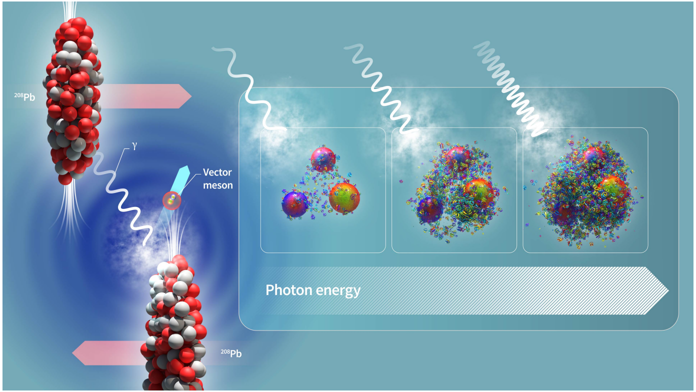
A new class of ultra-peripheral collisions in ALICE: Inelastic photonuclear interactions and open charm photoproduction

Sigurd Nese (University of Oslo)
For the ALICE collaboration

Hard Probes 2024
Nagasaki, Japan
25. September 2024

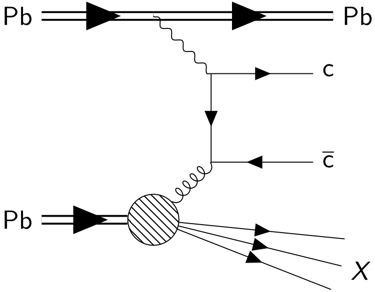
In ultra-peripheral heavy-ion collisions, electromagnetic interactions dominate

- Impact parameter is greater than the sum of the radii → strong interactions suppressed
- Heavy nuclei are sources of strong EM fields → equivalent flux of photons



Heavy quarks are produced in inelastic photonuclear interactions

- Photon can interact in direct or anomalous process
- Can result in photoproduction of charm quarks, emerging as open- or hidden-charm hadrons
- The QCD scale is given by $Q^2 = 4(m_Q^2 + p_T^2) \to$ pQCD calculations are applicable down to $p_T = 0$.
- One gluon interacts $\to$ one factor of gluon PDF
- Measuring charm hadrons gives access to gluon PDF down to $x \lesssim 10^{-4} \to$ probe saturation, shadowing

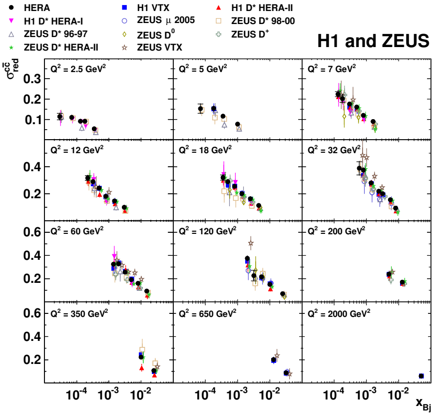


- Theoretical calculation: $\sigma(\mathrm{Pb} + \mathrm{Pb} \to \mathrm{Pb} + c\bar{c} + \mathrm{X}) \approx 2\,\mathrm{b}$

Spencer R. Klein, Joakim Nystrand, and Ramona Vogt. "Heavy quark photoproduction in ultraperipheral heavy ion collisions". In: *Phys. Rev. C* 66 (2002), p. 044906.

Charm production has been studied previously in DIS and fixed-target experiments

- Photoproduction of charm has been studied in fixed target experiments at Fermilab and the CERN SPS at lower energies
- Charm production was studied in deep inelastic ep scattering at HERA

