High-energy quarkonia photoproduction at heavy-ion colliders: from RHIC to LHC

PHOTON'07 Int'l Conference

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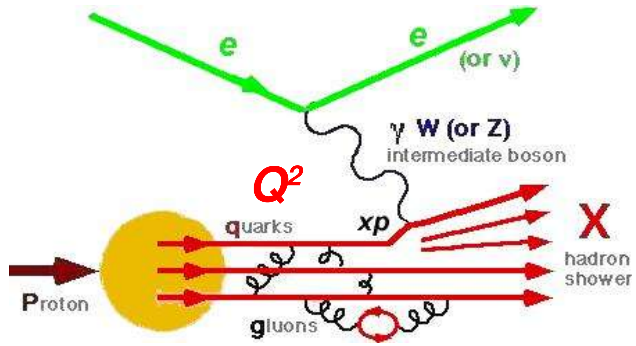
Overview

- Introduction:
  - Low-x PDFs (proton, nucleus)
  - Exclusive QQbar as a probe of small-x PDFs
  - Electromagnetic (Ultra-peripheral) A-A collisions (RHIC, LHC)
- UPC AuAu→(γ Au)→J/Ψ Au* in PHENIX (RHIC)
  - Experimental setup, trigger.
  - Preliminary results.
- UPC PbPb→(γ Pb)→ϒ Pb* in CMS (LHC)
  - Theoretical cross-sections for signal (ϒ) & background ($\gamma\gamma\to e^+e^-$, $\mu^+\mu^-$)
  - Trigger considerations: L1, background rates
  - $\Upsilon\to e^+e^-$, $\mu^+\mu^-$ acceptances & efficiencies
  - Mass distributions for ϒ signal + $\ell^+\ell^-$ background
  - Expected dN/dp_T, dN/dy, dN/dm_{inv} for $\int\mathcal{L}\,dt = 0.5\ nb^{-1}$
- Summary

Parton structure at low-*x*

- DIS *e*p collisions probe partonic distributions in the proton:



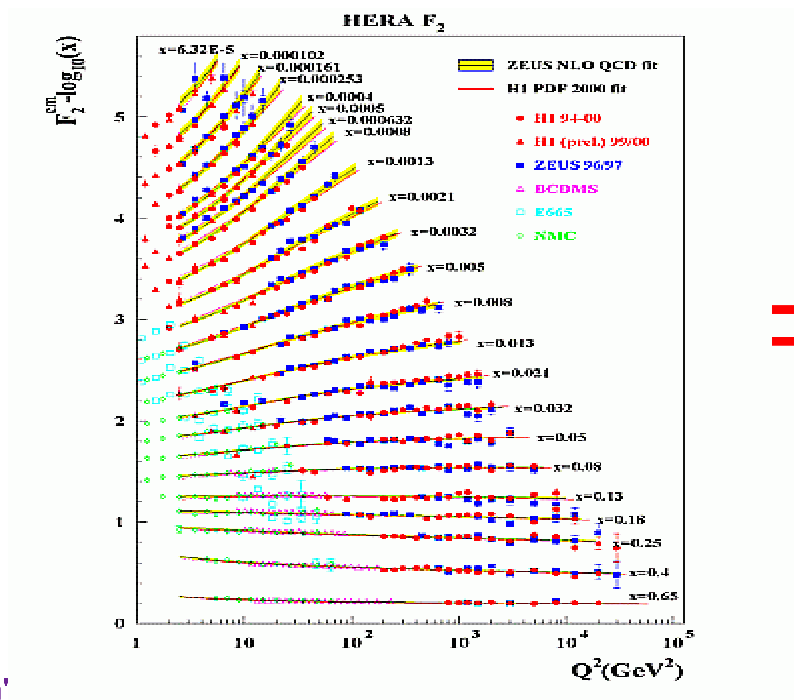
Q^2 = "resolving power"

Bjorken x = momentum fraction carried by parton

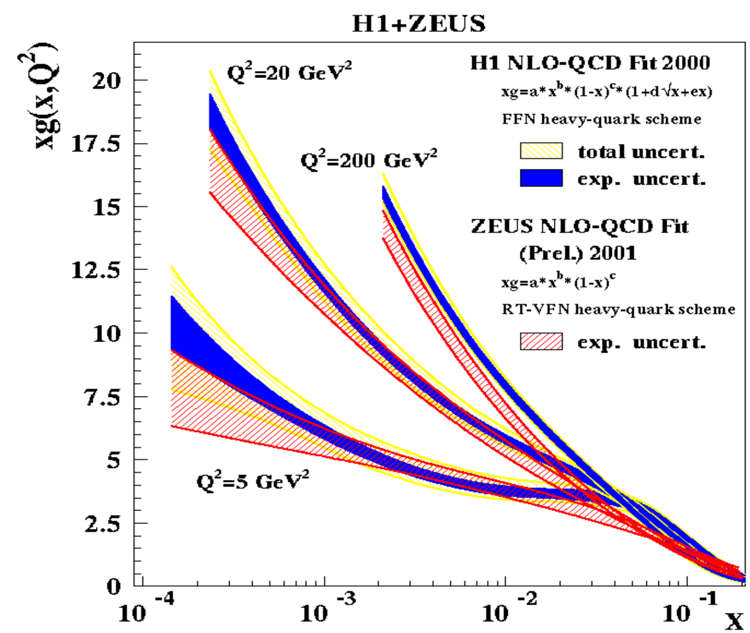
$$\frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\alpha^2}{xQ^4}\left[2xy^2F_1 + 2(1-y)F_2\right]$$

F_1,F_2 = proton structure functions.

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

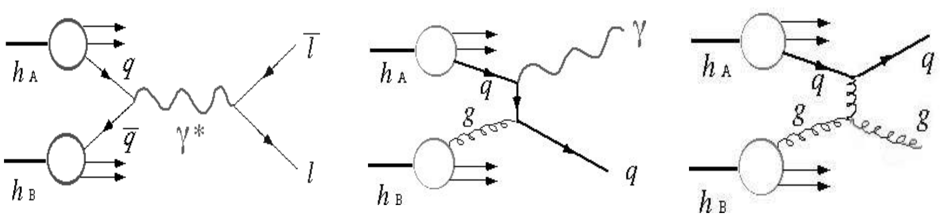


⇒



Experimental probes of low-x PDFs

- Perturbative processes:
  - p-p,A-A: DY, prompt γ, (di)jets, heavy-Q



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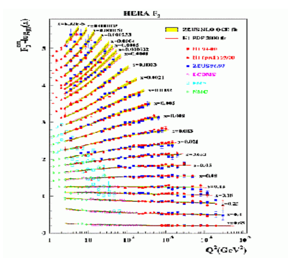
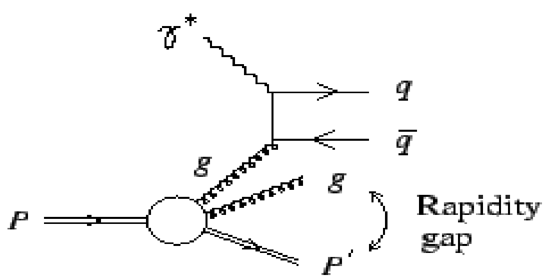
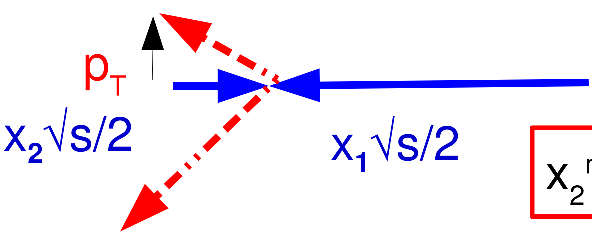
  - γ-p,γ-A: F_2, heavy-Q, diffractive $\bar{Q}Q$



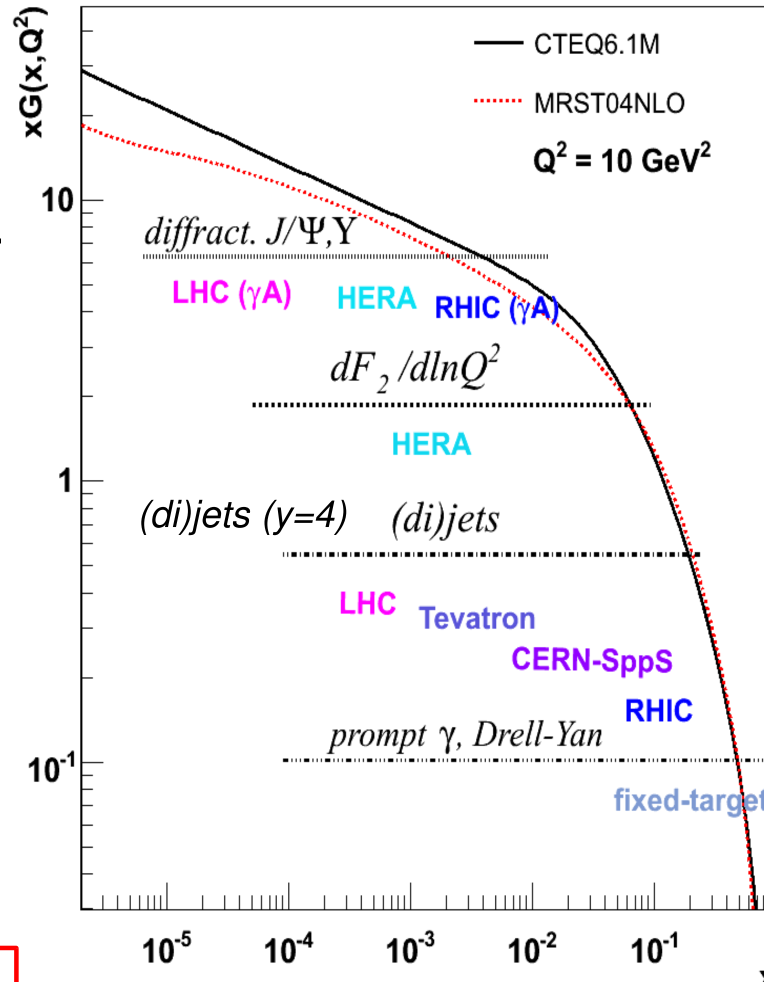


- Forward production $\Rightarrow$ lower x



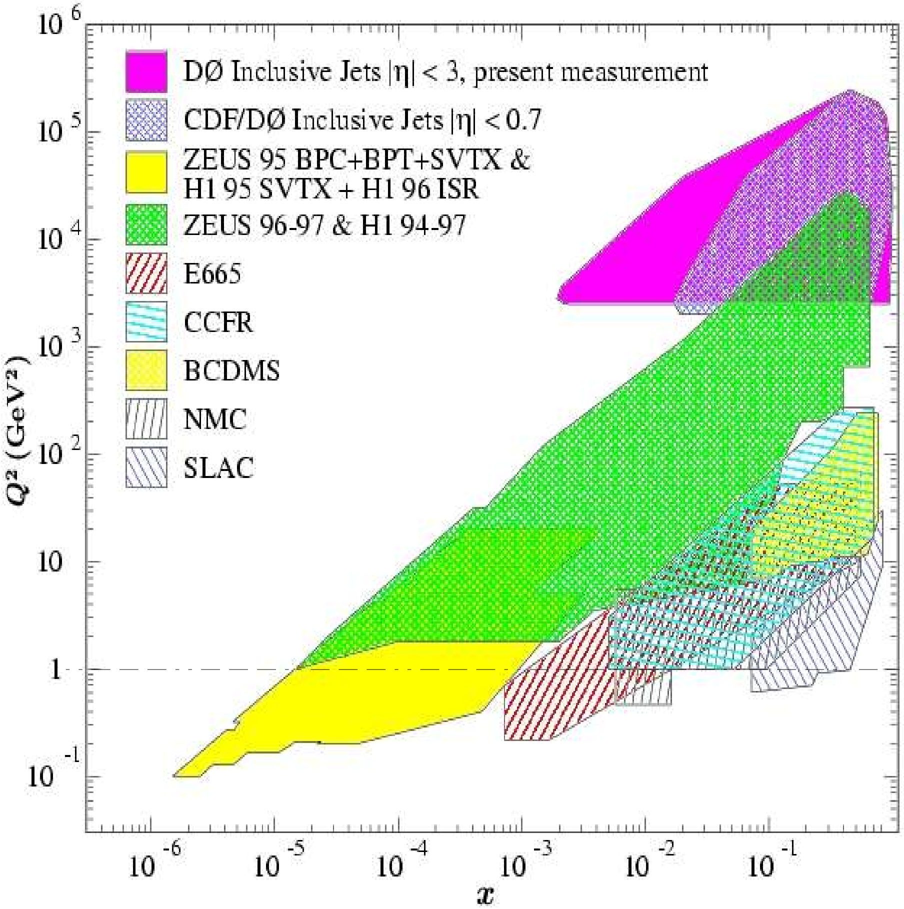
$$x_2^{min} \sim p_T/\sqrt{s} \cdot e^{-y} = x_T \cdot e^{-y}$$

Every 2-units of y, x^{min} decreases by ~10

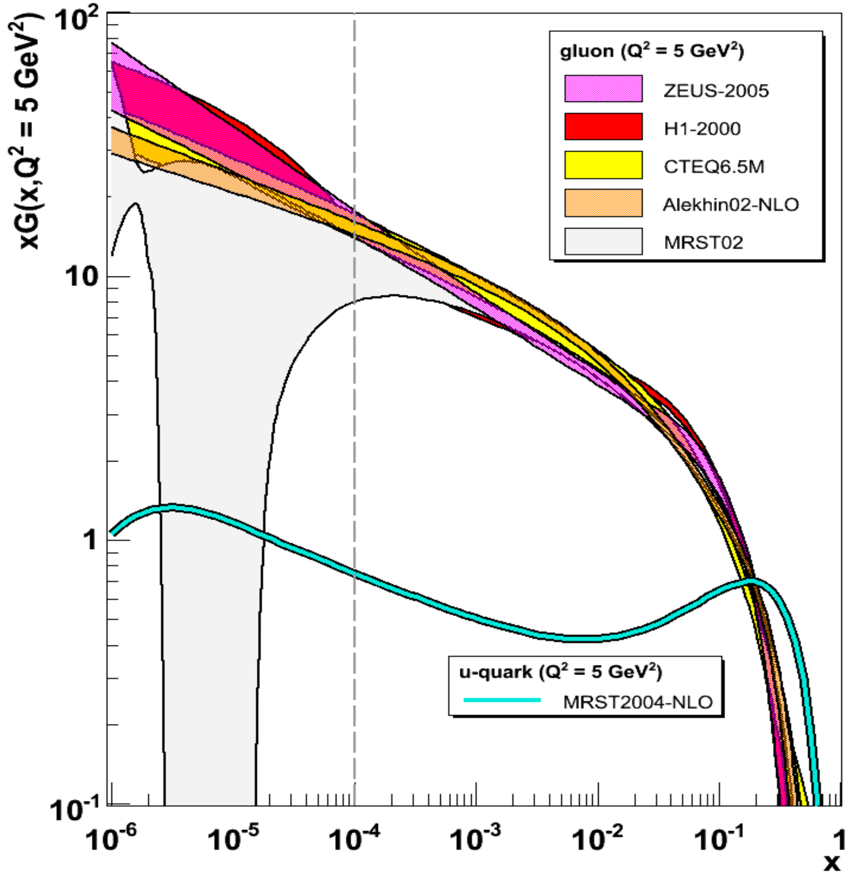


Proton PDFs at low-x

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

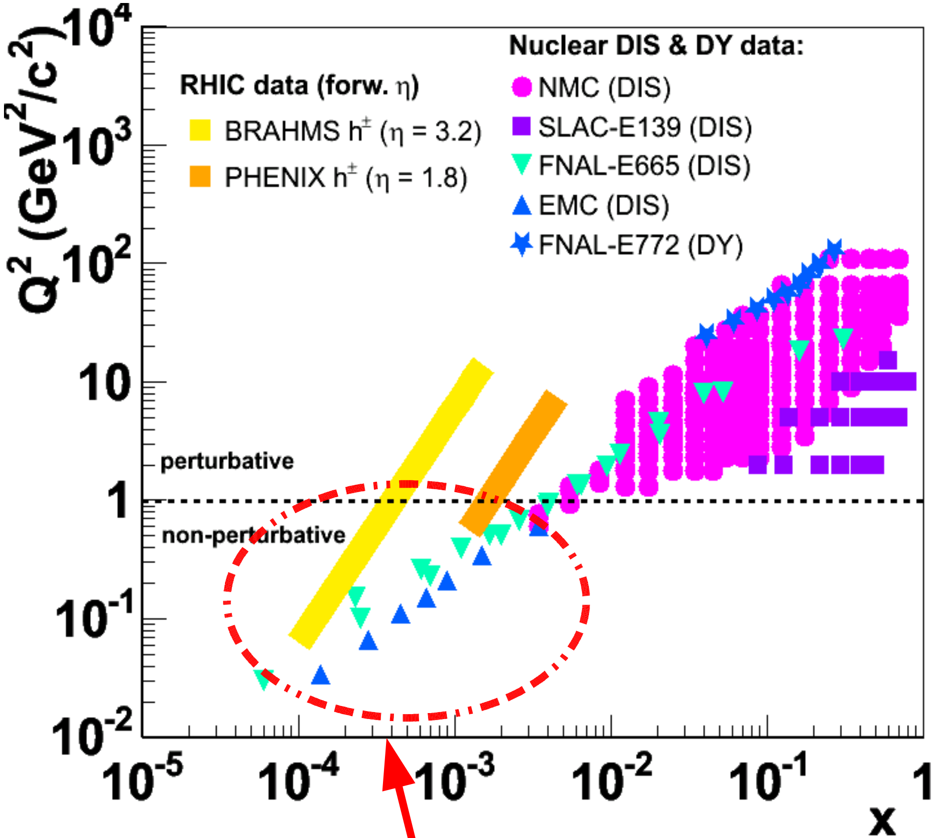


- xG(x,Q^2) poorly constrained for x<10^{-4}, by existing (F_2) data !



