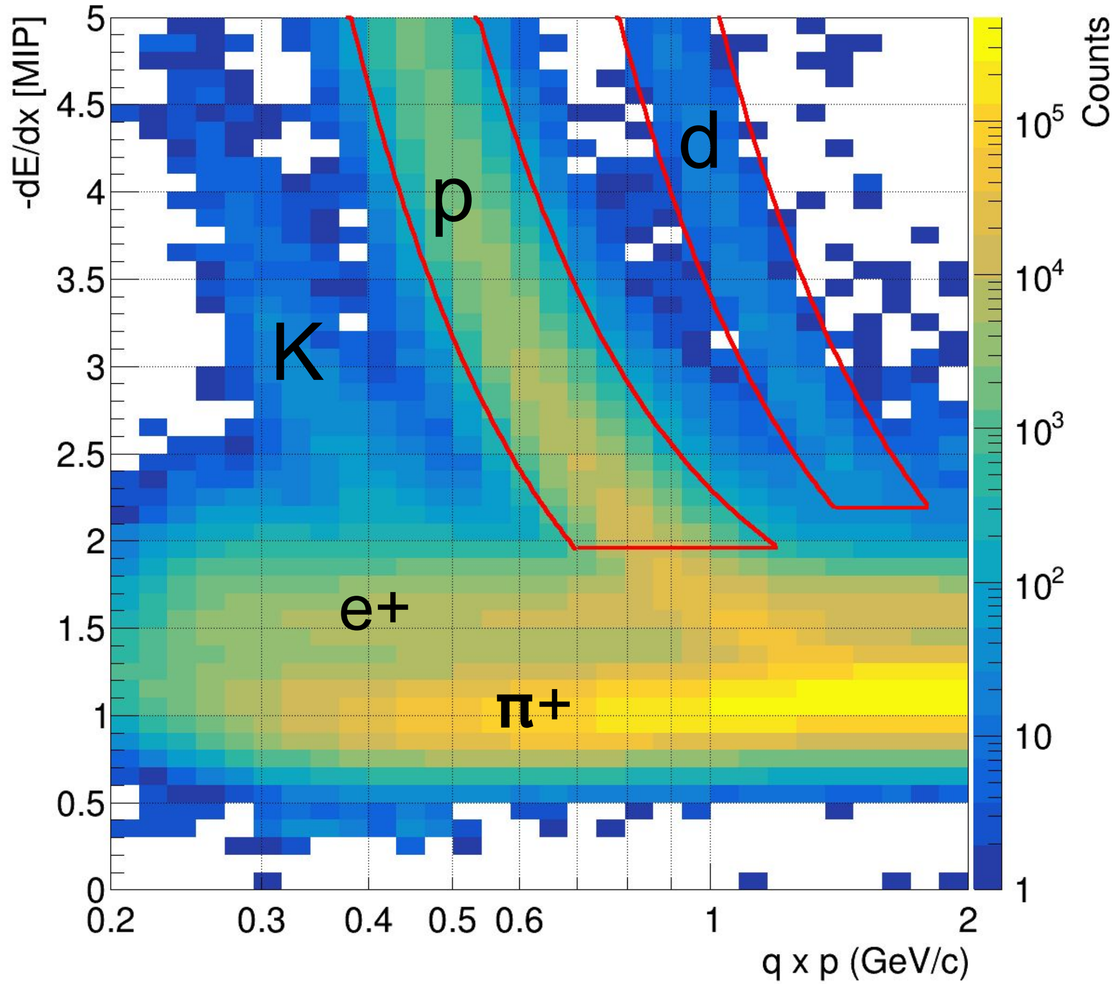


Track selection

- We start with events that have at least one well-reconstructed track coming from the p-p interaction.
- Tracks with low χ^2.
- Track momentum < 100 GeV/c.
- Energy deposition < 5 MIPs.
- Optimized criteria to retain low-momentum tracks.
- We are able to retain more than 25% of the total tracks.



