Chiral odd fragmentation function At Belle

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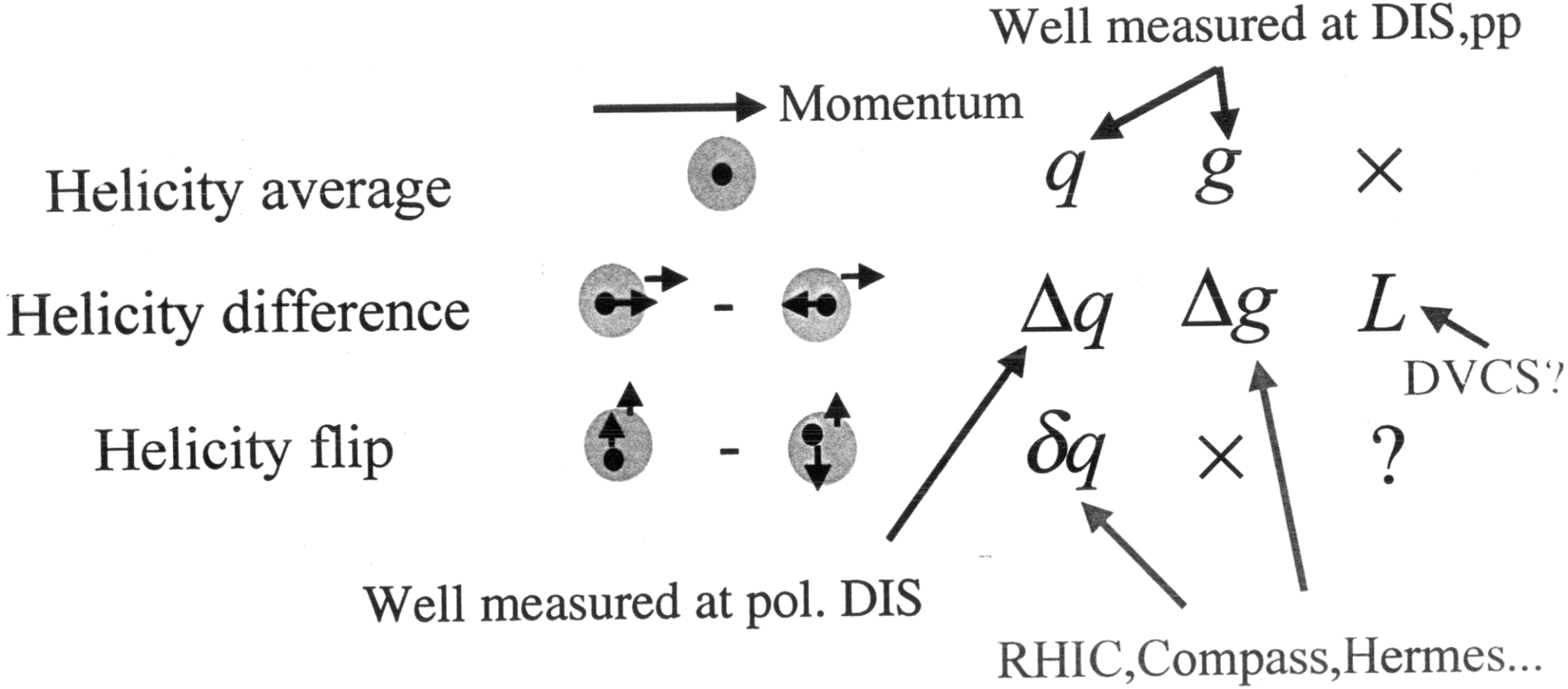
Special thanks to
Soeren Lange
Frankfurt (Belle / STAR)

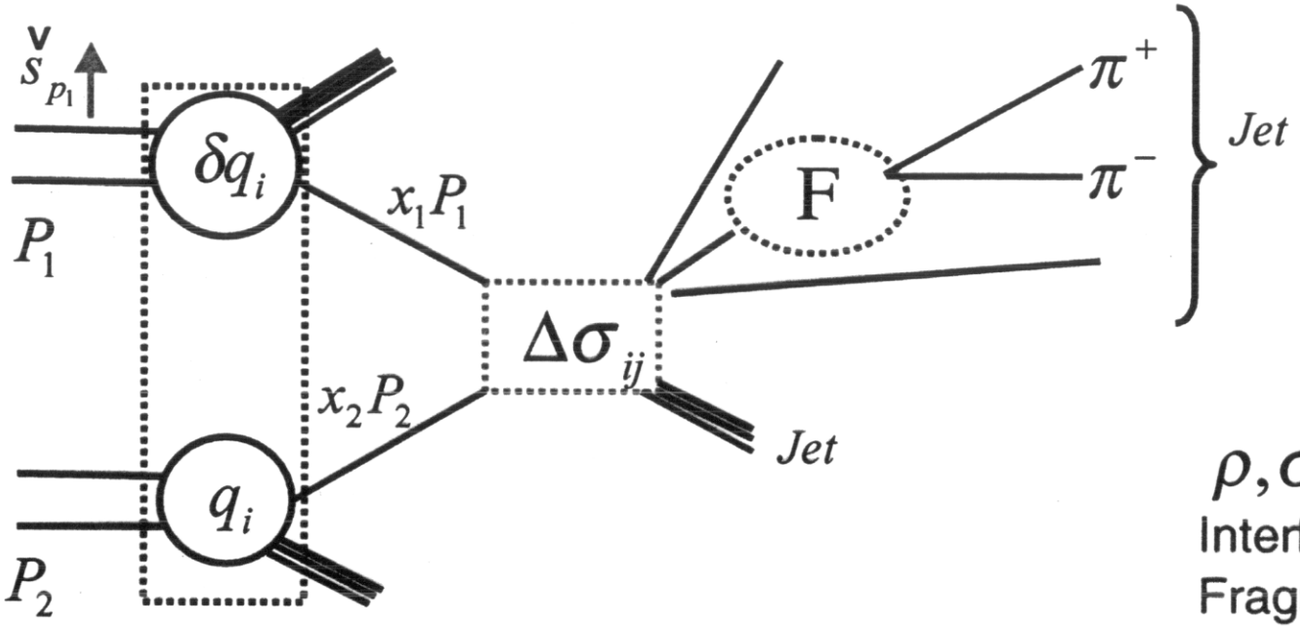
Leading twist quark distribution

$$F = \frac{q}{2} I \times I + \frac{\Delta q}{2} \sigma_3 \times \sigma_3 + \frac{\delta q}{2} (\sigma_+ \times \sigma_- + \sigma_- \times \sigma_+)$$



Transversity is the last missing piece
at leading twist quark distribution

Nucleon Transversity at $p^{\uparrow}$ p



ρ, σ
Interference
Fragmentation

$$\frac{d^6\sigma_H\left(pp^{\uparrow} \to \pi^+\pi^- X\right)}{dx_1 dx_2 dt dz dm^2 d\phi} \propto \delta q(x_1)\cdot q(x_2) \frac{d^3\sigma(q_1 q_2 \to q_3 q_4)}{dx_1 dx_2 dt} \frac{d^3 F}{dz dm^2 d\phi}$$

Proton Structure

Hard Scattering Process

Jian Tang , Thesis MIT, June 1999
R. Jaffe, X.Jin, J. Tang Phys. Rev. D57 (1999)5920
X. Ji, Phys. Rev. D49 (1994)114
J. Collins, S. Heppelmann, G. Ladinsky, Nucl.Phys. B420 (1994)565

Fragmentation Function(FF)

"Probability of a parton to hadronize into a specific final state"

Factorization theorem ensures universality

Collins FF & 2 pion interference FF

Initial parton with transverse spin - chiral odd

Azimuthal asymmetry in hadron final state

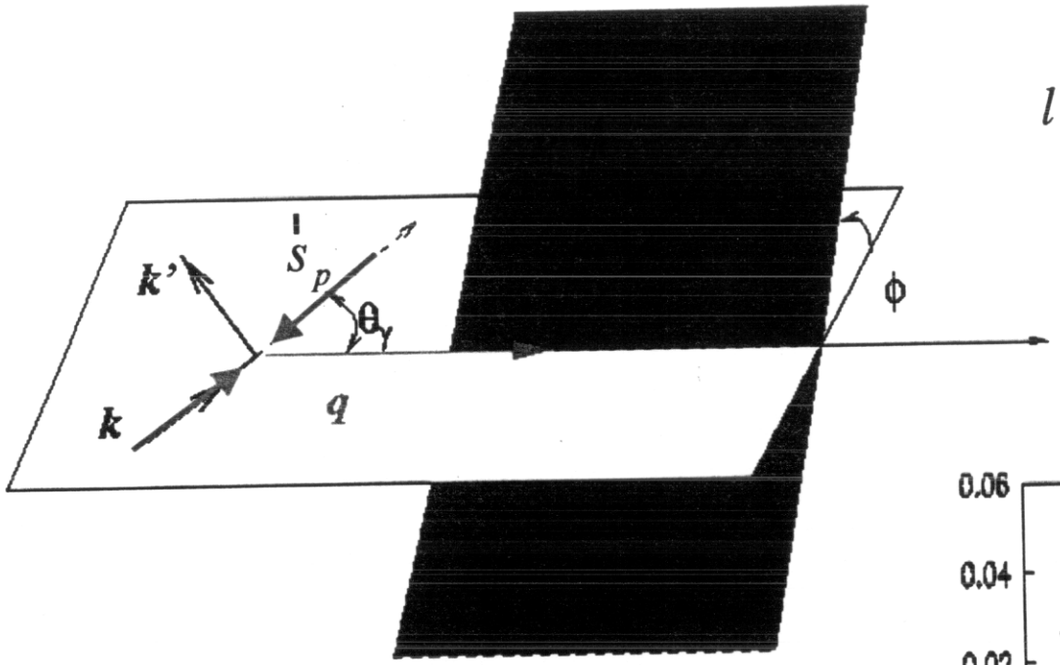
Currently unknown

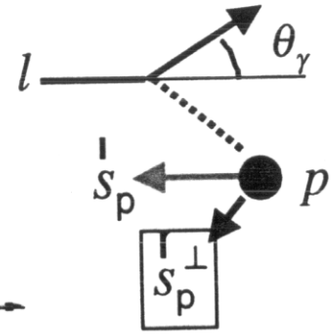
Theoretical Interests : Q^2 evolution is as fundamental as PDF

