

Perspectives for UPC at the LHC Run 2

E. Scapparone
June 4, 2014

- The present: measurements performed so far in p-p, p-Pb, Pb-Pb
- What can we learn on UPC at the LHC Run 2 ?
- Is Run 2 enough for a comprehensive UPC study ?

Thanks to P.Collins(LHCb), J. Hollar(CMS), I. Katkov(CMS), V. Podznieakov(ATLAS) for their inputs

Run 1:

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

Run 2 assumptions:

- pp: $\sqrt{s} = 13$ TeV (later may be higher), 75-100 fb⁻¹ → factor 3000 **...but pileup has to be tamed**
- Pb-Pb: $\sqrt{s} = 5.1$ TeV, 1 nb⁻¹ → factor 7 (may be 10)
- p-Pb: ~ 50 nb⁻¹, \sqrt{s} under discussion.... (5.1 or ~8 TeV ?) → factor 2

pA in Run 2 and after LS2

In view of the intriguing findings in high-multiplicity p-Pb:

- p-Pb run in Run 2 requested by all experiments ($\sim 50/\text{nb}$)
 - Preferred energy under discussion: either 5.1 TeV like PbPb or maximum energy ~ 8 TeV
 - Argument for 5.1 TeV: limit the number of pp reference data sets needed (needs more physics studies to balance the gain in high p_T statistics vs. availability of reference data)
 - Argument for maximum energy: ultra-peripheral collisions (unique γp collider), measure the total $\sigma_{\gamma p}$ at the maximum possible energy
- Request for a very high lumi ($\sim 1/\text{pb}$) p-Pb run after LS2
 - Exploiting the upgraded detector capabilities

Trigger:

General comment: UPC triggering not trivial:

- HW/technology:

- Few tracks (2 to 4) → requires low noise detectors;
- Low p_T (low mass mesons challenging with ~ 1 T field)
- relatively small cross section → background rejection

- Sociology:

Often considered an «out of stream» physics, competition to get bandwidth

- ALICE advantages: low material budget, low B, low p_T threshold

→ barrel: silicon detector (low background), but background from the huge e^+e^- cross section

- gas detectors far from IP (noise to be tamed for few hits trigger, physics background from late particles)

- hadronic background, easier to reject

→ life harder at Run2 with shorter bunch spacing (easier for pileup)



- CMS,ATLAS advantages:

Large acceptance, excellent calorimetry, thr may be high for low mass mesons, but should be OK for Υ

Workaround: triggering with the Zero Degree Calorimeters. But:

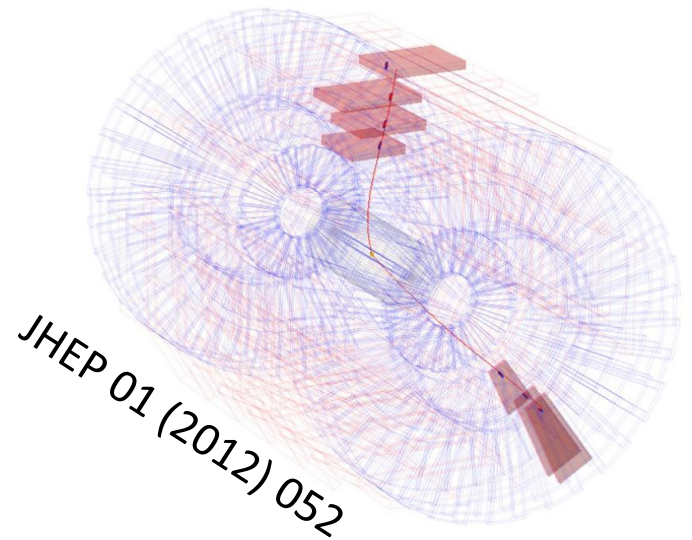
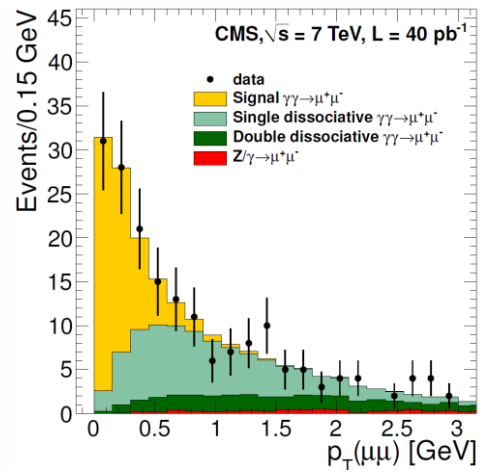
- Only a part of the cross section can be taken;
- Event generator do not include neutron production in the final state. Bias ?

The Run1 harvest:



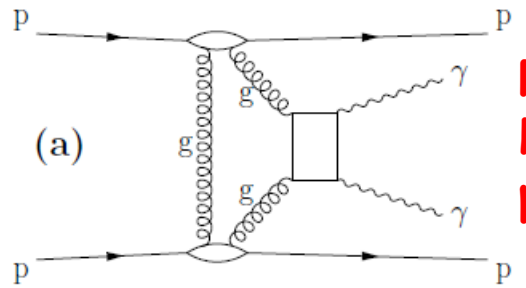
p-p

- Exclusive two-photon production of lepton pairs, 40 pb^{-1} ,
 $\sigma(p \rightarrow p\mu^+\mu^-p) = 3.38^{+0.58}_{-0.55} \text{ (stat.)} \pm 0.16 \text{ (syst.)} \pm 0.14 \text{ (lumi.) pb}$

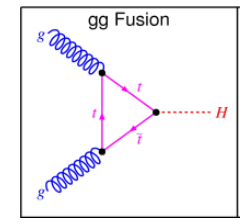


- Central exclusive $\gamma\gamma$ production
- No candidates;

CMS calorimetry (em + hadronic) at work.
 Powerful search for γ ($E_T > 5 \text{ GeV}$).



Related to Higgs production



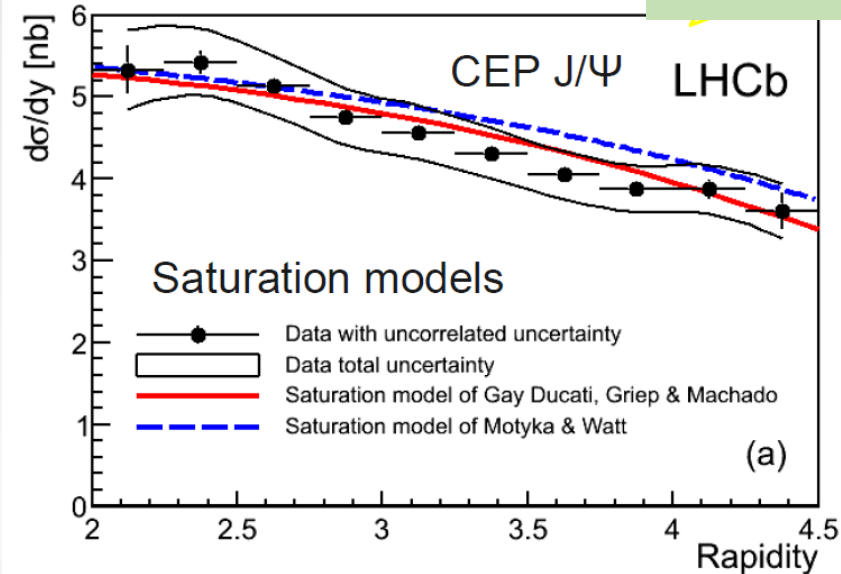
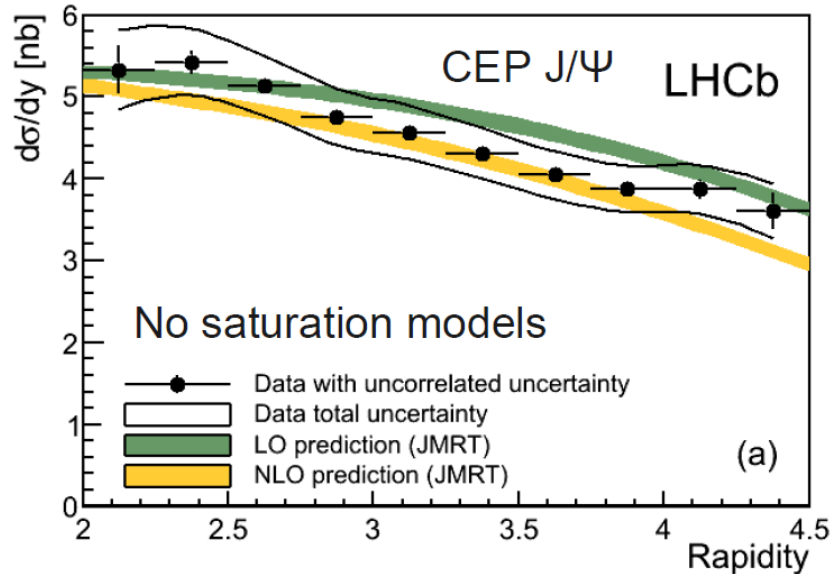
JHEP 1211 (2012) 080