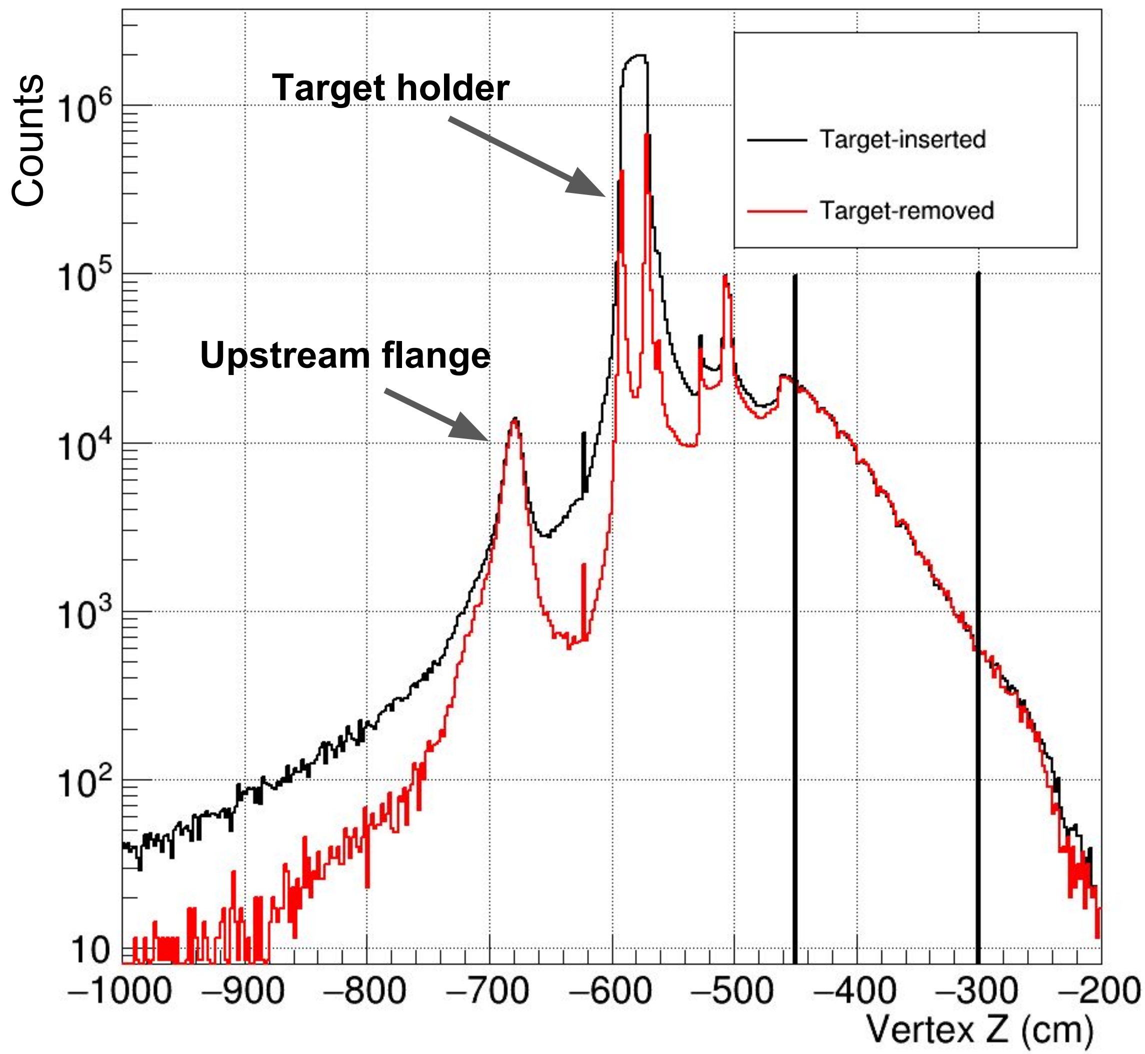
Particle Identification



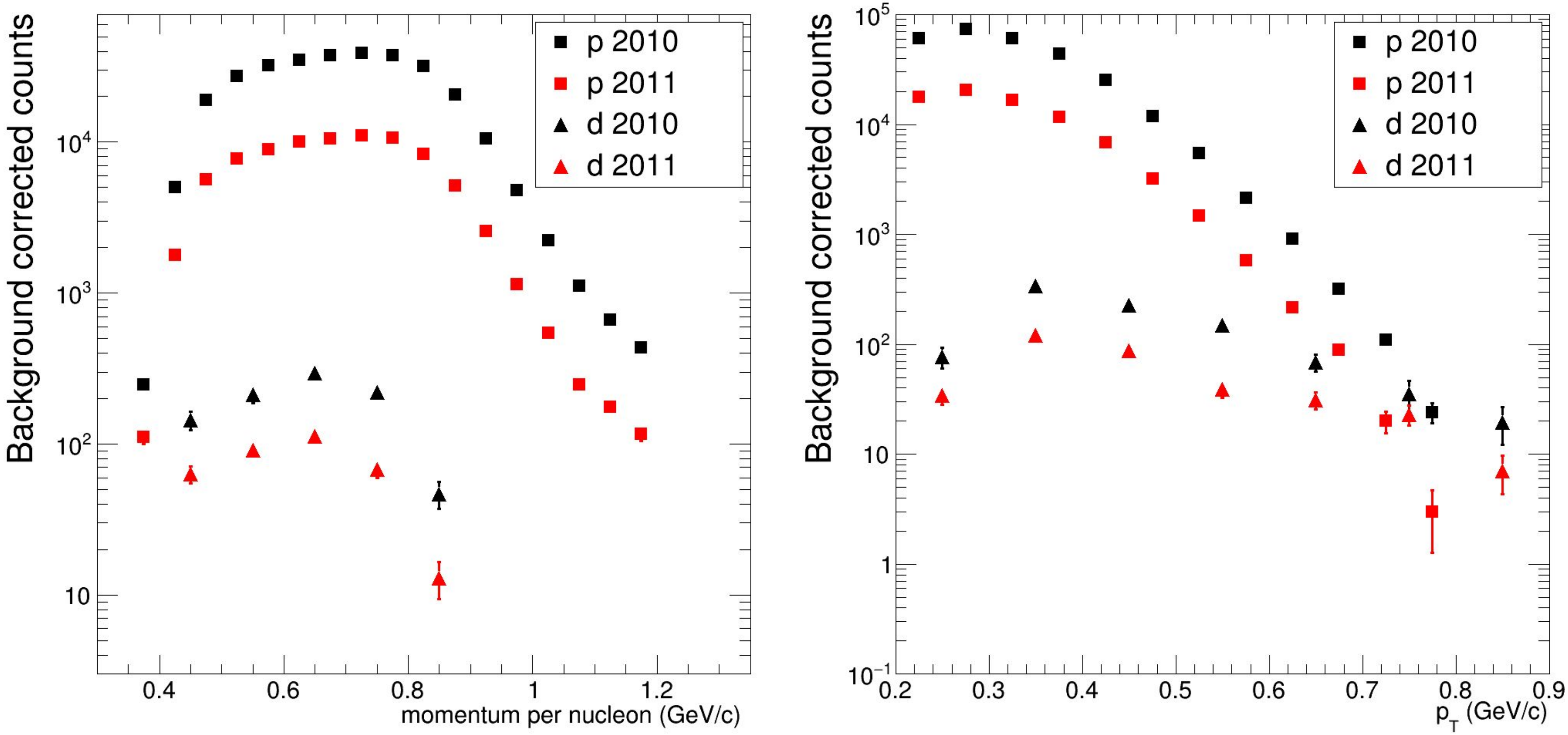
Particles are identified by their energy deposition dE/dx as a function of momentum.

