Study of short-lived resonances in the ALICE experiment in a "first physics" scenario

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Hadronic resonances

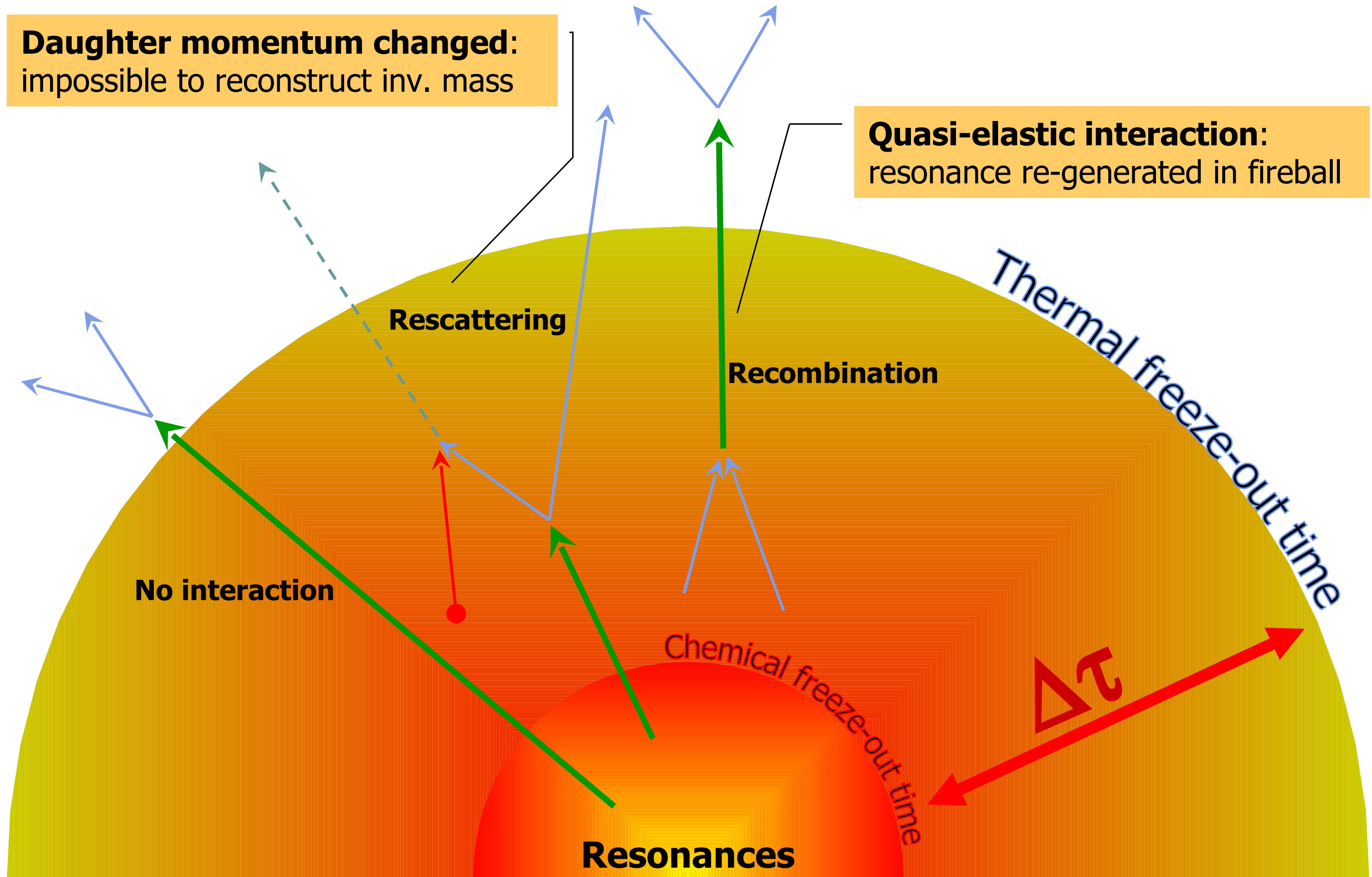
- Excited quark bound states
  - larger mass than that of “stable” particles
  - small lifetime (few fm/c)
    - comparable with fireball lifetime
    - resonance daughters indistinguishable from primary tracks
  - strong decay

	K^0_s	$K^*(892)^0$
Mass	~497 MeV	~896 MeV
Lifetime	$\sim 10^{-10}$ s	$\sim 10^{-23}$ s

Topics addressed with resonances

- Chiral simmetry restoration
  - mass/width shift
- Strangeness enhancement
- Hadron formation mechanisms
  - yield ratios (ϕ/K, ϕ/h)
  - elliptic flow (v_2)
  - transverse flow ($\langle p_T \rangle$)
- Probe the fireball collective properties

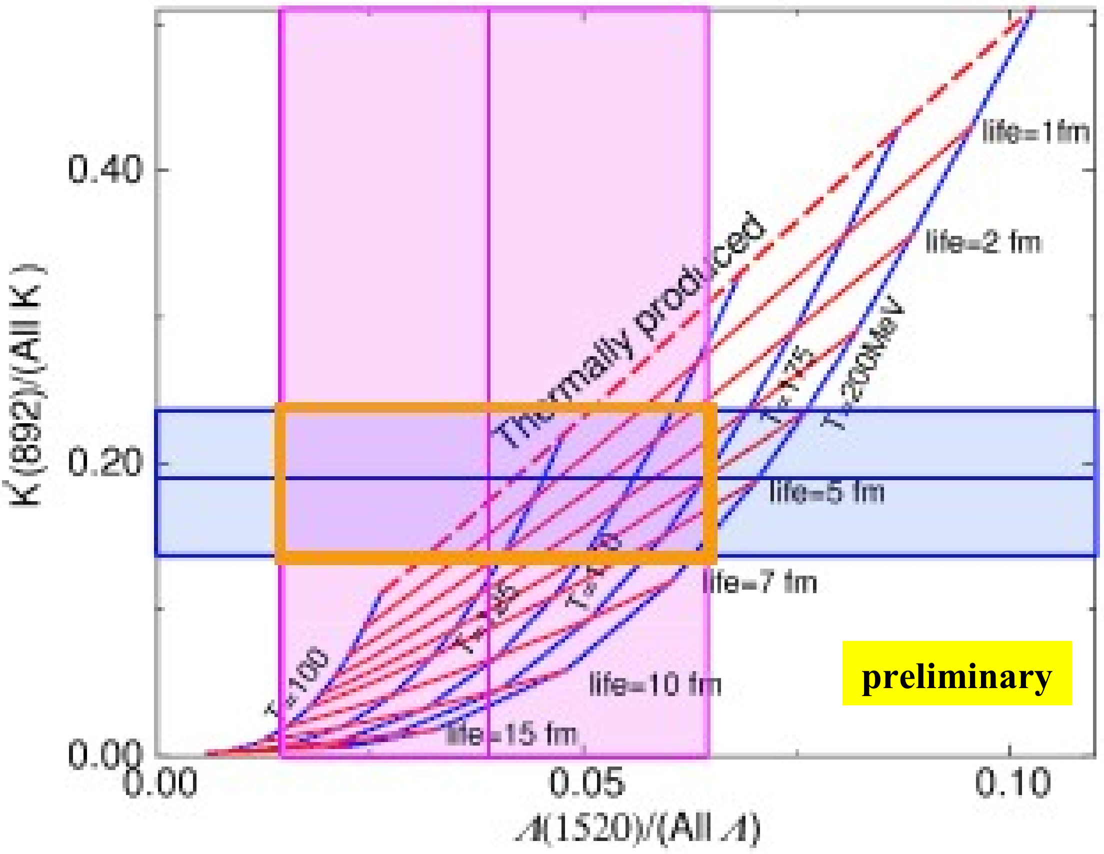
Resonance interaction with fireball



Using K* and Λ(1520) to estimate temperature and lifetime of the fireball

0-20% most central Au+Au

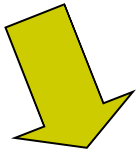
G. Torrieri and J. Rafelski, Phys. Lett. **B509** (2001) 239



K*/K and Λ(1520)/Λ ratios depend on temperature and time delay between chemical and thermal freeze out.

Model: yield of thermally produced particles + rescattering. NO regeneration.

T = 175 MeV → Δτ = 4-6 fm/c
Δτ = 0 fm/c → T= 110-130 MeV

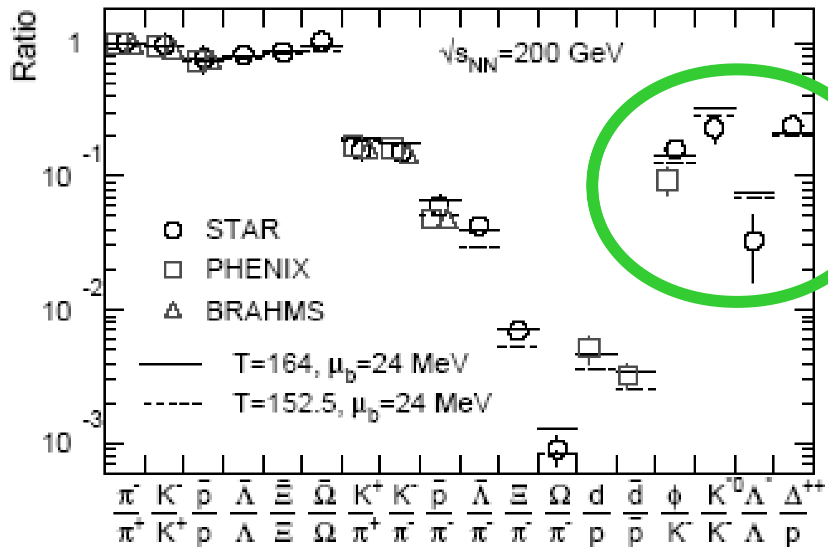


C. Markert, J. Phys. **G31** (2005) 1045.

Δτ > 4 fm/c and T=160 MeV

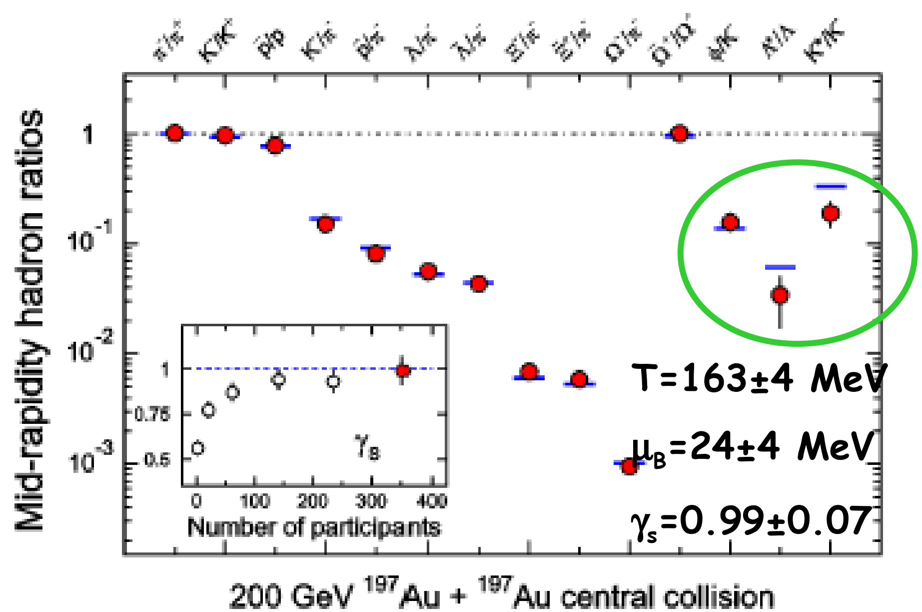
Thermal models and particle ratios

A. Andronic, P. Braun-Munzinger, J. Stachel, nucl-th/0511071



The study of short lived resonances produced in heavy ion collisions with the help of models may permit to distinguish between sudden and staged hadronization scenario

STAR Collaboration, Nucl. Phys. **A757**(2005) 102

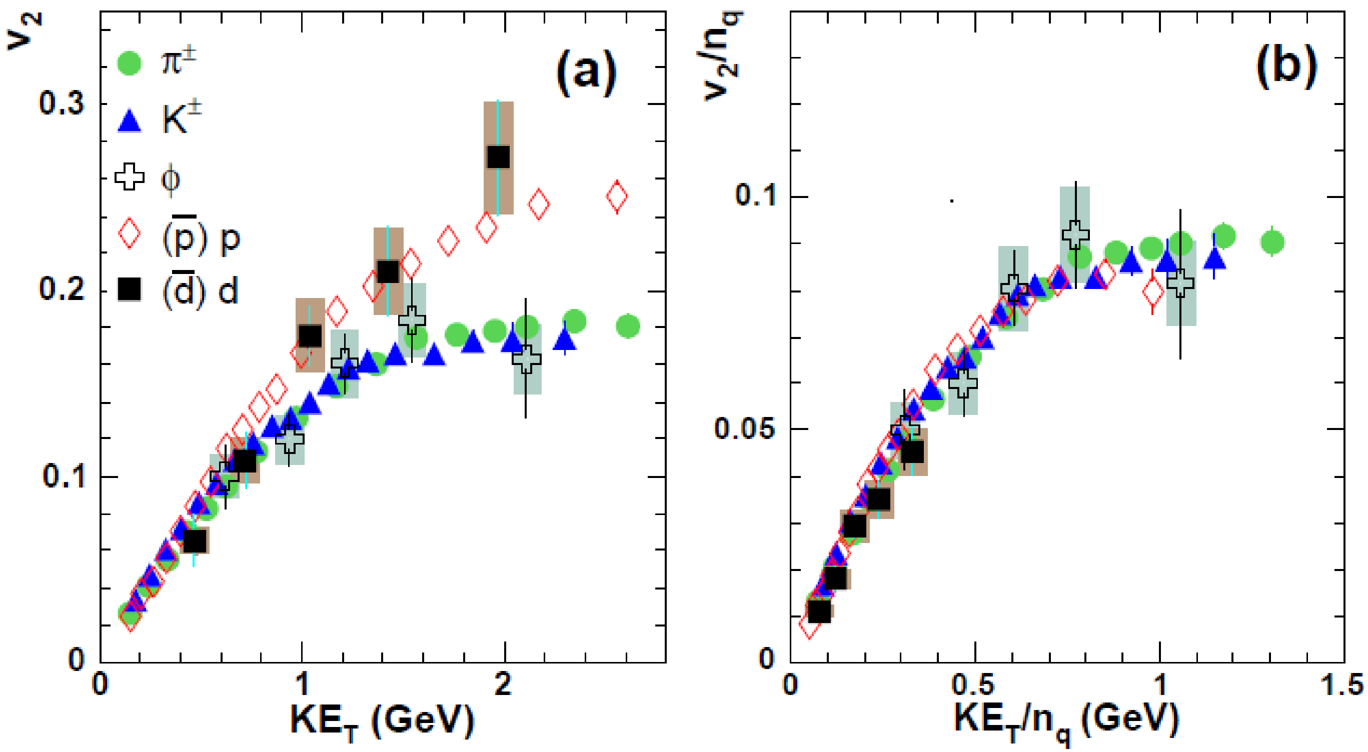


ALICE PPR Vol. II

Deviations from thermal model could be due to rescattering and regeneration after chemical freeze-out

Elliptic flow of resonances

Measurement of flow for meson and baryon resonances is of great interest to further validate the picture sorting of this scaling i.e. that partonic collectivity dominates the transverse expansion dynamics.



