



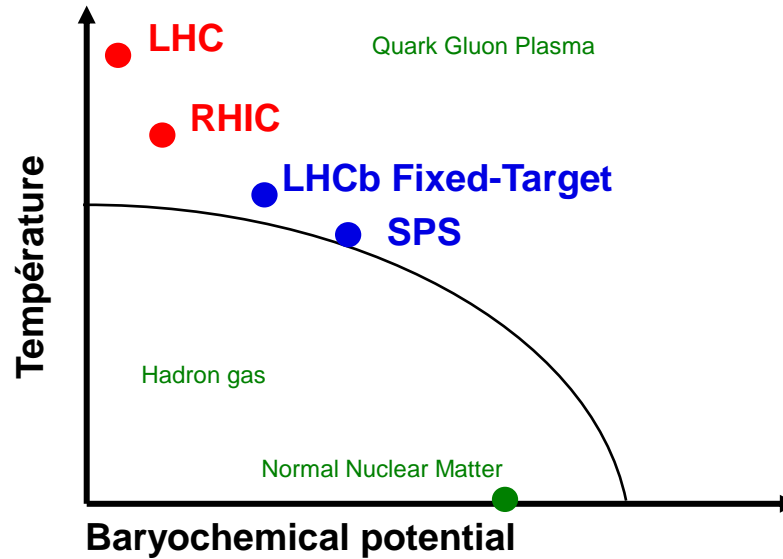
# Activités LHCb au LLR

Précédente présentation au CS : 16-11-2016

Le CS se réjouit qu'un post-doc financé par P2IO soit arrivé au labo. Le CS recommande que cette activité reste basée au LLR. Il félicite les membres du "groupe" pour les résultats très encourageants qu'ils ont montrés, et se réjouit que le projet de thèse proposé soit une priorité du laboratoire. Le CS reconnaît également le grand intérêt de la mesure de la luminosité et la forte visibilité qui en résulte.

**Aujourd'hui : CS du 19-06-2018**

**Activités « Ion and Fixed Target »**



- **Physics case**
- **The LHCb detector**
- **Programme ions lourds – fixed-target**
- **Futur**
  - court-terme
  - moyen-terme

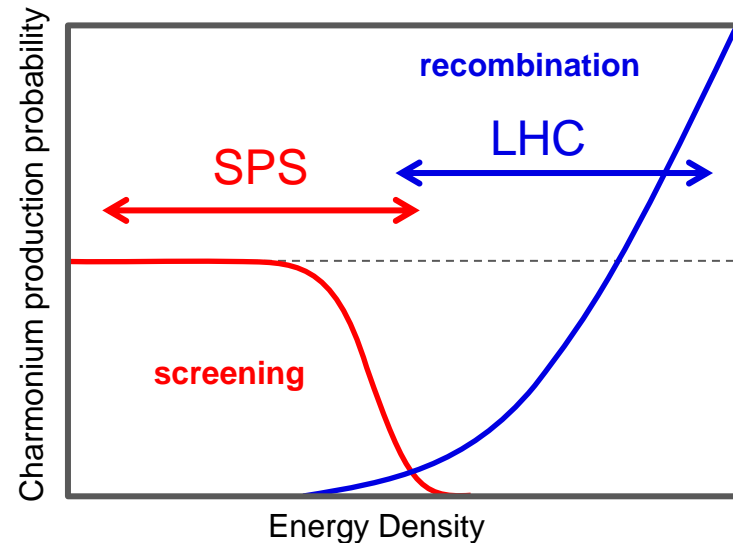
- Experimentally, charmonium is a privileged probe of QGP ( $m_c \gg T_c$ )
  - QGP phase should modify charmonium ( $c\bar{c}$ ) bound state yields
  - Charmonium production in A+A collisions studied at:
    - CERN-SPS ( $\sqrt{s}=17$  GeV) NA38, NA50, NA60 experiments
    - BNL-RHIC ( $\sqrt{s}=200$  GeV) PHENIX, STAR experiments
    - CERN-LHC ( $\sqrt{s}=2.76, 5$  TeV) ALICE, CMS experiments
  - Short summary for  $J/\Psi$ :
    - NA50 (PbPb@SPS) observed an *anomalous*  $J/\Psi$  suppression
    - PHENIX (AuAu@RHIC) observed a *similar* suppression (than NA50)
    - ALICE (PbPb@LHC) observed a *smaller* suppression (than PHENIX)

→ Possible Color screening starting at SPS

- Color screening in a QGP decreases quarkonium binding
- Color screening should lead to a suppression of quarkonium production yields

→ Possible recombination occurring at LHC

- at sufficiently high  $\sqrt{s_{NN}}$ , heavy quarks are abundantly produced.
- After thermalisation, statistical combination can lead to an enhancement of quarkonium production yields



- **What next to be done with charmonium**

To confirm (and study) charmonium color screening and recombination, one must compare charmonium and open charm production in A+A collisions

- Since most of the produced  $c\bar{c}$  pairs hadronize into open charm ( $\sim 90\%$ ), open charm production reflects the original  $c\bar{c}$  pair production
- Open charm is therefore an (the?) appropriate reference to calibrate charmonium screening/recombination studies.

- **Charmonium recombination : > 1 TeV**

- Both  $J/\Psi$  and open charm will be measured in PbPb at large energy densities at LHC

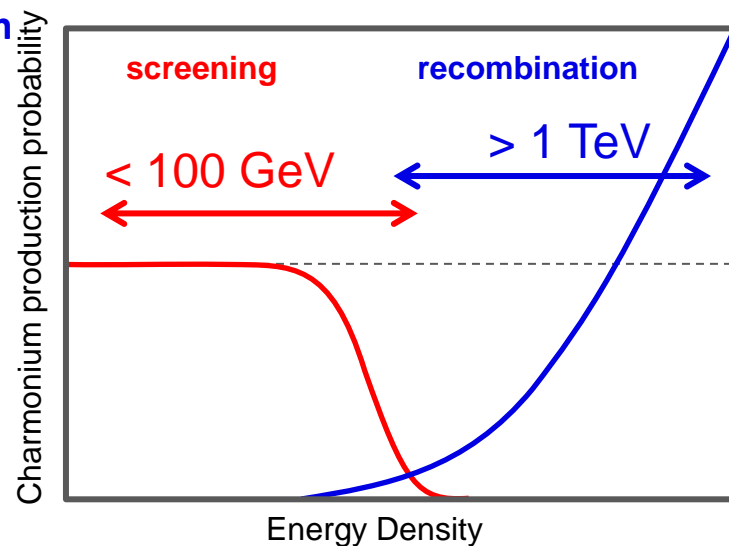
➔ **Best place to study charmonium recombination**

