Hadronic Resonances in Heavy-Ion Collisions at ALICE

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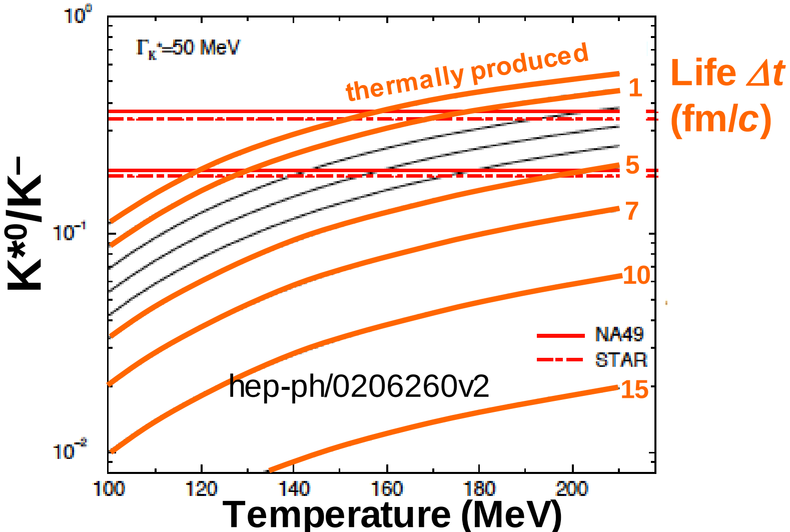
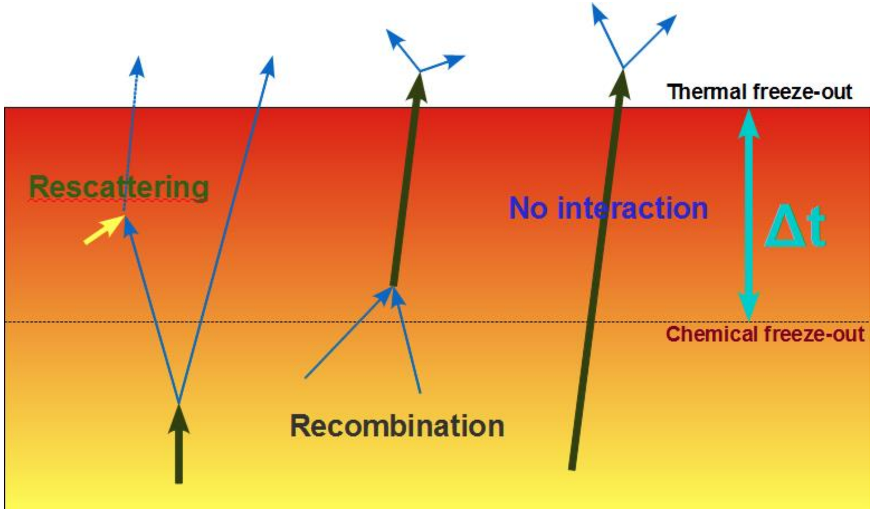
25 July 2013

Introduction

- This Presentation: K^{*0} and ϕ in Pb–Pb collisions
- Hadronic Phase: Temperature and Lifetime of fireball
  - Resonance formation at hadronization, through regeneration
  - Re-scattering prevents resonance reconstruction
    - Most important at low p_T (< 2 GeV/c)
  - Statistical models and UrQMD predict resonance/stable ratios
    - Given chemical freeze-out temperature and/or time between chemical and thermal freeze-out (Δt)
- Chiral Symmetry Restoration
  - Resonances that decay when chiral symmetry was at least partially restored would exhibit mass shifts and width broadening



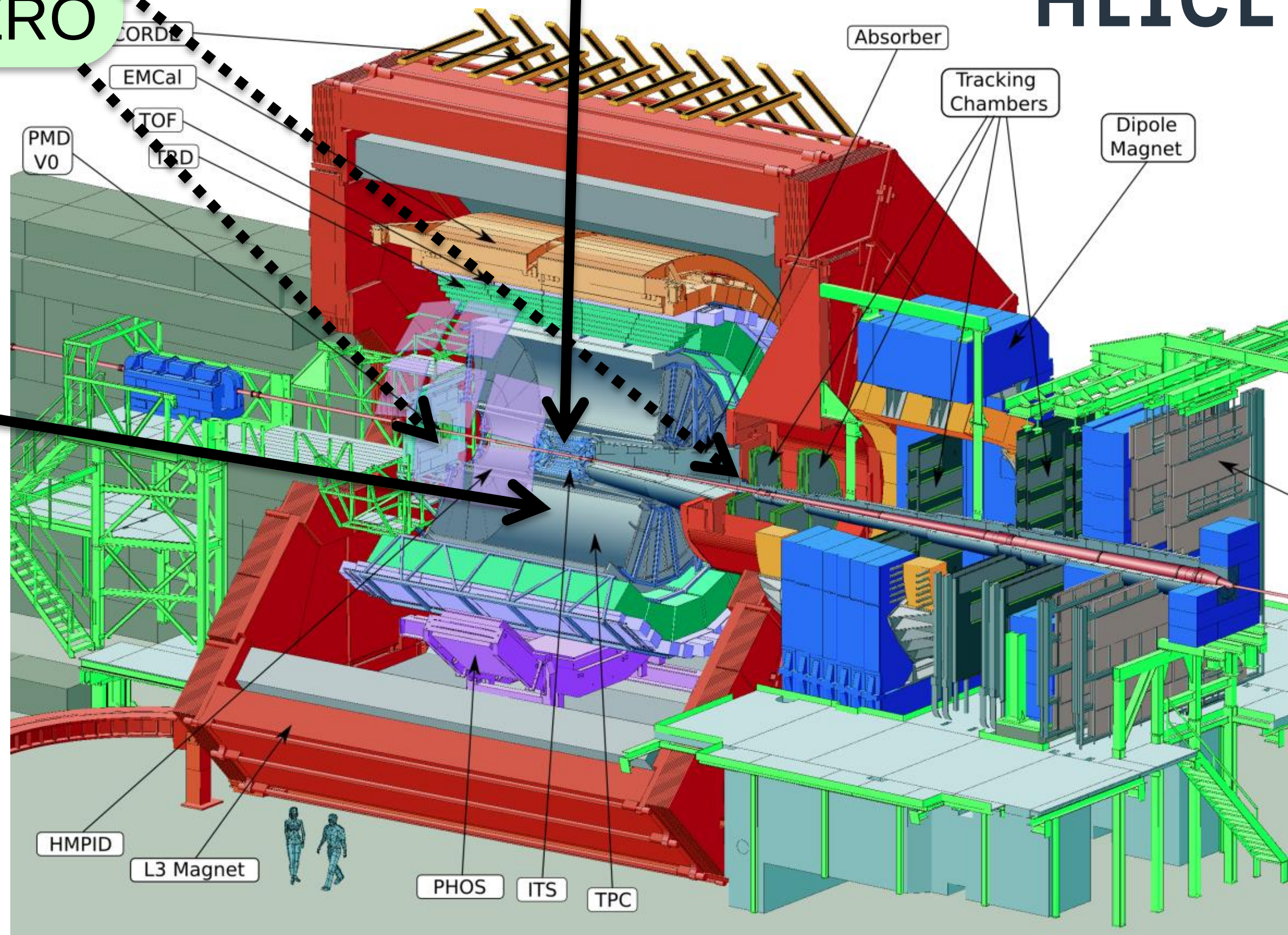


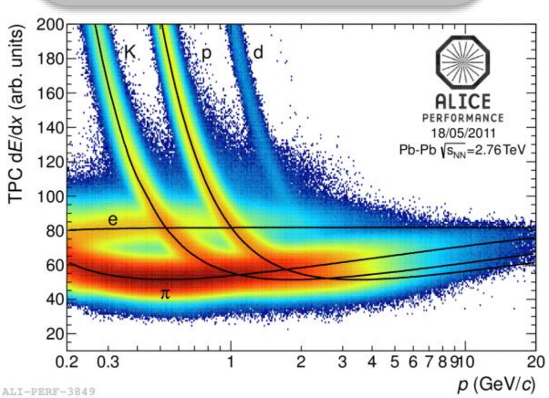
ALICE Detector

VZERO (scintillators): centrality estimate through measurement of amplitude in VZERO

ITS (silicon): Tracking and Vertexing

TPC: Tracking and Particle ID through dE/dx

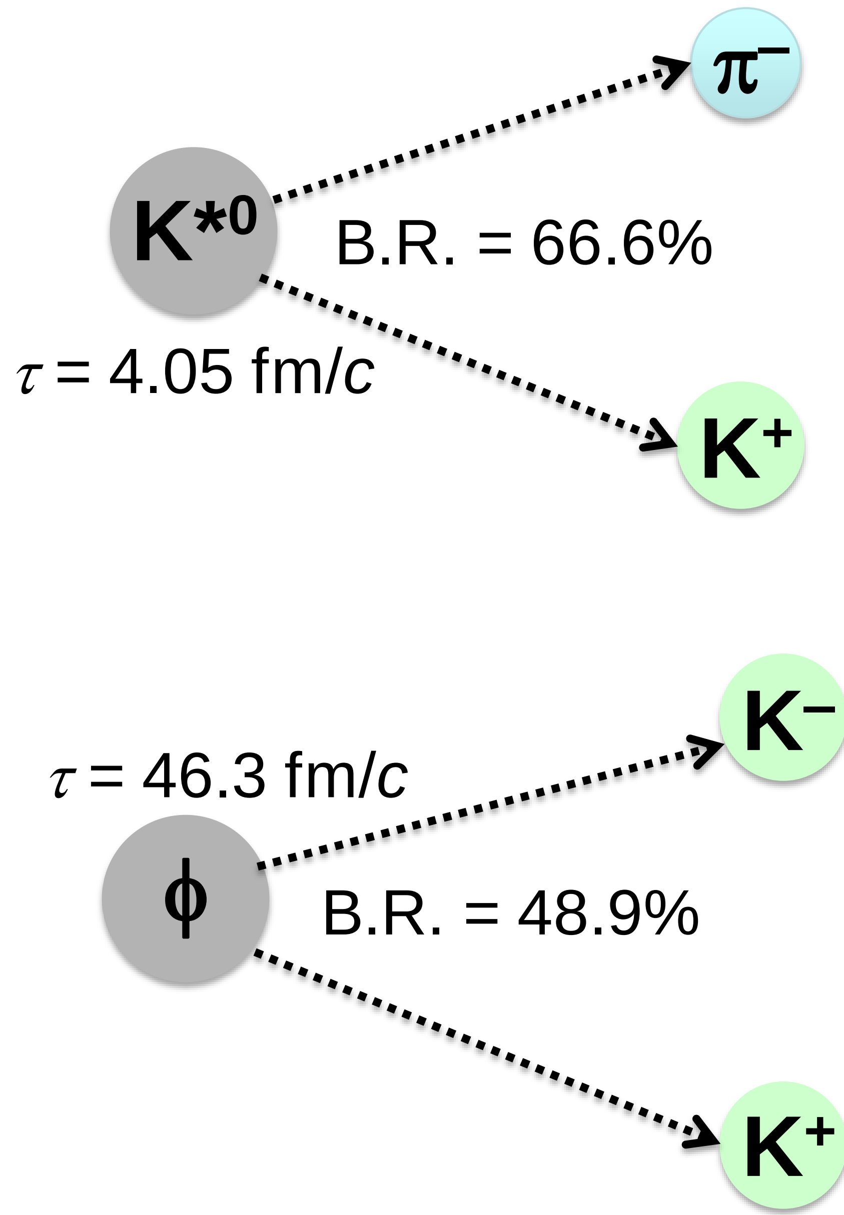




K^{*0} and ϕ in Pb-Pb

Resonance Reconstruction

- Event Selection:
  - $|v_z|<10$ cm
  - K^{*0}: 8.2 M events
  - ϕ: 9.5 M events
- Hadronic Decays
- PID: TPC dE/dx: $2\sigma_{TPC}$ cut
- Combinatorial Background: Event Mixing
  - Require similar v_z, multiplicity, event plane
- Fit Residual Background + Peak



