Σ^+ and Σ^0 Production Measured at LEP with the L3 Detector

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Hyperons, Charm and Beauty Hadrons (Genova, Italy)

Introduction

Hadron Production Rates in e^+e^- Annihilation

General Features present at $\sqrt{s}$ =10, 30, 91 GeV

- Constituent Quark Content
- Spin Angular Momentum
- Hadron Mass (or Binding Energy)

$\sqrt{s}$-Dependent Effects

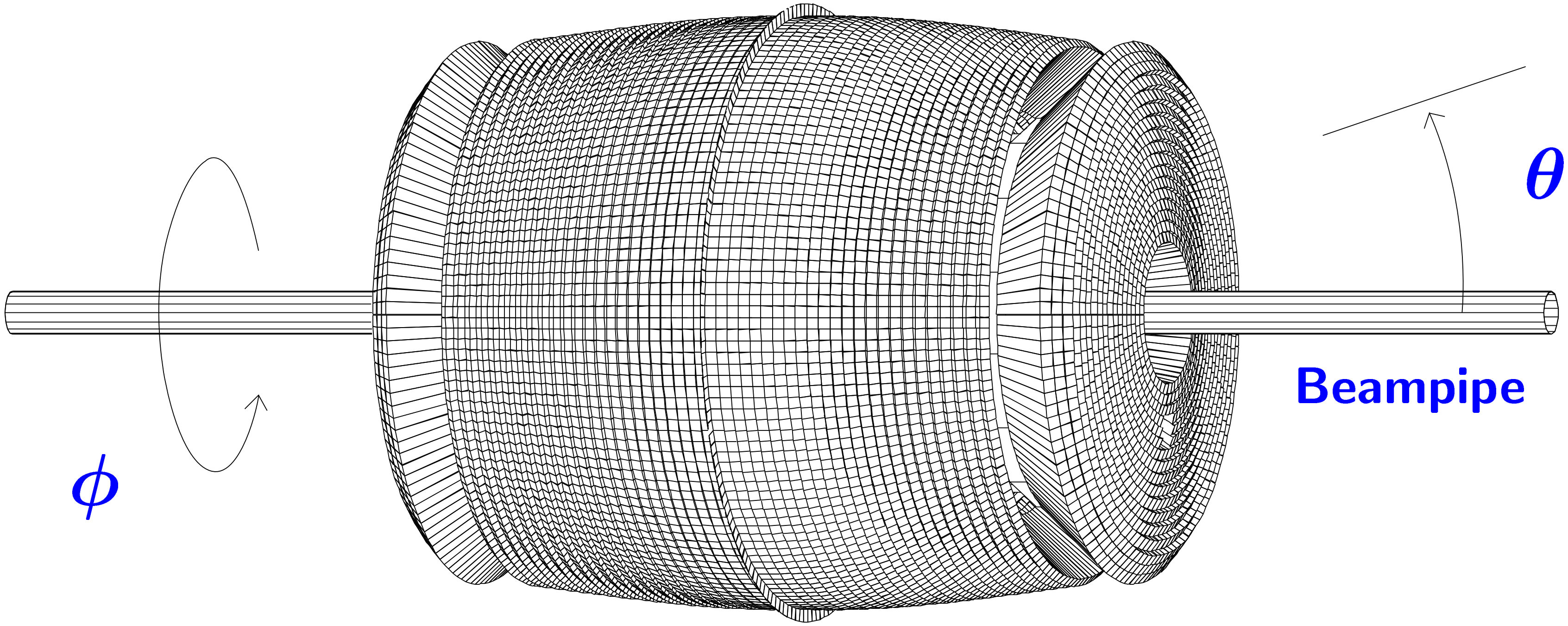
- Charge Multiplicity
- Quarks from the Primary Vertex

