High parton densities and low-x QCD at LHC

II HERA-LHC Workshop

CERN, June 8th 2006

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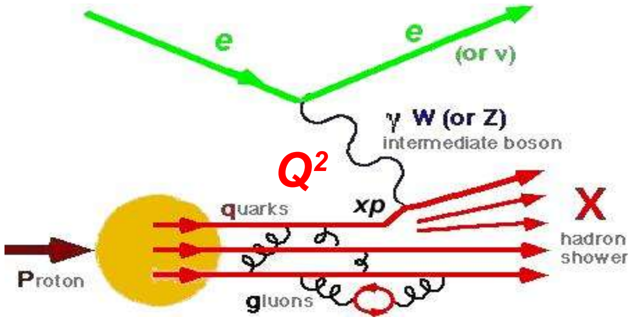
Overview

- Introduction:
  - Parton structure & evolution at low-x
  - Gluon saturation / non-linear evolution = Colour Glass Condensate (CGC)
  - HERA (proton) – RHIC (nucleus) – LHC (p,A) connection
- Experimental status:
  - Measuring parton distributions: processes, kin. domains, ...
  - Results at HERA (proton) and RHIC (nucleus)
- Low-x perspectives at LHC (p,A):
  - ALICE, ATLAS, CMS, LHCb capabilities
  - Examples: “Mueller-Navelet” jets, DY, γA in UPC AA, ...
- Summary

Parton structure at low-x

- DIS *ep* collisions probe partonic distributions in the proton:



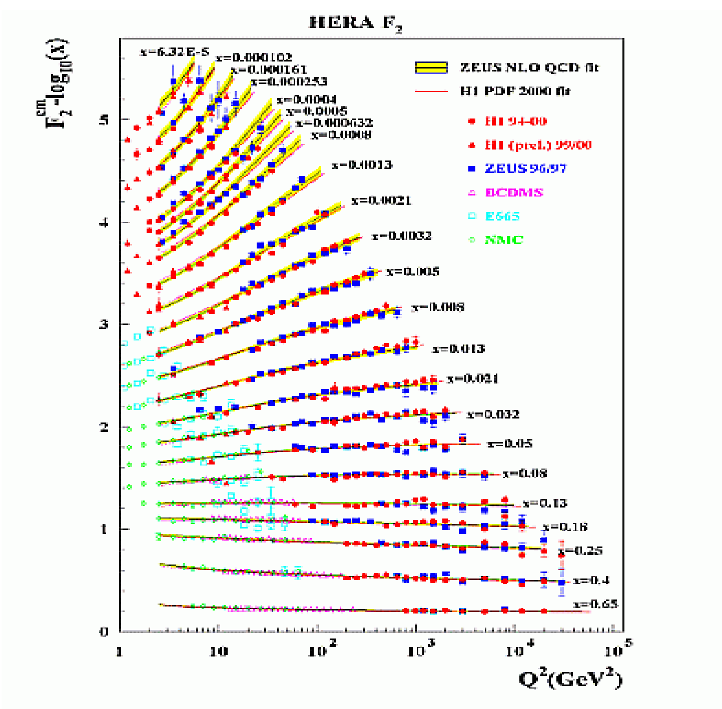
Q^2 = "resolving power"

Bjorken x = momentum fraction carried by parton

$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[2xy^2F_1 + 2(1-y)F_2\right]$$

F_1,F_2 = proton structure functions , (y = inelasticity).

- HERA: strong rise at low-x of $F_2(x,Q^2)$ ~ sea-quarks, $\partial \ln F_2/\partial \ln Q^2$ ~ gluons



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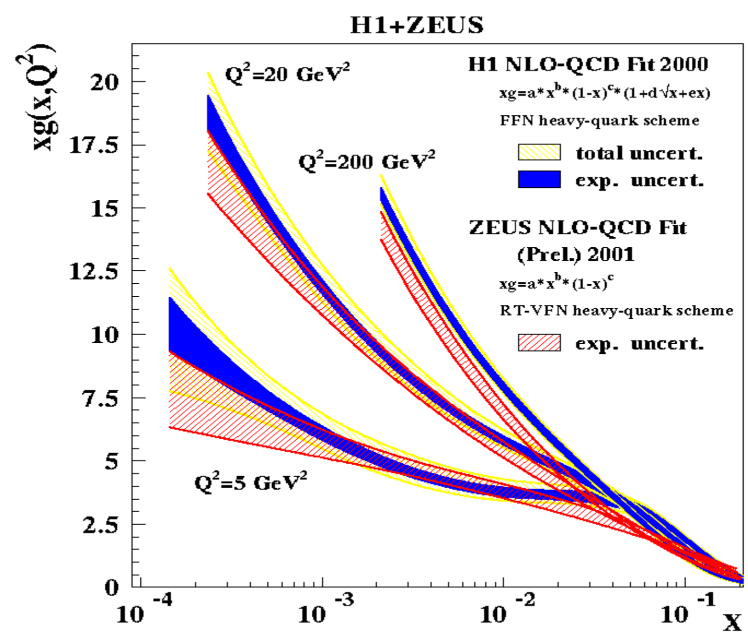
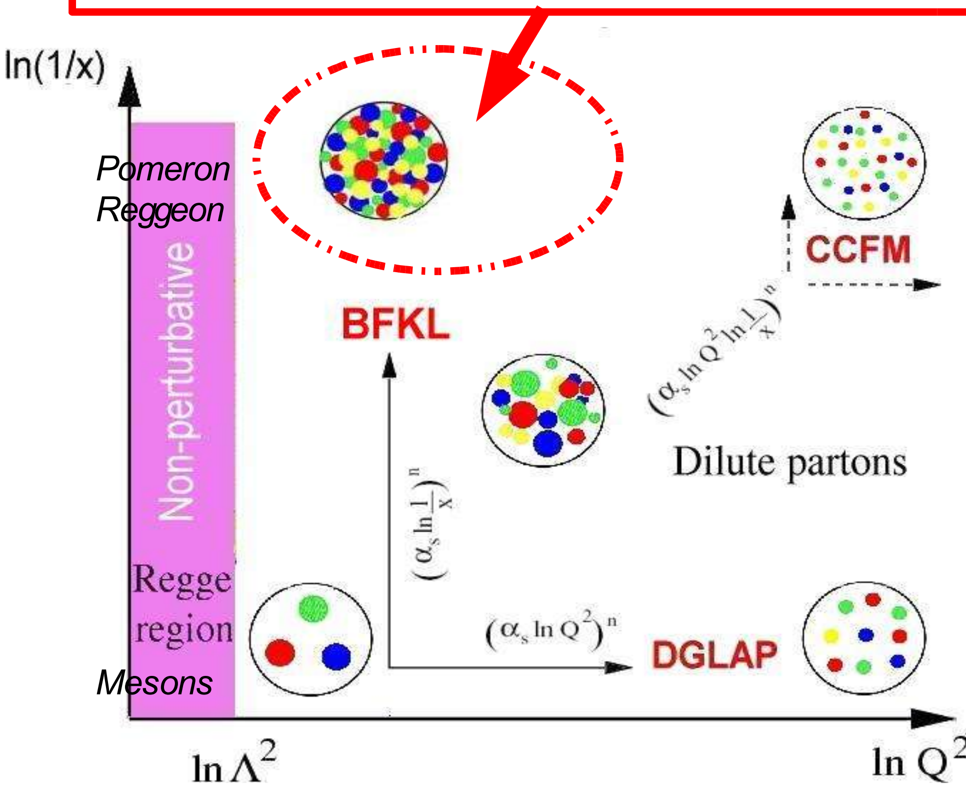
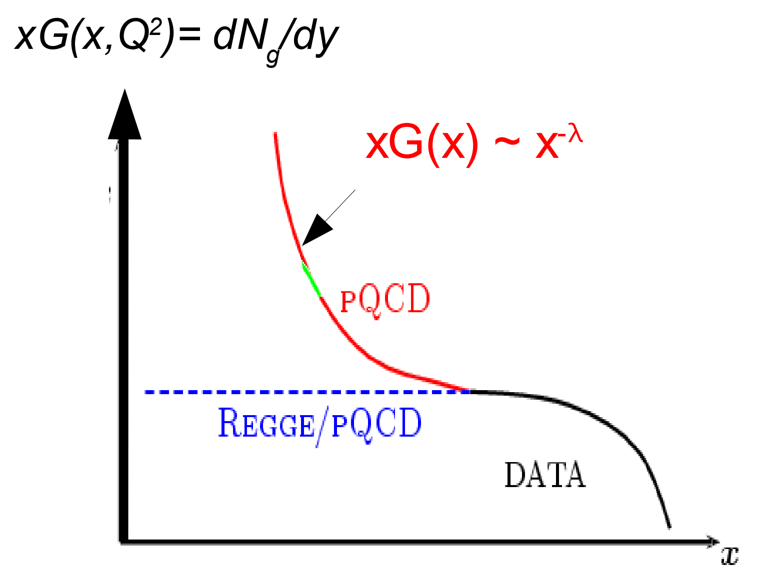


(x,Q^2) evolution of PDFs

- **Q^2 - DGLAP** (parton branch.): $F_2(Q^2) \sim \alpha_s \ln(Q^2/Q_0^2)^n$, $Q_0^2 \sim 1$ GeV^2 [LT, coll. factoriz.]
- **x - BFKL** (parton emission ordered in p_L): $F_2(x) \sim \alpha_s \ln(1/x)^n$ [uPDFs, k_T-factoriz.]
- Linear equations (single parton radiation/split). Cannot work at low-x (esp. nucleus):

(i) Too high gluon density : nonlinear multi-gluon fusion balances splittings
(ii) pQCD (collinear & k_T) factorization should break (HT, no incoherent parton scatt.)
(iii) Violation of unitarity even for $Q^2 >> \Lambda^2$ (too large perturbative cross-sections)



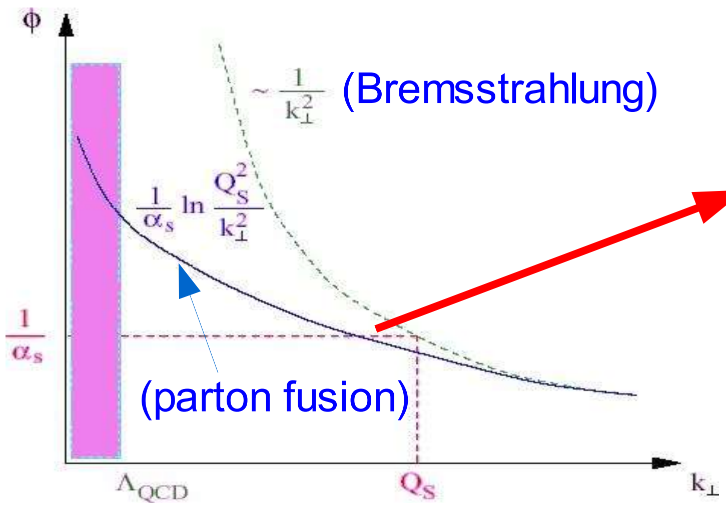


Colour Glass Condensate (CGC)

[McLerran, Venugopalan, Kharzeev, Kovchegov, Jalilian-Marian, Mueller, Iancu, Gelis, Tuchin, Ikatura, Dumitru, ...]

- CGC = EFT in high-energy (small-x) QCD limit:
  - Hadrons = classical fields below "saturation scale" Q_s:

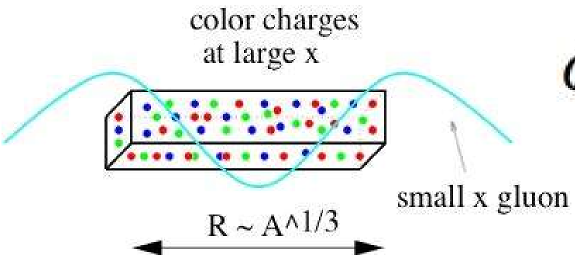
"saturated gluon wave function"



- Gluons overlap for momenta below:

$$Q_s^2 \sim \alpha_s \frac{x G_A(x, Q_s^2)}{\pi R_A^2}$$

- Saturation enhanced in nucleus:



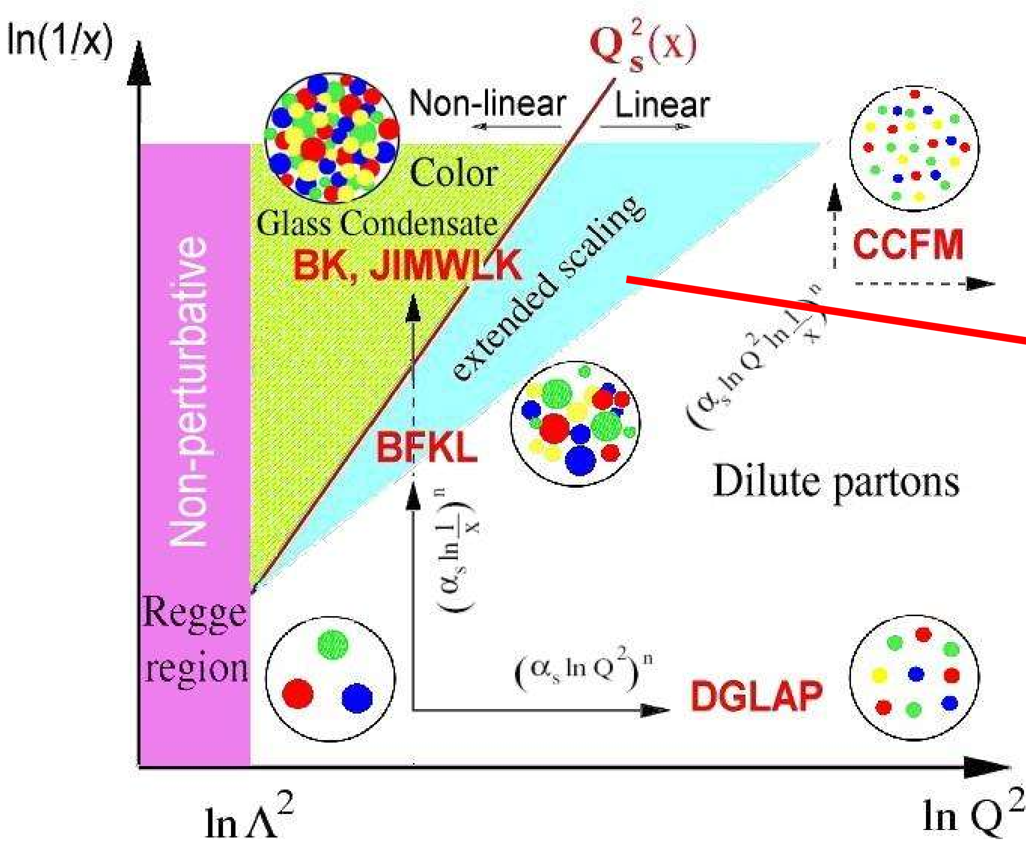
$$Q_s^2 \sim A^{1/3} \sim 6$$

- Q_s hard enough ⇒ perturbative calc. (strong $F_{\mu\nu}$, weak coupling): $\alpha_S(Q_s^2) << 1$
- p,A+A = Collision of gluon wave function(s): "resums" all multiple scatts.
- **C**olor **G**lass (quarks ~ "static" color sources) **C**ondensate (high gluon occupation)

Non-linear QCD evolution equations

- Quantum evolution of classical fields governed by JIMWLK eqs.
  - Non-linear, all-twist equations in saturation regime
  - Generalized Fokker-Planck eq. (diffussion of wave-function)
  - Large N_c limit → **BK** → Weak-field limit → **BFKL**.

[Jalilian-Marian, Iancu, McLerran, Kovner, Leonidov, Weigert]



Additional quantum corrections: lead to anomalous dimension in "extended scaling" region:

$$\frac{1}{Q^2} \rightarrow \left(\frac{1}{Q^2}\right)^\gamma \quad \gamma \simeq 1/2$$

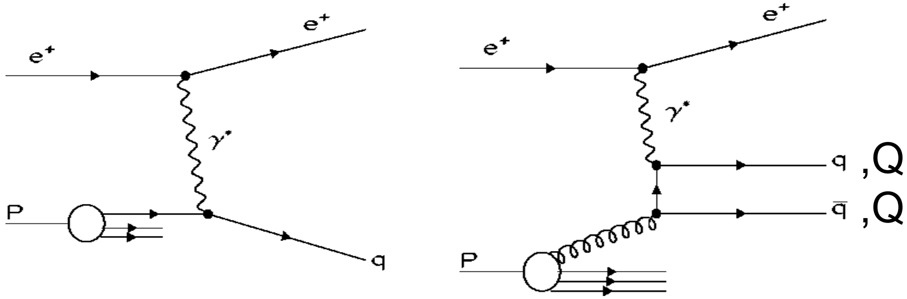
extended window of "applicability" outside CGC !

$$Q_s^2 < Q^2 < Q_s^4/\Lambda^2$$

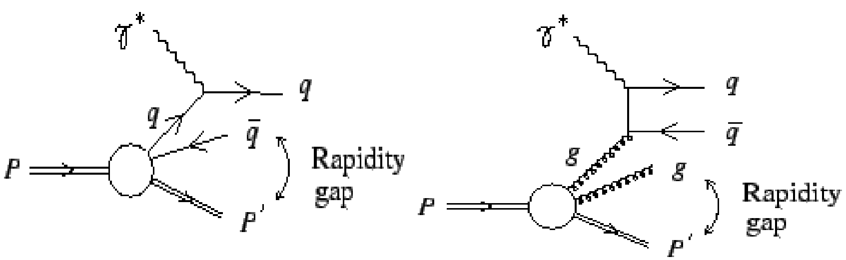
Low-x QCD: experimental methods

Measuring parton distributions (p,A)

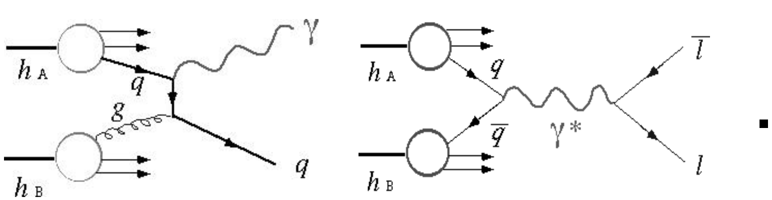
- High-p_T, heavy-Q (ep,eA):



- "Diffractive" QQbar (ep, γp, γA):



- Prompt γ, DY, dijets, Q (pp,pA,AA):



