Electromagnetic Dissociation in UPC

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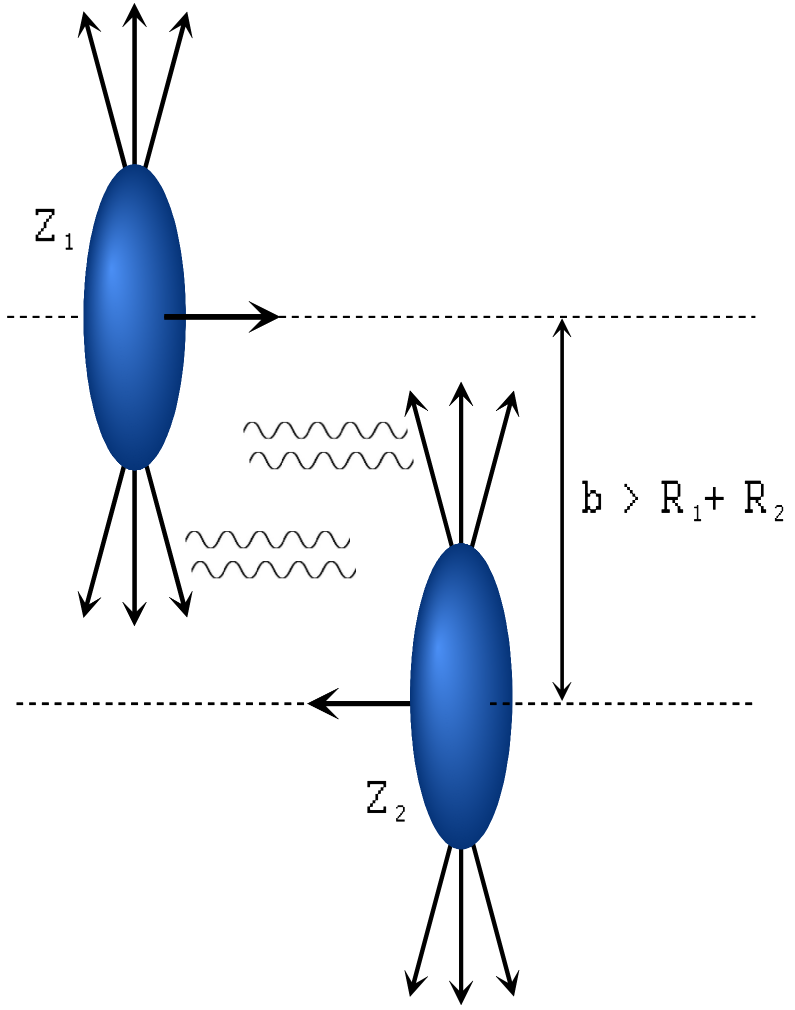
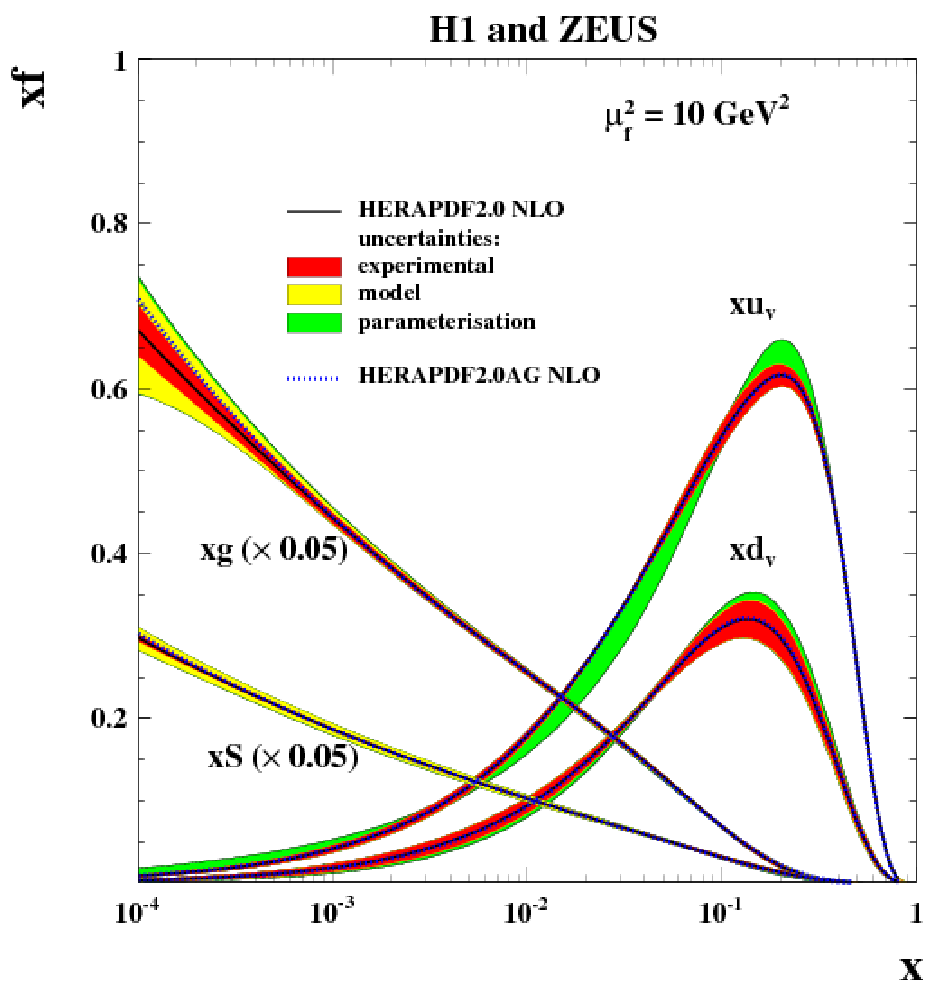
What are ultra-peripheral collisions (UPC)?

- EM field of a **relativistic particle** acts as a beam of quasi-real photons
  - Intensity of the EM field proportional to Z_1^2 or Z_2^2
  - Two potential sources and two potential targets
- Impact parameter b > sum of radii
  - **Ultra-peripheral collision**
  - Hadronic interaction suppresed
- Type of interactions (**photoproduction**):
  - photon – photon
  - photon – nucleus (proton)





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- The structure of a proton is described by a **parton distribution function**
- At low Bjorken-x the proton structure is dominated by **gluons**
- The number of gluons cannot grow indefinitely
  - Recombination will appear and balance it = **saturation**

- Nucleus is not a sum of nucleons => **Nuclear shadowing**

Vector meson photoproduction in UPC

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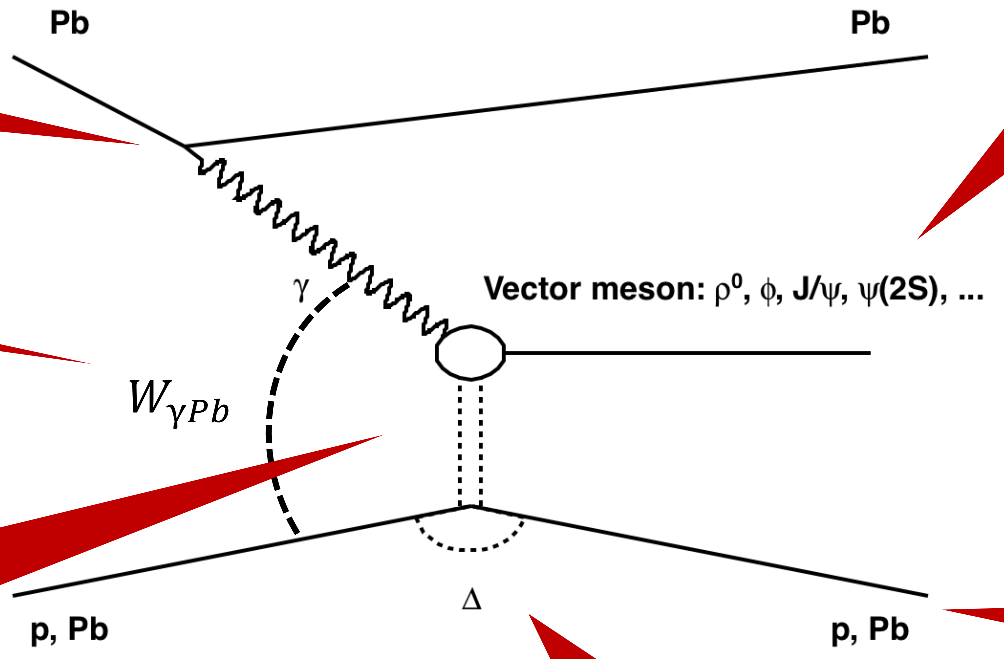
Emission of a photon - flux is given by QED

γ-Pb energy at CMS

In LO pQCD, the cross section is proportional to the gluon density squared



Rapidity is related to the center-of-mass energy of the photon-target system: $W_{\gamma\mathrm{Pb}}^2 = 2E_{p,Pb}M_{VM}e^{\pm y}$

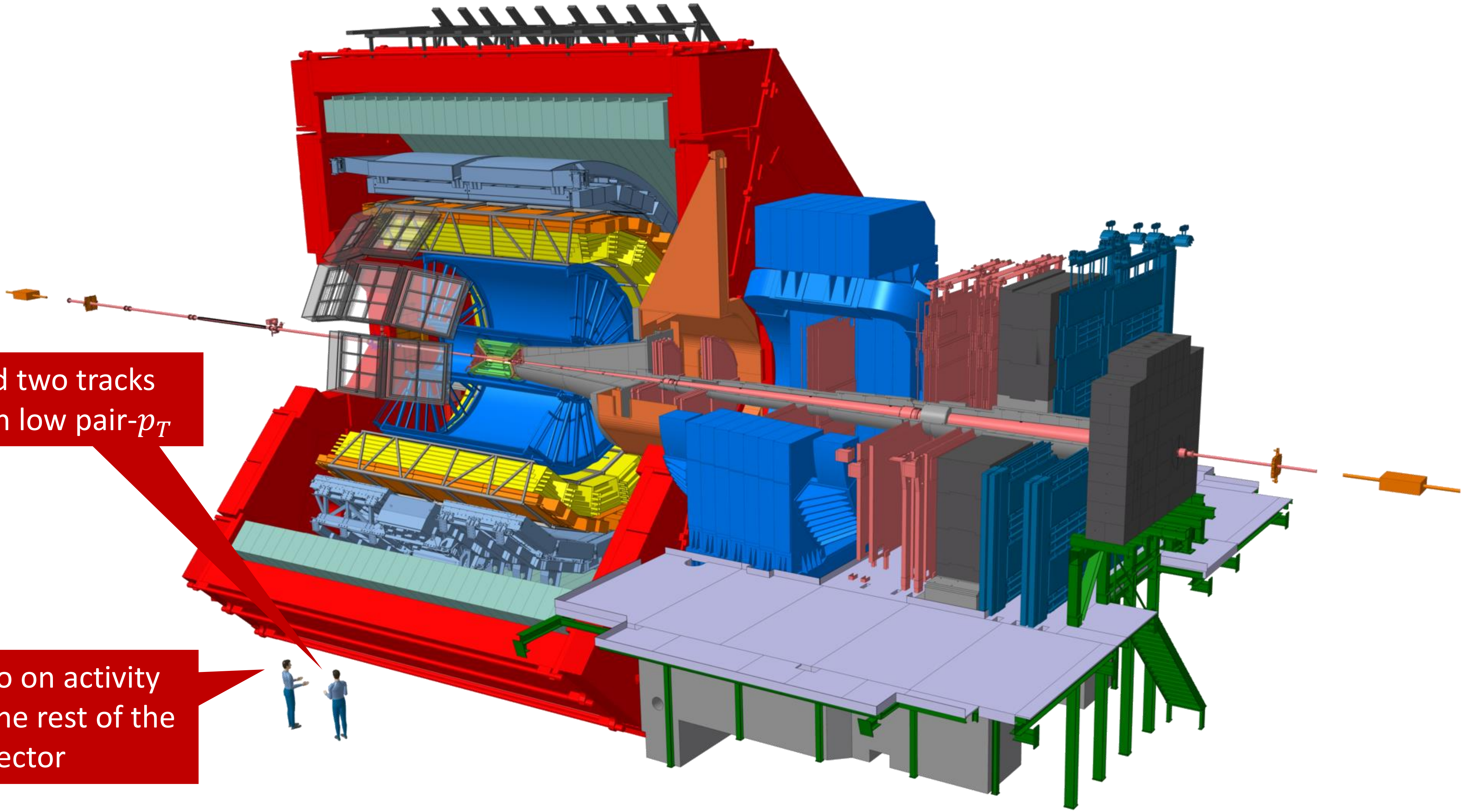
Coherence condition implies low transverse momentum p_T (few tens of MeV)

Nothing else in the detector

$$\left.\frac{\mathrm{d}\sigma_{\gamma A\to J/\psi A}}{\mathrm{d}t}\right|_{t=0} = \frac{M_{J/\psi}^3\Gamma_{ee}\pi^3\alpha_s^2(Q^2)}{48\alpha_{\mathrm{em}}Q^8}\left[xg_A(x,Q^2)\right]^2$$

Transverse momentum is related to the momentum transfer in the target vertex $\vec{\Delta}^2 = -t$