- Two-photon production of W pairs and limits on anomalous quartic gauge couplings

JHEP 1307 (2013) 116

- Υ coming soon ?

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

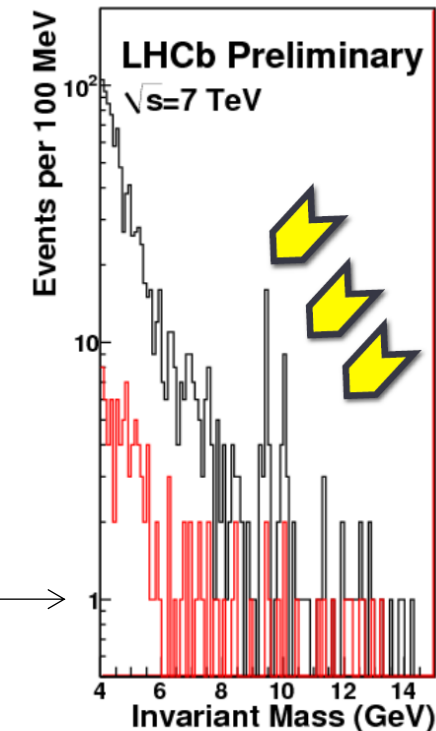


arXiv: 1401.3288

Run1: Luminosity: 930 pb^{-1}

J/Ψ statistics ok ($1/3$ of the sys error); could be improved for $\Psi(2S)$ in Run 2 (factor 2 larger than sys error).

With $L = 930 \text{ pb}^{-1} \rightarrow \sim 30\,000 J/\Psi$ collected ("purity included"). If we consider $\sigma_{\Upsilon} \sim 1/200 * \sigma_{J/\Psi}$, different branching to $\mu\mu$, few events should be already there..

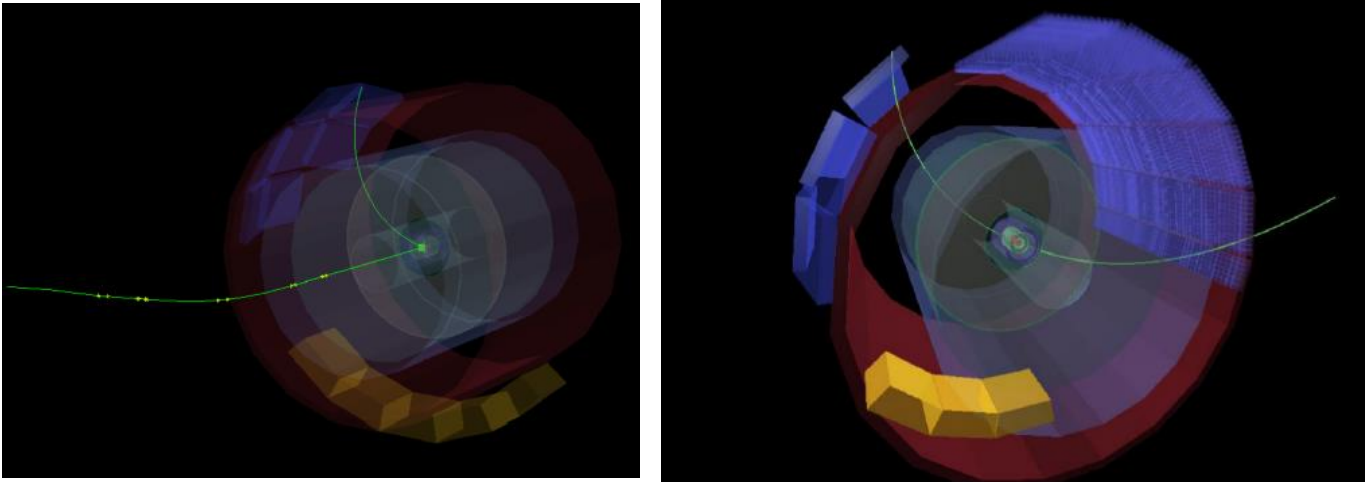
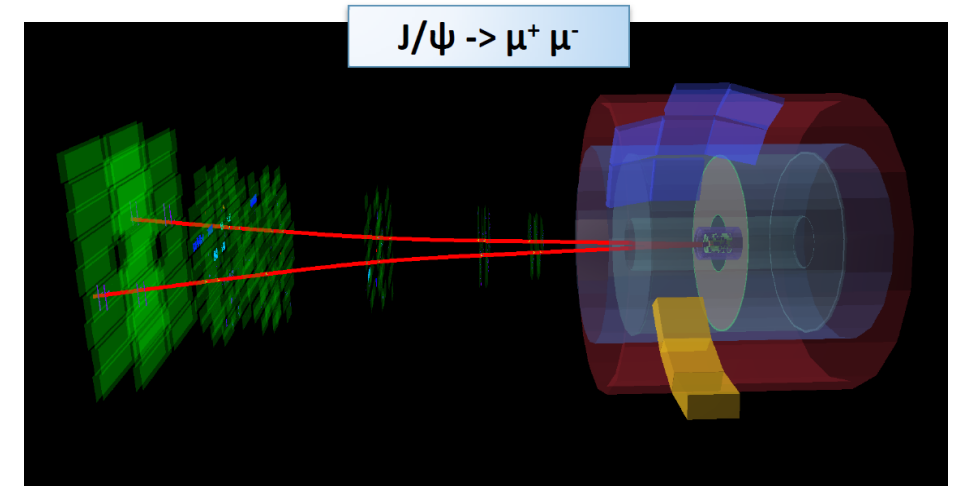


p-Pb

ALICE:

- J/Ψ study in p-Pb collisions $\sim (300 + 100 \text{ events})$ at two different range of γp centre of mass energies W ; at the moment results available at forward rapidities.

