Characterising open-charm hadronisation processes with LHCb experiment

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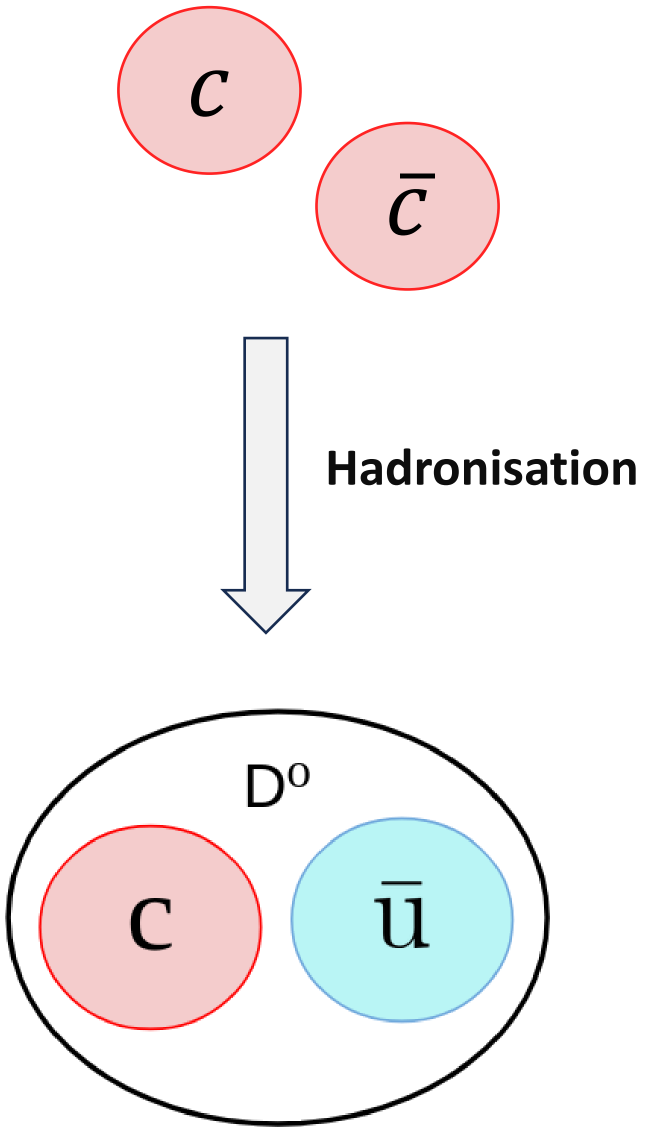
Introduction

- Open charm mesons: one c (or $\bar{c}$) with a light quark
- $c\bar{c}$ produced at early times in the collision
- Hadronise into open charm or charmonia

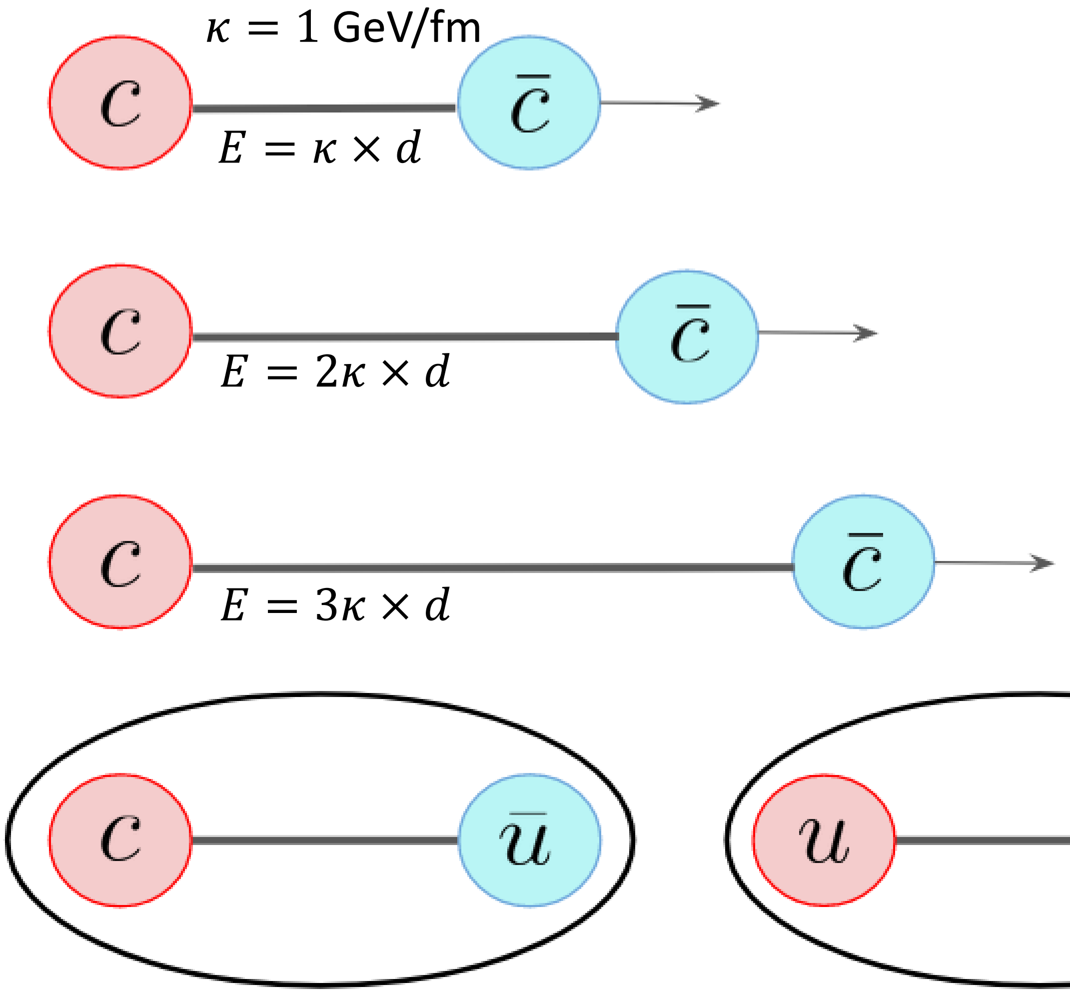
used as a reference ← open charm | charmonia → sensitive to the medium

► **Hadronisation process(es) still not well understood**



Introduction

Fragmentation: a universal process?

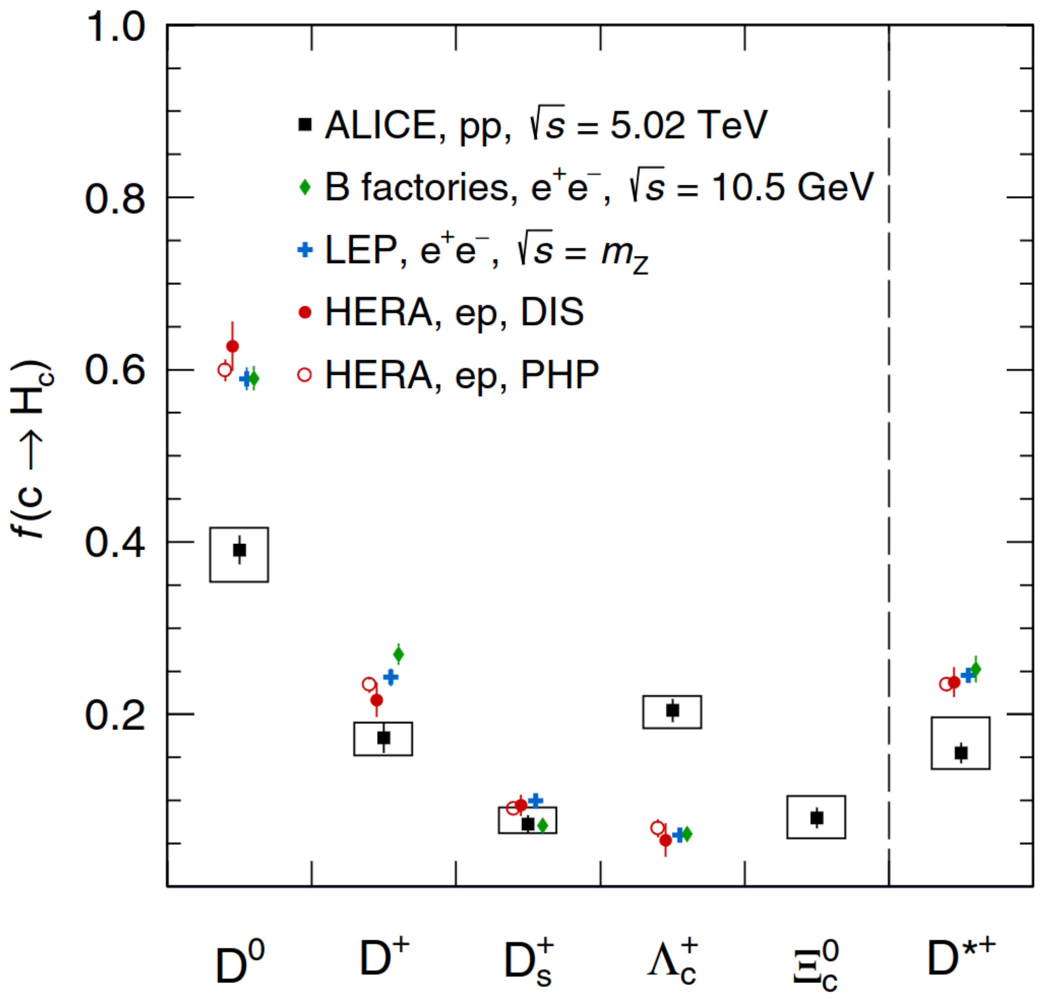


- Force field between $q\bar{q}$ pair can be seen as a string
- Potential energy of the string increases linearly with length
- Fragmentation function : probability of forming a given hadron
- **Independent of energy and colliding system**

Introduction

Fragmentation: a universal process?

- Charm quark fragmentation function measured by ALICE
- Differences between *pp* and e^+e^- collisions
- Must be other processes involved



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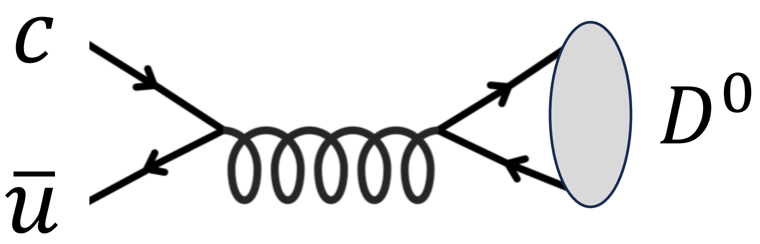
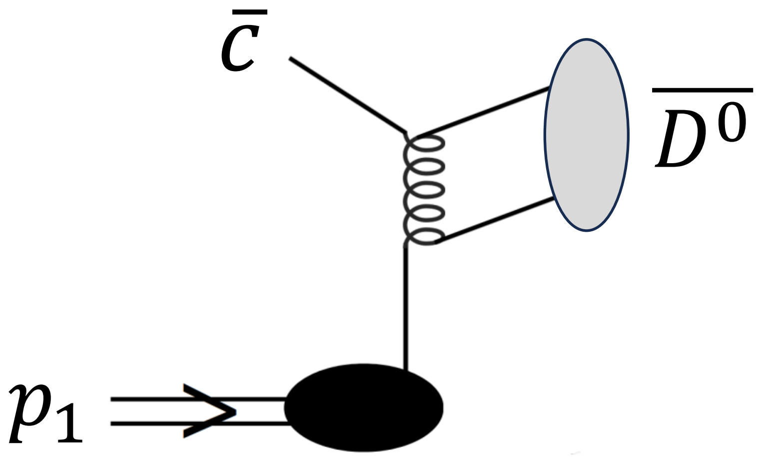
Introduction

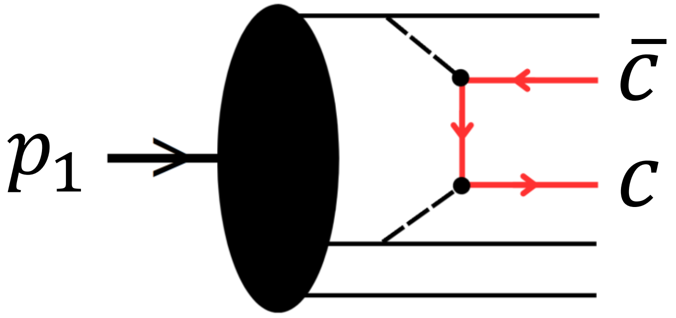
Coalescence



Between quarks produced in the collision



With spectator quark from the beam



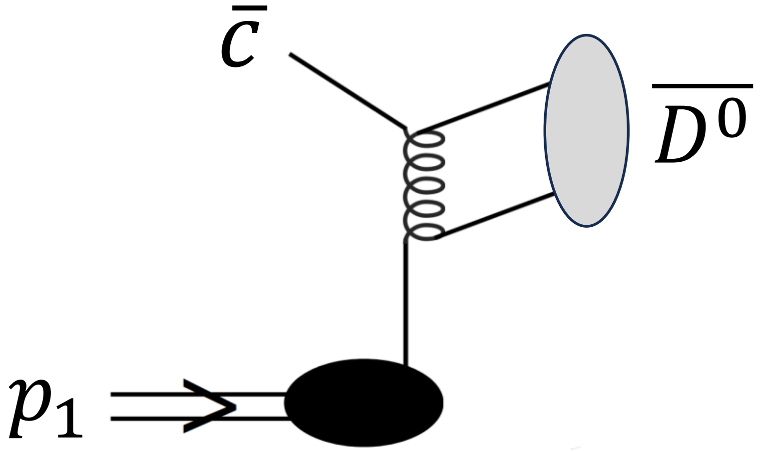
Intrinsic charm of the proton
$(uudc\bar{c})$

Coalescence

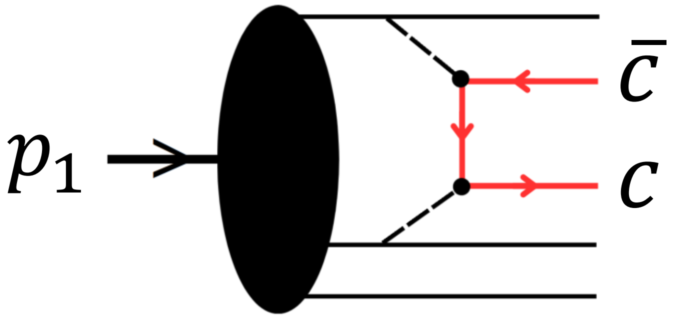
More hadrons containing valence quarks of the proton