The ALICE Detector



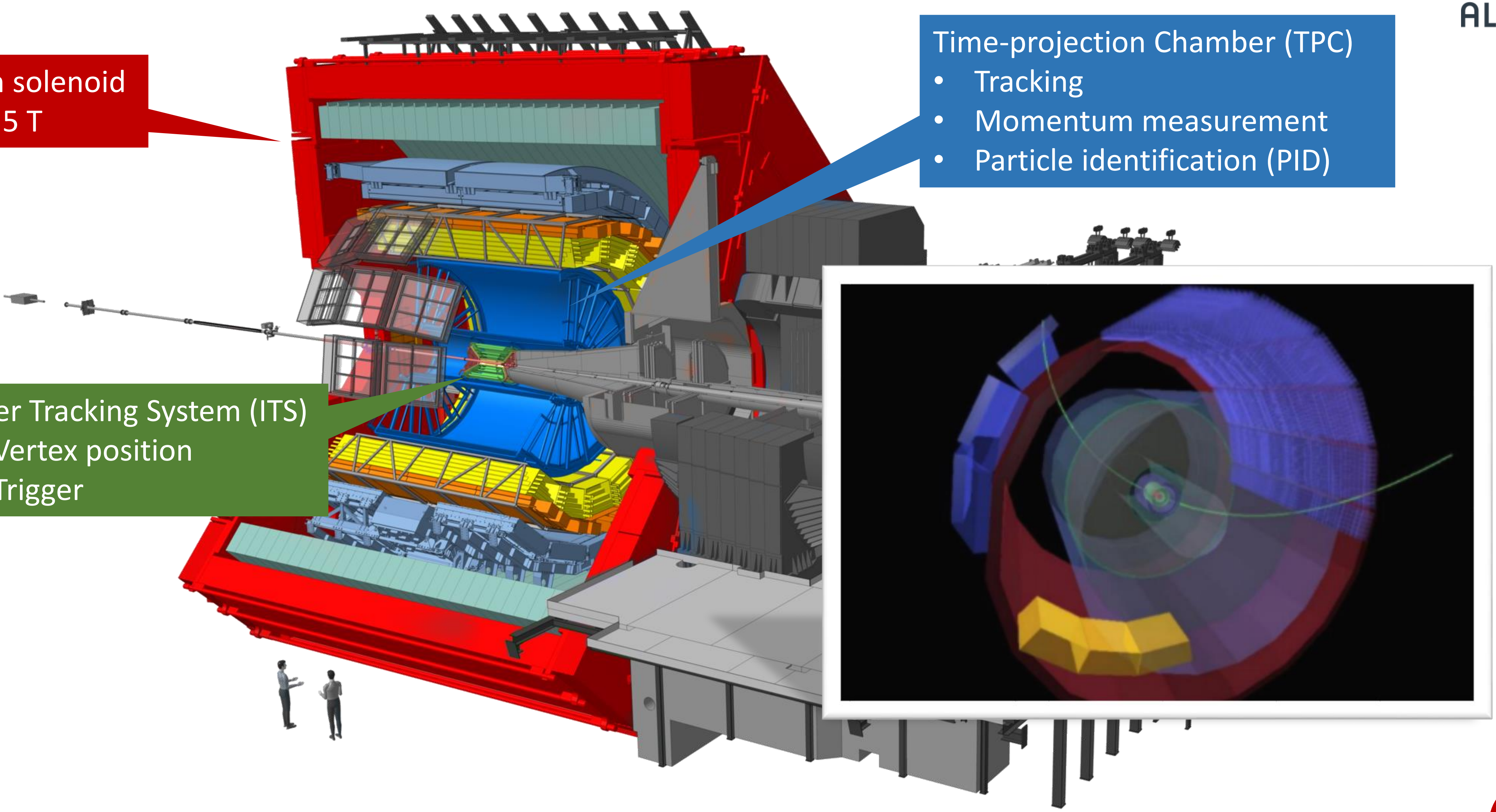
Find two tracks with low pair-p_T

Veto on activity in the rest of the detector

Central Barrel

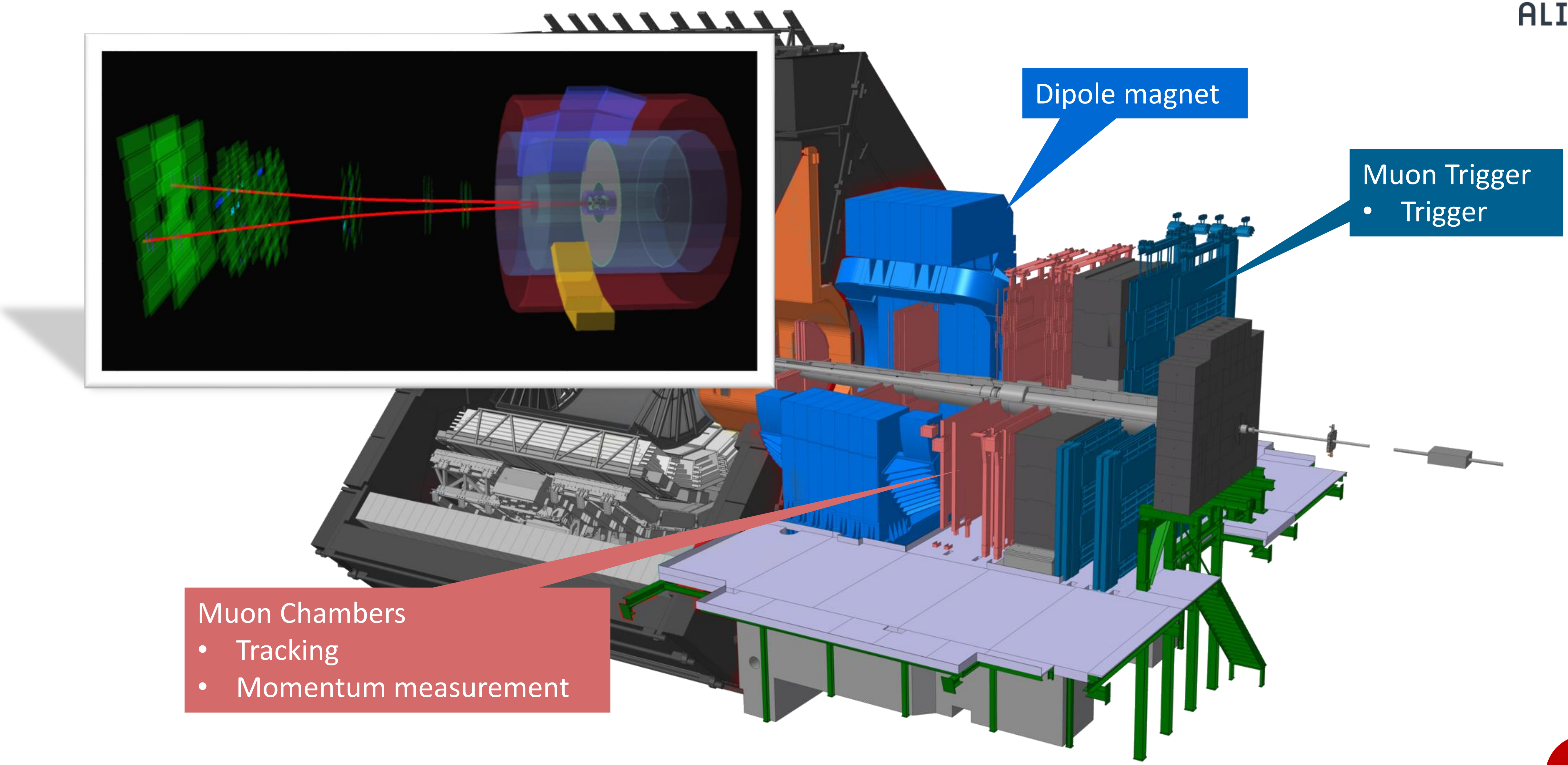
Main solenoid
- 0.5 T

Time-projection Chamber (TPC)
- Tracking
- Momentum measurement
- Particle identification (PID)



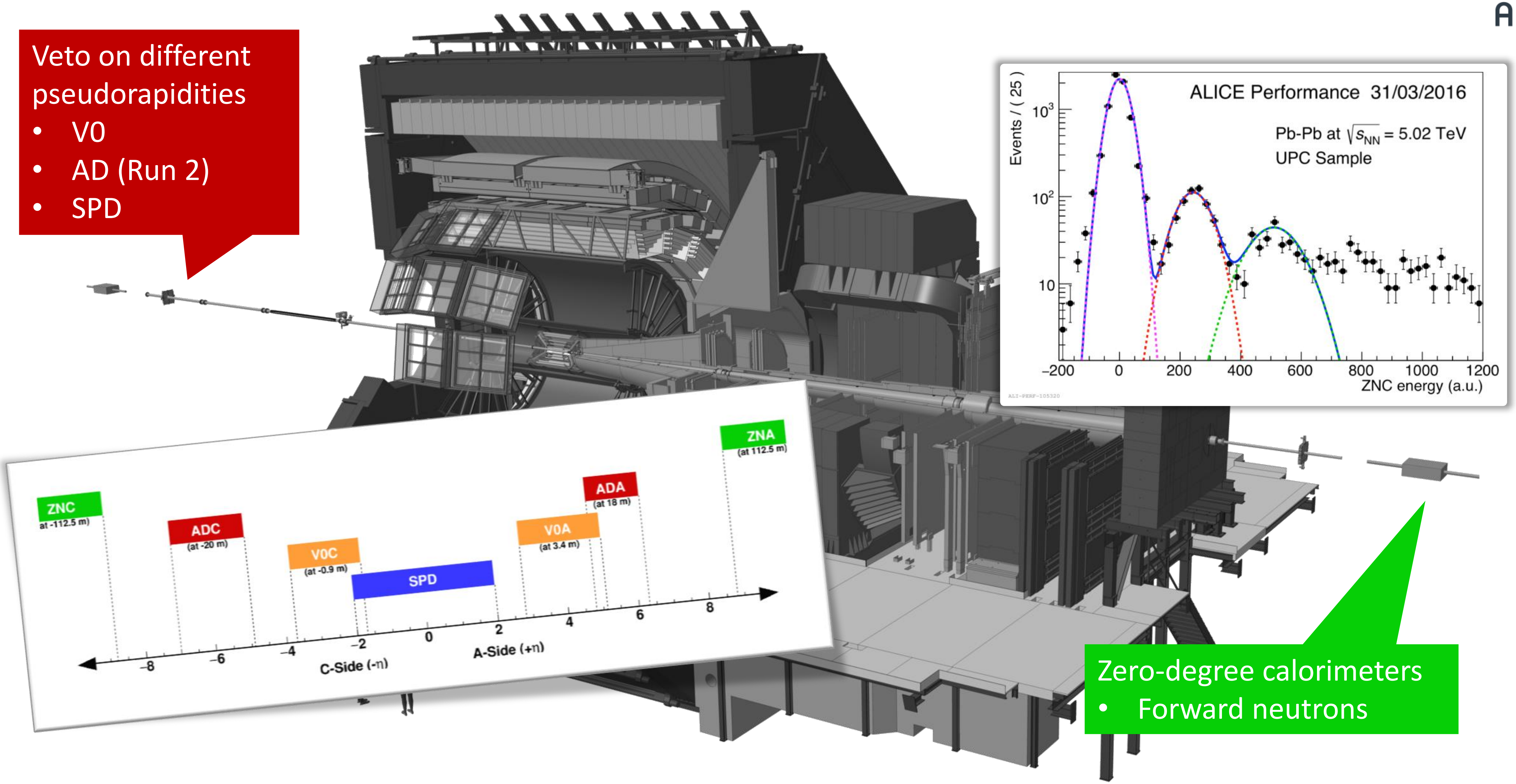
Inner Tracking System (ITS)
- Vertex position
- Trigger

Forward Muon Spectrometer



Veto and neutrons

Veto on different pseudorapidities
- V0
- AD (Run 2)
- SPD



Zero-degree calorimeters
- Forward neutrons

Coherent ρ^0 production in Pb-Pb (Run 1)

- ALICE PbPb measurements at $\sqrt{s_{NN}} = 2.76$ TeV

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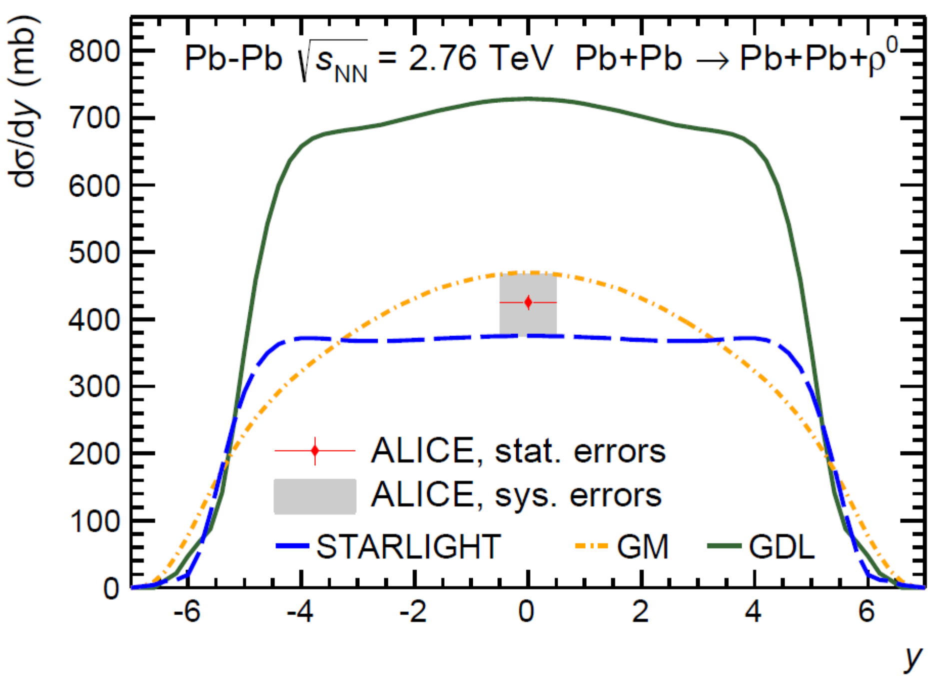
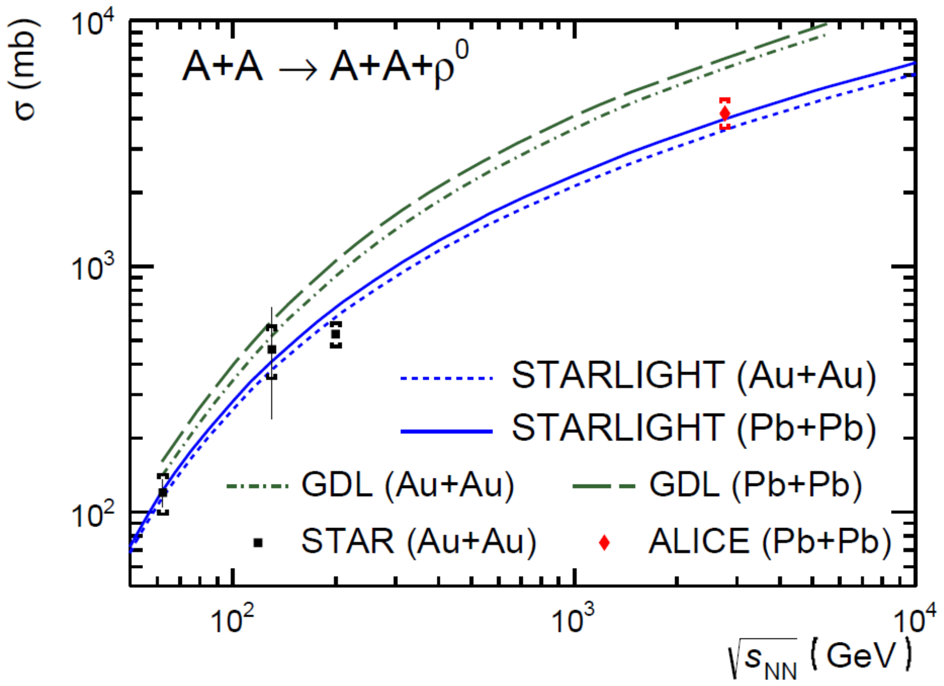




- Physics of coherent photoproduction of ρ^0:
  - dynamics of QCD at a **semi-hard scale**
  - Large cross section: possibility to study the approach to the **black disk limit of QCD**

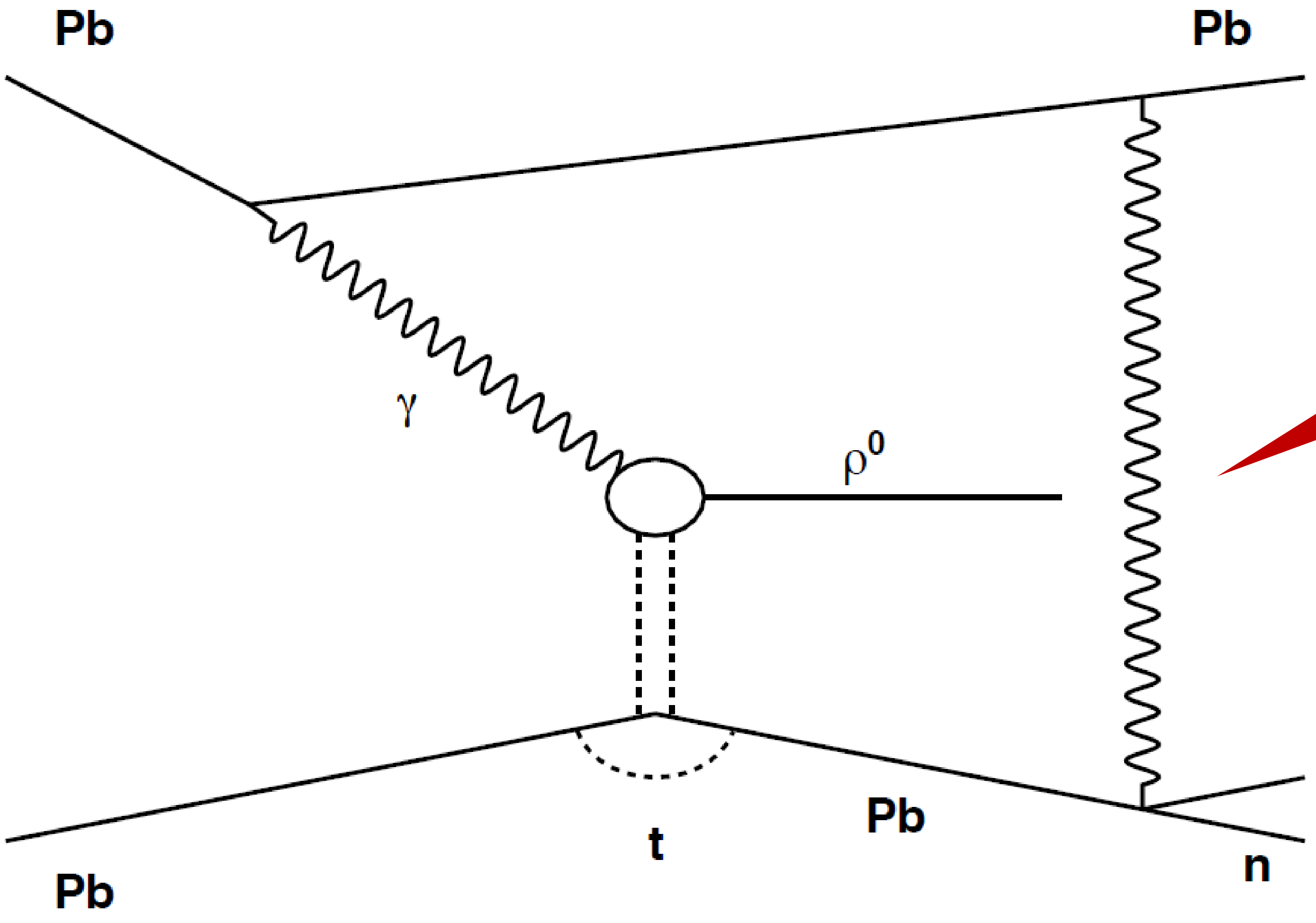
Coherent ρ^0 production in Pb-Pb (Run 2)

