Inclusive cross sections for pairs of identified light charged hadrons and single protons from Belle e^+e^- annihilation data

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BELLE

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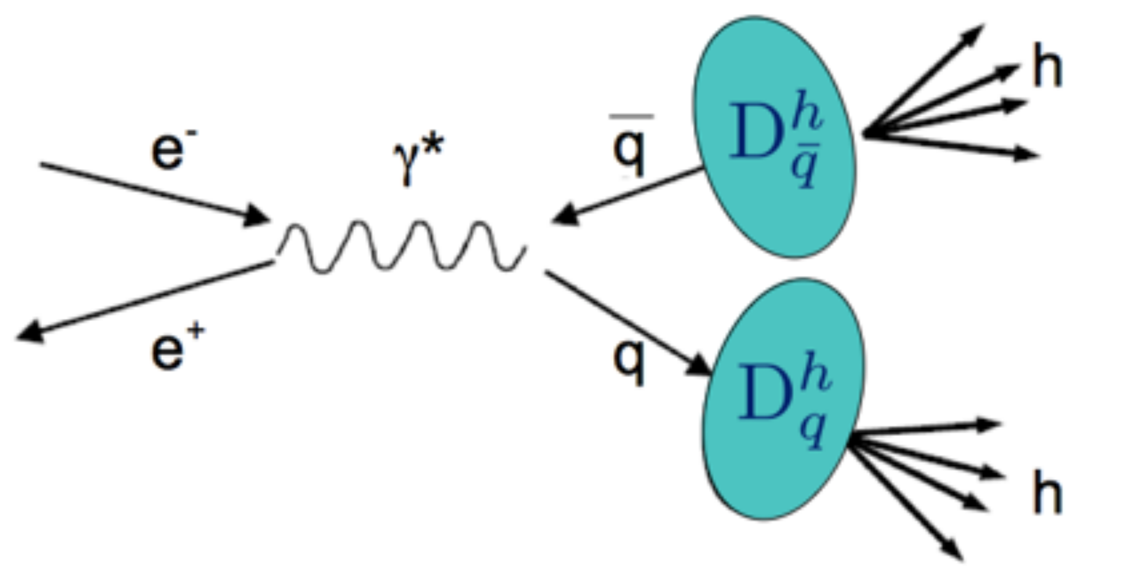
Outline

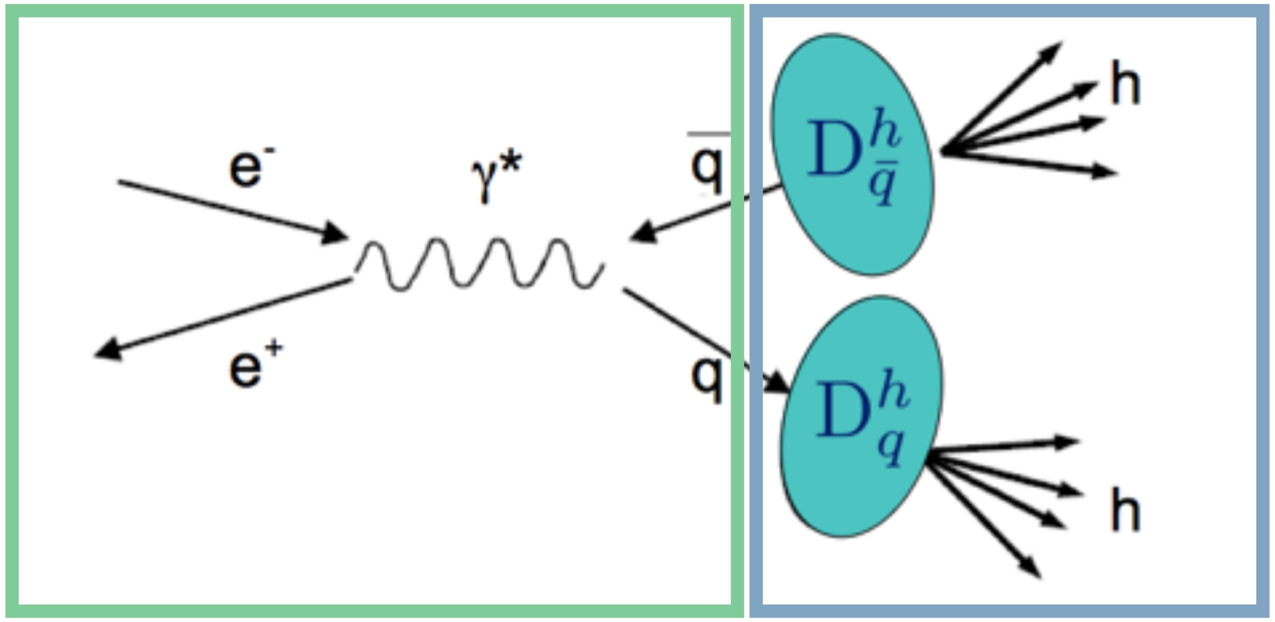
- e^+e^- annihilation and fragmentation functions
- Belle experiment
- Extraction of cross sections for pairs of light charged hadrons and single protons
- Results
- Summary

