Hyperon and Antihyperon Production in Pb-Pb Collisions at 158 AGeV/*c*

Ivan Králik, WA97 Collaboration

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[redacted]

Monday PPE seminars

Contact: FABIOLA GIANOTTI / PPE
Tel. 78965

The WA97 collaboration:

E. Andersen[c], A. Andrighetto[k], F. Antinori[e,k], N. Armenise[b], J. Bán[g],
D. Barberis[f], H. Beker[e], W. Beusch[e], J. Böhm[m], R.Caliandro[b], M. Campbell[e],
E. Cantatore[e], N. Carrer[k], M.G. Catanesi[b], E. Chesi[e], M. Dameri[f], G. Darbo[f],
J.P. Davies[d], A. Diaczek[l], D. Di Bari[b], S. Di Liberto[o], A. Di Mauro[b], D. Elia[b],
D. Evans[d], K. Fanebust[c], R.A. Fini[b], J.C. Fontaine[i], B.R. French[e], J. Ftáčnik[g],
W. Geist[r], B. Ghidini[b], G. Grella[p], M. Guida[p], E.H.M. Heijne[e], H. Helstrup[c],
A.K. Holme[e], D. Huss[i], A. Jacholkowski[b], P. Jovanovic[d], A. Jusko[g],
V.A. Kachanov[q], T. Kachelhoffer[r], J.B. Kinson[d], A. Kirk[d], W. Klempt[e],
K. Knudson[e], I. Králik[e], J.C. Lassalle[e]†, V. Lenti[b], J.A. Lien[j], R. Lietava[g],
R.A. Loconsole[b], G. Løvhøiden[j], M. Lupták[g], I. Mácha[n], V. Mack[i], V. Manzari[b],
P. Martinengo[e], M.A. Mazzoni[e], F. Meddi[o], A. Michalon[r],
M.E. Michalon-Mentzer[r], P. Middelkamp[e], M. Morando[k], M.T. Muciaccia[b],
E. Nappi[b], F. Navach[b], K. Norman[d], B. Osculati[f], B. Pastirčák[g], F. Pellegrini[k],
K. Piška[m], F. Posa[b], E. Quercigh[e], R.A. Ricci[h], G. Romano[p], G. Rosa[p], L. Rossi[f],
H. Rotscheidt[e], K. Šafařík[e], S. Saladino[b], C. Salvo[f], L. Šándor[e], T. Scognetti[b],
G. Segato[k], M. Sené[l], R. Sené[l], P. Sennels[j], S. Simone[b], A. Singovski[q], B. Sopko[n],
P. Staroba[m], J. Šťastný[m], T. Storås[j], S. Szafran[l], T.F. Thorsteinsen[c],
G. Tomasicchio[b], J. Urbán[g], M. Vaníčková[m], G. Vassiliadis[a]†, M. Venables[d],
O. Villalobos Baillie[d], T. Virgili[p], A. Volte[l], C. Voltolini[r], M.F. Votruba[d] and
P. Závada[m].

[a] Nuclear Physics Departement, Athens University, GR-15771 Athens, Greece
[b] Dipartimento di Fisica dell'Università and Sezione INFN, I-70124 Bari, Italy
[c] Fysisk institutt, Universitetet i Bergen, N-5007 Bergen, Norway
[d] University of Birmingham, Birmingham B15 2TT, UK
[e] CERN, European Laboratory for Particle Physics, CH-1211 Geneva 23, Switzerland
[f] Dipartimento di Fisica dell'Università and Sezione INFN, I-16146 Genoa, Italy
[g] Institute of Experimental Physics, SK-04353 Košice, Slovakia
[h] INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy
[i] GRPHE, Université de Haute Alsace, F-68093 Mulhouse, France
[j] Fysisk institutt, Universitetet i Oslo, N-0316 Oslo, Norway
[k] Dipartimento di Fisica dell'Università and Sezione INFN, I-35131 Padua, Italy
[l] Collège de France and IN2P3, F-75231 Paris, France
[m] Institute of Physics, Czech Academy of Sciences, CZ-18040 Prague, Czech Republic
[n] Department of Physics, Technical University, CZ-11519 Prague, Czech Republic
[o] Dipartimento di Fisica dell'Università "La Sapienza" and Sezione INFN, I-00185 Rome, Italy
[p] Dipartimento di Fisica dell'Università di Salerno and Sezione INFN, I-84100 Salerno, Italy
[q] Institute I.H.E.P., RU-142284 Protvino, Russia
[r] Centre de Recherches Nucléaires, F-67037 Strasbourg, France
† Deceased

- Introduction
- Strangeness studies in heavy ion collisions with the Omega spectrometer (WA85, WA94 experiments)
- WA97 experiment and experimental program
- Method of hyperon detection
- Results (most recent)
- Conclusions
- What next?

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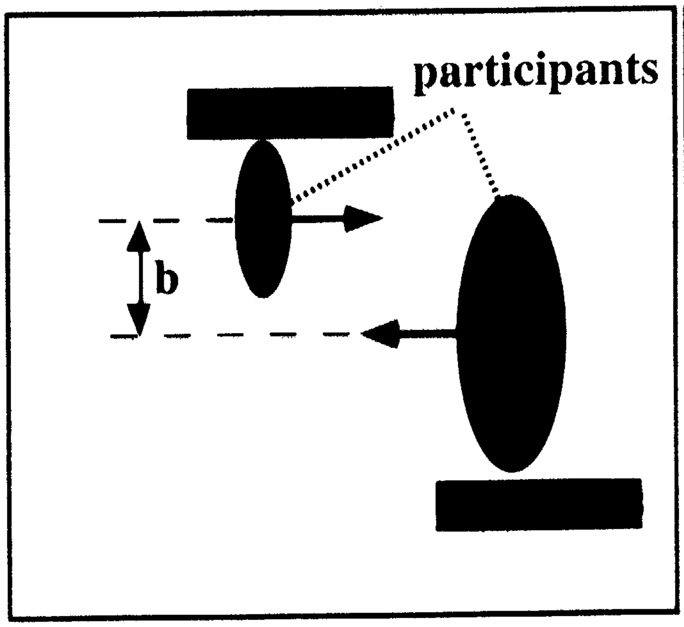
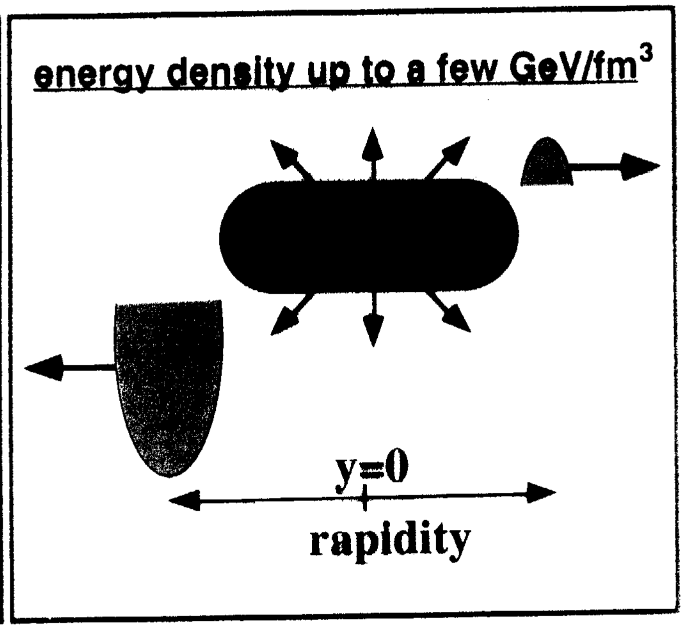
☞ Study properties of extended, strongly interacting system





- Interesting in its own
  ☞ Study properties of <u>QCD Vacuum</u>

- Relevance to other fields:
  - cosmology (early universe, ~ 10^{-5} s)
  - astrophysics (neutron stars, supernovae)

- Theoretical language:
  - non-perturbative QCD
  - thermodynamics

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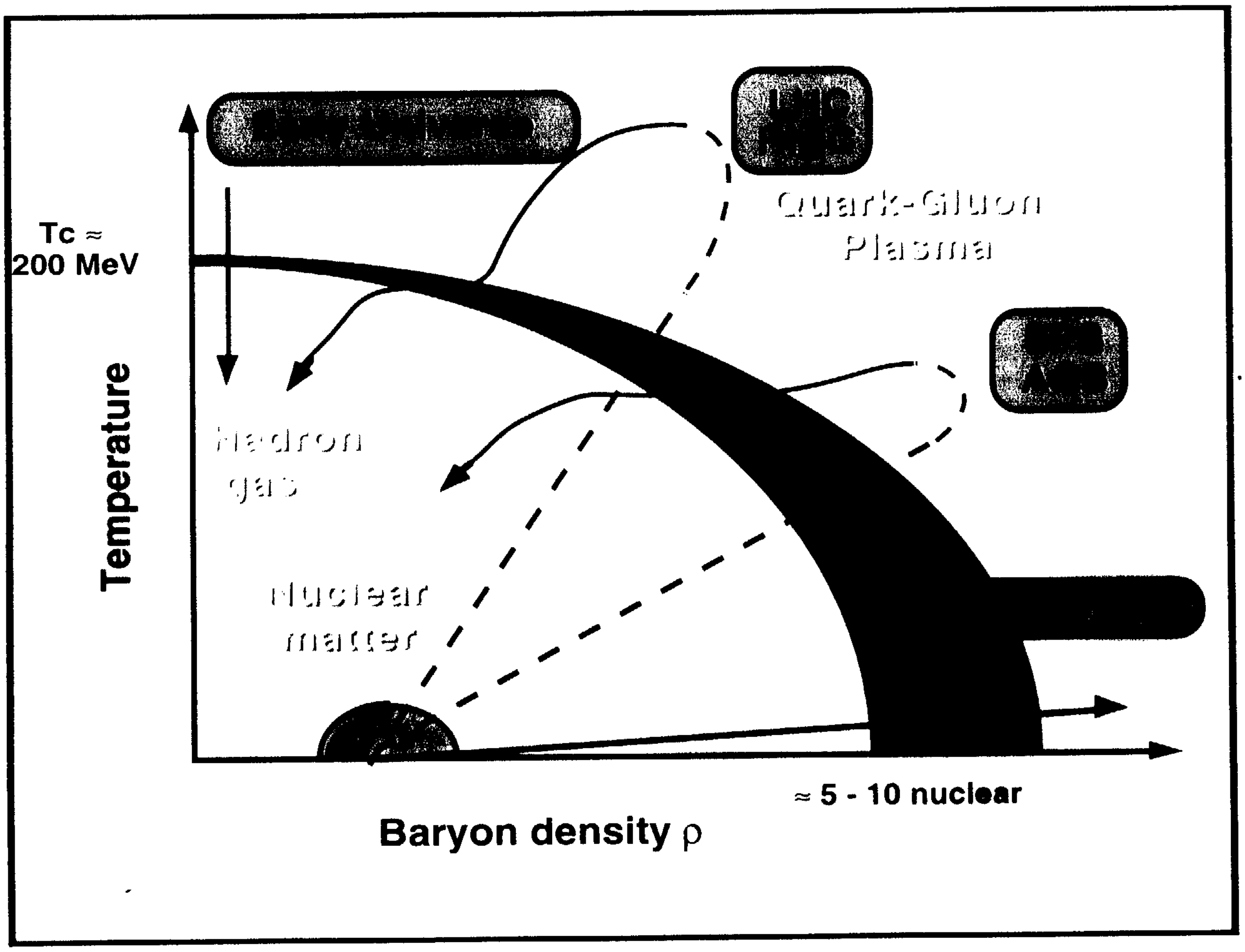
☞ At large enough temperature and/or baryon density → phase transition:

i) deconfinement (hadrons → quarks and gluons)

ii) (partial) restoration of chiral symmetry (constituent q masses → current q masses)



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Observables, QGP Signatures

- dN/dy, 0° energy, p_T, HBT interferometry,... (global observables)
- <u>strangeness</u> (probe of flavour-chemical equilibrium) (charm?)
- J/ψ, ψ',...,Υ,Υ',... (probe of color screening)
- γ, e^+e^-, $\mu^+\mu^-$ (electromagnetic probes, unaffected by strong interaction)
- resonance mass shifts?
- strangelets?, free quarks?, ...