- **Charmonium screening : < 100 GeV**

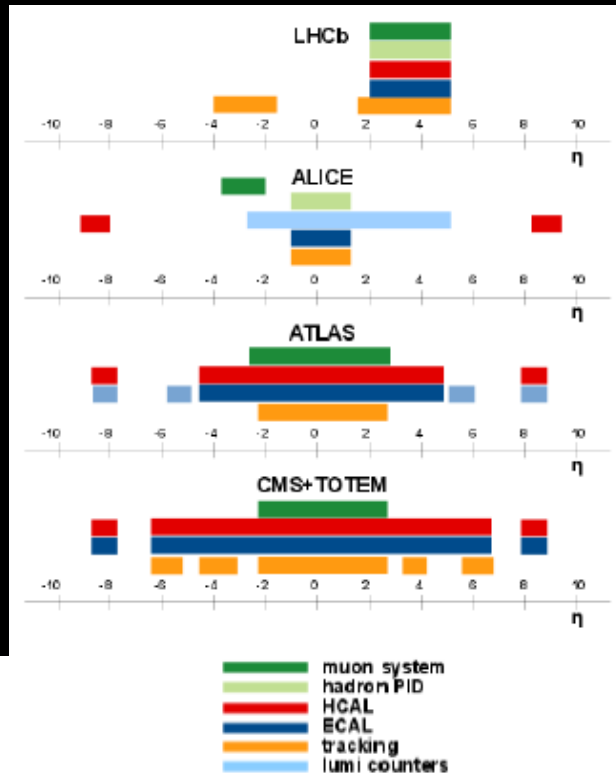
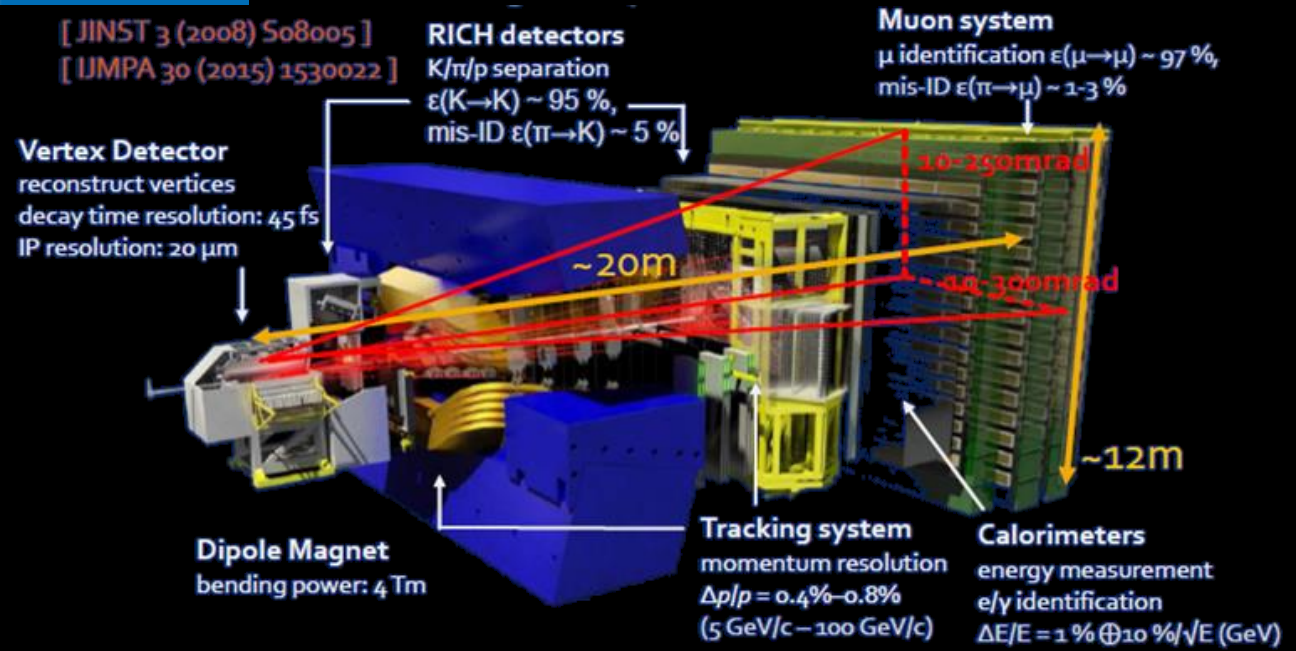
- At SPS energies, in Pb+Pb collisions,  $J/\Psi$  suppression occurs in the middle of the accessible energy density range

➔ **Best place to study color screening**

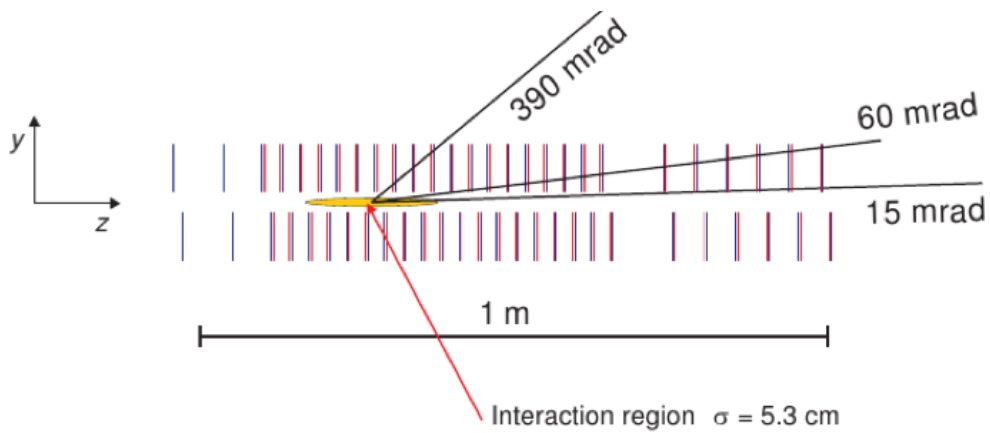
- *Needs measurement of open charm yields*
- *Needs precise measurements of several  $c\bar{c}$  states to test if color screening leads indeed to a sequential suppression*



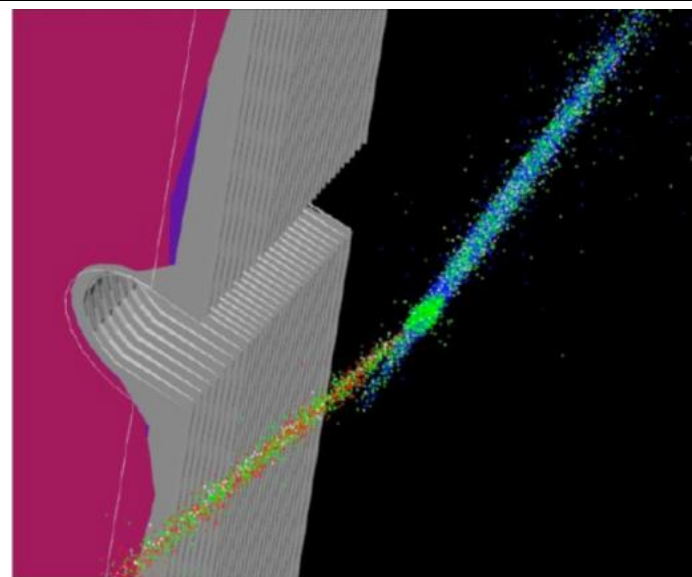
# The LHCb detector



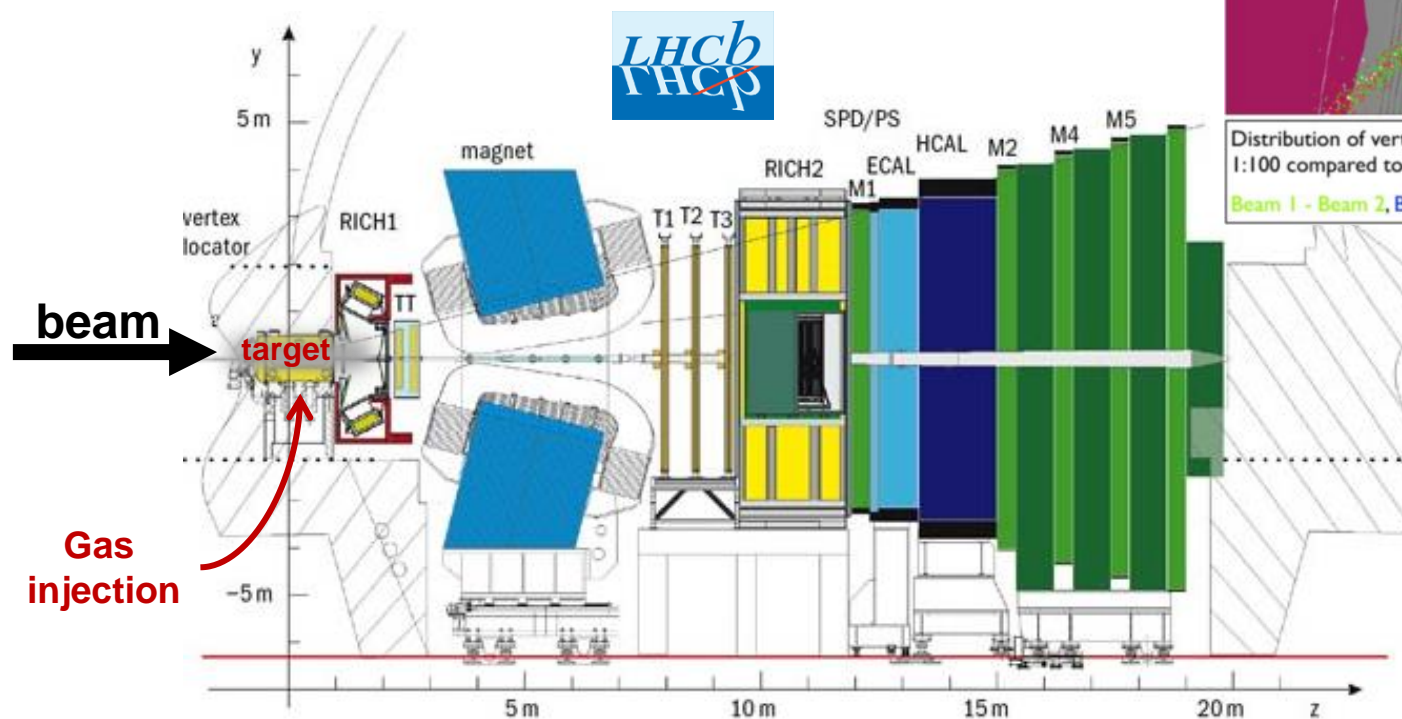
## Le VELO (VERTeX LOcator)



- Can also operate in **fixed-target mode**: unique at LHC
  - Injecting gas in the LHCb VERTeX LOcator (VELO) tank, primarily done to perform luminosity measurement.
  - Can be used as an **internal gas target**
  - Allows measurement of  $p$ -gas and ion-gas interactions



Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.  
 Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

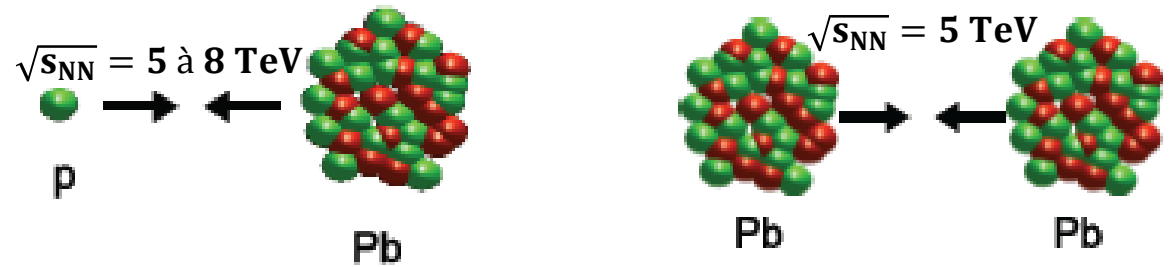


**Noble gas only :**  
 (very low chemical reactivity)

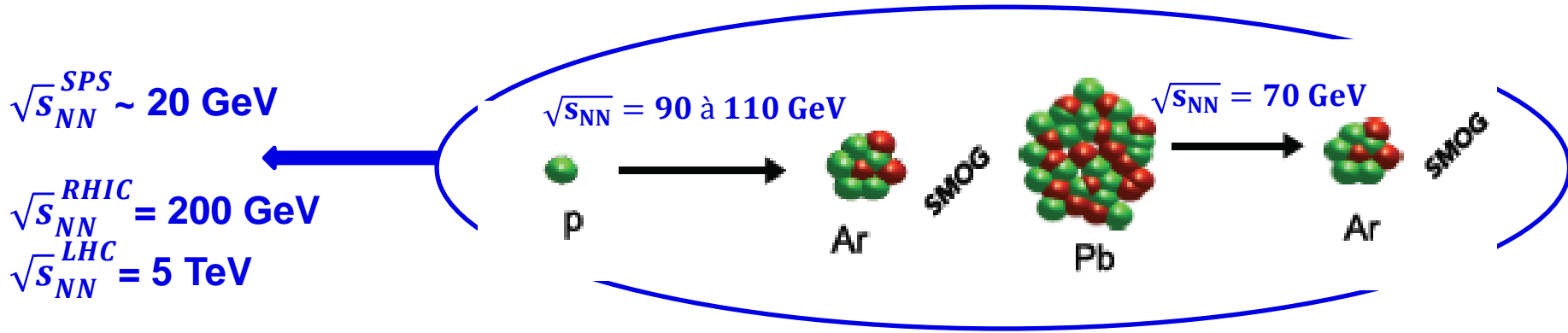
He, Ne, Ar, Kr, Xe  
 $A = 4, 20, 40, 84, 131$

Gas pressure:  
 $10^{-7}$  to  $10^{-6}$  mbar

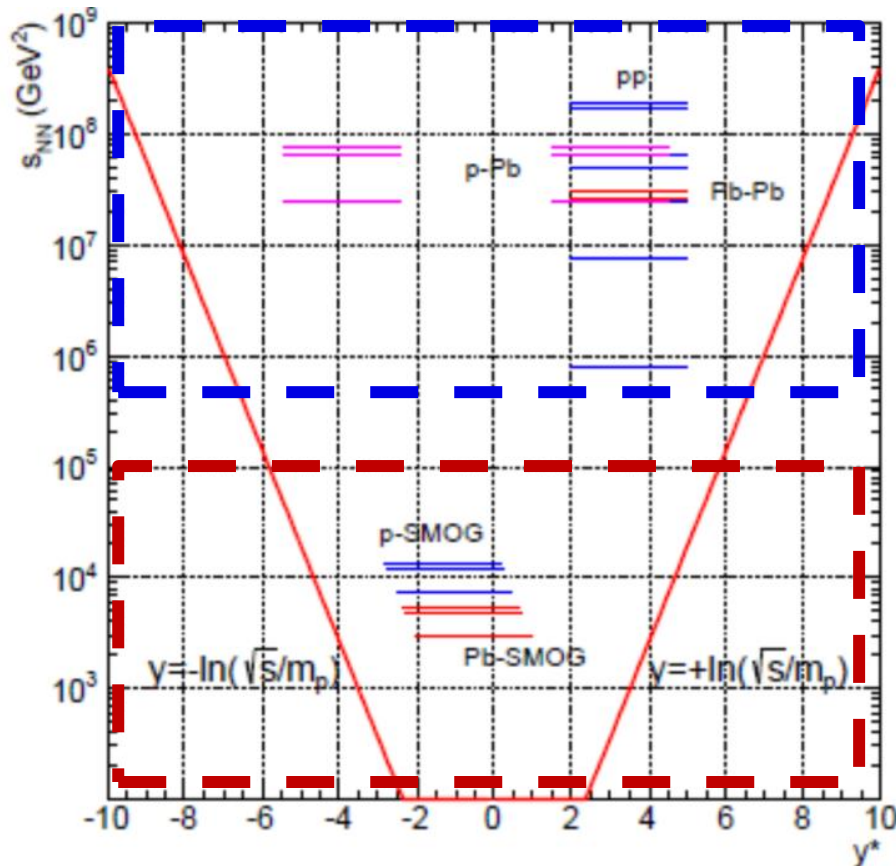
- LHCb fonctionne en deux modes
  - Mode collisionneur



- Mode « cible fixe »



- acceptance



← Mode collisionneur

$E_{\text{beam}}(p)$	pp	p-SMOG	p-Pb/Pb-p	Pb-SMOG	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5. TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.1 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

← Mode cible-fixe

LHCb rapidity:  $2.5 < y_{\text{LHCb}} < 4.5 \Rightarrow \left\{ \begin{array}{l} 7 \text{ TeV beam: } -2.3 < y_{\text{LHCb}}^* < -0.3 \\ 2.75 \text{ TeV beam: } -1.8 < y_{\text{LHCb}}^* < 0.2 \end{array} \right.$



- **The IFT (Ion and Fixed Target) working group**

- *Juillet 2015 : proposal for LHCb Participation to the Heavy Ion Runs*
  - 10 signataires dont 5 français (LAL+LLR)
- ~ 15 à 20 personnes en novembre 2016
  - 6 français (4 LAL, 2 LLR) ≡ l'essentiel de l'effort sur la mesure des saveurs lourdes

LHCb-INT-2015-019

July 29, 2015

version 0.5

- **Participation française ions lourds = LAL+LLR**

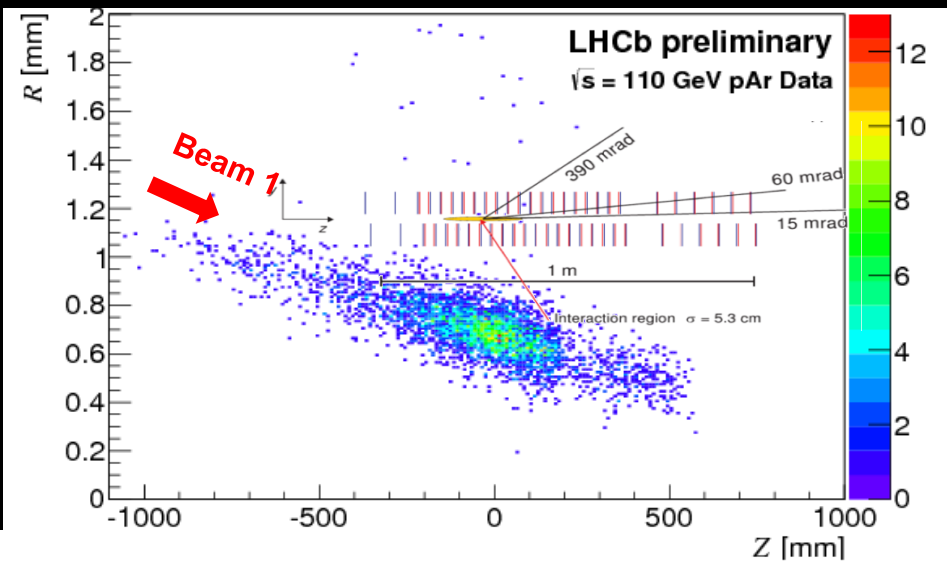
- Étude de la production des saveurs lourdes dans les collisions pPb @ 8 TeV (principalement au LAL)
- Étude de la production des saveurs lourdes dans SMOG (principalement au LLR)
- Fortes synergies LAL/LLR
  - Permanents : **P. Robbe** (LAL), **F. Fleuret** (LLR)
  - Postdocs : ~~F. Bossu~~ (LAL), **E. Maurice** (LLR), ~~M. Winn~~ (LAL), ~~Y. Zhang~~ (LAL)
  - Thésards : (à partir de septembre) **Elisabeth Niel** (LAL), **Felipe Garcia** (LLR)

