PRECISE PION AND KAON CROSS SECTIONS @ BELLE

PSHP2013, November 11-13, 2013, Frascati

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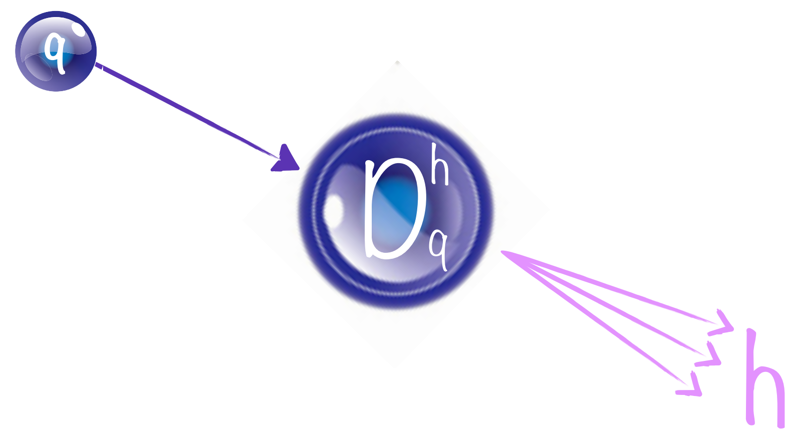
for the BELLE collaboration

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

BELLE

Fragmentation process
or how do the hadrons get formed?



- Fragmentation function describes the process of hadronization of a parton
- Strictly related to quark confinement

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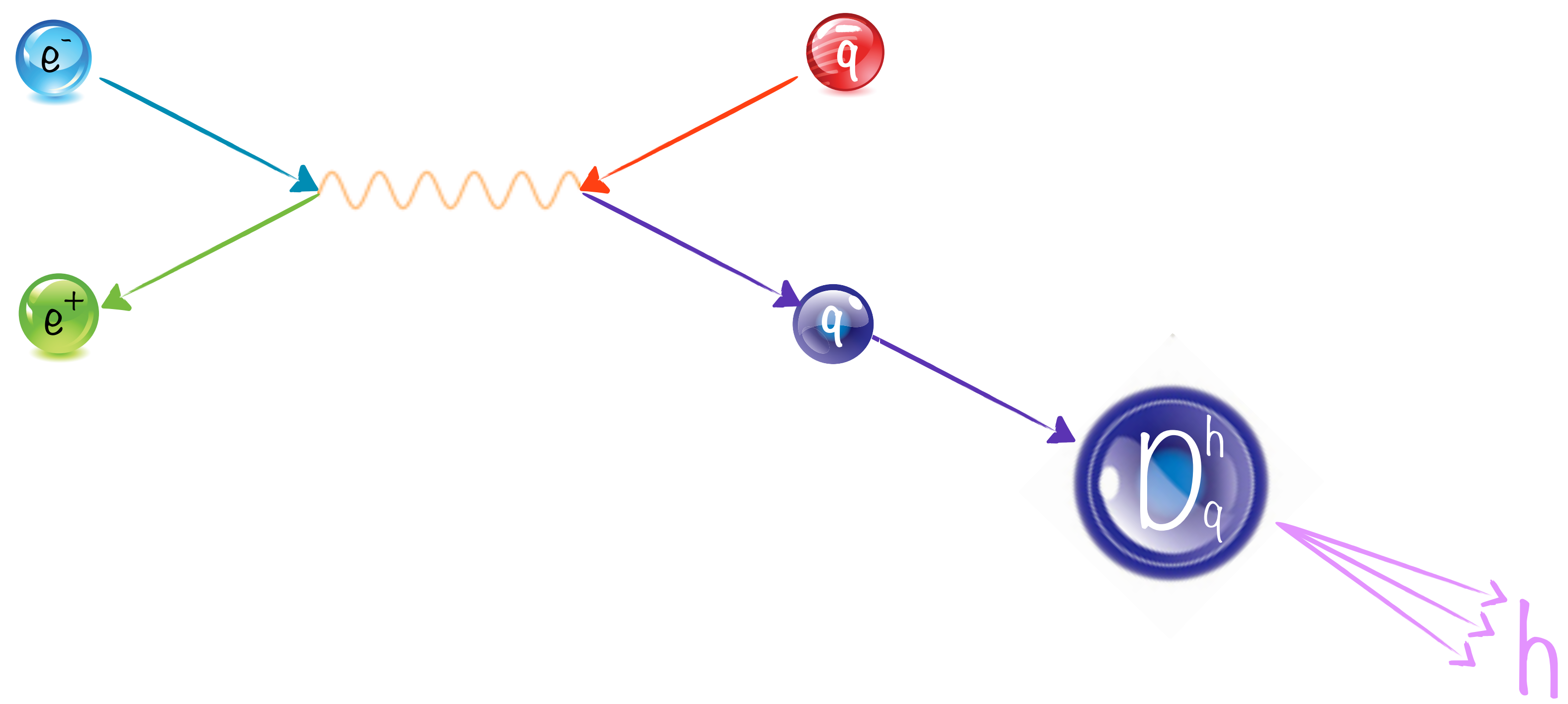

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- Strictly related to quark confinement
- Cleanest way to access FF is in $e^+e^- \rightarrow q\bar{q}$

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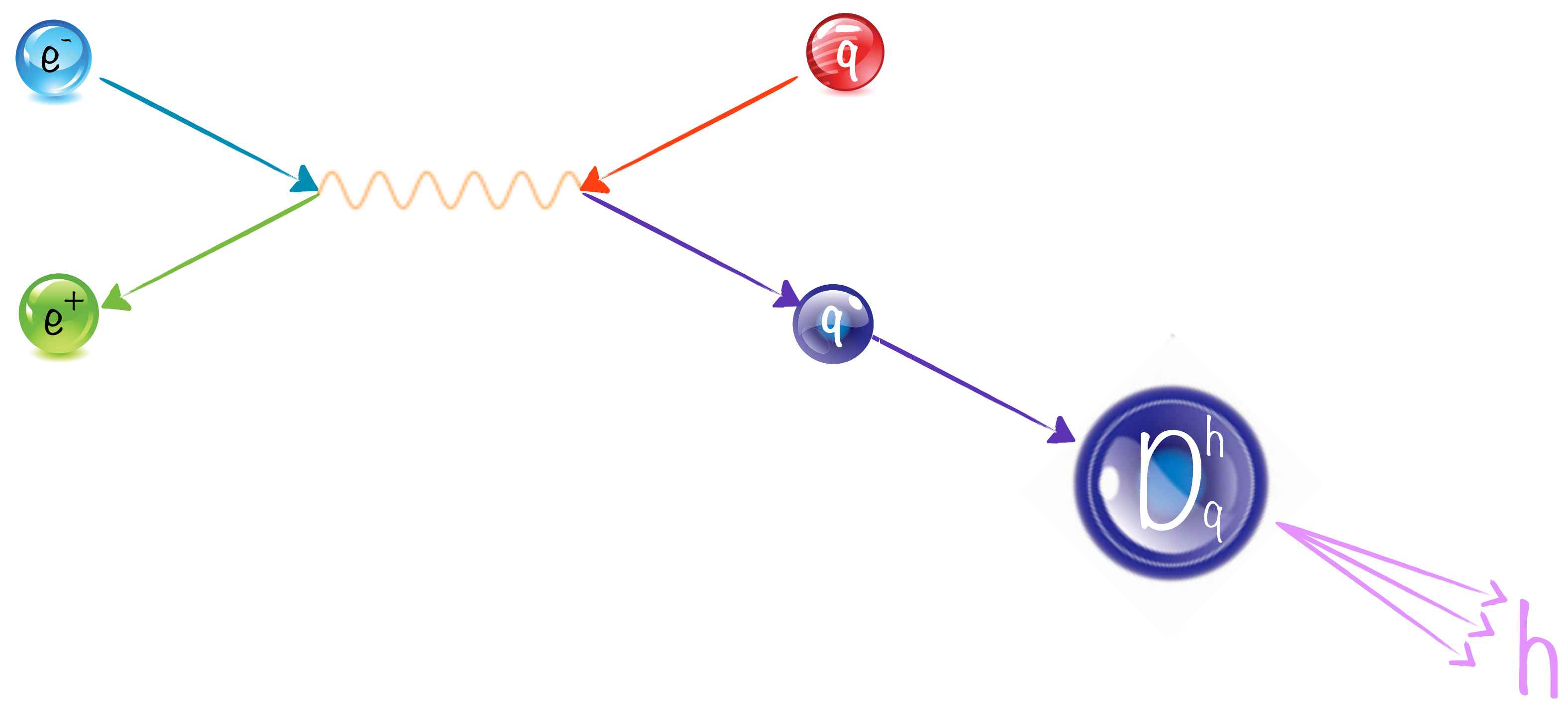

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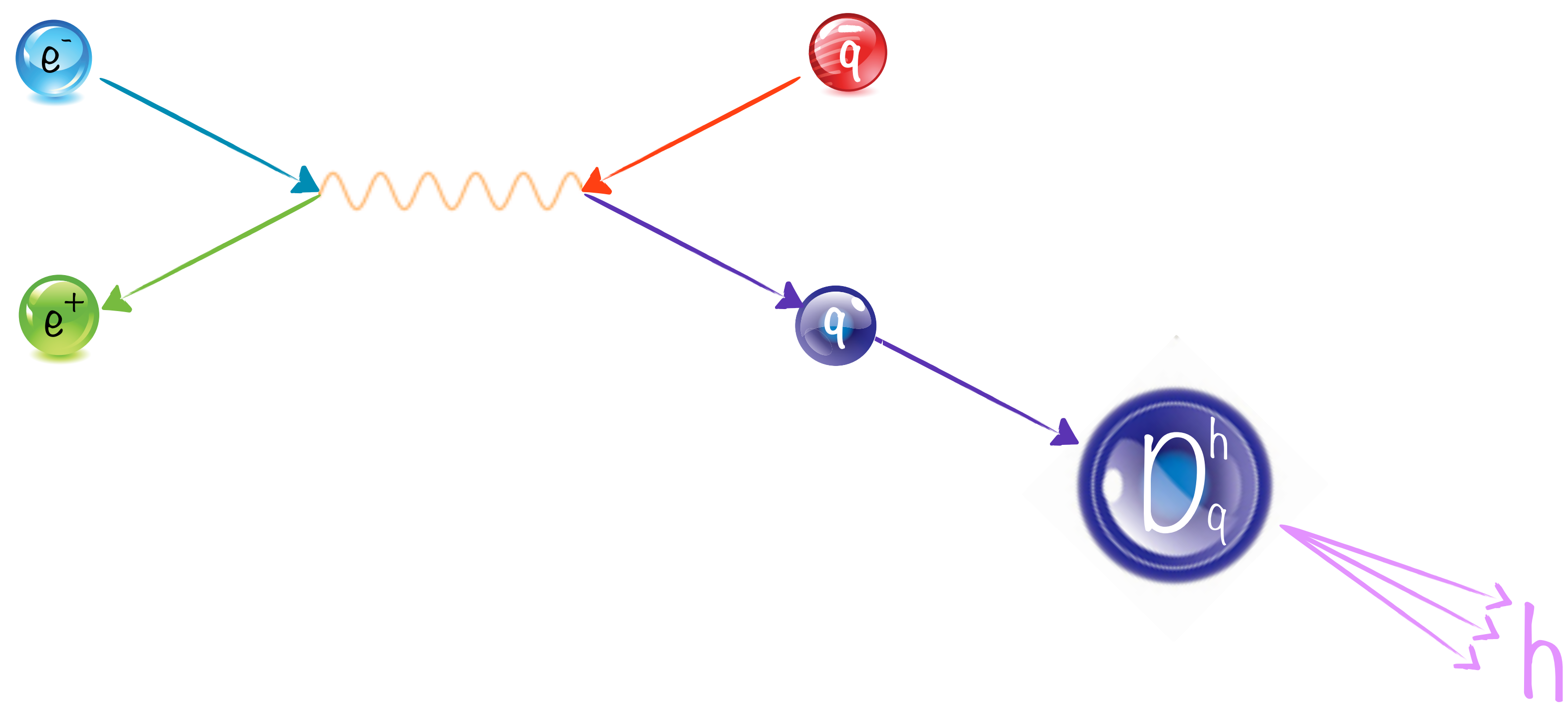
- Strictly related to quark confinement
- Cleanest way to access FF is in $e^+e^- \rightarrow q\bar{q}$
- Universal: can be used to study the nucleon structure when combined with SIDIS and hadronic reactions data

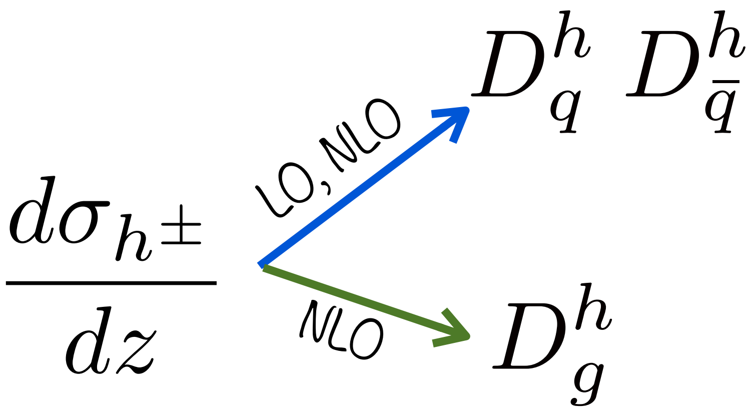
$$A^h_{LL} = \frac{\sigma^{\overrightarrow{\Rightarrow}} - \sigma^{\overrightarrow{\Leftarrow}}}{\sigma^{\overrightarrow{\Leftarrow}} + \sigma^{\overrightarrow{\Leftarrow}}} \propto D^h_q D^h_g$$

$$A^h_{UT} = \frac{\sigma^{\uparrow\Uparrow} - \sigma^{\uparrow\Downarrow}}{\sigma^{\uparrow\Uparrow} + \sigma^{\uparrow\Downarrow}} \propto D^h_q$$

Fragmentation process

or how do the hadrons get formed?





