AFTER@LHC

ECT* Workshop, Feb 4-13, 2013

Summary 1 of WG3:
Quarkonia, Heavy-flavour, pA, AA & (n)PDF

I. Schienbein (LPSC Grenoble)
E. Ferreiro (USDC, Spain)

Topics

(see Physics Reports 522(2013)239; Stan's talk)

AFTER @ LHC

- Nucleon partonic structure
- Nuclear matter
  - nuclear PDFs
  - cold nuclear matter effects; A-dependance
- Heavy flavour phyics
  - Open and hidden heavy-flavours better go together!
- Vector boson production (W,Z) close to threshold
- Heavy ion physics
  - QGP in rest frame of target nucleus
- Spin physics
- Diffractive physics on nucleons and nuclei
- Production of ccq to ccc to bbb states
- Ultra-peripheral collisions
- D and B physics?
- Secondary beams
  - high-energy, high-lumi neutrinos?
  - pion, kaon beams
- Cosmic ray simulations

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Iterative procedure

(we are in the first round)

- Huge list of possible topics/observables
  (see Physics Reports 522(2013)239; Stan's talks)
- Identify *possible* Key Observables
  - Taking into account the competition from other current and future approved experiments
  - Ignoring any constraints from budget, available space for detector
- Identify experimental signatures and resulting detector requirements
  - Many constraints: Budget, available space for detector, political issues
  - Even for a multi-purpose detector: not everything can be measured and one has to make choices
- Need dedicated numerical studies and simulations
- Da Capo al Fine (until EOI as a first milestone!?)

Partonic structure of nucleons

Where can AFTER contribute?

- PDFs at large-x poorly known
  - gluon
  - sea quark distributions
  - intrinsic charm/bottom
- Questions
  - Which processes at AFTER allow to constrain some of these distributions?
  - Large-x PDFs will also be measured at JLAB in DIS. Complementary?
    Probably yes. Global analyses require different observables for flavour-decomposition!
  - Intrinsic charm/bottom will likely also be constrained at the LHC.
    More refined studies with AFTER possible?
  - Where is the tiny large-x gluon relevant?
    Need parton-parton luminosities; decomposition in subprocesses
  - What is the contribution of the gluon at $0.5<x<1$ to the momentum sum?

Data used in global analyses of PDFs

Data:

• Deep inelastic scattering data
  • H1 ,ZEUS (ep)
  • BCDMS,NMC (μp,μd)
  • CCFR (υ-Fe)
	Backbone: 10^-5 < x < 0.1
	up > down, evolution of F2 -> gluon
	$F_L \to \text{gluon}$

• p+pbar -> jet +X : D0, CDF	large-x gluon: 0.01 < x <0.5 dominated by systematics
• DY pp: E605	$q\bar{q} \to \mu^+\mu^-$ info on sea
• DY pd/pp: NA51, E866 (updated)	Asymmetry: info on $\bar{d}/\bar{u}$
• W-lepton asymmetry: CDF	*d/u* at large-x $(u\bar{d} \to W^+ \, , \, d\bar{u} \to W^-)$
• υ-DIS dimuon data: Nutev	$s \, , \, \bar{s}$

Data sets fitted in MSTW 2008 NLO analysis [arXiv:0901.0002]

Data set	χ^2 / $N_{\text{pts.}}$
H1 MB 99 e^+p NC	9 / 8
H1 MB 97 e^+p NC	42 / 64
H1 low Q^2 96–97 e^+p NC	44 / 80
H1 high Q^2 98–99 e^-p NC	122 / 126
H1 high Q^2 99–00 e^+p NC	131 / 147
ZEUS SVX 95 e^+p NC	35 / 30
ZEUS 96–97 e^+p NC	86 / 144
ZEUS 98–99 e^-p NC	54 / 92
ZEUS 99–00 e^+p NC	63 / 90
H1 99–00 e^+p CC	29 / 28
ZEUS 99–00 e^+p CC	38 / 30
H1/ZEUS $e^\pm p$ F_2^{charm}	107 / 83
H1 99–00 e^+p incl. jets	19 / 24
ZEUS 96–97 e^+p incl. jets	30 / 30
ZEUS 98–00 $e^\pm p$ incl. jets	17 / 30
DØ II $p\bar{p}$ incl. jets	114 / 110
CDF II $p\bar{p}$ incl. jets	56 / 76
CDF II $W \to l\nu$ asym.	29 / 22
DØ II $W \to l\nu$ asym.	25 / 10
DØ II Z rap.	19 / 28
CDF II Z rap.	49 / 29

Data set	χ^2 / $N_{\text{pts.}}$
BCDMS μp F_2	182 / 163
BCDMS μd F_2	190 / 151
NMC μp F_2	121 / 123
NMC μd F_2	102 / 123
NMC $\mu n/\mu p$	130 / 148
E665 μp F_2	57 / 53
E665 μd F_2	53 / 53
SLAC ep F_2	30 / 37
SLAC ed F_2	30 / 38
NMC/BCDMS/SLAC F_L	38 / 31
E866/NuSea pp DY	228 / 184
E866/NuSea pd/pp DY	14 / 15
NuTeV νN F_2	49 / 53
CHORUS νN F_2	26 / 42
NuTeV νN xF_3	40 / 45
CHORUS νN xF_3	31 / 33
CCFR $\nu N \to \mu\mu X$	66 / 86
NuTeV $\nu N \to \mu\mu X$	39 / 40
All data sets	**2543 / 2699**

- Red = New w.r.t. MRST 2006 fit.

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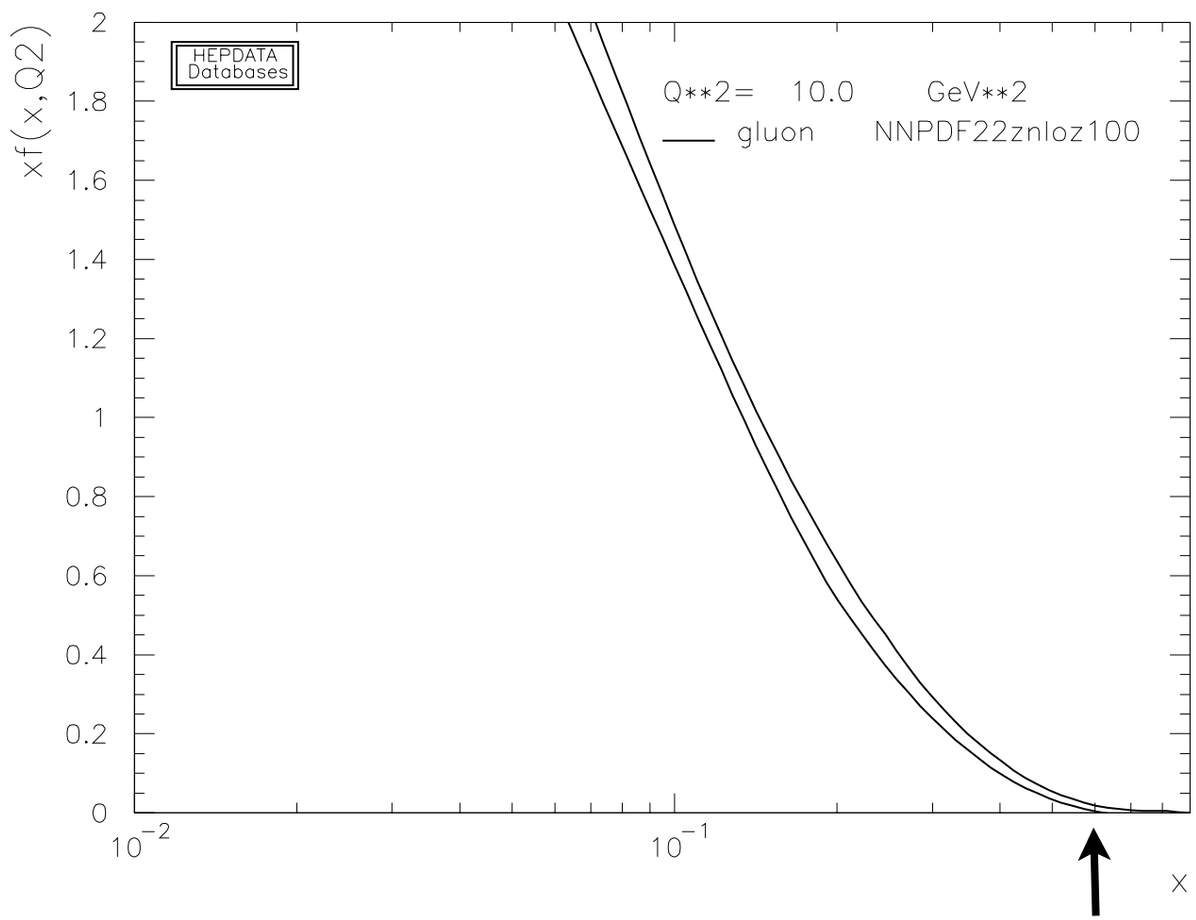
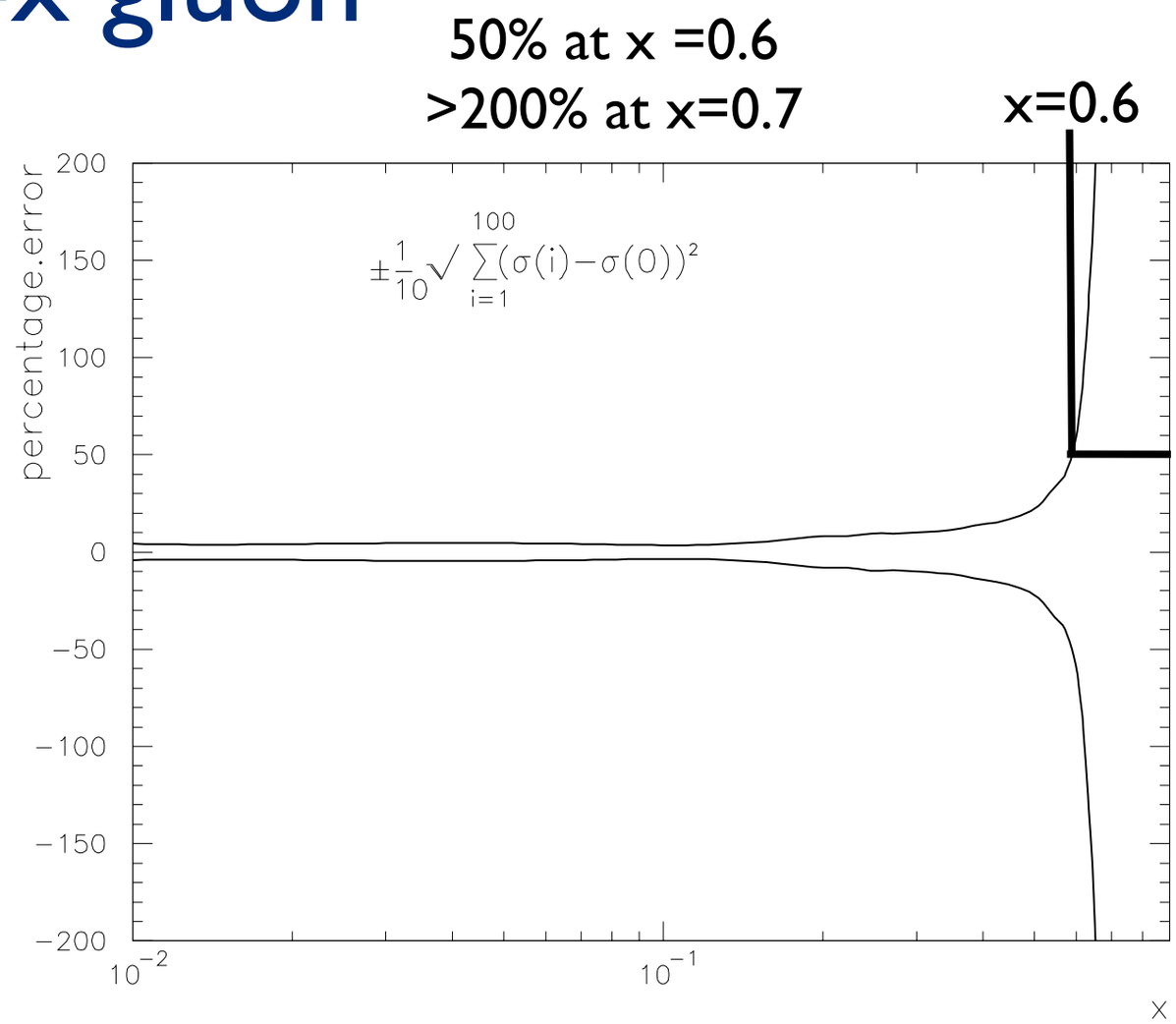
Large-x gluon

- Need to constrain gluon at x > 0.4
- Gluon sensitive processes:
  - prompt photon production very promising
    (see David D'Enterria's talk)
  - jet production at AFTER?
  - quarkonia production
    IF theoretical uncertainty due to different "models" < PDF uncertainty
    (ToDo!)
  - open heavy flavour production? (ToDo: need predictions)

Large-x gluon



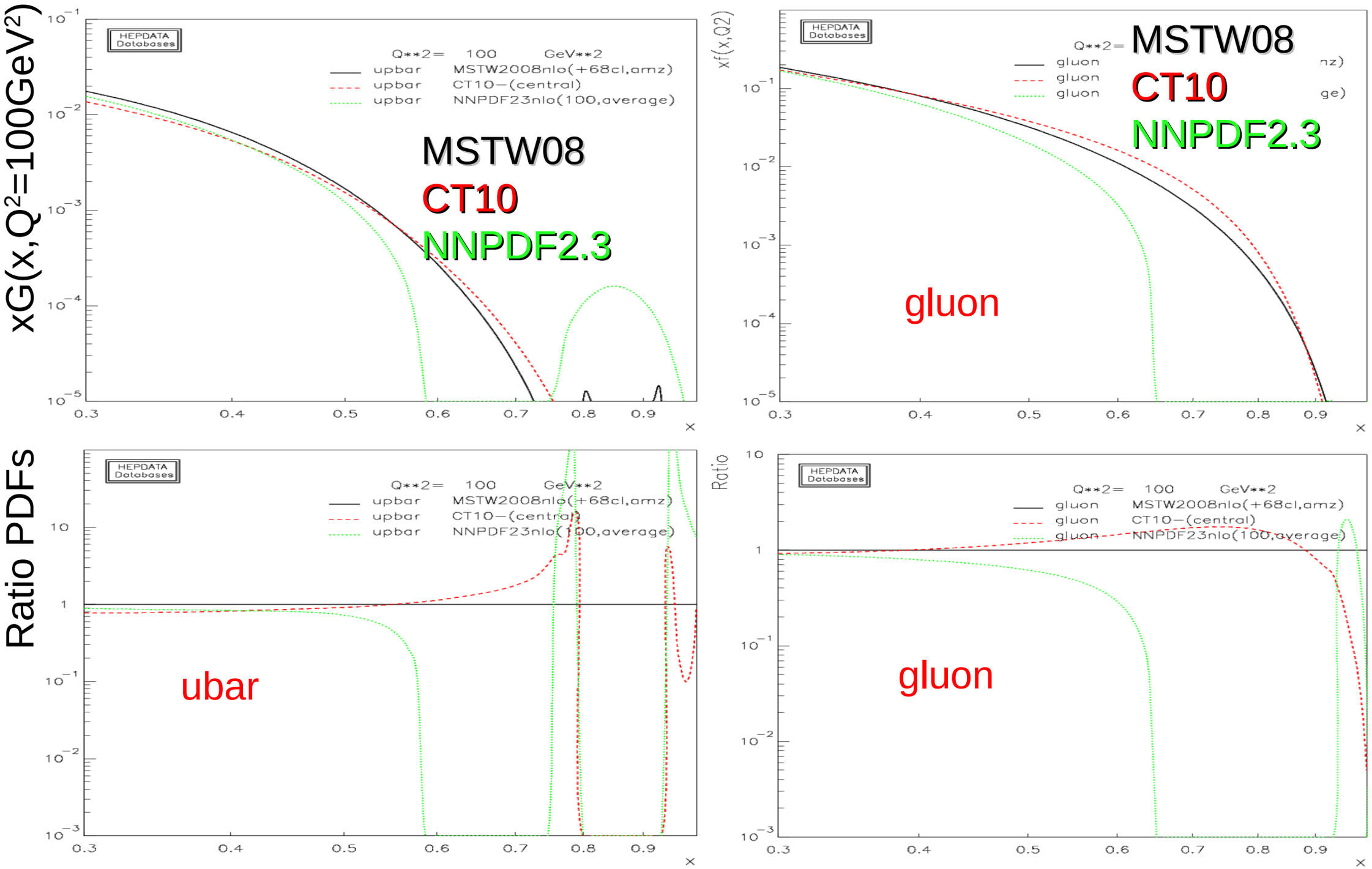


Naturally, the uncertainties get large where the gluon distribution is very small

Need: gluon sensitive subprocesses split into contributions from gg-channel and qqbar-channel to see where the qqbar-channel takes over; parton-parton-luminosities also useful!

Uncertainties in proton PDFs at high-x

- Isolated-γ at "low"-√s & high-p_T are sentitive to high-x gluons & sea:



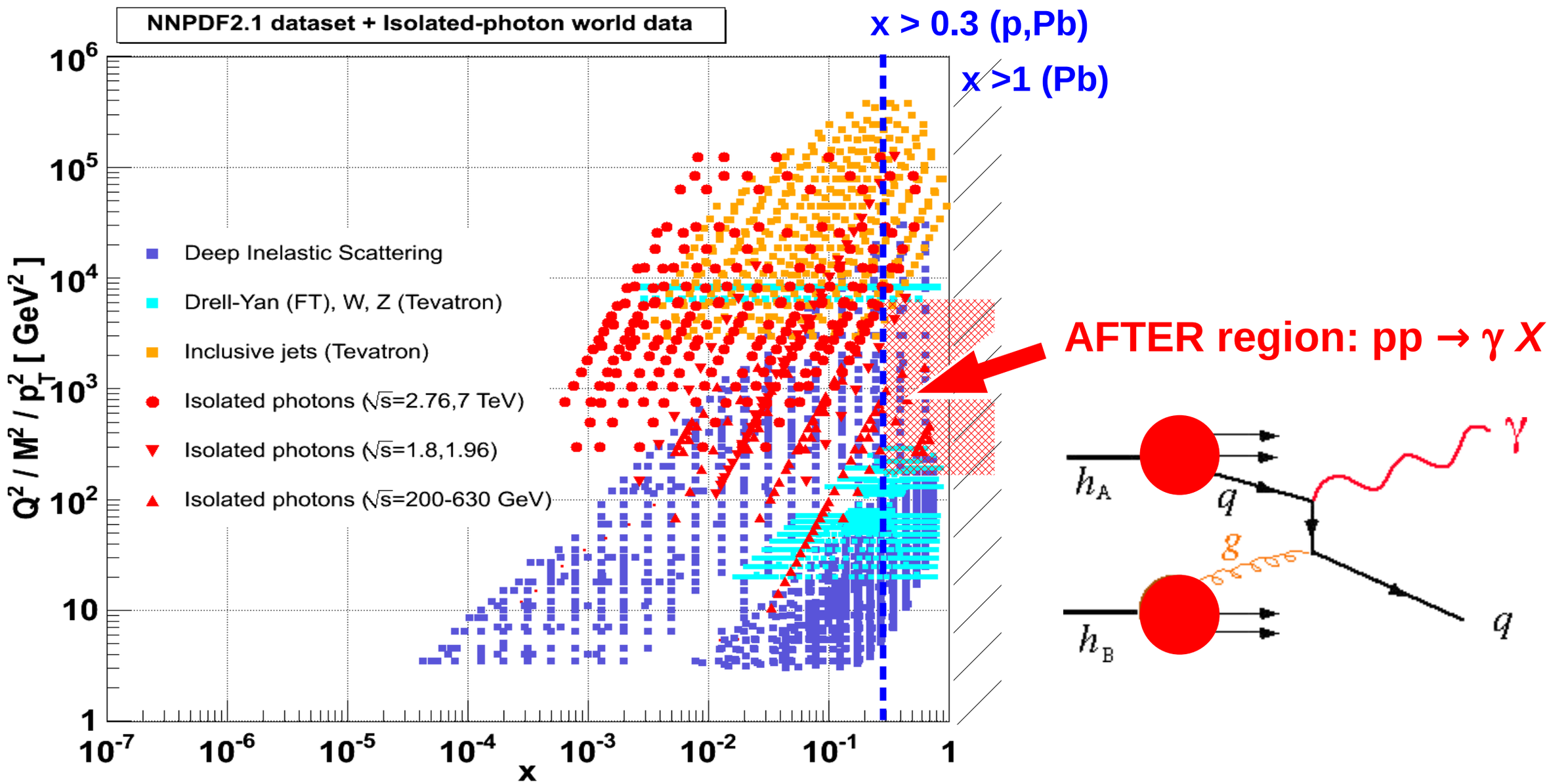
Very large uncertainties above x~0.3, also at large Q² !

