# Fragmentation function measurements @ RHIC

Fragmentation Function workshop
November 2012, RIKEN

Francesca Giordano

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

# Fragmentation process

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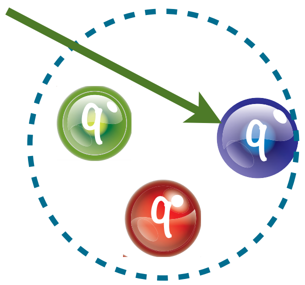

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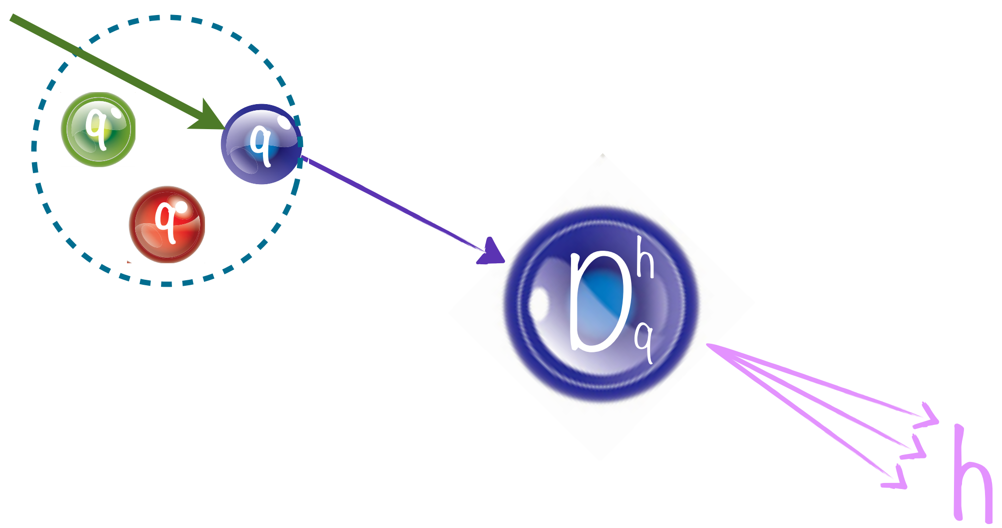


✦ Fragmentation function describes the process of hadronization of a parton

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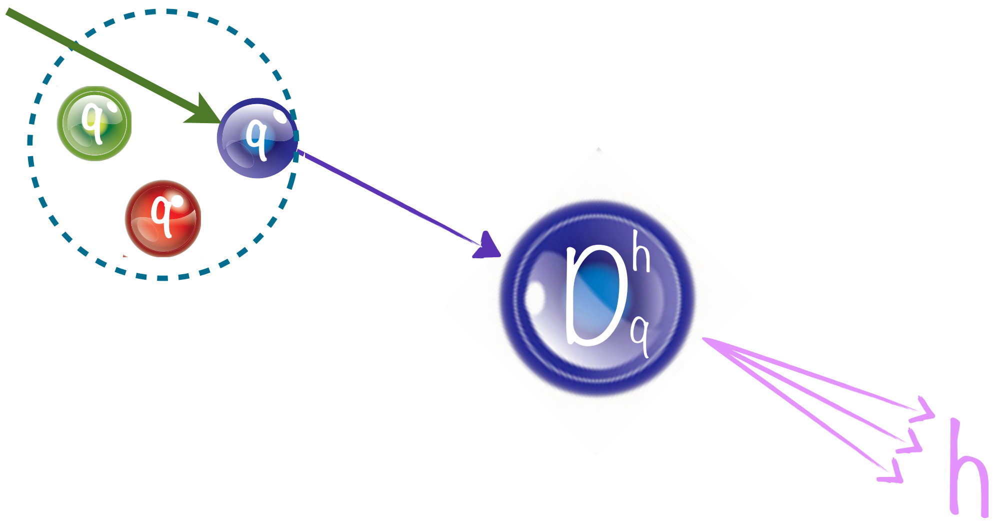


- Fragmentation function describes the process of hadronization of a parton
- Strictly related to quark confinement

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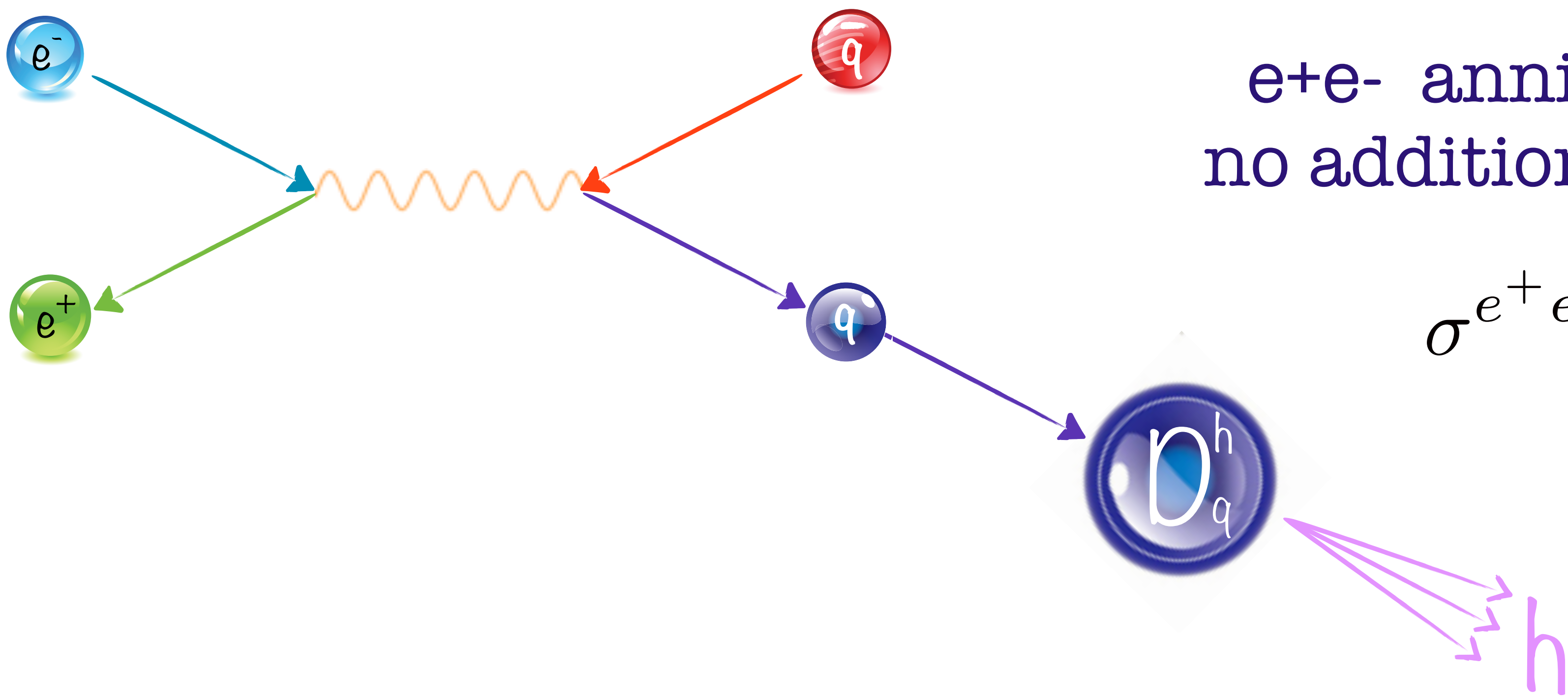


e+e- annihilation cleanest reaction
no additional non-perturbative terms

$$\sigma^{e^+e^- \to hX} \propto \sum_{i=q\bar{q}} \sigma^{e^+e^- \to q\bar{q}} \times D_q^h$$

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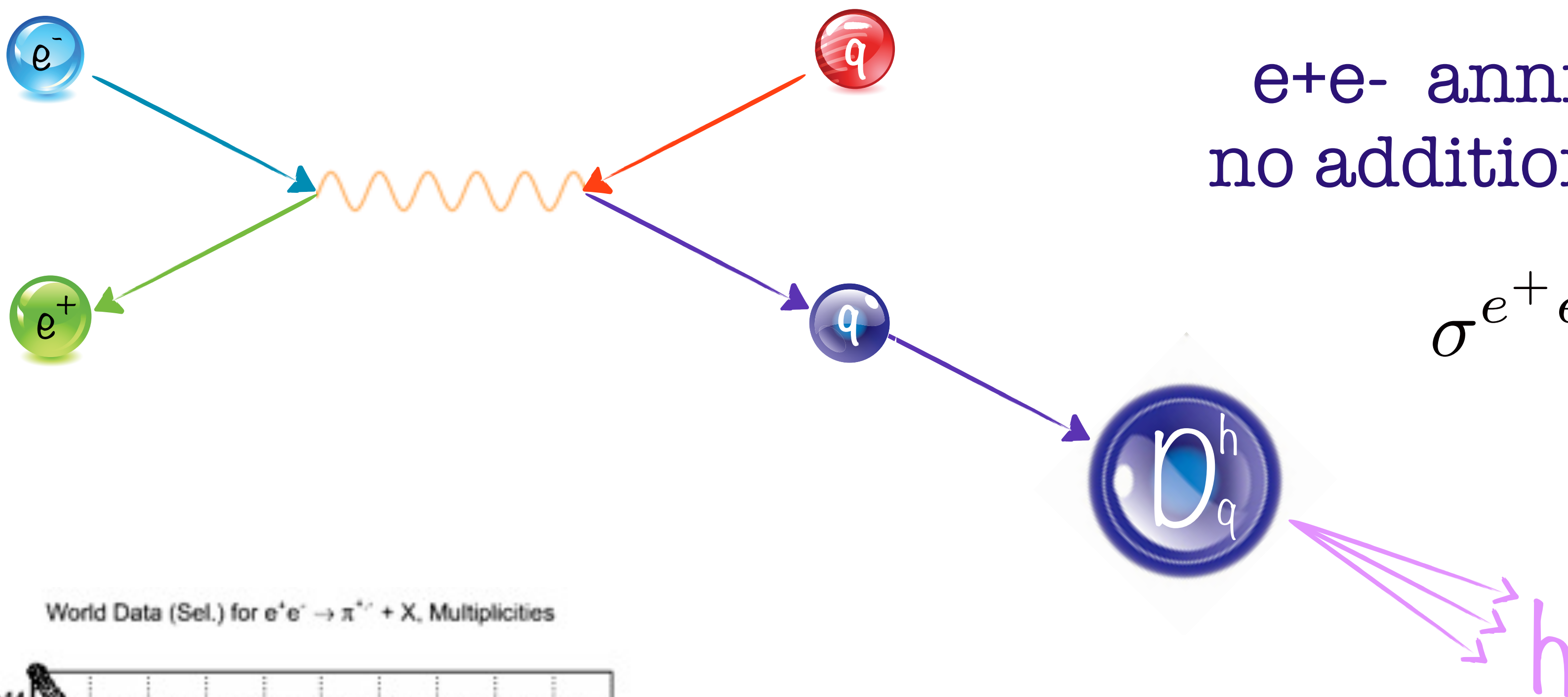


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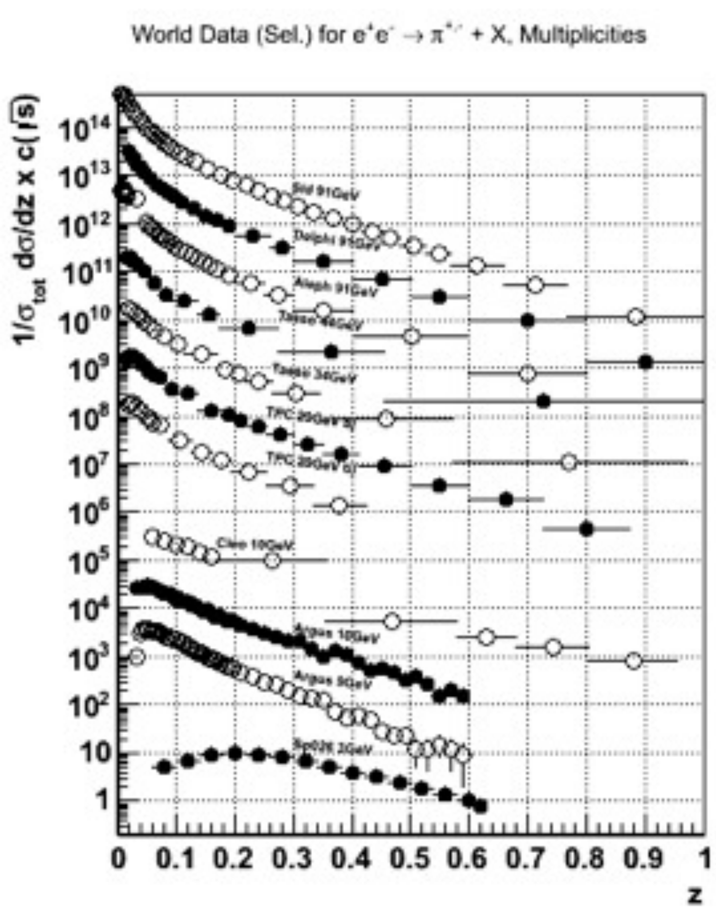


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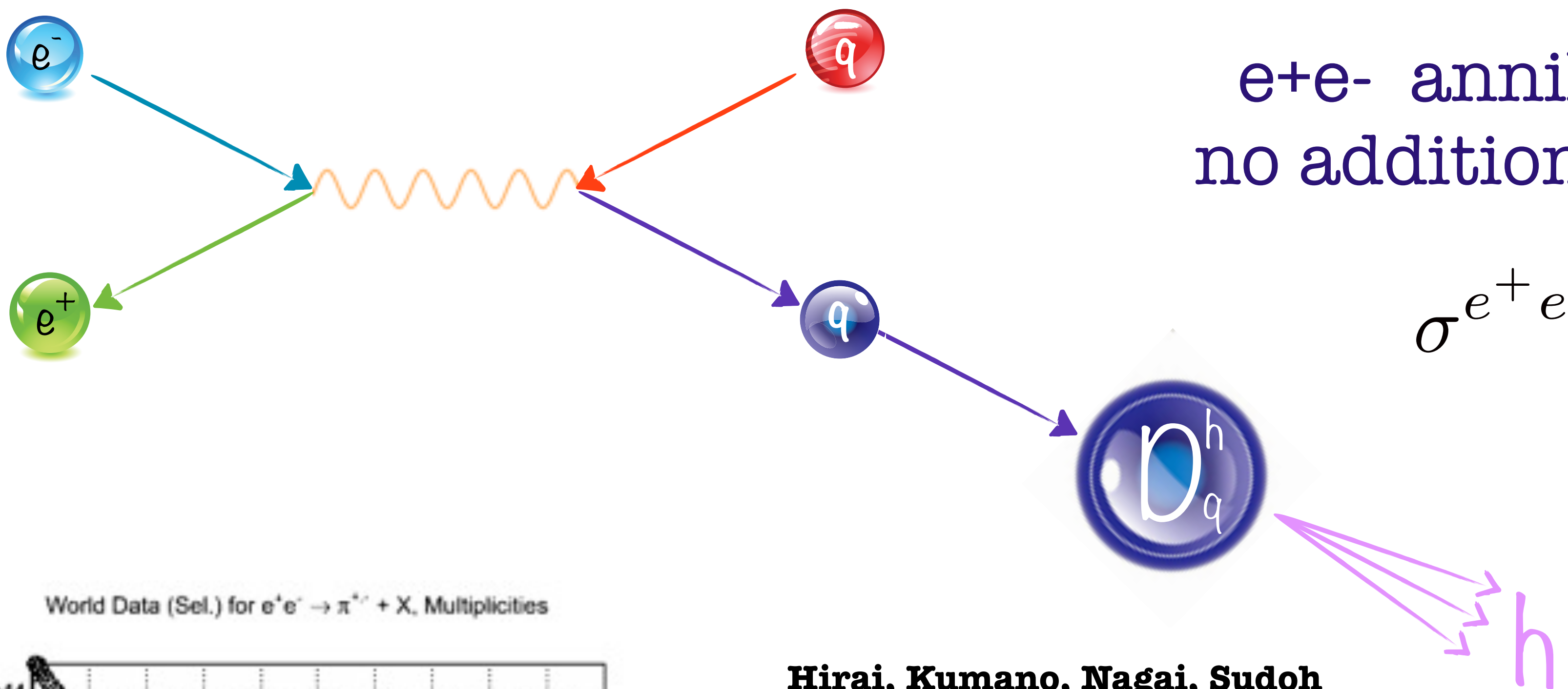


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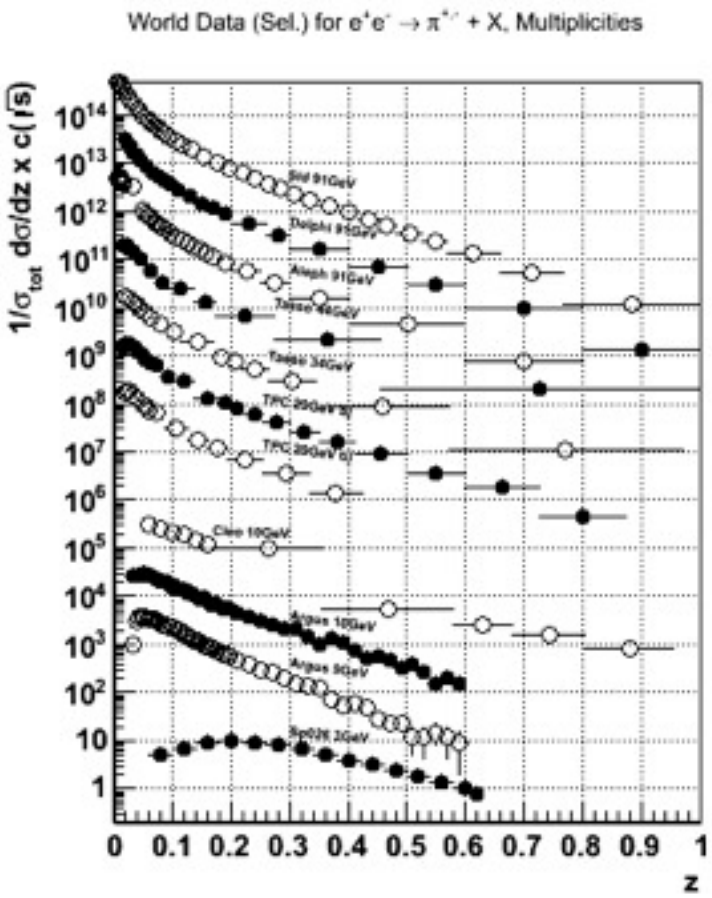


**Hirai, Kumano, Nagai, Sudoh**
**Phys. Rev. D 75, 094009 (2007)**

2007: First unpolarized FF extraction with estimated uncertainties!

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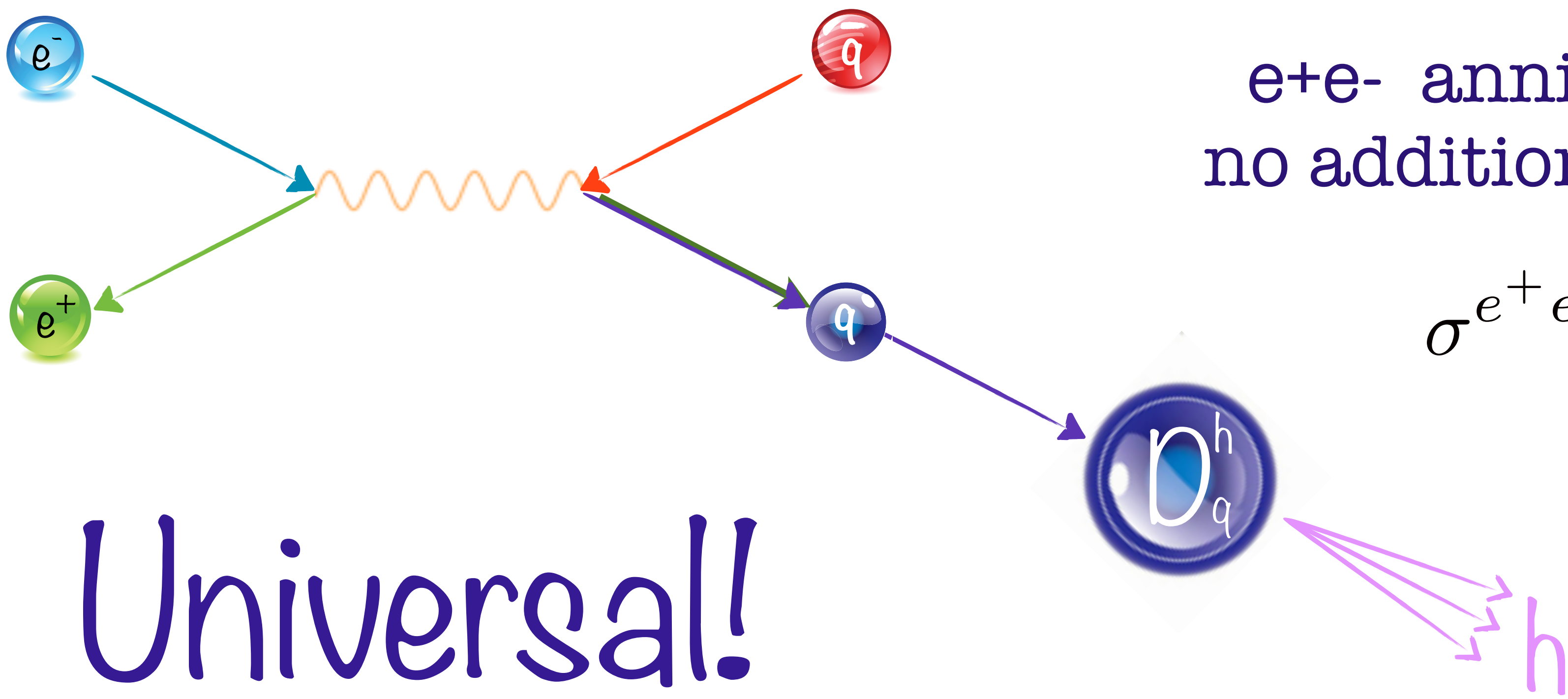
- Strictly related to quark confinement

# Fragmentation process




Universal!