e^+e^- annihilation and fragmentation functions



e^+e^- annihilation and fragmentation functions

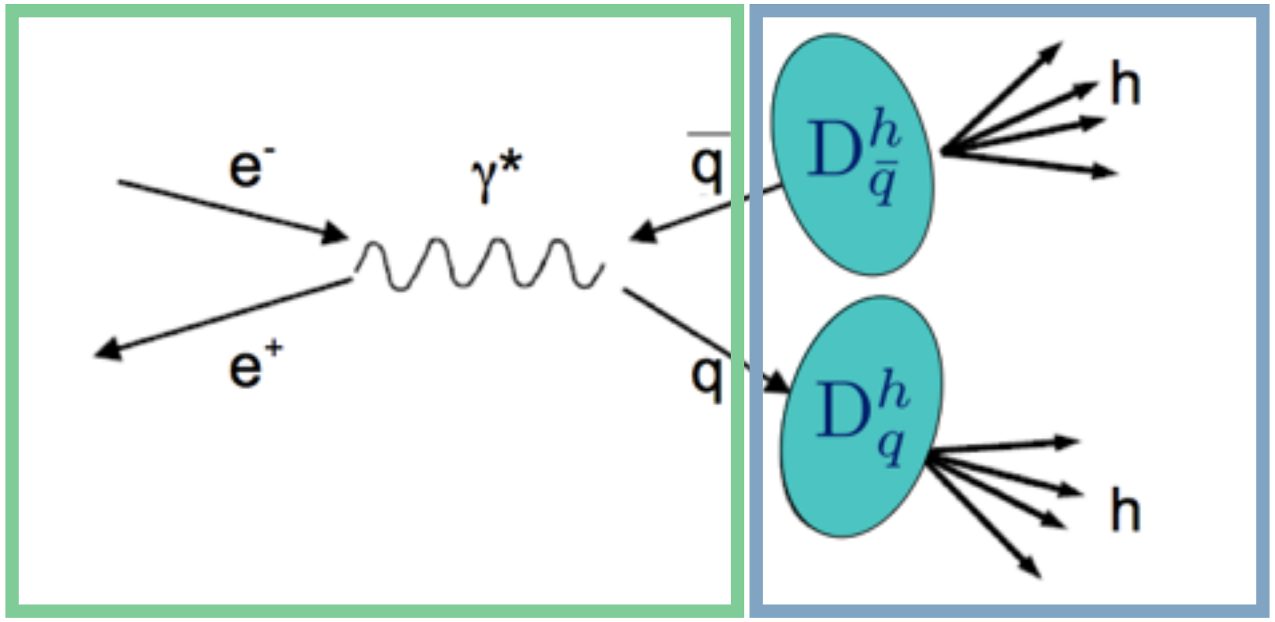
calculable



non-perturbative

e^+e^- annihilation and fragmentation functions

calculable



non-perturbative

$$\frac{d\sigma(e^+e^- \to hX)}{dz}$$

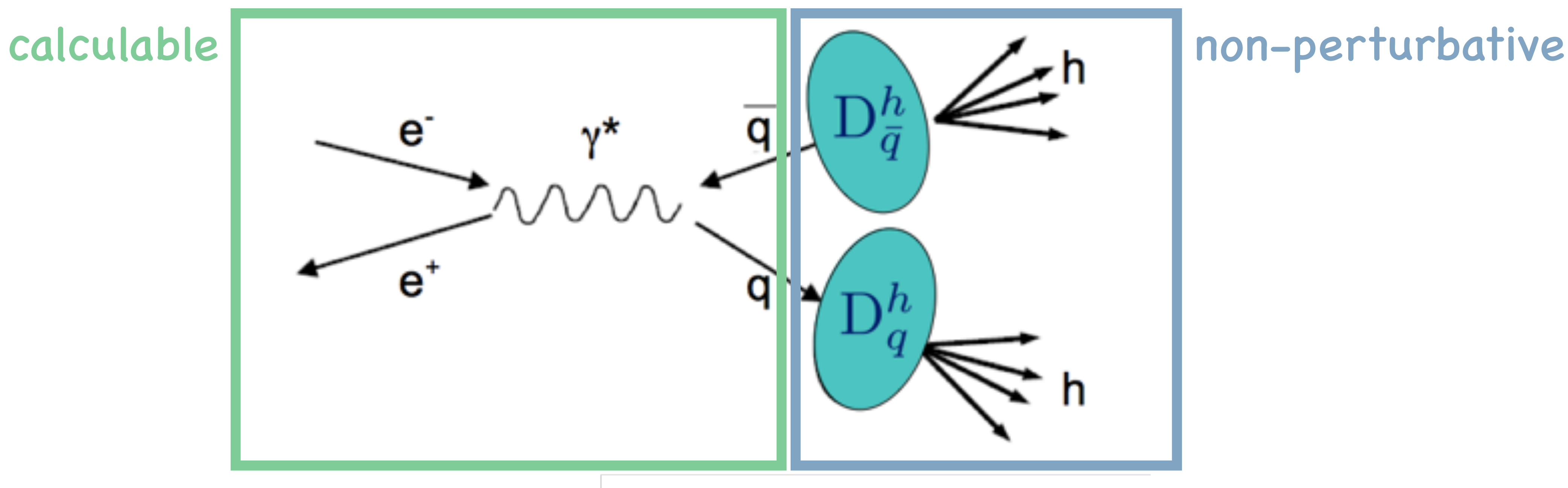
$$\overset{\mathrm{LO}}{\propto} \sum_q e_q^2 \left[D_q^h(z,Q^2) + D_{\bar q}^h(z,Q^2)\right]$$

$$\overset{\mathrm{NLO}}{\propto} \sum_q [C_q^{NLO}(z,\alpha_s) \otimes D_q^h(z,Q^2) + C_{\bar q}^{NLO}(z,\alpha_s) \otimes D_{\bar q}^h(z,Q^2)]$$

$$+C_g^{NLO}(z,\alpha_s) \otimes D_g^h(z,Q^2)$$

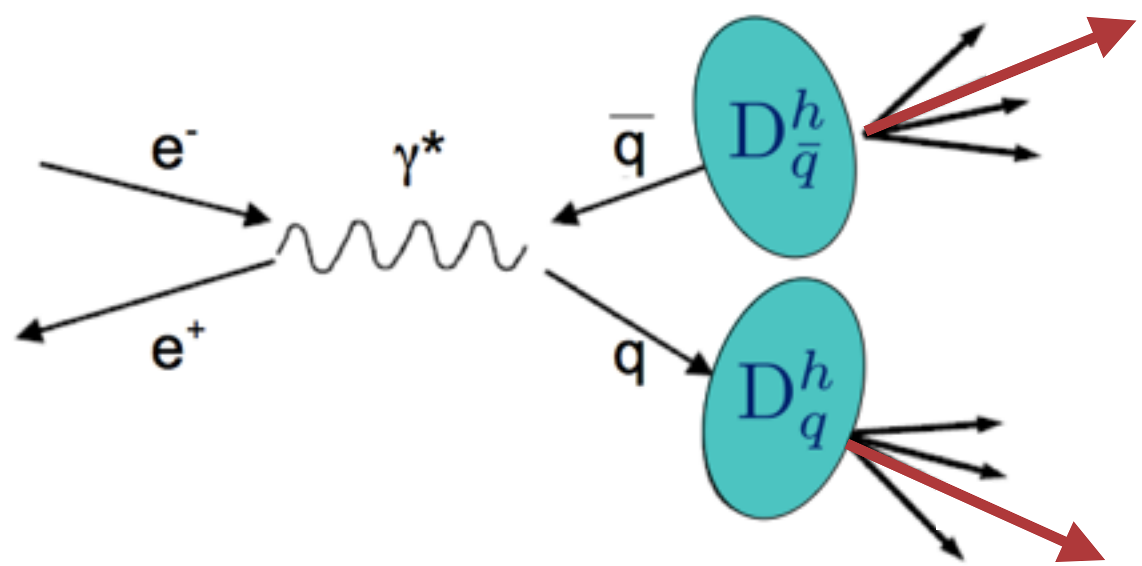
$$\boxed{z = \frac{E_h}{\sqrt{s}/2} \qquad Q = \sqrt{s}}$$

e^+e^- annihilation and fragmentation functions



- e^+e^- annihilation provides cleanest access to fragmentation functions
- universality of fragmentation functions: use as input for nucleon-structure investigation in semi-inclusive DIS and proton-proton collisions
- no $q\bar{q}$ and less flavor discrimination: need global analysis, including measurements from semi-inclusive DIS and proton-proton collisions.

Hadron-pair production in e⁺e⁻ annihilation and fragmentation functions



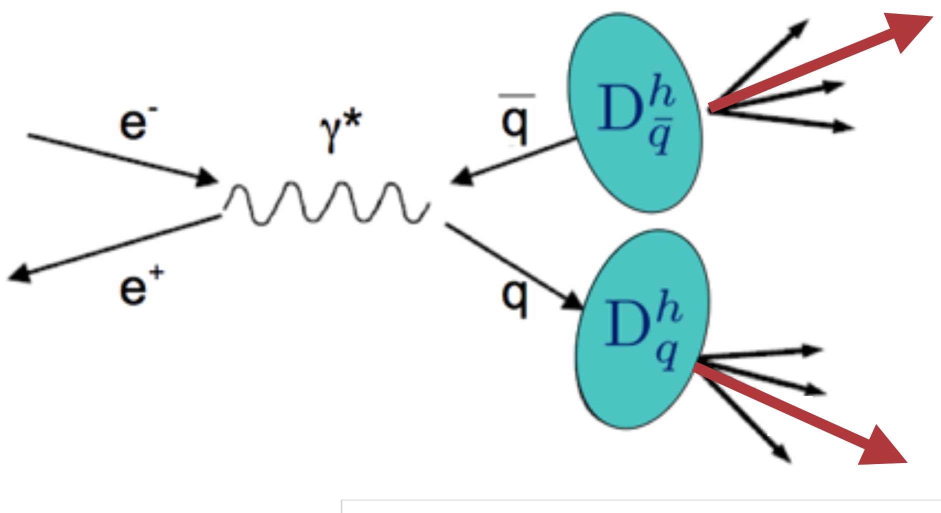
$$\frac{d\sigma(e^+e^- \to h_1 h_2 X)}{dz_1 dz_2}$$

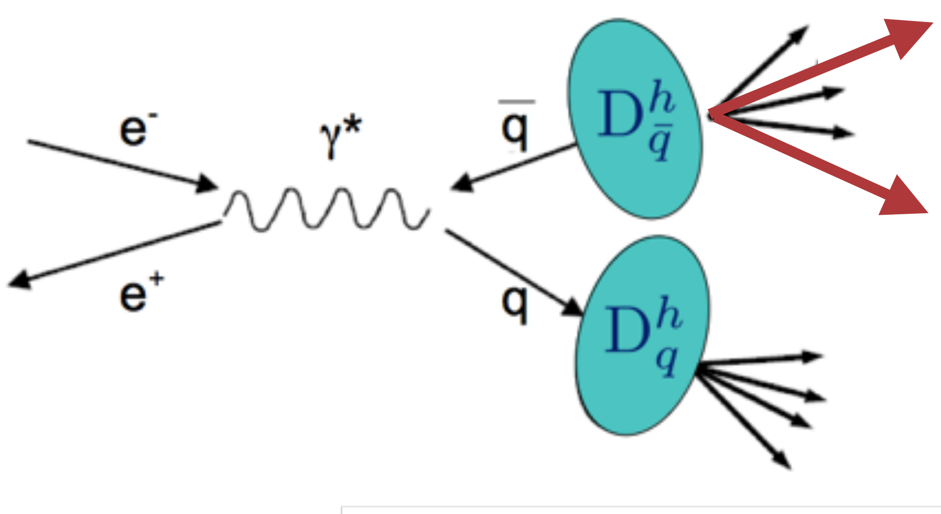
$$\stackrel{\text{LO}}{\propto} \sum_q e_q^2 [D_q^{h_1}(z,Q^2)\, D_{\bar{q}}^{h_2}(z,Q^2) + D_q^{h_2}(z,Q^2)\, D_{\bar{q}}^{h_1}(z,Q^2)]$$

→ sensitivity to favoured and disfavoured fragmentation functions

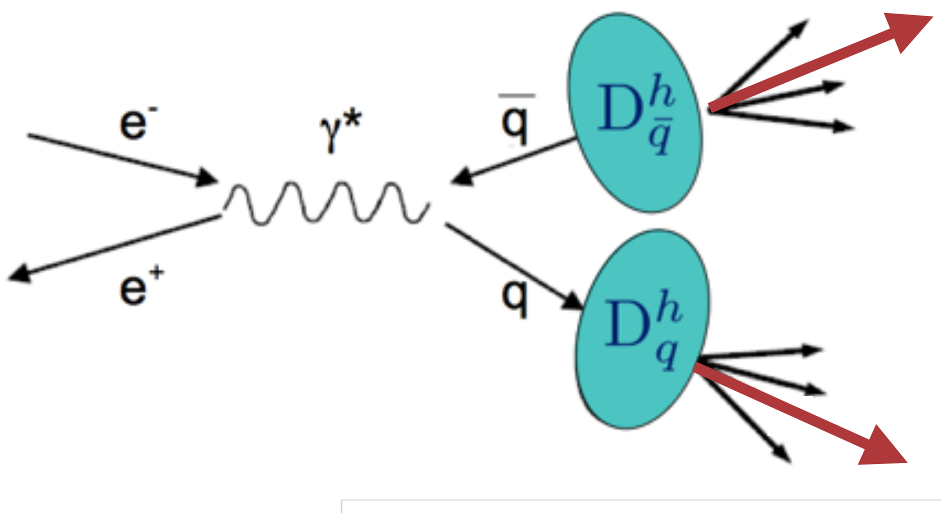
oppositely charged pions:	same-sign pions:
$u \to \pi^+ \times \bar{u} \to \pi^-$ $+ u \to \pi^- \times \bar{u} \to \pi^+$	$u \to \pi^+ \times \bar{u} \to \pi^+$

