$f_0(980)$ Production with ALICE

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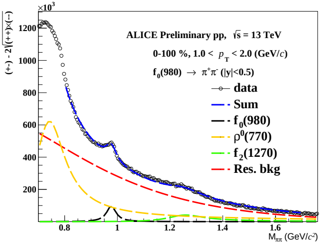
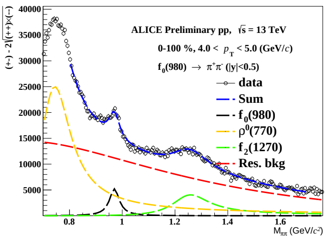
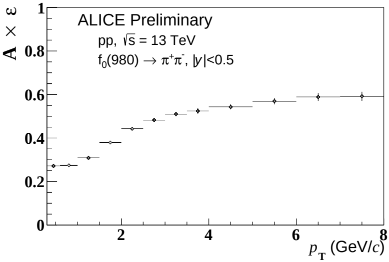
Status Summary for $f_0(980)$ Analysis

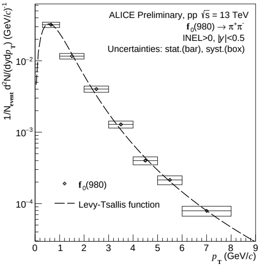
- $f_0(980)$ production in pp collisions at $\sqrt{s} = 5.02$ TeV
  - Preliminary result has been approved in QM 2018.
  - Analysis Note : `https://alice-notes.web.cern.ch/node/801`
- Multiplicity dependent $f_0(980)$ production in pp collisions at $\sqrt{s} = 13$ TeV
  - The transverse momentum spectrum with INEL>0 event class has been approved.
  - Multiplicity dependent study has not been approved in the summer conferences.
  - We are aiming Hard Probes 2020 for the approval.
  - Analysis Note : `https://alice-notes.web.cern.ch/node/884`
- Multiplicity dependent $f_0(980)$ production in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
- $f_0(980)$ production in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV
  - Analysis are going to be finalized to check the consistency with pp analysis results.
  - Preparation of approval in Hard Probes 2020.
  - Analysis Note : `https://alice-notes.web.cern.ch/node/1018`

Approved Figures

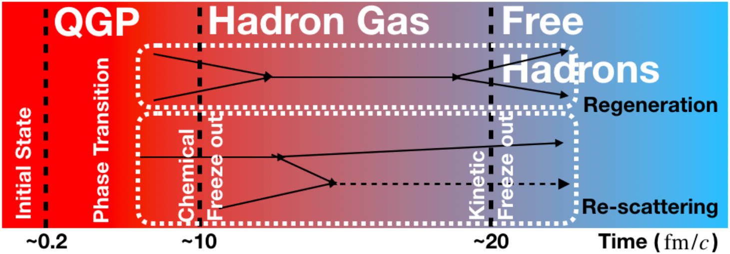








Short-lived Resonances

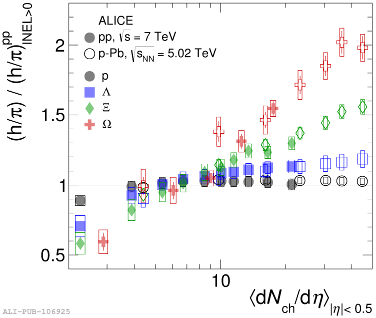


- Measured resonance yields are modified in the hadronic phase via regeneration and re-scattering.
- Short-lived resonances are powerful probes to understand late hadronic phase.
- The measurements of short-lived resonances in small collision systems provide the baseline for heavy-ion collisions measurement.

$f_0(980)$ Resonance

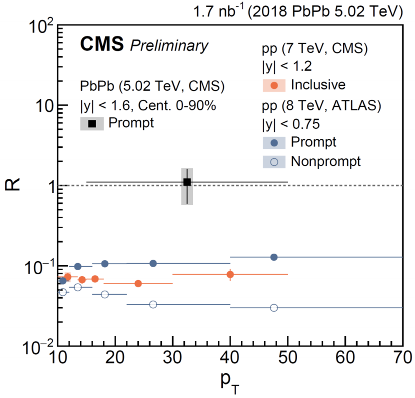
- Quark contents of $f_0(980)$ is still controversial if it is a molecular state or resonance including a glueball case.
- Recently, enhancement of strangeness particles has been observed even in small systems.
- Measurement of enhancement of $f_0(980)$ would give a hint of quark contents of $f_0(980)$.

