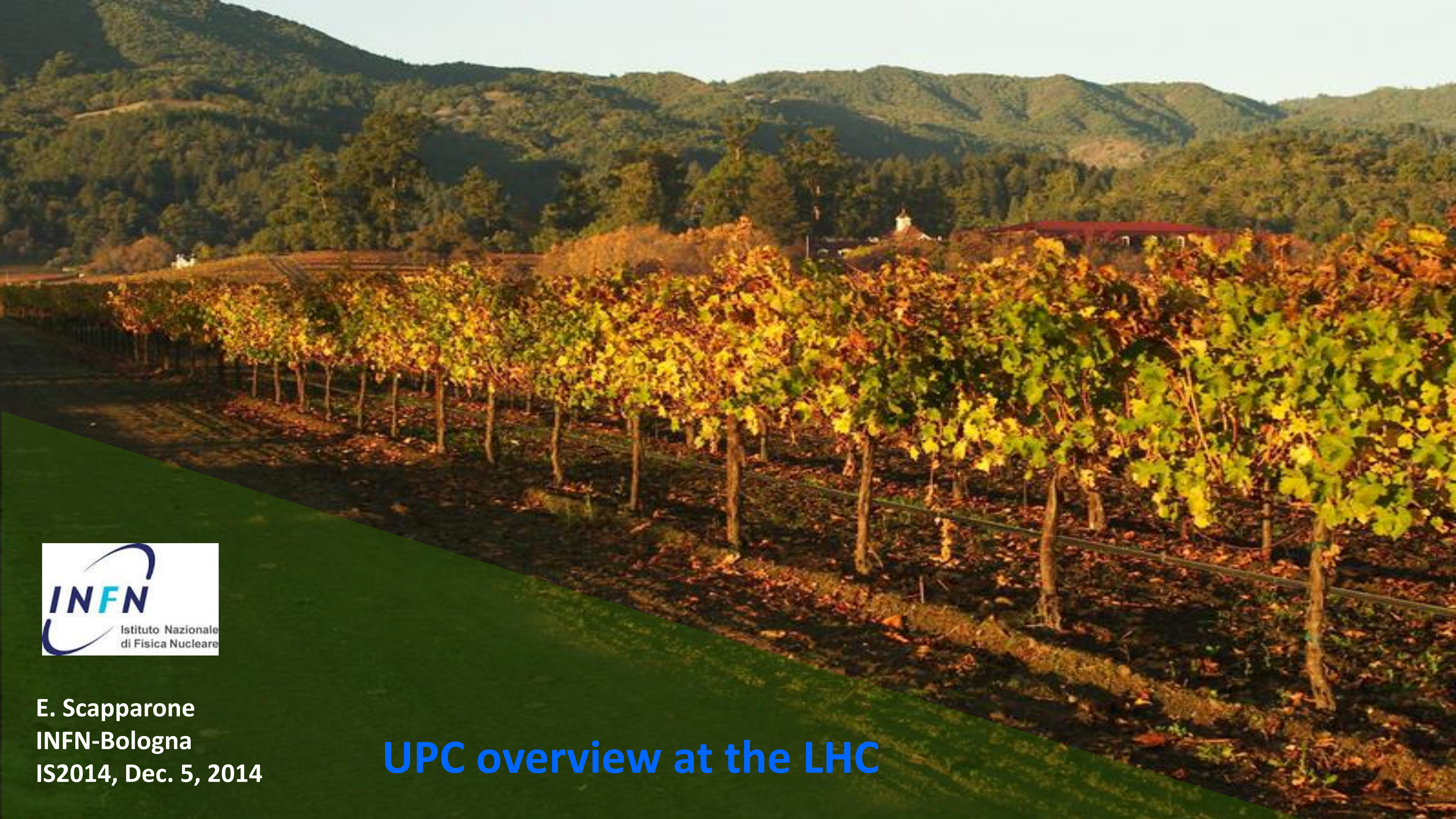
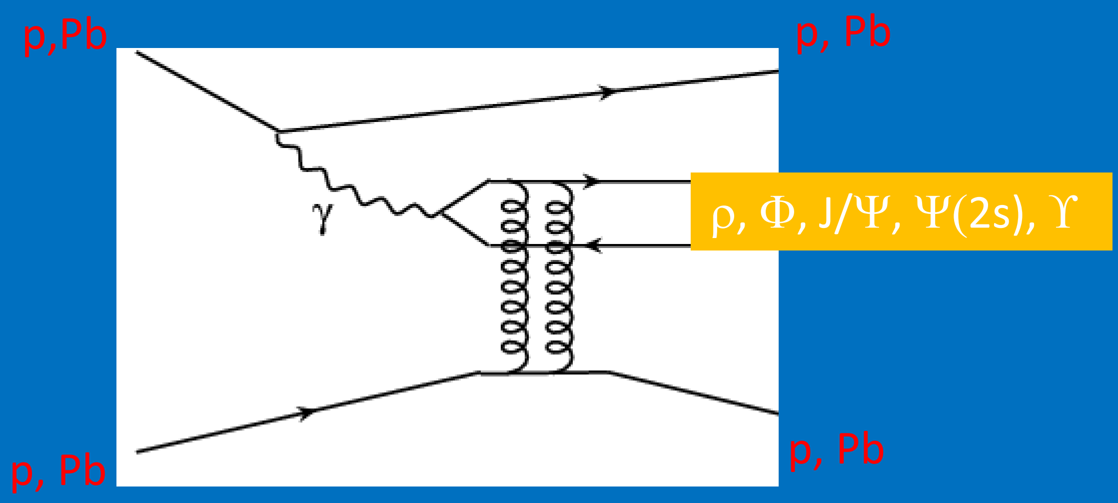


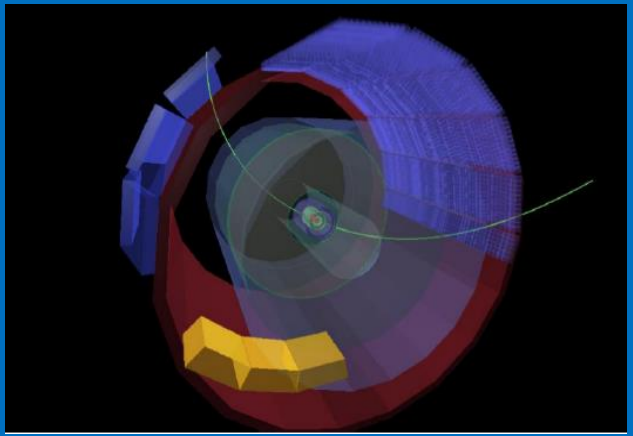
UPC overview at the LHC

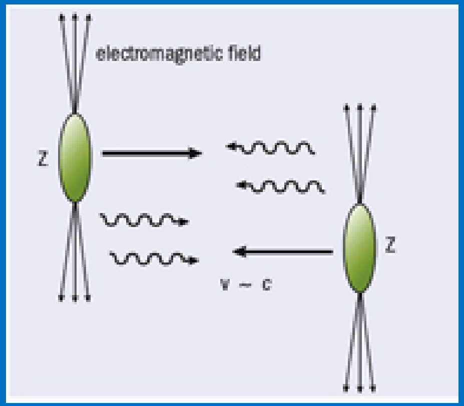
E. Scapparone
INFN-Bologna
IS2014, Dec. 5, 2014

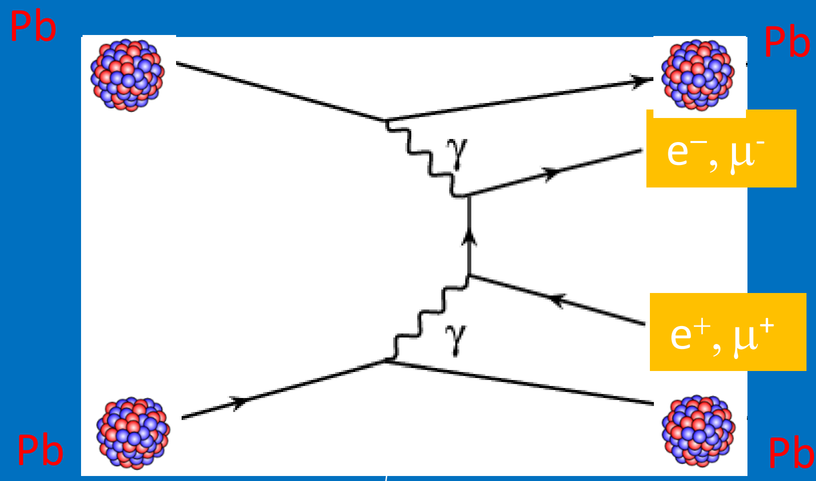
UPC physics is shedding light on a given target (p, A or γ): to tame hadronic cross section you've to go ultra peripheral

Photon flux $\propto$ Z^2



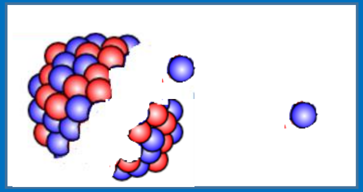






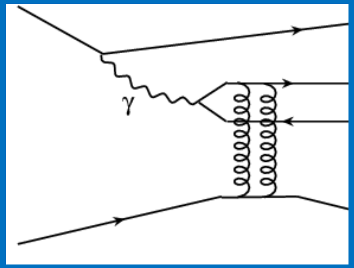
$\alpha \rightarrow Z\sqrt{\alpha}$: QED test

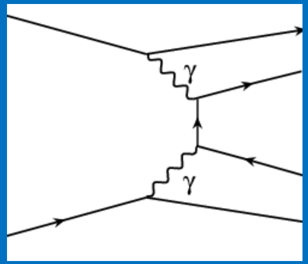
Two (or four) tracks in an oterwhise empty detector...
...and may be neutrons