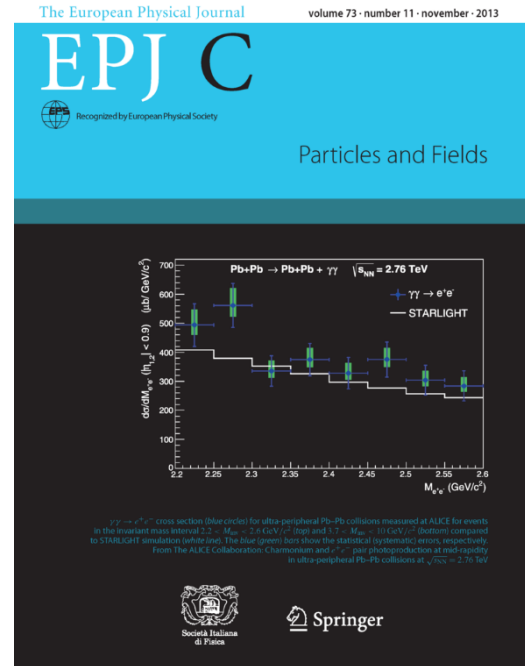
Semi-central (one muon in the forward spectrometer and one muon in the barrel), mid-rapidity (barrel) in progress.



CMS:

- $\gamma\gamma$ study in p-Pb collisions (talk by I. Katkov) $L=35 \text{ nb}^{-1}$, good agreement to LO QED.
- $\Upsilon(1s,2s,3s)$ study in p-Pb collisions (ongoing, see proc. DAE Symp. on Nucl. Phys. 58 (2013));

Pb-Pb

$\gamma\gamma \rightarrow ee$ ~ 280 events ($2.3 < M_{\gamma\gamma} < 10$) GeV/c² ~ 300 events ($0.6 < M_{\gamma\gamma} < 2.0$) GeV/c² (C. Mayer talk)

EPJ C73 (2013) 2017

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

Vector meson production

ρ (*)	$\sim 10^4$	✓	stat error \ll sys err
J/ Ψ	~ 500 (midrapidity)+ ~ 100 (forward)	~	(stat error $<$ sys)
$\Psi(2s)$ (***)	~ 50	✗	stat error $\sim 25\%$ (a factor 3 larger than sys error)

(*) 2010 Run, $0.26 \mu\text{b}^{-1}$ luminosity collected for this trigger

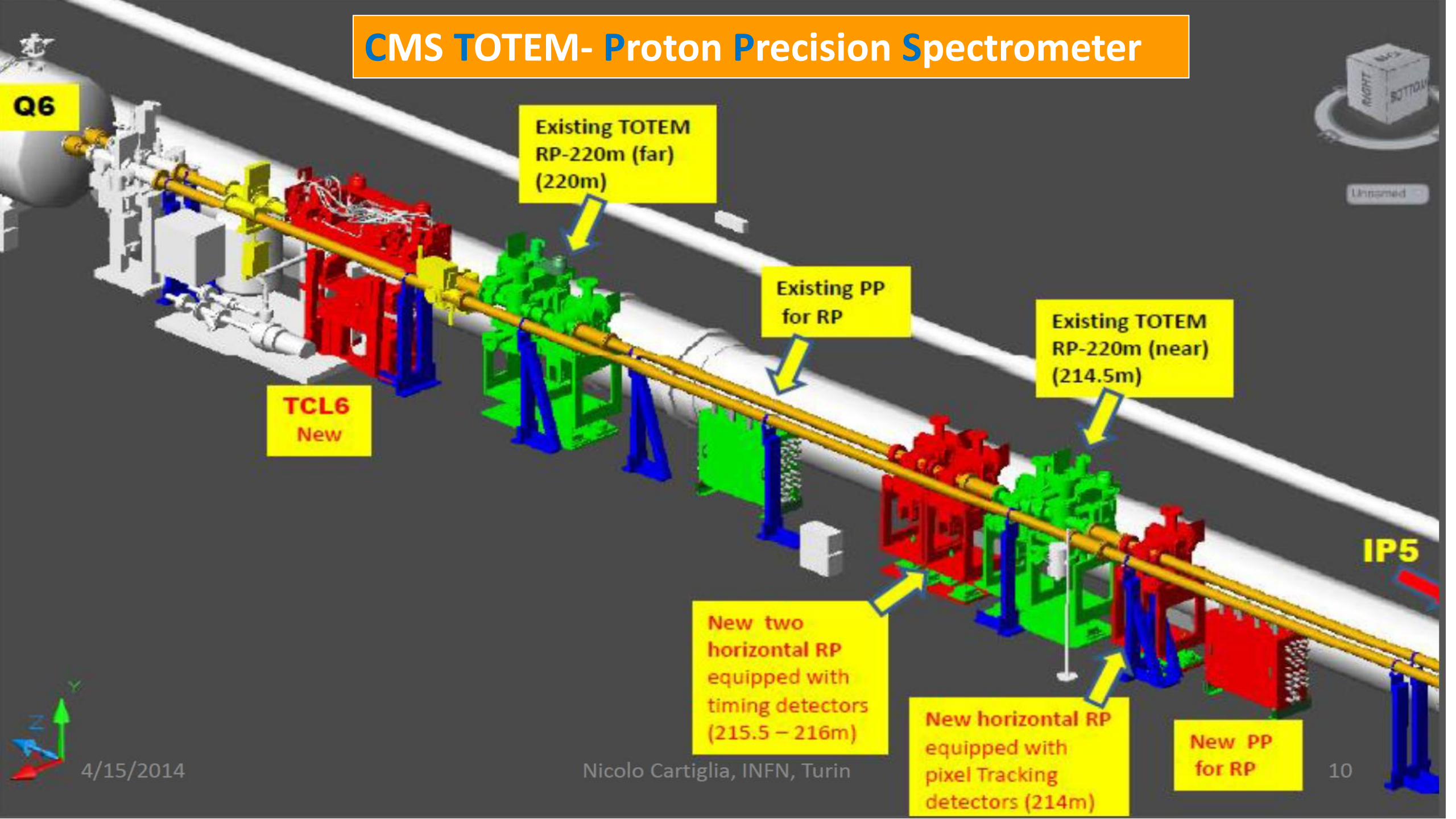
(**) 2011 Run, $22 \mu\text{b}^{-1}$ luminosity collected for this trigger