	ρ^0	K^*	$f_0(980)$	ϕ
Mass(MeV)	775	892	990	1020
J^P	1^-	1^-	0^+	1^-
Quark	$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$d\bar{s}$	???	$s\bar{s}$



Recent X(3872) Results

- Recent measurement shows the increasing trend of particle ratio from small system (∼0.1) to large system (∼1).
- Indication of enhancement of recombination in the late phase of collisions due to lower bounding energy.
- Signature of mesonic molecule?



$$R = \frac{N_{X(3872)}}{N_{\psi(2S)}}$$

Experimental Data Sets and M.C. production

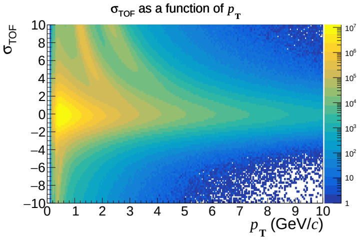
- proton-proton collisions at $\sqrt{s} = 5.02$ TeV
  - LHC15n_pass3 (Preliminary result)
- proton-proton collisions at $\sqrt{s} = 13$ TeV
  - LHC16g, LH16h, LH16i, LHC16j, LHC16k(pass2), LHC16l(pass2), LHC16o, LHC16p (2016)
  - LHC17g, LHC17i, LHC17j, LHC17k, LHC17l, LHC17m, LHC17o, LHC17r (2017)
- proton-Lead collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
  - LHC16q, LHC16t
  - CENT_wSDD + FAST for maximal statistics
- proton-Lead collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV
  - LHC16r
  - CENT_wSDD + FAST for maximal statistics
- Two types of M.C. production have been used.
  - Resonance injected M.C. for evaluating efficiency and acceptance
  - General purpose M.C. for evaluating normalization factors.

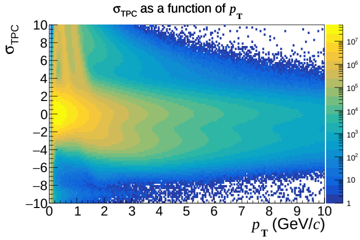
Nominal Selection

- Event Selection
  - kINT7 Trigger
  - The number of SPD vertex contributor ≥ 1
  - $\mid z_{\mathrm{vtx}} \mid < 10$ cm
  - SPD pileup rejection(MultBins)
- Track Selection
  - Global Trackig(0x20 in AOD)
  - $p_{\mathrm{T}} > 0.15$ GeV/c
  - $\mid \eta \mid < 0.8$
- Multiplicity Estimator as V0M for pp
- Multiplicity Estimator as V0A for p-Pb
  - Reference : `https://twiki.cern.ch/twiki/bin/viewauth/ALICE/ReferenceMult`

Particle Identification (pp@13 TeV)

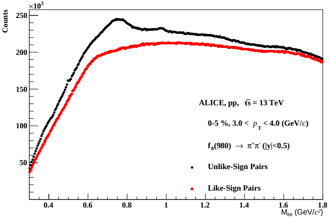
- $f_0(980)$ have been reconstructed via $f_0(980) \to \pi^+\pi^-$ decay.
  - PID is needed to select charged pions only.
- TOF and TPC subsystems have been used to select pion tracks.
  - The number of σ with pion mass assumption has been used
  - $\mid \sigma_{\mathrm{TOF}} \mid < 3$ if TOF is available.
  - $\mid \sigma_{\mathrm{TPC}} \mid < 2$ if TOF is not available.

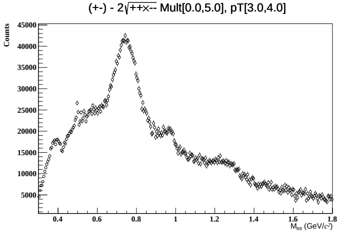




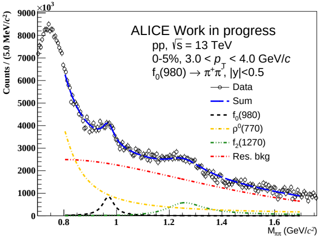
Like-Sign(LS) Background Subtraction

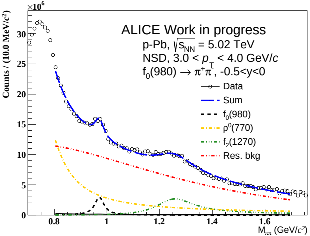
- Major uncorrelated background shape has been estimated by Like-Sign Shape in a given event class
  - $y_{\mathrm{LS}} = 2\sqrt{y_{++}y_{--}}$
- After subtracting combinatory background, peaks of all resonances decaying to $\pi^+\pi^-$ come out.