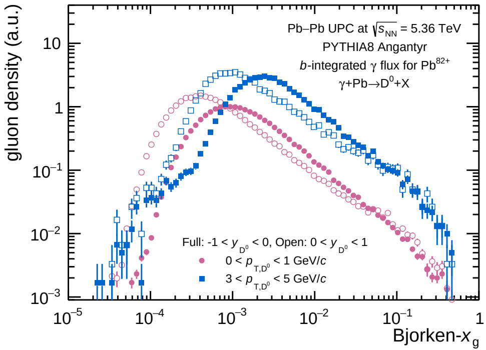


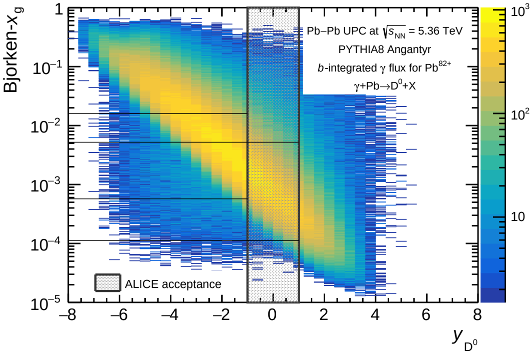
Halina Abramowicz et al. "Combination and QCD analysis of charm and beauty production cross-section measurements in deep inelastic ep scattering at HERA". In: *The European Physical Journal C* 78 (2018), pp. 1–32.

M. P. Alvarez et al. "Study of charm photoproduction mechanisms". In: *Z. Phys. C* 60 (1993), pp. 53–62.

J. C. Anjos et al. "A Study of the Semileptonic Decay Mode D0 → K- e+ Electron-neutrino". In: *Phys. Rev. Lett.* 62 (1989), pp. 1587–1590.

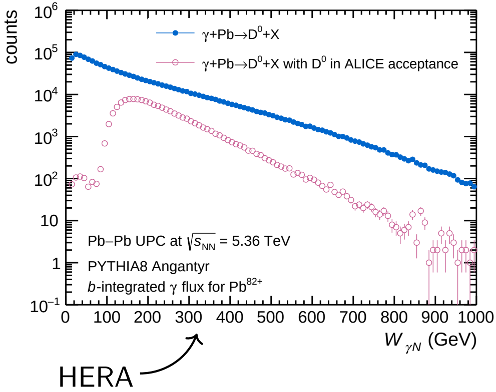
Measuring charm photoproduction gives access to the low-x region of gluon PDF

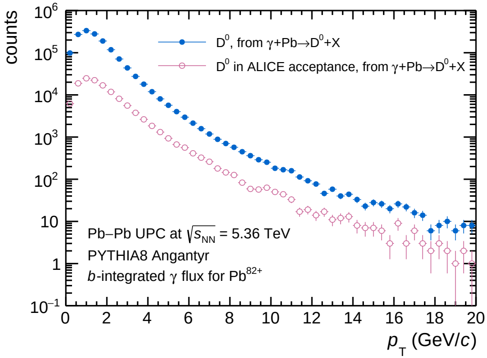




- Low-p_T charm hadrons on the gap side reach smaller gluon Bjorken-x
- Gluon x is correlated with charm hadron rapidity

Energy and p_T probed by ALICE corresponds to important dynamical range of photoproduction process

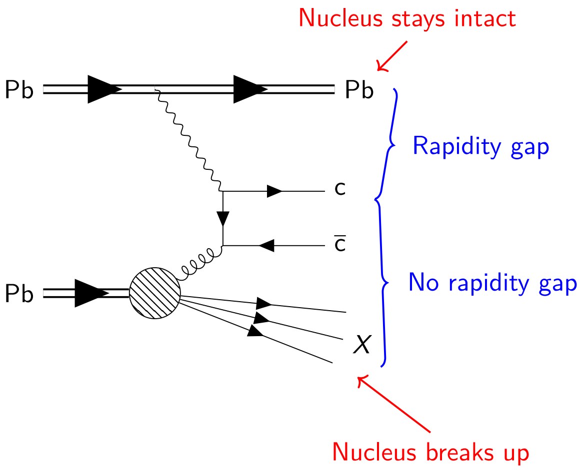




- Wide range of photon-nucleon CoM energies $W_{\gamma N}$ seen
- Low p_T peak of photoproduced charm is within reach

