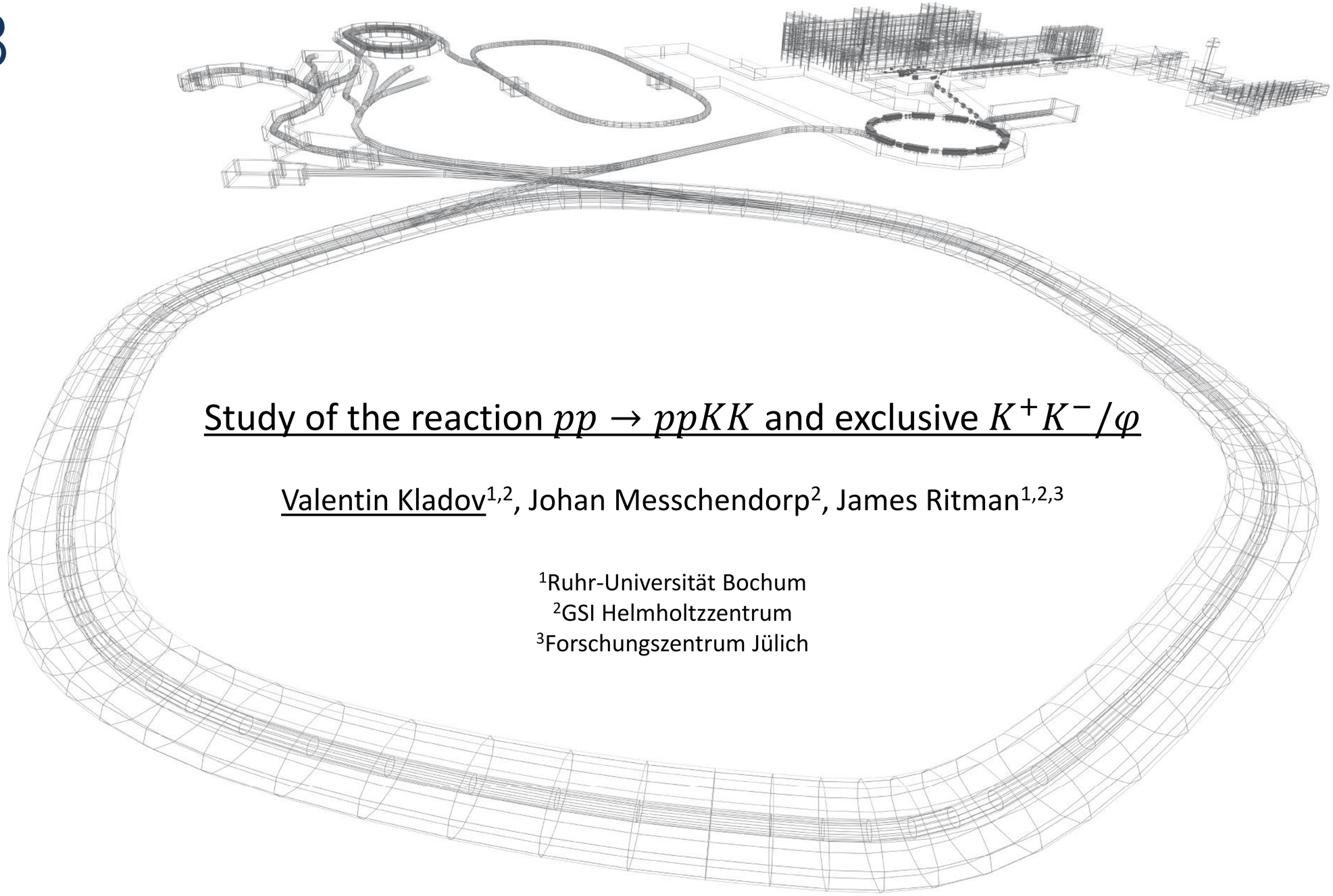


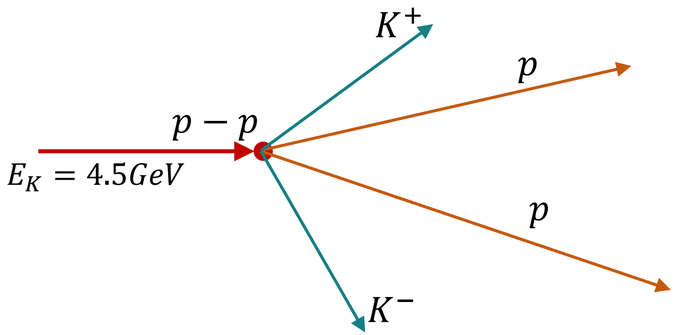
Study of the reaction $pp \to ppKK$ and exclusive K^+K^-/φ

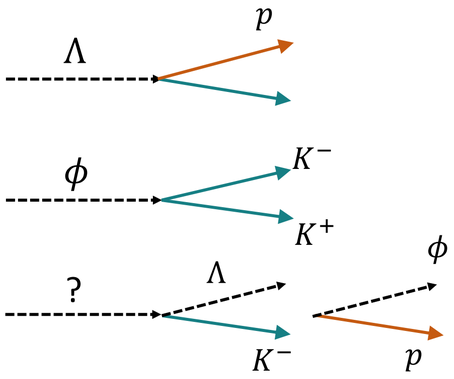
Valentin Kladov[1,2], Johan Messchendorp[2], James Ritman[1,2,3]

[1]Ruhr-Universität Bochum
[2]GSI Helmholtzzentrum
[3]Forschungszentrum Jülich

Motivation

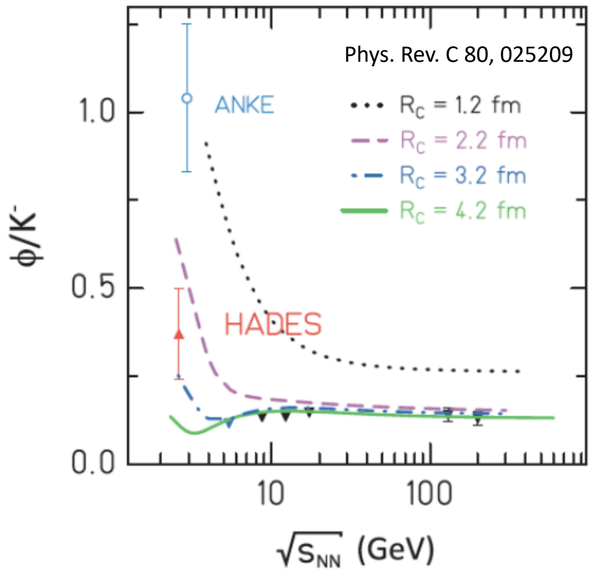
- Study the production mechanisms of the resonances with strangeness.
- Develop techniques for future exclusive analyses.





Is there anything interesting?

Complementary research



ϕ/K^- ratio

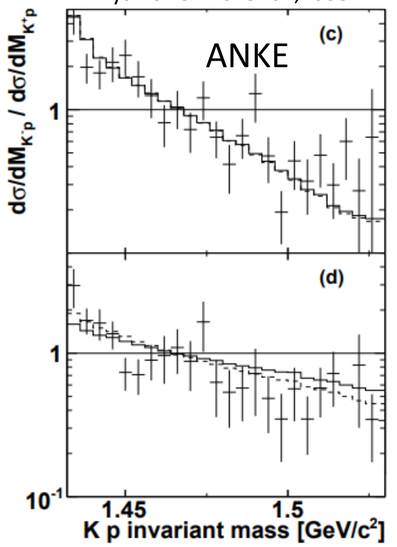
K^- rescattering study

Differential cross section measurements

Detailed partial wave analysis

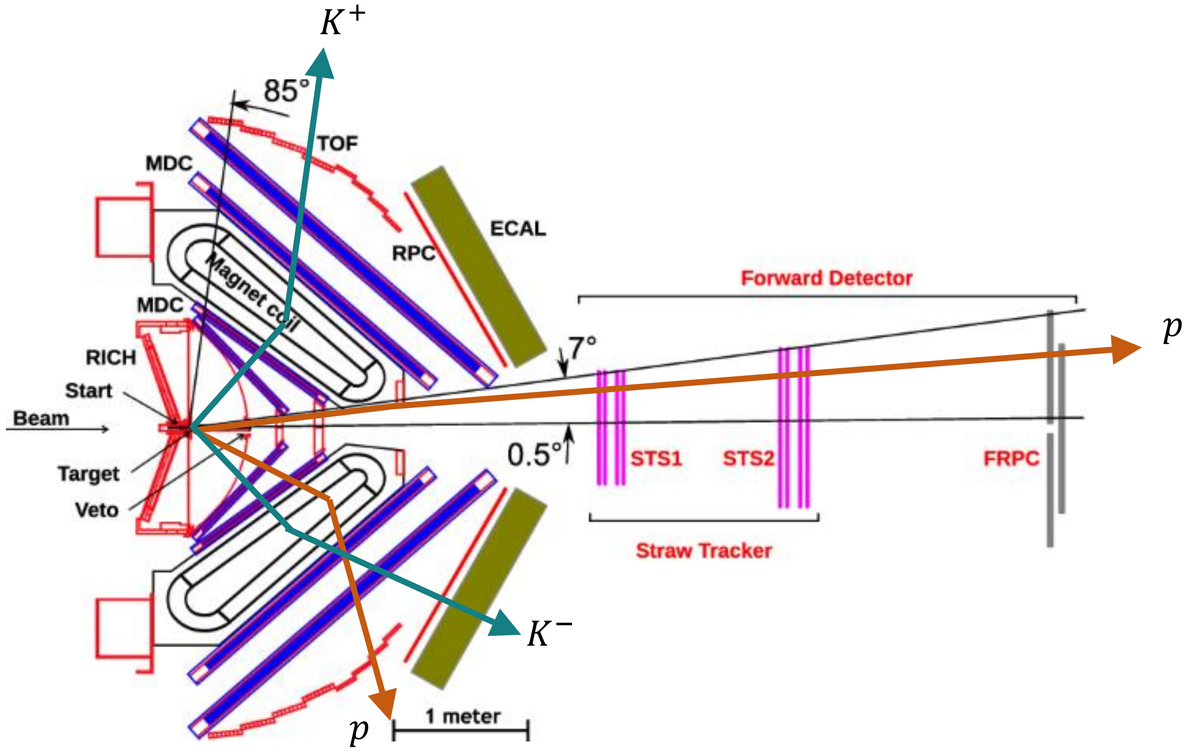
...

Phys.Rev.C77:015204,2008



Selection strategy

General strategy: Exclusive study, identifying and reconstructing 4-momenta of all four final state particles.



- *HParticle cuts:* $0 < \beta < 1, P > 50\ MeV/c$, kIsUsed.
- *Multiplicity:* $N_p \geq 2\ (HF), N_{K^+} \geq 1(H), N_{K^-} \geq 1(H)$.
- *PID in HADES:* Neural network, $\pi^{\pm}, K^{\pm}, p$ separation.
- *Kinematic fit:* χ^2 cut & $\chi^2_{KK} < \chi^2_{\pi\pi}$.
- Beta correction (high energy pions), energy loss (H), beamTilt (HF)...

Particle identification

Input parameters

- $Momentum$
- $Charge$
- $Theta$
- dE/dx_{MDC}
- dE/dx_{TOF}
- ToF
- $Distmeta$
- $Beta$
- $Metamatch$
- $Mass^2$

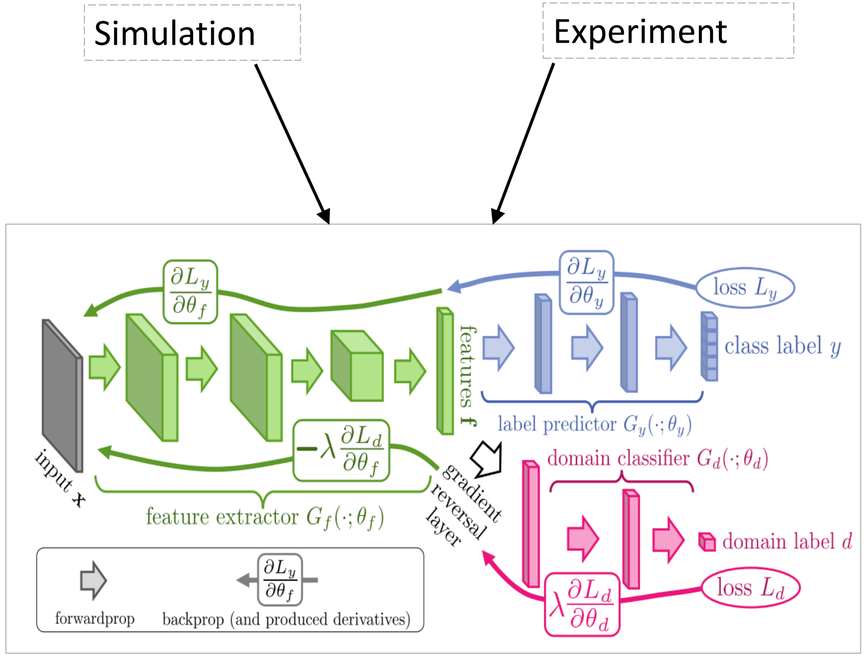


Image source: https://doi.org/10.48550/arXiv.1505.07818

Predicted probabilities

- P_p
- P_{π^+}
- P_{π^-}
- P_{K^+}
- P_{K^-}

Intermediate features trained to be indifferent to the input type (Sim/Exp)

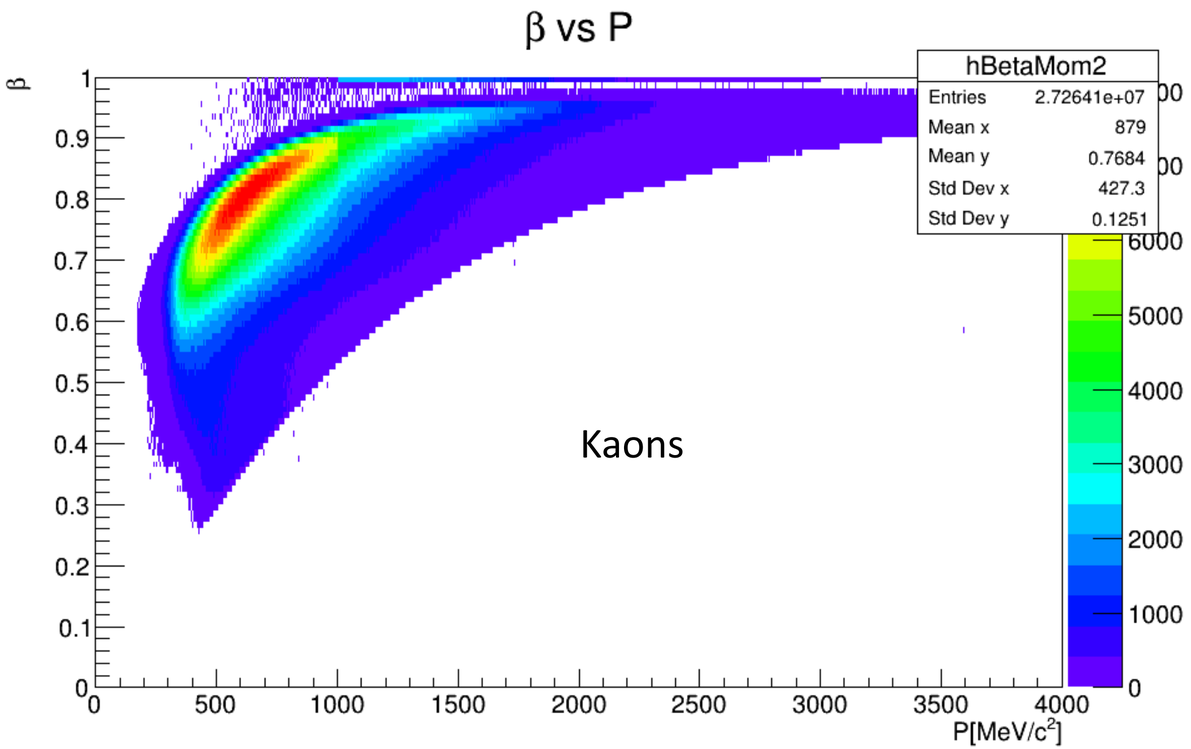
Fine-tuning options

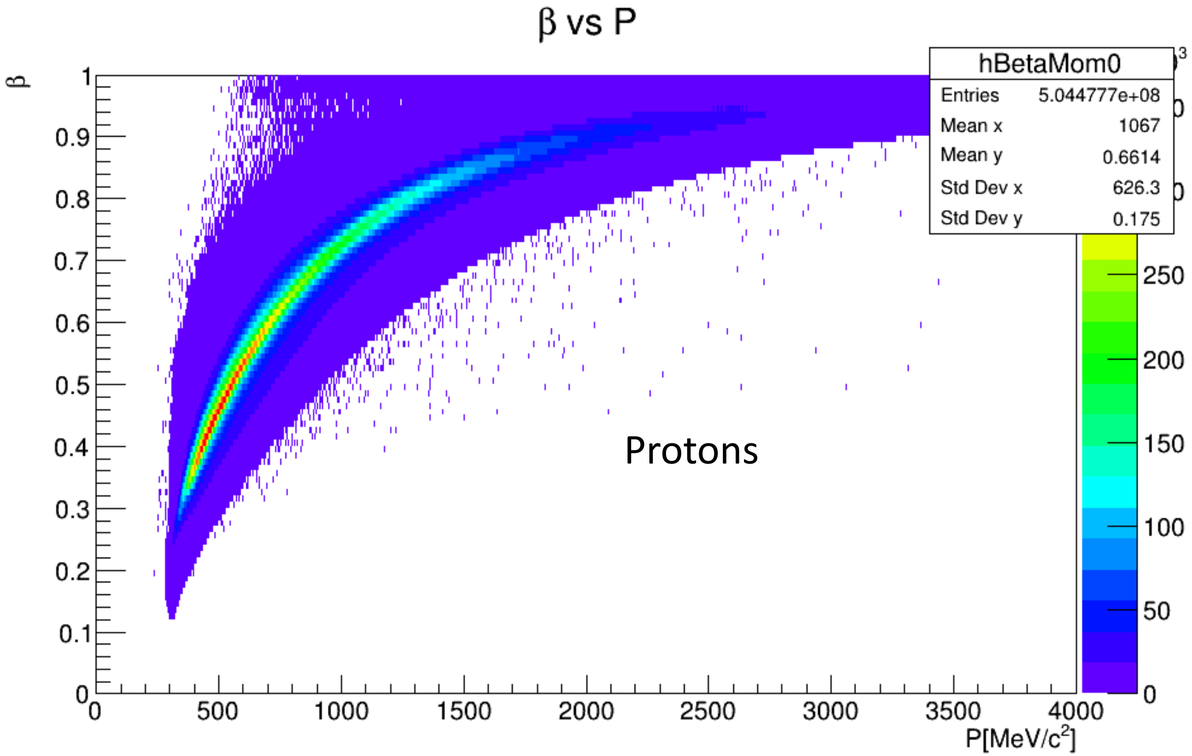
- Exp/sim size balance;
- Weighting of classes;
- Weighting of losses;

Prioritize suppression of pions in experiment.