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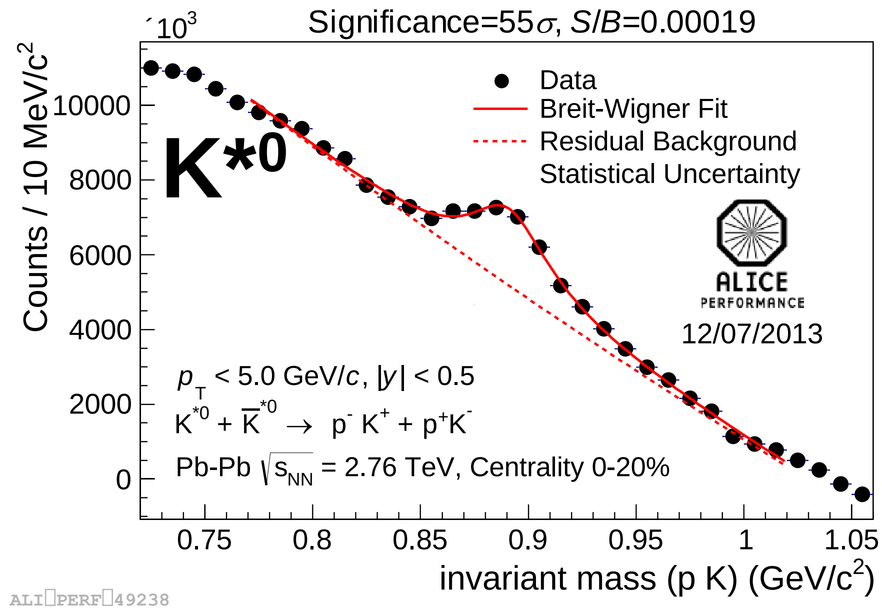
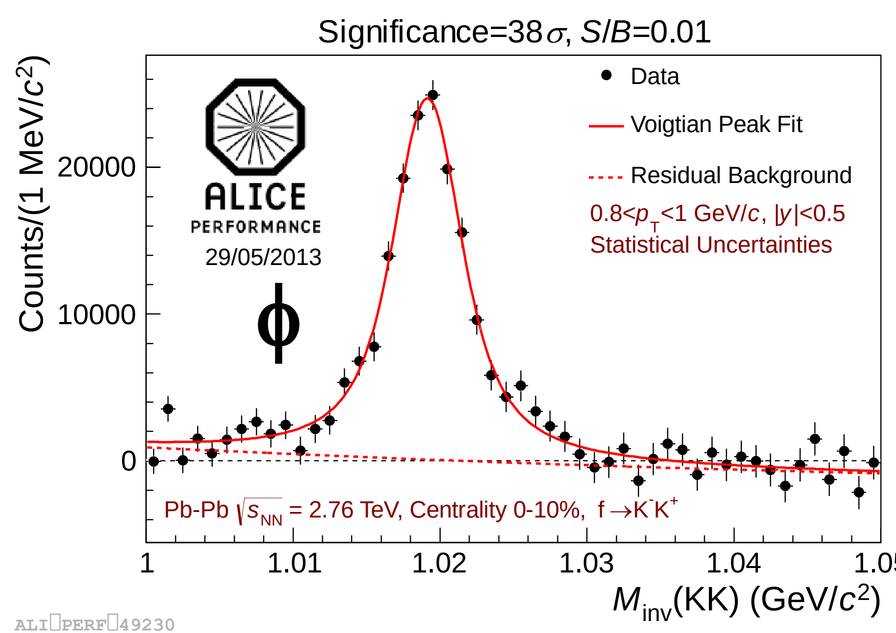
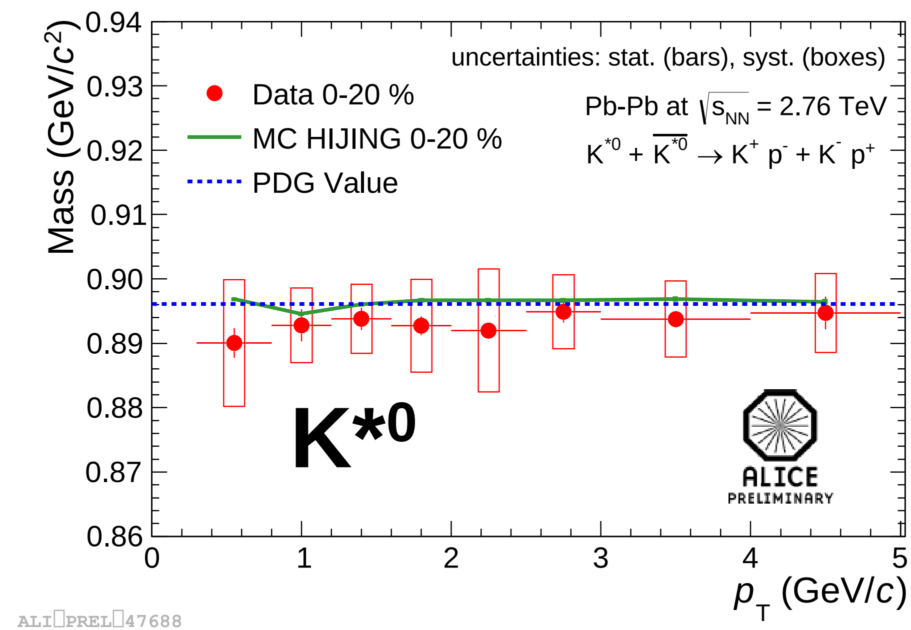
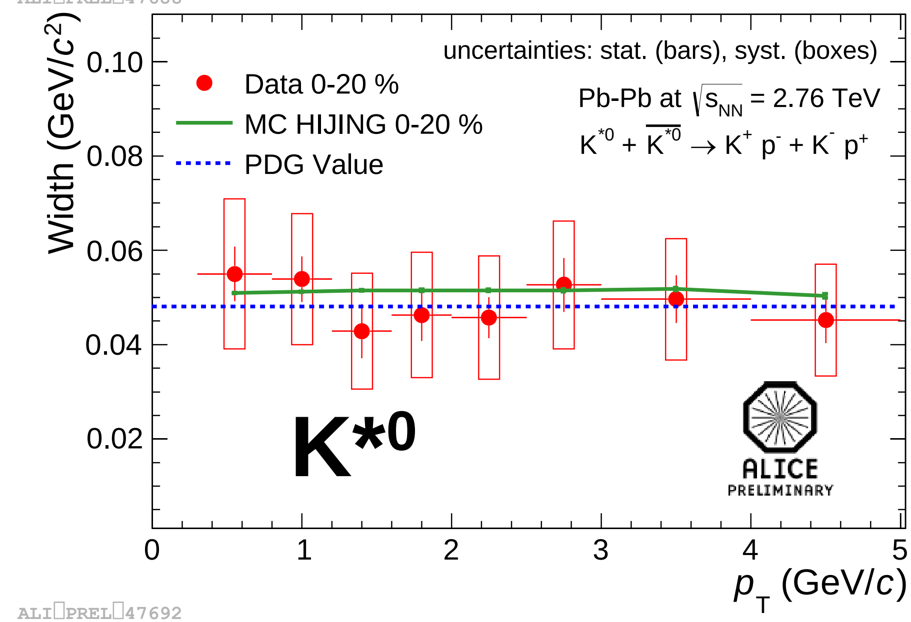




Mass and Width

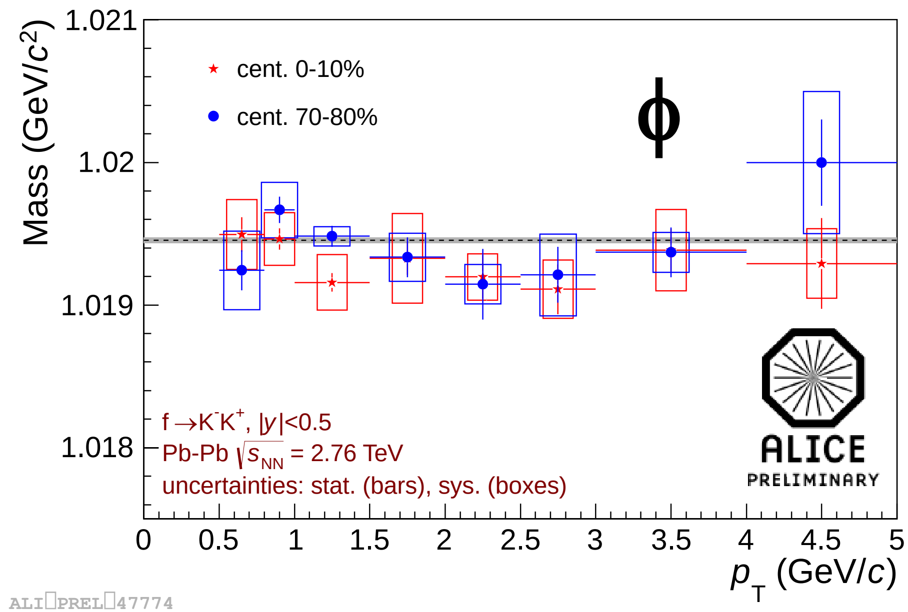
- K^{*0}: Mass and width consistent with MC HIJING Simulation
  - No centrality dependence

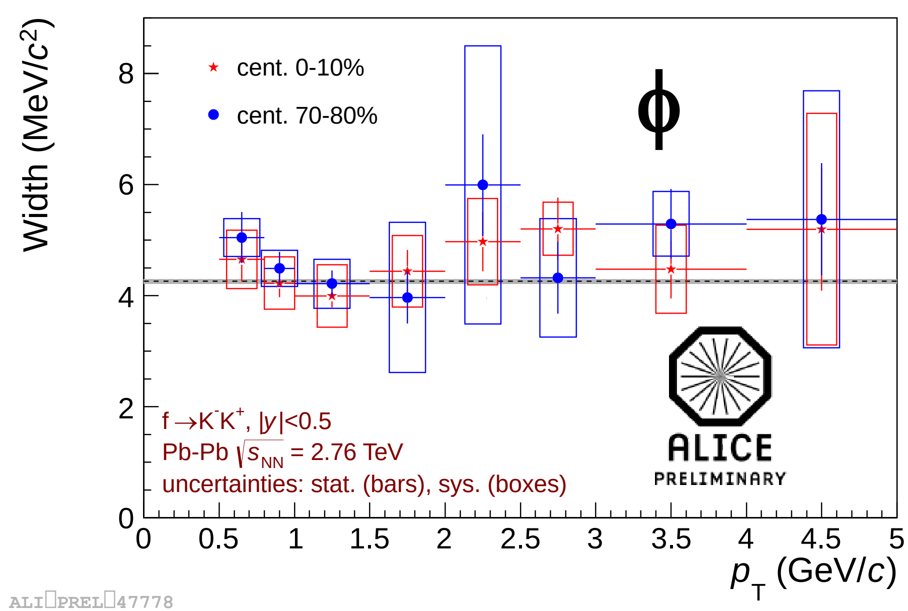




Mass and Width

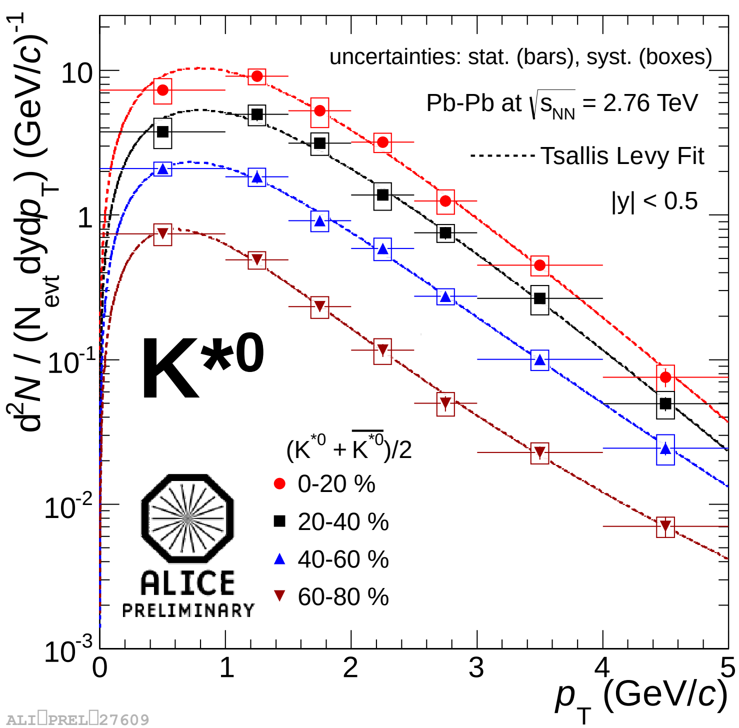
- K^{*0}: Mass and width consistent with MC HIJING Simulation
  - No centrality dependence
- ϕ: Mass and width consistent with Vacuum Values
  - No centrality dependence
- Signatures of chiral symmetry restoration are not observed
  - Caveat: reconstructing the hadronic decays

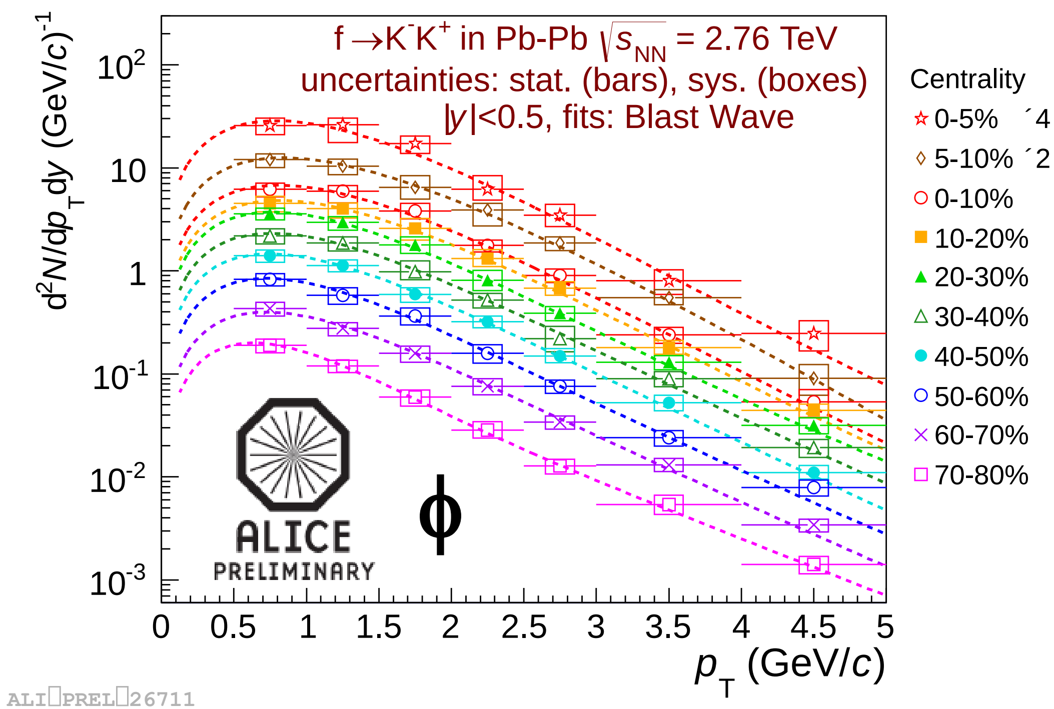




Spectra

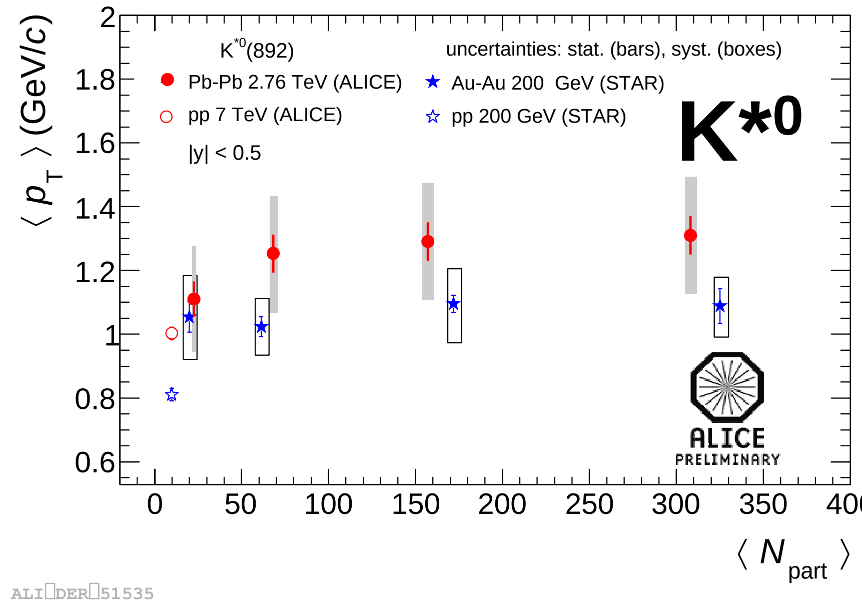
- Fit Corrected Spectra (in centrality intervals)
  - ϕ: Boltzmann-Gibbs Blast Wave Function
    - Extrapolate ϕ yield to low p_T (~15% of total yield)
  - K*⁰: Lévy-Tsallis Function
    - Spectrum reaches p_T=0, no extrapolation needed