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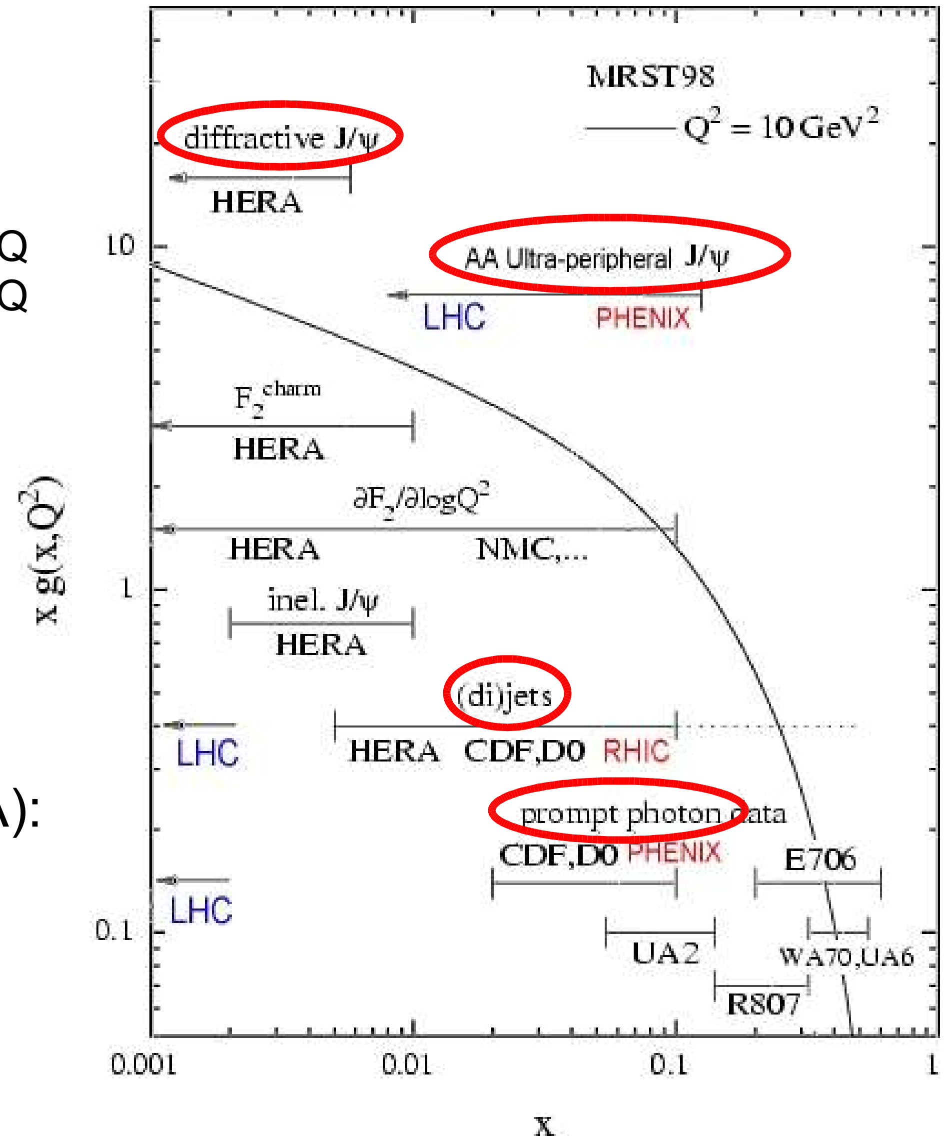
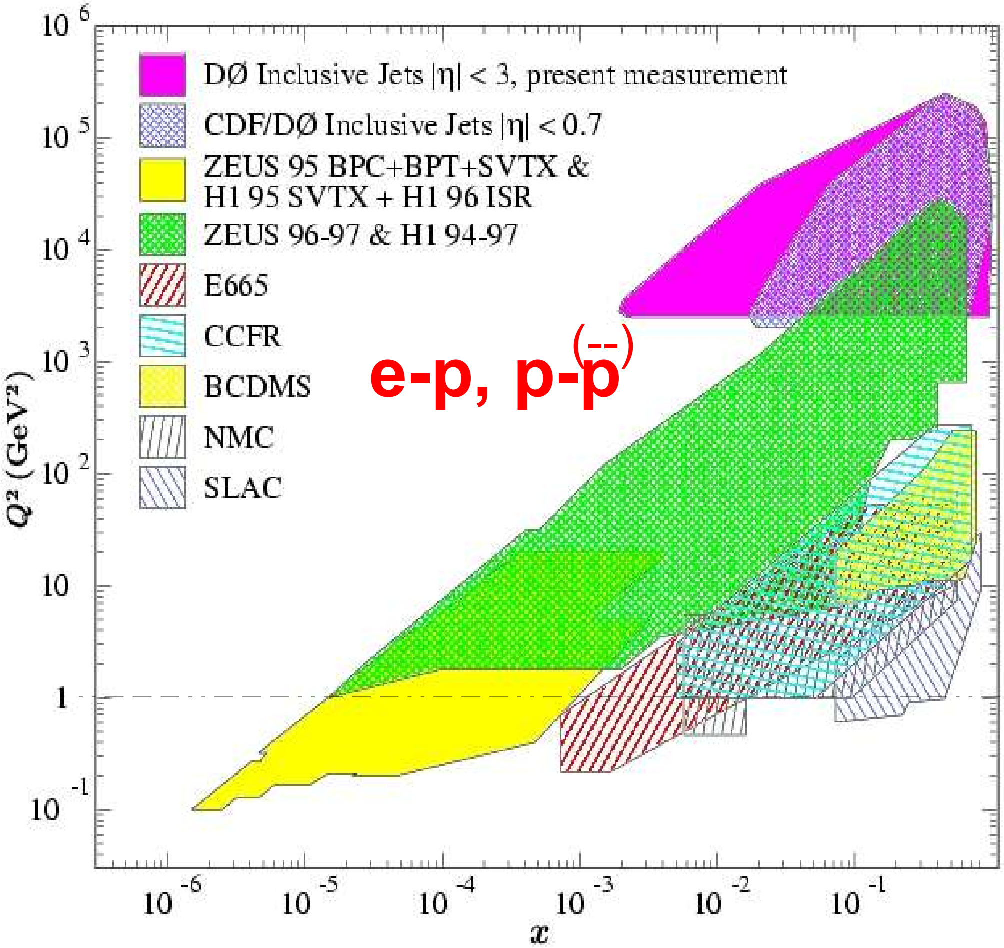


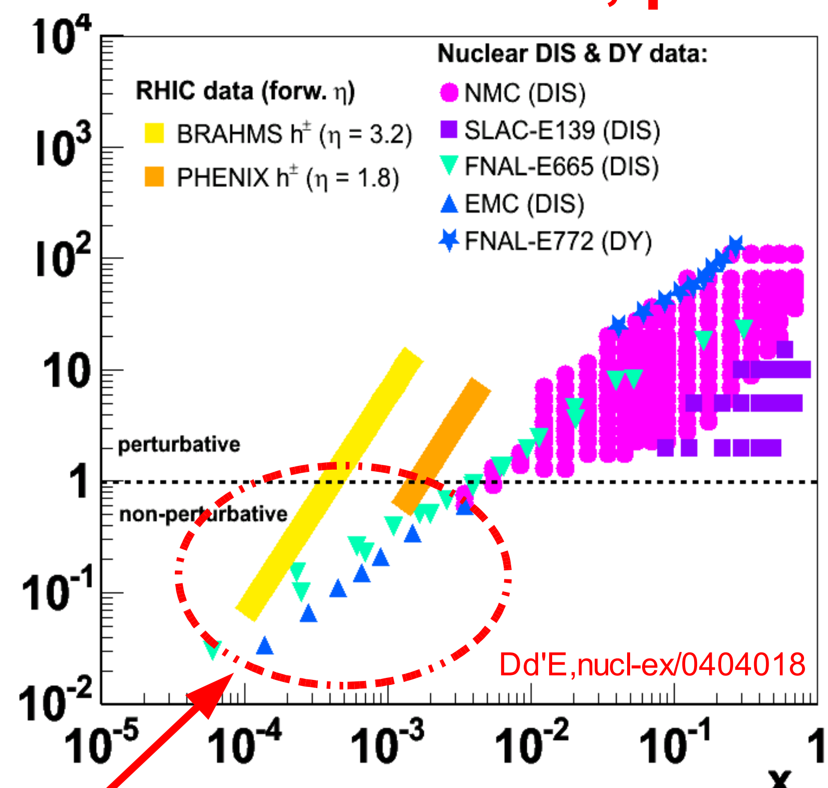
PDF (x,Q^2) domains: proton, nucleus

- Kinematical (x,Q^2) domains covered experimentally:



much less nuclear PDF data available:

e-A, p-A

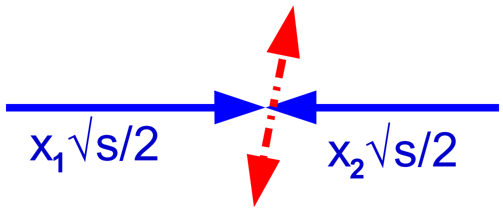


- Note: most existing low-x nPDFs measurements in the non-perturbative regime

Small-x → Forward rapidities

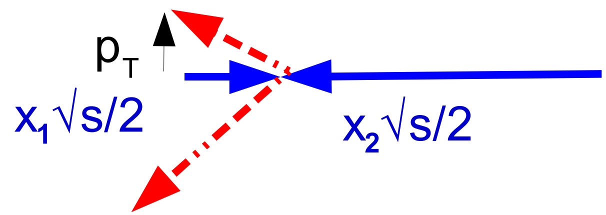
- 2 → 2 parton kinematics:

y = 0: $x_1 \sim x_2 \sim x_T = 2p_T/\sqrt{s}$



$$x_{1,2}^{2\to 2} = \frac{p_T}{\sqrt{s}}(e^{\pm y} + e^{\pm y'})$$

⇒ Every 2-units of y, *x* decreases by ~10



e.g. LHC, p_T = 10 GeV/c

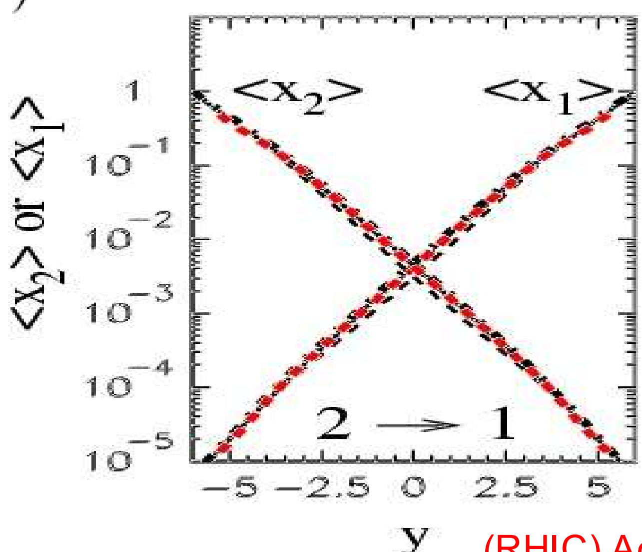
$\theta < 10^{-3}$ ($\eta > 7$): $x < 10^{-6}$

- 2 → 1 (gluon fusion) kinematics: even much lower *x* allowed in CGC

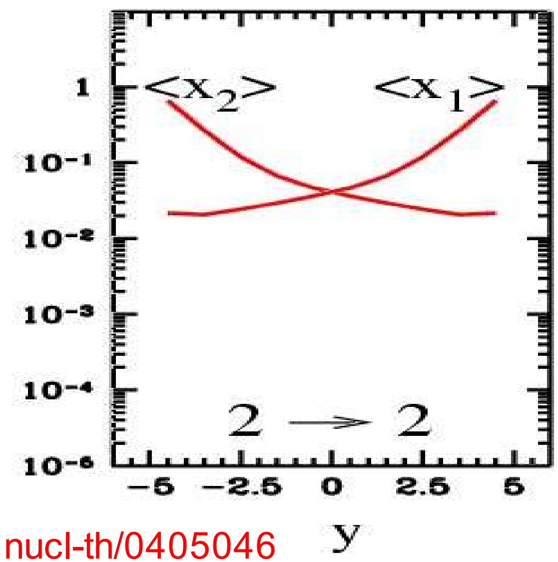
$$x_{1,2}^{2\to 1} = \frac{p_T}{\sqrt{s}}(e^{\pm y})$$

Momentum balanced by the "medium" ("gluon ladder")

CGC: $x(y=4) \sim 10^{-4}$

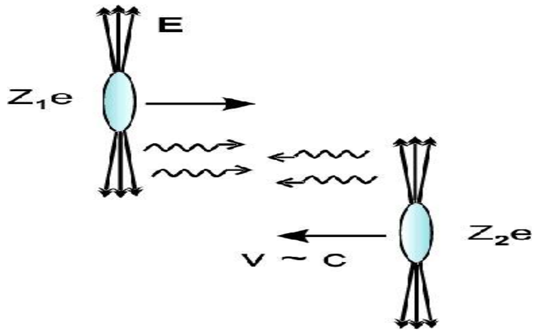


pQCD: $x(y=4) \sim 10^{-2}$



(RHIC) Accardi, nucl-th/0405046

Photoproduction (γA) in UPC AA collisions

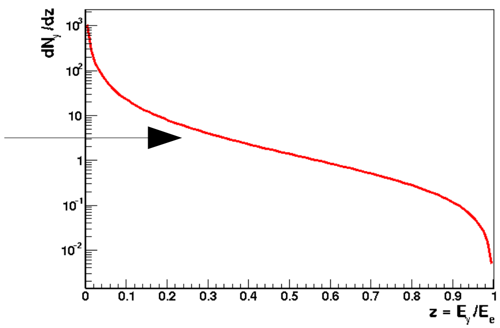


- Heavy-ions (charge *Z*) produce strong EM fields (coherent action of all protons):

- Equivalent flux of photons in electromagnetic (aka. Ultra-Peripheral, $b_{min} \sim 2R_A$) A+A :

$$\frac{dN_\gamma}{dE}(b > b_{min}) \propto \frac{\alpha_{em} Z^2}{\pi}\frac{1}{E}$$

(soft bremsstrahlung γ spectrum)



- Photon beams:
  - **Flux ~ Z^2** (~$7\cdot10^3$ for Pb).
  - "Coherence condition" : γ wavelength > nucleus size

  Maximum γ energy: $\omega < \omega_{max} \approx \frac{\gamma}{R}$ ~ 80 – 160 GeV (Pb,Ca)

  - Center of mass-energies (LHC): **$\sqrt{s_{\gamma A}} \approx$ 0.7 – 2. TeV ≈ (3 – 10) × $\sqrt{s_{\gamma p}}$(HERA)**
  - Bjorken x range in nucleus:

    (y=0): x(J/Ψ) ~$3\cdot10^{-3}$, x(ϒ)~10^{-2}

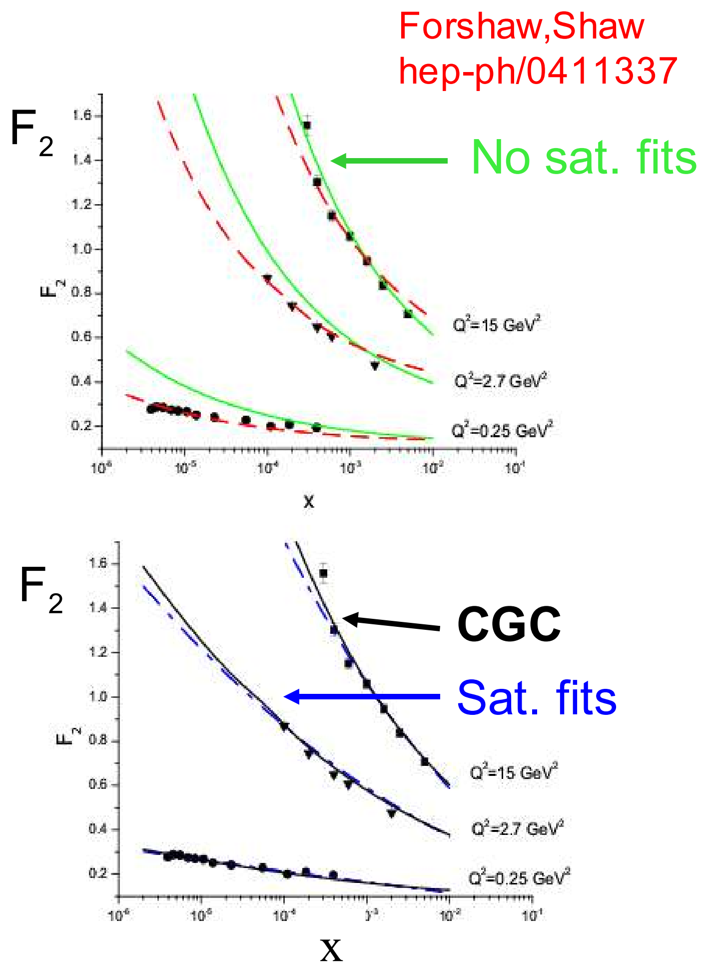
    (y=3): x(J/Ψ) ~ $2\cdot10^{-5}$, x(ϒ)~10^{-4}

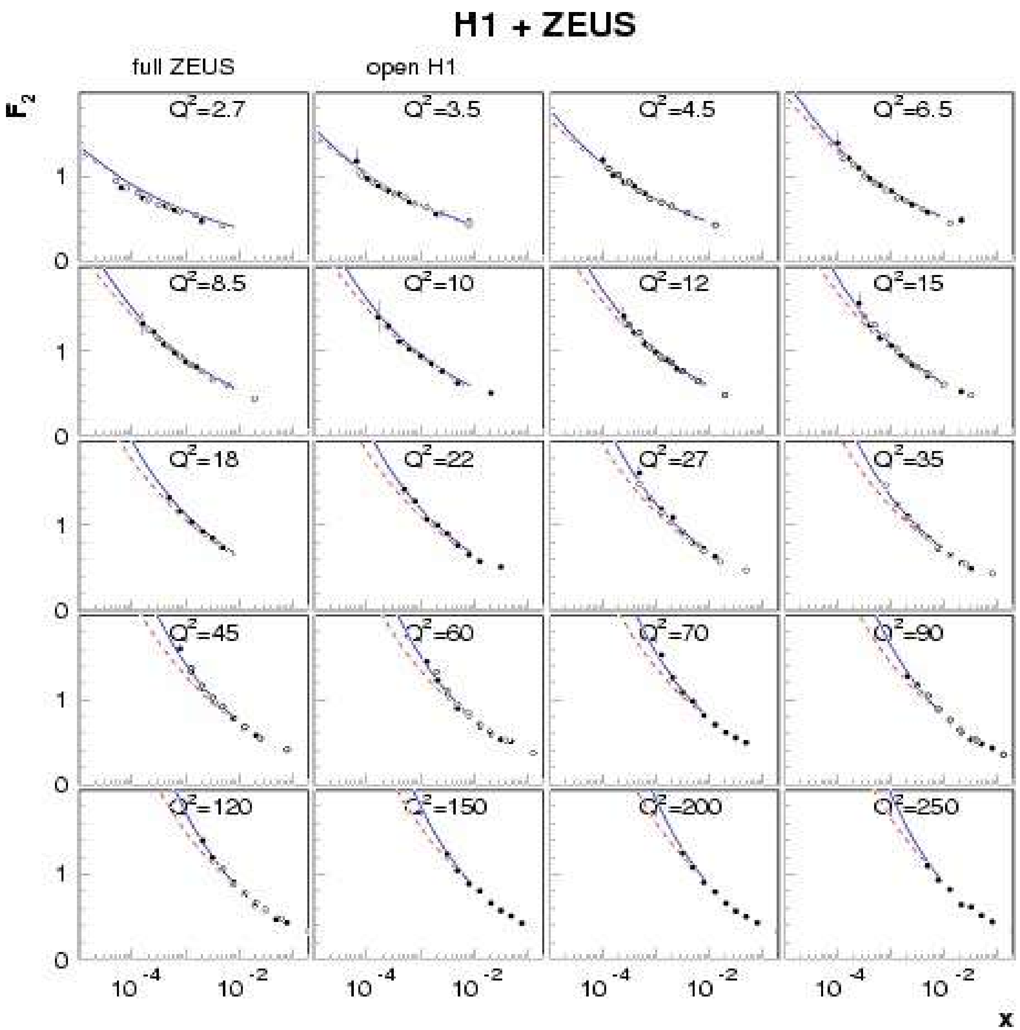
- Forward neutron-tagging (ZDC): ~50% UPC colls. lead to nuclear breakup.

