Charm In Heavy Ion Collisions

Measuring χ_c in nucleus-nucleus collisions

with ~~CHIC~~ **LHCb** at ~~SPS~~ **LHC**

CHIC Physics case

SMOG / LHCb

Frédéric Fleuret - LLR (fleuret@in2p3.fr)

The Physics case

- **Heavy quarks and Quark Gluon Plasma (QGP)**

Heavy quarks are "special " QGP probes *:* m_Q >> QGP critical temperature T_C (~170 MeV),

➔ Heavy quarks should be produced in ***initial*** nucleon-nucleon collisions only, the **QGP phase shouldn't modify the overall heavy quark yields**,

➔ ***QGP phase should modify relative heavy quark (hidden/open) bound state yields***

Heavy quark hadronization ($c\bar{c}$ example):

- ~90% of $c\bar{c}$ pairs → open charm
- ~10% of $c\bar{c}$ pairs → hidden charm (charmonia)

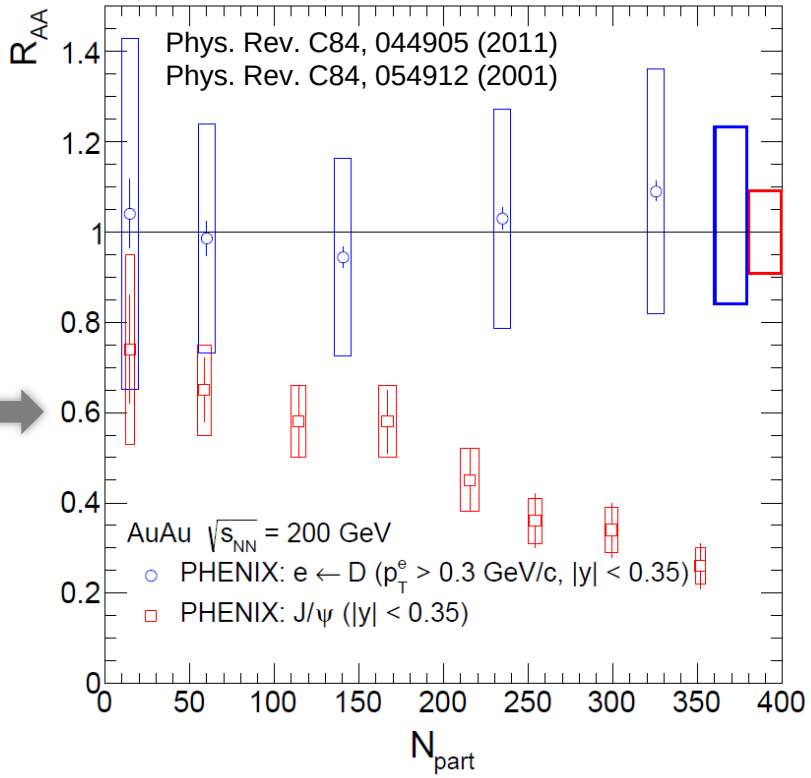
Since most of the produced $c\bar{c}$ pairs hadronize into open charm (~90%), **open charm production reflects the *original* charm quark yield.**

PHENIX Au+Au collisions @ $\sqrt{s_{NN}}$ = 200 GeV

Blue = open charm

Red = hidden charm

- no (little) modification of open charm yield
- modification of J/Ψ (*$c\bar{c}$ bound state)* yield



The Physics case

- **Heavy quarks and Quark Gluon Plasma (QGP)**

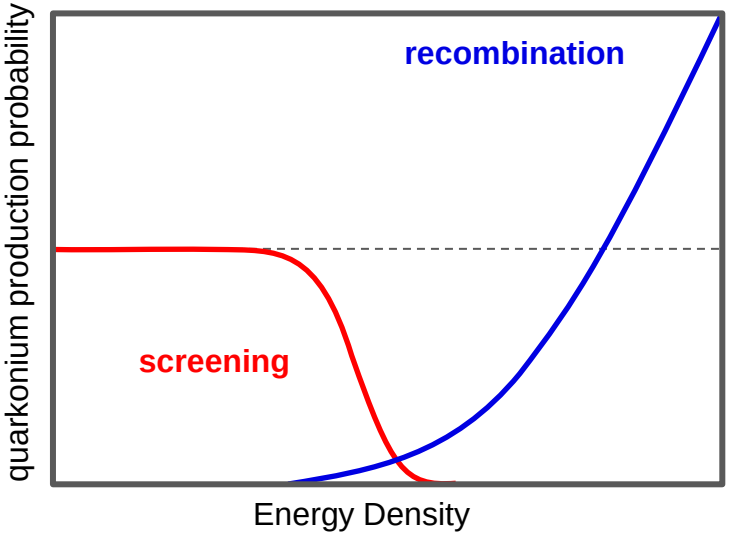
Heavy quarks are "special " QGP probes *:* m_Q >> QGP critical temperature T_C (~170 MeV),