Inelastic UPC events are characterized by a rapidity gap on one side

- Relatively low photon energy results in peak of particle production being shifted in rapidity
- No dedicated trigger for events with single rapidity gap in Run 1 and Run 2 – In Run 3, ALICE uses continuous readout $\rightarrow$ Inelastic photonuclear events are collected



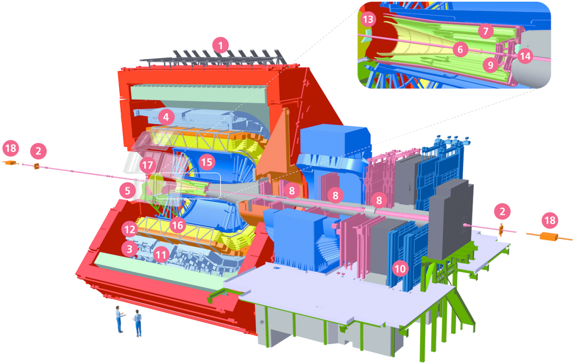
ALICE layout in Run 3

This analysis:

13 14 18 Event selection: FT0, ZDC

6 7 15 Tracking: ITS, TPC

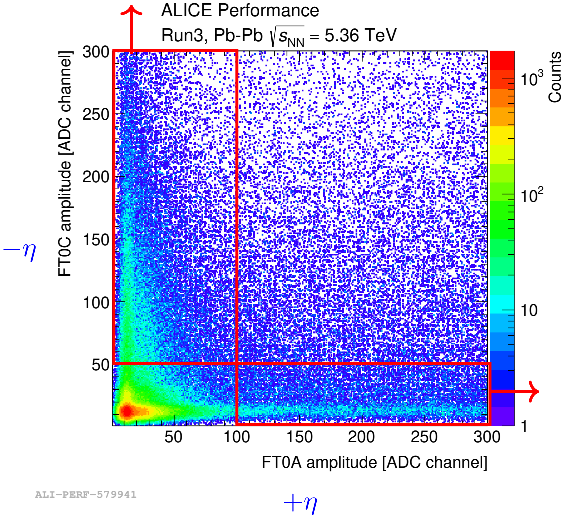
12 15 PID: TPC, TOF



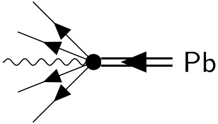
Zero Degree Calorimeter:
Measures energy of spectator nucleons

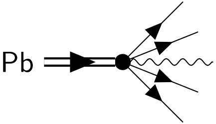
Rapidity gap selection is done using the FT0 detectors

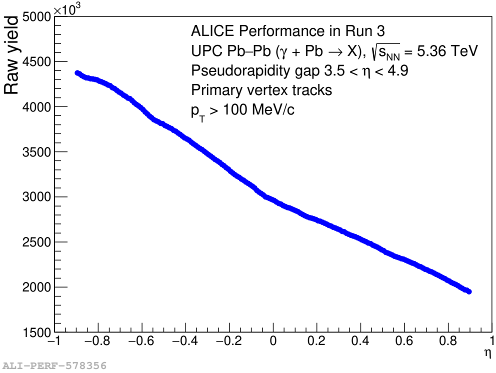
- FT0 measures charged particles at very forward rapidities:
- FT0-A: $3.5 < \eta < 4.9$
- FT0-C: $-3.3 < \eta < -2.1$
- Require amplitude below threshold on photon side, above threshold on gluon side

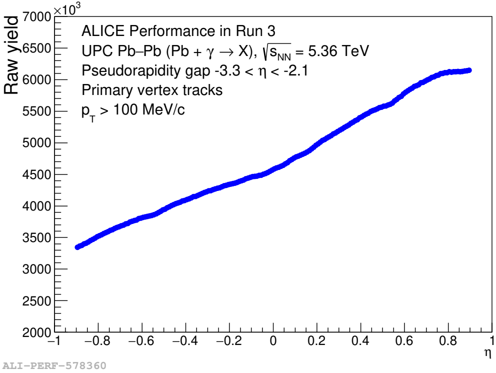


Event selection leads to asymmetric track pseudorapidity distributions in the central barrel



