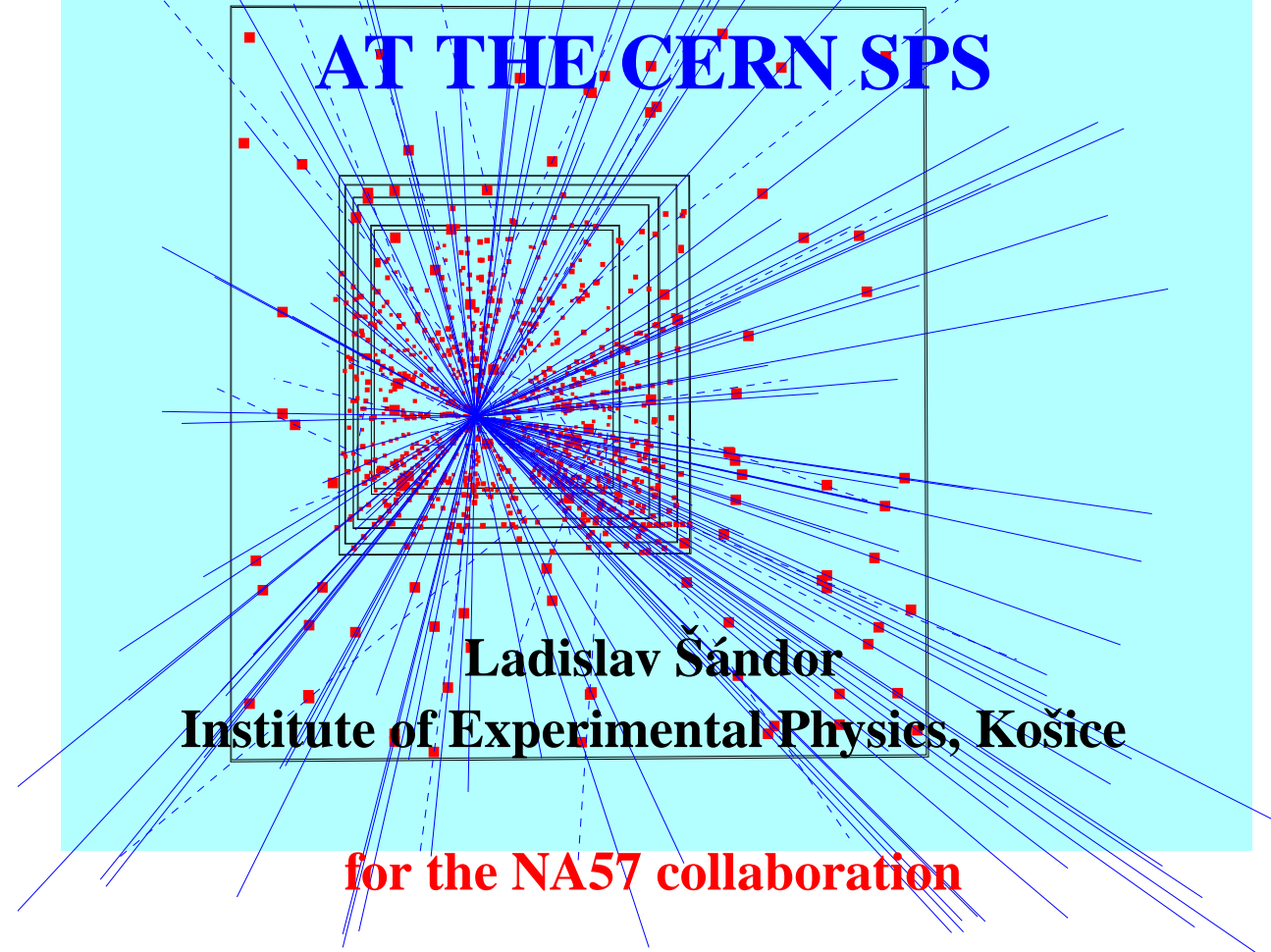


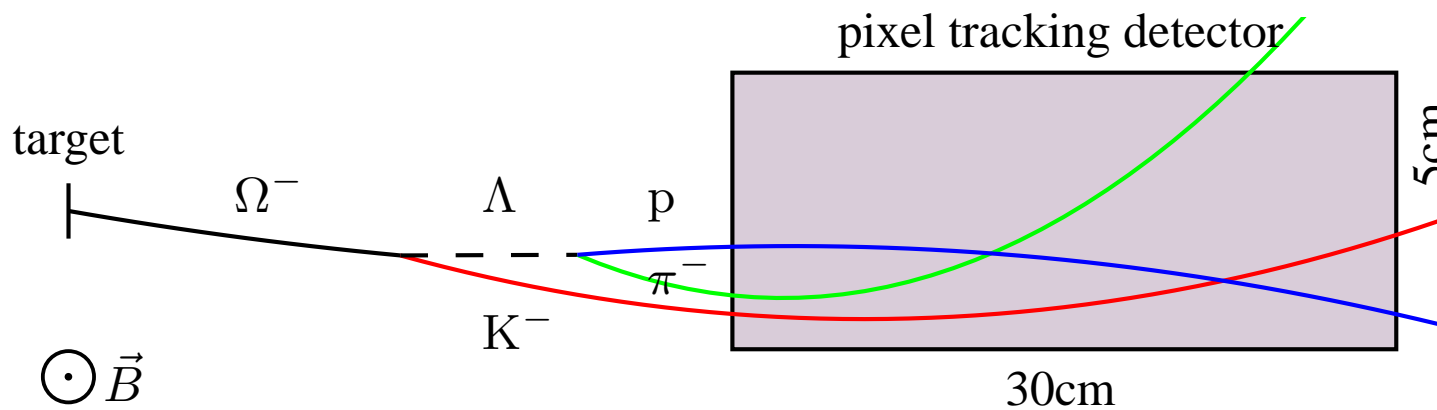
STRANGE BARYON PRODUCTION IN Pb–Pb INTERACTIONS AT THE CERN SPS