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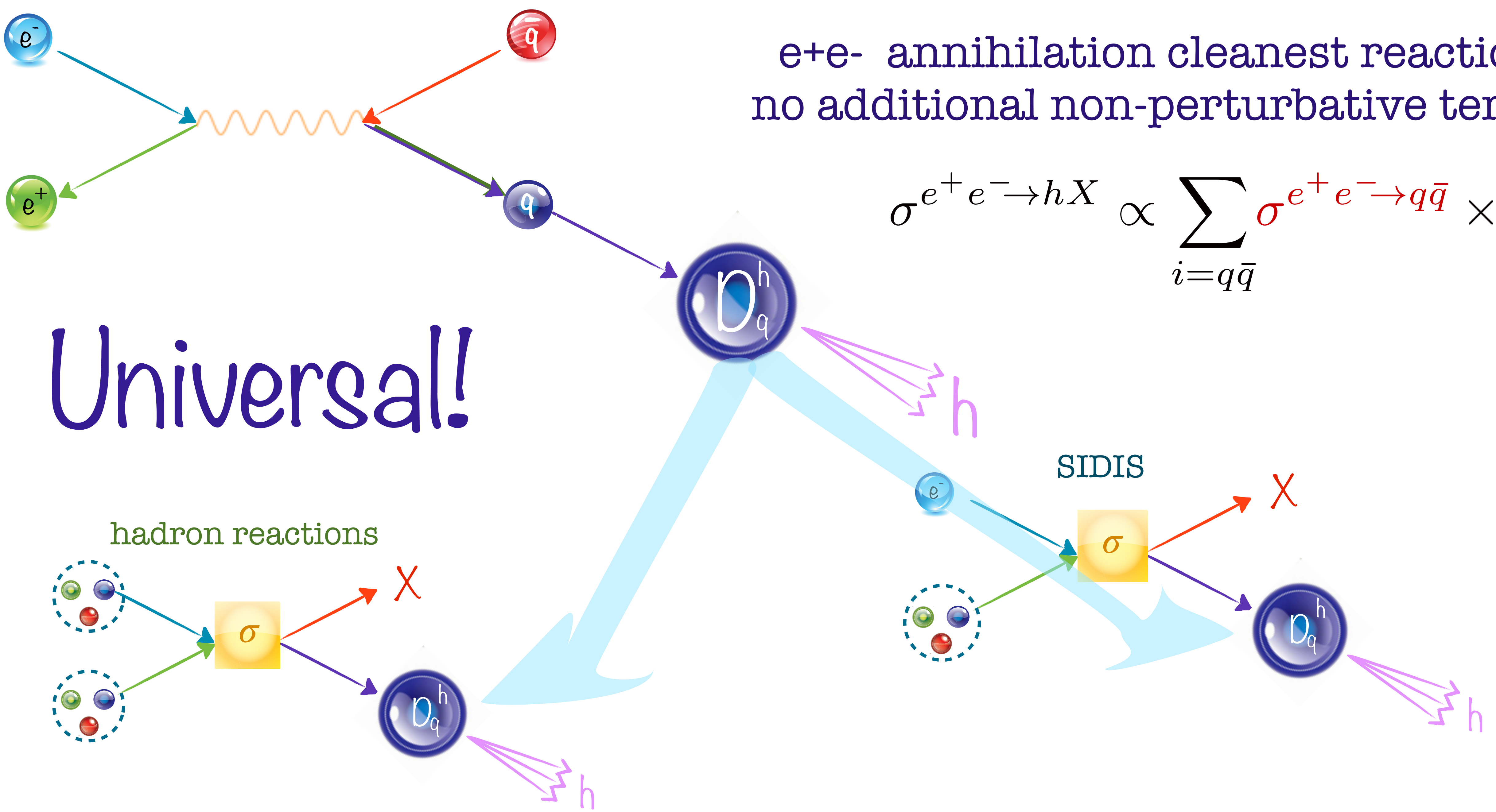

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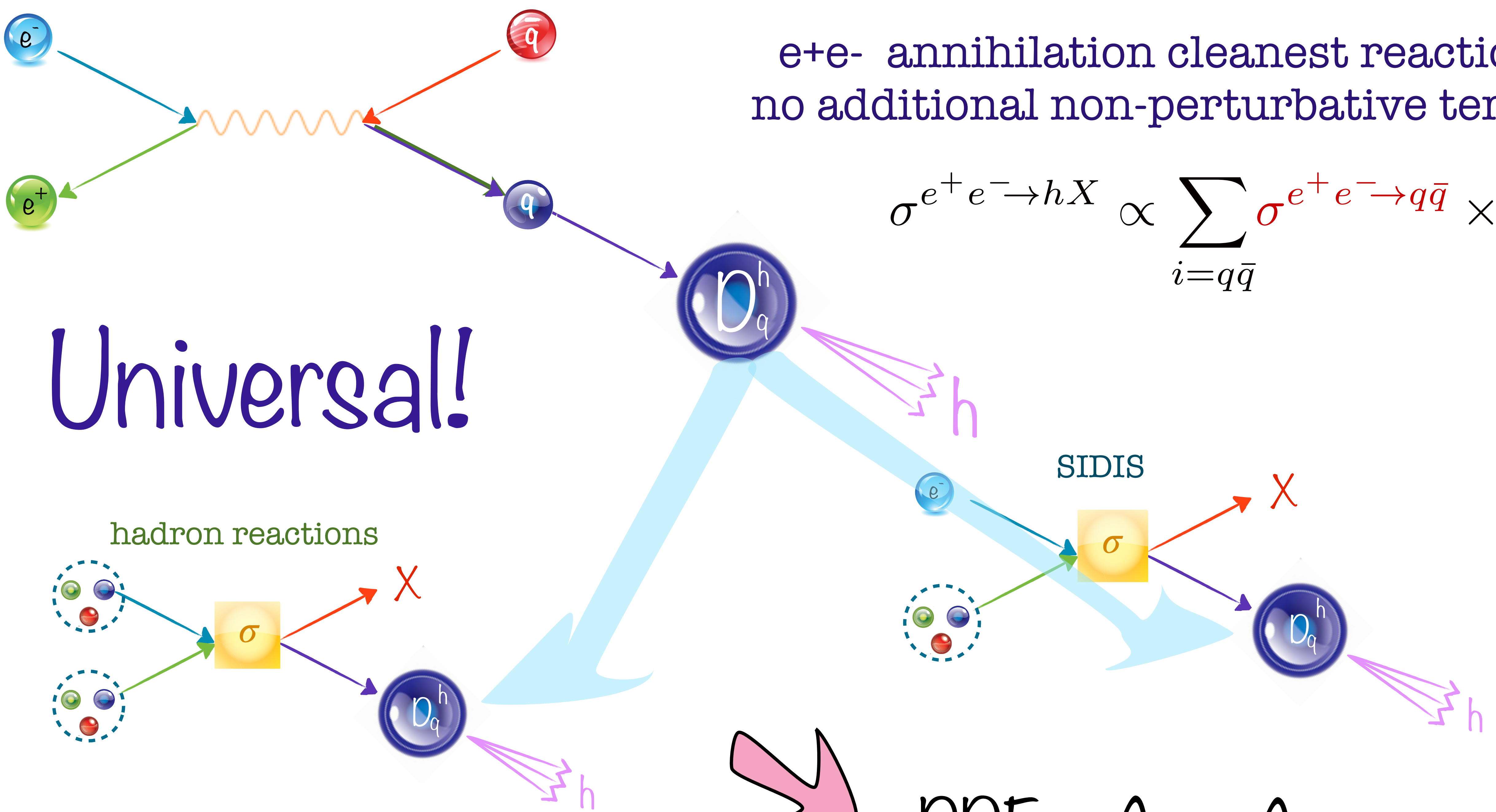
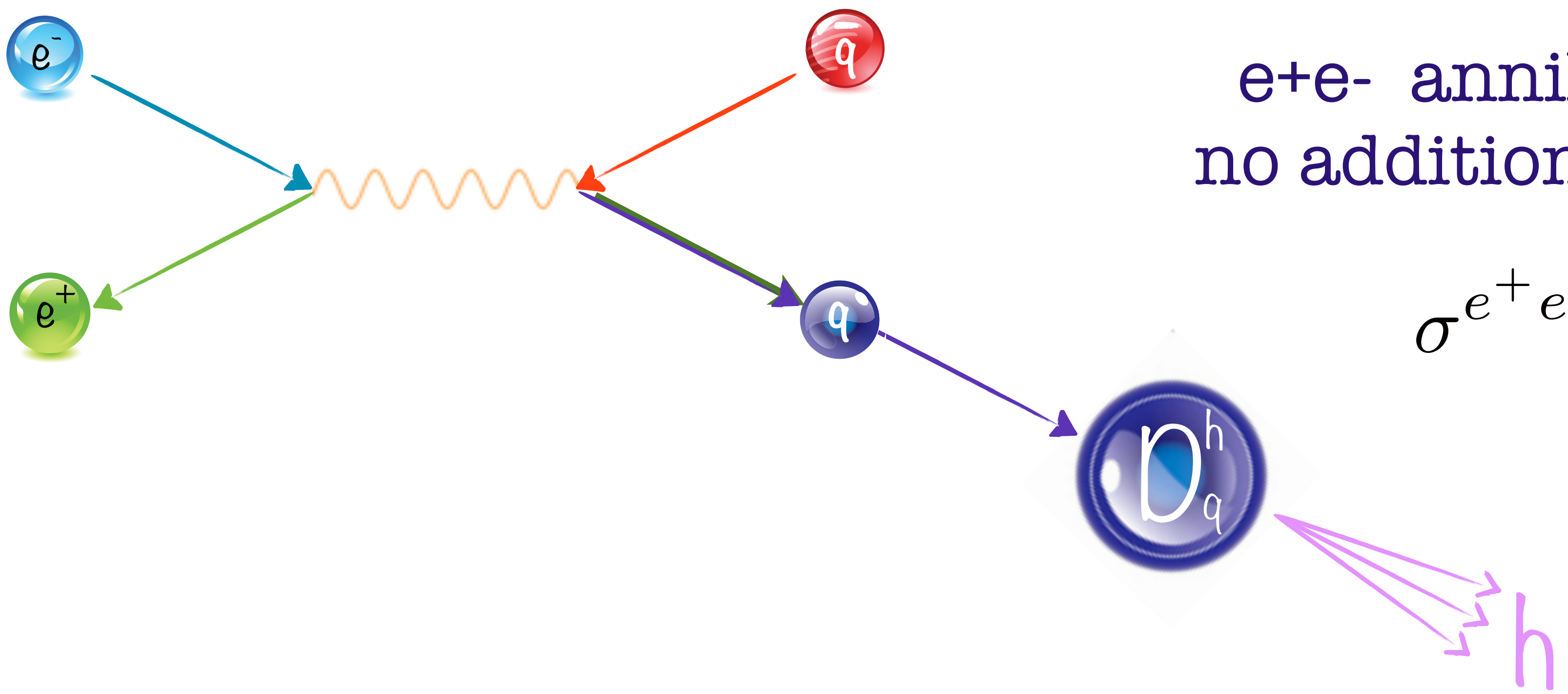



PDFs $A_{UT}$ $A_{LL}$
Evolution

# $e^+e^-$ annihilation

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- No charge separation possible ($\pi^+ + \pi^-$, $K^+ + K^-$, ...)

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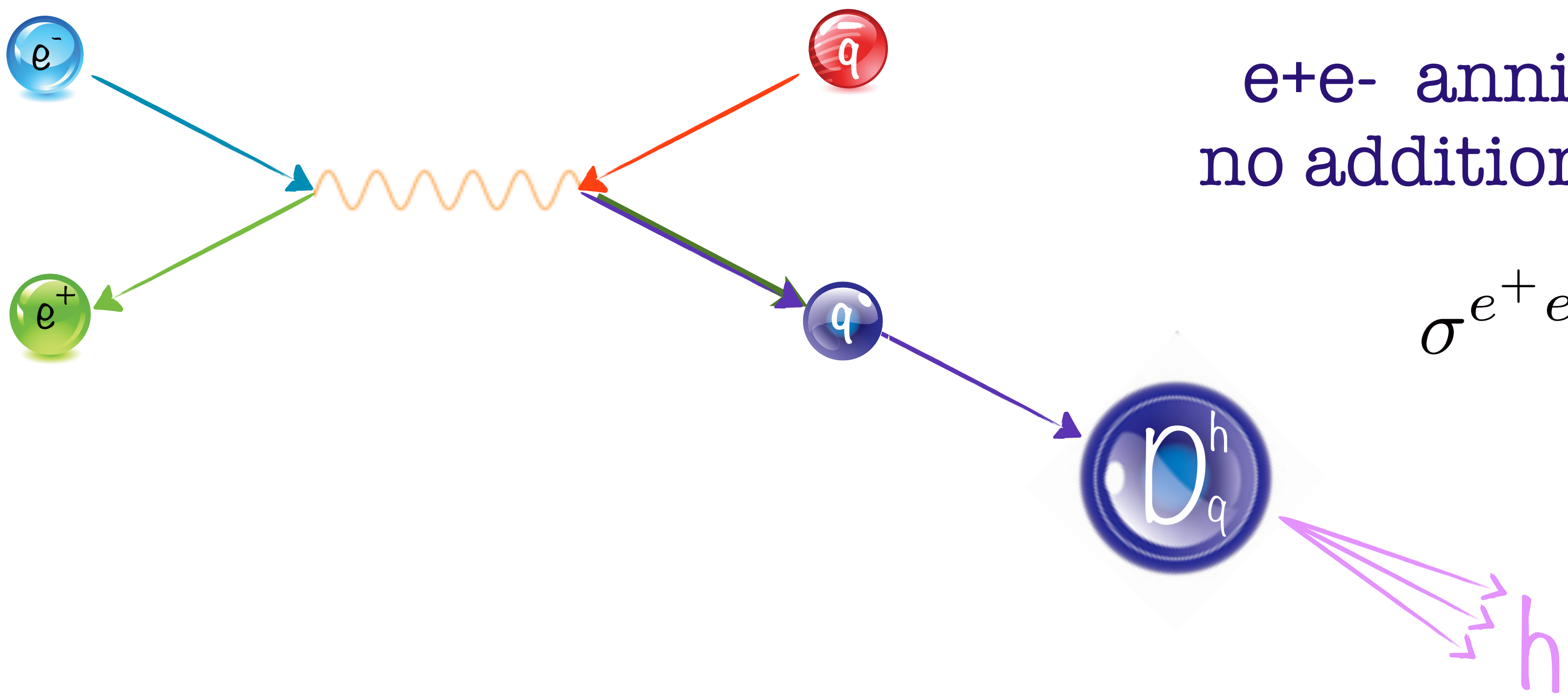


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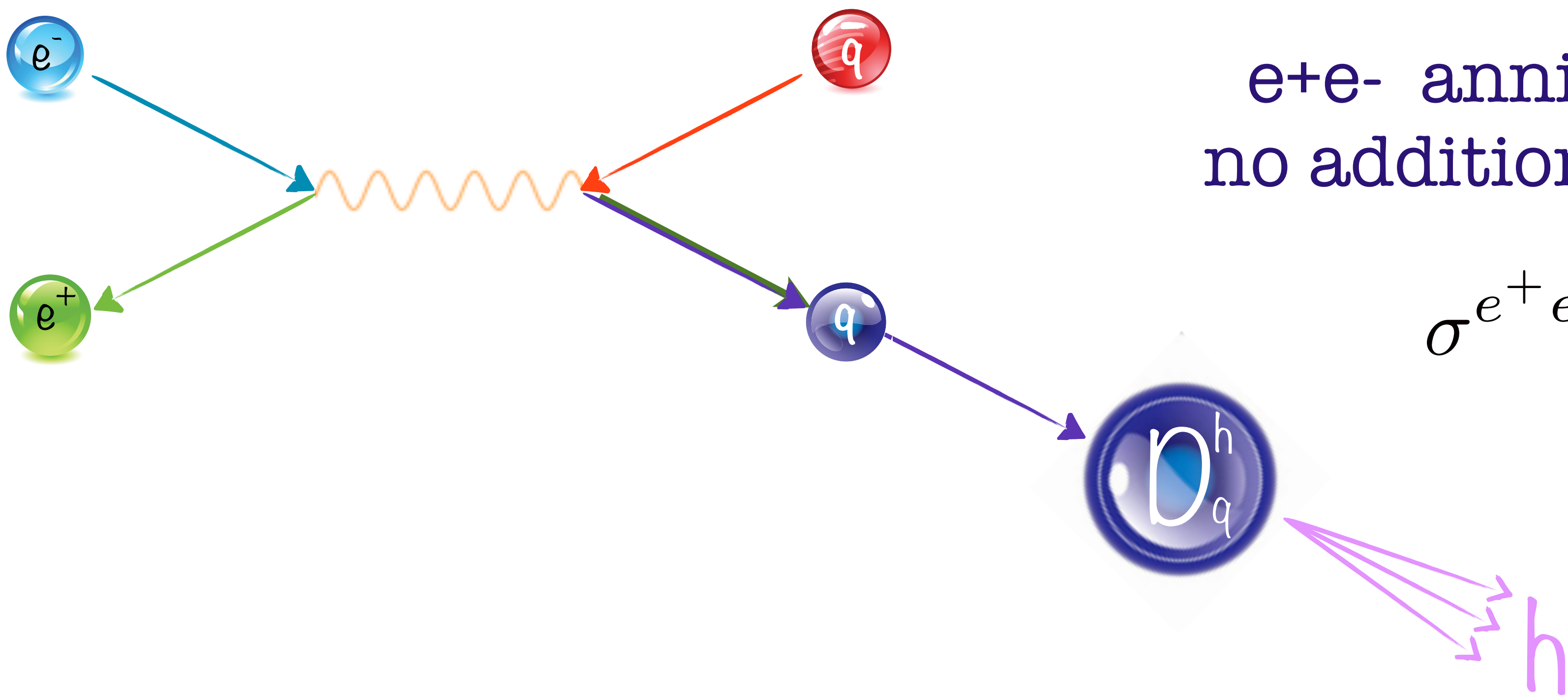


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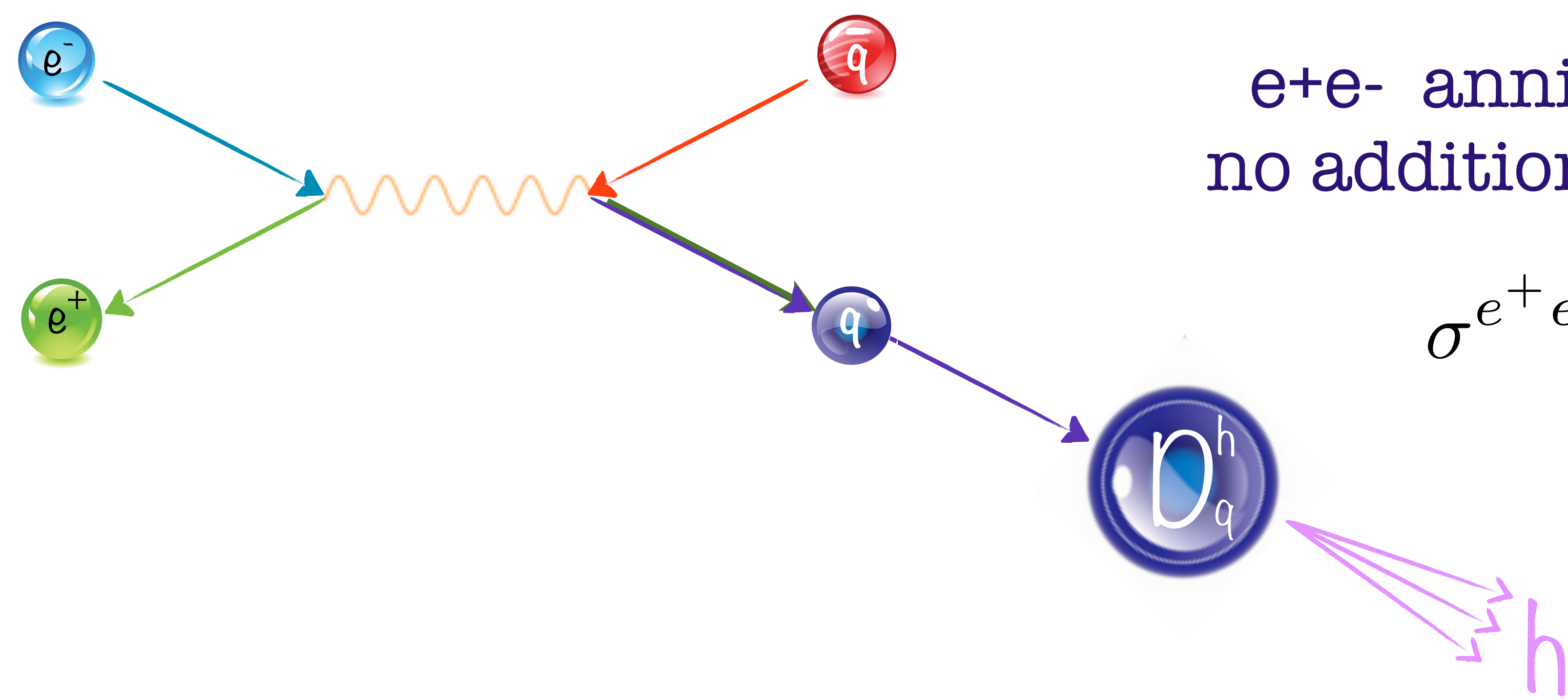


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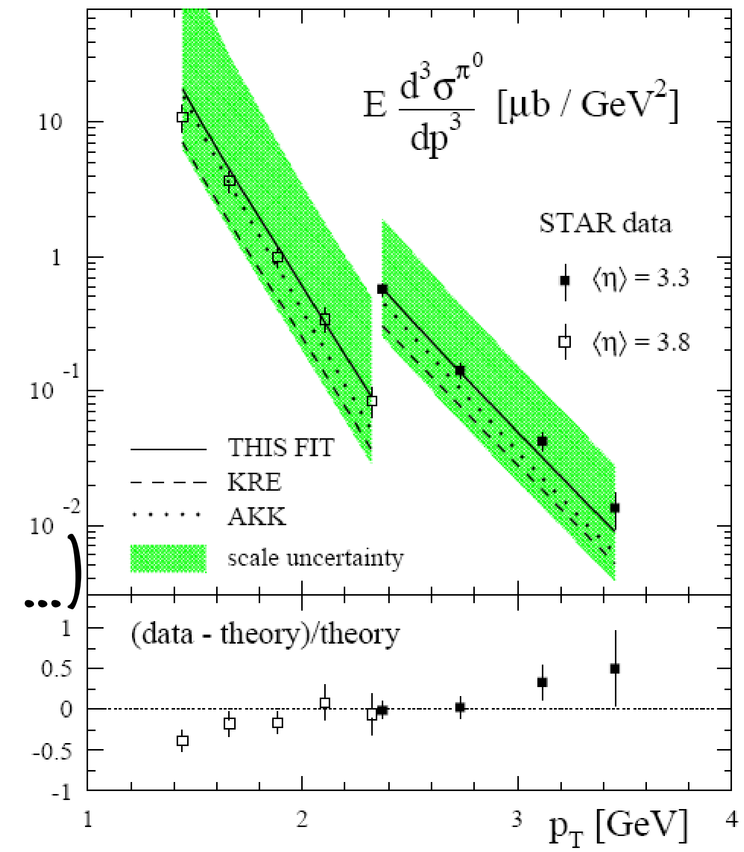


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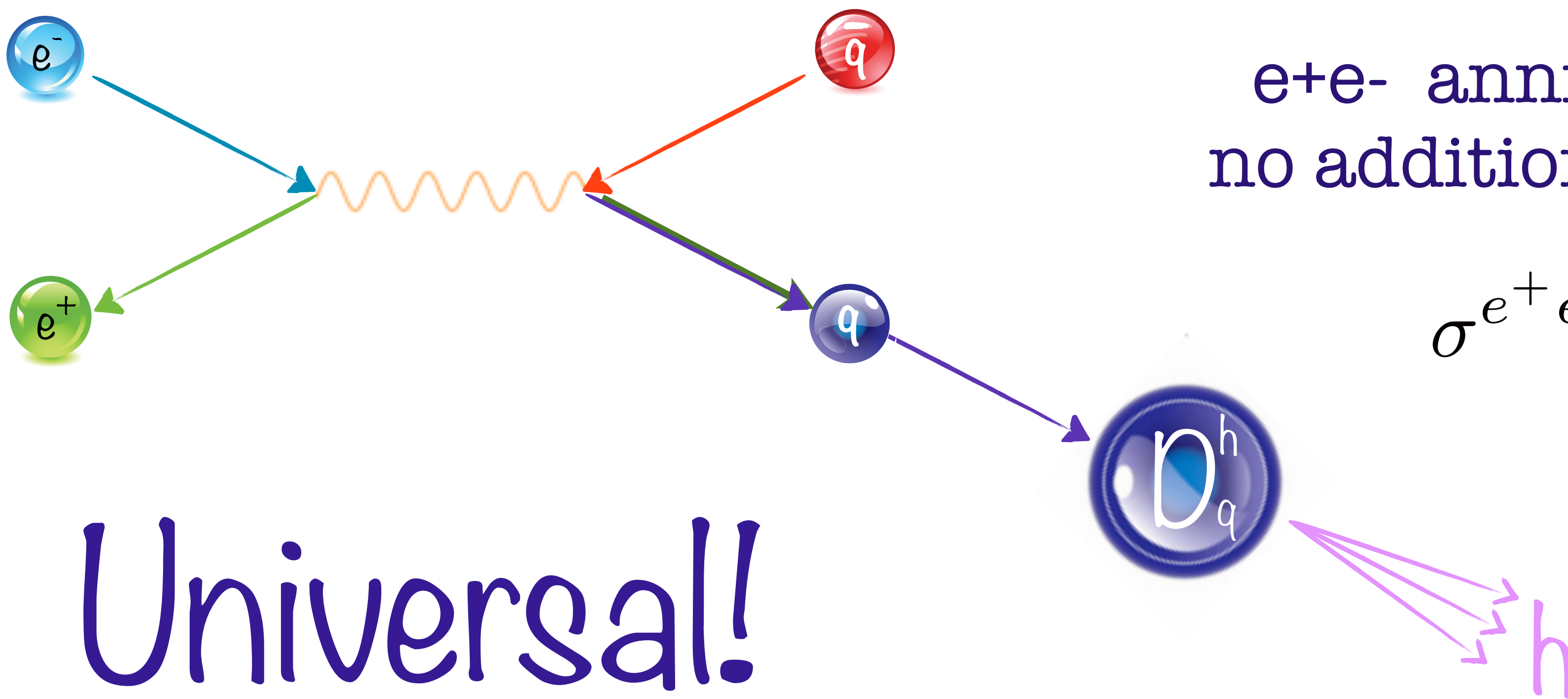


