Cross section for quasi-real photoproduction of charged hadrons with high p_T in μ-d scattering

DIS 2012, Bonn
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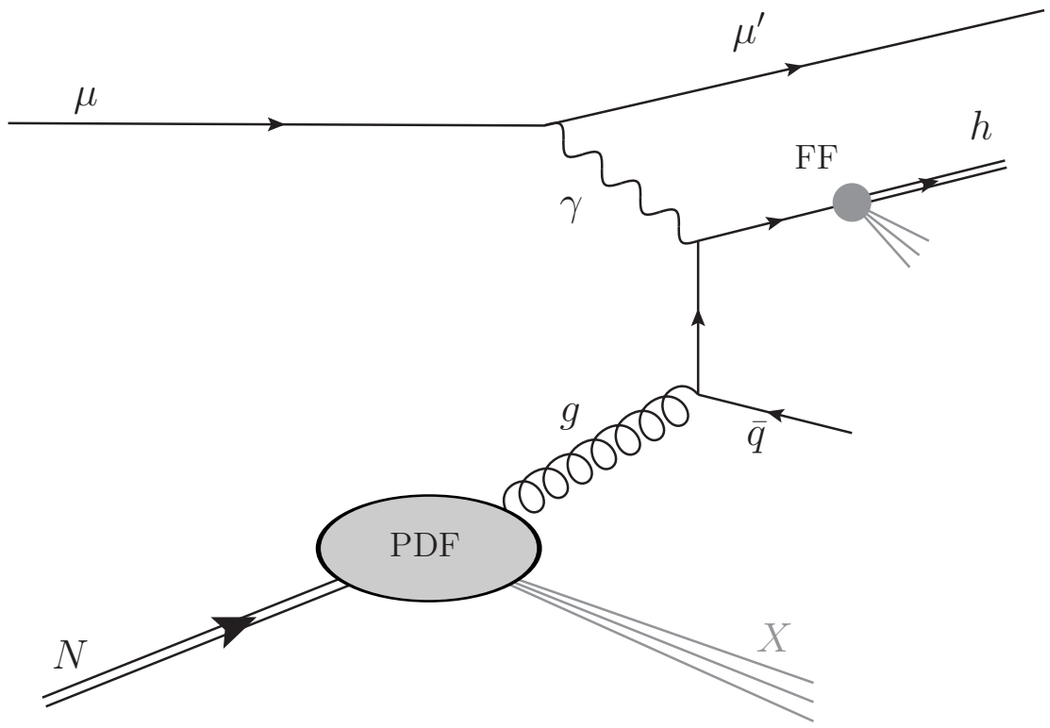
on behalf of the COMPASS Collaboration
March 29th 2012

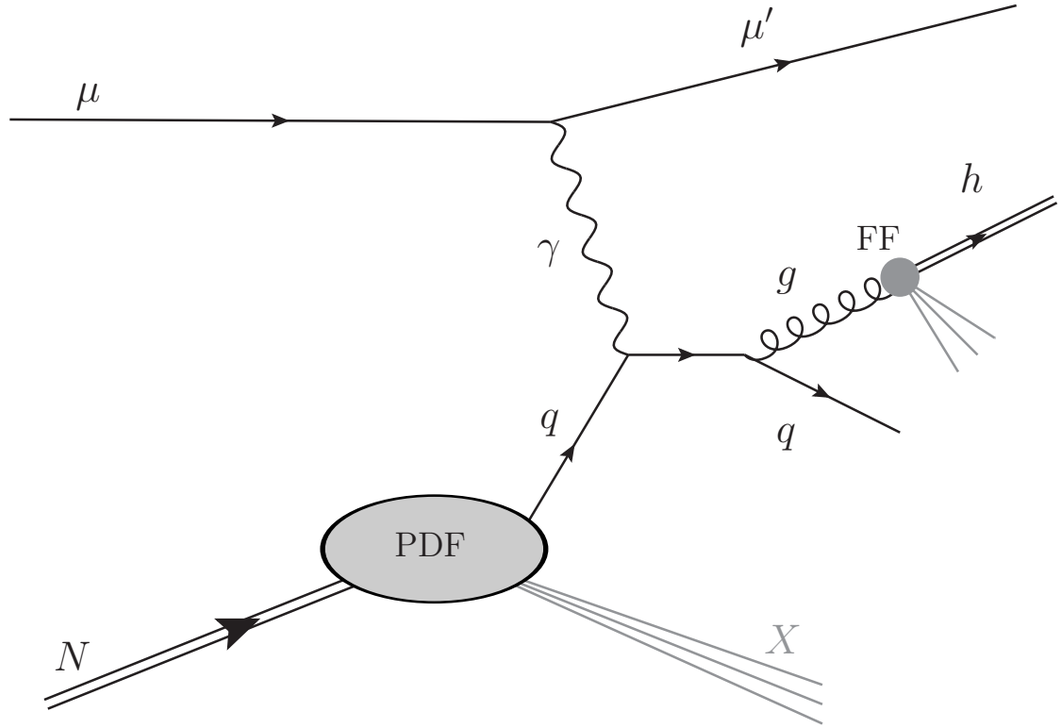
Outline

- Introduction
- The COMPASS experiment at CERN SPS
- Ingredients for cross section
  - Luminosity
  - Hadron yield
  - Acceptance correction
- Results and comparison to NLO pQCD

Lepton-Nucleon Scattering in pQCD

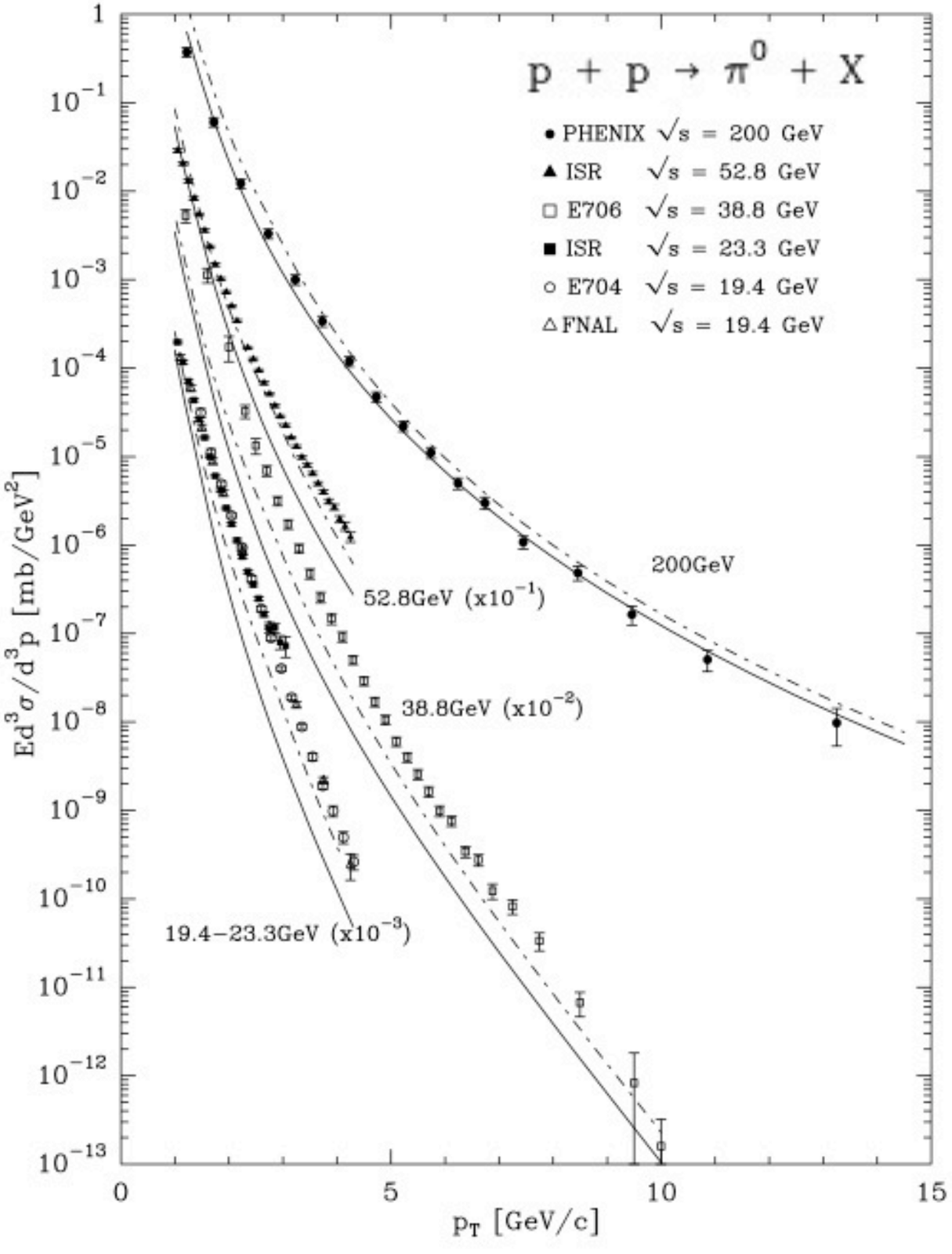
- Lepton-nucleon scattering: probe the quark and gluon (spin-)structure of the nucleon
- Theory framework to interpret the data: perturbative QCD (pQCD)
- High-p_T (high transverse momentum) hadron production





- Quasi-real photoproduction (low Q^2): Unpolarized cross section and double-spin asymmetry calculable up to NLO in pQCD (including resolved-photon processes)
  [B. Jäger et al., EPJ C 44 (2005) 533]
- Applicability of NLO pQCD: Compare cross sections experiment vs. theory
  → does NLO pQCD account for all significant contributions?

NLO pQCD vs. Experiment



[C. Bourrely & J. Soffer, EPJ C 36 (2004) 371]

<u>Proton-proton scattering</u>

- Works well at collider energies (RHIC)
- Increasing underprediction with decreasing center-of-mass energy

