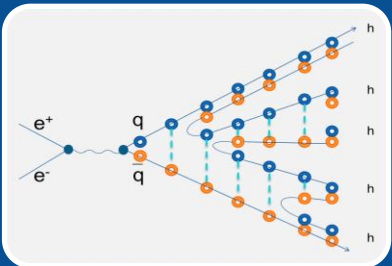
Fragmentation measurements in Belle

KEK Hadron and nuclear physics workshop
01/07/2017

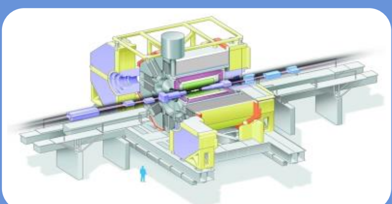
Ralf Seidl (RIKEN)

What are fragmentation functions?



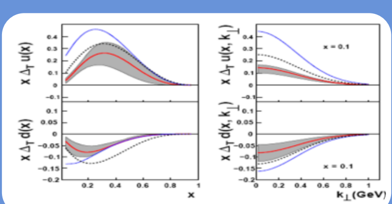
How do quasi-free partons fragment into confined hadrons？

- Does spin play a role？Flavor dependence?
- What about transverse momentum (and its Evolution)？



What experiments measure：

- Normalized hadron momentum in CMS： $e^+e^- \rightarrow h(z)\,X$; $z = 2E_h/\sqrt{s}$
- Hadron pairs' azimuthal distributions： $e^+e^- \rightarrow h_1\,h_2\,X$; $<\cos(\phi_1+\phi_2)>$; Collins FF、Interference（IFF）
- Cross sections or multiplicities differential in z: ep->hX, pp->hX

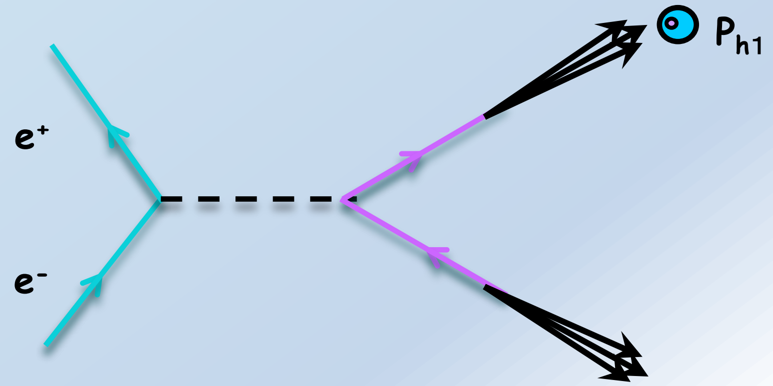


Additional benefits of the FF measurements：

- Pol FFs necessary input to transverse spin SIDIS und pp measurements to extract Transversity distributions function
- Flavor separation of all Parton distribution functions (PDFs) via FFs (including unpolarized PDFs)
- Baseline for any Heavy Ion measurement
- Access to exotics?

Unpolarized fragmentation functions

$$D_{1,q}^{h}(z, Q^2)$$

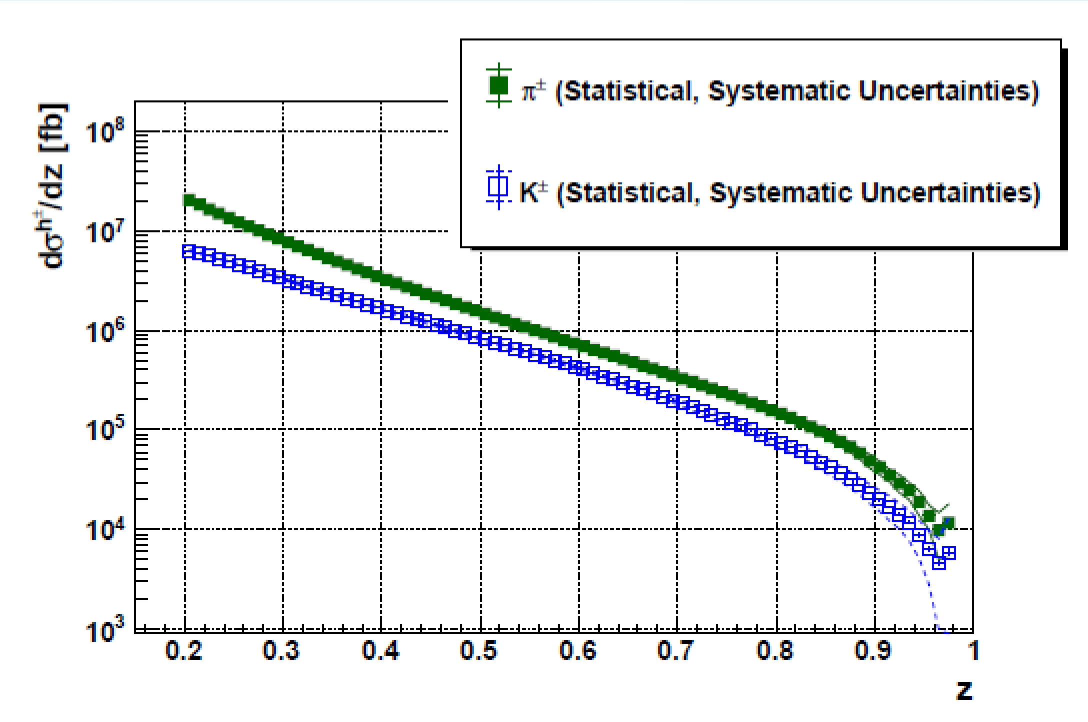


Unpolarized light hadron fragmentation

In e^+e^- annihilation:

$$Q = \sqrt{s}$$
$$z = \frac{2E_h}{Q} \approx \frac{E_h}{E_q}$$

Phys.Rev.Lett. 111 (2013) 062002,
Leitgab, RS, et al (Belle)



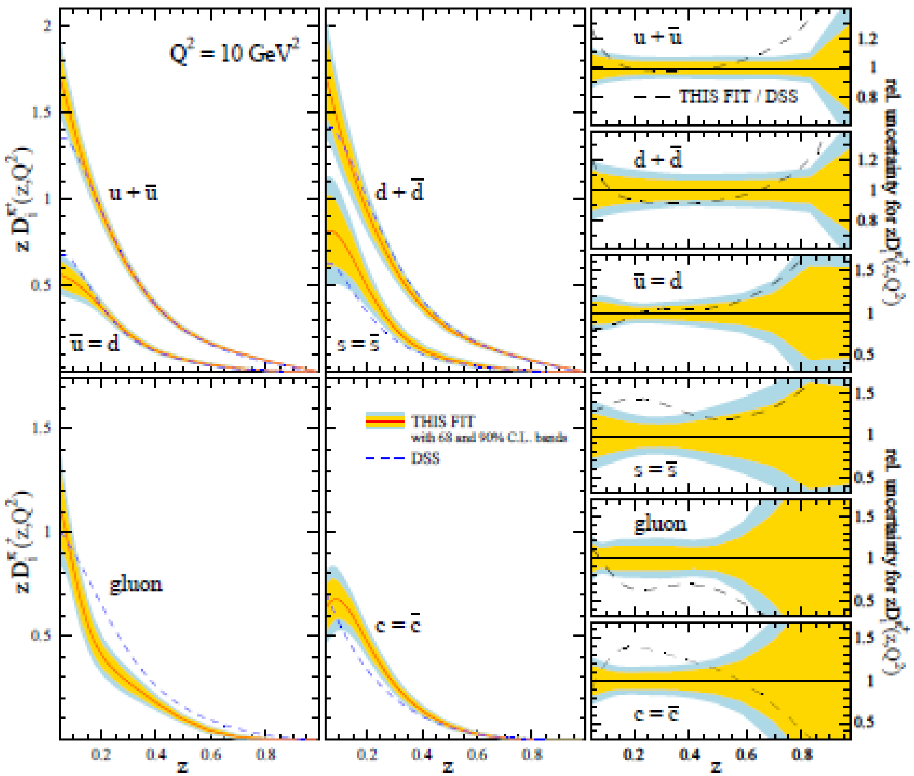
- Single-hadron cross sections at leading order in α_s related to fragmentation functions

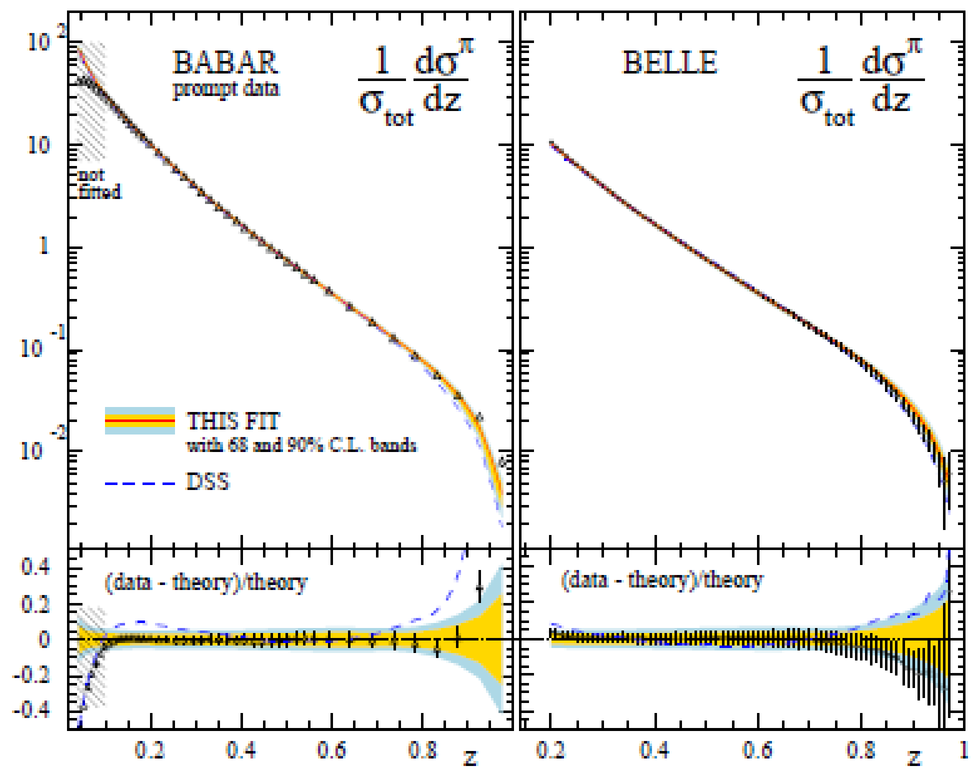
$$\sigma(e^+e^- \to hX) \propto \sum_q e_q^2 \left(D_{1,q}^h(z) + D_{1,\bar{q}}^h(z)\right)$$