➔ Heavy quarks should be produced in ***initial*** nucleon-nucleon collisions only, the **QGP phase shouldn't modify the overall heavy quark yields**,

➔ ***QGP phase should modify relative heavy quark (hidden/open) bound state yields***

– **Modifying hidden bound state yields**
Possible QGP effects on quarkonium:

- **Color screening:** $Q\bar{Q}$ ***bound states suppression***
  - Color screening in a QGP decreases quarkonium binding
  - Color screening should lead to a suppression of quarkonium production yields
- **Recombination:** $Q\bar{Q}$ ***bound states enhancement***
  - at sufficiently high $\sqrt{s_{NN}}$, heavy quarks are abundantly produced.
  - After thermalisation, statistical combination can lead to an enhancement of quarkonium production yields

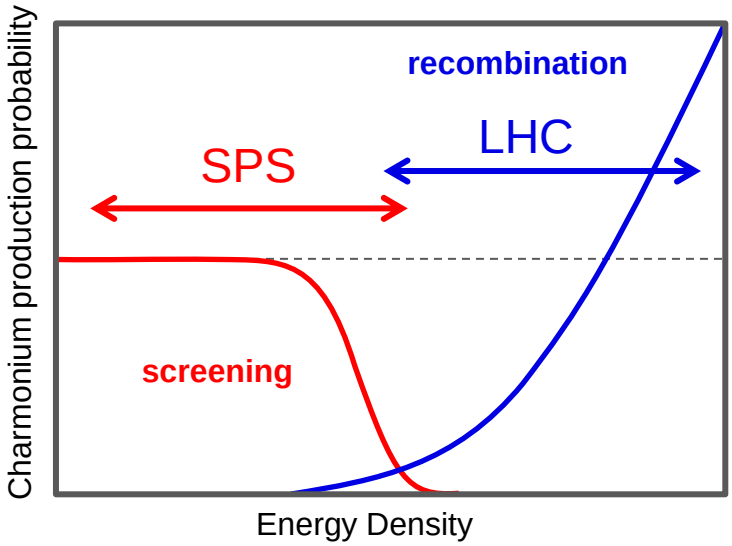


The Physics case

- **Experimentally, charmonium is a priviledged probe**
  - 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 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
➔Possible recombination occuring at LHC

- **Within the SPS+RHIC+LHC energy range, charm seems to be the adequate probe to investigate both screening and recombination.**



The Physics case

- **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

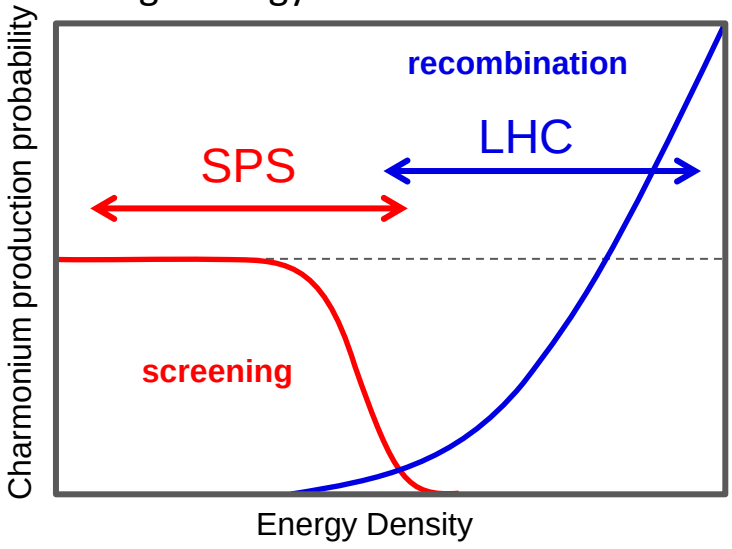
  - Since most of the produced $c\bar{c}$ pairs hadronize into open charm (~90%), open charm production reflects the original $c\bar{c}$ pair production
  - Open charm is therefore an (the?) appropriate reference to calibrate charmonium screening/recombination studies.