Subtracting background

- To estimate off-target correction, 10% of the data were collected with empty target.
- The normalization factor was calculated from the distribution of the z-coordinate of all interaction vertices.
- It is the ratio of the number of events with vertex outside the target for target-inserted and removed data.
- The normalized target-removed yield was subtracted from target-inserted data.

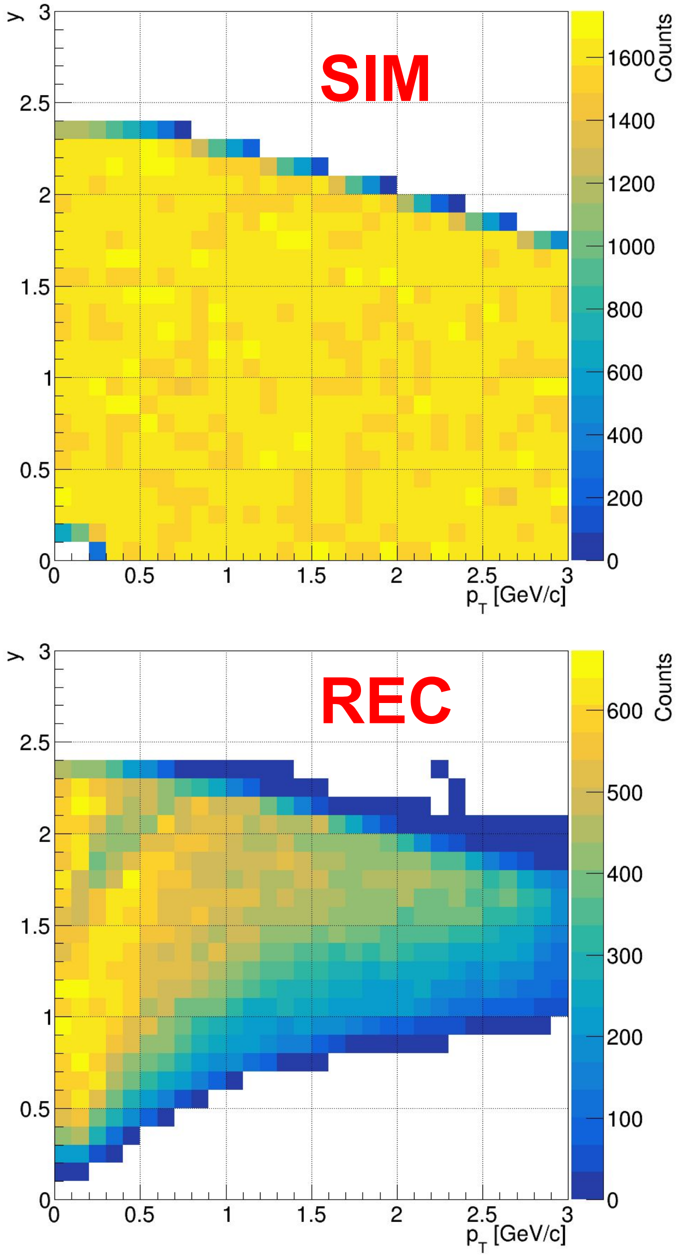


Particle counts



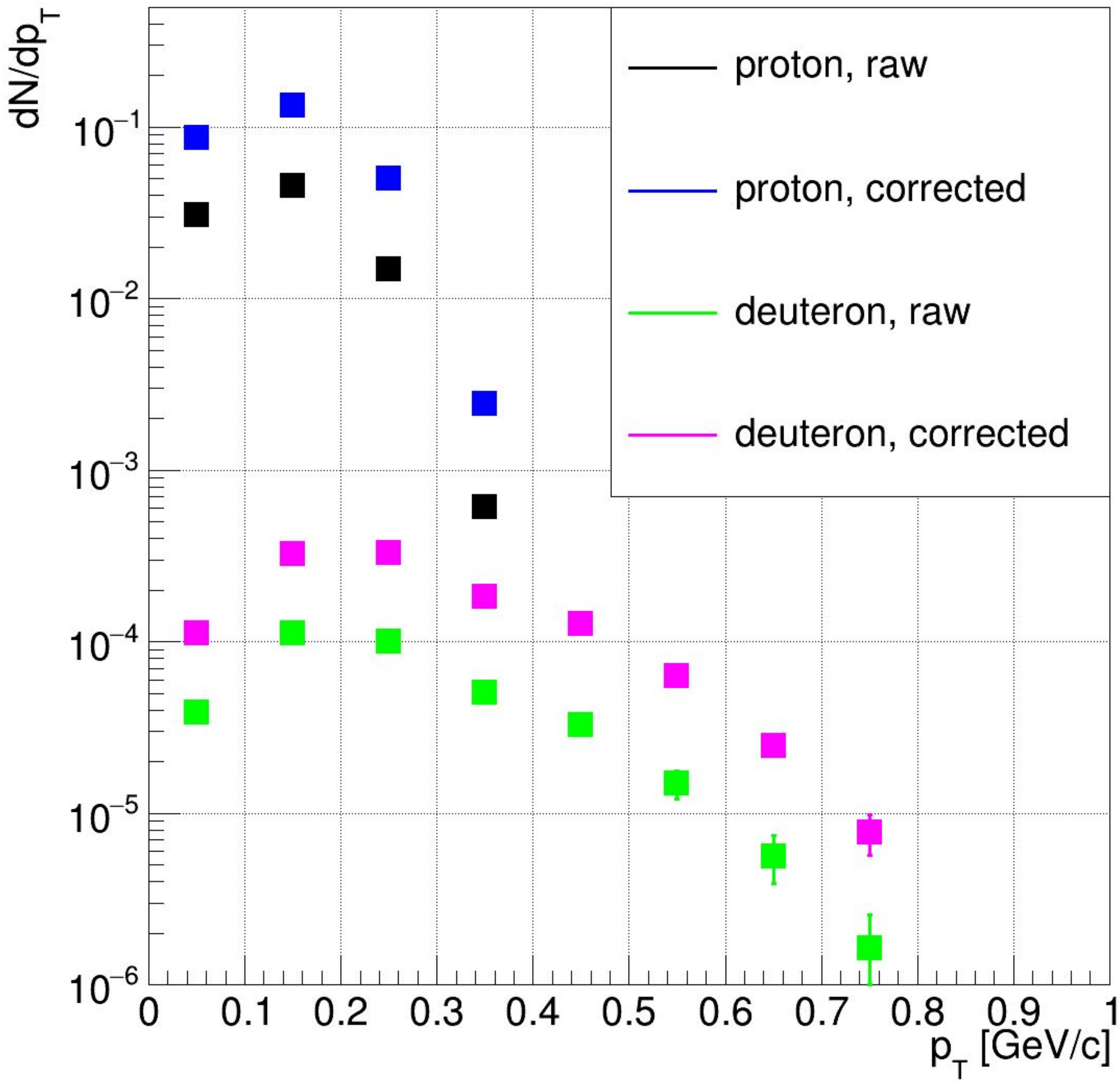
Background-subtracted counts for protons and deuterons

