SMOG data and heavy flavors

nucleus-nucleus : Quark Gluon Plasma

proton-nucleus : Cold Nuclear Matter

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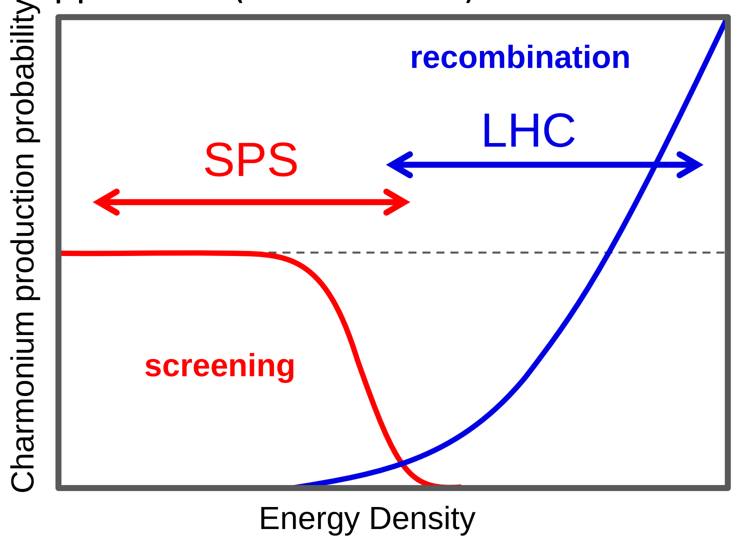
- **Experimentally, charmonium is a priviledged probe of QGP $(m_c \gg T_c)$**
  - **QGP phase shouldn't modify the overall heavy quark yields**
  - **QGP phase should modify relative (hidden/open) heavy quark bound state yields**

  Charmonium production in A+A collisions studied at:
    - CERN-SPS (√s=17 GeV) NA38, NA50, NA60 experiments
    - BNL-RHIC (√s=200 GeV) PHENIX, STAR experiments
    - CERN-LHC (√s=2.76, 5 TeV) ALICE, CMS experiments
  - Short summary for J/Ψ:
    - NA50 (PbPb@SPS) observed an *anomalous* J/Ψ 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 occuring 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 (~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/Ψ and open charm will be measured in PbPb at large energy densities at LHC

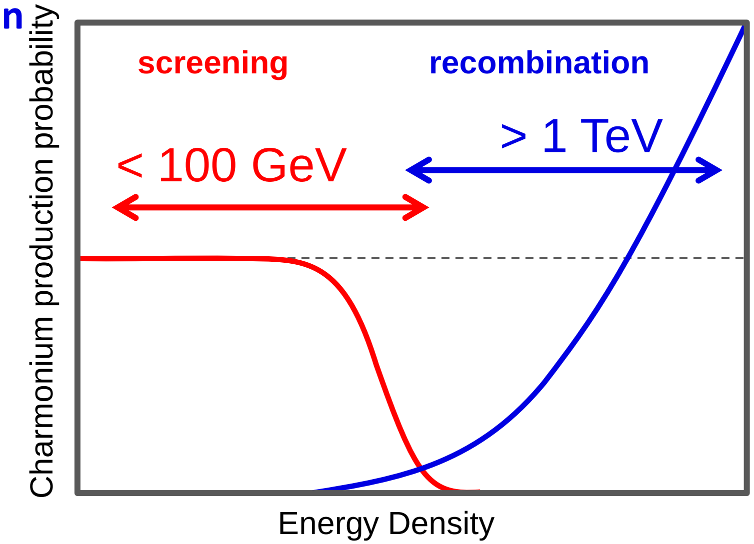
➔ **Best place to study charmonium recombination**

– **Charmonium screening : < 100 GeV**

- At SPS energies, in Pb+Pb collisions, J/Ψ 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*



Quark Gluon Plasma w/ Charm quarks

- **Can be studied in fixed-target mode at LHC**
  - 2.75 TeV Pb beam on fixed target ➔ $\sqrt{s_{NN}} \sim 71$ GeV

- **PbAr@71 GeV .vs. PbPb@17 GeV**
  - Multiplicity is related to event centrality and center-of-mass energy
  - Multiplicity can be used to compare different A+B collisions at different $\sqrt{s_{NN}}$

System \ centrality	60 – 100%	50 – 60%	40 – 50%	30 – 40%	20 – 30%	10 – 20 %	0 – 10%
PbNe – 71 GeV	108.6	254.4	392.5	588.0	814.5	1086.0	1494.9
PbAr – 71 GeV	**123,6**	**308,8**	**496,5**	**806,6**	**1228,3**	**1711,9**	**2372,7**
PbKr – 71 GeV	196,9	533,6	919,1	1451,2	2205,5	2986,6	4084,3
PbPb – 17 GeV	**124,2**	**331,6**	**605,9**	**919,6**	**1338,7**	**2035,8**	**2980,5**

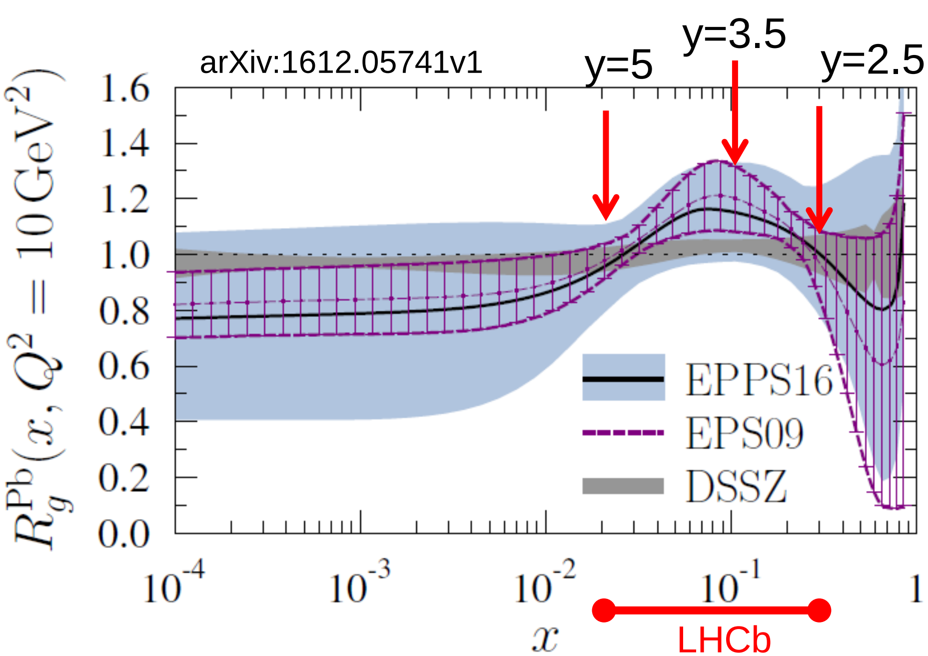
(based on EPOS-LHC-v3400)