  – **TeV scale**: Charmonium recombination
  - Both J/Ψ and open charm will be measured in PbPb at large energy densities at LHC

  ➔ **Best place to study charmonium recombination**

  – **20-GeV Scale**: Charmonium color screening
  - 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*



Sequential suppression

Color screening

- **Quarkonium sequential suppression**
  - **Quarkonium sequential suppression** in a Quark Gluon Plasma is a prediction of **lattice QCD** :

H. Satz, J. Phys. G 32 (2006)

$$\frac{\text{quarkonium dissociation temperature}}{\text{critical QGP temperature}} \rightarrow$$

state	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	> 4.0	1.76	1.60	1.19	1.17

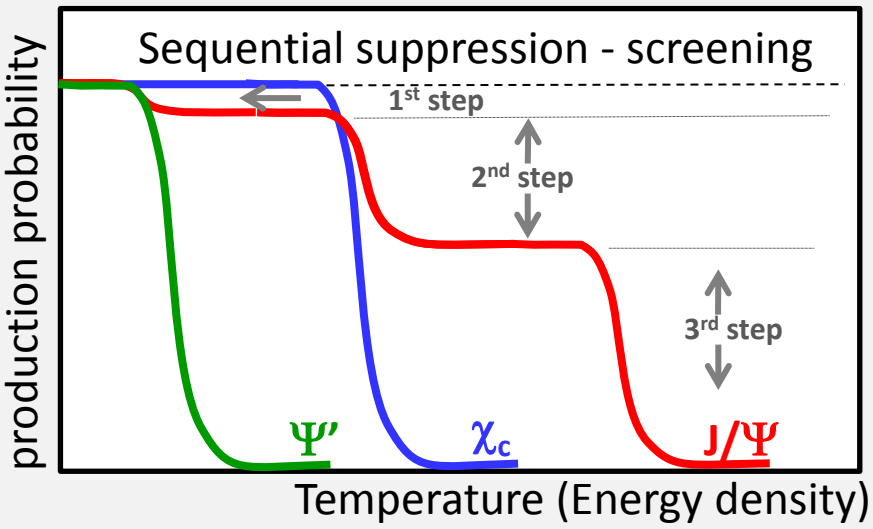
  - Because of feed-downs and different T_d, **sequential suppression** should show up.

Feed-downs contributing to J/Ψ inclusive yield

60% direct J/Ψ
+ 30% $\chi_c \rightarrow J/\Psi+\gamma$
+ 10% $\Psi' \rightarrow J/\Psi + X$
Inclusive J/Ψ yield

