Performance of the precise electromagnetic calorimeter ALICE/PHOS and upgrade plans

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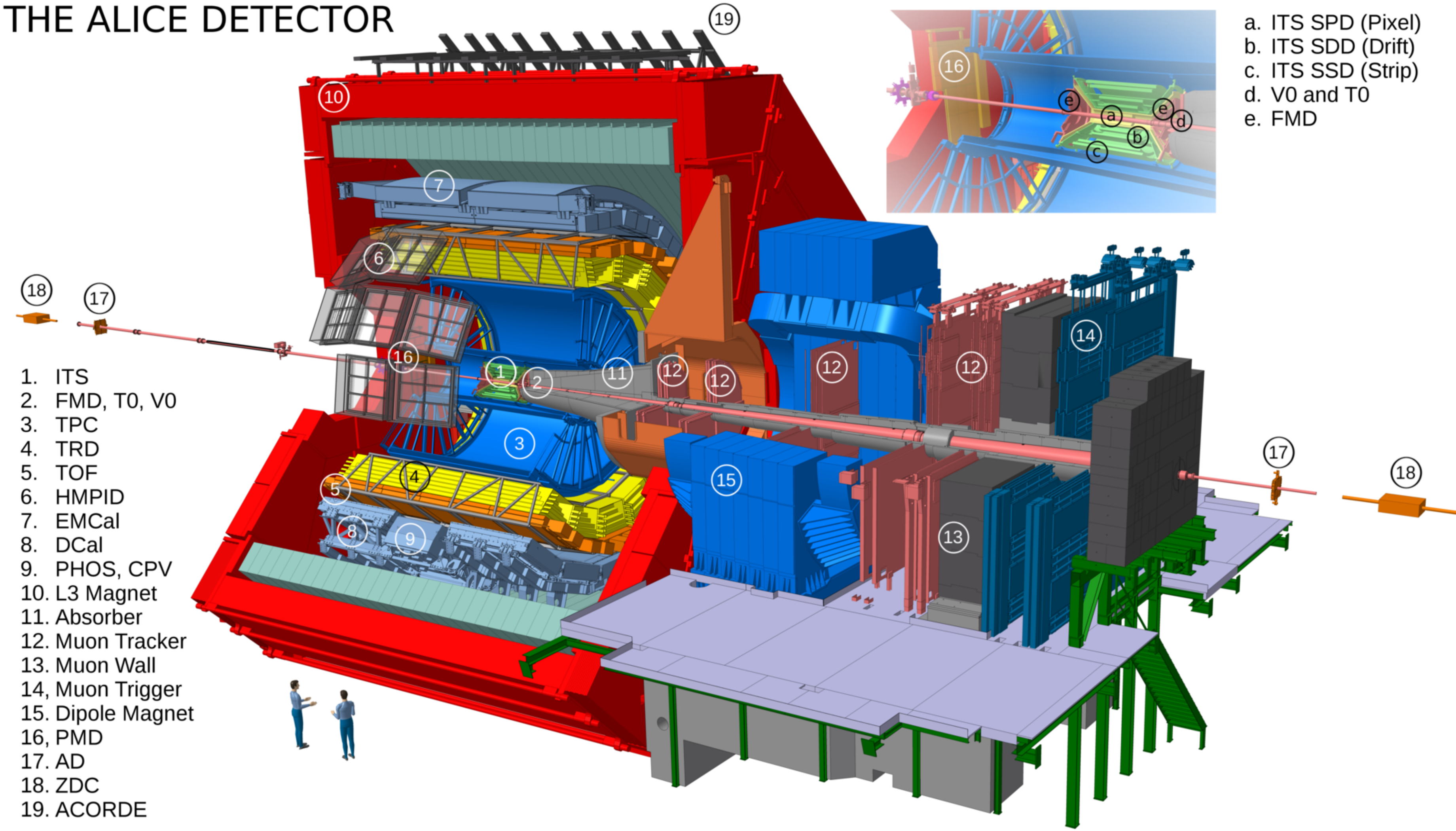
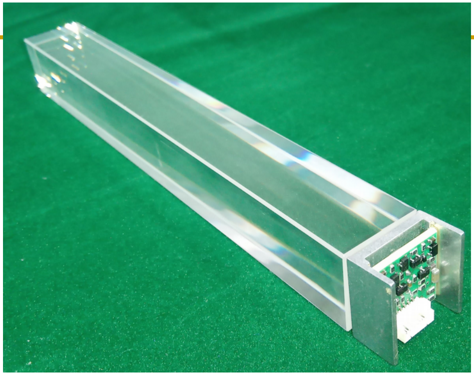
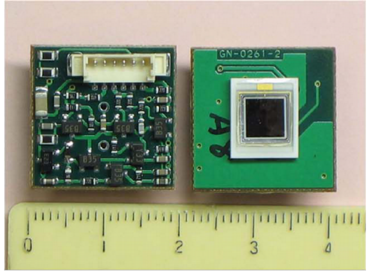
THE ALICE DETECTOR