Polarized DIS & pp experiment can measure FF*Transversity

Unpolarized e^+e^- experiment can measure FF*FF

HERMES result on azimuthal asymmetry

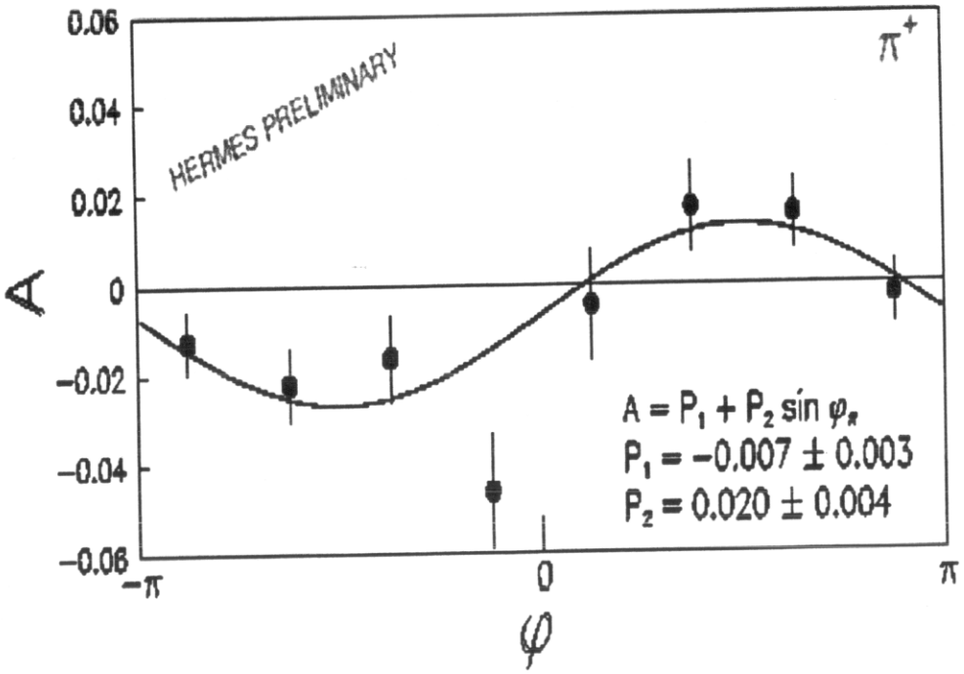




$$s_p^\perp = |s_p| \sin\theta_\gamma$$

$$\theta_\gamma \approx 150 \text{ mrad}$$

Non-zero transverse polarization!



Results shows that both Collins Function and Transversity are non zero, and rather large

"Complete" Measurements

BNL - Star/Phoenix/Phobos

$\pi^+\pi^-$ Interference Fragmentation: $A_T\left(p_\perp + p \to jet(\pi^+,\pi^-) + X\right) \Leftrightarrow \delta q \cdot \delta\hat{q}_I$

Collins Effect : $A_T\left(p_\perp + p \to jet(h) + X\right) \Leftrightarrow \delta q \cdot C$

Drell Yan: $A_{TT}(p_\perp p_\perp \to ll) \Leftrightarrow \delta q \cdot \delta\bar{q}$

Inclusive hadron: $A_N(p_\perp p \to h) \Leftrightarrow \delta q \cdot C$ + 2 other terms

DESY-Hermes & CERN-Compass (BNL eRHIC, DESY Tesla-N)

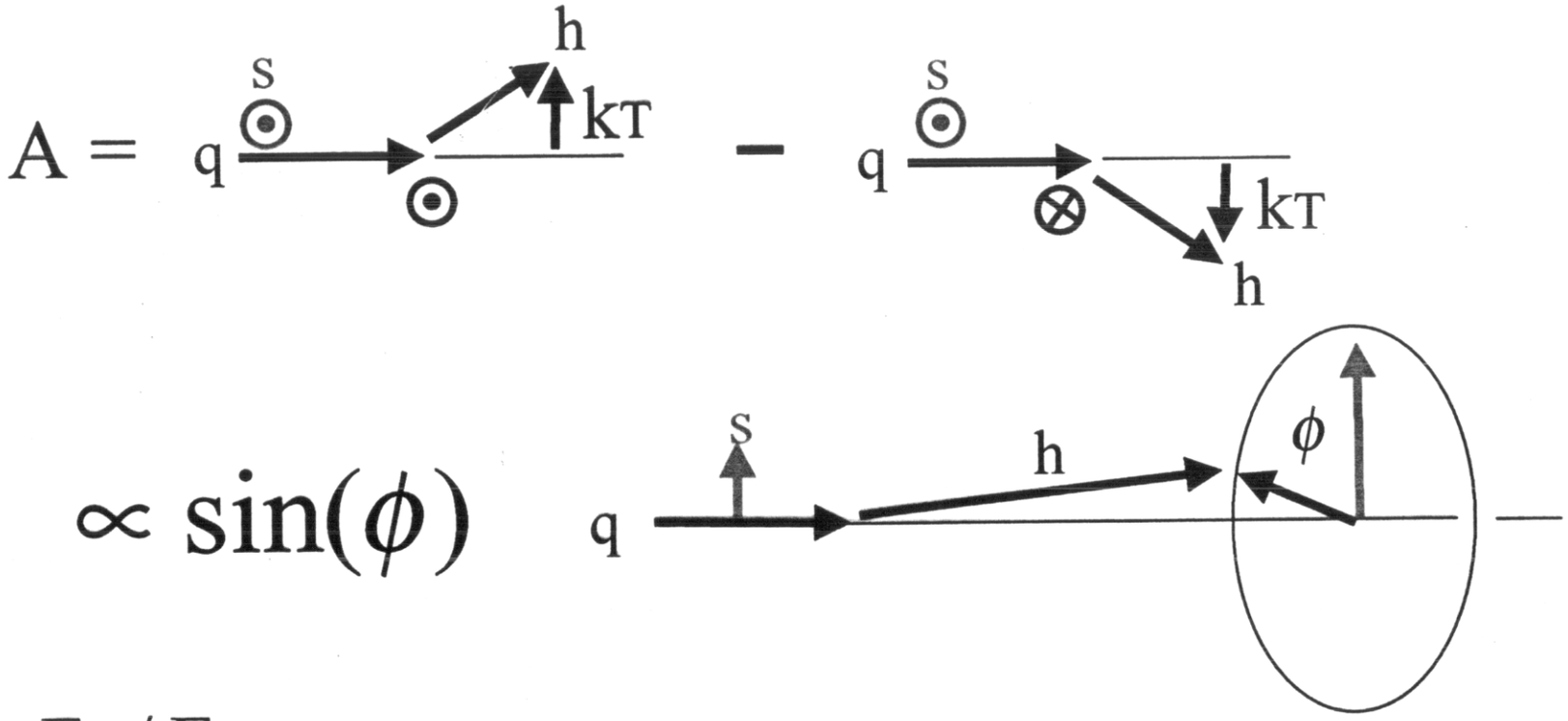
Collins Effect : $A_T(lp_\perp \to l + \pi + X) \Leftrightarrow \delta q \cdot C$

$\pi^+\pi^-$ Interference Fragmentation: $A_T\left(lp_\perp \to jet(\pi^+,\pi^-) + X\right) \Leftrightarrow \delta q \cdot \delta\hat{q}_I$

e+e- collider

$e^+e^- \to dijet$ $\quad C \cdot C \;,\; \delta\hat{q}_I \cdot \delta\hat{q}_I \;\;\&\;\; C \cdot \delta\hat{q}_I$

