PNN ANALYSIS
STATUS AND PROSPECTS

F. BRIZIOLI, R. FIORENZA, J. SWALLOW

renato.fiorenza@cern.ch

NA62 ITALIA

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SSM Scuola Superiore Meridionale

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

INFN NAPOLI

STATUS OF 2021-2022 PAPER

- Draft v6 is on CDS: https://cds.cern.ch/record/2915193/
- Some comments already received and addressed
- Thanks in advance for submitting any more comments! Deadline: 20/11/2024

2021-2022 RESULT CHANGES SINCE PRELIMINARY RESULT

- Contamination from $K^+ \to \pi^+\pi^0_D$ in normalization sample ($K^+ \to \pi^+\pi^0, \pi^0 \to \gamma\gamma$): 0.2% from MC studies
  - MC $K_{2\pi}$ (used for acceptance) is only $\pi^0 \to \gamma\gamma$; π^0_D is suppressed in normalization selection by multiplicity criteria
  - Subtract contamination with 100% relative syst uncertainty to $N_{\pi\pi}$
  - Effect on N(πνν): -0.2%, σ(N(πνν)): negligible

- Random veto correction: $\varepsilon_{RV} = \varepsilon_{RV,data} / \varepsilon_{RV,MC}$ (to account for events rejected by the μ^+ activity)
  - Previously: $\varepsilon_{RV} = \varepsilon_{RV,data} + (1 - \varepsilon_{RV,MC})$
  - Correction now correctly takes into account coincidence of μ^+ activity and accidental activity
  - Effect on N(πνν): -0.6%, σ(N(πνν)): negligible

- Overall change on BR:

$BR_{2021\text{-}22}$ $\left(16.0^{+5.0}_{-4.5}\right) \times 10^{-11} = \left(16.0\ ^{(+4.8)}_{(-4.2)}\text{stat}\ ^{[+1.4]}_{[-1.3]}\text{syst}\right) \times 10^{-11} \longrightarrow \left(16.2^{+5.1}_{-4.5}\right) \times 10^{-11} = \left(16.2\ ^{+4.9}_{-4.3}|_{\text{stat}}\ ^{+1.4}_{-1.4}|_{\text{syst}}\right) \times 10^{-11}$

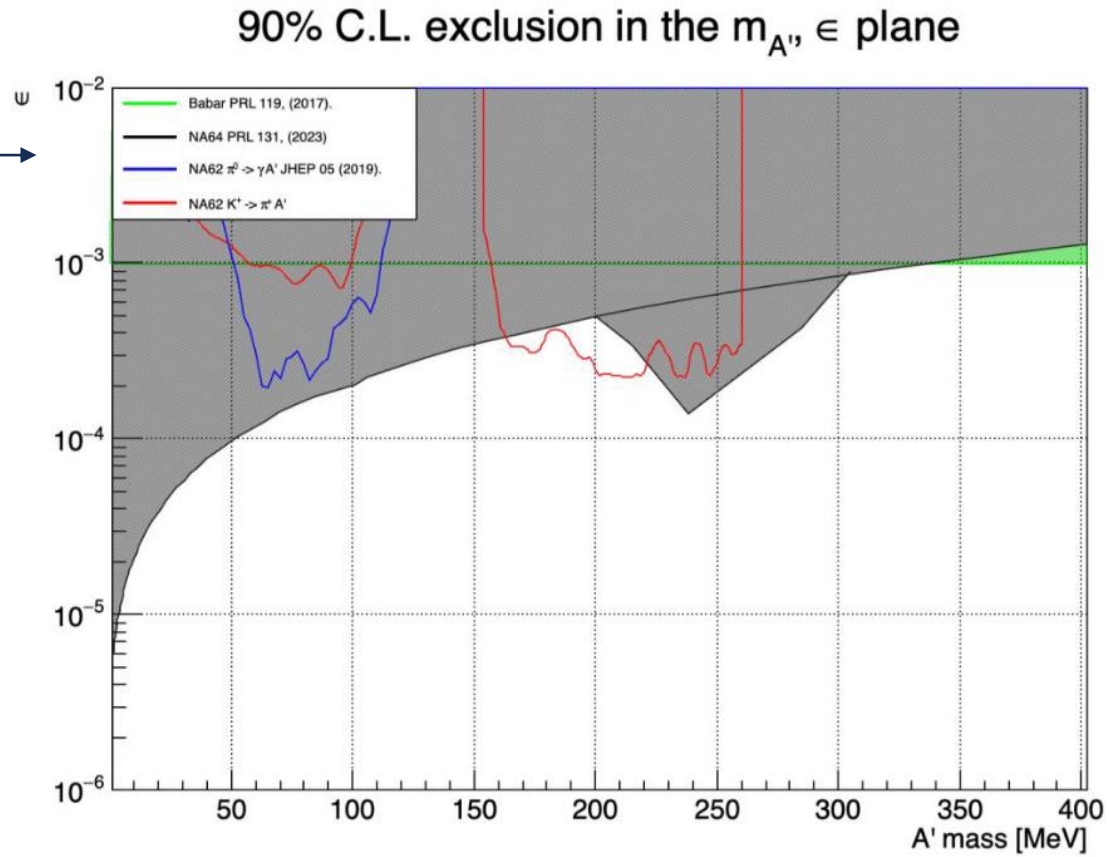
$BR_{2016\text{-}22}$ $\left(13.0^{+3.3}_{-2.9}\right) \times 10^{-11} = \left(13.0\ ^{(+3.0)}_{(-2.7)}\text{stat}\ ^{[+1.3]}_{[-1.2]}\text{syst}\right) \times 10^{-11} \longrightarrow \left(13.0^{+3.3}_{-3.0}\right) \times 10^{-11} = \left(13.0\ ^{+3.0}_{-2.7}|_{\text{stat}}\ ^{+1.3}_{-1.3}|_{\text{syst}}\right) \times 10^{-11}$