▶ **more $\overline{D^0}(u\bar{c})$ than $D^0(\bar{u}c)$**

Between quarks produced in the collision

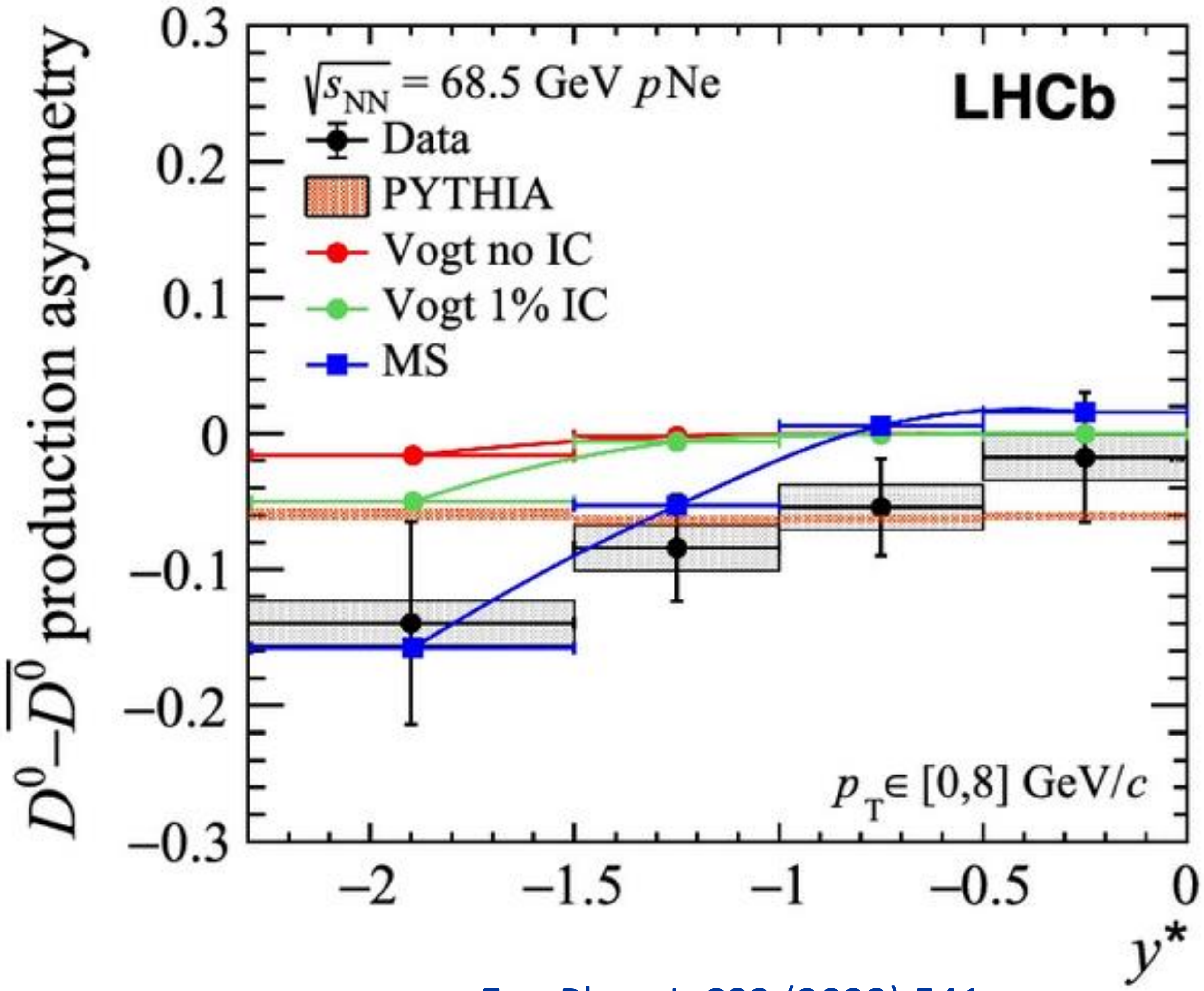


With spectator quark from the beam



Intrinsic charm of the proton
$(uudc\bar{c})$

D^0- $\overline{D^0}$ asymmetry



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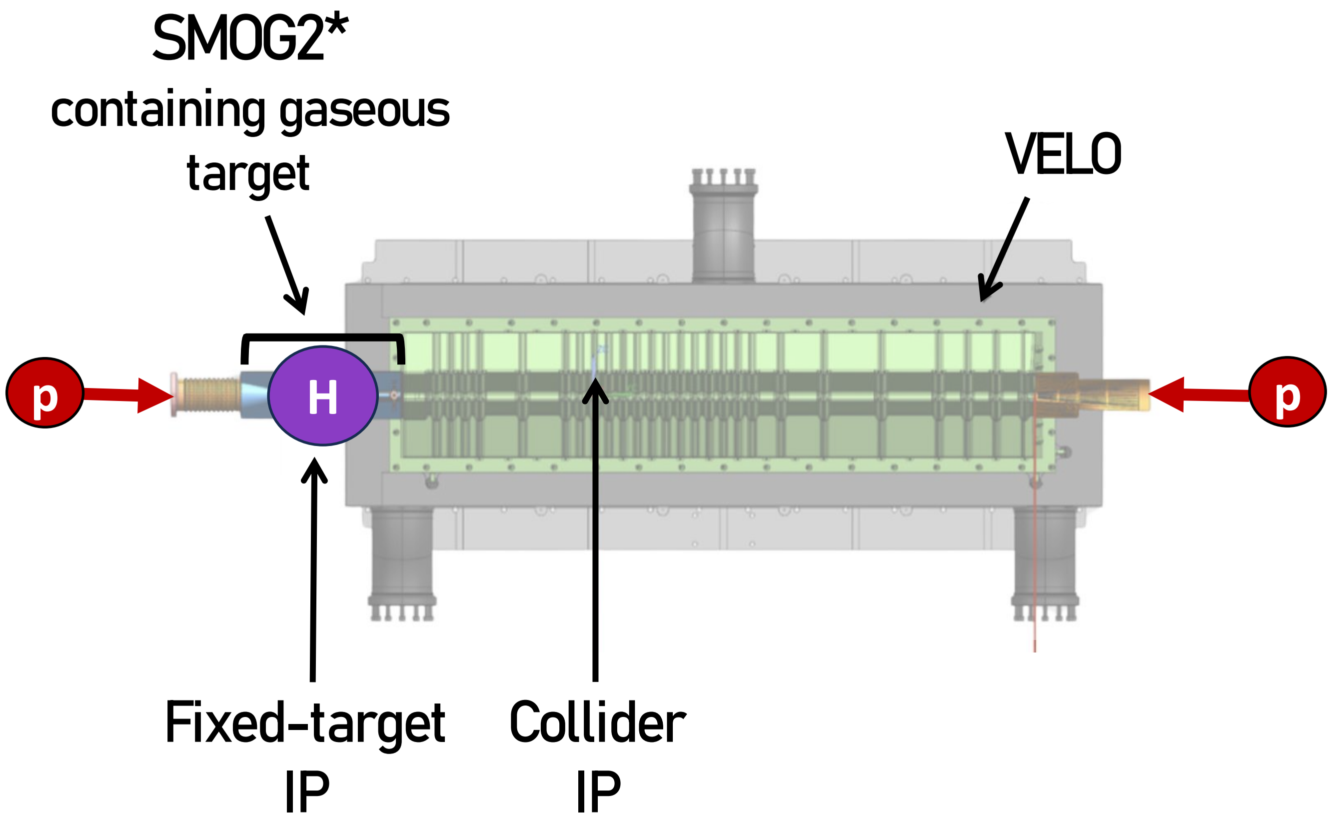
$$\mathcal{A} = \frac{N(D^0) - N(\bar{D}^0)}{N(D^0) + N(\bar{D}^0)}$$

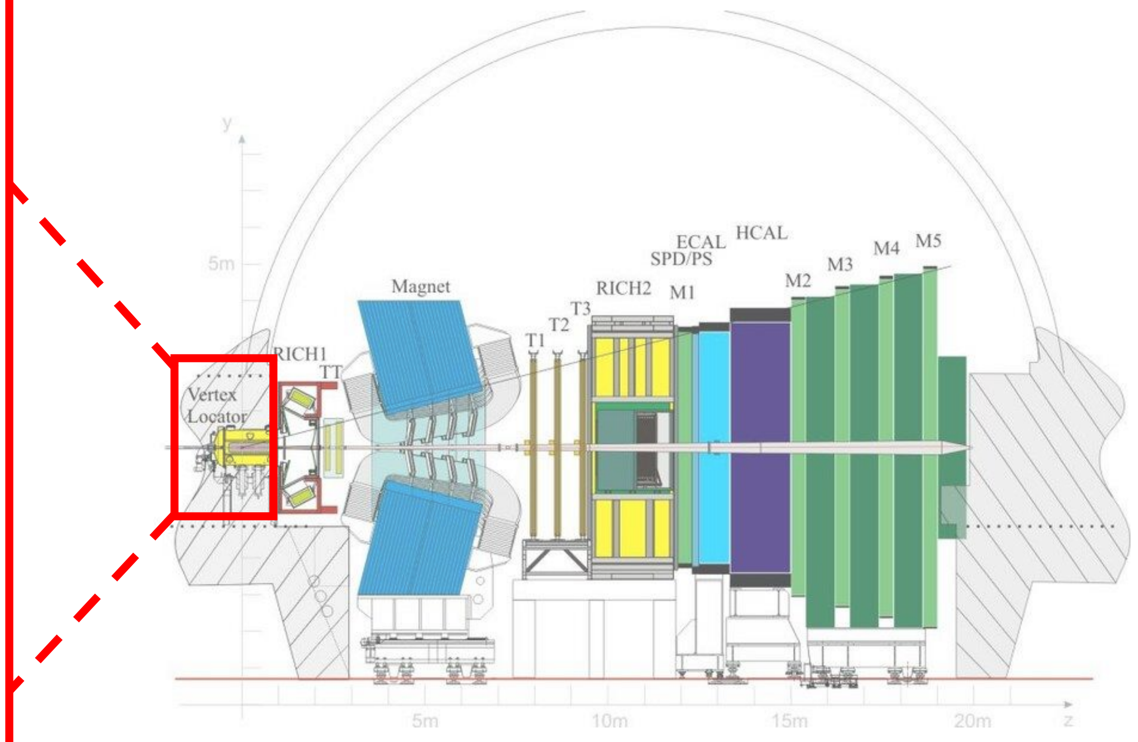
- Experimentally: up to -15% and y* dependent
- Pythia: -6% and flat
- Large discrepancy between Pythia and data

