Measurement of the electromagnetic dissociation cross section of Pb nuclei at $\sqrt{s}$ = 2.76 A TeV with the ALICE ZDC

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for the ALICE Collaboration

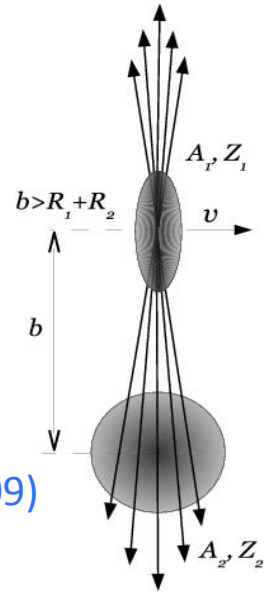
Talk contents:

- EM dissociation: model and data
- Measured cross-sections:
  - Single EM dissociation + hadronic
  - Single - mutual EM dissociation
  - Mutual EM dissociation and hadronic
  - Single EM dissociation

EM DISSOCIATION

EM DISSOCIATION (EMD) ➡ in ultra-peripheral ($b \geq 2R_{Pb}$) heavy-ion interactions the nuclei interacts via long-range EM forces

Weizsäcker-Williams framework ➧ interaction with equivalent photons (flux αZ^2)



Cross sections for EM processes at LHC energies exceeds hadronic cross section value by order of magnitude ➧ for Pb-Pb @ 5.54 A TeV:

σ^{had}~8 b, σ^{e+e-}~281b, σ^{EMD}~226 b

R. Bruce *et al.*, Phys.Rev. 12 071002 (2009)

➧ limit to heavy ion beam lifetime

EM interaction can lead to:

- nucleus excitation followed by break-up
- GDR excitation followed by neutron emission ➧ dominant channel for heavy nuclei

Definitions:

SINGLE EMD ➡ AT LEAST 1 neutron emitted by one of the 2 Pb nuclei

MUTUAL EMD ➡ AT LEAST 1 neutron emitted by BOTH nuclei

Neutrons emitted in EMD processes have a rapidity close to the beam one

➧ detected by the Zero Degree Calorimeters (ZDCs)

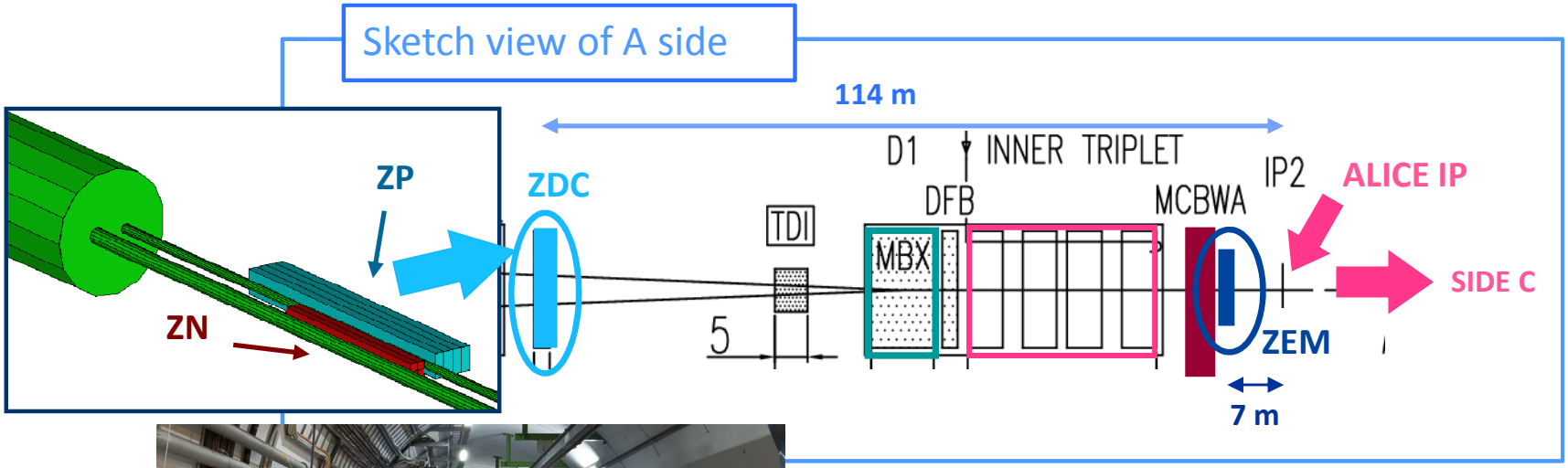
ALICE ZDCs

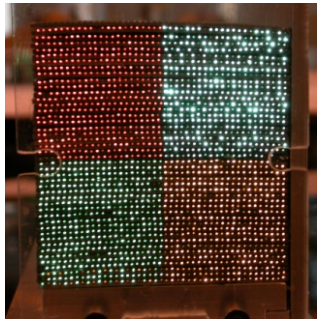
ALICE neutron ZDCs (ZNs) ➡ placed at 0° w.r.t LHC axis, ~114 m far from IP on both sides (ZNC on C side, ZNA on A side), ''spaghetti'' calorimeters, dimensions (7x7x100) cm^3

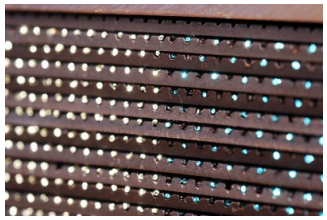
The ZDC system is completed by:

- 2 proton calorimeters placed at ~114 m from the IP external to the beam pipe
- 2 small (7x7x21) cm^3 EM calorimeters (ZEM1, ZEM2) placed at ~7.5 m from the IP, at ±8 cm from LHC axis, only on A side covering the range $4.8<\eta<5.7$

ZN acceptance for neutrons emitted in EMD of Pb nuclei at $\sqrt{s}$ = 2.76 A TeV ➧ 99 %







RELDIS MODEL

Relativistic ELectromagnetic DISsociation

I.A. Pshenichnov *et al.* Phys.Rev. C **60** 044901(1999)
I.A. Pshenichnov, Phys. Part. Nuclei **42** 215 (2011)

RELDIS describes EMD of ultra-relativistic nuclei including:

- single and double virtual photon absorption by nuclei
- intranuclear cascades of produced hadrons
- statistical decay of excited residual nuclei (evaporation, fission and multifragmentation)