According to lattice calculations,
$T_d(\Psi') < T_d(\chi_c) < T_d(J/\Psi)$

➔ **One should observe a step-like suppression pattern**



NA50 results

- **Anomalous suppression at SPS**

Eur.Phys.J.C49:559-567,2007

L = length of nuclear matter seen by quarkonium state

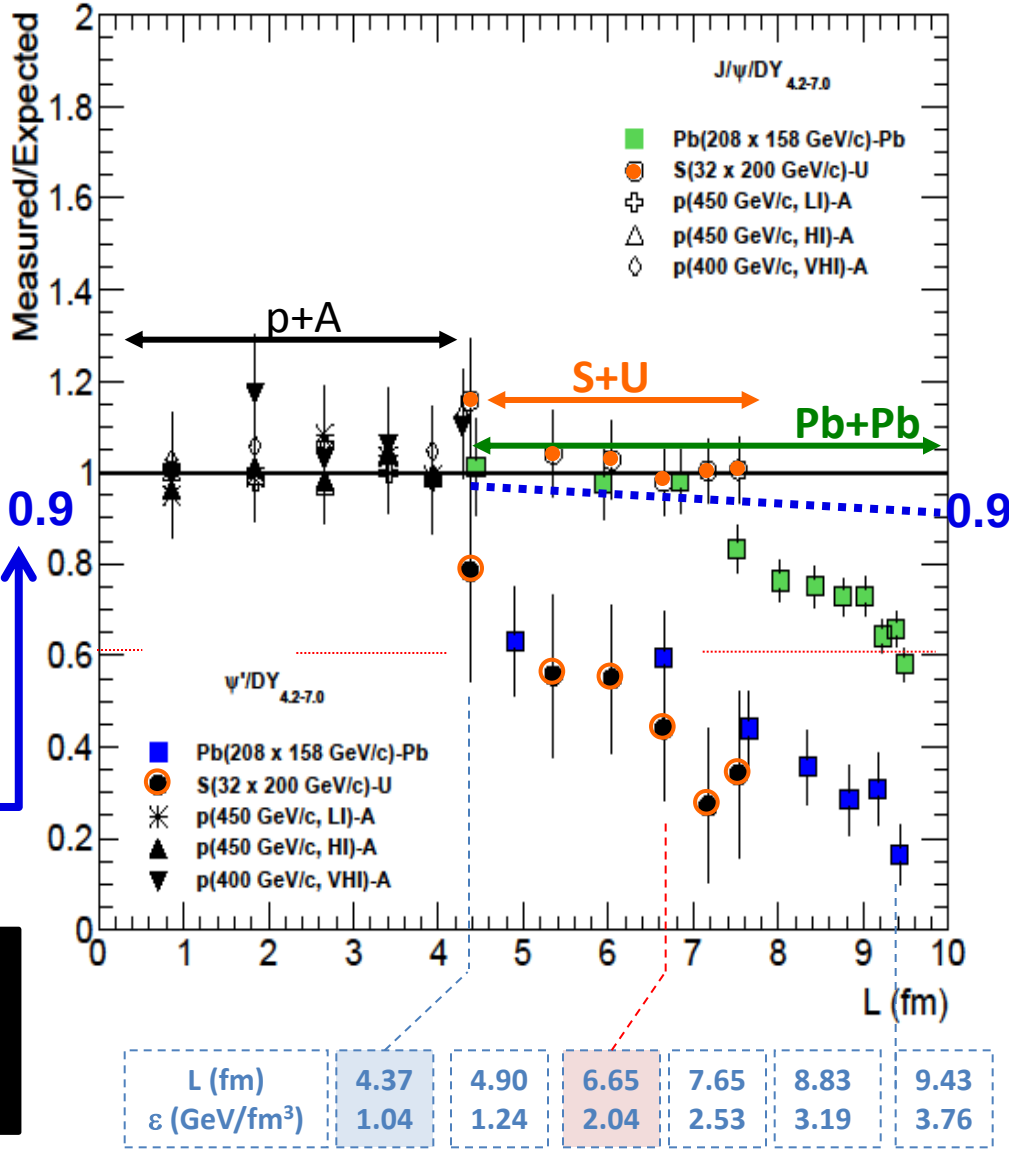
Expected = measured yields in p+A extrapolated to large L

Color screening ?

NA50 measured J/Ψ and Ψ', but,
- **too small Ψ'→ J/Ψ *feed-down***
- **too fragile Ψ'**

to answer the question

→ need of a larger feed-down fraction
→ Need of a stronger bound state
→ Need to measure χ_c yield !