Saturation effects at HERA (ep) and RHIC (dA,AA)

HERA: $F_2(x,Q^2)$ at moderate Q^2

- Saturation models describe well $F_2(x,Q^2)$ in "transition region" of moderate/low Q^2 (also DGLAP, though at limit of applicability)

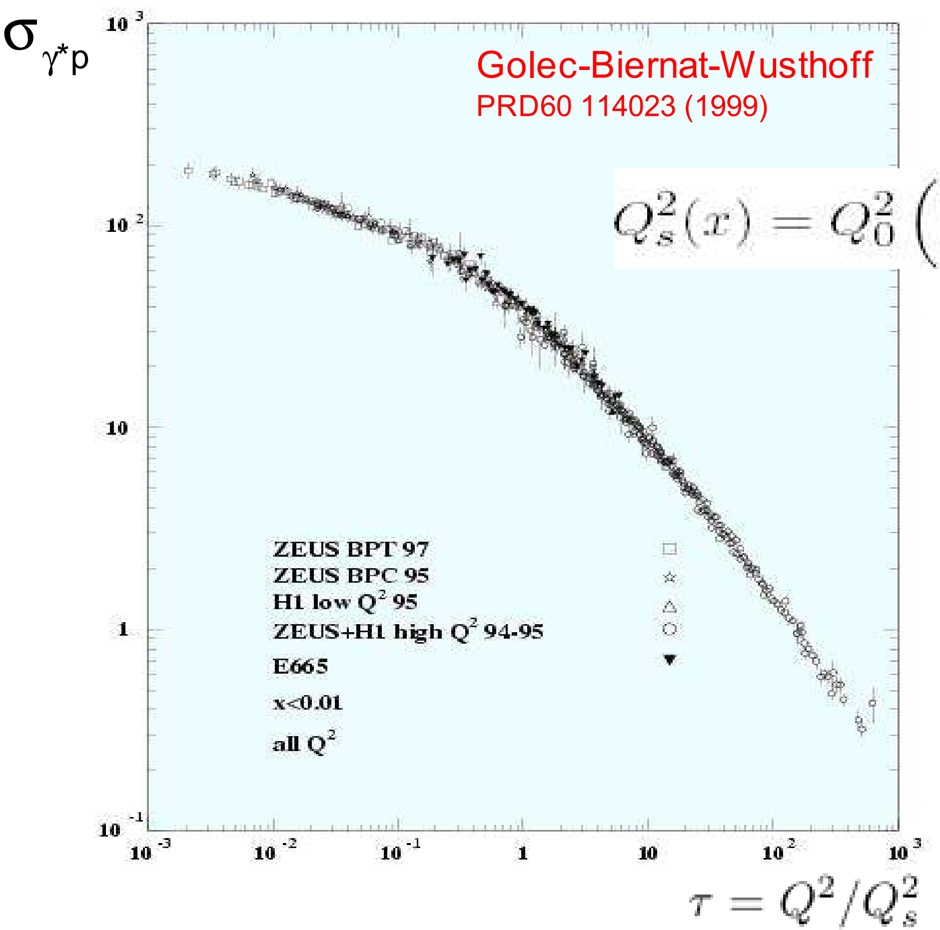




HERA: "Geometric scaling" of low-x $F_2(x,Q^2)$

- Saturation predicts low-x structure dependence on single scale Q^2_s

  DIS inclusive cross-section shows scaling for all **x < 0.01**, $0.045 < Q^2 < 450$ GeV^2



$$Q_s^2(x) = Q_0^2 \left(\frac{x_0}{x}\right)^{\lambda}$$, Q_0 = 1 GeV, λ = 0.3

described by "dipole cross-section" model (derivable within CGC):

$$\sigma_{\gamma^* H}(\tau, Q^2) = \int_0^1 dz \int d^2 r_\perp \, |\Psi(z, r_\perp; Q^2)|^2 \, \sigma_{\mathrm{dipole}}(\tau, r_\perp)$$

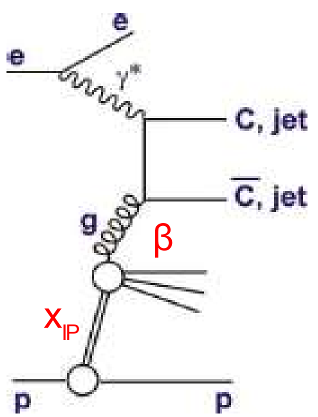
$$\sigma_{q\bar{q}p}(r_\perp, x) = \sigma_0 \left[1 - \exp\left(-\frac{r_\perp^2 Q_s^2(x)}{4}\right)\right]$$

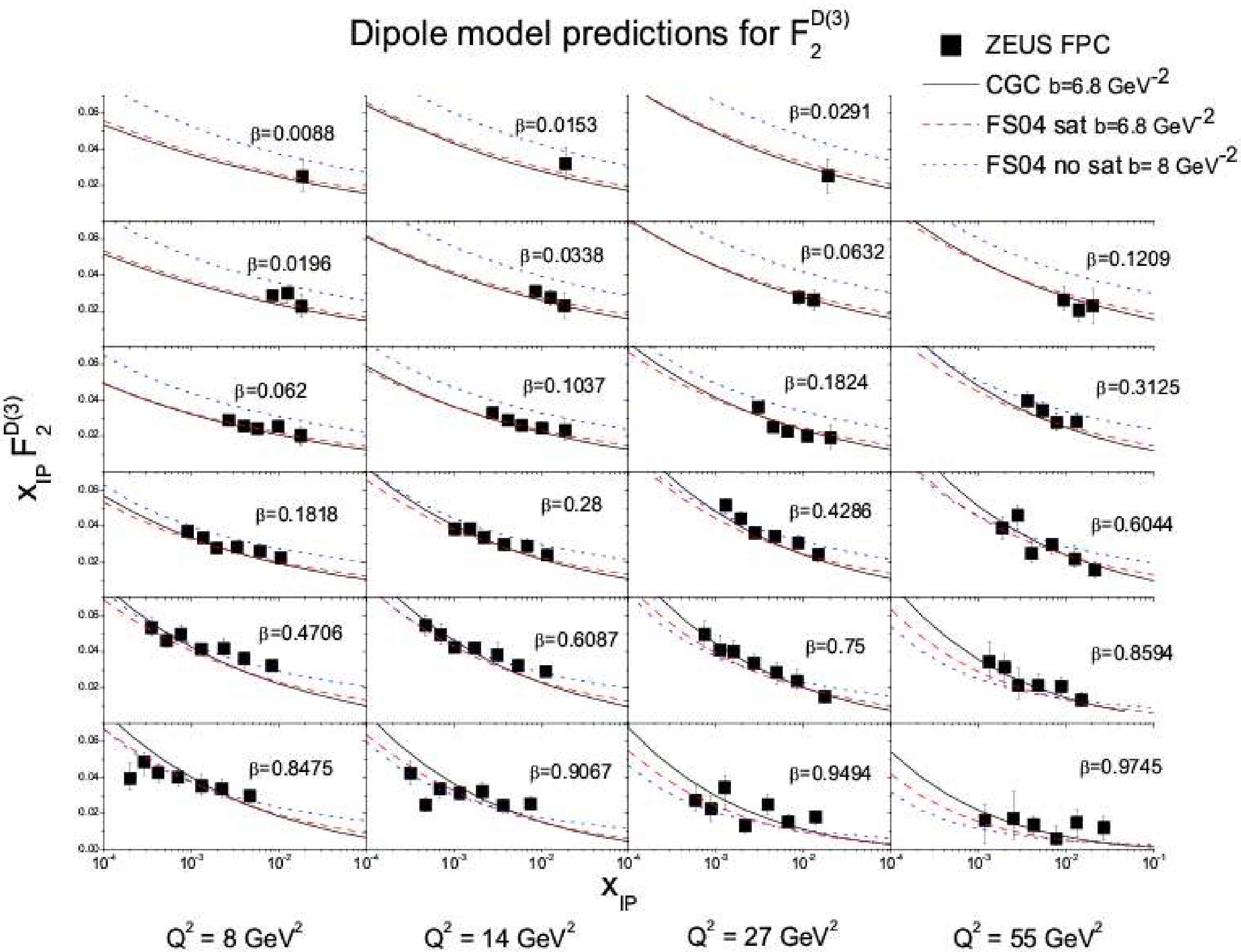
up to relatively large Q^2 ("extended scaling" region):

$$Q_s^2 < Q^2 < Q_s^4/\Lambda^2$$

HERA: Diffractive structure function (dPDFs)

- Saturation models can describe consistently total γp x-section (F_2) and DDIS ($x_{IP}F_2^{D(3)}$, Pomeron structure) and DVCS forward amplitudes:





x_{IP} = fraction of p momentum carried by Pomeron

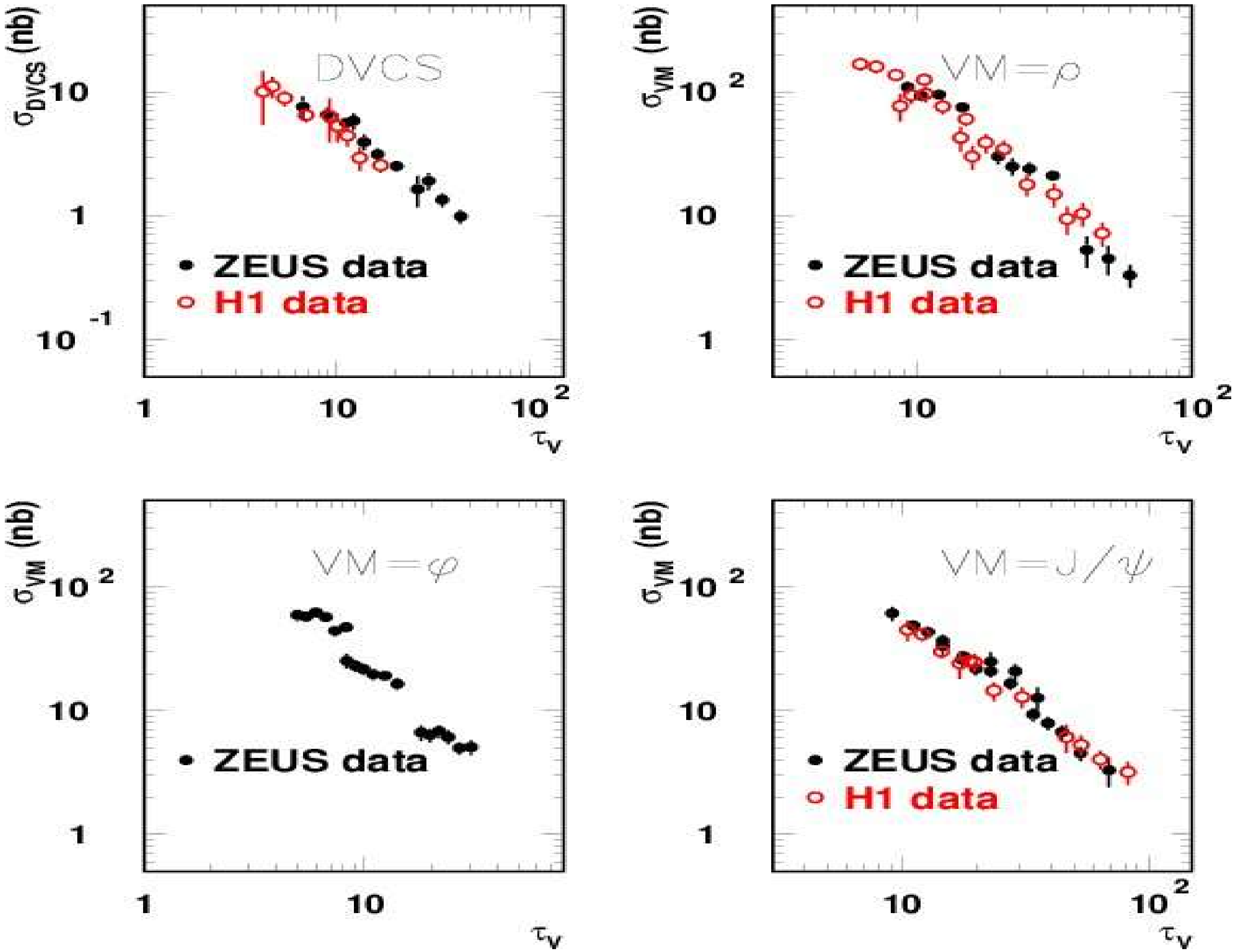
β = fraction of IP momentum carried by struck parton

Forshaw, Shaw
hep-ph/0411337

HERA: Geometric scaling in diffractive DIS

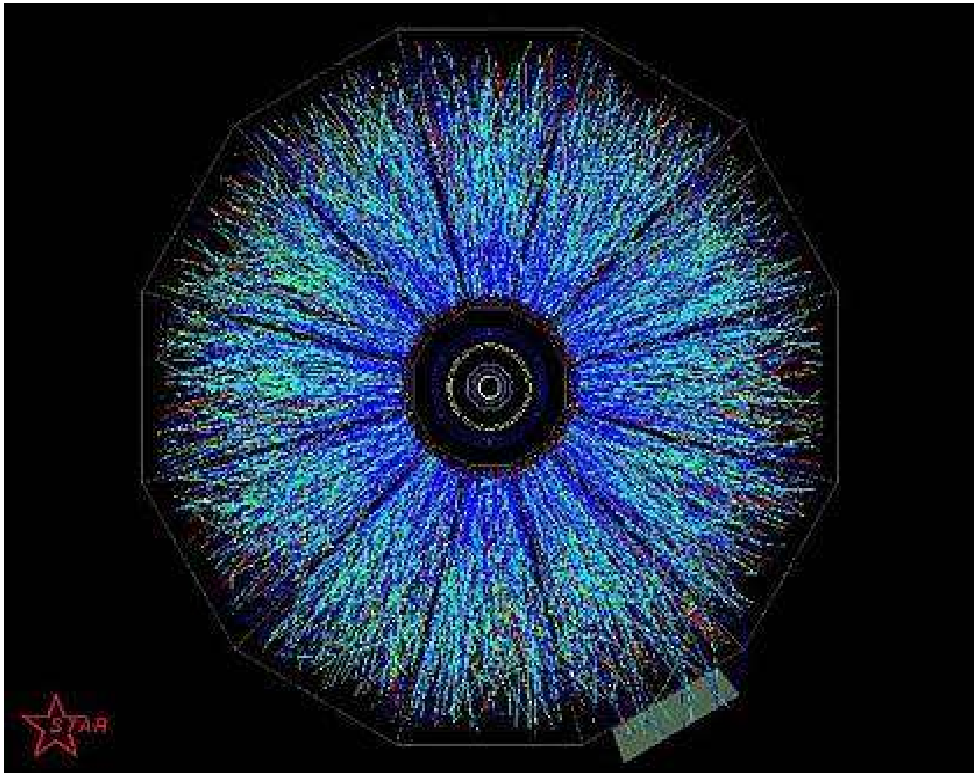
- Geometric scaling also observed in diffractive observables: DVCS, exclusive vector-meson:

C.Marquet, L. Schoeffel
hep-ph/0606079



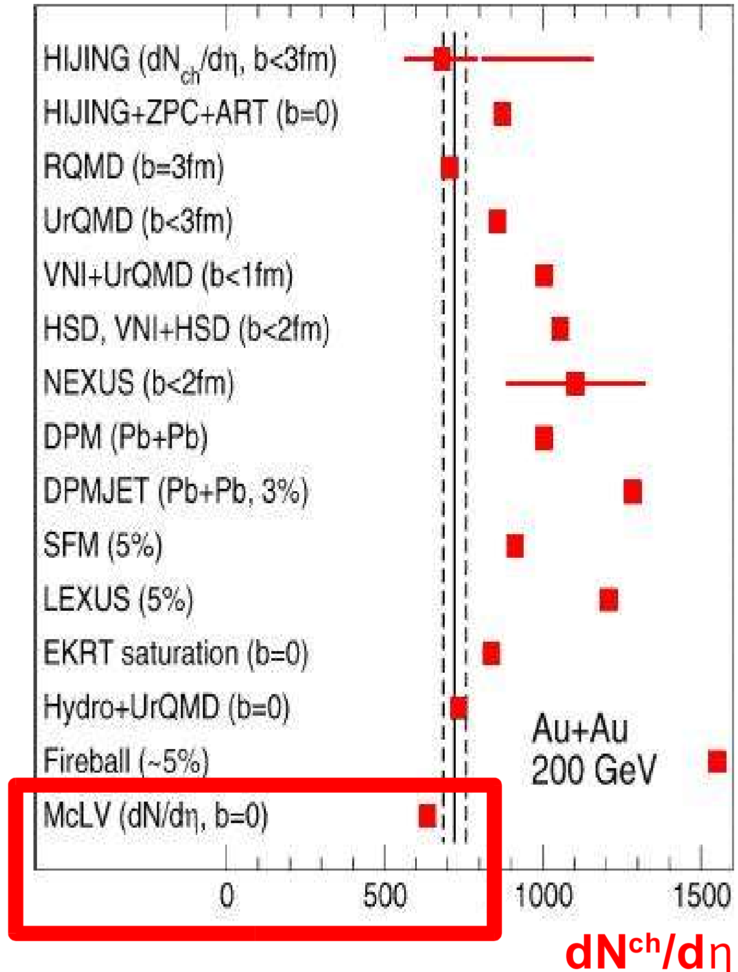
RHIC: Total AA hadron multiplicity (I)

➤ AuAu (200 GeV) 0-5% central collisions:



~ 700 charged particles per unit rapidity at y=0

Armesto-Pajares IJMP-A 14 (2000) 2019



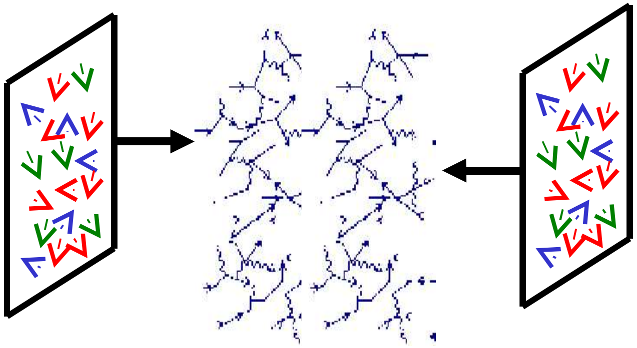
➤ "Reduced" multiplicity predicted by saturation models.

RHIC: Total AA hadron multiplicity (II)

- Final multiplicity ∝ Initial multiplicity of released gluons ∝ Q_s:

Nardi, PLB507(01)121 :

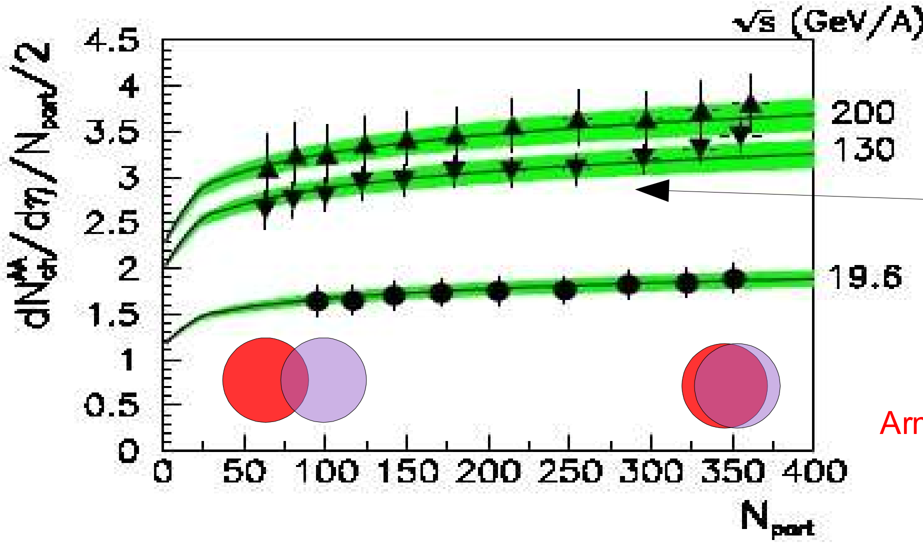
$$\frac{dN}{d^2b\,d\eta} \propto \frac{1}{\alpha_s(Q_s^2)}\,Q_s^2 \propto xG(x,Q_s^2)A^{1/3}$$



+ "local parton-hadron duality" assumption
  (*1 gluon = 1 final hadron*)

- Centrality (and √s) dependence of hadron multiplicities described:

AuAu – 200 GeV



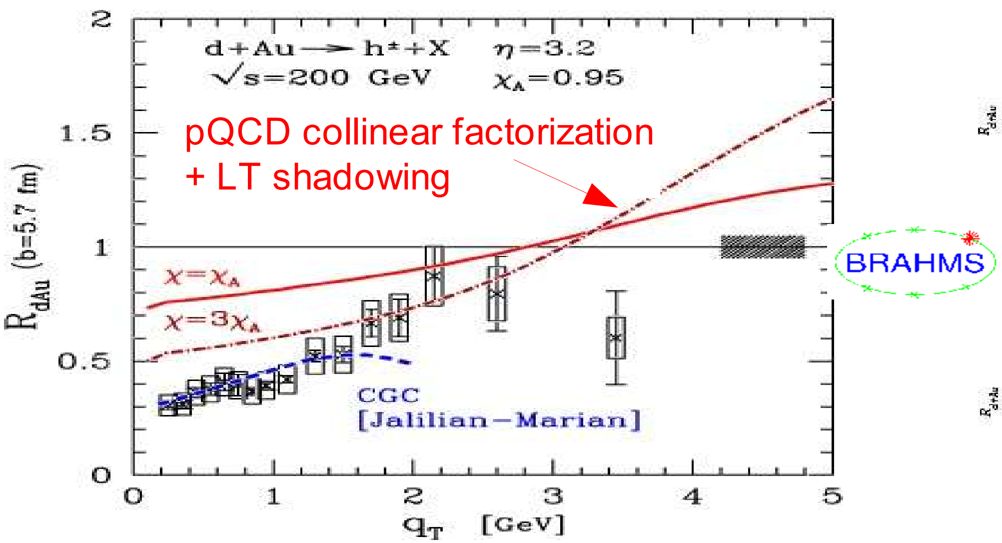
$$\sim \frac{1}{\alpha_s(Q_s^2)}$$

Armesto et al., hep-ph/0407018

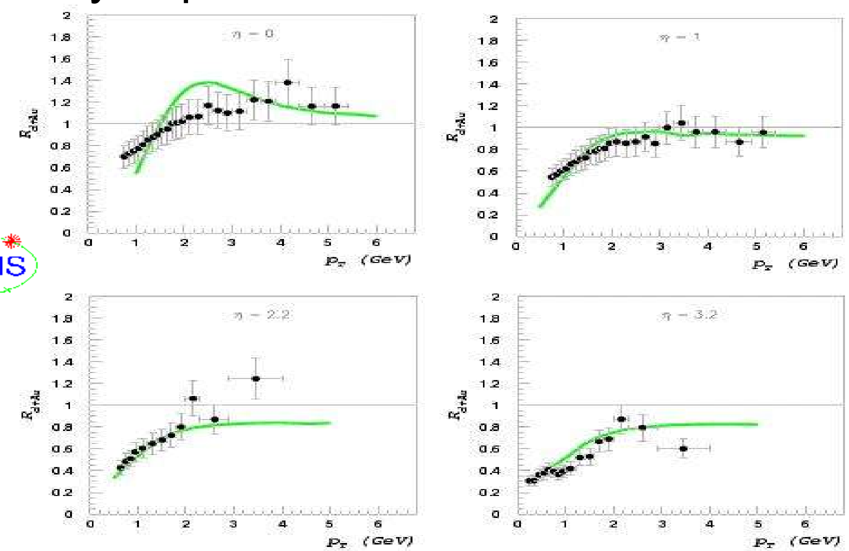
RHIC: forward dAu p_T spectra

- Suppression of hadron spectra: p_T ~ 2 – 4 GeV/c at forward rapidities (reduced number of partonic scattering centers at low-x):

Ratio dAu to pp (200 GeV) **y = 3.2**



y dependence:



Kharzeev, Tuchin, Kovchegov, hep-ph/0405045

- Plus, CGC can explain other pA phenomenology ...