LHCb experiment

Fixed-target configuration



* System for Measuring the Overlap with Gas

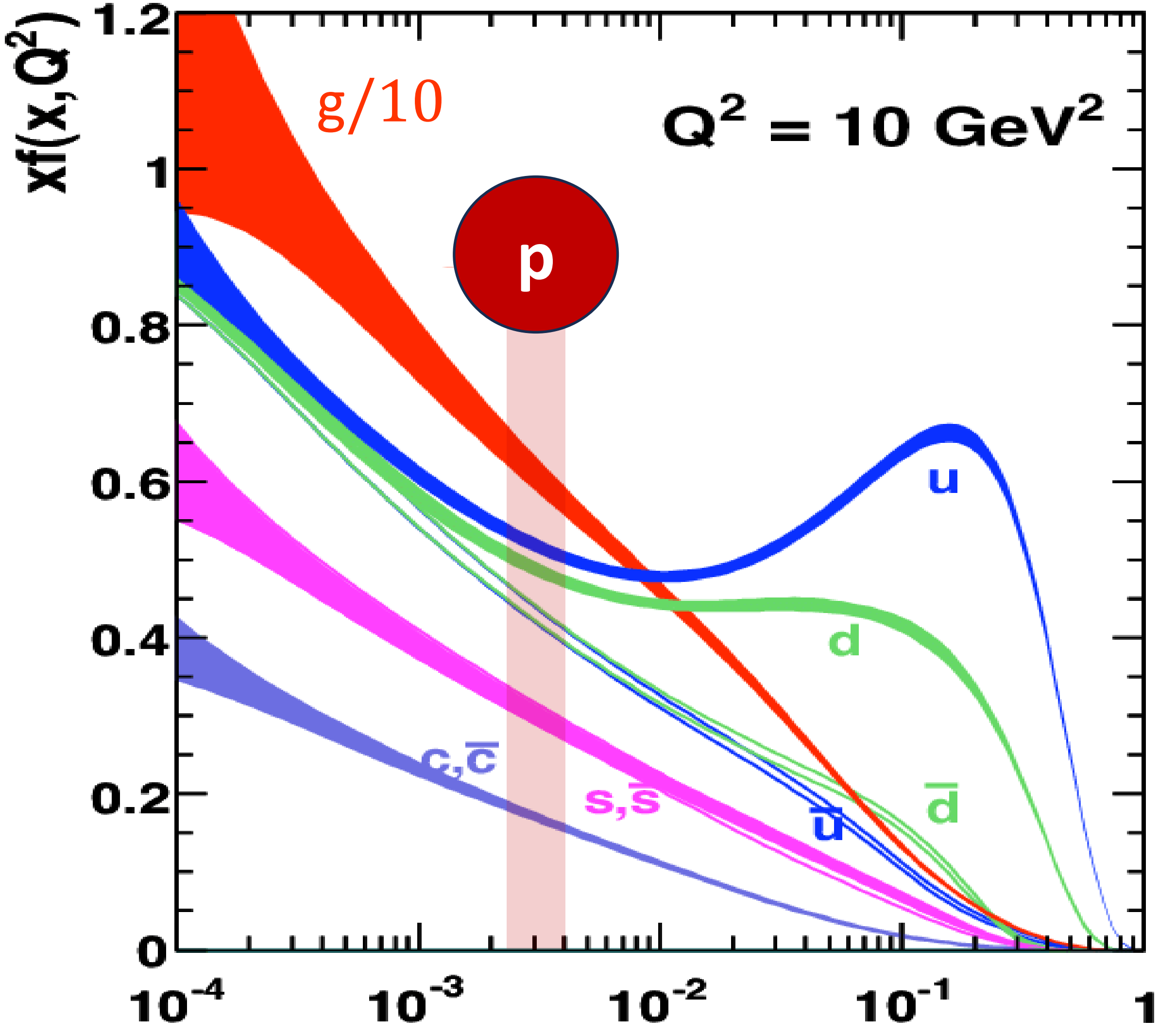


Collider mode ⟶ Fixed target

$2 \leq y \leq 4.6$ ⟶ $-2.5 \leq y^{*} \leq 0$

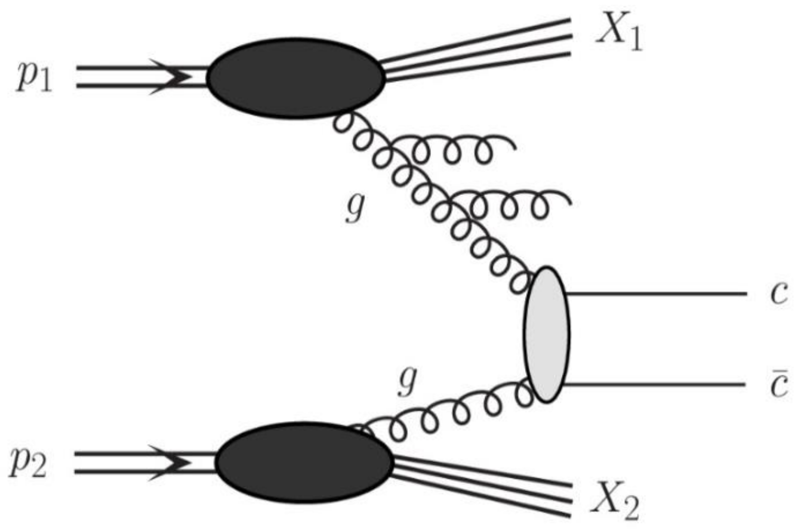
LHCb experiment

Fixed-target configuration



Eur.Phys.J.C69:379-397,2010

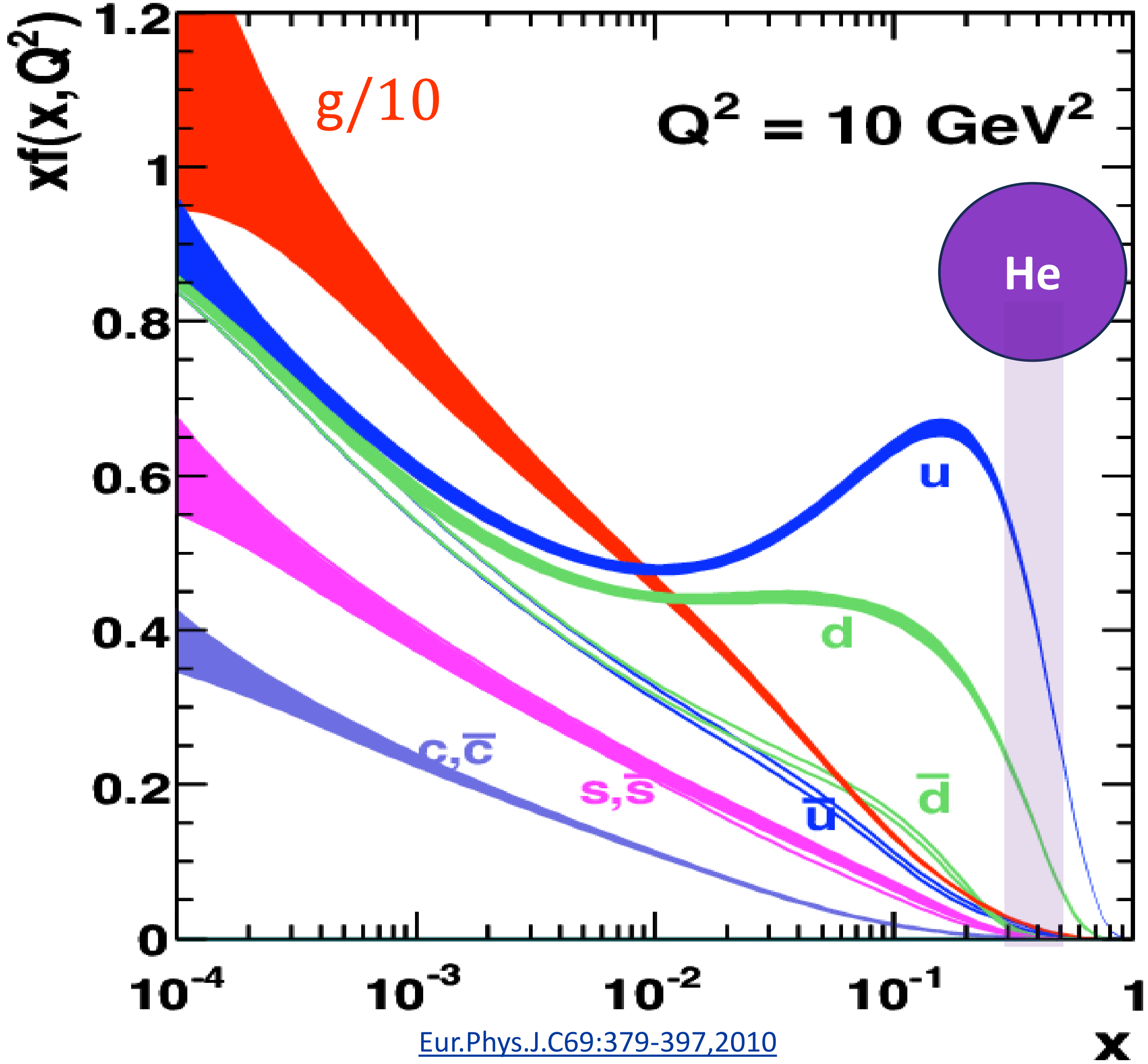
$$x_{1-2} = \frac{M_T}{\sqrt{s}} e^{\pm y^*} \rightarrow$$ Projectile : $x_1 \sim 2.10^{-3}$



Asymmetry coming from sea quarks

LHCb experiment

Fixed-target configuration



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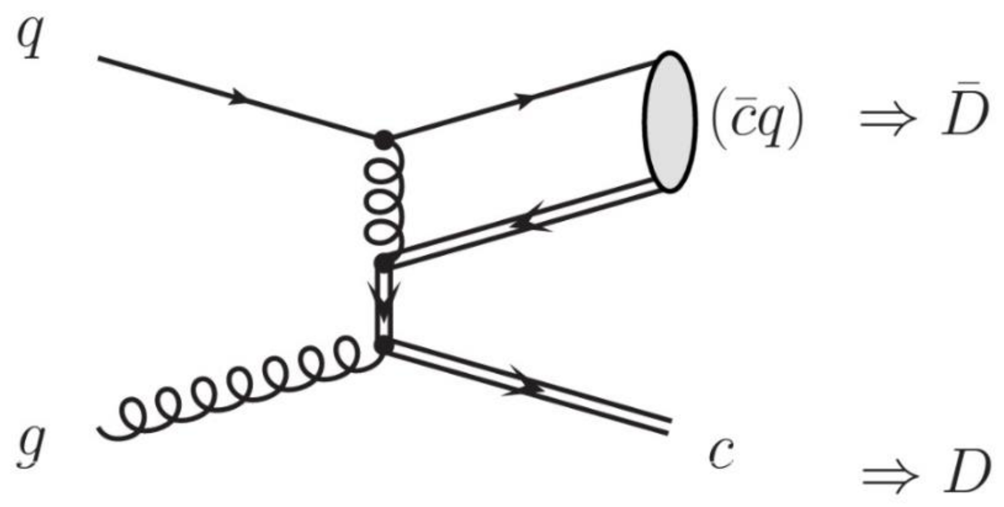
$$x_{1-2} = \frac{M_T}{\sqrt{s}} e^{\pm y^*} \rightarrow \text{Target} : x_2 \sim 0.3$$



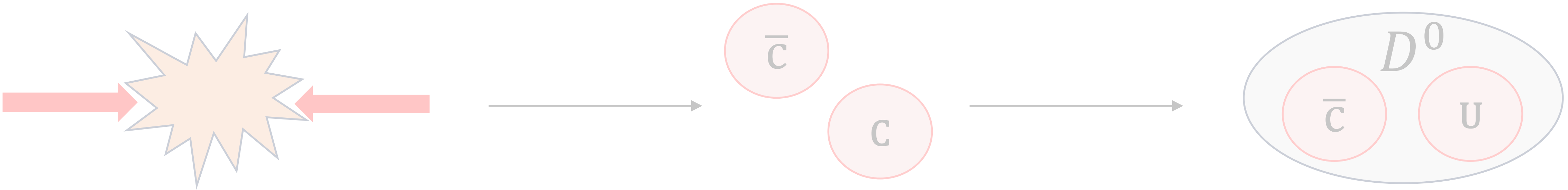
Asymmetry should increase at backward rapidity

Objectives

Origin of asymmetry given by Pythia?

1) Produce Pythia simulations of *pp* collisions at $\sqrt{s}_{NN} = 68.5$ GeV

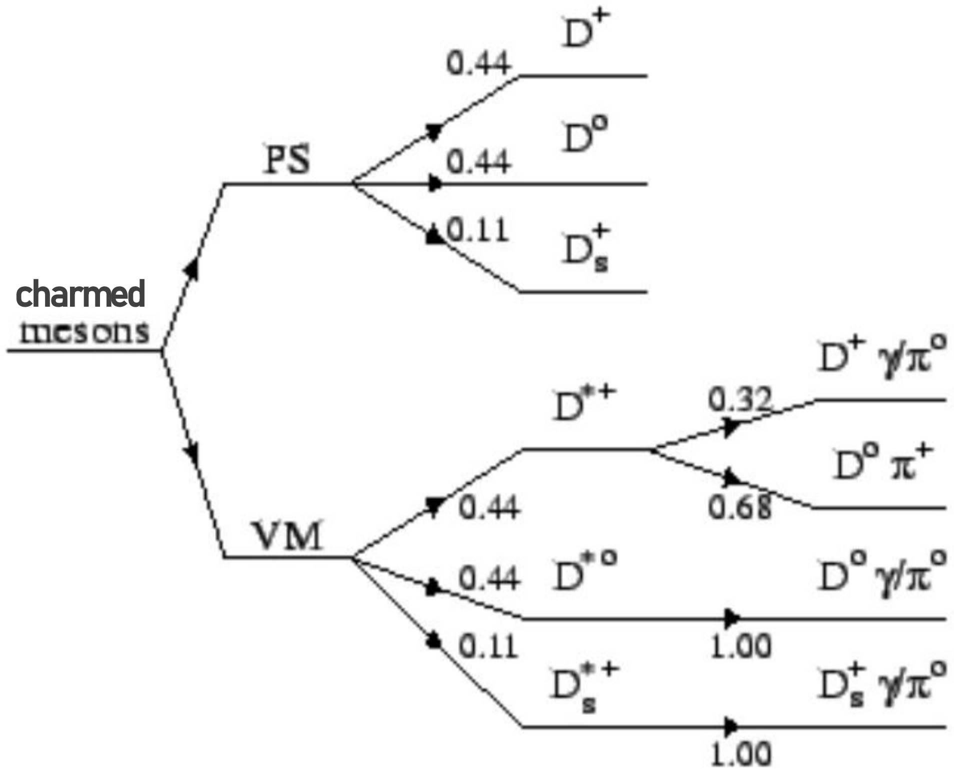
2) Study $D^0 - \overline{D^0}$ asymmetry as a function of p_T and y^*



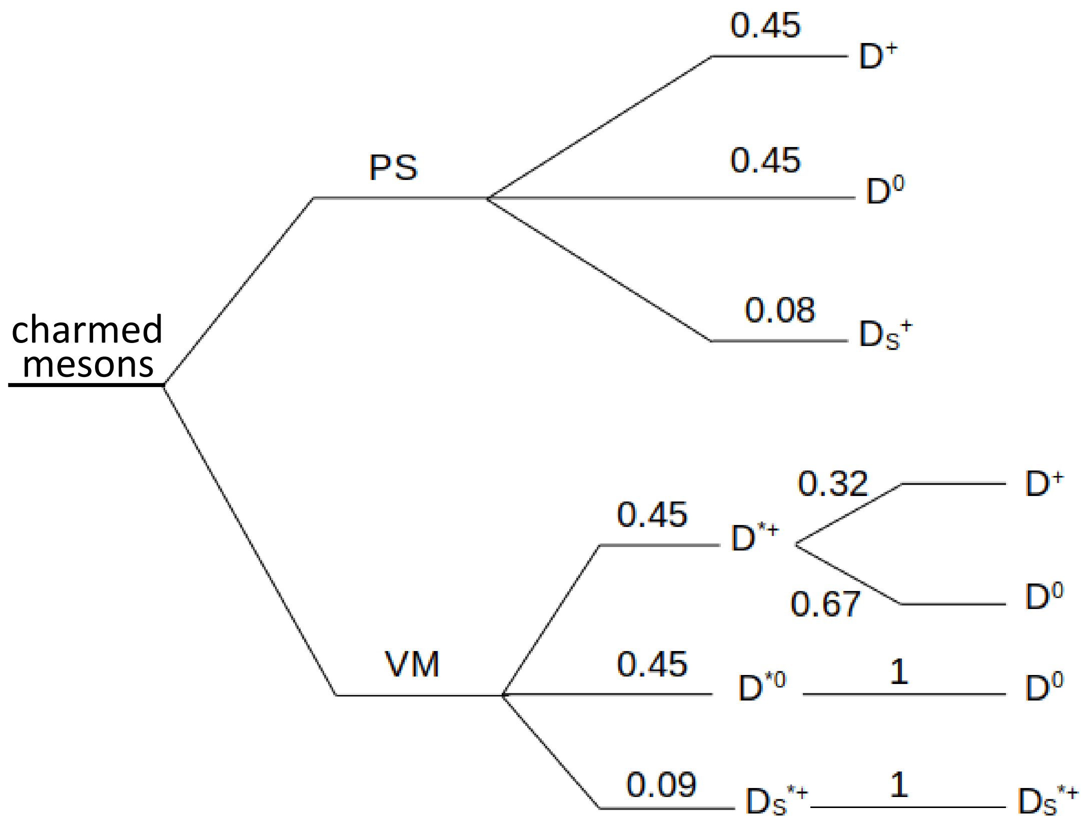
3) Predictions for Run3 measurements with LHCb in pH and pHe collisions at $\sqrt{s}_{NN} = 113$ GeV

