Azimuthal Asymmetries in Fragmentation Processes at KEKB

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Outline

- Transversity Measurements
- Spin-Dependent Fragmentation Functions
- KEK/Belle
- Analysis Method
- Summary

Access to Transversity using Spin-Dependent Fragmentation Functions

$$\sigma^{pp^{\uparrow}\longrightarrow\pi^{+}\pi^{-}X} = \sum_{q} f^{H\longrightarrow q} \otimes \sigma^{q_1 q_2\longrightarrow q_3 q_4} \otimes D^{q\longrightarrow\pi^{+}\pi^{-}}$$

- Polarized *pp* [RHIC Phenix/Star (BNL)] and polarized DIS [Hermes (DESY) / Compass (CERN) / JLAB] can measure:
  - $\delta q \otimes FF$

=> Extraction of δq requires the knowledge of novel spin-dependent *FFs*

- Unpolarized e^+e^- [Belle (KEK) / Babar (SLAC) / LEP (CERN) / CLEO] can measure:
  - $FF \otimes FF$

Transversity Project at RBRC

1. Measure

   $A_T(p_\perp p \rightarrow jet+X) \Rightarrow \delta q \otimes FF$

   $A_{TT}(p_\perp p_\perp \rightarrow ll, jet+jet) \Rightarrow \delta q \otimes \delta\bar{q}$

   at BNL [Phenix/Star]

2. Measure

   $FF \otimes FF$ in $e^+e^- \rightarrow jet+jet$

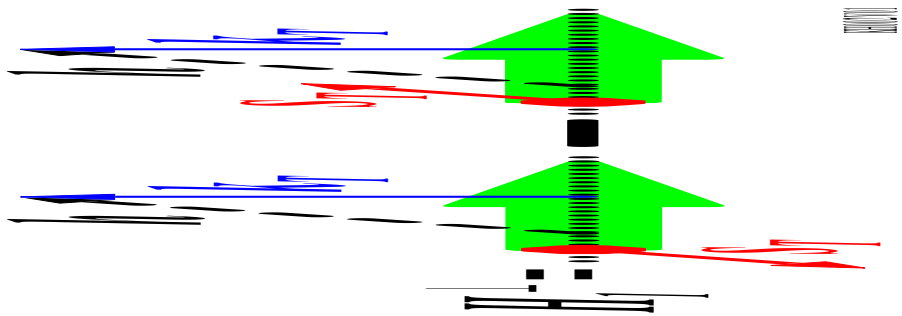
   at KEK [Belle]

3. Lattice calculation of tensor charge

   at BNL [RBRC lattice computer] (T. Blum *et al.*)

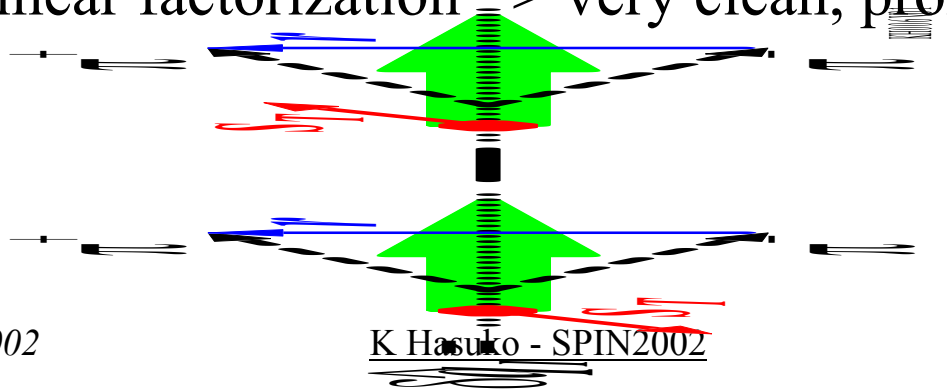
Spin-Dependent Fragmentation Functions

- Collins-Heppelmann FF: $H_1^{\perp}$
  - Describes the fragmentation of a transversely polarized quark into a hadron with k_T related to jet axis
  - Collins effect causes azimuthal hadron asymmetry in jet fragmentation
  - A candidate to probe the quark transversity distribution