Nuclear PDFs at low-x

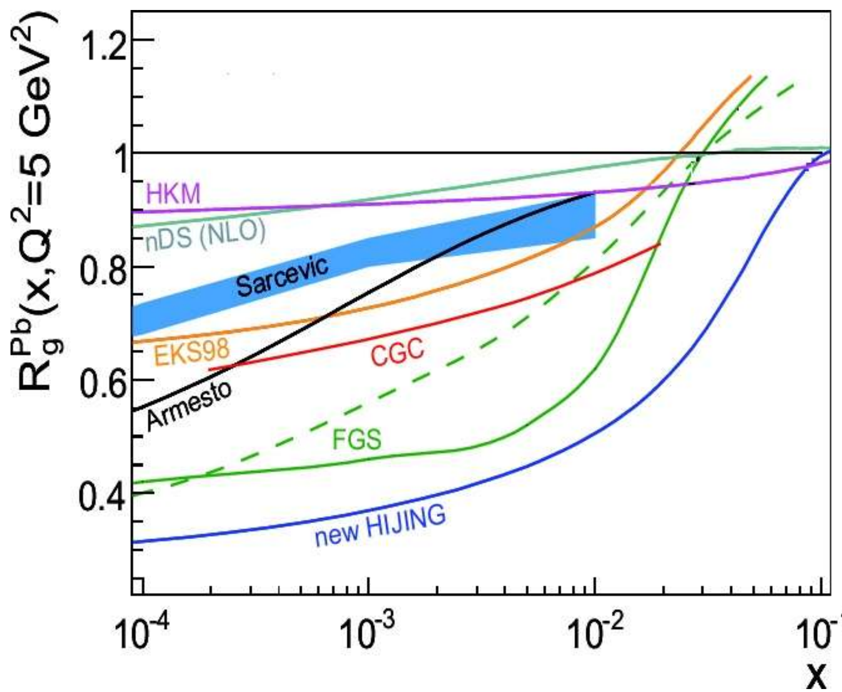
- Kinematical (x,Q^2) domains covered experimentally:



- Most low-x nPDFs measurements in non-perturbative regime

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

Ratio of gluon densities in Pb to p



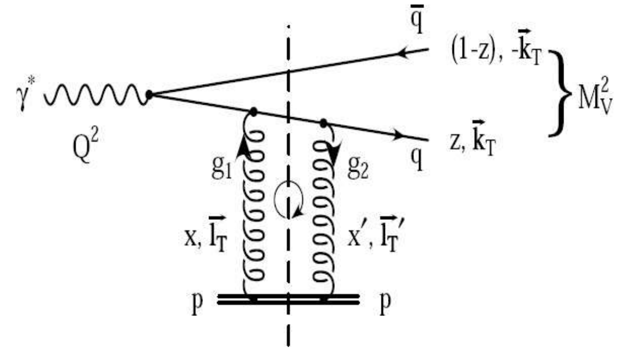
Armesto, J.Phys.G32:R367 (2006)

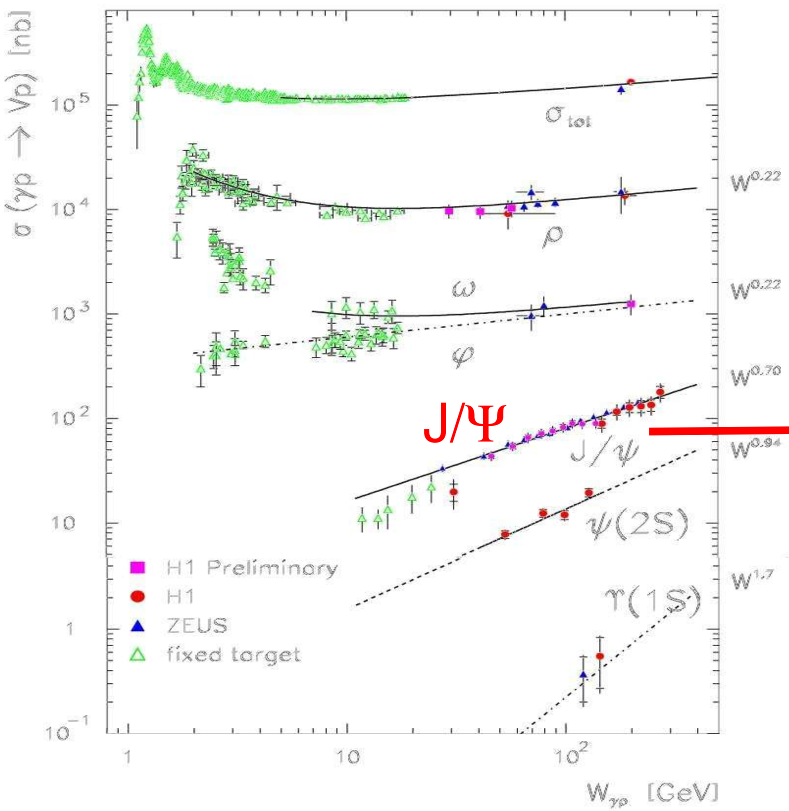
$xg(x,Q^2)$ via diffract. $Q\bar{Q}$ γ-production @ HERA

- γ+p→VM+p (VM=J/Ψ,ϒ) sensitive to gluon distribution squared:

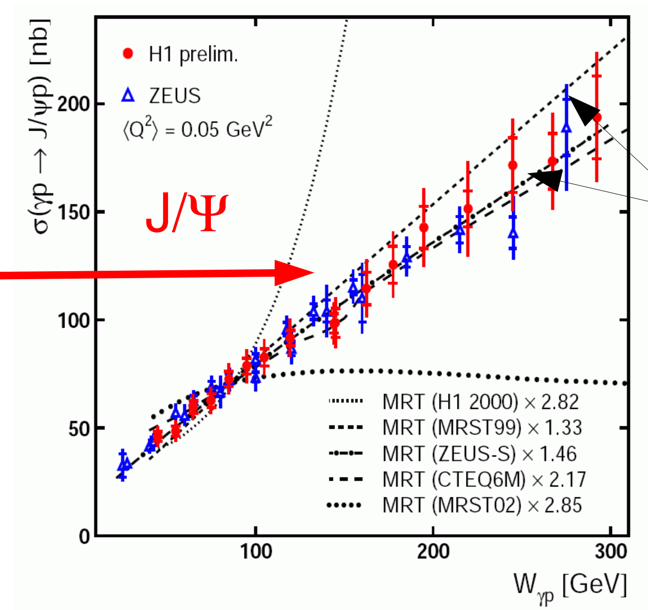
$$\left.\frac{d\sigma(\gamma p \to V p)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xG(x,Q^2)\right]^2 \text{, with } Q^2 = M_V^2/4$$
$$x = M_V^2/W_{\gamma p}^2$$

Ryskin et al. ZPC 76 (1997)231





perturbative QCD calculations available:

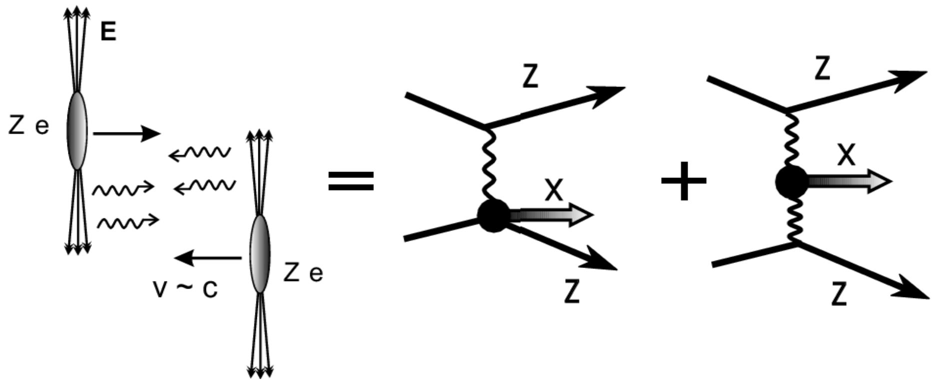


Discriminates different Ansätze of $xG(x,Q^2)$

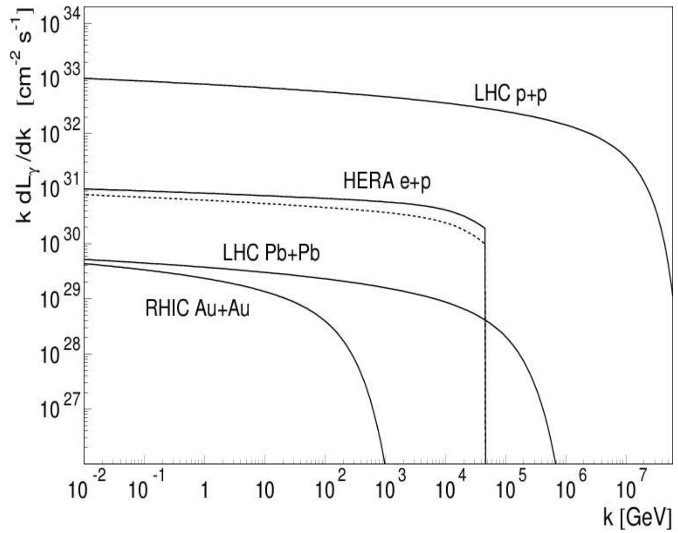
Fleischmann,Teubner DIS07

Photoproduction in UPC A-A at the LHC

- High energy heavy-ions produce strong EM fields due to coherent action of $Z = 82$ protons:



- Equivalent flux of photons in EM UltraPeripheral ($b_{min} \sim 2R_A \sim 20$ fm) AA:



- **Photon fluxes:**

  $\sigma(\gamma A) \sim Z^2$ (~10^4 for Pb), $\sigma(\gamma\gamma) \sim Z^4$ (i.e. ~$5 \cdot 10^7$) times larger than $e^\pm$ beams !

- Very low γ virtuality (γ wavelength > nucleus size): $Q^2 = (\omega^2/\gamma^2 + q_\perp^2) \lesssim 1/R_A^2$ ~50 MeV

- Max. γ energies: $\omega < \omega_{max} \approx \frac{\gamma}{R}$, $E_{\gamma max}$ ~ 80 GeV (PbPb-LHC)

- Max. center-of-mass energies: γA: max. $\sqrt{s_{\gamma A}} \approx$ 1. TeV $\approx$ 3. - 4. × $\sqrt{s_{\gamma p}}$(HERA)

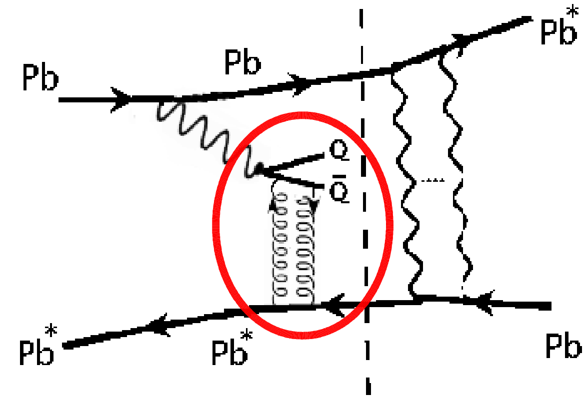
  $\gamma\gamma$: max. $\sqrt{s_{\gamma\gamma}} \approx$ 160 GeV $\approx \sqrt{s_{\gamma\gamma}}$(LEP)

xG(x,Q²) via $Q\bar{Q}$ γ-production in UPC

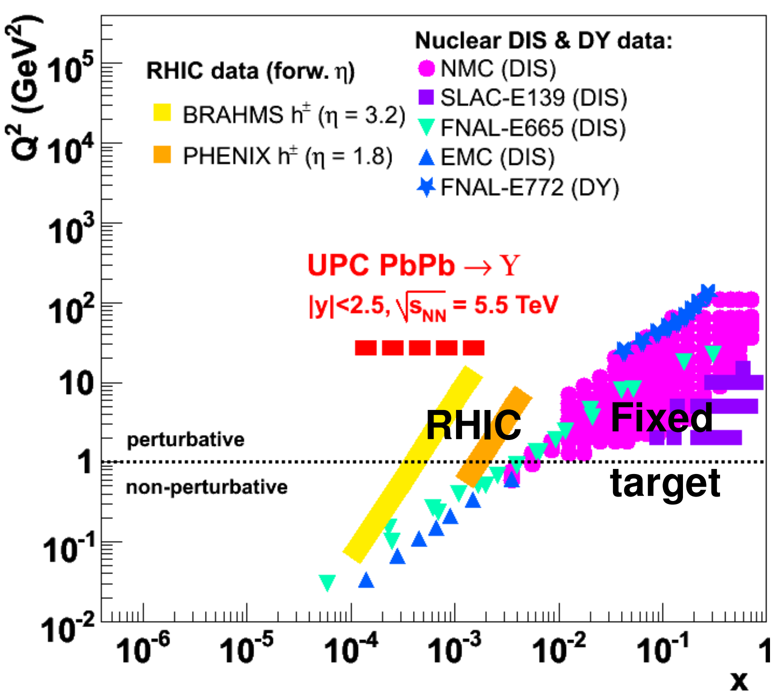
- γ+A→VM+A (VM=J/Ψ,ϒ) sensitive to gluon density squared:

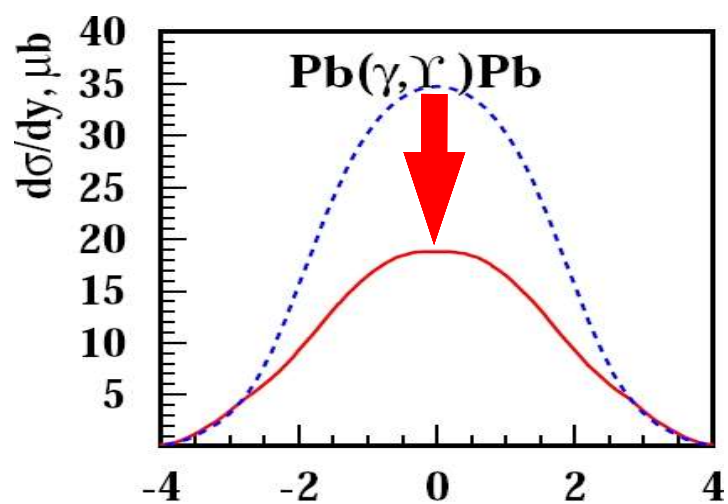
$$\sigma_{\gamma A\to VA}(s_{\gamma N}) \sim \frac{d\sigma_{\gamma N\to VN}(s_{\gamma N})}{dt}\Big|_{t=t_{\min}} \left[\frac{G_A(x_1,x_2,t=0,Q^2_{\text{eff}})}{AG_N(x_1,x_2,t=0,Q^2_{\text{eff}})}\right]^2$$

Strikman, Frankurt, Guzey, et al.



- Unexplored (x,Q²) regime of nPDFs:





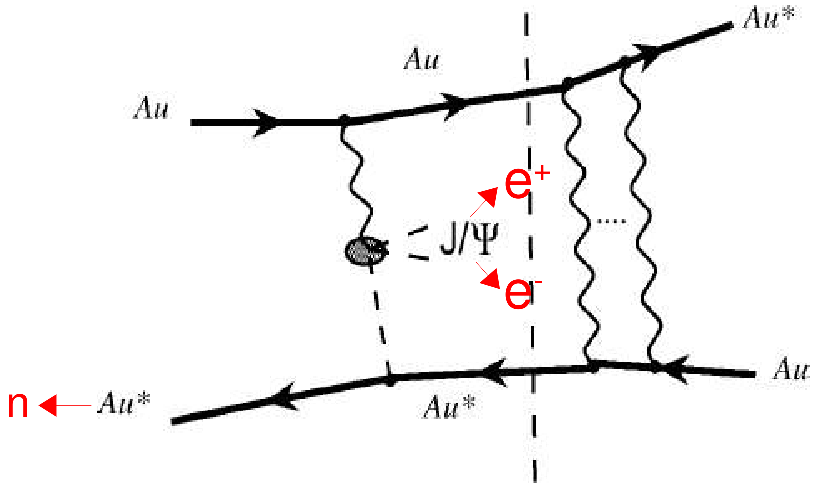
Impulse:	σ = 133 mb
LT shadowing:	σ = 78 mb