Hadron-pair production in e^+e^- annihilation and fragmentation functions

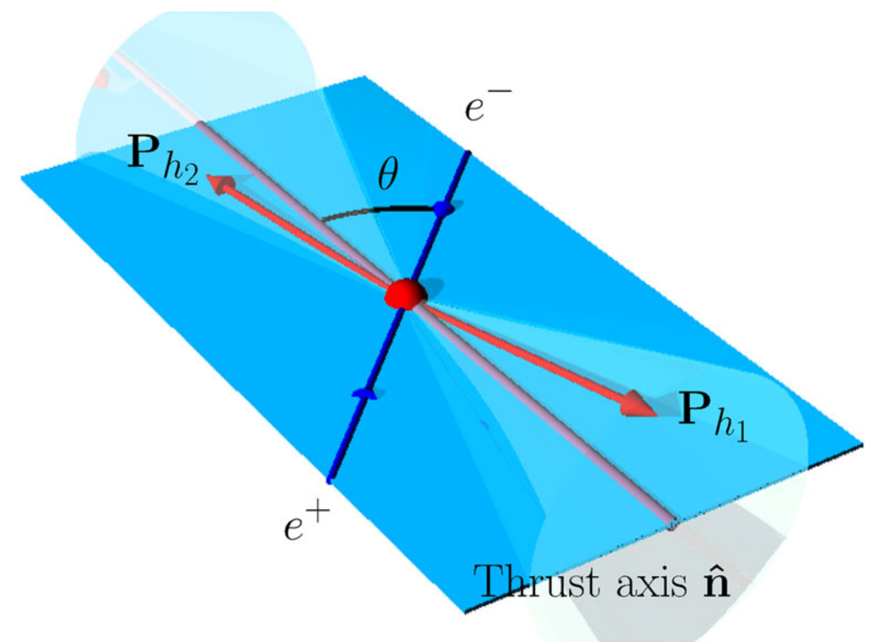


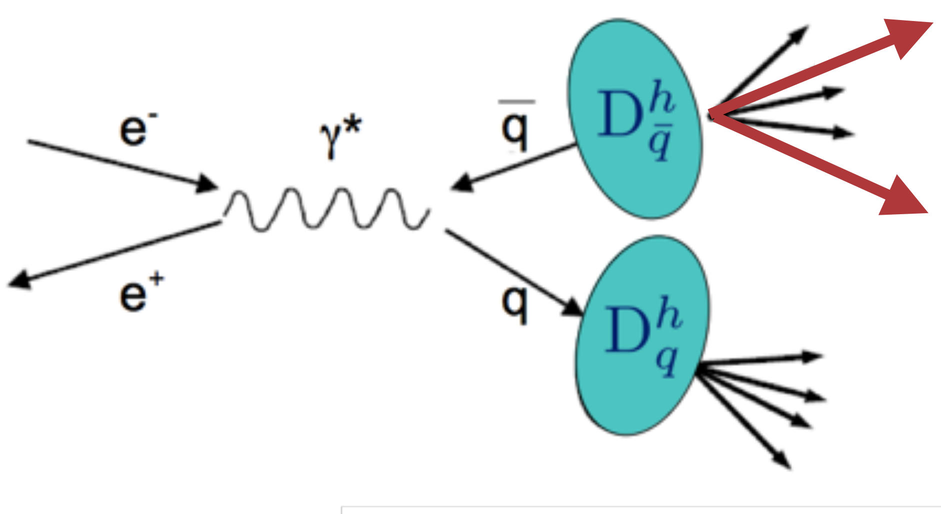


Hadron-pair production in e^+e^- annihilation and fragmentation functions

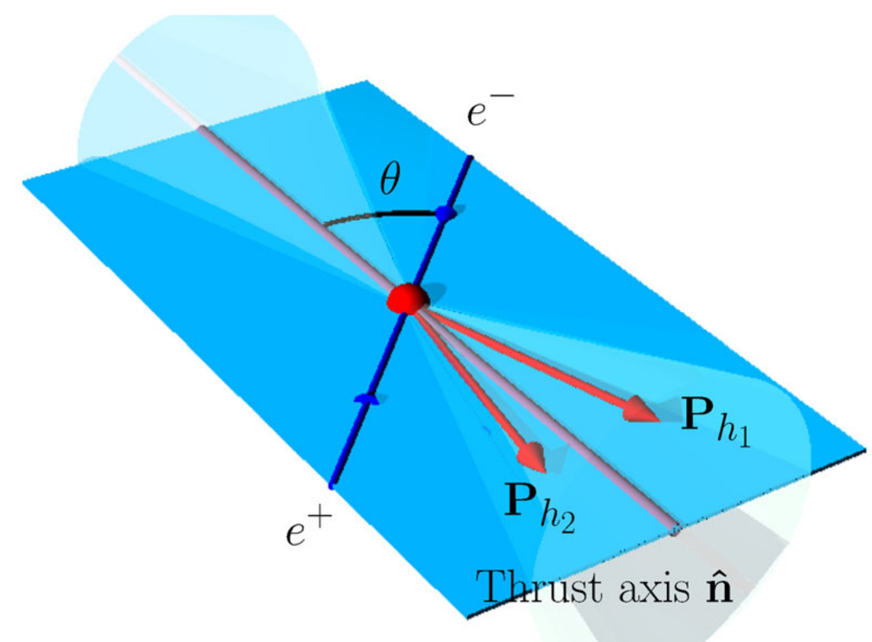


more likely if

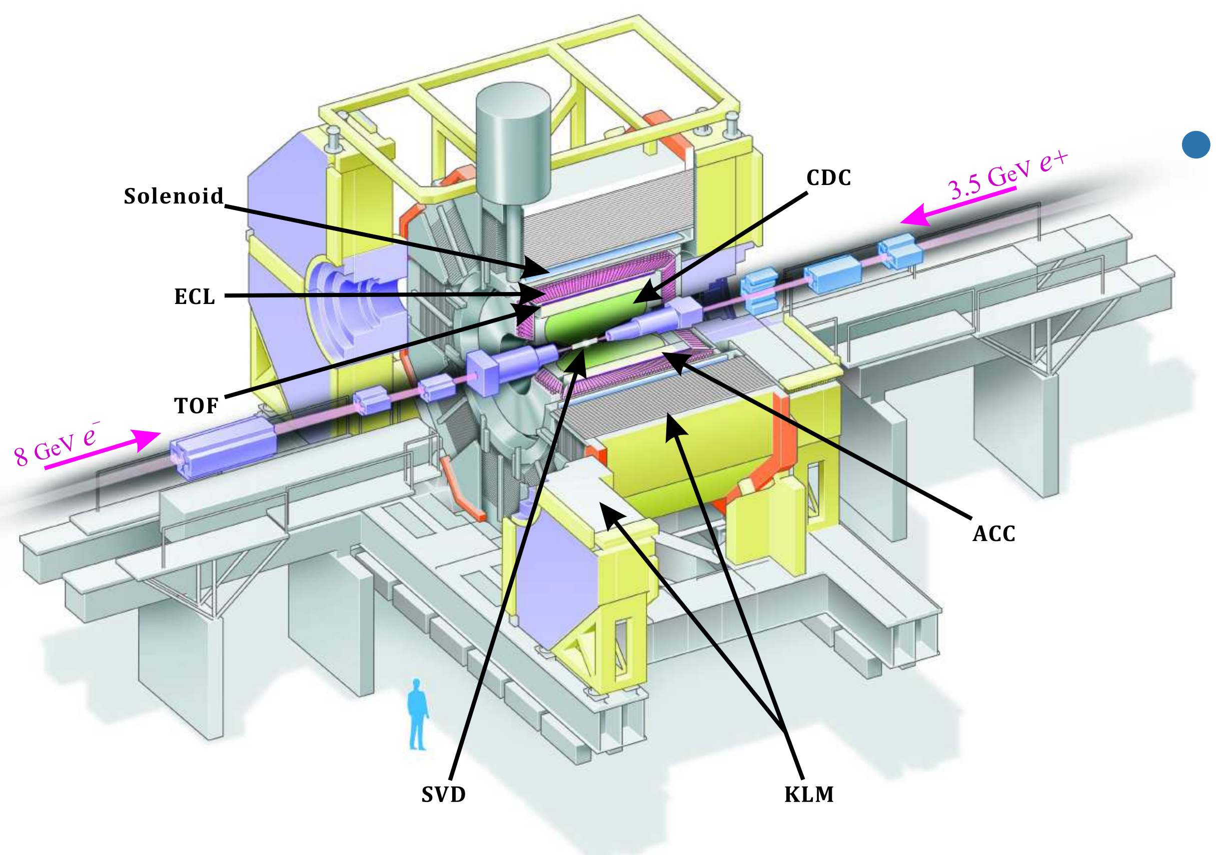




more likely if



Belle experiment



- located at the asymmetric e+e- KEKB collider

$$\sqrt{s} = 10.58\,\mathrm{GeV} : \; e^+e^- \to \Upsilon(4S) \to B\bar{B}\,\mathrm{decay}$$
$$\sqrt{s} = 10.52\,\mathrm{GeV} : \; e^+e^- \to q\bar{q}\; (q = u, d, s, c)$$