(x,Q^2) map of AFTER isolated-γ

[D.d'E & J.Rojo, NPB 860 (2012) 311]

- p-p kinematics at fixed-target LHC:

To access $x > 0.3$ one needs isolated-γ with: $p_T = x_T\sqrt{s}/2 > 10\text{-}20$ GeV/c

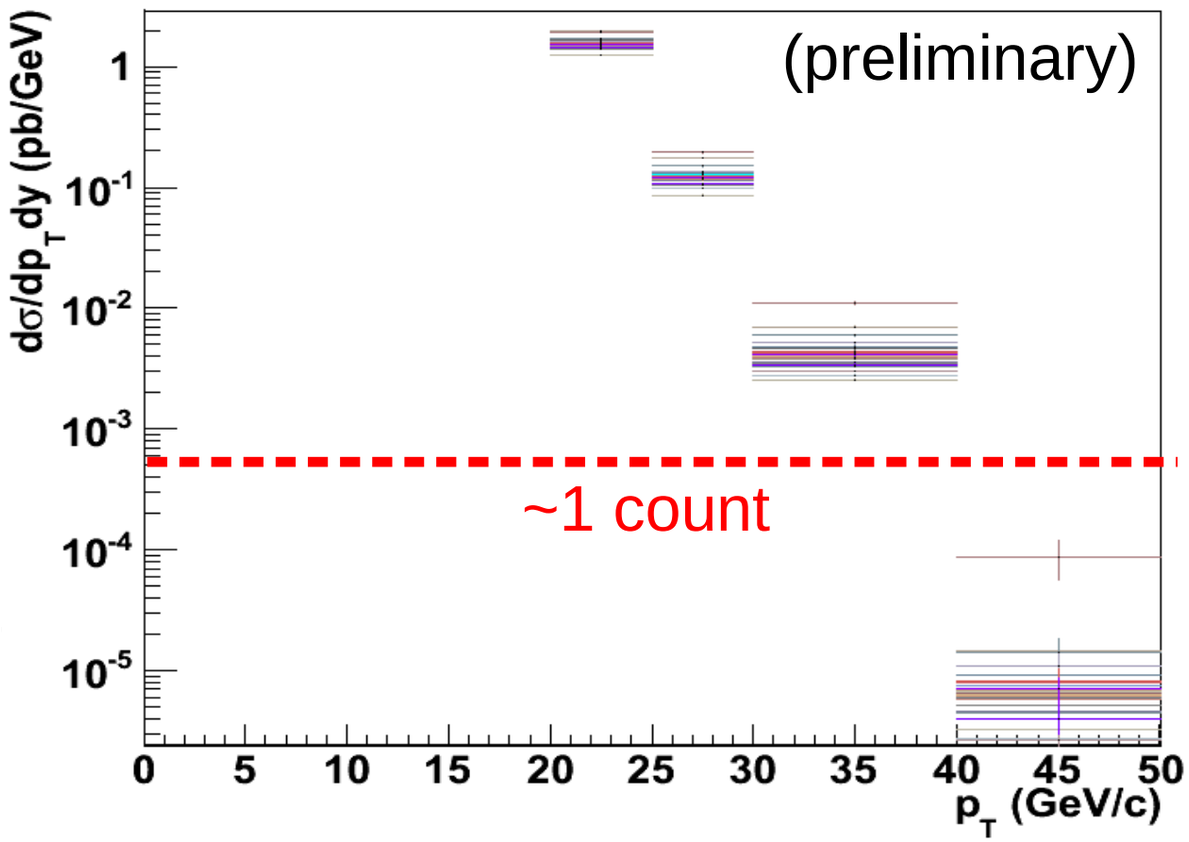


Isolated-γ in p(7 TeV)-p(rest): √s ~ 115 GeV

- p-p photon kinematics at fixed-target LHC (backwards rapidities):
  To access x > 0.3 one needs isolated-γ at: $p_T = x_T\sqrt{s}/2e^{-y} > 10$ GeV/c
- JETPHOX NLO pQCD calculations:

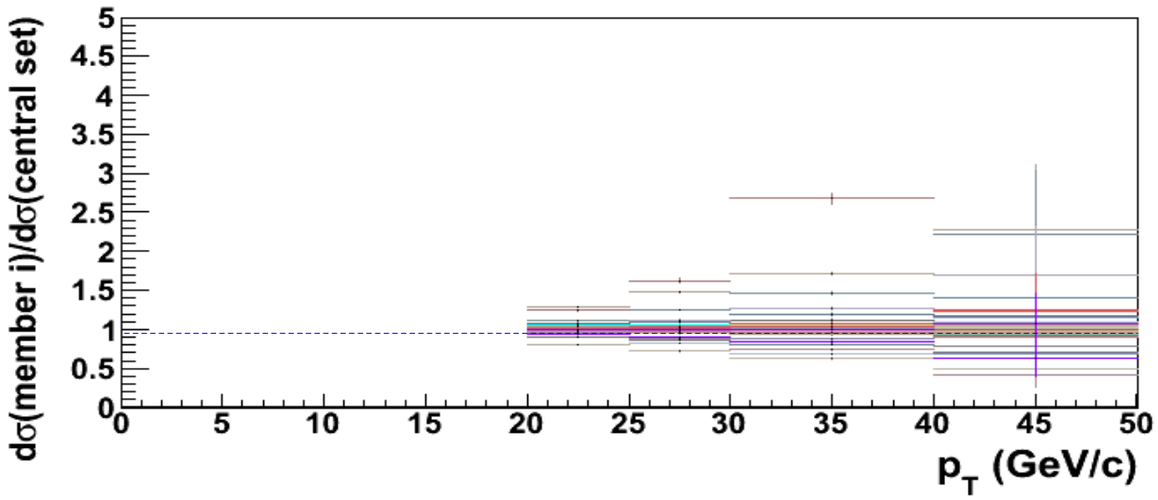
  p-p at √s=115 GeV
  0<y<-3., p_T>20 GeV/c
  Isolation: R=0.4, E_T^{had}<5 GeV

  $\mathcal{L}$(10 cm H_2-target) ~ $2 \bullet 10^3$ pb^{-1}/year

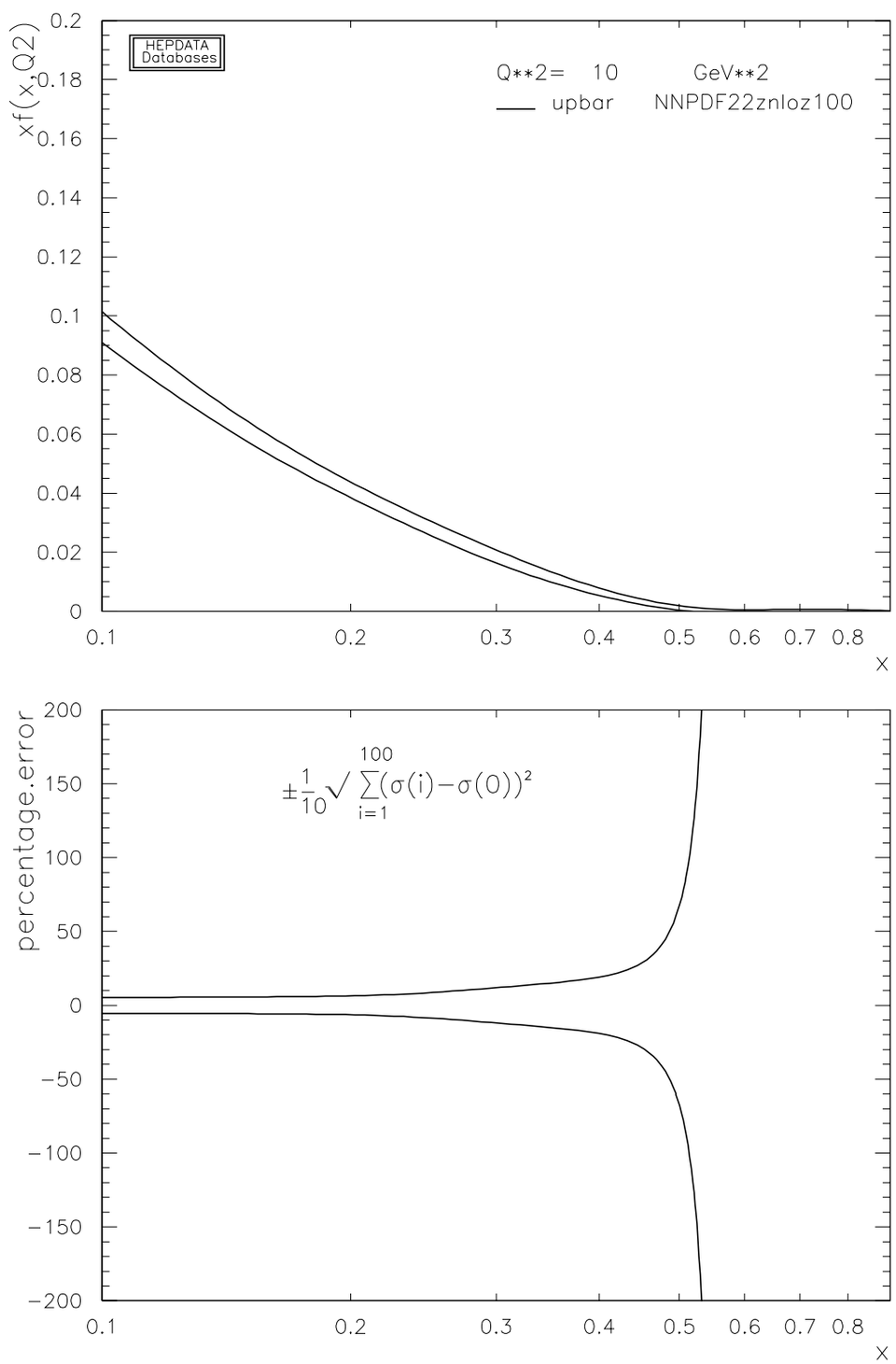


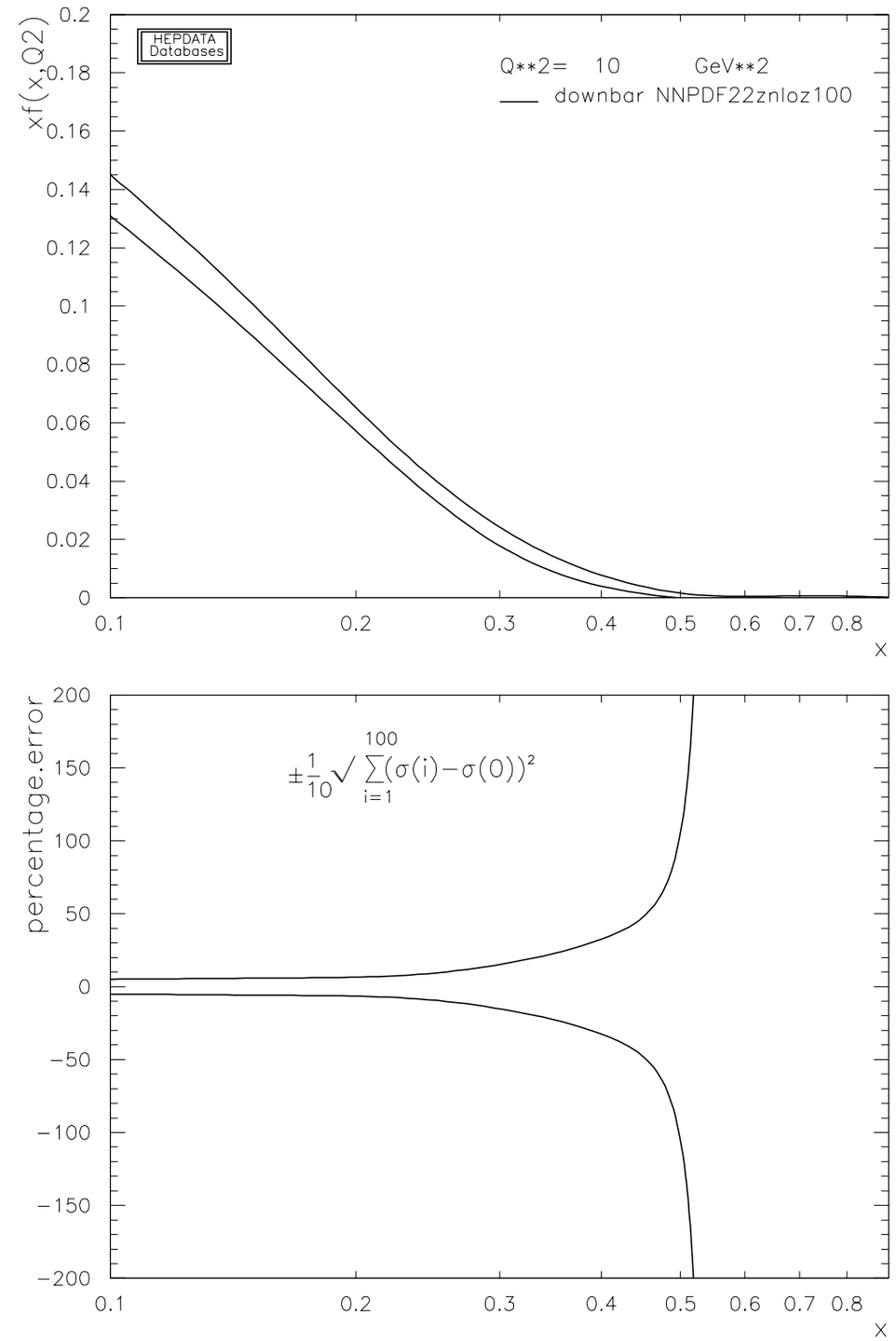
PDF: CT10 52 eigenval. (90% CL)
Scales: $\mu_i = p_T$
FF = BFG-II
x-section uncertainties(*) of ±170%

(*) (68%CL)/(90% CL) ~ 1.65



Large-x sea quarks





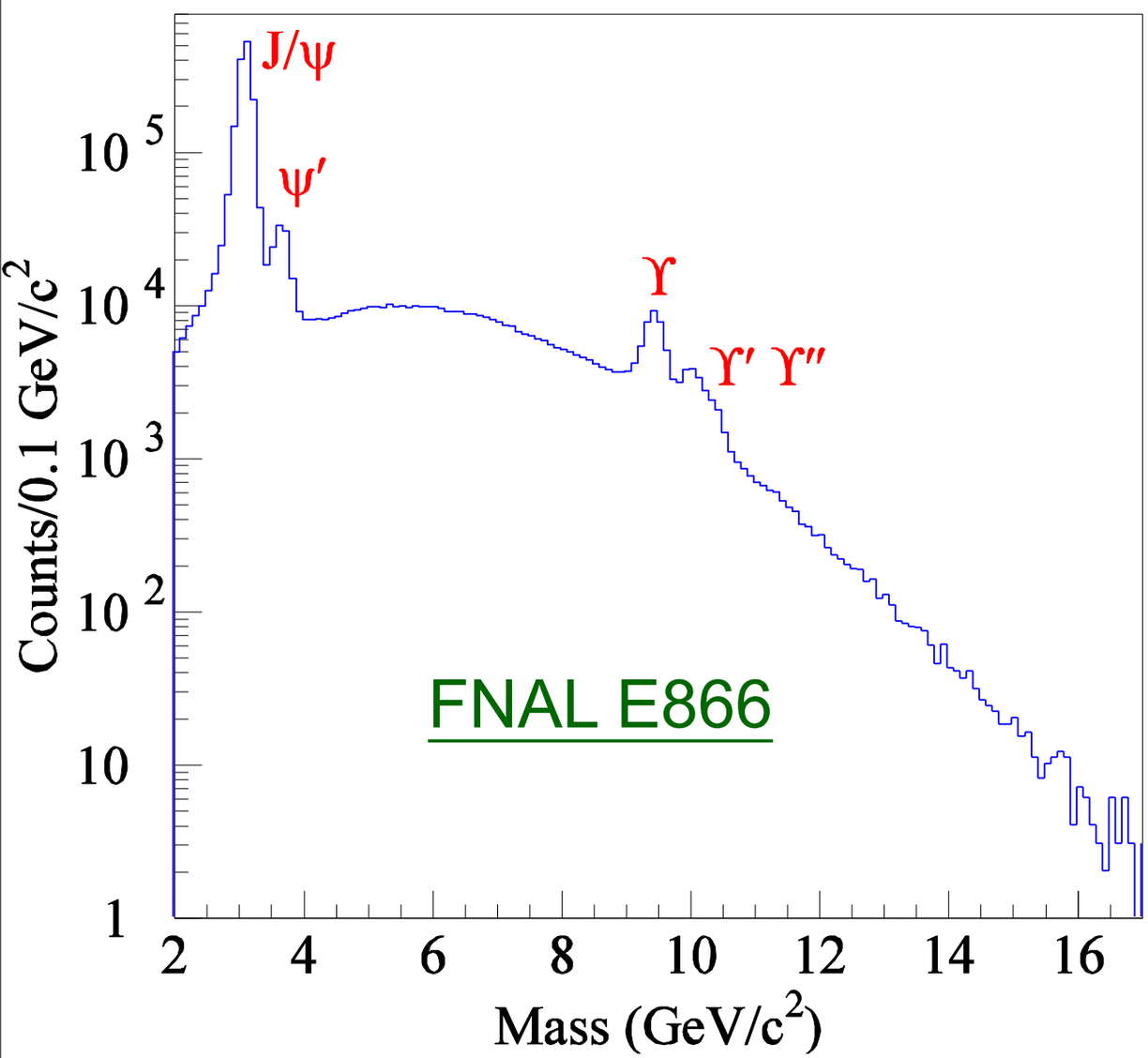
Large-x sea quarks

- Important for new physics searches at LHC (very heavy states, very large pT)
- Can be constrained by Drell-Yan process
- Benchmark against E906/SeaQuest!
- Question: What can LHC do to constrain large-x PDFs?
- Together with DIS data improves flavour-separation in a global analysis

Dilepton production in hadron-hadron collision

Talk by J.-C. Peng

$p + p(d) \rightarrow \mu^+\mu^- x$ at 800 GeV/c



Two components in the dilepton mass spectrum

(a) Continuum: Drell-Yan process

- Electromagnetic process
- Quark - antiquark annihilation

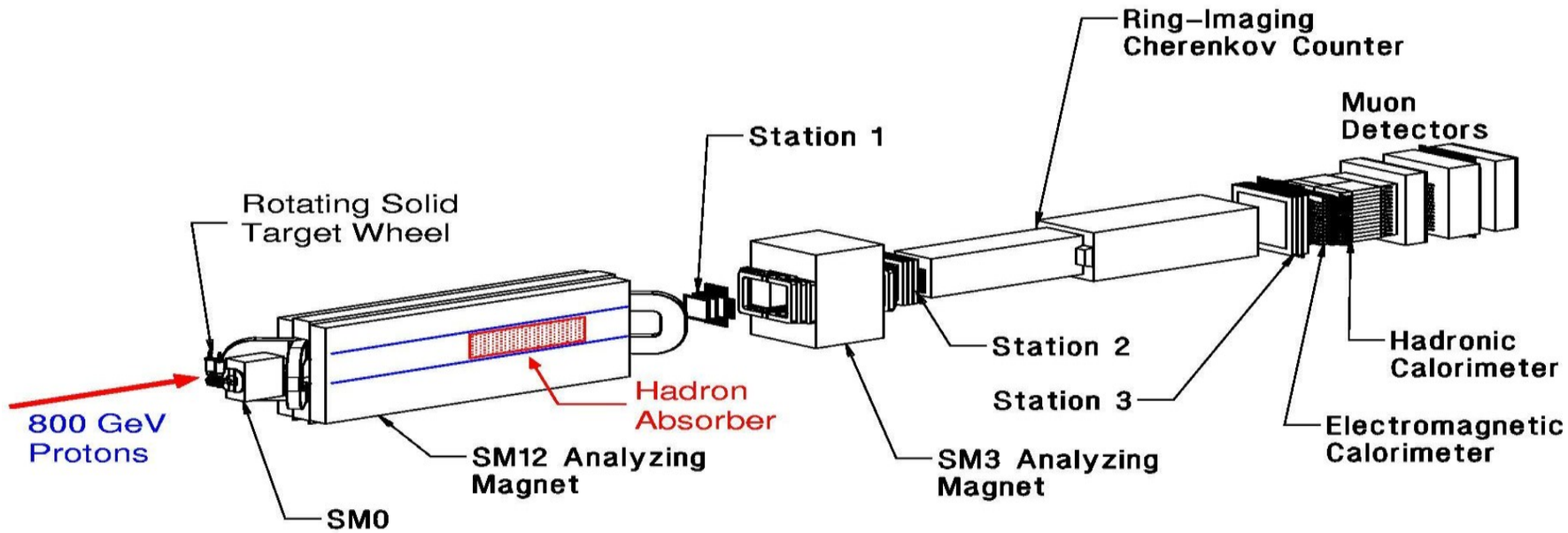
(b) Vector mesons: J/ψ, Y

- Strong interaction
- Gluon - gluon fusion

  (quark - antiquark annihilation)

