Updates from RICH simulation studies

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5th ALICE Upgrade Week

Krakow, October 7, 2024

Outline

Update on the latest bRICH PID performance

- PID performance from p-p to central Pb-Pb events
- Machine learning based PID vs classic HT method
- Option: effect gaseous radiator to enhance $e^{\pm}$ PID

Full simulation of bRICH physics performance

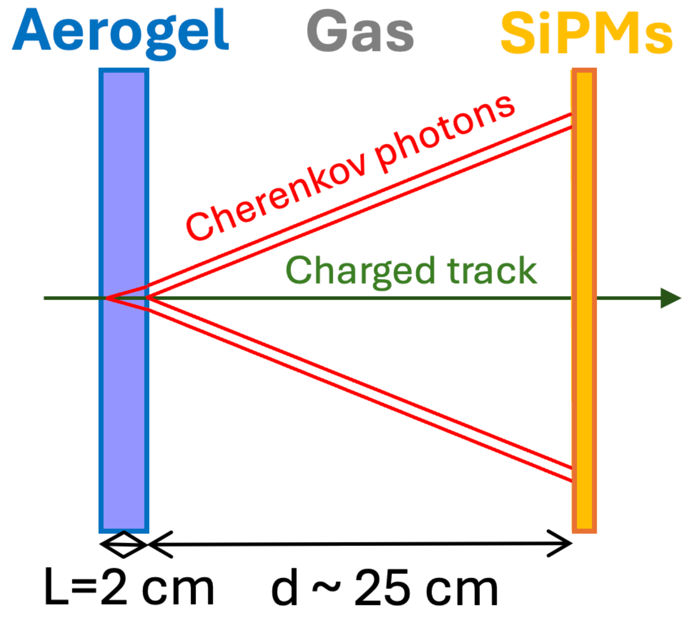
- Acceptance and efficiency of $\rho^0 \rightarrow e^+e^-$ and $D^0 \rightarrow K^-\pi^+$
- Impact of bRICH on ρ^0 and D^0 identification vs η and p/p_T
- Testing oTOF alone, combined oTOF+bRICH and gas option

bRICH: Layout

Proximity-focusing RICH based on aerogel+SiPMs in a projective geometry

Components

- Aerogel: $L \approx 2\text{ cm},\ n = 1.03$
- SiPM-based photodetector
- 2x2 mm^2 cells, PDE(450 nm) > 40%

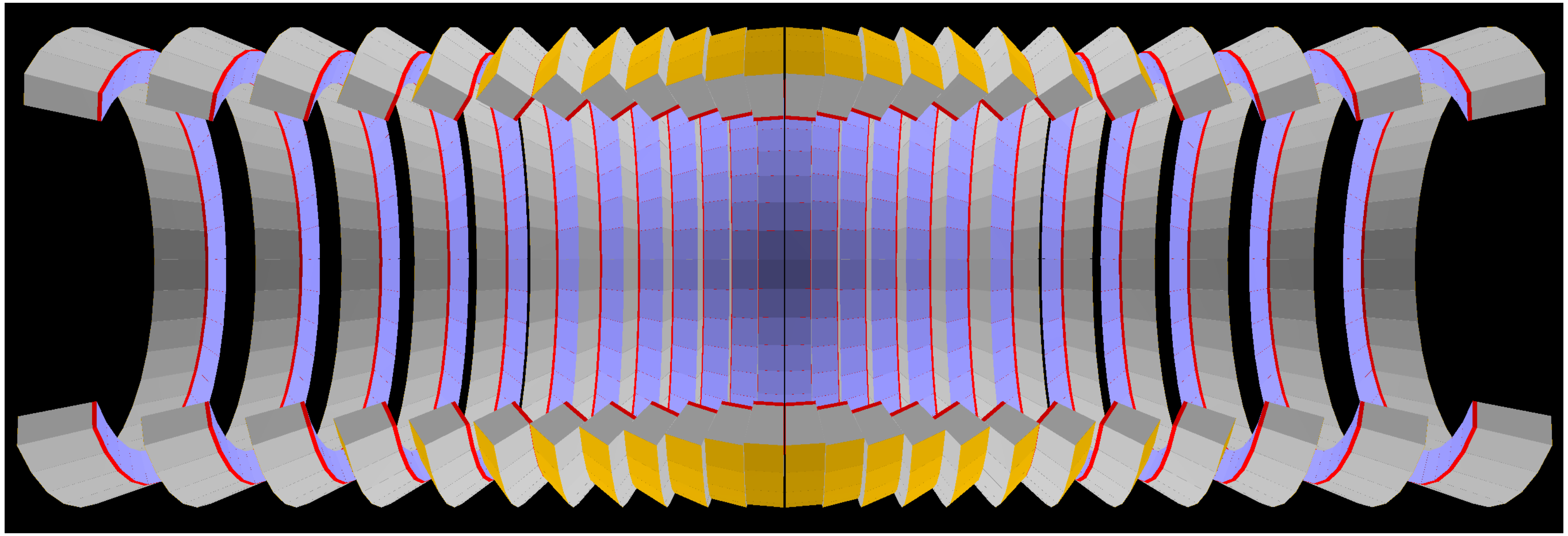


Geometry

- All tiles oriented toward nominal interaction point
- Full coverage to charged particles without overlaps
- Trapezoidal tile profile to maximize the acceptance

Segmentation

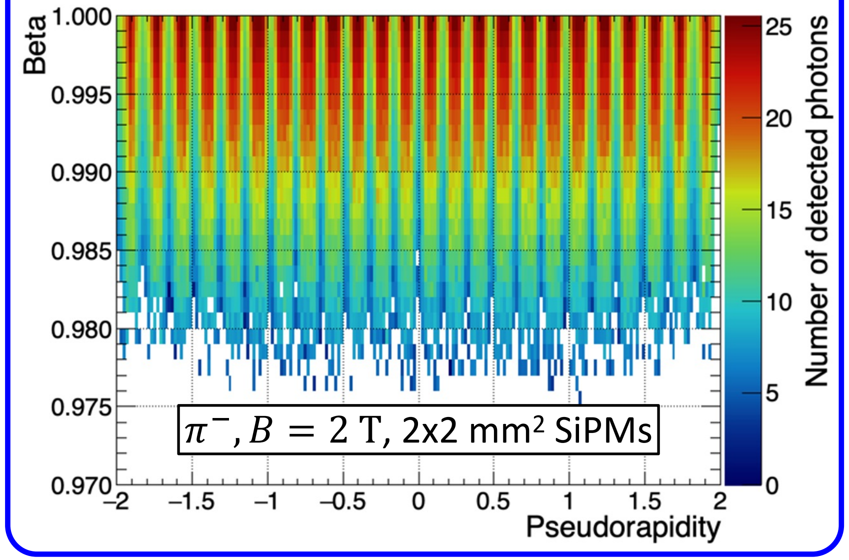
- 24 sectors x 36 modules
- Sensor area ≈ 30.7 m^2
- Total N channels ≈ 7M



bRICH performance simulation

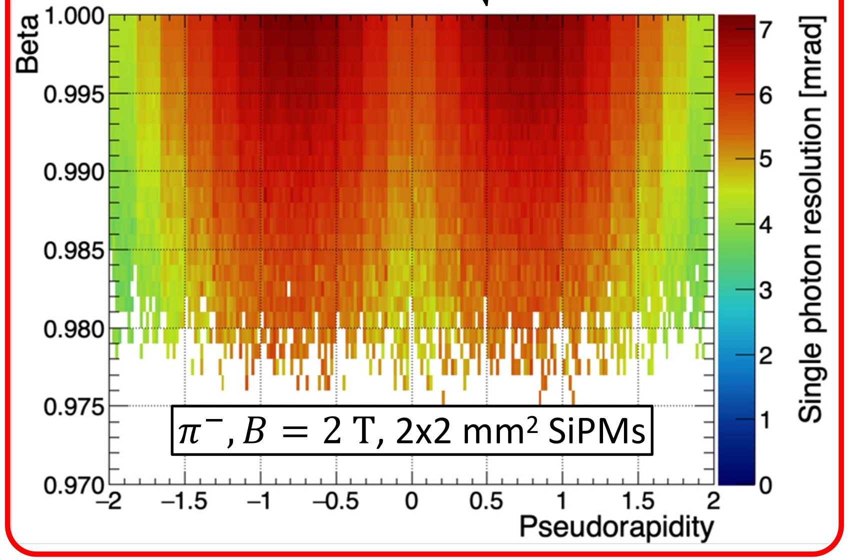
Number of detected photons

- $N_{p.e} \propto \sin^2\theta_c \oplus \text{phot. acceptance}$



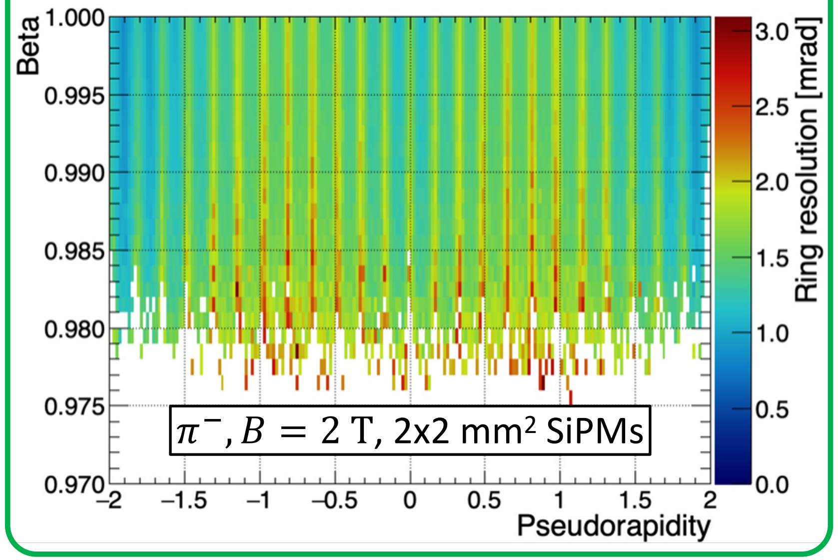
Single photon resolution

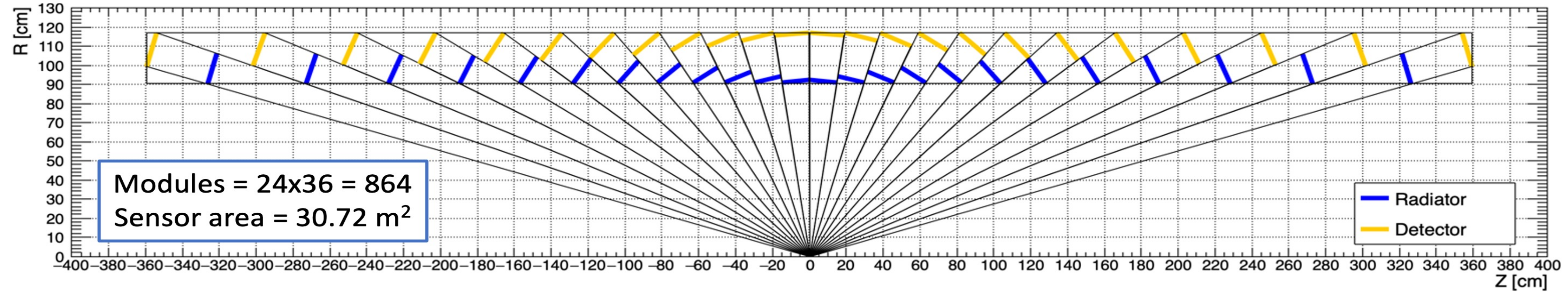
- Expected: $\sigma_{\theta_c}^{p.e.} = \sqrt{\sum_i \sigma_{\theta_c}^2(i)}$



Ring angular resolution

- Expected: $\sigma_{\theta_c}^{ring} = \sigma_{\theta_c}^{p.e.} / \sqrt{N_{p.e}}$