$655\,\mathrm{fb}^{-1}$: hadron-pair analysis

$159\,\mathrm{fb}^{-1}$: single-proton analysis

1. Silicon Vertex Detector
2. Central Drift Chamber
3. Aerogel Cherenkov Counter
4. Time-of-flight Counter
5. CsI Calorimeter
6. KLM Detector
7. Superconducting Solenoid
8. Superconducting Final Focussing System

- Track/momentum reconstruction:
- silicon vertex detector, central drift chambers
- 1.5 T solenoid

- Particle identification
- pion, kaon, proton, electron, muon identification

Extracted observables

- Dihadron cross sections for $\pi\pi$, πK, KK pairs for different charge combinations
  - 16x16 equidistant bins in z in [0.2,1.0]
  - any hemisphere, opposite hemisphere, same hemisphere
- Single-proton cross section
  - 16 equidistant bins in z in [0.2,1.0]

Extracted observables

- Dihadron cross sections for ππ, πK, KK pairs for different charge combinations
  - 16x16 equidistant bins in z in [0.2,1.0]
  - any hemisphere, opposite hemisphere, same hemisphere
- Single-proton cross section
  - 16 equidistant bins in z in [0.2,1.0]
- From raw yields to cross sections:

$$
\begin{aligned}
\frac{d\sigma^h}{dz} &= \frac{1}{\mathcal{L}} N^h(z) \\
&= \frac{1}{\mathcal{L}}\ \epsilon_{ISR/FSR}(z)\, \epsilon_{acc.}(z)\ \epsilon_{non-q\bar{q}}(z)\ P^{-1}_{smear}(z, z_{rec}) \\
&\quad \times\ P^{-1}_{PID,hh'}(\cos\theta_{lab}, p_{lab})\ \ N^{h'}_{raw}(\cos\theta_{lab}, p_{lab})
\end{aligned}
$$

Applied corrections

- Particle misidentification ≈10%, but up to 50% ⟶ correction needed!
  construct PID matrix from experimental + Monte-Carlo (where limited statistics) data
- Smearing correction: compare for z bins Monte-Carlo generated and reconstructed events
- Non-$q\bar{q}$ background:
  - subtract QED processes: $e^+e^- \to \tau\tau$, $e^+e^- \to e^+e^- q\bar{q}$
  - subtract resonant $\Upsilon(4S) \to B\bar{B}$
- Acceptance corrections
- Optional correction for weak decays, based on Monte-Carlo
  (here not shown)
- Initial-state photon radiation: exclude hadrons from events with $E_\gamma > 0.5\% \sqrt{s}/2$

Results hadron pairs: any topology

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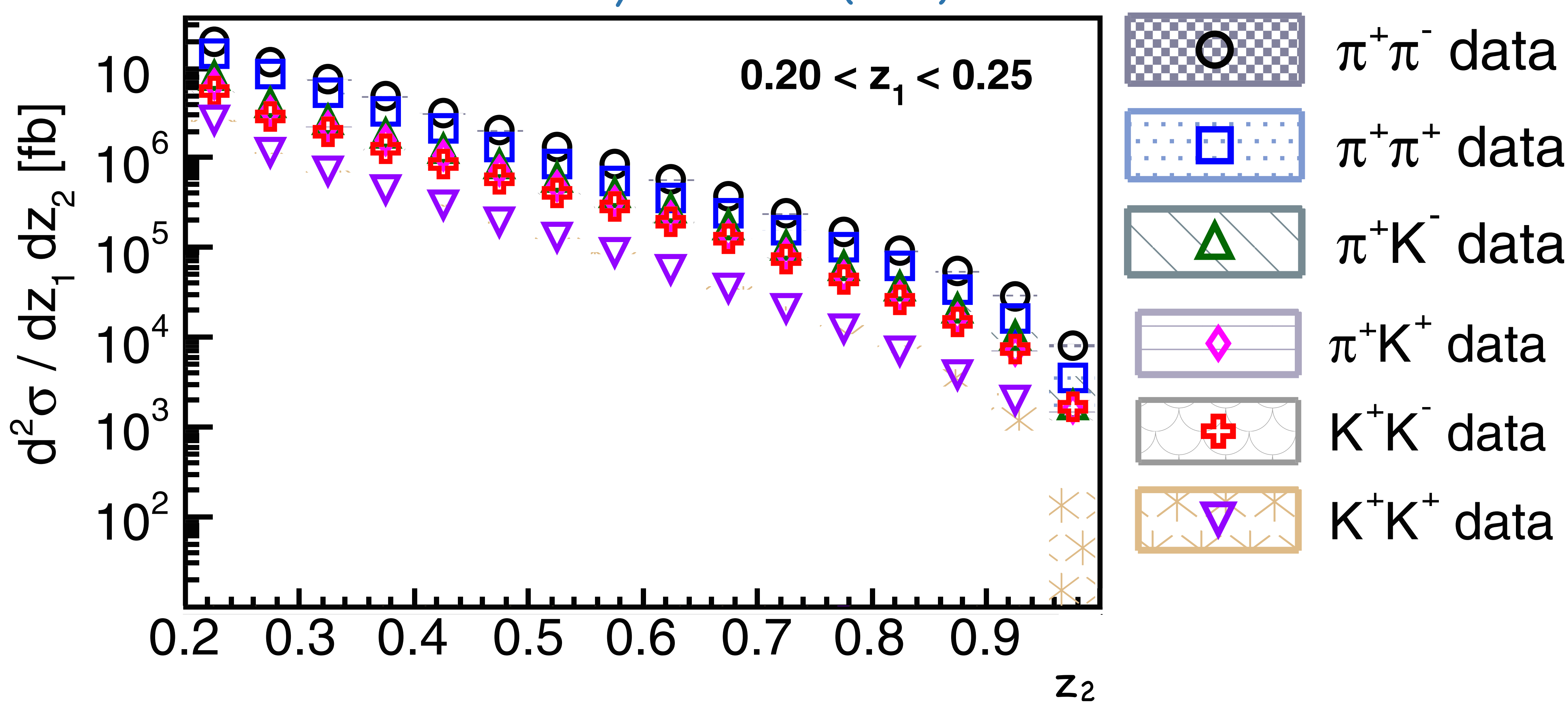
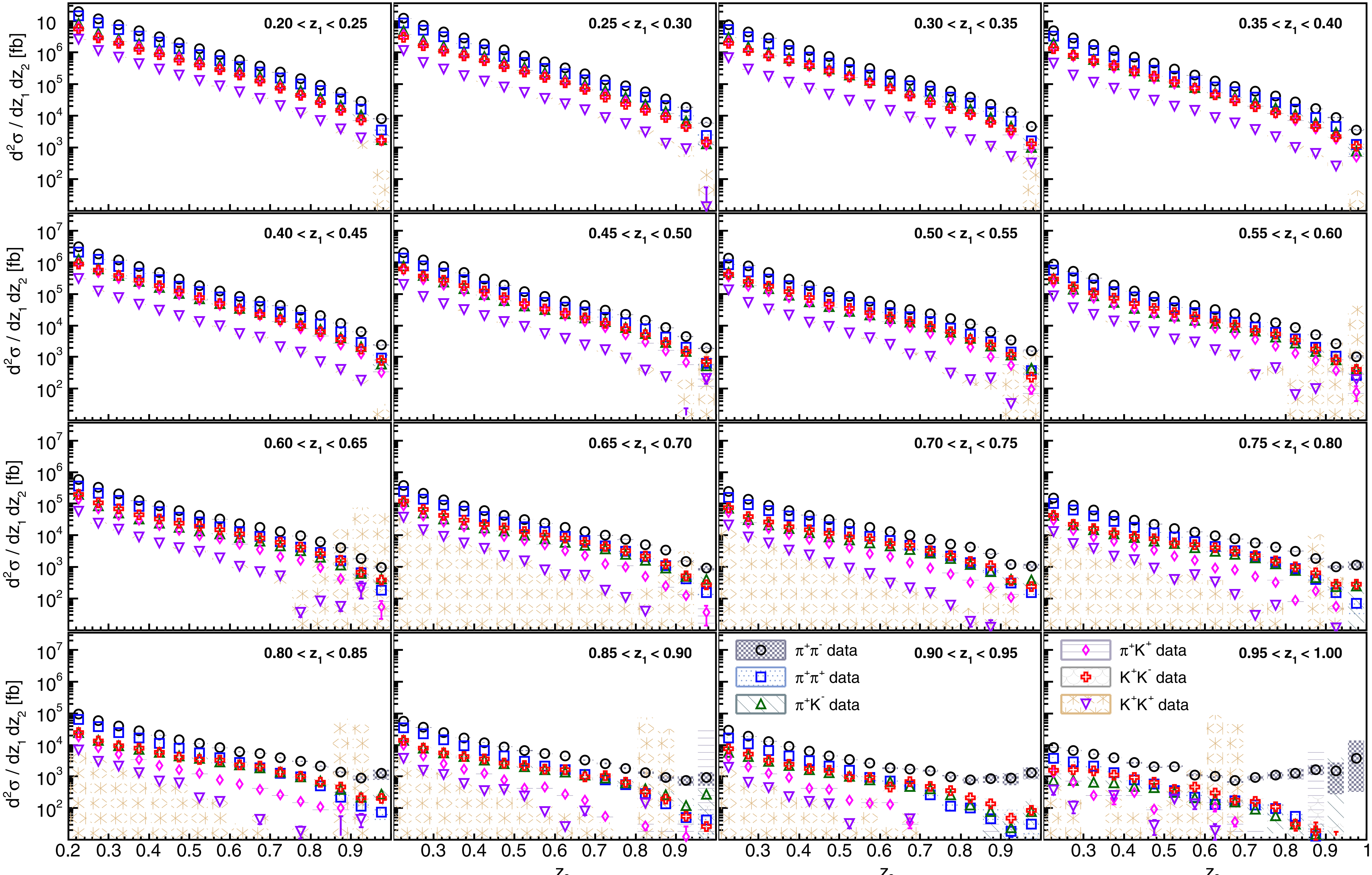