➧ good description of data at SPS energies M.B. Golubeva *et al.*, Phys.Rev. C **71**, 024905 (2005)

RELDIS x-section predictions for Pb-Pb @ $\sqrt{s}$ = 2.76 A TeV

Process	σ (b)
Single EMD (at least 1n emitted)	185.2 ± 9.2
Mutual EMD (at least 1n on both sides)	5.5 ± 0.6
Hadronic	7.7 ± 0.4

Baltz *et al.* calculation (STARLIGHT generator) A.J. Baltz et al. Phys. Rev. E **54** (1996) 4233

➧ difference on single EMD cross-section w.r.t. RELDIS prediction (~5%) is included as a systematic error on RELDIS single EMD cross section A.J. Baltz et al., Physics Reports 458 (2008) 1

Van der Meer SCAN

During 2010 Pb RUN a Van der Meer scan has been performed

➡ Preliminary results from the Van der Meer scan:

PROCESS	ZDC TRIGGER	VdM σ (b)	RELDIS σ (b)
2*single EMD – mutualEMD + hadronic	ZNC || ZNA	362.61 ± 0.02 stat.	372.6 ± 13.0
hadronic	(ZNC && ZNA) && (ZEM1 || ZEM2)	7.08 ± 0.15 stat.	7.7 ± 0.4
mutual EMD	(ZNC && ZNA) && !(ZEM1 || ZEM2)	5.91 ± 0.18 stat.	5.5 ± 0.6

➡ Very preliminary systematic errors on Van der Meer results (68% CL):

- ±4% from VdM data analysis (ALICE)
- ±3% from beam current measurement (LHC)
- -0%/+ 11% from ghost charge fraction measurement (asymmetric) (LHC)

➡ From LHC: beam current + ghost charge fraction ➧ -3% / +11%

➡ ±4% (ALICE), -3% +11% (LHC)

DATA

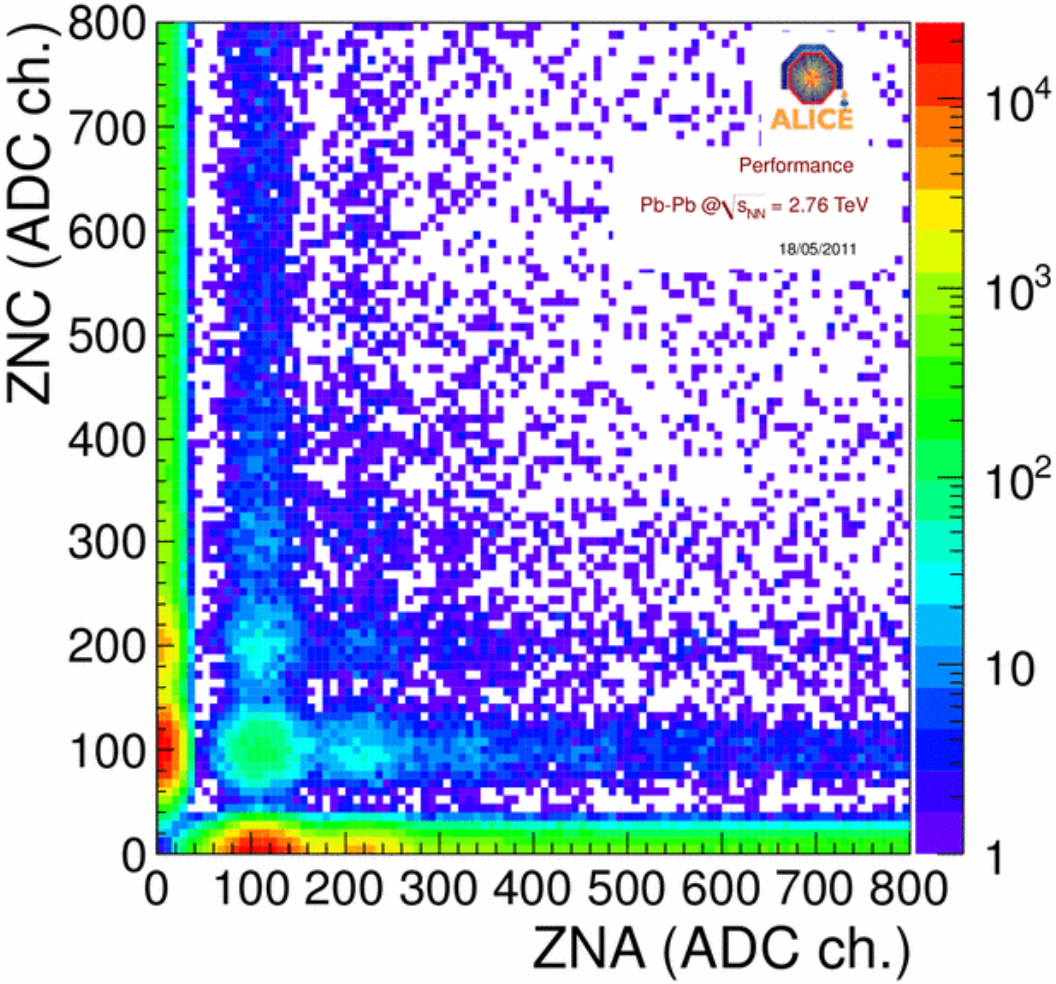
Sample ➧ dedicated RUN, $2.8 \cdot 10^6$ events collected

