Baryon Production and Correlations from LEP to FCC-ee

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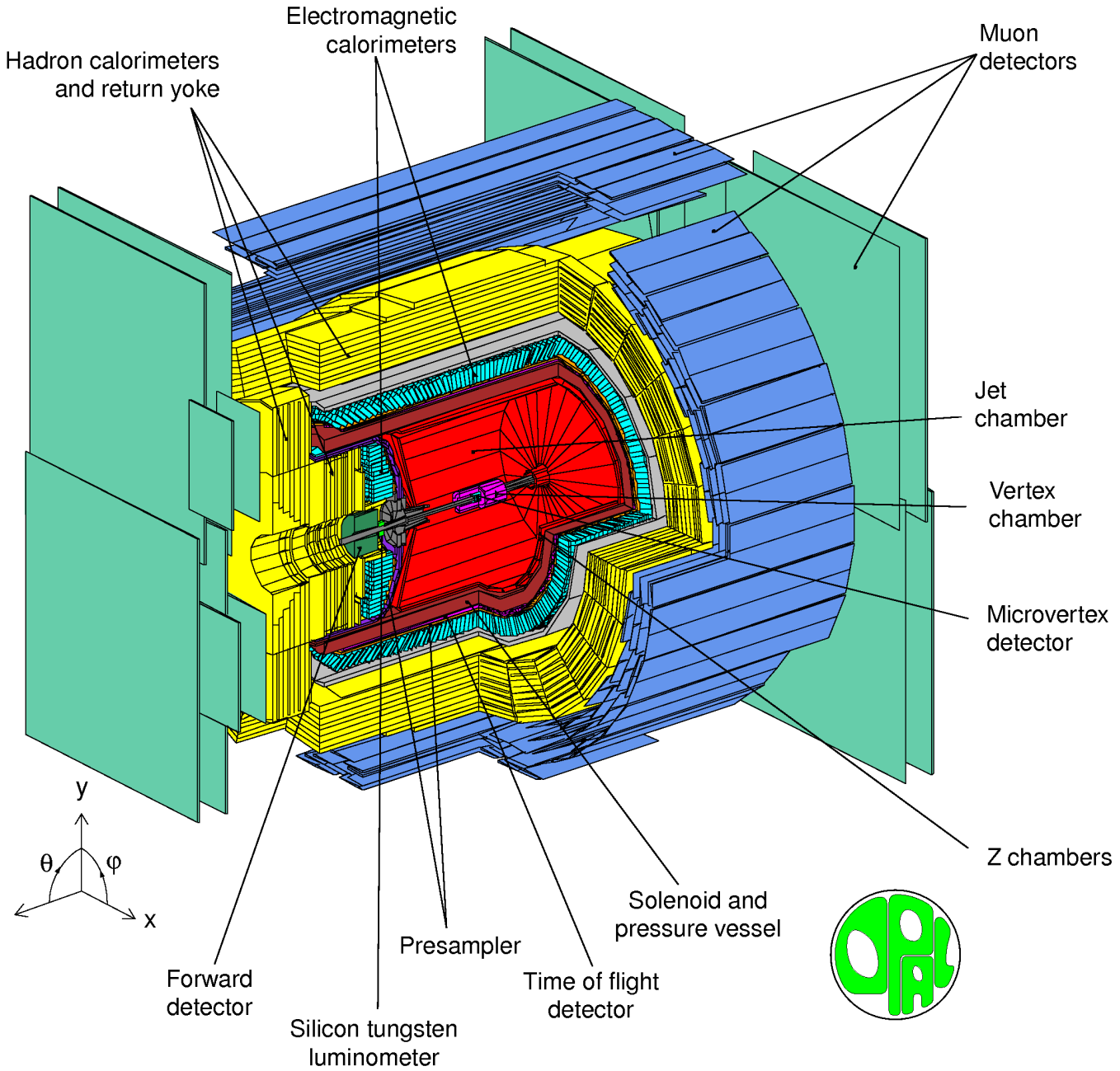
Introduction

- Concentrate on OPAL papers
  - Limited time … suggestions of conveners
  - I know both analyses at least partially
  - Try extrapolation to new e^+e^- collider
- Parton fragmentation with $\Lambda\bar{\Lambda}$ correlations
  - Based on rapidity differences
- Σ^--antihyperon correlations
  - Particle production only, less model dependence