PHOS

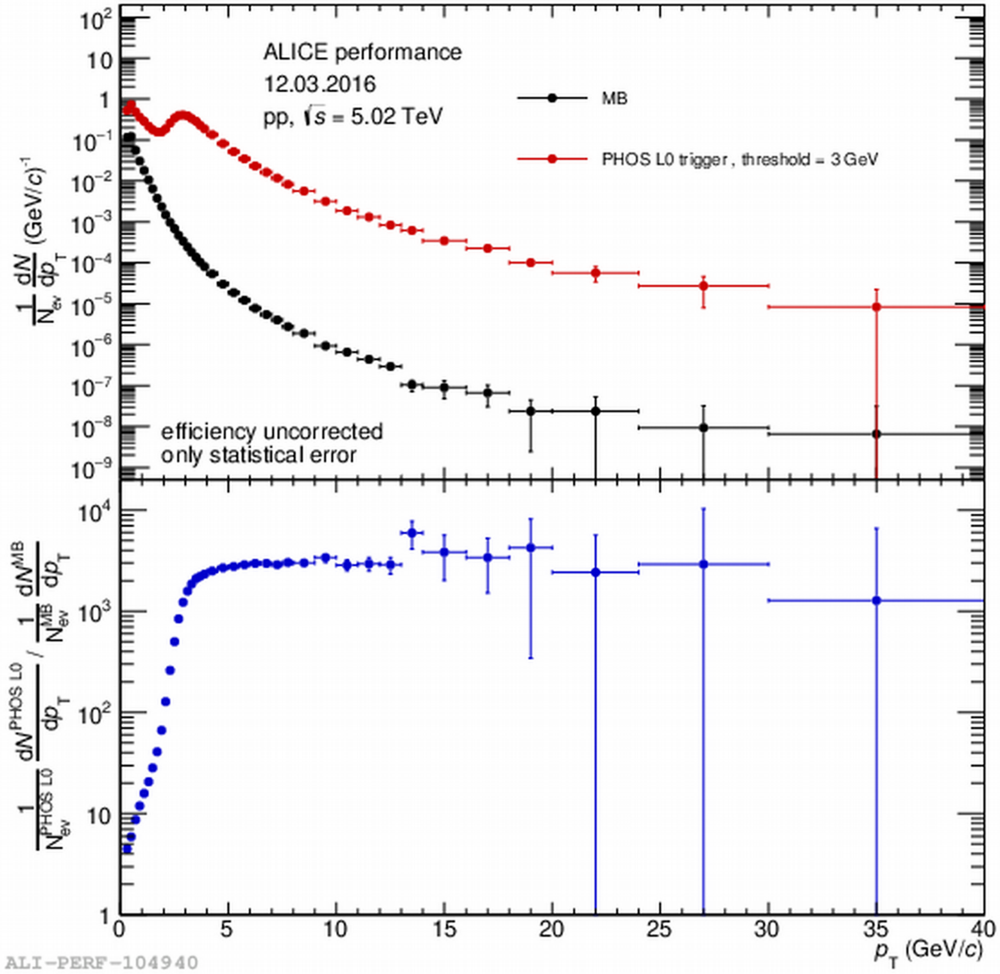
Active element	Homogeneous crystals $PbWO_4$
Molière radius	2.0 cm
Photodetector	Avalanche Photodiode 5×5 mm^2
Depth	20 X_0
Acceptance	Run 1: $\lvert\eta\rvert<0.12$, $260 < \varphi < 320°$ Run 2: $\lvert\eta\rvert<0.12$, $250 < \varphi < 320°$
Granularity	Cell 2×2 cm^2 $\Delta\varphi\cdot\Delta\eta = 0.0048\cdot0.0048$ rad
Modularity	3+1/2 modules 12544 cells
Dynamic range	0.01-100 GeV
Distance from IP	460 cm, 0.2 X_0





PHOS trigger

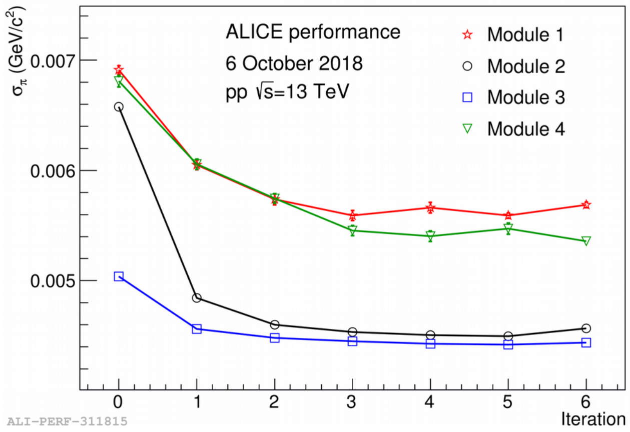
- ALICE calorimeters provide triggers at levels L0 (1.2 μs) and L1 (7 μs)
- PHOS L0: trigger on energy sum of 4×4 cells within area covered by trigger region units (TRUs) above a threshold
- PHOS L1: trigger on photons with 3 thresholds
  - Thresholds are adjustable depending on collision rate, trigger rejection factor, readout time. Typical threshold: 4 GeV
  - pp collisions: low trigger rate → only PHOS L0 trigger is required
  - p-Pb, Pb-Pb collisions: L1 triggers become effective

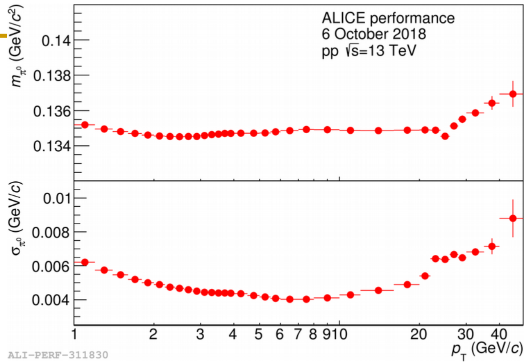


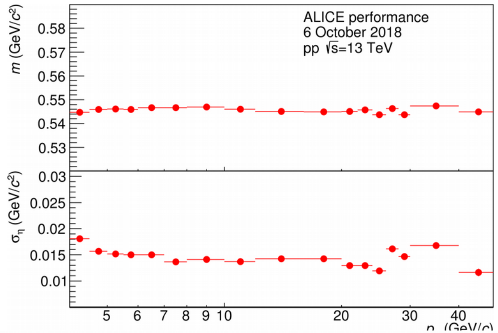
PHOS calibration

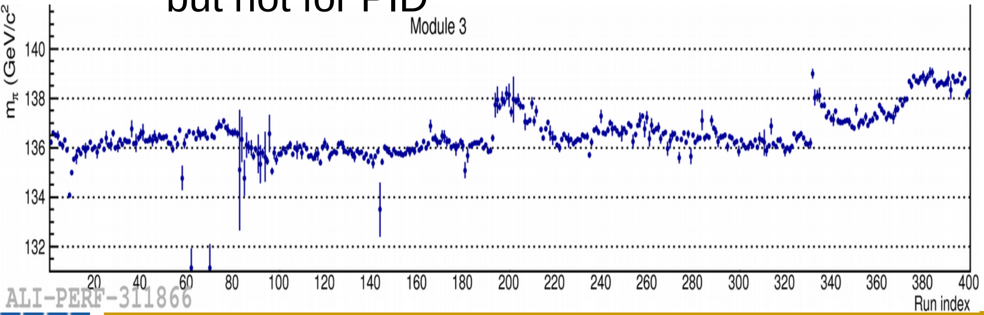
JINST 14 P05025 (2019)