see Mauro Raggi's presentation

$K^+ \to \pi^+ X$ REINTERPRETATION

Dedicated paper on limits on $K^+ \to \pi^+ X$ based on 2016-2018 data, including all interpretations:

- BC2: dark vector decaying to DM fermions (new)
- BC10: ALP coupling to fermions (update from 2017 data)
- BC11: ALP coupling to gluons (existing in $K^+ \to \pi^+ \gamma\gamma$ paper)
- BC4: dark scalar (existing in PNN paper)

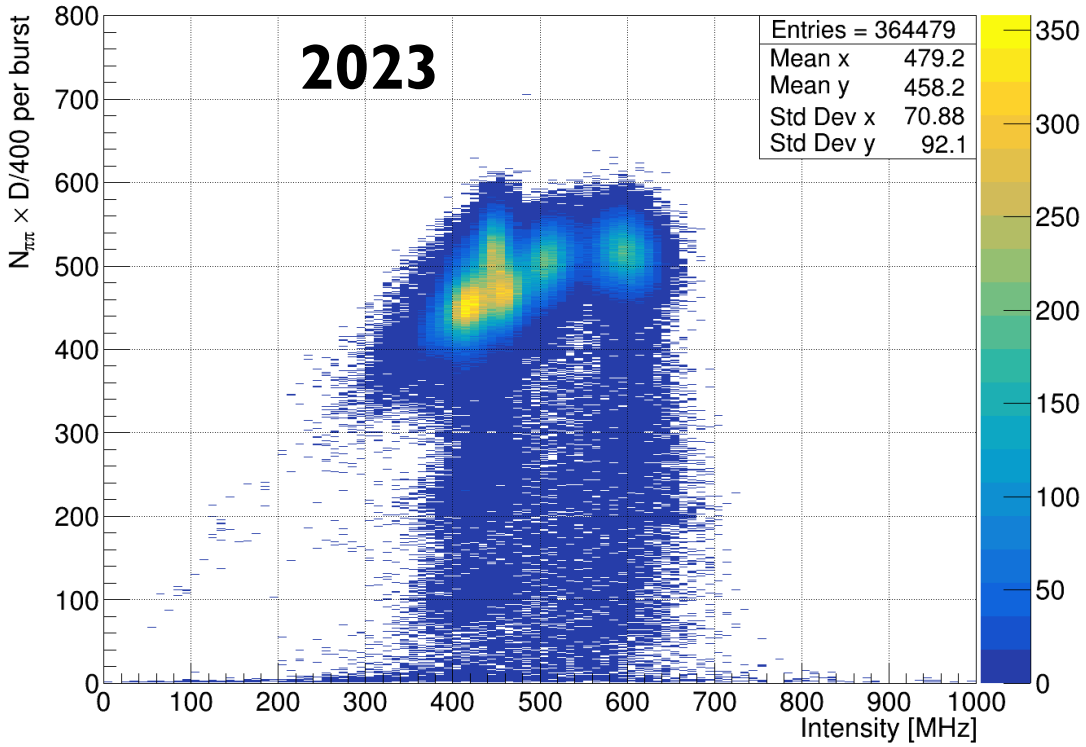


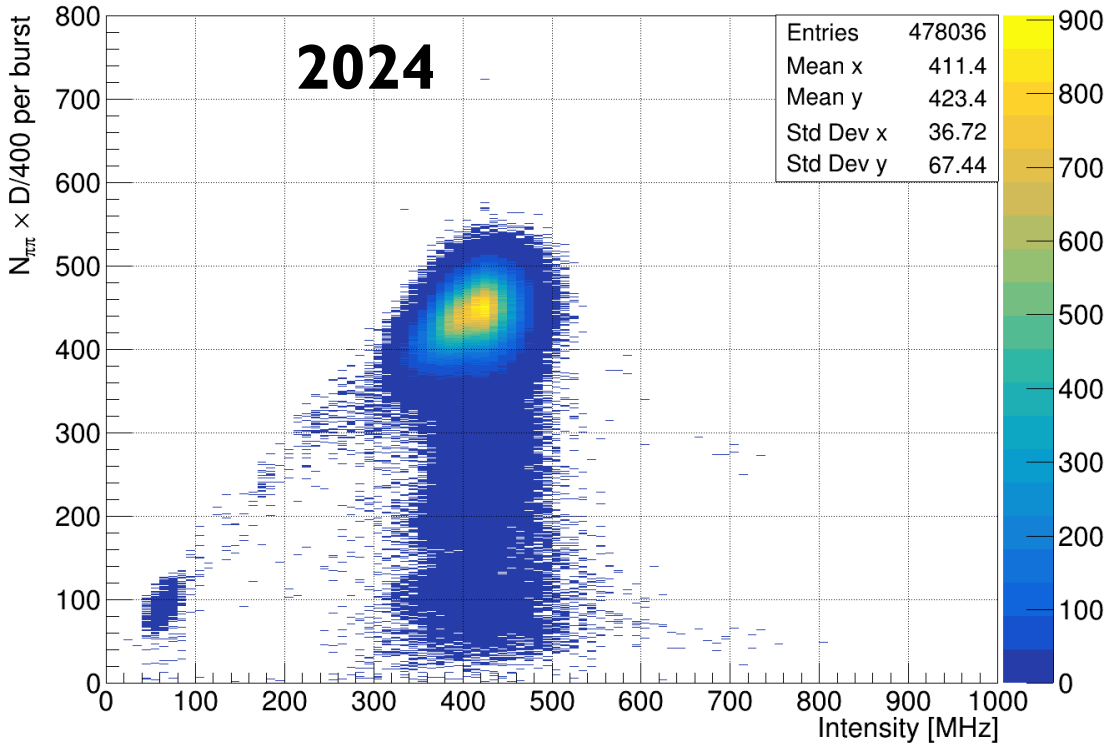
2023-2024 DATA

COPY-PASTING 2021-2022 ANALYSIS…

- 2023: v3.9.10, fully processed and reduced