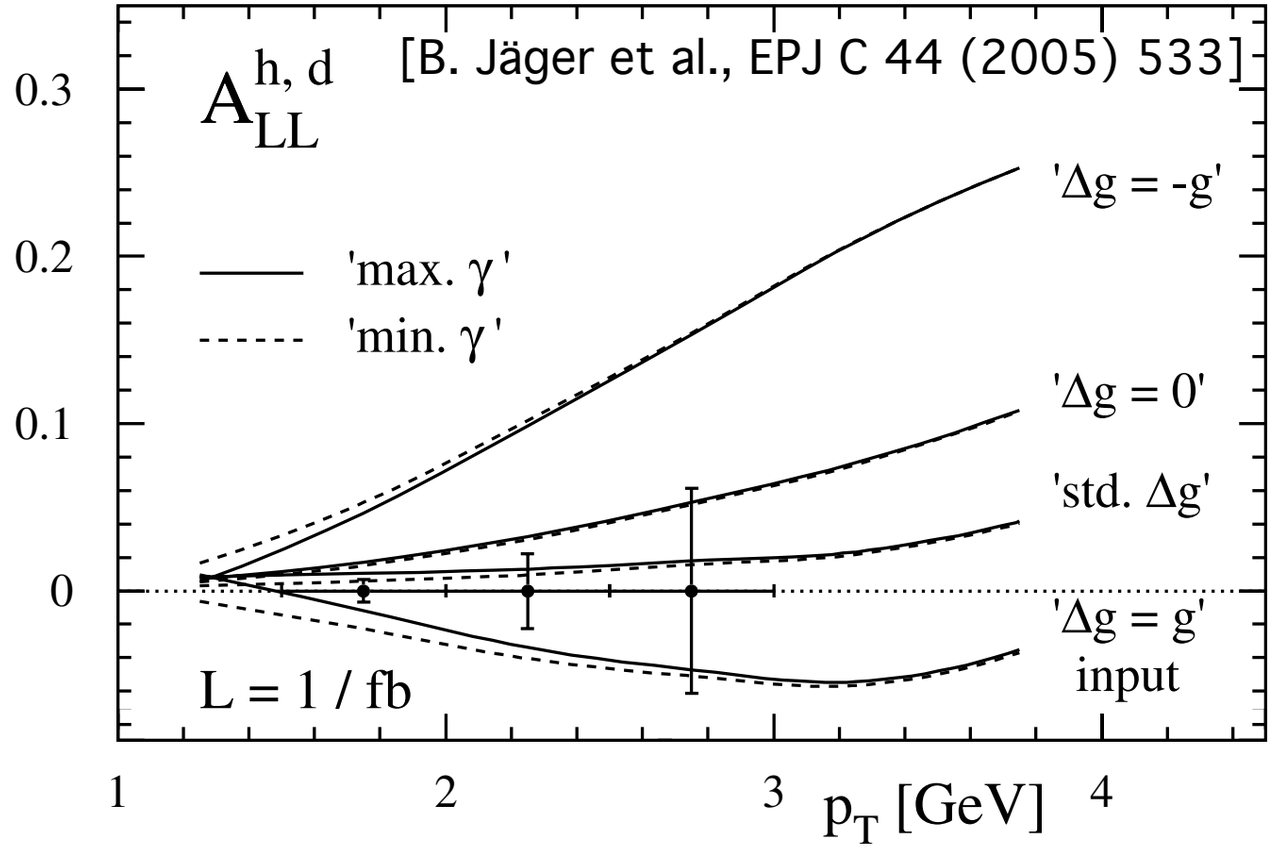
<u>Quasi-real photoproduction</u>

- Works well at collider energies (HERA $\sqrt{s} = [142, 293]\,\mathrm{GeV}$)
  [S. Chekanov et al., PRD 76 (2007) 072011]
- At COMPASS energies ($\sqrt{s} = 17.4\,\mathrm{GeV}$) ?

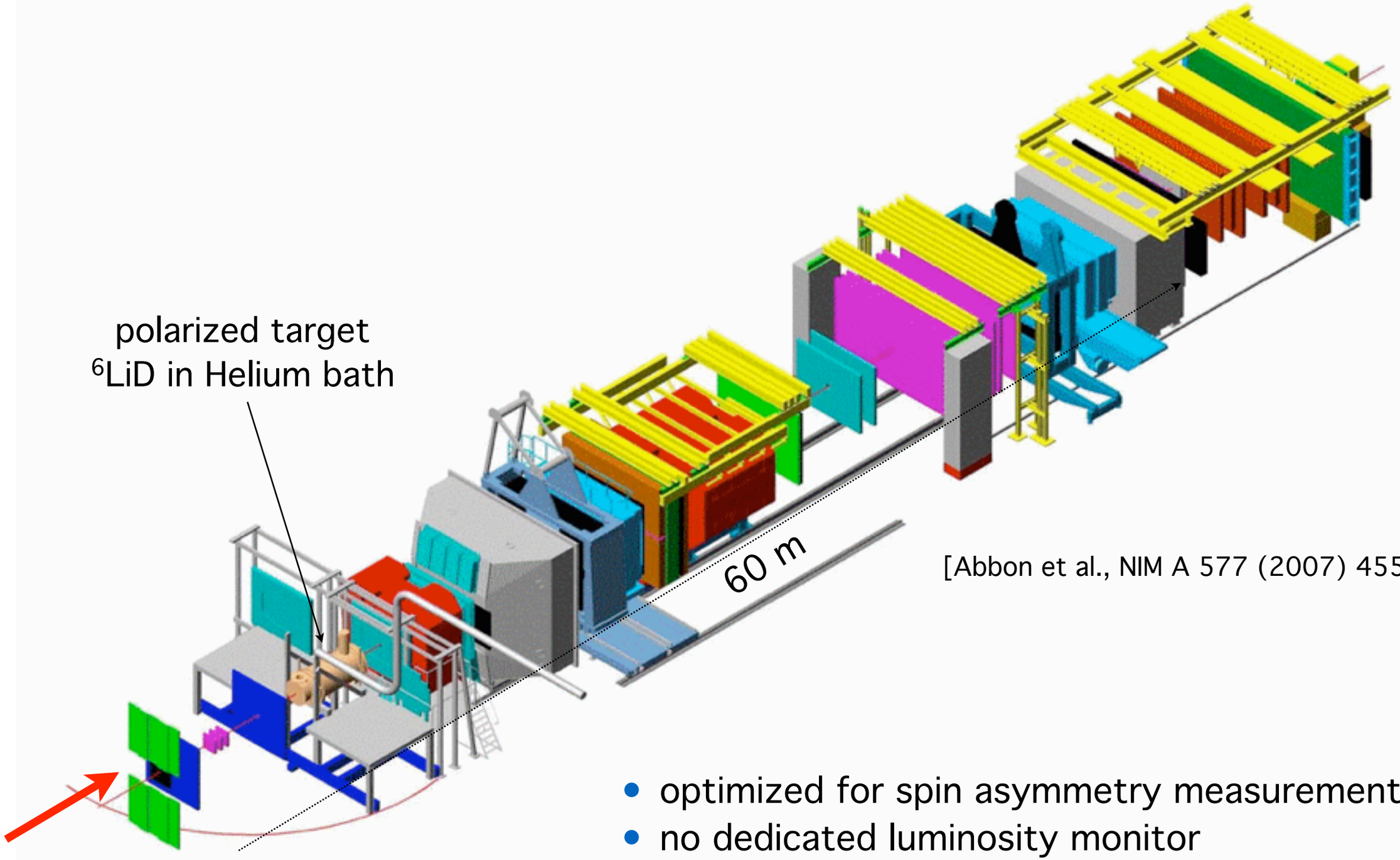
Gluon Polarization in the Nucleon

Once applicability of pQCD to the process is established via cross section:

- Extract double-spin asymmetry of cross section for high-p_T hadrons at low Q^2
- Compare to NLO pQCD calculation of double-spin asymmetry with different input Δg distributions



COMPASS Experiment at CERN SPS



[Abbon et al., NIM A 577 (2007) 455]

- optimized for spin asymmetry measurements
- no dedicated luminosity monitor

Definition of Cross Section

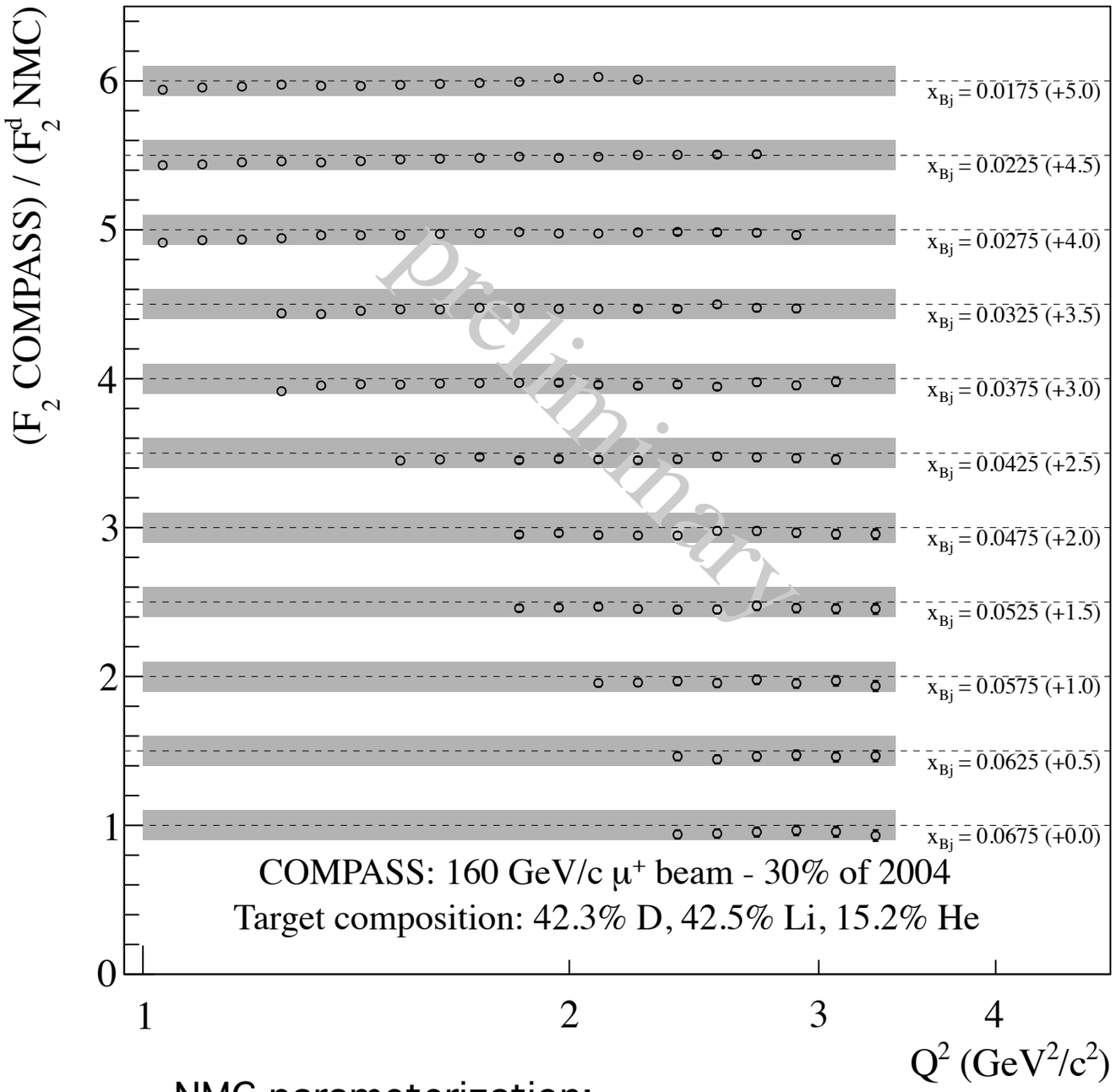
- Cross section in bin: $p_T \in [p_{T,i,1}, p_{T,i,2}]$

$$\frac{\mathrm{d}\sigma_i}{\mathrm{d}p_T} = \frac{1}{p_{T,i,2} - p_{T,i,1}} \cdot \frac{1}{\tilde{L}} \cdot \left(\frac{\tilde{N}_i}{\epsilon_i} \right)$$

- Ingredients:
  - Integrated luminosity: $\tilde{L}$
  - Number of observed hadrons in the bin: $\tilde{N}_i$
  - Acceptance correction factors from MC: $\epsilon_i = \frac{N_{i,\mathrm{MC}}^{\mathrm{rec}}}{N_{i,\mathrm{MC}}^{\mathrm{gen}}}$