Hadron Decays

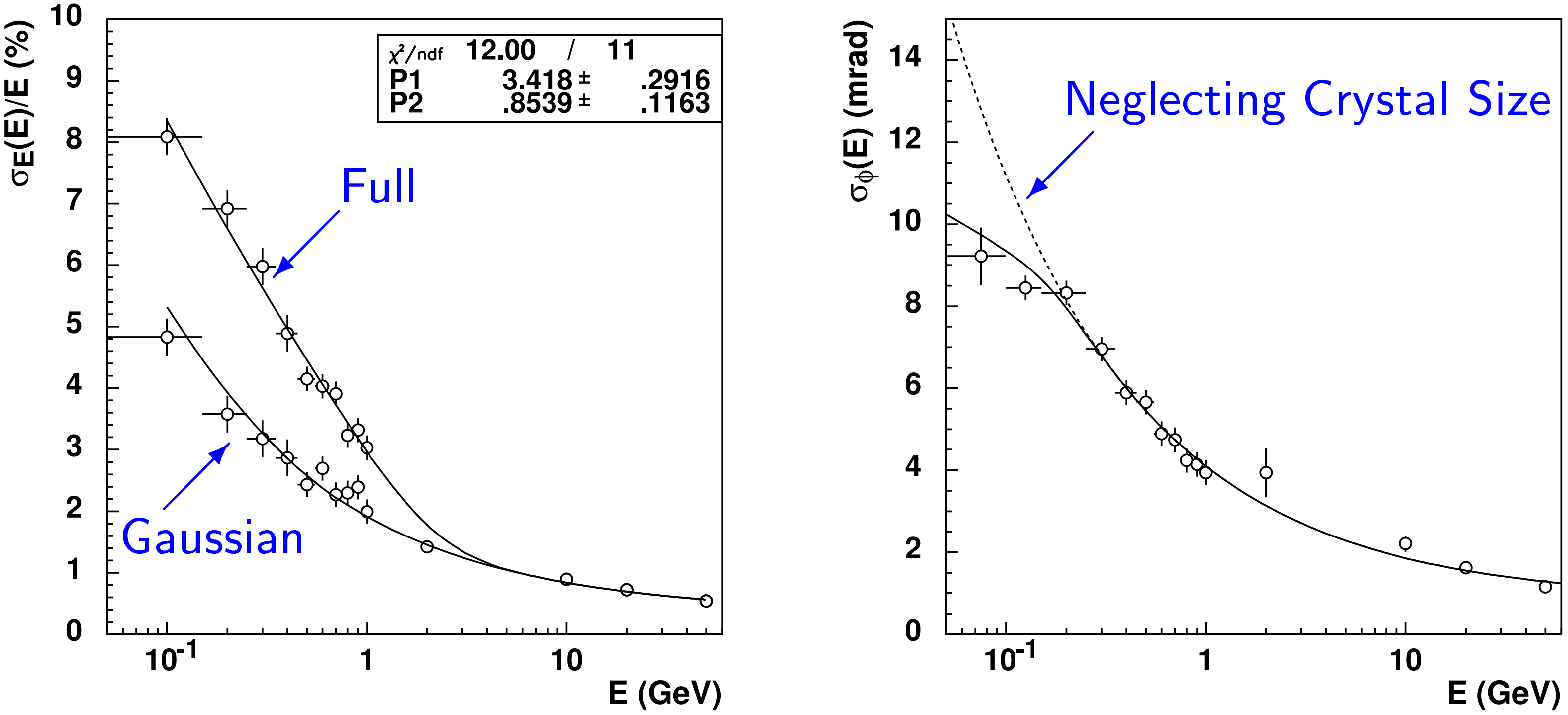
- Feed-Down Calculations

L3 Electromagnetic Calorimeter

- **10734 Individually Instrumented Bismuth Germanate Crystals**
- **21 Radiation Lengths of Material for Electromagnetic Showers**
- **Accurately Identifies and Measures Photons (50 MeV–200 GeV)**



BGO Electromagnetic Calorimeter Geometry



BGO Resolution Functions in Energy and ϕ-Angle

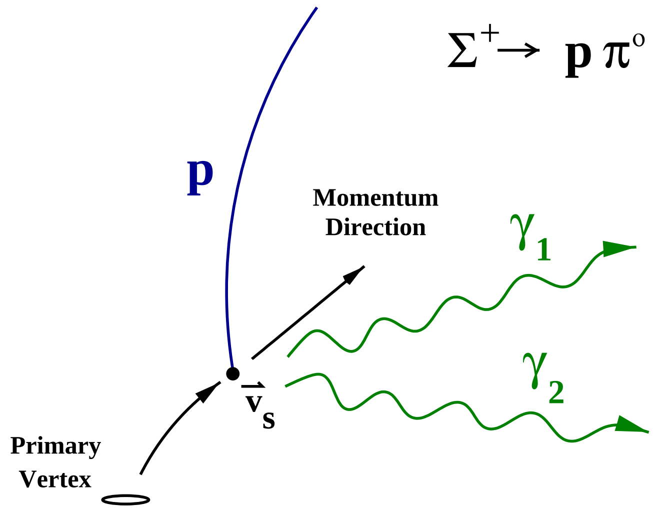
Modification for Electronic Noise and Calibration Errors

$$\sigma_E^{\mathrm{Full}}(E)^2 = \sigma_E^{\mathrm{Full}}(E)^2 + N \cdot \sigma^2_{\mathrm{intrinsic}} + (N \cdot \sigma_{\mathrm{correlated}})^2 + (\sigma_{\mathrm{calibration}} \cdot E)^2$$

with $\sigma_{\mathrm{intrinsic}} = 1$ MeV, $\sigma_{\mathrm{correlated}} = 1.6$ MeV and $\sigma_{\mathrm{calibration}} = 1.5\%$.
N is the number of crystals used to compute the shower energy.

Measurement of the Σ^+ Baryon

Decay Kinematics.
The $\mathbf{\Sigma}^+$ baryon decays
at the point $\vec{\mathbf{v}}_\mathbf{s}$.