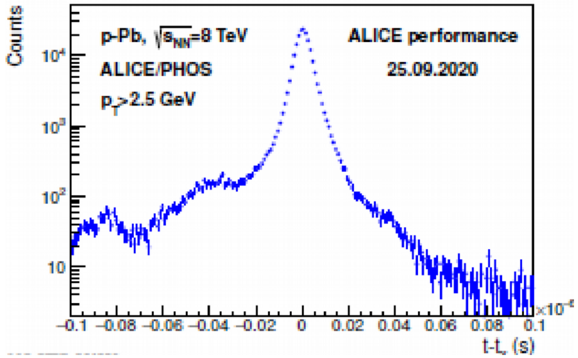
- Energy calibration
  - Pre-calibrated using APD gains
  - Final calibration using π^0 peak, procedure optimized using MC simulations
  - Cross-check using η peak and electron E/p peak
  - Time-dependent correction based on π^0 peak position
- Time calibration
  - Resolution sufficient for pileup rejection, but not for PID

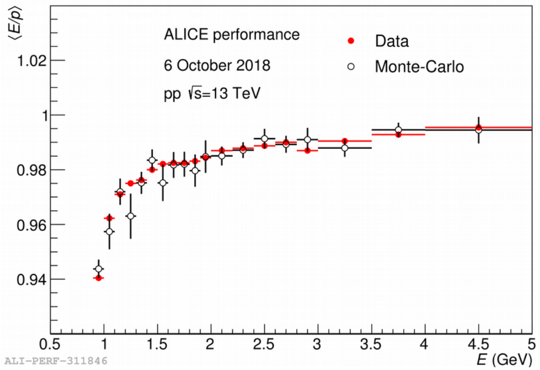






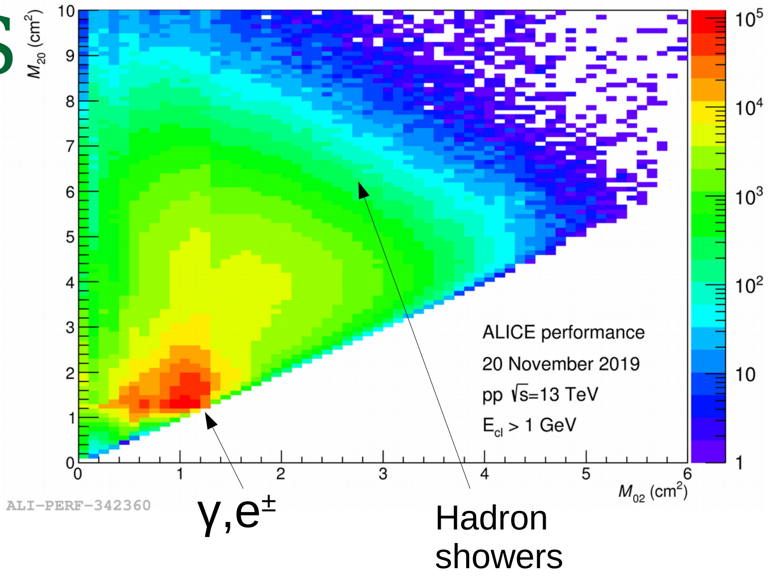


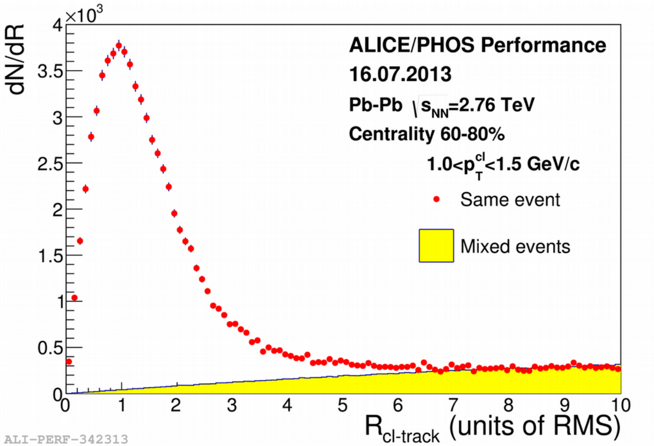


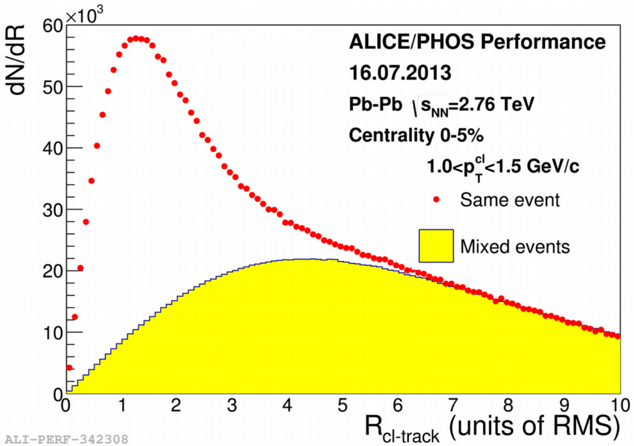


Particle identification in PHOS

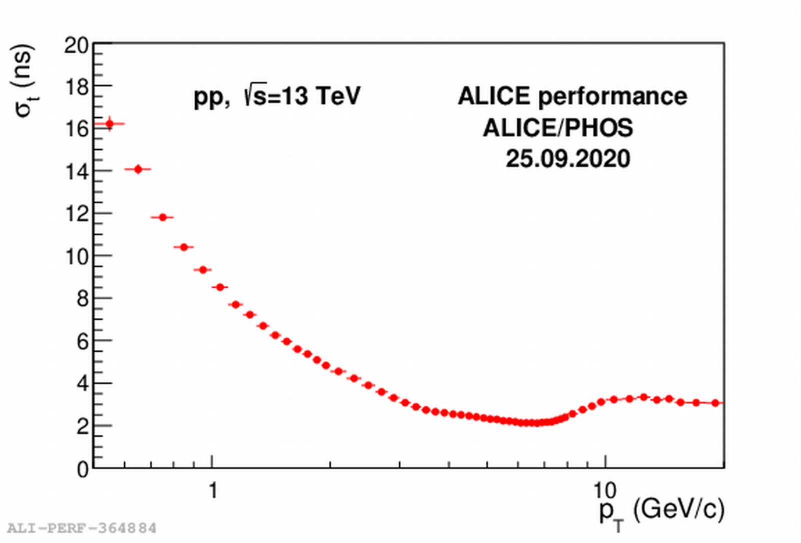
- Shower shape
  - Use eigenvalues of 2D dispersion matrix
- Neutrality (track matching)
  - Parameterize distance from clusters to track extrapolation and normalize in units of standard deviations