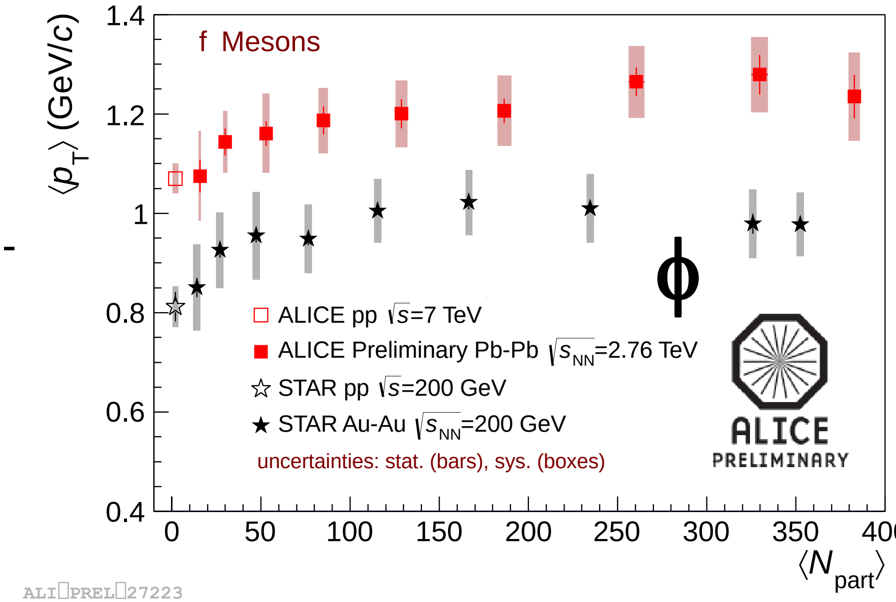




Mean p_T

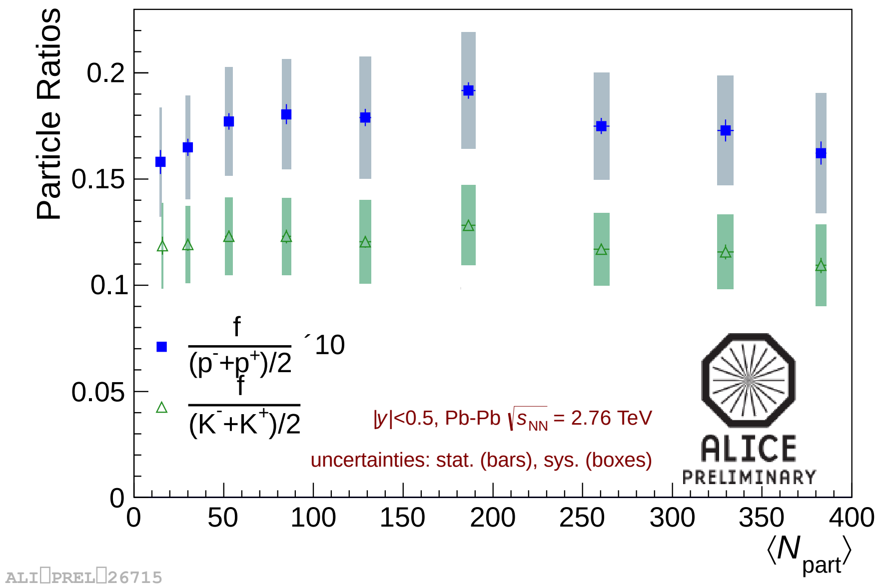
- $<p_T>$ appears to increase for more central Pb–Pb collisions
- $<p_T>$ in pp at $\sqrt{s}$=7 TeV
  - Consistent with peripheral Pb–Pb
  - Lower than central Pb–Pb
- $<p_T>$ greater at LHC than RHIC
  - For K^{*0}: 20% larger
  - For ϕ: 30% larger
- ALICE π,K,p spectra: global blast-wave fit shows ~10% increase in radial flow w.r.t. RHIC
  - B. Abelev *et al*. (ALICE), CERN-PH-EP-2013-019, arXiv:13030737v1 (2013)
  - See Also: Talk by M. Chojnacki, SQM 2013

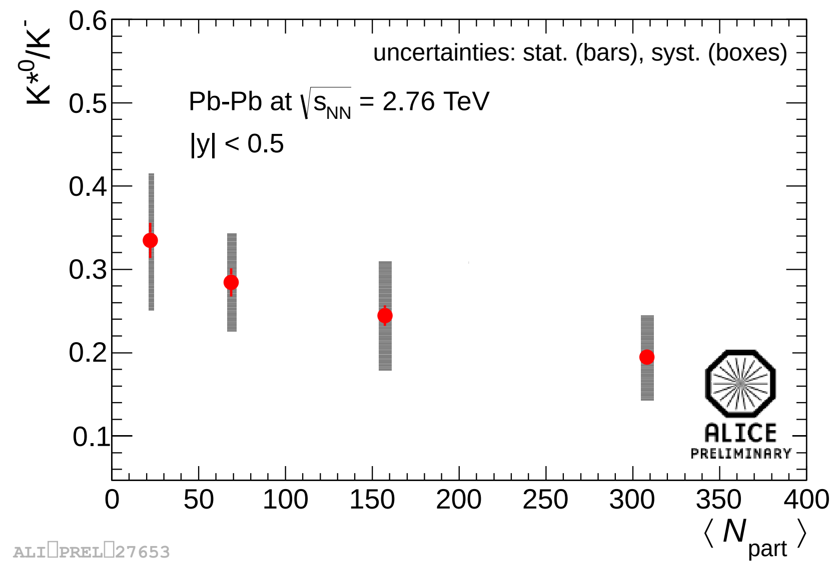




Particle Ratios vs. Centrality

- ϕ/π and ϕ/K independent of centrality
- K*⁰/K⁻: apparent decrease for central collisions
  - Suggests re-scattering effects in central collisions





K^{*0}/K^- vs. Energy

- Measured K^{*0}/K^- ratio in central Pb–Pb smaller than in pp
  - Similar behavior at RHIC
- Model Predictions:

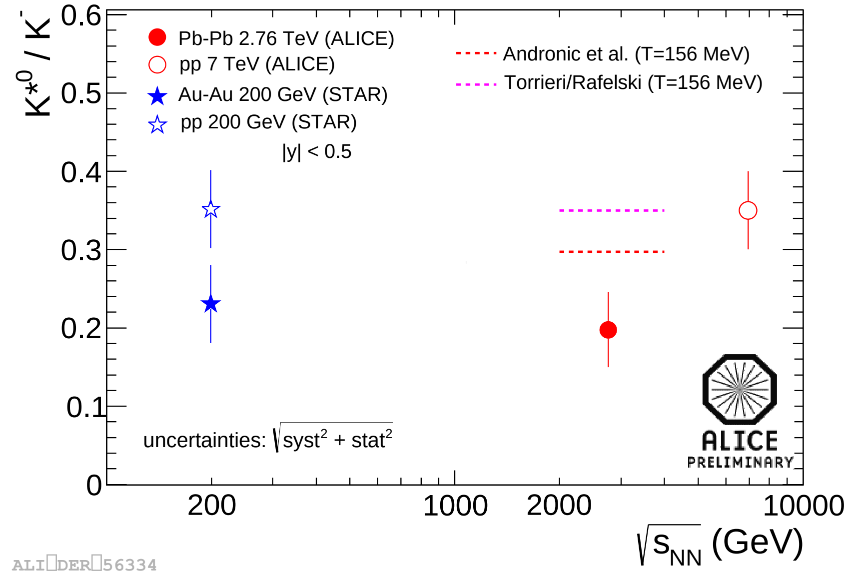
Andronic [1]
no re-scattering
T_{ch} = 156 MeV

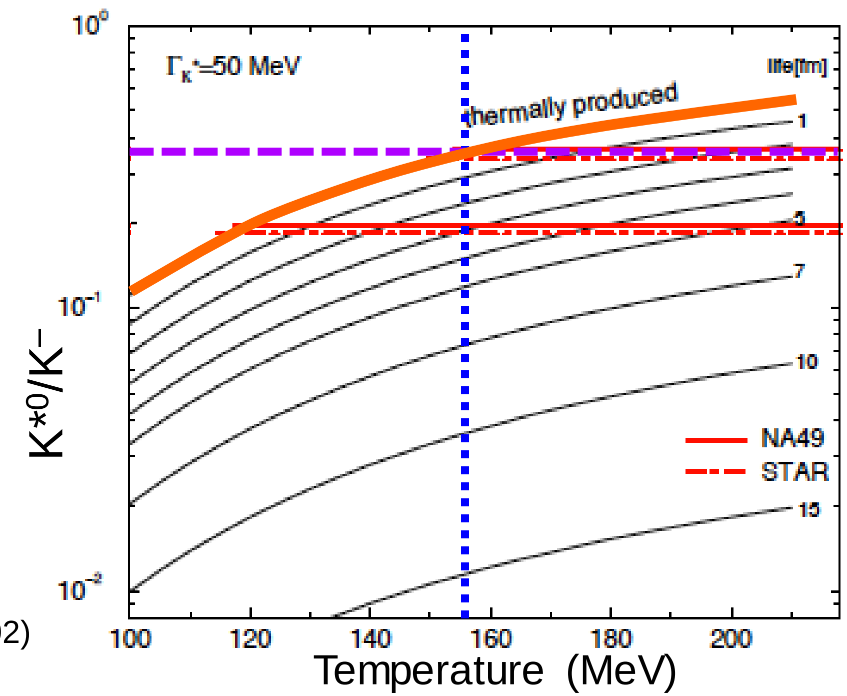
→ Prediction:
$K^{*0}/K^- = 0.30$

Torrieri/Rafelski [2-4]
no re-scattering
T_{ch} = 156 MeV

→ Prediction:
$K^{*0}/K^- = 0.35$

our assumption, based on thermal model fits of ALICE data





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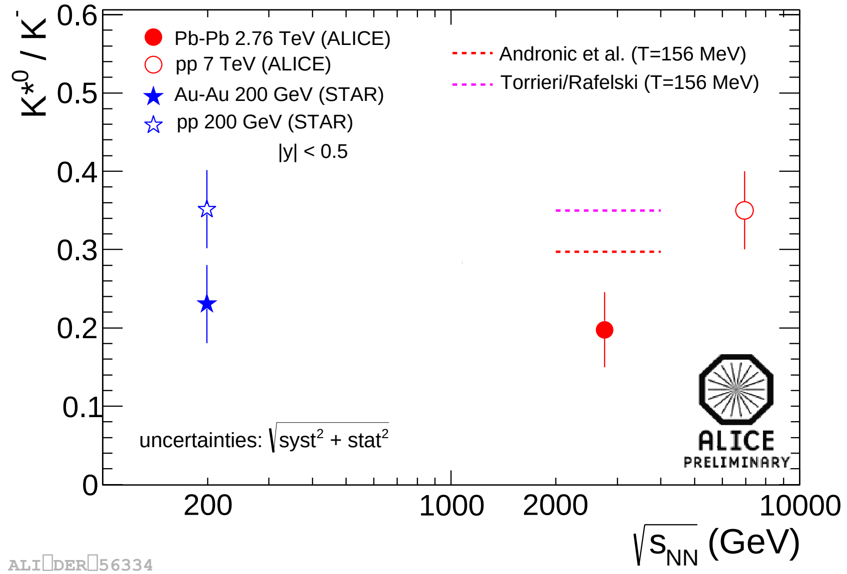
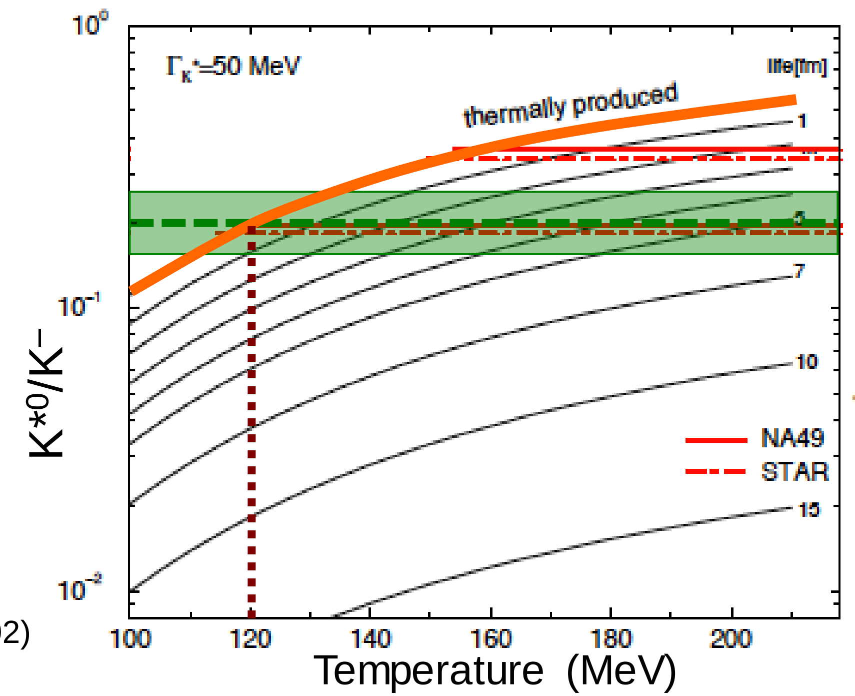
Torrieri/Rafelski [2-4]
no re-scattering
measured K^{*0}/K^-
→ Prediction: T_{ch} = 120±13 MeV

K^{*0}/K^- = 0.194±0.051





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  - Similar behavior at RHIC
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T_{ch} = 156 MeV
→ Prediction: K^{*0}/K^{-} = 0.30