Pythia simulations

Charm fragmentation functions



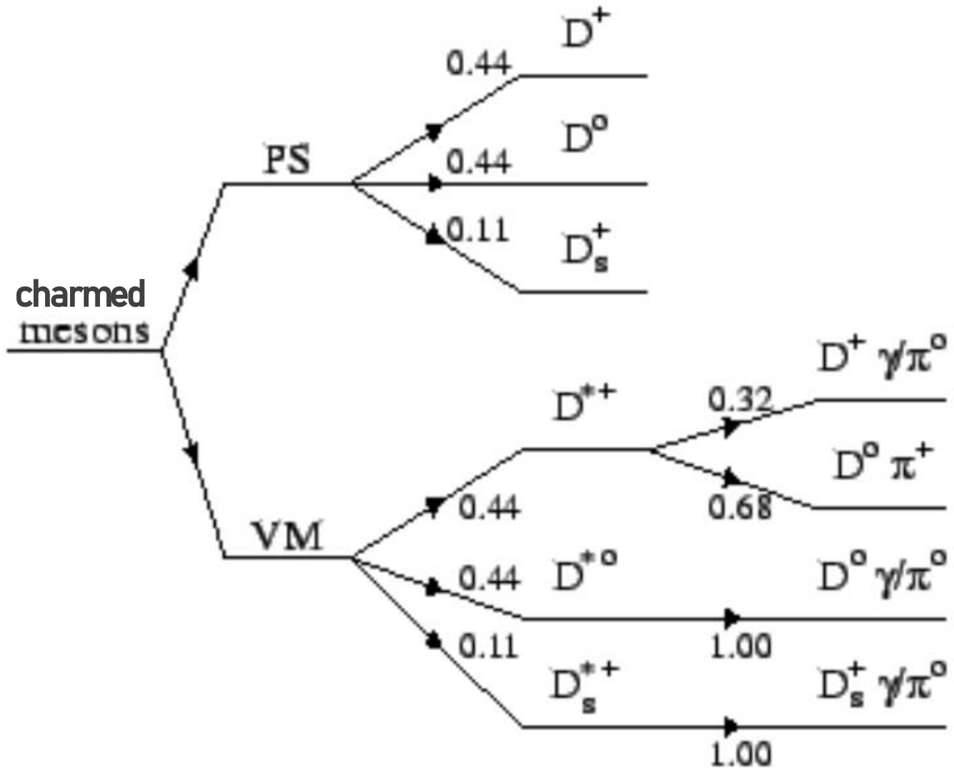
e^+e^- data



pp collisions Pythia

Pythia simulations

Charm fragmentation functions



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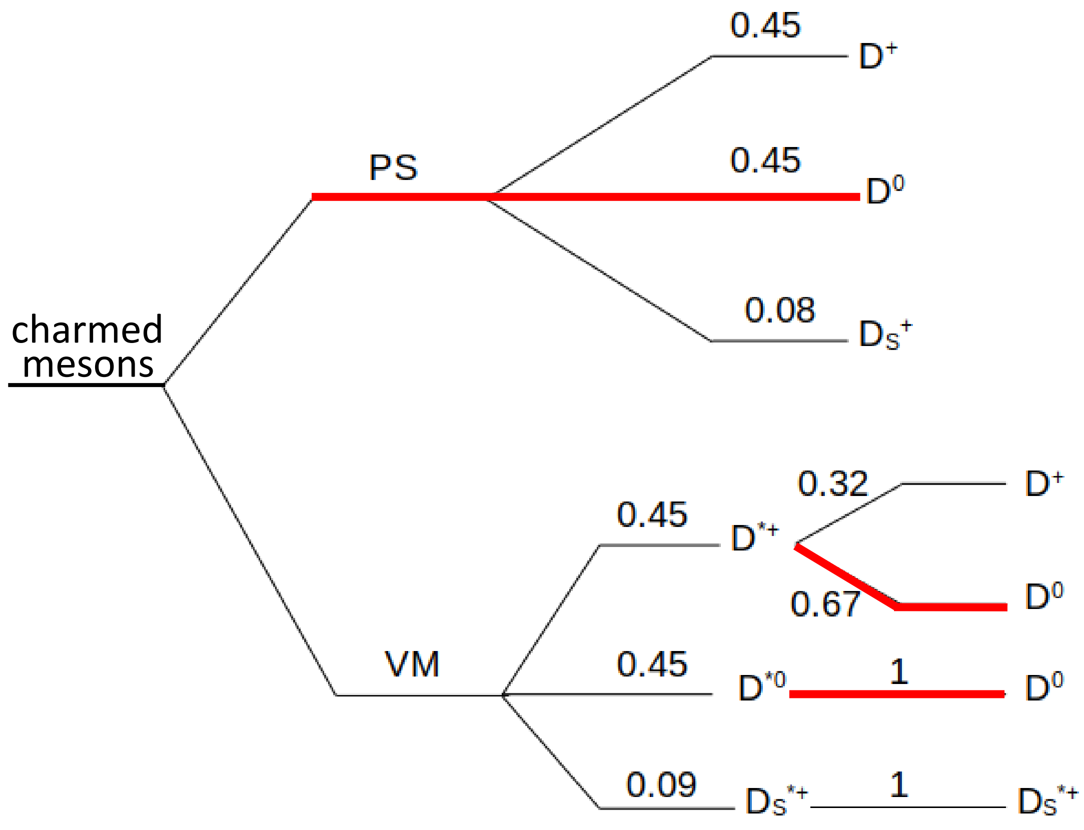
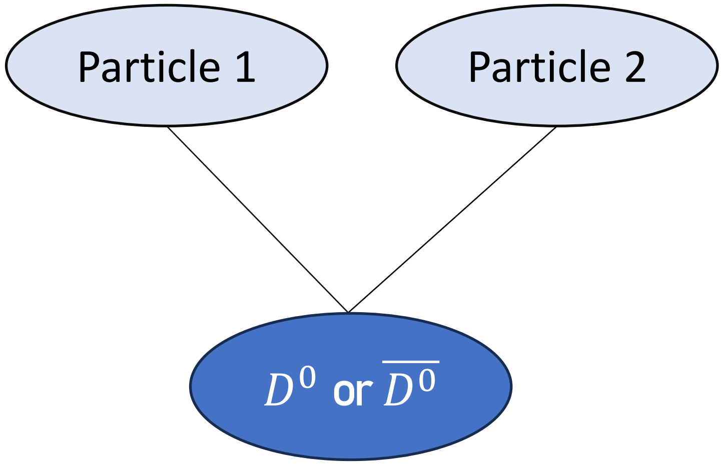
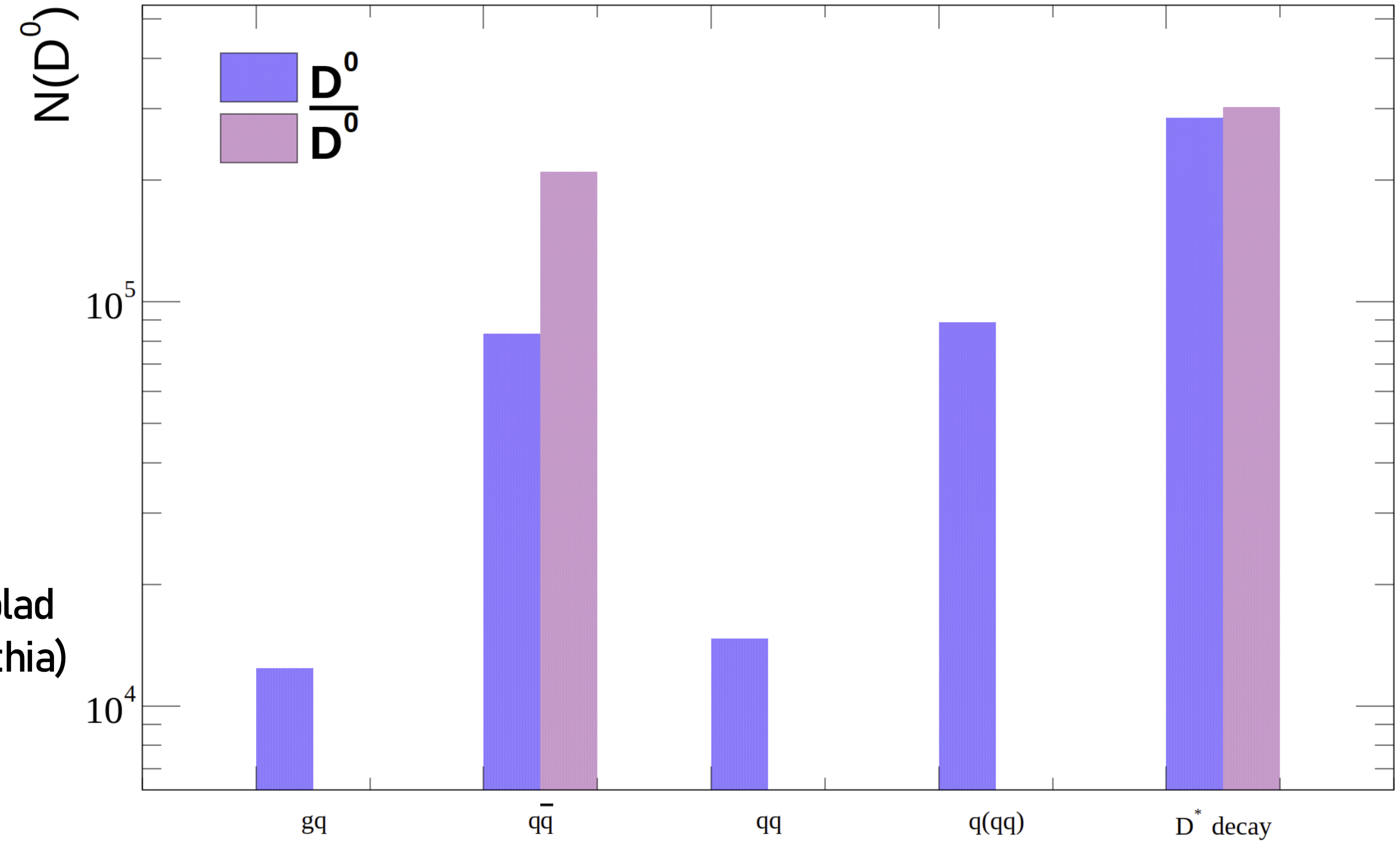


pp collisions Pythia

Pythia simulations

D^0 production





→ In discussion with Pr. Leif Lönnblad (implementing hadronisation in Pythia)

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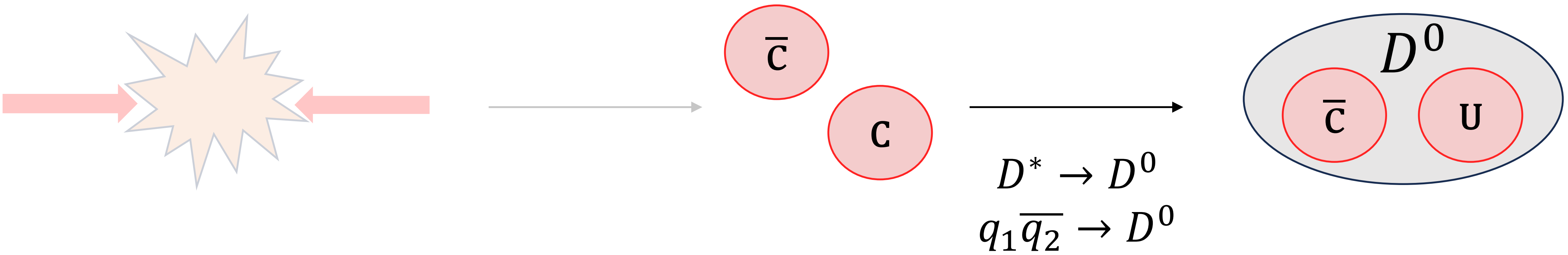