The OPAL Experiment



1989 to 2000

$\sqrt{s} = \sim m_Z$ to 209 GeV

ca. $4 \cdot 10^6$ hadronic Z decays

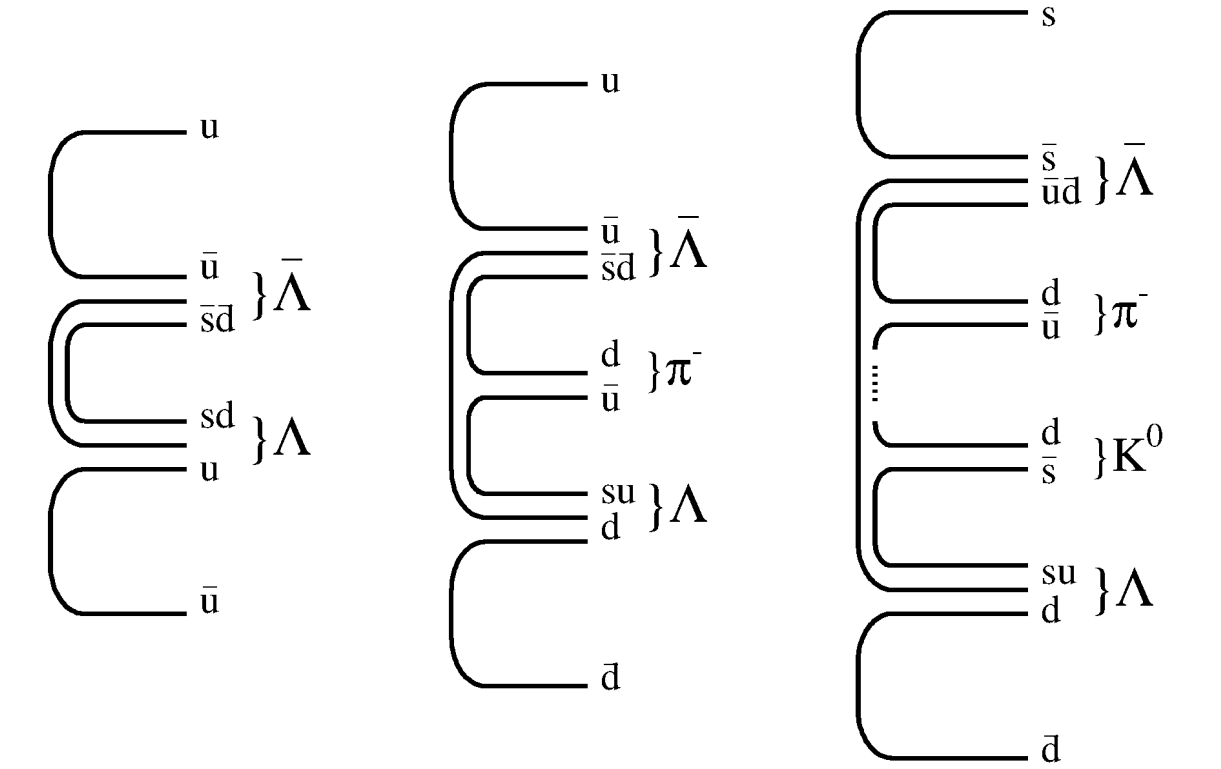
Solenoid 0.435 T

Si-vertex, wire Vertex-, Jet- and Z-chambers

Tracks down to $p_t = 150$ MeV

$\Lambda\bar{\Lambda}$ Correlations in OPAL

[Eur. Phys. J. C13 (2000) 185-195]



(a) Diquark ($B\bar{B}$) JETSET/MOPS

(b) Popcorn ($BM\bar{B}$) JETSET

(c) Popcorn ($B(n*M)\bar{B}$) MOPS

Expect influence on $\Lambda\bar{\Lambda}$ production kinematics

Study baryon quantum number compensation in jet fragmentation using $\Lambda\bar{\Lambda}$ pairs