[redacted]

QGP → strange particle production enhanced
(Prediction: J.Rafelski and B.Müller, 1982)

Two mechanisms:

i) <u>(partial) chiral symmetry restoration</u>:

m_s : ~ 500 MeV (constituent)

↓

~ 150 MeV (current)

$g\,g \rightarrow s\,\bar{s}$ $N(s) \propto e^{-m_s/T}$

ii) <u>Pauli blocking</u>:

at large baryon density (SPS) u and d quarks abundant → lower levels are filled
Production of $s\bar{s}$ pair can be favoured if lowest available u, d levels have energy larger than $2\,m_s$:

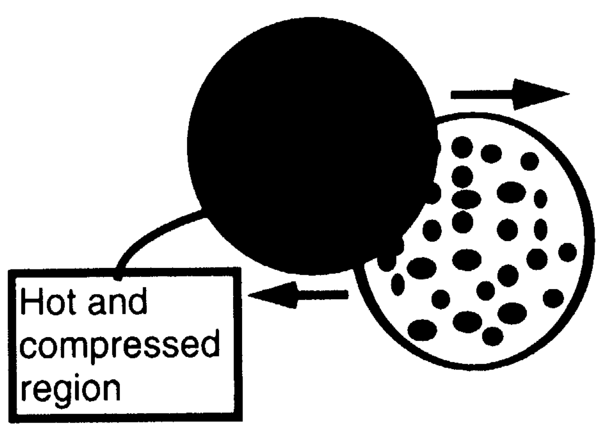
☞ $E_F^{u,d} \sim 450$ MeV $> 2\,m_s$ $(\rho \sim 10\rho_o)$

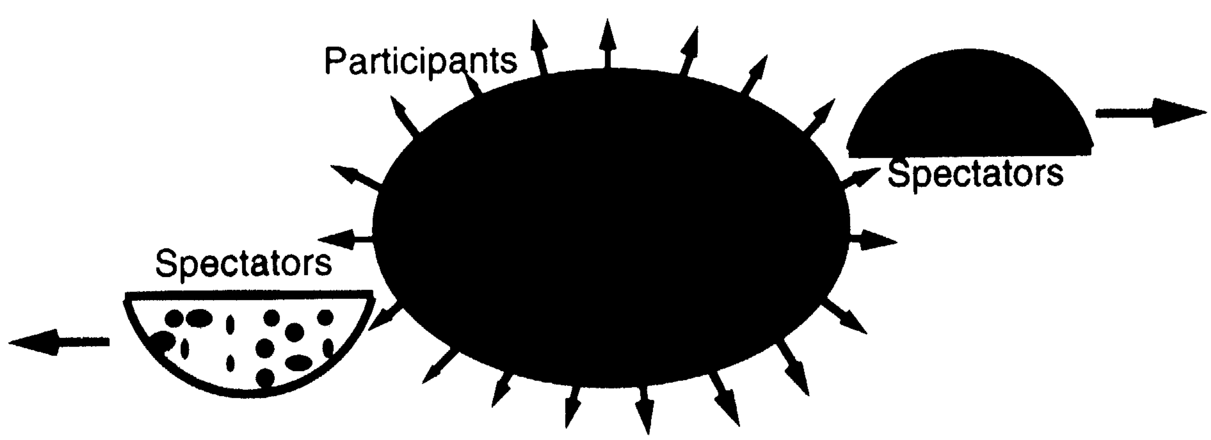
[redacted]

→ Enhancement of strangeness can also be obtained without QGP, e.g. by <u>secondary rescattering</u> in the hadronic fireball formed in a nucleus-nucleus collision:

$$\text{e.g.:}\quad \pi + \pi \rightarrow K + K$$
$$\pi + N \rightarrow \Lambda + K$$

Nucleus-Nucleus Collision





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but:
- multi-strange baryons not easy
- " " anti-baryons especially difficult

☞ <u>especially interesting!</u>

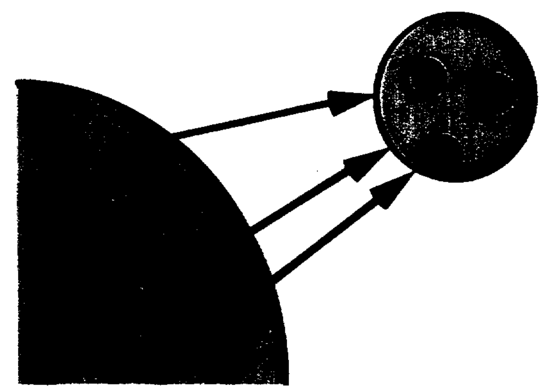
e.g.: to produce an $\overline{\Omega}$:

direct: e.g.: $\pi+\pi \rightarrow \Omega+\overline{\Omega}$ → high threshold (3.3 GeV)

or multiple rescatterings:

e.g.:
- i) antinucleon $\overline{N}$
- ii) $\pi+N \rightarrow \Lambda+K$
- iii) $\overline{N}+K \rightarrow \overline{\Lambda}+\pi$
- iv) $\overline{\Lambda}+K \rightarrow \overline{\Xi}+\pi$
- v) $\overline{\Xi}+K \rightarrow \overline{\Omega}+\pi$

☞ <u>long times needed for "chemical" equilibration</u> (100's fm/*c* for multi-strange antibaryons; heavy-ion collision ~ 5÷10 fm/*c* !)

	HADRONIC GAS	QGP
Strangeness equilibration	slow (high thresholds)	fast ($m_s \sim T_c$)
Multistrange (anti-)baryons	especially slow (e.g.: $\overline{\Omega}^+$ threshold ~ 3.3 GeV)	easily assembled 

WA97 Experiment is the last of three ion experiments performed at the OMEGA spectrometer at CERN

- **WA85**: p-W and S-W collisions at 200 AGeV/c
- **WA94**: p-S and S-S collisions at 200 AGeV/c
- **WA97**: p-Pb, p-Be and Pb-Pb collisons at 158 AGeV/c

Aim of these experiments:

Study of strange and multistrange particle (and antiparticle) production via the measurement of particle ratios, cross sections, and spectra (at central rapidity and medium transverse momenta) in different reactions with emphasis on **multistrange baryons and antibaryons**.

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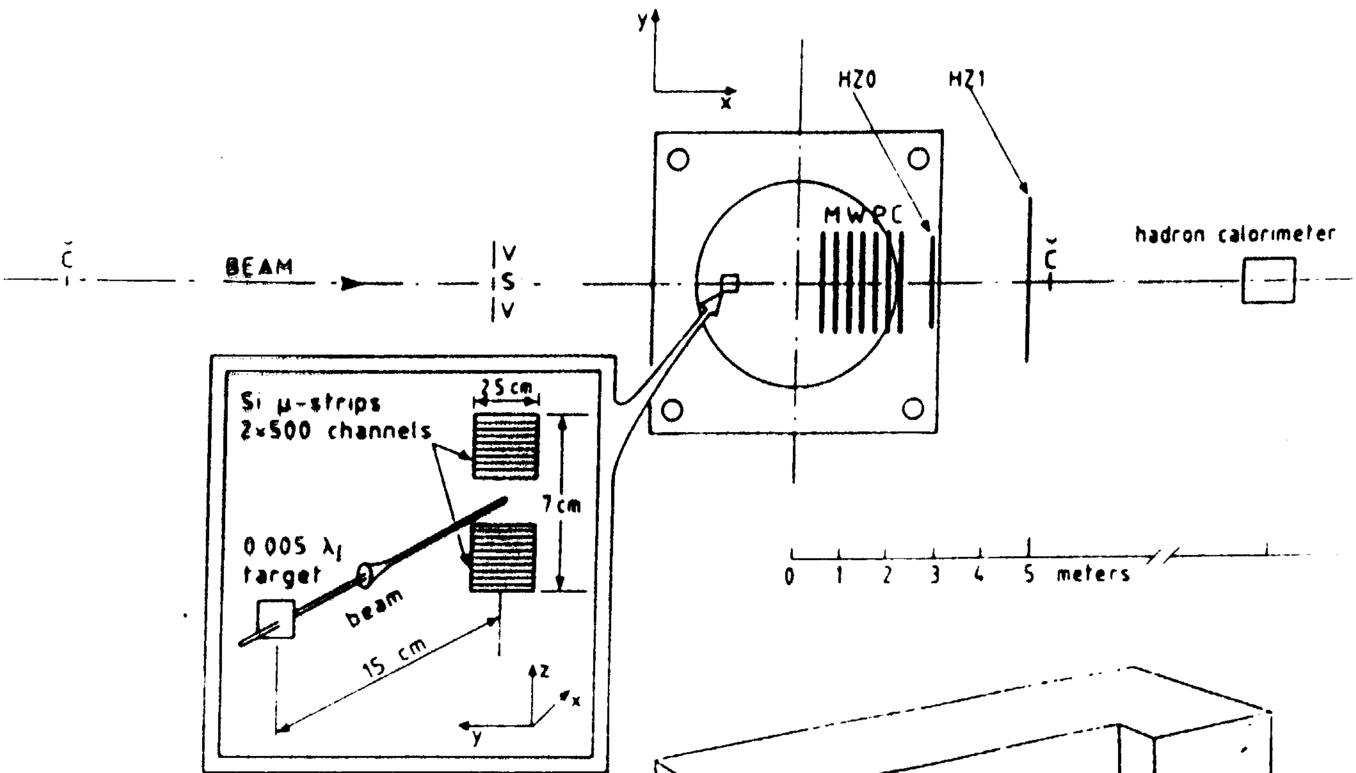
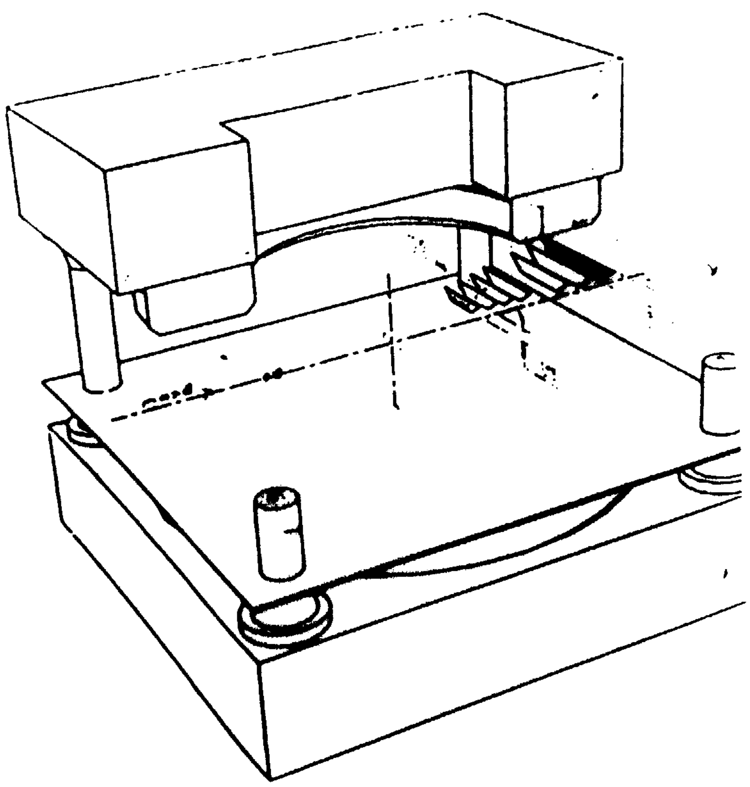
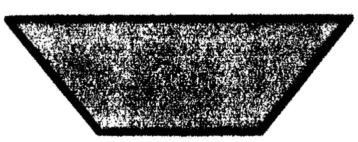
Ω magnet





