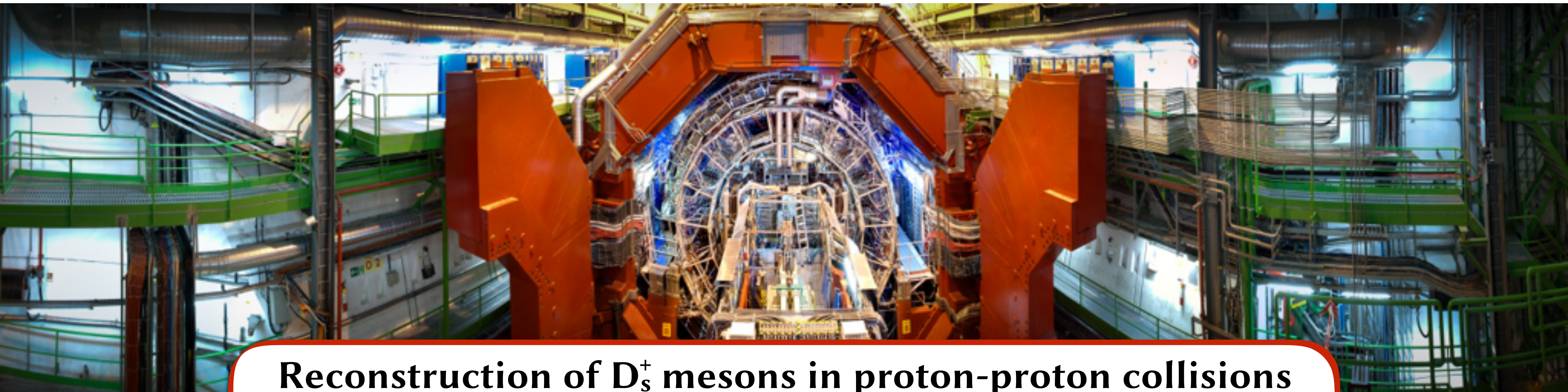


Reconstruction of D_s^+ mesons in proton-proton collisions at central rapidity with ALICE

Julien Hamon

Université de Strasbourg

Institut Pluridisciplinaire Hubert Curien

Rencontres QGP France 2016

October 10-13

Julien.Hamon@cern.ch

Outline

- Introduction on D-meson and D_s physics
- Reconstruction of a new decay channel in ALICE: $D_s^+ \longrightarrow K_S^0 K^+$
- D_s cross-section in pp collisions at $\sqrt{s} = 7$ TeV
- Conclusion

Heavy-quark specificities

madai-public.cs.unc.edu

Charm ~ 1.3 GeV/c^2
Beauty ~ 4.2 GeV/c^2

Why are heavy quarks interesting?

Heavy quarks are interesting *probes* offering insights into the strong interaction

a./ Produced in hard scattering processes: sensitive test of pQCD (large quark masses)

b./ Short formation time: heavy quarks are produced before the QGP formation
$\Delta t_c < 1/(2m_c) \sim 0.1$ fm/c < $\tau_{QGP} \sim 0.3$ - 1 fm/c at LHC

c./ Negligible annihilation rate: heavy quarks experience the *whole* collision history

d./ Interact with the medium constituents: via elastic (collisions) and/or inelastic (radiations) processes?

e./ Hadronize: via fragmentation and/or coalescence processes?

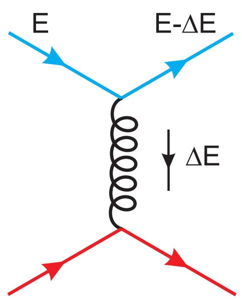
Heavy-flavour hadrons

Front door to access the medium properties affecting heavy quarks: **D**, **B**, J/Ψ, Ψ(2S), Υ(1S, 2S, 3S), Λ_c ...

Heavy quark interactions with the medium

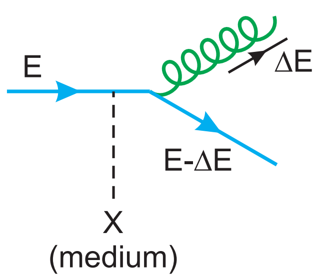
Medium properties are accessible by understanding the *interactions* of heavy quarks with the medium constituents.

Heavy quark energy loss:



1./ Elastic processes (*collisional*): scatterings with other partons, *dominate at low p_T ($p_Q < 10\ m_Q$)*

2./ Inelastic processes (*radiative*): gluon radiations, *dominate at high p_T ($p_Q > 10\ m_Q$)*



- Colour-charge dependence Baier, Dokshitzer, Mueller, Peigné, Schiff: Nucl. Phys. B483 (1997) 291-320
  Casimir factor: $C_R = 3$ for gluons; 4/3 for quarks
- Mass dependence: *dead-cone effect* Dokshitzer, Kharzeev: Phys. Lett. B519 (2001) 199-206
  Energy distribution of radiated gluons is suppressed by an angle-dependent factor

+ Other processes: in-medium hadron formation and dissociation Adil, Vitev: Phys. Lett. B649 (2007) 139-146