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$$A_{LL}^h = \frac{\sigma^{\overrightarrow{\Rightarrow}} - \sigma^{\overrightarrow{\Leftarrow}}}{\sigma^{\overleftarrow{\Rightarrow}} + \sigma^{\overleftarrow{\Leftarrow}}} \propto D_q^h D_g^h$$

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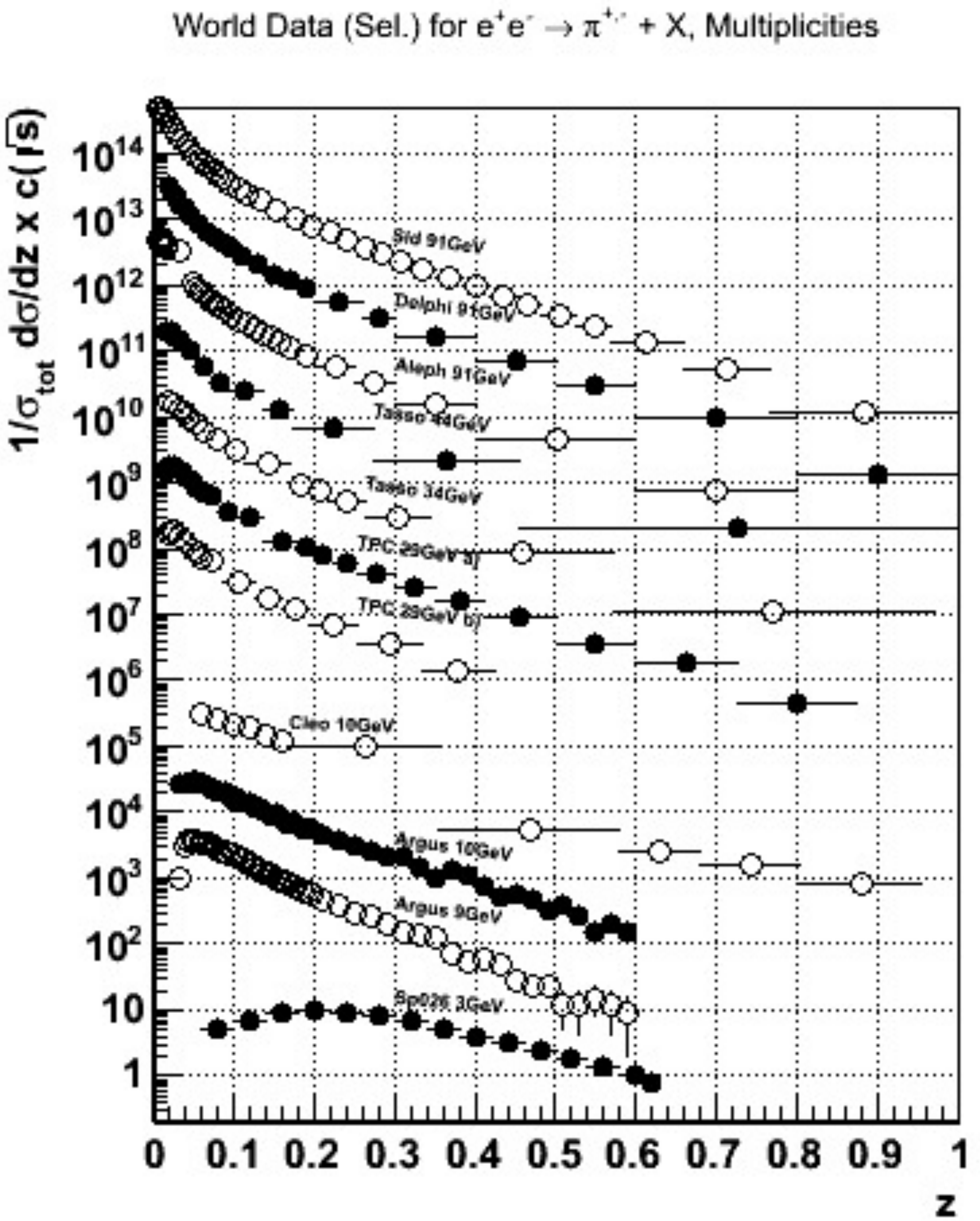
e^+e^- data



2007: First unpolarized FF extraction
with estimated uncertainties!

Hirai, Kumano, Nagai, Sudoh
Phys. Rev. D 75, 094009 (2007)

Global analises:
e+e-, SIDIS, pp: (including uncertainties)

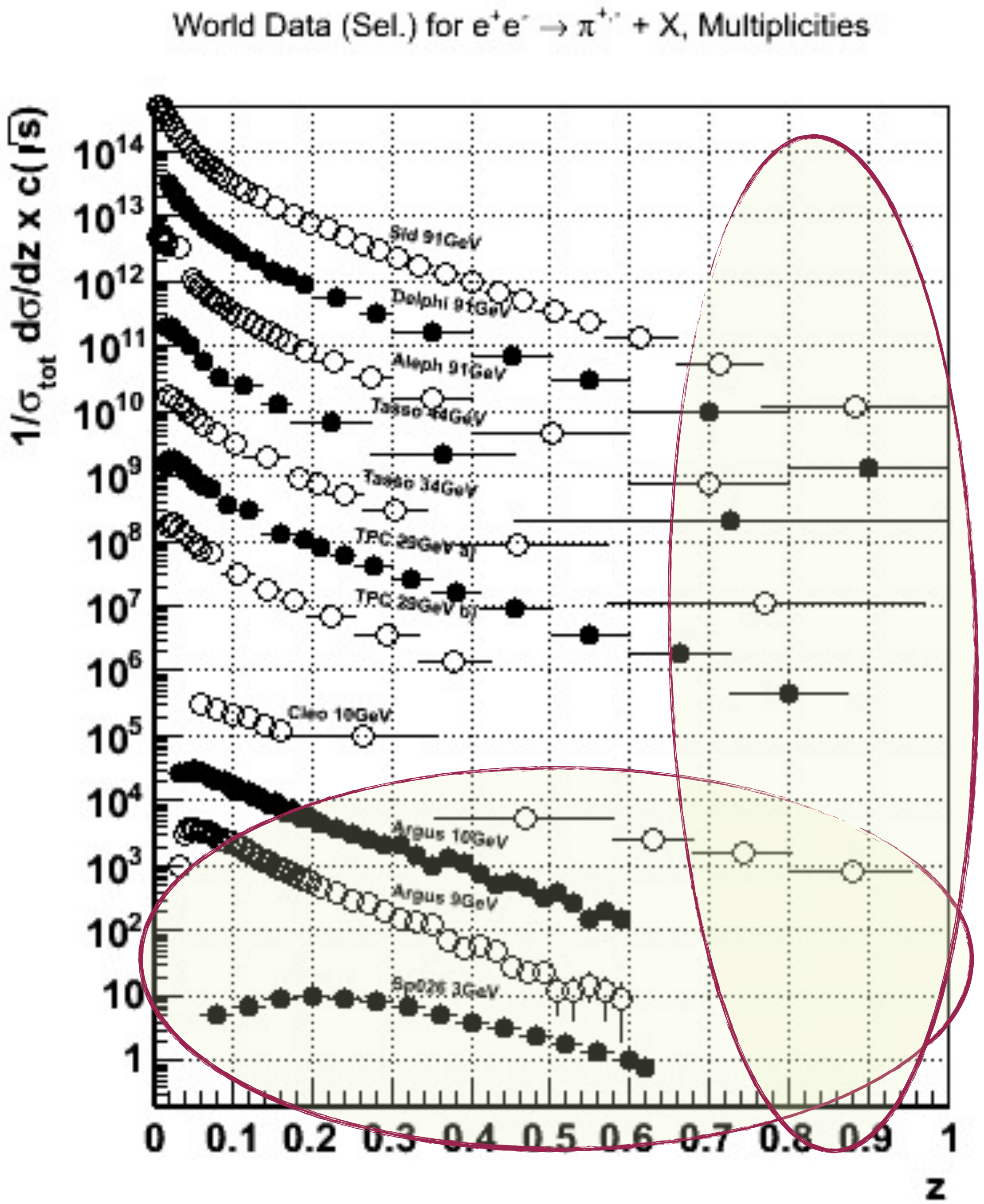
de Florian, Sassot, Stratmann
Phys. Rev. D 75, 114010 (2007) and
Phys. Rev D 76, 074033 (2007)

Epele, Llubaroff, Sassot, Stratmann
arXiv:1209.3240 [hep-ph]

e+e-, pp:

Albino, Kniehl, Kramer
Nucl. Phys. B 803, 42 (2008)

e+e- data



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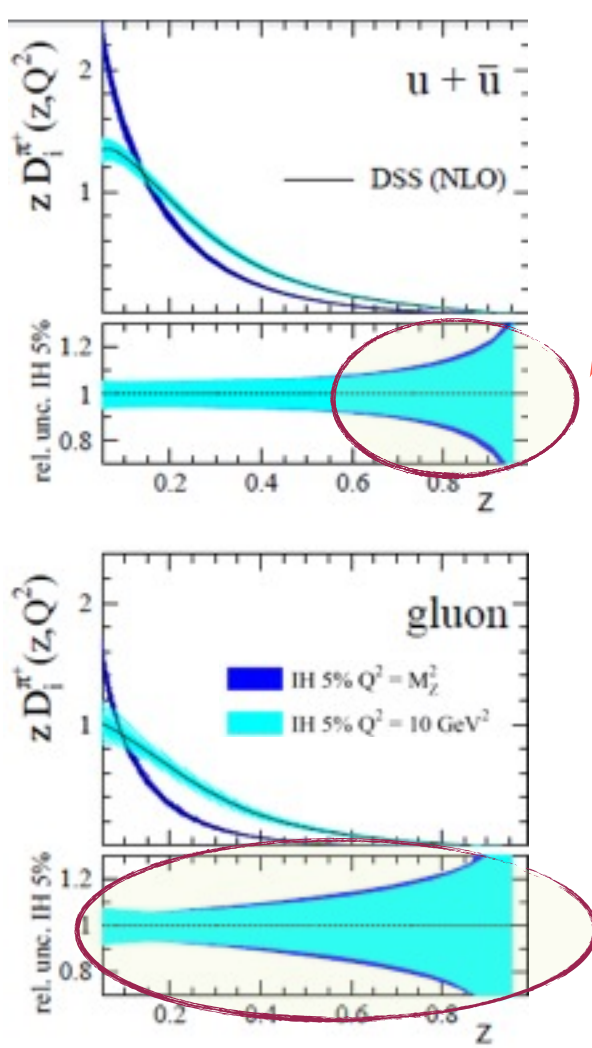
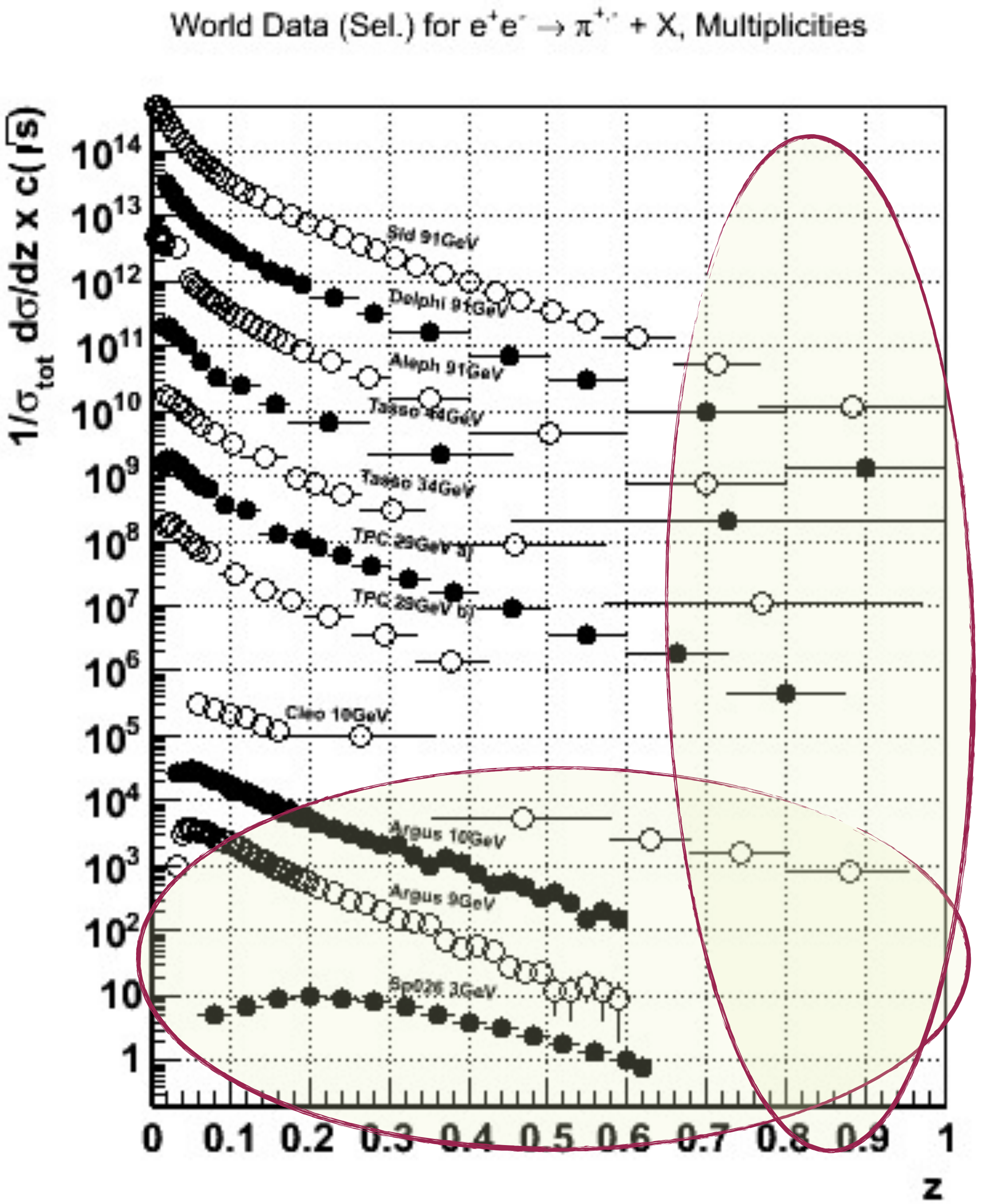