Au-Au @200 GeV

Mass ϕ meson ~ Mass proton

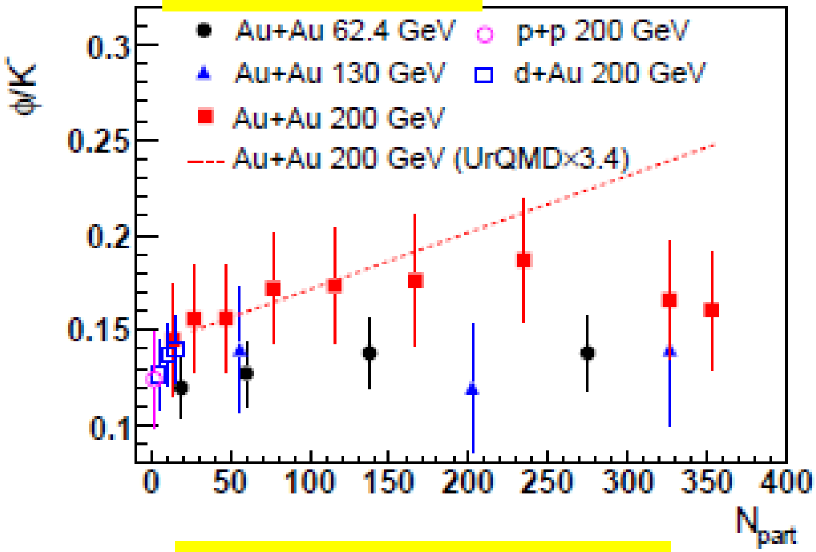
v_2 of ϕ mesons confirms this universal scaling

S. Afanasiev et al. (PHENIX Coll.) nucl-ex 0703024

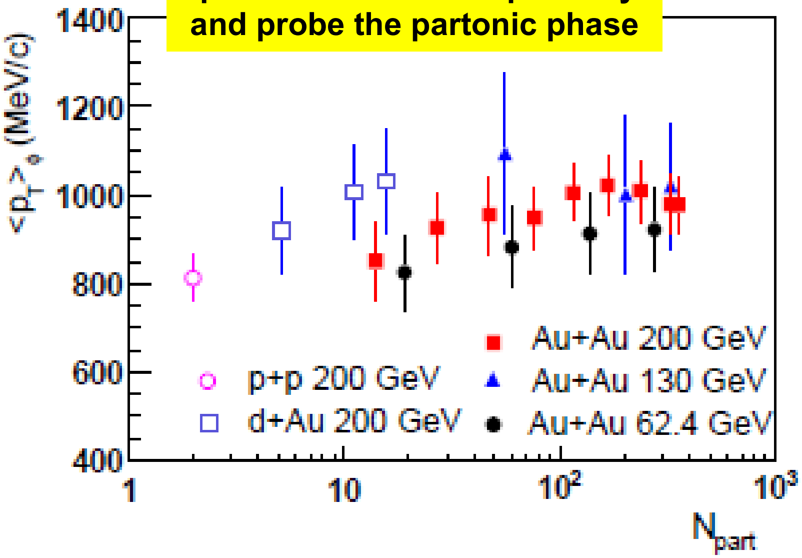
Strangeness enhancement and the φ resonance

STAR, nucl-ex 0901.0313.v1

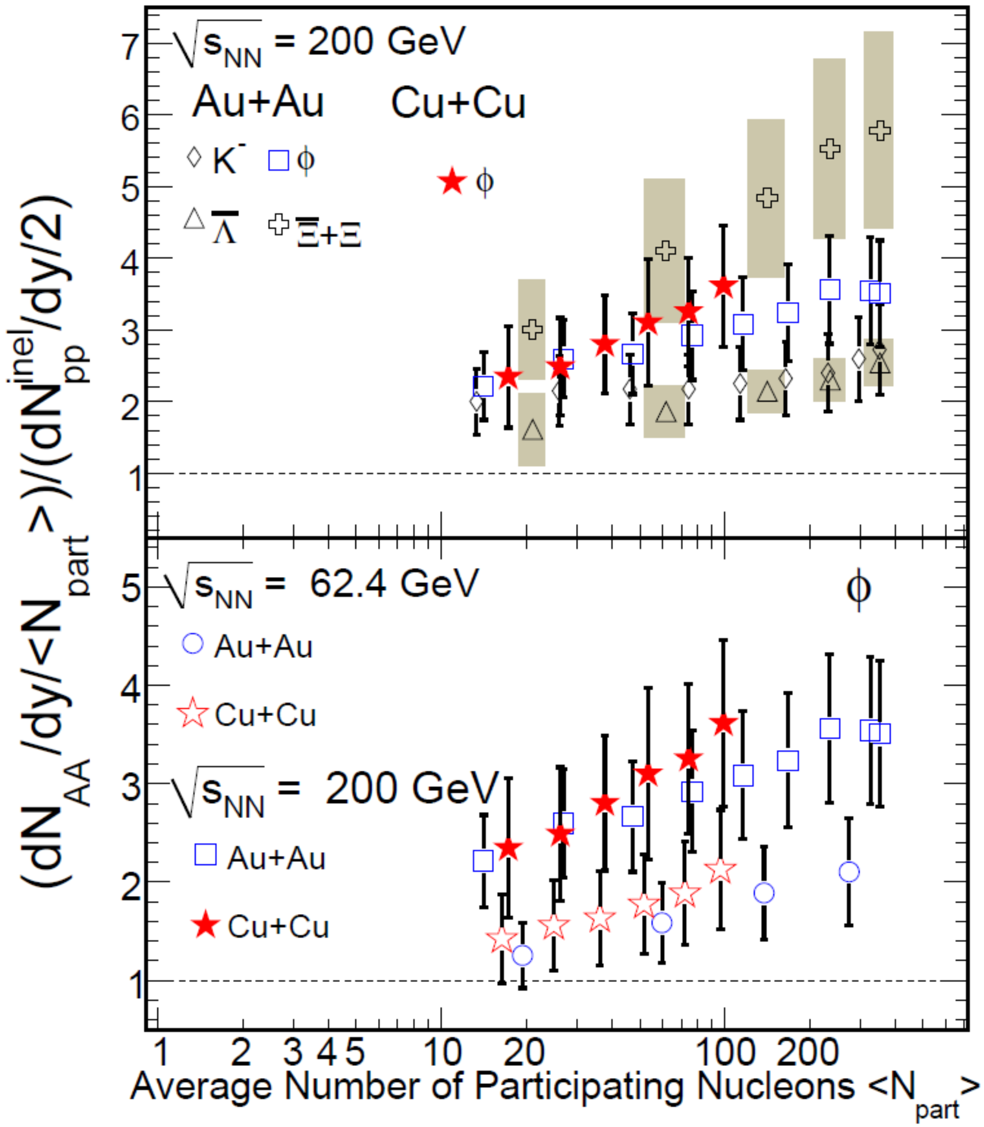
KK coalescence?



φ resonances decouple early and probe the partonic phase



φ enhancement vs. K/Λ/Ξ enhancement

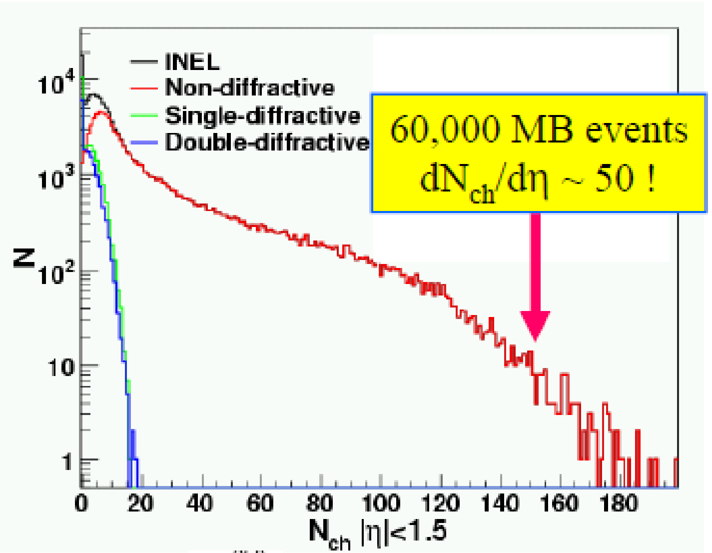


STAR, Phys. Lett. B673, 183

pp collisions @ LHC

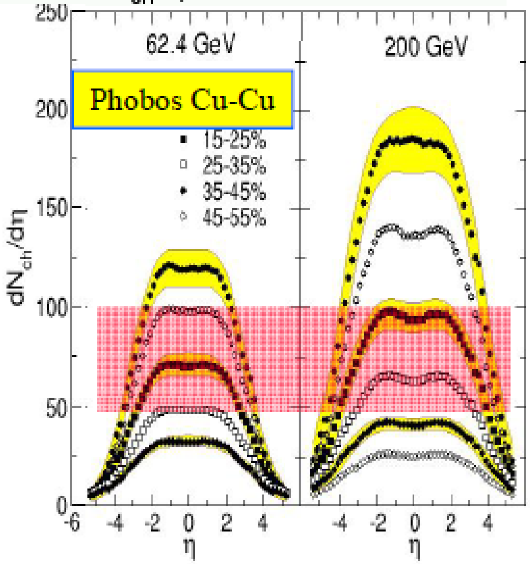
J. Schukraft, ALICE Physics week 2008 (Prague)

- Multiplicity distribution at LHC
  - ⇨ quite respectable particle densities
    - ✪ $dN_{ch}/d\eta$ ~ 50 – 100 can be reached !
    - ✪ > central S+S @ SPS, mid-central Cu-Cu @ RHIC
  - ⇨ naïvely, energy density ε > 5 – 10 GeV/fm^3
    - ✪ τ_0 = 1 fm, V = 5 fm^3
    - ✪ τ_0 << 1 fm at RHIC/LHC densities
      => proton is (relativ) BIG



- even protons get obese these days
  - ⇨ p@LHC ~ small (but very dense) nucleus@SPS

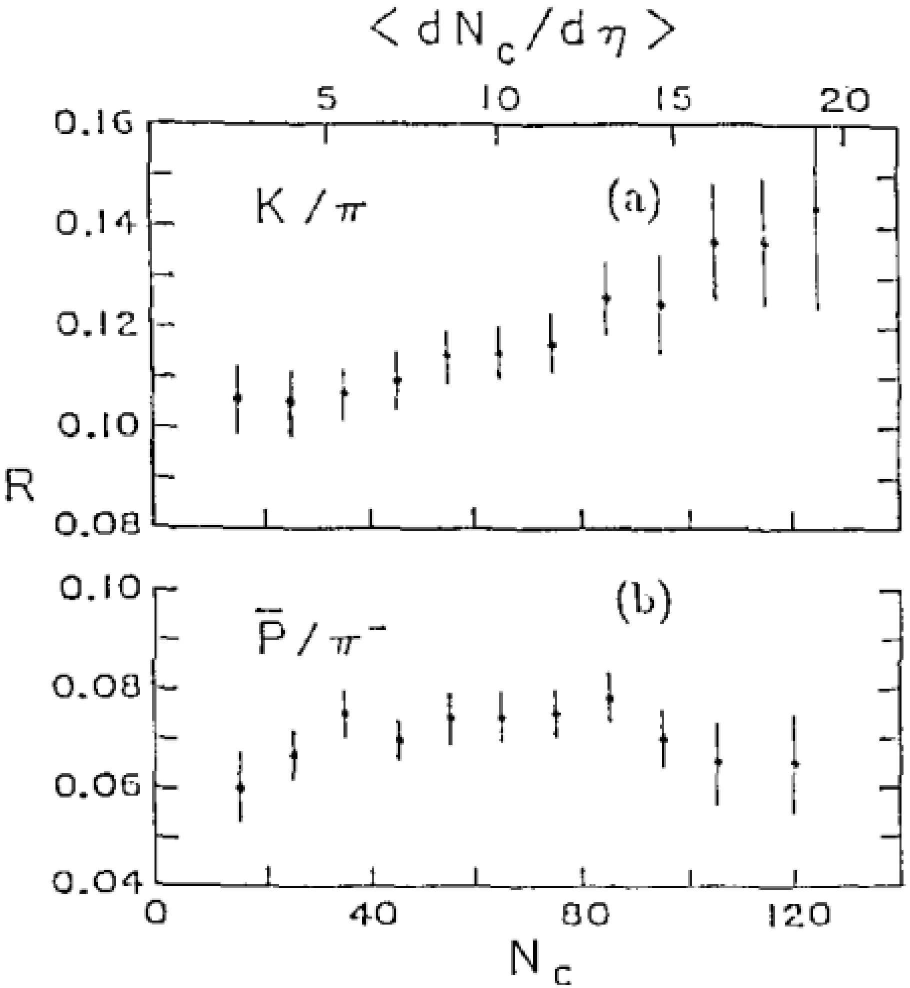
	SPS	RHIC	LHC
# of partons in proton 3 + ∫ g(x > 2GeV)	4	10	30

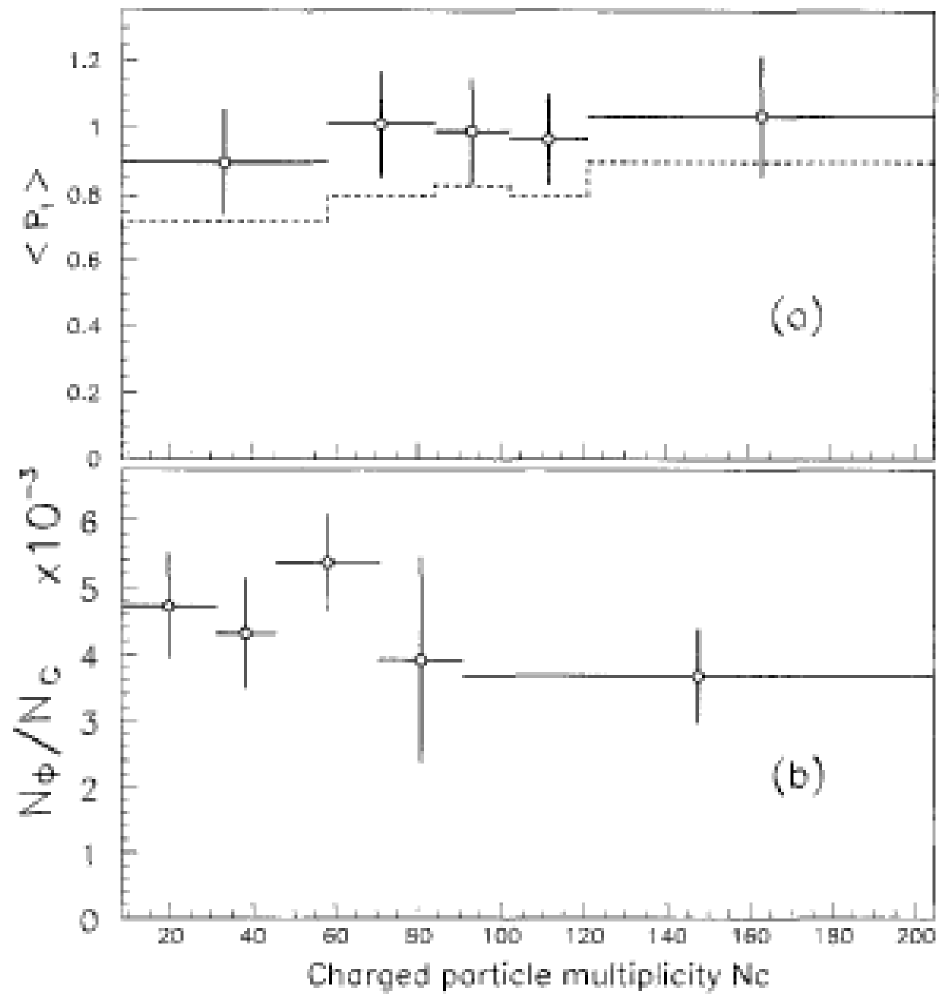


- 'QGP' physics with protons
  - ⇨ at least: onset of hadronic FS interactions
  - ⇨ maybe: collective hadronic/partonic dynamics
  - ⇨ why not: the QGP, mini serving