ALICE

- Highlights of the new measurement (PbPb 2015 at $\sqrt{s_{NN}} = 5.02$ TeV)
  - More data, better precision
  - Possibility to measure ω contribution
  - Rapidity dependence of the cross section
  - Measurement for different classes of forward neutron activity: possibility to extract the energy dependence of the cross section

- UPC cross section
  - $\frac{\mathrm{d}\sigma_{PbPb}(y)}{\mathrm{d}y} = N_{\gamma Pb}(y, \{b\}) \cdot \sigma_{\gamma Pb}(y) + N_{\gamma Pb}(-y, \{b\}) \cdot \sigma_{\gamma Pb}(-y)$
  - Photon flux given by QED
  - Mid-rapidity – both contributions are equal
  - other rapidities – two different contributions

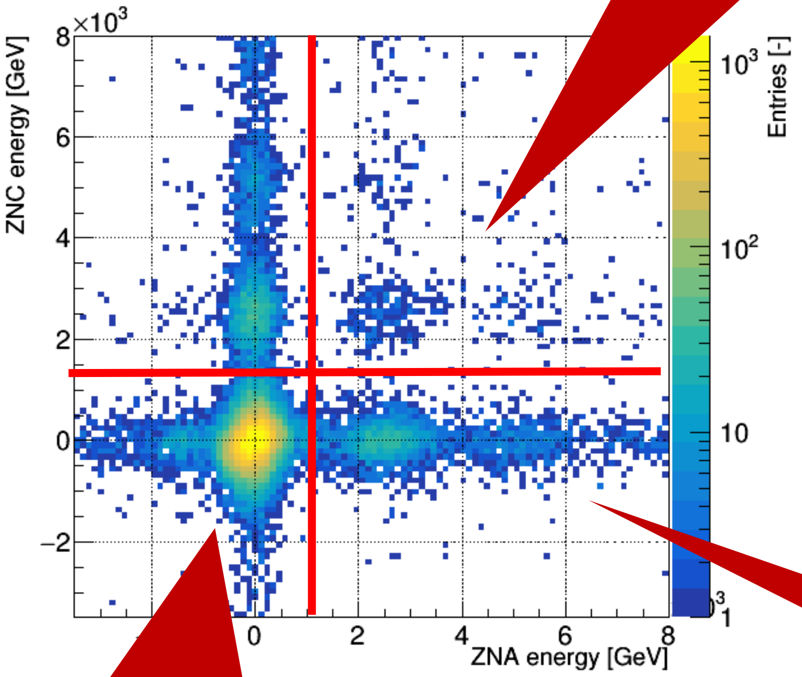
Secondary interactions!



Independent secondary interaction, which may induce EMD of one or both nuclei

Forward-neutron samples

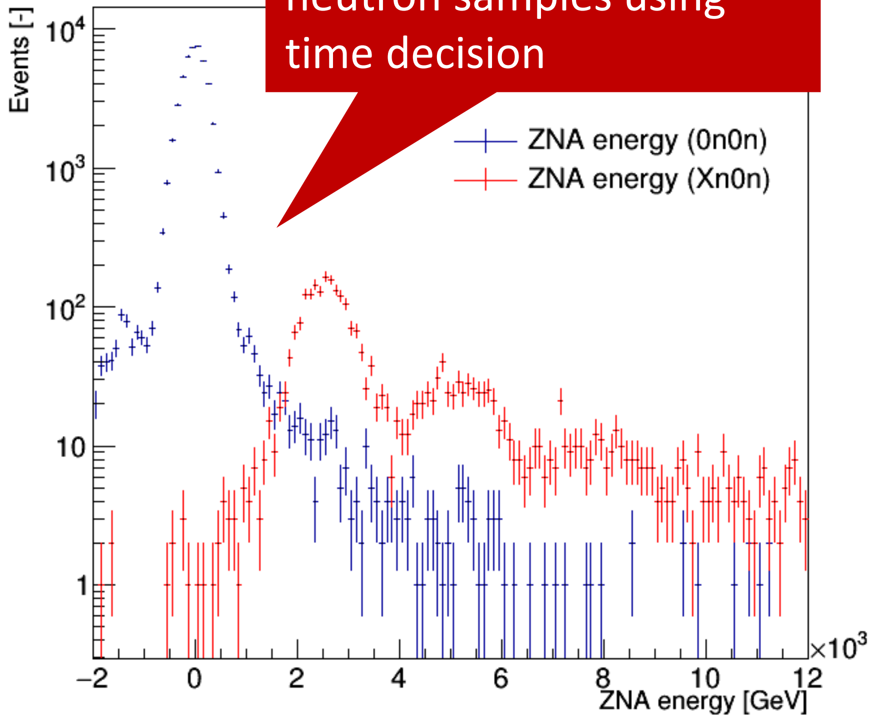
XnXn – at least one neutron detected on each side



0n0n – no neutrons are detected at both sides of the detector

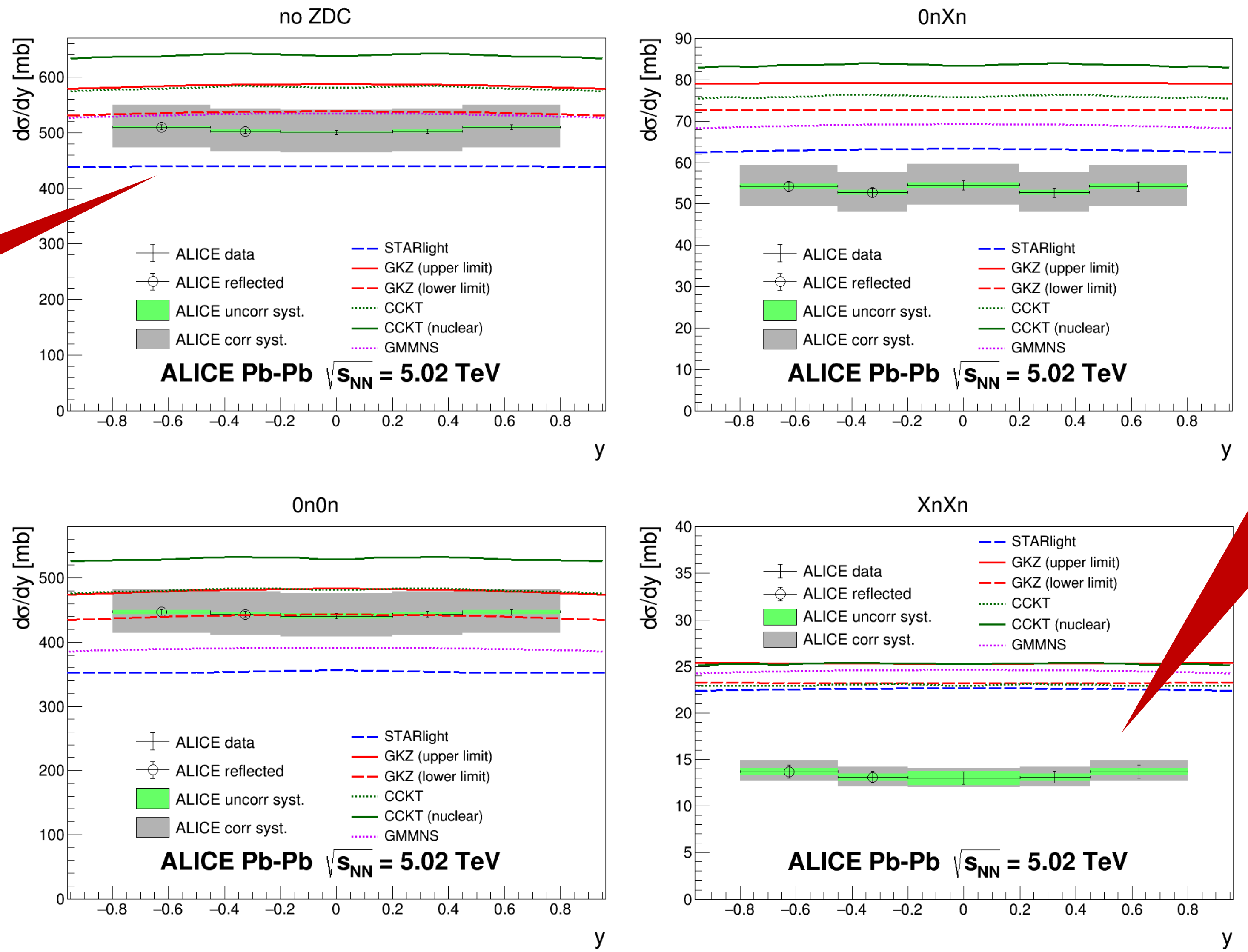
0nXn (0nXn + Xn0n) – at least one neutron is detected on one side but none on the other side

Excellent separation of neutron samples using time decision



Coherent ρ^0 production in Pb-Pb (Run 2) - results

Symetrical bins fitted together



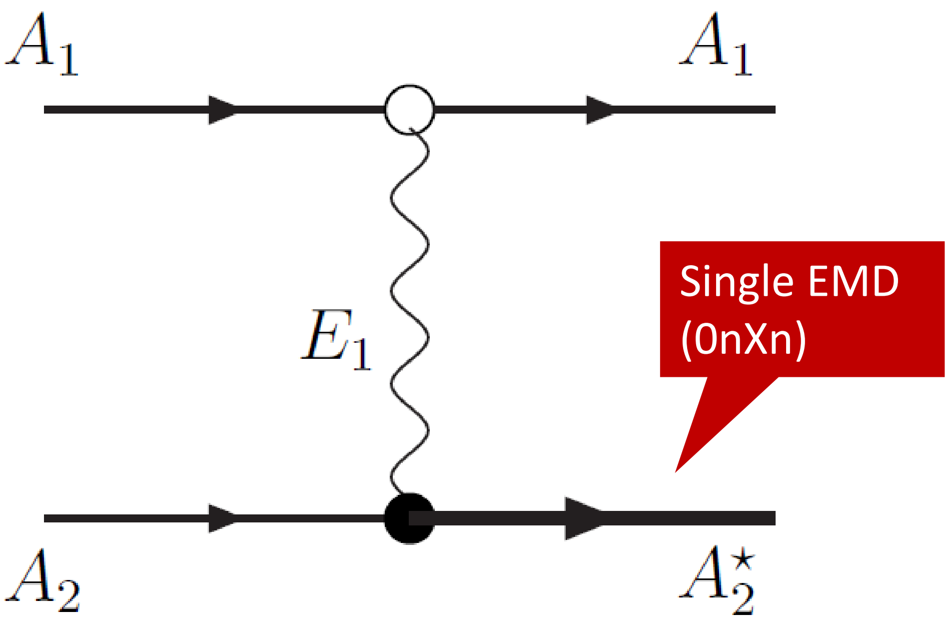
0nXn and XnXn samples far below theoretical predictions

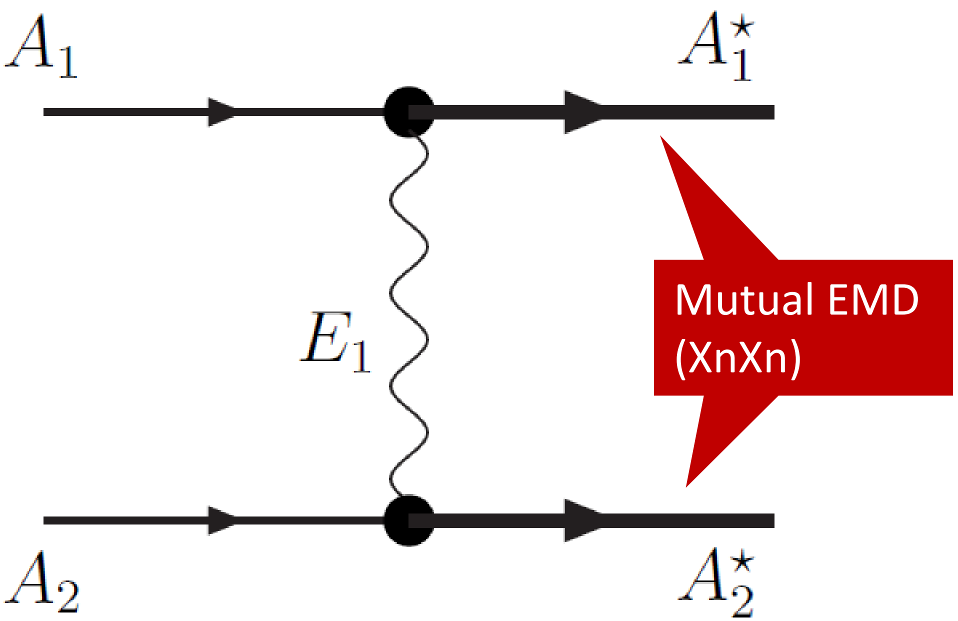
Why so wrong?

Electromagnetic dissociation!

What is an EMD?

- Electromagnetic dissociation (EMD) is a proces where one or both outgoing particles are excited after an exchange of a virtual photon.