Larger suppression expected due to gluon saturation effects

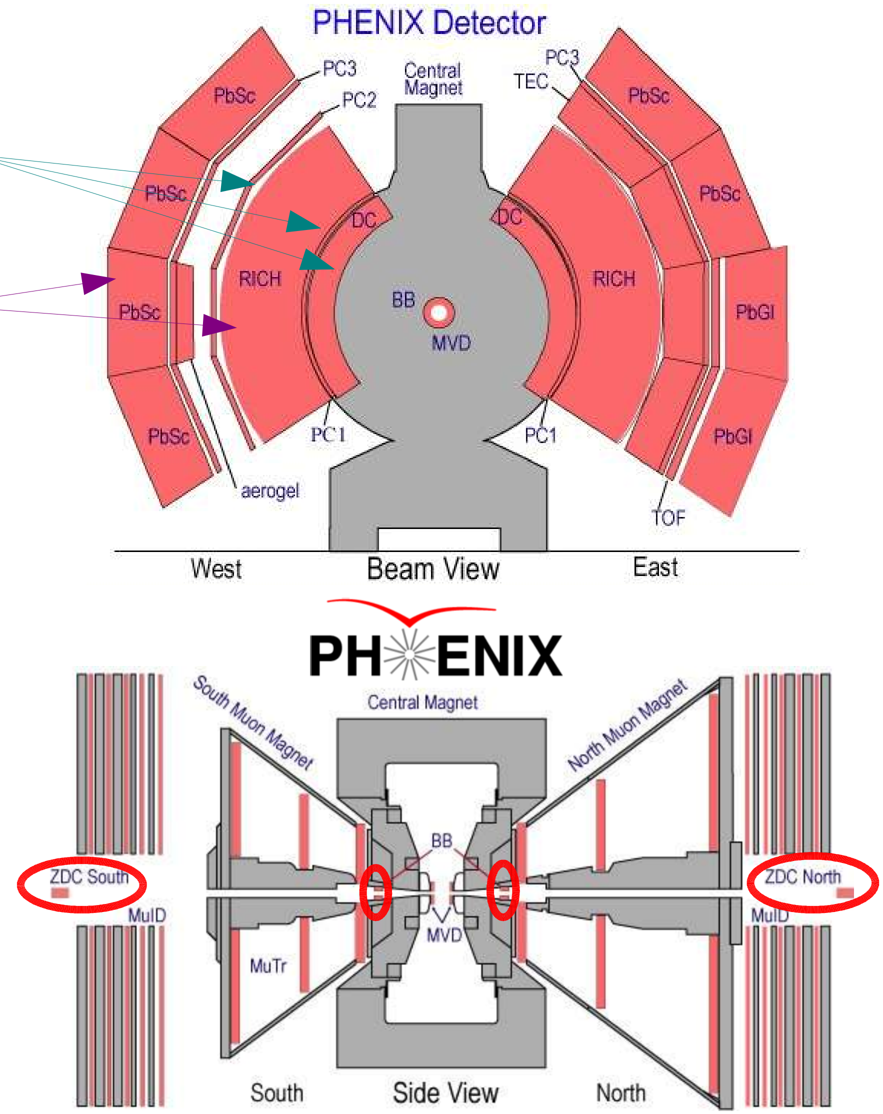
RHIC (preliminary) results

Au-Au UPC in PHENIX: γ Au → J/Ψ(→e⁺e⁻)+Au*

- **DC + PCs**: Full central-arm charged tracking ($e^{\pm}$ momentum)
- **RICH + EMCal**: $e^{\pm}$ identification

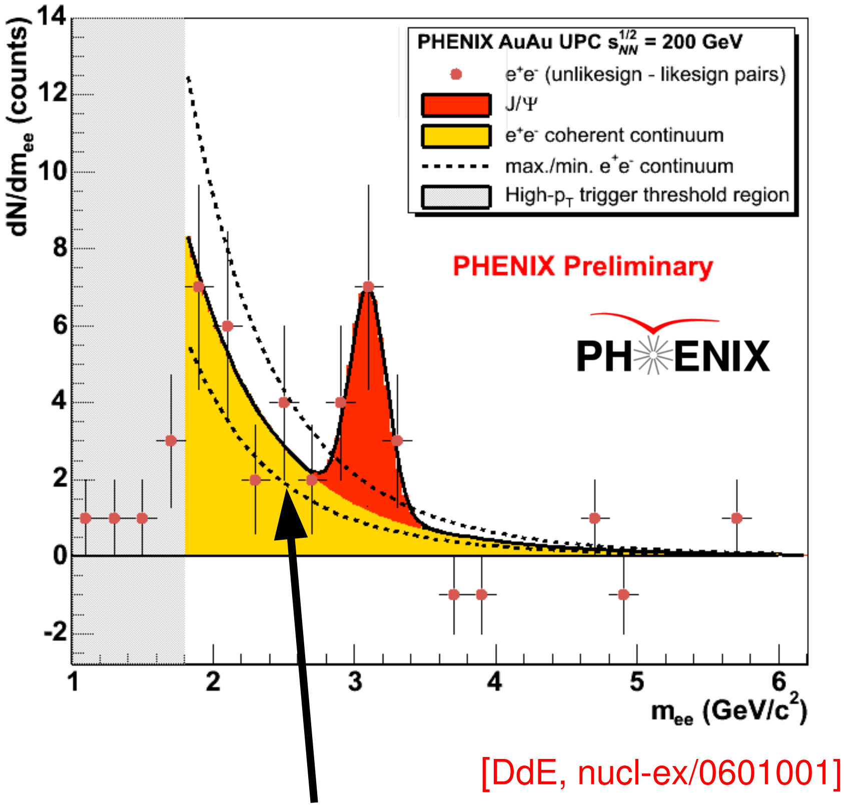


- **BBC veto**: Rap-gap ($3<|\eta|<4$)
- **ZDC**: Forward neutron detection (Au* dissociation)



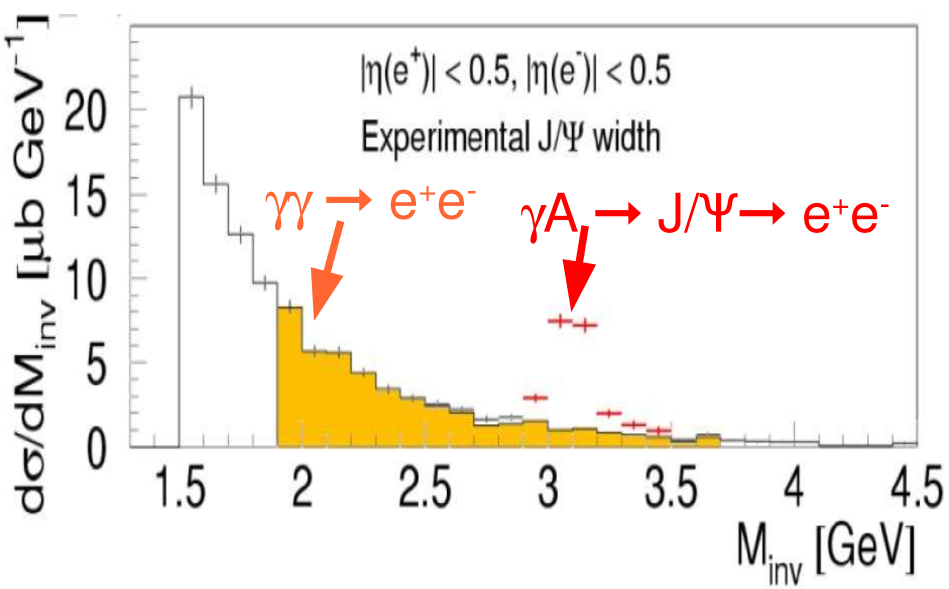
Au-Au UPC results (I): dN/dm_{inv} e^+e^- pairs

- dN/dm_{inv} (backgd subtracted) & with 2 fits of expected e^+e^- continuum shape (normalized at m_{ee} = 1.8 – 2.2 GeV/c^2)



[DdE, nucl-ex/0601001]

Expected signals (STARLIGHT MC)



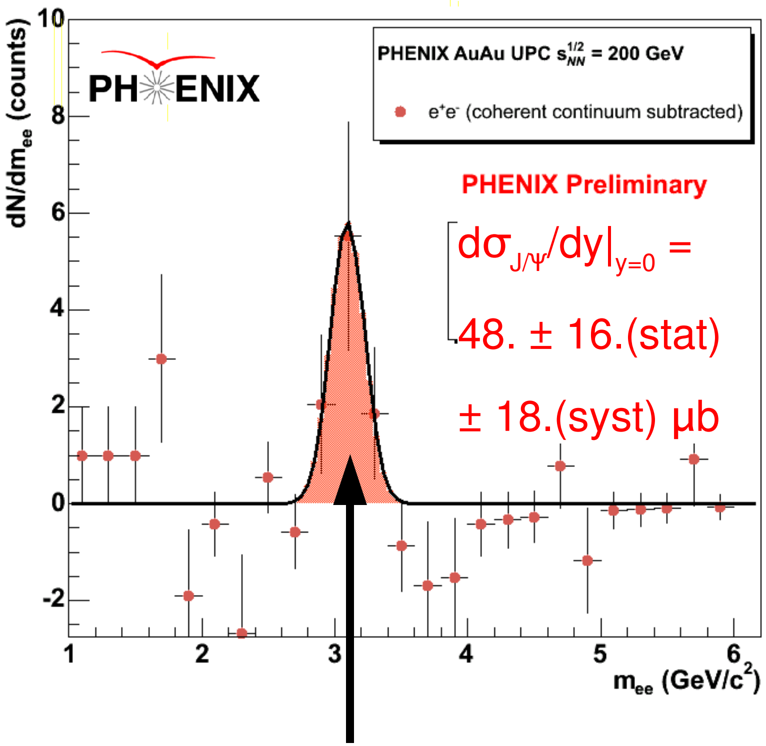
[J.Nystrand, NPA 752 (2005)470c]

Shape of e^+e^- continuum obtained from theoretical input + full-MC resp.+ reco

Au-Au UPC results (II): dN/dm, dN/dp$_T$, dσ/dy

[DdE, nucl-ex/0601001]

- dN/dm$_{e+e-}$ (e^+e^- continuum subtracted):

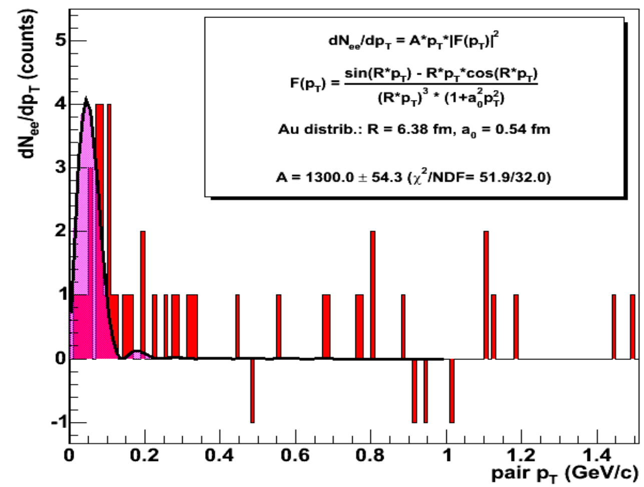


J/Ψ peak & width in good agreement

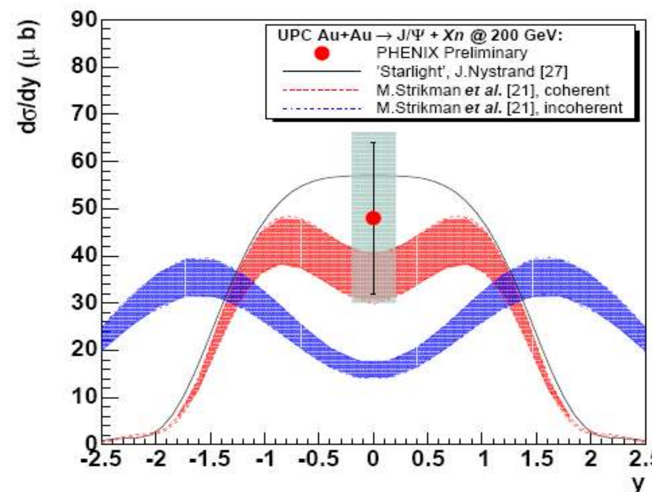
w/ theoretical input + full MC resp.+reco

$m_{J/\Psi}$ ~ 3.097 GeV ± 130 MeV

- dN$_{ee}$/dp$_T$ peaked at p$_T$~90 MeV/c

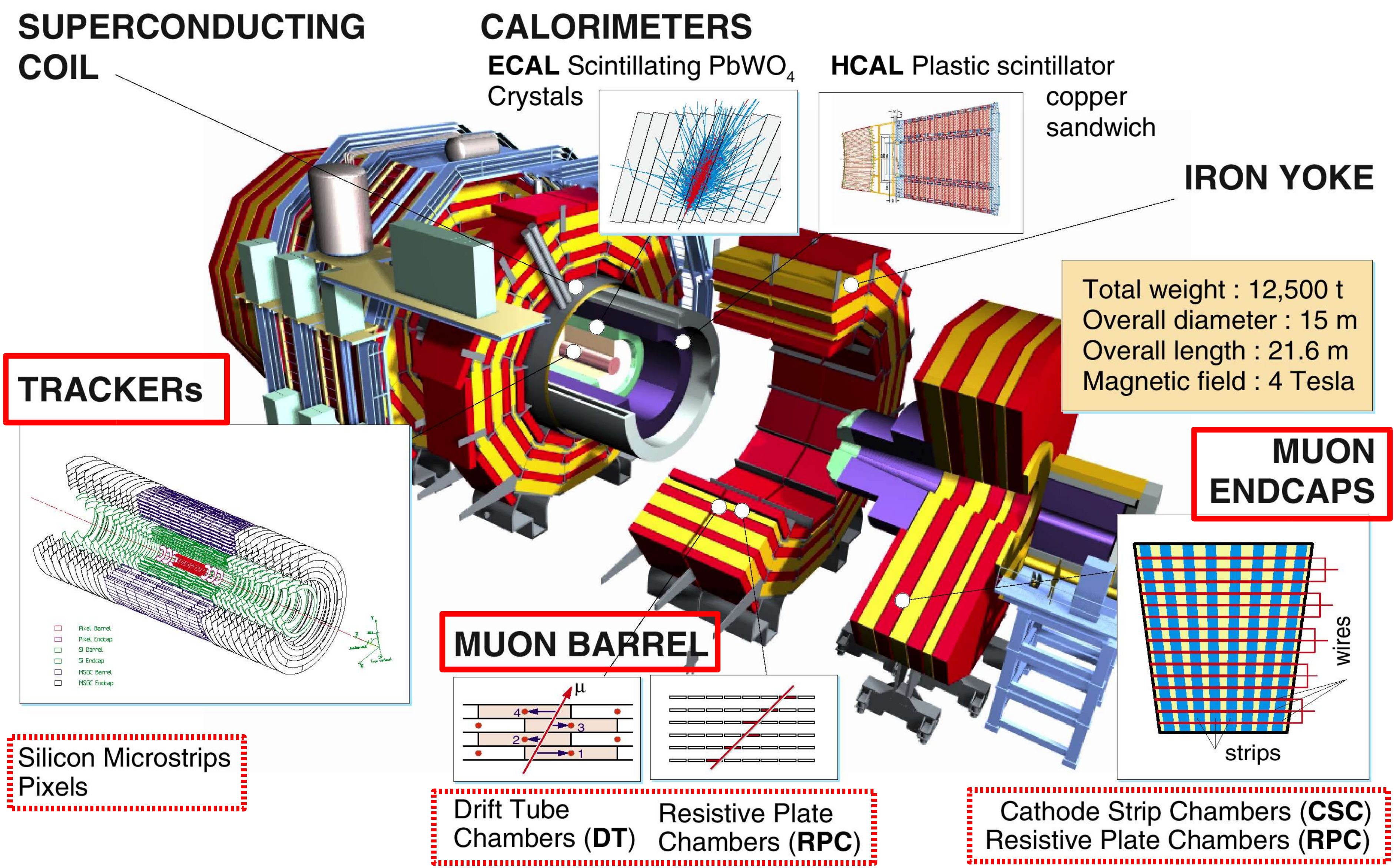


- Current large (stat) uncertainties preclude yet $xG_A(x,Q^2)$ constraint



Υ photoproduction in CMS (full simu+reco results)

Compact Muon Solenoid (|η|<5)

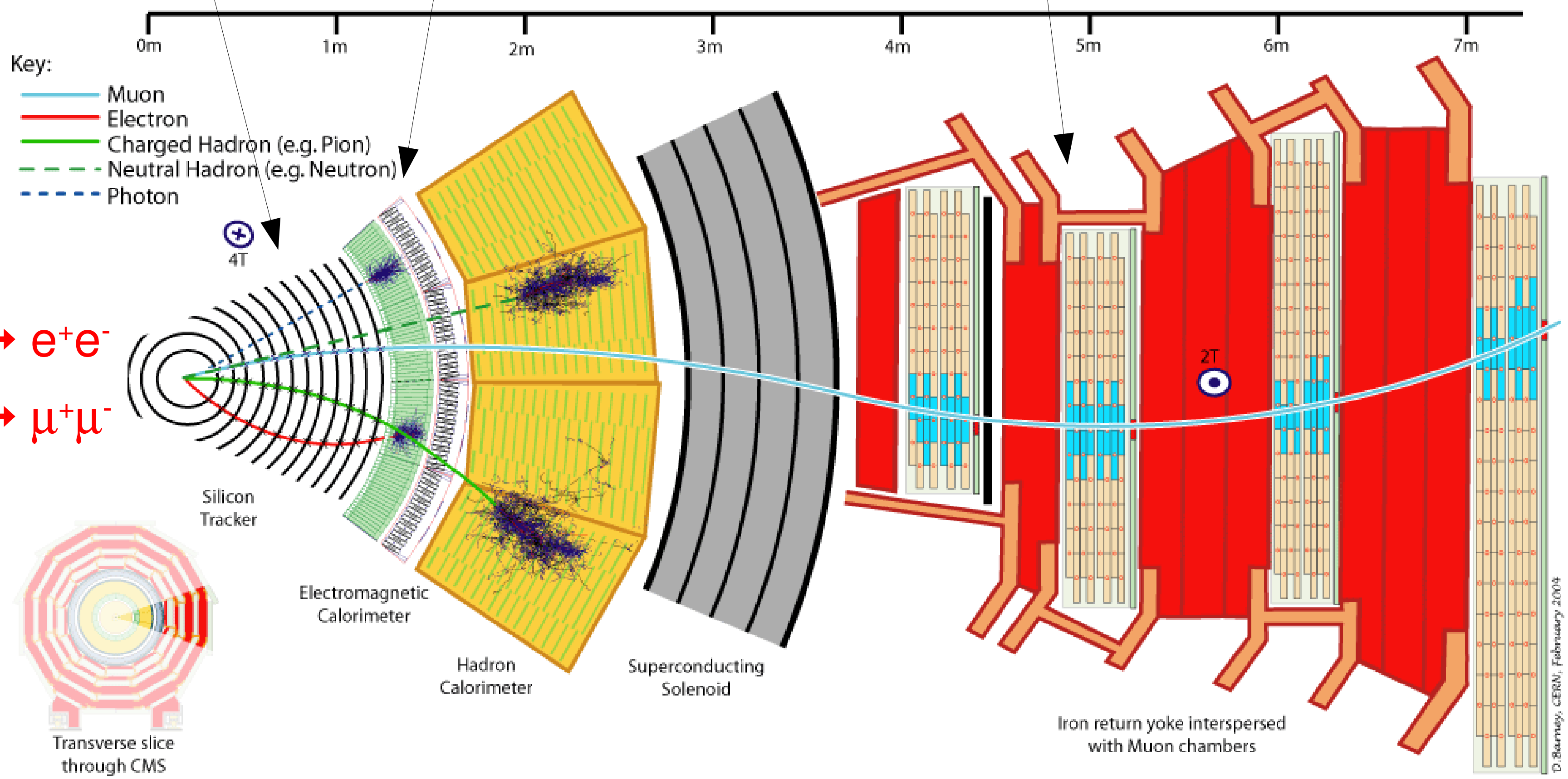


$e^\pm$ and $\mu^\pm$ measurement in CMS ($|\eta|<2.4$)