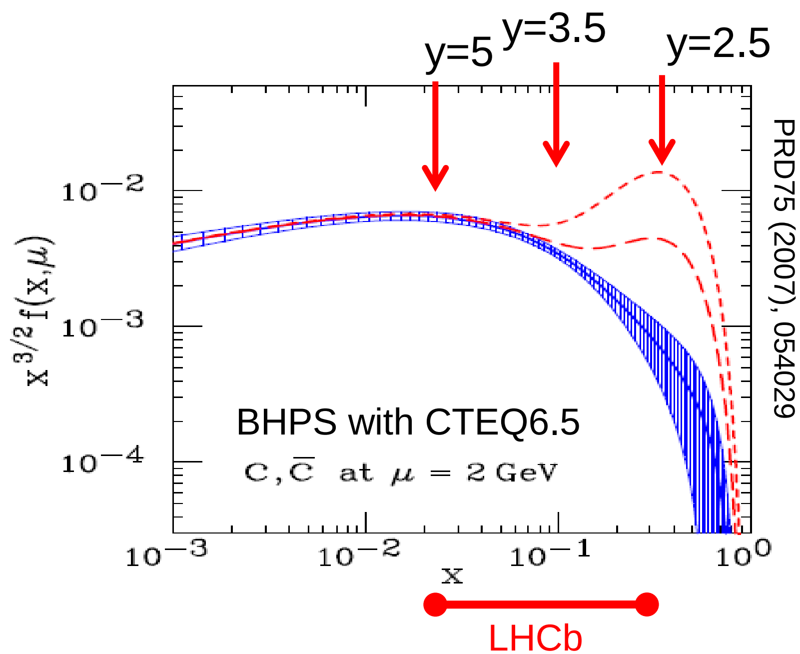
  - PbAr @ 71 GeV multiplicity ≡ PbPb@17 GeV multiplicity

    ➔ **PbAr @ 71 GeV is a good starting point to compare with NA50 (SPS)**

Cold Nuclear Matter w/ Charm quarks

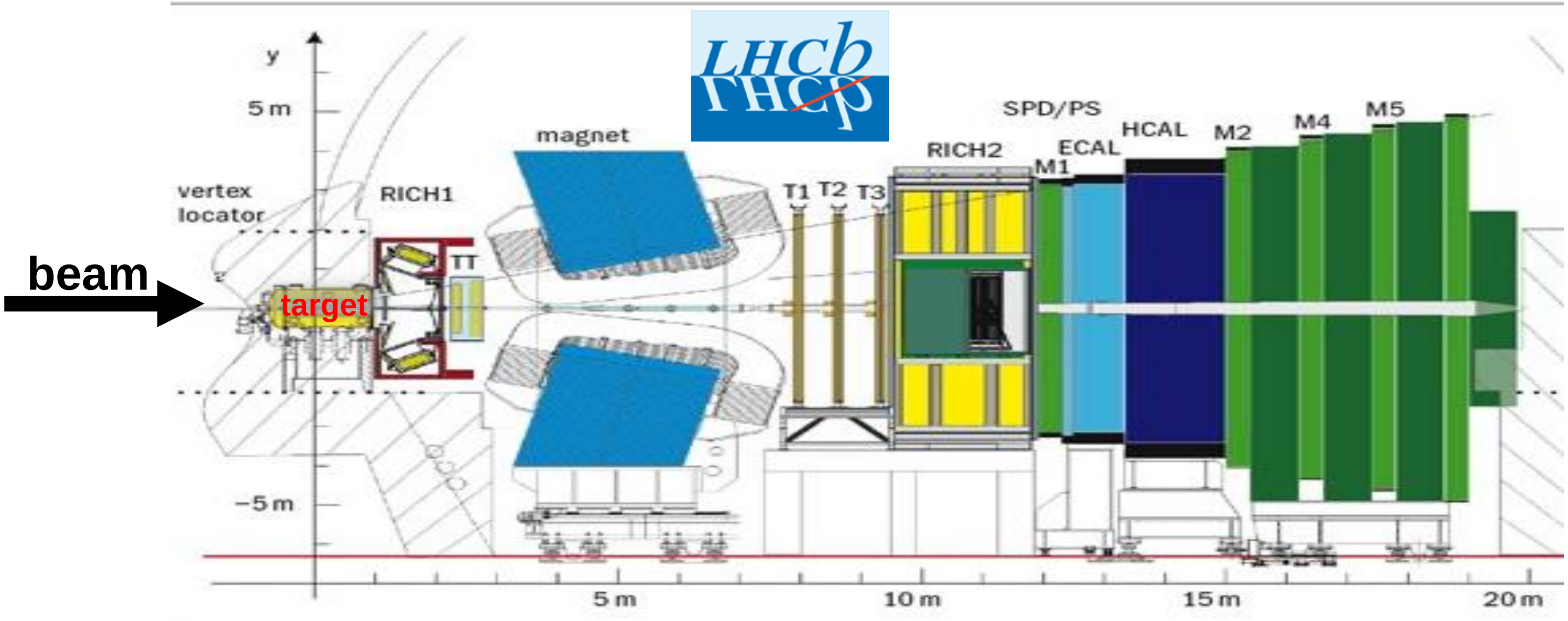
- A thorough p+A program is mandatory to study Cold Nuclear Matter effects
  - as a reference to study Hot Nuclear Matter effects (QGP)
  - nPDF, saturation, energy loss, nuclear absorption, …
- LHCb offers a unique opportunity to measure **several quarkonium states** (J/ψ, ψ', χ_c) as well as **several open charm states** (D^0, $D^{+/-}$, D_S, λ_c,…)
- LHCb offers a large rapidity coverage (~3 rapidity units) at **large bjorken-x x_2**
  - Give access to **nPDF anti-shadowing** region and **intrinsic charm** content in the nucleon





SMOG (System for Measuring Overlap with Gas)

- **Injecting gas in LHCb Vertex Locator (VELO) region**
  - Primary role : luminosity measurement
  - Can be used as an internal gas target
  - Noble gas only : (very low chemical reactivity)
    - He (4), Ne (20), Ar (40), Kr (84), Xe (131)
    - Gaz pressure : 10^{-7} to 10^{-6} mbar