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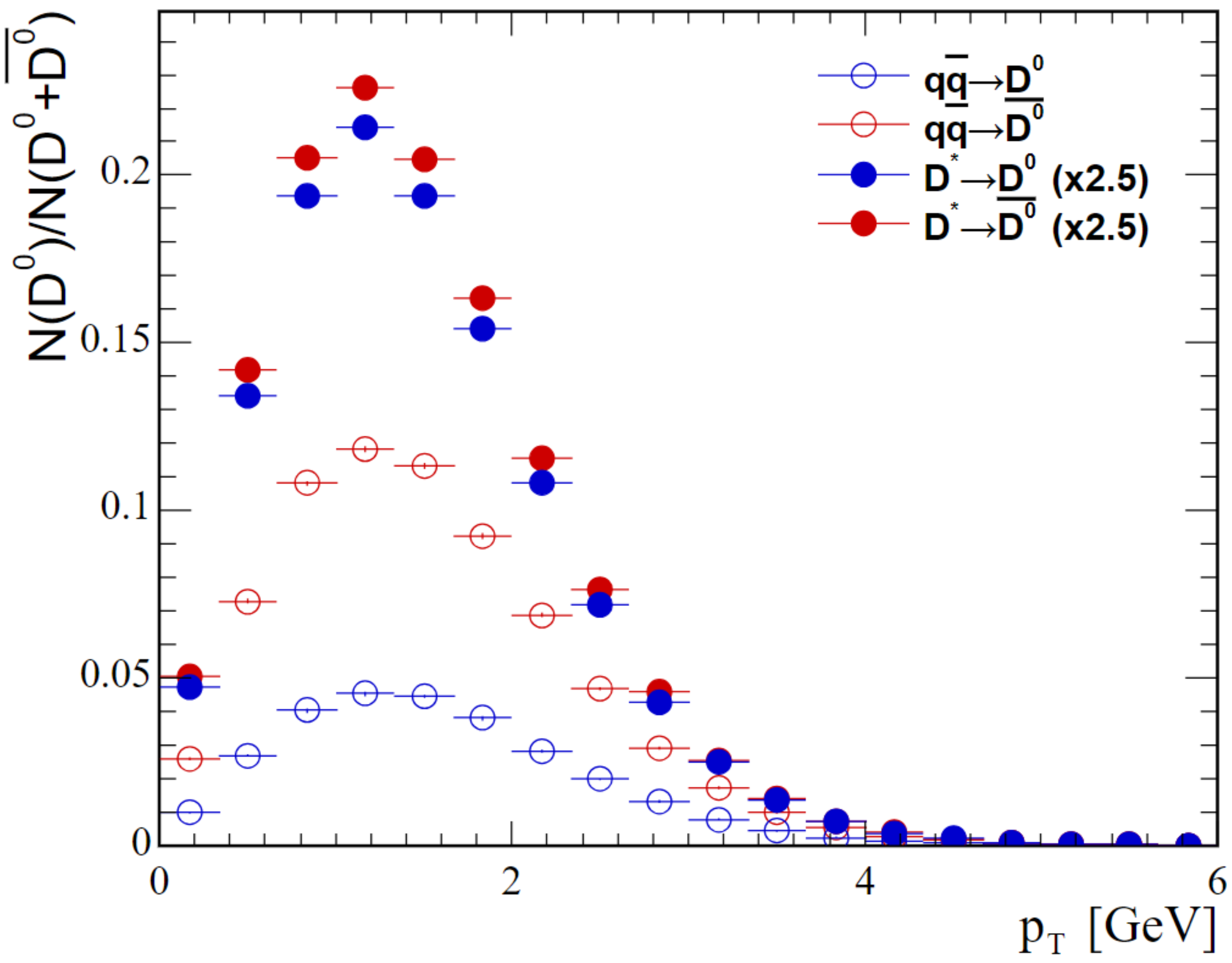
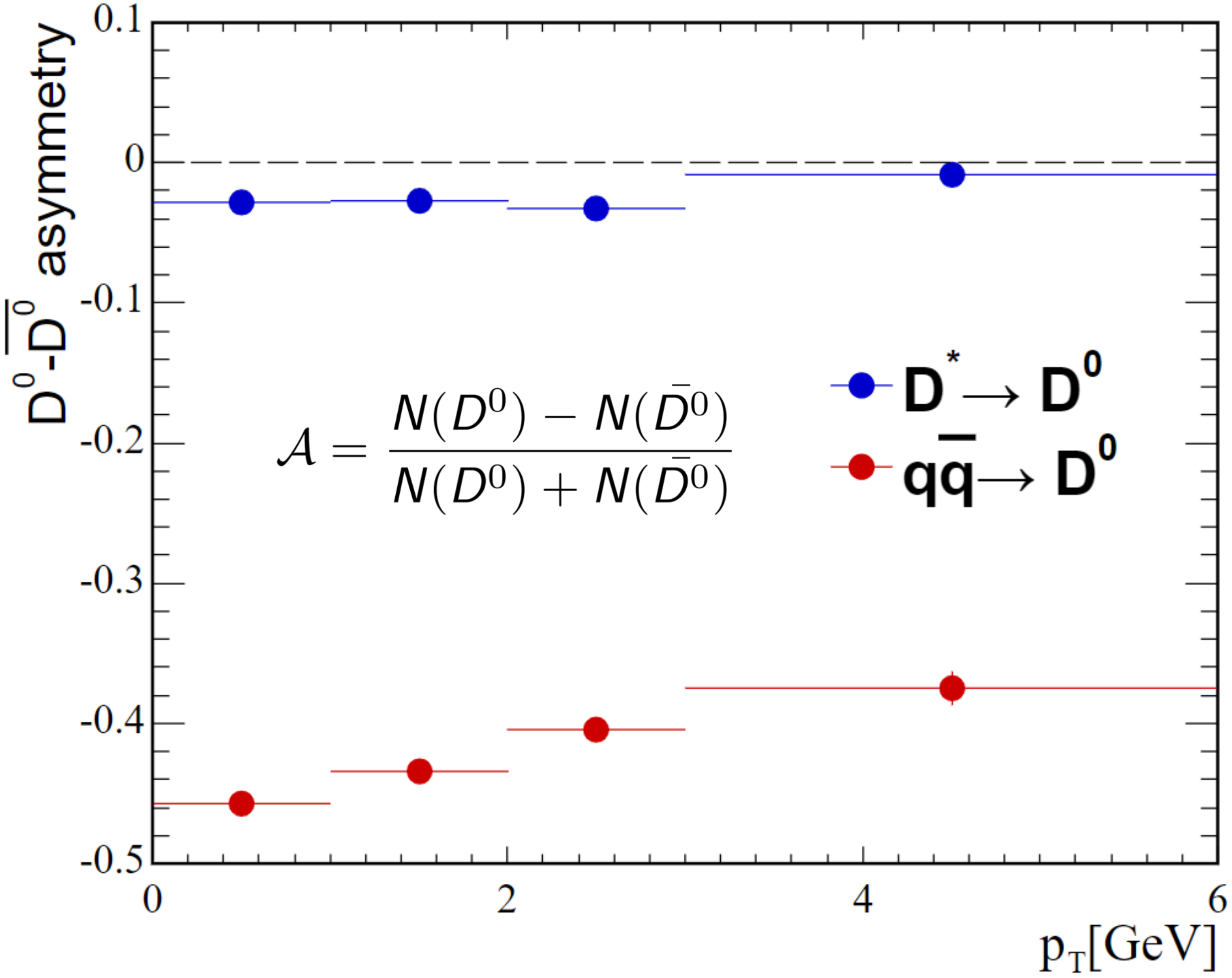
Pythia simulations

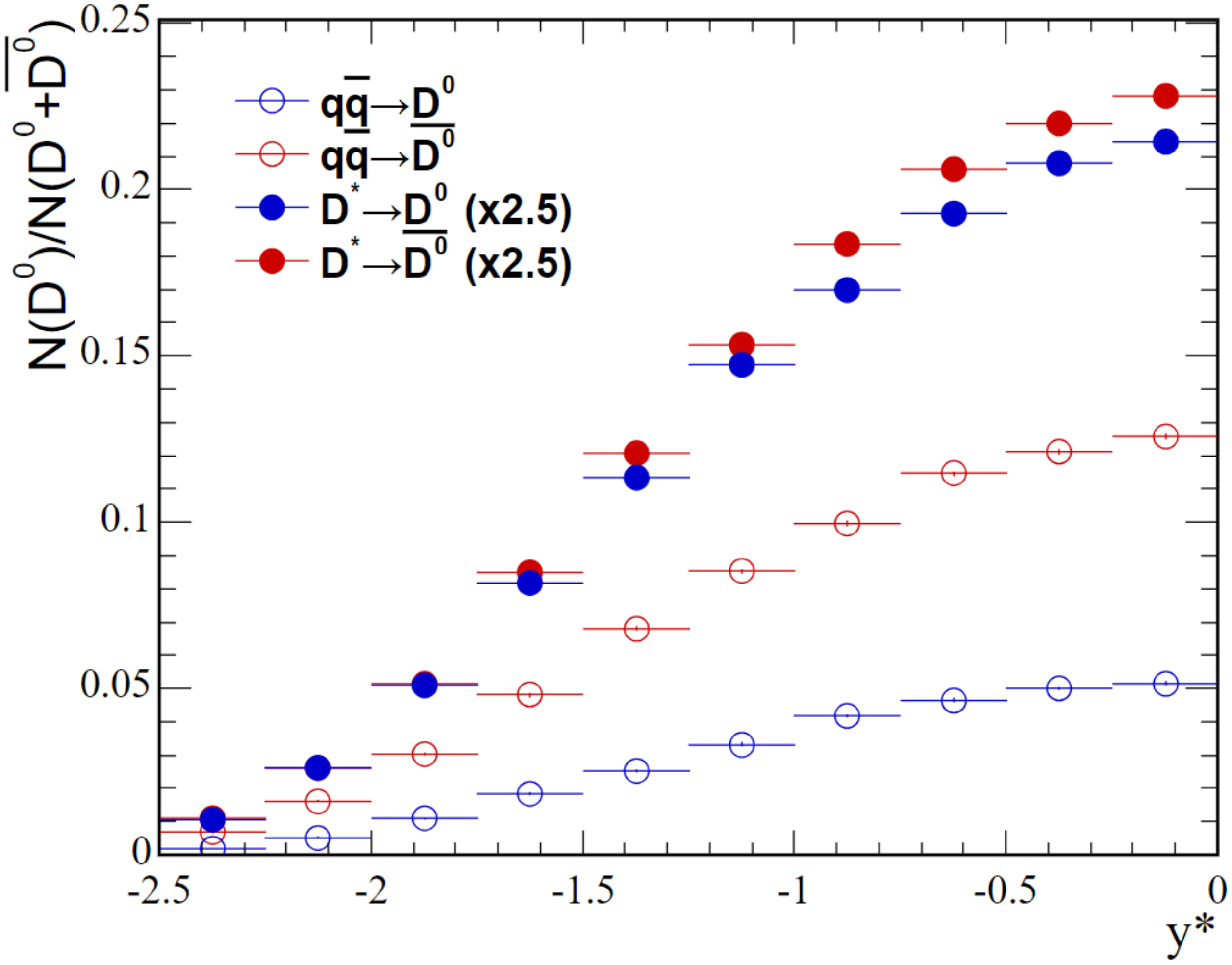
p_T distribution

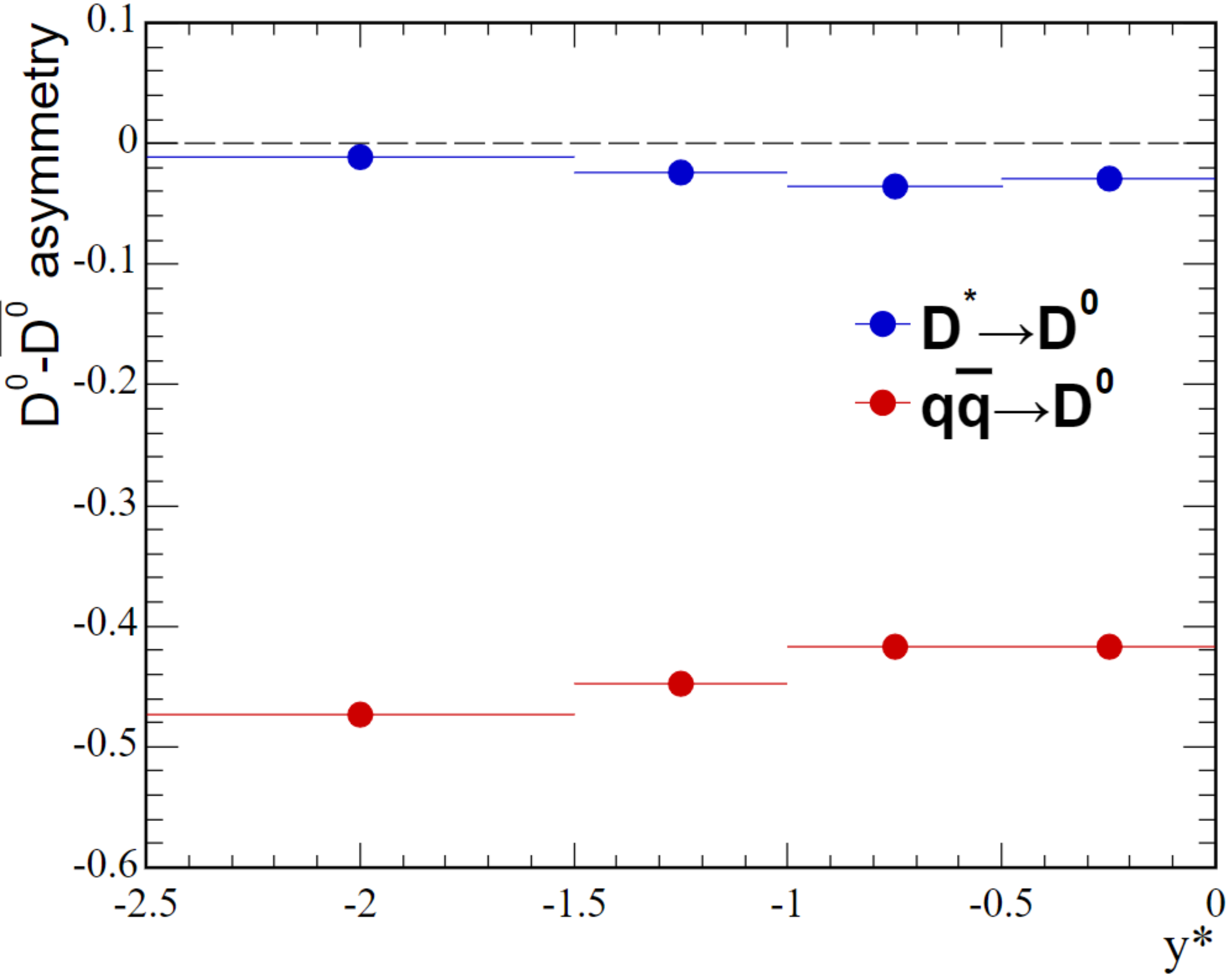




Pythia simulations

D^0 - $\overline{D^0}$ asymmetry





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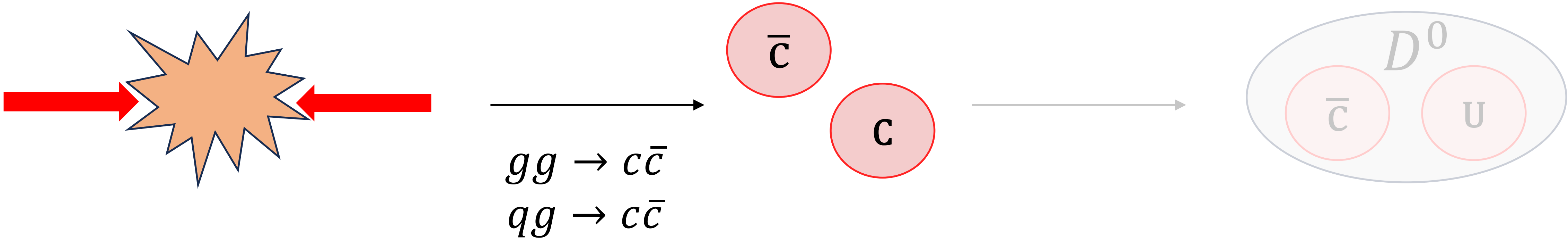