uncertainties:
- systematic+statistical
- driven by systematics

Results hadron pairs: any topology



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Results hadron-pair ratios: any topology

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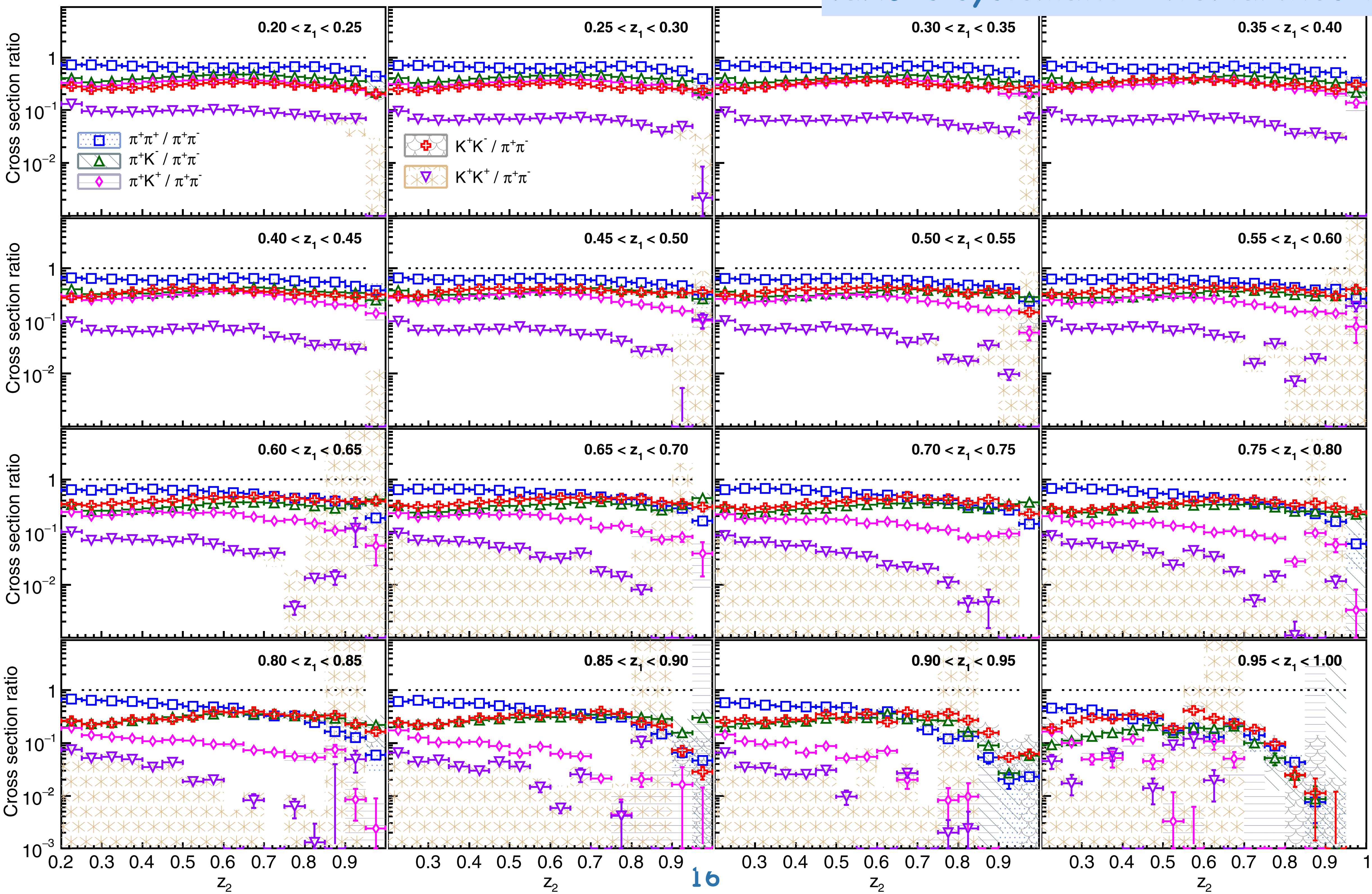
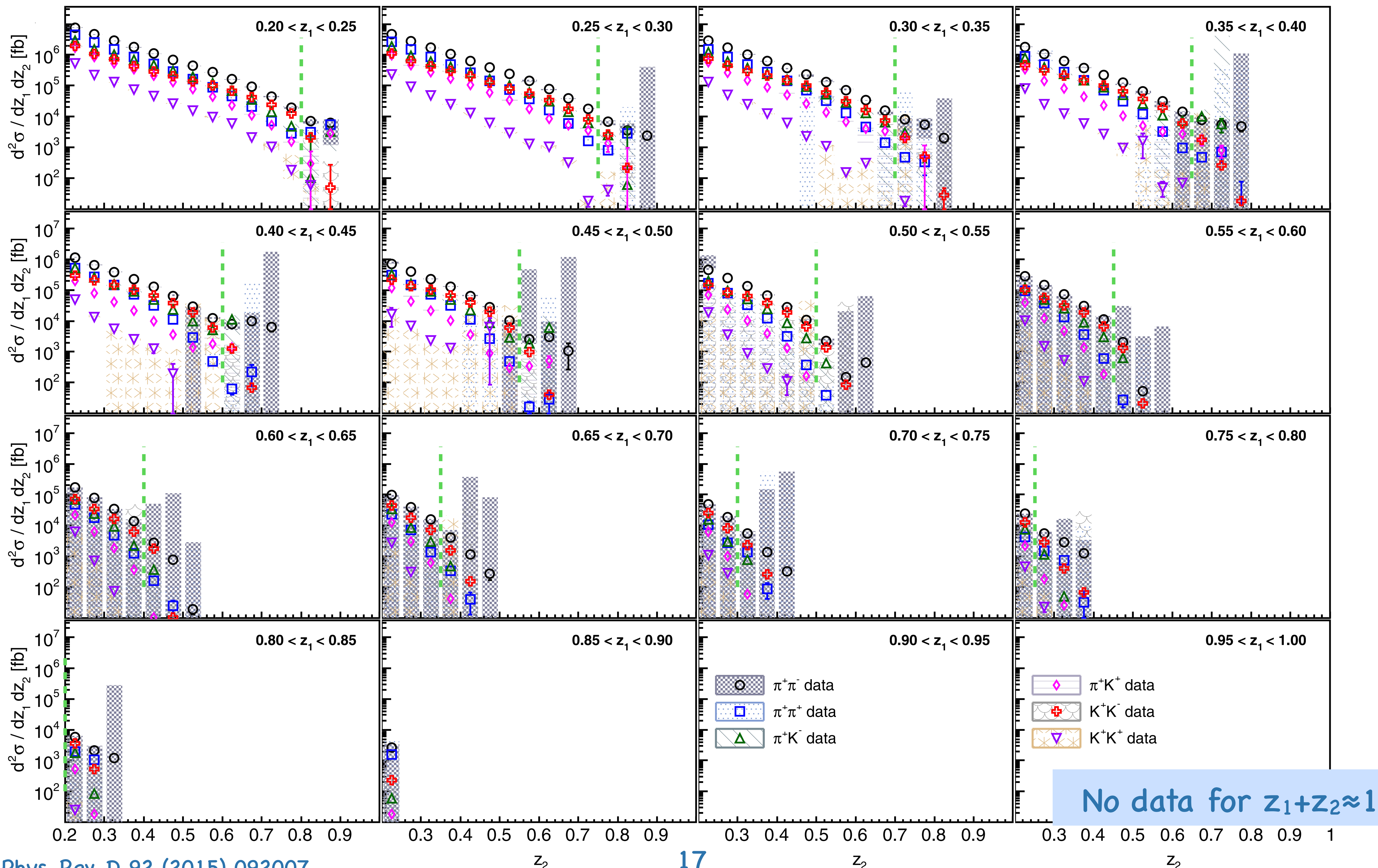
various systematic uncertainties cancel