Fermilab Dimuon Spectrometer

(E605 / 772 / 789 / 866 / 906)



1) Fermilab E772 (proposed in 1986 and completed in 1988)

"Nuclear Dependence of Drell-Yan and Quarkonium Production"

2) Fermilab E789 (proposed in 1989 and completed in 1991)

"Search for Two-Body Decays of Heavy Quark Mesons"

3) Fermilab E866 (proposed in 1993 and completed in 1996)

"Determination of $\bar{d}/\bar{u}$ Ratio of the Proton via Drell-Yan"

4) Fermilab E906 (proposed in 1999, run started in 2012)

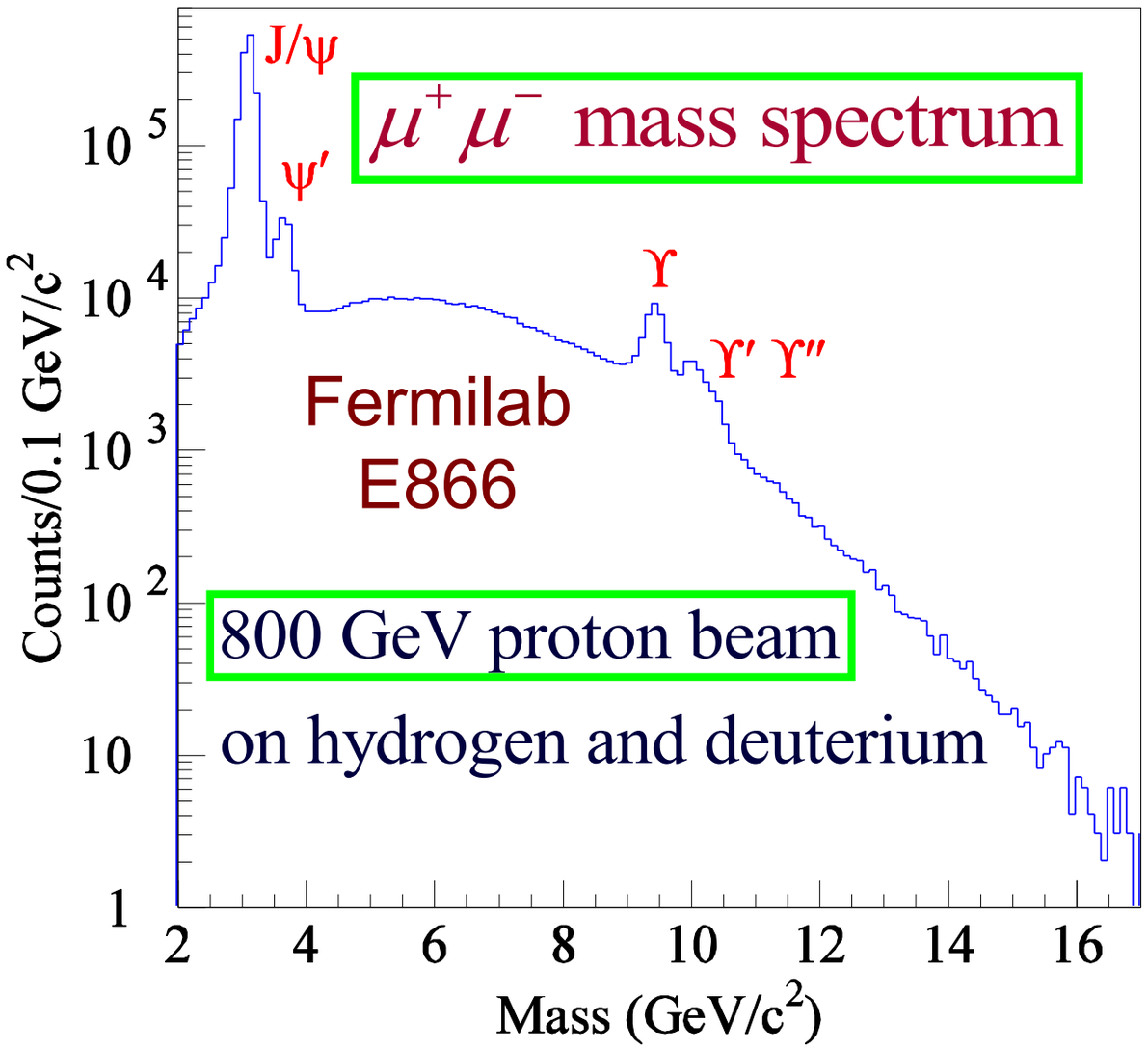
"Drell-Yan with the FNAL Main Injector"

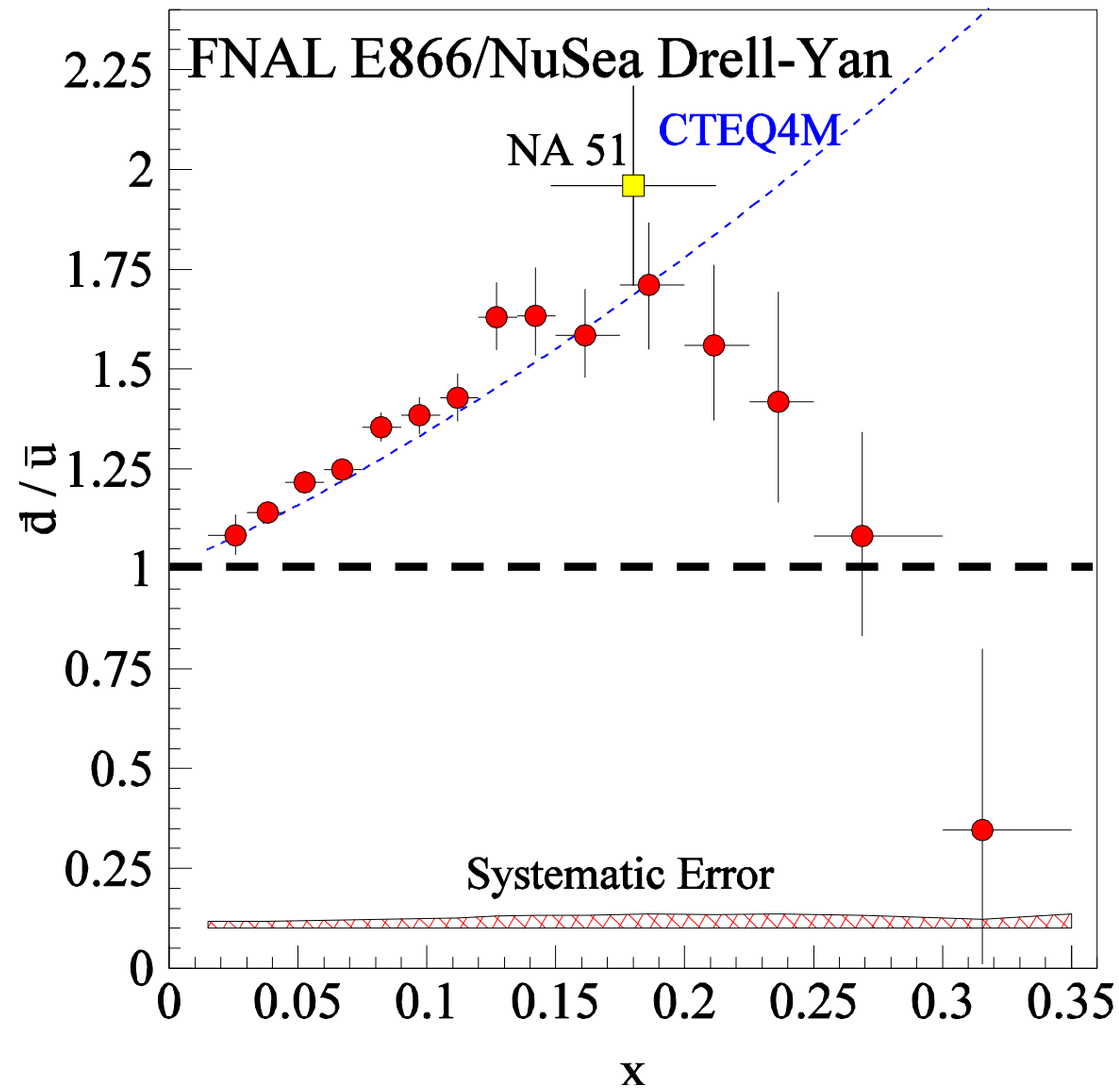
ToDo: Table of fixed target experiments

Experiment	Beam energy [GeV]	CMS energy [GeV]	Luminosity
E866/ Nusea	800	38.8	?
E906/ SeaQuest	120	15.5	?
AFTER	7000	115	?
...	...	...	...

$\bar{d}/\bar{u}$ flavor asymmetry from Drell-Yan

$$\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2)+\bar{q}_a(x_1)q_a(x_2)\right]$$

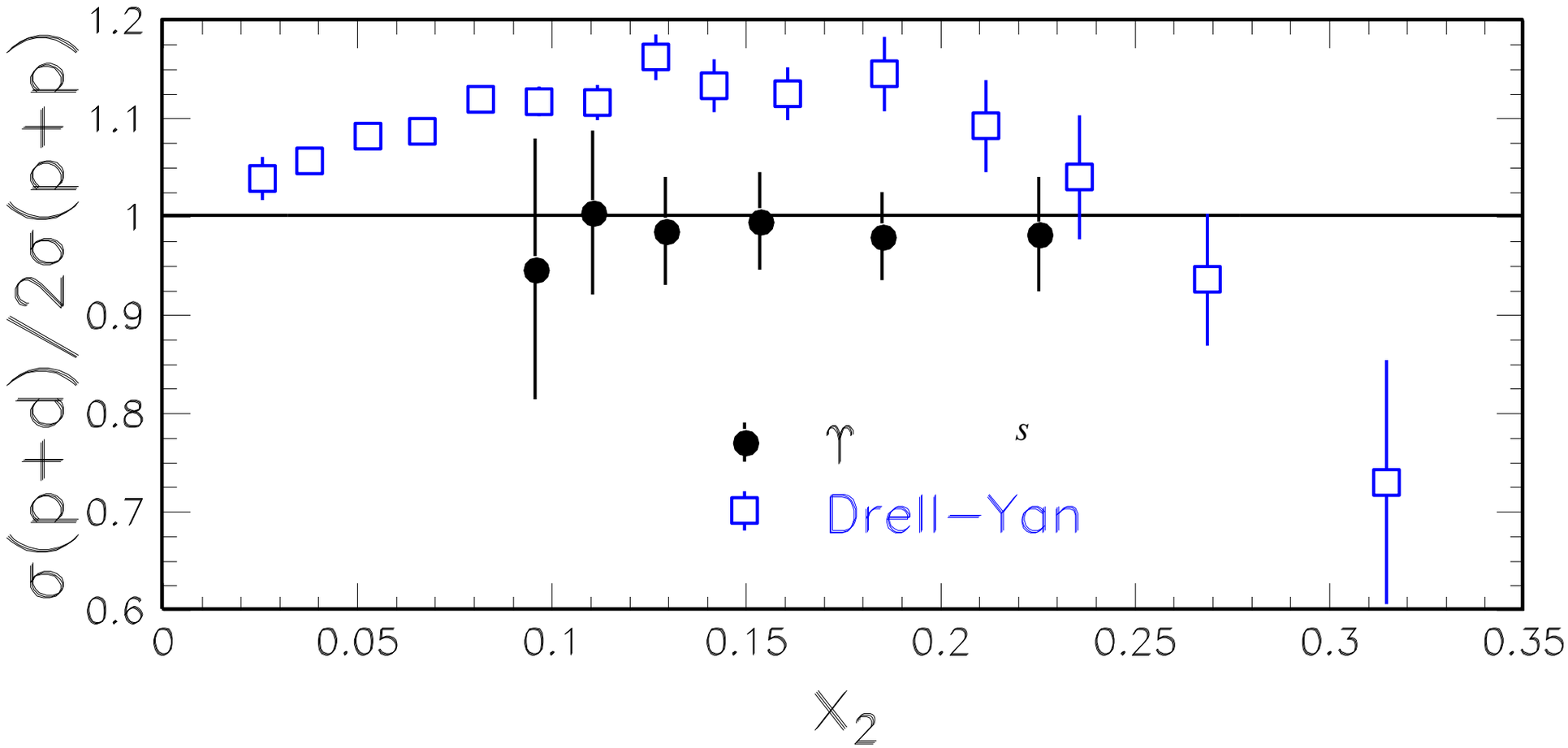




$at\ x_1 > x_2$: Drell-Yan: $\sigma^{pd}/2\sigma^{pp} \sim \frac{1}{2}(1+\bar{d}(x_2)/\bar{u}(x_2))$

Gluon distributions in proton versus neutron?

$$\text{E866 data}: \sigma(p+d \to \Upsilon X)/2\sigma(p+p \to \Upsilon X)$$



Lingyan Zhu et al., PRL, 100 (2008) 062301 (arXiv: 0710.2344)

$$Drell-Yan: \quad \sigma^{pd}/2\sigma^{pp} \simeq [1+\bar{d}(x)/\bar{u}(x)]/2$$

$$J/\Psi, \Upsilon: \quad \sigma^{pd}/2\sigma^{pp} \simeq [1+g_n(x)/g_p(x)]/2$$

If gluon distributions in proton and neutron are different, then charge-symmetry is violated at the partonic level

Discussion

- Charge symmetry violation in PDF? (u_p ≠ d_n?)
  - Yes, already due to QED radiation since photon couples differently to up and down quarks; but also non-perturbative mechanisms
  - See also review of CSV in arXiv:0906.3563
- Origin of ubar ≠dbar?
- SeaQuest is adressing these questions. Where can AFTER contribute? Higher energy, higher lumi!
  - Higher invariant masses of lepton pair
    Suppress higher twist contributions!
  - Extended x-range
  - Different nuclear targets! (Which ones?)
  - ToDo: Make plot of kinematic plane!

Intrinsic charm/bottom

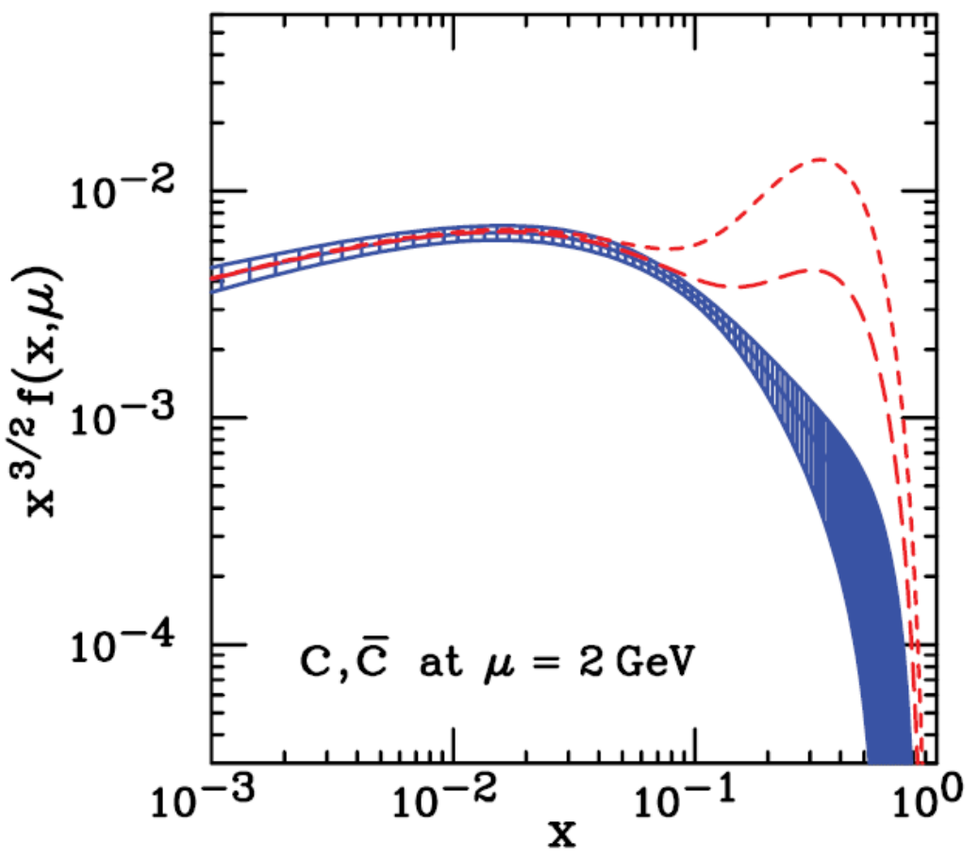
- Has to be there if QCD is right! Question: what is the normalization?
- Need to "measure" heavy quark PDFs:
  - Essential for new physics searches, electroweak observables and backgrounds!
  - Many important b-quark initiated processes
- Processes at AFTER sensitive to IC/IB
  - Gamma+Q production (see talk by T. Stavreva)
  - Probably inclusive D meson (B meson) production
- LHC will likely provide constraints on IC/IB
- Question: What can AFTER do better?
  - Probe extended x-region? (probe entire BHPS x-shape?)
  - Distinguish between intrinsic charm and anti-charm?
  - Better precision?
  - Disentangle gluon PDF at large-x from intrinsic charm
    Should be doable using different processes: prompt photons, jets, gamma+c, open/hidden charm

A global fit by CTEQ to extract intrinsic-charm

PHYSICAL REVIEW D 75, 054029 (2007)

Charm parton content of the nucleon

J. Pumplin,[1,*] H. L. Lai,[1,2,3] and W. K. Tung[1,2]



Blue band corresponds to CTEQ6 best fit, including uncertainty

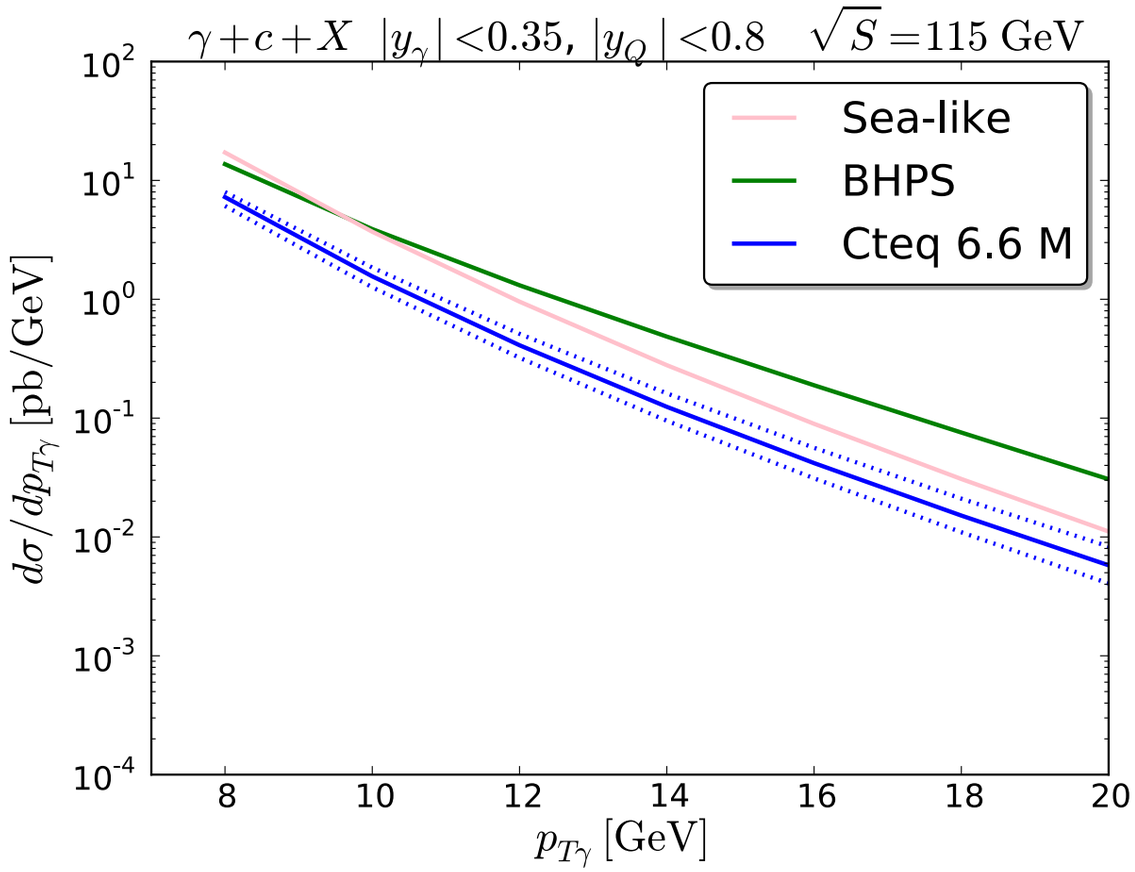
Red curves include intrinsic charm of 1% and 3% (χ^2 changes only slightly)

