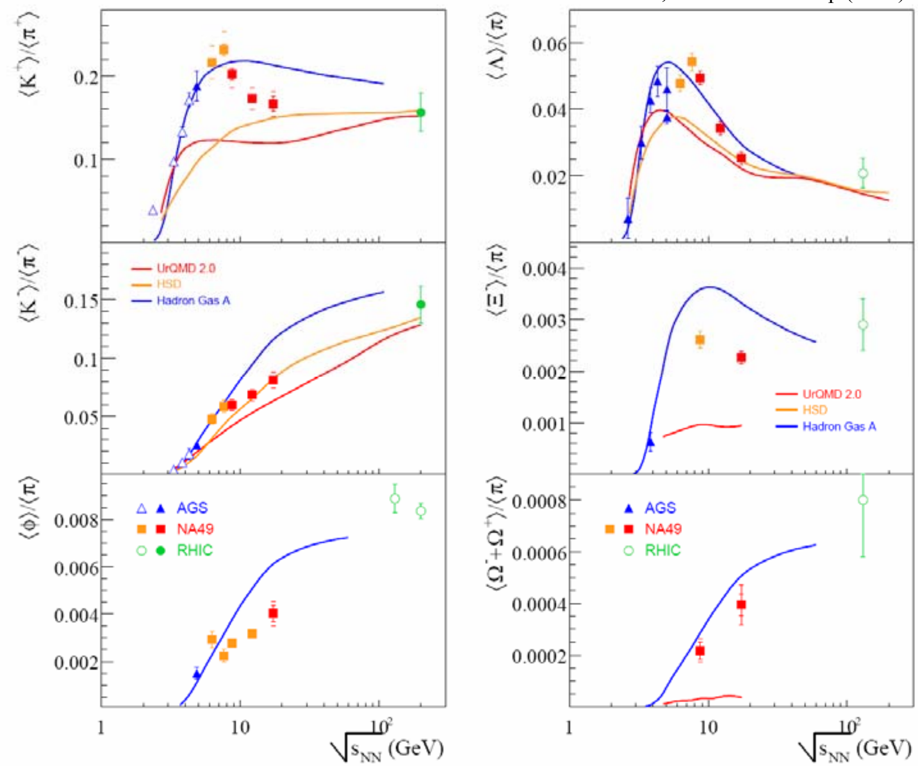
# Strangeness in medium

C.Blume, VI-SIM workshop (2006)




## Motivation

kaon effective mass and potential

## Evidence at SIS18

(anti)kaon yield

(anti)kaon flow

Λ phase space distributions

## 'Review' of AGS results

flow of strange particles

## Exotic effects

exited hyperon states

deeply bound kaonic states

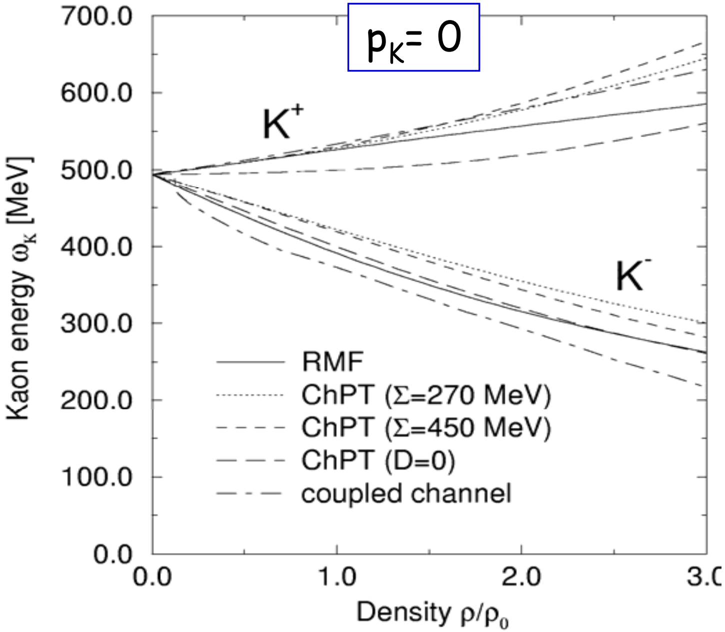
## Role of CBM: hadron program at SIS100 (2 – 10AGeV, $\sqrt{s_{NN}}$<4.5 GeV)

staging scenario, setup, acceptance

## Conclusion

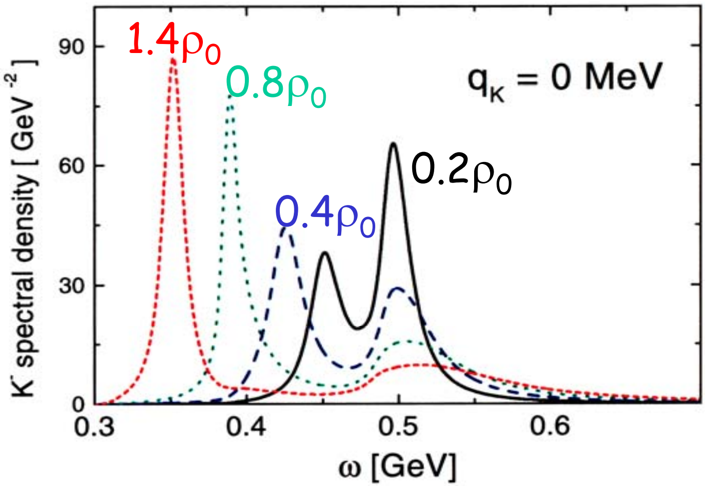
# Kaons in hadronic matter

**in-medium energy**




**spectral function of antikaons in dense matter**

Coupled channel calculation
M. Lutz, Phys. Lett. B426 (1998) 12




$$\omega_{K^\pm}(p,\rho) = \left(m^{*2} + p^2\right)^{\frac{1}{2}} = U + \left(m_K^2 + p^2\right)^{\frac{1}{2}}$$

**effective mass** **Kaon potential**

**Production: P ~ exp (-m*/T) → K-yields**

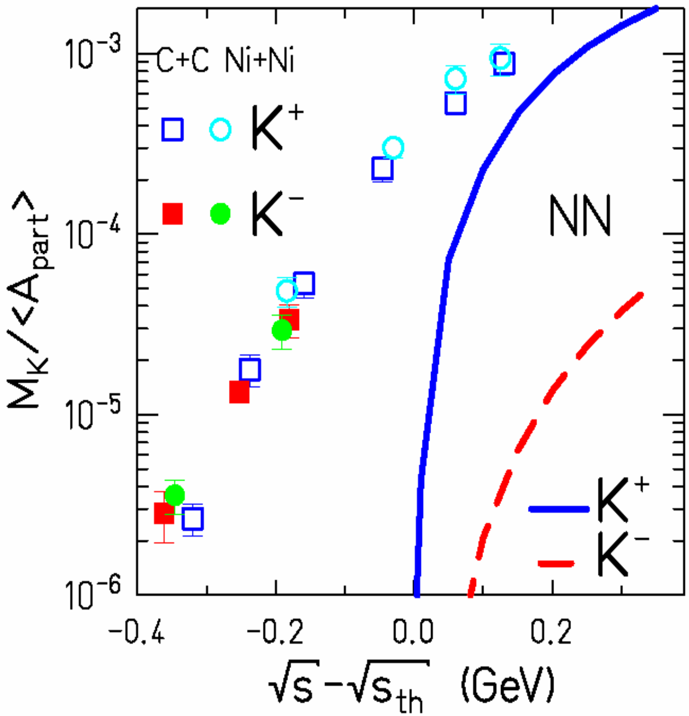
**Propagation: F=-∇U → K-flow**

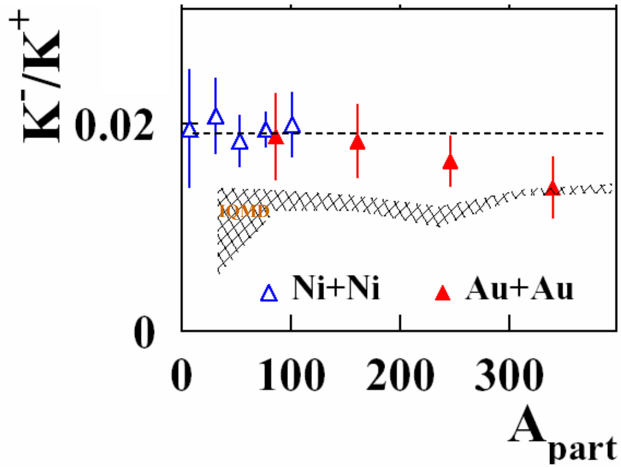
# Kaon & Antikaon Yields

P.Senger et al. (KAOS),
F. Laue et al. , PRL 82 (1999), updated

A.Förster et al. (KAOS), PRL 91, 152301(2003)