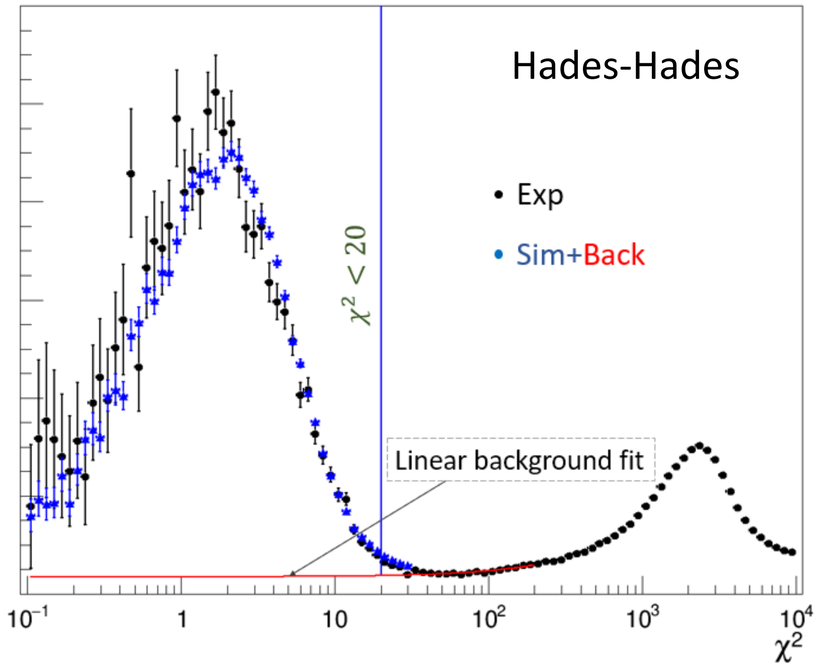
Original DANN article and image: https://doi.org/10.48550/arXiv.1505.07818

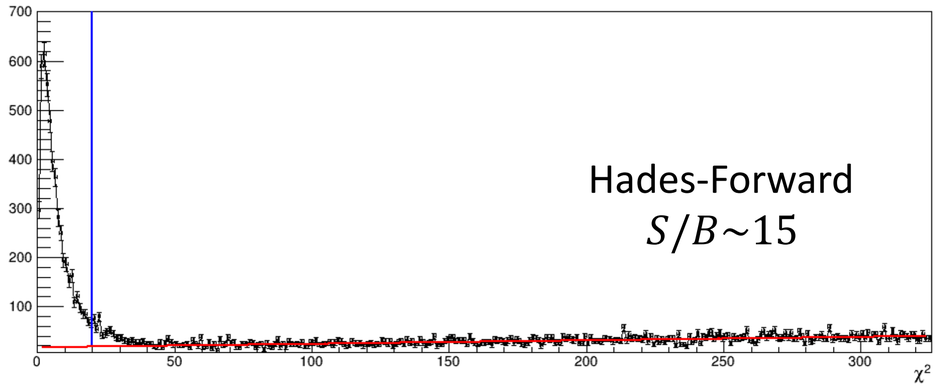
Particle identification





Kinematic fit for $pp \rightarrow ppKK$

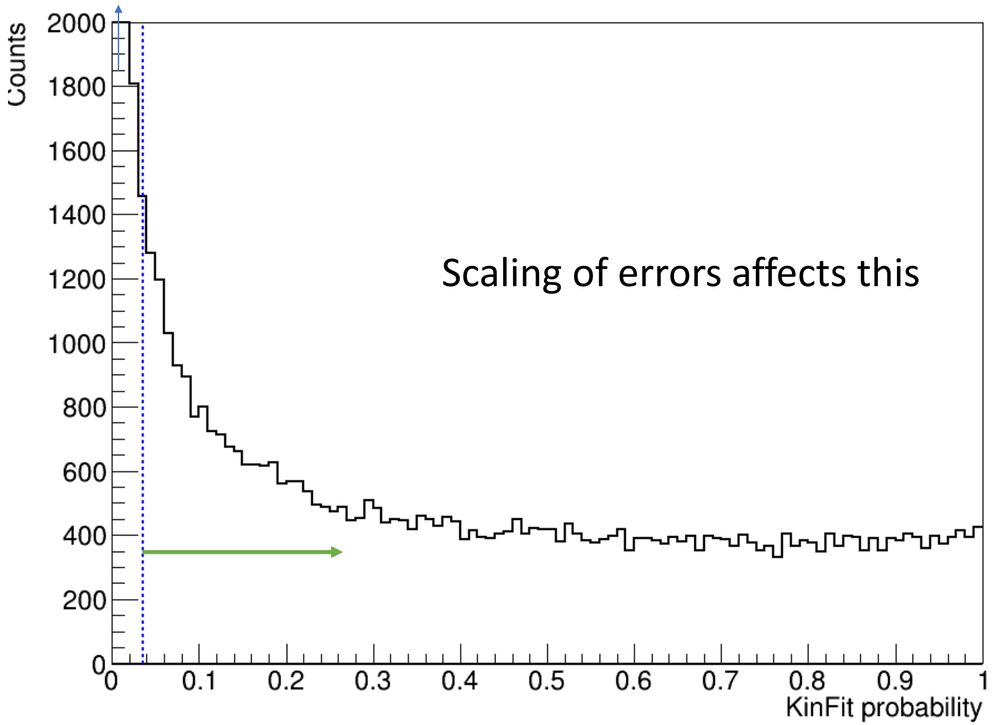




Minimization: $\chi^2 = (\vec{y} - \vec{\eta})^T V^{-1} (\vec{y} - \vec{\eta})$

Constraint: 4C $\sum P_i - P_{beam} = 0$

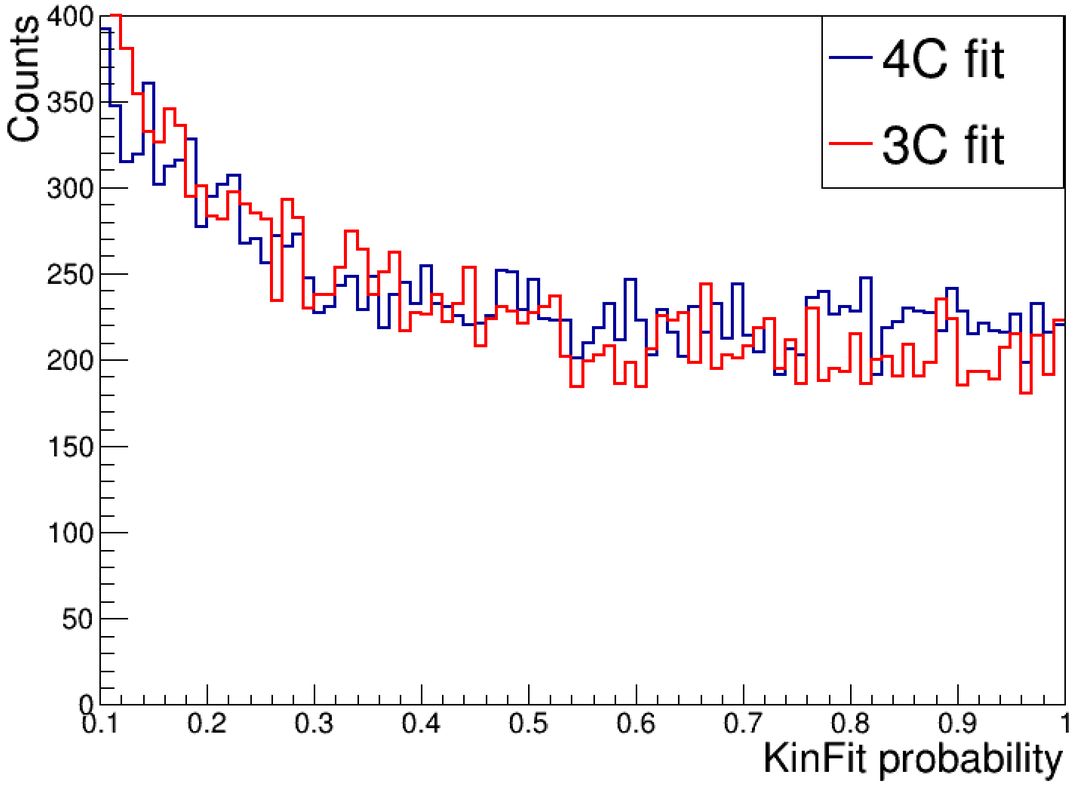
Probability distribution should flatten at high values.



Original KinFit package: https://doi.org/10.1007/s41781-023-00112-x

Errors for KinFit

Error segmentation:
$p - \varphi$ for Hades, p for Forward

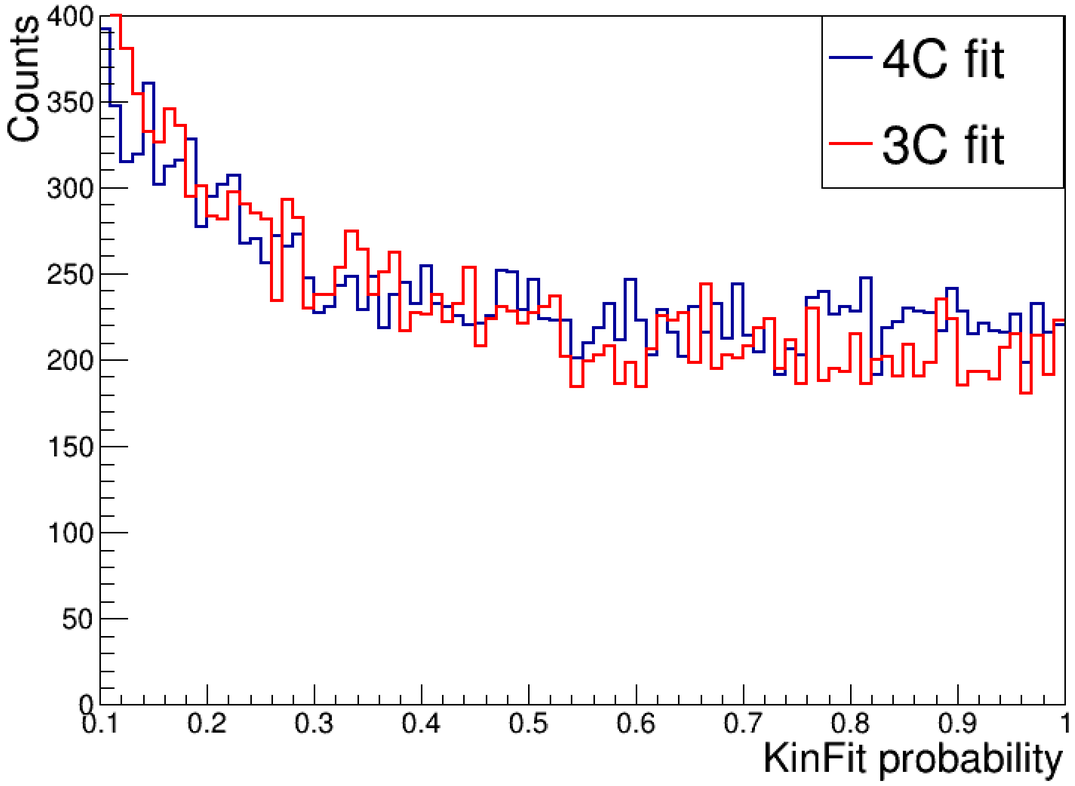


- 3C over constraint: $\sum P_i - P_{beam} = 0$, $|p_F|$ as not measured.
- 4c depends on all errors (p, θ, φ), 3c only on angles.
- If probability distribution is not flat – adjust the errors separately.

Hades:	No scaling needed for flat probability distribution
Forward:	Small scaling of forward errors is still needed

Errors for KinFit

Error segmentation:
$p - \varphi$ for Hades, p for Forward



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Hades:	No scaling needed for flat probability distribution
Forward:	Small scaling of forward errors is still needed

Wide-range error parametrization:
Szymon, Adam, Iza

White sim for Kaons can fix the issue!

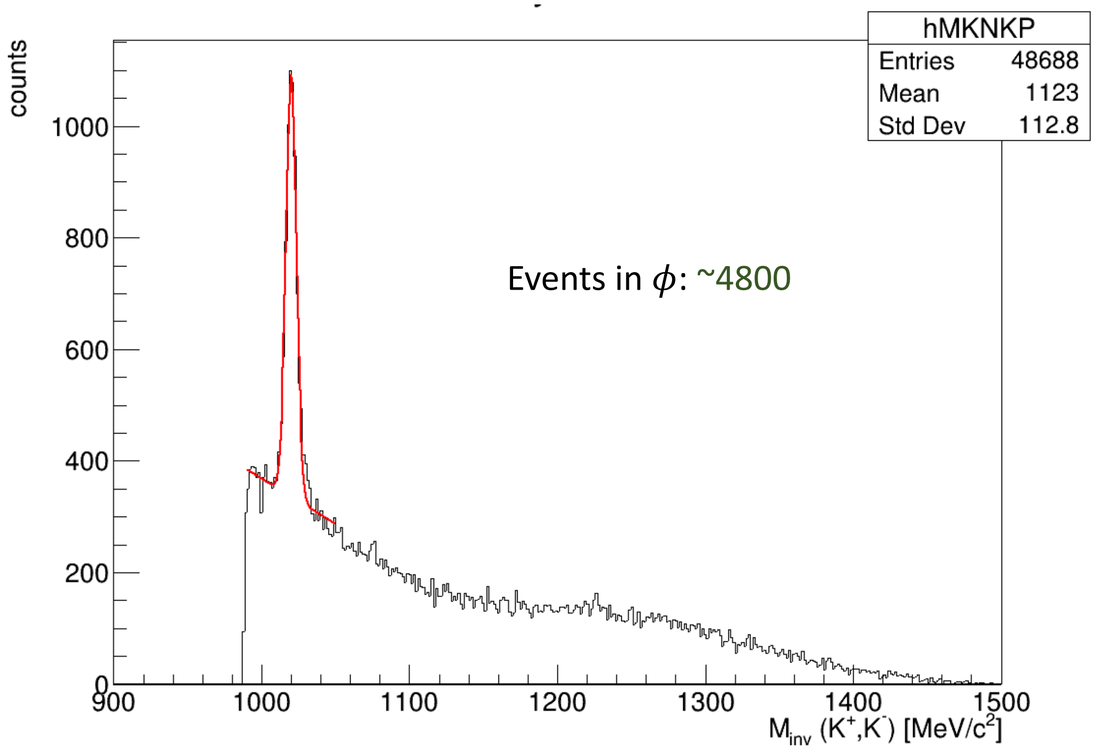
Universal tool for HADES?