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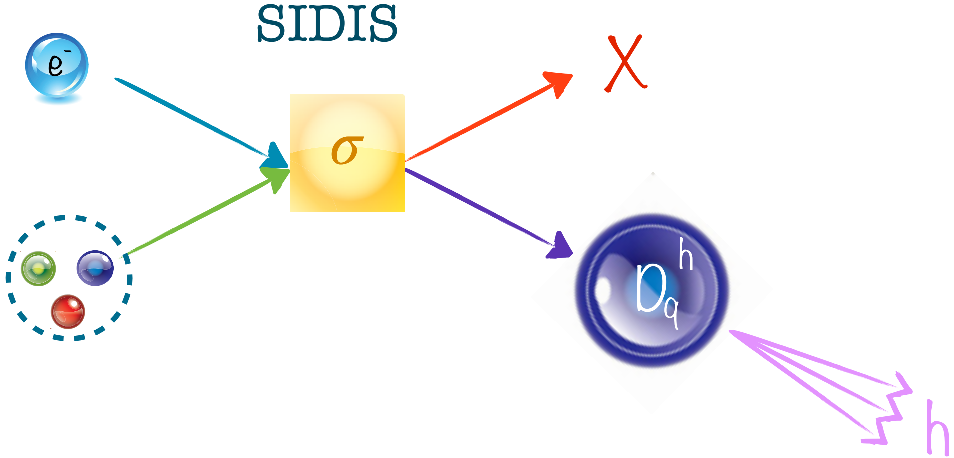
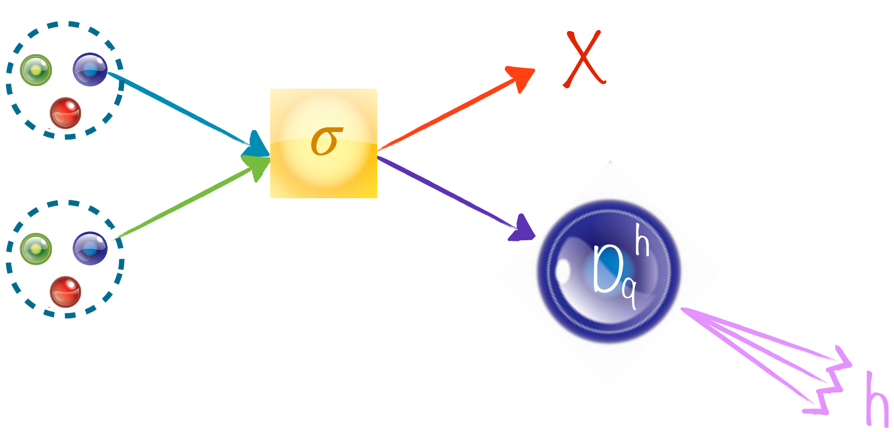
SIDIS




hadron reactions



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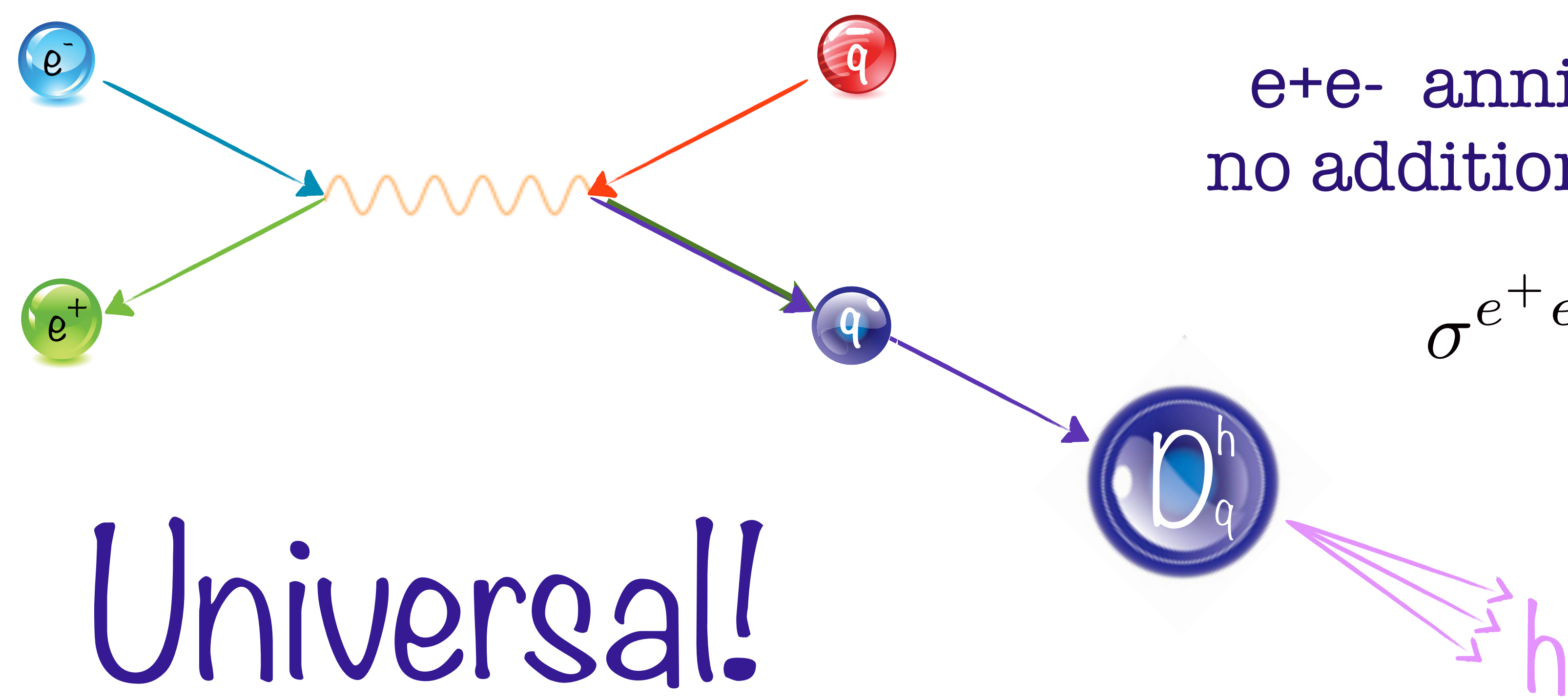


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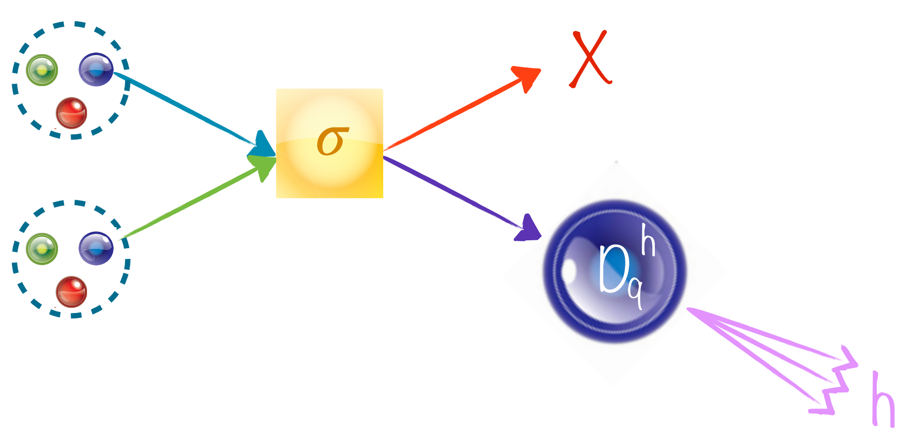
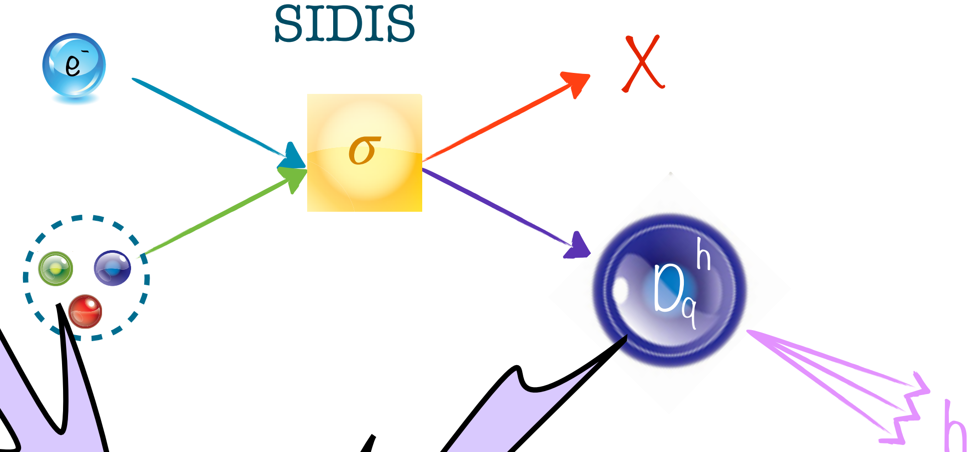



SIDIS




Global analysis

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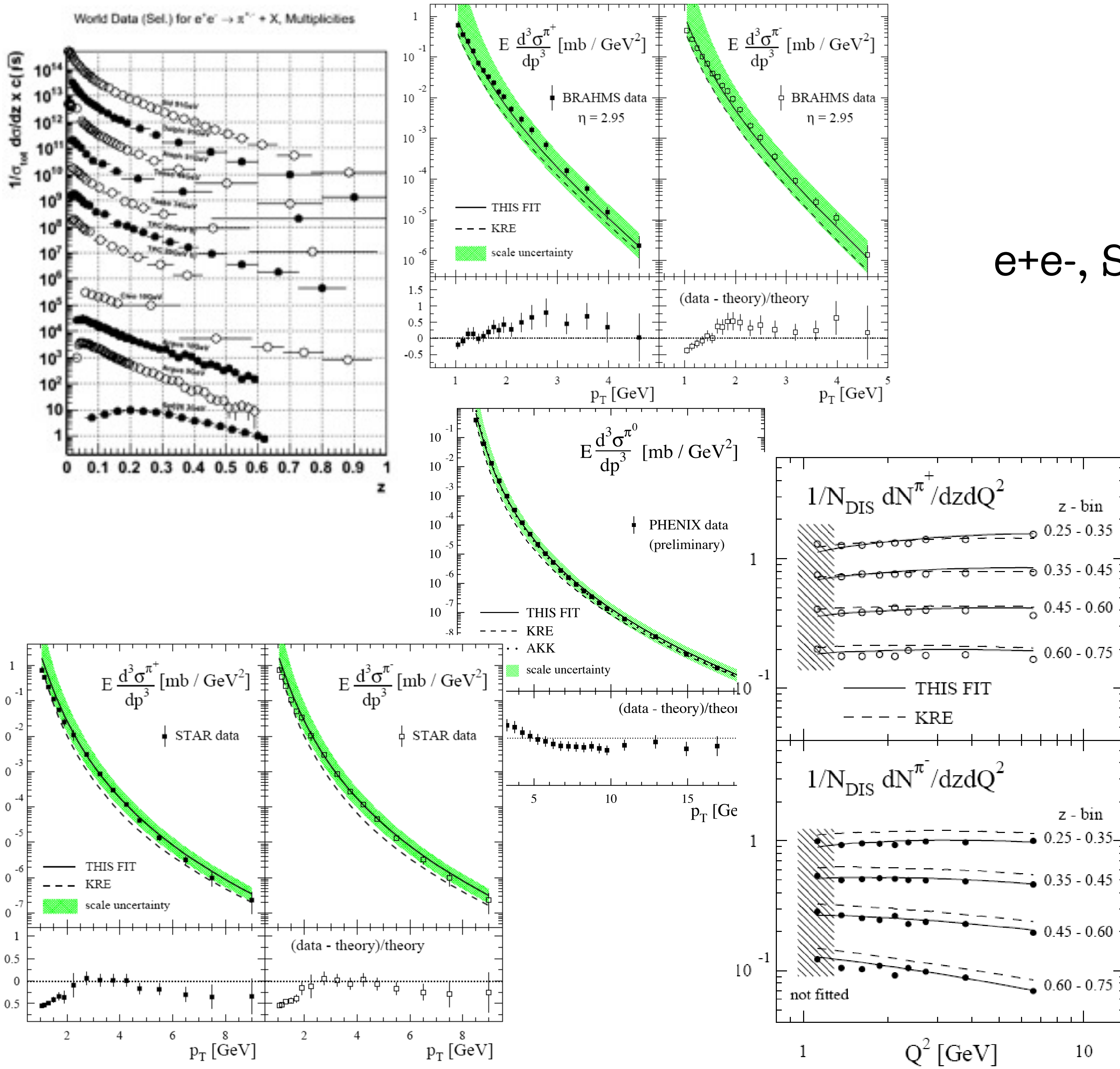



Global analises:
e+e-, SIDIS, pp: (including uncertainties)

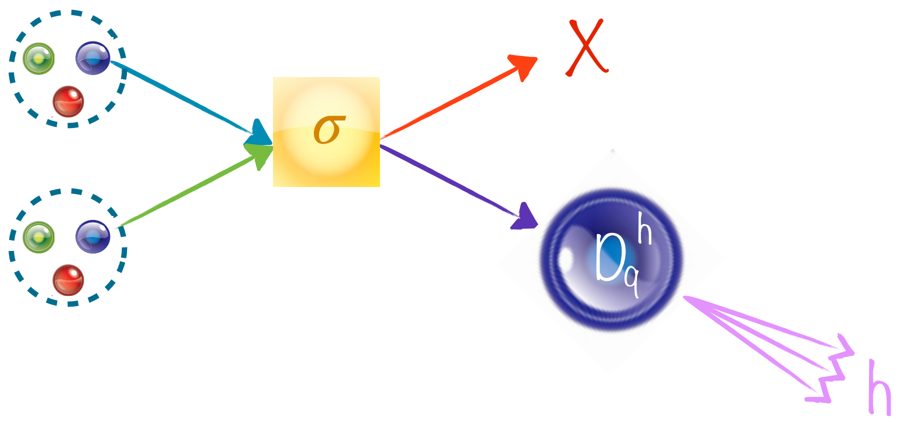
**de Florian, Sassot, Stratmann**
**Phys. Rev. D 75, 114010 (2007) and**
**Phys. Rev D 76, 074033 (2007)**

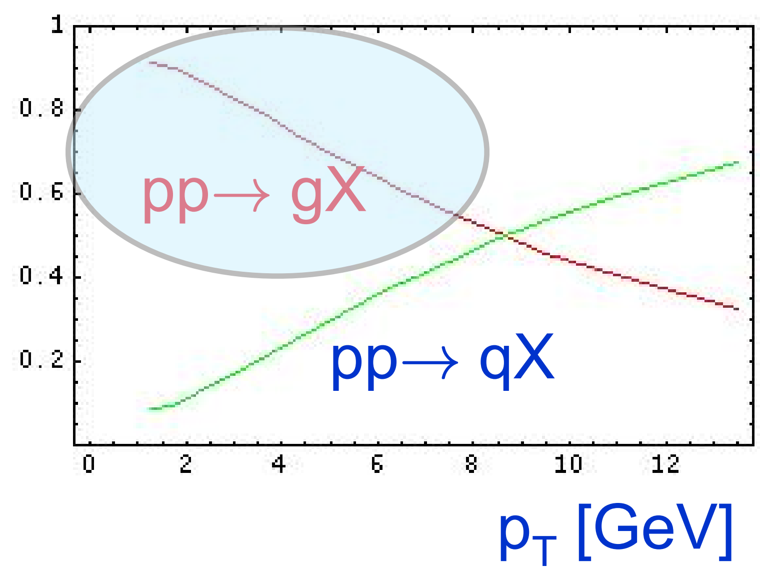
**Epele, Llubaroff, Sassot, Stratmann**
**arXiv:1209.3240 [hep-ph]**

e+e-, pp:

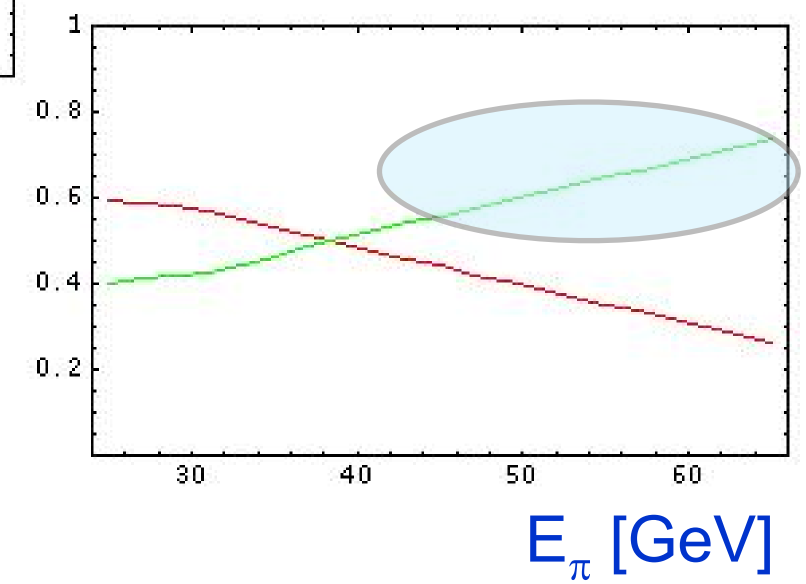
**Albino, Kniehl, Kramer**
**Nucl. Phys. B 803, 42 (2008)**

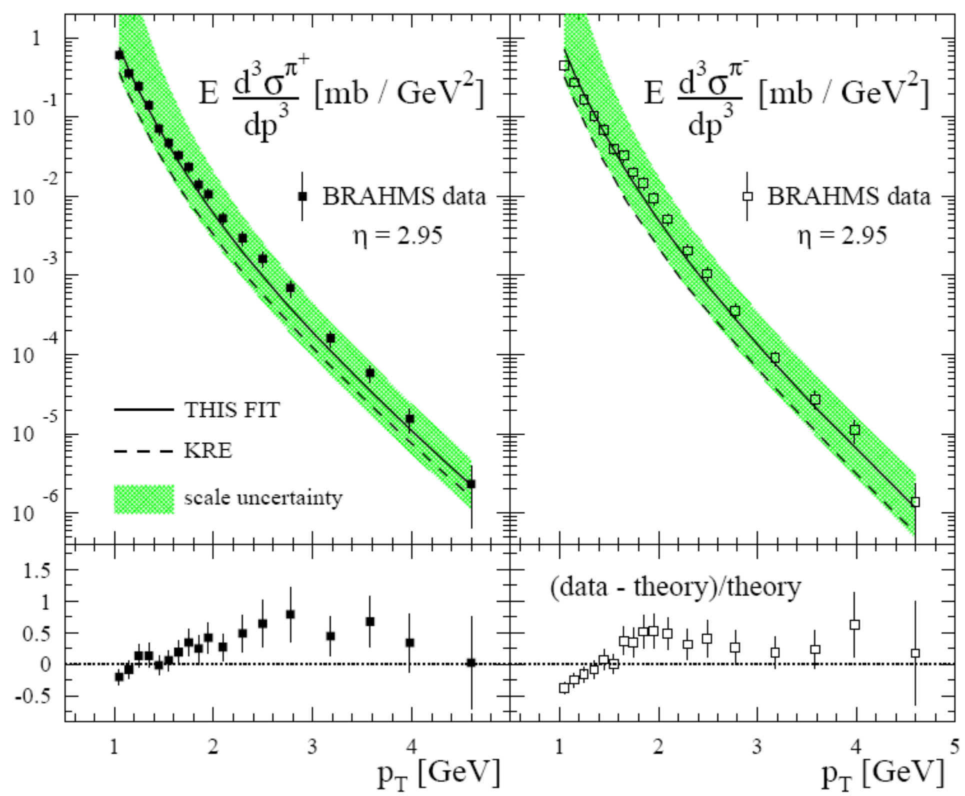
# Hadronic interations




Sensitive to gluons!




Sensitive to flavor!

# Proton-Proton collider

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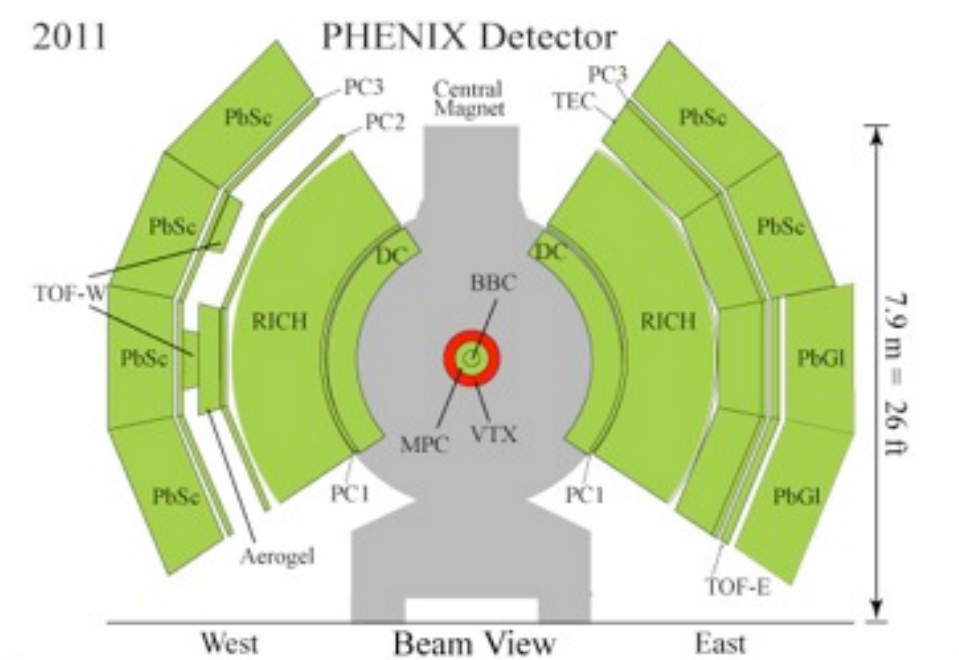
Hadron-Hadron collider
$\sqrt{s}$ of 62 GeV, 200 GeV, 500 GeV

# Phenix

## Central Arms:

$|\eta| < 0.35$

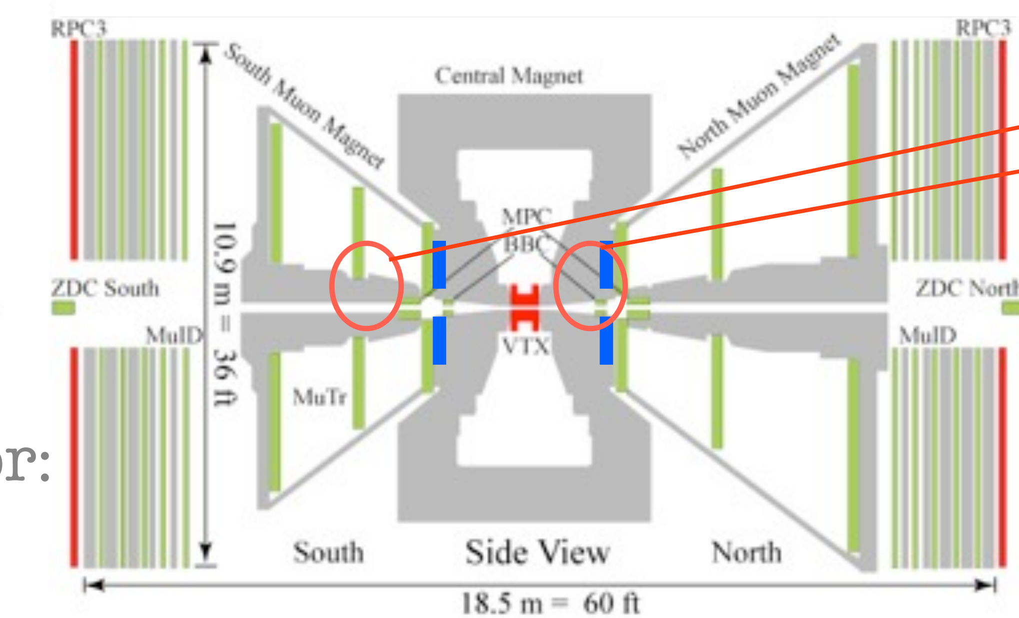



Tracking, Momentum and PID for:
- ☆charged and neutral hadrons
- ☆direct photons
- ☆e+e-