Suppression patterns

- **Anomalous suppression at SPS**

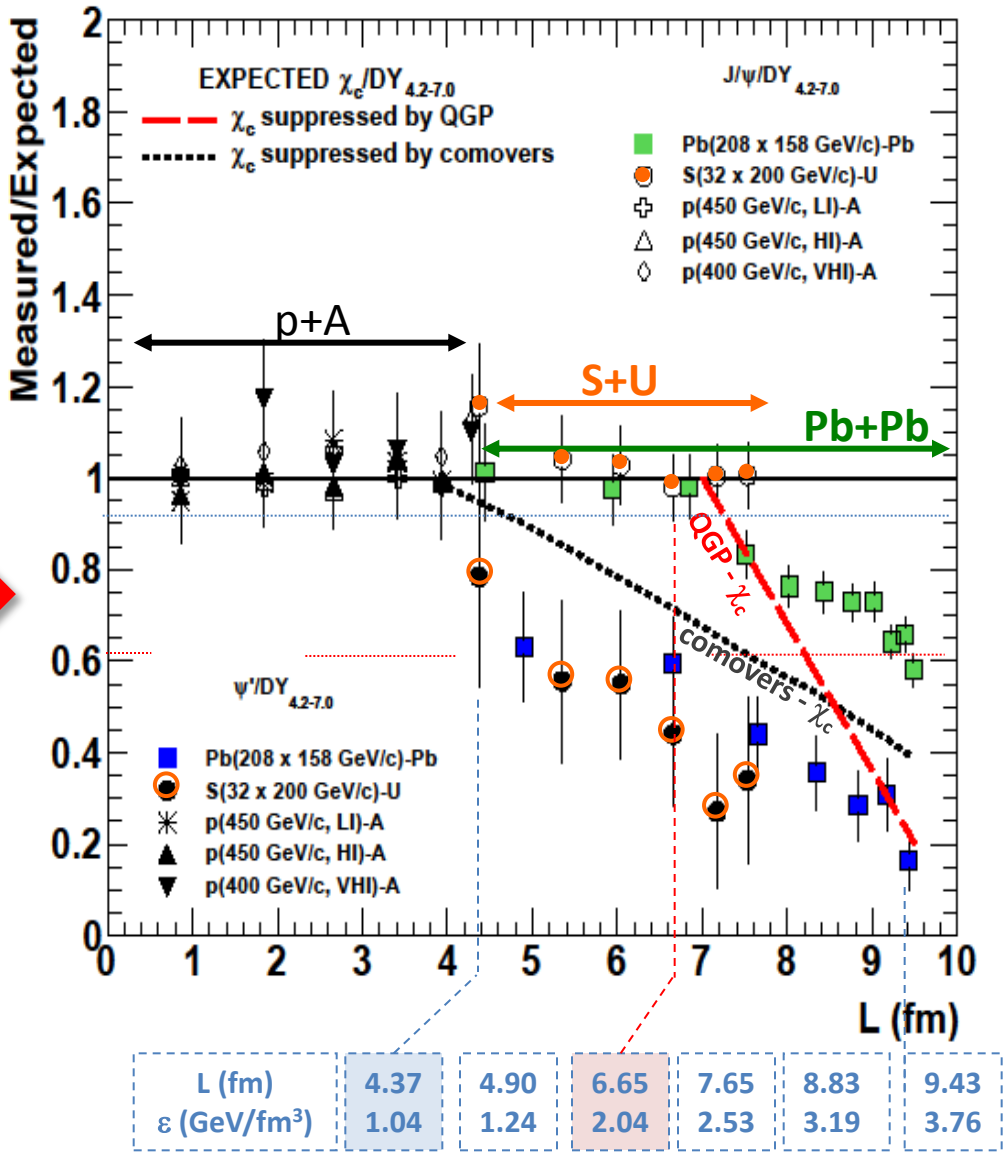
Eur.Phys.J.C49:559-567,2007

Color screening ?

Take advantage of large $\chi_c \rightarrow J/\Psi$ feed-down fraction

60% direct J/Ψ
+ 30% $\chi_c \rightarrow J/\Psi+\gamma$
+ 10% $\Psi' \rightarrow J/\Psi + X$
Inclusive J/Ψ yield

Measuring J/Ψ, Ψ' and χ_c suppression patterns will give the answer



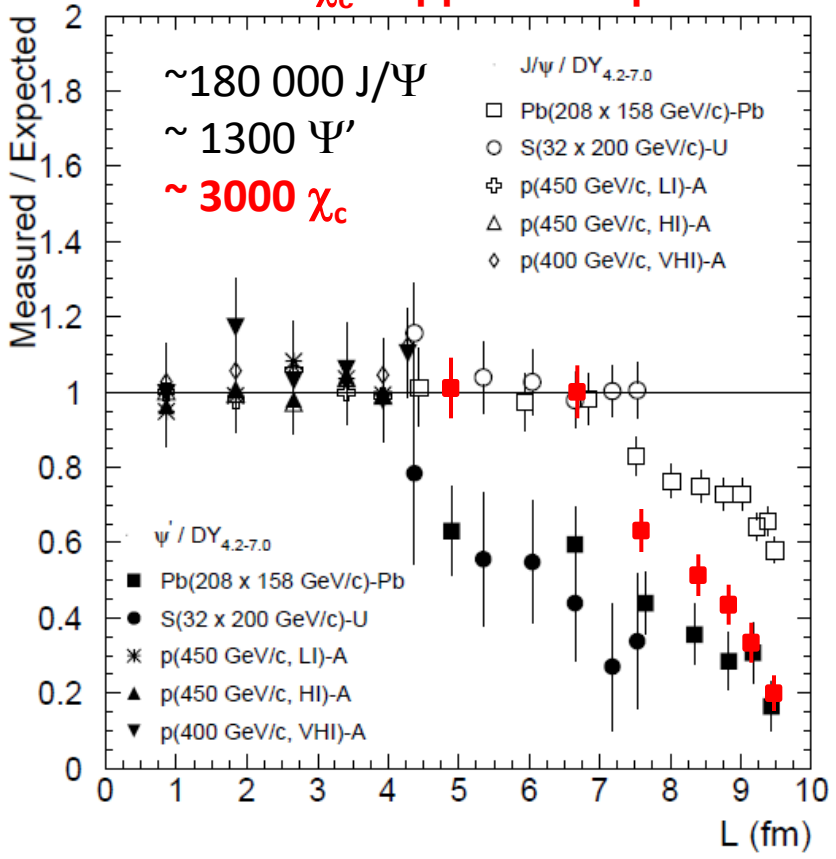
- ***Alternative (no QGP) scenario: suppression by comoving hadrons***
  - *Smooth suppression*
  - *Same suppression-starting point*
  - *Slopes related to binding energy :* $S_{\Psi'} > S_{\chi} > S_{J/\Psi}$

