

International Spring School of the GDR PH-QCD
QCD prospects for future ep and eA colliders
Laboratoire de Physique Théorique, Orsay, June 7th 2012



QCD at the Large Hadron Electron Collider at CERN

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for the LHeC Study group, <http://cern.ch/lhec>

Contents:

1. Introduction.

2. The Large Hadron Electron Collider.

3. Precision QCD:

- Parton densities.
- Coupling constant.
- Heavy flavors.
- Jets.
- Photoproduction.

CDR to appear within one week;
cern.ch/lhec;
LHeC workshop 14-15/6/2012

4. Small x and eA :

- Inclusive measurements and small- x glue.
- Inclusive diffraction.
- Exclusive diffraction.
- Final states.

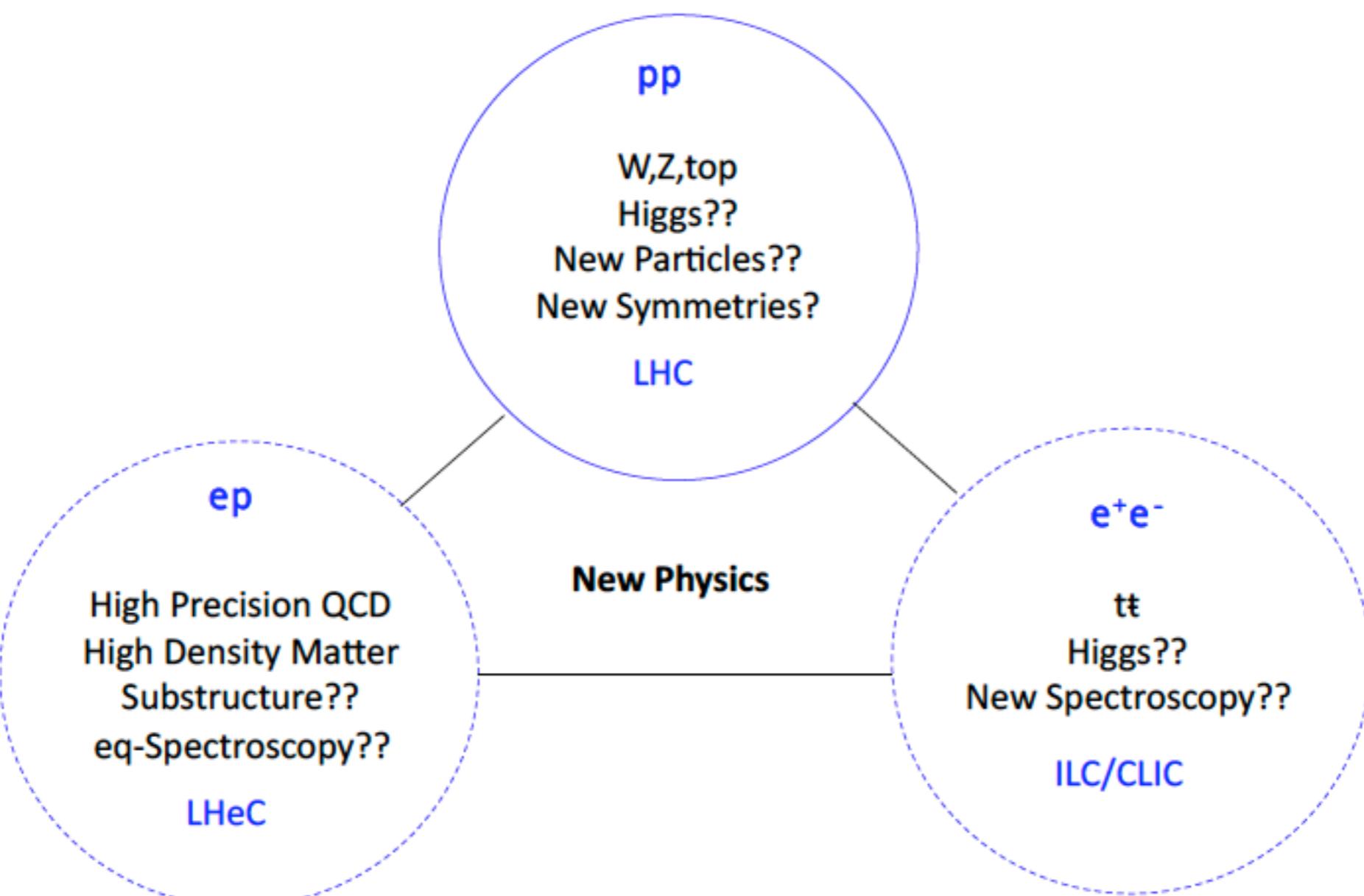
Related seminar by
F. Sabatié on the EIC.

5. Summary and outlook.

Motivation:

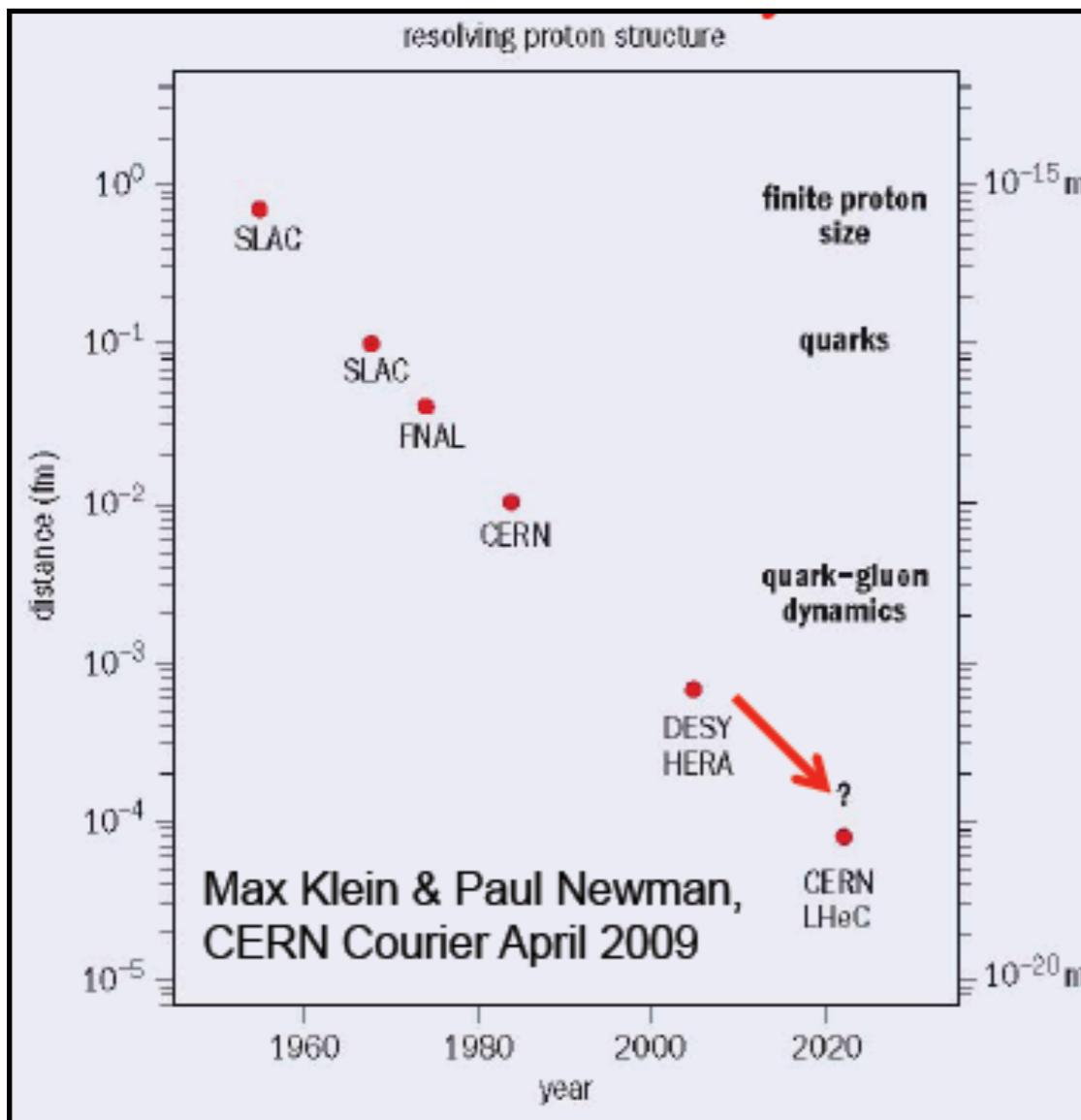
- **Complementarity** of the three kind of collisions for our understanding of the interaction of matter:

The TeV Scale [2010-2035..]

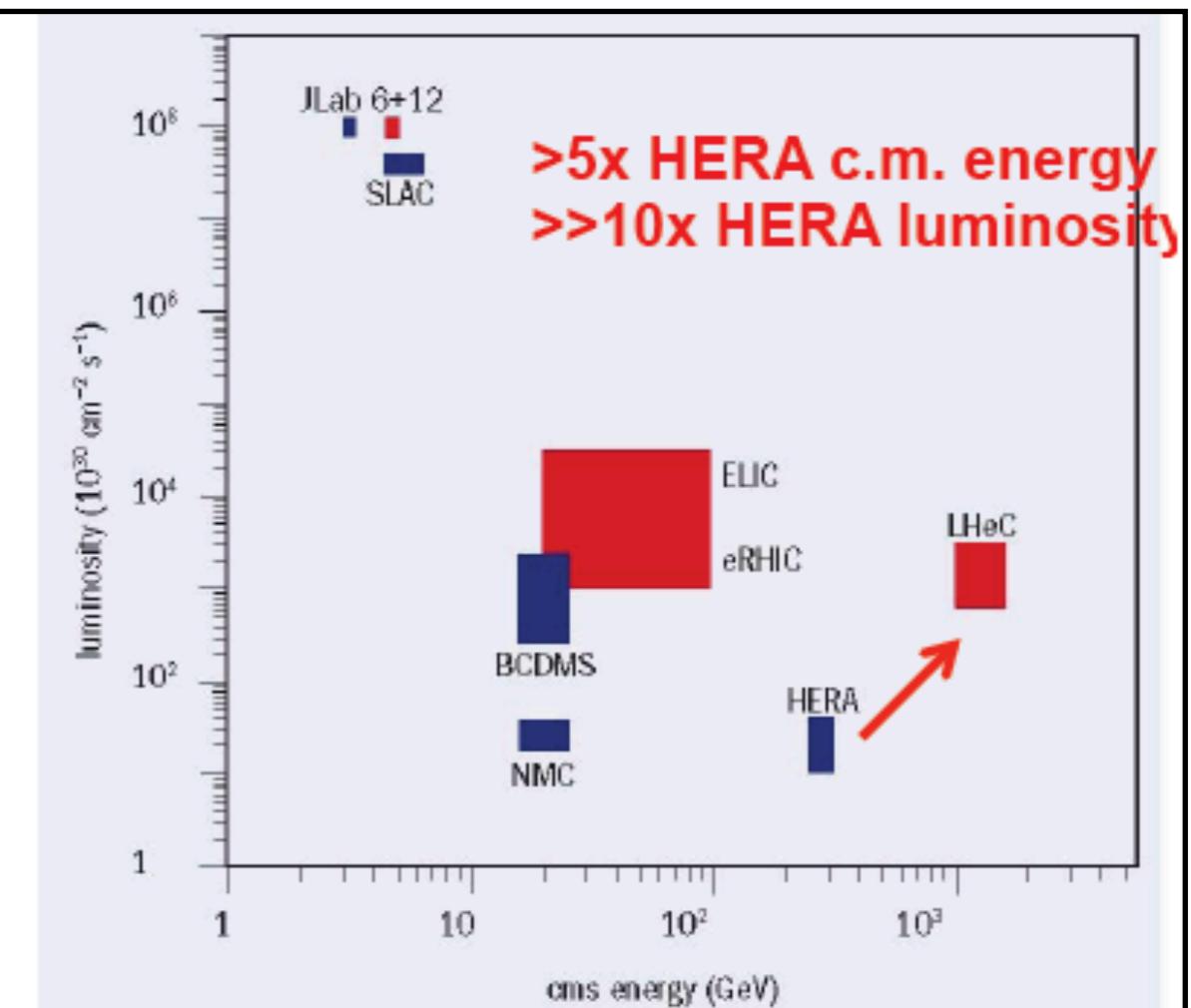


Motivation:

- **Complementarity** of the three kind of collisions for our understanding of the interaction of matter:



distance scales resolved in lepton-hadron scattering experiments since 1950s, and some of the new physics revealed

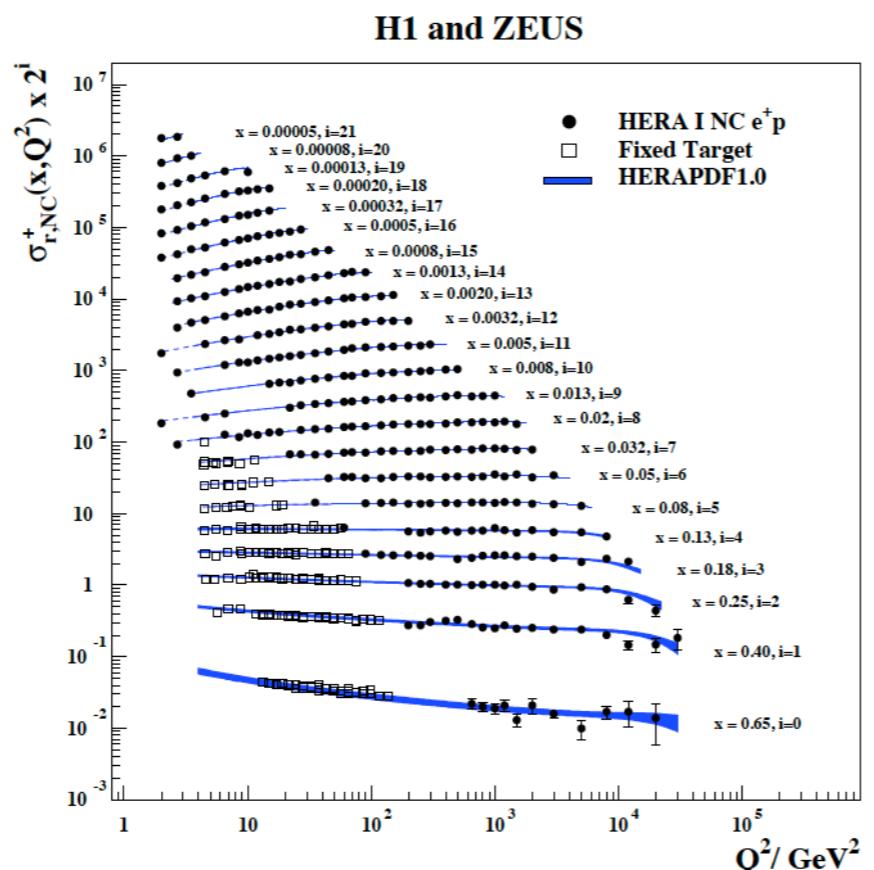


Max Klein & Paul Newman, CERN Courier April 2009

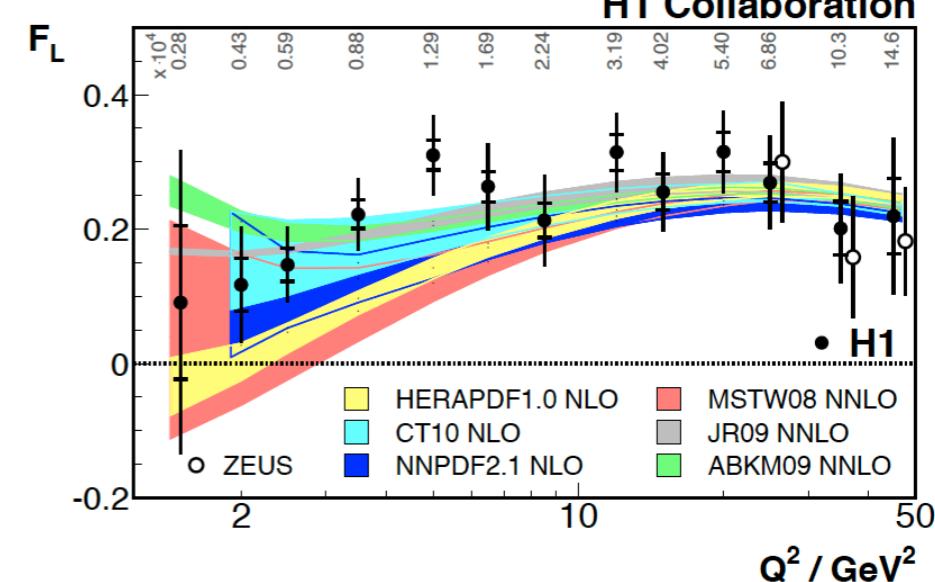
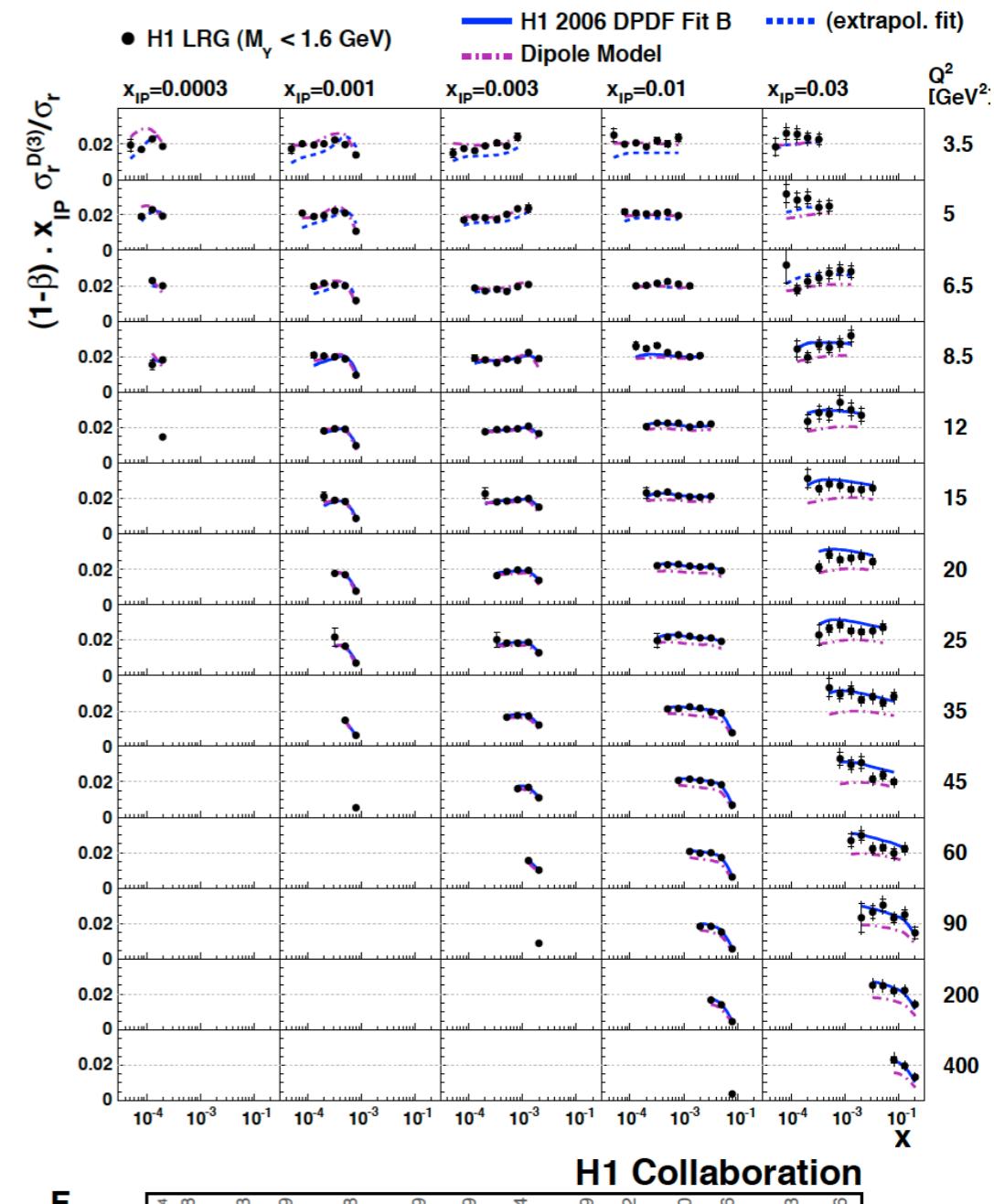
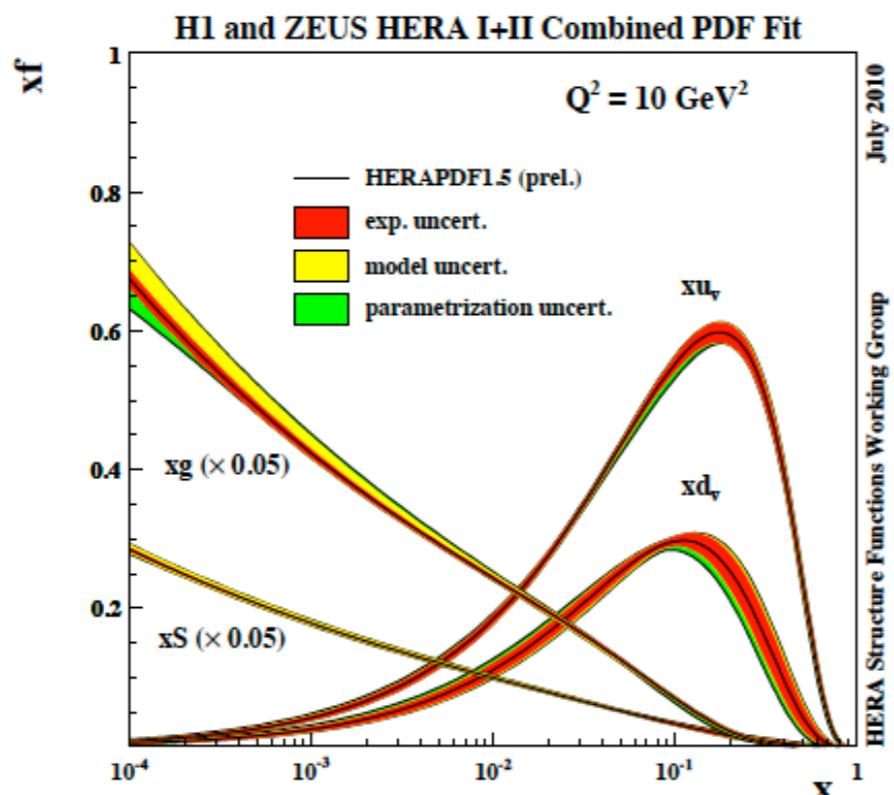
energies and luminosities of existing and proposed future lepton-proton scattering facilities

Messages from HERA:

- Very good description of $F_2(c,b)$ (F_L ?) within DGLAP, steep gluon in $1/x$.

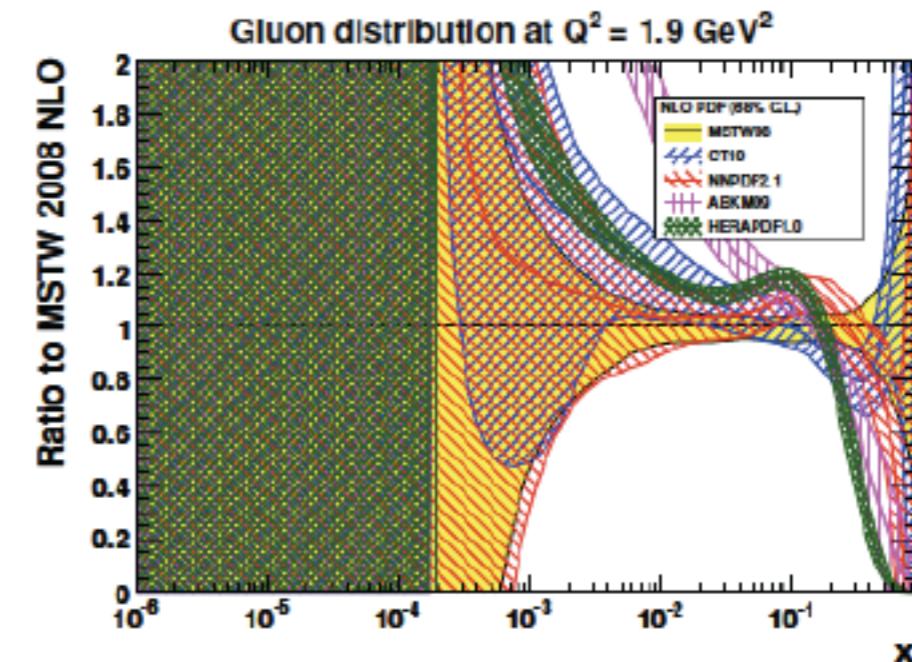
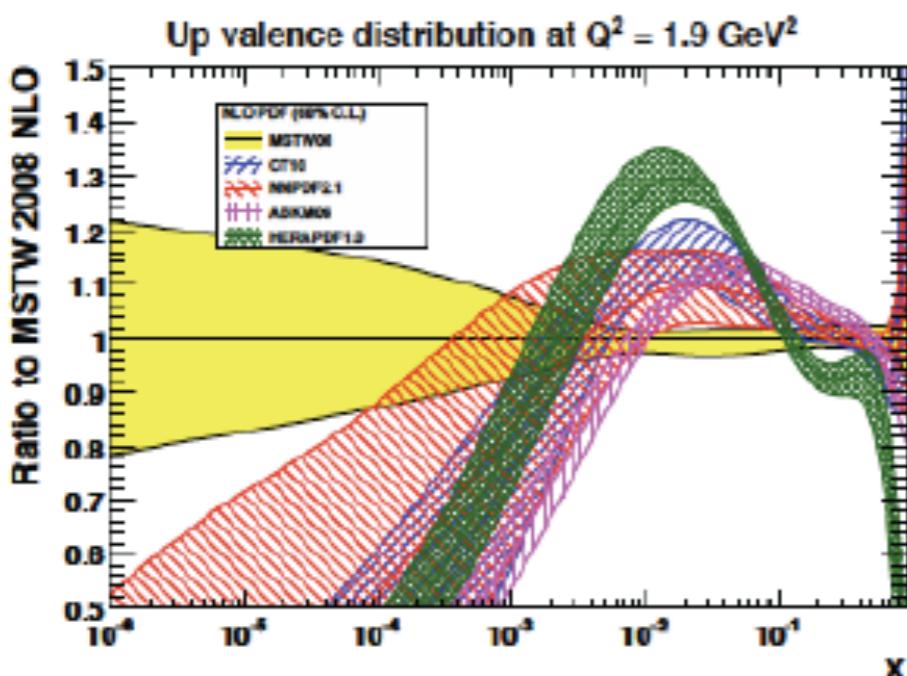
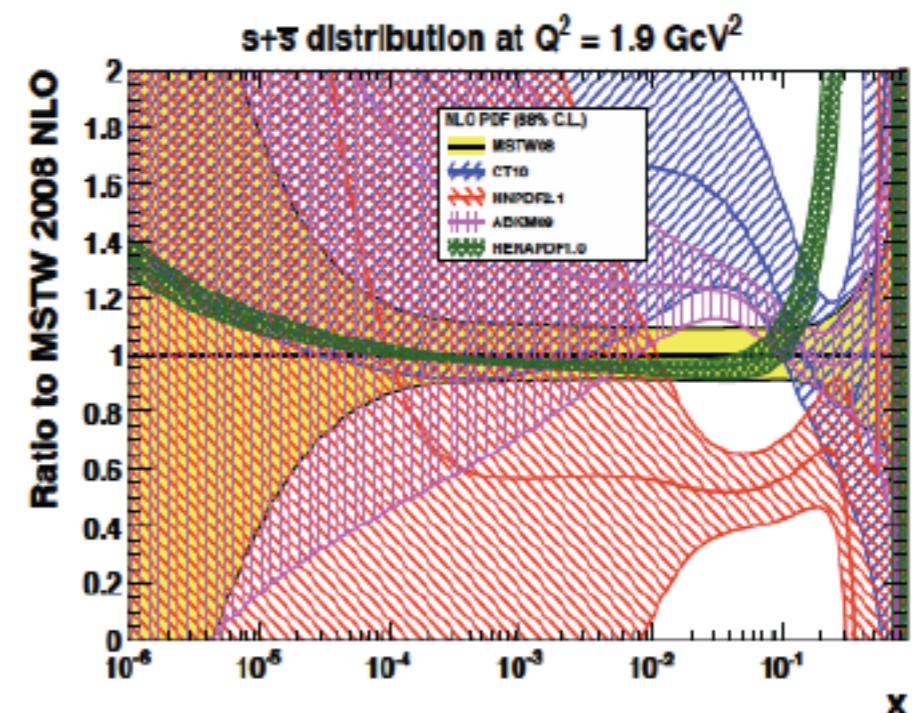
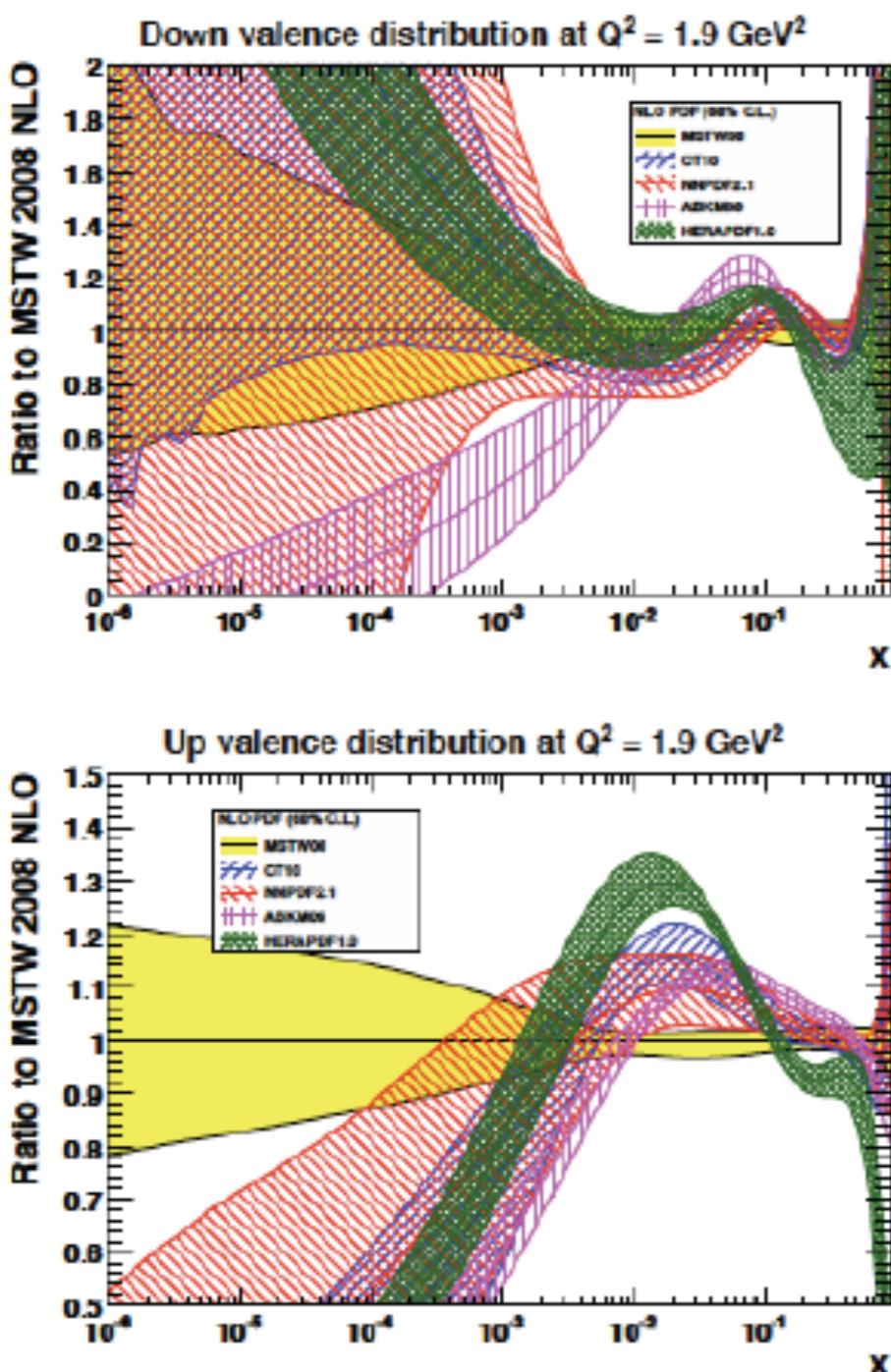


- Large fraction of diffraction $\sigma_{\text{diff}}/\sigma_{\text{tot}} \sim 10\%$ (Cooper-Sarkar, 1206.0984).



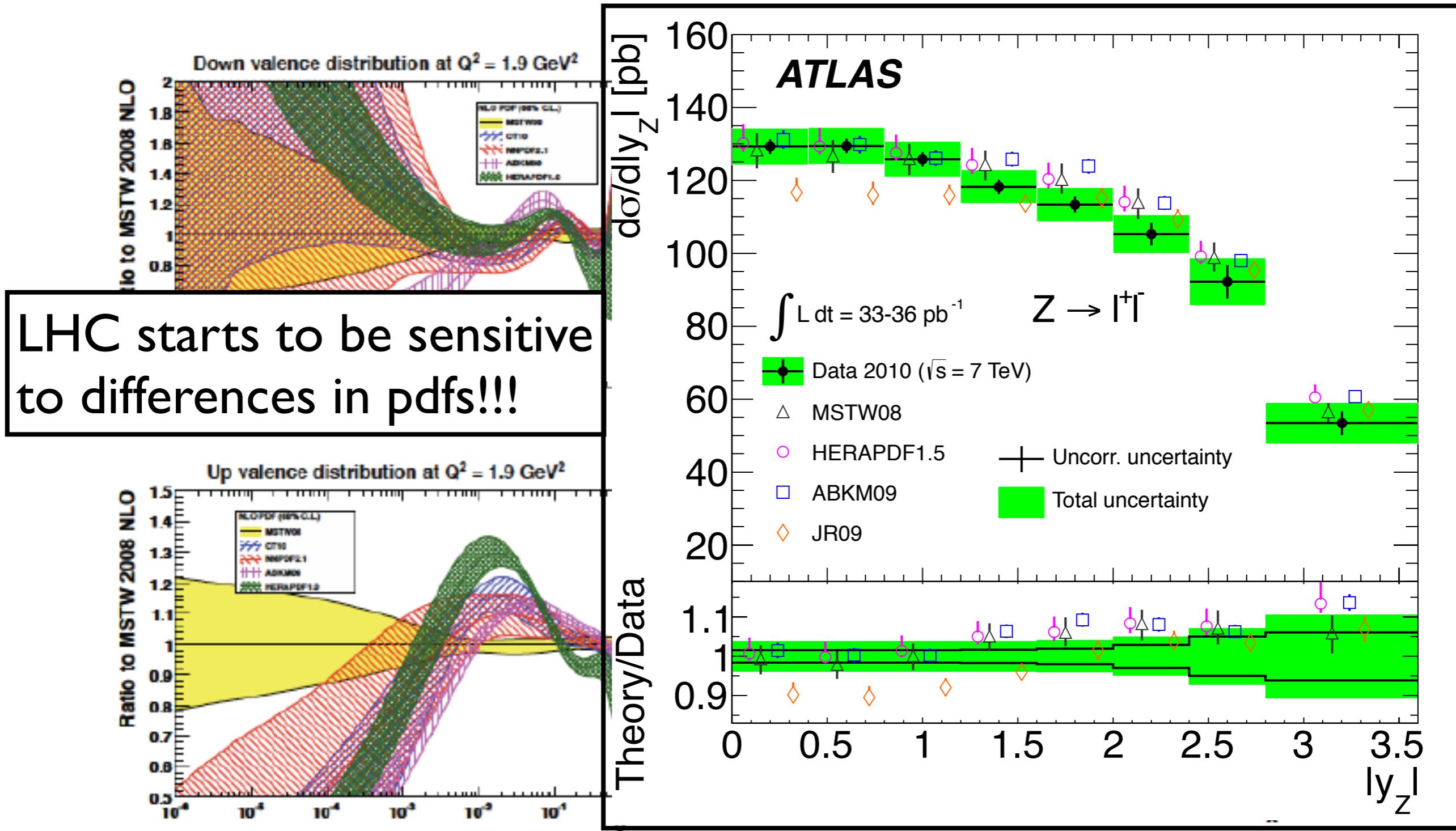
Motivation:

- **HERA**: successful but unfinished QCD program - eA, eD, high and small x , new concepts (TMDs,...), instantons, odderon,...



Motivation:

- **HERA**: successful but unfinished QCD program - eA, eD, high and small x , new concepts (TMDs,...), instantons, odderon,...



Global fits:

⇒ Cross sections computed in collinear factorization

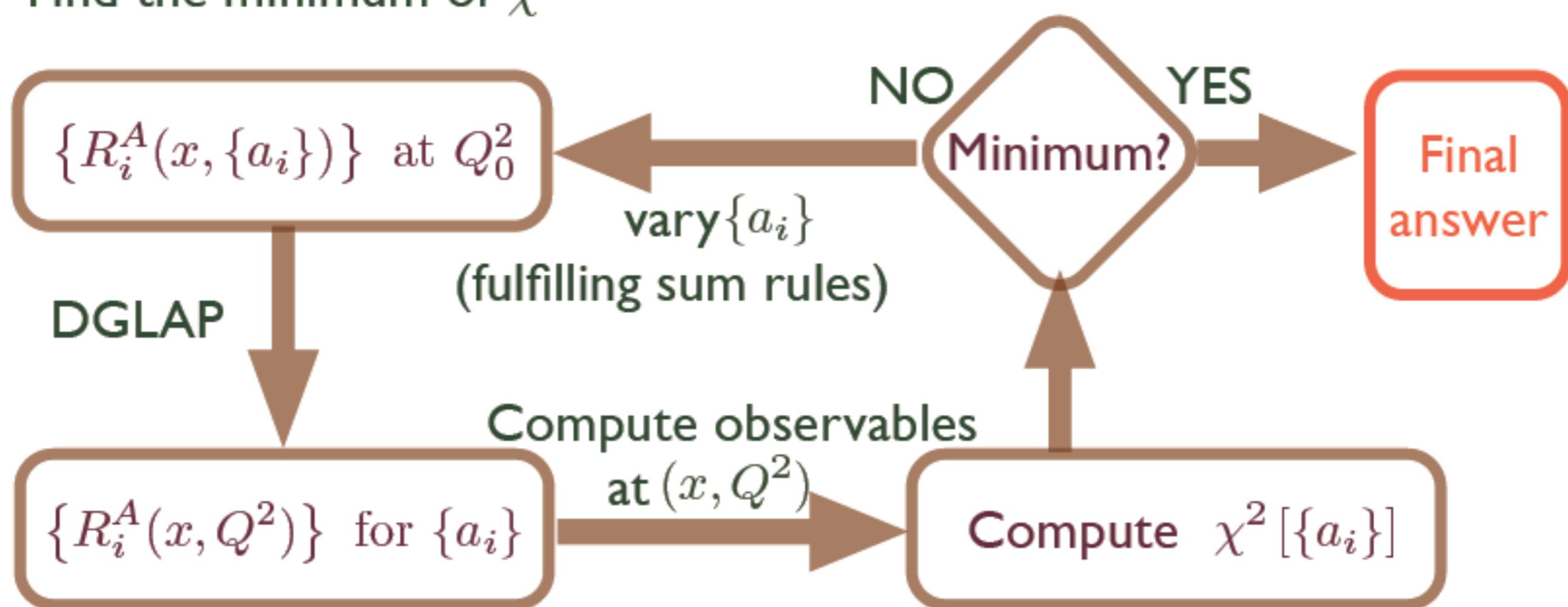
⇒ Define

$$R_i^A(x, Q^2) = \frac{f_i^A(x, Q^2)}{f_i^p(x, Q^2)}$$

⇒ Using a known set for free protons (CTEQ, MRST....)

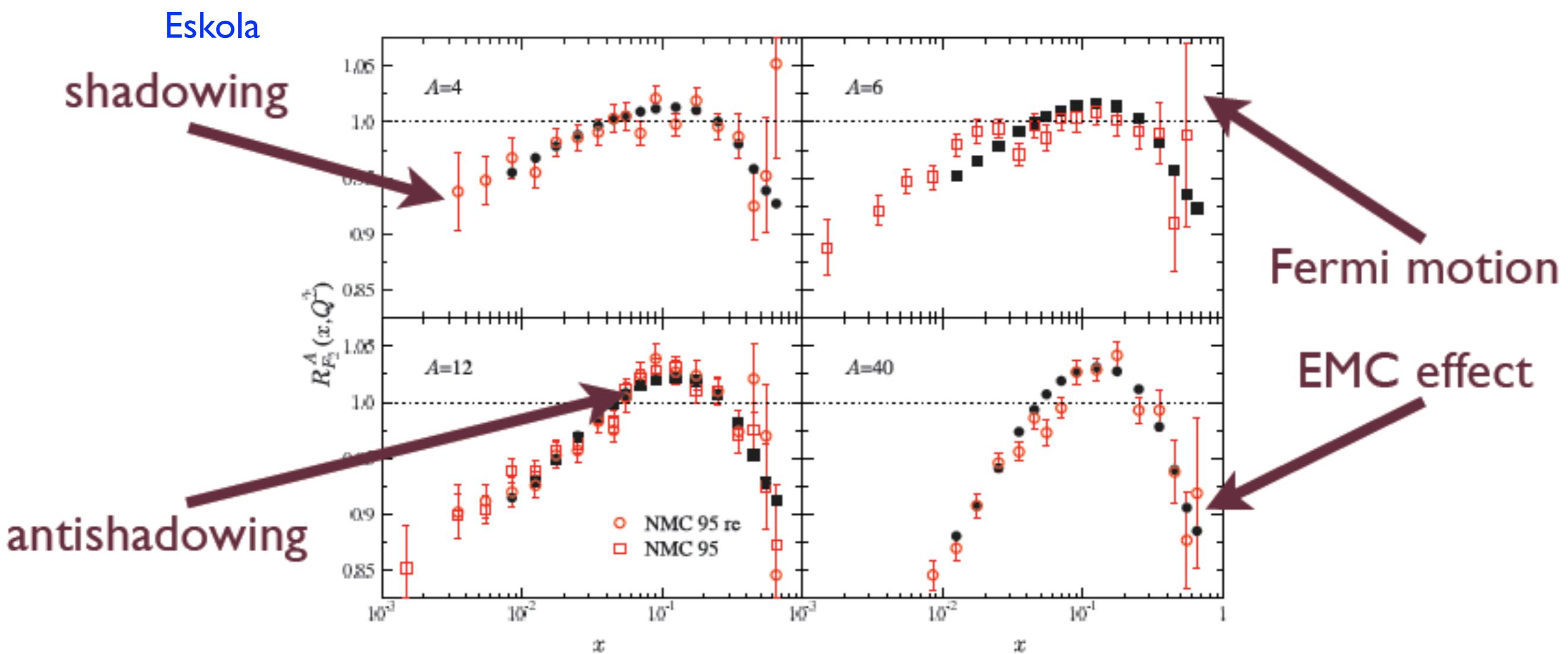
⇒ and DGLAP evolution of the nuclear and free proton PDFs

⇒ Find the minimum of χ^2



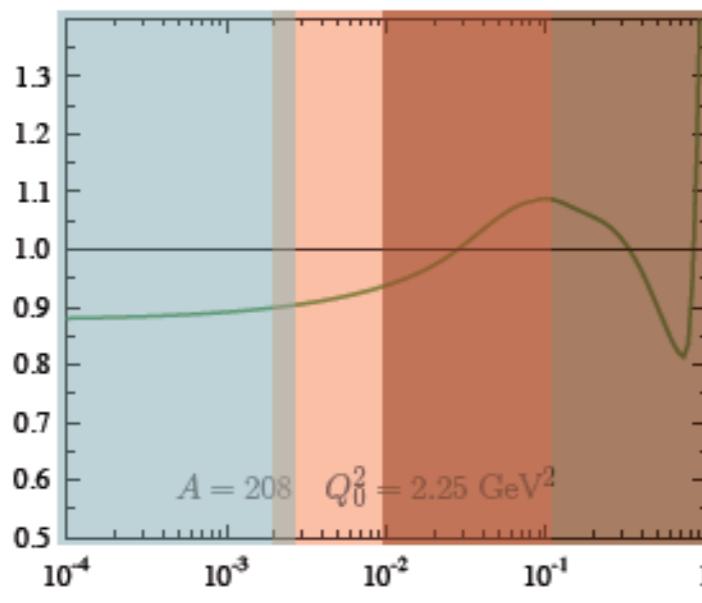
nPDFs (I):

$$R_{F_2}^A(x, Q^2) = \frac{F_2^A(x, Q^2)}{AF_2^p(x, Q^2)}$$



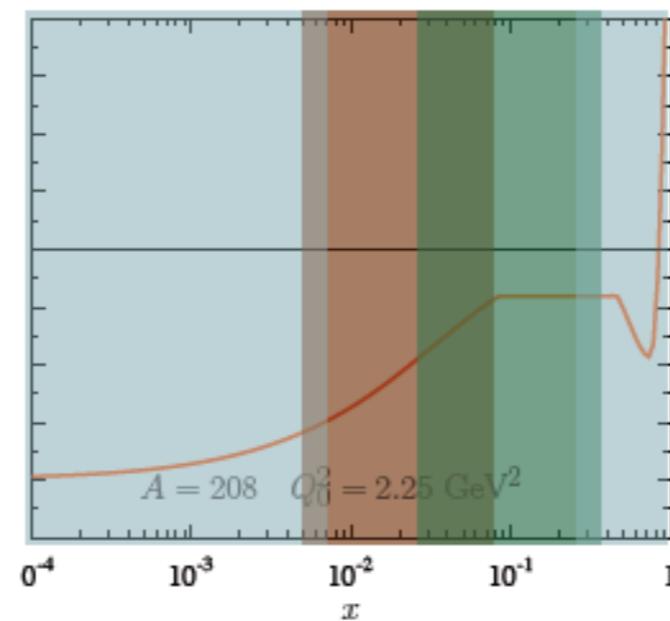
nPDFs (I):

Valence

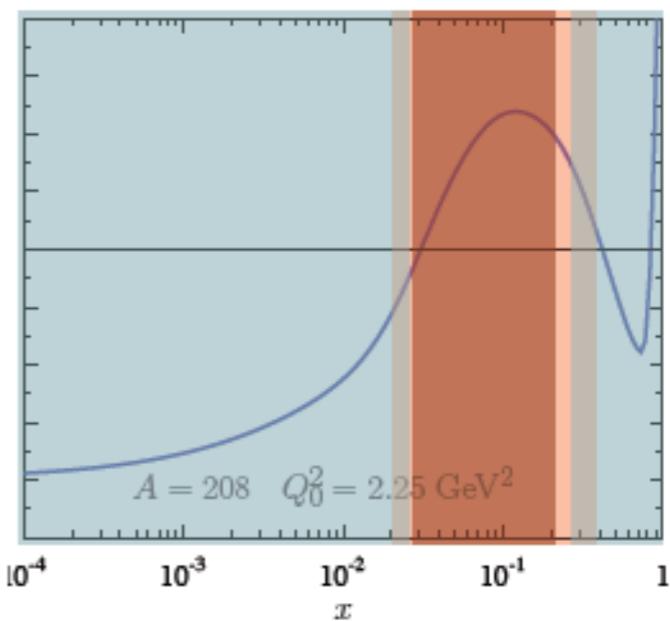


Salgado

Sea quarks



Gluons



Constrained by DIS



Constrained by DY

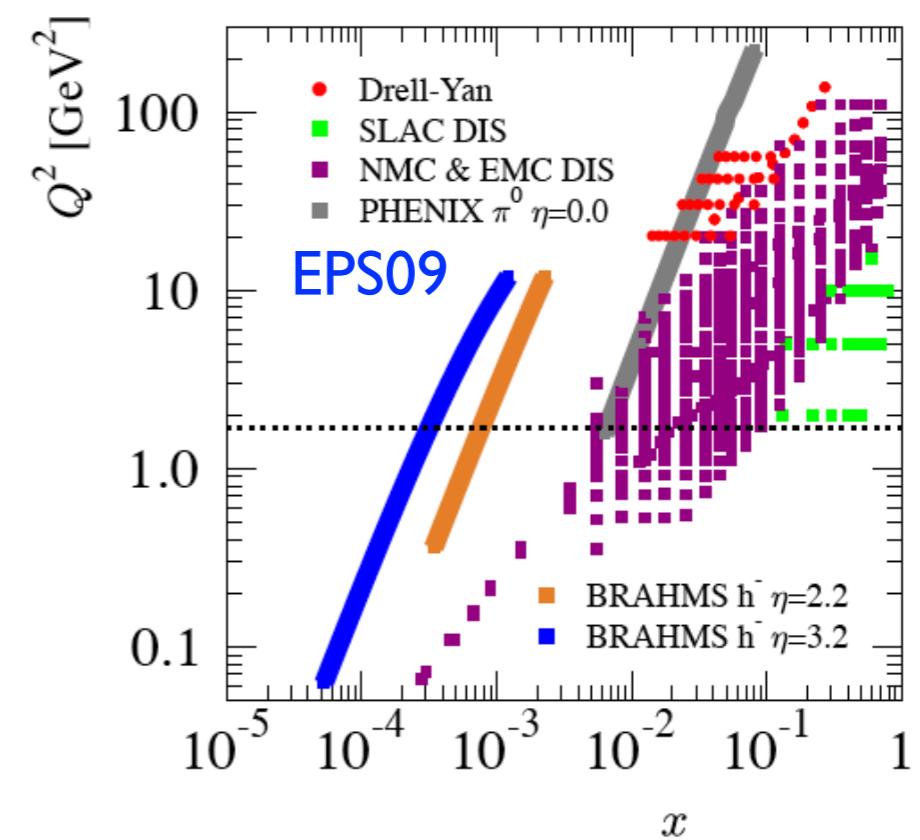


Constrained by Sum rules

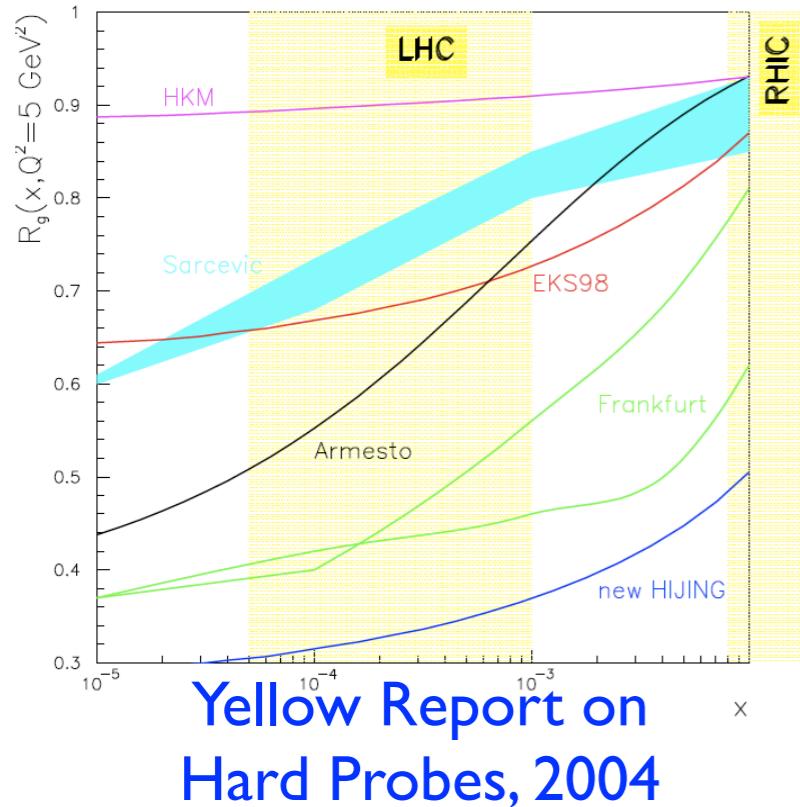


Assumptions

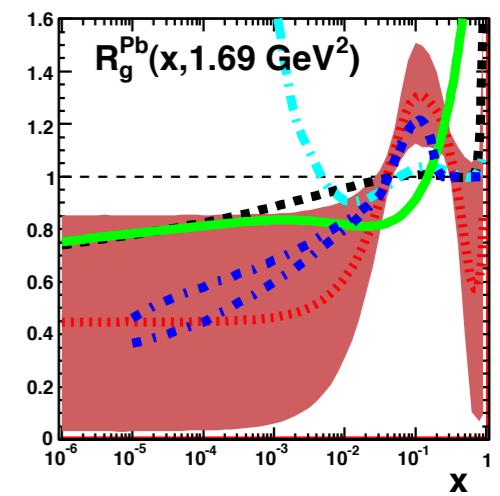
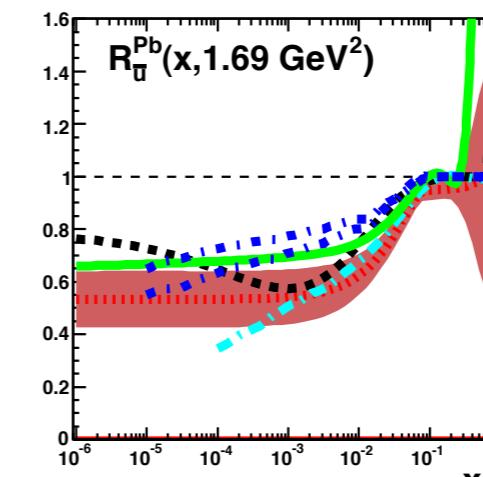
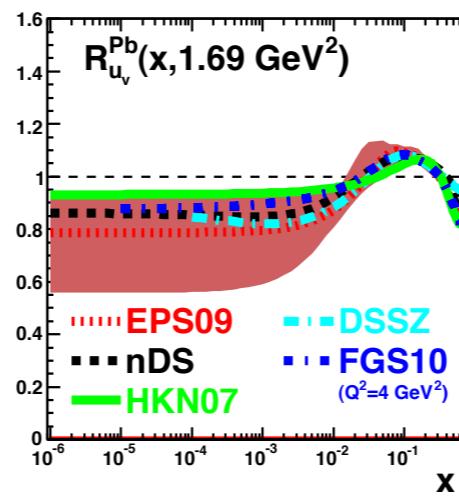
- Lack of experimental data makes the small- x region unconstrained \Rightarrow uncertainties on observables.



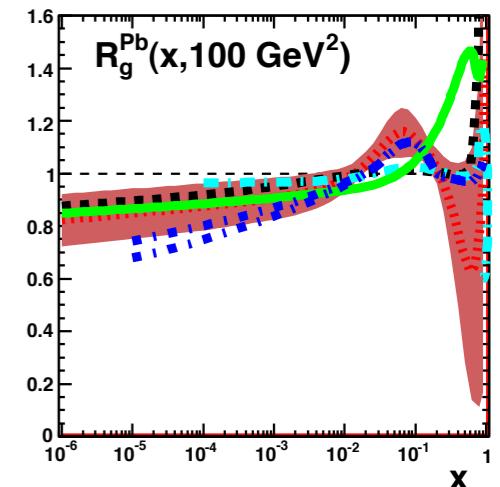
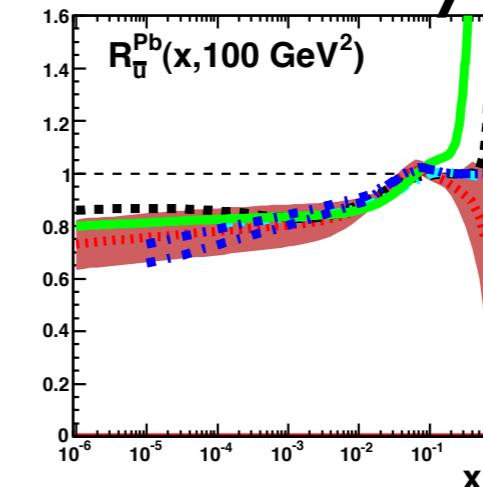
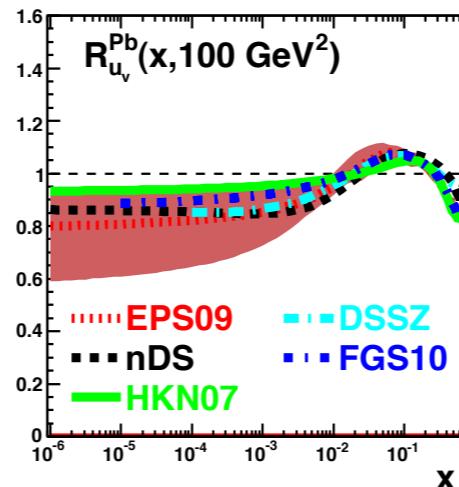
nPDFs (II):



- Lack of data \Rightarrow models give vastly different results for the nuclear glues at small scales and x : problem for benchmarking in HIC.



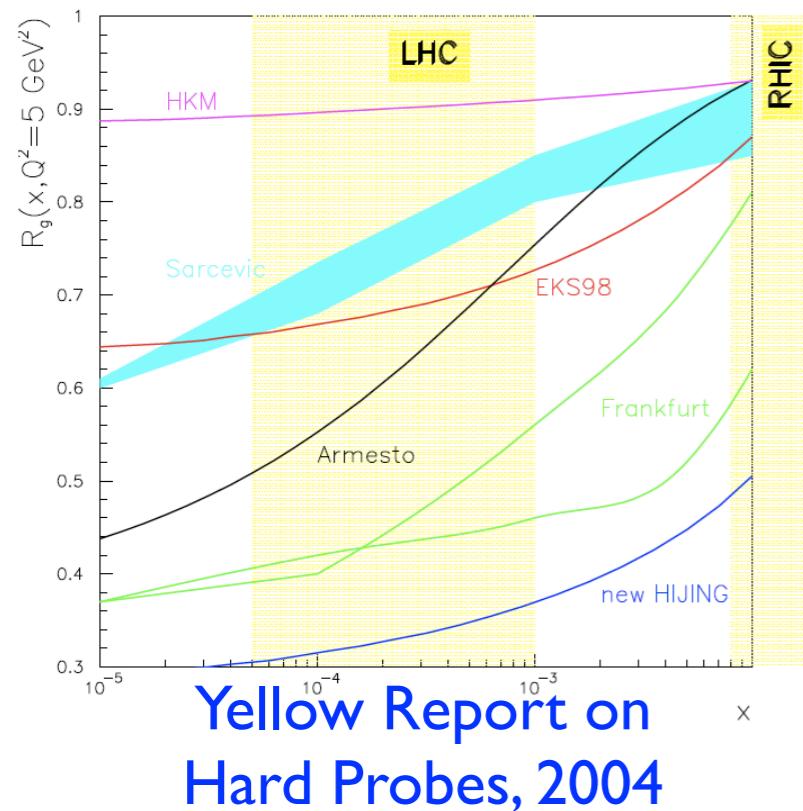
NLO analysis



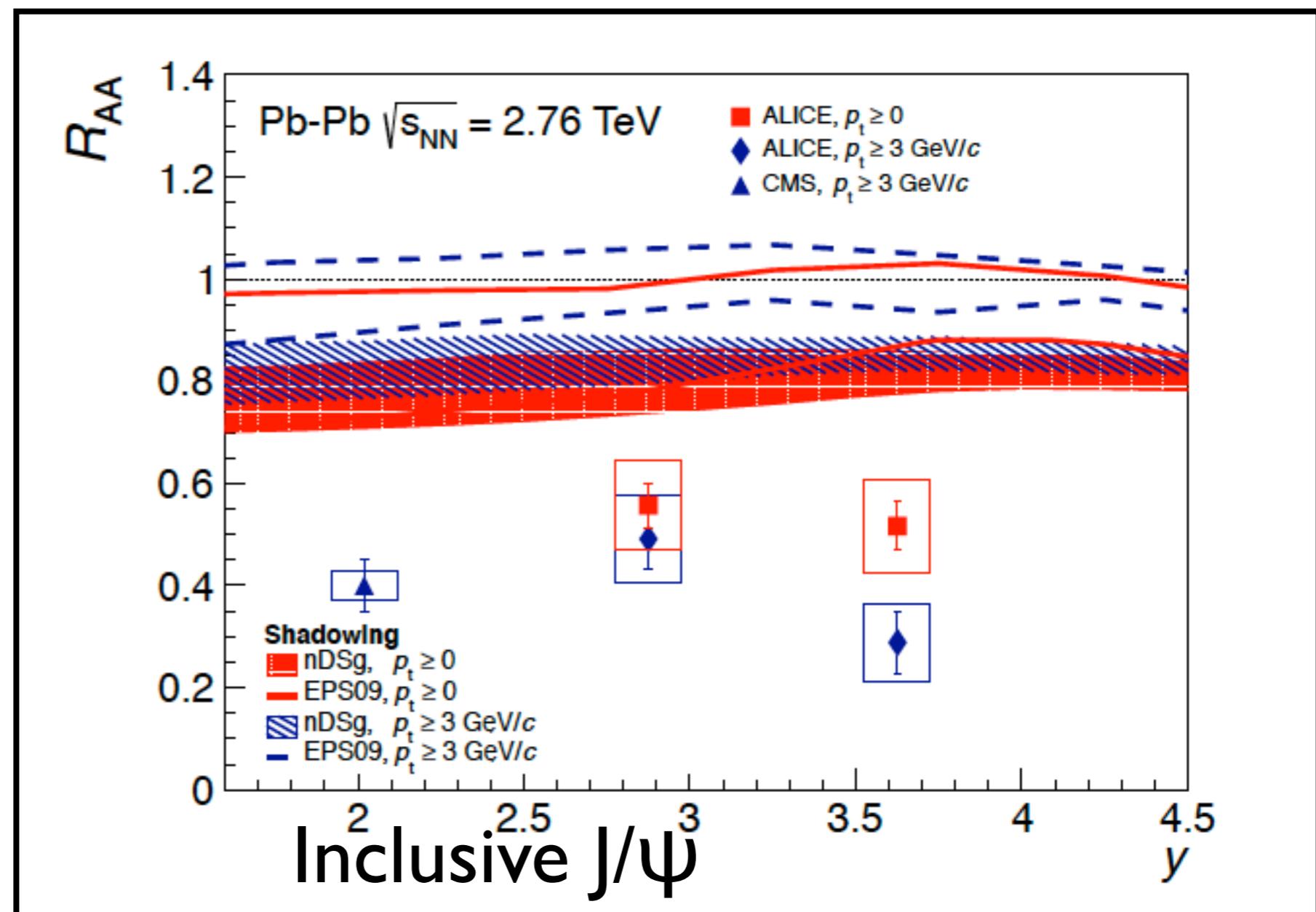
- Available DGLAP analysis at NLO show large uncertainties at small scales and x .
- eA colliders not available before \sim 2020: EIC,LHeC?