ZDC (d_{IP} ~ 100 m) may detect these neutrons

UPC trigger:





General comment: UPC triggering not trivial:

- **hw:**
  - Few tracks (2 to 4) → requires low noise detectors ;
  - *Low p_T decay products (below threshold)*;
  - relatively small cross section → background rejection;
  - soft QED e+e- pairs have large cross section

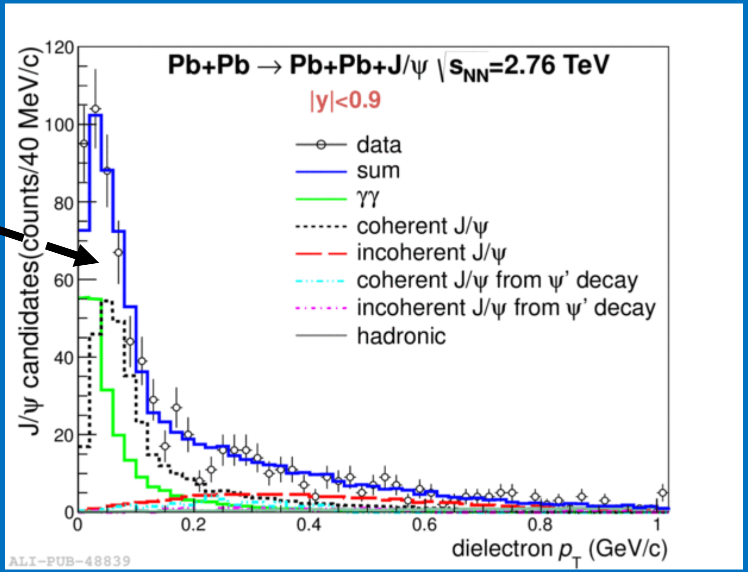
Measurements at different rapidity (different Bjprken-x) important

→ barrel: - silicon detector (low intrinsic background), but background from the huge e^+e^- cross section at low
- gas detectors far from IP (noise to be tamed for «few hits»- trigger, physics background from late particles)
- hadronic background, easier to reject by forward scintillators

Workaround: triggering with the Zero Degree Calorimeters. But can we really rely on that ?

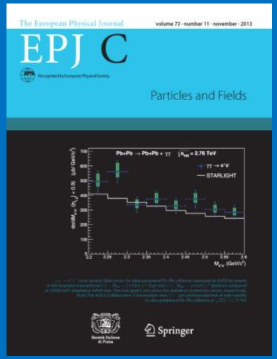
Coherent ?

Coherent interactions: $\lambda \sim R_N \sim$ 6 fm ~ $\hbar c/p_T$ → $p_T \sim$ 197 MeV/fm / 6 fm ~ 33 MeV/c



Does the nucleus stay <u>always</u> intact after the collision ? No, it's just a 70% probabiliy !
J/Ψ coherent production with neutrons ≥1:
Starlight(Klein, Nystrand): 68%;
Rebyakova, Strikman and M. Zhalov: 78%;

→ ALICE data: 0.70± 0.05



EPJ C73 (2013) 2017

Comments on ZDC triggering:

- only a part of the cross section can be taken. Rescale required to compare to the full σ (add ing a 10% sys error)

- event generator do not include neutron production in the final state. Bias ?

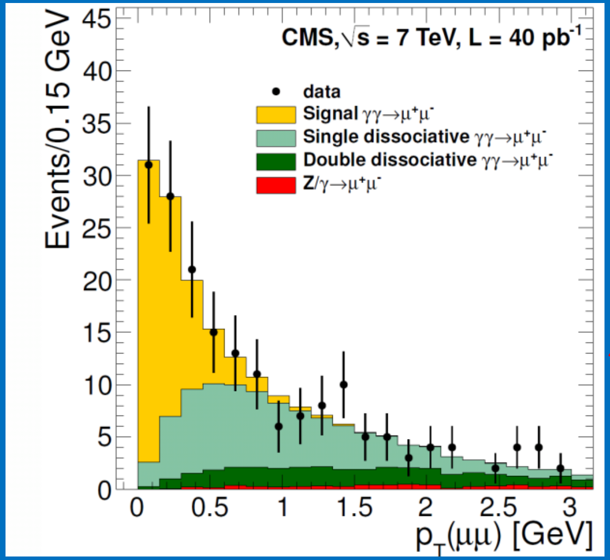
The LHC Run1 grape harvest:

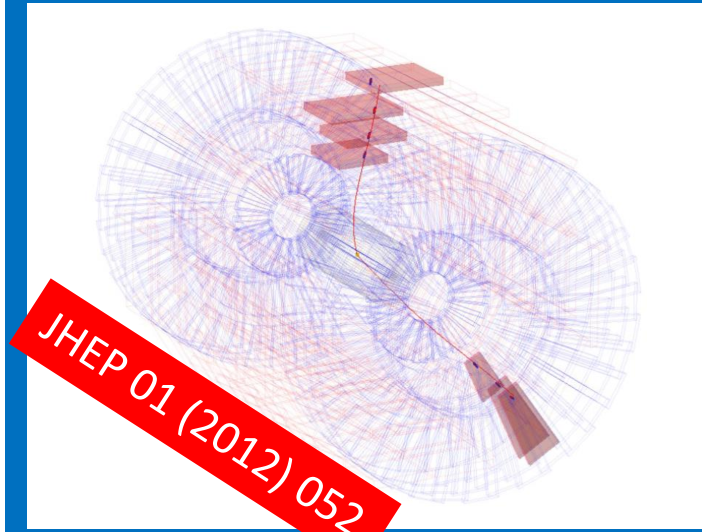
p-p

CMS

- Exclusive two-photon production of lepton pairs, 40 pb^{-1}

$$\sigma(p \to p\mu^+\mu^- p) = 3.38^{+0.58}_{-0.55}\ (\text{stat.}) \pm 0.16\ (\text{syst.}) \pm 0.14\ (\text{lumi.})\ \text{pb}$$

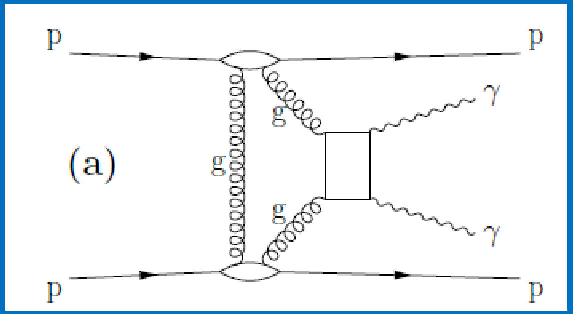




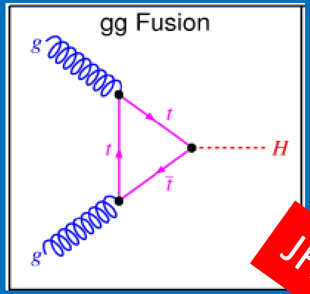
JHEP 01 (2012) 052

- Central exclusive γγ production
→ no candidates

CMS calorimetry (em + hadronic) at work.
Powerful search for γ (E_T > 5 GeV).



Related to Higgs production



JHEP 1211 (2012) 080

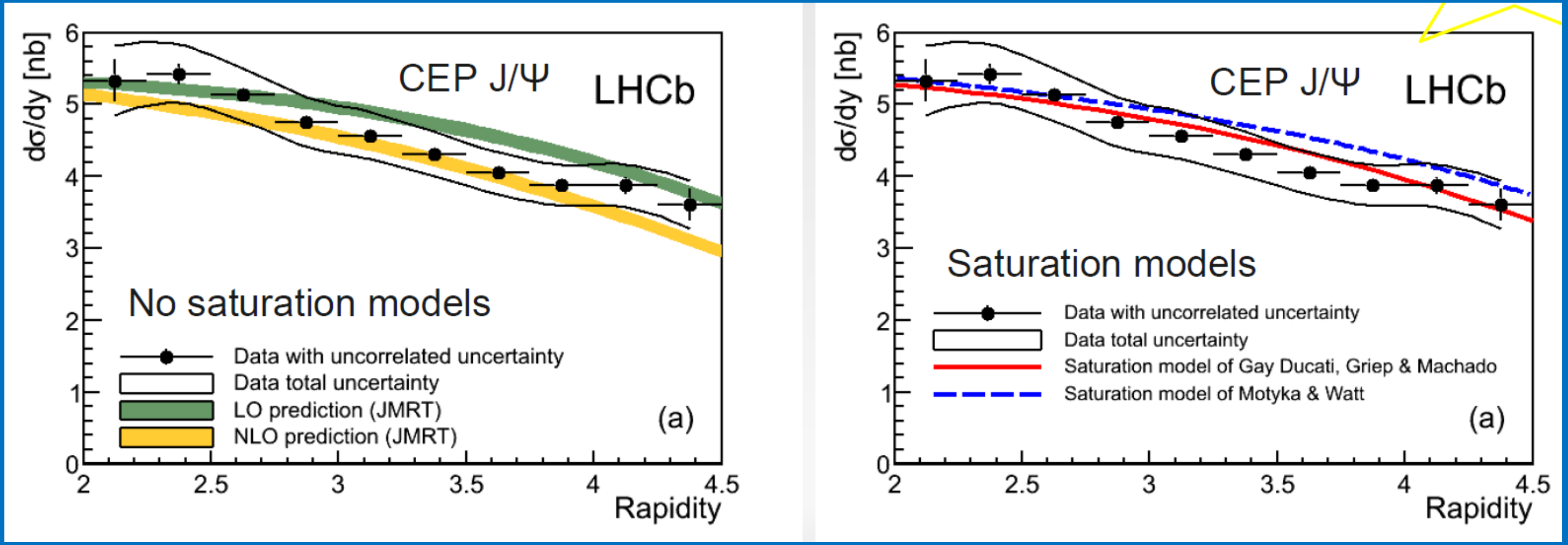
LHCb

- **Exclusive J/Ψ and Ψ(2S) vector meson production has been studied in the dimuon channel using the LHCb detector.**