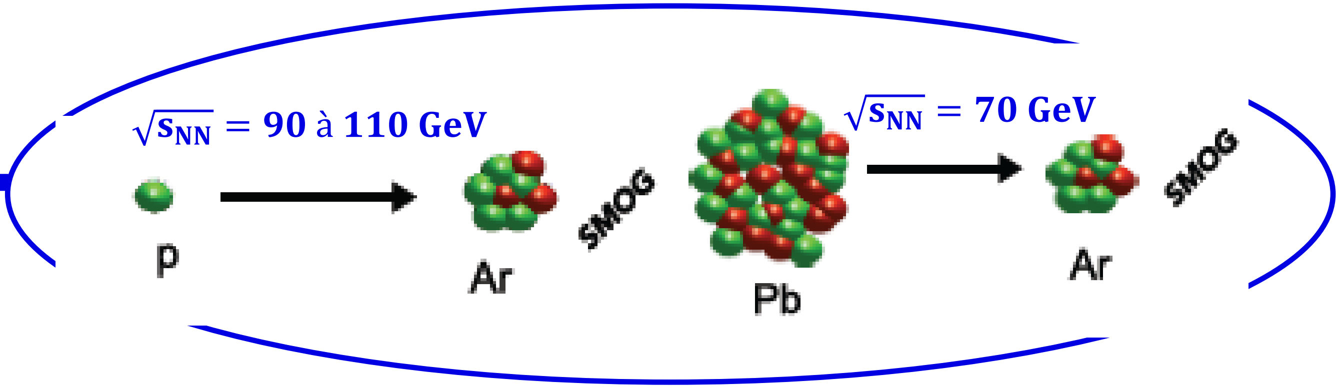


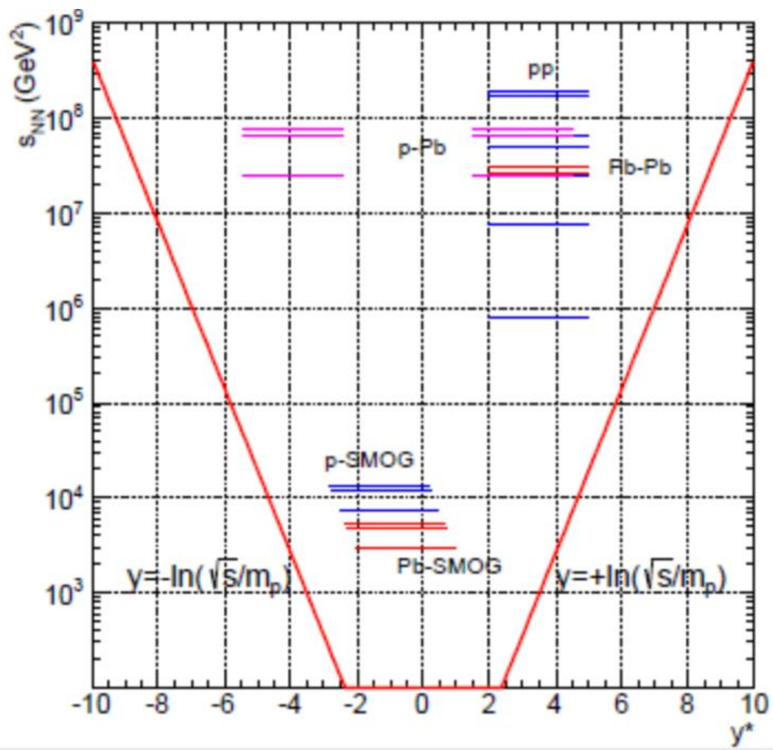
Fixed-target program

$\sqrt{s_{NN}^{SPS}} \sim 20$ GeV

$\sqrt{s_{NN}^{RHIC}} = 200$ GeV

$\sqrt{s_{NN}^{LHC}} = 5$ TeV





Colliding mode

E_{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	5.02 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

Fixed-target mode

Data – fixed-target mode

- **Data recorded in 2015**
  - Gas pressure in the velo : ~ 1 – 2 10^{-7} mbar
    - pHe : ~7h @110 GeV w/ 299 non-colliding bunches in september
    - pNe : ~12h @110 GeV w/35 non-colliding bunches in august
    - **pAr : ~ 17h @ 110 GeV w/685 non-colliding bunches in october *(available for analysis)***
    - pAr : ~11h @ 69 GeV w/44 non-colliding bunches in november
    - **PbAr : ~100h @ 69 GeV w/ 500 non-colliding bunches in december *(not yet available for analysis)***

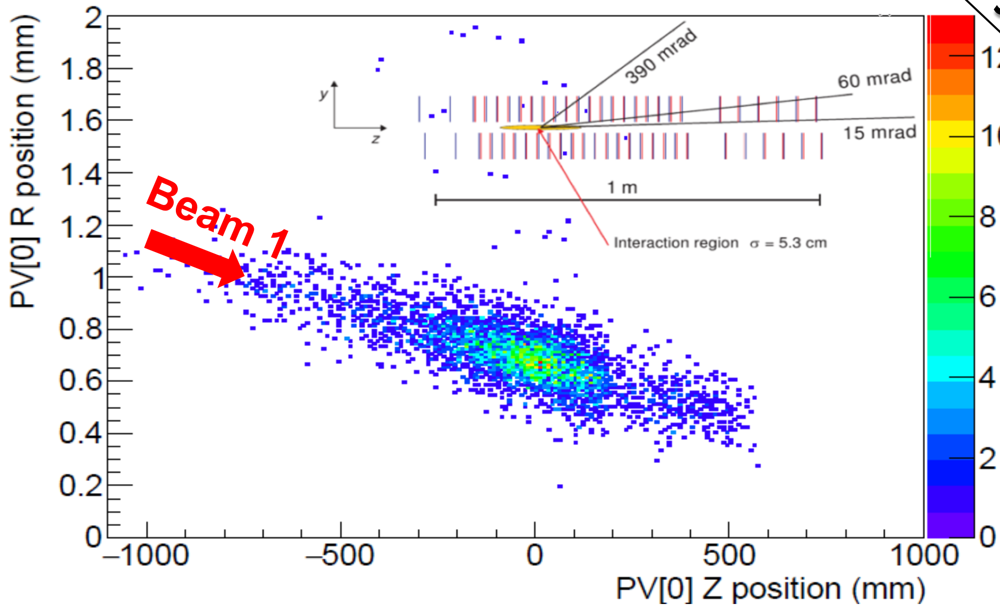
- **Data recorded in 2016**
  - **pHe : ~87h @ 87 GeV : statistic ≡ pAr data *(not yet available for analysis)***

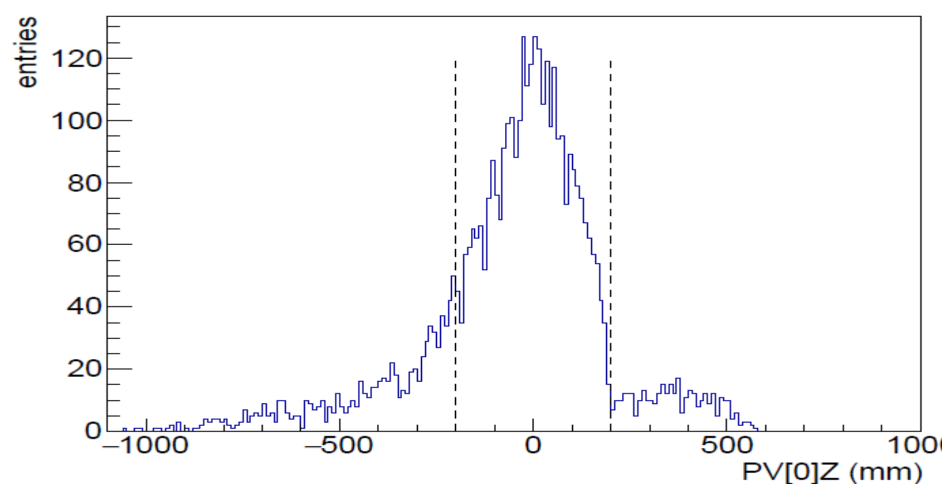
- **Presented here : pAr @ 110 GeV (analysis under internal review)**
  - Very preliminary results on heavy flavor production with SMOG
  - Luminosity not available yet
  - **Study J/ψ and D^0 production in $\sqrt{s_{NN}}$=110 GeV proton-argon collisions** as a demonstration of feasibility of the heavy- flavor LHCb fixed-target program

pAr data @ 110 GeV

- 17h of pAr collisions with 685 non-colliding bunches
- Select events with Beam 1 only at interaction point
- Apply topological cuts to remove possible ghost charge pollution
- **Select events with Z_{vertex} inside VELO**

