Measurement of Spin Dependent Fragmentation Functions at Belle: A Brief Status Report

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on

Deep Inelastic Scattering

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Measurement of Spin Dependent Fragmentation Functions at Belle: A Brief Status Report

- Motivation: → The Collins-Heppelman and Interference Fragmentation functions as input at HERMES, COMPASS and RHIC
- Feasibility: → Analysis of Delphi data by Efremov et al. Universality and Factorization?

- KEK/Belle
- Experimental Method
- Summary

Motivation: Transversity at RHIC (and at HERMES and COMPASS)

Physics Channels

$\int Ldt = 320\ \mathrm{pb}^{-1}, \sqrt{s} = 200\mathrm{GeV}$

- Collins Effect in Jets:

  $$A_T(pp_\perp \to \pi + Jet + X)$$

  J.C. Collins, Nucl. Phys. B396, 161(1993)

- π^+, π^- Interference Fragmentation :

  $$A_T\left(p_\perp p \to (\pi^+, \pi^-) + X\right)$$

  J. Collins, S. Heppelmann, G. Ladinsky, Nucl.Phys. B420 (1994)565

  R. Jaffe, X.Jin, J. Tang Phys. Rev. D57 (1999)5920

- Inclusive jet production

  $$5 \cdot 10^{-4} \le A_{TT} \le 3 \cdot 10^{-3}$$

  W. Vogelsang and M. Stratmann, RBRC Workshp on Transversity (2000)

- A_{TT} in Drell Yan requires $\int Ldt > 320\mathrm{pb}^{-1}$

  O.Martin, A. Schafer, M. Stratmann, W. Vogelsang Phys.Rev. D60, 117502(1999)

STAR

PHENIX

Observables are $\propto \delta q \cdot H_1^\perp$

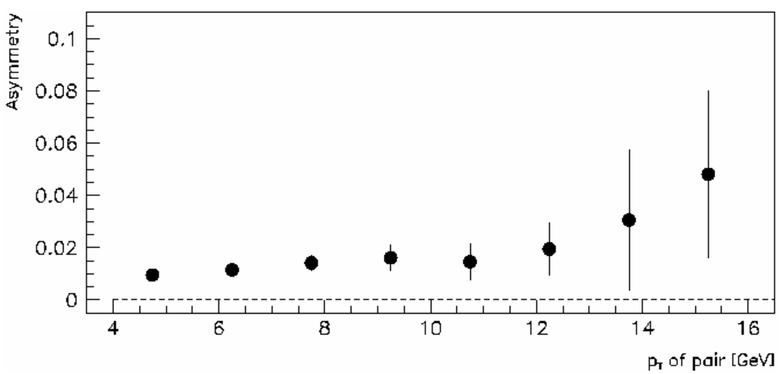
$\propto$ distribution function

$\times$ fragmentation function

Example: Interference Fragmentation in PHENIX

$A_T(p_\perp \to \pi^+\pi^- + X)$ vs p_T^{pair}

Statistical sensitivity for $32\mathrm{pb}^{-1}$



Need independent Measurement of spin dependent fragmentation functions

SIDIS, polarized pp, e^+e^-: Global Analysis

I	Single transverse spin asymmetries in SIDIS $\propto \delta q \cdot H_1^{\perp}$	HERMES COMPASS
II	Measure $\delta\hat{q}_I, H_1^{\perp}$ in e^+e^- using b - factory data	Belle
III	Measure $\delta q \cdot \delta\hat{q}_I$ $\delta q \cdot H_1^{\perp}$ in polarized pp: A_N, A_T, A_{TT} **See STAR and PHENIX talks later**	BRAHMS PHENIX PHOBOS STAR

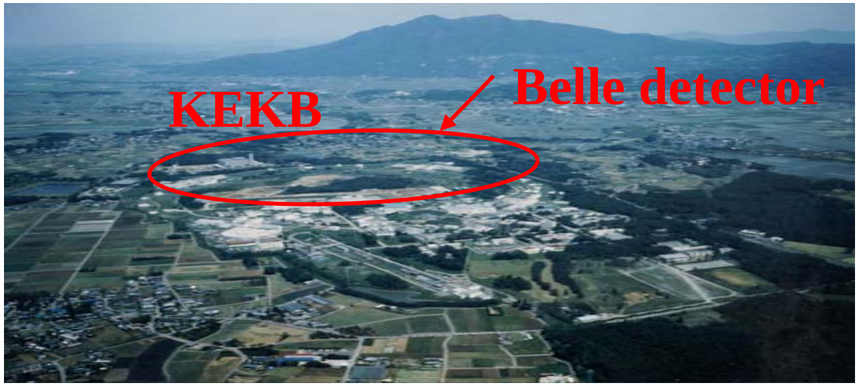
→ Input to a global analysis!