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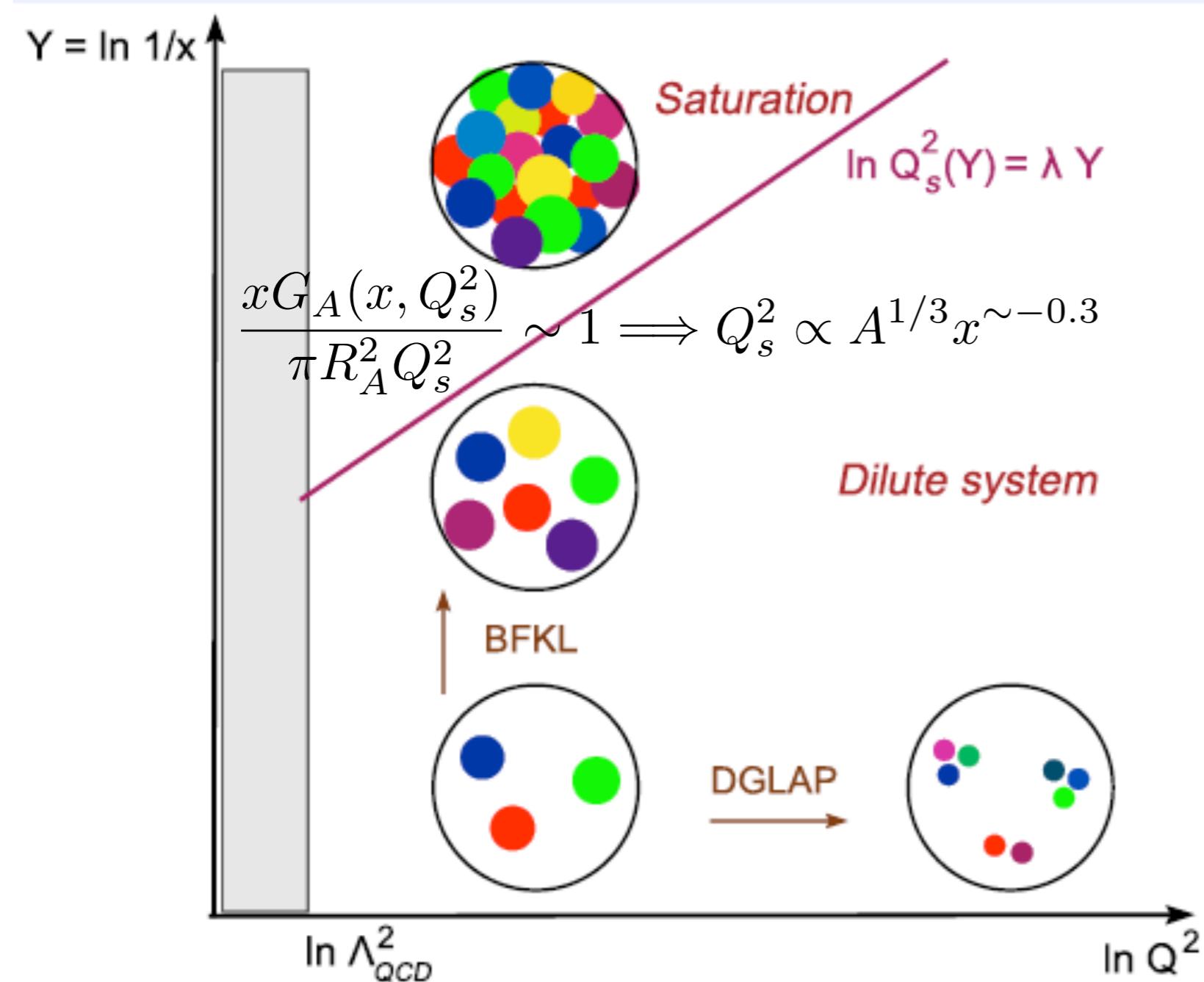


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The ‘QCD phase’ diagram:

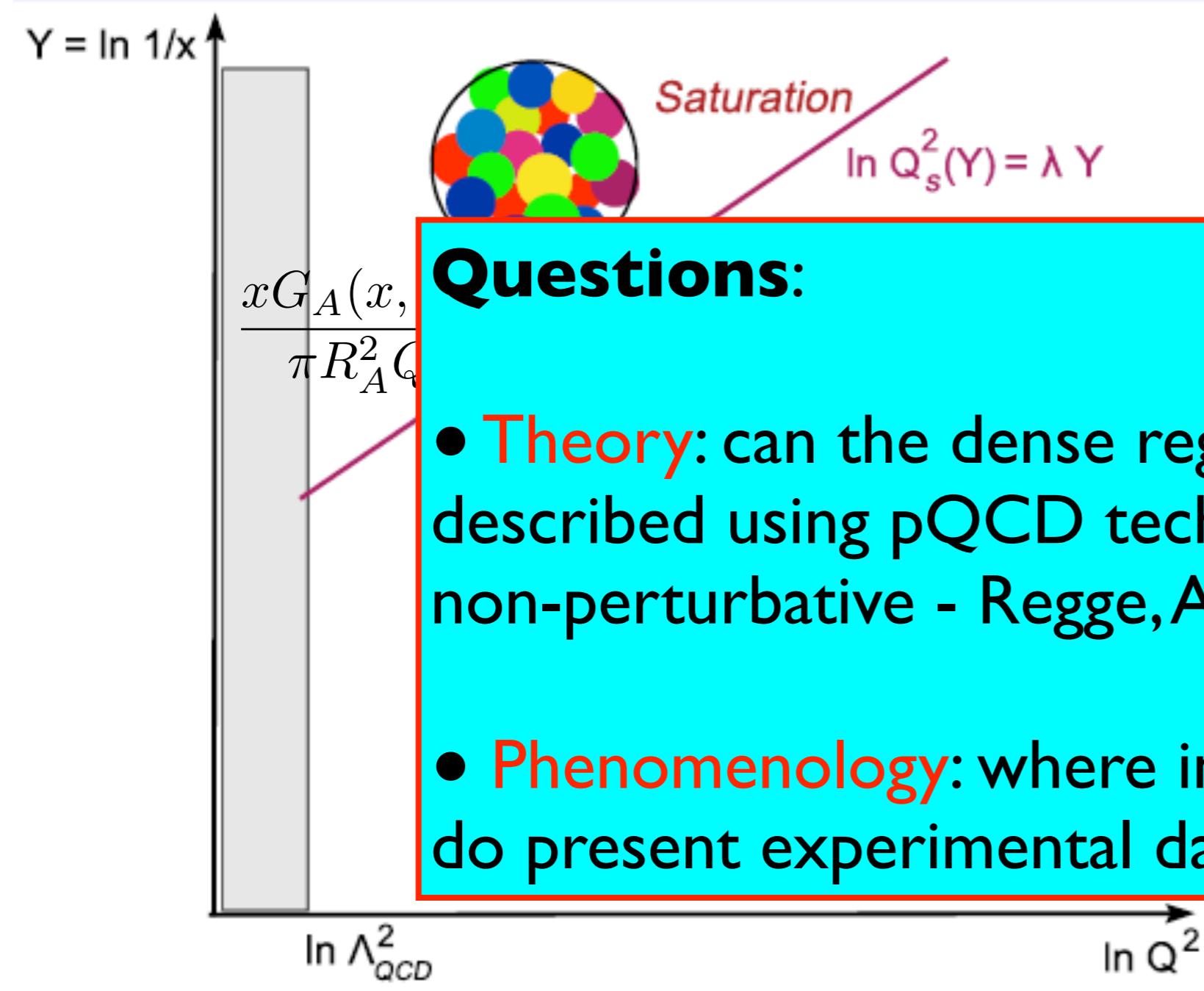
**Our aims:
understanding**



Origin in the early 80's: GLR, Mueller et al, McLerran-Venugopalan.

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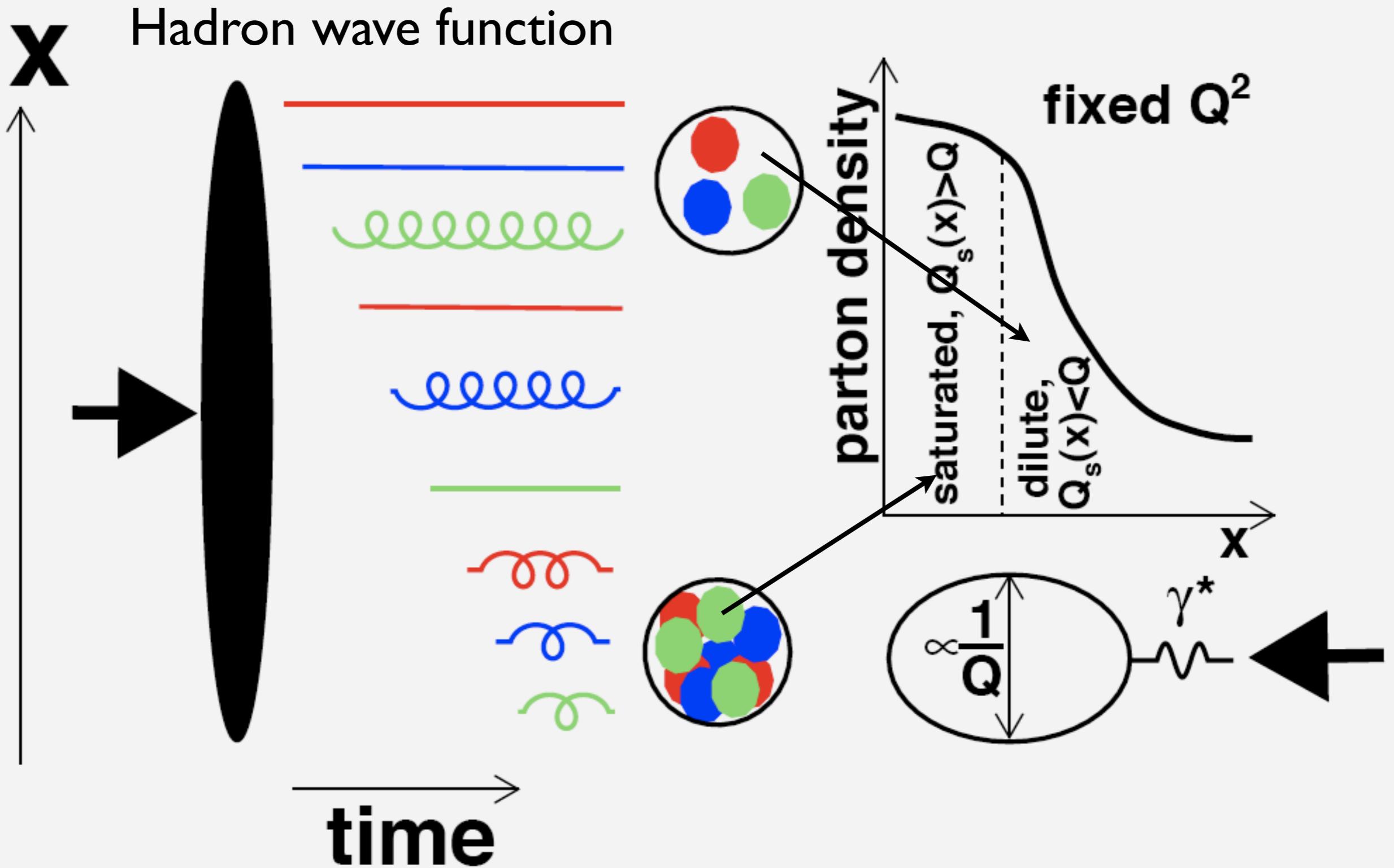
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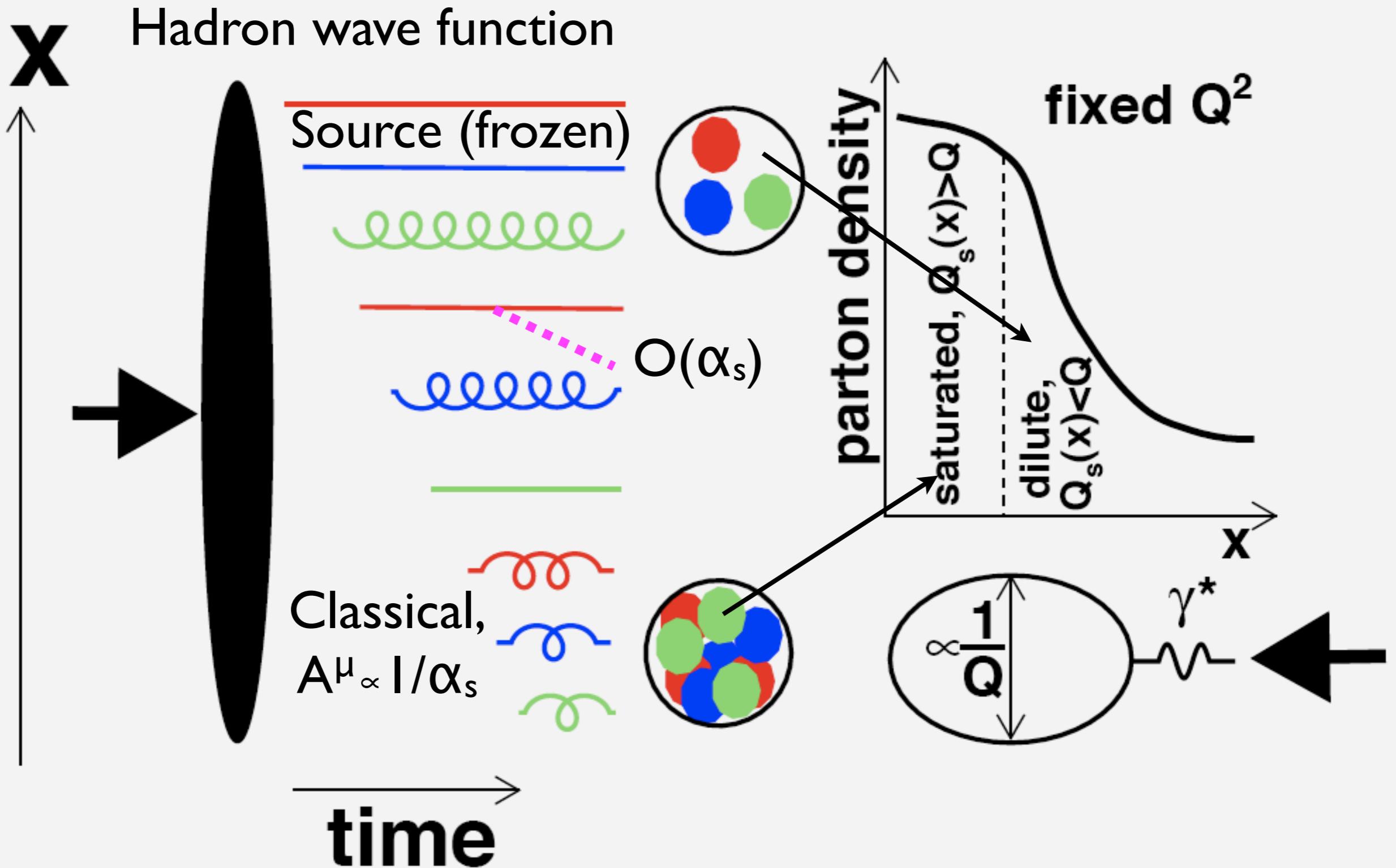
Origin in the early 80's: GLR, Mueller et al, McLerran-Venugopalan.

- ations of QFT.
- ior of QCD at es.
- n wave small x.
- The initial conditions for the creation of a dense medium in heavy-ion collisions.

Saturation ideas: CGC



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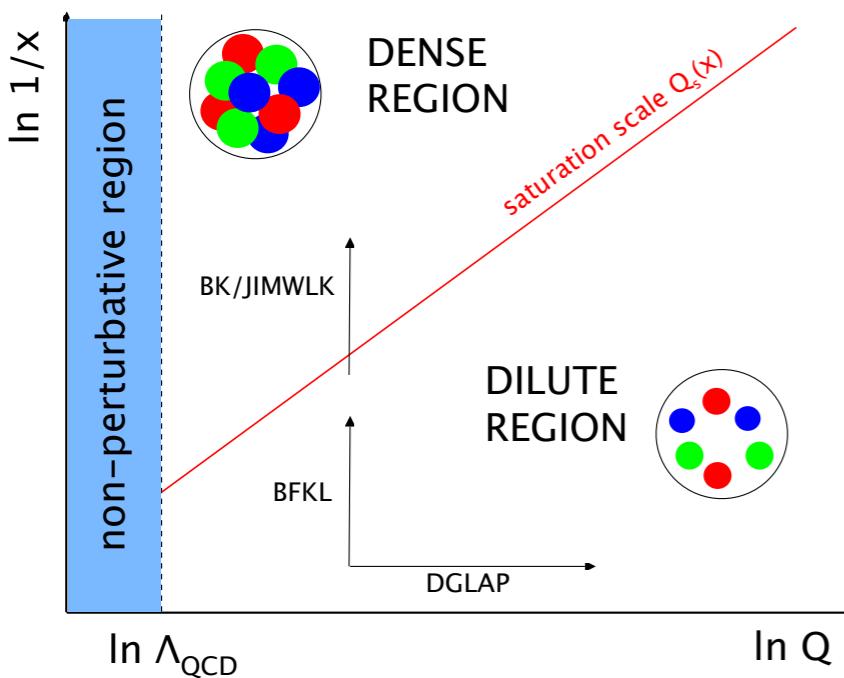


Status of small-x physics:

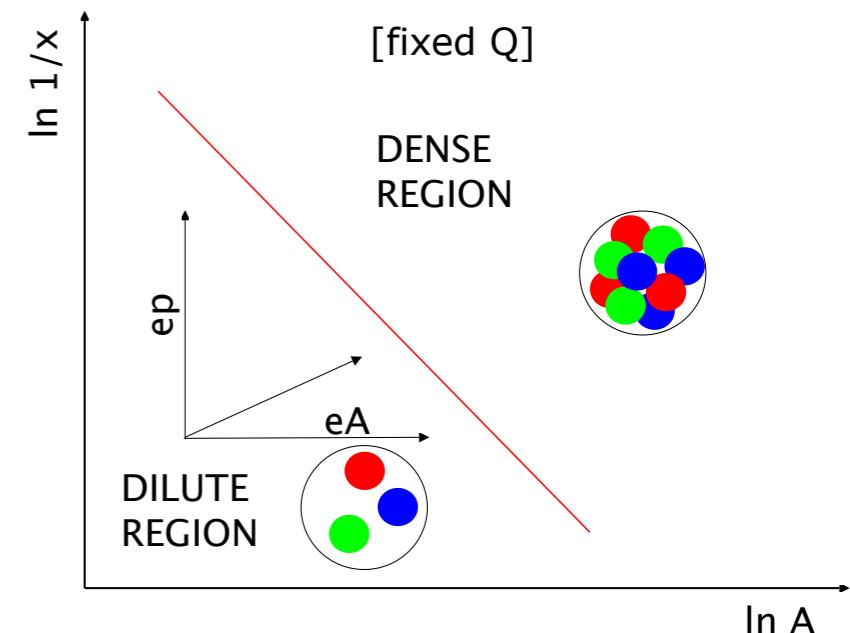
- Three pQCD-based alternatives to describe small-x ep and eA data:
 - DGLAP evolution (fixed order PT).
 - Resummation schemes.
 - CGC (dipole models and rcBK).

Differences lie at moderate $Q^2(>\Lambda_{\text{QCD}}^2)$ and small x . Hints of deviations from NLO DGLAP at small x ([Caola et al'09](#), [Albacete et al'12](#)).

- **Unitarity** (non-linear effects): where?



Two-pronged approach: $\downarrow x / \uparrow A$. **eA:** test/ enhance density effects.



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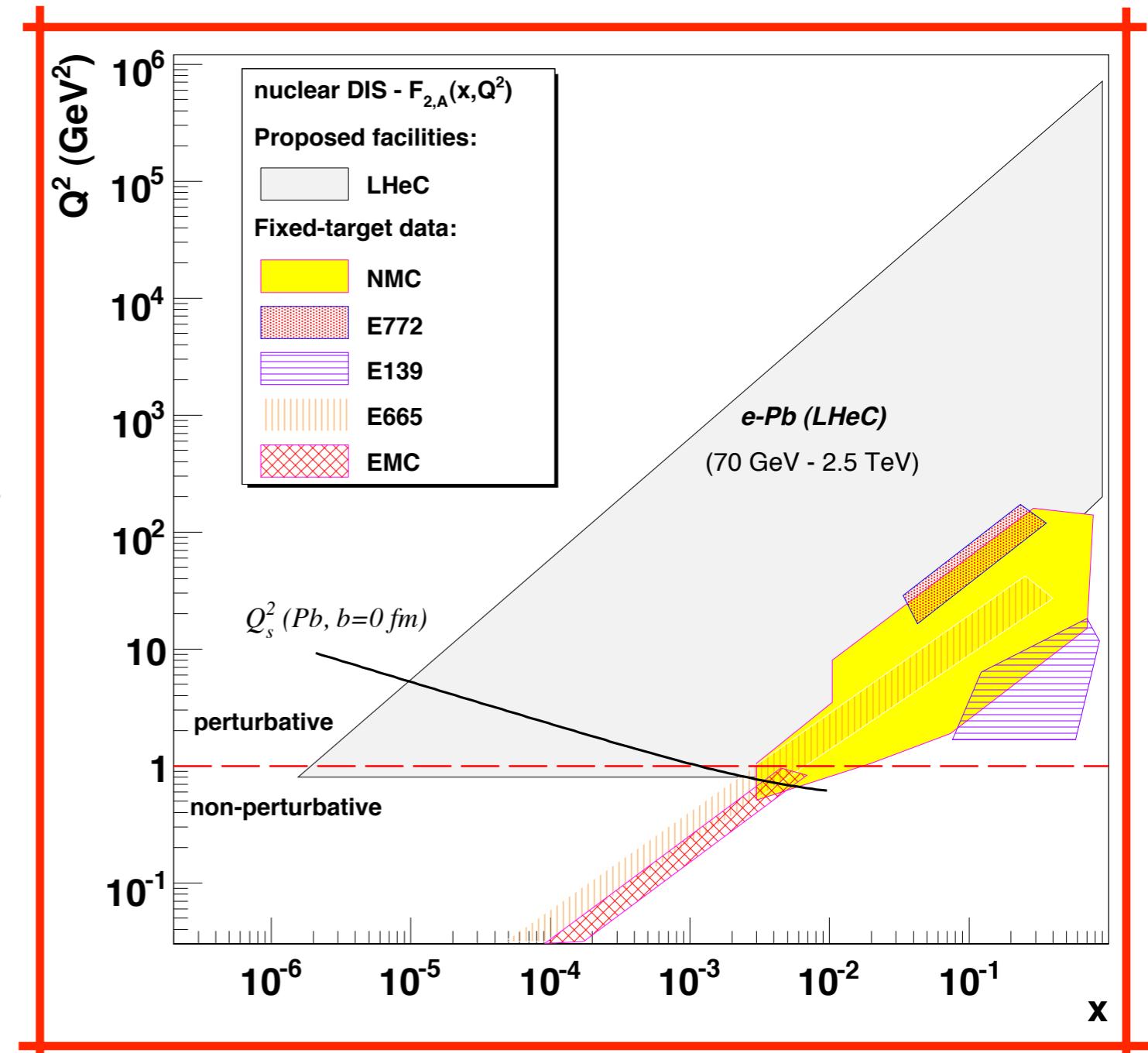
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- Inclusive diffraction.
- Exclusive diffraction.
- Final states.

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Project:

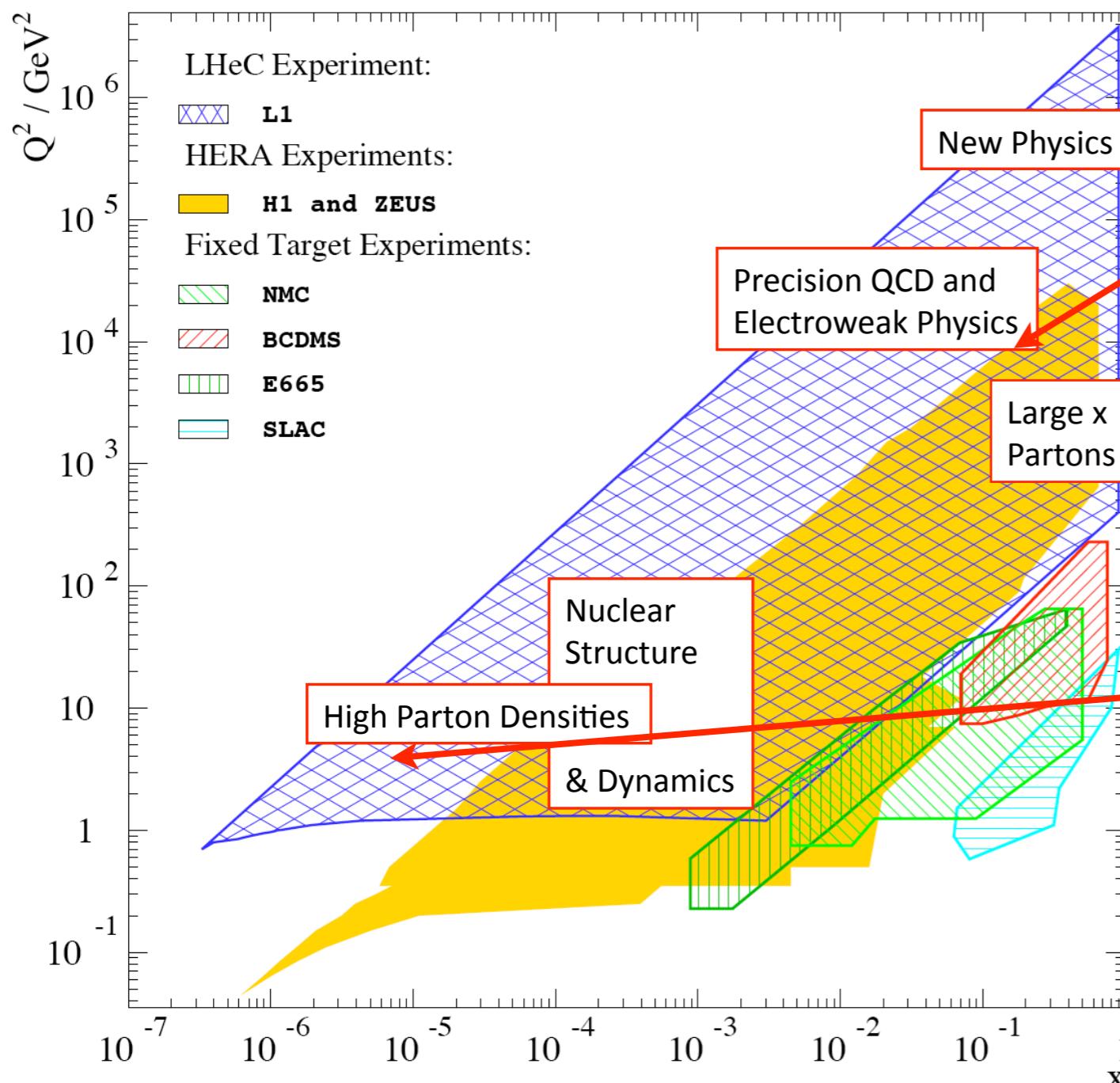
- **LHeC@CERN** → ep/eA experiment using p/A from the LHC:
 $E_p = 7 \text{ TeV}$, $E_A = (Z/A)E_p = 2.75 \text{ TeV}/\text{nucleon}$ for Pb.
- New e^+/e^- accelerator: $E_{cm} \sim 1-2 \text{ TeV}/\text{nucleon}$ ($E_e = 50-150 \text{ GeV}$).
- **Requirements:**
 - * Luminosity $\sim 10^{33} \text{ cm}^{-2}\text{s}^{-1}$.
 - * Acceptance: 1-179 degrees (low- x ep/eA).
 - * Tracking to 0.1 mrad.
 - * EMCAL calibration to 0.1 %.
 - * HCAL calibration to 0.5 %.
 - * Luminosity determination to 1 %.
 - * Compatible with LHC operation.



Project:

Requirements	LHeC	HERA	How?
high lumi for high x and Q^2	10^{33}	$1-5 \times 10^{31}$	
large acceptance	1-179 deg.	7-177 deg.	kinematic coverage
tracking	0.1 mrad	0.2-1 mrad	modern Si
EMcal	0.1 %	0.2-0.5 %	kinematic reconstruction
Hcal	0.5 %	1 %	tracking + calo e/h
accurate lumi/pol	0.5 %	1 %	demanding

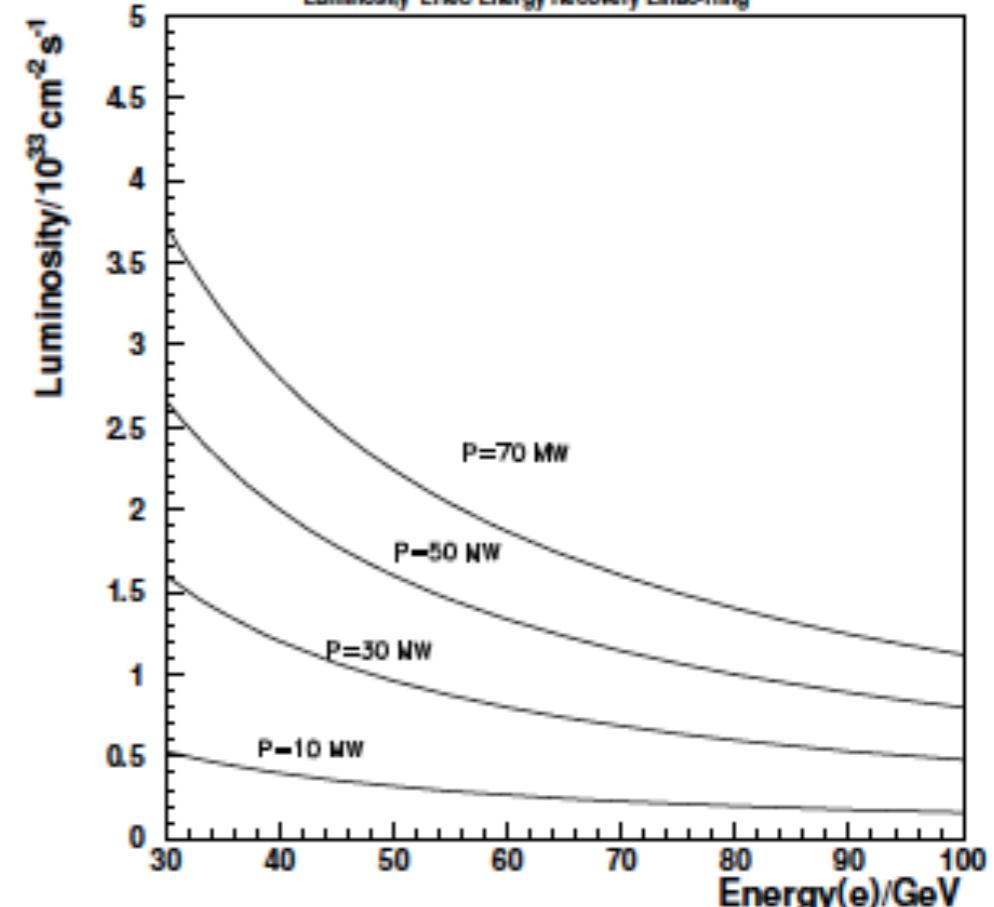
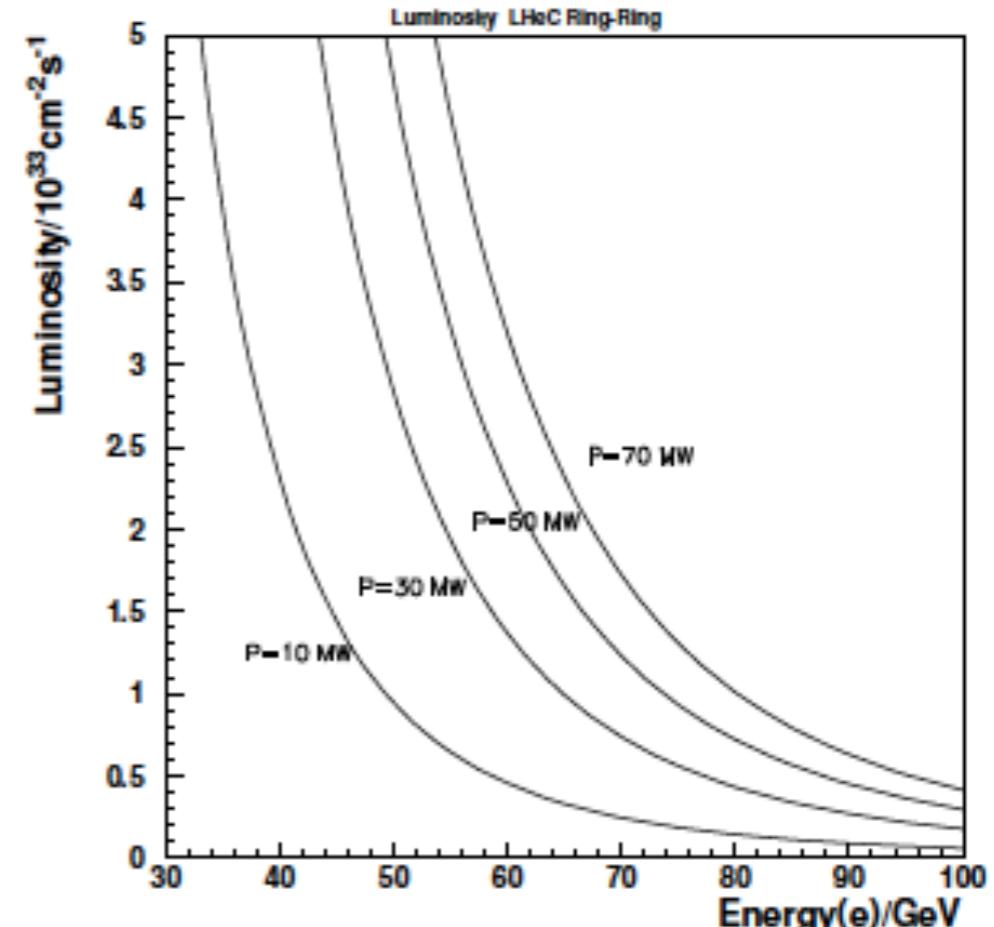
Physics goals:



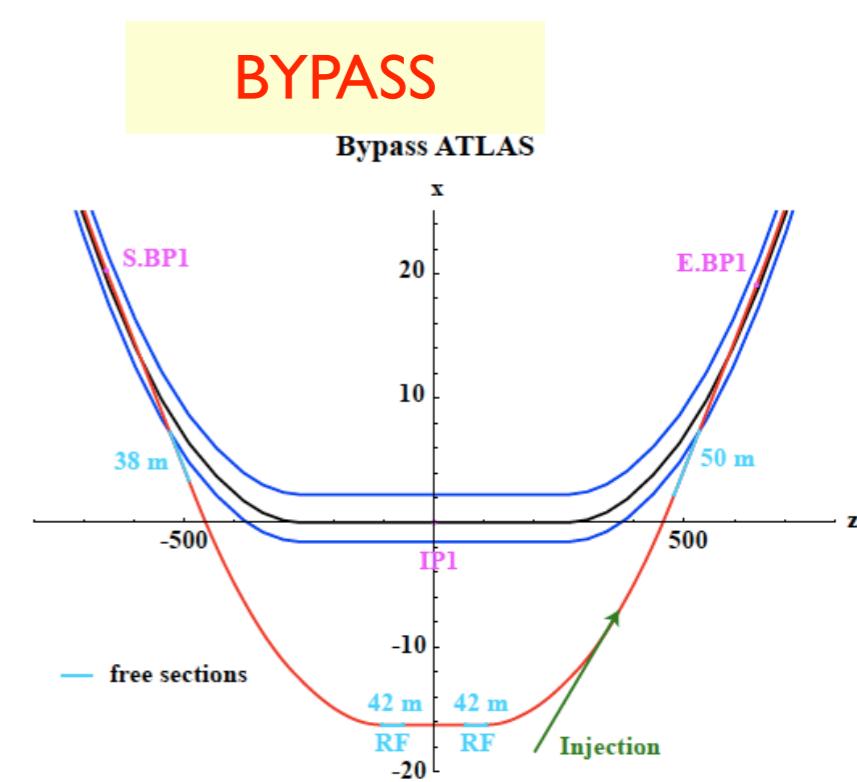
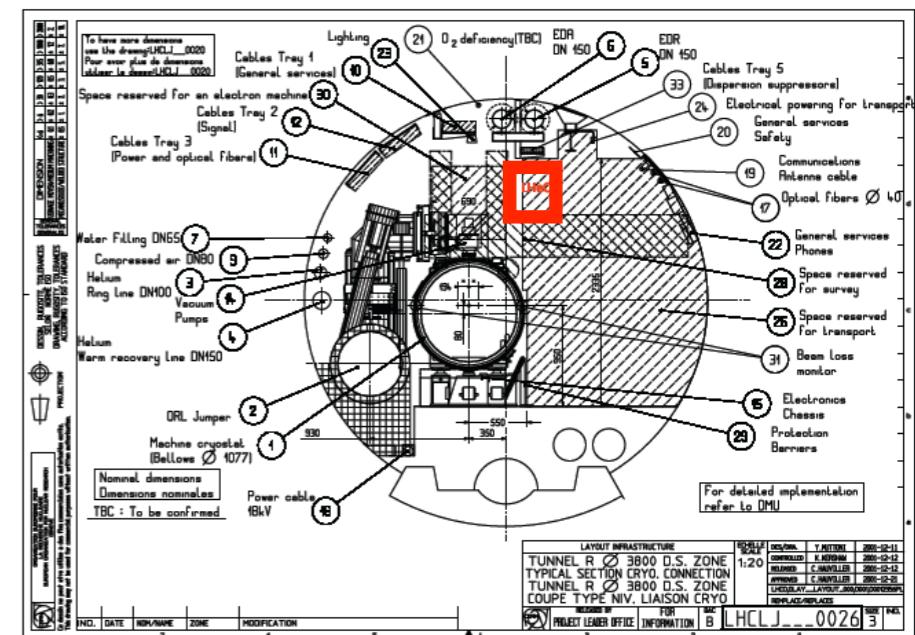
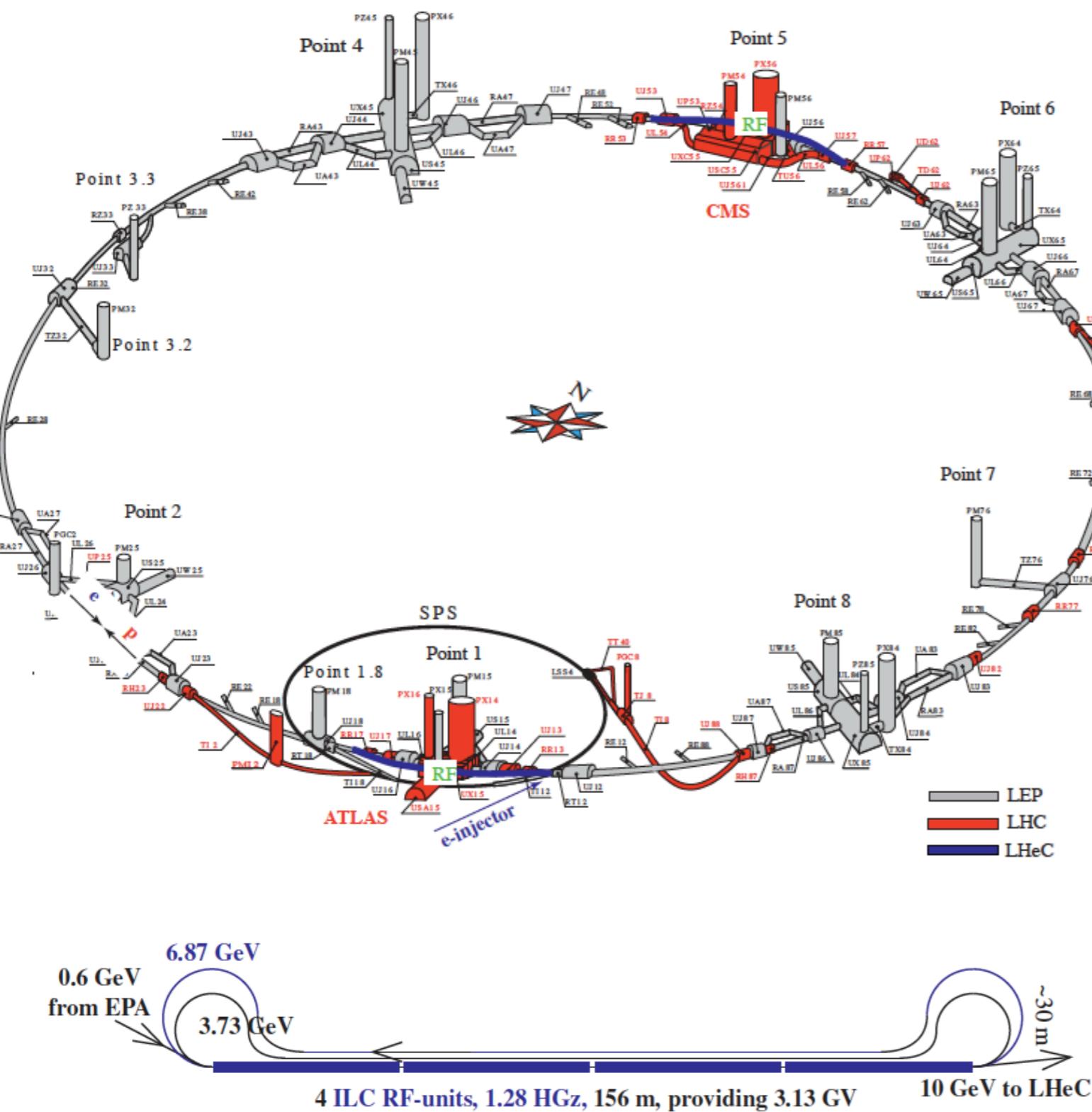
- Proton structure to a few 10^{-20} m: Q^2 lever arm.
- Precision QCD/EW physics.
- High-mass frontier (leptoquarks, excited fermions, contact interactions).
- Unambiguous access, in ep and eA, to a qualitatively novel regime of matter predicted by QCD.
- Substructure/parton dynamics inside nuclei with strong implications on QGP search.

LHeC Power constraints and design considerations:

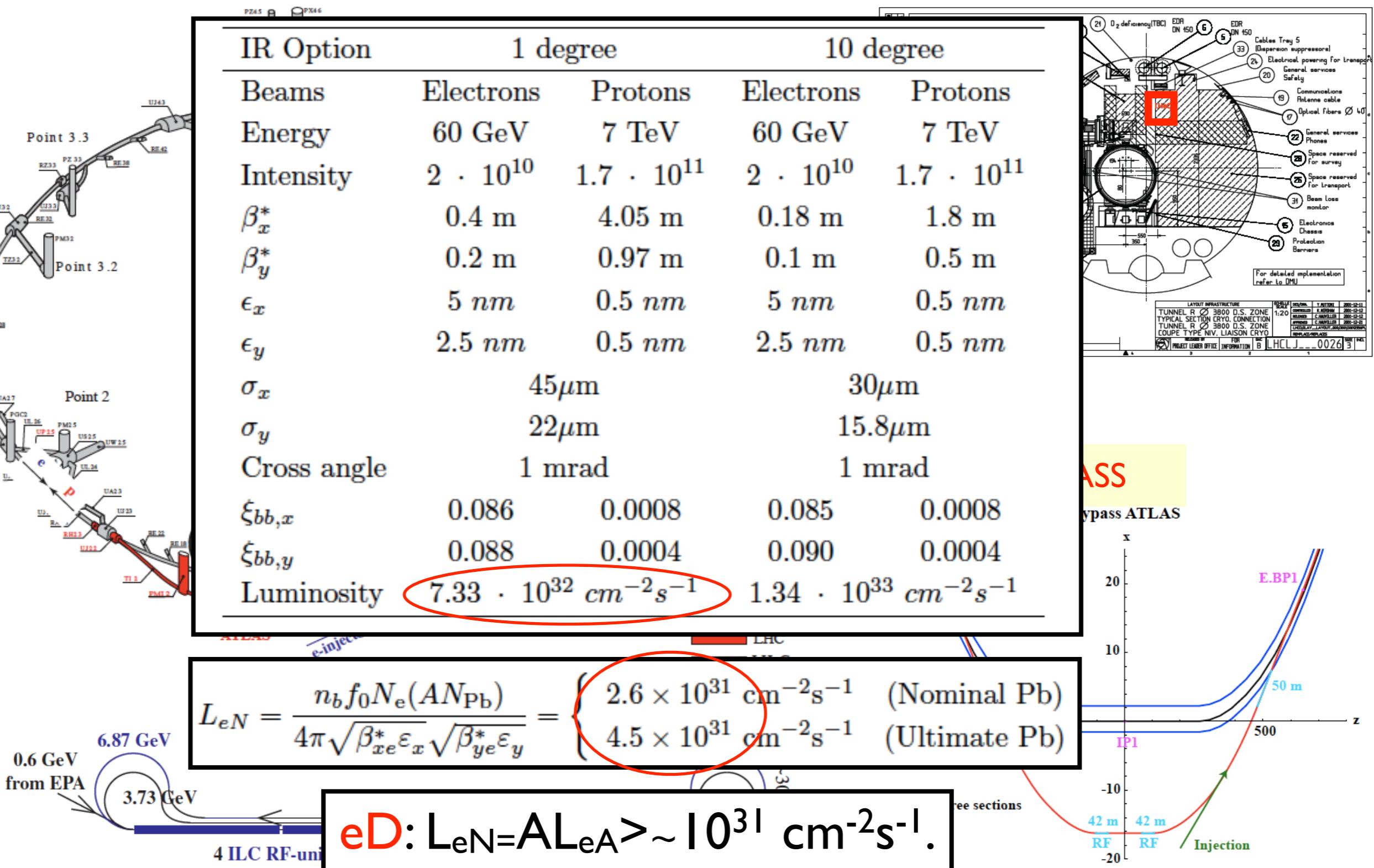
	Ring	Linac
electron beam 60 GeV		
$e^- (e^+)$ per bunch $N_e [10^9]$	20 (20)	1 (0.1)
$e^- (e^+)$ polarisation [%]	40 (40)	90 (0)
bunch length [mm]	10	0.6
tr. emittance at IP $\gamma\epsilon_{x,y}^e$ [mm]	0.58, 0.29	0.05
IP β function $\beta_{x,y}^*$ [m]	0.4, 0.2	0.12
beam current [mA]	131	6.6
energy recovery intensity gain	—	17
total wall plug power [MW]	100	100
syn rad power [kW]	51	49
critical energy [keV]	163	718
proton beam 7 TeV		
protons per bunch $N_p [10^{11}]$	1.7	1.7
transverse emittance $\gamma\epsilon_{x,y}^p$ [μm]	3.75	3.75
collider		
Lum $e^- p (e^+ p) [10^{32}\text{cm}^{-2}\text{s}^{-1}]$	9 (9)	10 (1)
bunch spacing [ns]	25	25
rms beam spot size $\sigma_{x,y}$ [μm]	30, 16	7
crossing angle θ [mrad]	1	0
$L_{eN} = A L_{eA} [10^{32}\text{cm}^{-2}\text{s}^{-1}]$	0.3	1



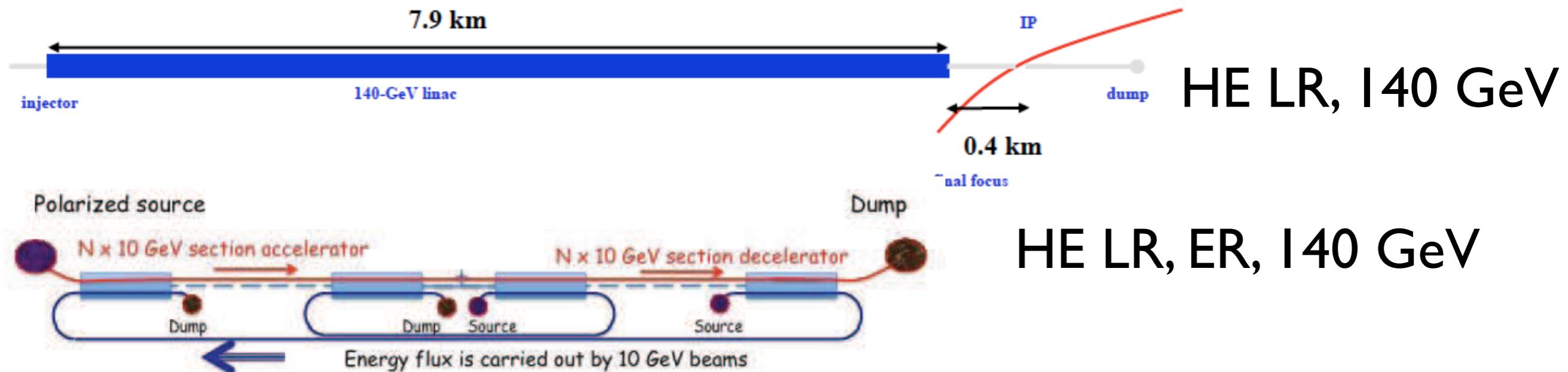
Machine: Ring-Ring option



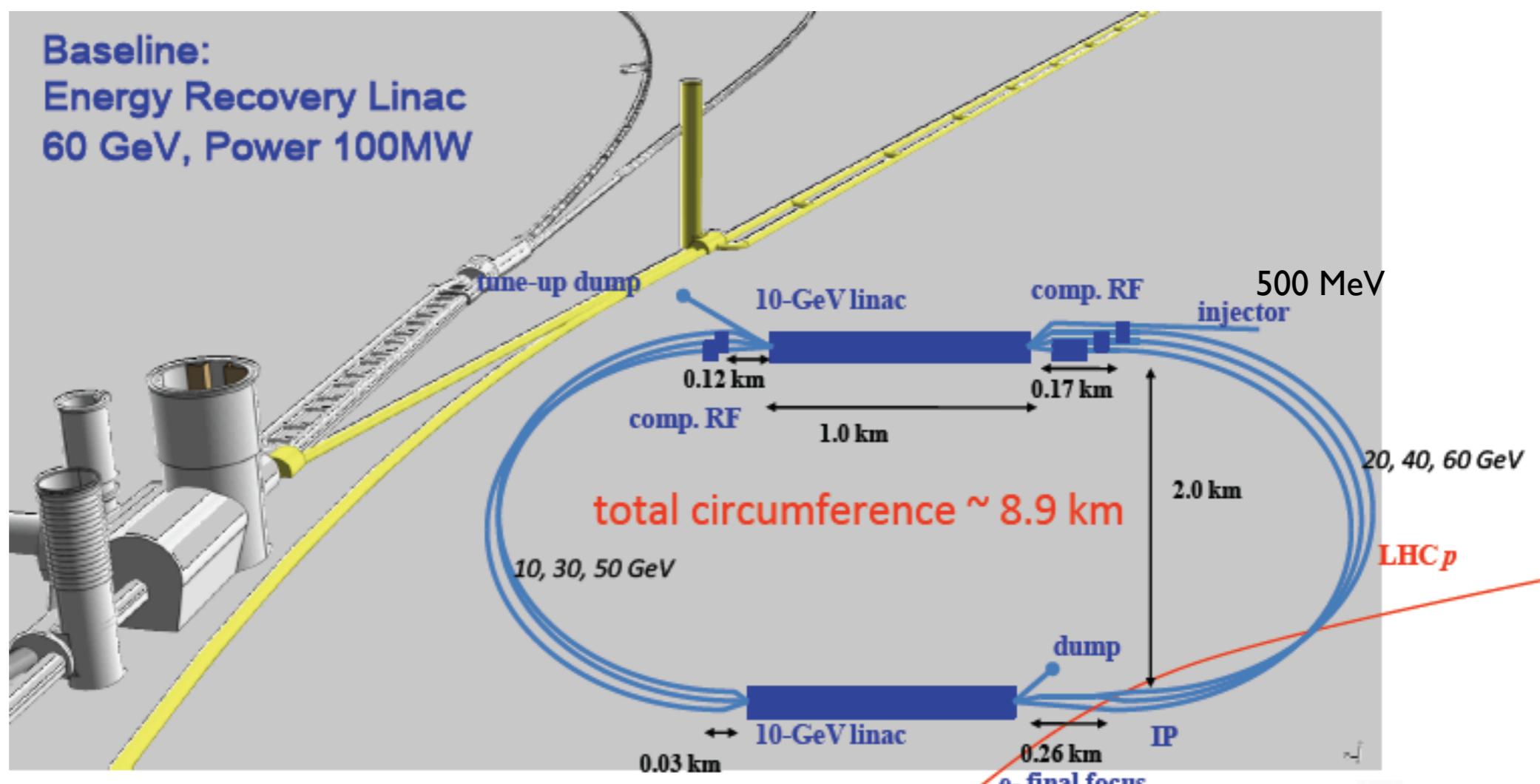
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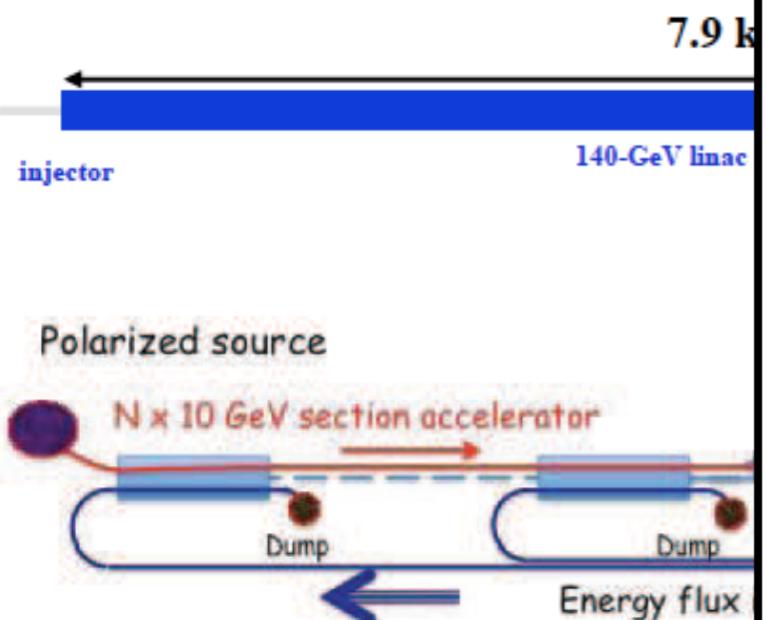
Machine: Linac-Ring option



Preliminary; Bogacz@DISI I; LHeC
Design Study Report, CERN 2012



Machine: Linac-Ring option

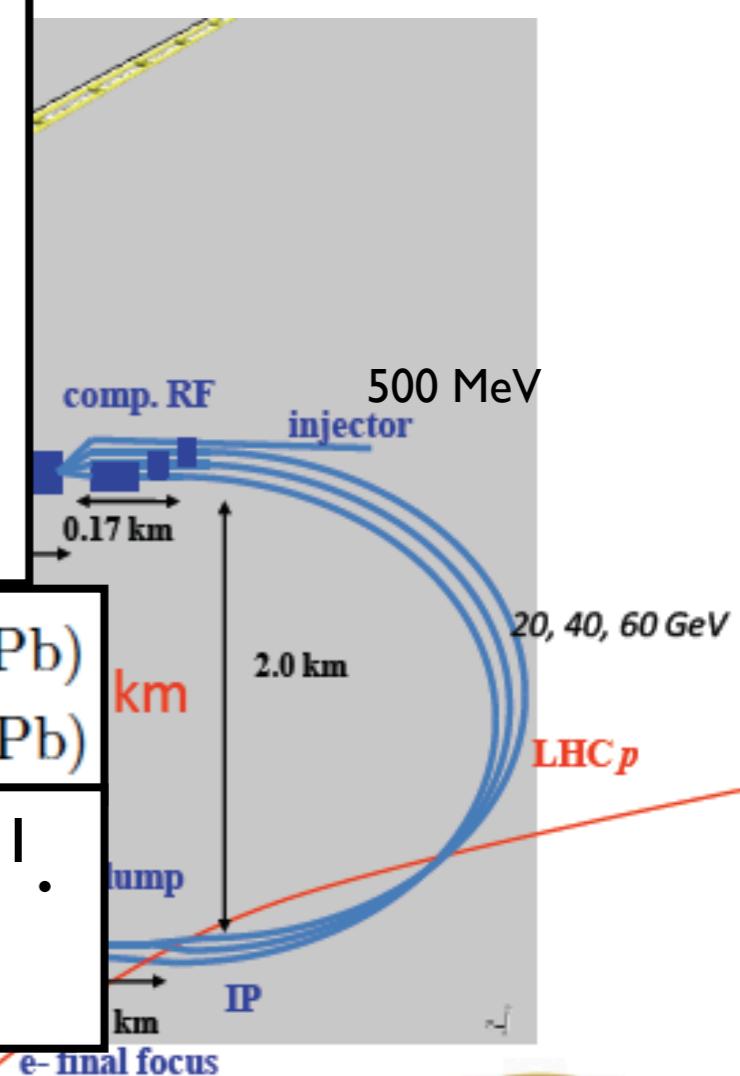


electron beam	LR FRL	LR
e- energy at IP[GeV]	60	140
luminosity [$10^{32} \text{ cm}^{-2}\text{s}^{-1}$]	10	0.44
polarization [%]	90	90
bunch population [10^9]	2.0	1.6
e- bunch length [mm]	0.3	0.3
bunch interval [ns]	50	50
transv. emit. $\gamma \epsilon_{x,y}$ [mm]	0.05	0.1
rms IP beam size $\sigma_{x,y}$ [μm]	7	7
e- IP beta funct. $\beta^*_{x,y}$ [m]	0.12	0.14
full crossing angle [mrad]	0	0
geometric reduction H_{hg}	0.91	0.94
repetition rate [Hz]	N/A	10
beam pulse length [ms]	N/A	5
ER efficiency	94%	N/A
average current [mA]	6.6	5.4
tot. wall plug power[MW]	100	100

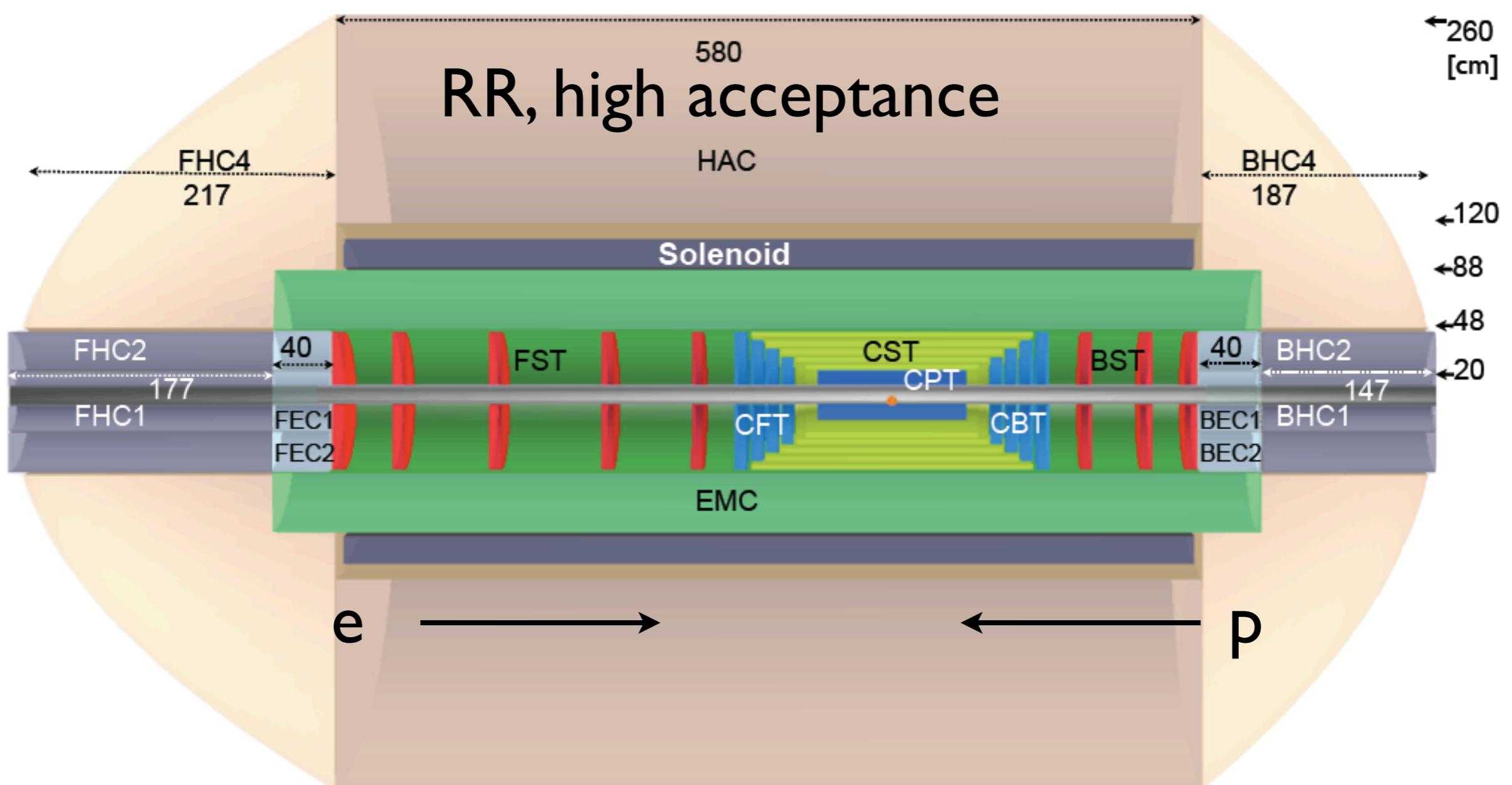
$$L_{eN} = \begin{cases} 9 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1} & (\text{Nominal Pb}) \\ 1.6 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} & (\text{Ultimate Pb}) \end{cases}$$

eD: $L_{eN} = A L_{eA} > \sim 3 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$.