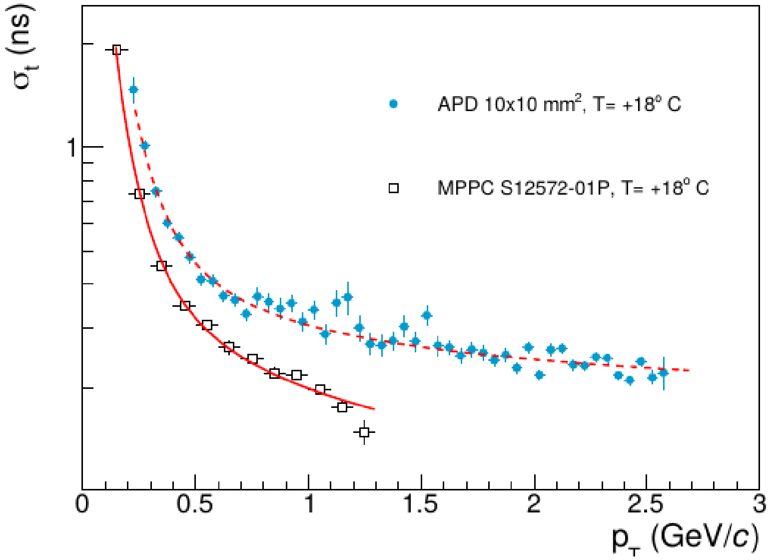




PHOS time resolution



PHOS prototype beam-test results

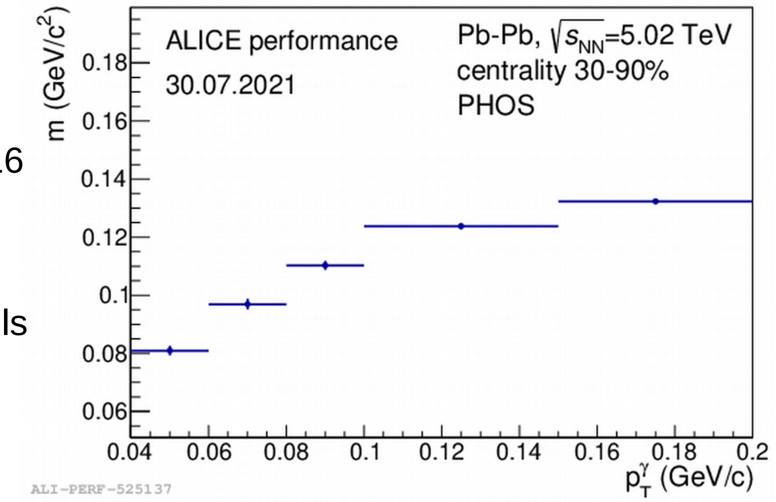


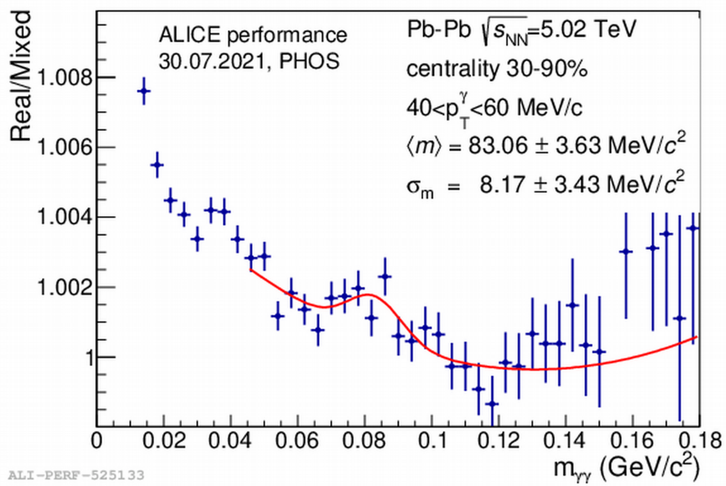
Current electronics was not designed to have good time resolution. Present resolution is modest and can not be used for particle identification, only for pileup rejection.

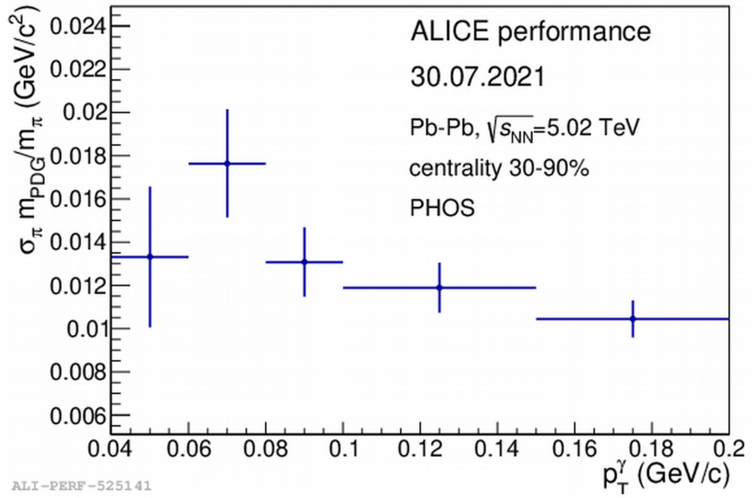
Beam-test results with specialized electronics. SiPM with dedicated electronics provides resolution up to 200 ps.

PHOS dynamic range

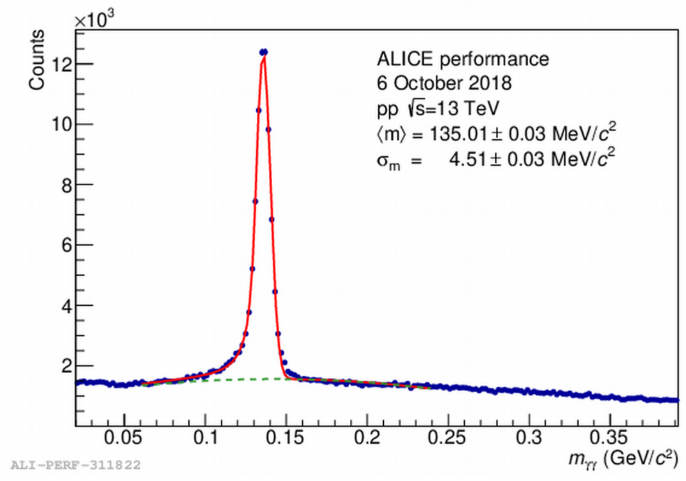
- PHOS electronics has 2 channels with 10 bit ADC each, with gain ratio ~16
- Gain adjusted so that 1 ADC channel ~ 5 MeV
- To test possibility to measure low-energy photons a dedicated reconstruction was performed with reduced threshold on the energy of cells contributing to cluster
  - PWO light yield sufficient to measure photons with E~40 MeV
  - MC simulations show that resolution is still defined by the electronics noise