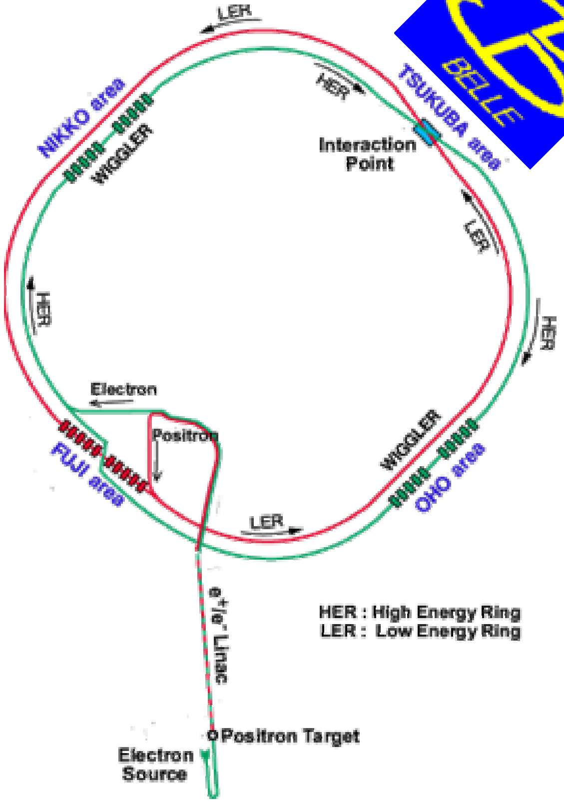
Open questions: Factorization and Universality
(Brodsky et al., Metz, Collins, Mulders et al.,
ongoing work by Collins and Metz)

KEKB: $L=1.2\times10^{34}cm^{-2}s^{-1}$!!

- KEKB
  - Asymmetric collider
  - 8GeV e^- + 3.5GeV e^+
  - $\sqrt{s}$ = 10.58GeV (Y(4S))
  - Off-resonance: 10.52 GeV
  - **Integrated Luminosity: 232 fb^{-1}**

    23fb^{-1} => 69 million hadronic events off-resonance





Belle Collaboration

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Budker Institute of Nuclear Physics
Chiba Univ.
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High Energy Accelerator Research Organization (KEK)
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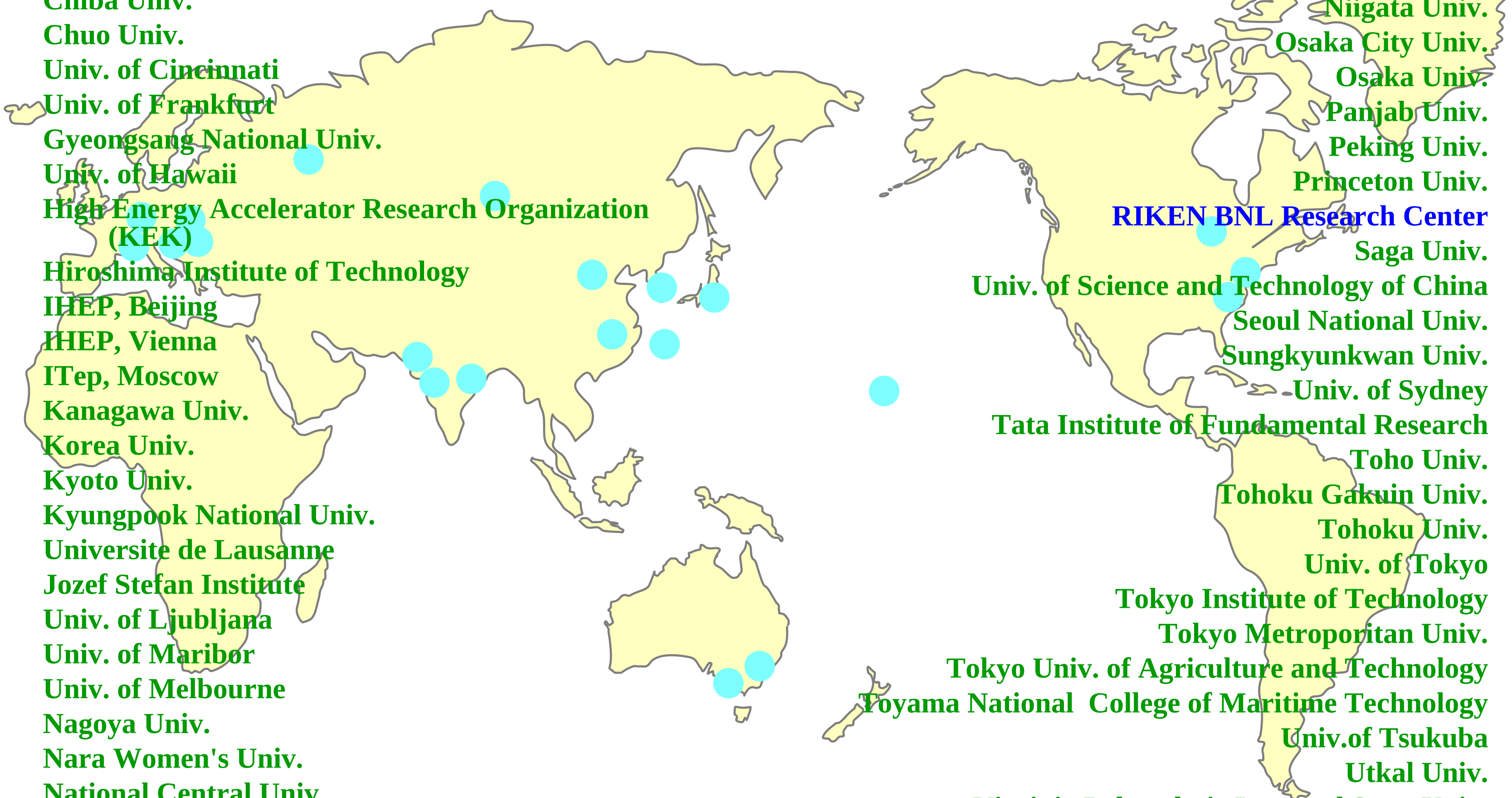
Univ. of Maribor
Univ. of Melbourne
Nagoya Univ.
Nara Women's Univ.
National Central Univ.
National Kaohsiung Normal Univ.
National Lien-Ho Institute of Technology
National Taiwan Univ.