Kinematic Constraints:

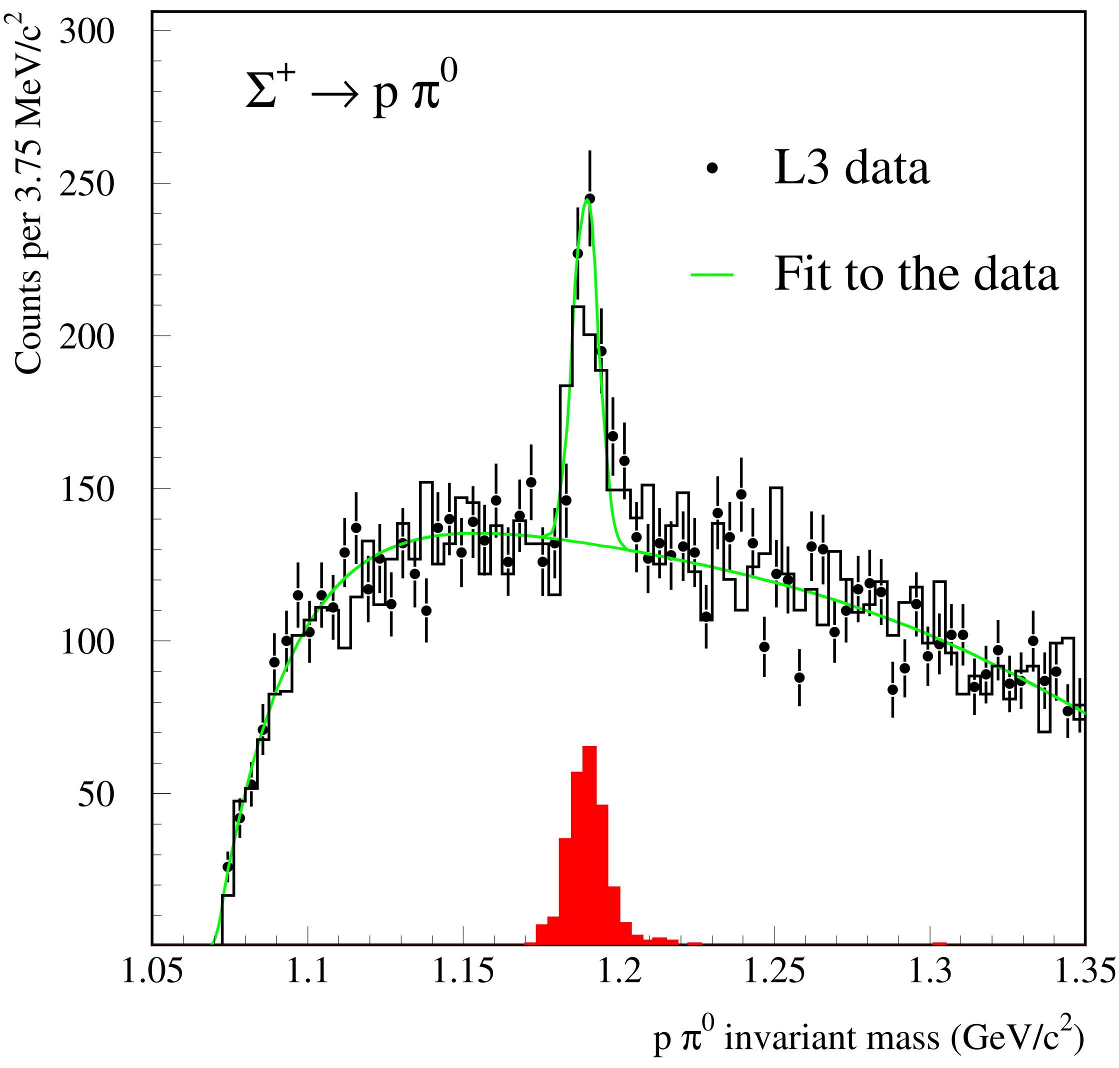
$$\vec{\mathbf{d}}'(\vec{\mathbf{v}}_\mathrm{s}) \times [\vec{\mathbf{p}}_\mathrm{p}(\vec{\mathbf{v}}_\mathrm{s}) + \vec{\mathbf{p}}_{\gamma_1}(\vec{\mathbf{v}}_\mathrm{s}) + \vec{\mathbf{p}}_{\gamma_2}(\vec{\mathbf{v}}_\mathrm{s})] = 0$$

$$\mathrm{m}_{\gamma_1\gamma_2}(\vec{\mathbf{v}}_\mathrm{s}) = \mathrm{m}_{\pi^0}$$

Detectors:

γ's	-	measured with BGO detector
p	-	Silicon strips and Drift Chamber
Primary Vertex	-	all charged particles from Z decay