(1) Leading-twist “shadowing”: extended scaling region

(2) Cronin-enhancement at y=0: gluons redistributed from low- to higher x

- However: RHIC/HERA saturation “evidences” at moderate p_T
  Q_s ~ 1 – 2 GeV/c too close to non-perturbative regime.

Low-x QCD at LHC

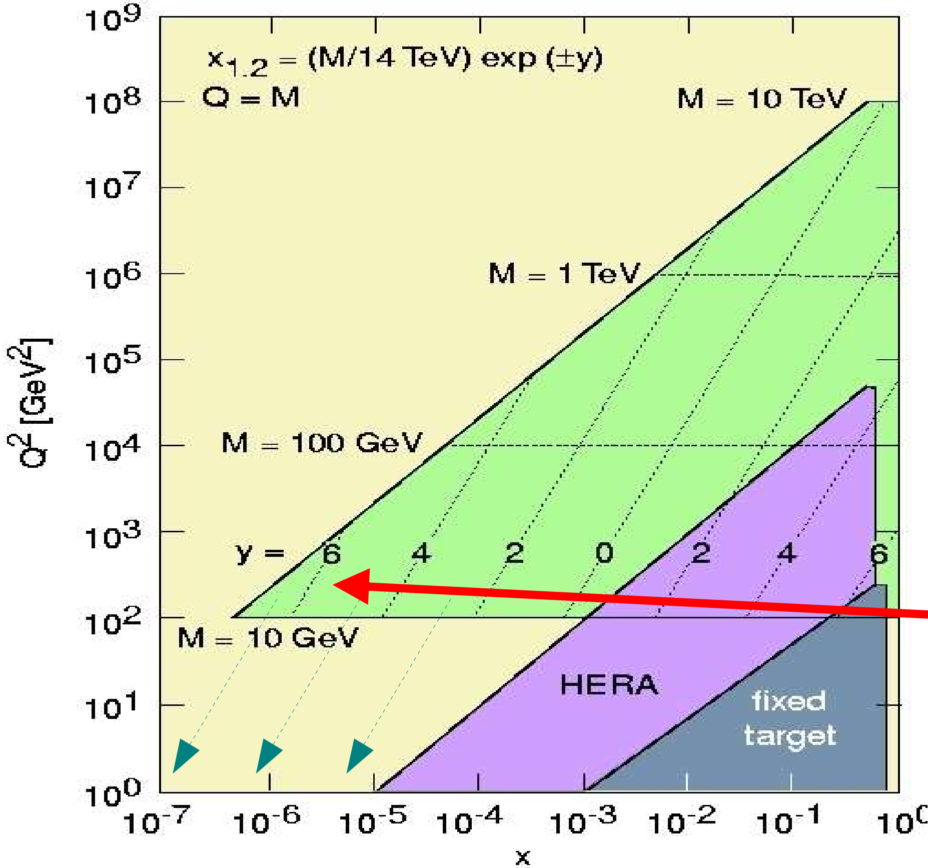
LHC: low-x proton PDF

- pp @ 14 TeV :

  (i) Very high $\sqrt{s}$ $\Rightarrow$ Bjorken $x=2p_T/\sqrt{s}$ ~70 times lower than pp @ RHIC

  (ii) Saturation momentum: $Q_s \sim 0.2\,(\sqrt{s})^{0.2\text{-}03} \sim 2$ GeV

  (iii) Very large perturbative cross-sections.



Processes:

$p(p_1)+p(p_2)\to \mathrm{jet}+\gamma+\ X$ Prompt γ

$p(p_1)+p(p_2)\to l\bar{l}+\ X$ Drell-Yan

$p(p_1)+p(p_2)\to \mathrm{jet}_1+\mathrm{jet}_2+\ X$ Jets

$p(p_1)+p(p_2)\to \mathrm{Q}+\bar{\mathrm{Q}}+\ X$ Heavy Flavours

$p(p_1)+p(p_2)\to W/Z+\ X$ W,Z production

For y > 5, M < 10 GeV

$\Rightarrow$ x down to 10^{-6}-10^{-7} !

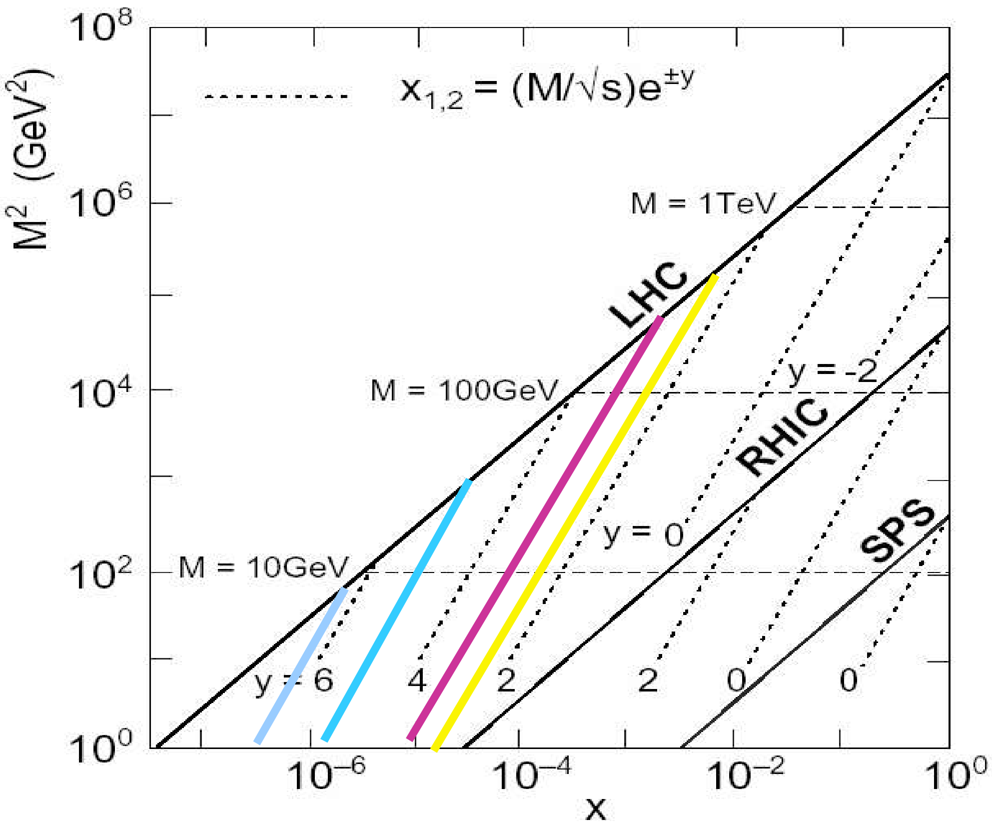
LHC: low-x nuclear PDF

- PbPb @ 5.5 TeV, pPb @ 8.8 TeV:

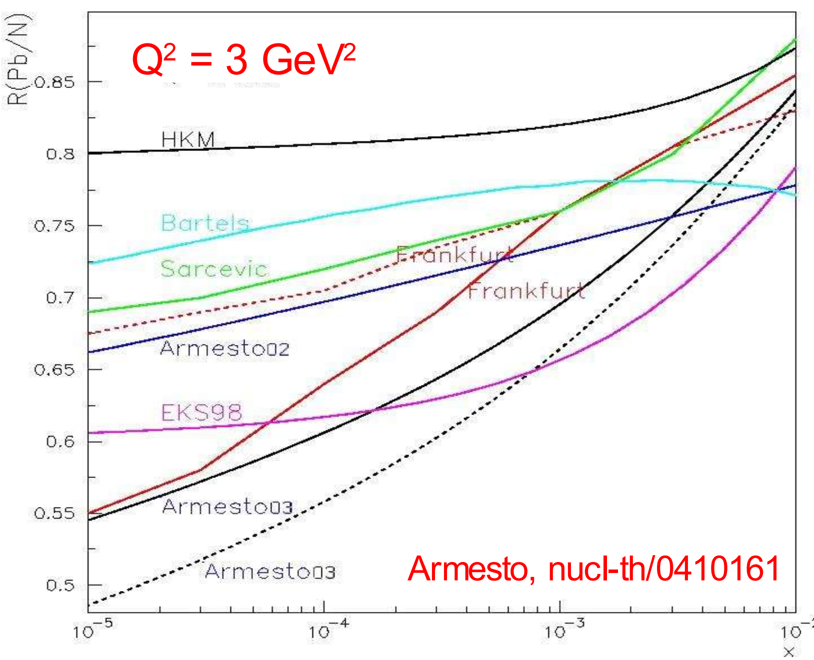
  (i) Very high $\sqrt{s}$ $\Rightarrow$ Bjorken $x=2p_T/\sqrt{s}$ ~30-45 times lower than AuAu,dAu @ RHIC

  (ii) Saturation momentum: $Q_s \sim 0.2\, A^{1/6}\, (\sqrt{s})^{0.2\text{-}03} \sim 3$ GeV

  (iii) Very large perturbative cross-sections.



Ratio of gluon densities in Pb to p:



Nuclear $xG(x,Q^2)$ basically unknown for $x<10^{-3}$!

Forward Detectors in CMS/ATLAS

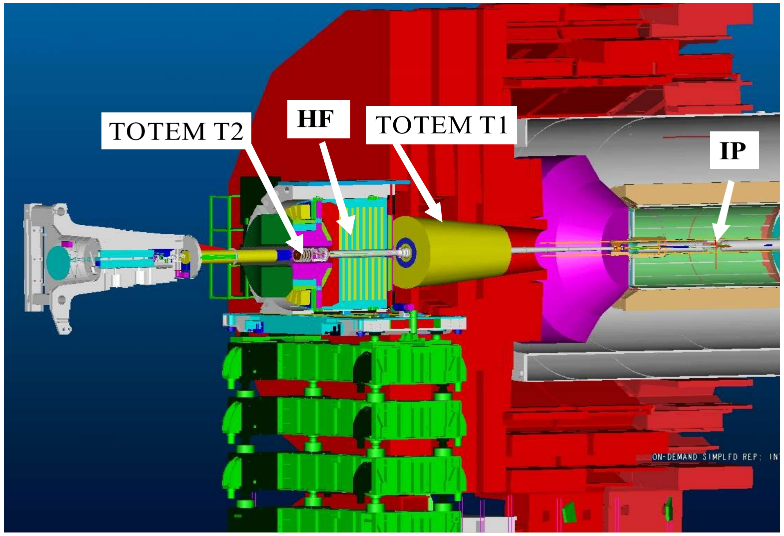
- CMS + TOTEM:

  HF (Iron-Q-fiber calo): 3 < η < 5

  TOTEM-T1: 3.1 < η < 4.7
  TOTEM-T2 (GEM telescope): 5.3 < η < 6.7

  CASTOR (W/-Q-fiber calo): 5.25 < η < 6.5

  ZDC (W/Q-fiber calo): η > 8.5 (neutral)

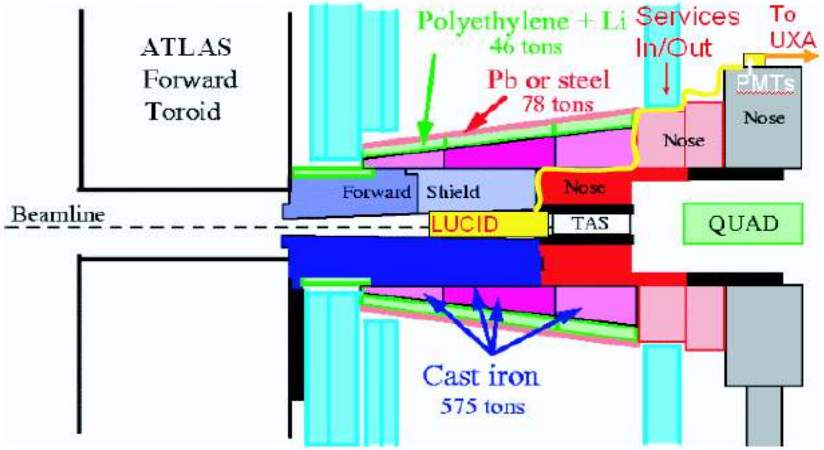


- ATLAS:

  Forw. Cal.: 3 < η < 5

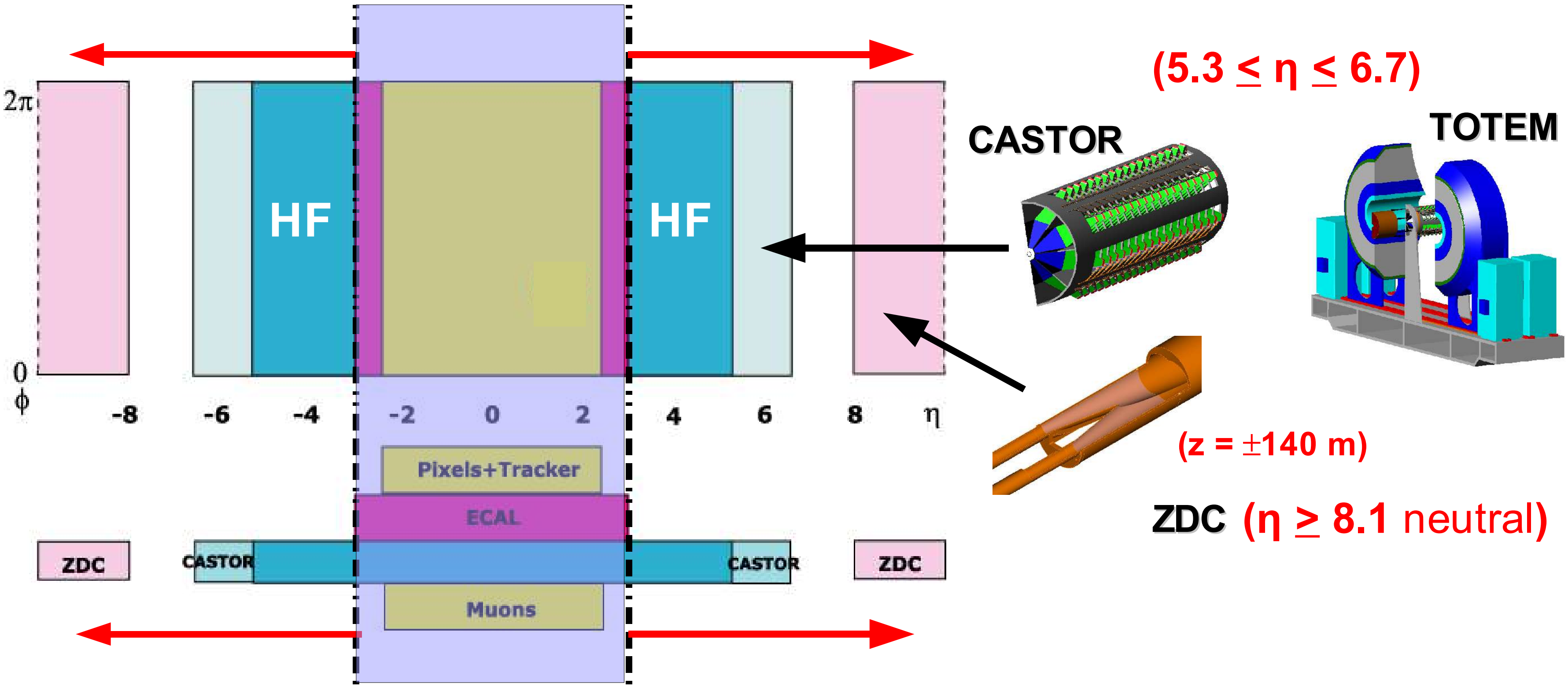
  LUCID (Cerenkov Counter): 5.4 < η < 6.1

  ZDC (W/Q-fiber calo): η > 8.5 (neutral)



CMS + TOTEM forward detectors

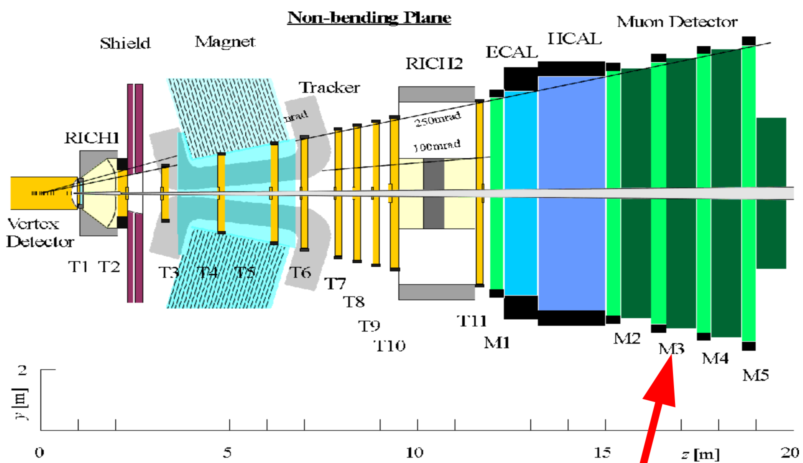
- HF,CASTOR,ZDC + TOTEM: Quasi-full acceptance at LHC

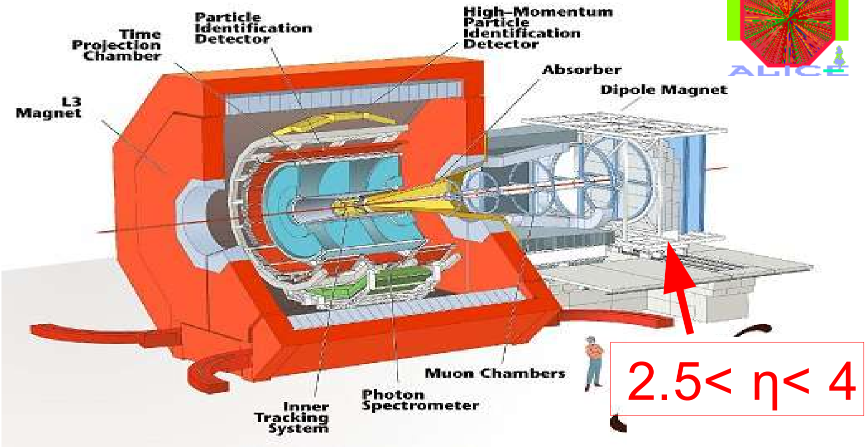


- Detection capabilities within $\eta \leq 6.7$ (and $\eta \geq 8.1$, neutral).
- Hard scattering measurements (jets, high-p_T hadrons, DY) down to $x \sim 10^{-6}$ in pp, pA, AA at LHC.