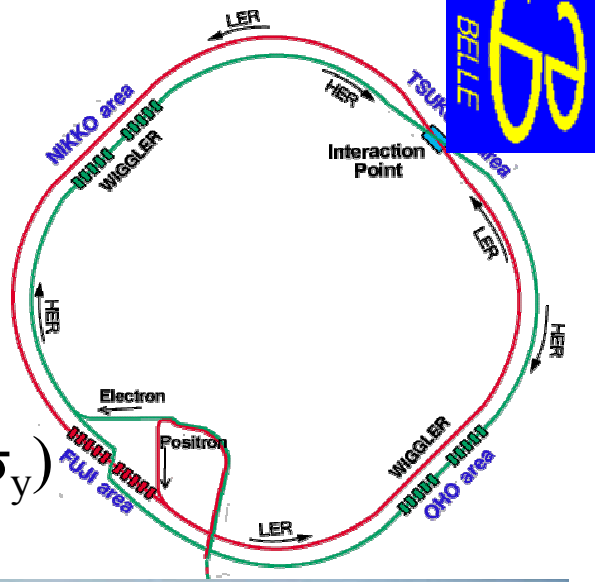
Spin-Dependent Fragmentation Functions

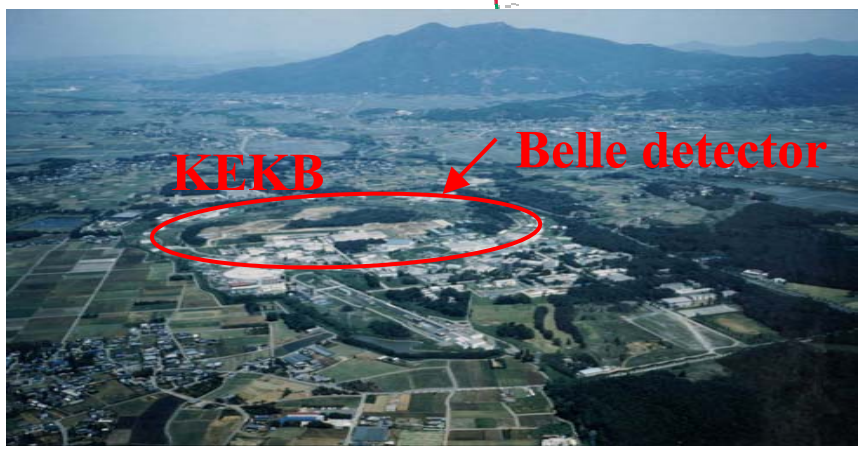
- Two-hadron interference FF: $\delta\hat{q}_I$
  - Describes the fragmentation of a transversely polarized quark into a hadron pair
  - Interference between different partial waves can give rise to a chiral-odd FF (*e.g.* ρ–σ interference for ππ)
  - Models of IFF
    - R.L. Jaffe, X. Jin and J. Tang, Phys.Rev.D57 (1998) 5920
    - A. Bianconi, S. Boffi, D. Boer, R. Jakob and M. Radici, hep-ph/0010132
  - collinear factorization => very clean, promising