Signal Extraction



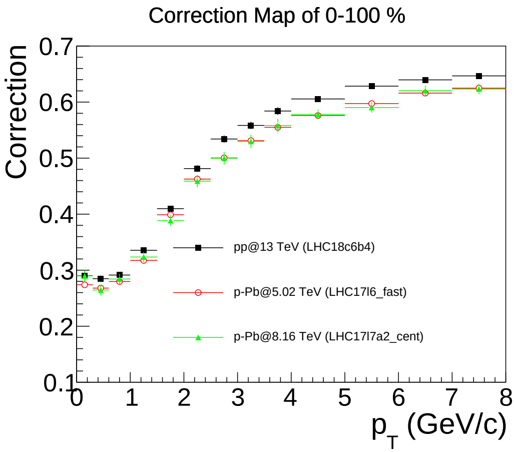


- Three resonances and remaining backgrounds have been considered to extract $f_0(980)$.
  - Each resonance is described as relative Breit Wigner function
  - Empirical distribution for backgrounds.
    - $f_{\mathrm{BG}}(M_{\pi\pi}) = (M_{\pi\pi} - 2m_\pi)^n A\exp(BM_{\pi\pi} + CM_{\pi\pi}^2)$
  - $f(M_{\pi\pi}) = N_\rho \mathrm{rBW}_{\rho^0}(M_{\pi\pi}) + N_{\mathrm{f}_0}\mathrm{rBW}_{\mathrm{f}_0}(M_{\pi\pi}) + N_{\mathrm{f}_2}\mathrm{rBW}_{\mathrm{f}_2}(M_{\pi\pi}) + f_{\mathrm{BG}}(M_{\pi\pi})$

Corrections to the Spectrum

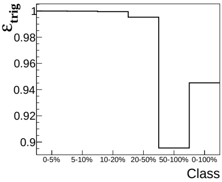
- $$\frac{d^2N}{dydp_{\mathrm{T}}} = \frac{1}{N_{\mathrm{evt}}}\frac{1}{\Delta y \Delta p_{\mathrm{T}}}\frac{N_{\mathrm{raw}}}{\mathrm{Acc}\times\epsilon}\frac{1}{\mathrm{B.R.}}\epsilon_{\mathrm{trig}} f_{\mathrm{vtx}} f_{\mathrm{S.L.}}$$
  - Acc corresponds to acceptance correction.
  - ϵ corresponds to efficiency correction.
    - $\mathrm{Acc}\times\epsilon = \dfrac{\mathrm{N_{rec}}}{\mathrm{N_{gen}}}$
  - ϵ_{trig} corresponds to trigger efficiency
  - f_{vtx} corresponds to event loss from vertex selection
  - $f_{\mathrm{S.L.}}$ corresponds to signal loss from event selection
- $$\frac{Y_{\mathrm{INEL}>0}}{N_{\mathrm{INEL}>0}} = \frac{Y_{\mathrm{kINT7\ \&\ vtx}}}{N_{\mathrm{kINT7\ \&\ vtx}}} \times \frac{N_{\mathrm{kINT7}}}{N_{\mathrm{INEL}>0}} \times \frac{N_{\mathrm{kINT7\ \&\ vtx}}}{N_{\mathrm{kINT7}}} \times \frac{Y_{\mathrm{INEL}>0}}{Y_{\mathrm{kINT7\ \&\ vtx}}}$$
  - $\epsilon_{\mathrm{trig}} = \dfrac{N_{\mathrm{kINT7}}}{N_{\mathrm{INEL}>0}}$
  - $f_{\mathrm{vtx}} = \dfrac{N_{\mathrm{kINT7\ \&\ vtx}}}{N_{\mathrm{kINT7}}}$
  - $f_{\mathrm{S.L.}} = \dfrac{Y_{\mathrm{INEL}>0}}{Y_{\mathrm{kINT7\ \&\ vtx}}}$

Acceptance and efficiency correction

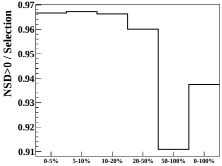


- Acc $\times \epsilon$ is estimated using resonance-injected M.C. production.
- Correction map is prepared as a functiion of multiplicity class and p_{T}.