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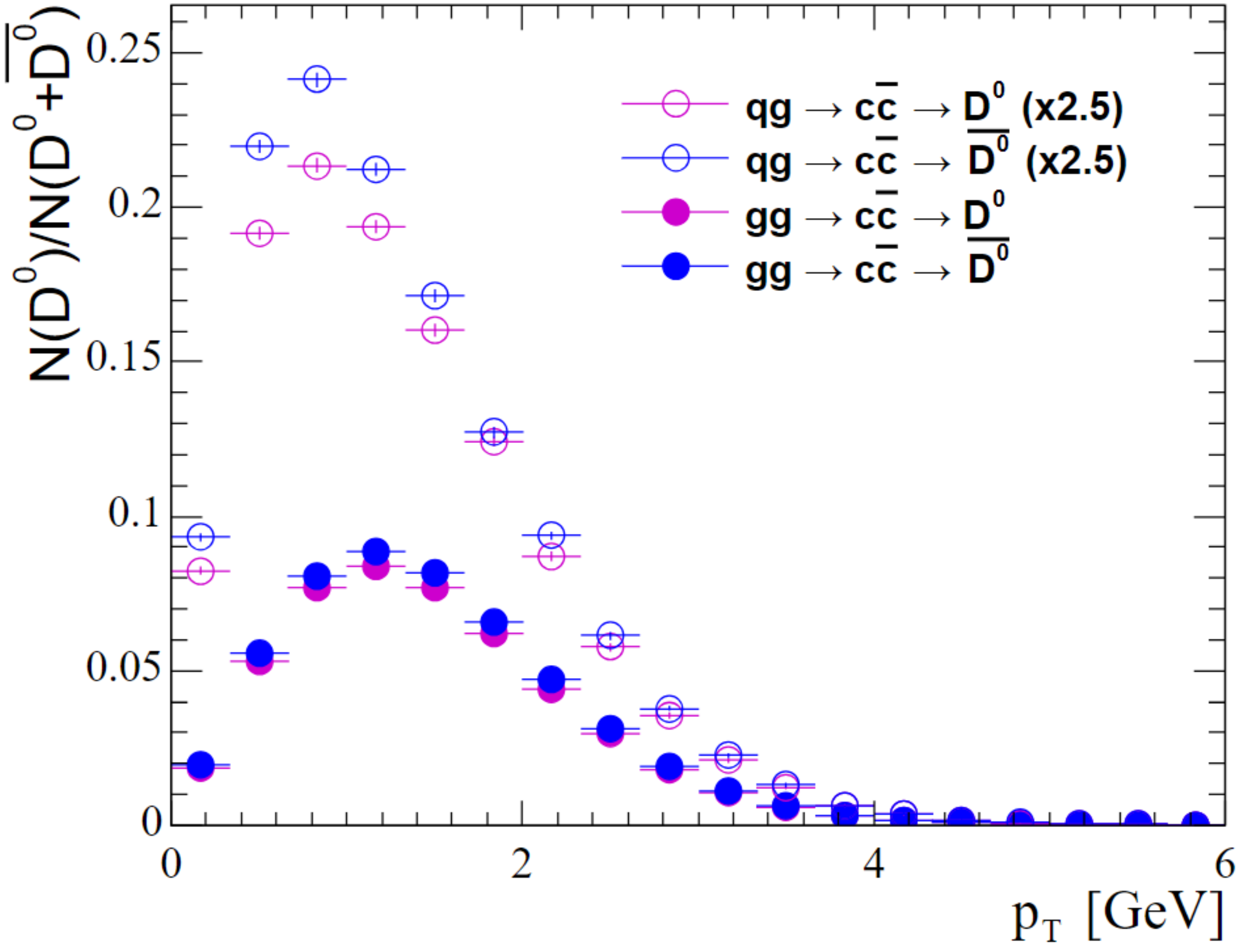
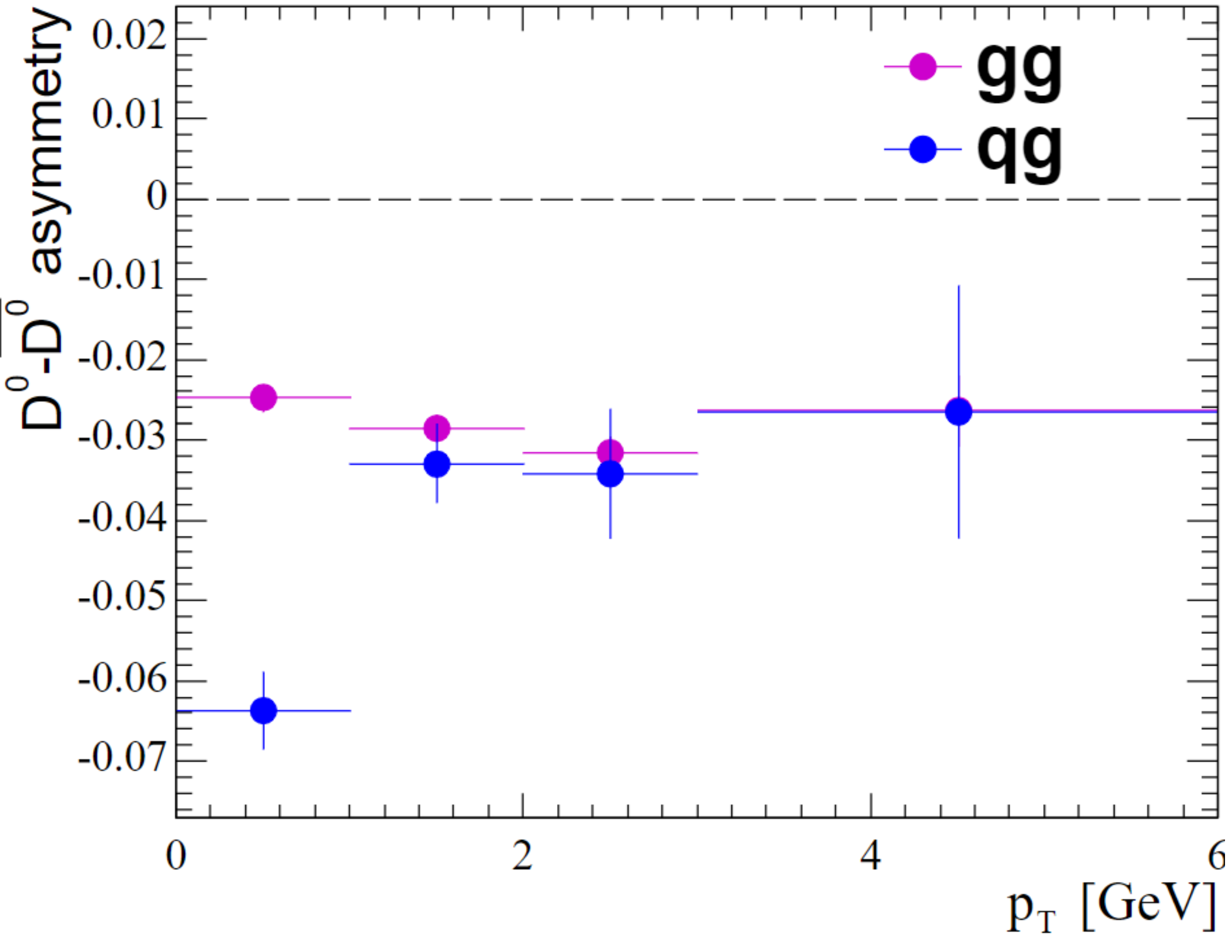
Pythia simulations

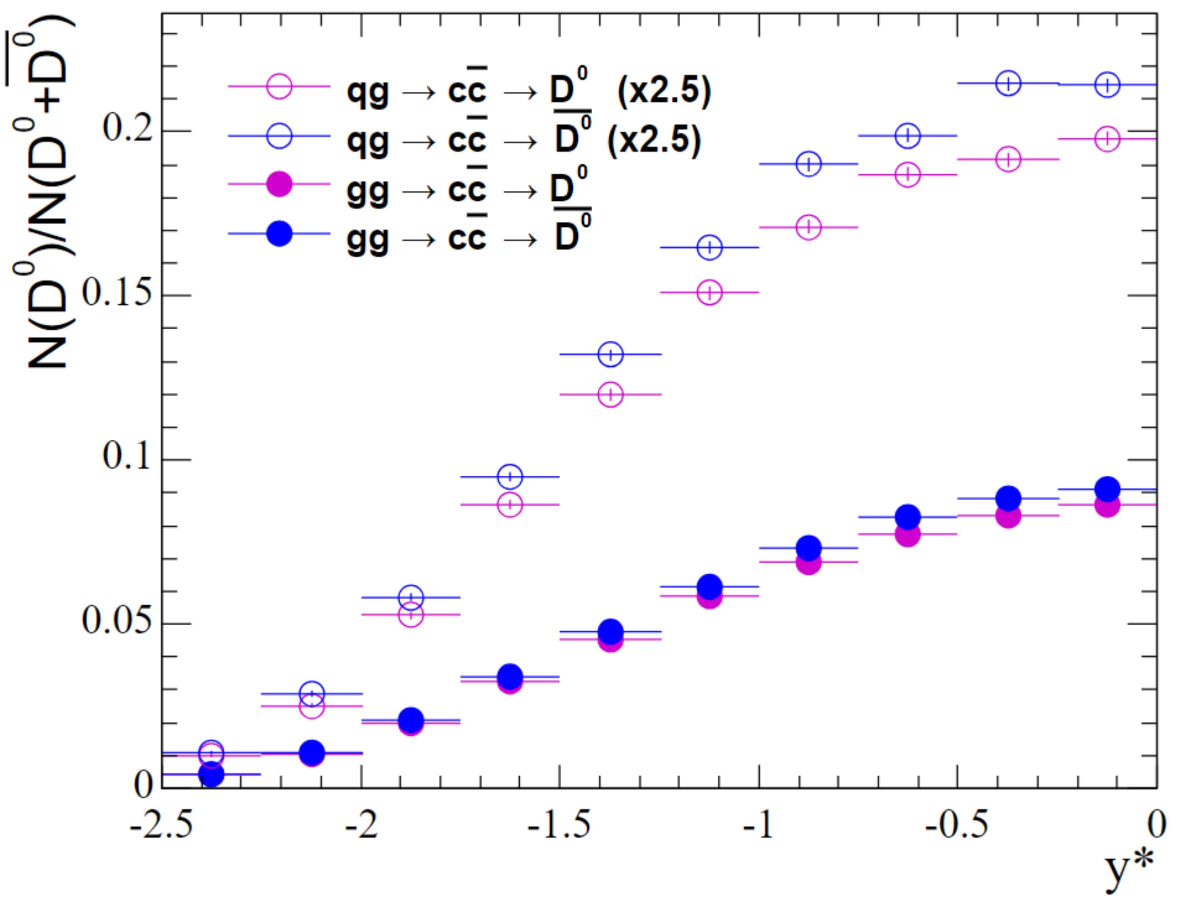
p_T distribution

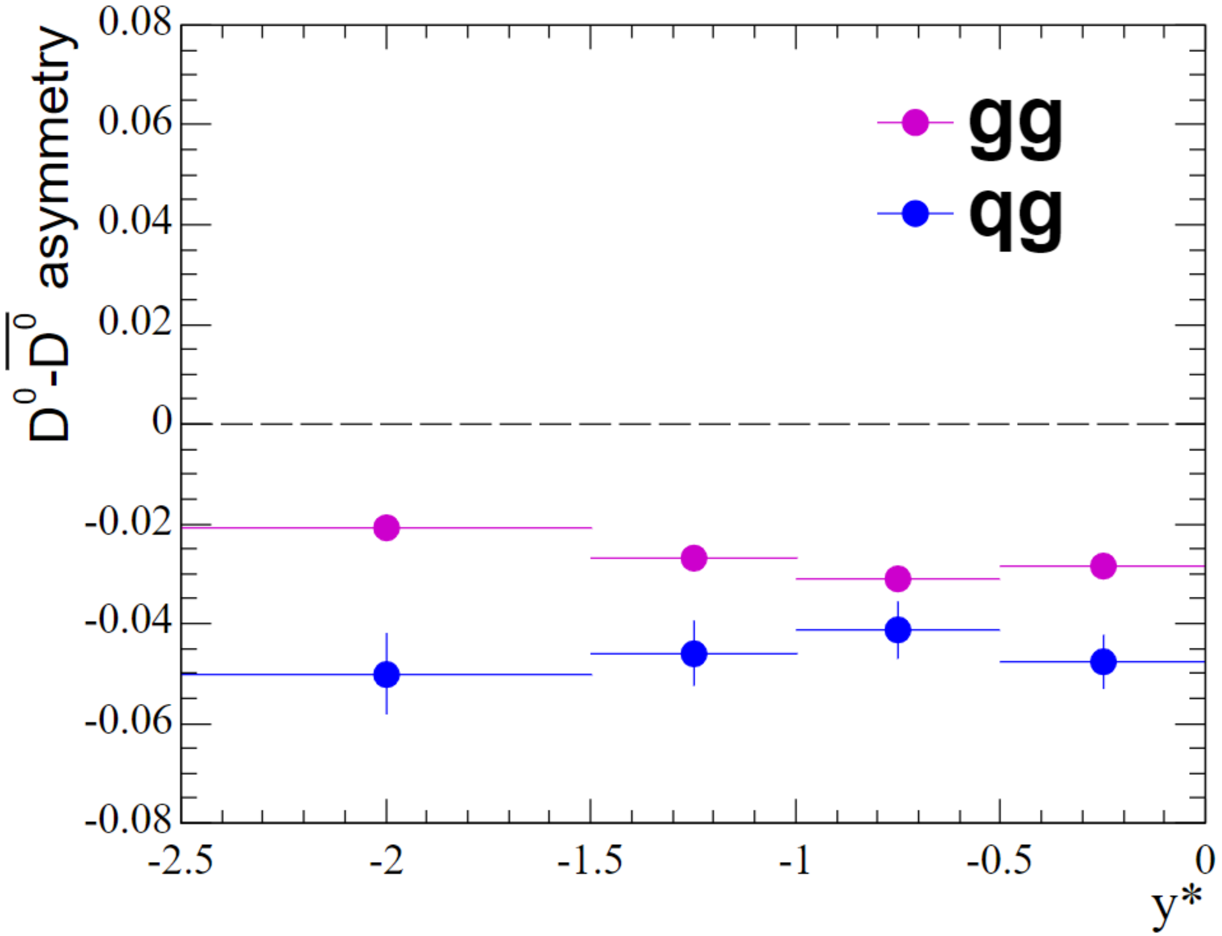




Pythia simulations

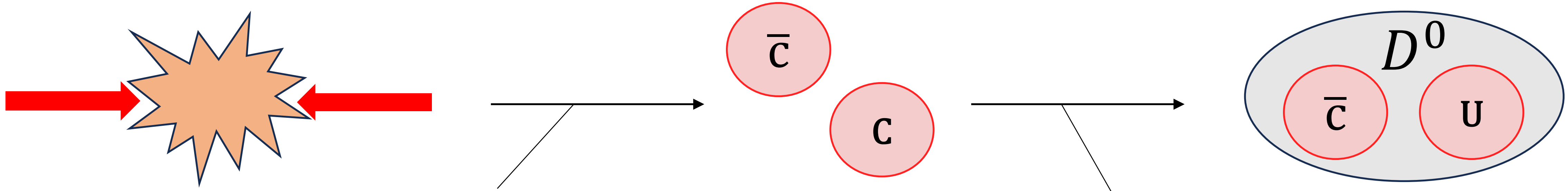
y distribution





Pythia simulations

Pythia simulations summary



$gg \rightarrow c\bar{c}$

- $\sim -3\%$ asymmetry
- Dependence in p_T and y^*

$qg \rightarrow c\bar{c}$

- $\sim -5\%$ asymmetry
- Dependence in p_T and y^*

-6% ??

