Charge-integrated pion and kaon multiplicities from Belle e^+e^- annihilation data

C. Van Hulse, M. Leitgab, F. Giordano, M. Grosse-Perdekamp, W. Jacobs, N. Kobayashi, H. Li, A. Ogawa, G. Schnell, R. Seidl, A. Vossen, for the Belle collaboration

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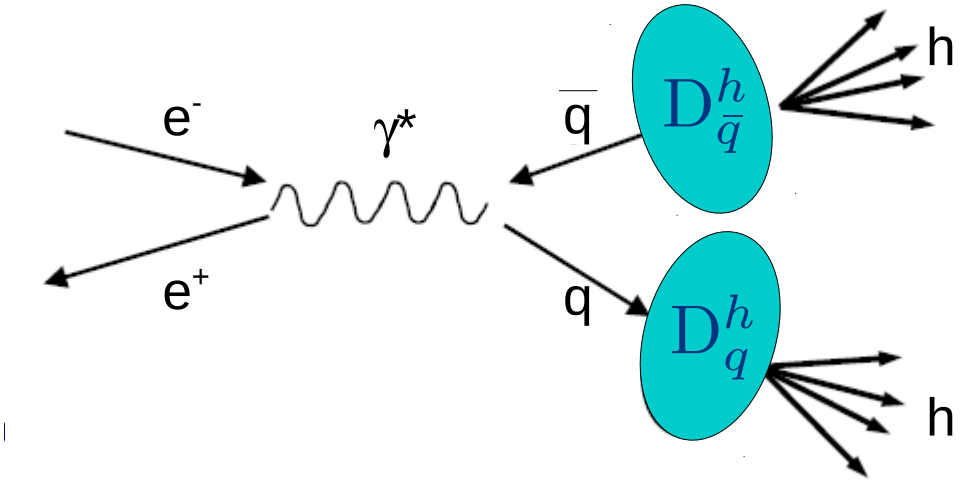
Outline

- e^+e^- annihilation and fragmentation functions
- Belle experiment
- extraction of π/K multiplicities
- applied corrections
- results
- comparison to world data
- summary

e^+e^- annihilation and fragmentation functions (FFs)



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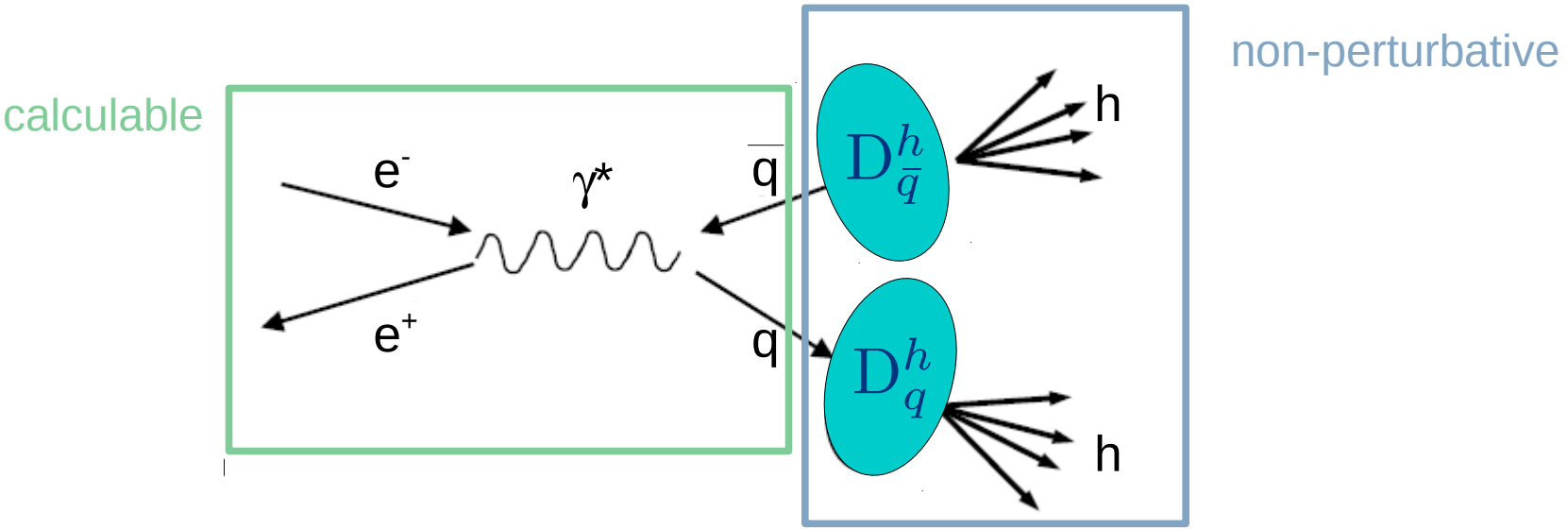

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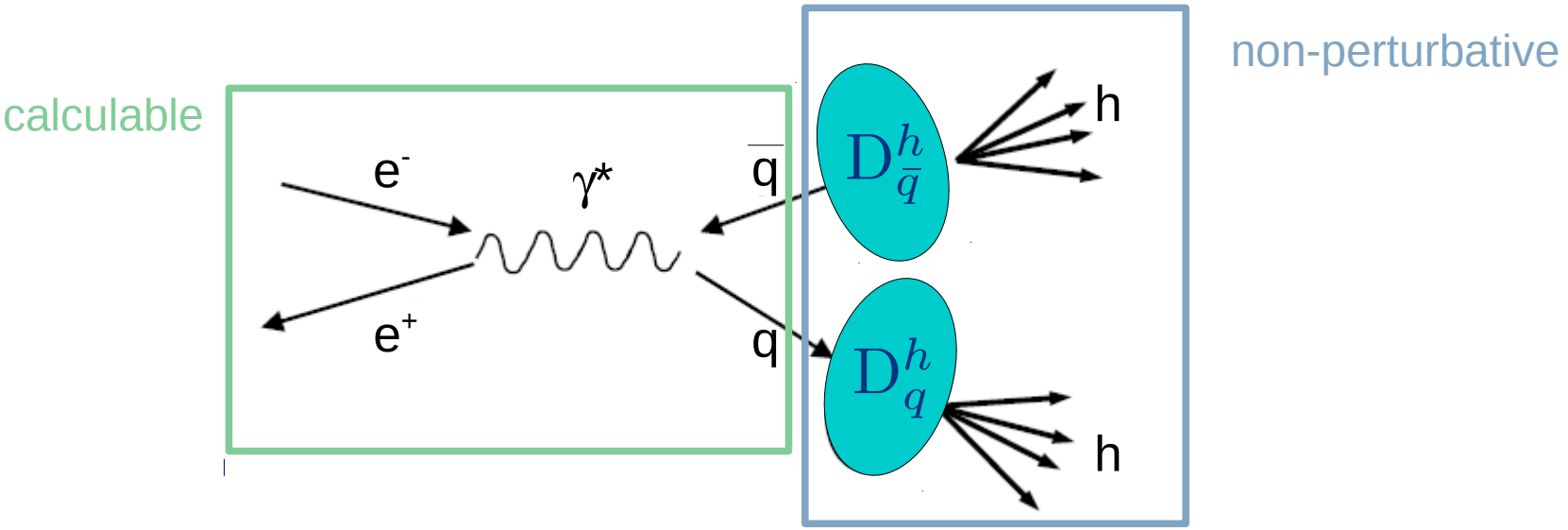
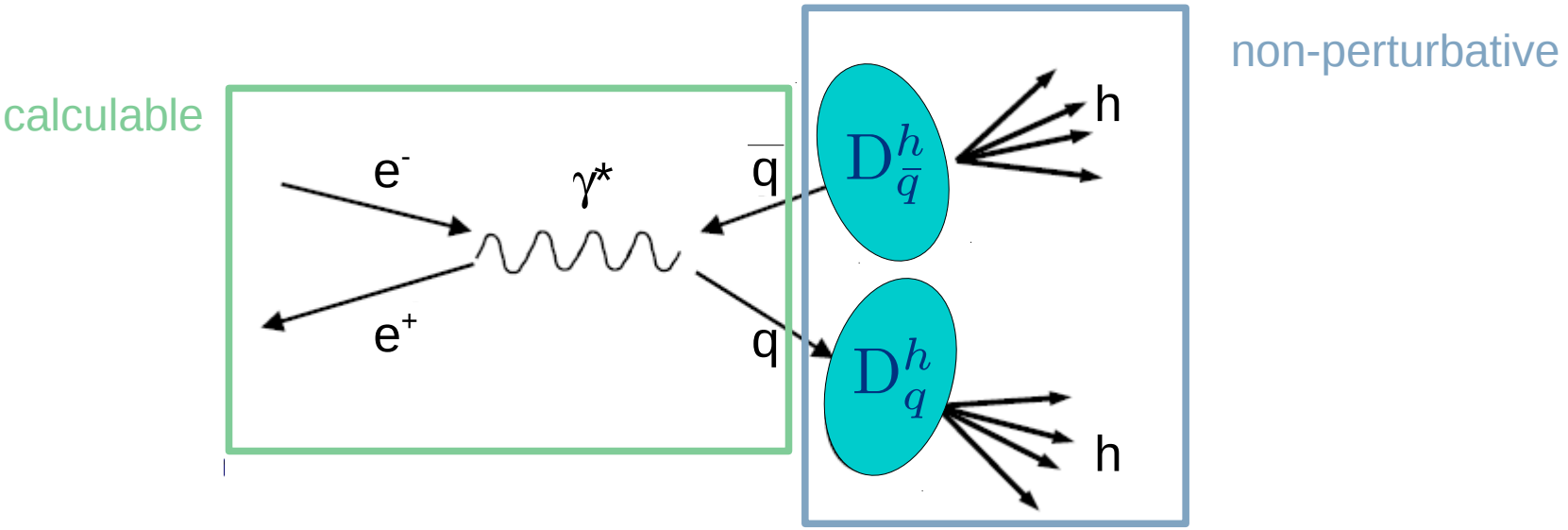