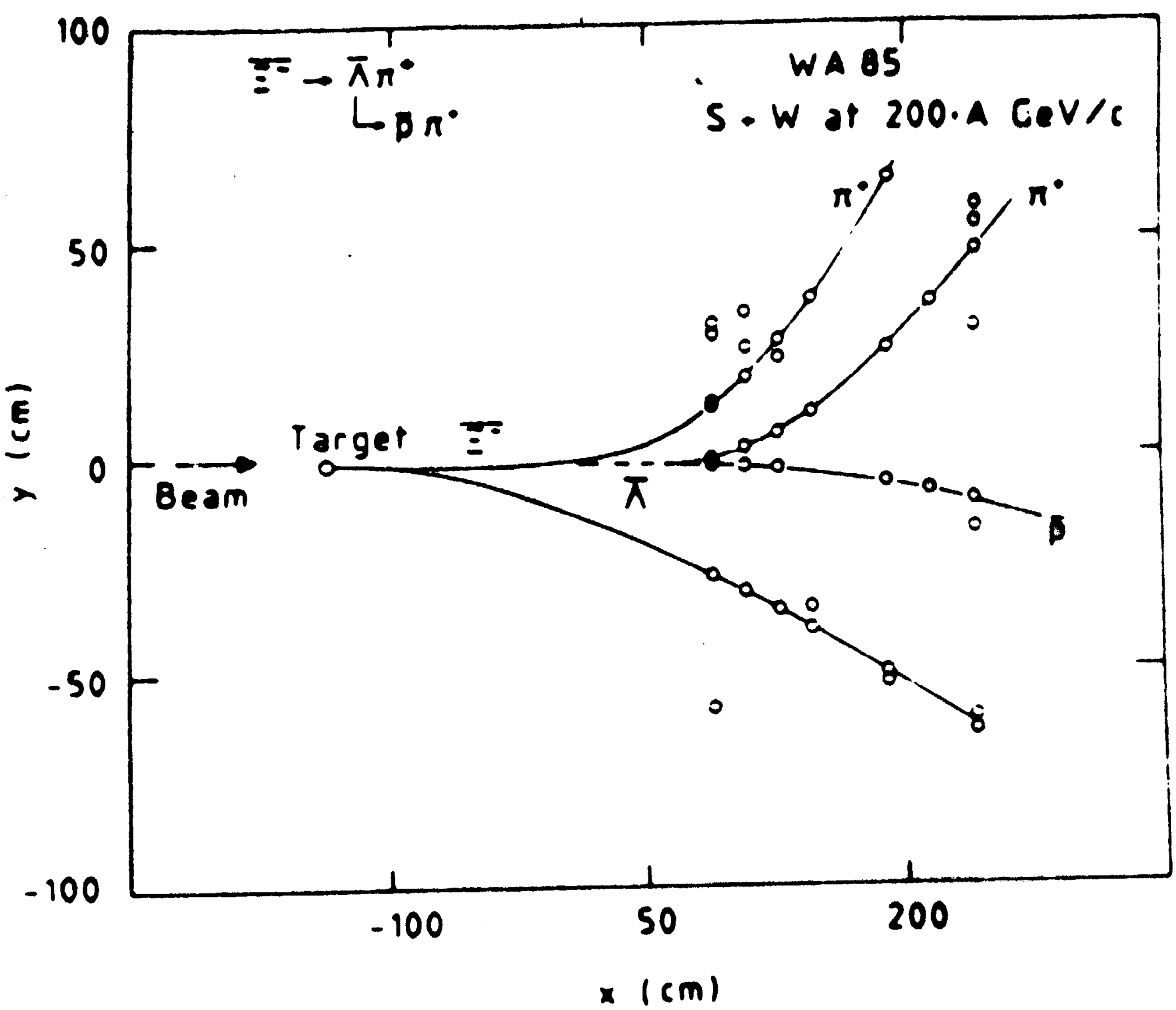
"Butterfly" MWPC



$2.3 < y < 3.0$
$p_T > 1$ GeV/c

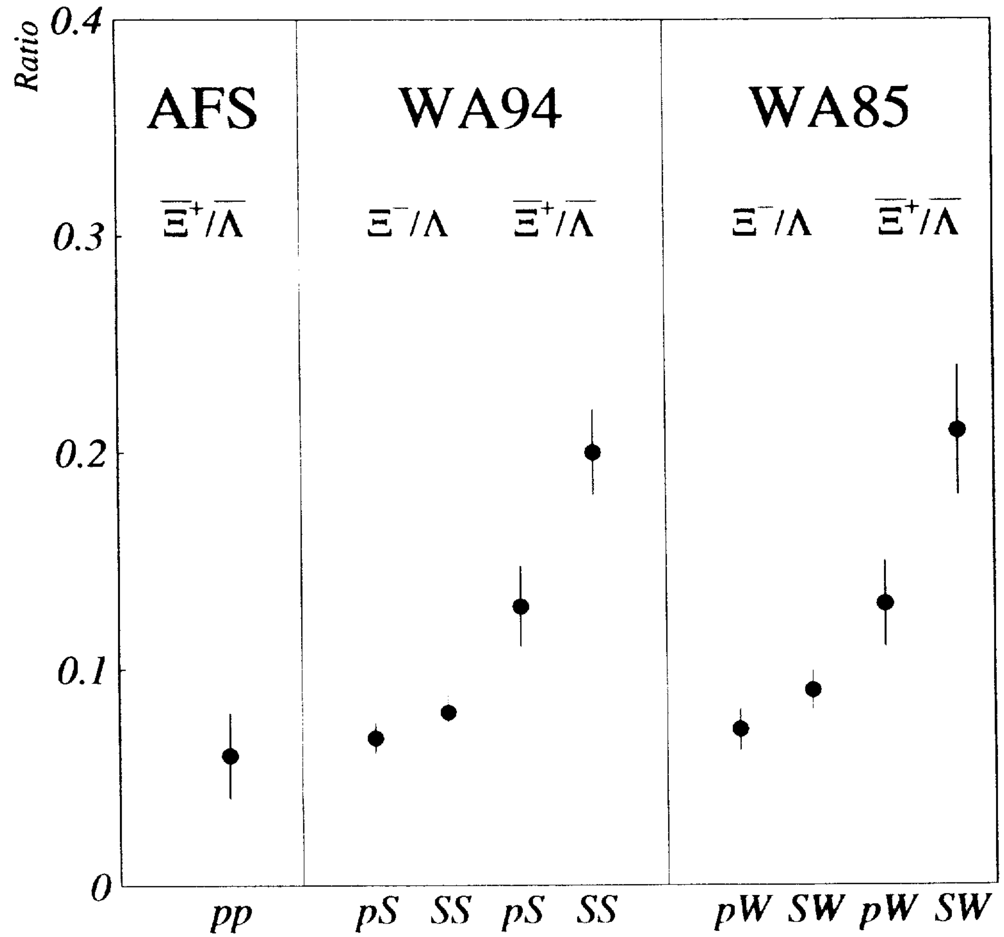
S+W (WA85), S+S (WA94)

[redacted]