Baryons in JETSET or PYTHIA from

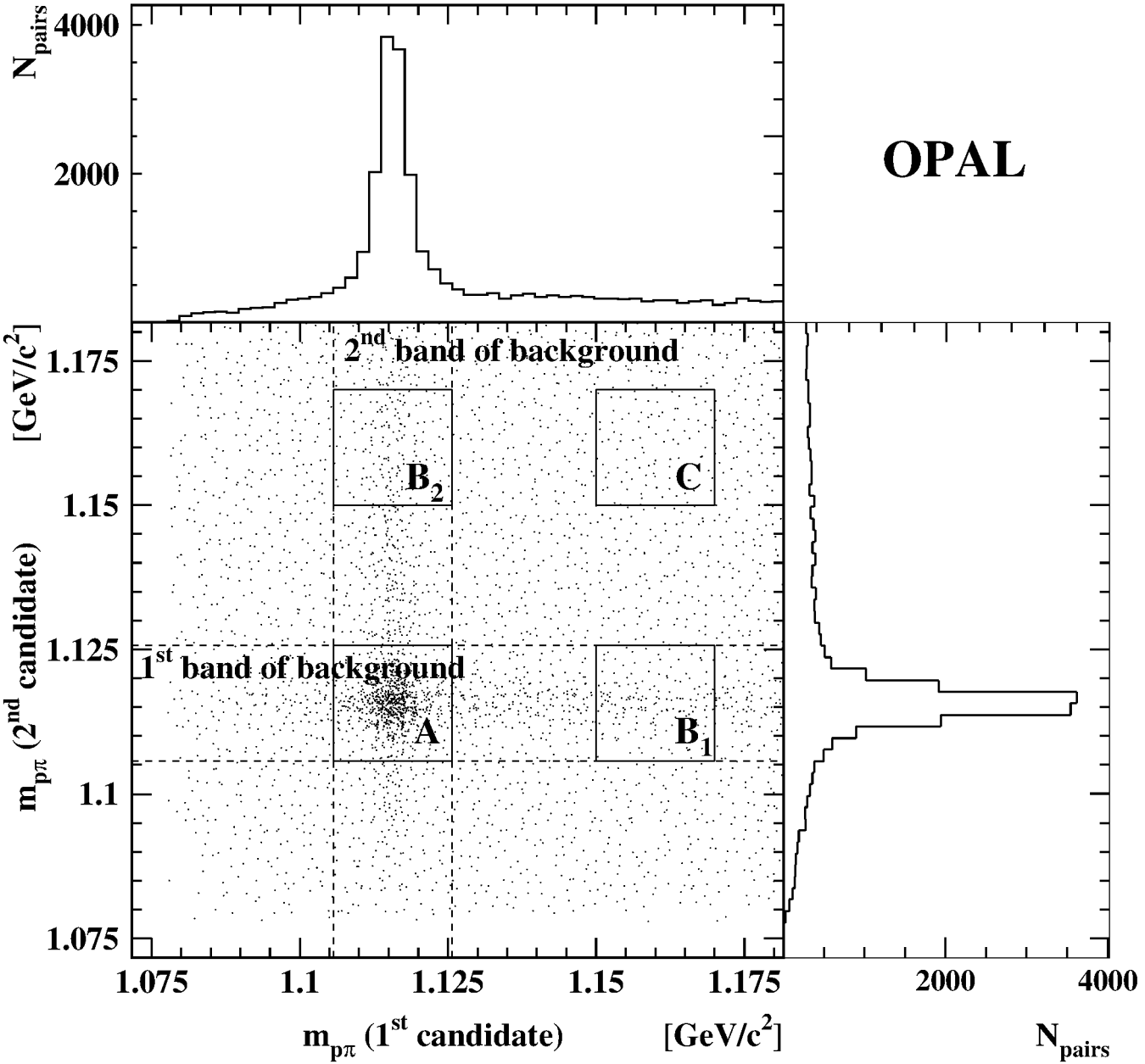
- Diquarks
- Popcorn
- MOPS

In HERWIG from cluster fragmentation

Observables

- Λ ($\underline{\Lambda}$) reconstruction
  - In channel $\Lambda \rightarrow \pi^{-}p$ as displaced 2-track opp. sign secondary vertex (V0)
  - Use dE/dx to clean π and p IDs
- Rapidity difference $|\Delta y|$
  - Rapidity $y = 1/2\ln((E+p_{||})/(E-p_{||}))$, E is particle energy, $p_{||}$ is momentum $||$ to thrust axis
  - Difference $|\Delta y| = |y_{\Lambda} - y_{\underline{\Lambda}}|$
- Λ decay angle $\cos(\theta^{*})$
  - Angle between thrust axis and Λ in $\Lambda\underline{\Lambda}$ restframe

Exp. corrections



$N_S = N_A - (N_{B1}+N_{B2}-N_C)$

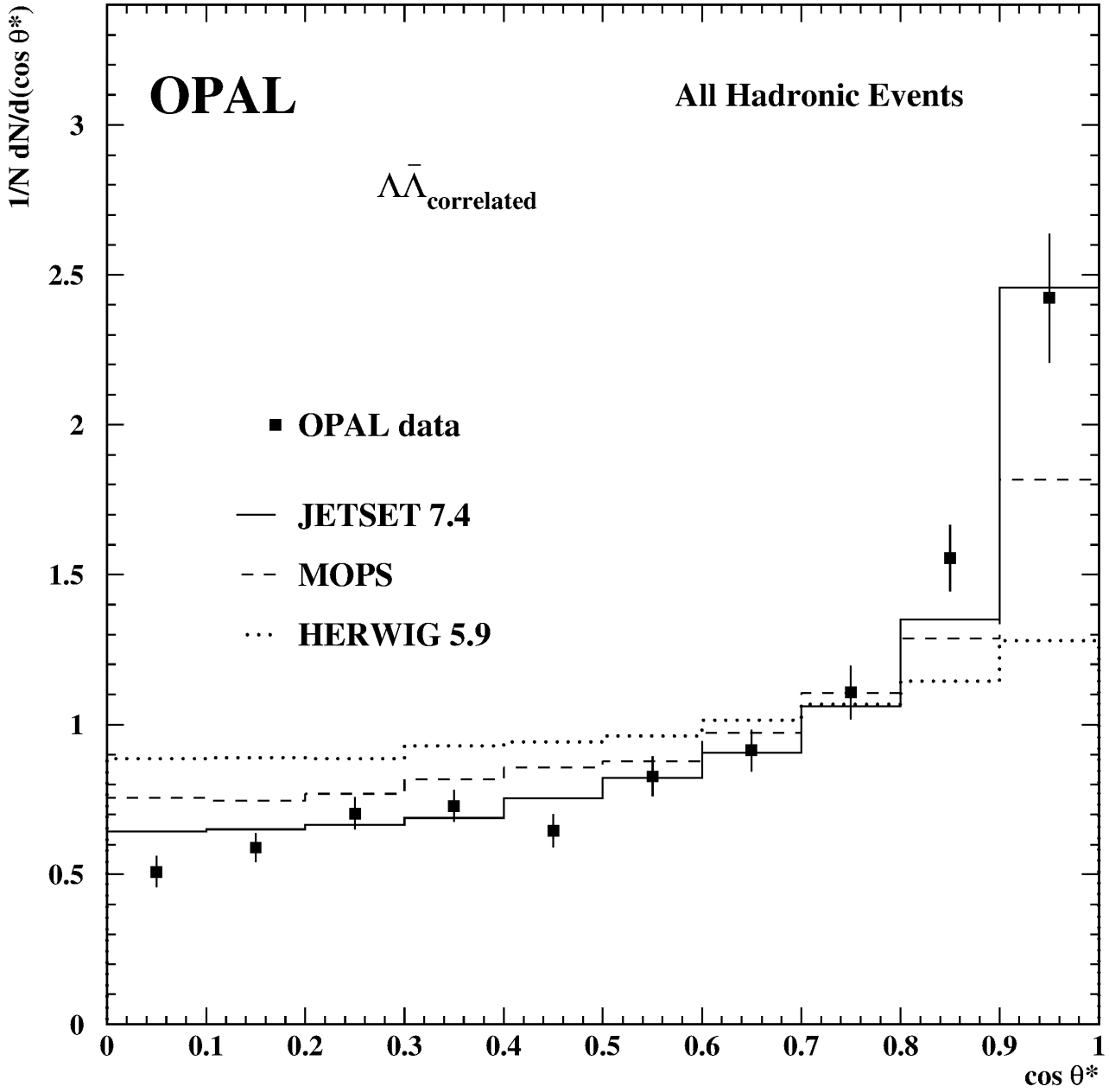
Correct for acceptance and efficiency in bins of $|\Delta y|$ and $\cos(\theta^*)$ ($\varepsilon \simeq 2\%$)