$$M^h(z,Q^2) = \frac{1}{\sigma_{tot}} \frac{d\sigma(e^+e^- \to hX)}{dz} \qquad \text{with } z = \frac{E_h}{\sqrt{s}/2}$$

$$\overset{LO}{\propto} \sum_{i=q,\bar{q}} e_i^2 \, D_i^h(z,Q^2) \longrightarrow \text{quark FFs } \mathrm{D}^h_{q,\bar{q}}$$

$$\overset{NLO}{\propto} \sum_{i=q,\bar{q},g} C_i^{NLO}(z,\alpha_s) \otimes D_i^h(z,Q^2) \longrightarrow \text{gluon FFs } \mathrm{D}^h_g$$

e^+e^- annihilation and fragmentation functions (FFs)



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

State-of-the-art FF extraction

- e^+e^- annihilation
  M. Hirai, S. Kumano, T.-H. Nagai, K. Sudoh, Phys. Rev. D **75** (2007) 114010,
  with first theoretical and experimental uncertainties on FFs

- global analyses

  - e^+e^- annihilation & proton-proton collisions:
    S. Albino, B. A. Kniehl, G. Kramer, Nucl. Phys. B **803** (2008) 42

  - e^+e^- annihilation, proton-proton collisions, and semi-inclusive DIS:
    D. de Florian, R. Sassot, M. Stratmann, Phys. Rev. D **75** (2007) 094009
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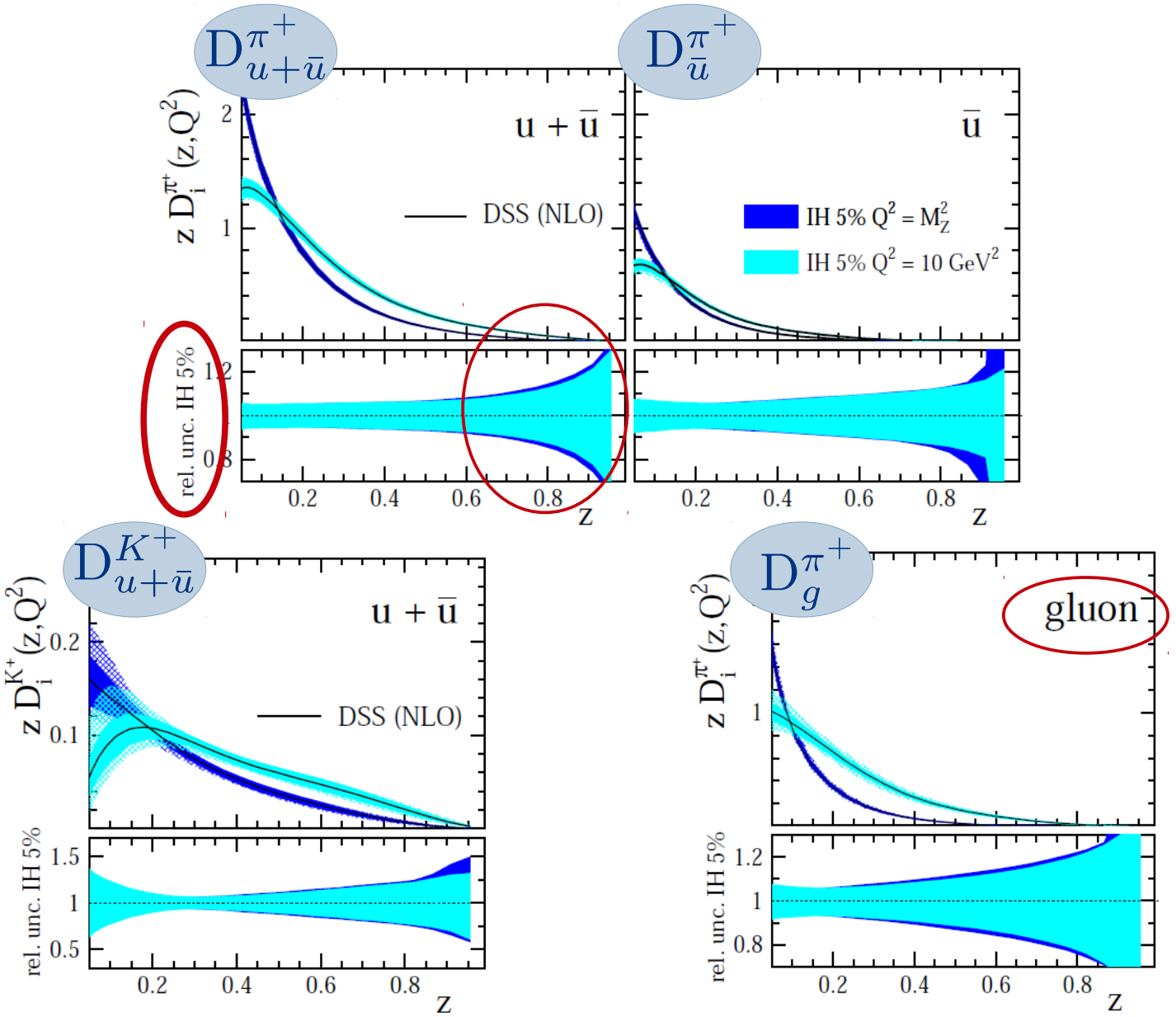
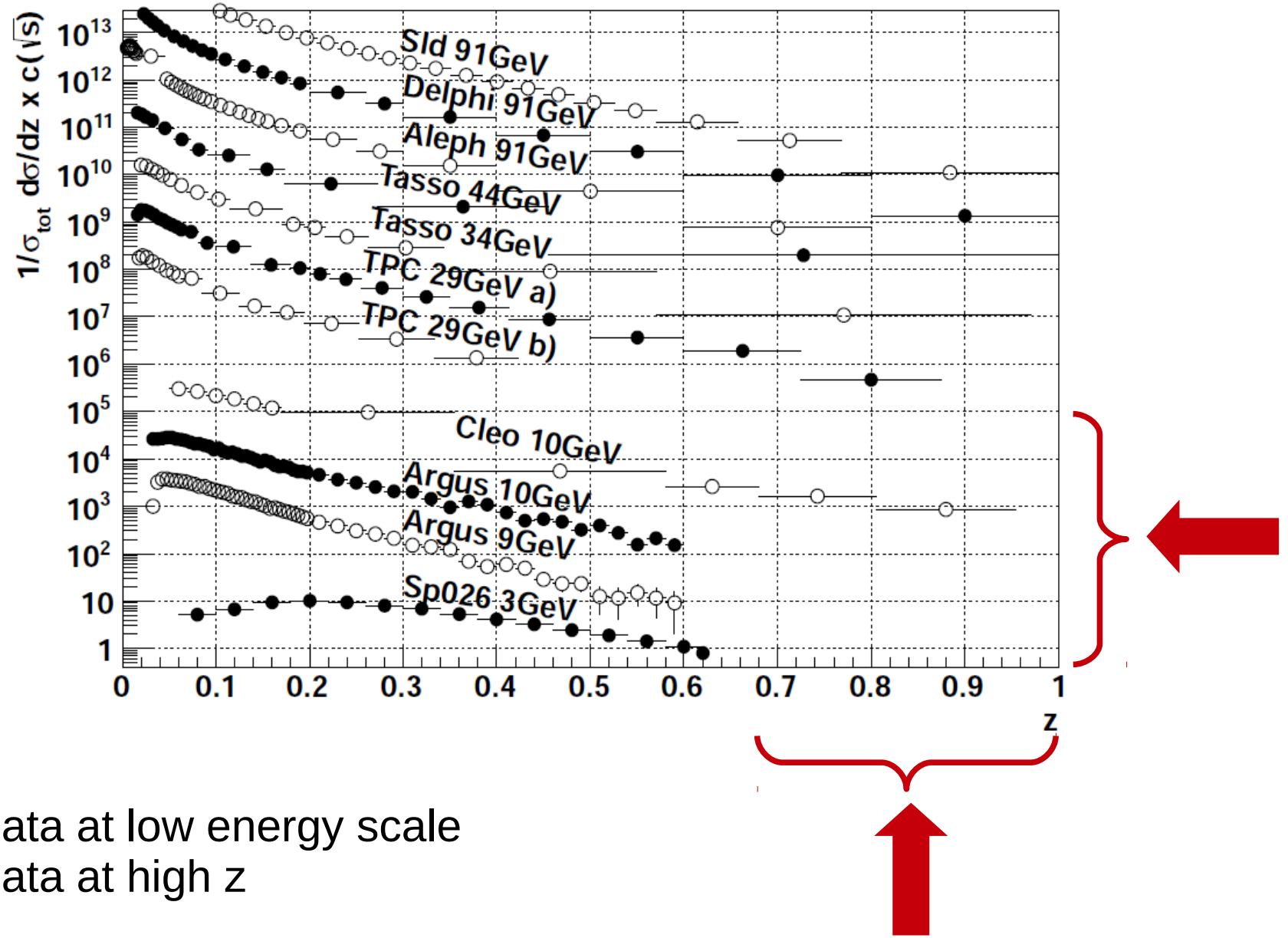