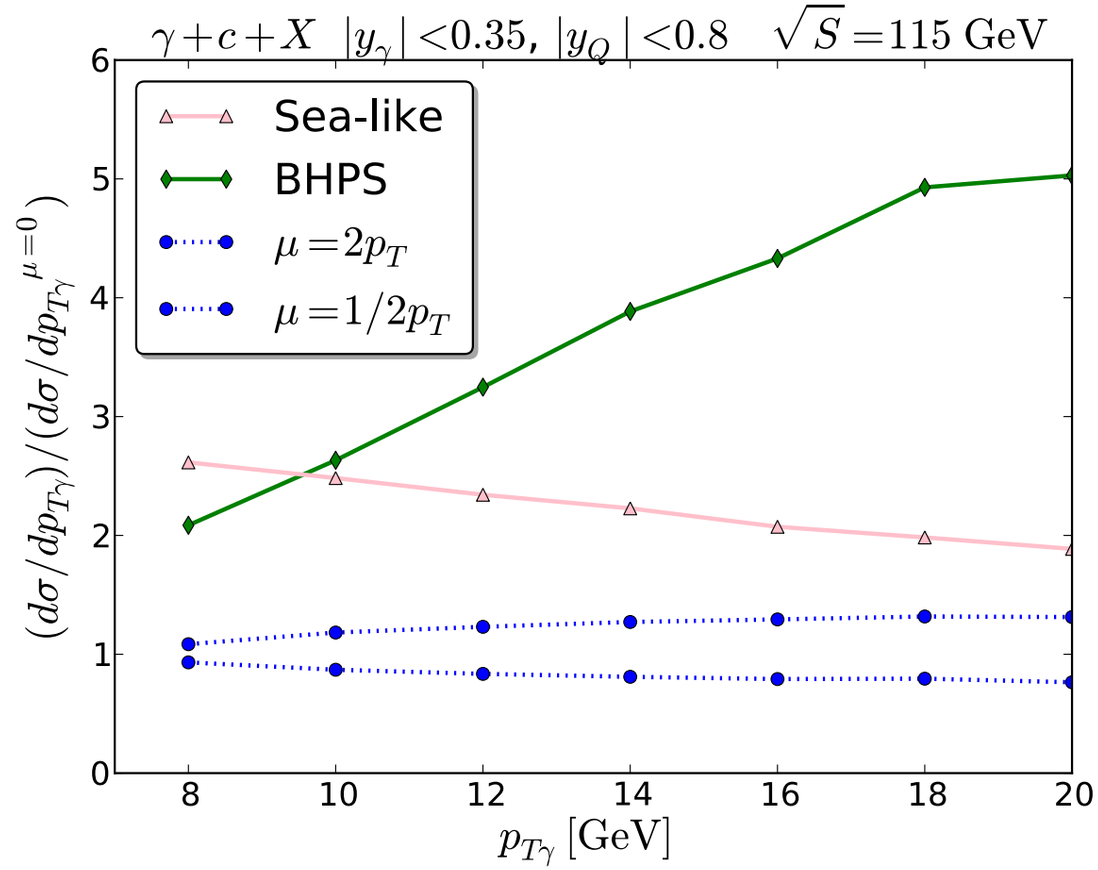
We find that the range of IC is constrained to be from zero (no IC) to a level 2–3 times larger than previous model estimates. The behaviors of typical charm distributions within this range are described, and their implications for hadron collider phenomenology are briefly discussed.

No conclusive evidence for intrinsic-charm

Probing IC with γ+Q at AFTER

See talk by T. Stavreva

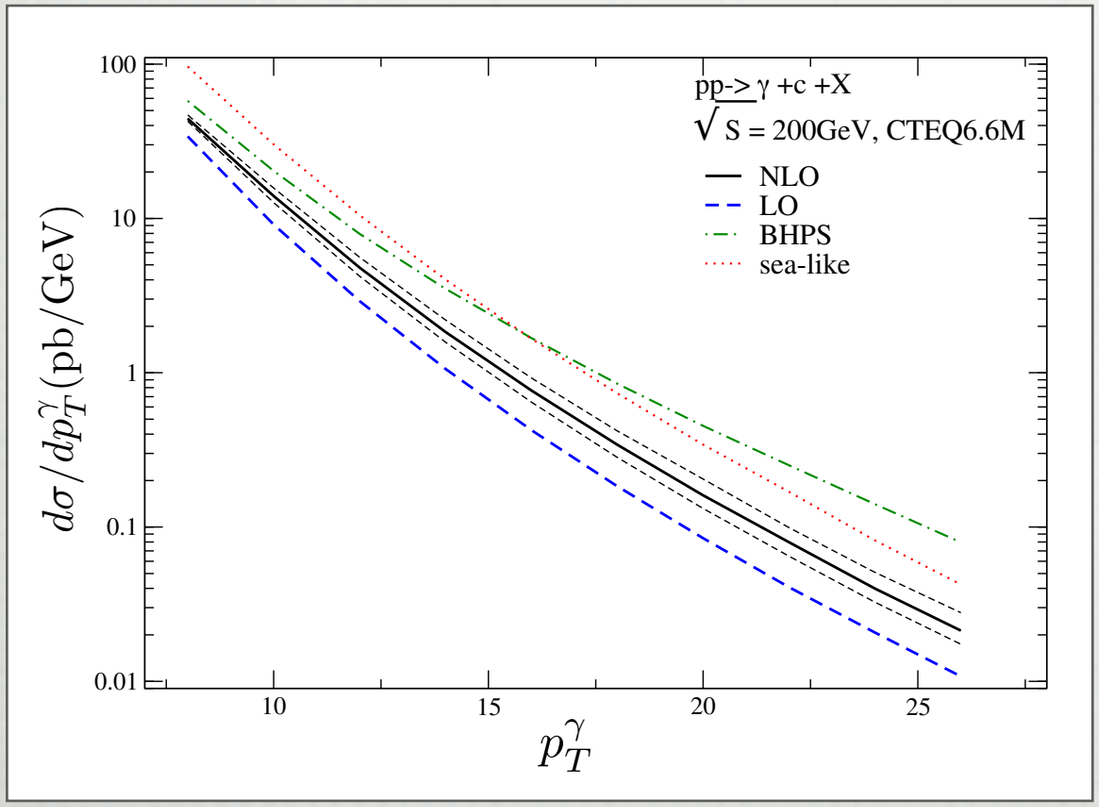


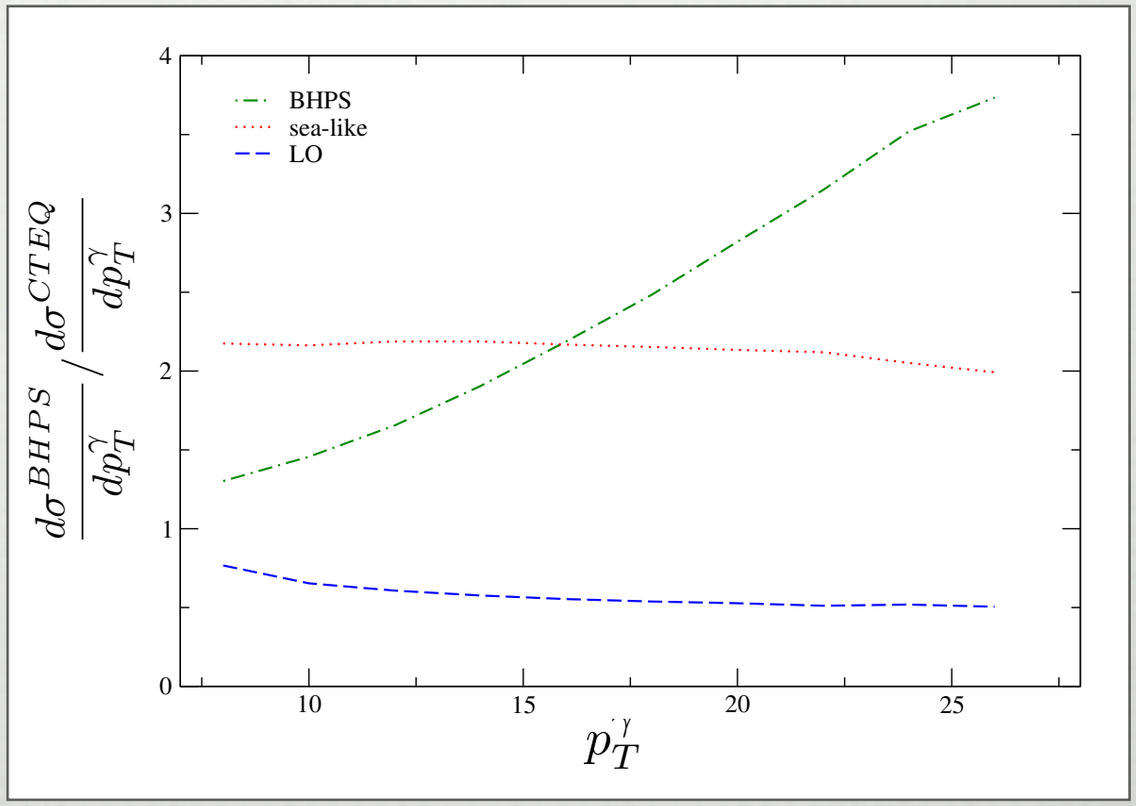


RHIC-PHENIX

- Direct photon in association with charm / bottom quark jets @ RHIC
  - smaller c.m.s energy @ RHIC probes higher x - very sensitive to intrinsic charm

	p_T min	Rapidity	Isolation
Photon	7 GeV	$\lvert y_\gamma \rvert < 0.35$	R=0.5, p_T = 0.7GeV
Heavy Jet	5 GeV	$\lvert y_Q \rvert < 0.8$	---

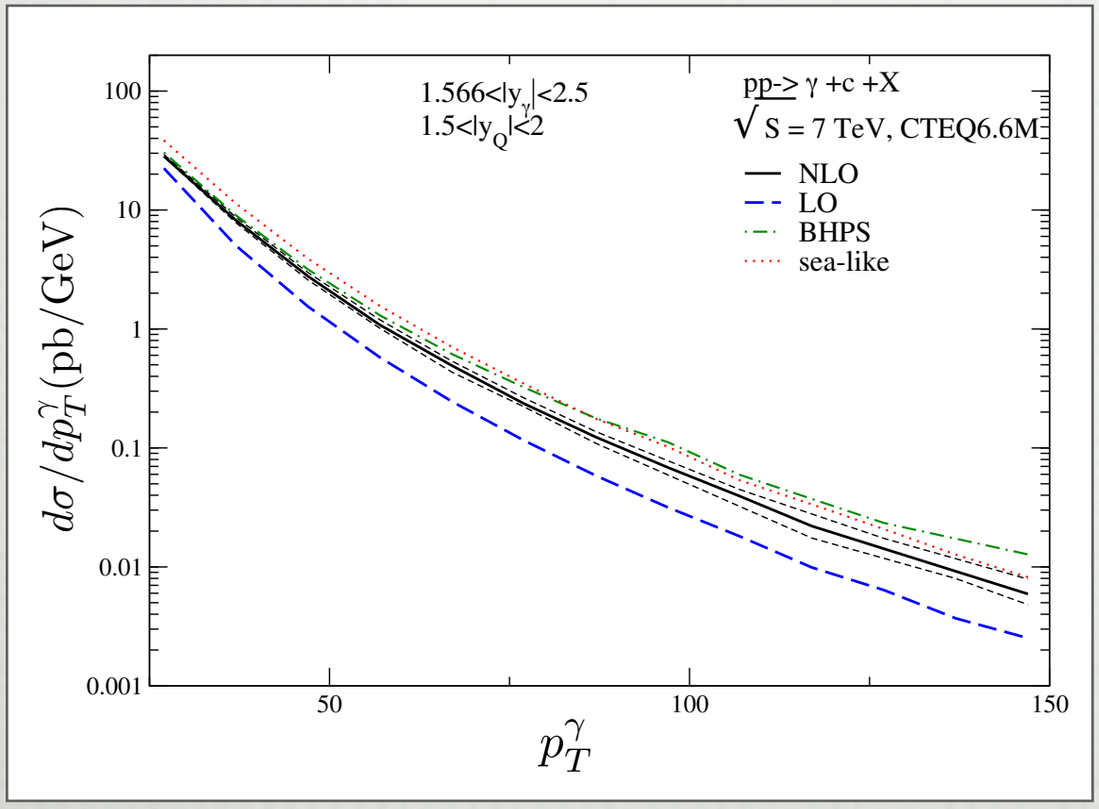


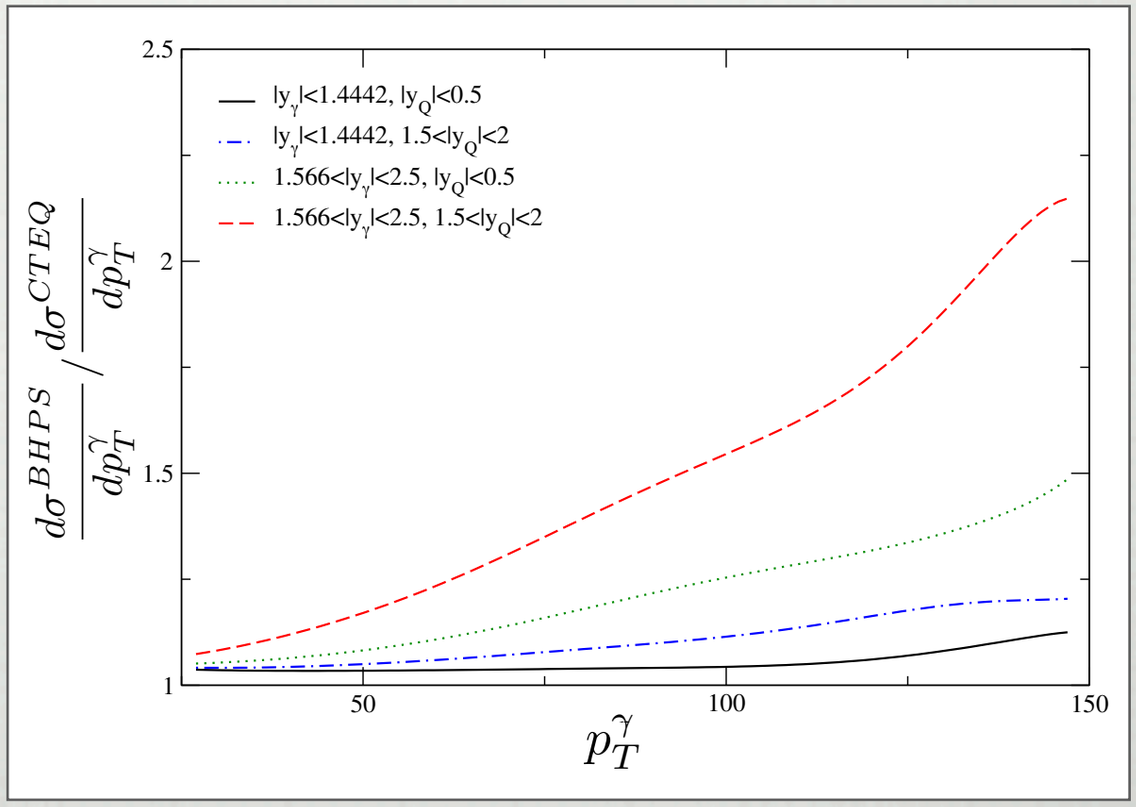


LHC-CMS

- Direct photon in association with charm / bottom quark jets @ CMS
  - CMS cuts on photon & HQ transverse momentum, rapidity & isolation cuts

	p_T min	Rapidity	Isolation
Photon	20 GeV	$\lvert y_\gamma\rvert<1.4442$	R=0.4, p_T = 4.2GeV
		$1.56<\lvert y_\gamma\rvert<2.5$	
Heavy Jet	18 GeV	$\lvert y_Q\rvert<2.0$	---

