Hadronic resonances at ALICE

Anders G. Knospe
on behalf of the ALICE Collaboration
The University of Texas at Austin

Hot Quarks

20 October 2012

Outline

- Introduction
- Resonances in pp at $\sqrt{s}$ = 7 TeV
  - $\phi(1020)$, $K^*(892)^0$, $\Sigma^*(1385)^\pm$
  - In progress: $\rho(770)^0$, $\Delta(1232)^{++}$, $\Lambda^*(1520)$, $\Xi^*(1530)^0$
- Resonances in Pb–Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
  - $\phi(1020)$, $K^*(892)^0$

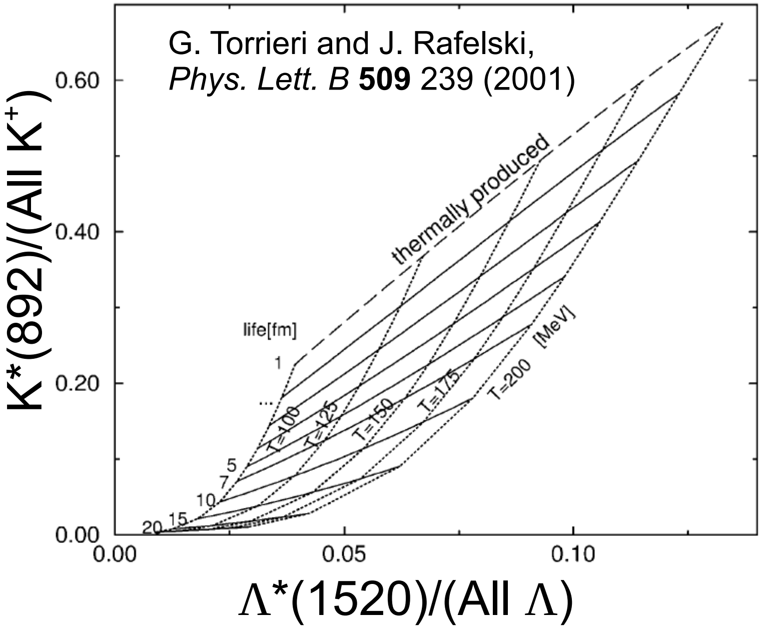
Name	Mass (MeV/c^2)	Width (MeV/c^2)	Decay Products	Branching Ratio
$K^*(892)^0$	895.94	48.7	π^-K^+, π^+K^-	66.6%
$\phi(1020)$	1019.455	4.26	K^-K^+	48.9%
$\Sigma^*(1385)^+$	1382.80	36.0	$\pi^+\Lambda \rightarrow \pi^+\pi^-p$	56.0%
$\Sigma^*(1385)^-$	1387.2	39.4	$\pi^-\Lambda \rightarrow \pi^-\pi^-p$	56.0%

Resonances in pp

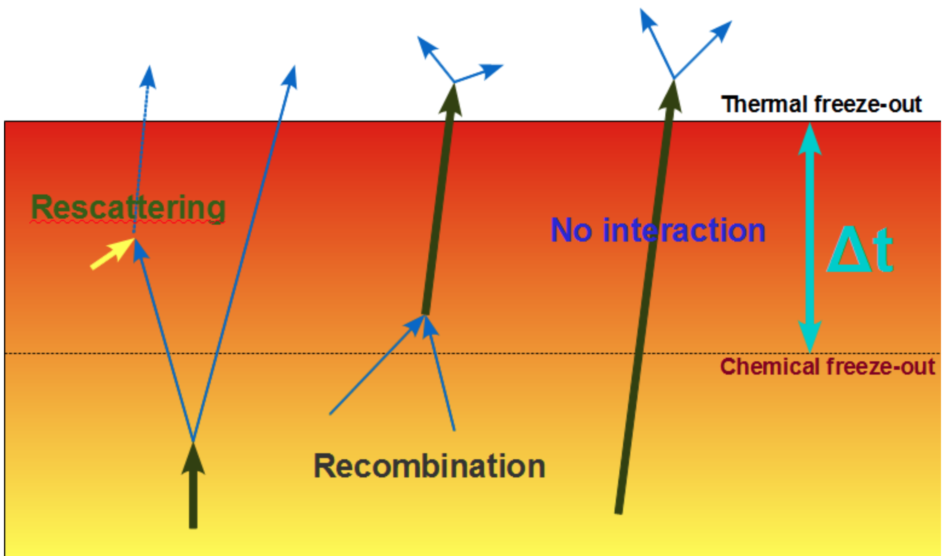
- Provide input for QCD-inspired models (PHTHIA, PHOJET, …)
  - Models tuned using particle spectra
- Baseline for comparison with A–A collisions
  - Masses, widths, particle ratios in absence of partonic medium
  - Denominator for R_{AA}

Resonances in A–A

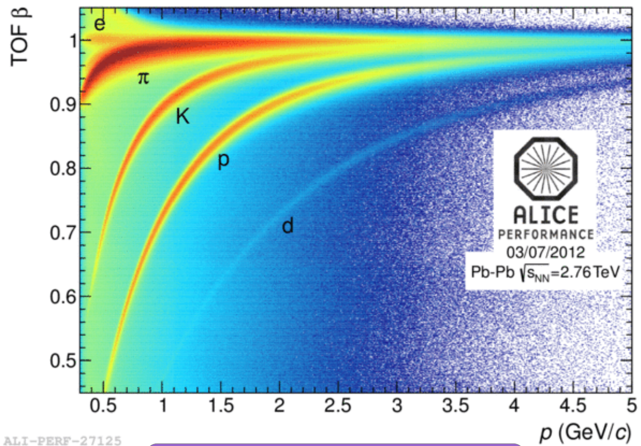
- Temperature and lifetime of fireball (hadronic phase)
  - Resonance formation through recombination
  - Re-scattering prevents resonance reconstruction
  - Statistical models, UrQMD predict resonance/non-resonance ratios
    - Given chemical freeze-out temperature and time between chemical and thermal freeze-out (Δt)
- Chiral symmetry restoration
  - Resonances may decay when chiral symmetry was (at least partially) restored
  - Mass shift and width broadening
    - Near T_C ρ lifetime may increase by factor of ~5*



*R. Rapp, *AIP Conf.Proc.*1322:55-63 (2010)



ALICE Detector

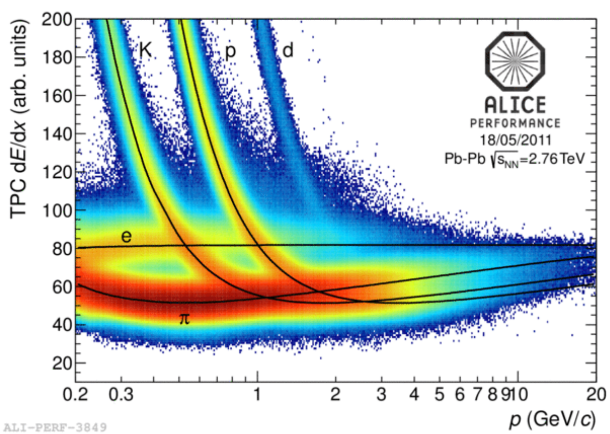


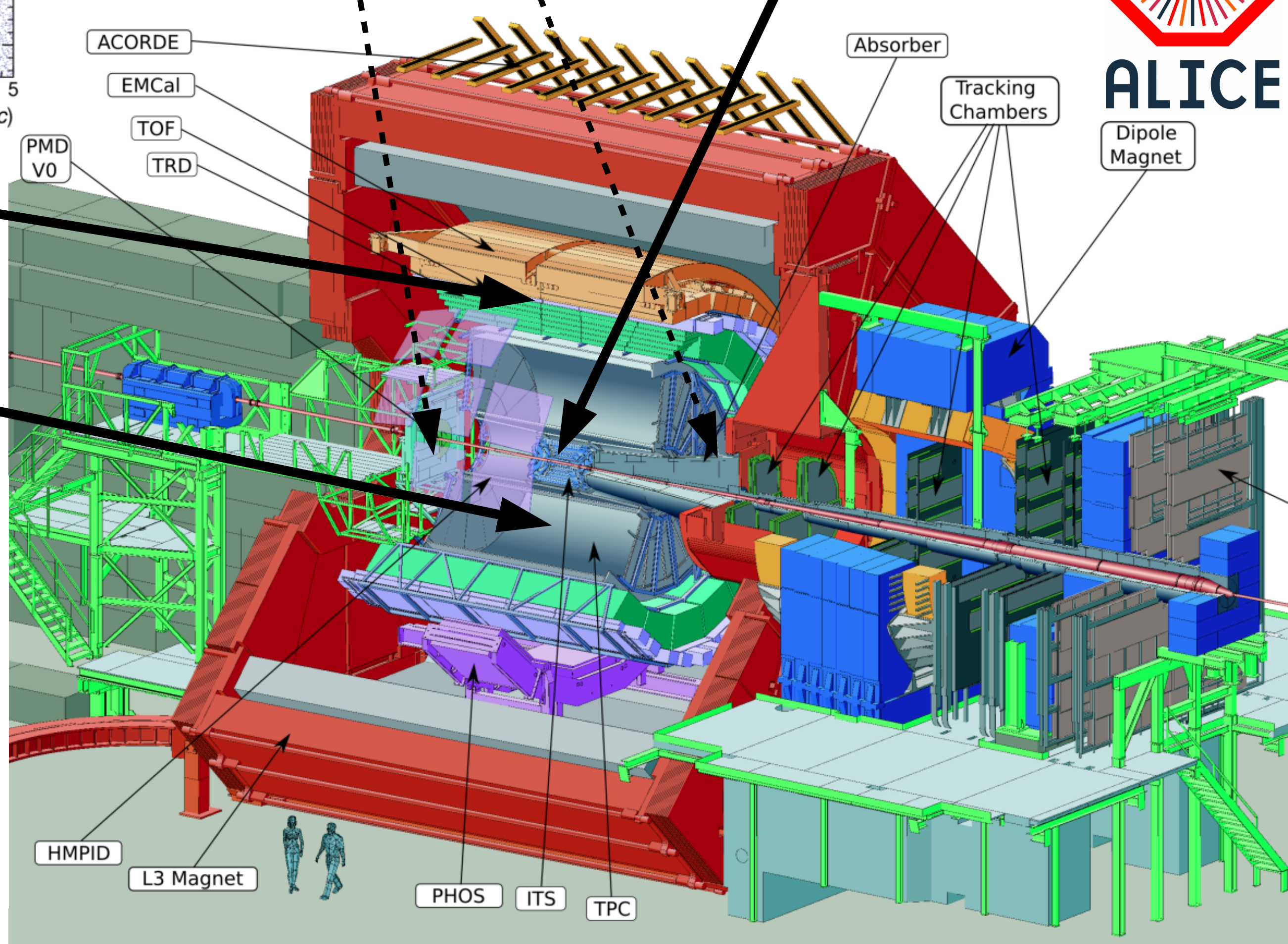
TOF: Particle ID

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

ITS (silicon): Tracking and Vertexing

TPC: Tracking and Particle ID through dE/dx





Finding Resonances

Find decay products

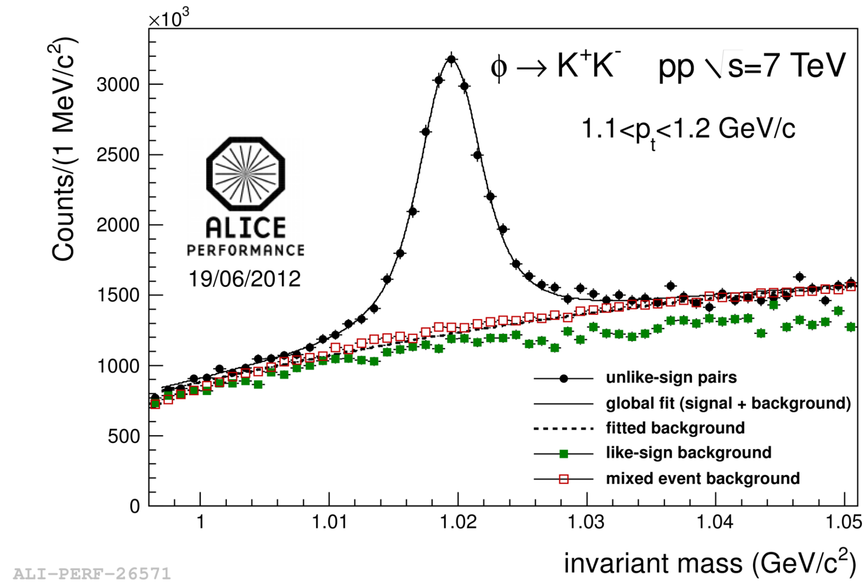
Find $\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$:

- **Track cuts:**
  - Number of TPC clusters
  - track χ^2
  - DCA to primary vertex
  - Others...
- **Particle Identification:**
  - TPC energy loss
  - TOF particle velocity

Finding Resonances

Find decay products

Construct invariant mass distribution



Example: ϕ in pp

Compute invariant mass of pairs of decay products

Finding Resonances

Find decay products

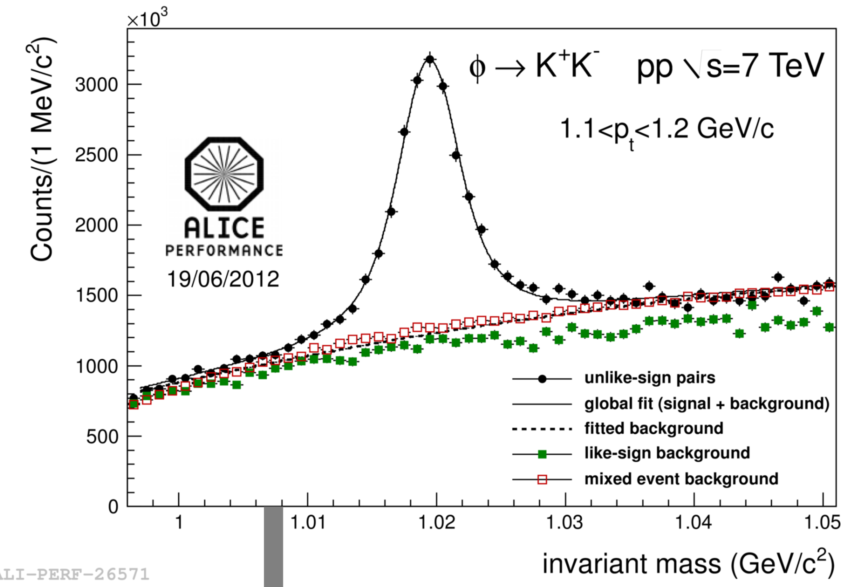
Construct invariant mass distribution

Describe background

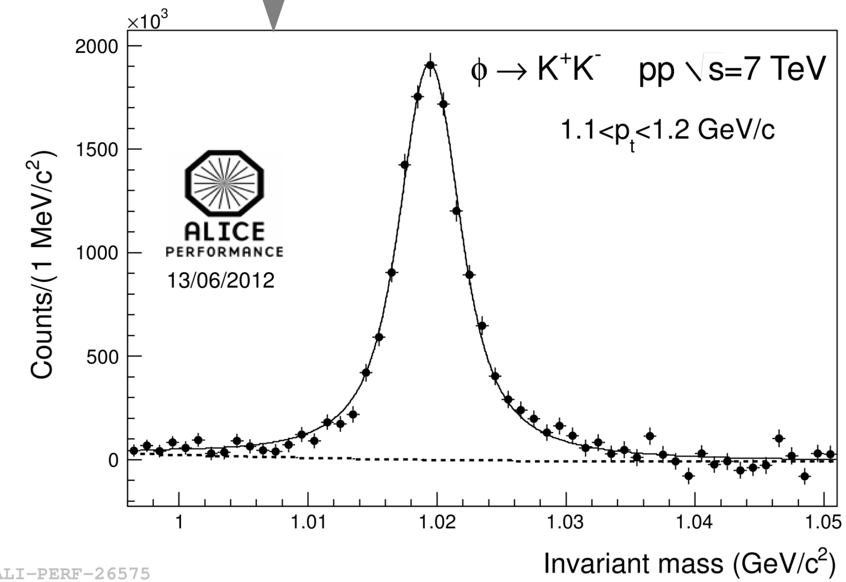
Fit background

Like-Sign Event mixing

Event mixing: cuts to ensure similar v_z, multiplicity, event plane



Background Subtraction



Finding Resonances

Find decay products

Construct invariant mass distribution

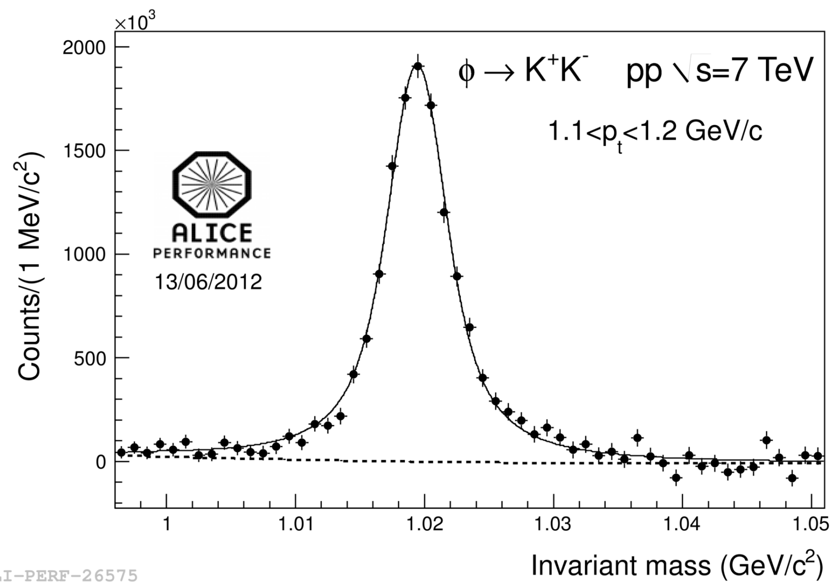
Describe background

Fit background

Like-Sign Event mixing

Describe residual background

Fit residual background, usually with polynomial



Finding Resonances

Find decay products

Construct invariant mass distribution

Describe background

Fit background

Like-Sign Event mixing

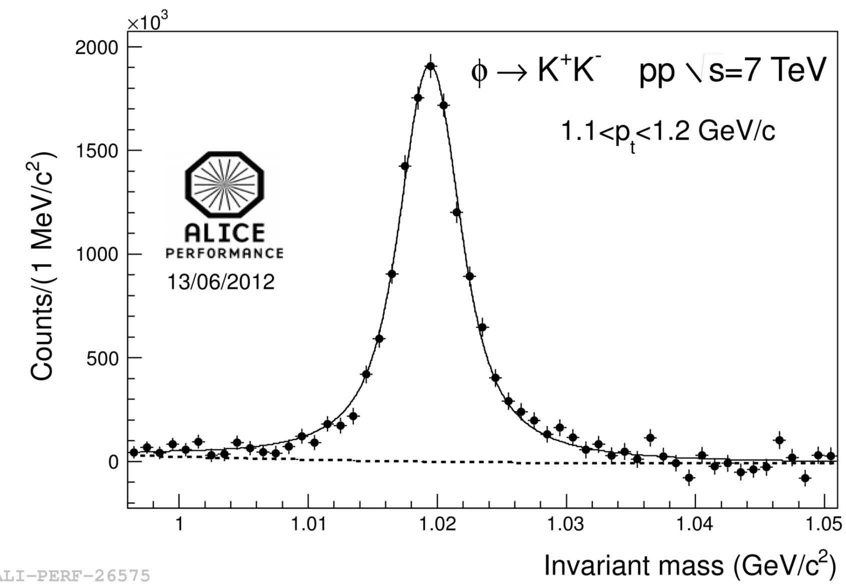
Describe residual background

Fit peak

Extract yield, mass, width

Fit peak with:
- **Breit-Wigner**
- **Voigtian**

  B-W convoluted with Gaussian to describe detector resolution (σ = 1-2 MeV/c^2)



Resonances in pp Collisions at $\sqrt{s}$ = 7 TeV (K^{*0}, ϕ, $\Sigma^{*\pm}$)

$K^*(892)^0$ in pp

80 M Events

Decay products: $\pi^{\pm}K^{\mp}$

PID: TOF

If no TOF signal, TPC used

Pair Cuts: $|y_{pair}| < 0.5$

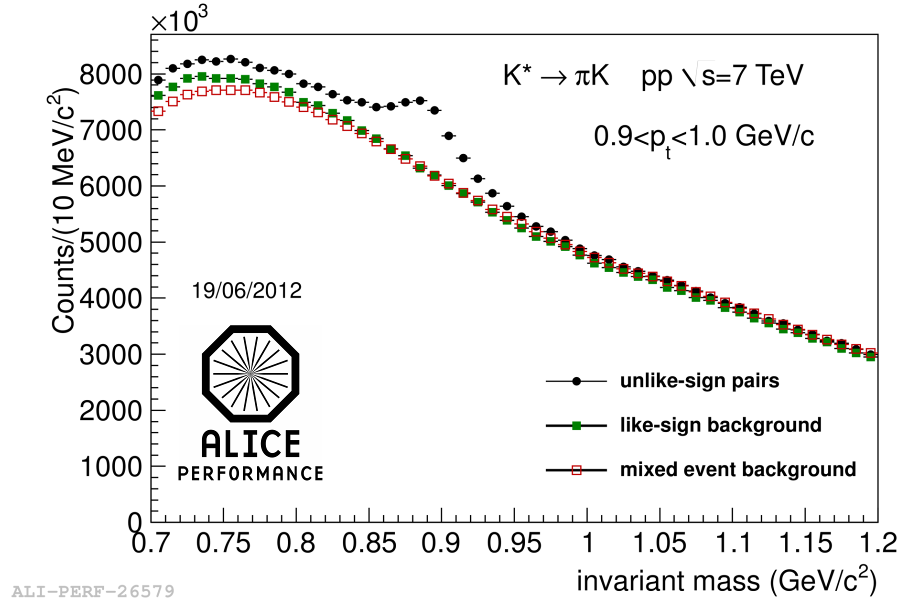
Background:

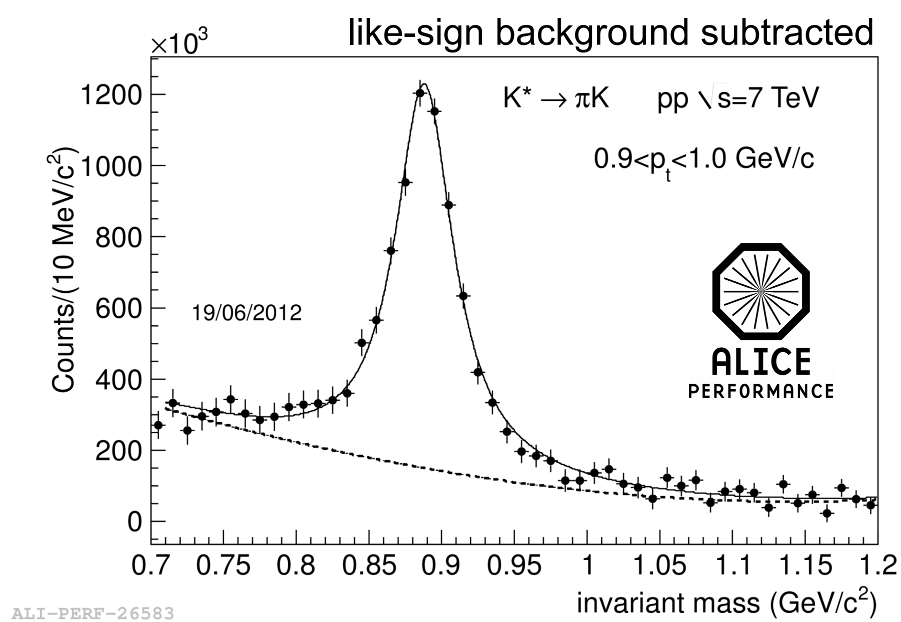
Like-sign (event mixing)

Residual Background:

2^{nd}-order polynomial

Peak Fit: Breit-Wigner





$\phi(1020)$ in pp

60 M Events

Decay products: $K^{-}K^{+}$

PID: TPC

+ TOF if signal present

Pair Cuts: $|y_{pair}| < 0.5$

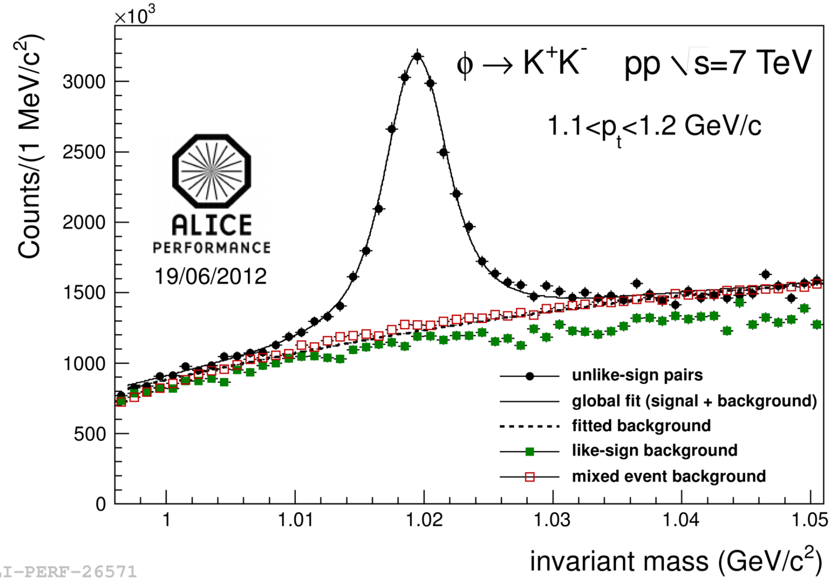
Background:

Event mixing (like-sign)

Residual Background:

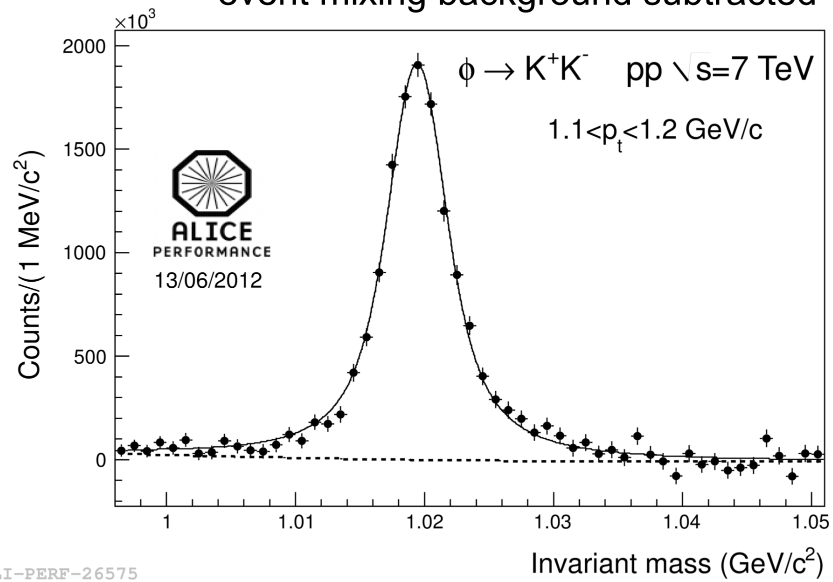
2nd-order polynomial

Peak Fit: Voigtian



ALI-PERF-26571

event mixing background subtracted



ALI-PERF-26575

$\Sigma^*(1385)^{\pm}$ in pp

211 M Events

Decay products: $\Lambda\pi^{\pm} \rightarrow p\pi^{-}\pi^{\pm}$

Track cuts:

- DCA of decay daughters
- Λ pointing angle

Pair Cuts: $|y_{pair}| < 0.8$

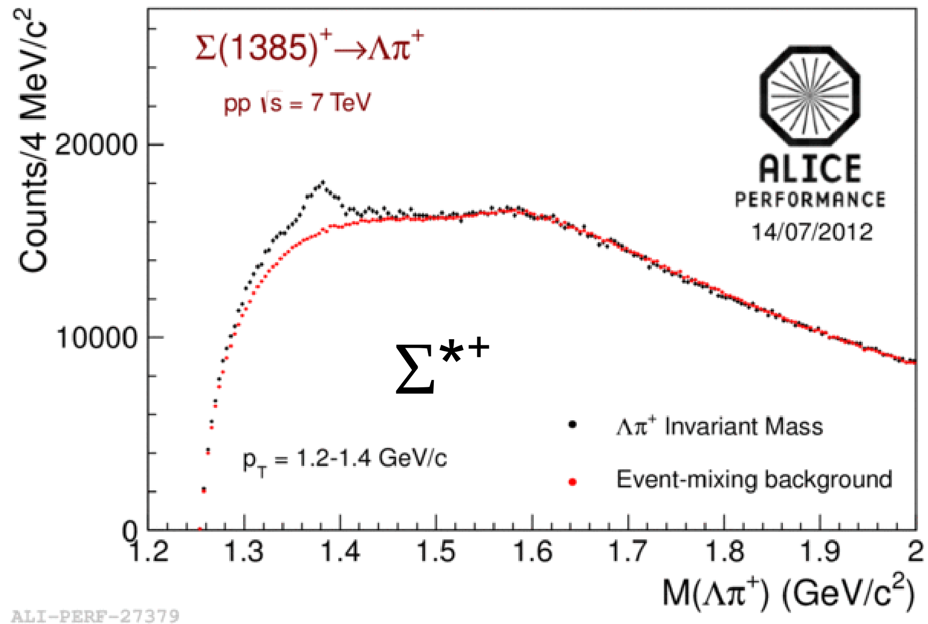
Background:

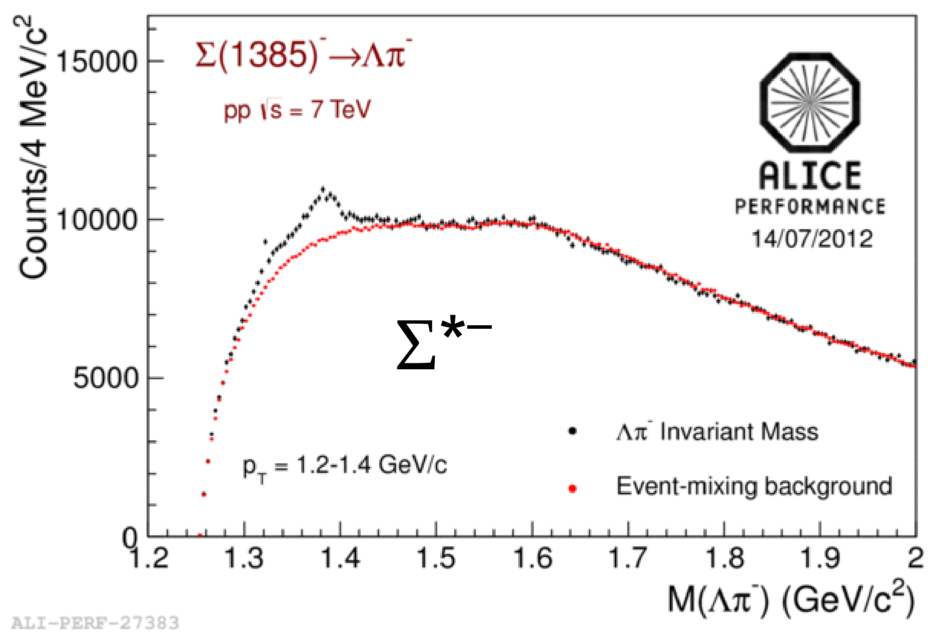
- Event mixing

Residual Background:

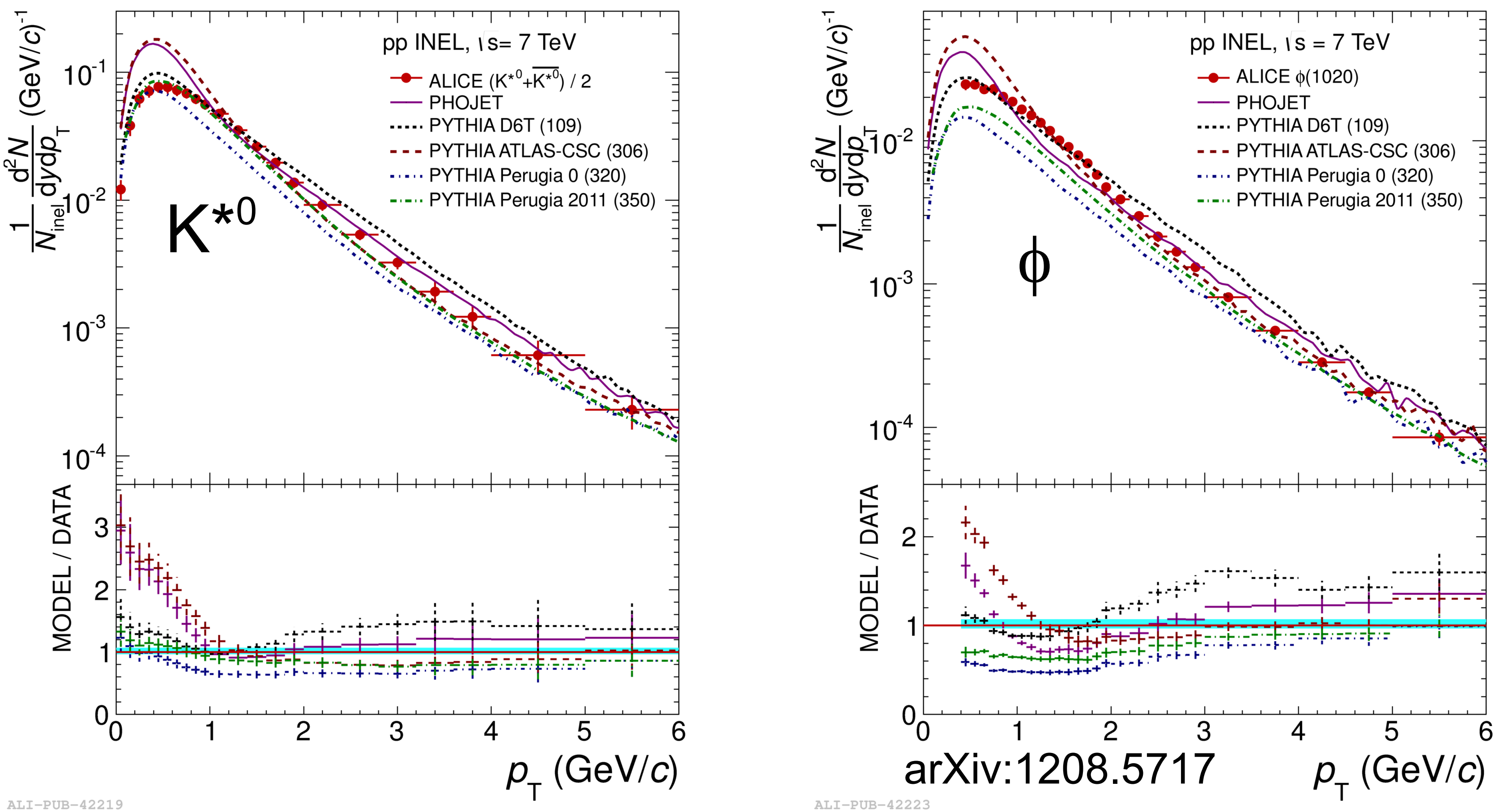
- parametrized using MC, scaled to match data

Peak Fit: Breit-Wigner





K*(892)^0 and ϕ(1020) in pp



arXiv:1208.5717

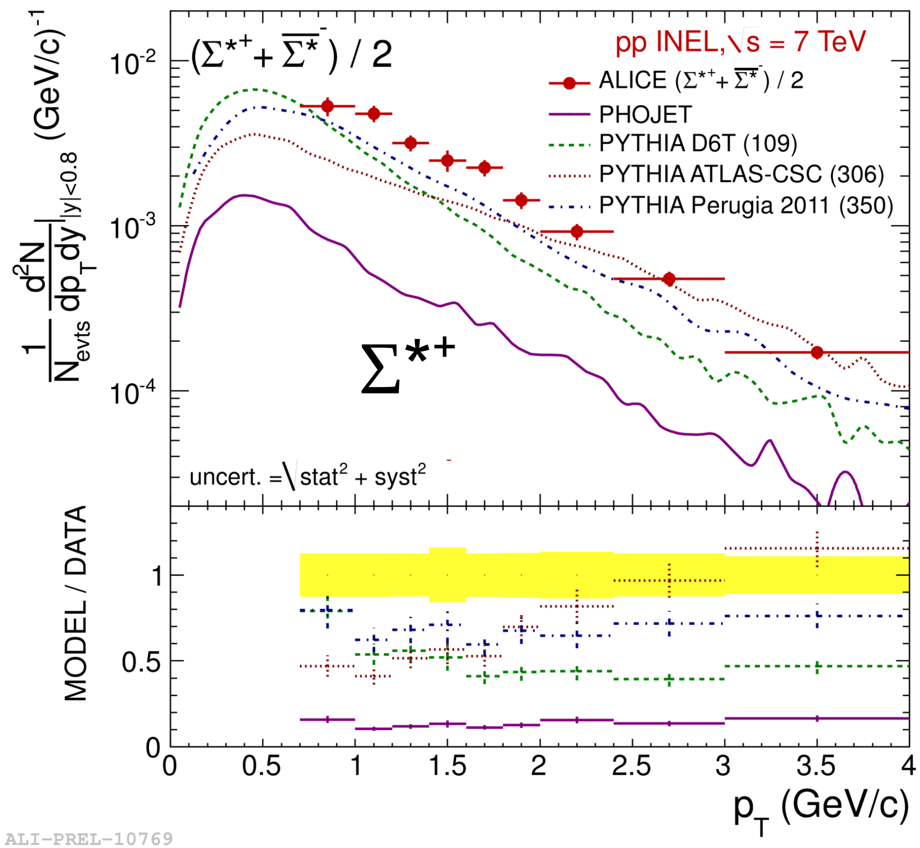
PYTHIA Perugia 2011: reproduces K*^{0} and ϕ (p_T > 3 GeV/c) well

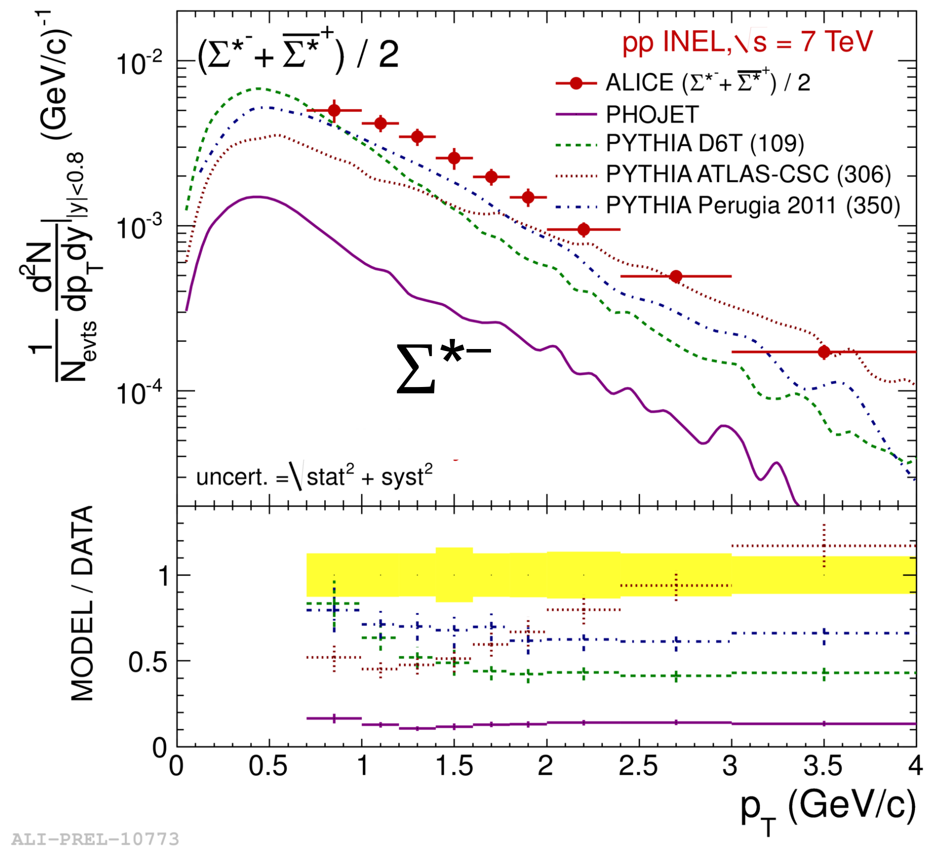
PHOJET, PYTHIA ATLAS-CSC: overestimate spectra for p_T < 1 GeV/c, describe high p_T well

PYTHIA D6T: deviates at high p_T

PYTHIA Perugia 0: underestimates spectra for p_T > 0.5 GeV/c

Σ*(1385)± in pp





PYTHIA ATLAS-CSC: good agreement for p_T > 2 GeV/c

PHOJET; PYTHIA D6T, Perugia 2011: under-predict data

Resonances in Pb–Pb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV (K^{*0}, ϕ)

$K^*(892)^0$ in Pb–Pb

8.2 M Events

Decay products: $\pi^{\pm}K^{\mp}$

PID cuts: TPC

Pair Cuts: $|y_{pair}| < 0.5$

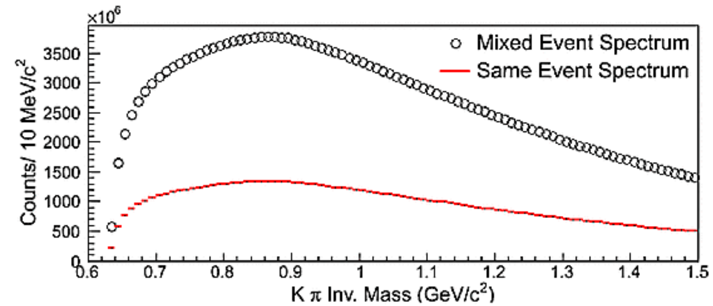
Background:

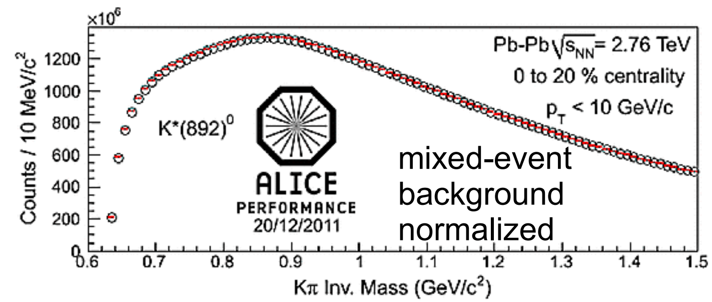
Like-sign

Residual Background:

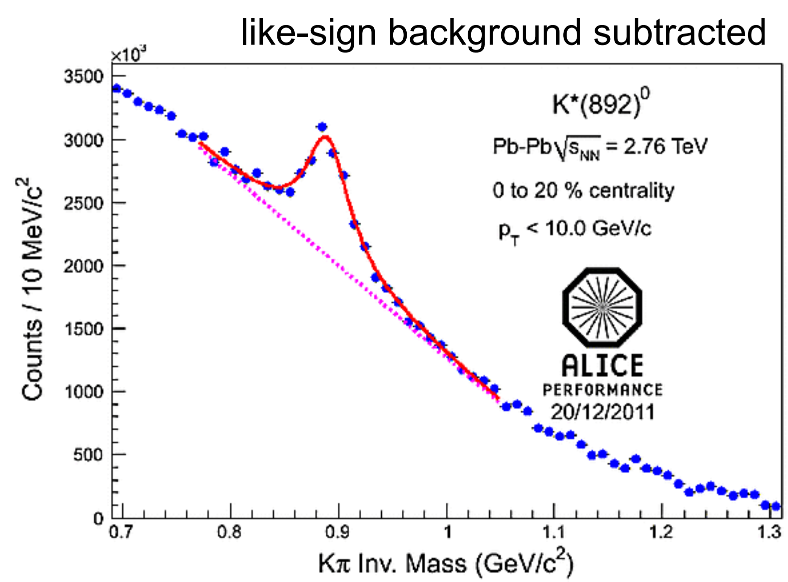
1st-order polynomial

Peak Fit: Breit-Wigner





ALI-PERF-12965

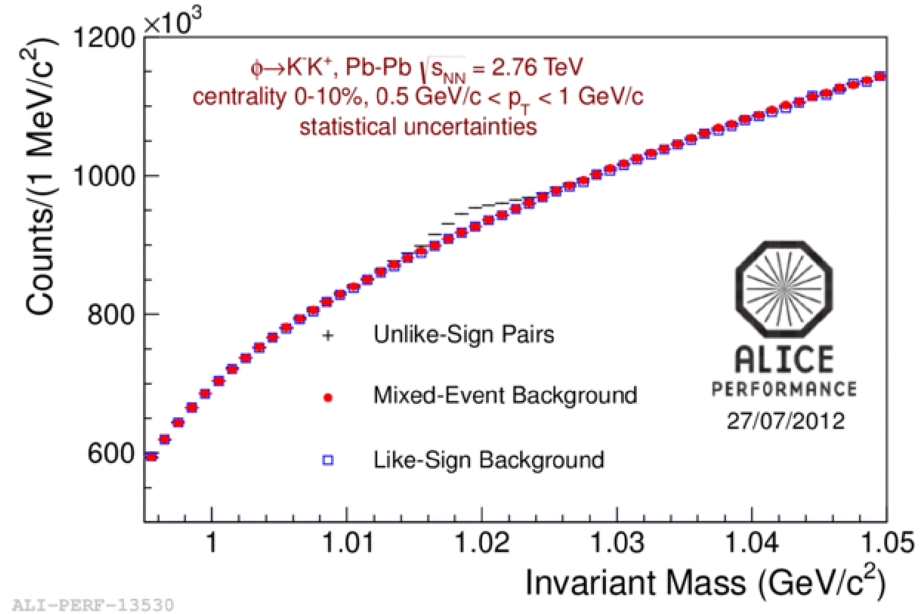


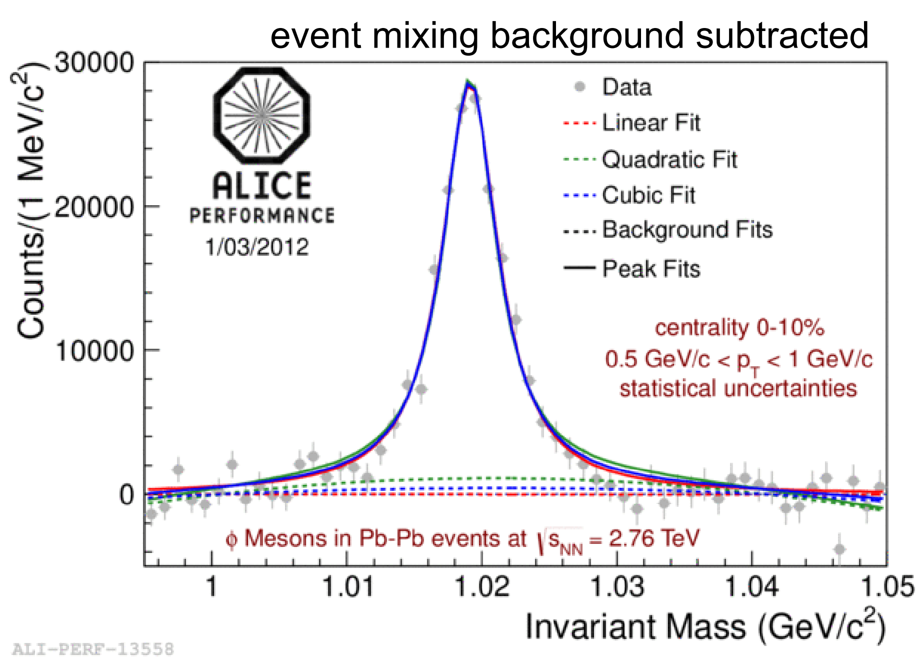
ALI-PERF-12961

$\phi(1020)$ in Pb–Pb

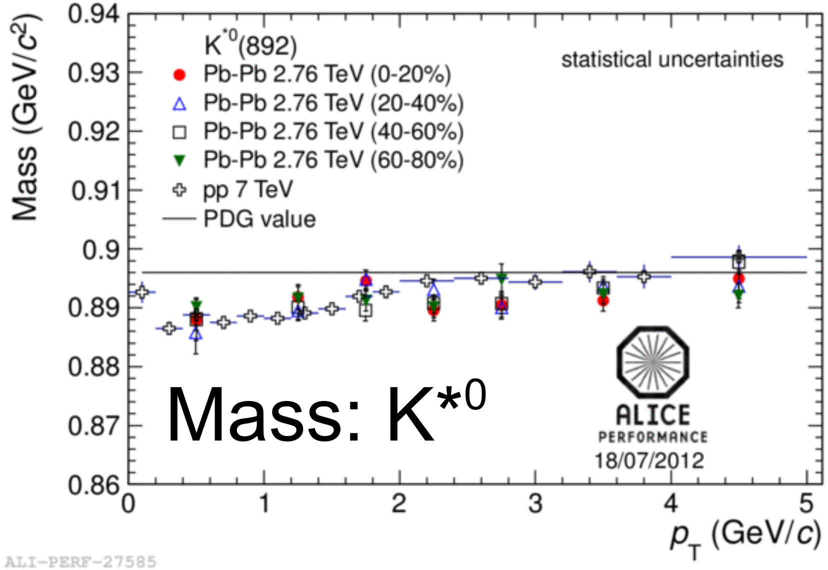
9.5 M Events
Decay products: K^-K^+
PID cuts: TPC

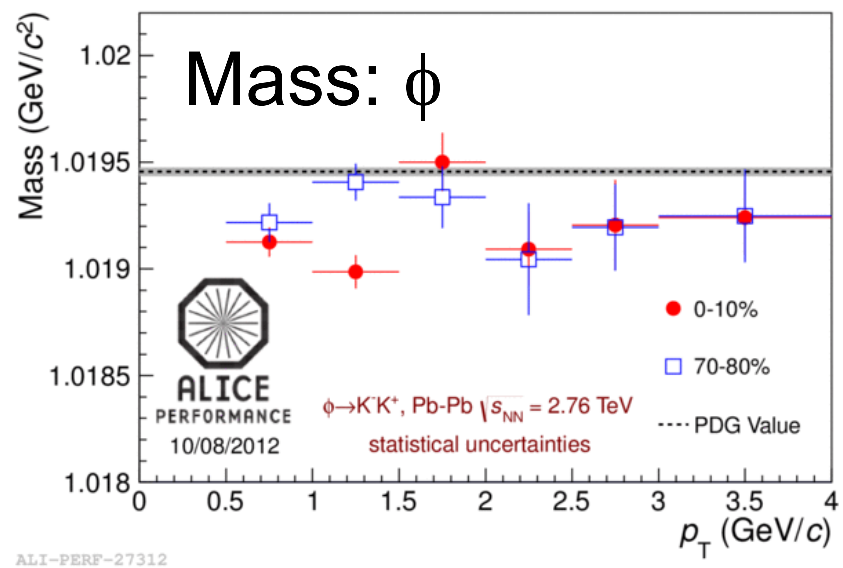
Pair Cuts: $|y_{pair}| < 0.5$
Background:
  Event mixing (like-sign)
Residual Background:
  2^{nd}-order polynomial
Peak Fit: Breit-Wigner