Results hadron pairs: same hemisphere



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Results hadron pairs: comparison of hemispheres

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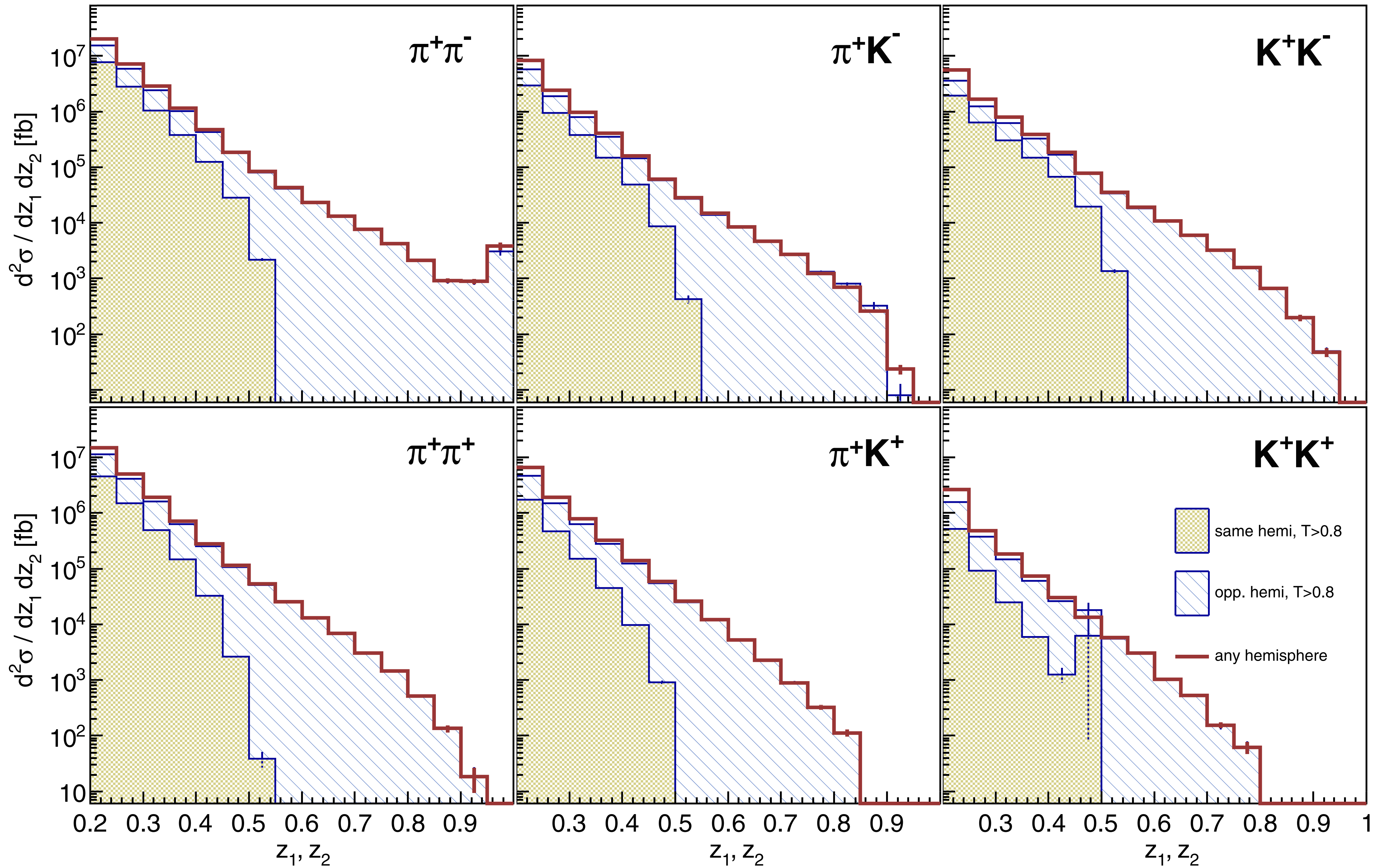
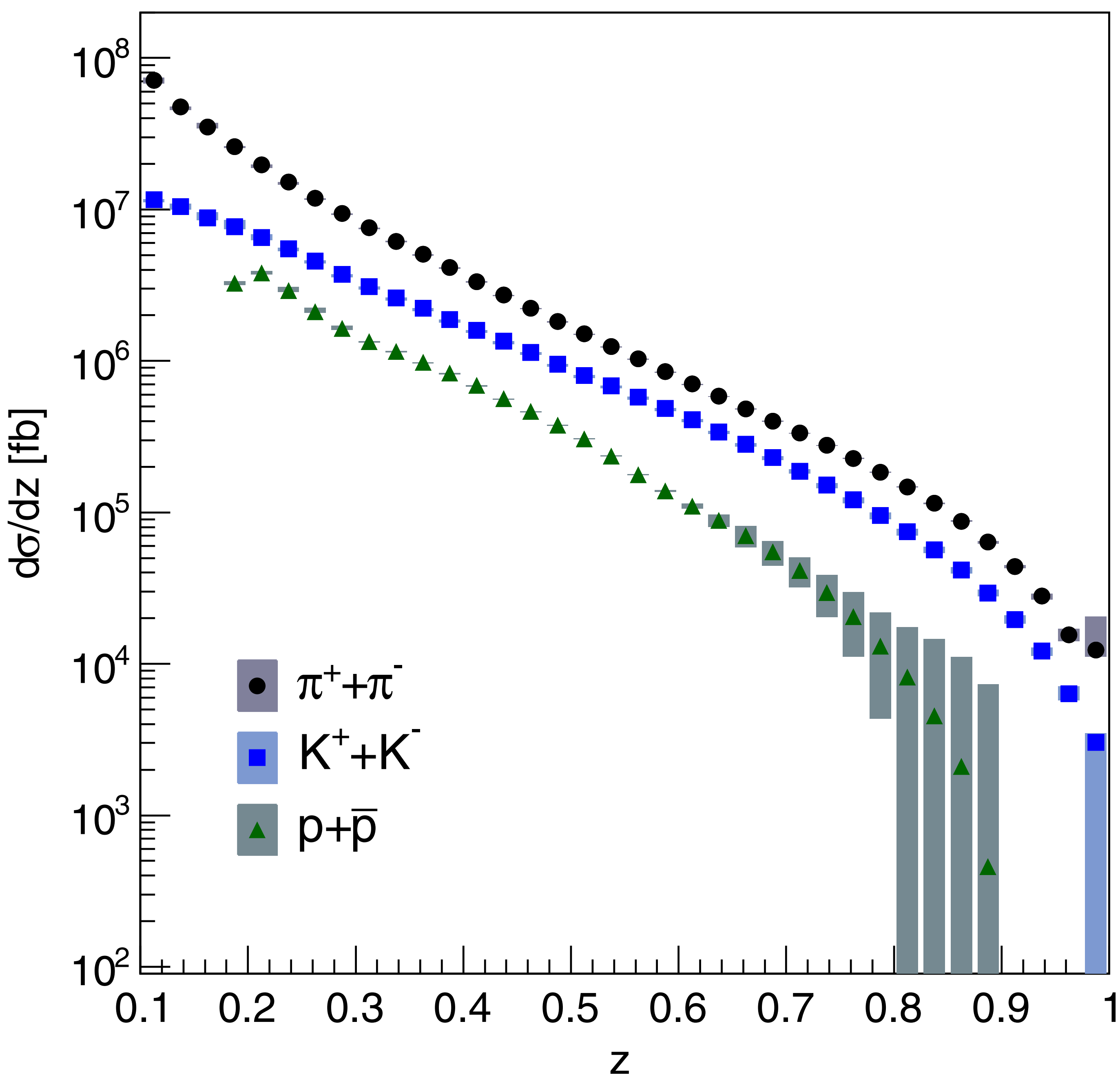


data not corrected for T>0.8 cut

$z_1 = z_2$

Results single protons



uncertainties: ● systematic+statistical

Pions and kaons already published with different binning in Phys. Rev. Lett. 111 (2013) 062002

Summary

- Cross sections for pairs of charged hadrons extracted:
  - Results consistent with disfavoured fragmentation being suppressed:
    same-sign pion pairs fall-off more rapidly with z in opposite hemispheres than opposite-sign pion pairs
  - suppression of fragmentation with creation of strangeness
  - vanishing cross section for semi-hemisphere hadrons for $z \geq 1$
    consistent with hadrons in same hemisphere predominantly from same quark
    consistent with hadrons in opposite hemisphere predominantly from different quarks
    $\longrightarrow$ help constrain single-hadron fragmentation functions
- Cross sections for single protons extracted:
  - allow constrain of proton fragmentation functions