- 2024: prompt processing ⟶ inherently ±10~20% (v3.9.11 processing ongoing!)

NORMALIZATION SAMPLE





2022

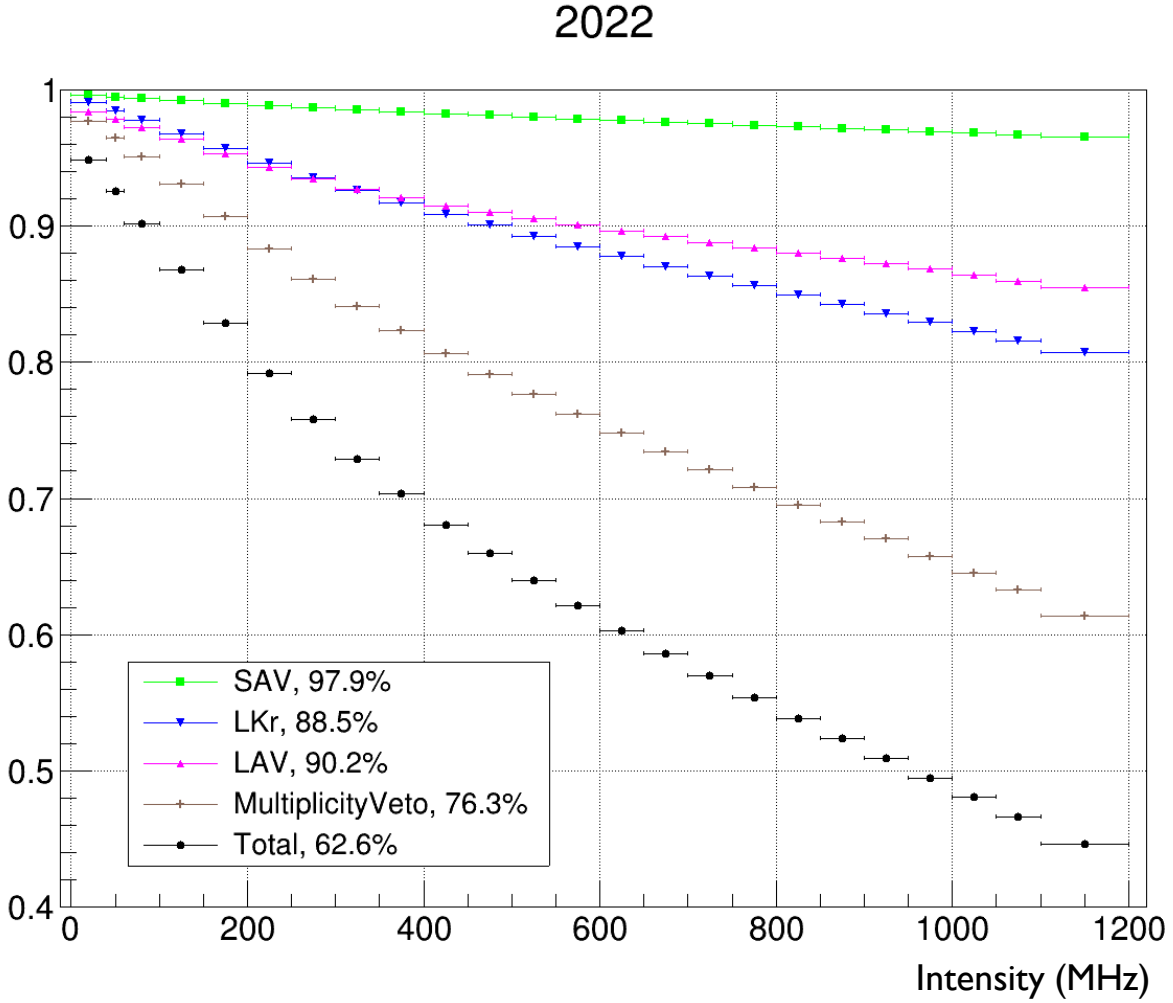
Entries	327100
Mean x	571.7
Mean y	488.8
Std Dev x	41.78
Std Dev y	95.48

- N(good bursts) increases with year!
- More efficient data taking in 2023 and 2024 than in 2022
- On average, wrt 2022,
  - 2023 has -15% intensity, -6% $N_{\pi\pi}$
  - 2024 has -30% intensity, -13% $N_{\pi\pi}$

RANDOM VETO

- RV efficiency (uncorrected)
  - 2022: 63%
  - 2023: 67%
  - 2024: 73%

- Extra improvement of RV vs intensity
  GTK intensity estimator bias?
  Better beam?
  Better overall detector performance?