Searches for QGP in pp collisions: E735

E735 collaboration: Z. Phys C. 67 (1995), 411





E735 collaboration:
FERMILAB-Conf-91/336

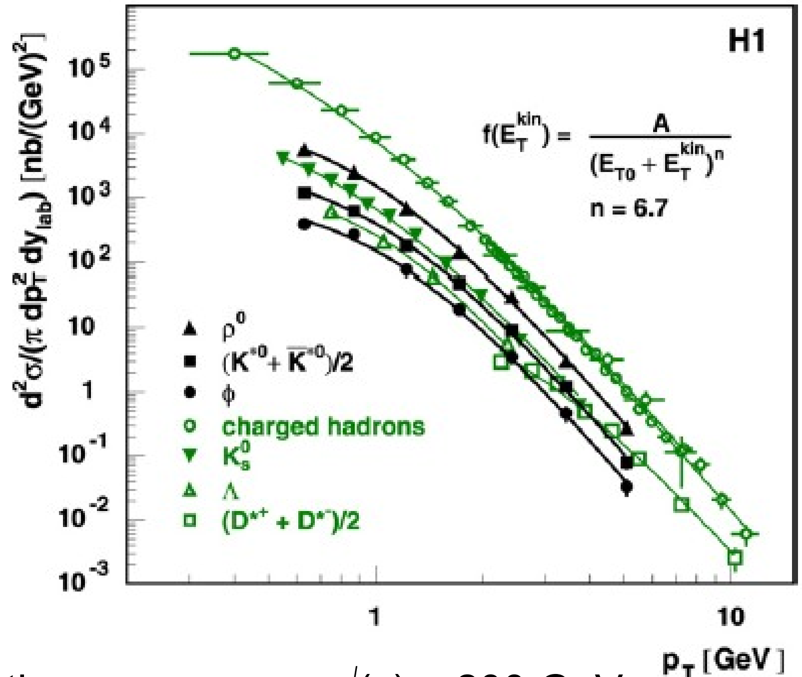
Nc

ϕ production in γp collisions: HERA

		ρ^0	$(K^{*0}+\bar{K}^{*0})/2$	ϕ
γp (H1)	$\langle d\sigma/dy_{lab}\rangle_{\lvert y_{lab}\rvert<1}$ [μb]	23.6 ± 2.7	5.22 ± 0.60	1.85 ± 0.23
	T [GeV]	0.151 ± 0.011	0.166 ± 0.012	0.170 ± 0.012
	$\langle E_T\rangle$ [GeV]	1.062 ± 0.018	1.205 ± 0.020	1.333 ± 0.022
	$\langle E_T^{kin}\rangle$ [GeV]	0.287 ± 0.018	0.313 ± 0.020	0.314 ± 0.022
	$\langle p_T\rangle$ [GeV]	0.726 ± 0.027	0.810 ± 0.030	0.860 ± 0.035
pp (STAR)	$\langle p_T\rangle_{pp}$ [GeV]	0.616 ± 0.062	0.81 ± 0.14	0.82 ± 0.03
Au–Au (STAR)	$\langle p_T\rangle_{AuAu}$ [GeV]	0.83 ± 0.10	1.08 ± 0.14	0.97 ± 0.02

Experiment	Measurement	$R(\phi/K^{*0})$
H1	γp, $\langle W\rangle = 210$ GeV, $\lvert y_{lab}\rvert < 1$	0.354 ± 0.060
STAR	pp, $\sqrt{s} = 200$ GeV, $\lvert y\rvert < 0.5$	0.35 ± 0.05
	Au–Au, $\sqrt{s_{NN}} = 200$ GeV, $\lvert y\rvert < 0.5$	0.63 ± 0.15

H1 Collaboration,
Phys. Lett. B 673 (2009) 119–126



Similar behaviour in pp (RHIC) and γp (H1) at roughly the same energy √(s) ~ 200 GeV

Interesting observables

- P_t distributions
  - temperature parameter
  - total yield → particle ratios → thermal model
  - $\langle p_T \rangle$ → radial flow → decoupling from fireball
    - ϕ resonance decouple earlier from fireball → probe of partonic phase
    - K^*, Λ^* interact with fireball → rescattering/recombination

- Multiplicity dependence:
  - N_{res} / N_{ch} → hadron production mechanisms
  - N_{ϕ} / N_{K-} → KK coalescence

Strategy for reconstruction of $\phi \rightarrow KK$

- Full analysis on a sample of PYTHIA *pp* minimum bias events @ 10 TeV (recentmost PDC production), which is splitted into two halves:
  - one half is used for running resonance analysis with RSN Aliroot package
    - invariant mass distributions
    - background with like-sign technique
  - other half is used to compute efficiencies using the official ALICE Offline Correction Framework

- Estimate reconstructed yields

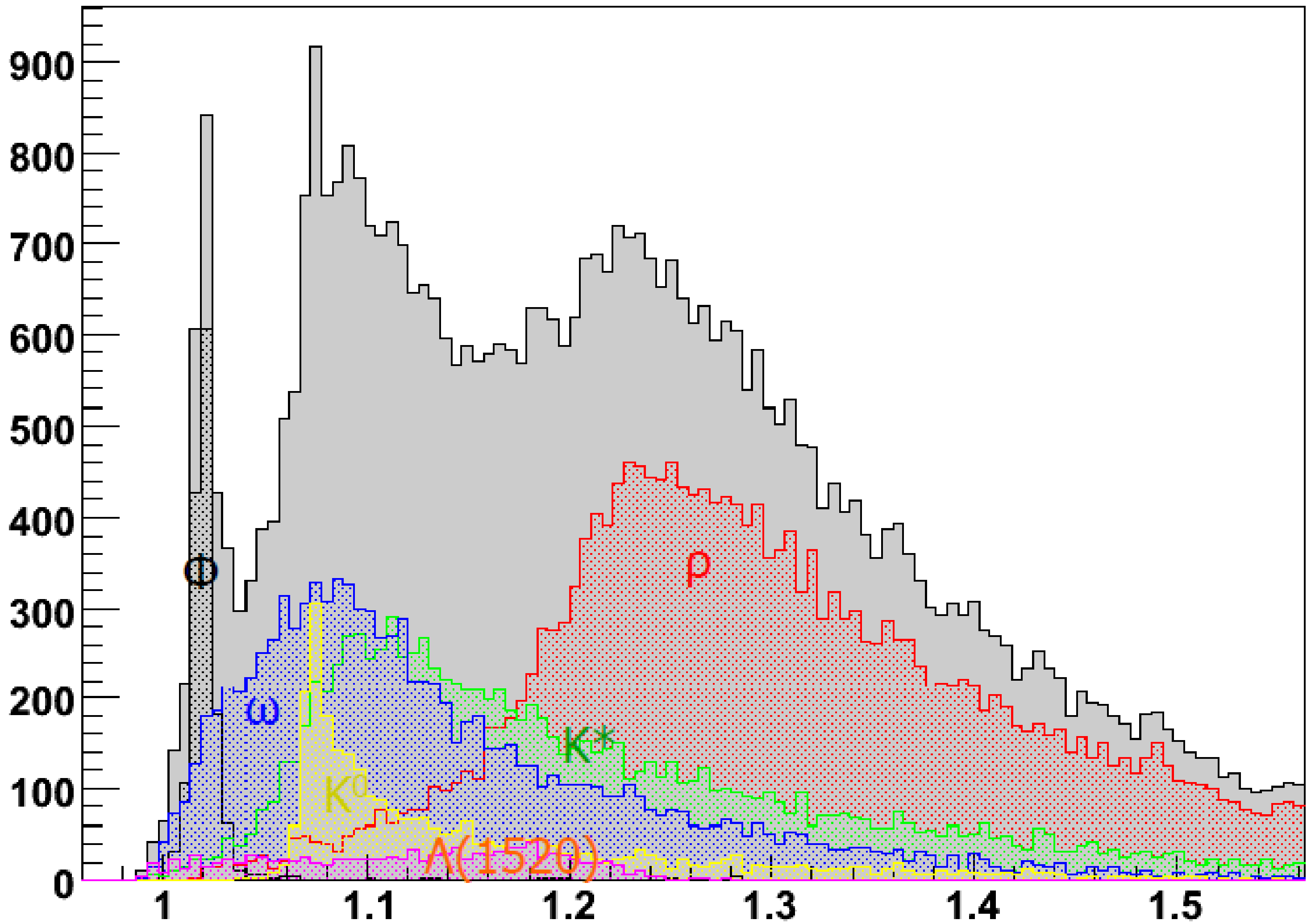
- Correct reconstructed yields for acceptance and efficiency and compare with generated yields

- All analysis is done in several bins of transverse momentum

Event and track selection

- Primary vertex quality
  - require a "good" vertex status
  - require a sufficient number of contributors to its computation
- Track quality
  - require at least ***50*** clusters in the TPC
  - Cut values on track covariance matrix
  - Maximum χ^2 / # TPC clusters: ***3.5***
- Primary tracks selection
  - reject kink daughters
  - require at least **4σ** to primary vertex

NO PID issue: resonances overlapped



→ require a track selection strategy with a minimum PID, if available

Global PID strategy in ALICE

- Each PID detector associates to each track the probability ("PID weight") to be identified as *e*, μ, *π*, *K*, *p*
- A global PID weight is computed multiplying the ones of each detector
- A set of *a priori* probabilities is defined by the analyzer.

a priori probability to produce a particle of tipe *k* in the event (taking into account all track selection criteria)

global PID weight

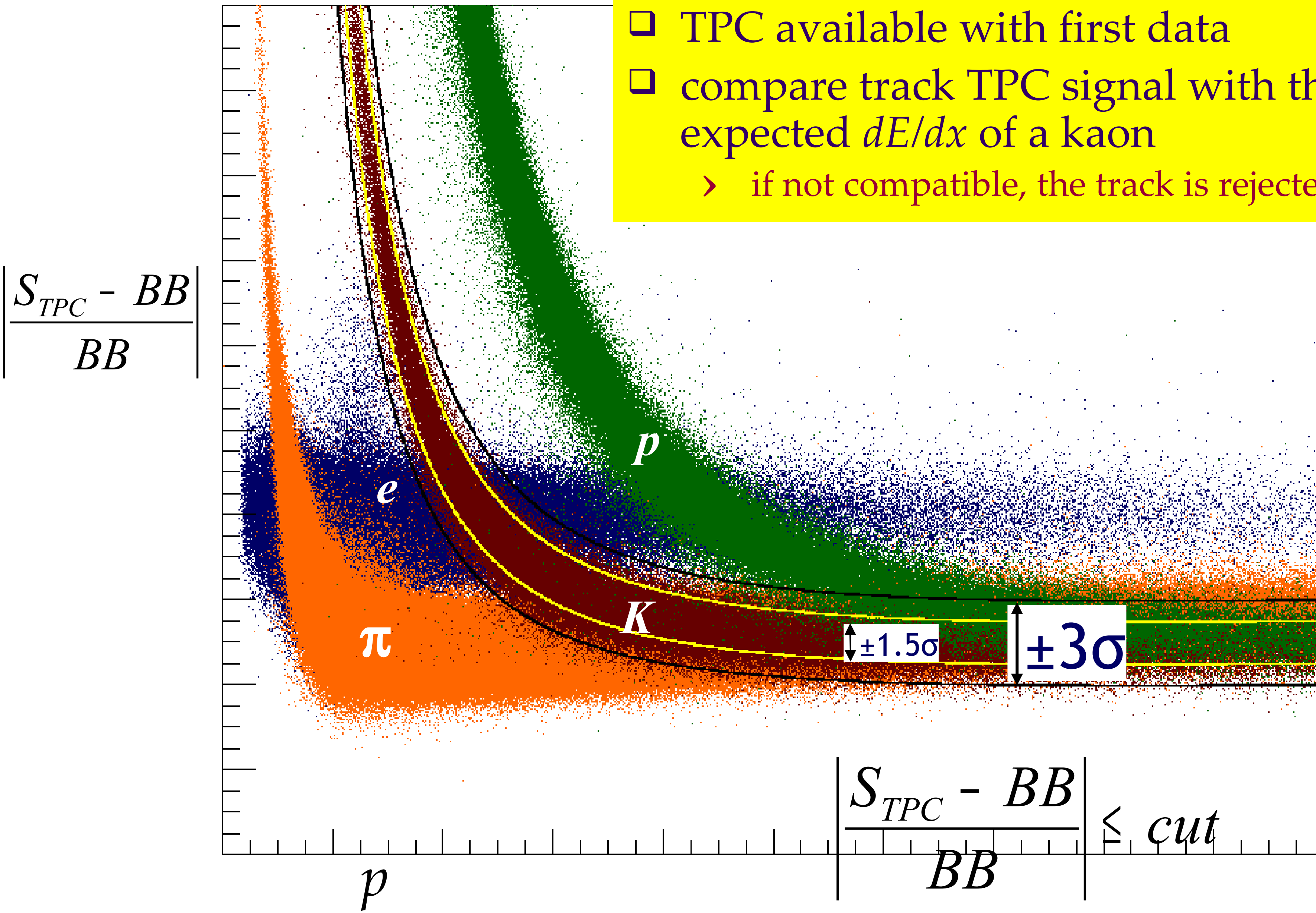
$$p_k = \frac{C_k w_k^G}{\sum_i C_i w_i^G} \qquad k = e, \mu, \pi, K, p$$

$$w_k^G = w_k^{ITS} \cdot w_k^{TPC} \cdot w_k^{TRD} \cdot w_k^{TOF} \cdot w_k^{HMPID}$$