Plan of talk

- The NA57 experiment
- Results on particle yields and enhancements
- Transverse mass distributions at 160 A GeV/ c
- Conclusions

**A sketch of hyperon weak decay to charged particles
and its detection in the NA57 set-up :**



The NA57 experiment

NA57 – a successor of the WA97 experiment which contributed significantly to the observation of a new state of matter at the CERN SPS. NA57 utilizes the same philosophy as WA97 but significantly upgraded detectors, DAQ and software.

160 A GeV/c WA97 data at midrapidity exhibit enhancements in Pb–Pb hyperon yields with respect to p–A collisions (see E. Andersen *et al.*, Phys. Lett. **B449** (1999) 401). These enhancements increase with the strangeness content of particle (QGP prediction) reaching more than one order of magnitude for Ω .

NA57 confirms this pattern (V. Manzari *et al.*, Nucl. Phys. **A715** (2003) 140c) and continues the study of strangeness enhancements as a function of

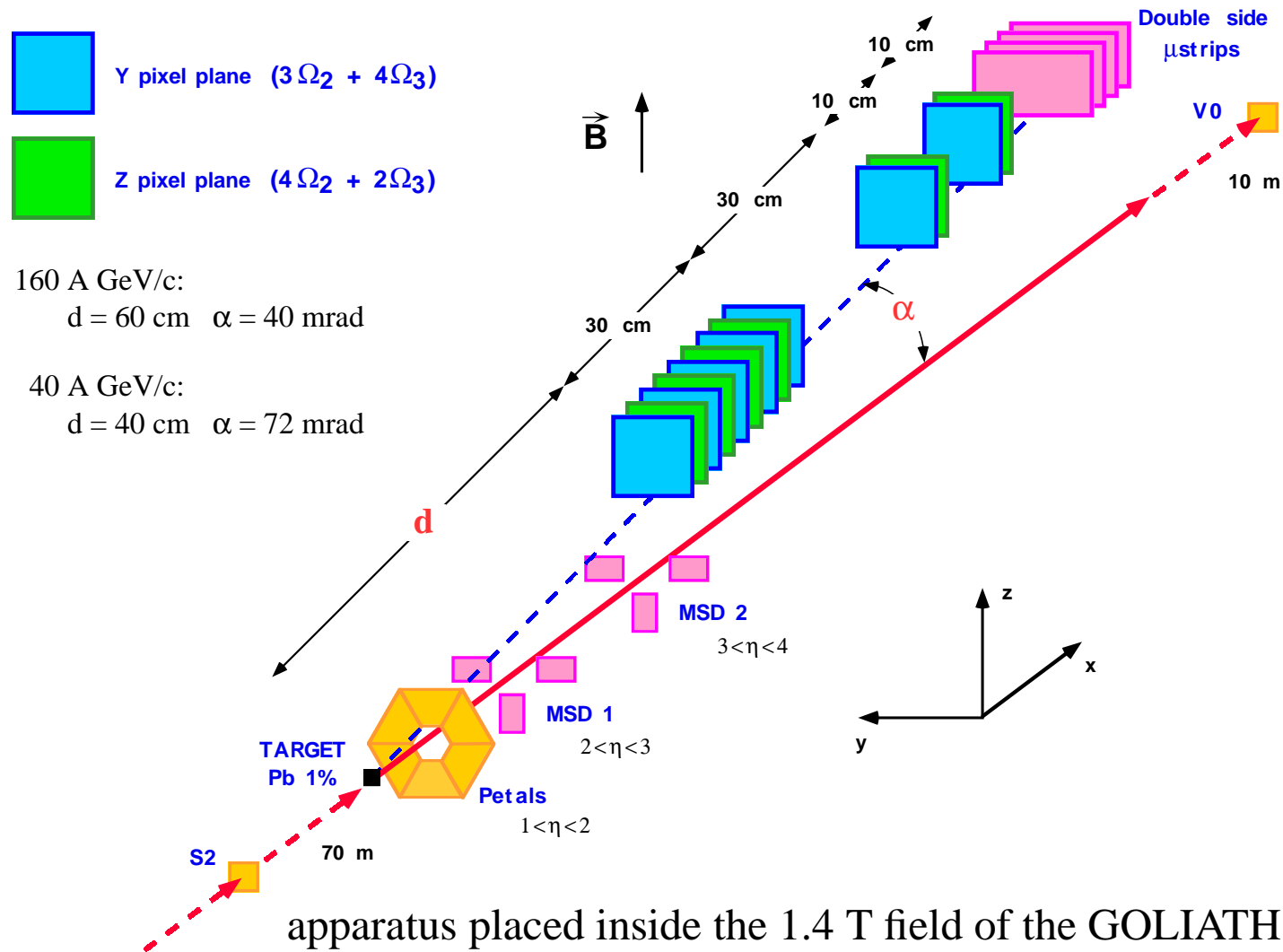
- extended centrality range (down to $N_{wound} \sim 50$) in Pb–Pb at 160 A GeV/c
- beam energy (data at 40 and 160 A GeV/c)

Both 160 and 40 A GeV/c Pb–Pb samples analysed.