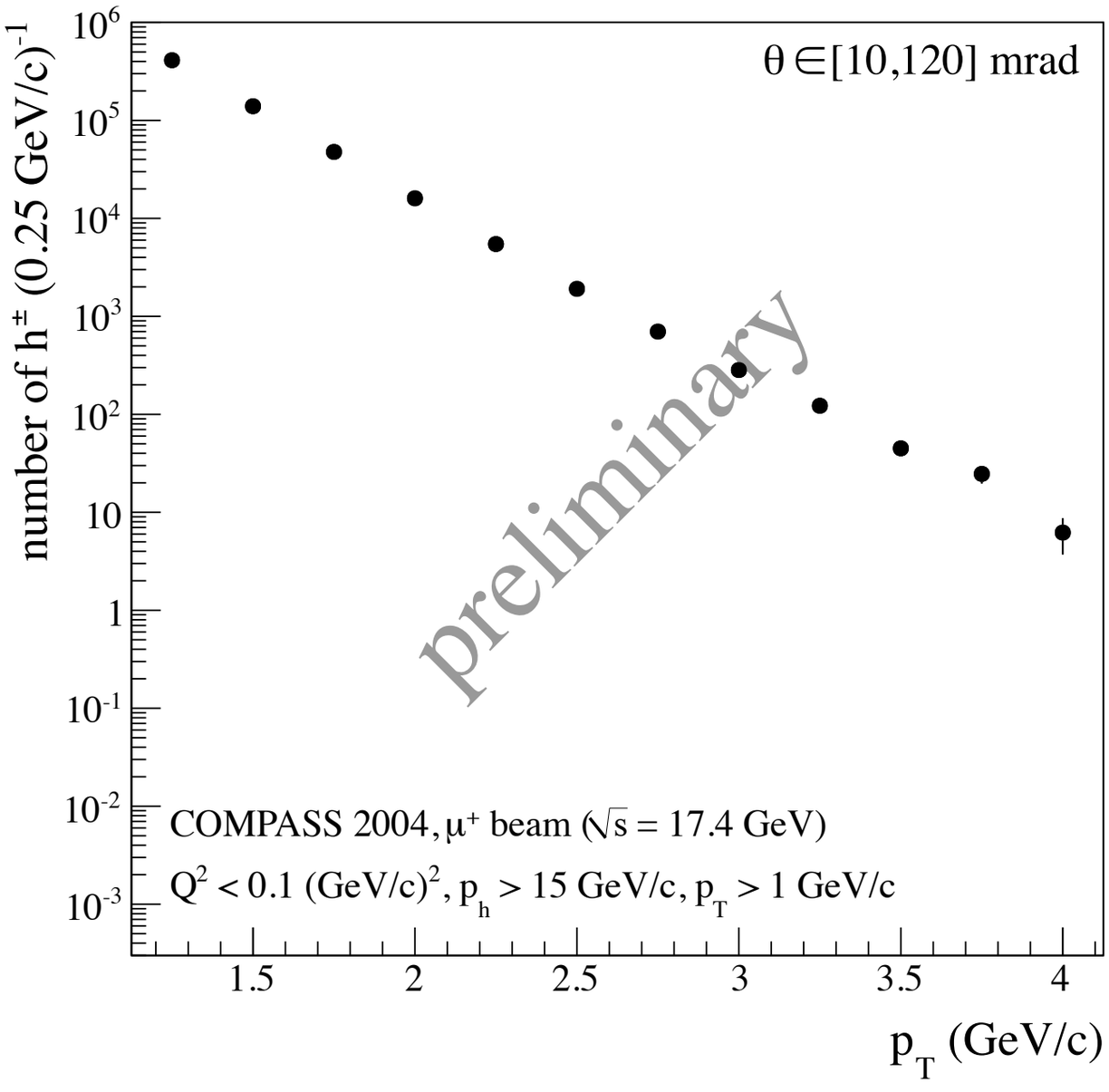
Luminosity

- Luminosity is determined via direct measurement of beam flux on target
- Correction of all dead times and inefficiencies
- Resulting luminosity (30% of 2004 data): 142.4 pb^{-1} ± 10% (syst.)
- Luminosity is checked via structure function F_2 → comparison with NMC



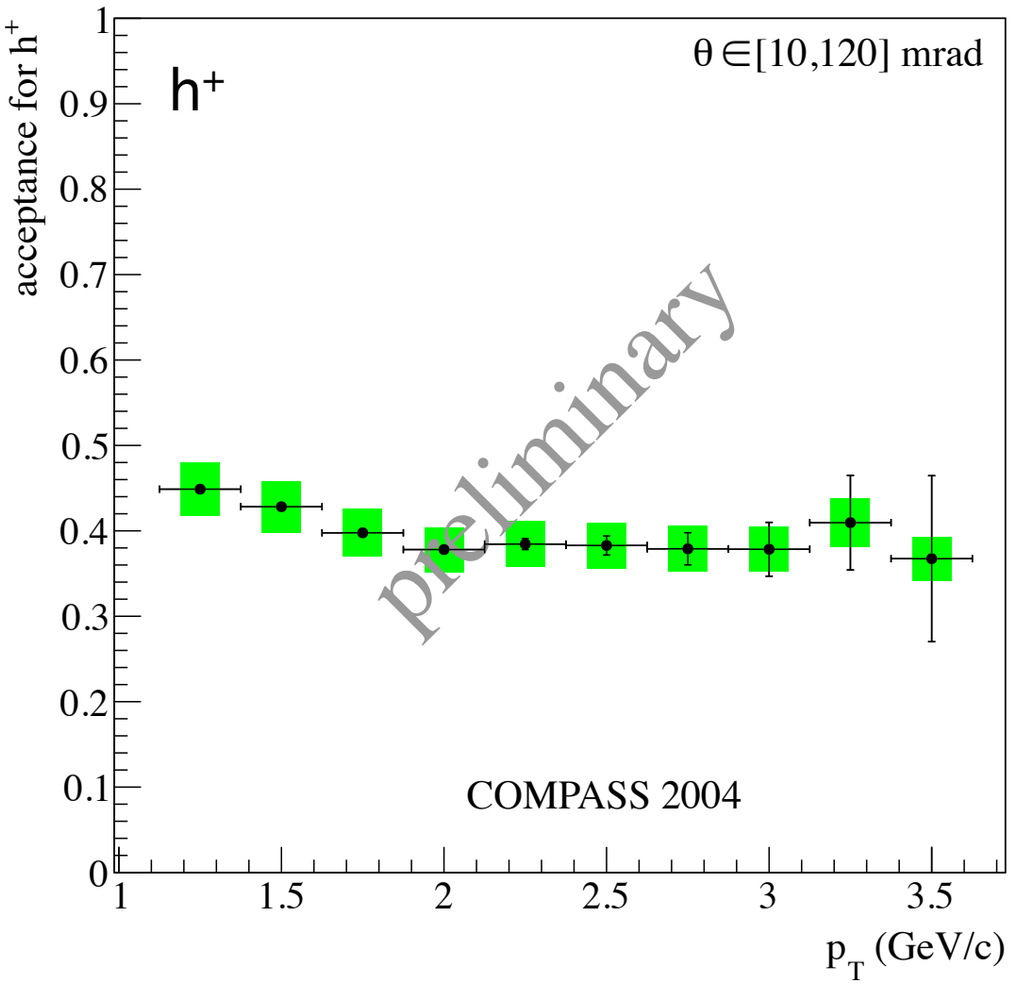
NMC parameterization:
[M. Arneodo et al., PLB 364 (1995) 107]

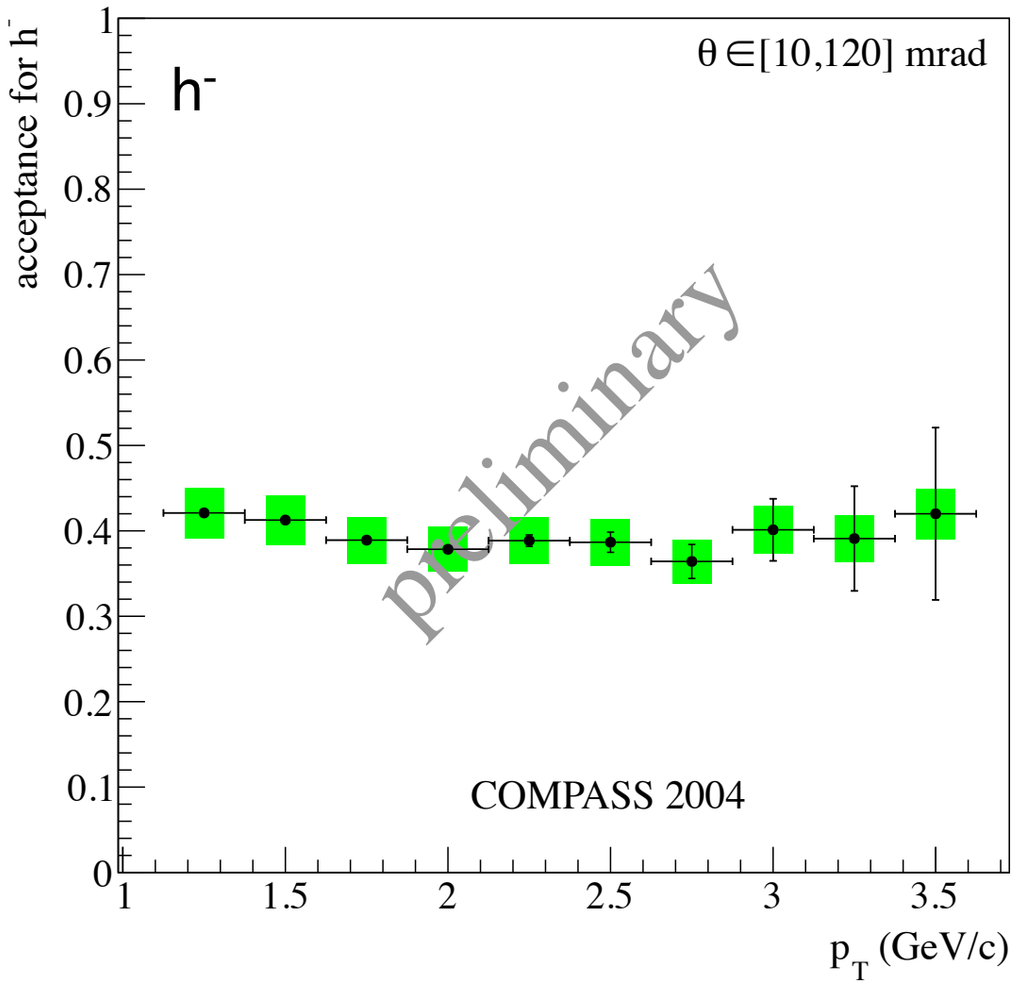
Hadron Yield



- $Q^2 < 0.1\,(\mathrm{GeV}/c)^2$,$(Q^2 = -q^2)$
- $y \in [0.2, 0.8]$, $(y = \frac{\nu}{E})$
- $z \in [0.2, 0.8]$, $(z = \frac{E_h}{\nu})$
- $|\vec{p}_h| > 15\,\mathrm{GeV}/c$
- $\theta \in [10, 120]\,\mathrm{mrad}$, $(\angle(\vec{p}_h, \vec{q}))$