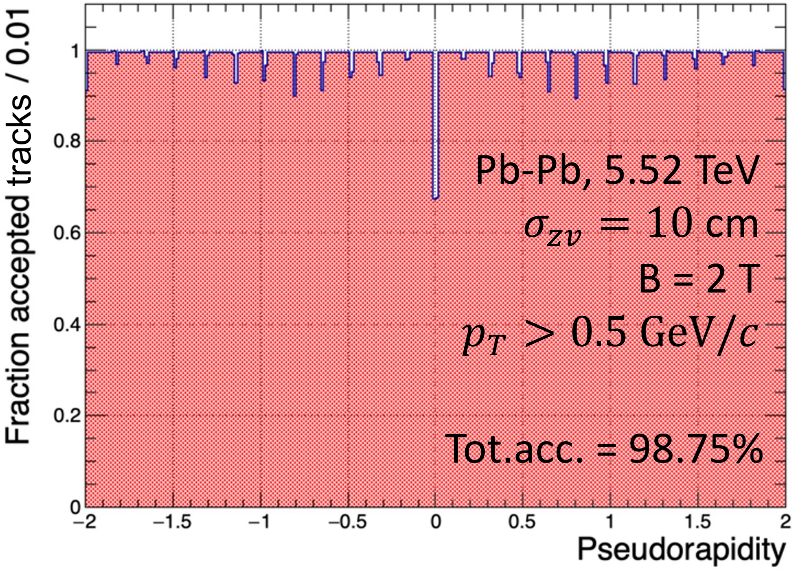




bRICH performance simulation

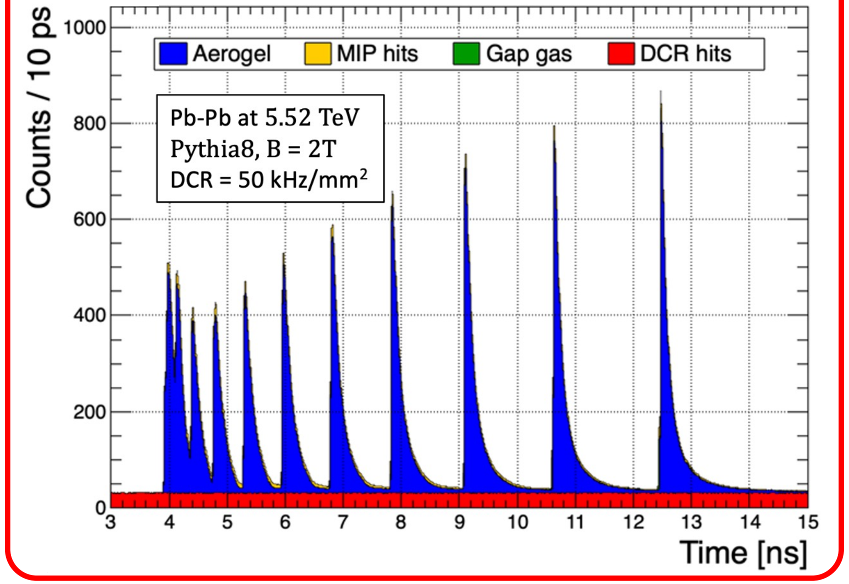
Charged particle acceptance

- Minor losses at sector boundaries



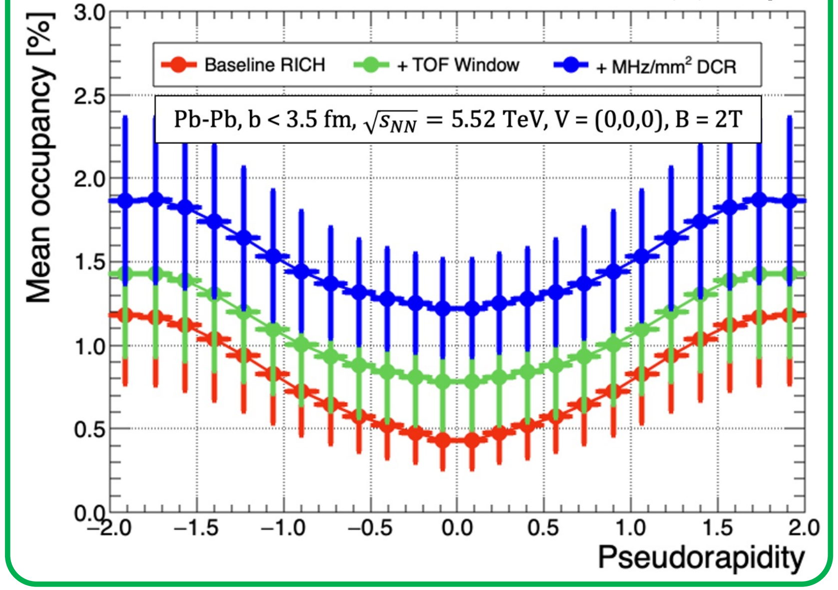
Time profile of Pb-Pb events

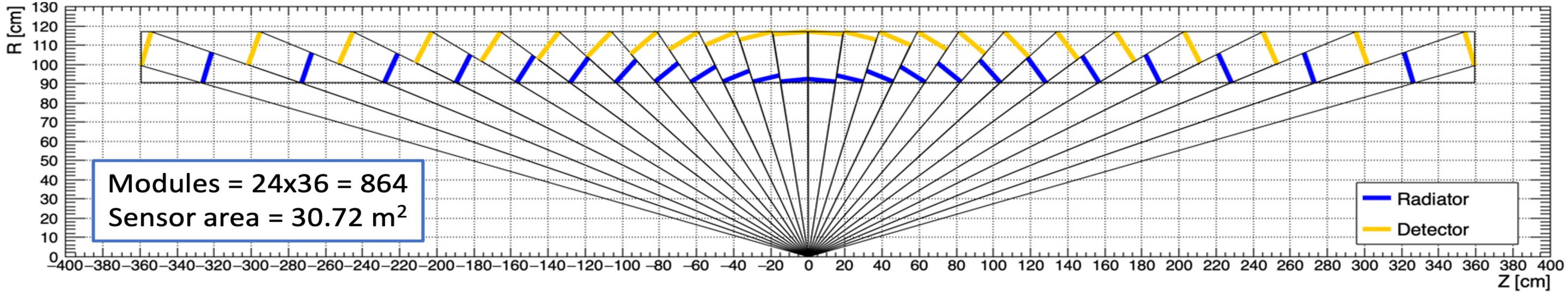
- Signal hits clustered in ≈ ns intervals



Photodetector occupancy

- Consistent with expected $dN_{ch}/d\eta$





bRICH PID in central Pb-Pb using ML

Dataset

- 5k Pb-Pb (b < 3.5 fm), B = 2T
- $\approx$ 20.0 M charged tracks at bRICH
- Composition: $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}, p, \bar{p}$

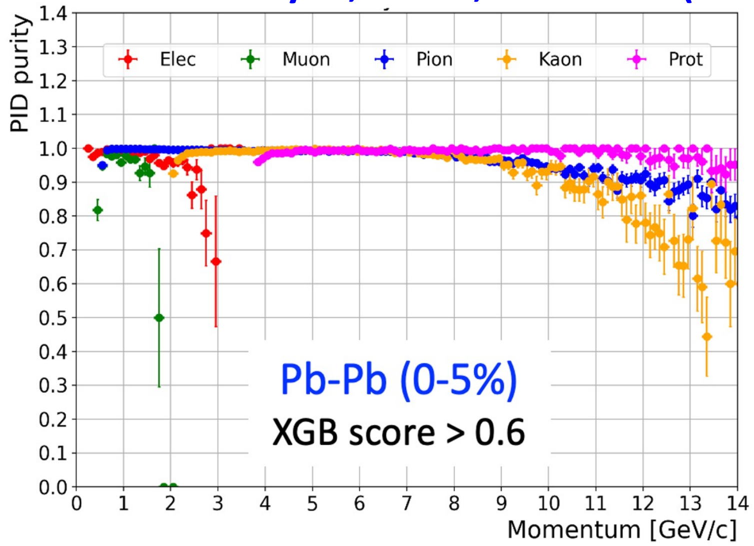
ML algorithm

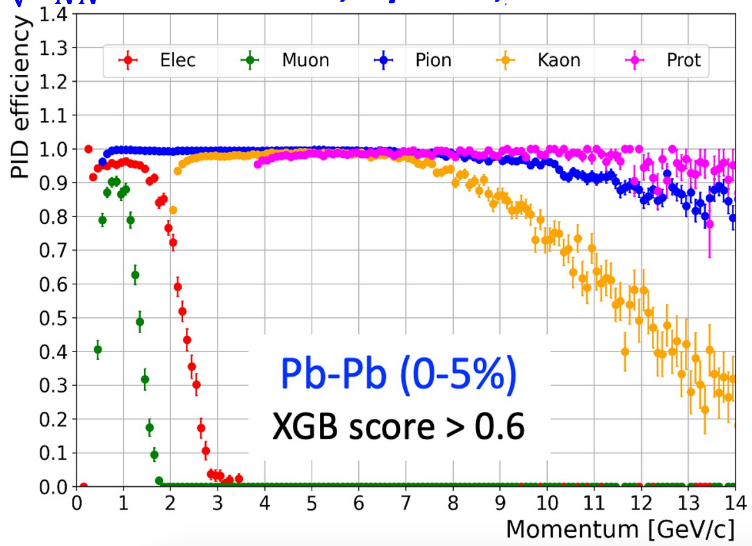
- 5 x XGBoost for binary PID probs. of each species vs all other species
- Assigning PID with max. score or optimizing for dedicated analyses

ML vs HTM-based PID

- **Overall better PID effciency $\times$ purity achieved using ML w.r.t. HTM+Bayes**
- Note: Efficiency limits in HTM due to N_{HTM} decrease at sector boundaries
- Automatically learned in ML analysis
- **Slight ML worsening above 10 GeV/*c***
- Limited statistics of high-p particles

ML analysis, Pb-Pb, b < 3.5 fm (0-5%) , $\sqrt{s_{NN}} = 5.52$ TeV, Pythia8, B = 2 T





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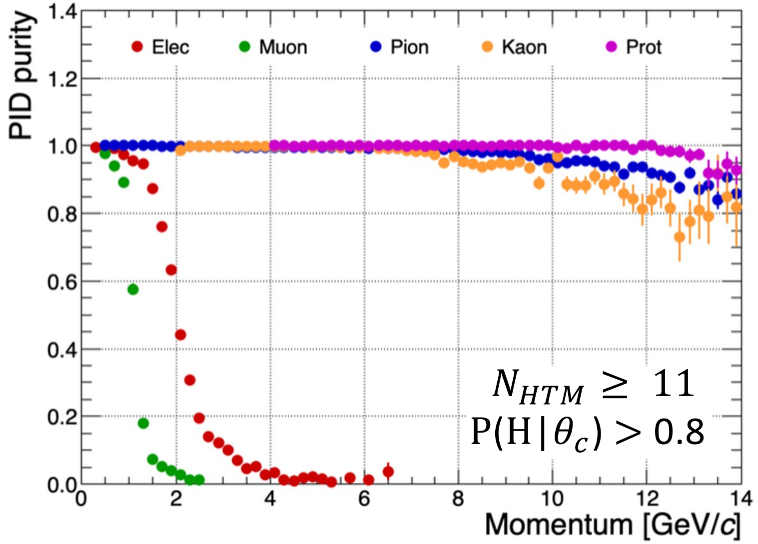
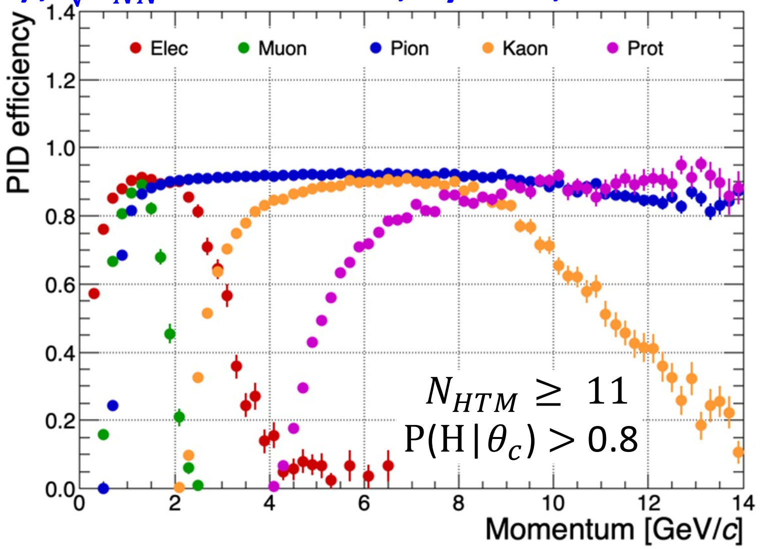




bRICH $e^{\pm}$ purity enhancement

Goal

- Extend electron/positron identification above 4 GeV/c
- Required for dielectrons and quarkonia, e.g. J/ψ → e^+e^-

Strategy

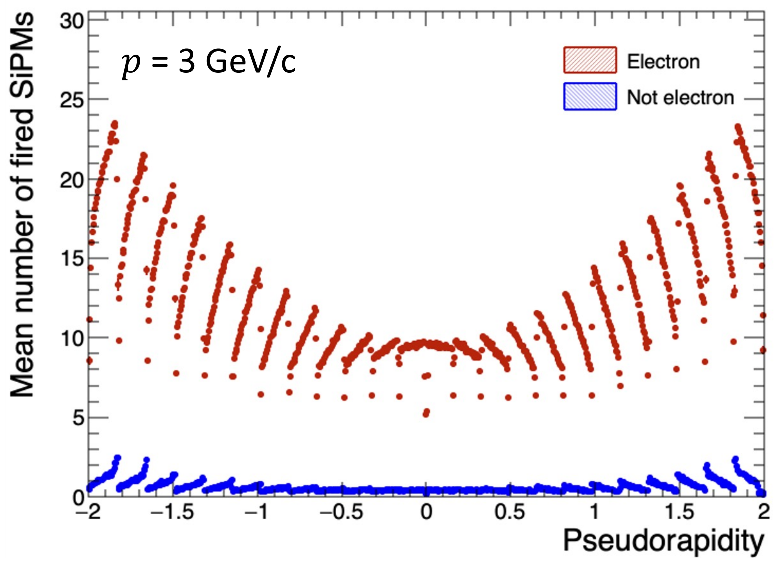
- Fill aerogel RICH gap with gas radiator having n ≈ 1.0006
- **$e^{\pm}$ purity enhanced by looking at the size of gas clusters**