State-of-the-art multiplicity data

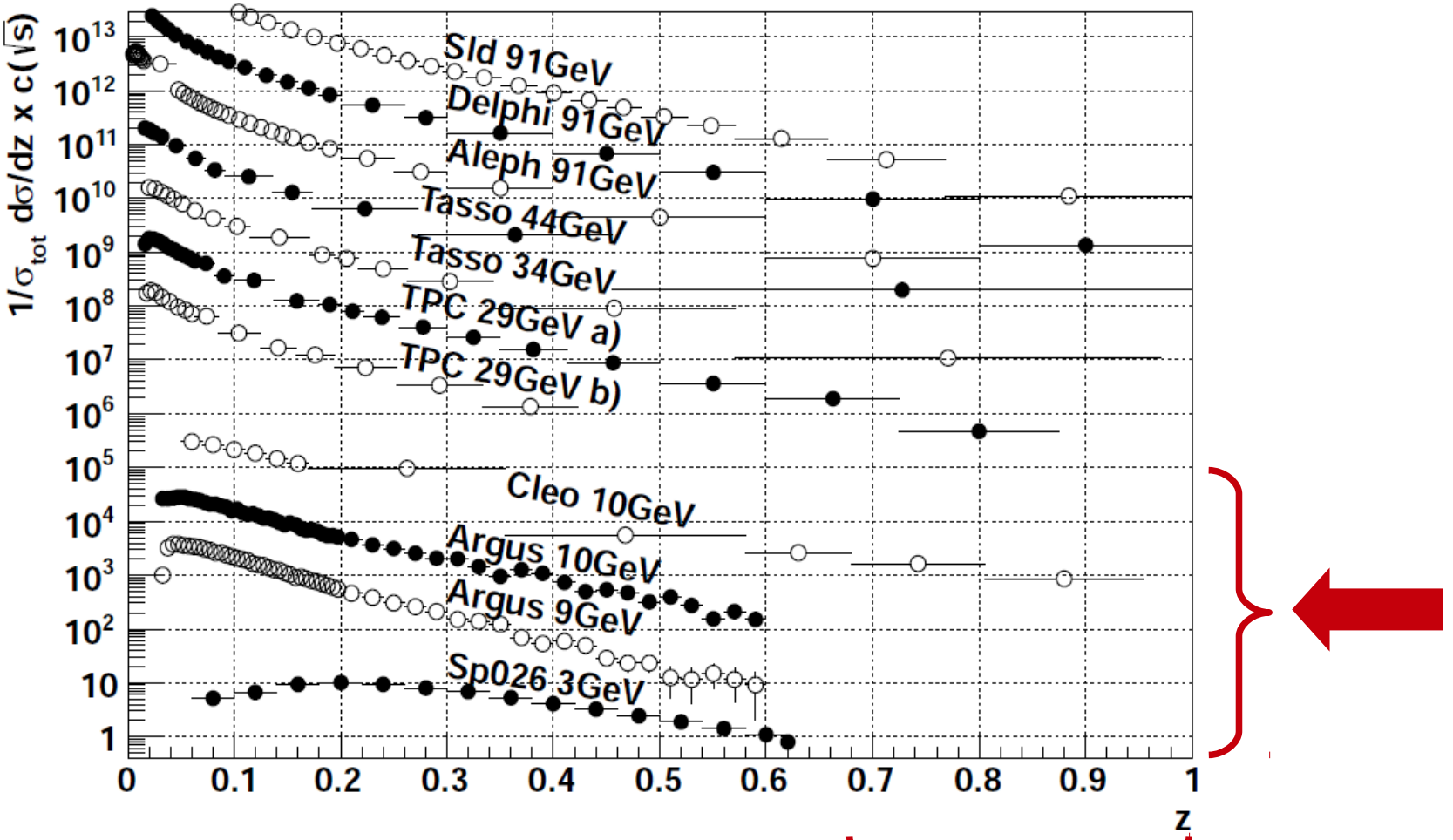
$$e^+e^- \to \pi^\pm + X \text{ multiplicities}$$



- limited data at low energy scale
- limited data at high z

State-of-the-art multiplicity data

$e^+e^- \to \pi^\pm + X$ multiplicities



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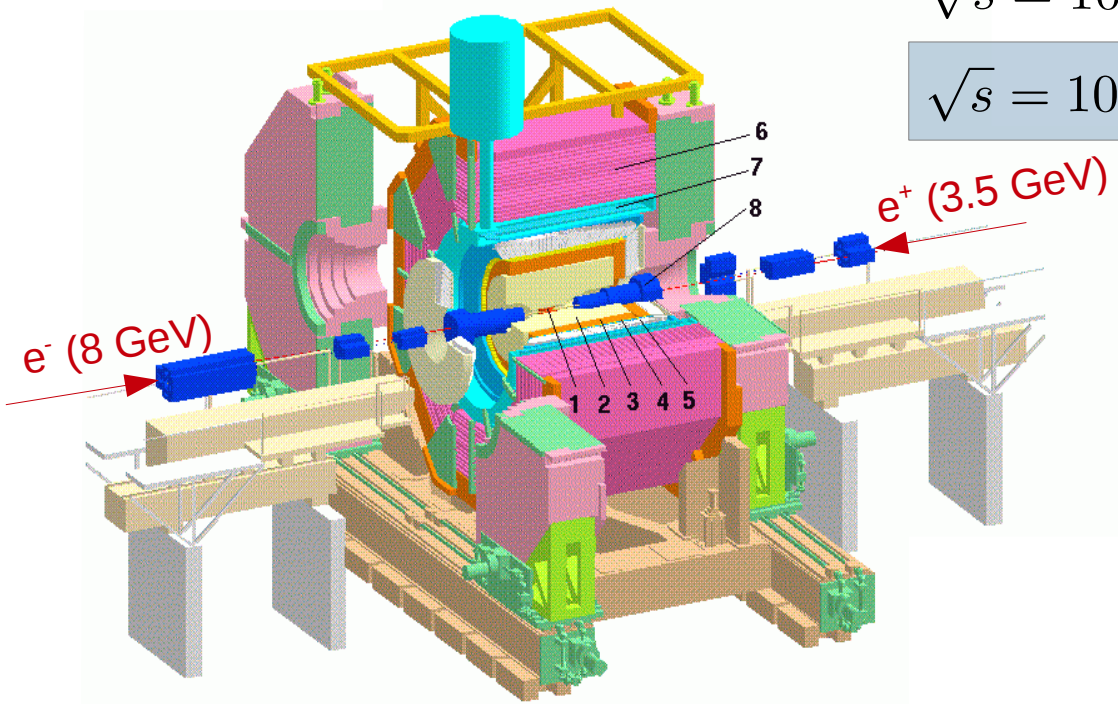
Belle experiment