J. Phys. G40 (2013) 045001

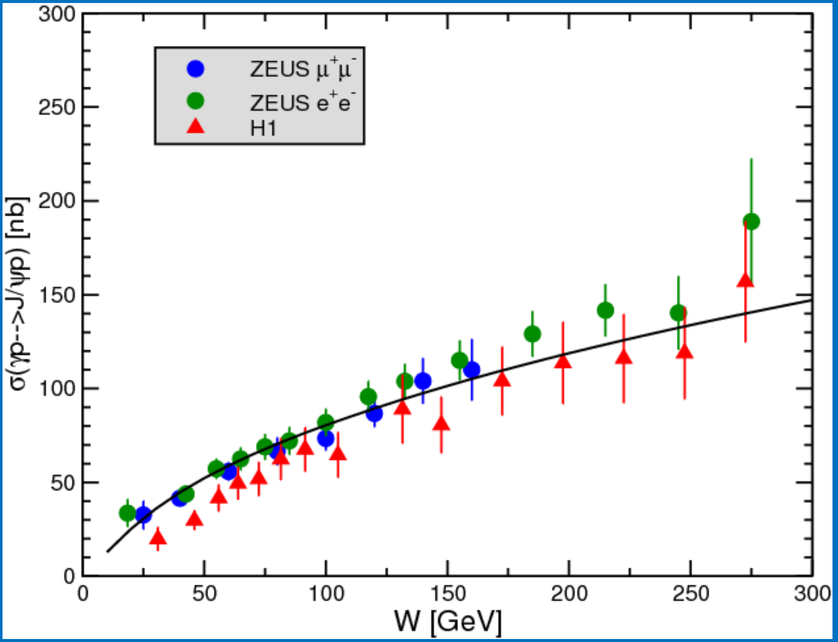
J. Phys. G 41 , 055002 (2014)

$$\sigma_{pp\to J/\psi\to\mu^+\mu^-}(2.0 < \eta_{\mu^\pm} < 4.5) = 291 \pm 7 \pm 19 \text{ pb},$$
$$\sigma_{pp\to\psi(2S)\to\mu^+\mu^-}(2.0 < \eta_{\mu^\pm} < 4.5) = 6.5 \pm 0.9 \pm 0.4 \text{ pb},$$



Data agree well with models including saturation...but with models not including saturation too.

Hunting for proton gluon saturation



Hera data up to $\mathbf{W_{\gamma p}}$ ~ 300 GeV

Growth of the cross section interpreted by pQCD model as an increase of gluon density approaching smaller Bjorken-x

Main issues: in pp you cannot tag the proton that radiated the photon.

$\mathbf{W_{\gamma p}{}^2 = 2E_p M_{J/\psi} e^{\pm y}}$

$$\frac{d\sigma}{dy}_{pp\to pJ/\psi\, p} = r_+ k_+ \frac{dn}{dk_+}\sigma_{\gamma p\to J/\psi\, p}(W_+) + r_- k_- \frac{dn}{dk_-}\sigma_{\gamma p\to J/\psi\, p}(W_-)$$

A model dependent result can be obtained assuming a power law, and extracting σ(W+) by using HERA fit for σ(W+) and viceversa

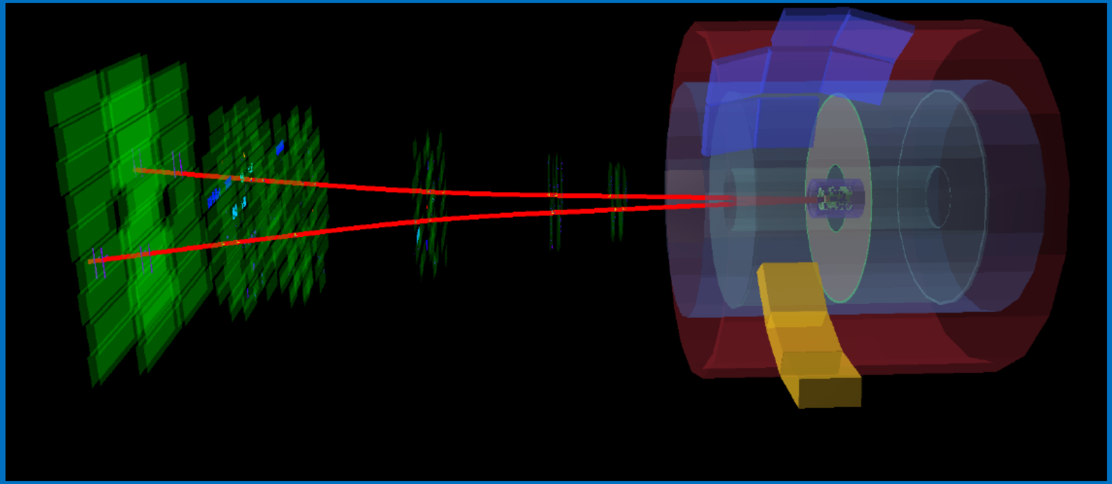
a) **You have a $W_{\gamma p}{}^+$ and $W_{\gamma p}{}^-$ solution for each event: power low assumption required "a priori"**
b) **The background from inelastic events is W dependent (quite different for $W_{\gamma p}{}^+$ and $W_{\gamma p}{}^-$)**
   ...the average has large uncertainties

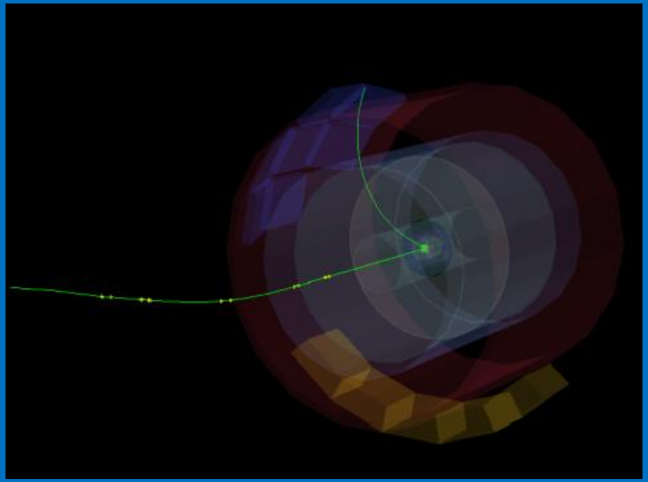
In p-Pb event the photon is radiated by the Pb nuclus in 96% of the events

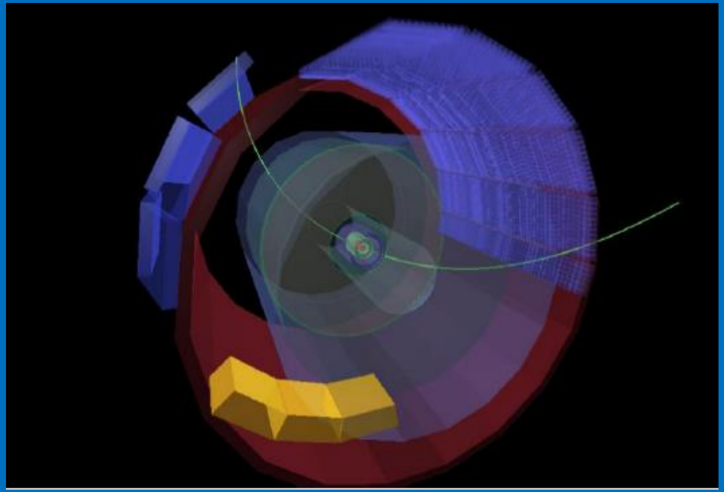
p-Pb

ALICE:

- J/Ψ study in p-Pb collisions in two different interval of γp centre of mass energies W; at the moment results available at forward rapidities.