Trigger ➧ OR of the ZNs ➧ same input sent to Van der Meer scan scalers

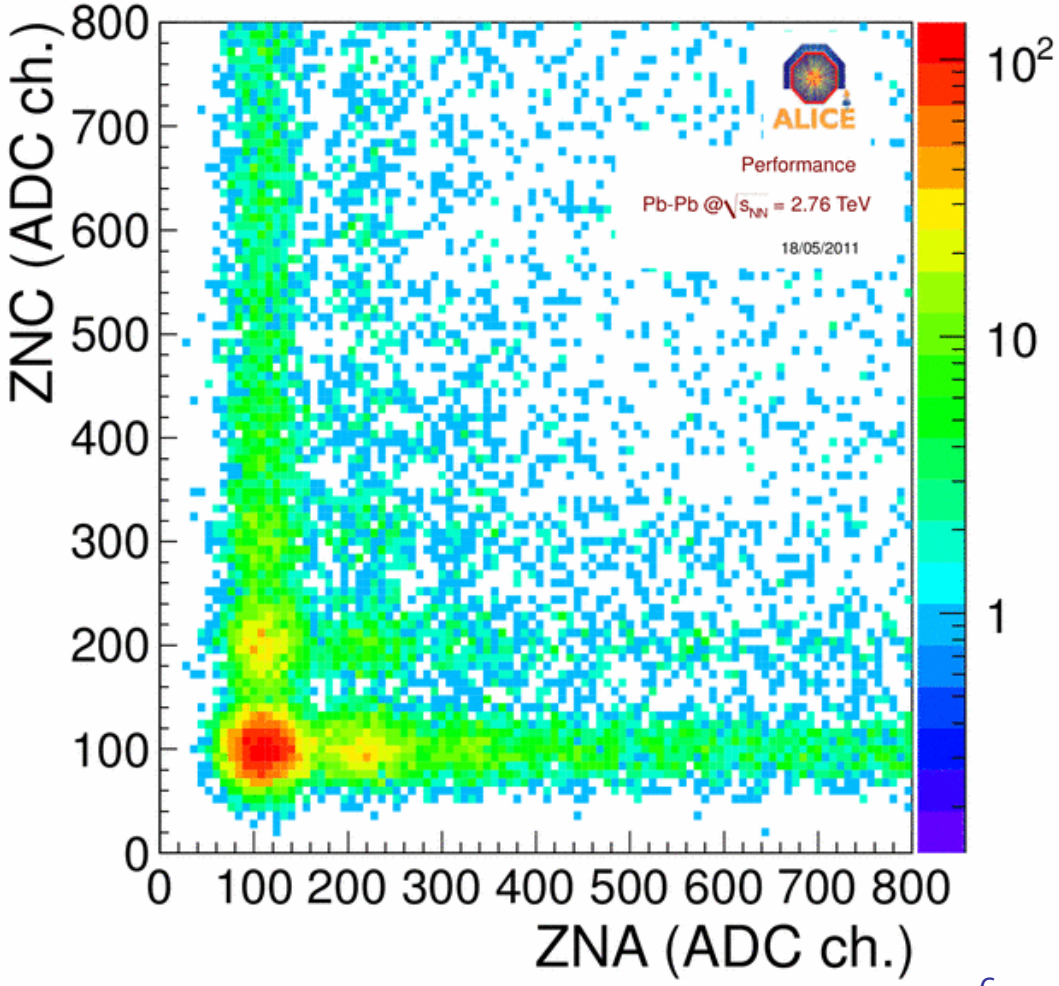
Energy thresholds ➧ ZNC~500 GeV, ZNA~450 GeV (3σ below 1n mean value)