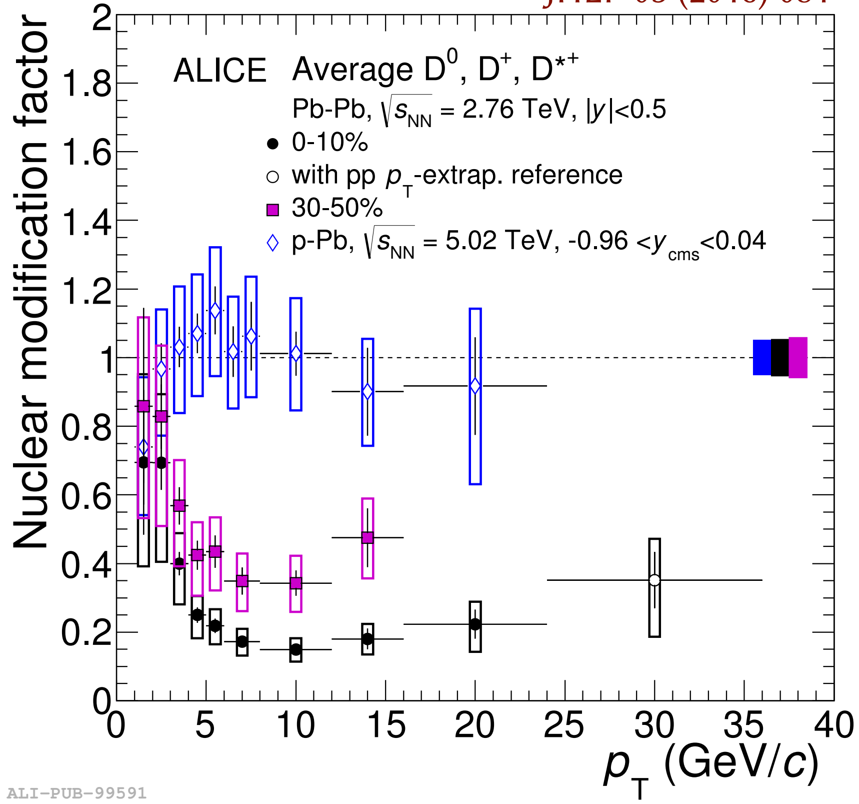
$\Delta E(g) > \Delta E(u,d,s) > \Delta E(c) > \Delta E(b)$ $\xrightarrow{?}$ $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$

The reduction of parton energy leads to a reduction of the average momentum of the produced parton, quantified by the ***nuclear modification factor:***

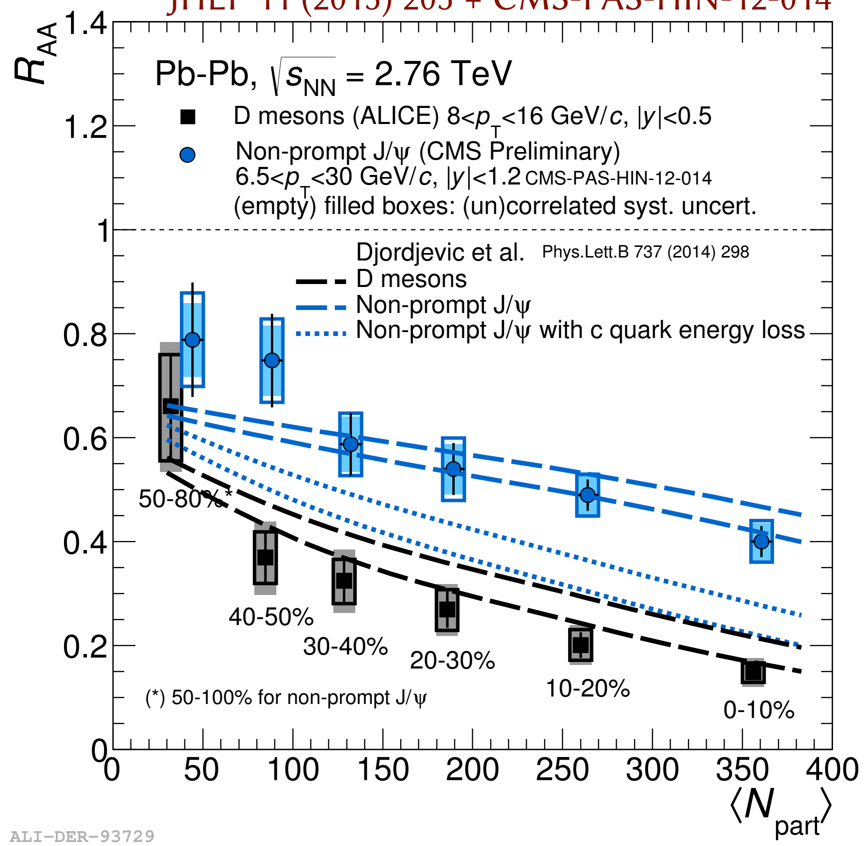
$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \cdot \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

D-meson suppression as a function of centrality

JHEP 03 (2016) 081



JHEP 11 (2015) 205 + CMS-PAS-HIN-12-014



- Large *suppression* of D mesons (D$^+$, D^0, D^{*+}) in **Pb-Pb** collisions
- Stronger suppression for **central Pb-Pb collisions**, up to a factor of 5-6, than for **semi-central collisions**, up to a factor 3.

0-10% **30-50%**

- No significant suppression in MB **p-Pb collisions** for p_T > 2 GeV/c
  Phys. Rev. Lett.113 (2014) 232301

***Interpretation*:**

- suppression observed in Pb-Pb cannot be caused by Cold Nuclear Matter effects
- stronger energy loss in central collisions due to the increase of medium density, size and lifetime

$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$?