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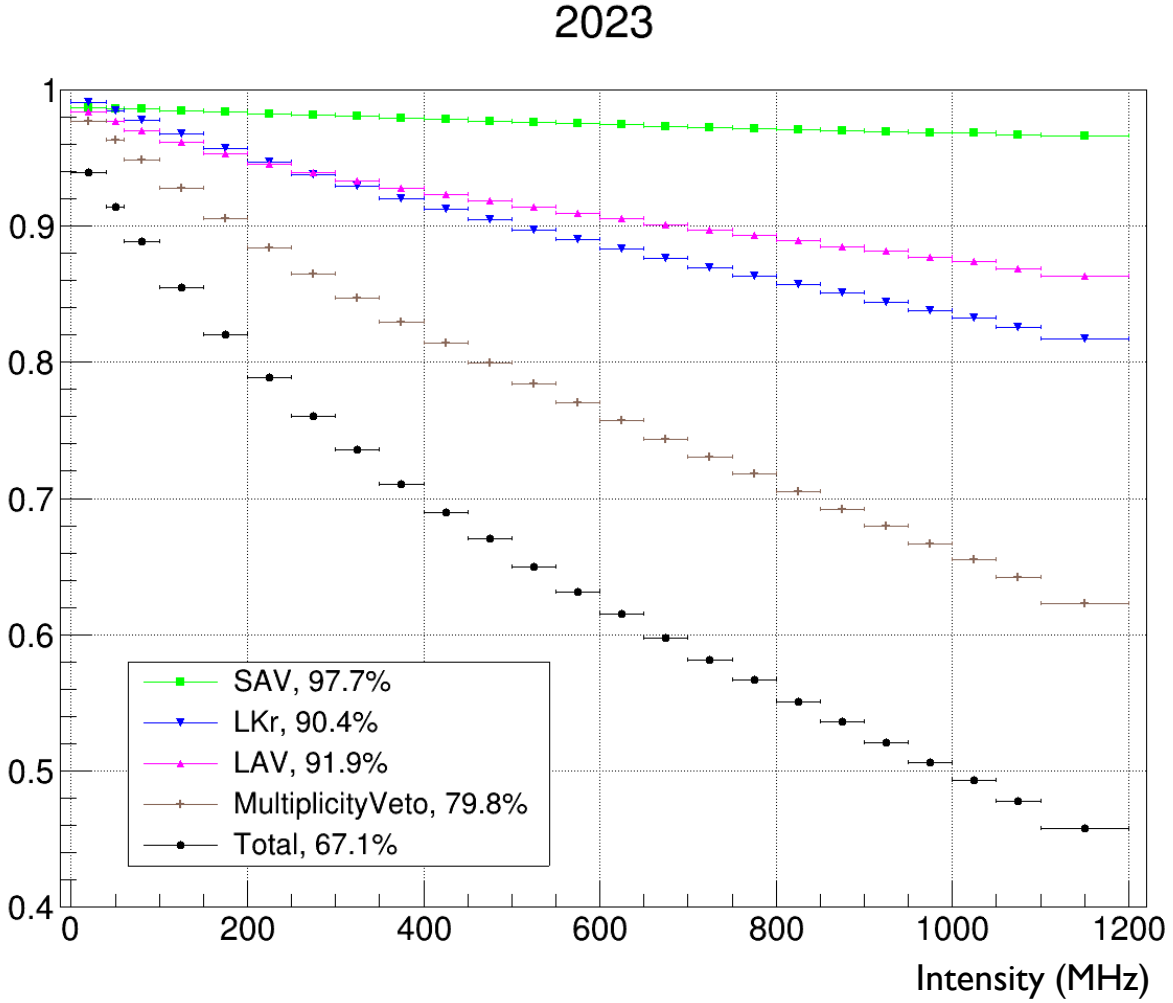

