The Norwegian ALICE Program

Joakim Nystrand
University of Bergen

Outline

- The ALICE Experiment and Norwegian contributions

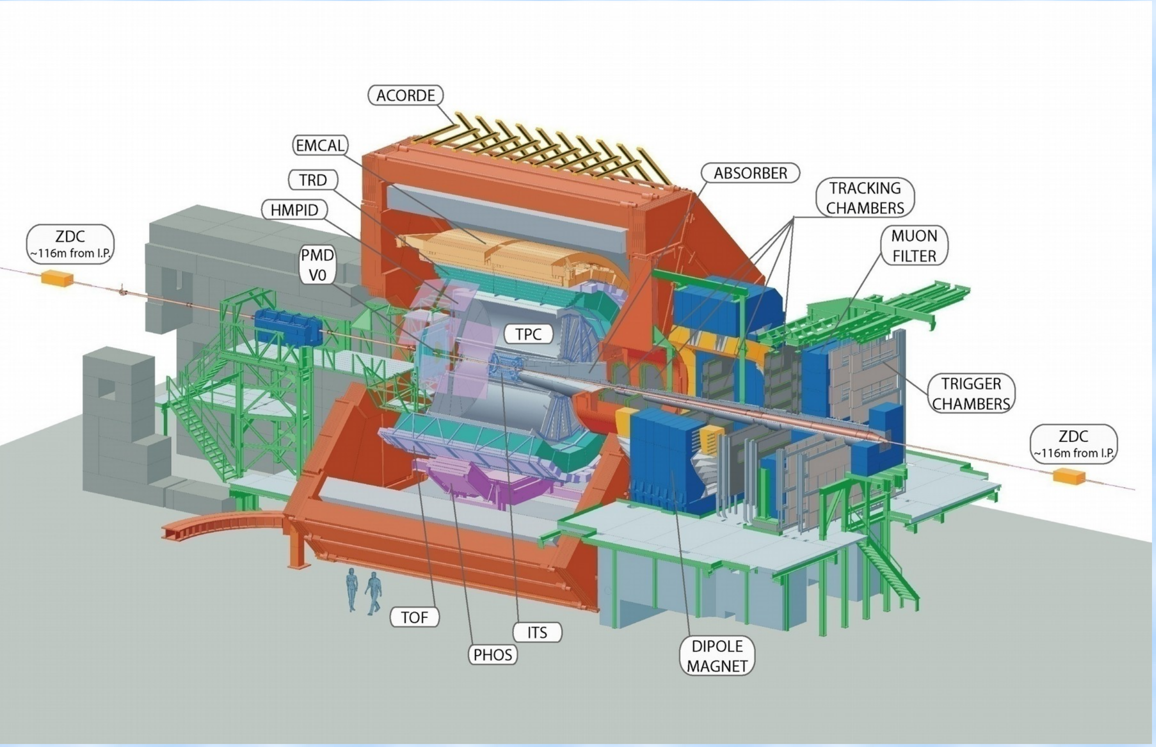
- Heavy-Ion Physics – hot and dense QCD matter

- Heavy-Ion Physics – other topics

- ALICE Upgrade plans

The ALICE Experiment

A dedicated experiment for ultra-relativistic heavy-ion physics at the LHC.
≈1000 collaborators



- A central tracking system with particle identification.
- Time Projection Chamber (TPC), Inner tracking system (ITS).
- Time-of-Flight (TOF) for particle ID, partial EMCAL coverage
- Acceptance $|\eta| \leq 0.9$, $p_T > 100$ MeV/c

- A muon arm at forward rapidities $-4.0 < \eta < -2.5$. Triggering, tracking and identification of muons.
- Zero-Degree Calorimeters (ZDC) – 114 m from interaction point.

ALICE - Norway

Norwegian participation in ALICE since the beginning (1993).

Groups at University of Oslo, University of Bergen, Bergen University College, Buskerud and Vestfold University College.

Main focus

Physics:

- Production of charm quarks in heavy-ion collisions
  (Ionut Arsene (Oslo) convenor of Working Group Dileptons and quarkonia)
- Ultra-peripheral collisions, two-photon and photonuclear interactions
  (Joakim Nystrand (Bergen) convenor of Working Group Ultra-peripheral collisions.)

Instrumentation (hardware, firmware, software):

- TPC Electronics. Improved Read-out Control Unit (RCU2); SAMPA chip for continuous read-out during Run 3.
- Earlier also PHOS (high res. EMCAL) and High-Level Trigger (HLT).

Computing:

- Operation of Tier-1 within the Nordic Datagrid Facility.

ALICE - Norway

Manpower in the groups

University of Oslo: 2 Professors (+2 emeriti), 40% of Senior Engineer, 1 postdoc, 4-6 PhD students.

University of Bergen: 3 Professors, 1 Researcher (grid computing), 50% of Senior Engineer, 2 postdocs, 4-6 PhD students.

Bergen University College: 4 professors. 1-2 PhD students.

Buskerud and Vestfold University College: 2 professors.

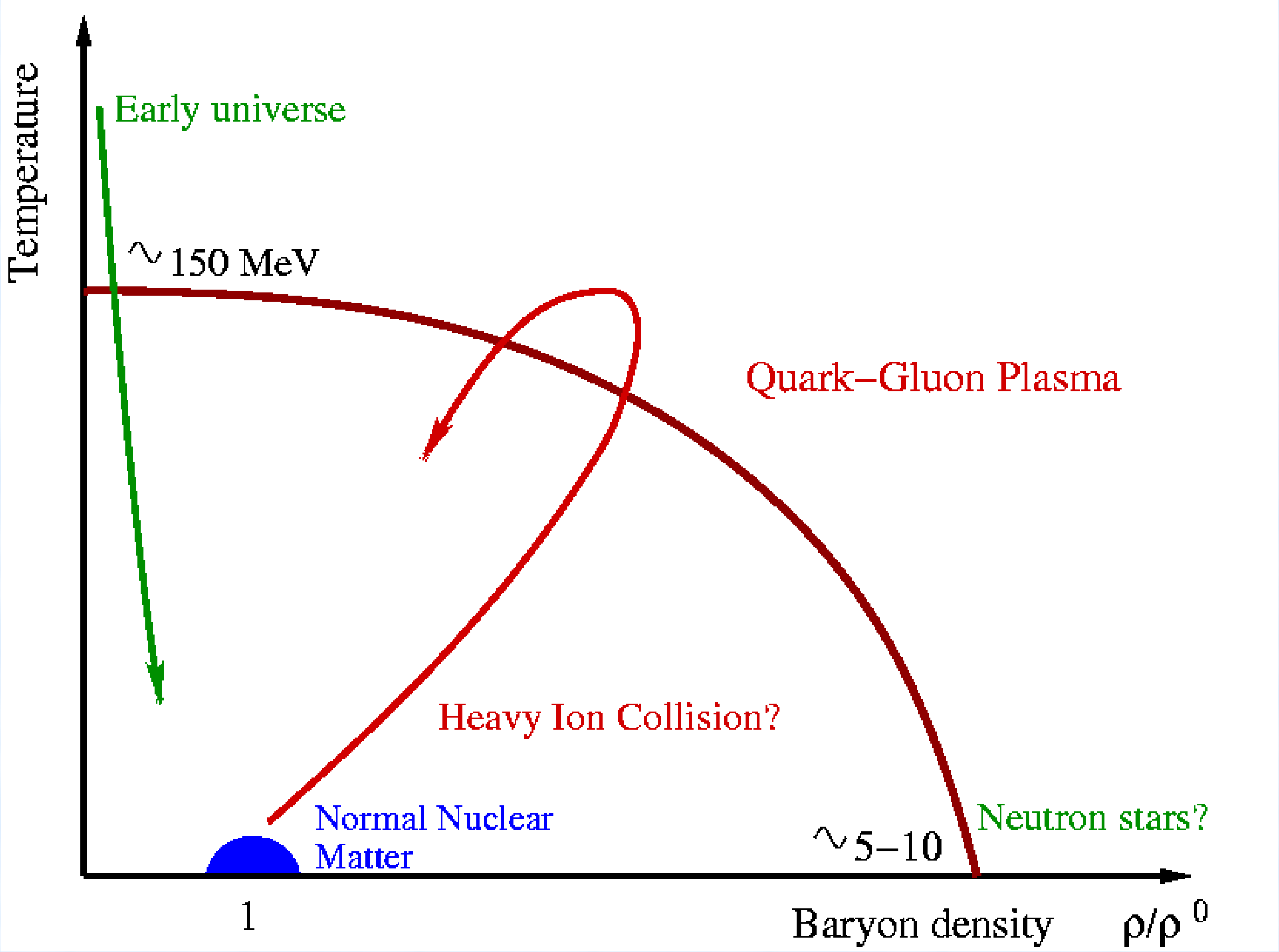
Grant from Norwegian Research Council – CERN related research

≈8 MNOK per year for 2012 – 2015
Covers ALICE M&O, Travel and subsistence, Computing grid, 2-3 postdocs.

Application for 2016 – 2019 recently submitted.

Ultra-relativistic Heavy-Ion Physics

The goal is to produce a long-lived (on a subatomic time scale), hot and dense state of matter in the laboratory and thus explore the nuclear phase diagram.



The nuclear phase diagram

Ultra-relativistic Heavy-Ion Physics

Two key observations:

- Jet-quenching

Suppression of particles with high p_T.

Most likely explanation: gluon bremsstrahlung as the partons traverse the hot and dense medium produced in the collision.

- Collective flow

Anisotropic particle production relative to the reaction plane.