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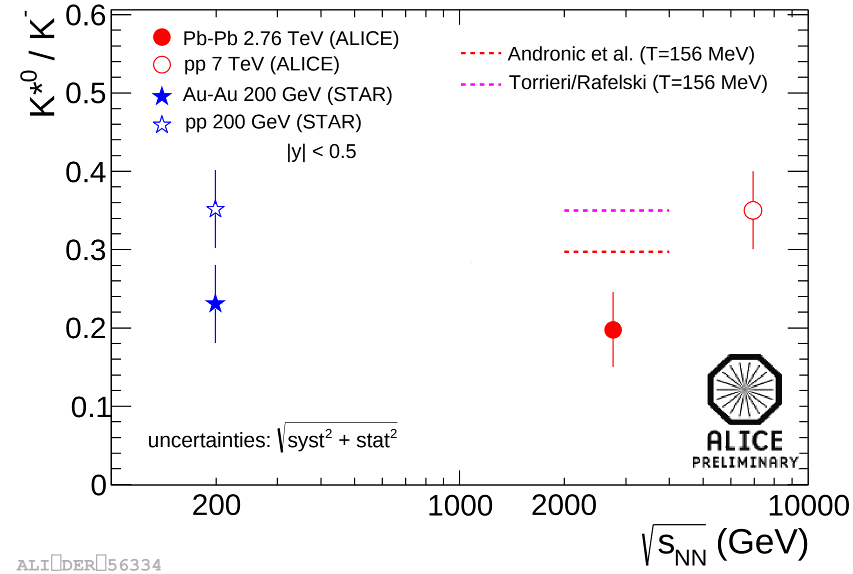
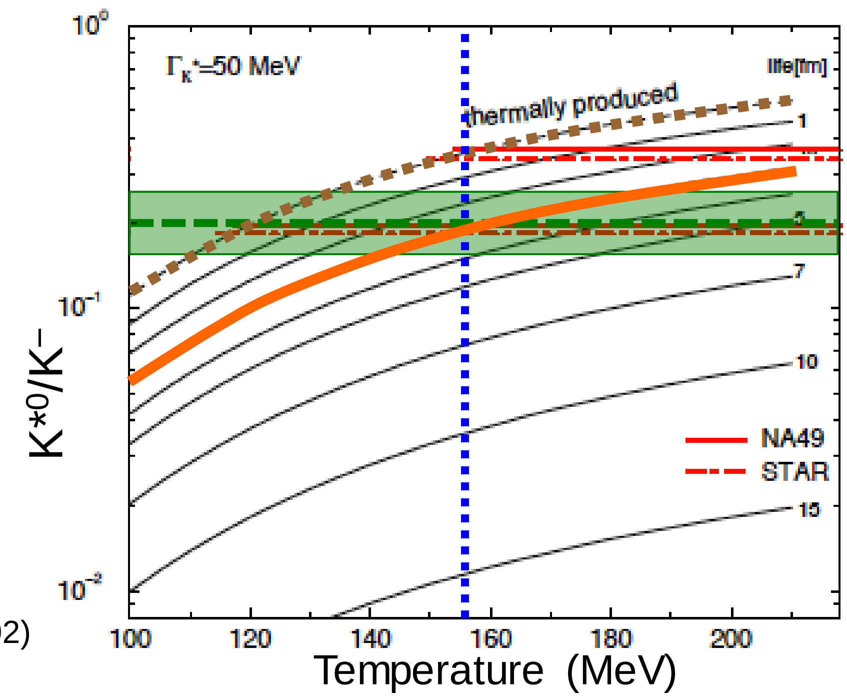
no re-scattering
measured K^{*0}/K^{-}
→ Prediction: T_{ch} = 120±13 MeV

Torrieri/Rafelski [2-4]
measured K^{*0}/K^{-}
T_{ch} = 156 MeV
→ Prediction: Lifetime ≥ 1.5 fm/c

Calculation for SPS/RHIC energies





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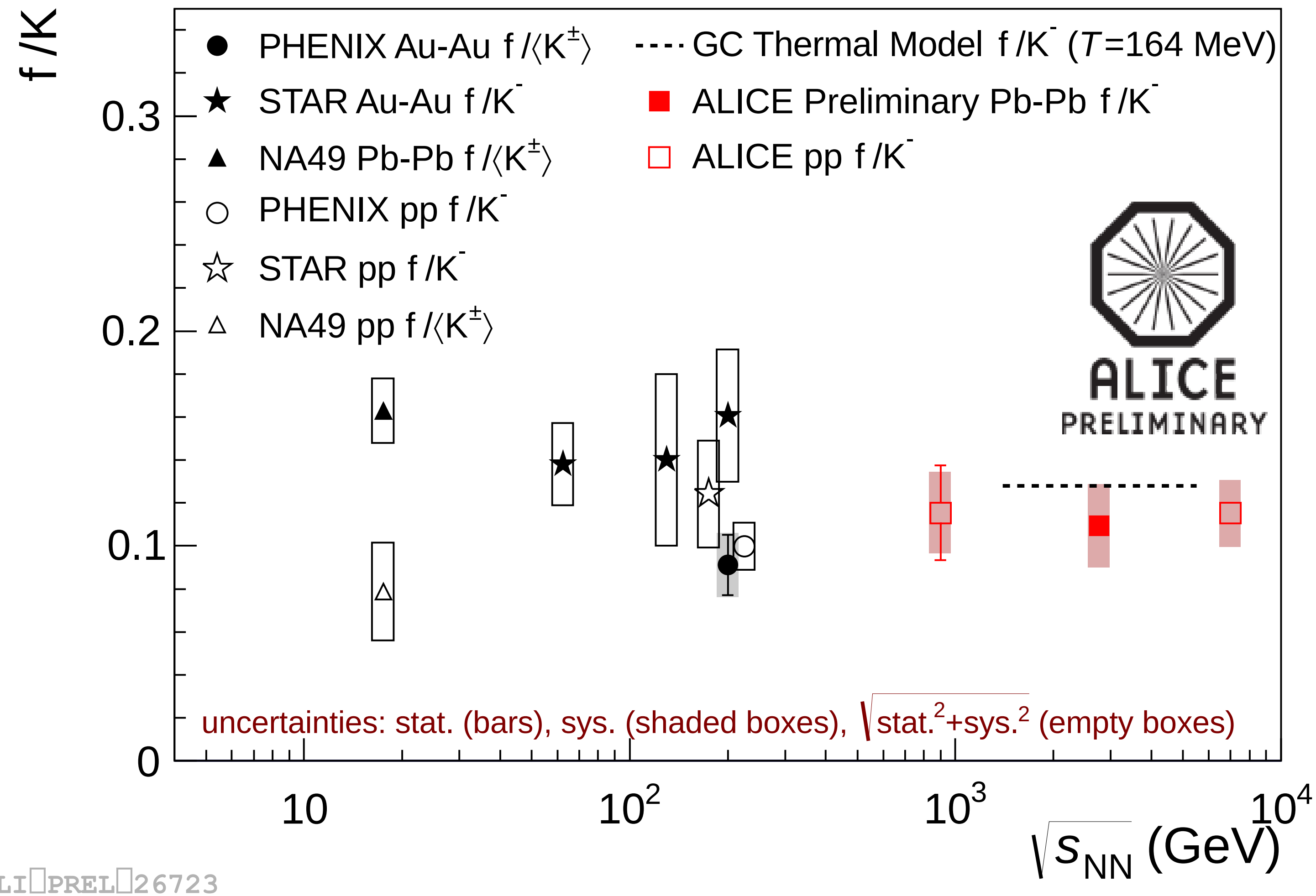
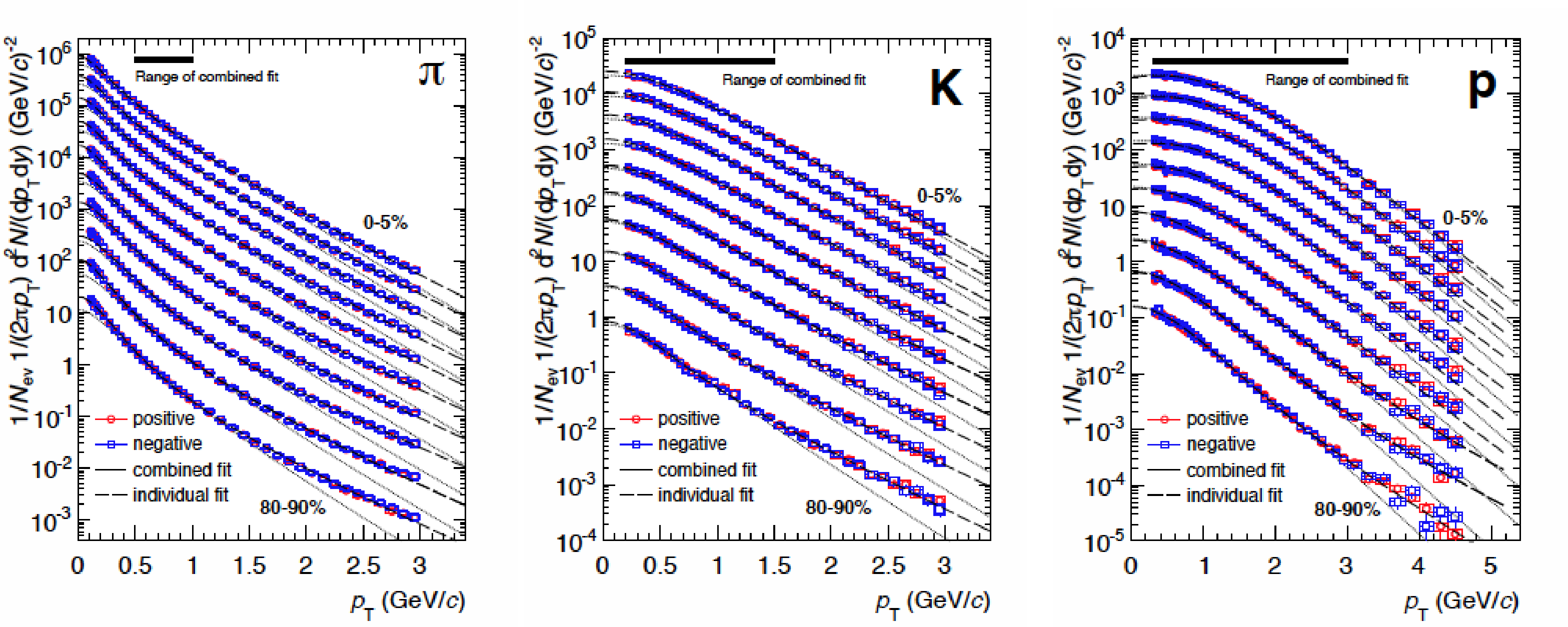
φ/K vs. Energy

- φ/K independent of energy and system from RHIC to LHC energies
  - Ratio in Pb–Pb consistent with Grand Canonical thermal model prediction (Andronic *et al*., *J. Phys. G* **38** 124081 (2011))



Spectrum Shapes

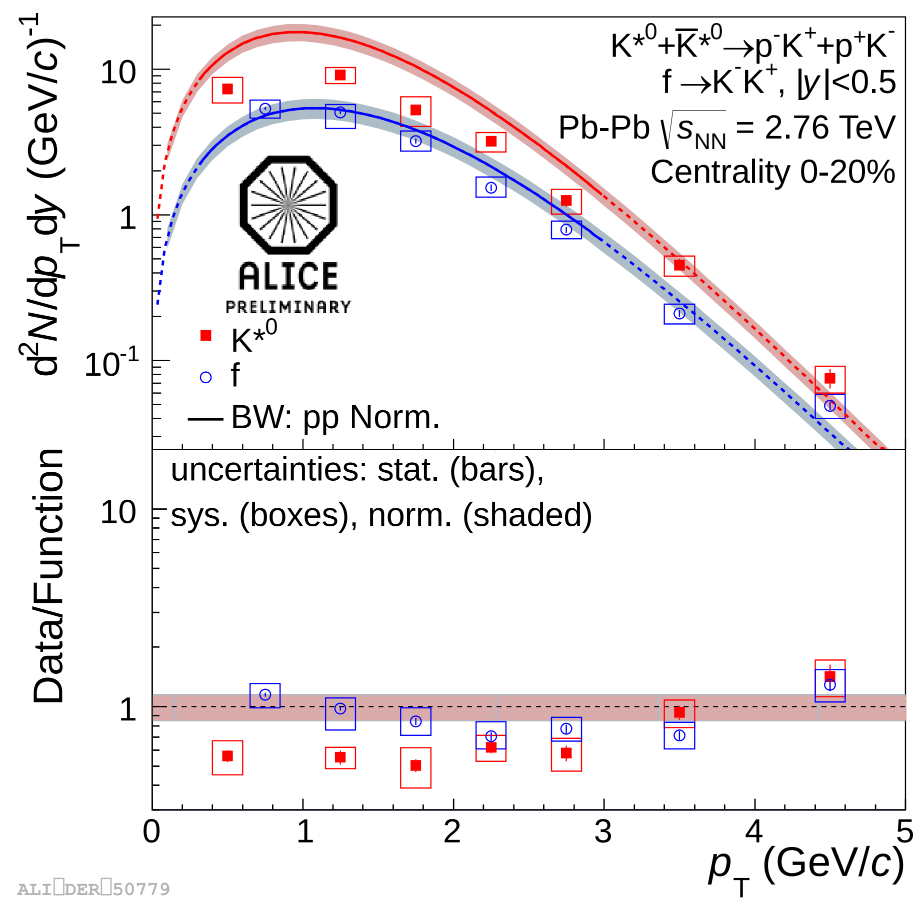
- K^{*0} yield is modified by re-scattering, ϕ yield is not
  - Models (UrQMD) predict re-scattering strongest for p_T<2 GeV/*c*
  - Can we observe p_T dependence of resonance suppression?
- Generate predicted K^{*0} and ϕ spectra:
  - Use blast-wave model, parameters (T_{kin}, n, and β_s) measured in global BW fits of π, K, and p in Pb–Pb collisions
  - B. Abelev *et al*. (ALICE), CERN-PH-EP-2013-019, arXiv:13030737v1 (2013)