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Princeton Univ.
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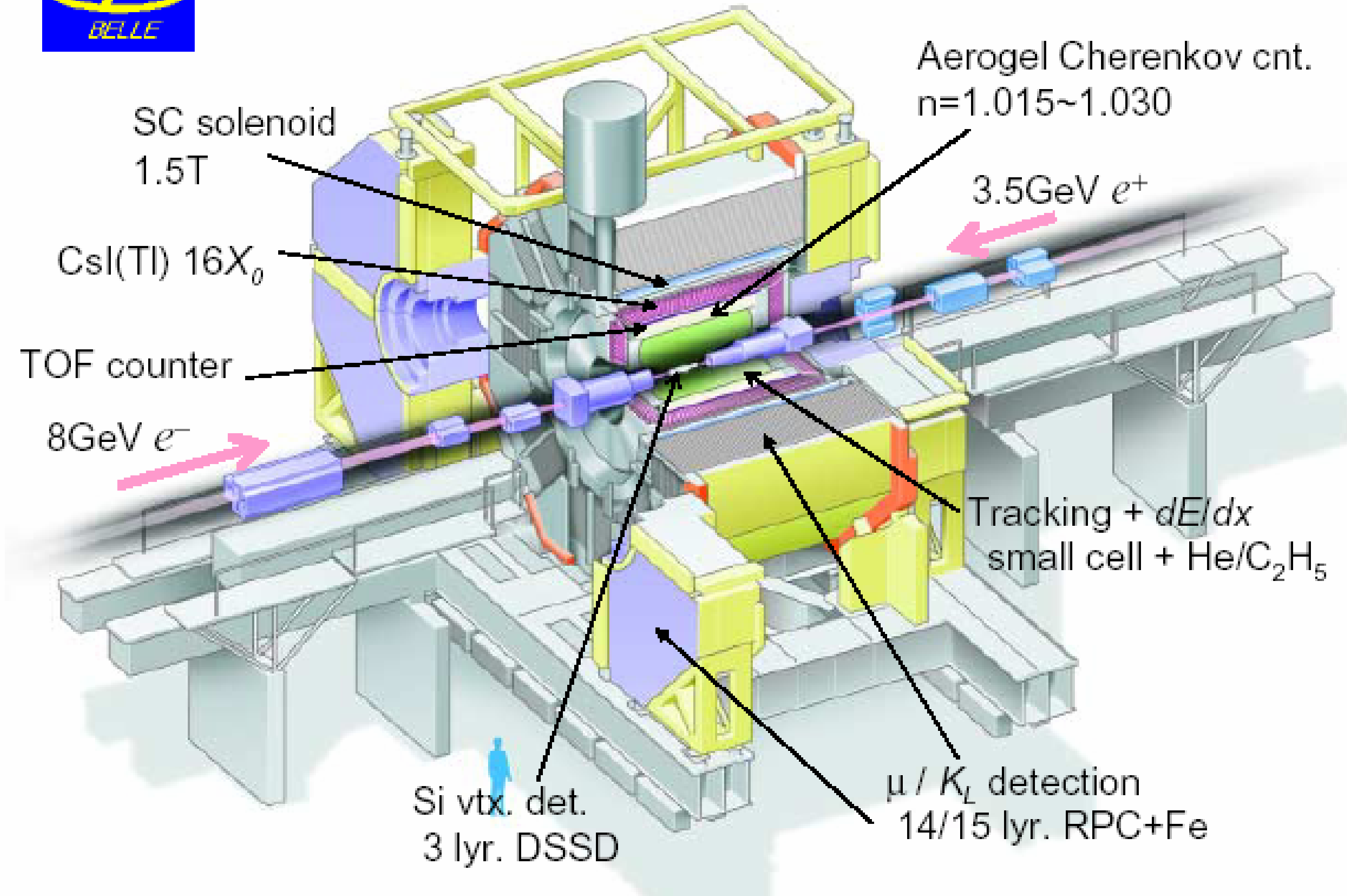
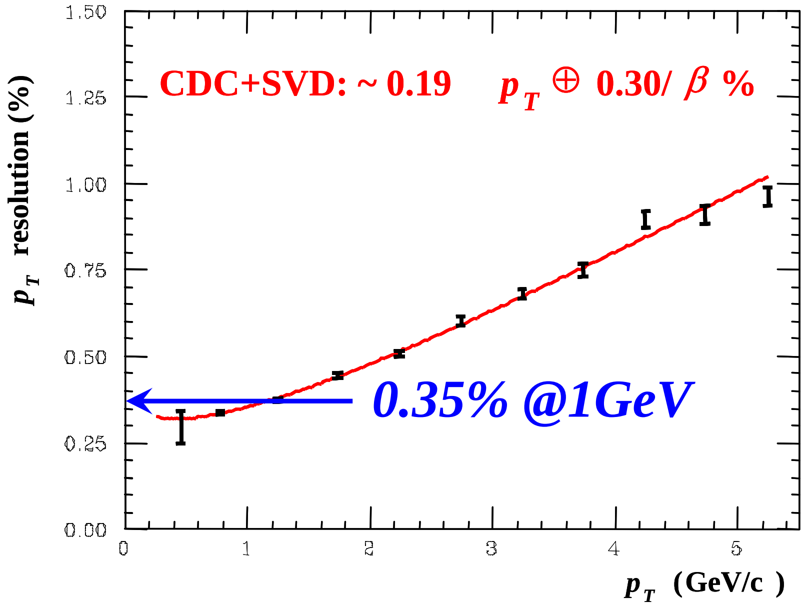
Tokyo Metroporitan Univ.
Tokyo Univ. of Agriculture and Technology
Toyama National College of Maritime Technology
Univ.of Tsukuba
Utkal Univ.
Virginia Polytechnic Inst. and State Univ.
Yokkaichi Univ.
Yonsei Univ.