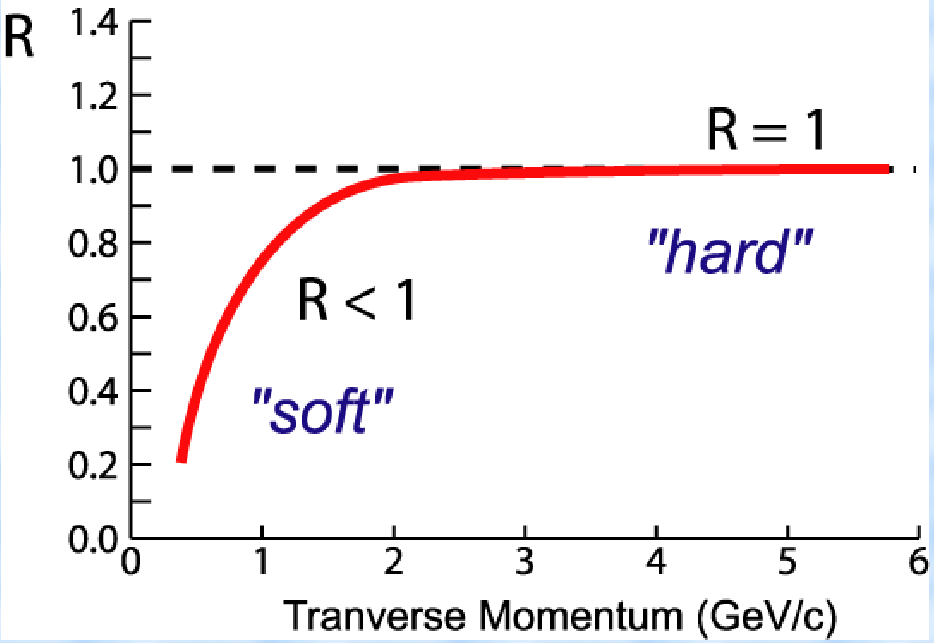
The pressure of the medium converts the initial spatial anisotropy into a an isotropy in momentum space.

Jet-quenching

Quantify the suppression by the R_{AA} measure.

Scaling pp data with the number of binary collisions expected from the nuclear geometry (Glauber model)

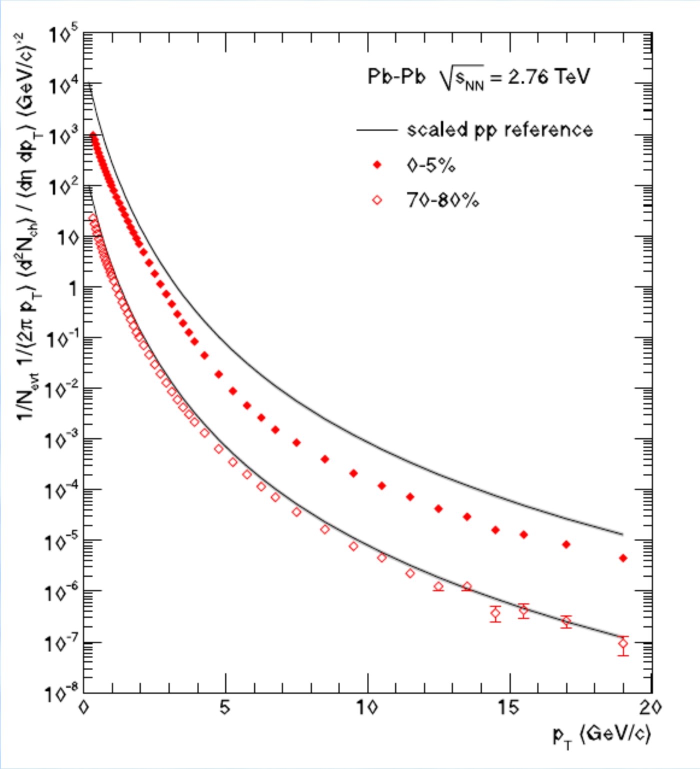
$$R_{AA}(p_T) = \frac{(1/N_{EVT})\, d^2 N_{AA}^{\pi 0} / dp_T dy}{< T_{AB}(b) > \times d^2 \sigma_{pp}^{\pi 0} / dp_T dy}$$

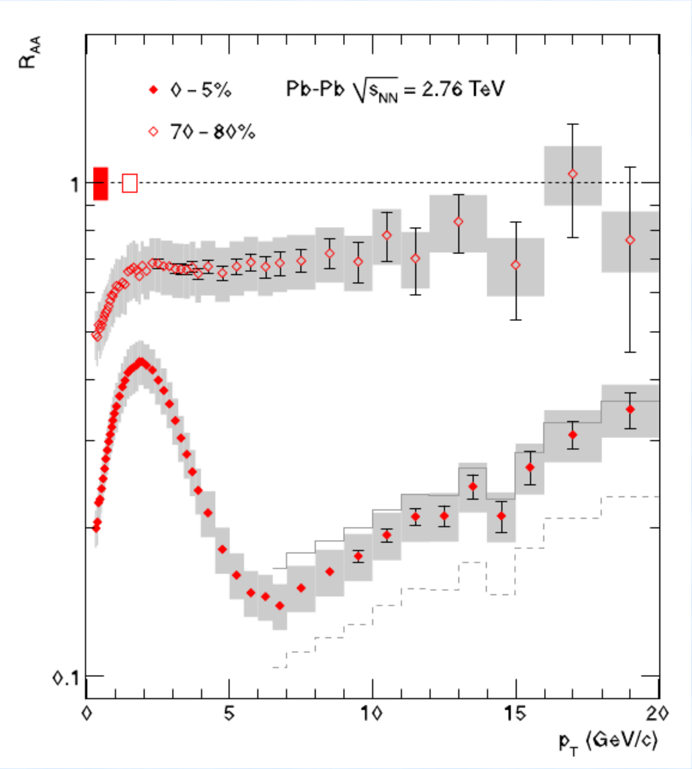


Expectation in absence of nuclear effects.

Jet-quenching

- Clear suppression at high p_T in central (head on) collisions.
- No or very small suppression in peripheral collisions.

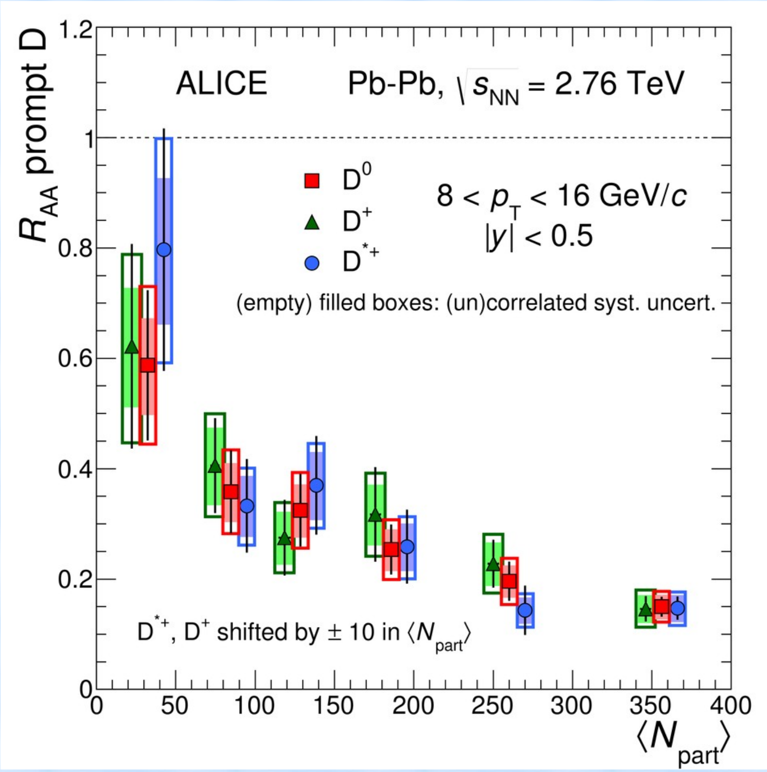




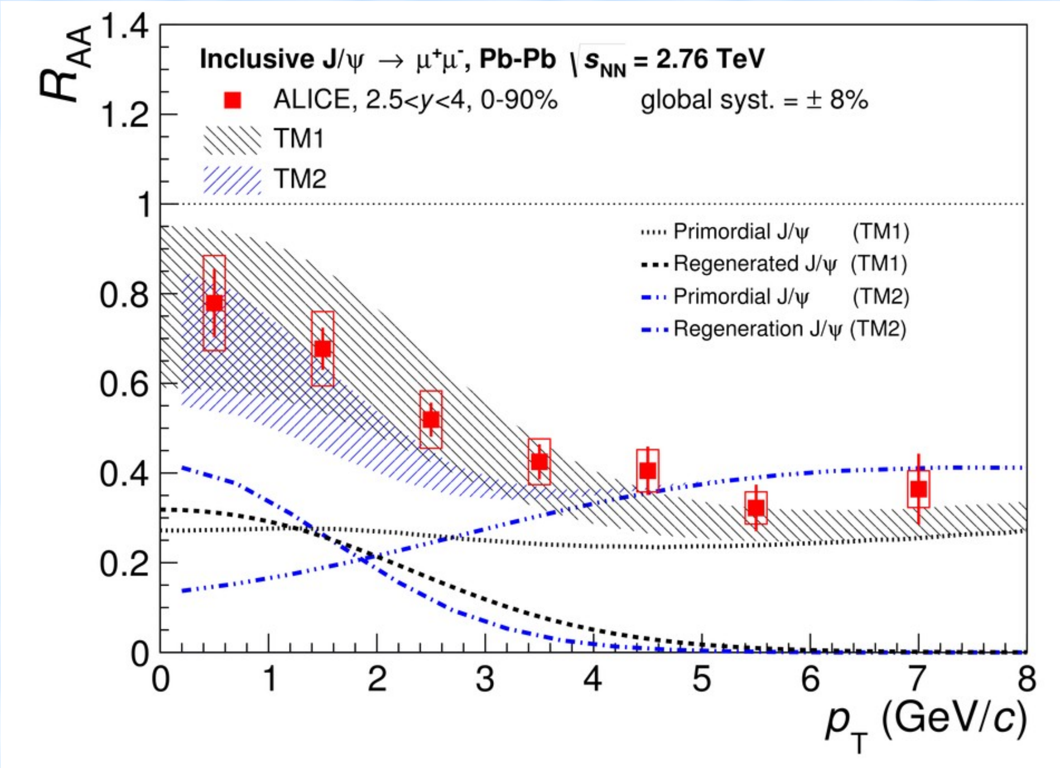
ALICE Collaboration, Phys. Lett. B 696 (2011) 30.