Tracking + ECAL + muon-chambers

$\Upsilon \rightarrow e^+e^-$

$\Upsilon \rightarrow \mu^+\mu^-$



Si TRACKER

Silicon Microstrips and Pixels

CALORIMETERS

ECAL $PbWO_4$

HCAL Plastic Sci/Steel sandwich

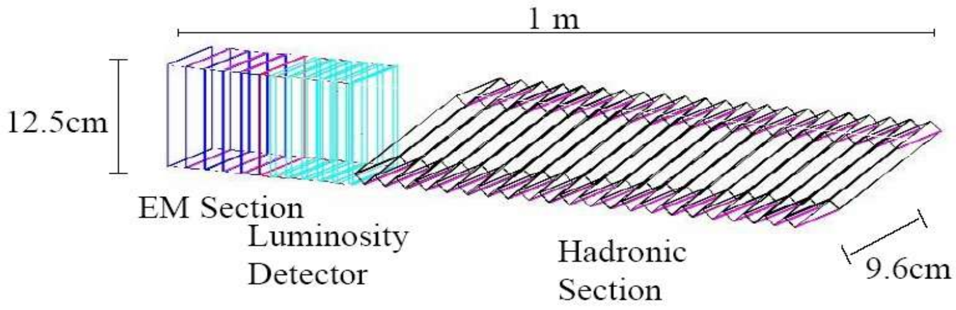
MUON BARREL

Drift Tube Chambers (**DT**)

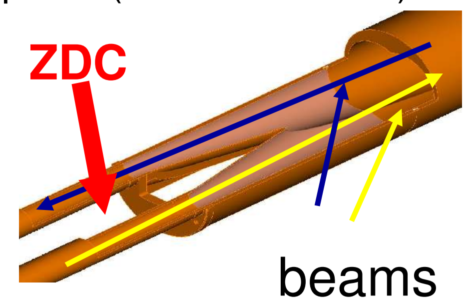
Resistive Plate Chambers (**RPC**)

Forward neutron detection in ZDC ($|\eta| \geq 8.3$)

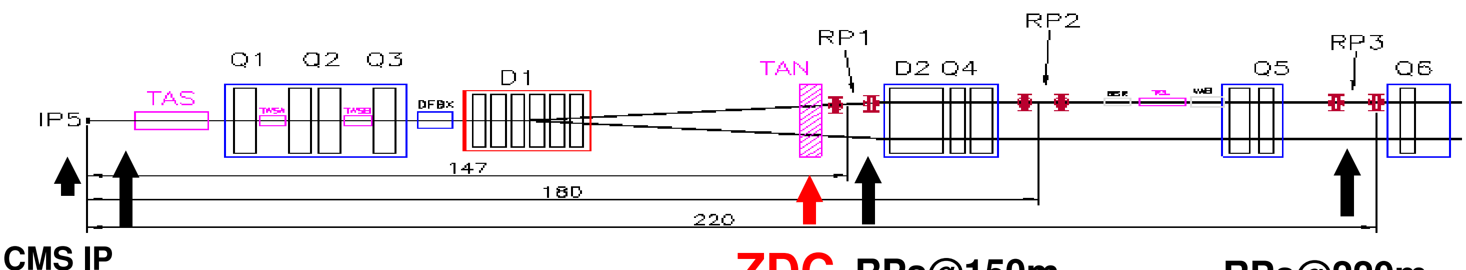
- ZDC = tungsten+quartz-fibre sampling Cerenkov calorimeter with HAD and EM sections:



Downstream1st beam separator dipoles (140 m from IP5)



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



T1/T2, Castor

$5.32 \leq |\eta| \leq 6.86$

Acceptance (neutral):

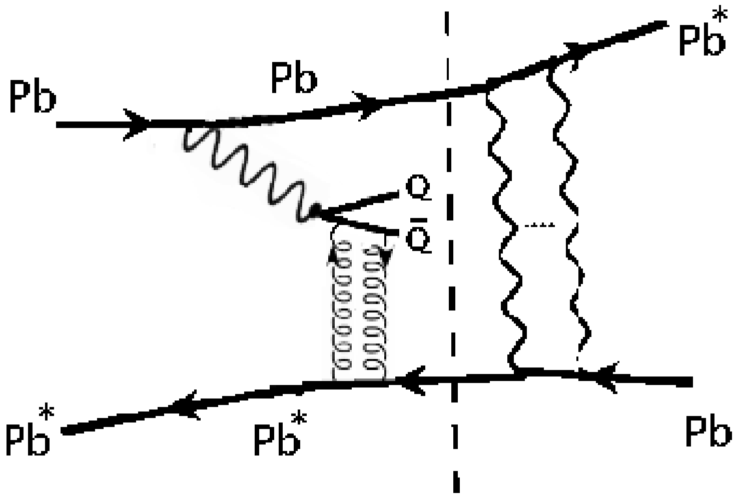
θ<~(5.cm) /140.m <~400 μrad

$|\eta| \geq 8.3$, $p_T < O(2.$ GeV/c)

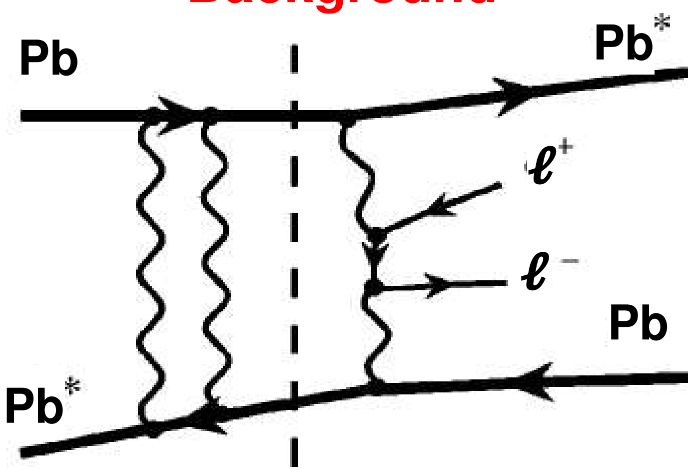
Input MC: Υ signal, $\ell^+\ell^-$ backgd. cross-sections

- Input MC: STARLIGHT [J. Nystrand, S.Klein, NPA752(2005)470]

Signal



Background



Process	σ_{tot}	σ_{Xn}	$\sigma_{Xn\|Xn}$
$PbPb \to \gamma Pb \to J/\psi + X$	32 mb	8.7 mb	2.5 mb
$PbPb \to \gamma Pb \to \Upsilon(1S) + X$	173 μb	78 μb	25 μb

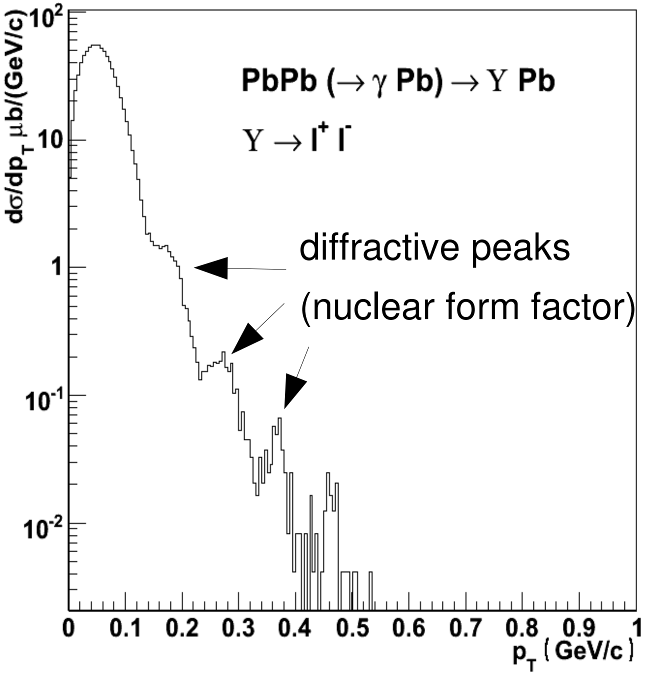
Process	$\gamma\gamma \to e^+e^-$	$\gamma\gamma \to \mu^+\mu^-$
$\sigma(m_{inv} > 1.5\ \mathrm{GeV}/c^2)$	139 mb	45 mb
$\sigma(m_{inv} > 6.0\ \mathrm{GeV}/c^2)$	2.8 mb	1.2 mb

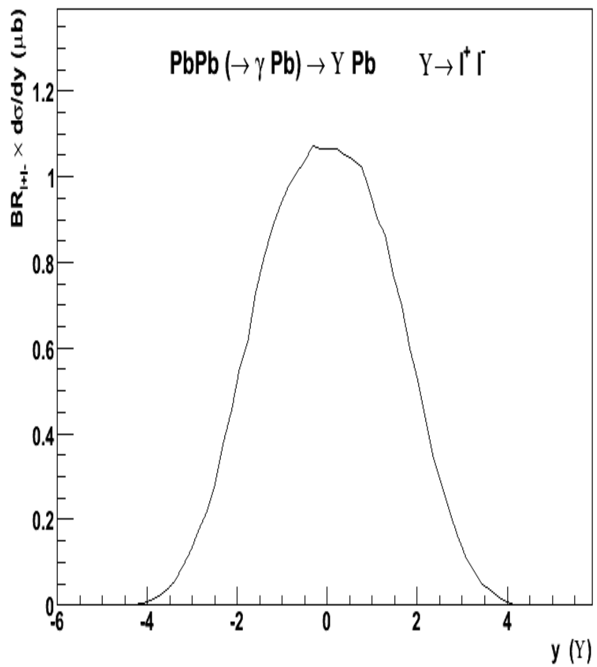
- Trigger: ~50% of UPC interactions with nuclear breakup (fwd neutron emission)

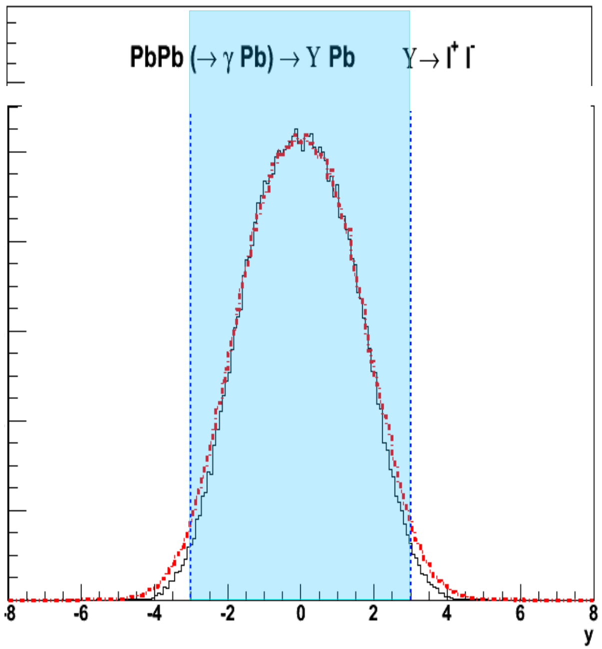
Input MC: ϒ signal distributions

- STARLIGHT Upsilon p_T, rapidity distributions:

CMS $e^{\pm}$, $\mu^{\pm}$ acceptance







Peaked at very low p_T

$p_T \sim 2\hbar c/R \sim$ 50 MeV/c

(“coherence condition”)

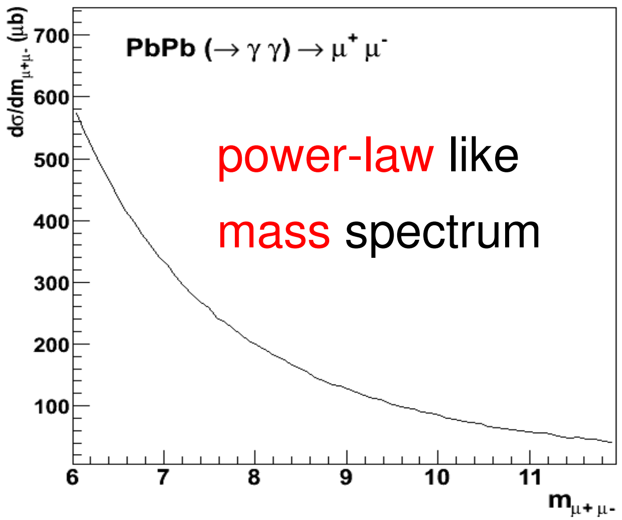
ϒ centered at midrapidity

(narrow dσ/dy)

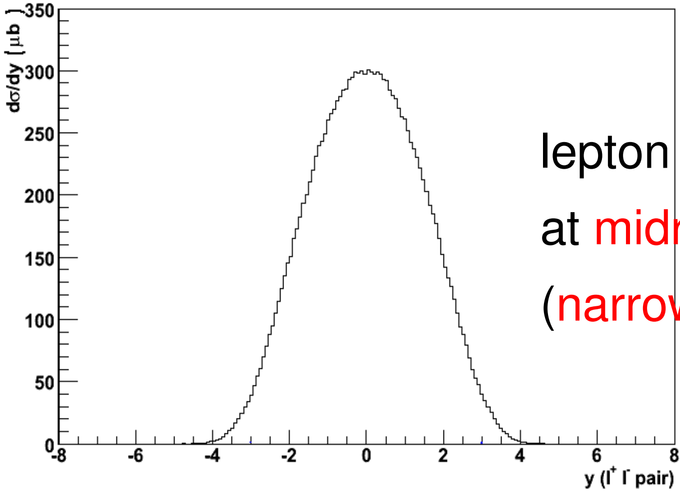
Decay leptons also well within CMS acceptance

Input MC: $\ell^+\ell^-$ backgd. distributions

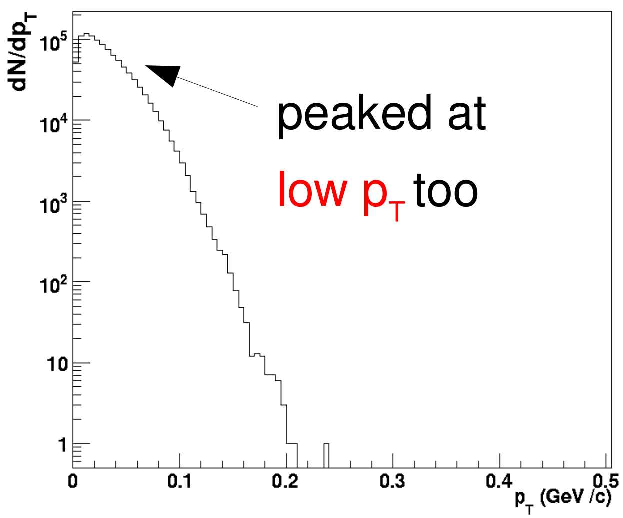
➢ STARLIGHT dilepton continuum mass, p_T, rapidity distributions:



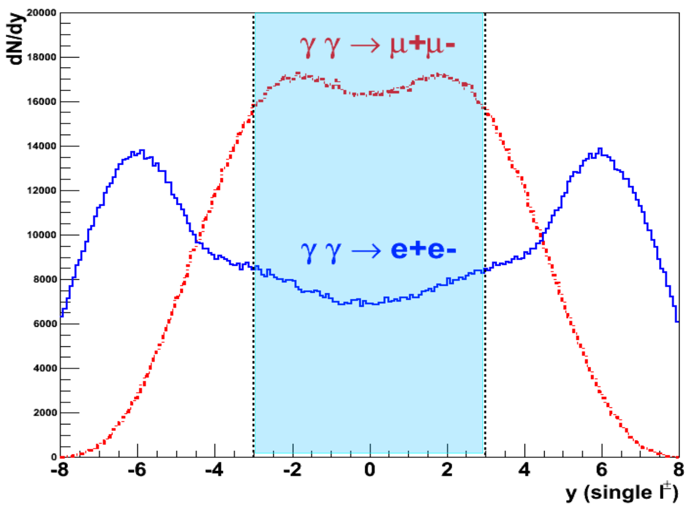
power-law like mass spectrum



lepton pairs centered at midrapidity (narrow dσ/dy)



peaked at low p_T too



But most single leptons fwd peaked. Outside CMS acceptance !