Raw invariant mass distributions

$\phi(1020) \rightarrow KK$

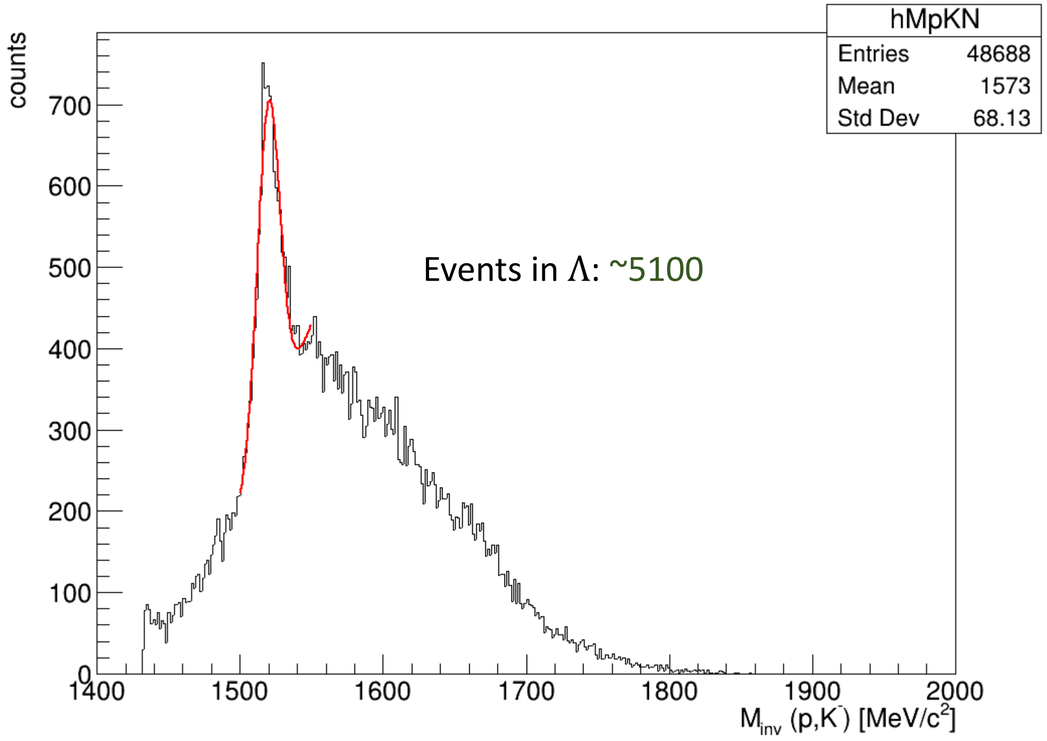
$\mu = 1019.9 \pm 0.5\ MeV$ (1019.461±0.016 MeV*)

*PDG



$\Lambda(1520) \rightarrow pK$

$\mu = 1520.0 \pm 0.5 MeV$ (≈ 1519 MeV*)

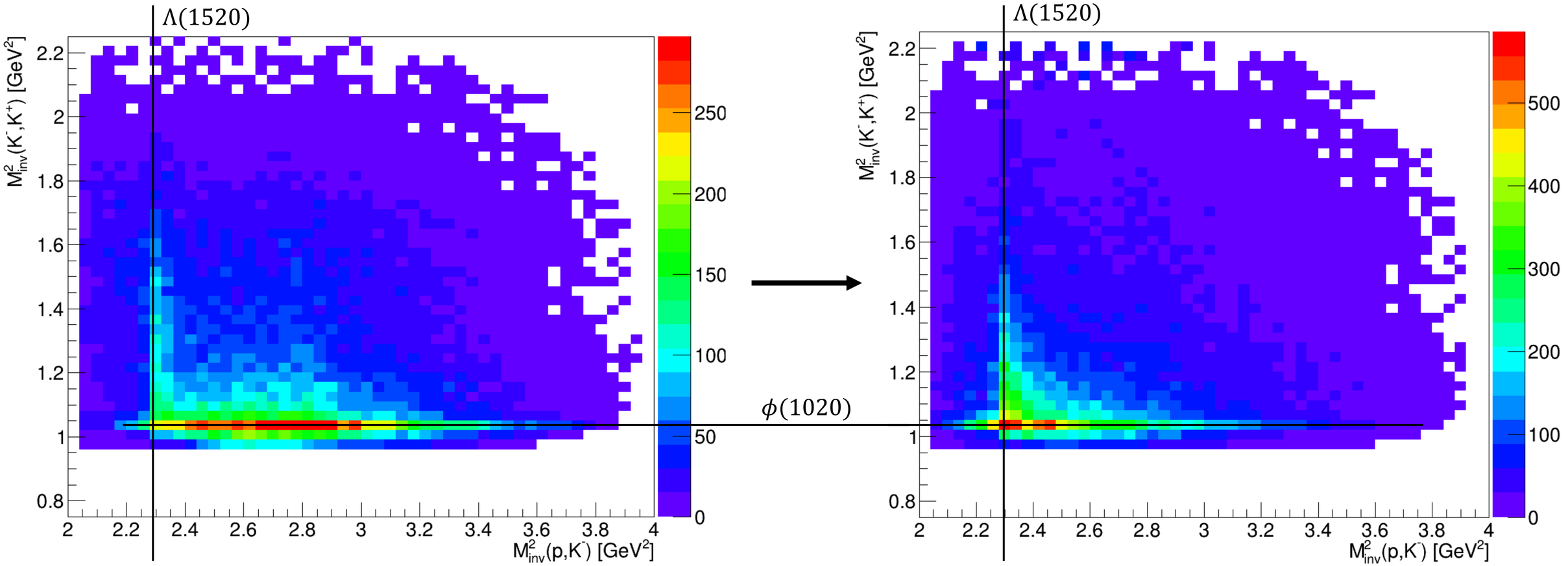


(50% of total available dataset)

Mass distributions

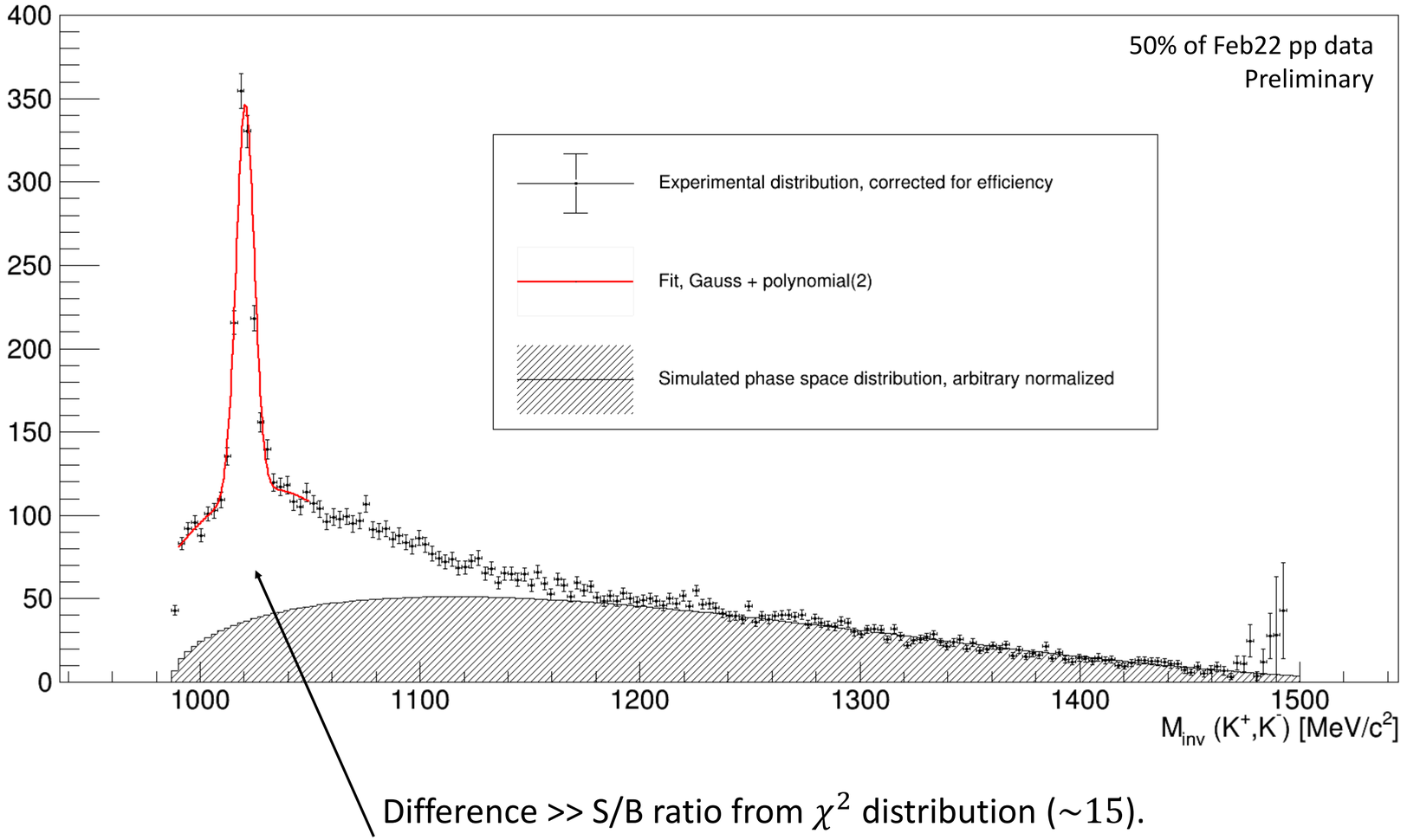
Raw data

Corrected for efficiency



Reconstruction efficiency & acceptance play big roles.

Efficiency corrected yield

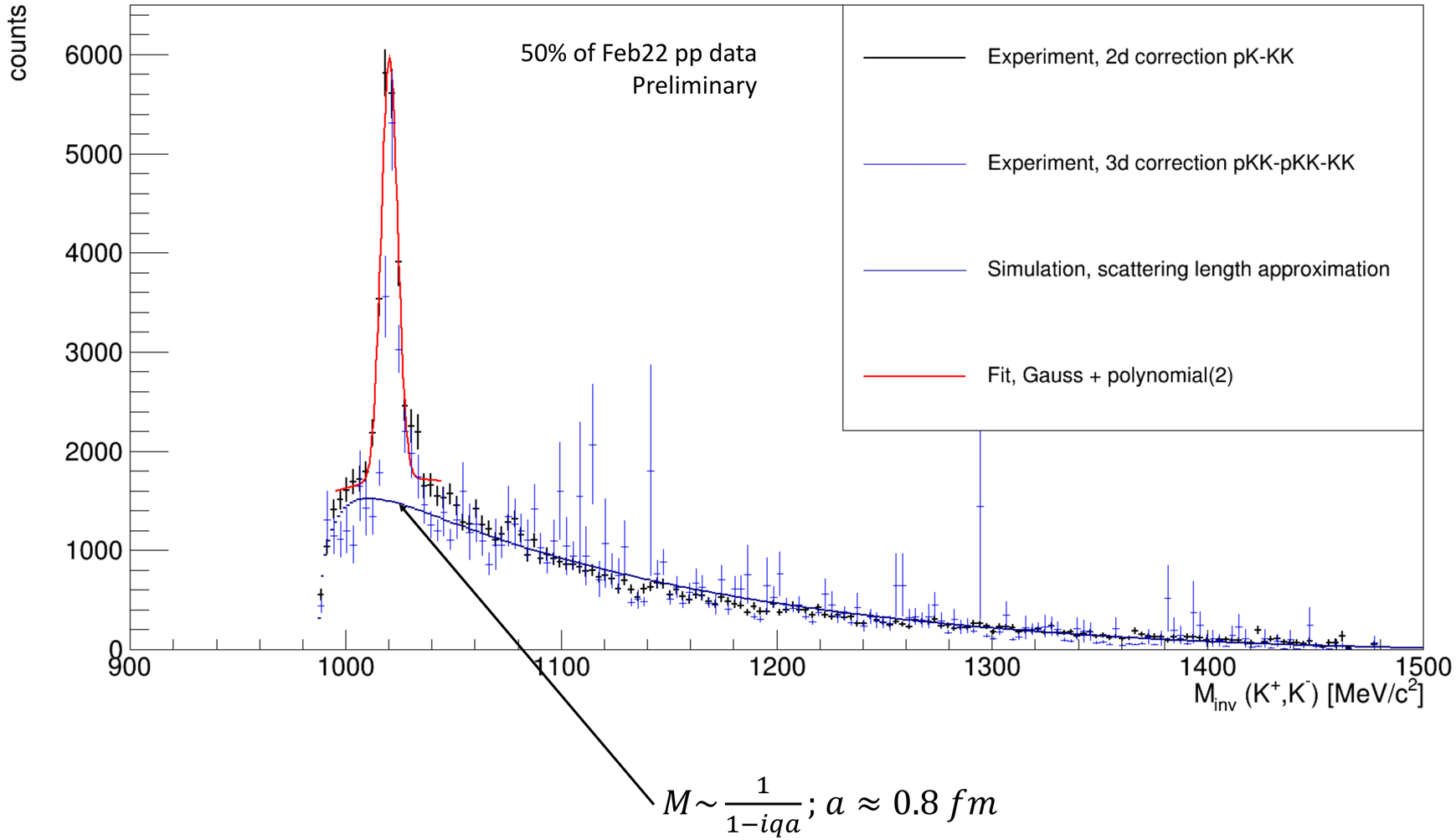


Difference >> S/B ratio from χ^2 distribution (~ 15).

Shape stays the same for stricter χ^2 cuts.

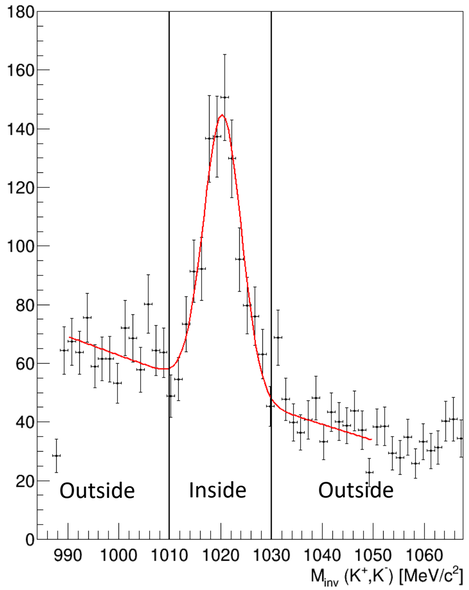
- Efficiency and acceptance corrected spectrum based on simulation.
- Efficiency = selected / generated bin by bin.
- Prone to simulation systematics.

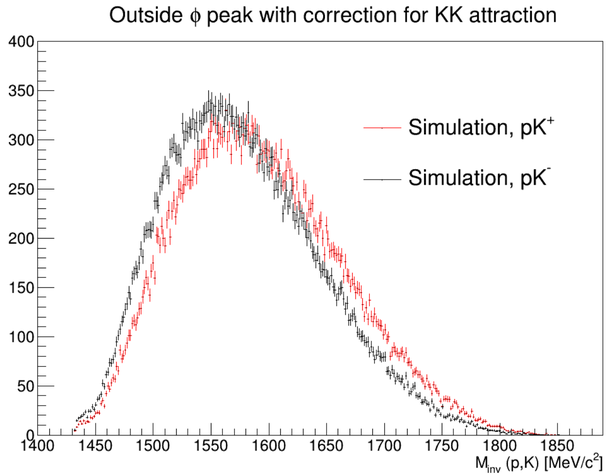
Effects of FSI & different efficiency corrections



- Need different efficiency corrections for different distributions.
- Background shape can be described in terms of KK FSI.
- Other effects can also contribute to the shape of KK.

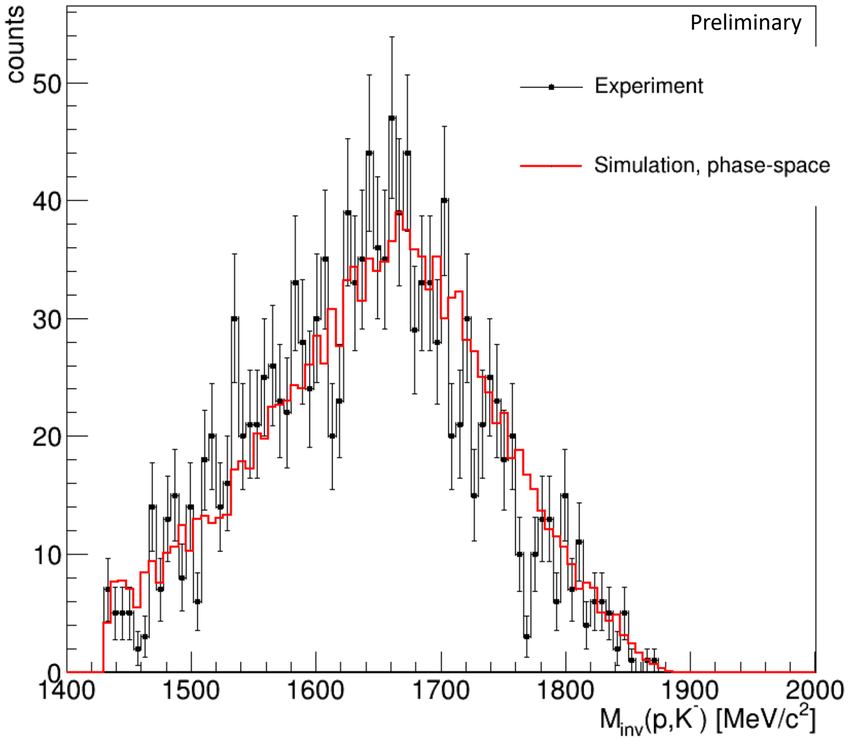
Final state interactions (FSI): K^- rescattering





Inside ϕ peak

$1.01 < M_{KK} < 1.03\ GeV/c^2$

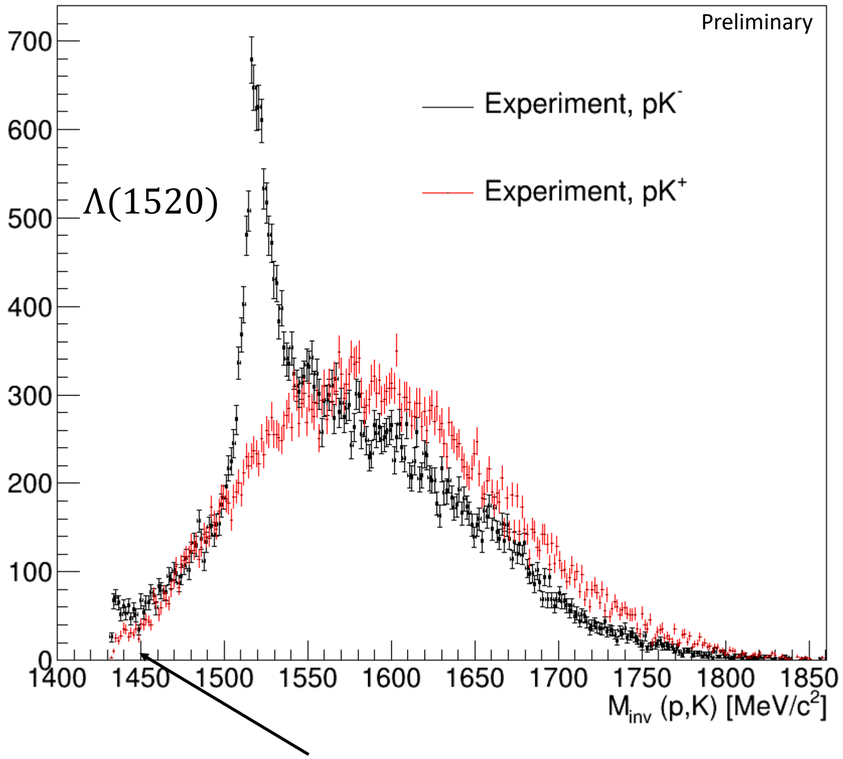


Data can be described by a pure phase space distribution (only HH)

Outside ϕ peak

$M_{KK} < 1.01\ GeV/c^2$

$M_{KK} > 1.03\ GeV/c^2$

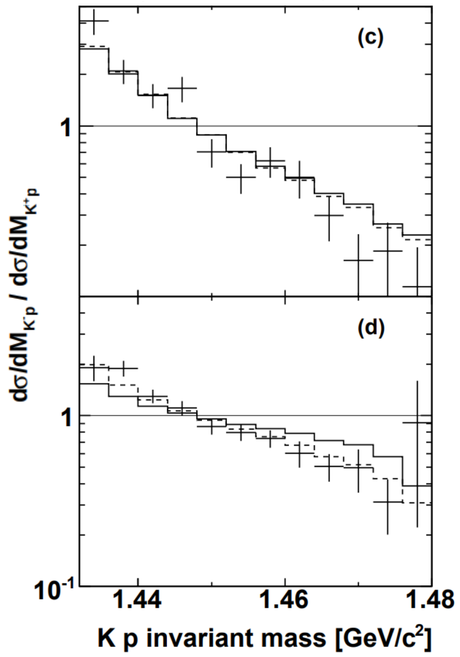


Is it an attraction between p and K^- (FSI) or under-threshold resonance?