Jet-quenching

- Measured also for charmed particles ($m_Q \approx 1.5$ GeV/c^2)
- Reduced J/ψ suppresion at low p_T, indicating regeneration of J/ψ in the quark-gluon plasma.



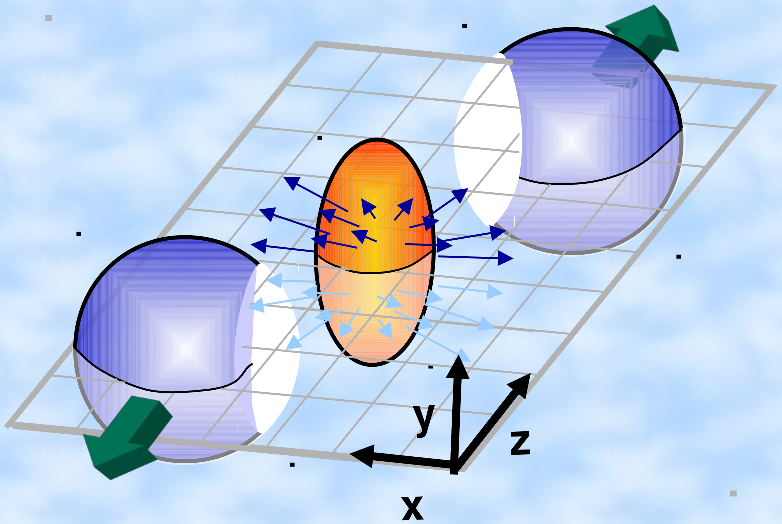
ALICE Collaboration, arxiv:1506.06604

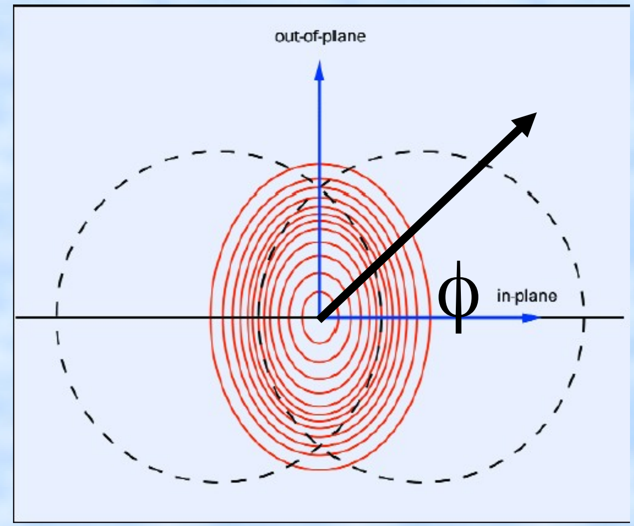


ALICE Collaboration, arxiv:1506.08804.

Collective flow

- Reaction plane defined by beam axis and impact parameter (**b**).
- Hydrodynamical pressure converts the initial spatial anisotropy to anistropic momentum distribution.

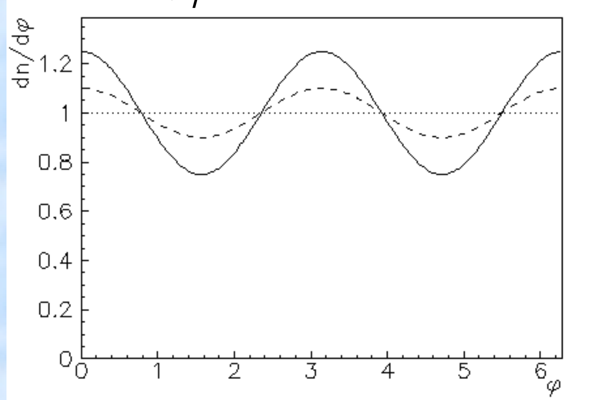




The magnitude of the flow measured by v_2.

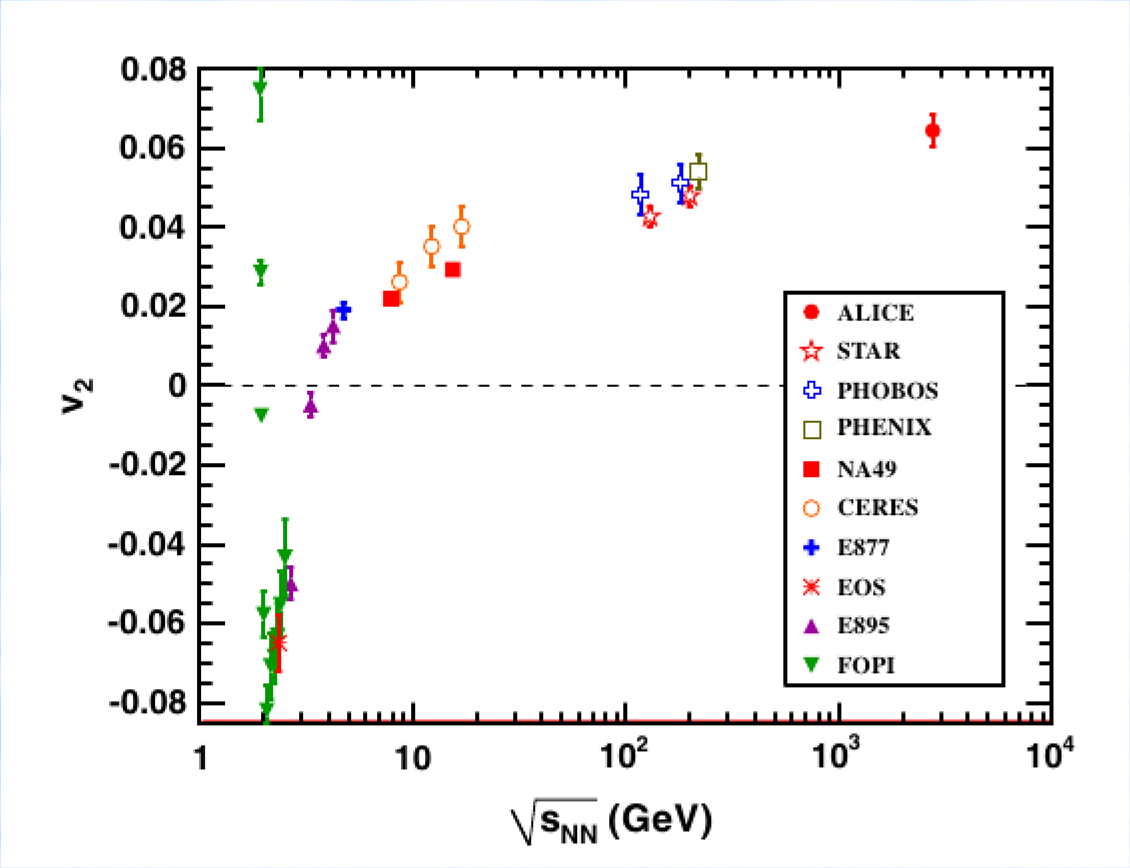
- φ azimuthal angle in transverse plane.

$$\frac{dN}{d\phi} = 1 + v_2 \cos(2\phi)$$



Collective flow

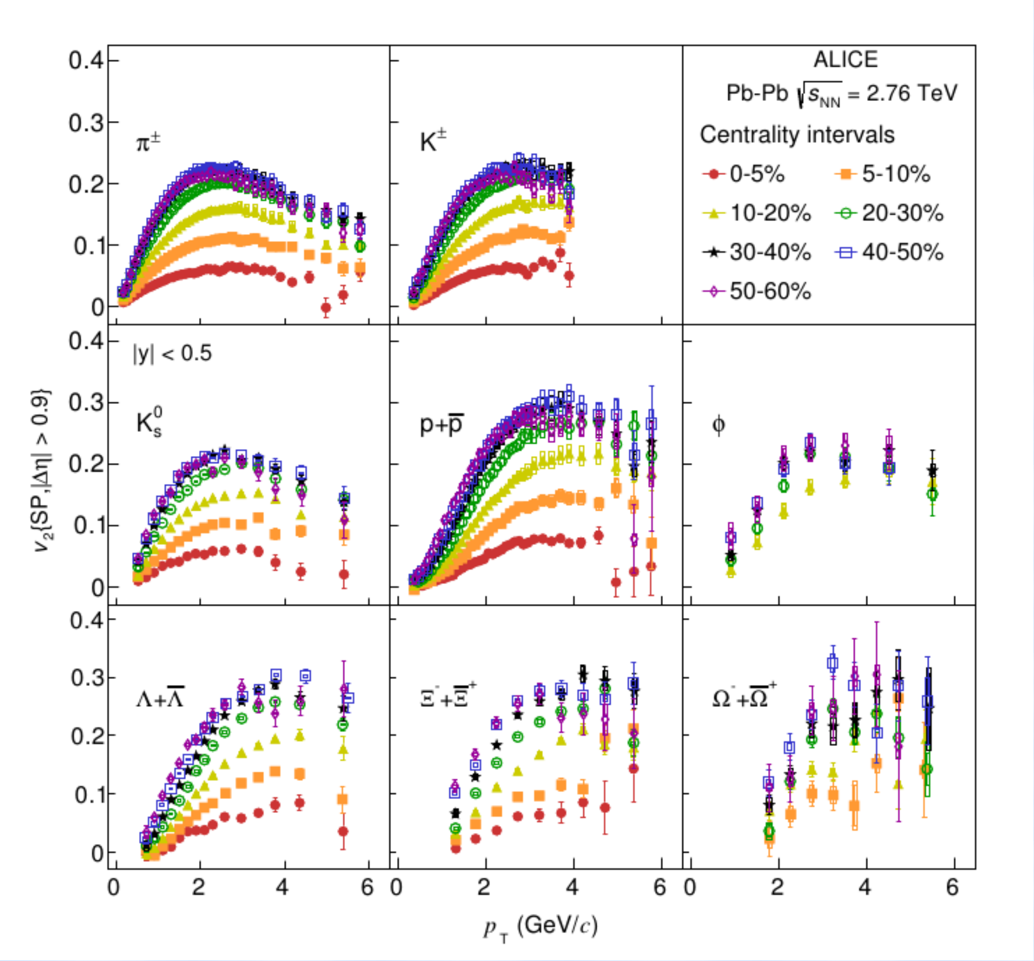
- Strength of flow increases monotonically at high energies.