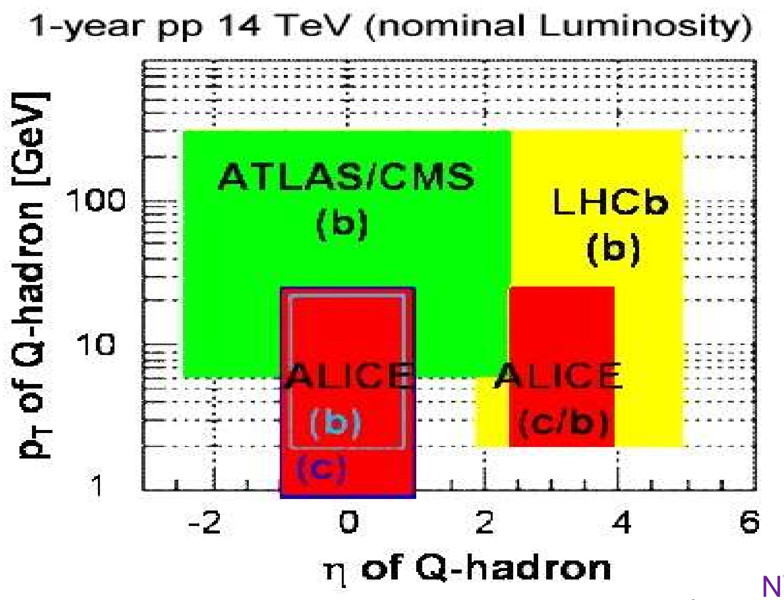
Forward Detectors in ALICE/LHCb

- ALICE, LHCb forward muon spectrometers:





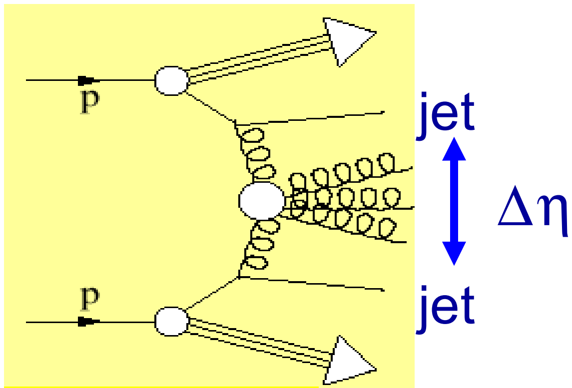
- Good capabilities for heavy-Q, QQbar measurements at low-x:



Example I: Forward jets

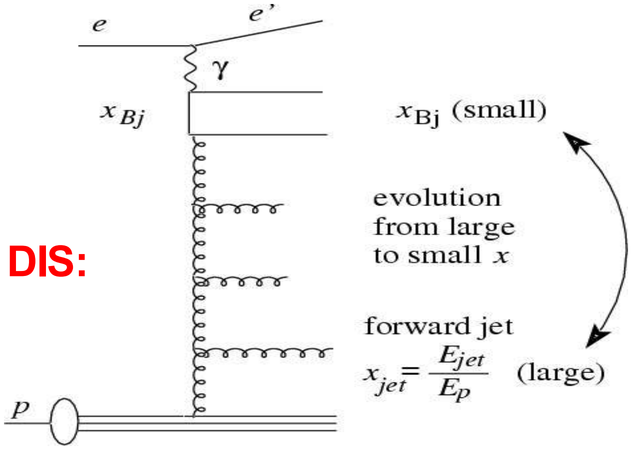
- Forward jet production ("Mueller-Navelet" jets):

hadron-hadron:



A. de Roeck, Blois'03

DIS:

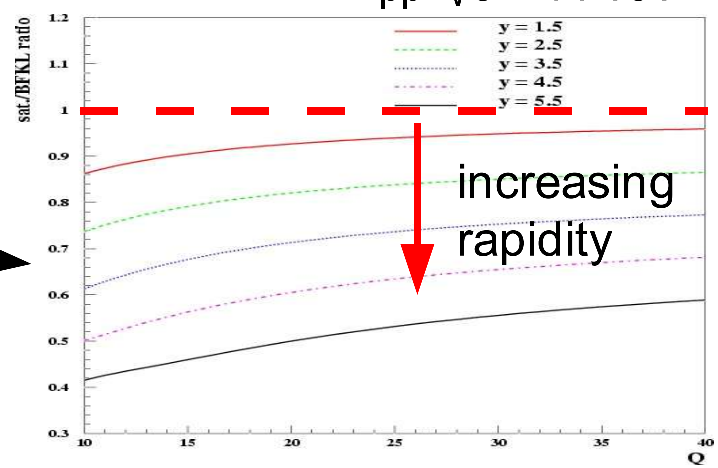


Jets separated by several Δη very sensitive to non-DGLAP evolution (BFKL, gluon saturation):

Suppresed ratio sat./BFKL for forward jets at LHC

Marquet, Royon, hep-ph/0510266

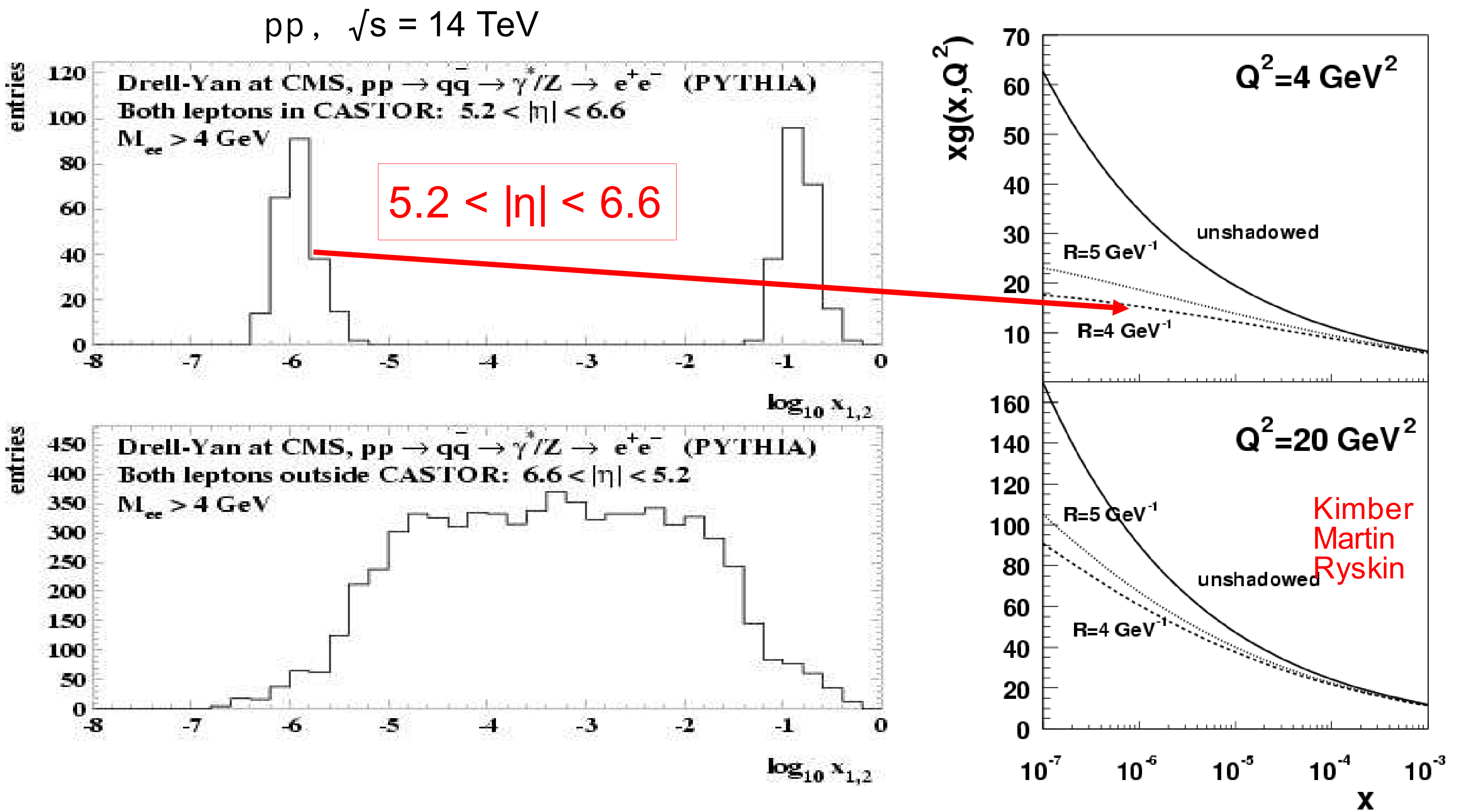
pp $\sqrt{s}$ = 14 TeV



- Measurement feasible in ATLAS/CMS forward calorimeters ($3 < \eta < 5$)

Example II: Forward Drell-Yan

- Drell-Yan feasibility studies with CMS (CASTOR) + TOTEM (T2):



- T2 tracker+ CASTOR calo needed to deal w/ large QCD (and QED) bckgd.

Van Mechelen, Ochesanu, Sarkysian, CMS PTDR2 (see also M.Grothe talk)

Example III: Quarkonia photoproduction

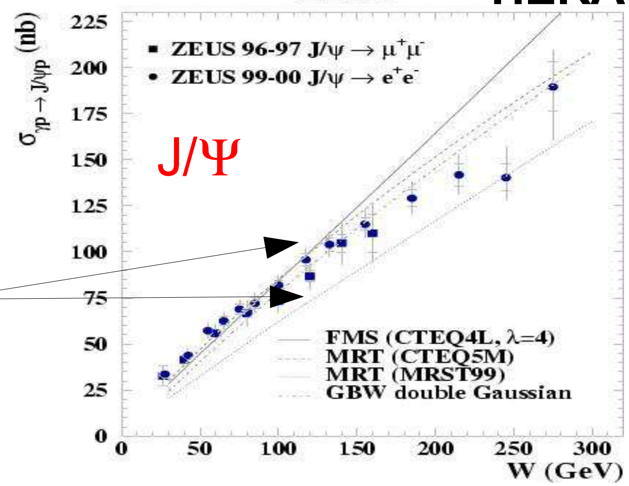
- Exclusive QQbar: $\gamma p \rightarrow Vp$ ($V=J/\Psi,\Upsilon$) very sensitive to small-x gluon:

$$\left.\frac{d\sigma(\gamma p \to Vp)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xG(x,Q^2)\right]^2$$

Ryskin et al. ZPC 76 (1997)231

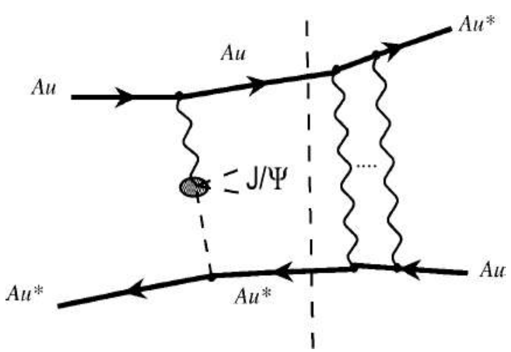
$$x = M_V^2 / W_{\gamma p}^2$$

HERA

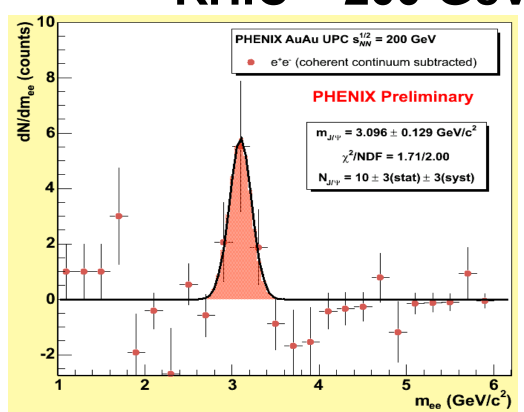


Discriminates different Ansätze & evolutions of $G(x,Q^2)$ at HERA

- $J/\Psi,\Upsilon$ photoproduction in UPC AA: access to nuclear xG

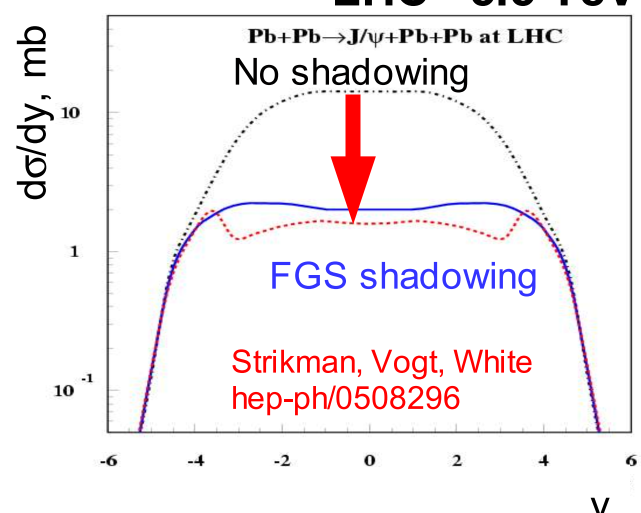


RHIC – 200 GeV



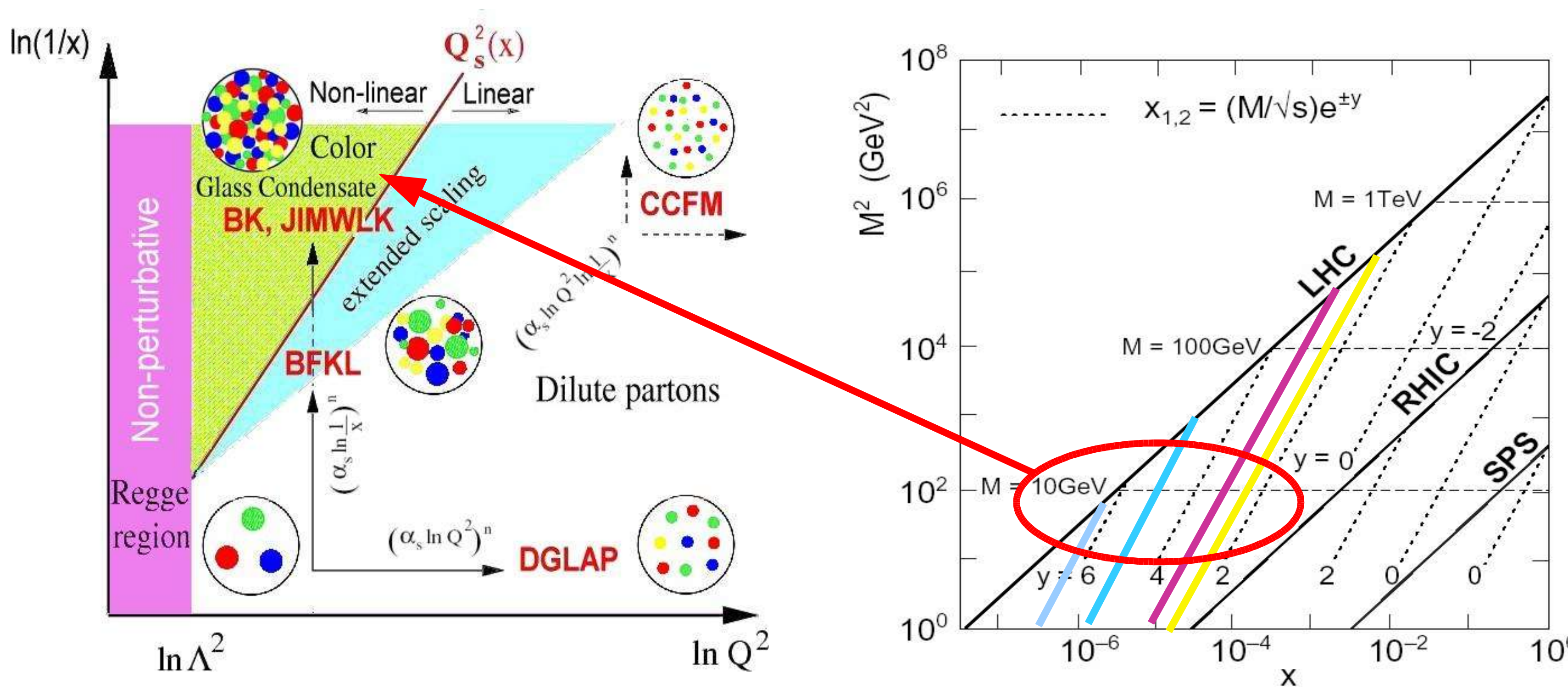
Dd'E, nucl-ex/0601001

LHC– 5.5 TeV



Summary

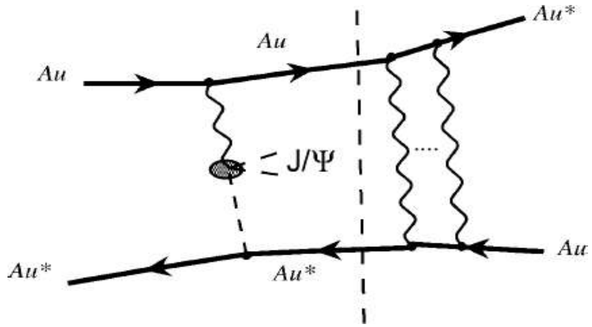
- Gluon saturation and non-linear evolution <u>must</u> set-in at (some) low-x in hadronic wave-functions → Fundamental info on high-energy limit of QCD
- Hints of non-linear QCD dynamics in *ep* (HERA) and dA,AA (RHIC)
- LHC: provides a unique lab to study high parton density /evolution down to $x \sim 10^{-6}$ (and $Q_s \sim$2-3 GeV) with forward detectors using perturbative probes in pp, pA, AA collisions



Backup slides

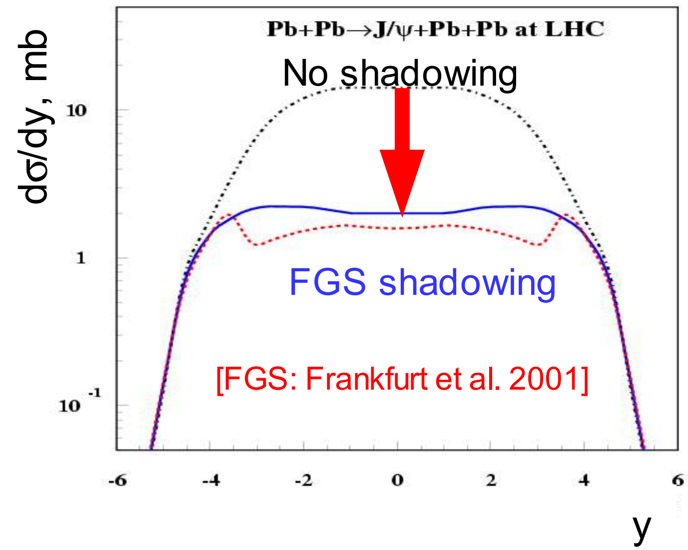
ZDC-tagged (hard) photoproduction

- Quarkonia: γ+A→ J/Ψ,Υ +A very sensitive to nuclear gluon density:



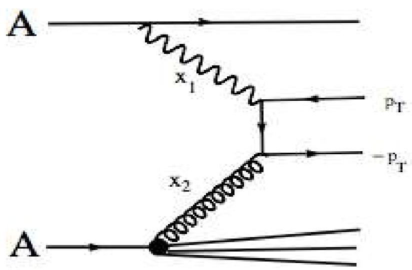
$\sigma(J/\Psi,\Upsilon) \sim |\, xG(x,Q^2)|^2$

~30% reduction of $G(x,Q^2) \Rightarrow 0.5\cdot\sigma_{J/\Psi,\Upsilon}$



- Dijet: via gluon exchange (well described in QCD & tested @ HERA)

Wider range of Q^2 than QQbar.
Photon-jet (~1% of dijet rate) has clear signature
ttbar possible in pA collisions (measure charge of top quark)