Fit ranges: 0.5<p_T(p)<1 GeV/*c* 0.2<p_T(K)<1.5 GeV/*c* 0.3<p_T(p)<3 GeV/*c*

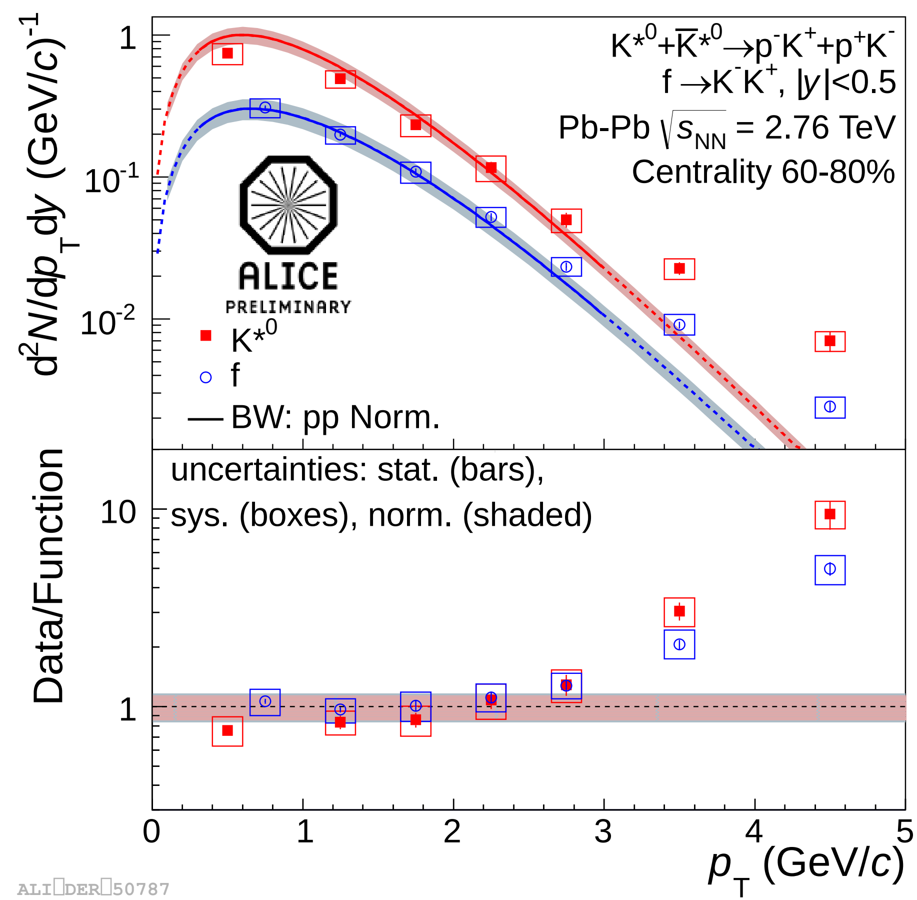
Predicted Spectra

- Model (0-20%): T_{kin}=97.1 MeV, n=0.725, β_s=0.879
  - K^{*0}: Integral = Yield($K^{\pm}$,Pb–Pb) × Ratio(K^{*0}/K,pp)
  - ϕ: Integral = Yield($K^{\pm}$,Pb–Pb) × Ratio(ϕ/K,pp)
  - Assumes no re-scattering and common freze-out
- Centrality 0-20%
  - K^{*0} yield suppressed w.r.t. prediction for p_T<3 GeV/c
    - Suppression is flat (≈0.6) for p_T<3 GeV/c
  - ϕ yield not suppressed
  - K^{*0} and ϕ follow similar trend for high p_T



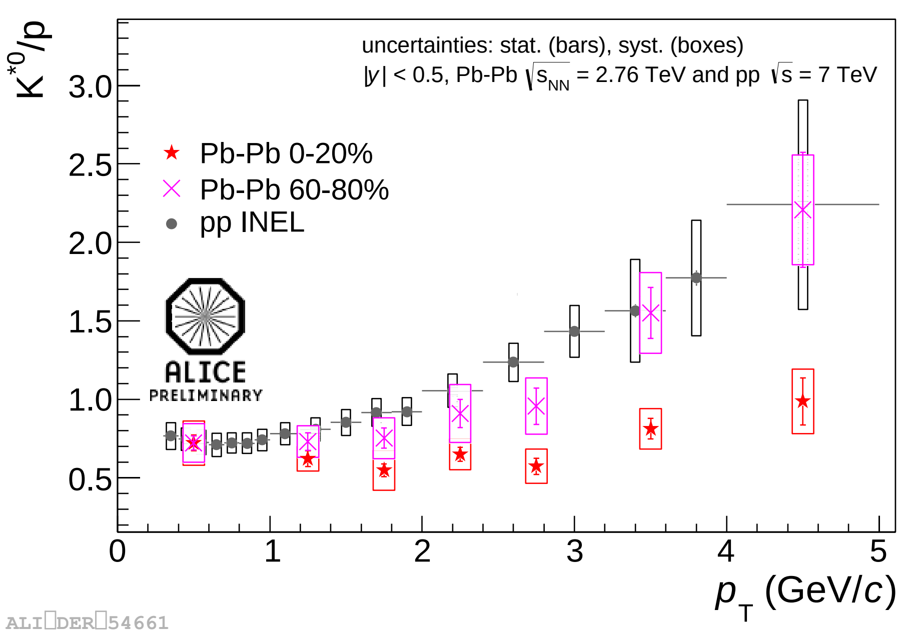
Predicted Spectra

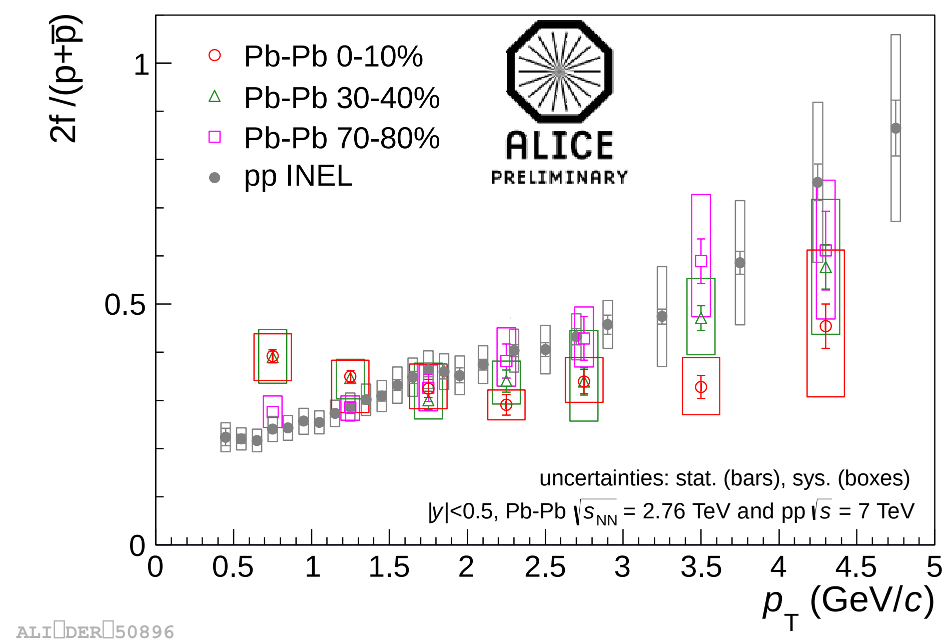
- Model (60-80%): T_{kin}=132.2 MeV, n=1.382, β_s=0.798
  - – K*⁰: Integral = Yield(K±,Pb–Pb) × Ratio(K*⁰/K,pp)
  - □ ϕ: Integral = Yield(K±,Pb–Pb) × Ratio(ϕ/K,pp)
  - – Assumes no re-scattering and common freze-out
- Centrality 0-20%
  - – K*⁰ yield suppressed w.r.t. prediction for p_T<3 GeV/c
    - Suppression is flat (≈0.6) for p_T<3 GeV/c
  - □ ϕ yield not suppressed
  - – K*⁰ and ϕ follow similar trend for high p_T
- Centrality 60-80%
  - – Neither suppressed
  - – Deviations at high p_T similar to other particles



K^{*0}/p and ϕ/p vs. p_T

- K^{*0}/p and ϕ/p:
  - Flat for central collisions
  - Increasing slope for peripheral collisions
  - Peripheral Pb–Pb similar to pp ($\sqrt{s}$=7 TeV)
- Different production mechanism for K^{*0}, p, or ϕ in central vs. peripheral & pp?
- $\langle p_T \rangle$ peripheral→central:
  - $\langle p_T \rangle$ of $\pi^{\pm}$, $K^{\pm}$, K^{*0}, and ϕ increases by ~20%
  - $\langle p_T \rangle$ of protons increases by 50%

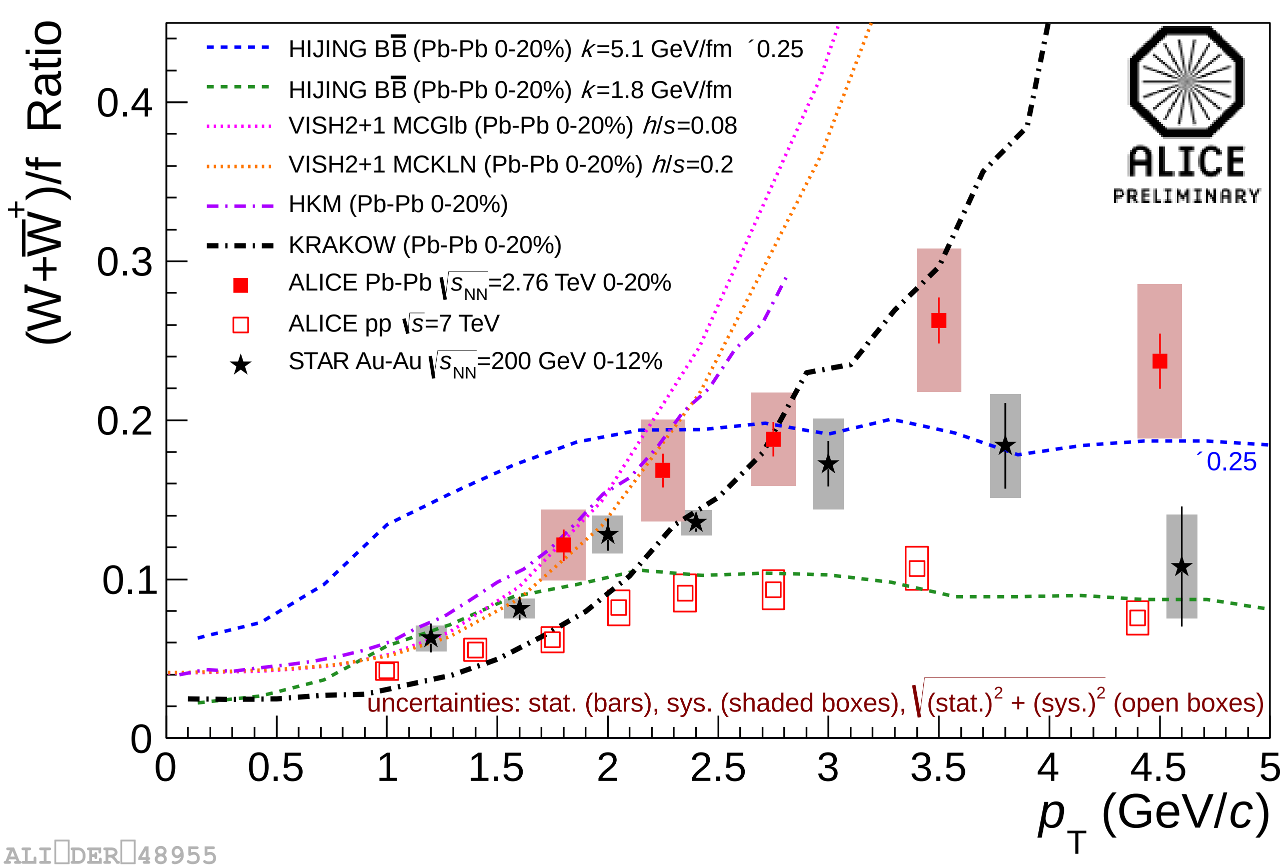




Ω/ϕ vs. p_T

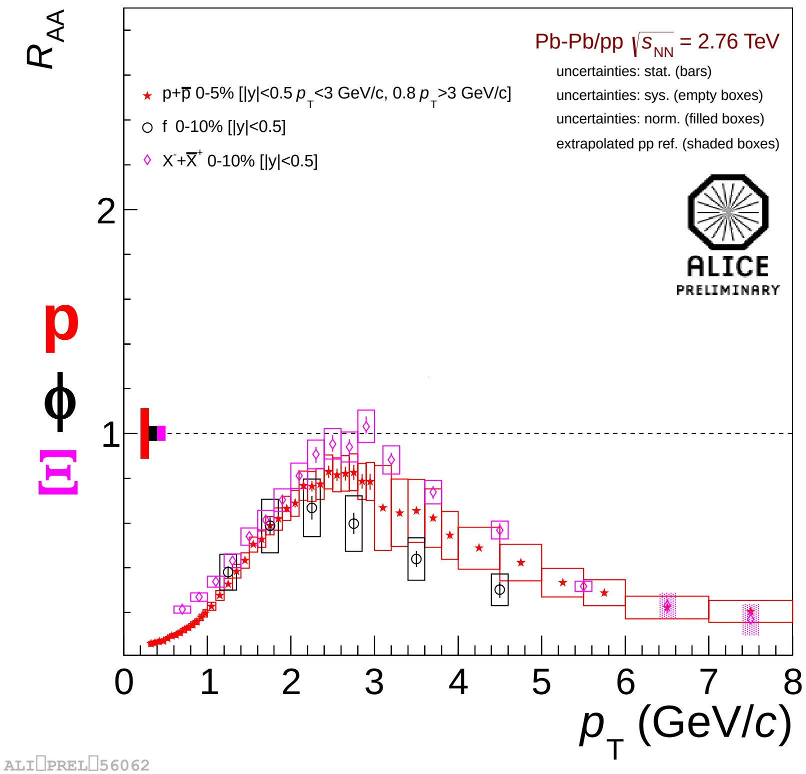
- Ratio in Pb-Pb consistent with Au-Au (200 GeV) for p_T<3.5 GeV/c
- VISH2+1 and HKM (hydro) predictions consistent with data for p_T<2.5 GeV/c
- **KRAKOW** model (hydro) consistent with data for 2.5<p_T<3.7 GeV/c
- HIJING/B$\bar{B}$ does not describe data (does predict flat ratio at high p_T)