## Forward Arms:

$1.2 < |\eta| < 2.4$

Tracking and Momentum for:
- ☆ $\mu^{\pm}$

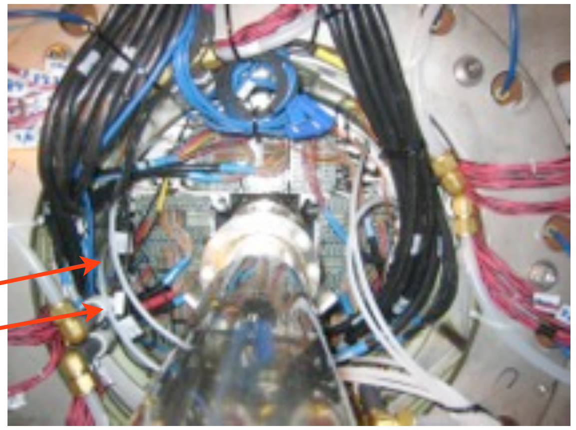



## Even more forward: MPC

$3.1 < |\eta| < 3.9$

$\gamma$

$\pi^0 \to \gamma\gamma$



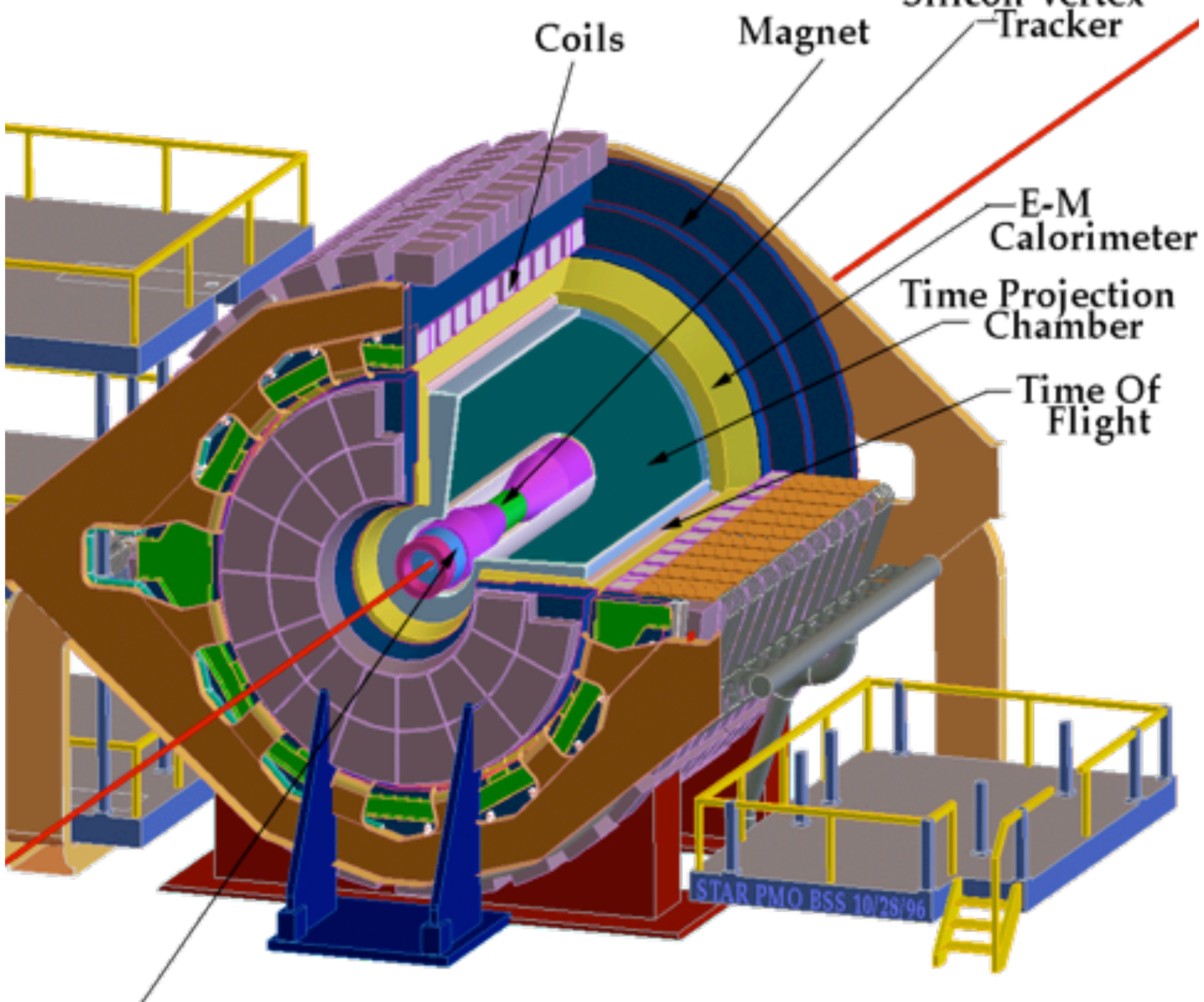
# Star

## Central Spectrometer:

$|\eta| < 1$

Tracking, Momentum and PID for:

☆Charged and neutral hadrons, jets




## Forward region:

Forward meson spectrometer

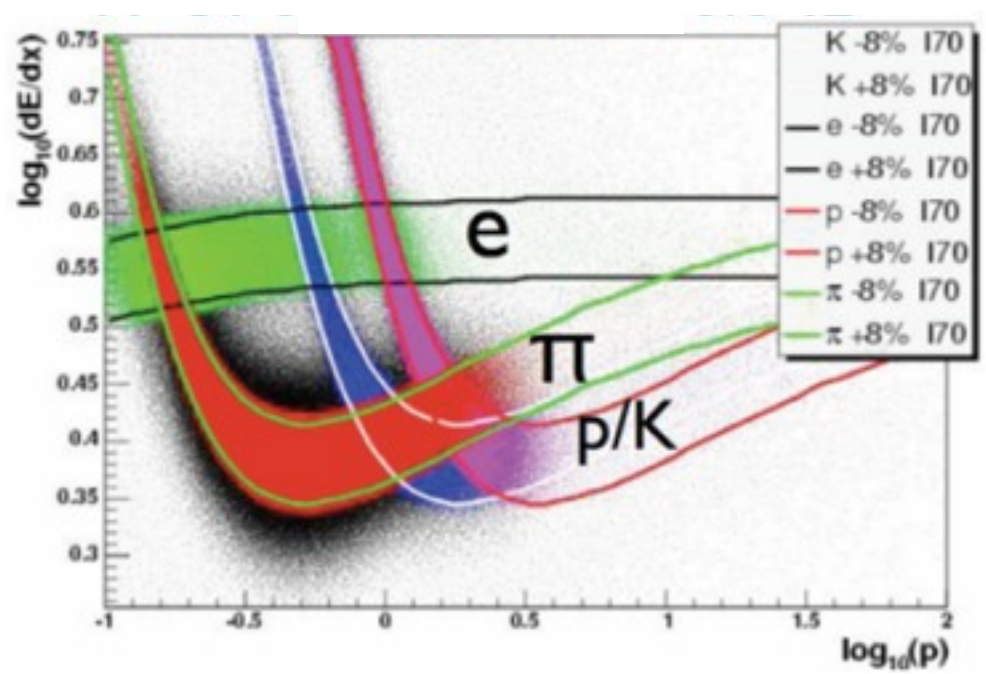
$2 < |\eta| < 4$

☆ $\pi^0$, η

Endcap Calo

$1 < |\eta| < 2$

☆ $\pi^0$, η, jets

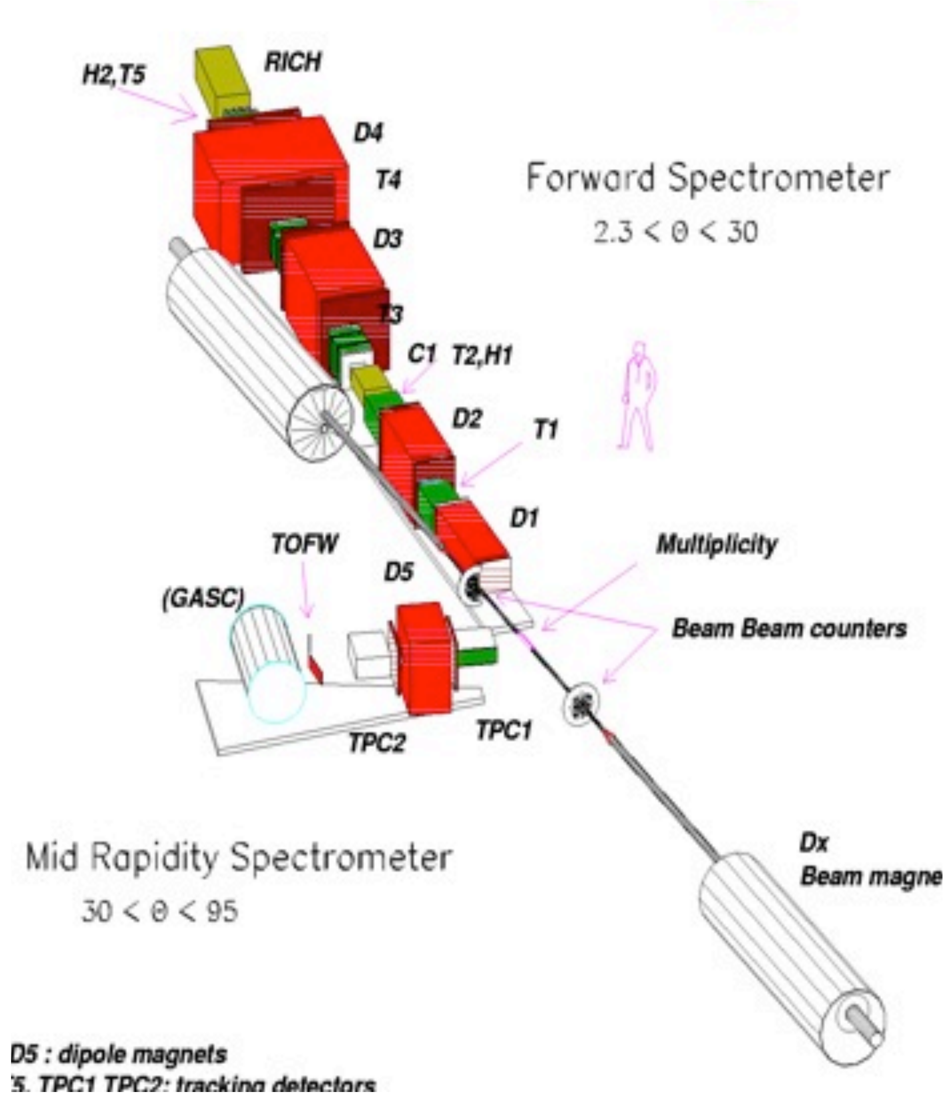


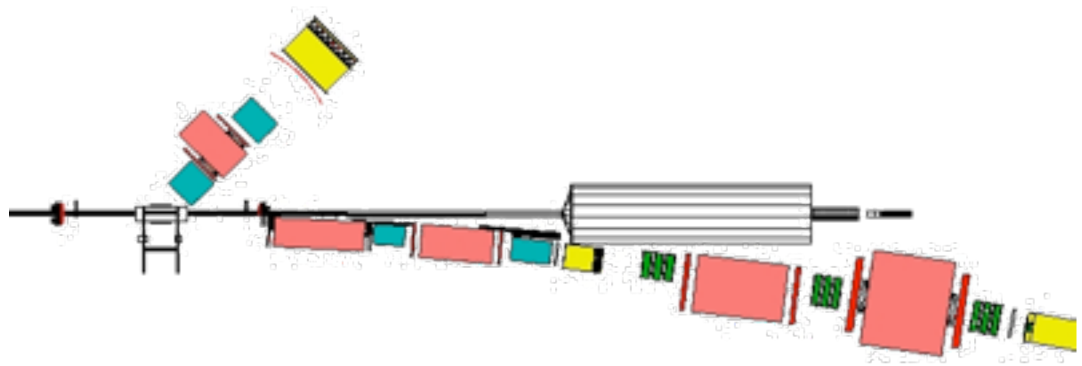
# Brahms

## Central Arm:

$0 < \eta < 1.5$

Tracking, Momentum and PID for:
⭒Charged hadrons



## Forward Arm:

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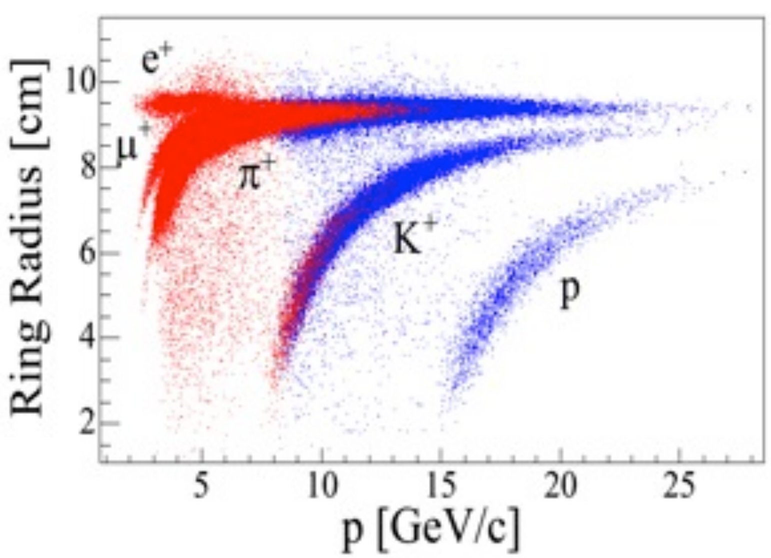
Tracking, Momentum and PID for:
⭒Charged hadrons



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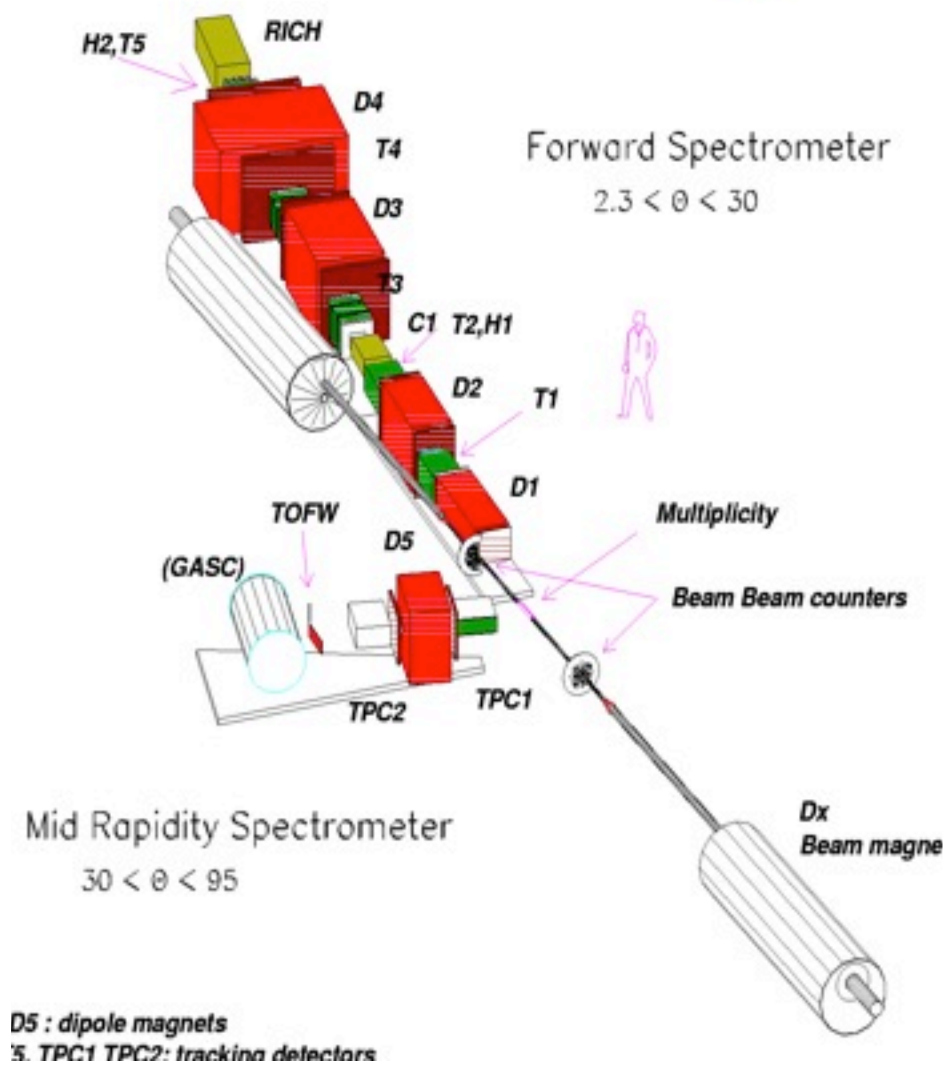


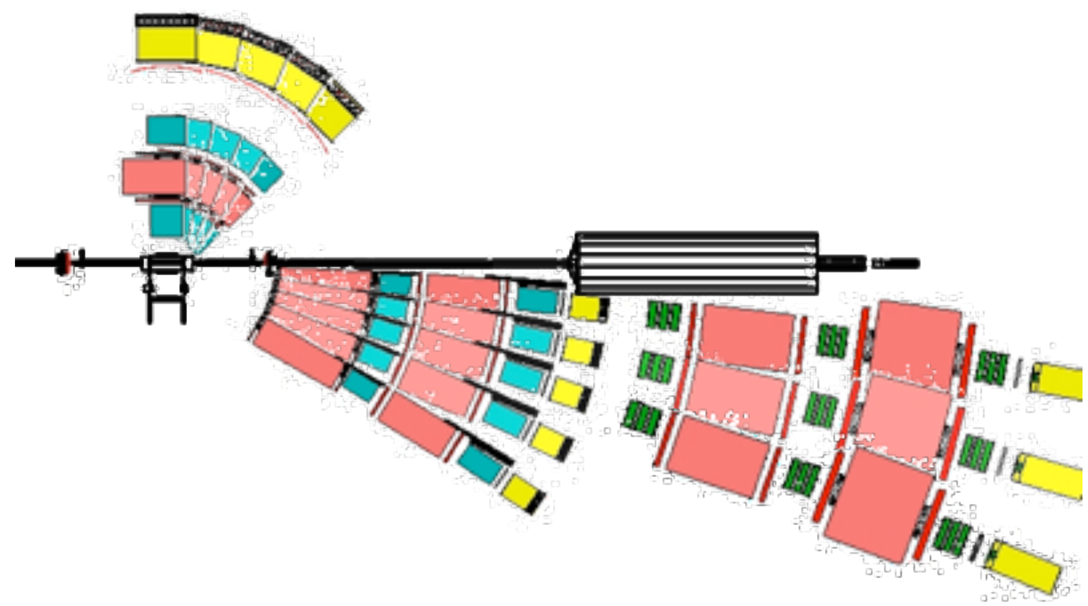

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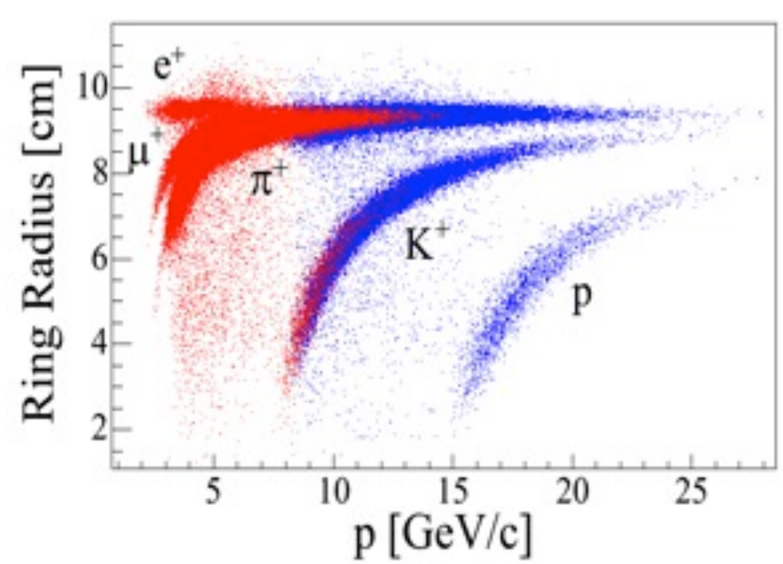
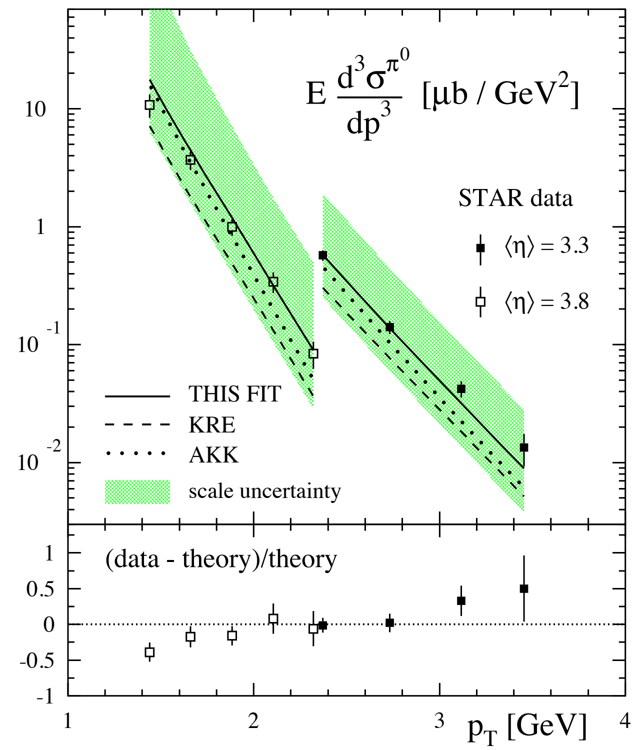


# Global fit results: pions

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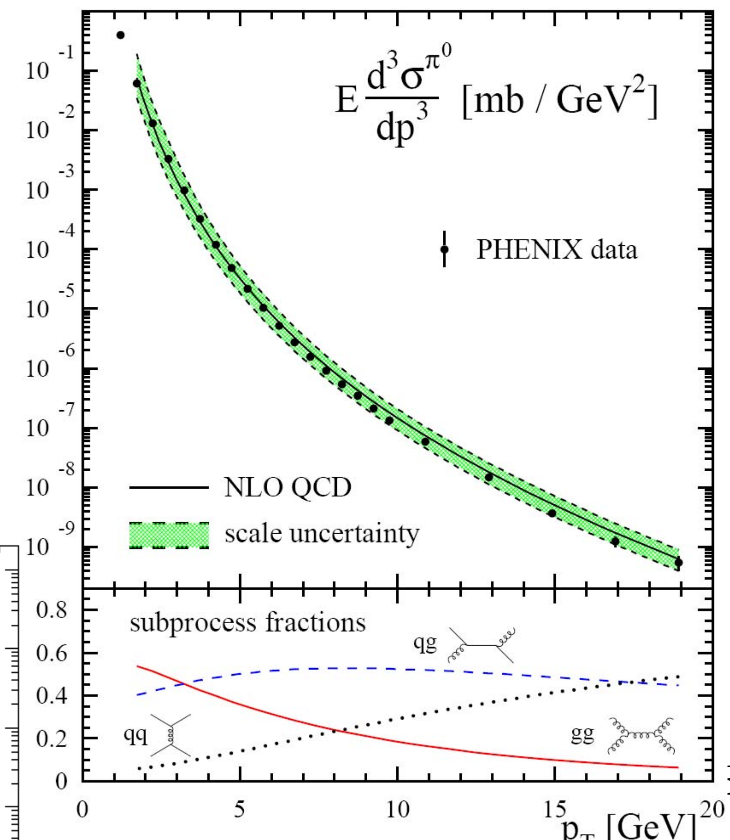
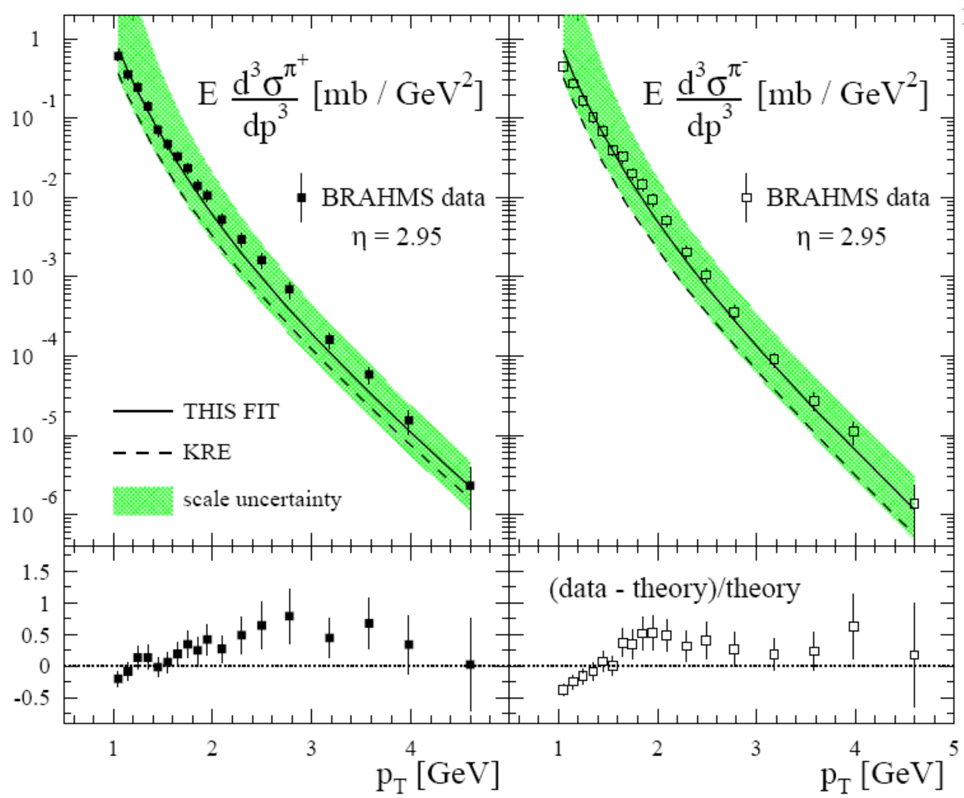
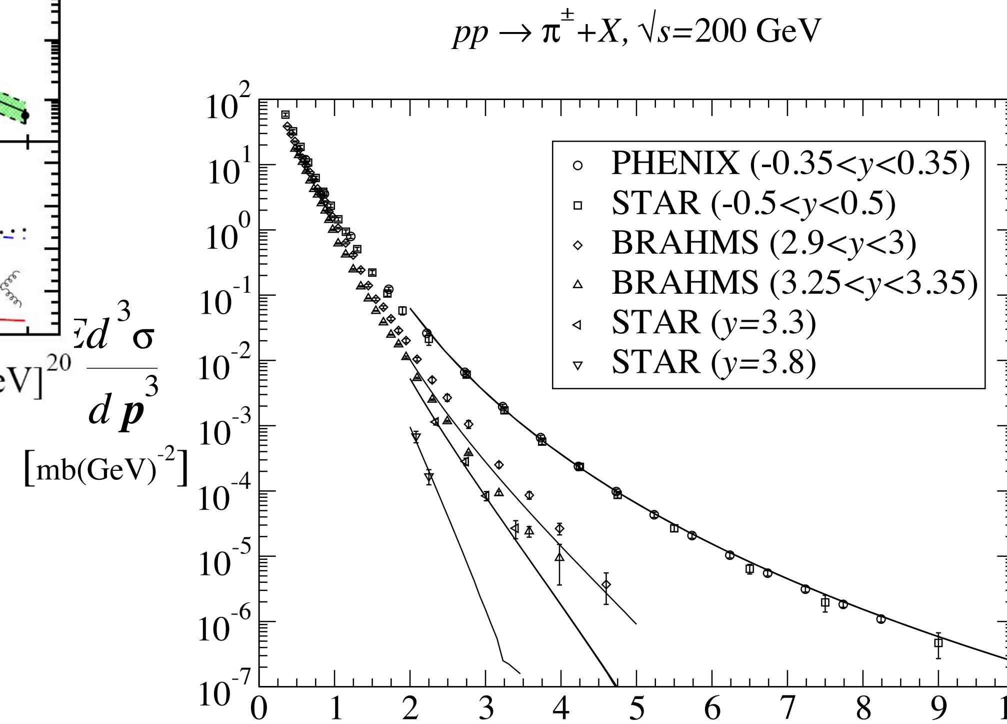