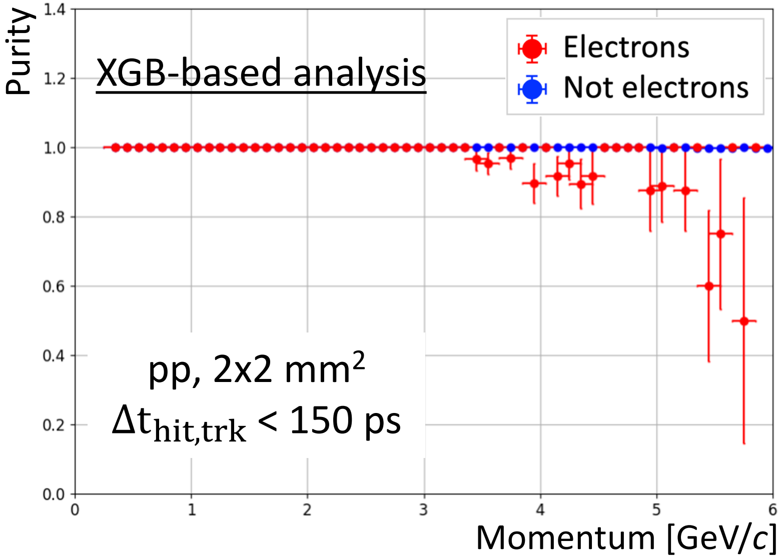
Gas options

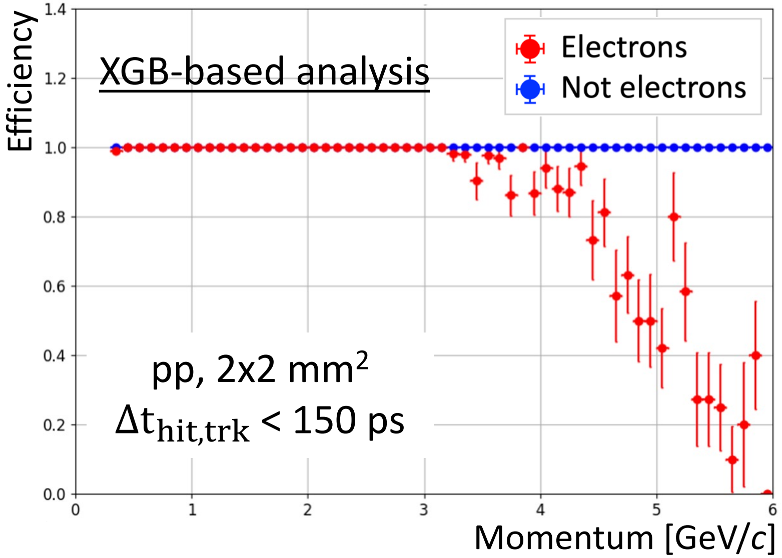
- Gases with large GWP (CF_4, C_4F_{10}, …) must be avoided
- Solution: Gas mixtures, e.g. $C_5F_{10}O$ (20%) + N_2 (80%)

p_{th} ≡ momentum threshold for Cherenkov emission

n	β_{th}	p_{th} (GeV/c)				
		e	μ	π	K	p
1,0006	0,9994	0,0147	3,0496	4,0284	14,2491	27,0815







*Only cells fired by photons are considered

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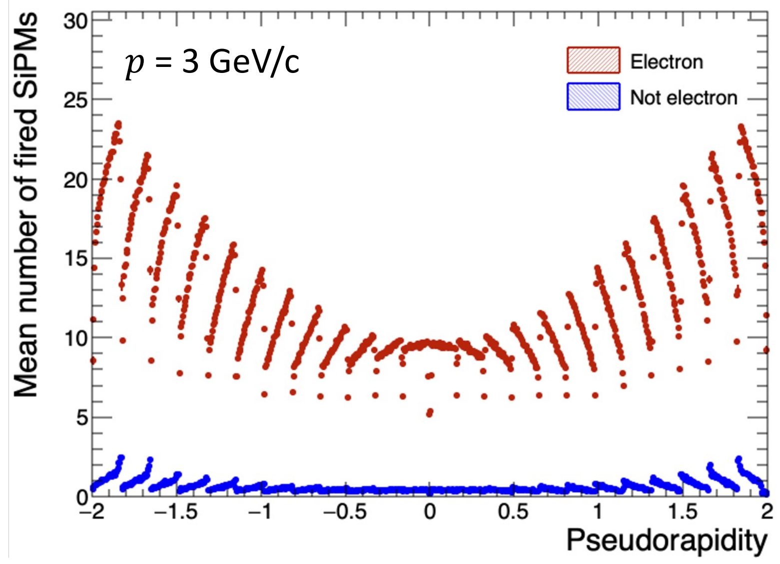
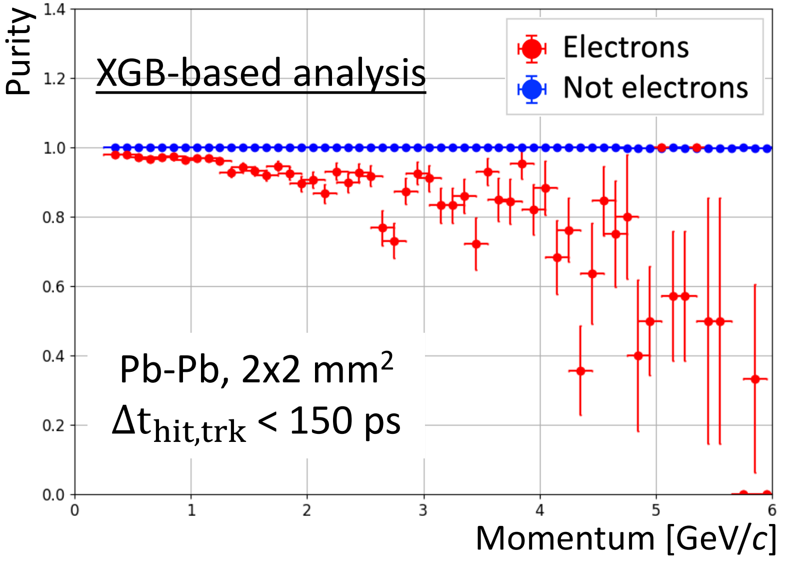
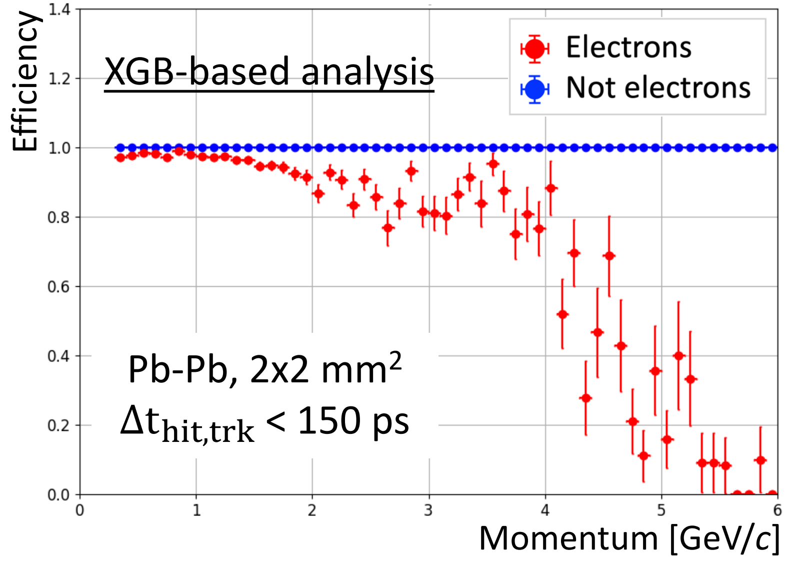






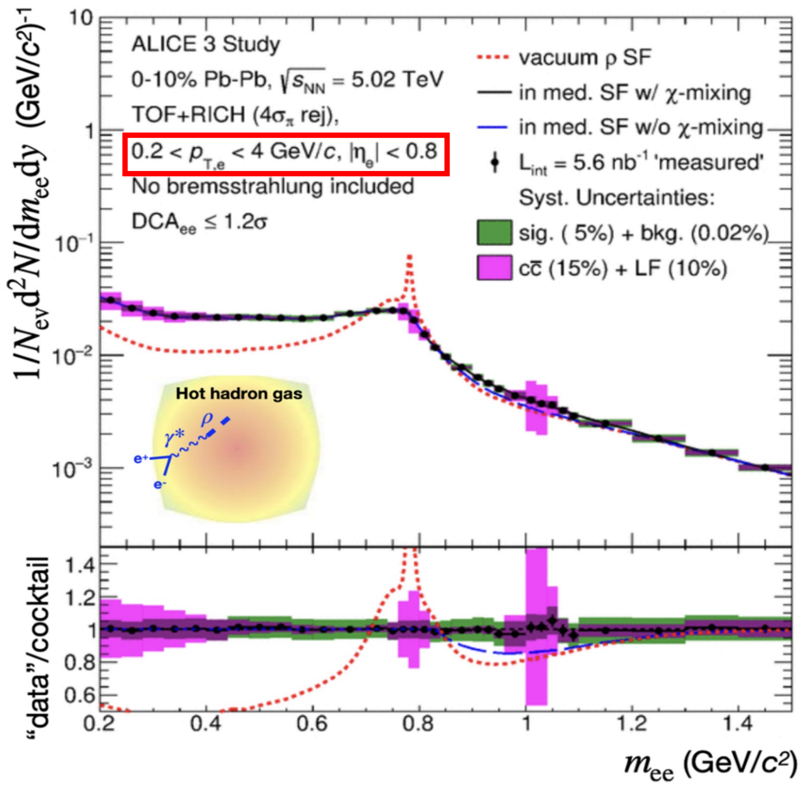
*<u>**Only cells fired by photons are considered**</u>

bRICH impact on ALICE 3 physics

$\rho \to e^+e^-$ motivation

Measurements of the m_{ee} spectrum in the ρ mass region provide direct access to CSR mechanisms in the QGP like ρ-a_1 mixing

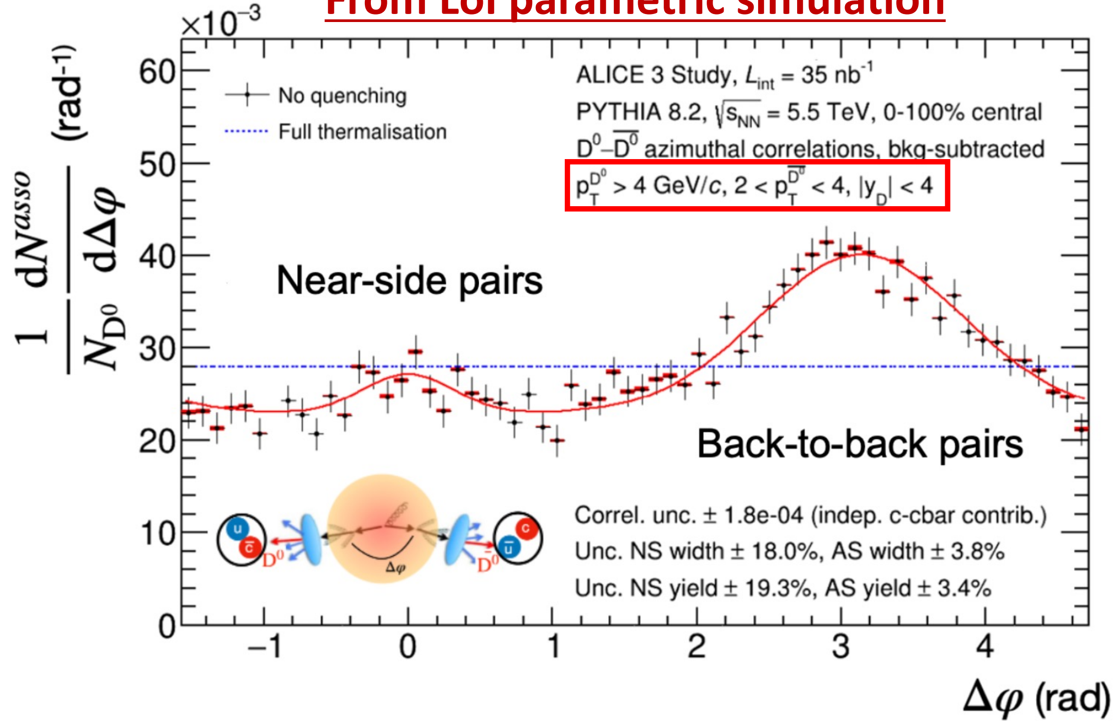
From LoI parametric simulation



$D^0 \to K^-\pi^+$ motivation

Charm hadron correlations ($D^0\overline{D}^0$, D^0D^{*+}) give access to energy loss mechanisms in the QGP and search for exotic bound states

From LoI parametric simulation



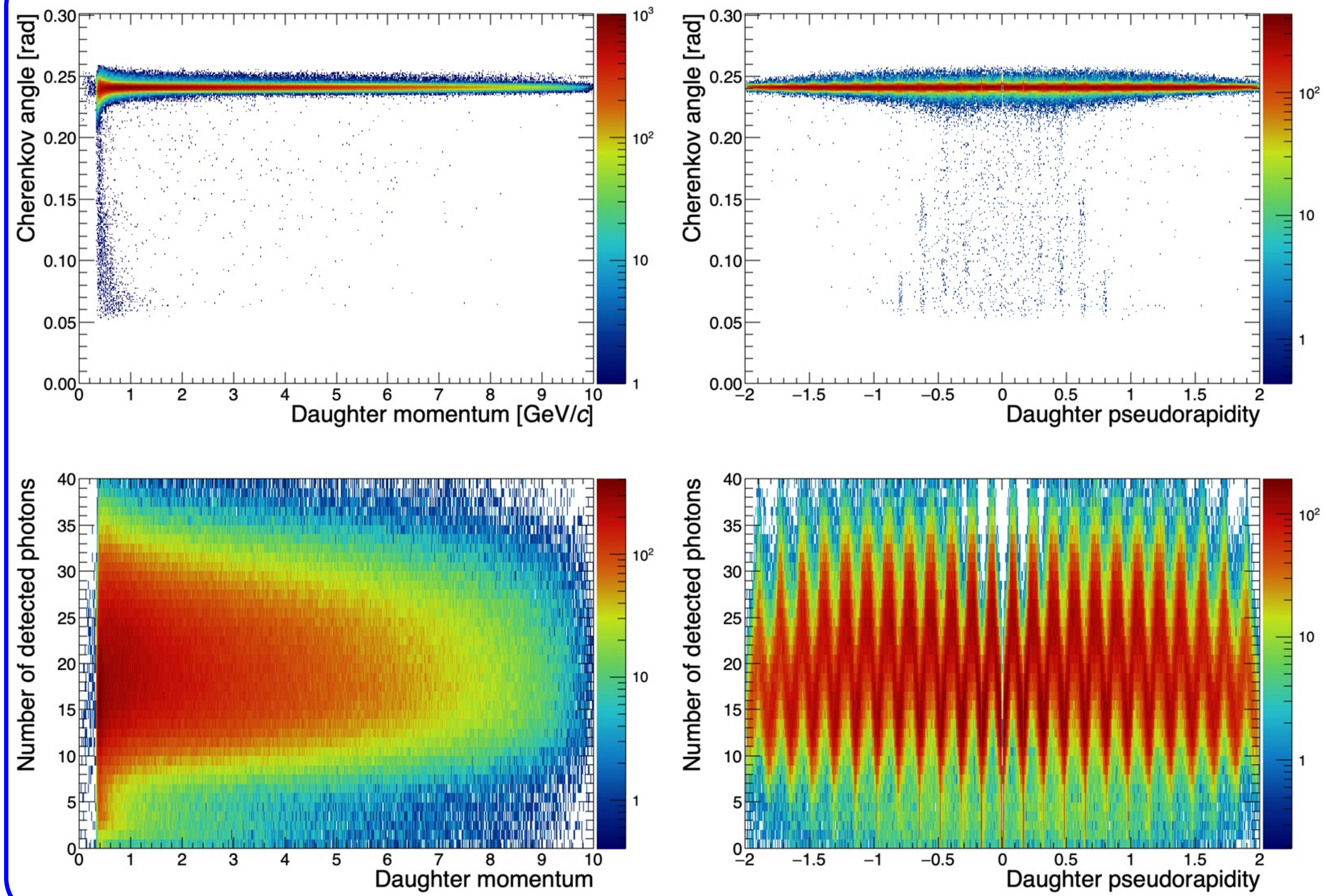
bRICH impact in $\rho^0 \rightarrow e^+e^-$