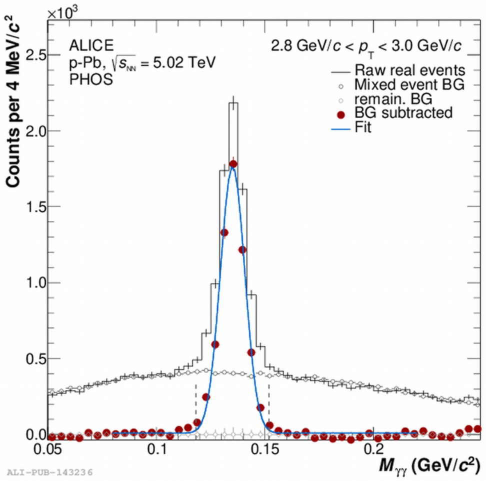


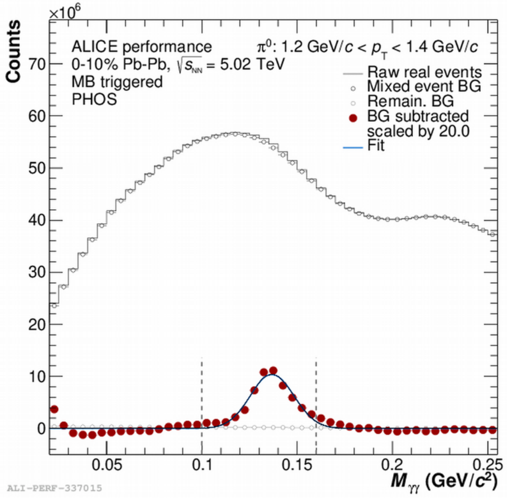


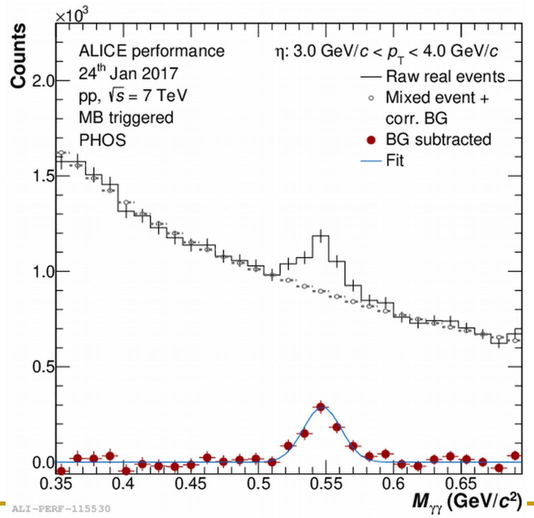


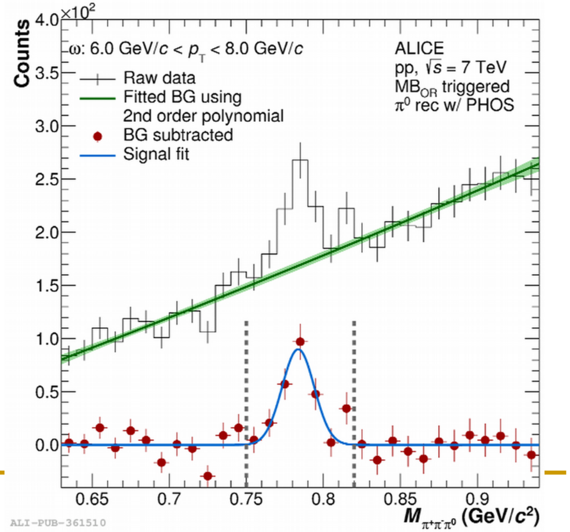
Neutral mesons







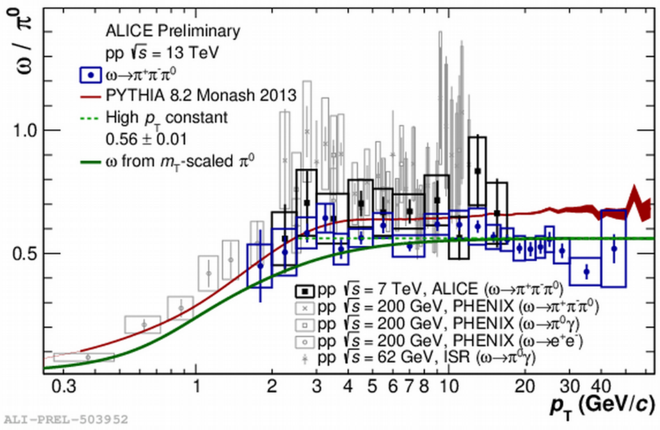


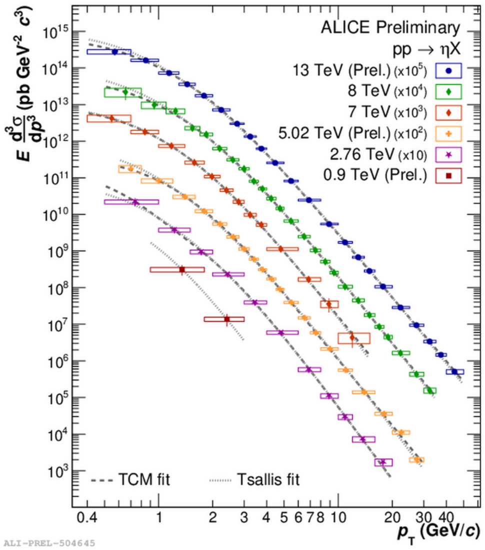


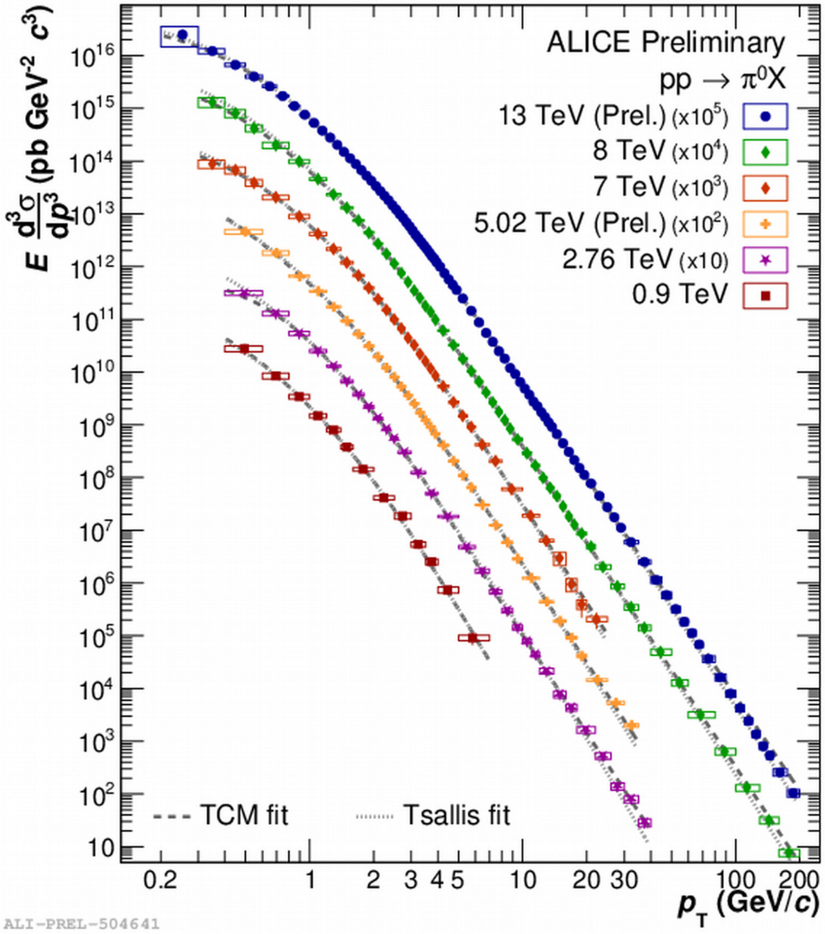
- PHOS reconstructs neutral mesons π^0, η, ω in a wide p_T range
- In all colliding systems
  - pp, pA, AA

Neutral meson spectra

- Neutral meson measurements in a wide p_T range provide inputs for global PDF and FF fits