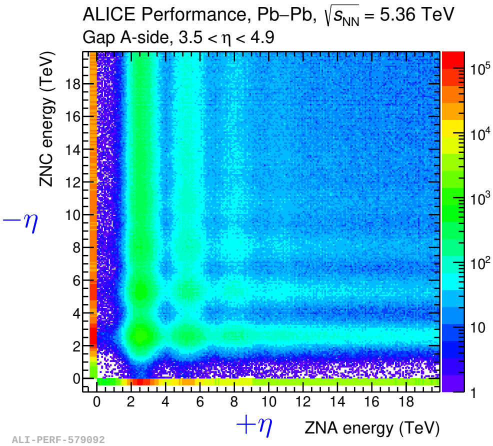


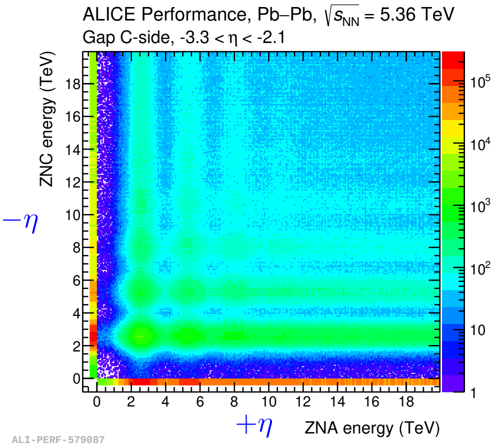




Further event selection is done by selecting on neutron emission

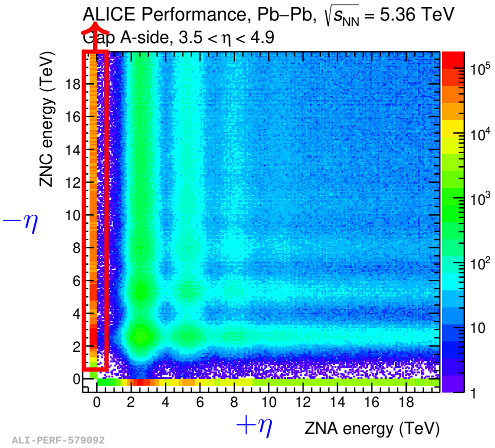
- Require 0 neutrons on the side with rapidity gap
- Require at least 1 neutron on the side opposite the rapidity gap

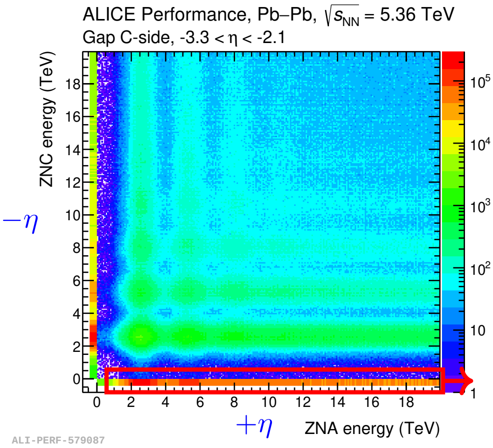




Further event selection is done by selecting on neutron emission

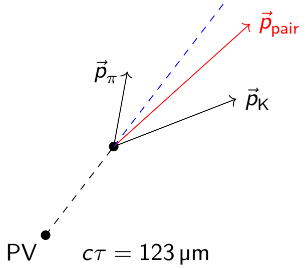
- Require 0 neutrons on the side with rapidity gap
- Require at least 1 neutron on the side opposite the rapidity gap