$D^* \rightarrow D^0/\overline{D^0}$

- Flat
- $\sim -3\ \%$
- $\sim 55\%$ of D^0 production

$q_1\overline{q_2} \rightarrow D^0/\overline{D^0}$

- $\sim -40\%$
- Strong y^*, p_T dependence
- $\sim 35\%$ of D^0 production

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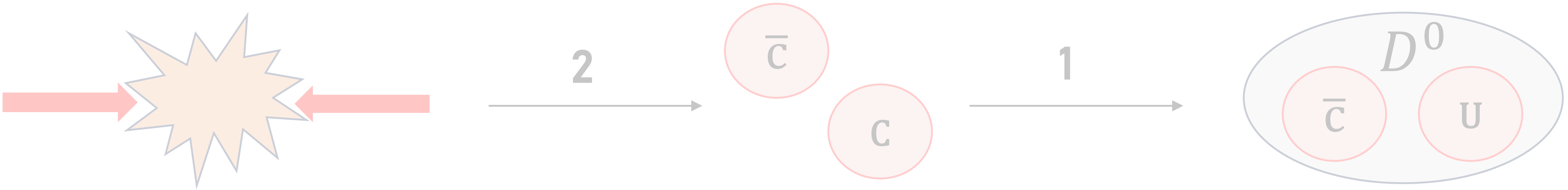
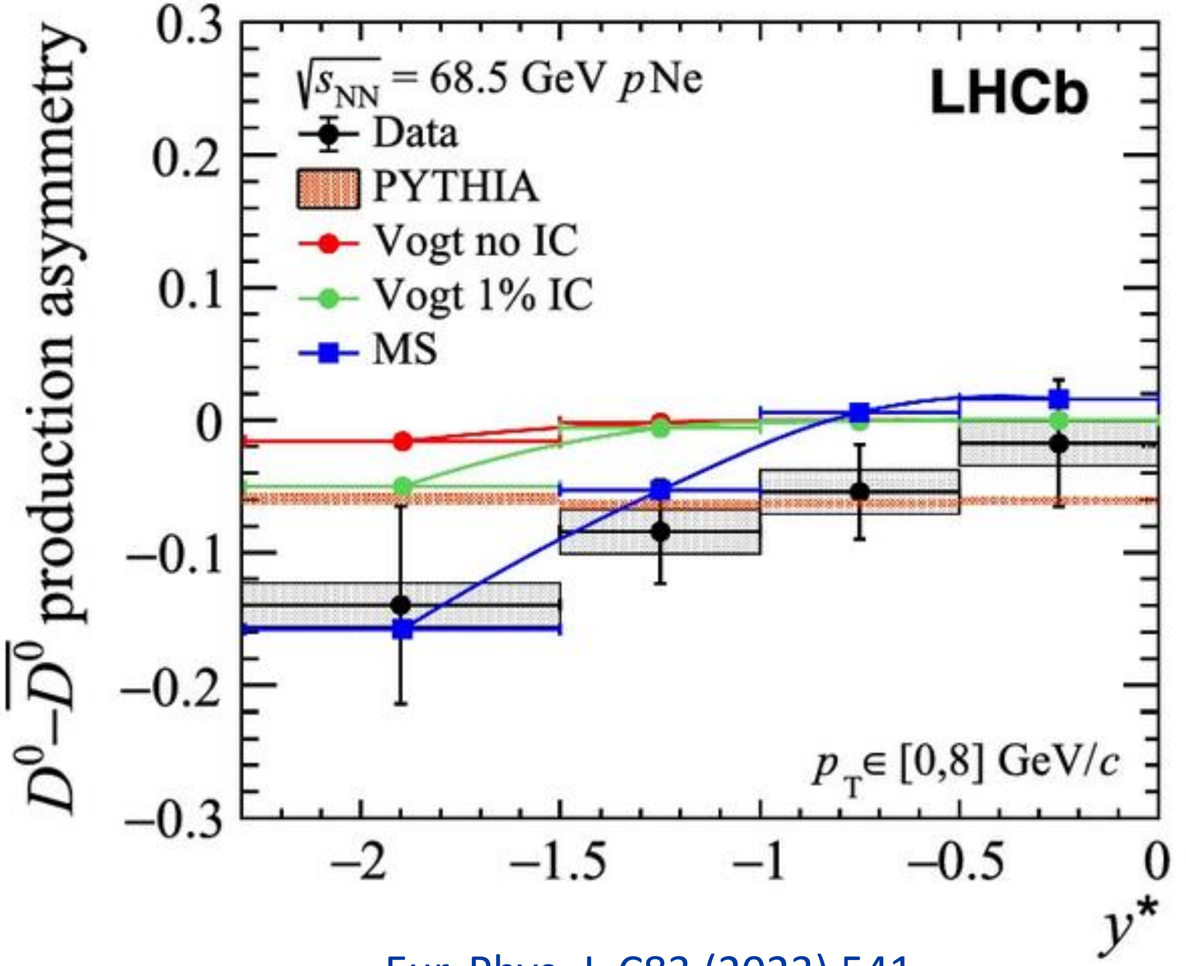


3) Predictions for Run3 measurements with LHCb in *p*H and *p*He collisions at $\sqrt{s}_{NN} = 113$ GeV

Predictions for LHC Run3



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Objective: $N(D^0) = 1$ million in pH and pHe

From cross-section formula:

$$\sigma_{D^0}^{acc} = \frac{N(D^0)}{A \times \epsilon \times L \times \boldsymbol{t} \times B(D^0 \to K^{\pm}\pi^{\pm})}$$

For pH:

$\boldsymbol{t = 216 \pm 11}$ **h ~ 9 days of data taking**

For pHe:

$\boldsymbol{t = 121 \pm 10}$ **h ~ 5 days of data taking**

Conclusion

- $D^0 - \overline{D^0}$ asymmetry in Pythia still not fully understood
- Evidence for different behaviors depending on production mechanisms
- Mix of several mechanisms: which ones and in which proportion?
- Still many open questions!

What's next?

→ Currently exchanging with one of Pythia's developers

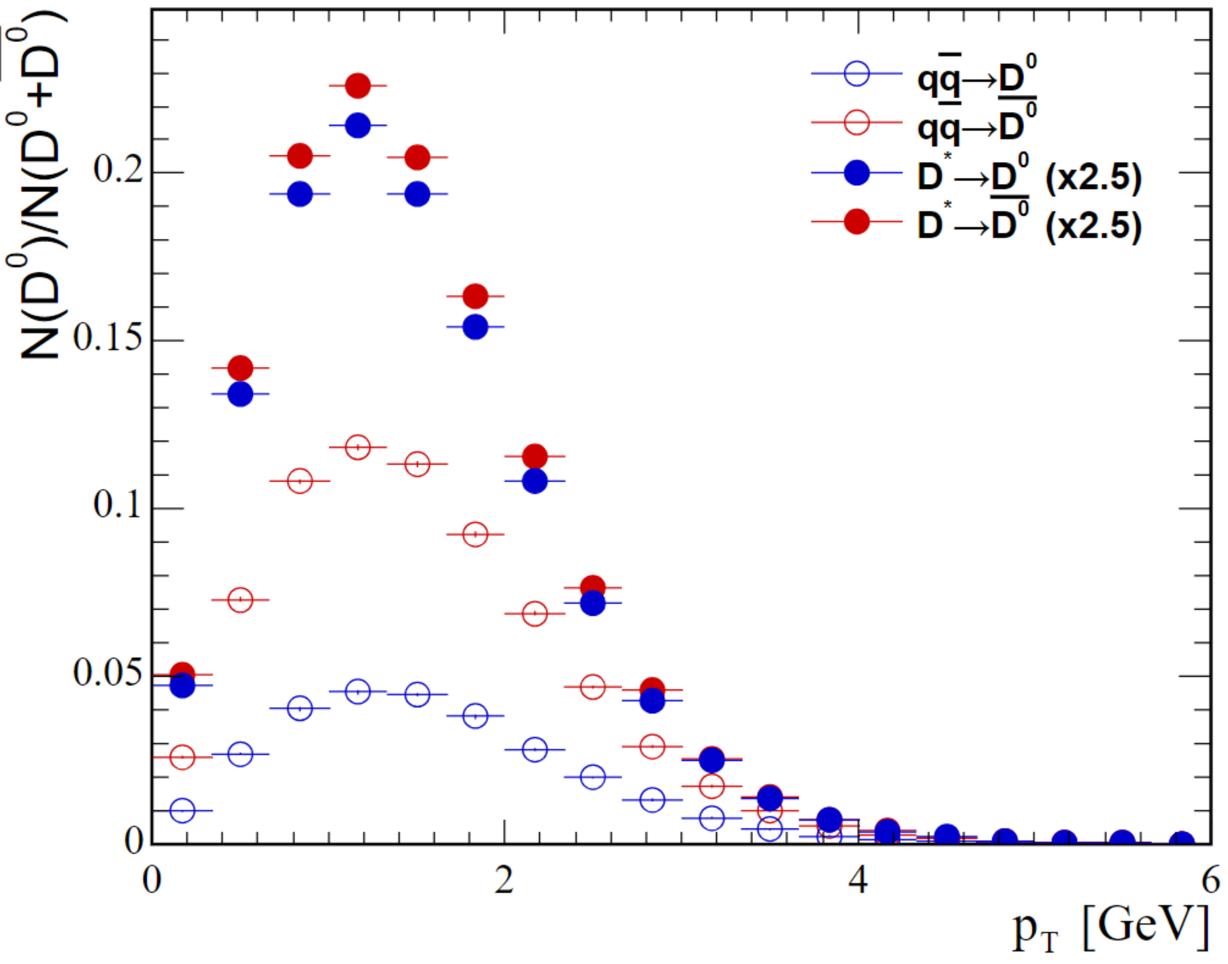
→ Compare to pHe collisions at $\sqrt{s_{NN}} = 68.5$ GeV

→ Waiting for new data with more statistics!

Thank you for your attention ☺

Pythia simulations

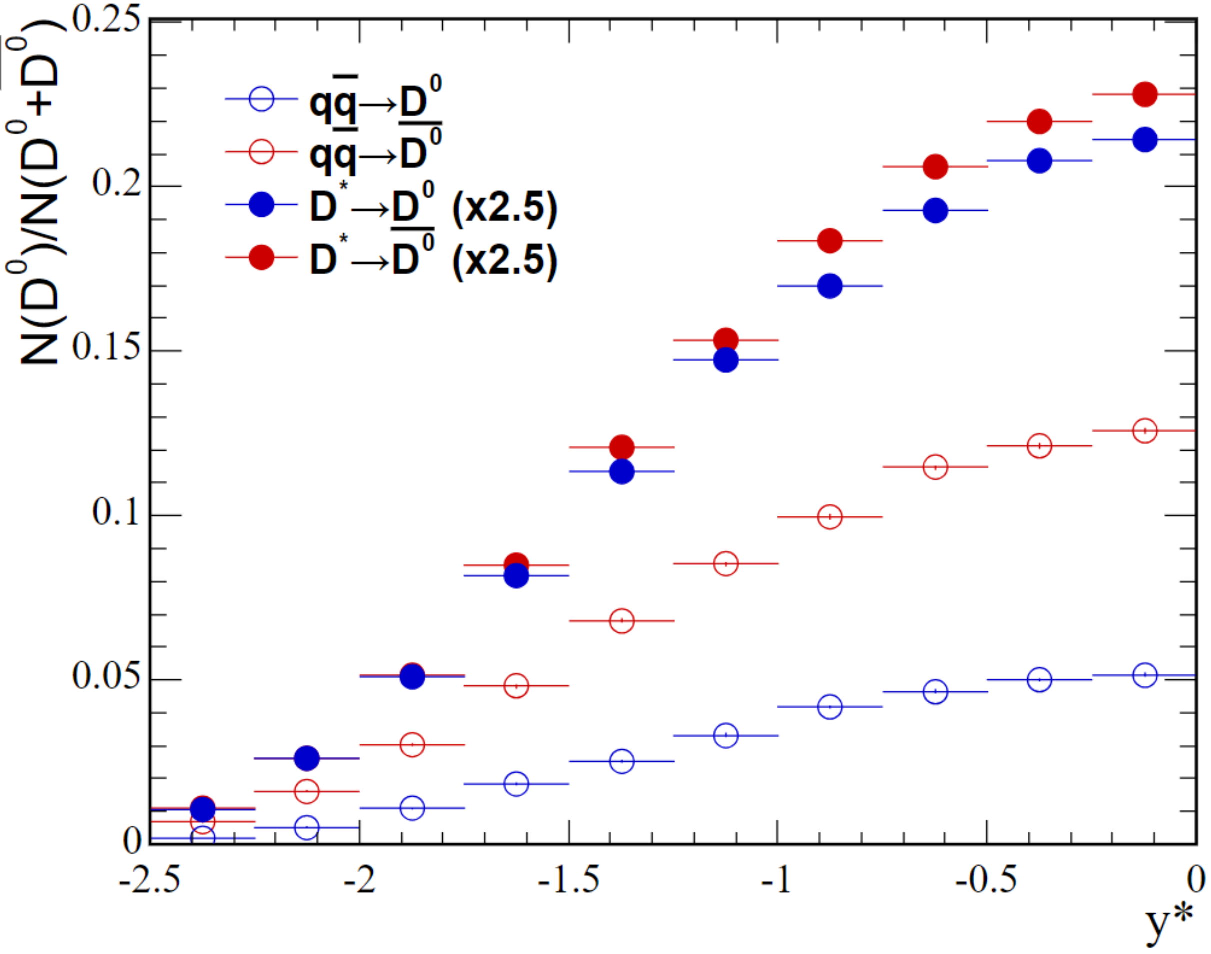
p_T distribution



Process	$\langle p_T \rangle$[GeV]
$q\bar{q} \to D^0$	1.58
$q\bar{q} \to \overline{D^0}$	1.53
$D^* \to D^0$	1.47
$D^* \to \overline{D^0}$	1.47