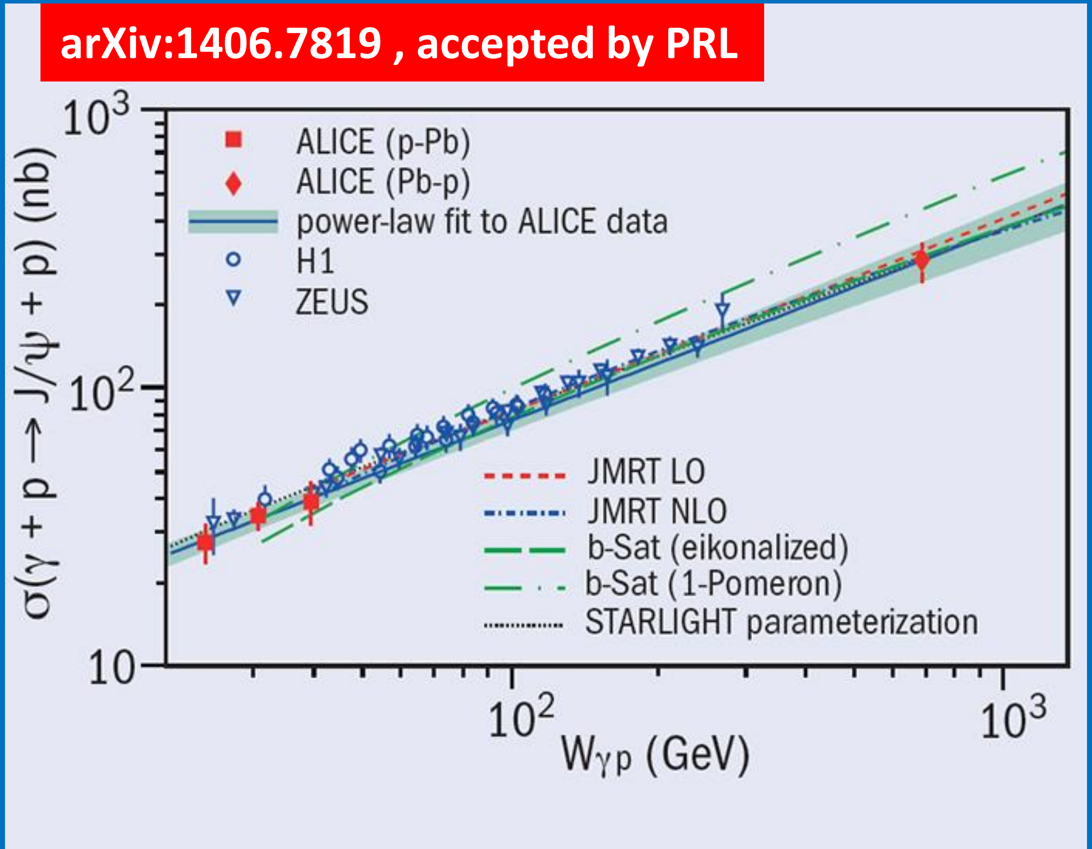




Hunting for proton gluon saturation

Hera data fit by a Power low $\sigma \propto W_{\gamma p}^{\alpha}$ $\alpha = (0.69 \pm 0.02(stat) \pm 0.03\ (syst))$ Zeuss

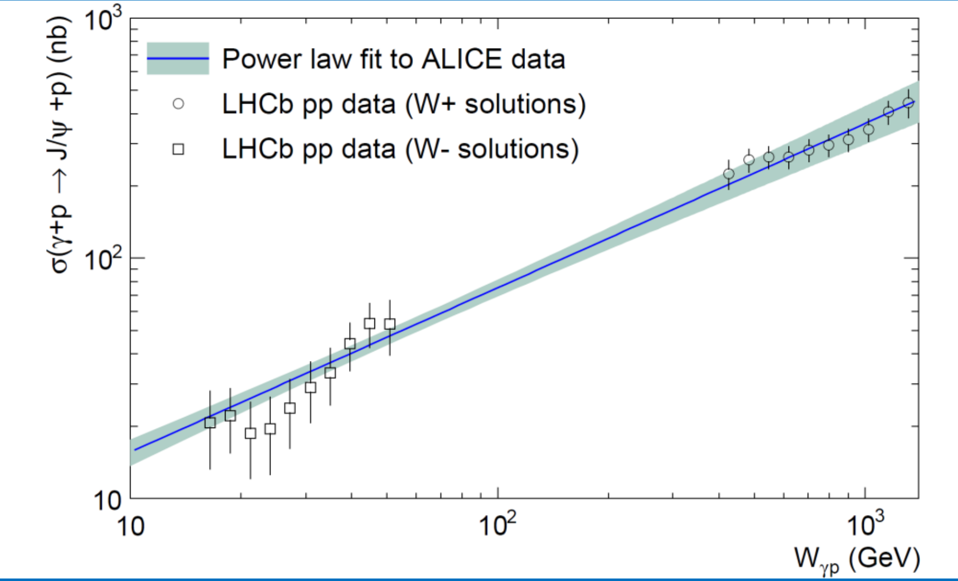
$\alpha = (0.67 \pm 0.03\ (stat + syst)\ )$ H1



ALICE data up to ~ 700 GeV

$\alpha = (0.68 \pm 0.06\ (stat + syst)\ )$

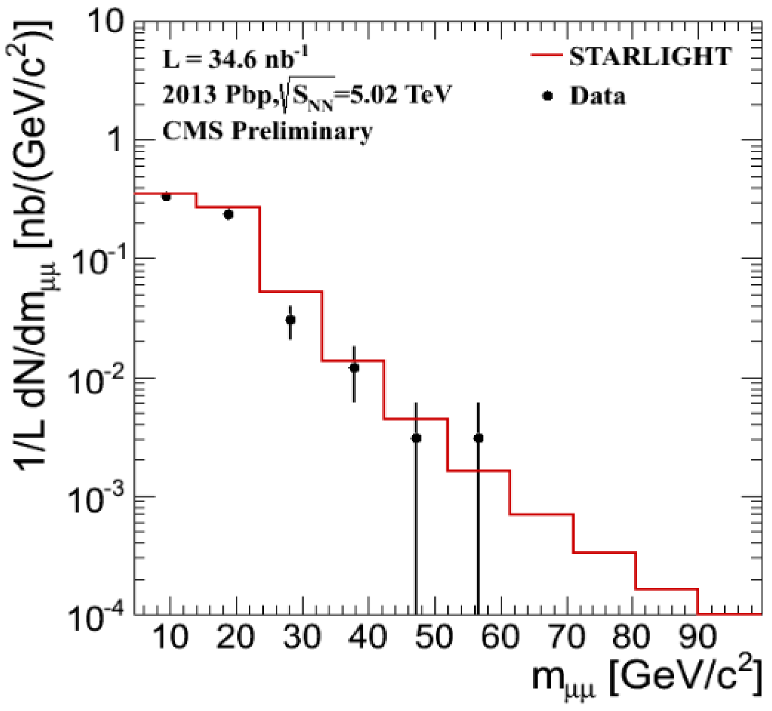
→ No smoking guns of a change of gluon PDF behavior from HERA to LHC (within the errors)

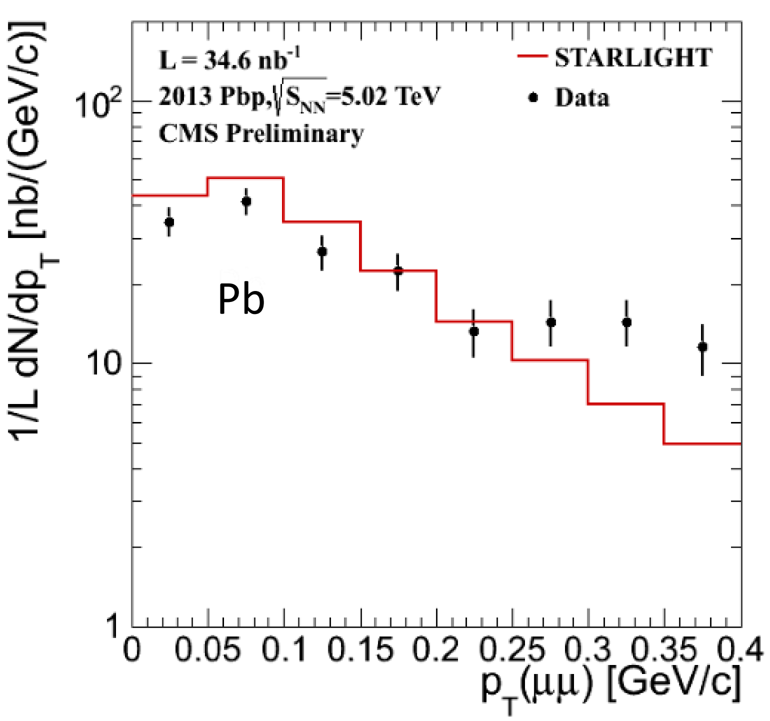


Next pPb run: go to higher energies would be important for this measurement

CMS:

– $\gamma\gamma \rightarrow l^+l^-$ study in p-Pb collisions , L=35 nb^{-1},
(I. Katkov, at PhotonLHC2014)
→ good agreement to LO QED.