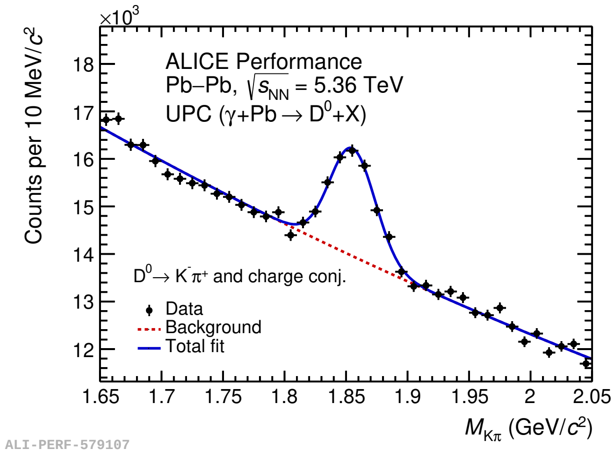




D^0 and $\overline{D}^0$ were reconstructed in the $K\pi$ decay channel

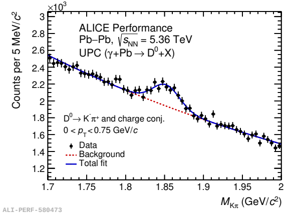
- Track $|\eta| < 0.9$, $p_T > 0.5\,\mathrm{GeV}/c$
- Kaon PID using TPC dE/dx and time-of-flight
- Selection on decay length projected along momentum

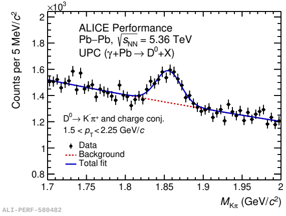


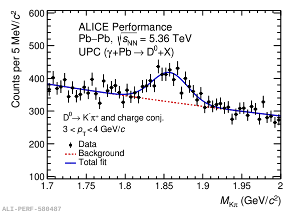


- Signal described by Gaussian, background by exponential function

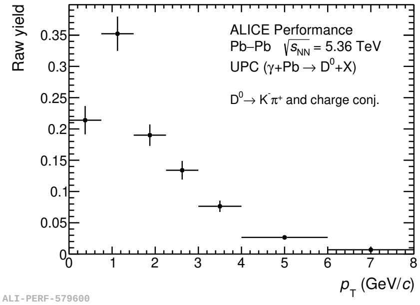
D^0 and $\overline{D}^0$ candidates are reconstructed down to $p_T = 0$





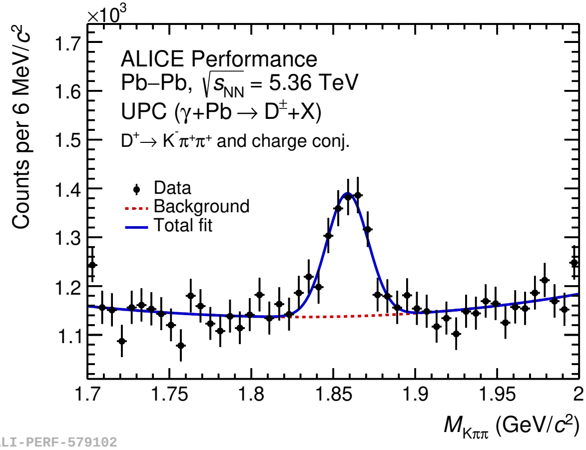


- Extract yield of D^0 in bins of p_T
- Bulk of production is at low p_T
- **ALICE covers down to $p_T = 0$, where low-x gluon dynamics is most relevant**



$D^{\pm}$ were reconstructed in the $K\pi\pi$ decay channel

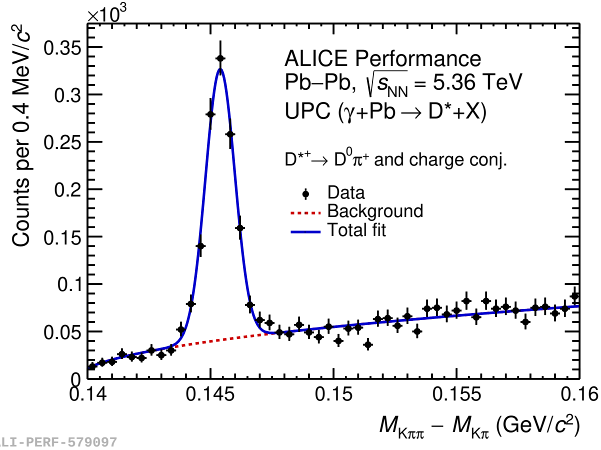
- Track $|\eta| < 0.9$, $p_T > 0.5\,\mathrm{GeV}/c$
- Kaon PID using TPC $\mathrm{d}E/\mathrm{d}x$ and time-of-flight
- Selection on decay length projected along momentum