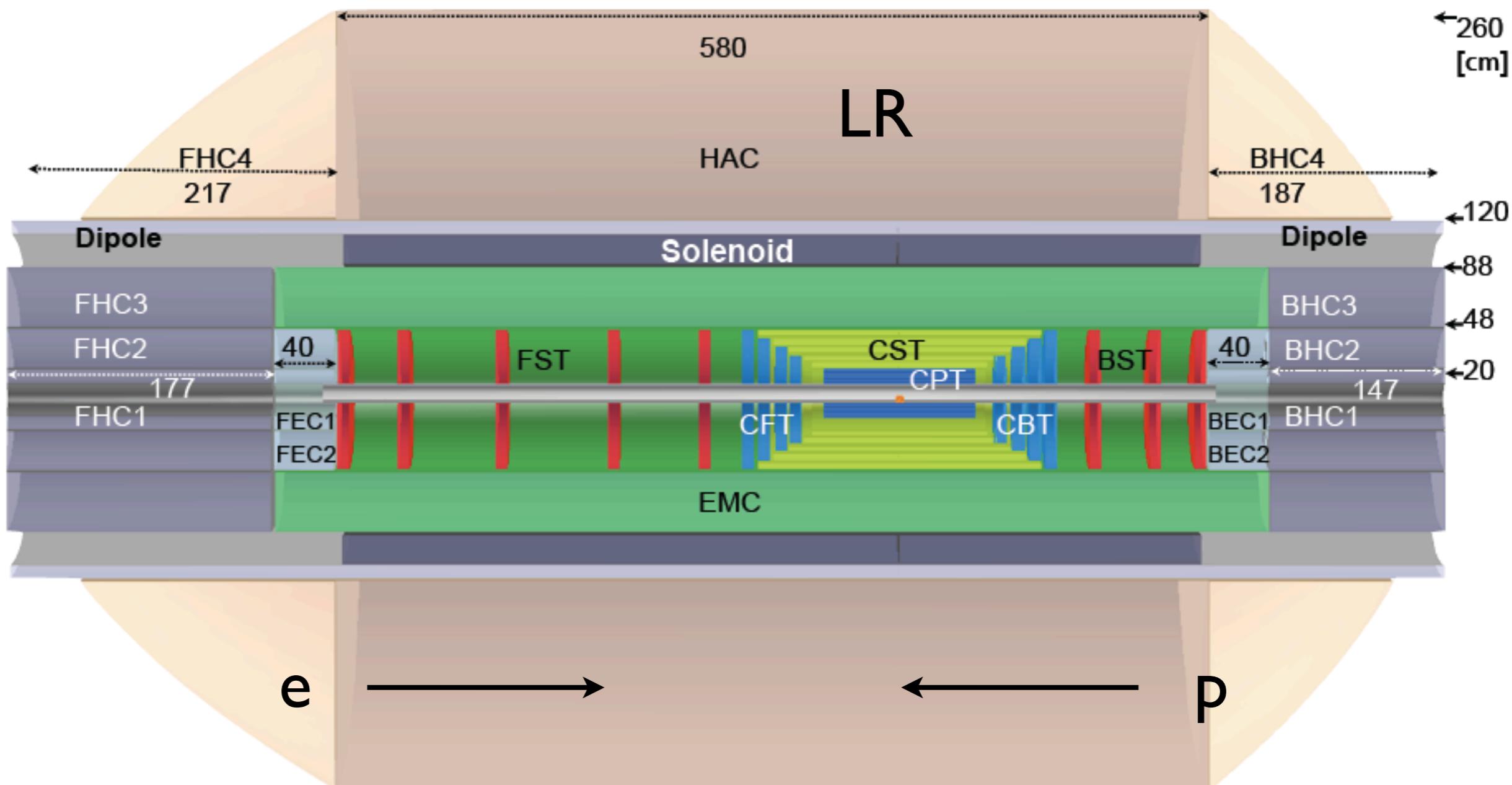
Large L for e^+ challenging.



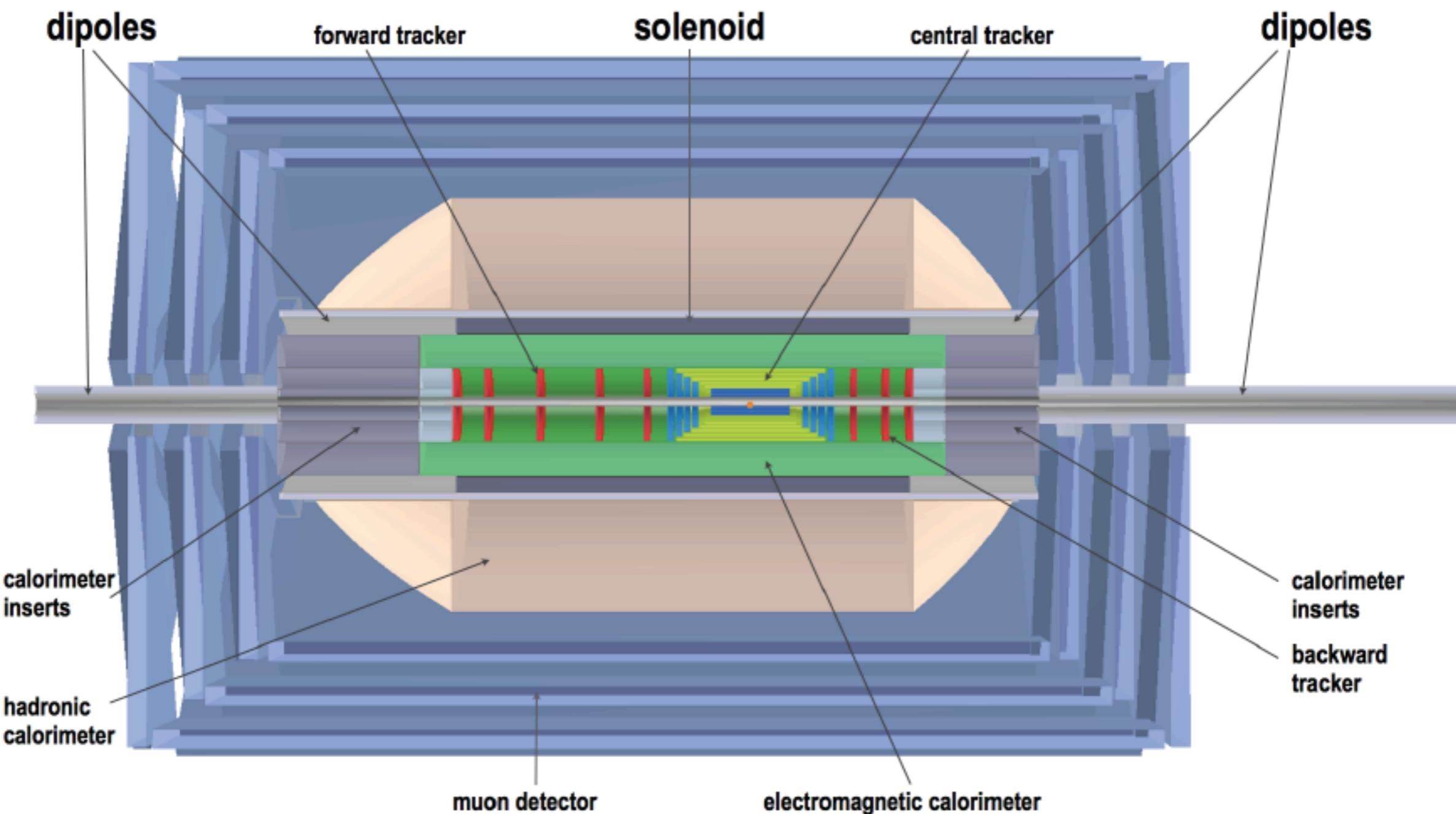
The detector: low-x/eA setup



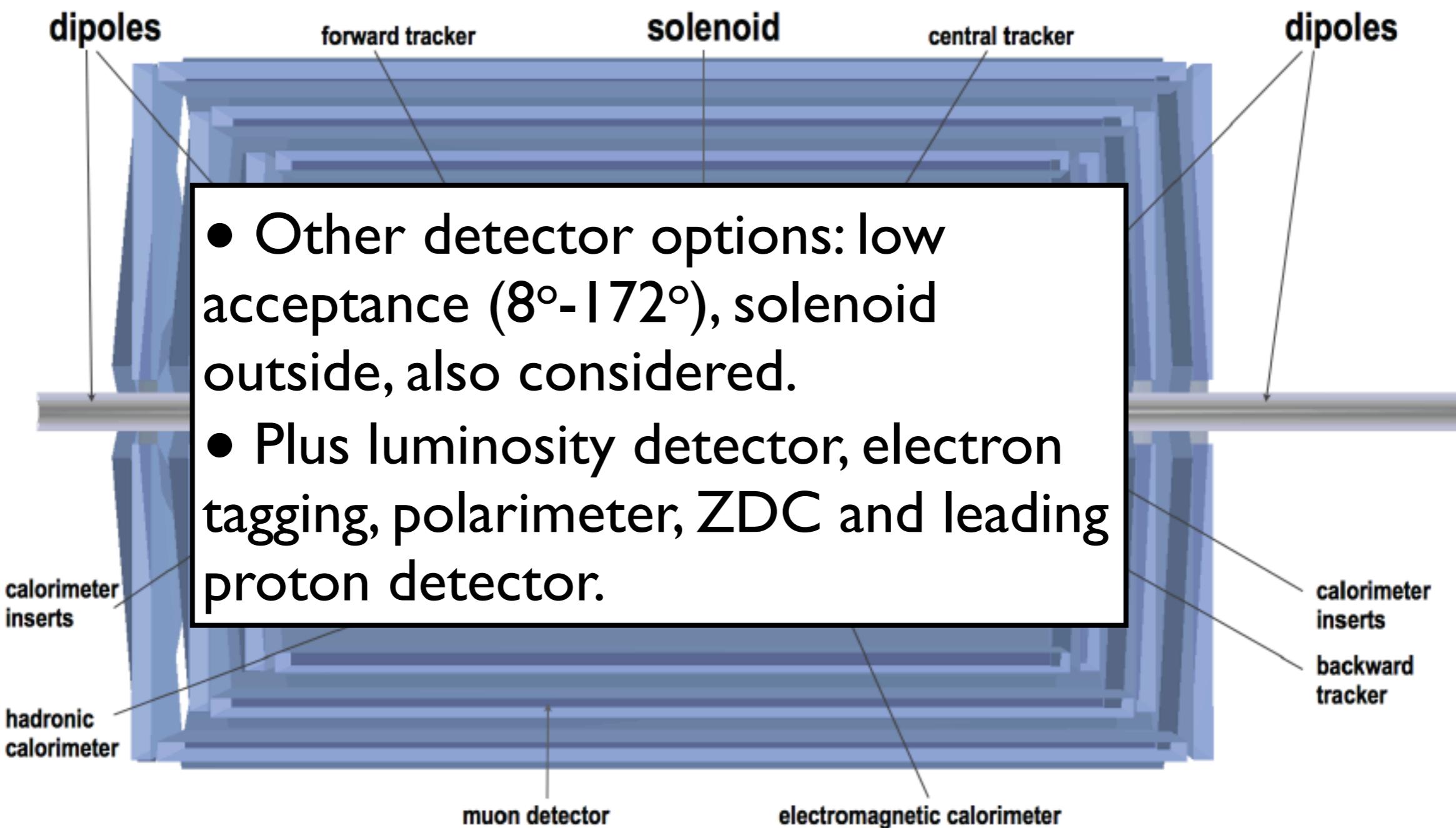
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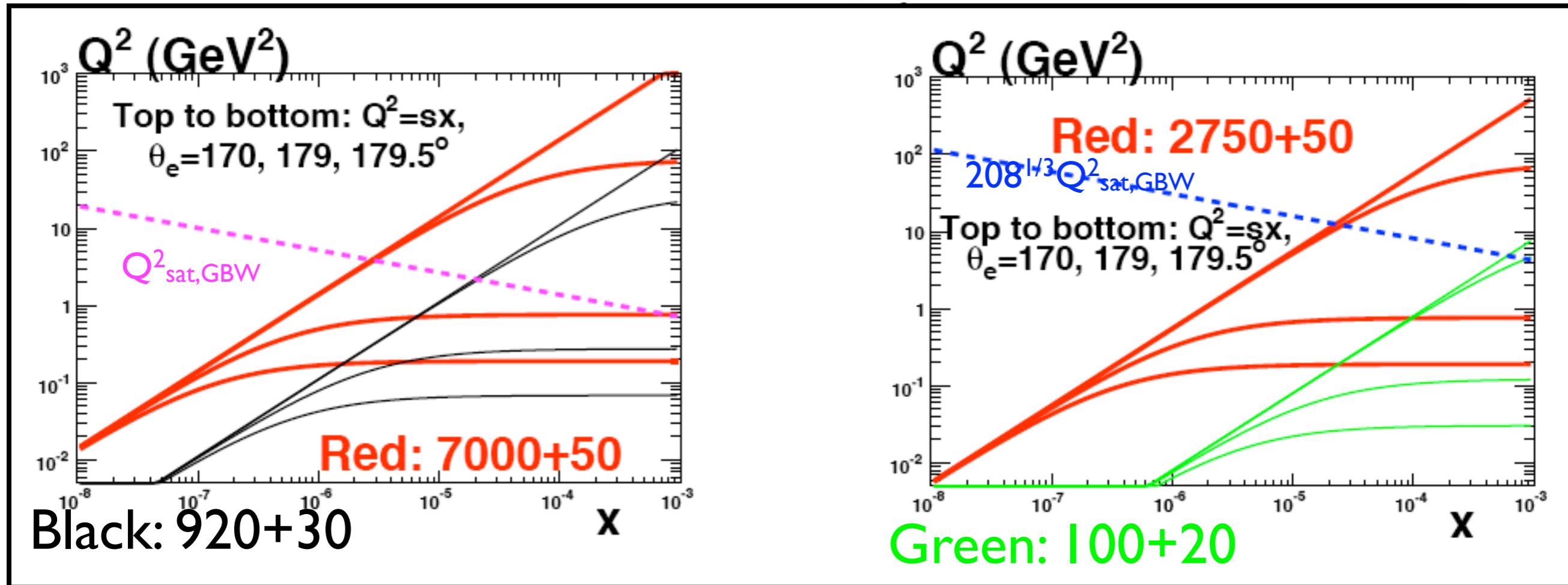
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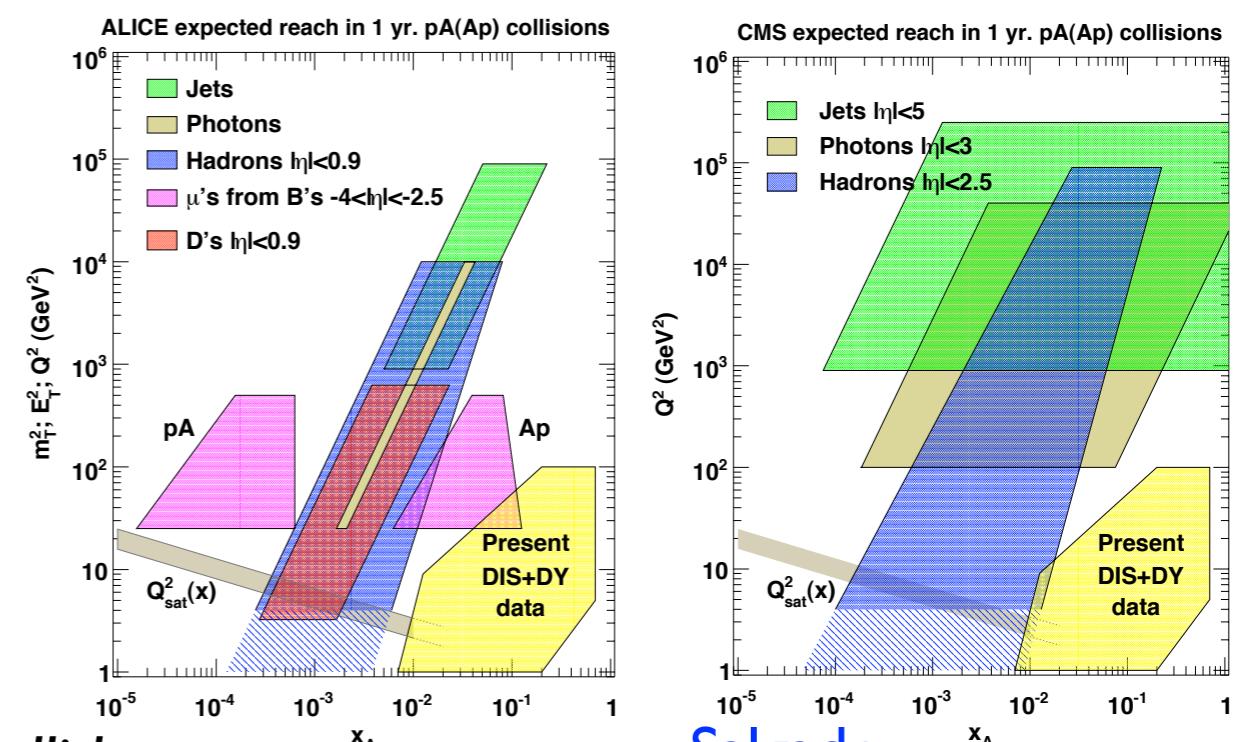
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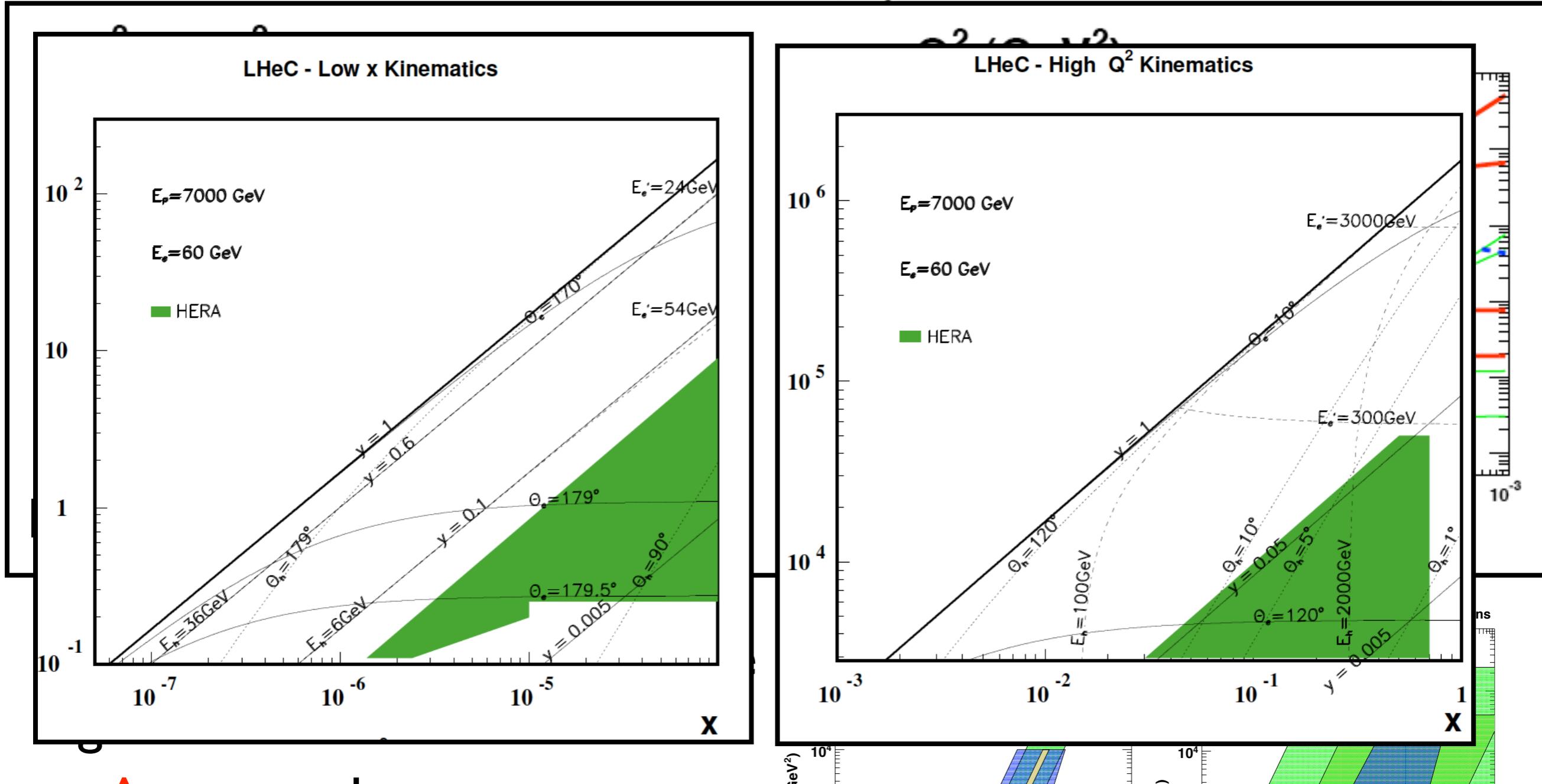
Kinematics:



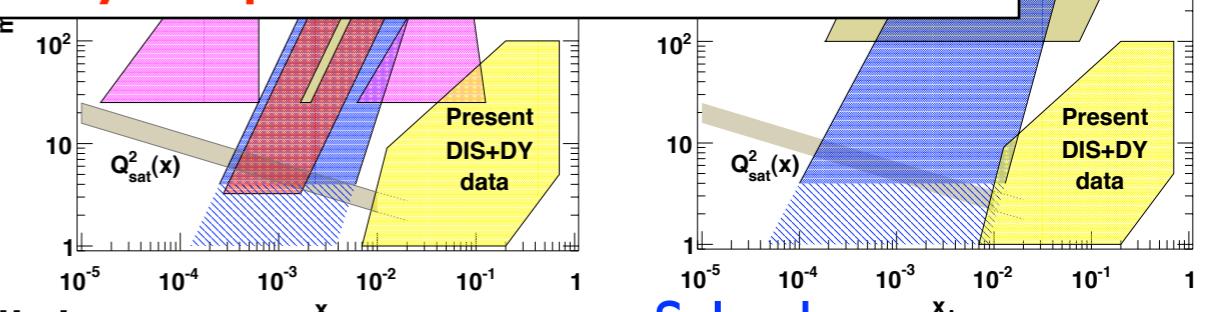
- **ep**: access to the perturbative region below $x \sim$ a few 10^{-5} .
- **eA**: new realm.
- **No small-x physics without ~ 1 degree acceptance.**



Kinematics:



- eA
- Preliminary; LHeC Design Study Report, CERN 2012
- No small- x physics without ~ 1 degree acceptance.

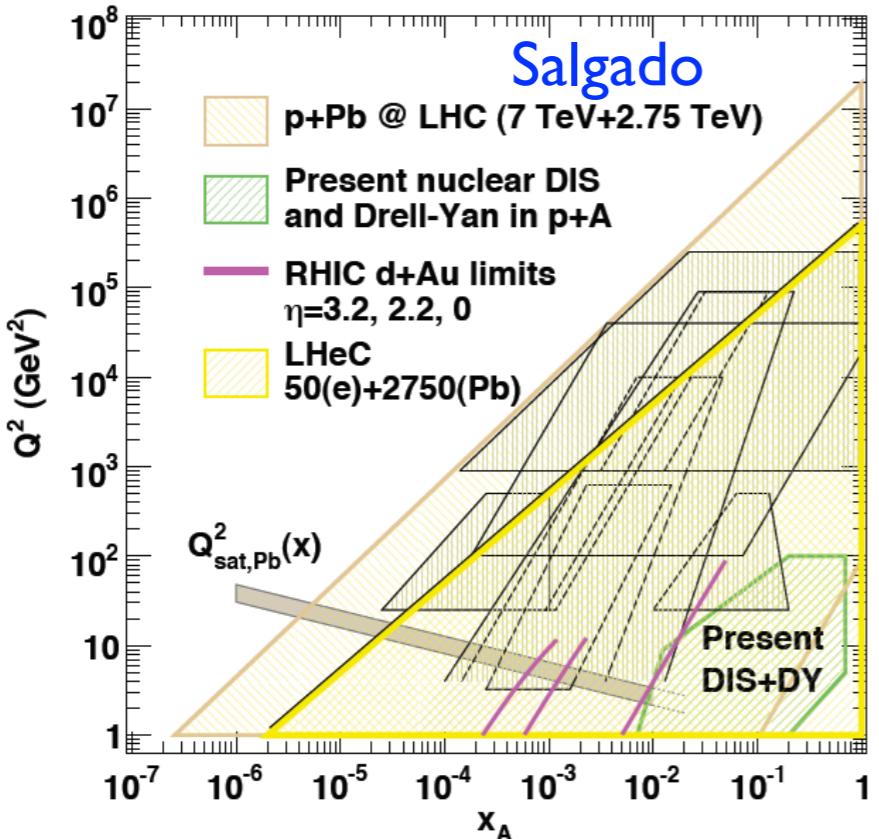
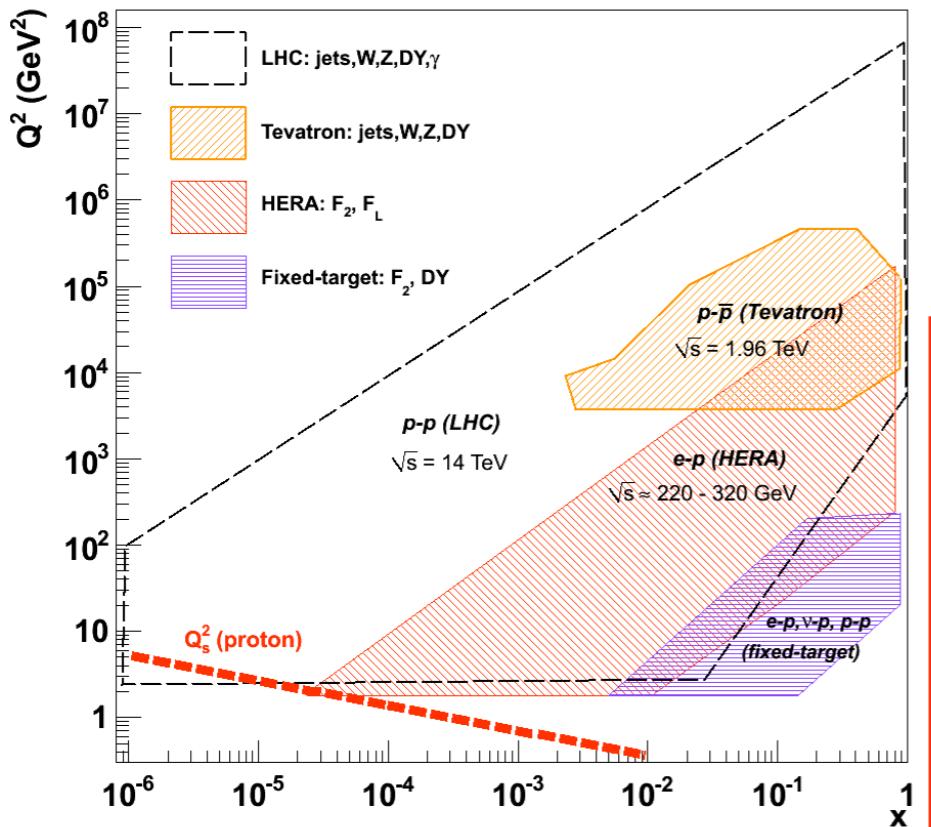


LHeC scenarios:

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	Pol	$L/10^{32}$	P/MW years	type
For F_2									
A	20	7	p	1	1	-	1	10	SPL
B	50	7	p	50	50	0.4	25	30	2 RR hiQ ²
C	50	7	p	1	1	0.4	1	30	1 RR lo x
D	100	7	p	5	10	0.9	2.5	40	2 LR
E	150	7	p	3	6	0.9	1.8	40	2 LR
F	50	3.5	D	1	1	--	0.5	30	1 eD
G	50	2.7	Pb	10^{-4}	10^{-4}	0.4	10^{-3}	30	1 ePb
H	50	1	p	--	1	--	25	30	1 lowEp
I	50	3.5	Ca	$5 \cdot 10^{-4}$?	$5 \cdot 10^{-3}$?	?	eCa

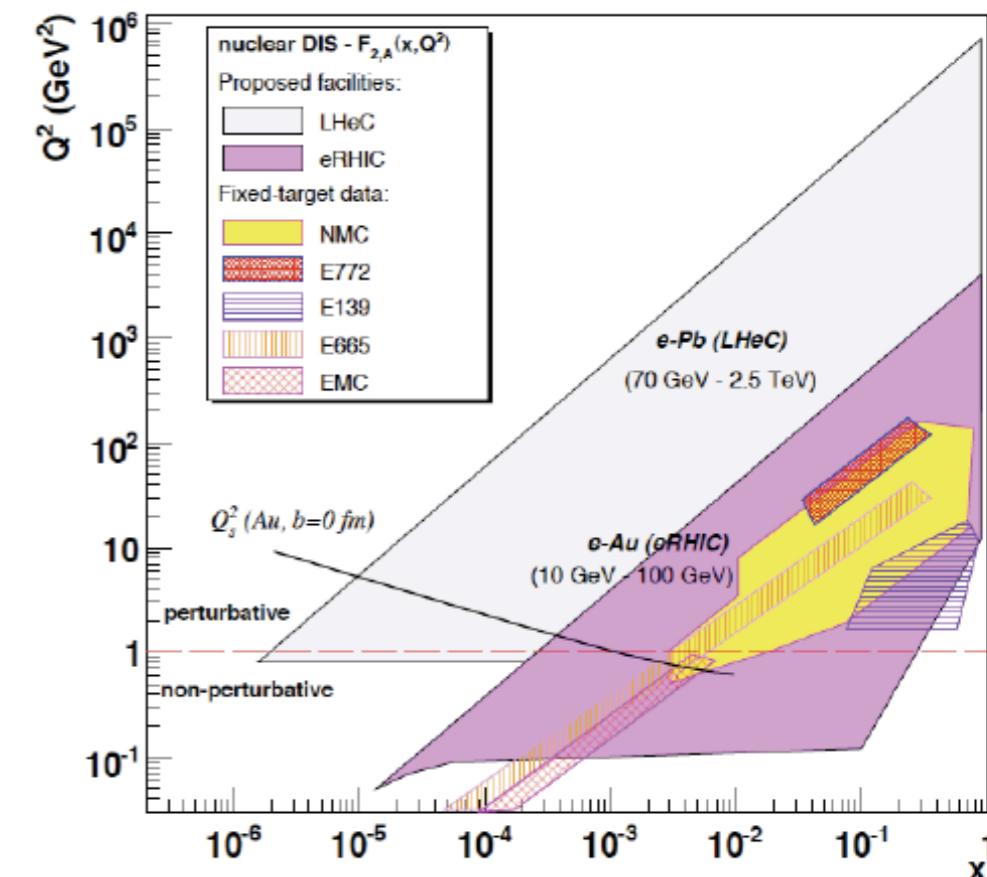
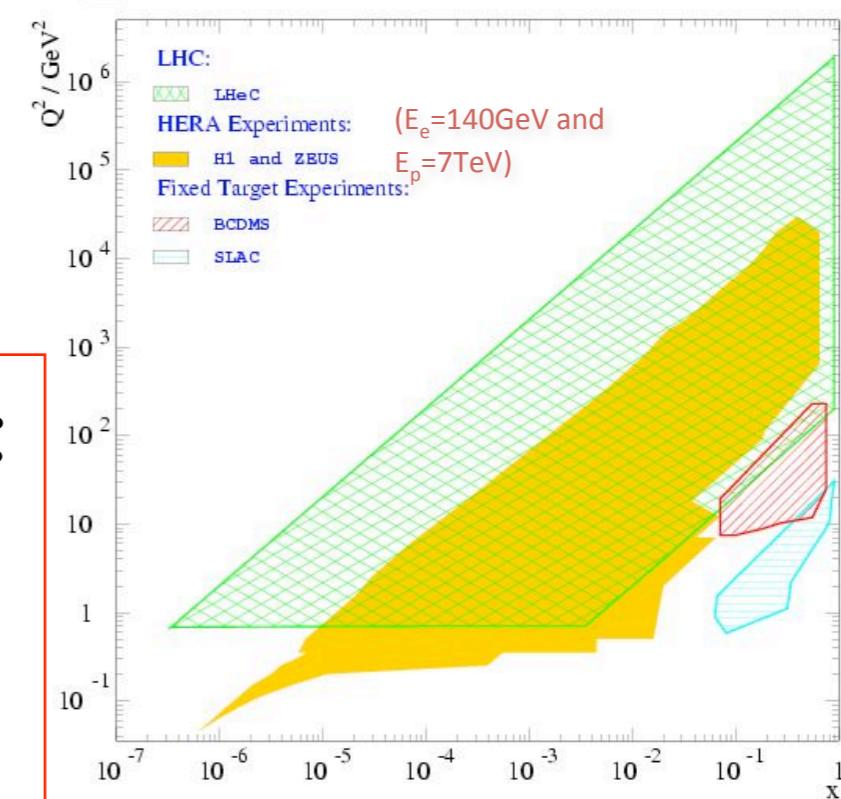
- For F_L : 10, 25, 50 + 2750 (7000); $Q^2 \leq sx$; Lumi=5,10,100 pb⁻¹ respectively; charm and beauty: same efficiencies in ep and eA.
- QCD at the LHeC: 2. The Large Hadron Electron Collider.*

Kinematics: LHC vs. LHeC

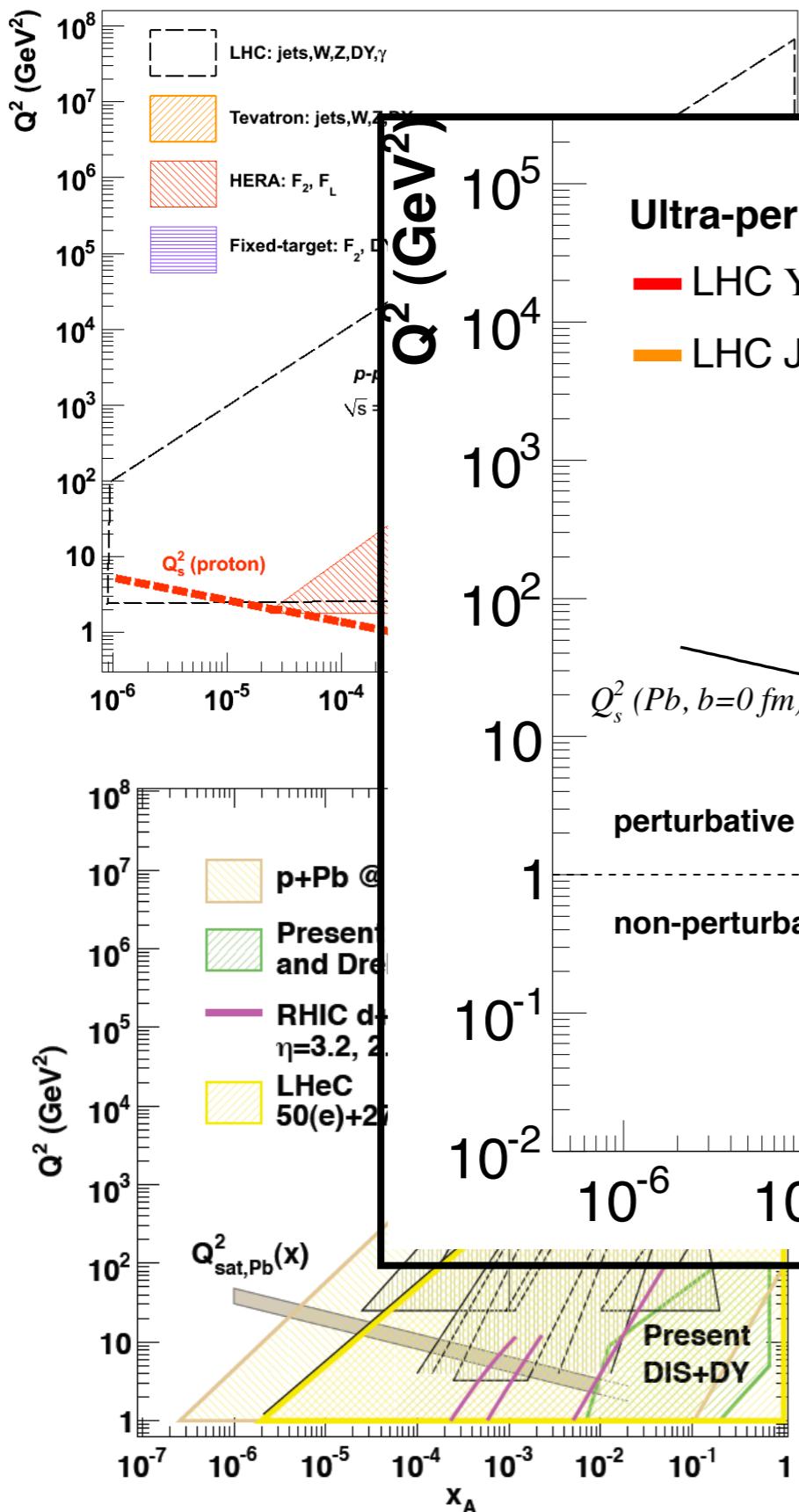


d'Enterria

- Existing ep: $p\bar{p}$ @LHC at $y=0$; eA: not even dAu @RHIC.
- LHeC: clean scan of the LHC x - Q^2 domain.



Kinematics: LHC vs. LHeC



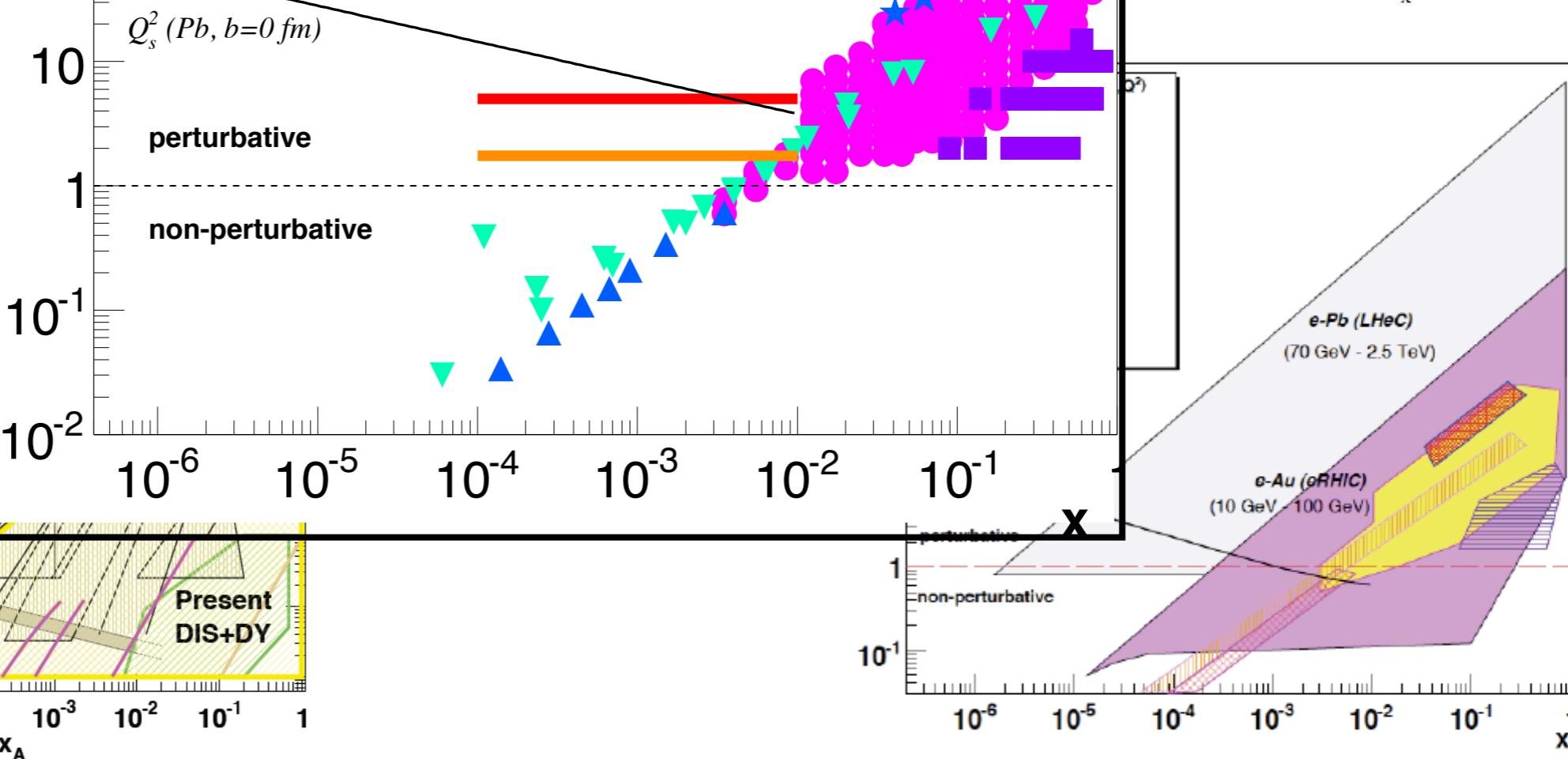
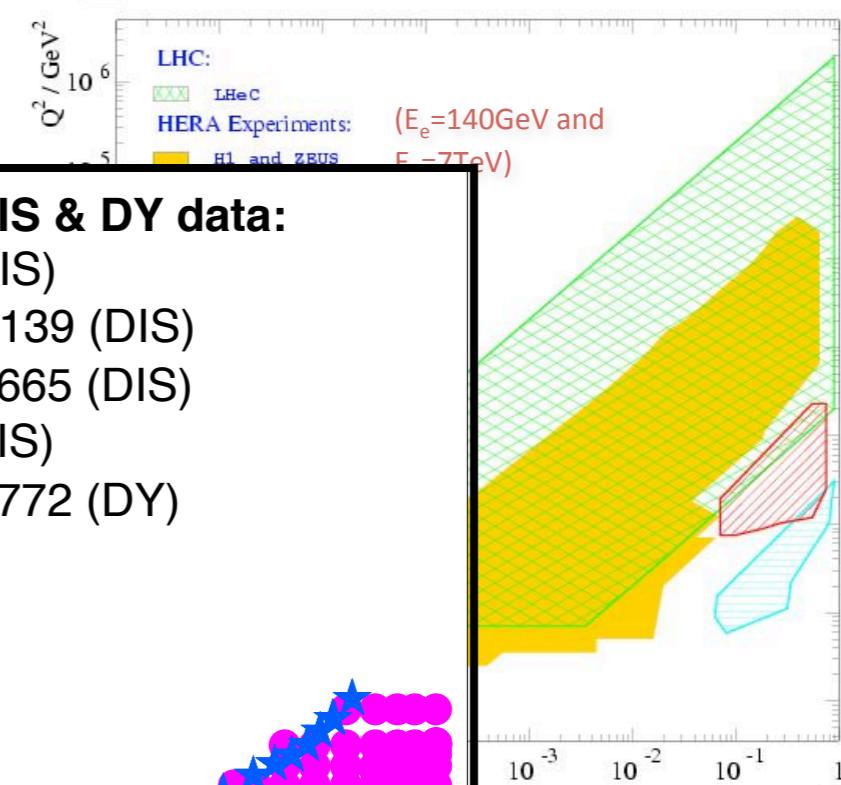
d'Enterria

Ultra-peripheral QQ:

- LHC Y ($|y| < 2.5$)
- LHC J/ Ψ ($|y| < 2.5$)

Nuclear DIS & DY data:

- NMC (DIS)
- SLAC-E139 (DIS)
- FNAL-E665 (DIS)
- EMC (DIS)
- FNAL-E772 (DY)



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2. The Large Hadron Electron Collider.

3. Precision QCD:

- Parton densities.
- Coupling constant.
- Heavy flavors.
- Jets.
- Photoproduction.

CDR to appear within one week;
cern.ch/lhec;
LHeC workshop 14-15/6/2012

4. Small x and eA :

- Inclusive measurements and small- x glue.
- Inclusive diffraction.
- Exclusive diffraction.
- Final states.

5. Summary and outlook.

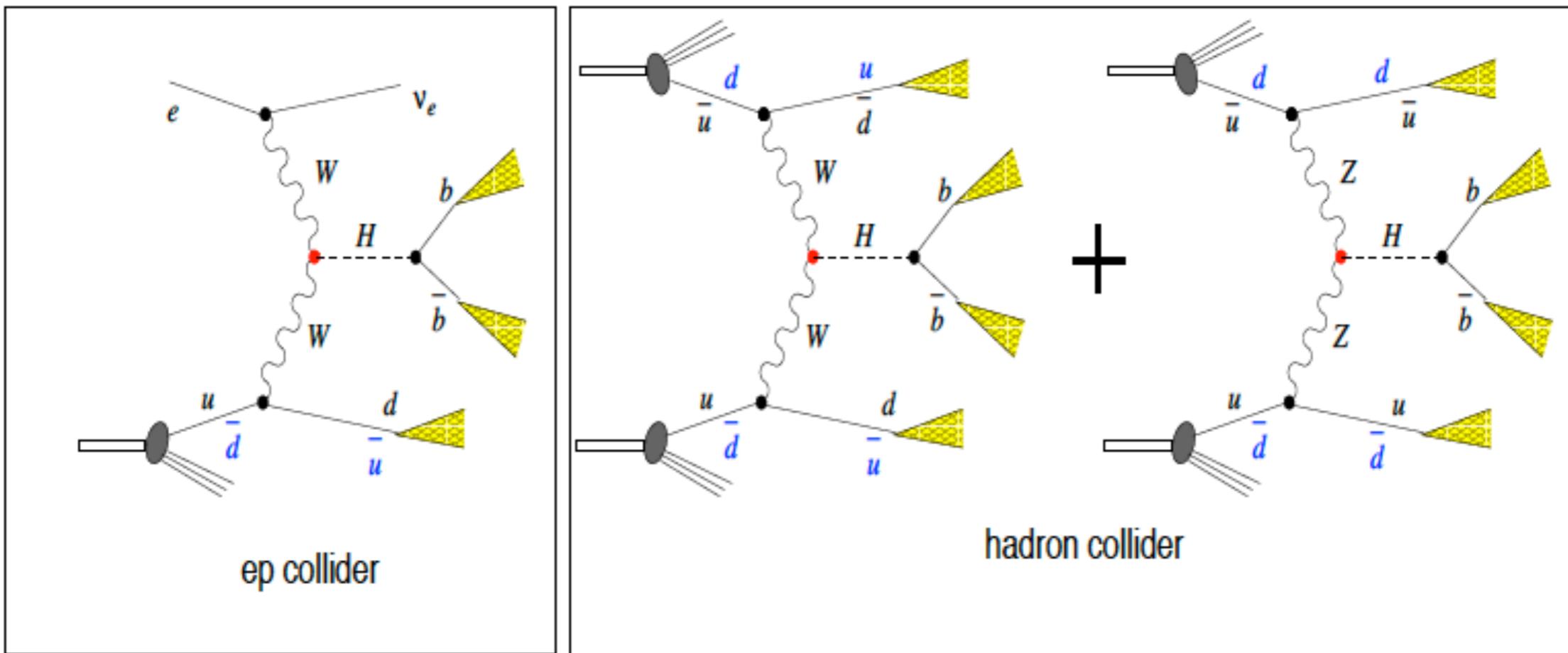
One example of EW process:

LHeC: probing the HWW vertex.

VBF at LHC and LHeC: comparison

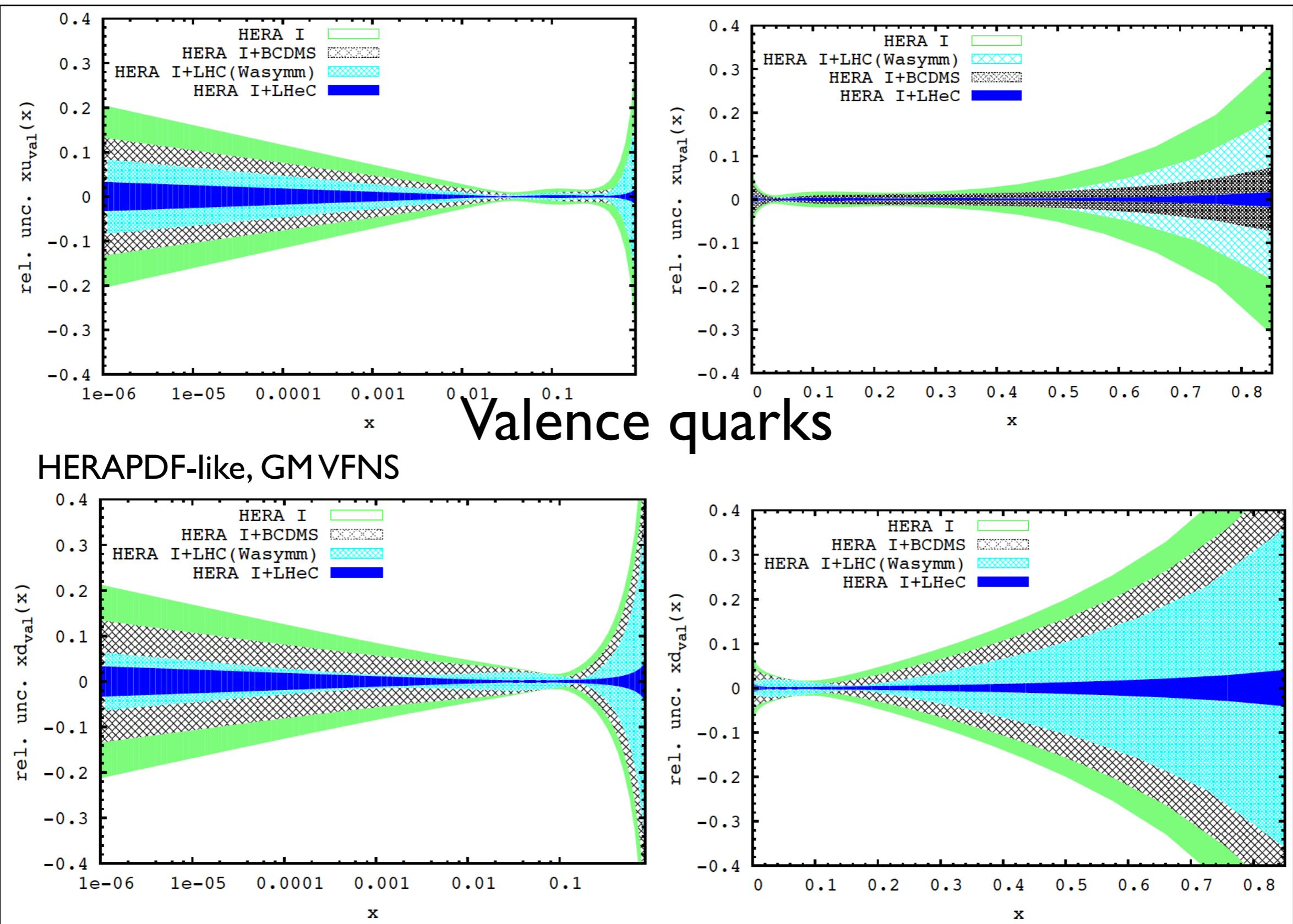
higgs + 2jets: VBF (LHC), higgs + jet + missing E_T (LHeC)

Rohini at DIS2012

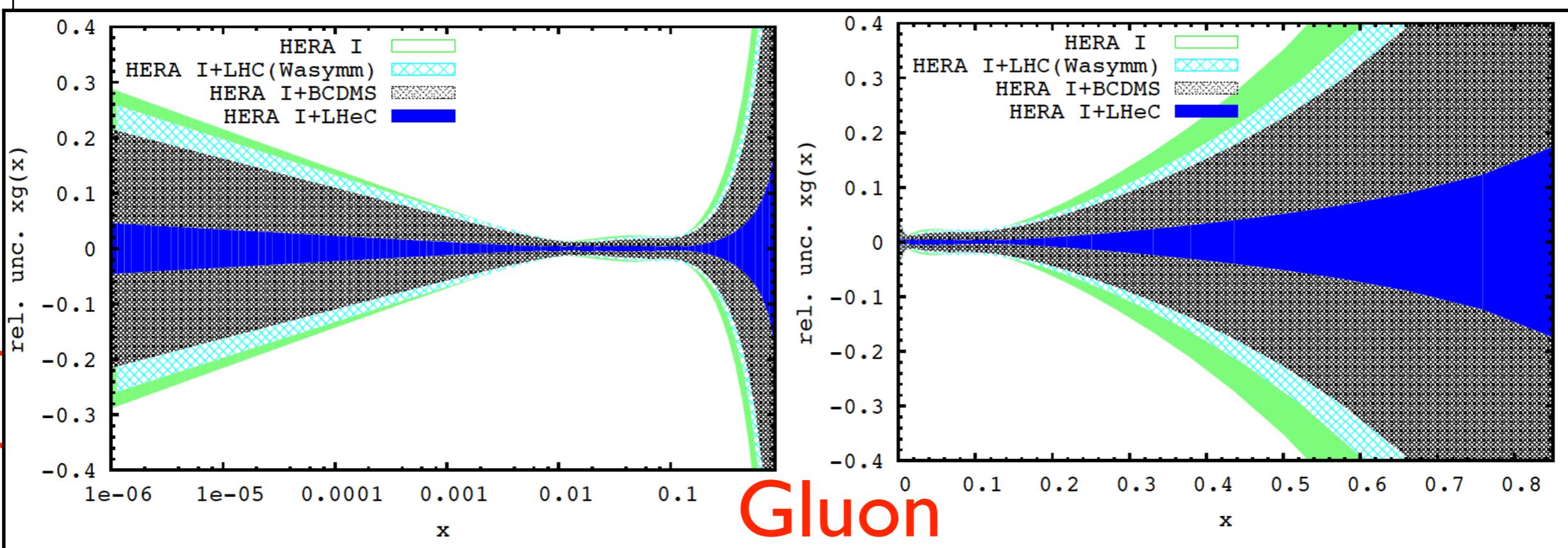


ep process uniquely addresses the HWW vertex.