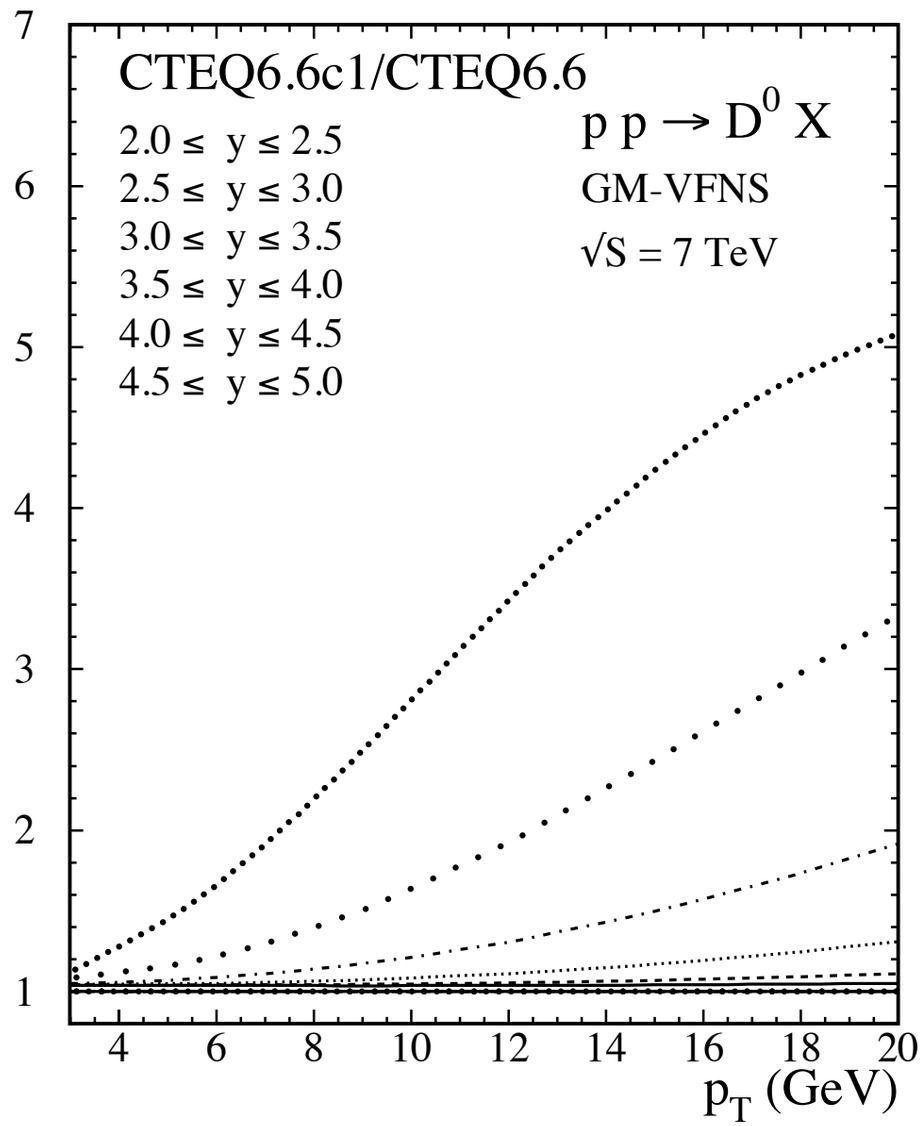


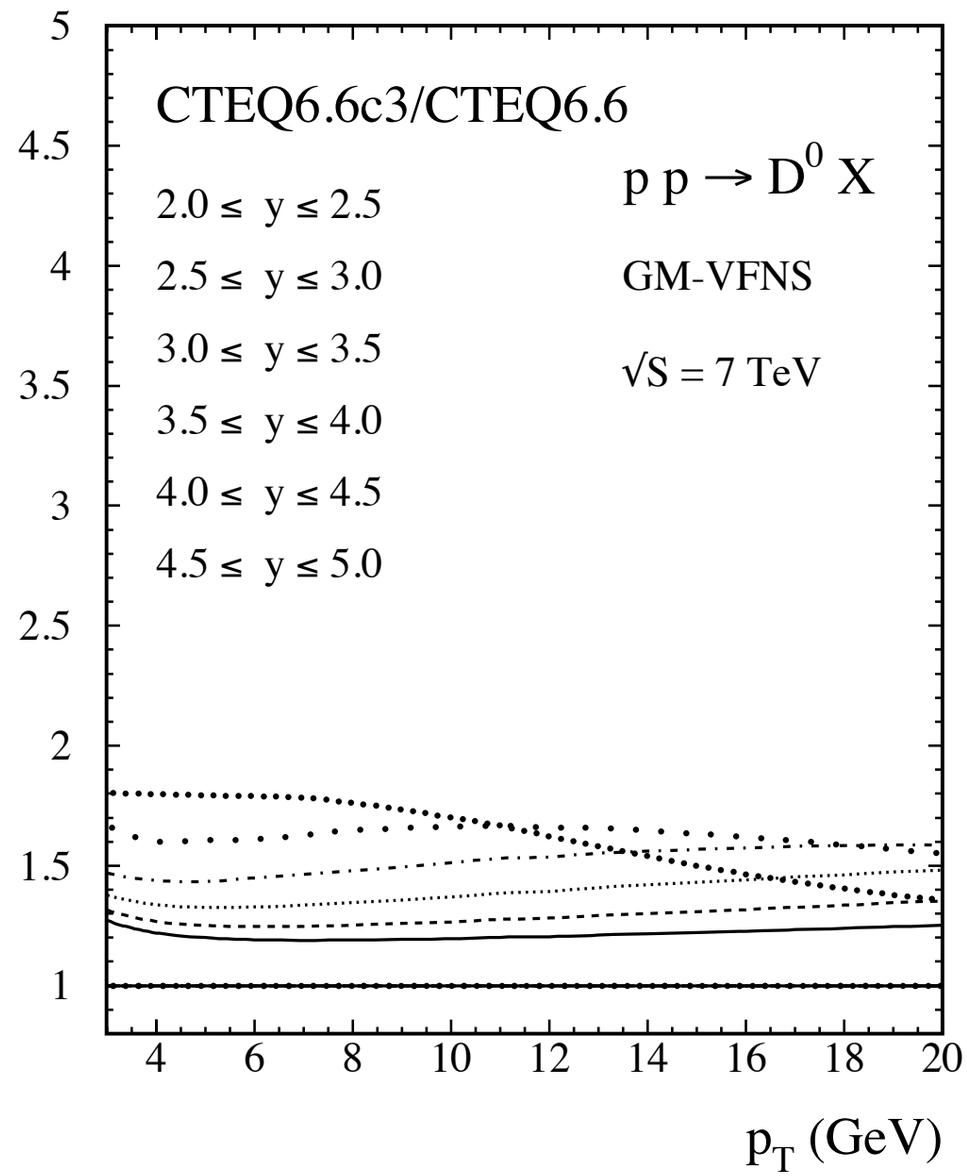


[CMS notes: CMS PAS EGM-10-005, CMS PAS BPH-10-009]

INTRINSIC CHARM: LHCB

arXiv:1202.0439, arXiv:0901.4130



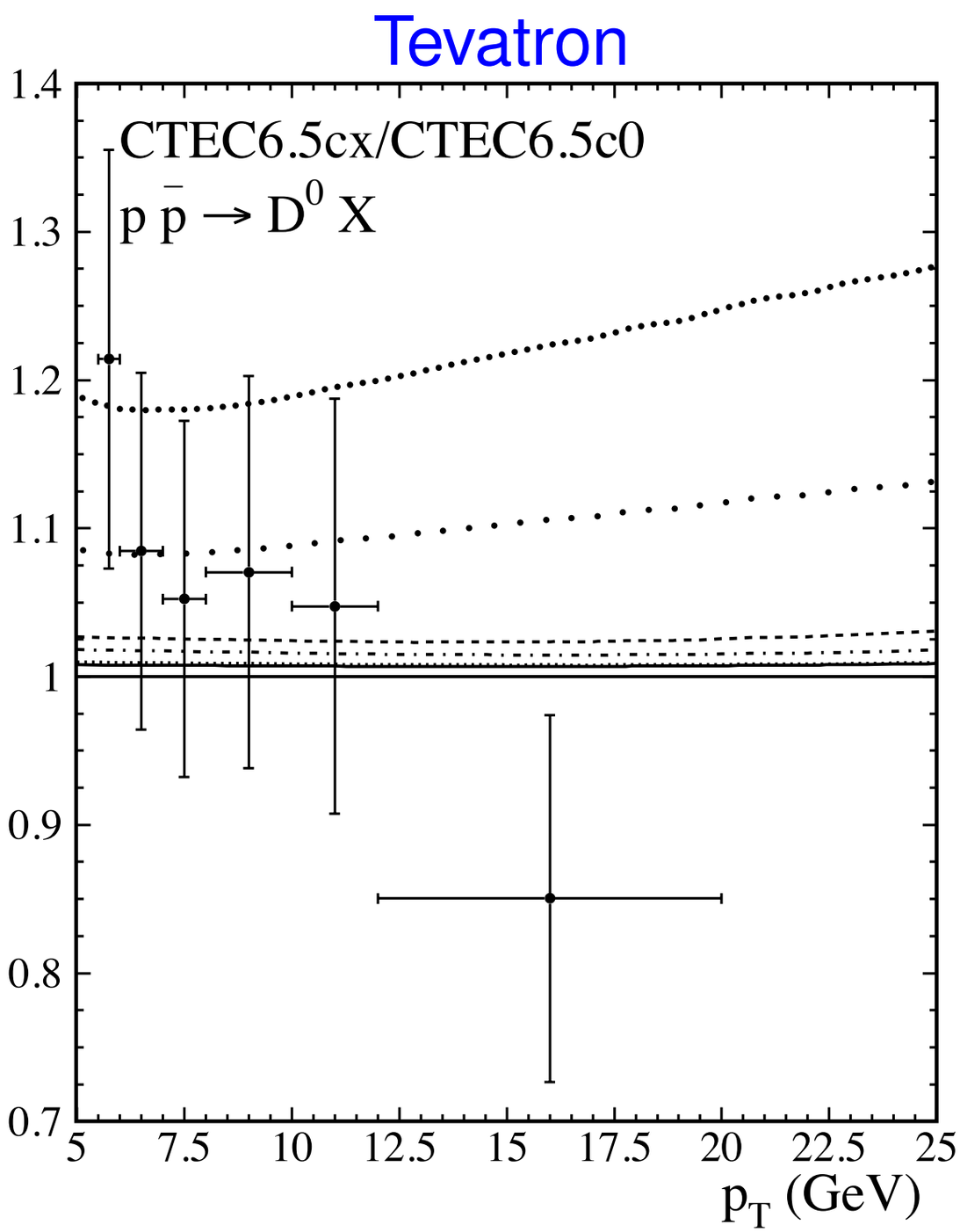


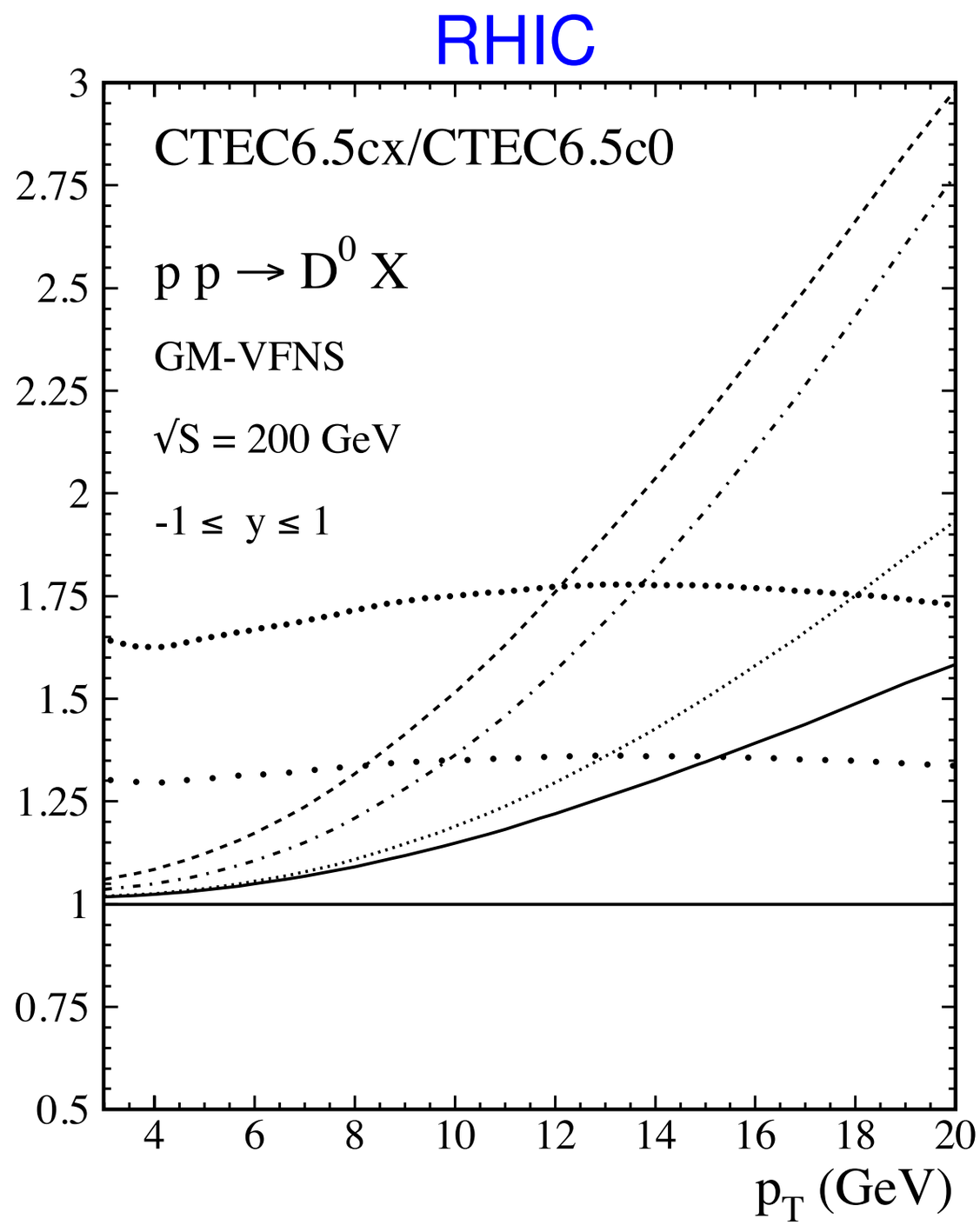
CTEQ6.6 updated:

BHPS, 3.5 % $(c + \bar{c})$ at $\mu = 1.3$ GeV high-strength sea-like charm

➜ large effects expected at large rapidities

Intrinsic charm: Tevatron and RHIC





PRD79, 2009

Partonic structure of nuclei

Where can AFTER contribute?

- nPDFs at large-x very(!) poorly known
  - gluon
  - sea quark distributions
  - intrinsic charm/bottom (will probably not be constrained at LHC!?)
- no need to model A-dependence if sufficient data for a single nucleus (A,Z) available!
- Questions (similar as in proton case)
  - Which processes at AFTER allow to constrain some of these distributions? Likely the same as in the proton case.
  - Large-x PDFs will also be measured in eA at JLAB in DIS. Complementary?
  - Where is the tiny large-x gluon relevant? Same question as for proton case.

EXPERIMENTAL INPUT

Use same data as HKN'07 (up to cuts)

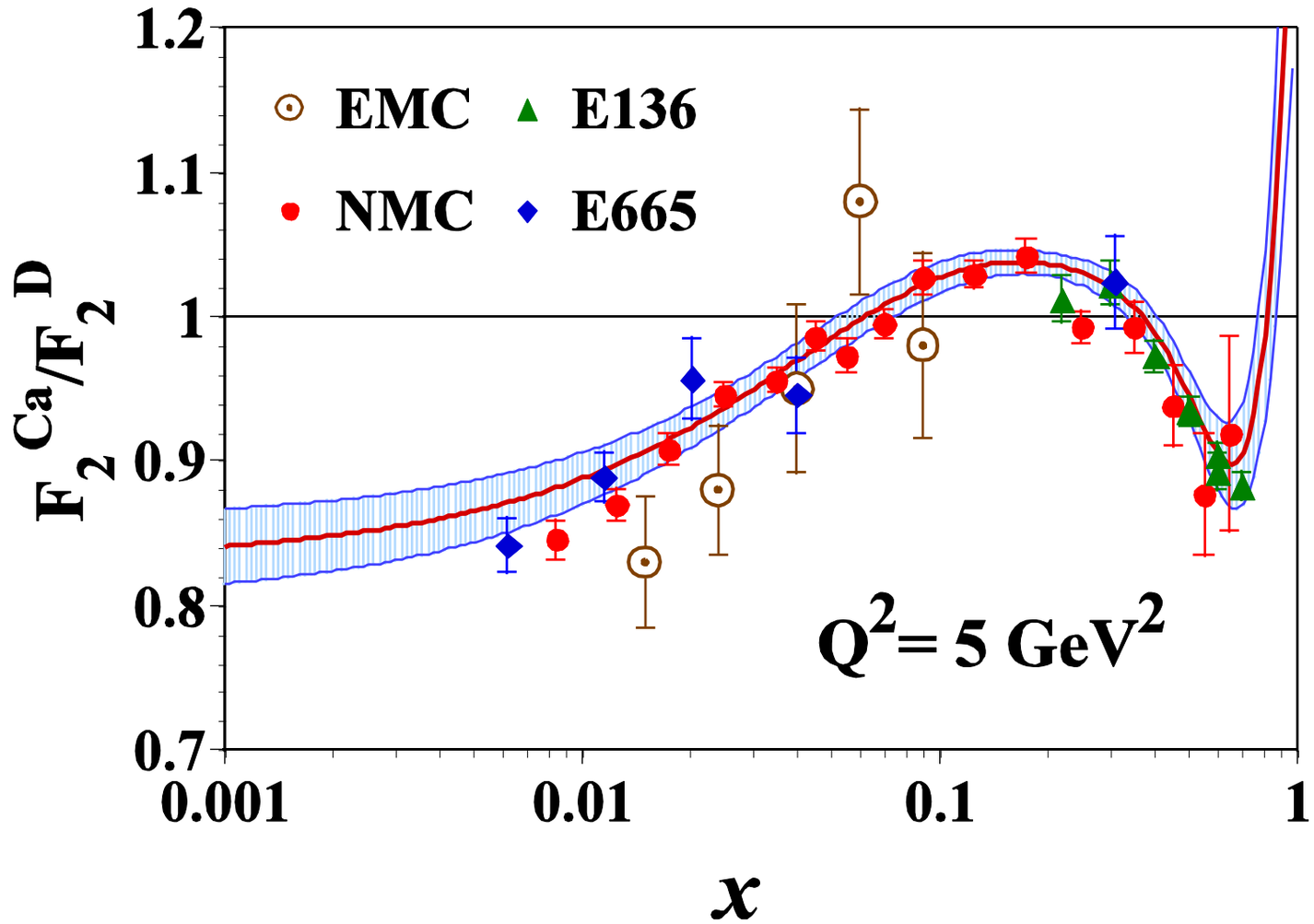
- DIS F_2^A/F_2^D data sets: 862 points (before cuts)
- DIS $F_2^A/F_2^{A'}$ data sets: 297 points (before cuts)
- DY data sets $\sigma_{\rm DY}^{pA}/\sigma_{\rm DY}^{pA'}$: 92 points (before cuts)

Table from Hirai et al.,arXiv:0909.2329

	R	Nucleus	Experiment	EPS09	HKN07	DS04
DIS		D/p	NMC		O	
	A/D	4He	SLAC E139	O	O	O
			NMC95	O (5)	O	O
		Li	NMC95	O	O	
		Be	SLAC E139	O	O	O
		C	EMC-88, 90		O	
			NMC 95	O	O	O
			SLAC E139	O	O	O
			FNAL-E665		O	
		N	BCDMS 85		O	
			HERMES 03		O	
		Al	SLAC E49		O	
			SLAC E139	O	O	O
		Ca	EMC 90		O	
			NMC 95	O	O	O
			SLAC E139	O	O	O
			FNAL-E665		O	
		Fe	SLAC E87		O	
			SLAC E139	O (15)	O	O
			SLAC E140		O	
			BCDMS 87		O	
		Cu	EMC 93	O	O	
		Kr	HERMES 03		O	
		Ag	SLAC E139	O	O	O
		Sn	EMC 88		O	
		Au	SLAC E139	O	O	O
			SLAC E140		O	
		Pb	FNAL-E665		O	
	A/C	Be	NMC 96	O	O	O
		Al	NMC 96	O	O	O
		Ca	NMC 95		O	
			NMC 96	O	O	O
		Fe	NMC 96	O	O	O
		Sn	NMC 96	O (10)	O	O
		Pb	NMC 96	O	O	O
	A/Li	C	NMC 95	O	O	
		Ca	NMC 95	O	O	
DY	A/D	C	FNAL-E772	O	O	O
		Ca		O (15)	O	O
		Fe		O (15)	O	O
		W		O (10)	O	O
	A/Be	Fe	FNAL E866	O	O	
		W		O	O	
π pro	dA/pp	Au	RHIC-PHENIX	O (20)		

Modification of Parton Distributions in Nuclei

EMC effect observed in DIS



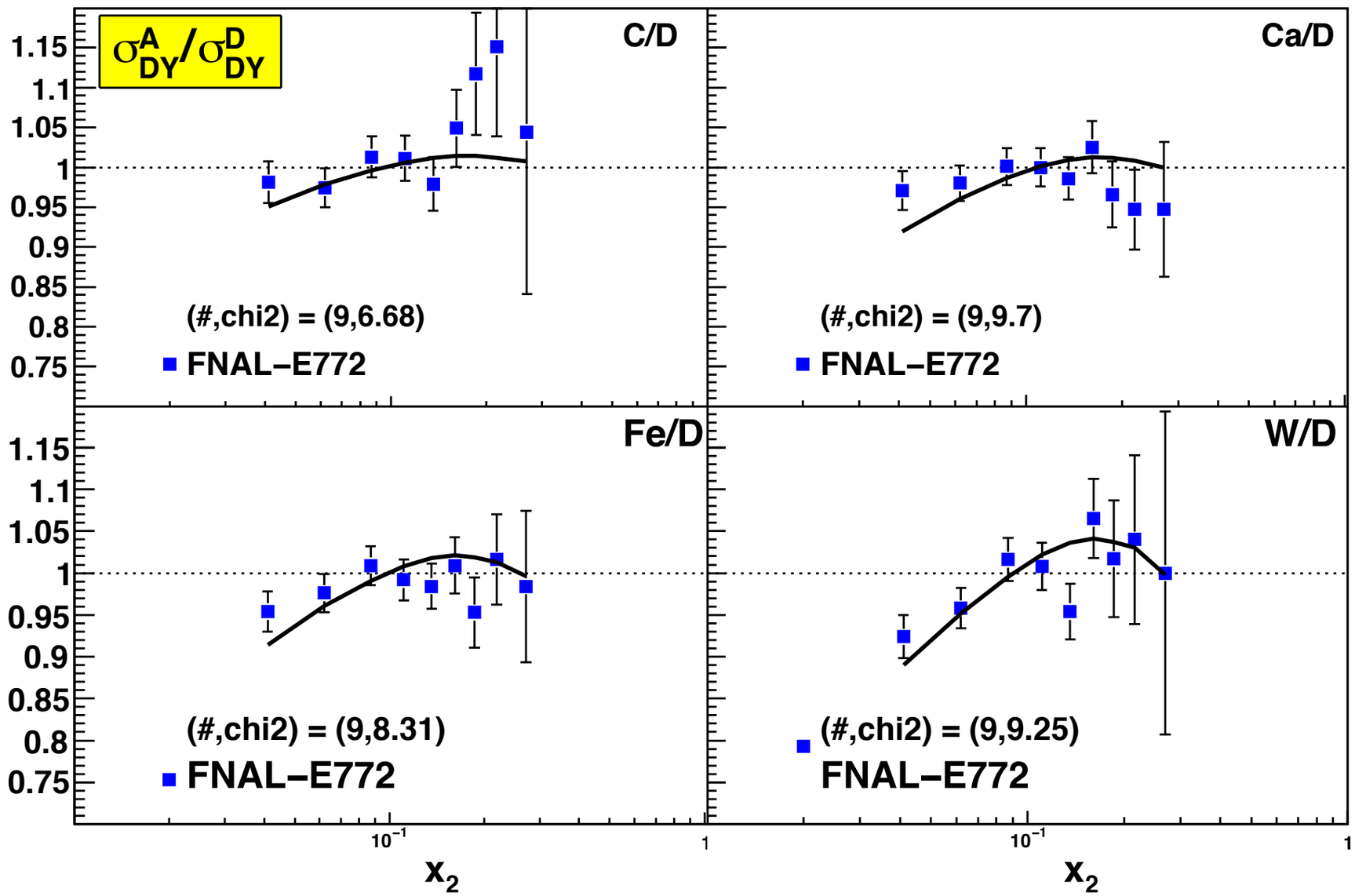
(Ann. Rev. Nucl. Part. Phys., Geesaman, Sato and Thomas)

F_2 contains contributions from quarks and antiquarks

How are the antiquark distributions modified in nuclei?