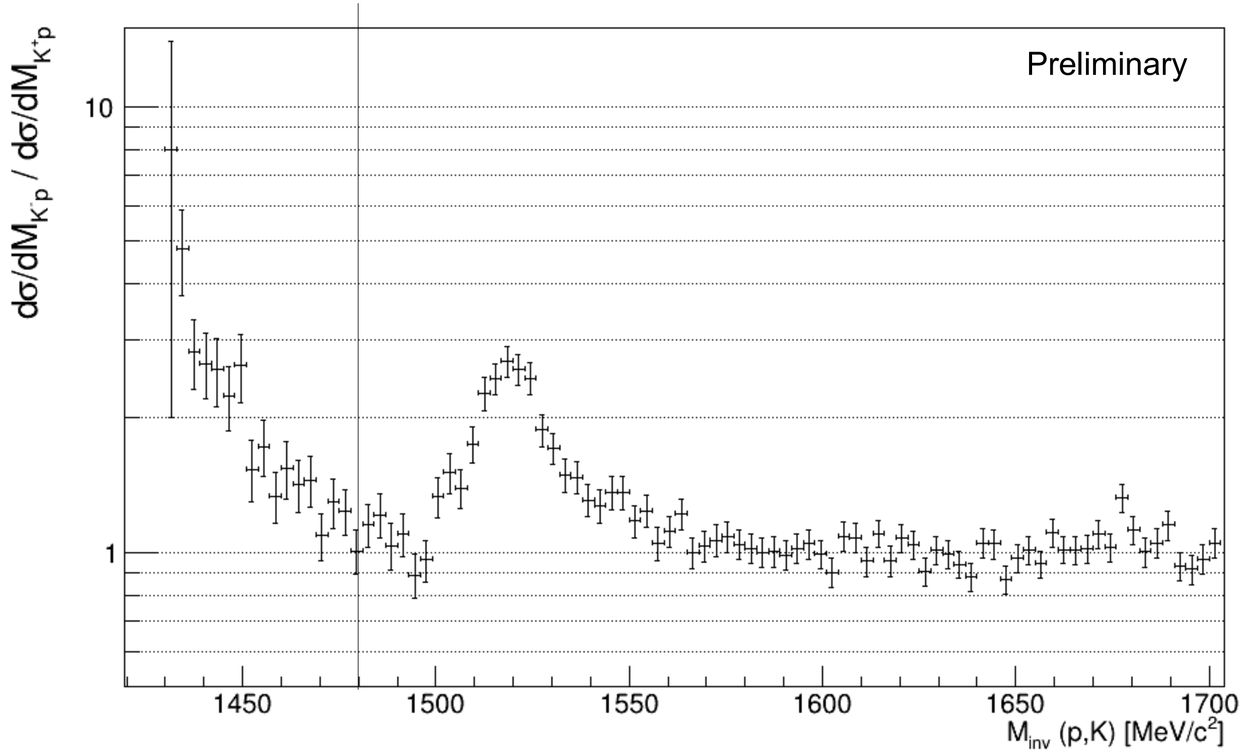
Final state interactions (FSI): K^- rescattering

ANKE collaboration
$M_{KK} < 1.01\ GeV/c^2$
E_{beam}= 2.65 GeV

Phys.Rev.C77:015204,2008



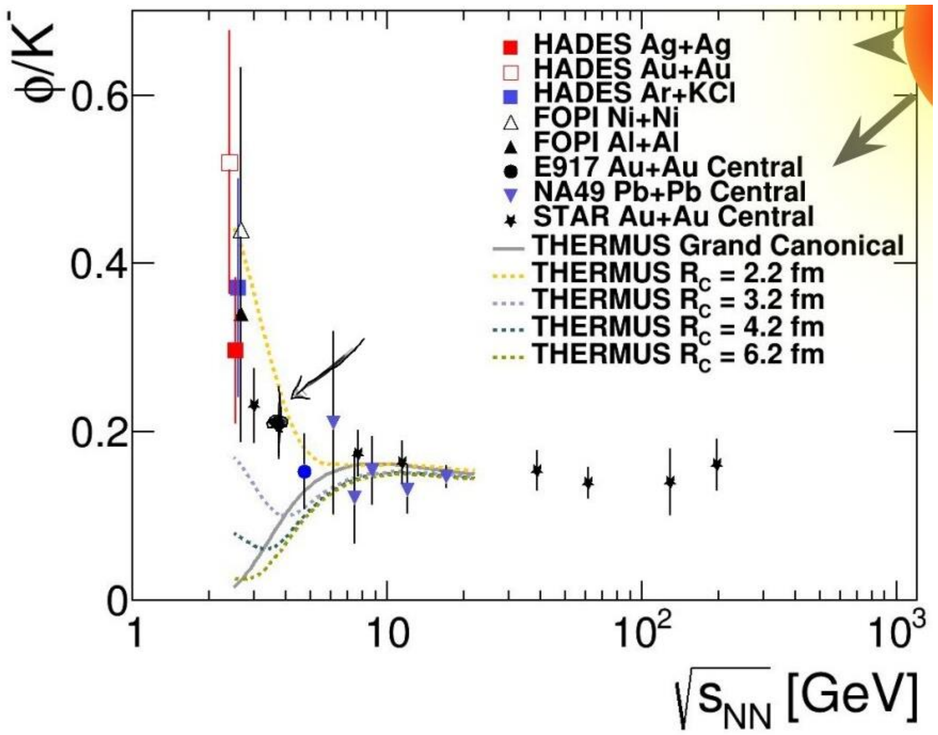
$M_{KK} < 1.01\ GeV/c^2$
$M_{KK} > 1.03\ GeV/c^2$
E_{beam}= 4.5 GeV



- Similar pattern at low masses, different energy region.
- Looks more like under-threshold production. $\Lambda(1405)$

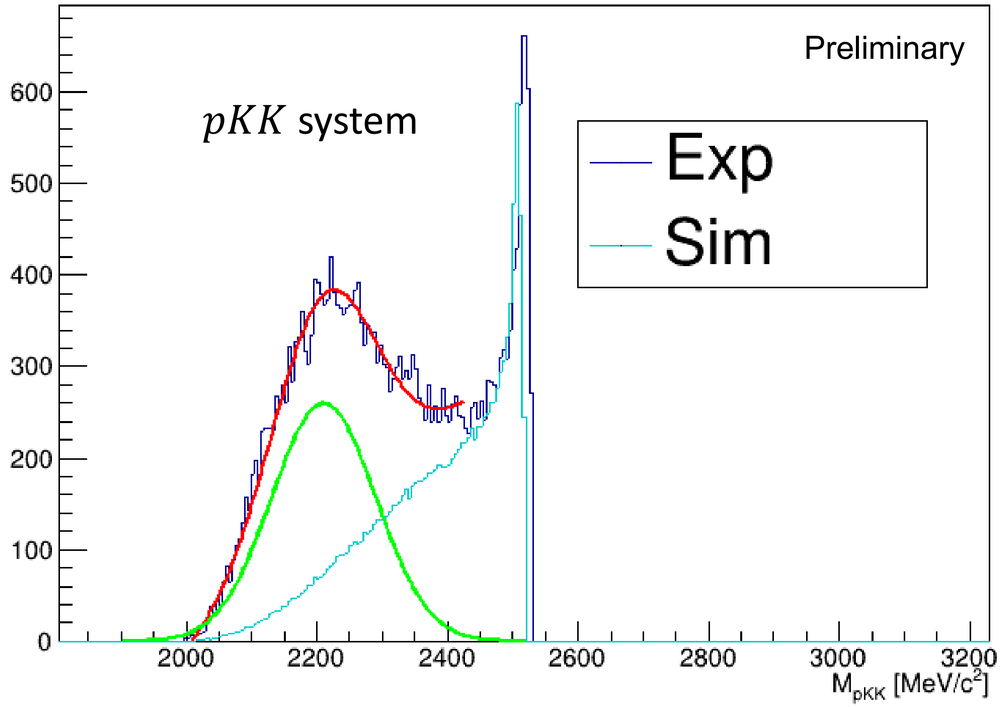
ϕ/K share & pKK system

- $\phi/K \approx 0.195$ (no background corrected)
- $\phi/K \approx 0.205$ (corrected for ~7% from χ^2)



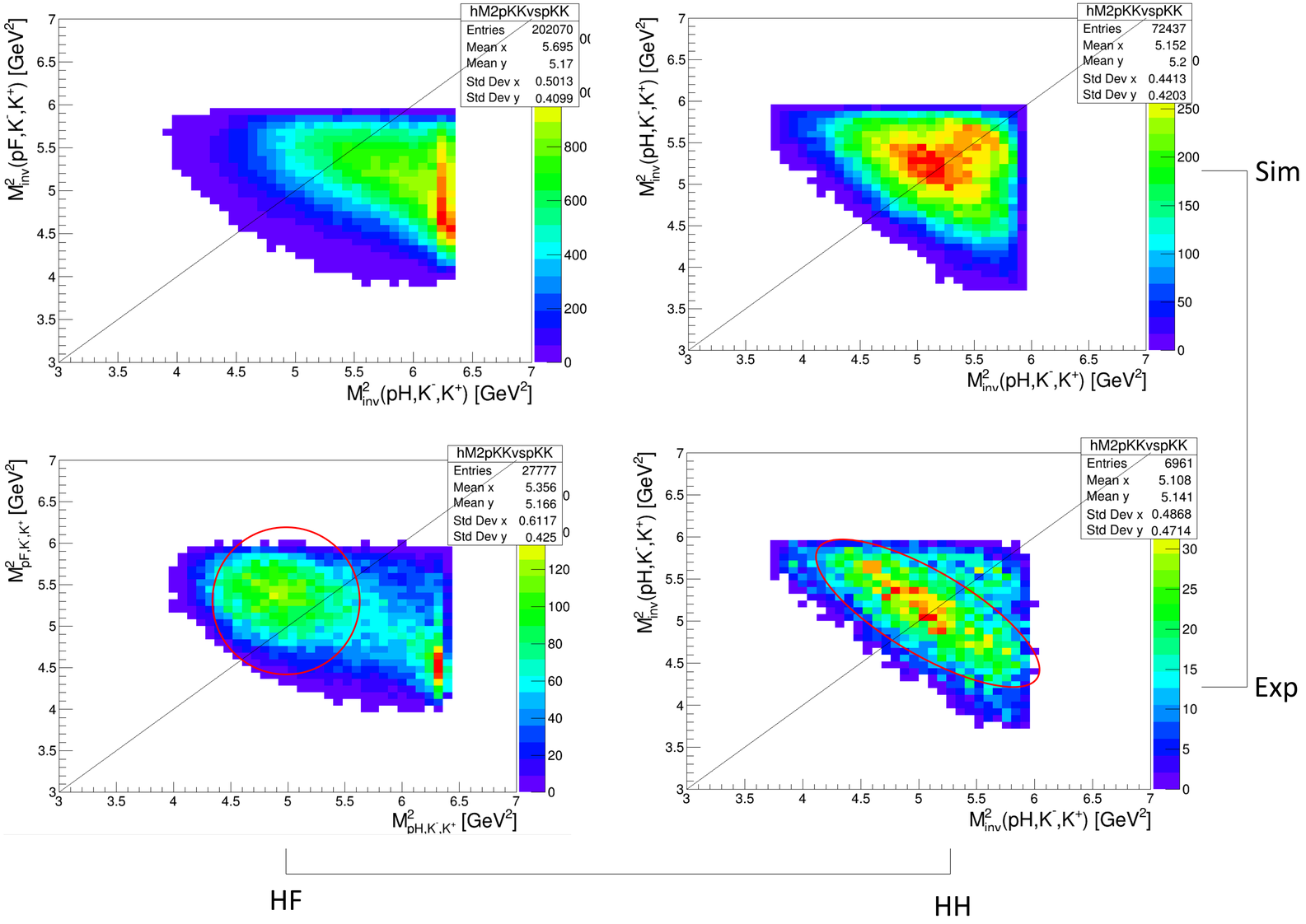
For more accurate results we need to make a more model-independent efficiency correction.

- Several mechanisms possible:
- $pp \rightarrow pX \rightarrow pp\varphi \,/\, pK\Lambda$
- $pp \rightarrow pp\varphi \,/\, pK\Lambda$
- $pp \rightarrow ppKK$
- …

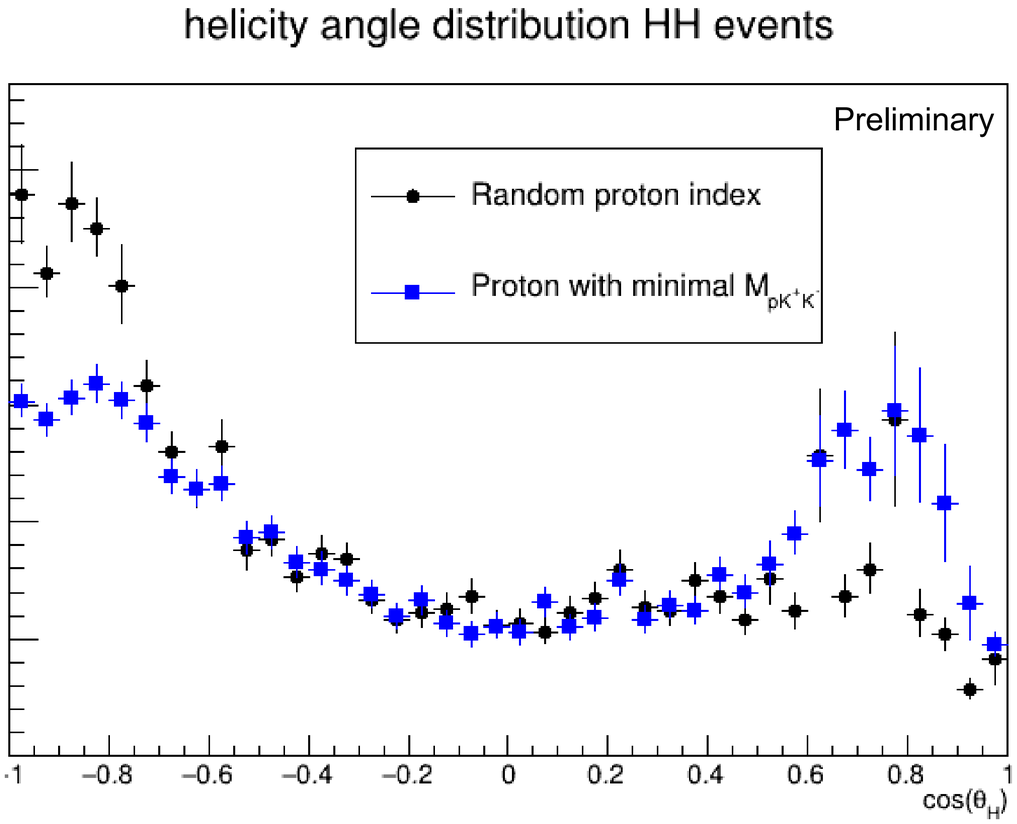


pKK mass distributions

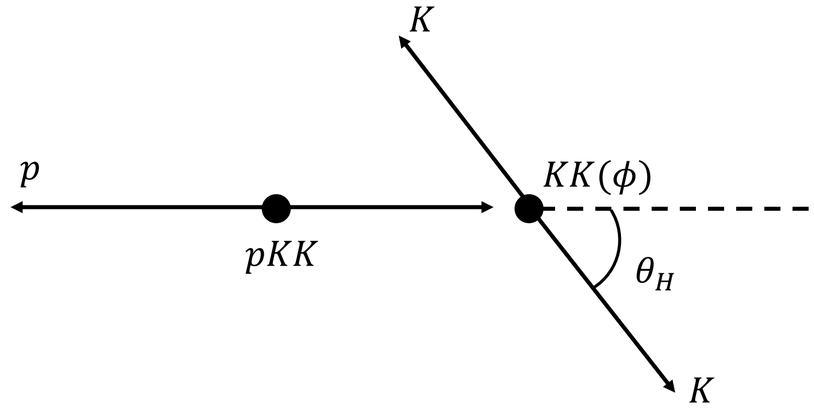
- Hints on interesting dynamics in the amplitude.
- Shape partially can be approximated by FSI (backup).
- Similar inside and outside ϕ/Λ peaks….



pKK helicity angle



$X \to p\varphi \to pKK$
$X \to \Lambda K \to pKK$



- Resonance decaying into pϕ and $K\Lambda$ is at least not dominant.
- Depends strongly on the choice of proton. (only one of 2 p)
- Depends on efficiency correction.
- However, hints on non-trivial dynamics are visible.
  (not uniform as for phase space simulation)

Summary & Outlook

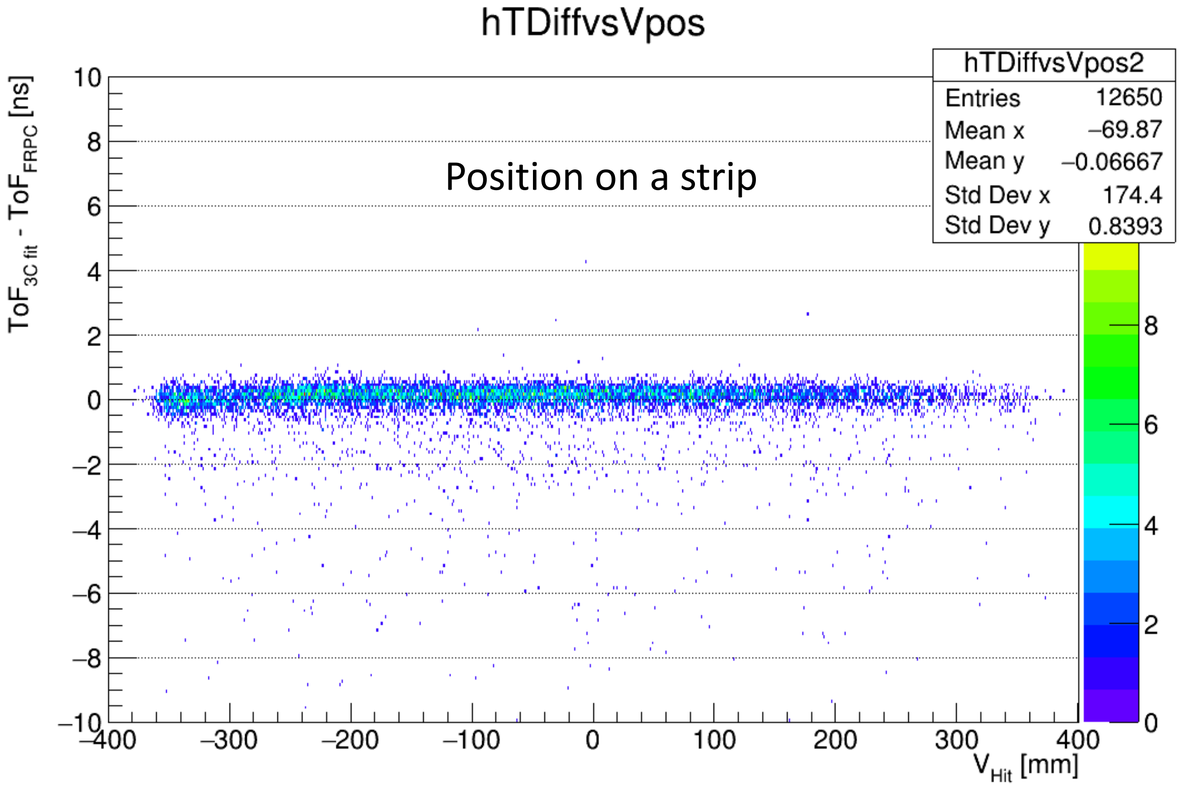
- Neural network PID improved and uploaded to github.
- Need for KinFit errors scaling in Hades removed by error segmentation.
- Scaling of p and θ/φ errors for forward determined separately with 3C fit.
- Efficiency corrected spectra acquired, effects of different efficiency parametrizations studied.
- FSI fits to nonresonant part done.
- φ/K ratio estimated with potential for a more precise measurement.
- Signs of non-trivial dynamics found in pKK distributions.