Centrality dependence




**Production thresholds:**

**NN →NK$^+$Λ** **$E_{lab}$= 1.6 AGeV**

**NN →K$^+$K$^-$NN** **$E_{lab}$= 2.5 AGeV**

**Enhanced Production of K$^+$,K$^-$ observed in HI - collisions**

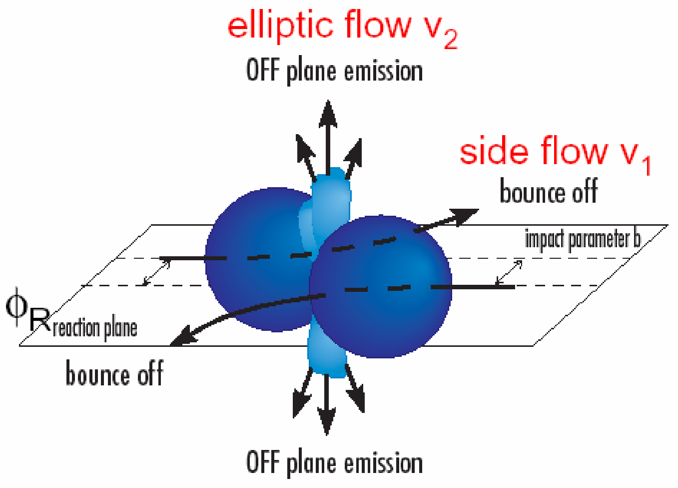
**multistep processes: ΔN →NK$^+$Λ**

**EOS**

**Transport models: no sensitivity of K$^-$/K$^+$ - ratio to in-medium mass of K$^-$**

**? Role of πΛ↔K$^-$N ?**

# Kaon sideflow



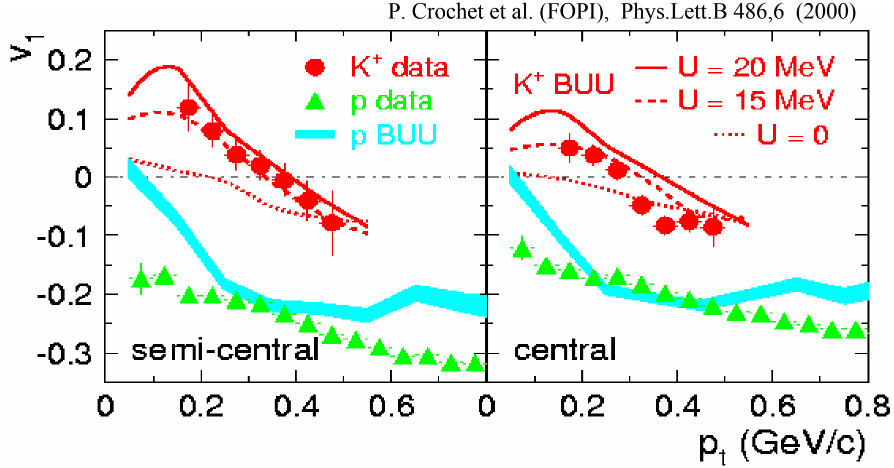

**Azimuthal distributions with respect to reaction plane**

$$\varphi' := \varphi - \Phi_R$$

$$\frac{d^3N}{p_t dp_t dy d\varphi'} \propto (1 + 2v_1 \cos(\varphi') + 2v_2 \cos(2\varphi') + \ldots)$$

Ru+Ru @ 1.7 AGeV

P. Crochet et al. (FOPI), Phys.Lett.B 486,6 (2000)



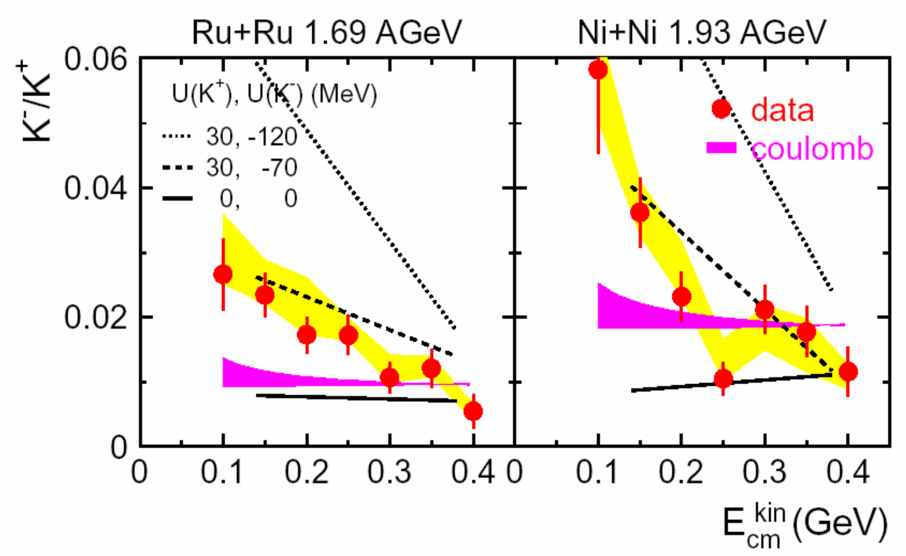

**Differential $K^+$- sideflow**

**$\Rightarrow U_K(\rho_0)$=15-20MeV by model comparison!**

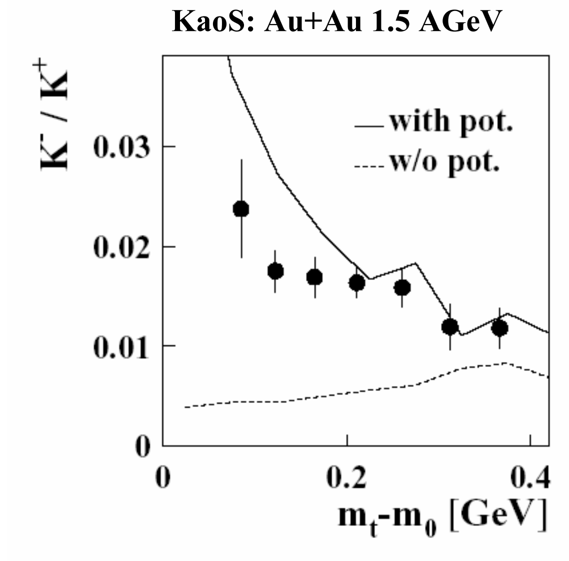
# Antikaon phase space distributions

## $K^-/K^+$ ratio

K. Wisniewski et al., (FOPI), Eur.Phys.J.A9,515 (2000)




A.Förster et al., (KaoS), PRL 91, 152301 (2003)



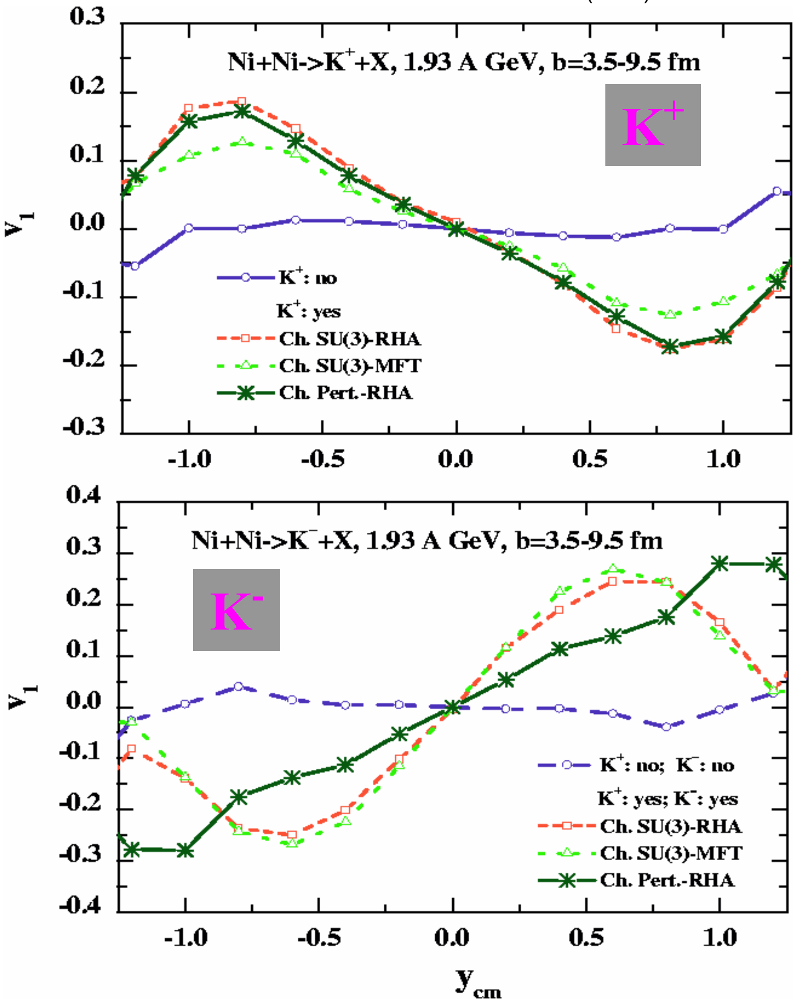

**$K^-$ phase space distribution different from $K^+$**

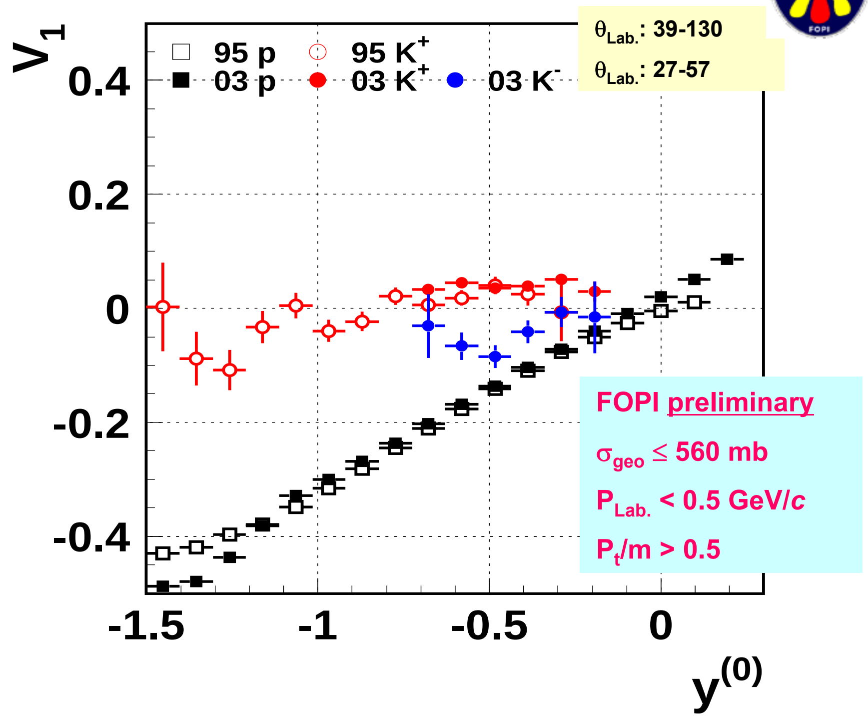
**⇒ $U_{K^-}(\rho_0)$= - 70 MeV by model comparison (RBUU)**

Note: Integrated $K^-$ - yield not directly sensitive to $K^-$ - potential due to strangeness exchange reaction $K^-N \leftrightarrow \pi\,\Lambda$ .