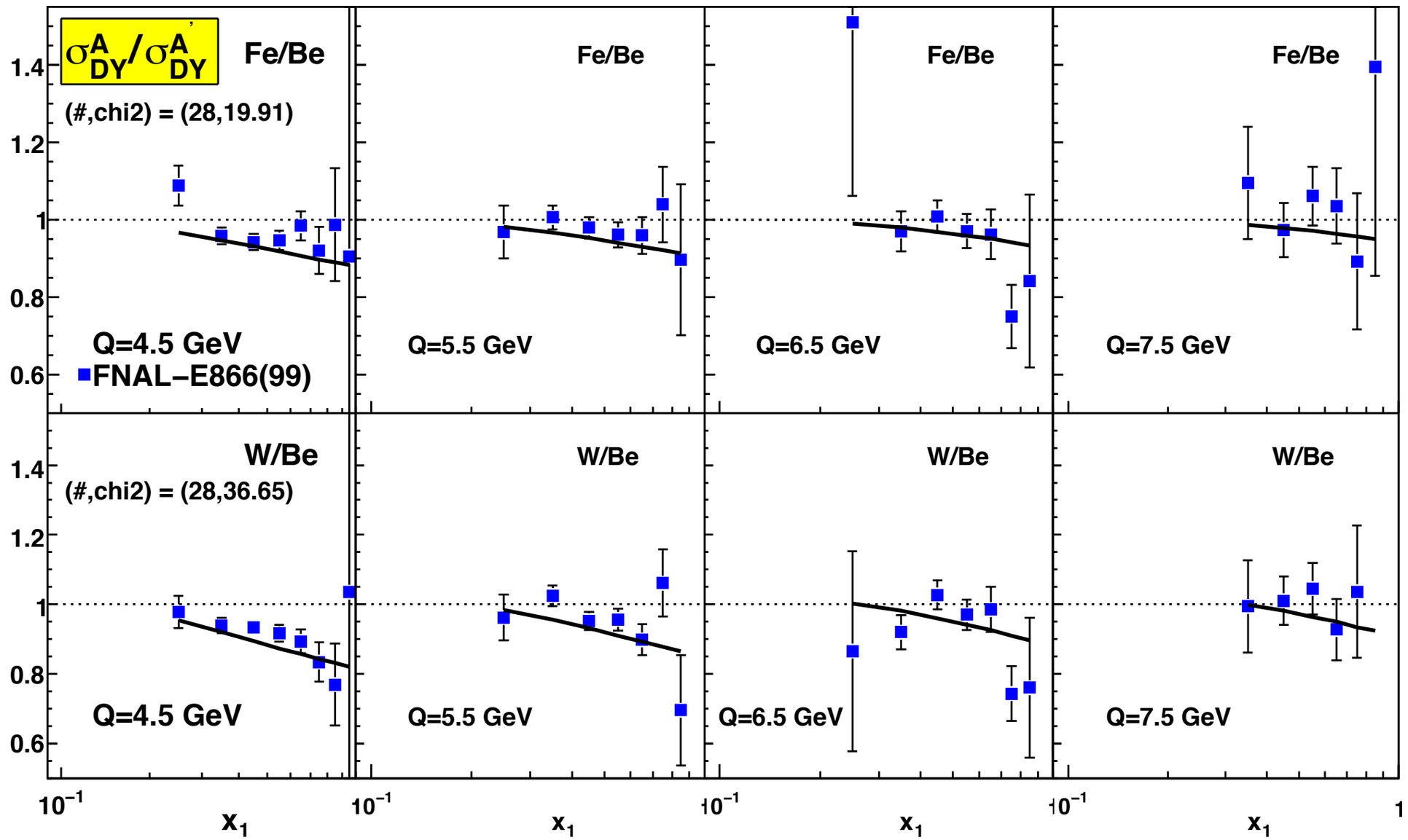
Results: decut3 fit

Drell–Yan data

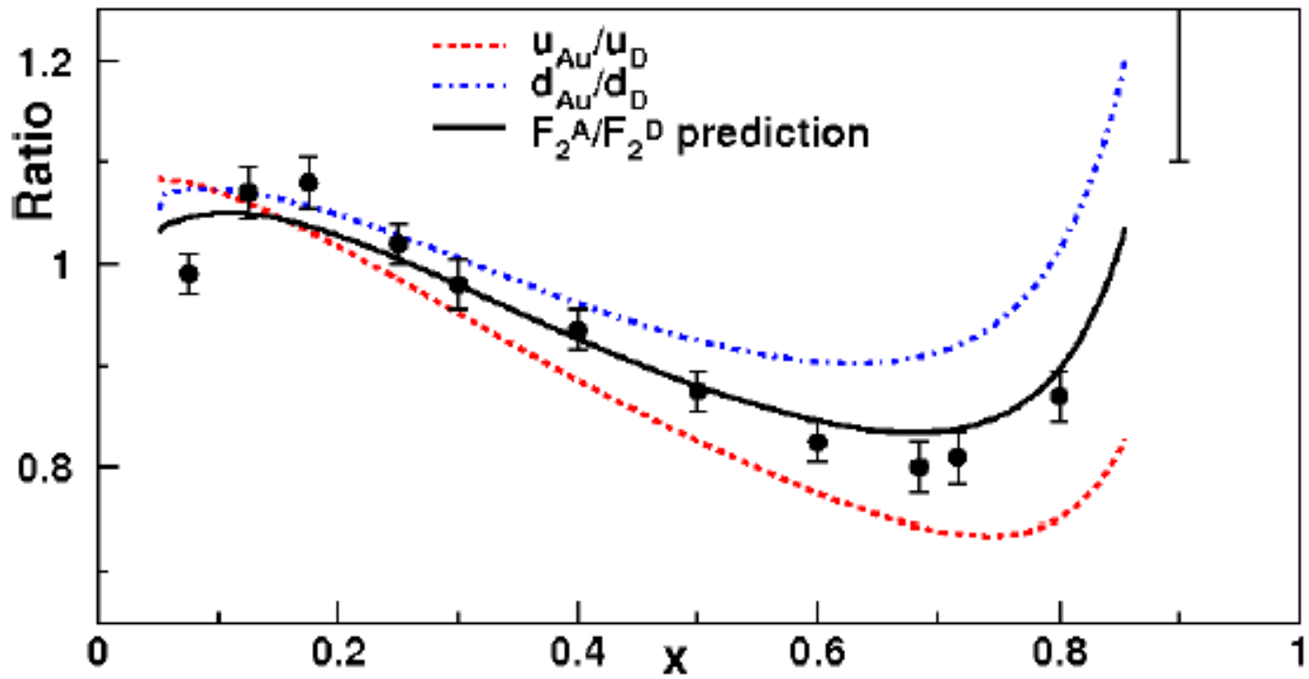


Results: decut3 fit

Drell–Yan data



Flavor dependence of the EMC effects ?



Isovector mean-field generated in Z≠N nuclei can modify nucleon's *u* and *d* PDFs in nuclei

Cloet, Bentz, and Thomas, arXiv:0901.355
(see also Kumano et al.)

How can one check this prediction?

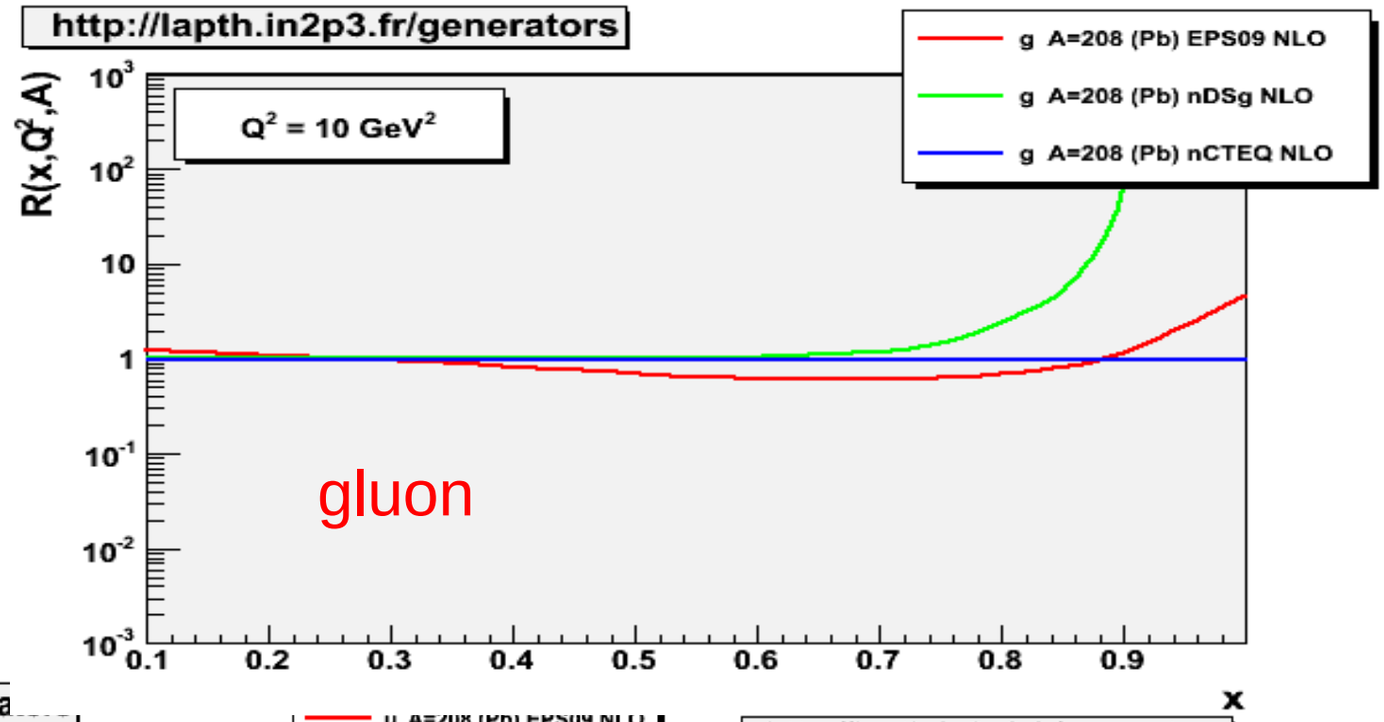
- SIDIS (Semi-inlusive DIS) and PVDIS (Parity-violating DIS)
- Pion-induced Drell-Yan

Summary: used hadronic processes

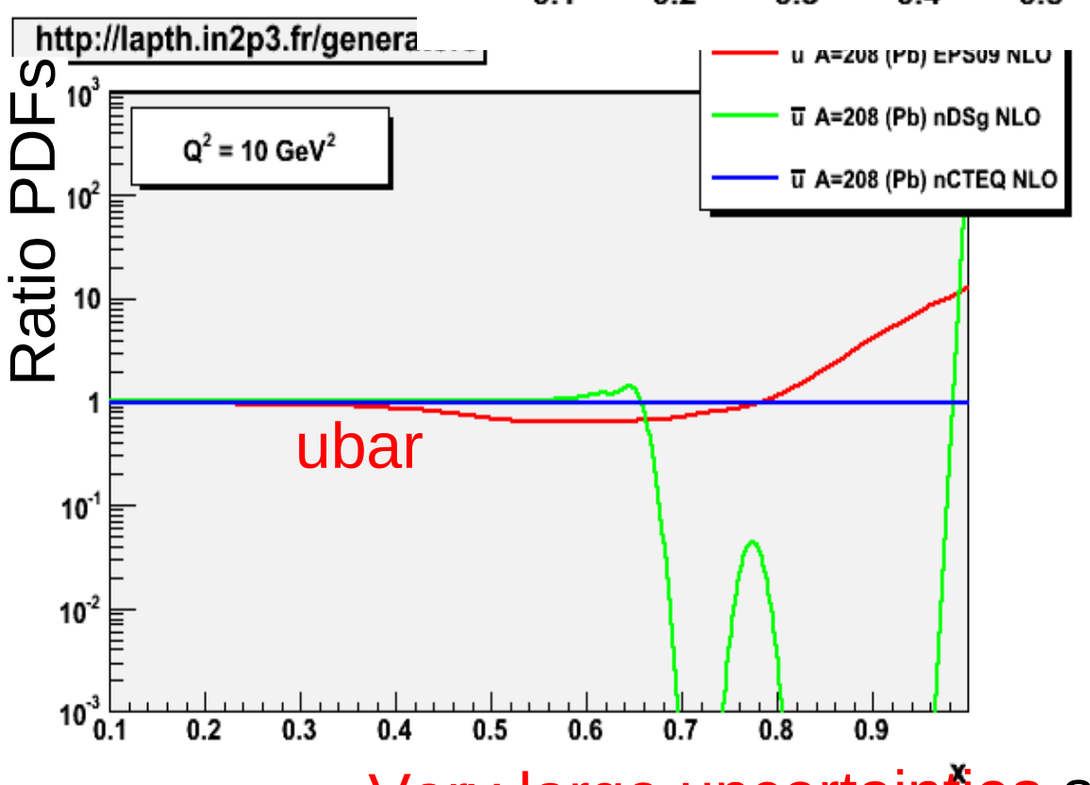
- **Proton case:**
  - **DY**: FNAL E605 (pCu) →info on quark sea
  - **DY**: FNAL E866=NuSea (pd/pp) → info on dbar(x)/ubar(x)
  - **W-asymmetry** (D0 II, CDF II) →info on d(x)/u(x) at large x
  - **Z-rapidity** (CDF II)
  - **Inclusive jet production** (D0 II, CDF II) → info on gluon at large x
- **Nuclear case:**
  - **DY**: FNAL E772 (C/D, Ca/D, Fe/D, W/D) → info on quark sea
  - **DY**: FNAL E866 (Fe/Be, W/Be) → info on quark sea
  - **Inclusive pion production**: RHIC PHENIX (dAu/pp) → info on gluon
  - Note: NO inclusive jet production data available so far;
    AFTER could measure this with pT = 20 ... 40 GeV →large-x gluon nPDF

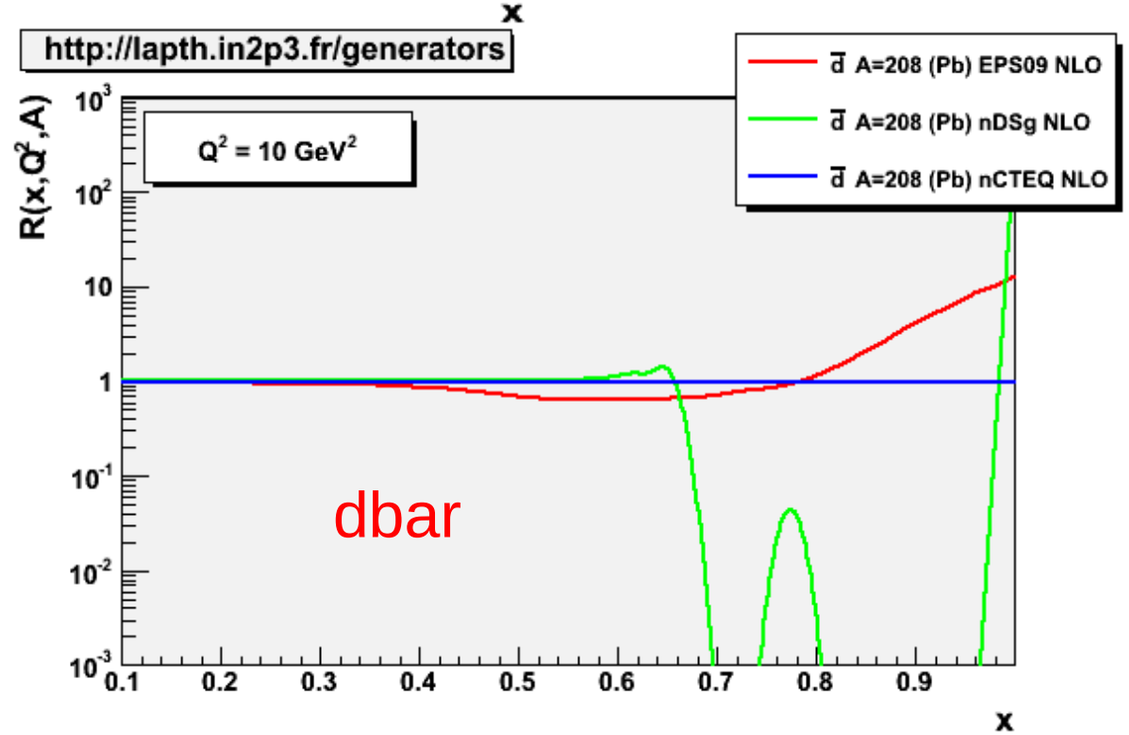
Uncertainties in nuclear PDFs at high-x

- Isolated-γ at "low"-$\sqrt{s}$ & high-p_T are sentitive to high-x gluons & sea:



EPS09 NLO
nDSGg NLO
nCTEQ NLO





Very large uncertainties above x~0.3, also at large Q^2 !