$R_{AA}(\mathbf{D}) < R_{AA}(\mathbf{J/\Psi} \leftarrow B)$ as expected since $\Delta E(c) > \Delta E(b)$

Data in qualitative agreement with ***Djordjevic*** model, which contains:

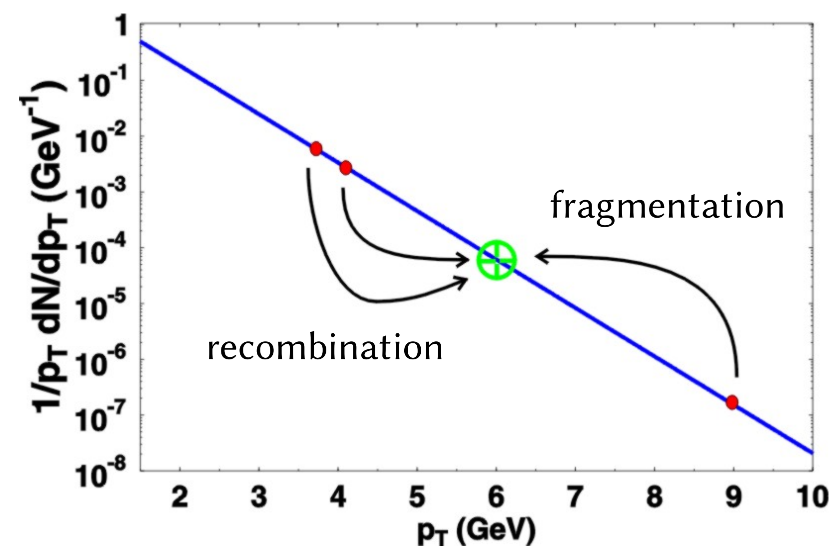
- Mass-dependent energy loss for gluons, light and heavy quarks: radiative & collisional
- Hadronization by fragmentation outside the medium

D_s^+ meson: a probe for hadronization

Hadronization:

1./ Fragmentation: in the vacuum, *dominates at high p_T*

2./ Recombination: for quarks close in the phase space, *may dominate at low p_T*

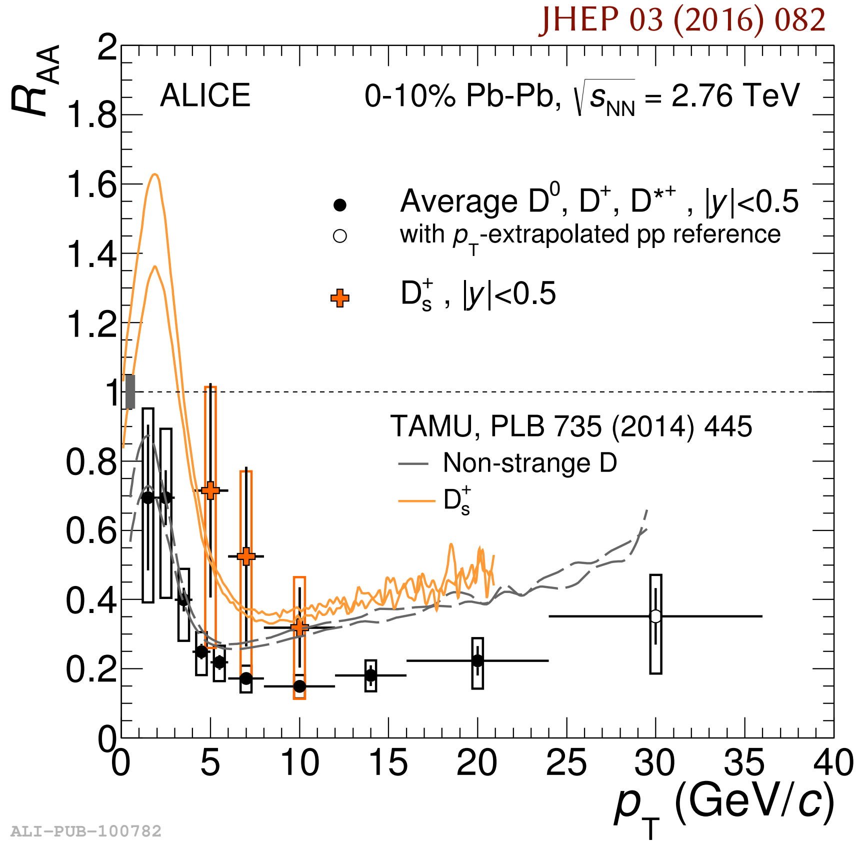


If charm quarks recombine in the QGP, the relative fraction of strange vs. non-strange D mesons might increase at low p_T

$R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$?

$R_{AA}(D^+, D^0, D^{*+}) < R_{AA}(D_s^+)$?

JHEP 03 (2016) 082



- **TAMU** expects enhancement of the D_s/D in heavy-ion collisions

Expanding medium (3+1d ideal hydrodynamic)	Collisional ***energy loss*** (HQ transport + scattering in hadronic phase)	Fragmentation ***Recombination***

- D_s points seem systematically above the non-strange D-meson ones, but measurements are compatible within uncertainties