KEKB/Belle Experiment

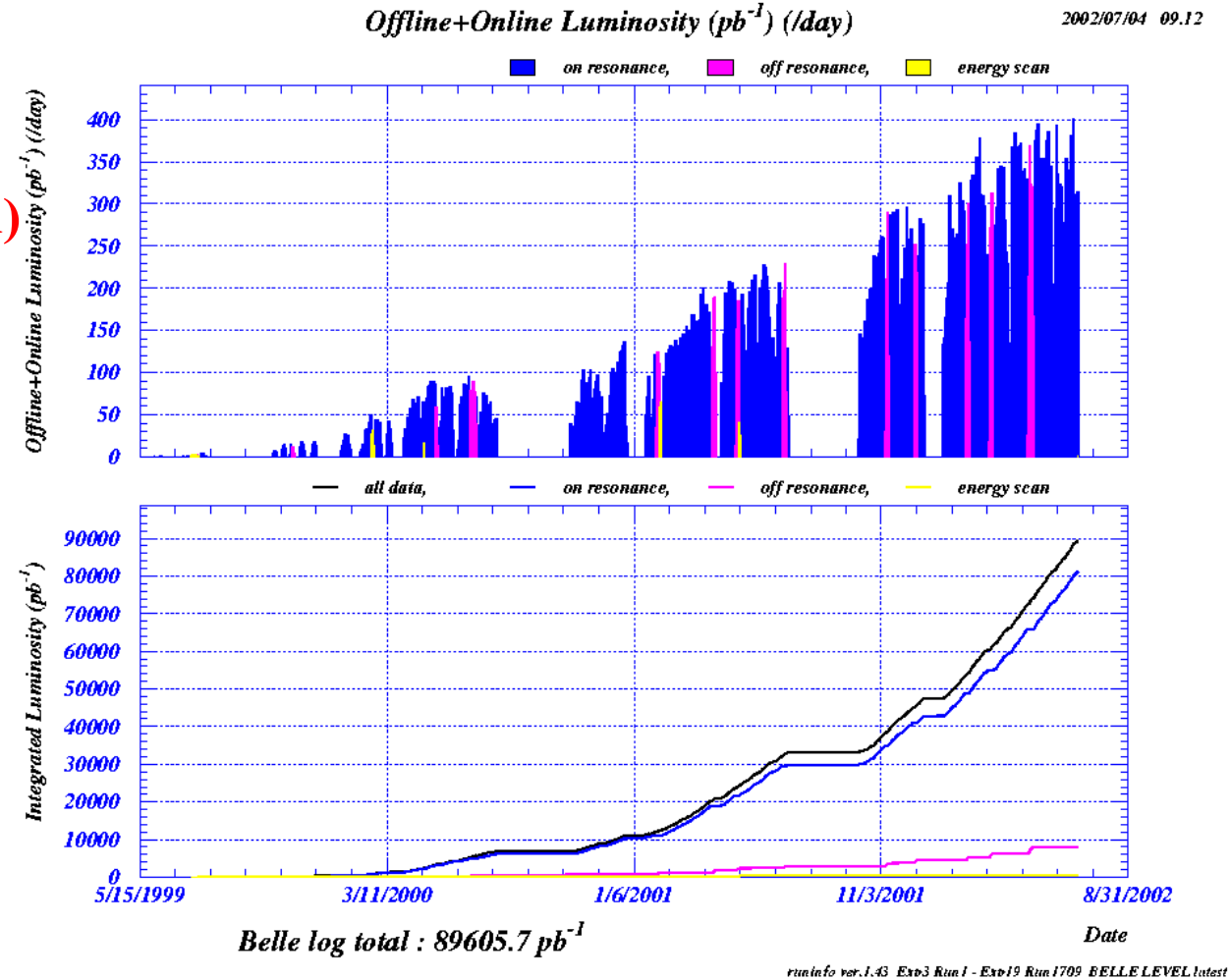
- KEKB
  - Asymmetric collider
  - 8GeV e^- + 3.5GeV e^+
  - $\sqrt{s}$ = 10.58GeV (Y(4S))
  - Beam size: 100 μm(σ_x) x 3 μm(σ_y)
  - Crossing angle: 11mr