Simulation assumptions

- Generating single $\rho^0 \rightarrow e^+e^-$ events
- Assuming emission in (0,0,0) cm
- Using the same pattern recognition and PID cuts used for the pp analysis + threshold e ID below π threshold
- Goal: Study $\rho^0 \rightarrow e^+e^-$efficiency using bRICH alone, oTOF in bRICH (assuming 20 ps resolution) and gas

Daughter reconstruction

- Fluctuations of detected photons follow the projective segmentation
- Worsening of $e^{\pm}$ reconstruction for $p_T \rightarrow 0.3$ GeV due to shallow angles for large curvature in magnetic field



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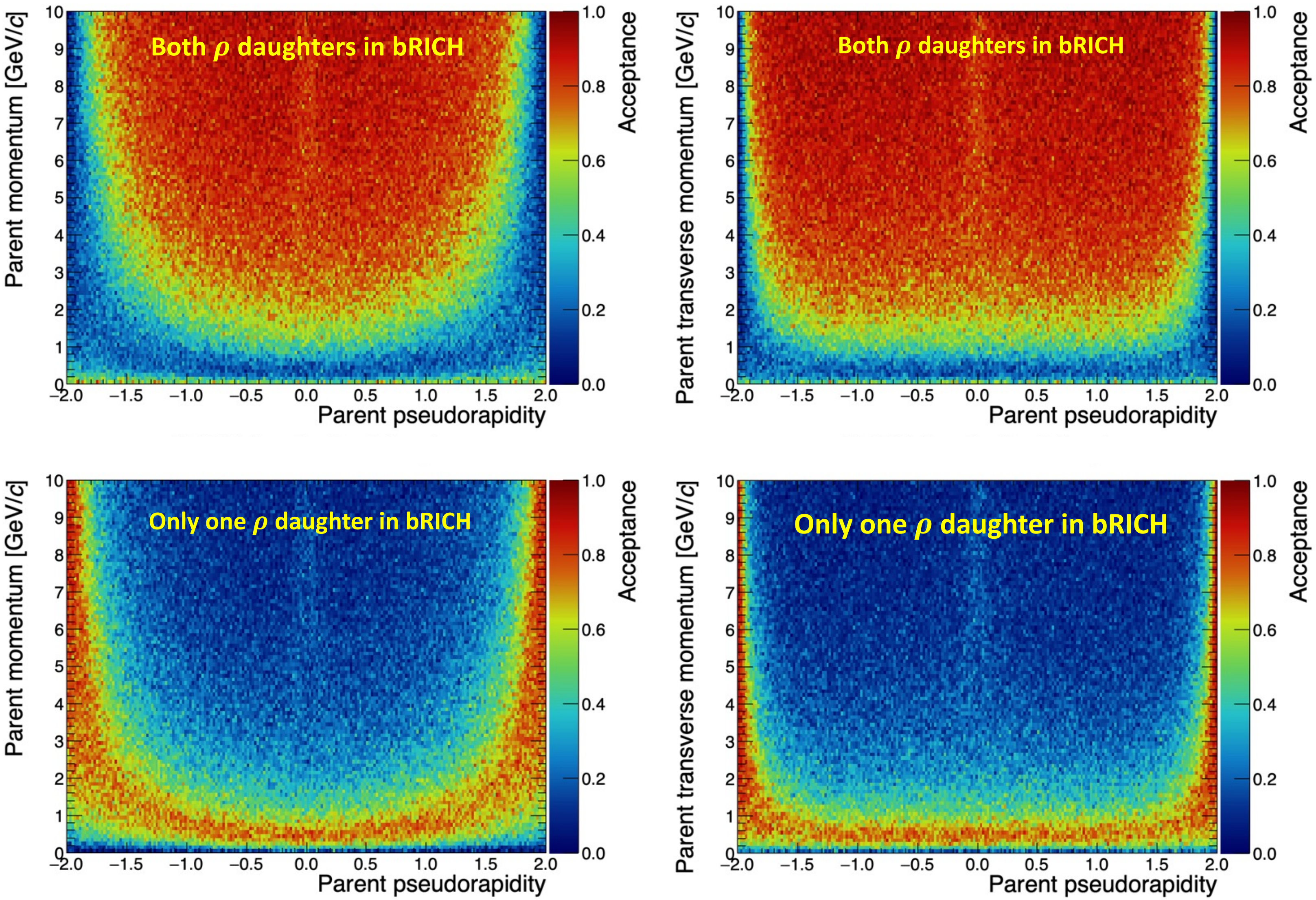
Acceptance

- Almost full acceptance to ρ daughters
- Loss of $e^{\pm}$ for ρ $p_T \to 0$ and $|\eta| \to 2$
- They are detected by iTOF, oTOF, fTOF and fRICH, which are not included here



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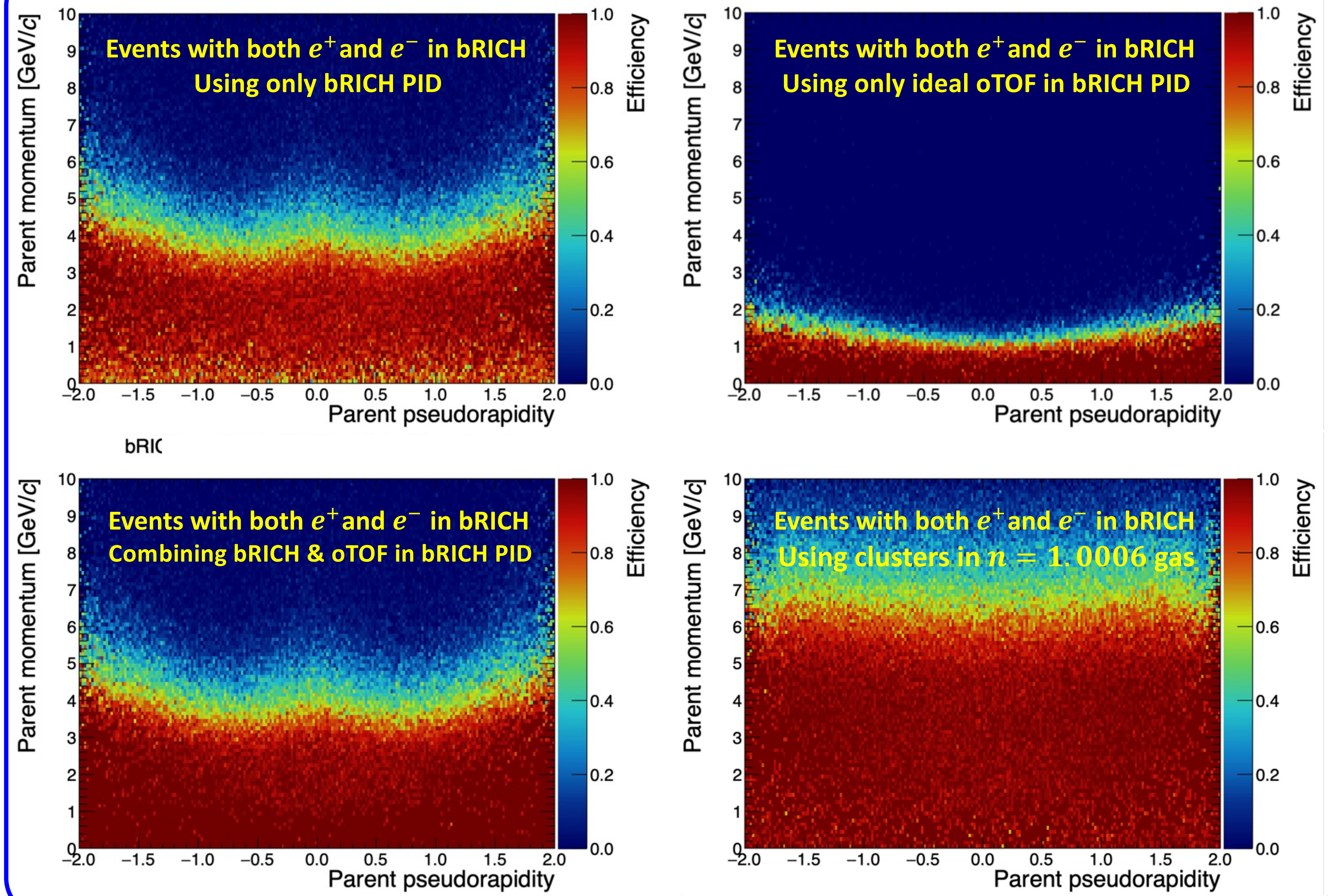
- **Goal**: Study $\rho^0 \to e^+e^-$efficiency using bRICH alone, oTOF in bRICH (assuming 20 ps resolution) and gas

Efficiency

- Excellent coverage up to $p \approx 4$ GeV/c
- oTOF ρ PID limited to $p \approx 1.4$ GeV/c
- Improvement using oTOF + bRICH PID
- Coverage up to p $\approx$ 6 GeV/c with gas



bRICH impact in $\rho^0 \rightarrow e^+e^-$

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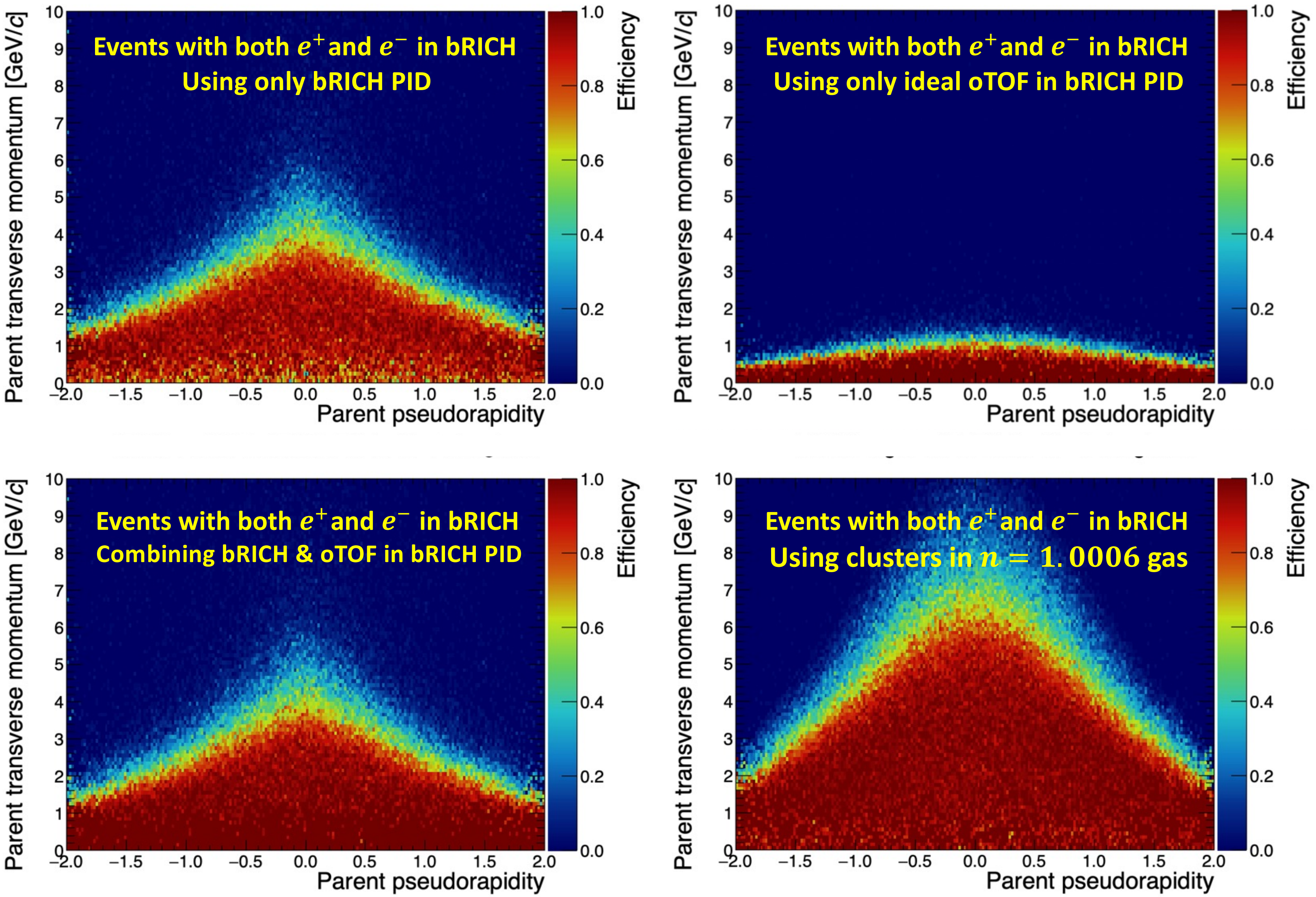
- Using the same pattern recognition and PID cuts used for the pp analysis + threshold e ID below π threshold
- Goal: Study $\rho^0 \rightarrow e^+e^-$efficiency using bRICH alone, oTOF in bRICH (assuming 20 ps resolution) and gas