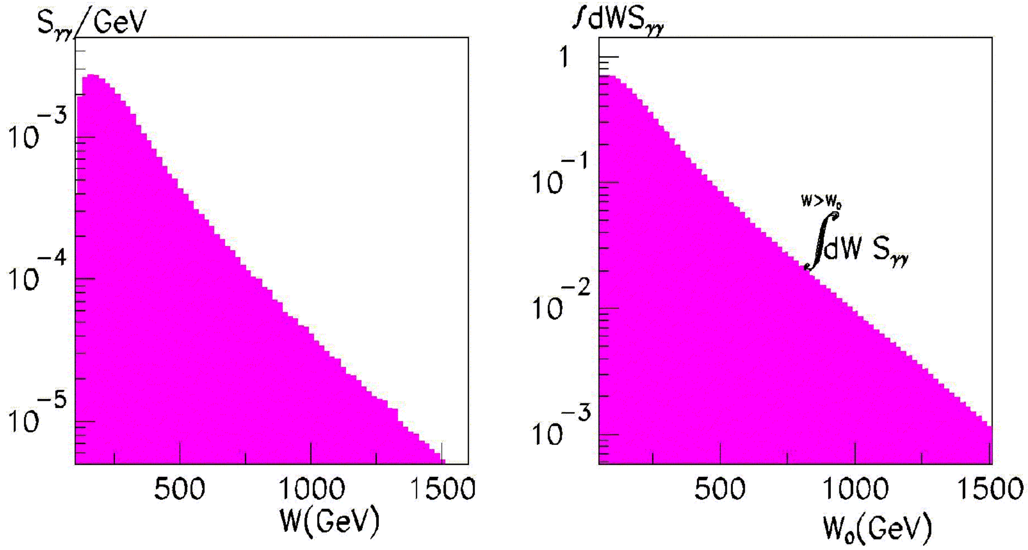


- ~50% of gA events accompanied w/ nuclear breakup (forw. n emission): ZDC- tag needed for triggering

γp interactions at the LHC

K Piotrzkowski

- γg luminosity spectra:

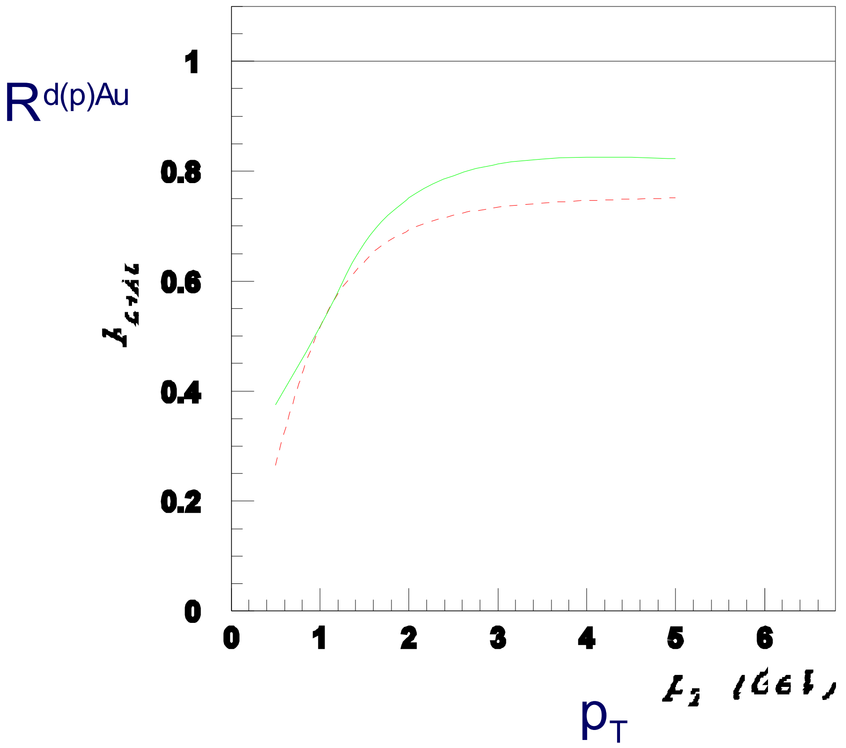


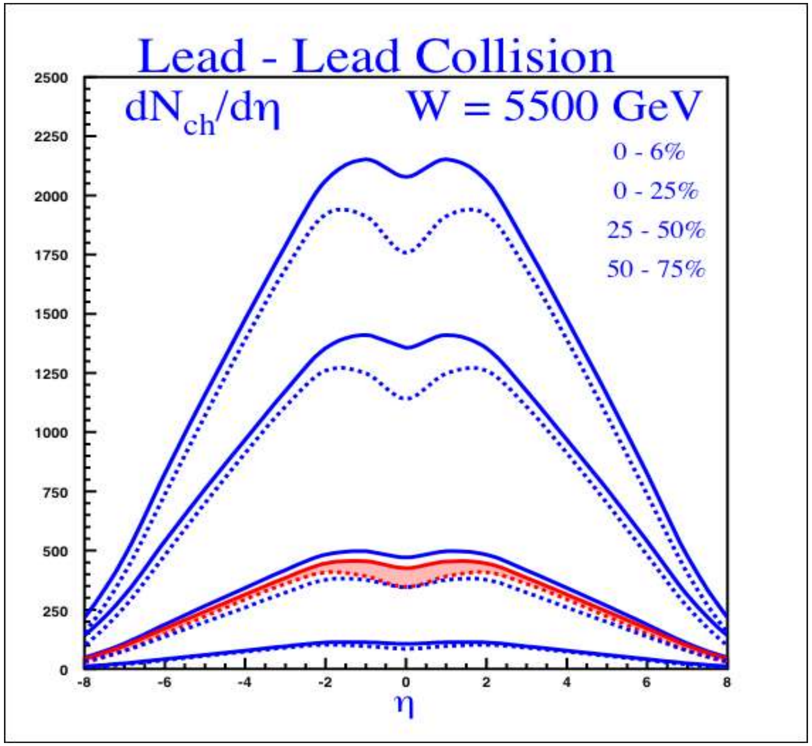
- 0.01 < x < 0.1, γ tagging range
- 0.005 < x < 0.3, Bjorken-x range

γp physics Menu:

- anomalous W and Z production at $W_{\gamma q} \geq$ 1 TeV
- top pair production – top charge + threshold scanning?
- single top production and anomalous Wtb vertex
- SM BEH – for example, γ b → H b, γ q → H W q
- SUSY studies (complementary to the nominal ones) - H^+t production (and H^{++}), b and t spairs, $\tilde{t}\chi$ pair, ...
- Exotics: compositness, excited quarks, .

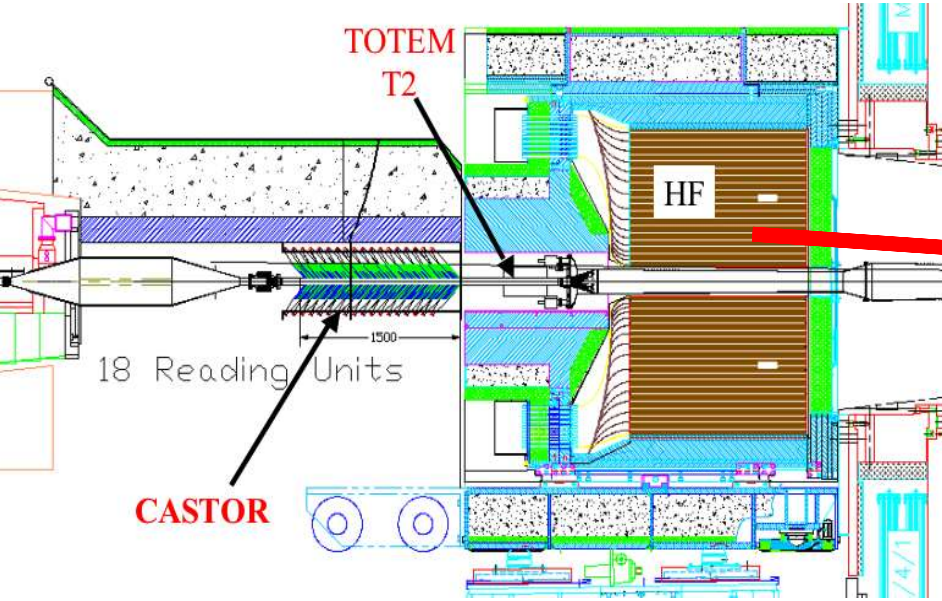
Saturation predictions @ LHC (nucleus)

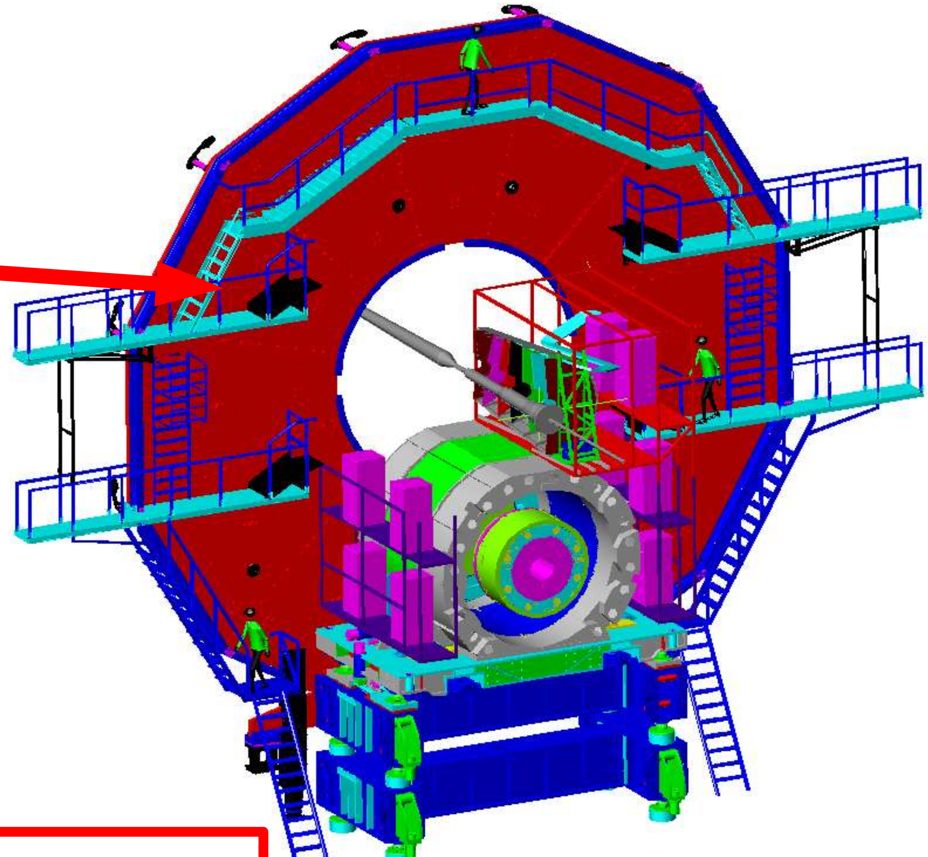




Hadronic Forward Calorimeter (2.5 <η< 5)

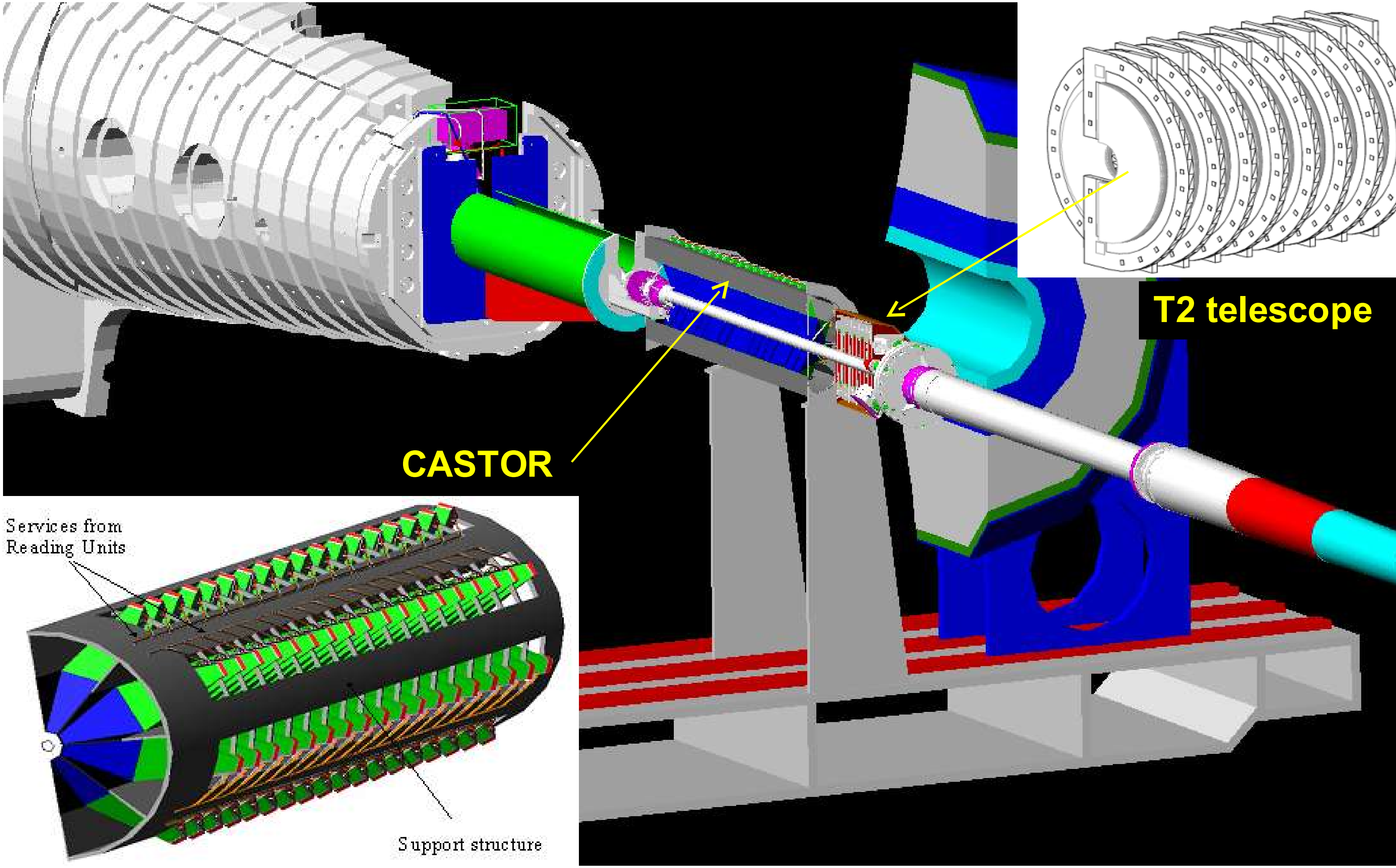
- ..



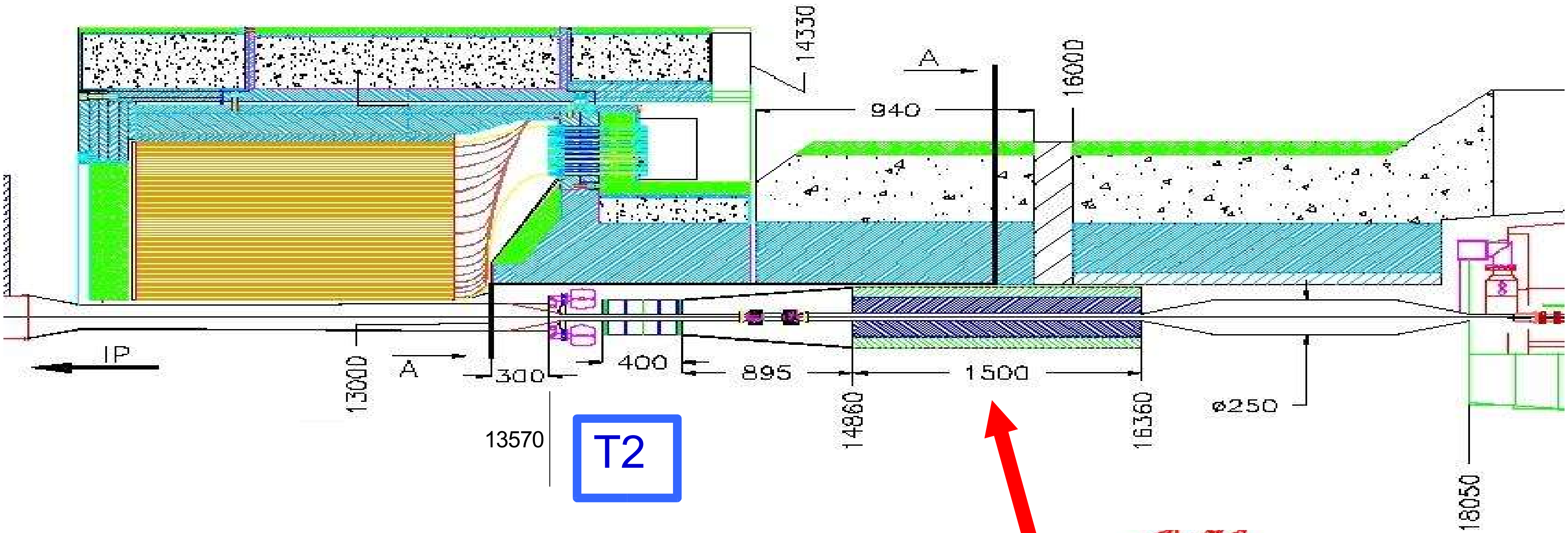


- 11.2 m from IP5.
- Steel+quartz-fibre Cherenkov (EM+HAD) calorimeter
- 1.65 m absorber depth
- 900 towers (1200 channels): $\Delta\eta \times \Delta\Phi \sim 0.18 \times 0.18$
- Hamamatsu R7525 rad-hard PMTs

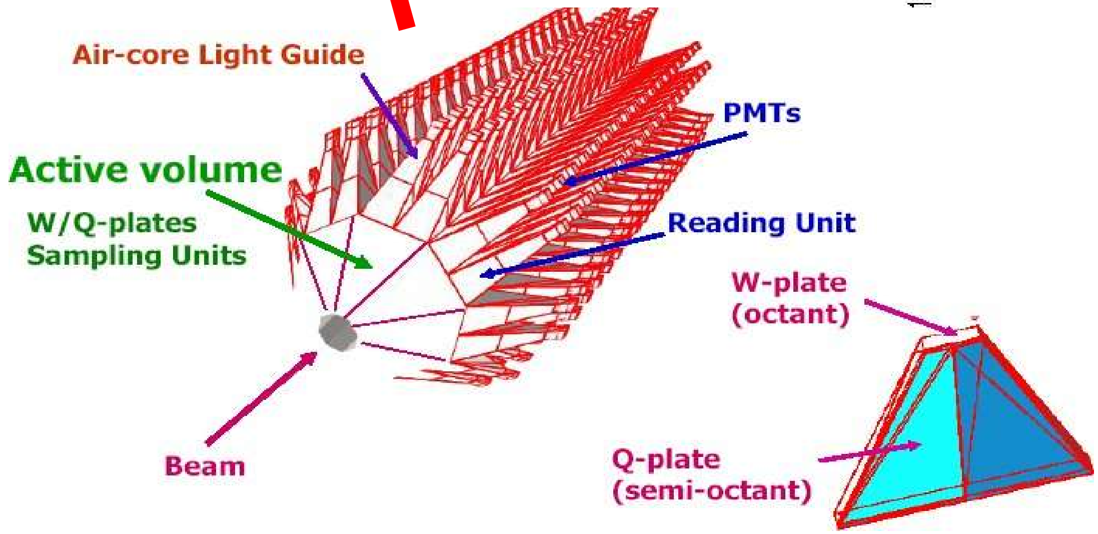
T2 and CASTOR (5.1 < η < 6.7)



CASTOR forward calorimeter (5.1 <η < 6.6)