(***) 2011 Run, $55 \mu\text{b}^{-1}$ luminosity collected for this trigger

.. and Run2 sowing

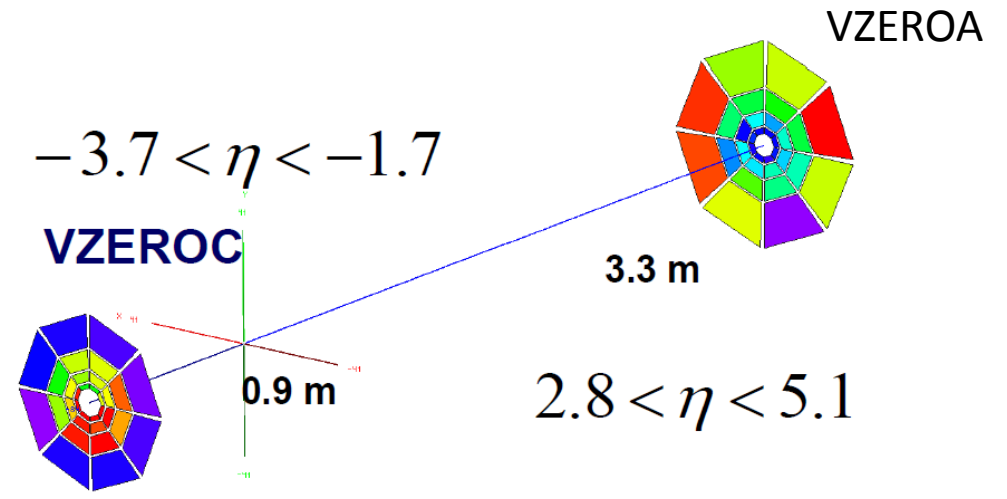


CMS TOTEM- Proton Precision Spectrometer



A new entry in ALICE @ run 2

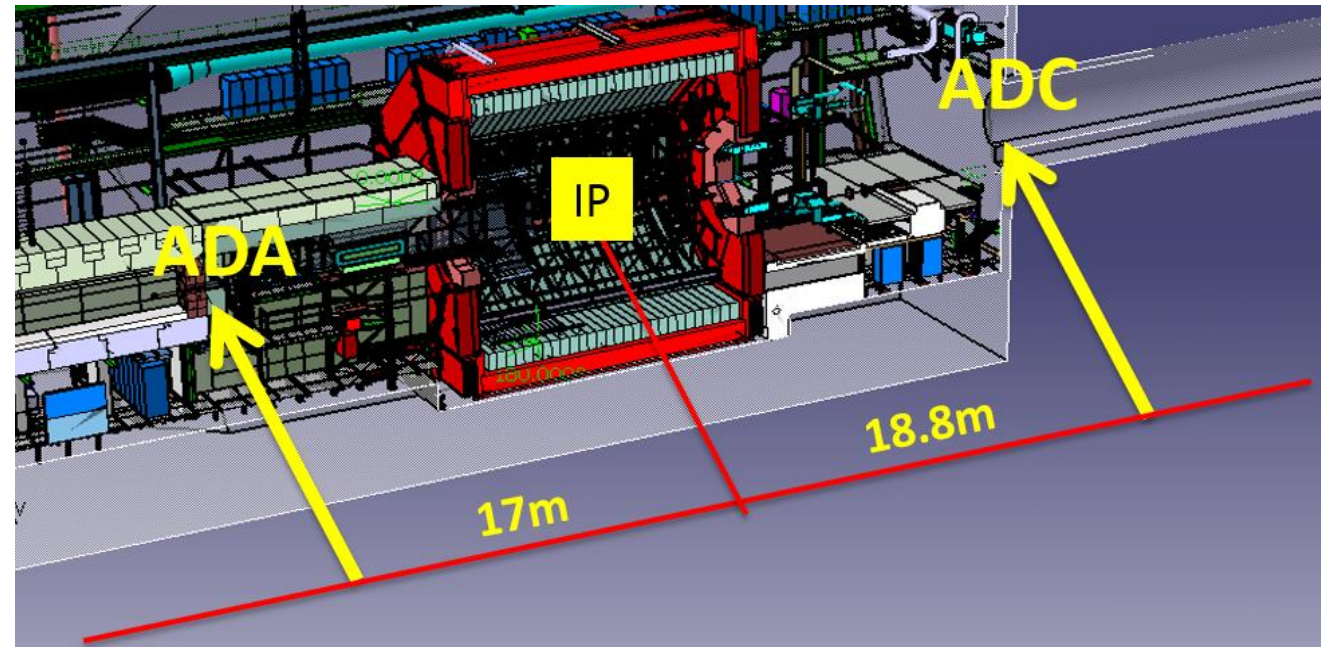
- ADA, ADD detectors can be used to make the veto to non UPC event stronger (now VZERO detectors used).



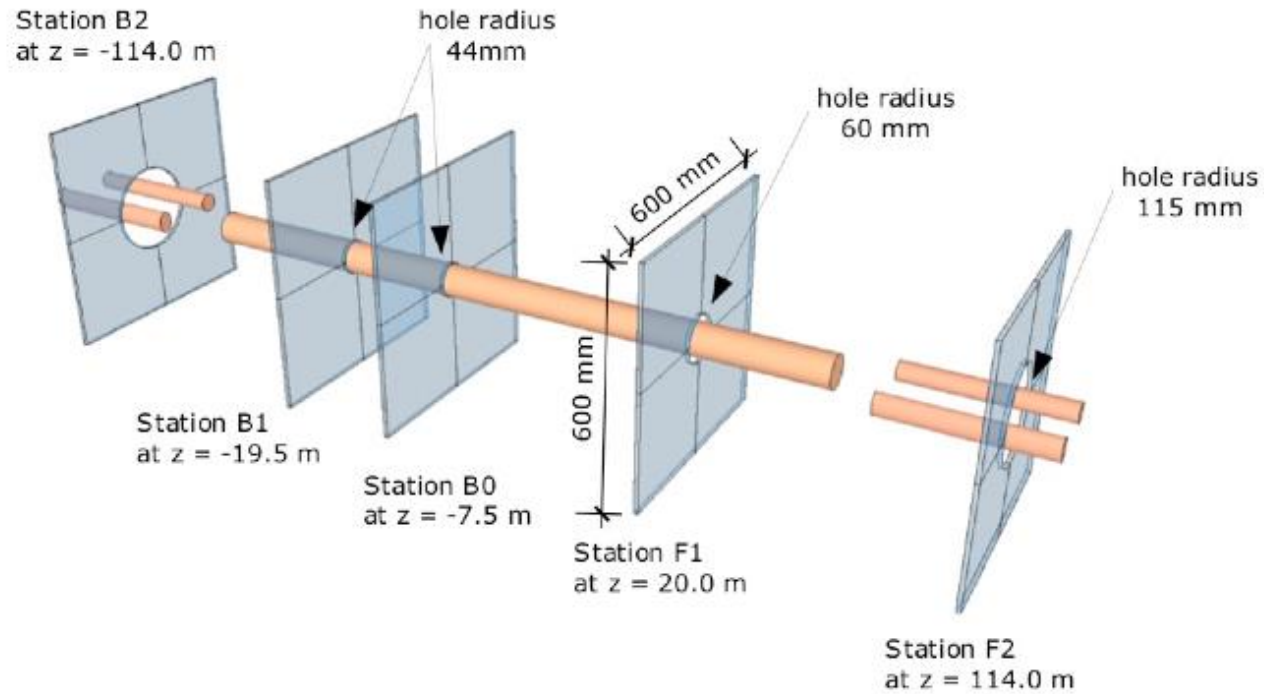
Two scintillators (two layers each, in coincidence).