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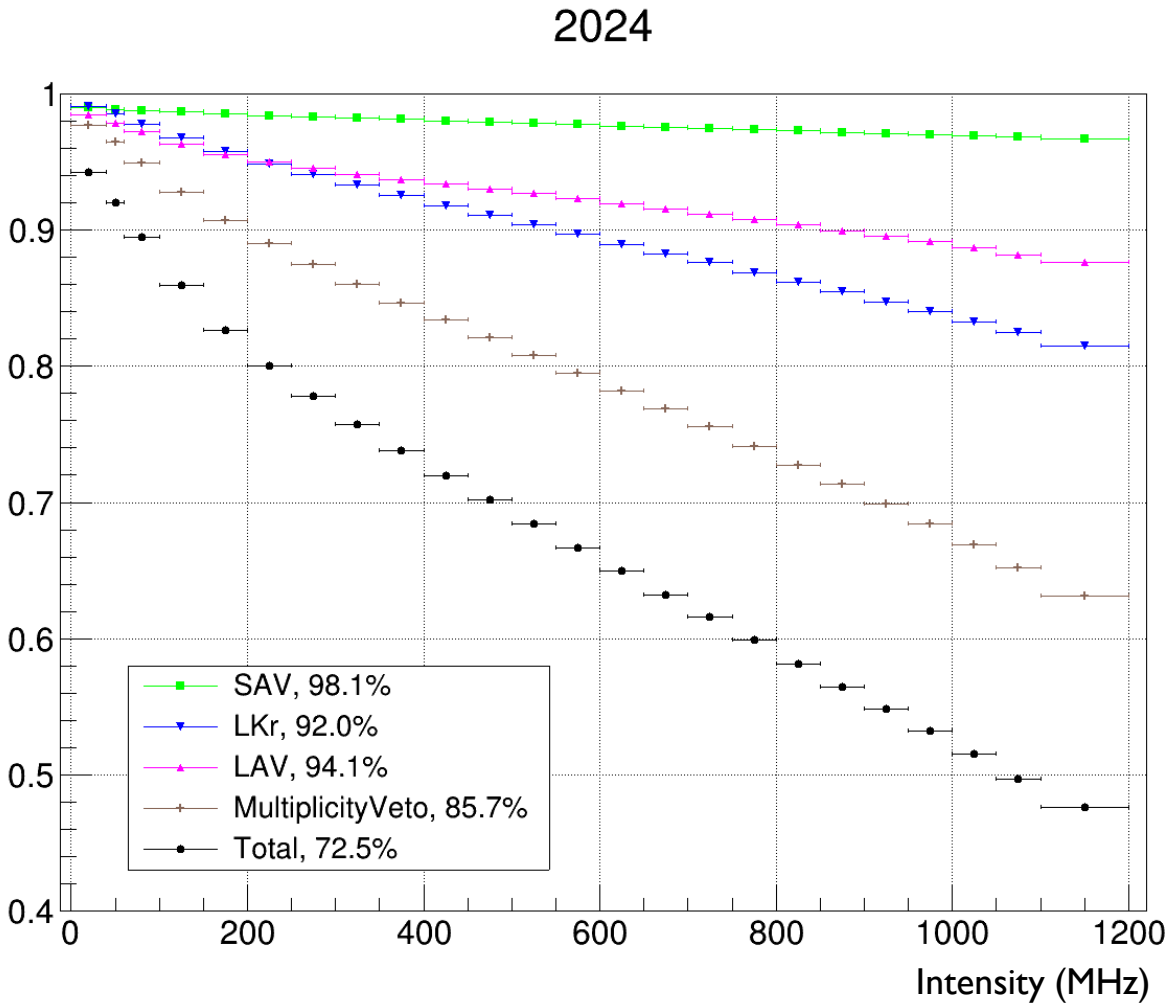
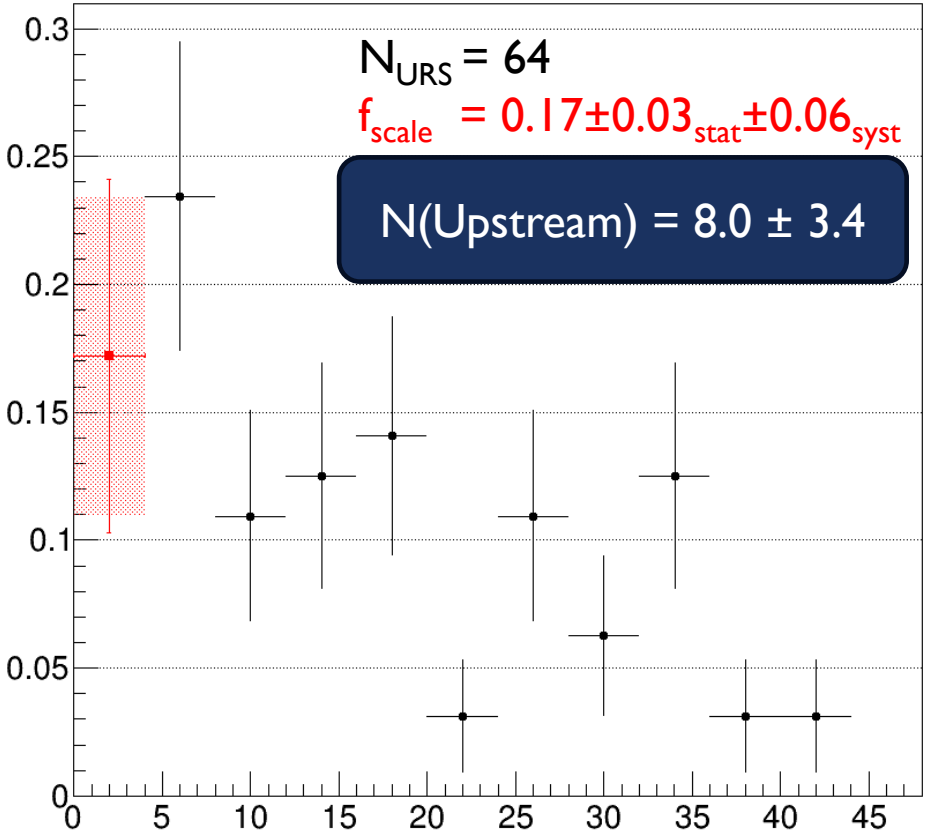
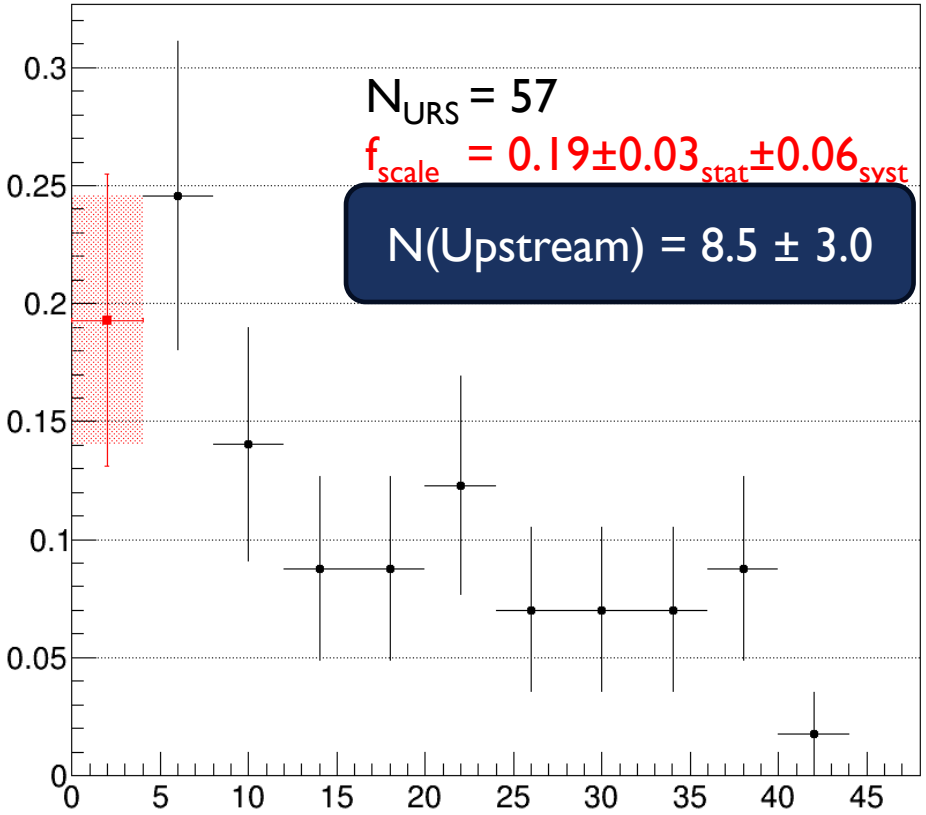