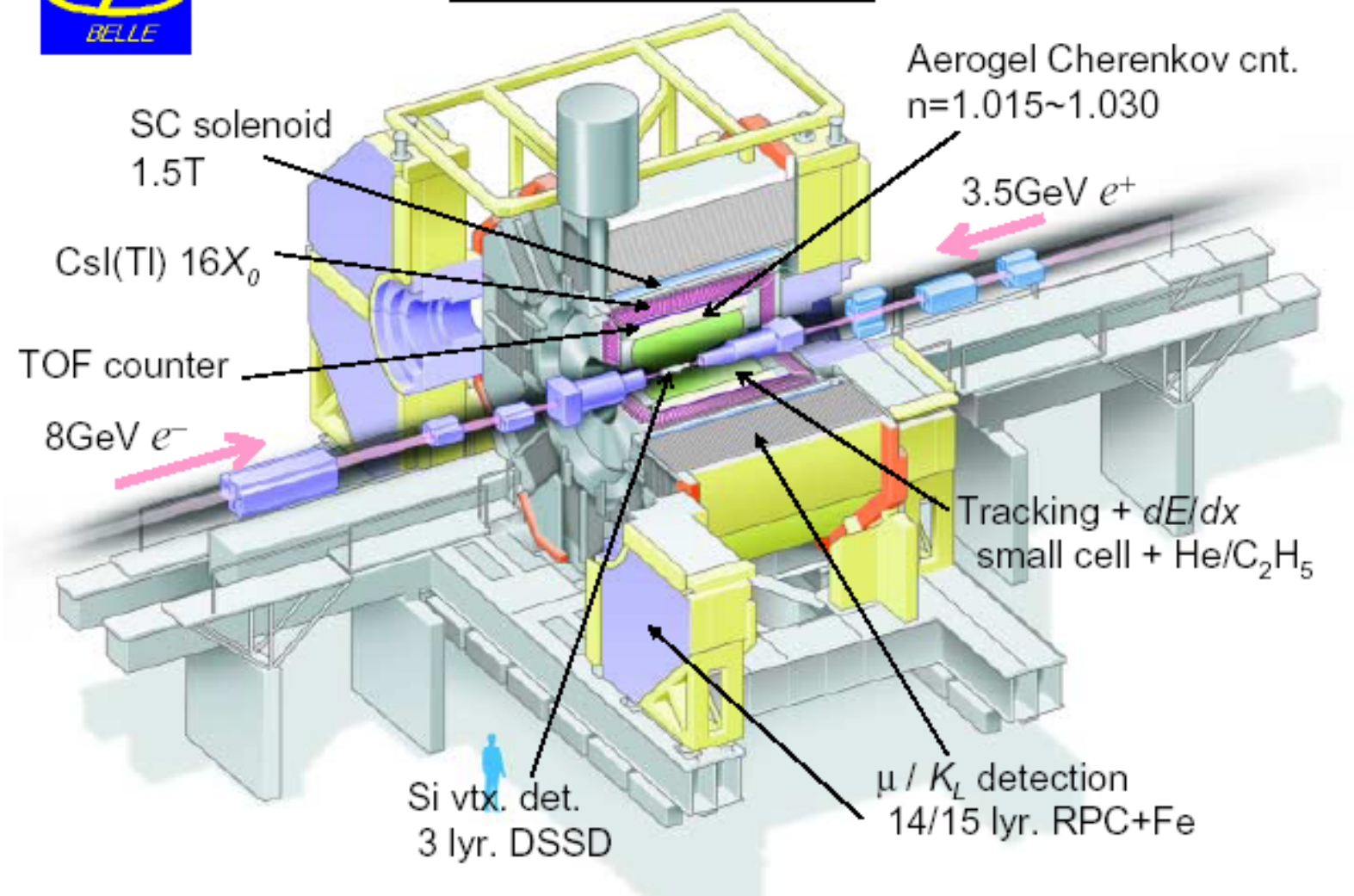


Luminosity at KEKB/Belle

- Luminosity
  7.4×10^{33} /cm^2/sec
  (peak; world record)
  (design: 10.0×10^{33})
- Integrated luminosity:
  89.6 fb^{-1}
  (10% off-resonance)
  > 10^8 events in tapes