➡ZNC vs. ZNA signal

➧ single EMD processes



➧ mutual EMD processes

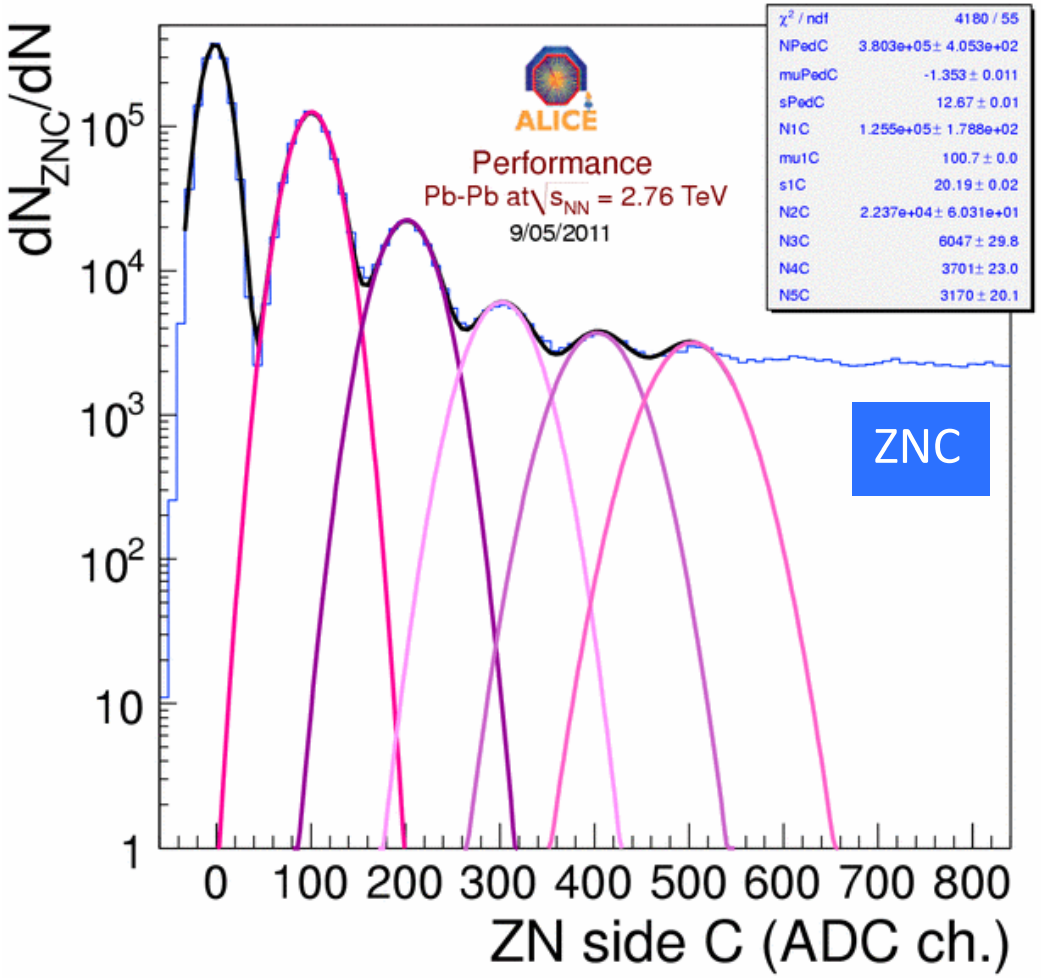


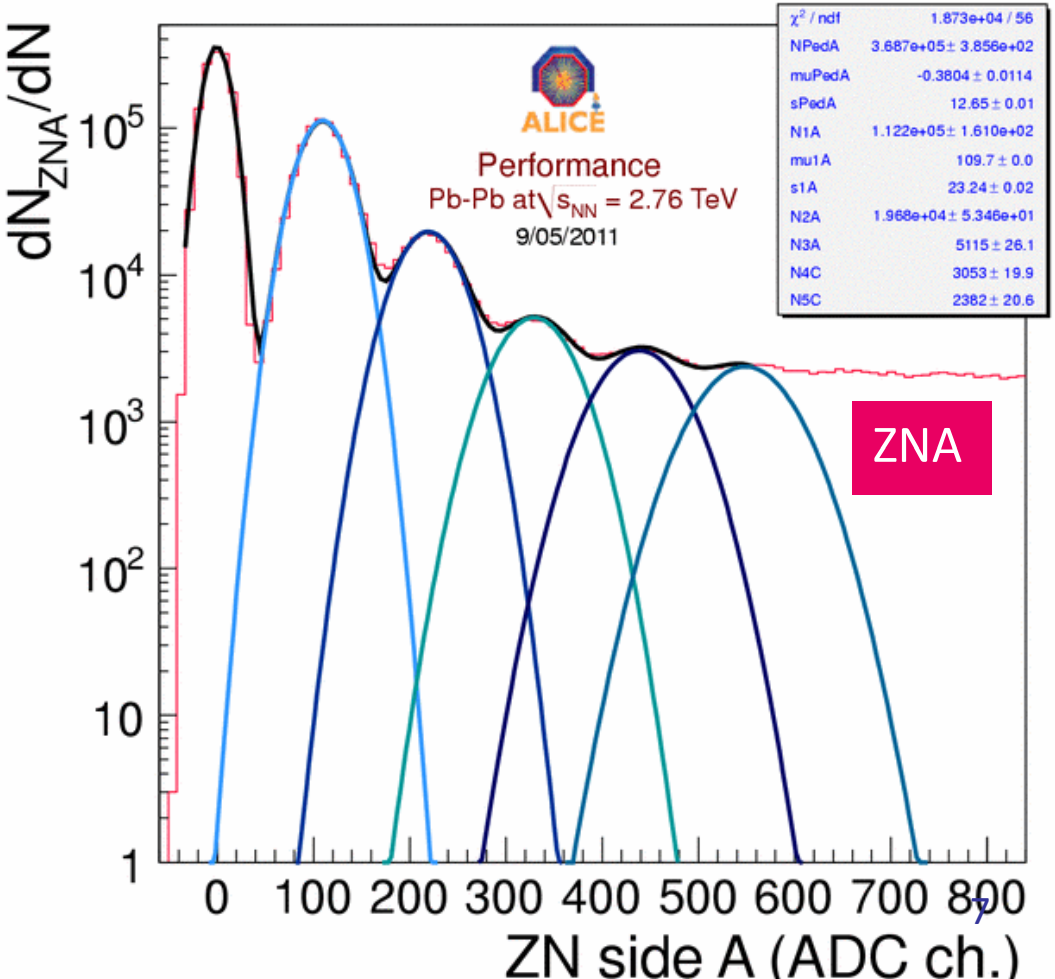
SINGLE EMD + HADRONIC

Trigger: signal in ZNC OR ZNA ➧ single EMD (including 0 neutron emission from 1 nucleus)
➧ single EMD AND hadronic interactions selected

Spectra fitted with the sum of 6 gaussians ➧ pedestal (3 free parameters) + 1n peak (3 free parameters) + 4 gaussians (free normalization, $\mu_n = n*\mu_{1n}$, $\sigma_n = \sqrt{n(\sigma_{1n}^2 - \sigma_{ped}^2) + (n-1)\sigma_{ped}^2}$ to take into account pedestal width affecting 1n peak width)

Resolution on 1n peak ➧ 20.0% ZNC, 21.2% ZNA





SINGLE EMD + HADRONIC

The x-section for the considered process can be calculated using the VdM cross section:

$$\sigma^{sEMD+had} = \sigma^{(OR)}_{VdM} \cdot (N_{ev}^{sEMD+had} - N_{ev}^{PEDESTAL})/N_{ev}^{TOT(OR)}$$

where $\sigma^{(OR)}_{VdM}$ and $N_{ev}^{TOT(OR)}$ refer to the same trigger (OR)

ZNC	ZNA
(190.43 ± 0.18) b	(195.84 ± 0.18) b

Systematic error sources:

- different fit of ZN spectra: ~ 0.2%
- side A vs. side C difference: ~ 2.9%
- difference in background in VdM fill w.r.t. background in analysed RUN: ~ 0.8%
- systematic error on VdM x-section: ±4% (ALICE), -3% +11% (LHC)

$$\sigma^{sEMD+had} = (193.1 \pm 0.1 \text{ stat.} \; ^{+23.9}_{-11.6} \text{ syst.}) \text{ b}$$

➧ To compare σ values with RELDIS model predictions, experimental values must be corrected for the detection probability obtained from MC:

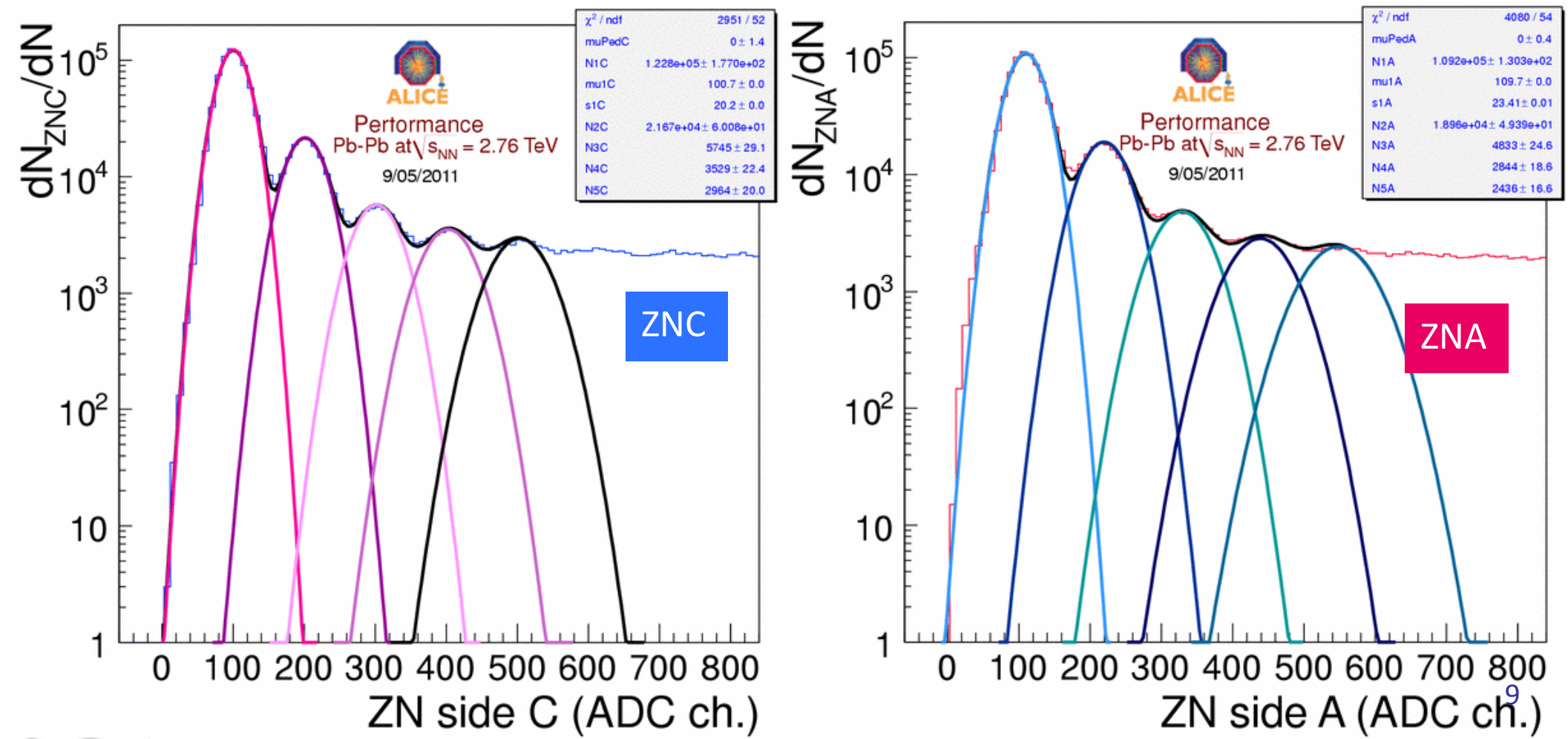
$$F = \frac{\text{prob. to emit at least 1n from RELDIS}}{\text{prob. to emit and detect at least 1n in ZN}} = \frac{0.969}{0.957} = 1.012$$

	DATA	RELDIS MODEL
$\sigma^{sEMD} + \sigma^{had}$	$(195.6 \pm 0.1 \text{ stat.} \; ^{+24.2}_{-11.7} \text{ syst.})$ b	$(192.9 \pm 9.2 \text{ syst.})$ b

SINGLE EMD – MUTUAL EMD

Event selection: signal in one ZN BUT NOT on the other ➧ single EMD with emission only from 1 Pb nucleus ➧ single EMD but NOT mutual EMD nor hadronic interactions

Spectra fitted with the sum of 5 gaussians ➧ 1n peak (3 free parameters) + 4 gaussians (free normalization, $\mu_n = n*\mu_{1n}$, $\sigma_n = \sqrt{n(\sigma_{1n}^2 - \sigma_{ped}^2) + (n-1)\sigma_{ped}^2}$ with σ_{ped} fixed from previous fits)



SINGLE EMD – MUTUAL EMD

Using the VdM cross section and the number of events collected with the same trigger:

$$\sigma^{sEMD\text{-}mEMD} = \sigma^{(OR)}_{VdM} * N_{ev}^{sEMD\text{-}mEMD} / N_{ev}^{TOT(OR)}$$

ZNC	ZNA
(173.26 ± 0.18) b	(176.17 ± 0.18) b

Systematic error sources:

- different fits of ZN spectra ~0.8%
- side A vs. side C difference ~1.7%
- difference in background in VdM fill w.r.t. background in analysed RUN ~ 0.8%
- systematic error on VdM x-section: ±4% (ALICE), -3% +11% (LHC)

➧ $\sigma^{sEMD\text{-}mEMD} = (174.7 \pm 0.1\ \text{stat.}\ ^{+21.3}_{-10.5}\ \text{syst.})\ \text{b}$

➧ Detection probability correction (from MC):

$$F = \frac{\text{prob. to emit at least 1n from RELDIS}}{\text{prob. to emit and detect at least 1n in ZN}} = \frac{0.969}{0.957} = 1.012$$

	DATA	RELDIS MODEL
$\sigma^{sEMD} - \sigma^{mEMD}$	$(176.9 \pm 0.1\ \text{stat.}\ ^{+21.6}_{-10.6}\ \text{syst.})$ b	(179.7± 9.2 syst.) b

SINGLE EMD – MUTUAL EMD

- with the chosen event selection no hadronic contribution in the sample (neutrons emitted only from one nucleus)

- neutron multiplicities can be compared with the predictions from the RELDIS model