Isolated-γ in Pb(2.76 TeV)-Pb(rest): $\sqrt{s_{NN}}$~72 GeV

- Pb-Pb photon kinematics at fixed-target LHC:

  To access x > 0.3 one needs isolated-γ at: $p_T = x_T\sqrt{s}/2 > 10$ GeV/c

- JETPHOX NLO pQCD calculations:

  Pb-Pb at $\sqrt{s_{NN}}$=72 GeV

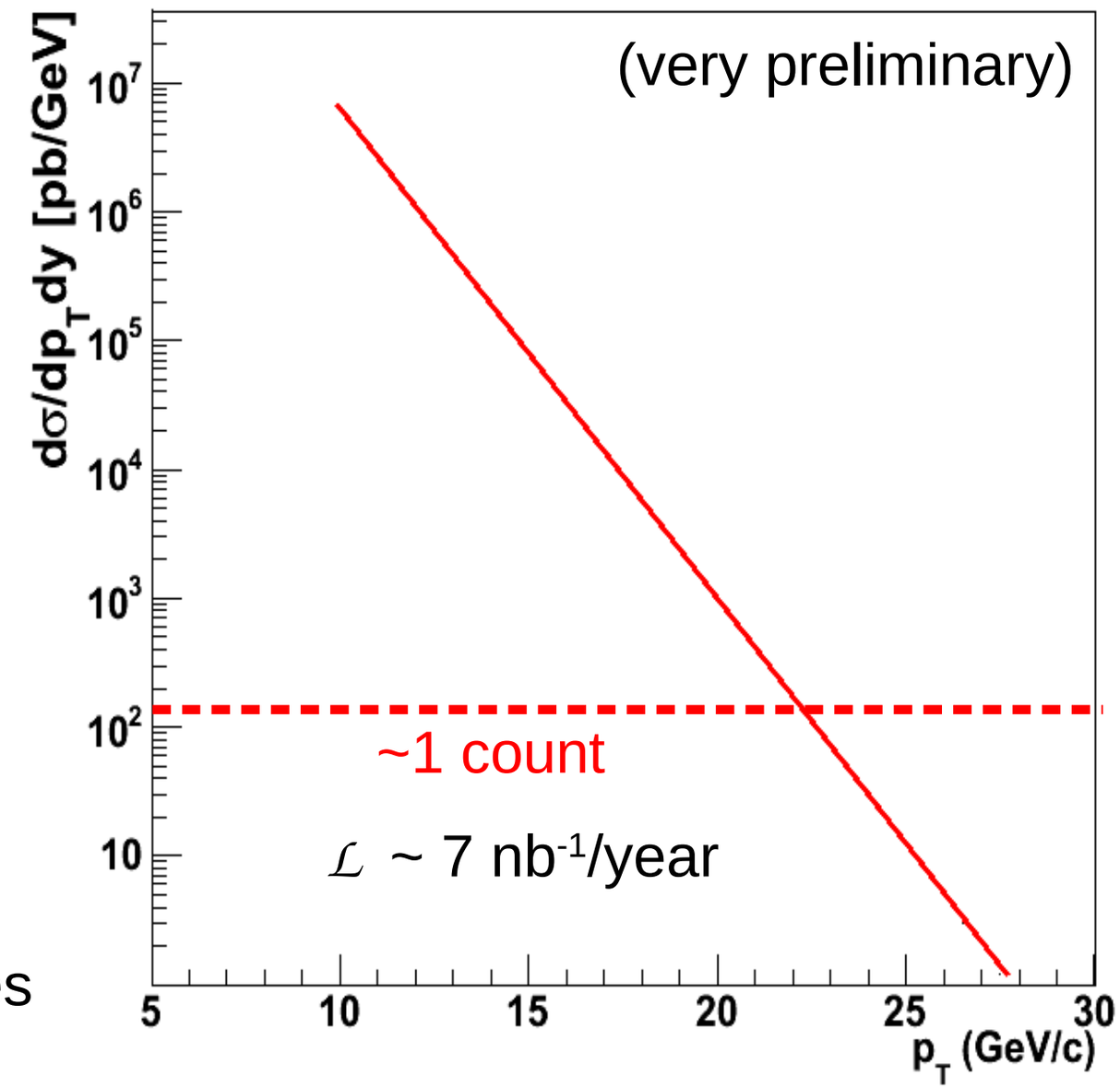
  $|y|<0.5$, $p_T>20$ GeV/c

  Isolation: R=0.4, $E_T^{had}<5$ GeV

  PDF: EPS09

  Scales: $\mu_i = p_T$

  FF = BFG-II



(Ongoing determination of uncertainties with 40 EPS09 eigenvalues ...)

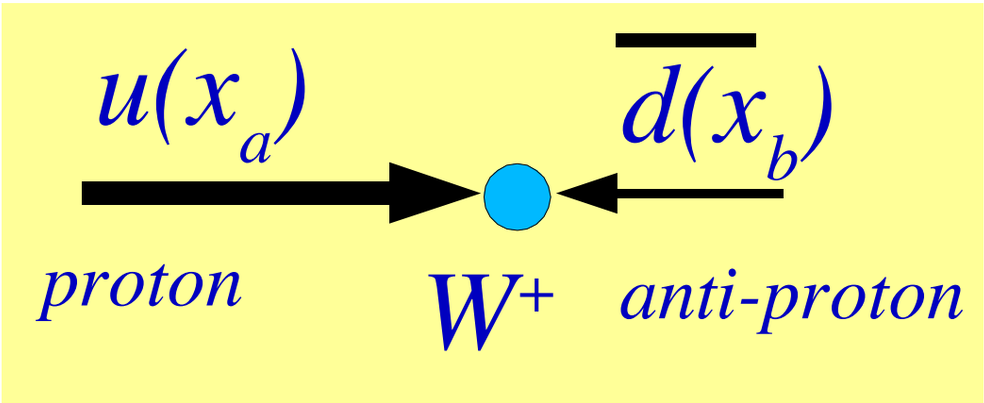
W and Z boson production at AFTER

Discussion

- Production of W,Z close to threshold!
  Test lab. for production of heavy resonances W',Z'
  (Maybe too late?)
- Test lab. for QCD calculations of threshold resummation
- ToDo (IS): prediction for W,Z production at NLO at AFTER (VRAP)
- There exist calculations including threshold resummation for W, Z production: invite speakers
- Statistics probably not high enough for PDF studies [measurement of d(x)/u(x)]

Where do the W's and Z's come from ???

$$\frac{d\sigma}{dy}(W^{\pm}) = \frac{2\pi}{3}\frac{G_F}{\sqrt{2}}\sum_{q\bar{q}}|V_{q\bar{q}}|^2\left[q(x_a)\,\bar{q}(x_b) + q(x_b)\,\bar{q}(x_a)\right]$$



For anti-proton:

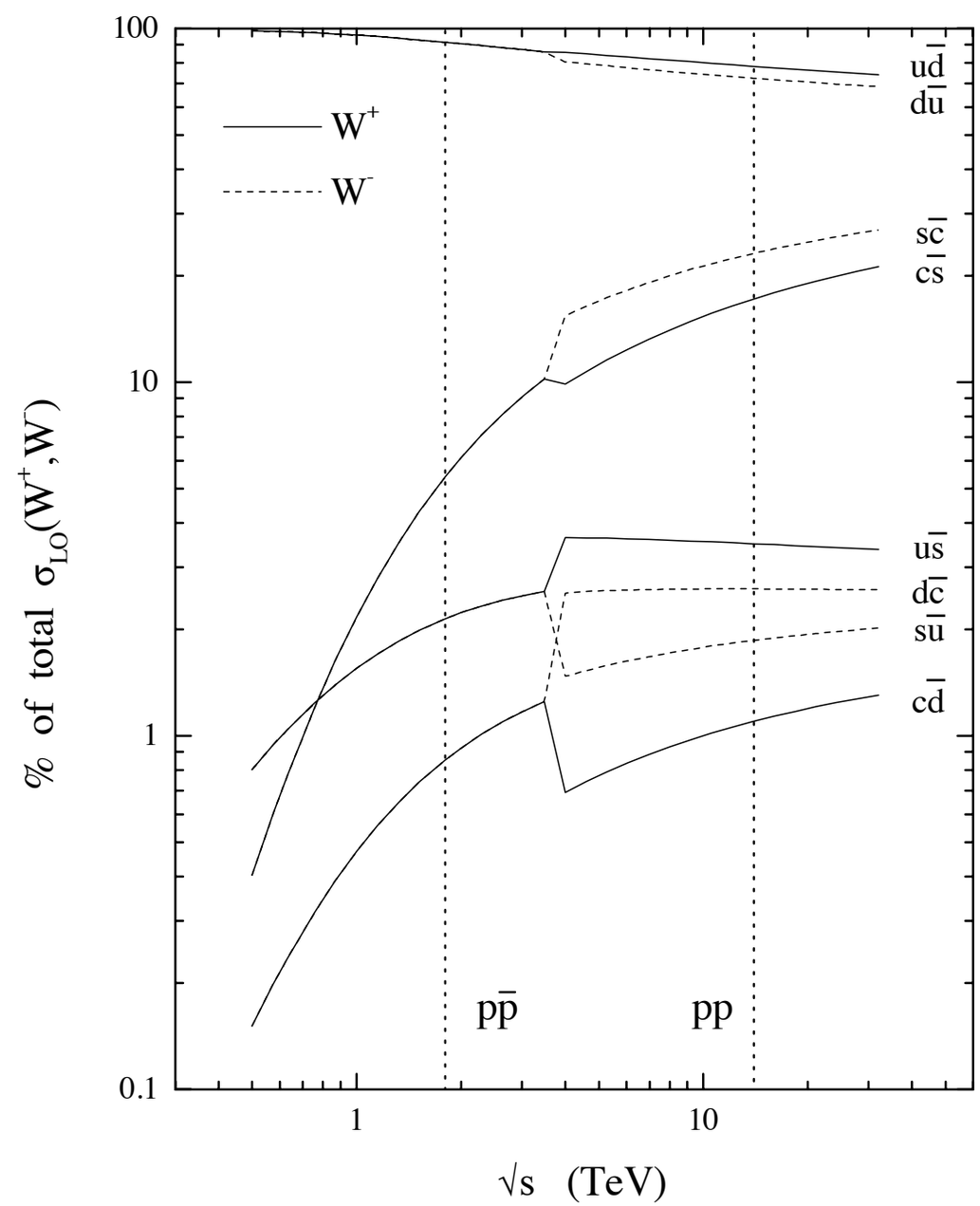
$$u(x) \Leftrightarrow \bar{u}(x) \qquad d(x) \Leftrightarrow \bar{d}(x)$$

Therefore

$$\frac{d\sigma}{dy}(W^{+}) \approx \frac{2\pi}{3}\frac{G_F}{\sqrt{2}}\left[u(x_a)\,d(x_b)\right]$$

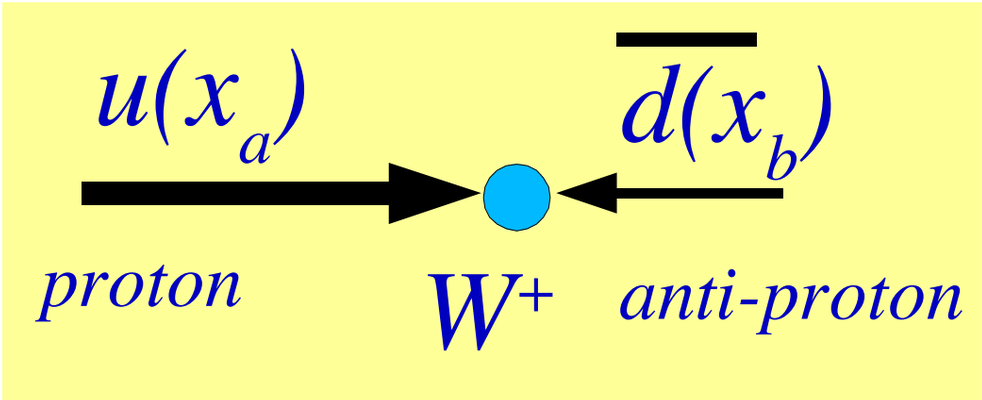
$$\frac{d\sigma}{dy}(W^{-}) \approx \frac{2\pi}{3}\frac{G_F}{\sqrt{2}}\left[d(x_a)\,u(x_b)\right]$$

flavour decomposition of W cross sections



A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C23, 73 (2002); Eur. Phys. J. C4, 463 (1998)

A bit of calculation



$$A(y) = \frac{\frac{d\sigma}{dy}(W^+) - \frac{d\sigma}{dy}(W^-)}{\frac{d\sigma}{dy}(W^+) + \frac{d\sigma}{dy}(W^-)}$$

With the previous approximation,

$$A \approx \frac{u(x_a)d(x_b) - d(x_a)u(x_b)}{u(x_a)d(x_b) + d(x_a)u(x_b)} = \frac{R_{du}(x_b) - R_{du}(x_a)}{R_{du}(x_b) + R_{du}(x_a)}$$

where $R_{du}(x) = \dfrac{d(x)}{u(x)}$

$$x_{1,2} = x_0 e^{\pm y} \simeq x_0(1 \pm y)$$

We can make Taylor expansions:

$$R_{du}(x_{1,2}) \approx R_{du}(x_0) \pm y\, x_0 R'_{du}(\sqrt{\tau})$$

Thus, the asymmetry is:

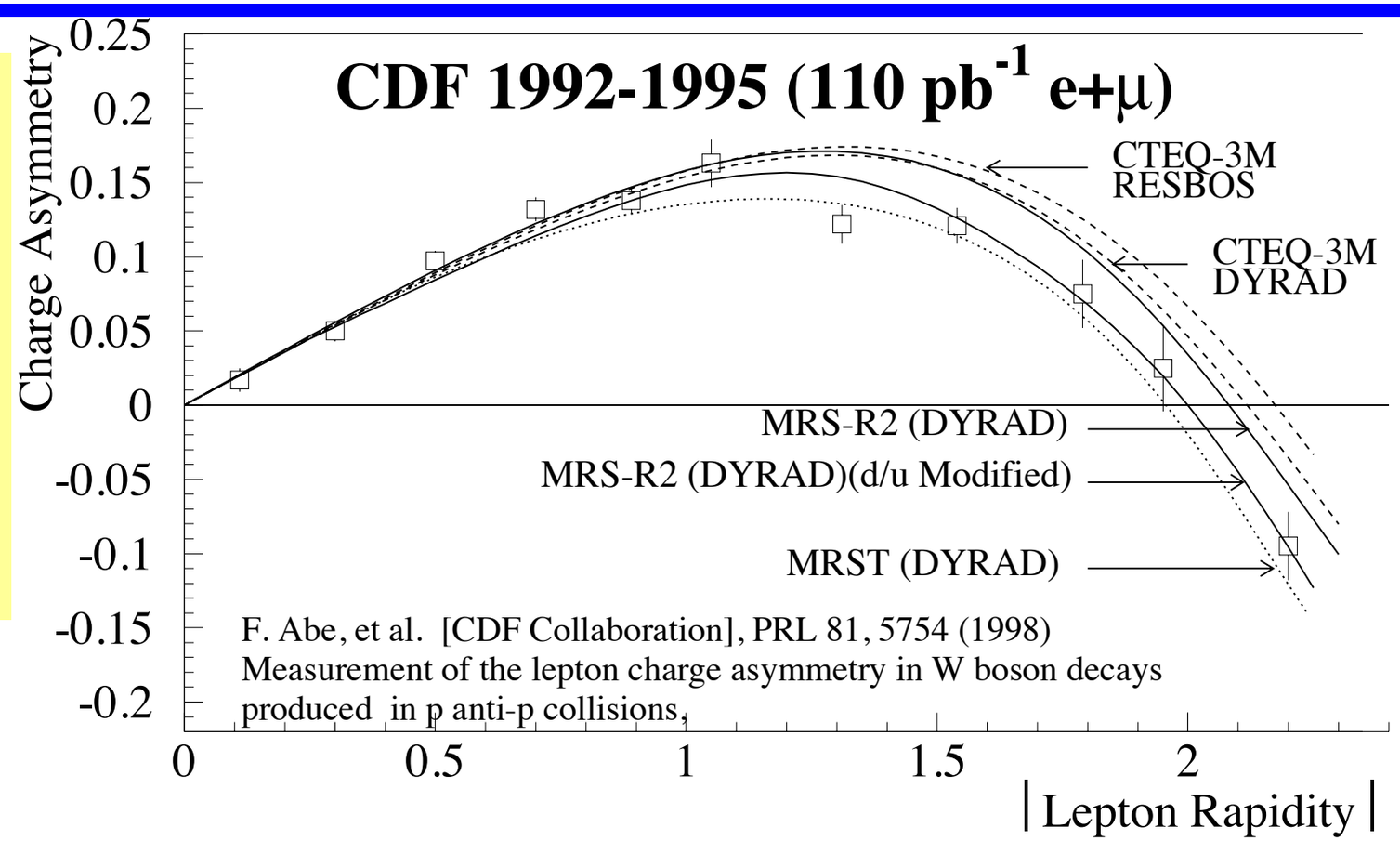
$$A(y) = -y\, x_0 \frac{R'_{du}(x_0)}{R_{du}(x_0)}$$

EXERCISE: Verify the above.

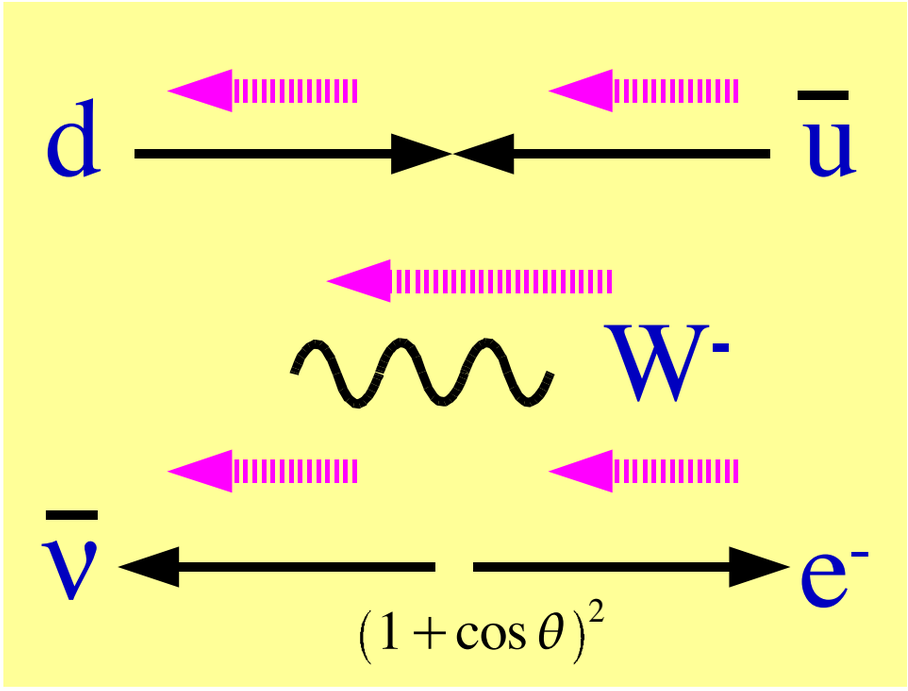
Charged Lepton Asymmetry

Unfortunately,
we don't measure the W
directly since W→eν.

Still the lepton contains
important information



$$A(y) = \frac{\frac{d\sigma}{dy}(l^+) - \frac{d\sigma}{dy}(l^-)}{\frac{d\sigma}{dy}(l^+) + \frac{d\sigma}{dy}(l^-)}$$