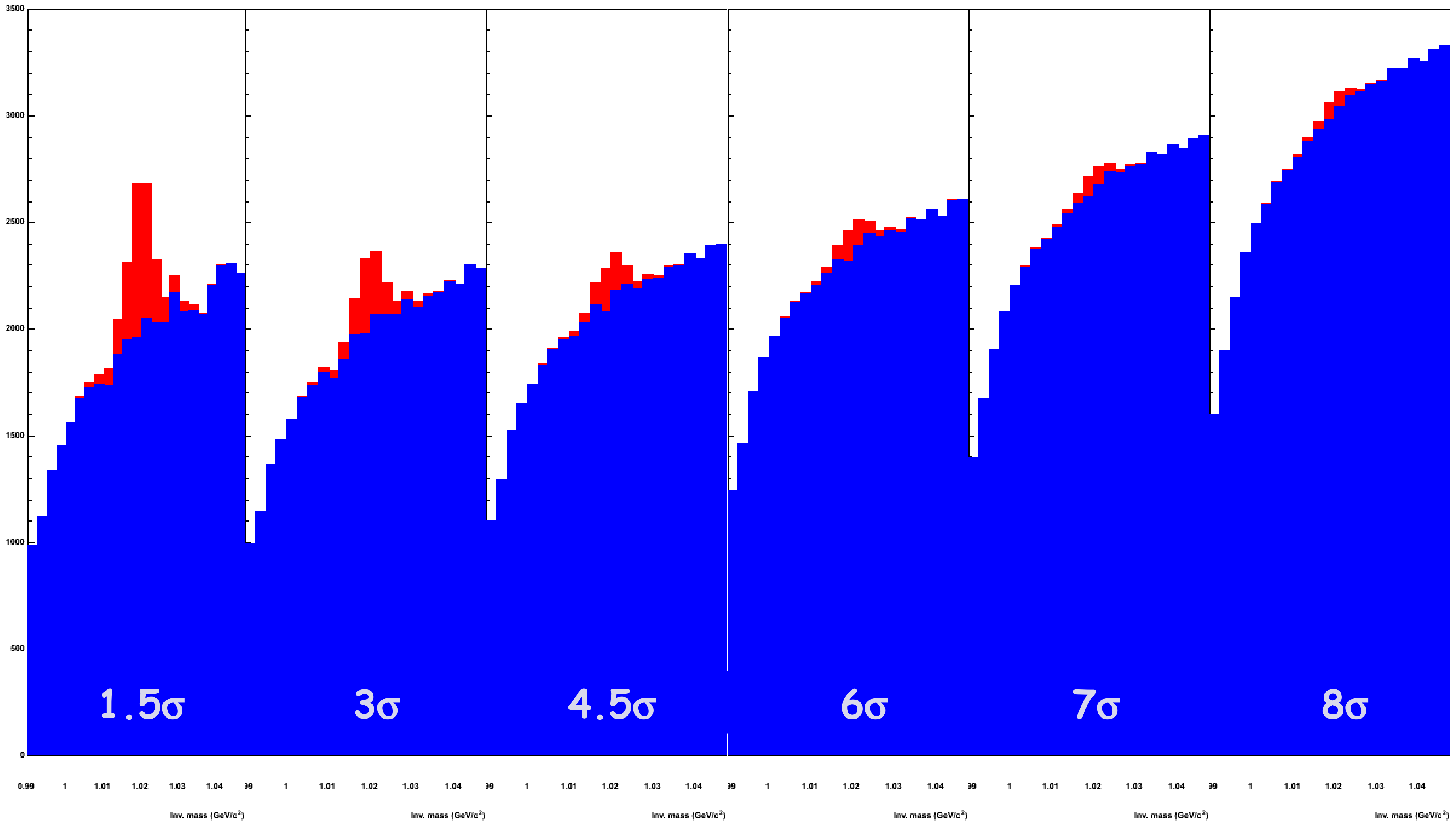
…but with the first data not all of them will be perfectly tuned

TPC PID compatibility cut

- TPC available with first data
- compare track TPC signal with the expected *dE/dx* of a kaon
  - if not compatible, the track is rejected



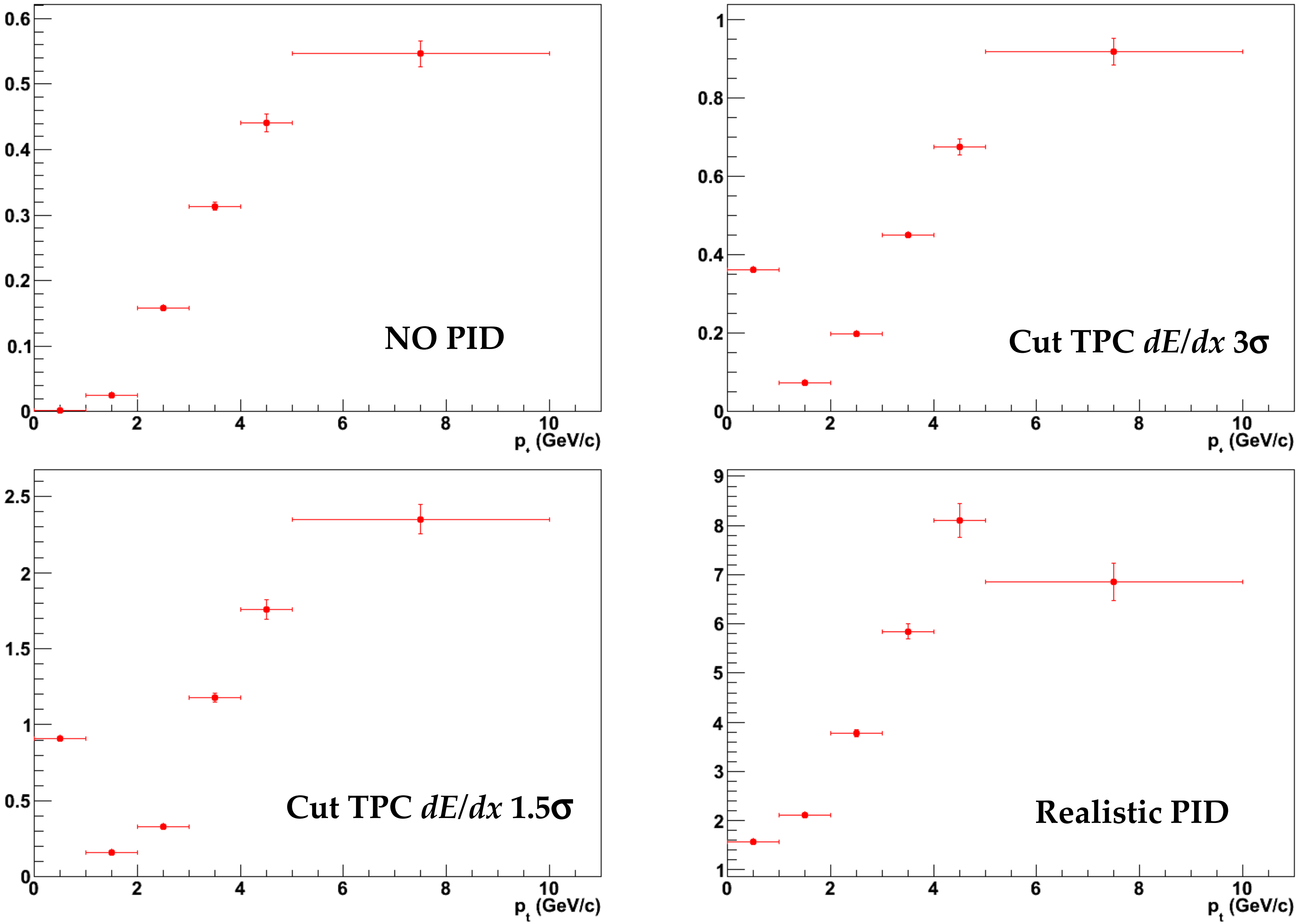
Visual cut effectiveness



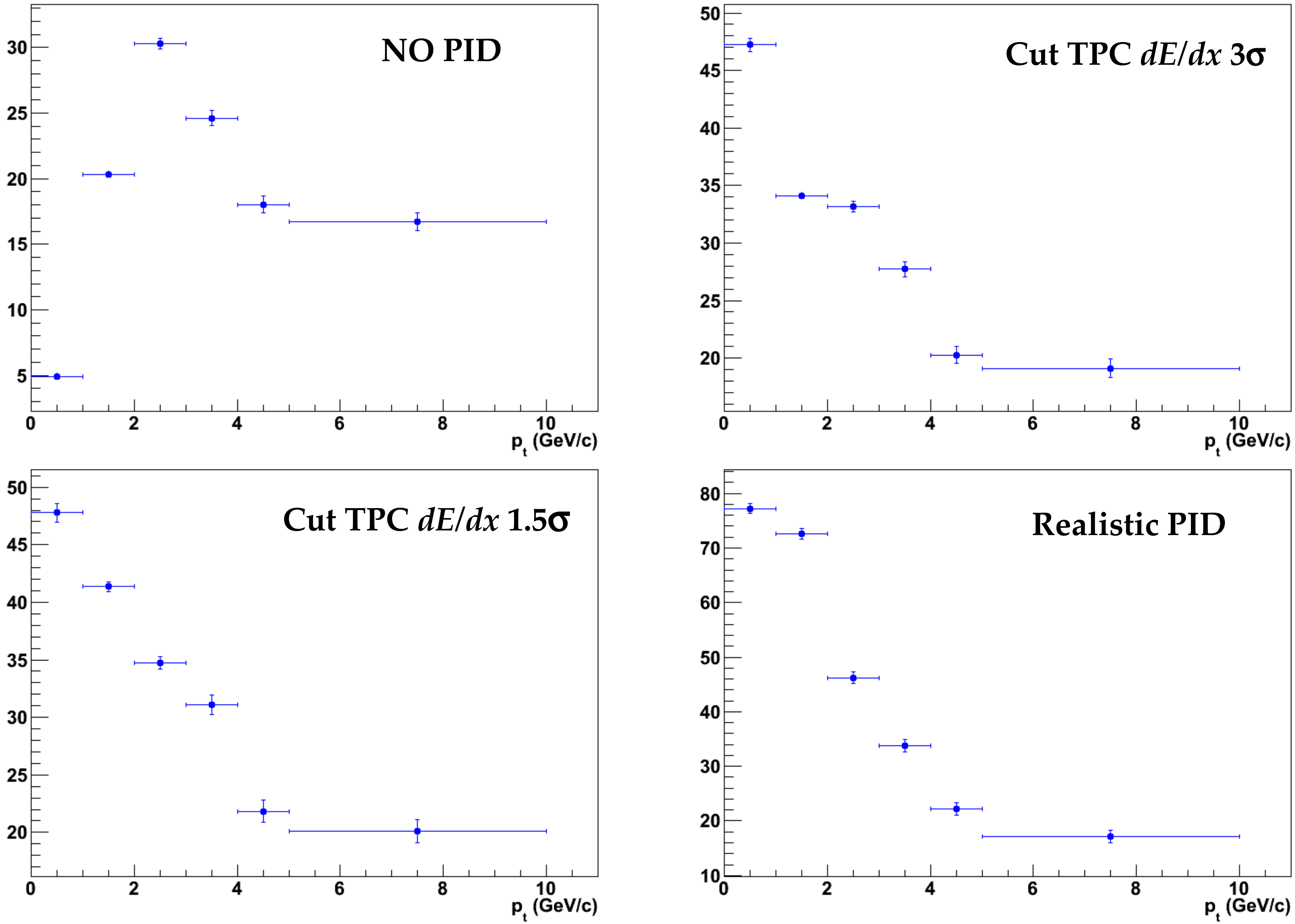
Kaon selection strategies adopted

- Absolutely NO PID
  - compute inv. mass spectra with all track pairs which pass preliminary quality track selections
- TPC compatibility within **3σ** around Bethe-Bloch value
- TPC compatibility within **1.5σ** around Bethe-Bloch value
- Realistic PID using Bayesian combination of PID weights from all detectors and prior probabilities