UPC Level-1 trigger: signature & rates

- Use of following L1 primitives:
  - Veto ('OR') on simultaneous activity in HF+/- (3<|η|<5): 1 or 2 rap-gaps
  - Neutron signal in ZDC+ or ZDC- (|η|>8.3): nuclear breakup tagging
  - Isolated ECAL tower above 3 GeV: ϒ decay electron
  - Signal in muon RPCs (|η|<2.1) or CSCs (0.8<|η|<2.4): ϒ decay muon (>4 GeV)

- 2 UPC-L1 triggers: UPC-mu-L1 = (ZDC+ .OR. ZDC-) .AND. ($\overline{HF+}$ .OR. $\overline{HF-}$) .AND. (muonRPC .OR. muonCSC)

  UPC-elec-L1 = (ZDC+ .OR. ZDC-) .AND. ($\overline{HF+}$ .OR. $\overline{HF-}$) .AND. ECALtower(E>2.5 GeV)

- L1 trigger (background) rates ($\mathcal{L}$ = 0.5 $mb^{-1}s^{-1}$) ~ 2 – 4 Hz

$$N_{UPC-\Upsilon} = \langle\mathcal{L}\rangle \times \sigma_{PbPb\to\gamma Pb\to\Upsilon} \times BR(\Upsilon \to l^+ l^-) = 0.5\ \mathrm{mb}^{-1}\mathrm{s}^{-1} \times 0.078\ \mathrm{mb} \times 0.024 = \boxed{0.001\ \mathrm{Hz}}$$

$$N_{PbPb-ED+cosmic-backgd} = 2 \times N_{PbPb-ED} \times N_{\mu-cosmic} \times \Delta t_{trig} \approx 10^5\ \mathrm{Hz} \times 180\ \mathrm{Hz} \times 10^{-8}\ \mathrm{s} \approx 0.2\ \mathrm{Hz}$$

$$N_{PbPb-periph-backgd} = \langle\mathcal{L}\rangle \times \sigma_{tot\ PbPb} \times \epsilon_{periph} \times \epsilon_{high-p_T\ \mu/e} = 0.5\ \mathrm{mb}^{-1}\mathrm{s}^{-1} \times 8000\ \mathrm{mb} \times 0.05 \times 2\cdot 10^{-3} \approx 0.4\ \mathrm{Hz}$$

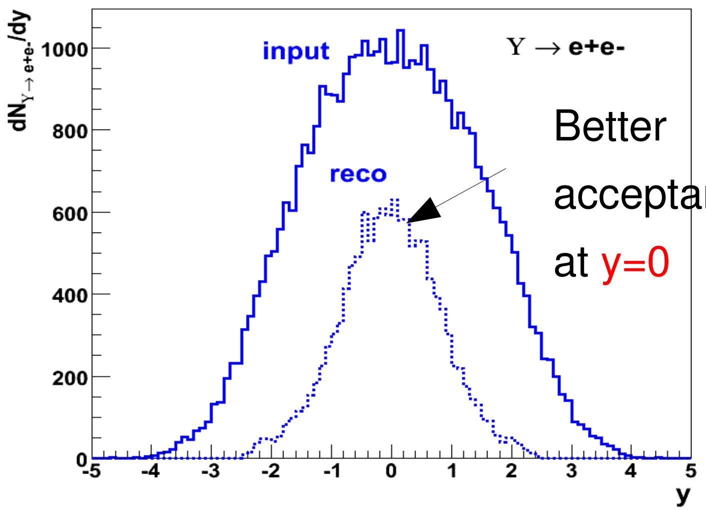
$$N_{\gamma\gamma-em-backgd} = \langle\mathcal{L}\rangle \times \sigma_{\gamma\gamma\to e^+e^-} \times \epsilon_{high-p_T\ e} = 5\cdot 10^{26}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \times 10^{-27}\ \mathrm{cm}^2\ \mathrm{mb}^{-1} \times 139\ \mathrm{mb} \times 0.01 = 0.7\ \mathrm{Hz}$$

N_{other} ~ (other diffractive γ-Pb, IP-Pb, γγ → X hard processes)~ 2 Hz

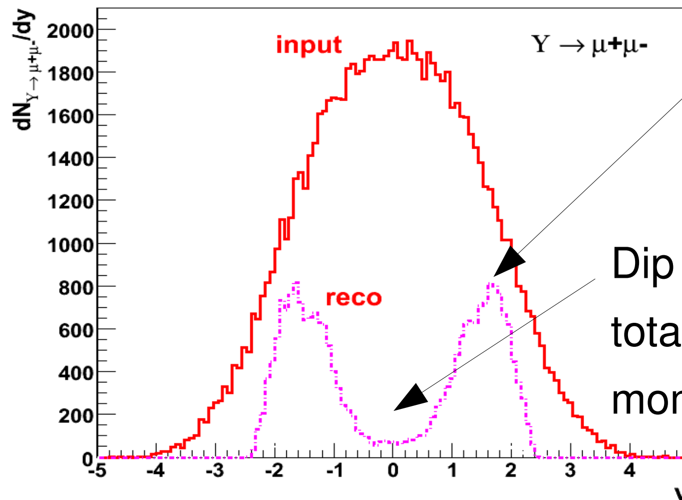
Fully reconstructed ϒ distributions

- Input & output ϒ rapidity and p_T distributions:

electrons | **muons**

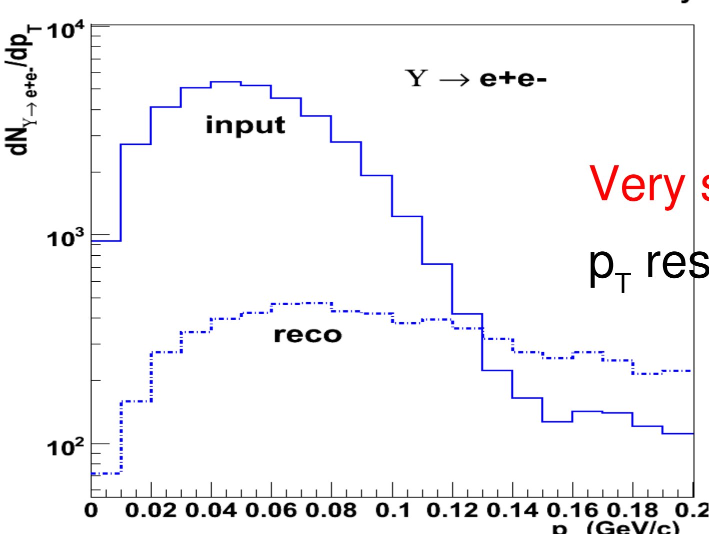


Better acceptance at y=0

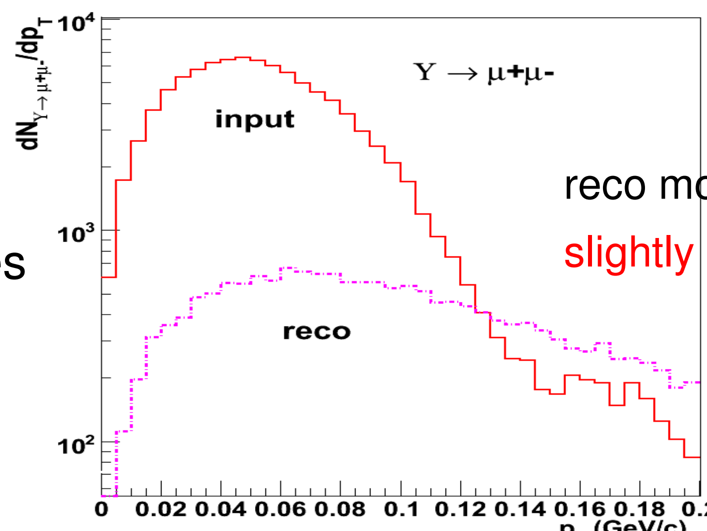


Better acceptance at |y|~2

Dip at y=0 (lowest total muon momentum)



Very similar p_T responses



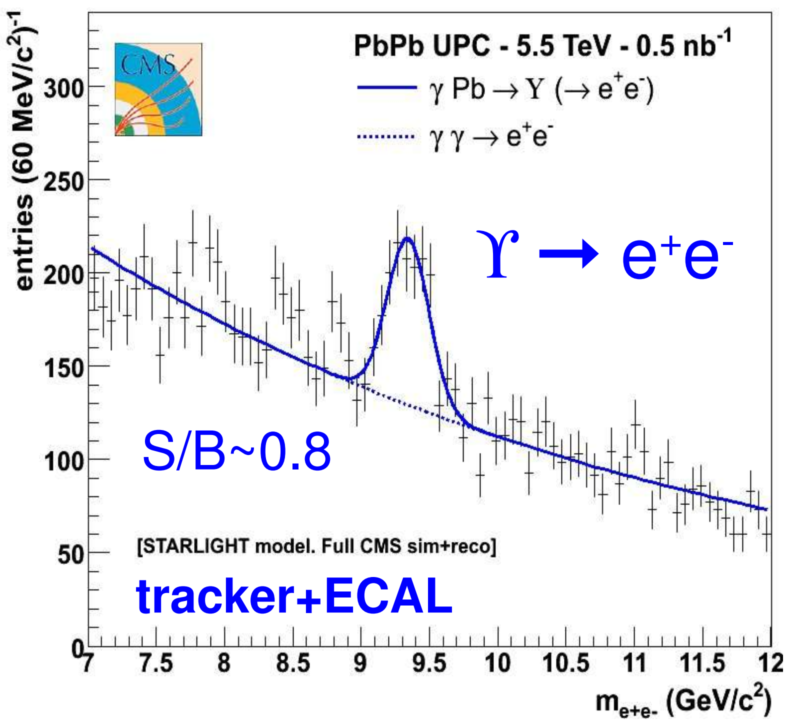
reco momentum slightly boosted.

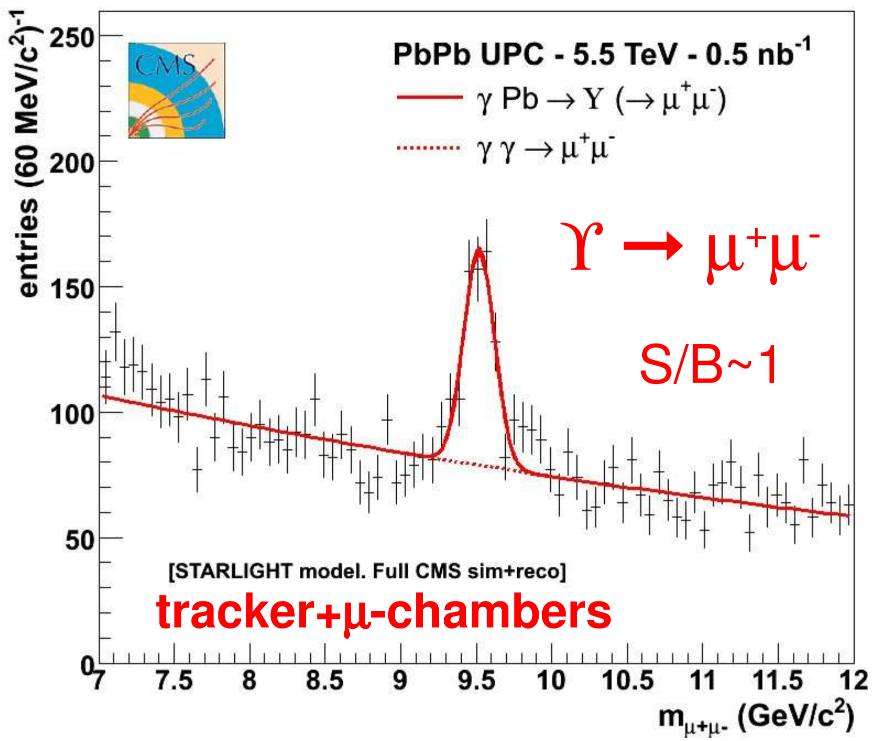
Mass distributions signal+background

- Signal+background mixed according to relative cross-sections & BR:

$$\frac{N_{signal}}{N_{continuum}} = \frac{\sigma_{PbPb\to\gamma Pb\to\Upsilon} \times BR(\Upsilon \to l^+ l^-)}{\sigma_{PbPb\to\gamma\gamma\to l^+ l^-}(m_{inv} = 6.-12\ \mathrm{GeV}/c^2)} \approx 0.35\%\ \ (0.15)\% \quad \text{for } \mu^+\mu^-\ (e^+e^-)\,,$$

DdE, A.Hees, CMS-AN06-107





Peak position: ~9.35 GeV/c^2

Mass resolution: ~150 MeV/c^2

Peak position: ~9.52 GeV/c^2

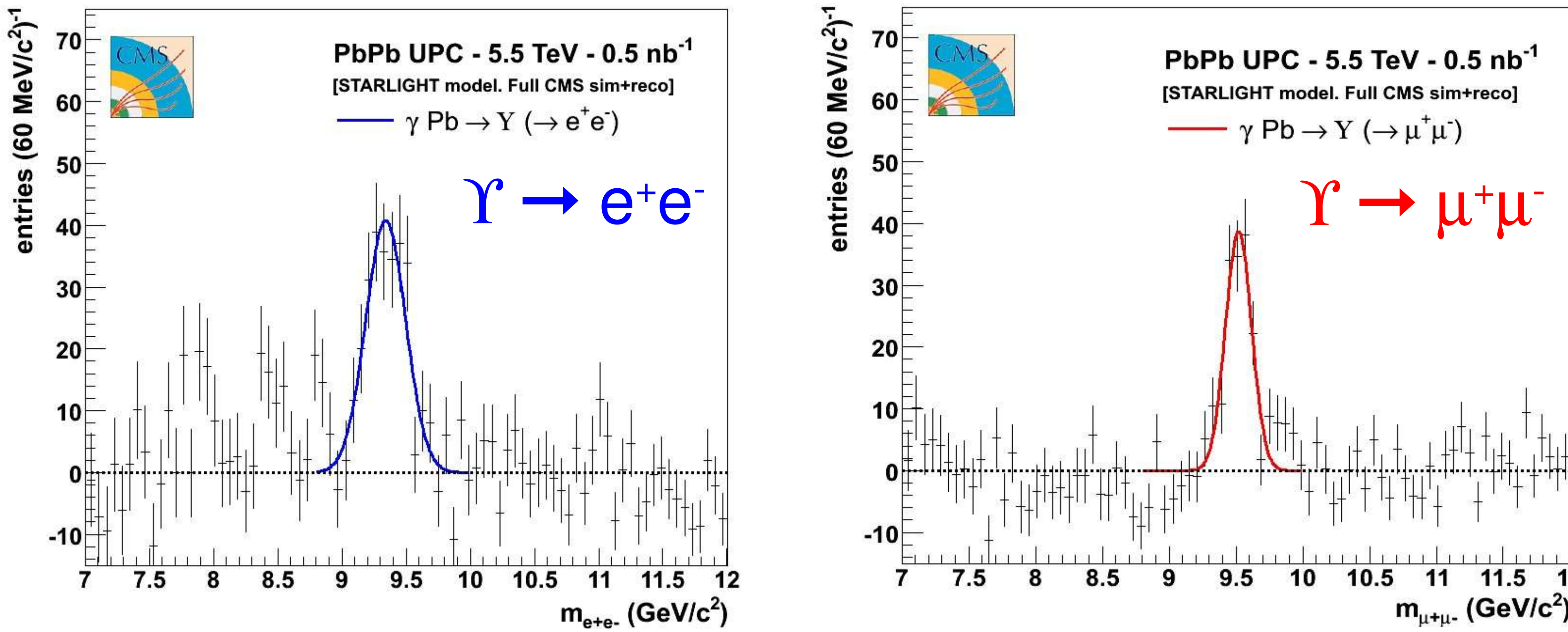
Mass resolution: ~90 MeV/c^2

- Excellent $m_{\mu\mu}$ resol.: higher mass $b\bar{b}$ states (Υ',Υ'' not yet in MC) can be resolved

Expected Υ yields (PbPb 1-"year" luminosity)

- Backgd. subtracted dN/dm_{inv} for $\int \mathcal{L}\, dt = 0.5\ nb^{-1}$ PbPb-5.5 TeV ($t=10^6$ s)
  (error bars = expected stat. uncertainties)

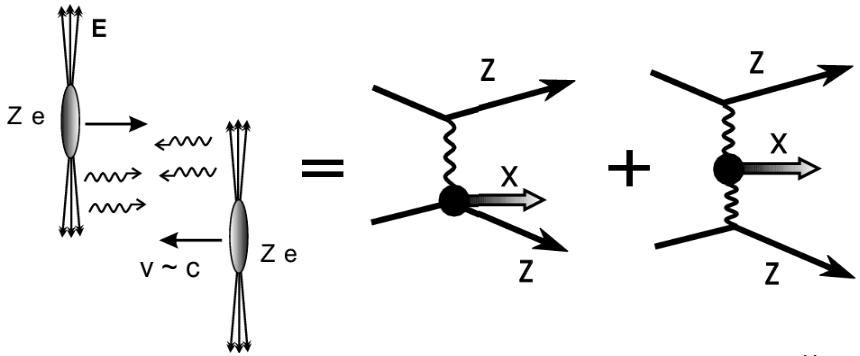
DdE, A.Hees, CMS-AN06-107



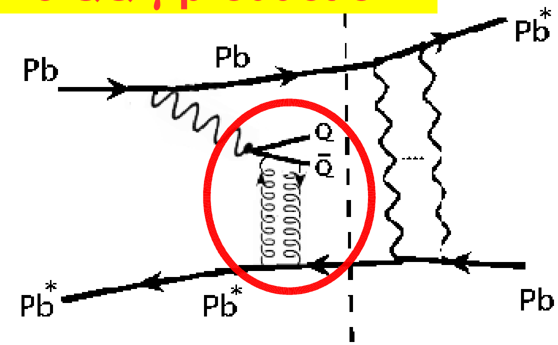
- Syst. uncertainties (dominated by backgd. subtraction, ±5% lumin.): ~10%
- Final total rates : $N(\Upsilon \rightarrow e^+e^-, \mu^+\mu^-) \sim 500 \pm 20(stat) \pm 10\%(syst)$
  (±3σ integration around mass peak)
- Enough stats. for detailed studies (including y-dependence) of gluon PDF