Efficiency

- Excellent coverage up to $p \approx 4$ GeV/c
- oTOF ρ PID limited to $p \approx 1.6$ GeV/c
- Minor gain using oTOF + bRICH PID
- Coverage up to p $\approx$ 6 GeV/c with gas
- Note: Lower upper p_T limits vs $|\eta|$



bRICH impact in $D^0 \rightarrow K^-\pi^+$

ALICE

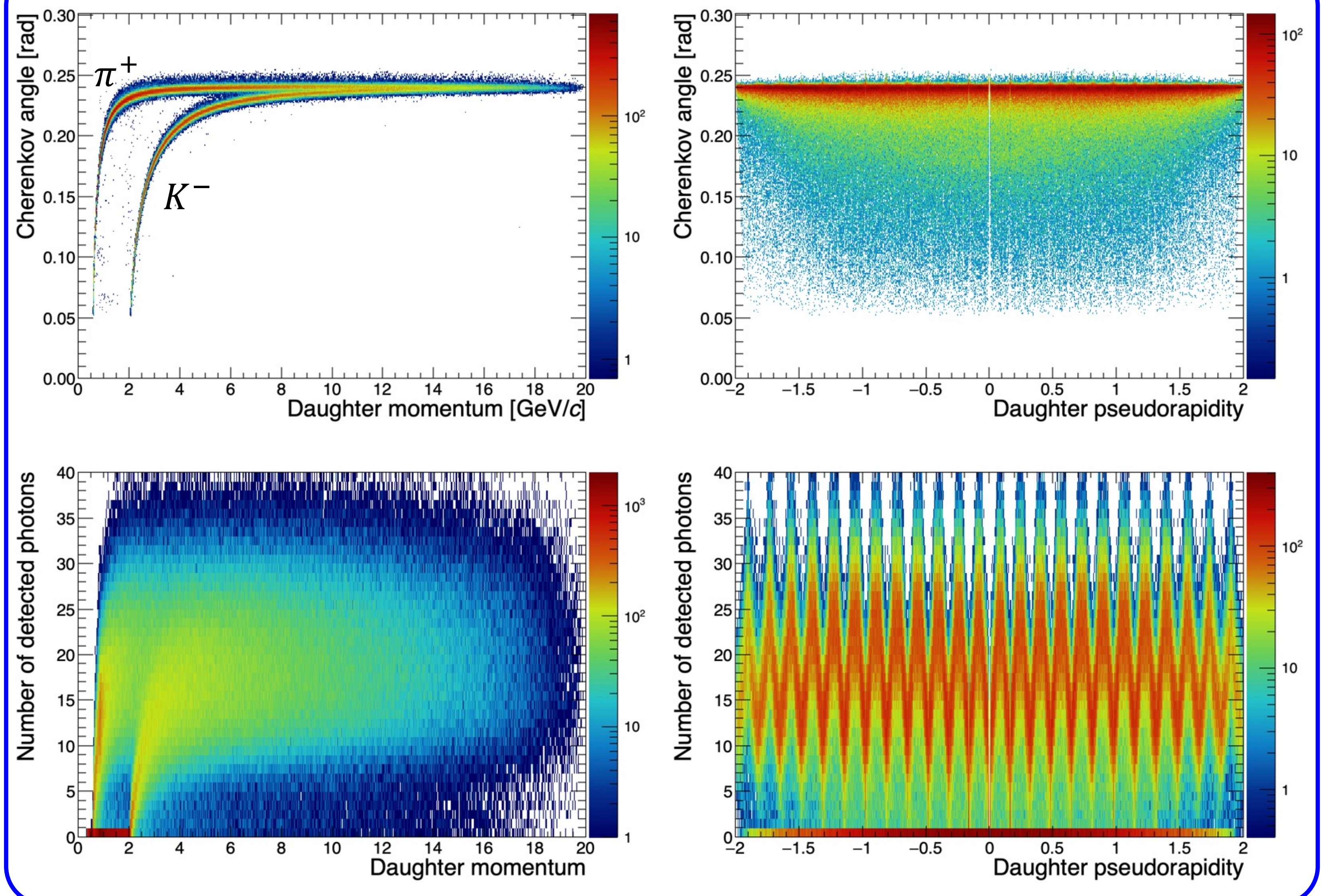
Simulation assumptions

- Generating single $D^0 \rightarrow K^-\pi^+$ events
- Assuming emission in (0,0,0) cm
- Using the same pattern recognition and PID cuts used for the pp analysis
- **Goal**: Study $D^0 \rightarrow K^-\pi^+$ efficiency using bRICH alone, oTOF in bRICH (assuming ideal 20 ps resolution)

Daughter reconstruction

- Fluctuations of detected photons follow the projective segmentation
- Most of the tracks with no detected photons are kaons below momentum threshold for Cherenkov emission

- $p_{th,\pi} \approx 0.6\ GeV/c$, $p_{th,K} \approx 2\ GeV/c$



bRICH impact in $D^0 \rightarrow K^-\pi^+$

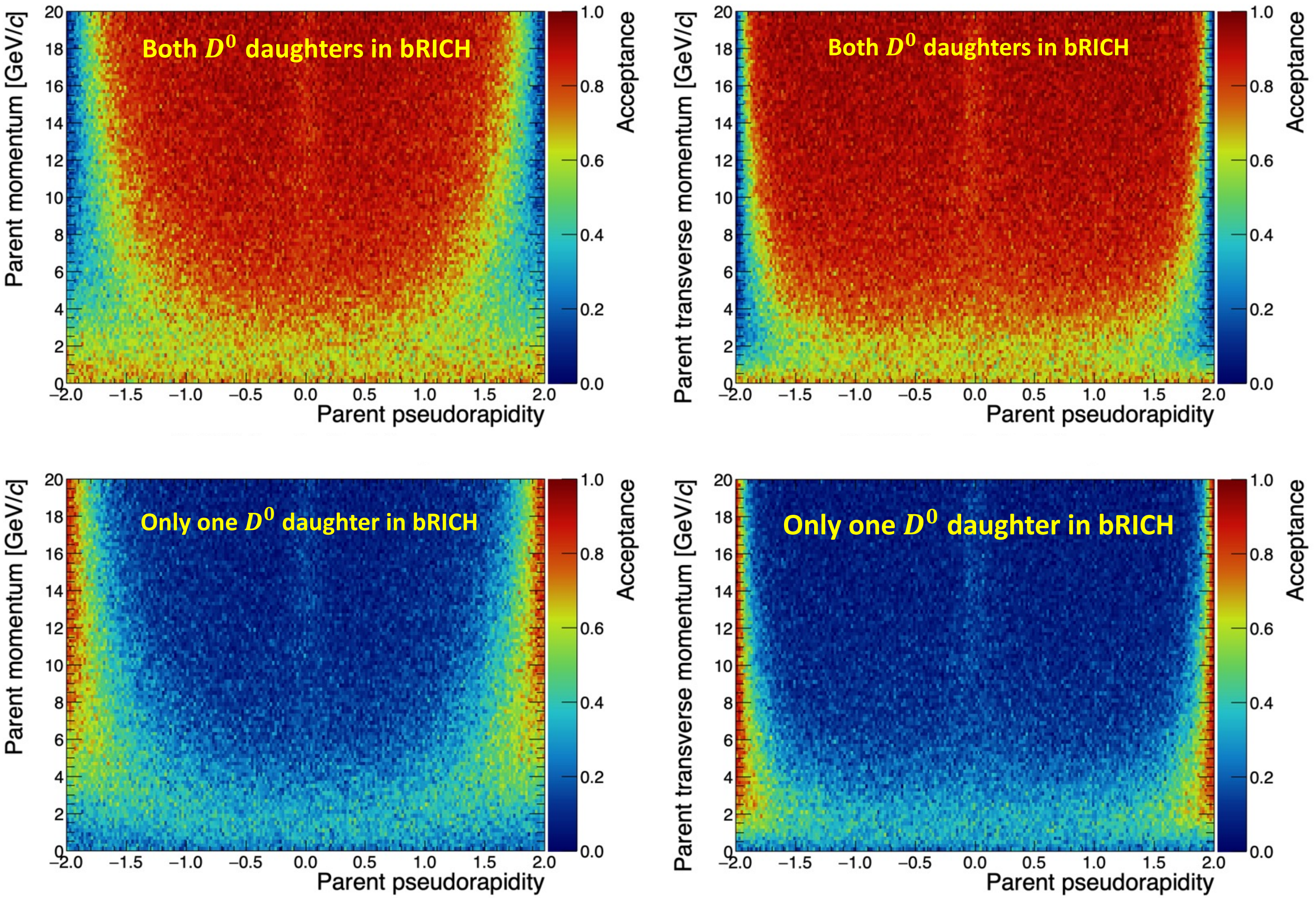
Simulation assumptions

- Generating single $D^0 \rightarrow K^-\pi^+$ events
- Assuming emission in (0,0,0) cm
- Using the same pattern recognition and PID cuts used for the pp analysis
- **Goal**: Study $D^0 \rightarrow K^-\pi^+$efficiency using bRICH alone, oTOF in bRICH (assuming ideal 20 ps resolution)

Acceptance

- Almost full acceptance to D^0 daughters
- Loss of K/π for $p_T \rightarrow 0$ and $|\eta| \rightarrow 2$

\- They are detected by iTOF, oTOF, fTOF and fRICH, which are not included here



bRICH impact in $D^0 \rightarrow K^-\pi^+$

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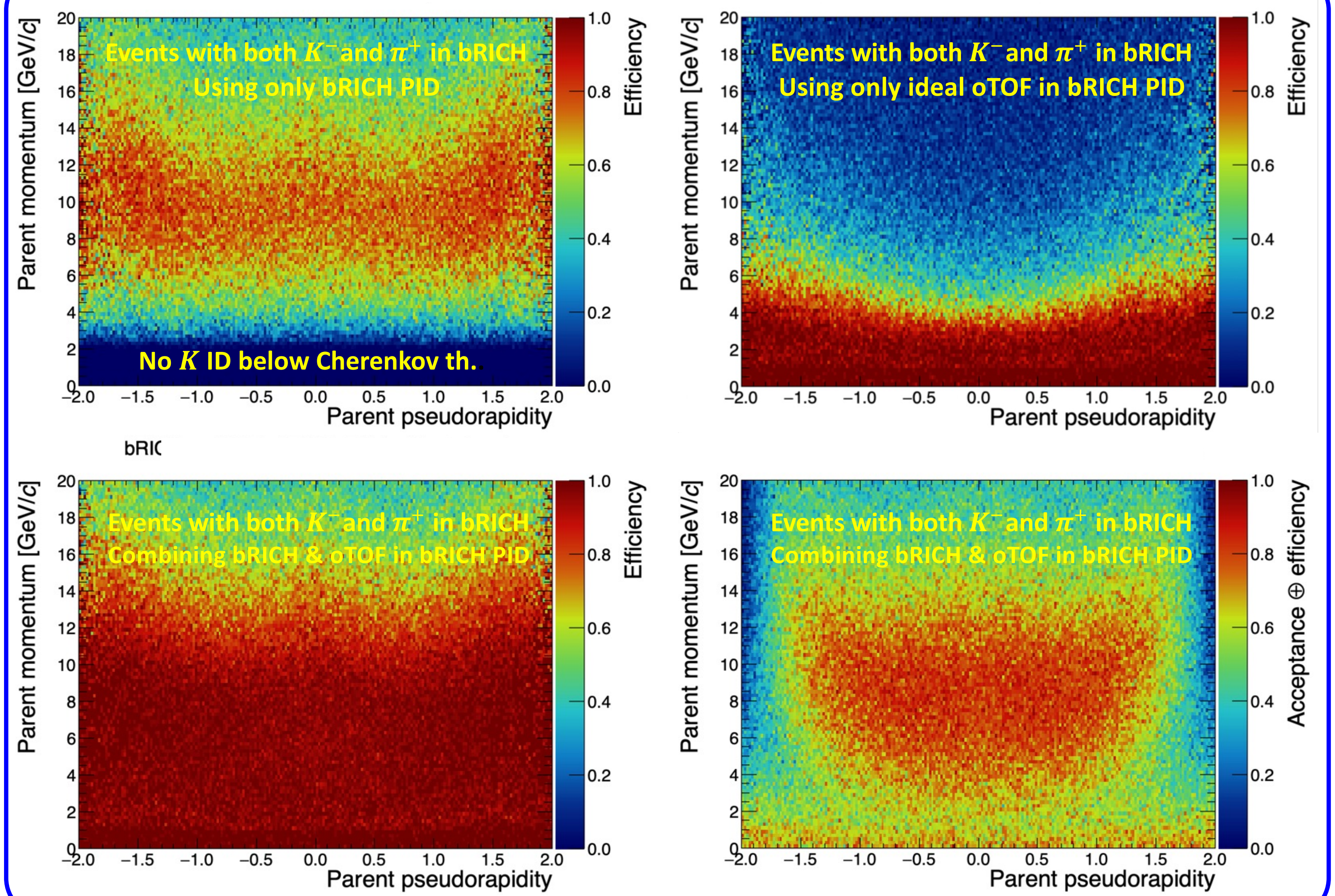
- Assuming emission in (0,0,0) cm
- Using the same pattern recognition and PID cuts used for the pp analysis
- Goal: Study $D^0 \rightarrow K^-\pi^+$ efficiency using bRICH alone, oTOF in bRICH (assuming ideal 20 ps resolution)

Efficiency

- Stand-alone bRICH alone limited by inefficiency to K^- below $\approx$ 2 GeV/c
- oTOF mandatory for D^0 $p_T \rightarrow 0$
- Minor gain using oTOF + bRICH PID
- Coverage up to $p \approx$ 6 GeV/c with gas