ADA: $5.5 \leq \eta \leq 7.5$

ADD: $7.5 \leq \eta \leq 5.5$

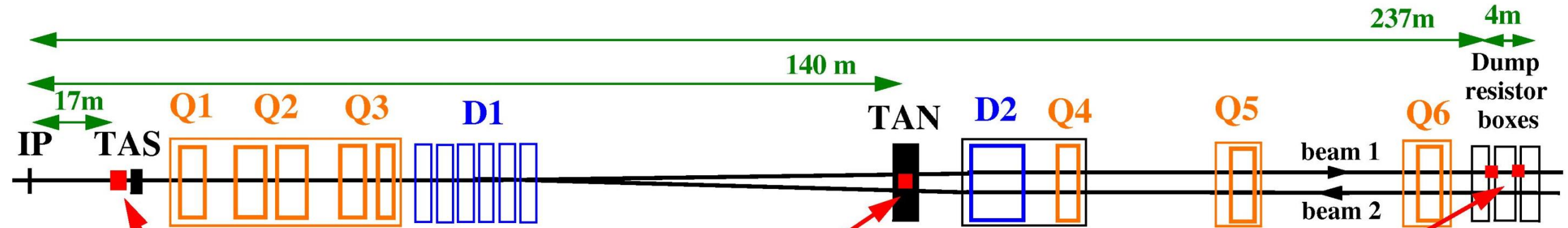


High Rapidity Shower Counters for LHCb: The HeRSChelL Project

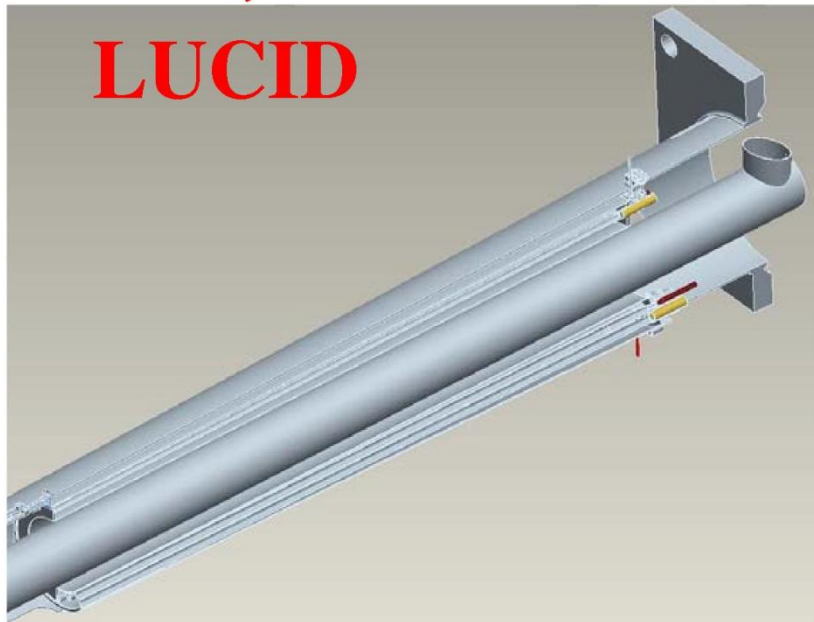


Detectors consist of 4 plastic scintillator plates, 20 mm thick, glued to "fishtail" light guides

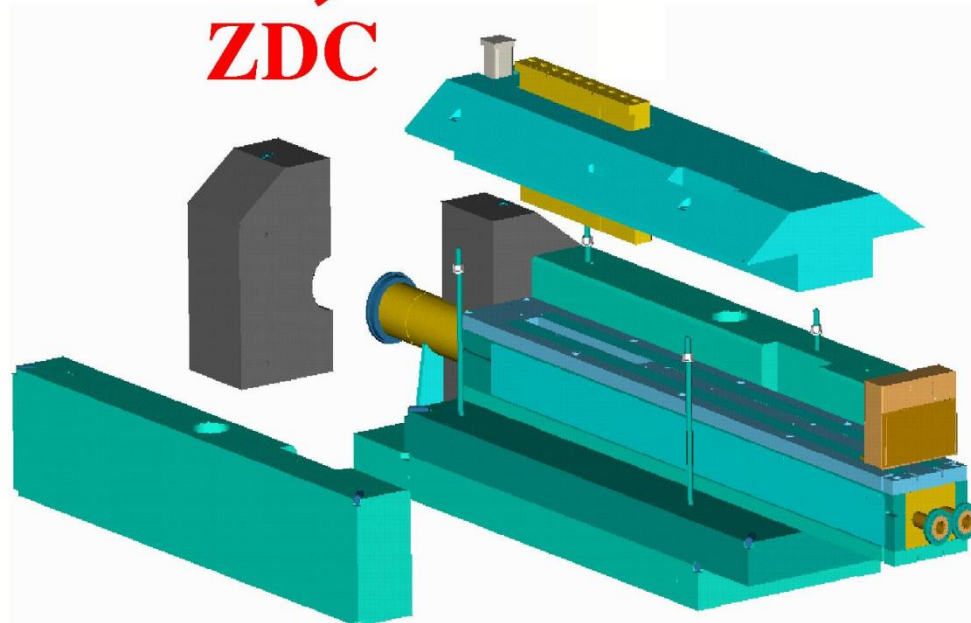
ATLAS Forward Detectors Project



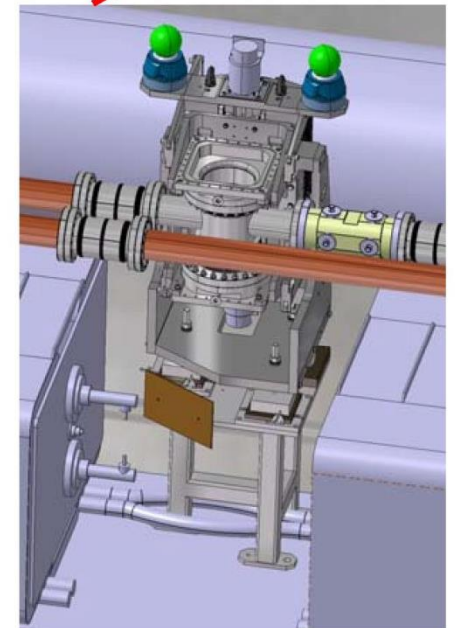
LUCID



ZDC



ALFA



p-p

- Central exclusive $\gamma\gamma$ production

No diphoton event found with

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

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

Run2: $L \sim 100 \text{ fb}^{-1} \rightarrow$ 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:

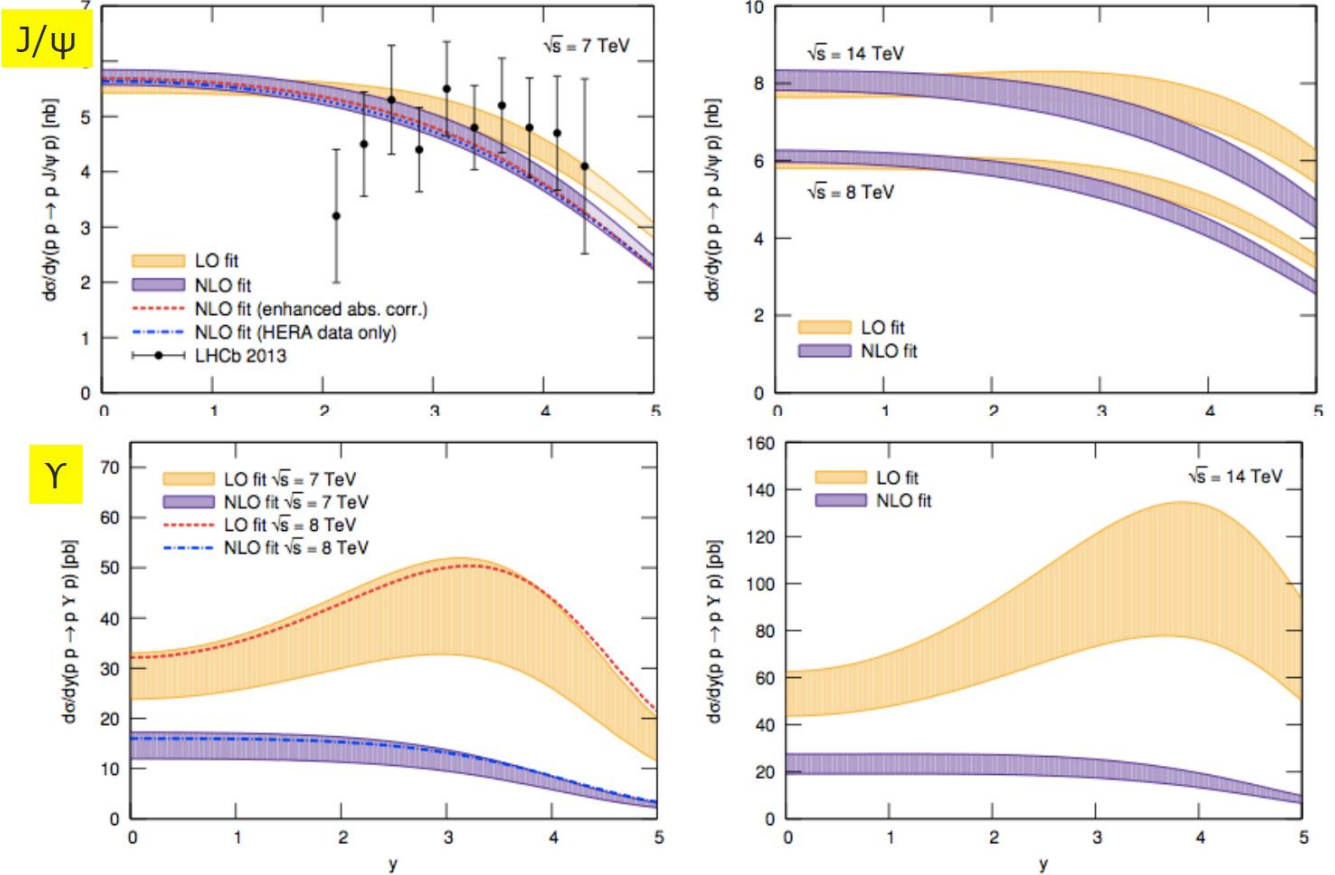
Central exclusive production $pp \rightarrow pp+X$ ($X = WW, ZZ, \gamma\gamma, \text{di-jets}, \dots$)