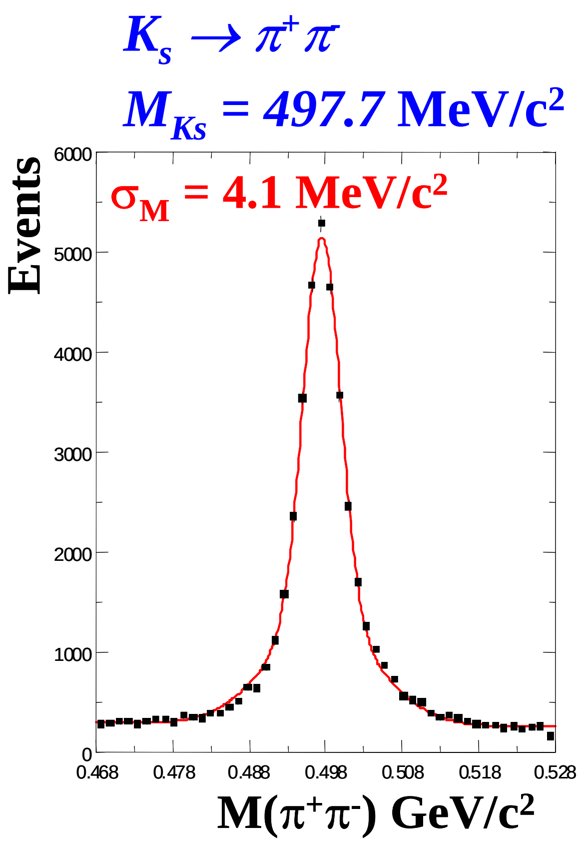
Belle Detector



Excellent tracking and particle identification!

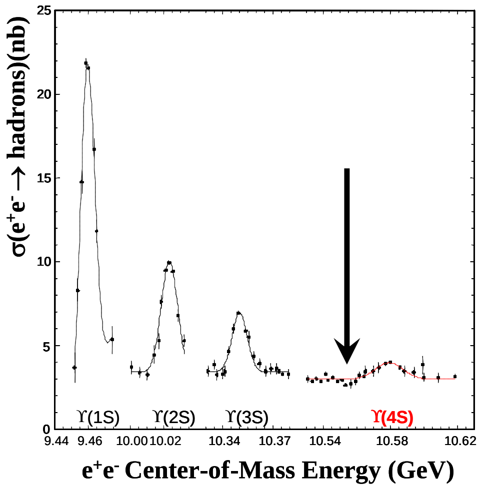
Tracking Performance





Belle is well suited for FF measurements:

- Good detector performance (acceptance, momentum resolution, pid)



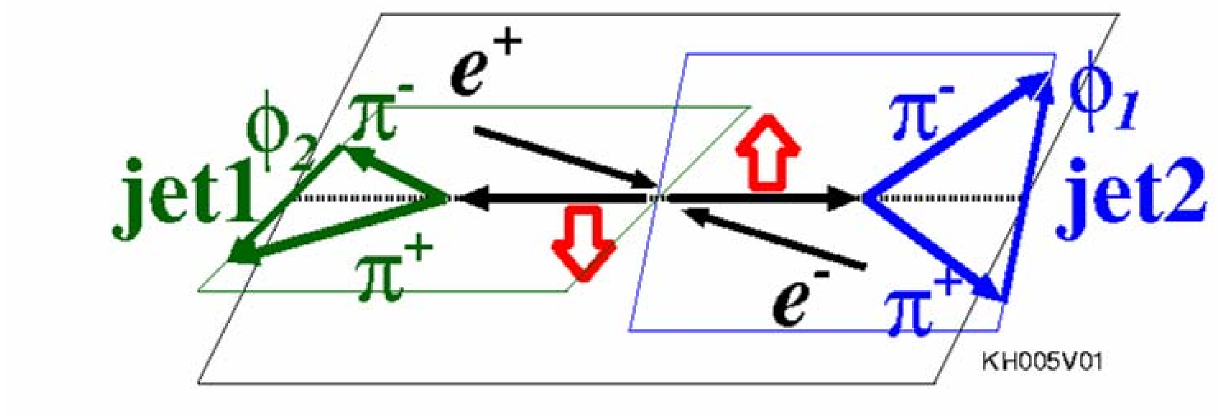
- Jet production from light quarks
  => off-resonance (60 MeV below resonance)
  69M events available (~10% of all data)