$N_{\Lambda\underline{\Lambda}}^{cor.} = N_{\Lambda\underline{\Lambda}} - (N_{\Lambda\Lambda}+N_{\underline{\Lambda}\underline{\Lambda}})$

$N_{\Lambda\underline{\Lambda}} = 9479$

$N_{\Lambda\Lambda}+N_{\underline{\Lambda}\underline{\Lambda}} = 4217$

Λ decay angle cos(θ*)



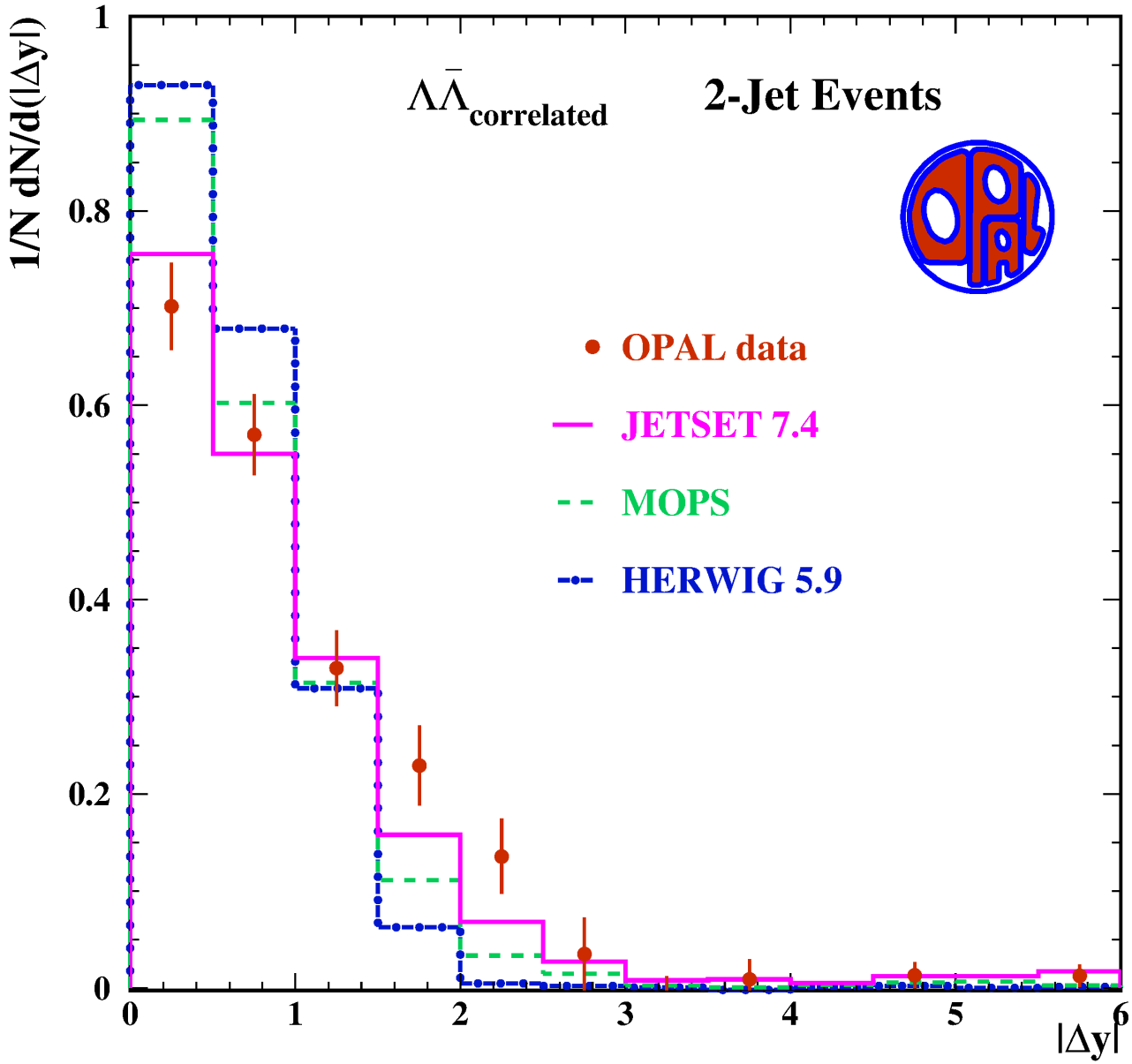
After correction for correlated $\Lambda\underline{\Lambda}$

HERWIG 5.9 and MOPS fail

JETSET ok

Still true today (Pythia8, H7, Sherpa)?