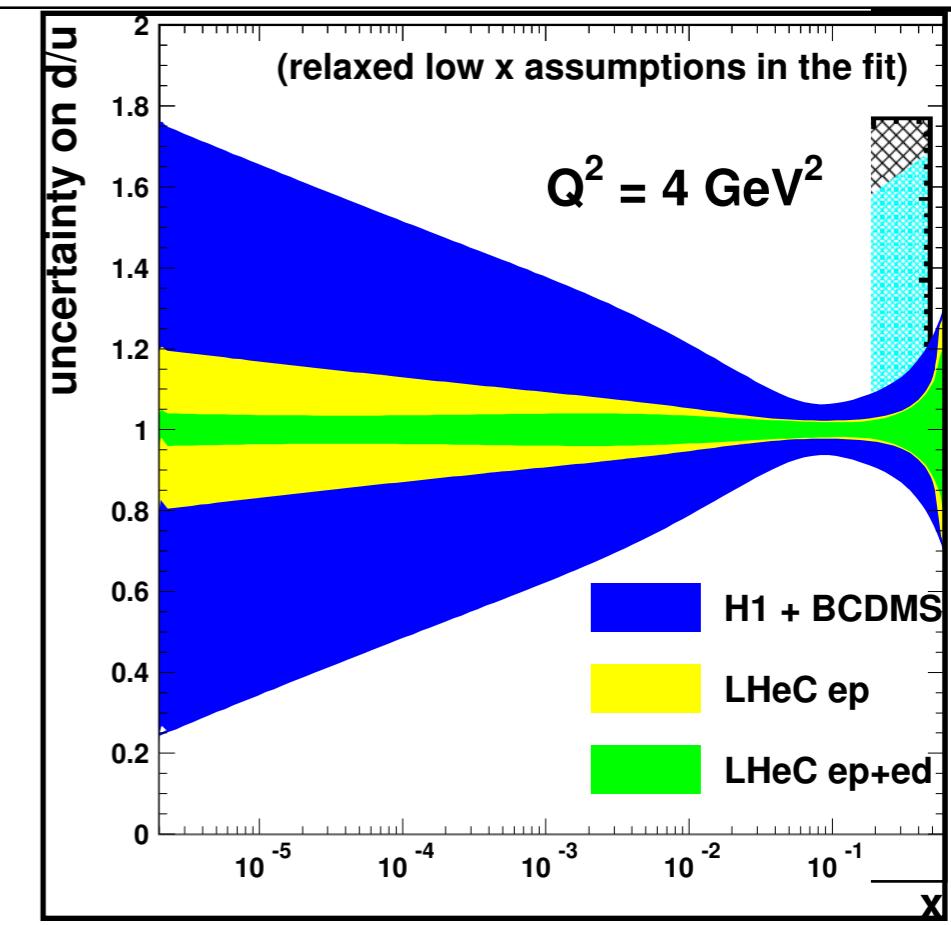
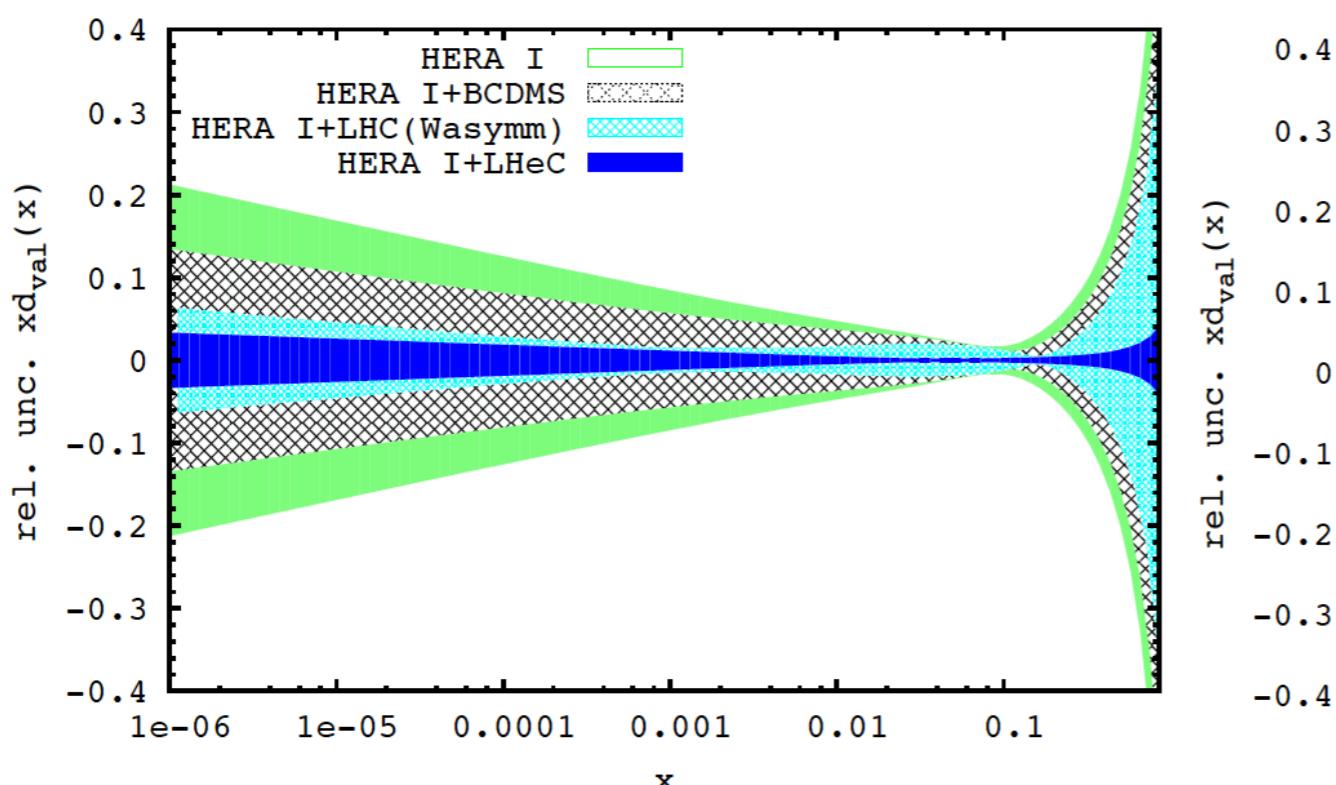
Parton densities:



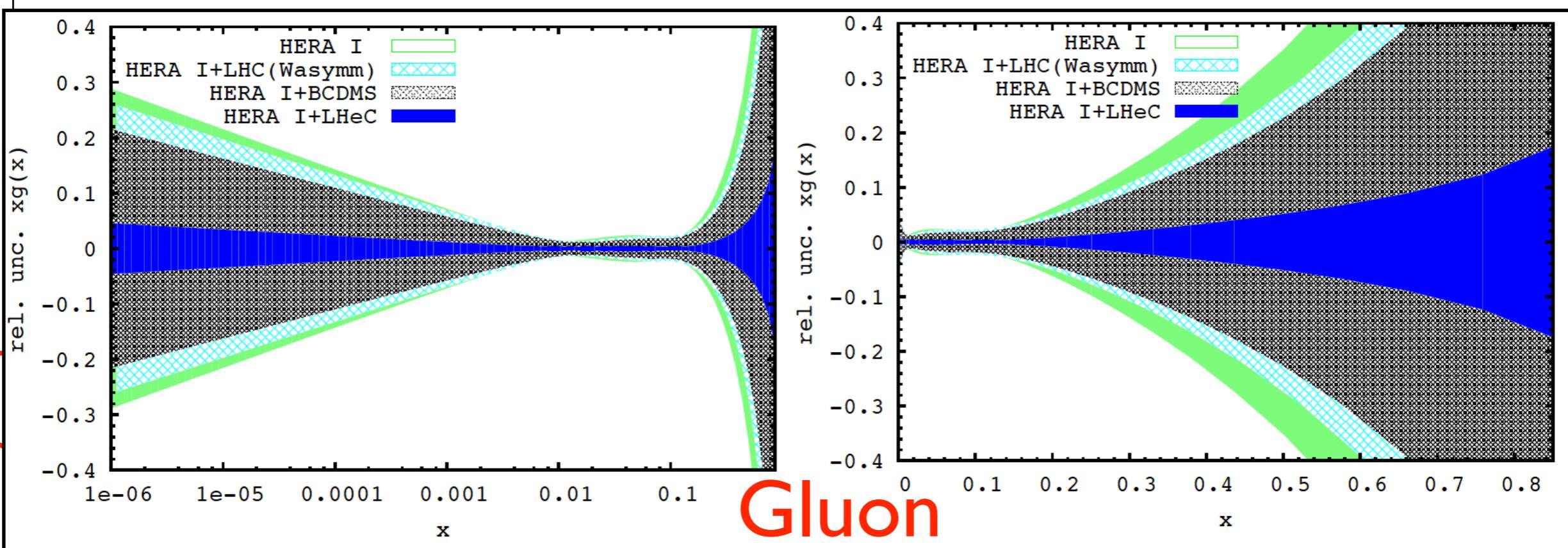
Parton densities:



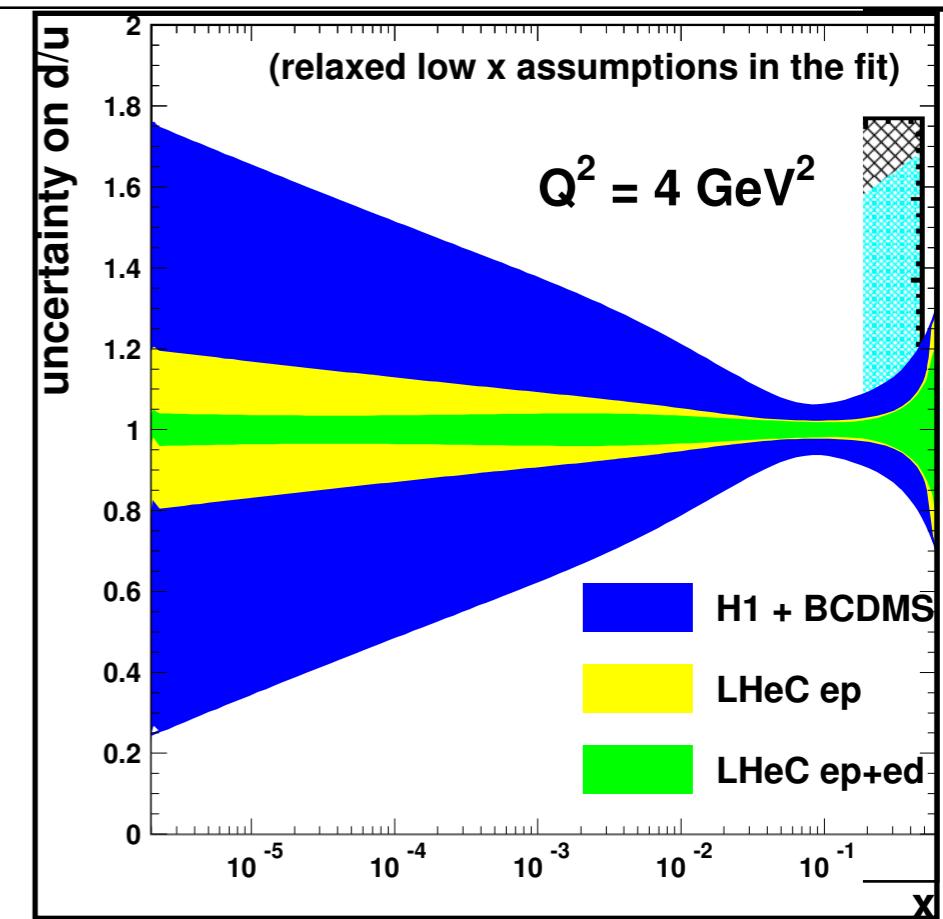
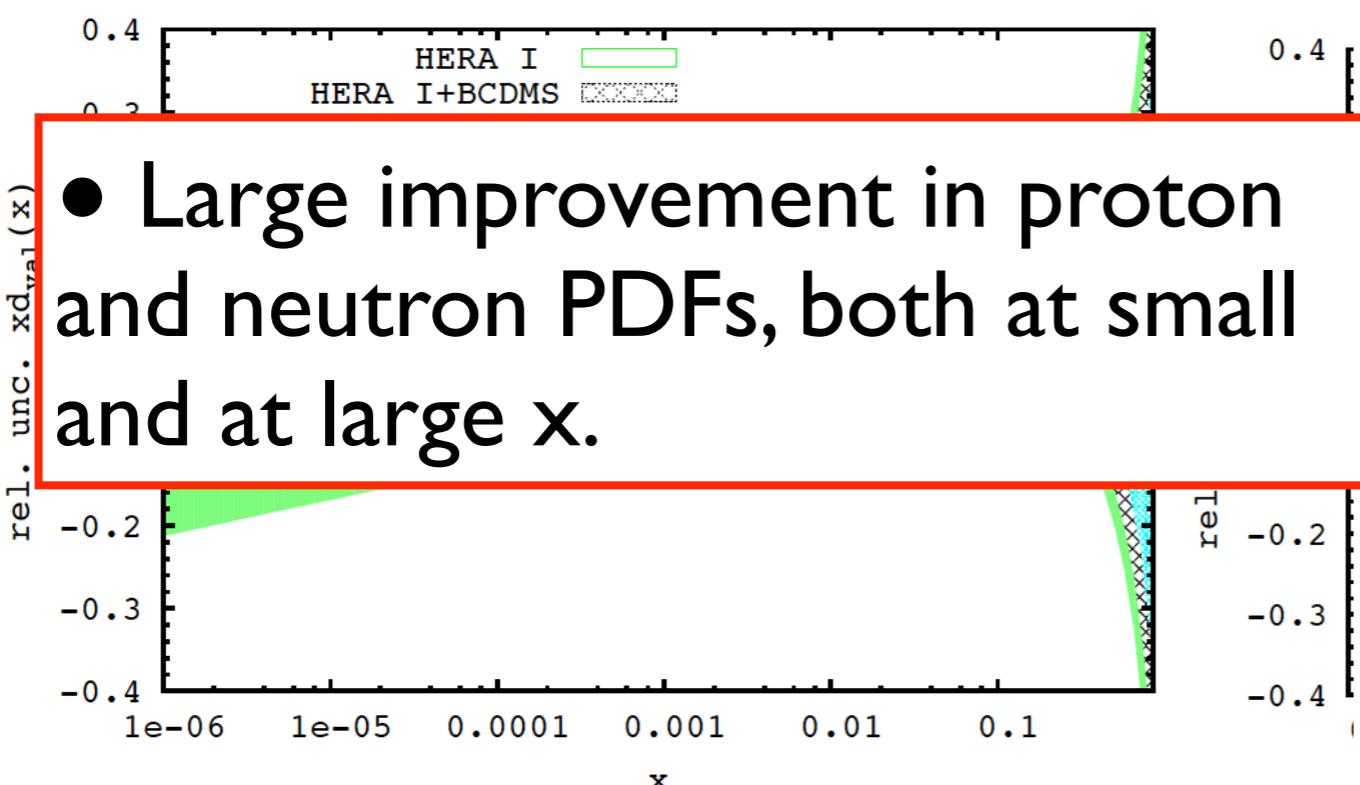
HERAPDF-like, GMVFNS



Parton densities:



HERAPDF-like, GMVFNS



Coupling constant:

DIS extractions of α_s

	$\alpha_s(M_Z^2)$	DIS extractions of α_s
BBG	$0.1134^{+0.0019}_{-0.0021}$	valence analysis, NNLO [80]
GRS	0.112	valence analysis, NNLO [81]
ABKM	0.1135 ± 0.0014	HQ: FFNS $N_f = 3$ [82]
ABKM	0.1129 ± 0.0014	HQ: BSMN-approach [82]
JR	0.1124 ± 0.0020	dynamical approach [83]
JR	0.1158 ± 0.0035	standard fit [83]
MSTW	0.1171 ± 0.0014	[84]
ABM	0.1147 ± 0.0012	FFNS, incl. combined H1/ZEUS data [85]
BBG	$0.1141^{+0.0020}_{-0.0022}$	valence analysis, N ³ LO [80]

case	cut [Q^2 in GeV^2]	α_s	\pm uncertainty	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	0.11529	0.002238	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.12203	0.000995	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.11680	0.000180	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.11796	0.000199	0.17
LHeC only (14p)	$Q^2 > 20.$	0.11602	0.000292	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11769	0.000132	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.11831	0.000238	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.11839	0.000304	0.26

- Open issues on m_c , scales, order of perturbation th.,...

Coupling constant:

DIS extractions of α_s

	$\alpha_s(M_Z^2)$	DIS extractions of α_s
BBG		
GRS		
ABK		
ABK		
JR		
JR	0.1158 ± 0.0035	standard fit [83]
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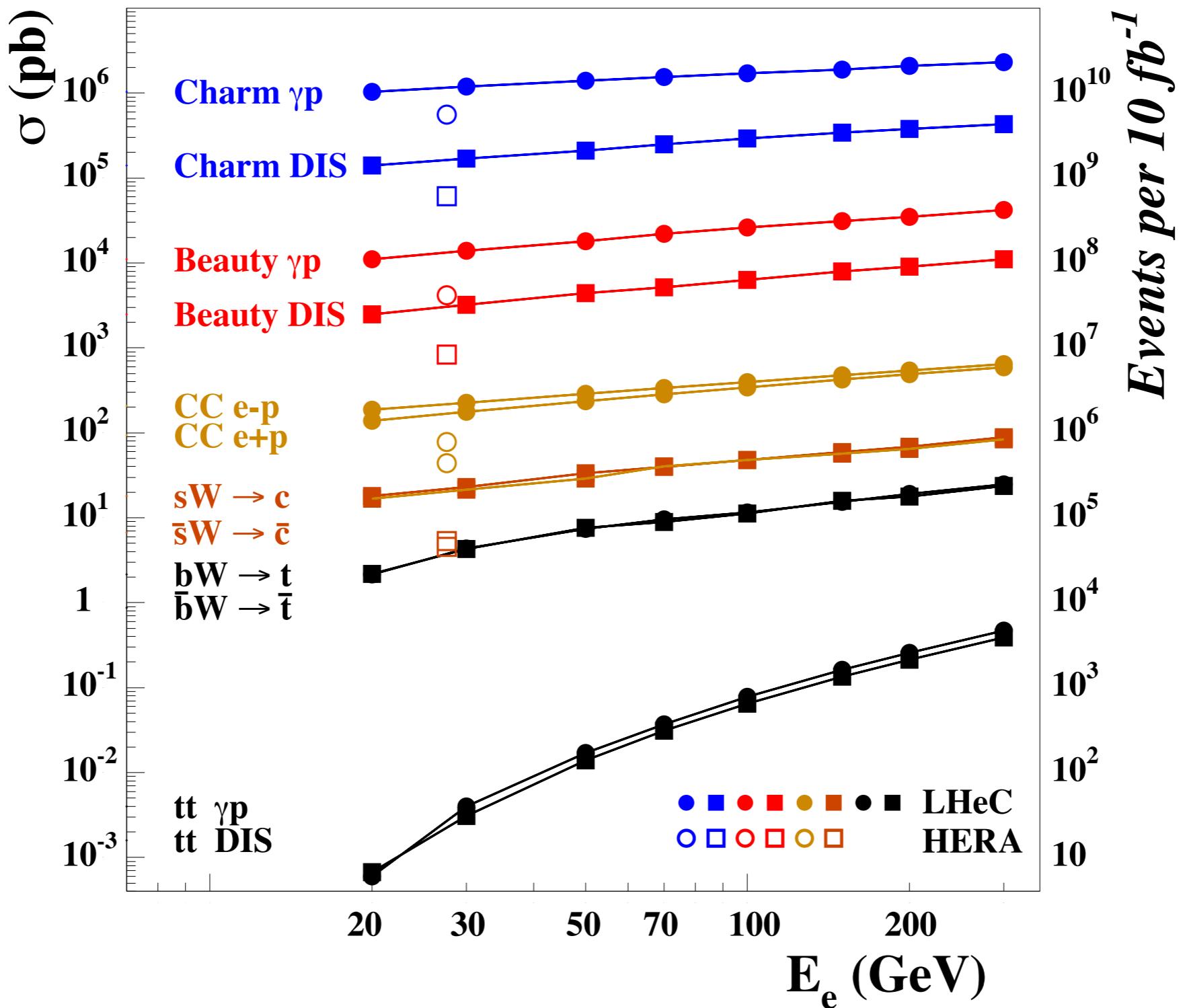
- Substantial improvement in the less known coupling constant, combination with jets still pending.

case	cut [Q^2 in GeV^2]	α_s	\pm uncertainty	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	0.11529	0.002238	1.94
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- Open issues on m_c , scales, order of perturbation th.,...

Heavy flavors:

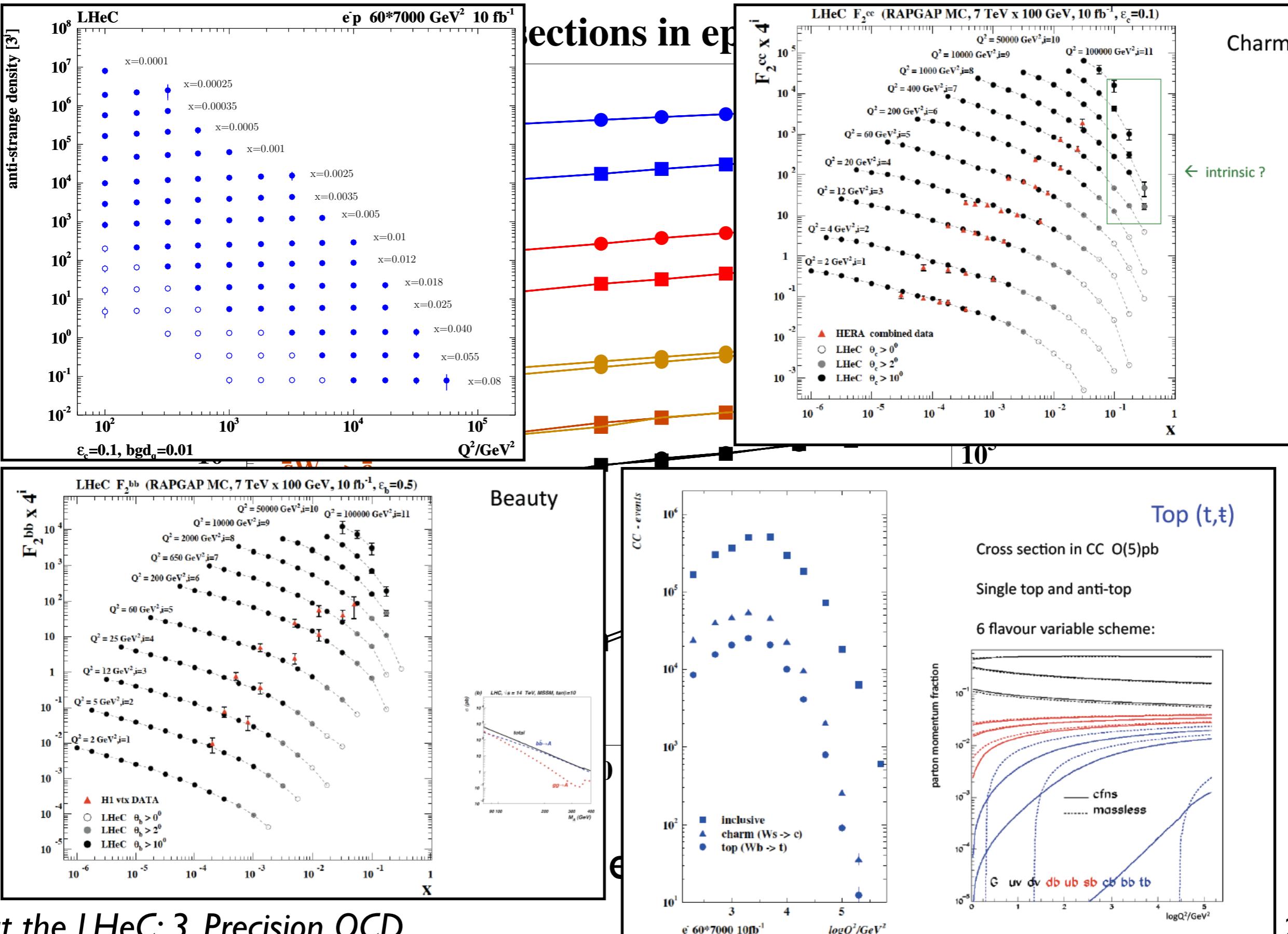
Total cross sections in ep collisions



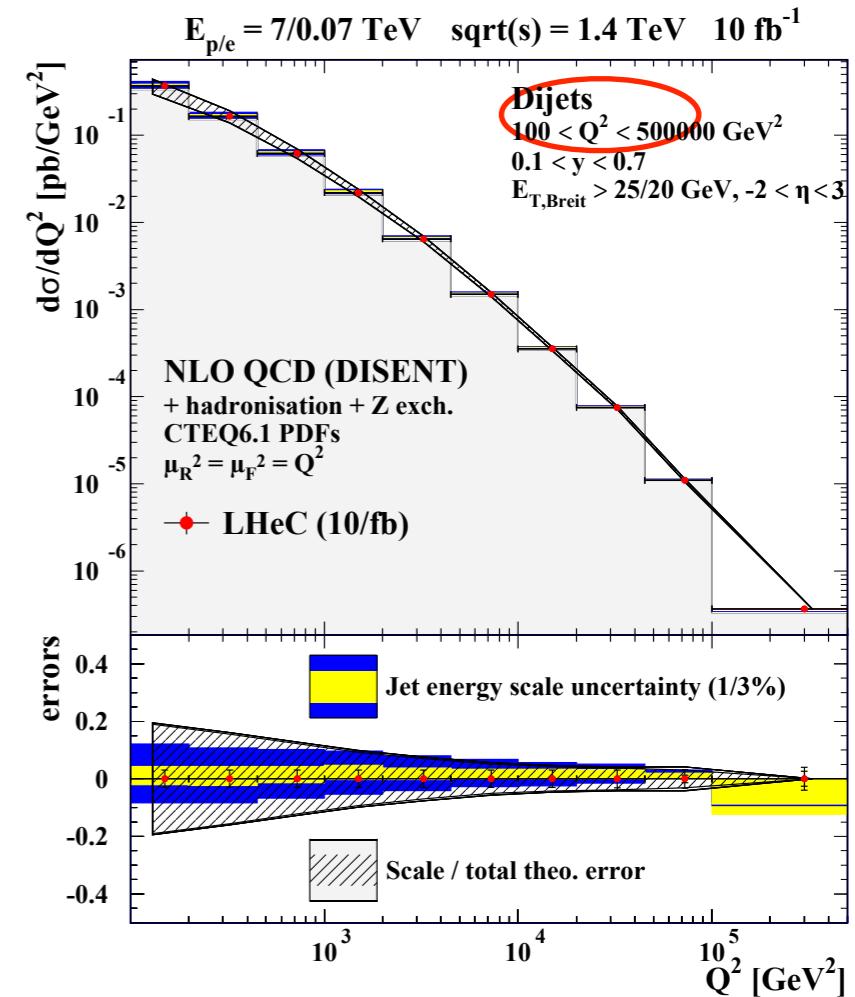
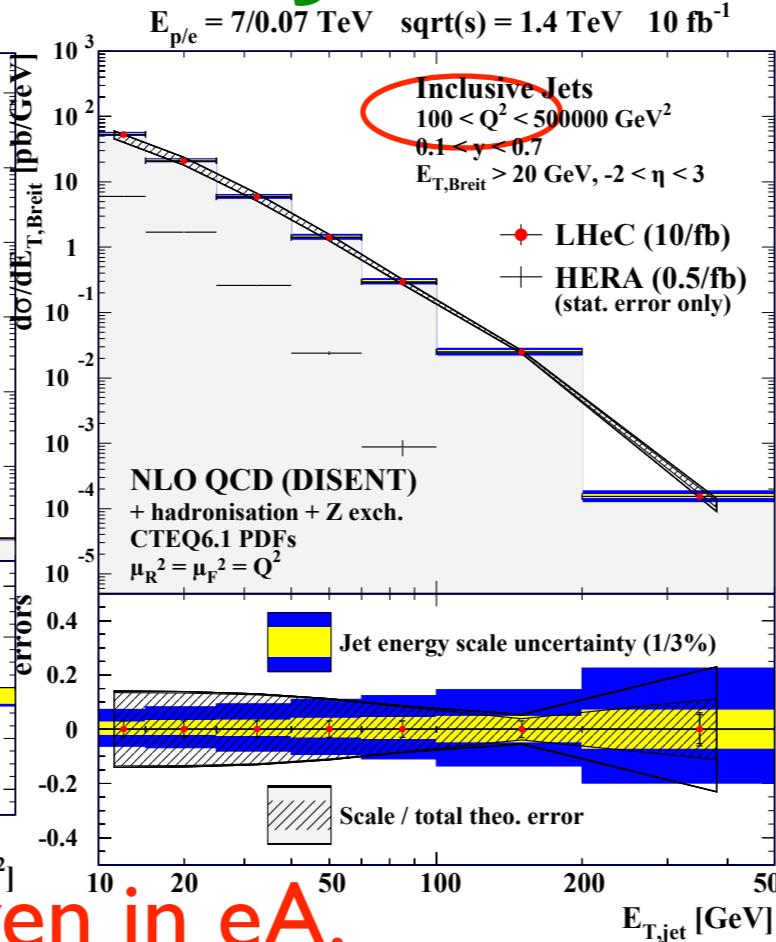
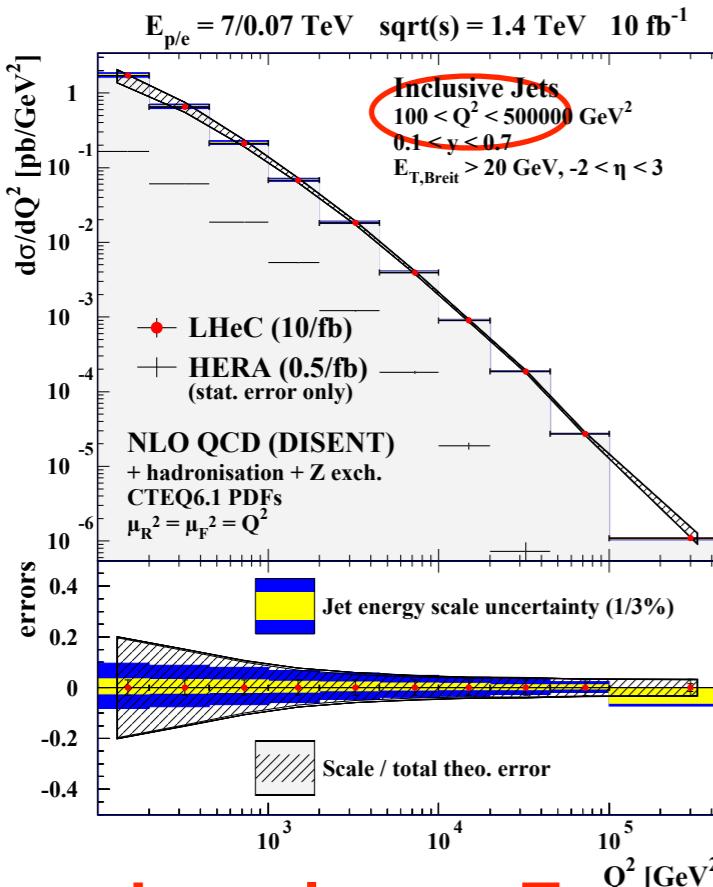
- Compared to HERA: higher lumi plus better efficiencies.

Heavy flavors:

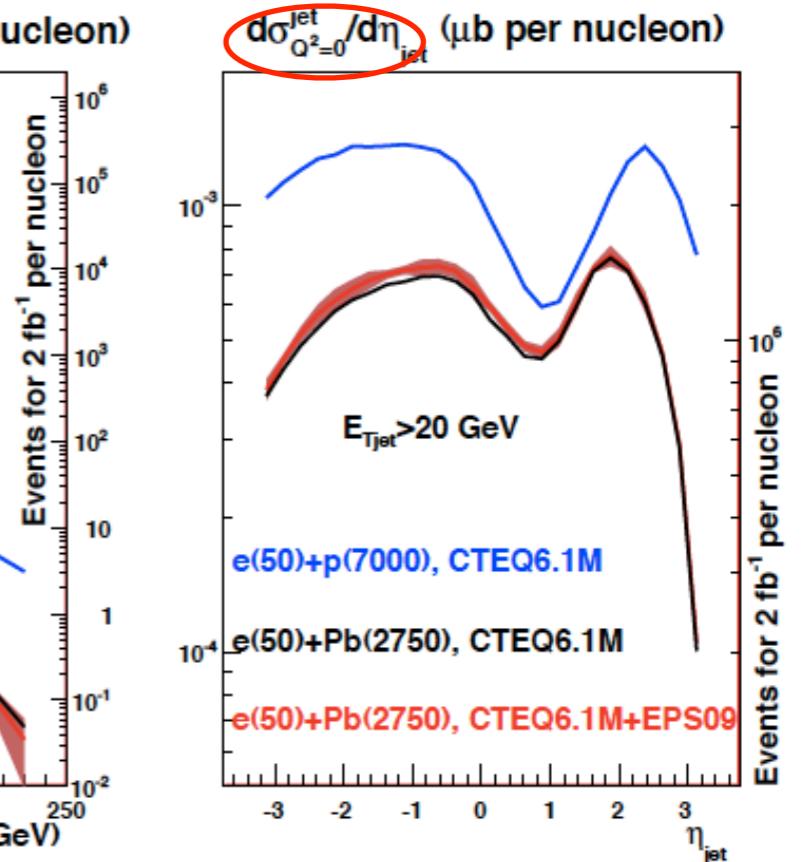
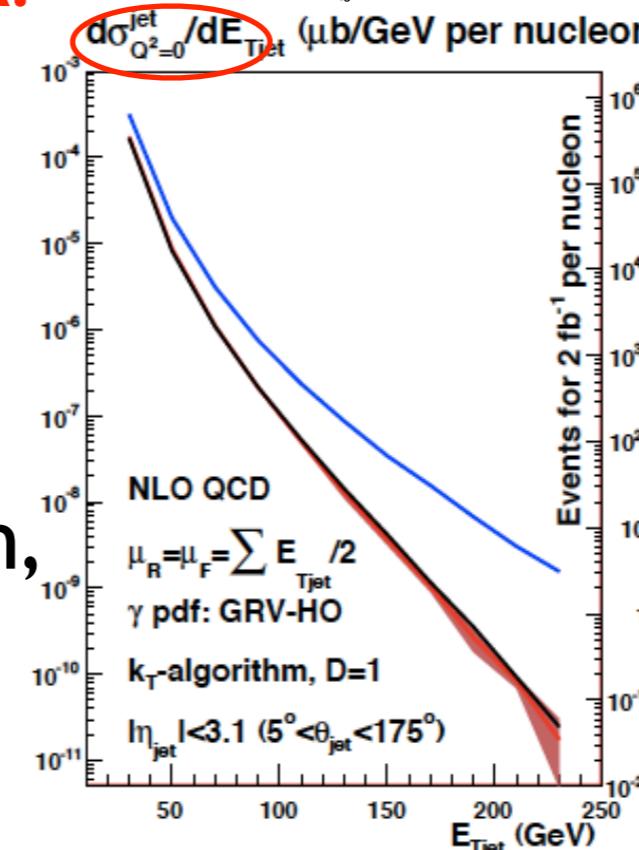
sections in ep



Jets:

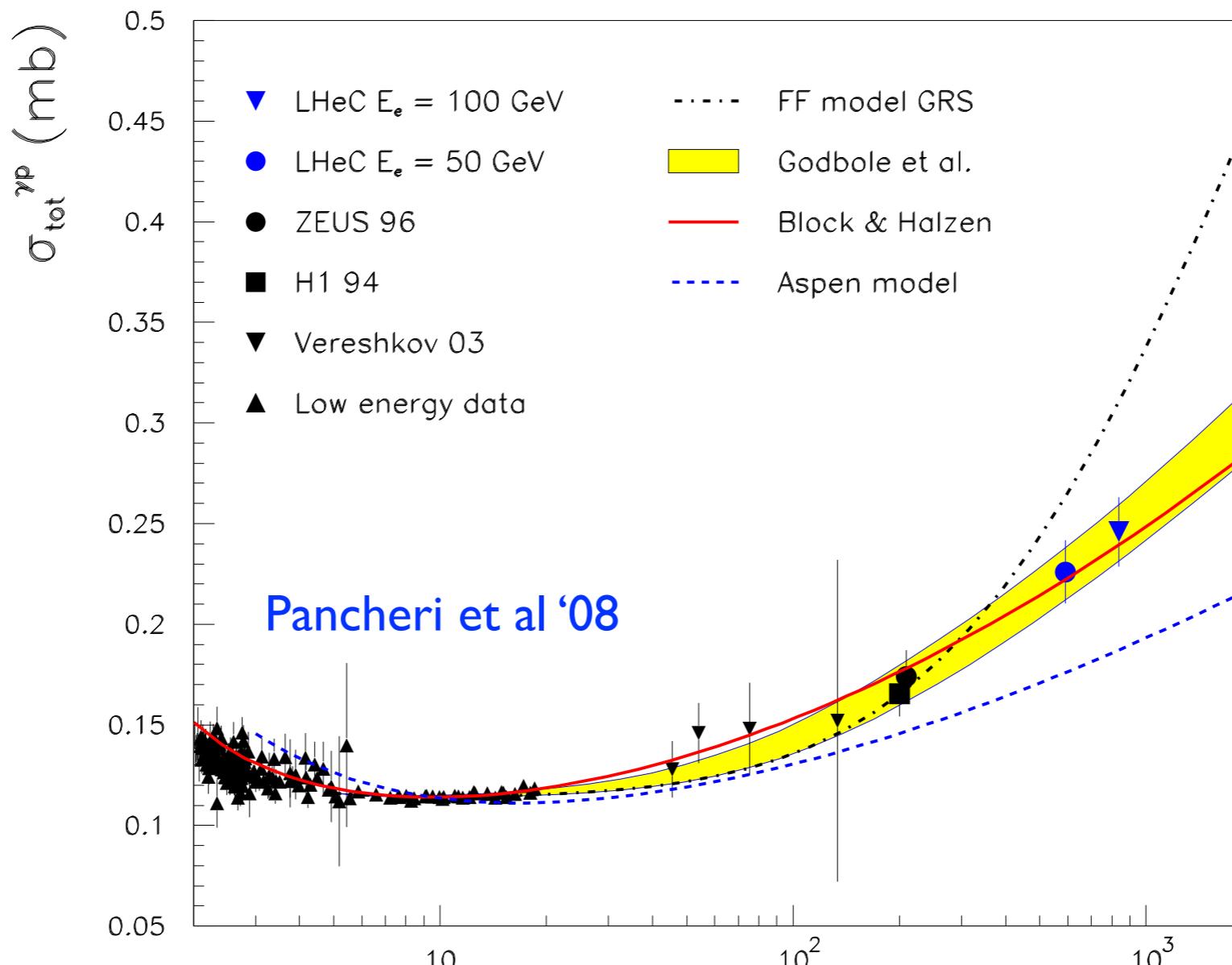


- Jets: large E_T even in eA.
- Useful for studies of parton dynamics in nuclei (hard probes), and for photon structure.
- Background subtraction, detailed reconstruction pending.

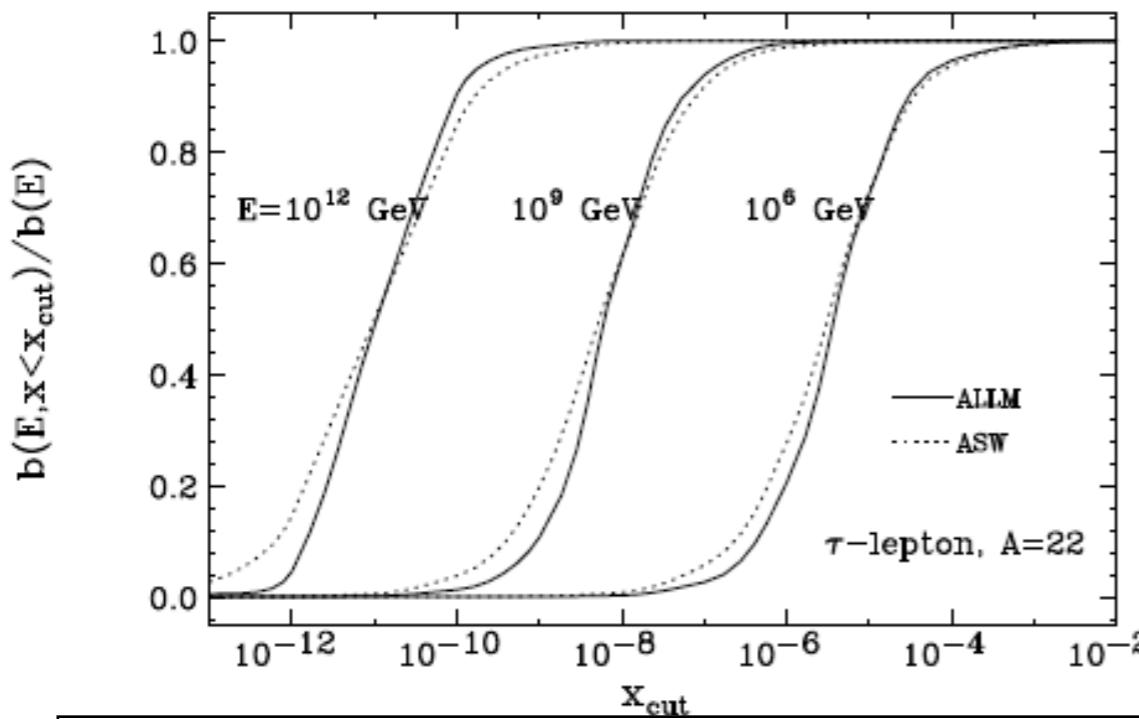
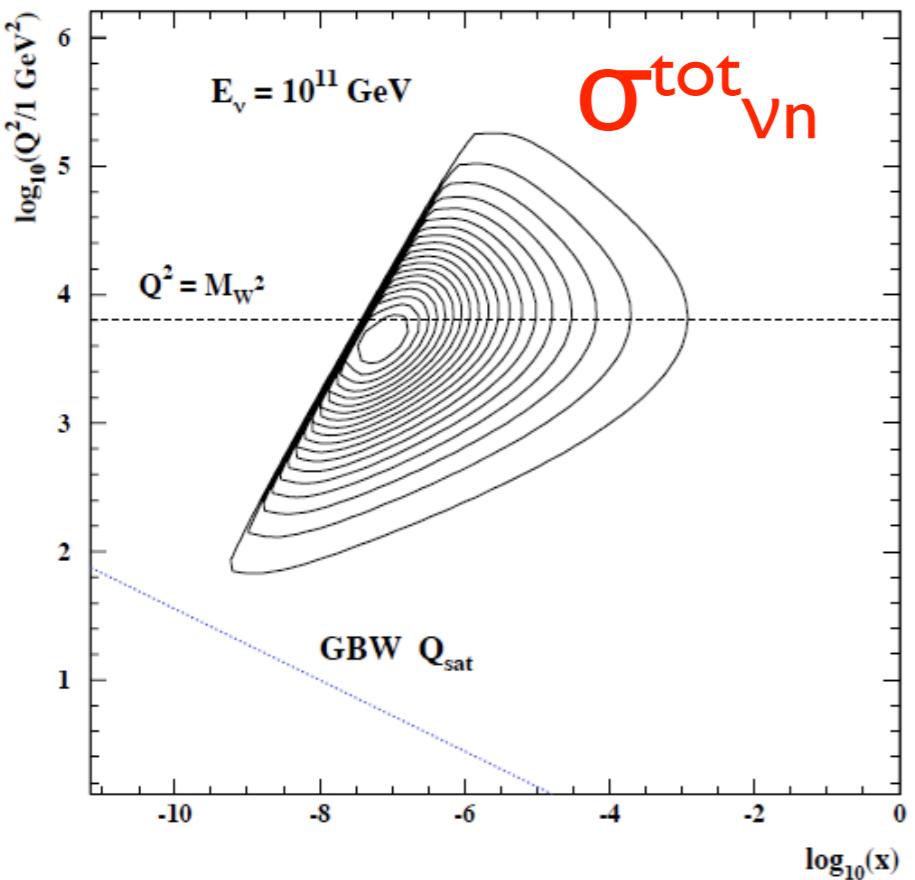


Photoproduction cross section:

- Small angle electron detector 62 m far from the interaction point: $Q^2 < 0.01 \text{ GeV}$, $y \sim 0.3 \Rightarrow W \sim 0.5 \sqrt{s}$.
- Substantial enlarging of the lever arm in W .

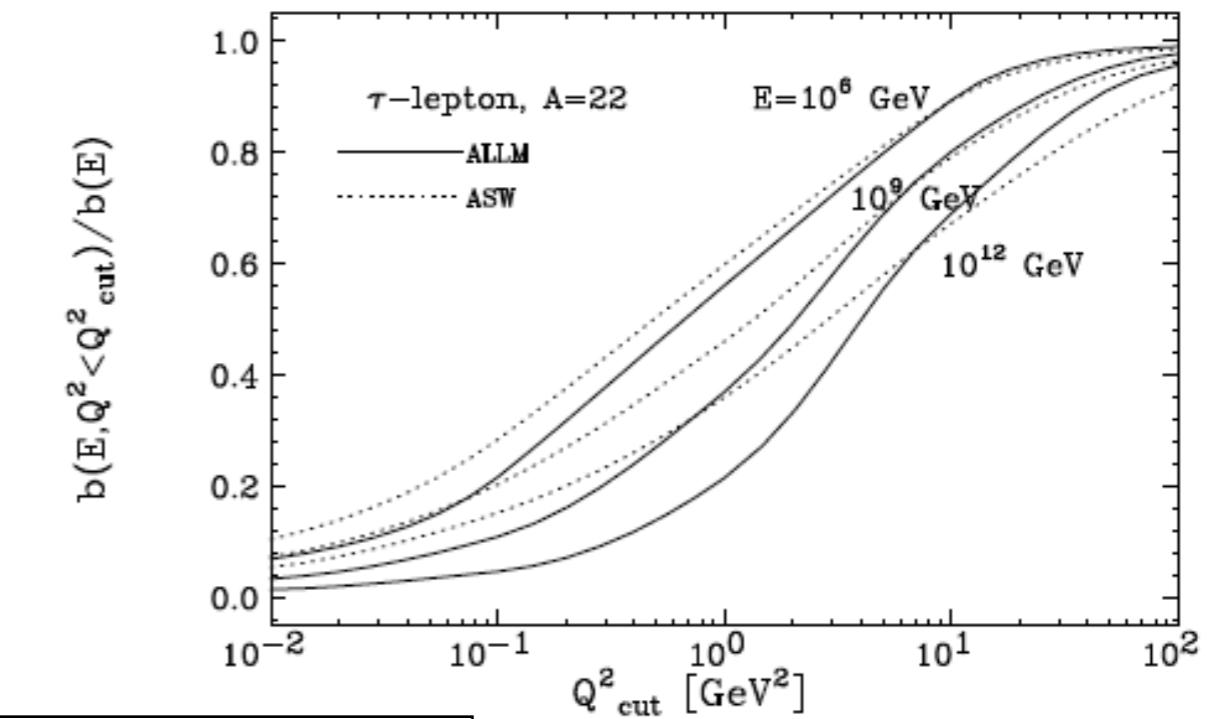
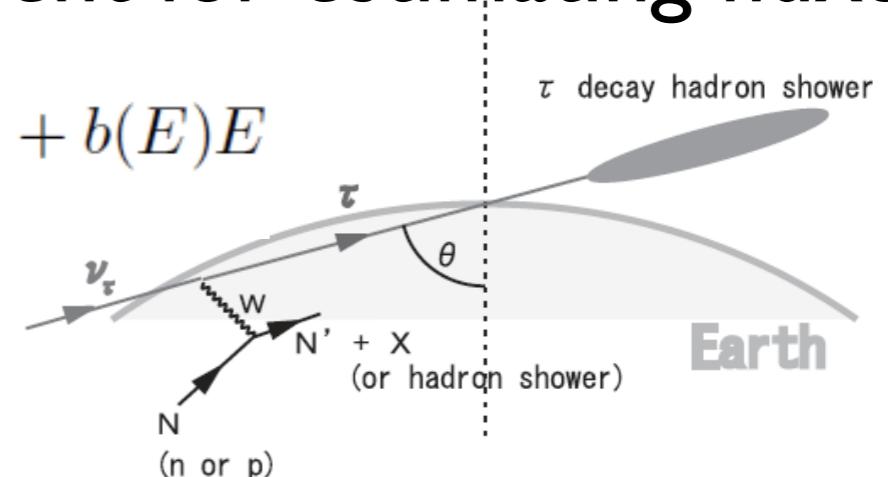


Implications for UHEV's:



- ν -n/A cross section (τ energy loss) dominated by DIS structure functions / (n)pdfs at small-x and large (small) Q^2 .
- Key ingredient for estimating fluxes.

$$-\left\langle \frac{dE}{dX} \right\rangle = a(E) + b(E)E$$



Preliminary; LHeC Design Study Report, CERN 2012

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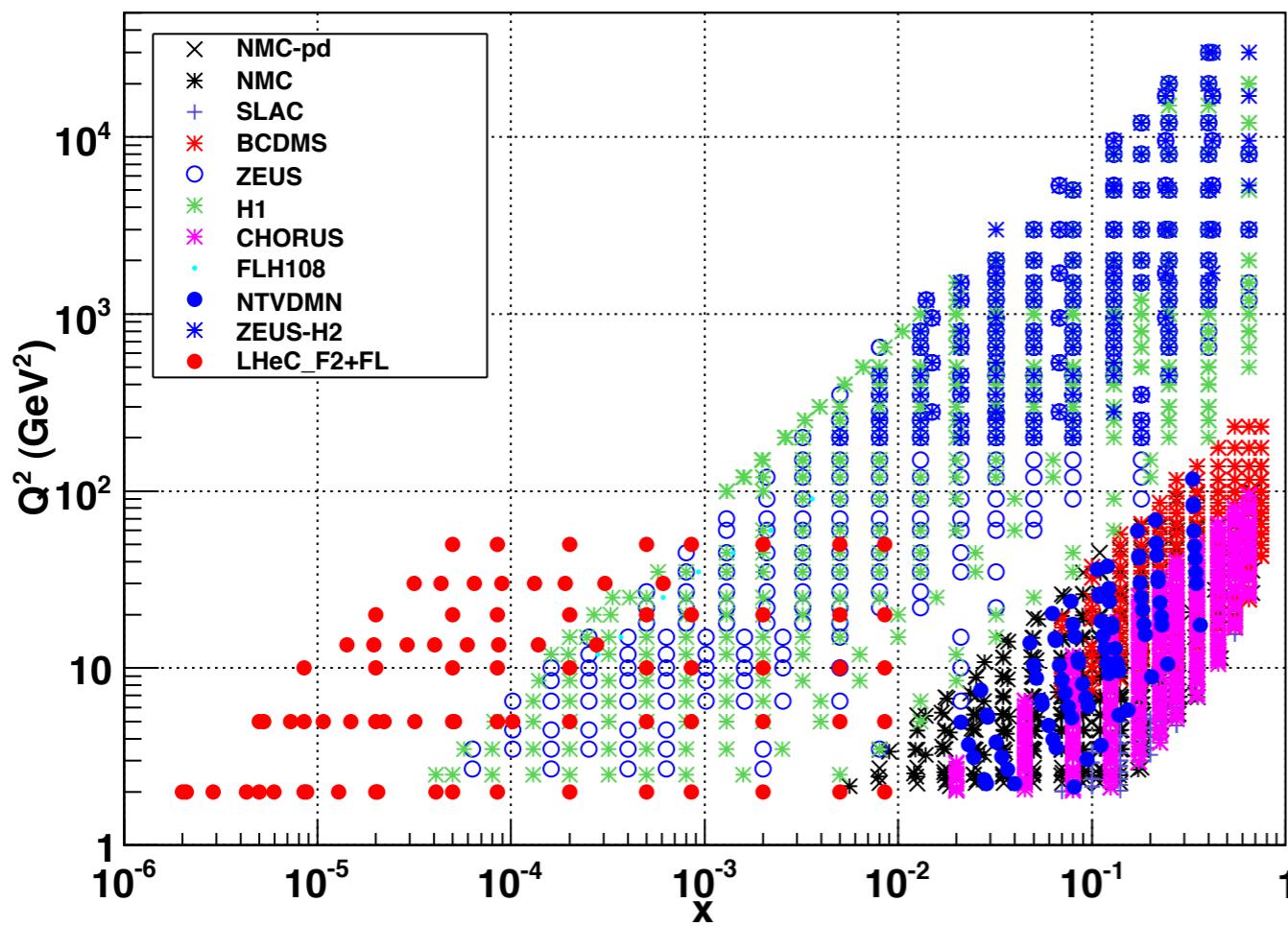
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- Inclusive measurements and small- x glue.
- Inclusive diffraction.
- Exclusive diffraction.
- Final states.

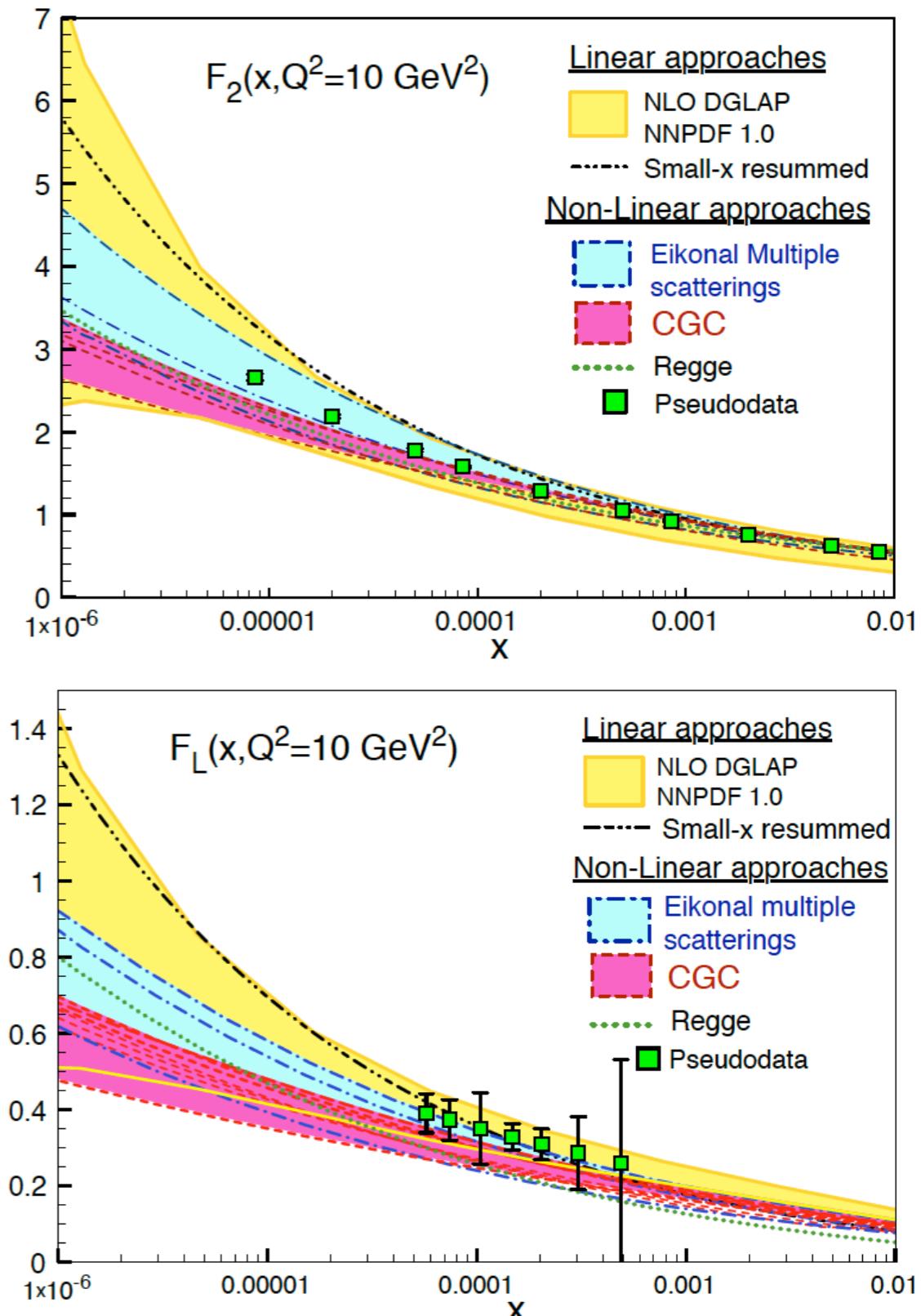
5. Summary and outlook.

ep inclusive: comparison

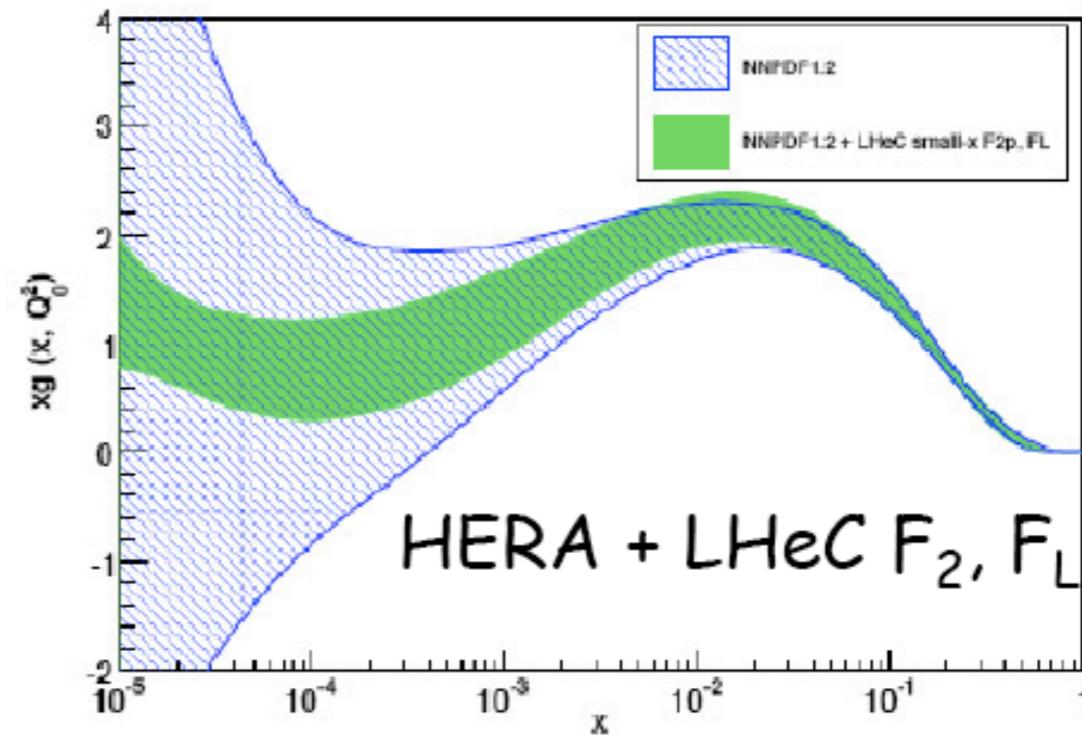
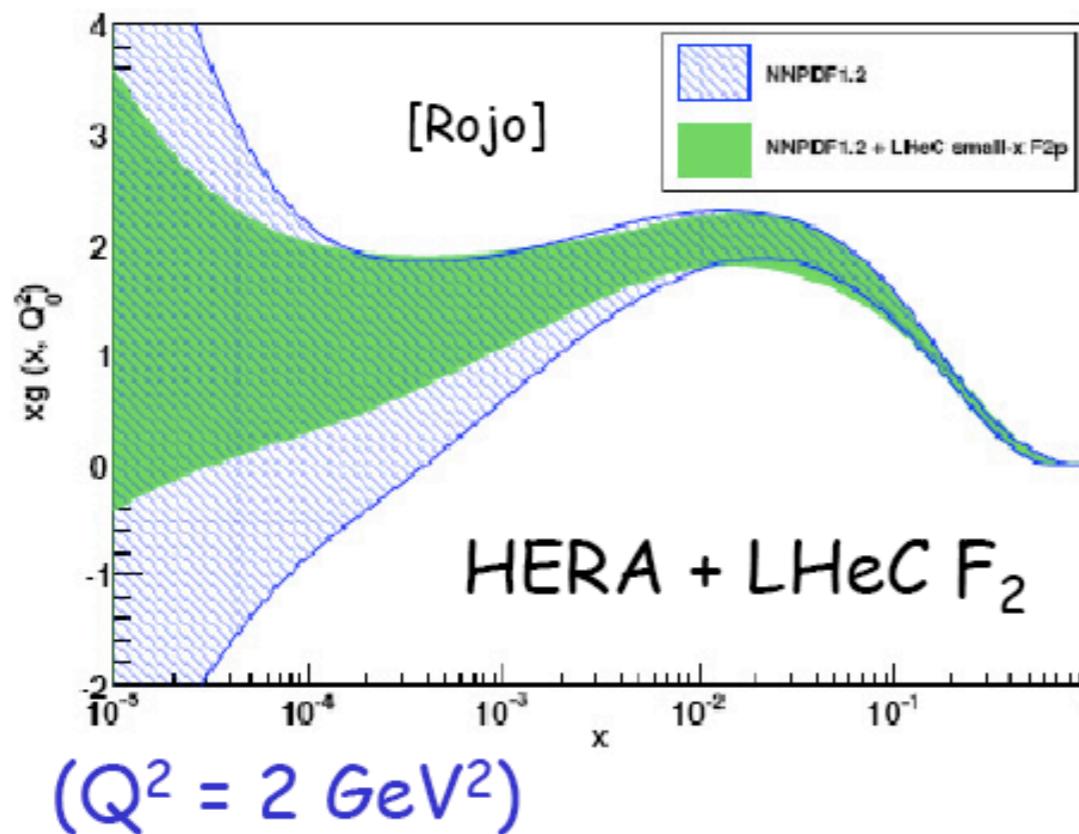
- Extensive model comparison: LHeC will have discriminative power.
- Note: size of radiative corrections pending (see the talk by Spiesberger at DIS2012).



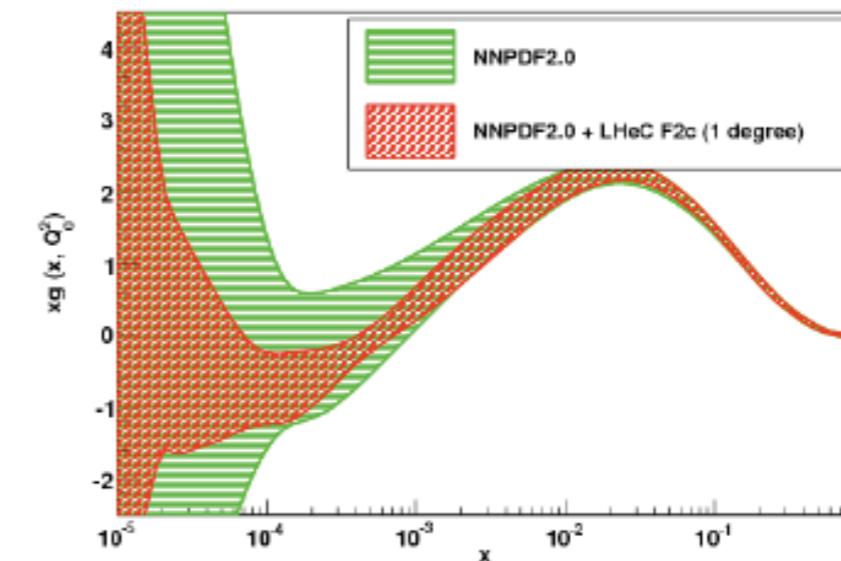
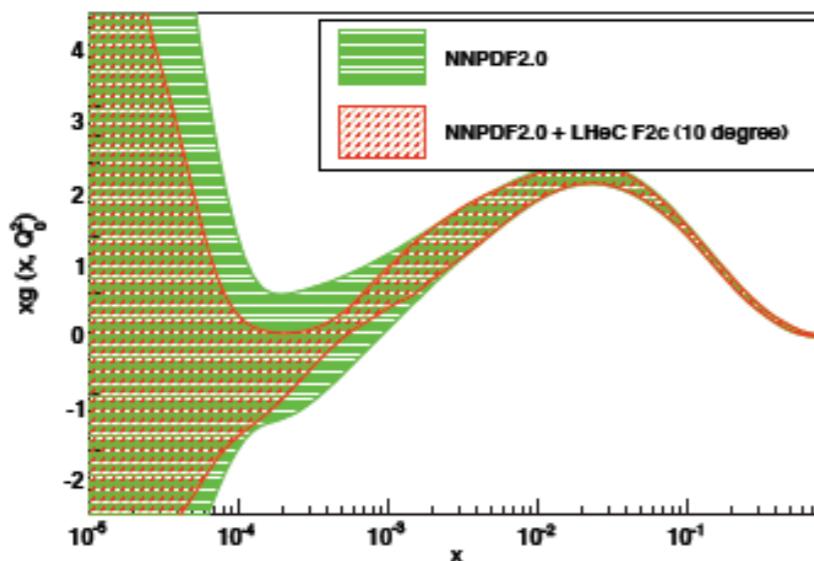
Preliminary; LHeC Design
Study Report, CERN 2012



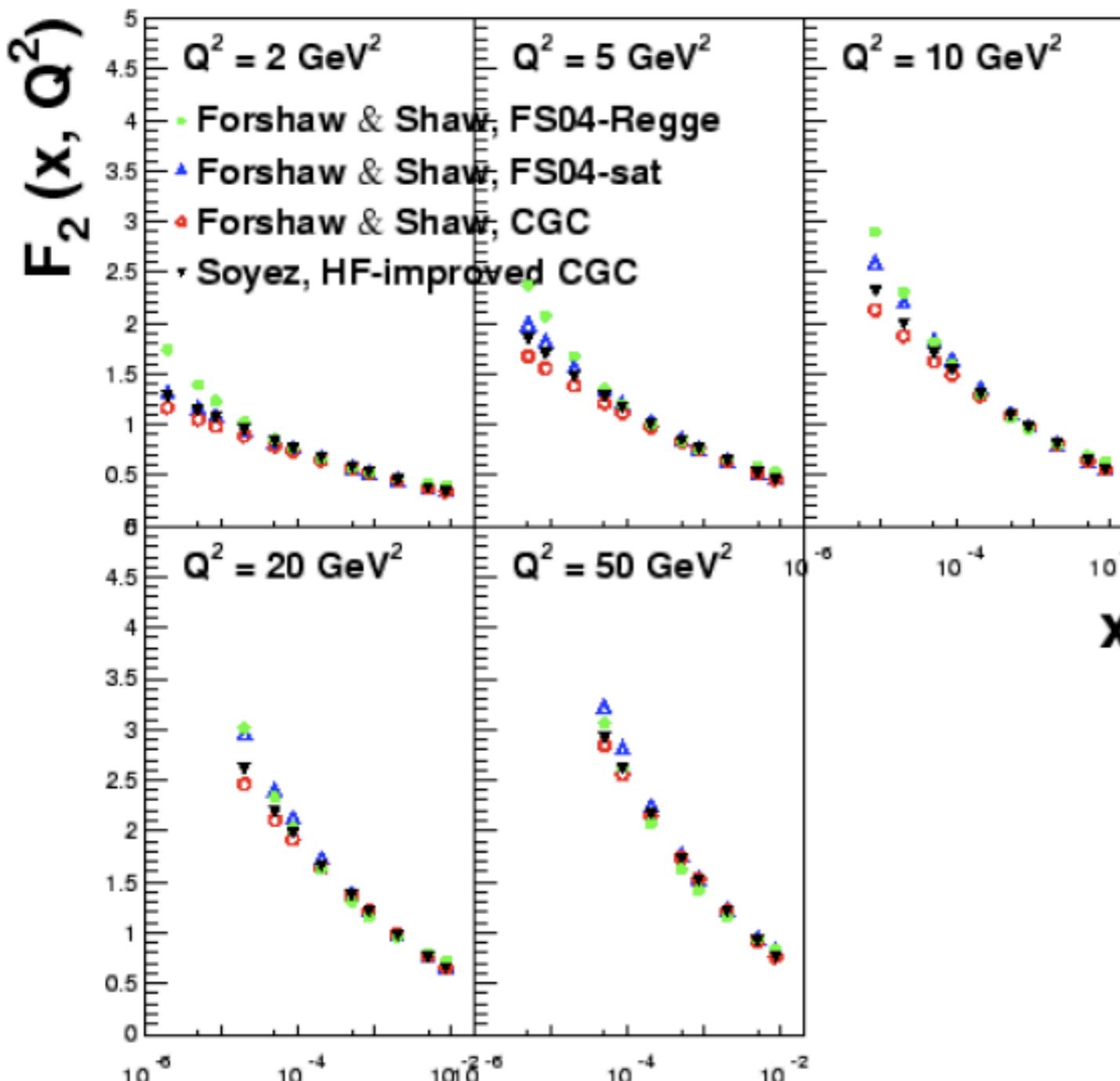
ep inclusive: extracting the glue



- LHeC substantially reduces the uncertainties in global fits: F_L and heavy flavor decomposition most useful.