Measurement of the Σ^+ Baryon



The Mass Distribution of Σ^+ Candidates

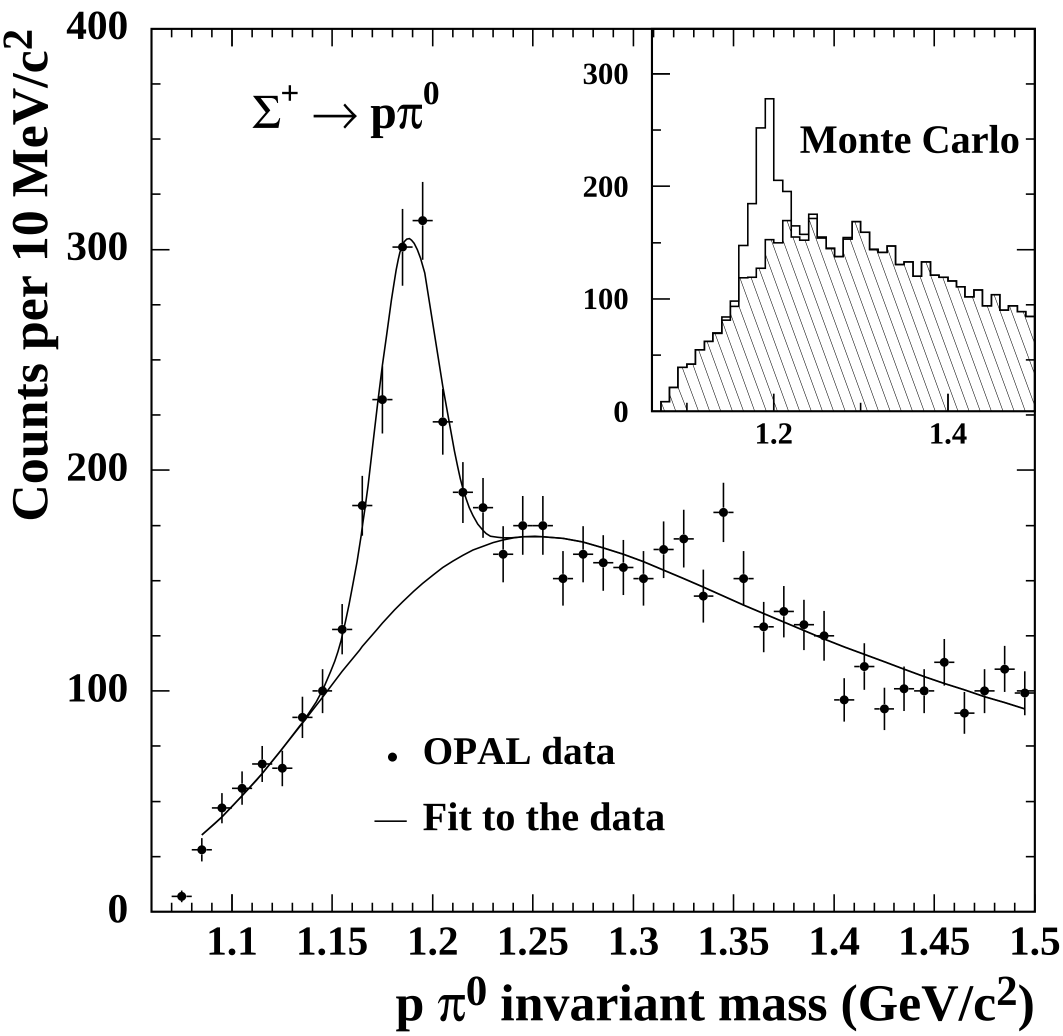
Data Statistics = 1.6 Million Hadronic Z^0 Decays

$$m_{\Sigma^+} = 1.1906 \pm 0.0007 \text{ GeV}$$

$$\sigma_{m_{\Sigma^+}} = 0.0045 \pm 0.0007 \text{ GeV}$$

$$\left\langle N_{\Sigma^+ + \overline{\Sigma}^+} \right\rangle = 0.092 \pm 0.011_{stat} \pm 0.011_{syst}$$

Comparison with Other LEP Experiments



The OPAL Σ^+ Measurement

Data Statistics = 2.8 Million Hadronic Z^0 Decays

$$m_{\Sigma^+} = 1.1874 \pm 0.0012 \text{ GeV}$$

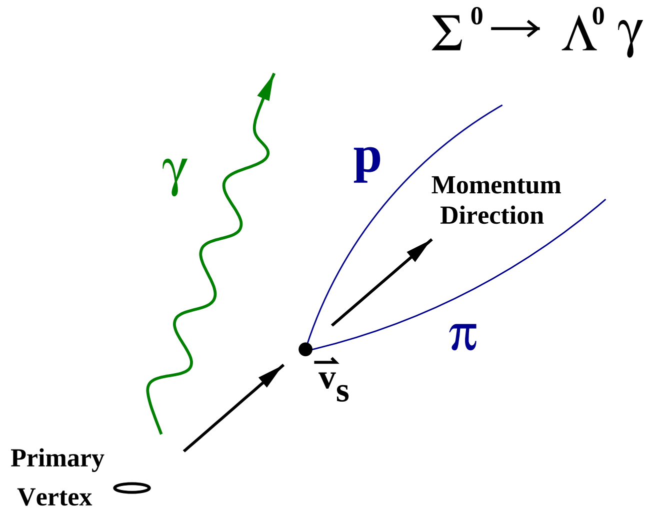
$$\sigma_{m_{\Sigma^+}} = 0.0150 \pm 0.0014 \text{ GeV}$$

$$\left\langle N_{\Sigma^+ + \overline{\Sigma}^+} \right\rangle = 0.099 \pm 0.008_{stat} \pm 0.013_{syst}$$

Measurement of the Σ^0 Baryon

Decay Kinematics.

The $\mathbf{\Sigma^0}$ baryon decays
at the primary vertex.
The $\mathbf{\Lambda^0}$ decays
at the point $\vec{\mathbf{v}}_\mathbf{s}$.