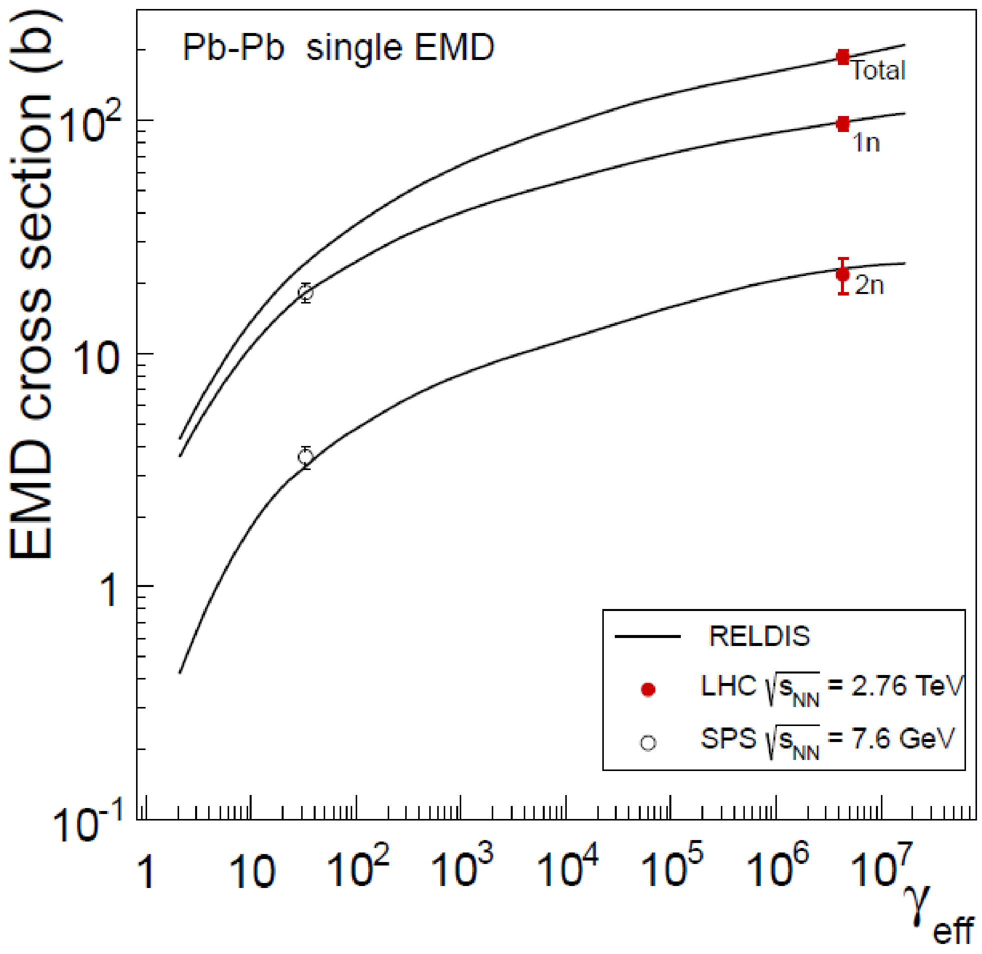


Mostly forward neutrons are produced due to the emission from Giant Dipole Resonance

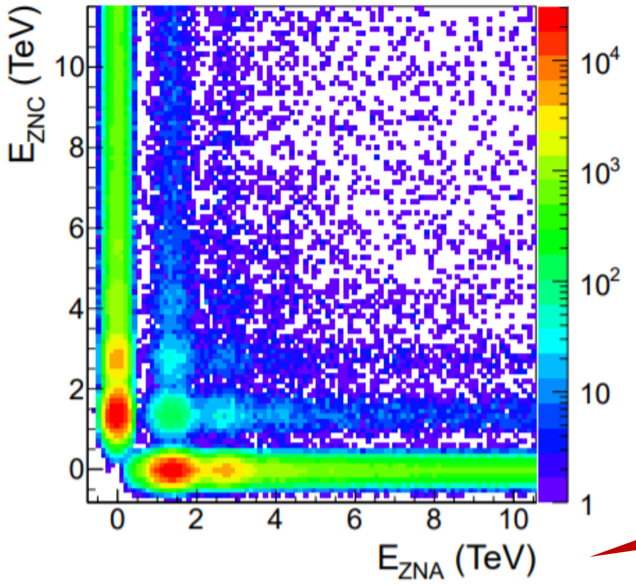
EMD at ALICE (PbPb at 2.76 TeV)

Physical Process	Data	RELDIS
single EMD + hadronic	194.8 ± 0.3 stat. $^{+13.6}_{-11.5}$ syst.	192.9 ± 9.2
single EMD - mutual EMD	181.3 ± 0.3 stat. $^{+12.8}_{-10.9}$ syst.	179.7 ± 9.2
mutual EMD	5.7 ± 0.1 stat. ± 0.4 syst.	5.5 ± 0.6
hadronic	7.7 ± 0.1 stat. $^{+0.6}_{-0.5}$ syst.	7.7 ± 0.4
single EMD	187.4 ± 0.2 stat. $^{+13.2}_{-11.2}$ syst.	185.2 ± 9.2

Relativistic ELectromagnetic DISsociation (RELDIS) model provides a good description



Large EMD cross section (barn) compared to the hadronic one



Energy deposition in zero-degree calorimeters

What‘s the problem?

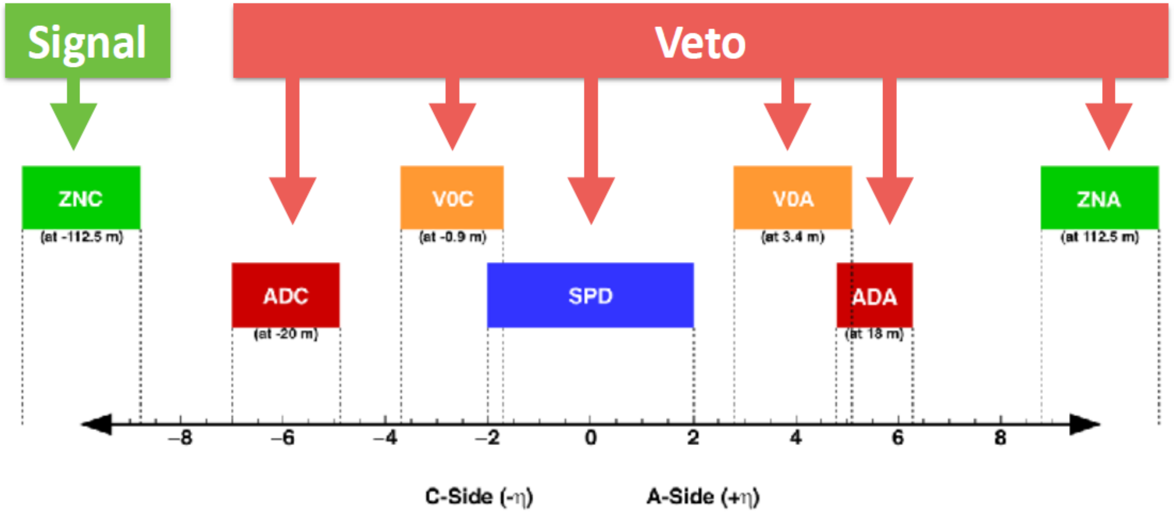
EMD pile-up

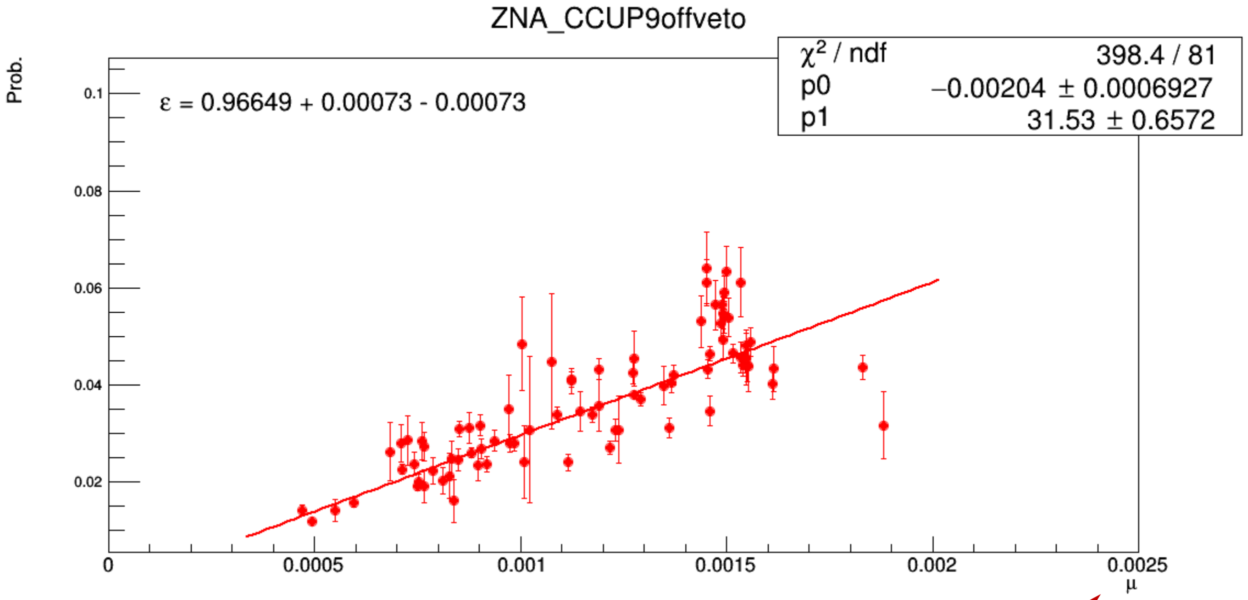
- Due to the large EMD cross section there is a big probability to have another UPC collision producing an EMD event
  - This will lead to misidenfication of the ZDC class (e.g. an event will be identified as 0nXn even if it was originally 0n0n)
- => We have to deal with the same physical and experimental process but from another collision in the same bunch-crossing…
  - This effect is even enhanced by a slow detector readout (which is several bunch-crossings!)
- We can compute it, if we know the probability to have an EMD on top of the studied process
  - In other words, what is the probability to have an EMD signal in the otherwise empty detector

Correction factors

- **CTRUE** trigger = trigger that is fired each bunch crossing (and downscaled)

We can find probabilities that only ZDC detector is fired and everything else is empty





Plotted agains pile-up factor of the run

Expected linear dependence was found, correction factor was obtained by lumi-weight sum.

Migration formulas

ALICE

ε^A	Efficiency to detect ZNA activity.
ε^C	Efficiency to detect ZNC activity.
P^A	Probability of pile-up in ZNA (measured with CTRUE, it includes ZN efficiency)
P^C	Probability of pile-up in ZNC (measured with CTRUE, it includes ZN efficiency)
σ^{fit}_{0n0n}	cross section of the 0n0n class from the fit; that is, before corrections for ZDC pile-up and efficiency
σ^{fit}_{0nXn}	cross section of the 0nXn class from the fit; that is, before corrections for ZDC pile-up and efficiency
σ^{fit}_{Xn0n}	cross section of the Xn0n class from the fit; that is, before corrections for ZDC pile-up and efficiency
σ^{fit}_{XnXn}	cross section of the XnXn class from the fit; that is, before corrections for ZDC pile-up and efficiency
σ^{M}_{0n0n}	cross section of the 0n0n class after correction for ZDC pile-up and efficiency
σ^{M}_{0nXn}	cross section of the 0nXn class after correction for ZDC pile-up and efficiency
σ^{M}_{Xn0n}	cross section of the Xn0n class after correction for ZDC pile-up and efficiency
σ^{M}_{XnXn}	cross section of the XnXn class after correction for ZDC pile-up and efficiency

$\sigma^{fit}_{0n0n} = \sigma^{M}_{0n0n}$

$- \sigma^{M}_{0n0n}[P^A(1-P^C)+P^C(1-P^A)+P^AP^C]$	Loses due to pile-up in 0n0n
$+ \sigma^{M}_{Xn0n}(1-\varepsilon^A)(1-P^A)(1-P^C)$	gains due to efficiency losses in Xn0n
$+ \sigma^{M}_{0nXn}(1-\varepsilon^C)(1-P^A)(1-P^C)$	gains due to efficiency losses in 0nXn
$+ \sigma^{M}_{XnXn}(1-\varepsilon^A)(1-\varepsilon^C)(1-P^A)(1-P^C)$	gains due to efficiency losses in XnXn

$\sigma^{fit}_{0nXn} = \sigma^{M}_{0nXn}$

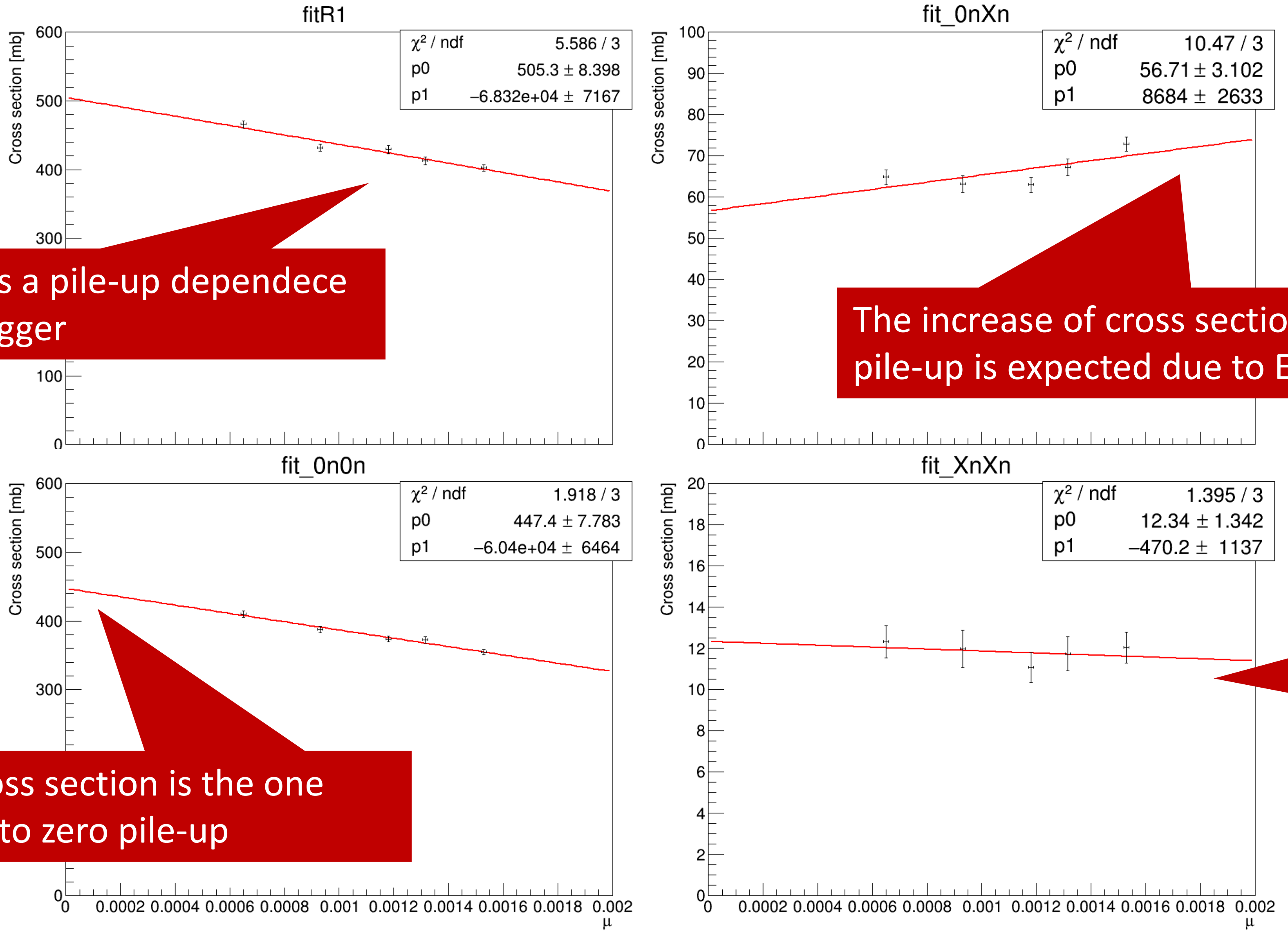
$- \sigma^{M}_{0nXn}(1-\varepsilon^C)(1-P^C)[(1-P^A)+P^A]$	Loses into 0n0n+Xn0n
$- \sigma^{M}_{0nXn}[\varepsilon^CP^A+(1-\varepsilon^C)P^AP^C)$	Loses into XnXn
$+ \sigma^{M}_{0n0n}(P^C)(1-P^A)$	gains due to pile-up in 0n0n
$+ \sigma^{M}_{Xn0n}(1-\varepsilon^A)(1-P^A)P^C$	gains due to efficiency losses in Xn0n
$+ \sigma^{M}_{XnXn}(1-\varepsilon^A)(1-P^A)[\varepsilon^C+(1-\varepsilon^C)P^C]$	gains due to efficiency losses in XnXn

$\sigma^{fit}_{XnXn} = \sigma^{M}_{XnXn}$

$- \sigma^{M}_{XnXn}(1-\varepsilon^A)(1-P^A)[\varepsilon^C+(1-\varepsilon^C)P^C]$	Loses due to efficiency in 0nXn
$- \sigma^{M}_{XnXn}(1-\varepsilon^C)(1-P^C)[\varepsilon^A+(1-\varepsilon^A)P^A]$	Loses due to efficiency in Xn0n
$- \sigma^{M}_{XnXn}(1-\varepsilon^A)(1-\varepsilon^C)(1-P^A)(1-P^C)$	Loses into 0n0n
$+ \sigma^{M}_{0n0n}(P^AP^C)$	gains due to pile-up in 0n0n
$+ \sigma^{M}_{0nXn}[(\varepsilon^CP^A+(1-\varepsilon^C)P^AP^C]$	gains due to pile-up in 0nXn
$+ \sigma^{M}_{XnXn}[(\varepsilon^AP^C+(1-\varepsilon^A)P^AP^C]$	gains due to pile-up in Xn0n

The other way?