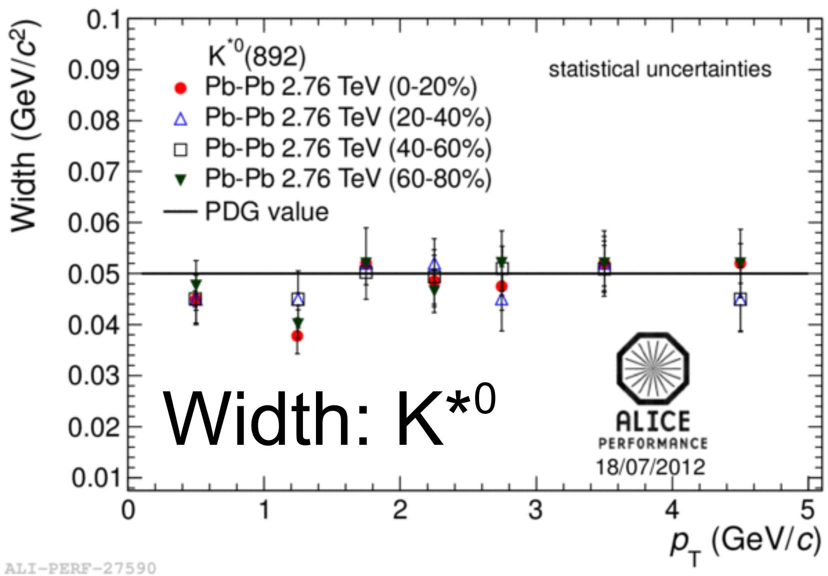
Masses and Widths

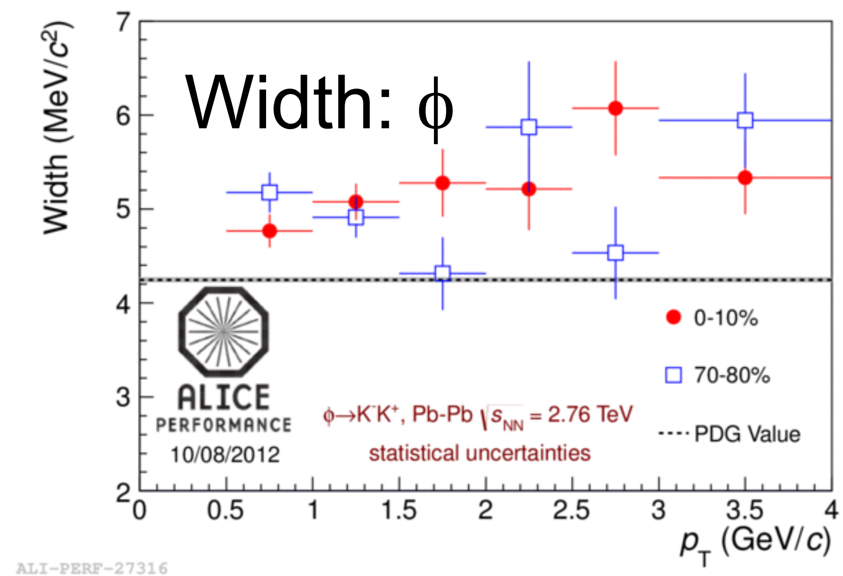




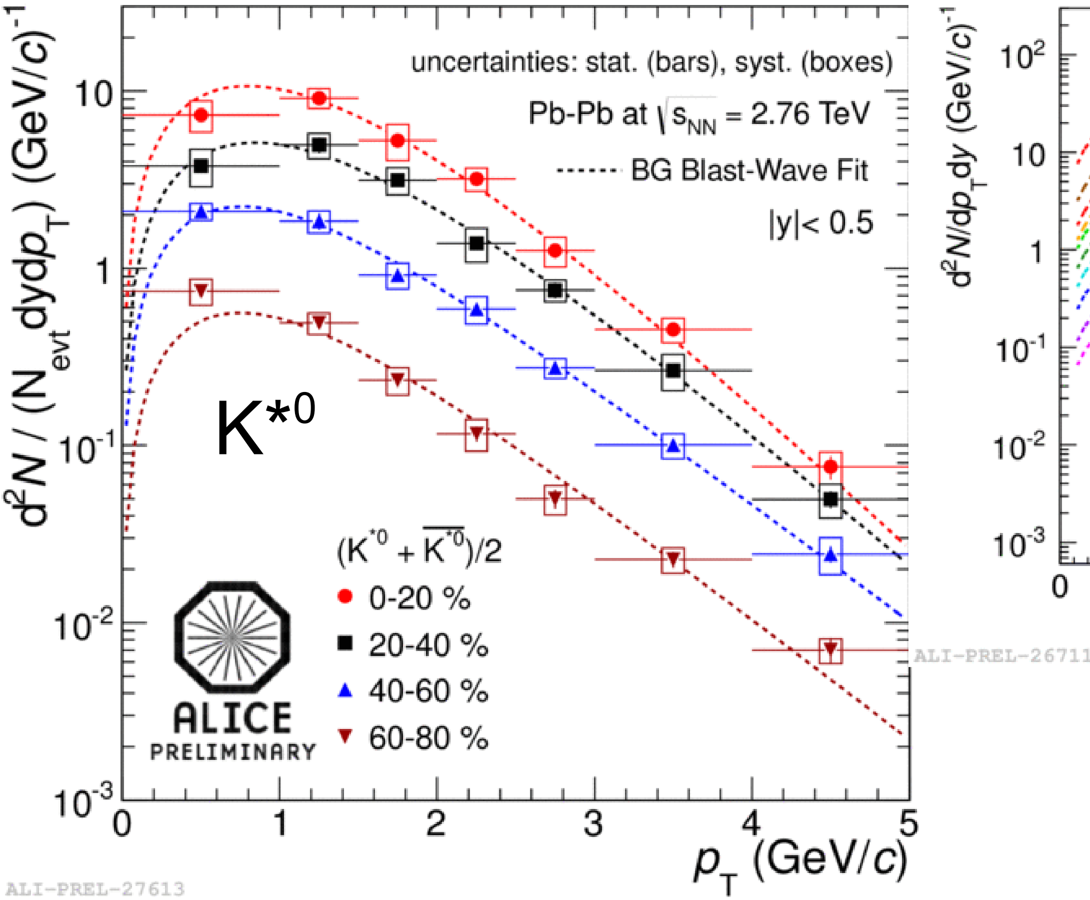
Mass in Pb–Pb consistent with pp
Width in Pb–Pb consistent with PDG

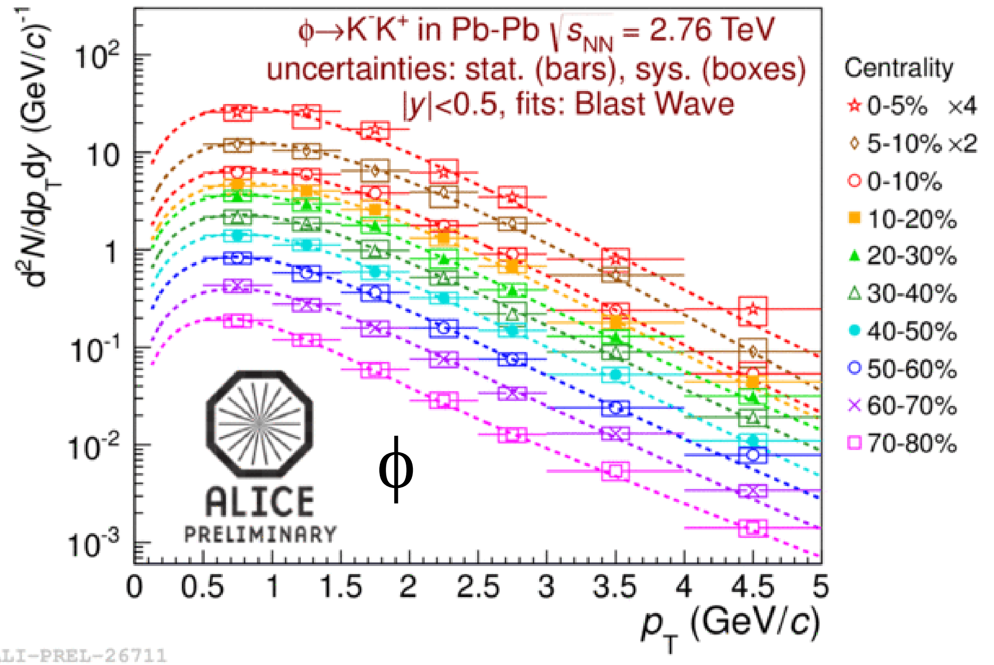
Similar values from fits of MC data
Resolution = 1-2 MeV/c^2





K*(892)^0 and ϕ(1020) in Pb–Pb

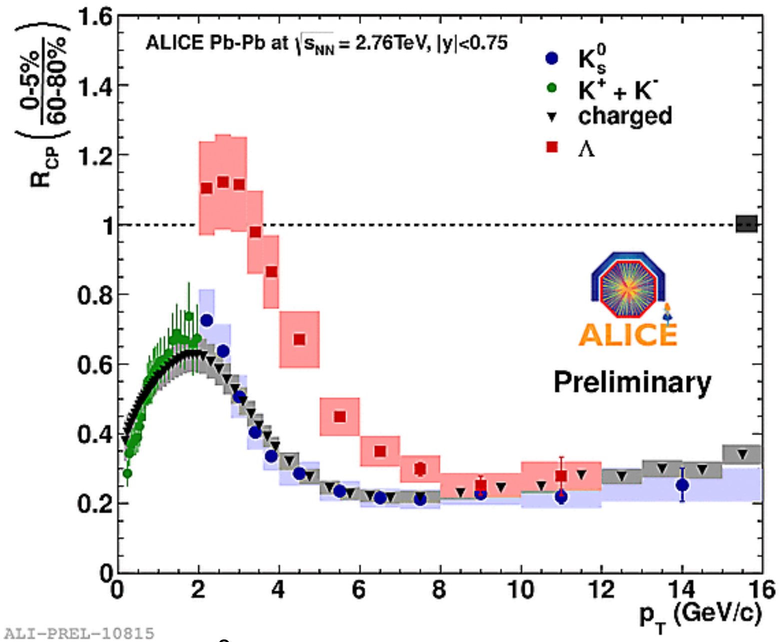




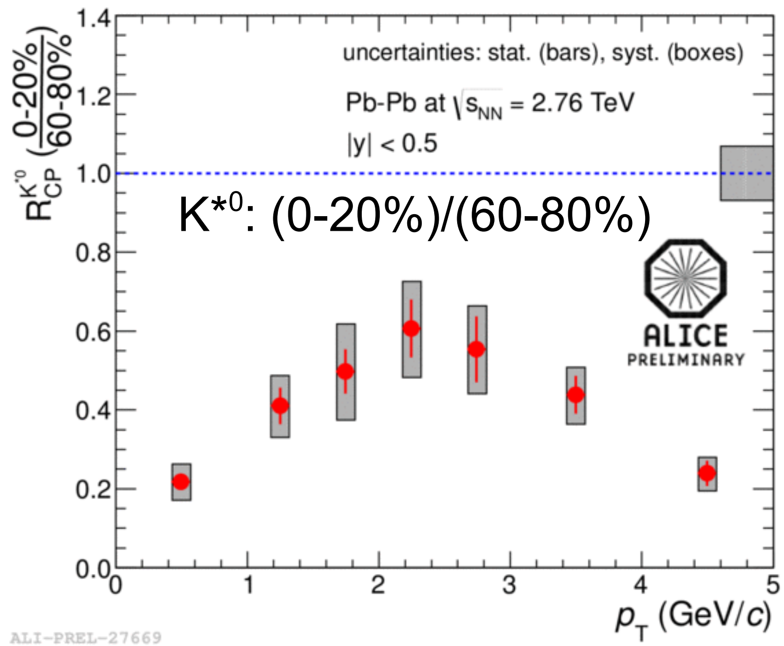
Corrected Spectra fit with Boltzmann-Gibbs Blast-Wave functions

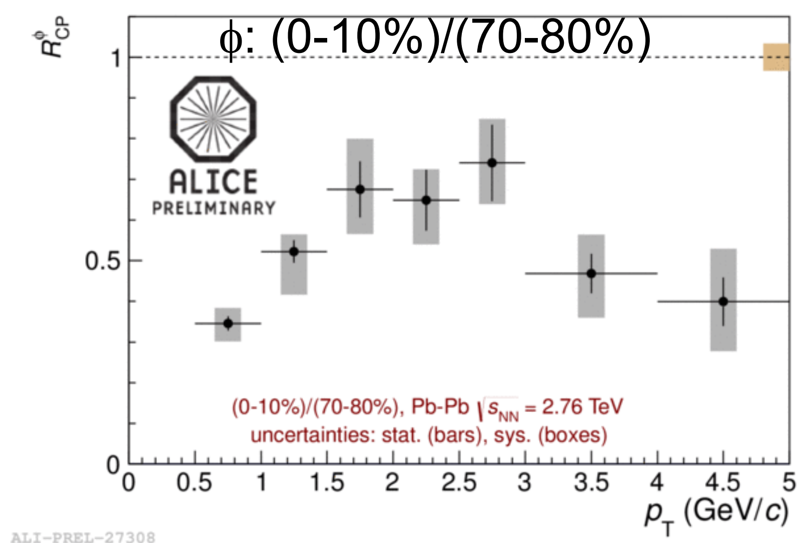
For ϕ: fit used to extrapolate yield to low p_T (~15% of total dN/dy)

R_{CP} for $K^*(892)^0$ and $\phi(1020)$



$K^{\pm}$, K^0_S, Λ, charged hadrons: (0-5%)/(60-80%)





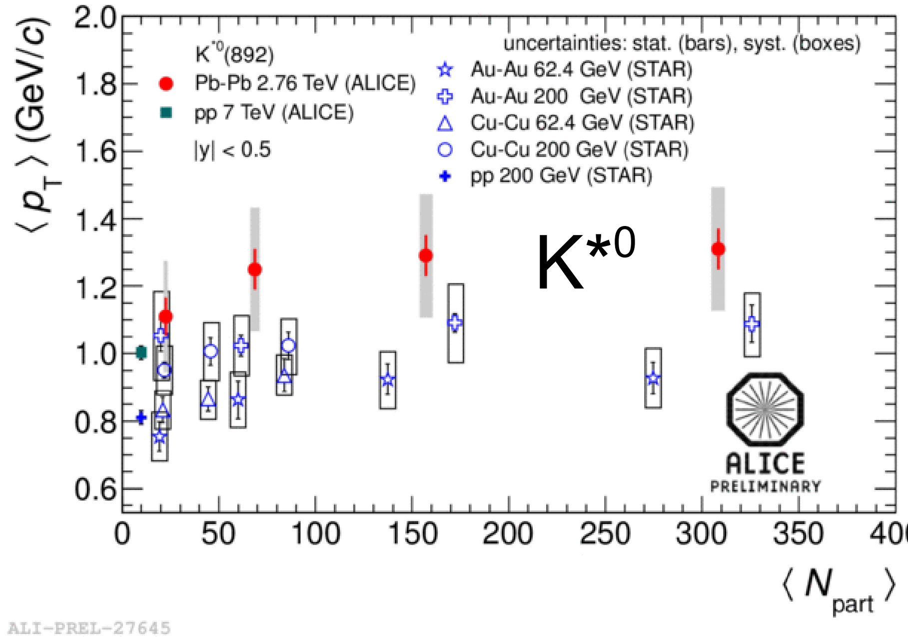
R_{CP} for K^{*0} and ϕ:

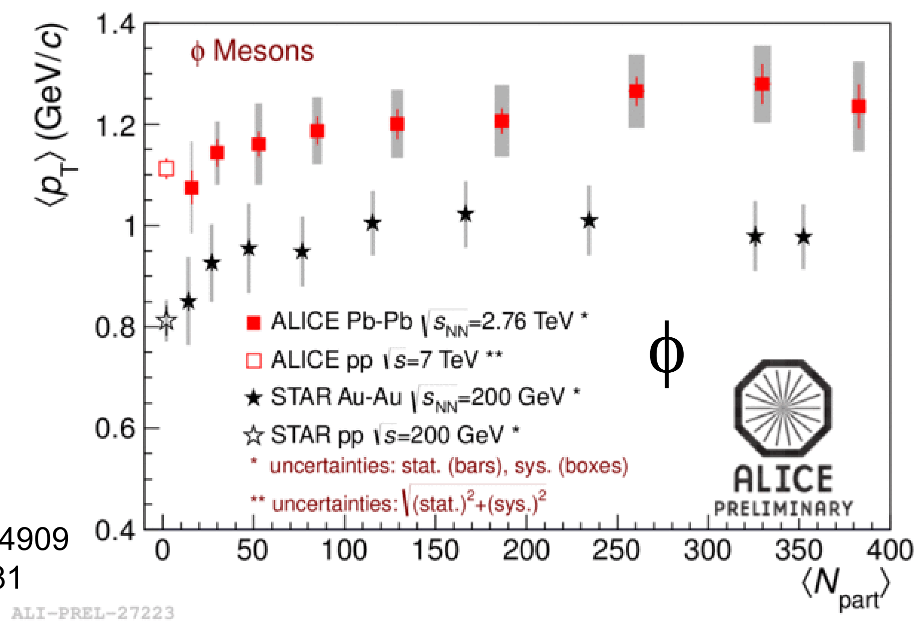
- $p_T > 2$ GeV/c: consistent with K^0_S, lower than Λ
- $p_T < 1.5$ GeV/c: lower than $K^{\pm}$

Caveat: Different centrality bins in numerator and denominator

$<p_T>$ vs. $<N_{part}>$

- $<p_T>$ 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
- $<p_T>$ at LHC energies is greater than $<p_T>$ at RHIC energies
- ALICE π/K/p spectra: global Blast-Wave fit shows ~10% increase in $<\beta_T>$ over RHIC**
  - Suggest stronger radial flow at LHC than at RHIC
  - ALICE K*0, ϕ $<p_T>$ results consistent with this conclusion

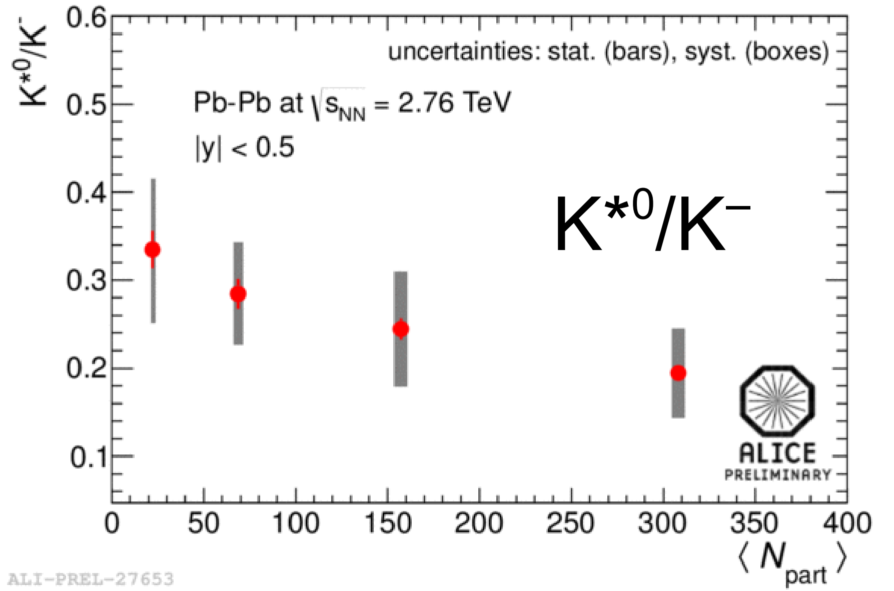


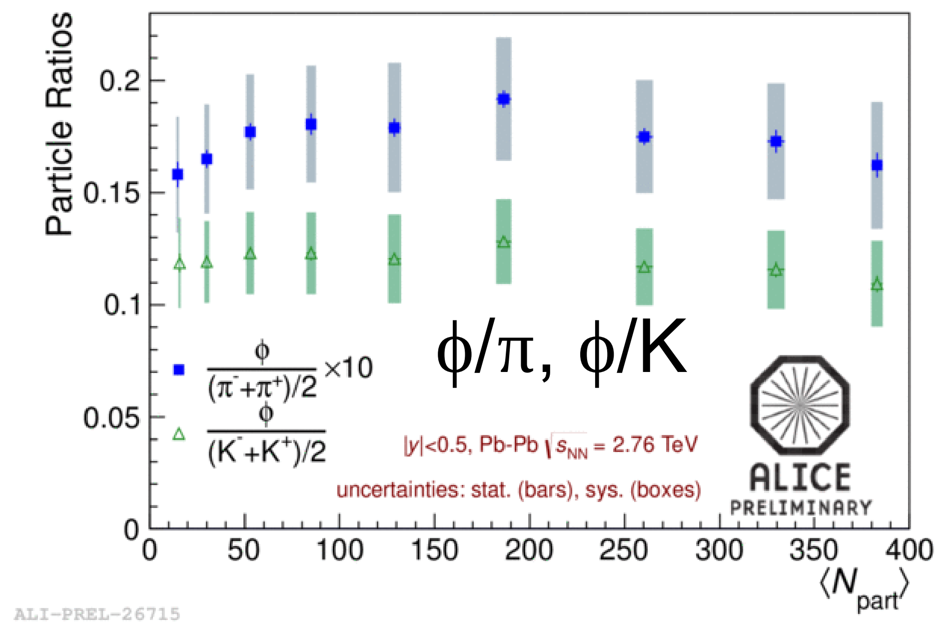


**arXiv:1208.1974v1 (ALICE)
STAR K*0: *Phys. Rev. C* **71** (2005) 064902, *Phys. Rev. C* **84** (2011) 34909
STAR ϕ: *Phys. Rev. C* **79** (2009) 064903, *Phys. Lett. B* **612** (2005) 181

Particle Ratios vs. $\langle N_{part} \rangle$

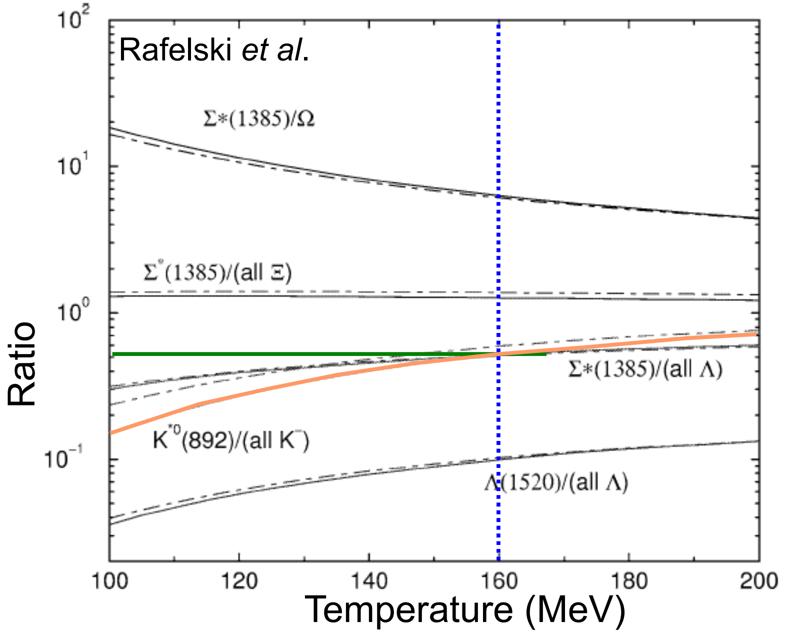
- K^{*0}/K^- decreases for central collisions
  - Suggests possible re-scattering effects in central collisions
- ϕ/π independent of centrality
- ϕ/K independent of centrality
  - Disfavors ϕ production through kaon coalescence