- **Participation du LLR dans LHCb**

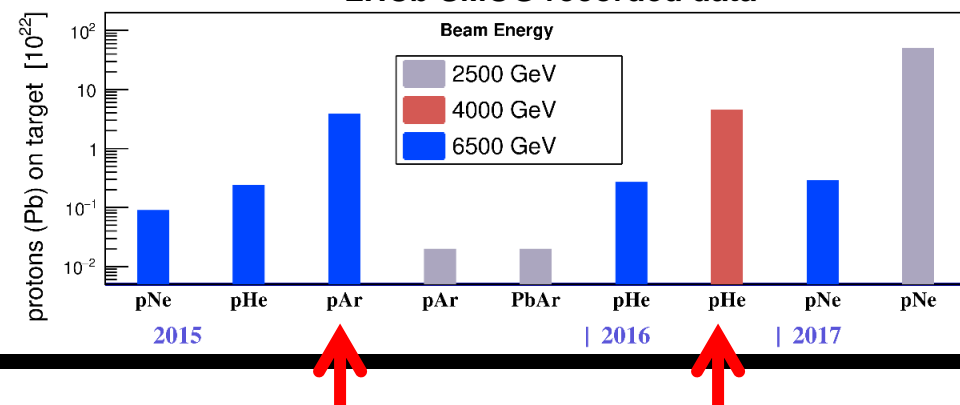
- **Vladislav Balagura** (50%) : mesures de luminosité
- **Emilie Maurice** (100%) : prod. du charme dans SMOG, co-conveener du groupe « luminosity and ion runs »
- **Frédéric Fleuret** (100%) : prod. du charme dans SMOG, co-conveener du groupe « Ion and Fixed Target »
- **Felipe Garcia** (100% à partir de septembre) : thèse, production du charme dans SMOG
- **Elena Ferreira** (théoricienne, professeur Santiago) : accueil pendant un an sur programme d'Alembert (Paris-Saclay)

## Objectifs scientifiques:

- Mesurer la ligne de base en proton-noyau (He, Ne, Ar)
- Mesurer les effets de QGP en Pb-noyau (Ne, Ar)



LHCb SMOG recorded data



## Two data sets presented here:

- $\sqrt{s_{NN}} = 110$  GeV proton-Ar interactions 2015:  $\sim 4 \times 10^{22}$  Protons On Target (17h)
- $\sqrt{s_{NN}} = 86.6$  GeV proton-He interactions 2016:  $\sim 4 \times 10^{22}$  POTs (87h)

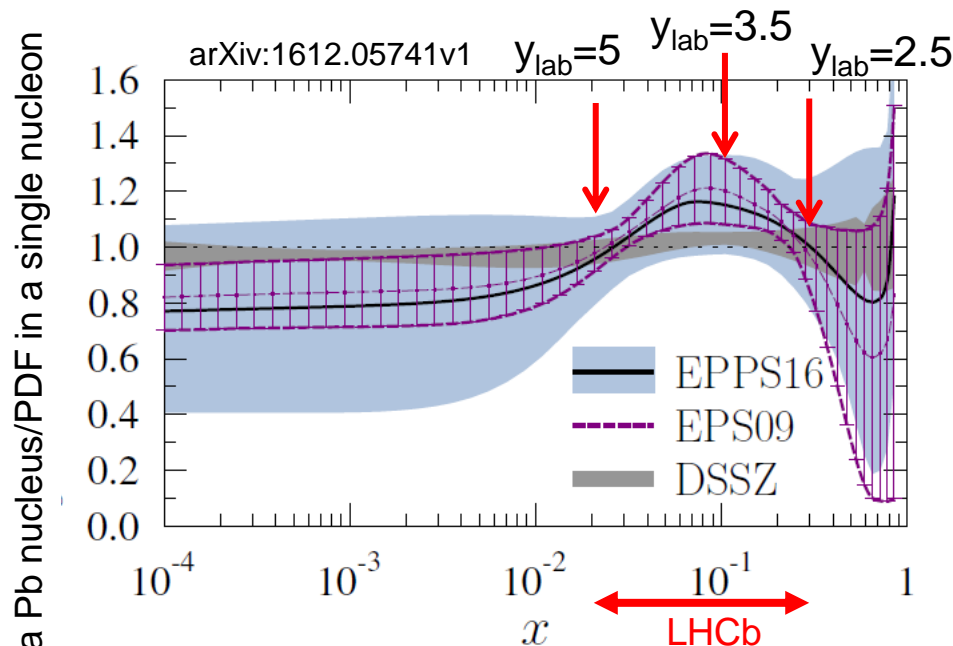
$$\mathcal{L}_{pHe} = 7.6 \pm 0.5 \text{ nb}^{-1}$$

- **Proton-nucleus collisions**

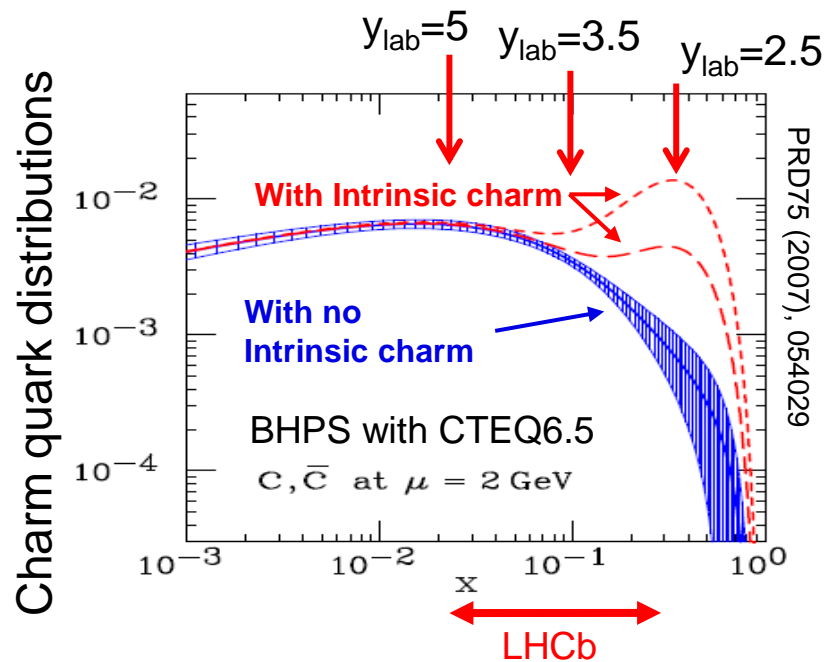
- Serve as a baseline for nucleus-nucleus collisions
- Study of nuclear PDF (nPDF), nuclear absorption, ...

- **With LHCb-SMOG, large rapidity coverage ( $\sim 3$  rapidity units) at large Bjorken- $x$  in the target ( $x_2$ )**

- Give access to **nPDF anti-shadowing** region and **intrinsic charm** content in the nucleon

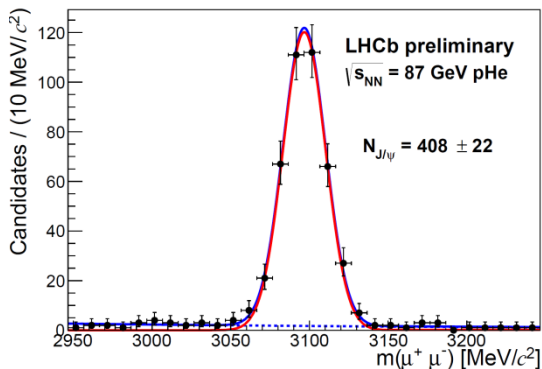


Bjorken- $x$  = fraction of the nucleon momentum carried by a parton

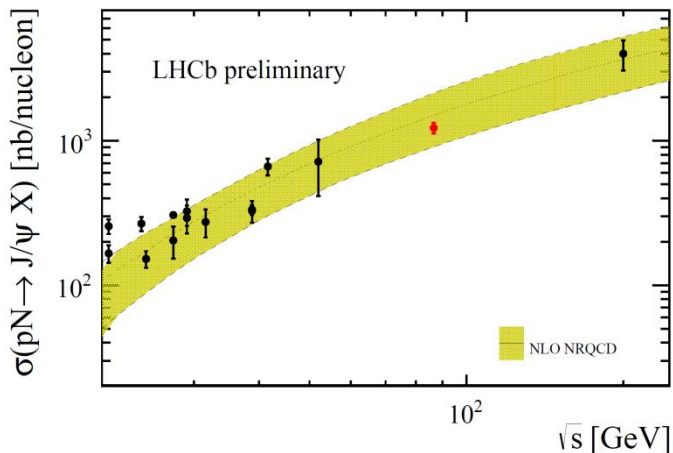


- $J/\psi \rightarrow \mu^+\mu^-$  and  $D^0 \rightarrow K^{\mp}\pi^{\pm}$  inclusive cross sections in  $pHe$  @86.6 GeV