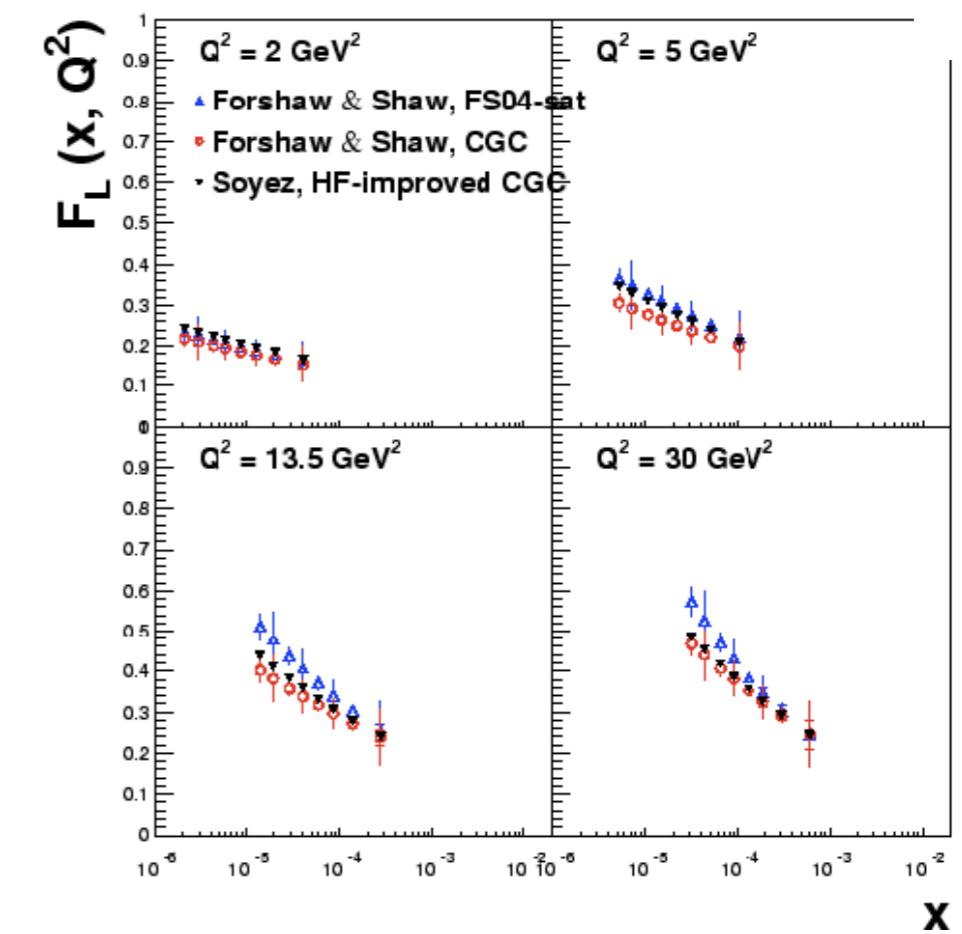


ep inclusive: searching

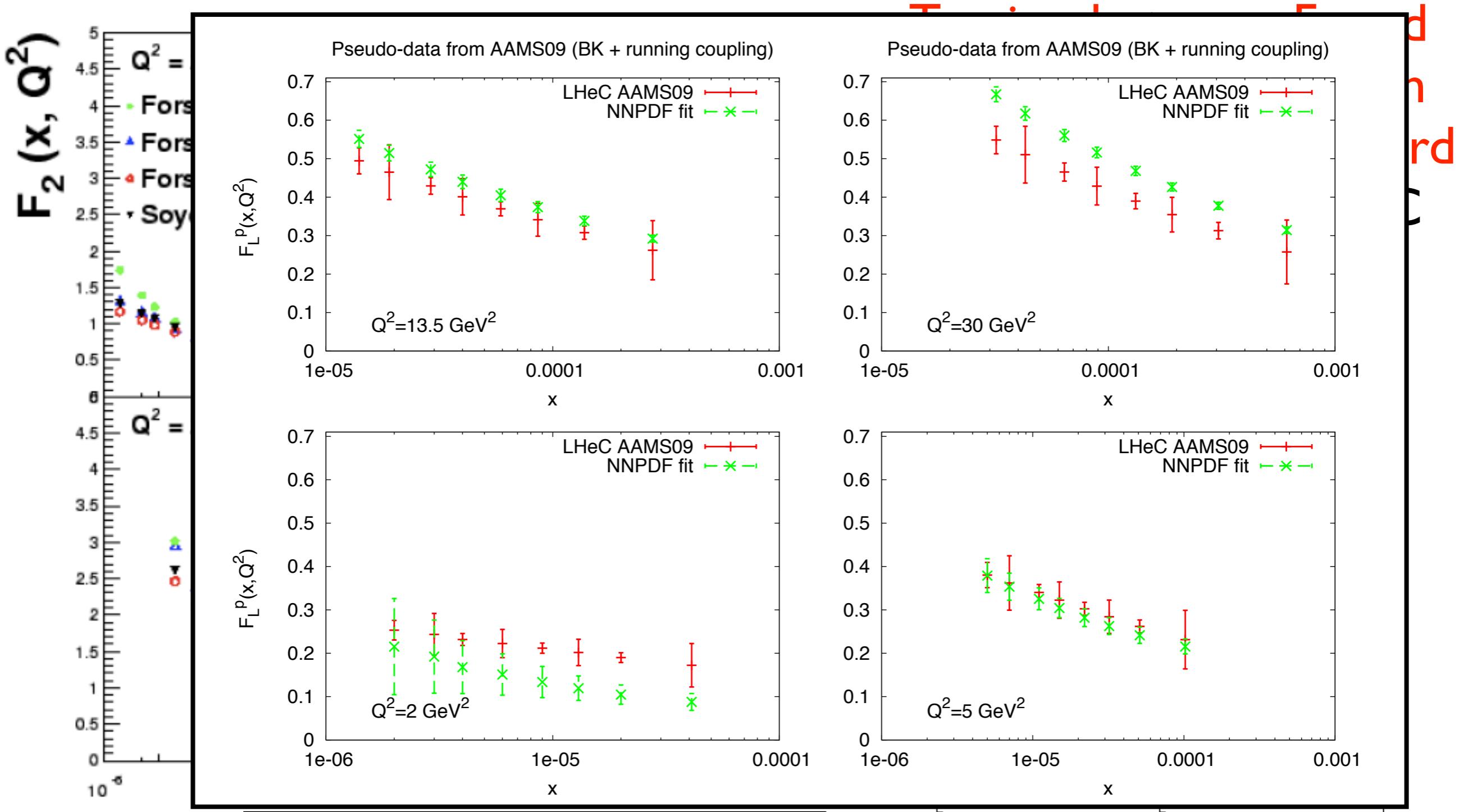


Preliminary; LHeC Design
Study Report, CERN 2012

- Tension between F_2 and F_L in DGLAP fits as a sign of physics beyond standard DGLAP (GBW and CGC models).



ep inclusive: searching

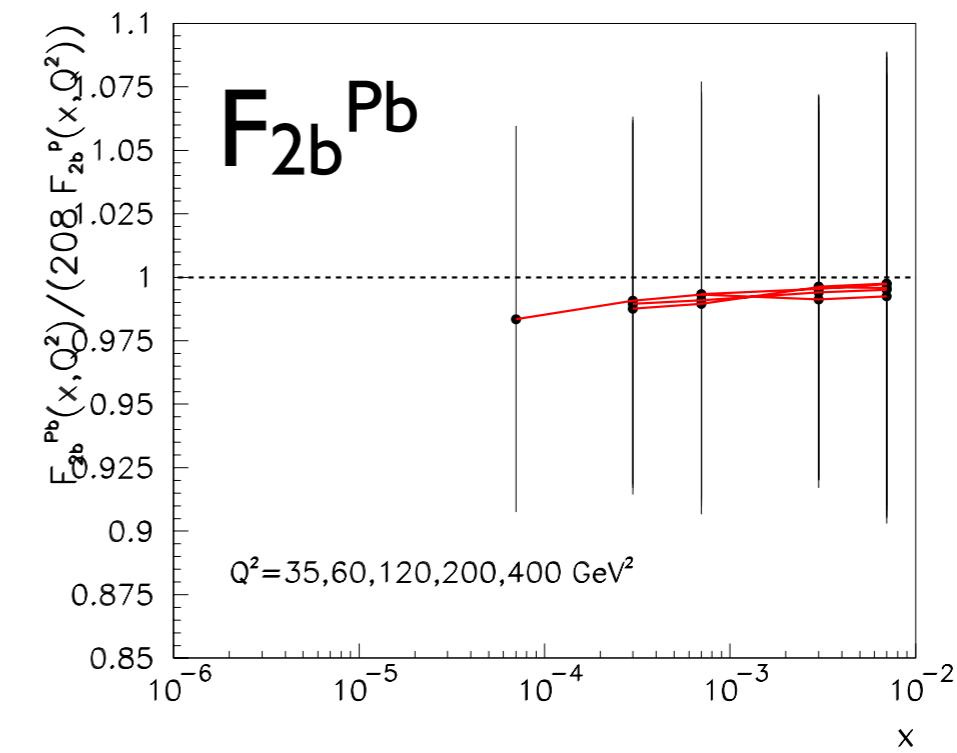
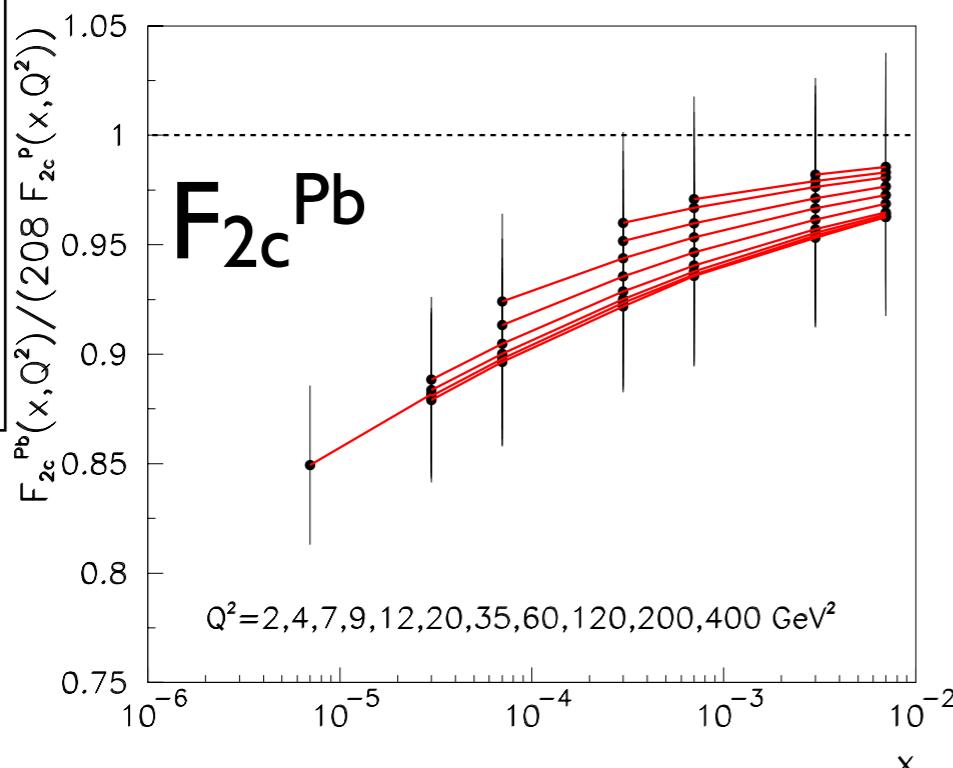
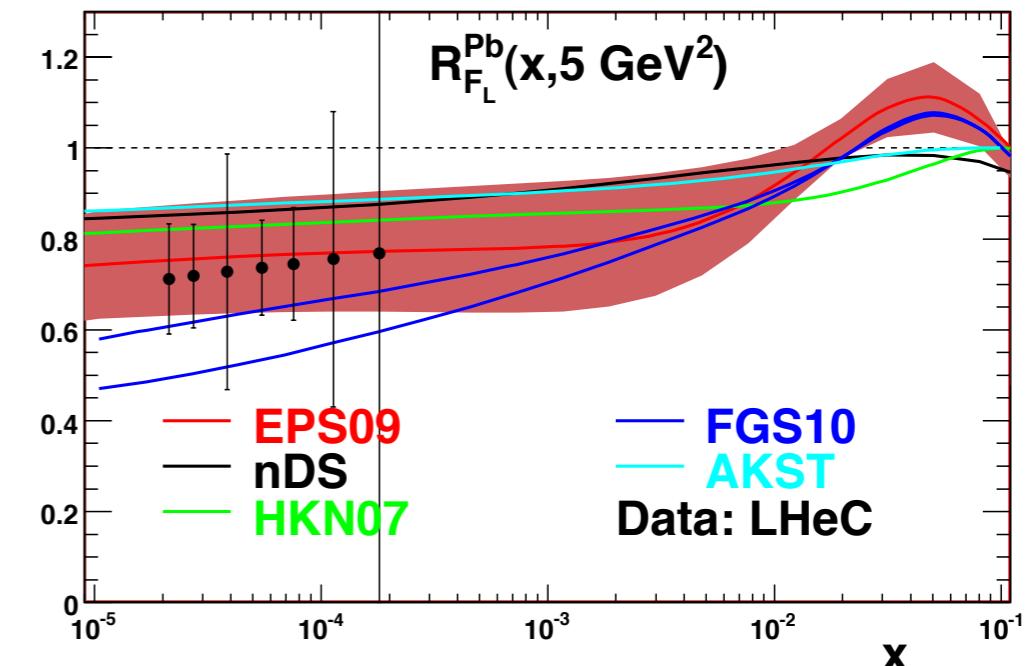
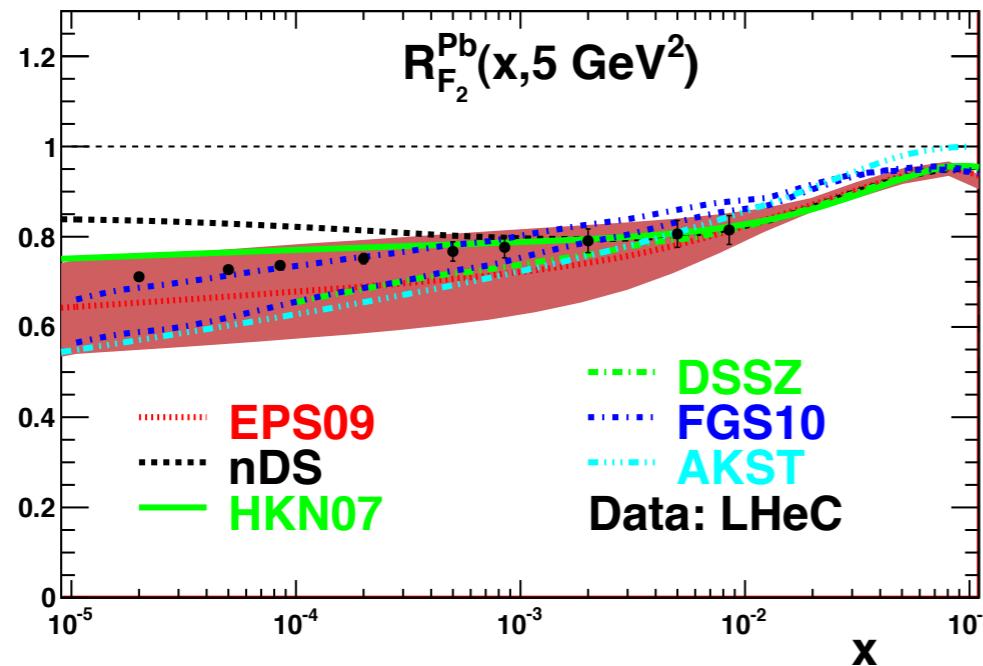


Preliminary; LHeC Design
Study Report, CERN 2012

eA inclusive: comparison

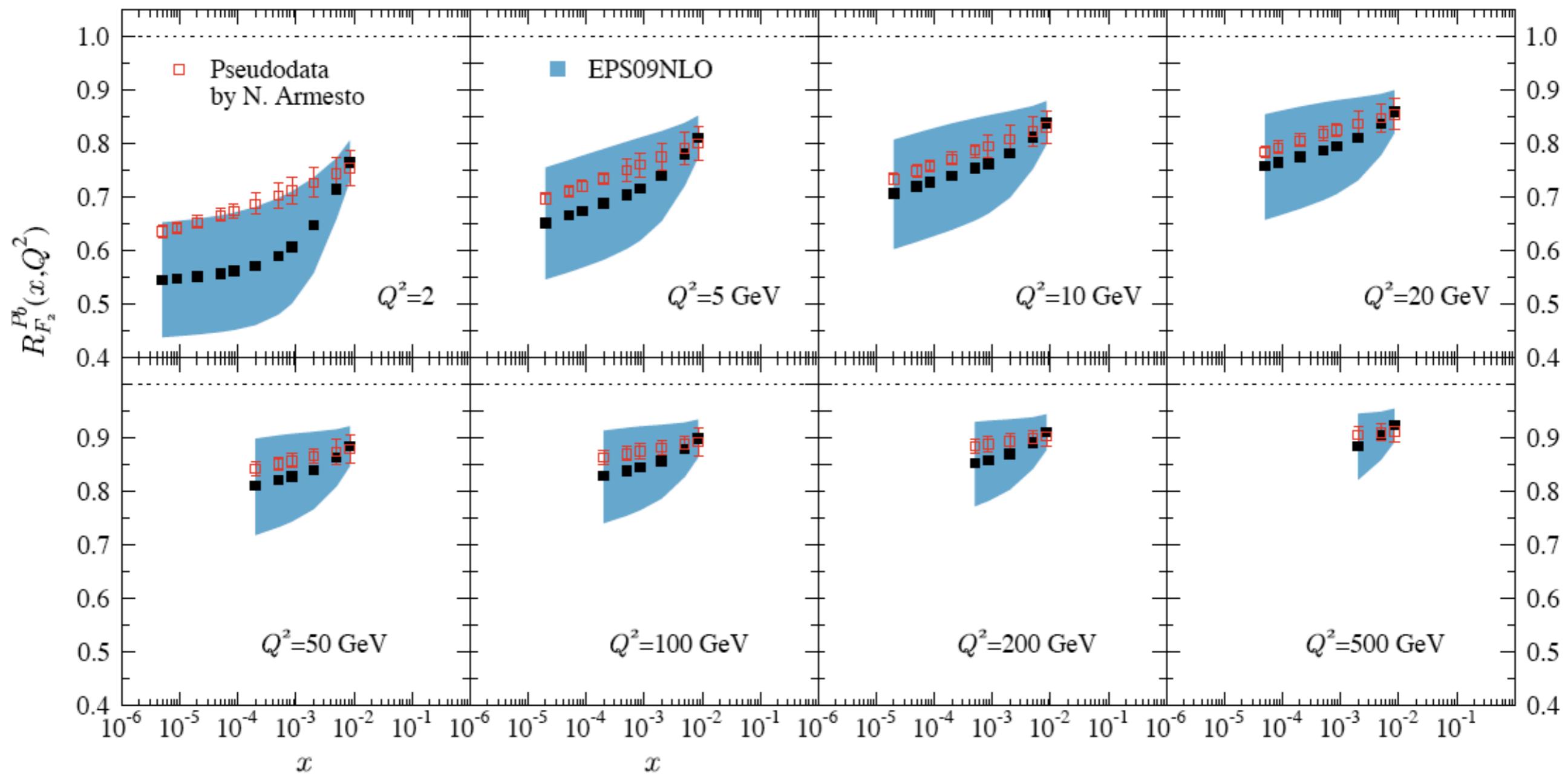
- Good precision can be obtained for $F_{2(c,b)}$ and F_L at small x
 (Glauberized 3-5 flavor GBW model, NA '02).

Preliminary; LHeC Design
Study Report, CERN 2012



eA inclusive: constraining pdfs

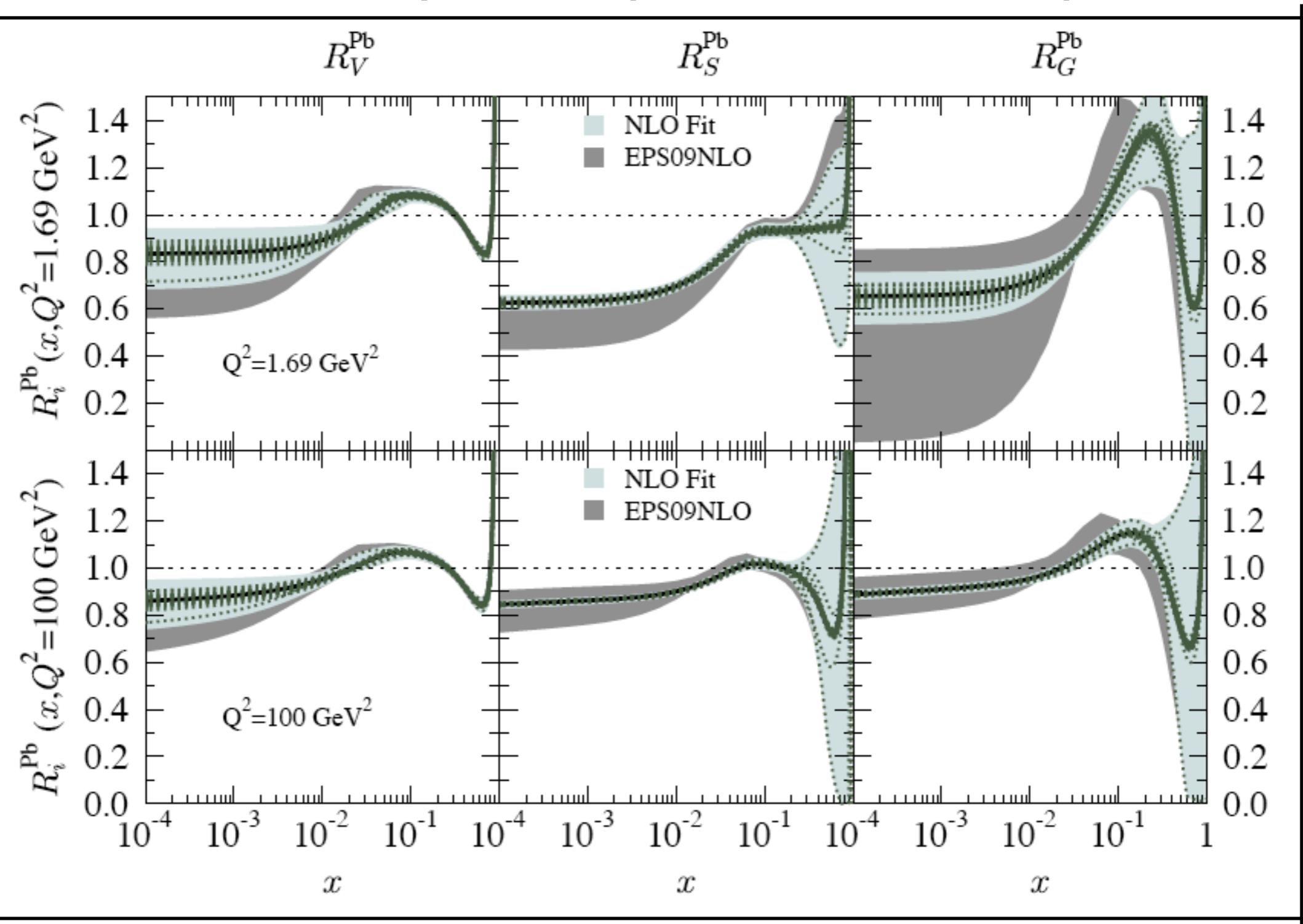
- F_2 data substantially reduce the uncertainties in DGLAP analysis; inclusion of charm, beauty and F_L done.



eA inclusive: constraining pdfs

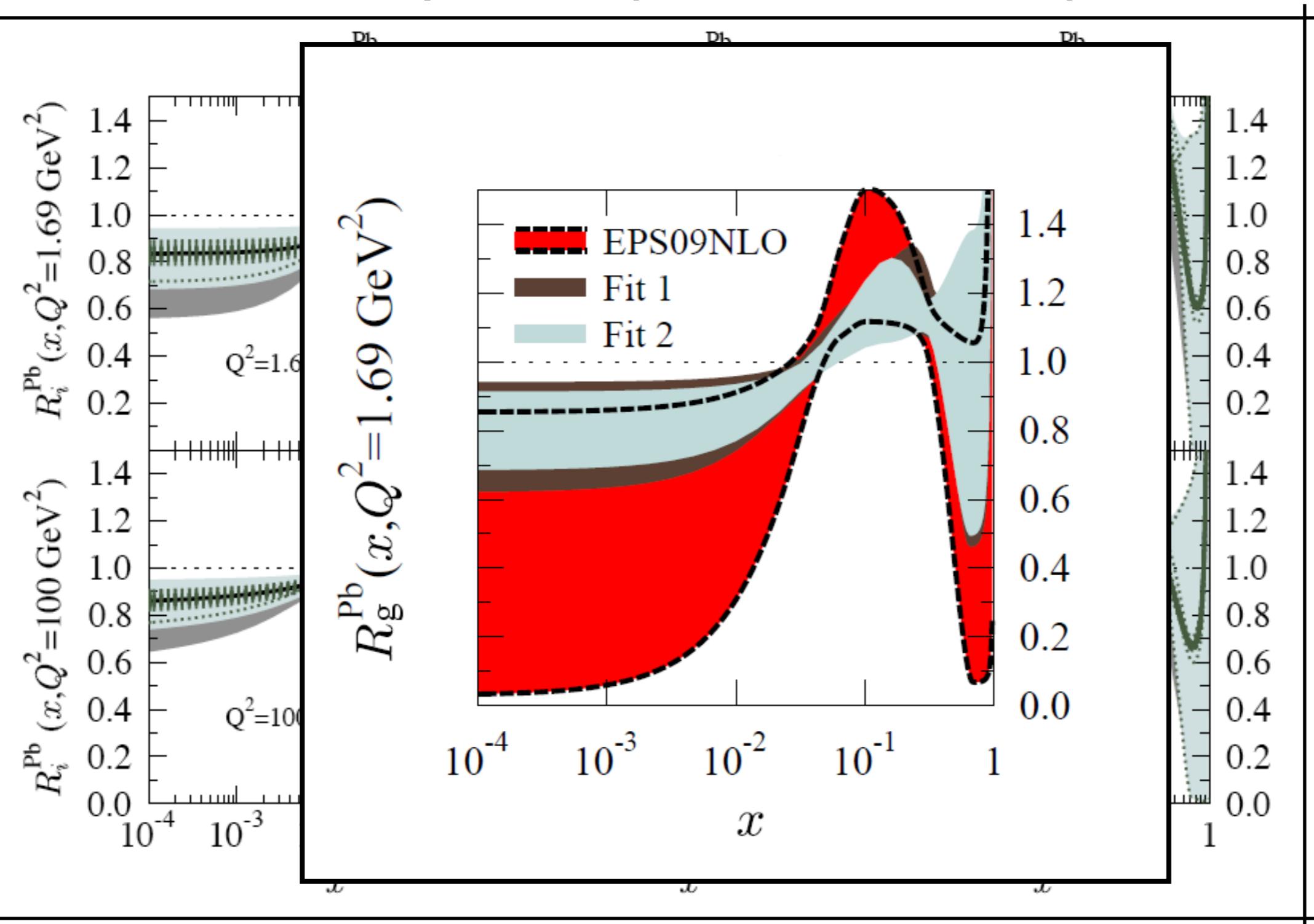
- F_2 data substantially reduce the uncertainties in DGLAP analysis; inclusion of charm, beauty and F_L produce minor improvements.

Preliminary; LHeC Design
Study Report, CERN 2012



eA inclusive: constraining pdfs

- F_2 data substantially reduce the uncertainties in DGLAP analysis; inclusion of charm, beauty and F_L produce minor improvements.



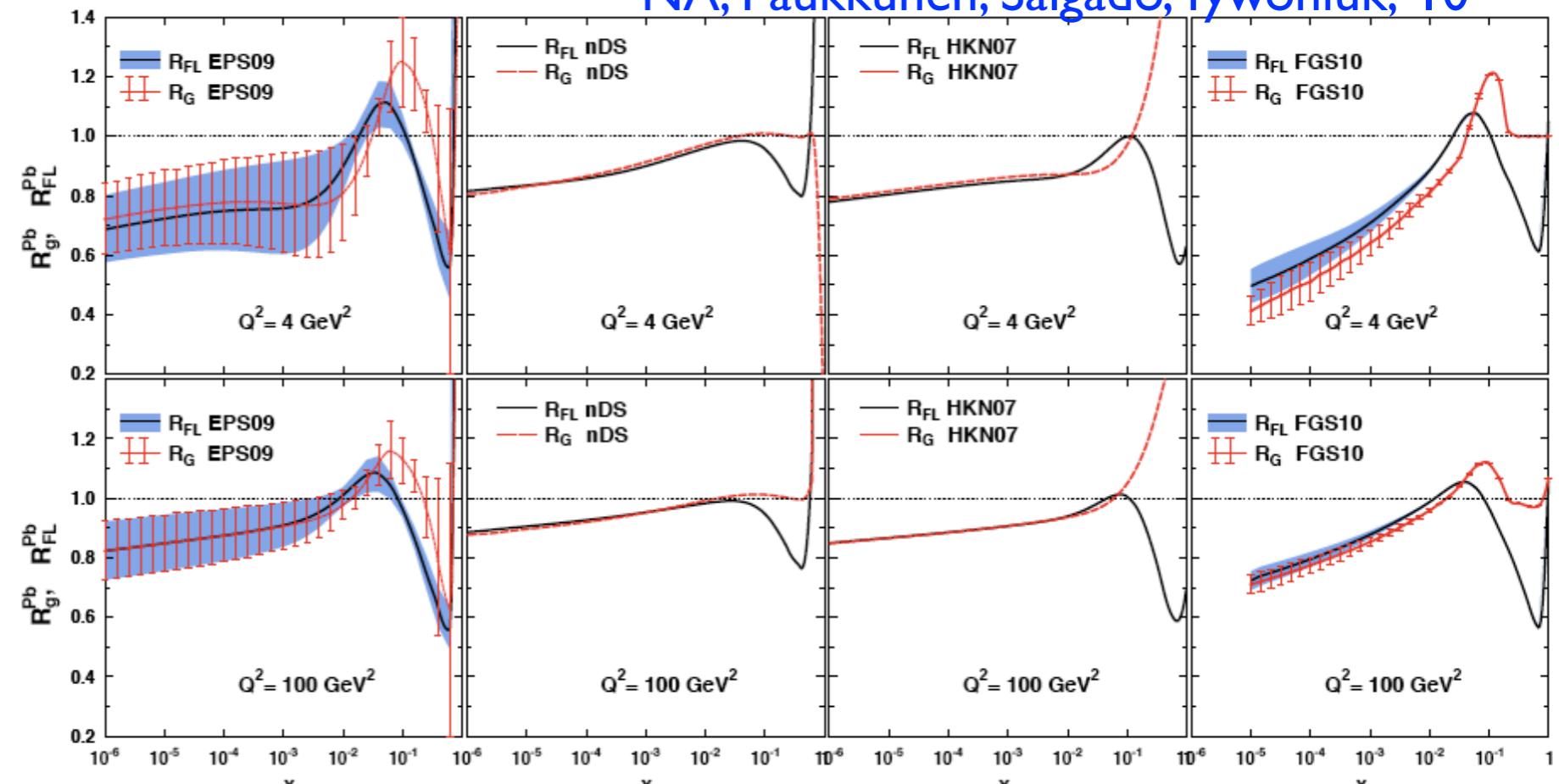
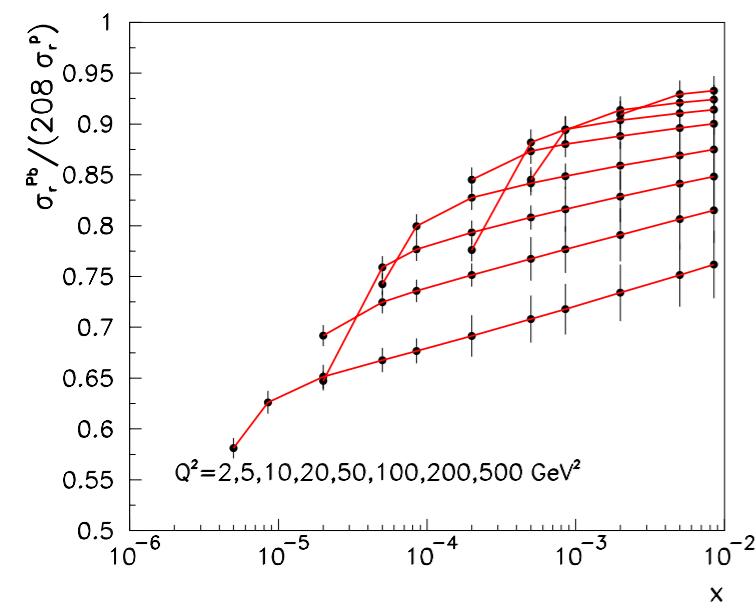
Preliminary; LHeC Design
Study Report, CERN 2012

Note: F_L in eA

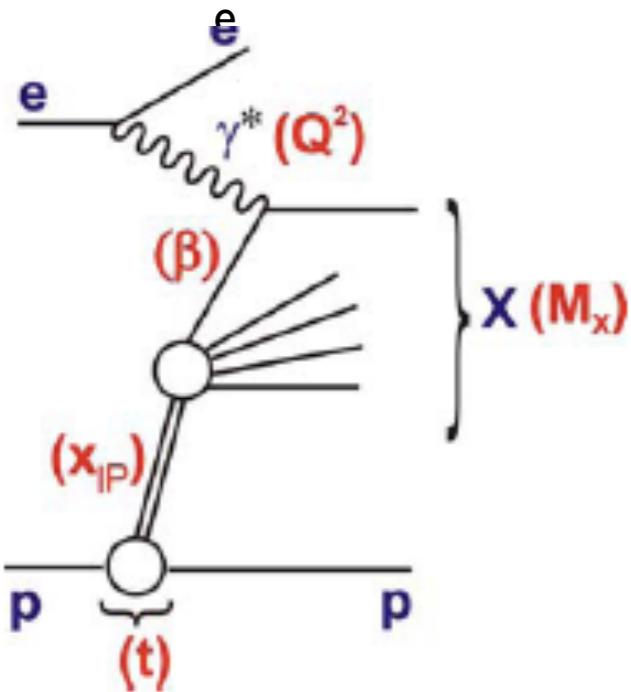
$$\sigma_r^{NC} = \frac{Q^4 x}{2\pi\alpha^2 Y_+} \frac{d^2\sigma^{NC}}{dxdQ^2} = F_2 \left[1 - \frac{y^2}{Y_+} \frac{F_L}{F_2} \right], \quad Y_+ = 1 + (1 - y)^2$$

- F_L traces the nuclear effects on the glue (Cazarotto et al '08).
- Uncertainties in the extraction of F_2 due to the unknown nuclear effects on F_L of order 5 % (larger than expected stat.+syst.) \Rightarrow measure F_L or use the reduced cross section (but then ratios at two energies...).

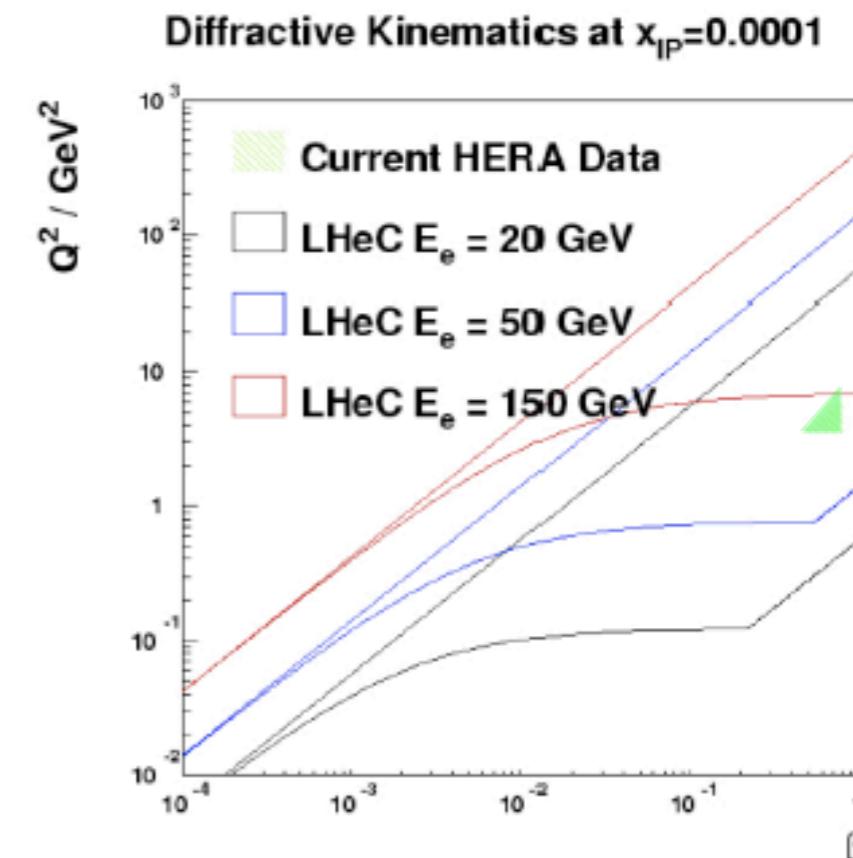
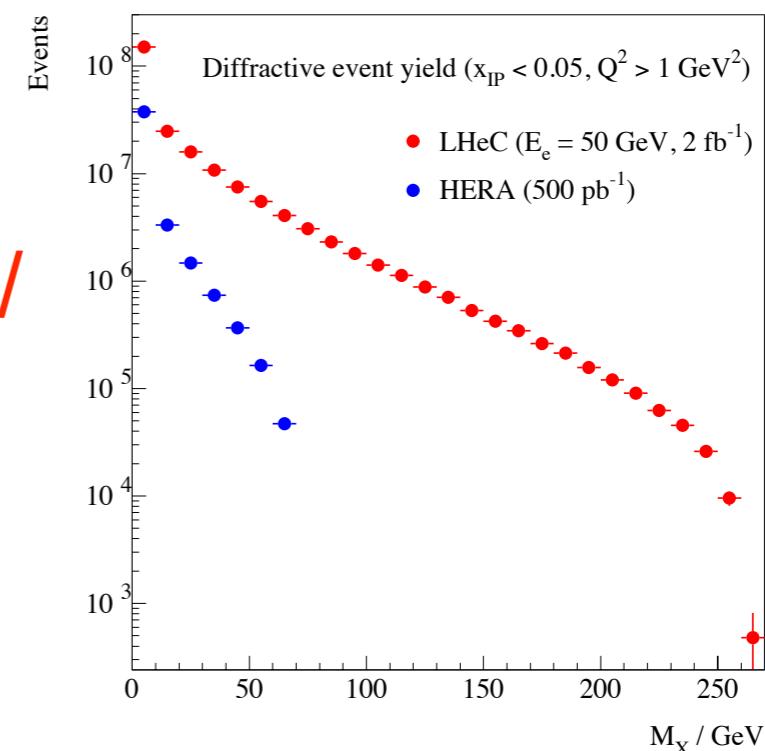
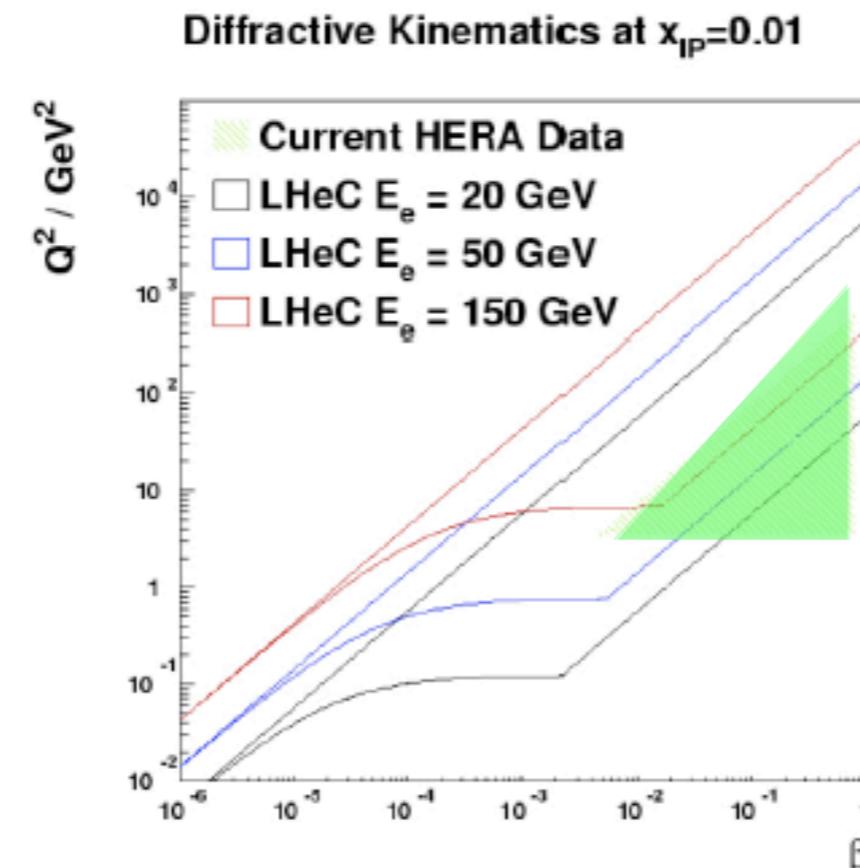
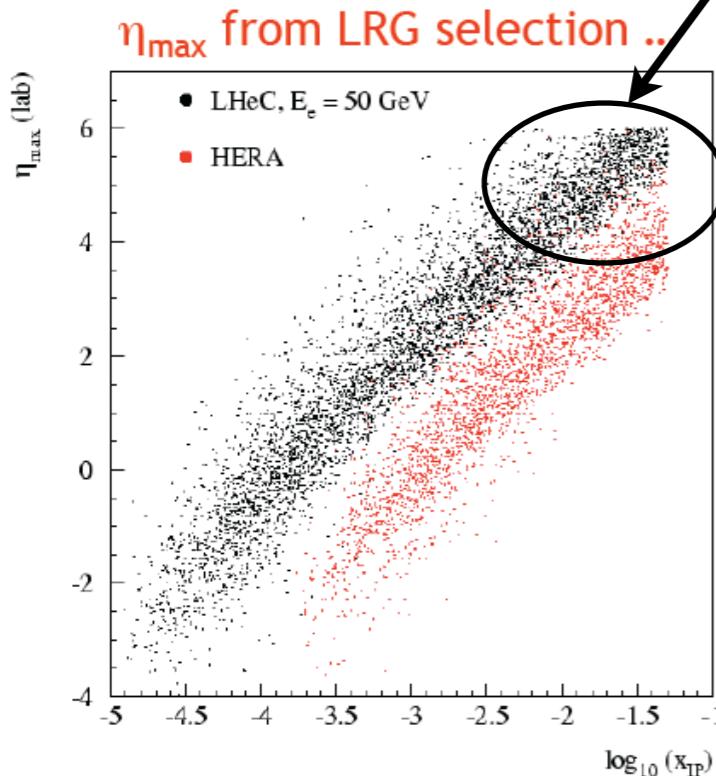
NA, Paukkunen, Salgado, Tywoniuk, '10



ep diffractive pseudodata:

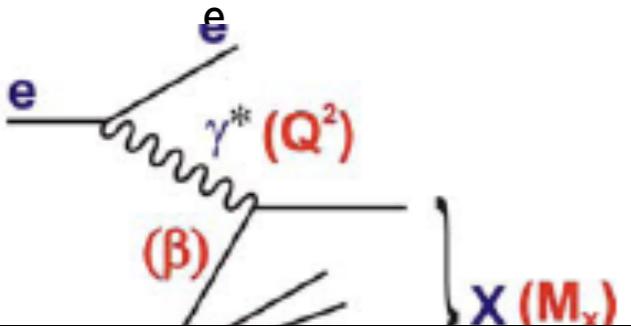


- Large increase in the $M^2, x_P = (M^2 - t + Q^2) / (W^2 + Q^2), \beta = x/x_P$ region studied.
- Possibility to combine LRG and LPS.

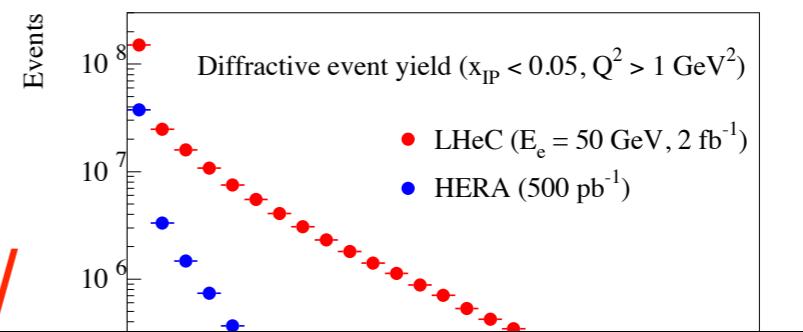


Preliminary; LHeC Design
Study Report, CERN 2012

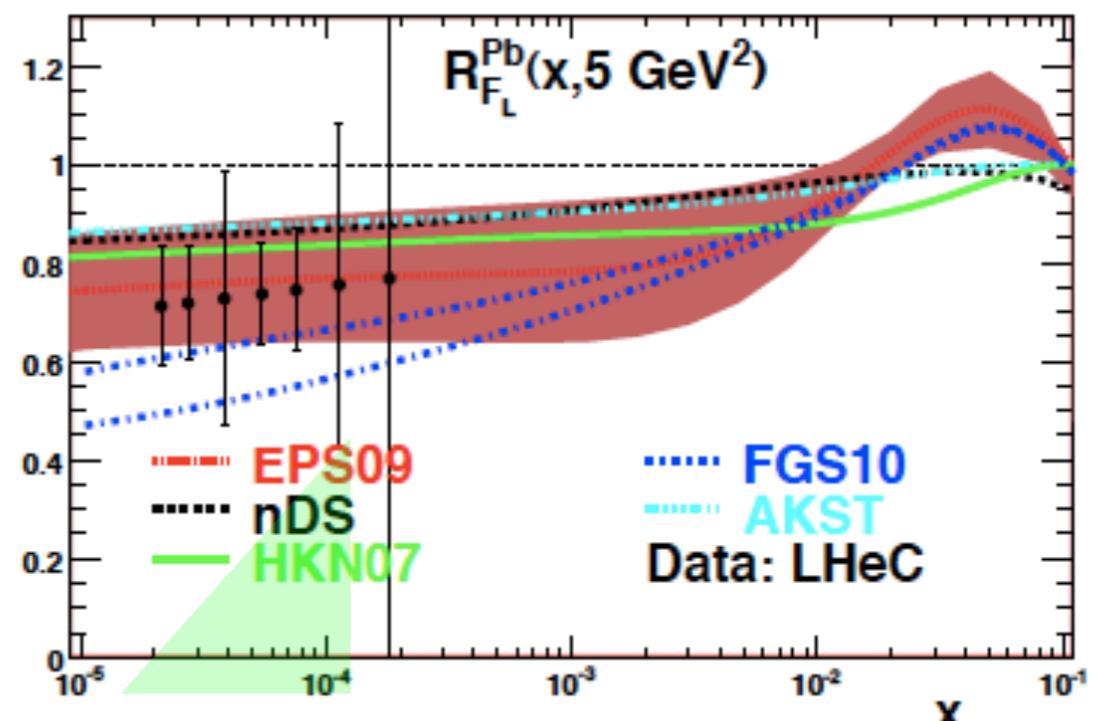
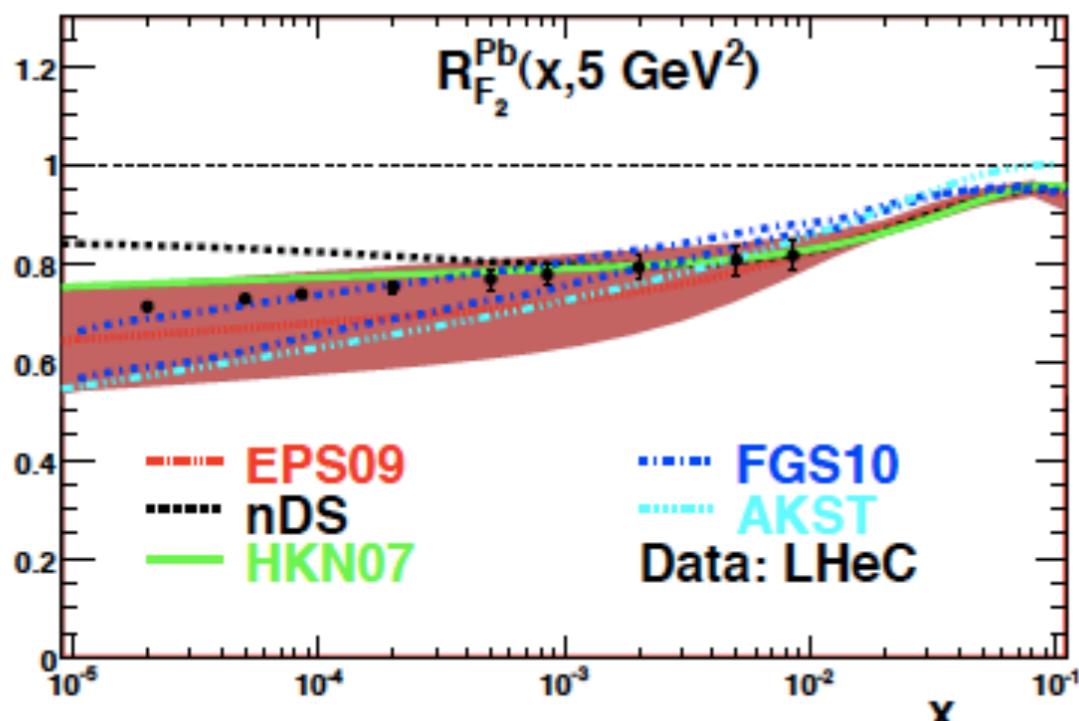
ep diffractive pseudodata:



- Large increase in the $M^2, x_P = (M^2 - t + Q^2)/(W^2 + Q^2), \beta = x/$

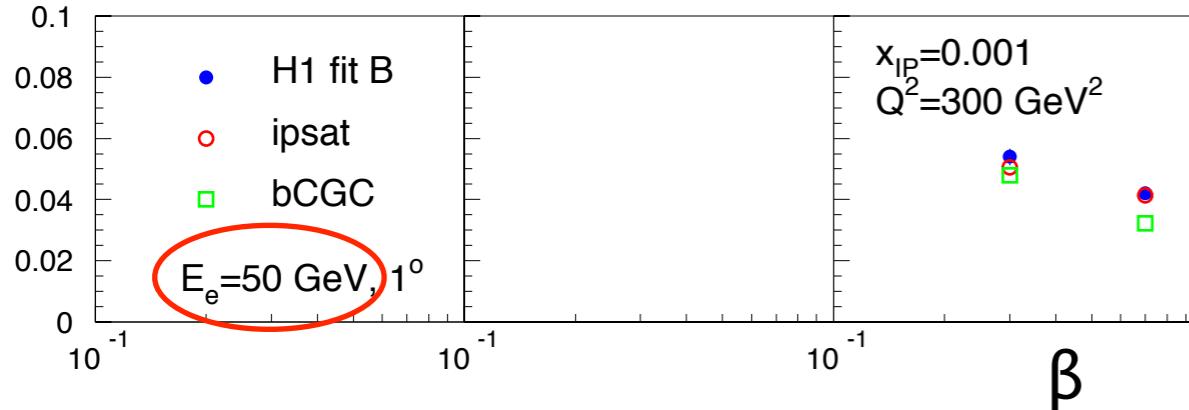
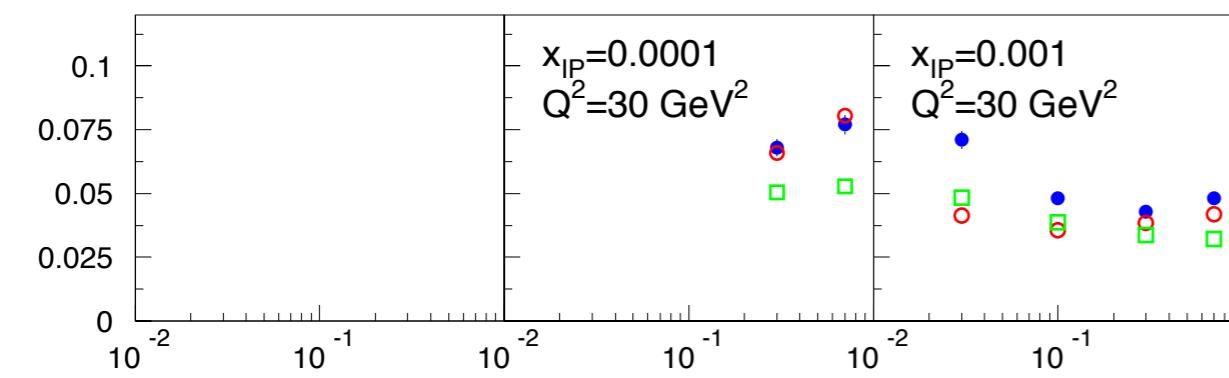
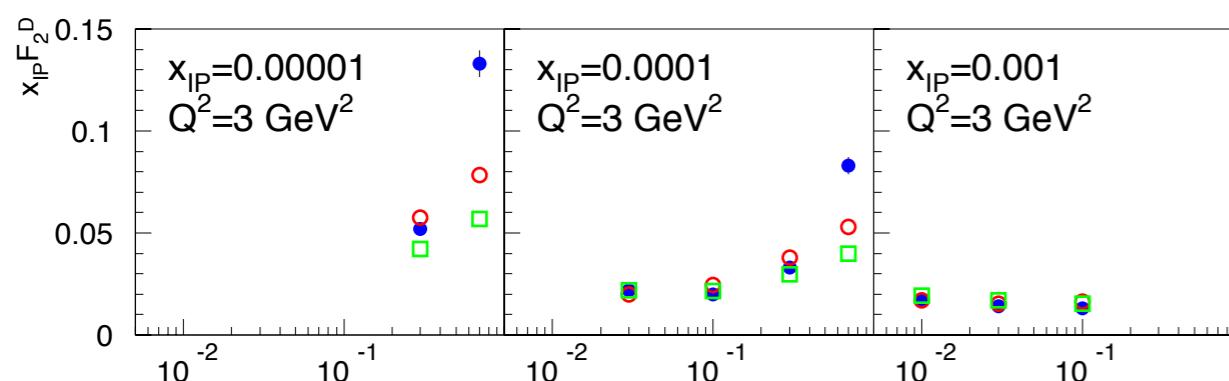


Note: diffraction in ep is linked to shadowing in eA
(Gribov): FGS, Capella-Kaidalov et al,...

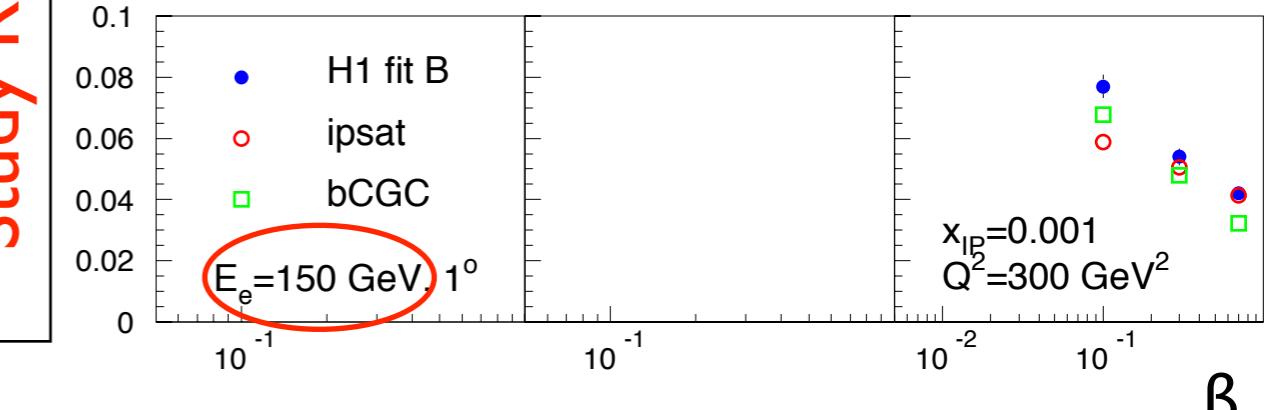
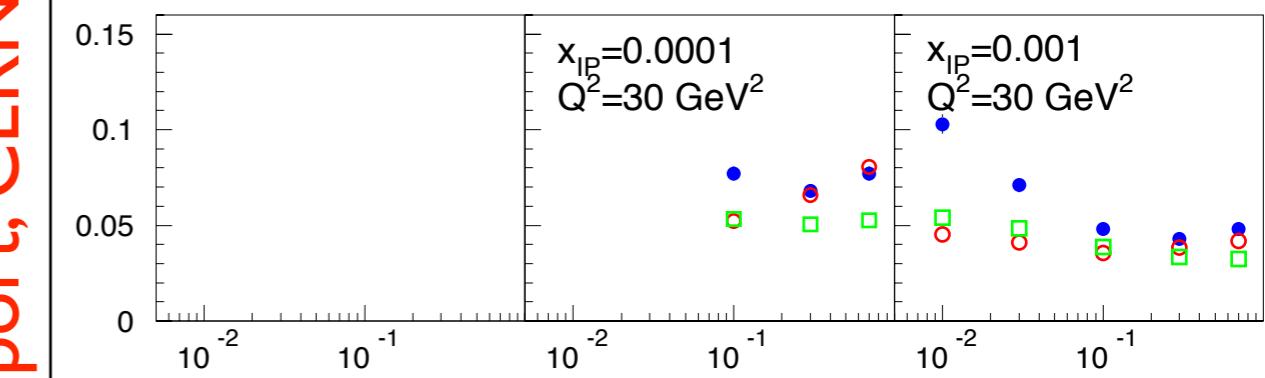
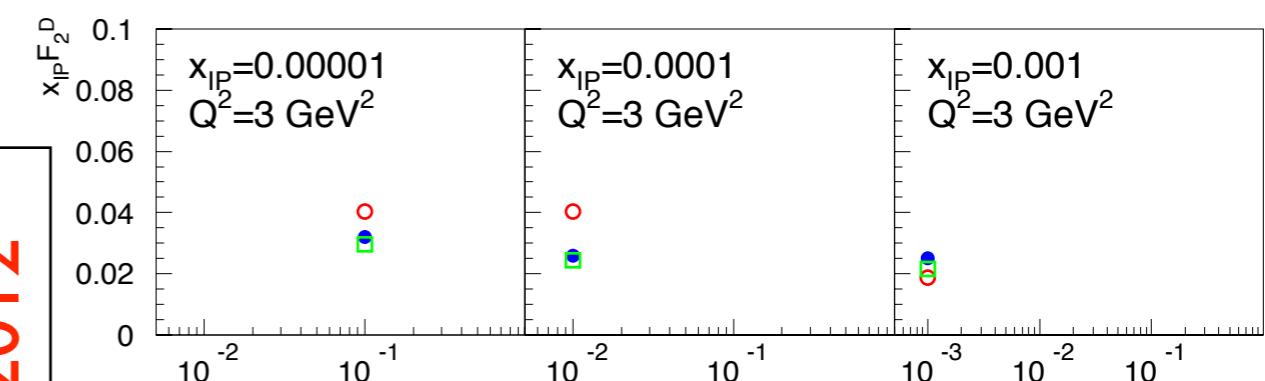


Diffraction and non-linear dynamics:

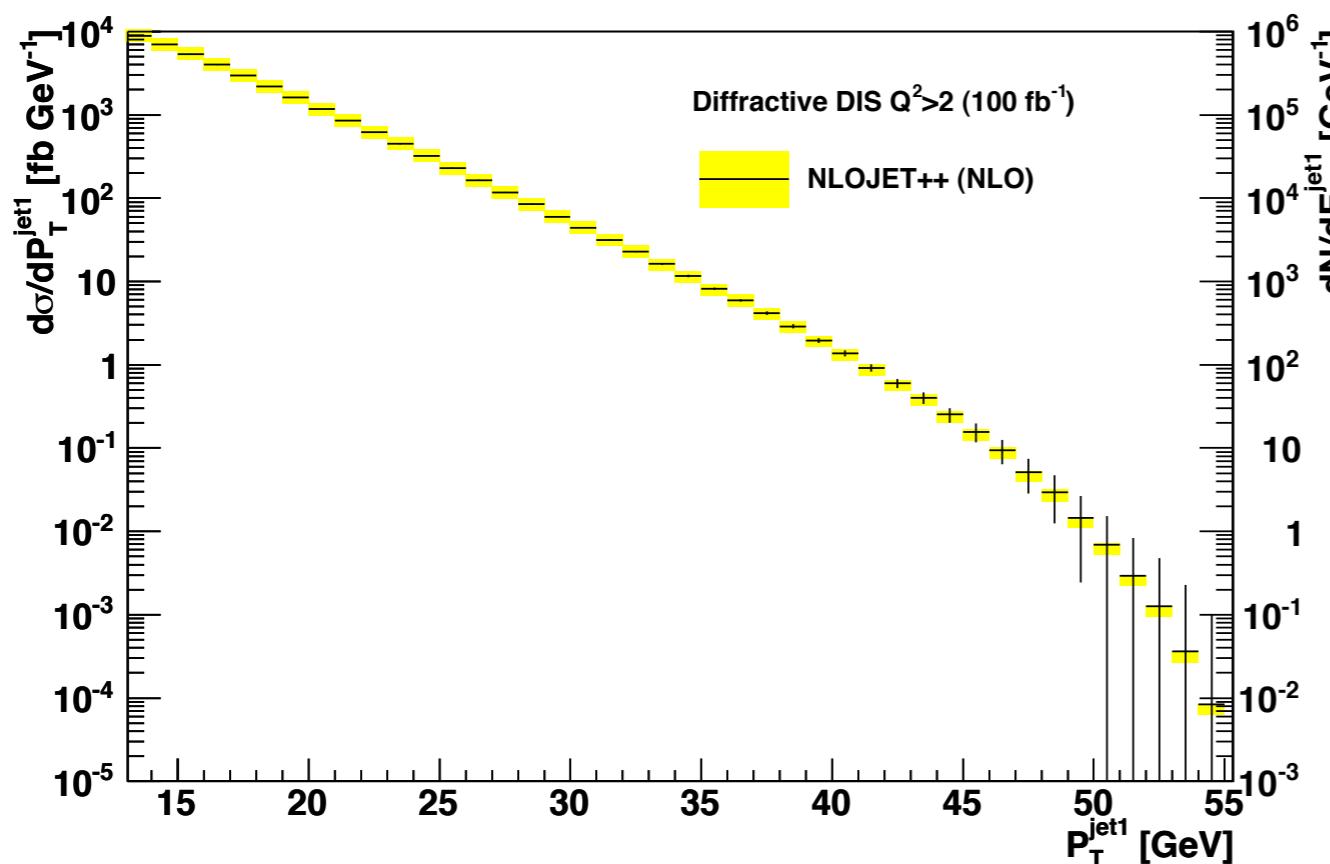
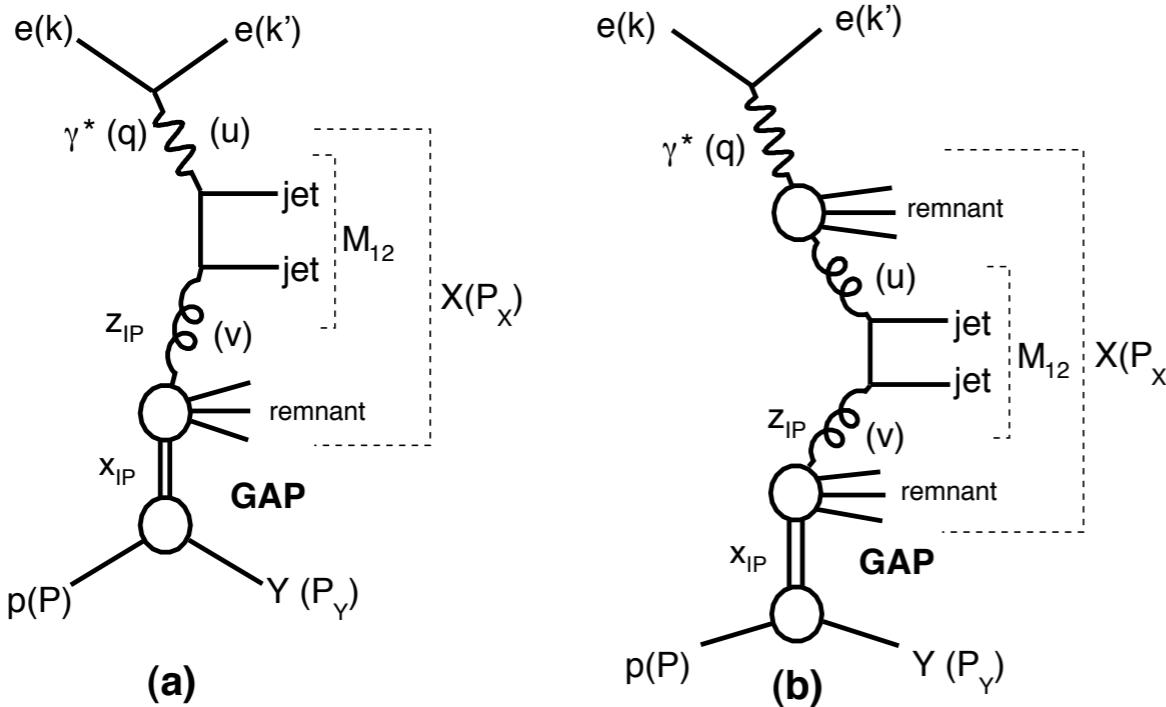
- Dipole models show differences with linear-based extrapolations (HERA-based dPDF's) and among each other: possibility to check saturation and its realization.