Analysis of the reference p–Be data at 40 A GeV/c near to completion.

The WA97 p–Be sample used as reference data at 160 A GeV/c.

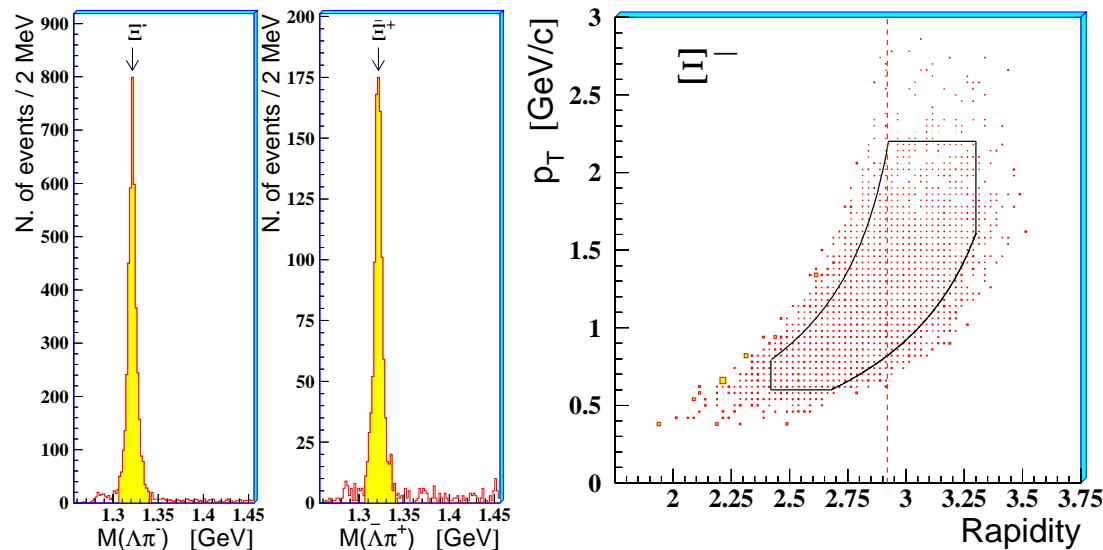
NA57 experimental set-up



Experimental procedure

Reconstructed decay channels: $\Omega^- \rightarrow \Lambda + K^-$, $\Xi^- \rightarrow \Lambda + \pi^-$, $\Lambda \rightarrow p + \pi^-$

- Signals of hyperons and anti-hyperons extracted by geometrical and kinematical cuts with negligible level of background
- Geometrical acceptance of apparatus (p_T -dependent) and symmetry of Pb–Pb collision allow measurement in one unit of rapidity centered at mid-rapidity
- Data corrected for acceptance and for detector and reconstruction efficiency.

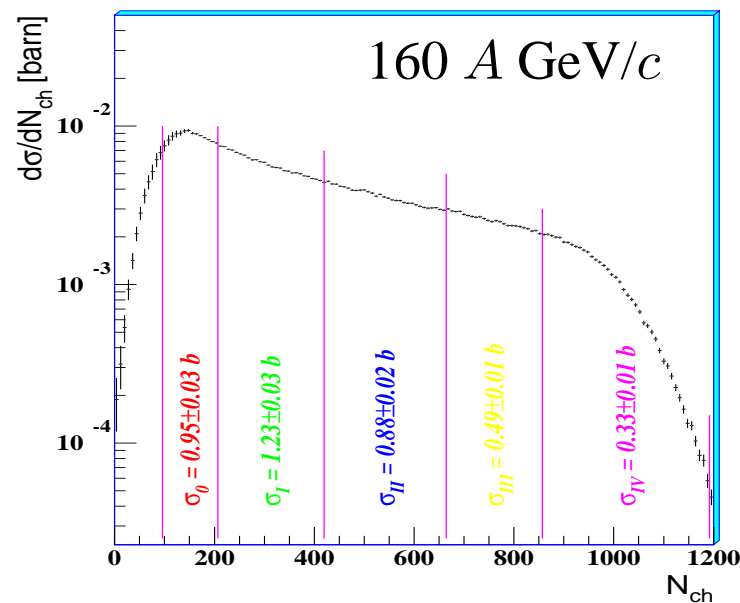


Estimate of systematic errors: $\simeq 10\%$ for Λ, Ξ , $\simeq 15\%$ for Ω

Centrality of Pb–Pb collision

Centrality determination from charged particle multiplicity measurement

N_{wound} from trigger cross sections (Glauber model calculations)



160 GeV: 56% most central events in 5 classes (bins 0 to IV),
 bin IV – 5%, bins III+IV – 12% of most central collisions

40 GeV: determination of classes close to that for 160 GeV

Quantities under study

The double-differential (y, m_T) distribution parametrised as

$$\frac{d^2 N}{dm_T dy} = f(y) m_T \exp\left(-\frac{m_T}{T_{app}}\right)$$

assuming $f(y) = const.$ (flat rapidity distribution) in our acceptance region. T_{app} - inverse slope of the m_T distribution, free parameter of fit.