$\Lambda\bar{\Lambda}$ rapidity difference $|\Delta y|$



After correction for correlated $\Lambda\bar{\Lambda}$

Events with 2 Durham jets with $y_{cut} = 0.005$

HERWIG 5.9 and MOPS fail

JETSET ~ok

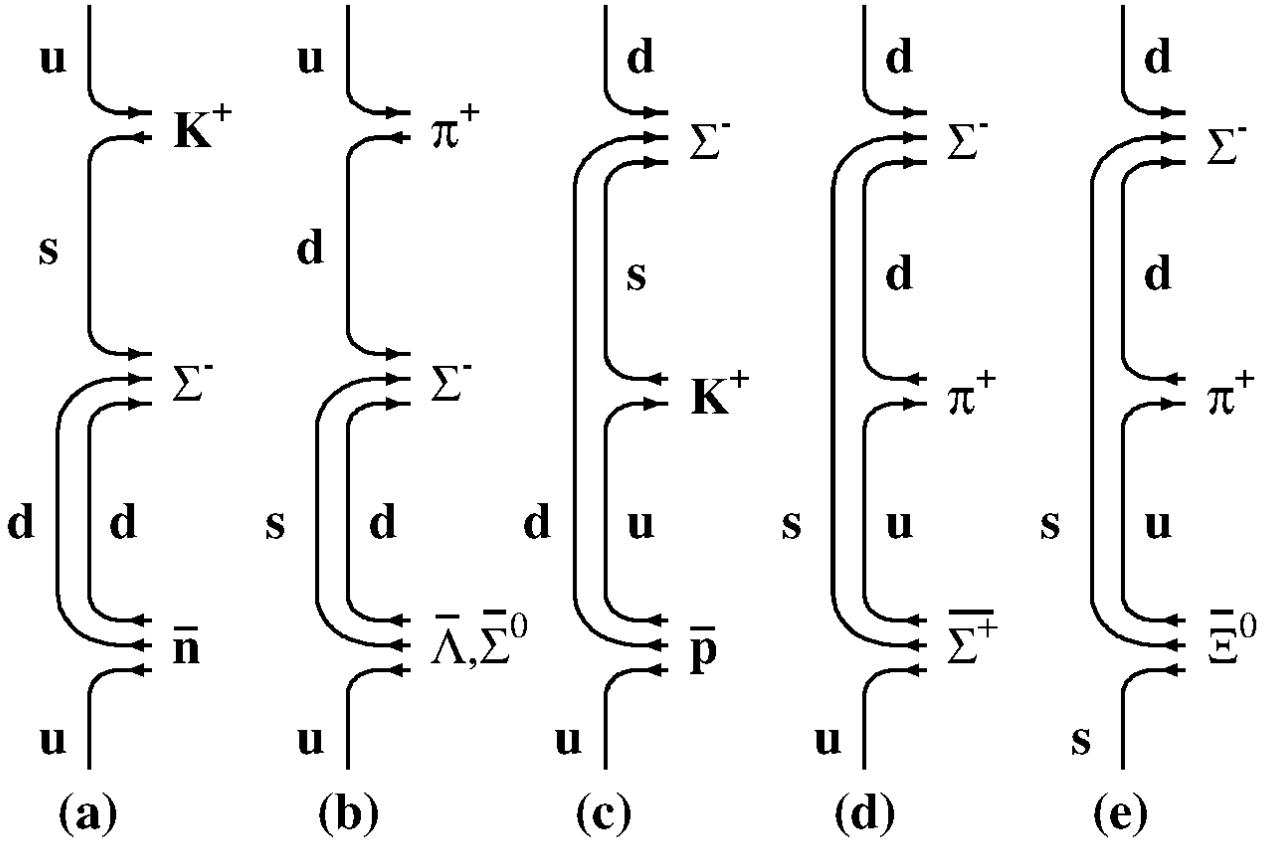
Still true today (pythia8, H7, Sherpa)?

Conclusions $\Lambda\bar{\Lambda}$ correlations

- Λ decay angle $\cos(\theta^*)$
  - Sensitive to fragmentation kinematics
  - String model preferred, others fail
- $\Lambda\bar{\Lambda}$ rapidity difference $|\Delta y|$
  - Sensitive to correlation strength
  - Enhanced by requiring 2-jet topology
  - String model preferred, others fail
- $\Lambda\bar{\Lambda}$ pairs dominantly in same jets
  - Local correlations (LPHD)

Σ^--antihyperon correlations

[Eur. Phys. J. C 64 (2009) 609-625]



Study Σ^- since baryon and strangeness conserved, compensation by anti-nucleon, kaon or anti-hyperon

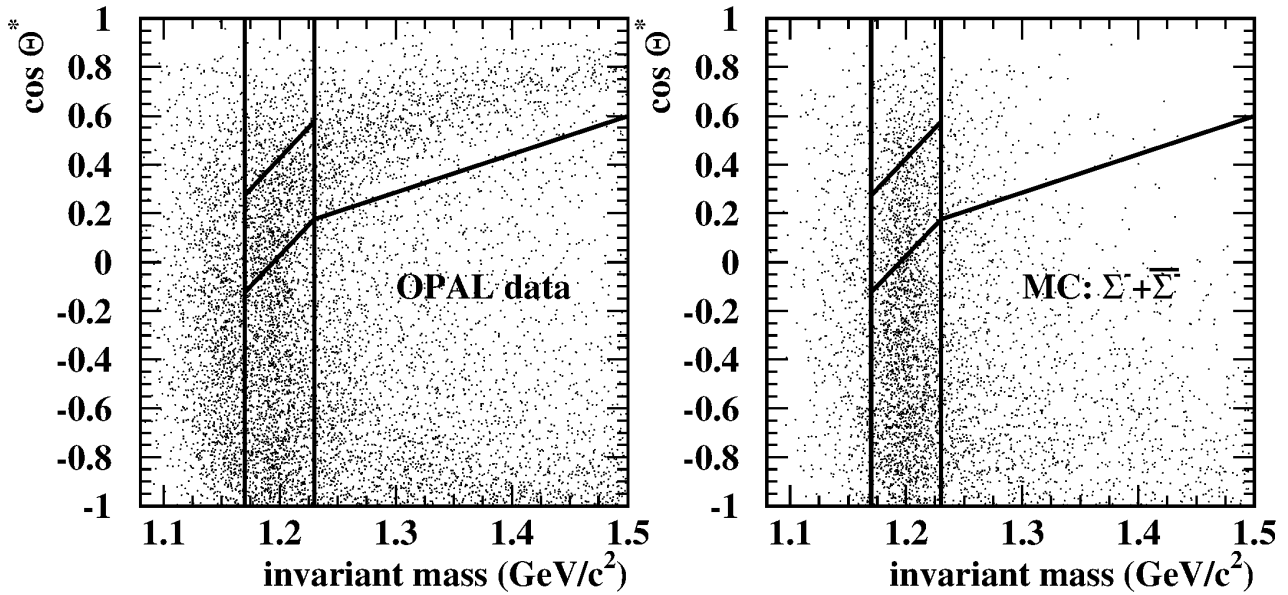
Observable is $F_{\underline{H}} = F_{\Sigma^-,\underline{\Sigma}^-} + F_{\Sigma^-,\underline{\Lambda}} + F_{\Sigma^-,\underline{\Xi}^-}$ i.e. Σ^- together with $\underline{\Sigma}^-$, $\underline{\Lambda}$, or $\underline{\Xi}^-$