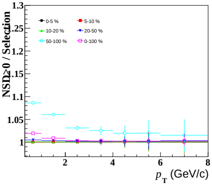
ϵ_{trig}, f_{vtx} and $f_{\mathrm{S.L.}}$ (pp@13 TeV)



(a) ϵ_{trig}



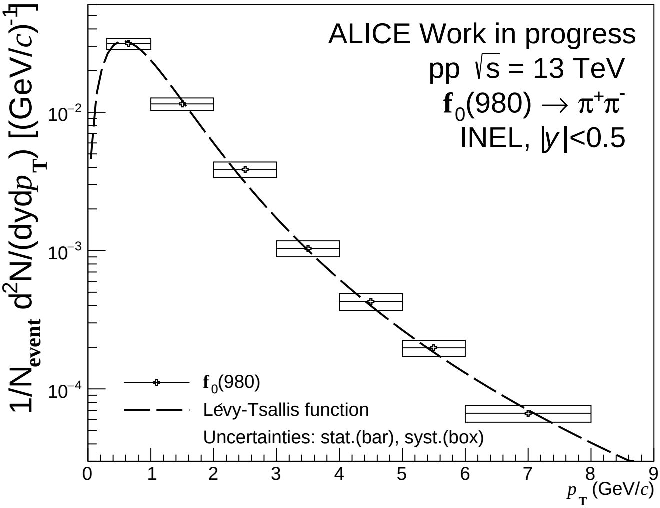
(b) f_{vtx}



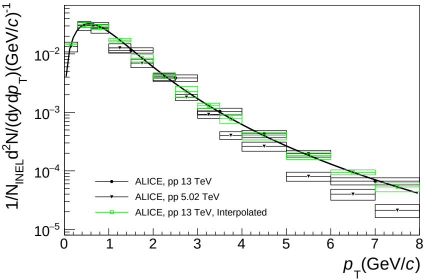
(c) $f_{\mathrm{S.L.}}$

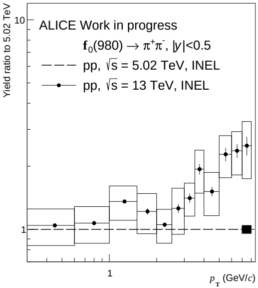
- Each correction has been applied to normalize measurement to INEL>0.
- All factors are obtained from general-purpose M.C.
  - Large statistical uncertainty in $f_{\mathrm{S.L.}}$ due to the small number of generated $\mathrm{f}_0(980)$.
    - Solution : Usage of abundant particles