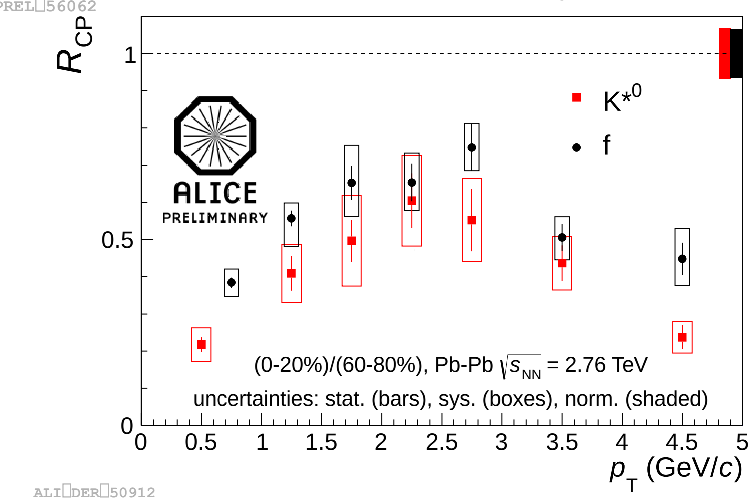
HIJING B$\bar{B}$
HIJING B$\bar{B}$
VISH2+1 MCGlb
VISH2+1 MCKLN
HKM
KRAKOW
ALICE Pb-Pb
ALICE pp
STAR Au-Au



R_{AA} and R_{CP}

- Central Collisions:
  - Low p_T: $\boldsymbol{R_{AA}(\phi)}$ follows R_{AA}(p) and $R_{AA}(\Xi)$
  - High p_T:
    - $\boldsymbol{R_{AA}(\phi)}$ between $R_{AA}(\pi$,K) and R_{AA} (p)
    - $\boldsymbol{R_{AA}(\phi)}$ tends to be below R_{AA}(p) despite larger ϕ mass, but consistent within uncertainties
    - $\boldsymbol{R_{AA}(\phi)}$ below $R_{AA}(\Xi)$, despite similar strange quark content
    - All R_{AA} values converge around $p_T \approx 7$ GeV/c
- Peripheral Collisions:
  - $\boldsymbol{R_{AA}(\phi)}$ follows R_{AA}(p) and $R_{AA}(\Xi)$
  - All R_{AA} values converge around $p_T \approx 4$ GeV/c
- $R_{CP}(K^{*0})$ tends to be lower than $\boldsymbol{R_{CP}(\phi)}$, but same within uncertainties





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    - **R_{AA}(ϕ)** below R_{AA}(Ξ), despite similar strange quark content
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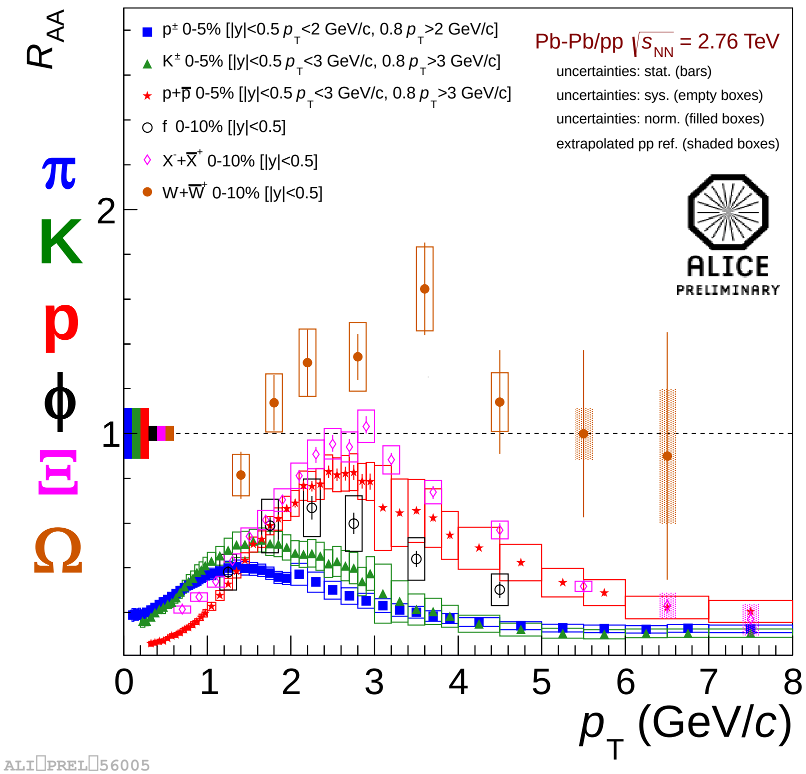

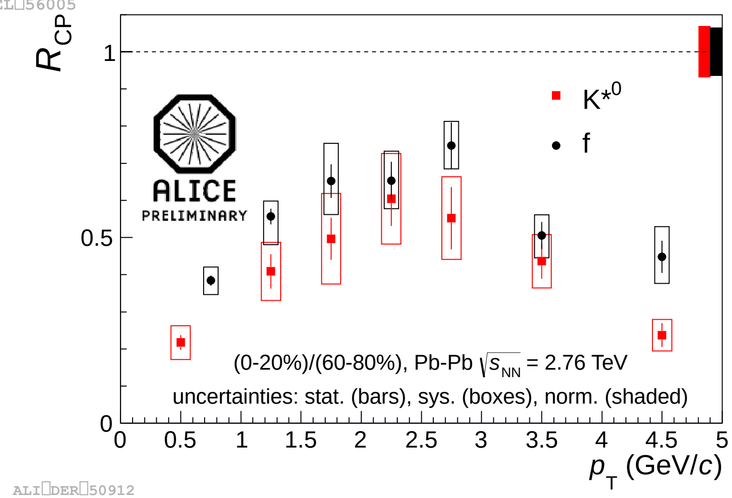

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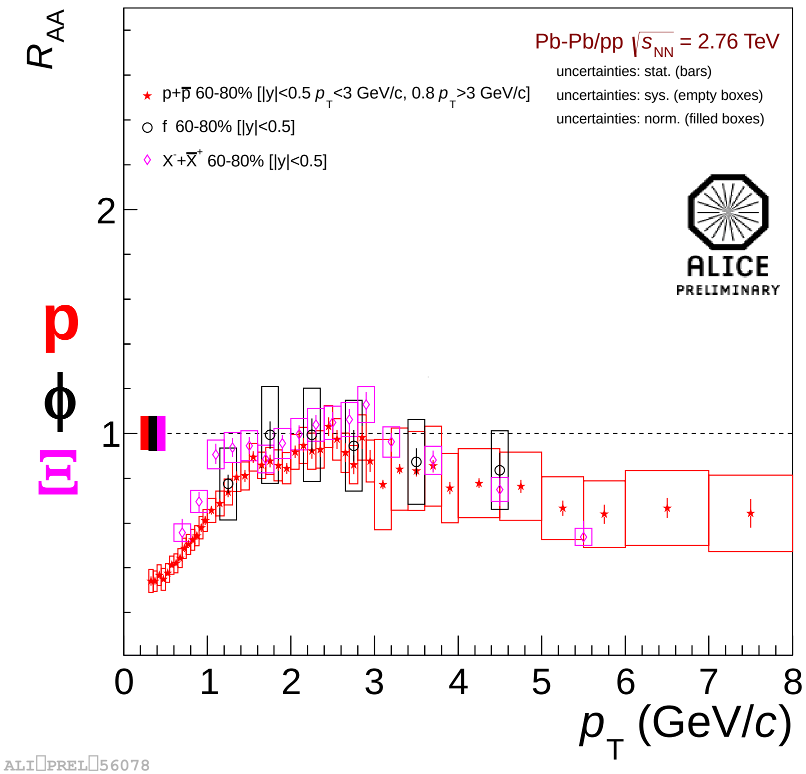

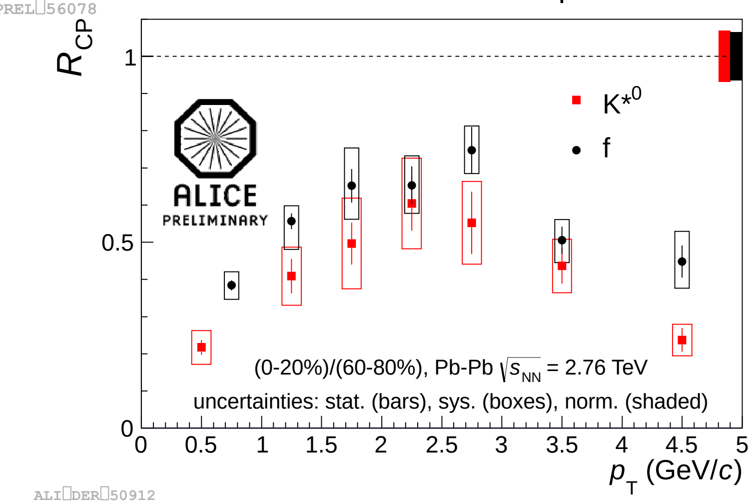

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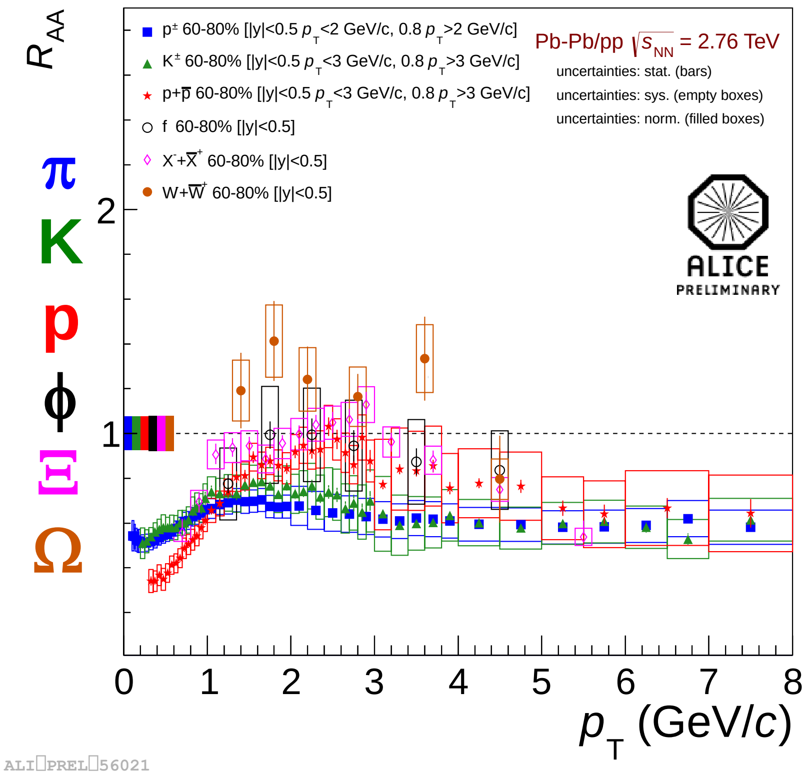
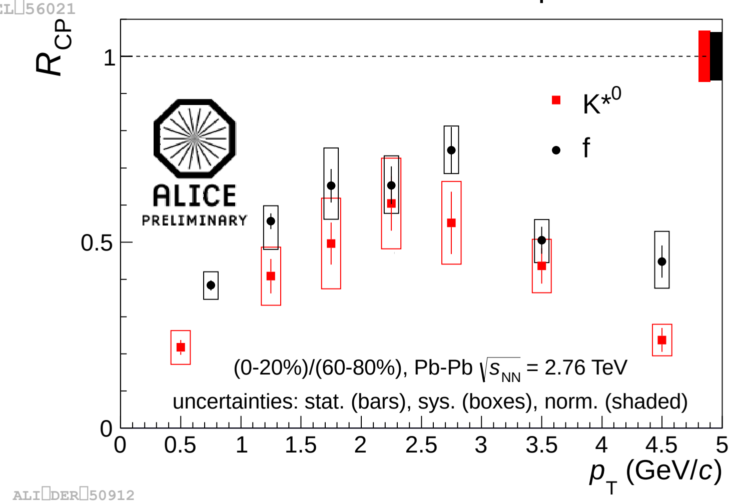




Conclusions

- Resonance Mass and Width
  - When K^{*0} and ϕ are reconstructed via hadronic decays, no mass shifts or width broadening
- $\langle p_T \rangle$ larger for more central collisions
  - Larger at LHC than at RHIC (increased radial flow)
- ϕ/K flat with centrality
- But K^{*0}/K decreases with centrality (re-scattering may reduce reconstructible K^{*0} yield)
  - Use measured K^{*0}/K + thermal model + re-scattering [Torrieri/Rafelski] to estimate lifetime of hadronic phase: $\geq$1.5 fm/c
- K^{*0} suppression flat in p_T ($\approx$0.6) for p_T<3 GeV/c
- K^{*0}/p and ϕ/p ratios vs. p_T:
  - Flat in central collisions
  - Increasing slope for peripheral collisions (despite very similar masses of these particles)
- R_{AA} at low p_T: $\boldsymbol{R_{AA}(\phi)}=R_{AA}(p)=R_{AA}(\Xi)$
- R_{AA} at intermediate p_T: $R_{AA}(\pi,K) \leq \boldsymbol{R_{AA}(\phi)} \leq R_{AA}(p) \leq R_{AA}(\Xi) \leq R_{AA}(\Omega)$

Backup

Finding Resonances

Find Decay Products

Event Selection:

$|v_z| < 10$ cm

8.2 M events for K^{*0}

9.5 M event for ϕ

Find $\pi^{\pm}$, $K^{\pm}$:

- Track Cuts:

Number of TPC Clusters

Track χ^2

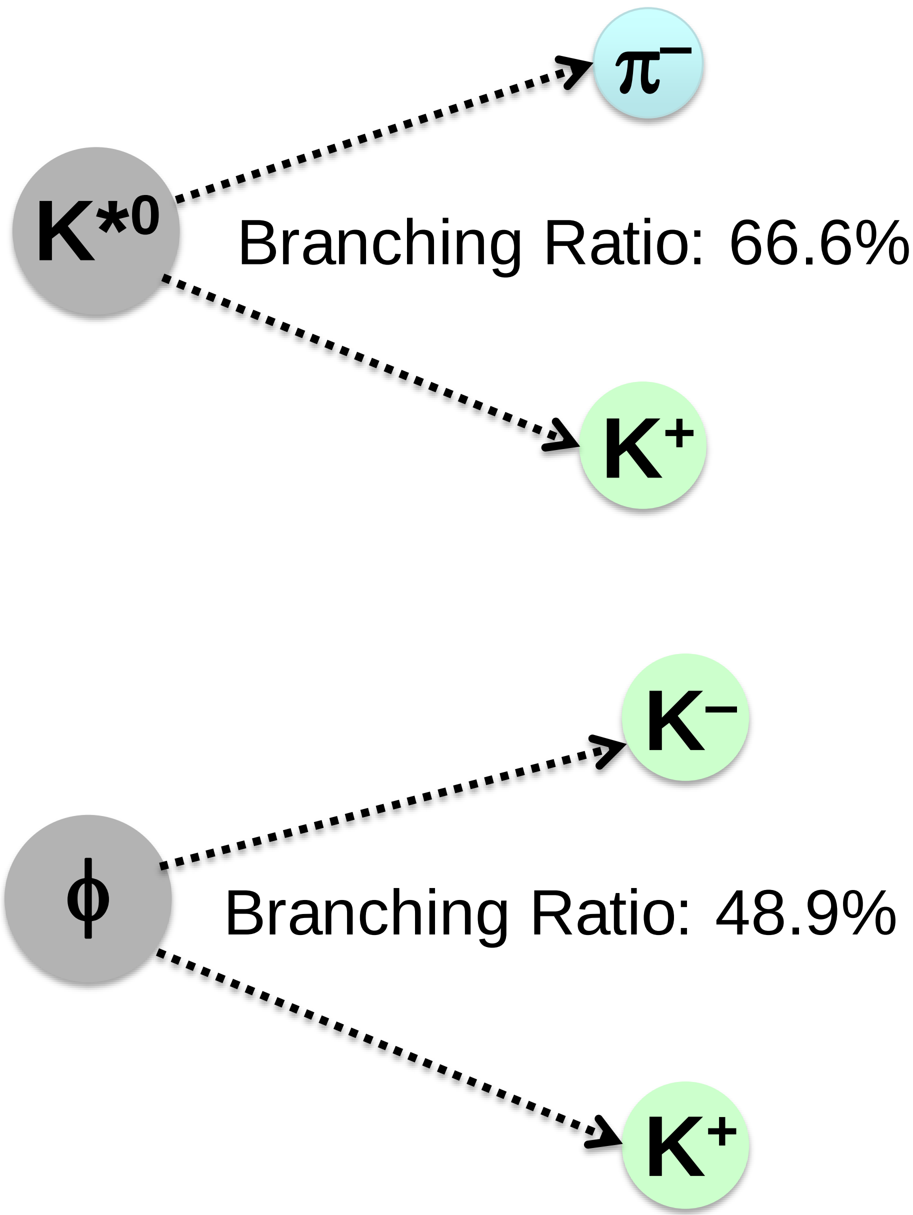
DCA to Primary Vertex

Others…

- Particle Identification:

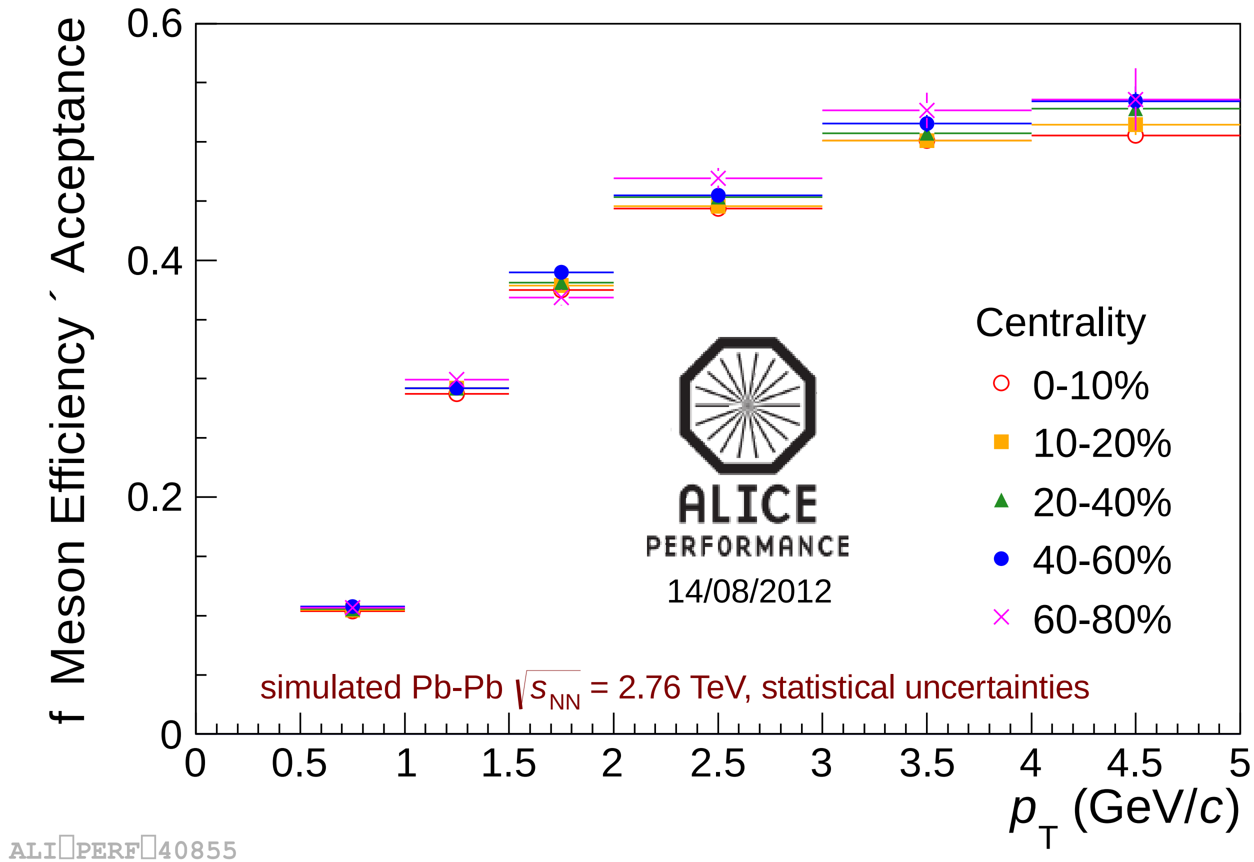
TPC Energy Loss (d*E*/d*x*)

$2\sigma_{TPC}$ cut for π and K



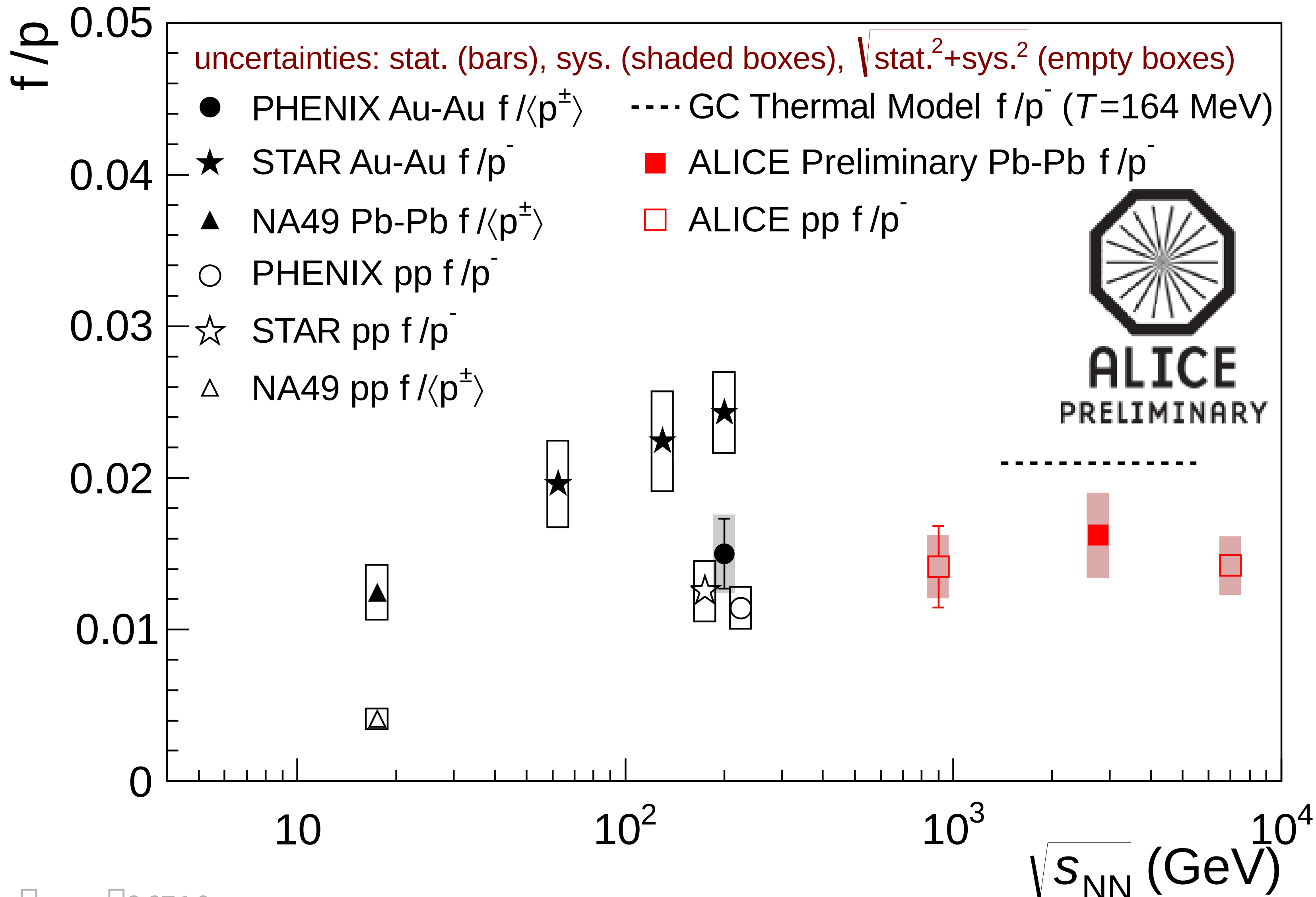
Corrections

- Corrections:
  - Efficiciency × Acceptance from simulation
  - PID Efficiency ($2\sigma_{TPC}$ dE/dx cuts on each daughter → ε_{PID}=91%)



φ/π vs. Energy

- φ/π independent of energy and system at LHC energies



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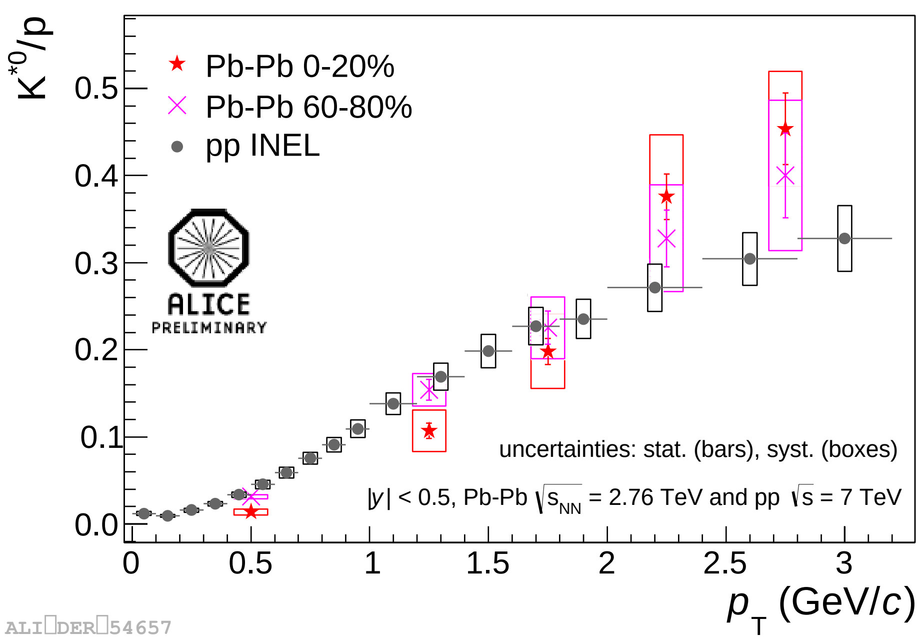
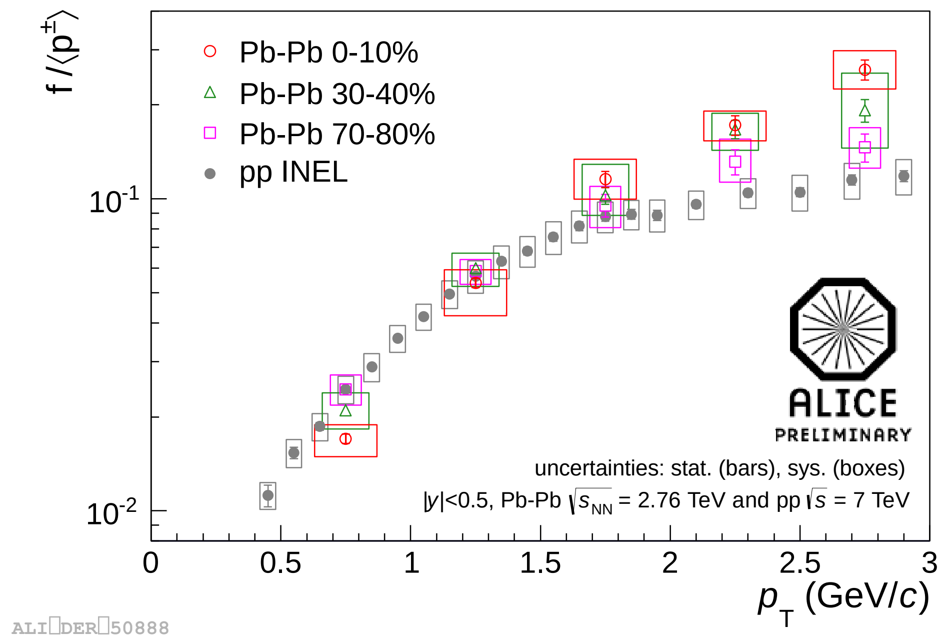
K*⁰/π and φ/π vs. p_T