Back up

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  construct PID matrix from experimental + Monte-Carlo (where limited statistics) data
- Smearing correction: compare for z bins Monte-Carlo generated and reconstructed events
- Non-$q\bar{q}$ background:
  - subtract QED processes: $e^+e^- \to \tau\tau$, $e^+e^- \to e^+e^- q\bar{q}$
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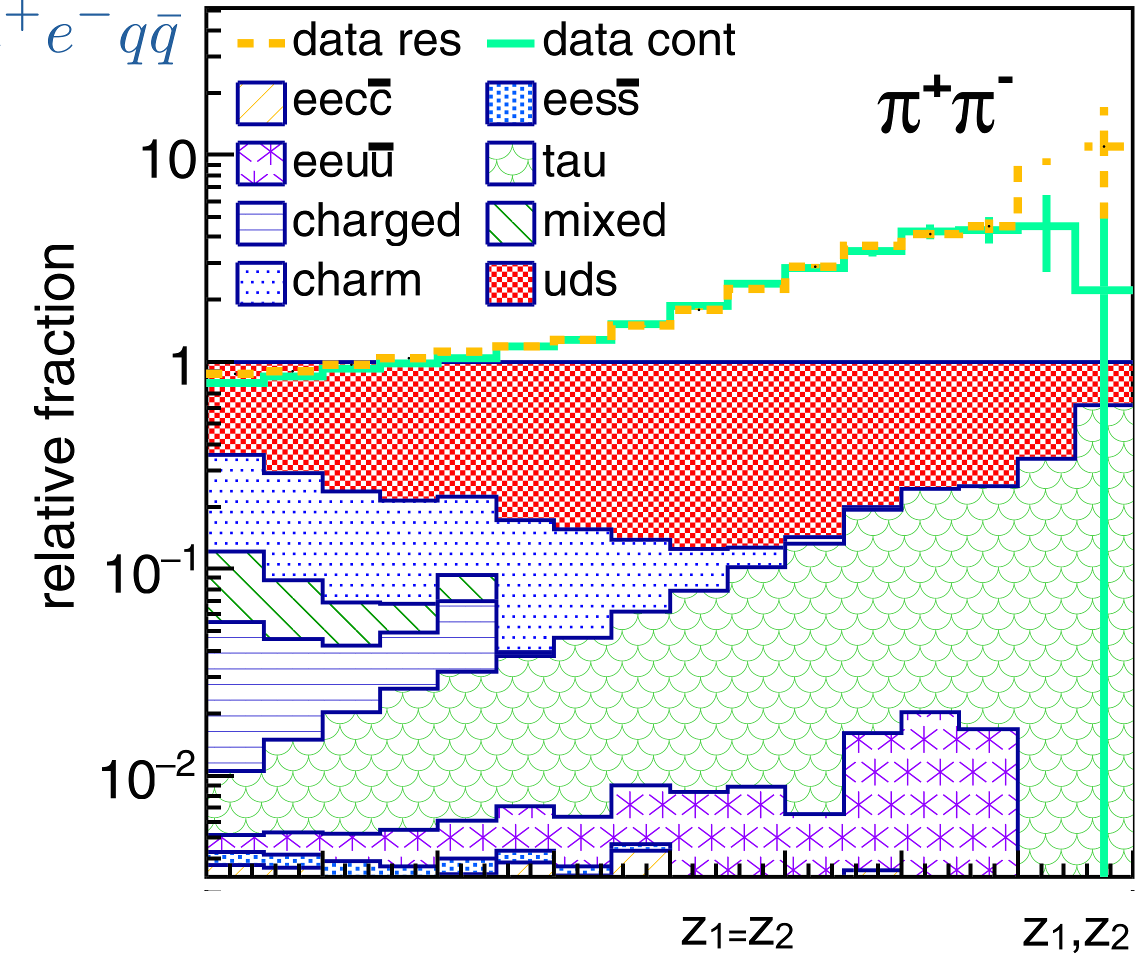
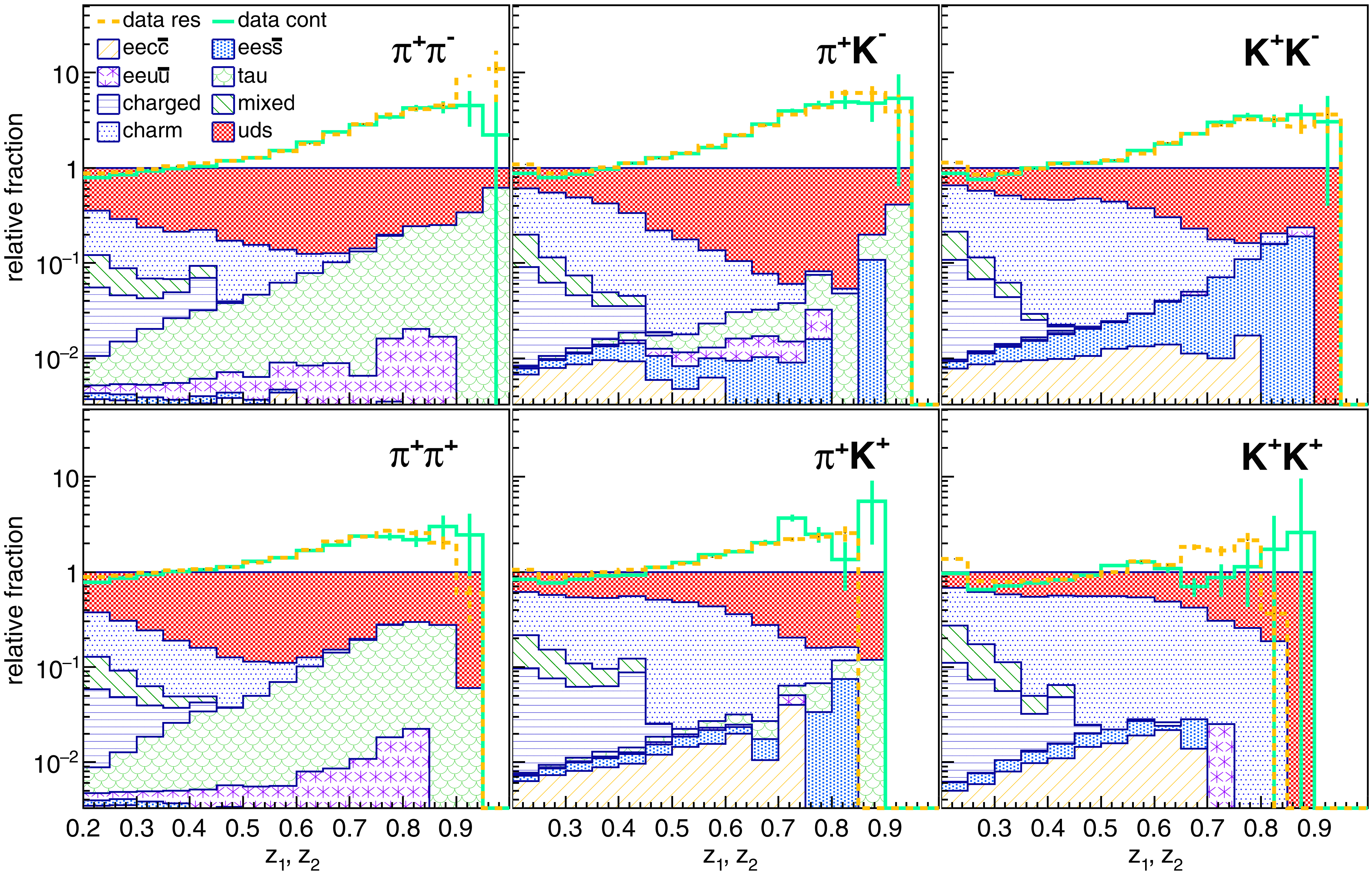