S/B Ratio vs. p_T



Significance: $S / (S + B)^{1/2}$ vs. p_T

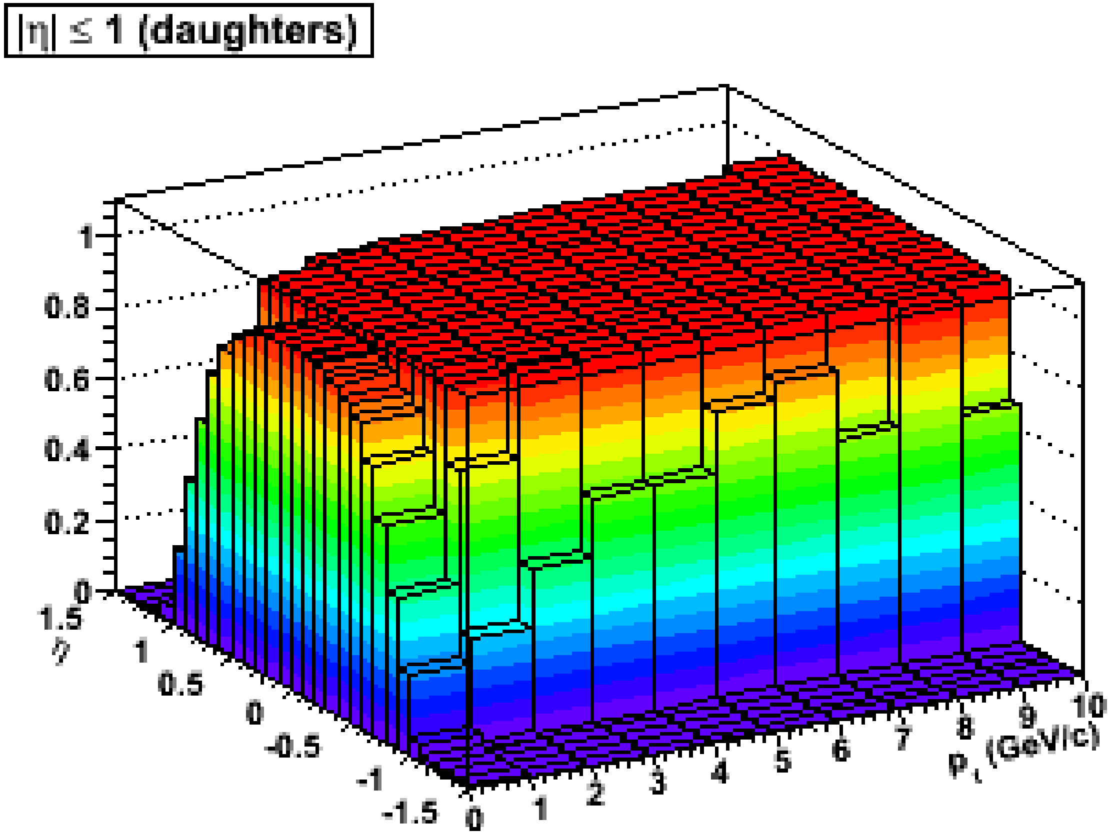


Efficiency computation

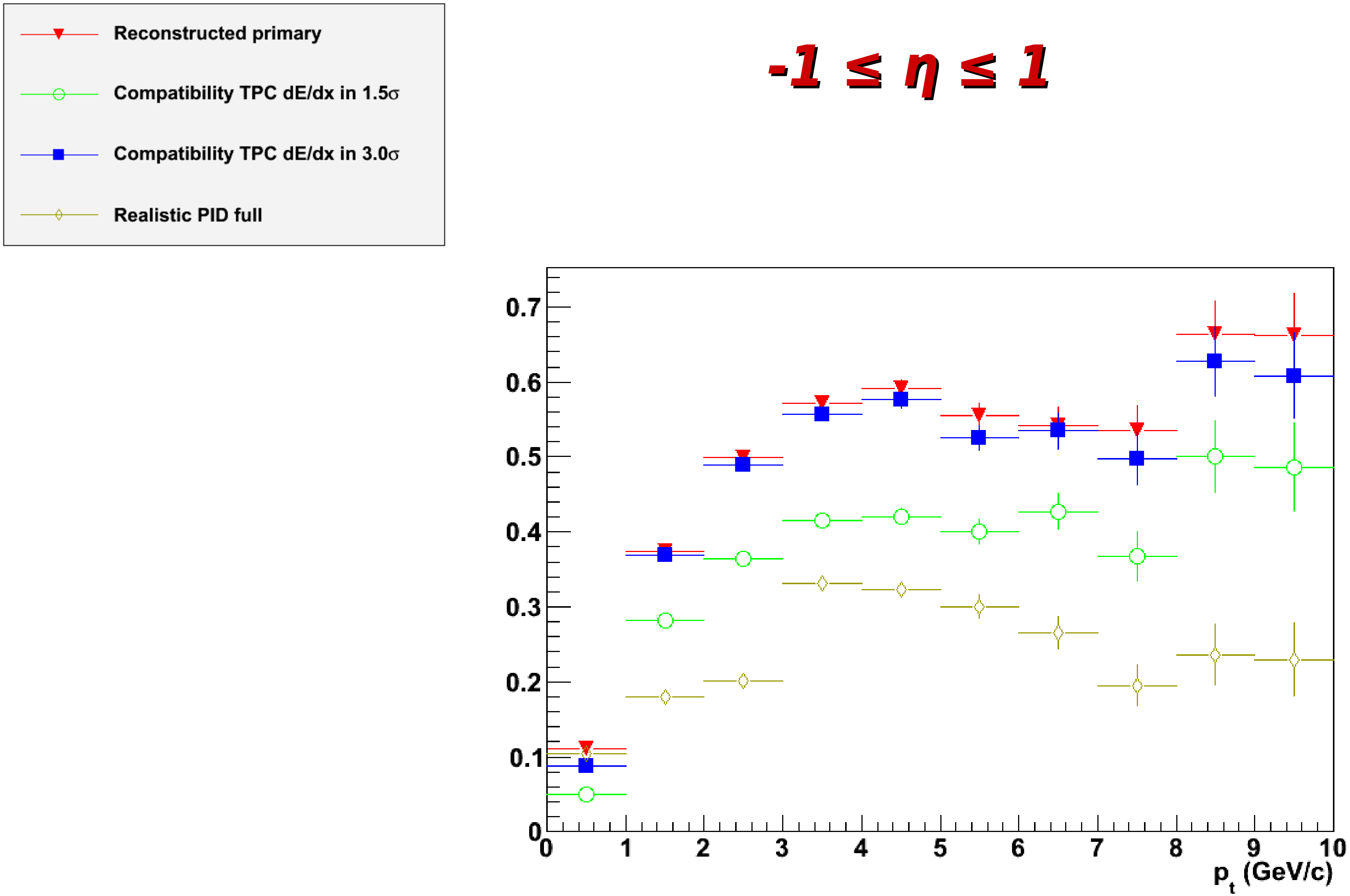
- To evaluate the effect of several selections due to different cuts we implemented a CORRFW analysis task with several steps:
  - 0: all ϕ's in PYTHIA decaying into charged *K*
  - 1: all ϕ's in PYTHIA whose daughters fall into the geometrical acceptance [$|\eta| \leq 1$]
  - 2: all ϕ's whose daughter were reconstructed and whose tracks pass the primary track selection cuts
    - → NO PID analysis
  - 3a: all ϕ's whose daughter tracks pass the **3σ** compatibility cut in TPC
  - 3b: all ϕ's whose daughter tracks pass the **1.5σ** TPC compatibility cut
  - 3c: all ϕ's whose daughter tracks are identified as *K* after **realistic PID** (with all detectors)

Efficiency: daughters acceptance correction

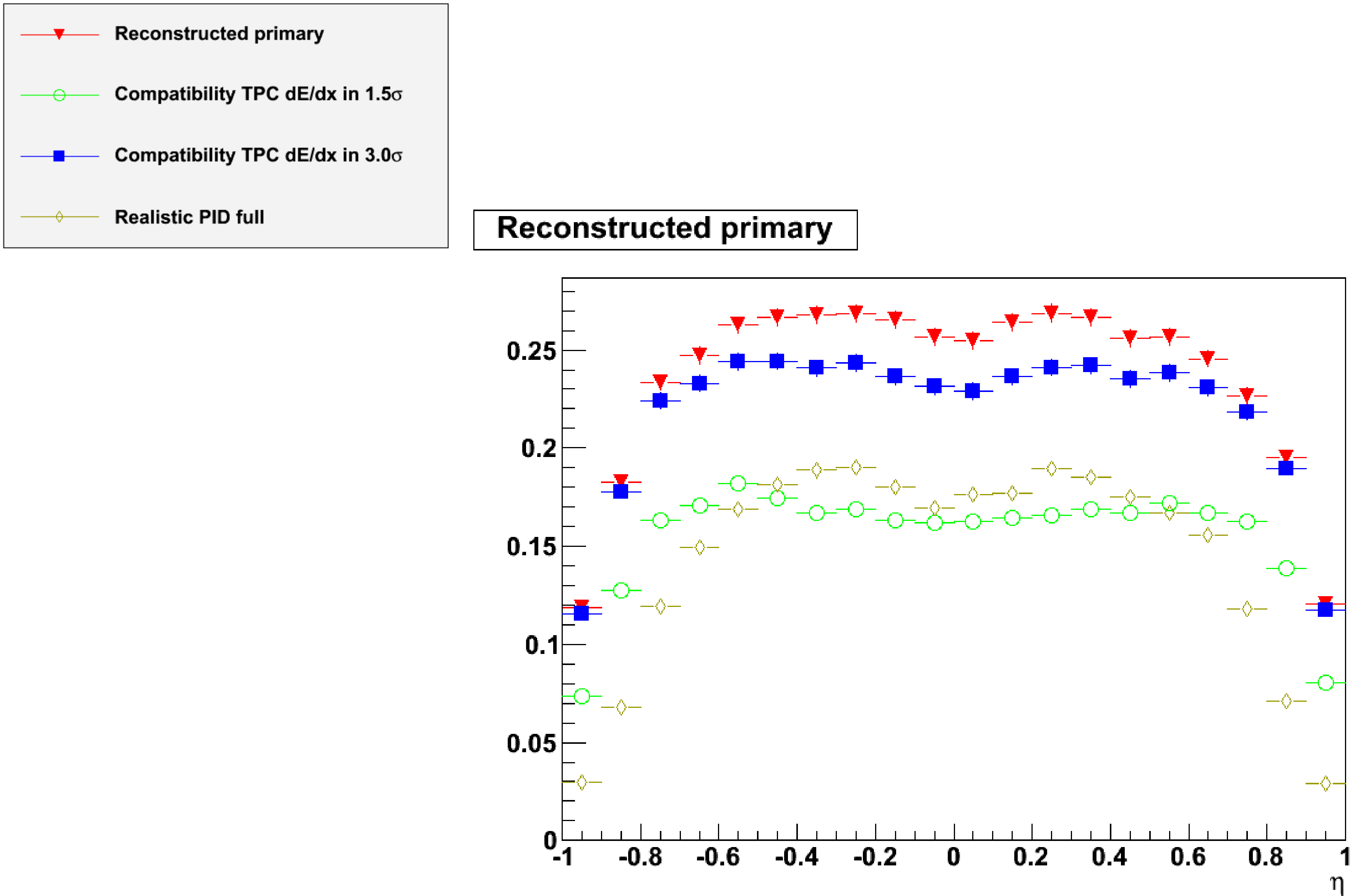
$$\frac{\text{STEP 1}}{\text{STEP 0}}$$



Combined efficiency + acceptance vs. p_T



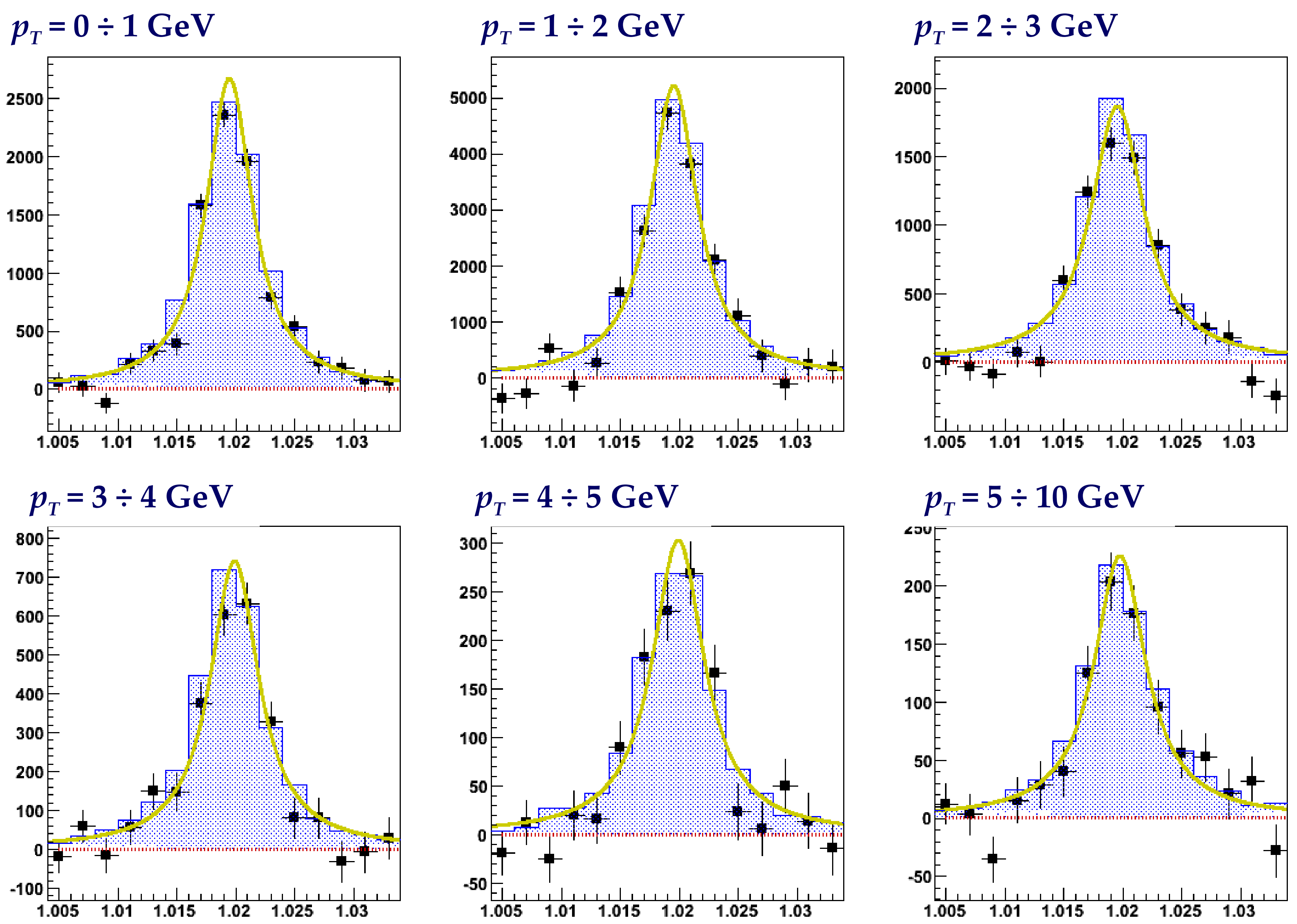
Combined efficiency + acceptance vs. η



Signal extraction

- Estimate background through like-sign pairs
  - $B(m) = 2 \cdot R \cdot [\, N_{++}(m) \cdot N_{--}(m)\,]^{-1/2}$
- Subtract background from K^+K^- $\boldsymbol{m}_{\mathbf{inv}}$ distribution
- Fit with a Breit-Wigner
  - in some cases, a residual background is present, which is fitted with a straight line
- Estimate the reconstructed yield from the integral of the fitted Breit-Wigner function.