Kinematic Constraints:

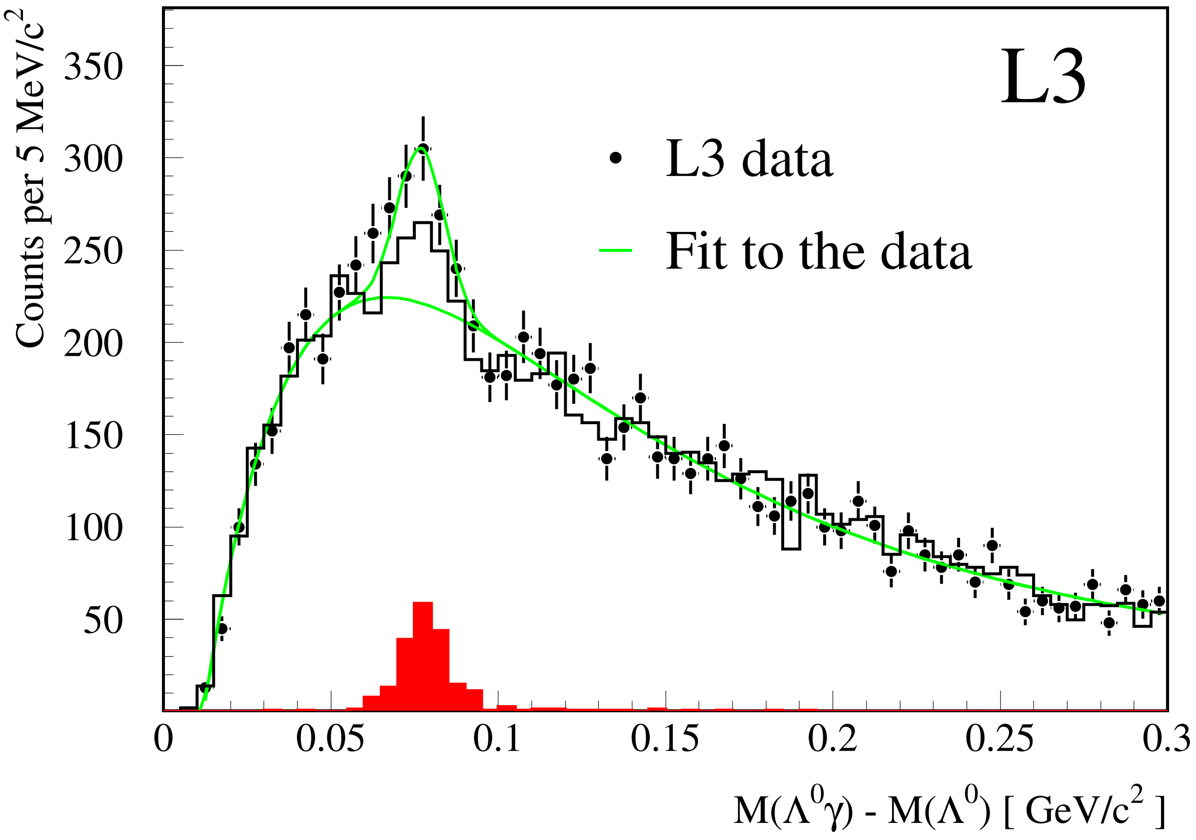
$$\vec{\mathbf{d}}(\vec{\mathbf{v}}_\mathrm{s}) \times [\vec{\mathbf{p}}_\mathrm{p}(\vec{\mathbf{v}}_\mathrm{s}) + \vec{\mathbf{p}}_\pi(\vec{\mathbf{v}}_\mathrm{s})] = 0$$

$$\mathrm{m}_{\mathrm{p}\pi}(\vec{\mathbf{v}}_\mathrm{s}) = \mathrm{m}_{\Lambda^0}$$

Detectors:

γ	-	measured with BGO detector
p,π	-	Silicon strips and Drift Chamber
Primary Vertex	-	all charged particles from Z decay