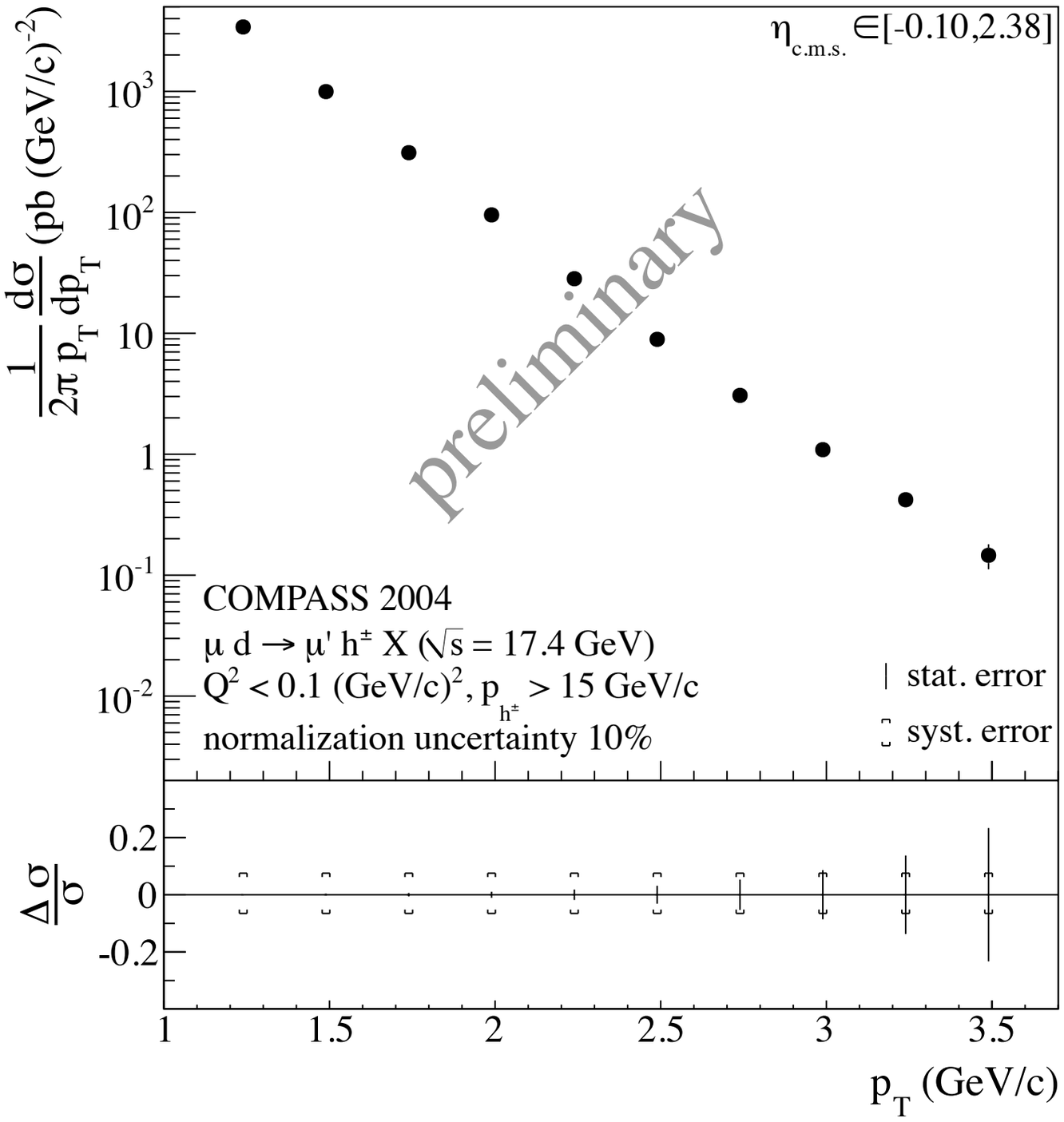
Acceptance Correction



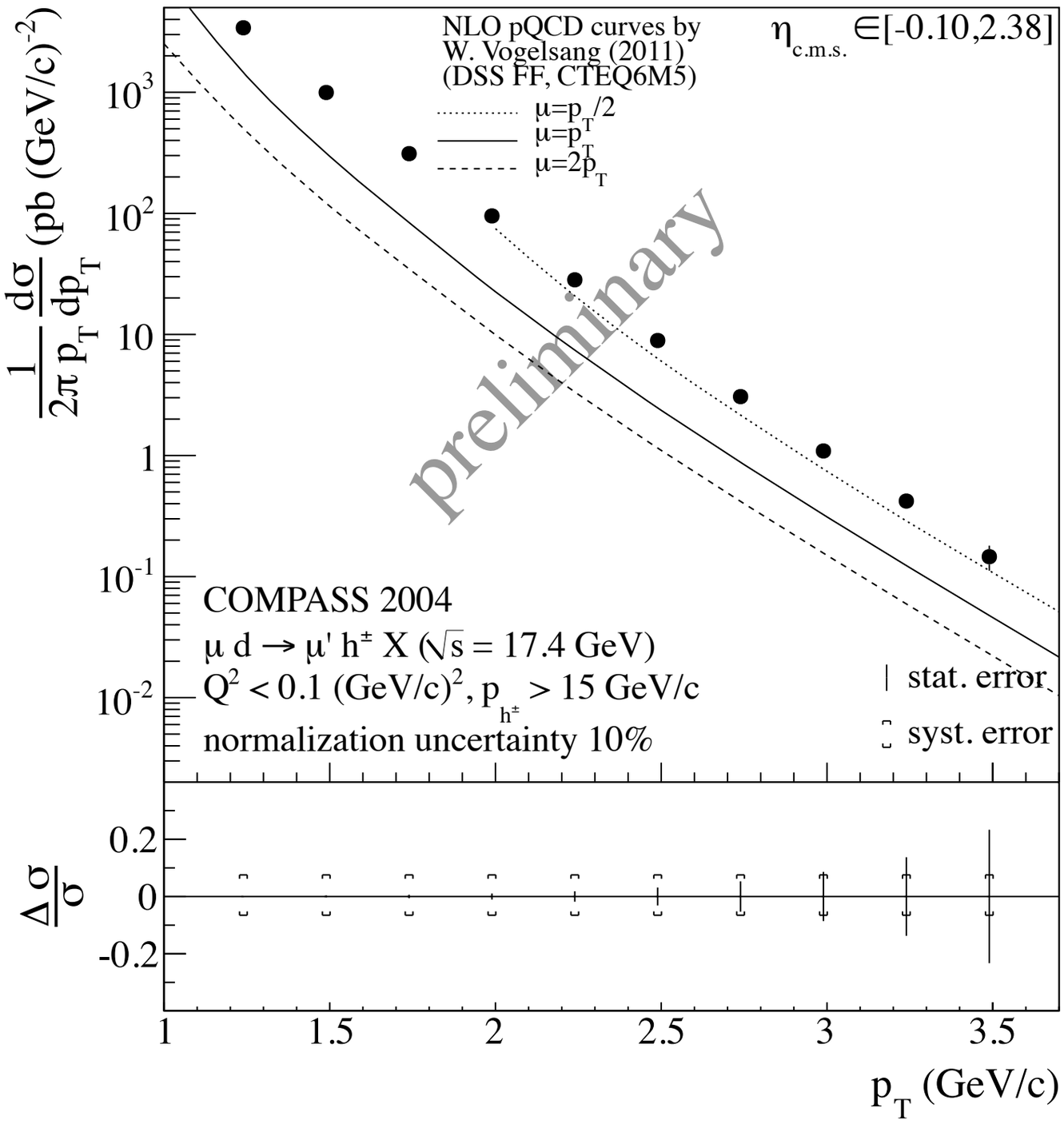


- Software chain: PYTHIA6, GEANT3, COMPASS reconstruction
- Systematic error: 7%
  - Possible background from secondary hadrons
  - Multidimensional acceptance

Cross Section

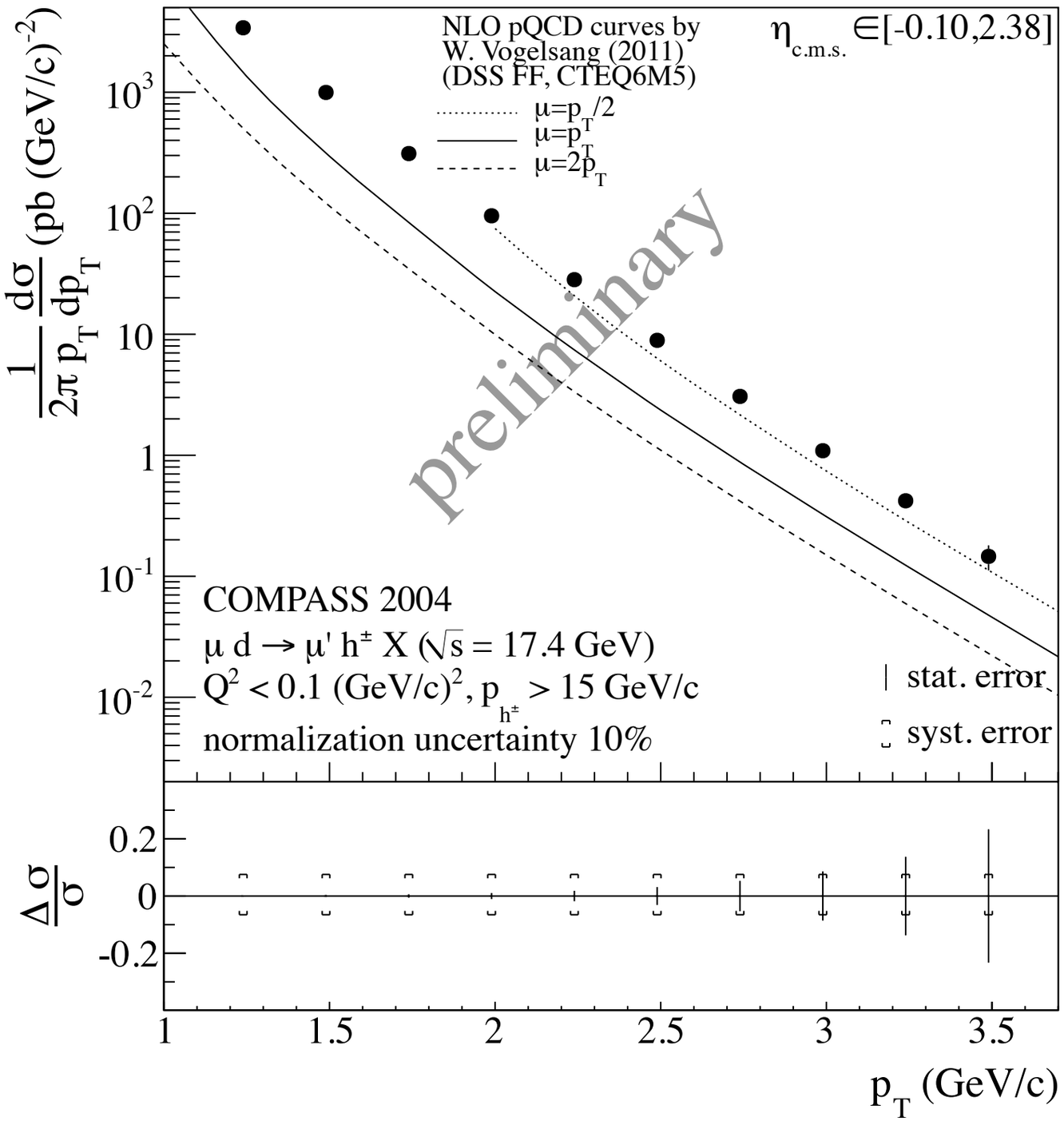


Cross Section



- Underprediction by NLO pQCD for p_T > 1.75 GeV/c by factor 3-4
- Spectral shape is predicted well