$d^2N/dydp_{\mathrm{T}}$ with INEL event class



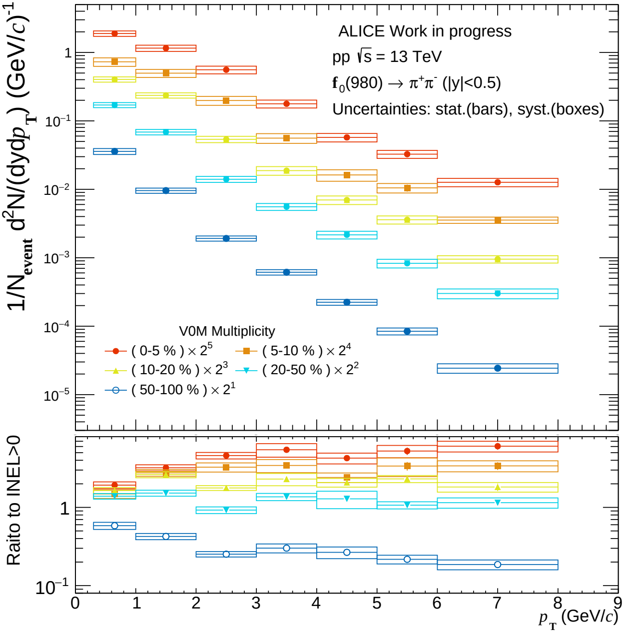
Comparison with 5 TeV Results



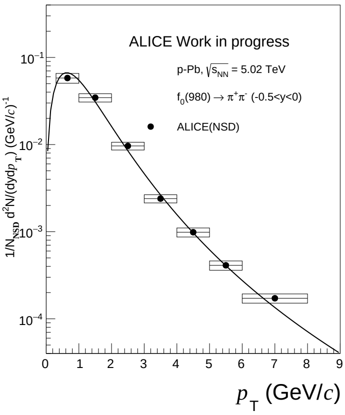


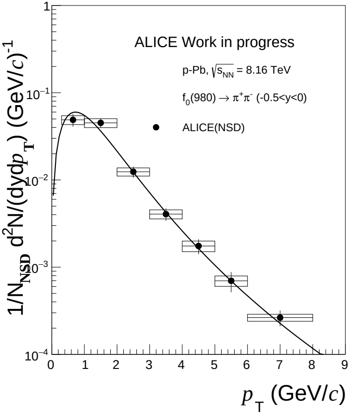
- Consistent behaviour in the low p_T
- Difference increases as p_T increases.

Multiplicity dependent $d^2N/dydp_\mathrm{T}$ in pp



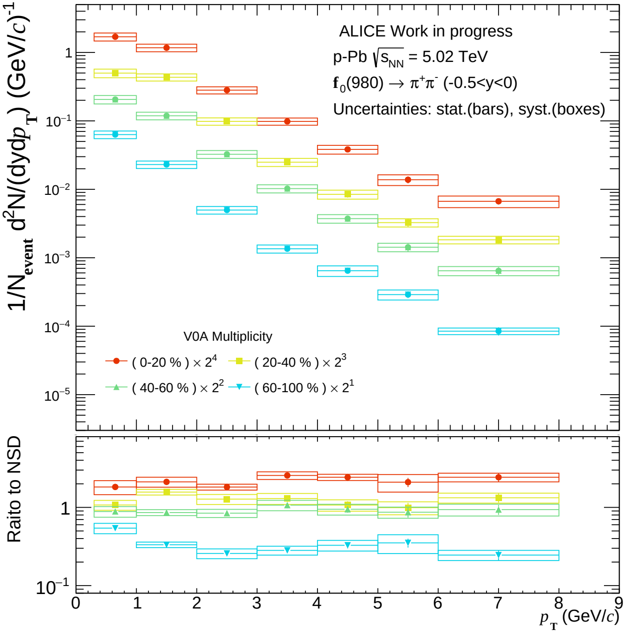
$d^2N/dydp_{\mathrm{T}}$ with NSD event class



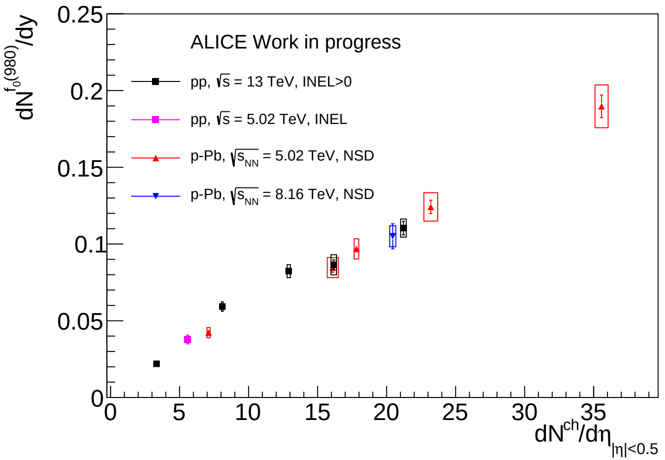


- 0-0.3 GeV$/c$ is extrapolated with the fitted function(Levy-Tsallis).