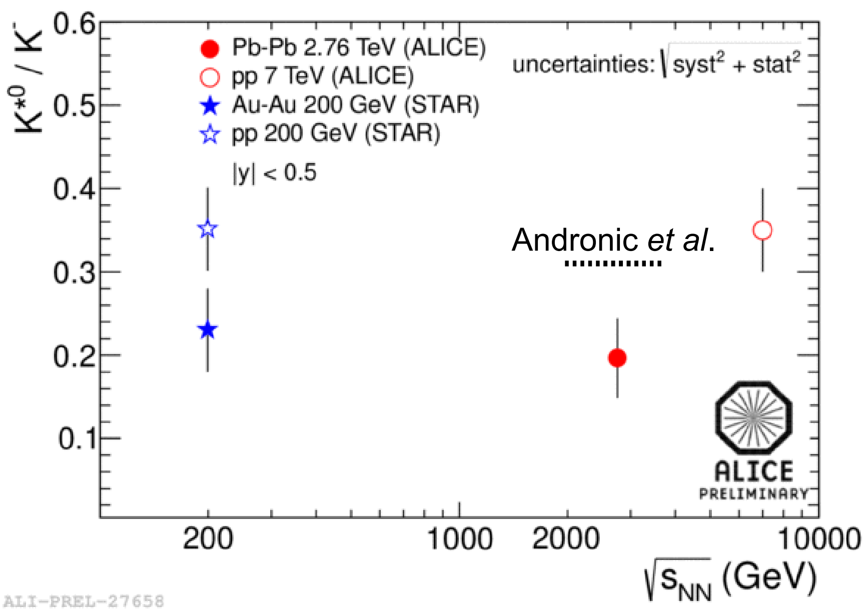


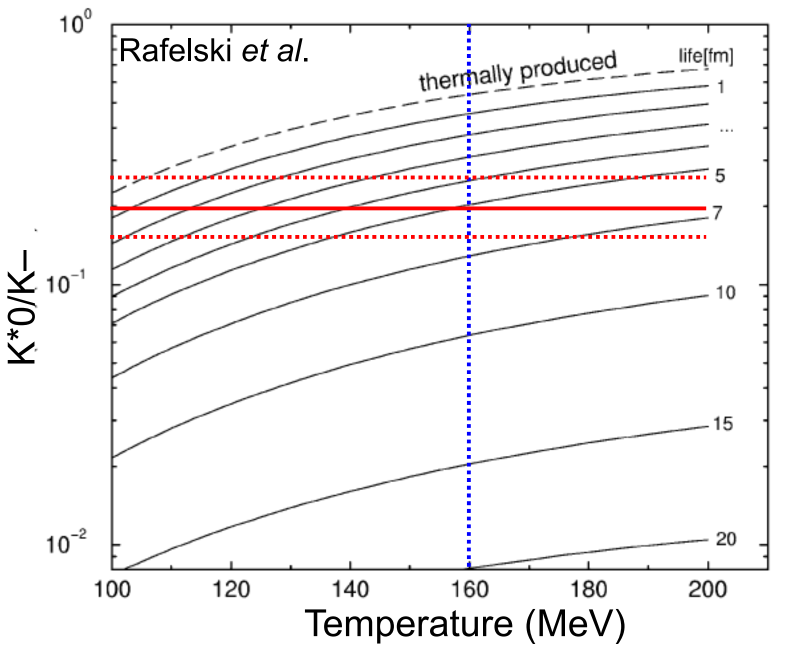


K^{*0}/K^{-} Ratio vs. Energy

- K^{*0}/K^{-}: ratio in central Pb–Pb less than in pp
  - Similar behavior at RHIC
- Model predictions for central Pb–Pb:
  - Andronic *et al*. (*T*=164 MeV):
    - K^{*0}/K^{-} = 0.310
    - *Phys. Lett. B* **673** (2009) 142
  - Rafelski *et al*. (*T*=160 MeV):
    - Without re-scattering: K^{*0}/K^{-} = 0.5
    - With re-scattering: K^{*0}/K^{-} = 0.2 → lifetime ≥ 5 fm/*c*
    - *Phys. Lett. B* **509** (2001) 239

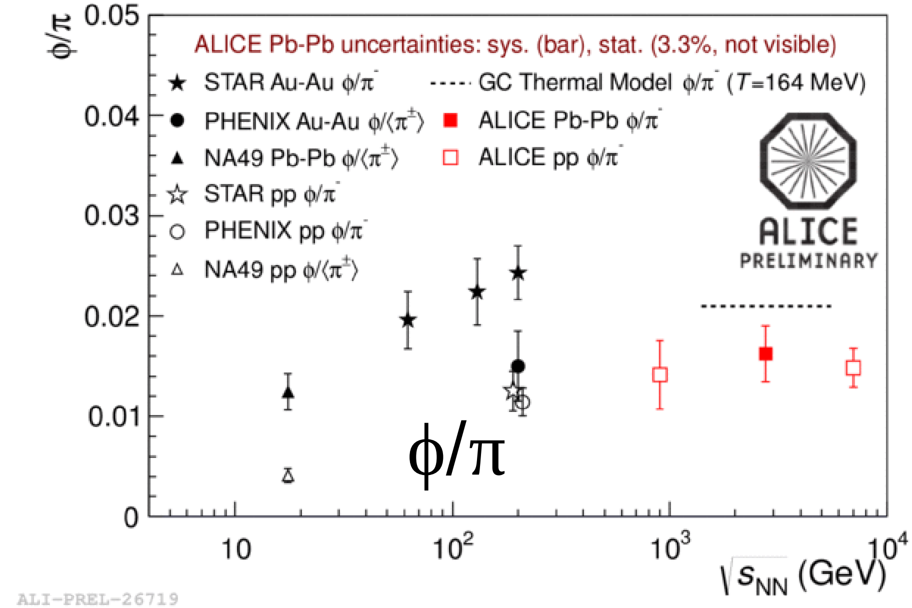


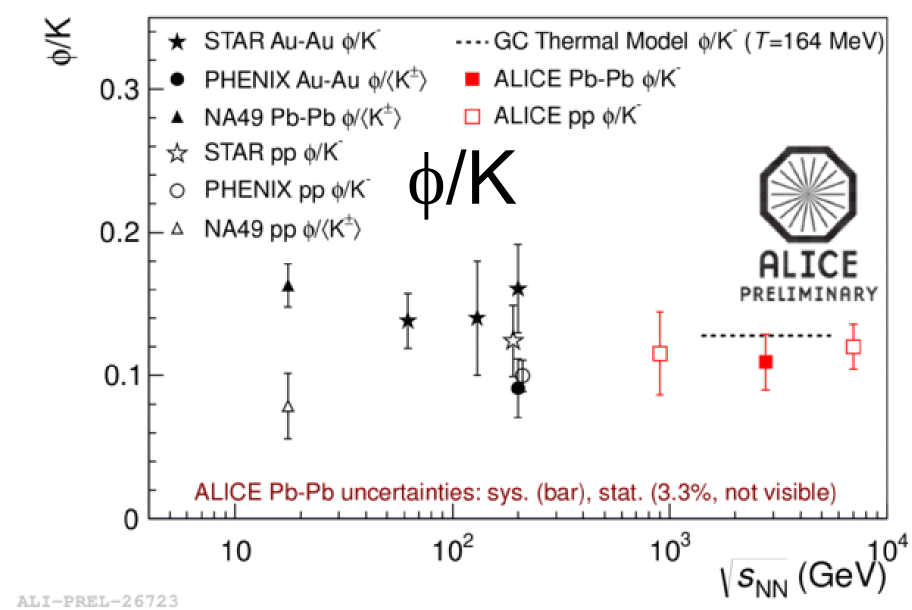




ϕ/π, ϕ/K Ratios vs. Energy

- ϕ/π independent of energy at LHC energies
  - Ratio in Pb–Pb below GC thermal model (Andronic *et al.*)
- ϕ/K independent of energy and collision system
  - Ratio in Pb–Pb consistent with GC thermal model (Andronic *et al.*)





Conclusions

- Resonances in pp
  - Analyses of ρ^0, Δ^{++}, Λ^*, Ξ^{*0} in progress
  - K^{*0} and ϕ spectra compared to event generators:
    - PYTHIA Perugia 2011 describes K^{*0} and high-p_T (<3 GeV/c) ϕ well
    - PHOJET and PYTHIA ATLAS-CSC describe p_T > 1 GeV/c
    - PYTHIA D6T describes p_T < 2 GeV/c
  - $\Sigma^{*\pm}$ spectra described by PYTHIA ATLAS-CSC for p_T > 2 GeV/c
- Resonances in Pb–Pb
  - Mass and Width:
    - K^{*0} mass consistent with pp, width consistent with PDG
    - ϕ: deviates from PDG, but similar values observed for simulated peaks
  - $\langle p_T \rangle$ at LHC energies larger than at RHIC:
    - Suggests increased radial flow (*cf.* ALICE π/K/p spectra)
  - K^{*0}/K^- smaller in central collisions than in peripheral Pb–Pb or pp
    - Suggests possible re-scattering effects in central collisions
  - ϕ/K independent of centrality
    - Disfavors ϕ production through kaon coalescence

Backup Slides

Track and PID Cuts

K*(892)^0 in pp:

- $p(K^\pm) < 0.7$ GeV/c
- $p_T < 1.5$ GeV/c: $2\sigma_{TOF}$
- $p_T > 1.5$ GeV/c: $3\sigma_{TOF}$
- If no TOF signal:
  - $p_T < 0.35$ GeV/c: $5\sigma_{TPC}$
  - $0.35 < p_T < 0.5$ (GeV/c): $3\sigma_{TPC}$
  - $p_T > 0.5$ GeV/c: $2\sigma_{TPC}$

ϕ(1020) in pp:

- $p_T < 0.35$ GeV/c: $2\sigma_{TPC}$
- $p_T > 0.35$ GeV/c: $3\sigma_{TPC}$
- If TOF signal present: $3\sigma_{TOF}$

K*(892)^0 and ϕ(1020) in Pb–Pb:

- $2\sigma_{TPC}$

Σ*(1385)$^\pm$ in pp:

- $DCA_{xy}(\Lambda) < 0.5$ cm
- $DCA_{xy}(\pi^\pm) < 0.05$ cm
- DCA Λ daughters < 0.5 cm
- cos(Λ pointing angle) > 0.99

Standard Track Selection Cuts:

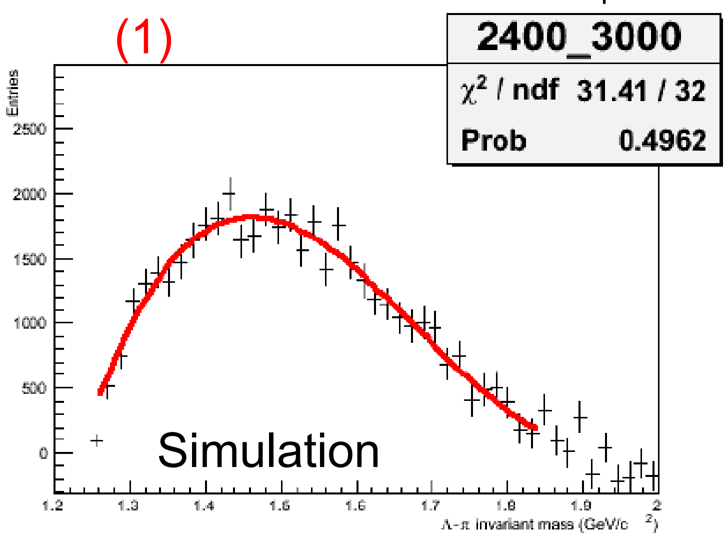
- $p_T > 0.15$ GeV/c
- $|\eta| < 0.8$
- Number of TPC clusters > 70
- χ^2 per cluster in TPC < 4
- > 1 cluster in ITS
- $DCA_z < 2$ cm
- Reject kink daughters

Σ*± Residual Background

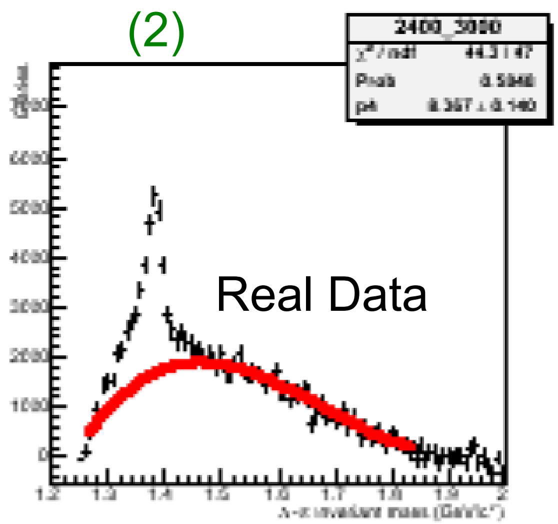
- Residual background from correlated Λπ pairs
  - Monte-Carlo simulations
  - Fit with 3rd-order polynomial (1)
  - Scaled to match residual background in real data (2)
- Lp pairs from Λ*(1520) → Λππ decays:
  - Monte-Carlo simulations:
    - Fit with Gaussian, mean and σ extracted
  - Real data:
    - Fit with Breit-Wigner peak (Σ*) + Gaussian (Λ* contamination) (3)
    - Gaussian mean and σ constrained using value from simulations

Example Plots: 2.4 < p_T < 3 GeV/*c*

(1)



(2)



(3)