ALICE Collaboration, Phys. Rev. Lett. 105 (2010) 252302.

Collective flow

- Has been measured by ALICE differentially in p_T and for several particle species.



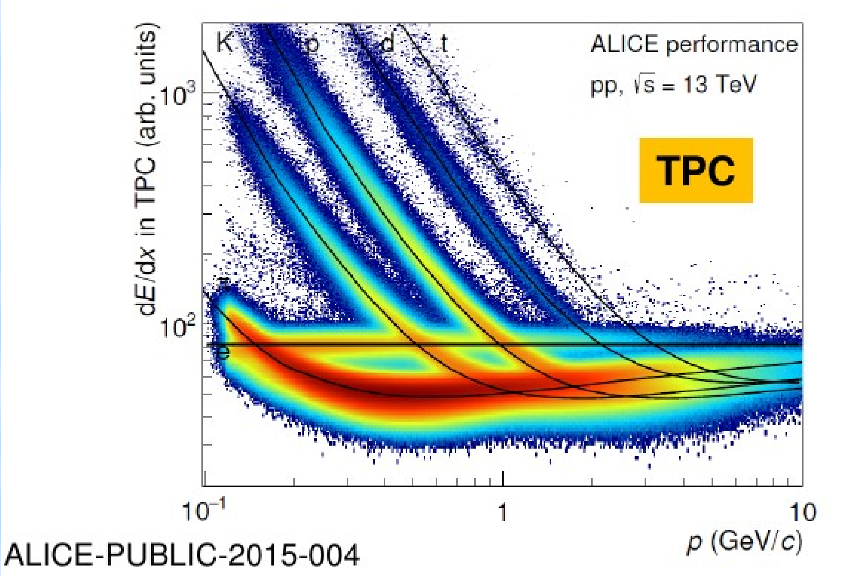
ALICE Collaboration, JHEP 06 (2015) 190.

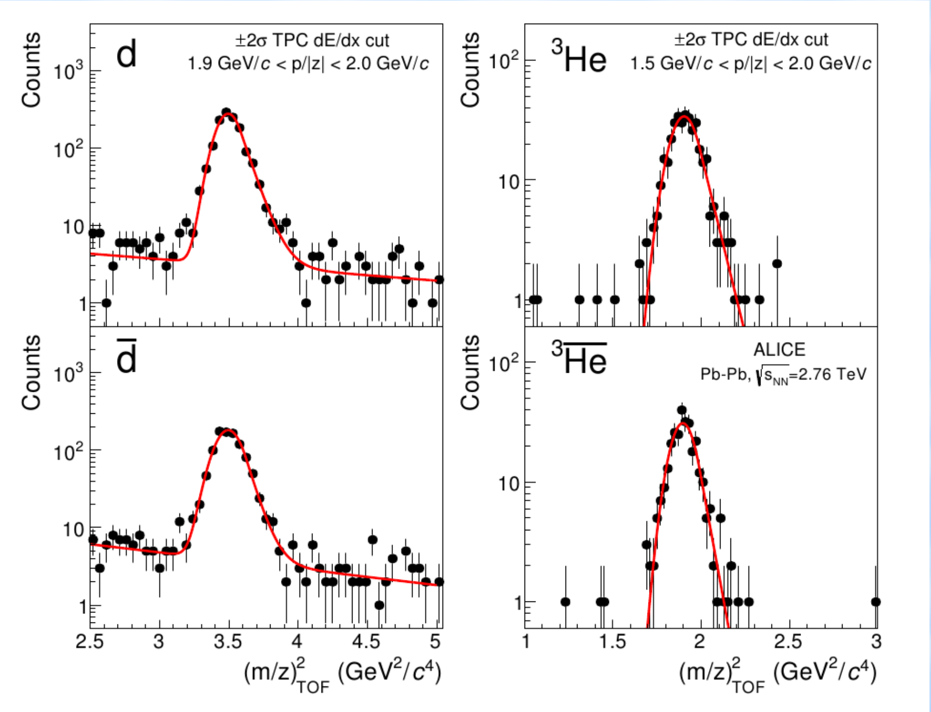
- Probes the hydro-dynamical evolution of the early partonic state.

- ϕ, Ξ, Ω less sensitive to scattering in the later hadronic phase.

Bound states of anti-matter

- Unique particle identification from TPC dE/dx and TOF, including nuclei and anti-nuclei.
- Allows relative mass measurement at the 10^{-4} (d/dbar) and 10^{-3} (He/anti-He) level.

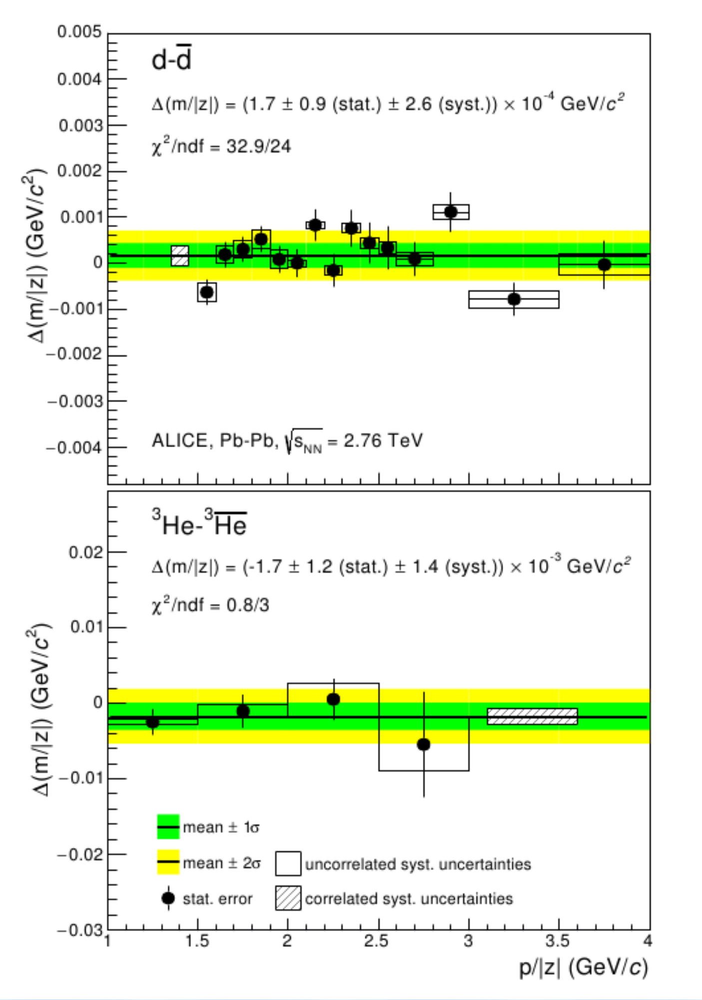


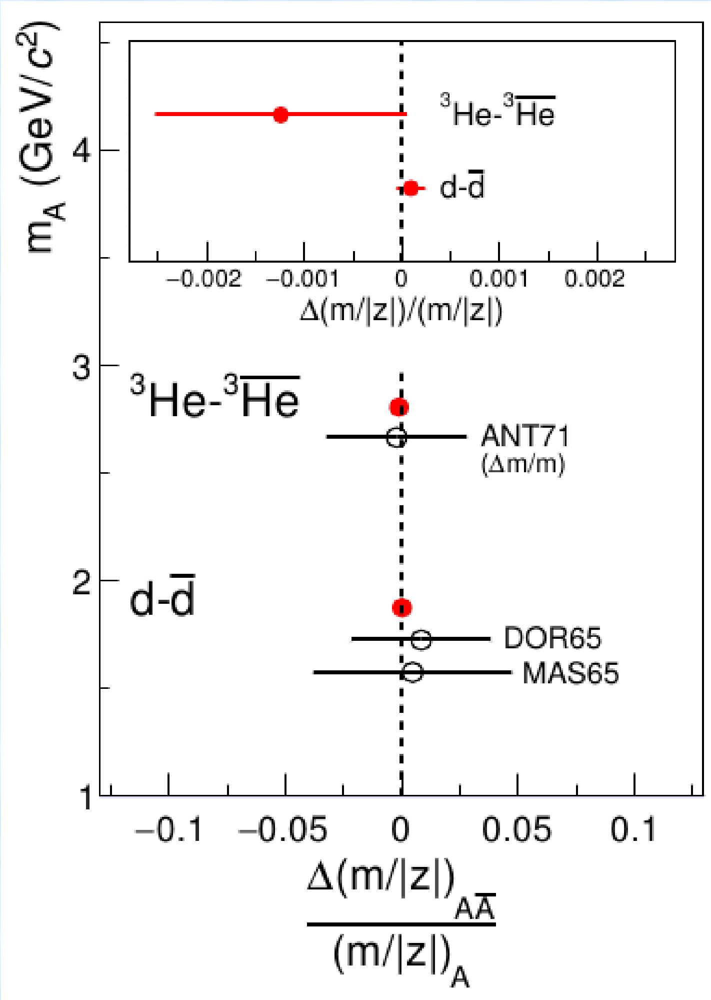


ALICE Collaboration, Nature Physics (2015), arxiv:1508.03986.