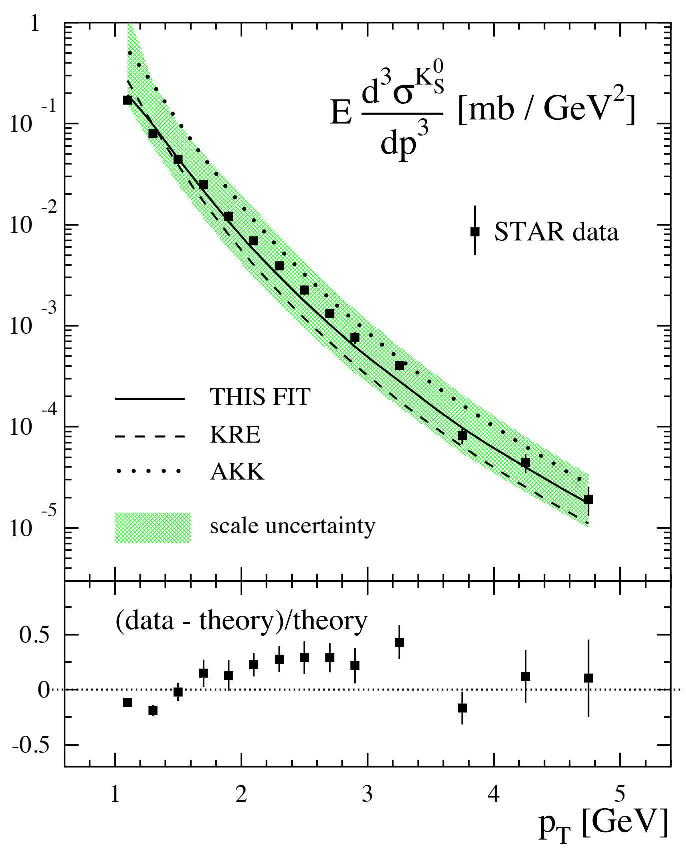



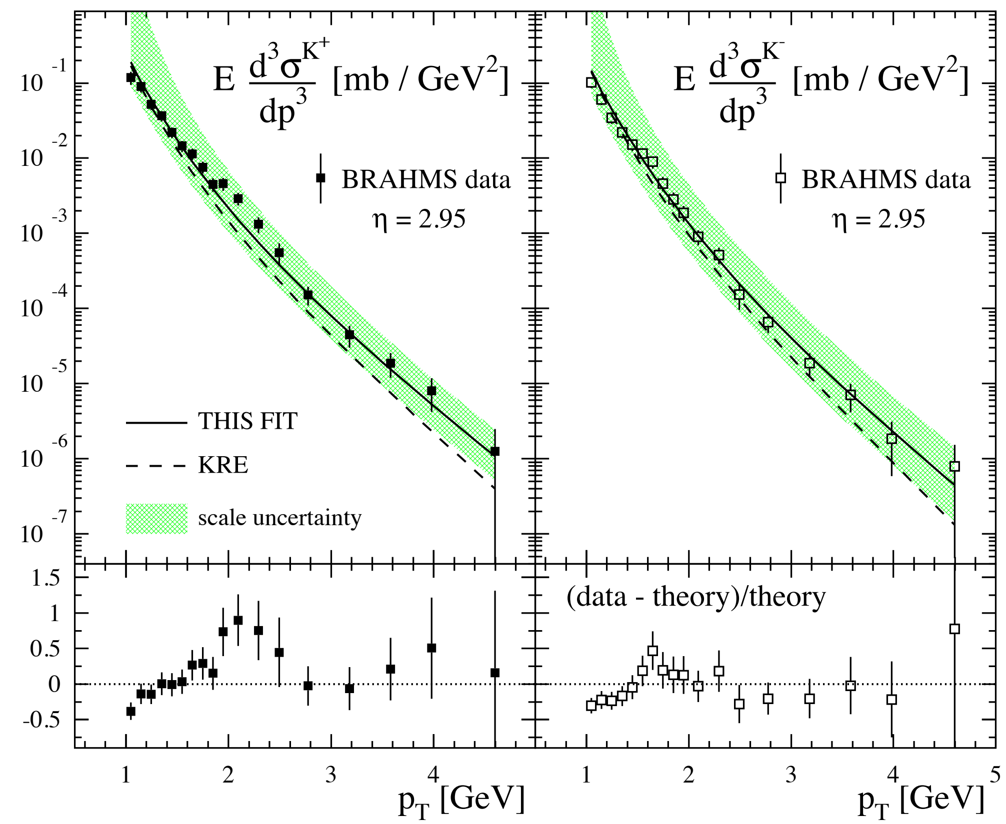

**Albino, Kniehl, Kramer**
**Nucl. Phys. B 803, 42 (2008)**



# Global fit results: kaons

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

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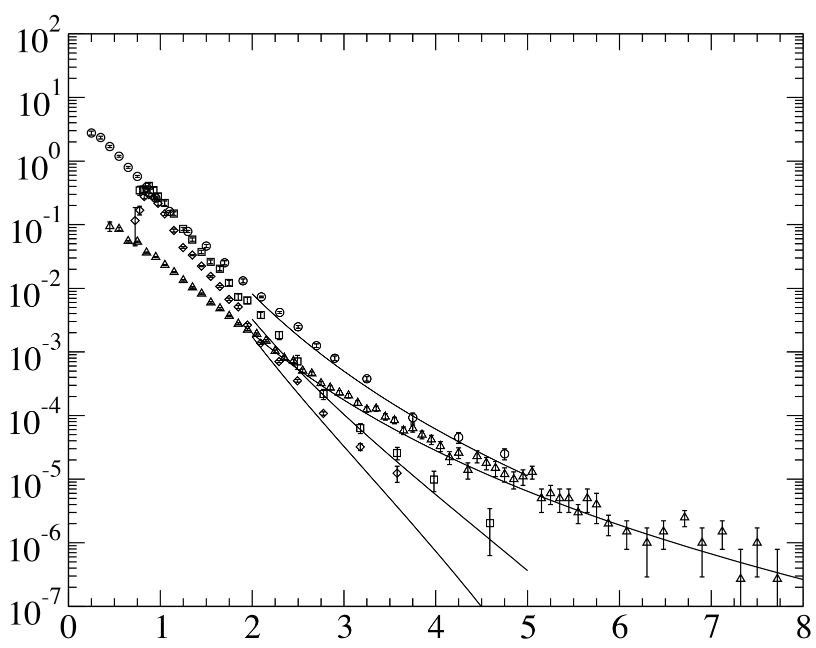
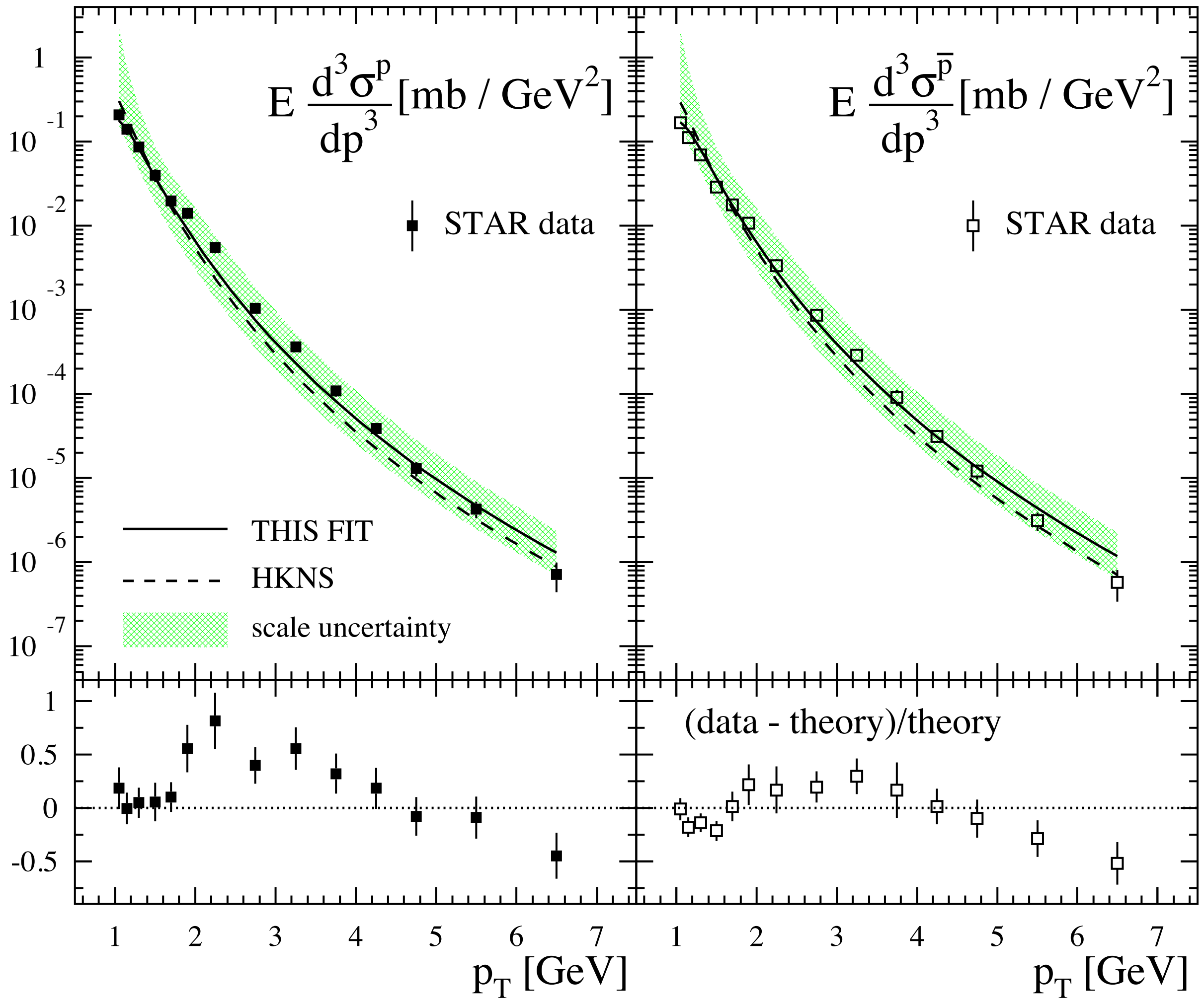


# Global fit results: proton

**de Florian, Sassot, Stratmann**
**Phys. Rev D 76, 074033 (2007)**

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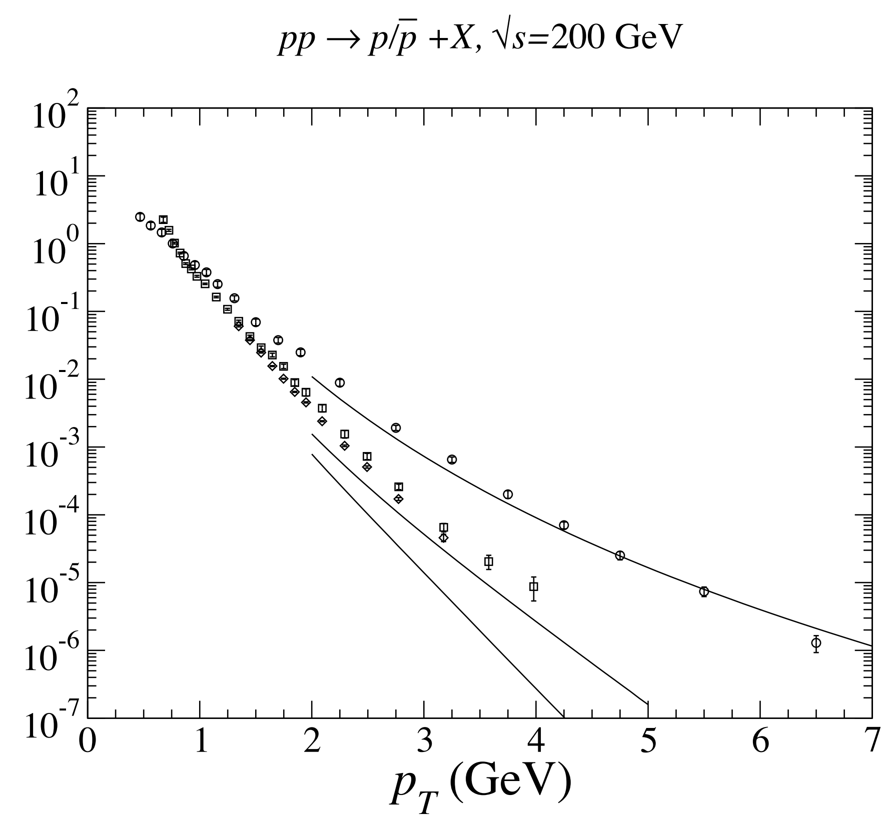
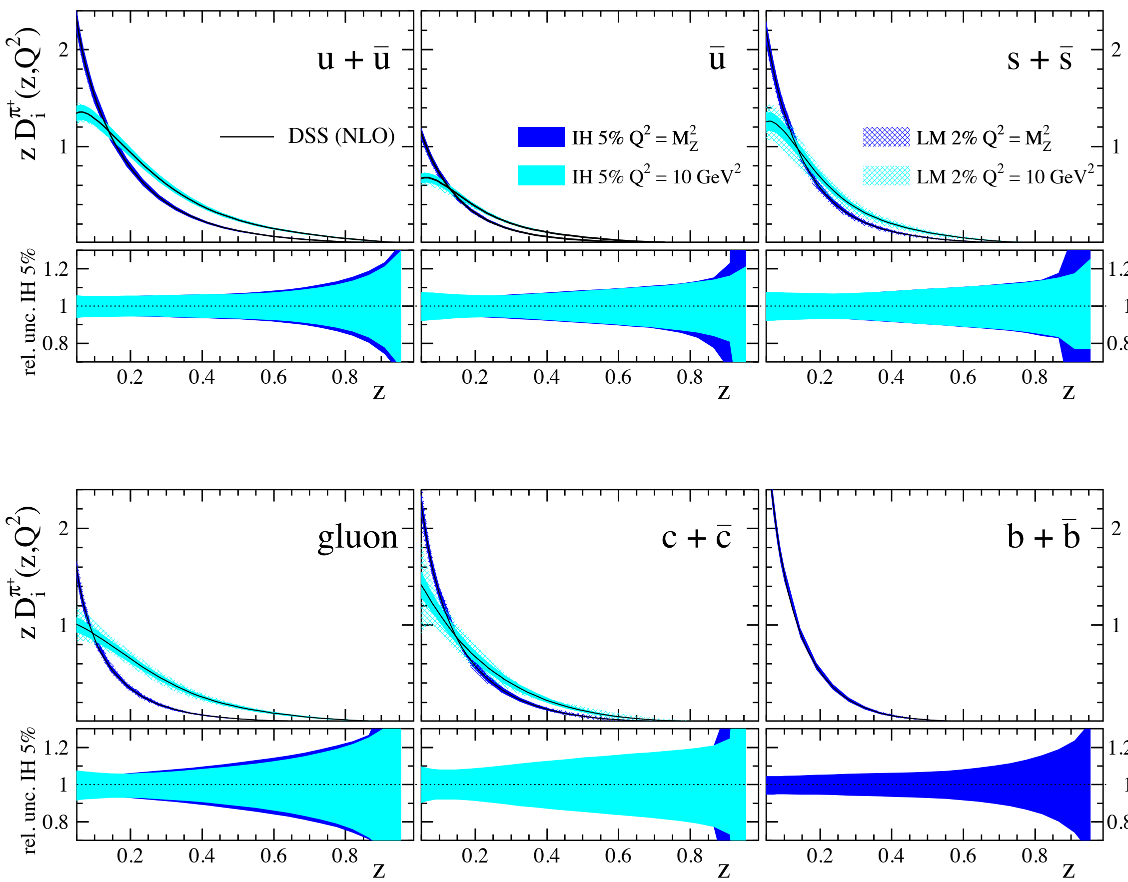
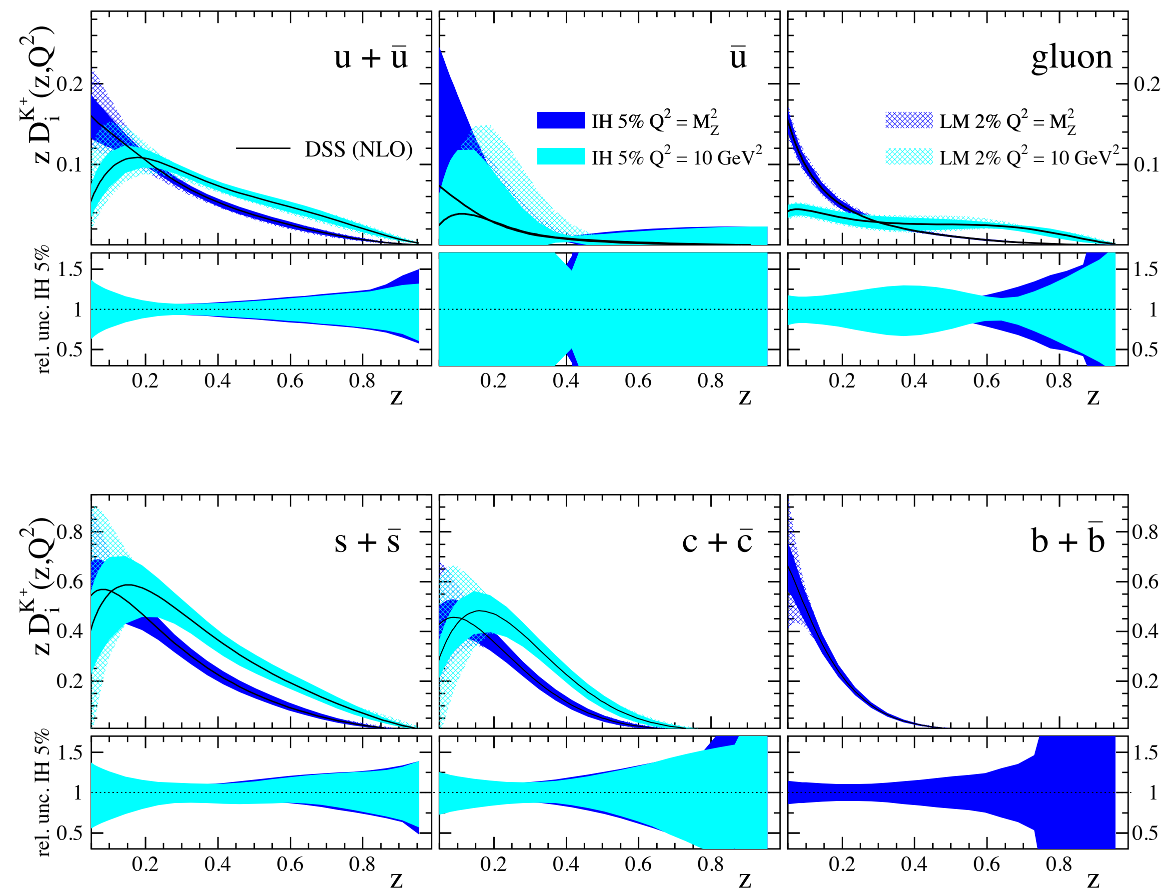


# Global fit results

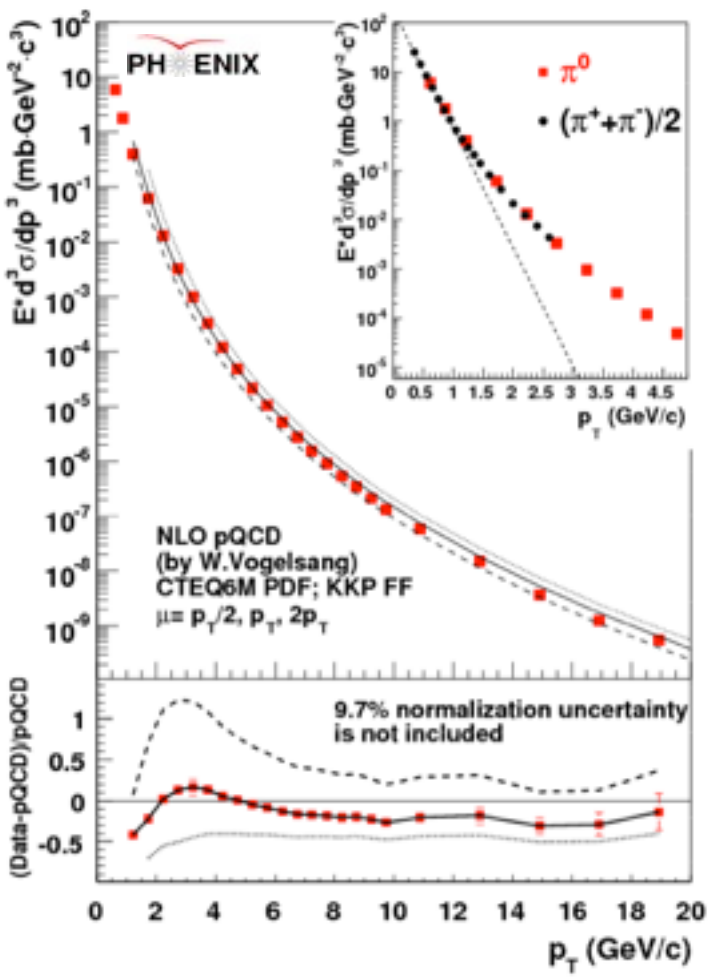
**Epele, Llubaroff, Sassot, Stratmann**
**arXiv:1209.3240 [hep-ph]**



# Phenix data

PRL 98, 012002



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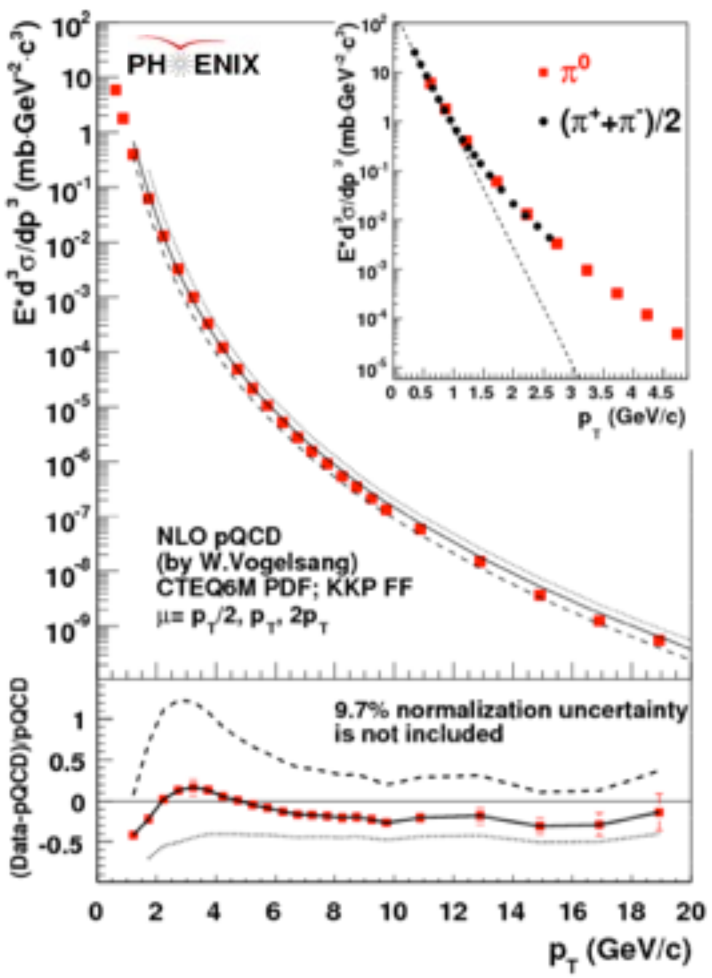
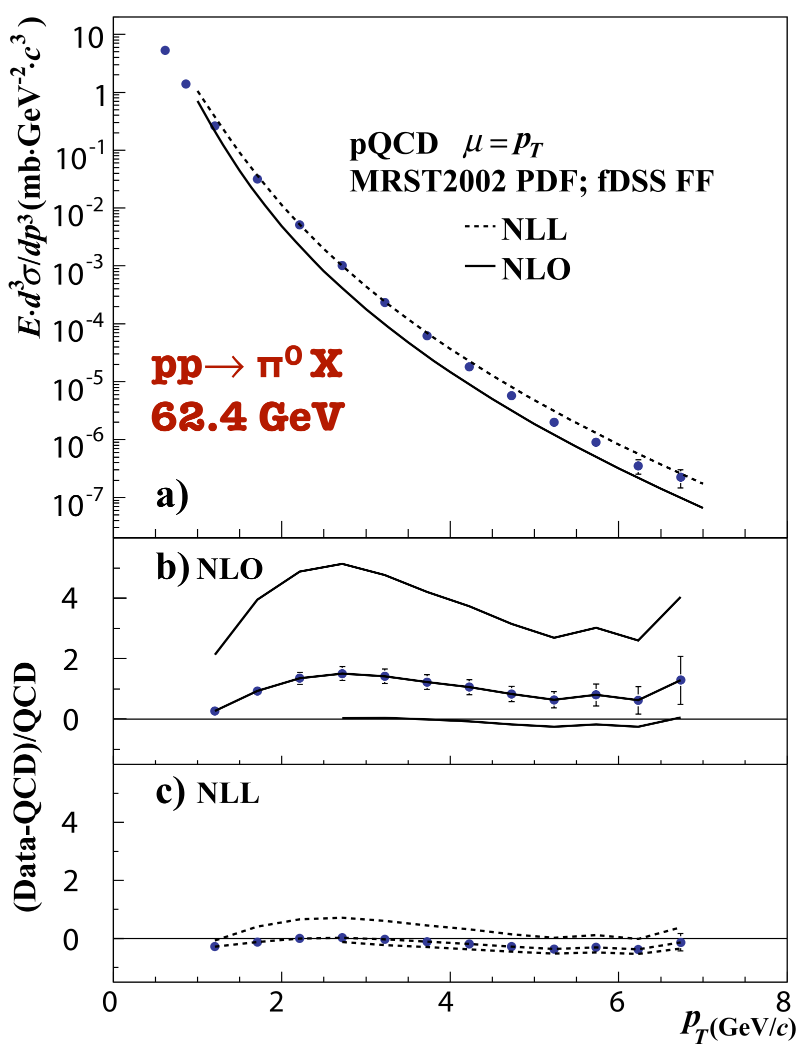