Cross Section

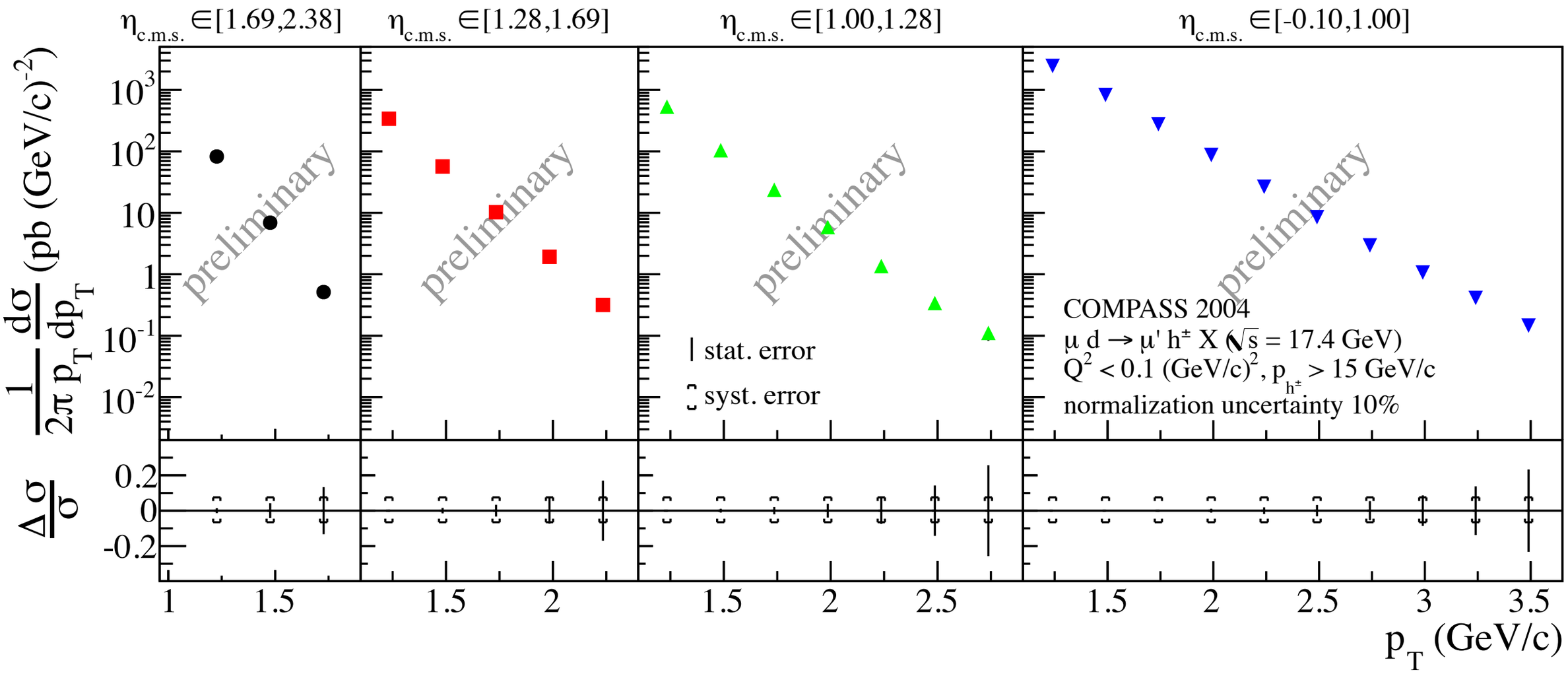


- Underprediction by NLO pQCD for p_T > 1.75 GeV/c by factor 3-4
- Spectral shape is predicted well

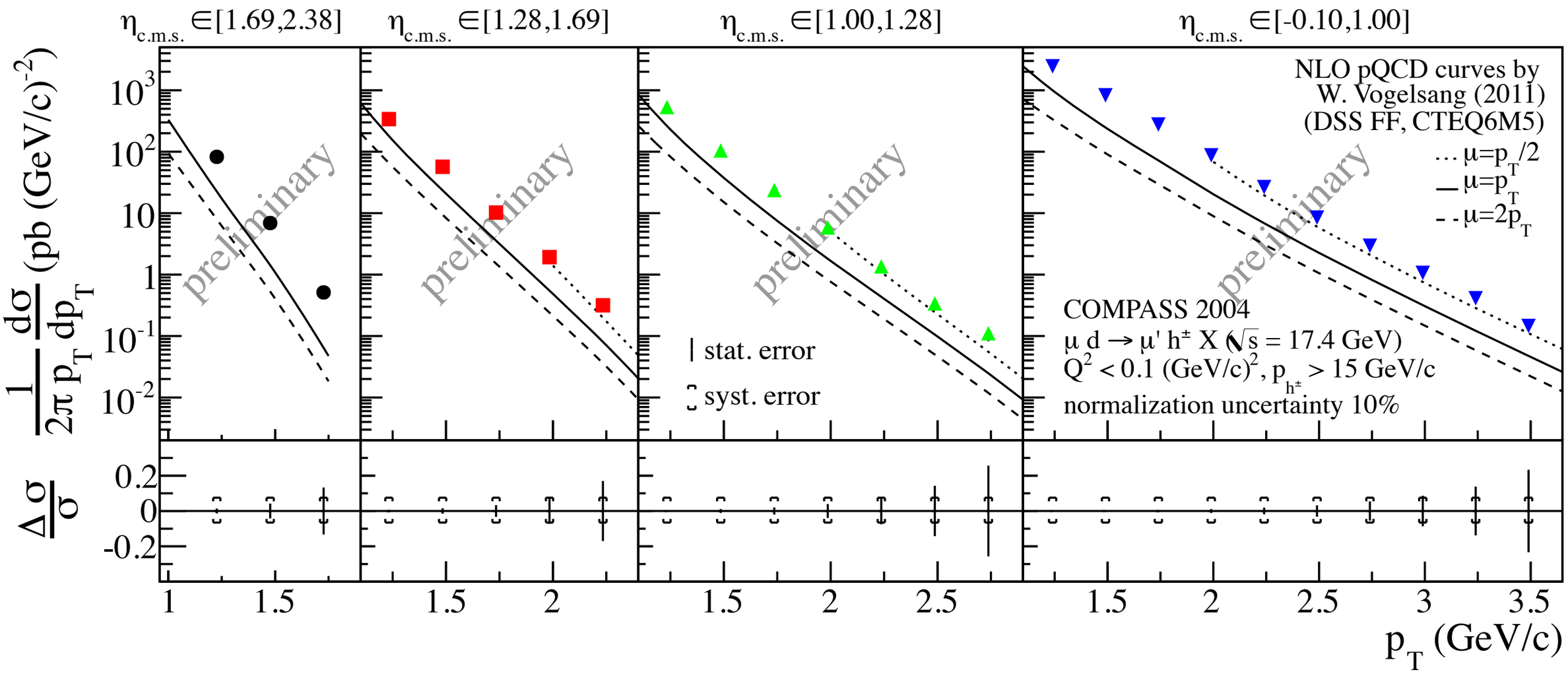
Analogy to proton-proton scattering:

- Underprediction by a factor of the same order of magnitude at fixed-target energies
- All-order resummation of threshold logarithms (soft gluon radiation) reconcile discrepancy
  [D. de Florian & W. Vogelsang, PRD 71 11 (2006) 152302]