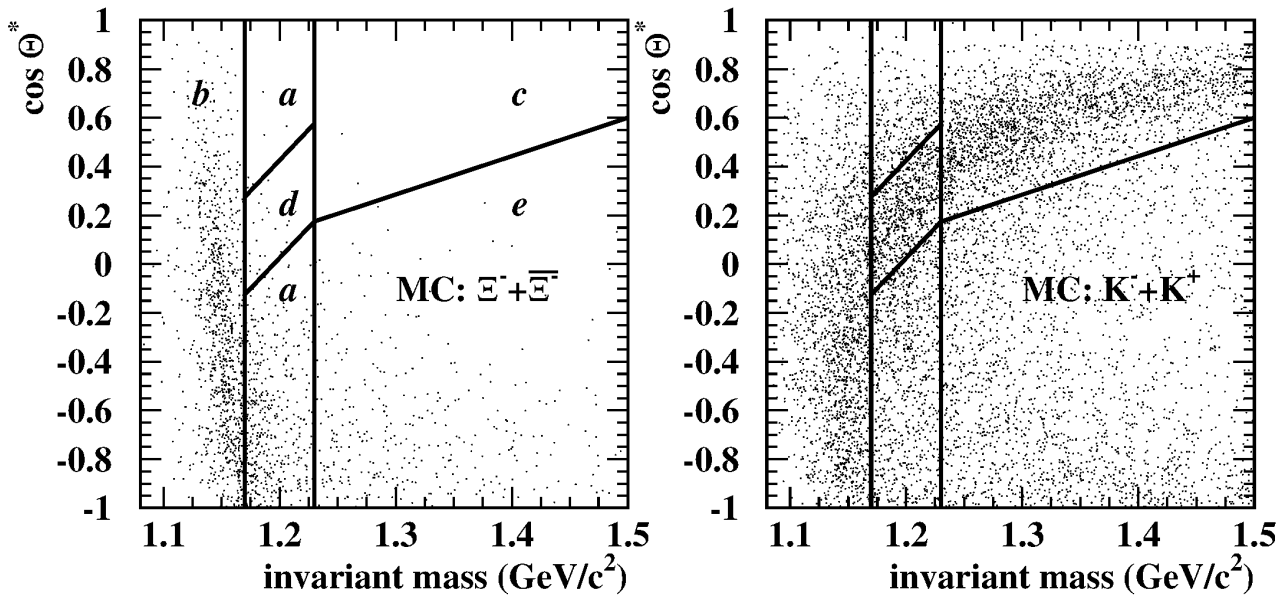
All $F_{\Sigma^-,x}$ possible in diquark and popcorn models

Method

- Σ^- reconstruction using "kinky" tracks
  - $\Sigma^- \rightarrow n\pi^-$, n not reconstructed
- Displaced pion tracks
  - Impact parameter large
  - Contributions from $\underline{\Lambda}$ and $\underline{\Xi}^-$
- $\underline{\Lambda}$ using V0 topology
  - $\underline{\Lambda} \rightarrow \underline{p}\pi^+$, impact parameter cut to suppress direct production

Σ^- Background subtraction





Σ^- candidates from

$\Sigma^- \rightarrow n\pi^-$

$\underline{\Sigma}^{\pm} \rightarrow \underline{n}\pi^-$

$\Xi^- \rightarrow \Lambda\pi^-$

K^- decays

secondaries

5 bins in m_{Σ^-} - $\cos\theta^*$ plane

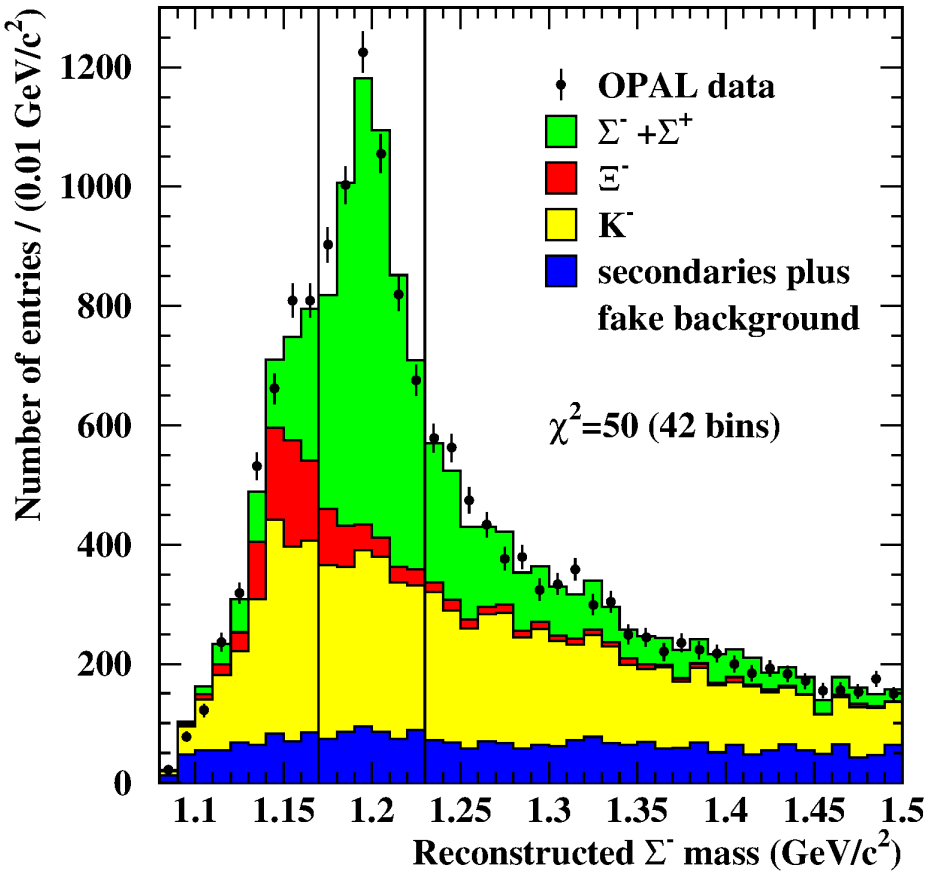
$\cos\theta^*$ is decay angle of π in Σ^- cm