- Signal described by Gaussian, background by 2nd degree polynomial

D^* were reconstructed in the $D^* \to D^0\pi \to K\pi\pi$ decay channel

- Track $|\eta| < 0.9$
- D^0 daughter candidates: $p_T > 0.5\,\text{GeV}/c$
- Primary π candidates: $p_T > 0.1\,\text{GeV}/c$
- Kaon PID using TPC dE/dx and time-of-flight
- Selection on D^0 decay length projected along momentum

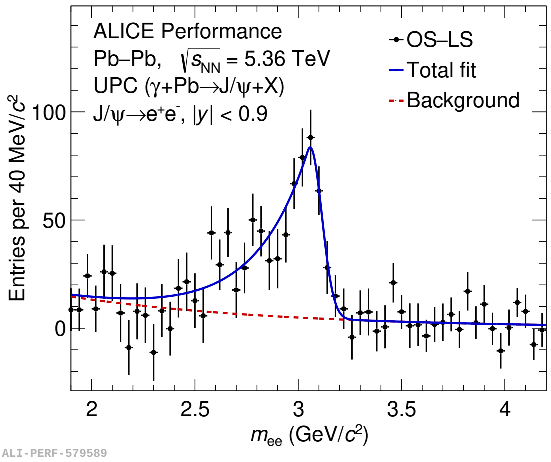


- Signal described by Gaussian, background by function $\alpha\sqrt{\Delta M - m_\pi}$

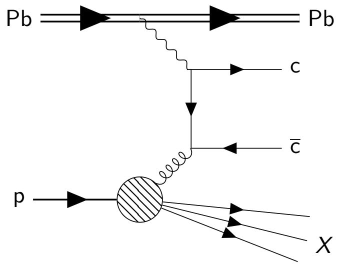
J/ψ was reconstructed in the dielectron channel

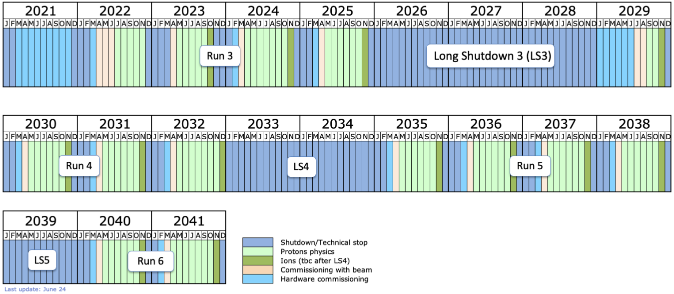
- Track $|\eta| < 0.9$
- Electron PID using TPC dE/dx and time-of-flight
- Electron $p_T > 1\,\text{GeV}/c$
- This is another example of physics processes never studied in UPCs before

- Access to many charm channels gives better handle on hadronization



p-Pb collisions in Run 4 will provide γ+p reference data

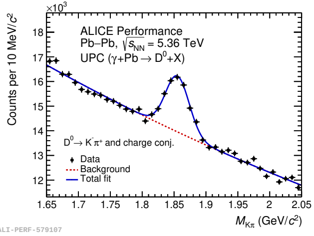


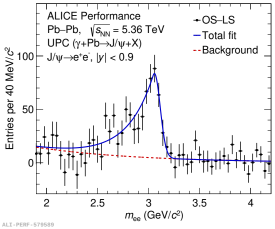


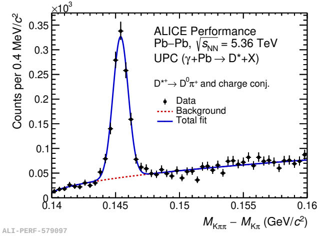
- p-Pb collisions planned for Run 4 will provide γ+p reference data
  $\rightarrow$ quantify nuclear effects