Few data at high z

Few data at low energy

e+e- data



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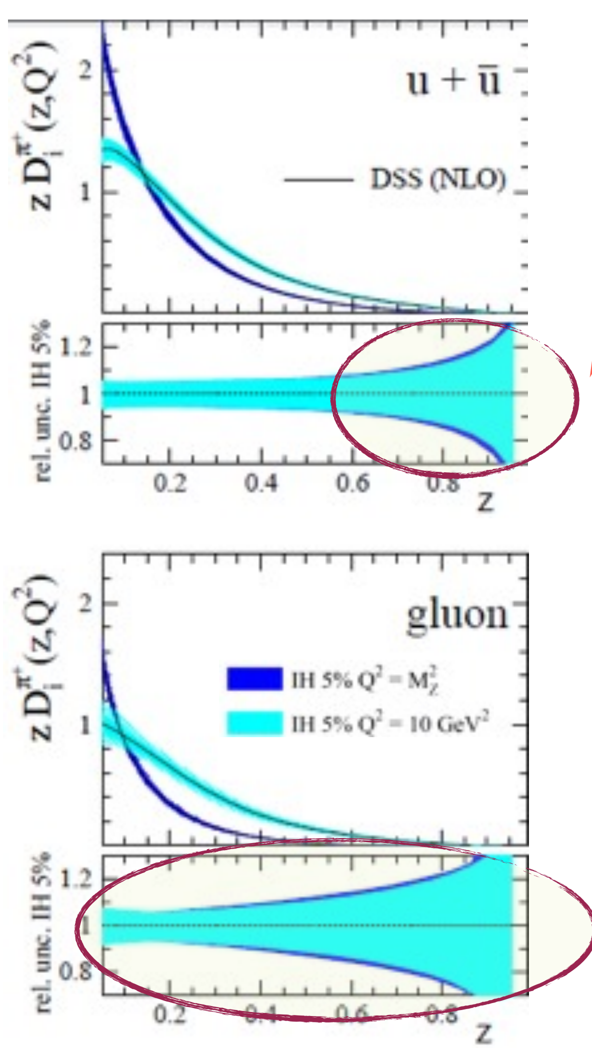


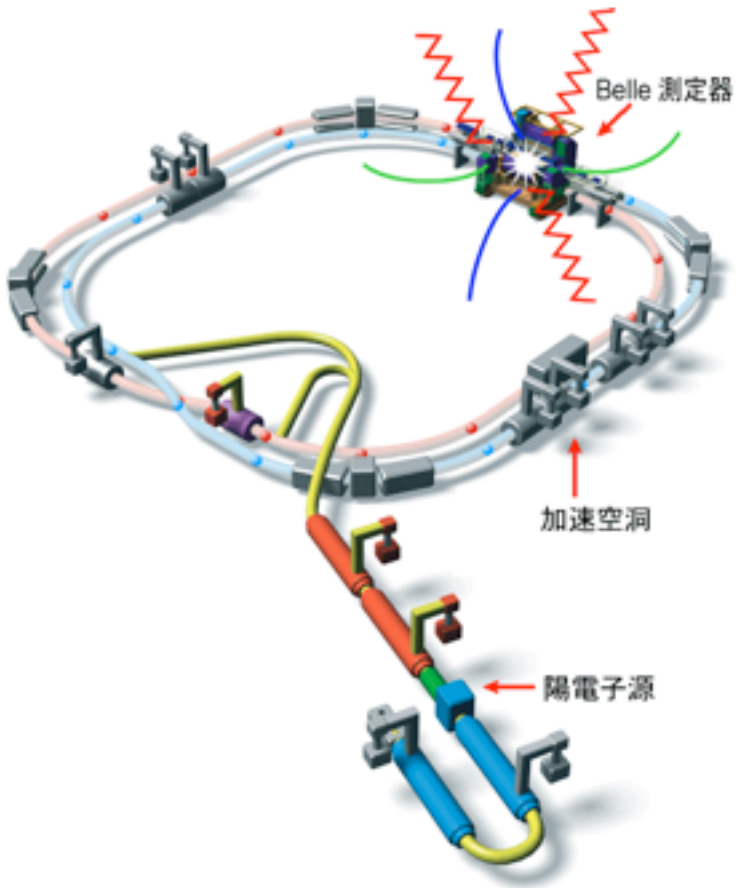
Few data at high z

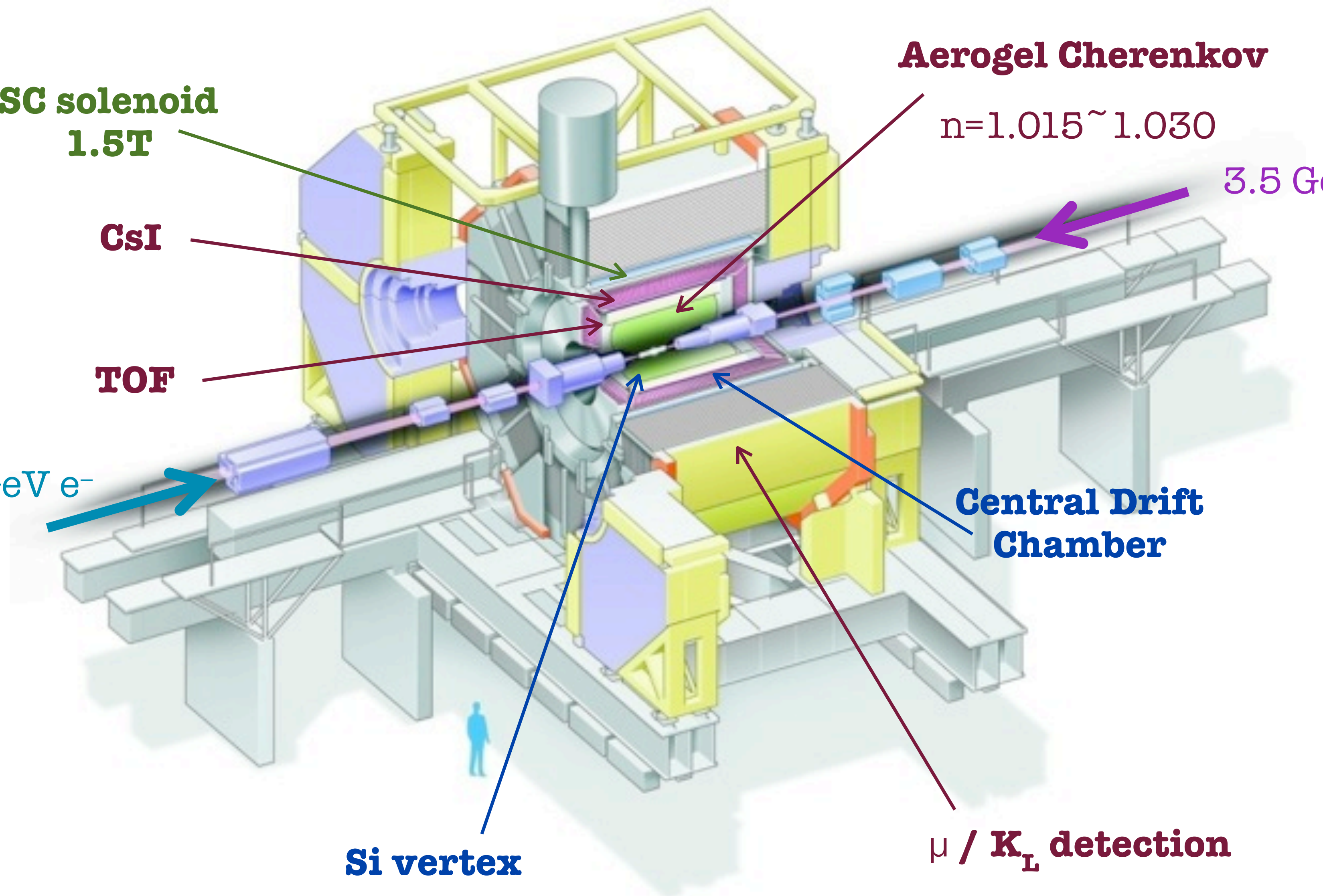
Few data at low energy

BELLE @ KEKB

Asymmetric
e^+ (3.5 GeV) e^- (8 GeV) collider

BELLE @ KEKB





Asymmetric e+ e- collider

On resonance: $\sqrt{s}$ = 10.58 GeV (e+ e- → Υ(4S) → $B\bar{B}$)

Off resonance $\sqrt{s}$ = 10.52 GeV (e+ e- → $q\bar{q}$ (q=u,d,s,c))

~220 * 10^6 events

Good tracking Θ [17^0;150^0]

Good PID: ε(π) ≳ 90%

ε(K) ≳ 85%

Cross sections extraction

$i = \pi, K$

$$\frac{d\sigma_i}{dz} = \frac{1}{L_{tot}} \epsilon^i_{joint}(z)\,\epsilon^i_{ISR/FSR}(z)\,S^{-1}_{zz_m}\,\epsilon^i_{impu}(z_m)\,P^{-1}_{ij}\,N^{j,raw}(z_m)$$

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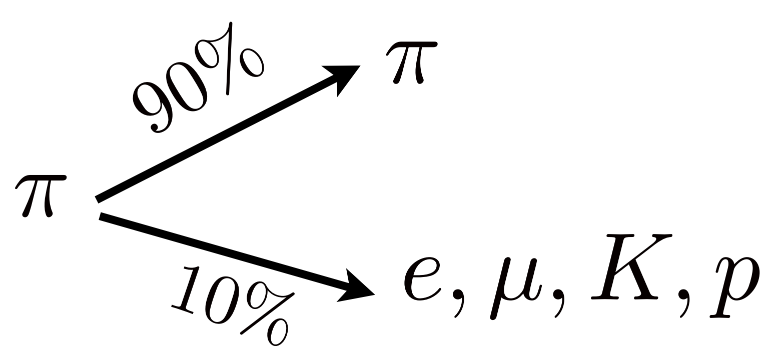
Perfect PID ⇨ $j = i$

$j = e, \mu, \pi, K, p$

BUT!!