PRD79:012003




pp→ $\pi^0$ X
62.4 GeV

PRL 98, 012002

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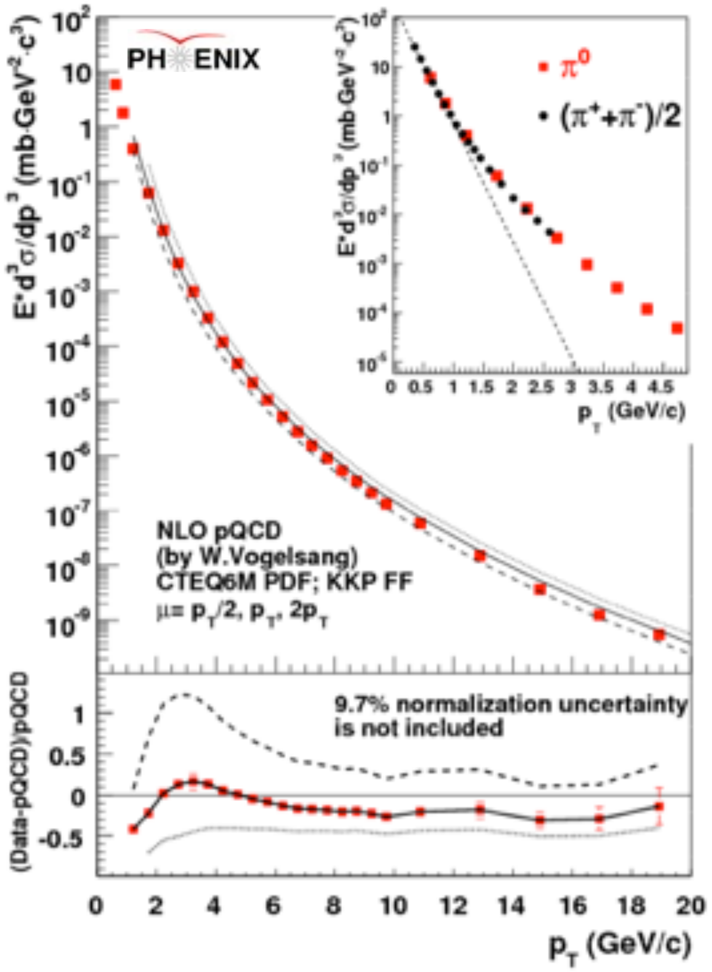


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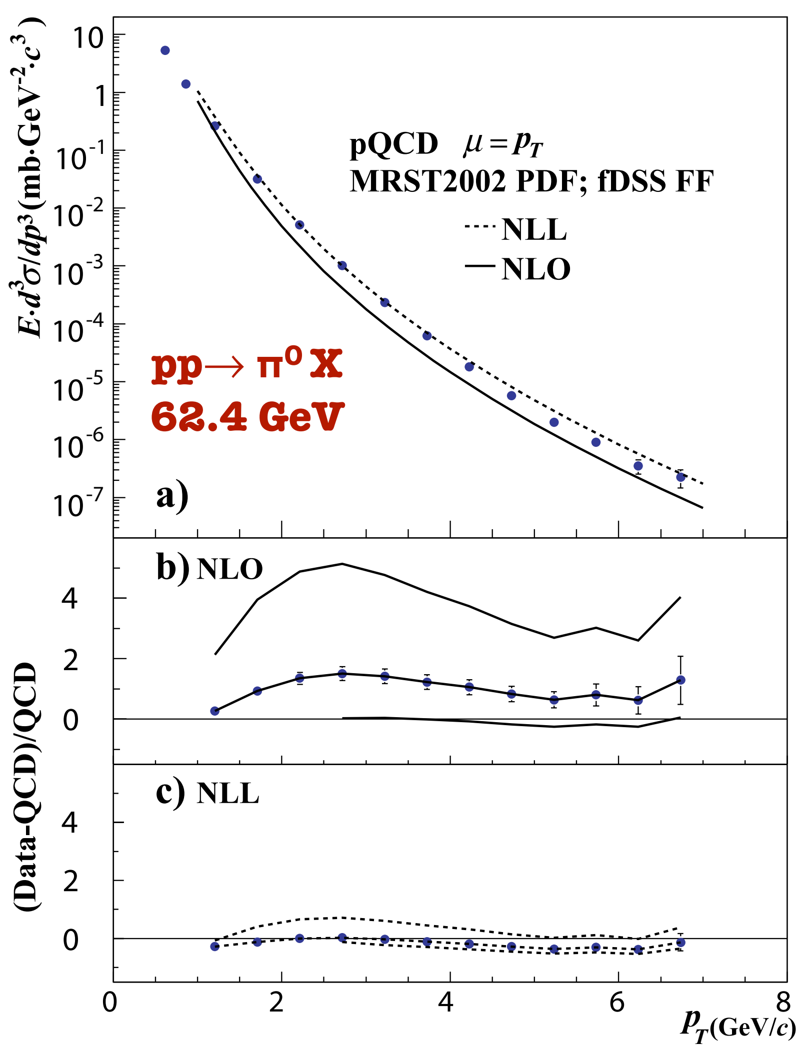


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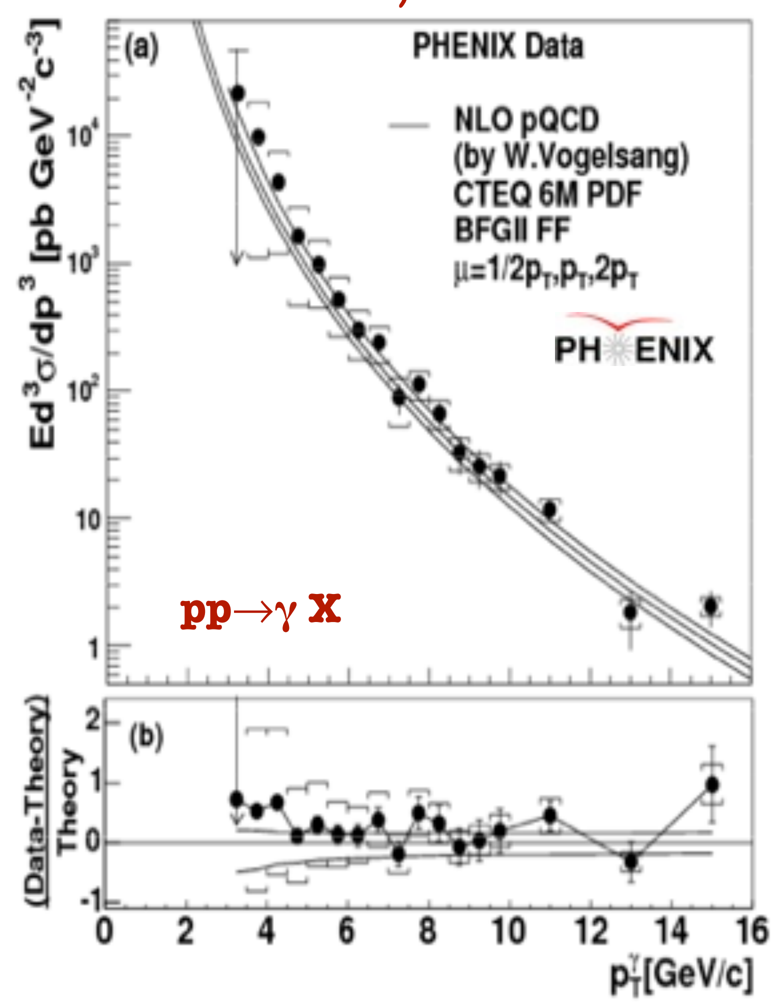
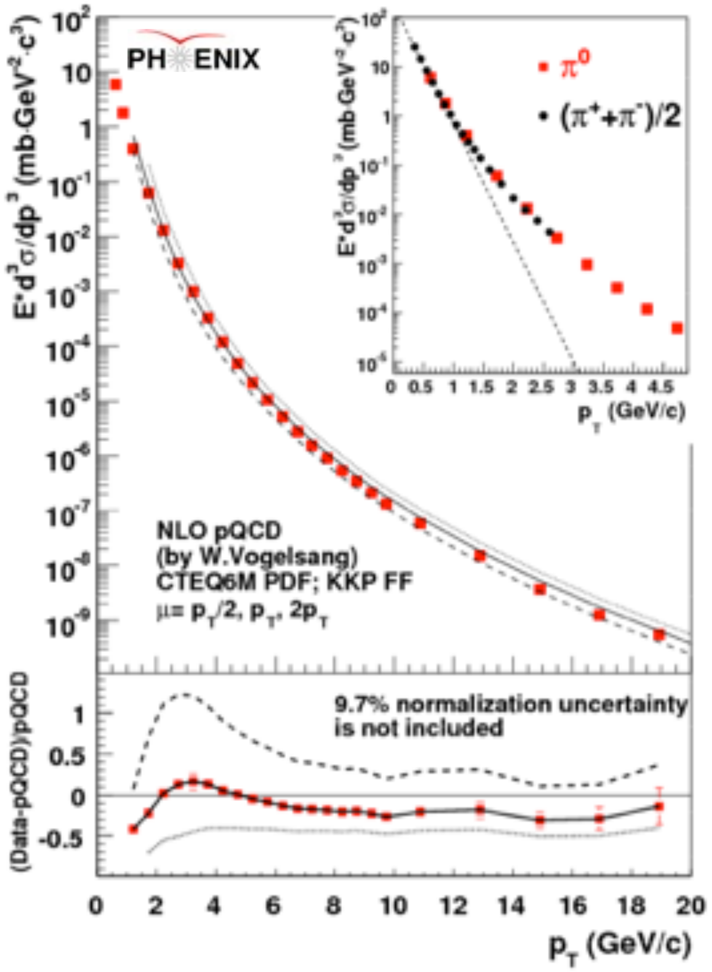
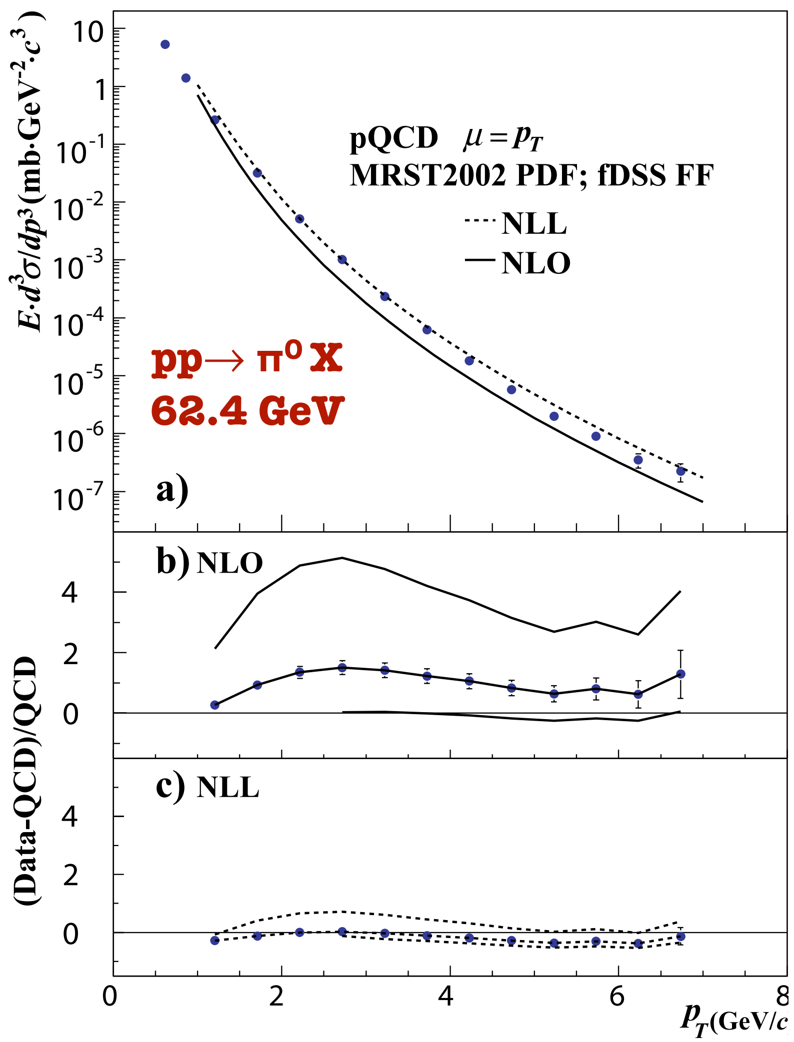


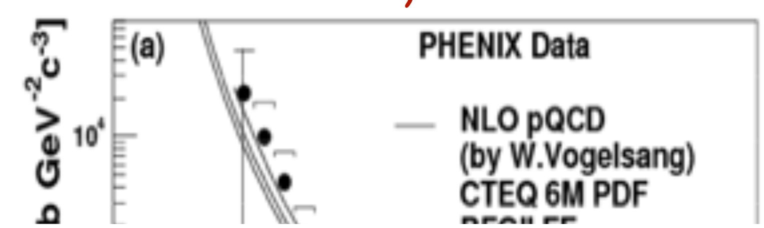
# Phenix data



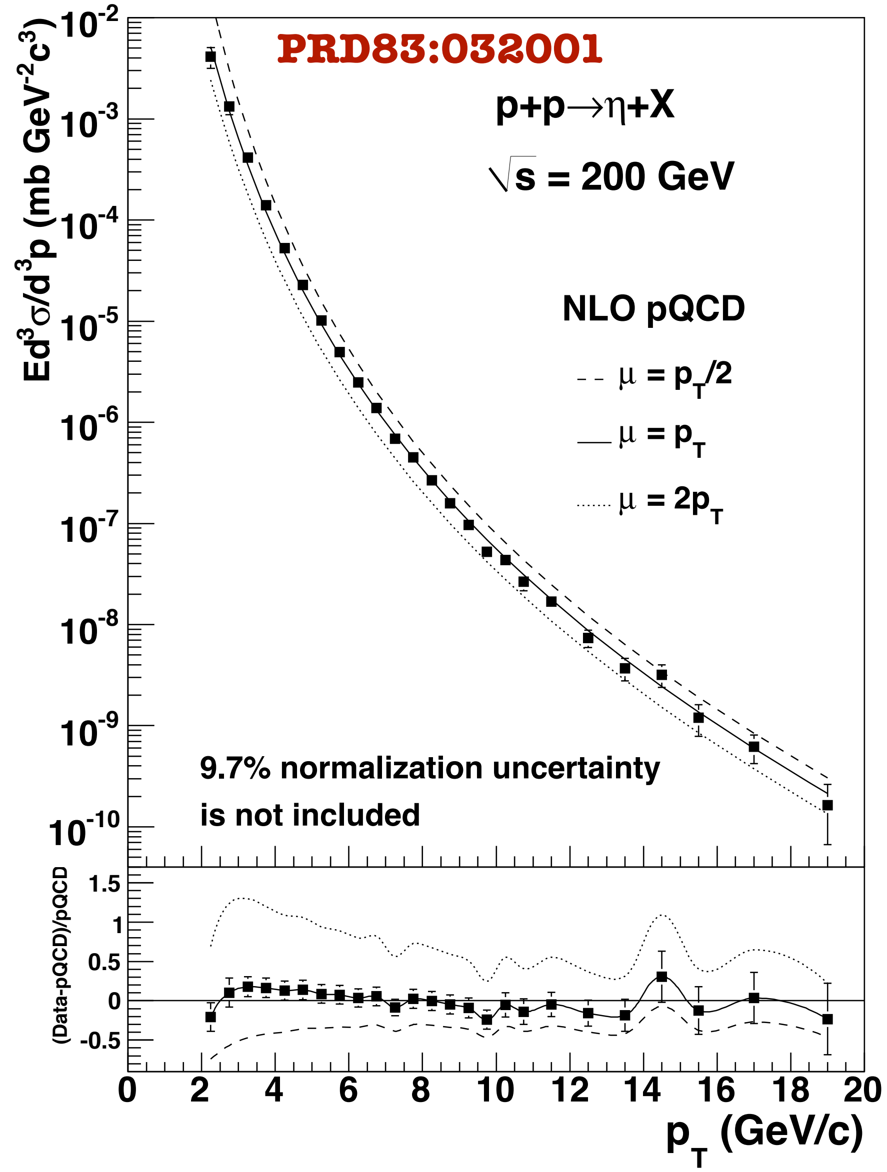

PRD79:012003




PRL 98, 012002




PRD83:032001



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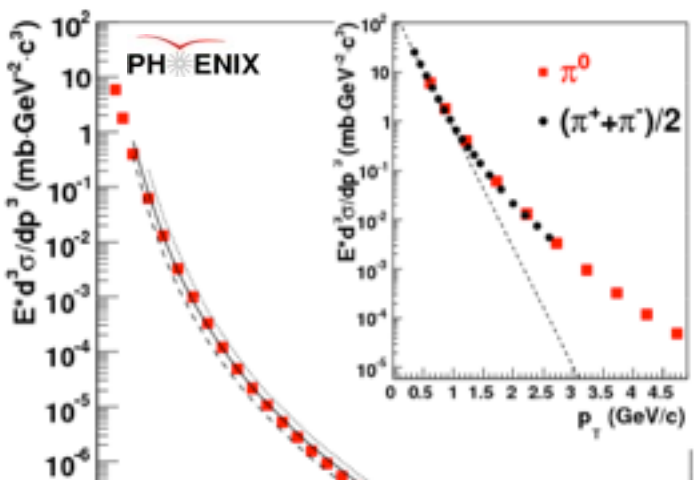
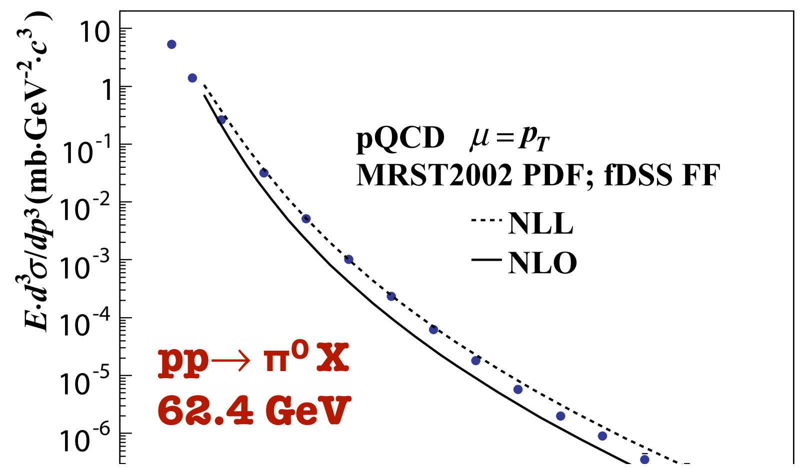
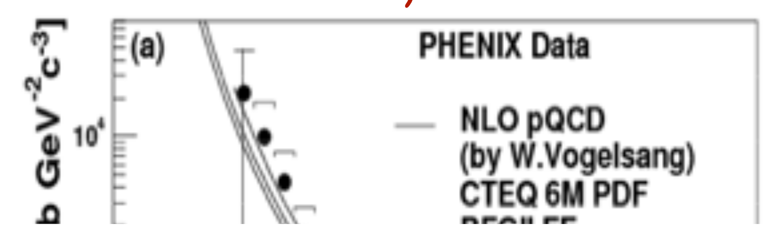
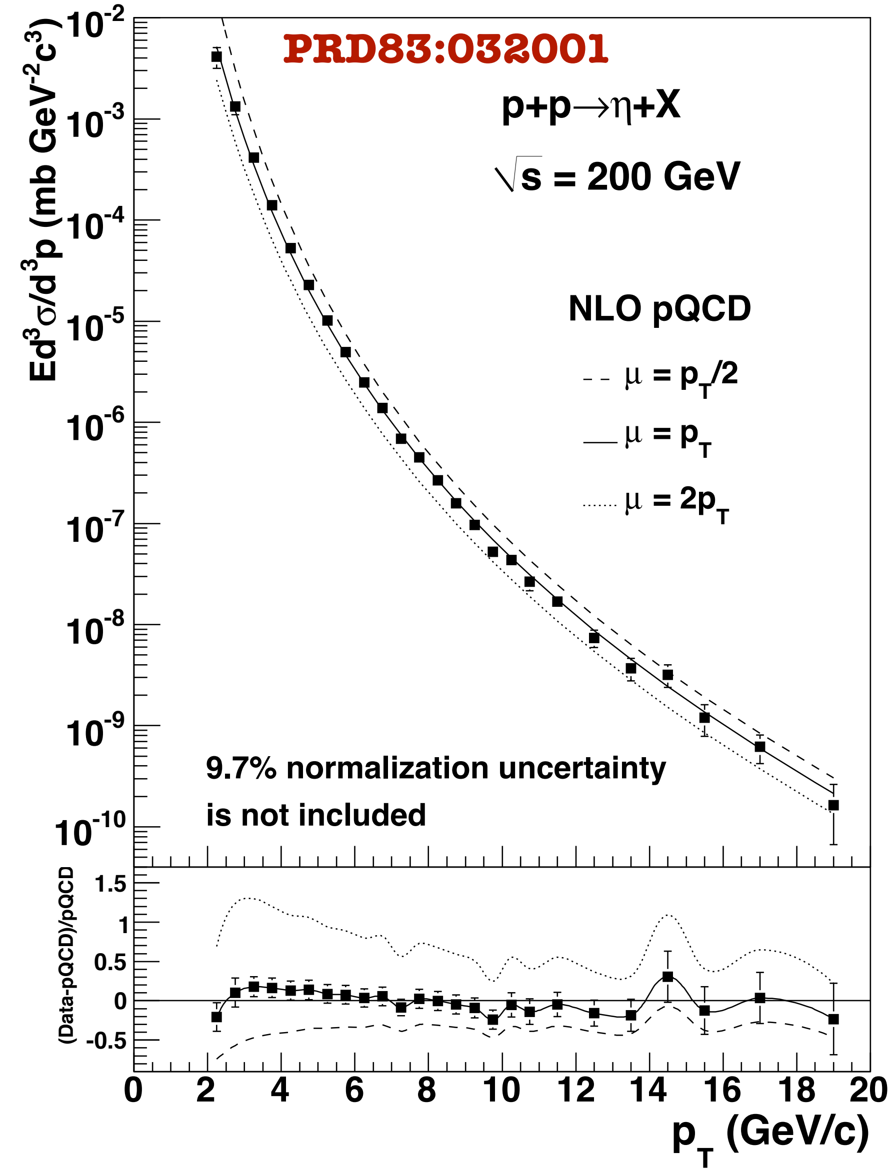