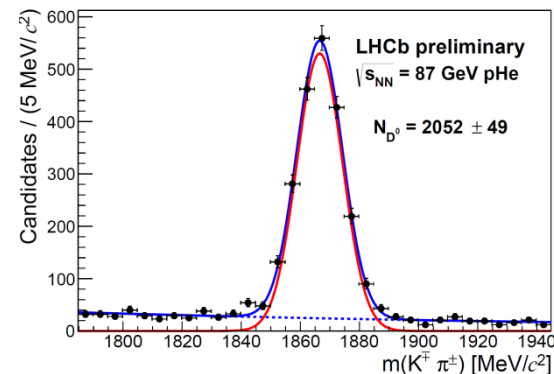
LHCb-PAPER-2018-023  
in preparation



$$\sigma_{J/\psi} = 1225.6 \pm 62.0 \text{ (stat)} \pm 81.6 \text{ (syst) nb/nucleon}$$



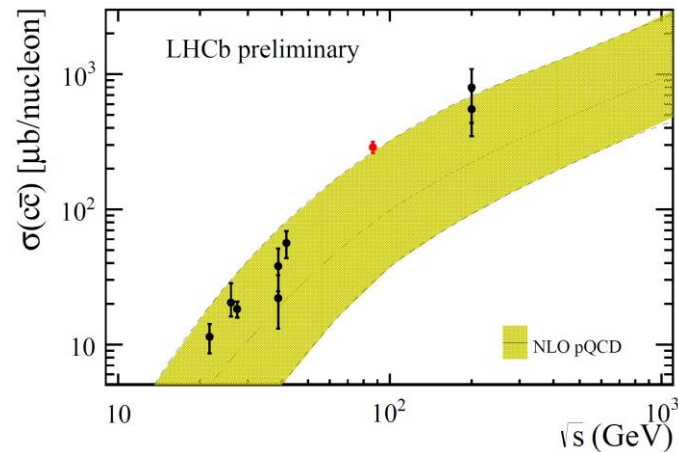
LHCb result in good agreement with NRQCD fit and other measurements



$$\sigma_{D^0} = 156.0 \pm 4.6 \text{ (stat)} \pm 12.3 \text{ (syst) } \mu\text{b/nucleon}$$

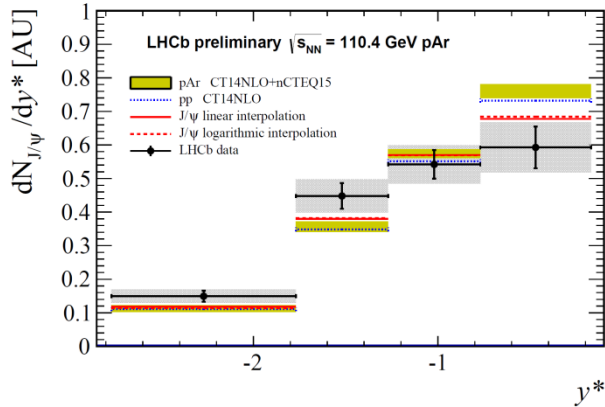
with fraction ( $c \rightarrow D^0$ ) =  $0.542 \pm 0.024$

$$\sigma_{c\bar{c}} = 287.8 \pm 8.5 \text{ (stat)} \pm 25.7 \text{ (syst) } \mu\text{b/nucleon}$$



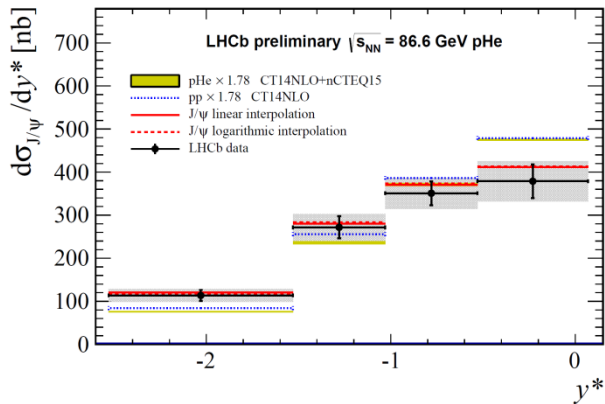
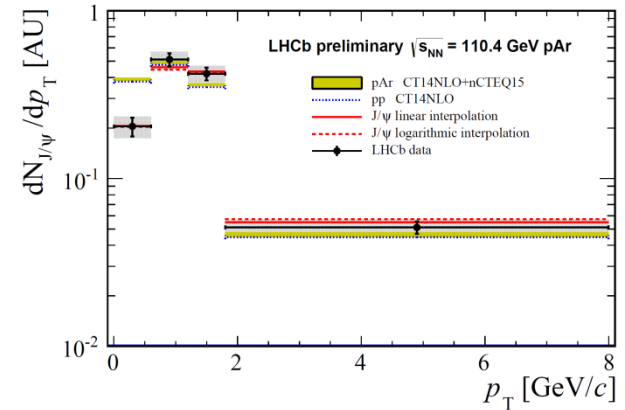
LHCb result in reasonable agreement with NLO pQCD (MNR) predictions and other measurements

- **J/ψ Differential yields (pAr@110 GeV) and cross sections (pHe@86.6 GeV)**
  - Plain and dashed **red lines**, phenomenological parametrization: JHEP 05 (2013) 155
  - **HELAC-ONIA** predictions for pp (blue lines) and pA (yellow boxes): EPJC(2017) 77:1

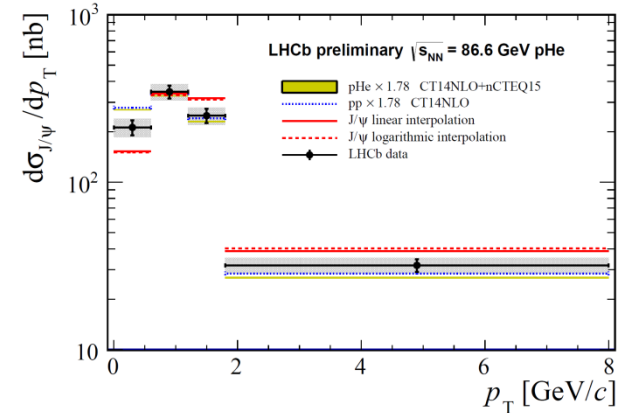


LHCb-PAPER-2018-023  
in preparation

pAr @ 110 GeV  
yields

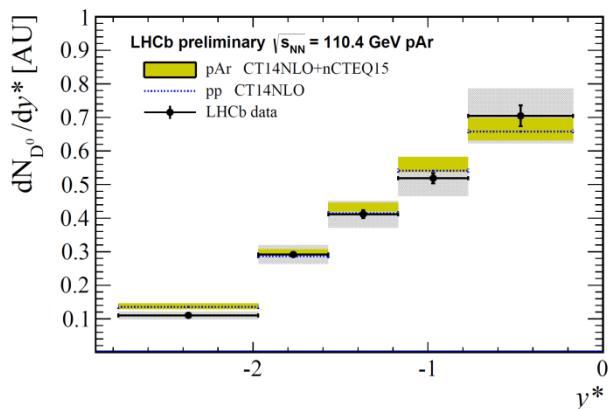


pHe @ 86.6 GeV  
Cross sections



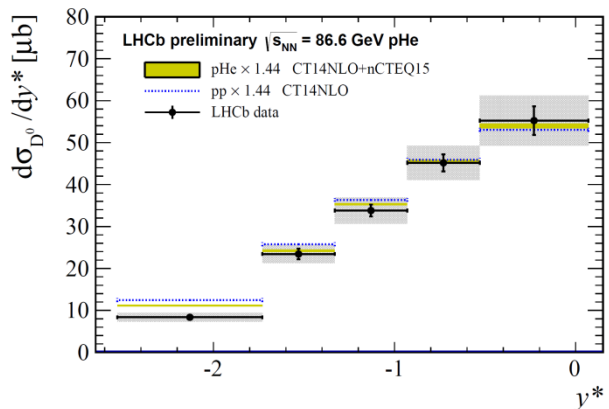
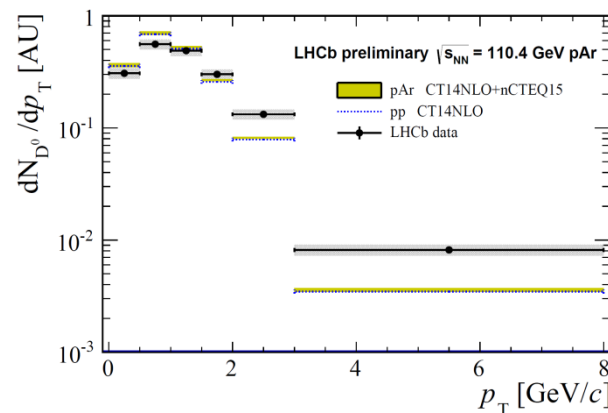
- **HELAC-ONIA under-estimate J/ψ cross section (pHe) by a factor 1.78**
- **Good shape agreement with phenomenological predictions**