- Sufficiently high scale (Q^2 ~ *100 GeV*)
  => can apply pQCD

- Not too high energy ($\sqrt{s}_{Belle} < M_Z$)
  => avoids additional complication from Z interference
  => Sensitivity = A^2*sqrt(N)* ~ **x19** *(60)* compared to LEP
  $A_{\text{Belle}} / A_{\text{LEP}}$ ~ **x2** (*A* scales as *ln* Q^2)
  $L_{\text{Belle}} / L_{\text{LEP}}$ ~ **x23** *(230)*

Two-Hadron Fragmentation

Collins, Heppelman, Ladinsky, Jaffe, Jin, Tang



- $e^+e^- \rightarrow (\pi^+\pi^-)_{jet1}(\pi^-\pi^+)_{jet2}X$
- Stay in the mass region around ρ–mass
- Find pion pairs in opposite hemispheres
- Observe angles $\phi_1+\phi_2$ between the event-plane (beam, jet-axis) and the two pion planes.
- $A \propto \delta q_I(z_1, m_1)\ \delta q_I(z_2, m_2)\ \cos(\phi_1+\phi_2)$

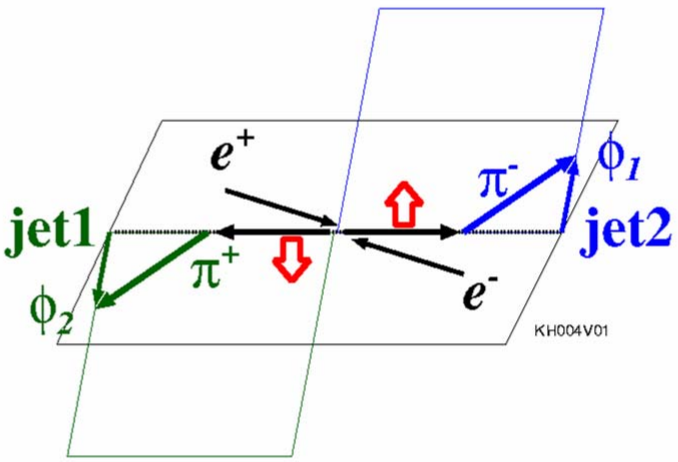
Collins-Heppelman Fragmentation Function

I) Two-Jet-method

- $e^+e^- \to \pi^+_{jet1}\pi^-_{jet2}X$
- Reaction plane defined with beam (z-axis) and jet axis
- Hadron plane defined with π and jet axis on each side:

  ϕ_i → angle between the planes

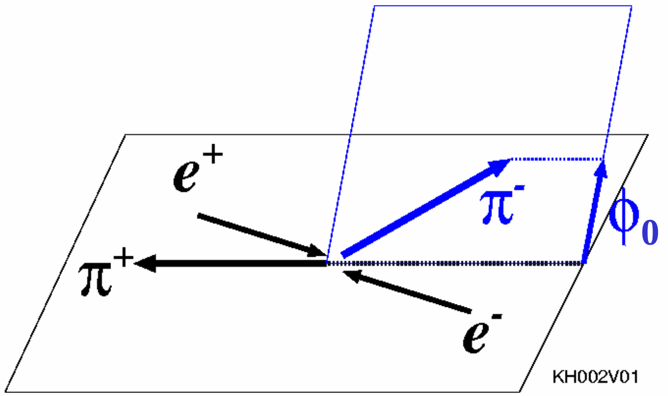
$$A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(\phi_1+\phi_2)$$



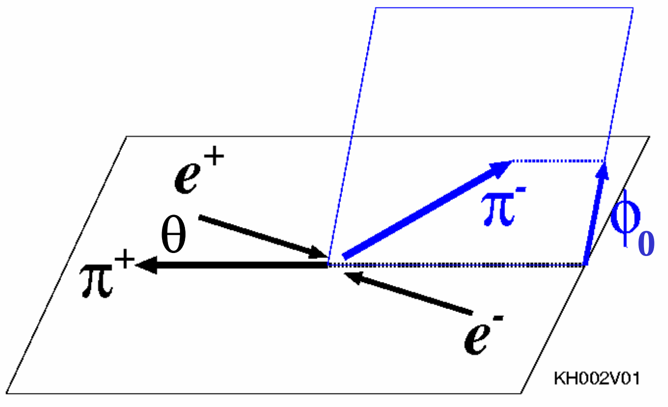
II) Two-hadron-method

- Can analyze with/without using jet axis

$$A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(2\phi)$$



Angular Dependence in the Cross Section



$$\frac{1}{\sigma_0}\frac{d\sigma^{e^+e^-\longrightarrow\pi^+\pi^-X}}{dz_1 dz_2}$$

$$\sim \quad (1+\cos^2\theta\sum_q D_q^{\pi+}(z_1)\overline{D_{q'}^{\pi^-}(z_2)}$$

$$+ \quad \sin^2\theta\cos 2\phi_0\sum_q H_1^\perp(z_1)\overline{H_1^\perp(z_2)})$$