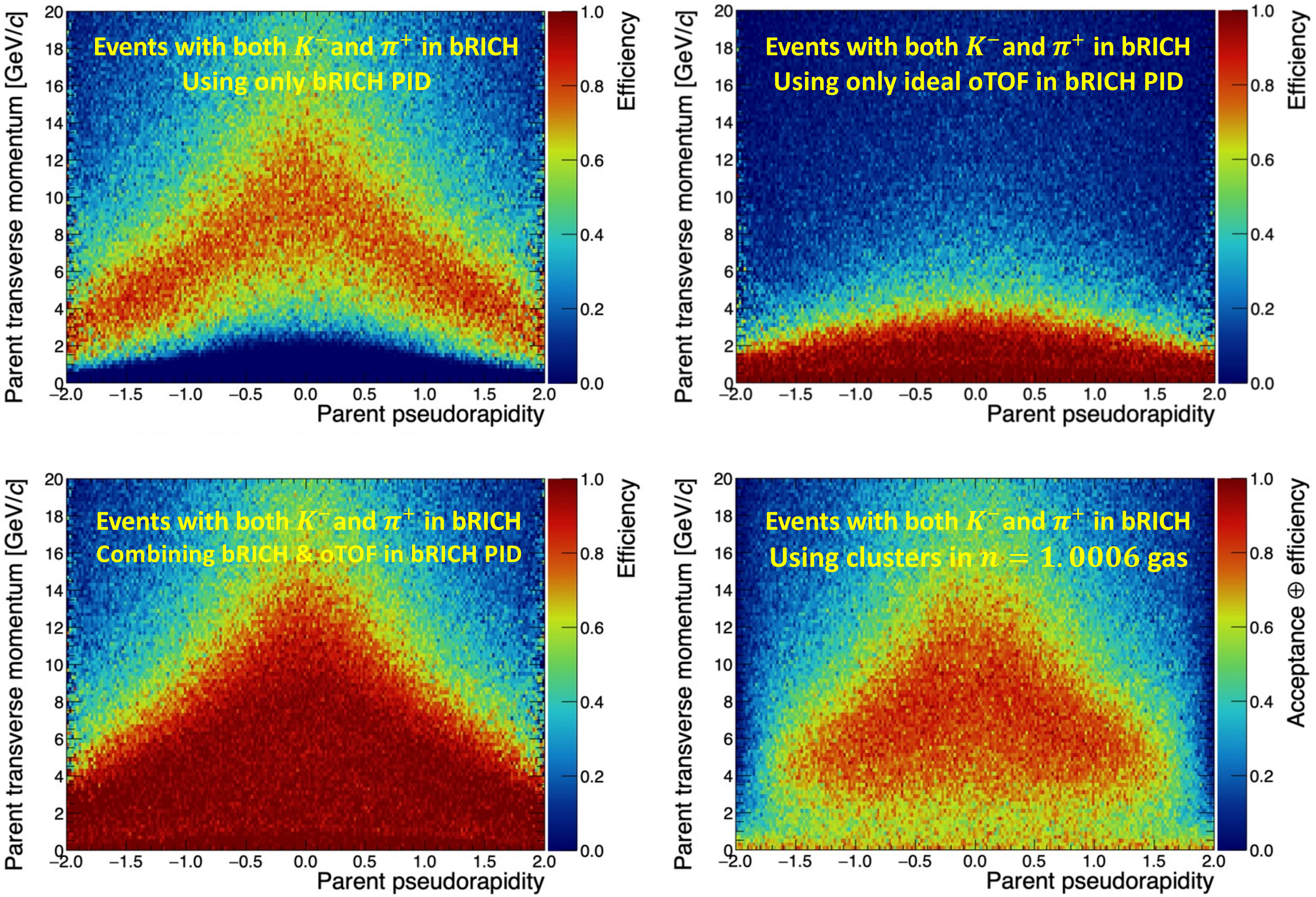
bRICH impact in $D^0 \rightarrow K^-\pi^+$

Simulation assumptions

- Generating single $D^0 \rightarrow K^-\pi^+$ events
- Assuming emission in (0,0,0) cm
- Using the same pattern recognition and PID cuts used for the pp analysis
- **Goal**: Study $D^0 \rightarrow K^-\pi^+$ efficiency using bRICH alone, oTOF in bRICH (assuming ideal 20 ps resolution)

Efficiency

- Excellent coverage up to $p \approx 4$ GeV/c
- oTOF D^0 PID limited to $p \approx 1.6$ GeV/c
- Minor gain using oTOF + bRICH PID
- Coverage up to $p \approx 14$ GeV/c combining bRICH and oTOF PID
- **Note**: Lower upper p_T limits vs $|\eta|$



Conclusions

bRICH physics performace study

- The proposed RICH fulfills the ALICE 3 design PID requirements
- Simulations show huge potential impact on physics programme
  - Use of high-index gas very promising for extensive $e^{\pm}$ PID
  - Next steps: Including fRICH, SiPM DCR and mutual track bkg. in high multiplicity events in $\rho^0 \rightarrow e^+e^-$ and $D^0 \rightarrow K^-\pi^+$ analysis

Other ongoing simulation studies

- Geometry optimization to fully include electronics and services
- Careful check of performance stability in high-DCR environment
- Machine learning-based PID with high DCR and track multiplicity

Thank you for your attention

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Backup

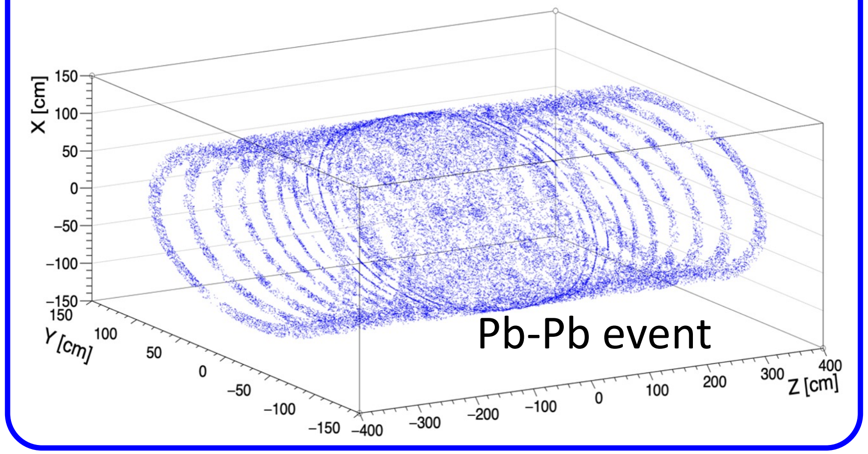
bRICH PID in p-p and central Pb-Pb

Angle reconstruction
- Based on Hough Transform method
- Timing cut on hit-track matching
- HTM $N_{\mathrm{ph,min}}$ cut on clustered hits

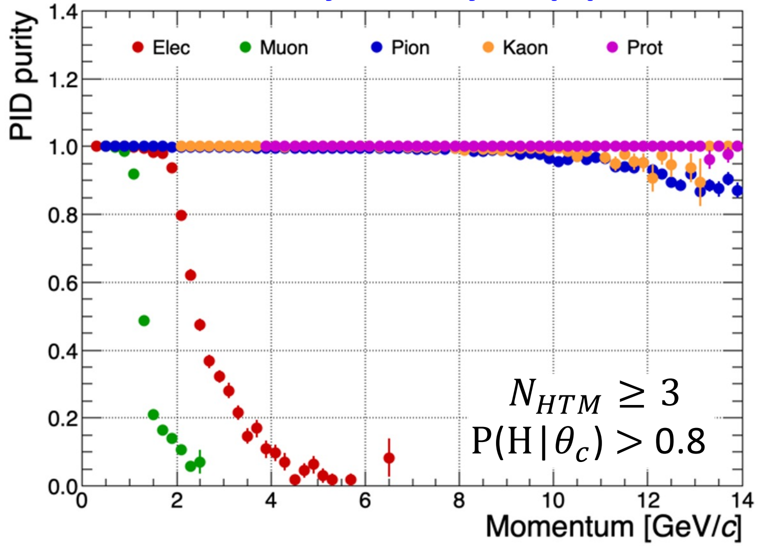
Classical PID analysis
- Bayesian approach + probability cut

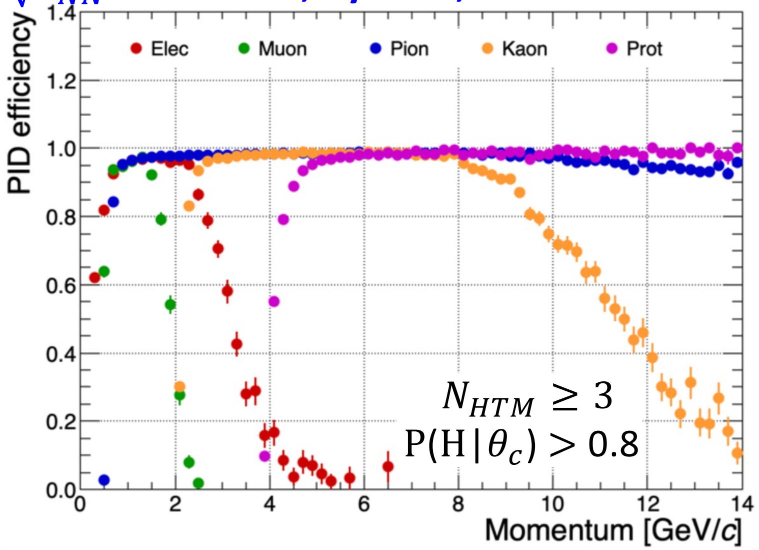
Background sources
- Photons emitted by different tracks
- Aerogel Rayleigh scattered photons
- SiPM dark count hits (in DAQ gate)

Photodetector hit map of Pb-Pb event

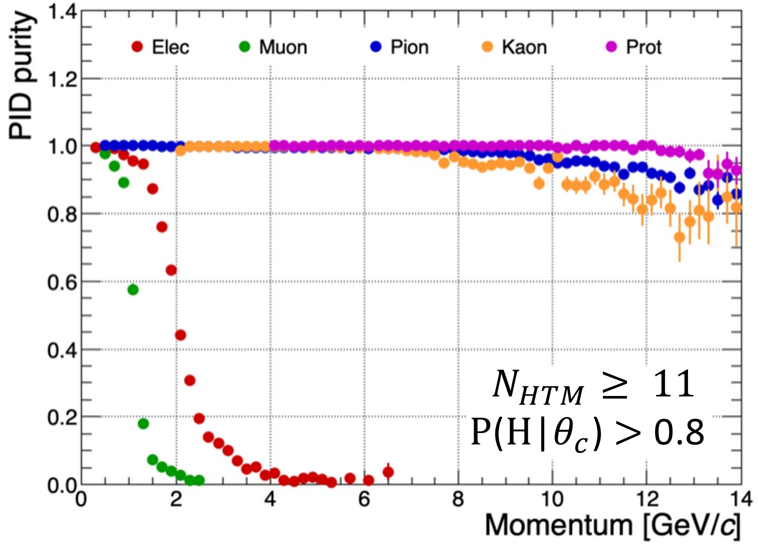


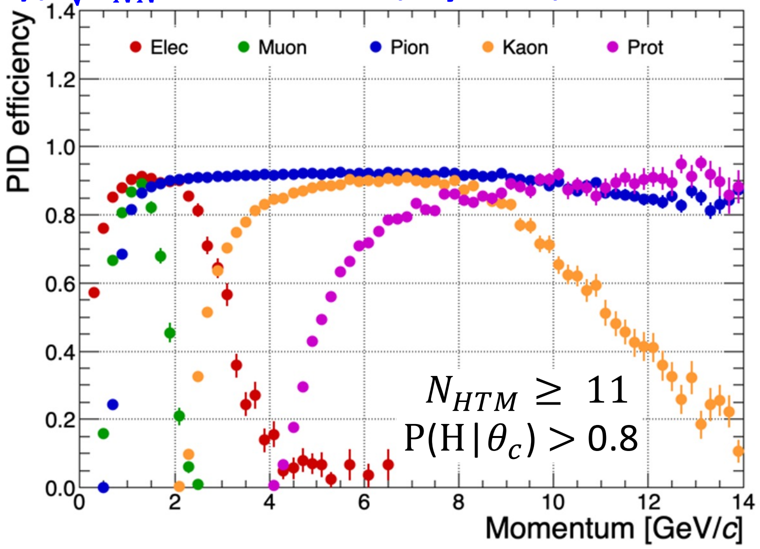
HTM+Bayes analysis, p-p , $c\bar{c}$ biased, $\sqrt{s_{NN}} = 14$ TeV, Pythia8, B = 2 T