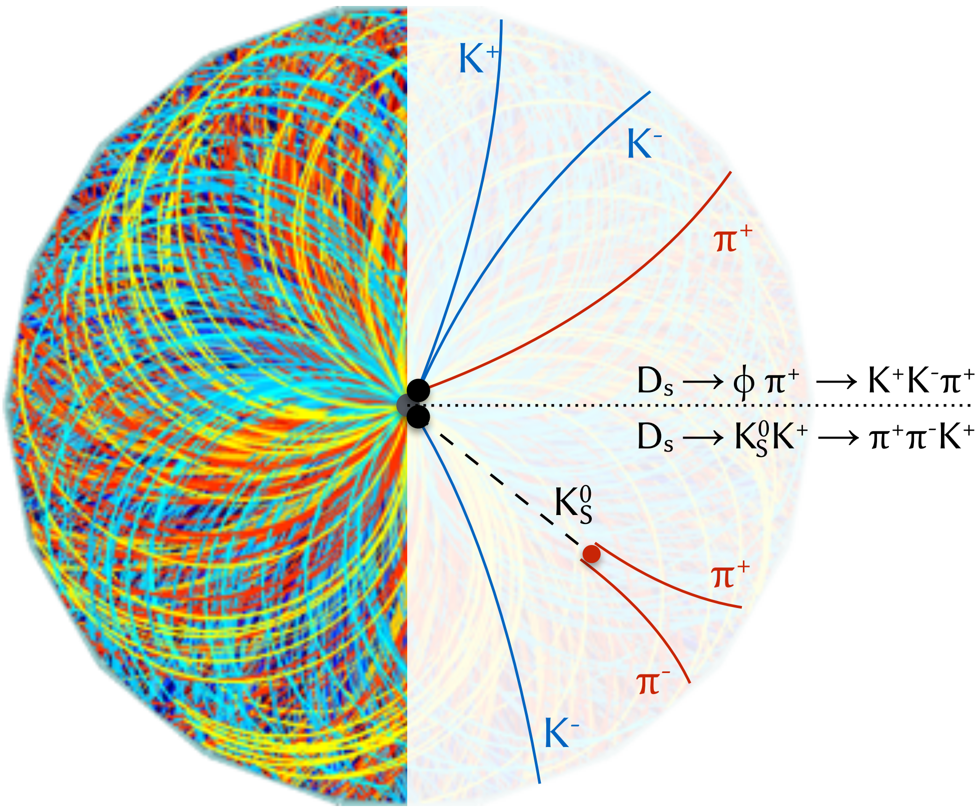
- No firm conclusion with this first measurement in Pb-Pb collisions

Need more precise measurements of D_s^+ mesons

Outline

- Introduction on D-meson and D_s physics
- Reconstruction of a new decay channel in ALICE: $D_s^+ \longrightarrow K_S^0 K^+$
- D_s cross-section in pp collisions at $\sqrt{s} = 7$ TeV
- Conclusion

D_s^+ alternative decay channel



D_s^+ (1968.3 MeV/c^2)	$\phi(1020)\pi^+$	(2.24 ± 0.10 %)	✔ Usual channel
	$K_S^0K^+$	(1.49 ± 0.06 %)	✔ Alternative

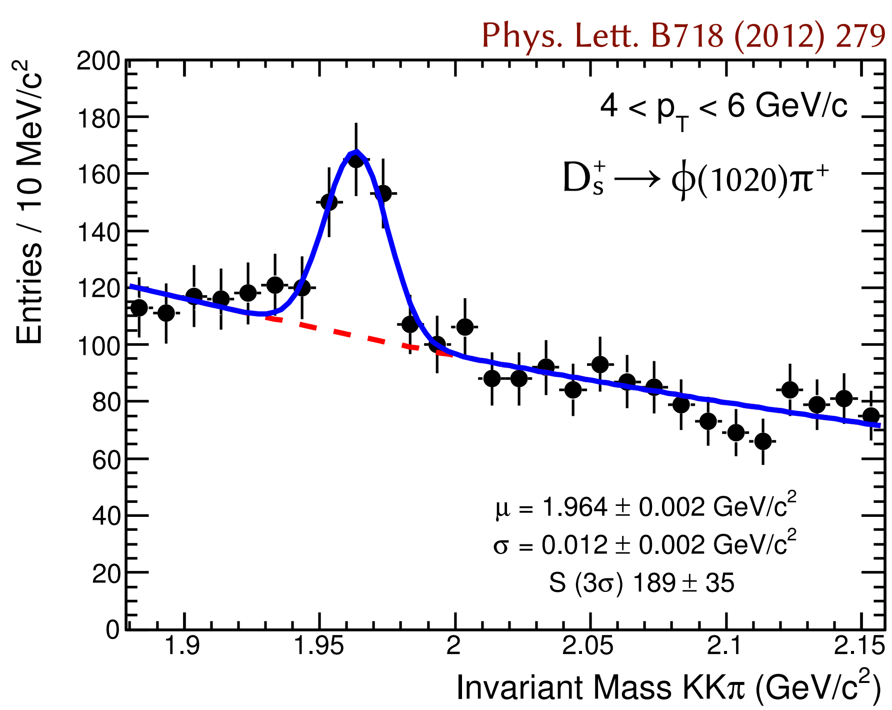
Cons:

- ✘ 33.5% lower branching ratio
- ✘ Lower resolution on the reconstructed mass of D_s^+ candidates

Pros:

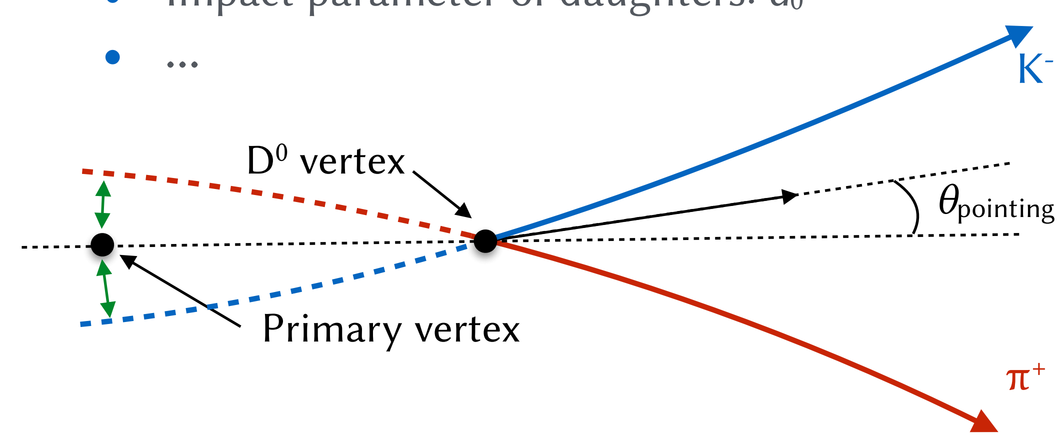
- ✔ High reconstruction efficiency for K_S^0 than for ϕ (especially at high-p_T)
- ✔ No need of detector PID to identify K_S^0
- ✔ Two decay channels allow to better control the systematics

Combinatorial background reduction performed by exploiting the **D_s^+ displacement** ($c\tau$ ~150 μm) and applying **topological** selections



Typical topological selections have to be optimised per p_T-bin

- D-meson decay length: L_{xy}
- D-meson pointing angle: $\cos(\theta_{pointing})$
- Impact parameter of daughters: d_0
- ...



D-meson studies with ALICE

***A Large Ion Collider Experiment*:** designed for the QCD study

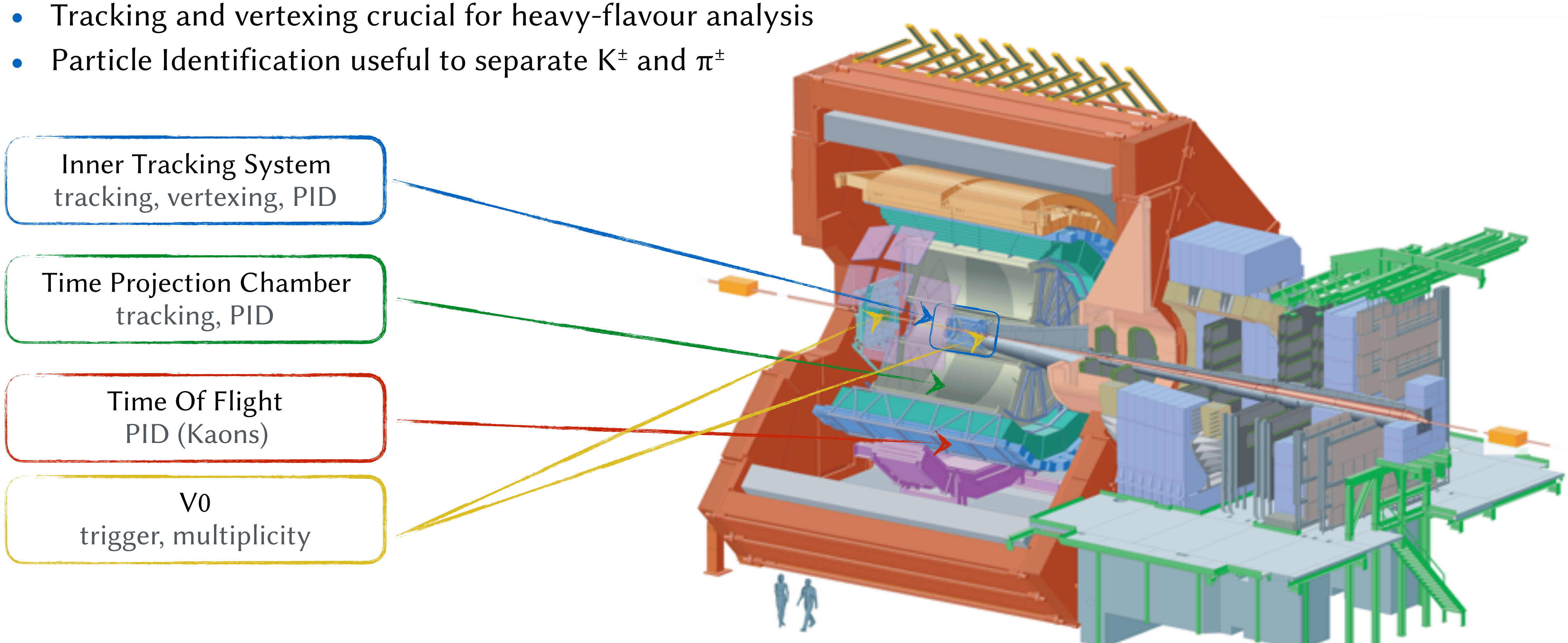
Optimised to work in high-track density environment, reach low p_T (~100 MeV/c) measurements with good PID capabilities

Open-charm hadrons studied in ALICE:

- Decay electrons: D, Λ_c^+, B $\longrightarrow$ e + X in $|\eta| < 0.9$
- Decay muons: D, Λ_c^+, B $\longrightarrow$ μ + X in $-4 < \eta < -2.5$
- Hadronic ($\pi^\pm$, $K^\pm$) channels in $|\eta| < 0.9$

Hadronic *full* reconstruction of D mesons: invariant mass analysis in $|\eta| < 0.9$

- Tracking and vertexing crucial for heavy-flavour analysis
- Particle Identification useful to separate $K^\pm$ and $\pi^\pm$