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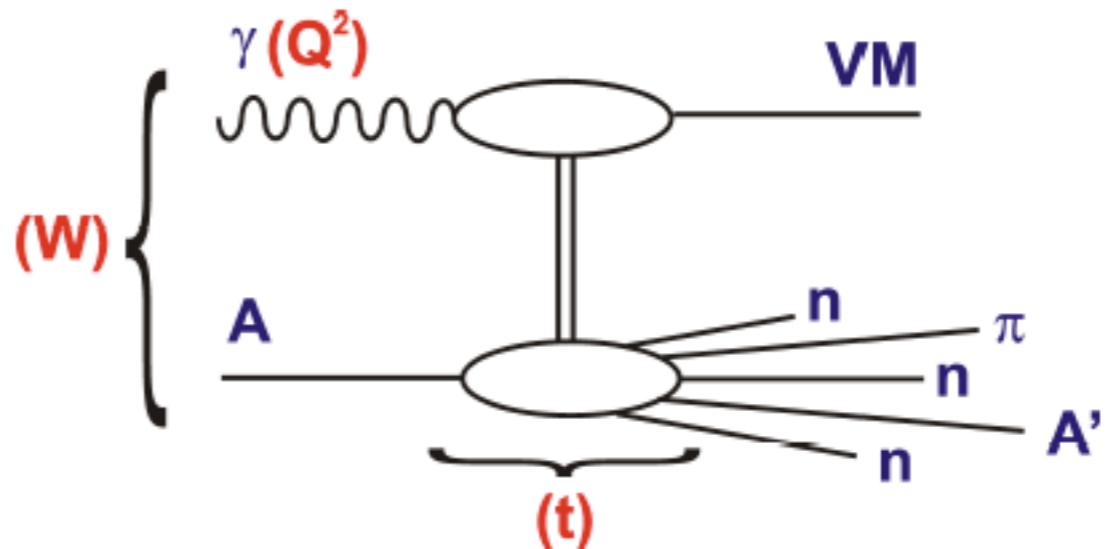
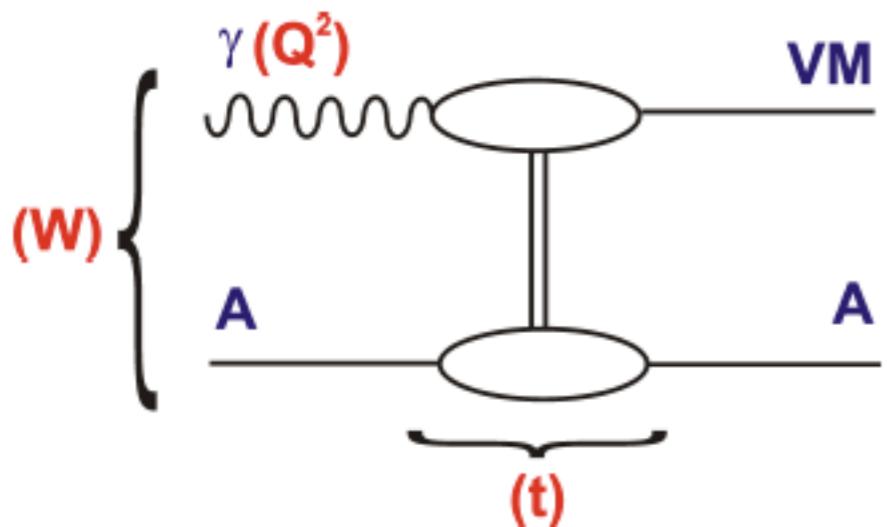


Diffractive dijets:



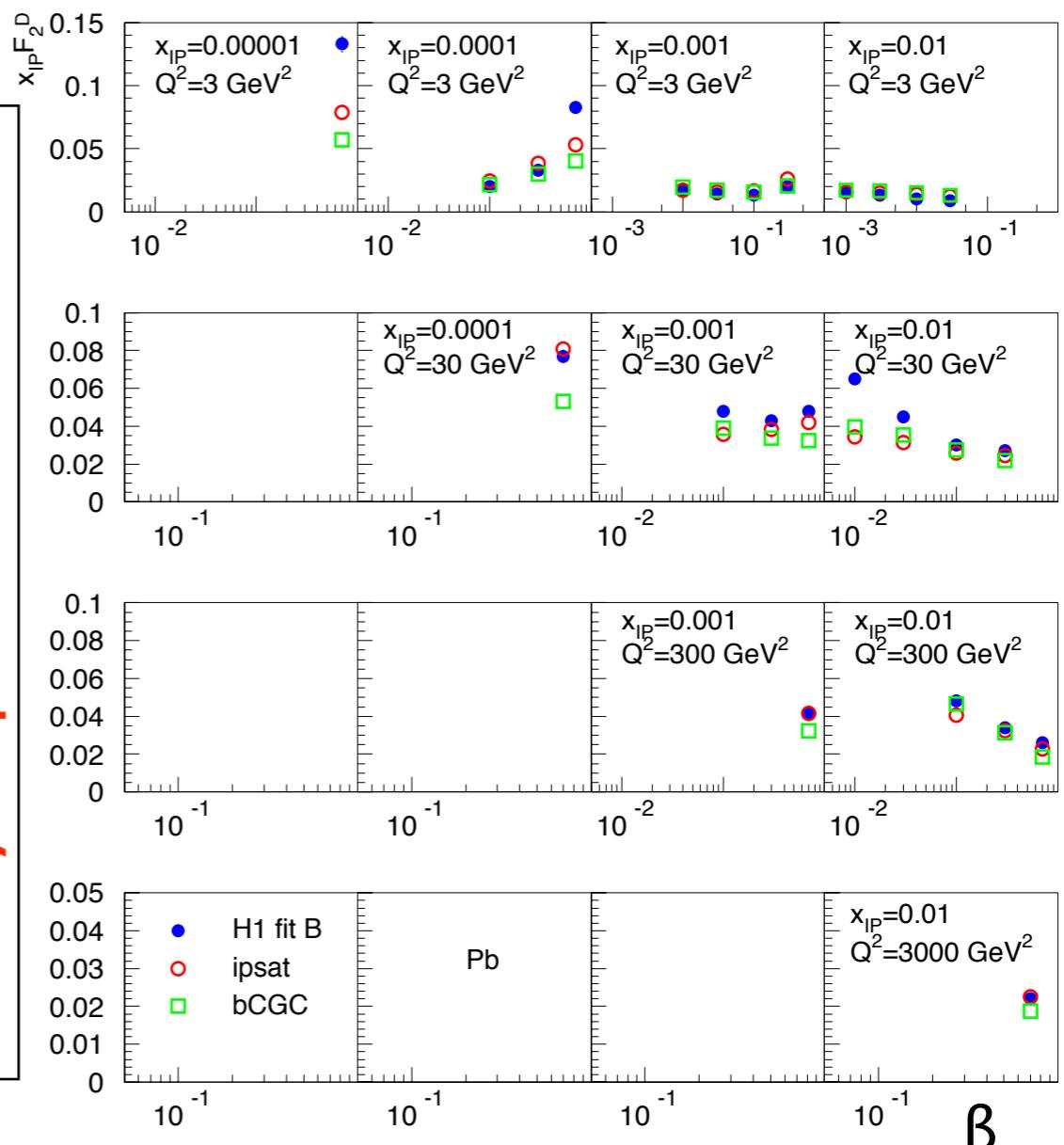
- Diffractive dijet and open heavy flavour production offer large possibilities for:
 - Checking factorization in hard diffraction.
 - Constraining DPDFs.
- Large yields upto large P_T^{jet1} .
- Direct and resolved contributions: photon PDFs.

LHeC Diffractive DIS on nuclear targets:

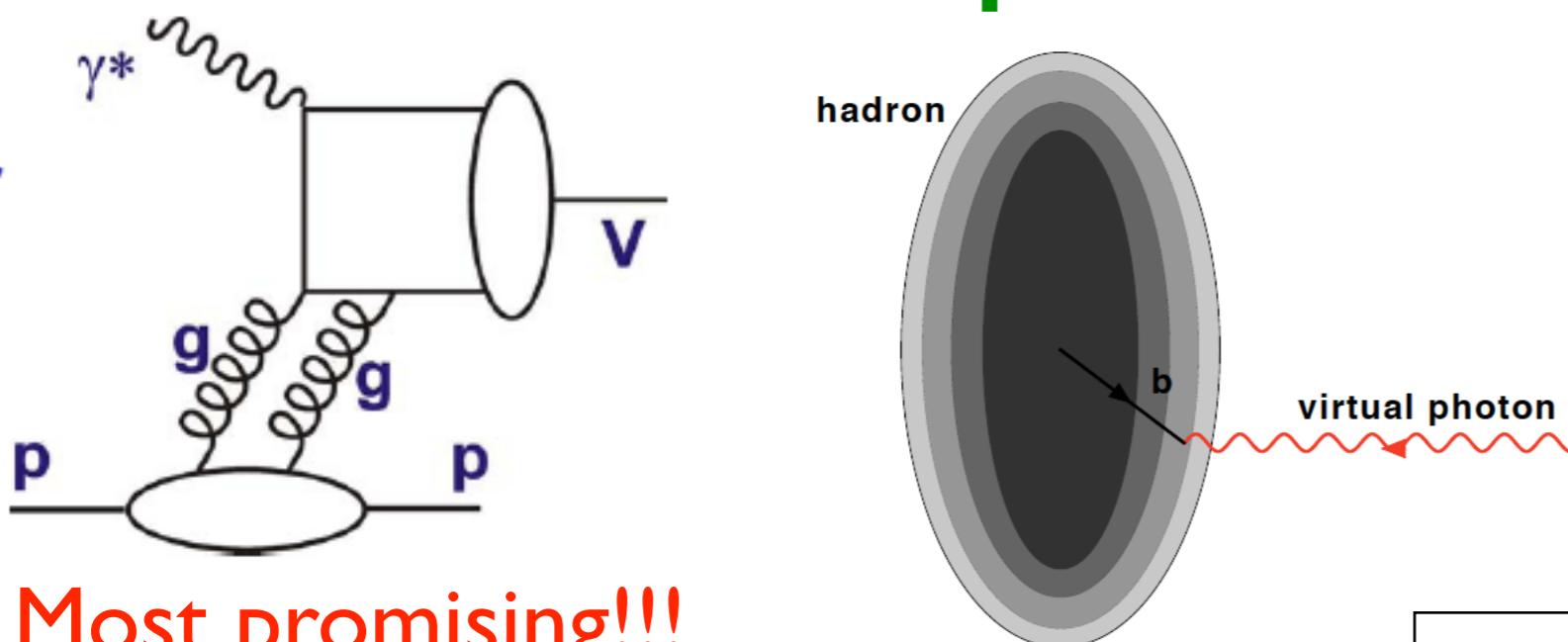


- Challenging experimental problem, requires Monte Carlo simulation with detailed understanding of the nuclear break-up.
- For the coherent case, predictions available.

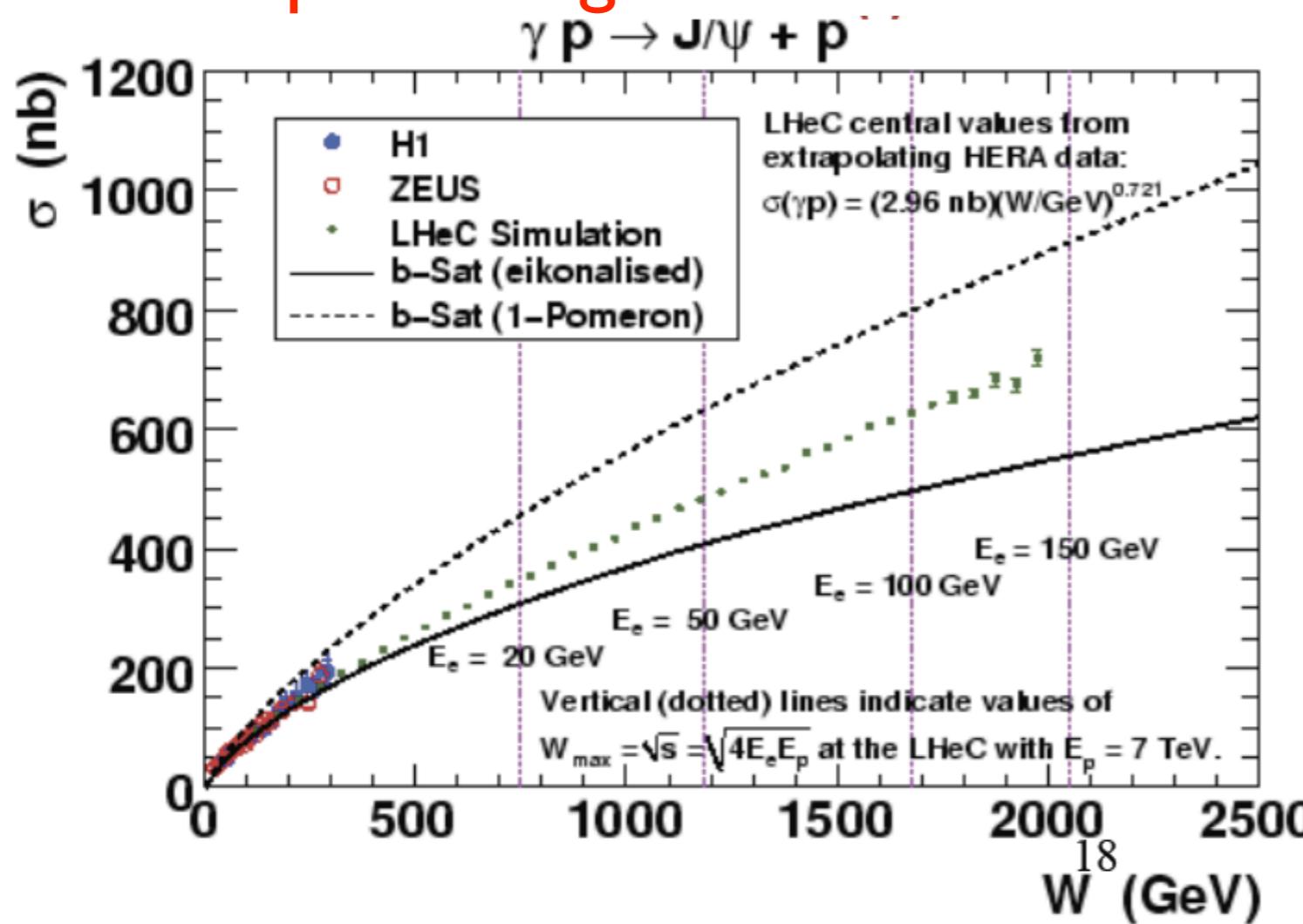
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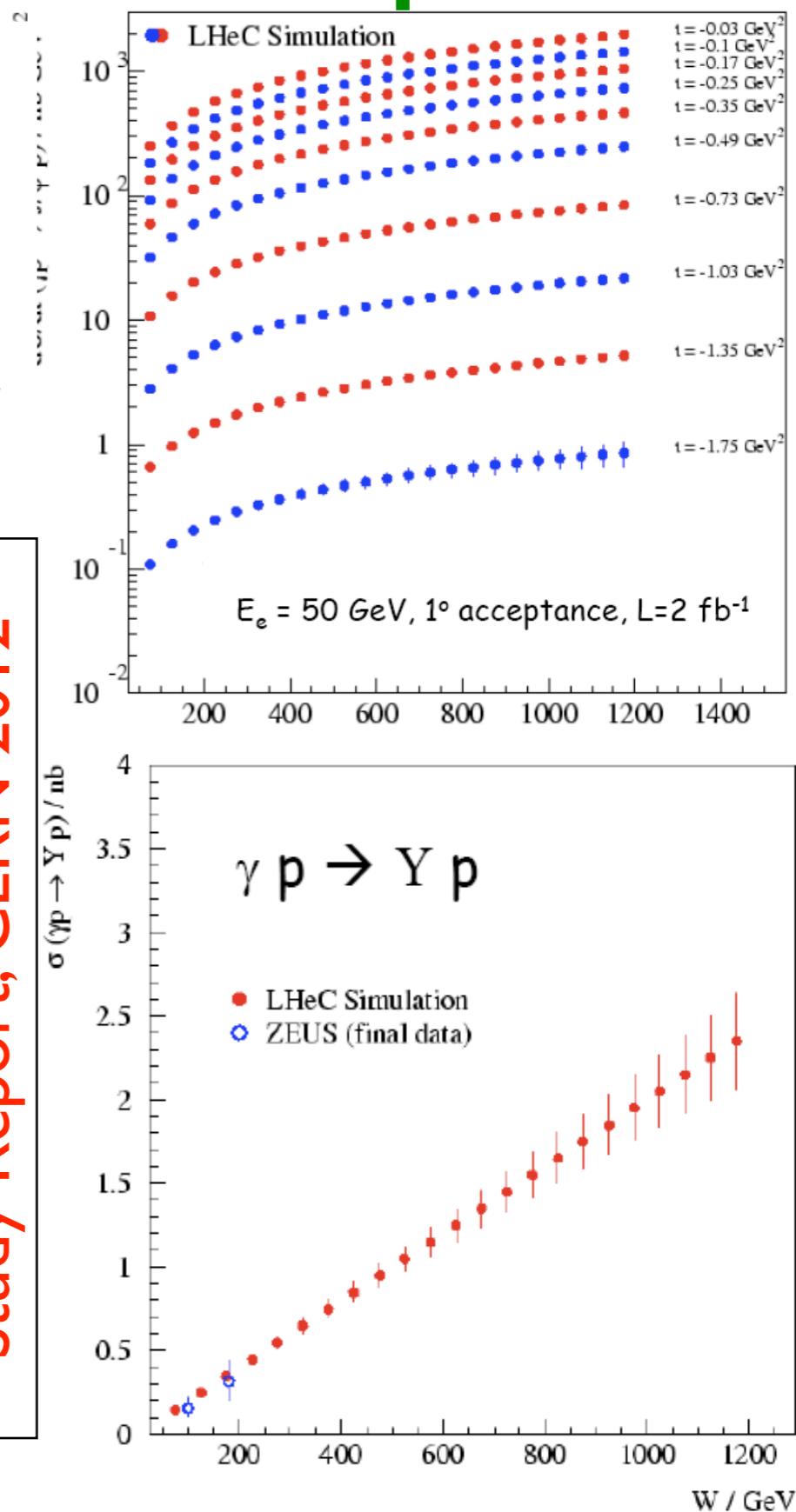
Elastic VM production in ep:



- Most promising!!!

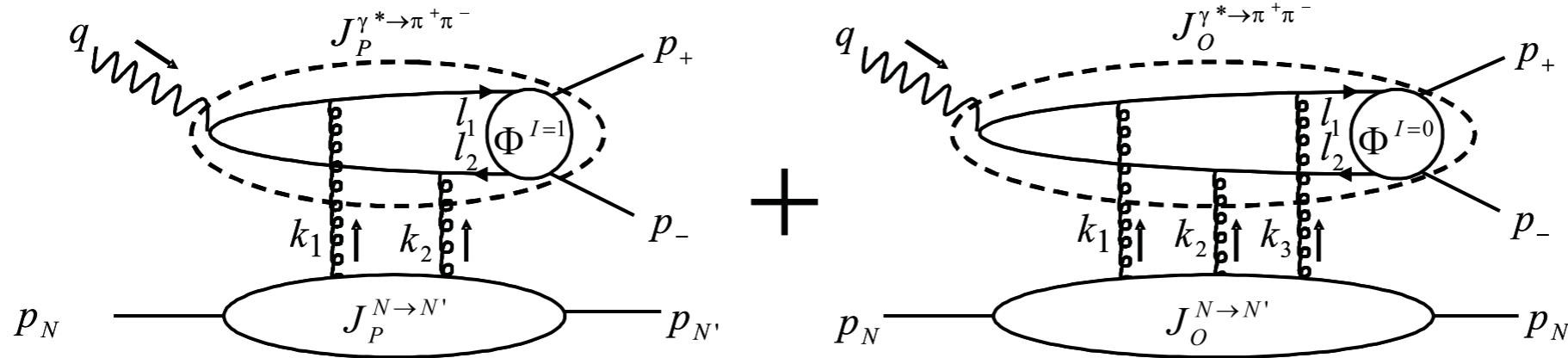


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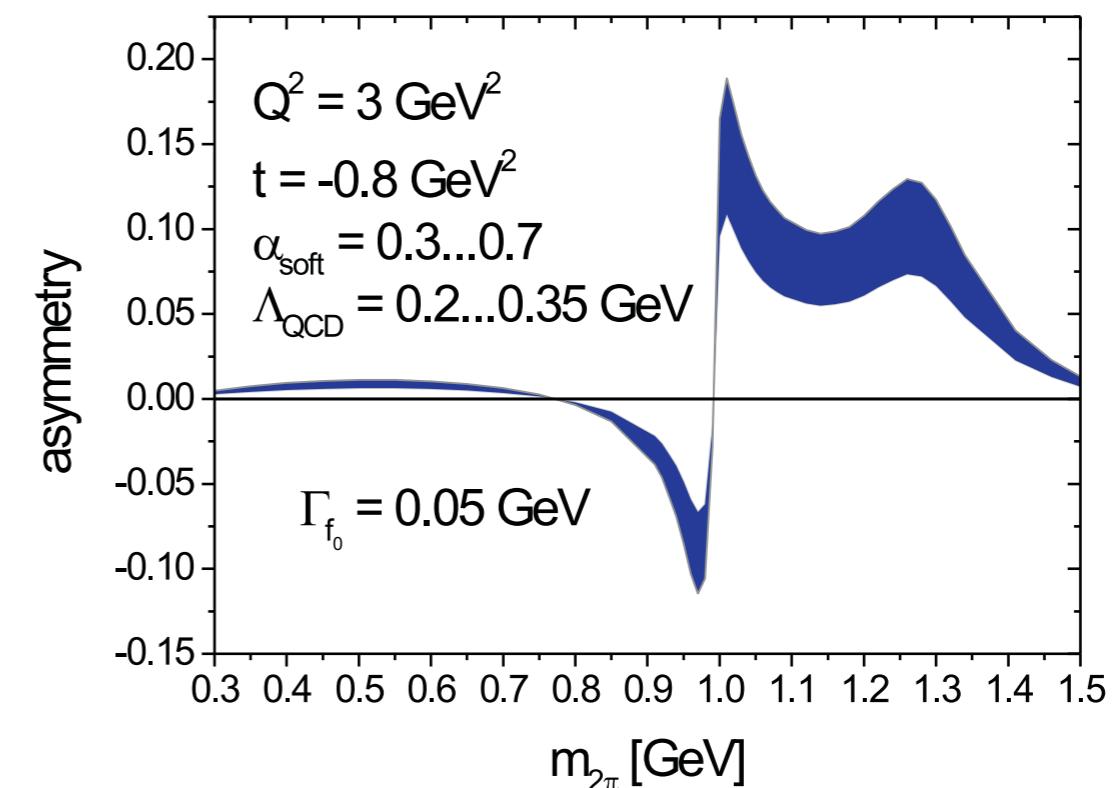
Odderon:

- **Odderon** (C-odd exchange contributing to particle-antiparticle difference in cross section) searched in $\gamma^{(*)} p \rightarrow Cp$, where $C = \pi^0, \eta, \eta', \eta_c \dots$ or through O-P interferences.



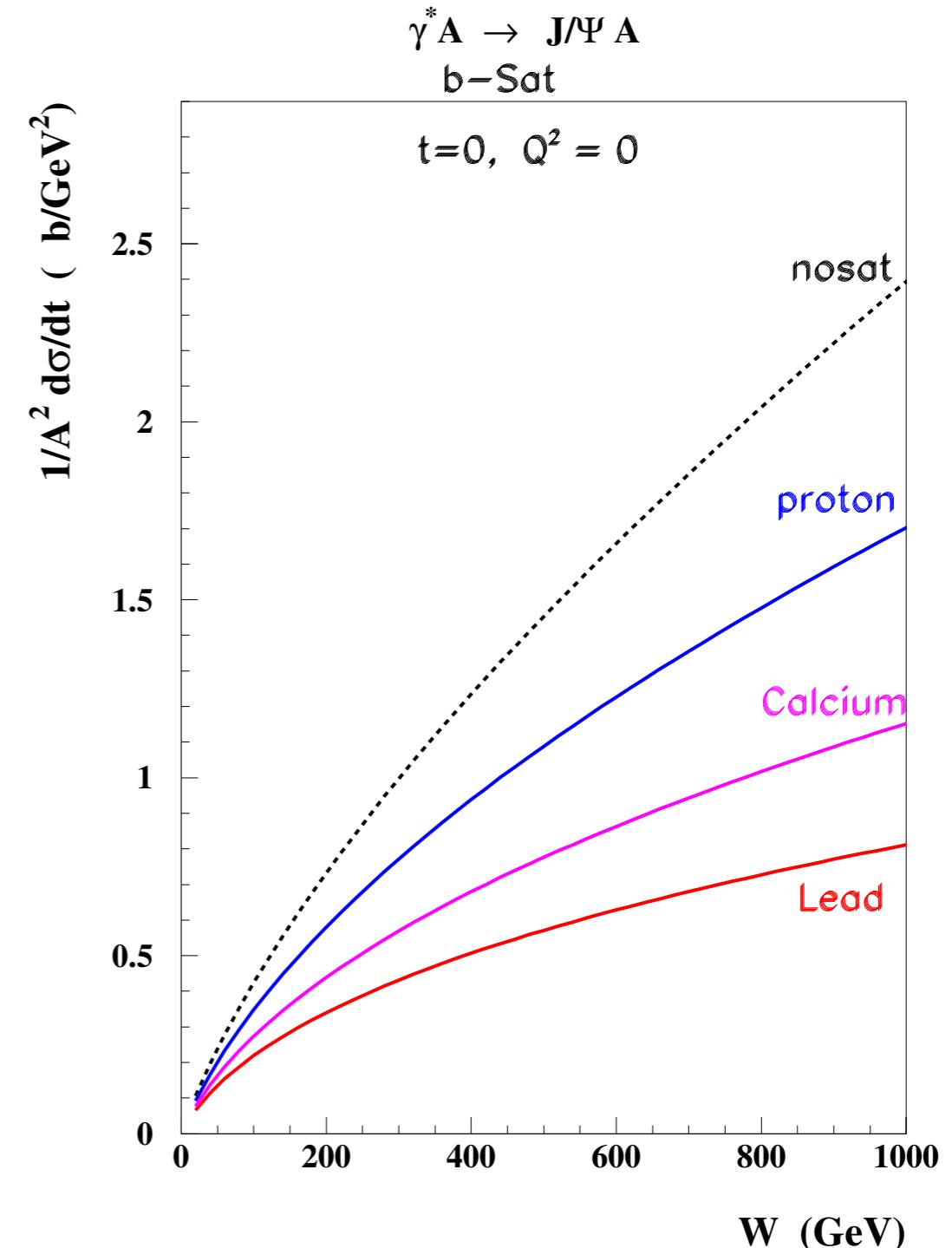
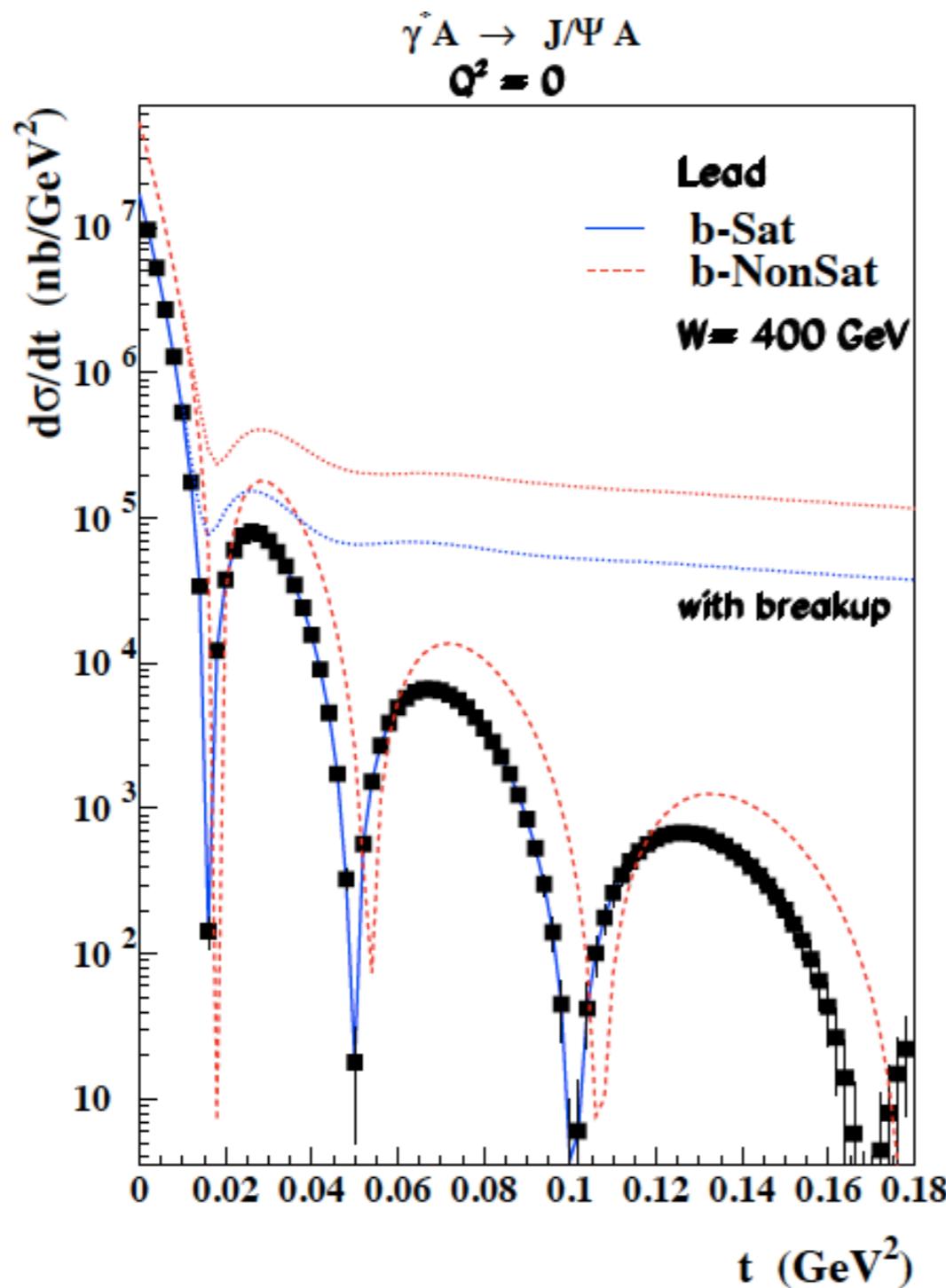
$$A(Q^2, t, m_{2\pi}^2) = \frac{\int \cos \theta d\sigma(W^2, Q^2, t, m_{2\pi}^2, \theta)}{\int d\sigma(W^2, Q^2, t, m_{2\pi}^2, \theta)} = \frac{\int_{-1}^1 \cos \theta d\cos \theta 2 \operatorname{Re} [\mathcal{M}_P^{\gamma^*} (\mathcal{M}_O^{\gamma^*})^*]}{\int_{-1}^1 d\cos \theta [|\mathcal{M}_P^{\gamma^*}|^2 + |\mathcal{M}_O^{\gamma^*}|^2]}$$

- Sizable charge asymmetry, yields and reconstruction pending.



Elastic VM production in eA:

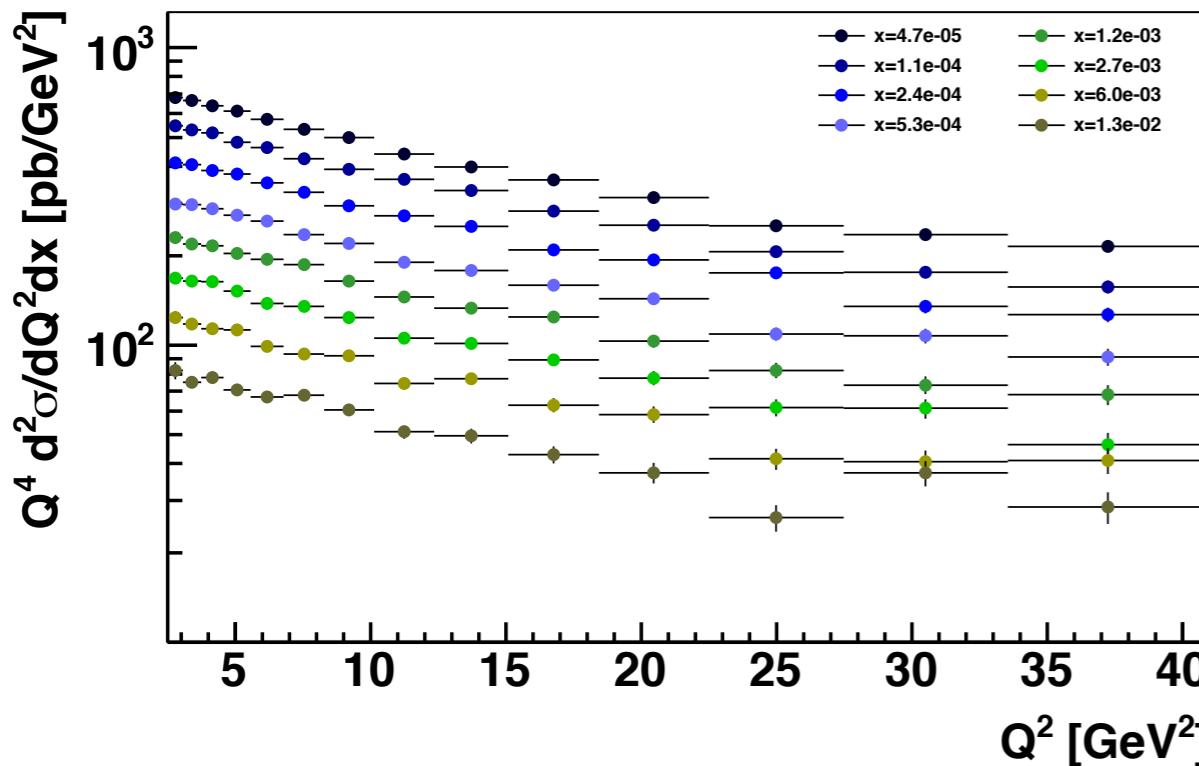
- Many interesting features in the nuclear case
(see also Lappi et al '10, Horowitz '11).



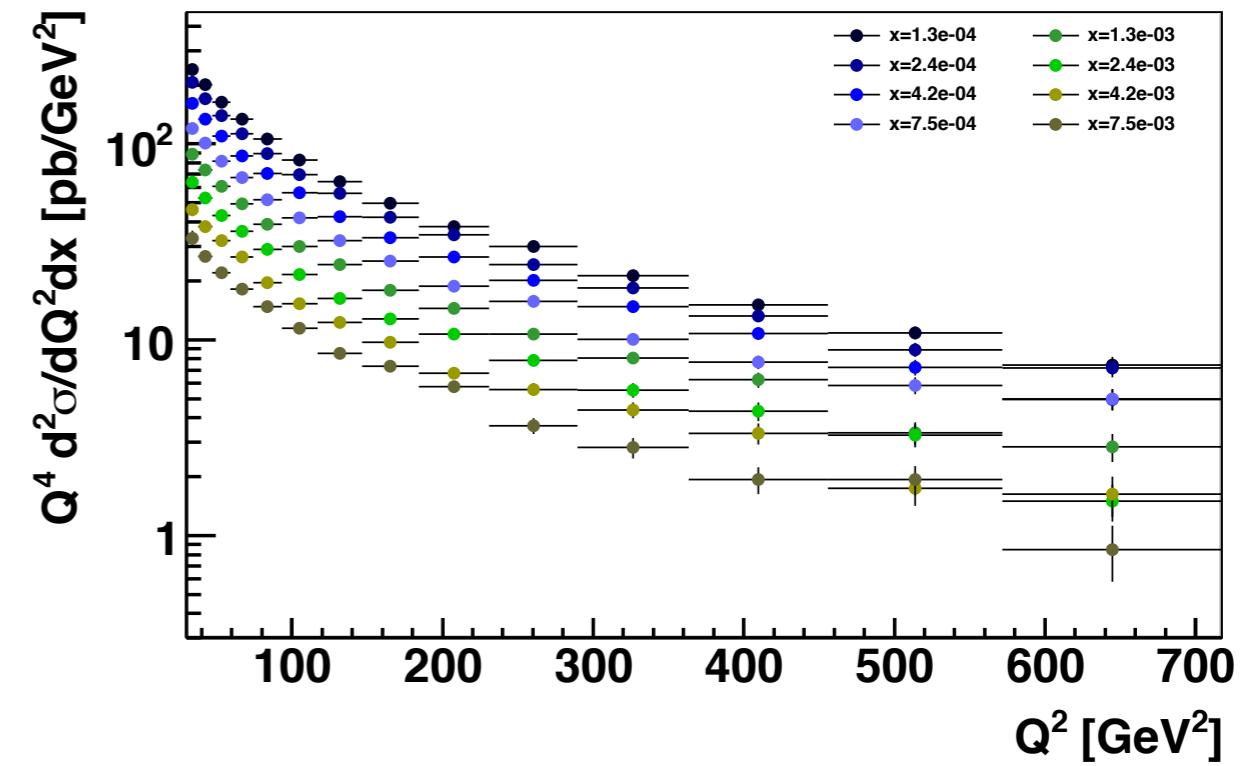
DVCS:

- Exclusive processes like $\gamma^* + h \rightarrow \rho, \phi, \gamma + h$ give information of GPDs, whose Fourier transform gives a transverse scanning of the hadron: key importance for both non-perturbative and perturbative aspects, like the possibility of non-linear dynamics.
- Only small-x case where higher luminosity really helps!!!

DVCS, $E_e = 50$ GeV, 1° ,
 $p_T^{\gamma, \text{cut}} = 2$ GeV, 1 fb^{-1}



DVCS, $E_e = 50$ GeV, 10° ,
 $p_T^{\gamma, \text{cut}} = 5$ GeV, 100 fb^{-1}

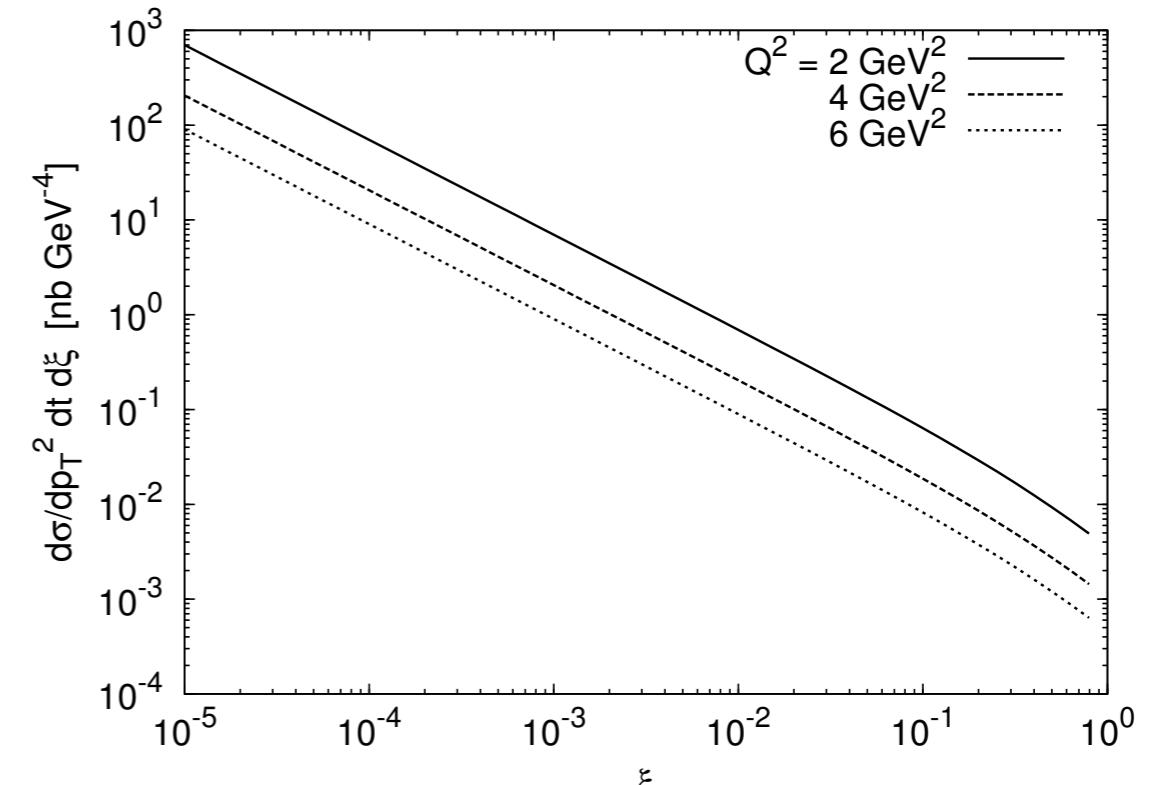
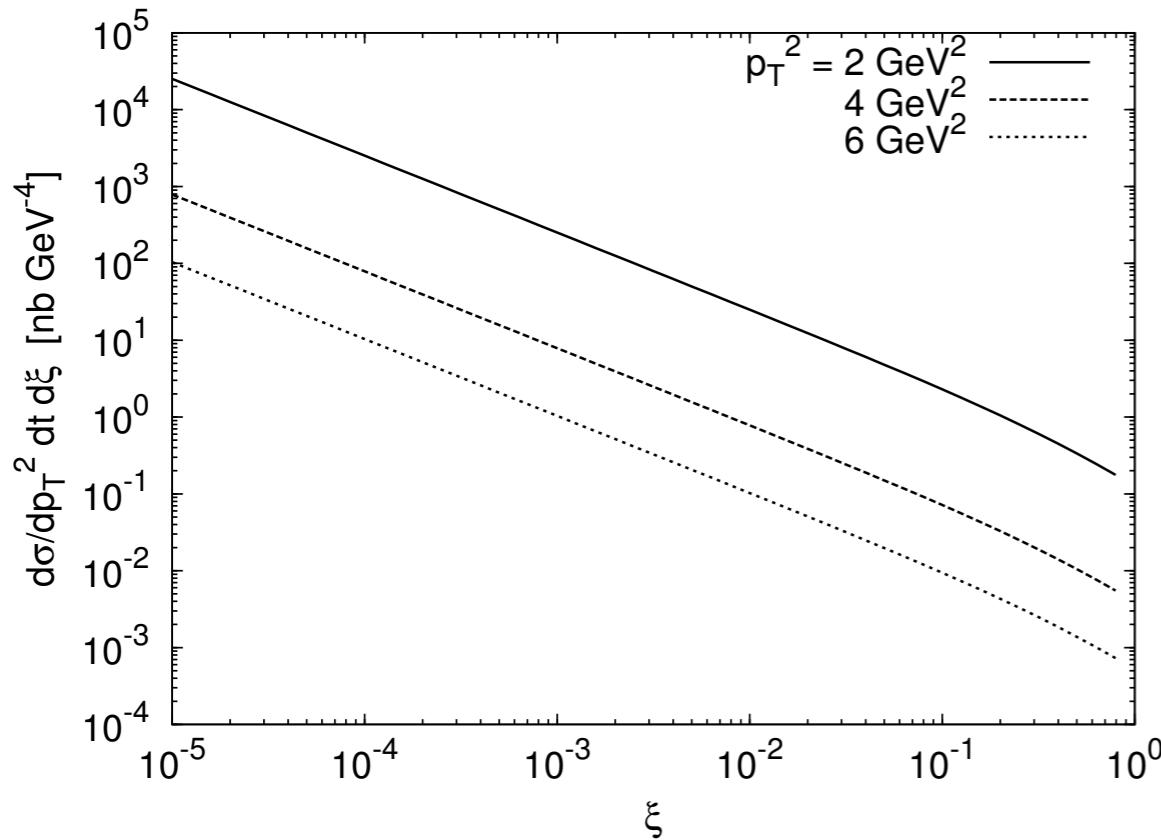
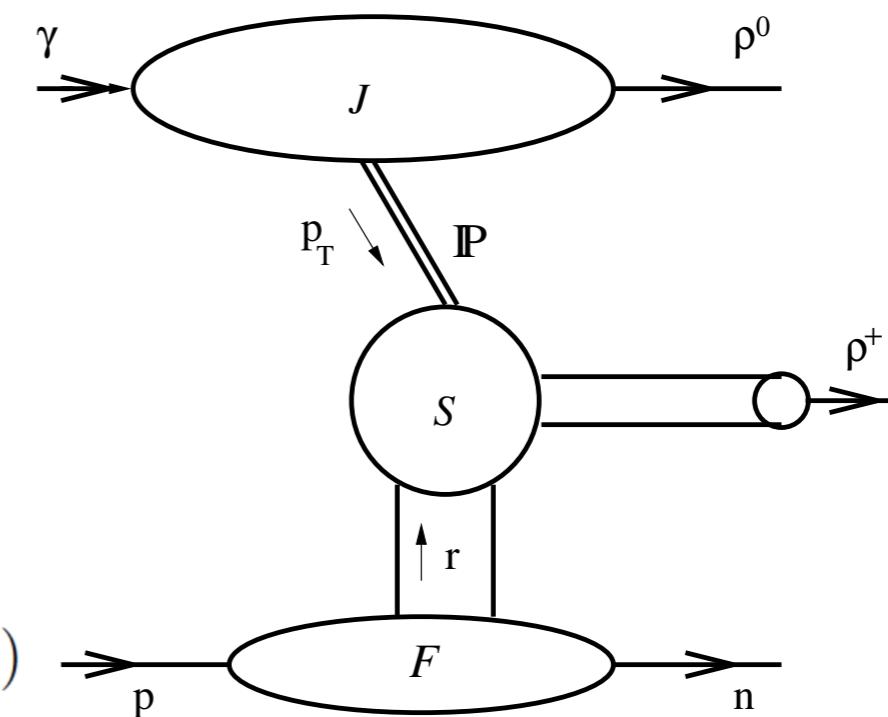


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Transversity GPDs:

- Chiral-odd transversity GPDs are largely unknown.
- They can be accessed through double exclusive production:

$$ep(p_2) \rightarrow e' \gamma_{L/T}^{(*)}(q) \quad p(p_2) \rightarrow e' \rho_{L,T}^0(q_\rho) \quad \rho_T(p_\rho) \quad N'(p_{2'})$$

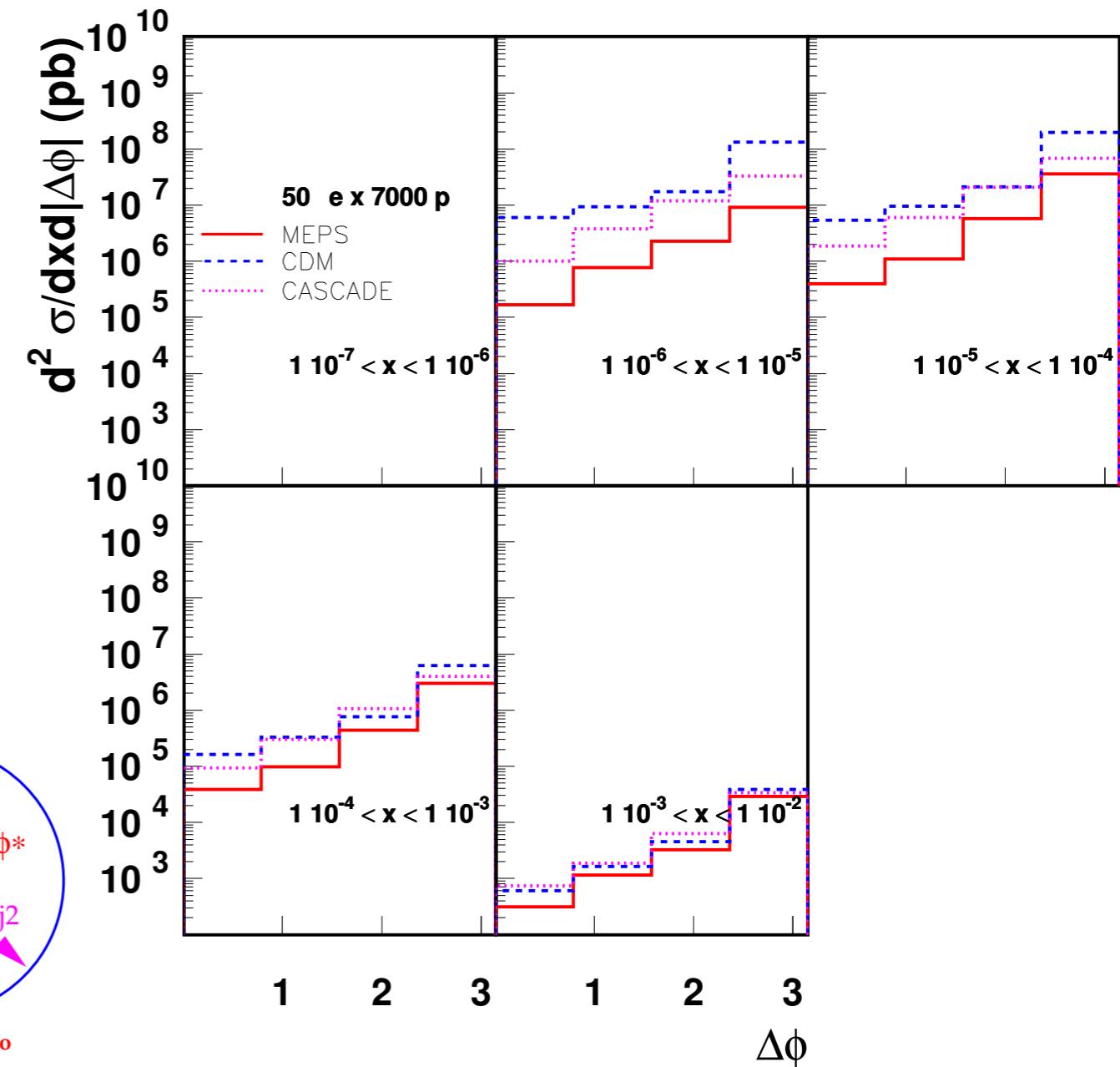
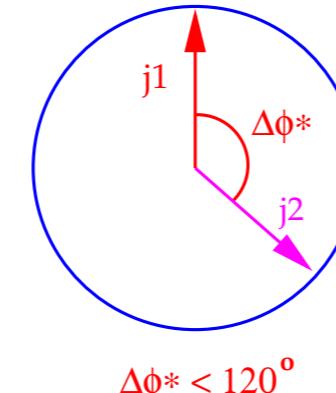
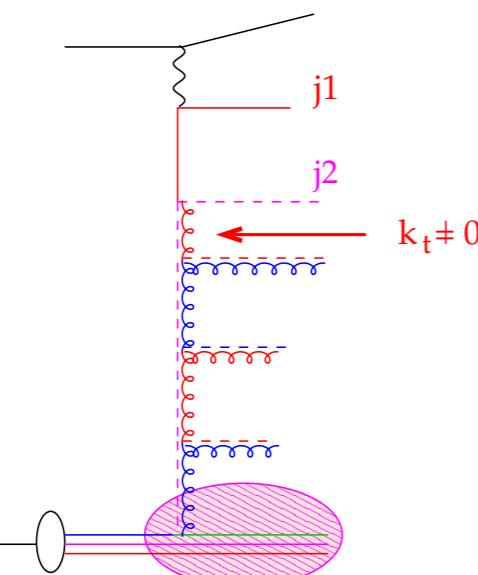


$$\xi \approx x_B / (2 - x_B)$$

Dijet azimuthal decorrelation:

- Studying **dijet azimuthal decorrelation** or forward jets ($p_T \sim Q$) would allow to understand the mechanism of radiation:
 - k_T -ordered: DGLAP.
 - k_T -disordered: BFKL.
 - Saturation?
- Further imposing a rapidity gap (diffractive jets) would be most interesting: perturbatively controllable observable.

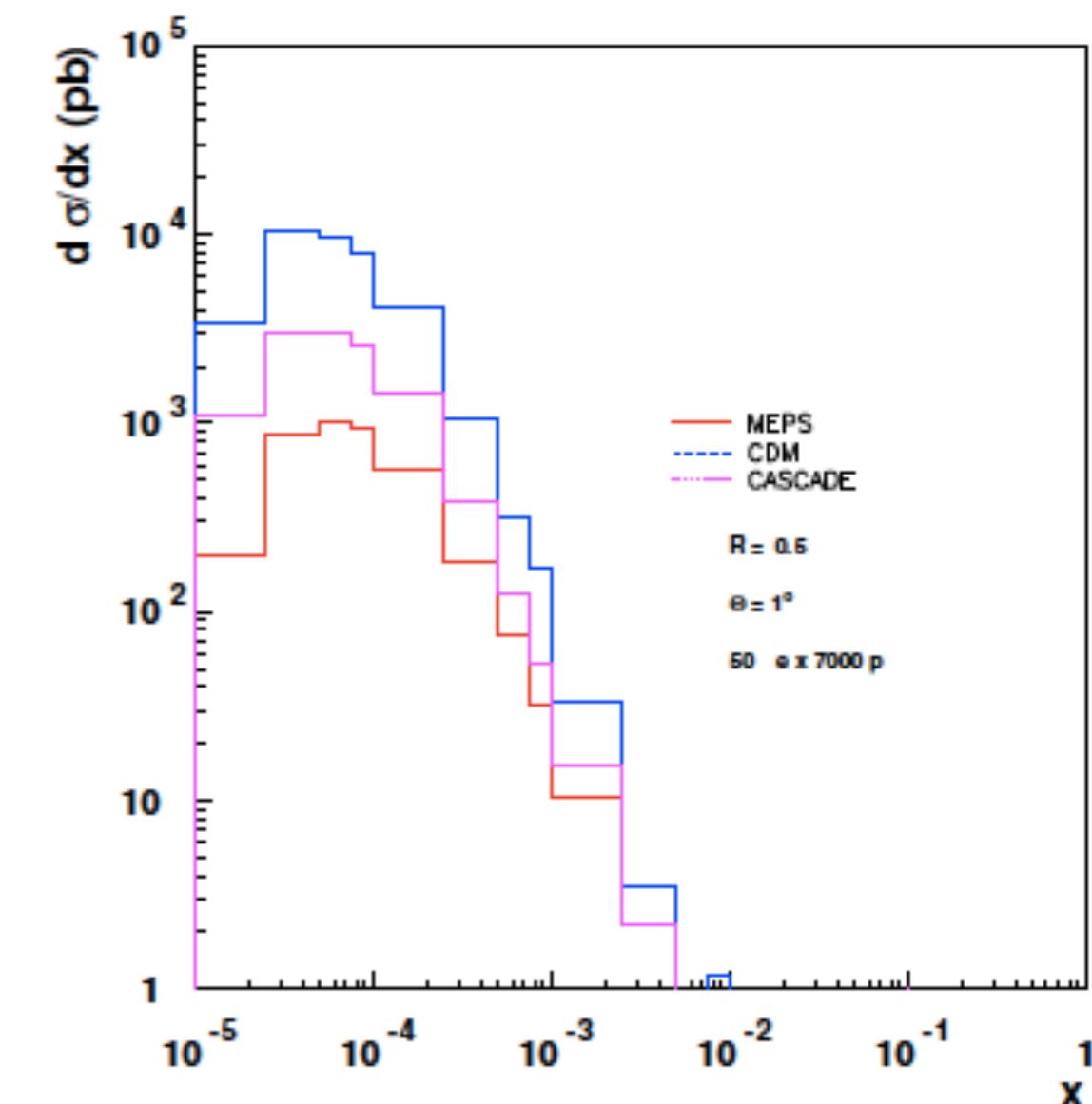
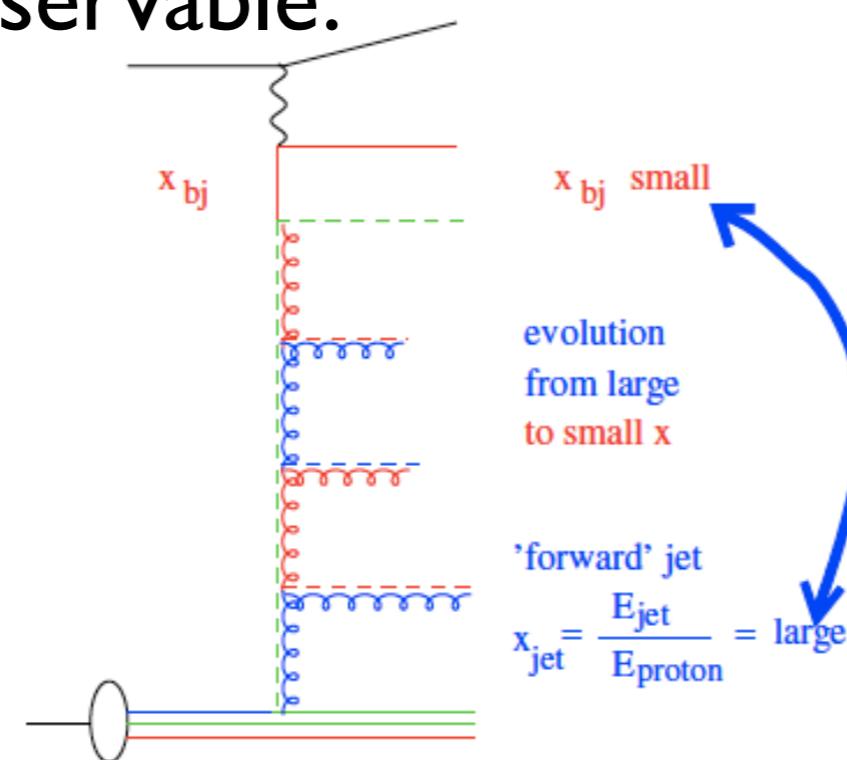
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Forward jets:

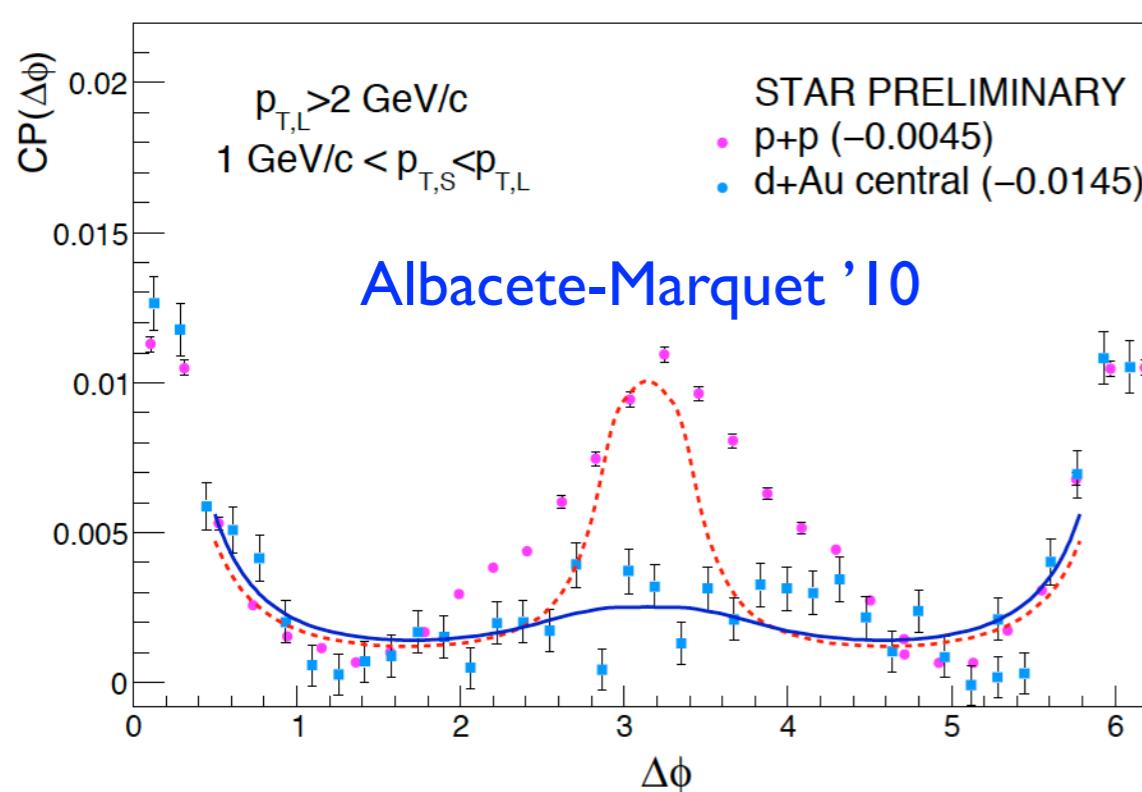
- Studying dijet azimuthal decorrelation or **forward jets** ($p_T \sim Q$) would allow to understand the mechanism of radiation:
 - k_T -ordered: DGLAP.
 - k_T -disordered: BFKL.
 - Saturation?
- Further imposing a rapidity gap (diffractive jets) would be most interesting: perturbatively controllable observable.