$Z_{vertex} \in$ [-20 cm : 20 cm]

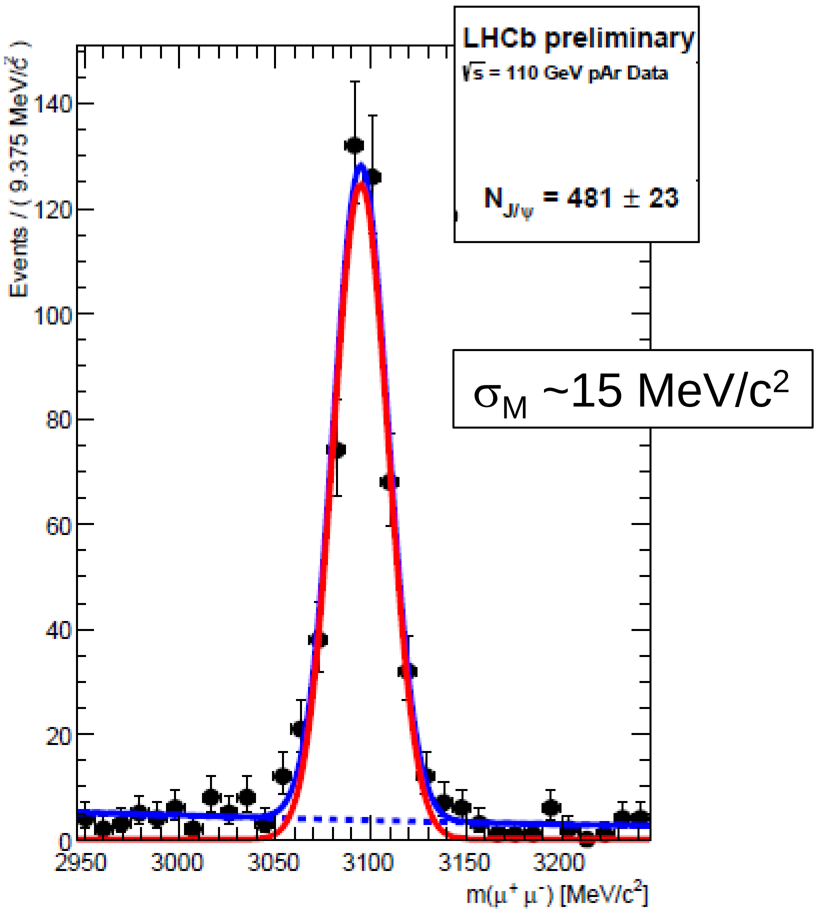


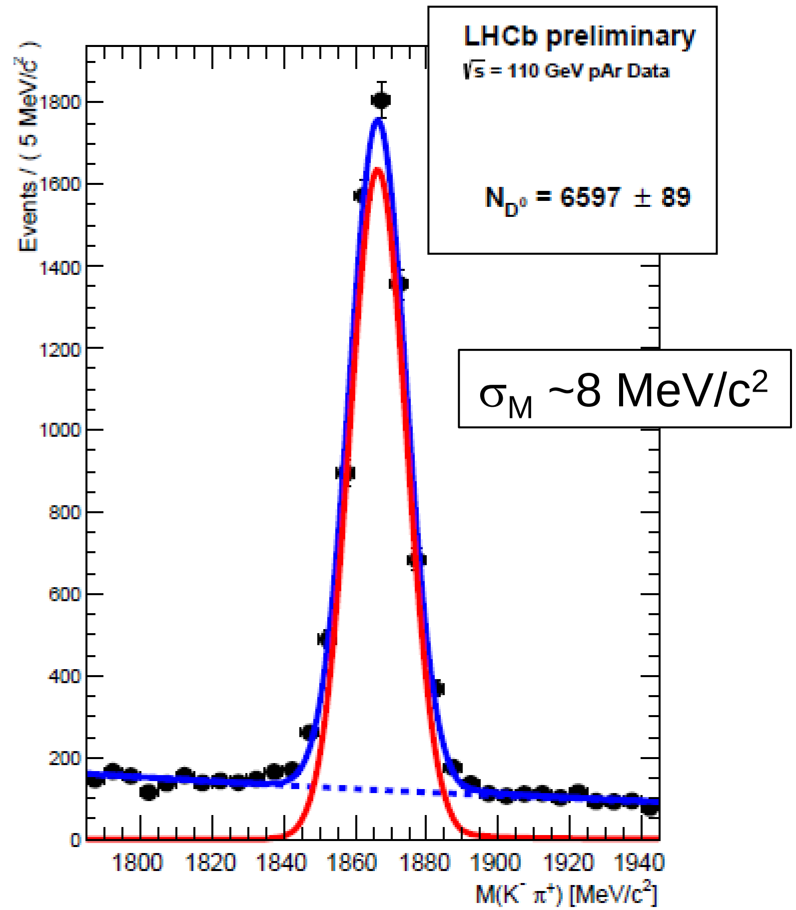


Signal extraction

preliminary

- **J/ψ and D^0 : Crystal ball functions to extract the signal**
  - Overall data (18h) : ~500 J/ψ ~6500 D^0