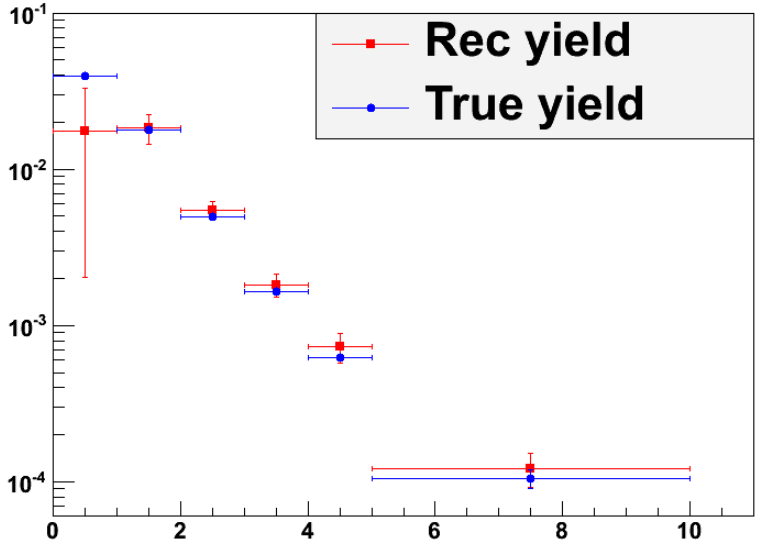
Peak extraction: TPC compatibility in 3



Corrected yields → $1/p_T\, dN/dp_T$

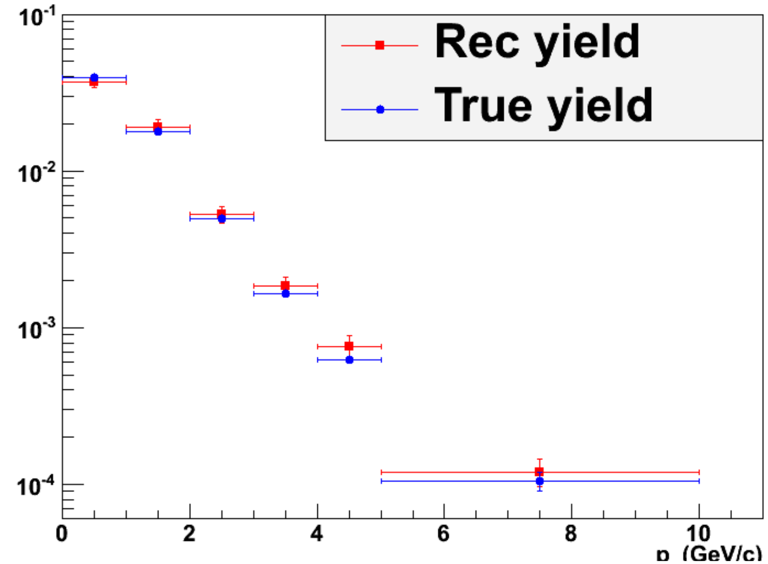
Graph

NO PID

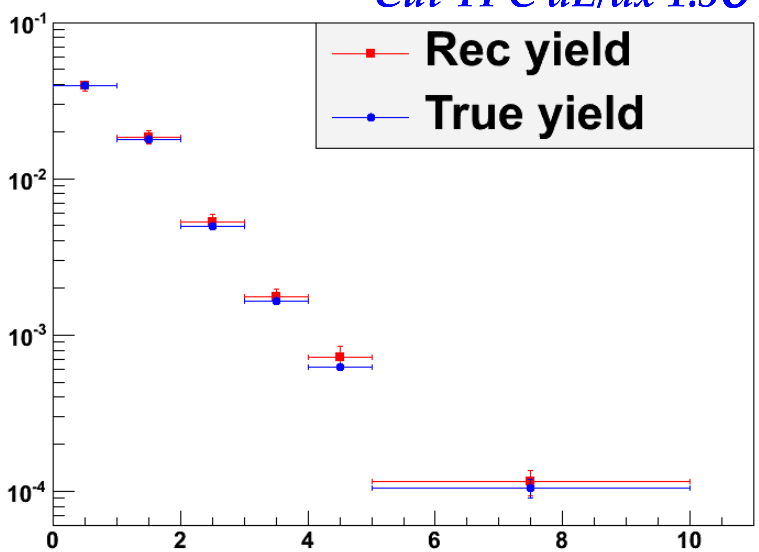


Graph

Cut TPC dE/dx 3σ

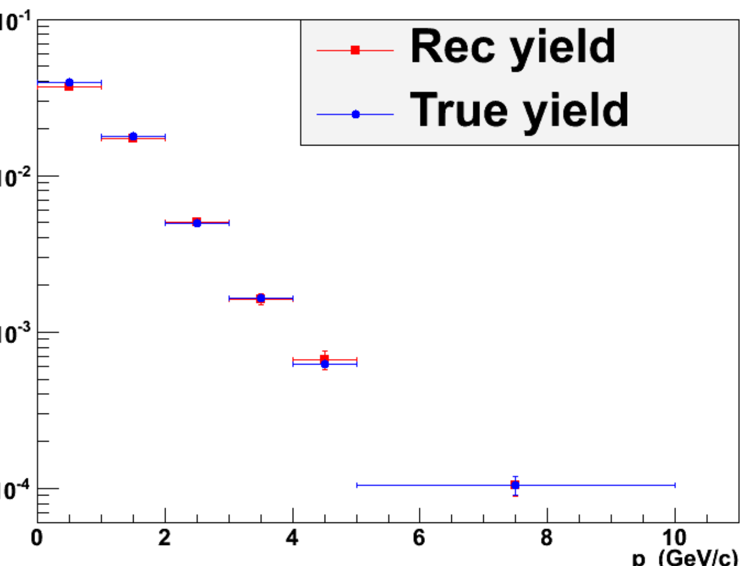


Cut TPC dE/dx 1.5σ



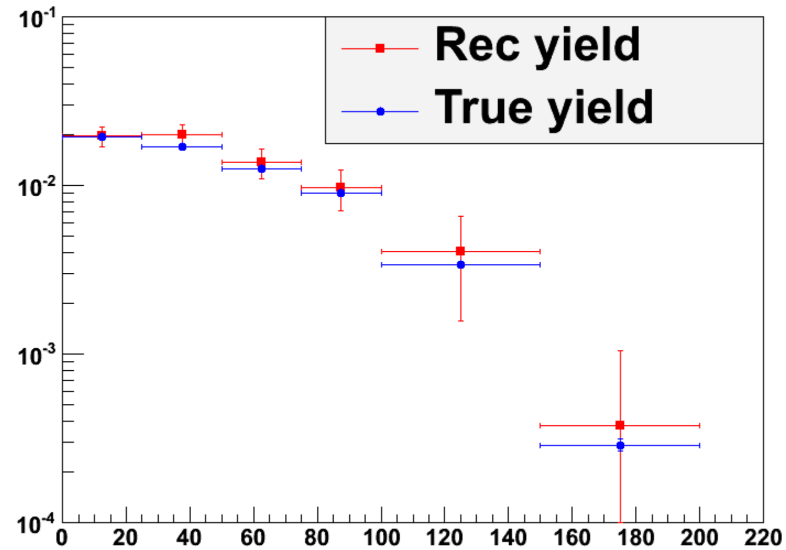
Graph

Realistic PID

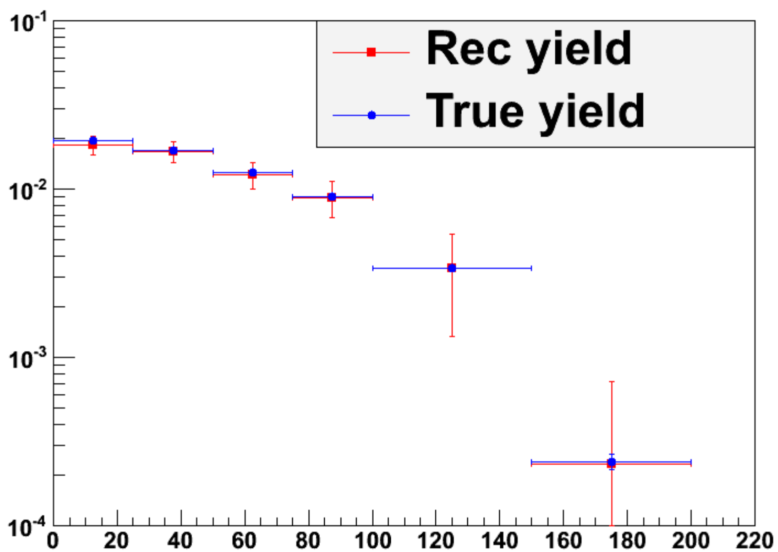


Corrected yields vs. mult

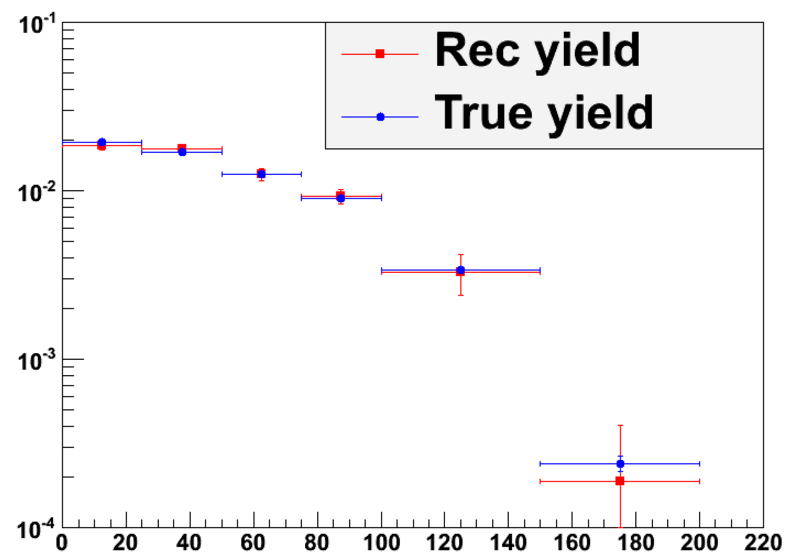
Cut TPC dE/dx 3σ



Cut TPC dE/dx 1.5σ



Realistic PID



Minimum number of MB events required → HM events sample estimation

- Adopted minimum significance threshold = **10**
- Significance scales as sqrt(num. of events)
  - **800K** events allow to have signif. > 10 in the 4-5 GeV p_T bin

- Assumption: high multipliciy events have $\langle N_{ch} \rangle \sim n \langle N_{ch} \rangle_{MB}$
  - S scales like n
  - B scales like n^2

- Assuming $n = 7$, the number of HM events required to have a significance 10 in the 4-5 GeV p_T bin depends on the PID method:
  - with TPC compatibility cut: **640K** events
  - with realistic PID: **160K** events

- Integrated significance in this scenario:
  - TPC compatibility cut (640K evts): ~**16**
  - realistic PID (160K evts): ~**18**

Conclusions

- First physics with ϕ resonance:
  - first target → yield estimation w.r.t. to multiplicity
    - almost impossible without PID, except for high p_T
    - feasible even in the worst scenario using TPC information
  - with few millions of MB events, p_T spectra can be estimated
    - systematic error evaluation in progress
    - preliminary evaluation of required number of HM events for a feasible study done (some aspects still under investigation)
  - perspectives:
    - other resonances (K*)
    - extend the "compatibility PID cut" criteria to other detectors (TOF, ITS, …)

Strangeness enhancement and the φ resonance

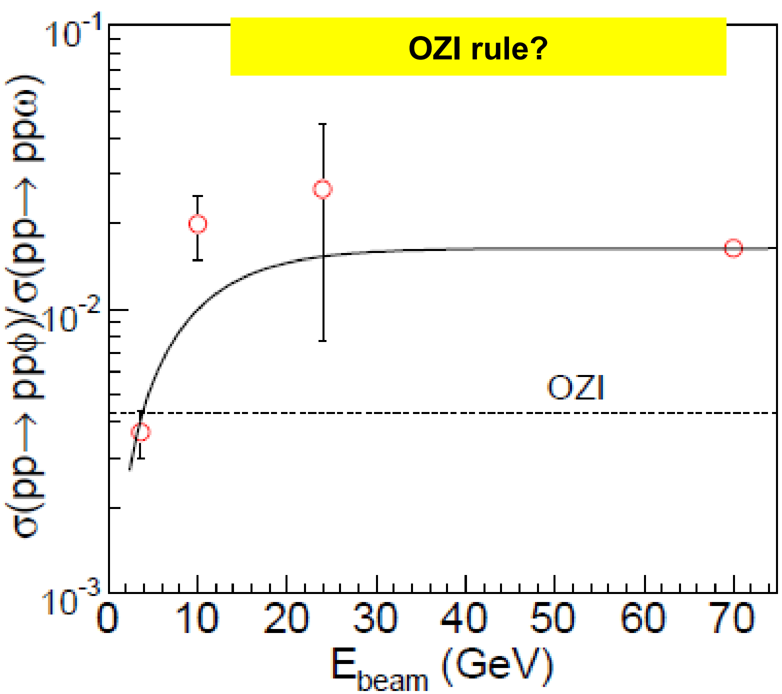
Canonical suppression:

pp cannot be treated as GC ensemble

Suppression of strangeness in *pp* which disappears in HI collisions.

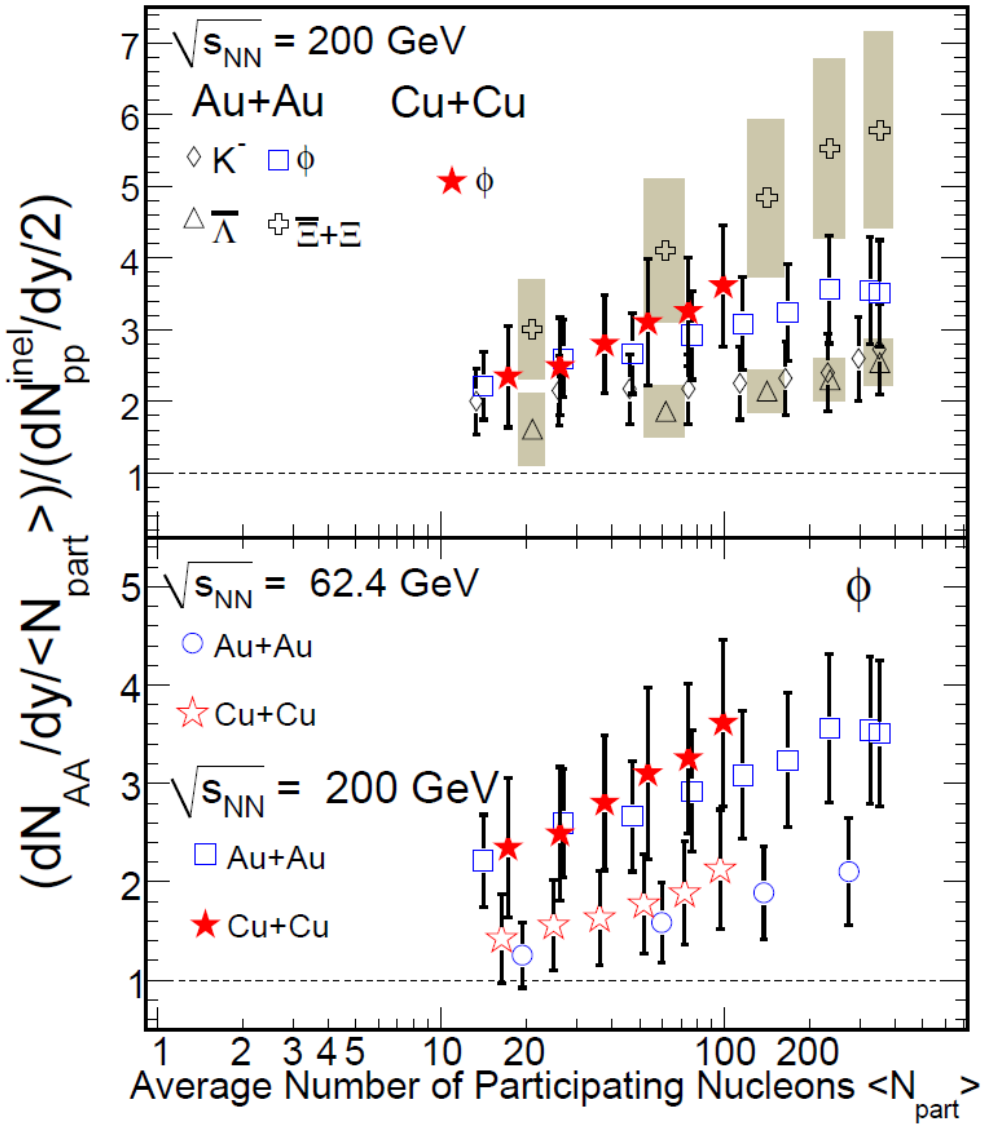
Enhancemend should scale as the number of constituent *s* quarks