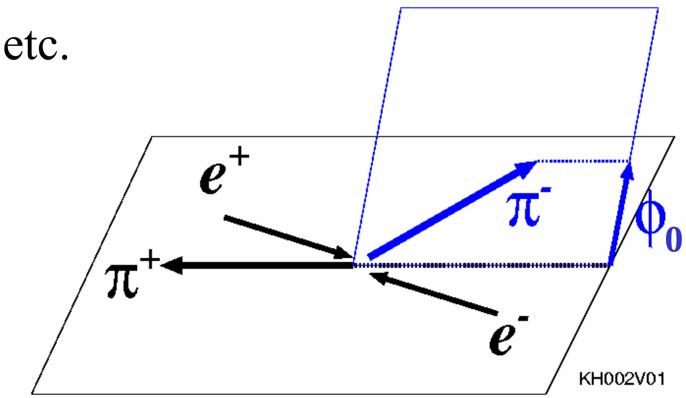
Analysis Procedure

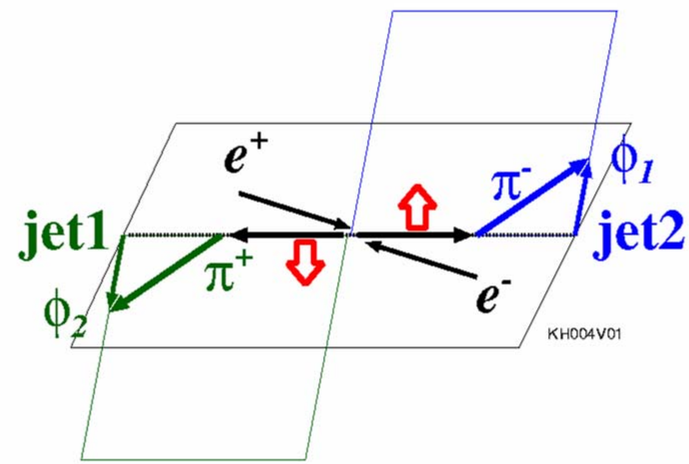
Collins-Heppelmann FF: $H_1^{\perp}(z)$ for $e^+e^- \rightarrow \pi^+_{jet1}\pi^-_{jet2}X$

- **Event Selection**
  - Light-quark events with event-shape, vertexing, etc.
  - 2-jet events with T>0.85
- **Track Selection**
  - Tracks from IP (vertex cut)
  - PID to select pions
- **Angle measurements**
  - Reaction plane defined with beam (z-axis) and jet axis
  - hadron planes defined with pions and jet axis
  - ϕ_i: angles between the planes
- **Asymmetry study**
  - Search azimuthal angle correlations

$A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(2\phi_0)$ or
$A \propto H_1^{\perp}(z_1)H_1^{\perp}(z_2)\cos(\phi_1+\phi_2)$

as functions of z



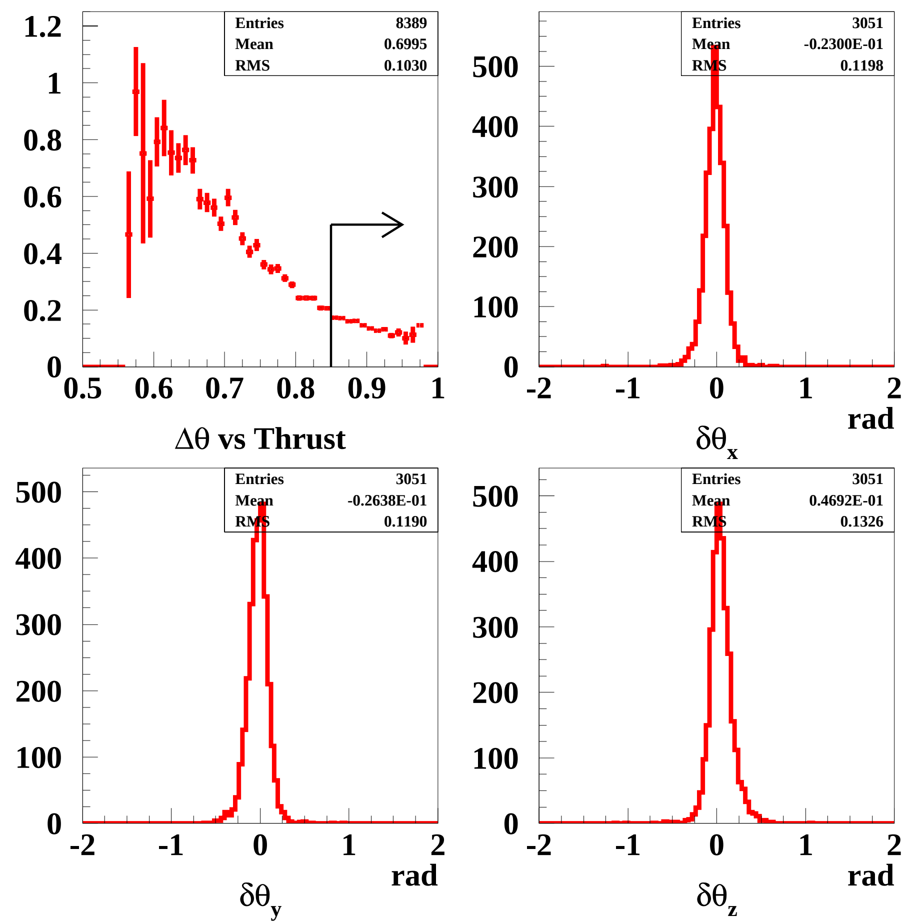


How well do we know the original quark momenta: Thrust ?