- **D<sup>0</sup> Differential yields (pAr@110 GeV) and cross sections (pHe@86.6 GeV)**
  - HELAC-ONIA predictions for pp (blue lines) and pA (yellow boxes): EPJC(2017) 77:1

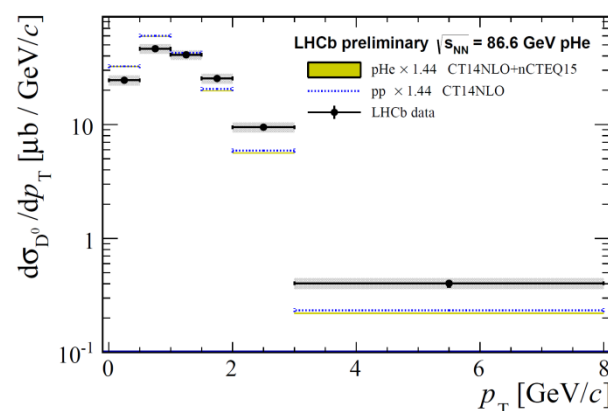


LHCb-PAPER-2018-023  
in preparation

pAr @ 110 GeV  
yields



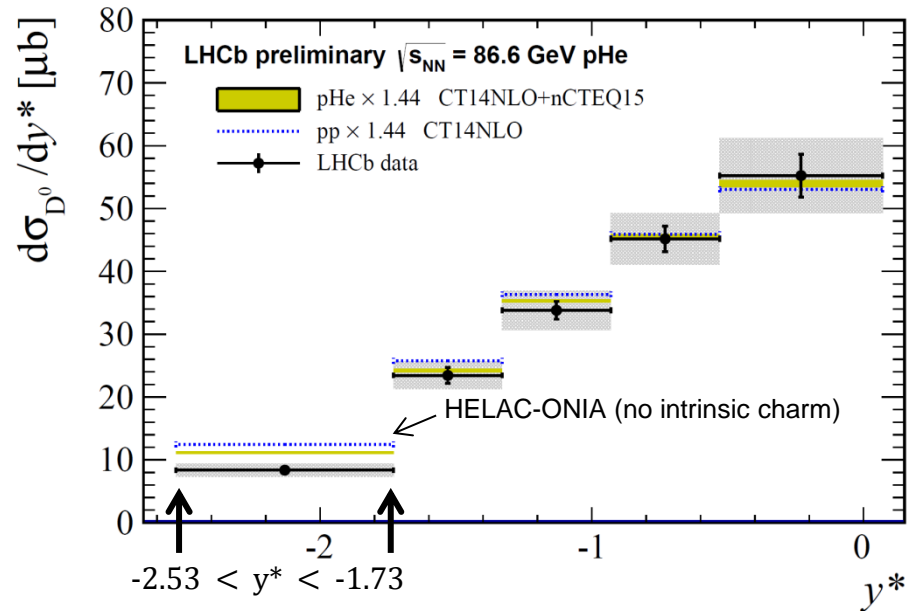
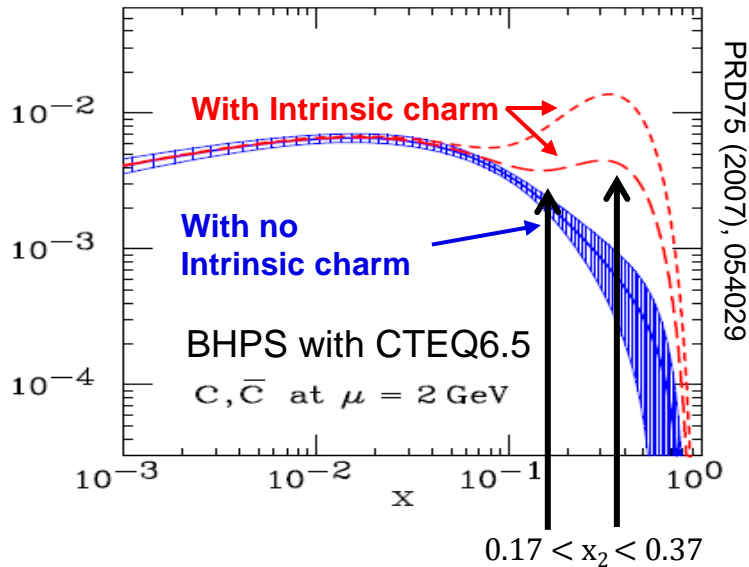
pHe @ 86.6 GeV  
Cross sections



- HELAC-ONIA under-estimate D0 cross section (pHe) by a factor 1.44
- Good agreement in rapidity shapes between data and predictions

- $D^0$  cross sections (pHe@86.6 GeV) .vs. Intrinsic charm
  - HELAC-ONIA predictions for pp (blue lines) and pA (yellow boxes): EPJC(2017) 77:1
  - With  $x_2 \simeq \frac{2 \times m_c}{\sqrt{s_{NN}}} \exp(-y^*)$   $y^* \in [-1.73, -2.53] \Leftrightarrow x_2 \in [0.17, 0.37]$

Charm quark distributions



- HELAC-ONIA does not contain intrinsic charm contribution
- **No evidence of strong intrinsic charm contribution**

- Analyse des données **pNe@68 GeV** (acquises en **nov. 2017**) comme référence pour l'étude des données **PbNe@68 GeV** (qui seront acquises en **nov. 2018**):
  - Sujet principal de la thèse de Felipe Garcia (début sept. 2018)
  - Mesure des  $J/\psi$ ,  $\psi'$  et  $\chi_c$ , et saveurs lourdes ouvertes ( $D^0$ ,  $D^\pm, \dots$ )

	Current SMOG result pHe@86 GeV	SMOG largest sample pNe@68 GeV
Int. Lumi.	7.6/nb	$\sim 100$ /nb
syst. error on $J/\psi$ x-sec.	7%	6 - 7%
$J/\psi$ yield	400	15k
$D^0$ yield	2000	100k
$\Lambda_c$ yield	20	1k
$\psi'$ yield	negl.	150
$\Upsilon(1S)$ yield	negl.	10
DY $\mu^+\mu^-$ yield ( $5 < M < 9$ GeV)	negl.	10

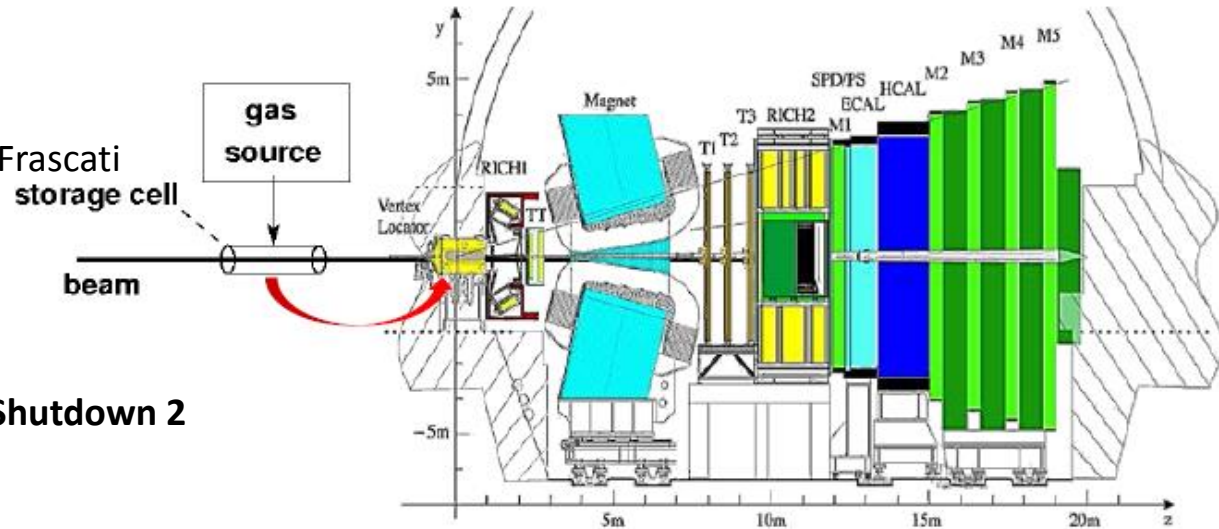
- **Participation à la prise de données Pb nov. 2018 et analyse**
  - PbNe @ 68 GeV  $\rightarrow$  objectif: 1<sup>ères</sup> mesures noyau-noyau avec SMOG
  - 2<sup>ème</sup> sujet pour la thèse de Felipe Garcia