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

- located at asymmetric e^+e^- KEKB collider:

$\sqrt{s} = 10.58\ \mathrm{GeV} : e^+e^- \to \Upsilon(4S) \to B\bar{B}$ decay

$\sqrt{s} = 10.52\ \mathrm{GeV} : e^+e^- \to q\bar{q}\ (q = u, d, s, c)$

$68\,\mathrm{fb}^{-1}$

- Track/momentum reconstruction system:
  - silicon vertex detector, central drift chamber
  - 1.5 T solenoid
- Particle identification system:
  pion, kaon, proton, electron, muon identification

Extracted observables

- pion/kaon yields $\mathrm{N}^h(z)$ extracted from z=0.2 to z=0.98/0.97 in bins of Δz=0.01
- extracted from raw yields $\mathrm{N}^{h'}_{raw}(z')$:

$$\mathrm{N}^h(z) = \epsilon_{ISR/FSR}(z)\,\epsilon_{acc.}(z)\,\epsilon_{ev.sel.}(z)\,\epsilon_{DIF,det.,rec.}(z)\times$$
$$\mathrm{P}^{-1}_{smear.}(z,z')\,\epsilon_{non-q\bar{q}}(z')\times$$
$$\mathrm{P}^{-1}_{PID,hh'}(\cos\theta_{lab},p_{lab})\,N^{h'}_{raw}(\cos\theta_{lab},p_{lab},z')$$

$$M^h(z) = \frac{1}{N_{tot}}\,N^h(z)$$

PID probabilities

- construct PID matrix from experimental data in 8 $\cos(\theta_{lab})$ x 16 p_{lab} bins, supplemented with Monte-Carlo data where limited statistics

probability that a true e
is correctly identified as an e

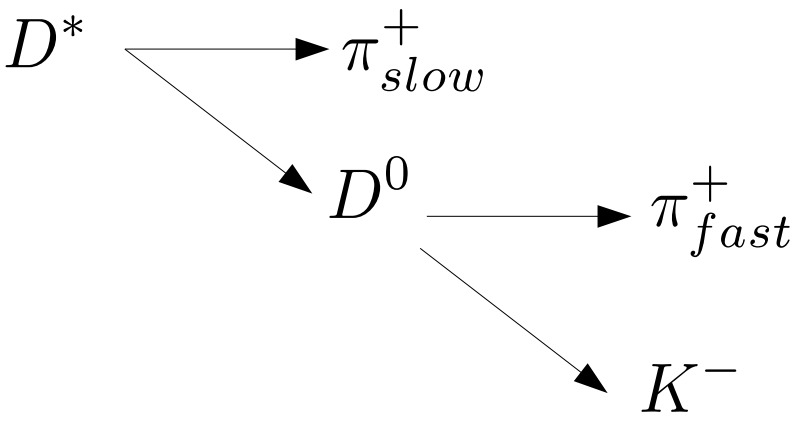
$$\mathrm{P}_{PID,hh'}(\cos\theta_{lab}, p_{lab}) = \begin{pmatrix} \mathrm{p}_{e\to e} & \mathrm{p}_{\mu\to e} & \mathrm{p}_{\pi\to e} & \mathrm{p}_{K\to e} & \mathrm{p}_{p\to e} \\ \mathrm{p}_{e\to \mu} & \mathrm{p}_{\mu\to \mu} & \mathrm{p}_{\pi\to \mu} & \mathrm{p}_{K\to \mu} & \mathrm{p}_{p\to \mu} \\ \mathrm{p}_{e\to \pi} & \mathrm{p}_{\mu\to \pi} & \mathrm{p}_{\pi\to \pi} & \mathrm{p}_{K\to \pi} & \mathrm{p}_{p\to \pi} \\ \mathrm{p}_{e\to K} & \mathrm{p}_{\mu\to K} & \mathrm{p}_{\pi\to K} & \mathrm{p}_{K\to K} & \mathrm{p}_{p\to K} \\ \mathrm{p}_{e\to p} & \mathrm{p}_{\mu\to p} & \mathrm{p}_{\pi\to p} & \mathrm{p}_{K\to p} & \mathrm{p}_{p\to p} \end{pmatrix}$$

probability that a true kaon
is misidentified as proton

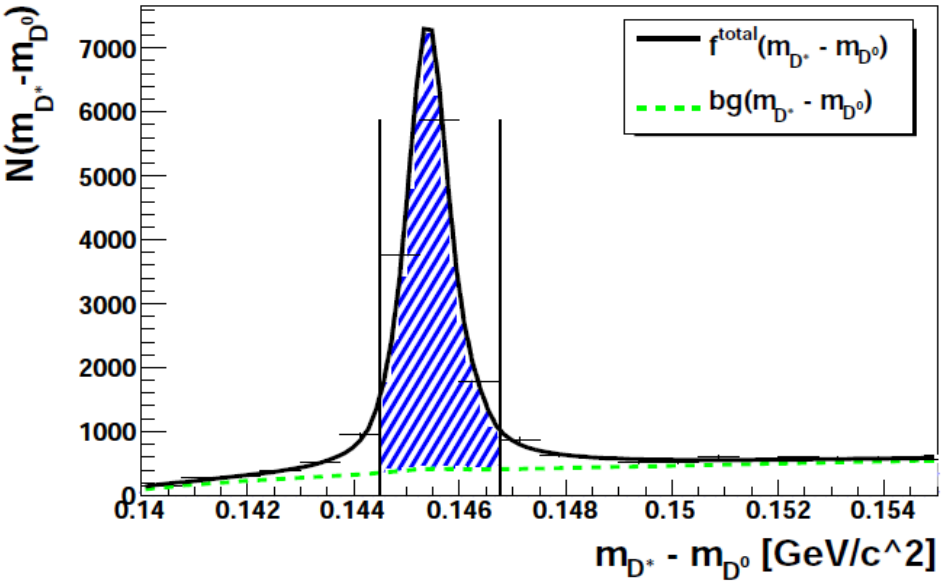
particle misidentification ~10%, up to 50%