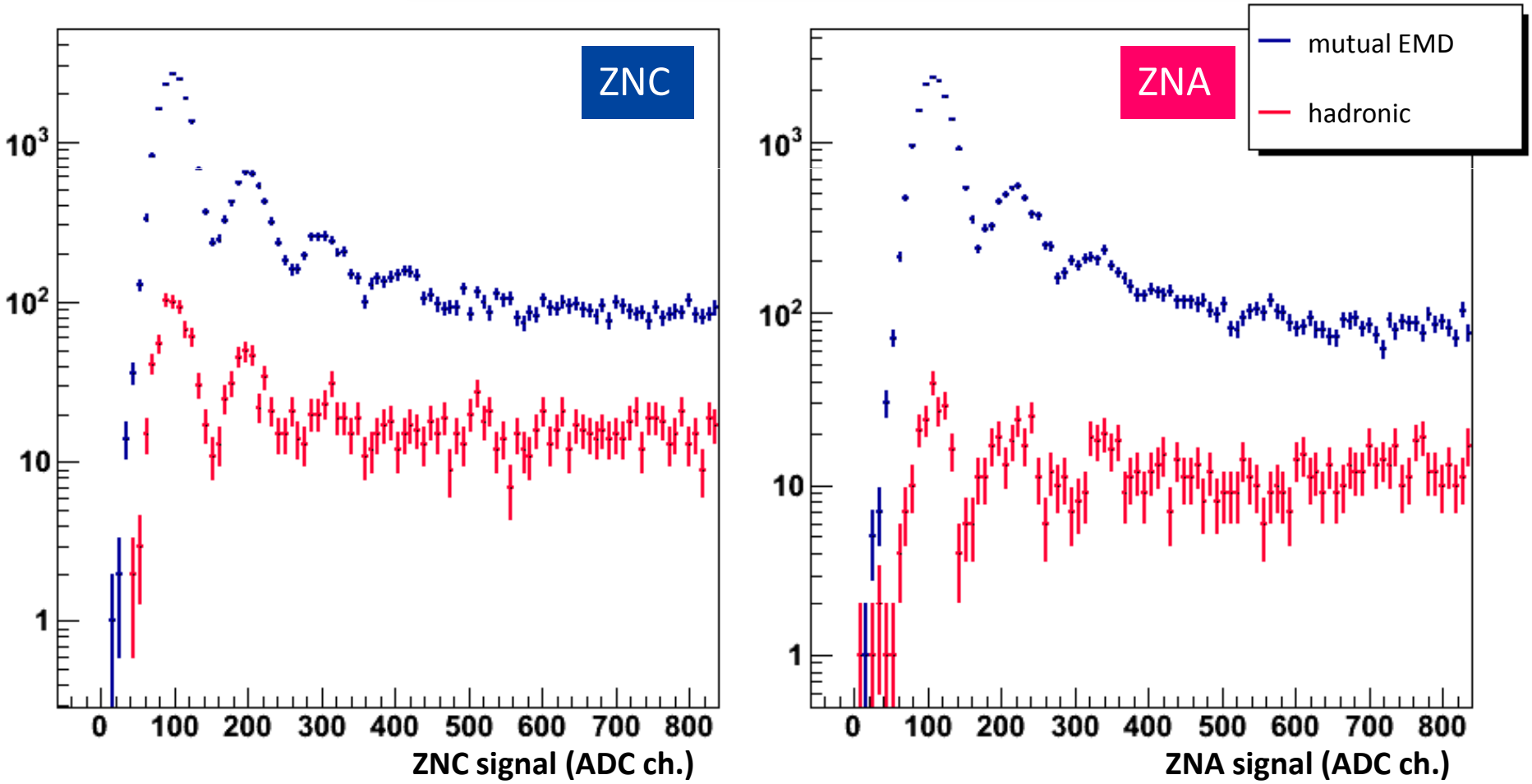
	DATA	RELDIS MODEL
$1n/N_{TOT}$	$(51.5 \pm 0.1$ stat. ± 0.4 syst.$)\%$	$(53.9 \pm 0.3)\%$
$2n/N_{TOT}$	$(11.6 \pm 0.1$ stat. ± 0.2 syst.$)\%$	$(12.6 \pm 0.1)\%$
$3n/N_{TOT}$	$(3.6 \pm 0.1$ stat. ± 0.1 sys.$)\%$	$(5.5 \pm 0.1)\%$

- The model overpredicts the fraction of 1n, 2n and 3n events

MUTUAL EMD AND HADRONIC

Event selection ➡

mutual EMD	(ZNC AND ZNA) AND NOT (ZEM1 OR ZEM2)
nuclear	(ZNC AND ZNA) AND (ZEM1 OR ZEM2)



- The use of ZEM (placed on A side) improves mutual EMD selection capability on A side ➡ higher fraction of nuclear events vs. mutual EMD on C side
- The hadronic contribution increases with increasing neutron multiplicity

MUTUAL EMD AND HADRONIC

Mutual EMD sample ➧ residual contamination of nuclear events (nuclear events with no signal in ZEM1 || ZEM2)

Hadronic sample ➧ mutual EMD events can fulfill the nuclear trigger condition (EMD events with signal in ZEM1 || ZEM2)

$$\begin{cases} E = \varepsilon_E * e + (1-\varepsilon_N) * n \\ N = (1-\varepsilon_E) * e + \varepsilon_N * n \end{cases}$$

E ➧ measured mutual EMD x-section

N ➧ measured hadronic x-section

e ➧ "true" mutual EMD x-section

n ➧ "true" hadronic x-section

ε_E ➧ fraction of events from RELDIS with no signal (E_{ZEMi}<15 GeV) in (ZEM1 || ZEM2)

ε_N ➧ fraction of events from HIJING MB with signal (E_{ZEMi}>15 GeV) in (ZEM1 || ZEM2)