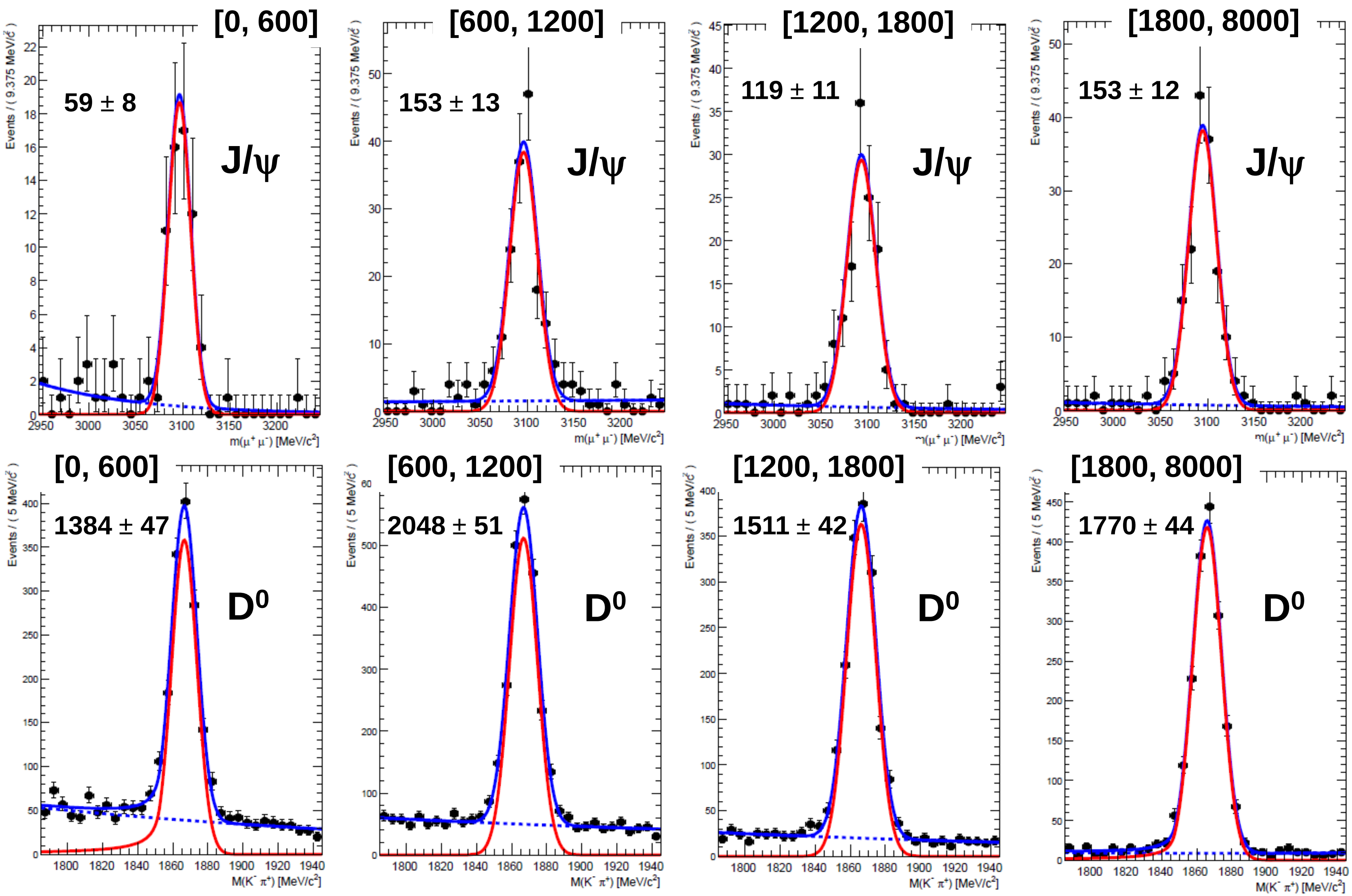




J/ψ and D^0 differential production

preliminary

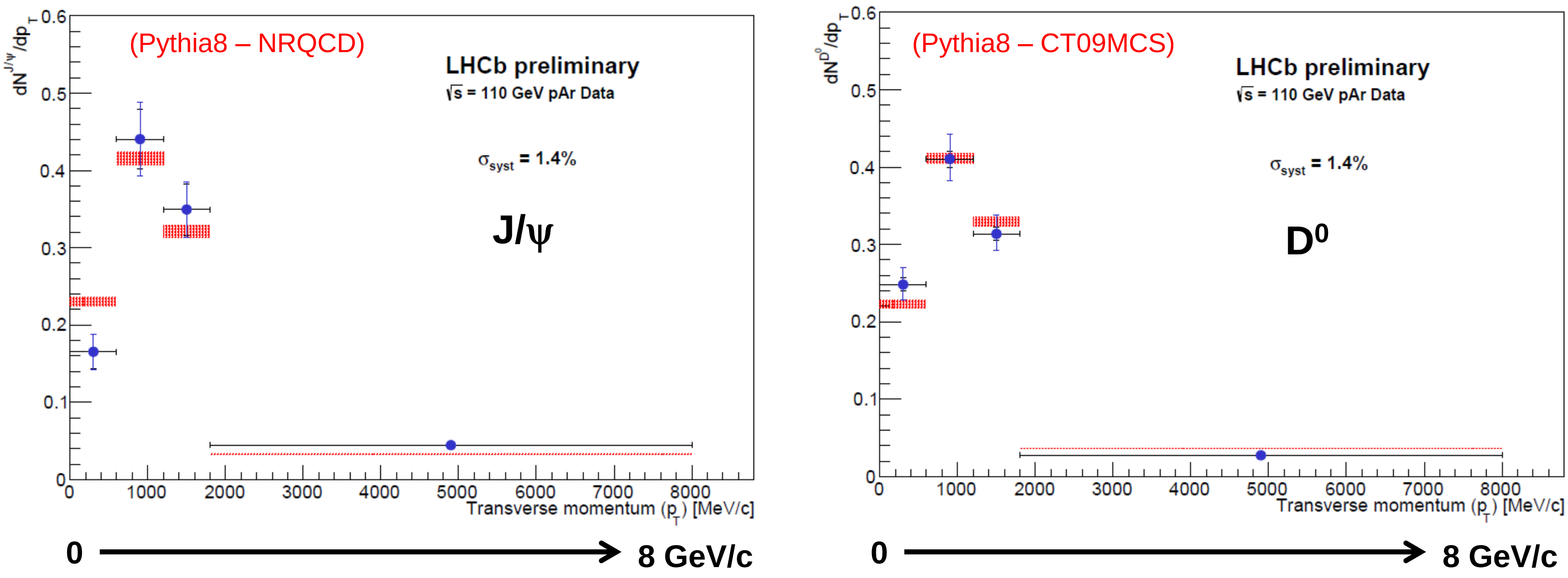
- pT bins ∈ [0, 600] – [600, 1200] – [1200, 1800] – [1800, 8000] MeV/c



J/ψ and D^0 differential production

preliminary

- **Transverse momentum distributions**
  - J/ψ and D^0 data and MC distributions are normalized