Particle yield (rapidity density at mid-rapidity y_0) :

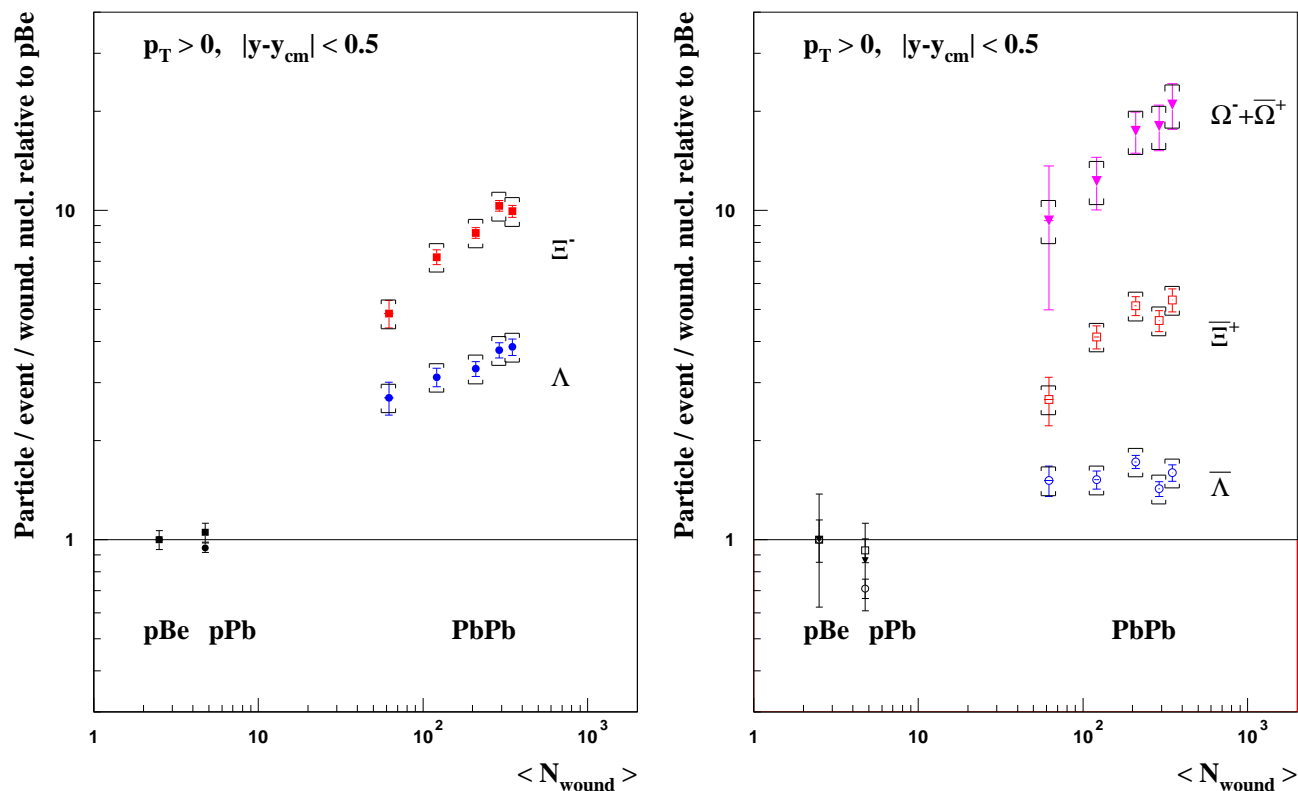
$$Y = \left. \frac{dN}{dy} \right|_{y=y_0} = \int_m^\infty dm_T \int_{y_0-0.5}^{y_0+0.5} \frac{d^2 N}{dm_T dy} dy$$

Enhancement :

$$E = \left(\frac{Y}{\langle N_{wound} \rangle} \right)_{Pb-Pb} / \left(\frac{Y}{\langle N_{wound} \rangle} \right)_{p-Be}$$

Particle yields and transverse mass spectra studied as a function of collision centrality, dividing data into 5 aforementioned classes with $\langle N_{wound} \rangle = 62 \pm 4, 121 \pm 4, 209 \pm 3, 290 \pm 2, 349 \pm 1.$

NA57 strangeness enhancements



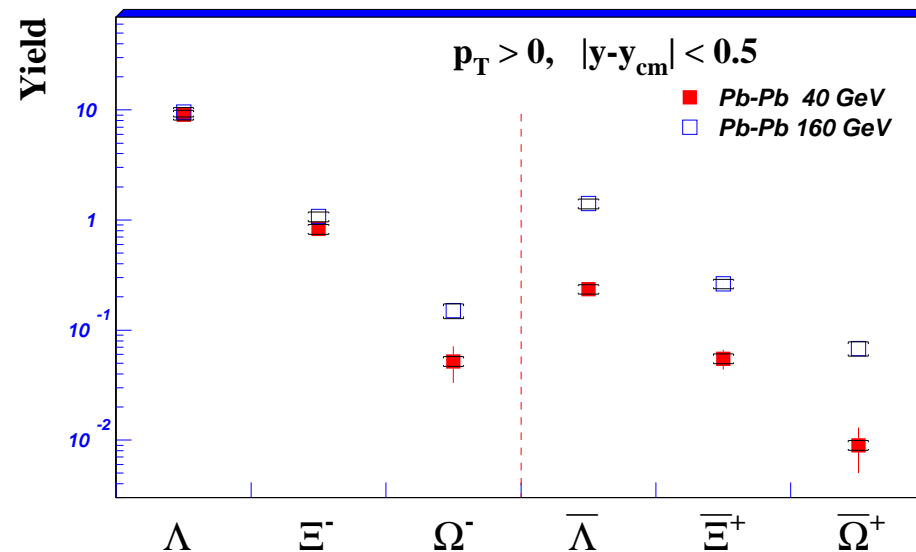
160 A GeV/c data

Significant centrality dependence of strangeness enhancement for all particles except for $\bar{\Lambda}$. Knowledge of yields in most peripheral class 0 essential. Saturation – possibly for two most central bins ($\simeq 10\%$).