UPSTREAM BACKGROUND

2023



2024



2022

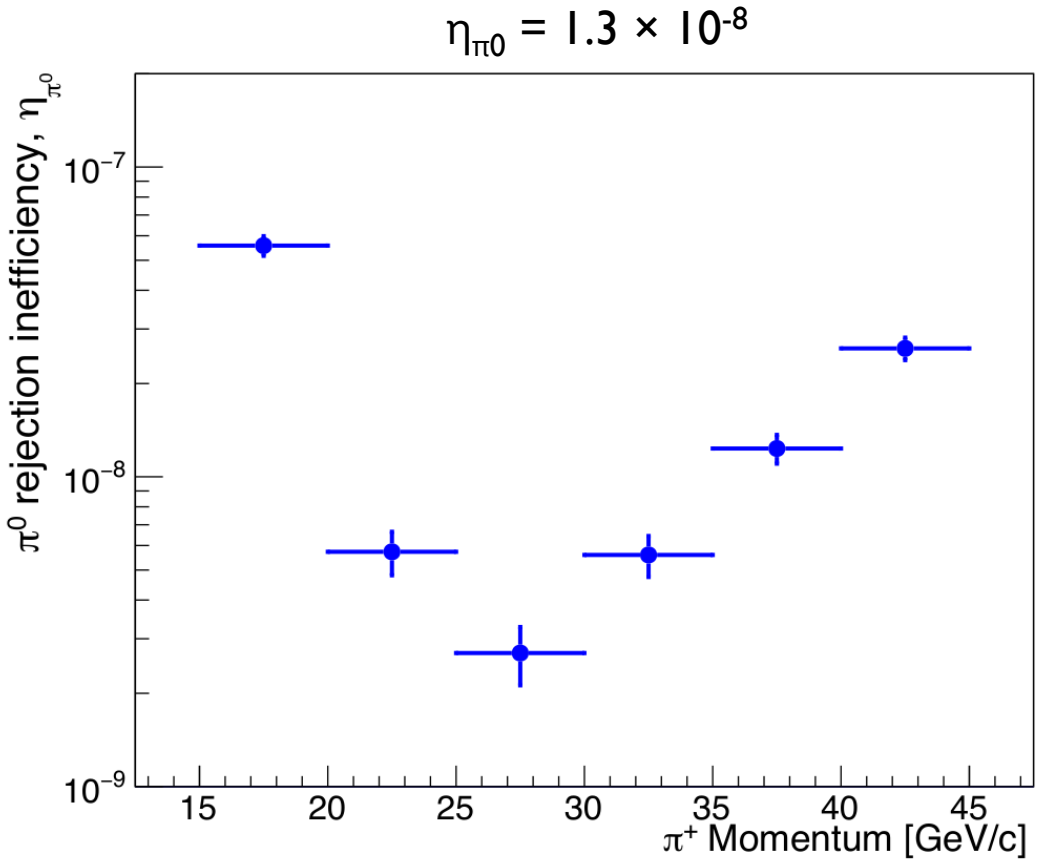
N_{URS} = 51
f_{scale} = 0.20 ± 0.03
N(Upstream) = 7.4 ± 2.0