W, Z, γ pair production search for anomalous coupling

Run 2: with $L = 5 \text{ fb}^{-1} \rightarrow \Upsilon$ fully accessible
 (different mass scale, DGLAP evolution test).

Predictions (arXiv: 1307.7099)

(Jones, Martin, Ryskin, Teubner)



R. McNulty, Central exclusive quarkonium production at LHCb 75

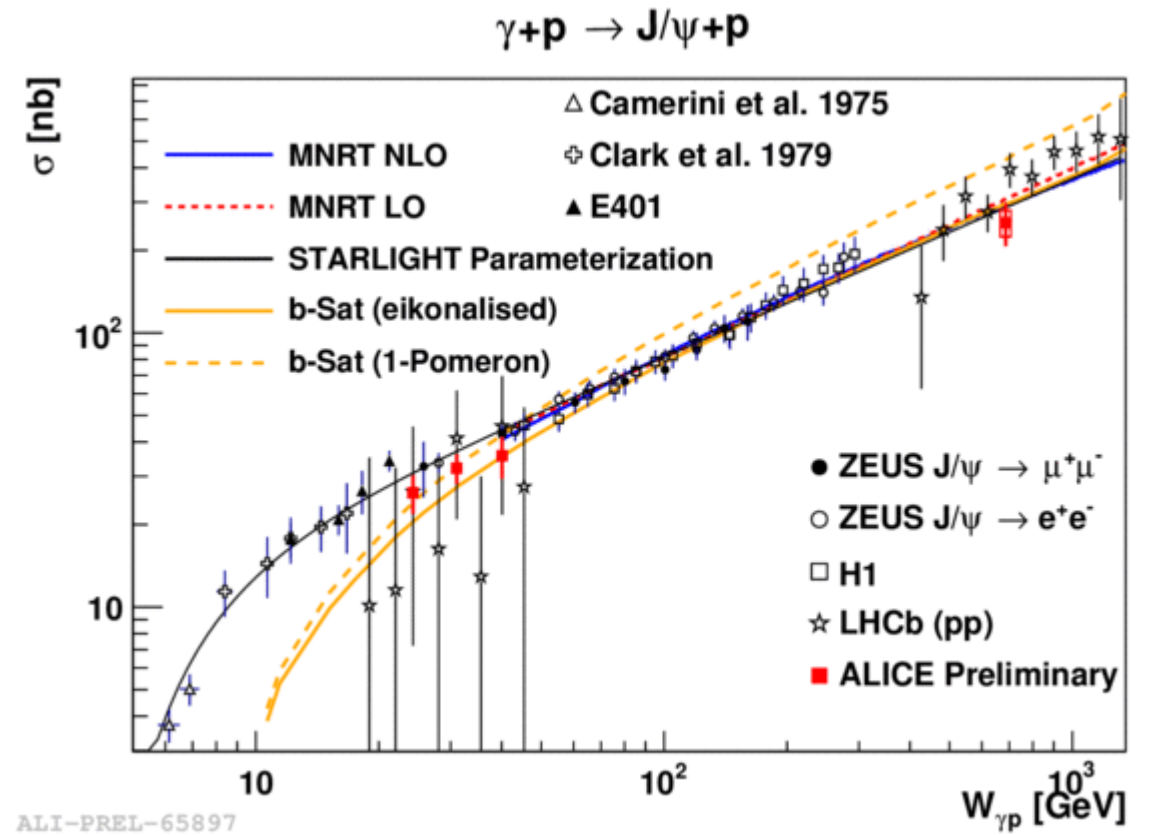
Other questions:

- Can X(3872) (arXiv:1302.6269) be produced exclusively ?

Interest in pp collisions from ALICE too. Dedicated trigger already collected data in run 1.
 J/Ψ in pp could be used to compare with Pb-Pb results.

p-Pb

y	w	x
2.5	700	2×10^{-5}
3.0	899	1×10^{-5}
3.5	1155	7×10^{-6}
4.0	1483	4×10^{-6}



Strong interest in ALICE UPC group to run at the highest possible energy in the next p-Pb run \rightarrow up to $W \sim 1.5$ TeV

Pb-Pb

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 $x \sim 10^{-2}$ and 10^{-5} .

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

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

Now: 5% of the UPC forward J/Ψ from low x . 20% of them with neutron emission.

With the present statistics ($55 \mu\text{b}^{-1}$) → $80 * 0.05 * 0.2 \sim 1$ event

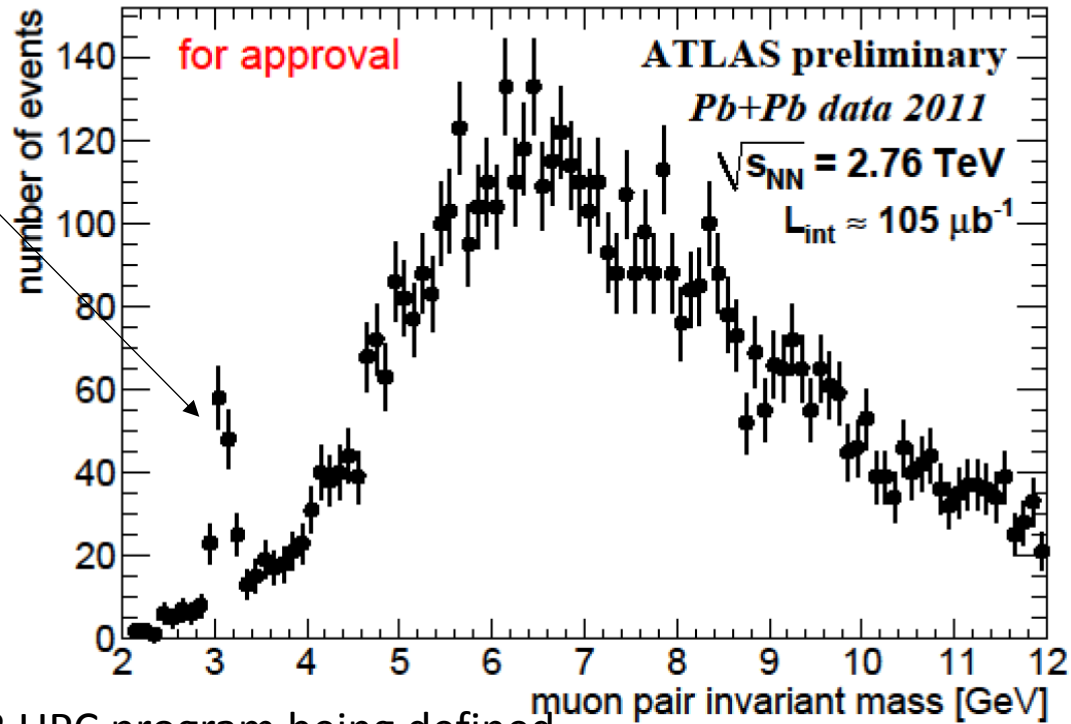
→ **Run2**: $2,500 \text{ J/}\Psi * 5 \% * 20 \% \sim 30$ tagged J/Ψ at $x \sim 10^{-4}$ (1 nb^{-1})