Measurement of the Σ^0 Baryon



Mass Difference Distribution of Σ^0 Candidates

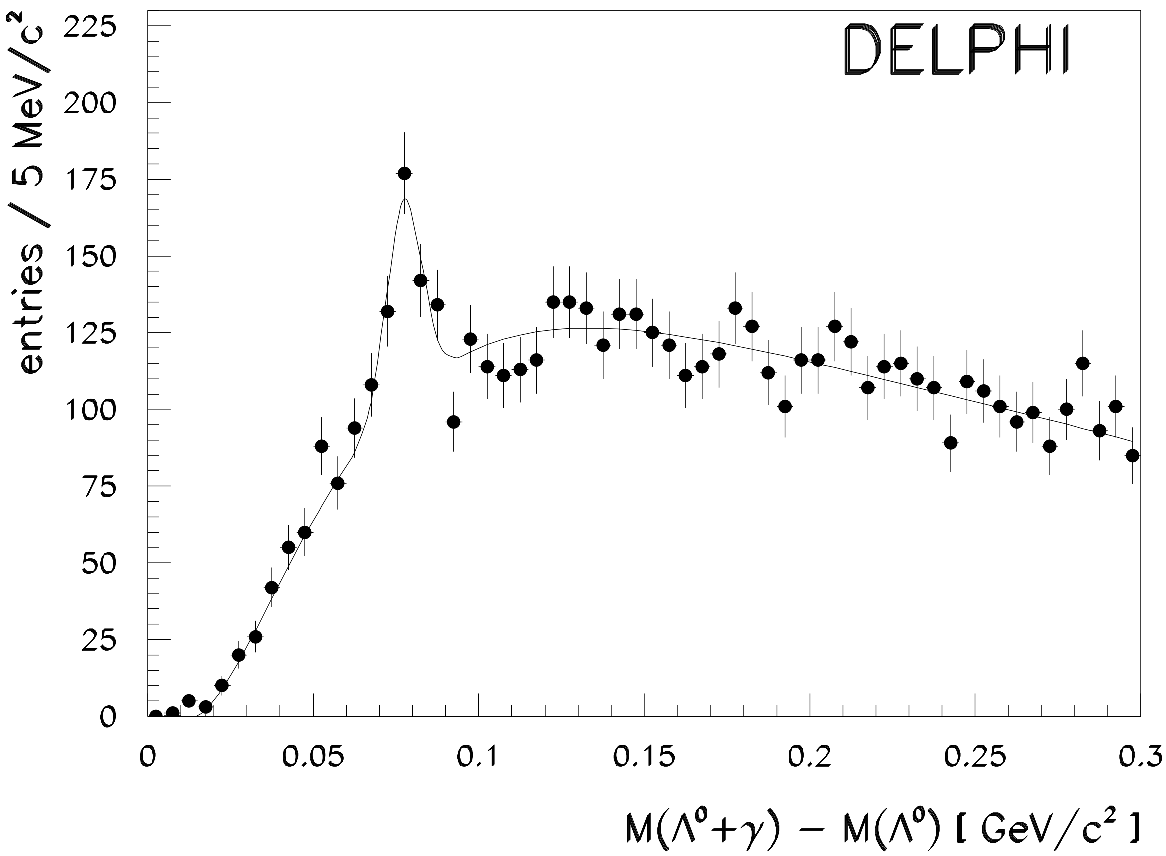
Data Statistics = 1.6 Million Hadronic Z^0 Decays

$$m_{\Sigma^0} - m_{\Lambda^0} = 0.0772 \pm 0.0012 \text{ GeV}$$

$$\sigma_{m_{\Sigma^0} - m_{\Lambda^0}} = 0.0046 \pm 0.0016 \text{ GeV}$$

$$\left\langle N_{\Sigma^0 + \overline{\Sigma}^0} \right\rangle = 0.112 \pm 0.016_{stat} \pm 0.025_{syst}$$

Comparison with Other LEP Experiments



The DELPHI Σ^0 Measurement

Data Statistics = 3.1 Million Hadronic Z^0 Decays

$$m_{\Sigma^0} - m_{\Lambda^0} = 0.078 \pm 0.001 \text{ GeV}$$

$$\sigma_{m_{\Sigma^0} - m_{\Lambda^0}} = 0.0053 \pm 0.0011 \text{ GeV}$$

$$\left\langle N_{\Sigma^0 + \overline{\Sigma}^0} \right\rangle = 0.070 \pm 0.010_{stat} \pm 0.010_{syst}$$

Kinematic Extrapolation

Kinematic Restrictions on the Σ^+:

$\gamma_{\pi^0} > 2.0$, $\cos\theta^* < 0.45$ and $|\vec{\mathbf{p}}_{\Sigma^+}| > 1.0$ GeV
$\mathrm{r_{min}} > 5$ mm $\quad (\mathrm{r_{max}} < 70$ mm)

Kinematic Restrictions on the Σ^0:

55 MeV $< \mathrm{E}_\gamma < 1$ GeV
$\cos\theta^* < 0.2$
Λ^0 Kinematic Restrictions:

$|\vec{\mathbf{p}}_{\mathrm{transverse}}| > 0.2$ GeV (for the proton and pion)
$\mathrm{r_{min}}$ is limited by the $\mathcal{P}_{\mathrm{pvtx}}$ requirement
($\mathrm{r_{max}} < 70$ mm)

Σ^+ *Polarization*

- **Quarks coming from Z^0 decay are highly polarized,**

$$\mathcal{P}_q = -\mathcal{P}_{\bar{q}} = \begin{cases} -67\% & u, c \\ -94\% & d, s, b \end{cases} .$$

Polarization can occur in light baryons produced in heavy baryon decays.