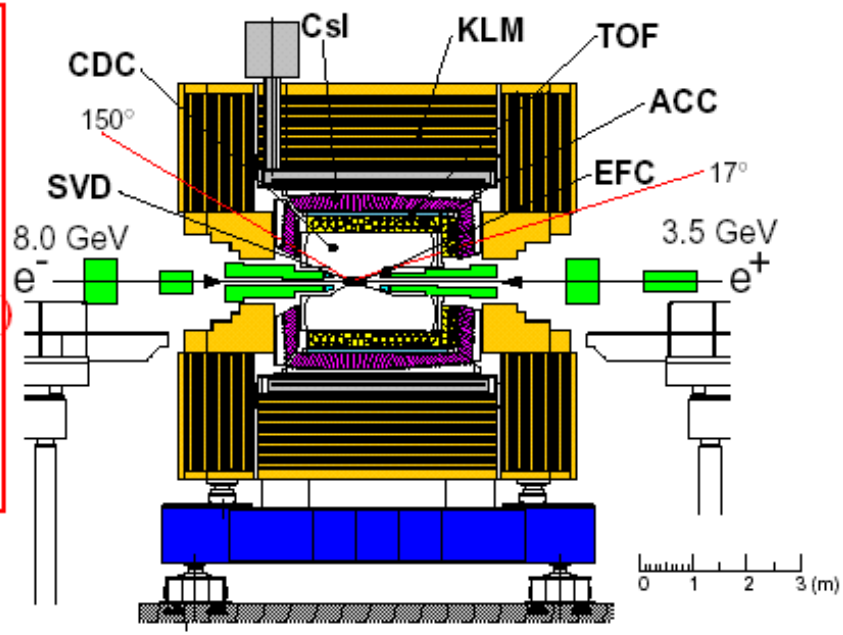
Belle Detector



Belle Detector Performance

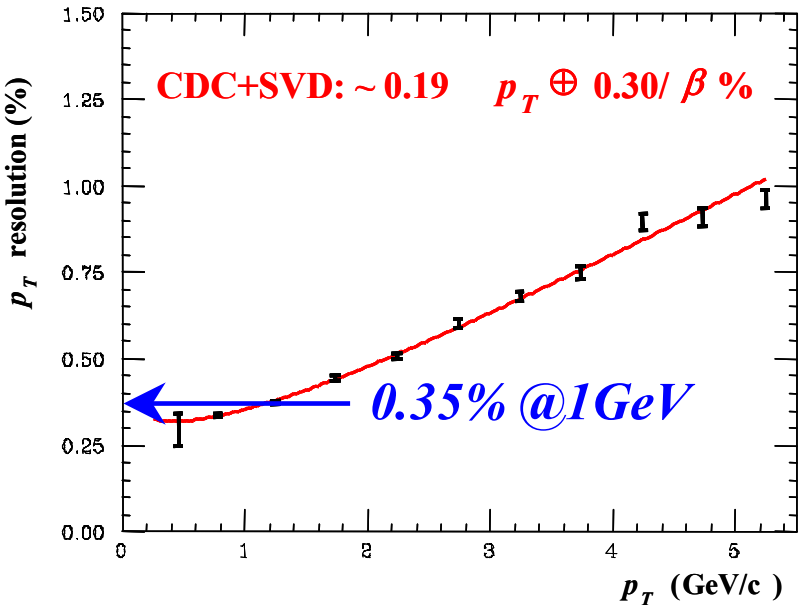
Tracking part :

Central Drift Chamber(CDC)
(50 layers)
$\sigma_{p_t}/p_t \sim 0.35\ \%$ @ 1 GeV/c
Silicon Vertex Detector(SVD)
(3 silicon layers/double−sided)
$\sigma \sim 55\,\mu m$ for 1GeV/c @ 90^0



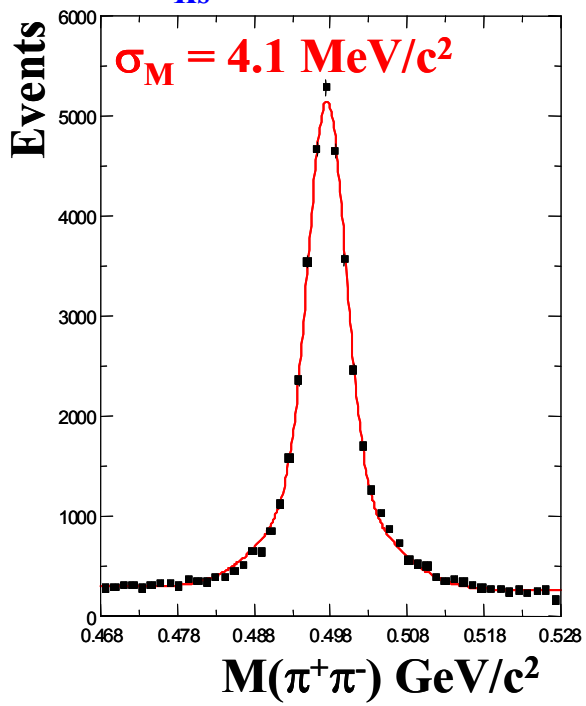
Particle identification ($K^{+/-}$id up to 3.5 GeV/c)
Aerogel Cherenkov Counter(ACC) : n=1.01 ~ 1.03
Time of Flight (TOF) $\sigma \sim 95$ ps
CDC (dE/dx) $\sigma_{dE/dx} \sim 7\%$
Electromagnetic Calorimeter(CsI(Tl) crystals) $\sigma_E / E_\gamma \sim 1.8\%$ @ 1 GeV
K_L and Muon detector (KLM = 14 layers) μ : $\varepsilon > 90\%$ and fake rate ~2%