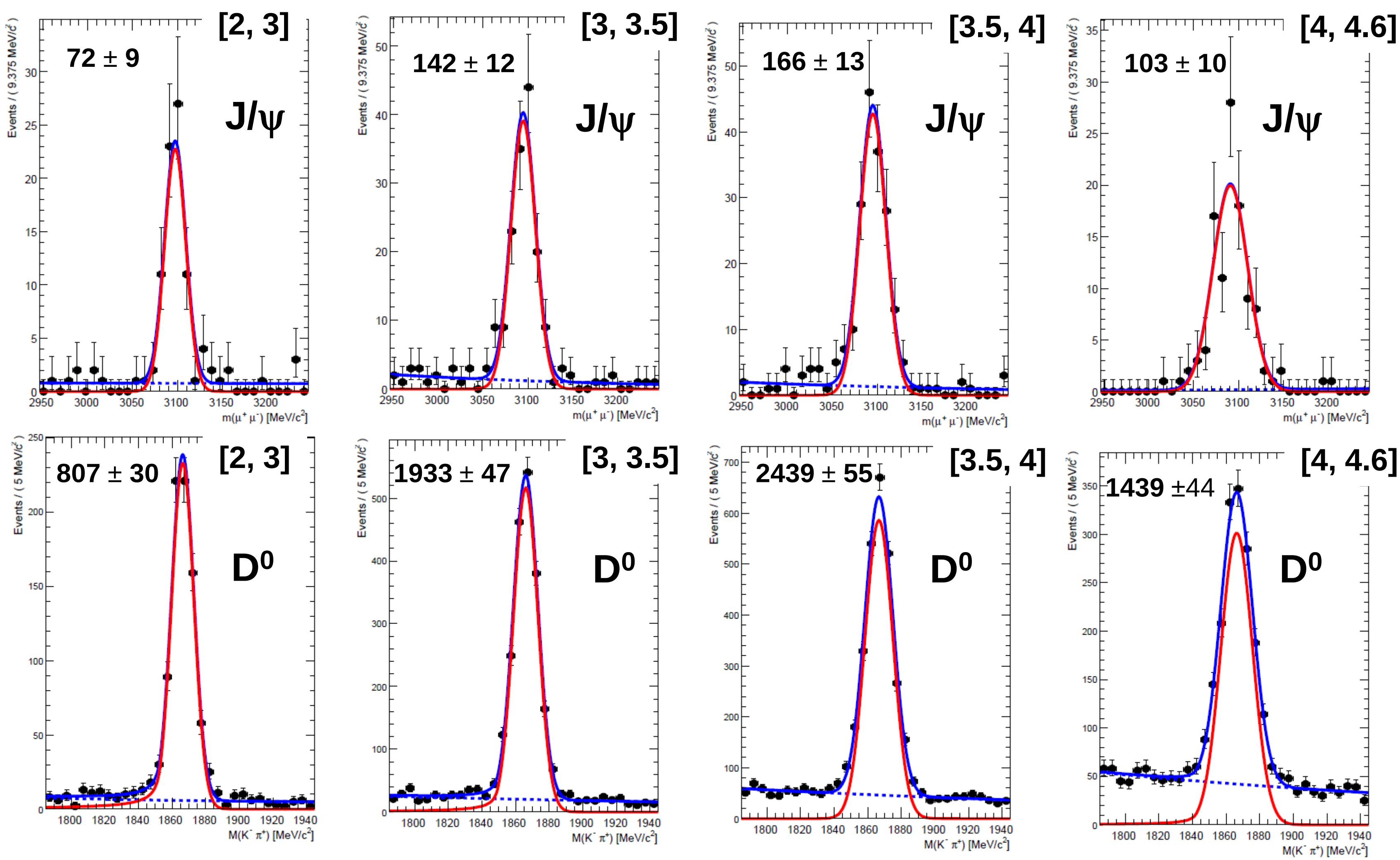


  - comparing data (blue points) with PYTHIA (red boxes) yields

J/ψ and D^0 differential production

preliminary

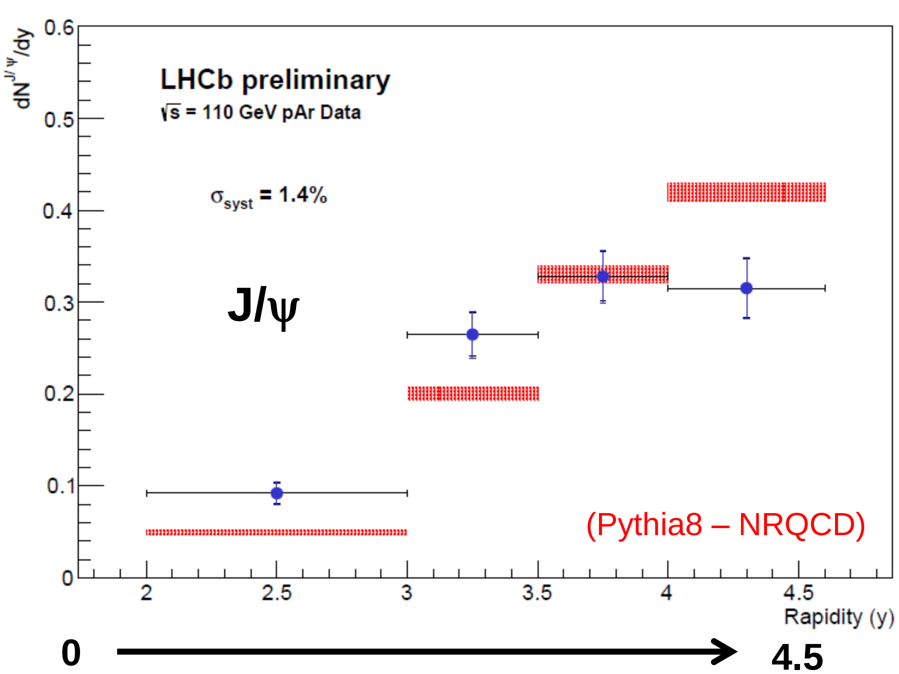
- **Rapidity bins : [2, 3] – [3, 3.5] – [3.5, 4] – [4, 4.6]**

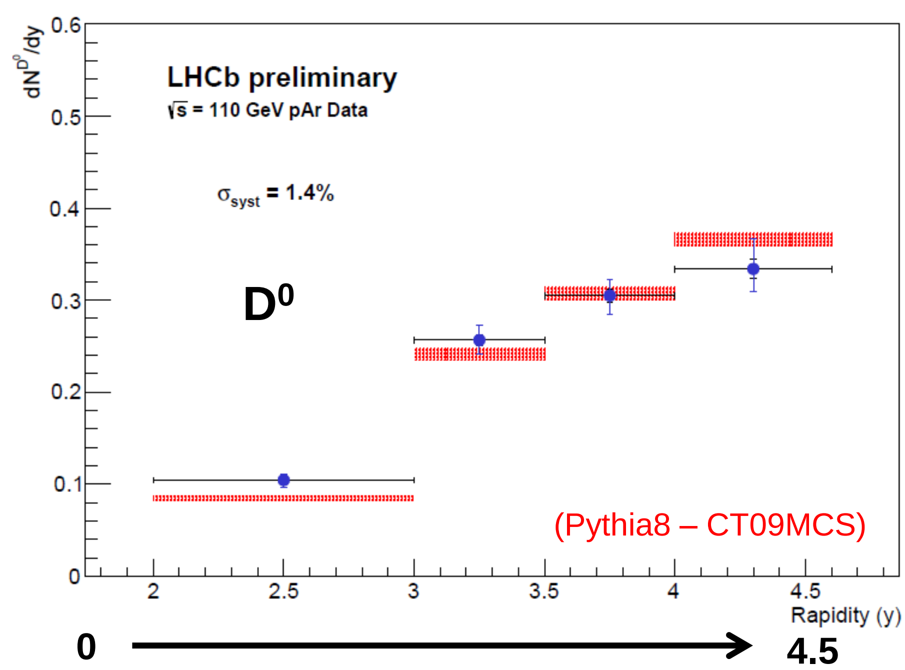


J/ψ and D^0 differential production

preliminary

- **Rapidity distributions**
  - J/ψ and D^0 data and MC distributions are normalized