Energy dependence of hyperon yields

Yields calculated for 42% most central Pb–Pb collisions (classes I–IV).

Black bars - systematic errors



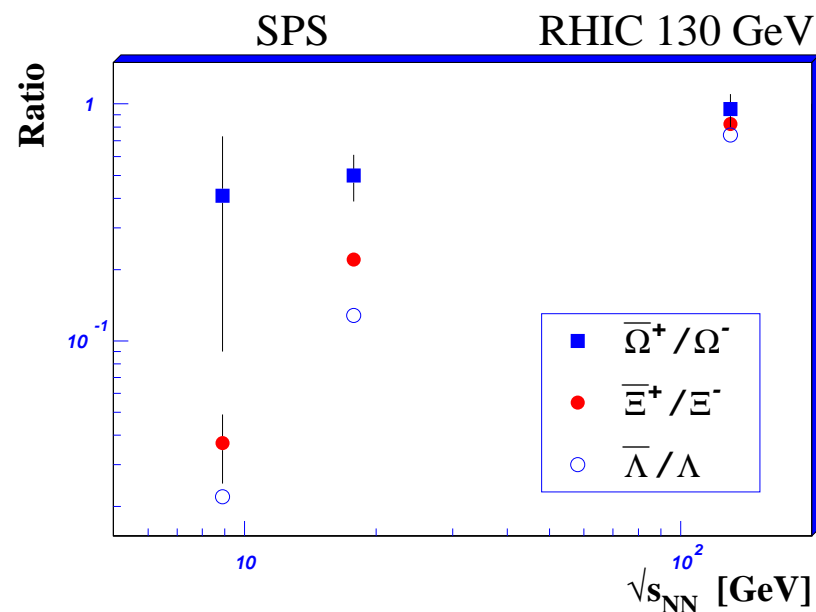
Going from 40 to 160 A GeV/ c :

- particle yields for Λ and Ξ^- similar, increased by a factor 3 for Ω^-
- antiparticle yields increased by factors from 5 to 7

Indication for larger baryon density at 40 A GeV/ c

Energy dependence of \bar{Y}/Y ratios

STAR 130 GeV data from: J. Adams *et al.*, nucl-ex/0211024 (submitted to Phys.Lett.B)
and references therein

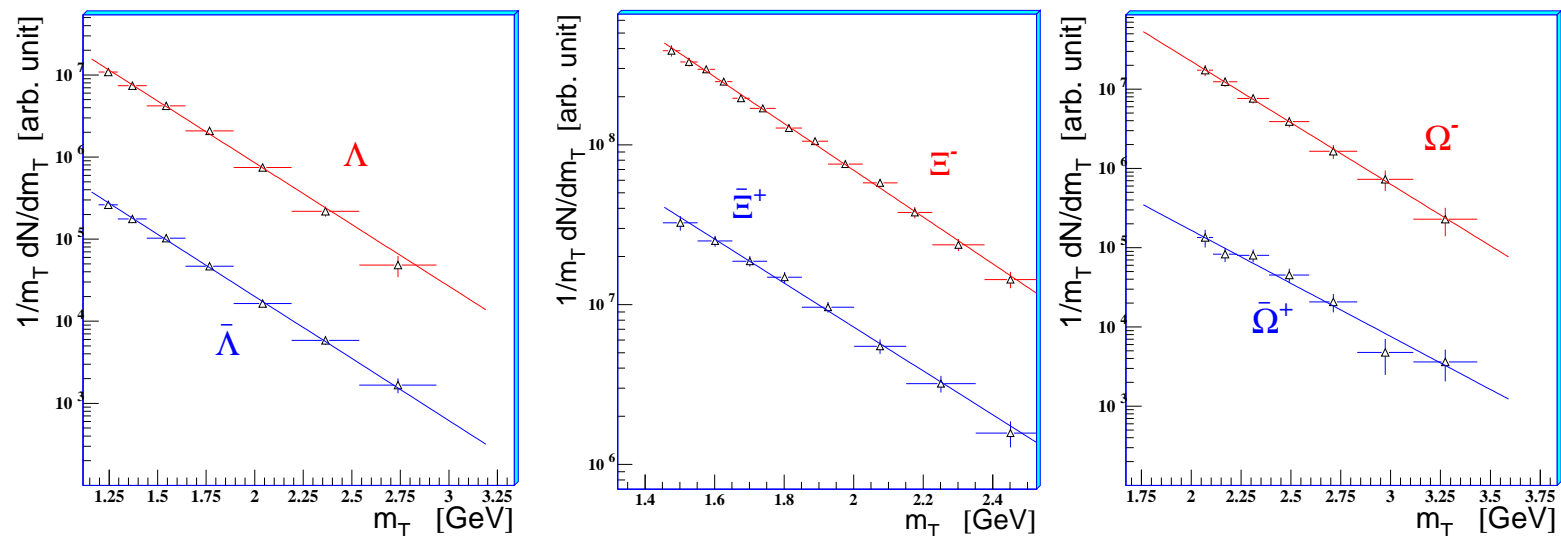


Centrality: 5% for Λ , $\simeq 10\%$ for Ξ, Ω

- \Rightarrow anti-hyperon/hyperon ratios increase with energy
- \Rightarrow energy dependence weaker for particle with higher strangeness