FEW TRACKS INSTEAD OF MANY

AFS, WA85 and WA94 data on Ξ/Λ ratios



FROM

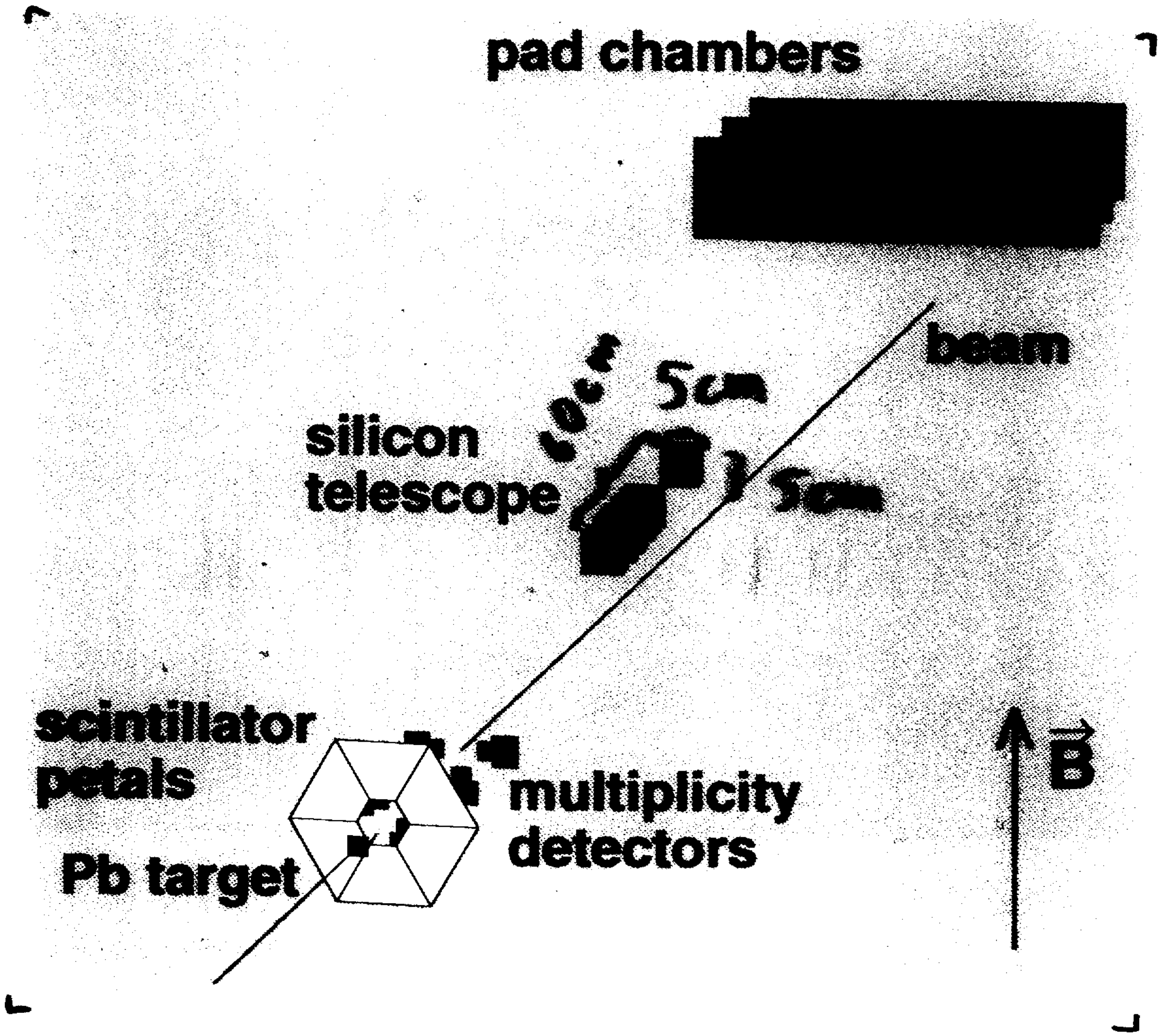
S-W & S-S

TO

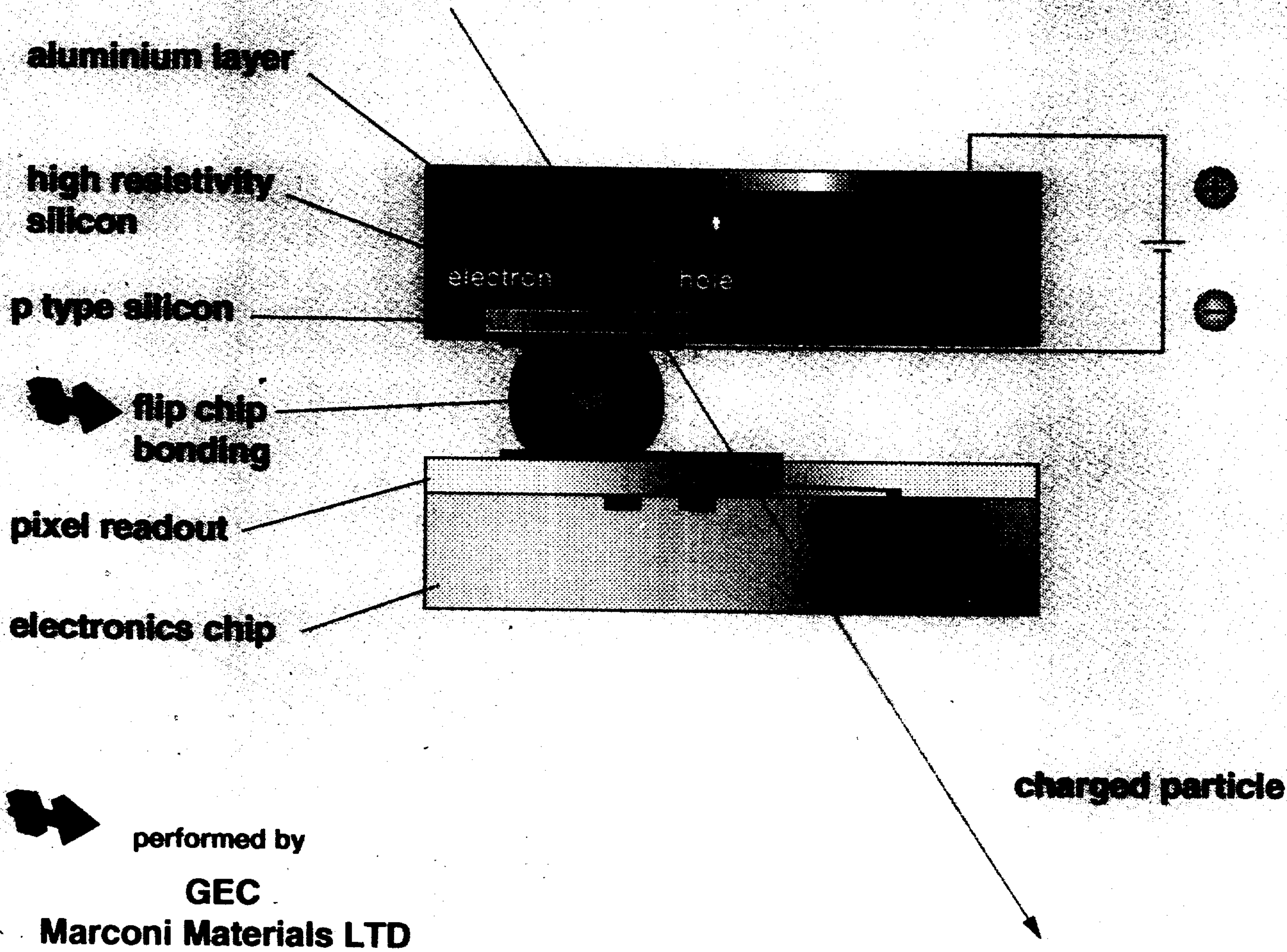
Pb-Pb

WA 97

WA97 set-up in the Omega magnet



Particle detection



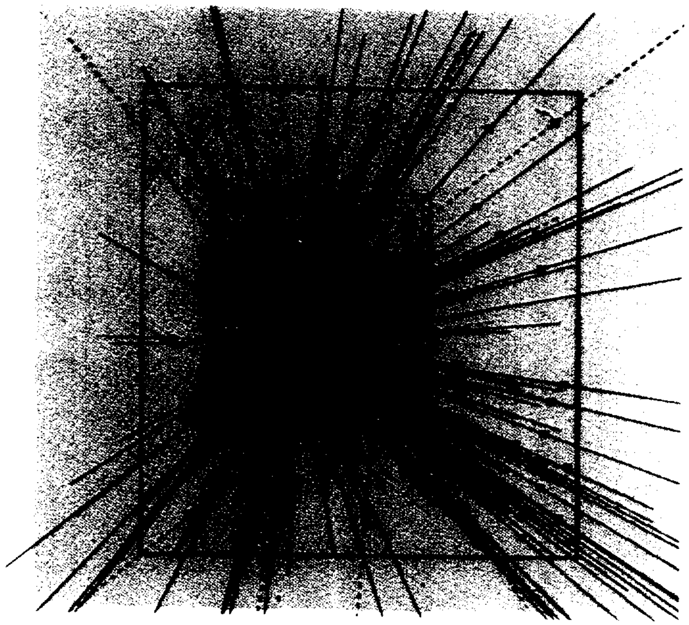
performed by

GEC
Marconi Materials LTD
Caswell . UK .

Milo Luptak

Ex17.4.97/2

Pixel Tracking Chamber - PTC



No-field event with 153 reconstructed tracks in the pixel tracking chamber

The average multiplicity of reconstructed PTC tracks in events with cascade decay candidates is

$$\langle n \rangle \simeq 20$$

In the silicon telescope :

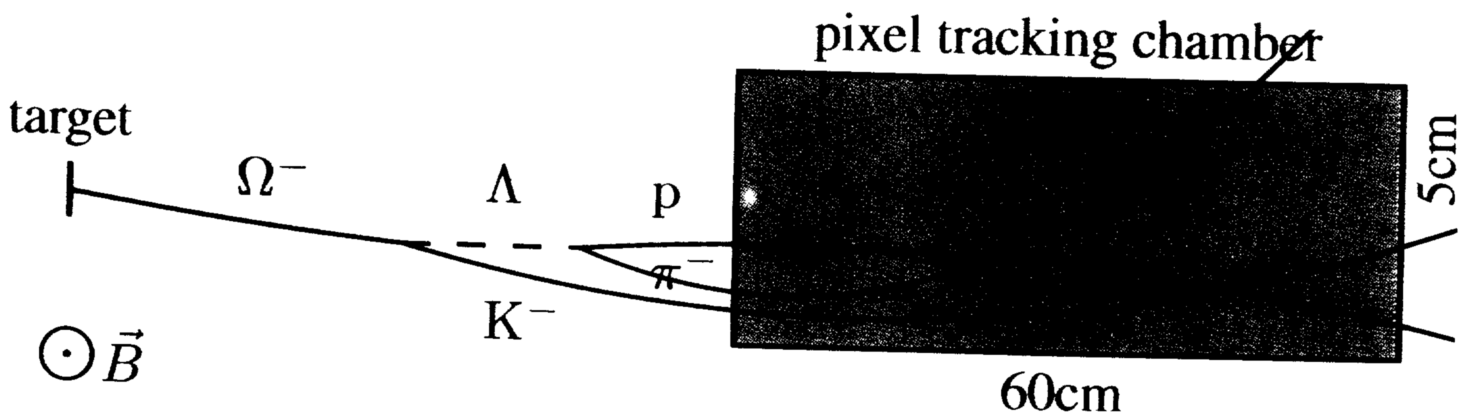
10 microstrip planes with 50 μm pitch

7 planes of the novel pixel detectors (RD19, E.Heijne et al). Each plane contains 72k of 75×500 μm^2 pixels

- real 3D detector with $\simeq 0.5 \times 10^6$ of channels acting as a pixel tracking chamber (PTC)
- powerful 3D track finding algorithm (ORHION, J.-C. Lassalle)