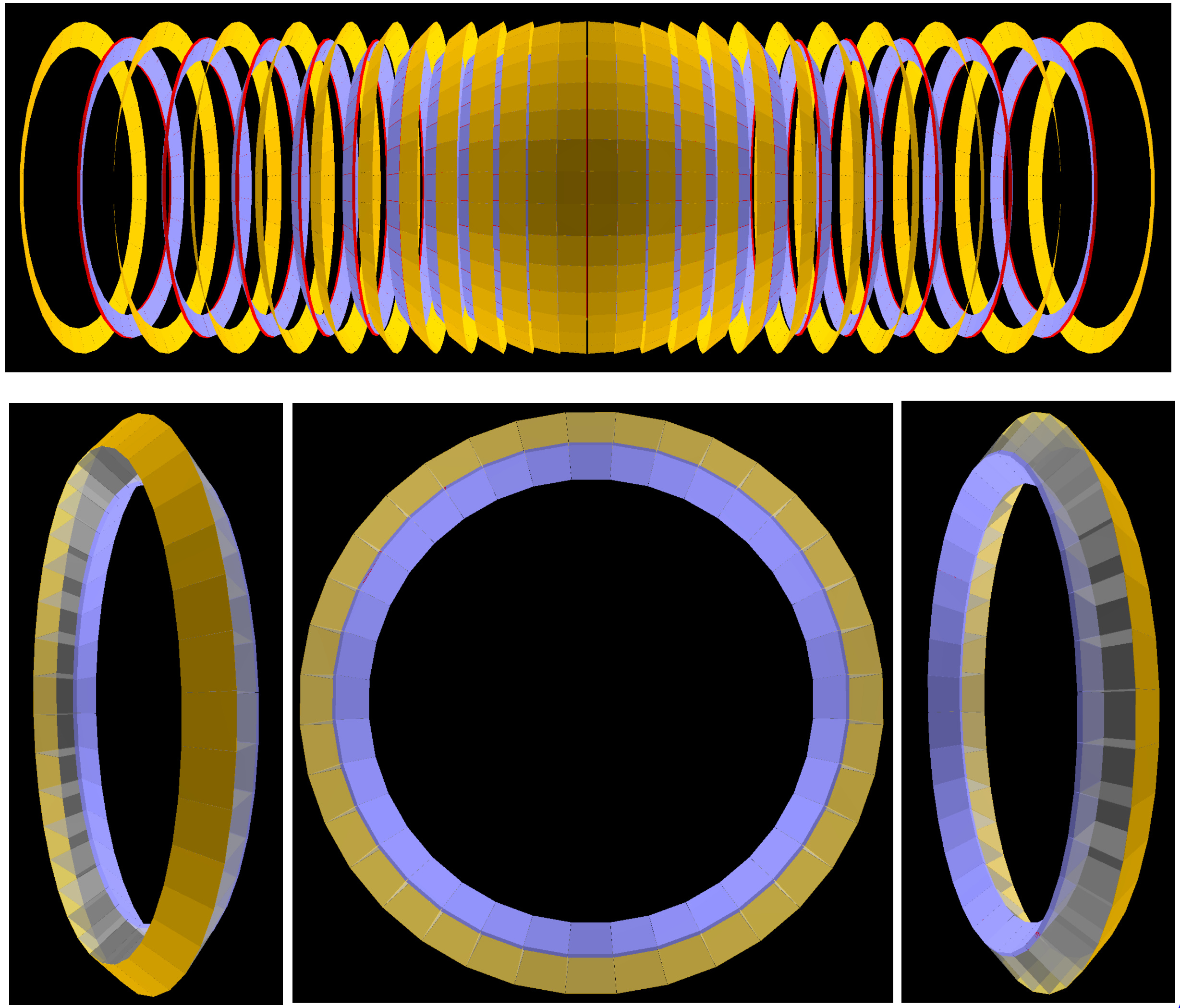
HTM+Bayes analysis, Pb-Pb, b < 3.5 fm (0-5%) , $\sqrt{s_{NN}} = 5.52$ TeV, Pythia8, B = 2 T



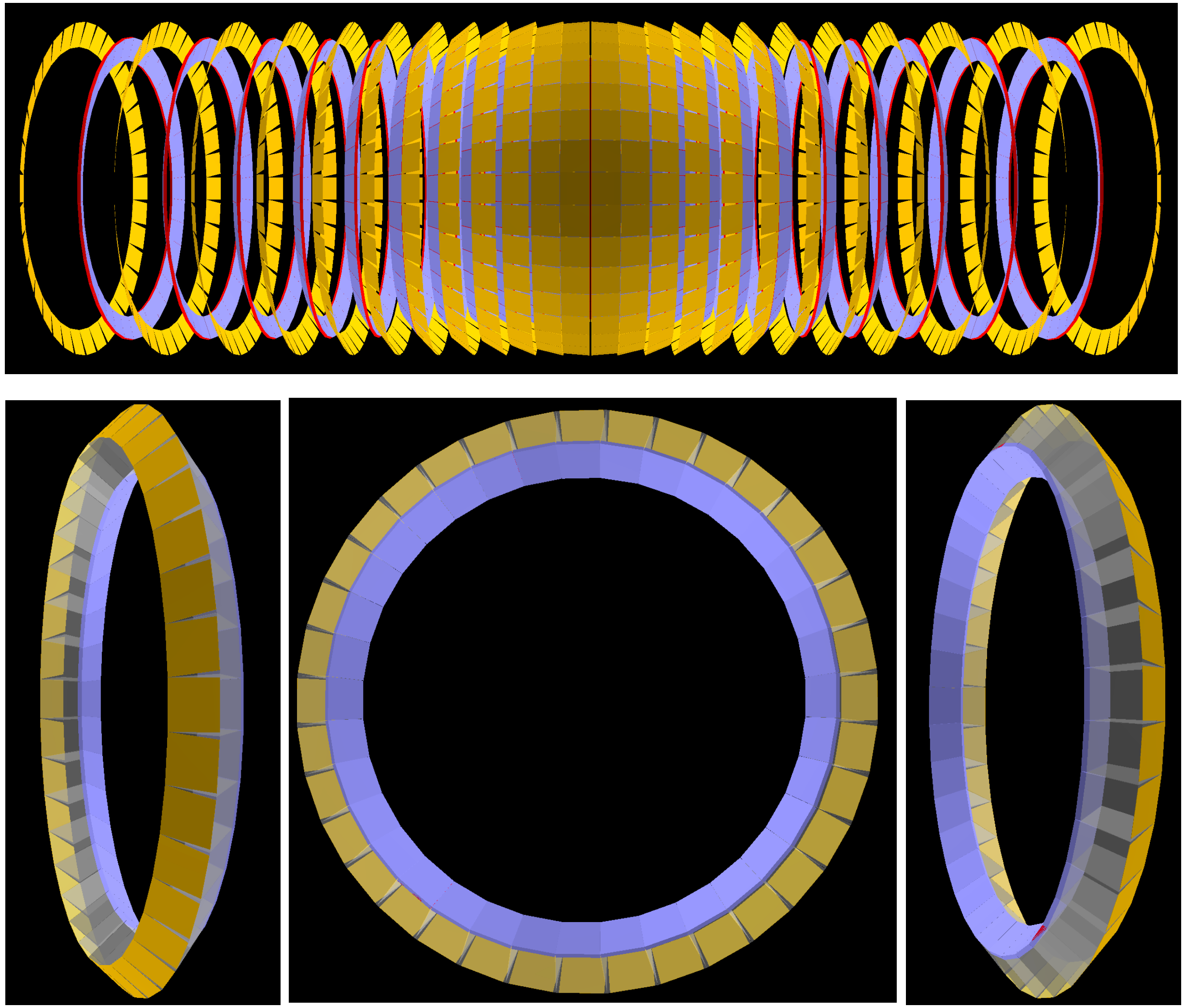


bRICH – Option rectangular tiles (I)

Trapezoidal modules: 30.72 m² SiPM area

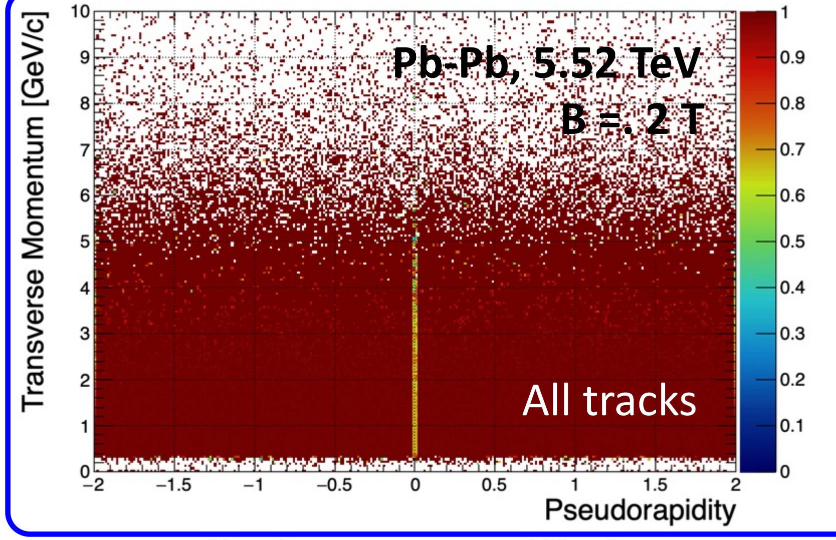


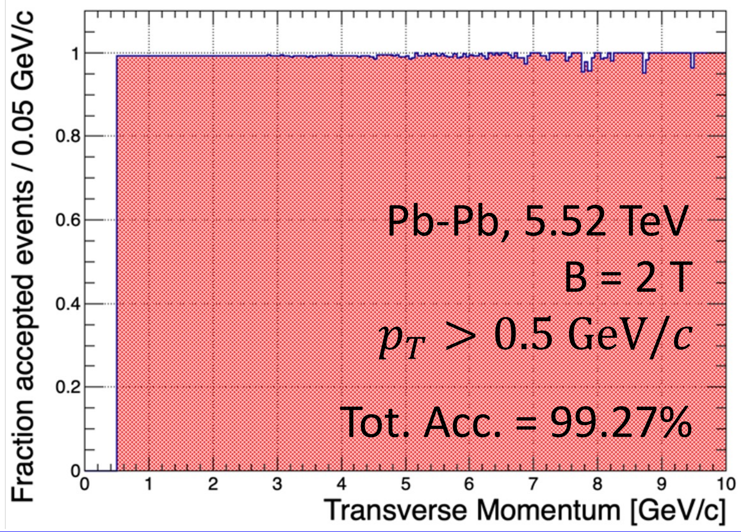
Rectangular modules: 29.05 m² SiPM area

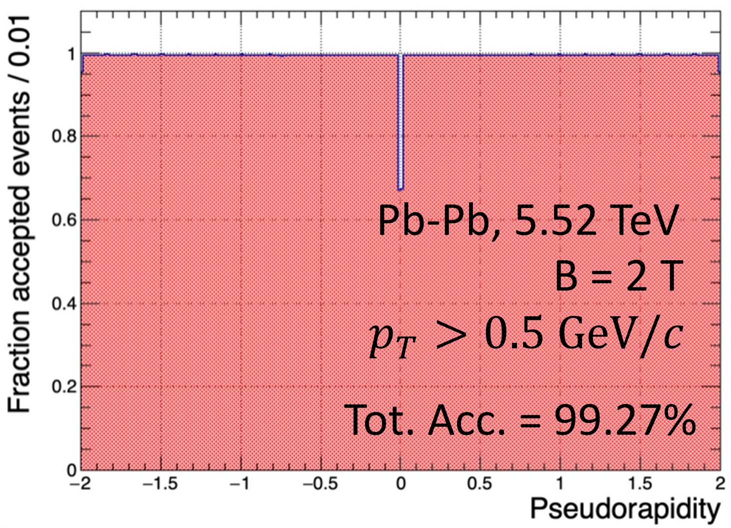


bRICH – Option rectangular tiles (II)