ε(π) ≳ 90% ε(K) ≳ 85%



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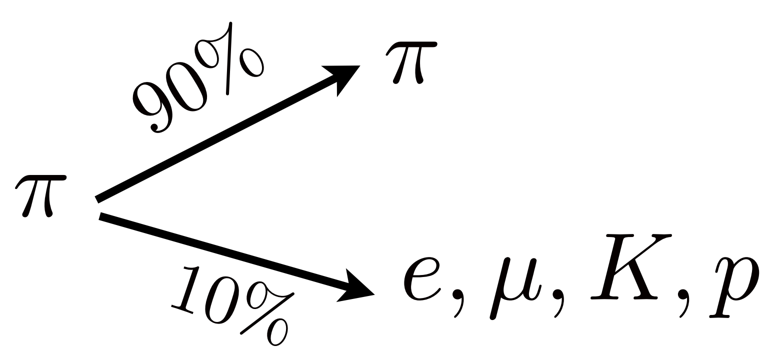

$$P_{ij} = \begin{pmatrix} P_{e\to e} & P_{e\to\mu} & P_{e\to\pi} & P_{e\to K} & P_{e\to p} \\ P_{\mu\to e} & P_{\mu\to\mu} & P_{\mu\to\pi} & P_{\mu\to K} & P_{\mu\to p} \\ P_{\pi\to e} & P_{\pi\to\mu} & P_{\pi\to\pi} & P_{\pi\to K} & P_{\pi\to p} \\ P_{K\to e} & P_{K\to\mu} & P_{K\to\pi} & P_{K\to K} & P_{K\to p} \\ P_{p\to e} & P_{p\to mu} & P_{p\to\pi} & P_{p\to K} & P_{p\to p} \end{pmatrix}$$

Cross sections extraction

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Perfect PID ⇨ $j = i$

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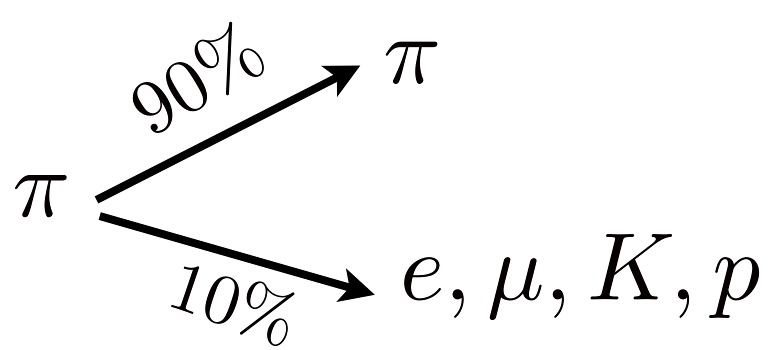

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How to determine the P_{ij}?

From data!

$$D^* \rightarrow D^0 \, \pi^+_{slow}, \quad D^0 \rightarrow K^- \, \pi^+_{fast}$$

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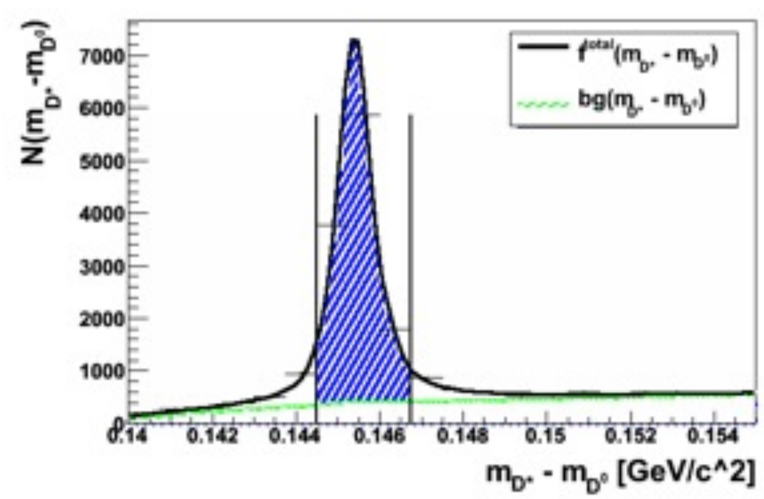
$$D^* \to D^0 \, \pi^+_{slow}$$

$$D^0 \to K^- \, \pi^+_{fast}$$

$$P_{K^- \to \pi^-}$$

$$m_D^* - m_D^0$$



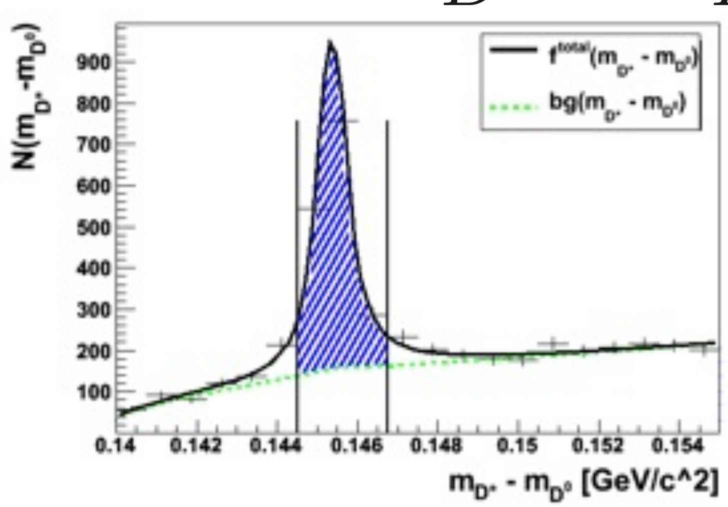
Negative hadron = K^-
(no PID likelihood used)

How to determine the P_{ij}?

From data!

$$D^* \longrightarrow D^0 \longrightarrow K^-$$
$$D^* \longrightarrow \pi^+_{slow}, \quad D^0 \longrightarrow \pi^+_{fast}$$

$$m_D^* - m_D^0$$



Negative hadron identified as π^-

$$P_{K^- \to \pi^-}$$

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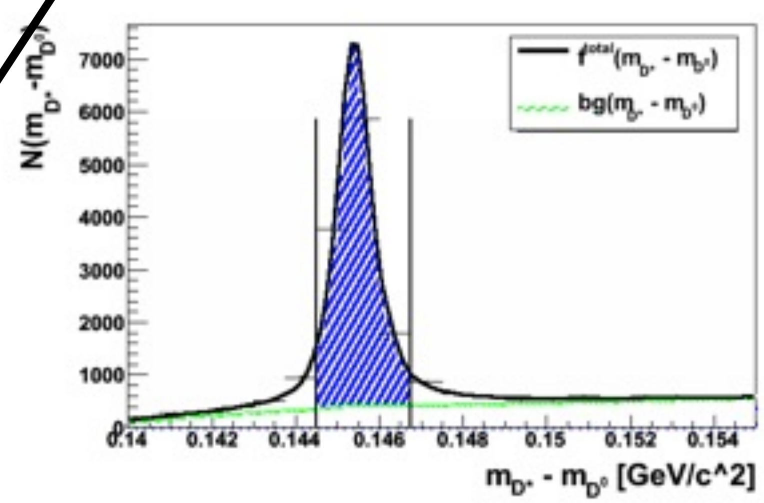

Negative hadron = K^-
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How to determine the P_{ij}?

$$D^* \rightarrow D^0 \pi^+_{slow}, \quad D^0 \rightarrow K^- \pi^+_{fast}$$

From data!

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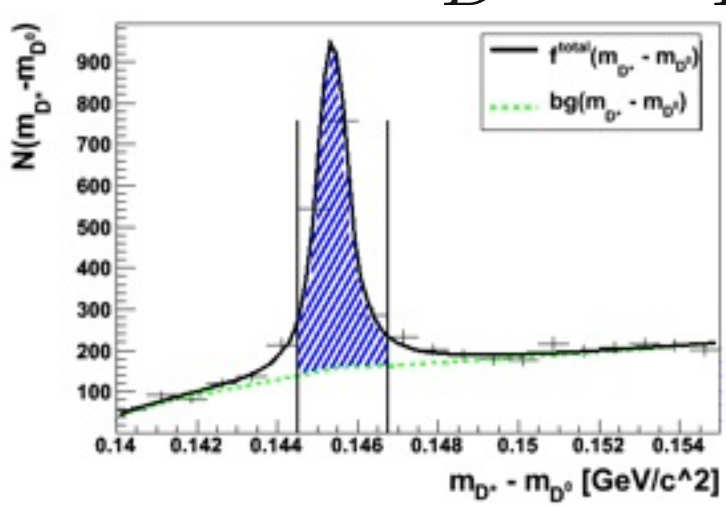
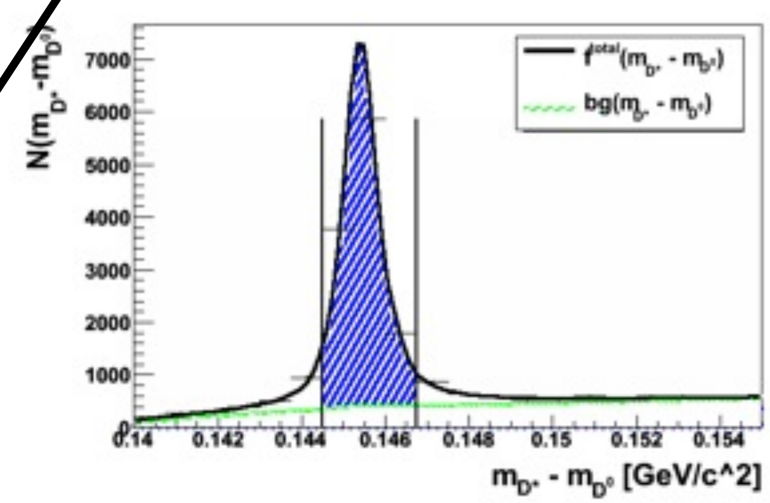


Negative hadron identified as π^-

$\pi^- \rightarrow K^-, \bar{p}, \mu^-, e^-$

$P_{K^- \rightarrow \pi^-}$

$m_D^* - m_D^0$



Negative hadron = K^-
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$P_{K^- \rightarrow K^-}$

$P_{K^- \rightarrow \bar{p}}$

$P_{K^- \rightarrow \mu^-}$

$P_{K^- \rightarrow e^-}$

How to determine the P_{ij}?

$$D^* \to D^0 \, \pi^+_{slow}$$
$$D^0 \to K^- \, \pi^+_{fast}$$

From data!

$p_{\pi, K \to j}$ from D* decay

$p_{\pi, p \to j}$ from Λ decay

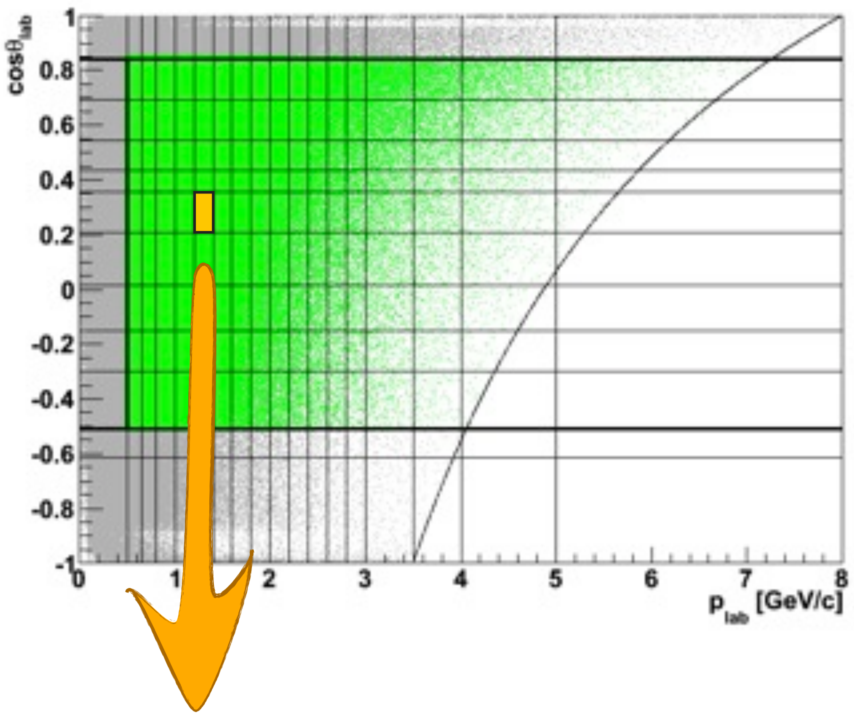
$p_{e, \mu \to j}$ from J/ψ decay

$$\begin{pmatrix} P_{e\to e} & P_{e\to\mu} & P_{e\to\pi} & P_{e\to K} & P_{e\to p} \\ P_{\mu\to e} & P_{\mu\to\mu} & P_{\mu\to\pi} & P_{\mu\to K} & P_{\mu\to p} \\ P_{\pi\to e} & P_{\pi\to\mu} & P_{\pi\to\pi} & P_{\pi\to K} & P_{\pi\to p} \\ P_{K\to e} & P_{K\to\mu} & P_{K\to\pi} & P_{K\to K} & P_{K\to p} \\ P_{p\to e} & P_{p\to mu} & P_{p\to\pi} & P_{p\to K} & P_{p\to p} \end{pmatrix}$$

$$P_{K^-\to\pi^-}$$
$$P_{K^-\to K^-}$$
$$P_{K^-\to\bar{p}}$$
$$P_{K^-\to\mu^-}$$
$$P_{K^-\to e^-}$$

2D correction

Detector performance depends on momentum and scattering angle!