Collins Fragmentation Function : C

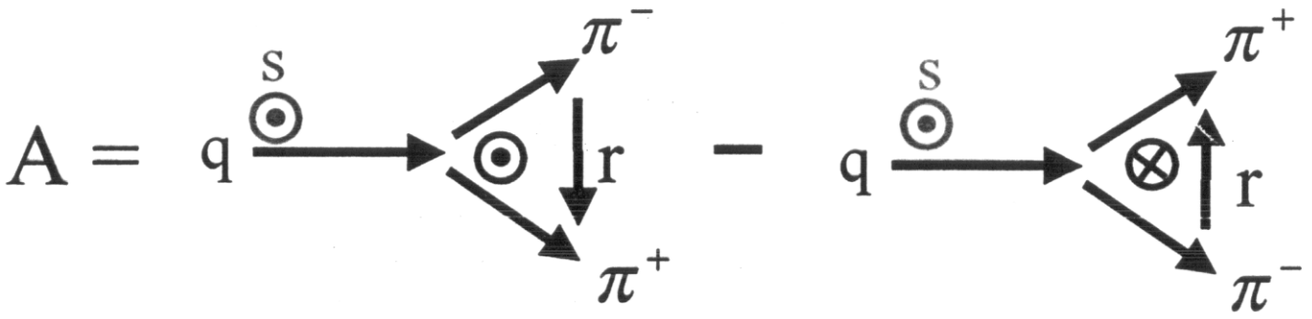


Z = E_h / E_q

ϕ = angle between S and k_T around quark (jet) axis

$$A \propto C(z)\sin(\phi) = C(z)s \cdot (q \times h)$$

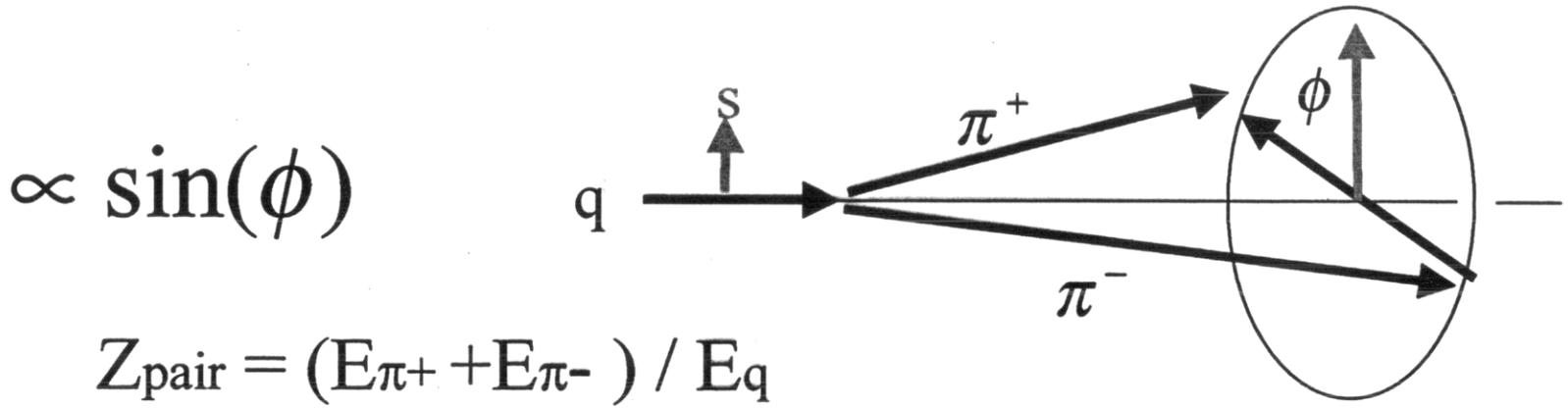
2 pion interference fragmentation function : $\delta\hat{q}_I$



$\pi^- = z^{\pi+} p^{\pi-} / z^{pair}$

$\pi^+ = z^{\pi-} p^{\pi+} / z^{pair}$

$r = \pi^+ - \pi^-$



$Z_{pair} = (E_{\pi+} + E_{\pi-}) / E_q$

m = invariant mass of 2 pions

ϕ = angle between s and r

$$A \propto \delta\hat{q}_I(z,m)\sin(\phi) = \delta\hat{q}_I(z,m)\, s \cdot \underline{(\pi^- \times \pi^+)}$$

The same thing for KK around ϕ

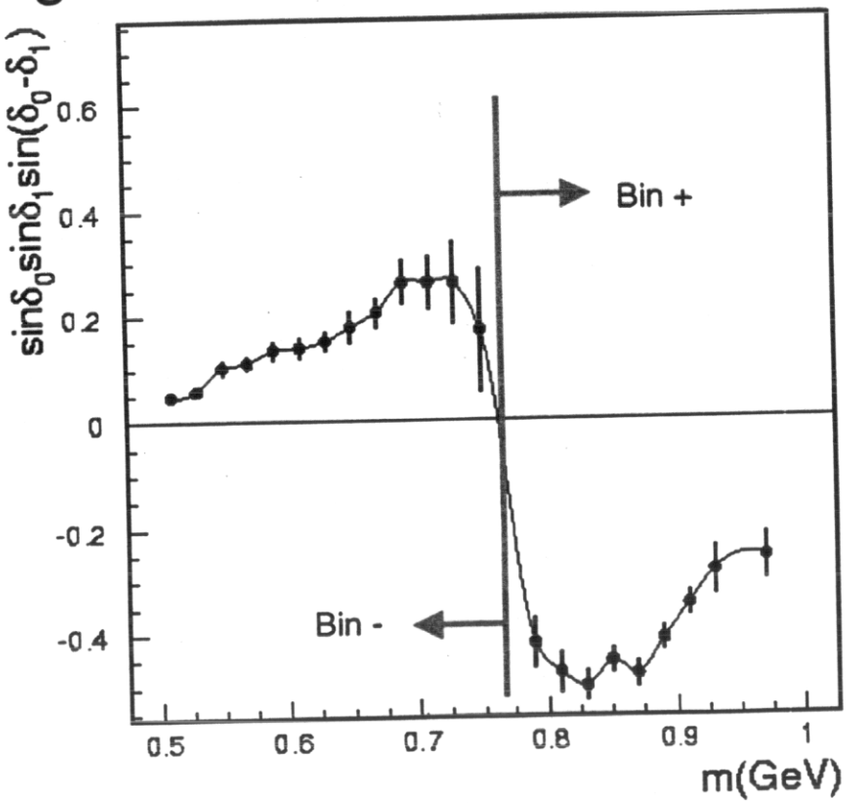
A model of Interference Fragmentation Function

$$\frac{d^2F}{dzdm^2} \propto \sin\delta_0 e^{i\delta_0}\left(\kappa\cdot\hat{q}_I(z)+\lambda\cdot\delta\hat{q}_I(z)\right)\sin\delta_1 e^{-i\delta_1}+\ldots$$

$\hat{q}_I(z), \delta\hat{q}_I(z)$
Spin average, difference FF

S- p wave interference around $\rho-\sigma$ mass

Strong interaction $\pi\pi$ phase shifts

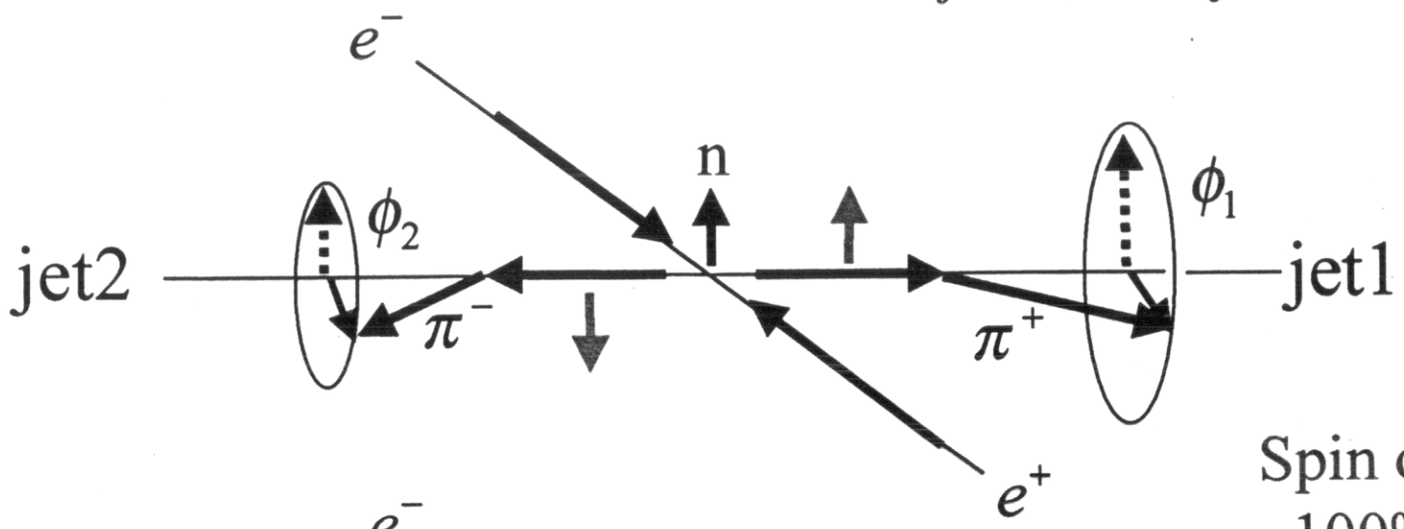


Non-vanishing "Analyzing power" above and below ρ mass and flip sign

Requires mass Resolution
Great for systematic study

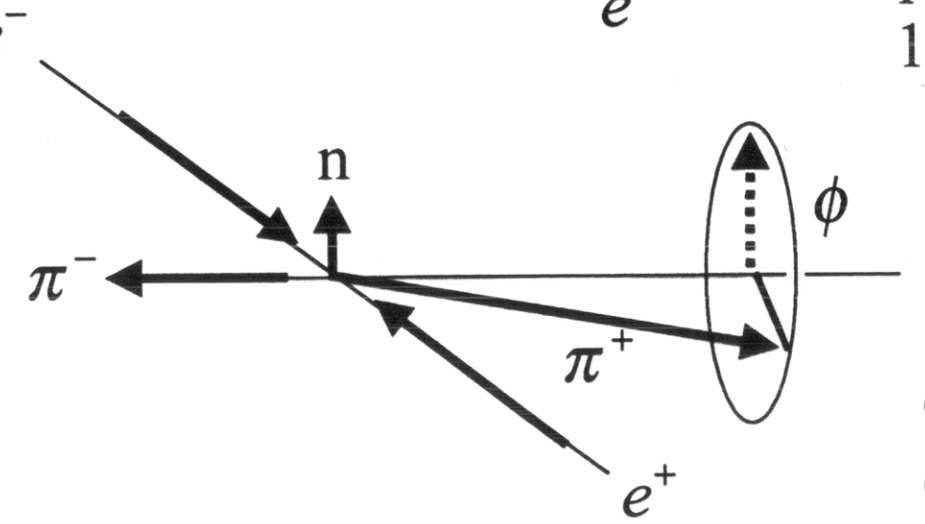
P. Estabrooks and A.D. Martin, Nucl. Phys. B79 (1974)301

$$e^+e^- \rightarrow (\pi^+)_{jet1}(\pi^-)_{jet2}X$$



Spin of quarks are 100% correlated!