Cross Section in Rapidity Bins

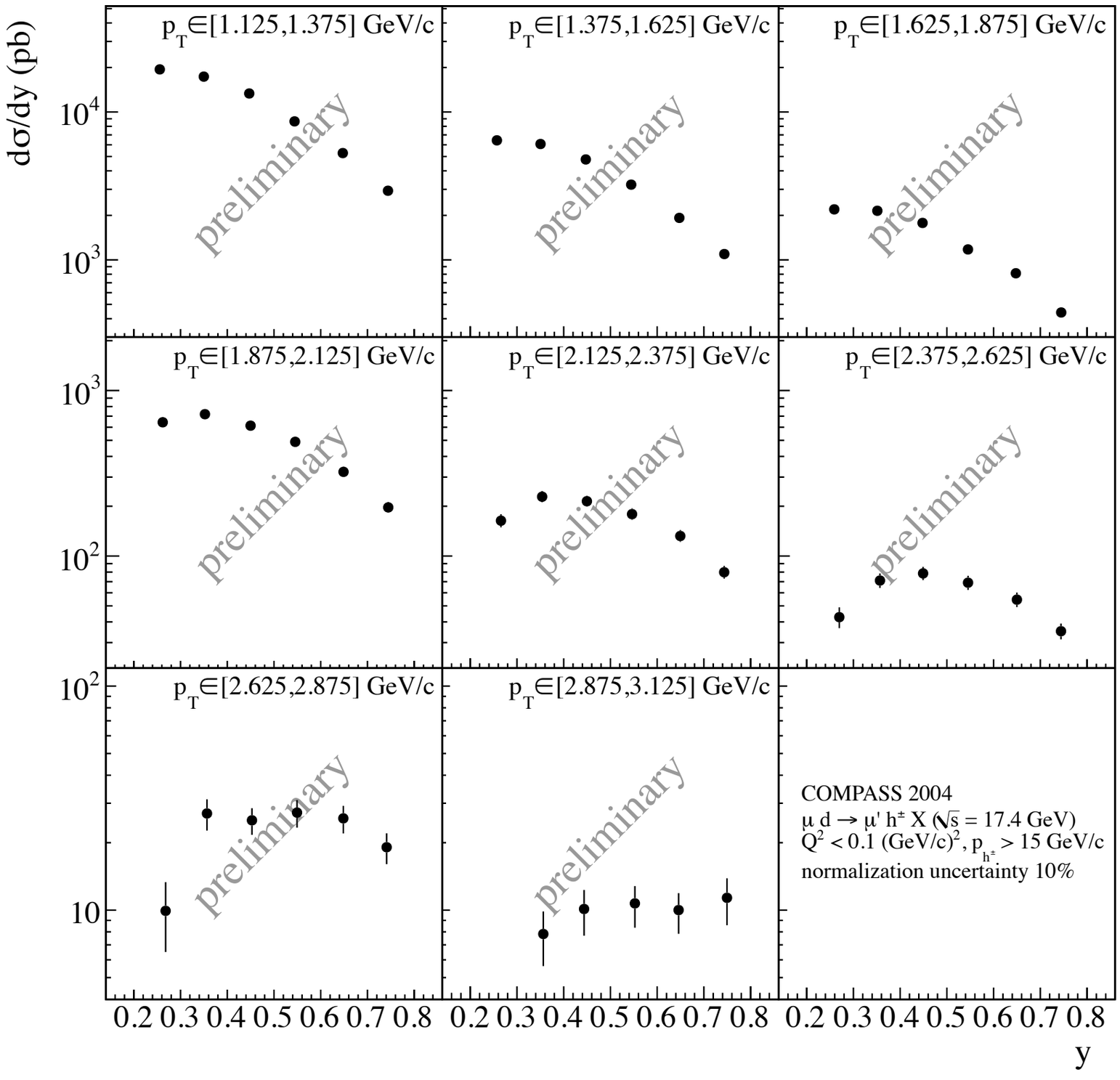


Cross Section in Rapidity Bins

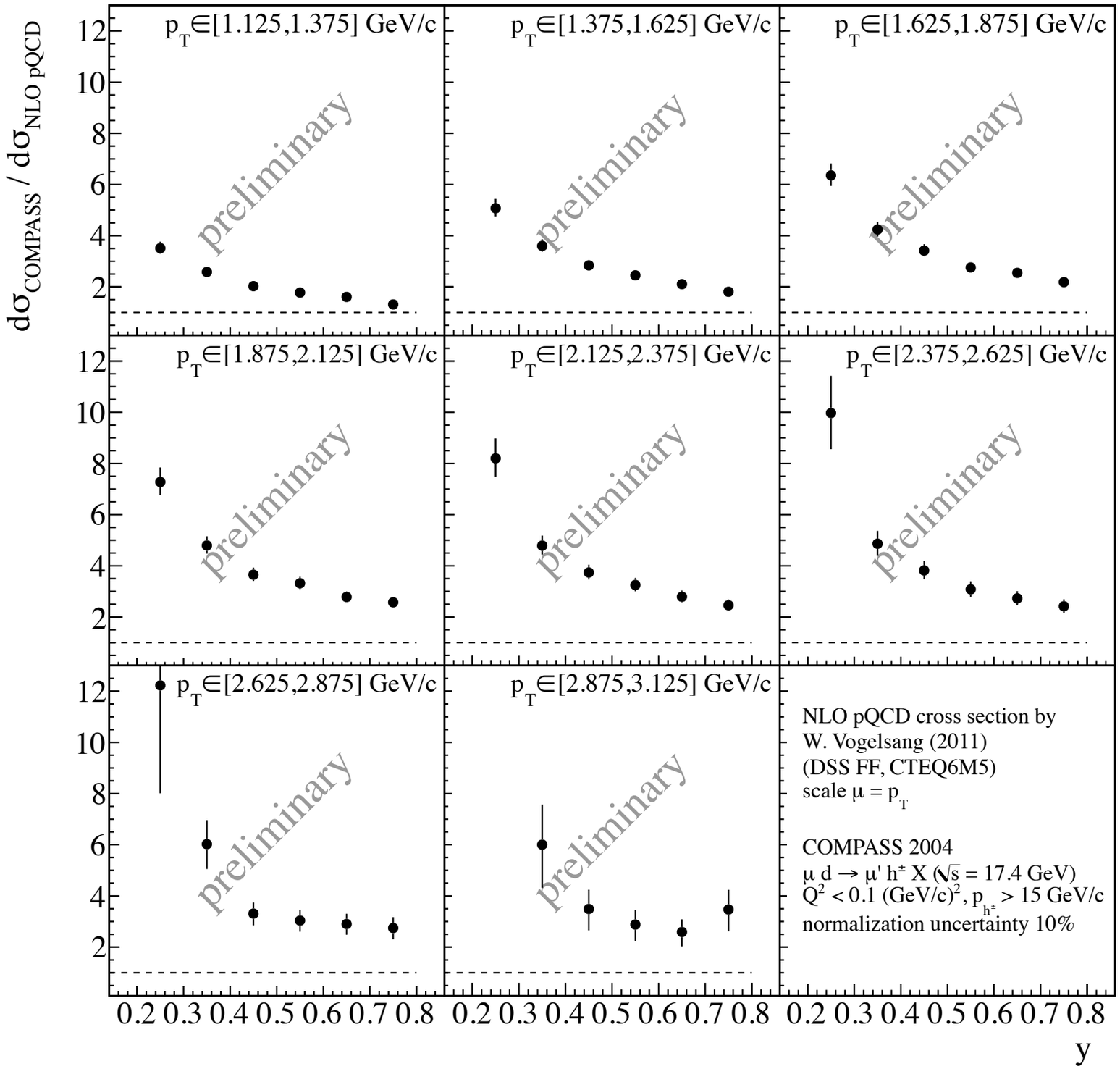


- Underprediction consistent over full rapidity range
- Spectral shape reproduced well over full rapidity range