# Kaon and Antikaon sideflow

A. Mishra *et al*. PRC 70(2004) 044904



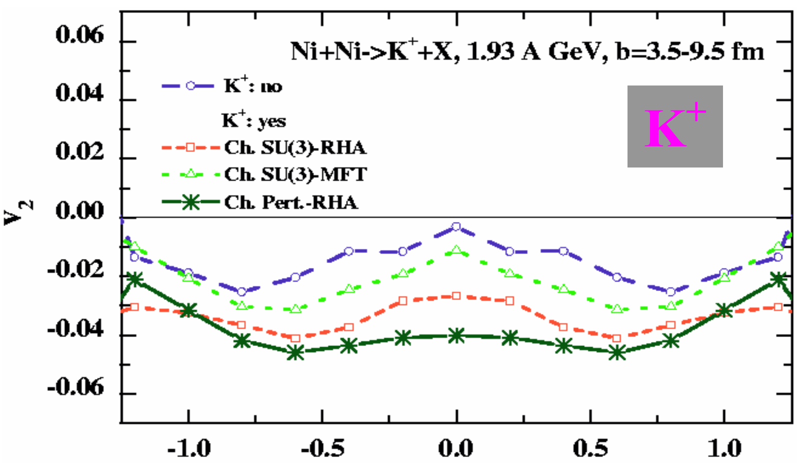



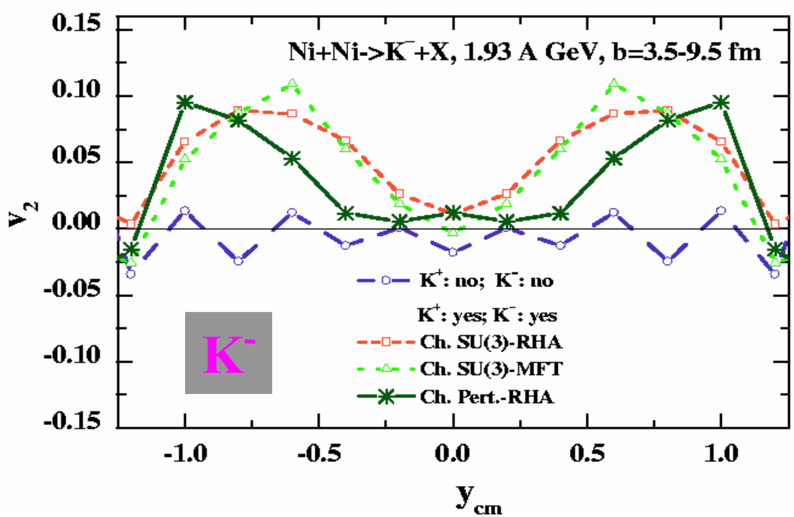

**$K^-$ - sideflow shows unpredicted dependence.**

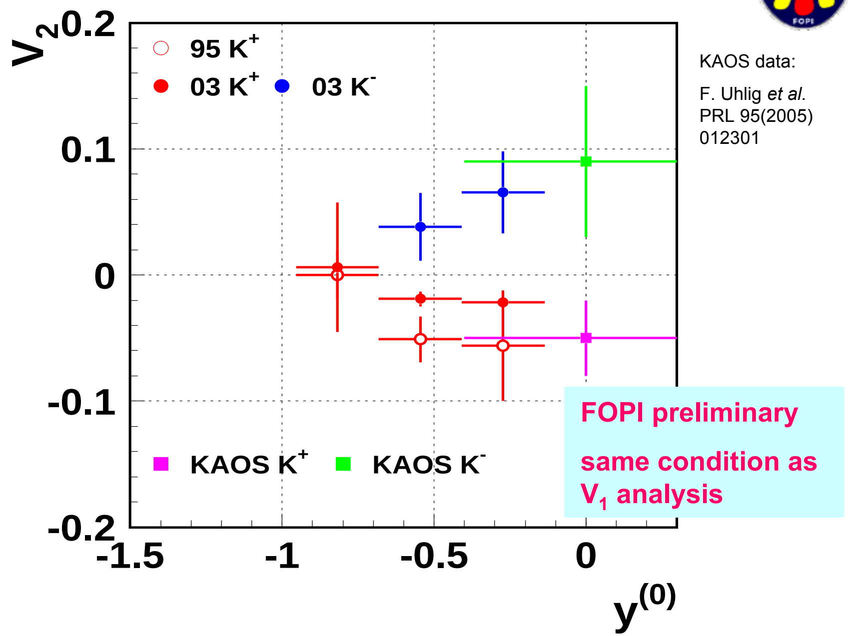
**$K^\pm$, $\pi^\pm$, p measurement with large phase space coverage and with sufficient statistics needed**

# Kaon and antikaon elliptic flow

A. Mishra *et al*. PRC 70(2004) 044904




**Kaon and antikaon have different sign.**

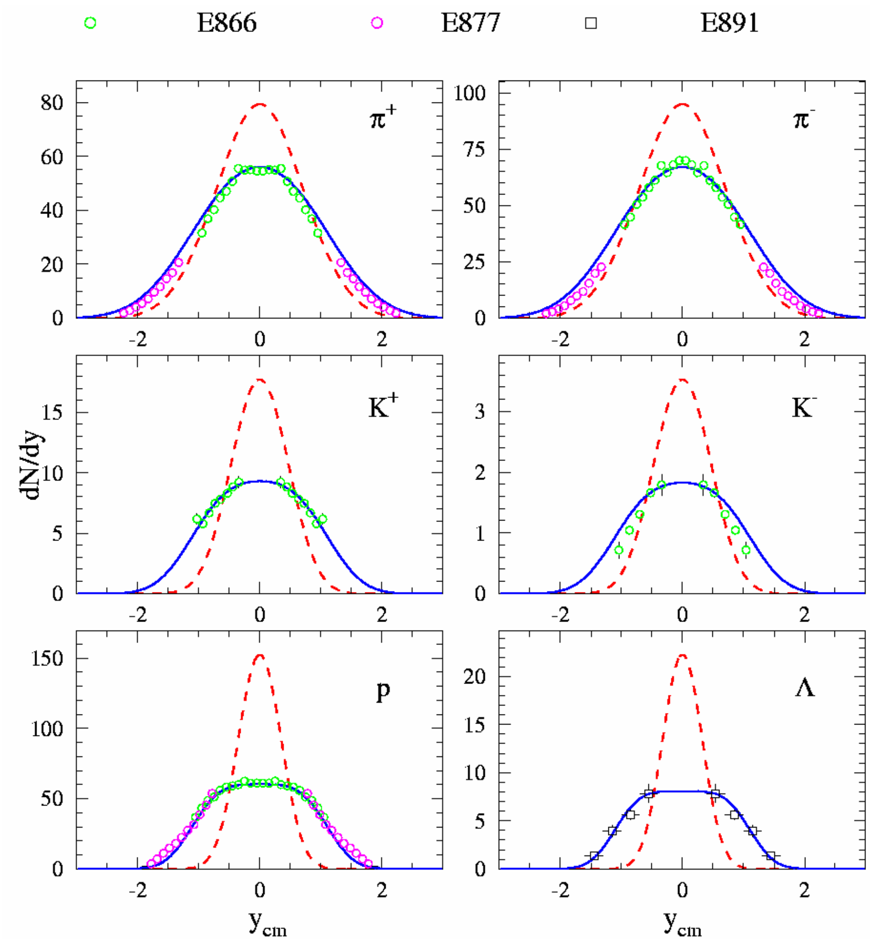
**Antikaon elliptic flow strongly in-plane.**

**Available statistics in FOPI (2003):**

$N_{ev} \sim 10^8$, $K^- \sim 5000$, $K^+ \sim 95000$

**For relevant statistical errors: $N(K^-) > 50000$ !**

# Rapidity distributions @ AGS




**Au + Au @ 10.7 AGeV**

**Different shapes of the rapidity density distributions for the various species**

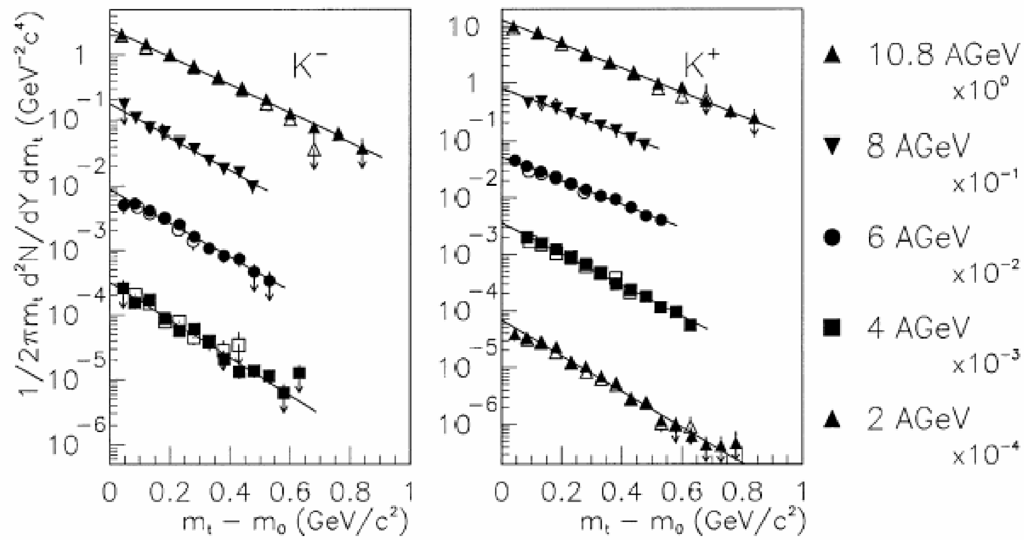
**Distributions can be described by longitudinal expansion**
**(superposition of longitudinally flowing fireballs)**