Pile-up dependence of the cross section



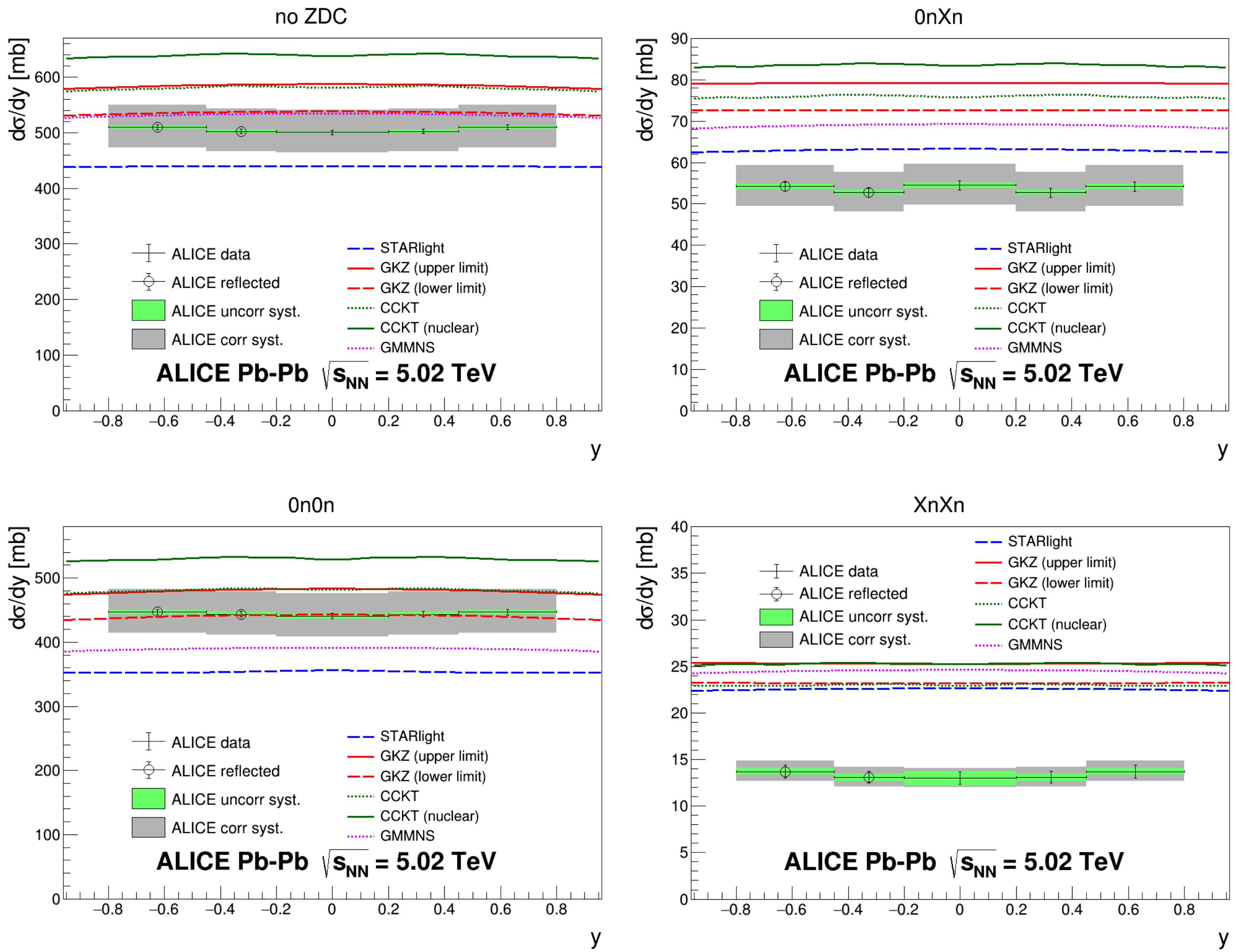
The total cross has a pile-up dependece because of the trigger

The increase of cross section in 0nXn sample with pile-up is expected due to EMD contamination

„Physical“ cross section is the one extrapolated to zero pile-up

They are in agreement with cross section obtain by computation

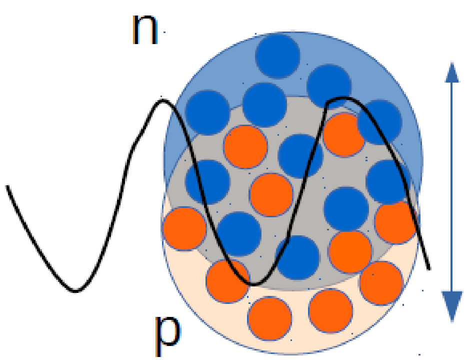
Still wrong? :-(

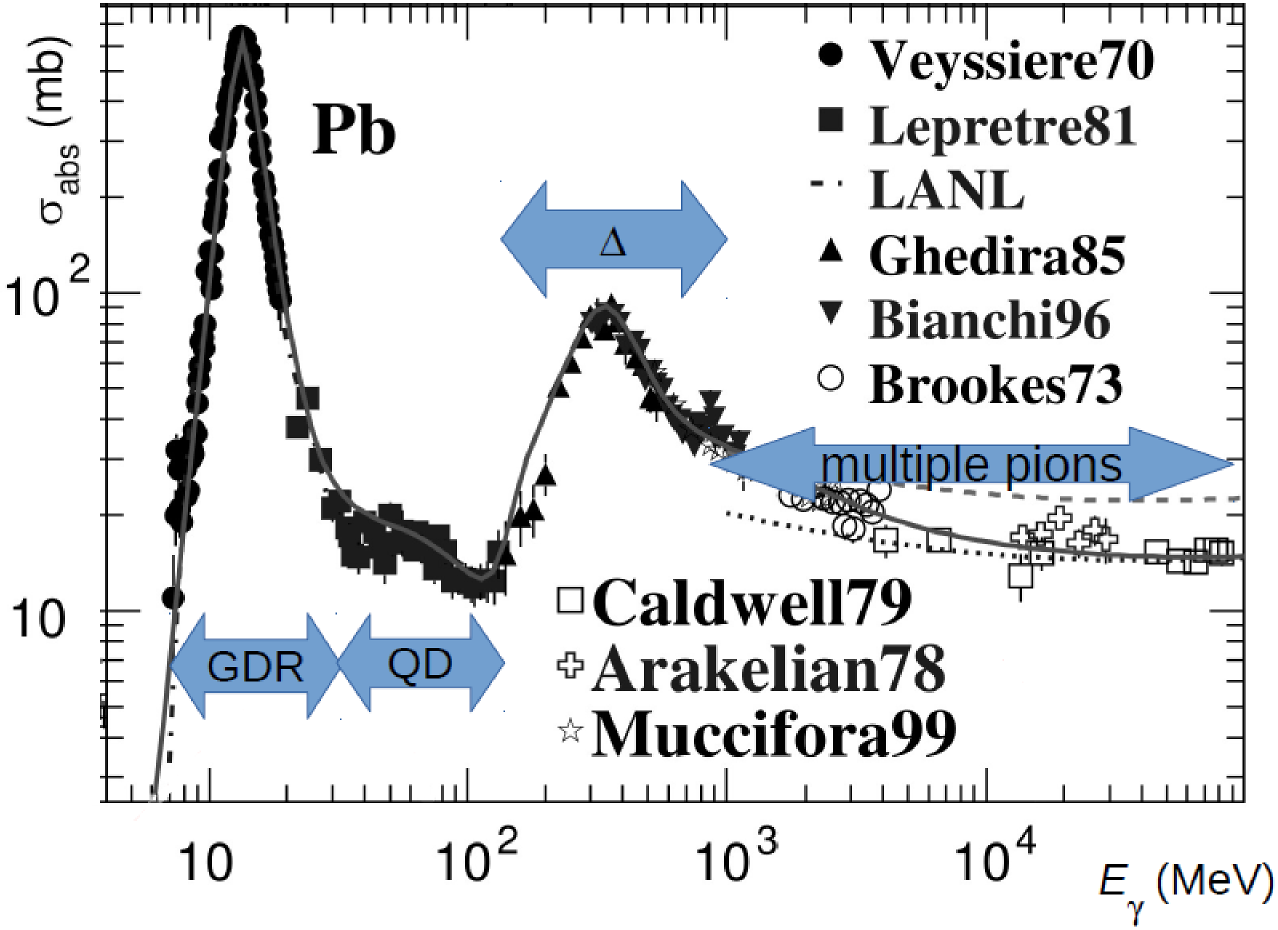

no ZDC
0nXn
0n0n
XnXn
dσ/dy [mb]
y
ALICE data
ALICE reflected
ALICE uncorr syst.
ALICE corr syst.
STARlight
GKZ (upper limit)
GKZ (lower limit)
CCKT
CCKT (nuclear)
GMMNS
ALICE Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

What‘s the problem?

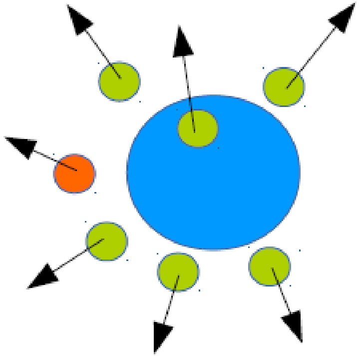
Giant Dipole Resonance

Giant Dipole Resonance (GDR) is a collective oscillation of all protons against all neutrons in a nucleus





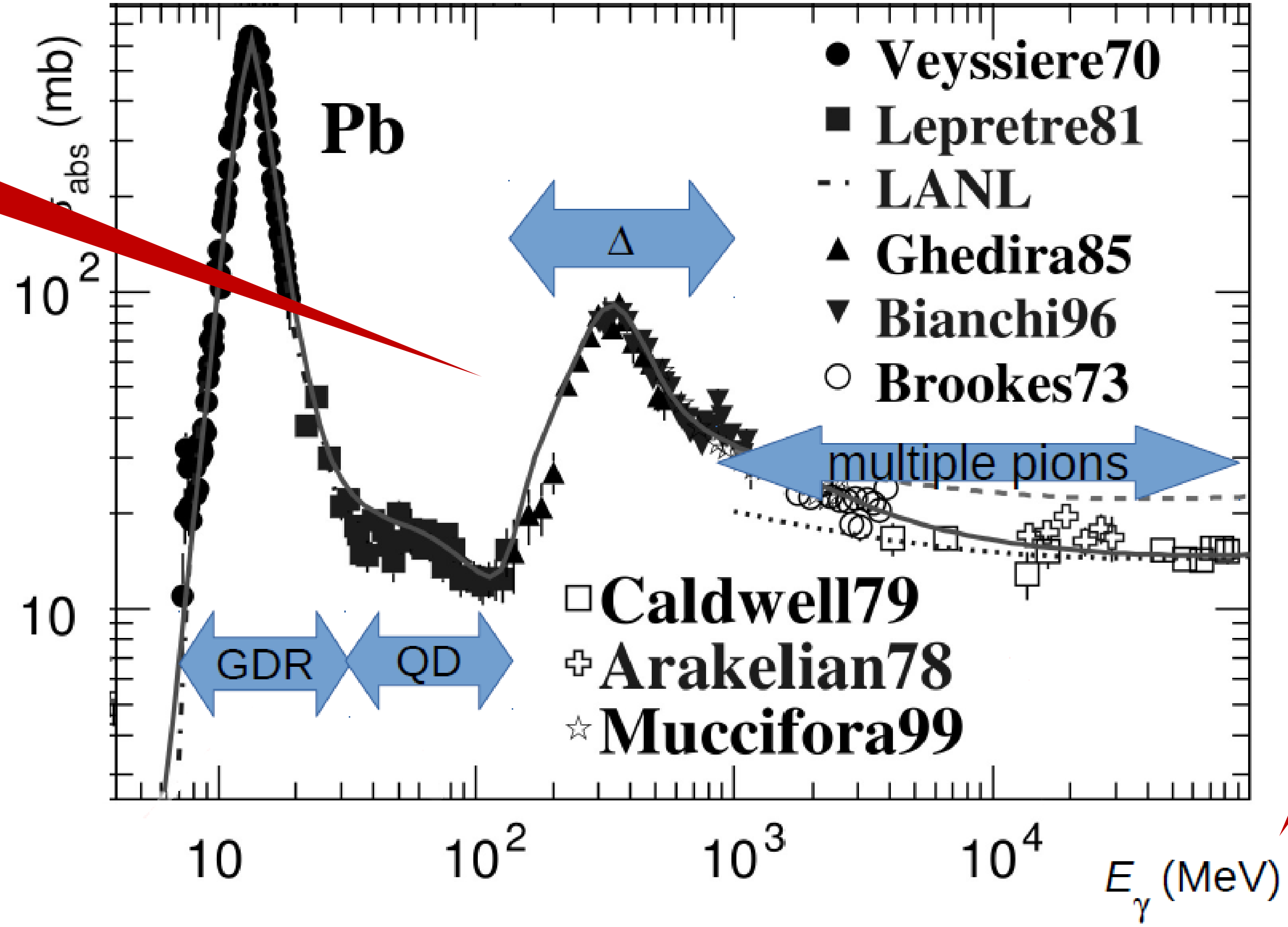
Mostly neutrons are evaporated from Pb nucleus



Delta resonance region

Δ (Delta resonance) is excited at higher photon energies

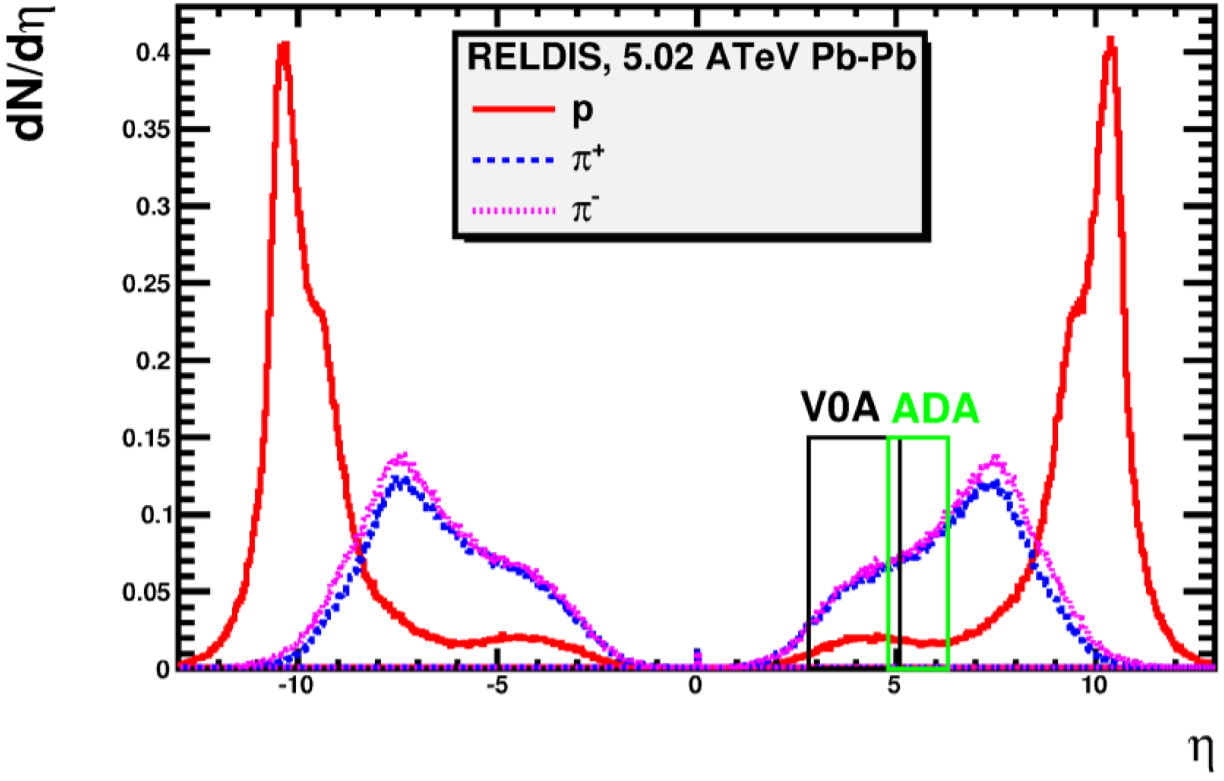
Δ decays mostly to neutron and pion

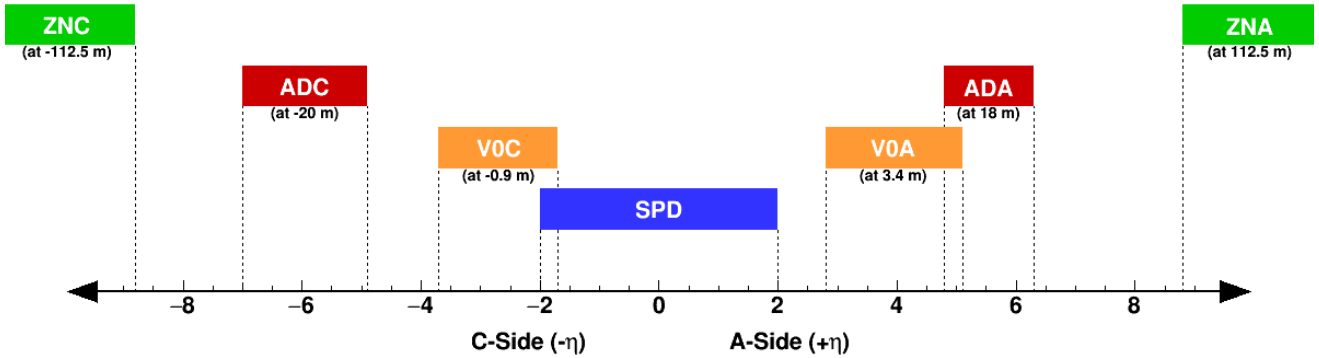


Smaller impact parameter = higher photon energy

For harder photons charged particles may be produced in the forward direction.