Bound states of anti-matter

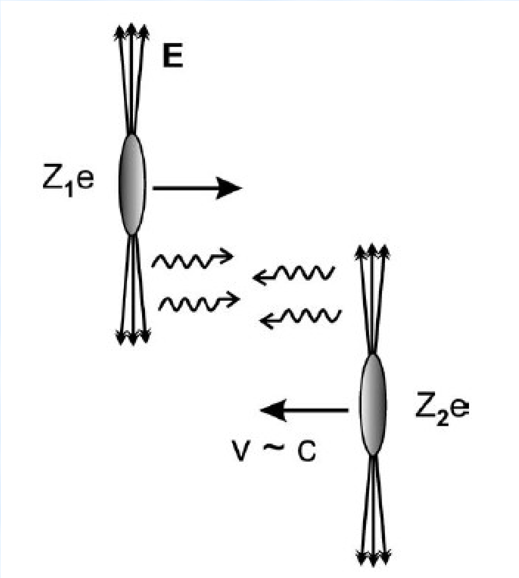
- Best measurement of Δm for nuclei so far.
- Sets limits on CTP invariance.





ALICE Collaboration, Nature Physics (2015), arxiv:1508.03986.

Photoproduction in ultra-peripheral collisions



The EM fields correspond to an equivalent flux of photons.

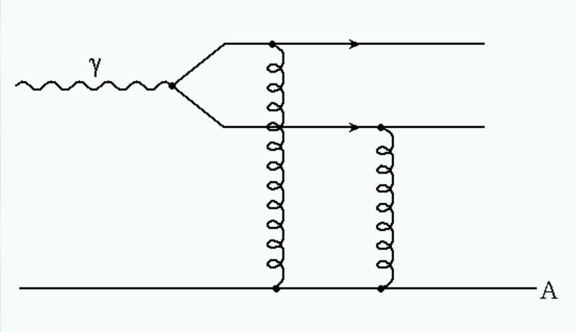
These can lead to two-photon or photonuclear interactions in collisions where no hadronic interactions occur (*b*>2*R*).

Exclusive vector meson production (γ+A → V+A) of particular interest as a probe of the gluon distribution g(x,Q^2).

Exclusive photoproduction of heavy vector mesons is calculable from pQCD, at LO:

$$\frac{d\sigma}{dt}\Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xg(x, \frac{M_V^2}{4})]^2$$

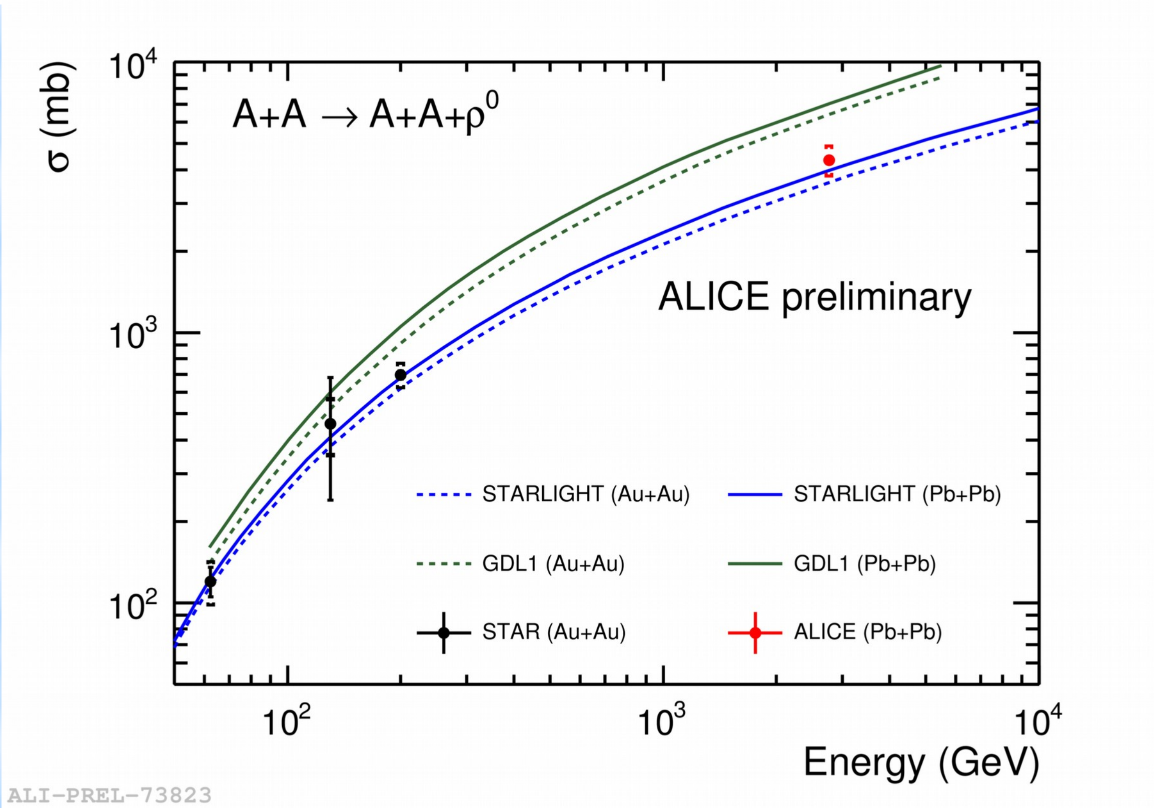
Ryskin 1993



Photoproduction in ultra-peripheral collisions

- Cross section for exclusive photoproduction of ρ^0 $\approx$1/2 of inelastic hadronic cross section!

$$\sigma(\rho^0)^{\text{coh.}} = \left(4.3 \pm 0.1(\text{stat.})\,^{+0.6}_{-0.5}(\text{sys.})\right)\ \text{b}$$

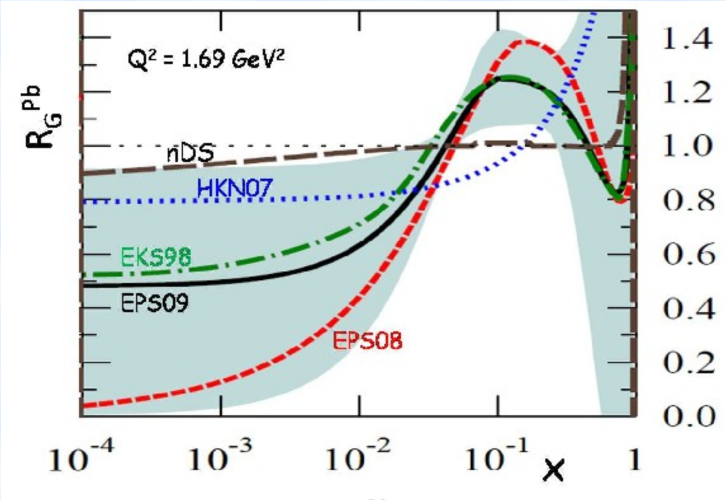


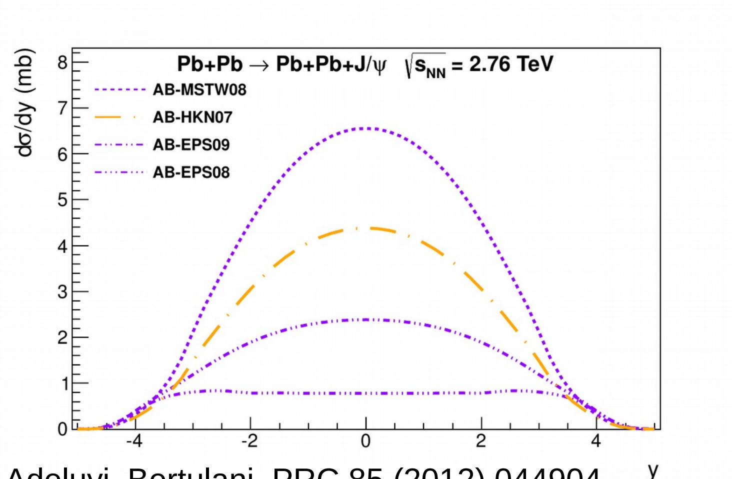
STAR Collaboration Data: Phys. Rev. Lett. 89 (2002) 272302; Phys. Rev. C 77 (2008) 034910; Phys. Rev. C 85 (2012) 014910.

ALICE Collaboration, arxiv:1503.09177 (to be published in JHEP).

Photoproduction in ultra-peripheral collisions

Uncertainty in nuclear gluon distribution translates into different cross section for photoproduction of J/ψ at mid-rapidity ($d\sigma/dy \propto [g(x,Q^2)]^2$).