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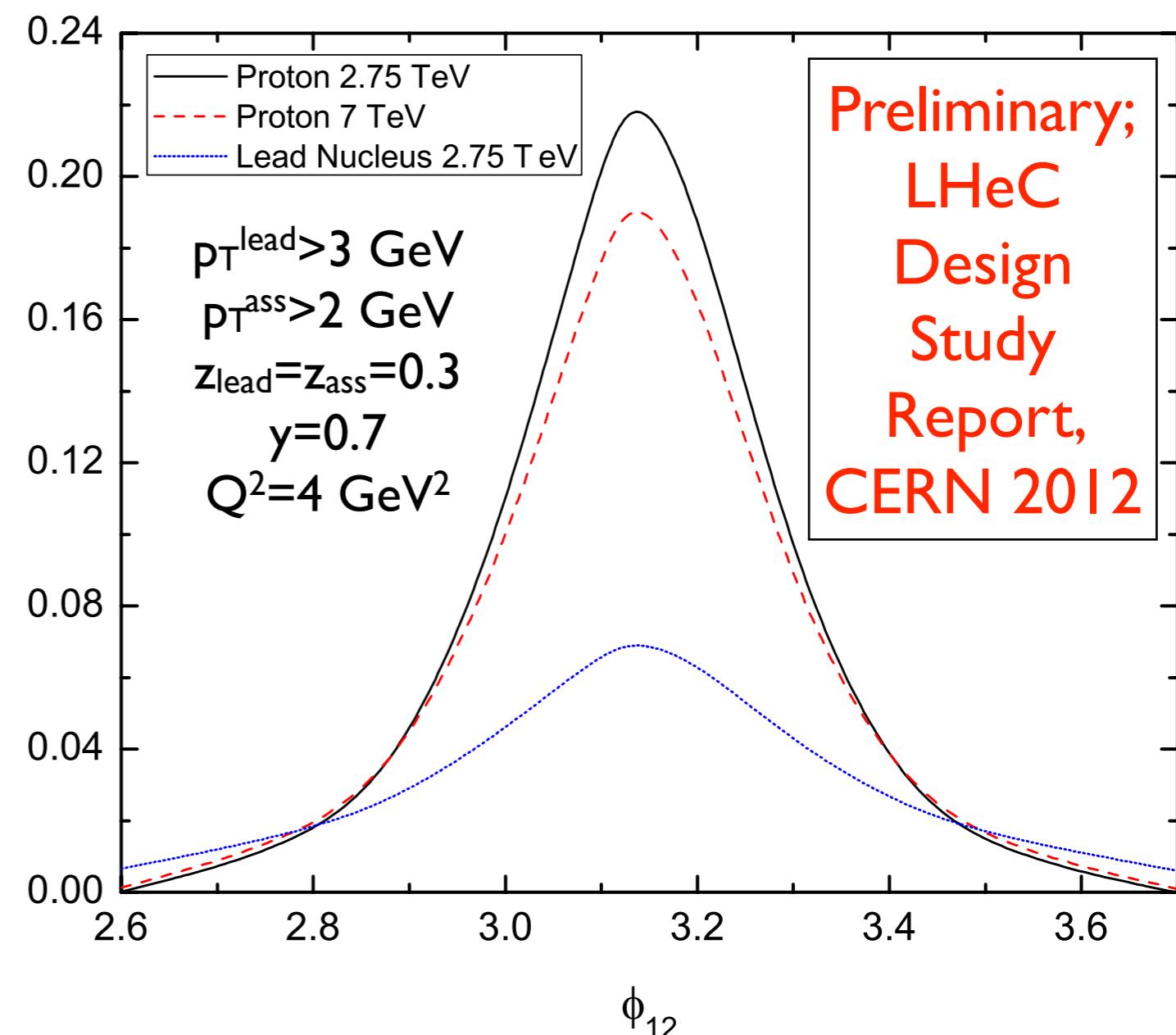


LHeC Dihadron azimuthal decorrelation:

- Dihadron **azimuthal decorrelation** is currently discussed at RHIC as one of the most suggestive indications of saturation.
- At the LHeC it could be studied far from the kinematical limits.



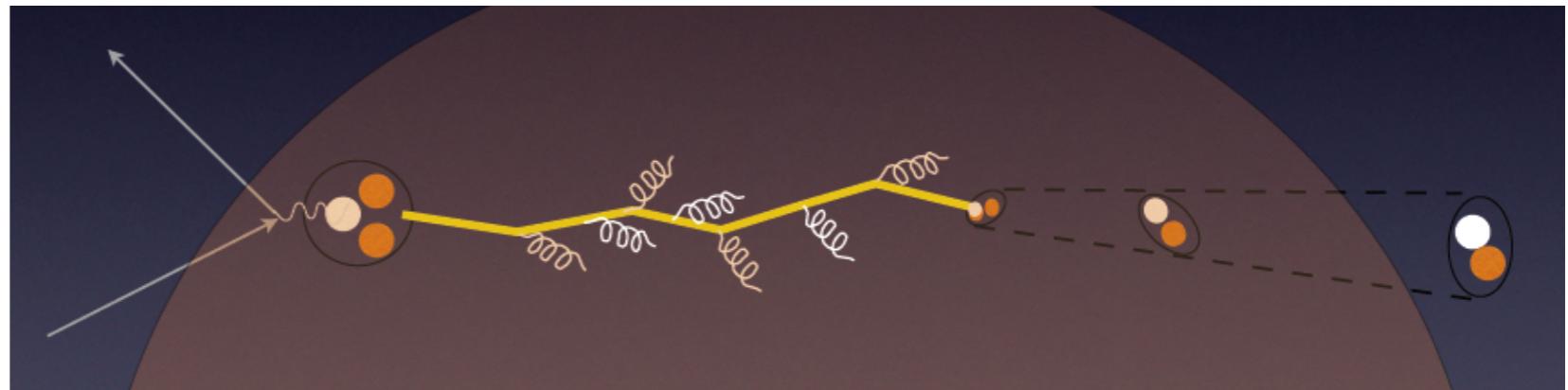
$$C(\phi_{12}) = \frac{1}{\frac{d\sigma(\gamma^* N \rightarrow h_1 X)}{dz_{h1}}} \frac{d\sigma^{\gamma^* N \rightarrow h_1 h_2 + X}}{dz_{h1} dz_{h2} d\phi_{12}}$$



In-medium hadronization (I):

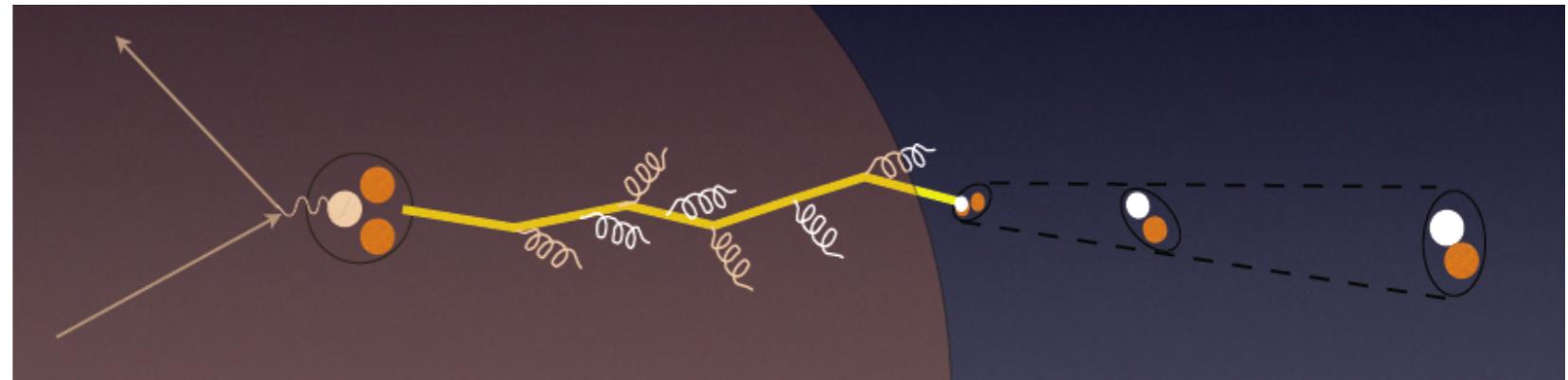
- The LHeC ($v_{\max} \sim 10^5$ GeV) would allow to study the dynamics of hadronization, testing the parton/hadron eloss mechanism by introducing a length of colored material which would modify its pattern (length/nuclear size, chemical composition).

- Low energy: need of hadronization inside → formation time, (pre-) hadronic absorption,...



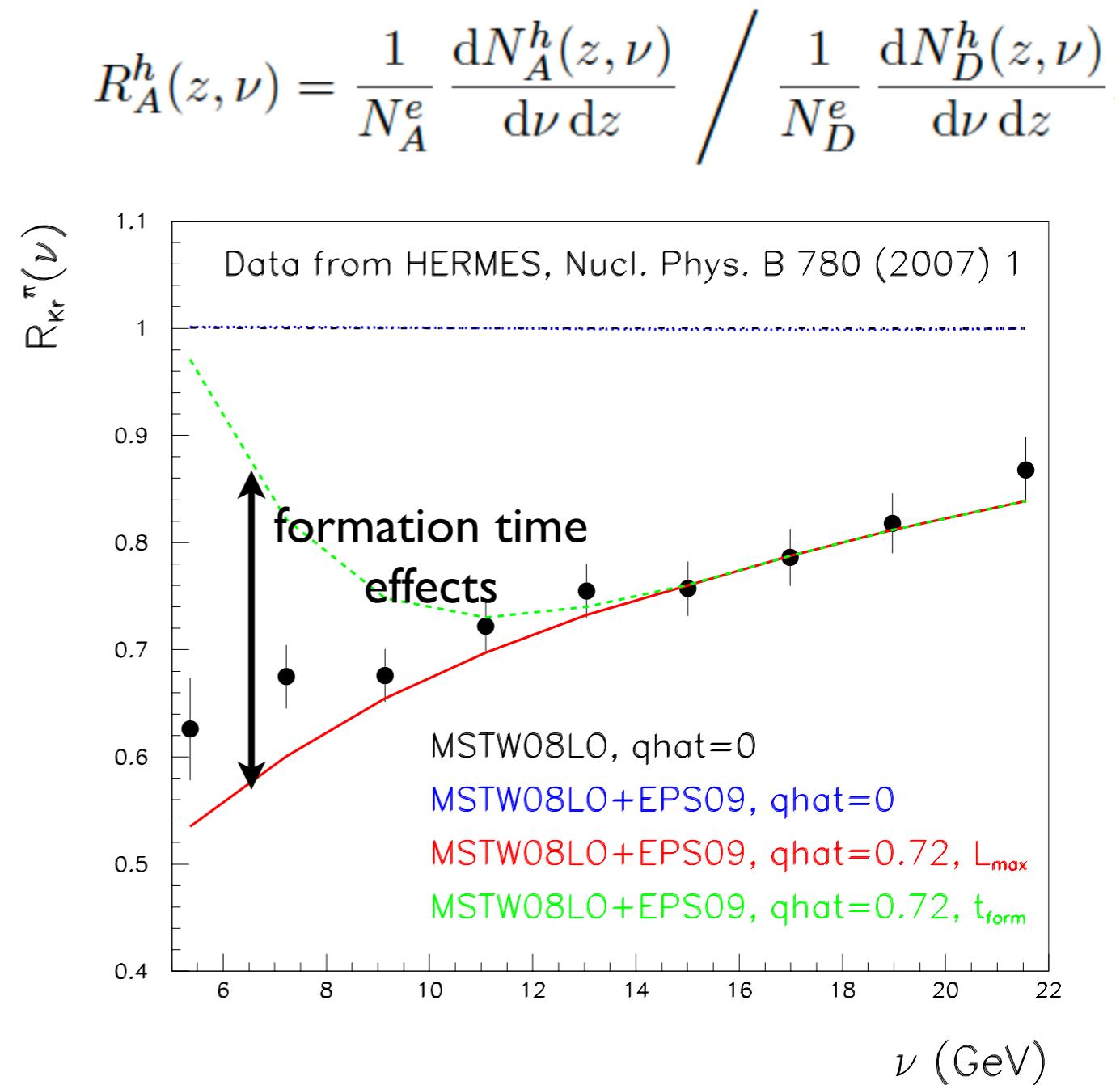
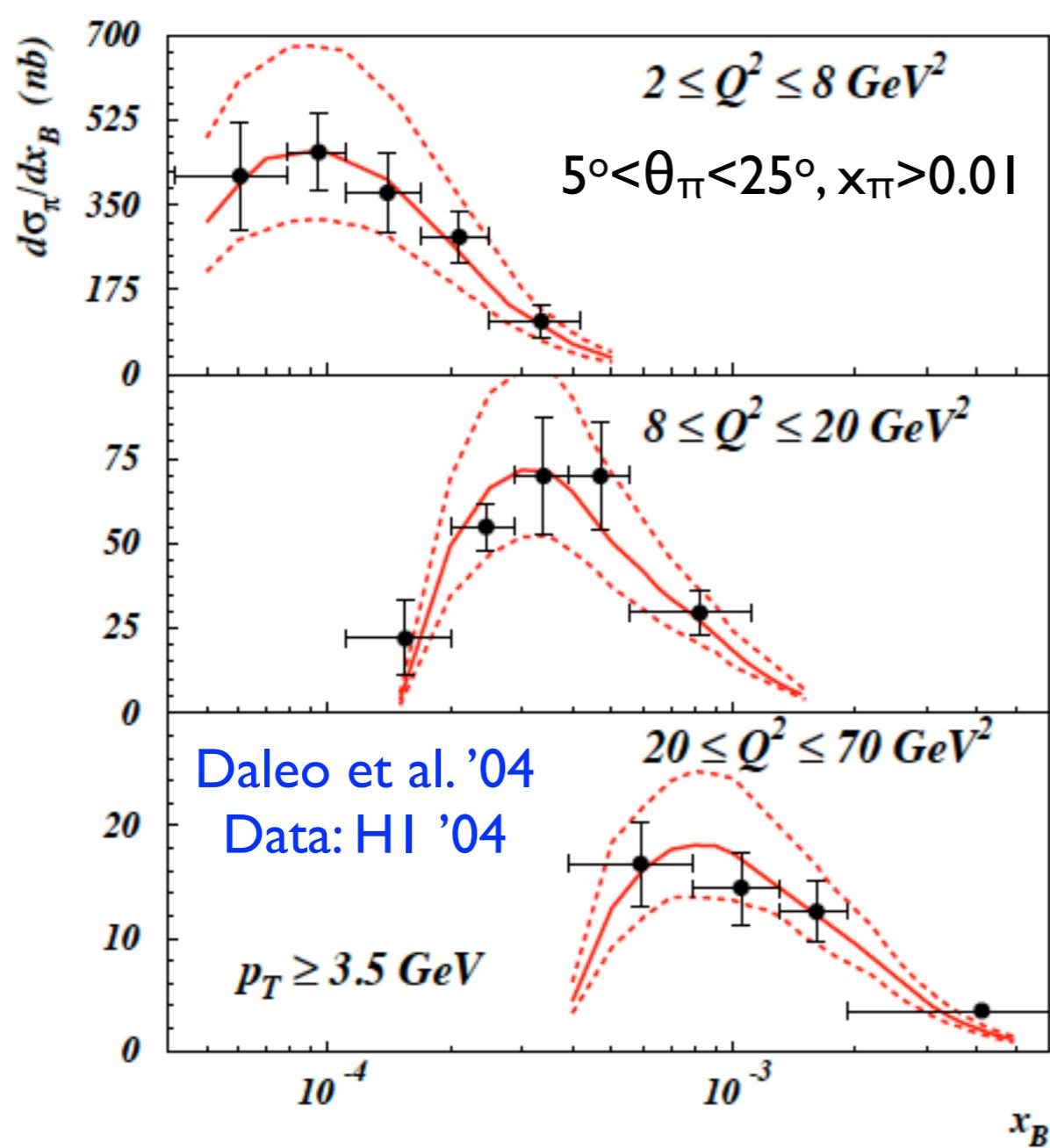
Brooks at Divonne'09

- High energy: partonic evolution altered in the nuclear medium, partonic energy loss.



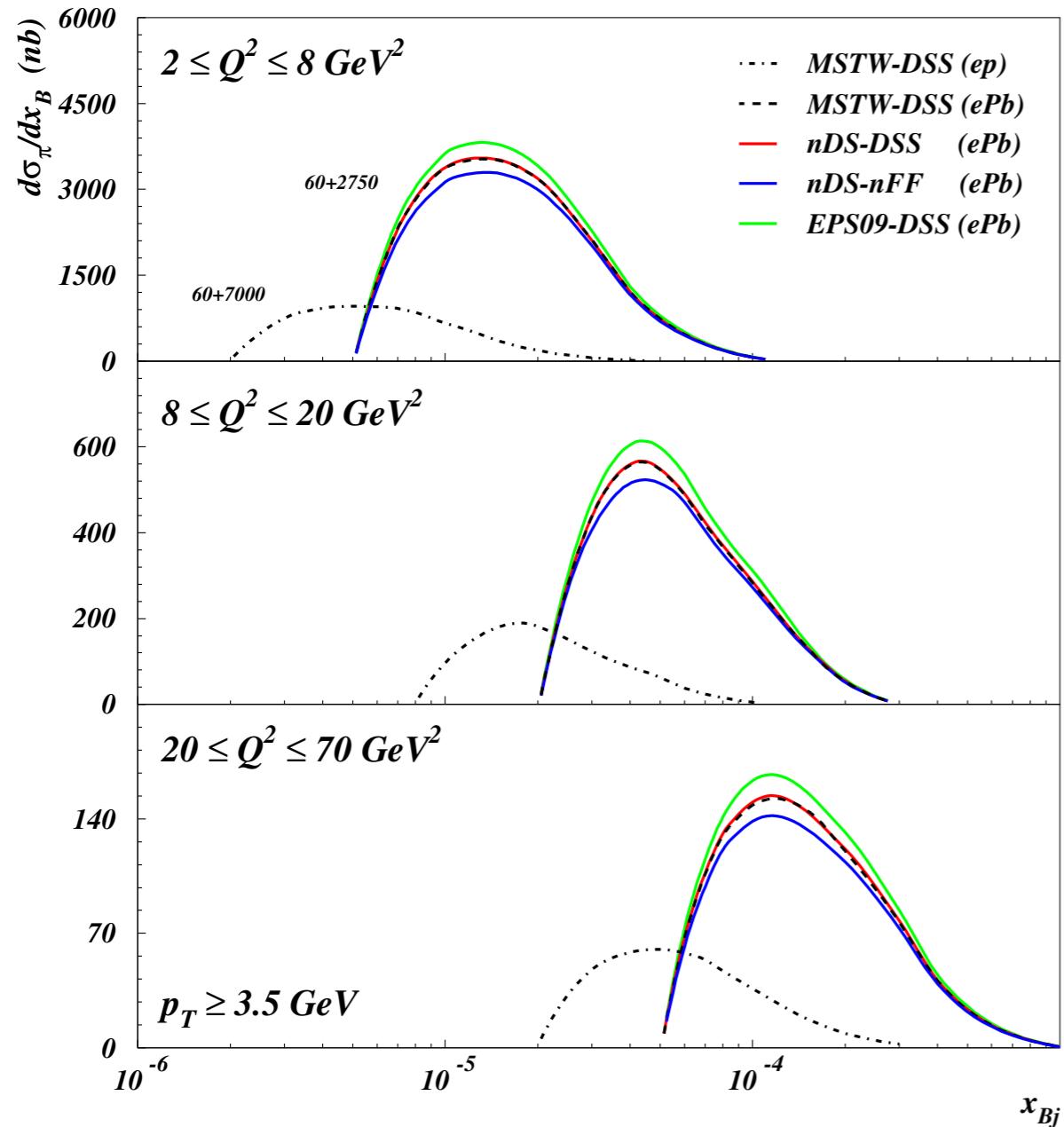
In-medium hadronization (II):

- Large (NLO) yields at small- x (HI cuts, 3 times higher if relaxed).
- Nuclear effects in hadronization at small ν (LO plus QW, Arleo '03).

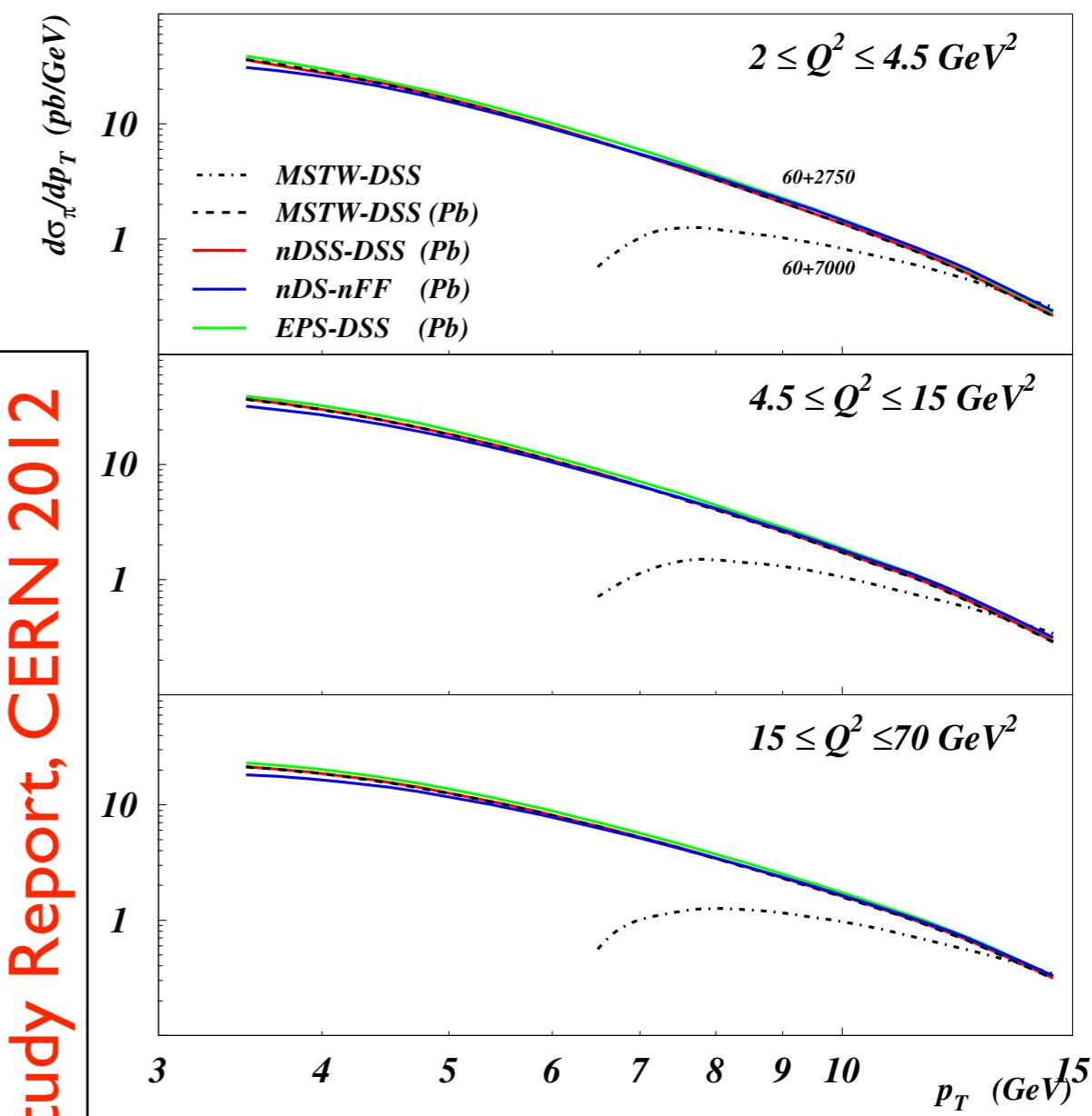


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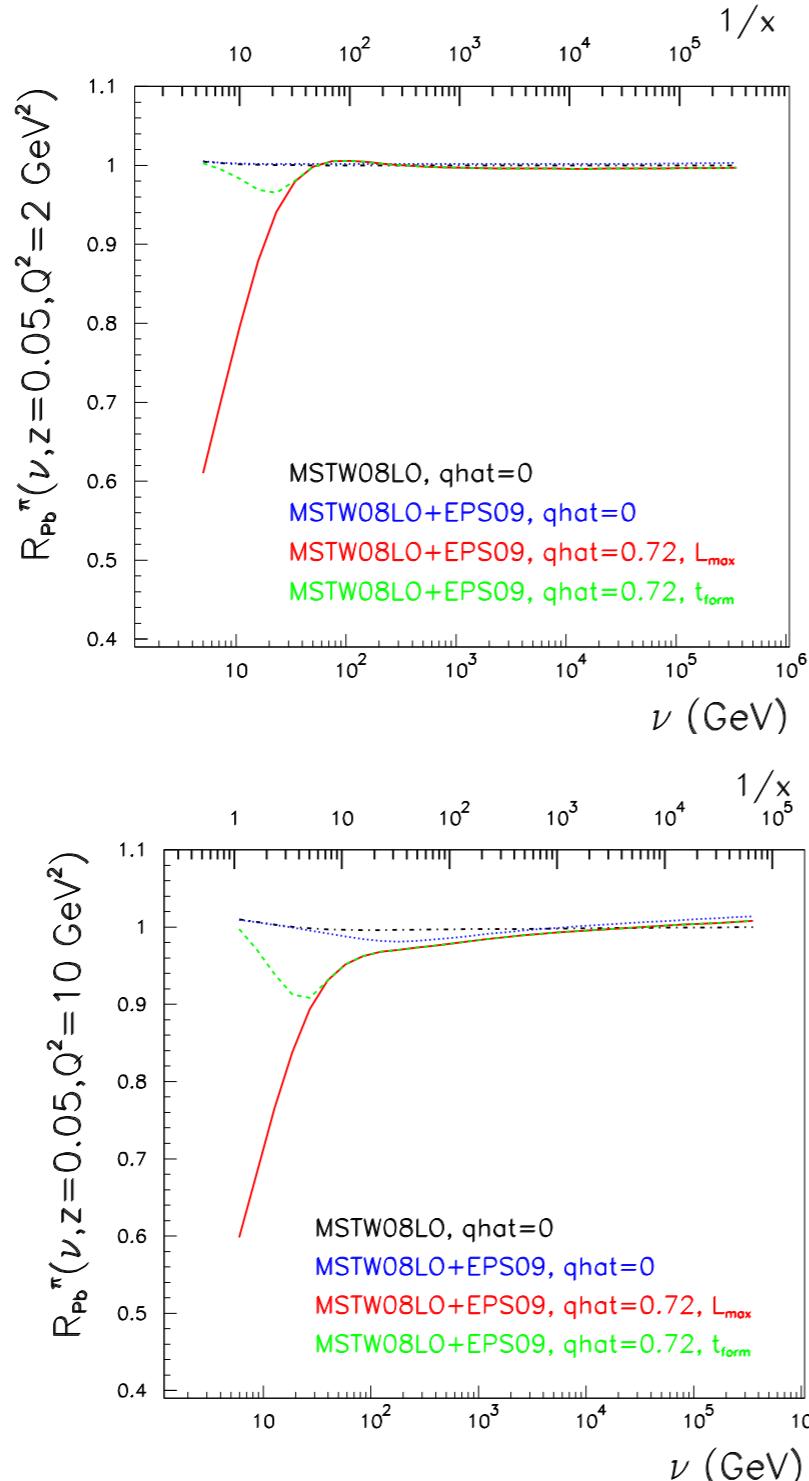
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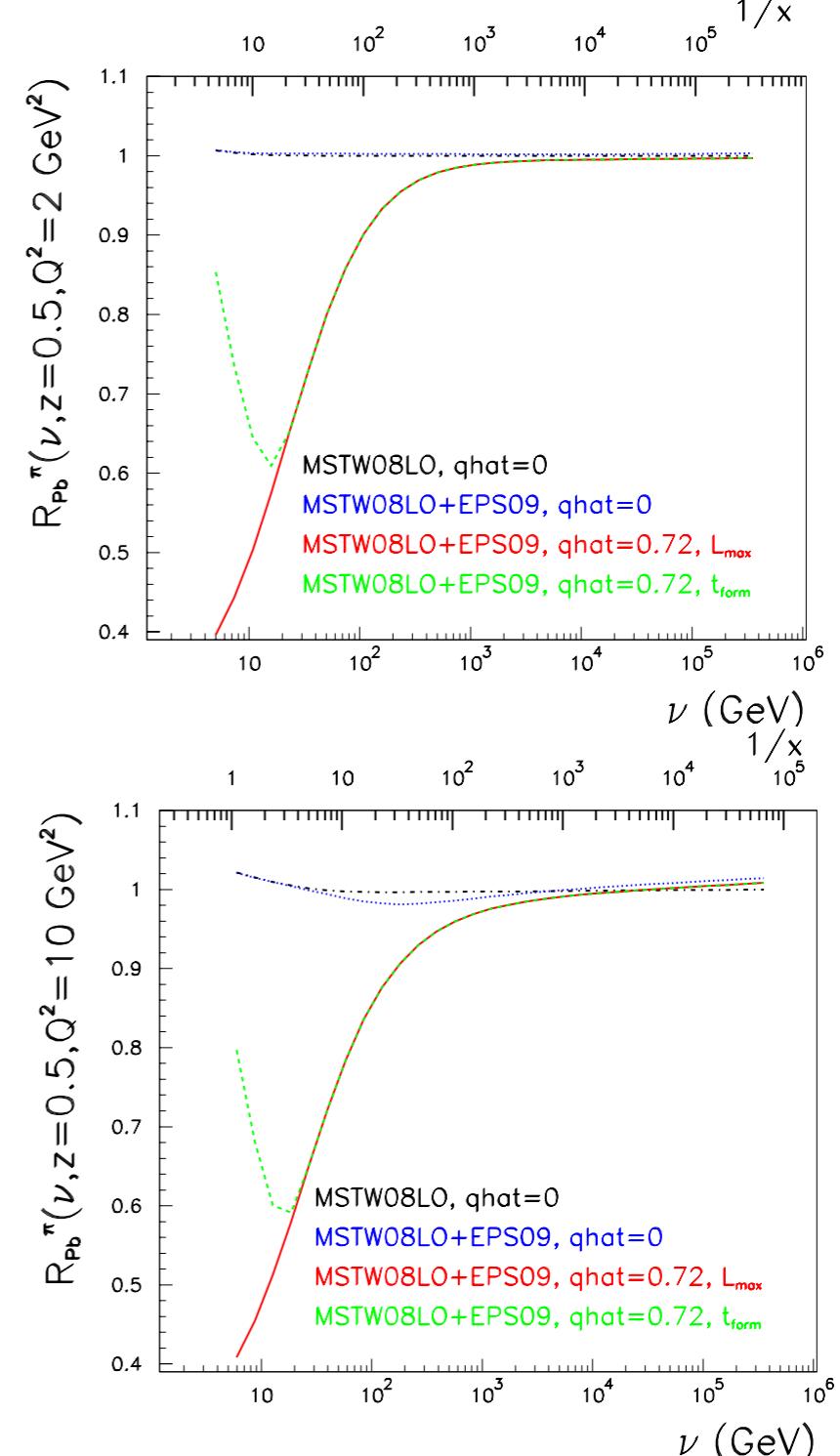
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$$R_A^h(z, \nu) = \frac{1}{N_A^e} \frac{dN_A^h(z, \nu)}{d\nu dz} / \frac{1}{N_D^e} \frac{dN_D^h(z, \nu)}{d\nu dz}$$



Summary:

- Many issues open about precision pQCD and small- x physics.
- Pdfs: current ep experiments cover pp@LHC at $y=0$; in eA, not even dAu@RHIC is really constrained.
- An ep/eA collider offers huge possibilities to test our ideas about QCD: hadron structure, high-energy behavior, radiation,...
- **eA**: amplifier of density effects, implications on UrHIC complementary to pA@LHC.
- **At an LHeC@CERN:**
 - Unprecedented access to small x in p and A for pdfs.
 - Novel sensitivity to physics beyond standard pQCD.
 - Stringent tests of the dynamics of QCD radiation.
 - High precision tests of collinear factorization(s).
 - Transverse scanning of the hadron at small x .
 - ...

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Anna M. Stasto (PennState)

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2007: Invitation by SPC to ECFA and by (r)ECFA to work out a design concept

2008: First CERN-ECFA Workshop in Divonne (1.-3.9.08)

The LHeC Study Group
<http://cern.ch/lhec>

2009: 2nd CERN-ECFA-NuPECC Workshop at Divonne (1.-3.9.09)

2010: Report to CERN SPC (June)

3rd CERN-ECFA-NuPECC Workshop at Chavannes-de-Bogis (12.-13.11.10)

NuPECC puts LHeC to its Longe Range Plan for Nuclear Physics (12/10)

2011: Draft CDR (530 pages on Physics, Detector and Accelerator) (5.8.11)
being refereed and updated

2012: Publication of CDR – European Strategy

New workshop June 14-15 2012



Goal: TDR by 2014

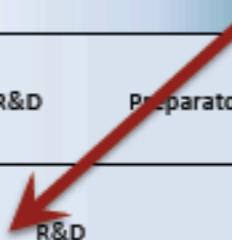
Perspective: Operation by 2023 (synchronous with pp)

Tentative timeline:

NuPECC – Roadmap 5/2010: New Large-Scale Facilities

			2010				2015						2020					2025	
FAIR	PANDA	R&D	Construction	Commissioning									Exploitation						
	CBM	R&D	Construction	Commissioning									Exploitation	SIS300					
	MuSTAR	R&D	Construction	Commissioning									Exploit.	NESR FLAIR					
	PAHEMC	Design Study	R&D	Tests									Construction/Cummissioning		Collider				
SPIRAL2		R&D	Constr./Commission.				Exploitation							150 MeV/u Post-accelerator					
HE-ISO LDE				Constr./Commission.			Exploitation							Injector Upgrade					
SPES				Constr./Commission.															
EURISOL		Design Study	R&D	Preparato															
LHeC		Design Study	R&D		Engineering Study								Construction/Cummissioning						

We are here: at the transition from
Design Study to R&D

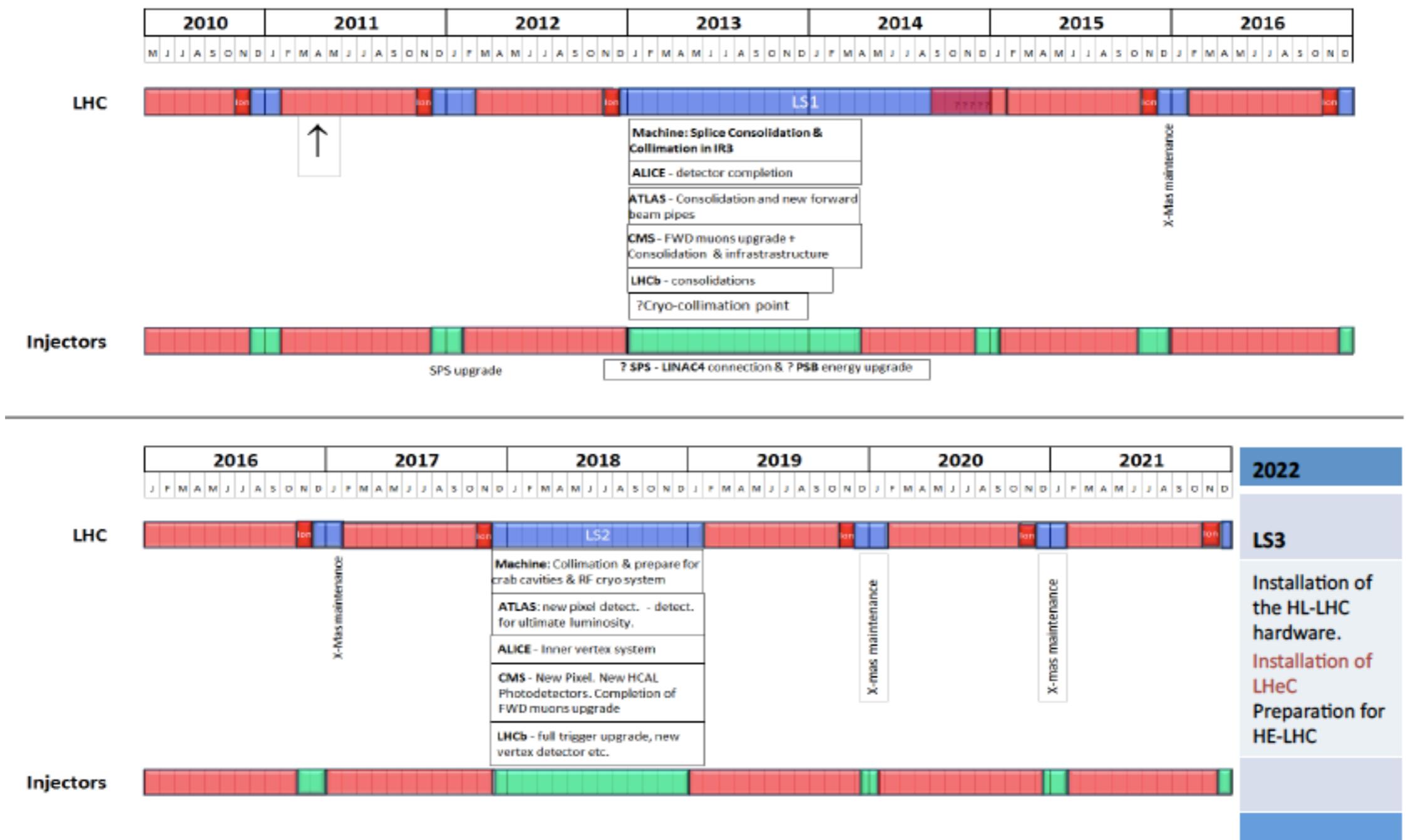


G. Rosner, NuPECC Chair, Madrid 5/10 – published in December 2010

Tentative timeline:

New rough draft 10 year plan

Not yet approved!



July 26, 2011

S. Myers, HEP2011, Grenoble

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Preliminary; LHeC Design Study Report, CERN 2012

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2010	2011	2012	2013	2014	2015	2016
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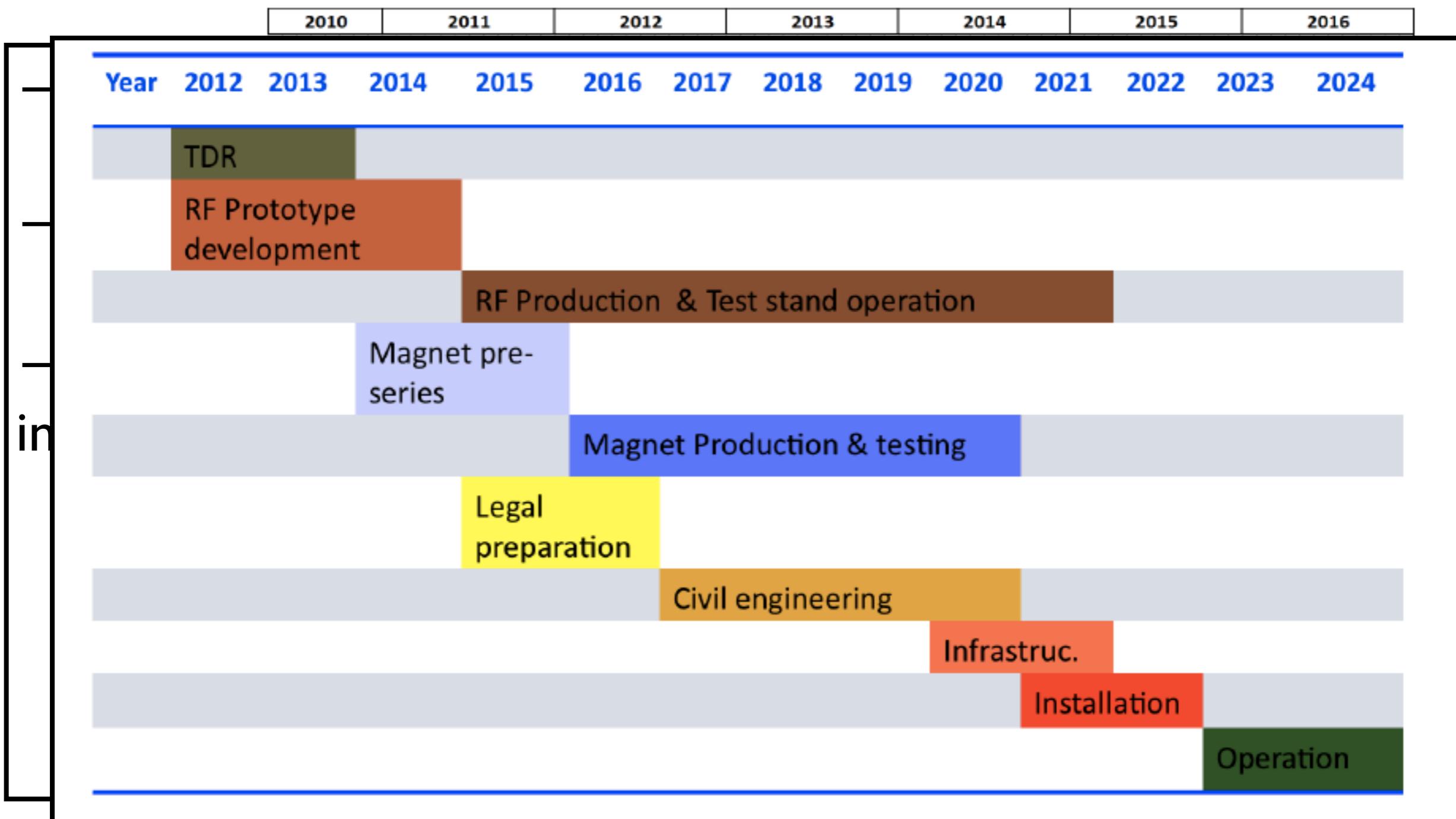
- LHC death by radiation damage estimated by 2030-2035.
- LHeC should work for ~ 10 years.
- No disturbance to LHC operation: built on surface, installation during LS3.



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2012 CERN-ECFA-NuPECC Workshop on the LHeC

14-15 June 2012 *Chavannes-de-Bogis, Switzerland*

Europe/Zurich timezone

Search

Overview

Workshop Programme

Registration

Registration Form

List of registrants

Venue

The 2012 Workshop on the Large Hadron electron Collider will provide an overview on the completed conceptual design report, and is directed to steps for the further development of the LHeC, its physics programme & detector design.

More information on LHeC [webpages](#).

Contact address:

ECFA-CERN LHeC Workshop Secretariat

Mailbox Lo1800

CERN

1211-Geneva 23

or [e-mail](#)

[✉ Support](#)

Dates: from 14 June 2012 09:00 to 15 June 2012 18:00

Timezone: Europe/Zurich

Location: *Chavannes-de-Bogis, Switzerland*

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Thanks to the organizers for the invitation!!!

Virtual design
sign.

Thanks to you all for your attention!!!

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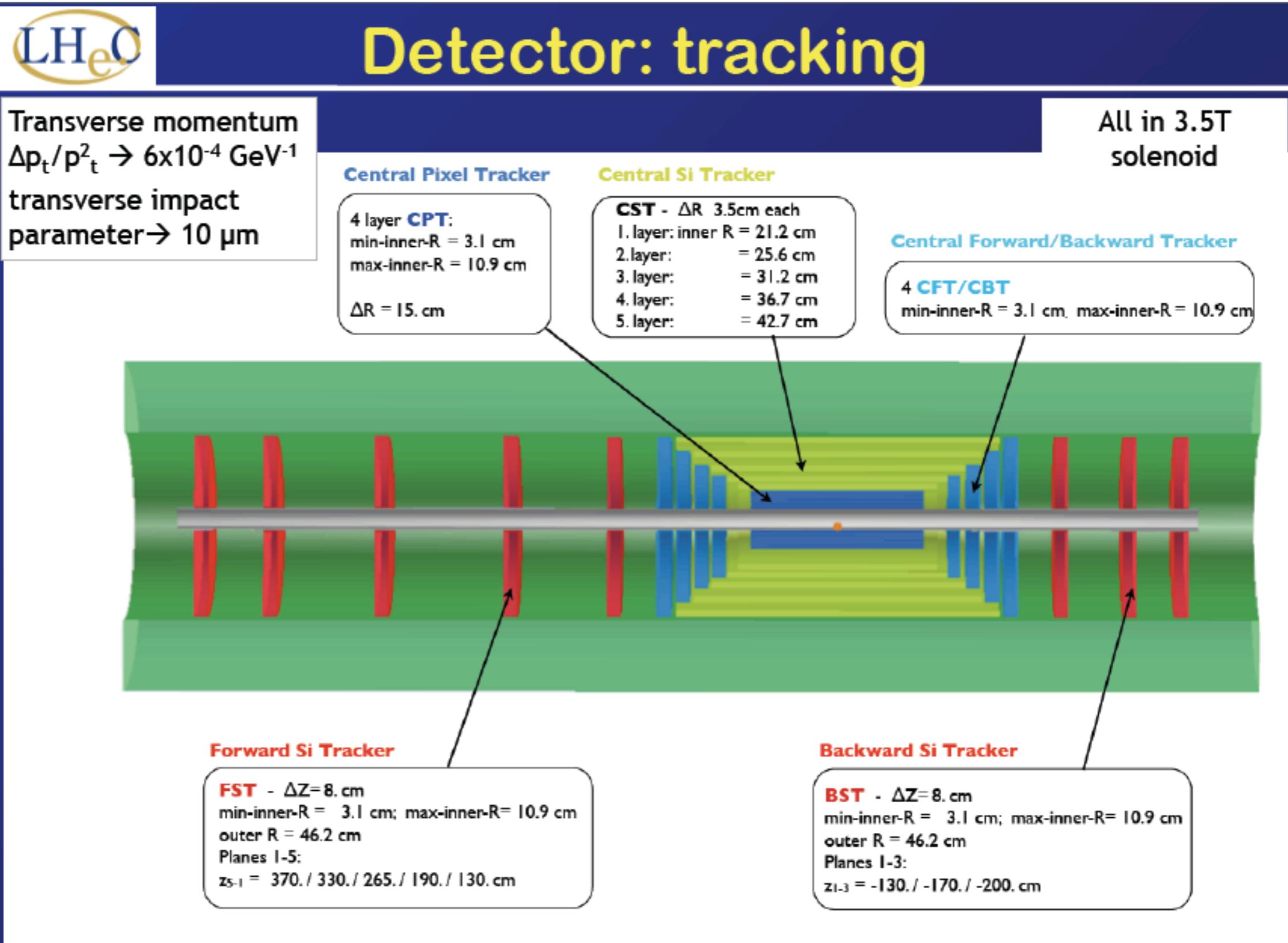
Preliminary; LHeC Design Study Report, CERN 2012

Backup:

The detector: some details

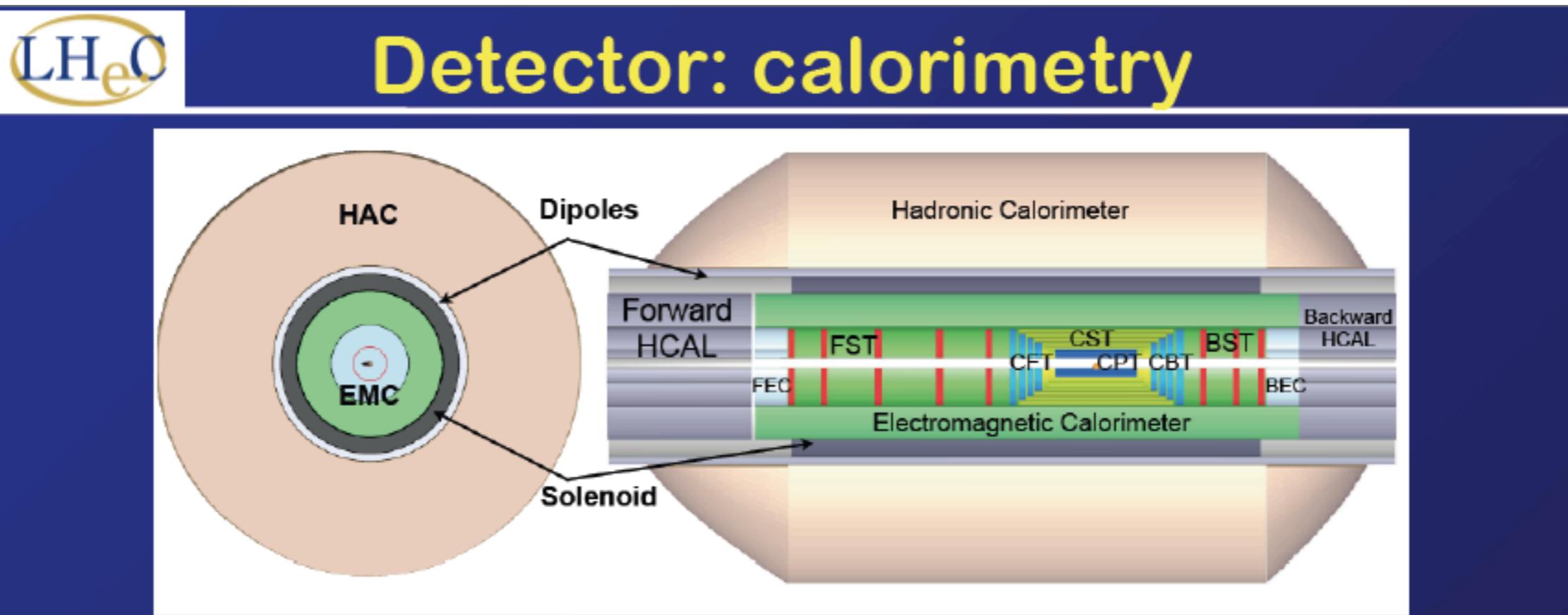
Detector: tracking

Preliminary; LHeC Design Study Report, CERN 2012;
B. Cole at HP2012



The detector: some details

Preliminary; LHeC Design Study Report, CERN 2012;
B. Cole at HP2012



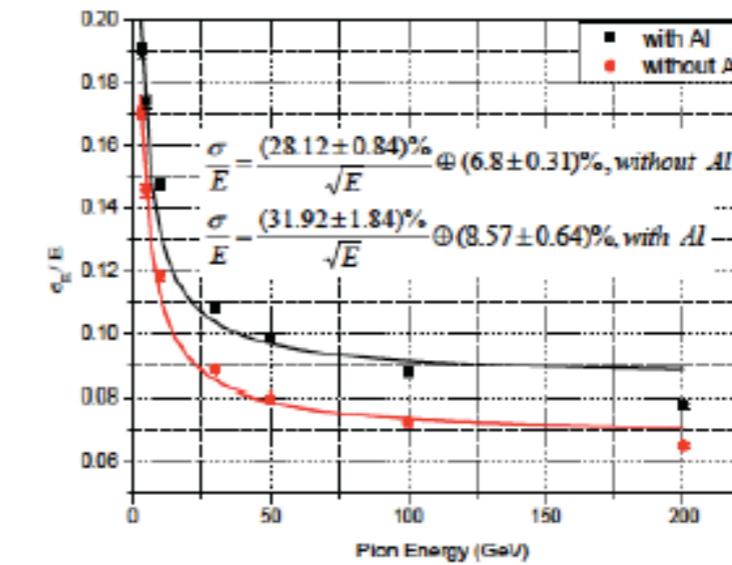
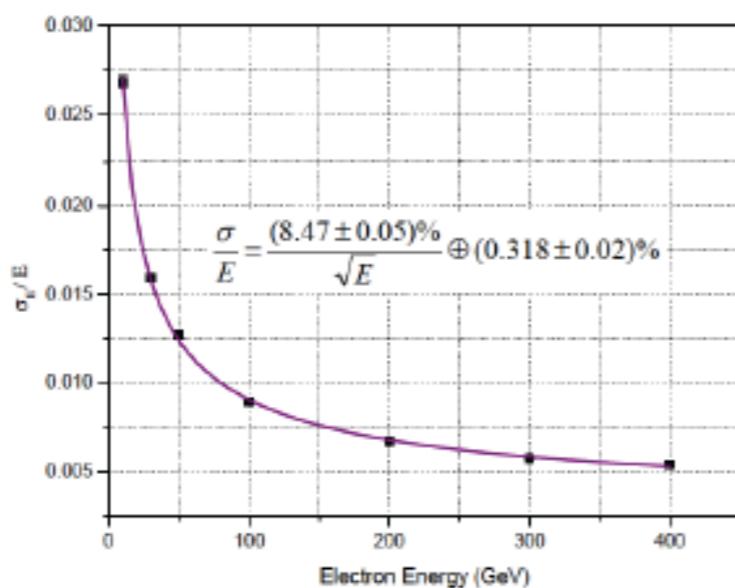
Liquid Argon EM Calorimeter [accordion geometry, inside coil]

Barrel: Pb, $20 X_0$, 11m^3

FEC: Si -W, $30 X_0$

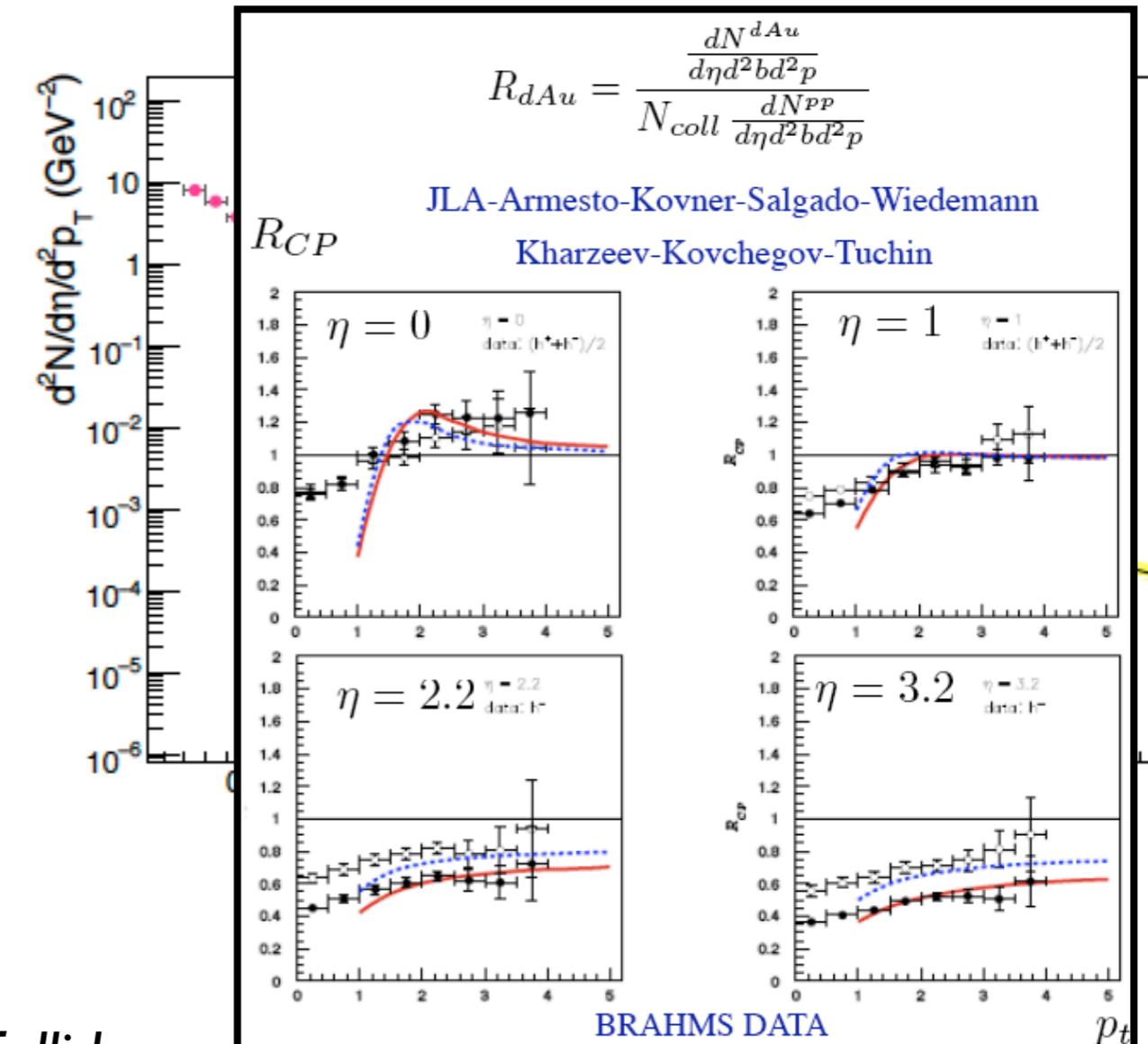
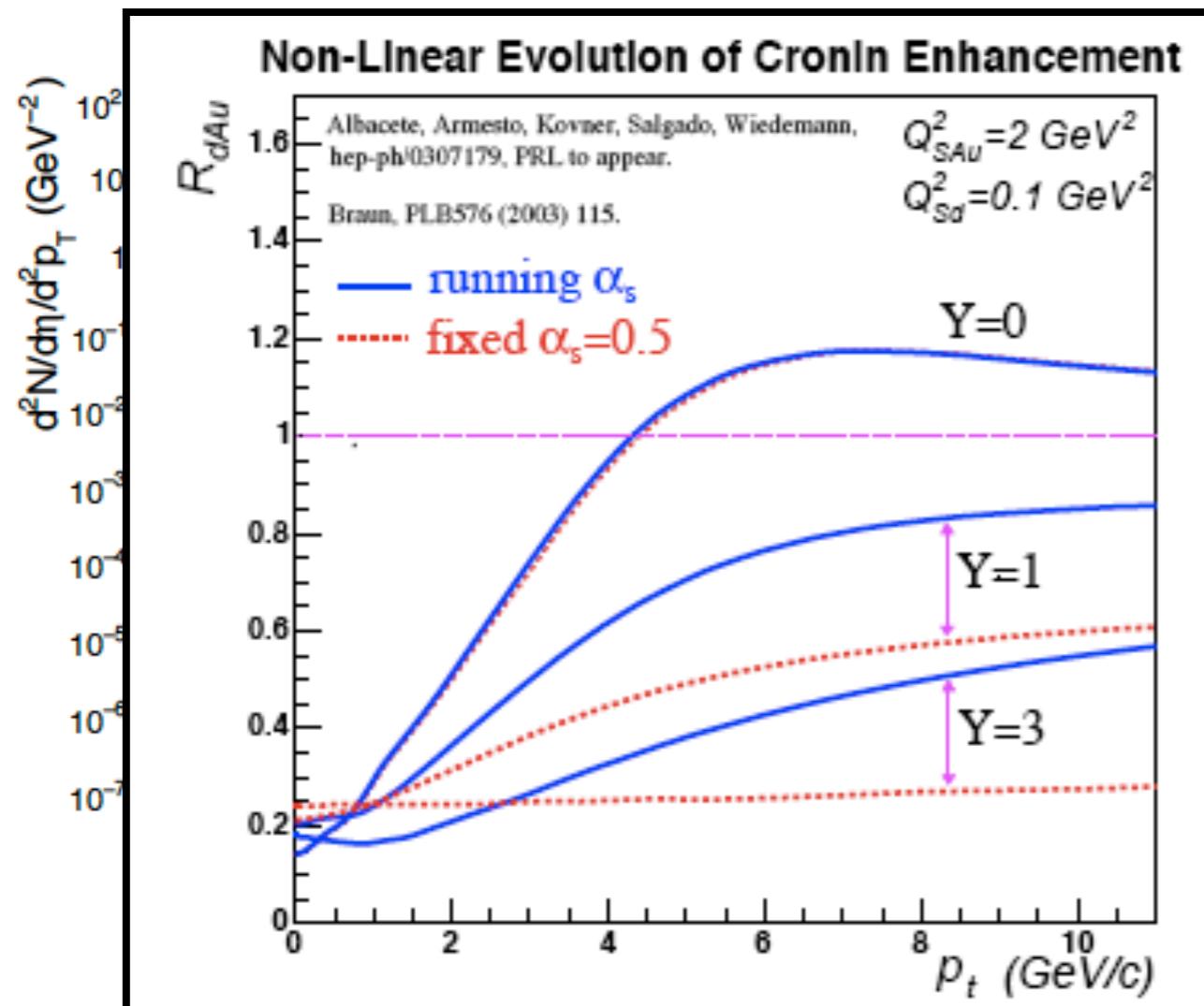
BEC: Si -Pb, $25 X_0$