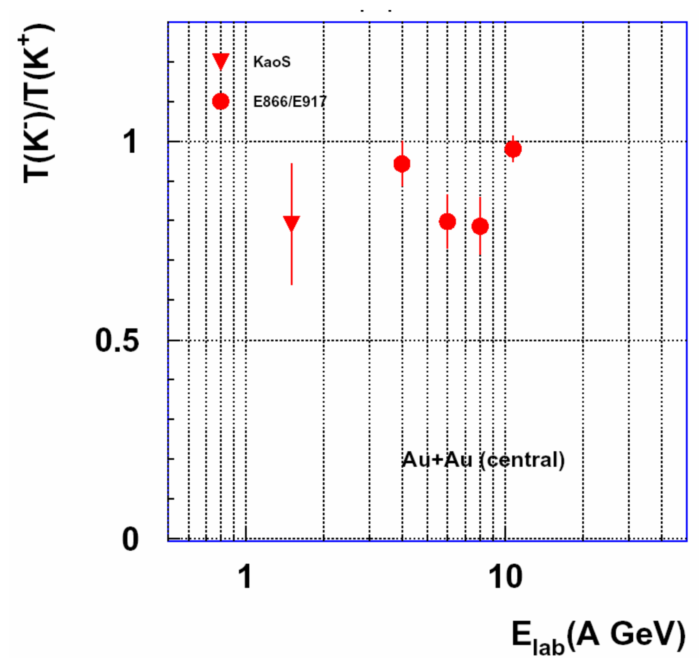
**$K^-$ show deviations**

# Slopes of Kaon Spectra @ AGS

L.Ahle et al. (E866,E917) PLB 490, 53 (2000)

**Au + Au (5% most central )**



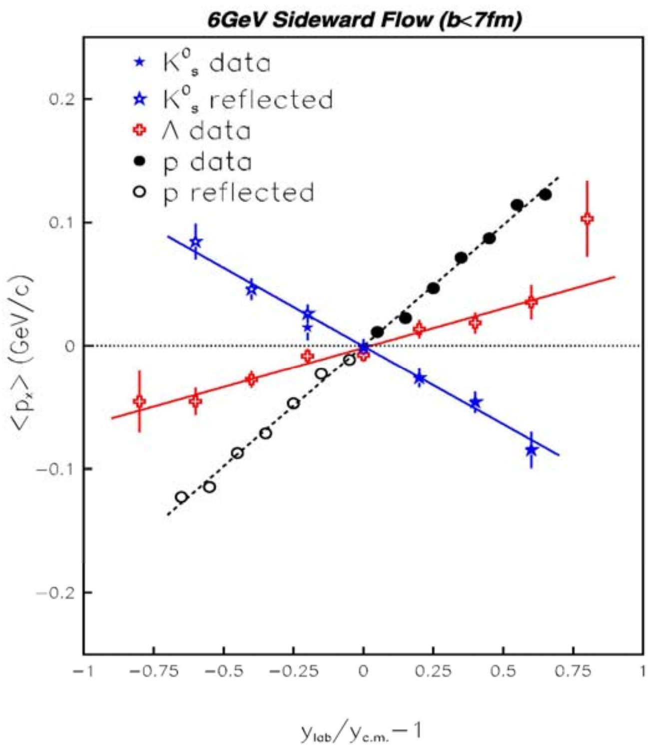



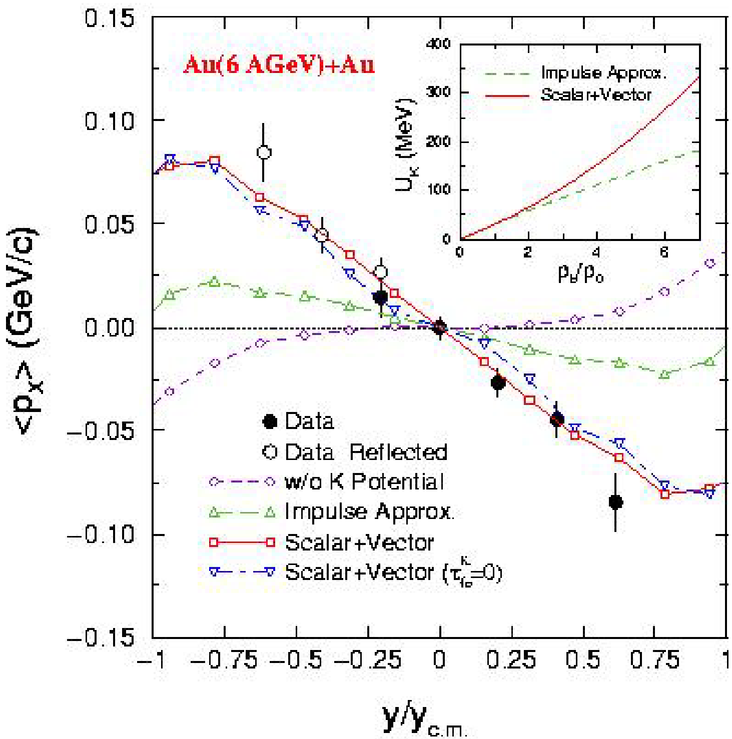

**Antikaon spectra are steeper than Kaon spectra.**
**No clear dependence on incident beam energy.**

# Kaon sideflow at 6AGeV

Data: P. Chung et al. (E895), PRL85, 940 (2000)

Theo: S. Pal et al., Phys.Rev.C62:061903, (2000)

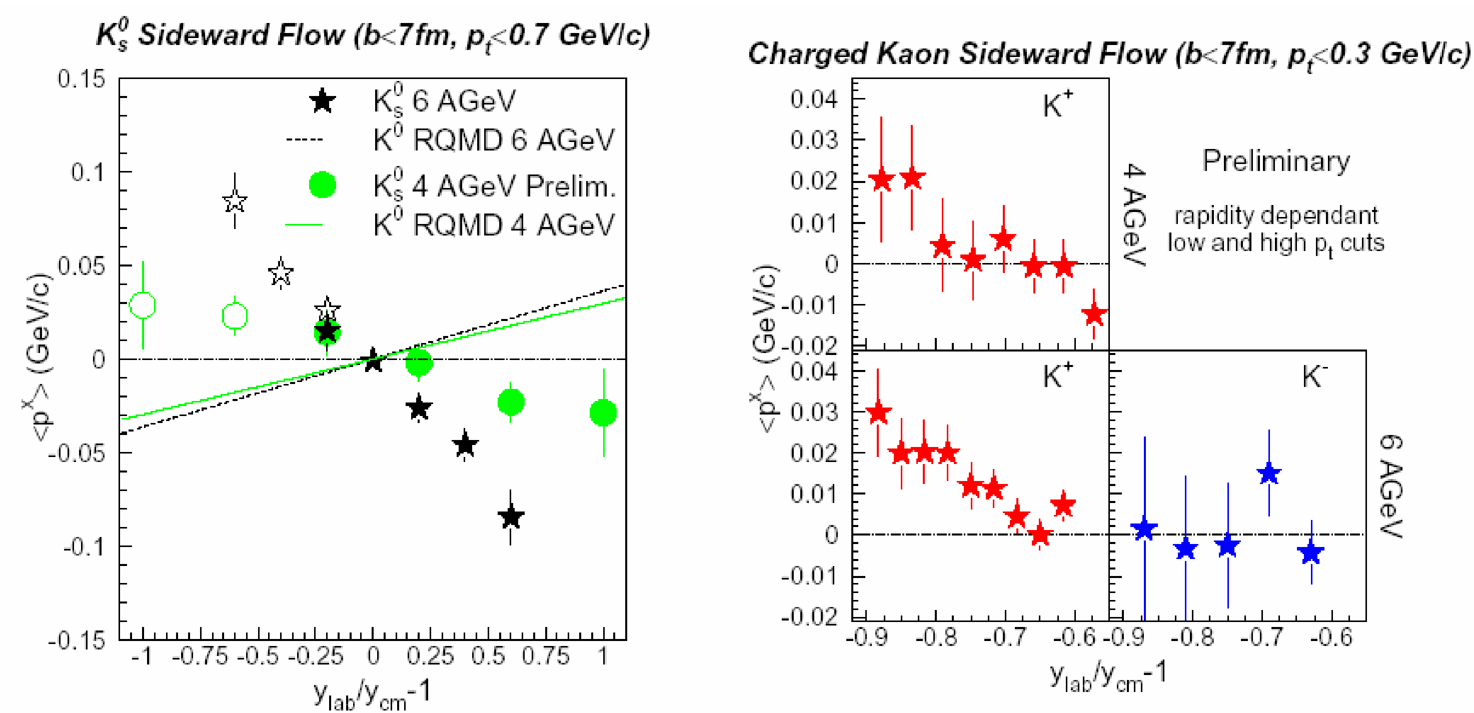



**Very strong Kaon antiflow signal, as big as proton flow!**

# Kaon sideflow @ AGS

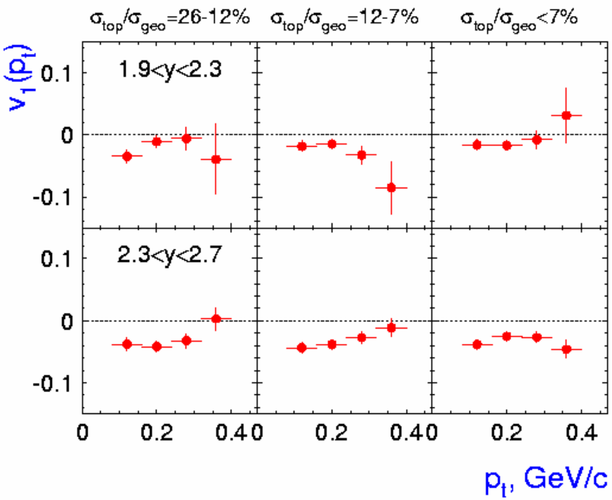
C. Pinkenburg et al. (E895), nucl-ex0104025



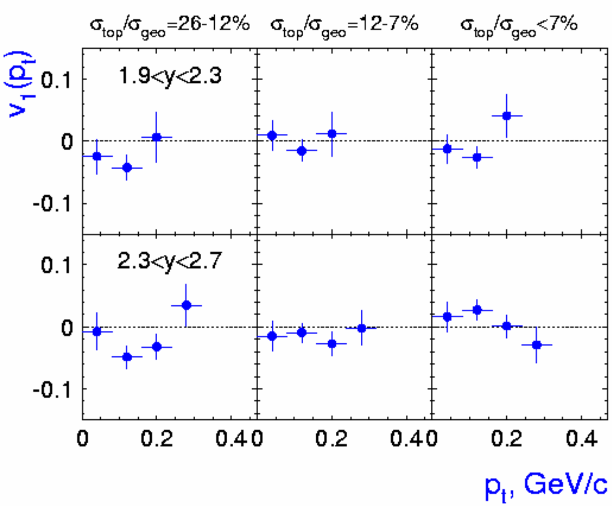

**Information on charged kaon flow limited to small acceptance.**
**Magnitude of charged kaon flow is much smaller than $K^0$ flow (strong $p_t$-dependence?).**

# Kaon sideflow @ AGS

**$K^+$:**




**$K^-$:**




## E877 – Data: Au+Au @ 10.7 AGeV

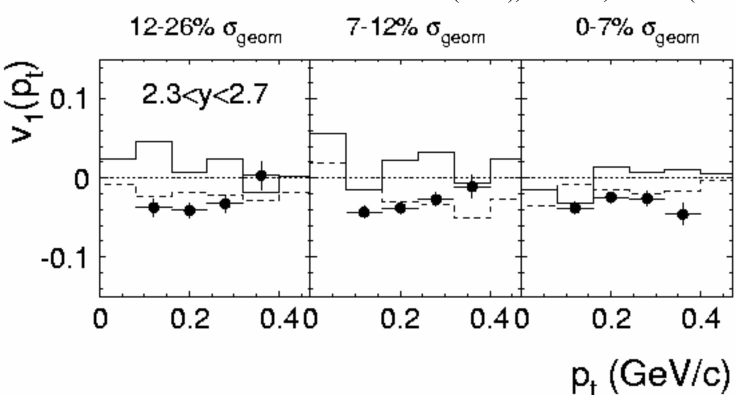
(K.Filimonov et al.)