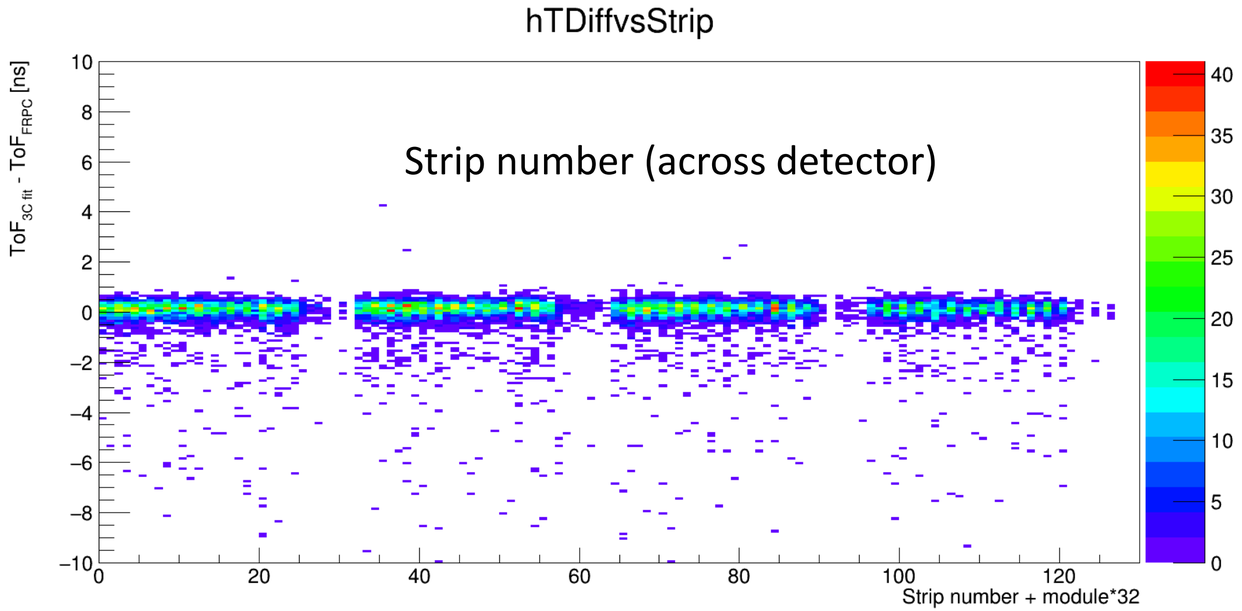
- ➢ Combined fit with simple amplitude models using GENBOD.
- ➢ Partial wave analysis attempt.

Backup

FRPC new gen check

1. 3C KinFit → Expected momentum.
2. Momentum + track distance → Expected ToF.
3. Compare with measured ToF in FRPC.

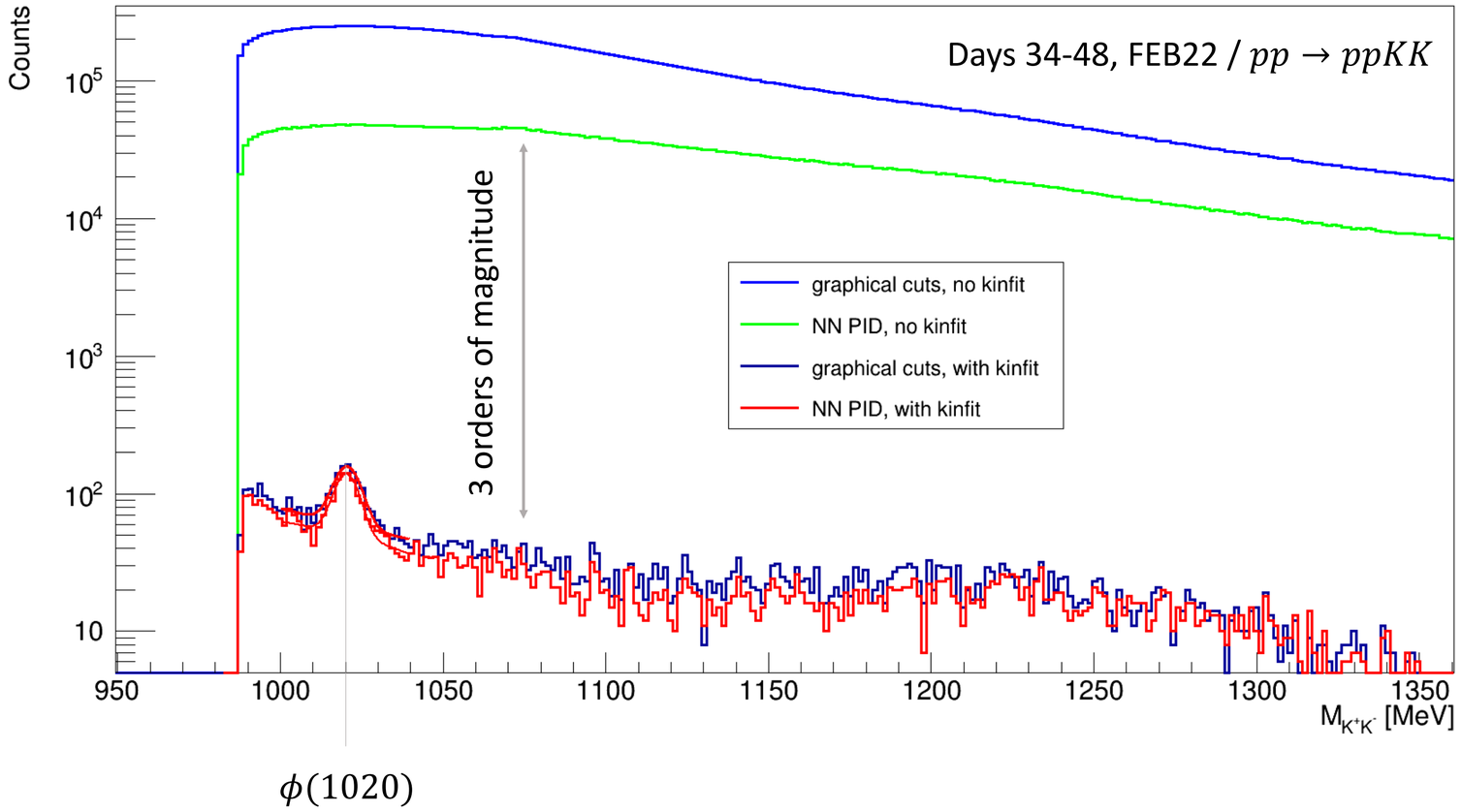




Properly working ToF measurements in the whole area of FRPC.

*No access to old data.

Raw invariant mass distributions

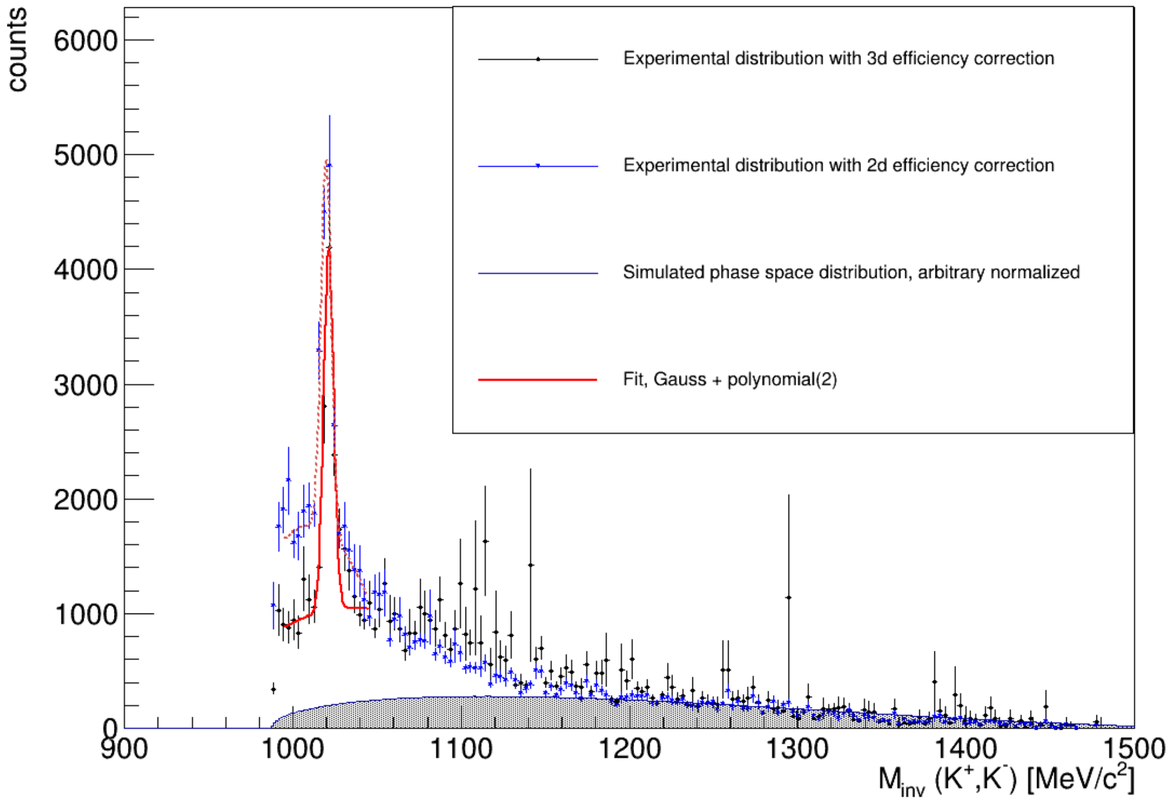


$\phi(1020)$

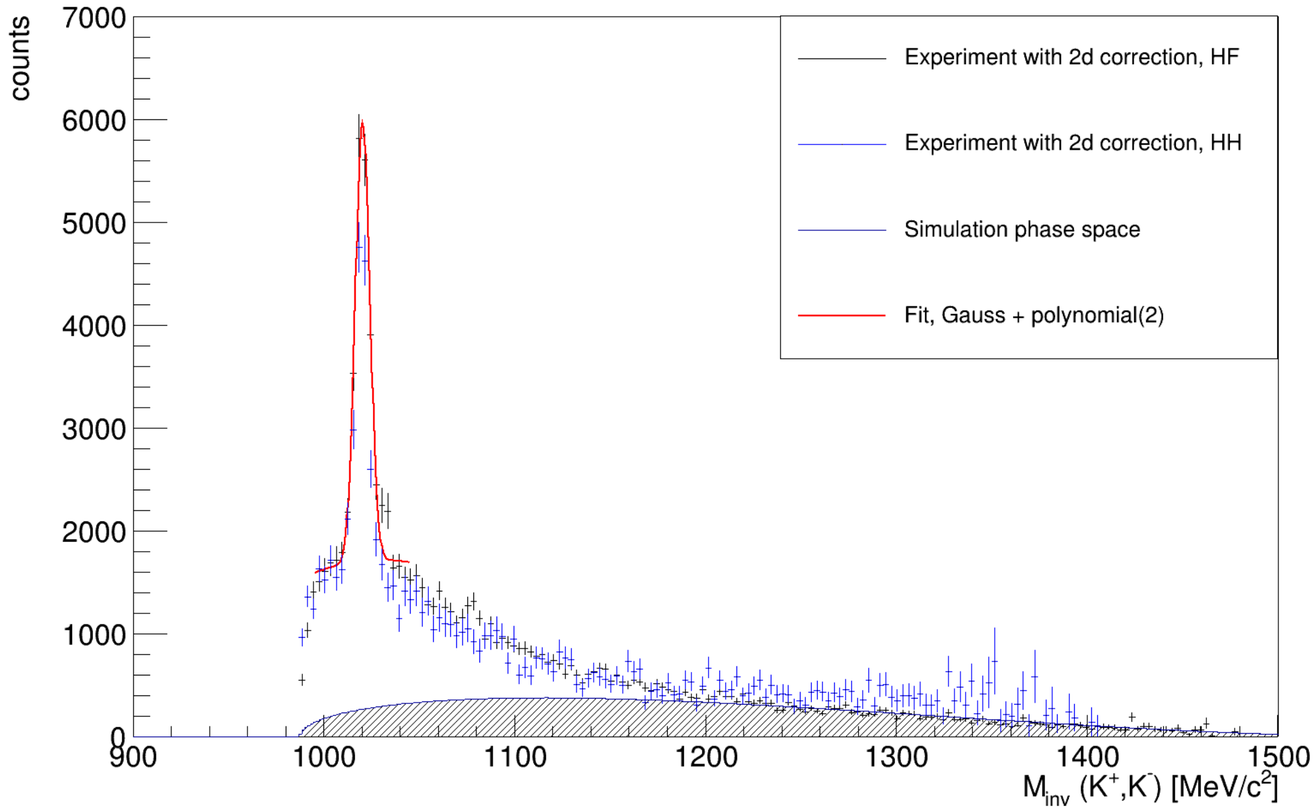
- 4C kinematic refit is very powerful in this case.
- NN PID significantly increases computation speed by lowering the amount of kinematic fit combinations.
- Will be more helpful for inclusive reaction studies without possibility to apply 4C fit.