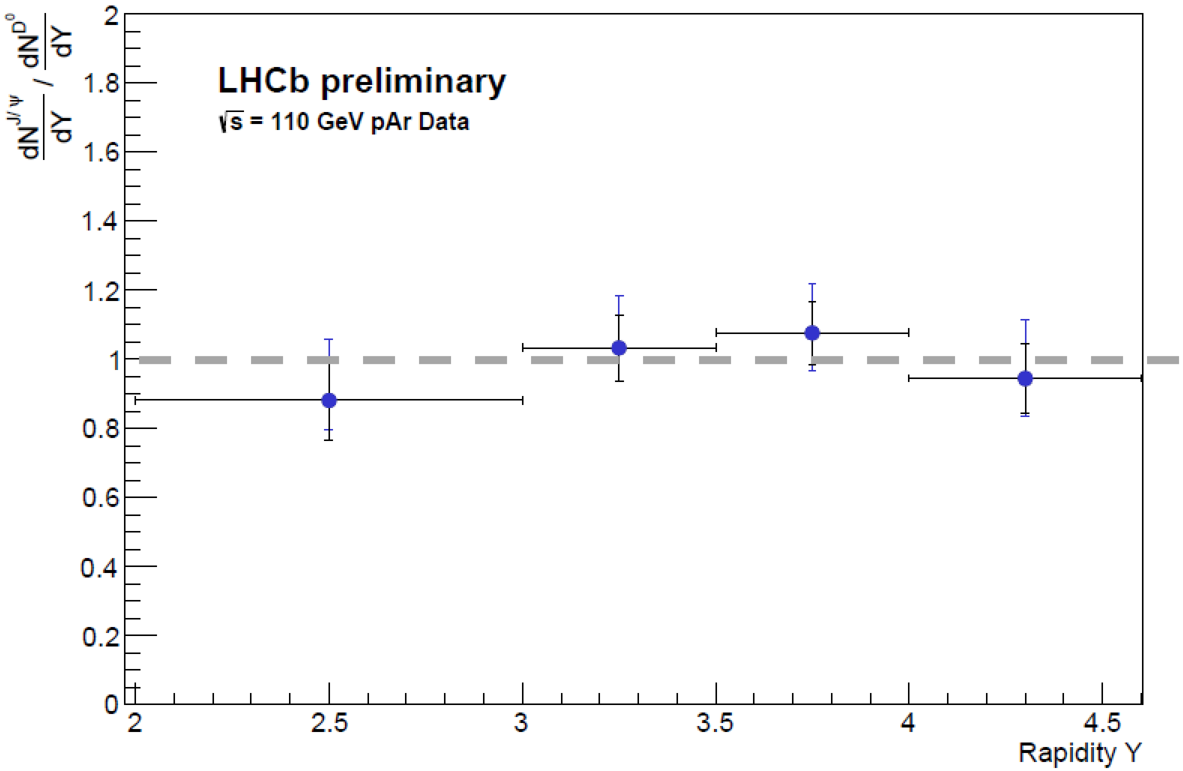


  - Comparing data (blue points) with PYTHIA (red boxes) yields

Bjorken-x and Feynman-x

preliminary

- **J/Ψ / D^0 ratio . VS. Rapidity**
  - No significant dependence of $\frac{J/\psi}{D^0}$ with rapidity



  - Will provide $\frac{\sigma_{J/\psi}}{\sigma_{D^0}}$ soon (since luminosity cancels out in the ratio)

Bjorken-x and Feynman-x

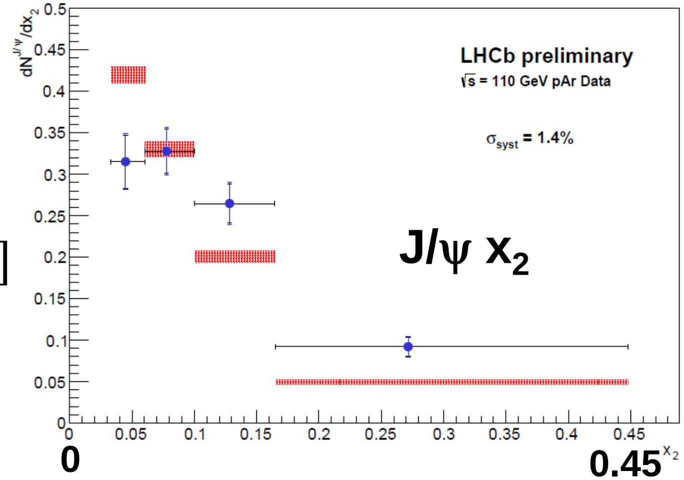
preliminary

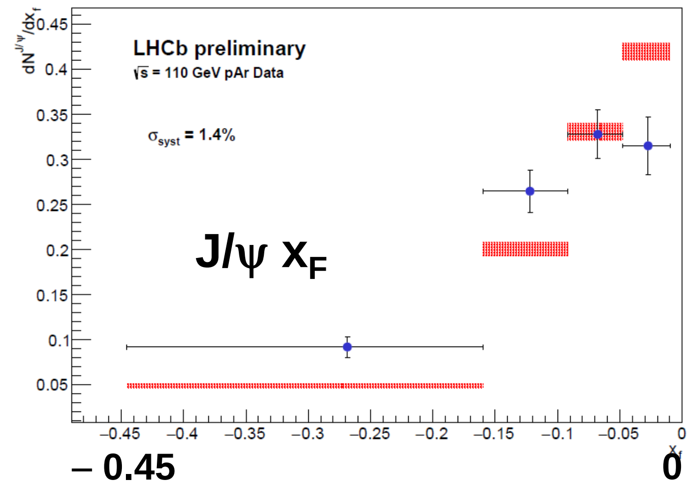
$$x_2 = \frac{M}{\sqrt{s_{NN}}} e^{-y^*} \qquad x_F = 2 \times \frac{M}{\sqrt{s_{NN}}} \sinh y^*$$