correction needed

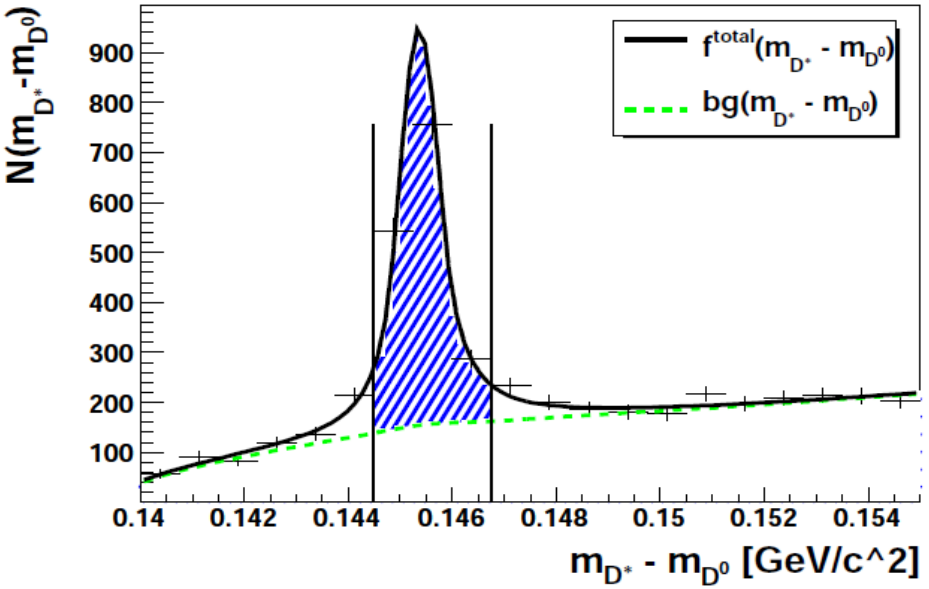
PID probability extraction



without PID selection



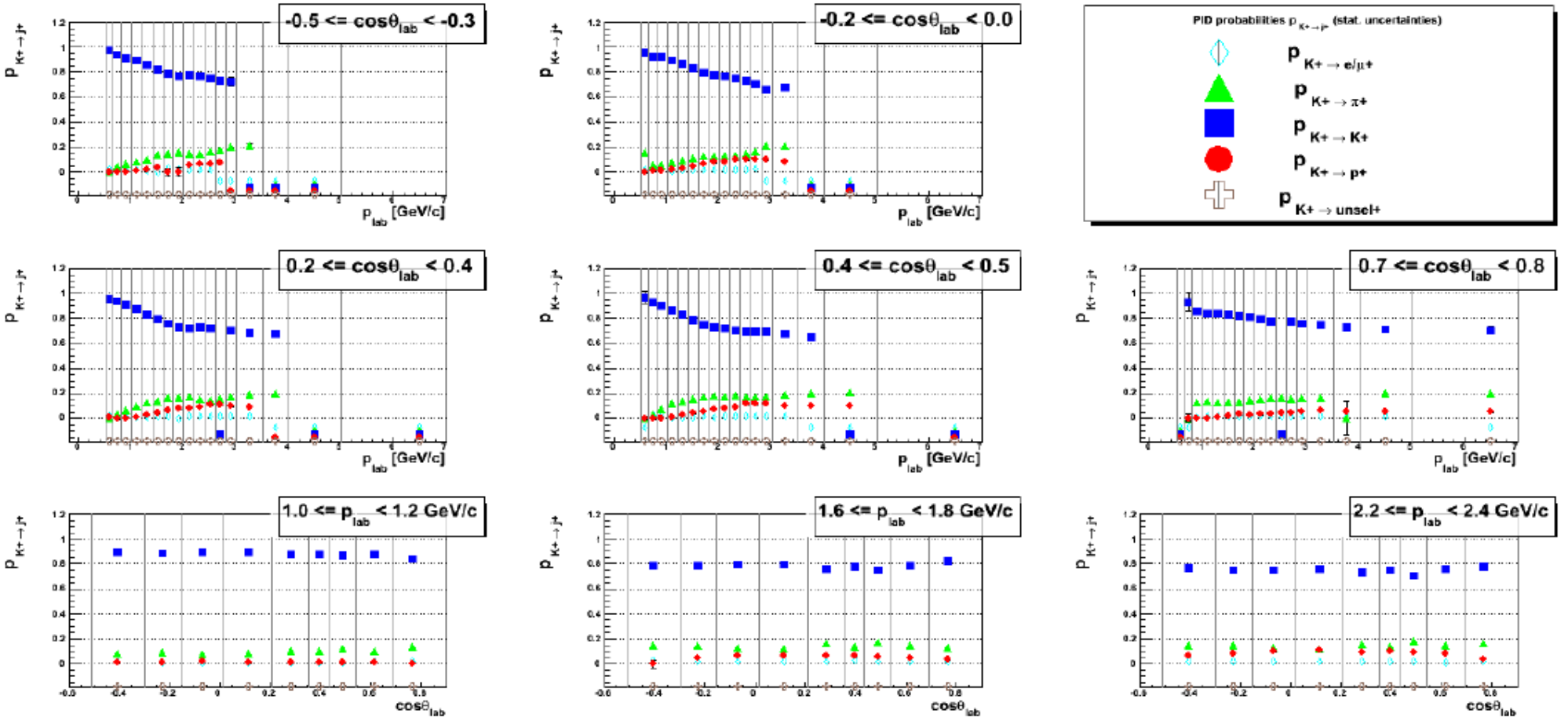
π PID selection on K track



probability $P_{K\to\pi}$
that K misidentified as π

PID probability extraction

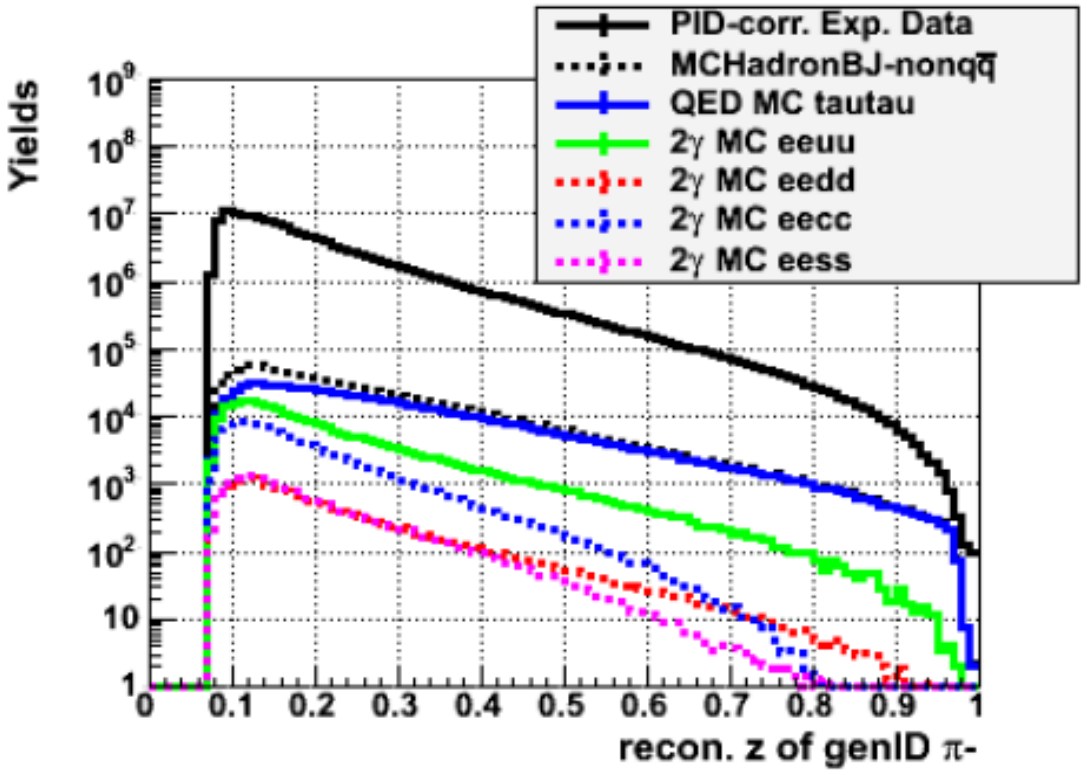
$8\ \cos(\theta_{lab}) \times 16\, p_{lab}$ bins