BACKGROUND FROM K^+ DECAYS

	2022	2023	2024
$K^+ \to \pi^+\pi^0(\gamma)$, tot	0.83 ± 0.04	0.57 ± 0.05	0.62 ± 0.06
$K^+ \to \mu^+\nu(\gamma)$, tot	1.7 ± 0.5	1.3 ± 0.4	1.7 ± 0.4
$K^+ \to \pi^+\pi^+\pi^-$	0.11 ± 0.03	0.10 ± 0.03	0.13 ± 0.04
$K^+ \to \pi^+\pi^-e^+\nu$	0.9 ± 0.3	0.8 ± 0.3	1.0 ± 0.3
Other	< 0.1	< 0.1	< 0.1
Total	3.5 ± 0.6	2.8 ± 0.5	3.4 ± 0.5

- Absolute yields are ~stable between years
- Since "discovery" of $K_{\mu 2\gamma}$, the $K^+ \to \mu^+\nu(\gamma)$ line is the largest in the table
- $K\mu 2$, $K\mu 2\gamma$, $K2\pi$, $Ke4$ all contribute ~comparably
- Overall, K^+ decays are kept under control

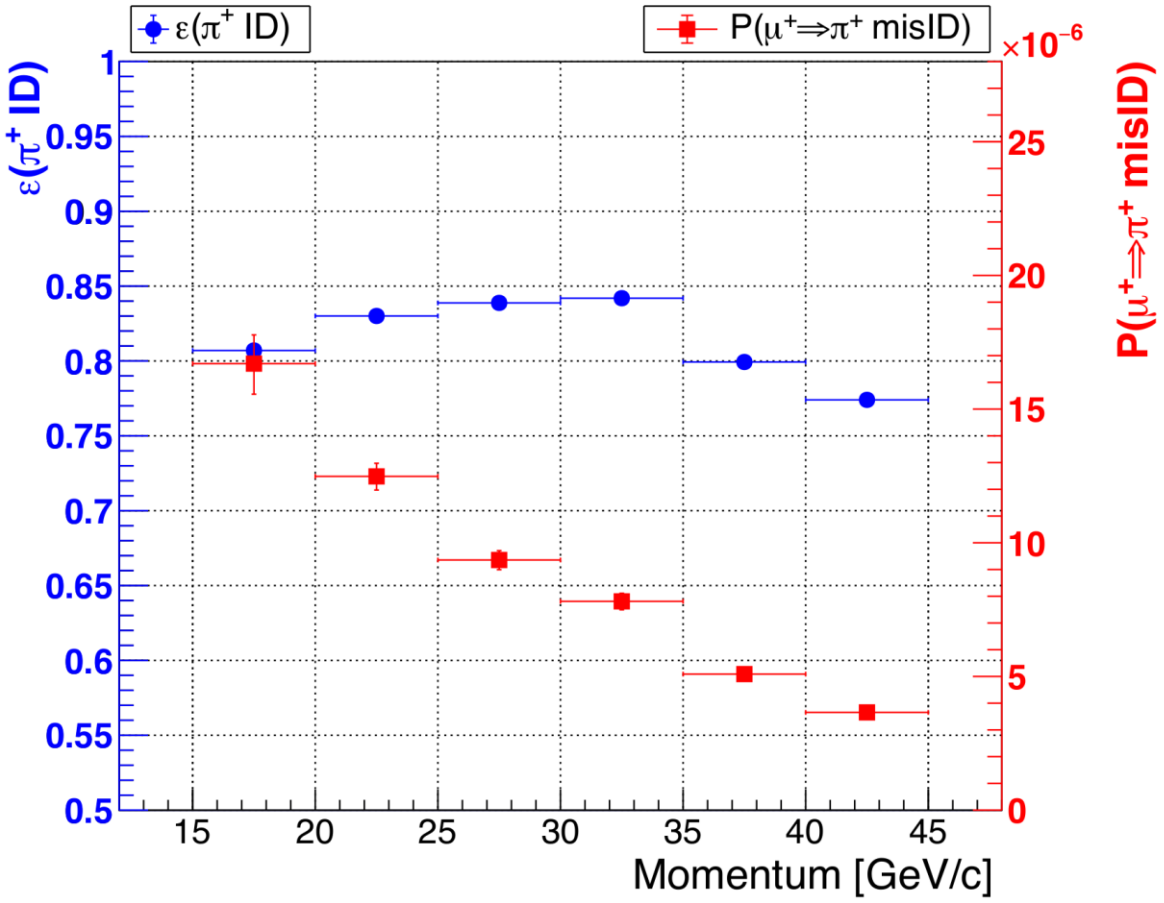
π^0 REJECTION



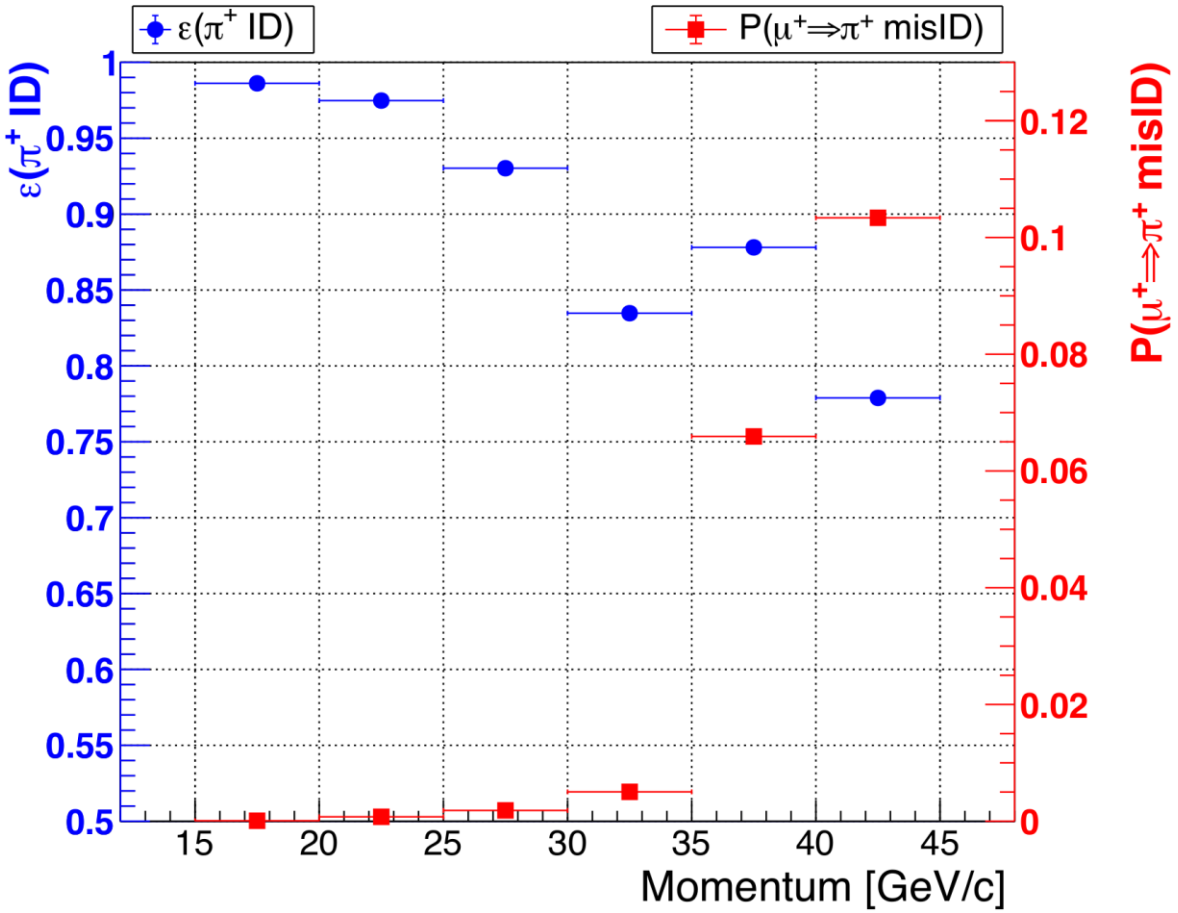
Not much dependence on intensity or year…

MUON REJECTION

Calorimetric (+ MUV3)



RICH



SUMMARY

RUN2 DATASET SUMMARY

	2021	2022	2023	2024
$N_{\pi\pi} \times D / 400 \times 10^{-8}$	0.4	1.6	1.7	2.0
Trigger efficiency	84%	87%	86%	86%
Random Veto efficiency	63%	64%	68%	74%
N(πνν) SM expected	~2	~8	~9	~11
$\sqrt{(S+B)} / S$	0.94	0.37	0.35	0.32

- On target for 10 SM πνν per year
- 2024 looks like the best dataset so far
  - Largest yield per year
  - Better ε(RV)
  - Best sensitivity
- 2023 – 2024 has similar yield as 2016 – 2022:
  next result is going to double the statistics again!
- Still improvements to be made!

IDEAS WE ARE EXPLORING, WORK IN PROGRESS…

Against the upstream background

- Improve BDT for upstream veto (XGBoost)
- Revise cuts on low-level STRAW reconstruction quality parameters: Δslope(before vs after fit), track quality
- Timing improvements:
  KTAG (likelihood-based timing), maybe apply same to RICH?

Better PID

- Finer RICH cut momentum dependence (maybe use machine learning?)
- Improve calorimetric ML-based PID, use CNN

Reconstruction

- Improve GTK reconstruction (ML, but not only)
- Account for LKr HV update in 2023

Analysis improvements

- Include $K^+ \to \pi^+\pi^0_D$ in MC for acceptance
- Study upstream from simulations (in-time component)
- Improve LKr trigger efficiency measurement
- Shape analysis for better background subtraction
- Shape analysis to understand nature of our signal (see Joel's presentation)