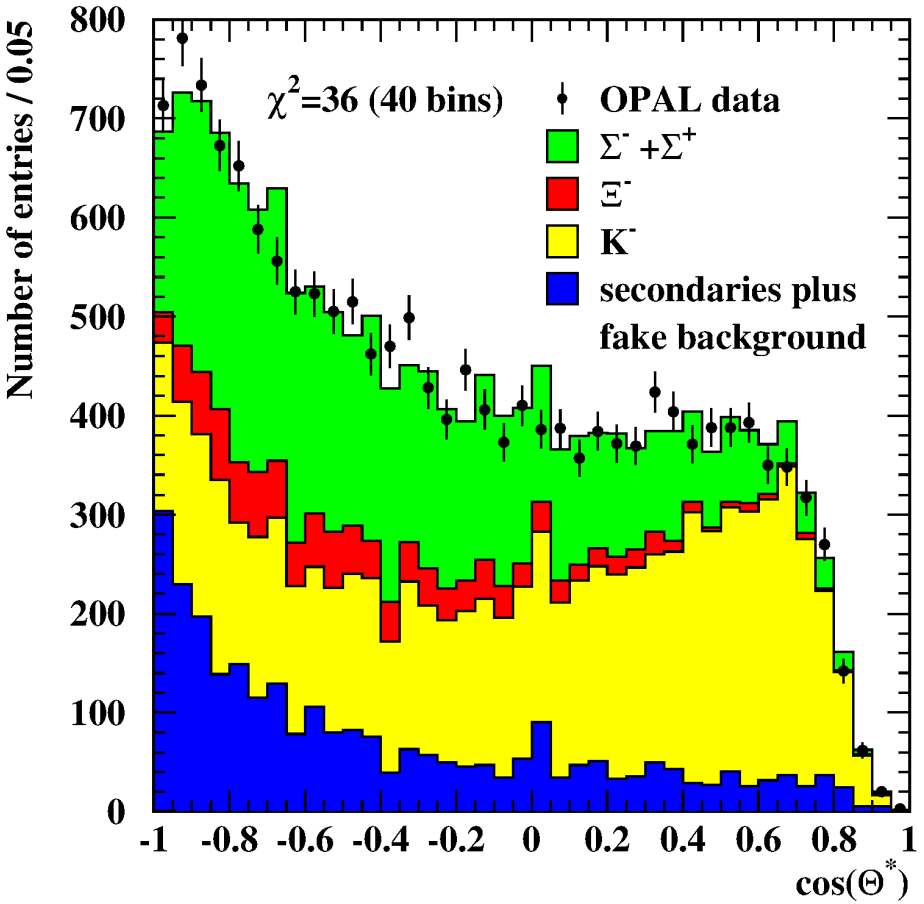
16790 kink candidates in data, 18754 in MC

Correlation partners

- Displaced pion track selection
  - Impact parameter w.r.t. beam > 2mm
  - dE/dx consistent, same hemisphere
  - 9965 $\Sigma^-\pi^-$ and 11951 $\Sigma^-\pi^+$ (10769 and 13818 in MC)
- "--" vs "-+" difference larger in MC w.r.t. data
  - Too many correlated antihyperons in MC
- Λ selection
  - Remove Λ pointing to kink ($\Xi^- \rightarrow \Lambda\pi^-$)
  - Same hemisphere