☞ PTC is a proper instrument for reliable reconstruction of the cascade hyperon decays in a high multiplicity environment

Decay topology



$$\Xi^- \rightarrow \Lambda + \pi^- \qquad BR = 99.89\%$$

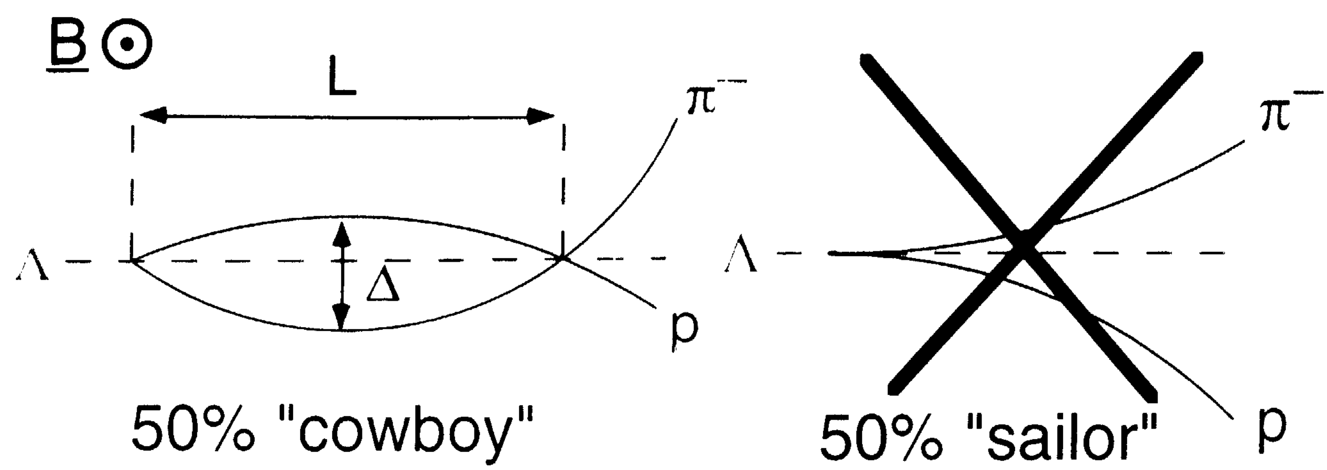
$$\hookrightarrow p + \pi^- \qquad BR = 63.9\ \%$$

$$\Omega^- \rightarrow \Lambda + K^- \qquad BR = 67.8\ \%$$

$$\hookrightarrow p + \pi^-$$

- Decays can be contained in a small x-section detector

e.g.: $\Lambda \rightarrow p\,\pi^-$ in a <u>magnetic field</u>



L Lorentz invariant, $\leq L_{MAX} \propto \dfrac{p^*}{|\underline{B}|}$

B = 1.8 Tesla $\rightarrow$ $L_{MAX} \sim 40$ cm

$\Delta \sim 5/\gamma$ cm

WA97 telescope x-section = 5 x 5 cm^2

WA97 experiment

Study of "strange particle enhancement" through measurement of A-dependence of inclusive cross sections.

Topics under study:

- Cross sections of Λ, Ξ^-, Ω^-, K^0_s, K^+ (and antiparticles),
- Particle and antiparticle ratios,
- Distributions and inverse slopes of transverse mass spectra.

The results from Pb-Pb collisions are to be compared with

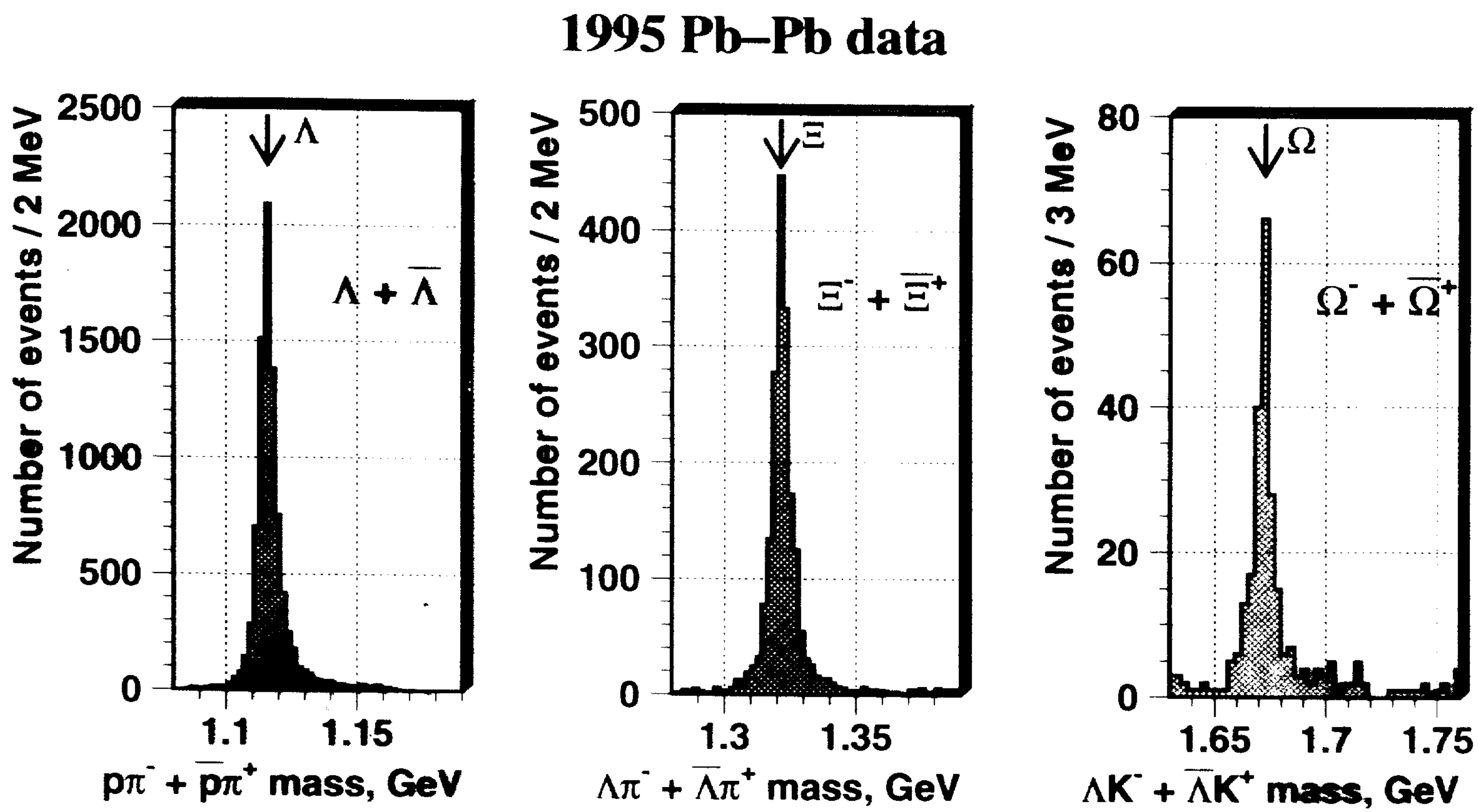
- results from p-Pb and p-Be measured in the same experiment and in the same kinematic window,
- results from p-W, p-S, S-W and S-S measured by WA85 and WA94.

STATUS REPORT

(STAY TUNED...

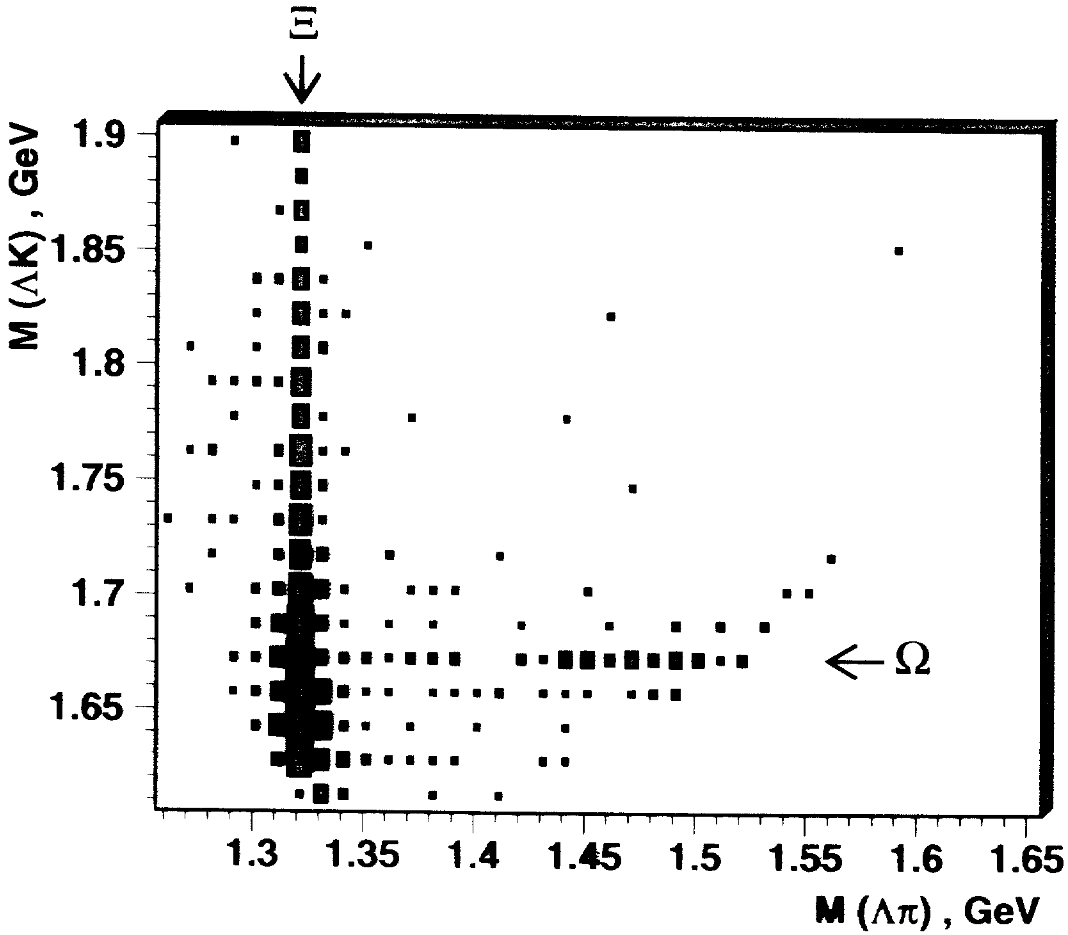
MORE TO COME...