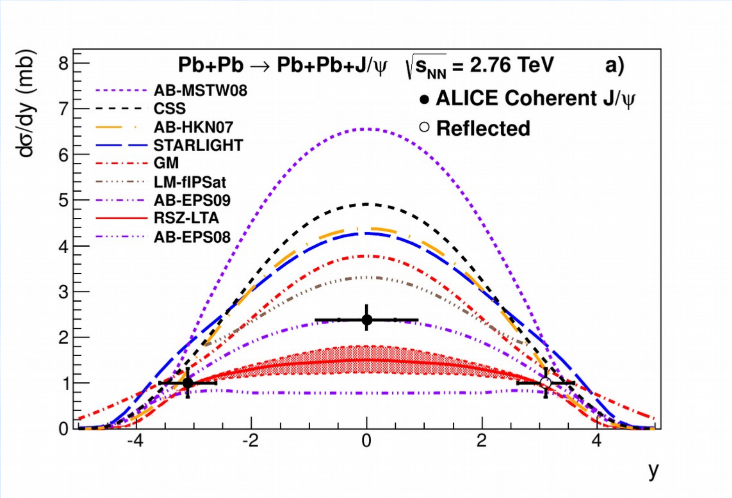




Adeluyi, Bertulani, PRC 85 (2012) 044904.

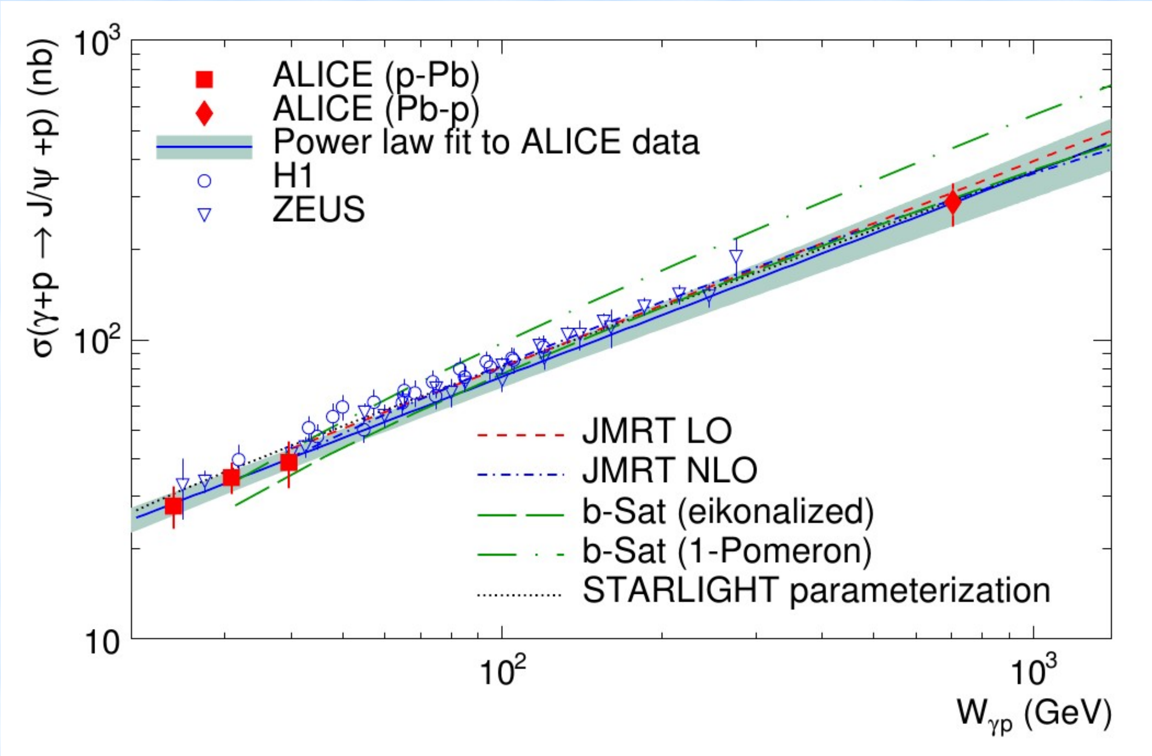
$R_G = g_A(x,Q^2)/[A \cdot g_p(x,Q^2)]$

ALICE Collaboration, Phys. Lett. B 718 (2013) 1273 (Muon arm), EPJC 73 (2013) 2617 (Central Barrel).



Photoproduction in ultra-peripheral collisions

- Strong photon flux from Pb-nucleus also in p+Pb collisions.
- Can be used to study γ+p reactions at energies higher than at HERA.



ALICE Collaboration, Phys. Rev. Lett. 113 (2014) 232504.

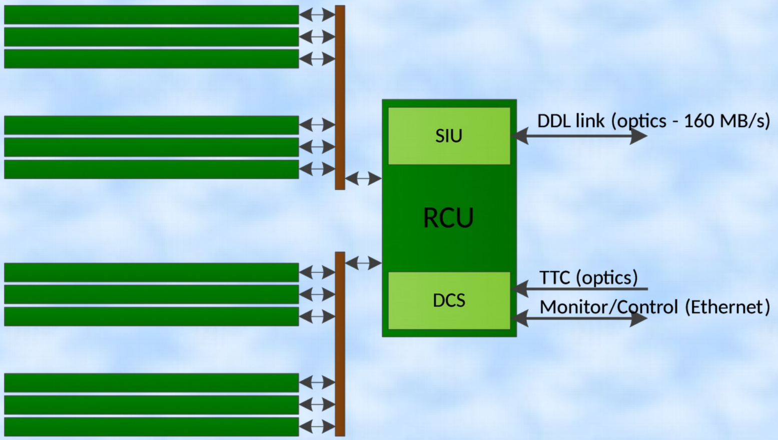
ALICE Upgrade Project

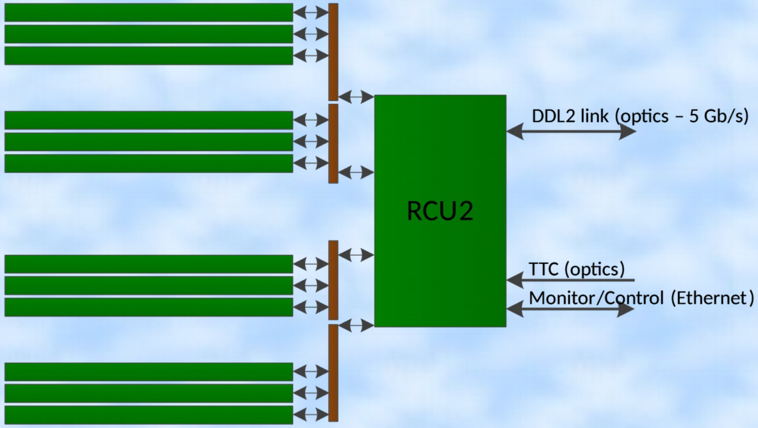
ALICE TPC Run 2 Upgrades

- We make a «simple» Upgrade!

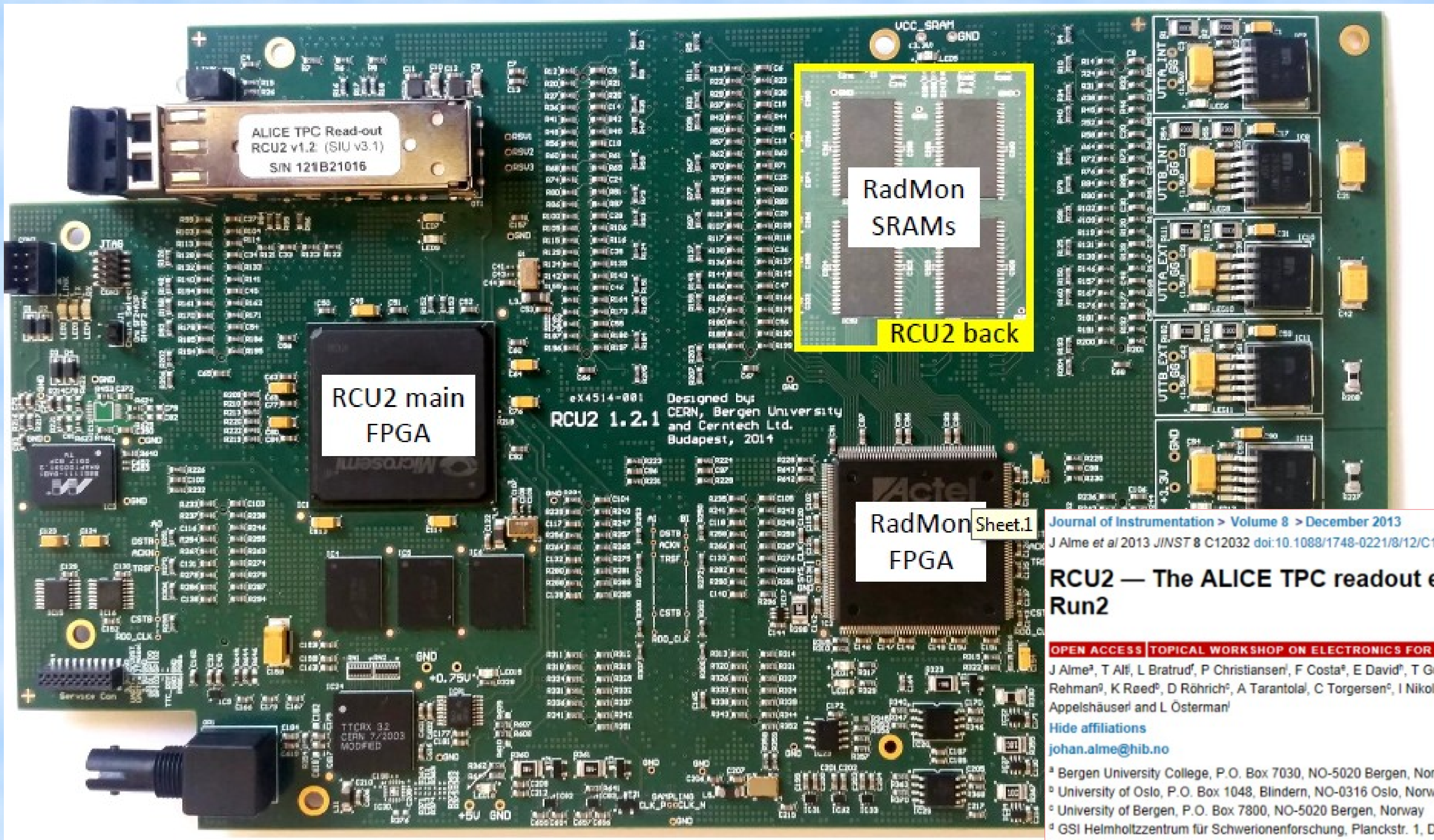
- Remove the bottleneck by splitting the parallel readout bus:
  - › Doubles the speed!