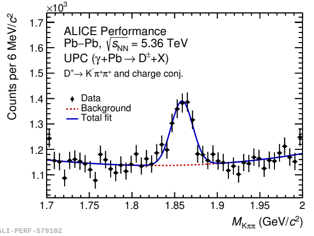
Summary and conclusions

- ALICE captures inelastic UPCs using continuous readout in Run 3
- D^0 and J/ψ are reconstructed down to $p_T = 0$
- Multiple charm channels will give better handle on hadronization
- Ongoing work to obtain normalized cross sections and compare to theory predictions



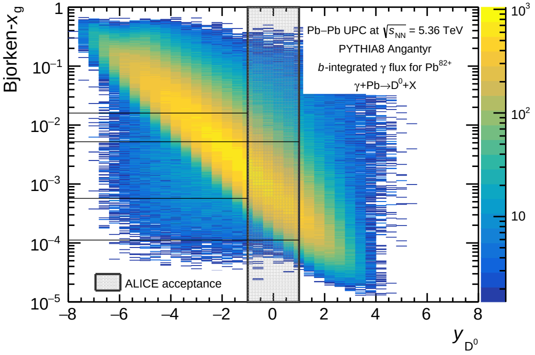


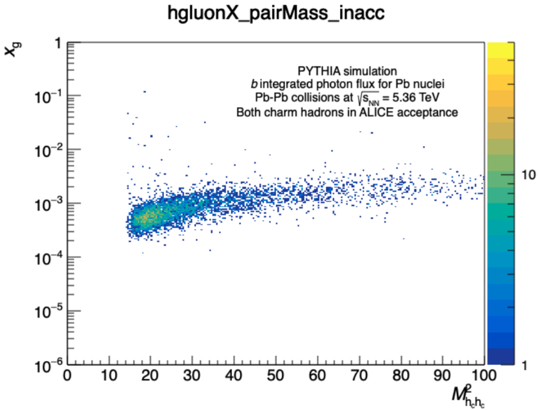




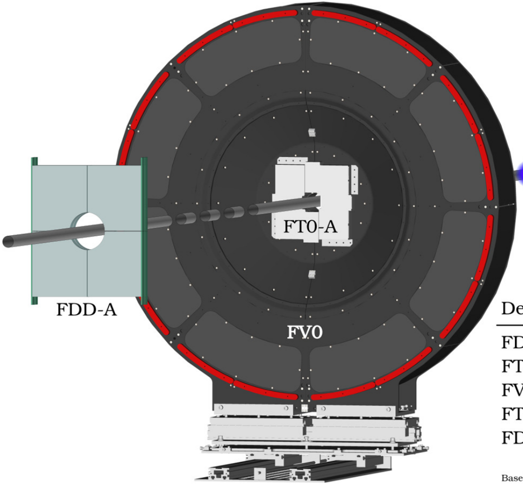
Backup

Reconstructing both charm hadrons in the event narrows the gluon x range of the measurement





FIT detector



Detector	z [mm]	η_{min}	η_{max}
FDD-A	16960	4.8	6.3
FT0-A	3346	3.5	4.9
FV0	3208	2.2	5.1
FT0-C	-843	-3.3	-2.1
FDD-C	-19566	-7.0	-4.9

z - distance parallel to beam direction between the nominal interaction point and the middle of sensitive detector element. Based on the latest detector position measurements as of 7.02.2022.

FT0

- Cherenkov quartz radiators with MCP-PMT for light detection. (MCP-PMT = Microchannel-plate photomultipliers)
- Each MCP divided into 4 channels.

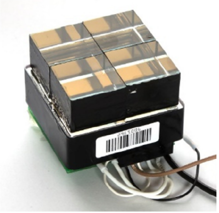


Fig. 2. MCP-PMT with coupled quartz radiator.