# Futur – moyen terme (2021 – 2025)

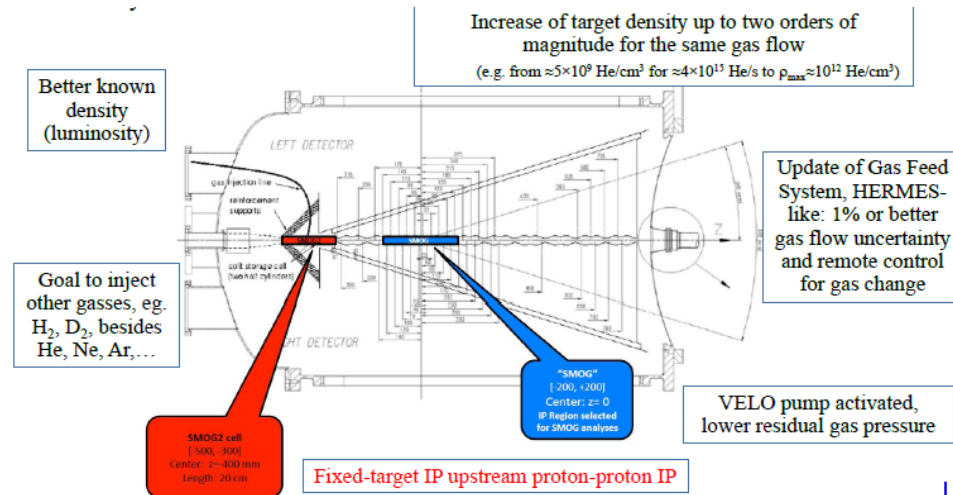
- **L'upgrade SMOG2**

- R&D en cours
- NIKHEF, INFN-Ferrara, INFN-Frascati

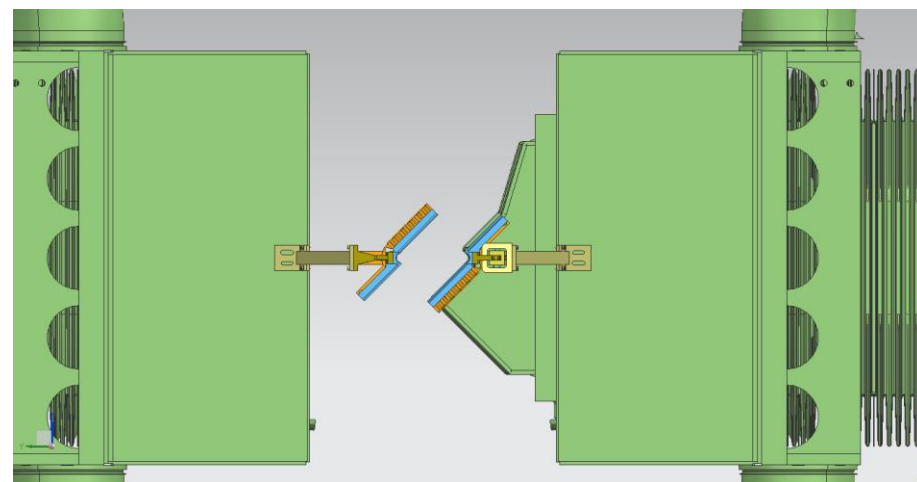
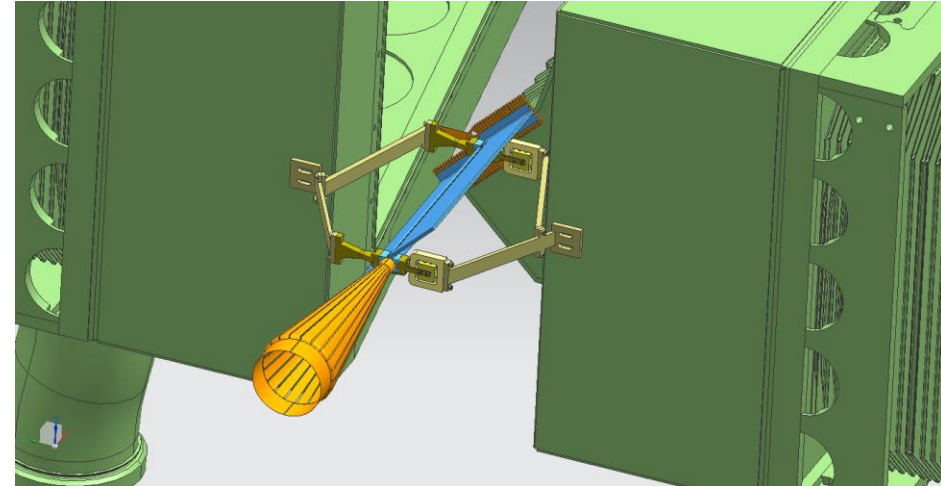
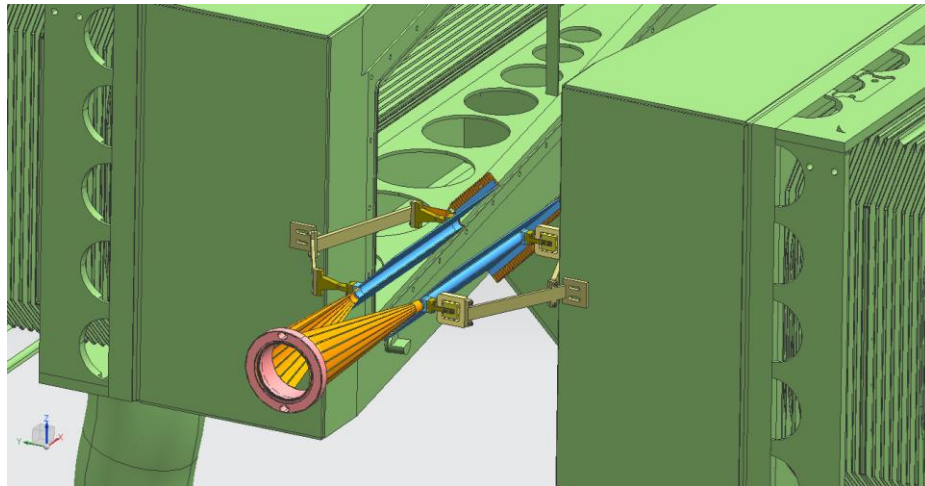


- **Upgrade de LHCb pendant Long Shutdown 2 (LS2: 2 ans, fin 2018)**

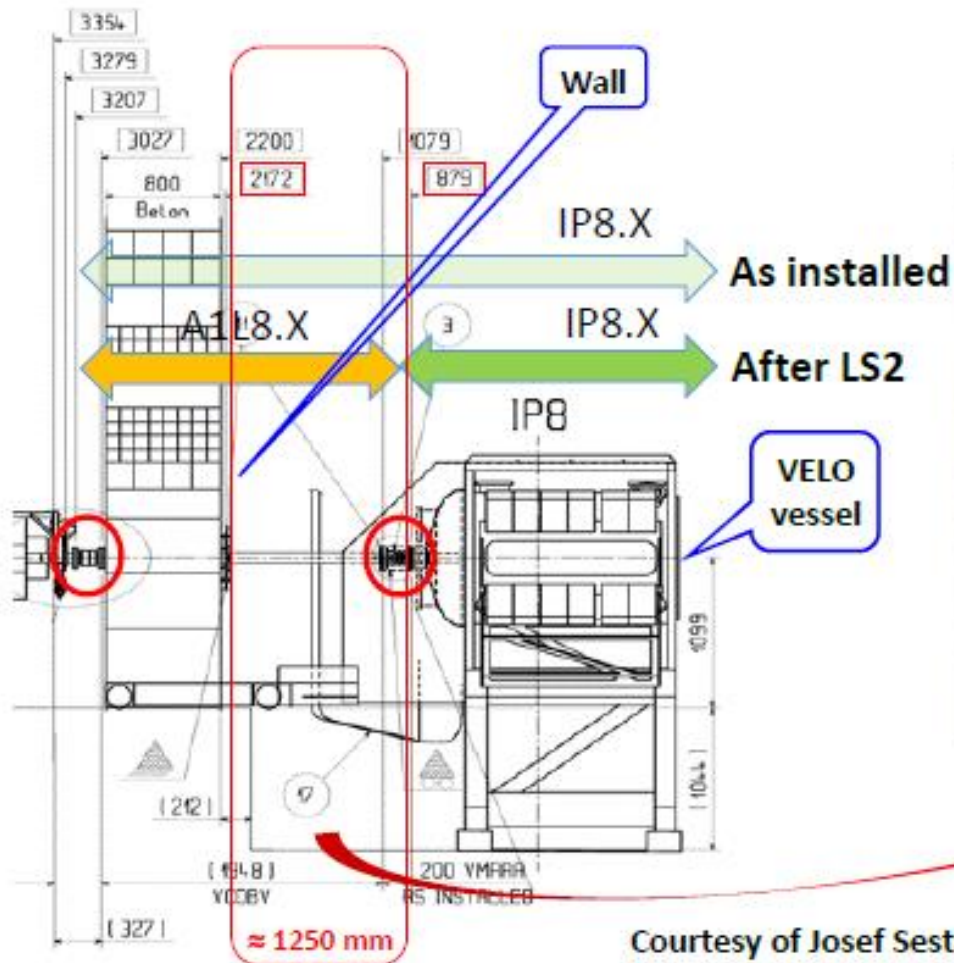
- Remplacement du VELO
  - Strips → pixels
- Installation d'une storage cell
  - Diamètre = 1cm, longueur = 20 cm
  - Placée en amont du VELO (-50 à -30 cm par rapport à IP)
  - Augmentation de la densité locale de gaz jusqu'à un facteur 100
  - Augmentation de la luminosité jusqu'à un facteur 100 par rapport à SMOG