Without using jet axis

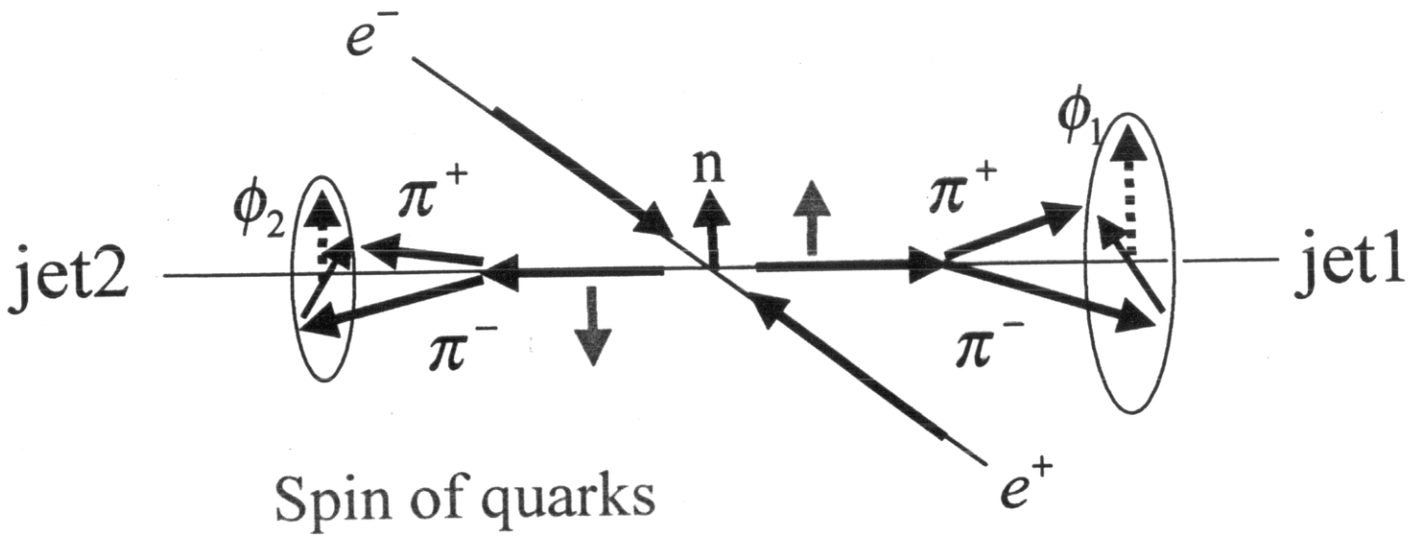


Gluon emission can cause same cos(2ϕ) But calculable

$$A \propto C(z_1)C(z_2)\cos(\phi_1 + \phi_2)$$

$$= C(z_1)C(z_2)\cos(2\phi)$$

$$e^+e^- \to (\pi^+\pi^-)_{jet1}(\pi^+\pi^-)_{jet2}X$$



Spin of quarks
are 100% correlated!

$$A \propto \delta\hat{q}_I(z_1, m_1)\delta\hat{q}_I(z_2, m_2)\cos(\phi_1 + \phi_2)$$

Gluon emission does NOT fake this asymmetry

Artru, Collins (1996)

Efremov (Delphi)

In e^+e^-	At B factories
High enough energy to produce jet	5GeV jets
to apply pQCD	$s \sim 100 GeV^2$
But not too high energy	
FF decreases as energy increases	$s(BF) << s(LEP)$
Observing Q^2 evolution is interesting	
Extra complication from Z pole	$\sqrt{s}(BF) < Mz$
Jet production from light quark	Off resonance data
	Exclude heavy flavors
Requires good detector:	
Wide acceptance	86% of 4 π (Belle)
Momentum/mass resolution	Great, they even can do b physics
PID capability	PID covers full momentum range
Requires many events	They are designed for high statistic

B factories : Belle, Babar, Cleo…

Belle

8GeV+3.5GeV
1.3/fb/week

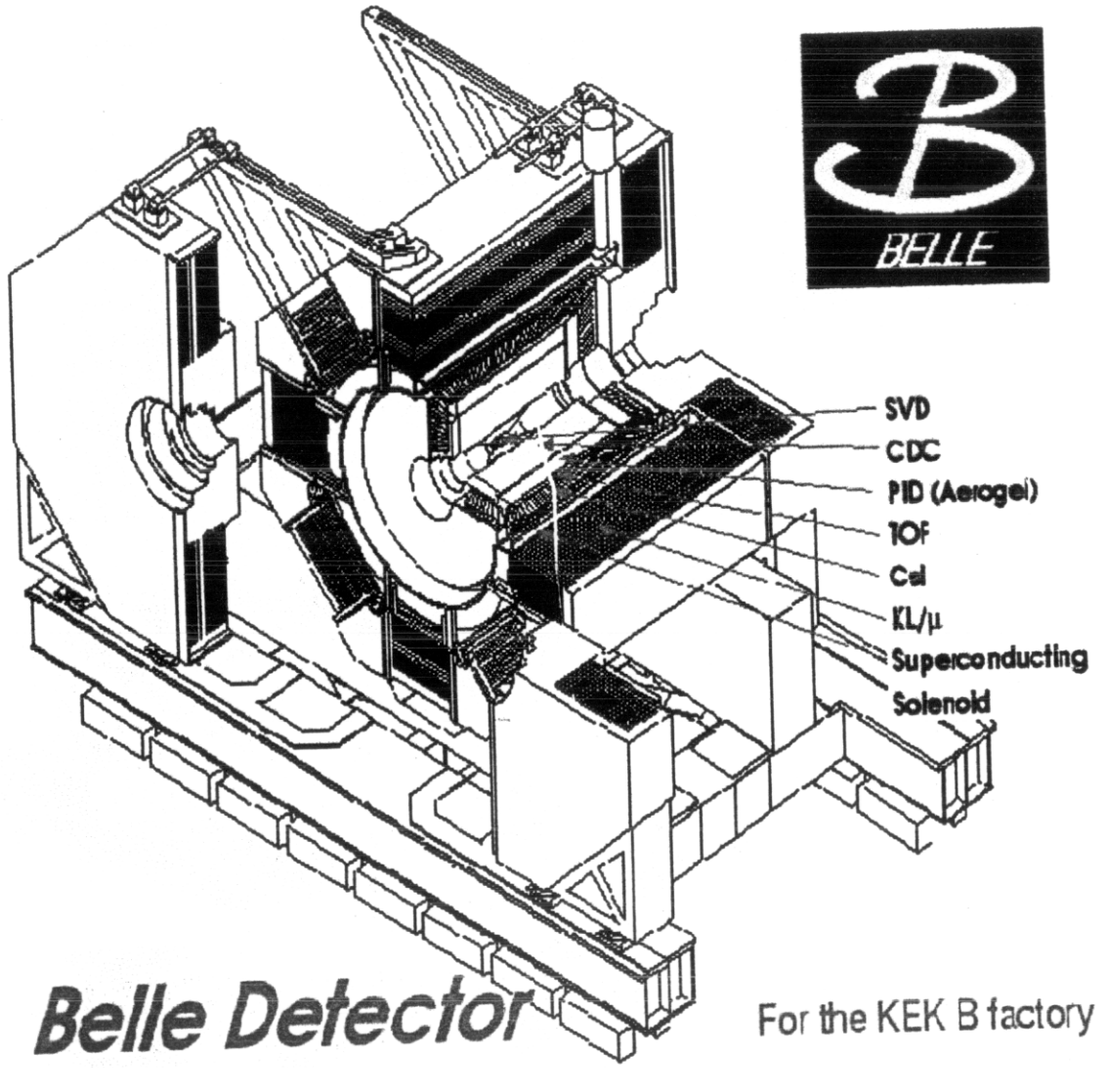
Babar

9GeV+3.1GeV
~1/fb/week

Cleo

4.7GeV+5.6GeV
~0.35/fb/week

All have almost hermetic collider detector with good PID



Fumihiko Takasaki
BELLE, KEK, Japan

Friday, July 6, 2001

Dr. Matthias Grosse Perdekamp
RIKEN BNL Research Center
Upton, NY 11973, USA

Dear Dr. Perdekamp,

Thank you for your interest in the Belle experiment. The application of the RIKEN-BNL group to join Belle was presented to the Belle group at the recently concluded group meeting. The application was well received and the Belle group members were enthusiastic about the prospect of the RIKEN-BNL group joining our collaboration.