- Only at higher orders access to gluon FFs

Belle data used in global FF fits

Phys.Rev. D91 (2015) 1, 014035





- Together with other new data substantial improvement in uncertainties
- Shift in central values

- Good description of B-factory data
- Also recent inclusion in JAMFF fit arXiv1609.00899

New addition: single protons

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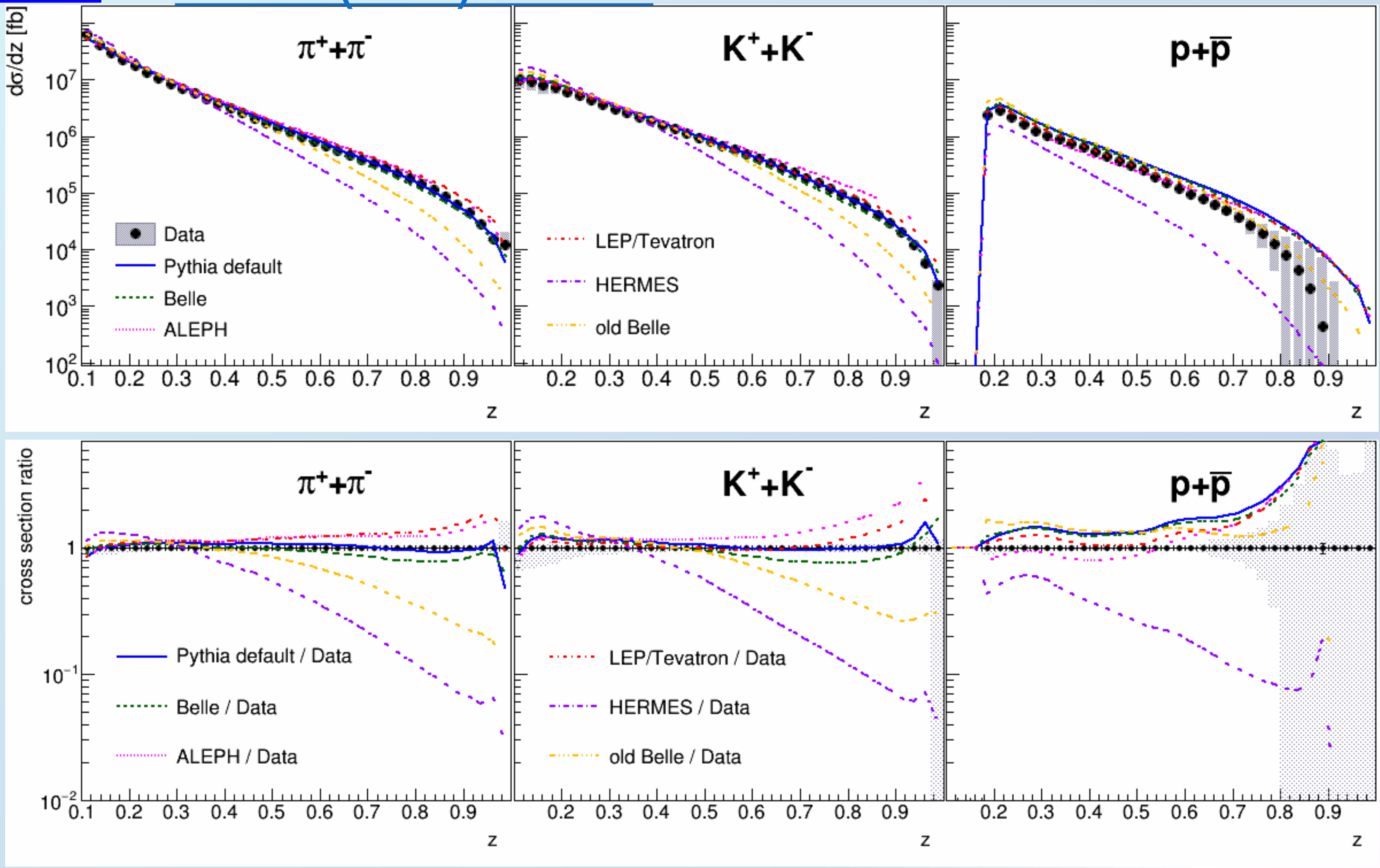


- Default Pythia and current Belle in good agreement with pions and kaons
- Protons not well described by any tune

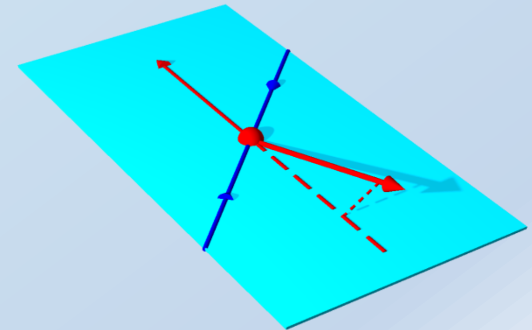
Transverse momentum dependence

Aka un-integrated PDFs and FFs

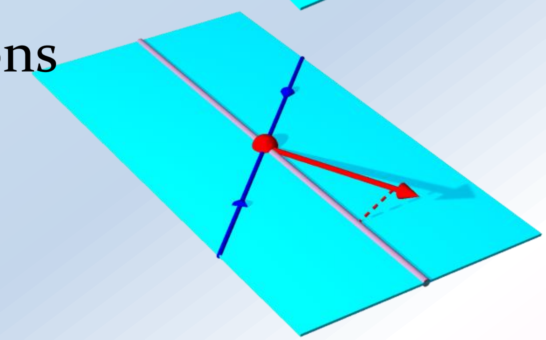
$$D_{1,q}^{h}(z, Q^2, k_t)$$

K_T Dependence of FFs

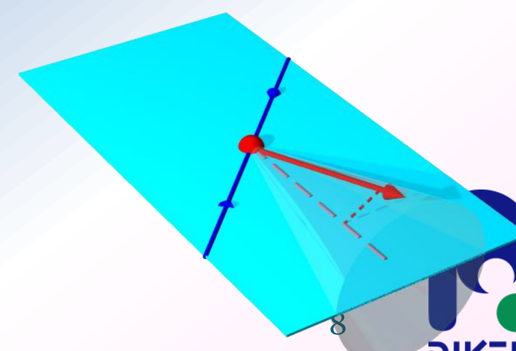
- Gain also sensitivity into transverse momentum generated in fragmentation
- Two ways to obtain transverse momentum dependence



  - Traditional 2-hadron FF
    - → use transverse momentum between two hadrons (in opposite hemispheres)
    - → Usual convolution of two transverse momenta



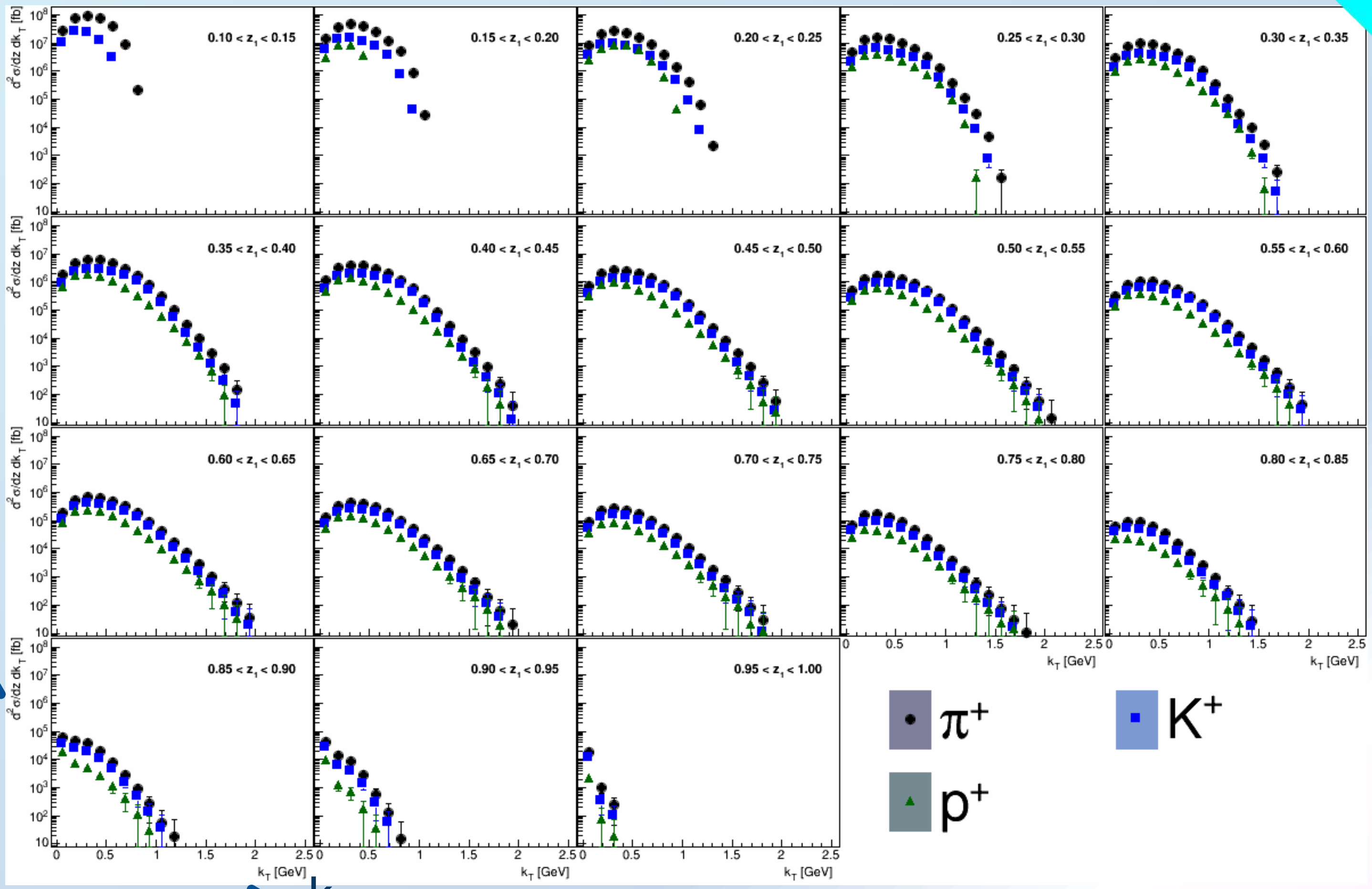
  - Single-hadron FF wrt to Thrust or jet axis
    - → No convolution
    - → Need correction for $q\bar{q}$ axis