Non-$q\bar{q}$ background contributions



any topology

Applied corrections

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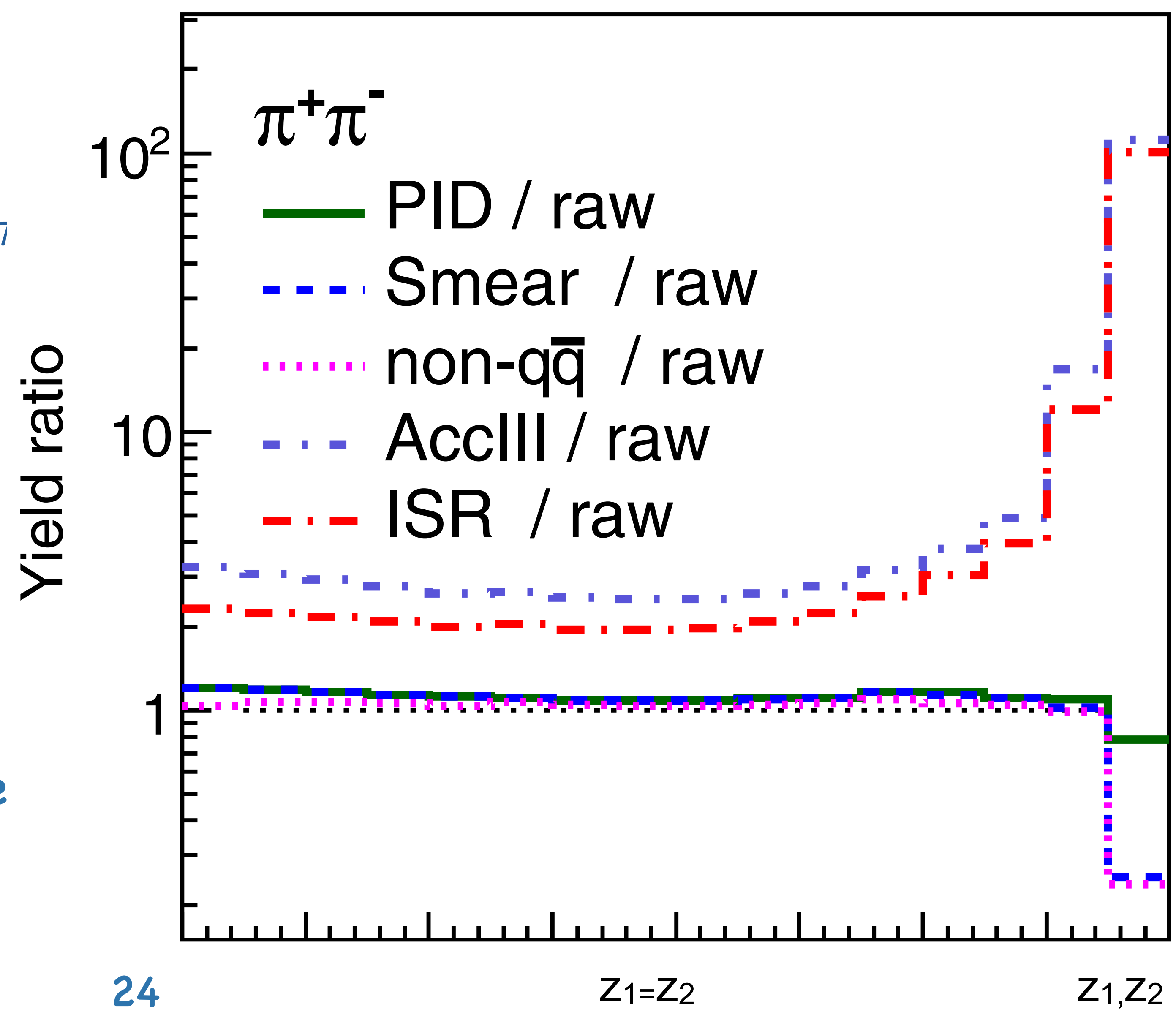
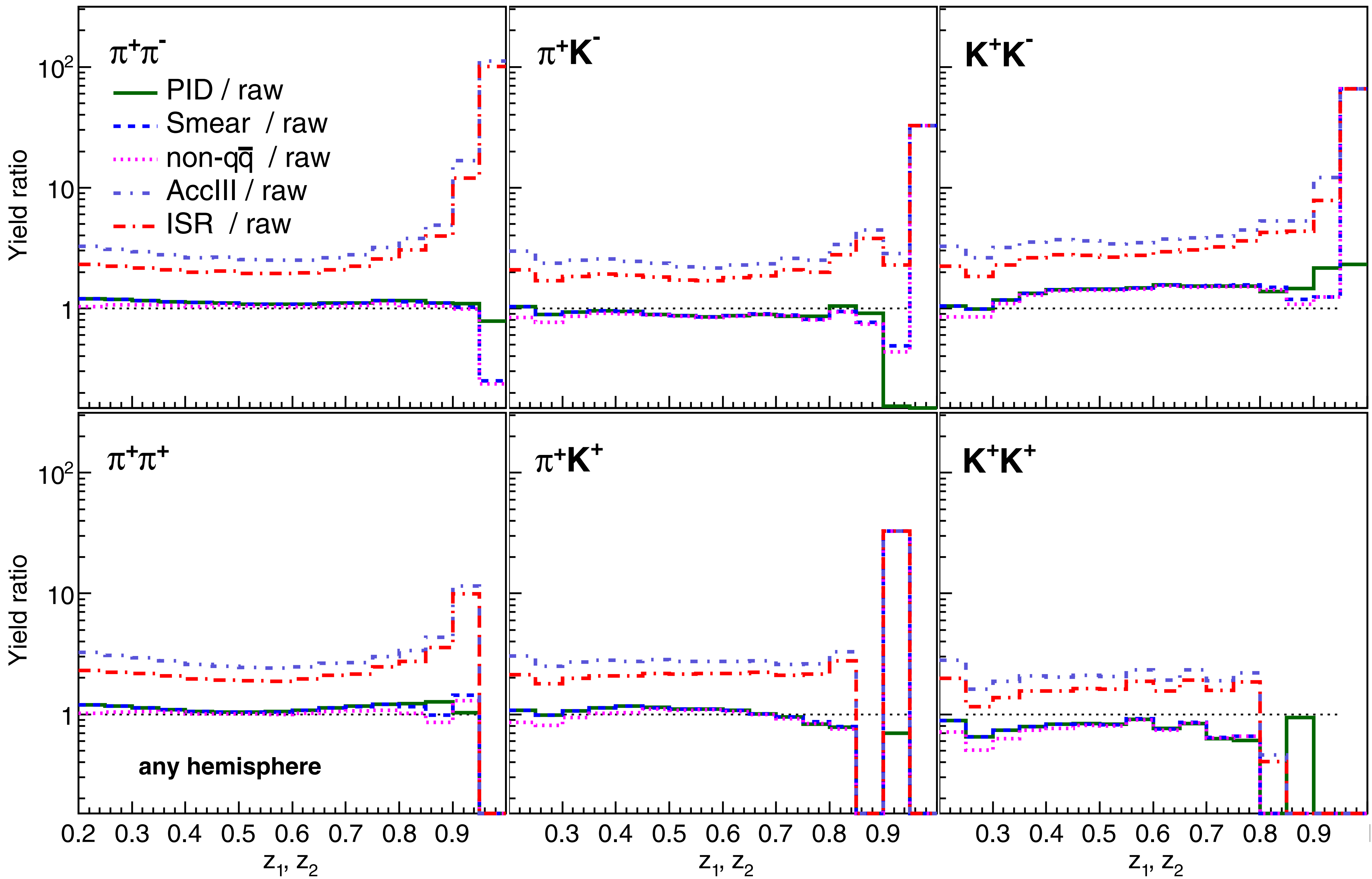
- Acceptance corrections:
- Optional correction for weak decays, (here not shown)
- Initial-state photon radiation: exclude



Total corrections hadron pairs

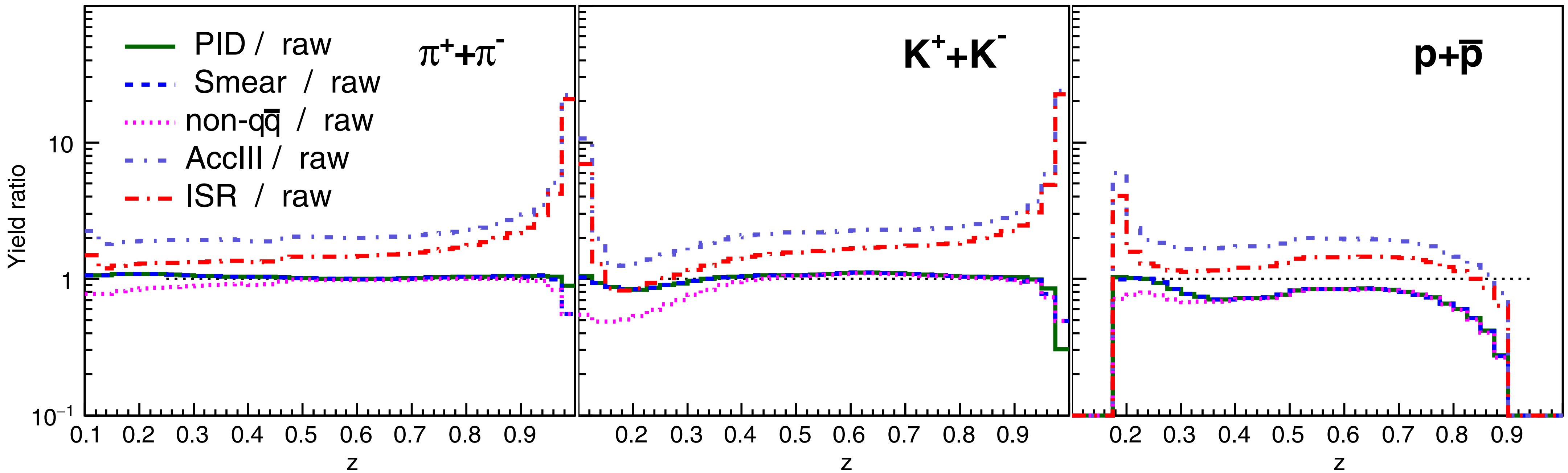


$z_1=z_2$

any topology

similar for single-protons

Total corrections single hadrons



$z_1 = z_2$