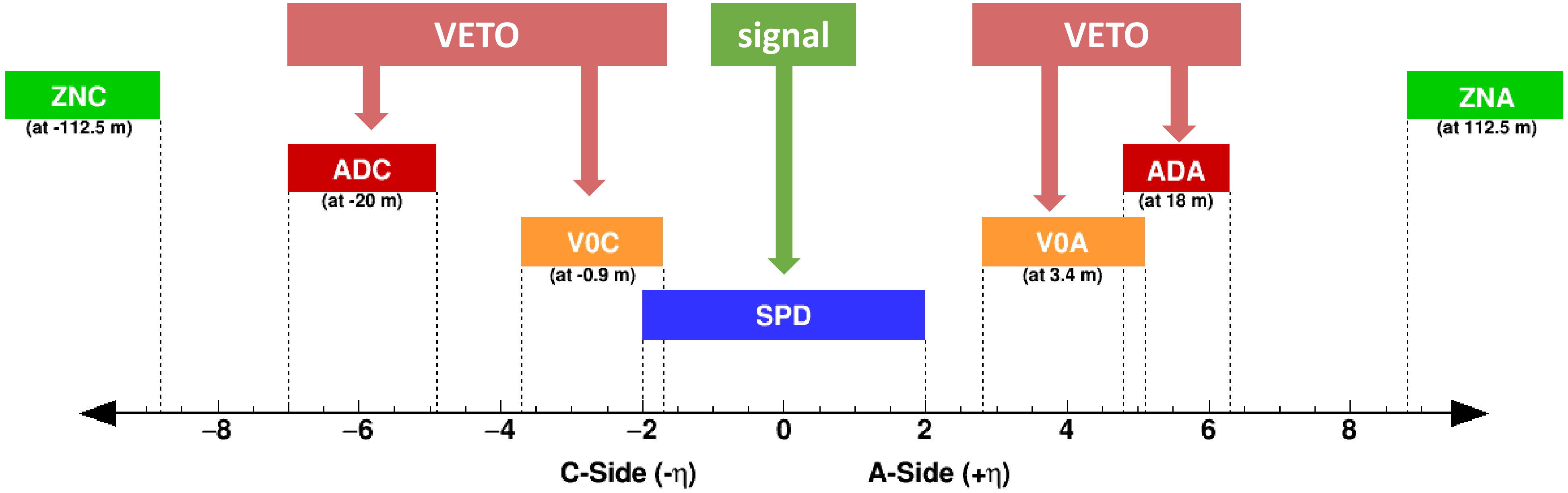
Charged particles in the EMD event



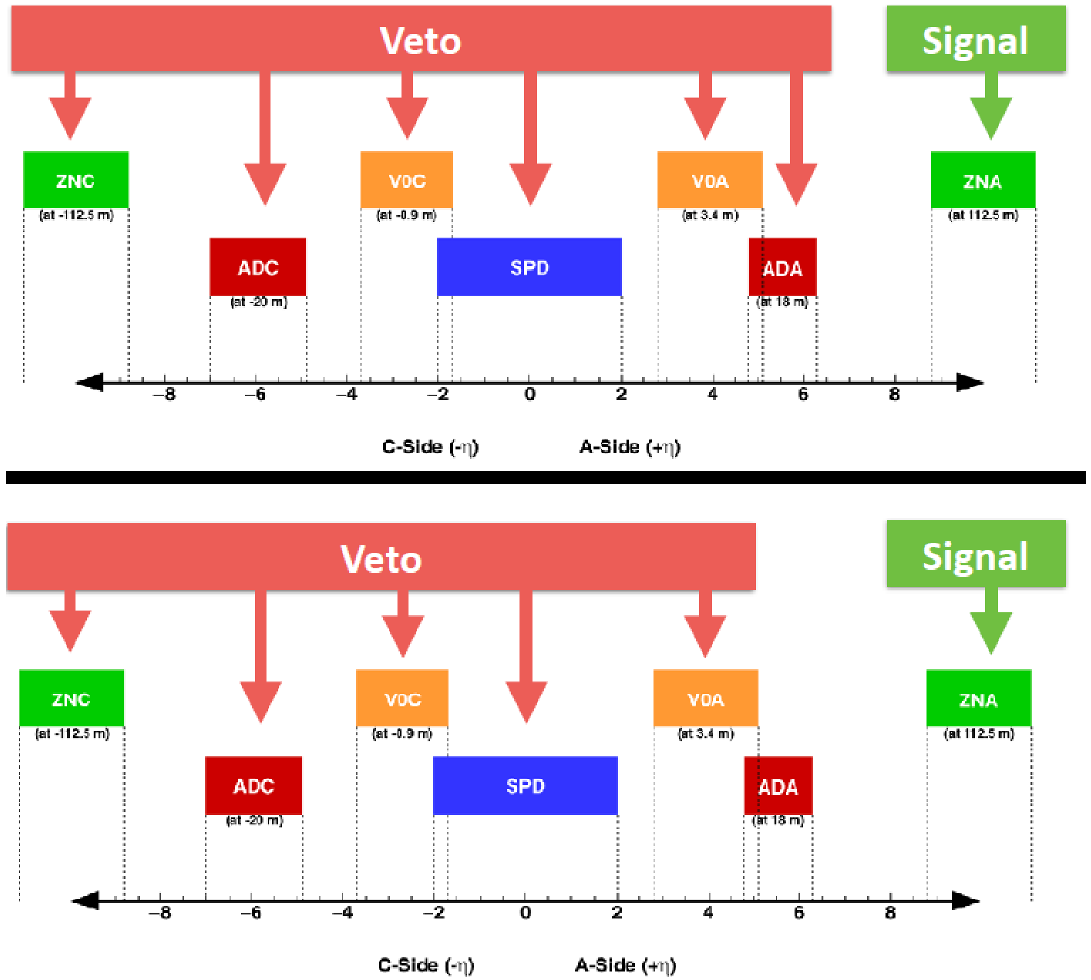


UPC Trigger for barrel candidates

- CCUP9 = !VBA & !VBC & !0UBA & !0UBC & 0STP
- V0A and V0C veto
- ADA and ADC veto
- Topology trigger in SPD
  - back-to-back events



Effect in the VETO detector



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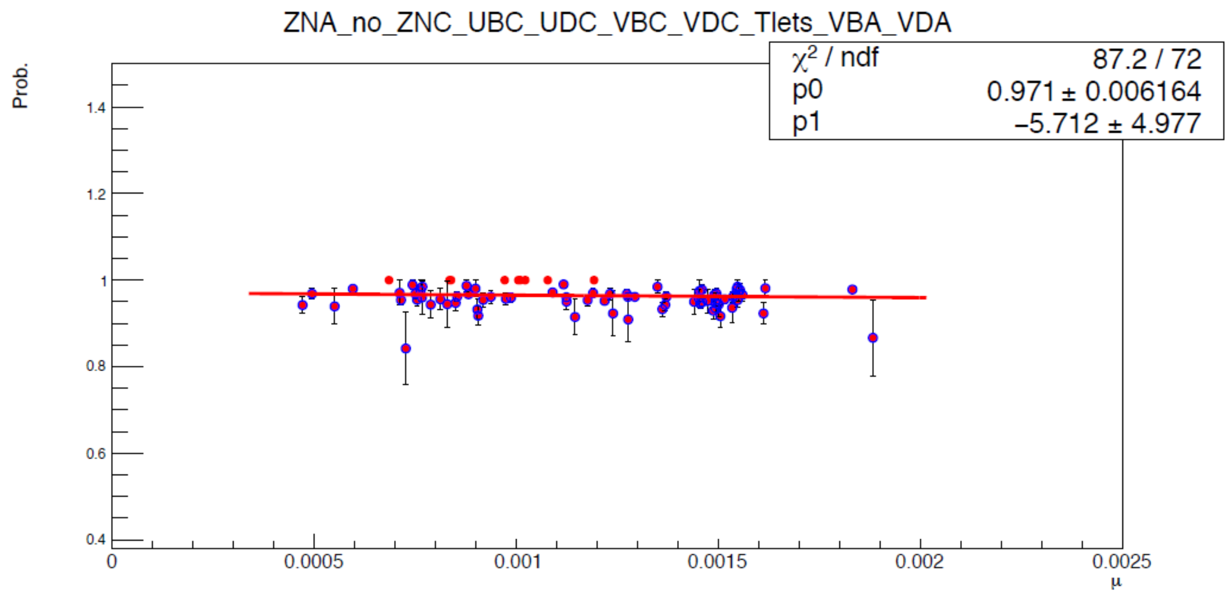
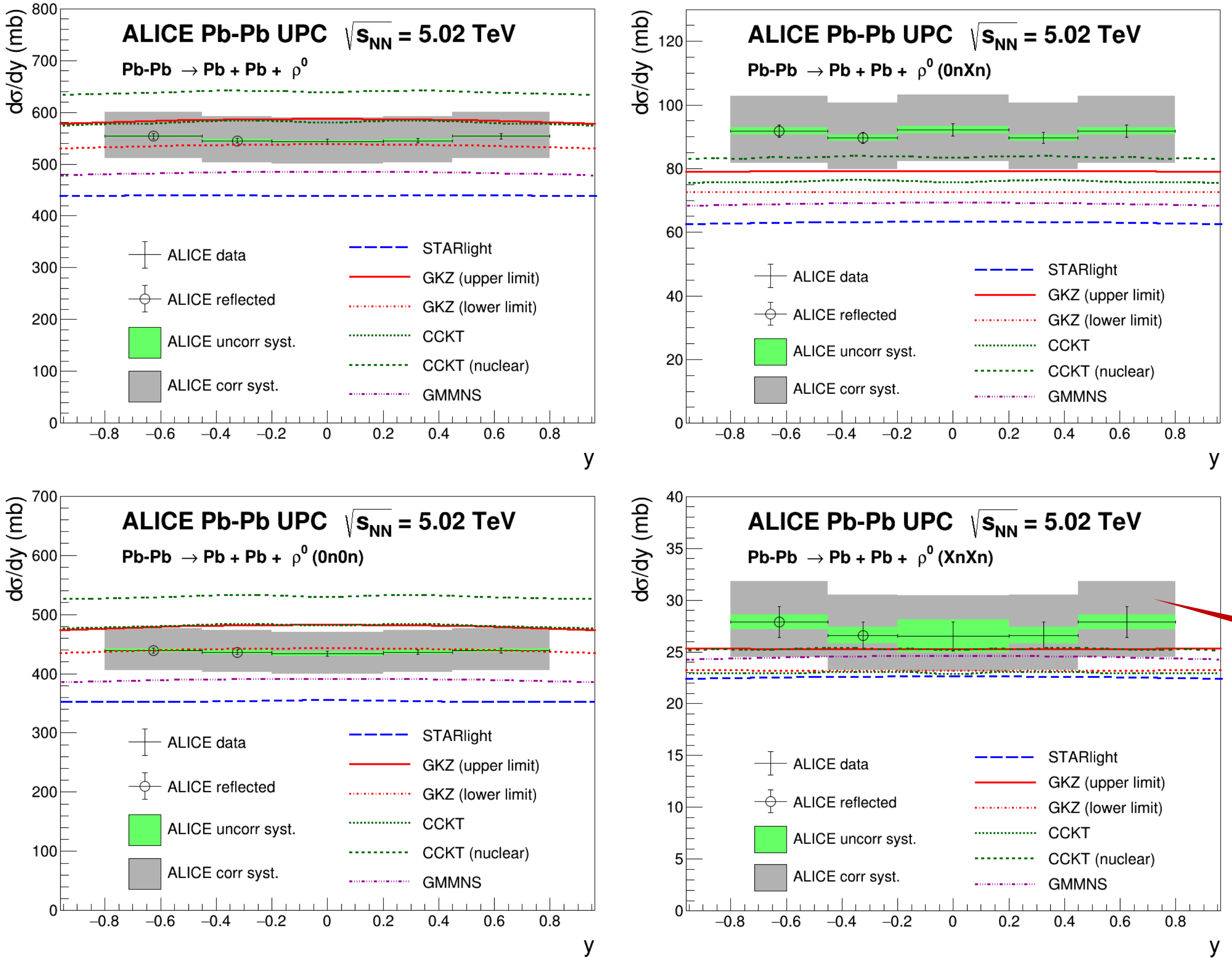


Finally final results?



0nXn and XnXn are now compatible with theoretical prediction

Larger systematic uncertainty from EMD correction factor

Summary

- ALICE is an excellent detector to **investigate QCD using UPC**.
  - We studies the approach to the black-disk limit of QCD with coherent ρ^0 production in Pb-Pb UPC.

- Coherent ρ^0 measured in Pb-Pb Run 2 data
  - Paper going to CR2 review.

- EMD background is causing a large trigger correction factor for neutron subsamples
  - Has to be used for all Run2 analysis.

- *Stay tuned for upcoming results!*

Thank you for your attention!

This work has been partially supported by the grant 18-07880S of the Czech Science Foundation (GACR).