Summary

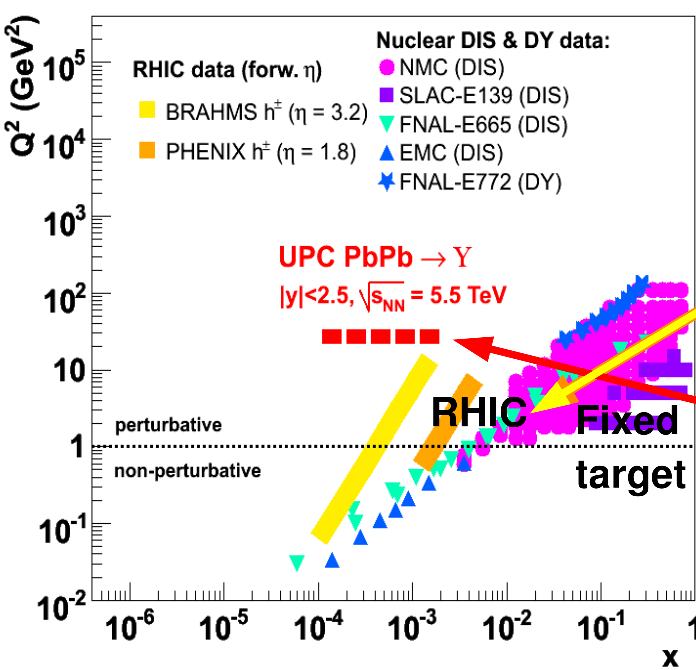
UPC = HE photoproduction studies:

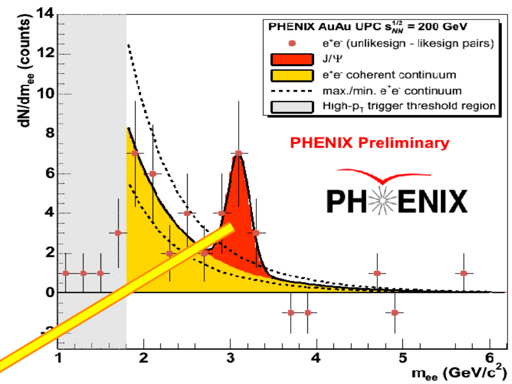


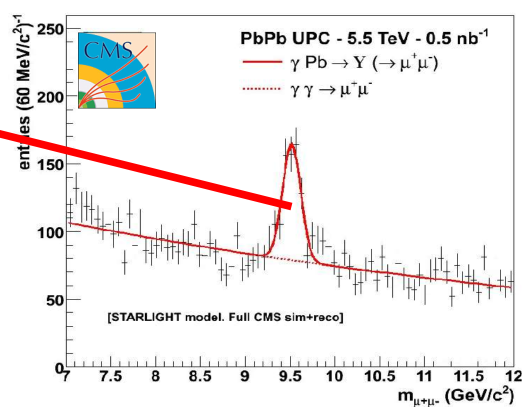
Exclusive QQ γ-production:



Nuclear xG(x,Q²) plane:







RHIC J/Ψ preliminary:

$d\sigma_{J/\Psi}/dy|_{y=0}$ = 48±16±18 μb

Measurement feasibility proven. More luminosity needed.

LHC Υ prospects:

$dN_{\Upsilon}/dy|_{|y|<2.5}$~500±20±10%

Enough stats. expected for detailed xG(x,Q²) studies in unexplored regime

Backup slides

Summary

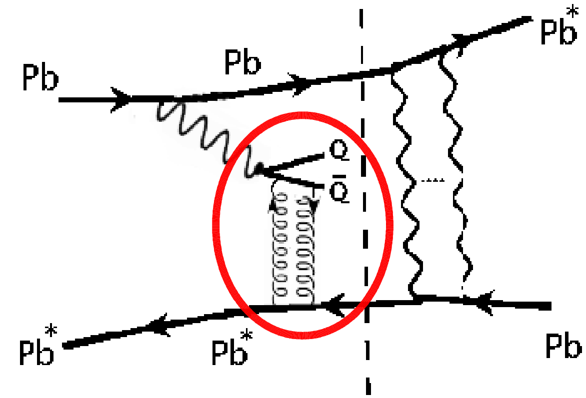
- UPC A+A collisions generate high-energy γ beams for photoproduction studies: $\gamma+\gamma$, γ+p,A physics as done at LEP & HERA.
- Unique access to nuclear $xG_A(x,Q^2)$ at small-x [Gluon saturation, non-linear QCD]
- Quarkonia UPC measurements at RHIC:
  - Trigger: forward neutron tagging (A* dissoc.), rapgap, GeV-dileptons at y=0
  - Good theoretical description of J/Ψ (pQCD) & high-mass e^+e^- (QED)
- Prospects for LHC:
  - Unexplored kinematic regime (up to $10\times\sqrt{s_{\gamma p}}$ HERA, $2\times\sqrt{s_{\gamma\gamma}}$ LEP, $x\sim10^{-4}$, ...)
  - Very large hard-probes rates. Excellent detector coverage.
  - High sensitivity to PDFs at small-x.
  - Study of PbPb→(γ Pb)→ϒPb* at 5.5 TeV with ϒ→e^+e^-, $\mu^+\mu^-$ in CMS as a tool to study low-x gluon density & evolution in the nucleus.
- Trigger considerations: ZDC neutron-tagging, L1 primitives, background rates, HLT strategy.
- Full CMS sim+digi+hit+reco chain. Input MC (STARLIGHT) for expected signal (ϒ) and dilepton continuum background PbPb→($\gamma\gamma$ Pb)→l^+l^-Pb*

xG(x,Q²) via $Q\bar{Q}$ γ-production in UPC

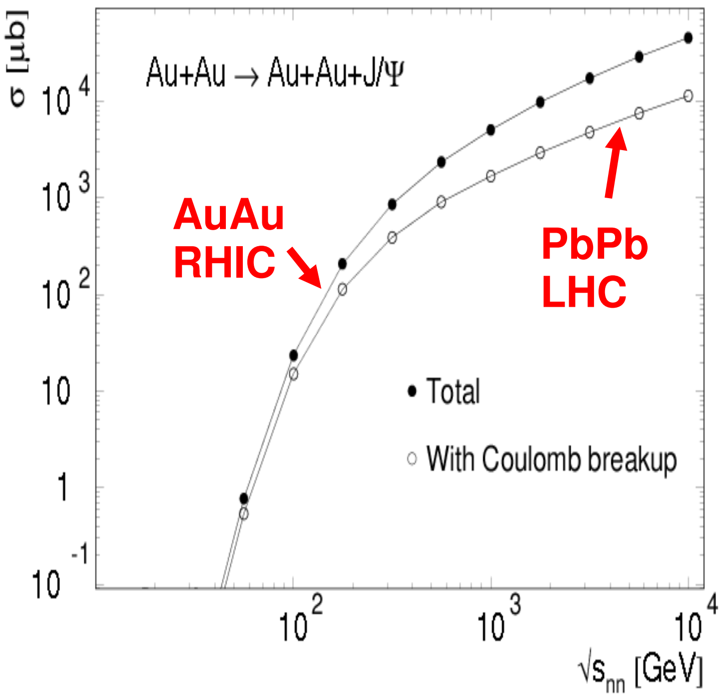
- γ+A→VM+A (VM=J/Ψ,ϒ) sensitive to gluon density squared:

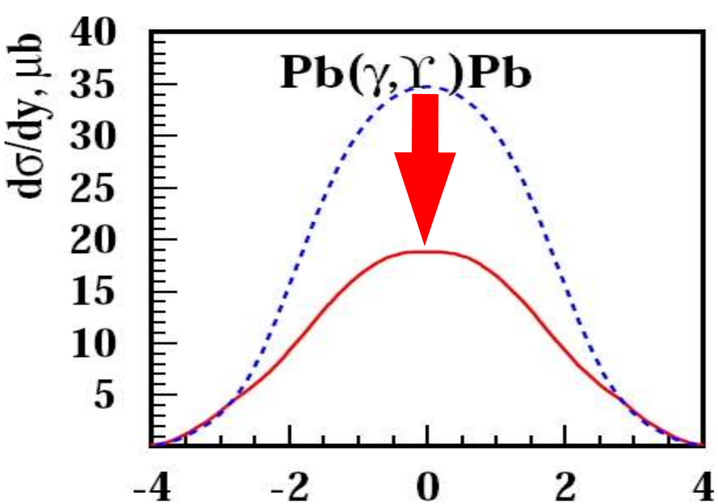
$$\sigma_{\gamma A\to VA}(s_{\gamma N}) \sim \left.\frac{d\sigma_{\gamma N\to VN}(s_{\gamma N})}{dt}\right|_{t=t_{\min}} \left[\frac{G_A(x_1,x_2,t=0,Q^2_{\rm eff})}{AG_N(x_1,x_2,t=0,Q^2_{\rm eff})}\right]^2$$

Strikman, Frankurt, Guzey et al.



Large cross-sections at the LHC



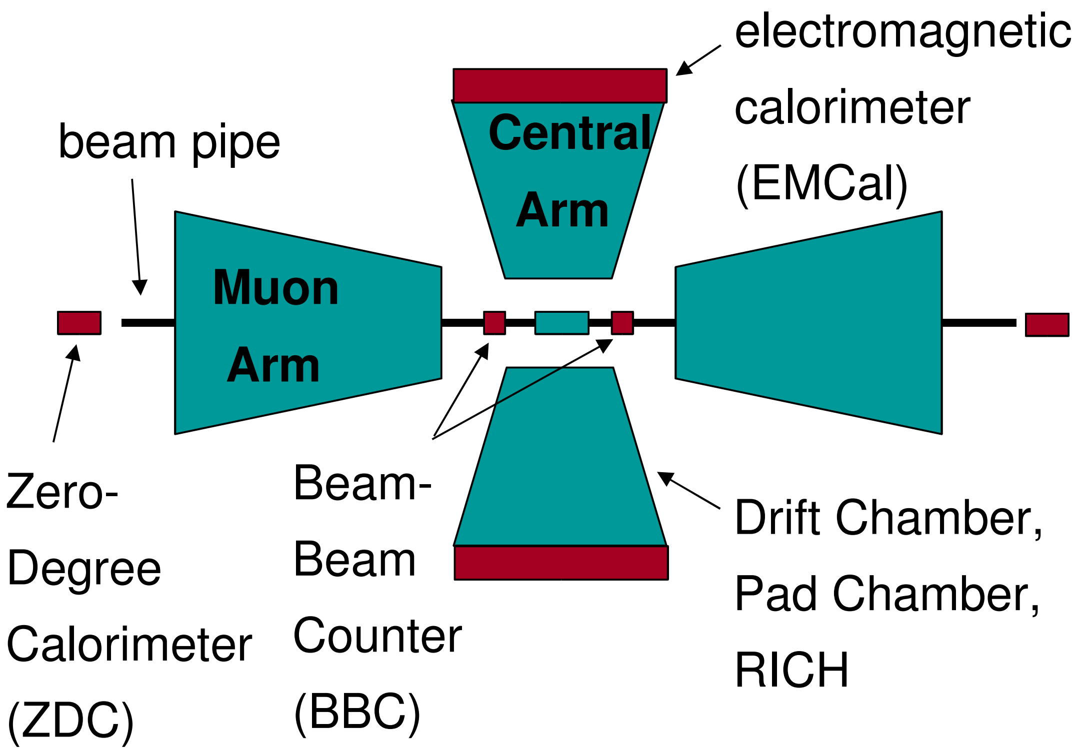


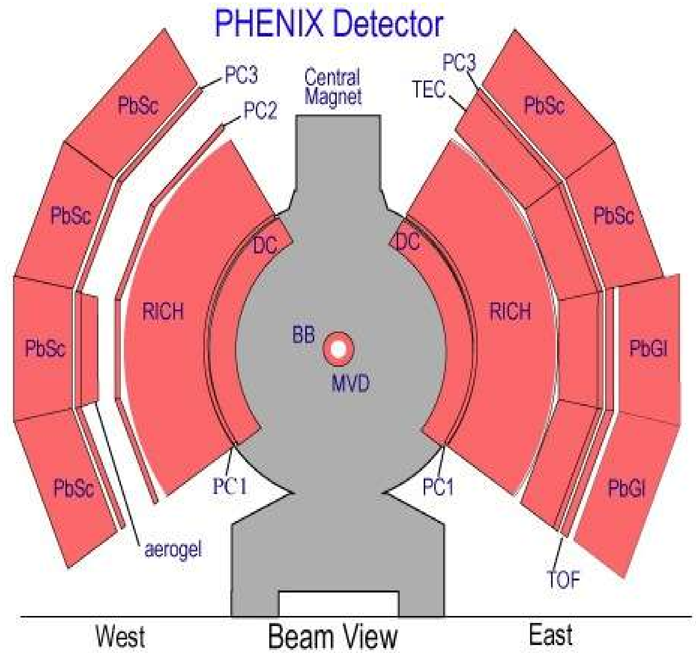
Impulse:	σ = 133 mb
LT shadowing:	σ = 78 mb

Larger suppression expected due to gluon saturation effects

PHENIX experiment at RHIC

- dN/dm_{inv} after e^+e^- continuum subtraction





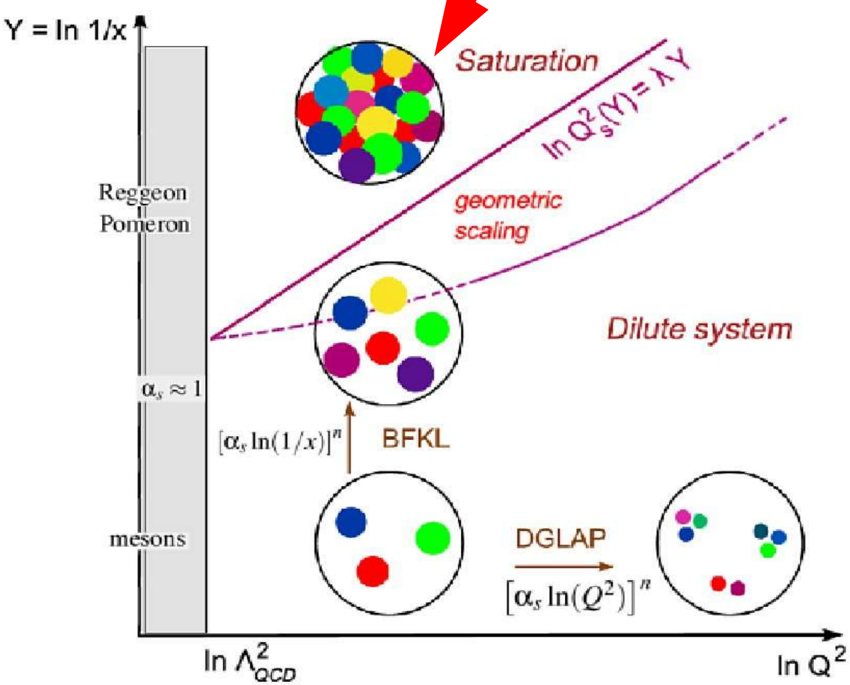
Parton (x,Q^2) evolution at low-x

- **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
- **x - BFKL** (parton emission ordered in p_L): $F_2(x) \sim \alpha_s \ln(1/x)^n$
- Linear equations (single parton radiation/splitting): cannot work at low-x

(i) High gluon density : nonlinear g-g fusion will balance parton branchings

(ii) pQCD (collinear & k_T) factorization should break (no incoherent parton scattering)

(iii) Violation of unitarity even for $Q^2 >> \Lambda^2$ (too large perturbative cross-sections)



- Gluon-gluon fusion balances parton branchings below "saturation scale": $Q_s^2 \sim [1\text{GeV}]^2 \cdot e^y$ (LHC)
- Enhanced in nuclei ($A^{1/3} \sim 6$) : $Q_s^2 \sim [5\ \text{GeV}^2] e^{(0.3y)}$ (LHC)
- CGC = effective-field theory describes hadrons as classical fields below Q_s.
- Non-linear JIMWLK/BK evolution eqs.

LHC PbPb: low-x nuclear PDF studies

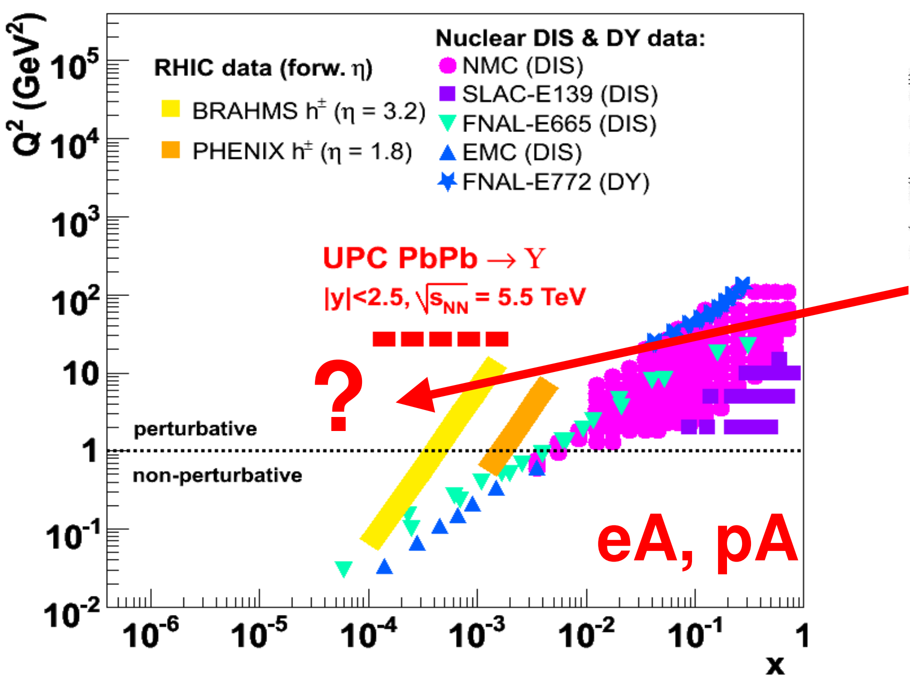
- PbPb @ 5.5 TeV, pPb @ 8.8 TeV:

  (i) Very high $\sqrt{s} \Rightarrow x_T = 2p_T/\sqrt{s} \sim 10^{-3}$ ~30-45 times lower than AuAu,dAu @ RHIC !