MIP acceptance: trapezoidal tiles vs rectangular tiles





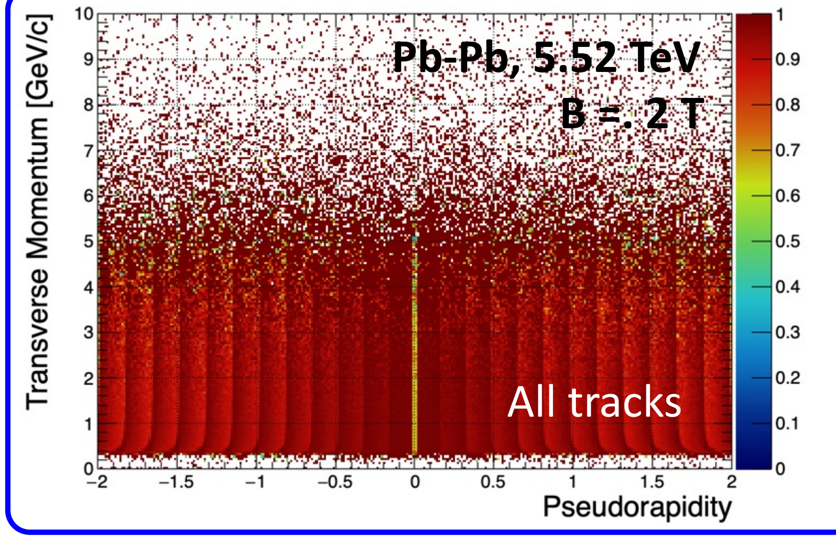


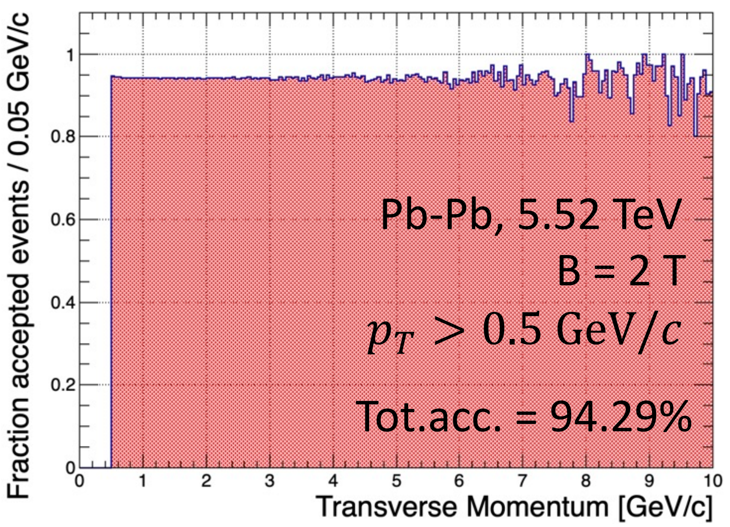
Trapezoidal SiPM tiles

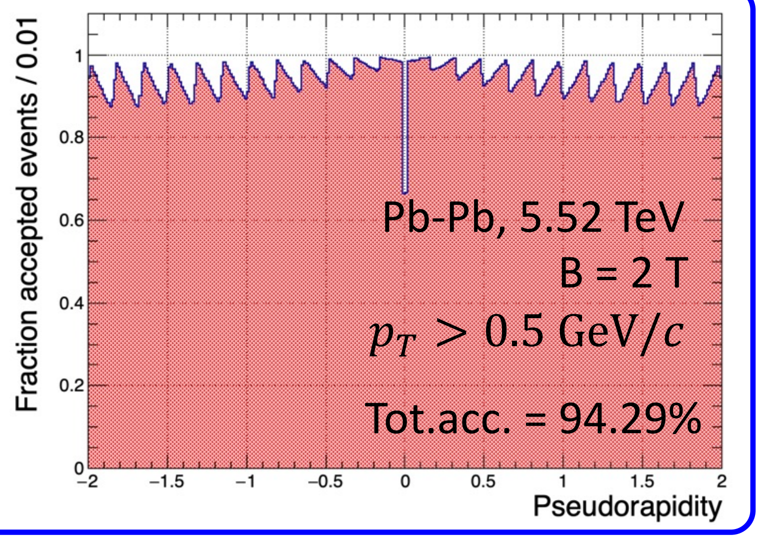
Photodetector acceptance to MIPs 2D

Photodetector acceptance to MIPs pt 1D

Photodetector acceptance to MIPs eta 1D



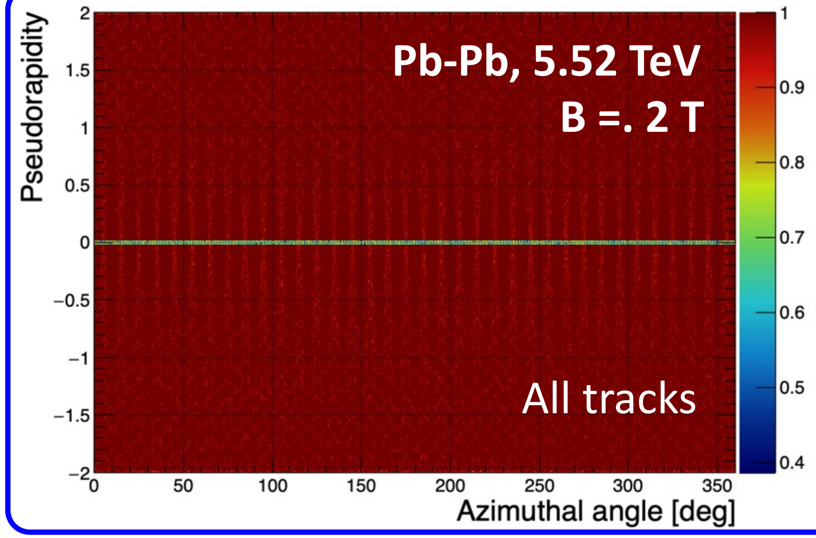


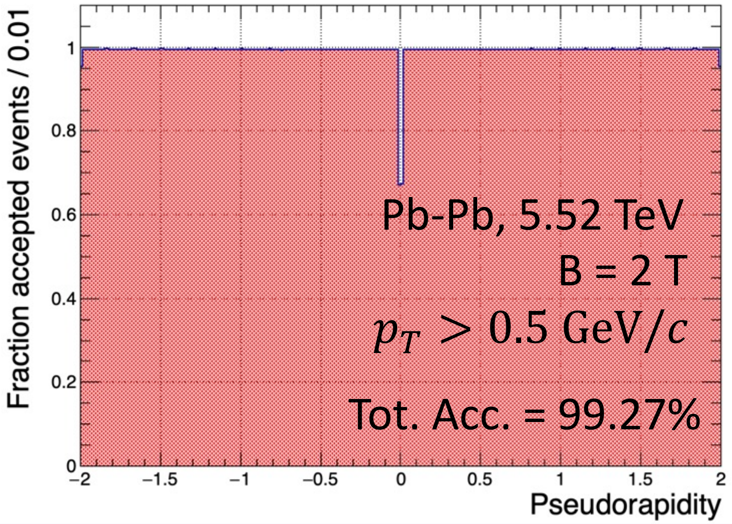


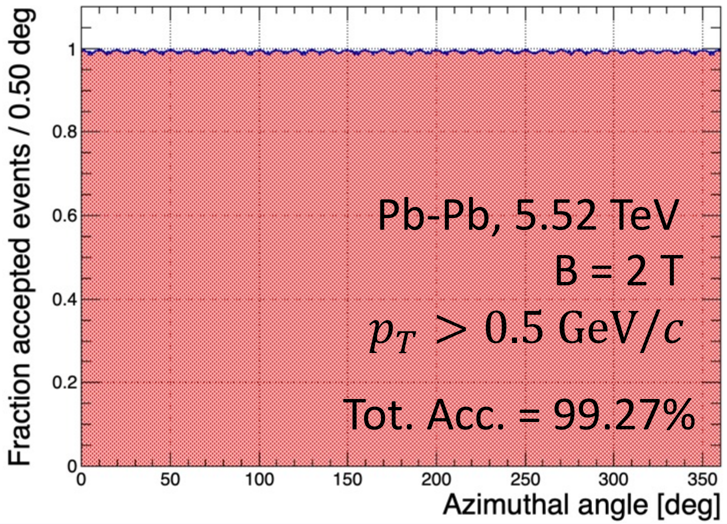
Rectangular SiPM tiles

bRICH: MIP acceptance vs σ_z (II)

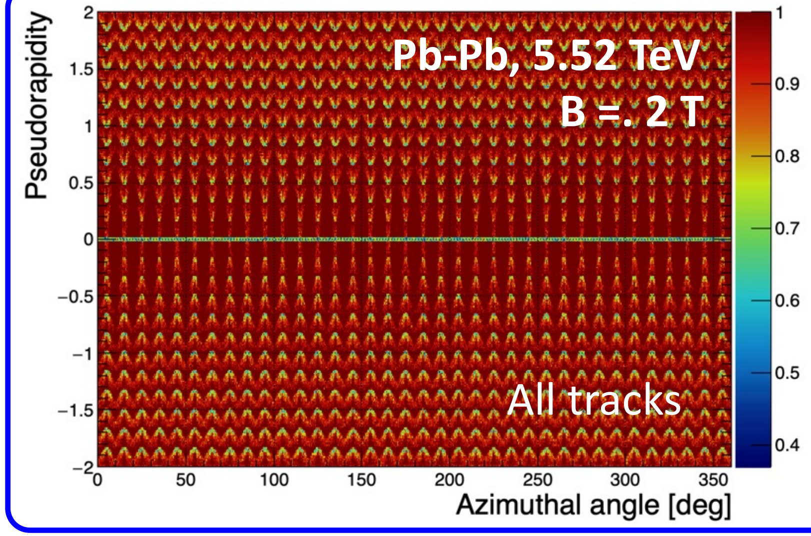
MIP acceptance: trapezoidal tiles vs rectangular tiles

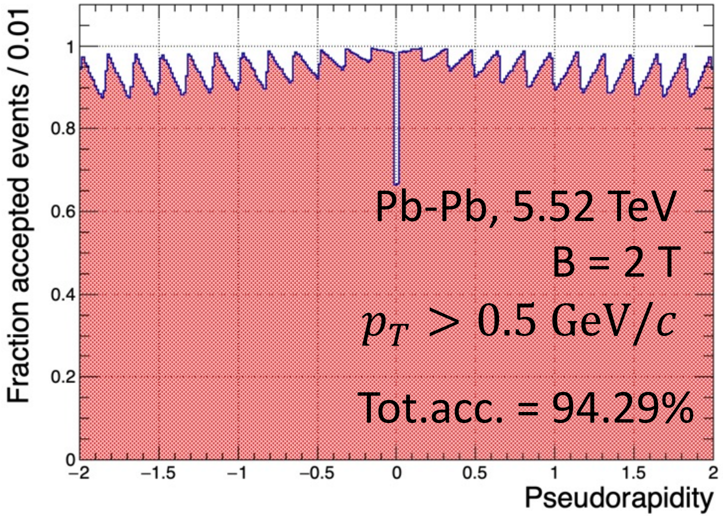


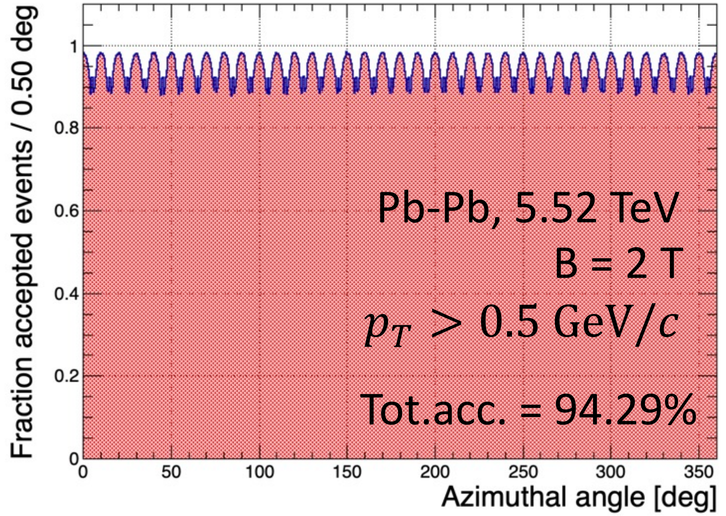




Trapezoidal SiPM tiles







Rectangular SiPM tiles

bRICH PID in p-p and central Pb-Pb

Angle reconstruction

- Based on Hough Transform method
- Timing cut on hit-track matching
- HTM $N_{ph,min}$ cut on clustered hits

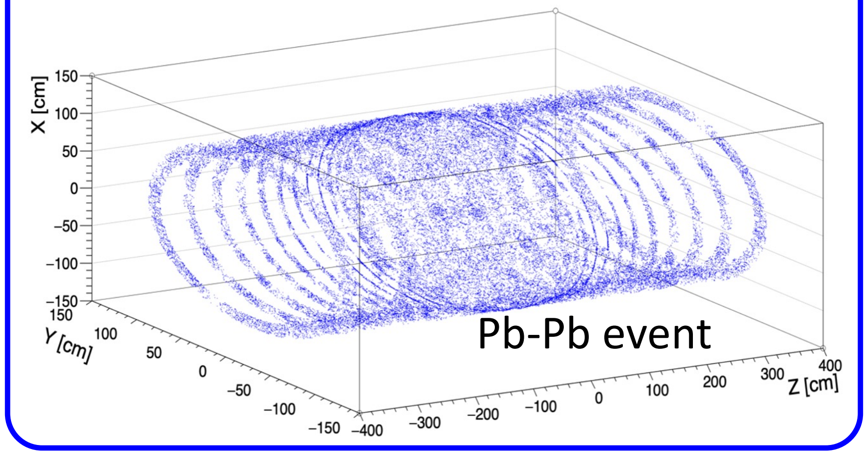
Classical PID analysis

- Bayesian approach + probability cut

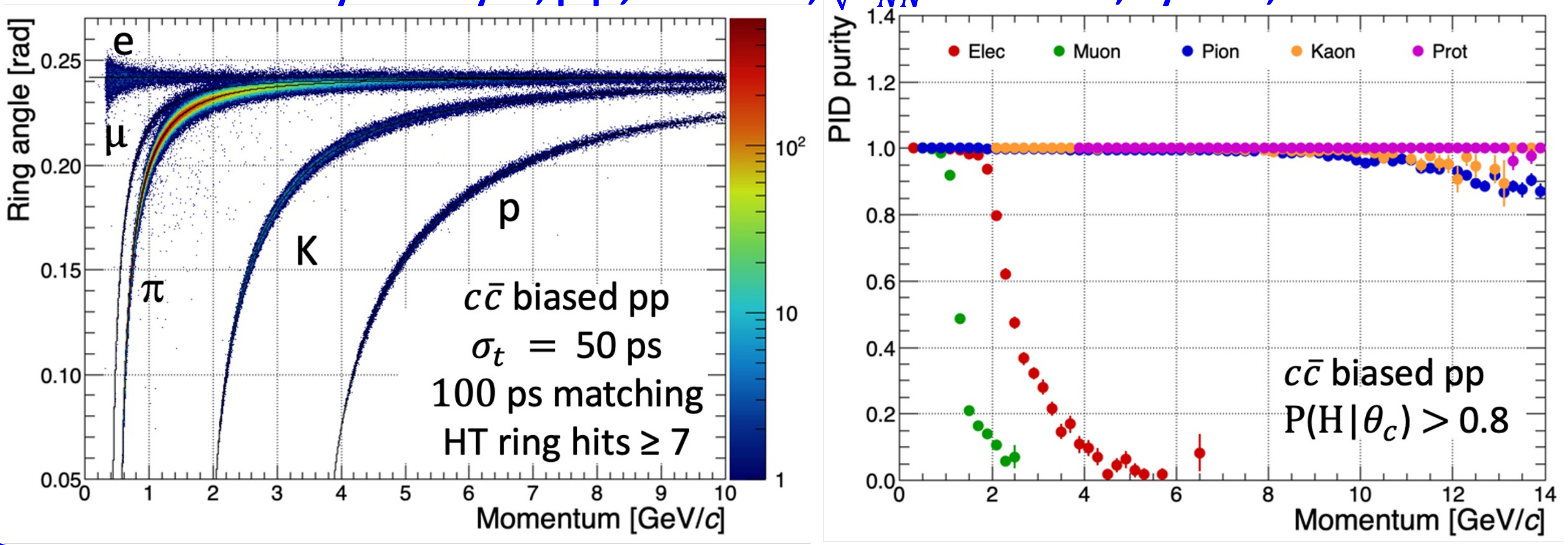
Background sources

- Photons emitted by different tracks
- Aerogel Rayleigh scattered photons
- SiPM dark count hits (in DAQ gate)

Photodetector hit map of Pb-Pb event



HTM+Bayes analysis, p-p , $c\bar{c}$ biased, $\sqrt{s_{NN}}$ = 14 TeV, Pythia8, B = 2 T



HTM+Bayes analysis, Pb-Pb, b < 3.5 fm (0-5%) , $\sqrt{s_{NN}}$ = 5.52 TeV, Pythia8, B = 2 T