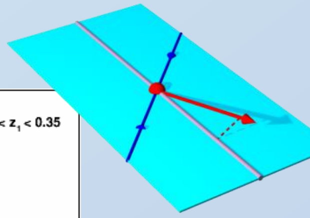
MC sample for various hadrons

MC simulation

$$\frac{d^2\sigma}{dz dk_T}$$

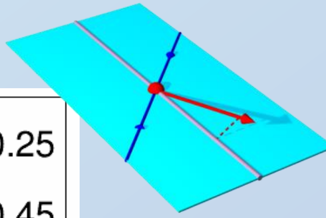


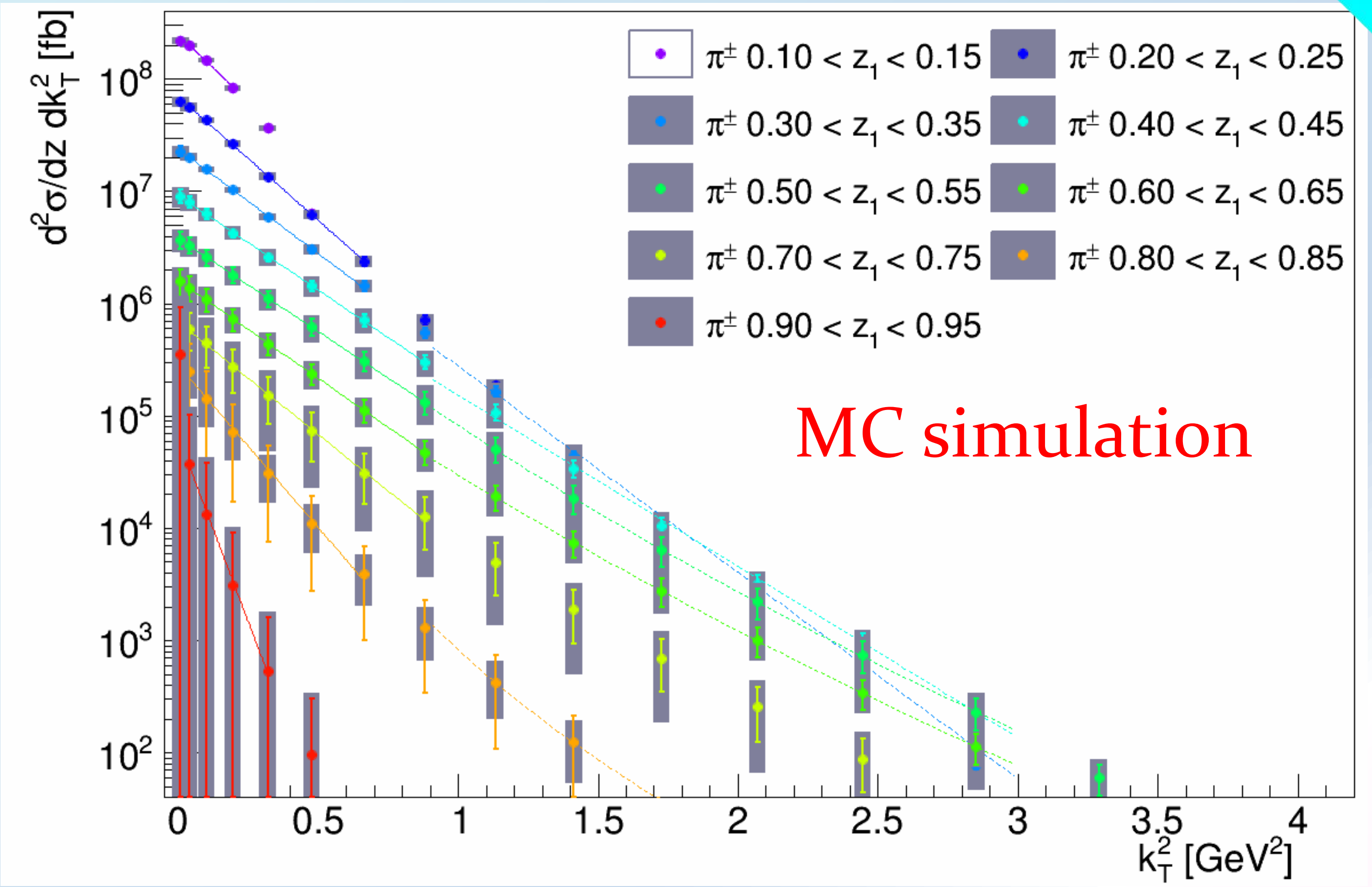
k_T



MC examples vs k_T^2

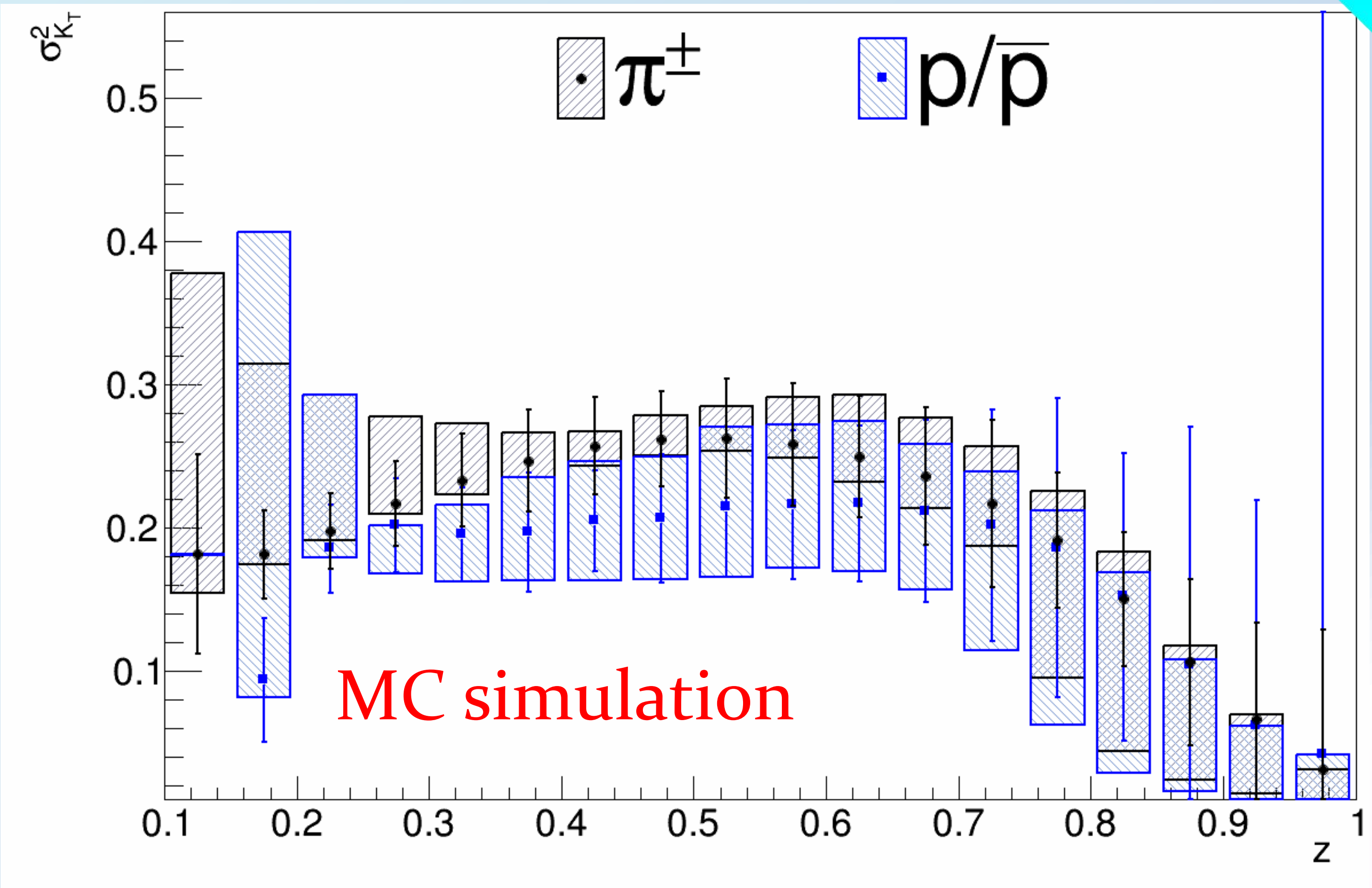
Fit exponential to smaller transverse momenta for Gaussian k_T dependence and power low at higher k_T

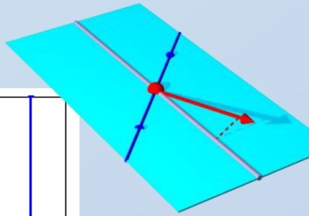




MC Gaussian widths

Once available for data this will be the first direct (no convolutions) measurement of z dependence of Gaussian widths





Di-hadrons

In e^+e^- annihilation:

$$Q = \sqrt{s}$$
$$z = \frac{2E_h}{Q} \approx \frac{E_h}{E_q}$$

- Single inclusive hadron multiplicities (e+e-→hX) sum over all available flavors and quarks and antiquarks:

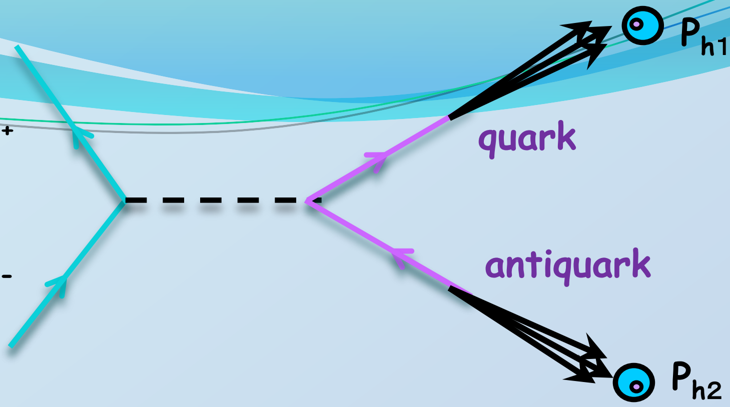
$$d\sigma(e^+e^- \to hX)/dz \propto \sum_q e_q^2 (D_{1,q}^h(z,Q^2) + D_{1,\bar{q}}^h(z,Q^2))$$

- Especially distinction between favored (ie u→π^+) and disfavored ($\bar{u}$ →π^+) fragmentation would be important
- Idea: Use di-hadron fragmentation, preferably from opposite hemispheres and access favored and disfavored combinations:

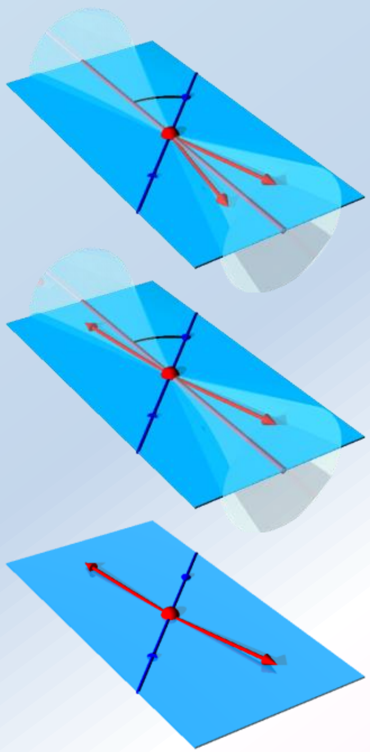
$$u\bar{u} \to \pi^+\pi^- X \quad \propto \quad D_{u,fav}^{\pi^+}(z_1,Q^2)\cdot D_{\bar{u},fav}^{\pi^-}(z_2,Q^2) + D_{\bar{u},dis}^{\pi^+}(z_1,Q^2)\cdot D_{u,dis}^{\pi^-}(z_2,Q^2)$$
$$u\bar{u} \to \pi^+\pi^+ X \quad \propto \quad D_{u,fav}^{\pi^+}(z_1,Q^2)\cdot D_{\bar{u},dis}^{\pi^+}(z_2,Q^2) + D_{\bar{u},dis}^{\pi^+}(z_1,Q^2)\cdot D_{u,fav}^{\pi^+}(z_2,Q^2)$$

- Also: unpol baseline for interference fragmentation

Setup



- Generally look at 4 x 4 hadron combinations (π, K, +,-)
  - Keep separate until end: only 6 independent yields
- 3 hemisphere combinations:
  - same hemisphere (thrust >0.8)
  - opposite hemisphere (thrust >0.8)
  - any combination (no thrust selection)
- 16 x 16 z_1 z_2 binning between 0.2 - 1



Correction chain

Correction	Method	Systematics
PID mis-id	PID matrices (5x5 for cos θ_{lab} and p_{lab})	MC sampling of inverted matric element uncertainties
Momentum smearing	MC based smearing matrices (256x256), SVD unfold	SVD unfolding vs analytically inverted matrix, reorganized binning, MC statistics
Non-qqbar BG removal	eeuu, eess, eecc, tau MC subtraction	Variation of size, MC statistics
Acceptance I (cut efficiency)	In barrel reconstucted vs udsc generated in barrel	MC statistics
Acceptance II	udsc Gen MC barrel to 4π	MC statistics
Weak decay removal (optional)	udcs check evt record for weak decays	Compare to other Pythia settings
Acceptance III	Extrapolation to $\|\cos\theta\| \rightarrow 1$ in (Fit to MC)	Fit uncertainties
ISR	Keep event fraction with E> 0.995 E_{cms}	

Full results for pion pairs

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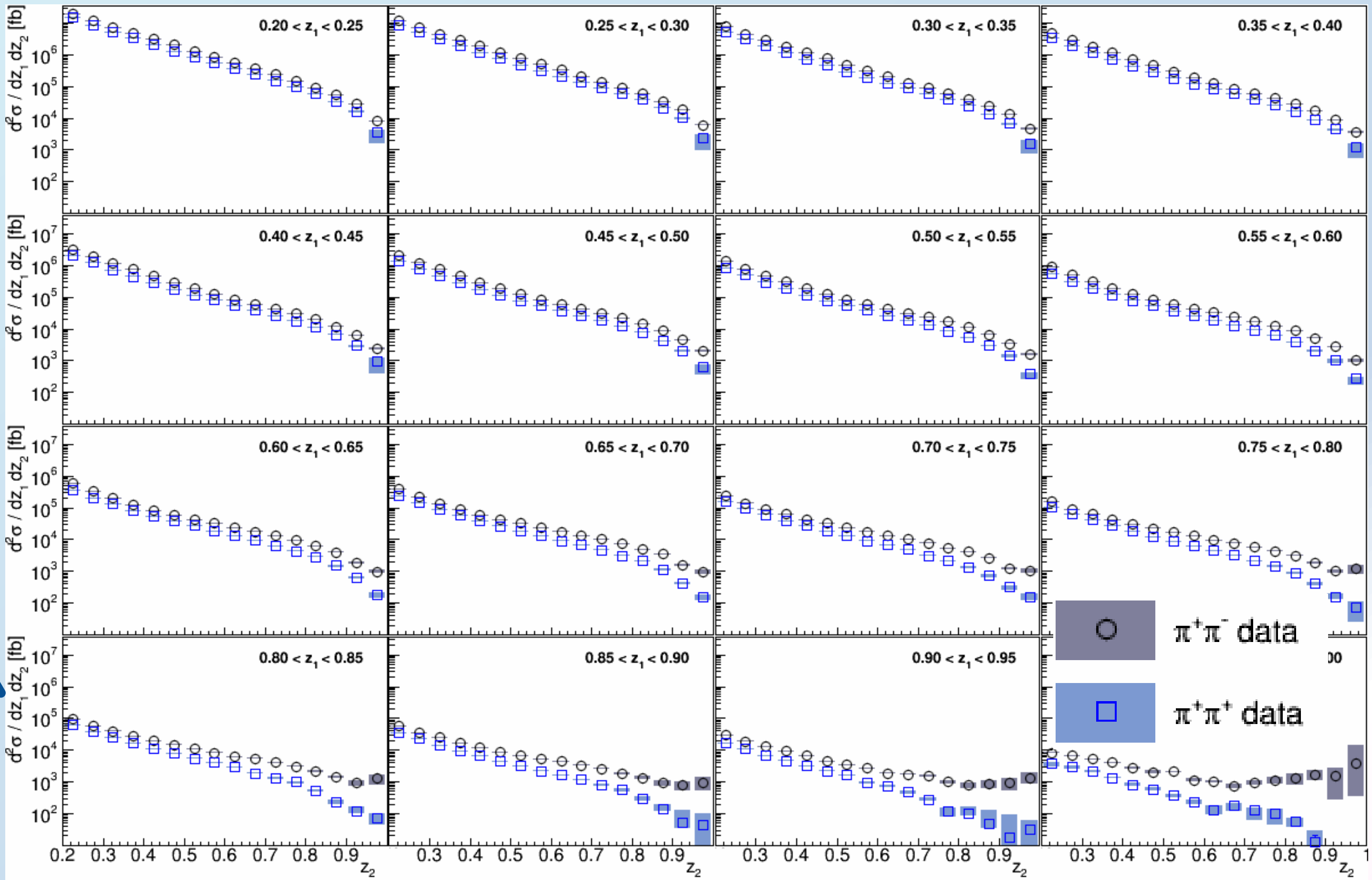
Pion pair example in any topology combination shown here

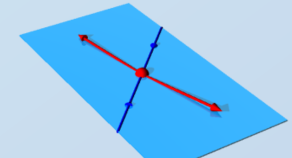


$$\frac{d^2\sigma}{dz_1 dz_2}$$

z_2

Ratios to opposite charge pion pairs

$$R \approx \frac{D_{fav}(z_1)D_{fav}(z_2) + D_{dis}(z_1)D_{dis}(z_2)}{D_{dis}(z_1)D_{fav}(z_2) + D_{fav}(z_1)D_{dis}(z_2)}$$



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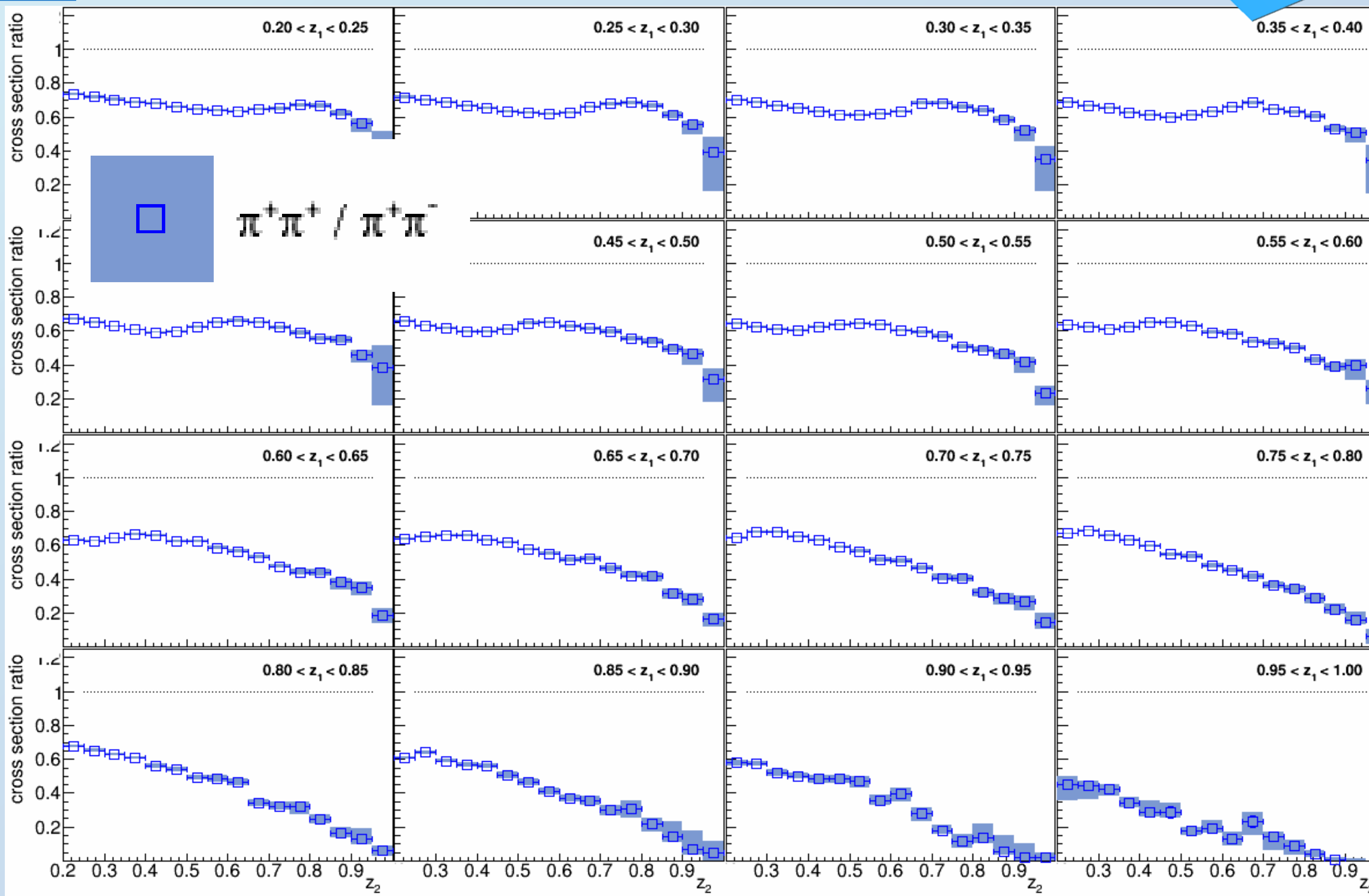
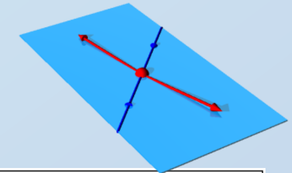
$\pi^+\pi^+$ comparable to $\pi^+\pi^-$ at low z, decreasing towards high z:

→ Favored and disfavored fragmentation similar at low z

→ Disfavored much smaller at high z



Results for diagonal z_1 z_2 bins



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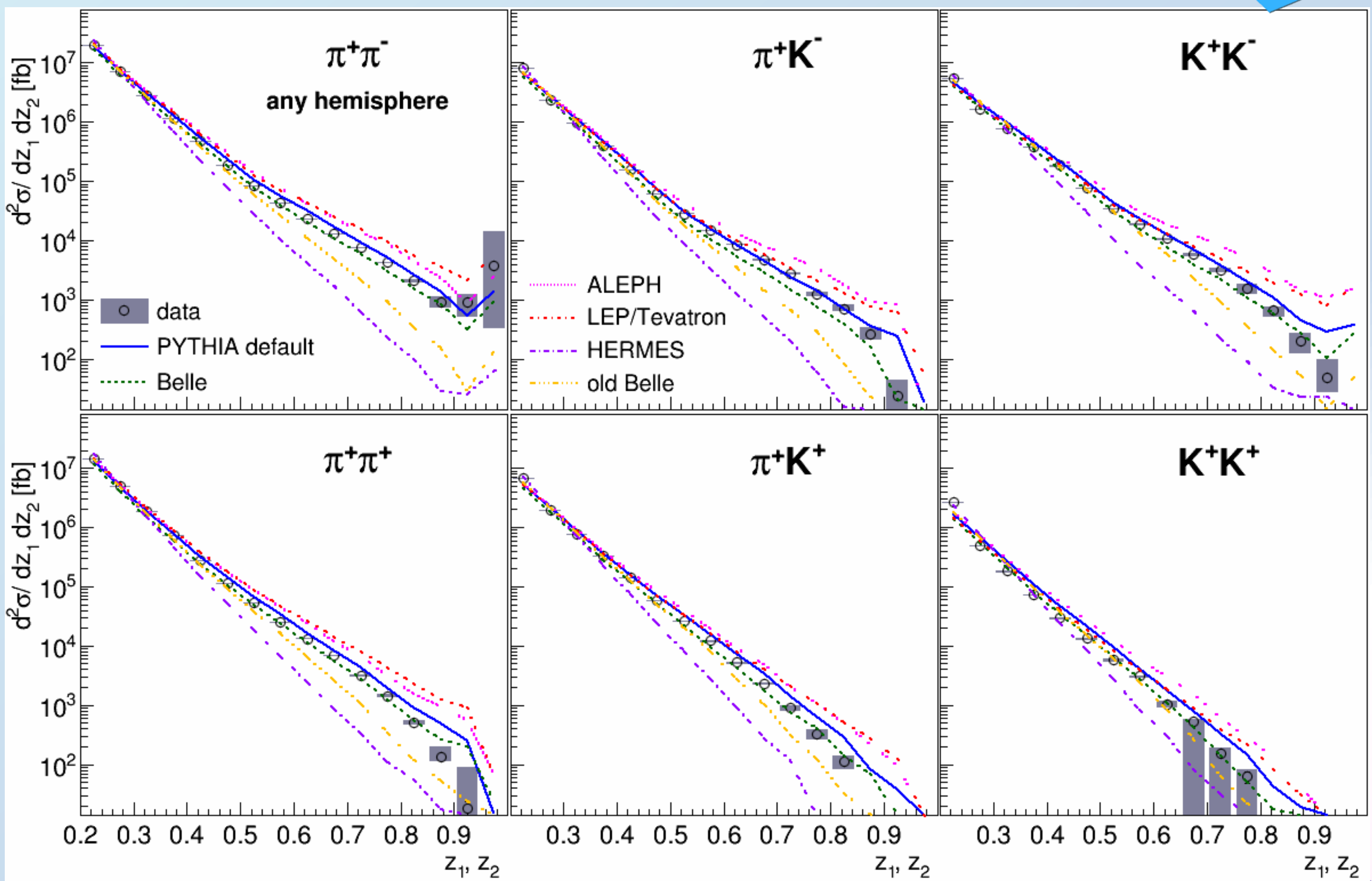
Diagonal z_1,z_2 bins



Low z dominates integral:
→Well defined, all tunes agree

High z not well measured, especially at Belle energies:
→large spread in tunes

Default Pythia settings and current Belle setting with good agreement

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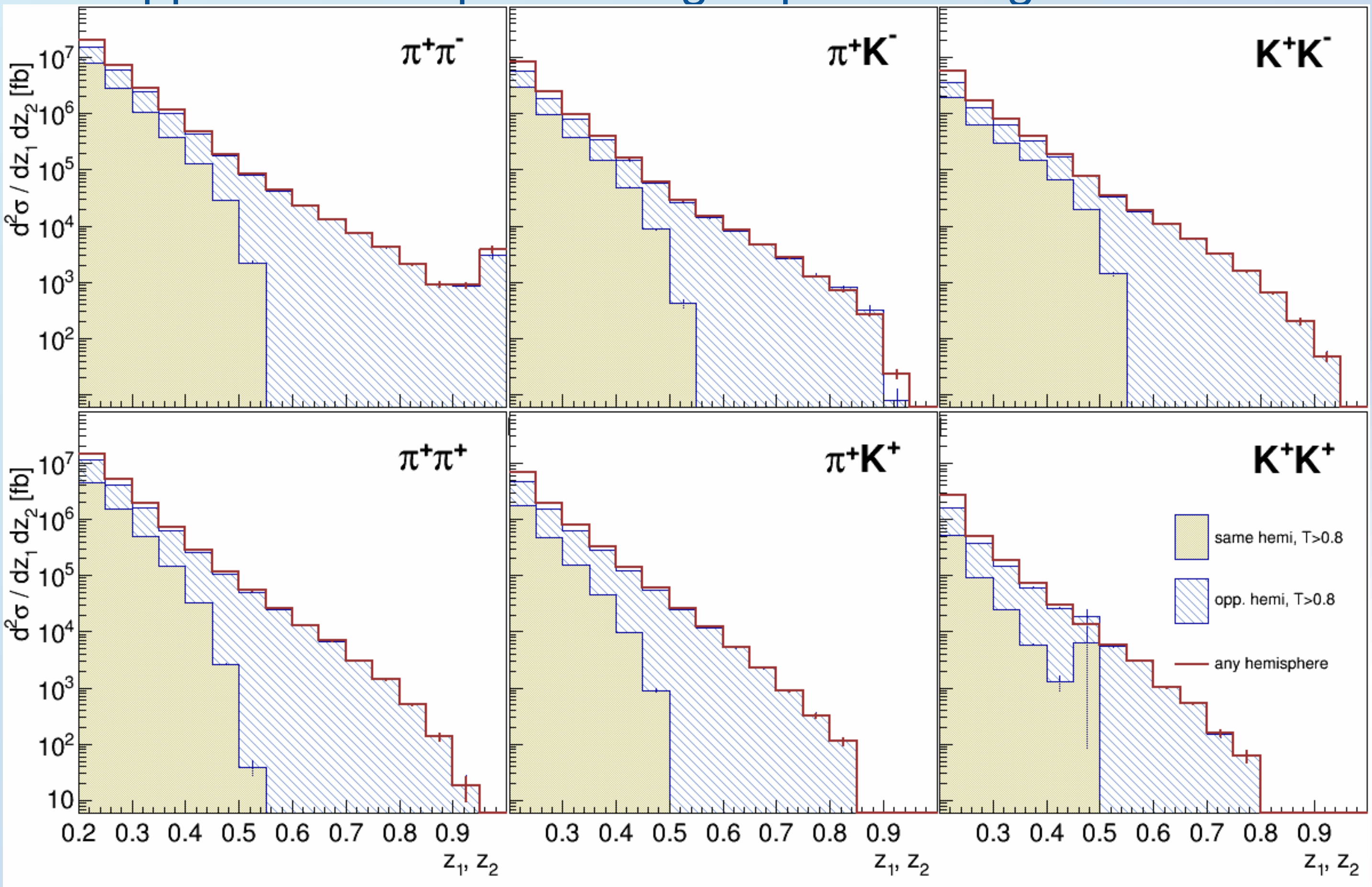
Hemisphere composition

Same hemisphere contribution drops rapidly
Consistent with LO assumption of
Same hemisphere: single quark → di-hadron FF: (z_1+z_2 <1)
Opposite hemisphere: single quark→single hadron FF