- Thrust appears to be a good estimator for the jet axis, but the angular resolution indicates that the knowledge of the original quark direction is limited by detector acceptance effects.

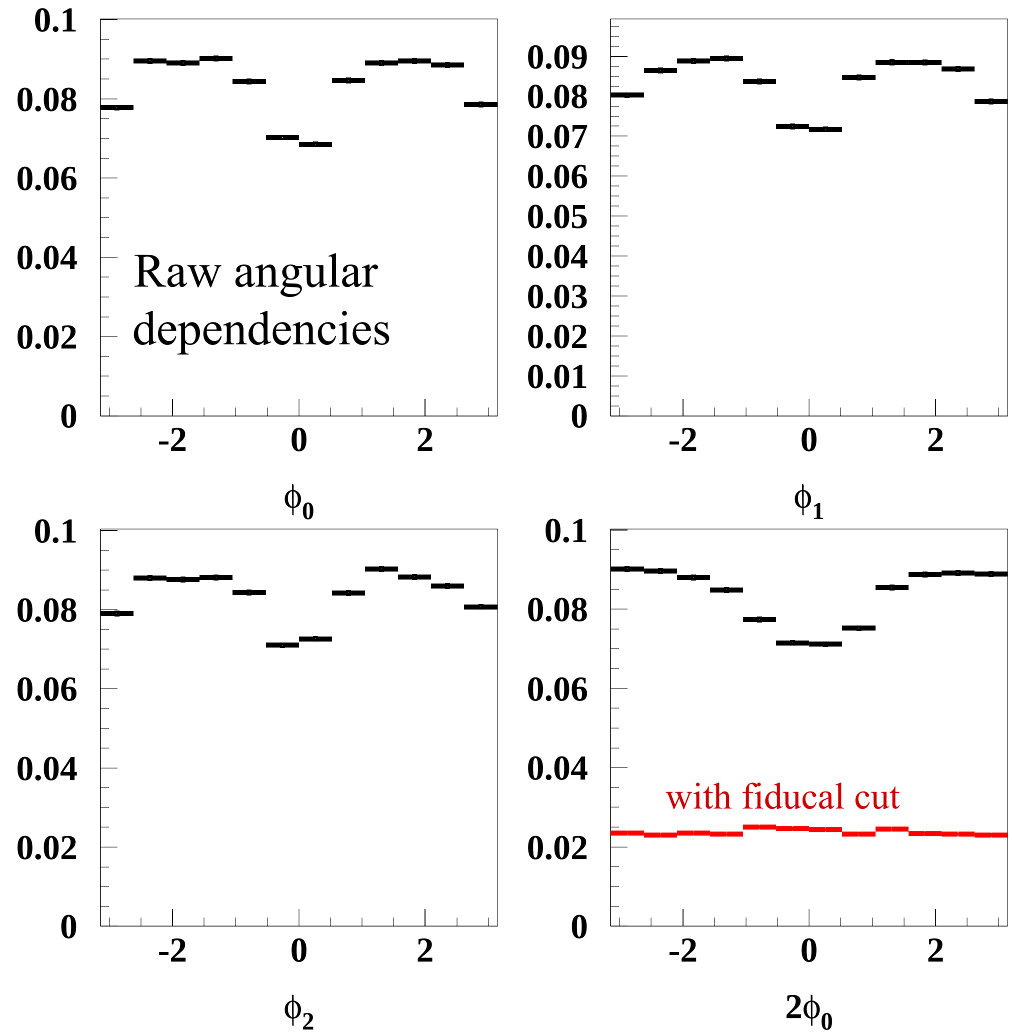
- T > 0.85 to enhance 2-jet events

MC: Quark momentum direction vs reconstructed thrust



Acceptance effects:

- Raw asymmetries for unlike-sign pion pairs
- Large asymmetries due to detector acceptance effects
- false asymmetries can be reduced by applying fiducial area cuts at the expense of statistics and difficulties in estimating the size of the remaining effect.



➔ Ratios:

$$R = \frac{\text{unlike - sign Data}}{\text{like - sign Data}},$$

$$R = \frac{\text{unlike - sign Data}}{\text{unlike - sign MC}},$$

$$\mathrm{R} = \mathrm{R}(\mathrm{H}_1^{\perp,\text{ favored}}, H_1^{\perp,\text{unfavored}}, D's)$$

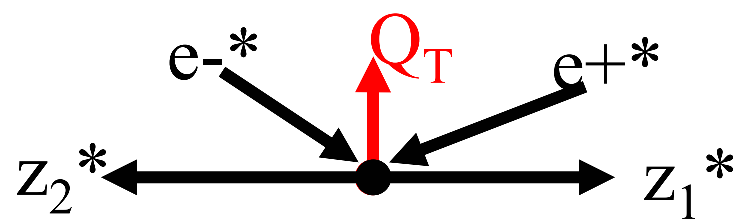
Background Sources

The following sources can generate azimuthal asymmetries:

- Limitation of detector acceptance
  - fiducial cut, ratios
- Beam background
  - vertex cut
- Weak decays
  - $\rho \to \pi\pi$ is dominant
  - low z
- Gluon emission

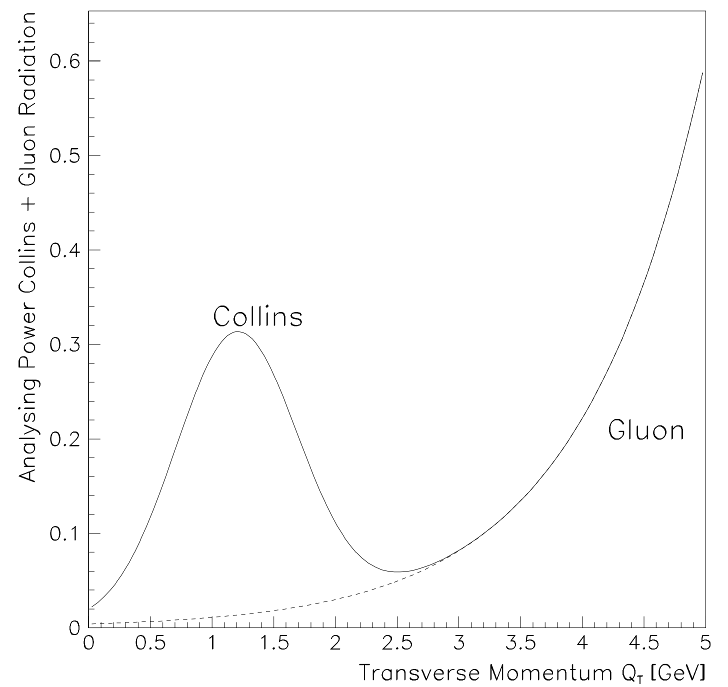
Gluon Radiation

- Gluon radiation can generate asymmetries!
- For gluon emission Q_T is large
(no calculation available for e^+e^-, however analogous effect for Drell-Yan discussed by D. Boer *et al Phys.Rev.D67:054003,2003*



pion rest frame

- Q_T dependence?
$\sim Q_T^2/Q^2 \cos 2\phi \cdot FF$



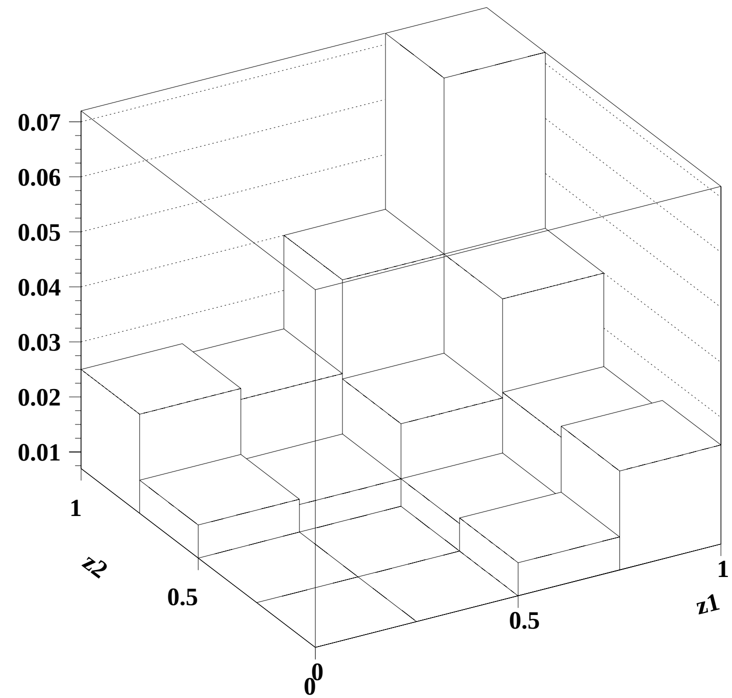
- Can we use Q_T dependence to separate Collins effects from gluon radiation?
- Formalism for e+e- is under development
(Daniel Boer)

Prospects: Available statistics
(for Collins Heppelman function)

- #events ~ 45M processed (off-resonance data)
- Event selection
  - Thrust > 0.85
  - $\pi^+\pi^-$ in different hemispheres (for Collins function)
  - 15 bins in $2\phi_0$ $(\phi_1+\phi_2)$

= 0.7% of statistical error for highest z-bin (z_1,z_2> 0.7) on A.

Statistical Errors vs z_1 and z_2



- 10 times more data available on-resonance

Summary

- Chiral-odd FFs are required
  - To measure transversity from *pp and SIDIS*
  - Collins FF and IFF
  - Chiral-odd FFs have interesting symmetry properties

- Belle experiment can determine the FFs:
  - Excellent luminosity, detector performance, beam energy, etc.
  - Analysis in progress
  - All off-resonance data have been processed and analyzed
  - We believe to understand the experimental systematic problems and the analysis focuses on the separation of Collins asymmetries from the physics background.

- Unpolarized FF analysis

  analysis for charged hadrons and idendified hadrons in progress

  very high statistics at high z