- φ has S=0 → no canonical suppression



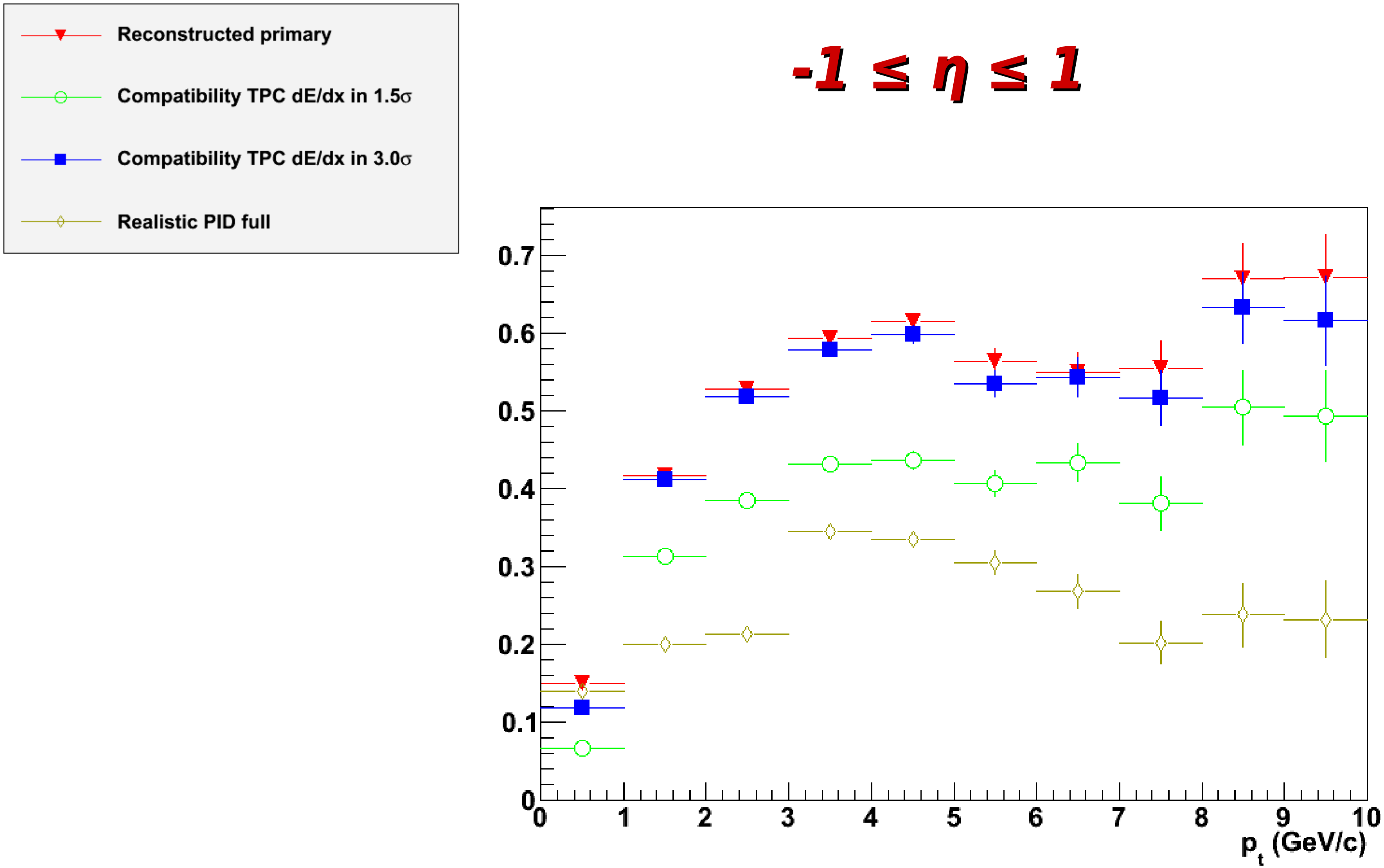
STAR, nucl-ex 0901.0313.v1

φ enhancement vs. K/Λ/Ξ enhancement

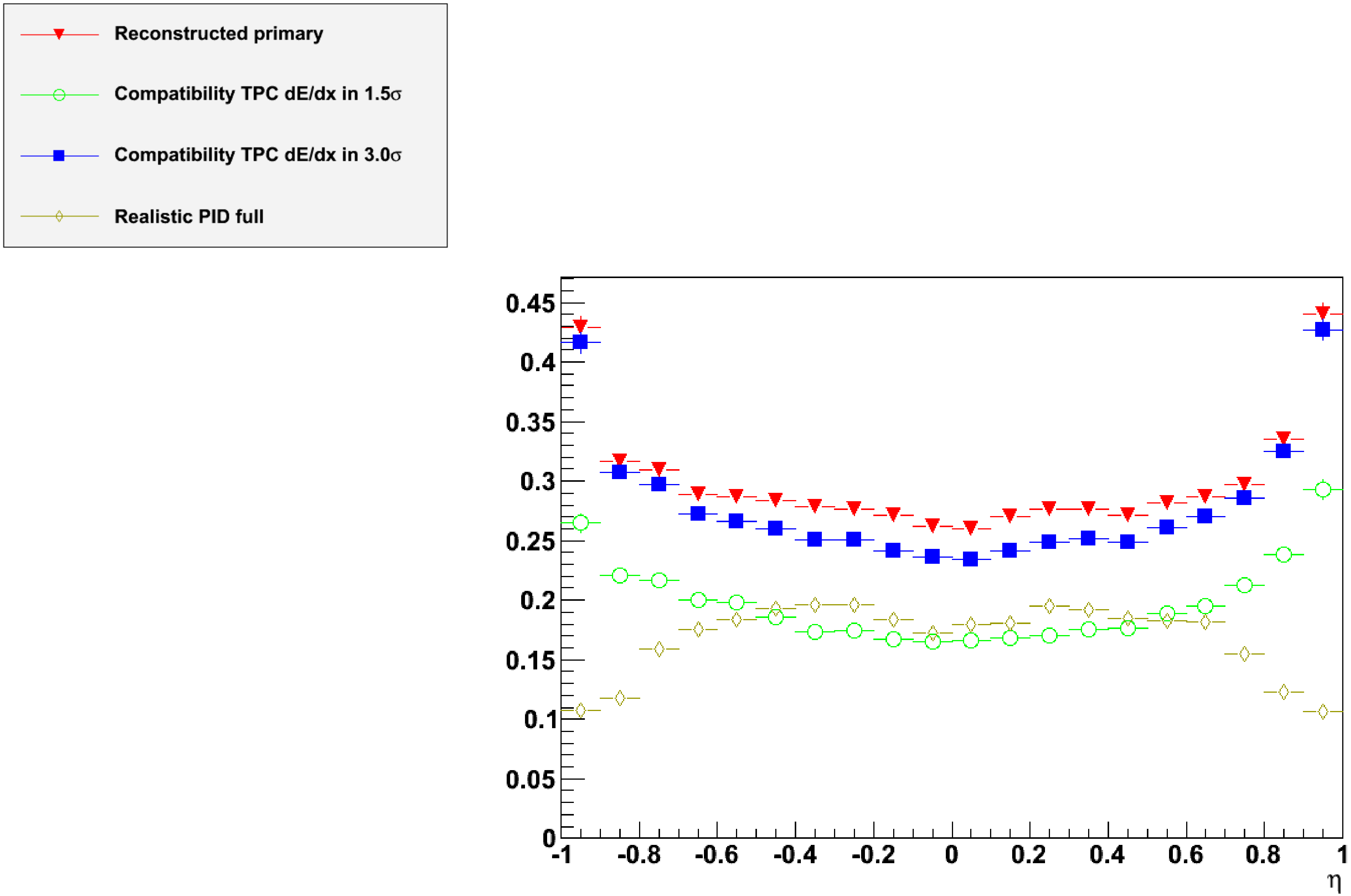


STAR, Phys. Lett. B673, 183

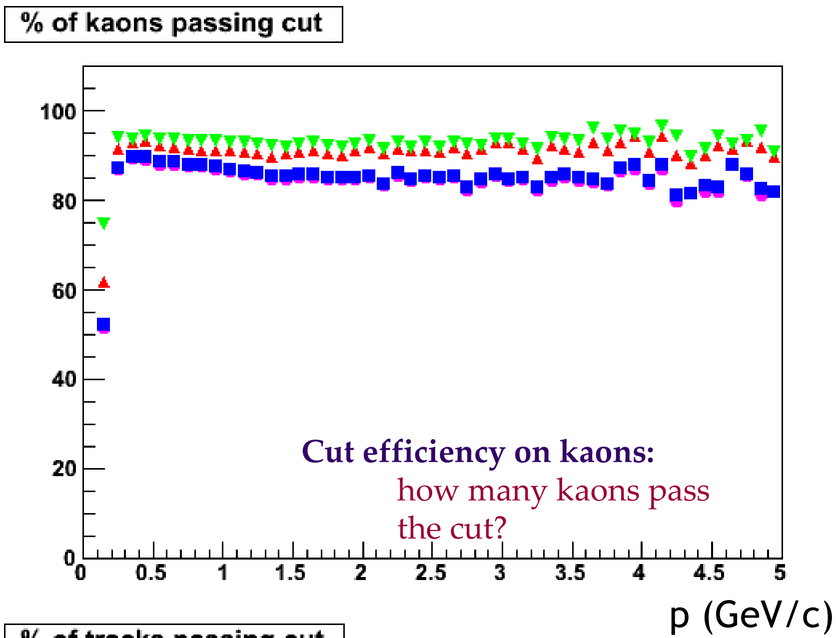
Efficiency vs. p_T in

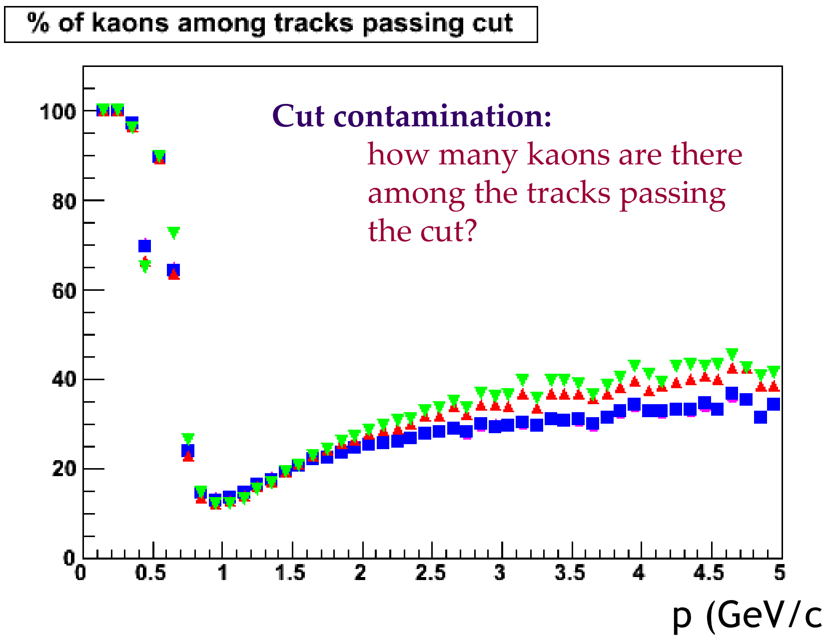


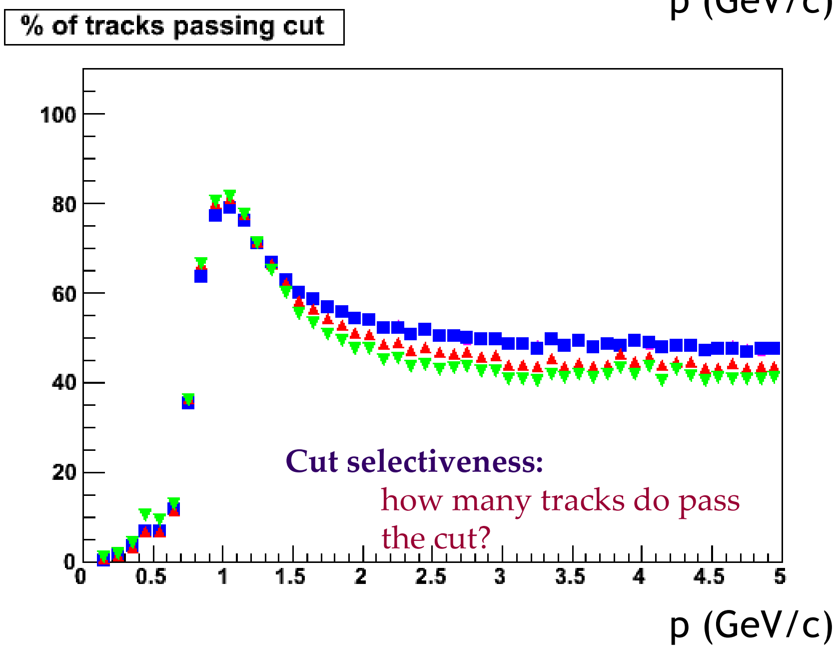
Efficiency vs. η



Cut evaluation

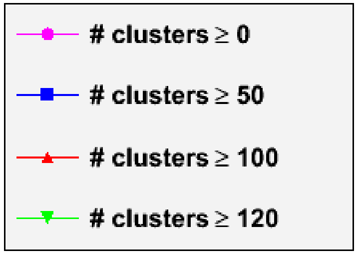




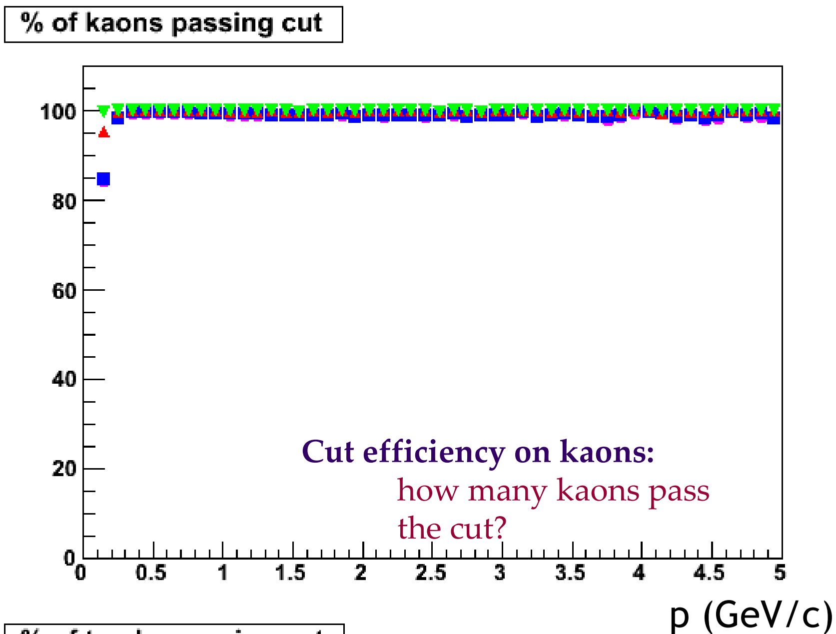


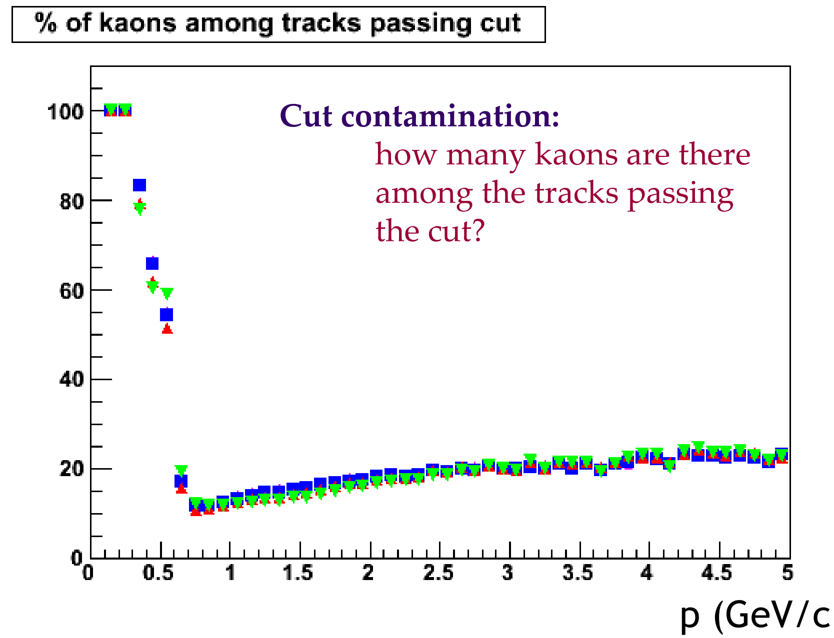
STRICT CUT

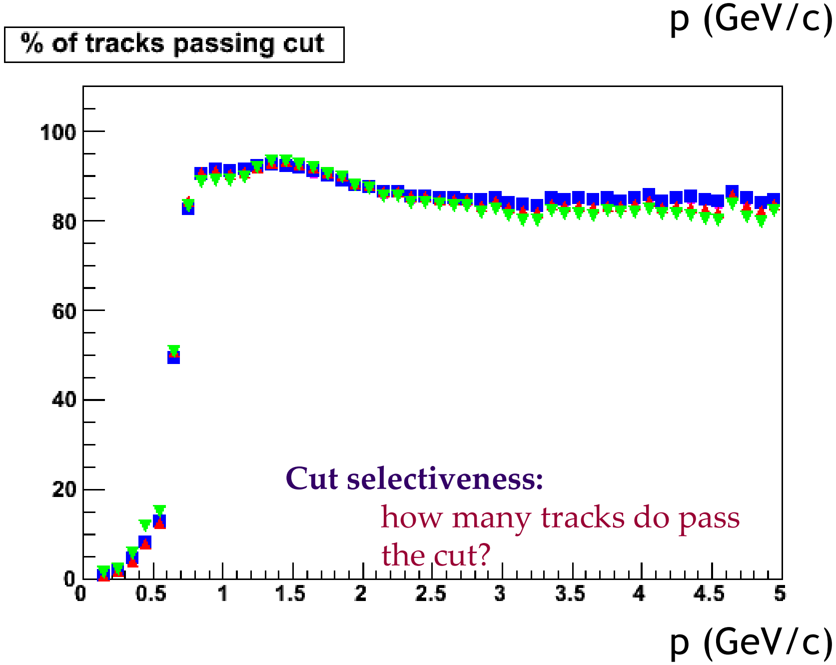
Accept tracks with relative difference within 1.5σ