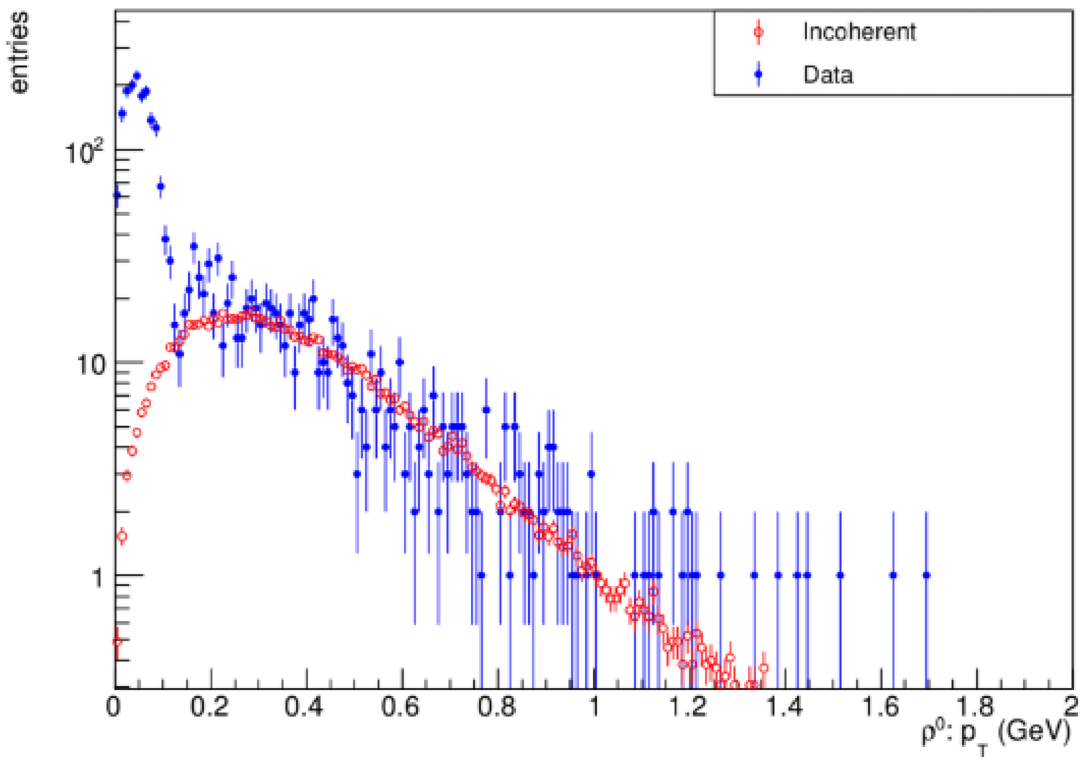
[1] *Coherent ρ^0 photoproduction in ultra-peripheral Pb–Pb collisions at* $\sqrt{s_{NN}} = 2.76$ *TeV.* arXiv:1503.09177v1 [nucl-ex], 31 Mar 2015, Journal reference: JHEP 09 (2015) 095
[2] *Coherent photoproduction of vector mesons in ultraperipheral heavy ion collisions: Update for run 2 at the CERN Large Hadron Collider*. arXiv:1602.01456 [nucl-th], 3 Feb 2016, Journal reference: Phys.Rev. C93 (2016) no.5, 055206
[3] *Coherent diffractive photoproduction of ρ^0 mesons on gold nuclei at RHIC.* arXiv:1702.07705v1 [nucl-ex], 24 Feb 2017
[4] *Luminosity determination for ultra-peripheral triggers in Pb–Pb at* $\sqrt{s_{NN}} = 5.02$ *TeV,* Evgeny Kryshen, 2017

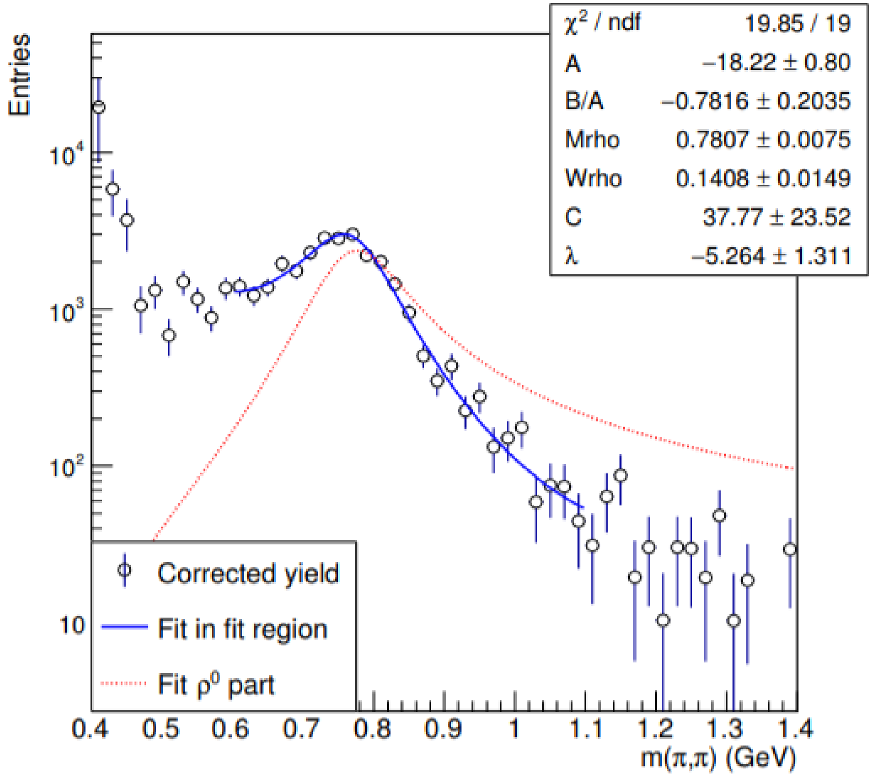
Backup Slides

ρ^0 in Run 2 (2017 Xe-Xe)

ρ^0 photoproduction in Xe-Xe

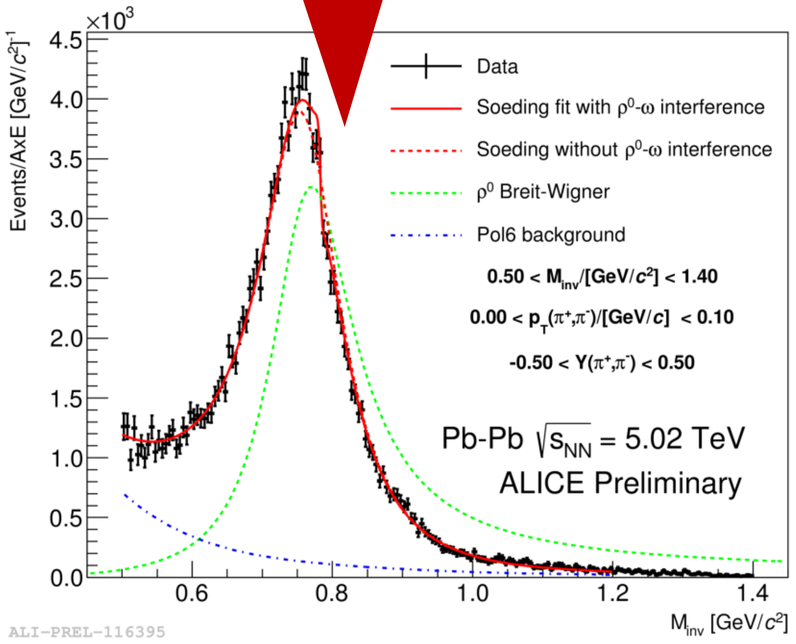
- First measurement of the cross section for coherent ρ^0 photoproduction off Xenon targets.
  - $\sqrt{s_{NN}} = 5.44$ TeV
  - Target size between p and Pb(Au)
  - The centre-of-mass energy in the photon–Xe system at mid rapidity is W = 64.7 GeV



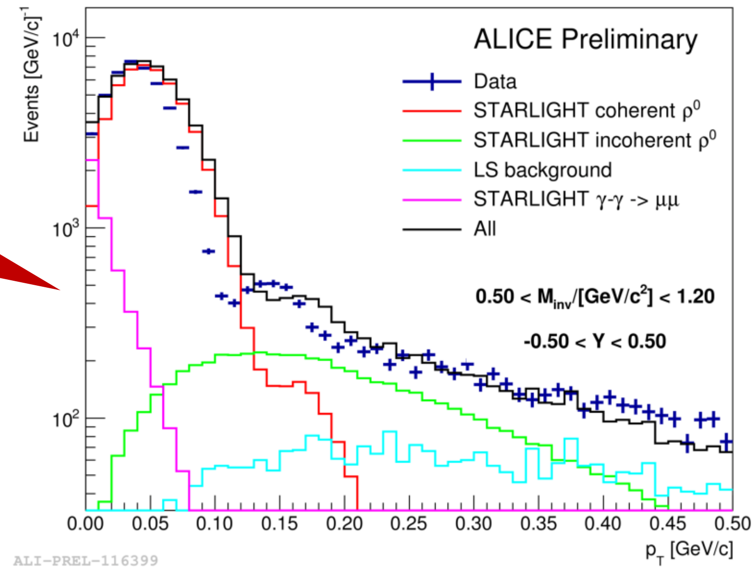


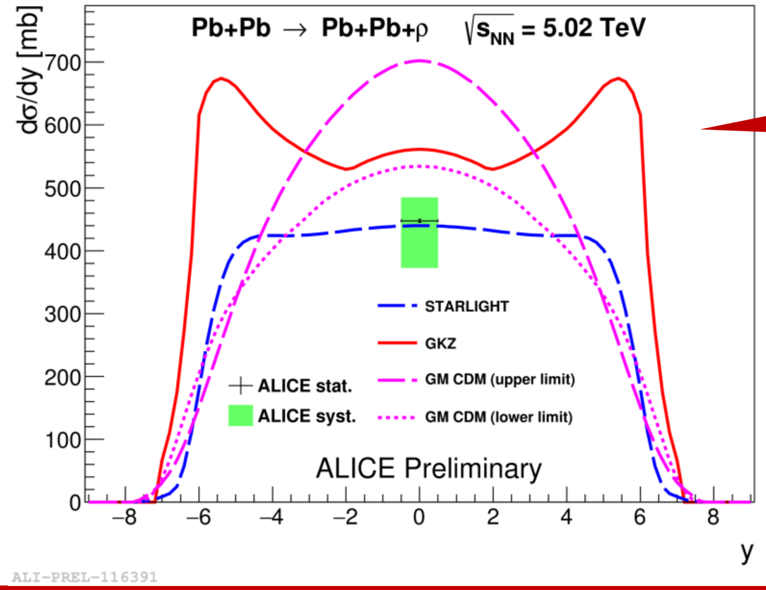
Coherent ρ^0 production in Pb-Pb (Preliminary)

ω seen through the interference (kink in the spectrum)



First and second **diffractive peaks** from ρ^0 clearly visible in the p_T spectrum





Some models close to the preliminary measurement.

Selection criteria

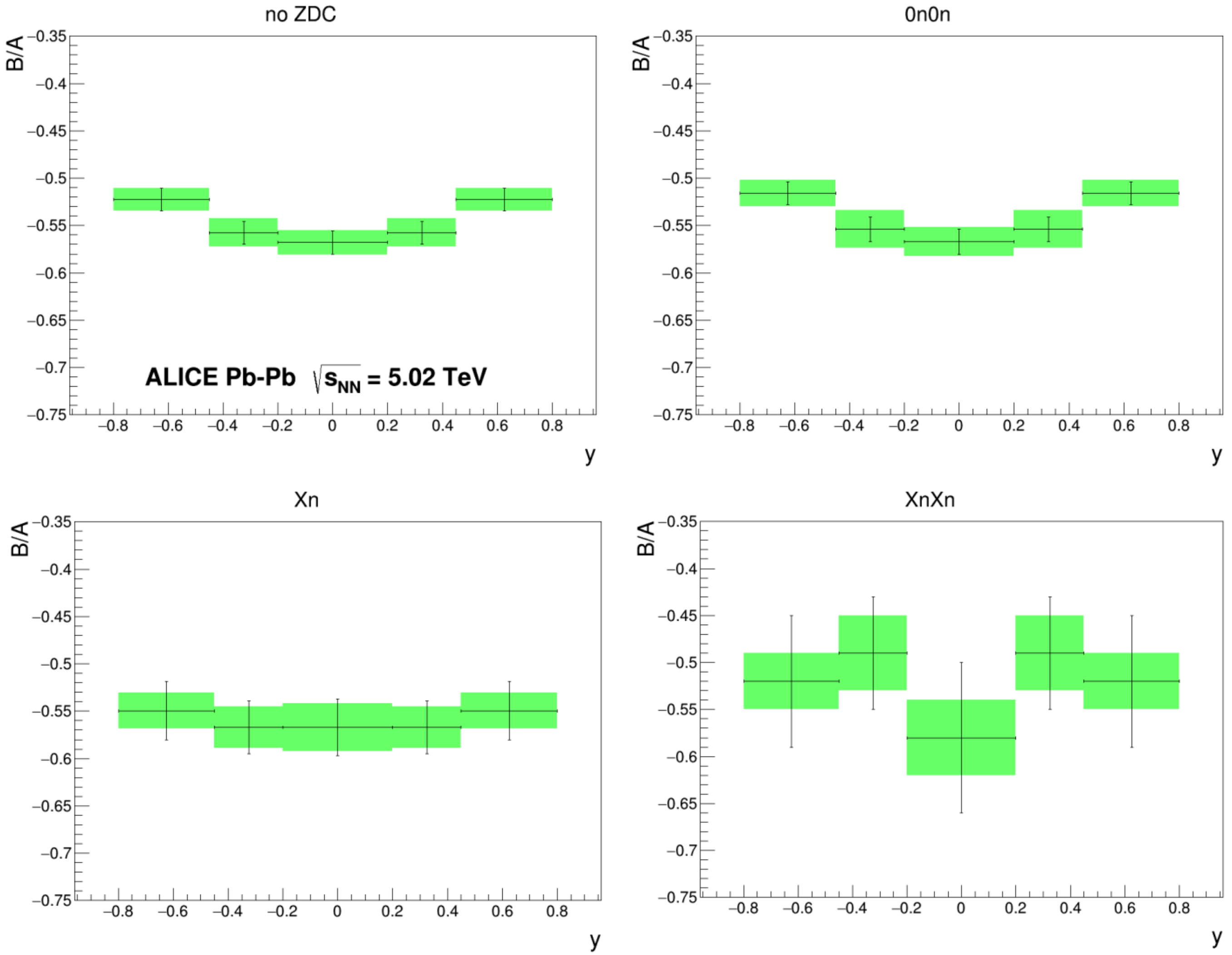
- Run selection
- Triggered by CCUP9
- 2 good tracks (bit0)
  - Has point on 0 and 1 ITS layer
- CCUP9 Matched Fast-OR chips
  - Explanation in next slides

- Opposite charge
- V0, AD offline veto
- TPC PID (pion hypothesis)
  - ${\sigma_{\pi+}}^2 + {\sigma_{\pi-}}^2 < 5^2$
- Kinematic selection (full sample)
  - $|y_{\pi^+\pi^-}| < 0.8$
  - $p_T(\pi^+\pi^-) < 0.2$ GeV
  - $0.55 < M_{\pi^+\pi^-} < 1.4$ GeV

B/A rapidity dependence

- $\frac{d\sigma}{dM_{\pi\pi}} = |A \cdot BW_{\rho} + B + C \cdot e^{i\phi} \cdot BW_{\omega}|^2 + N \cdot muon$

- Symetrical bins fitted together
  - We checked that both sides are compatible within statistical error
  - Equal number of events in each bin



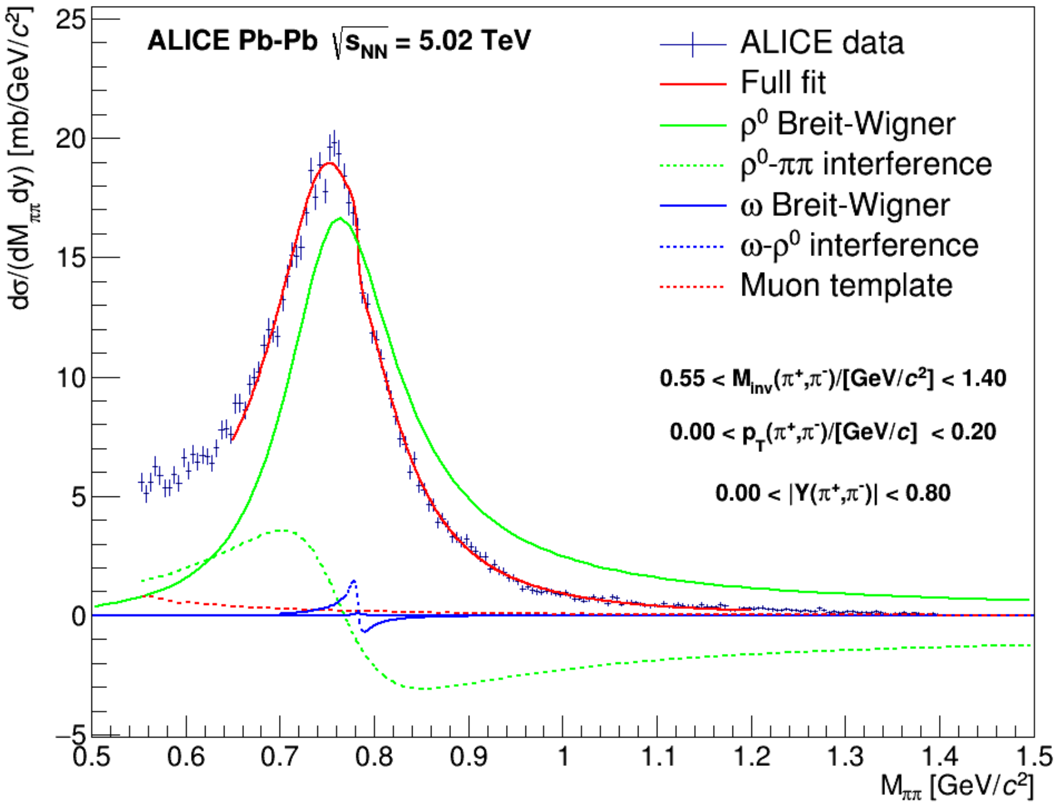
Background processes

- Measurement of $\rho^0 \rightarrow \pi^+ + \pi^-$
  - Decay to pions (~100%)
- $\gamma + \gamma \rightarrow e^+ + e^-$
  - Using the PID in TPC we are able to distinguish this process for small invariant masses where it is dominant
- $\gamma + \gamma \rightarrow \mu^+ + \mu^-$
  - Template fit
  - MC simulation (STARLIGHT)
  - Normalization using $\gamma + \gamma \rightarrow e^+ + e^-$ measurement with 2010 data
- Incoherent production of ρ^0
  - MC simulation STARLIGHT
  - Estimated using template fit of the pT spectrum tail
- Hadronic background
  - Like-sign events
  - Negligible contamination in the coherent ρ^0 kinematic region