**$K^+$ show flow, no potential required**

**$K^-$ ??**

## Model comparison to RQMD 2.3

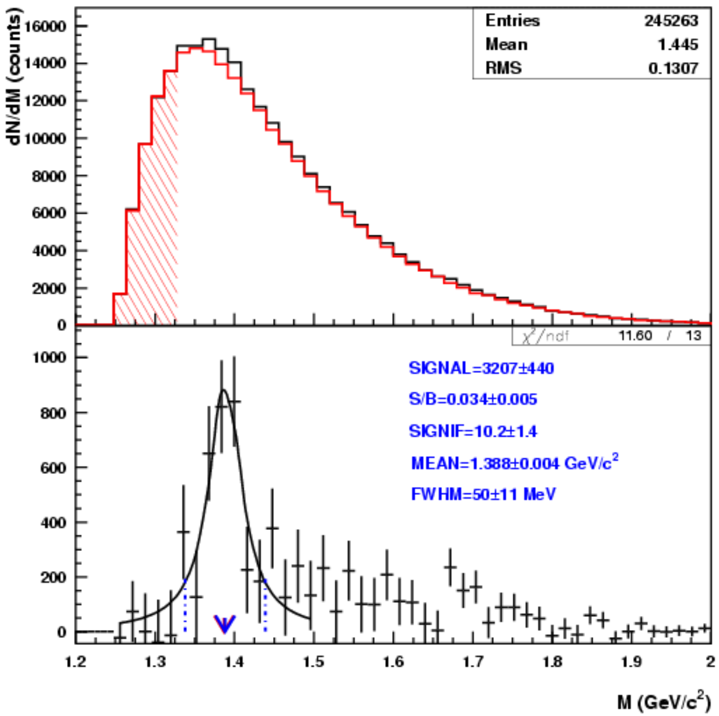
J.Barrette et al. (E877), NPA 661, 379c (1999)
J.Barrette et al. (E877), PR C 63, 014902 (2001)

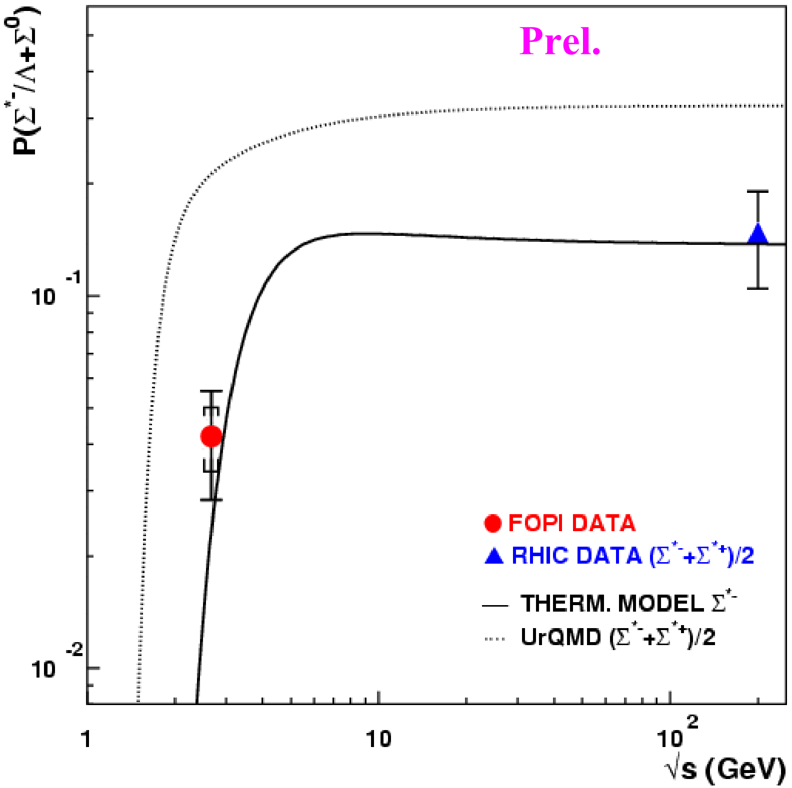



full histogram: mean field
dashed histogramm: cascade mode

# Production of strange baryon resonances

**Invariant mass distribution of $\Lambda + \pi^{\pm}$**



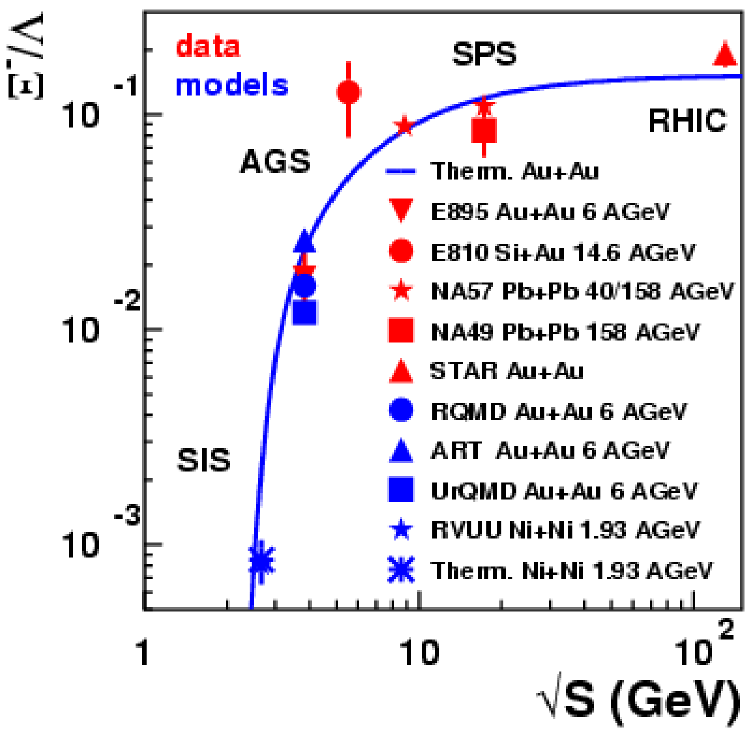




**Data: Al+Al @ 1.92AGeV**

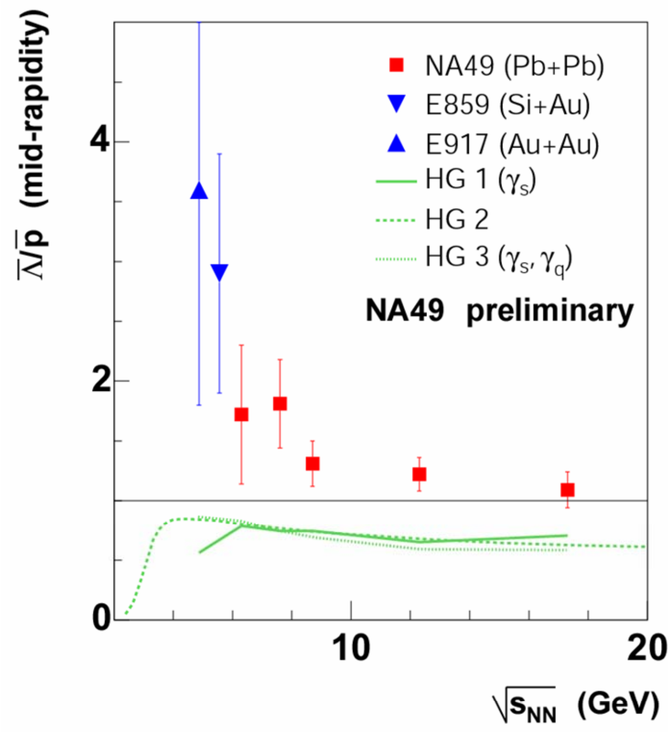
*RHIC DATA: S.Salur, nucl-ex/0410039*

*THERM. MOD.: .A. Andronic, private communication*

*URQMD MOD.: M. Bleicher, NPA 715 (2003) 85*




C.Blume, VI-SIM workshop (2006)




Models predict ratio < 1

Hadron Gas 1: J. Manninen et al.

Hadron Gas 2: K. Redlich et al.

Hadron Gas 3: J. Rafelski et al.