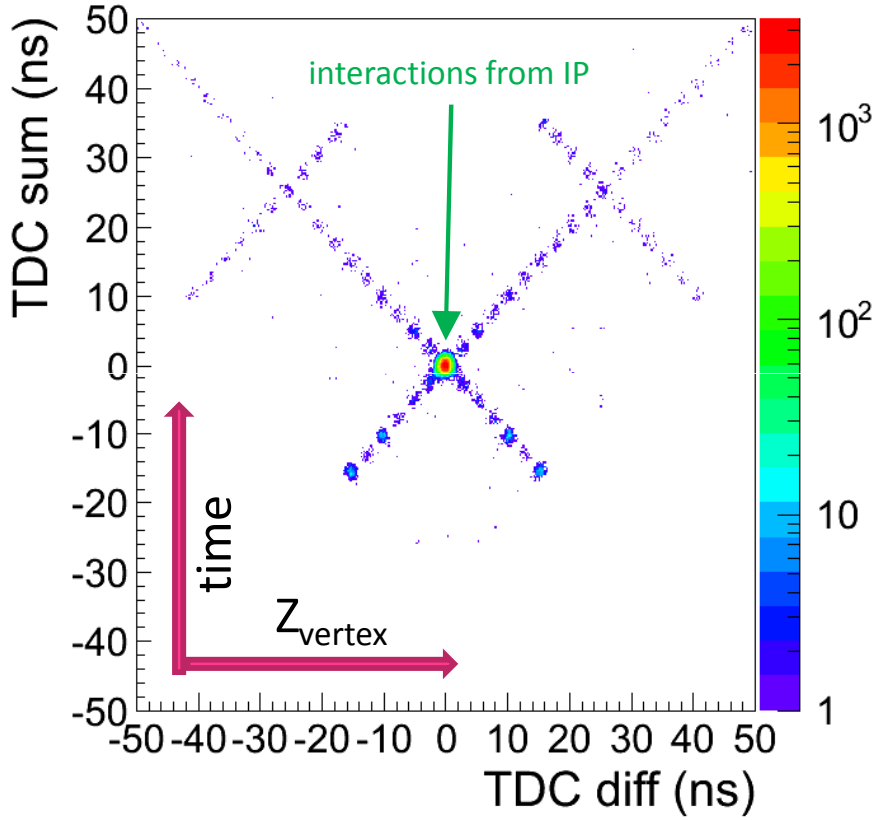
ε_E	ε_N
(97.0 ± 0.6)%	(92.2 ± 1.1)%

1st method ➧ solve the system using cross section values for mutual EMD and hadronic processes from Van Der Meer scan to evaluate "true" cross sections:

➧ $\sigma^{mEMD} = (\varepsilon_N * \sigma^{mEMD}_{VdM} - (1-\varepsilon_N) * \sigma^{had}_{VdM})/(\varepsilon_E-(1-\varepsilon_N))$

➧ $\sigma^{had} = (\varepsilon_E * \sigma^{had}_{VdM} - (1-\varepsilon_E) * \sigma^{mEMD}_{VdM})/(\varepsilon_E-(1-\varepsilon_N))$

MUTUAL EMD AND HADRONIC: EVENT SELECTION



- Events corresponding to interaction between satellite bunches can be identified using the ZN timing information
- not all satellite events are synchronized with the ADC gate ➧ ZEM signal is not correctly integrated in some cases ➧ select only events from IP
- rejecting events from satellite bunch interactions

3.8% events from mutual EMD sample and 2.6% events from the hadronic sample are removed

2nd method

- use the $\sigma^{(OR)}_{VdM}$ cross section to evaluate the measured σ:

Mutual EMD ➡ $\sigma^{mEMD}_{MEAS} = \sigma^{(OR)}_{VdM} * N_{ev}^{mEMD\ w.cut} / N_{ev}^{TOT(OR)\ w.cut}$

Hadronic ➡ $\sigma^{had}_{MEAS} = \sigma^{(OR)}_{VdM} * N_{ev}^{had\ w.cut} / N_{ev}^{TOT(OR)\ w.\ cut}$

- correct for the contaminations to extract ''true'' cross sections:

➡ $\sigma^{mEMD} = (\varepsilon_N * \sigma^{mEMD}_{MEAS} - (1-\varepsilon_N) * \sigma^{had}_{MEAS})/(\varepsilon_E-(1-\varepsilon_N))$

➡ $\sigma^{had} = (\varepsilon_E * \sigma^{had}_{MEAS} - (1-\varepsilon_E) * \sigma^{mEMD}_{MEAS})/(\varepsilon_E-(1-\varepsilon_N))$

MUTUAL, HADRONIC & SINGLE EMD x-SECTIONS

1st method	DATA	RELDIS MODEL
σ^{mEMD}	$(5.5 \pm 0.2\ \text{stat.}\ ^{+0.7}_{-0.3}\ \text{syst.})$ b	(5.5 ± 0.6) b
σ^{had}	$(7.5 \pm 0.2\ \text{stat.}\ ^{+0.9}_{-0.4}\ \text{syst.})$ b	(7.7 ± 0.4) b

2nd method	DATA	RELDIS MODEL
σ^{mEMD}	$(5.7 \pm 0.2\ \text{stat.}\ ^{+0.7}_{-0.3}\ \text{syst.})$ b	(5.5 ± 0.6) b
σ^{had}	$(7.2 \pm 0.2\ \text{stat.}\ ^{+0.9}_{-0.4}\ \text{syst.})$ b	(7.7 ± 0.4) b

- from all the calculated cross section values σ^{sEMD} can be estimated

$\sigma^{sEMD} + \sigma^{had}$ $\quad$ σ^{mEMD}

$\sigma^{sEMD} - \sigma^{mEMD}$ $\quad$ σ^{had}

$\Rightarrow$ σ^{sEMD}

	DATA	RELDIS MODEL
σ^{sEMD}	$(185.7 \pm 0.2\ \text{stat.}\ ^{+22.6}_{-11.1}\ \text{syst.})$ b	(185.2 ± 9.2) b

SUMMARY & CONCLUSION

- Cross sections for EMD processes have been measured in Pb-Pb collisions at 2.76 A TeV detecting the emitted neutrons with the ZDCs and using the absolute cross section values measured in the Van der Meer scan

	DATA (PRELIMINARY)	RELDIS MODEL
$\sigma^{sEMD} + \sigma^{had}$	$(195.6 \pm 0.1$ stat. $^{+24.2}_{-11.7}$ syst.) b	$(192.9 \pm 9.2$ syst.) b
$\sigma^{sEMD} - \sigma^{mEMD}$	$(176.9 \pm 0.1$ stat. $^{+21.6}_{-10.6}$ syst.) b	$(179.7 \pm 9.2$ syst.) b
σ^{mEMD}	$(5.7 \pm 0.2$ stat. $^{+0.7}_{-0.3}$ syst.) b	(5.5 ± 0.6) b
σ^{sEMD}	$(185.7 \pm 0.2$ stat. $^{+22.6}_{-11.1}$ syst.) b	(185.2 ± 9.2) b

- Experimental results are in very good agreement with predictions from RELDIS
- Errors are dominated by preliminary systematic errors on VdM cross section

➡ ALICE ZDCs can provide an independent monitor of the beam luminosity measuring the rate of neutron emission by EMD processes $\mathcal{L} = R^{mEMD} / \sigma^{mEMD}$