Outline

- Introduction on D-meson and D_s physics
- Reconstruction of a new decay channel in ALICE: $D_s^+ \longrightarrow K_S^0 K^+$
- D_s cross-section in pp collisions at $\sqrt{s} = 7$ TeV
- Conclusion

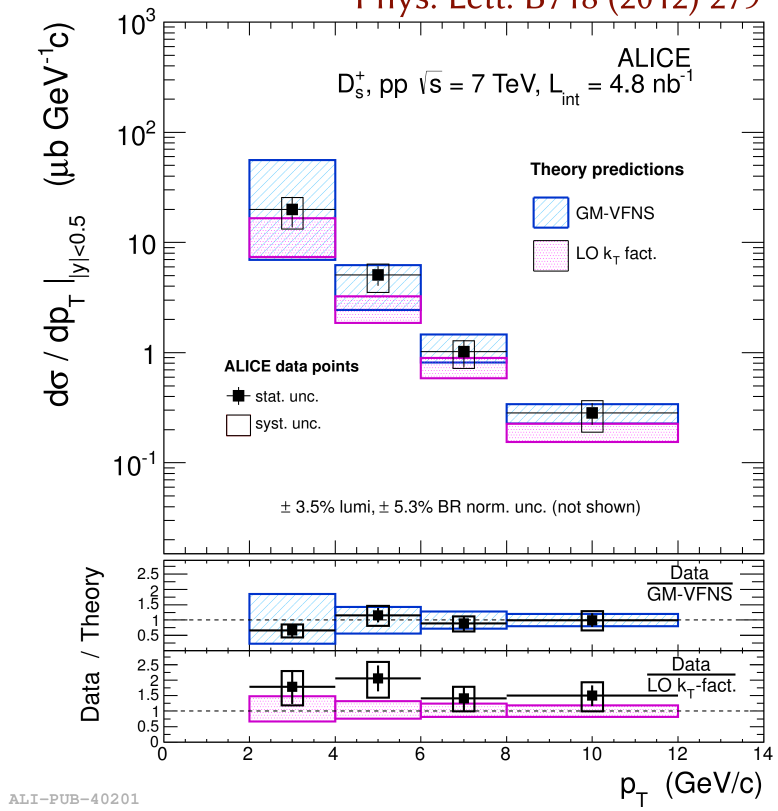
First attempt on LHC Run I data

Objective: explore the possibilities offered by the $D_s^+ \longrightarrow K_S^0 K^+$ channel

- prepare the analysis framework for the pp collisions at 13 TeV
- compare the published D_s^+ measurements (usual channel) with the new K_S^0 channel

Inclusive D_s cross section: in 390M minimum-bias proton-proton collisions at $\sqrt{s}$ = 7 TeV

Phys. Lett. B718 (2012) 279



$$\left.\frac{d\sigma}{dp_T}\right|_{|y|<0.5}^{\text{inclusive}} = \frac{1}{2 \cdot \underbrace{\text{BR} \cdot L_{\text{int}}}_{3.}} \frac{\overbrace{\left.N^{D_s^\pm}\text{ raw}\right|_{|y|<y_{\text{fid}}}}^{1.}}{\Delta y \cdot \Delta p_T \cdot \underbrace{(\text{Acc} \times \epsilon)_{\text{inclusive}}}_{2.}}$$

1. Extract the number of $D_s^\pm$ per p_T bin, in a given y-range
2. Correct the bias due to the experimental setup and reconstruction method
3. Known from previous studies

First attempt ***without*** systematics

1. Extract the D_s^+ raw yield

Particle identification: to identify the bachelor particle as a K^+

- combined use of TPC and TOF
- rather loose PID (TPC: 3σ from the expected value / TOF: within 2σ)

Topological selections: optimised by hand, per p_T bin. They can be further improved with the help of Monte Carlo.

Selection variables	Cut values
$\|M(V0) - M_{PDG}(K_S^0)\|$	< 3 σ
$d_0(\pi^\pm)$	> 700 µm
$DCA(\pi^+, \pi^-)$	< 1 σ
$c\tau(K_S^0)$	< 5
$r_{XY}(V0)$	> 0.5 cm
$p_T(K^+)$	> 1.7 GeV/c
$\cos(\theta_{pointing})$	> 0.75
$\|\cos(\theta^*)\|$	< 0.78
$DCA(K_S^0, K^+)$	< 0.5 cm
Decay length	> 300 µm

Signal (N^{raw}) extracted by **fitting**

Work in progress

A clear $D_s^+ \longrightarrow K_S^0 K^+$ signal is observed

1. Extract the D_s^+ raw yield

And then do the same for other p_T bins...