m_T spectra of hyperons

Pb–Pb data at 160 A GeV/ c , full centrality region

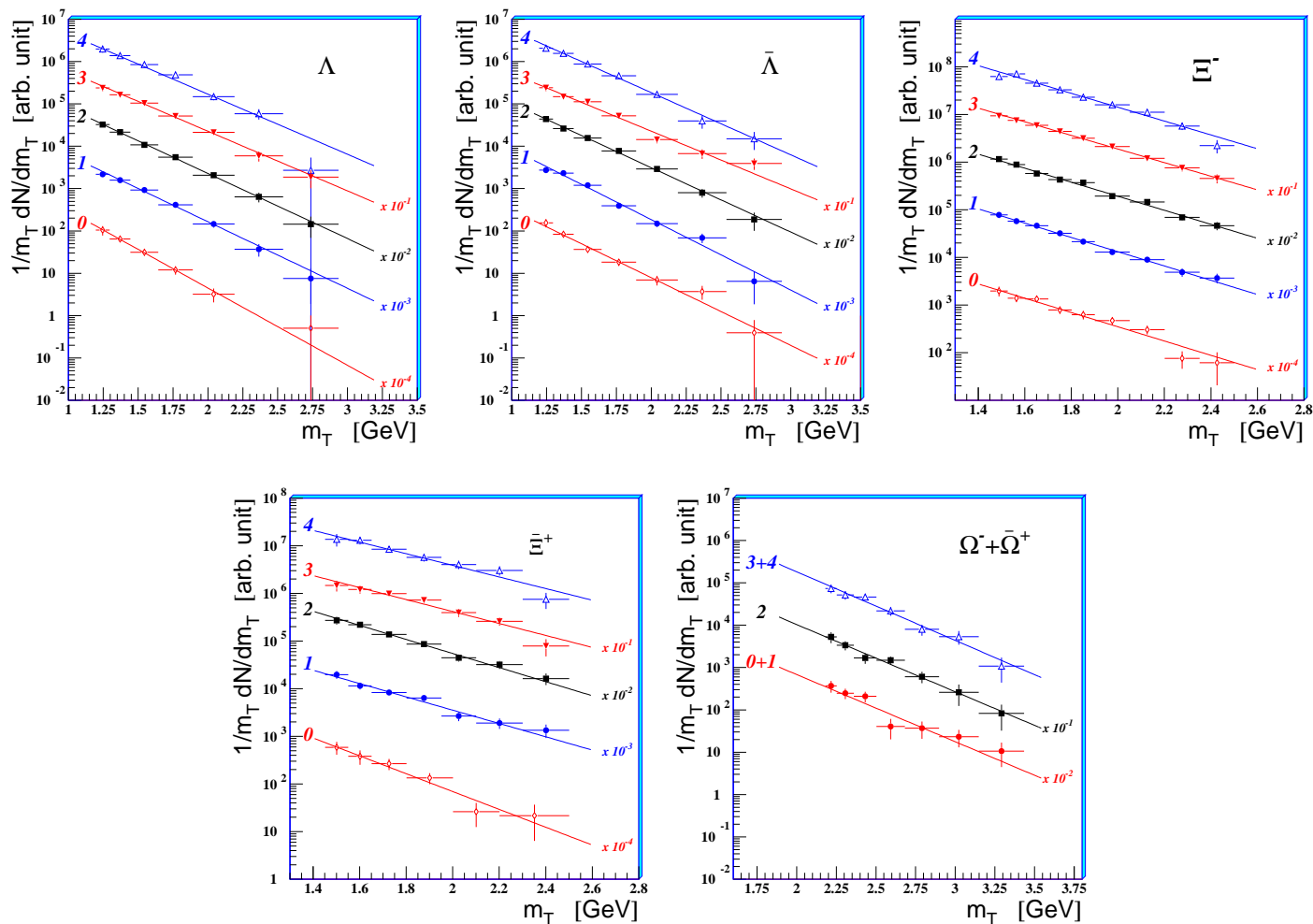


Shapes close to single exponential, similar slopes for all hyperons

particle	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-	$\bar{\Omega}^+$
T_{app} (MeV)	289 ± 7	287 ± 9	297 ± 5	316 ± 11	264 ± 19	284 ± 28

Agreement within error limits with WA97 results

Centrality dependence of m_T spectra



Weak centrality dependence of inverse slopes for all hyperons

Blast-wave analysis of m_T spectra

In the framework of model based on thermalization and hydro-dynamical transverse flow description (E. Schnedermann, J. Sollfrank and U. Heinz, Phys. Rev. **C48** (1993) 2462) the transverse mass spectrum of the hadron with mass m_i can be approximated as:

$$\frac{dN_i}{m_T dm_T} \propto m_T \int_0^R r dr K_1 \left(\frac{m_T \cosh \rho}{T} \right) I_0 \left(\frac{p_T \sinh \rho}{T} \right).$$

The fit of m_T spectra to the above function allows to disentangle the thermal freeze-out temperature T and the transverse flow velocity β_\perp . Here R is the transverse system size, K_1 and I_0 - the modified Bessel functions, $\rho = \text{atanh } \beta_\perp$ is a transverse boost,

$$\beta_\perp = \beta_S \left(\frac{r}{R} \right)^n, \quad \langle \beta_\perp \rangle = \frac{2}{2+n} \beta_S.$$