As you know, Belle started to take data only two years ago, after a five year construction period that involved strong and dedicated efforts on the part of the group members. Thus, although the experimental hardware seems to work at very near the design expectations, a considerable amount of effort is still required to reach the optimum performance levels. This primarily involves improvements in the inner tracker performance and in the reconstruction algorithms and calibration systems, as well as expedited data processing and storage systems. We are also starting to suffer from a shortage of CPU power for handing our large data sample; this will be a serious problem in the coming years in view of the rapid improvements in KEKB's luminosity. It would be very helpful for the successful integration of your group into Belle if your group could assume responsibility for some important and visible aspect of these service-like tasks.

We consider the minimum level of effort for a significant impact to be something like two full-time equivalents, about half of which would be done by someone (or persons) resident at KEK. As for specific tasks, we suggest that you and your colleagues make contact with Junji Haba, the leader of the Belle Silicon Vertex detector, and Nobu Katayama, the leader of the Belle software/computing group, and explore ways that you could contribute most effectively.

Although there is still plenty of room for improvement, we are very pleased with the first two year's performance of both KEKB and Belle. We believe that the results we published in the scientific journals and presented at the last conferences and workshops verify that the Belle detector is capable of accomplishing the goals of our experiment.

Sincerely,

H. Aihara, S.L. Olsen and F. Takasaki
Belle co-spokespersons

cc Leo Piilonen, IB chair
Dan Marlow, EB chair
Junji Haba, Leader, Belle Silicon Vertex detector
Nobu Katayama, Leader, Belle Software & Computing

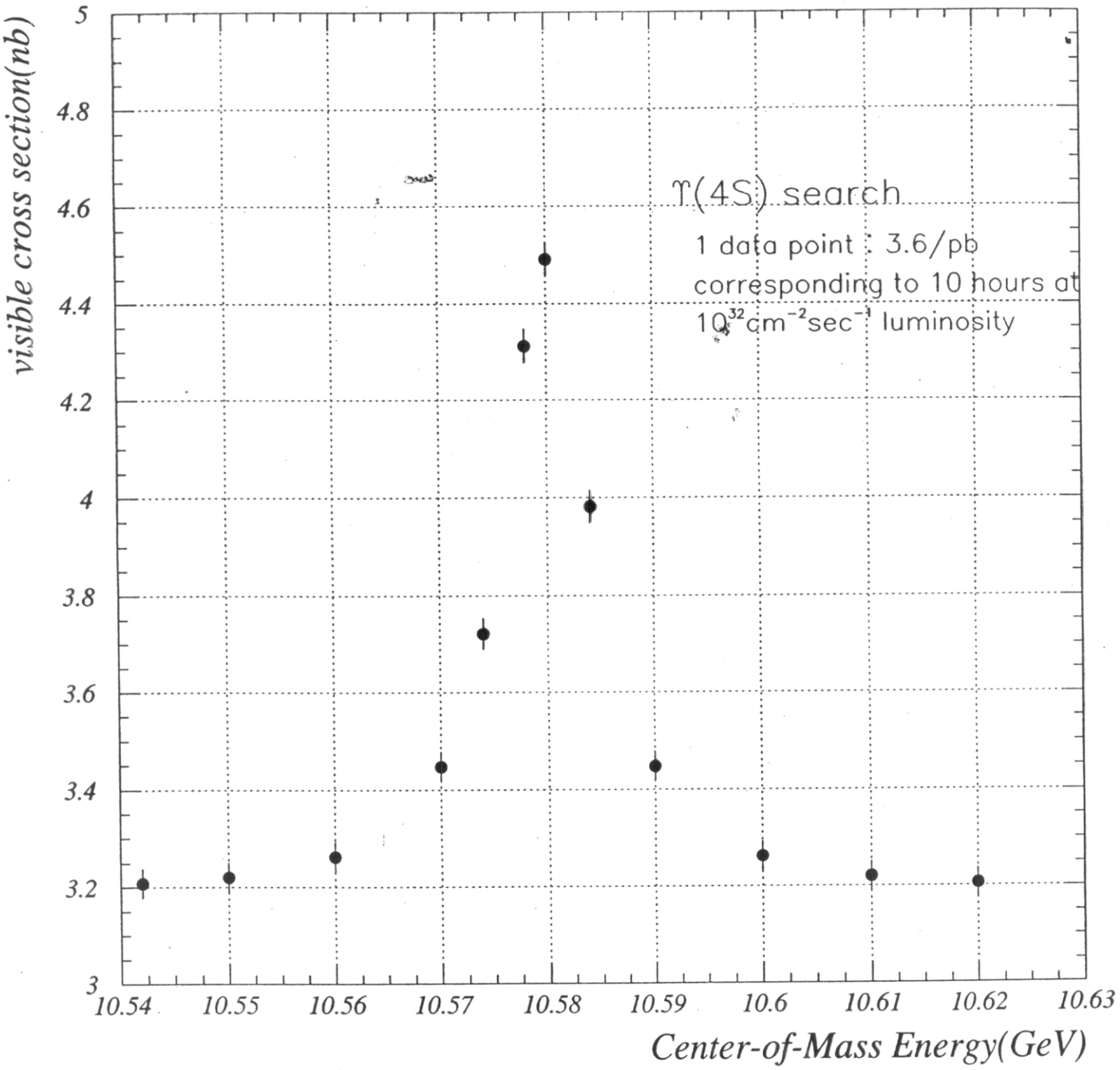
Fragmented experiments and people:

Belle A small group of RHIC spinners joined Belle
Matthias G. Perdekamp (RBRC)
Ogawa Akio (Penn State Univ)
+ …

Belle collaborators:
Soeren Lange (Frankfurt - STAR & Belle)
Bruce Yabsley (Sidney / KEK - Belle)

Theoretical aspects:
Daniel Boer (RBRC / Free University)
Robert Jaffe (MIT)

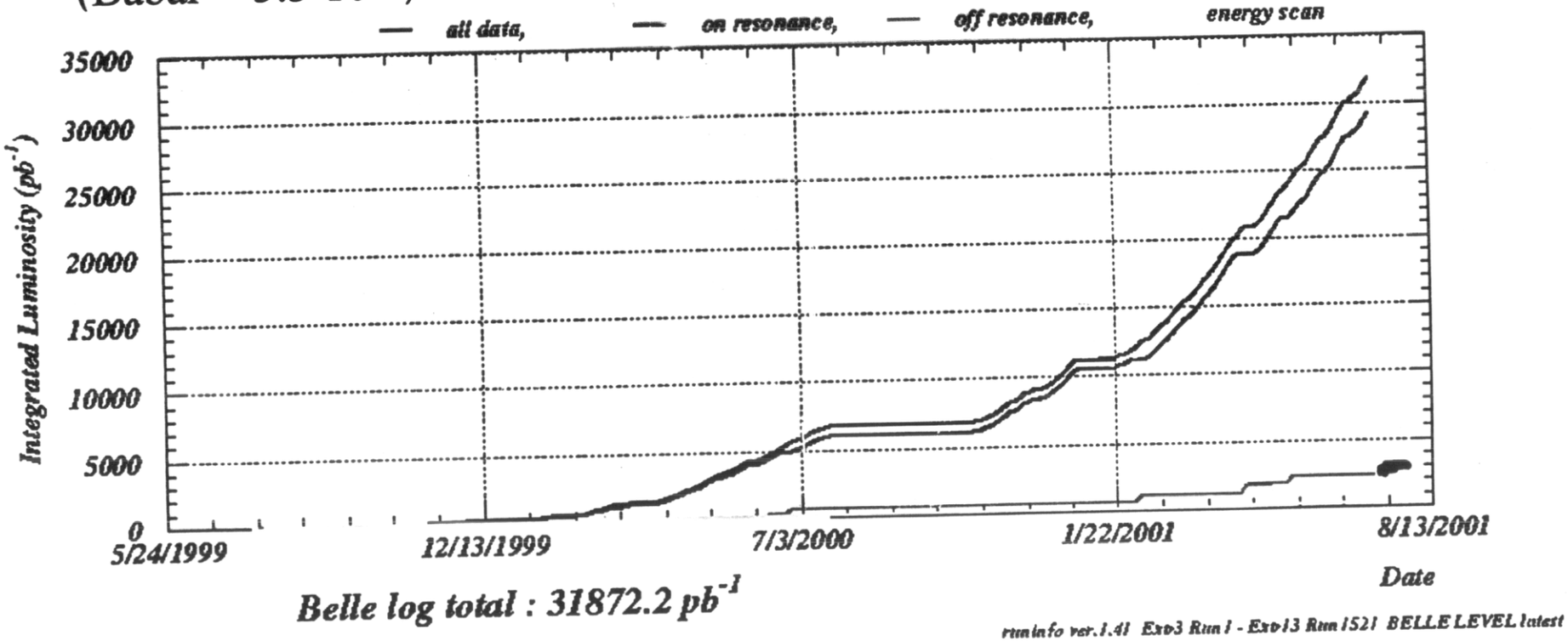
Delphi Oliver Passon (Wuppertal Univ)
Klaus Hamacher (Wuppertal Univ)
Opal Albert de Roeck (CERN)
Babar ?
Cleo ???