Hyperon identification and mass resolution



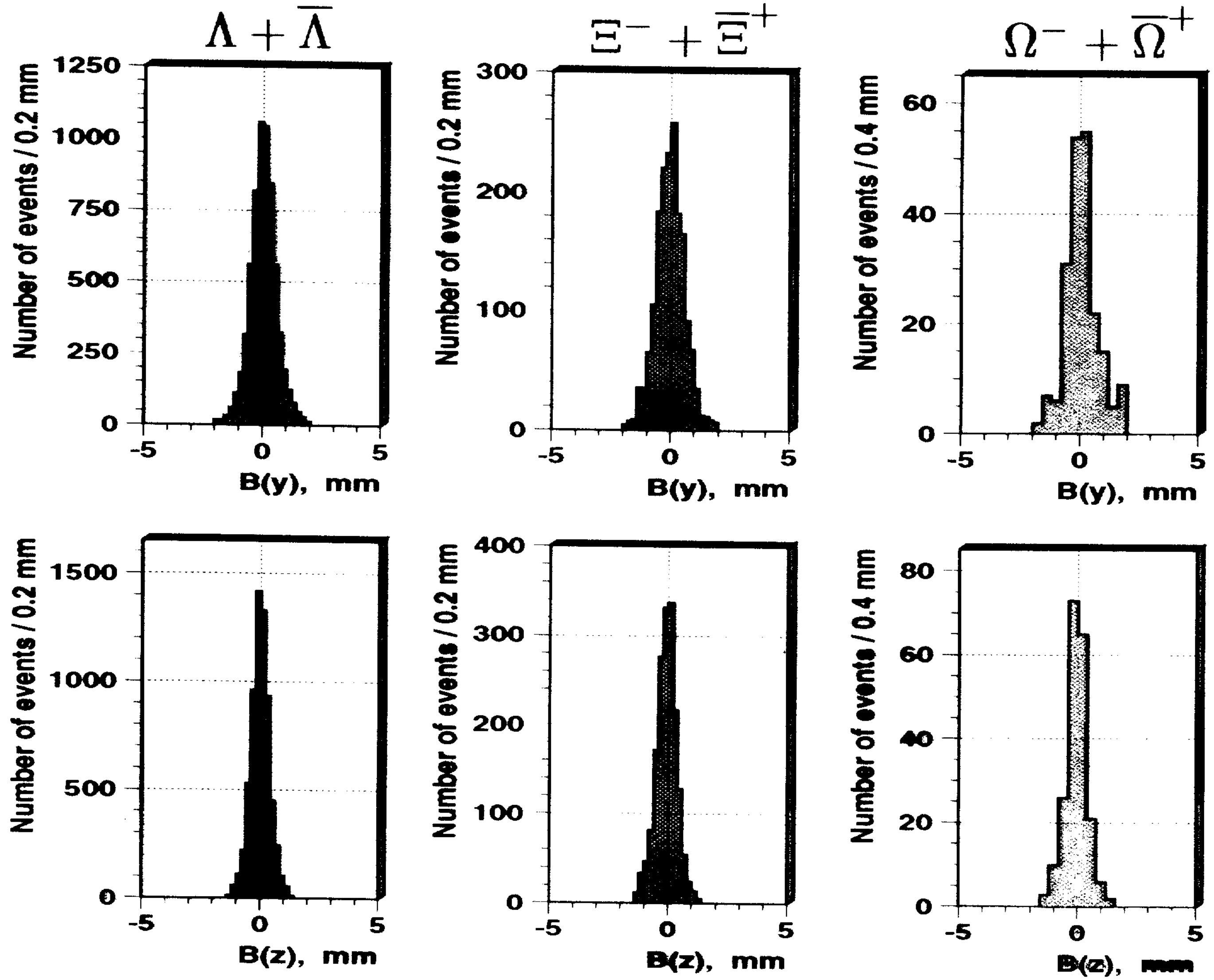
High multiplicity of reconstructed tracks allows to determine the vertex position with good precision on event-by-event basis. Knowledge of interaction point position is of principal importance for working out efficient selection criteria.

Hyperon cascade decay candidates



Pb–Pb data, 42 M of triggers

Hyperon impacts in the target plane



Calculation of weights for hyperons

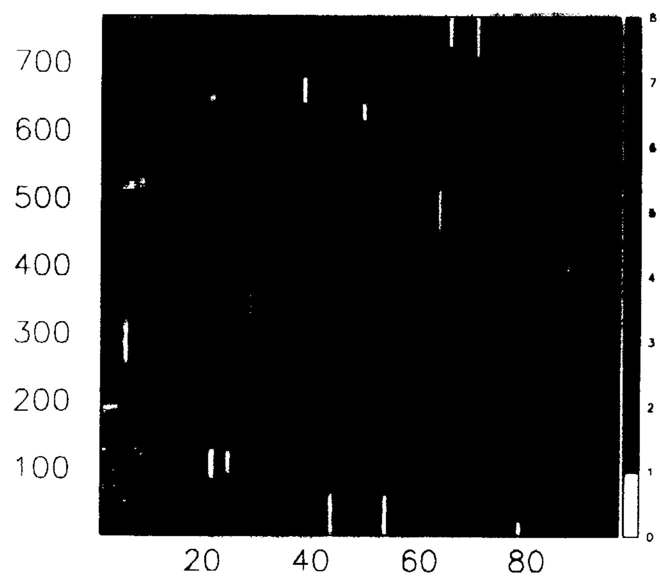
The signals are corrected for

- geometrical acceptance
- detector efficiency
- reconstruction efficiency.

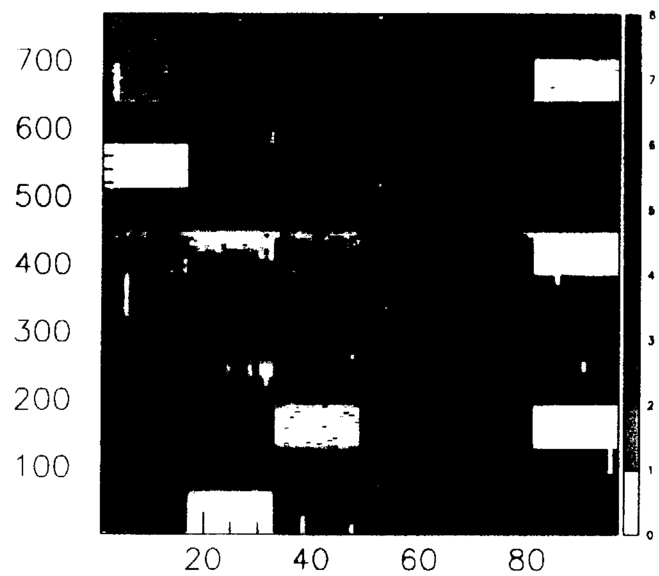
Weights for each selected particle were computed by a complex Monte Carlo procedure based on GEANT in the following main steps :

- generation of decays of hyperons with the measured
  - rapidity and transverse momentum
  - position of primary vertex (event-by-event)

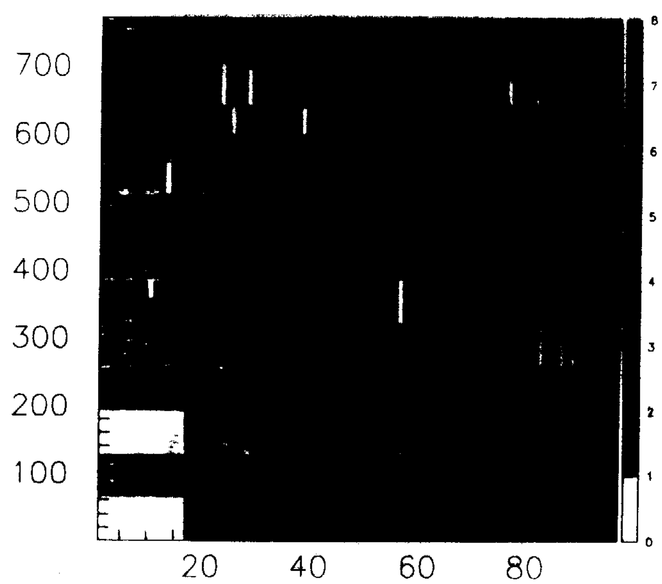
  and the propagation of decay tracks through the WA97 set-up
- simulation of the background tracks and the noise in the electronics by embedding the generated cascade into a background event with similar hit multiplicity in the PTC
- processing these mixed events by the chain of track reconstruction, V0 and cascade decay reconstruction as well as the analysis programs used for real data processing.