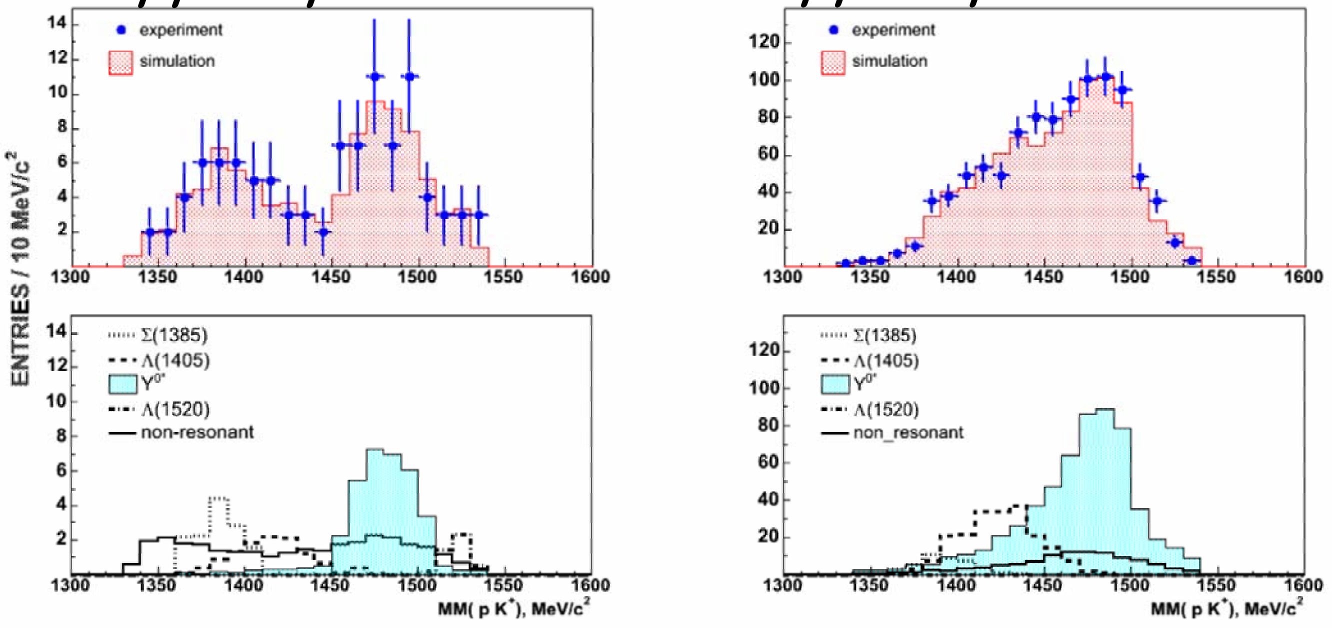
**Multistrange baryon and antibaryon production at threshold unknow or not understood**

# Evidence for an Excited Hyperon State in $pp \to pK^+Y^{0*}$

I. Zycchor et al., (ANKE), PRL 96, 012002 (2006), [nucl-ex/0506014]

$p_{beam}$= 3.65 GeV/c
$E_{beam}$= 2.83 GeV

$pp \to pK^+\pi^+X^-$ $\quad$ $pp \to pK^+\pi^-X^+$




$m_Y$ [MeV/c²] $\quad$ $m_Y$ [MeV/c²]

$Y^{0*}$: $M$ =1480 MeV/c², $\Gamma$ =60 MeV/c²

Cross section of a few 100 nb for both final states

Statistical significance ~ 4.8 σ

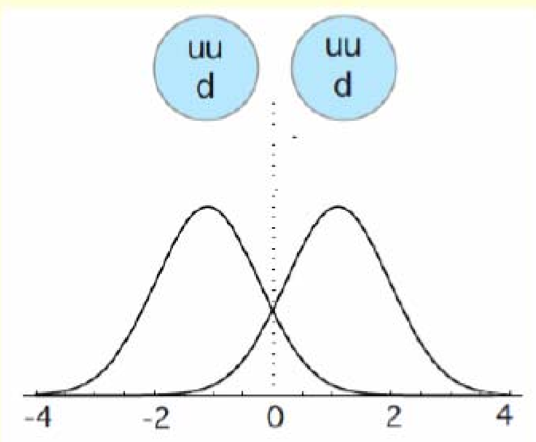
T.Yamazaki, HFD2006

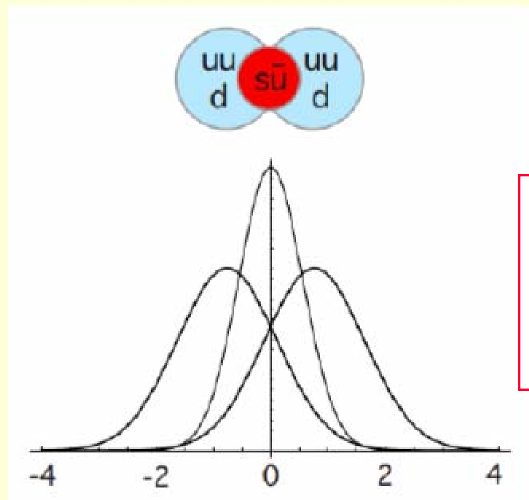
# $K^{bar}$ Nuclear Clusters $\rho_{av} \sim 3\,\rho_0$ !!

Why high-density nuclei possible ?
Against the nuclear physics "law" of $\rho$ = const.

Normally: N-N hard-core:
quark Pauli blocking
+ gluon entanglement

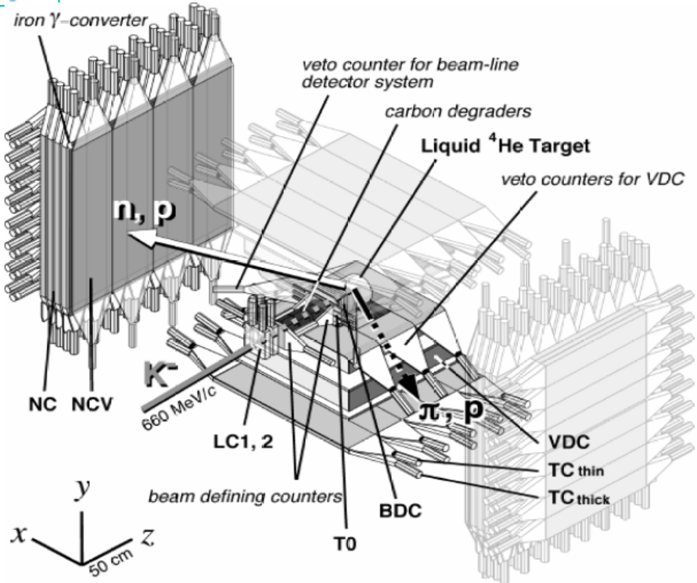
Exceptional:
$K^-$ = s $u^{bar}$: no u,d quark:
no Pauli repulsion; strong attraction in u-$u^{bar}$ and d-$d^{bar}$



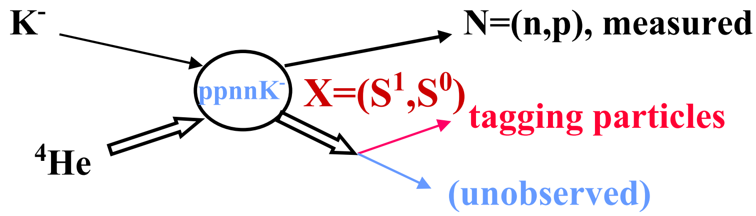




**Prediction of bound states based on deep optical potential:**
Y. Akaishi, T.Yamazaki,
Phys.Rev.C65, 044005 (2002),
Phys.Lett.B535, (2002)

# KEK experiment E471/E549



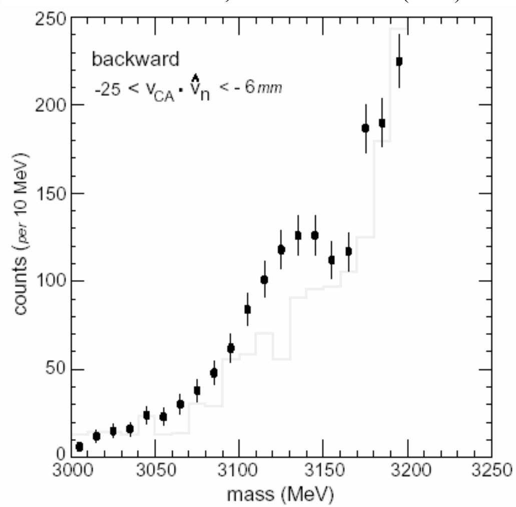

## Missing mass spectroscopy



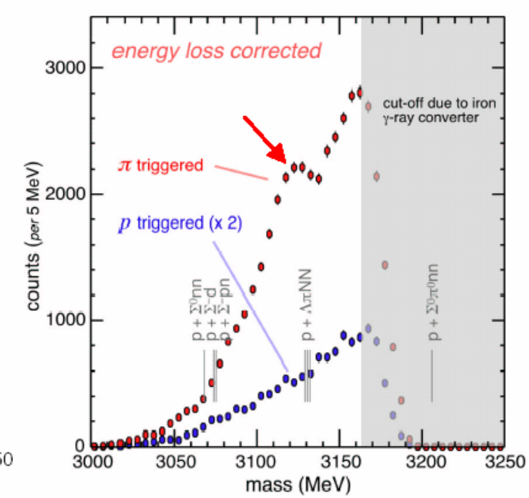

$^4$He(stopped K$^-$,n) ppnK$^-$( $T$=0,1)
$Mc^2$ = 3140 MeV, Γ ~ 20 MeV
$B_K$ = 170 MeV
S$^1$(3140)

$^4$He(stopped K$^-$,p) pnnK$^-$ ($T$=1)
$Mc^2$ = 3117 MeV, Γ~20 MeV
$B_K$ =190 MeV
S$^0$(3115)

M. Iwasaki et al., nucl-ex/0310018 (2003)




T. Suzuki et al., Phys. Lett. B 597 (2004) 263




**Statistics: 2 ×10$^8$ stopped kaons**

**S$^0$(3115)**
**formation probability: 1% / stopped K$^-$**
**Main decay channel: S$^0$ → ΣNN**

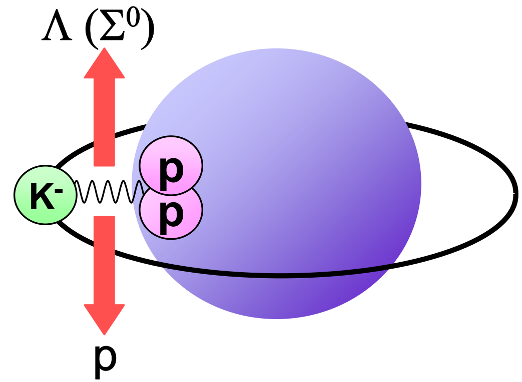
# Alternate view of KEK data

**Interpretation by E. Oset and H. Toki,**
*nucl-th/0509048*

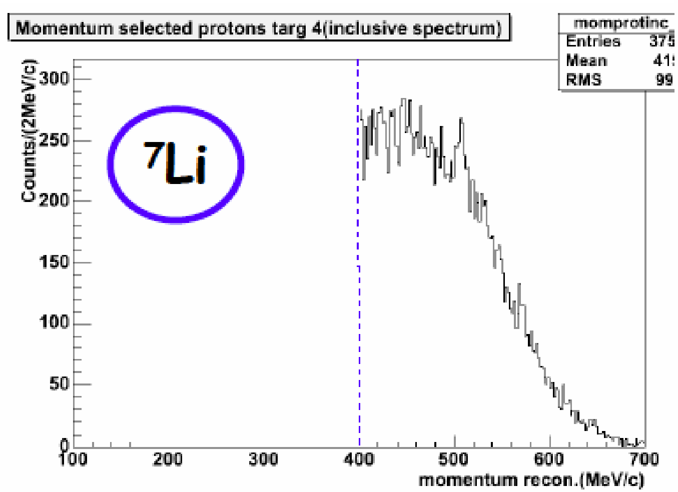
**<u>Absorption of $K^-$ on nucleon pair in $^4He$</u>**