- **Polarization Dependence on Decay Angles**

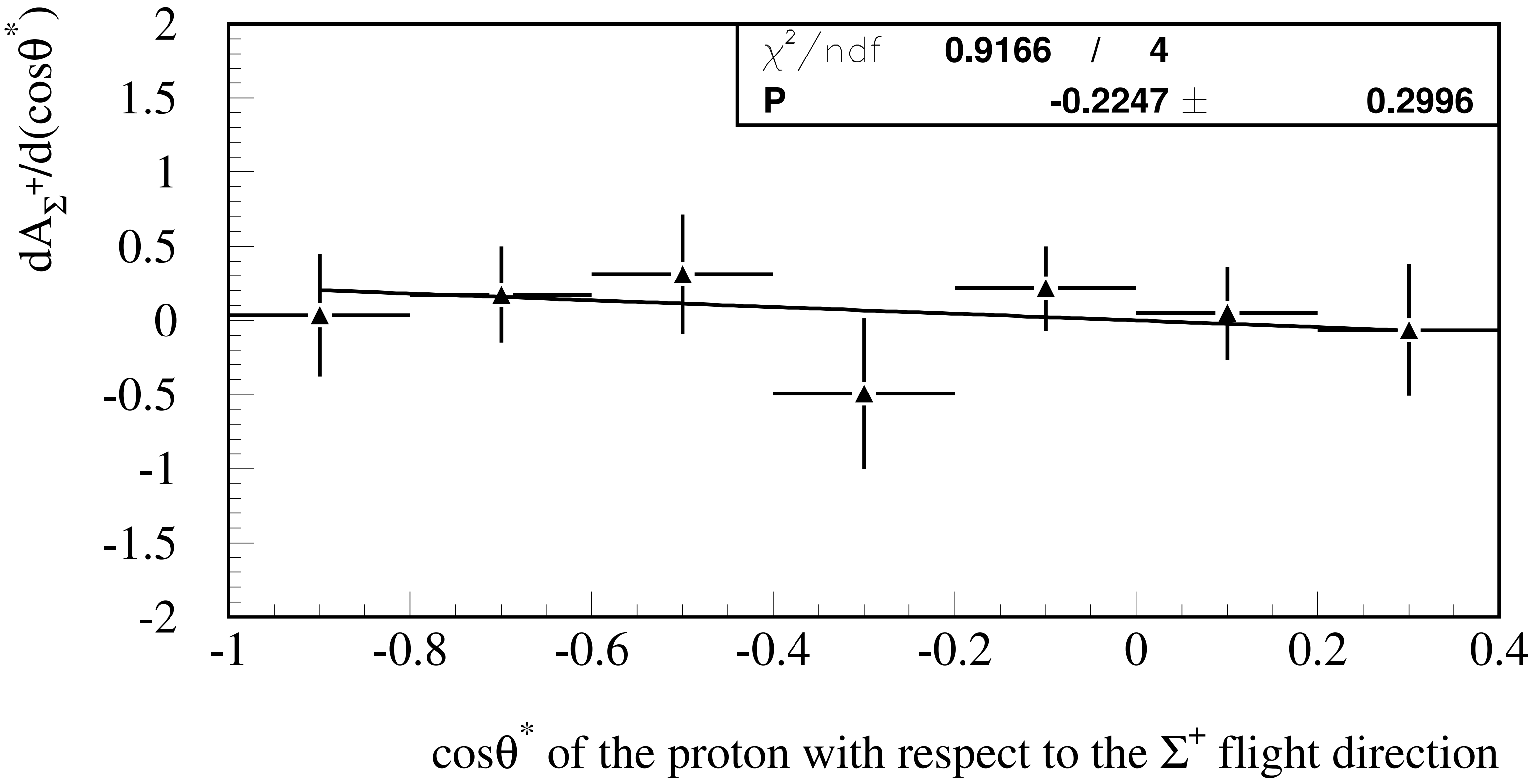
$$\frac{d\sigma_{\Sigma^+}}{d(\cos\theta_\pi)} \propto 1 + \mathcal{P}_{\Sigma^+} \cdot \alpha_{\Sigma^+} \cdot \cos\theta_\pi \qquad (\alpha_{\Sigma^+} = -0.98^{+0.017}_{-0.015})$$

where $\mathcal{P}_{\Sigma^+}$ is the magnitude of the polarization.

- **Baryon-Antibaryon Polarization Asymmetry**

$$\frac{\mathrm{d}\,\mathrm{A}_{\Sigma^+}}{\mathrm{d}\,(\cos\theta^*)} = \frac{\mathrm{d}}{\mathrm{d}\,(\cos\theta^*)} \left(\frac{n_{\Sigma^+} - n_{\overline{\Sigma}^+}}{n_{\Sigma^+} + n_{\overline{\Sigma}^+}} \right) .$$

Σ^+ *Polarization*



Longitudinal Polarization Measurement in Σ^+ Decays

$$\boxed{\mathcal{P}_{\Sigma^+} = (-23 \pm 31)\%}$$

Hadronization Phenomenology

- **Basic Features of Hadron Production Rates (Y.J. Pei, *Z.Phys.C* 72, 1996)**

$$\langle N \rangle = C_{\sqrt{s}} \cdot \frac{2J+1}{C_B} \cdot (\gamma_s)^{N_s} \cdot \mathrm{e}^{-\frac{E_{bind}}{T}}$$

$C_{\sqrt{s}}$ Depends on the Center-of-Mass Energy
C_B is a Suppression Factor for Baryons
T and γ_s are Universal
J, N_s, E_{bind} Depend on Properties of the Hadron
  J is the total intrinsic angular momentum
  N_s is the number of strange quarks constituents
  $E_{bind} = M_h - \sum_i m_{q_i}$ is called the binding energy

- **Also, F. Becattini, *Z.Phys.C* 69, 1996**

Hadronization Phenomenology

- **Basic Features of Hadron Production Rates**
  (Y.J. Pei, *Z.Phys.C* 72, 1996)