Cut evaluation

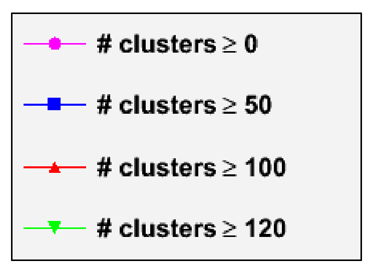






PERMISSIVE CUT

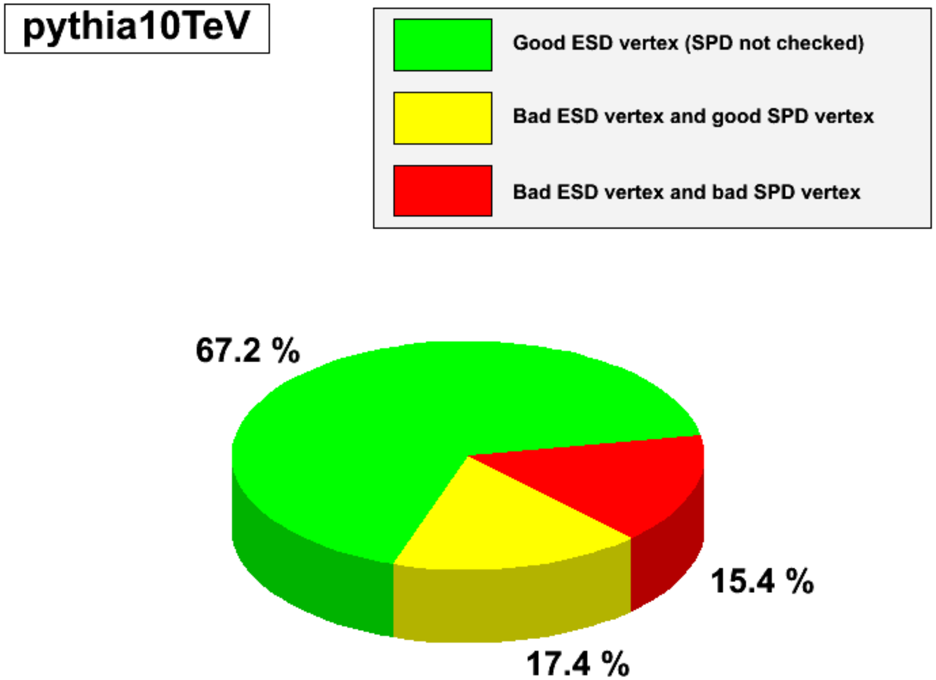
Accept tracks with relative difference within 3σ

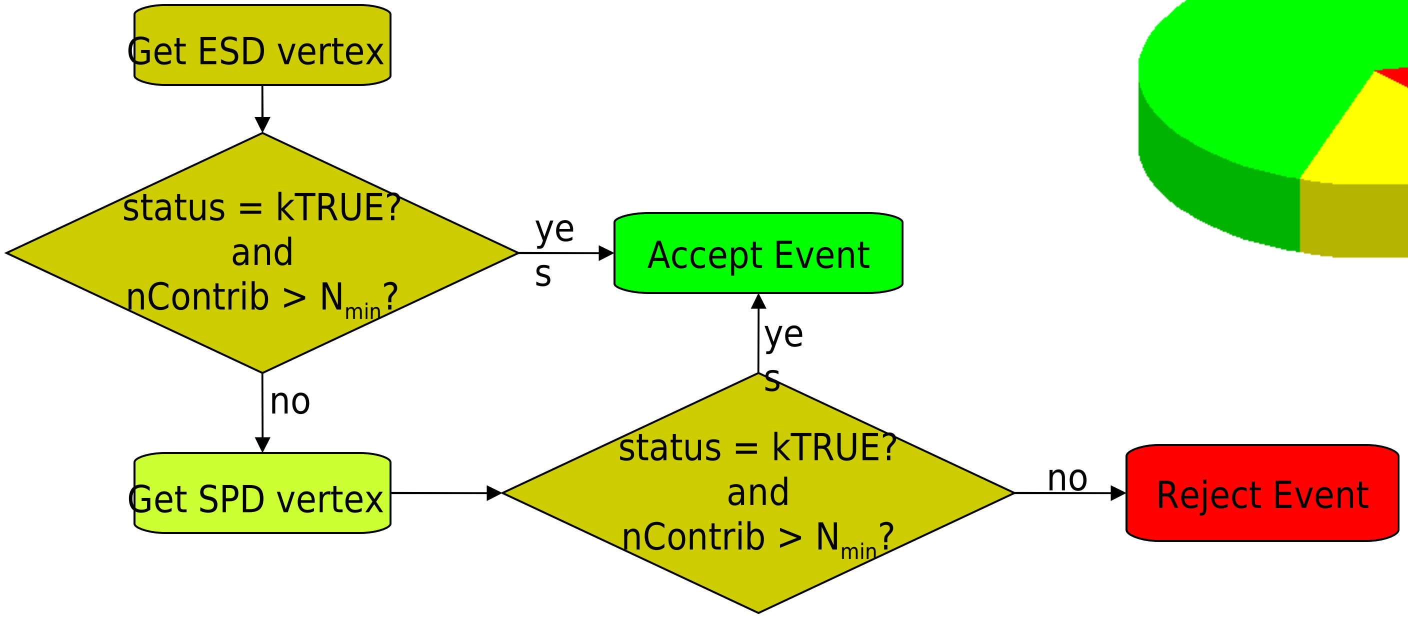


Primary vertex quality

- Not all events have a suitable primary vertex:
  - vertex "status" (Boolean)
  - number of "contributors" to vertex (I

- Two possibilities:
  - vertex computed with tracks ("ESD"
  - alternative: vertex computed with SP





From inclusive φ spectrum to yield

$$Yield = \frac{1}{\Delta\eta\,\Delta p_T} \cdot \frac{1}{Br} \cdot C_{\mathrm{geom}} \cdot C_{\mathrm{rec}} \cdot N / N_{trigger}$$

Definition of Ntrigger has to take into account also vertex identification and real trigger efficiency, for the moment this is just the number of analyzed event

N : number of detected φ in selected p_T-bin (raw spectrum)

Br: branching ratio

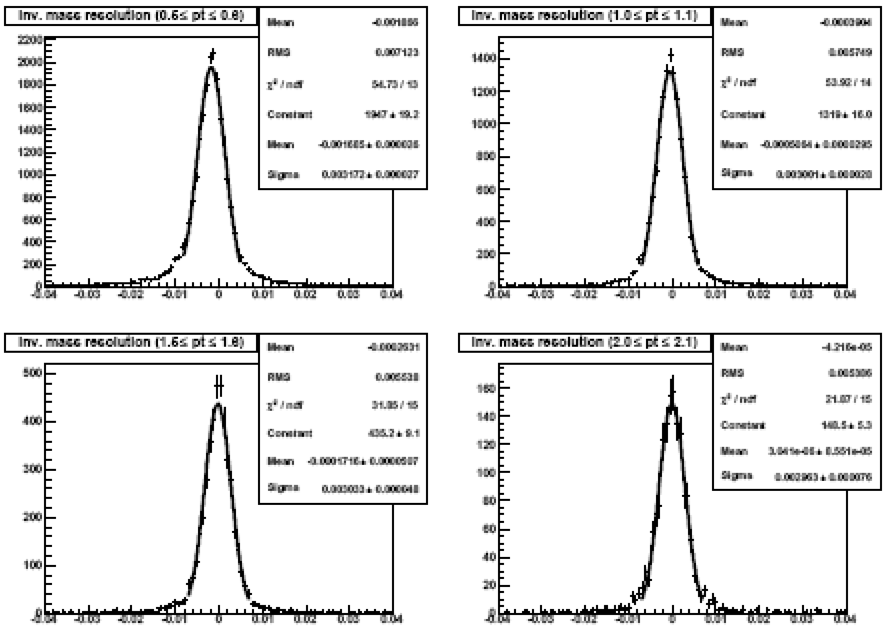
C_{geom} : geometrical acceptance

C_{rec} : reconstruction efficiency

Invariant mass resolution

K*(892)

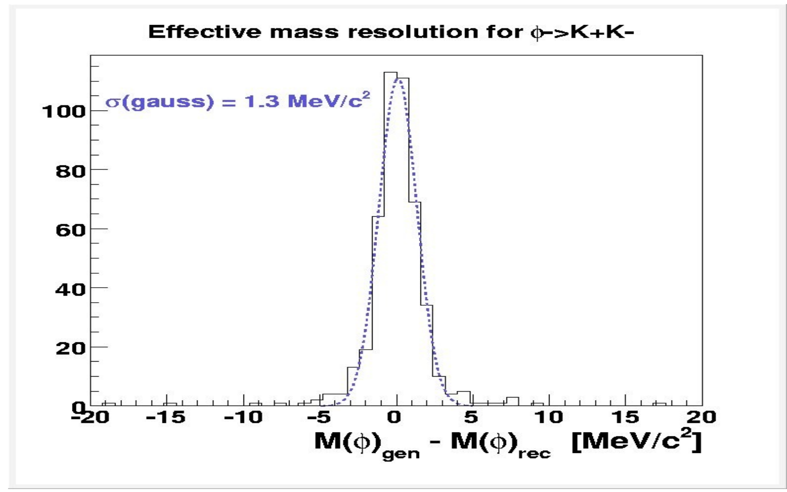
$0.6<p_t<0.8$ GeV/c $1.0<p_t<1.1$ GeV/c



$1.6<p_t<1.8$ GeV/c $2.0<p_t<2.1$ GeV/c

Mass resolution ~3 MeV/c²

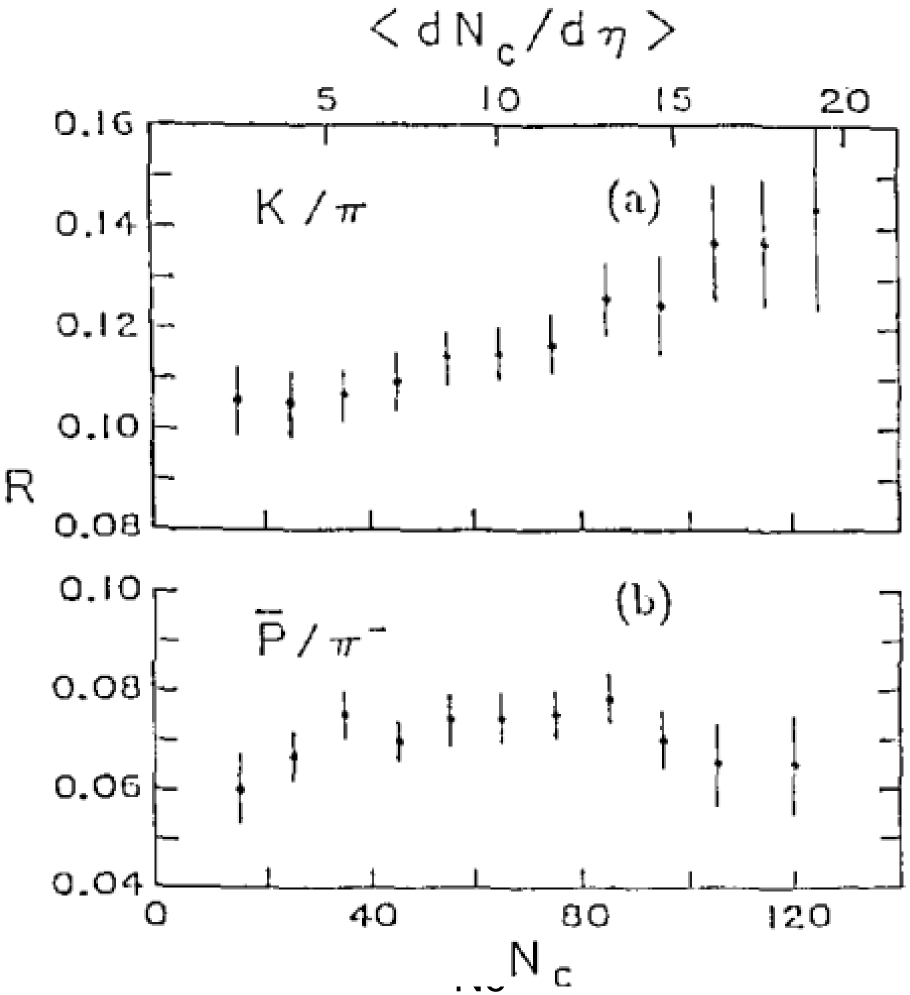
φ(1020)



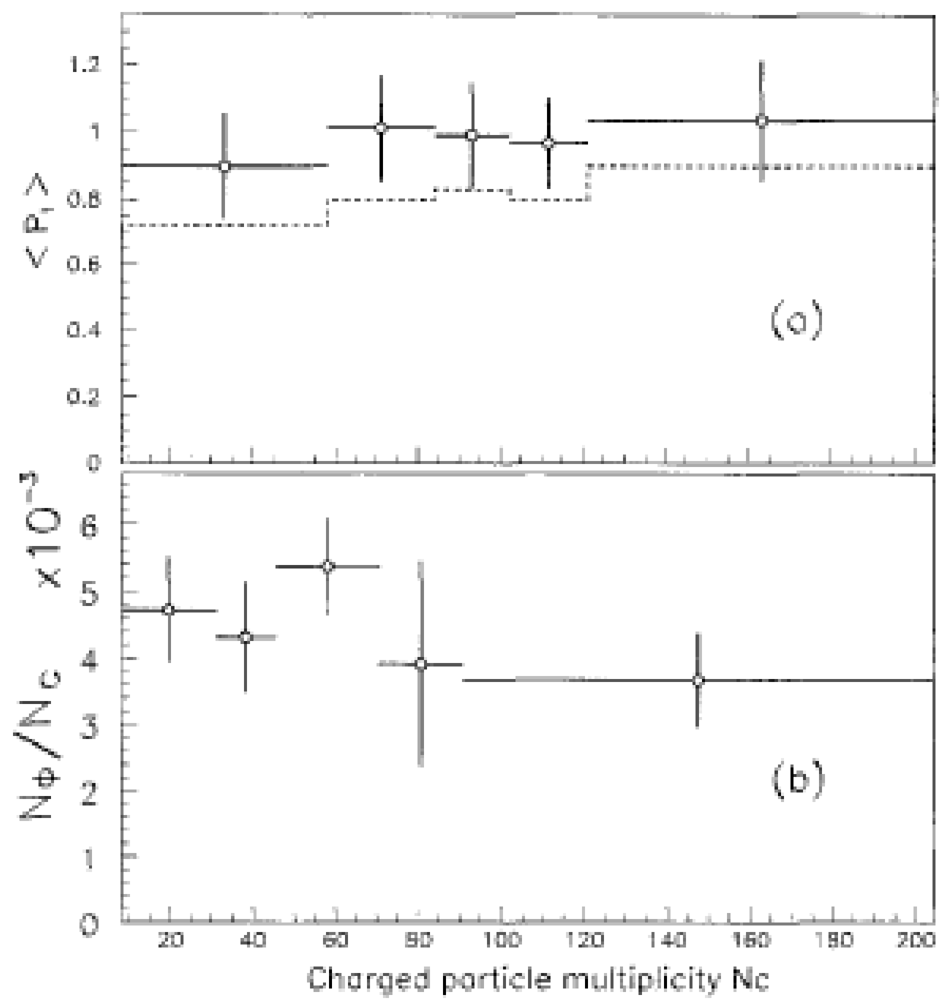
Mass resolution ~ 1.3 MeV/c²

Searches for QGP in pp collisions: E735

Energy density: $\frac{3}{2}\frac{dN_c}{d\eta}\frac{\left(\langle p_T\rangle^2+m_\pi^2\right)^{1/2}}{\tau\pi r^2}$



E735 collaboration: Z. Phys C. 67 (1995), 411



E735 collaboration:
FERMILAB-Conf-91/336