- Study strangeness production in η/π^0 ratio
- Study particle production mechanisms: multiplicity dependence, in-jet production, event shape dependence etc.

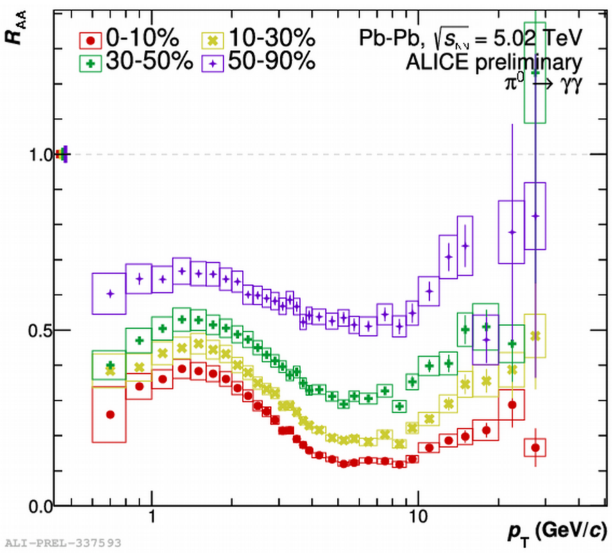


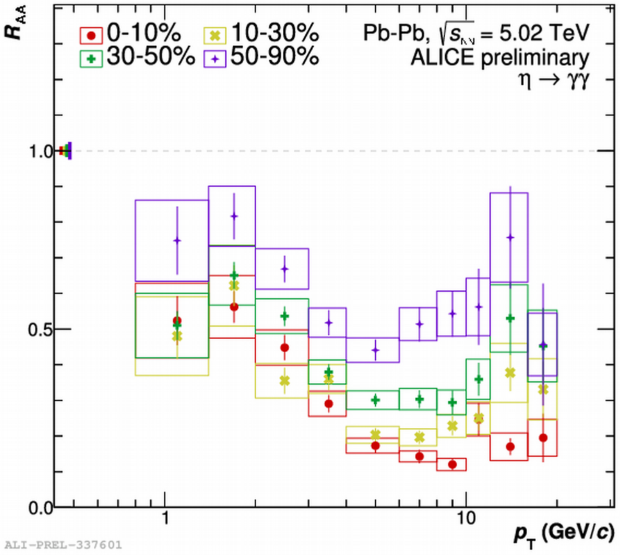


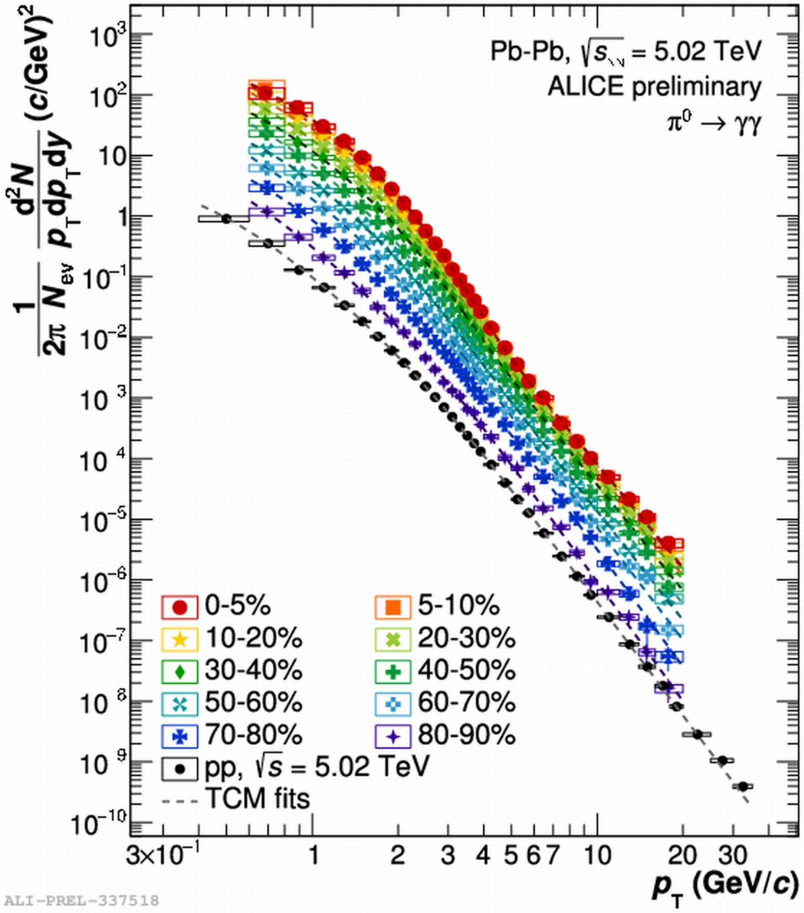


Parton energy loss in AA collisions

- Study of parton energy loss in a wide p_T range via identified hadrons
- Separately for π^0 and η mesons, look at strangeness and mass dependence