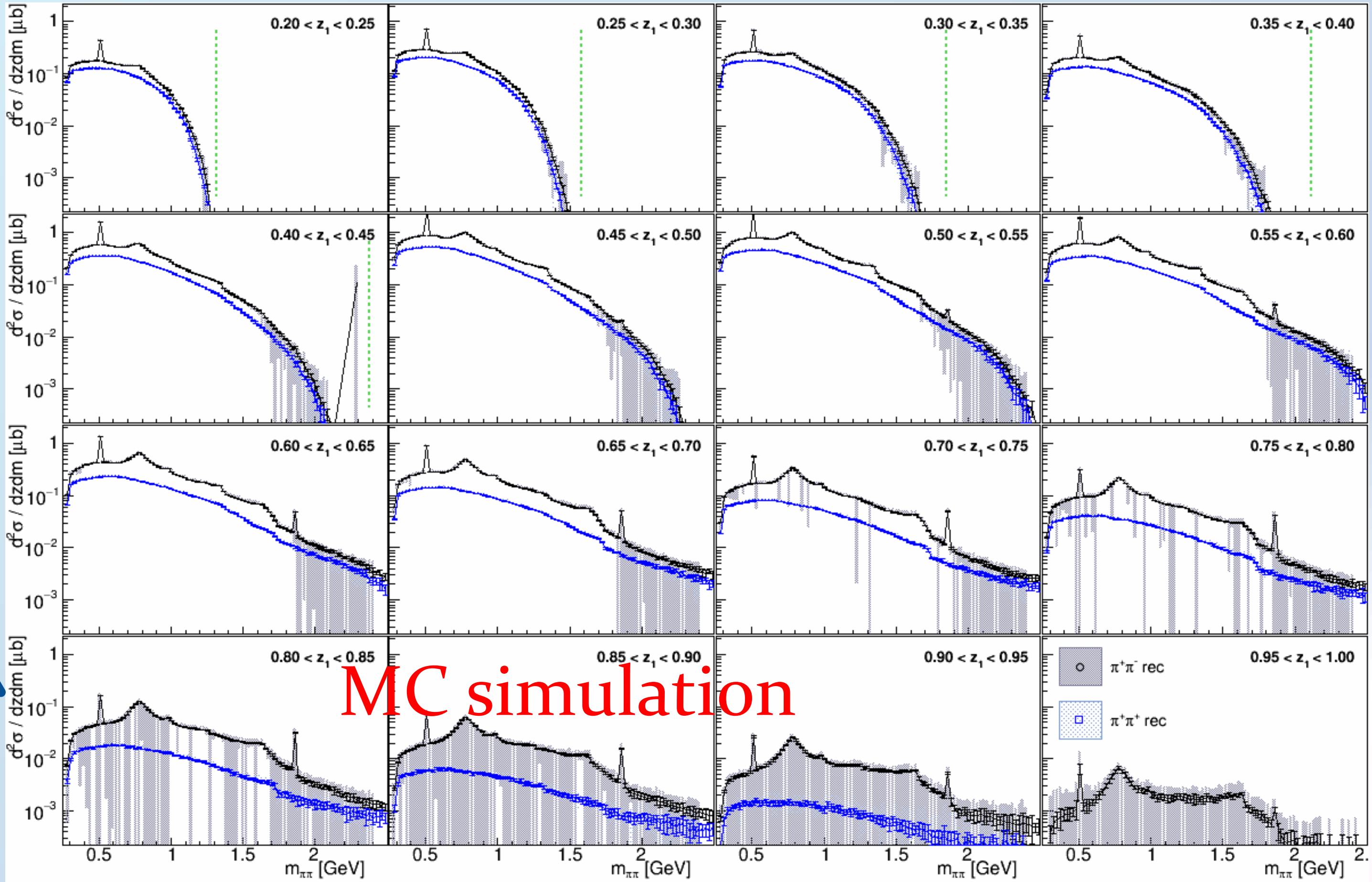
Diagonal z_1,z_2 bins



Systematic uncertainties not displayed

Di-hadron mass dependence

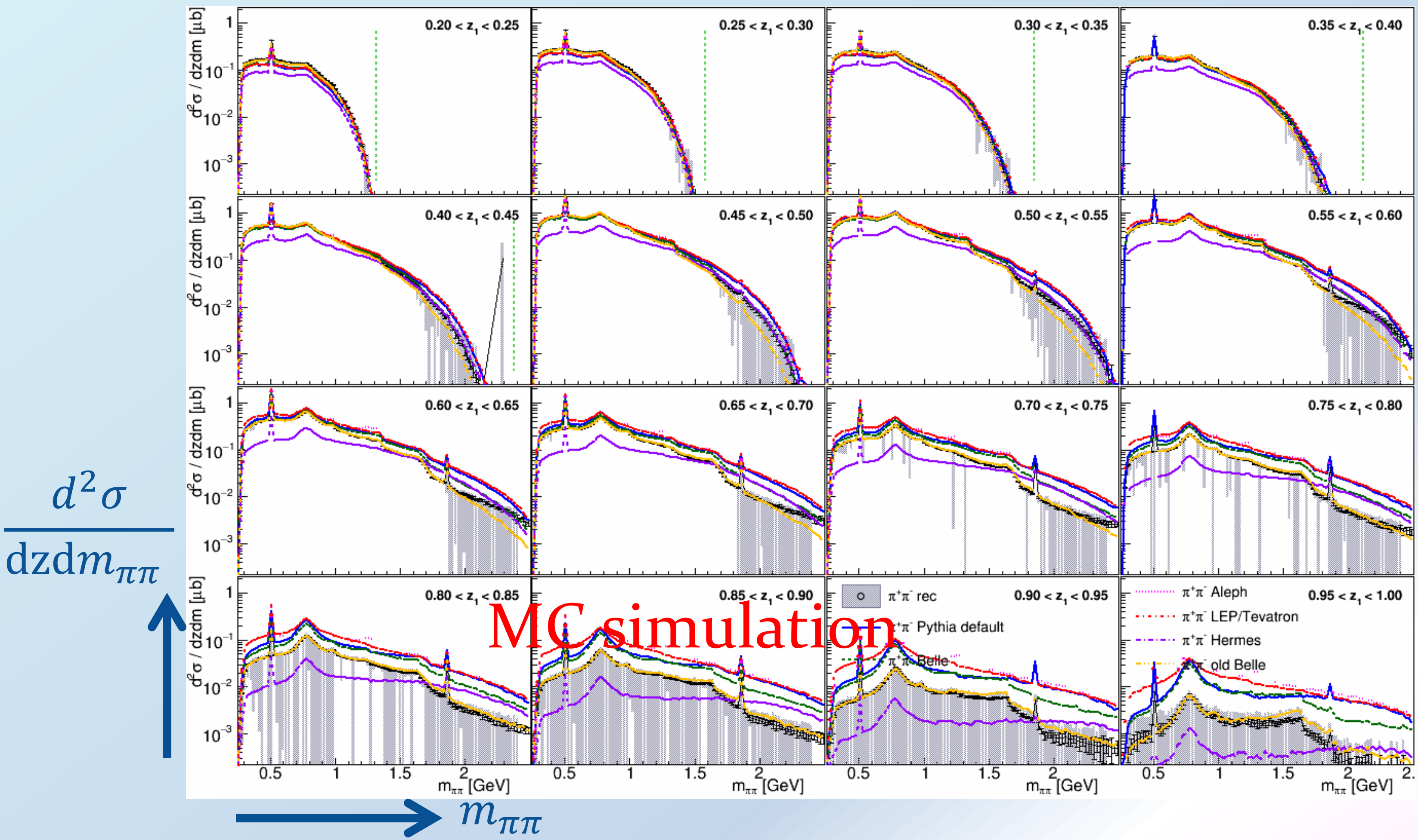
Similar analysis in same hemisphere and mass – combined z binning. Important input for IFF based transversity global analysis



$$\frac{d^2\sigma}{\mathrm{dzd}m_{\pi\pi}}$$

$m_{\pi\pi}$

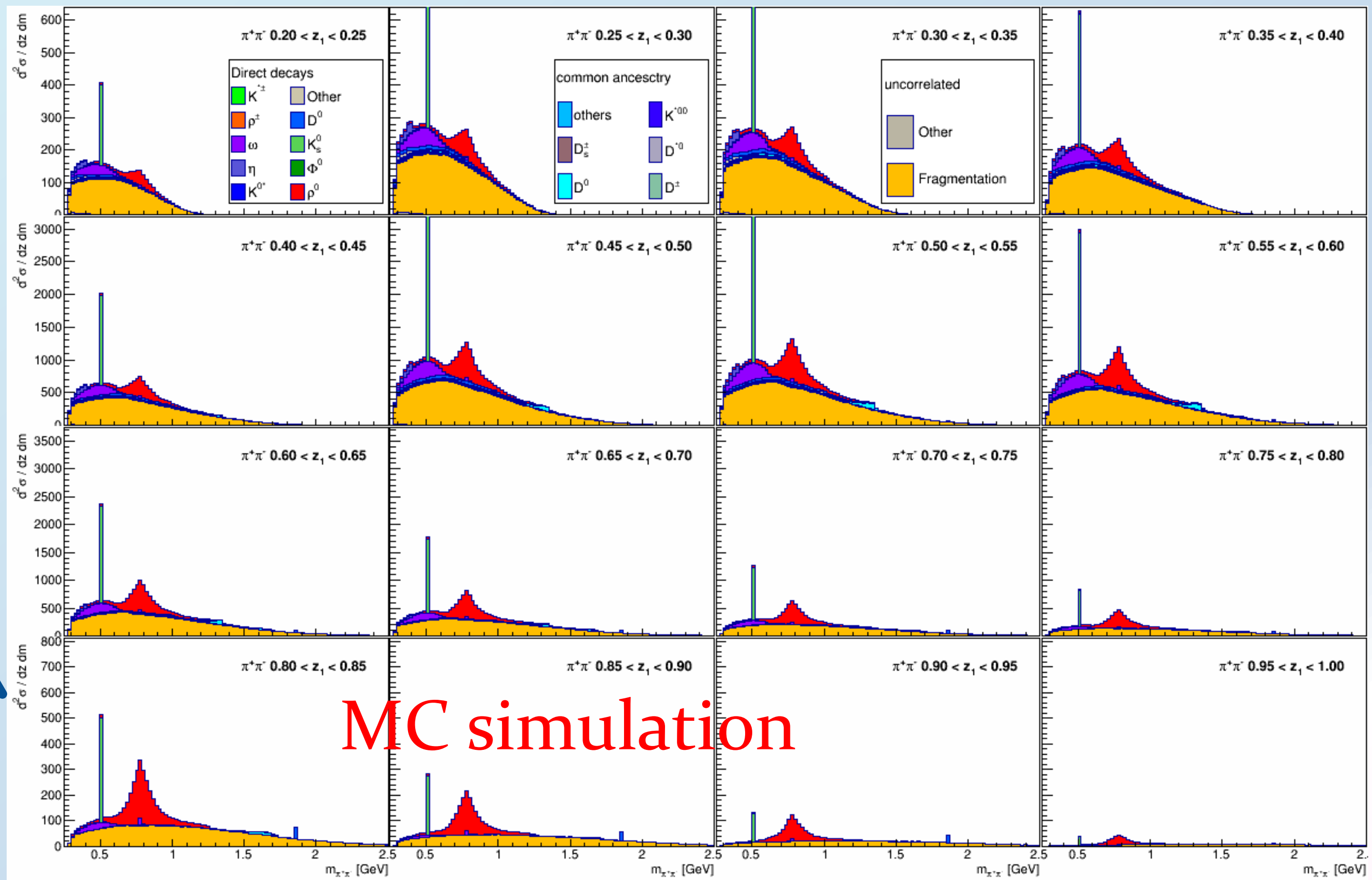
Mass dependence comparisons to Pythia tunes