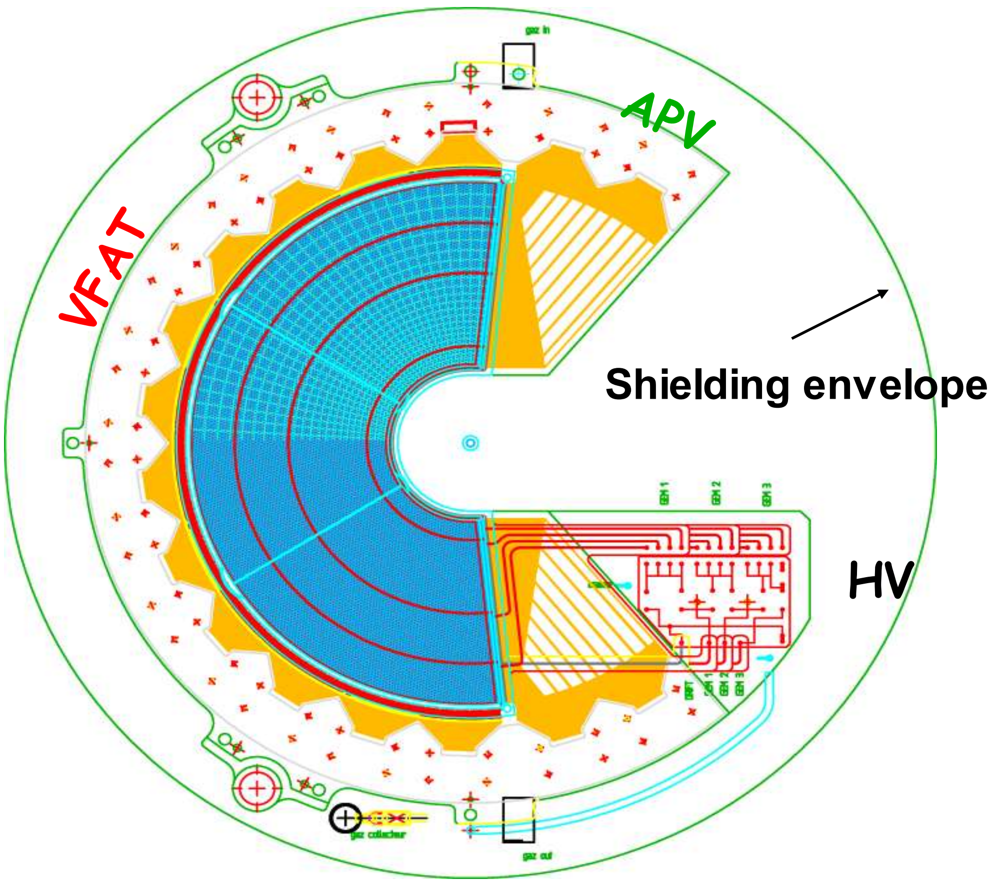


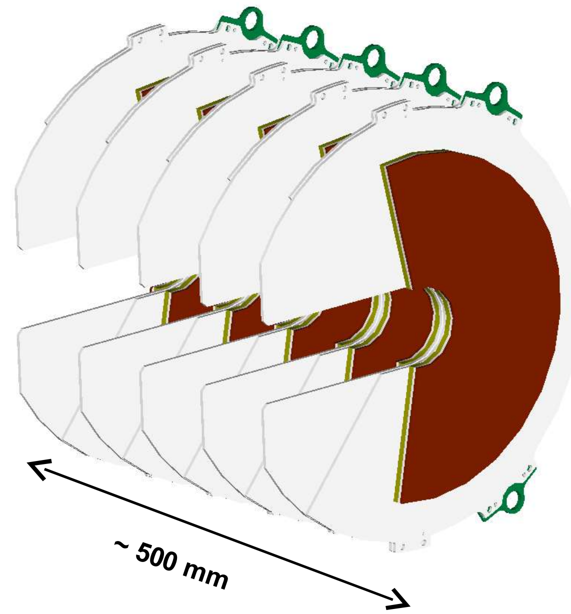
- Tungsten plates + quartz fibres
- Cherenkov sampling calorimeter
- Light-guides + APDs readout
- Azimuth segmented (8 octants)
- EM section: 11.2 cm ~ 19 X_0
- HAD+EM sections: 136 cm~ 10λ_I
- 192 channels



TOTEM T2 Tracker (5.3 <η< 6.7)

➢ TOTEM GEM (“Gas Electron Multiplier”) charged particle telescope detector:

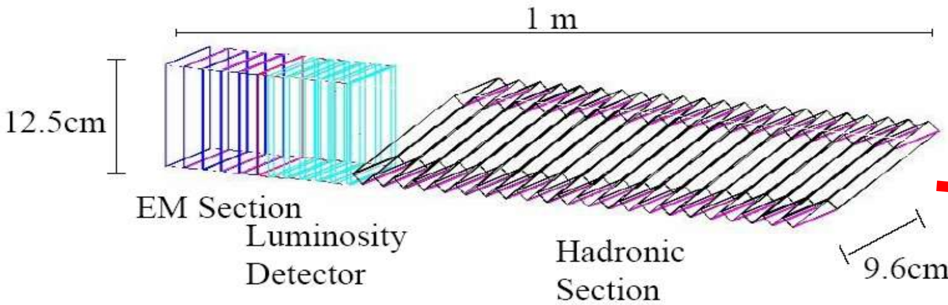


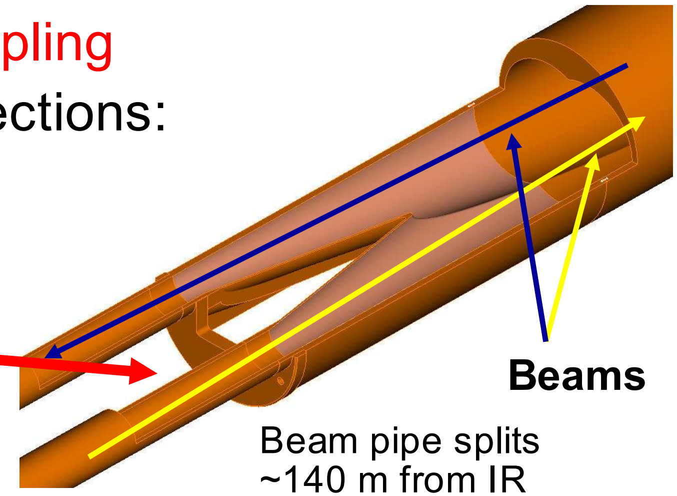


GEM half telescope

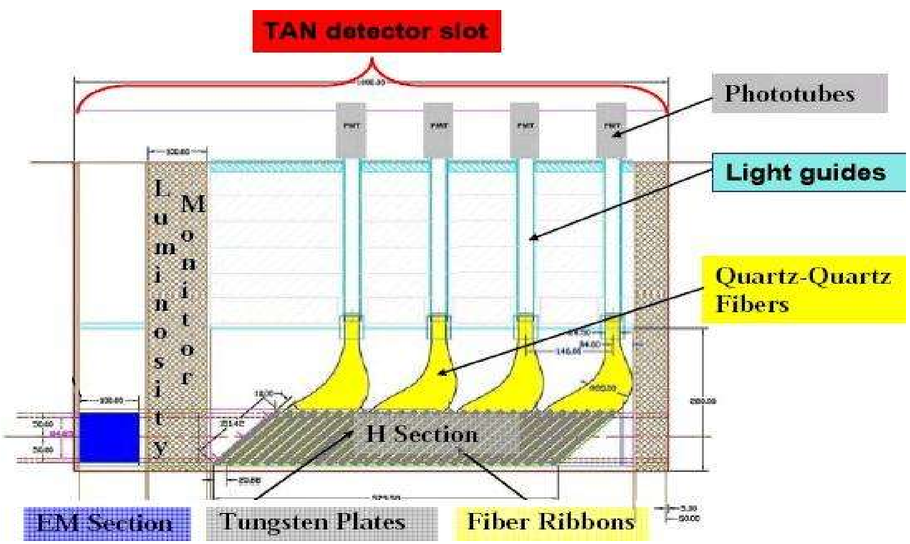
Zero Degree Calorimeter ($|\eta|$> 8.1 neutral)

- ZDC = Tungsten-plates+Quartz-fibres sampling Cerenkov calorimeter with HAD and EM sections:





- ZDC: forward neutral energy (n,γ) detection:



- *(Follows closely RHIC experience).*
- EM section: x33 2mm-W cells (~$19X_0$)
- HAD sect: x24 15mm-W cells (~$5.6\lambda_0$)
- PMTs: R7525 (as HF)
- Rad hard to ~20 Grad (AA, pp low lum.)
- Energy resolution (n,γ): σ/E~10%
- Position resolution: ~2 mm (EM sect.)
- Signals available for L1

Low-x at the LHC (nucleus)

TOTEM:

- Approved July 2004 (TDR of TOTEM web page http://totem.web.cern.ch/Totem/)
- TOTEM stand alone
  - Elastic scattering, total pp cross section and soft diffraction.

CMS:

- EOI submitted in January 2004: /afs/cern.ch/user/d/deroeck/public/eoi_cms_diff.pdf
  - Diffraction with TOTEM Roman Pots and/or rapidity gaps
- Technical Proposal in preparation for new forward detectors (CASTOR, ZDC,+…)
  - Diffractive and low-x physics part of CMS physics program (low + high)

CMS+TOTEM:

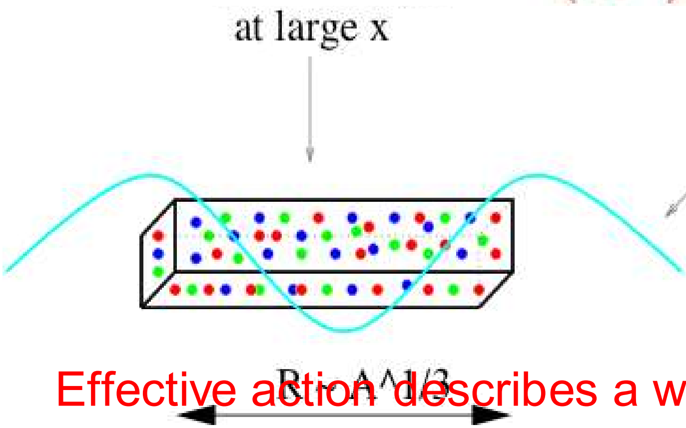
- Prepare common LOI due in Summer 2006 (M. Grothe/V. Avati organizing)
  - Full diffractive program with central activity. TOTEM will be included as a subdetector in CMS (trigger/data stream)

ATLAS:

- LOI submitted (March 04) for RP detectors to measure elastic scattering/ total cross sections/luminosity. Diffraction will be looked at later

ALICE, LHCb: no direct forward projects plans but keeping eyes open.

$$Q_S^2 \approx \alpha_S N_c \mu_A^2 \ln\left(\frac{\mu_A^2}{\Lambda^2}\right) \approx A^{1/3} \text{ for } A >> 1$$



McLerran, RV; Kovchegov; Jeon, RV

Effective action describes a weakly coupled albeit non-perturbative system

$$W_{\Lambda^+} = \exp\left(-\int d^2x_\perp \left[\frac{\rho^a\rho^a}{2\,\mu_A^2} - \frac{d_{abc}\,\rho^a\rho^b\rho^c}{\kappa_A}\right]\right)$$

$$\mu_A^2 = \frac{g^2 A}{2\pi R^2} \propto A^{1/3}$$

$$\kappa_A = \frac{g^3 A^2 N_c}{\pi^2 R^4} \propto A^{2/3}$$

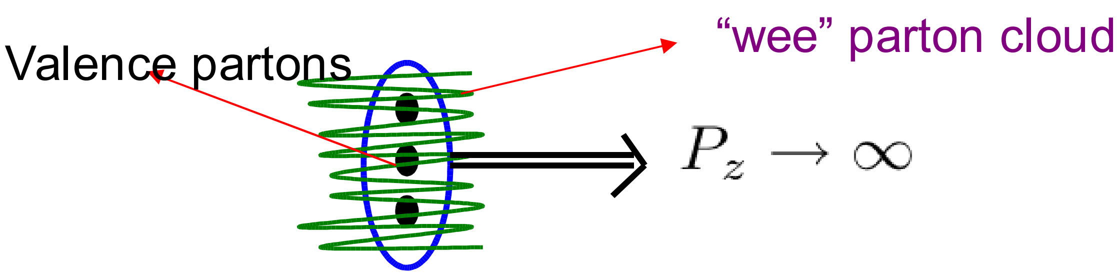
Mechanism for parton saturation

- **Competition between "attractive" bremsstrahlung and "repulsive" recombination effects.**

Maximal phase space density =>
$$\frac{1}{2(N_c^2-1)}\frac{x\,G(x,Q^2)}{\pi R^2\,Q^2}=\frac{1}{\alpha_S(Q^2)}$$

Saturated for

$$Q=Q_s(x)>>\Lambda_{\rm QCD}\approx 0.2\ {\rm GeV}$$

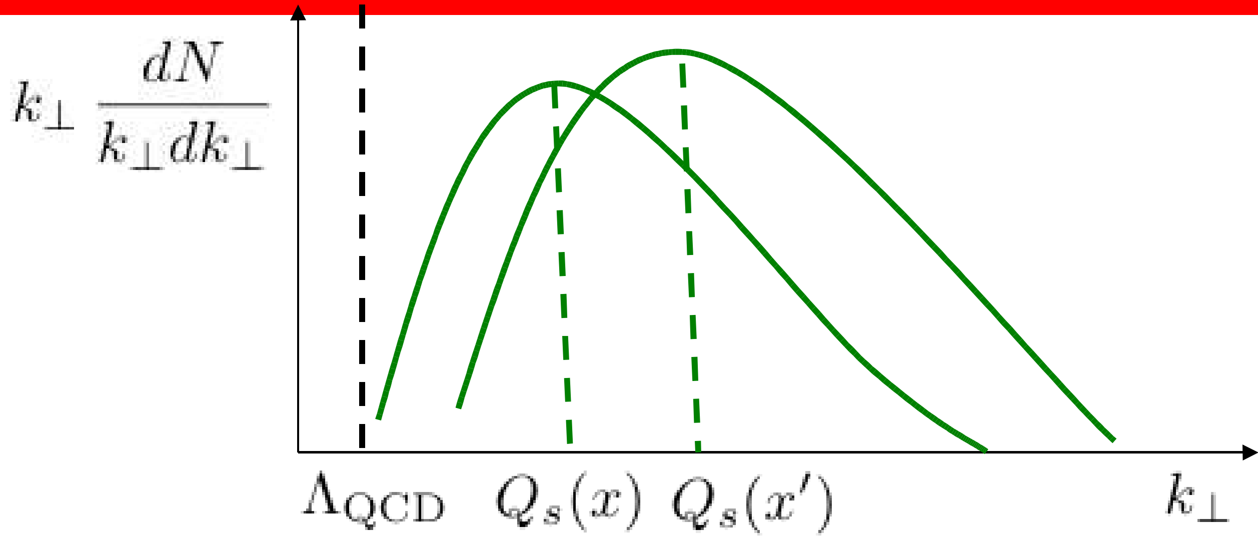


In infinite momentum frame (IMF) ,

$$|h>=|qqq>+|qqqg>+\cdots|qqqgg\cdots q\bar{q}g>$$

Construct "effective " theory of wee parton modes

Hadron at high energies is a Color Glass Condensate.



Gluons are colored

Random sources evolving on time scales much larger than natural time scales-very similar to spin glasses

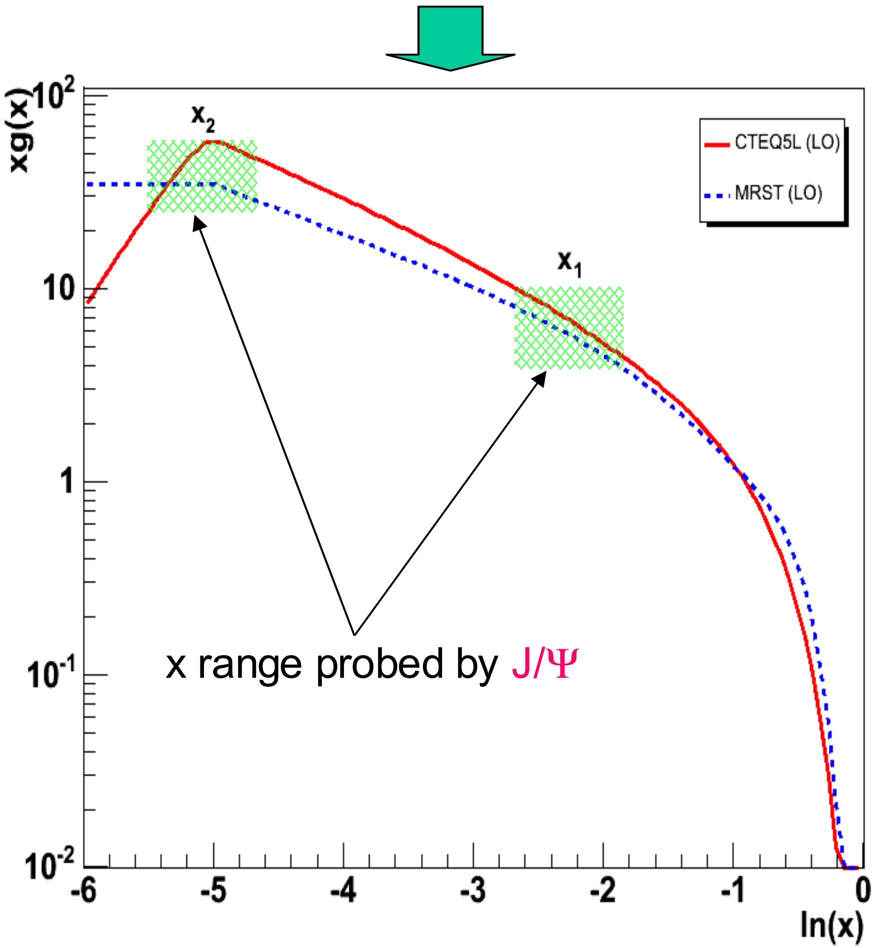
Bosons with large occupation # ~ $\frac{1}{\alpha_S}$ - form a condensate

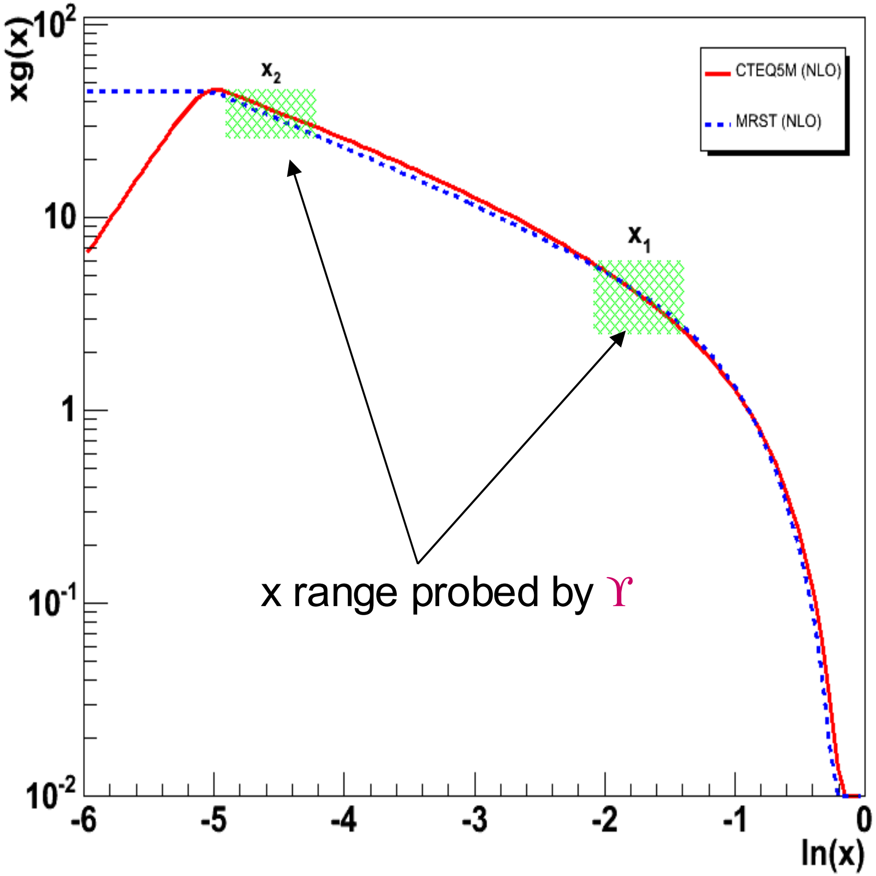
Typical momentum of gluons is Q_s

Low-x at the LHC (nucleus)

➢

LO CEM calculation





Gluon distribution functions at the scale of the charmonium calculation.