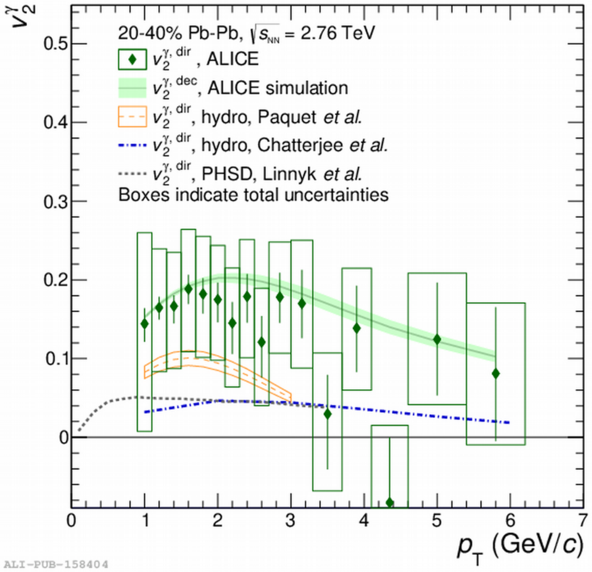


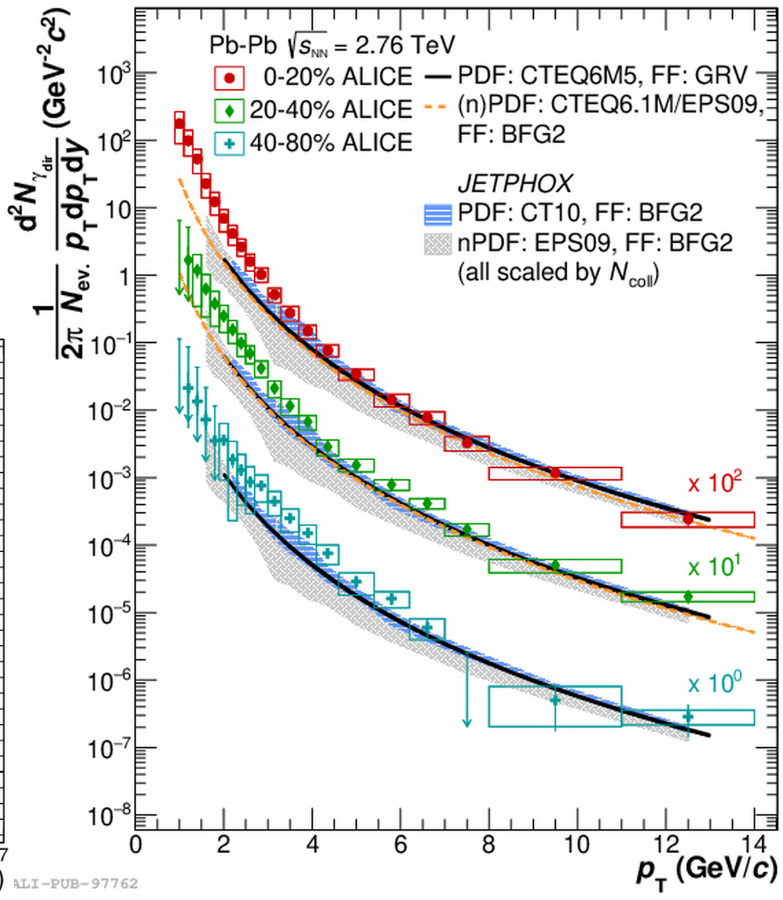


Direct photon spectra and flow

- Direct photon spectrum at hight p_T>5 GeV/c agrees with pQCD predictions scaled with the number of nucleon-nucleon collisions
- In central collisions there is clear excess at low p_T due to thermal emission

- Direct photon flow similar to flow of decay photons and stronger than predictions of hydrodynamic models (direct photon flow puzzle)
- However, uncertainties too large to make final conclusion



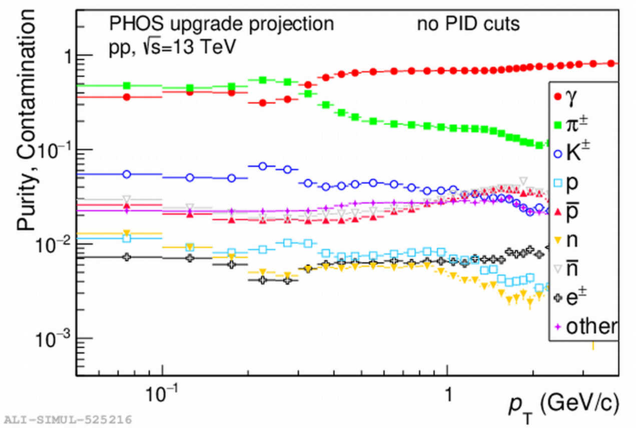


Reasons for PHOS upgrade

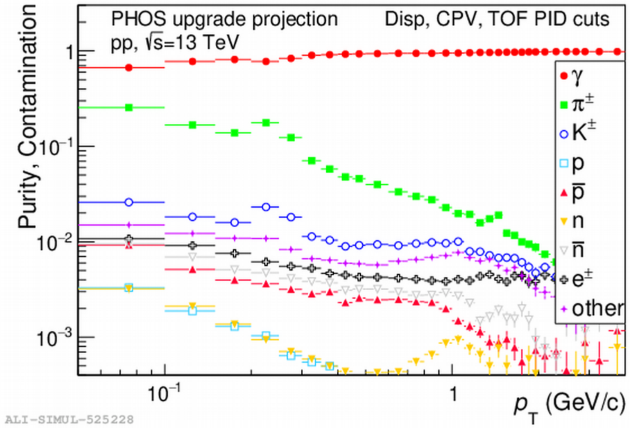
- Improve time resolution
  - Extend photon physics program to low p_T
    - Direct photon flow
    - Direct photon Bose-Einstein correlations
    - Test of Low theorem
    - Antineutron measurements
- Electronics upgrade
  - Spare parts of current FECs become obsolete and no longer produced
  - Possibility to reduce noise
  - New picoTDC chip is state-of-the art technology which will provide best possible timing capabilities of new cards
  - New readout units: designed for upgraded ITS. Will have bandwidth up to 200 MHz
- Mechanics upgrade
  - Provide access to FEE in course of data taking