Efficiency corrected yield

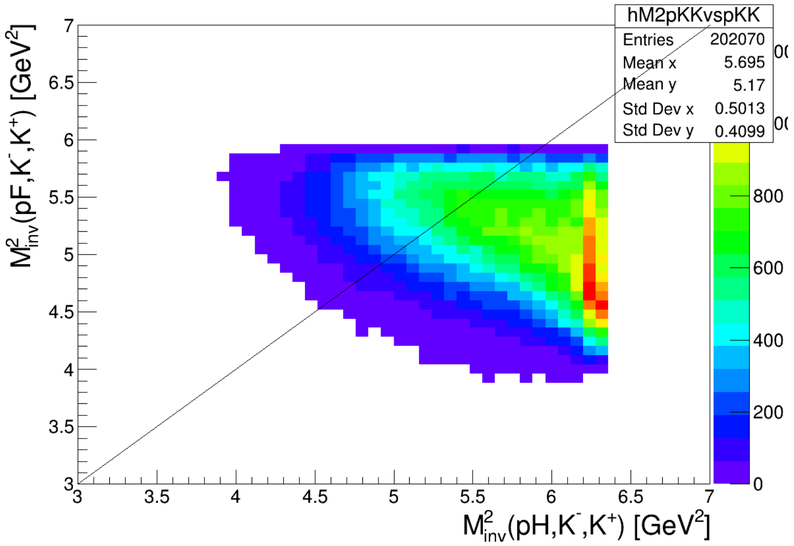
Different efficiency methods



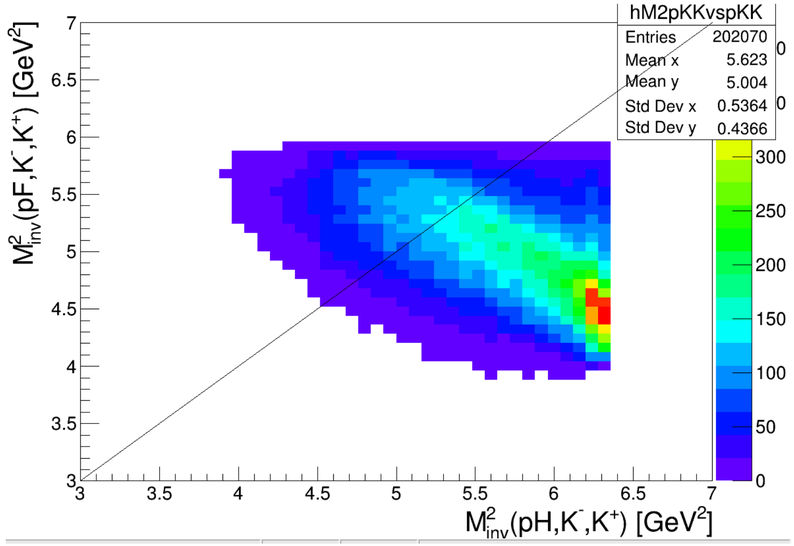
Difference Hades - Forward

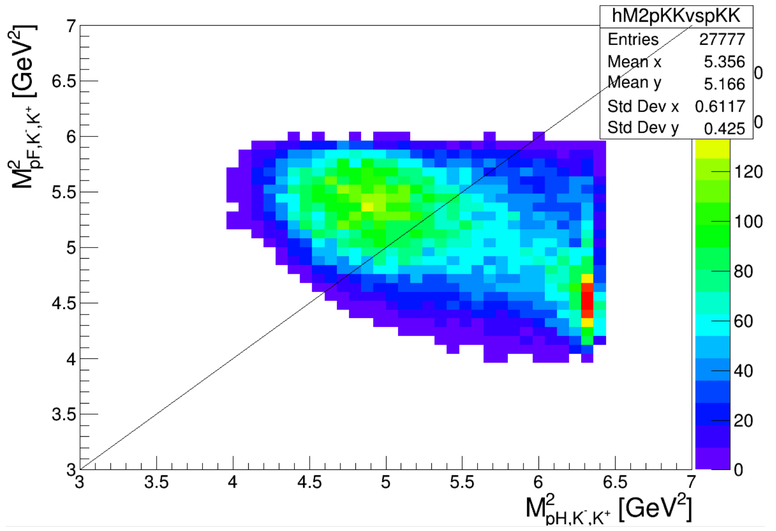


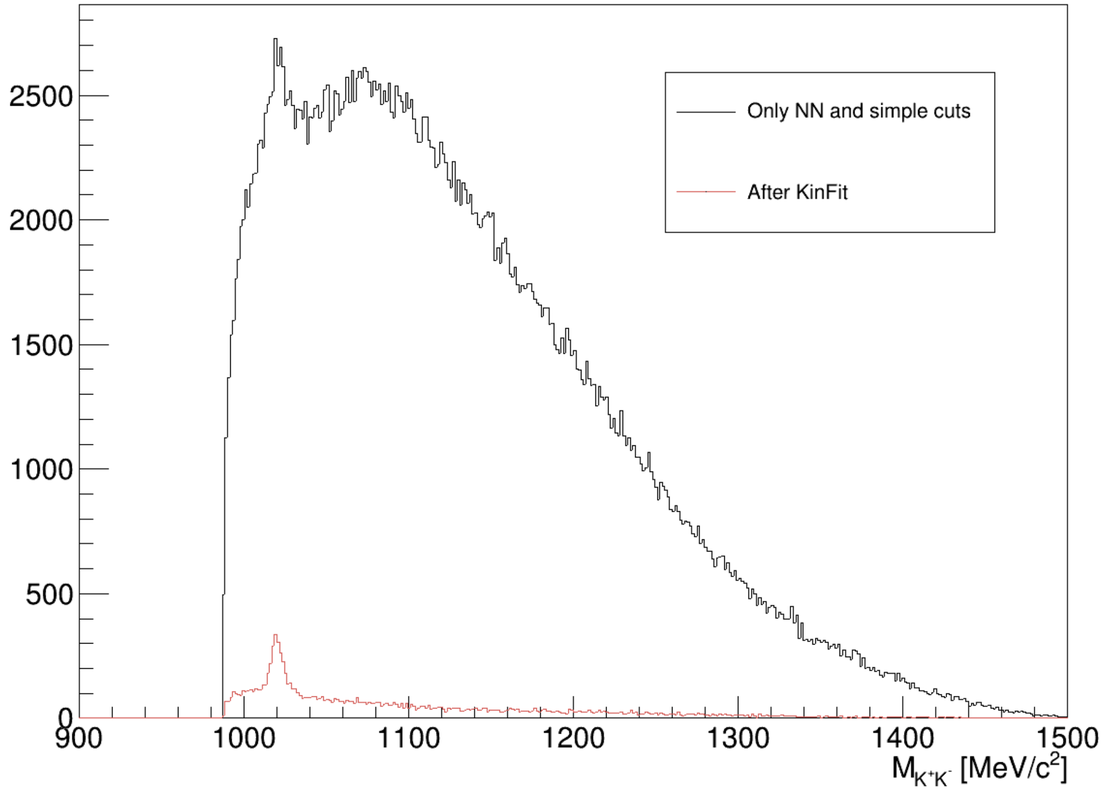
Efficiency corrected yield

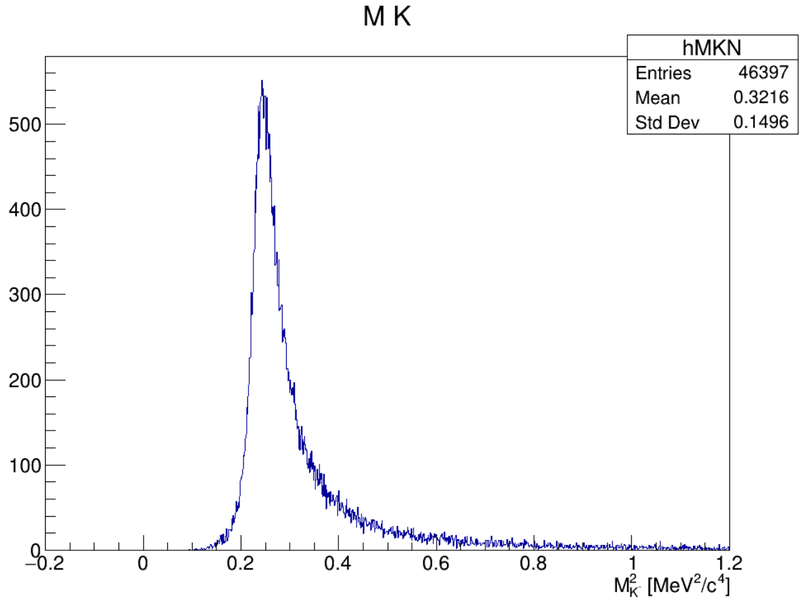


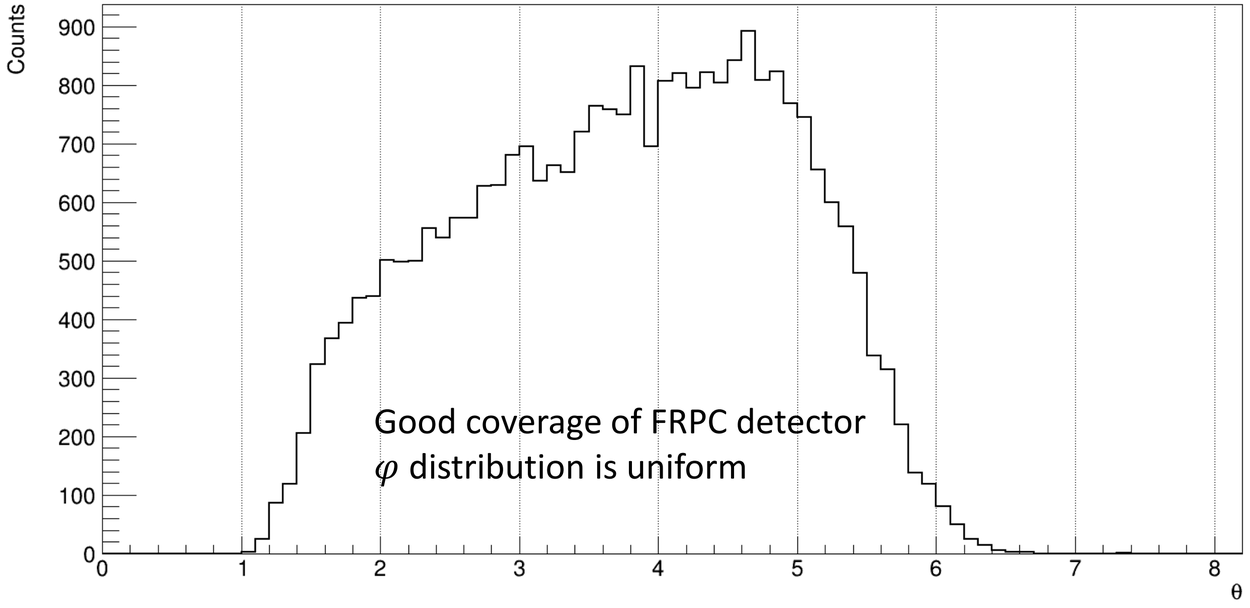
Just KK nonresonant scattering





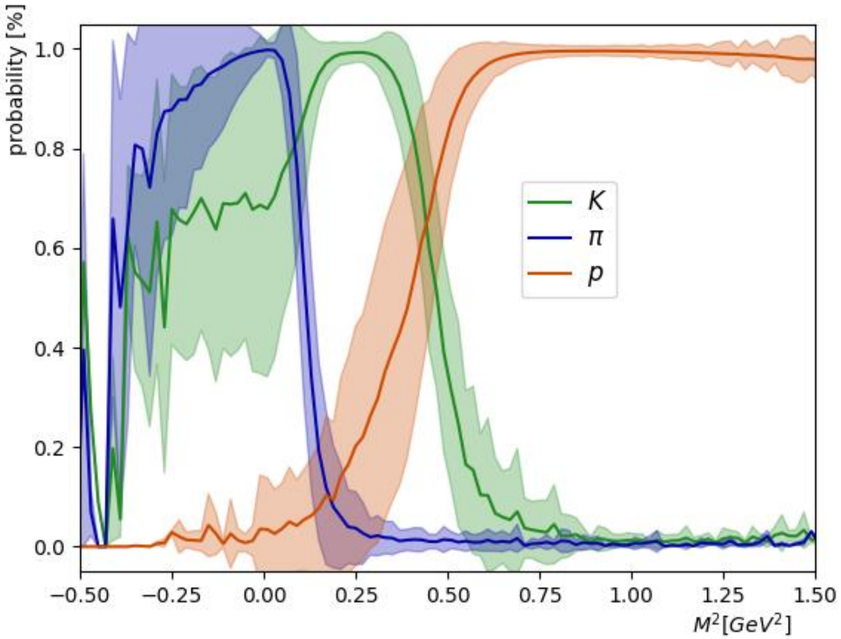

Only NN and simple cuts
After KinFit
2500
2000
1500
1000
500
0
900
1000
1100
1200
1300
1400
1500
$M_{K^+K^-}$ [MeV/c^2]


M K
hMKN
Entries 46397
Mean 0.3216
Std Dev 0.1496
500
400
300
200
100
0
−0.2
0
0.2
0.4
0.6
0.8
1
1.2
$M^2_{K^-}$ [MeV^2/c^4]


Counts
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
θ
Good coverage of FRPC detector
φ distribution is uniform

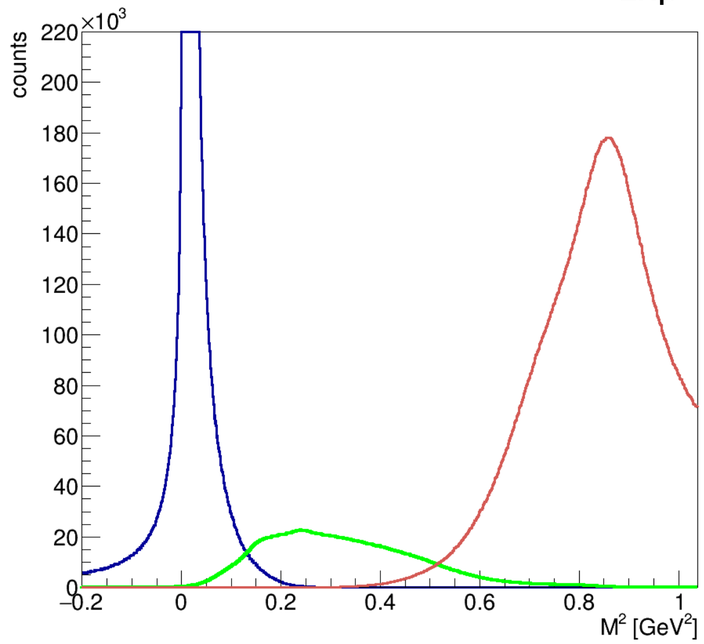
Particle identification performance

Sim

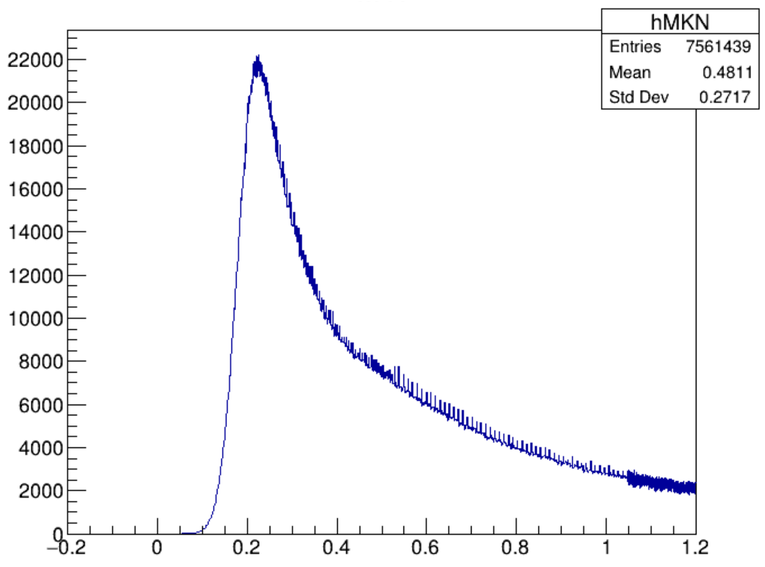


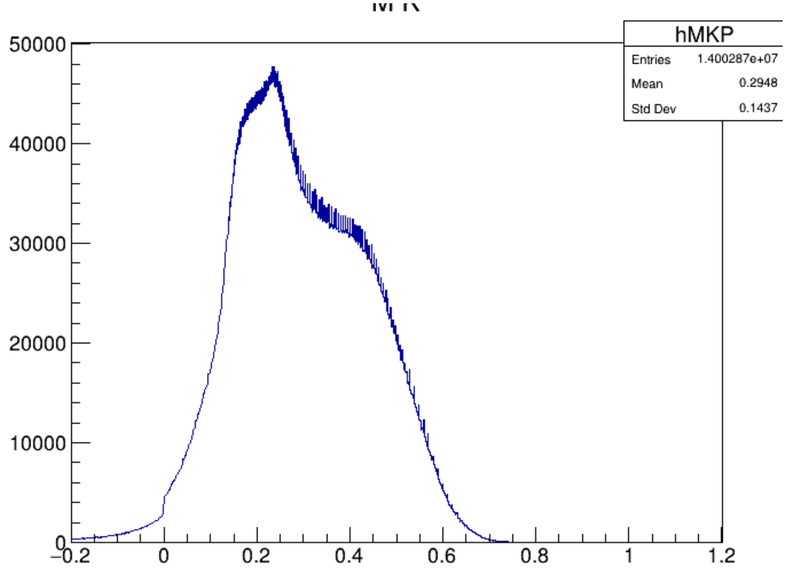
- Good peaked probabilities ~100% average
- Strong pion-kaon overlapping

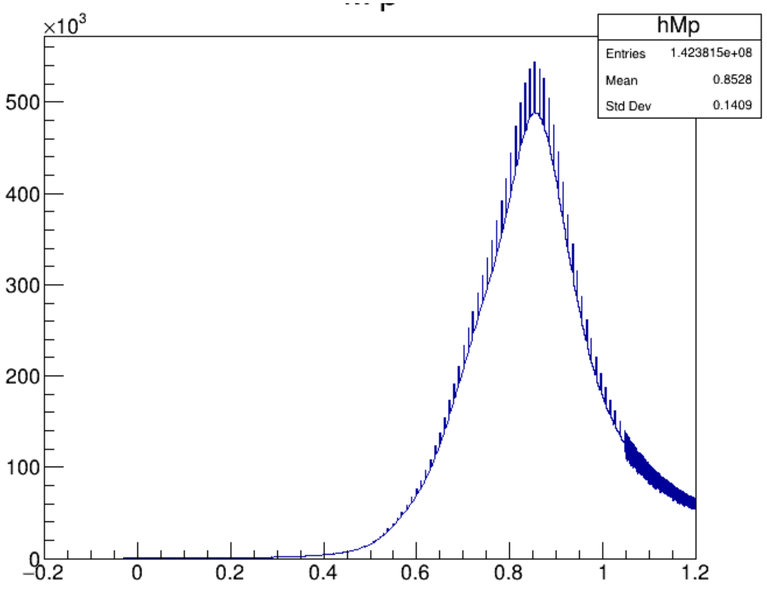
Exp

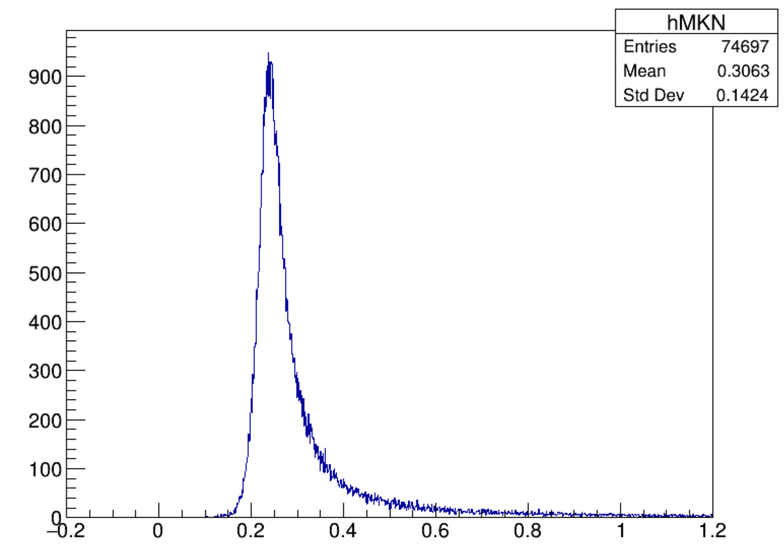


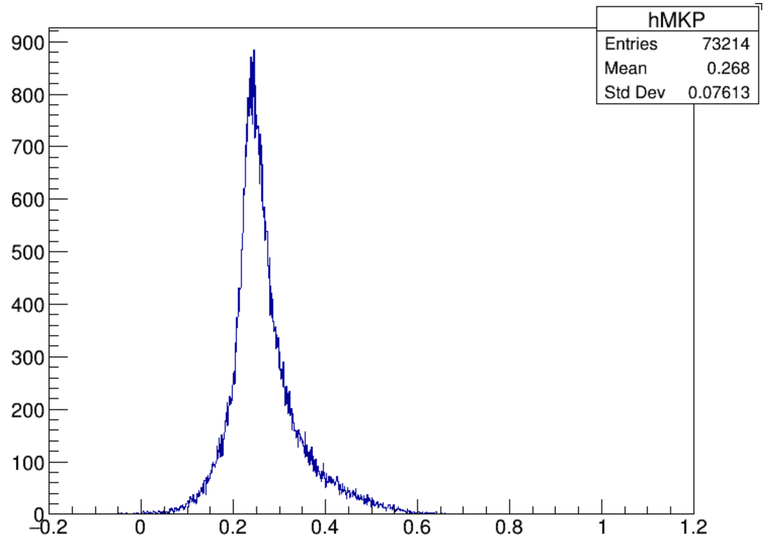
- Good distributions with tails
- Prone to mixing