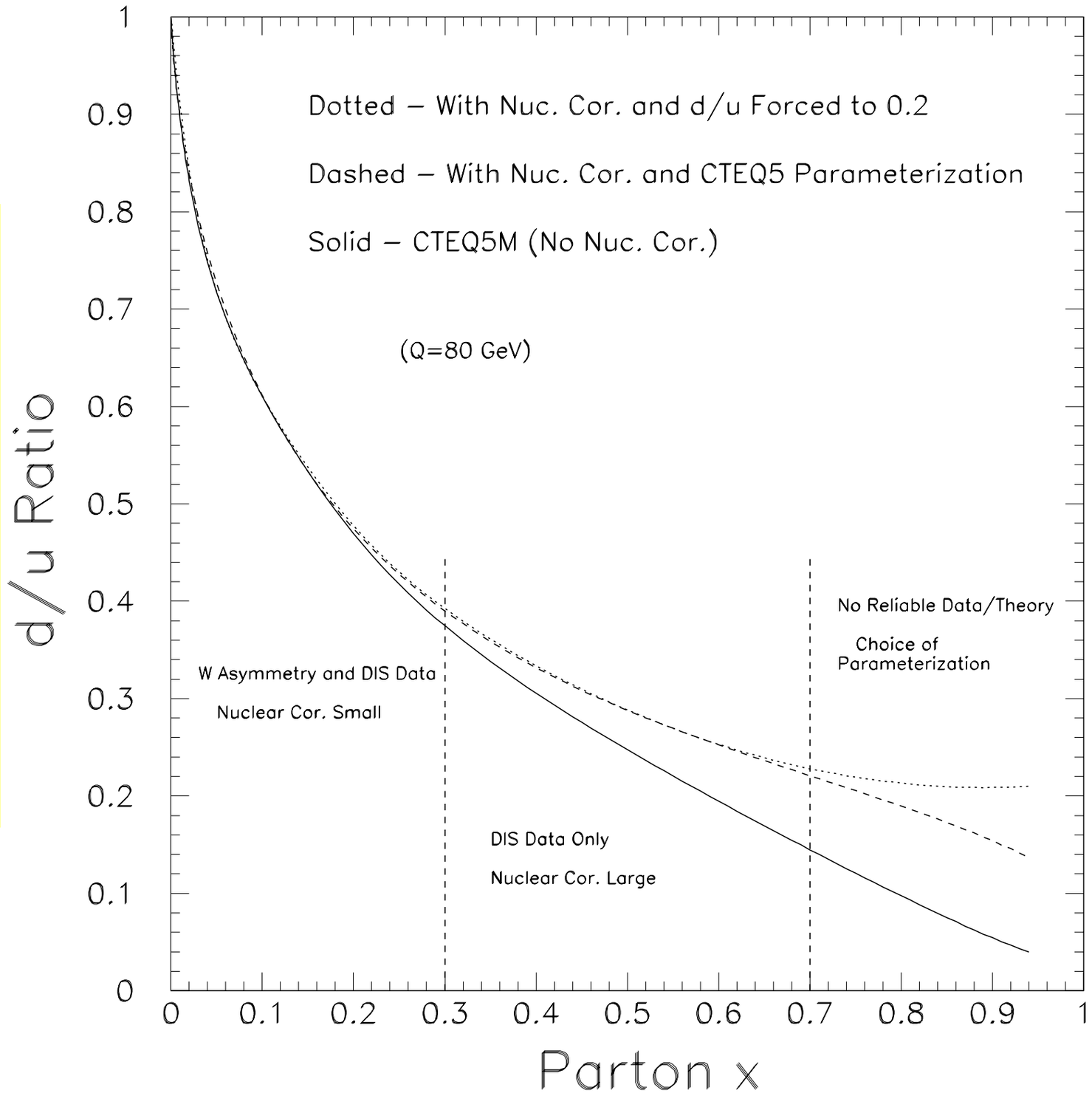


d/u Ratio at High-x

The form of the
d/u ratio at large x
as a function of

1) Parameterization

2) Nuclear Corrections

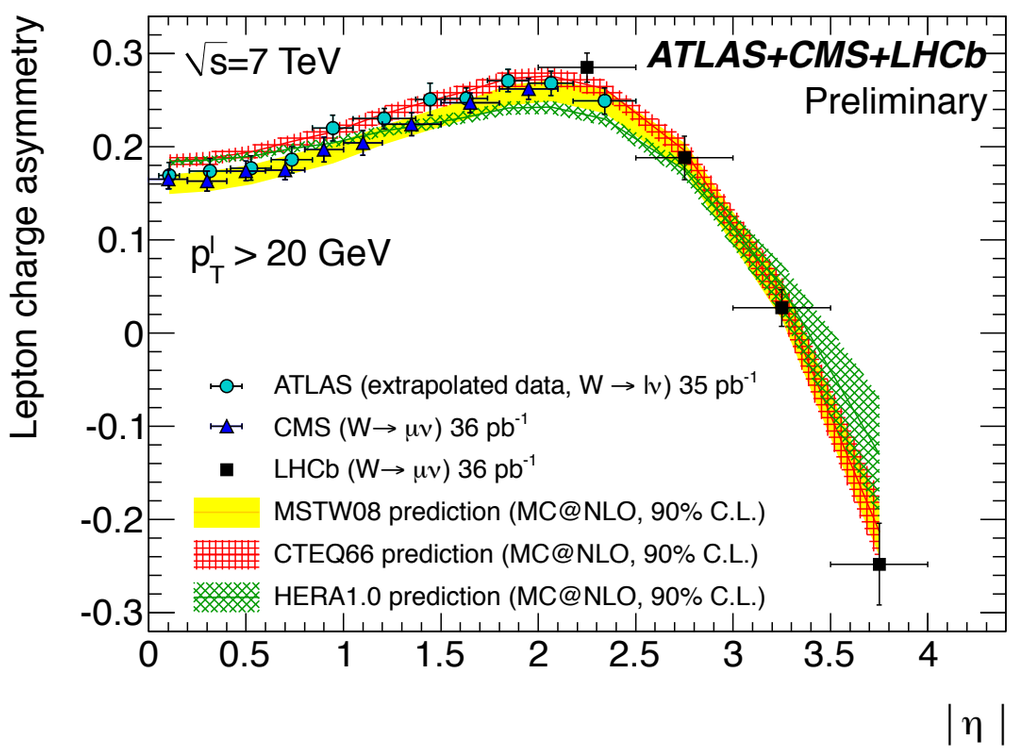


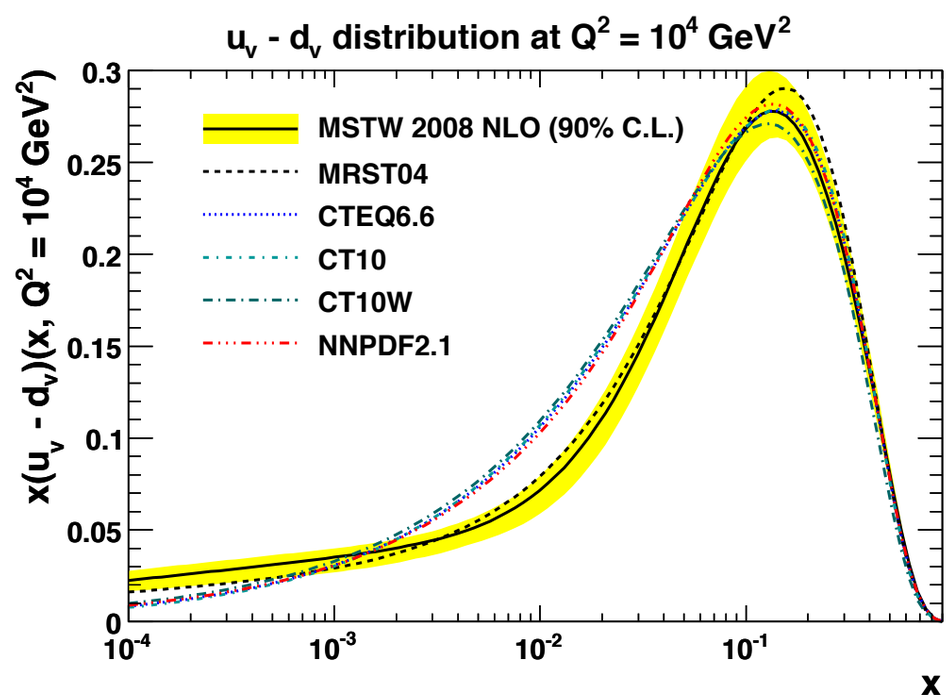
S. Kuhlmann, et al., Large-x parton distributions, PL B476, 291 (2000)

$W^\pm \to \ell^\pm \nu$ charge asymmetry at the LHC

$$A_W(y_W) = \frac{\mathrm{d}\sigma(W^+)/\mathrm{d}y_W - \mathrm{d}\sigma(W^-)/\mathrm{d}y_W}{\mathrm{d}\sigma(W^+)/\mathrm{d}y_W + \mathrm{d}\sigma(W^-)/\mathrm{d}y_W} \approx \frac{u_v(x_1) - d_v(x_1)}{u(x_1) + d(x_1)}$$

$$A_\ell(\eta_\ell) = \frac{\mathrm{d}\sigma(\ell^+)/\mathrm{d}\eta_\ell - \mathrm{d}\sigma(\ell^-)/\mathrm{d}\eta_\ell}{\mathrm{d}\sigma(\ell^+)/\mathrm{d}\eta_\ell + \mathrm{d}\sigma(\ell^-)/\mathrm{d}\eta_\ell} \equiv A_W(y_W) \otimes (W^\pm \to \ell^\pm \nu)$$





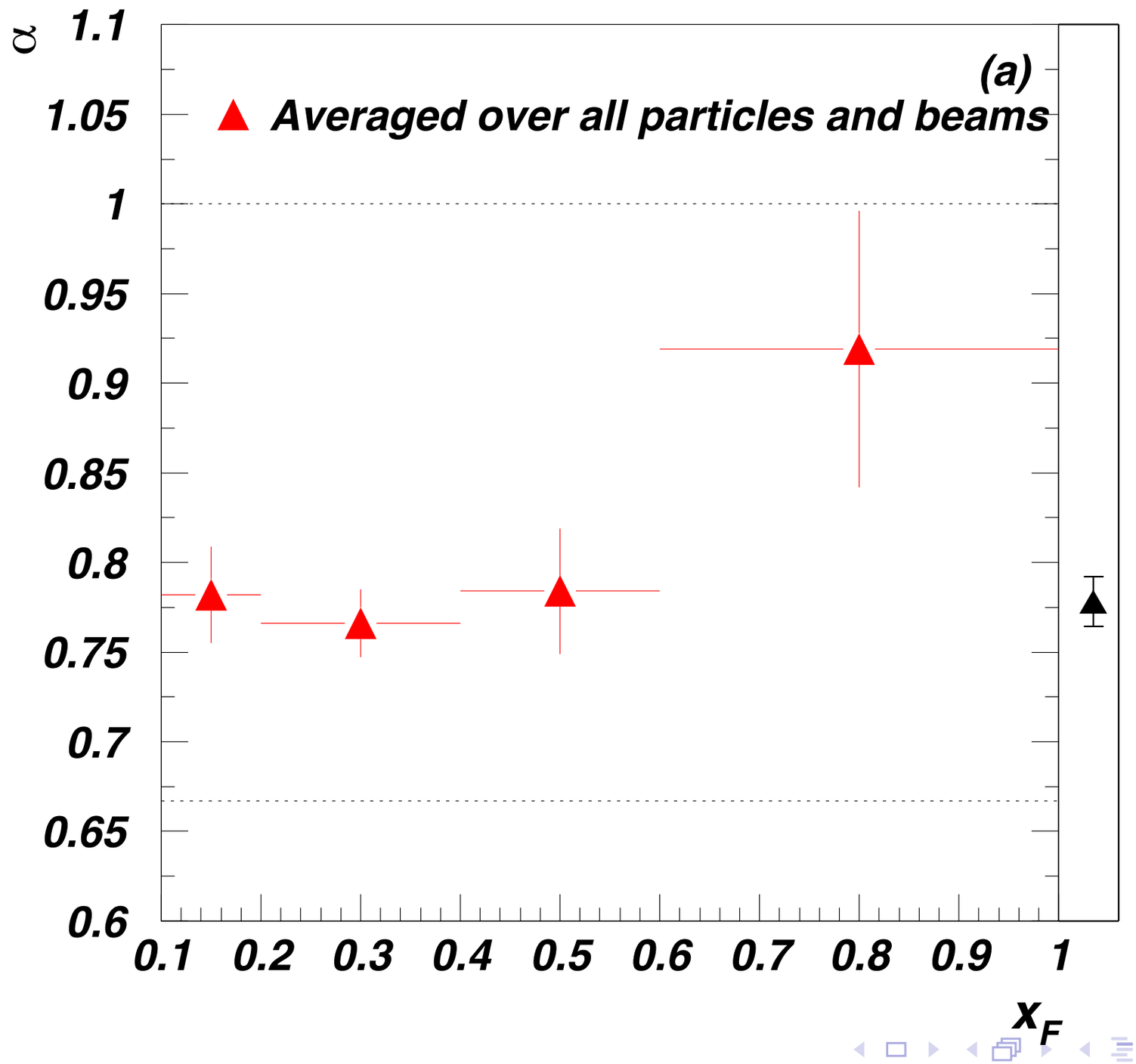
- First PDF constraint from LHC data ($\to$ NNPDF2.2).
- **MSTW08** has input $xu_v \propto x^{0.29\pm0.02}$ and $xd_v \propto x^{0.97\pm0.11}$.
  Many other groups **assume** equal powers $\Rightarrow$ potential bias.

Open/hidden heavy-flavour production in pA collisions

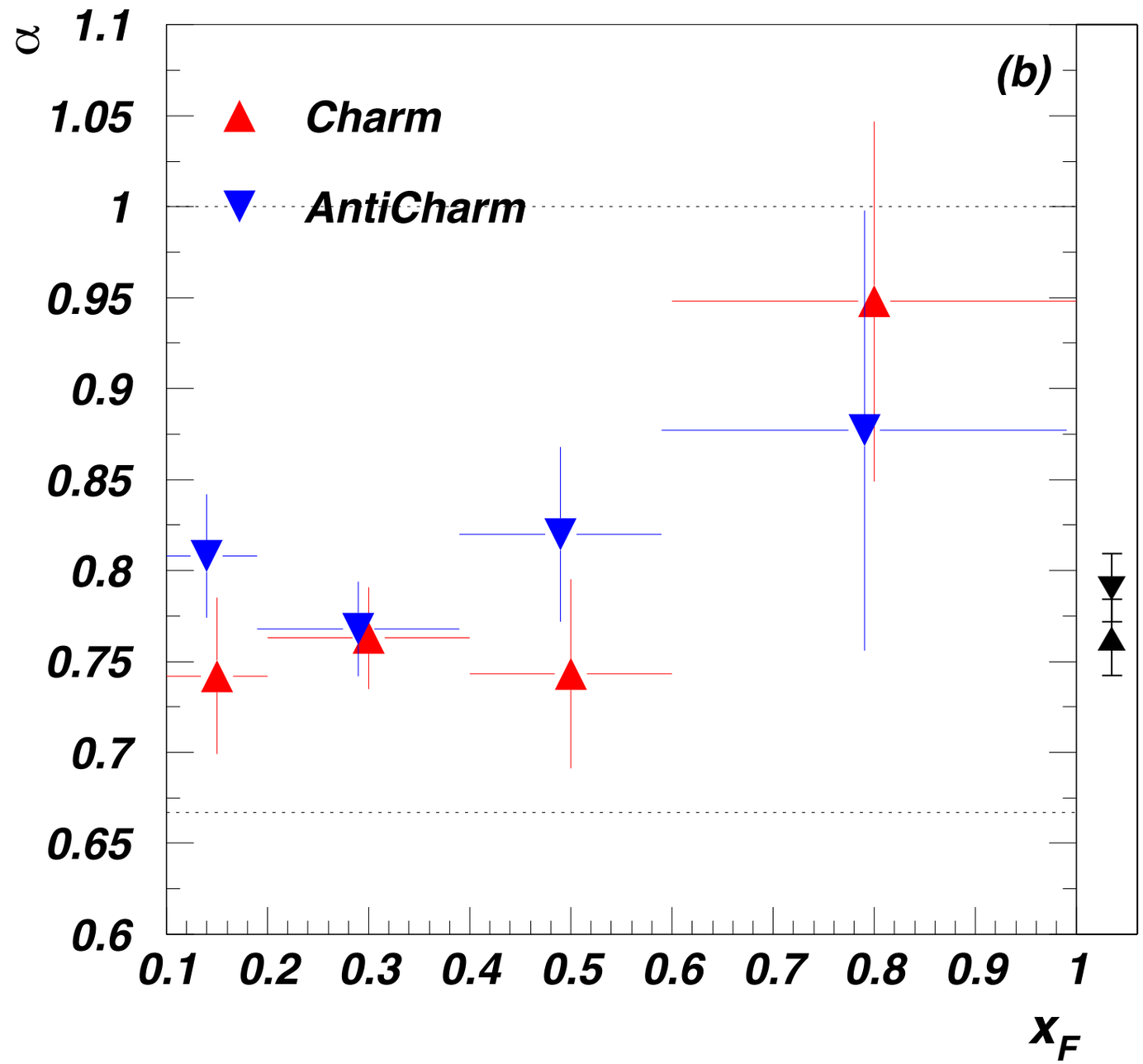
Heavy-flavour production in pA collisions: Discussions

- Want J/Psi, Psi(2S), Υ, X_c, X_b
  (X_c production in AA very difficult; one has to reconstruct forward photons)
- X_c measurement key point
  (was not possible at NA60 although simultations said it's possible)
  needs very accurate MC; very challenging in particular in pA;
  Bottomonia interesting, relevant and easier than X_c
- X_c relation to CHIC?
- Open and hidden heavy-flavour have to be measured together!
  (also in AA collisions, see talk by H. Satz)
- Measuring open charm requires particle ID.
  Consequences for the detector design!
- pA vs Ap mode: detectors would be very different
- A-dependence: A^{α}
  (see talk by Nora)
- ToDo (Ramona): prediction for AFTER: α vs x_F

α: All beams all particles



α: Charm / Anti-Charm



No difference when separating in charm and anti-charm final

Talk by Ramona Vogt

E866 Measured Open Charm and J/ψ vs x_F

E866 also measured open charm pA dependence using single muons with $p_T^\mu > 1$ GeV/c (unpublished)

Different from J/ψ for $y < 0.7$ but similar for higher y, suggests that dominant effects are in the initial state

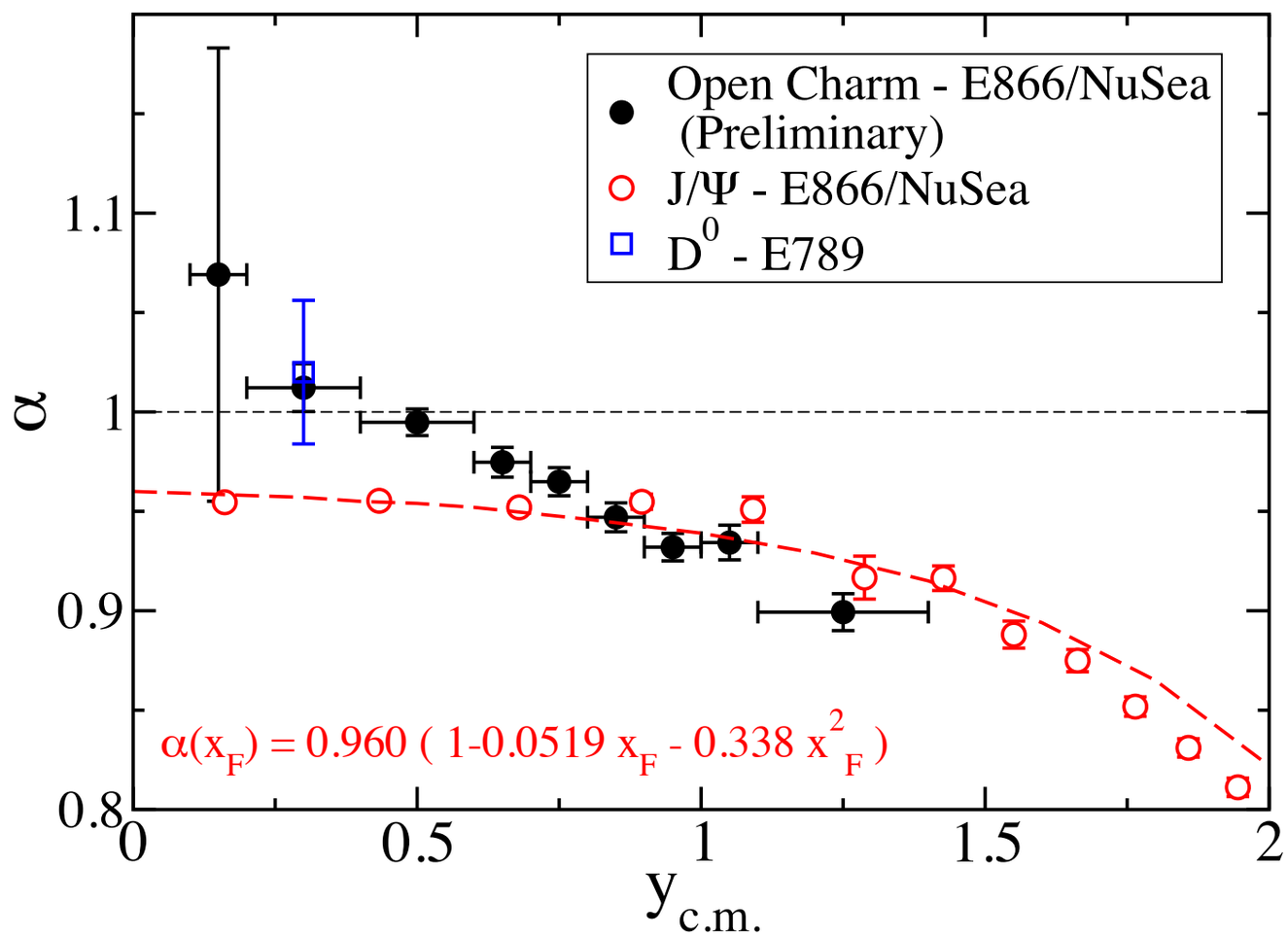


Figure 2: The J/ψ and open charm A dependence as a function of x_F (Mike Leitch).

Medium Effects Important with Nuclear Target

Nuclear effects often parameterized as

$$\sigma_{pA} = \sigma_{pp} A^{\alpha} \qquad \alpha(x_F, p_T)$$

For $\sqrt{s_{NN}} \leq 40$ GeV and $x_F > 0.25$, α decreases strongly with x_F – only low x_F effects probed by SPS and RHIC rapidity coverage

Possible cold matter effects

- **Nuclear Shadowing — initial-state effect on the parton distributions affecting total rate, important as a function of y/x_F**
- **Energy Loss — initial-state effect, elastic scatterings of projectile parton before hard scattering creating quarkonium state, need to study Drell-Yan production to get a handle on the strength when shadowing included**
- **Intrinsic Charm — initial-state effect, if light-cone models correct, should only contribute to forward production, assumed to have different A dependence than normal J/ψ production**
- **Absorption — final-state effect, after $c\bar{c}$ that forms the J/ψ has been produced, pair breaks up in matter due to interactions with nucleons**

Other discussions

Other discussions

- pA collisions: test region x>1
- Multiple heavy quarks; Double-charm baryons ccq, ccc, bbq, bbb
- Experimental questions

END