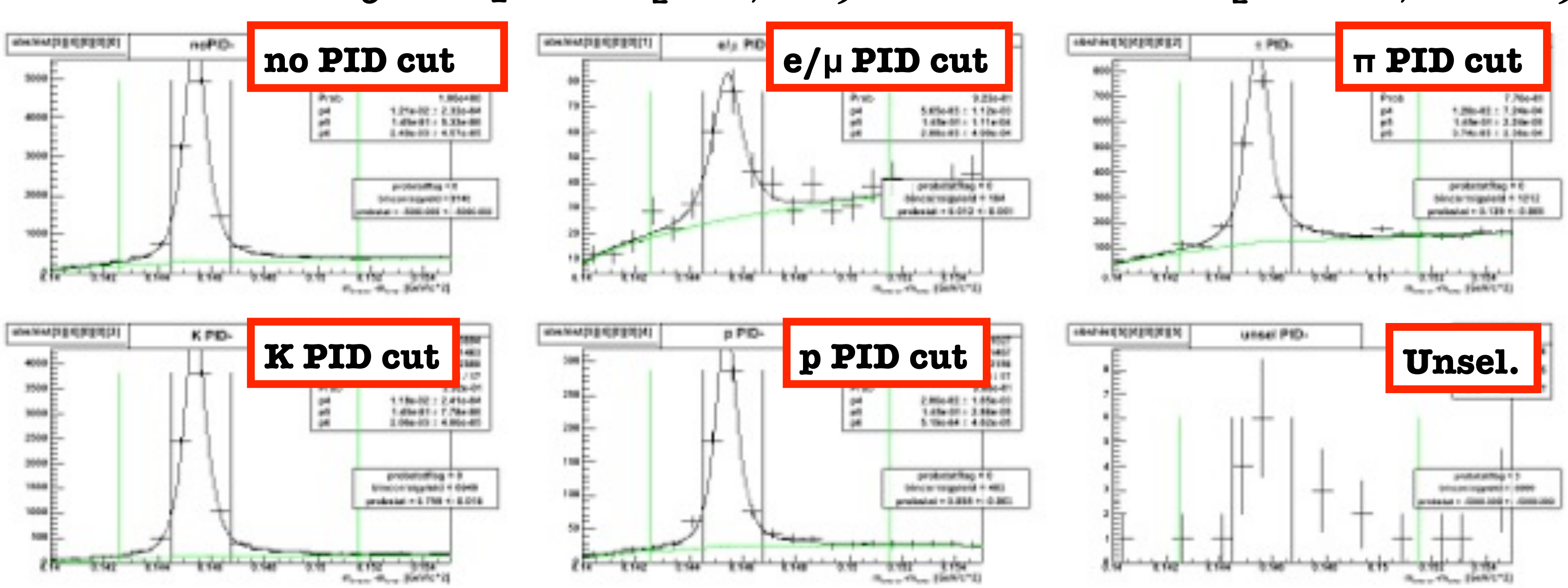


$$P_{ij} \Rightarrow P_{ij}(p,\theta)$$

Bin #	$\cos\theta_{lab}$ bin ranges
0	[-0.511,-0.300)
1	[-0.300,-0.152)
2	[-0.512,0.017)
3	[0.017,0.209)
4	[0.209,0.355)
5	[0.355,0.435)
6	[0.435,0.542)
7	[0.542,0.692)
8	[0.692,0.842)

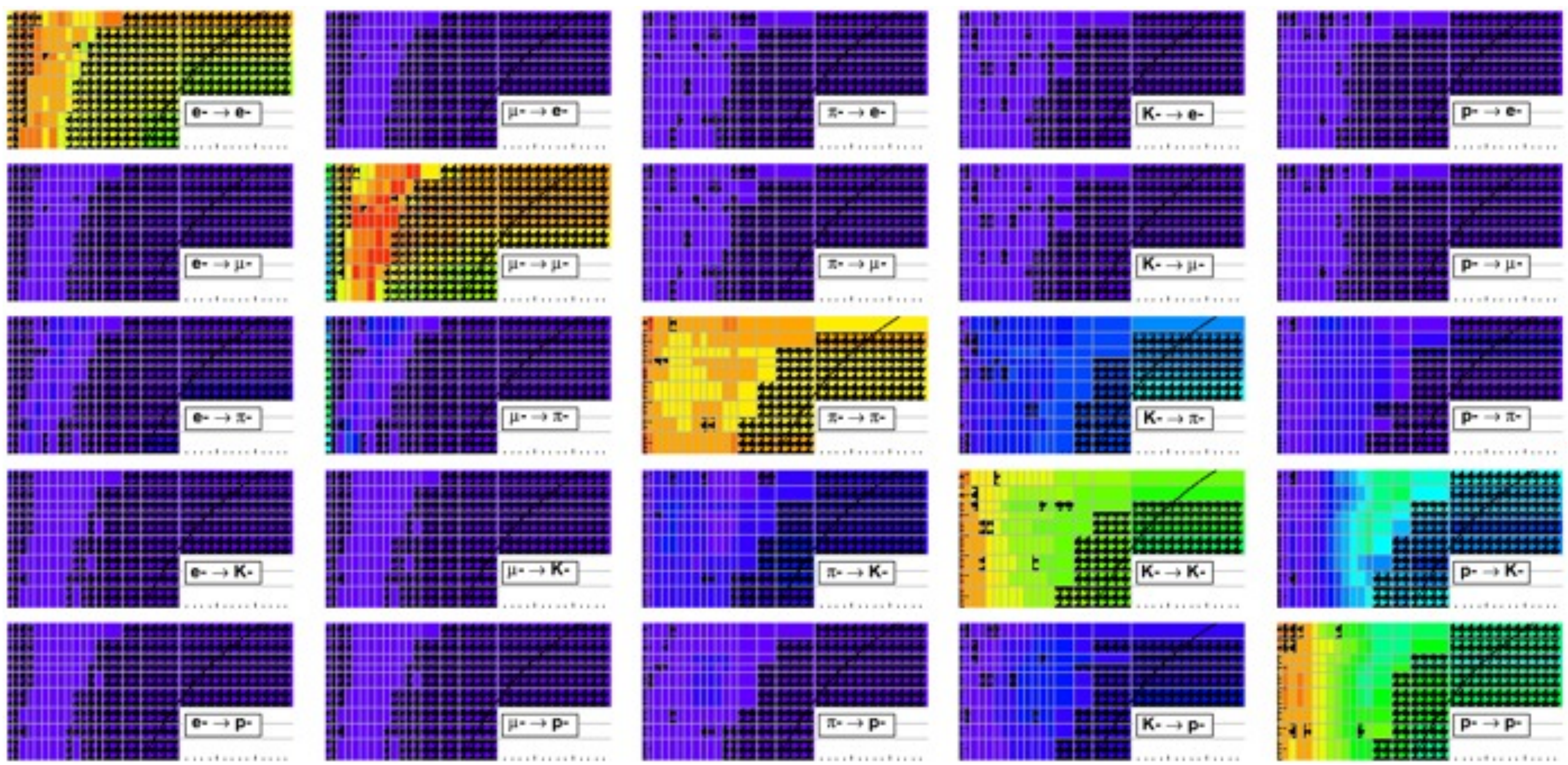
Bin #	p_{lab} [GeV/c] bin ranges
0	[0.5,0.65)
1	[0.65,0.8)
2	[0.8,1.0)
3	[1.0,1.2)
4	[1.2,1.4)
5	[1.4,1.6)
6	[1.6,1.8)
7	[1.8,2.0)
8	[2.0,2.2)
9	[2.2,2.4)
10	[2.4,2.6)
11	[2.6,2.8)
12	[2.8,3.0)
13	[3.0,3.5)
14	[3.5,4.0)
15	[4.0,5.0)
16	[5.0,8.0)

K from D* decay for p_{lab} in [1.4,1.6) and $\cos\theta_{lab}$ in [0.209,0.355)



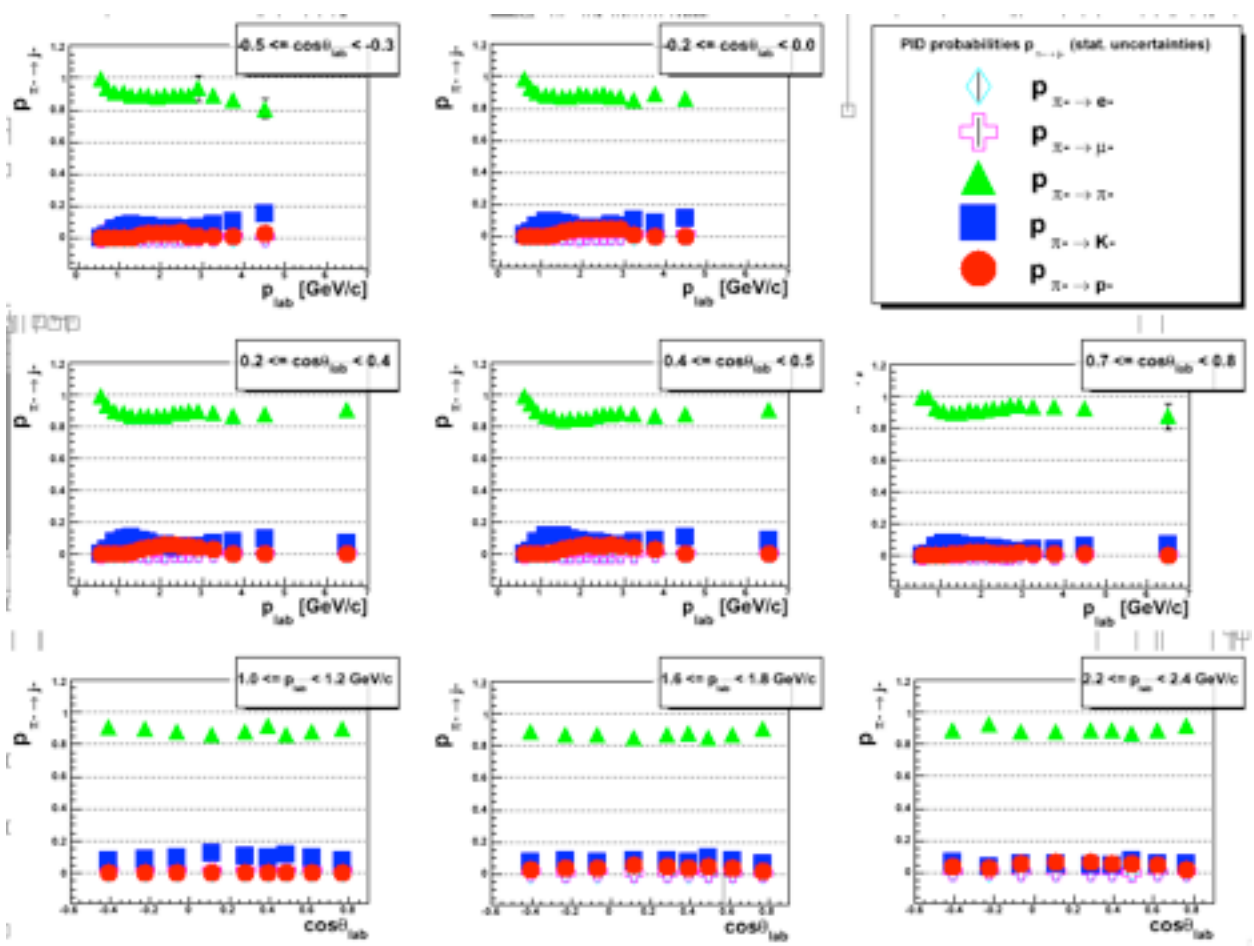
2D correction

$$\begin{pmatrix} P_{e\rightarrow e} & P_{e\rightarrow \mu} & P_{e\rightarrow \pi} & P_{e\rightarrow K} & P_{e\rightarrow p} \\ P_{\mu\rightarrow e} & P_{\mu\rightarrow \mu} & P_{\mu\rightarrow \pi} & P_{\mu\rightarrow K} & P_{\mu\rightarrow p} \\ P_{\pi\rightarrow e} & P_{\pi\rightarrow \mu} & P_{\pi\rightarrow \pi} & P_{\pi\rightarrow K} & P_{\pi\rightarrow p} \\ P_{K\rightarrow e} & P_{K\rightarrow \mu} & P_{K\rightarrow \pi} & P_{K\rightarrow K} & P_{K\rightarrow p} \\ P_{p\rightarrow e} & P_{p\rightarrow mu} & P_{p\rightarrow \pi} & P_{p\rightarrow K} & P_{p\rightarrow p} \end{pmatrix}$$