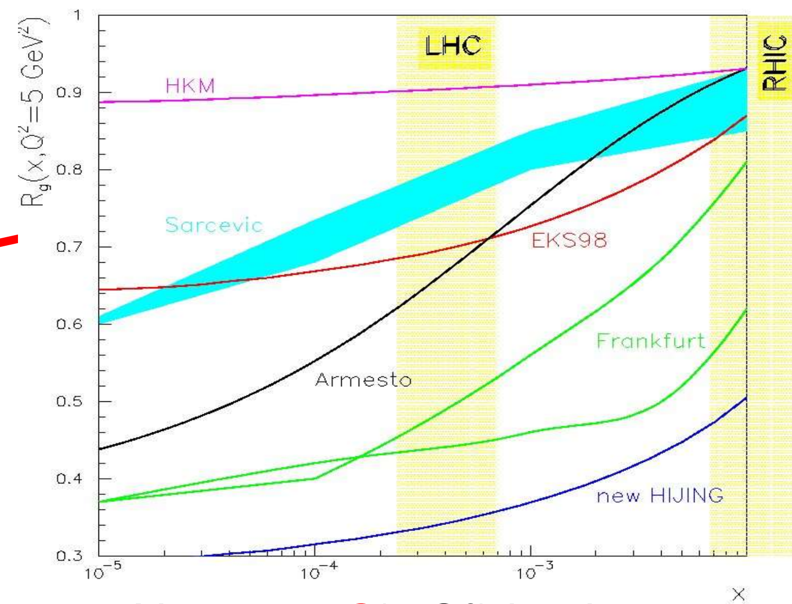
  (ii) Sat. momentum ($A^{1/3}$~6 enhancement factor): $Q_s^2 \sim [5\ \mathrm{GeV}^2]\cdot e^{(0.3\ y)}$

  (iii) Very large perturbative cross-sections.

Armesto, J.Phys.G32:R367 (2006)



Ratio of gluon densities in Pb to p:



Dd'E,J.Phys.G G30 (2004) S767

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

UPC HLT trigger strategy

- Allocated UPC bandwidth in HLT:

  2.25 Mb/s (1% total) = 1 – 2 Hz for UPC evt. size 1 – 2 Mb.

- Required L1→ HLT reduction factor: ~ 1 – 4

- Application of one (or more of the) following HLT algorithms:

  (i) Verification of L1 elect./muon candidates (clean hadronic background)

  (ii) Evt. vertex within z<15 cm (remove cosmic bckgd.)

  (iii) Low total transverse momentum (p_T<1 GeV/c removes most non-coh. prod.)

  (iv) Back-to-back dielec./dimuons (HLT GlobalCalo and GlobalMu objects)

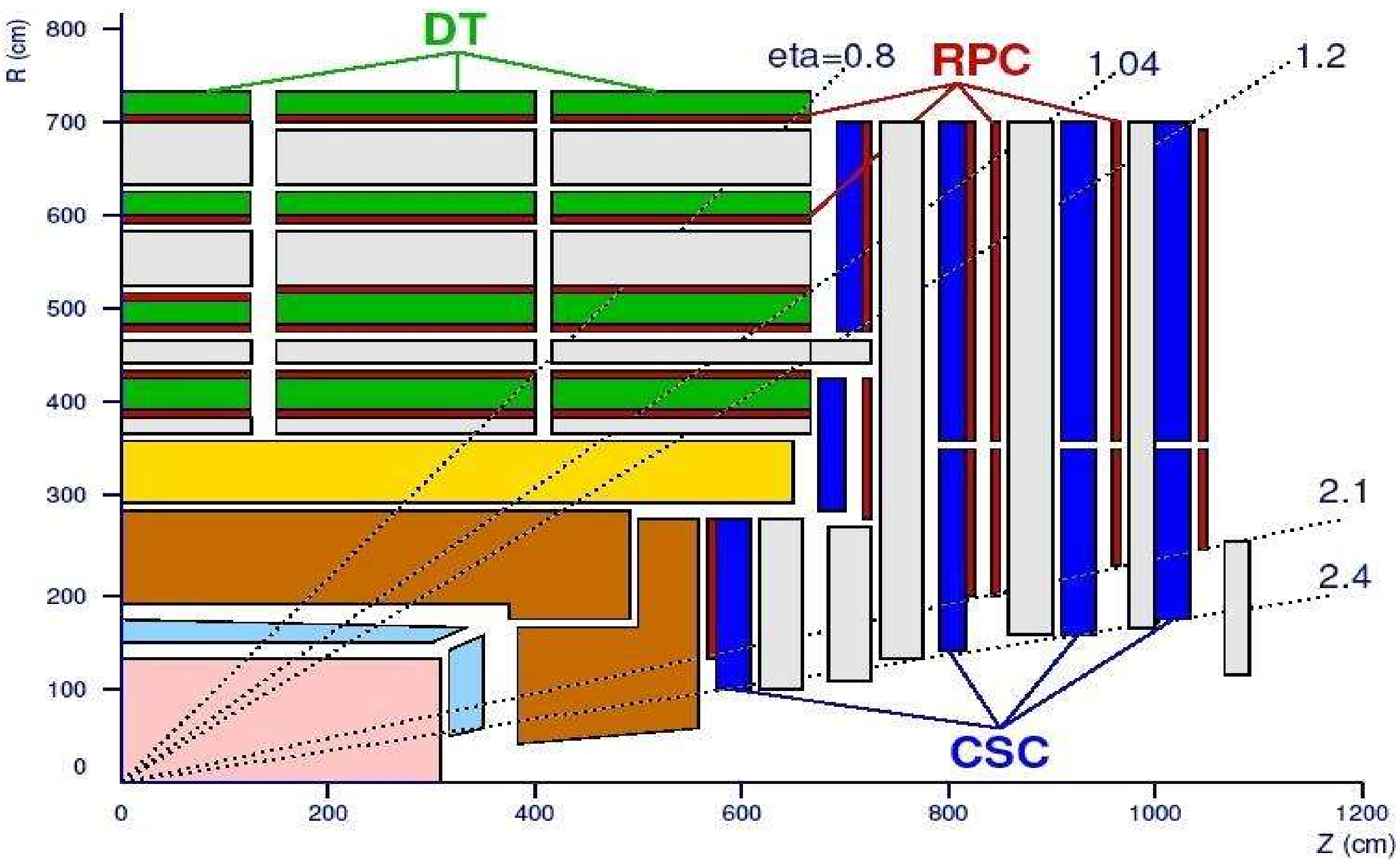
- If just condition (ii) is enough to reduce rates, one will be able to analyse offline other interesting diffractive processes too.

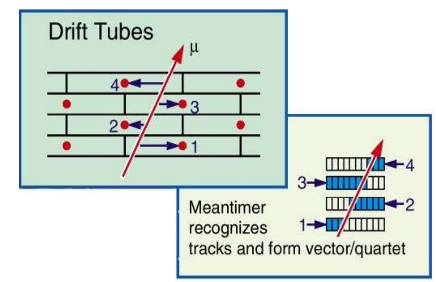
CMS muon system

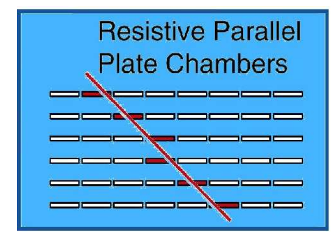
- 3 types of gaseous particle detectors for muon identification:
  - Drift Tubes (DT) in central barrel region
  - Cathode Strip Chambers (CSC) in endcap region
  - Resistive Plate Chambers (RPC) in barrel & endcaps

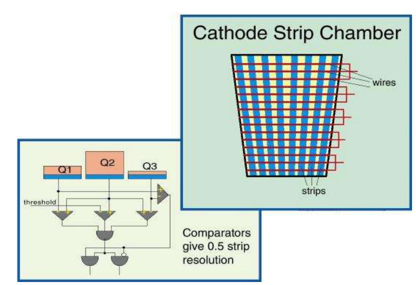
(DT, CSC) ➡ precise measurement of muon position (momentum)

(RPC) ➡ fast info for LVL-1 trigger





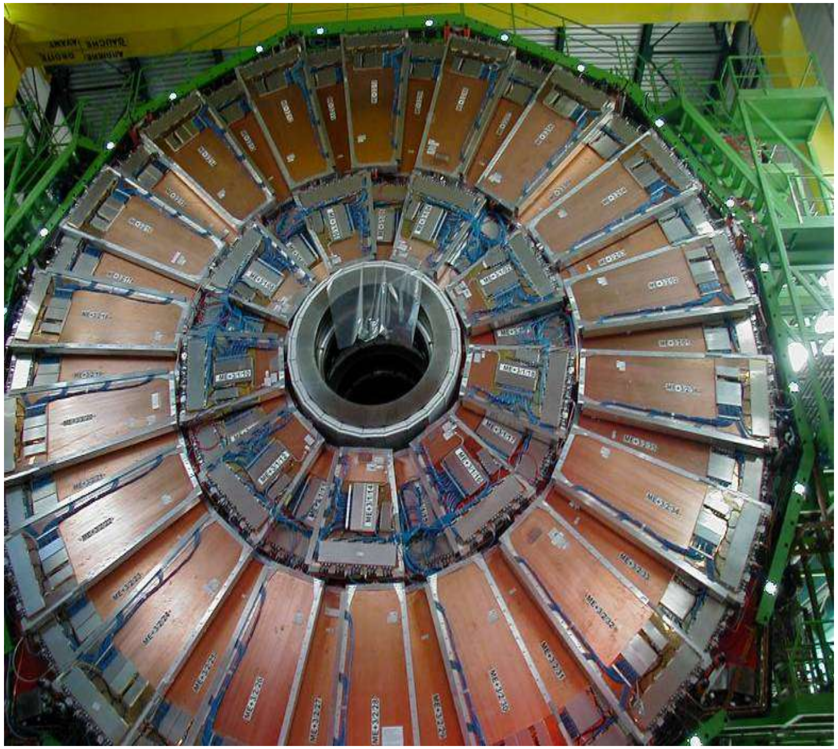




CMS muon system

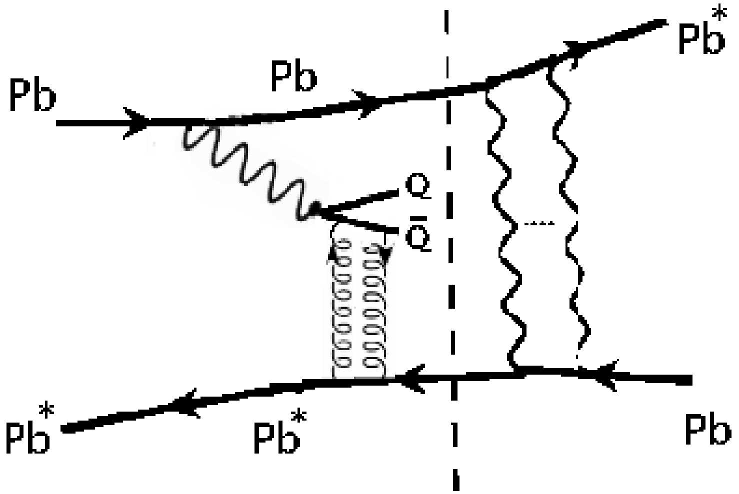
- Drift Tubes (DT) in central barrel
- Resistive Plate Chambers (RPC) in barrel and endcaps

- Cathode Strip Chambers (CSC) in endcap region



Cross-section predictions: UPC γ Pb → Υ

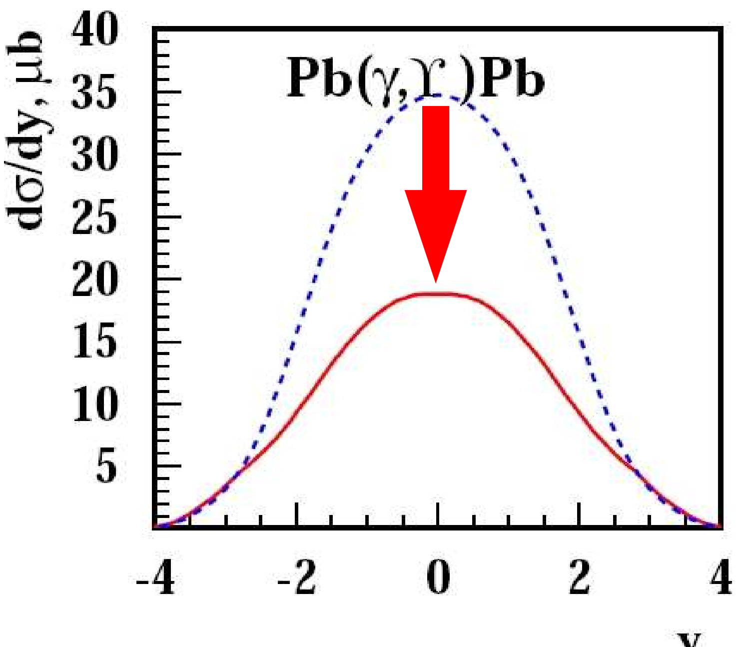
- Model predictions:



[Starlight: J. Nystrand, S.Klein, NPA752(2005)470]

Process	σ_{tot}	σ_{Xn}	$\sigma_{Xn\|Xn}$
$PbPb \to \gamma Pb \to J/\psi + X$	32 mb	8.7 mb	2.5 mb
$PbPb \to \gamma Pb \to \Upsilon(1S) + X$	173 μb	78 μb	25 μb

[similar calculations by Machado-Goncalves et al.]



[Frankfurt, Guzey, Strikman]

Impulse: σ = 133 mb

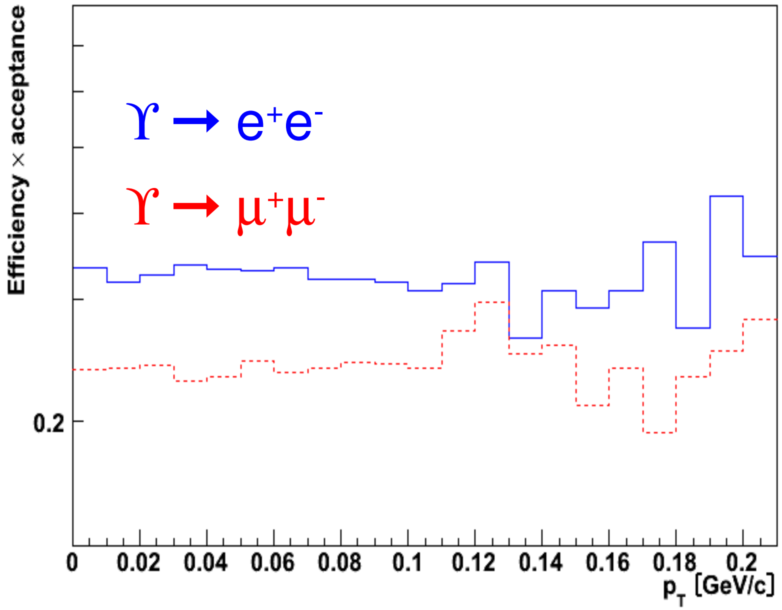
LT shadowing: σ = 78 mb

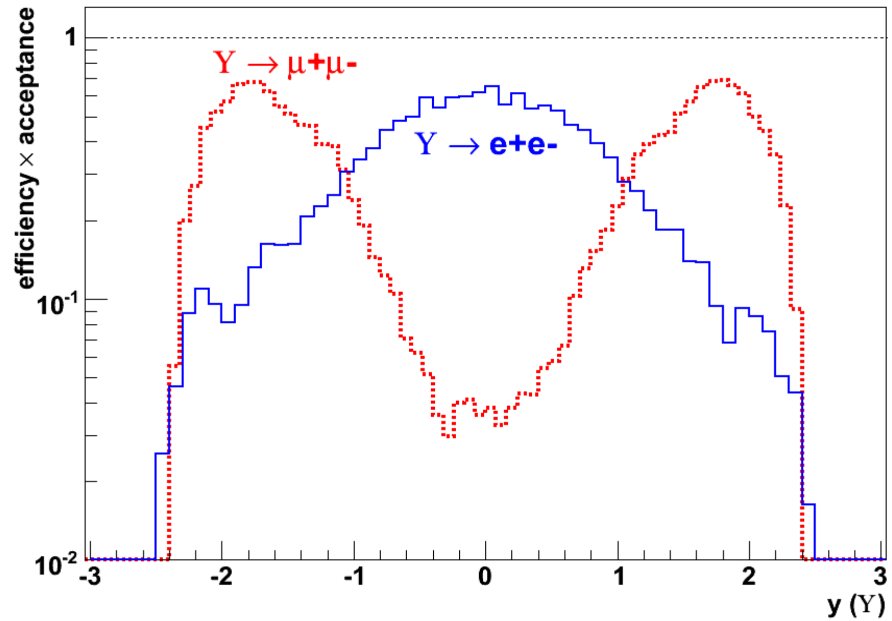
- Note: ~50% of UPC interactions have soft EM interactions leading to nuclear breakup w/ fwd. neutron (*Xn*) emission (important for triggering)