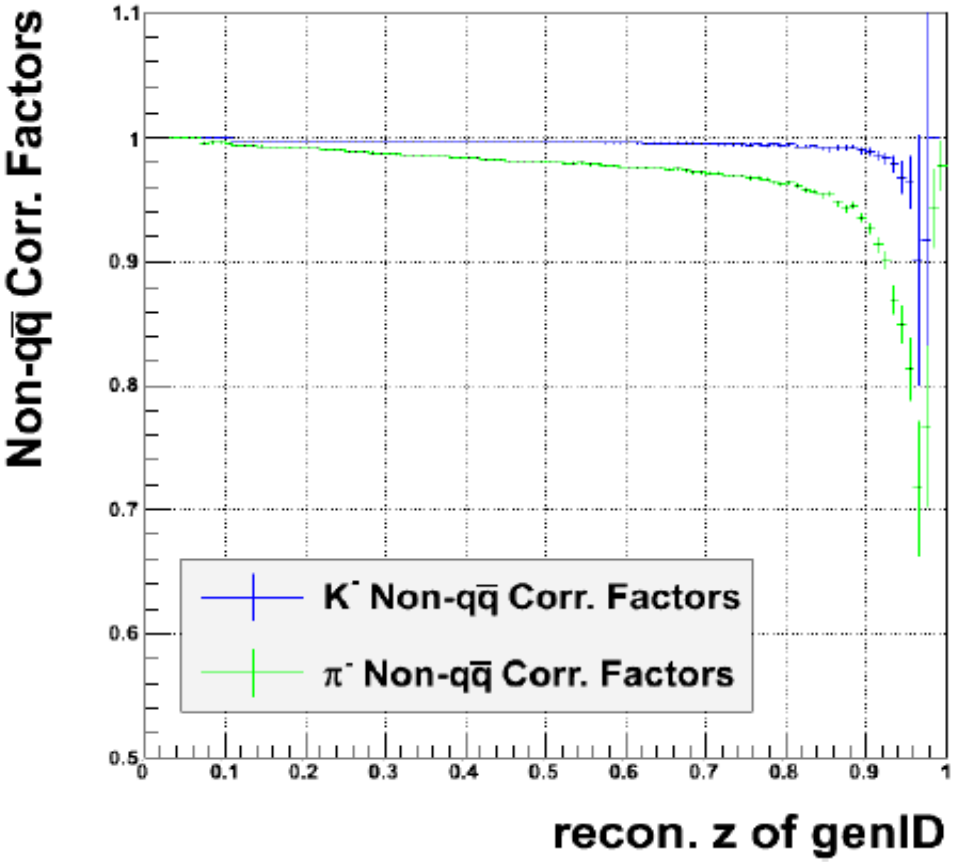
$P_{\pi,K\to h'}$	from D^* decay
$P_{\pi,p\to h'}$	from Λ decay
$P_{e,\mu\to h'}$	from J/ψ decay

Non-$q\bar{q}$ events

QED and 2γ Monte-Carlo simulation



extracted correction factors



main contributions: $e^+e^- \to \tau\tau$

$\gamma\gamma \to q\bar{q}$

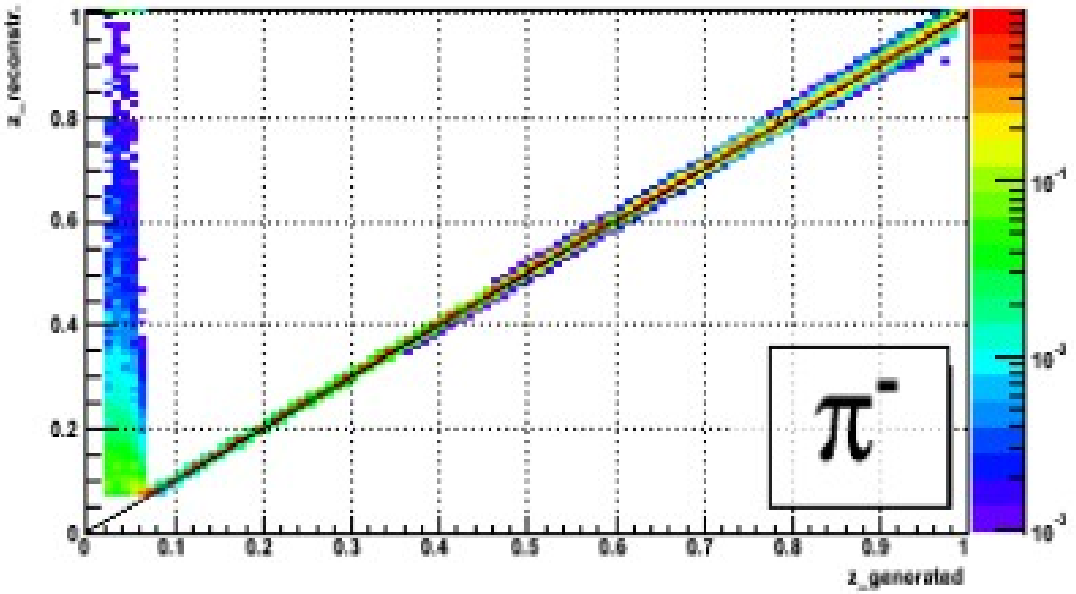
correction at high z: 30% for π

10% for K

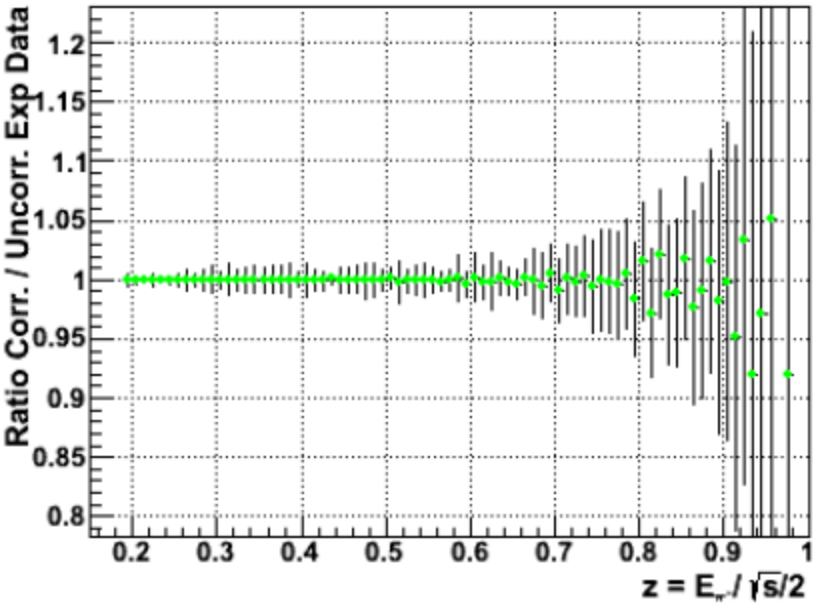
Smearing

- smearing correction matrix extracted from Monte-Carlo simulation
- evaluated down to z=0.08 for π and z=0.12 for K
- limits upper z range to z=0.98 for π and z=0.97 for K