Motivation for flat phase-space Monte-Carlo

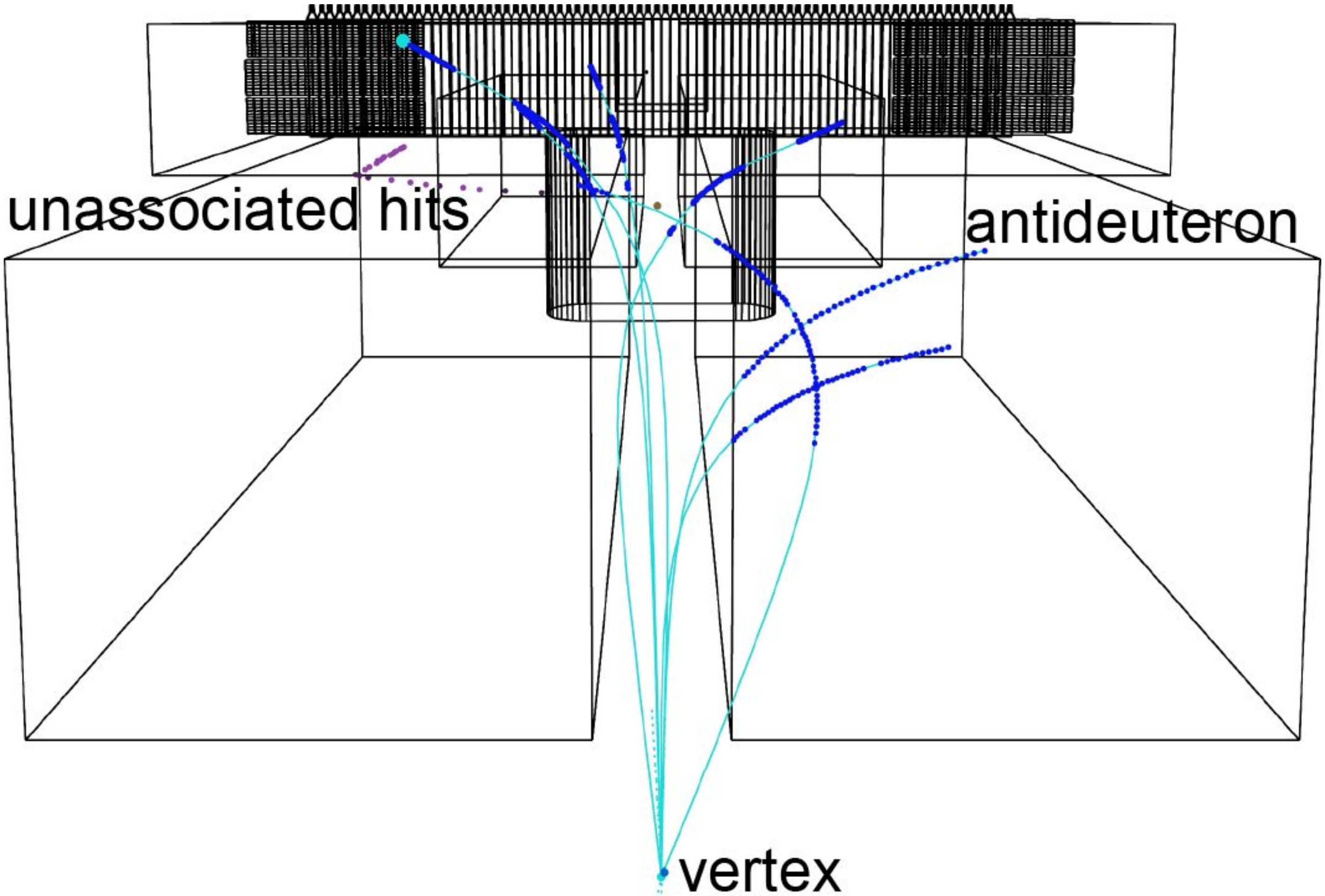


- Need to apply detector efficiencies and acceptance corrections.
- Existing Monte-Carlos like EPOS do not produce (anti)deuterons.
- In our current approach, a flat phase-space distribution of proton and deuteron tracks are sent through the Geant4 description of NA61 detector.

Preliminary yields as function of p_T



A candidate antideuteron track



A candidate track with dE/dx and momentum in the selection band for antideuterons

Next Steps

Ongoing:

- Bin migration of momentum.
- Correction for quasi-elastic proton-proton interaction cross-section.
- dE/dx template fitting to extend particle ID region.
- Using time-of-flight detector to further extend the particle ID region.

Final product:

- Production cross-sections of p, pbar, d, dbar.
- d/p and pbar/p ratios.
- Comparisons with EPOS.

Future:

- Study of different production channels in NA61 p-p data
- Study of angular correlations.
- Study of particle multiplicities.