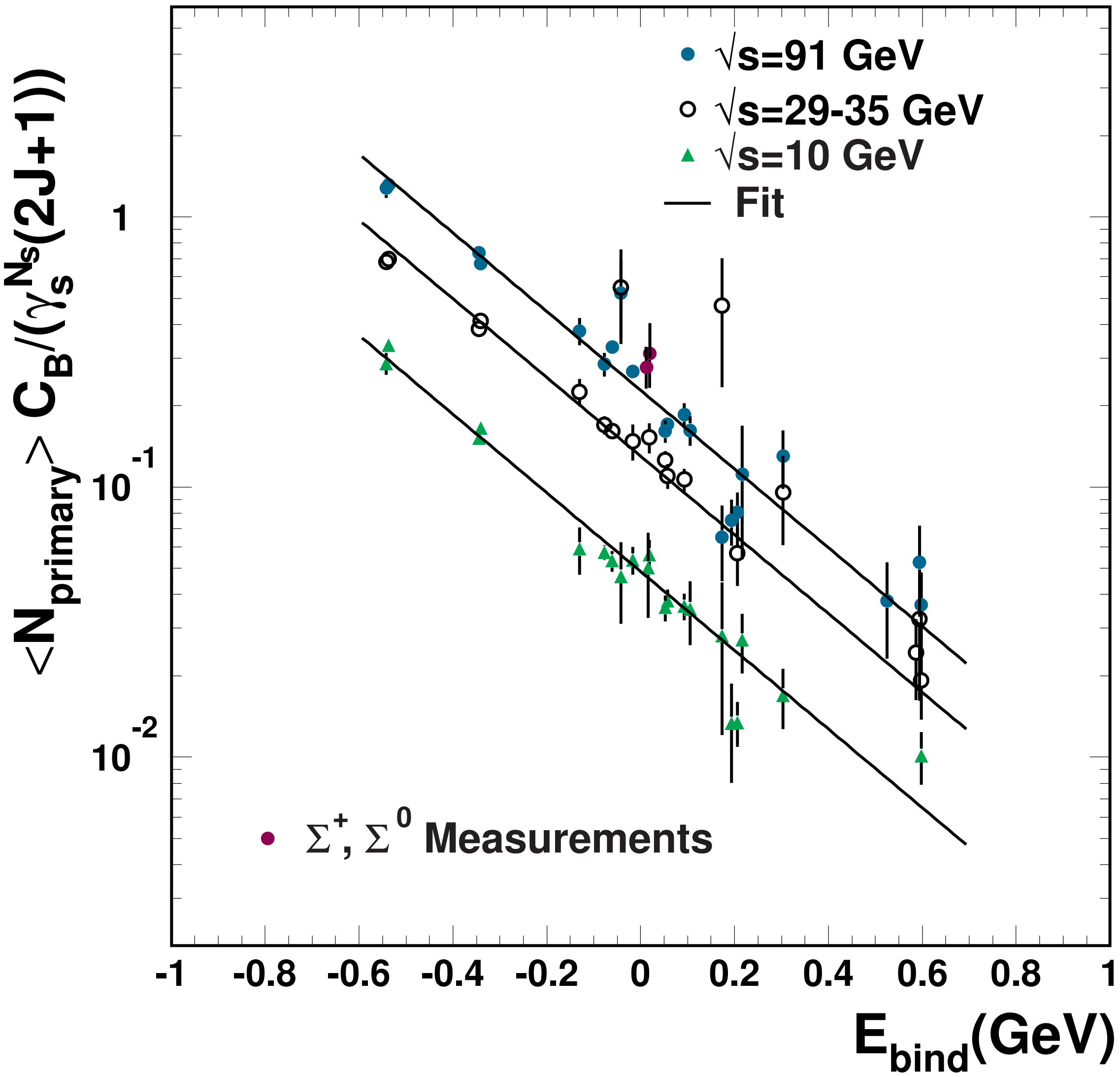
Parameters	$\sqrt{s} = 91$ GeV	Simultaneous Fit
γ_s	0.29 ± 0.03	0.29 ± 0.02
Δm (GeV)	0.150 ± 0.029	0.161 ± 0.024
T (GeV)	0.289 ± 0.020	0.298 ± 0.015
$C_{\sqrt{s}}$	0.209 ± 0.041	$C_{91} = 0.218 \pm 0.034$ *
C_B	10.0 ± 1.0	11.0 ± 0.9
χ^2/dof	$56.2/19$	$155.8/57$

* $C_{30} = 0.124 \pm 0.020, \quad C_{10} = 0.049 \pm 0.008$

- **Also, F. Becattini, *Z.Phys.C* 69, 1996**
  Parameters T, V and γ_s

Summary of Production Rate Measurements

(Y.J. Pei, *Z.Phys.C* 72, 1996)



Production Rate Measurements

$$\frac{\left\langle N_{\Sigma^0+\overline{\Sigma}^0}\right\rangle}{\left\langle N_{\Sigma^++\overline{\Sigma}^+}\right\rangle} = 1.22 \pm 0.23_{stat} \pm 0.31_{syst}$$

Summary

- **Σ^+ and Σ^0 Production Measured at LEP with the L3 Detector**

The average number of Σ^+ and Σ^0 per hadronic Z^0 decay was found to be

$$\left\langle N_{\Sigma^+ + \overline{\Sigma}^+} \right\rangle = 0.092 \pm 0.011_{stat} \pm 0.011_{syst}$$

and

$$\left\langle N_{\Sigma^0 + \overline{\Sigma}^0} \right\rangle = 0.112 \pm 0.016_{stat} \pm 0.025_{syst} \ ,$$

respectively.

- **These measurements are in agreement with those made by other LEP experiments.**

The basic features of hadron production rates in e^+e^- annihilation are successfully described by a small number of parameters.