Di-pion individual contributions

Contributions from various resonances and direct fragmentation

$$\frac{d^2\sigma}{dz dm_{\pi\pi}}$$

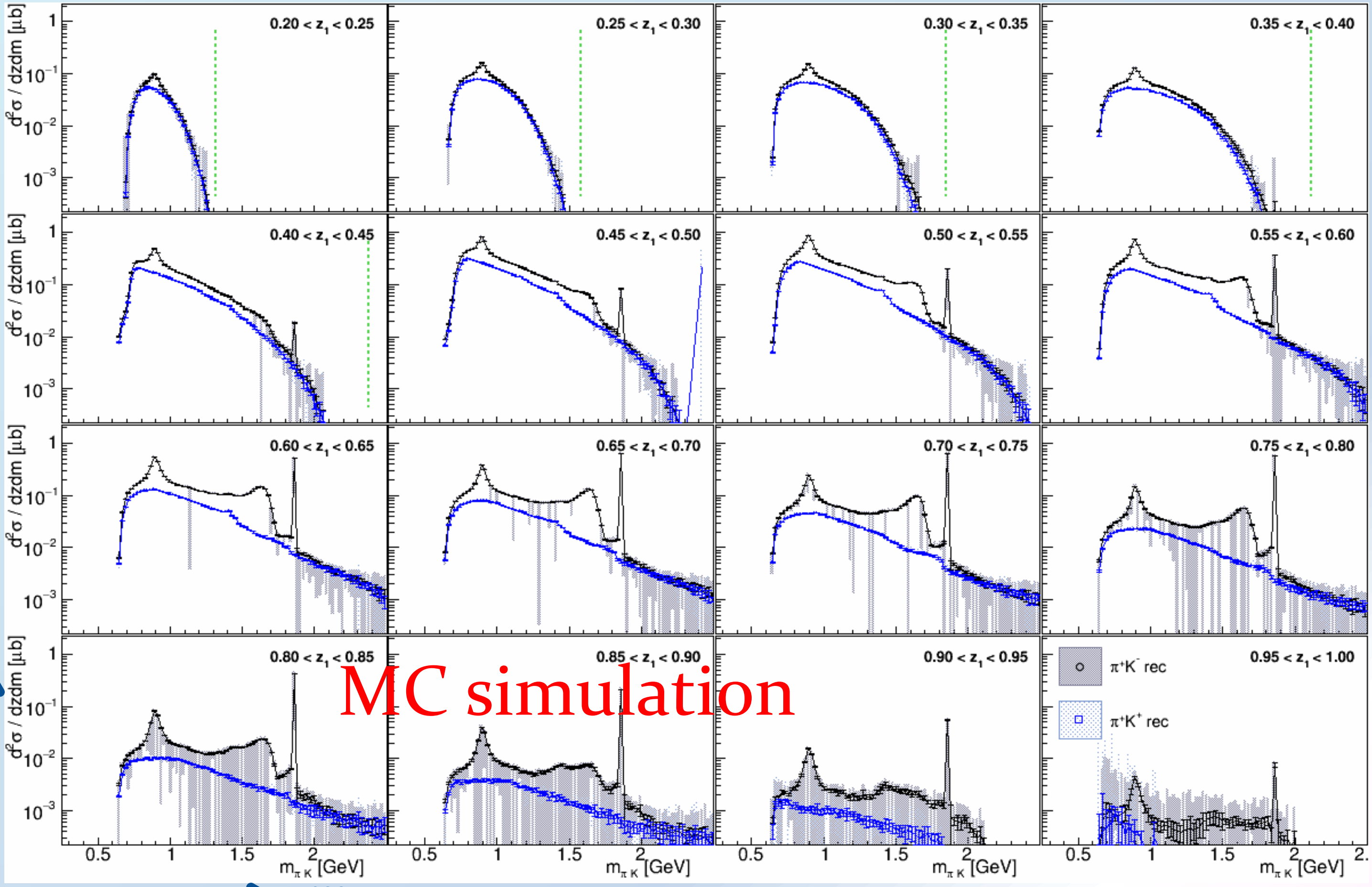


MC simulation

$m_{\pi\pi}$

Di-hadron mass dependence

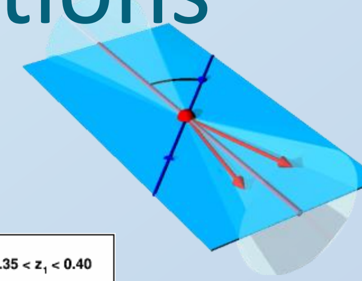
Pion – kaon pairs

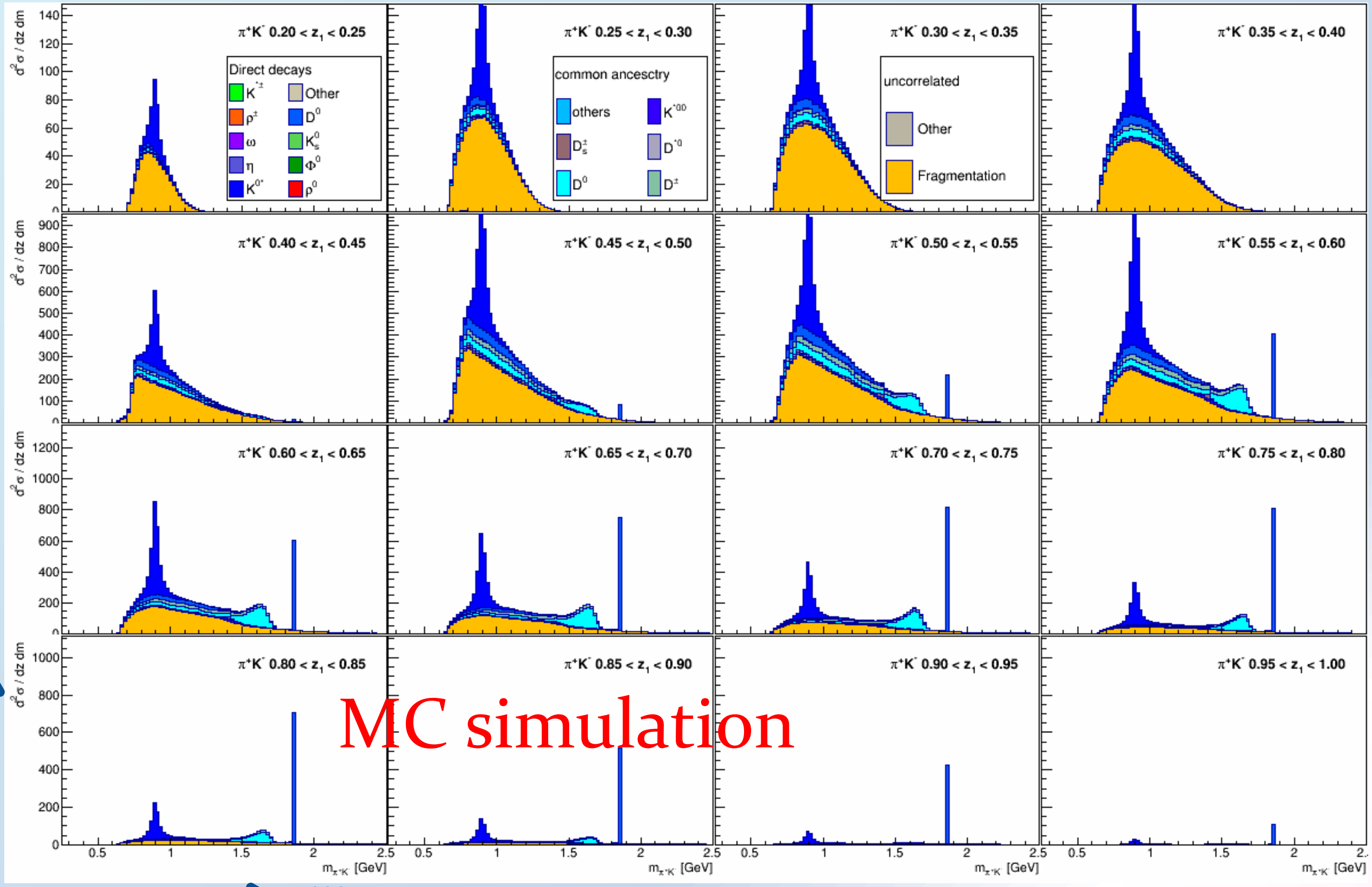


$$\frac{d^2\sigma}{\mathrm{dzd}m_{\pi K}}$$

$m_{\pi K}$

Pion-kaon individual contributions





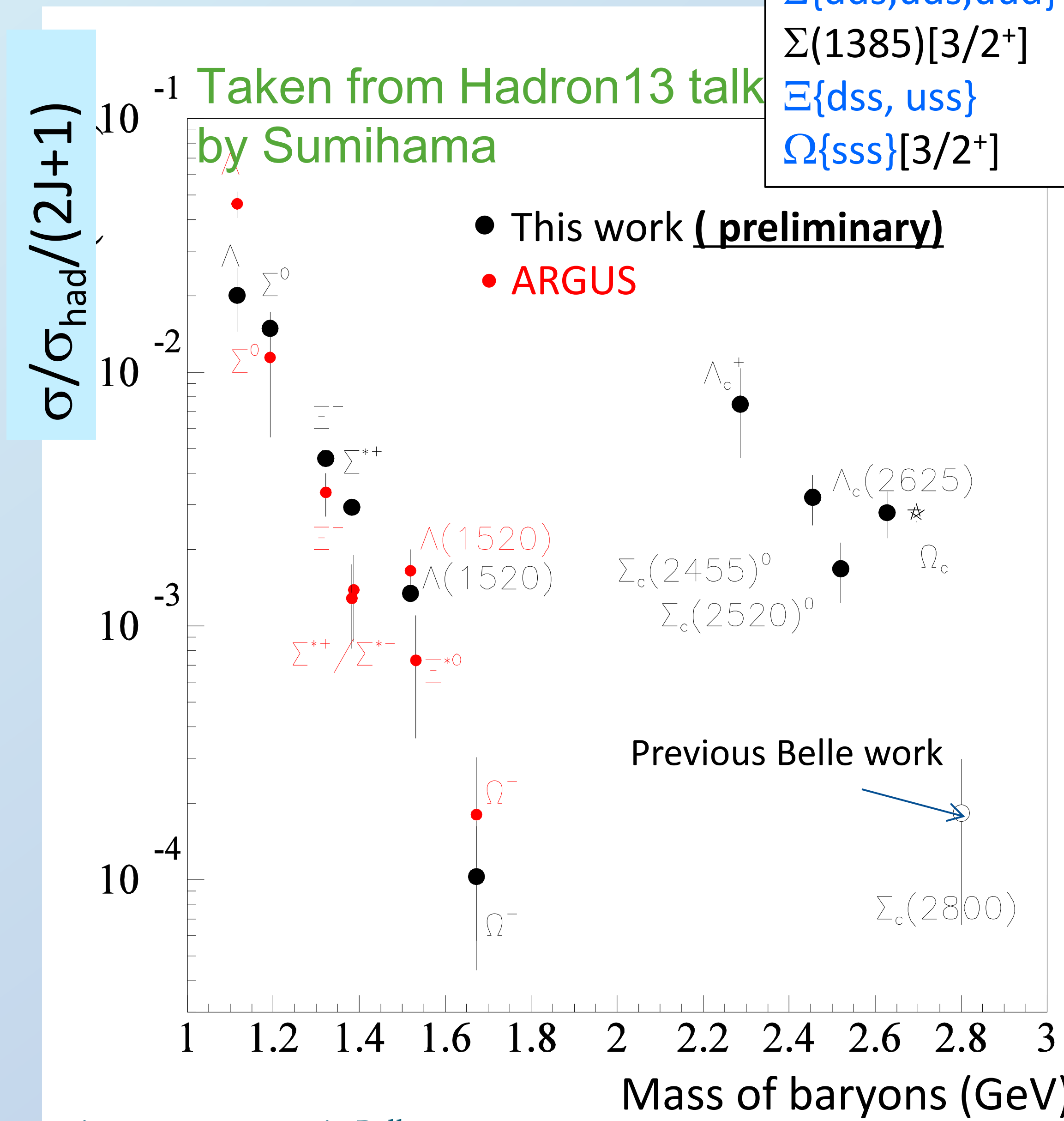
$$\frac{d^2\sigma}{dzdm_{\pi K}}$$

$m_{\pi K}$

Hyperon and charmed baryons

Λ{uds}
Λ(1520)[3/2⁻]
Σ{dds,uds,uud}
Σ(1385)[3/2⁺]
Ξ{dss, uss}
Ω{sss}[3/2⁺]