UPC full CMS simulation analysis

Acceptance x Efficiencies ϒ

- Efficiencies-acceptances versus y and p_T :
- Total Acc. × Effic. : ~21% ($\mu^+\mu^-$), 30% (e^+e^-)





Acc × Effic(p_T) ~flat vs p_T

Better for electrons (higher yield at y=0 where EMCAL is more efficient)

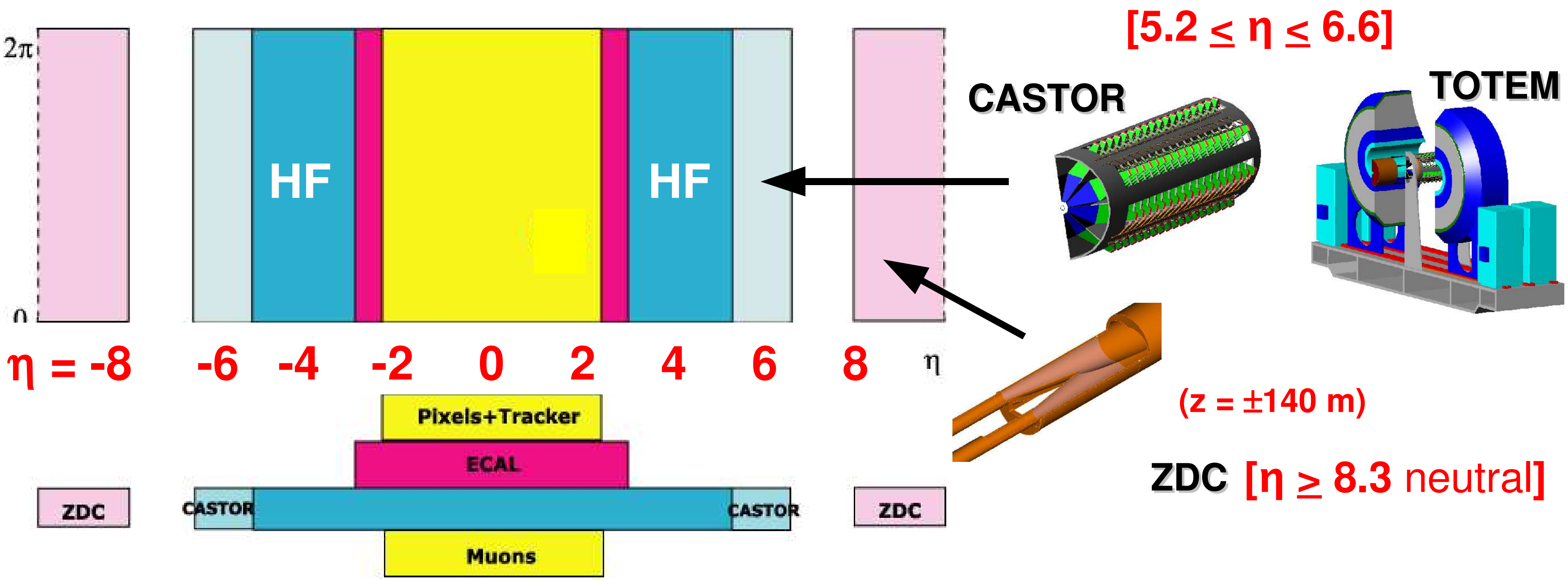
Electron and muon analyses have complementary rapidity acc. × effic:

$\mu^+\mu^-$: ~60% at |y|~1.5-2.5

e^+e^-: ~60% at |y|<0.5

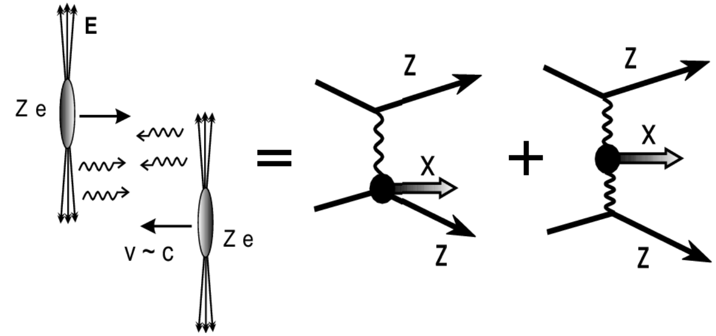
CMS-TOTEM acceptance

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



- Detection capabilities within η ≤ 6.7 (and η ≥ 8.1, neutral).
- Strong AA-UPC and rapidity-gap physics possible
- Hard scatt. measurements (jets, DY) possible at $x \sim 10^{-4}-10^{-6}$ in pp,pA

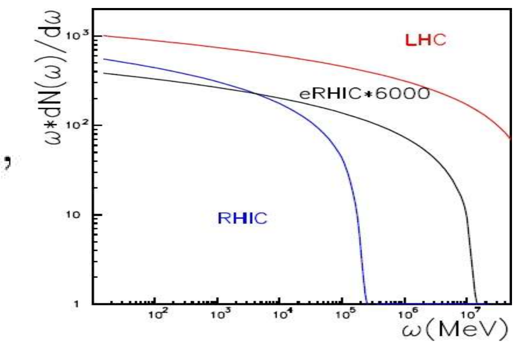
Photon beams at the LHC



- High energy heavy-ions produce strong E.M. fields due to coherent action of $Z = 82$ protons:

- Equivalent flux of photons in EM (aka. Ultra-Peripheral, $b_{min} \sim 2R_A \sim 20$ fm) AA colls.:

$$\frac{dN_\gamma}{dz}(b > b_{min}) = \frac{\alpha_{em} Z^2}{\pi} \frac{1}{z} \left[2xK_0(x)K_1(x) - x^2\left(K_1^2(x) - K_0^2(x)\right)\right] ,$$



- Photon beams:

  Flux ~ Z^2 (~$7 \cdot 10^3$ for Pb). **σ(γγ) ~ Z^4** (i.e. ~$4 \cdot 10^7$) times larger than $e^\pm$ beams !

  "Coherence condition" : γ wavelength > nucleus size ⇒ very low γ virtuality

$$Q^2 = (\omega^2/\gamma^2 + q_\perp^2) \lesssim 1/R_A^2 \quad \text{(where } \gamma \text{ is the beam Lorentz factor),}$$

$$\omega < \omega_{max} \approx \frac{\gamma}{R} \text{ , and } q_\perp \lesssim \frac{1}{R} \approx 30 \text{ MeV.}$$

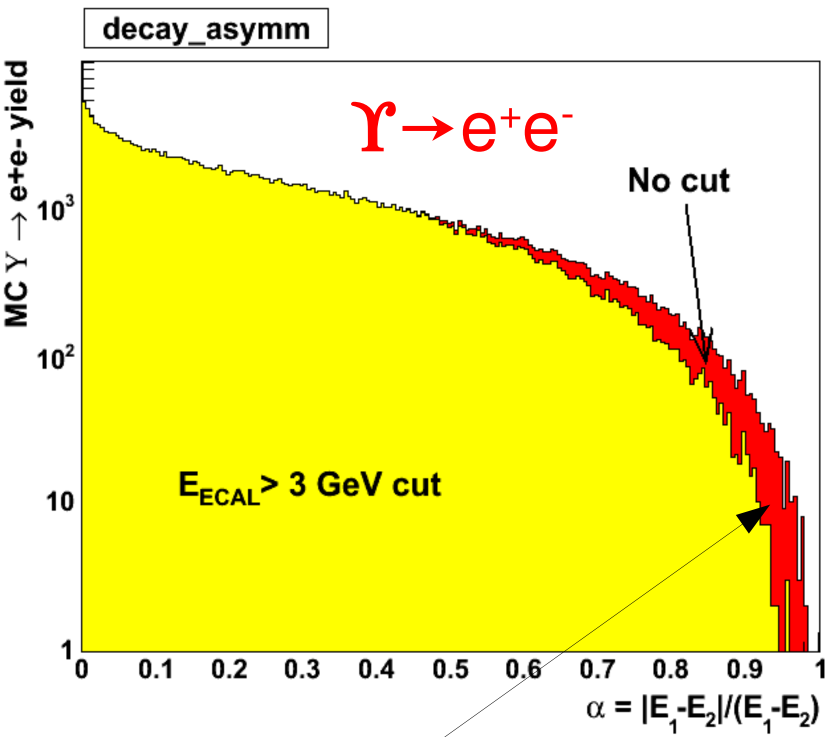
  Max. γ energy: $E_{\gamma max}$ ~ 80 GeV (PbPb-LHC)

  Center-of-mass energies: γA: max. $\sqrt{s_{\gamma A}} \approx$ 1. TeV ≈ 3. - 4. × $\sqrt{s_{\gamma p}}$(HERA)

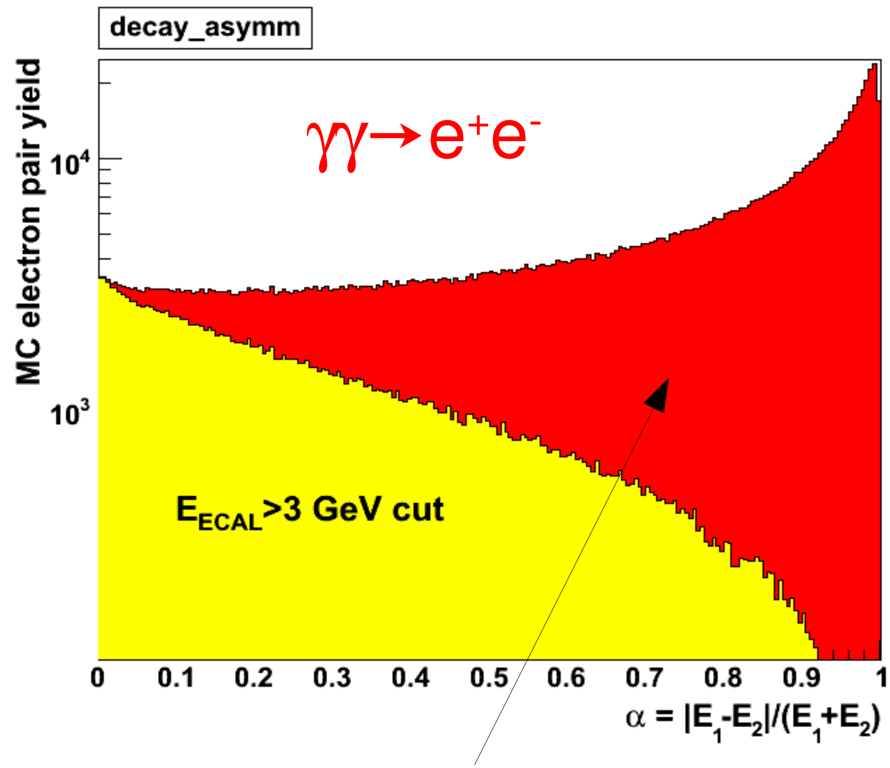
  γγ: max. $\sqrt{s_{\gamma\gamma}} \approx$ 160 GeV ≈ $\sqrt{s_{\gamma\gamma}}$(LEP)

Trigger efficiencies Υ

- Momentum threshold cut >3 GeV/c at |η|<2.5 for $e^{\pm}$ (and also effectively $\mu^{\pm}$) removes significantly the continuum pair background without Υ loss:



ε_{loss}~3.5% of Upsilon



~80% of lepton pairs removed

γ A : Hard central production

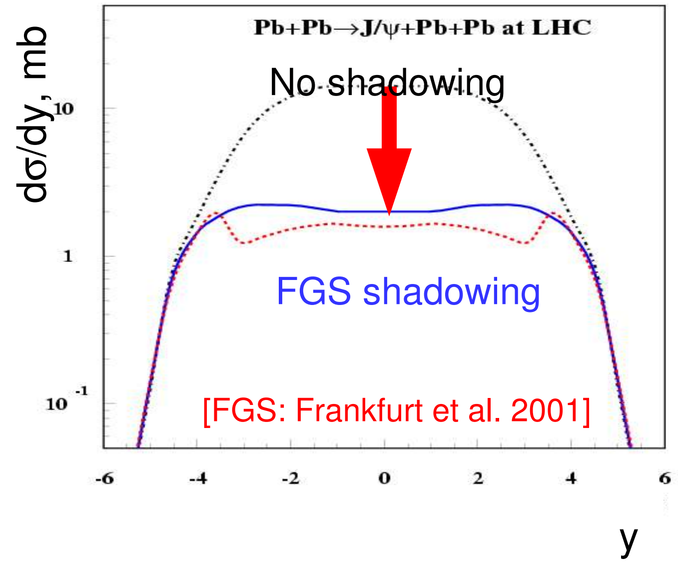
- Quarkonia: γ+A→ J/Ψ,ϒ+A very sensitive to nuclear gluon density at small-x:

  Perturbative process:

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

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

  Even stronger suppression expected if gluon saturation (CGC)

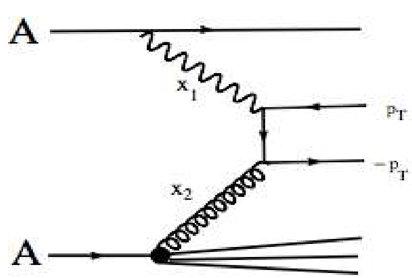


- Dijet: via gluon exchange (well described in QCD & tested @ HERA)

  Wider range of Q^2 than QQbar.

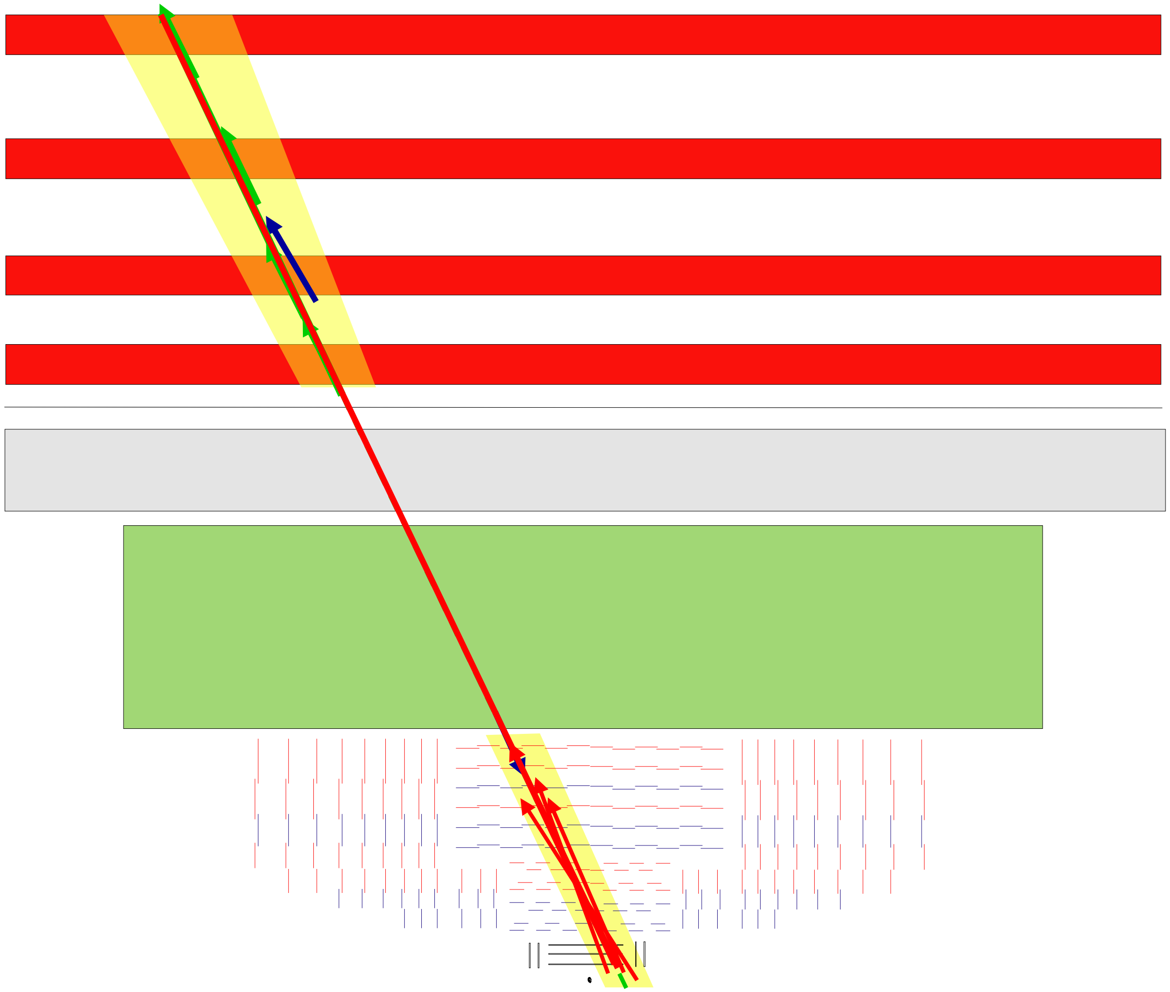
  Photon-jet (~1% of dijet rate) has clear signature

  ttbar possible in pA collisions (measure charge of top quark)



- Triggering in UPC processes only possible w/ ZDC neutron-tagging.

Muon reconstruction



- Best muon spectrometer at LHC (CMS)
- Excellent coverage: ~5 units of rapidity, 2π
- Strongest magnetic field: 4 T, 2 T (return yoke)
- Tag from mu-chambers, momentum resolution from Silicon tracker
- Ecal + Hcal + Magnet iron absorbs hadrons
  - Barrel: $p_T^{\mu} > 3.5$ GeV/c
  - Endcap: $p_L^{\mu} > 4.0$ GeV/c