y-Differential Cross Section

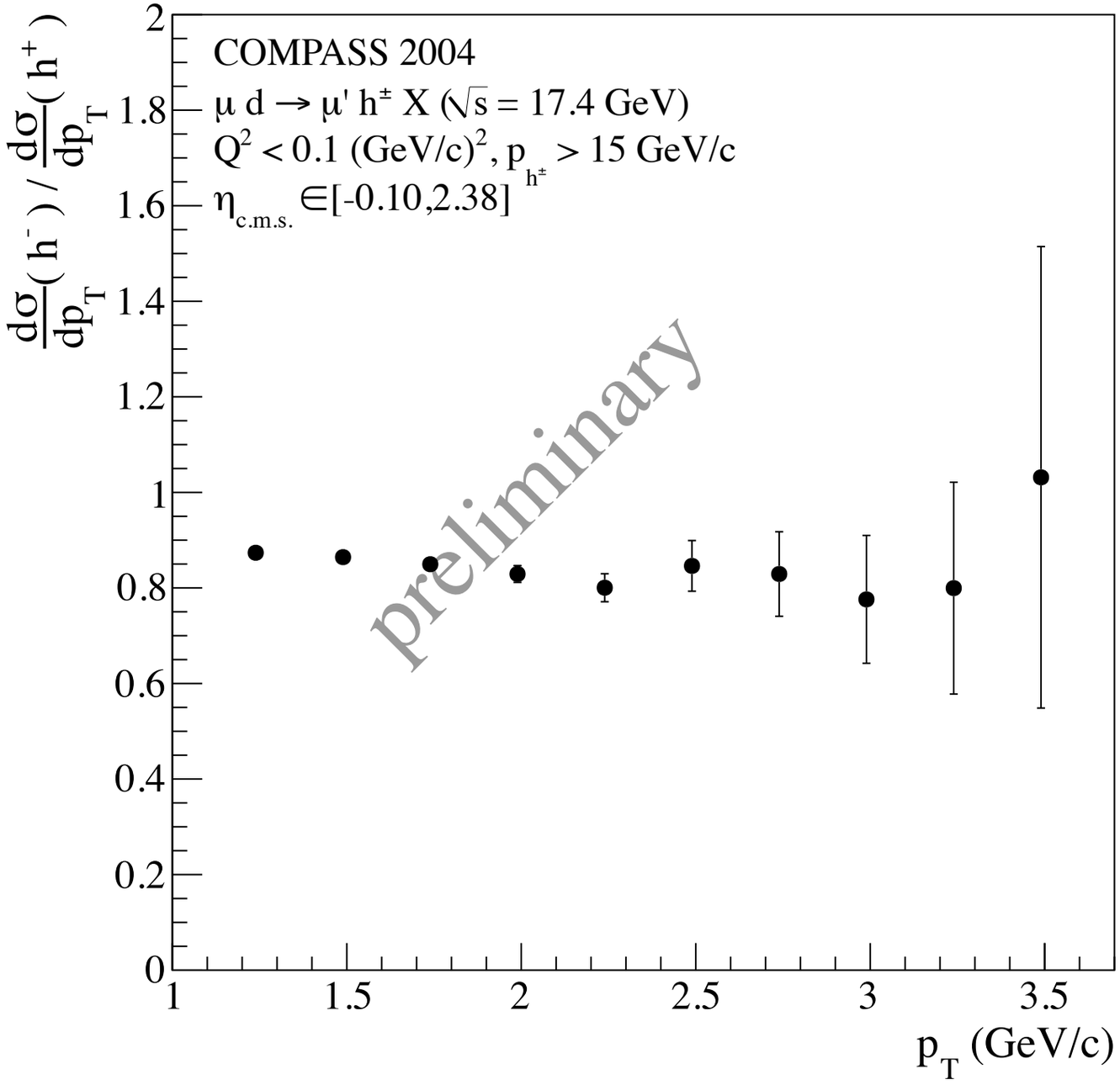


y-Differential Cross Section

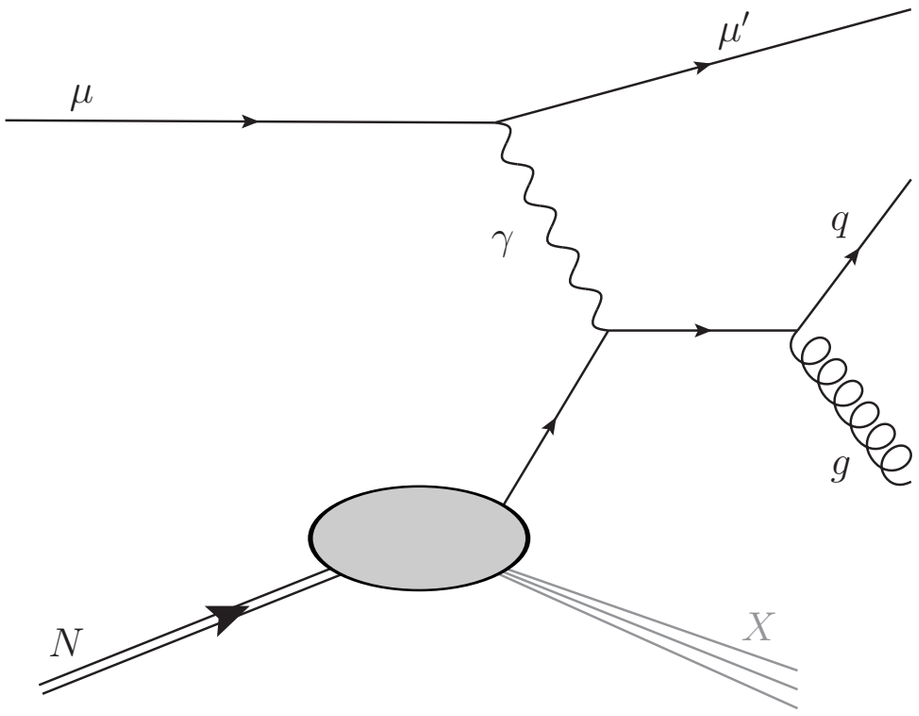


Underprediction by NLO pQCD clearly increases with decreasing photon energy

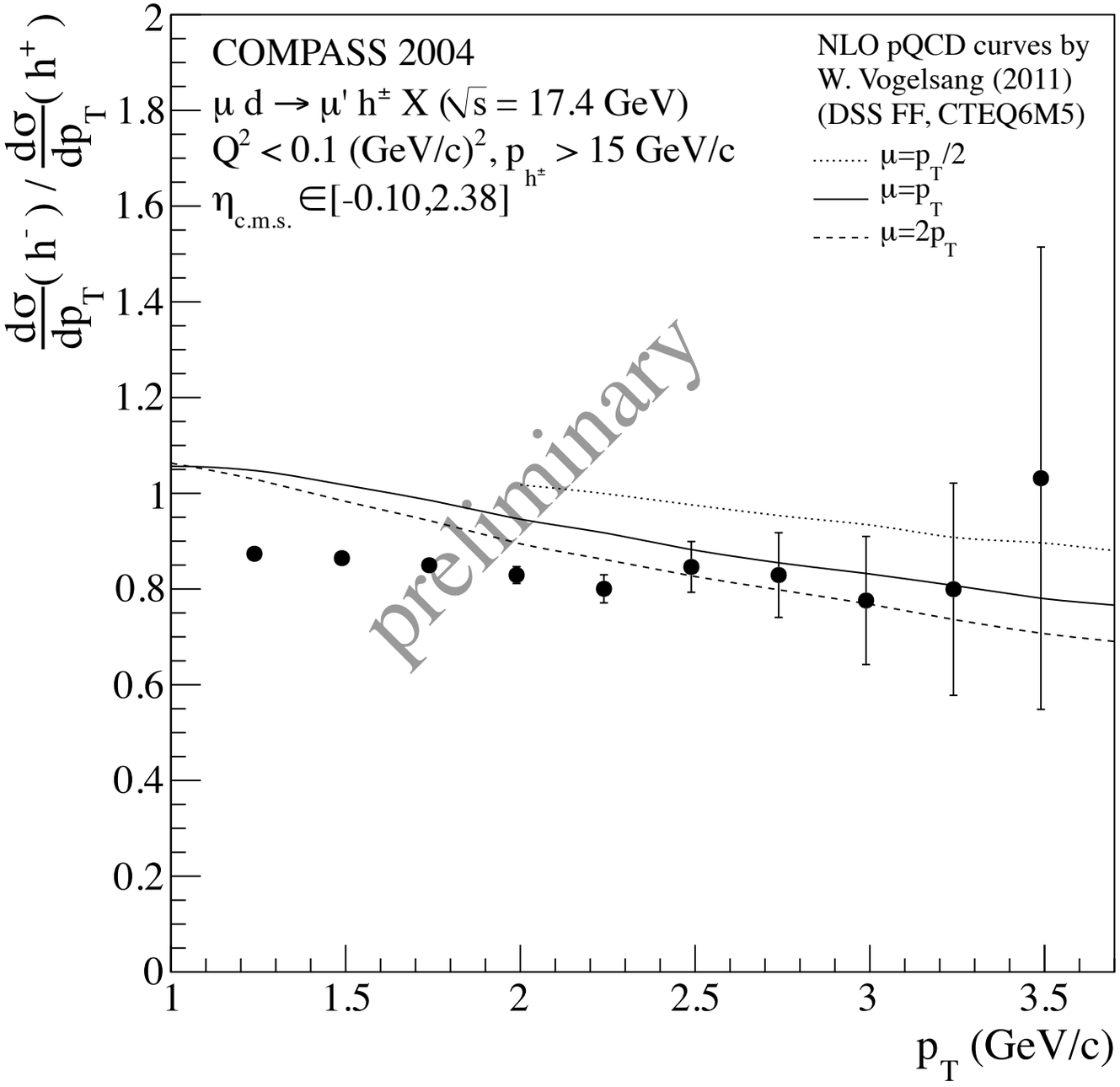
Charge Ratio of Cross Sections



- Experiment: ratio < 1 because of QCD Compton?



Charge Ratio of Cross Sections



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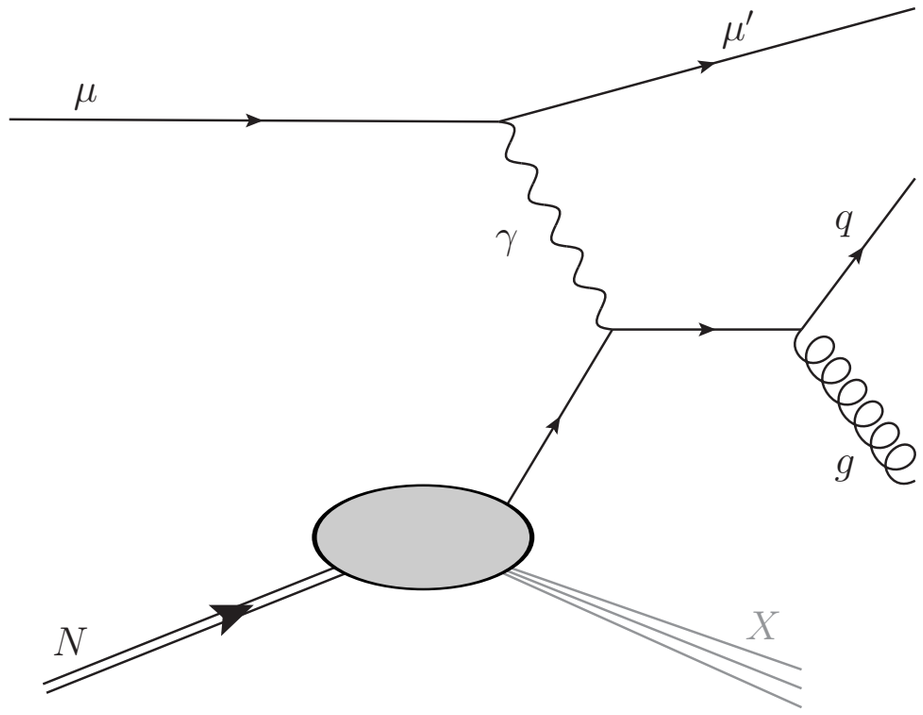


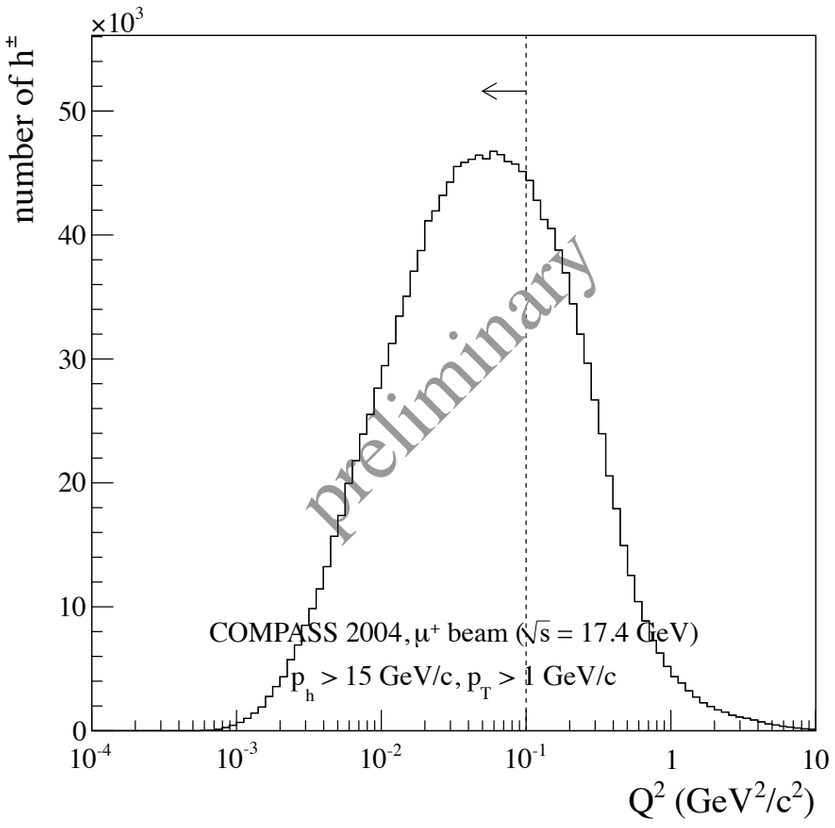
- Theory: ratio > 1 because of Fragmentation Functions?

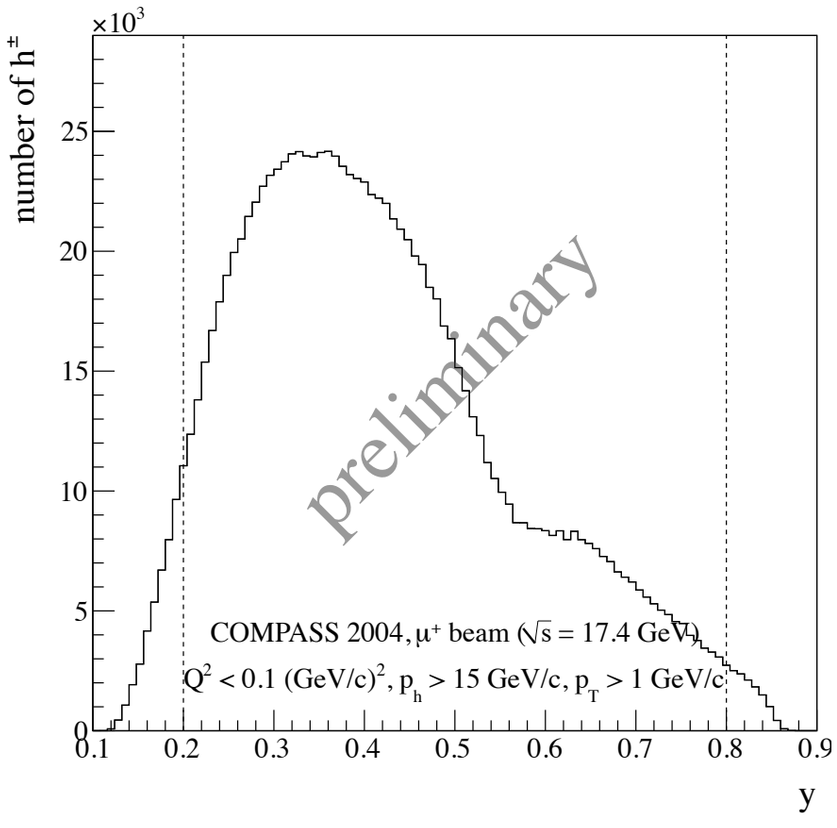
Conclusion and Outlook

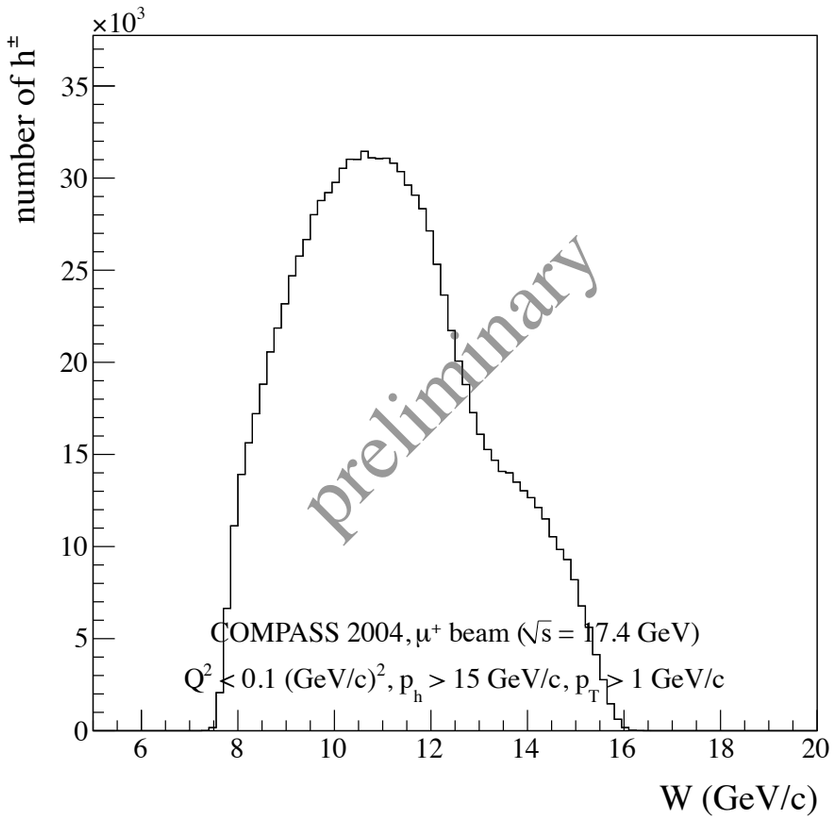
- Measurements of single-inclusive particle production cross sections provide an important benchmark for pQCD methods (especially at fixed-target energies)
- Unpolarized cross section for quasi-real photo-production of high-p_T charged hadrons at $\sqrt{s} = 17.4\,\mathrm{GeV}$ has been measured
- Less negative hadrons than positive hadrons, ratio almost independent of p_T
- Comparison to NLO pQCD:
  - Cross section is underpredicted by factor 3 - 4 (-> resummations?)
  - Spectral shape described well (over full rapidity range)
  - Underprediction increases clearly with decreasing photon energy
  - p_T dependence of charge ratio from pQCD not confirmed (-> fragmentation functions?)
- Once applicability of pQCD can be established:
  Potential to constrain gluon polarization via double-spin asymmetry of cross section for high-p_T hadron production at low Q^2