- Main focus of analysis on total production cross sections, but final publication will contain x_p dependence
- Production rates can be explained by separate lines for hyperons and charmed baryons and according to strangeness
- Large discrepancy to ARGUS likely due to proper feed-down treatment in Belle analysis



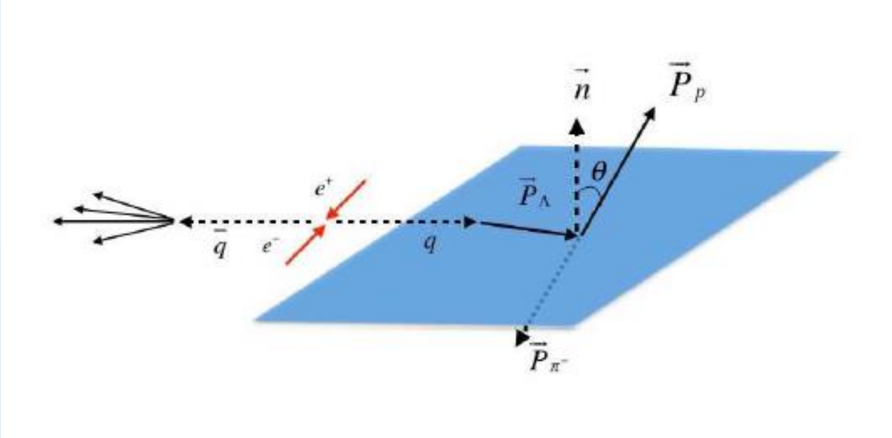
Single Λ polarization measurements

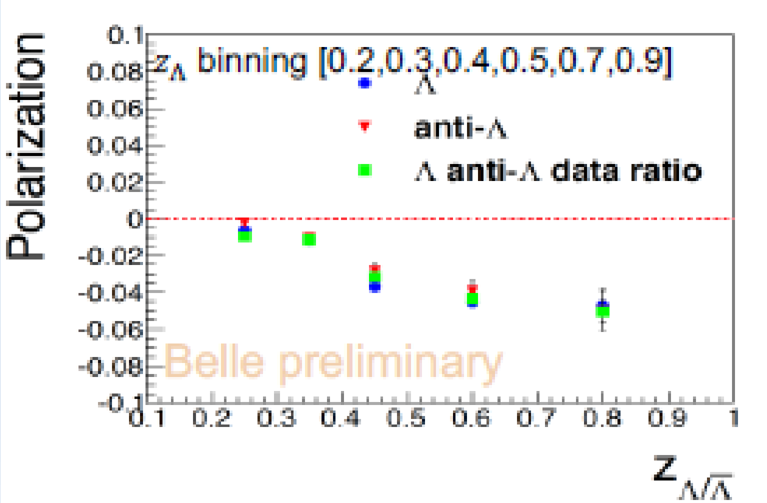
YingHui Guan (Indiana/KEK): arXiv:1611.06648

- Fragmentation counterpart to the Sivers Function:

  unpolarized parton fragments into transversely polarized baryon with transverse momentum wrt to parton direction

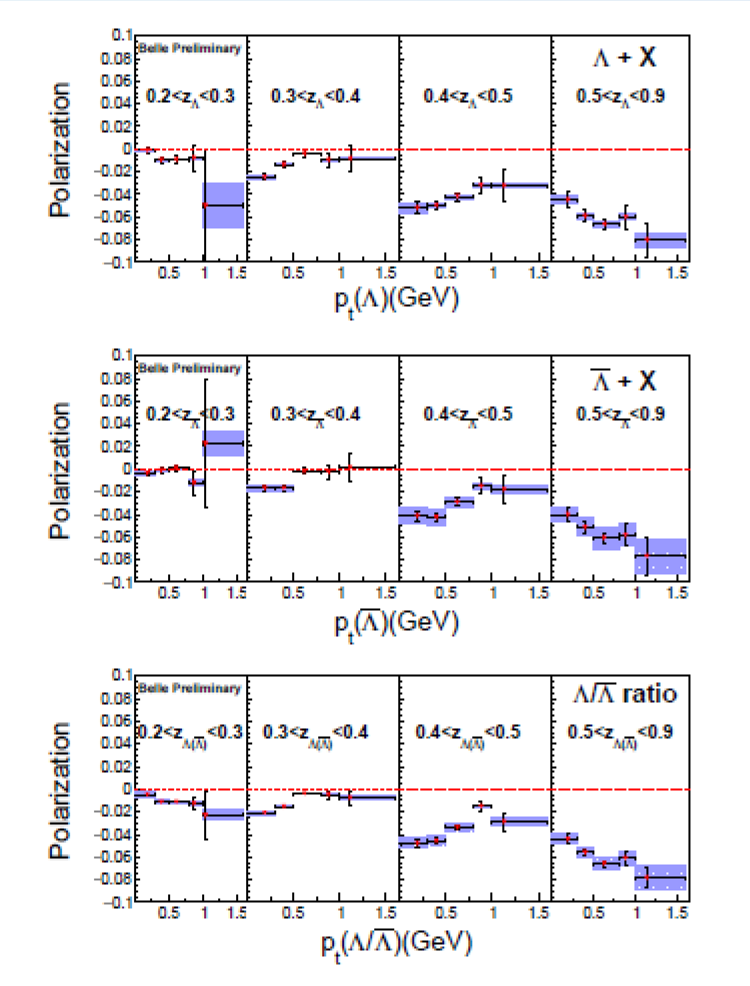
- Reconstruct Λ, its transverse momentum and polarization





Transverse momentum dependence

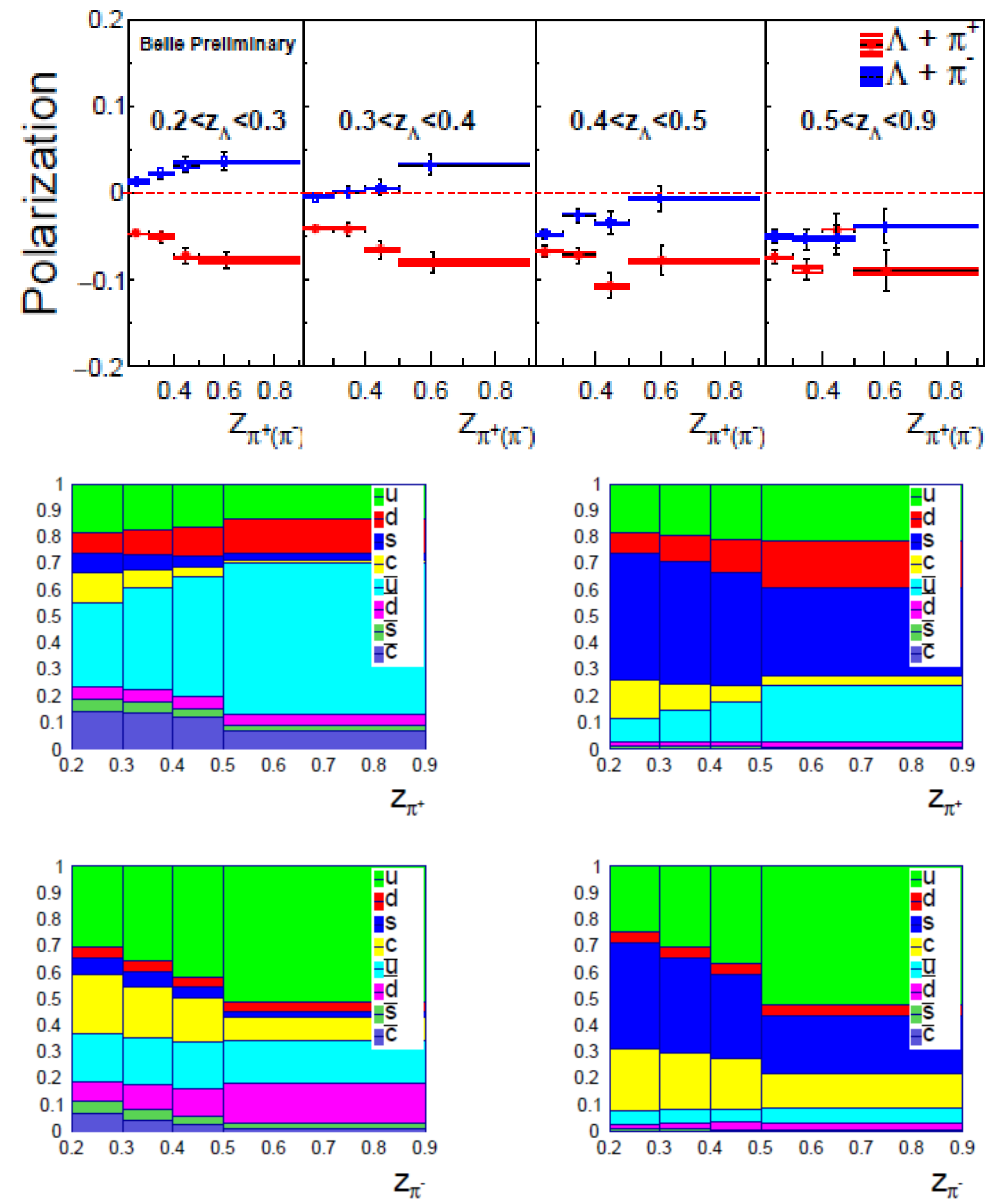
- Different behavior for low and high-z :
- At low z small
- At intermediate z falling Polarization with kt
- At high z increasing polarization with kt



Opposite hemisphere pion correlation

- Interesting z_π and z_Λ dependence :

- At low z_Λ light quark fragmentation dominant, some charm in π^- → different signs
- At high z_Λ strange + charm fragmentation more relevant → same signs



Continuation of spin-dependent FF analysis

- Finalization of Kaon related Collins analysis and its kt dependence ongoing
- Finalization of di-hadron handedness studies (arXiv:1505.08020) ongoing
- New neutral pion and eta Collins asymmetries close to being released

Summary and outlook

- Unpolarized single-hadron cross sections extracted and already used in global FF fits
- First di-hadron + single proton cross sections from e^+e^- extracted
  - Access to disfavored fragmentation via ordering of pion and kaon pairs
- Di-hadron mass dependent cross sections forthcoming
- First Λ polarization results
- Transverse momentum dependent FF analysis ongoing
- Finalization of kaon, π^0 and η related Collins results