PID correction

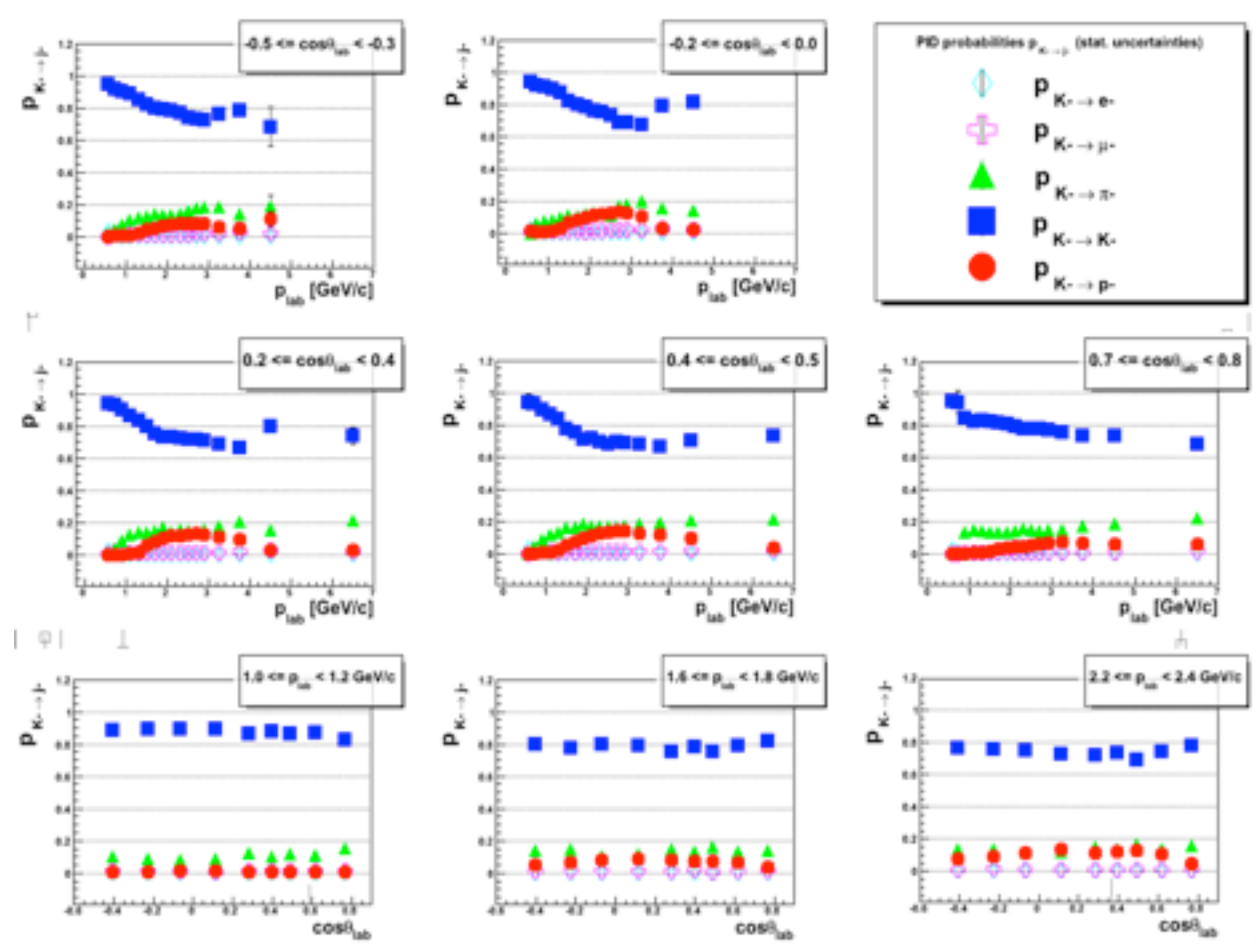
π^-



< 15%

K^-

30% >

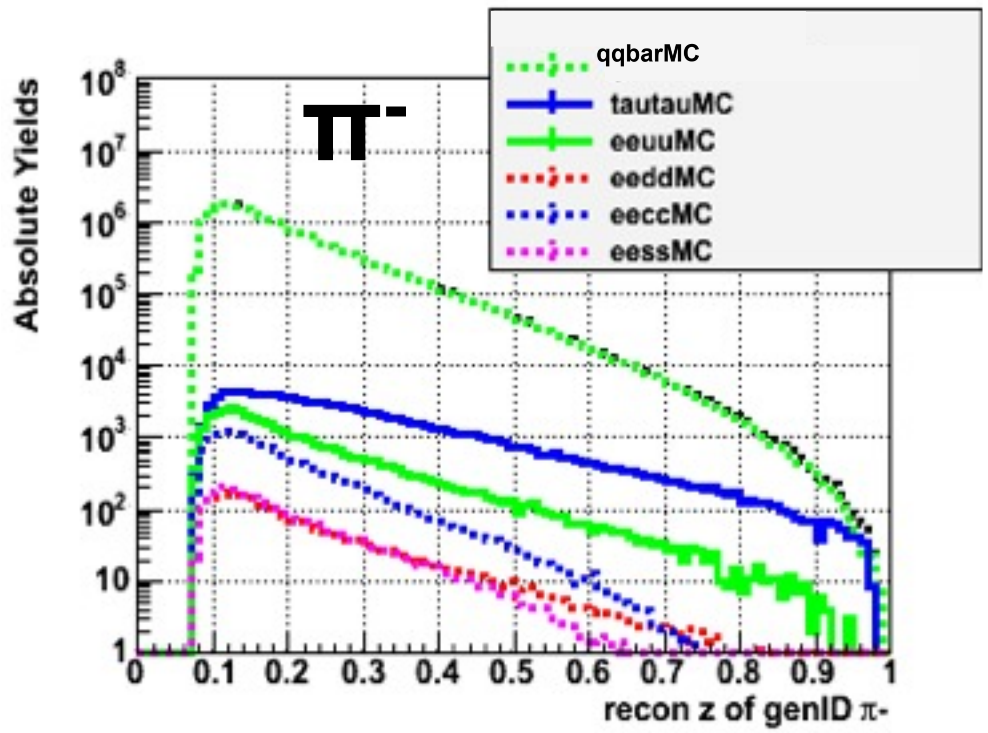


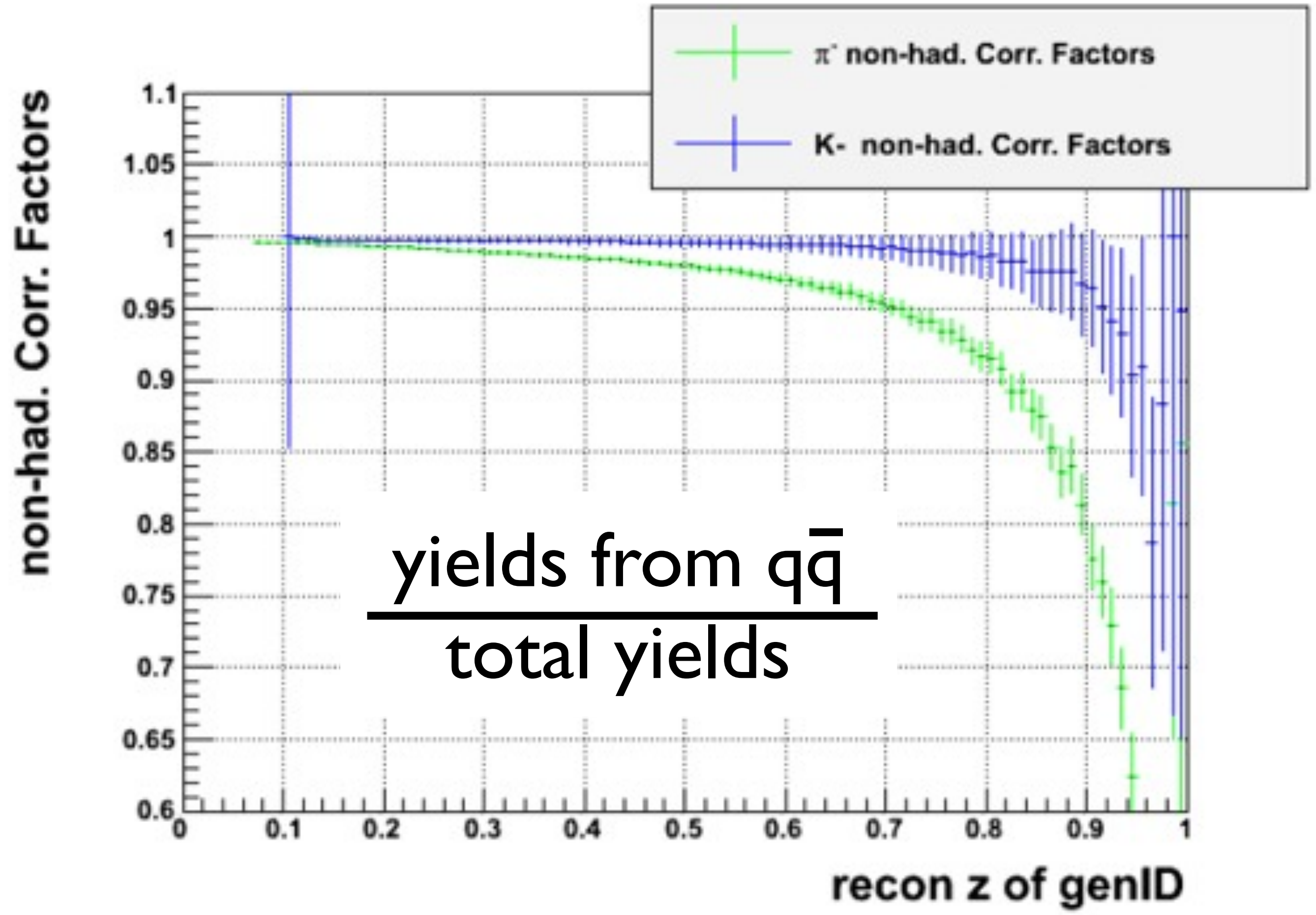
Impurity correction

$i = \pi, K$

$$\frac{d\sigma_i}{dz} = \frac{1}{L_{tot}} \epsilon^i_{joint}(z)\, \epsilon^i_{ISR/FSR}(z)\, S^{-1}_{zz_m}\, \epsilon^i_{impu}(z_m)\, P^{-1}_{ij}\, N^{j,raw}(z_m)$$

Correction for hadrons generated by ττ, 2γ



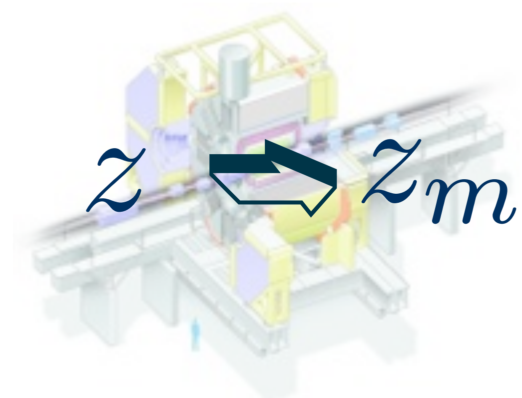


Smearing correction

$i = \pi, K$

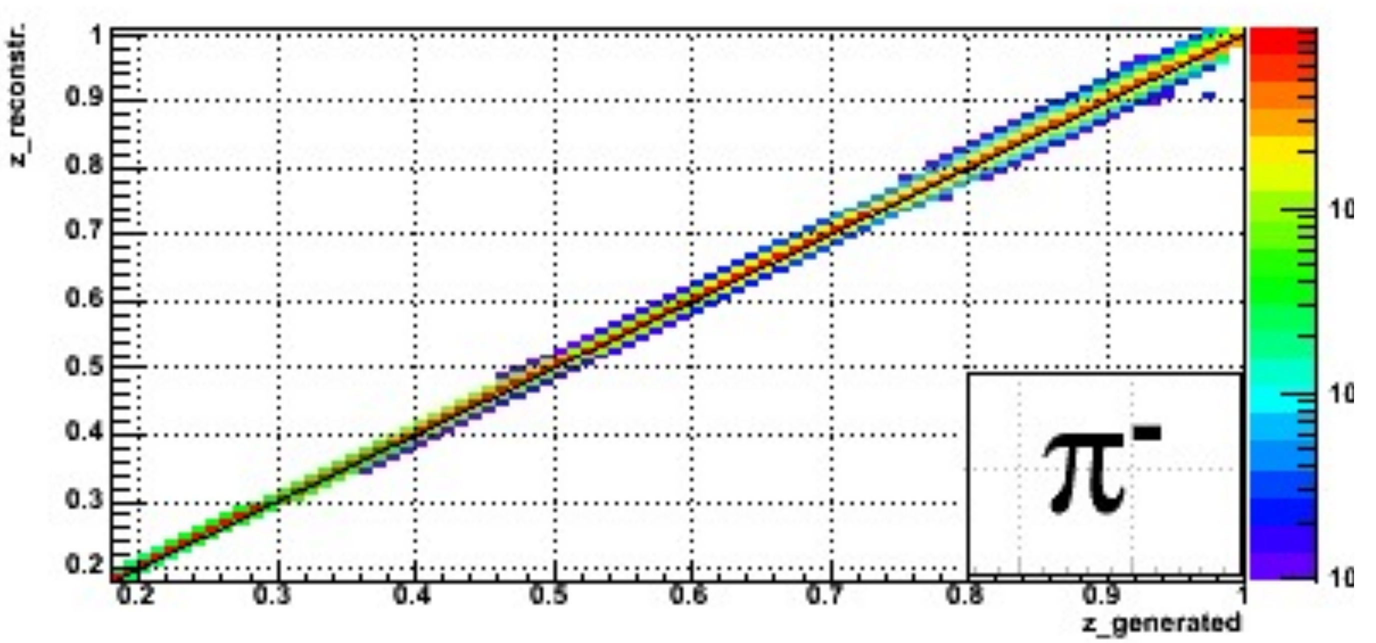
$$\frac{d\sigma_i}{dz} = \frac{1}{L_{tot}} \epsilon^i_{joint}(z)\, \epsilon^i_{ISR/FSR}(z)\, S^{-1}_{zz_m}\, \epsilon^i_{impu}(z_m)\, P^{-1}_{ij}\, N^{j,raw}(z_m)$$