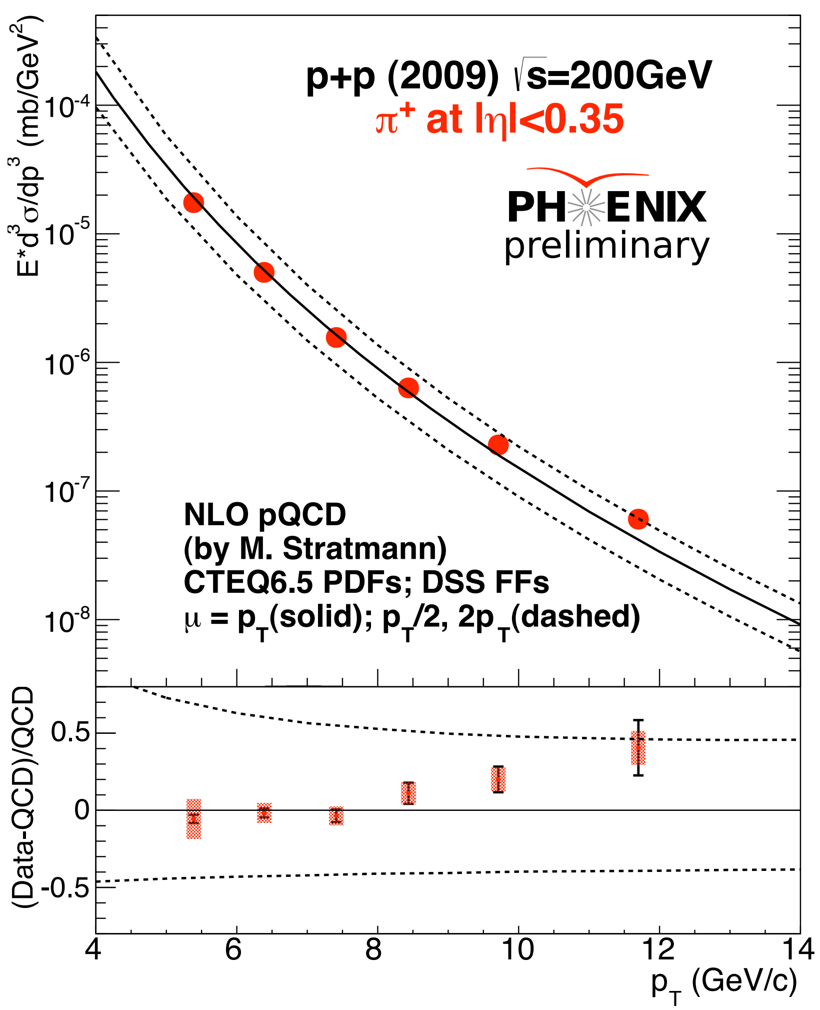

PRD79:012003

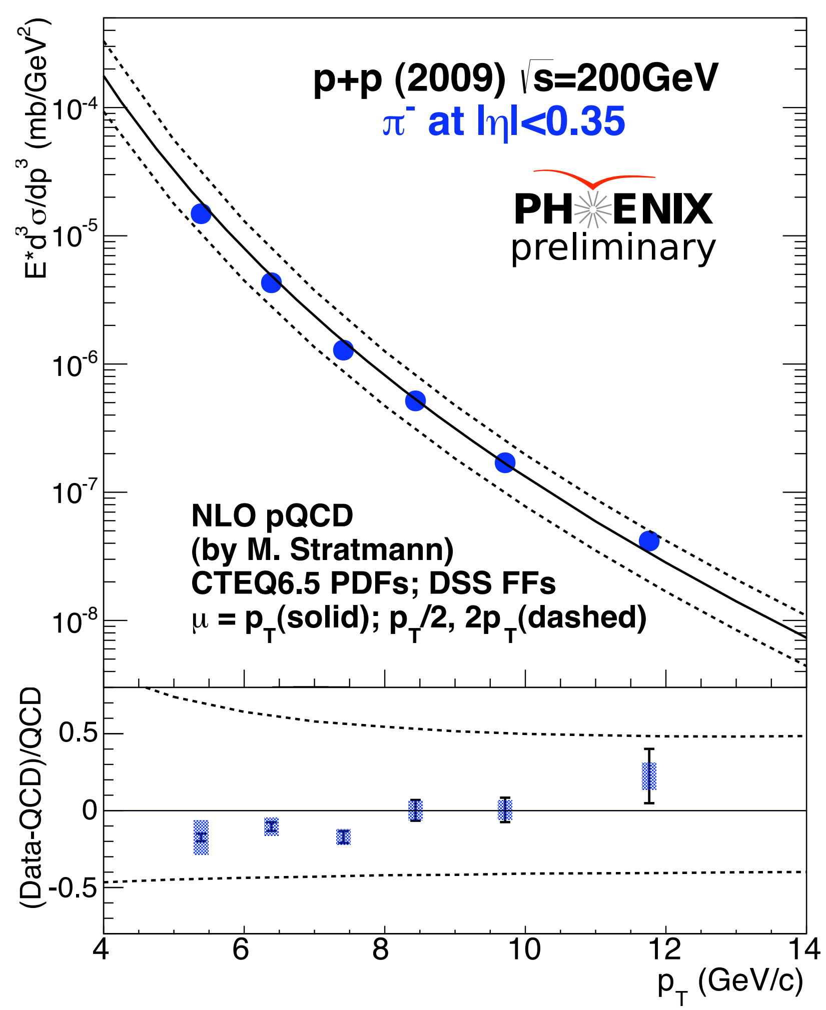



PRL 98, 012002

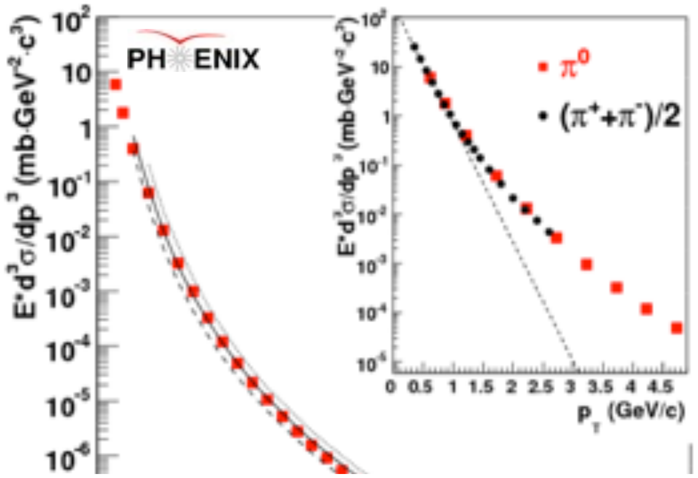


# Phenix data

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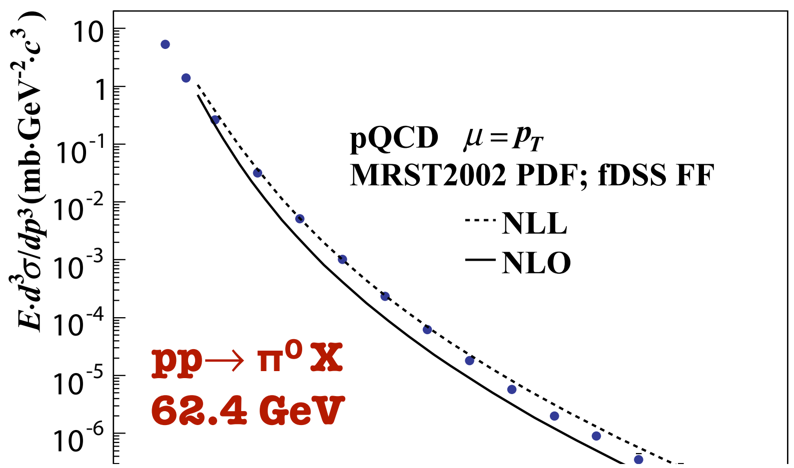
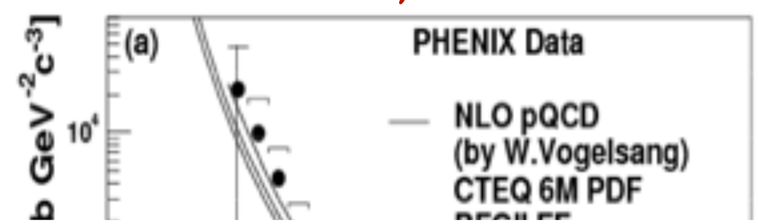
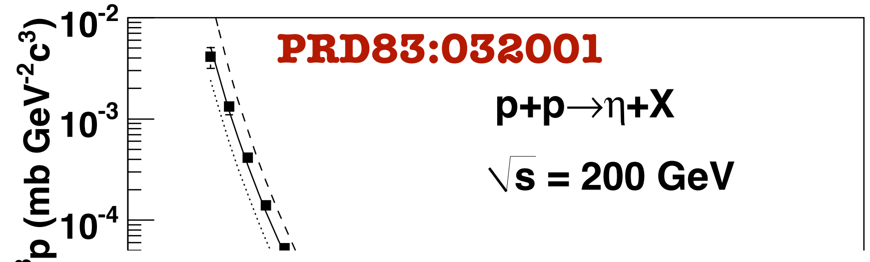
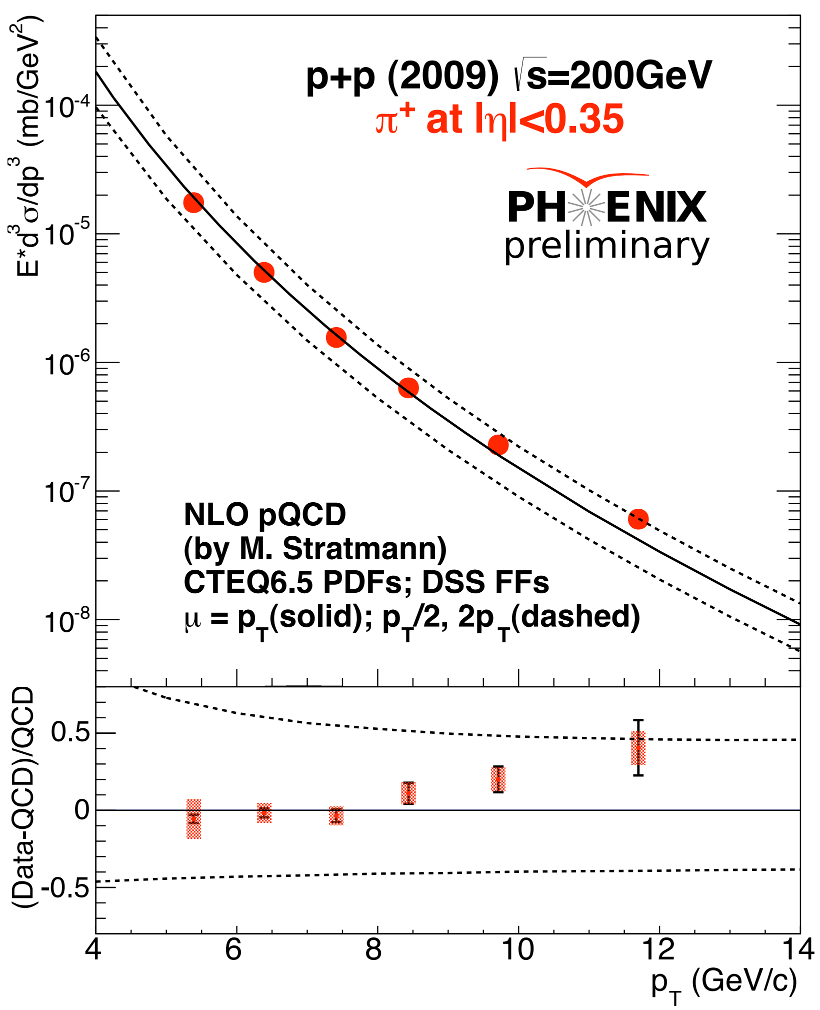
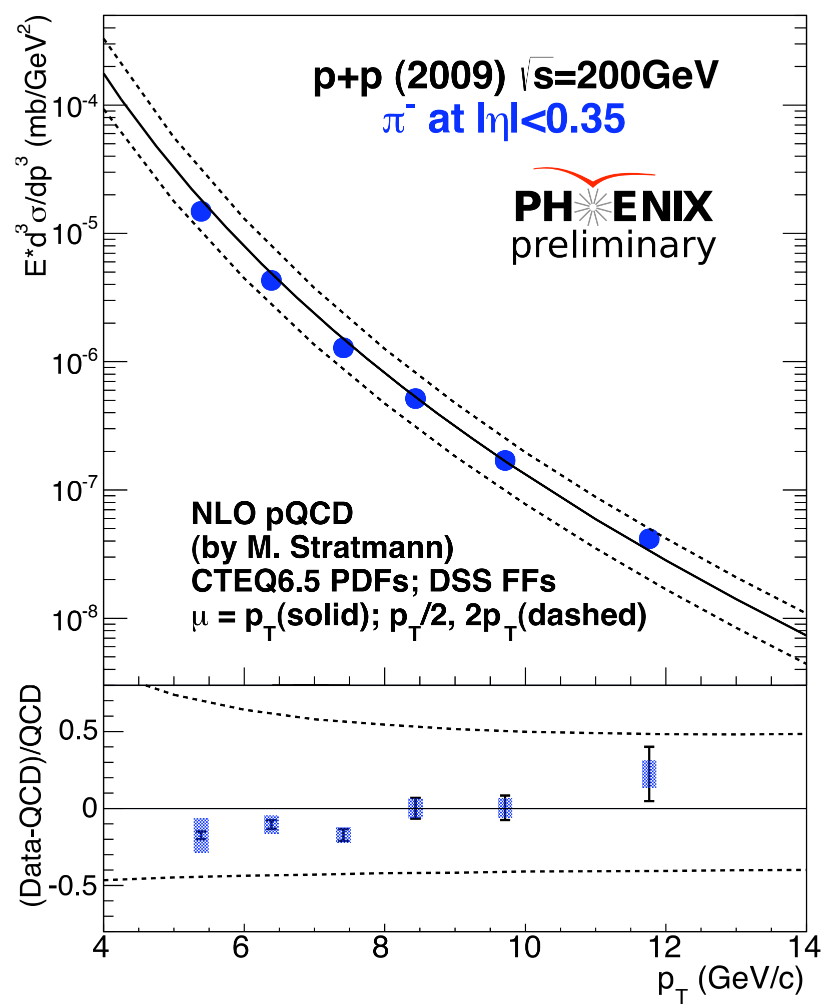


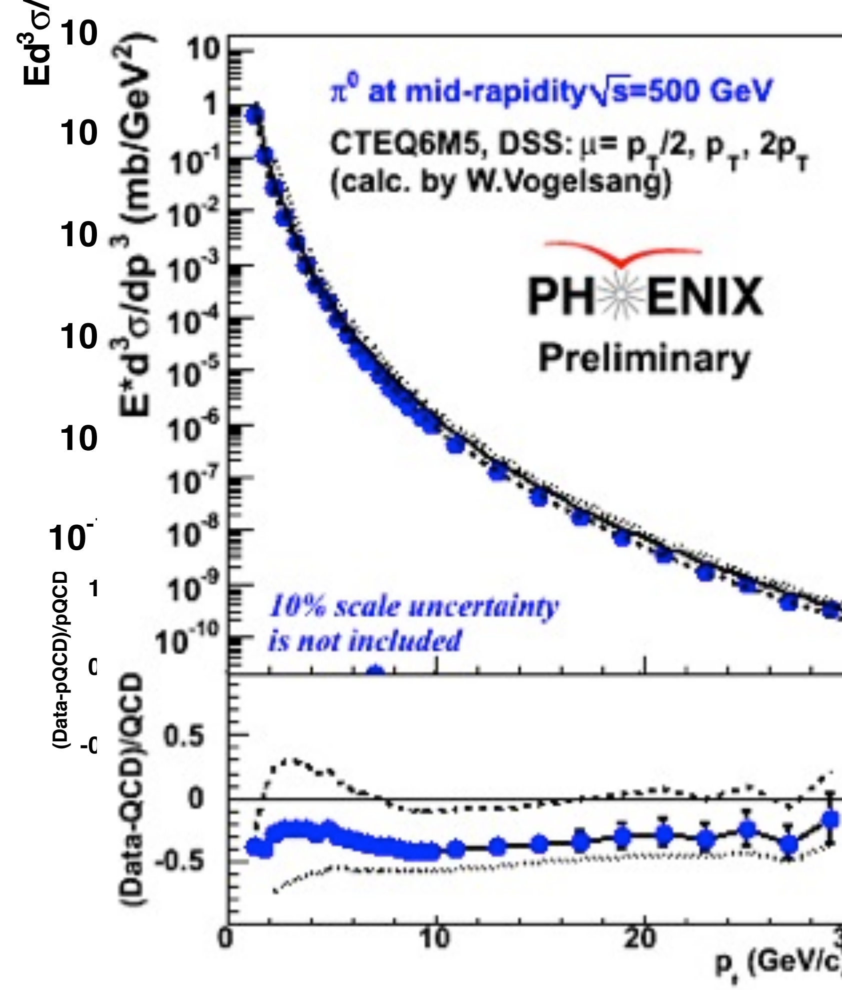

PRL 98, 012002



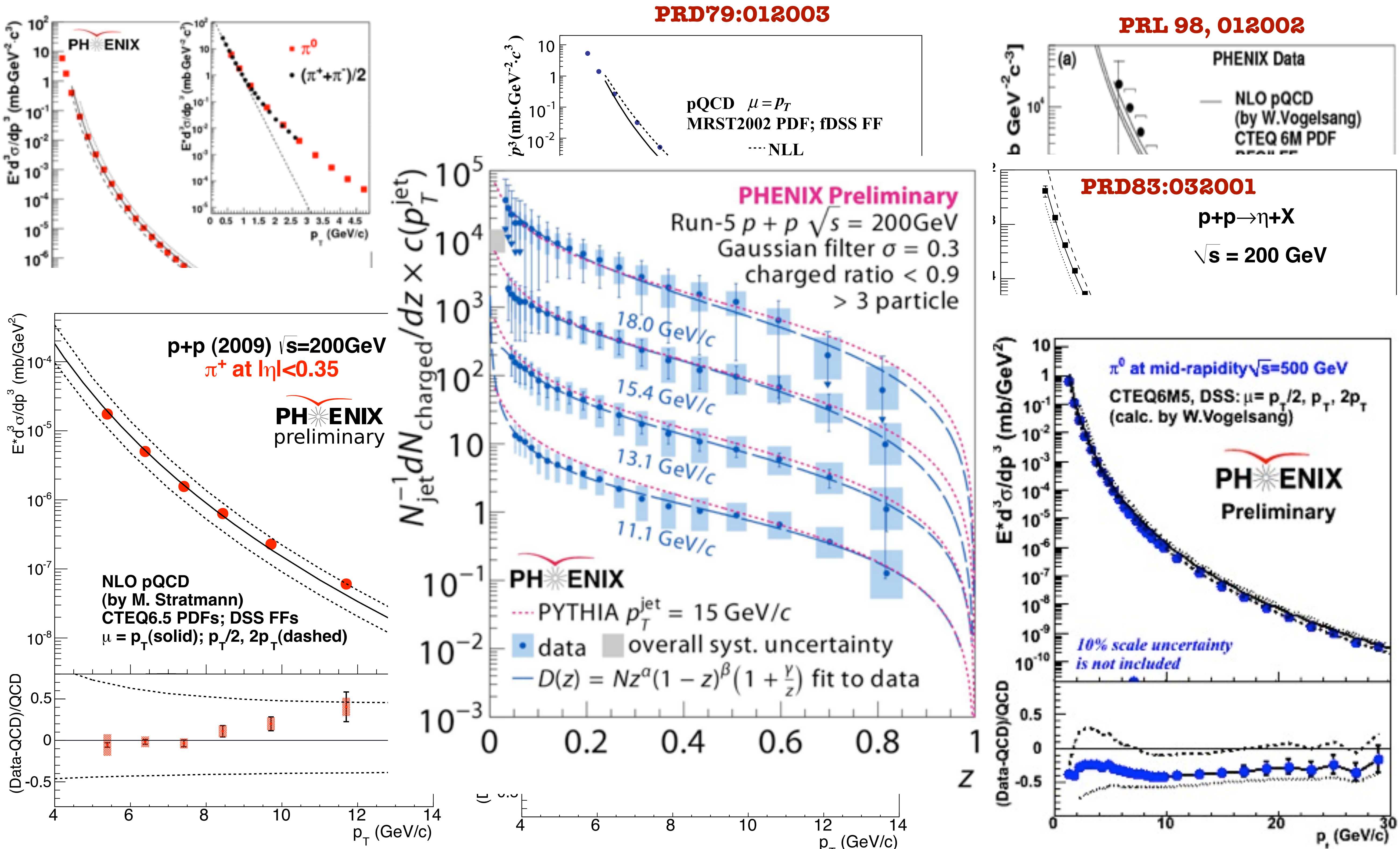



# Phenix data

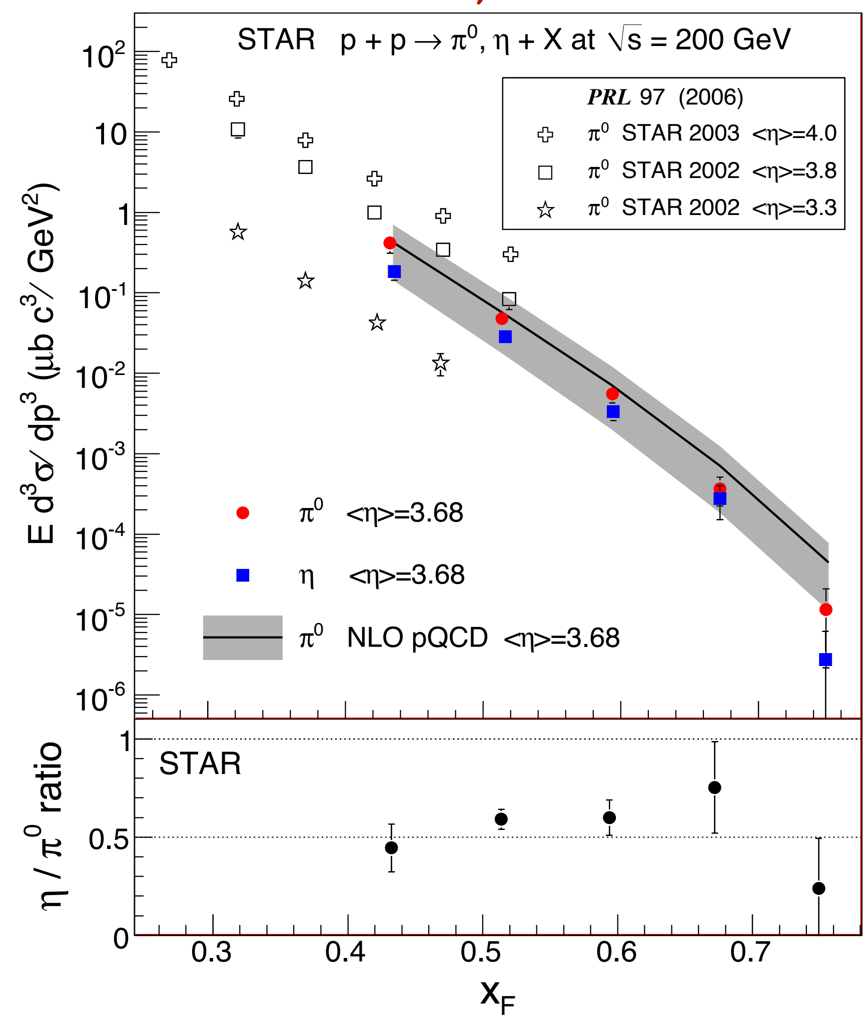


PRD79:012003
PRL 98, 012002
PRD83:032001
PH ENIX
$\pi^0$
$(\pi^+ + \pi^-)/2$
pQCD $\mu = p_T$
MRST2002 PDF; fDSS FF
NLL
(a)
PHENIX Data
NLO pQCD
(by W.Vogelsang)
CTEQ 6M PDF
p+p→η+X
$\sqrt{s}$ = 200 GeV
p+p (2009) $\sqrt{s}$=200GeV
$\pi^+$ at |η|<0.35
PH ENIX
preliminary
NLO pQCD
(by M. Stratmann)
CTEQ6.5 PDFs; DSS FFs
$\mu = p_T$(solid); $p_T/2$, $2p_T$(dashed)
(Data-QCD)/QCD
$p_T$ (GeV/c)
PHENIX Preliminary
Run-5 $p+p$ $\sqrt{s}$ = 200GeV
Gaussian filter $\sigma$ = 0.3
charged ratio < 0.9
> 3 particle
18.0 GeV/c
15.4 GeV/c
13.1 GeV/c
11.1 GeV/c
$N_{jet}^{-1} dN_{charged}/dz \times c(p_T^{jet})$
PH ENIX
PYTHIA $p_T^{jet}$ = 15 GeV/c
data
overall syst. uncertainty
$D(z) = Nz^{a}(1-z)^{\beta}(1+\frac{\gamma}{z})$ fit to data
z
$\pi^0$ at mid-rapidity $\sqrt{s}$=500 GeV
CTEQ6M5, DSS: $\mu = p_T/2$, $p_T$, $2p_T$
(calc. by W.Vogelsang)
PH ENIX
Preliminary
10% scale uncertainty
is not included
$E^* d^3\sigma/dp^3$ (mb/GeV$^2$)
$p_t$ (GeV/c)