- SMOG2: R&D on storage cell at NIKHEF, INFN-Ferrara, INFN-Frascati



- SMOG2: R&D on storage cell at LIKHEF, INFN-Ferrara, INFN-Frascati



Courtesy of Josef Sestak, CERN

- **SMOG2 : performances**

- Sur la base d'une augmentation de densité d'un facteur 100
- Environ 10 jours de prise de données

	Current SMOG result pHe@86 GeV	SMOG largest sample pNe@68 GeV	SMOG2 example pAr@115 GeV
Int. Lumi.	7.6/nb	~ 100/nb	~ 10/pb
syst. error on $J/\psi$ x-sec.	7%	6 - 7%	3 - 4 %
$J/\psi$ yield	400	15k	3.5M
$D^0$ yield	2000	100k	35M
$\Lambda_c$ yield	20	1k	350k
$\psi'$ yield	negl.	150	35k
$\Upsilon(1S)$ yield	negl.	10	3k
DY $\mu^+\mu^-$ yield ( $5 < M < 9$ GeV)	negl.	10	3k

- **Évolution depuis le CS de novembre 2016**
  - Analyse des données pAr 2015 et pHe 2016
    - First measurement of charm production in fixed-target configuration at LHC
    - Publication en cours de rédaction → PRL
  - Prises de responsabilité
    - Luminosity and ion runs operation group (Emilie Maurice)
    - Ion and Fixed target physics analysis group (Frédéric Fleuret, Michael Winn)
  - Équipe LAL/LLR
    - **à l'origine et actuel leader du groupe LHCb-IFT (conveeners: F. Fleuret, M. Winn)**
    - **Francesco Bossu (postdoc – LAL)** → recruté au SPhN (Jlab) en janvier 2018
    - **Michael Winn (postdoc – LAL)** → recruté au SPhN (Alice) en septembre 2018
    - **Yanxi Zhang (postdoc – LAL)** → fellow CERN (LHCb) en septembre 2018
    - Arrivée de deux doctorants en septembre:
      - **Elisabeth Niel (LAL)**
      - **Felipe Garcia (LLR)**
  - Le postdoc de 2 ½ ans d'Emilie Maurice se termine en février 2019
    - **Demande de complément de financement postdoc IN2P3 de 6 mois**
    - **Demande soutien du laboratoire pour permettre à Emilie de poursuivre jusqu'en sept. 2019**

TABLE I: Centrality bin, number of  $NN$  collisions, nuclear overlap function, charm cross section per  $NN$  collision, and total charm multiplicity per  $NN$  collision, in  $\sqrt{s_{NN}} = 200$  GeV Au+Au reactions.

Centrality	$N_{coll}$	$T_{AA}$ ( $\text{mb}^{-1}$ )	$\frac{1}{T_{AA}} \frac{dN_{c\bar{c}}}{dy} \Big _{y=0}$ ( $\mu\text{b}$ )	$N_{c\bar{c}}/T_{AA}$ ( $\mu\text{b}$ )
min. bias	$258 \pm 25$	$6.14 \pm 0.45$	$143 \pm 13 \pm 36$	$622 \pm 57 \pm 160$
0–10 %	$955 \pm 94$	$22.8 \pm 1.6$	$137 \pm 21 \pm 35$	$597 \pm 93 \pm 156$
10–20 %	$603 \pm 59$	$14.4 \pm 1.0$	$137 \pm 26 \pm 35$	$596 \pm 115 \pm 158$
20–40 %	$297 \pm 31$	$7.07 \pm 0.58$	$168 \pm 27 \pm 45$	$731 \pm 117 \pm 199$
40–60 %	$91 \pm 12$	$2.16 \pm 0.26$	$193 \pm 47 \pm 52$	$841 \pm 205 \pm 232$
60–92 %	$14.5 \pm 4.0$	$0.35 \pm 0.10$	$116 \pm 87 \pm 43$	$504 \pm 378 \pm 190$

Phys. Rev. Lett. 94, 082301 (2005)

**In central Au+Au collisions @ 200 GeV**

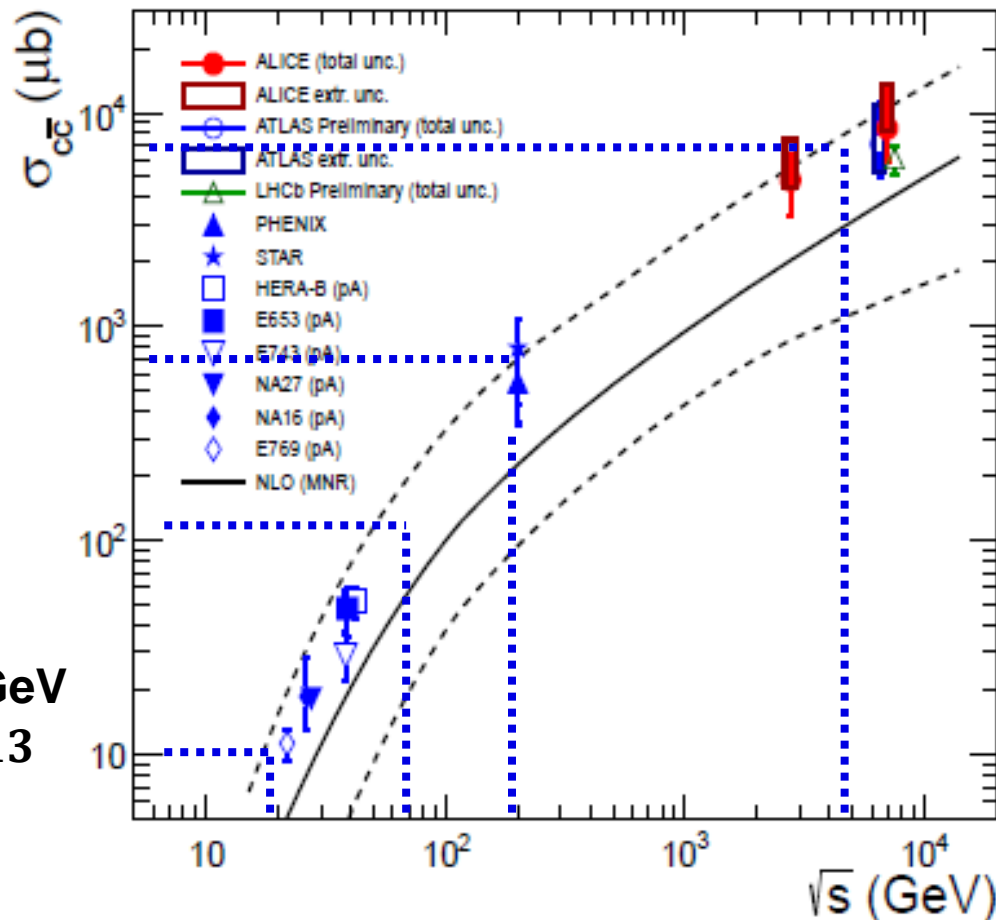
$$N_{c\bar{c}} \sim 597 \cdot 10^{-3} \text{mb} \times 22.8 \text{mb}^{-1} \sim 13$$

**~0.1  $c\bar{c}$  @ 20 GeV**

**~1  $c\bar{c}$  @ 70 GeV**

**~10  $c\bar{c}$  @ 200 GeV**

**~100  $c\bar{c}$  @ 5500 GeV**



$$\sigma_{c\bar{c}}^{5500 \text{ GeV}} \sim 10 \times \sigma_{c\bar{c}}^{200 \text{ GeV}} \sim 100 \times \sigma_{c\bar{c}}^{70 \text{ GeV}} \sim 1000 \times \sigma_{c\bar{c}}^{20 \text{ GeV}}$$