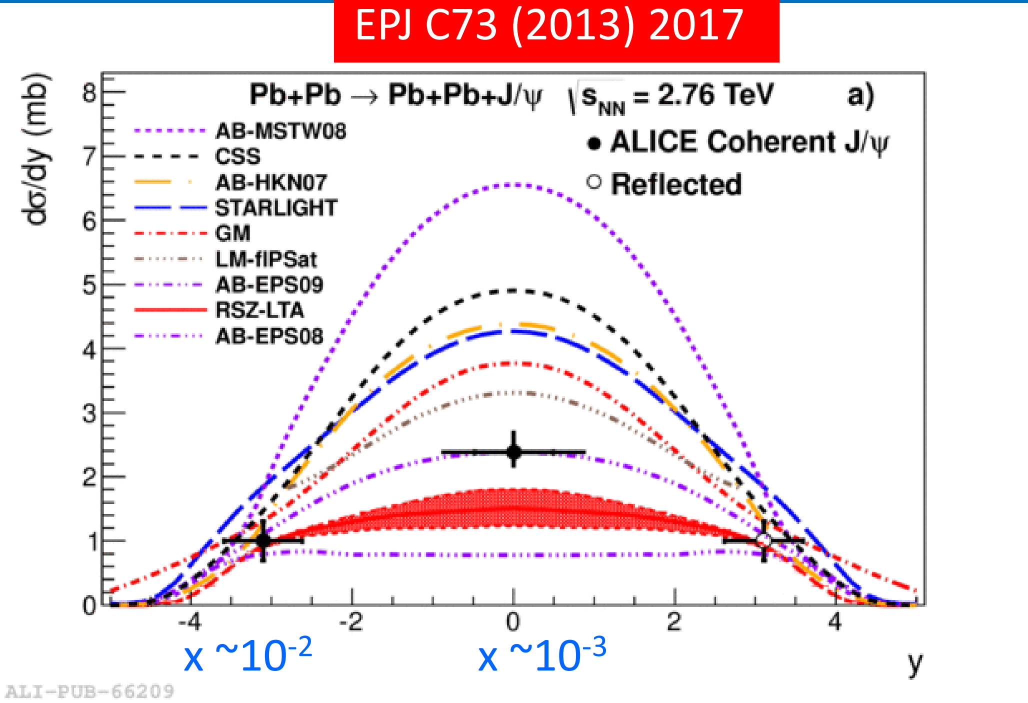




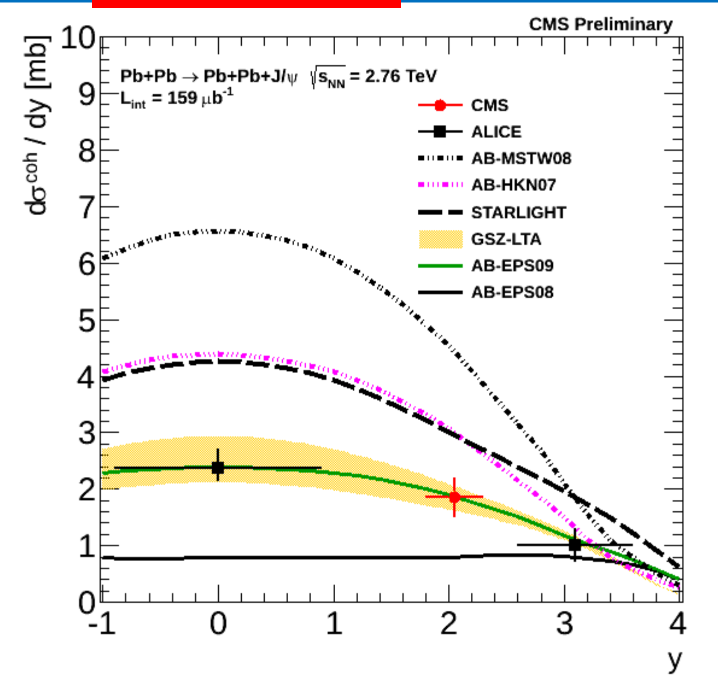
Pb-Pb

ALICE

EPJ C73 (2013) 2017



CMS-HIN-009



ALICE provided the first <u>direct</u> experimental evidence for nuclear gluon *shadowing* (*Talk by D. De Gruttola*)

(Talk by P. Kenny)

Few caveats:

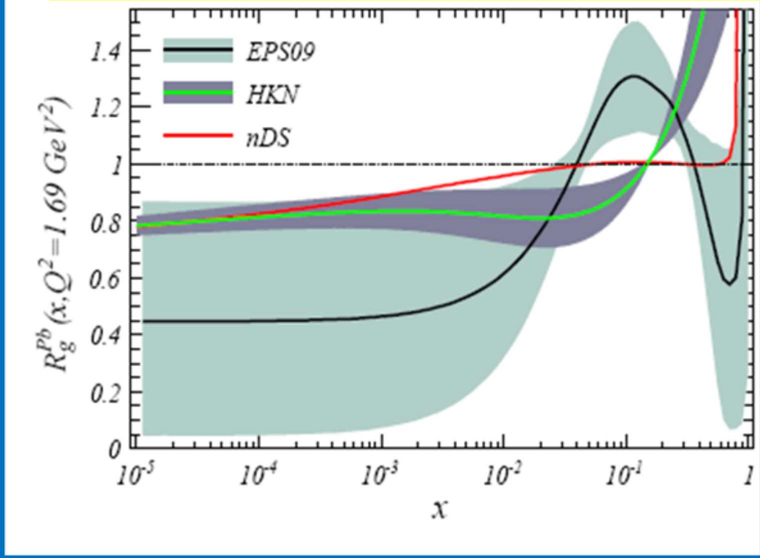
- ALICE results (and predictions) include Ψ(2s) feed-down subtraction (~ 10%)
- CMS result rescaled (triggered by ZDC,requiring neutron production)

Both experiment support gluon shadowing at Bjorken-x $10^{-2} – 10^{-3}$

In the past years we built-up UPC presentations showing the uncertainties in the plot below as a motivation to study J/Ψ photoproduction in A-A systems (given $\sigma_{J/\Psi} \propto |G(x,q^2)|^2$ at LO)

$$R_g^{Pb}(x,Q^2) = \frac{G_{Pb}(x,Q^2)}{A\, G_p(x,Q^2)}$$

Nuclear gluon shadowing factor vs x



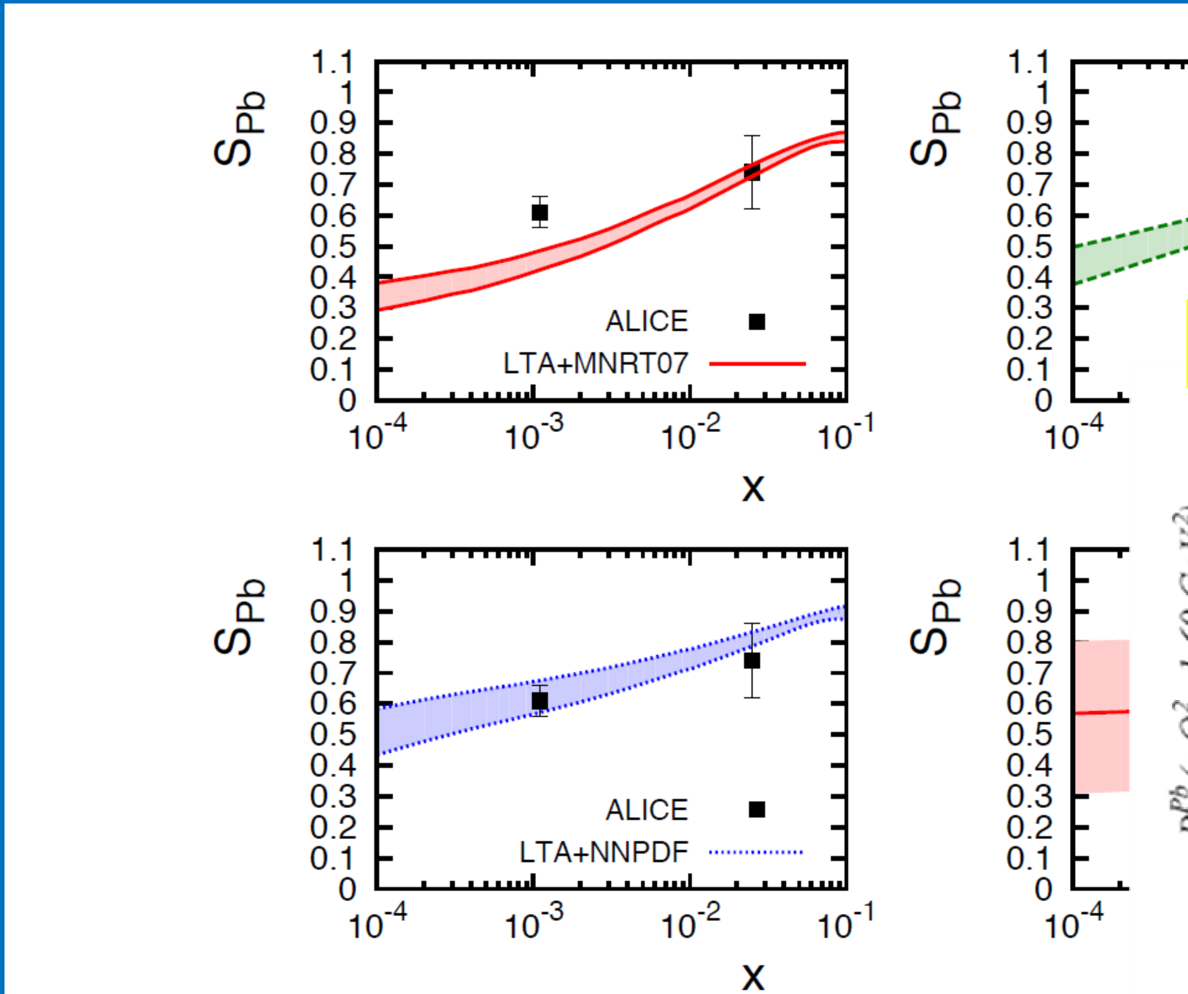
It's time to use these results to constrain the G(x,q2).

First attempt by Kryshen, Strikman and Zhalov : PLB 726 (2013) 270

Divide the J/Ψ cross section by the photon flux → γ+Pb → J/Ψ + Pb and by the IA (Impulse Approximatio) cross section (nucleus treated as the superposition of A nucleons)

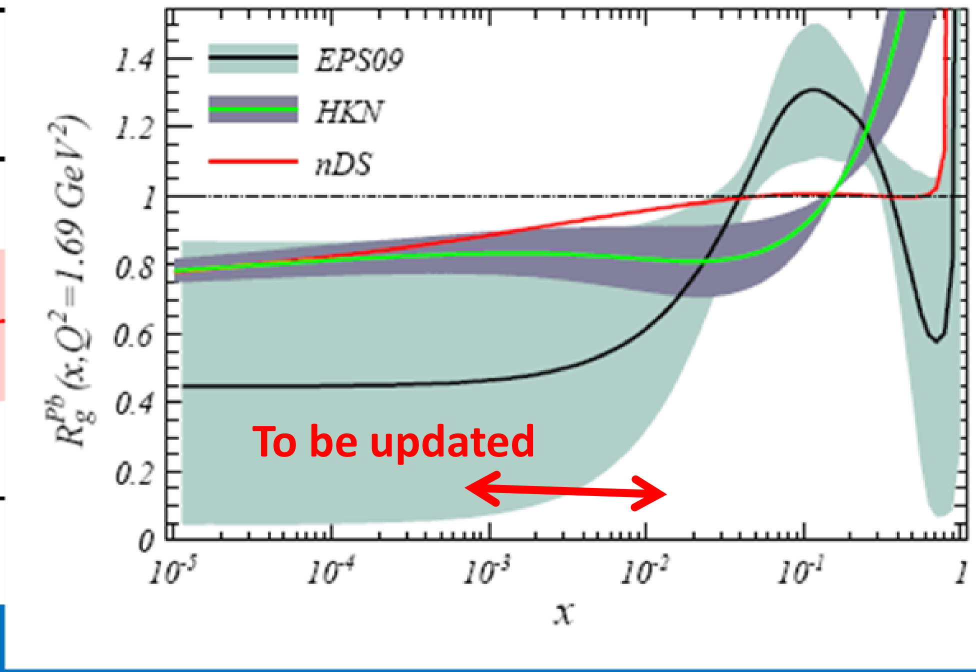
$$S(W_{\gamma p}) \equiv \left[\frac{\sigma^{\rm exp}_{\gamma Pb\to J/\psi Pb}(W_{\gamma p})}{\sigma^{\rm IA}_{\gamma Pb\to J/\psi Pb}(W_{\gamma p})}\right]^{1/2}$$

***S* can be interpreted as suppression due to the nuclear gluon shadowing**



Nuclear gluon shadowing factor vs x

6 (2013) 270



Strong shadowing, consistent with LTA (NNPDF,CTEQ6L1) or EPS09, CMS data useful

.. and Run2 sowing

Bread and butter: deeper into saturation and gluon shadowing

Υ study

Gluon shadowing at similar x but at a different mass scale !