# Star data

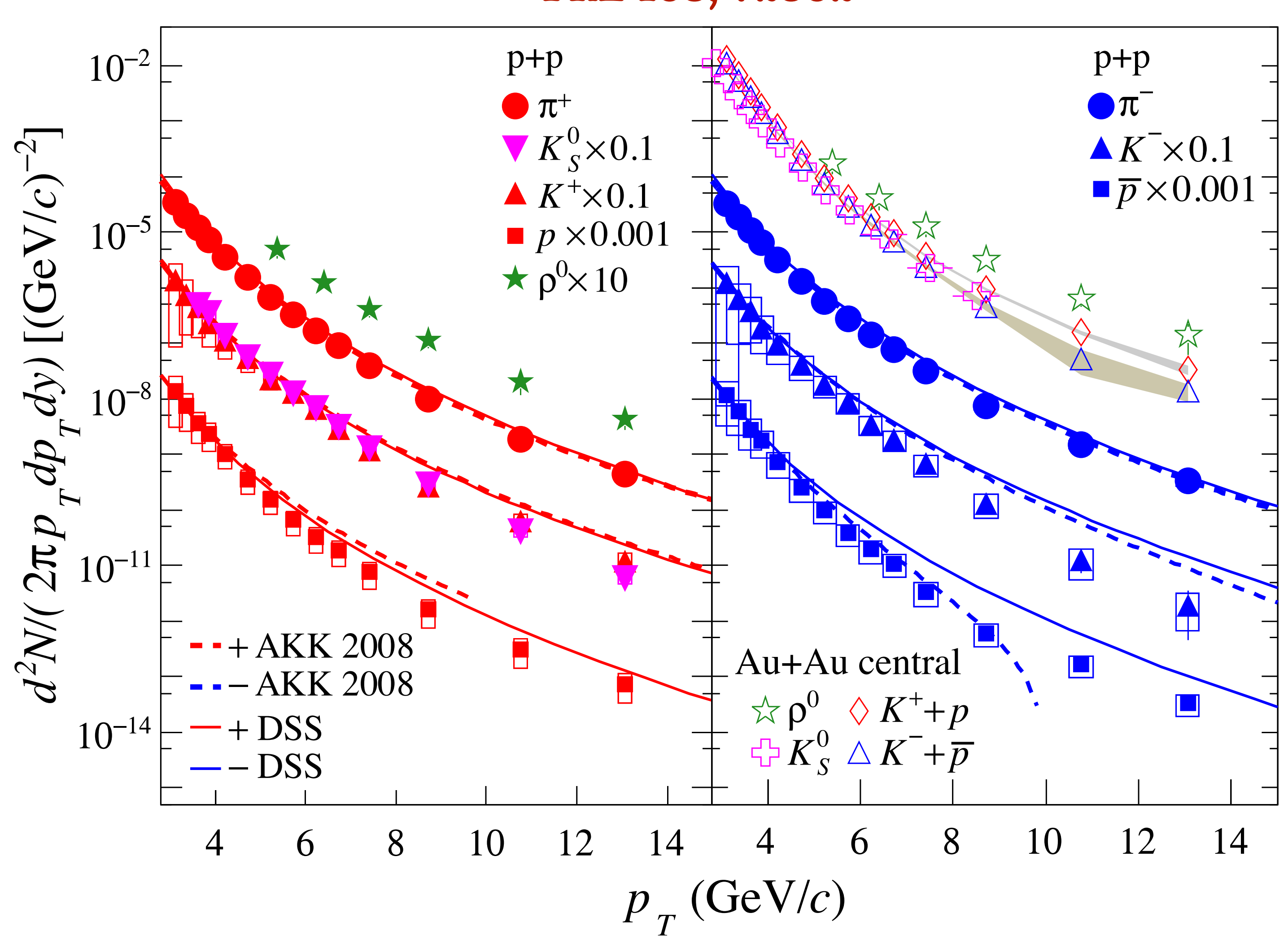
# Star data

PRD 86, 051101

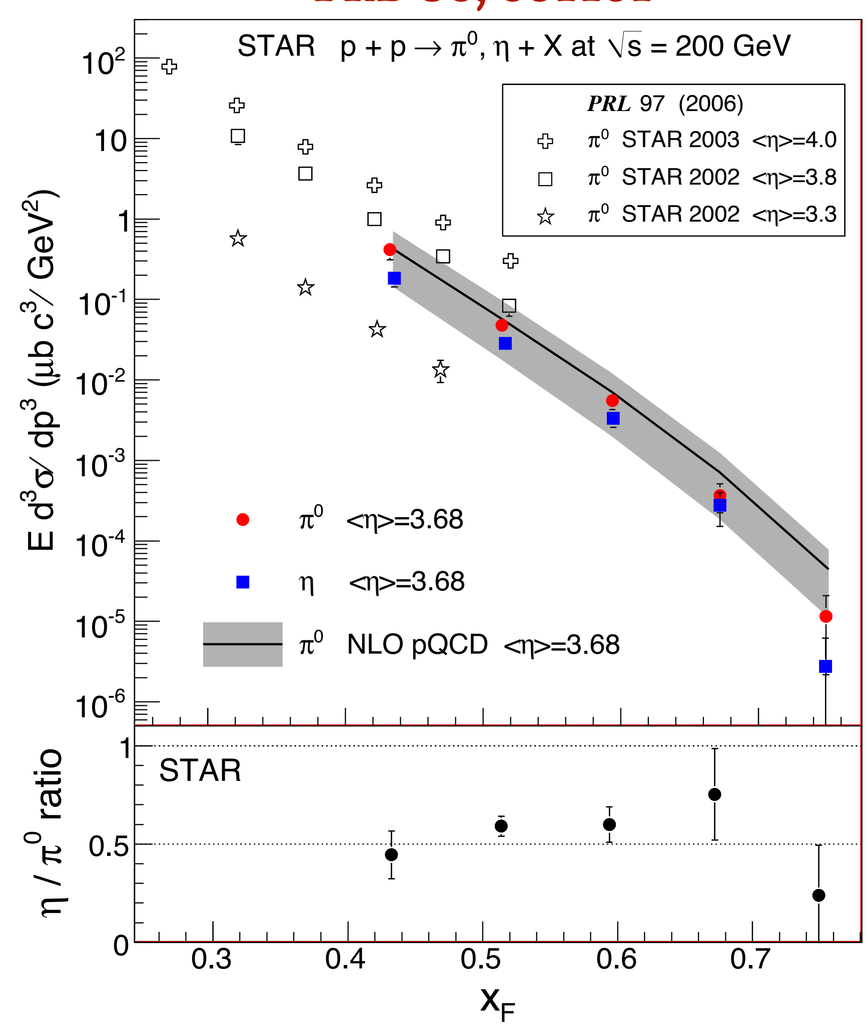


# Star data

PRL 108, 72302



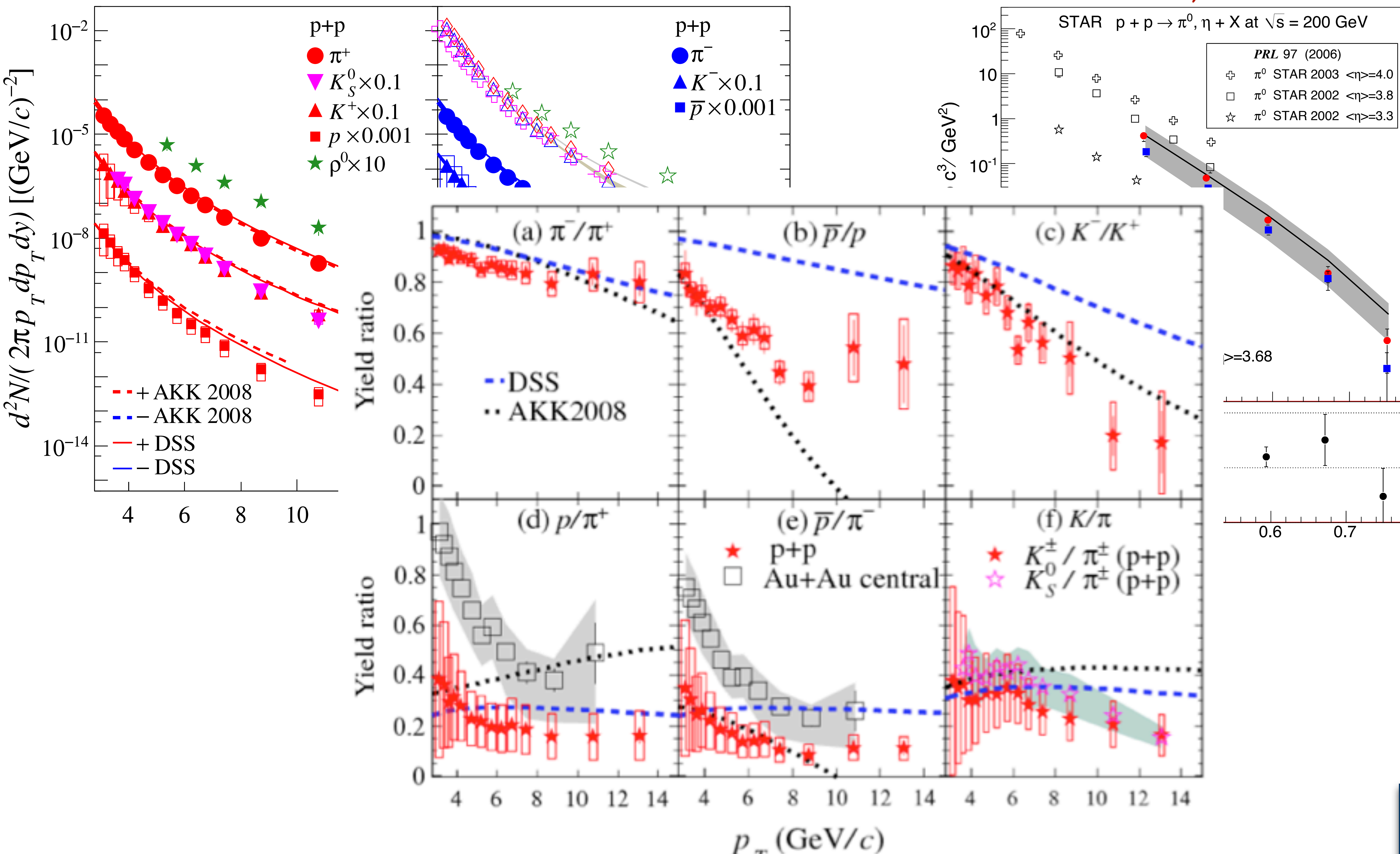

PRD 86, 051101



# Star data

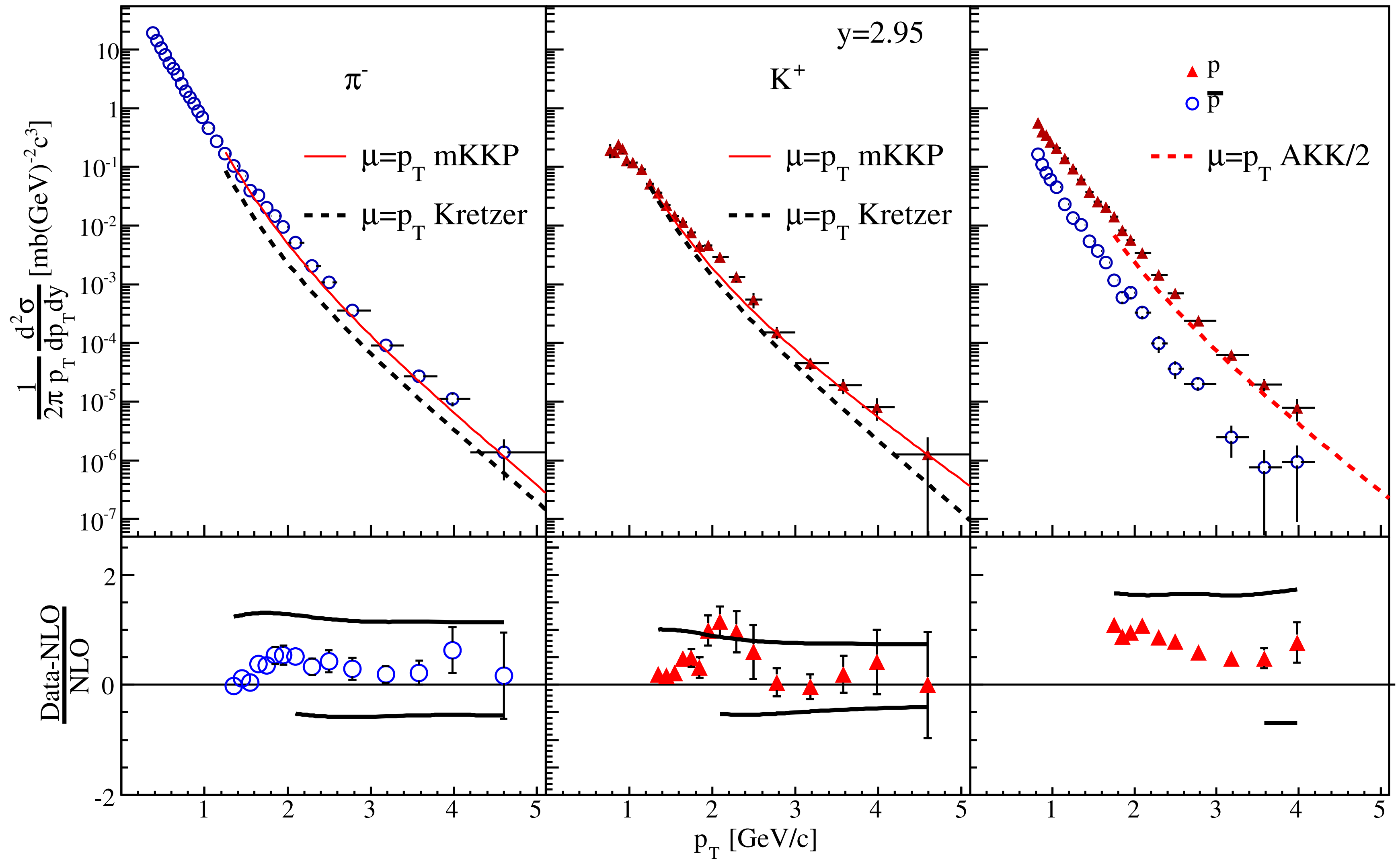
PRL 108, 72302

PRD 86, 051101

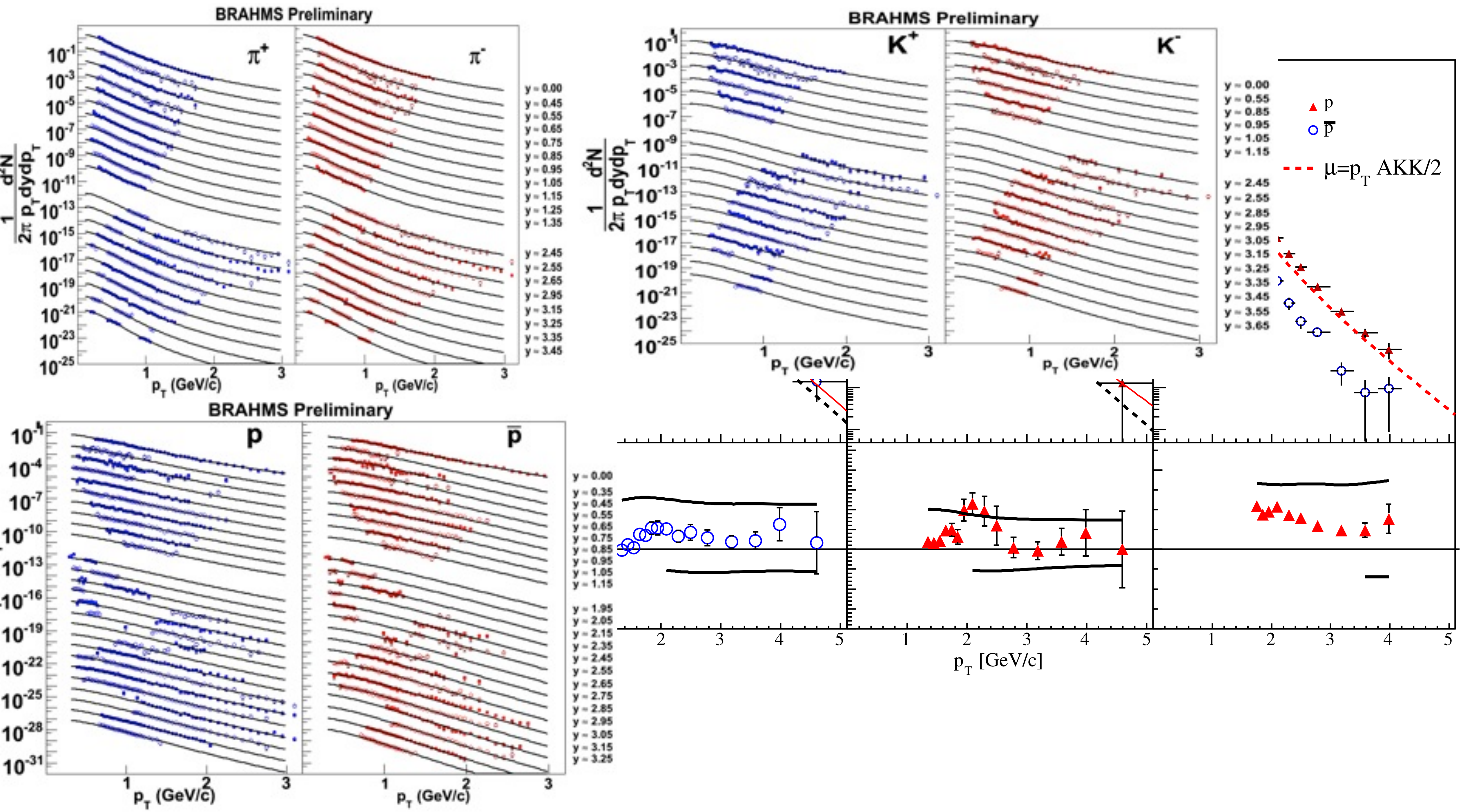


# Brahms data

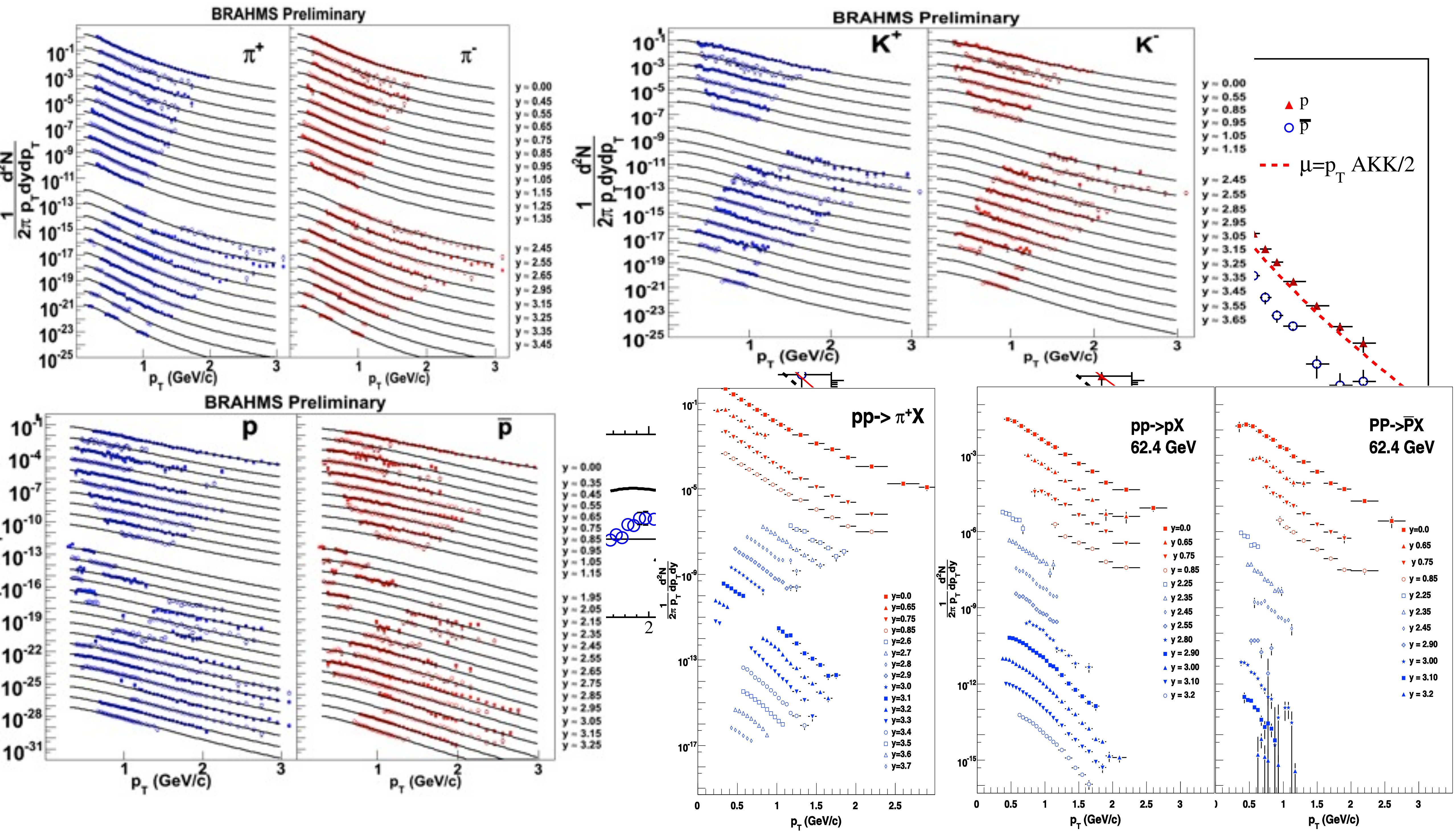
**PRL 98, 252001**



# Brahms data


BRAHMS Preliminary
$\pi^+$
$\pi^-$
$\frac{1}{2\pi}\frac{d^2N}{p_T dy dp_T}$
$p_T$ (GeV/c)
y = 0.00
y = 0.45
y = 0.55
y = 0.65
y = 0.75
y = 0.85
y = 0.95
y = 1.05
y = 1.15
y = 1.25
y = 1.35
y = 2.45
y = 2.55
y = 2.65
y = 2.95
y = 3.15
y = 3.25
y = 3.35
y = 3.45
BRAHMS Preliminary
$K^+$
$K^-$
BRAHMS Preliminary
p
$\bar{p}$
p
$\bar{p}$
$\mu = p_T$ AKK/2
$p_T$ [GeV/c]

# Brahms data


BRAHMS Preliminary
π+
π-
y = 0.00
y = 0.45
y = 0.55
y = 0.65
y = 0.75
y = 0.85
y = 0.95
y = 1.05
y = 1.15
y = 1.25
y = 1.35
y = 2.45
y = 2.55
y = 2.65
y = 2.95
y = 3.15
y = 3.25
y = 3.35
y = 3.45
p_T (GeV/c)
BRAHMS Preliminary
K+
K-
y = 0.00
y = 0.55
y = 0.85
y = 0.95
y = 1.05
y = 1.15
y = 2.45
y = 2.55
y = 2.85
y = 2.95
y = 3.05
y = 3.15
y = 3.25
y = 3.35
y = 3.45
y = 3.55
y = 3.65
p_T (GeV/c)
p
p̄
μ=p_T AKK/2
BRAHMS Preliminary
p
p̄
y = 0.00
y = 0.35
y = 0.45
y = 0.55
y = 0.65
y = 0.75
y = 0.85
y = 0.95
y = 1.05
y = 1.15
y = 1.95
y = 2.05
y = 2.15
y = 2.35
y = 2.45
y = 2.55
y = 2.65
y = 2.75
y = 2.85
y = 2.95
y = 3.05
y = 3.15
y = 3.25
p_T (GeV/c)
pp-> π+X
y=0.0
y=0.65
y=0.75
y=0.85
y=2.6
y=2.7
y=2.8
y=2.9
y=3.0
y=3.1
y=3.2
y=3.3
y=3.4
y=3.5
y=3.6
y=3.7
p_T (GeV/c)
pp->pX
62.4 GeV
y=0.0
y 0.65
y 0.75
y = 0.85
y 2.25
y 2.35
y 2.45
y 2.55
y 2.80
y = 2.90
y = 3.00
y = 3.10
y = 3.2
p_T (GeV/c)
PP->P̄X
62.4 GeV
y=0.0
y 0.65
y 0.75
y = 0.85
y 2.25
y 2.35
y 2.45
y 2.90
y = 3.00
y = 3.10
y = 3.2
p_T (GeV/c)

# Summary

It is possible to describe a variety of data from different reactions and energy by using a pQCD framework + factorization theorem

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Universality and factorization hold!

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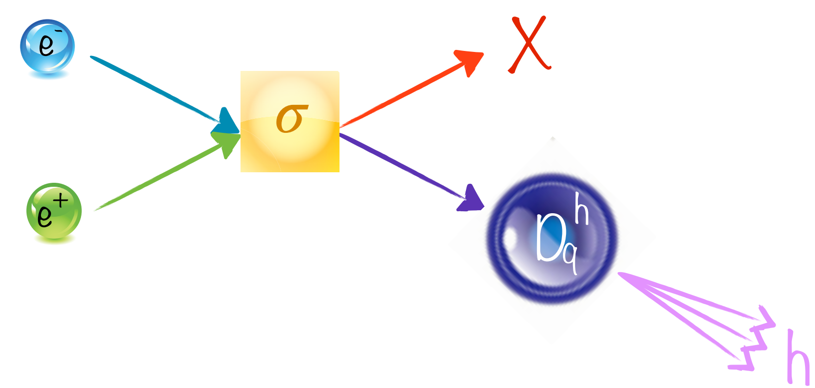
## Universality and factorization hold!




Various reactions provide access to different aspects of the fragmentation process