FULL LOGICAL PLANE – 1 –

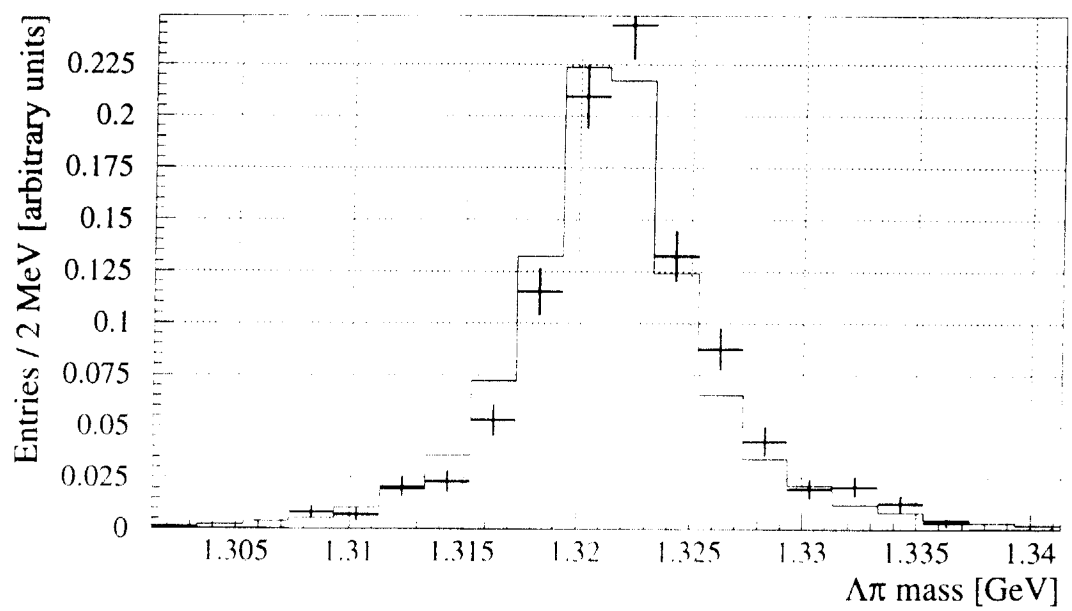


FULL LOGICAL PLANE – 4–

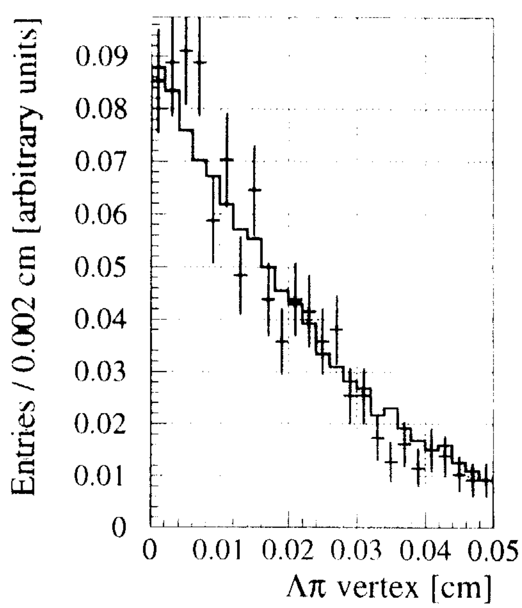


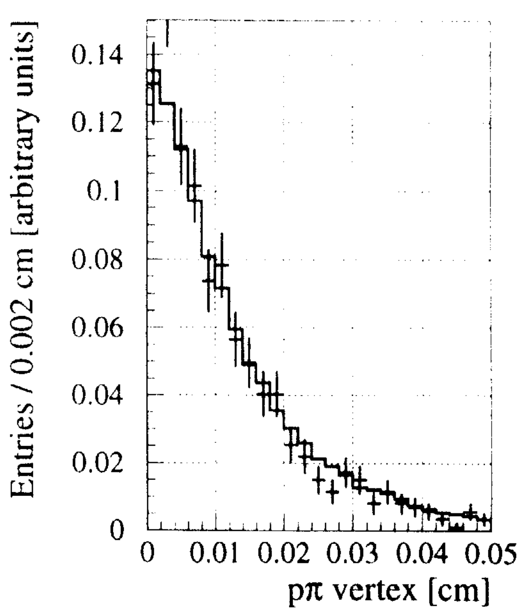
FULL LOGICAL PLANE – 6–

Ξ mass (histogram = MC)



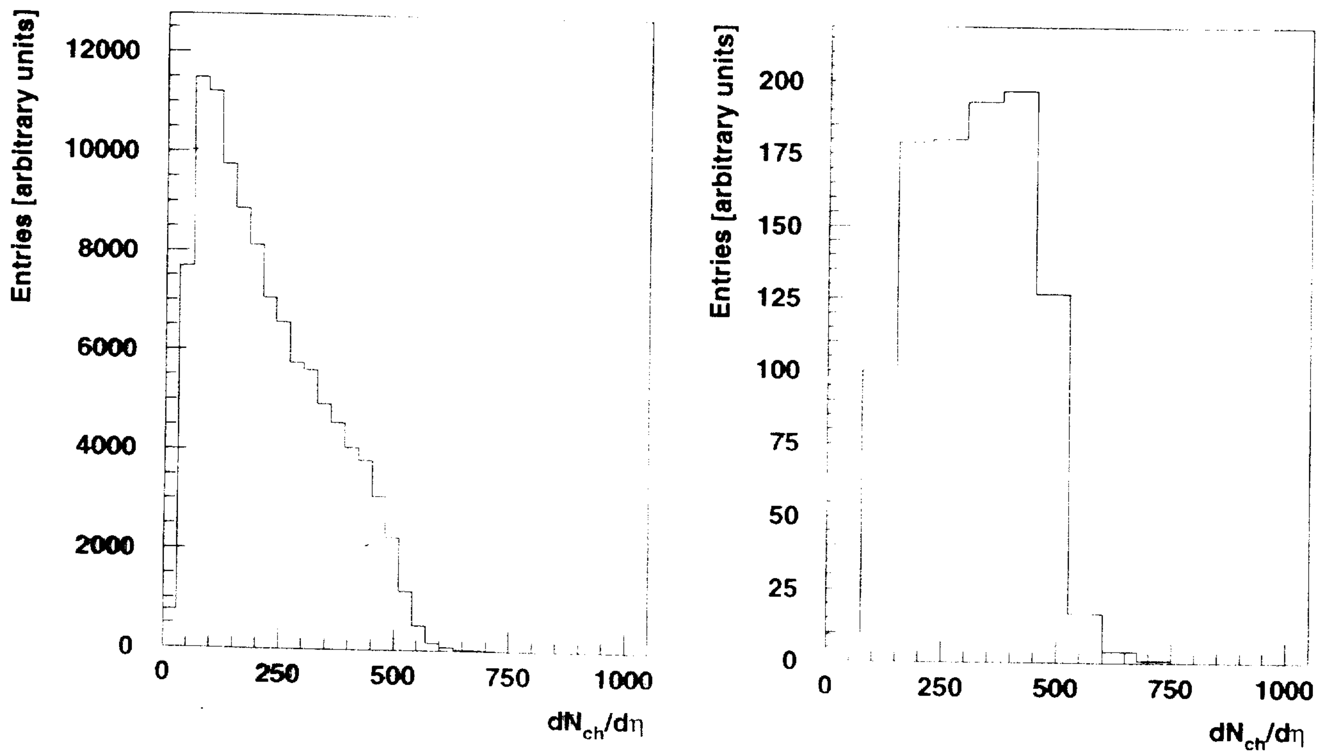
Distance of closest approach for reconstructed vertices



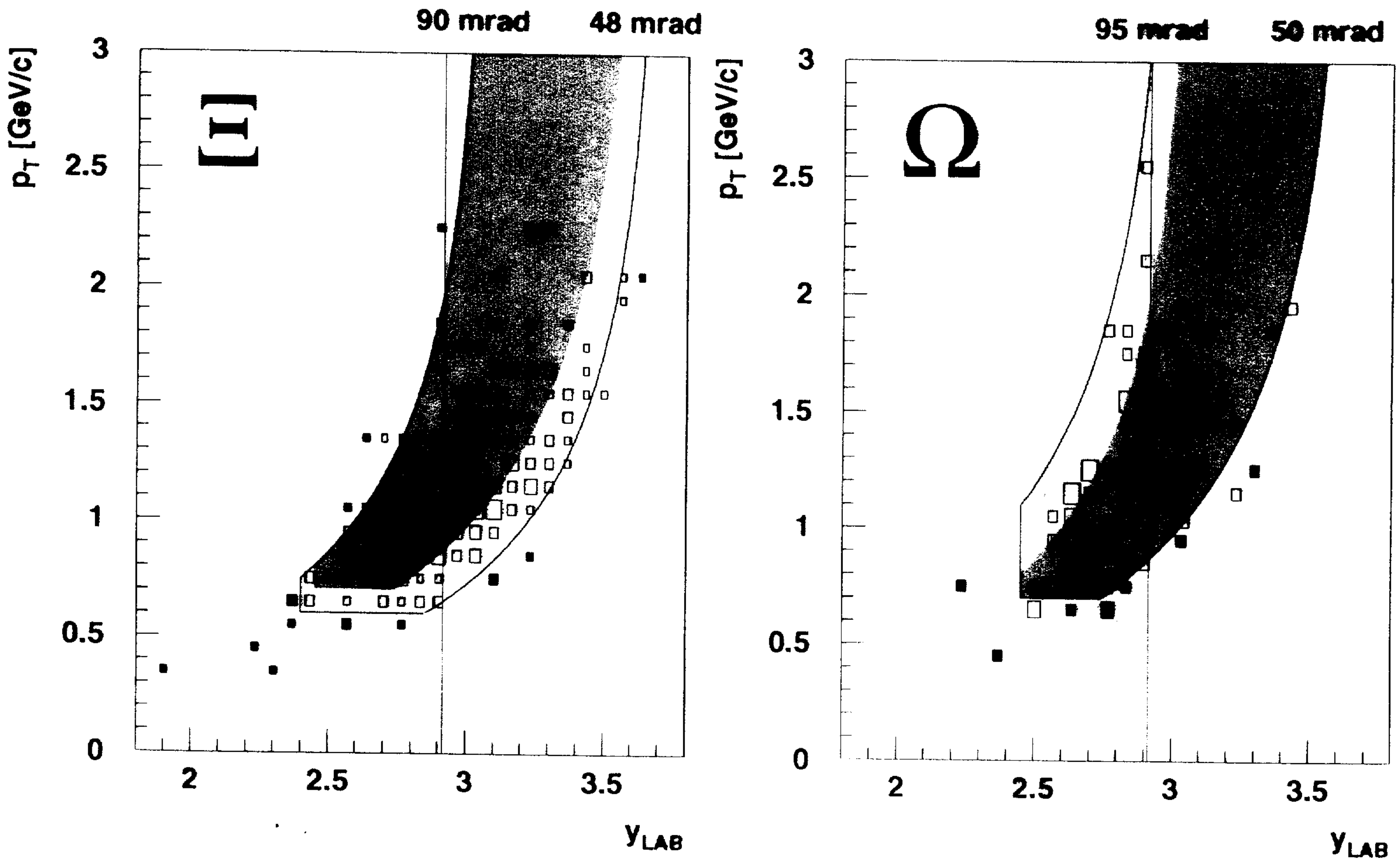


Charged particle multiplicity

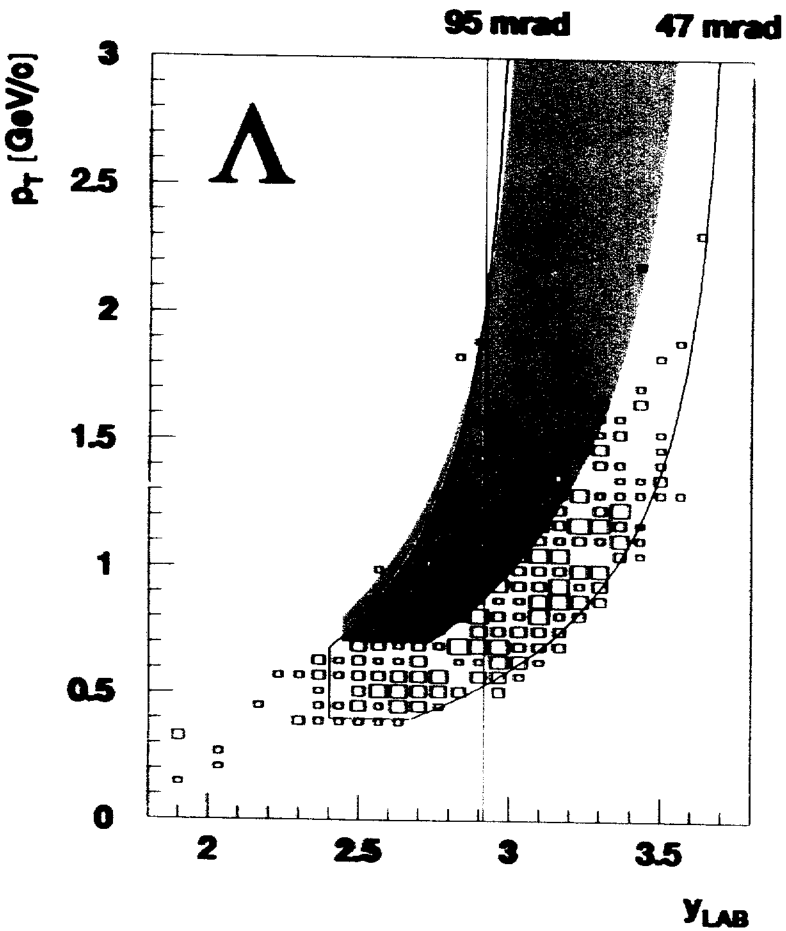
MSD can measure charged particle multipicity in $2 < \eta < 4$