Full sample: mass fit

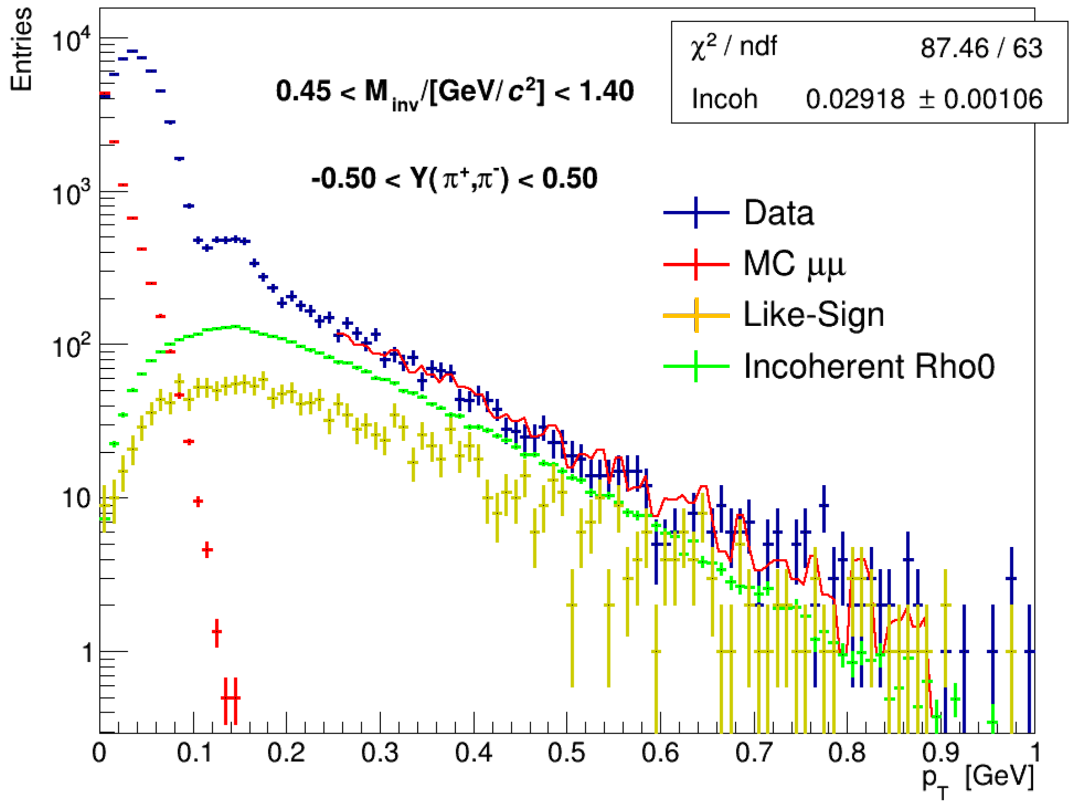
- Fit by the Söding formula + Omega + muon background
  - $\frac{d\sigma}{dM_{\pi\pi}} = |A \cdot BW_{\rho} + B + C \cdot e^{i\phi} \cdot BW_{\omega}|^2 + N \cdot muon$
- ρ^0 and ω mass and width compatible with PDG
  - Fixed to PDG values for subsamples
- Muon template fixed using measured cross section
- ω causing a „kink“ in the spectrum
  - We are sensitive to the C and ϕ parameters

	ALICE	STAR [3]
C/A	$0.12 \pm 0.03 \pm 0.02$	$0.36 \pm 0.03 \pm 0.04$
Phi	$1.6 \pm 0.2 \pm 0.2$	$1.46 \pm 0.11 \pm 0.07$



Incoherent component of ρ^0

- pT distribution used to compute the incoherent ρ^0 portion below 0.2 GeV (pT cut)
  - Incoherent ρ^0 (STARlight) template fit of the tail



Systematics

Total	+8.0%	-7.2%	
Luminosity	+5%	-5%	
Track selection	+1.5%	-1.5%	
Track matching	+3%	-3%	
Pileup	+3.8%	-3.8%	
Muon background	+0.2%	-0.3%	• +/- 10% change of template fit
AccXeff	+1%	-1%	• Using flat-mass MC
Fit range and binning	-	-	• Specific to each bin (green boxes in figures)
Fit model (RS)	+3.5%	0	• RS provides +3.5% on number of candidates
Incoherent component	<<+1%	<<-1%	
ZDC efficiency	-	-	• Estimated for each ZDC subsample
ZDC migration	-	-	• Estimated for each ZDC subsample

ZDC efficiency and migration

- ZDC efficiency ε = 0.93+/-0.01 (*Igor Pshenichnov*)
- ZDC migration
  - CTRUE analysis
  - Emptiness of an event is (f0VBA || f0VBC || f0UBA || f0UBC || fV0ADecision != 0 || fV0CDecision != 0 || fADADecision != 0 || fADCDecision != 0) (online+offline CCUP9)
  - pA = pC = 3.5%, pAC = 0.2%
  - Adding requirement for no tracklets
  - pA = pC = 3.1%, pAC = 0.17%

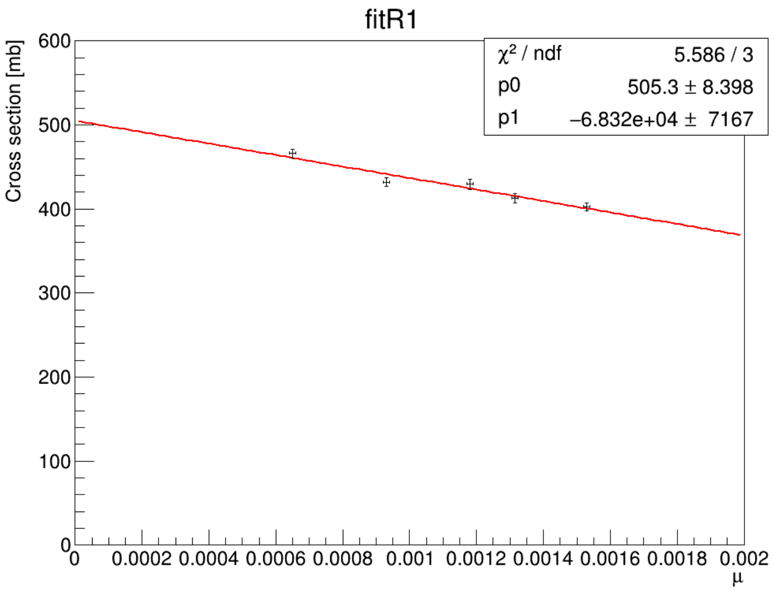
  - Based on this we taken pA = 3.1% +/- 0.2%

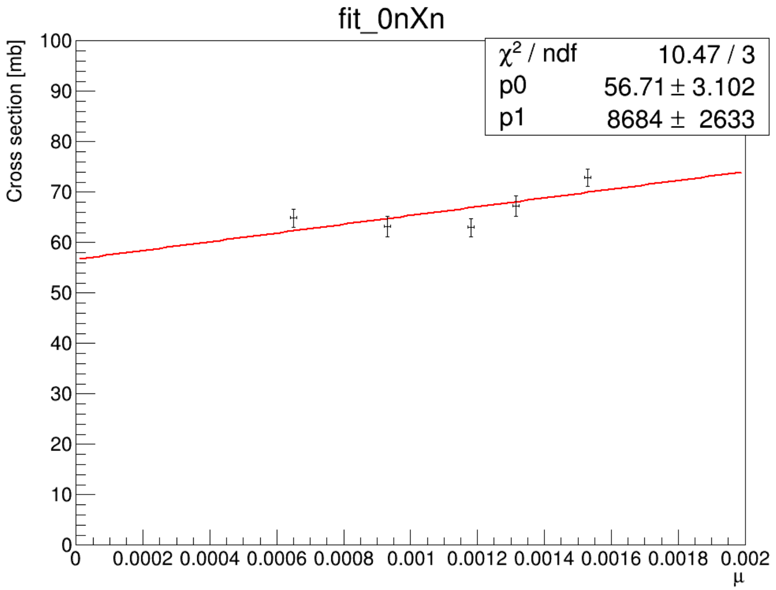
pileup error	3,1 +/- 0,2
0n0n	0,50%
xn	3,50%
xnxn	1%
ZN eff error	0,93 +/- 0,01
0n0n	0,10%
xn	0,60%
xnxn	2,20%

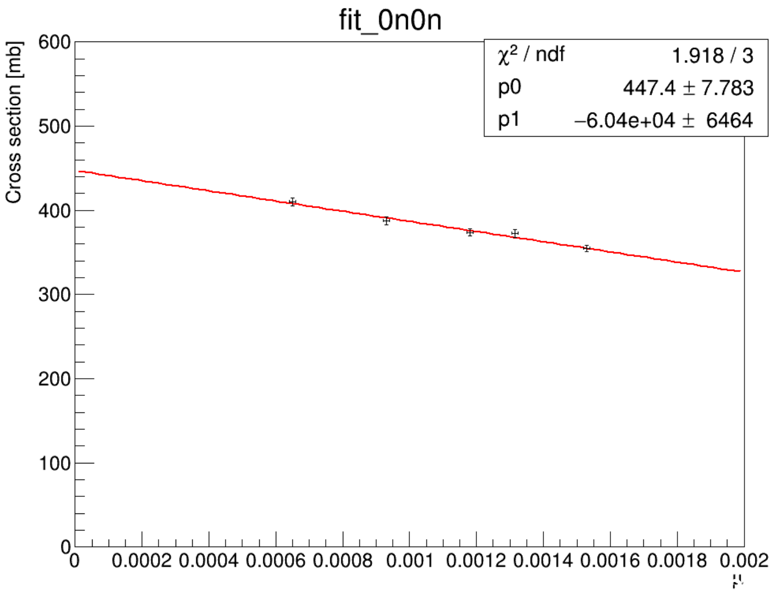
- Using variation we estimated propagation to cross section

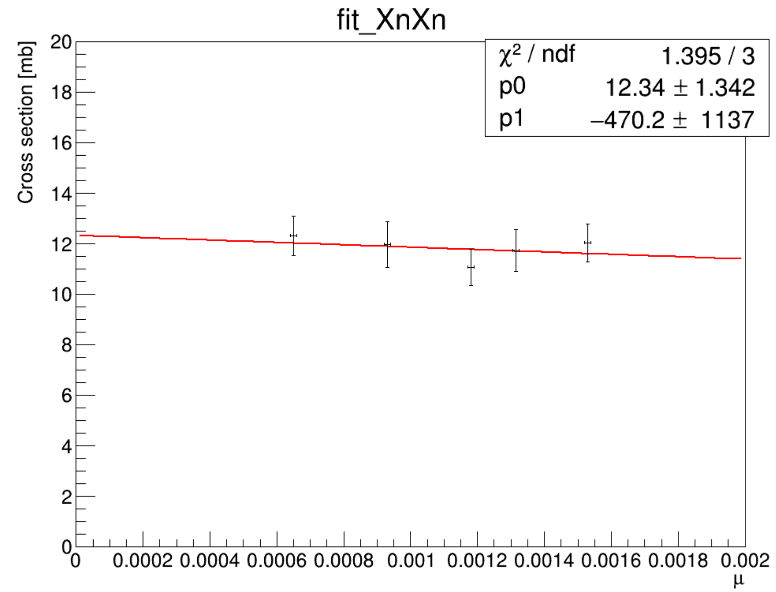
Pileup dependence of the cross section

- Cross section estimated in five mu-bins
- Expected cross section is p0









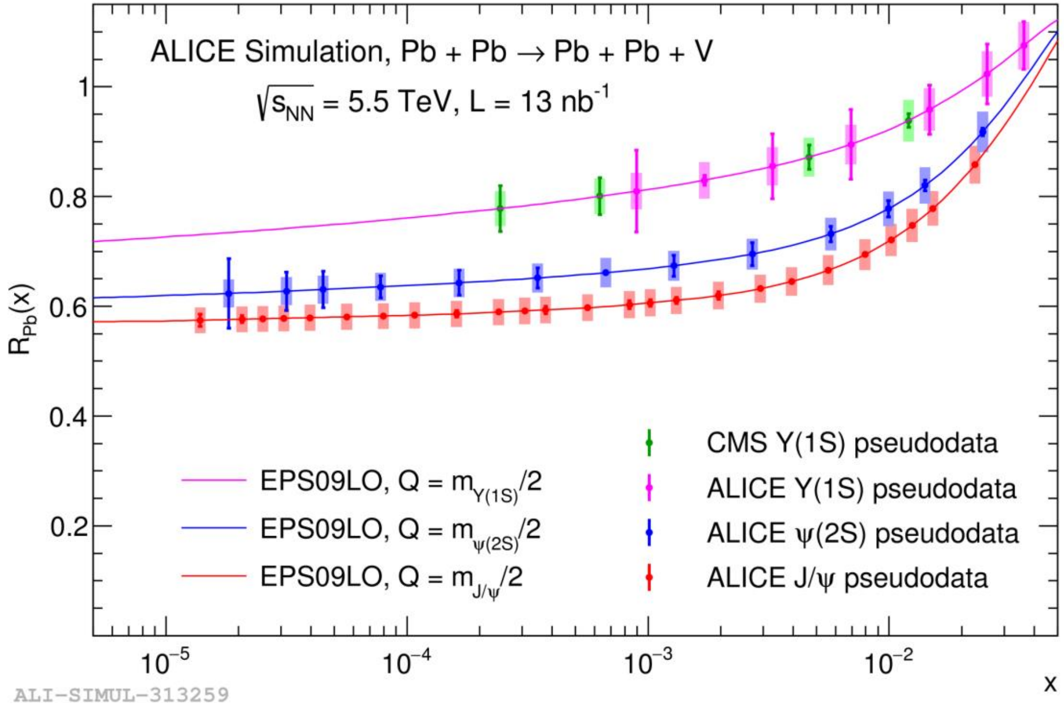
- Expected cross section is compatible with values obtained by computing ZDC migration

Future Run 3 + 4 expectations

arXiv:1812.06772v2 [hep-ph]

Expected 13/nb of PbPb collisions

PbPb, 13 nb^{-1}				
Meson	σ	Total	$\lvert\eta\rvert < 0.9$	$-4 < \eta < -2.5$
$\rho \to \pi^+\pi^-$	5.2b	68 B	5.5 B	4.9 B
$\rho' \to \pi^+\pi^-\pi^+\pi^-$	730 mb	9.5 B	210 M	190 M
$\phi \to K^+K^-$	0.22b	2.9 B	82 M	15 M
$J/\psi \to \mu^+\mu^-$	1.0 mb	14 M	1.1 M	600 K
$\psi(2S) \to \mu^+\mu^-$	30 μb	400 K	35 K	19 K
$\Upsilon(1S) \to \mu^+\mu^-$	2.0 μb	26 K	2.8 K	880



Gluon shadowing down to 10^{-5}

A high mass state

- Seen by the STAR and H1 collaborations
- Same selection as main analysis
- Like-sign events subtracted bin by bin
- Fit formula:
  - $A \cdot e^{-B\cdot(x-1.2)} + C + D \cdot e^{\left(-(x-M_x)^2/{\Gamma_x}^2\right)}$
- Significance estimation
  - $\text{Significance} = \frac{signal}{\sqrt{2*background}}$