→ ALICE (CMS): ~ 500 coherent J/Ψ using 22 μb^{-1} (160 μb^{-1})

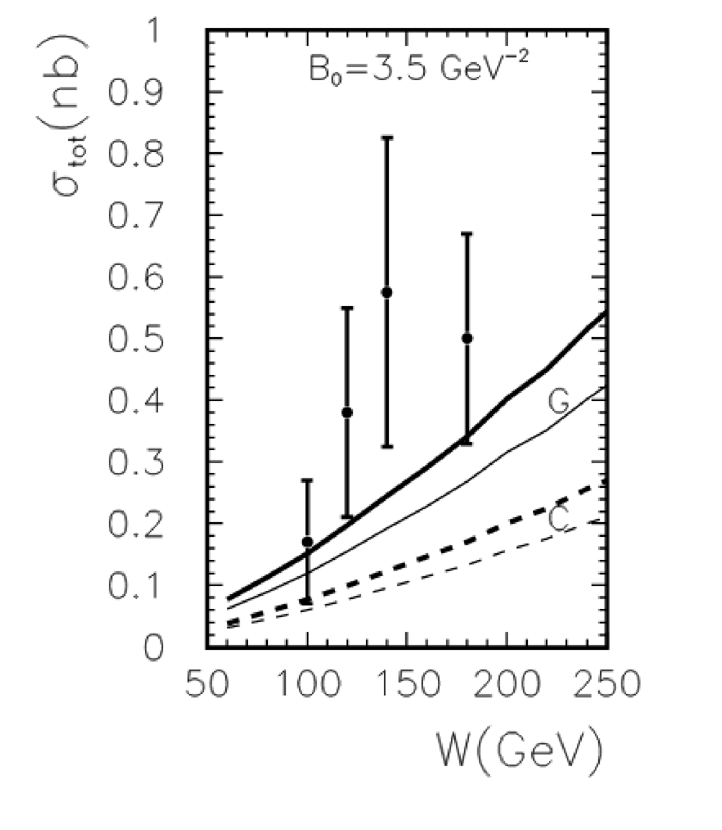
– $\sigma_{J/\Psi} / \sigma_{\Upsilon} \sim 180$;

– $\Gamma^{l+l-}_{J/\Psi} \sim 2 * \Gamma^{l+l-}_{\Upsilon}$)

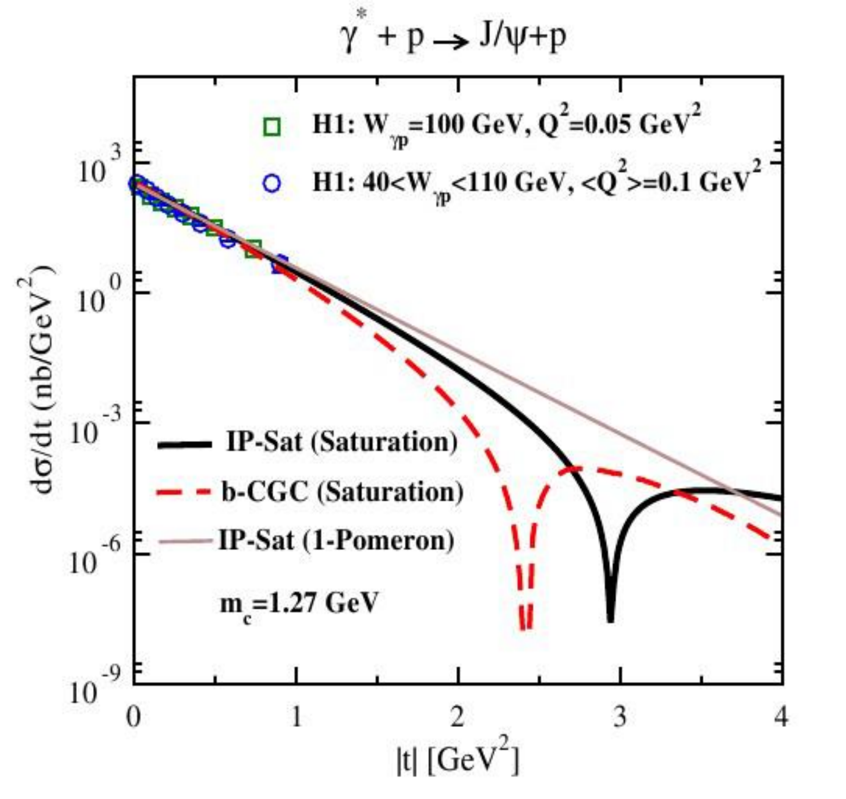
→ 1000 μb^{-1} /22 μb^{-1} * 500/180 *0.5 ~ 60 Υ

...a joint effort is required to keep statistical uncertainties at a reasonable level.

Caveat: HERA constrain to the γ-p cross section could really be poor



J/Ψ with high statistics



N. Armesto, A.H. Rezaeian, Phys. Rev. D 90 (2014) 054003:

t (=p_{T}^{2}) distribution of differential cross sections of photo-production of vector mesons may discriminate among saturation and non-saturation models.
→ dip (or multiple dips) in the t distribution of diffractive photoproduction of vector mesons"

J/Ψ rapidity tag

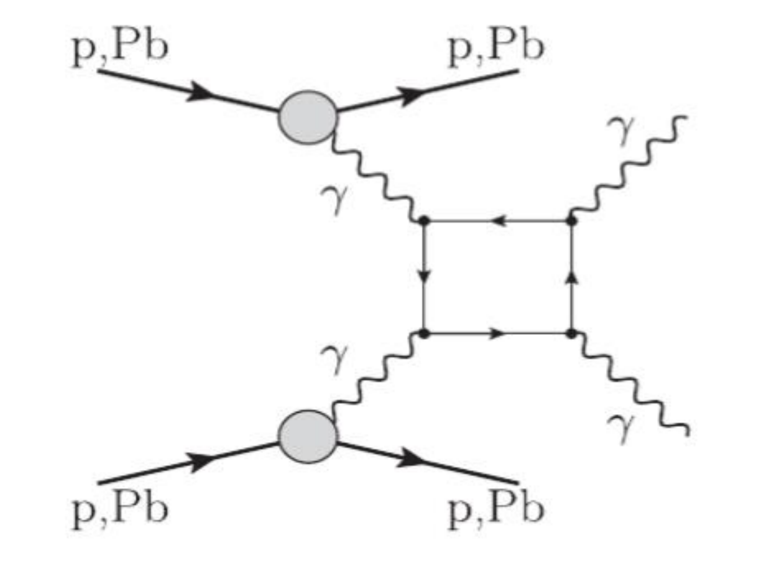
- At forward rapidity we have contributions both from x ~10^{-2} (95%) and 10^{-4} (5%), depending on the Pb nucleus emitting the photon.
  → tagging by using ZDC activity, see arXiv:1109.0737

→ Gluon shadowing at 10^{-4} feasible !

→ Run2: 2,500 J/Ψ * 5 % * 30 % ~ 40 tagged J/Ψ at x ~10^{-4} (1 nb^{-1})

UPC hunting for new physics beyond the SM

$\gamma\gamma \rightarrow \gamma\gamma$



A very important measurement ...UPC hunting for physics beyond SM

So far, no direct observation of this process.
In the SM the above box diagram involves quarks, W, etc,
→ Extra contributions from new heavy charged particles and/or super symmetric partners of SM particles ?
See **PRL 111, 080405 (2013)**
σ depends on the $M_{\gamma\gamma}$ threshold. $M_{\gamma\gamma} > 5$ GeV → $\sigma \sim 30–40$ nb

With 1 nb^{-1} , $\sqrt{s_{NN}}$=5.5 TeV → N~ 30-40 events (threshold $M_{\gamma\gamma} > 5$ GeV)

→ In ALICE a lower threshold could be used (but larger background expected).
a) γ conversion in/before the TPC
b) γ conversion in ECAL/DCAL

CMS/ATLAS: 50% (Acc x eff)
ALICE: Acceptance, efficiency to be evaluated; assuming a conservative 20%
→ **N ~20 events in CMS/ATLAS, 5-10 events in ALICE** (depending on the threshold).

Run3 is required for a large statistics , but we can start at Run2

Conclusions

UP-Cinderella..