Hadronic Tile Calorimeter [modular, outside coil: flux return]



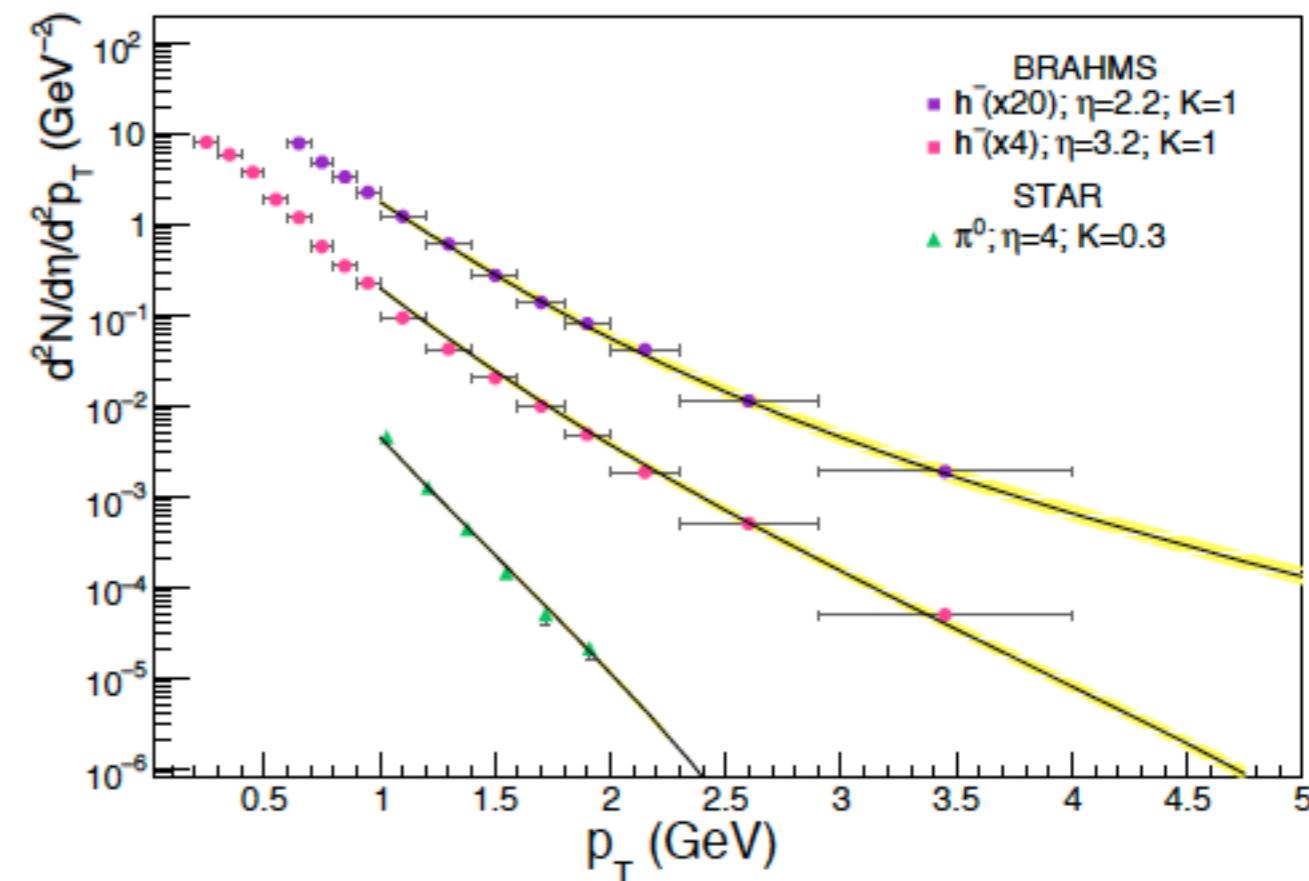
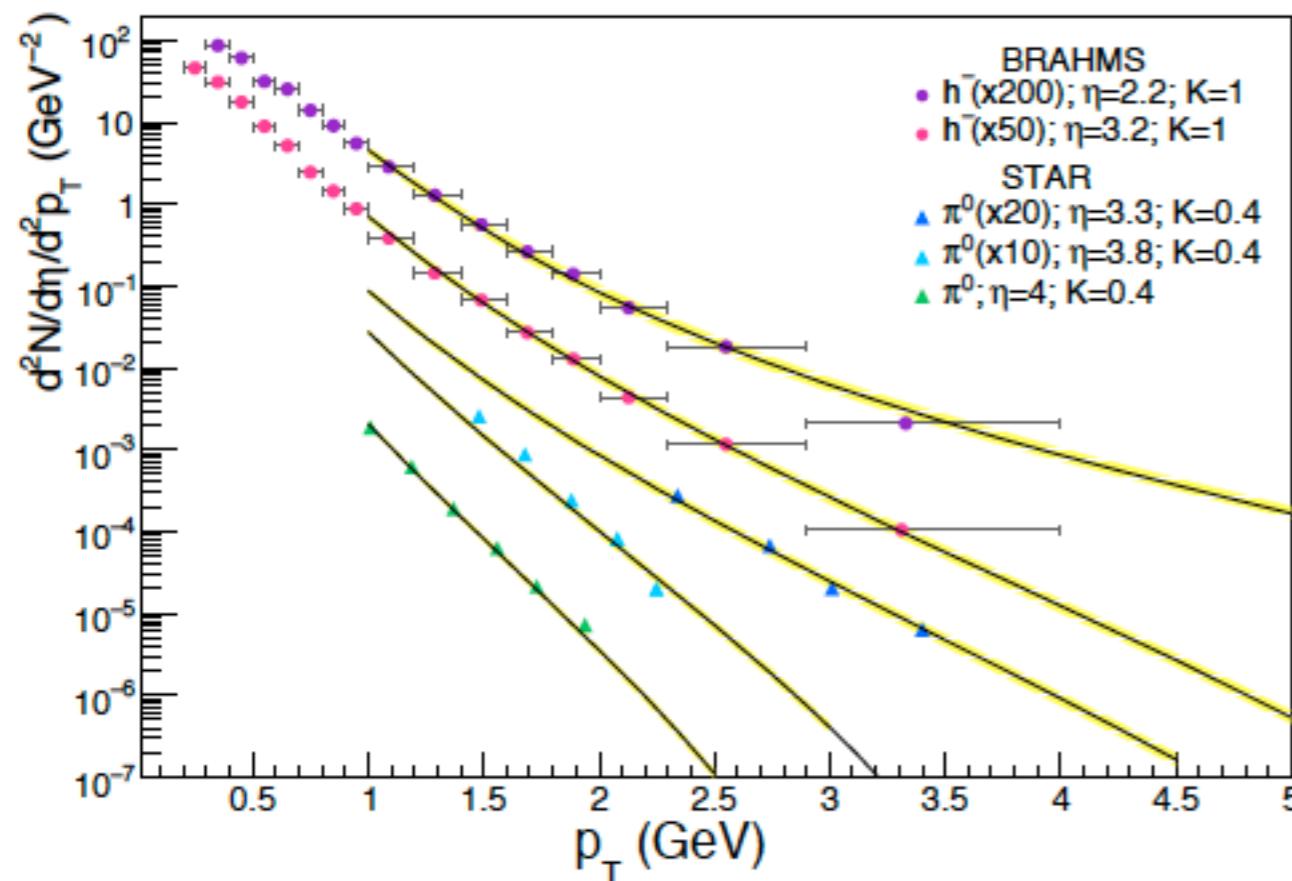
Features in dAu@RHIC:

- Control experiment for initial state effects in AA: Cronin in dAu at midrapidity ruled out initial state effects as the explanation for the suppression observed in AA.
- Suppression at forward rapidities predicted by small-x evolution.
- Azymuthal decorrelation in the forward region also seen.



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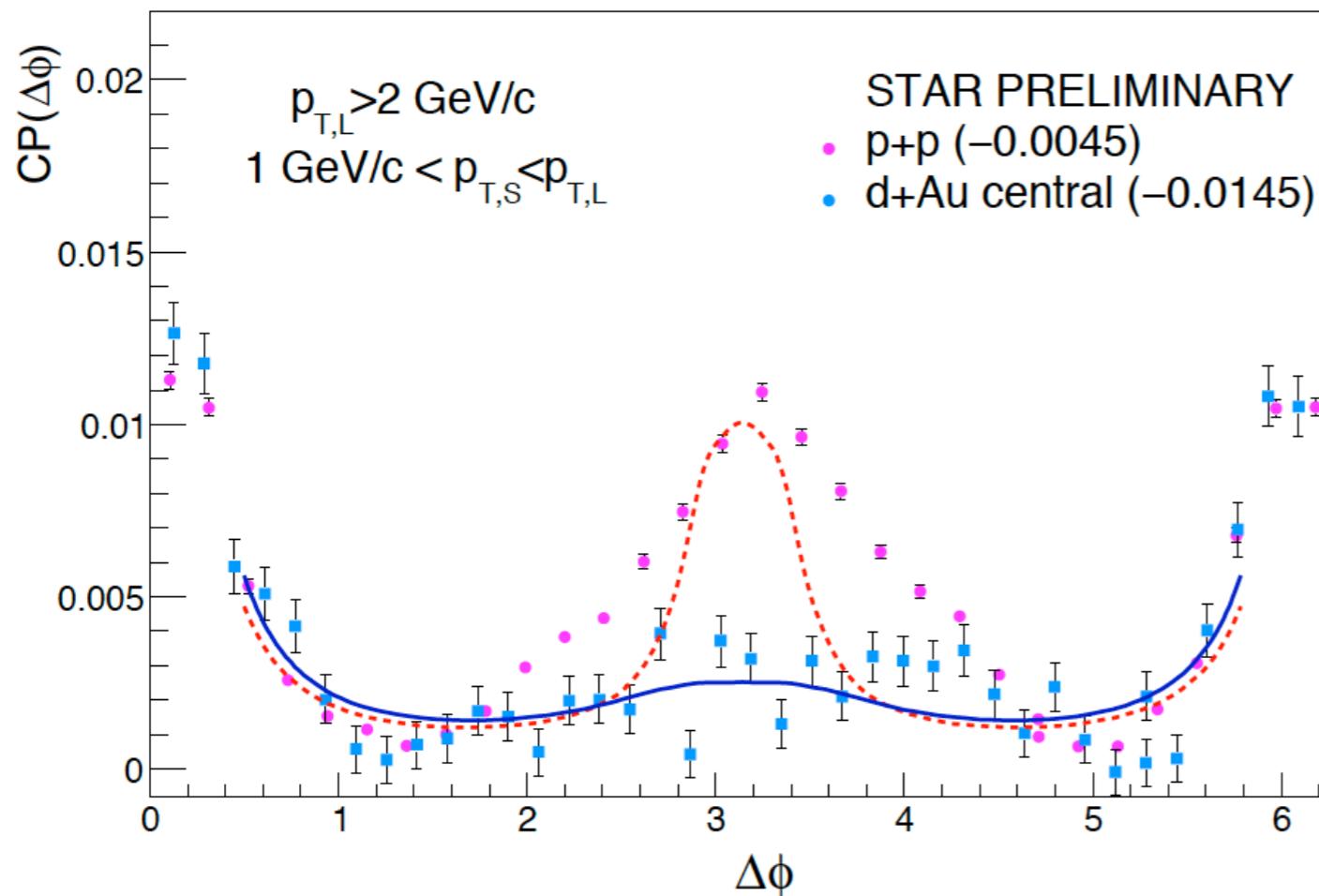
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Albacete-Marquet '10

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Albacete-Marquet '10

$$N_{pair}(\Delta\phi) = \int \frac{dN^{dAu \rightarrow h_1 h_2 X}}{d^3 p_1 d^3 p_2} / N_{trig} = \int \frac{dN^{dAu \rightarrow hX}}{d^3 p}$$

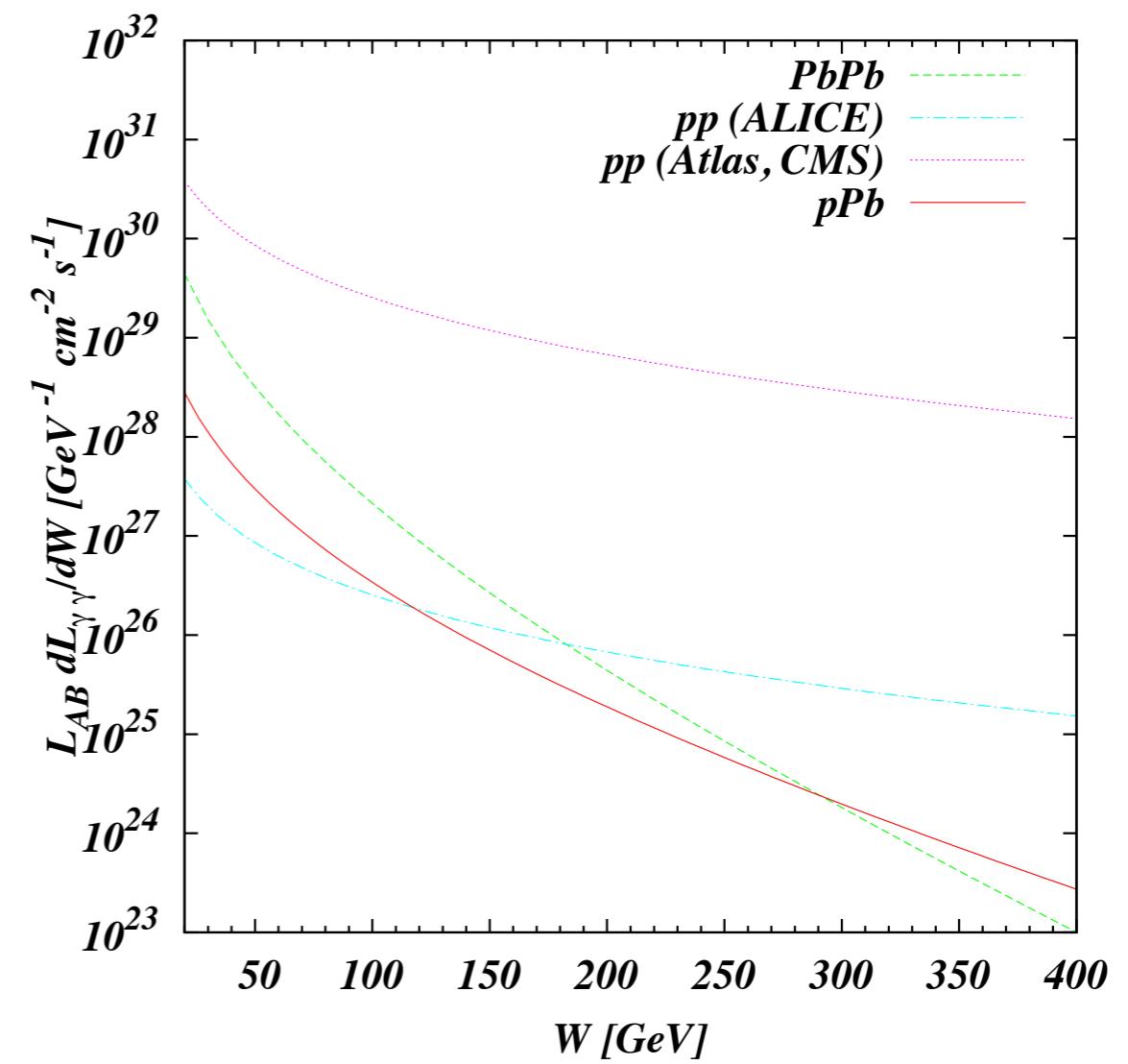
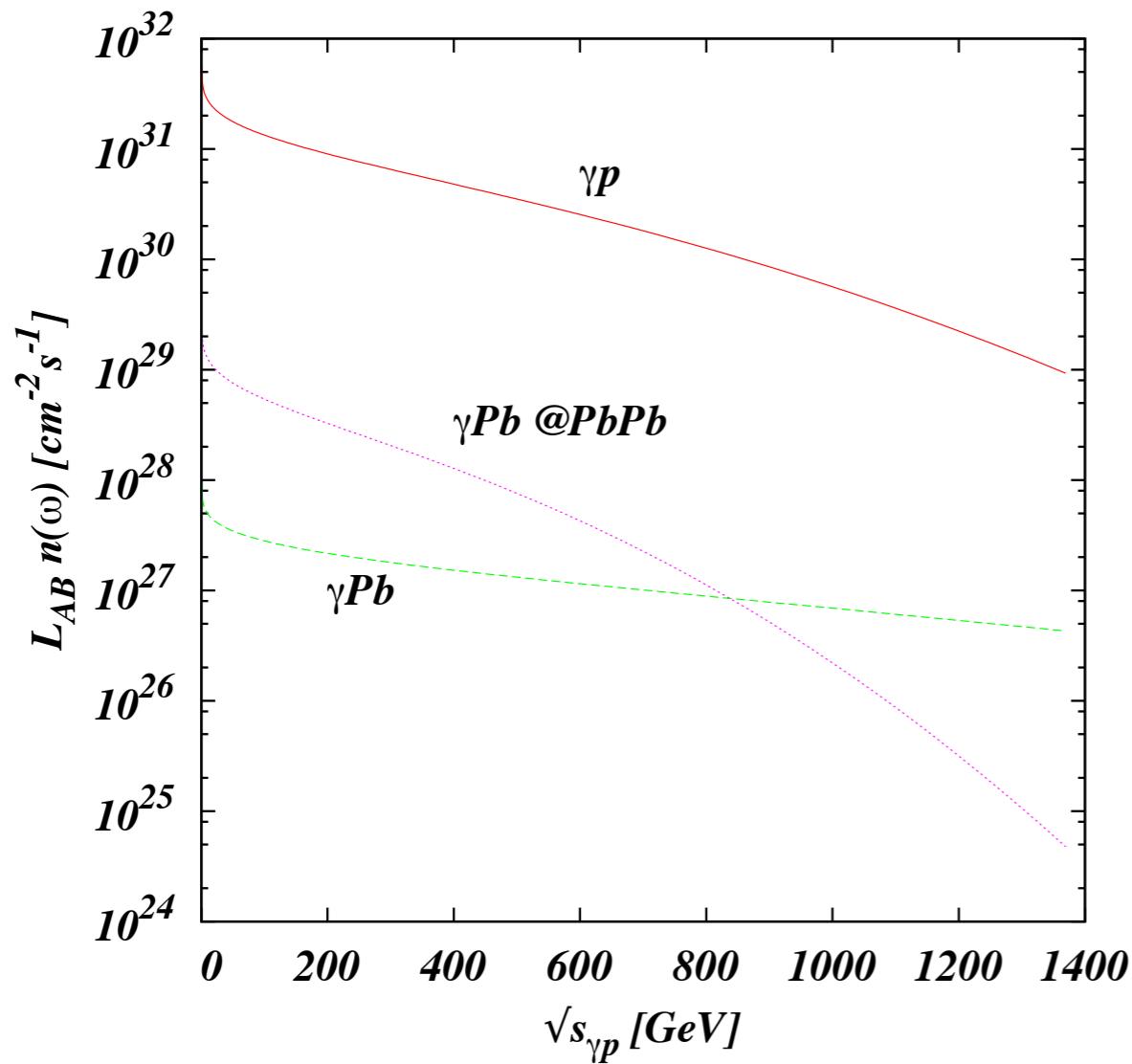
Features in dAu@RHIC:

- Control experiment for initial state effects in AA: Cronin in dAu

- Saturation physics describes these data, but:
 - The normalization is not determined by the calculation ↔ problems to compute the b-dependence.
 - A full NLO analysis is still missing.
 - RHIC data lie at the edge of phase space.
- Other descriptions exist: NLO pQCD (problems with pp reference), eloss models,...
- Note: these studies are very important to understand the mechanism of soft/semihard particle production: ridge, initial conditions for HIC, isotropization,... ⇒ ‘benchmarking’ the bulk.

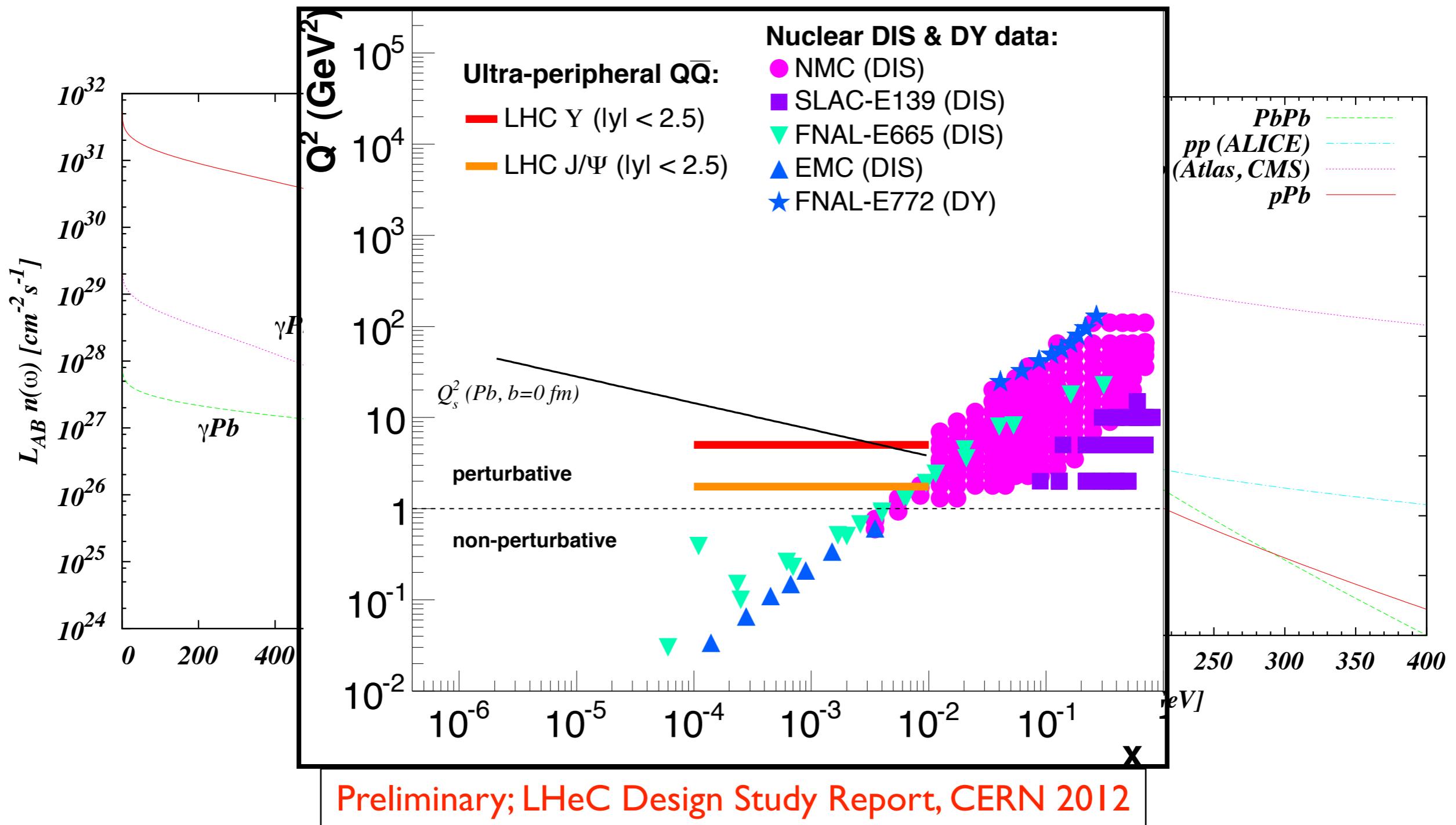
UPCs in pPb:

- Large luminosities in γp .
- Interesting kinematical coverage.



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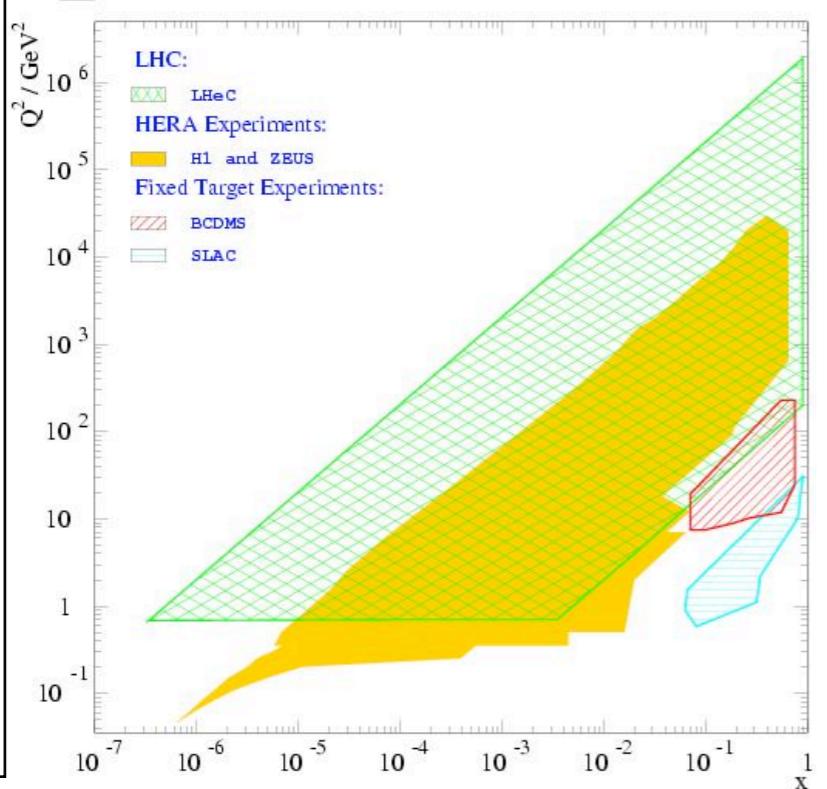
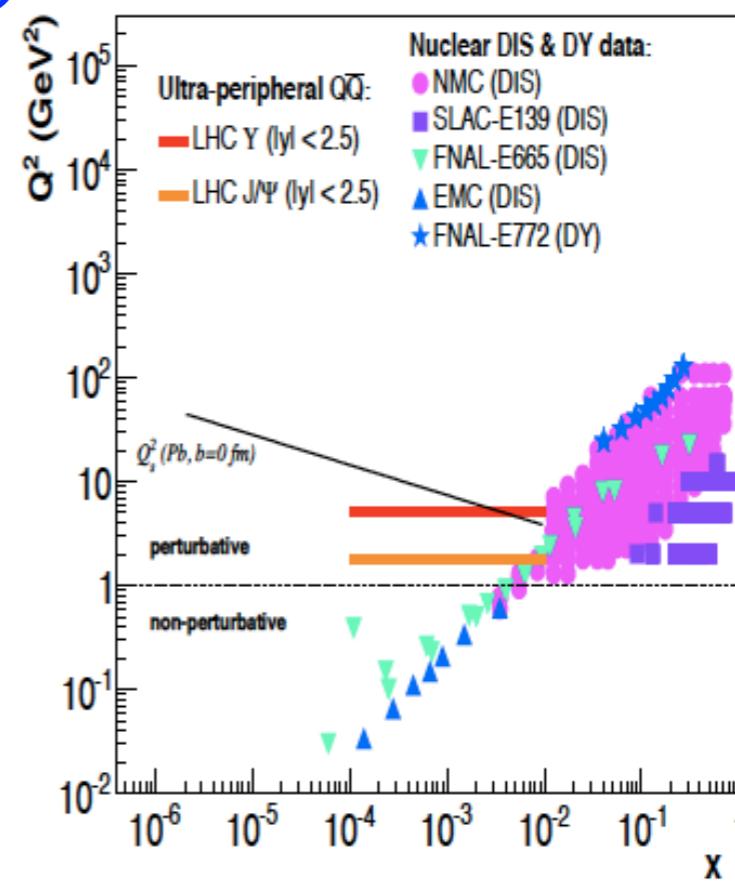
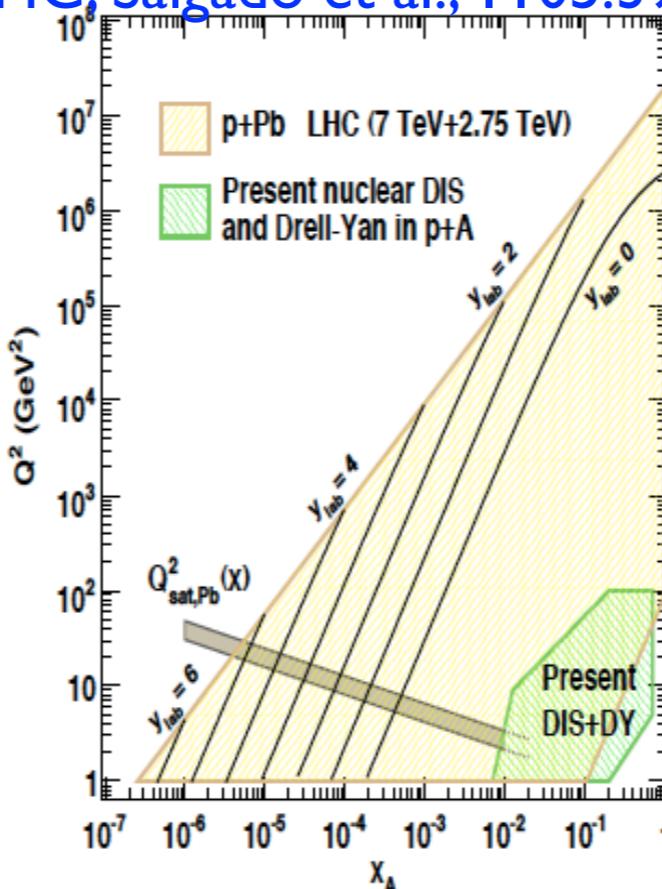
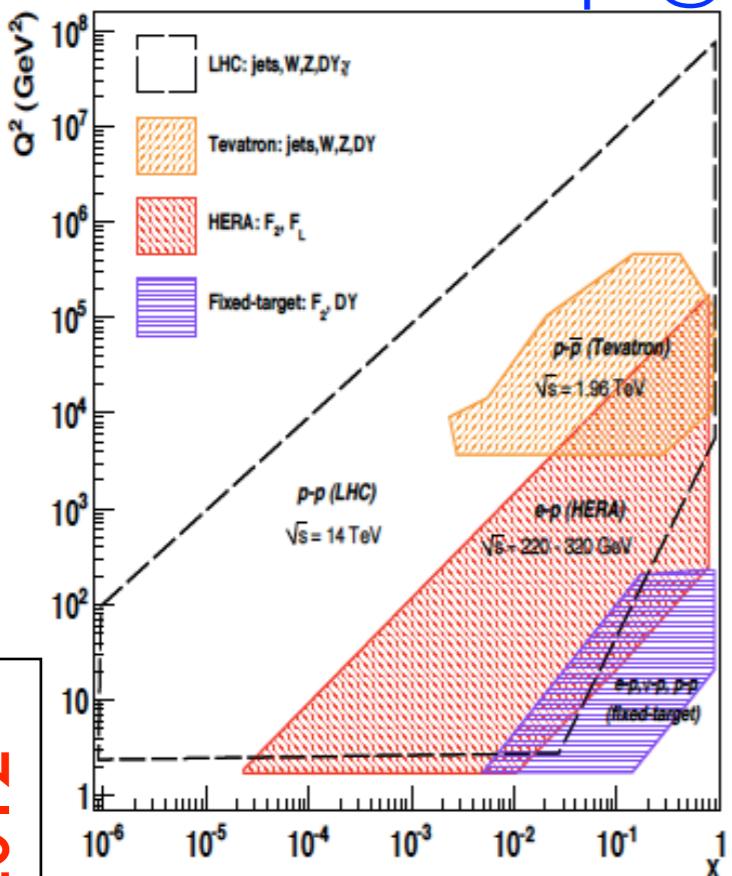
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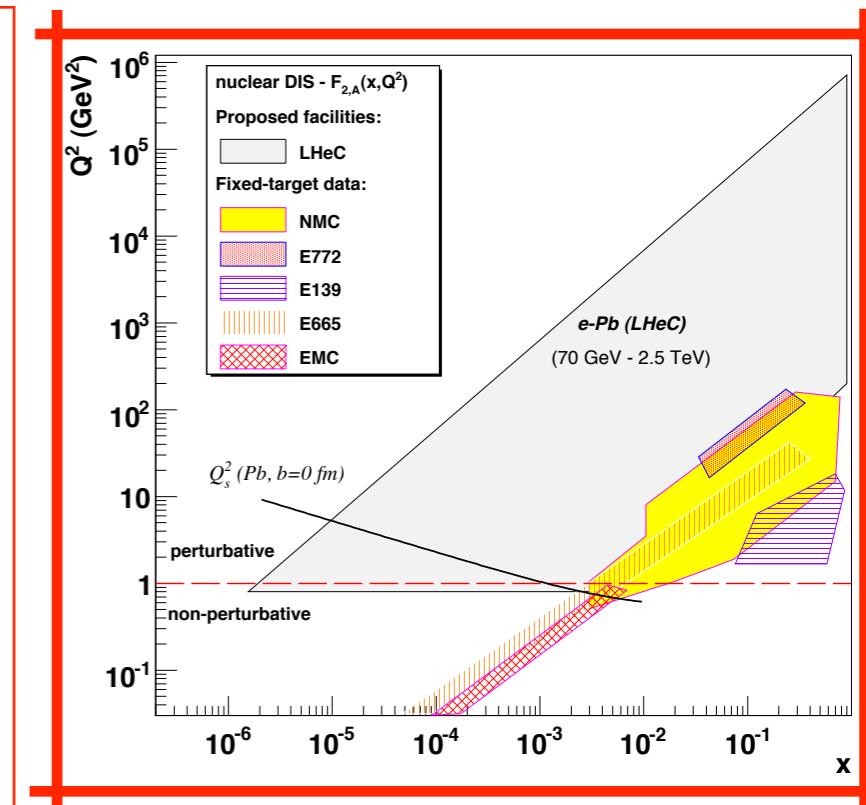
Kinematics: LHC vs. LHeC

pA@LHC, Salgado et al., 1105.3919

Preliminary; LHeC Design
Study Report, CERN 2012

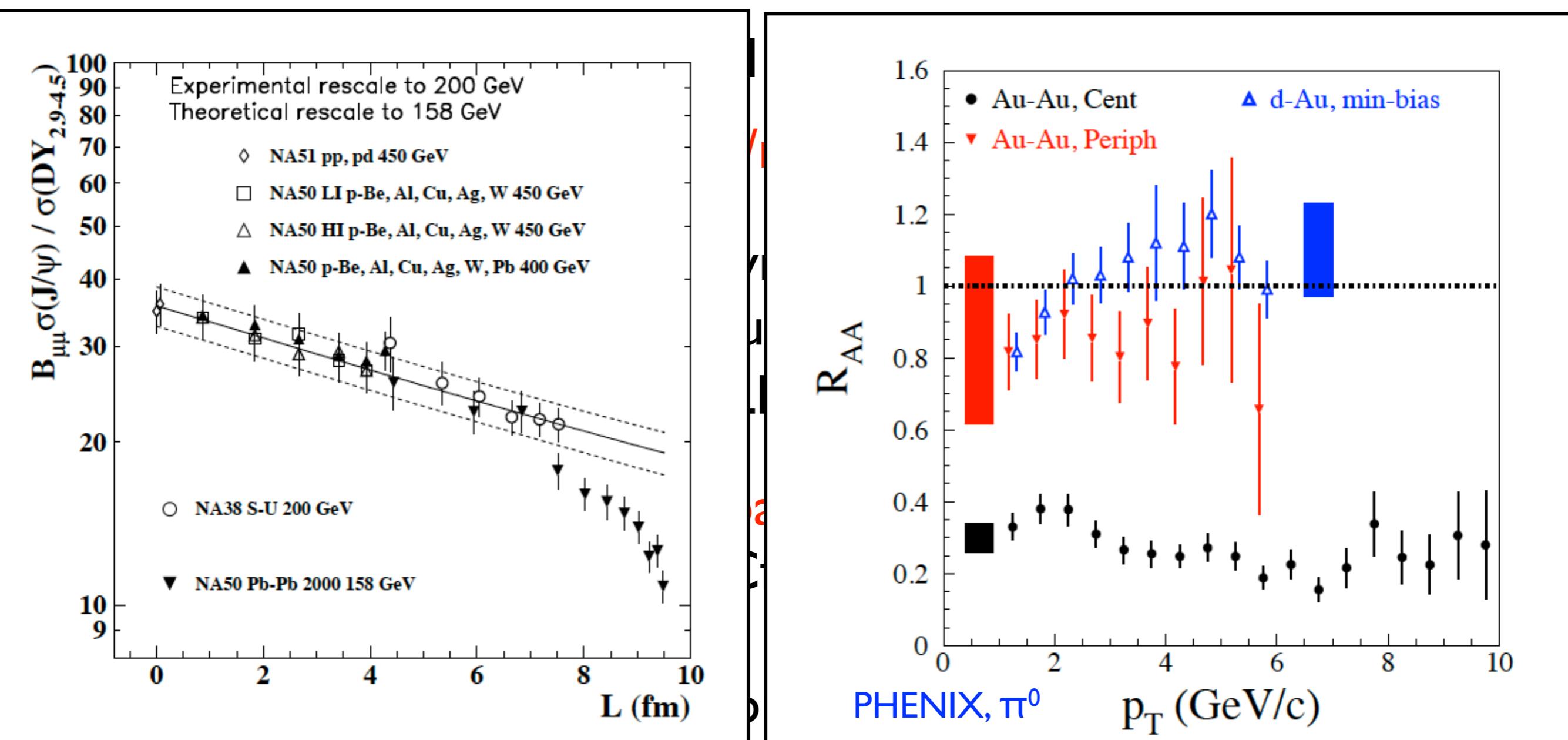


- Existing ep:
 $p\bar{p}$ @LHC at $y=0$;
 eA : not even
 dAu @RHIC.
- LHeC: clean
scan of the LHC
 x - Q^2 domain.



Introduction:

- At the SPS and at RHIC, pA (dAu) runs have been an essential part of the heavy-ion programs. Prominent examples:
 - SPS: J/ ψ absorption in pA → anomalous suppression in PbPb.
 - RHIC: Cronin in dAu → jet quenching in AuAu as a final state effect.



Introduction:

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 - SPS: J/ψ absorption in pA → anomalous suppression in PbPb.
 - RHIC: Cronin in dAu → jet quenching in AuAu as a final state effect.
- A pPb run @LHC with $\langle \mathcal{L} \rangle \sim 10^{29} (/3) \text{ cm}^{-2} \text{s}^{-1}$ for $\int \mathcal{L} dt \sim 0.1 (/3) \text{ pb}^{-1}$ in the 2012 run (4.4-5 TeV/n instead of nominal 8.8).
- Rapidity shift (0.46) due to asymmetric system, smaller for dPb (0.12) but no injector: p+Pb and Pb+p (ALICE μ-arm, LHCb).

$$\Delta y \approx \frac{1}{2} \log \frac{Z_1 A_2}{A_1 Z_2}$$
- All LHC experiments with capabilities for this running mode: ALICE, ATLAS, CMS, LHCb, LHCf,...
- Check in November 2011, approved in Chamonix last February.

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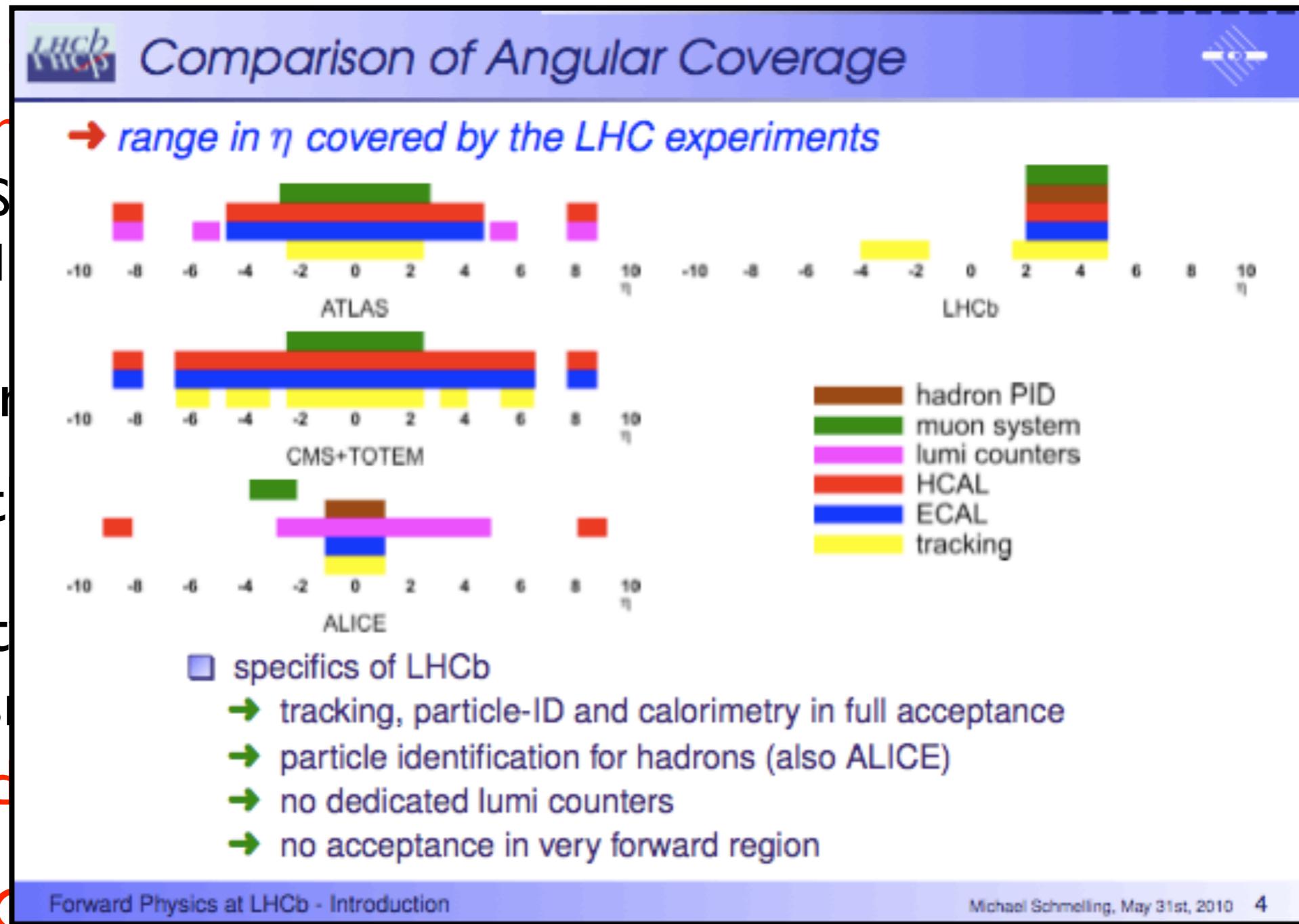
- At the part of the

→ SPS
→ RH

- A pPb run at $\sqrt{s_{NN}} = 2.76 \text{ pb}^{-1}$ in the range $2.4 < \eta < 4.9$

- Rapidity system, sensitivity to p+Pb and pPb

- All LHC experiments will have capabilities for the running mode:
ALICE, ATLAS, CMS, LHCb, LHCf,...



ential effect.

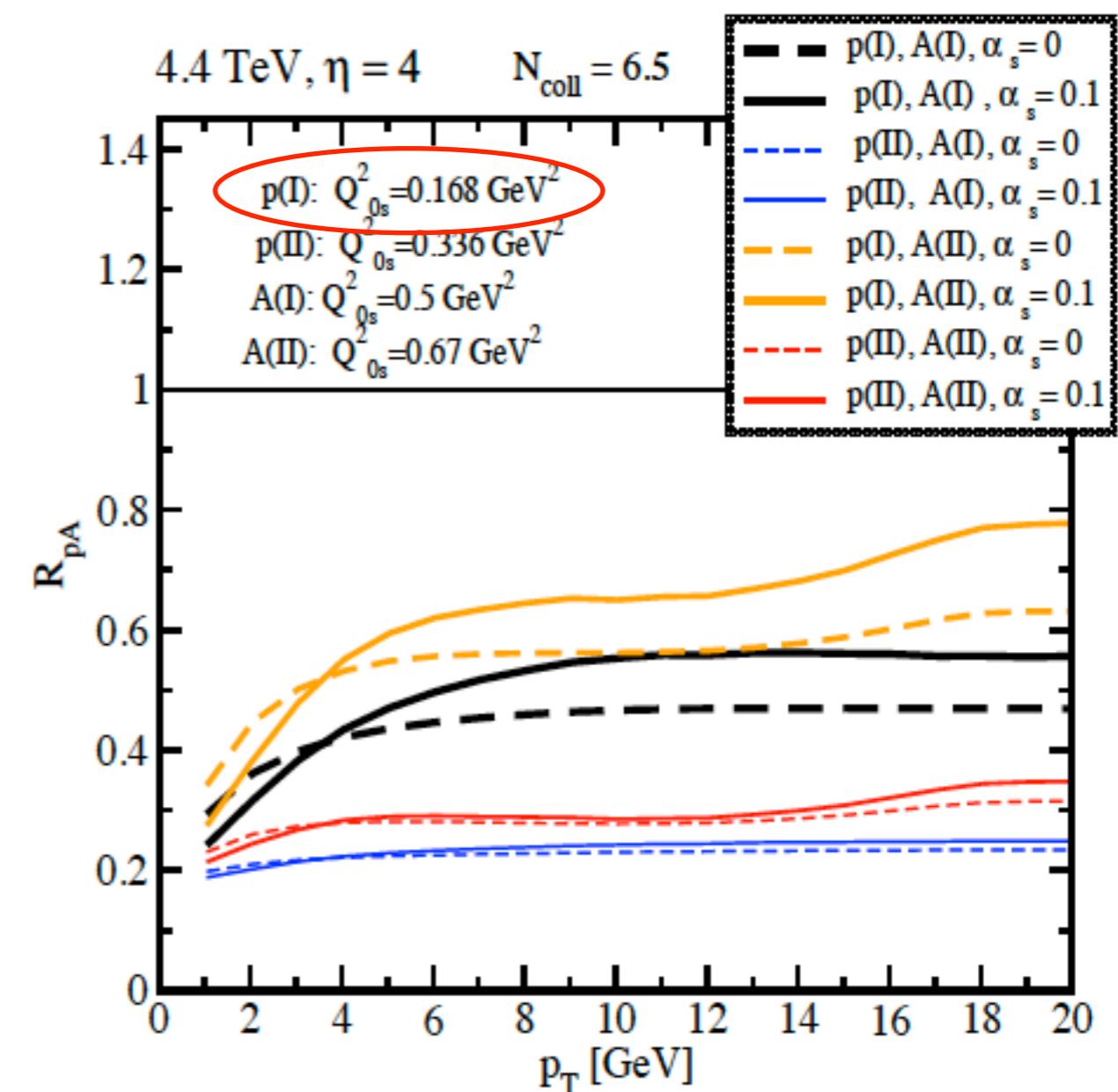
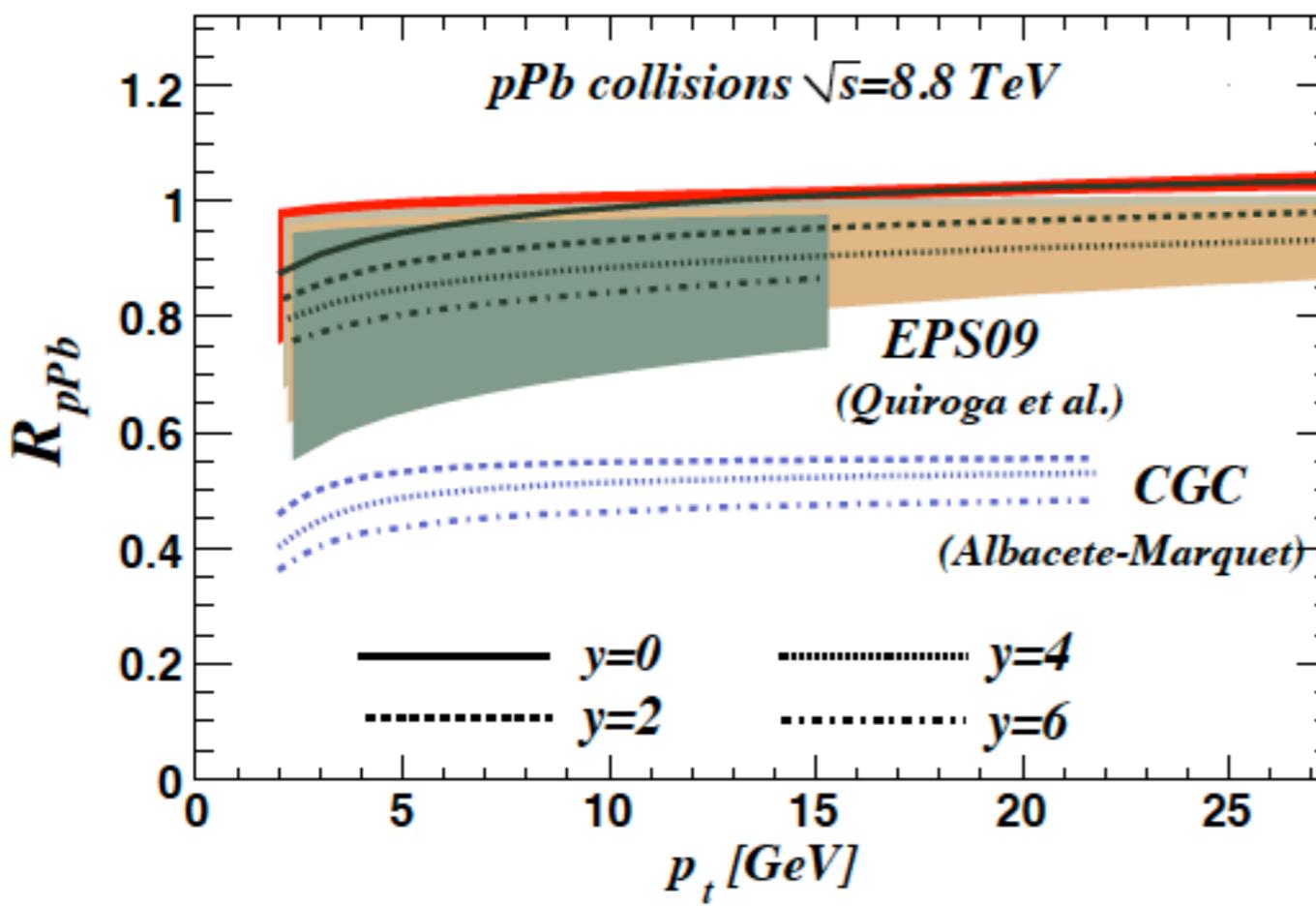
0.1(/3)

$$\log \frac{Z_1 A_2}{A_1 Z_2}$$

- Check in November 2011, approved in Chamonix last February.

pPb at the LHC:

- Offers the best possibility (before lepton-ion colliders) to test:
 - The small-x glue far from the kinematical limits.
 - The production mechanism: clear differences between collinear factorization and saturation?



Jalilian-Marian & Rezaeian, [JHEP02\(2010\)028](#)

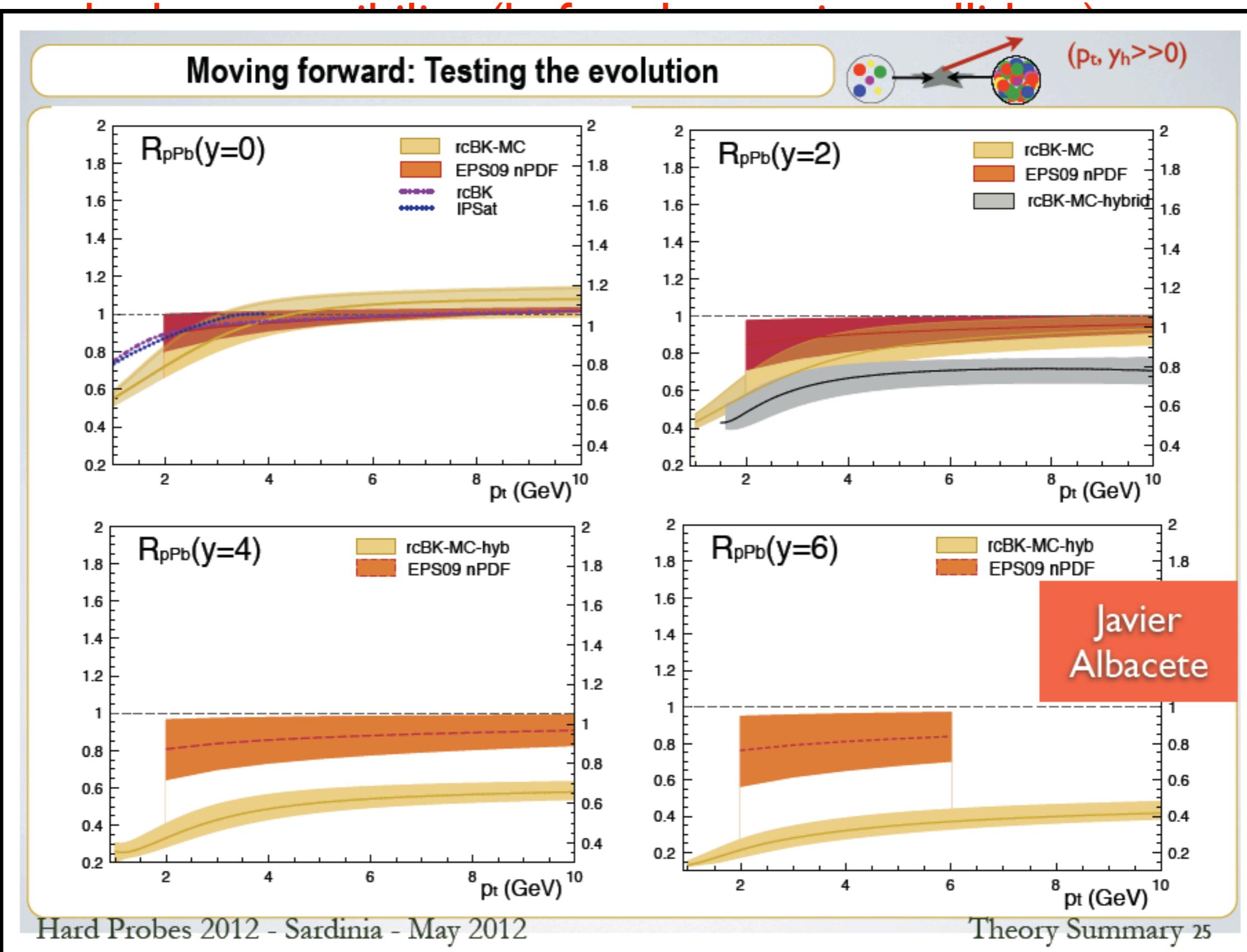
pPb at the LHC:

- Off



- CO

R_{pPb}



Hard Probes 2012 - Sardinia - May 2012

Theory Summary 25

Jainian-Tarian & Rezaeian, T110.2010

Summary:

- A pPb run at the LHC offers huge possibilities (unique before IA colliders) for:

A) Benchmarking for the HIC program, particularly for reducing uncertainties coming from nPDFs:

Observable	Expected impact of the p+A data for benchmarking of A+A
Jets	The expected effects from nPDFs are small. Cold nuclear matter effects in the structure of highly virtual jets are also expected to be small, but little experimental or theoretical information is available at present.
W/Z bosons	This observable provides unique possibilities for constraining the nuclear PDFs and also to serve as benchmark for Z+jet production in A+A .
Photons	The expected effects from nPDFs are small for most of the regions studied. A p+A run would serve as a benchmark for the A+A results.
Heavy flavour	Sizable uncertainties appear from nuclear PDFs for $p_T \lesssim 10$ GeV/c which could affect the interpretation of the A+A data. No information exists on the modification of the hadronization by cold nuclear matter.
Quarkonia	The effect of both the nuclear PDFs and the hadronization presents large uncertainties, especially for the case of J/Ψ integrated in p_T . p+A runs would be essential for a correct interpretation of the A+A results.

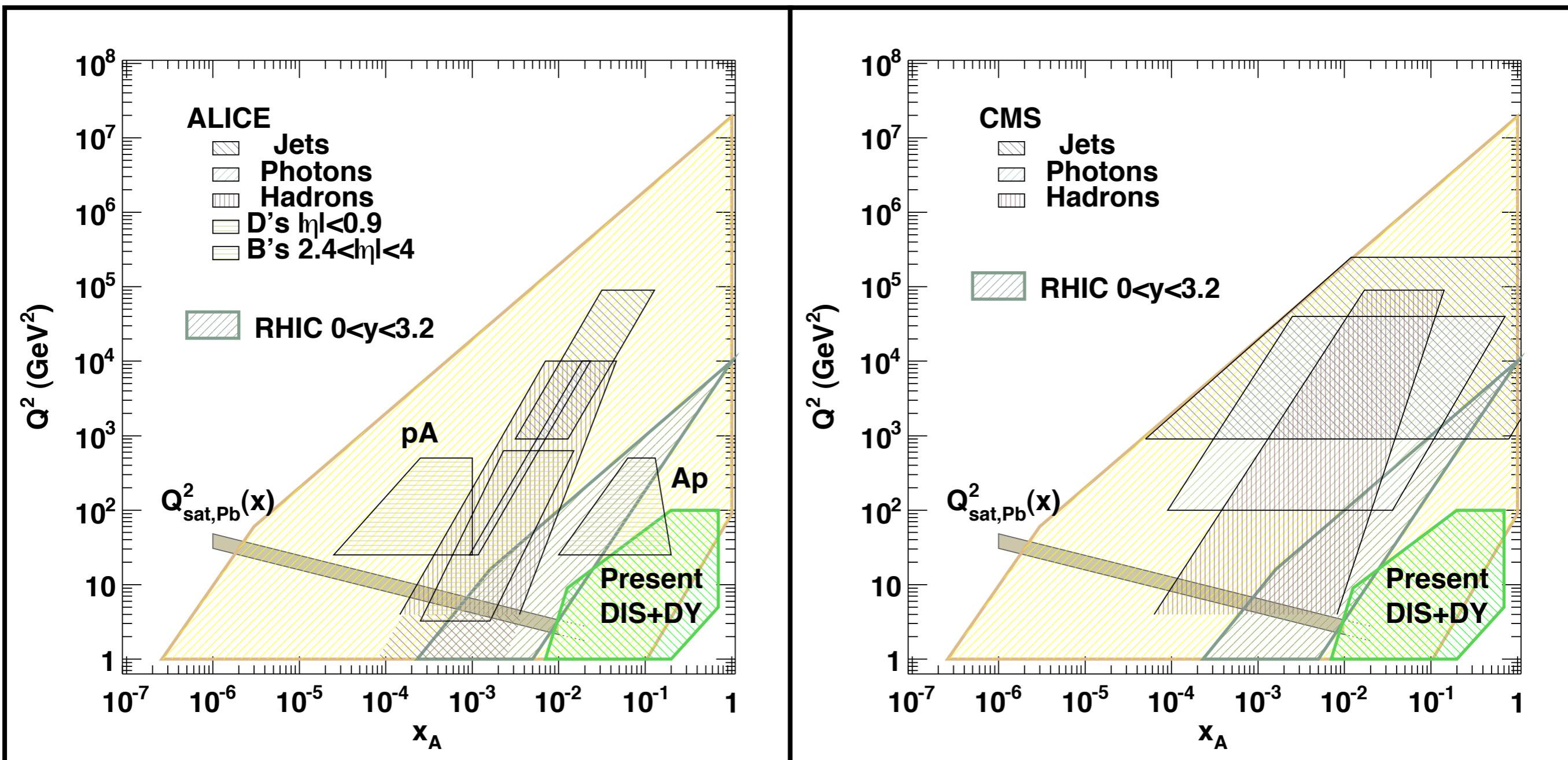
B) Discovery: clarifying the relevance of saturation physics.

C) Others: UPCs, measurements of interest for UHECR.

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