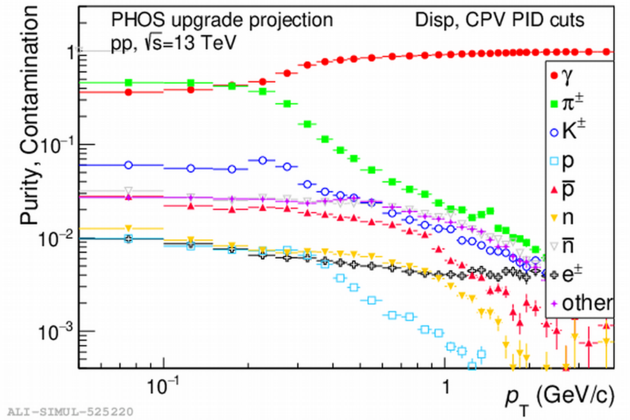
Upgrade: improvement of photon purity with time cut

- Shower shape cut not efficient for clusters with few cells
- Neutrality cut inefficient for low-p_T tracks (highly bent, non-perpendicular incidence to PHOS)



- TOF is the only effective cut at low p_T
  - with time resolution provided with new electronics TOF cut $-3\sigma_t < \tau < 2\sigma_t$ allows to reduce contamination down to ~10% at 100 MeV/*c*.





Upgrade: expected reduction of systematic uncertainties

- Expected improvements in Run 4 discussed in
  - arXiv:1812.06772 ; CERN-LPCC-2018-07
- Uncertainties in direct photon spectrum can be reduced by a factor of ~2 and spectrum can be extended to lower p_T
- Uncertainties in direct photon flow can be reduced by factor ~2
  - confirm/solve direct photon flow puzzle
  - observe negative v_2 due to quark Landau levels (X.Wang et al., Phys.Rev.D 102 (2020) 7, 076010)

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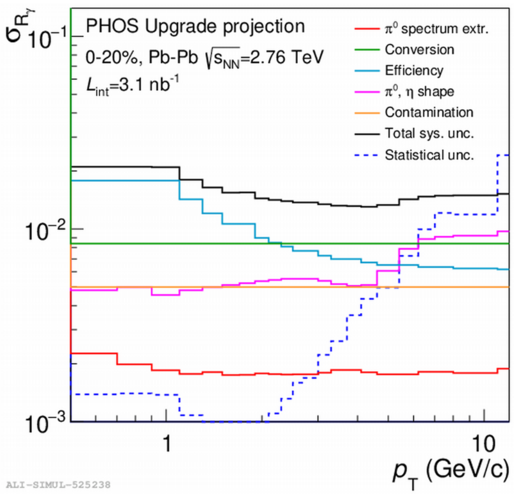
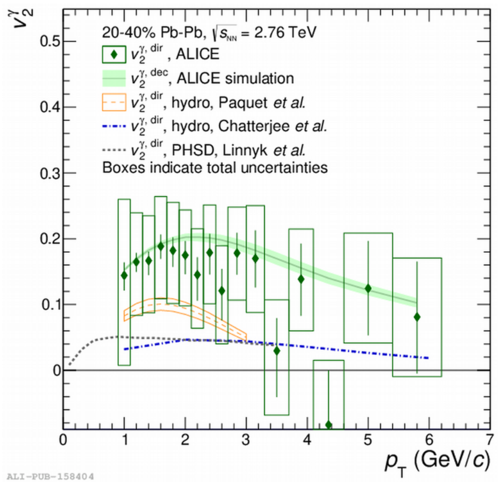
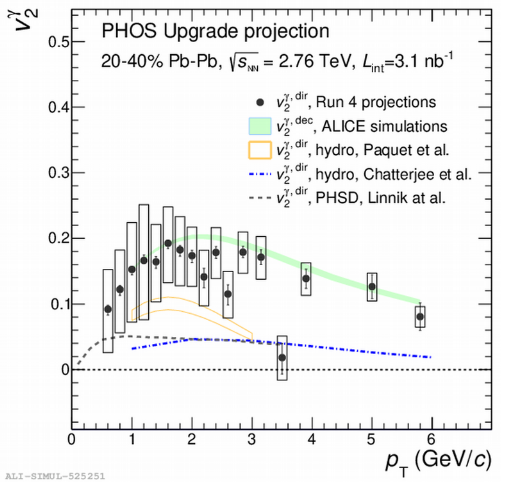
Centrality	0–20%		20–40%		40–80%	
p_T (GeV/c)	2	10	2	10	2	10
γ_{incl} yield						
Efficiency (B)	3.0	3.0	0.7	0.7	2.5	2.5
Contamination (B)	2.0	2.0	1.3	1.3	2.9	0.5
Conversion (C)	1.7	1.7	1.7	1.7	1.7	1.7
Acceptance (C)	1.0	1.0	1.0	1.0	1.0	1.0
*Global E scale (B)	9.6	9.0	6.1	5.9	5.8	6.3
*Non-linearity (B)	2.2	0.1	2.1	0.1	2.0	0.1
π^0 yield						
Yield extraction (A)	2.7	4.0	3.1	5.2	1.8	2.9
Efficiency (B)	1.8	1.8	2.7	2.2	2.5	2.5
Acceptance (C)	1.0	1.0	1.0	1.0	1.0	1.0
Pileup (C)	1.0	1.0	1.0	1.0	1.0	1.0
Feed-down (B)	2.0	2.0	2.0	2.0	2.0	2.0
γ_{decay}/π^0						
π^0 spectrum (B)	1.3	4.3	1.8	1.8	1.8	1.8
η contribution (B)	2.2	1.7	2.2	1.6	2.1	1.6
Total R_γ	6.8	7.9	5.9	6.5	6.1	6.0
Total γ_{incl}	12.4	12.7	9.7	10.0	9.8	9.6







Conclusions

- PHOS demonstrated excellent performance in Run 1 and Run 2 and contributed to all neutral meson and direct photon measurements of ALICE
  - superb energy resolution
  - good particle identification
- PHOS upgrade will allow to
  - extend physics program to lower energies
  - improve particle identification at lower energy

This work was supported by the Russian Science Foundation grant 22-42-04405