Pythia simulations

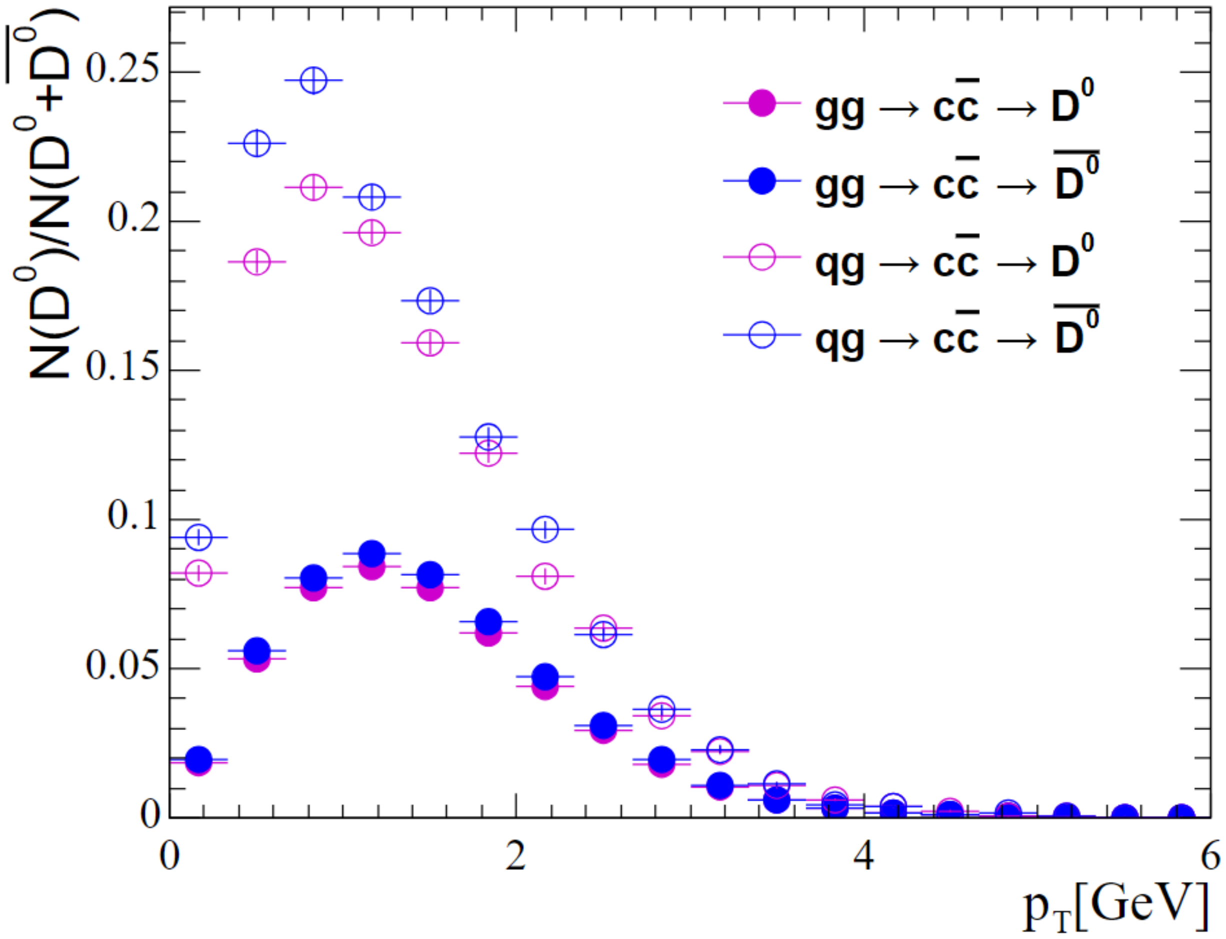
y distribution



Process	$\langle y^* \rangle$
$q\bar{q} \rightarrow D^0$	-0.80
$q\bar{q} \rightarrow \overline{D^0}$	-0.83
$D^* \rightarrow D^0$	-0.82
$D^* \rightarrow \overline{D^0}$	-0.82

Pythia simulations

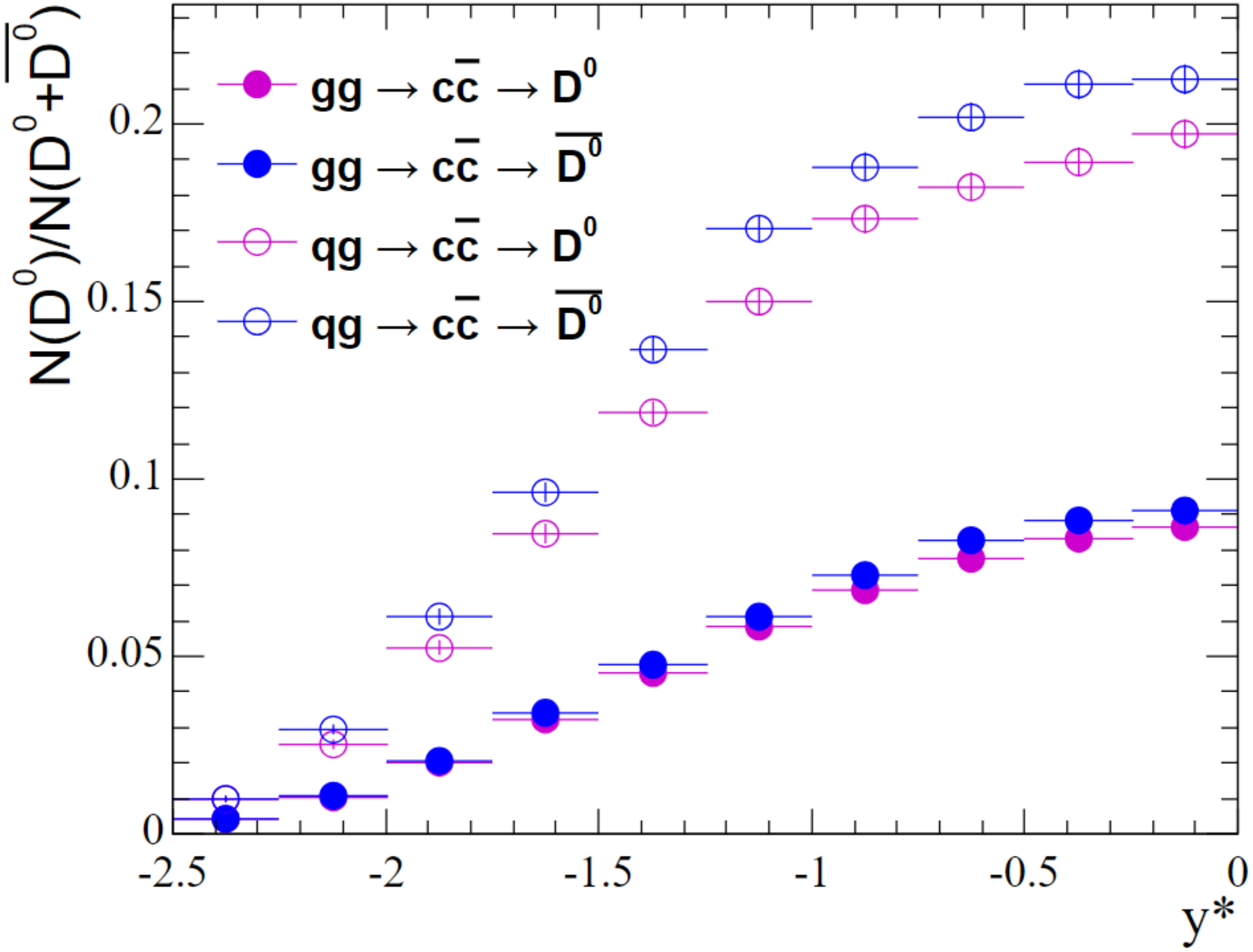
p_T distribution



Process	$\langle p_T \rangle$[GeV]
$gg \to D^0$	1.49
$gg \to \overline{D^0}$	1.49
$qg \to D^0$	1.33
$qg \to \overline{D^0}$	1.29

Pythia simulations

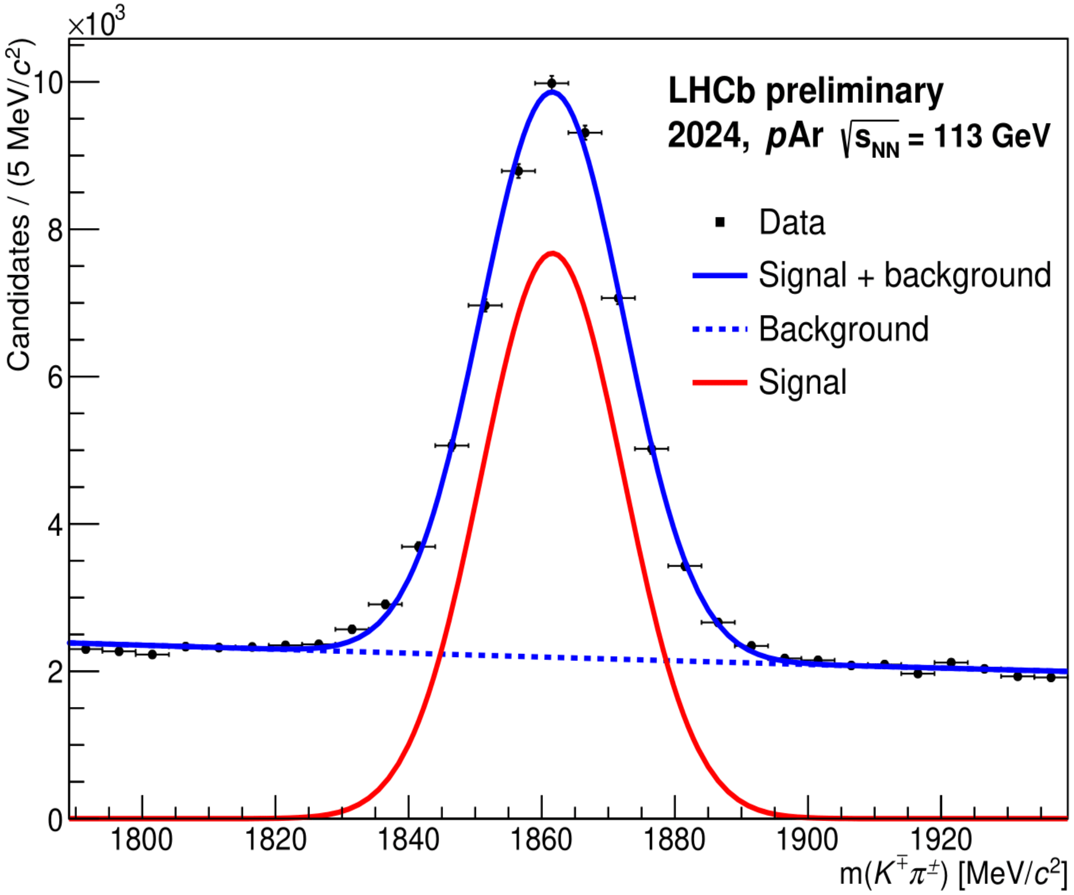
y distribution



Process	$\langle y^* \rangle$
$gg \to D^0$	-0.82
$gg \to \overline{D^0}$	-0.82
$qg \to D^0$	-0.85
$qg \to \overline{D^0}$	-0.86

Predictions for LHC Run3

Objective: $N(D^0) = 1$ million



From cross-section formula:

$$\sigma_{D^0}^{acc} = \frac{N(D^0)}{A \times \epsilon \times L \times t \times B(D^0 \to K^{\pm}\pi^{\pm})}$$

Acceptance-efficiency : 2.4%

Instantaneous luminosity (estimations for Run3):

$$L_{pH} = 6 \times 10^{31}\ cm^{-2}.s^{-1}$$
$$L_{pHe} = 3 \times 10^{31}\ cm^{-2}.s^{-1}\text{c}$$

Branching fraction to the measured decay product:

$$B = (3.950 \pm 0.031)\%$$

$\boldsymbol{\sigma_{D^0}^{acc}(p\mathrm{He})} = 80.8 \pm 2.4\ (stat.) \pm 6.3\ (sys.)$ μb/nucleon

Conclusion

- **What have been done:**

✓ Simulations of *pp* collisions at $\sqrt{s}_{NN} = 68.5$ GeV with Pythia

✓ Reproduce charm quark fragmentation functions measured in e^+e^-

✓ Study p_T and y^* dependence of $D^0 - \overline{D^0}$ asymmetry depending on D^0 and $c\bar{c}$ production mechanisms

✓ Predictions of the data taking time to get 1M D^0 during LHC Run3

What's next?

→ Compare to pHe collisions at $\sqrt{s}_{NN} = 68.5$ GeV

→ Same study for $D^+ - D^-$

Section

Subsection

Section

Subsection