Assumptions: kinetic freeze-out of matter at constant temperature T , cylindrically symmetric and longitudinally boost invariant fluid expansion

Blast-wave fit to NA57 data

Results of global fits to all strange particle spectra measured in the full accessible centrality range using different velocity profiles :

Profile	n = 0	n = 0.5	n = 1	n = 2
T (MeV)	158 ± 6	152 ± 6	144 ± 7	151 ± 11
$\langle \beta_{\perp} \rangle$	0.396 ± 0.015	0.394 ± 0.013	0.381 ± 0.013	0.316 ± 0.014
β_S	0.396 ± 0.015	0.493 ± 0.016	0.571 ± 0.019	0.633 ± 0.028
χ^2/ndf	39.6 / 48	36.9 / 48	37.2 / 48	68.0 / 48

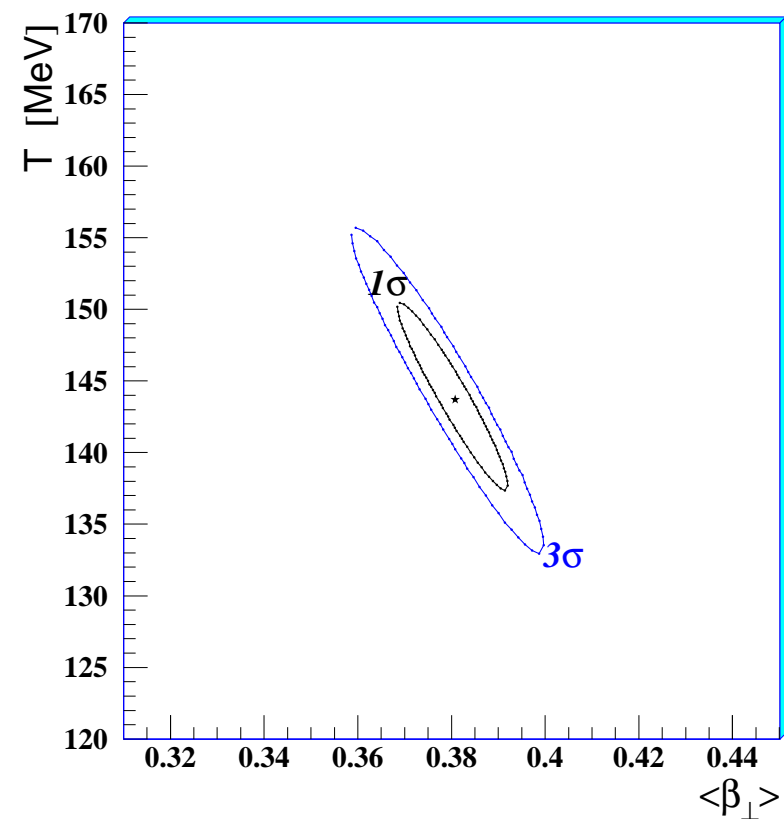
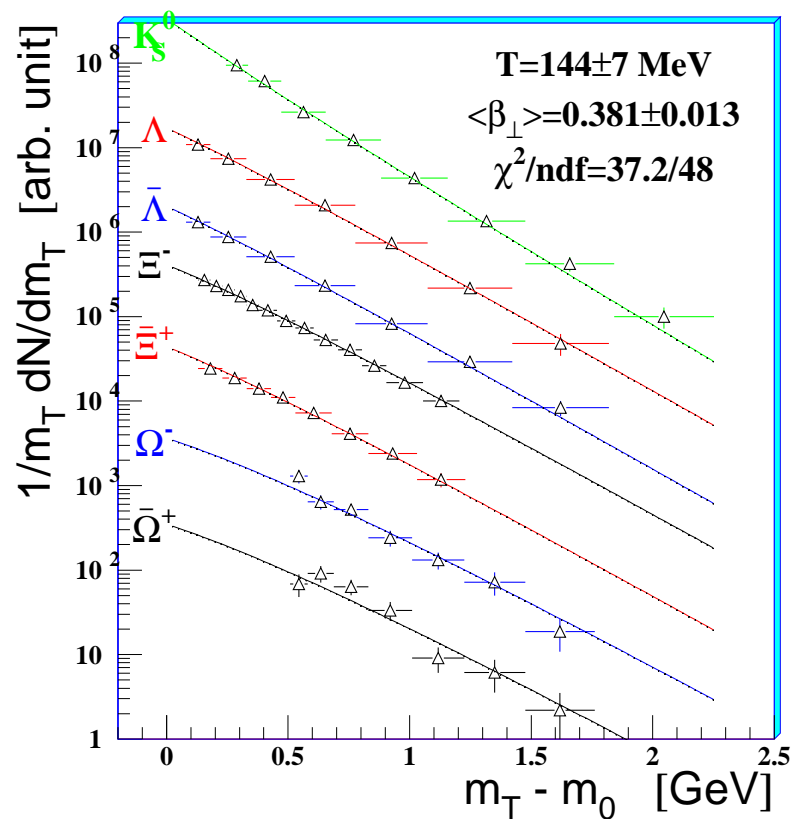
Separate fits for particles sharing at least one quark in common with the nucleons and for those which do not (using $n = 1$) :

Particles	T (MeV)	$\langle \beta_{\perp} \rangle$	χ^2/ndf
K_S^0, Λ, Ξ^-	146 ± 8	0.376 ± 0.015	18.1 / 23
$\bar{\Lambda}, \bar{\Xi}^+, \Omega^-, \bar{\Omega}^+$	130 ± 28	0.403 ± 0.032	18.5 / 23