Multiplicity dependent $d^2N/dydp_{\mathrm{T}}$ in p-Pb

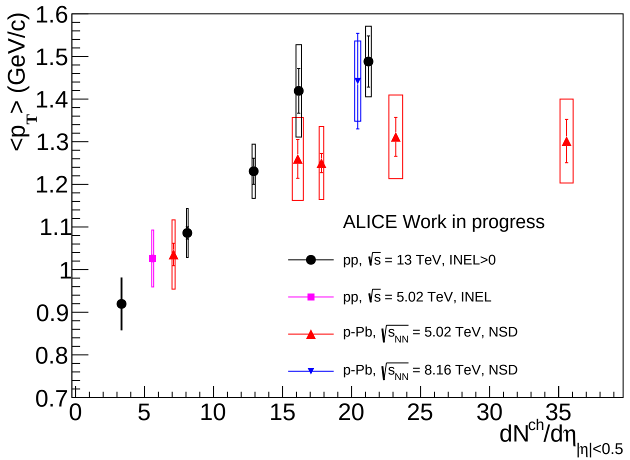


dN/dy as function of $dN_{\mathrm{ch}}/d\eta$



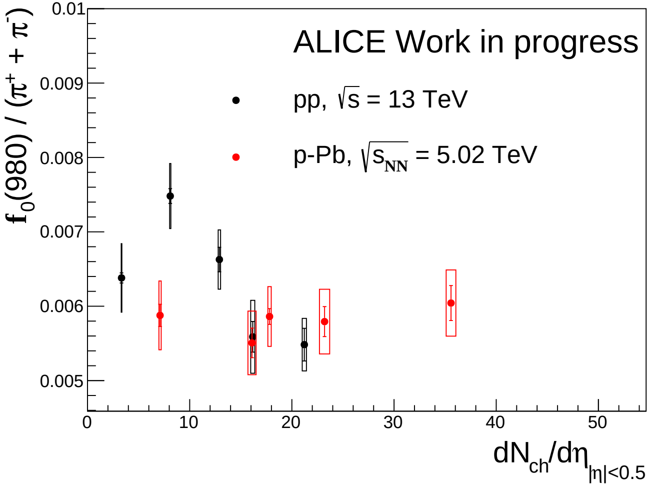
- Consistent behaviour can be seen between multiple collisions systems.

$< p_{\mathrm{T}} >$ as function of $dN_{\mathrm{ch}}/d\eta$



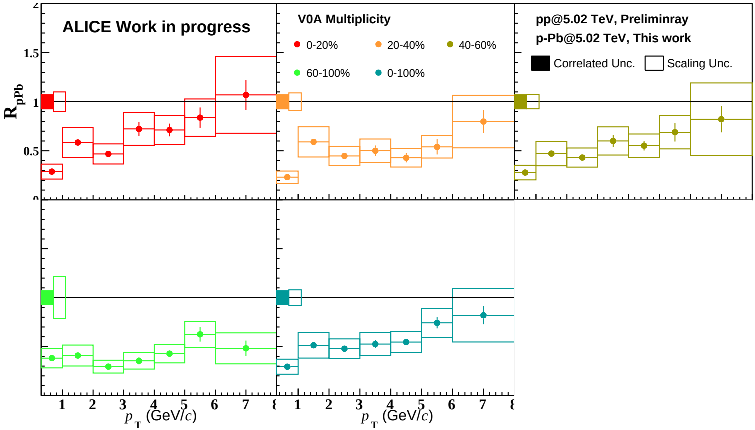
- Discrepancy has been observed between p-Pb@5.02 TeV and pp@13 TeV, which is also observed in other resonances.

Ratio of $f_0(980)$ to charged pions



- Relative enhancement of $f_0(980)$ has not been observed.

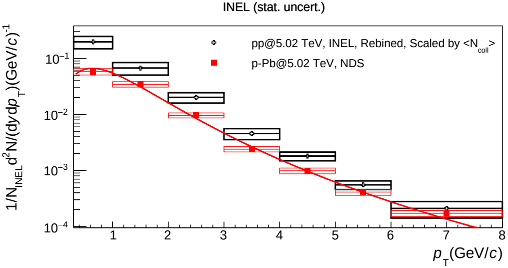
R_{pPb} of $f_0(980)$ at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV



- Unexpected strong suppression has been observed especially in peripheral collisions.
- Maybe missing a factor of 2?, still under investigation..

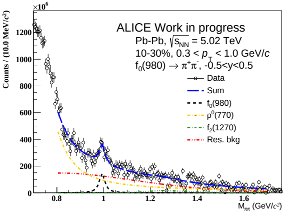
Mistake during calculation of R_{pPb}?