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

Υ study:

Important to measure gluon shadowing at similar x but different mass scale. Caveat: HERA constrain to the γ - p cross section could be poor (see yesterday Joakim talk)

→ ALICE: $\sim 50 \Upsilon$ ($\sigma_{J/\Psi} / \sigma_{\Upsilon} \sim 180$; $\Gamma^{l+l-}_{J/\Psi} \sim 2 * \Gamma^{l+l-}_{\Upsilon}$)



Run 2 UPC program being defined

ATLAS: so far no published results, but it has full capabilities to measure UPC J/Ψ ...

I. Yeletsikh

(jinr.ru/img_sections/Scient_Sess/SC111/7.1_Yeletsikh.pdf)

ALICE, ATLAS and CMS can study Υ at Run 2; statistics may be low...

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

Dark photon

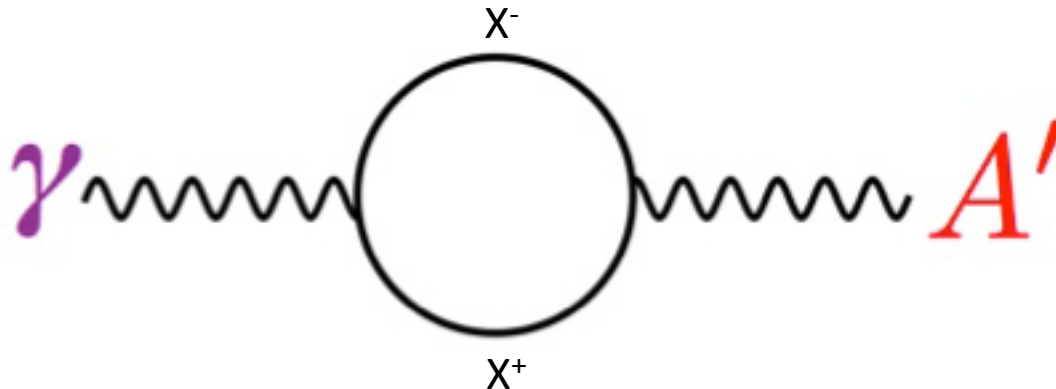
Particles of light, photons, interact with visible matter and its building blocks—protons, neutrons and electrons.

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 important part of the scientific program at JLAB: **HPS dedicated experiment**

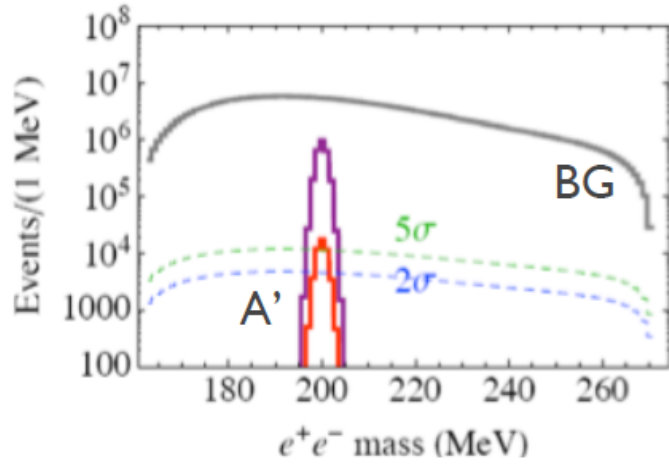
A' couples very weakly to electrons.

Fine structure constants $\alpha = e^2/4\pi$; $\alpha' = g'^2/4\pi$; $\epsilon^2 = \alpha' / \alpha$

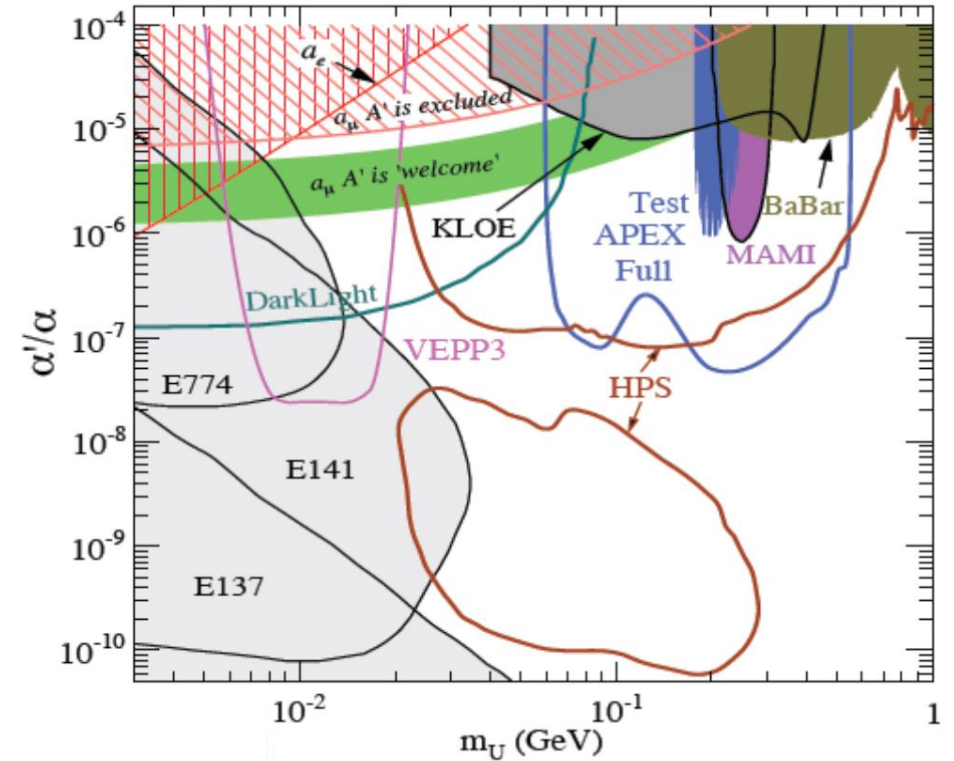
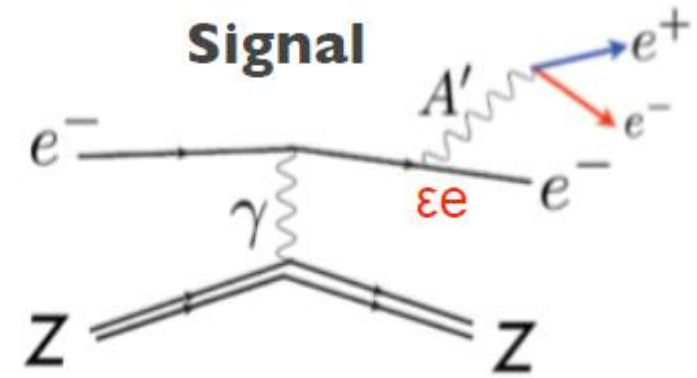
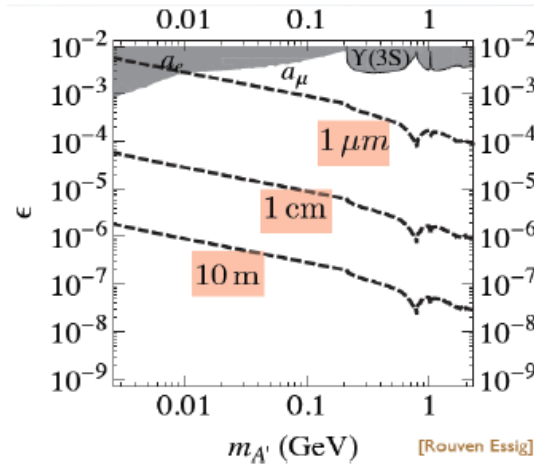