Extra Slides

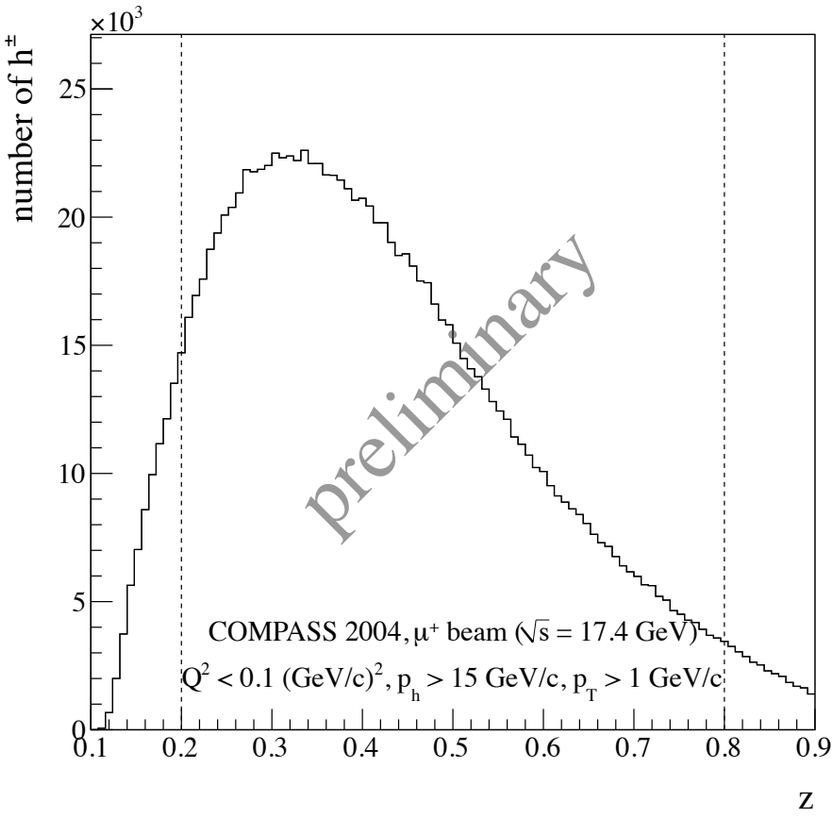
Kinematics

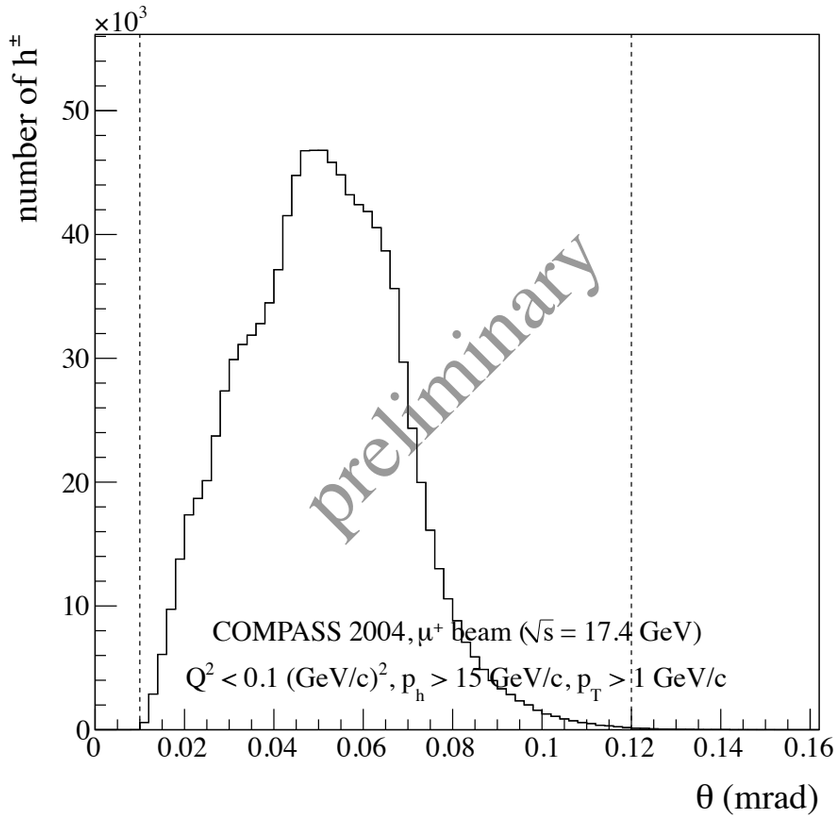

number of h±
×10³
50
40
30
20
10
0
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
10
Q² (GeV²/c²)
preliminary
COMPASS 2004, μ⁺ beam (√s = 17.4 GeV)
p_h > 15 GeV/c, p_T > 1 GeV/c


number of h±
×10³
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
y
preliminary
COMPASS 2004, μ⁺ beam (√s = 17.4 GeV)
Q² < 0.1 (GeV/c)², p_h > 15 GeV/c, p_T > 1 GeV/c


number of h±
×10³
35
30
25
20
15
10
5
0
6
8
10
12
14
16
18
20
W (GeV/c)
preliminary
COMPASS 2004, μ⁺ beam (√s = 17.4 GeV)
Q² < 0.1 (GeV/c)², p_h > 15 GeV/c, p_T > 1 GeV/c

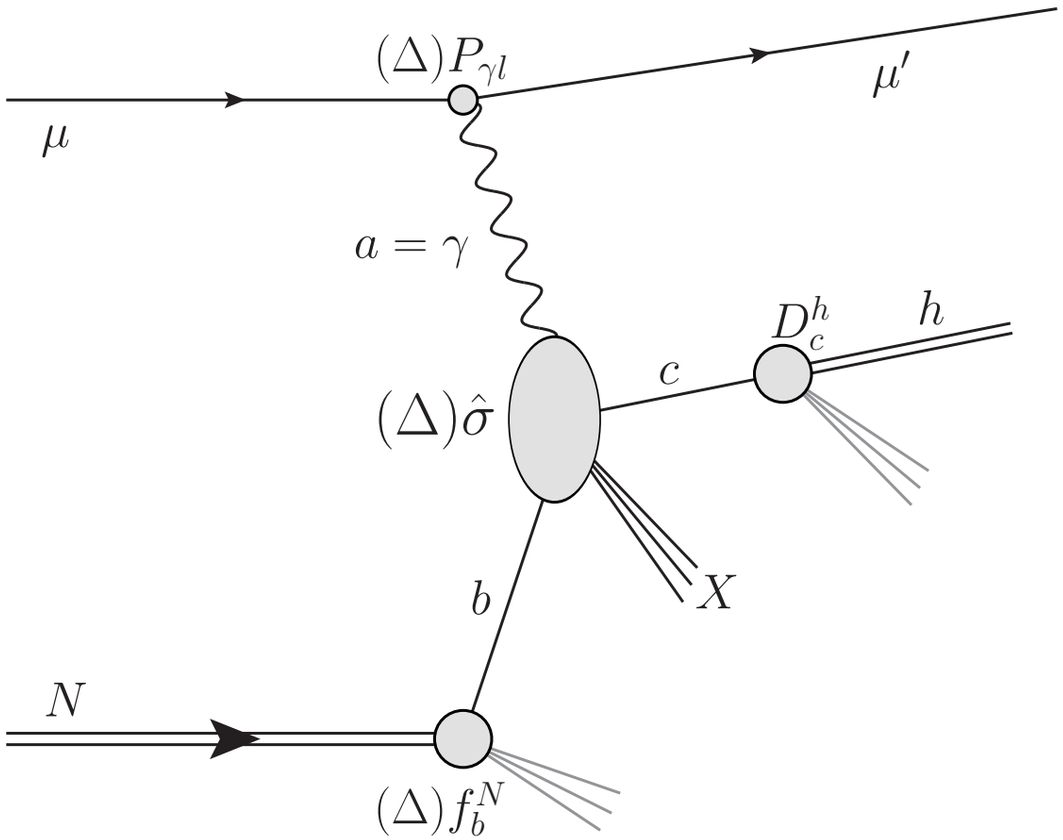
Kinematics


number of h±
×10³
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
z
preliminary
COMPASS 2004, μ+ beam (√s = 17.4 GeV)
Q² < 0.1 (GeV/c)², p_h > 15 GeV/c, p_T > 1 GeV/c

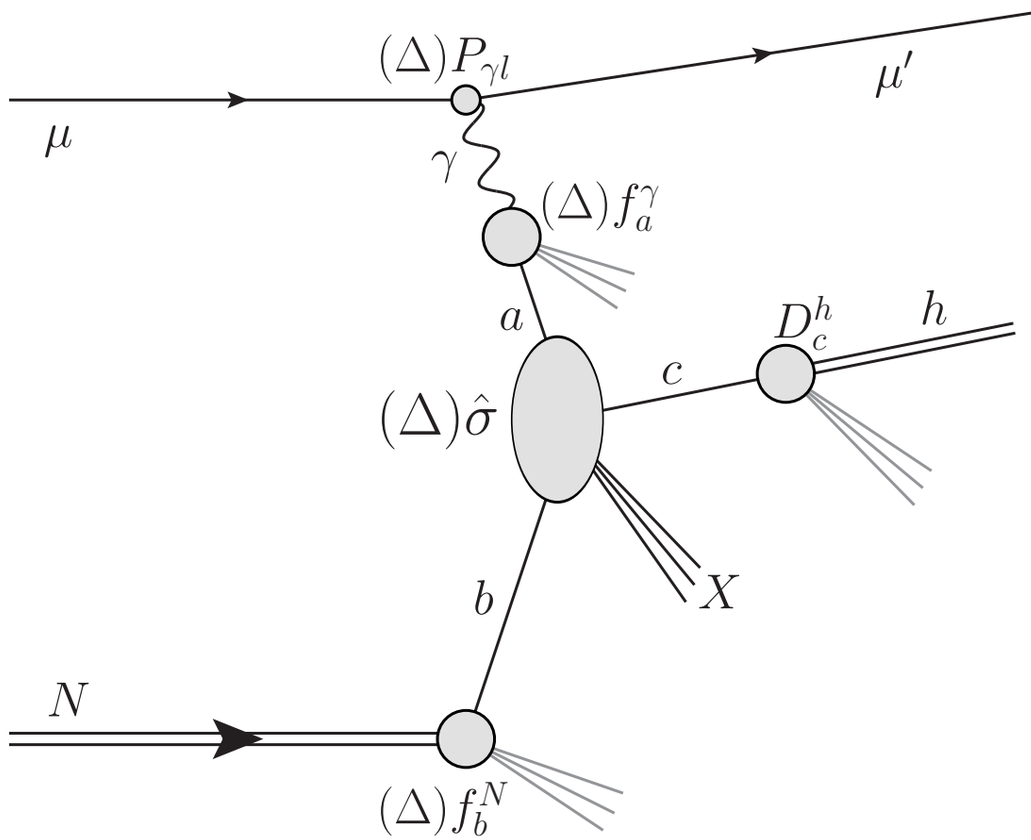

number of h±
×10³
50
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
θ (mrad)
preliminary
COMPASS 2004, μ+ beam (√s = 17.4 GeV)
Q² < 0.1 (GeV/c)², p_h > 15 GeV/c, p_T > 1 GeV/c

pQCD Calculation

- Calculation of cross section in pQCD:



(a) Direct-photon contribution.



(b) Resolved-photon contribution.

Fragmentation Functions