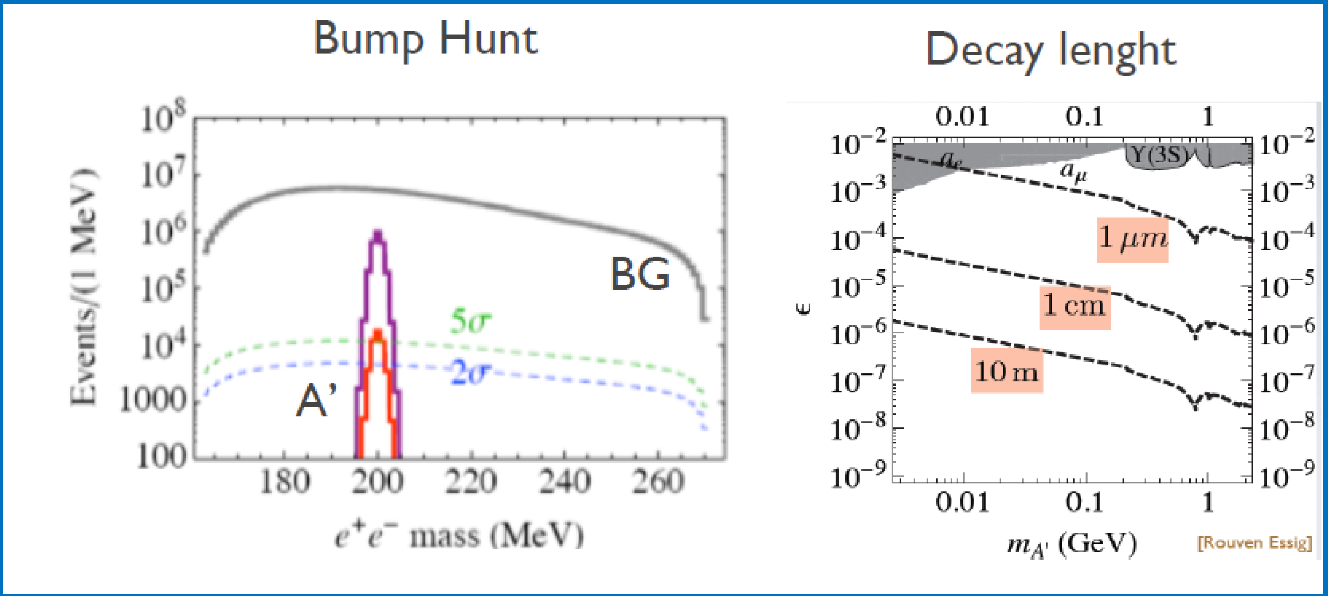
...became a princess

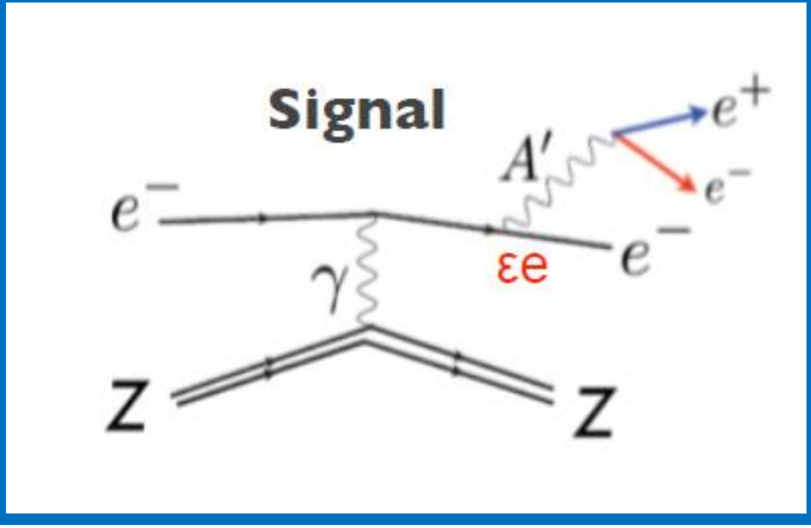
Thanks also to the previous effort at RHIC (STAR, PHENIX) & theoreticians working at UPCs.

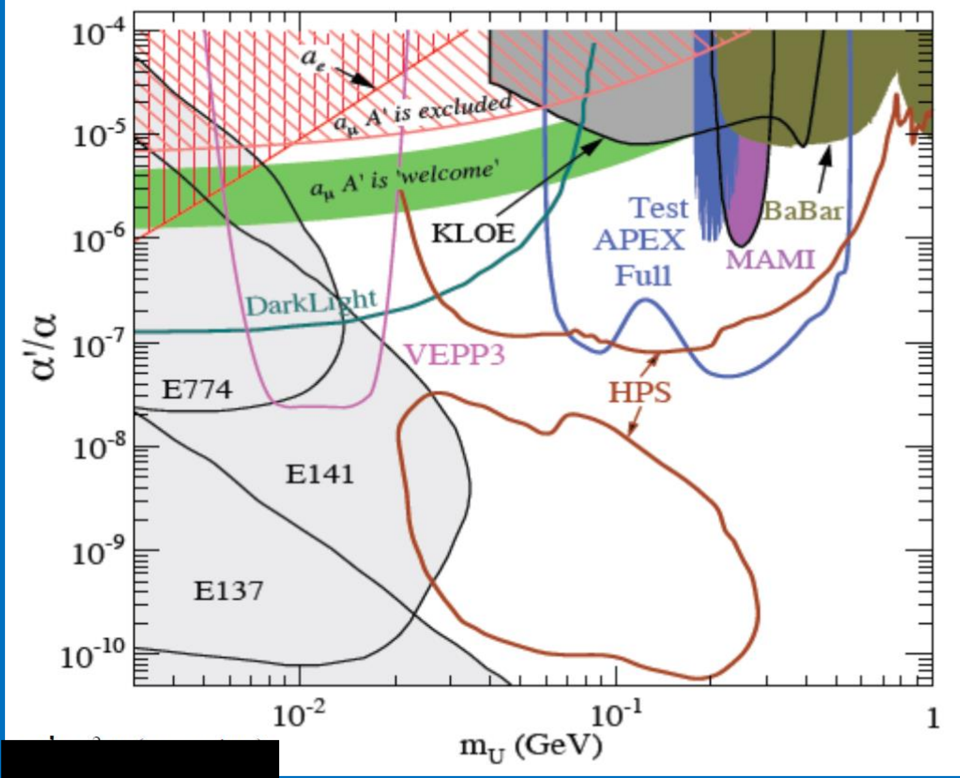
~15 experimental papers published/being submitted at the LHC by ALICE,LHCb,CMS; > 100 Proceedings.

But «they lived happily ever after» does not apply....Run2 will be exciting but challenging...

Example: HPS at JLAB







[redacted]

1) Bump Hunting (BH)

Narrow e+e-resonance over a QED background

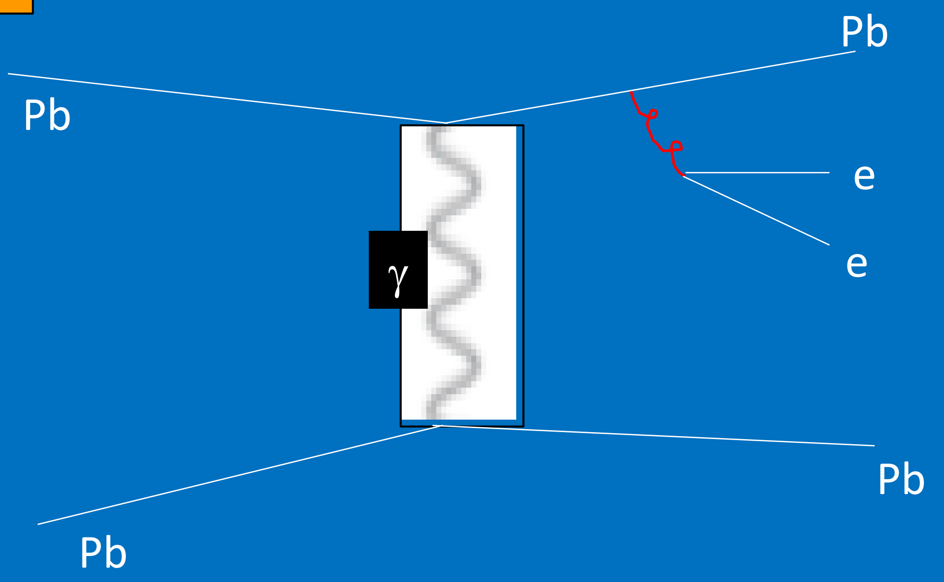
➡ good mass resolution: $\sigma_{A'mass}$~1 MeV

2) Secondary decay vertex (vertexing)