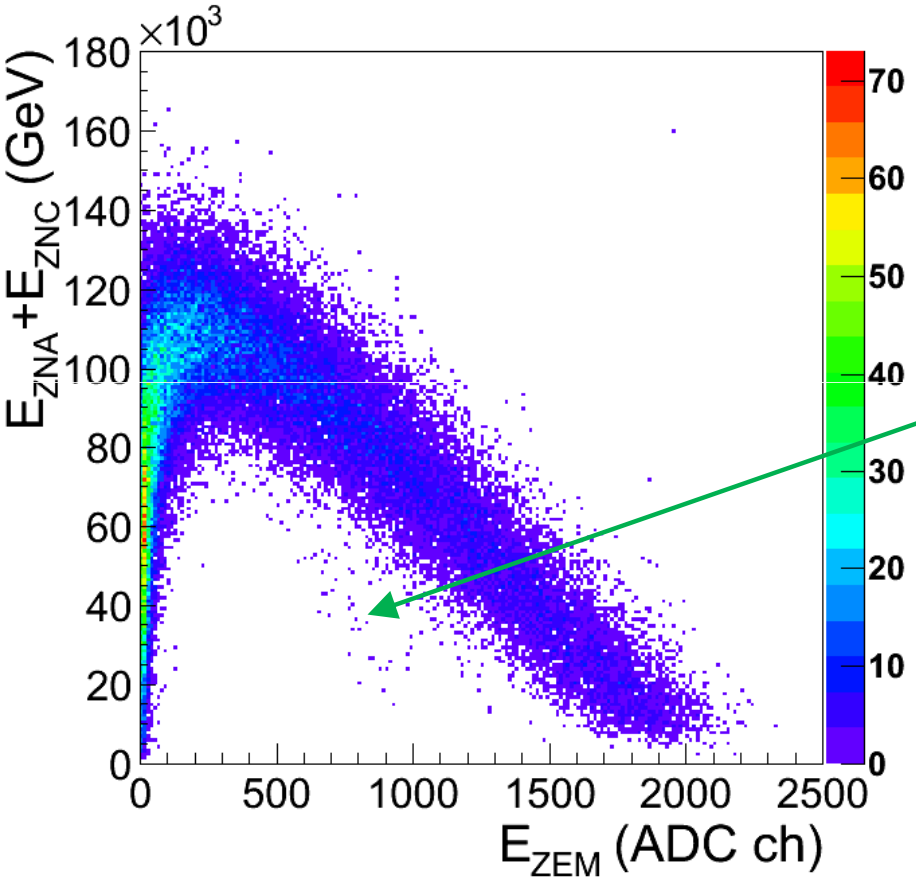
A.J. Baltz et al., Physics Reports 458 (2008) 1

➡ EM interactions between colliding ions can cause beam losses due to changes in ion magnetic rigidity ➧ nucleon emission in ultra-peripheral interactions can be studied to test theoretical predictions used in beam losses estimates

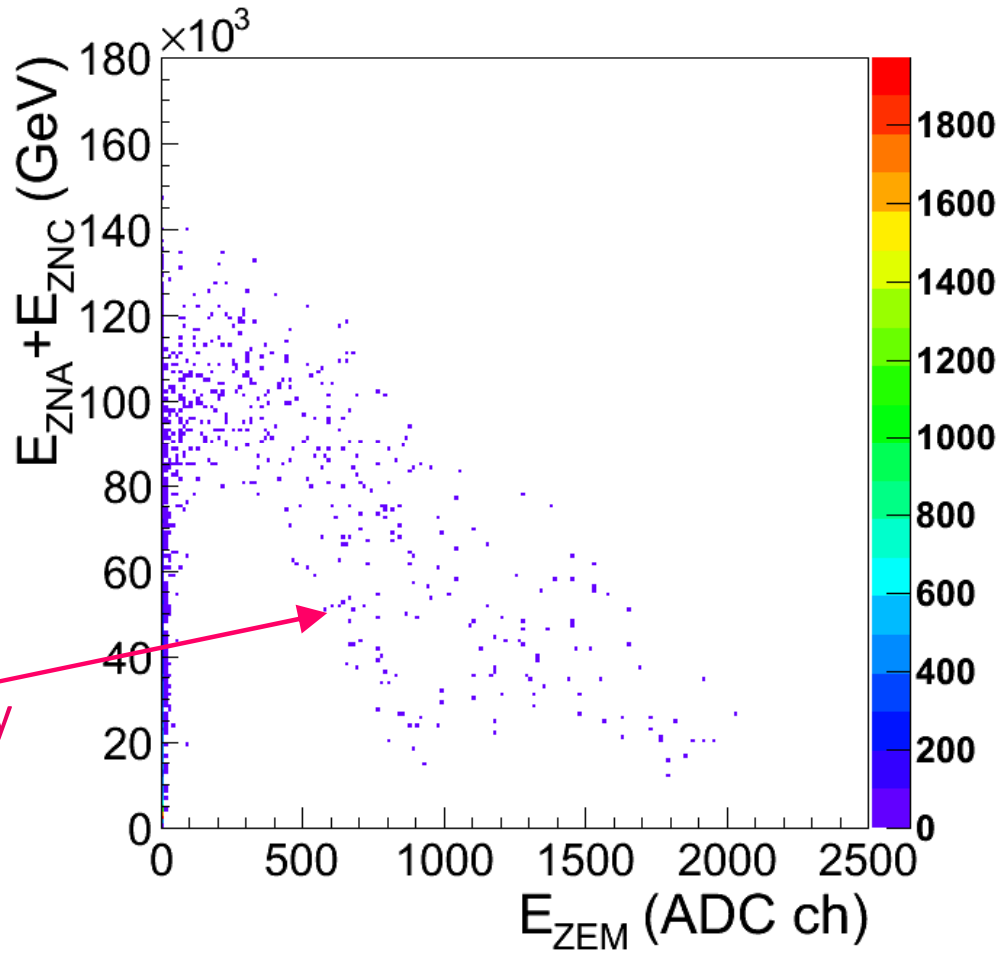
R. Bruce *et al.*, Phys.Rev. 12 071002 (2009)

BACKUP

BACKUP 1



➡ ZNA+ZNC energies vs. ZEM signal
(ZNA && ZNC) && (ZEM1 || ZEM2) selection
➧ "usual " MB hadronic correlation face + not correctly integrated ZEM signals



➡ ZNA+ZNC energies vs. ZEM signal
(ZNA && ZNC) && !(ZEM1 || ZEM2) selection
➧ events with high ZEM values ➡ signal not in time with the ADC gate opening ➡ not correctly integrated

BACKUP 2

- Events with high ZEM values are removed cutting events from satellite bunche interactions