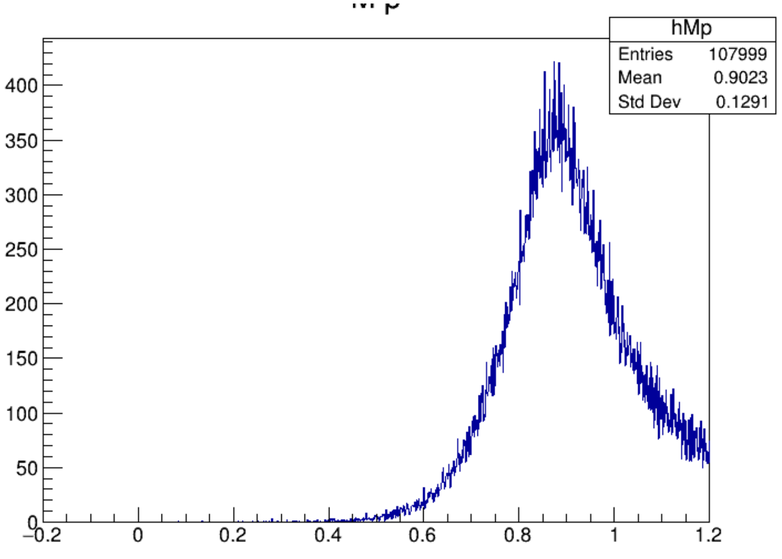

hMKN
Entries 7561439
Mean 0.4811
Std Dev 0.2717


hMKP
Entries 1.400287e+07
Mean 0.2948
Std Dev 0.1437


hMp
Entries 1.423815e+08
Mean 0.8528
Std Dev 0.1409


hMKN
Entries 74697
Mean 0.3063
Std Dev 0.1424

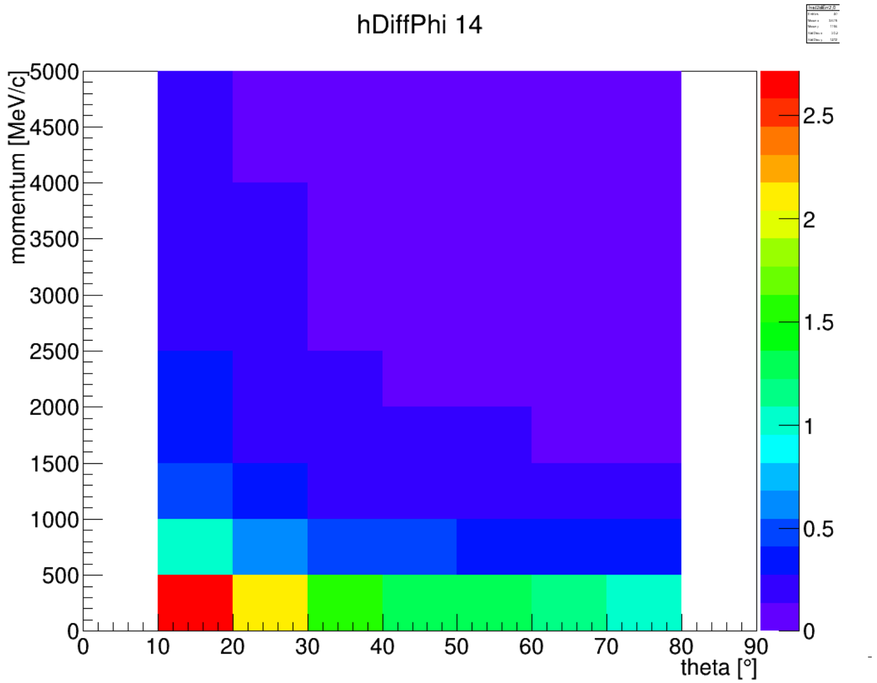

hMKP
Entries 73214
Mean 0.268
Std Dev 0.07613


hMp
Entries 107999
Mean 0.9023
Std Dev 0.1291

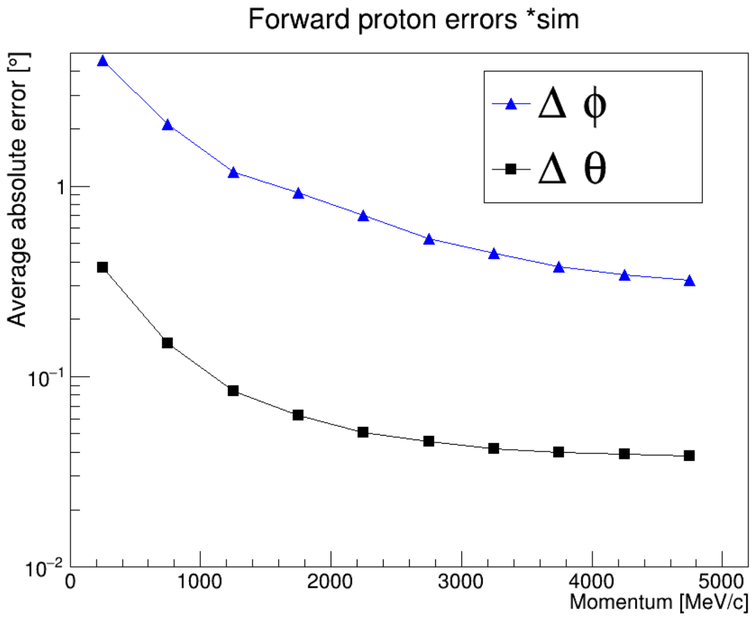
Errors for KinFit

Errors for V^{-1} from simulation

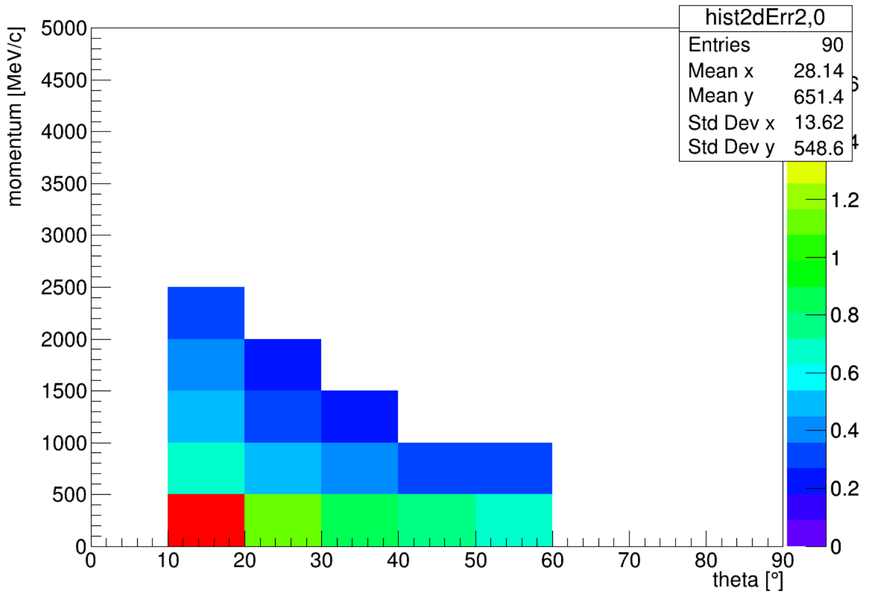
Segmentation by $p - \varphi$ for Hades ⟶ p white sim ⟶



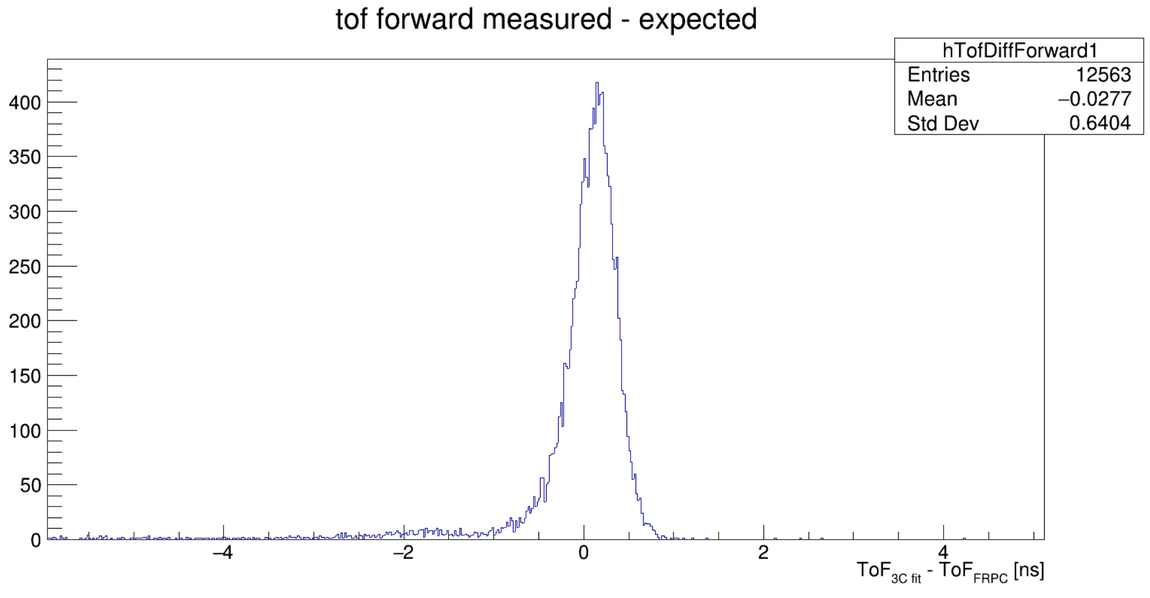
And by p for Forward

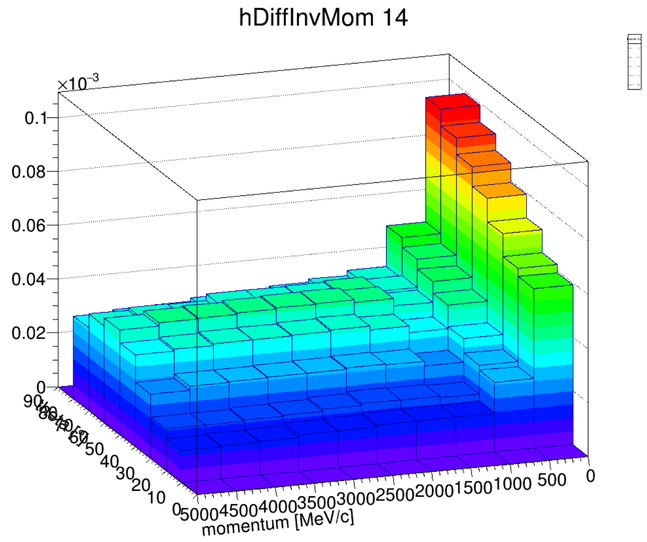


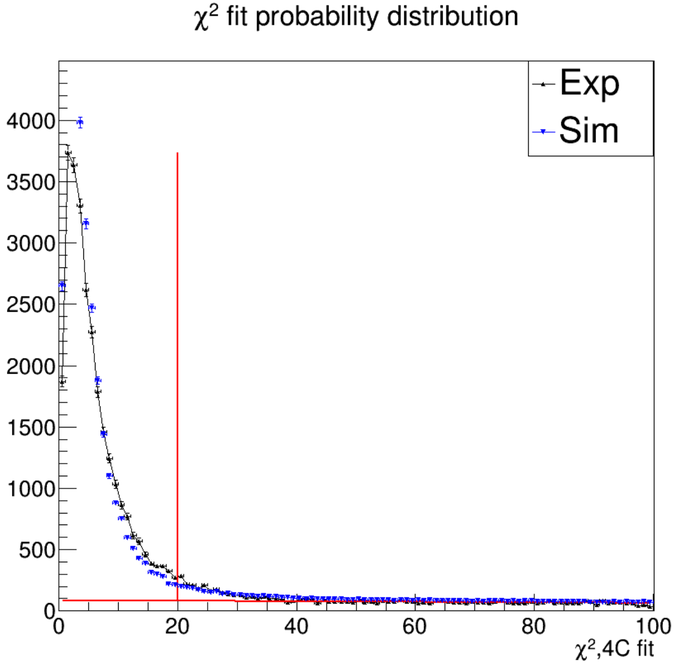
ppKK sim ⟶

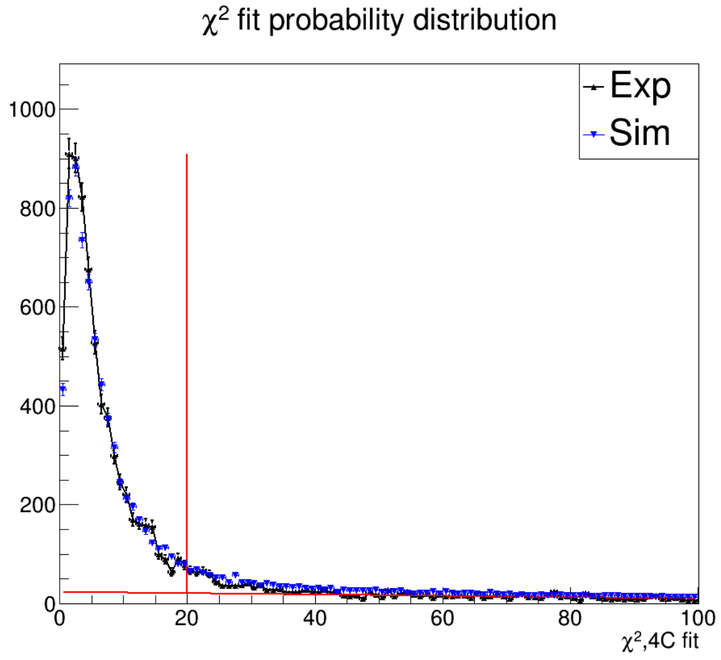


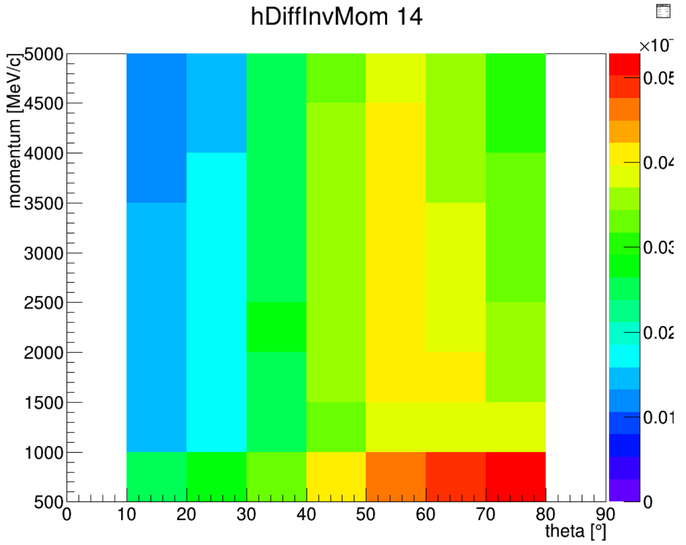
K/π white sim would be nice to have


tof forward measured - expected
hTofDiffForward1
Entries 12563
Mean −0.0277
Std Dev 0.6404
ToF3C fit - ToFFRPC [ns]


hDiffInvMom 14
momentum [MeV/c]