Unfolding of sources

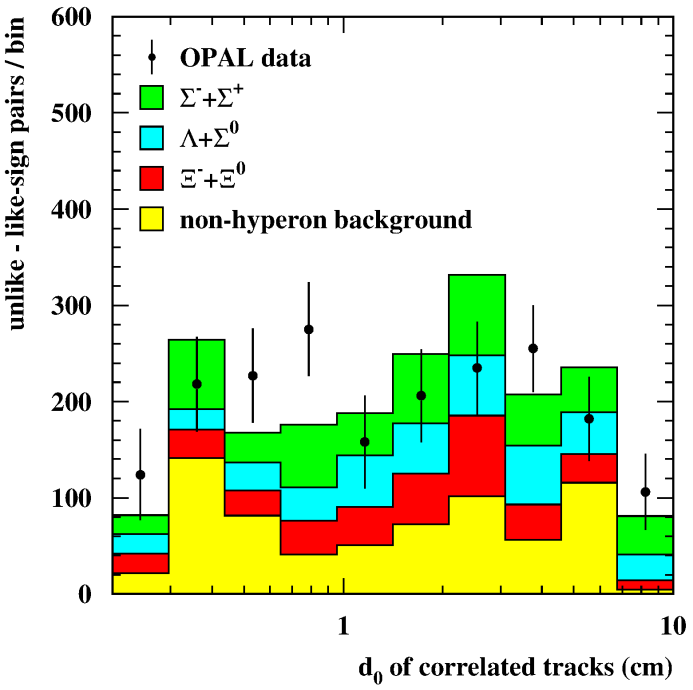


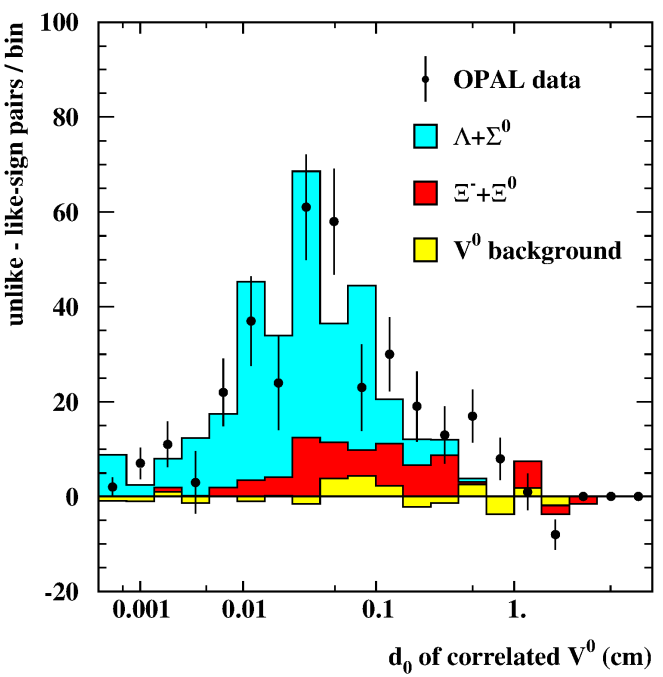


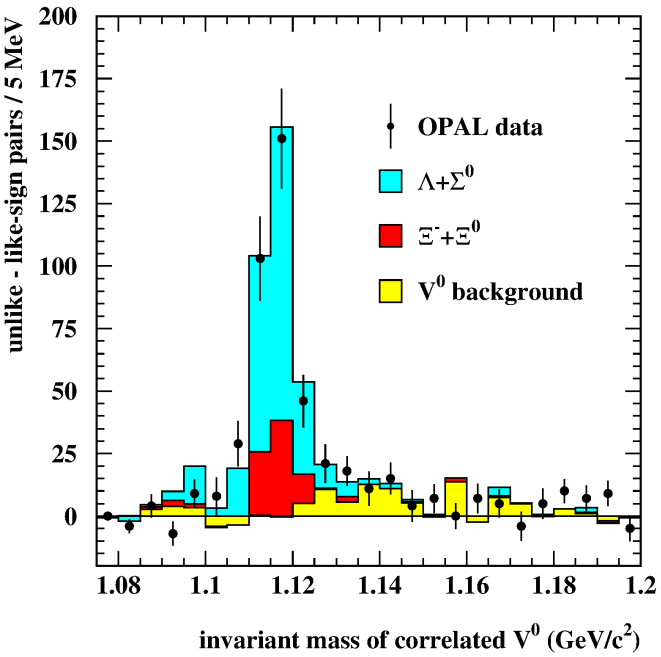
Fit number of events in 5 bins with MC shapes

Extraction of correlations

All plots unlike – likesign pairs







$F_{\underline{H}} = 0.48 \pm 0.10$

$F_{\Sigma^-,\underline{\Sigma^-}} = 0.17 \pm 0.11$

$F_{\Sigma^-,\underline{\Lambda}} = 0.057 \pm 0.056$

$F_{\Sigma^-,\underline{\Xi^-}} = 0.25 \pm 0.08$

Comparison with JETSET

popcorn parameter PARJ(5)		No popcorn 0.	0.5	1.	5.	
observable	data	MC1	MC2	MC3	MC4	MC5 advanced popcorn
χ^2	-	56	59	59	63	99
$N^{corr}_{\Lambda\overline{\Lambda}}$	0.0612 ± 0.0034	0.066	0.060	0.066	0.058	0.081
$\overline{\Delta y}_{\Lambda\overline{\Lambda}}$	0.71 ± 0.04	0.66	0.69	0.67	0.75	0.57
$F_{\Sigma^-,\overline{\Sigma^-}}$ (this work)	0.17 ± 0.11	0.39	0.34	0.30	0.19	0.20
$F_{\Sigma^-,\overline{\Xi^-}}$ (this work)	0.057 ± 0.056	0.18	0.16	0.15	0.09	0.08
$F_{\Sigma^-,\overline{\Lambda}}$ (this work)	0.25 ± 0.08	0.30	0.28	0.28	0.27	0.28
$F_{\overline{H}}$ (this work)	0.48 ± 0.10	0.87	0.79	0.73	0.55	0.56

In JETSET popcorn model(s) needed, “advanced” not as good

Conclusion Σ^--antihyperon corr.

- Popcorn needed in JETSET
  - Independent of kinematics
- No fragmentation model describes simultaneously $\Lambda\bar{\Lambda}$, $p\bar{p}\pi$, Σ^- antihyperon corr.
- Questions:
  - results for cluster fragmentation (H7)?
  - Pythia8, Sherpa?

FCC-ee outlook

- Particle production in MCs important for precision modelling
  - Should pay attention to LEP MC modeling tests
- Both OPAL measurements stat. limited
  - ~$4 \cdot 10^6$ hadronic Z decays
  - Would reach OPAL systematics at 10^8 Z decays
- LC detectors:
  - Particle ID, mom. resolution, displaced vertices :)
  - Low momentum particles? Run with scaled B-field on Z peak and WW threshold?

Summary

- Many MC modelling tests from LEP
  - Many not “Rivetized”
  - Should be in tuning, or in control plots
  - Start effort to rivetize these tests?
- New measurements at new e^+e^- collider
  - Could improve dramatically
  - No particular requirements on detector
    - If promise “much better than LEP experiments” holds