Work in progress

Work in progress

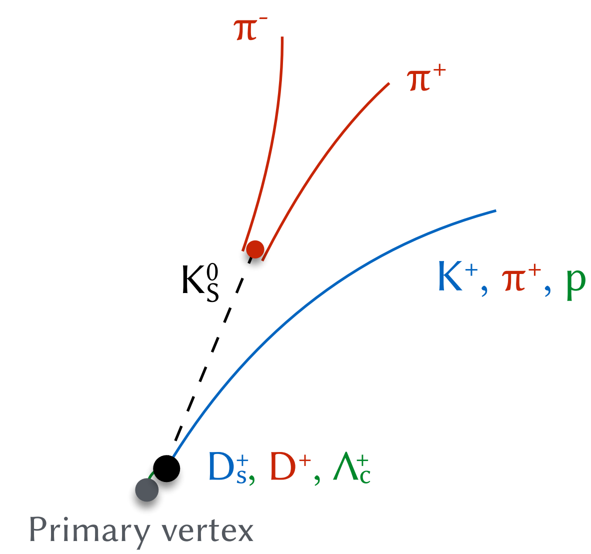
Work in progress

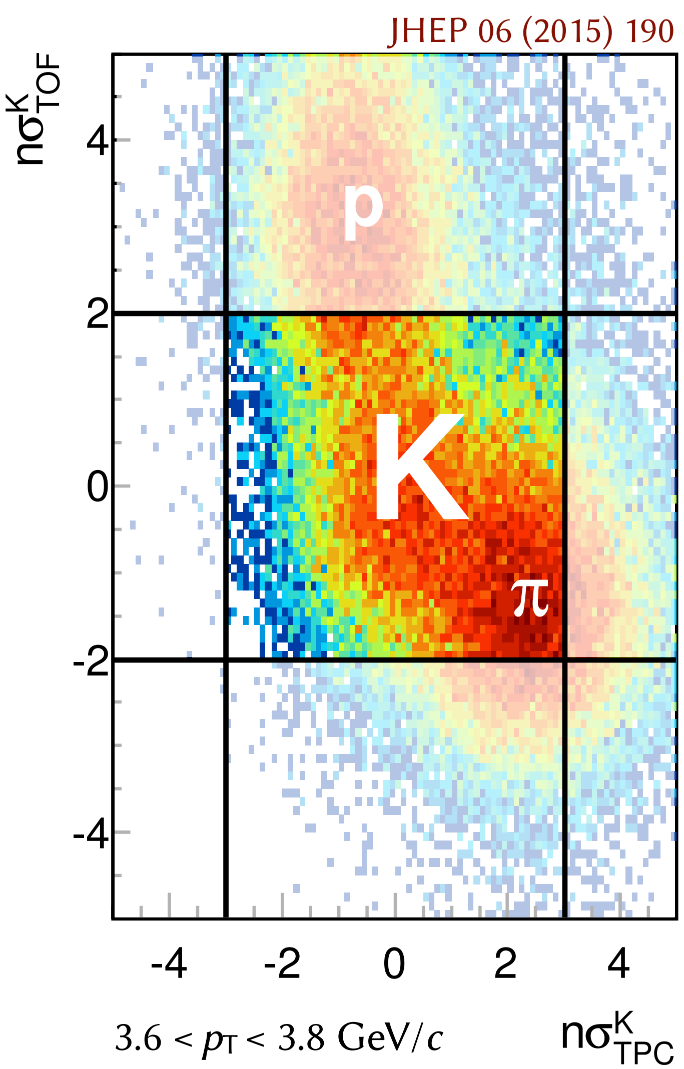
Work in progress

A clear $D_s^+ \longrightarrow K_S^0 K^+$ signal is observed

The combinatorial background is not fully reproduced by the background (exponential) function.

- Two similar decays can **contaminate** the signal region: $D^+ \to K^0_S \pi^+$, $\Lambda_c^+ \to K^0_S p$
- **No protection** has been applied to prevent this contamination so far, except (loose) PID





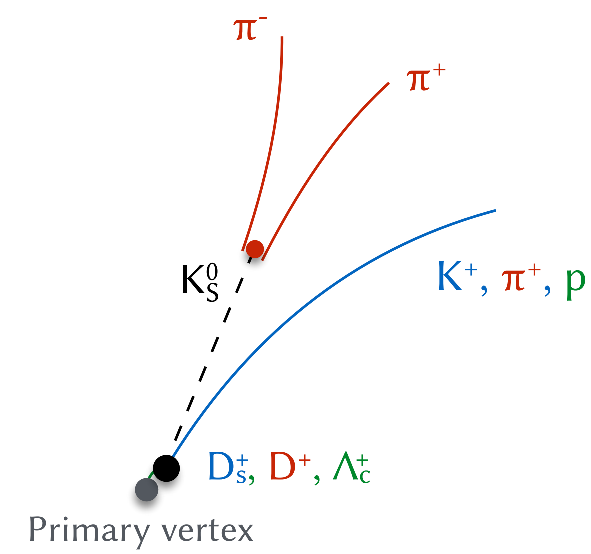
With the current loose PID, the $K^\pm$ candidates are contaminated by $\pi^\pm$, thus $D_s^+ \to K^0_S K^+$ candidates are contaminated by $D^+ \to K^0_S \pi^+$

Extract the D_s^+ raw yield

The combinatorial background is not fully reproduced by the background (exponential) function.

- Two similar decays can **contaminate** the signal region: $D^+ \rightarrow K^0_S \pi^+$, $\Lambda_c^+ \rightarrow K^0_S p$
- **No protection** has been applied to prevent this contamination so far, except (loose) PID
- Contamination **estimated** with the help of Monte Carlo simulations

$$N^{\text{raw}} = (1 - c^{\text{contamination, MC}}) \times N^{\text{raw, measured}}$$



Work in progress

Work in progress

A data-driven approach to limit (as drastically as possible) the D^+ contamination in the signal region is being investigated...