$K^-NN \rightarrow \Lambda\ N$ , p(proton) = 562 MeV/c
$\rightarrow \Sigma^0\ N$ , p(proton) = 488 MeV/c

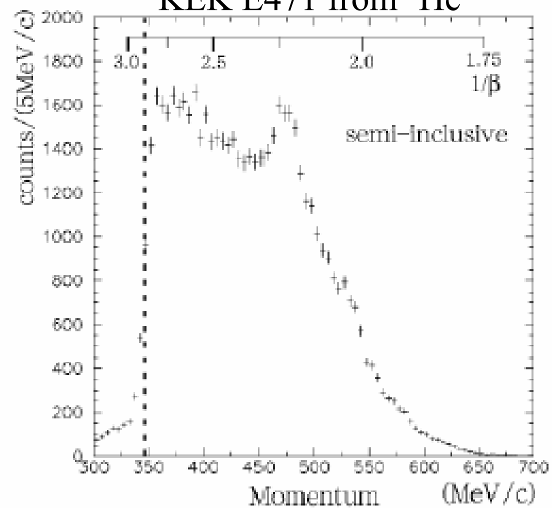
**The two baryons are emitted back to back if there is no initial momentum.**




FINUDA from $^7Li$




KEK E471 from $^4He$

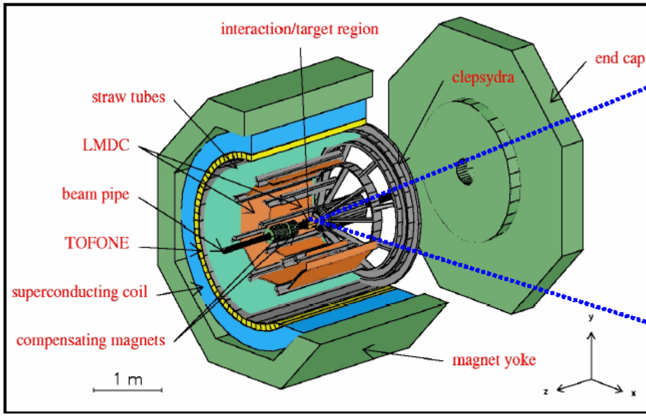


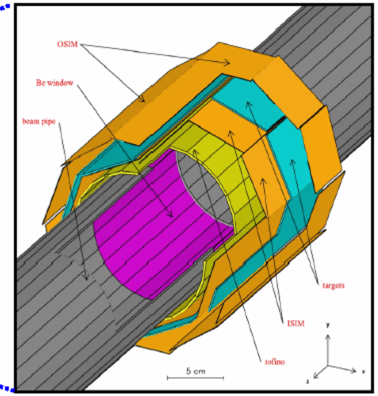

**Expectation for**
**$\Lambda$+p invariant mass:**
$M(\Lambda p) = 2 \cdot m_p + m_K$
$= 2.37$ GeV

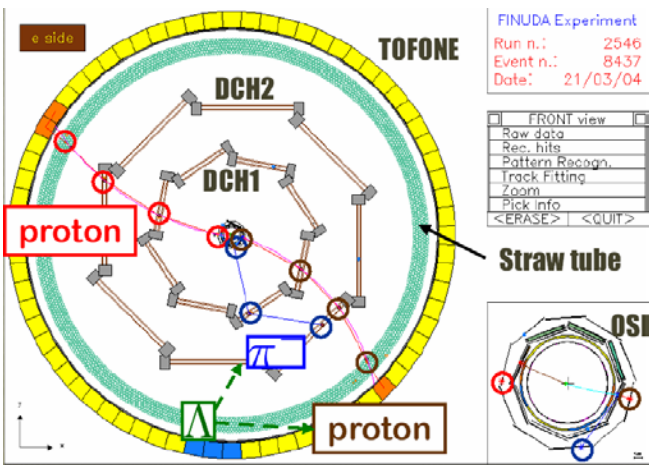
# Evidence for $(ppK^-)_{bound}$ by FINUDA @ DaΦne

**Invariant mass spectroscopy**
**$ppK^- \rightarrow \Lambda + p$**

M. Agnello et al.,
PRL 94, 212303 (2005)



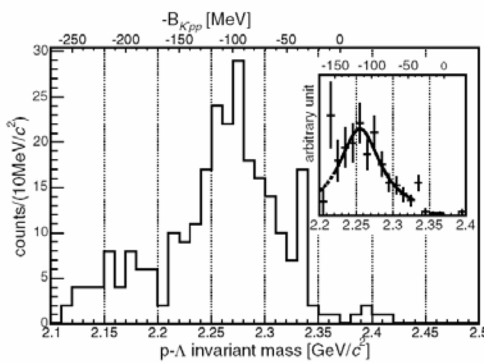




FIG. 3. Invariant mass of a Λ and a proton in back-to-back correlation ($\cos\theta^{\mathrm{Lab}} < -0.8$) from light targets before the acceptance correction. The inset shows the result after the acceptance correction for the events which have two protons with well-defined good tracks. Only the bins between 2.22 and 2.33 GeV/$c^2$ are used for the fitting.

**Production probability:**

P·BR = 0.1% per stopped $K^-$

**Peak parameter:**

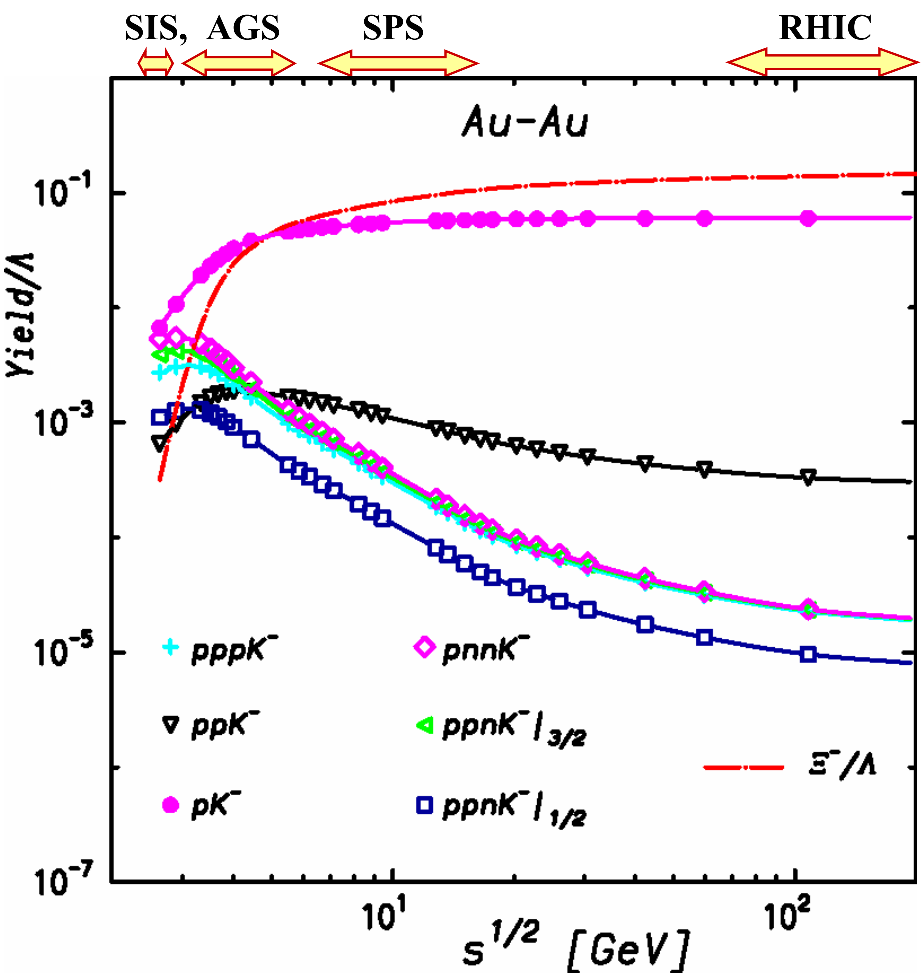
$$M = 2.255 \pm 0.009 \text{ GeV}$$

$$B = 115^{+6+3}_{-5-4} \text{ MeV}$$

$$\Gamma = 67^{+14+2}_{-11-3} \text{ MeV}$$

**AY-theoretical prediction:**
**$M(ppK^-)$ = 2.322 GeV**
**Γ = 61 MeV**

# Thermal model predictions




A.Andronic, P.Braun-Munzinger, K.Redlich (2005)
arXiv:nucl-th/0506083

**Density of species i :**
(in grandcanonical ensemble)

$$n_i(\mu,T) = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{\frac{E_i-\mu_B B_i-\mu_S S_i-\mu_{I_3} I_{3i}}{T}} \pm 1}$$