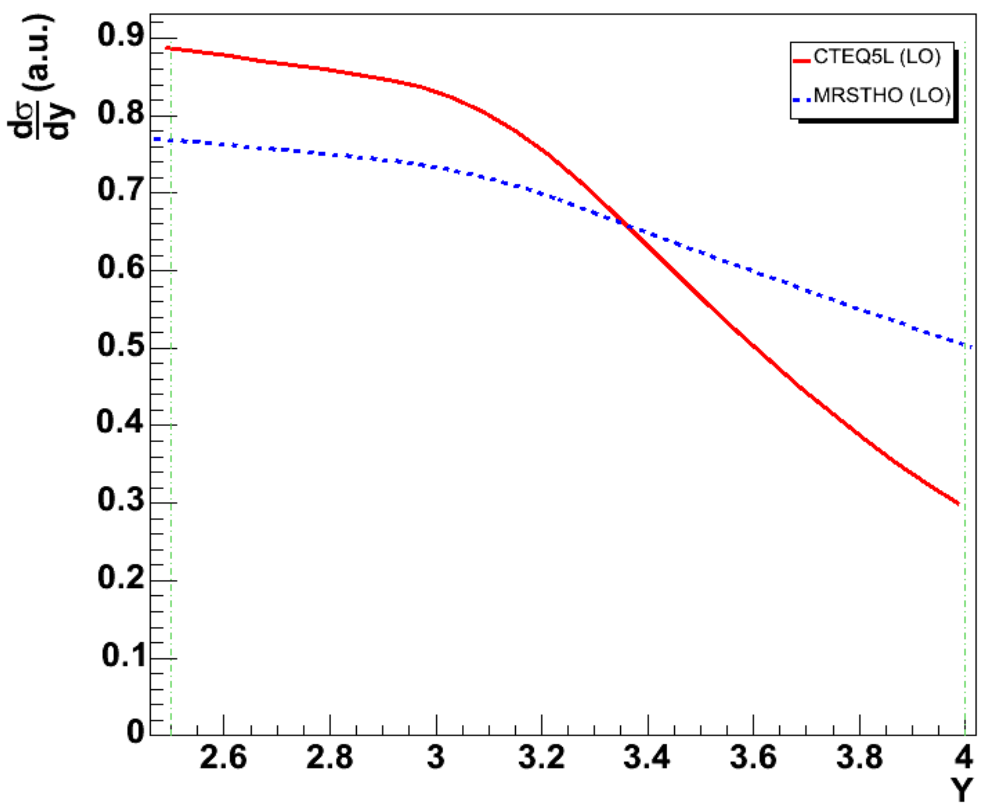
Rapidity distributions with different PDFs

➢

Approximations:
- Calculation LO
- gg contr. dominant

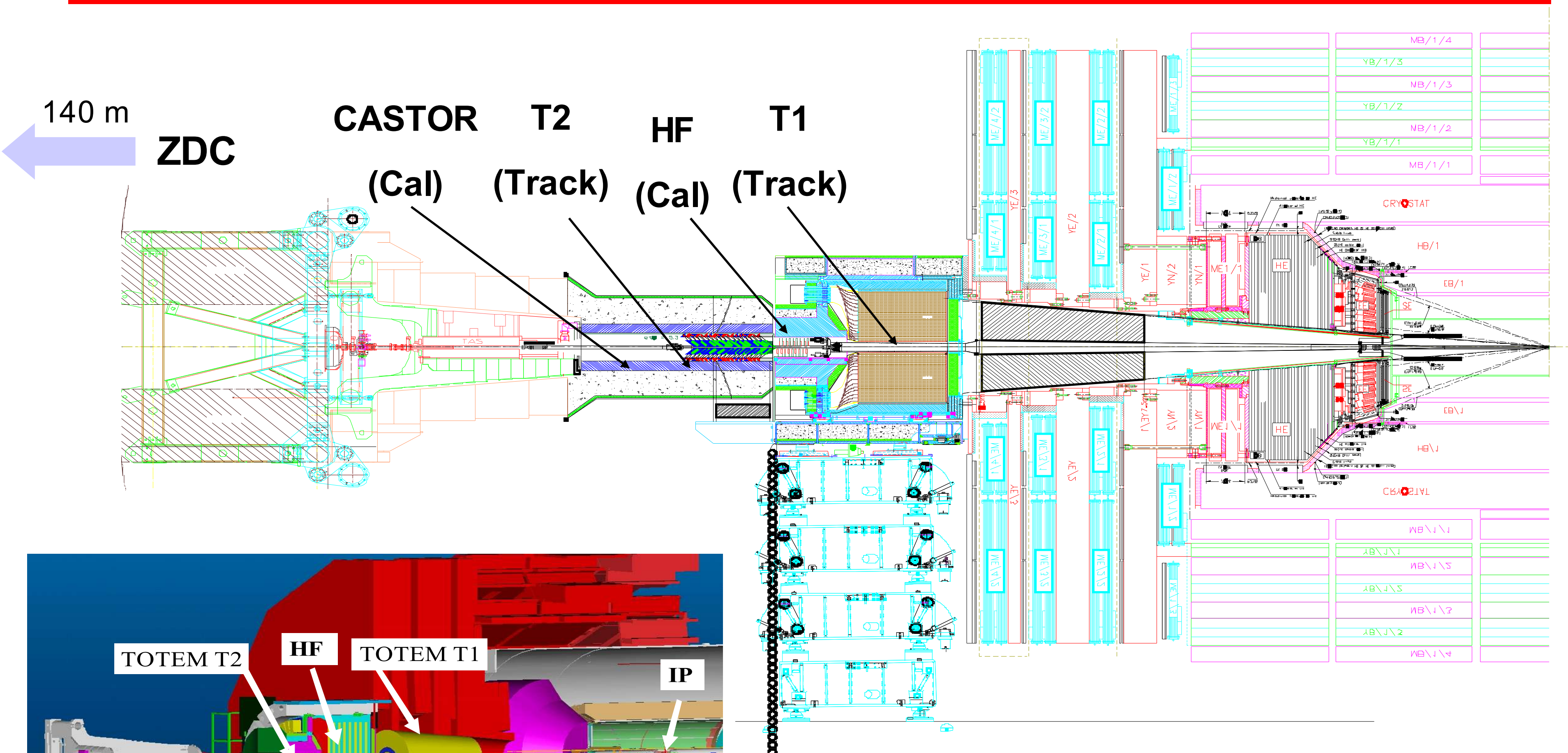
$$\hat{\sigma}_{ij}(\hat{s}) = \hat{\sigma}_{gg}$$

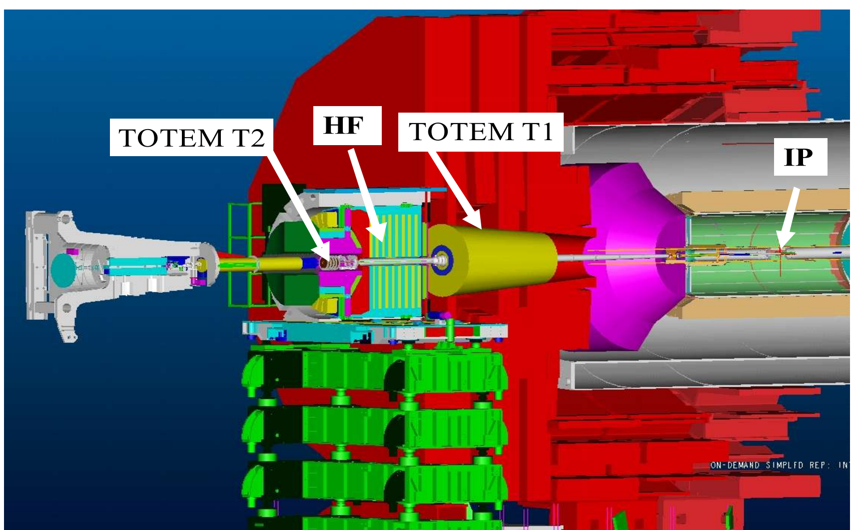
Integral in the rapidity acceptance (2.5<y<4.0) is normalized to 1



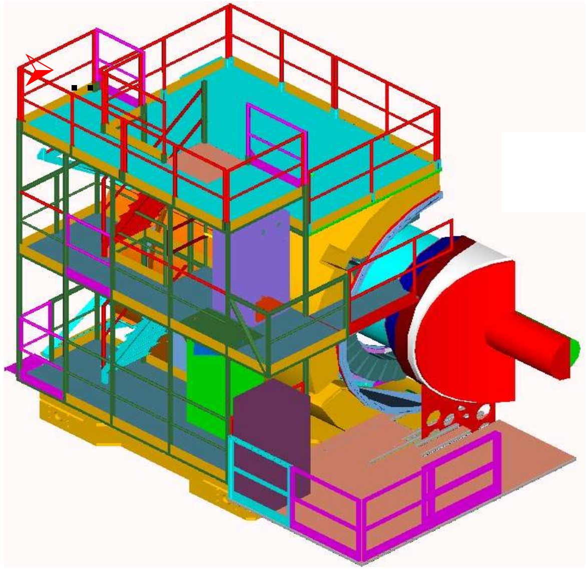
$$\frac{d\sigma_C^{CEM}}{dy} = K \int_{4m_Q^2}^{4m_H^2} d\hat{s}\hat{\sigma}_{gg} f_{i/A}\left(\sqrt{\frac{\hat{s}}{s}}e^{y}, \mu^2\right) f_{j/B}\left(\sqrt{\frac{\hat{s}}{s}}e^{-y}, \mu^2\right)$$

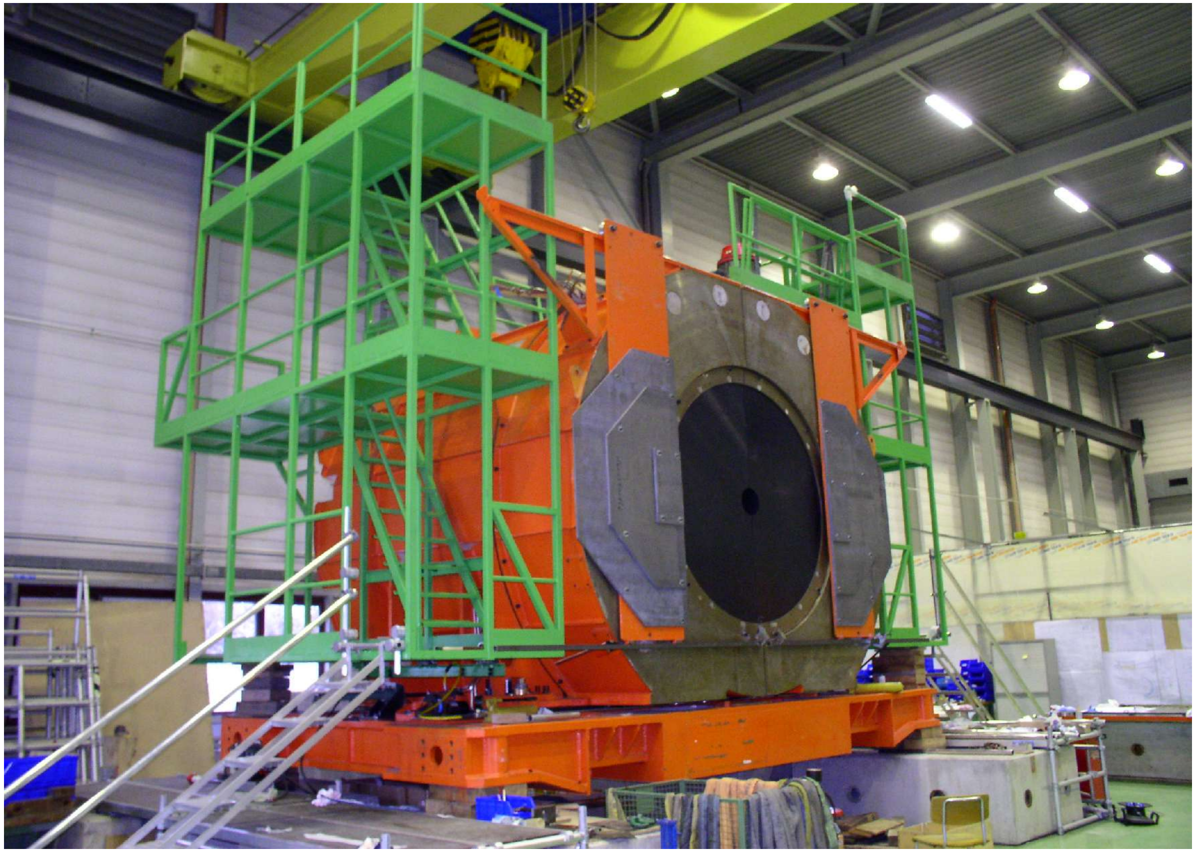
CMS-TOTEM forward detectors (|η |~3-6.7)





HF, TOTEM (T1,T2), CASTOR



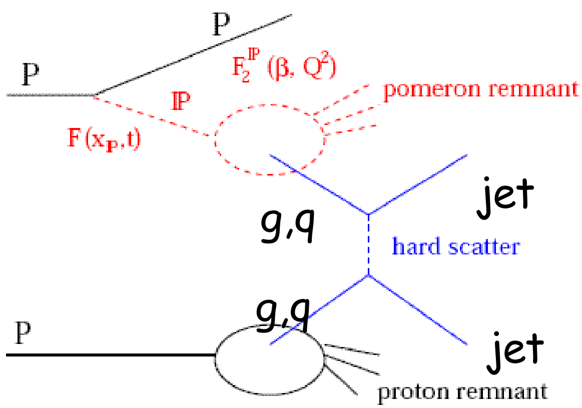


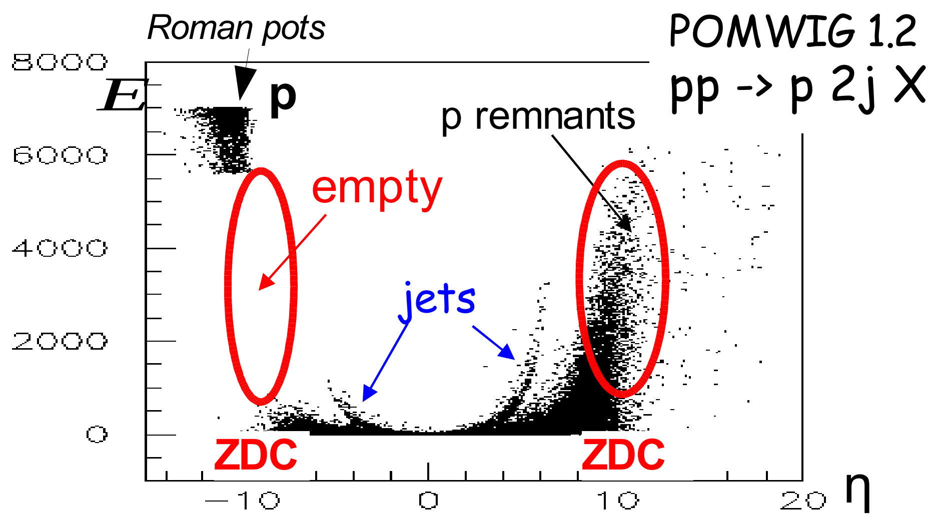
Backup slides

Diffractive pp collisions

- No ZDC activity = large rapidity gap. Complements (trigger & offline) leading proton detectors e.g. in dijet single diffraction:

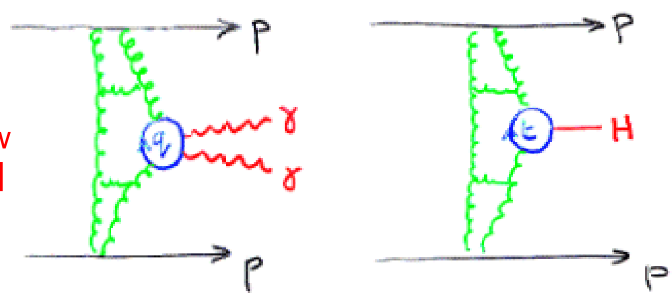
[from A.Sobol CMS, Feb'06]





- ZDC (even w/o leading p detection) can help "calibrate" DPE Higgs prod.:

[from M.Albrow CMS, Feb'06]

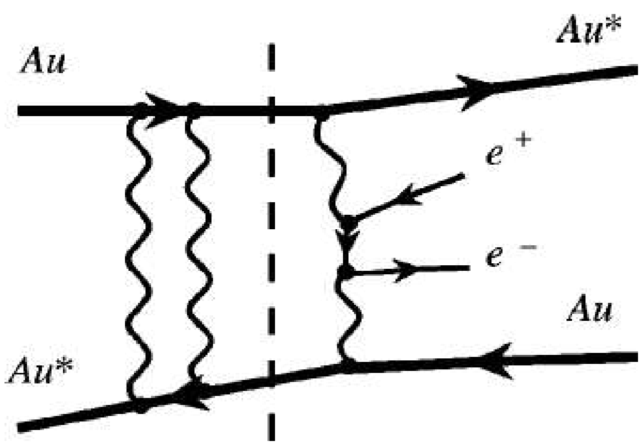


1[st] process measurable w/ ZDC.
Both closely related (QCD part identical).
Measurement of one constrains the other.

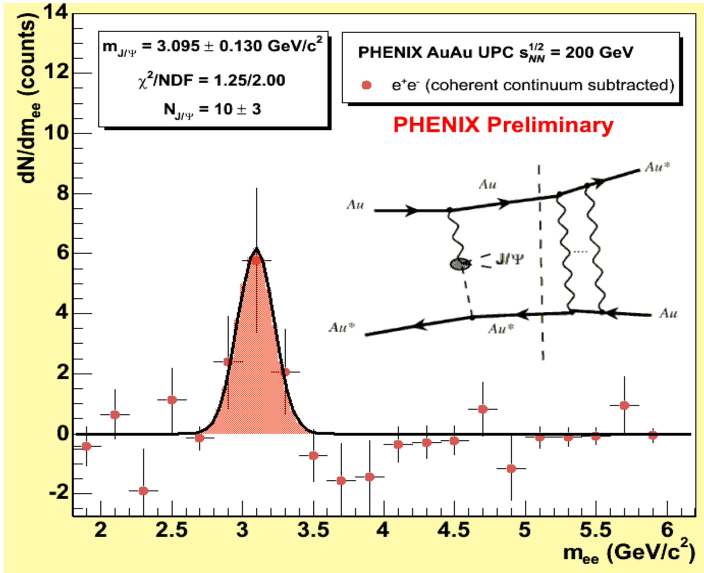
- Bottom line: ZDC reduces to "zero" holes & cracks in CMS (full 4π). Helps all diffractive ($\mathbb{P}$-, γ-mediated) analysis in pp,pA,AA.

$\gamma\gamma, \gamma A$: physics topics

- Typical diagrams for $\gamma\gamma$ and γA collisions:



Dd'E, nucl-ex/0601001

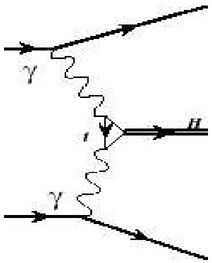


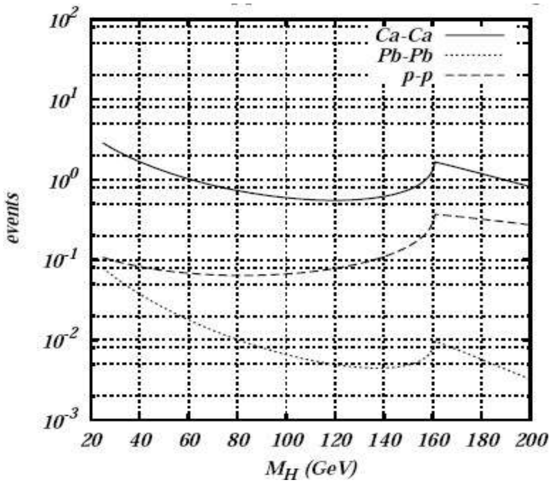
- Physics:	QED, precision QCD	Precision QCD *(low bckgd, simpler initial state than p,A+A*
- Measurements:	$\ell^+\ell^-$, C-even $c\bar{c}$ $b\bar{b}$, W^+W^-...	Quarkonia, heavy-Q, jets ...
- Topics:	QED in strong regime ($Z\alpha_{em}$~1), heavy-Q spectroscopy, [quartic GC ($WW\gamma\gamma$), ...]	Nuclear $G_A(x,Q^2)$, low-x physics, QQbar in cold nuclear matter

- All UPC measurements at RHIC: ZDC-triggered (neutron tagging) !

$\gamma\gamma$: Discovery physics & others

- $\gamma\gamma \rightarrow$ Higgs ($\rightarrow b\bar{b}$)
  - Rate is very low (better w/ lighter ions, pA or pp)
  - Establishes the nature of Higgs (J^{PC}, SM vs. MSSM)





- $\gamma\gamma \rightarrow W^+W^-$ & photoproduction of W^+W^-:
  - Study quartic/triple $\gamma\gamma WW$, γWW vertices
  - Anomalous coupling sensitive to new physics

- Other "discovery" channels:
  $\gamma\gamma$ production of magnetic monopoles, SUSY, ...

- Others:
  - e^+e^- pair production
    Tests QED in very strong fields (grazing b=2R colls ~ 5 e^+e^- pairs produced). Huge rates: σ~13,000 b in ALICE inner Si
  - Quantum correlations in multiple Vector Meson Production
  - QQbar spectroscopy: $\gamma+\gamma \rightarrow 0^{+-}2^{++}$ states (η_b, χ_{b0}, χ_{b2},...).