Example: HPS at JLAB

Bump Hunt



Decay length



1) Bump Hunting (BH)

Narrow e^+e^- -resonance over a QED background

→ good mass resolution: $\sigma_{A'_{\text{mass}}} \sim 1 \text{ MeV}$

2) Secondary decay vertex (vertexing)

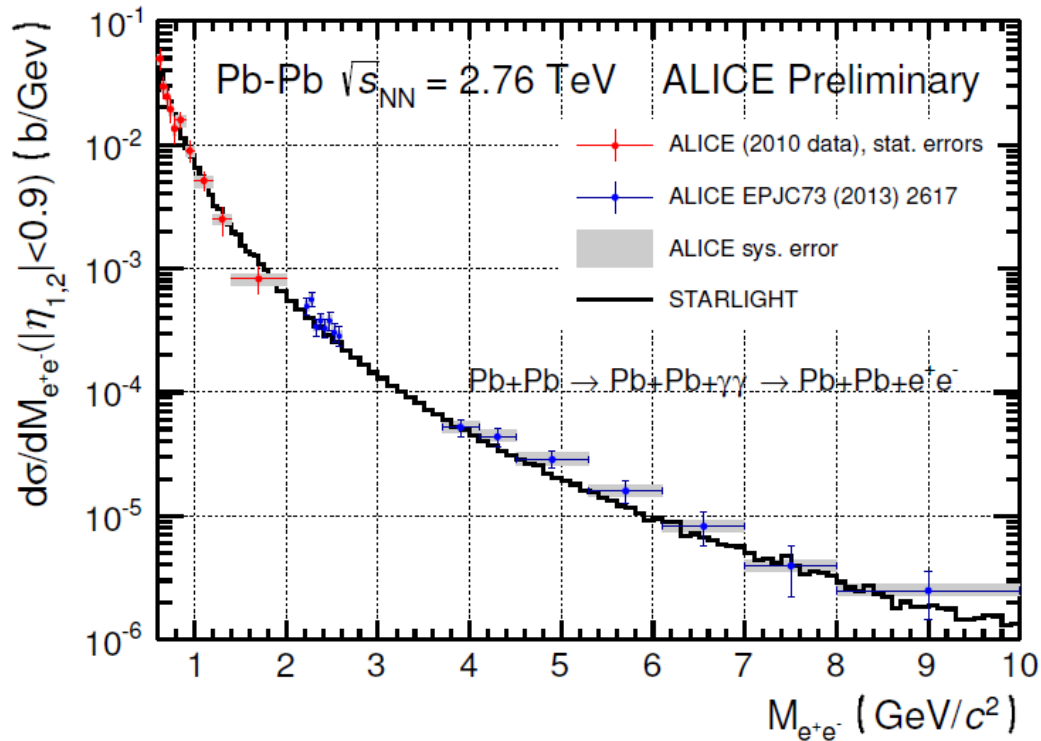
Detached vertex from few mm to tens cm

→ good spacial resolution: $\sigma_{\text{vertex}} \sim 1 \text{ mm}$

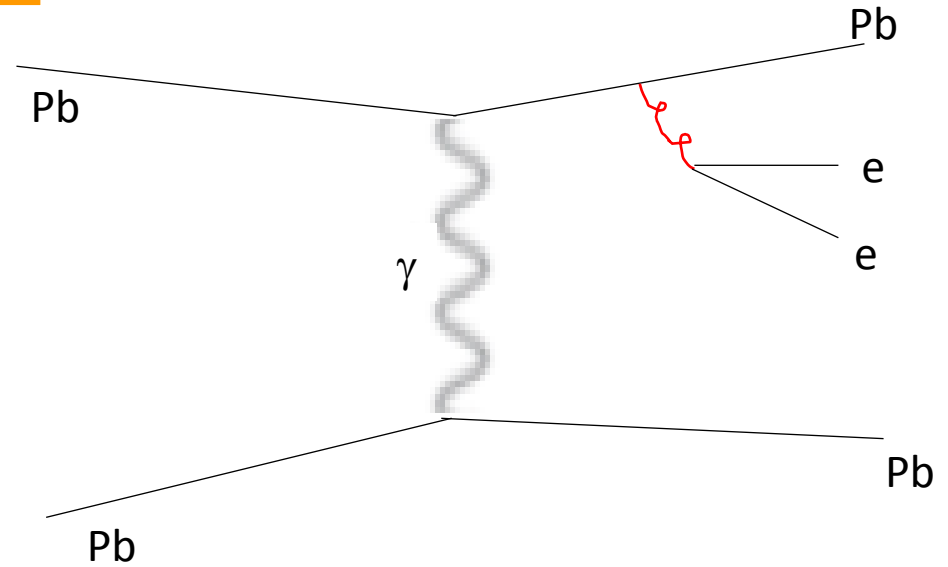
Can UPC help ?

At LHC nice preliminary results from ALICE in π^0 decay
 (but limited to $M < 100 \text{ MeV}/c^2$).

UPC can go up to few GeV:



ALI-PREL-69137

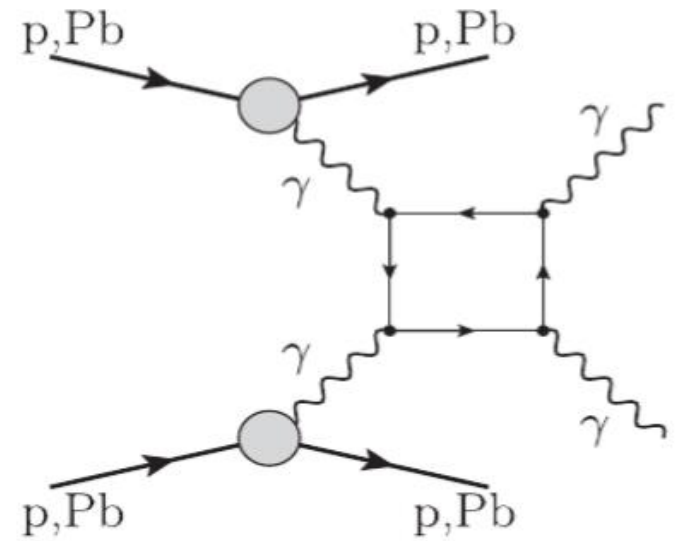


A large statistics is required...

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

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

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. $M_{\gamma\gamma} > 5 \text{ GeV} \rightarrow \sigma \sim 30\text{--}40 \text{ nb}$

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

→ In ALICE a lower threshold could be used (but background expected, see yesterday David talk).

- 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**

Is Run 2 enough ?

In Pb-Pb collisions, most of the analysis can start at Run 2, but need Run 3 for a reasonable statistics

Conclusion

UP-Cinderella..



...became a princess



LHC Run 1: **UP-Cinderella** became a princess (thanks also to the previous effort at RHIC (STAR, PHENIX), Tevatron + theoreticians working at this field).

Abstracts at several important conferences on UPC now always accepted and sometimes required.

~10 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 hard...

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».....