Fits suggest similar freeze-out conditions for the two groups

Systematic errors of T and β_{\perp} are estimated to be about 10% and 3%, respectively

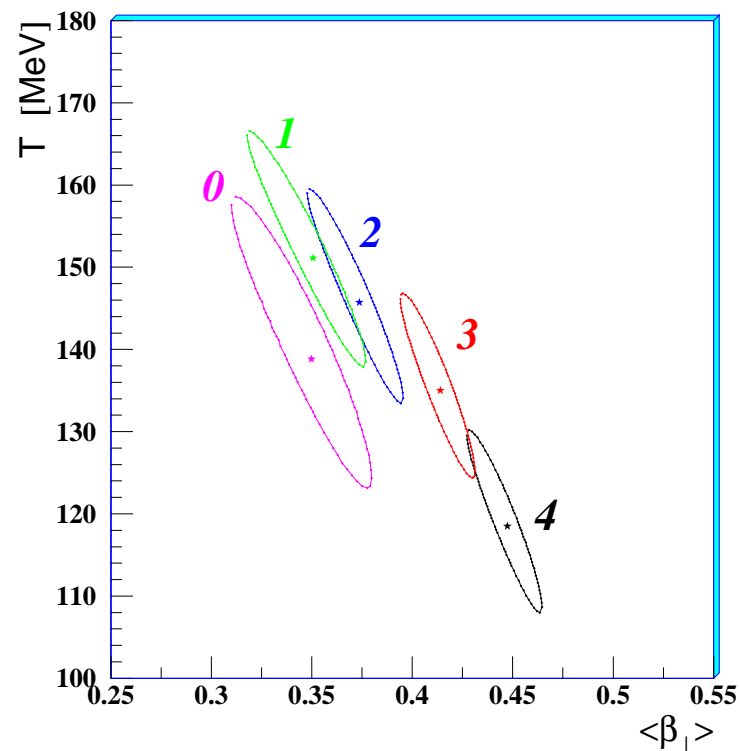
Global fit to NA57 data with $n = 1$ profile



Common description for all strange particles satisfactory.
 Separate fits to individual particle spectra result in T and $\langle \beta_{\perp} \rangle$ values which do not differ more than two standard deviations from the common scenario.

Centrality dependence of freeze-out parameters

The 1σ confidence level contours in $(\langle\beta_{\perp}\rangle - T)$ plane from fits to data samples for individual centrality classes ($n = 1$)



The suggested trend: increase of $\langle\beta_{\perp}\rangle$ and decrease of T with increasing collision centrality

Freeze-out parameters at SPS and RHIC

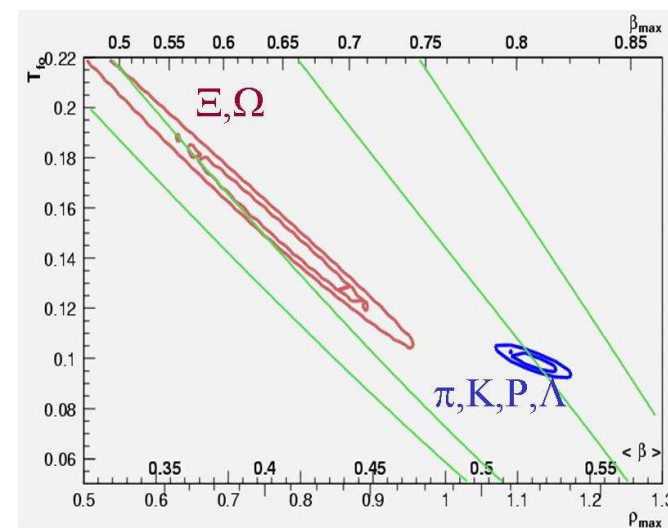
Results of fits to central NA57 160 A GeV and RHIC 130 GeV data ($n = 1$)

Experiment	centrality (%)	particles	T	β_S	χ^2/ndf
NA57	0-5	all strange	118 ± 13	0.67 ± 0.03	52.7 / 43
NA57	5-12	all strange	135 ± 14	0.62 ± 0.03	31.8 / 41
PHENIX	0-5	π, K, p	121 ± 4	0.70 ± 0.01	34.0 / 40
STAR	0-10	π, K, p, Λ	$\simeq 100$	$\simeq 0.81$	
STAR	0-10	Ξ, Ω	$\simeq 150$	$\simeq 0.64$	

PHENIX data: nucl-ex/0307010

Preliminary STAR results (fig.)
from talk by Javier Castillo at
SQM2003 (Atlantic Beach, USA)

Different freeze-out scenario
for π, K, p, Λ and multi-stranges ?



Conclusions

Strangeness enhancements at 160 A GeV/c :

- NA57 data confirm the enhancements and their hierarchy found by WA97
- significant centrality dependence of strangeness enhancement observed for all strange baryons except for $\bar{\Lambda}$

Energy dependence of hyperon yields :

- different behaviour of particles and anti-particles observed, indicating larger baryon density at lower energy

Transverse mass spectra at 160 A GeV/c :

- inverse slopes of particle and anti-particle are the same within error limits for all hyperons
- blast-wave model with linear velocity profile describes satisfactorily the spectra of all strange particles by common freeze-out parameters T, β_S
- indication for centrality dependence of freeze-out parameters found
- evidence for the similarity of freeze-out conditions at SPS and RHIC energies