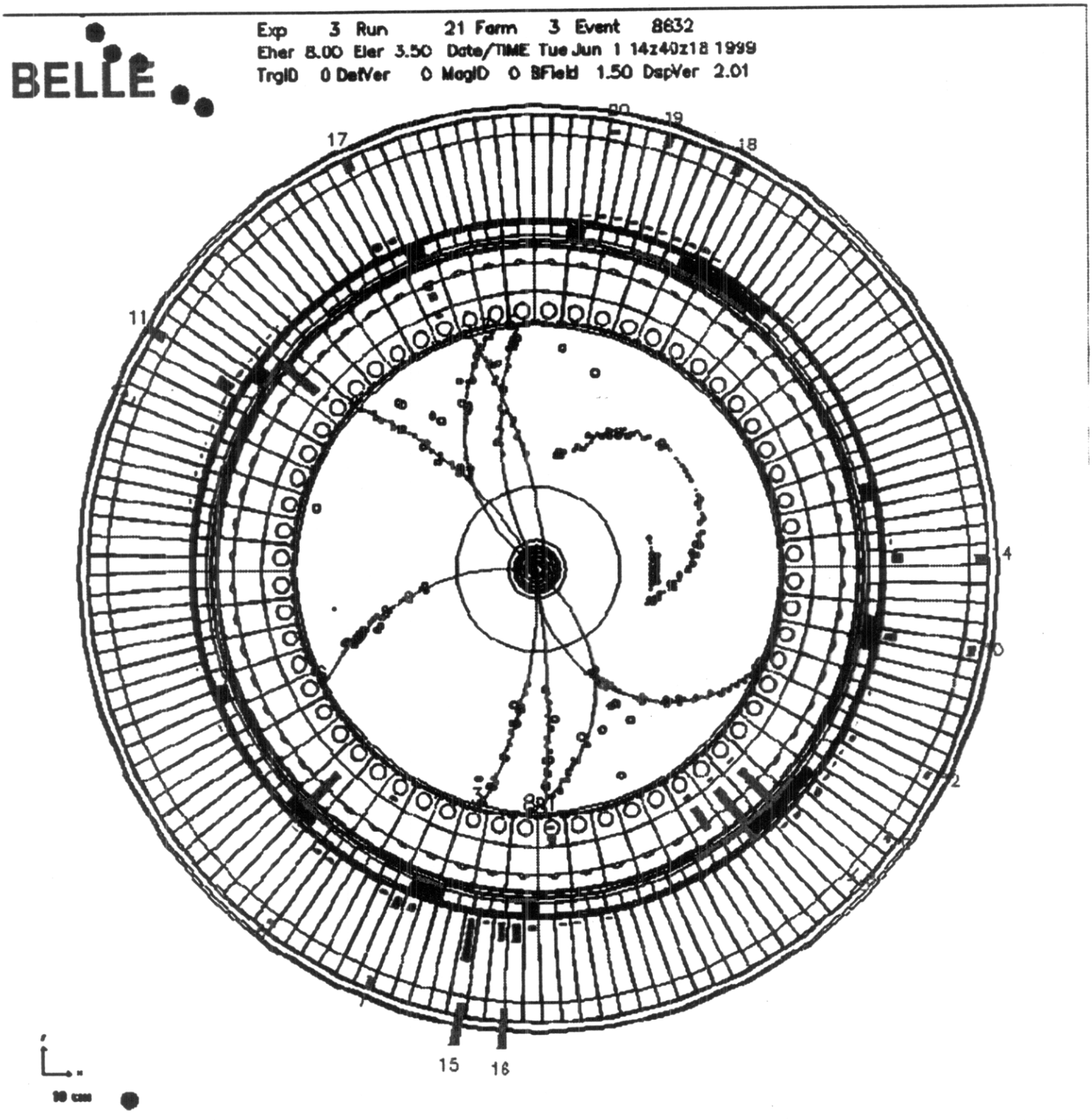

visible cross section(nb)
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
Υ(4S) search
1 data point : 3.6/pb
corresponding to 10 hours at
$10^{32}cm^{-2}sec^{-1}$ luminosity
10.54
10.55
10.56
10.57
10.58
10.59
10.6
10.61
10.62
10.63
Center-of-Mass Energy(GeV)

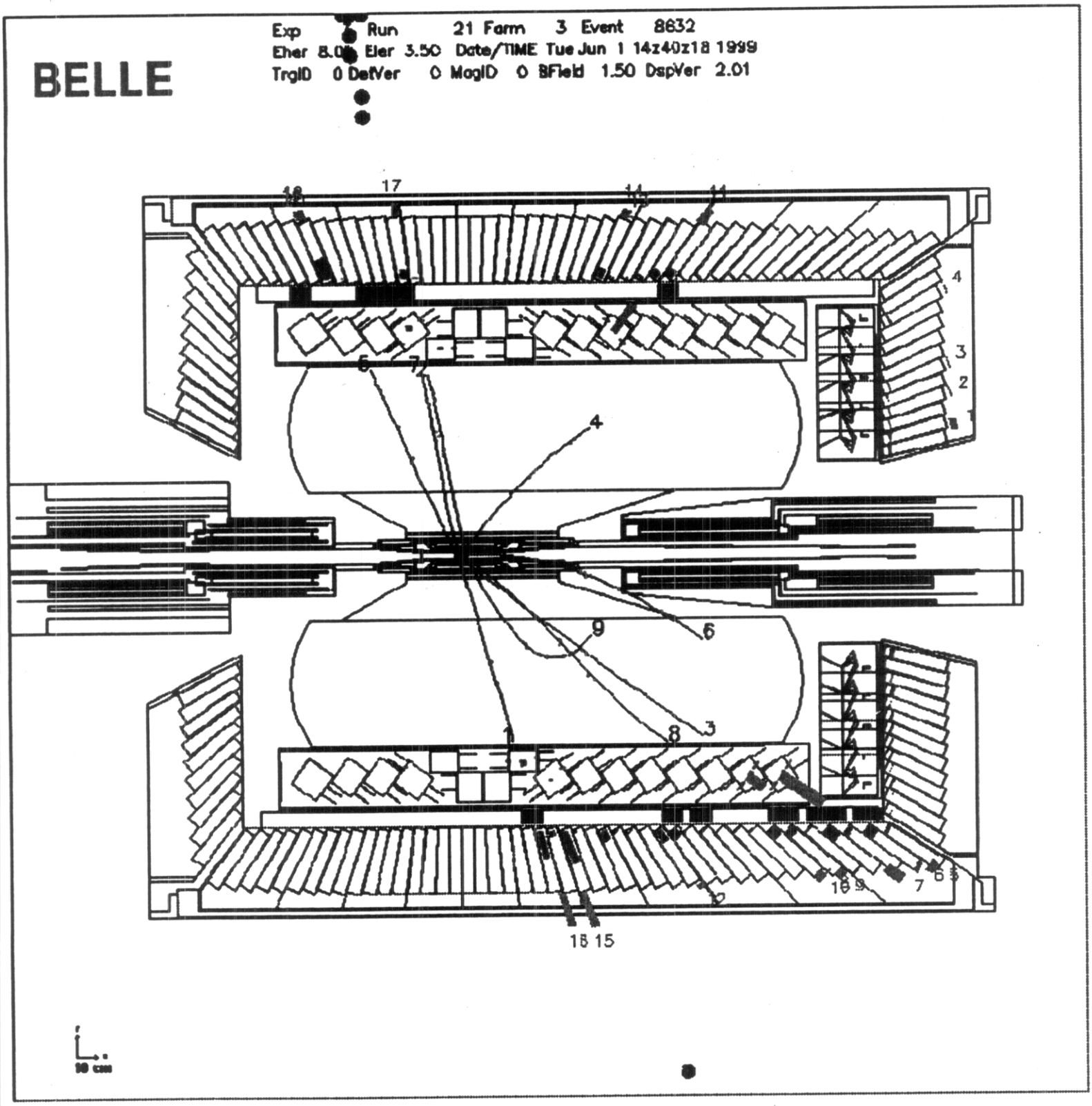
Belle Data *Number provided by J.S.Lange(Frankfurt)*

On-Resonance
- 10.58GeV
- bb cross section = 1.19nb
- ~32/fb on tape
- ~240/pb/day
- peak L = 4.44 10^{33}/cm/cm/s
  - World Record!
- design L = 10.0 10^{33}/cm/cm/s
- (Babar = 3.3 10^{33})

Off-Resonance
- 10.52GeV
- cross section = 3.08nb
- Motivation : Background study
- 3 ~~2.3~~/fb = ~~6.4~~ 9 10^6 Events on tape
- DST processing speed ~850/pb/day
- Analysis ~50 events/sec on i686 450MHz