Acceptance regions and the overlap window



Acceptance regions and the overlap window



Production cross sections in the overlap window

Particle	Cross section [mb]
Λ	2359 ± 193
$\overline{\Lambda}$	332 ± 64
Ξ^-	327 ± 30
$\overline{\Xi}^+$	87 ± 15
Ω^-	63 ± 10
$\overline{\Omega}^+$	26 ± 6

$p_\perp \gtrsim 0.7$ GeV/c

$\Delta y^* \approx 0.5$

~30% of Pb-Pb σ_{inel}

$$\sigma = \frac{1}{nL} \frac{\sum \text{weights}}{\sum \overline{\text{BEAM} \cdot \overline{\text{DT}}}}$$

n = number of target nuclei per unit volume

L = thickness of target

Integrated cross sections

Knowledge of differential spectra is needed for obtaining inclusive cross sections integrated over all $p_\perp$ and over one unit of rapidity around $y^\star = 0$

$$\sigma_Y = \int_0^{p_{\perp max}} dp_\perp \int_{\Delta y^\star = 1} dy^\star \frac{d\sigma_Y}{dp_\perp dy^\star}, \tag{1}$$

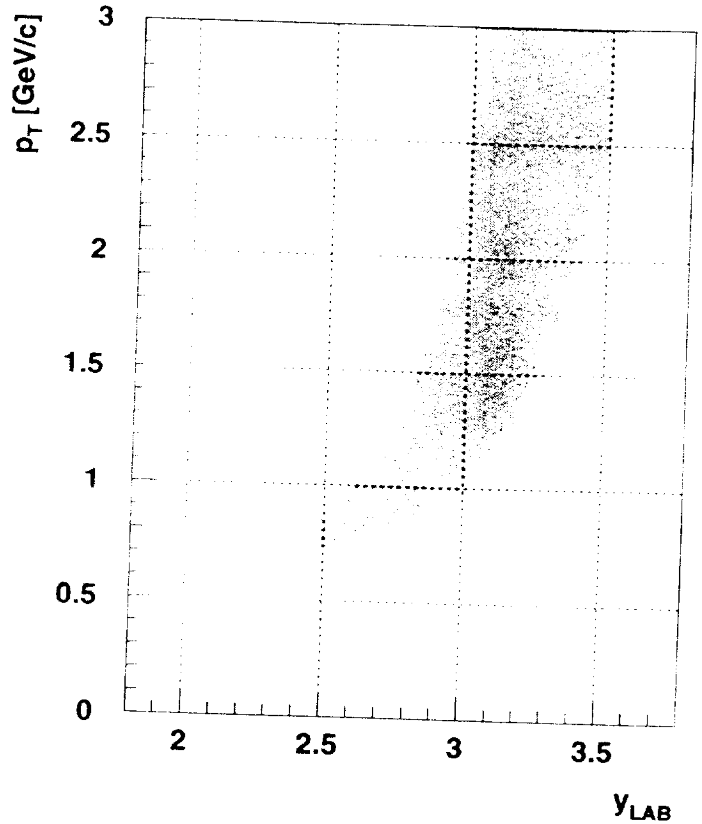
Our preliminary result for Ξ^- leads to

$$\sigma_\Xi \approx 1400 \text{ mb} \tag{2}$$

Work is going on ...

Particle ratios in the overlap window

Ratio	Uncorrected	Corrected
$\frac{\overline{\Xi}^+}{\Xi^-}$	0.27 ± 0.03	0.27 ± 0.05
$\frac{\overline{\Omega}^+}{\Omega^-}$	0.42 ± 0.10	0.42 ± 0.12
$\frac{\Omega^-}{\Xi^-}$	0.18 ± 0.02	0.19 ± 0.04
$\frac{\overline{\Omega}^+}{\overline{\Xi}^+}$	0.27 ± 0.06	0.30 ± 0.09
$\frac{\overline{\Lambda}}{\Lambda}$	0.13 ± 0.01	0.14 ± 0.03
$\frac{\Xi^-}{\Lambda}$		0.14 ± 0.02
$\frac{\overline{\Xi}^+}{\overline{\Lambda}}$		0.26 ± 0.05



COMPARISON

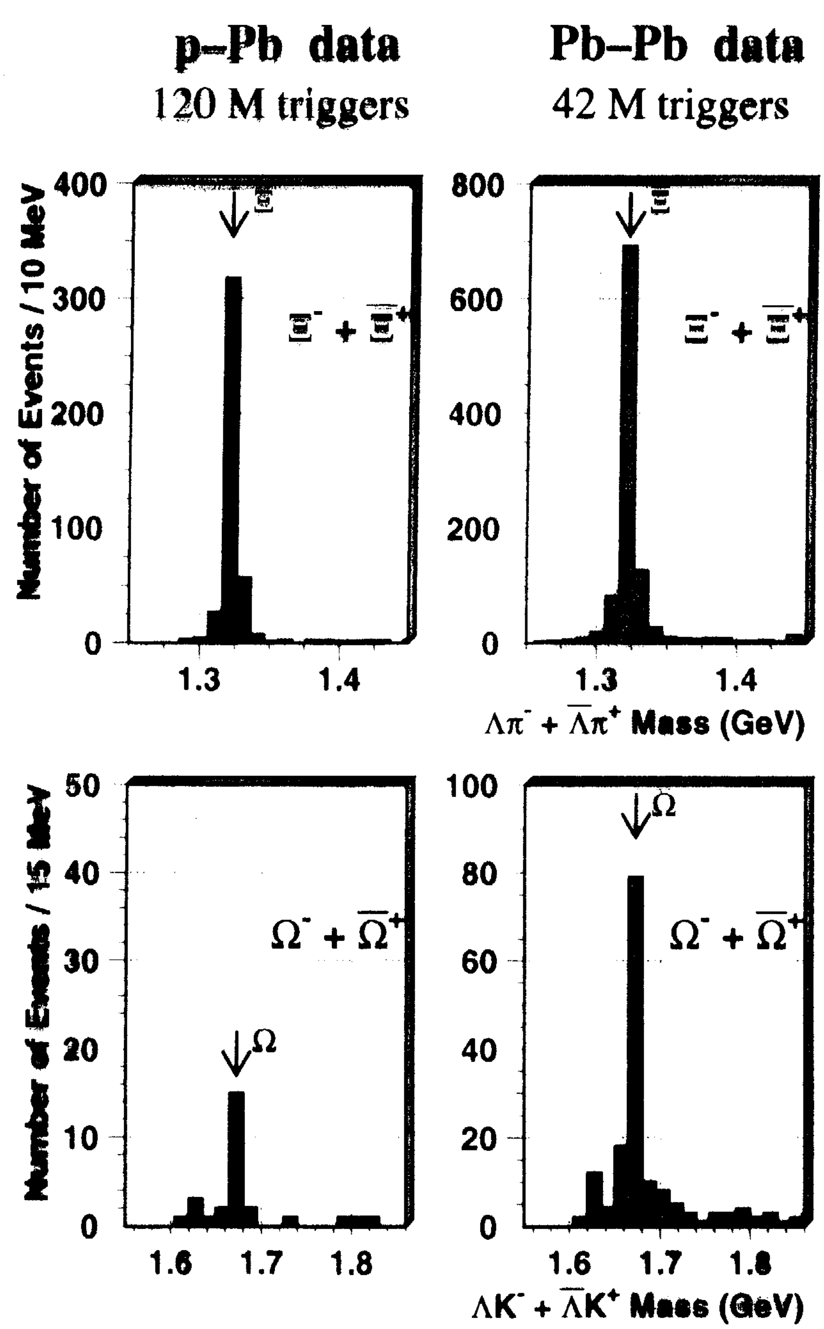
Pb - Pb

v. s.

p - Pb

& A- dependence

Ξ and Ω signals in Pb–Pb and p–Pb data



Enhancement of the Ω/Ξ ratio by about a factor 3 when going from p–Pb to Pb–Pb

Ω/Ξ enhancement

A striking difference between Ω/Ξ ratios in p–Pb and Pb–Pb data is observed

- Taking into account the knowledge of integrated geometrical acceptance (higher by $\simeq$10 % for Ω/Ξ ratio in Pb–Pb data) and
- assuming the same reconstruction efficiency for Ξ and Ω

$\Downarrow$

$$\frac{(\Omega^- + \overline{\Omega}^+ / \Xi^- + \overline{\Xi}^+)_{\mathrm{Pb-Pb}}}{(\Omega^- + \overline{\Omega}^+ / \Xi^- + \overline{\Xi}^+)_{\mathrm{p-Pb}}} \simeq 3\,.$$

The above ratio is >2 at the 95% C.L. (estimate based on stat. errors)

Assumption on the same reconstruction efficiency for Ξ and Ω was confirmed for Pb–Pb data. Calculations for p–Pb data are under way

Conclusions

- Cross sections and particle ratios for Ξ^-, $\overline{\Xi}^+$, Ω^-, $\overline{\Omega}^+$, Λ, $\overline{\Lambda}$ in a detector specific kinematic window were presented. Extrapolation to $p_\perp > 0$ and one unit of rapidity is under way.

- Enhancement by about a factor 3 in the $(\Omega^- + \overline{\Omega}^+)/(\Xi^- + \overline{\Xi}^+)$ ratio when going from p-Pb to Pb-Pb.

What next?

- Calculate corrections for p-Pb and enlarge corrected samples of Λ, $\overline{\Lambda}$, Ξ^-, $\overline{\Xi}^+$, Ω^-, $\overline{\Omega}^+$, in Pb-Pb data to obtain a comprehensive picture of hyperon enhancement.
- Study $m_\perp$ spectra.
- Study the multiplicity, rapidity and $m_\perp$ dependence of particle ratios.
- Process p-Be data (1996 run) to have more reference points for the investigation of the A dependence of strangeness production in p-A collisions.
- Continue and extend the study of strange and multistrange baryon production in the new NA57 experiment (... low energy run ...).