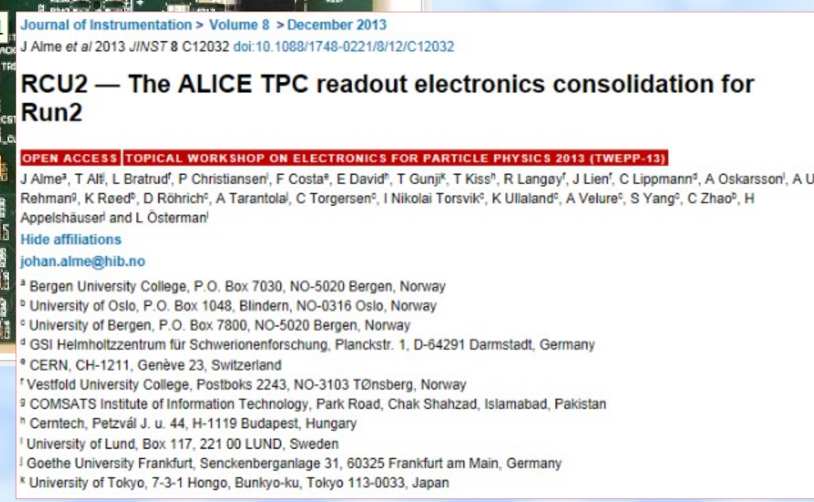
- Upgrades the RCU –> RCU2
  - › New state of the art System on Chip FPGA – Microsemi smartFusion2
  - › Faster, bigger, better in radiation! First flashbased FPGA with SERDES





RCU2 — The ALICE TPC readout electronics consolidation for Run2




Journal of Instrumentation > Volume 8 > December 2013

J Alme *et al* 2013 *JINST* 8 C12032 doi:10.1088/1748-0221/8/12/C12032

RCU2 — The ALICE TPC readout electronics consolidation for Run2

OPEN ACCESS | TOPICAL WORKSHOP ON ELECTRONICS FOR PARTICLE PHYSICS 2013 (TWEPP-13)

J Alme[a], T Alt[j], L Bratrud[f], P Christiansen[i], F Costa[e], E David[h], T Gunji[k], T Kiss[h], R Langøy[f], J Lien[f], C Lippmann[d], A Oskarsson[i], A Ur Rehman[g], K Røed[b], D Röhrich[c], A Tarantola[j], C Torgersen[c], I Nikolai Torsvik[c], K Ullaland[c], A Velure[c], S Yang[c], C Zhao[b], H Appelshäuser[j] and L Österman[i]

Hide affiliations

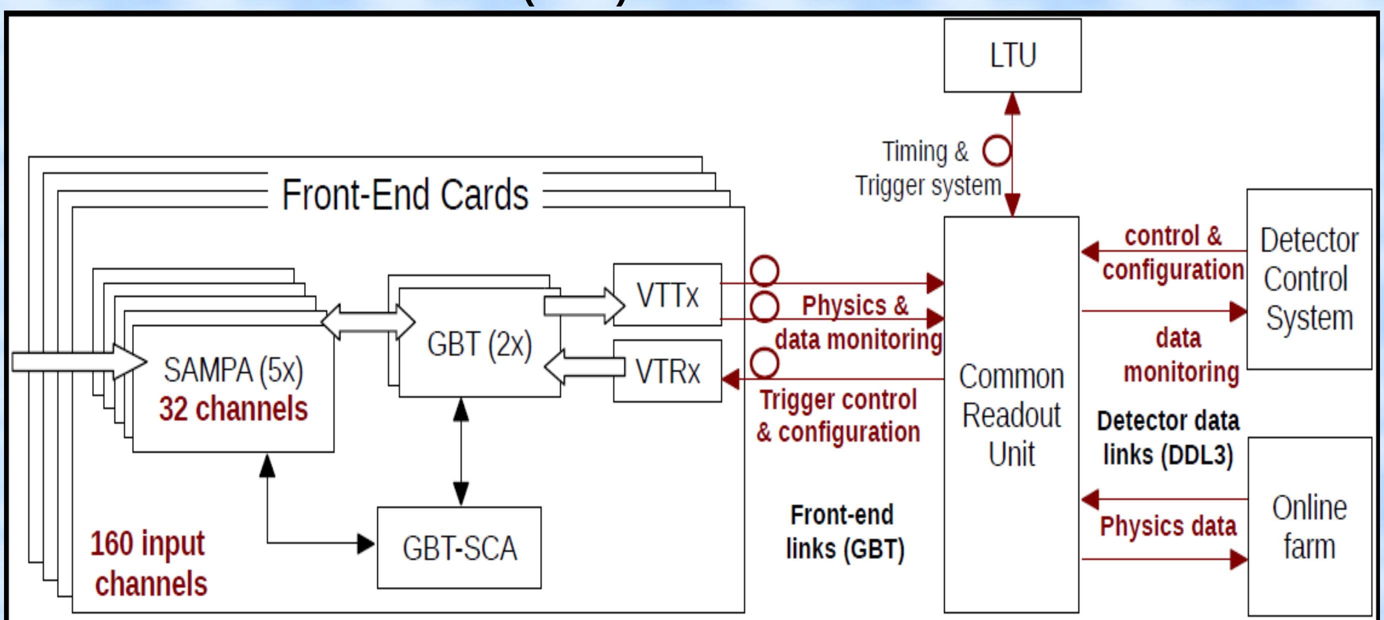
johan.alme@hib.no

[a] Bergen University College, P.O. Box 7030, NO-5020 Bergen, Norway
[b] University of Oslo, P.O. Box 1048, Blindern, NO-0316 Oslo, Norway
[c] University of Bergen, P.O. Box 7800, NO-5020 Bergen, Norway
[d] GSI Helmholtzzentrum für Schwerionenforschung, Planckstr. 1, D-64291 Darmstadt, Germany
[e] CERN, CH-1211, Genève 23, Switzerland
[f] Vestfold University College, Postboks 2243, NO-3103 TØnsberg, Norway
[g] COMSATS Institute of Information Technology, Park Road, Chak Shahzad, Islamabad, Pakistan
[h] Cerntech, Petzvál J. u. 44, H-1119 Budapest, Hungary
[i] University of Lund, Box 117, 221 00 LUND, Sweden
[j] Goethe University Frankfurt, Senckenberganlage 31, 60325 Frankfurt am Main, Germany
[k] University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

ALICE Upgrade Project

LS2 TPC upgrade

- 50 kHz interaction rate in Run 3
- GEM readout chambers
- continuous readout electronics
  - new frontend ASIC SAMPA
  - GBT link detector -> counting house
  - New Common Readout Unit (CRU)