smearing histogram from Monte Carlo



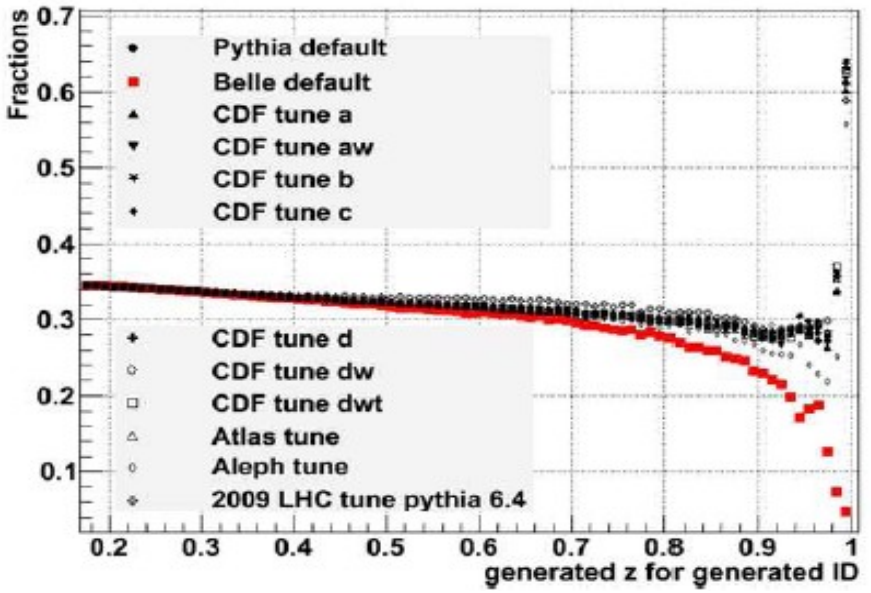
corrected/uncorrected data



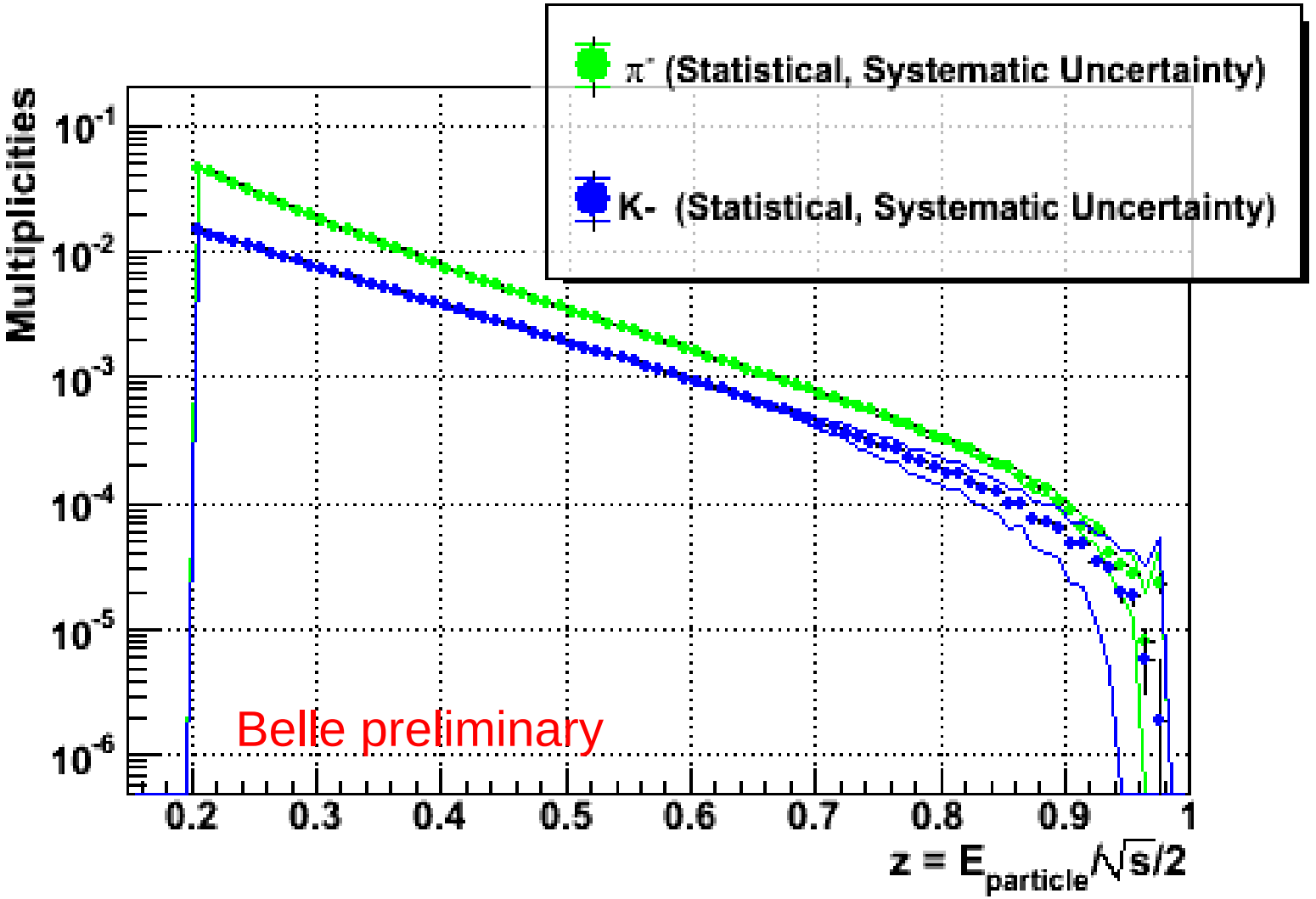
Further corrections

- decay in flight:
  - corrections for π/K lost due to decay in flight
  - no corrections for π/K created in weak decay
  - fractions from Belle Monte Carlo of π/K from weak and from strong decay provided
- correction for hadronic detector interactions from GEANT-FLUKA
- correction for analysis event and track selection cuts
- correction for acceptance
- initial- and final-state photon radiation:
  - exclude hadrons from events with $E_\gamma > 0.5\% \sqrt{s}/2$
  - corrections based on Belle Monte Carlo
  - in addition: 11 different Jetset/Pythia parameter sets for systematic uncertainty

exclusion factors for π^-



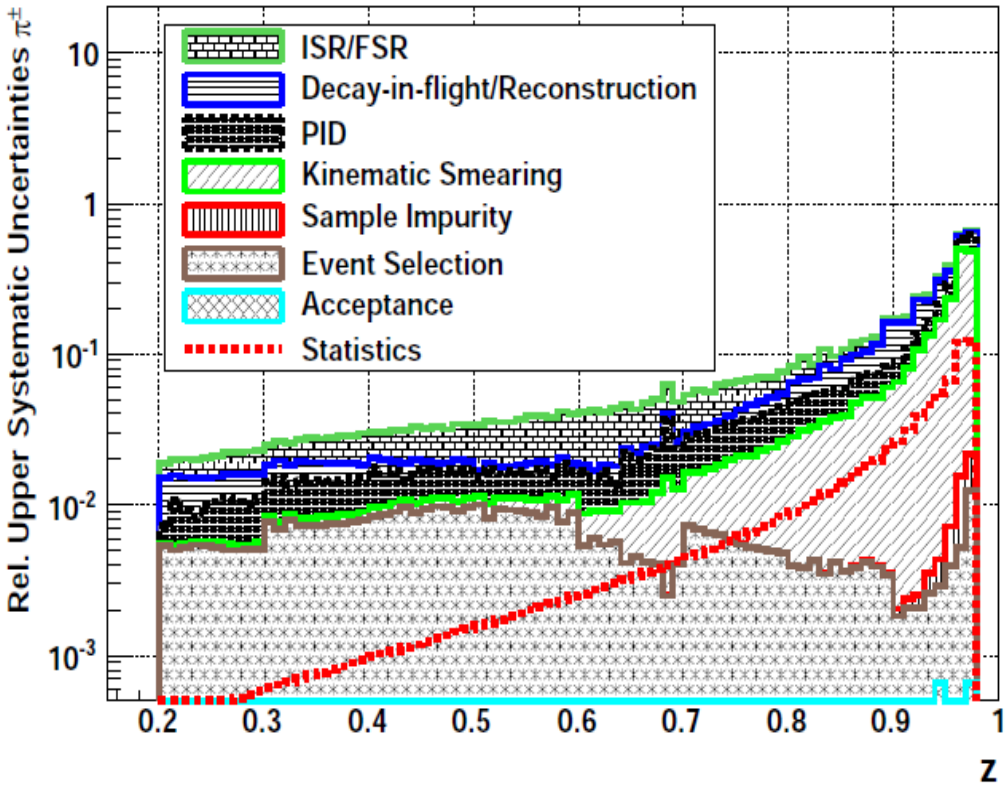
Results



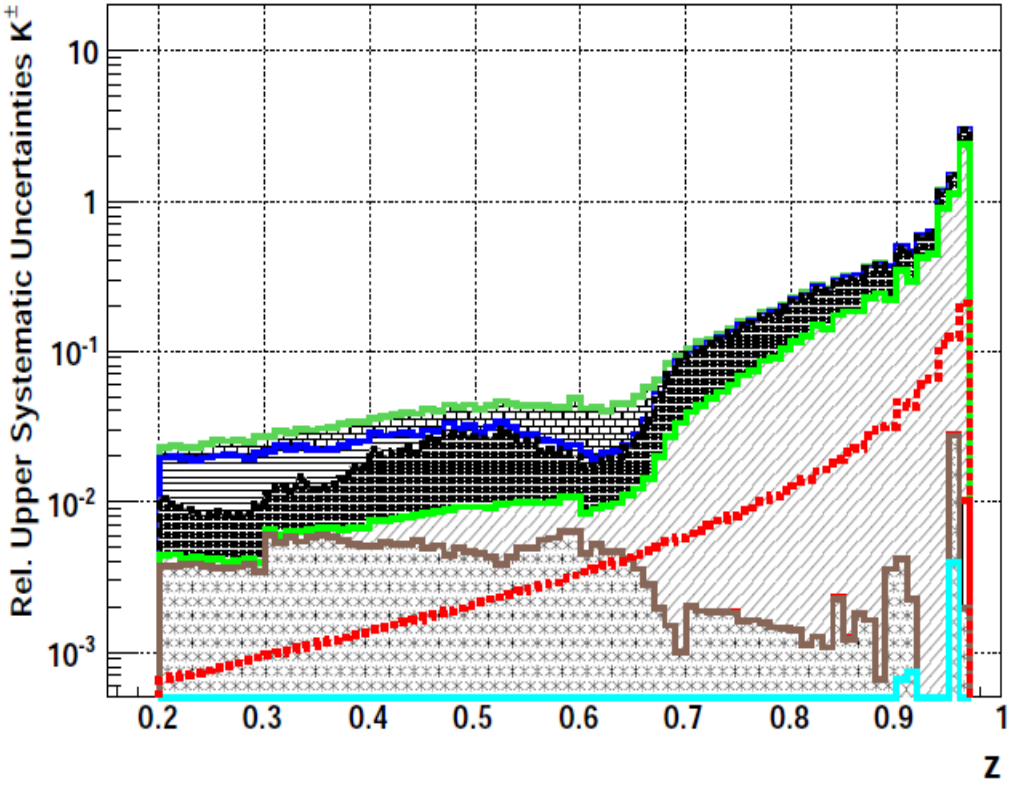
additional 1.4% normalization uncertainty not shown