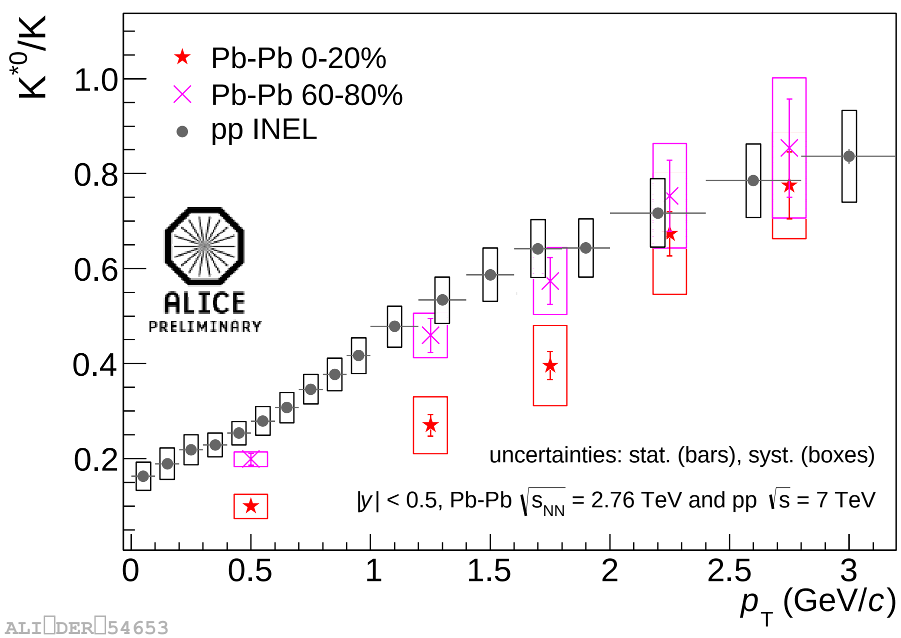
- K^{*0}/π and ϕ/π: increase with p_T
  - Slope decreases for peripheral collisions
  - Peripheral Pb–Pb similar to pp ($\sqrt{s}$=7 TeV)

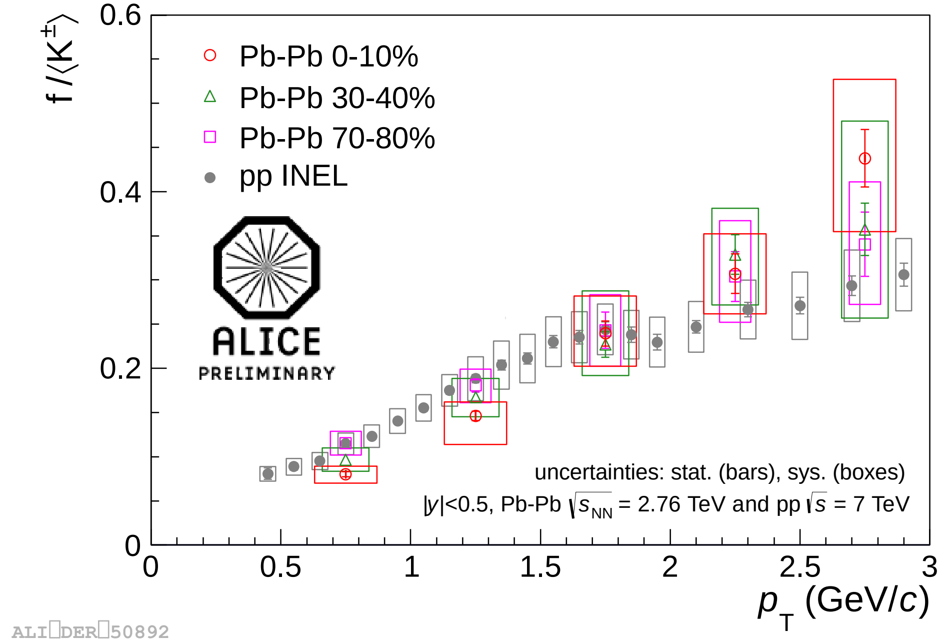




K^{*0}/K and ϕ/K vs. p_T

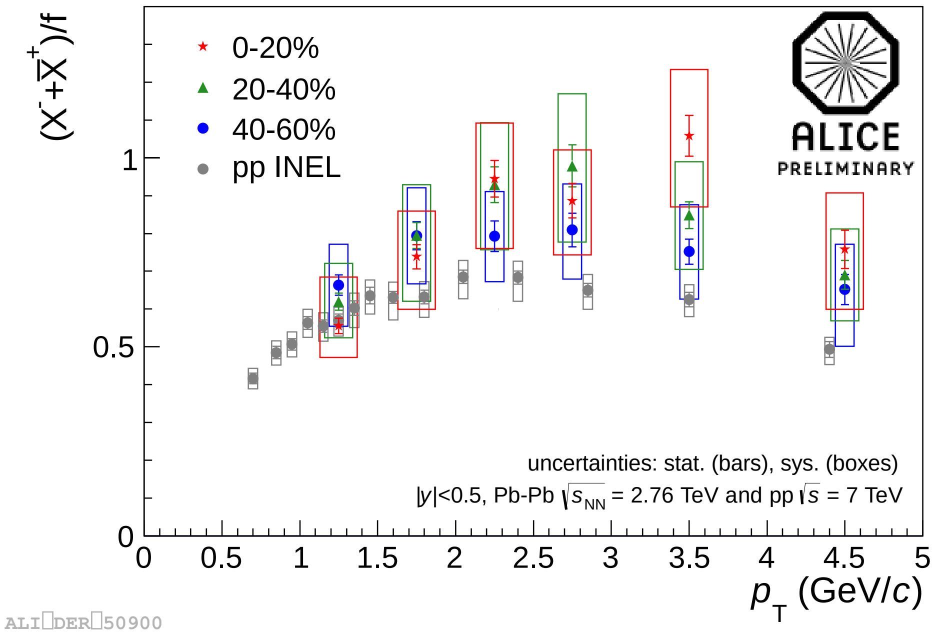
- K^{*0}/K and ϕ/K: (linear) increase with p_T
  - Slope decreases for peripheral collisions
  - Peripheral Pb–Pb similar to pp ($\sqrt{s}$=7 TeV)
  - Similar behavior in K^{*0}/π and ϕ/π ratios

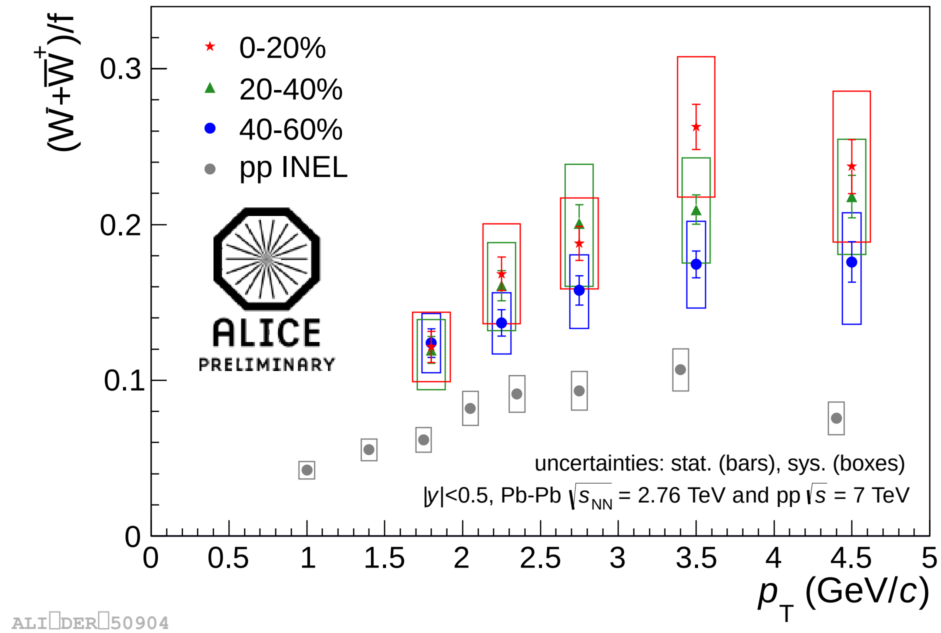




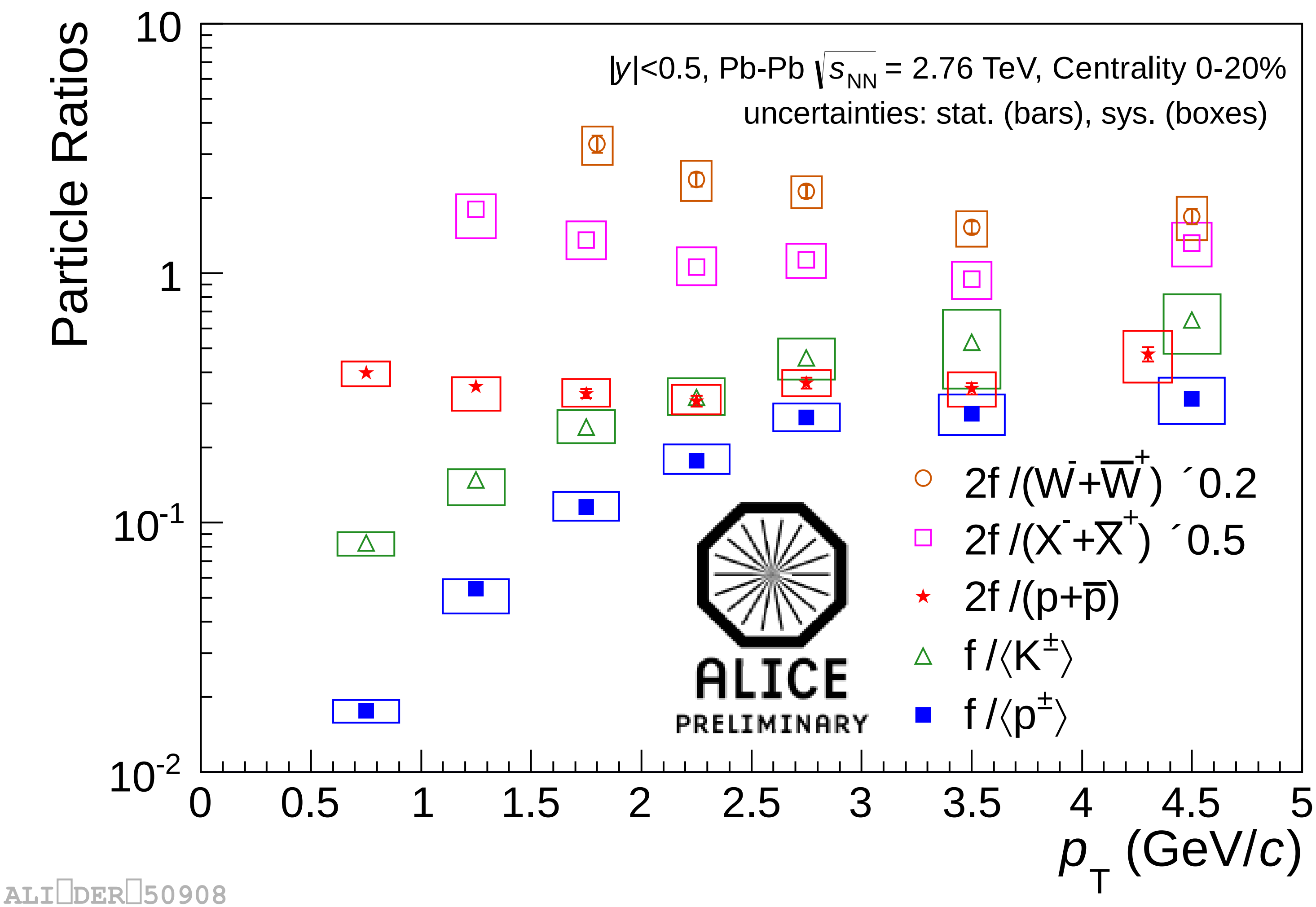
Ξ/ϕ and Ω/ϕ vs. p_T

- Ξ/ϕ and Ω/ϕ:
  - Increase with p_T at low p_T
  - Saturate or begin to decrease at high p_T
  - Become flatter for peripheral collisions



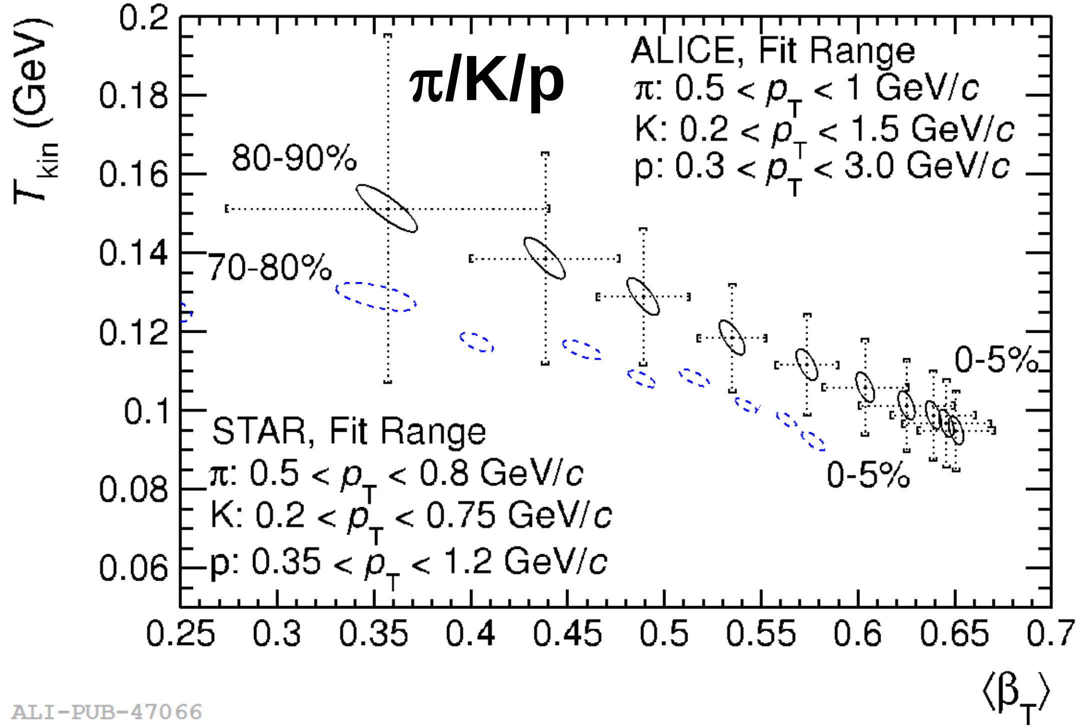


p_T-Dependent Ratios



Blast-Wave Fit Parameters

- Blast-wave parameters from π/K/p paper
  - central→peripheral: T_{kin} and n increase, β_s decreases



B. Abelev *et al*. (ALICE), CERN-PH-EP-2013-019, arXiv:13030737v1 (2013)