Tracking Performance



$K_s \rightarrow \pi^+\pi^-$

$M_{Ks} = 497.7$ MeV/c²



Advantages of Belle for FF Measurements

- Good detector performance
- Jet production from light quarks

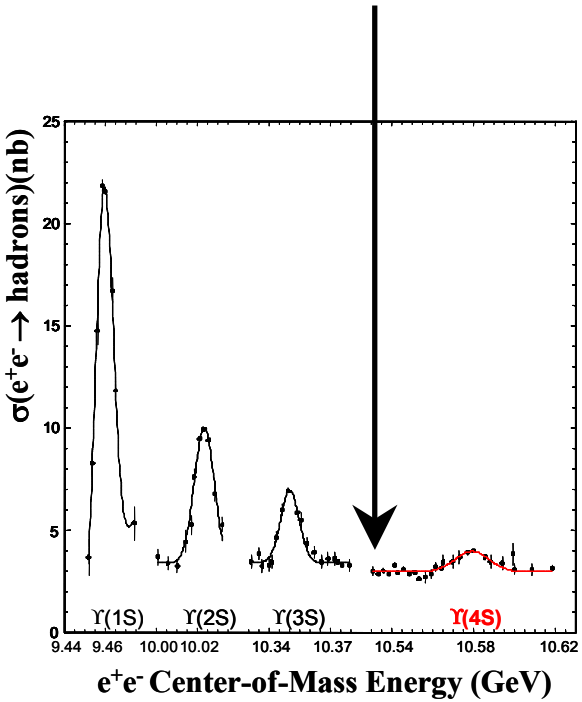
  => off-resonance (60 MeV below than resonance) data available
- High enough energy ($Q^2 \sim 100\ GeV$)

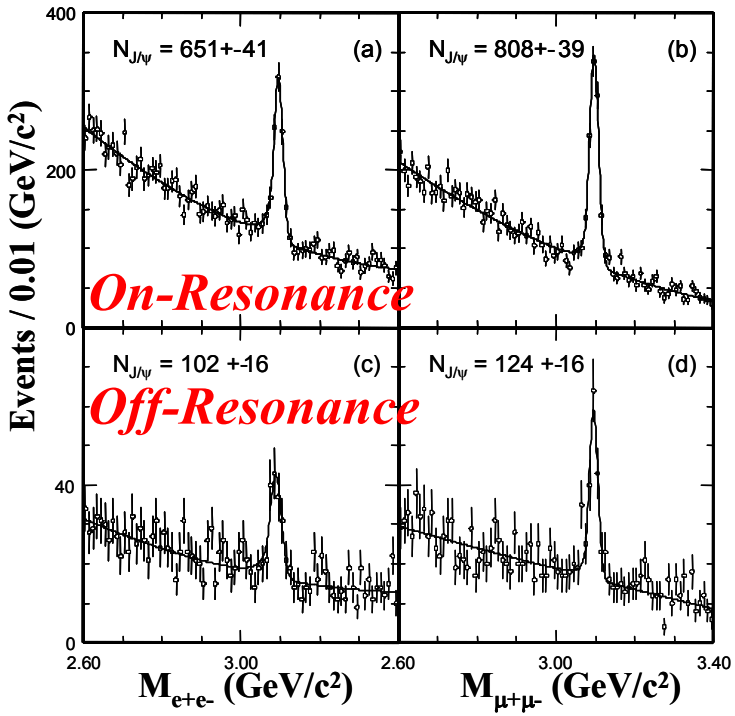
  => can apply pQCD
- Not too high energy ($\sqrt{s}_{Belle} < M_Z$)

  => can avoid additional complication from Z pole
- Sensitivity = $A^2 sqrt(N)$ ~ **x20** compared to LEP
  - $A_{\mathrm{Belle}} / A_{\mathrm{LEP}}$ ~ **x2** (A scale as $ln\ Q^2$)
  - $L_{\mathrm{Belle}} / L_{\mathrm{LEP}}$ ~ **x25**

Off-Resonance Data

- Jet production from light quarks
  => off-resonance data available
  60 MeV below than Y(4S)