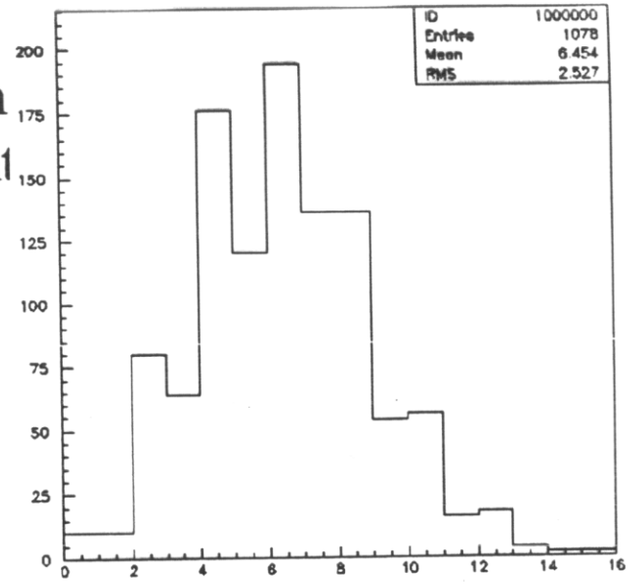



BELLE
Exp 3 Run 21 Farm 3 Event 8632
Eher 8.00 Eler 3.50 Date/TIME Tue Jun 1 14z40z18 1999
TrgID 0 DetVer 0 MagID 0 BField 1.50 DspVer 2.01
17
19
18
11
4
2
15
16
10 cm


BELLE
Exp Run 21 Farm 3 Event 8632
Eher 8.0 Eler 3.50 Date/TIME Tue Jun 1 14z40z18 1999
TrgID 0 DetVer 0 MagID 0 BField 1.50 DspVer 2.01
17
4
3
2
1
5
7
4
9
6
8
3
1
16 15
10 cm

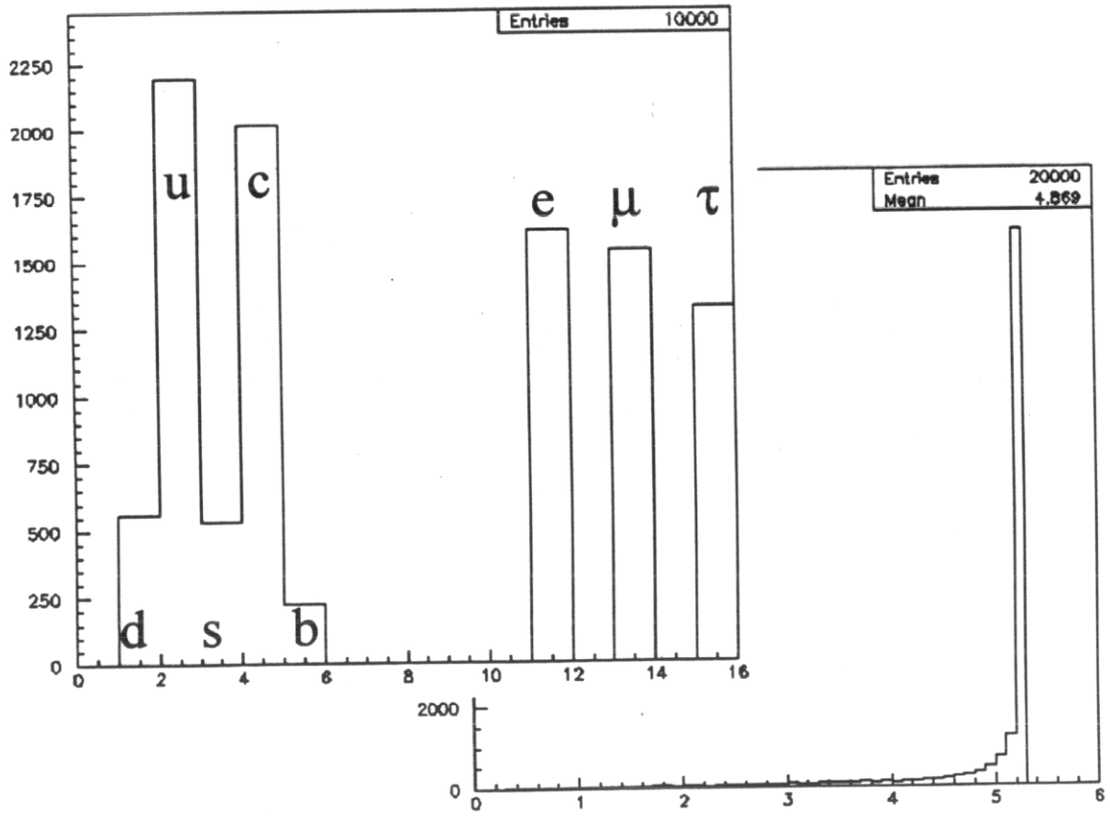
Some basic numbers from PYTHIA:

of charged pion in hadronic event average ~ 6.5 (for 4pi detector)

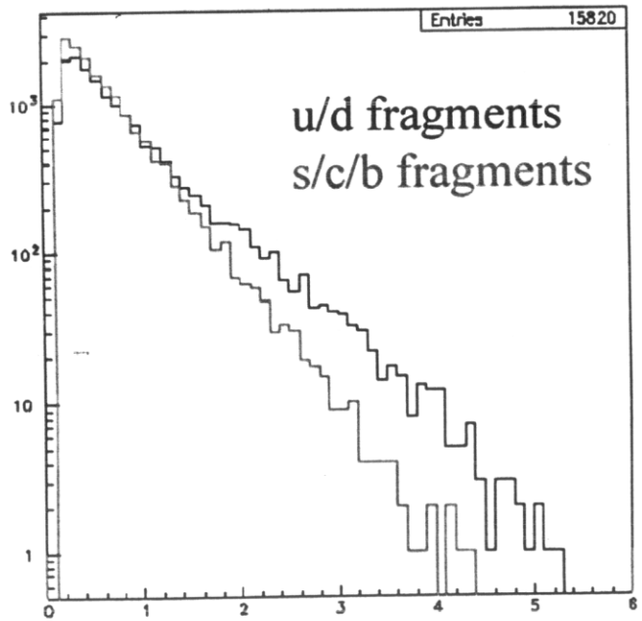


Simulation (pythia) at sqrt(s) = 10.52GeV gives:

6.6 nb (30% ud, 23% sc, 2% b, 45% leptons)