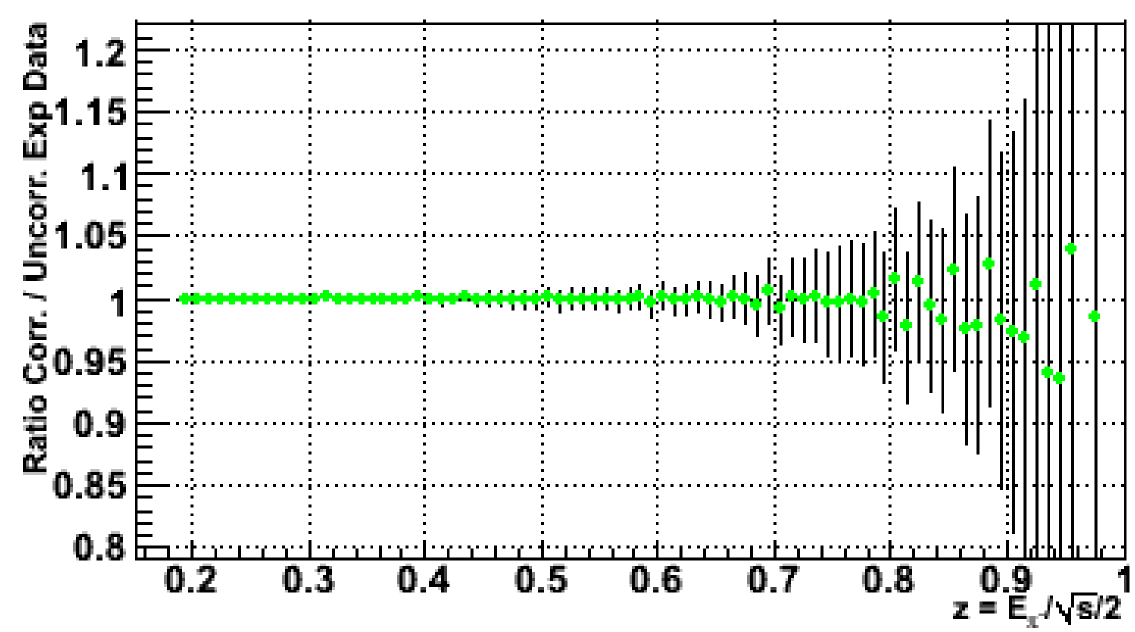
Detector smearing correction



$z \Rightarrow z_m$

before/after



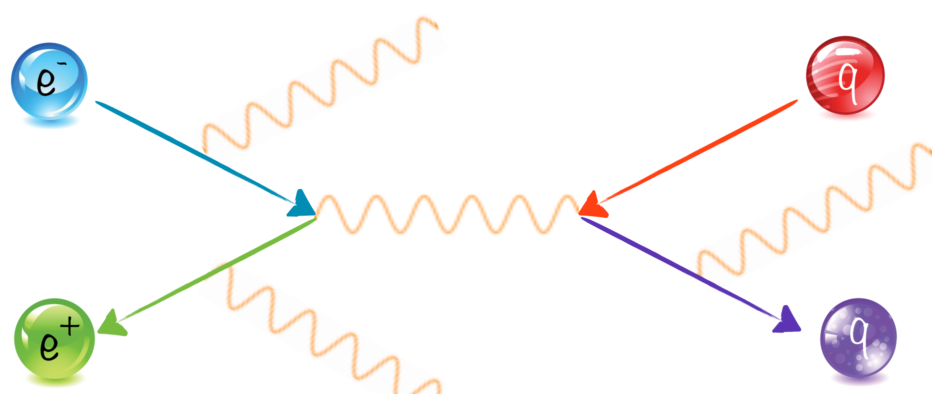


ISR/FSR correction

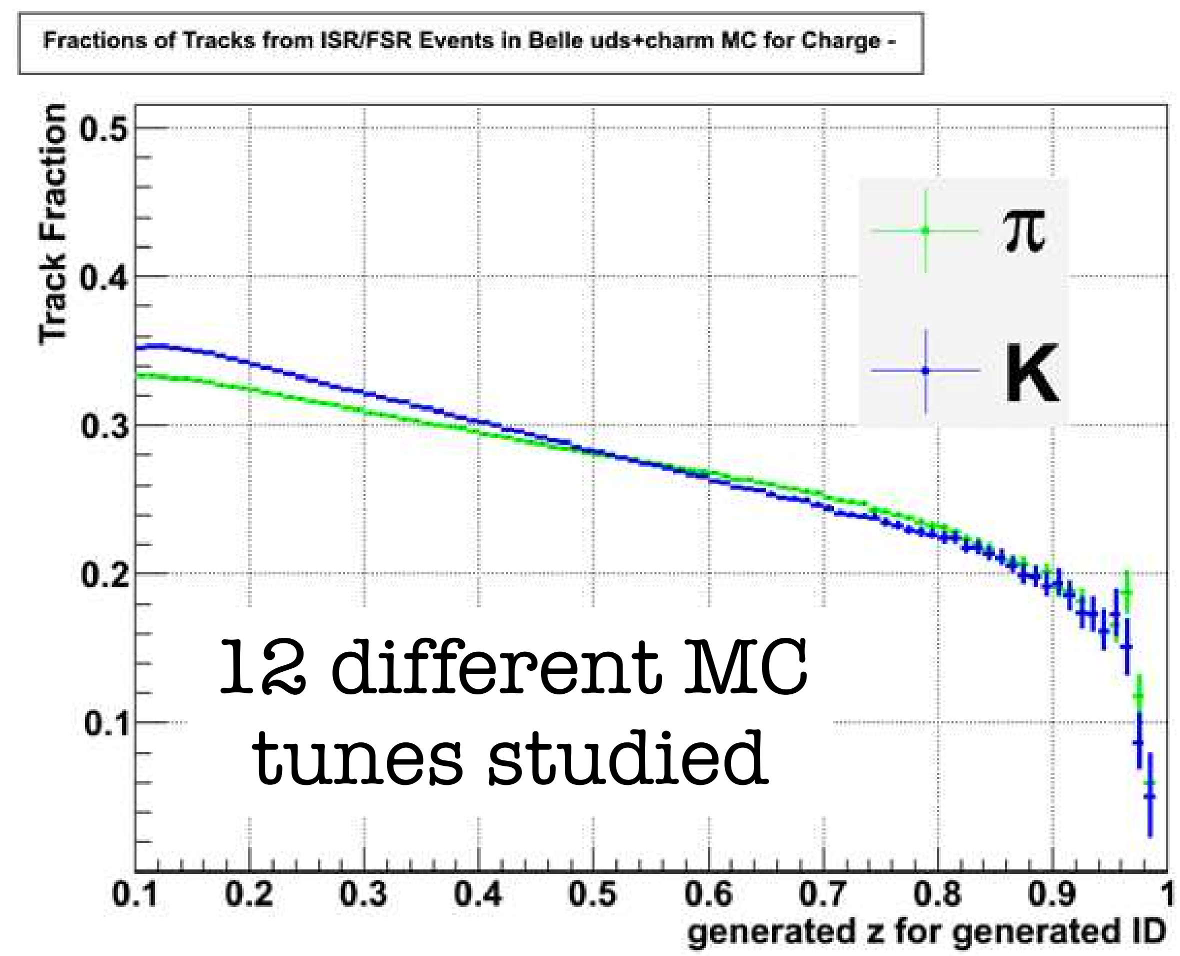
$i = \pi, K$

$$\frac{d\sigma_i}{dz} = \frac{1}{L_{tot}} \epsilon^i_{joint}(z)\, \epsilon^i_{ISR/FSR}(z)\, S^{-1}_{zz_m}\, \epsilon^i_{impu}(z_m)\, P^{-1}_{ij} N^{j,raw}(z_m)$$

Emission of a real photon changes the fragmentation energy scale



> 0.5% change in cms energy



More corrections

$i = \pi, K$

$$\frac{d\sigma_i}{dz} = \frac{1}{L_{tot}} \; \epsilon^i_{joint}(z)\, \epsilon^i_{ISR/FSR}(z)\, S^{-1}_{zz_m}\, \epsilon^i_{impu}(z_m)\, P^{-1}_{ij}\, N^{j,raw}(z_m)$$

Correction for particles lost due to

- decay in flight
- interaction with detectors
- detector/tracking inefficiencies
- geometric/kinematic acceptance