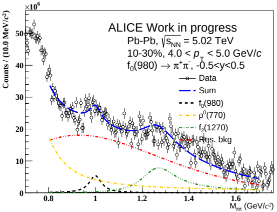
- In pp@5.02 TeV, $dN/dy = 0.0378$ at $dN_{\mathrm{ch}}/d\eta = 5.6$
- In p-Pb@5.02 TeV, $dN/dy = 0.0968$ at $dN_{\mathrm{ch}}/d\eta = 17.8$
  - Production of $\mathrm{f}_0(980)$ linearly increases as charged particle multiplicity increases.
- $< N_{\mathrm{coll}} > = 6.9$, `10.1103/PhysRevC.91.064905`
  - $R_{\mathrm{pPb}} \sim \dfrac{0.0968}{0.0378 \times 6.9} \sim 0.4$
- $< p_{\mathrm{T}} >$ in pp $= 1.0$ GeV/c and p-Pb $= 1.2$ GeV/c, similar shape?

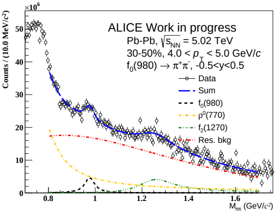


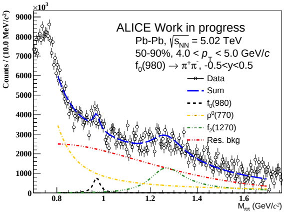
- At least, measured numbers look properly treated during the calculation...

Possible Study of $f_0(980)$ Production in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE



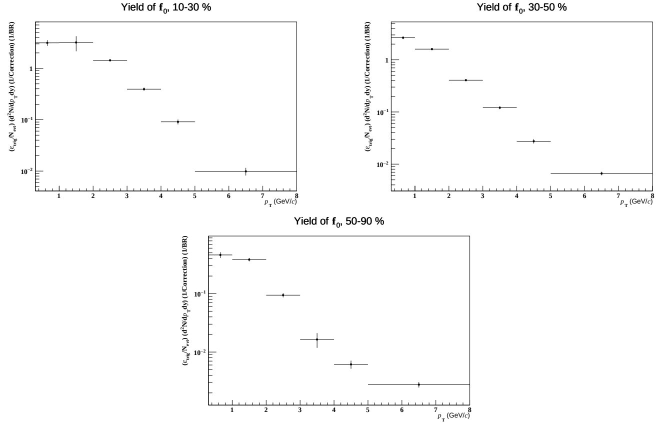






- kINT7 trigger + dedicated triggers(kSemiCentral, kCentral...)

Raw p_{T} Spectra of $\mathrm{f}_0(980)$ in Pb-Pb collisions



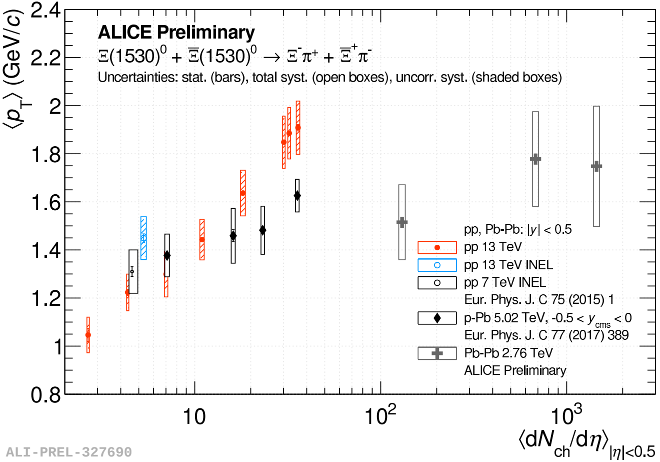
- Need optimization of fit quality and bin definition.
- Only efficiency and acceptance effects are corrected, need full normalization.
- Still analyzing most central event class(0-10%)

Summary

- Studies of $f_0(980)$ production have been done with ALICE.
  - Multiplicity dependent pp@13 TeV
  - Multiplicity dependent p-Pb@5.02 TeV
  - p-Pb@8.16 TeV
- Comparison between multiple collisions systems has been prepared.
- Strangeness enhancement has not been observed so far.
- Unexpected R_{pPb} have been measured.
  - Investigation of any possible mistakes are still ongoing.
  - Signature of molecular state particle??
    - Too hasty..
    - Coalescence process of $K\overline{K}$?
- $f_0(980)$ Production in Pb-Pb@5.02 TeV can be done.

Backup

$< p_{\mathrm{T}} >$ of $\Xi(1530)^0$



$< p_{\mathrm{T}} >$ of $\mathrm{K}^{*0}(892)$