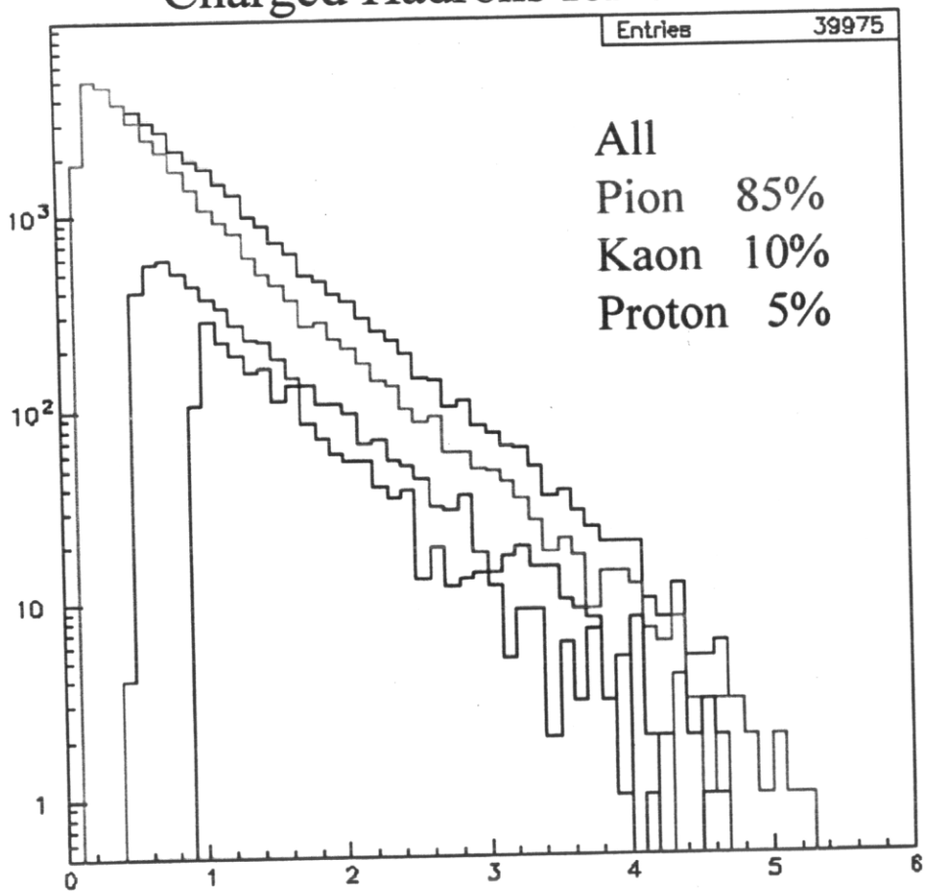
E_{parton}



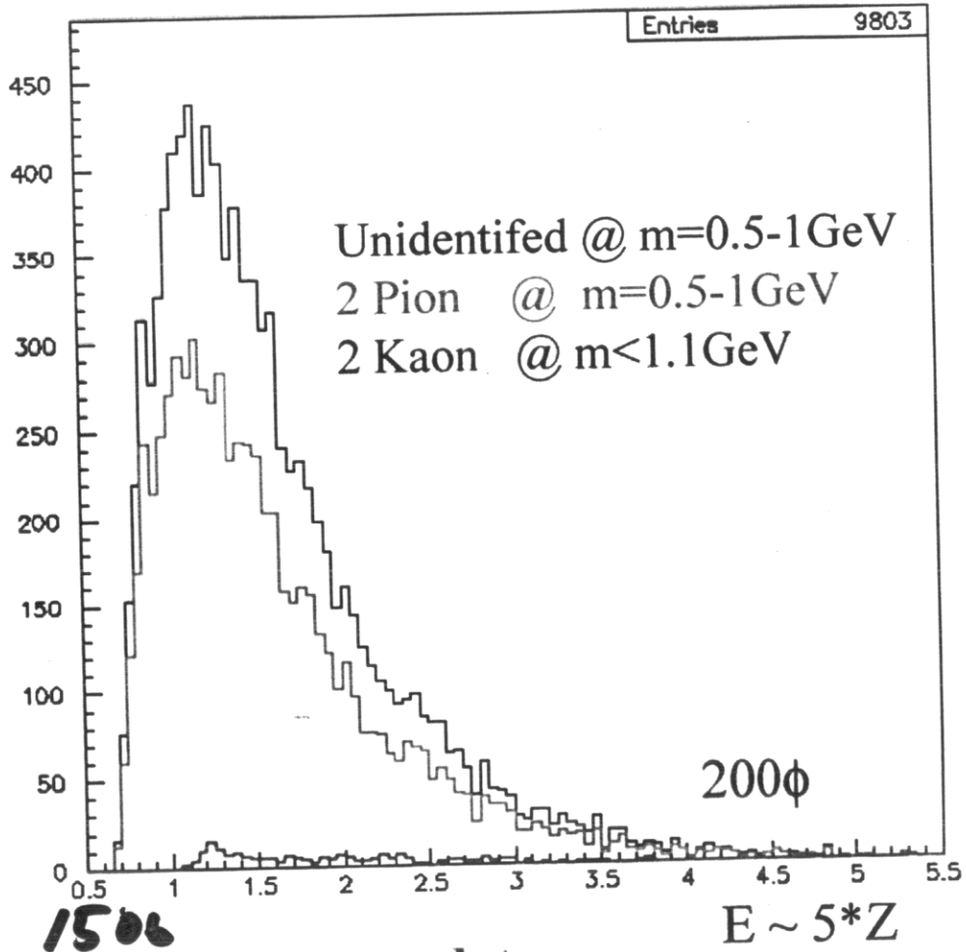
$E_{charged\ pion}$

Z distributions

Charged Hadrons for Collins



Pairs for $\delta\hat{q}_l$



10K total / 5K hadronic Event ~ **Belle has ~~1000~~ 150 times more data**

This is projection to one side : asymmetry depends on average of "the other side"

Statistics estimate

CC	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0 (z1)
0-0.2	0.00031	0.00068	0.0014	0.0032	0.0072
0.2-0.4	0.00068	0.0015	0.0031	0.0070	0.016
0.4-0.6	0.0014	0.0030	0.0063	0.014	0.032
0.6-0.8	0.0032	0.0070	0.014	0.033	0.073
0.8-1.0	0.0072	0.016	0.032	0.073	0.16

Cq					
0-0.2	0.0014	0.00063	0.0012	0.0027	0.0060
0.2-0.4	0.0029	0.0014	0.0027	0.0058	0.013
0.4-0.6	0.0061	0.0028	0.0055	0.012	0.027
0.6-0.8	0.014	0.0064	0.013	0.027	0.062
0.8-1.0	0.030	0.014	0.028	0.061	0.14

qq					
0-0.2	0.0058	0.0027	0.0053	0.012	0.026
0.2-0.4	0.0027	0.0013	0.0025	0.0053	0.012
0.4-0.6	0.0053	0.0025	0.0048	0.010	0.024
0.6-0.8	0.012	0.0053	0.010	0.023	0.051
0.8-1.0	0.026	0.012	0.024	0.051	0.12

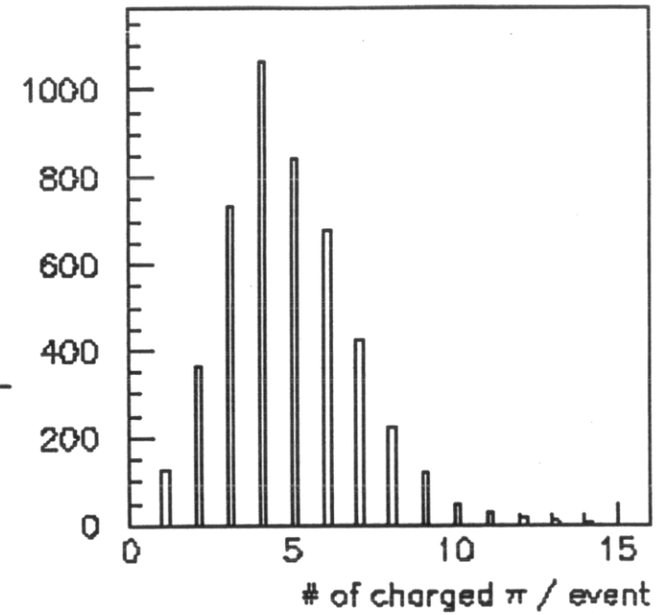
(Z2)

Estimate of
$\delta(F*F) = \delta A/\cos(\phi+\phi)$
For ~2.3/fb ~ 6M Events
Belle already have it (9M)
~2 weeks of off resonance
data taking at Belle

For example:
2pions + 2 pions
4 C*C
4 C*q
1 q*q
total 9 independent
measurements
in a event

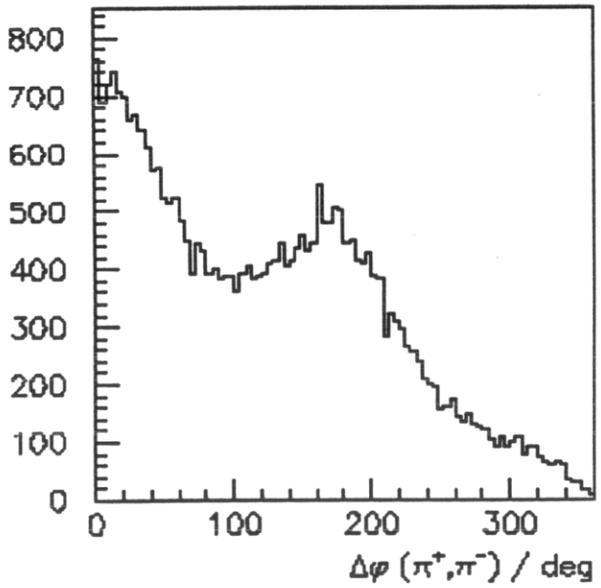
Belle off resonance data first look for fragmentation function analysis by J.S.Lange (Frankfurt)

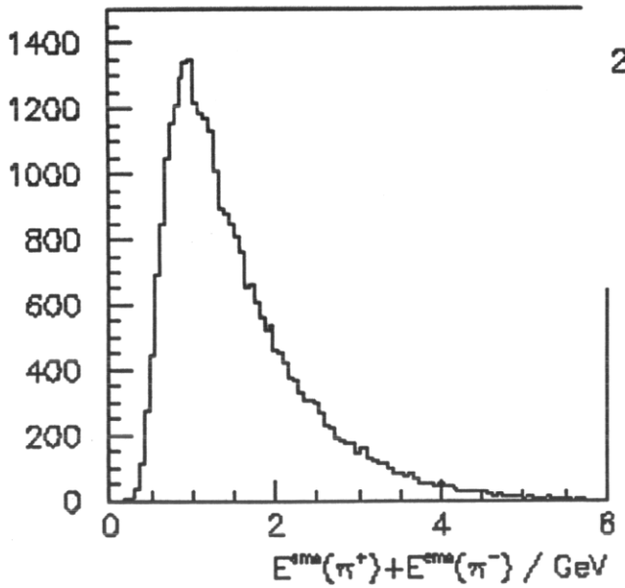
DST for a run
- ~ 1 hour 40min, 7.6/pb, 23K events
- ~5min for micro DST analysis



Average ~5 charged pions / event

BELLE exp. 7 run 2293 off-resonance (-60 MeV) 6/27/2000





Some comments:

Understanding jets production at sqrt(s) at ~10GeV

Effects of heavy flavours and weak decay background

Identified Pions, kaons & unidentified hadrons
Study dilution of analyzing power due to lack of PID at STAR (PHENIX's)

Extracting FFs from

$$C(z_1,k_{T1})\cdot C(z_2,k_{T2}) \;,\; \delta\hat{q}_I(z_1,m_1)\cdot\delta\hat{q}_I(z_2,m_2) \;\&\; C(z_1,k_{T1})\cdot\delta\hat{q}_I(z_2,m_2)$$

with gluon emission effects subtraction in Collins

Q^2 evolution
LEP analysis on the same FF at different energy (100GeV)
B factories ~ 10.5GeV
Other older & existing data 10 - 50GeV

More "Off resonance" data expected, more data in "On resonance data"....

Conclusion

- Collins FF and Interference FF are needed
  - to extract transversity from DIS/pp
  - to understand A_N for inclusive pion productions
  - FF itself is as fundamental as PDF

- e+e- can measure these FF $C * C$ & $\delta\hat{q}_I * \delta\hat{q}_I$ & $C * \delta\hat{q}_I$
  - B factories are the places to measure it
    - Luminosity, detector with PID, energy, etc
  - Comparison with LEP data will be interesting

- Belle accepted RBRC group (Matthias & me & some more)
  - RHIC Spinners will be on task