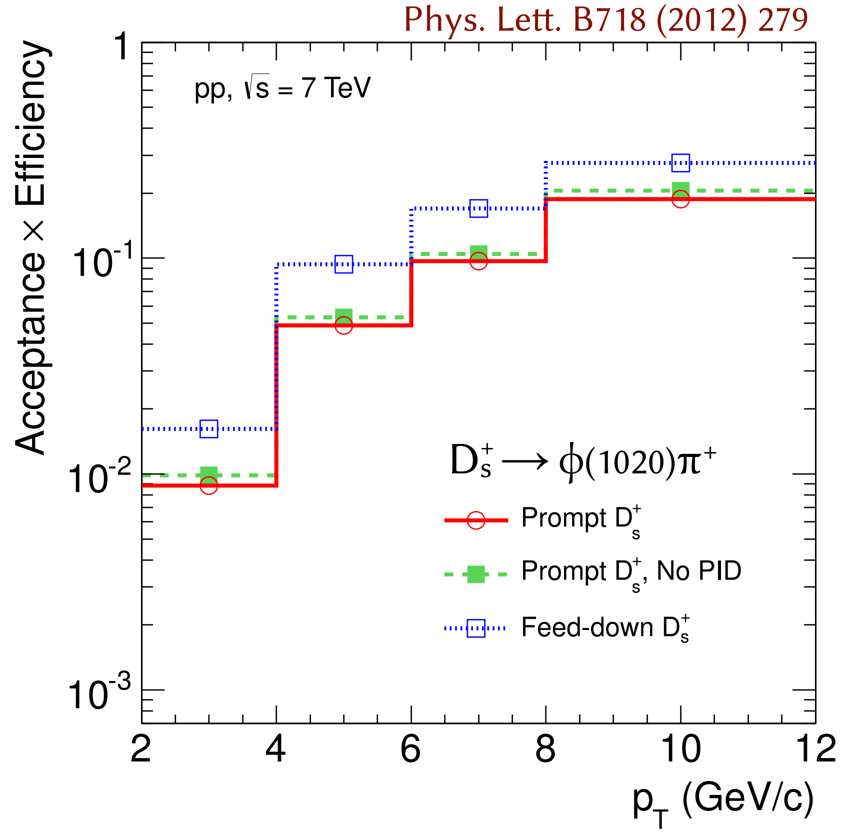
2. Acceptance and efficiency corrections

$$\left.\frac{d\sigma}{dp_T}\right|_{|y|<0.5}^{\text{inclusive}} = \frac{1}{2 \cdot \underbrace{\mathrm{BR} \cdot L_{\text{int}}}_{3.}} \frac{\overbrace{\left. N^{D_s^\pm \text{ raw}} \right|_{|y|<y_{\text{fid}}}}^{1.}}{\Delta y \cdot \Delta p_T \cdot \underbrace{(\mathrm{Acc} \times \epsilon)_{\text{inclusive}}}_{2.}}$$

Acceptance × Efficiency: have to be estimated to account for

- the limited acceptance of the detector
- the reconstruction efficiency of D_s mesons: tracks, vertex and selection cuts

Phys. Lett. B718 (2012) 279



ALI-PUB-40184

Work in progress

- Roughly similar (Acceptance × Efficiency) for prompt-D_s for the first 3 p_T bins

Comparison of D_s cross sections

D_s cross-section comparison: $D_s^+ \rightarrow \phi(1020)\pi^+$ vs. $D_s^+ \rightarrow K_S^0 K^+$

- Measurements in agreement within uncertainties
- Similar relative uncertainties, except for the last p_T bin

Work in progress

Work in progress

Combined measurements: $D_s^+ \rightarrow \phi(1020)\pi^+$ and $D_s^+ \rightarrow K_S^0 K^+$ have been **merged**, using their statistical uncertainties as weights

- All 3 measurements are in agreement within uncertainties
- Relative uncertainties significantly reduced for the first three p_T bins

$$\bar{\mu}_{\text{merged}} = \sum_i \frac{x_{\text{mean},i}}{\sigma^2_{\text{stat.},i}} \Bigg/ \sum_i \frac{1}{\sigma^2_{\text{stat.},i}}$$

p_T (GeV/c)	2 - 4	4 - 6	6 - 8	8 - 12
Statistical uncertainty reductions	Work in progress			

Outline

- Introduction on D-meson and D_s physics
- Reconstruction of a new decay channel in ALICE: $D_s^+ \longrightarrow K_S^0 K^+$
- D_s cross-section in pp collisions at $\sqrt{s} = 7$ TeV
- Conclusion

Conclusion and prospects

D_s meson as a probe for hadronization

- Recombination at low p_T: relative enhancement of D_s with respect to non-strange D-mesons (e.g. TAMU models)
- First ALICE measurements: do not allow a firm conclusion with the current statistics

New decay channel for D_s studies:

- $D_s^+ \longrightarrow K_S^0 K^+$: analysis framework has been implemented, based on LHC Run I data
- Comparison of cross-sections in pp collisions at $\sqrt{s}$ = 7 TeV:
  Similar results are obtained with the usual ($\phi(1020)\pi^+$) and the new decay channels ($K_S^0 K^+$)
  Merging both results allows to reduce the relative statistical uncertainties up to ~30%

Prospects:

- Run II data:
  proton-proton collisions at $\sqrt{s}$ = 13 TeV will be available soon... and $D_s^+ \longrightarrow K_S^0 K^+$ analysis will follow!
  Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV available since 5 days... and $D_s^+ \longrightarrow K_S^0 K^+$ analysis may follow.
- Improvement of the current analysis:
  Topological cuts and PID can be further improved, with the help of Monte Carlo simulations
  Methods preventing the $D^+ \longrightarrow K_S^0 \pi^+$ contamination will be tested
  Systematic uncertainties have to be evaluated