χ2 fit probability distribution
Exp
Sim
χ2,4C fit

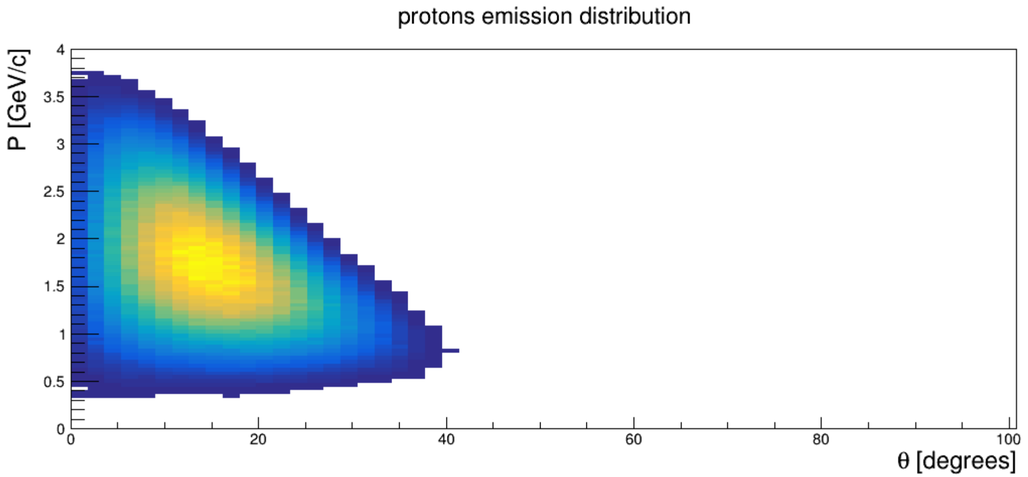

χ2 fit probability distribution
Exp
Sim
χ2,4C fit

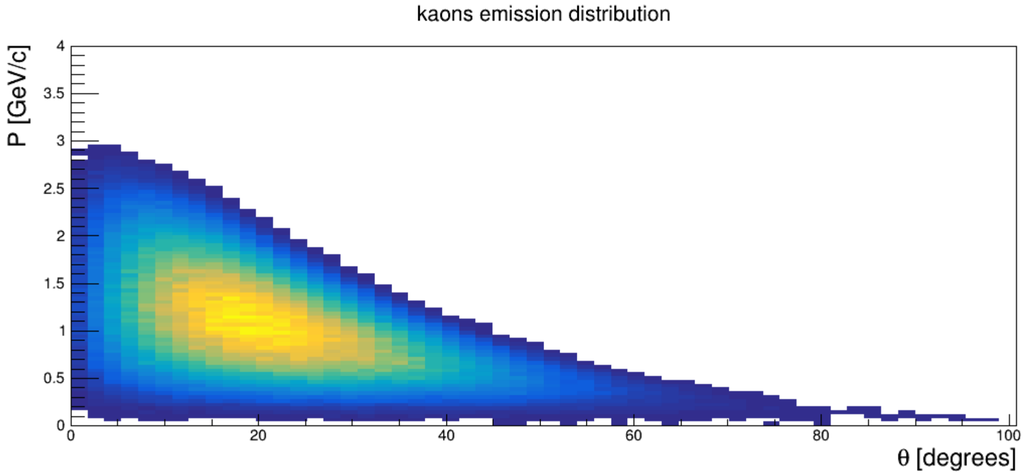

hDiffInvMom 14
momentum [MeV/c]
theta [°]

Efficiencies and situation with simulations

	K^+	K^-	p	**Total**
Acceptance	34%	36%	31%	1%
Identification	60%	70%	95%	30%
Kinfit	-			86.5%

0.2%



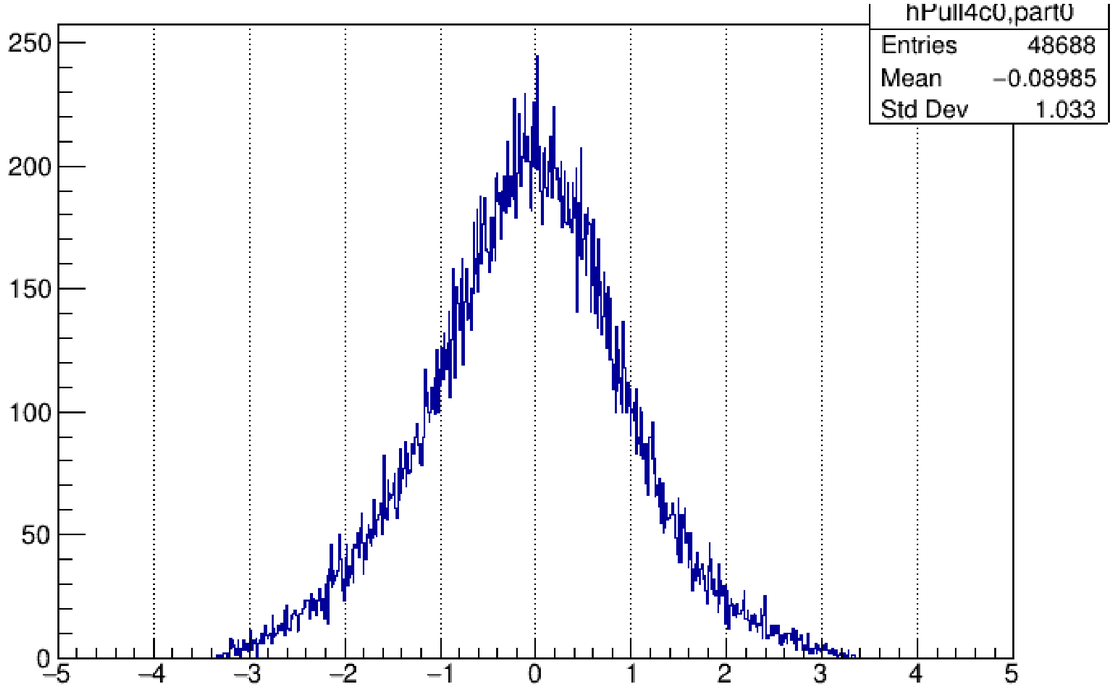


Kinematic fit for $pp \to ppKK$

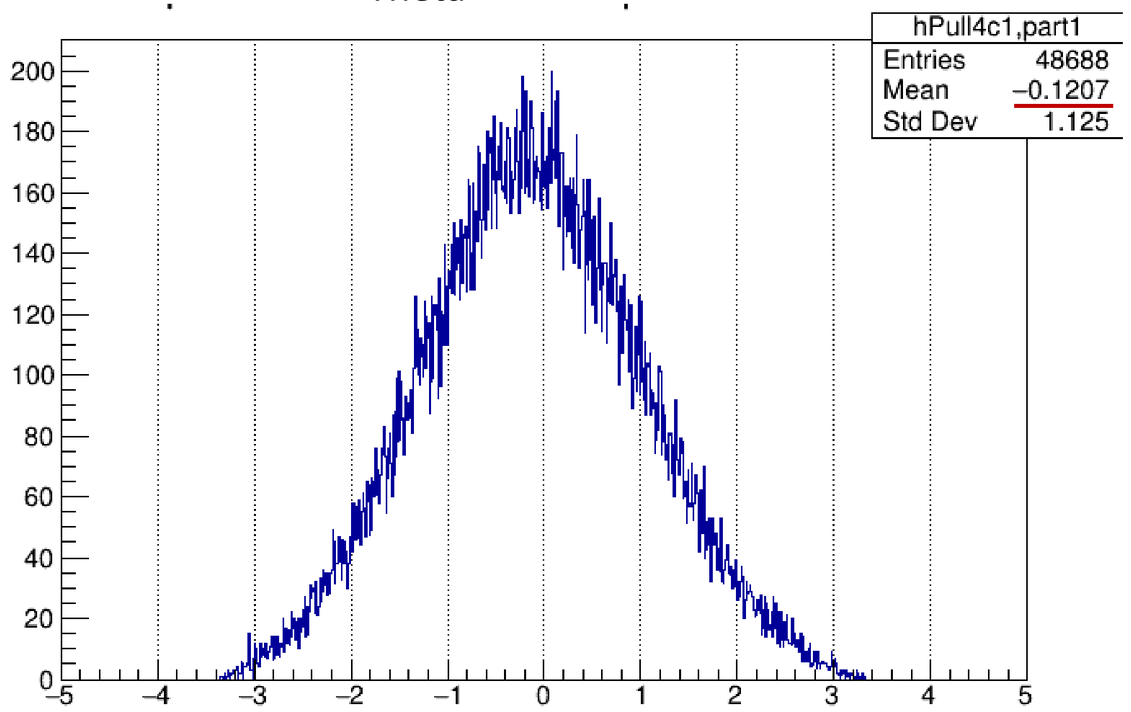
$$Pull = \frac{\eta - y}{\sqrt{\sigma^2(y) - \sigma^2(\eta)}}$$

Should be normal for signal events

Momentum



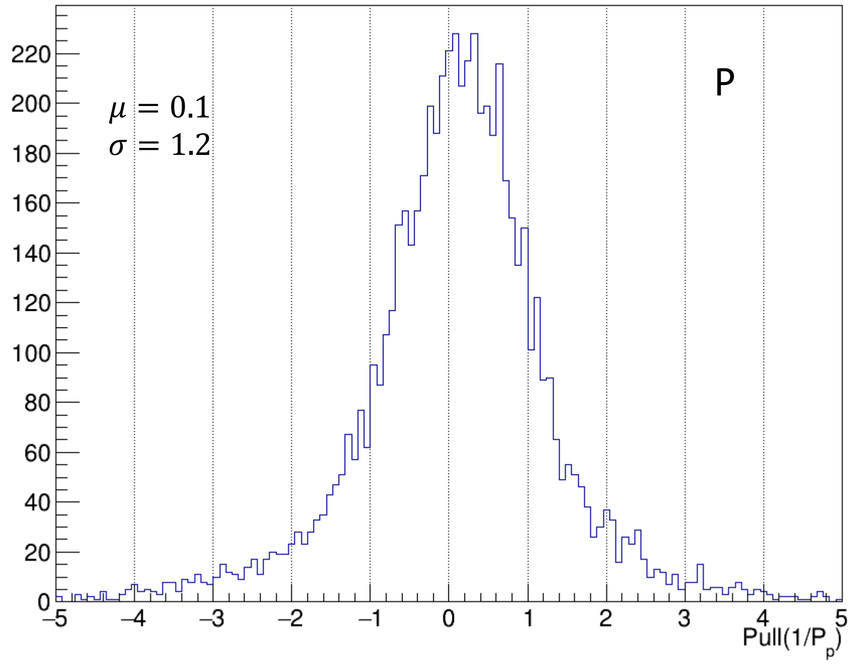
Theta

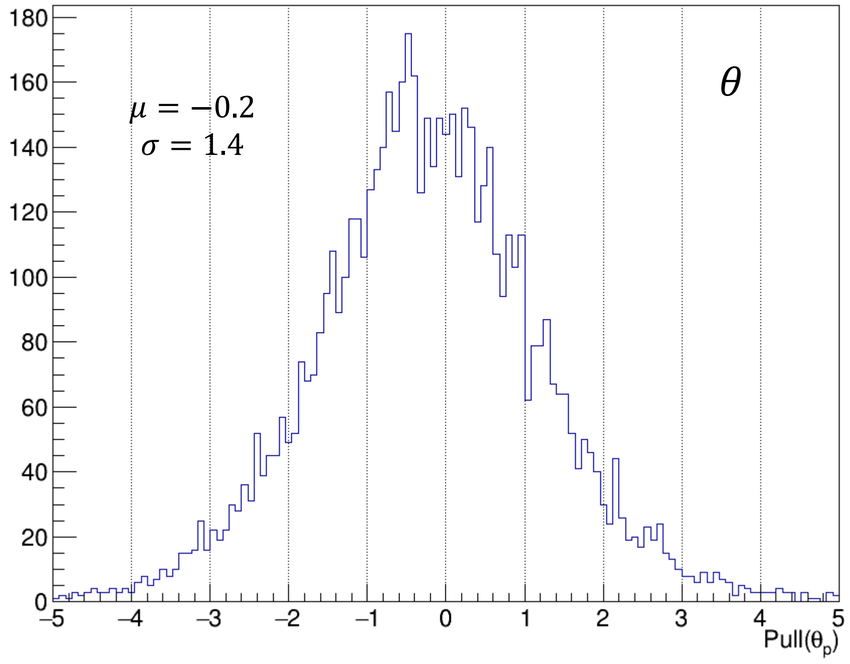


Other distributions for kinfit

Pulls

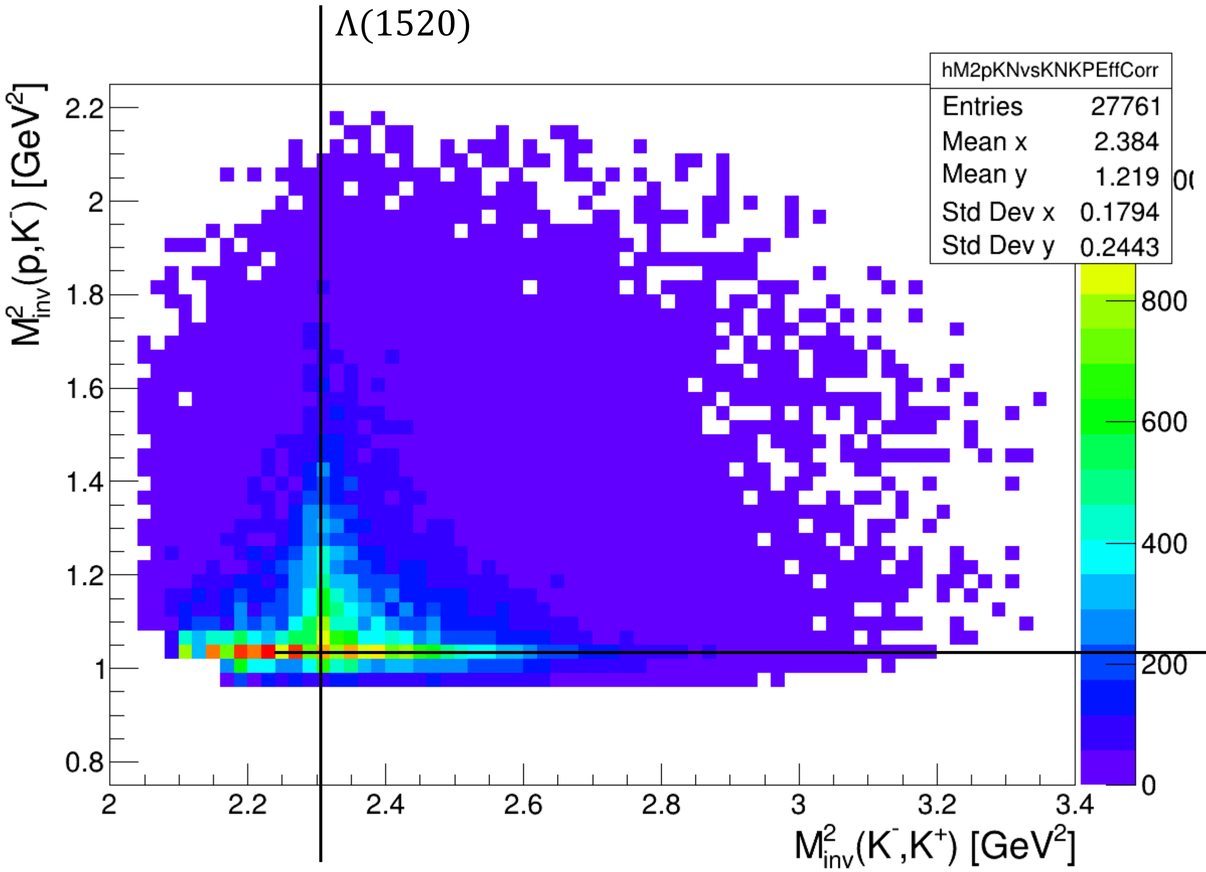
	P μ	P σ	θ μ	θ σ	φ μ	φ σ
p1	0.13	1.12	-0.26	1.27	0.01	1.28
p2	0.01	1.08	-0.20	1.29	-0.04	1.28
kn	0.30	1.22	-0.35	1.29	-0.01	1.25
kp	0.25	1.17	-0.32	1.26	0.05	1.28



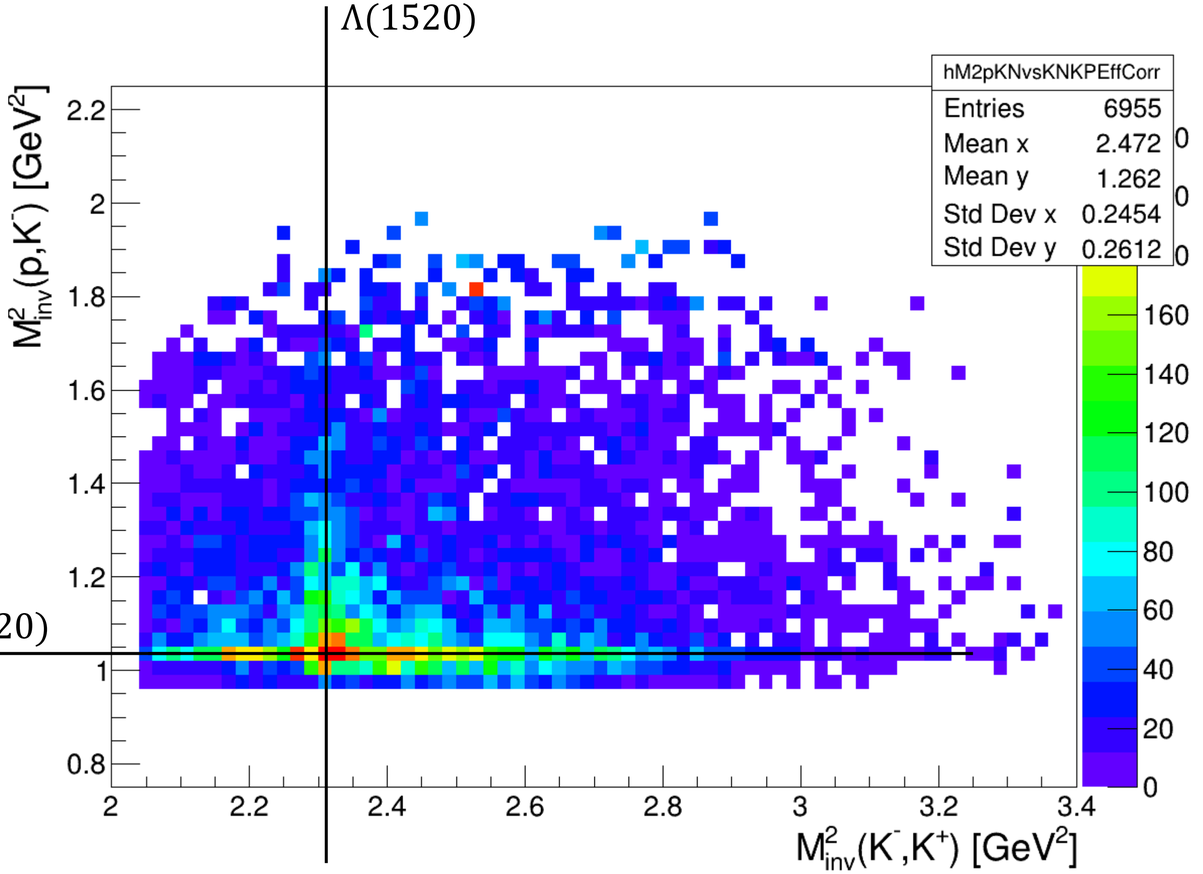


Mass distributions

HF



HH



Reconstruction efficiency plays a big role