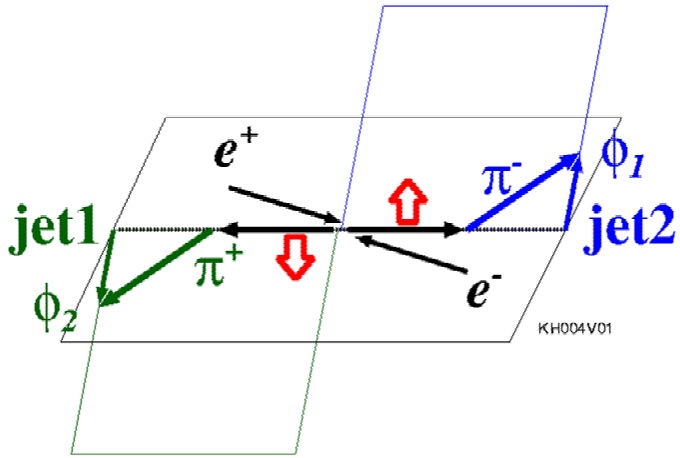


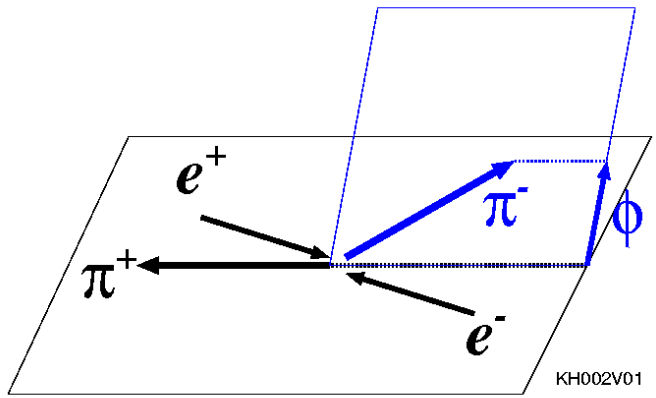
Analysis Method

- Reproduce spin-averaged FF from data
  - To estimate error sizes
  - To check the Q^2 evolution
- Use off-resonance data (also can use on-resonance data)
- Select light-quark events
  - Event-shape cuts
  - charm tag: vertexing, mass, etc.
  - bottom tag: in on-resonance; easy
- Require two-jet events
- Study azimuthal distribution as functions of z, m, k_T
- MC with and w/o spin-dependent FF models
- Use τ productions for cross checks

Collins-Heppelmann FF

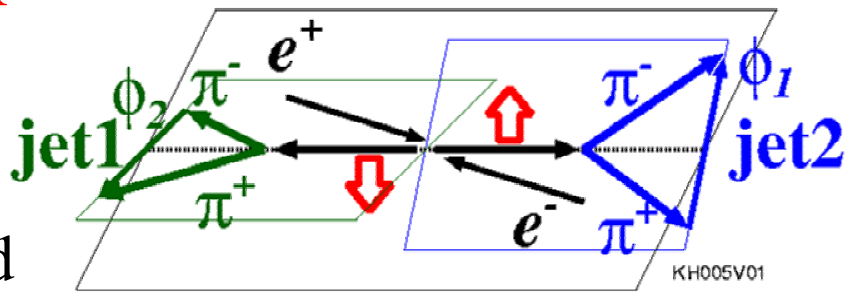
- $e^+e^- \rightarrow \pi^+_{jet1}\pi^-_{jet2}X$
- Quark spins are correlated
- $A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(\phi_1+\phi_2)$
  $= H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(2\phi)$
- Can analyze with/without using jet axis





Two-Pion Fragmentation

- $e^+e^- \rightarrow (\pi^+\pi^-)_{jet1}(\pi^-\pi^+)_{jet2}X$
- Stay in the mass region around ρ
- Quark spins are correlated
- $A \propto \delta q_1(z_1, m_1)\ \delta q_1(z_2, m_2) \cos(\phi_1+\phi_2)$



Summary

- Chiral-odd FFs are required
  - To measure transversity from *pp/DIS*
  - Collins-Heppelmann FF and IFF
  - Chiral-odd FFs themselves are interesting
- e^+e^- can extract the FFs:
  - By measuring azimuthal asymmetry/correlation
- Belle experiment can measure the FFs:
  - Advantage in luminosity, detector performance, beam energies, etc.
  - RHIC spinners are working on it!
  - Spin-dependent FFs can be used for HERMES, COMPAS, etc.
  - Can compare with the results from LEP
- Schedule of Transversity Project
  - Belle *CF, IF* 2002-2004
  - PHENIX *IF, DY,* A_N 2002-2007
  - STAR *IF, CF,* A_N 2002-2007
  - RBRC lattice *TC* 2005-?