Relative contributions of systematic uncertainties

pions

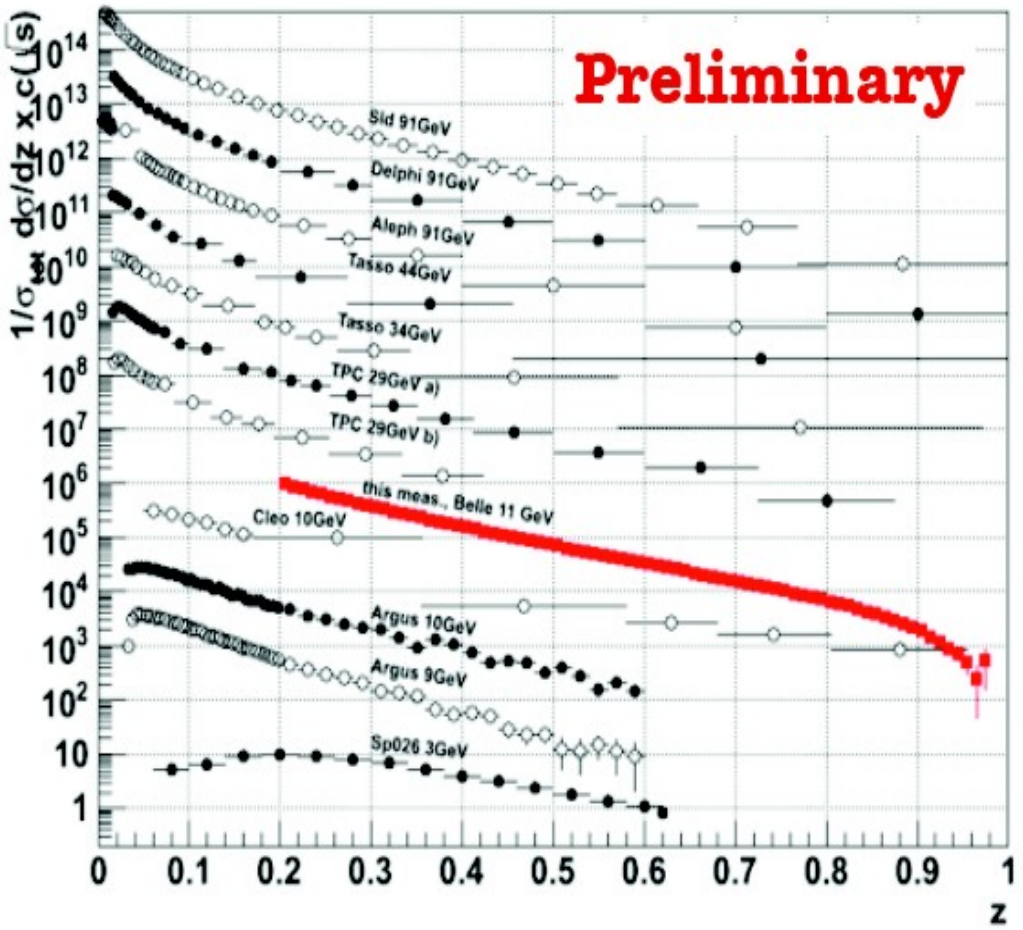


kaons

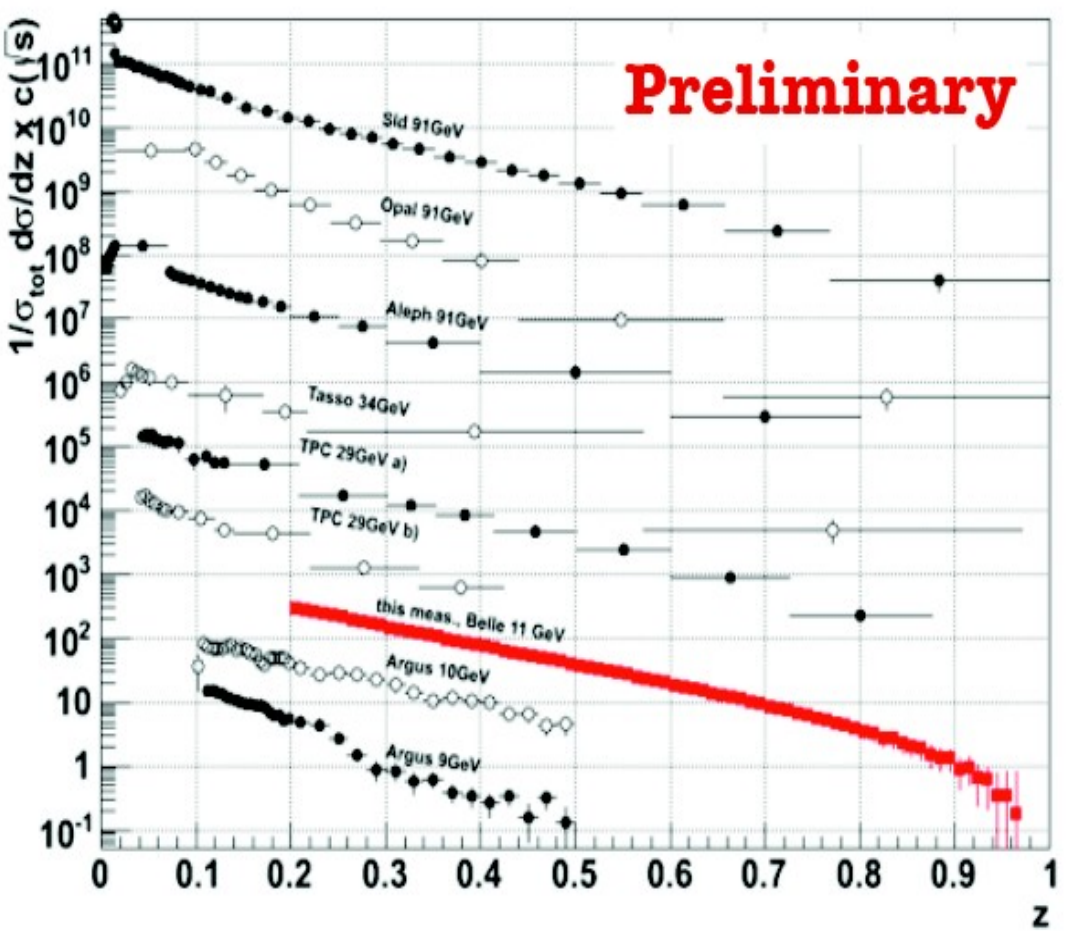


Comparison to world data

world data (sel.) for $e^+e^- \to \pi^\pm + X$ production



world data (sel.) for $e^+e^- \to K^\pm + X$ production



Fragmentation functions at Belle

- charge-integrated π and K multiplicities from e^+e^- annihilation at $\sqrt{s}$=10.52 GeV:

  - complement high-energy scale measurements
  - first precision measurement at z>0.7
  - paper submitted to PRL (arXiv: 1301.6183 [hep-ex])

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- pion Collins FFs via $e^+e^- \longrightarrow \pi\pi$ azimuthal asymmetries

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- Ongoing analyses:

  - π^0, η^0 spin-independent FFs
  - charged di-hadron FFs
  - transverse-momentum-dependent π, K FFs
  - K Collins FFs
  - π^0 Collins FFs
  - ρ^0 Collins FFs
  - πK, KK interference FFs

Thank you!