} < 10%

Cross sections

$i = \pi, K$

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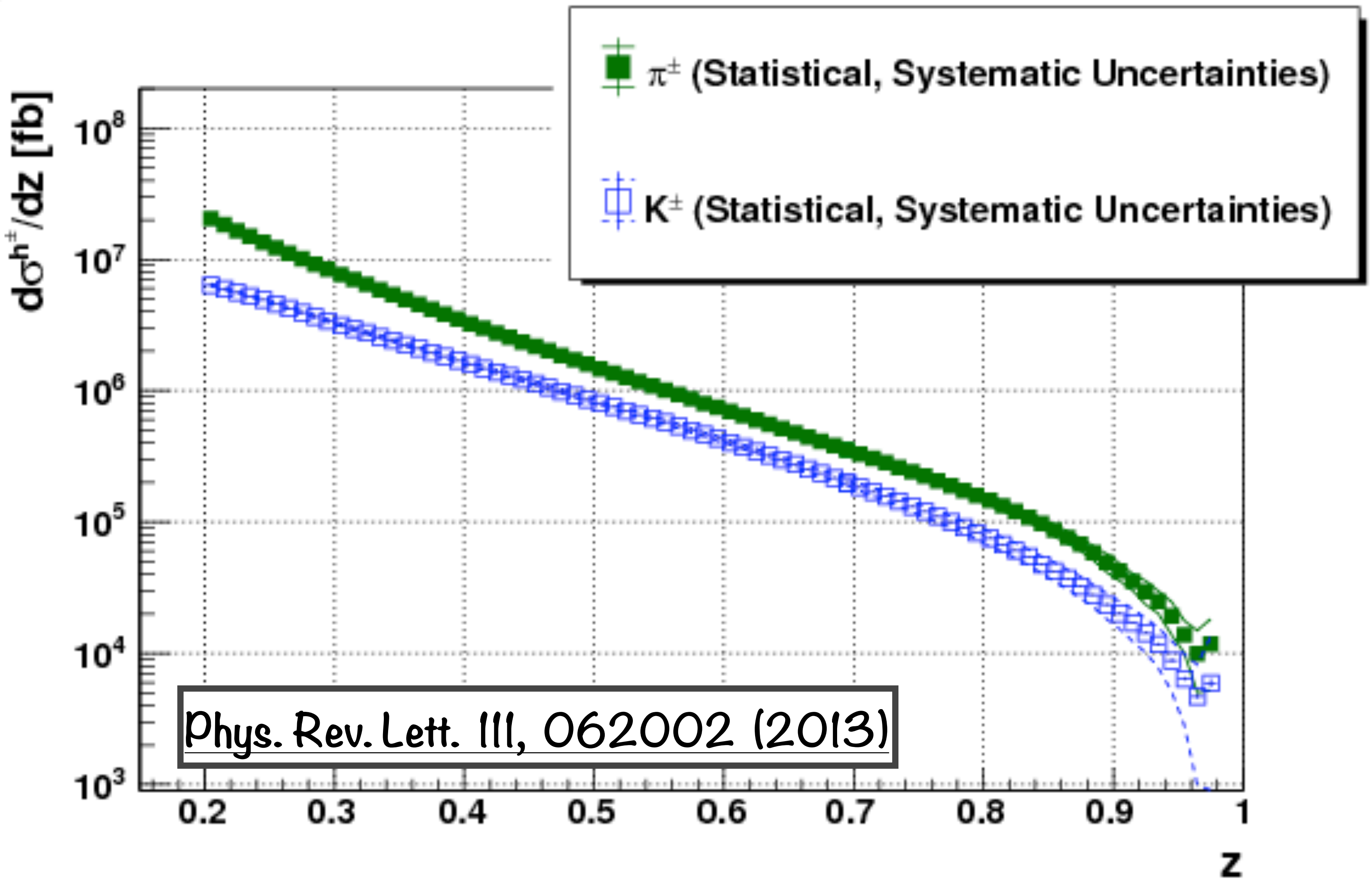
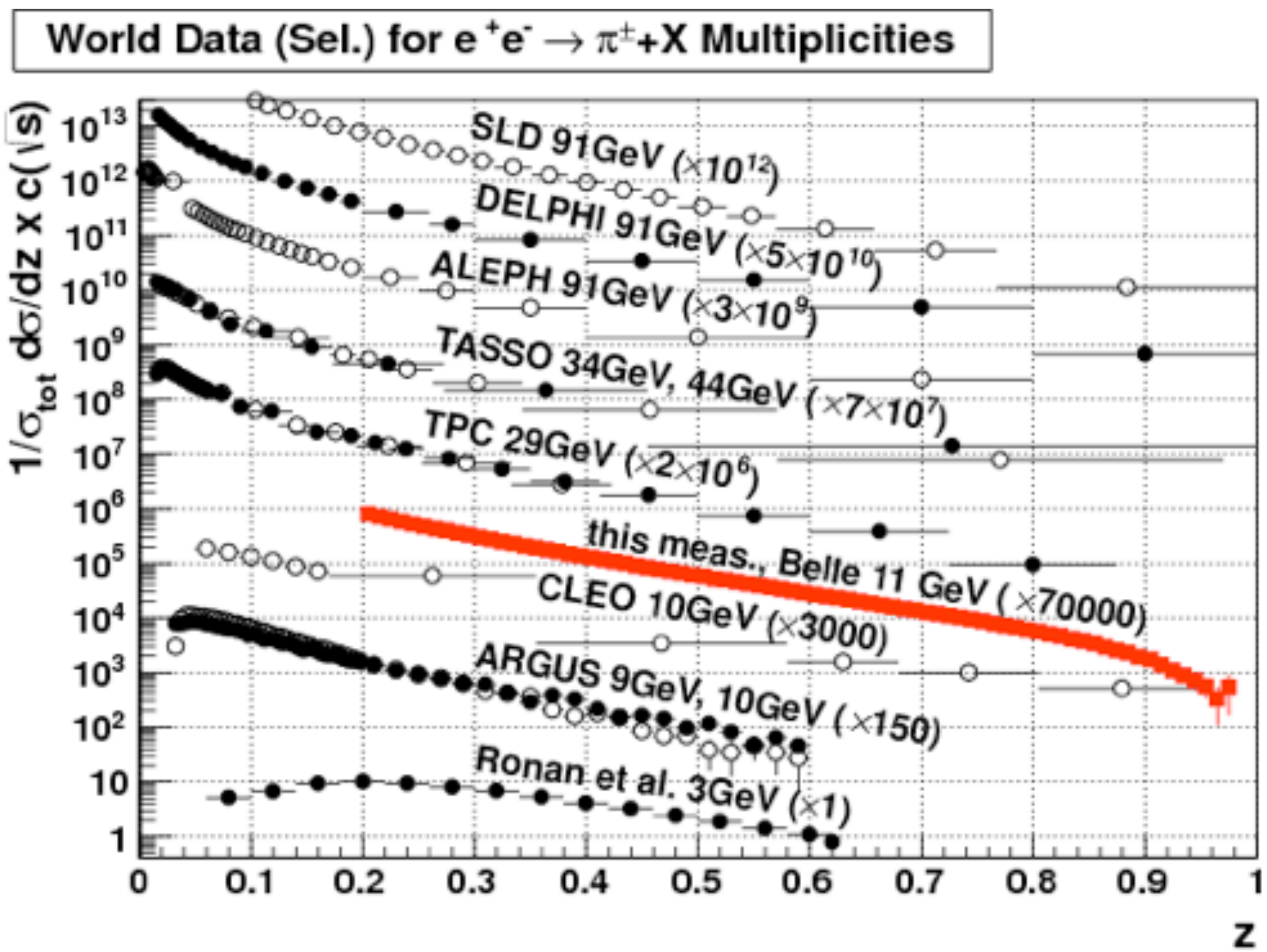
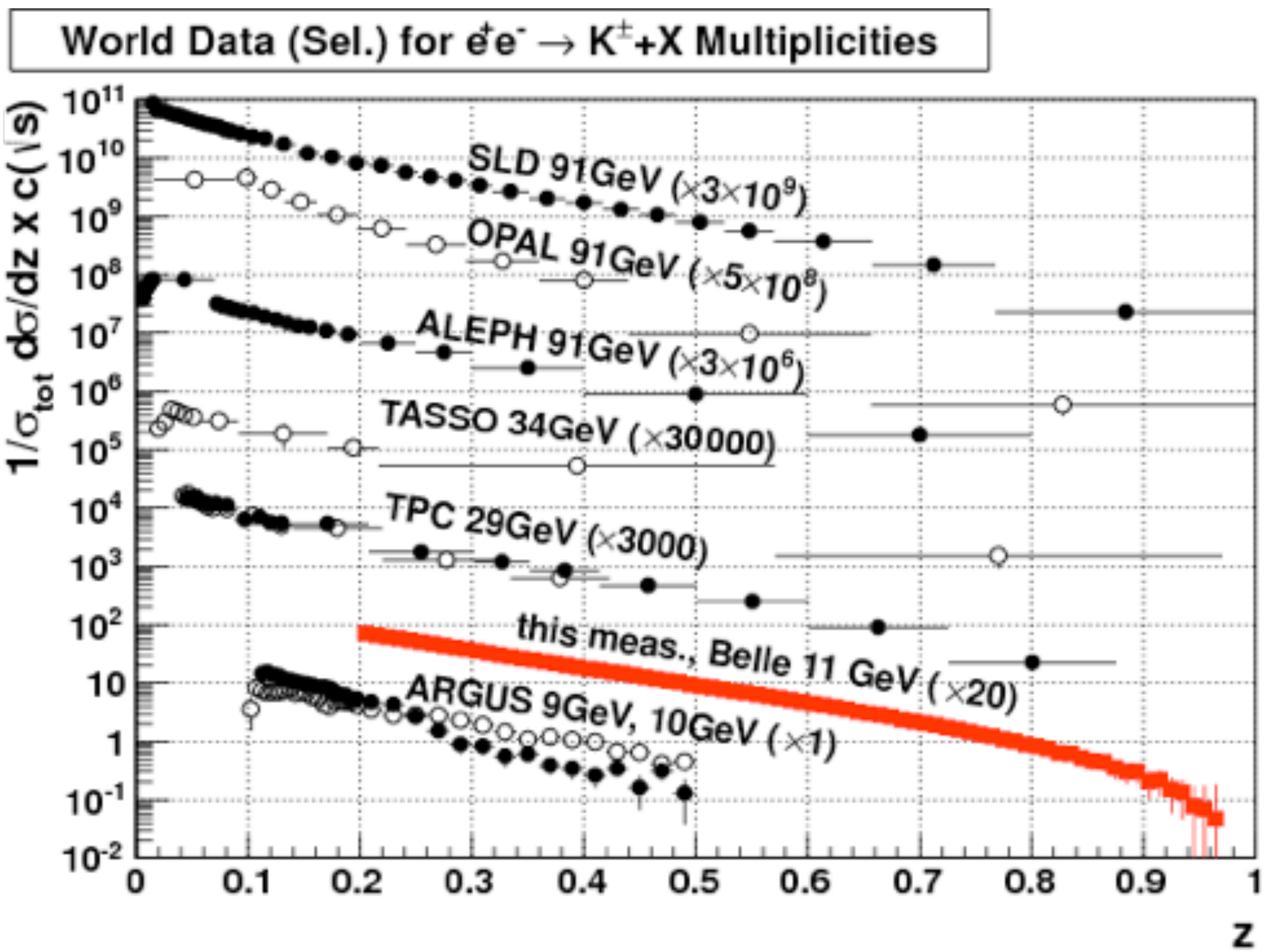


Updated e^+e^- world data





Phys. Rev. Lett. 111, 062002 (2013)

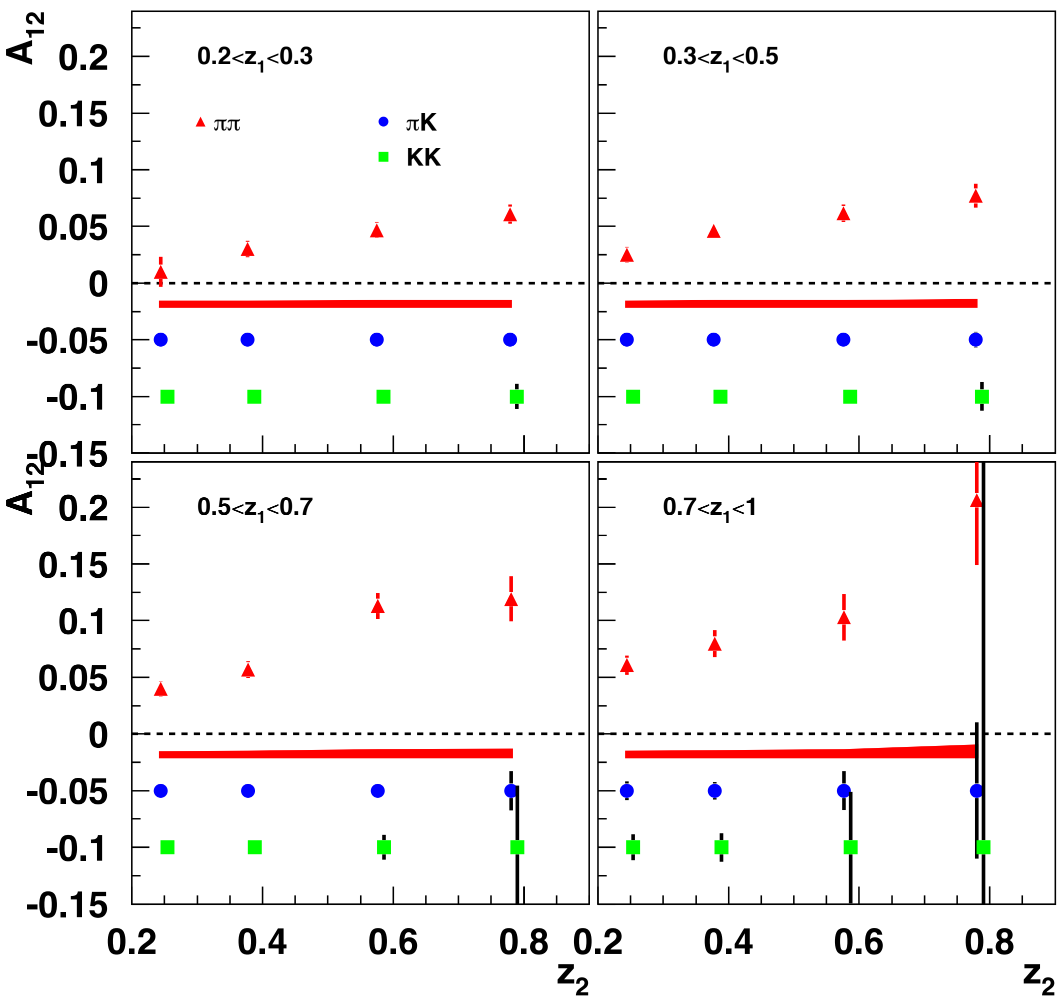
Outlook

- Precise pion and kaon cross sections published!
  Phys. Rev. Lett. 111, 062002 (2013)

- More high precision measurements to come

k_T spin-averaged FF for single and di-hadron

k_T Collins FF for kaons



You are all invited to the

Daniel Boer, Elena Boglione, Francesca Giordano (co-chair),
Matthias Grosse-Perdekamp, Marco Stratmann, Anselm Vossen (co-chair)

Registration and details:

http://www.indiana.edu/~ffwrkshp/

Thank you!