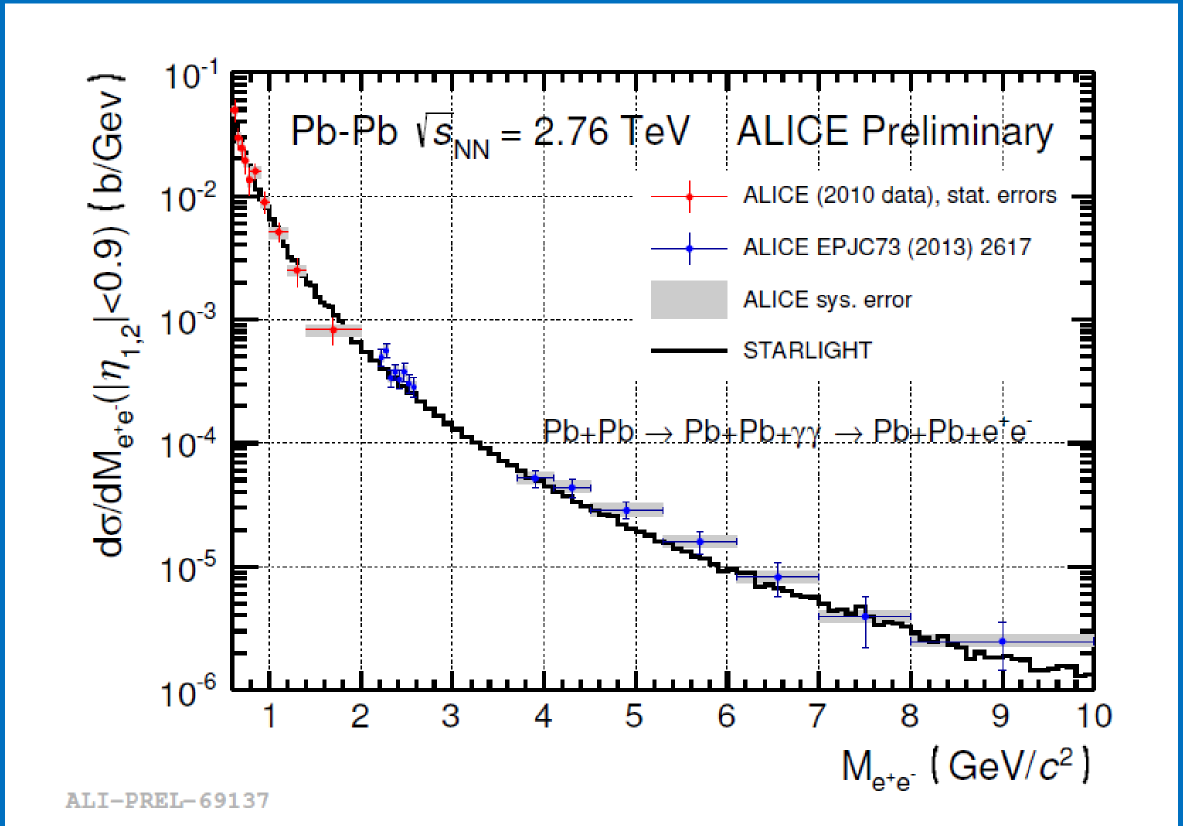
Detached vertex from few mm to tens cm

➡ good spacial resolution: σ_{vertex}~1mm

Can UPC help ?



At LHC nice preliminary results from ALICE in π^0 decay (but limited to M < 100 MeV/c2).
UPC can go up to few GeV:



A large statistics is required...

→ Collected 300 ee events with M< 2 GeV/c^2 (L=0.2 μb^{-1}). Factor 5000 larger statistics at Run 2

Summary (+ personal considerations)

- Run2 will be a great step forward in UPC for pp, P-Pb and Pb-Pb collisions

- Luminosity is important but it is just a required ingredient: UPC results need a proper, sometimes not straightforward, interpretation
  (several processes at work): a tight collaboration with theoreticians is mandatory.

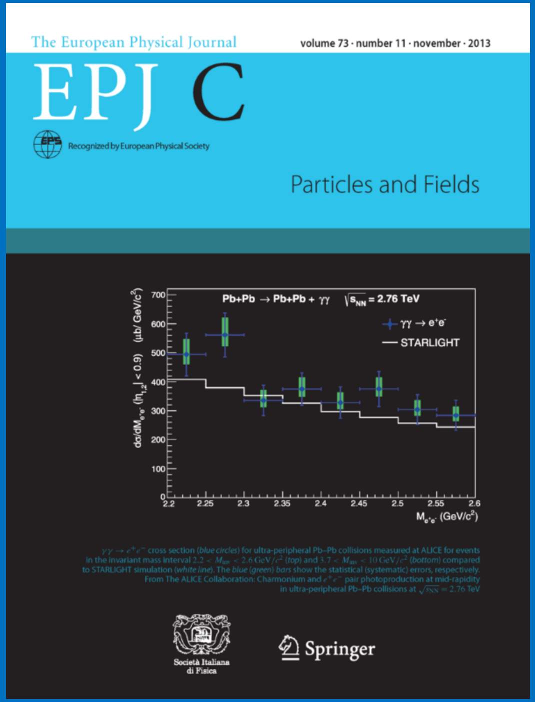
- Few analysis are at the statistical limit at Run2: a joint effort between LHC experiments would be a great help.

- Hope we will quote this workshop not as «the workshop on photon-induced collisions» but
  « the first workshop on photon-induced collisions»......

ALICE

$\gamma\gamma \rightarrow ee$ ~ 280 events ($2.3 < M_{\gamma\gamma} < 10$) GeV/$c^2$

~ 300 events ($0.6 < M_{\gamma\gamma} < 2.0$) GeV/$c^2$ (C. Mayer talk)



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	Data	STARLIGHT
$\sigma\left(M_{e^+e^-} \in [0.6, 2.0]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$:	$\left(9.8 \pm 0.6(\mathrm{stat.})\,^{+0.9}_{-1.2}(\mathrm{sys.})\right)$ mb	9.7 mb
$\sigma\left(M_{e^+e^-} \in [2.2, 2.6]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$:	$\left(154 \pm 11(\mathrm{stat.})\,^{+17}_{-11}(\mathrm{sys.})\right)$ mb	128 μb
$\sigma\left(M_{e^+e^-} \in [3.7, 10.0]\,\mathrm{GeV}/c^2;\ \lvert\eta_{1,2}\rvert < 0.9\right)$:	$\left(91 \pm 10(\mathrm{stat.})\,^{+11}_{-8}(\mathrm{sys.})\right)$ mb	77 μb

J/Ψ

12, 000 J/Ψ midrapidity dN/dy, dN/dt (see A. Stasto talk)
2,500 J/Ψ at forward rapidity
→ at forward rapidity we have contributions both from x ~10^{-2} and 10^{-5}.

How low in Bjorken x can we go at the moment ?

- Barrel → x ~10^{-3}
- At forward rapidity we have contributions both from x ~10^{-2} (95%) and 10^{-4} (5%), depending on the Pb nucleus emitting the photon.
  → tagging by using ZDC activity, see arXiv:1109.0737 → Gluon shadowing at 10^{-4} feasible !

Now: 5% of the UPC forward J/Ψ from low x. 30% of them with neutron emission.
With the present statistics (55 μb^{-1}) → 80 * 0.05 * 0.2 ~ 1 event

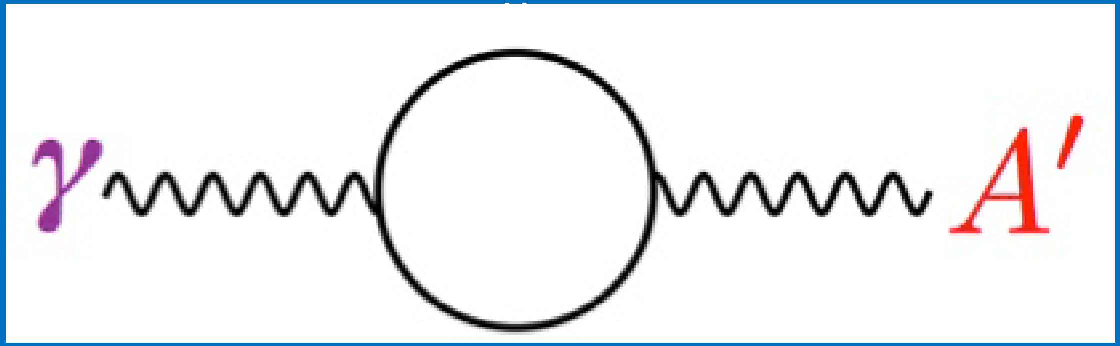
→ Run2: 2,500 J/Ψ * 5 % * 30 % ~ 40 tagged J/Ψ at x ~10^{-4} (1 nb^{-1})

Run 3 required for a good statistics, but results may come also at Run 2

Dark photon

Particles of light, photons, interact with visible matter and its building blocks—protons, neutrons and electrons.
Perhaps the same is true for dark matter. In other words, does the visible photon have a counterpart, a dark photon, that interacts with the components of dark matter?

Search for heavy (dark) photon A' (sometimes U) is an importan part of the scientifc program at JLAB: HPS dedicated experiment
A' couples very weakly to electrons.
Fine structure constants $\alpha = e^2/4\pi$; $\alpha' = g'^2/4\pi$; $\varepsilon^2 = \alpha' / \alpha$



X+

CMS:

- Central exclusive $\gamma\gamma$ production

No diphoton event found with

σ ($E_T(\gamma)$ > 5.5 GeV, $|\eta(\gamma)|$ < 2.5) < 1.18 pb using 37 pb^{-1}

CDF observed 43 events: $\sigma(E_T > 2.5\ \text{GeV},\ |\eta|<1) = (2.48\ ^{+0.4}_{-0.35}(\text{stat})\ ^{+0.4}_{-0.51}(\text{sys}))$ pb

Run2: L ~100 fb-1 → factor 3000 higher statistics (if pileup under control)

- Access to high statistics Υ production

- CMS &TOTEM: PPS (Proton Precision Spectrometer)

Mainly diffraction but UPC can be studied too:
Central exclusive production pp→ pp+X (X= WW, ZZ, $\gamma\gamma$, di-jets,...)
W, Z, γ pair production search for anomalous coupling

Run 1 at the LHC:

Year	system	energy $\sqrt{s}$ TeV	integrated luminosity
2010	p-p	7	45 pb^{-1}
2011	p-p	7	6 fb^{-1}
2012	p-p	8	23 fb^{-1}

year	system	energy $\sqrt{s_{NN}}$ TeV	integrated luminosity
2010	Pb – Pb	2.76	~ 10 μb^{-1}
2011	Pb – Pb	2.76	~0.15 nb^{-1}
2013	p – Pb	5.02	~ 30 nb^{-1}