Free parameter: chemical potential $\mu_B$
temperature T

Fixed by conservation laws: V, $\mu_S$, $\mu_{I3}$

**Yield of single strange clusters per Λ peaked at lowest beam energies**

**Abundance larger than $\Xi^-$ - baryon below √s<4GeV**

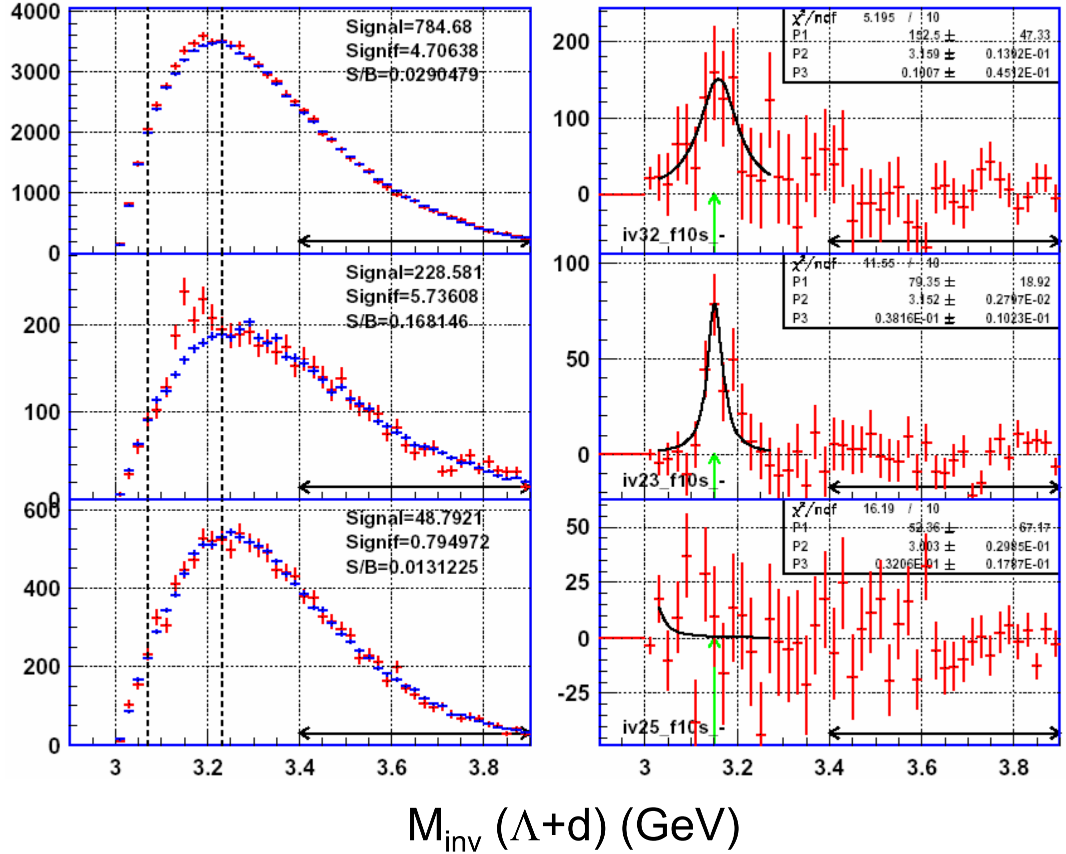
# Λd – Correlation Signal

Subevents rotated
Vertex shifted
Lambda Cut "s"

**Possible decay channel:**

$$ppnK^- \rightarrow \Lambda + d$$

**Preliminary**




**Data**

**additional cuts:**
$|\Delta\phi| < 30^0$
$y_{pair} < 0.65$

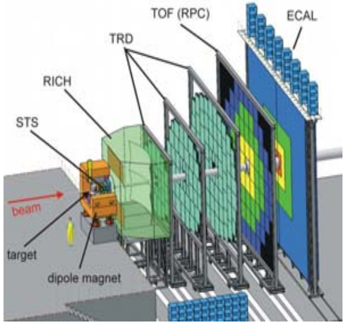
**Signal-MC**

**Background-MC**

**d-Cuts:**

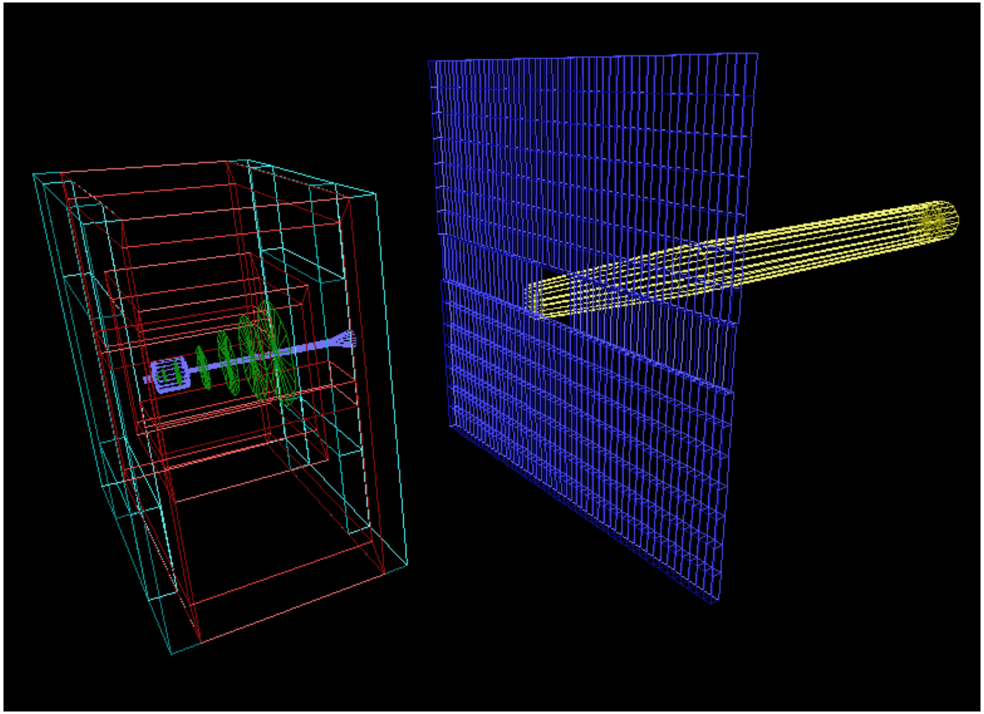
| | |
|---|---|
| HM3MIN | |
| D03MAX | |
| PT3MIN | |
| PT3MAX | |
| Sdxy3max | |
| M3LOW | 1,7 |
| M3HIGH | |
| DML | |
| DPHL3MIN | 30 |
| YDLMAX | 0,65 |
| PTDLMIN | |
| PTDLMAX | |
| CCNT | <10 |
| BM3MIN | |
| | F10 |

Properties ?
M ≈ M(KEK) = 3.14 GeV
Γ >> 20 MeV > Γ(KEK)




**Physics questions can be addressed with reduced CBM - setup,**
**Allows for staging of detector implementation**

**Minimal setup:** **Si-strip stations in Magnet**
**+ TOF**
**+ intermediate tracker for matching**
**+ high speed DAQ**

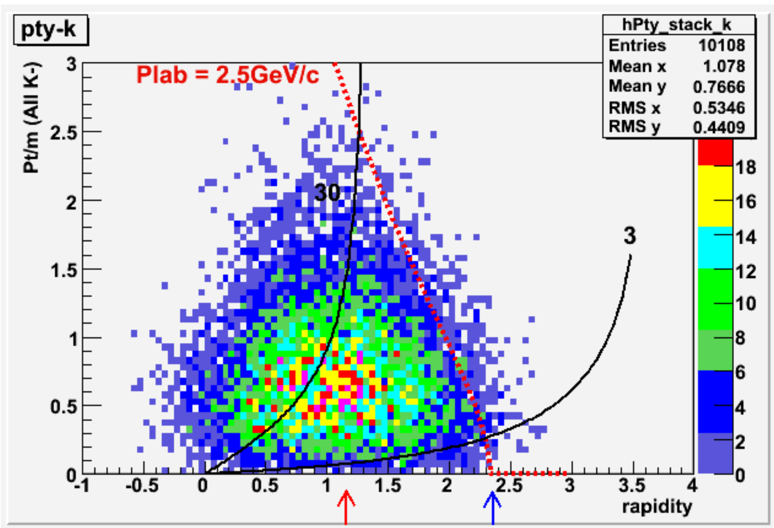


D(TOF) = 4 m (use inner part of final TOF wall, 16% of final detector)

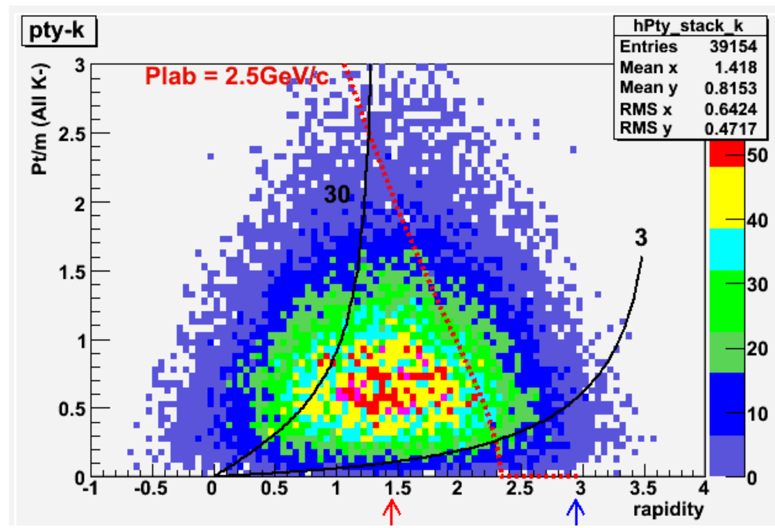
# Kaon acceptance @ SIS100

**URQMD acceptance simulations:**

**4AGeV**




**8AGeV**




**Charged Kaon acceptance with 3σ – TOF separation:**

| | | | |
|---|---|---|---|
| $E_{lab}$ (AGeV) | 4 | 6 | 8 |
| ε | 77% | 64% | 55% |

**Coverage of low – $p_t$ range of the spectrum !**

# Conclusion

**Status:**

**Strangeness production at SIS and AGS not fully understood yet.**

**$K^0$ antiflow at 6 AGeV surprisingly large.**

**Collective flow of strange particles from 2 – 10 AGeV largely unknown, differential flow signals essentially not available.**

**To be done:**

**Clarify density dependence of K – interaction in beam energy range from 2 – 8(10) AGeV !**

**Establish in-medium effects on strangeness as reference for charm production at threshold.**

**Allow for detection of rare decays of exotic strange resonances.**

**Option:**

**Hadron physics program with CBM subsystems at SIS100 ???**
- **What is most important ?**
- **Is there support from theory ?**
- **Staged implementation of CBM ?**