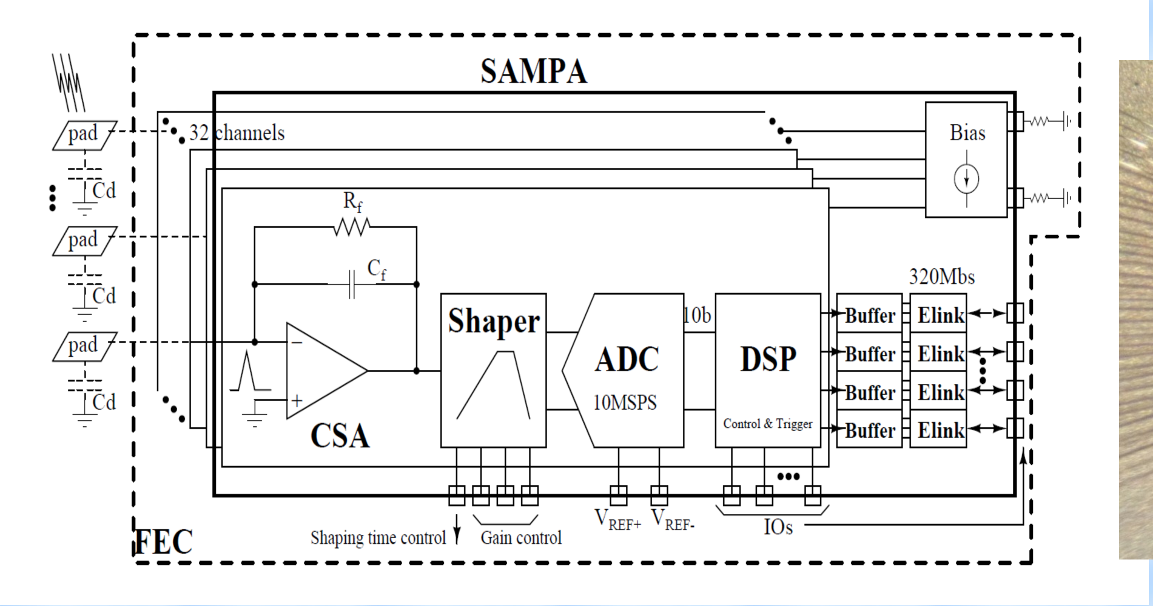


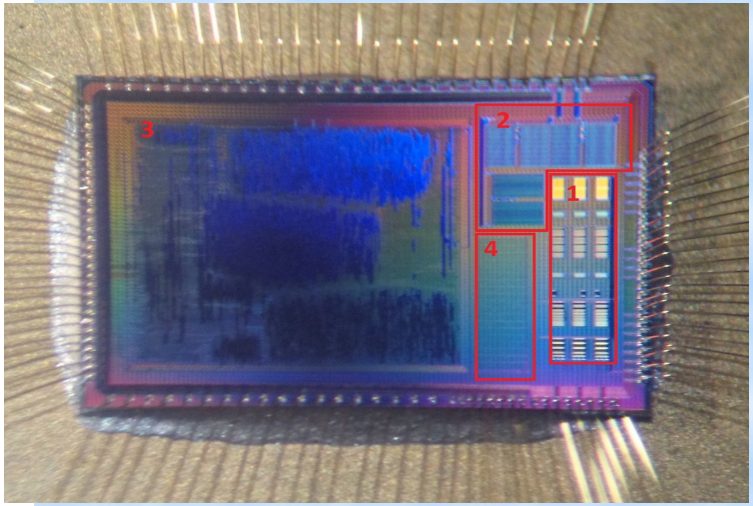
ALICE Upgrade Project

SAMPA

- **Design (Sao Paolo, UiB)**
- **Characterization of prototypes with GEM (UiB)**
- **Radiation tolerance (UiO)**

SAMPA design

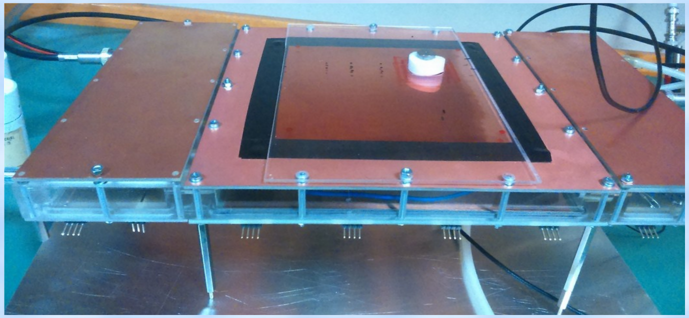




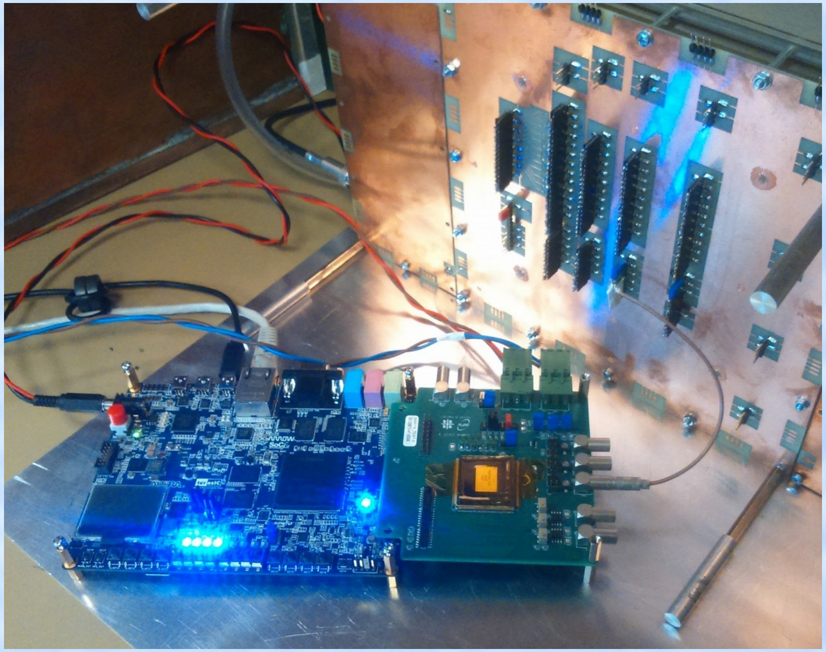
ALICE Upgrade Project

SAMPA characterization

- **GEM**



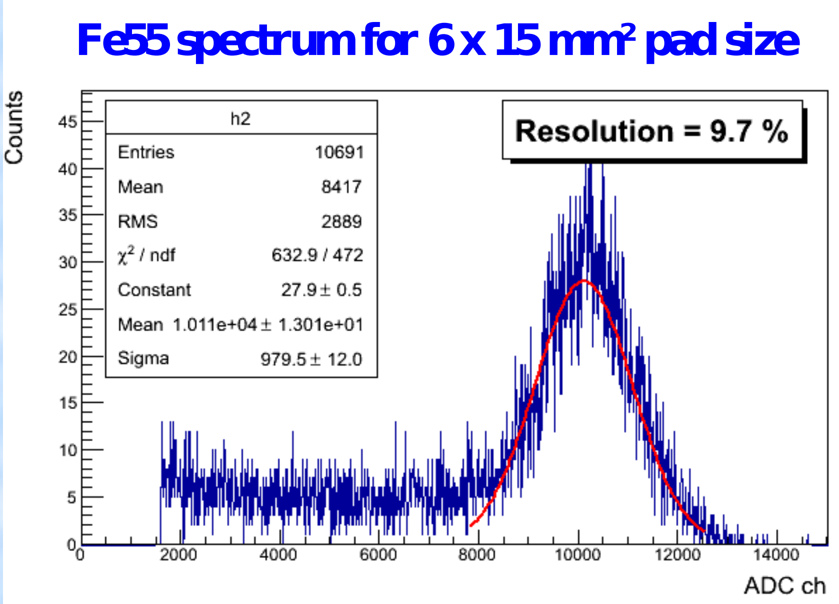
- **MPW1 carrier board and FPGA DAQ board**

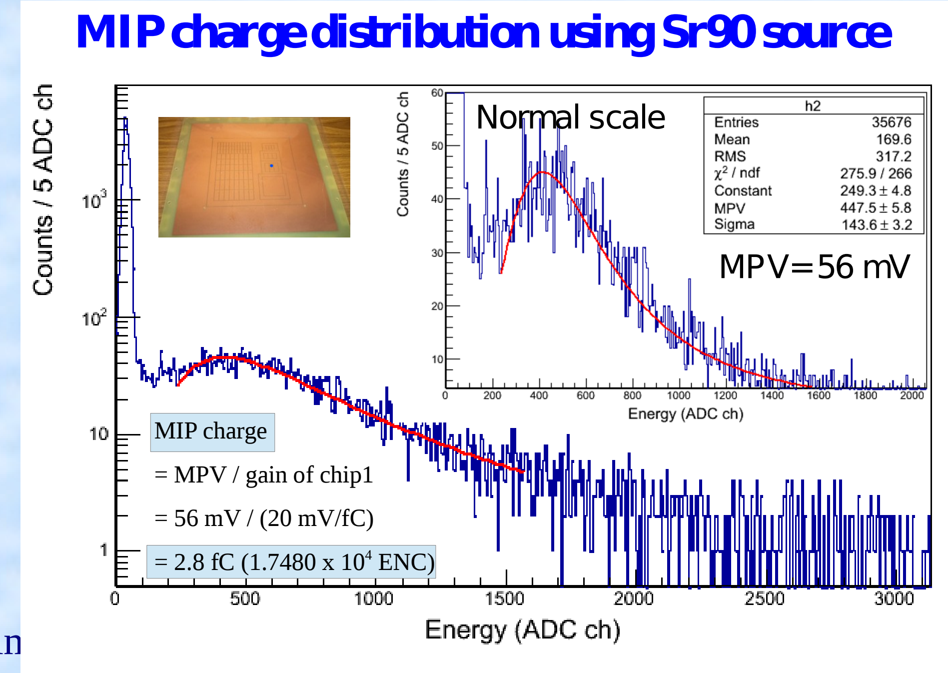


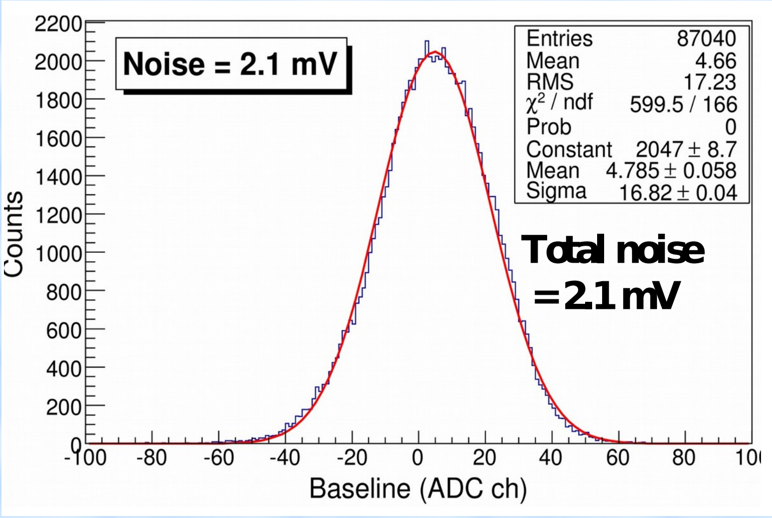
ALICE Upgrade Project

- **Resolution**

- **SNR = MIP charge / chip1 noise**
  = 27
  -> close to the requirement







Conclusions

- A multitude of new results from heavy-ion interactions in a novel energy range at the LHC.

- Hard and heavy probes can be studied with high statistics in heavy-ion interactions.

- Several results from ALICE on topics not related to hot and dense matter (ultra-peripheral collisions, anti-nuclei).

- ALICE Upgrade for Run 3 includes continuous read-out of the TPC.