J/ψ x_2 and x_F coverage

$x_2 \in [0.03, 0.45]$

$x_F \in [-0.45, -0.01]$

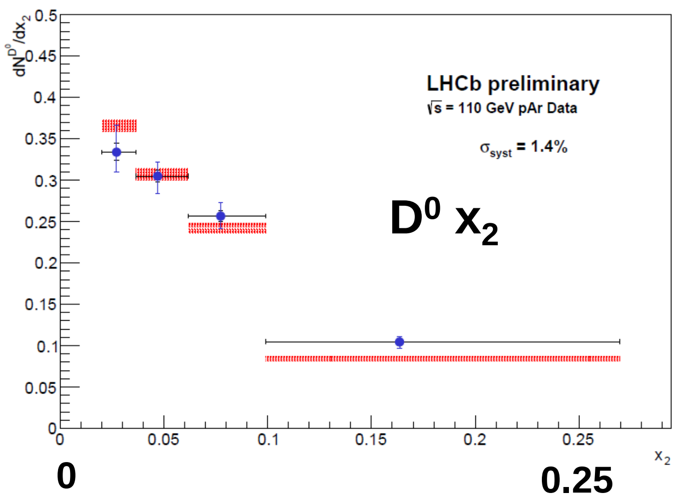


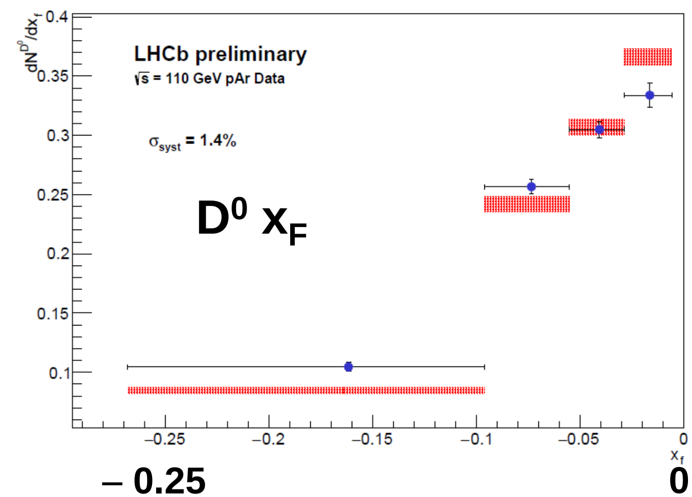


D^0 x_2 and x_F coverage

$x_2 \in [0.02, 0.27]$

$x_F \in [-0.27, -0.01]$



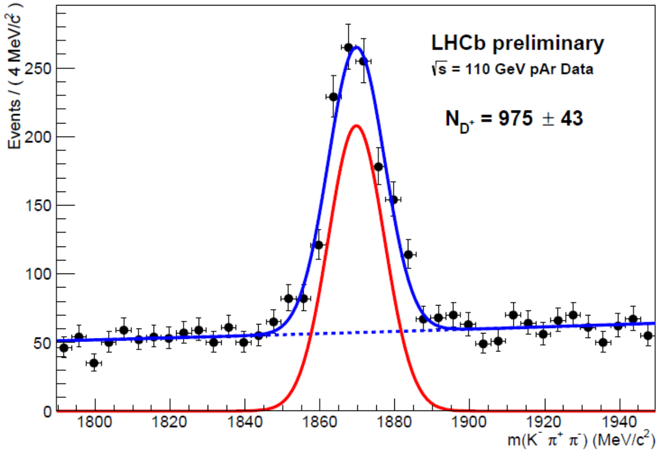


pAr @ 110 GeV

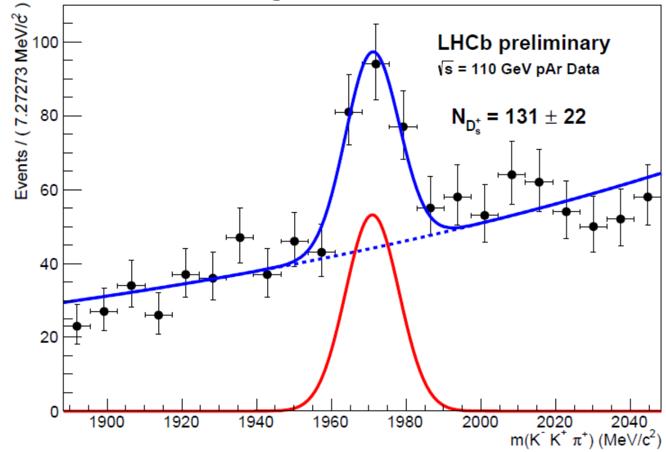
preliminary

- **Other possible measurements**

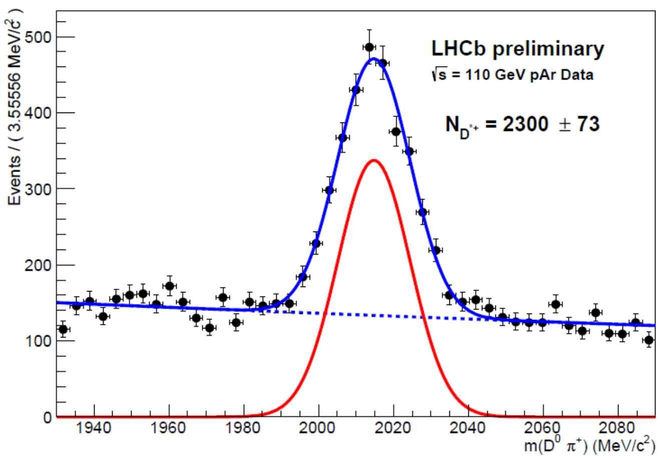
$D^+ \rightarrow K^-\pi^+\pi^+$



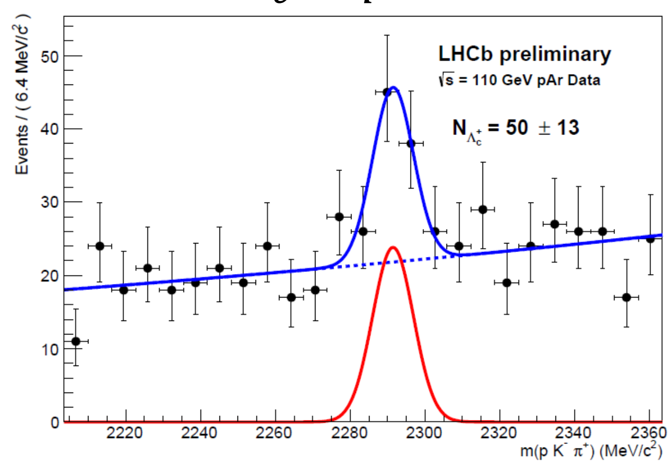
$D_s^+ \rightarrow K^-K^+\pi^+$



$D^{*+} \rightarrow D^0\pi^+$



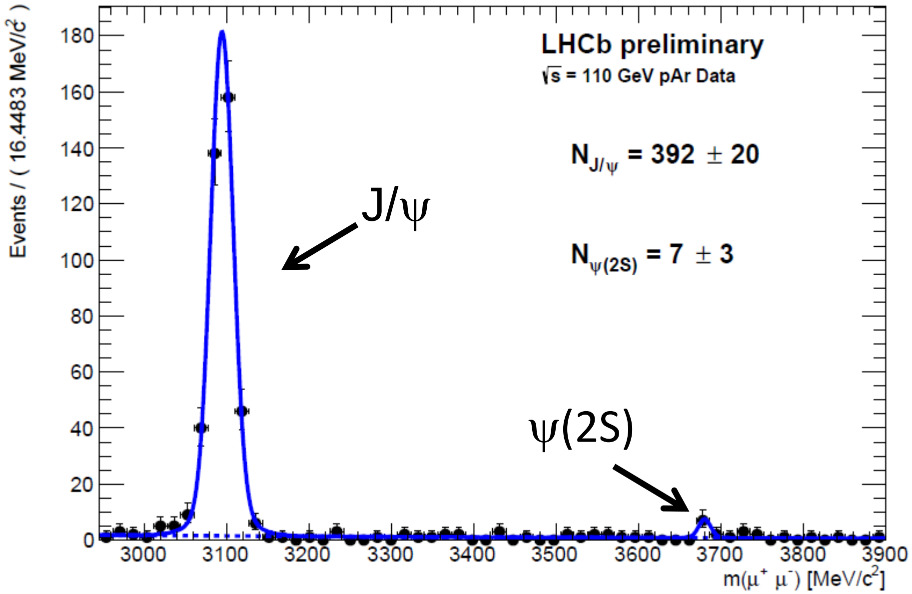
$\Lambda_c^+ \rightarrow pK^-\pi^+$



Conclusion

- **First analysis of heavy-flavor production with SMOG**
  - Study $J/\psi \rightarrow \mu^+\mu^-$ and $D^0 \rightarrow K\pi$ production in pAr@110 GeV
  - Collected overall ~500 J/ψ and ~6500 D^0
  - Cover large Bjorken-x x_2 and negative feynman-x x_F

- **Demonstrate the feasibility of the SMOG heavy flavor program**



- **To start physics, need**
  - More systems (He,…)
  - Larger statistics (10 to 100 larger)
    - get χ_c and ψ' (ψ' yield ~ 2% J/ψ yield), investigate Ξ_{cc}^{+} production
    - With optimal beam conditions can get x10 with 48h data taking