statistics

- **Typical 40-day Pb+Pb run @SPS** (**$10^7.s^{-1}$ Pb beam → 10% λ_I Pb target**)
  - ~ 180 000 J/Ψ→$\mu^+\mu^-$ recorded by NA50
  - ~ 1300 Ψ' → $\mu^+\mu^-$ recorded by NA50
  - If capable of measuring χ_c -> J/Ψγ, in NA50 acceptance :

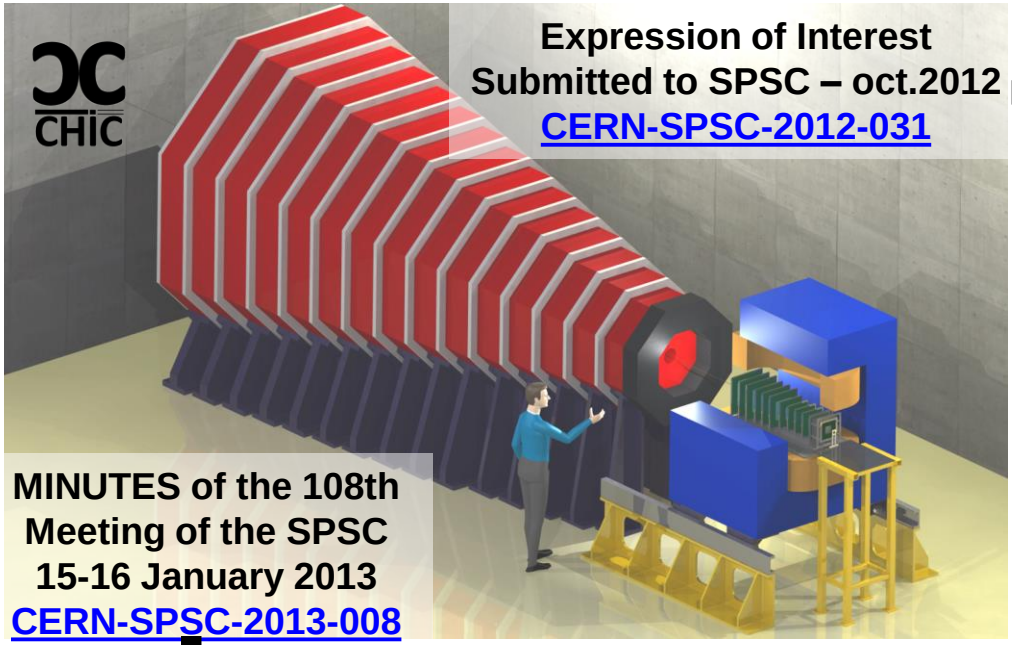
Expect 3000 < χ_c < 7000

Possible χ_c suppression pattern



CHIC : a new experiment at SPS

- **EoI submitted to the SPS Committee (oct. 2012)**



EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

Expression of Interest

for an experiment to study charm production with proton and heavy ion beams

(CHIC: Charm in Heavy Ion Collisions)

F. Fleuret[a,*], F. Arleo[b], E. G. Ferreiro[c], P.-B. Gossiaux[d], S. Peigné[d]

[a]*LLR-École polytechnique, CNRS-IN2P3, Palaiseau, France*
[b]*LAPTh, Université de Savoie, CNRS, Annecy-le-Vieux, France*
[c]*Departamento de Física de Partículas, Universidad de Santiago de Compostela, Spain*
[d]*SUBATECH, Université de Nantes, CNRS-IN2P3, Nantes, France*

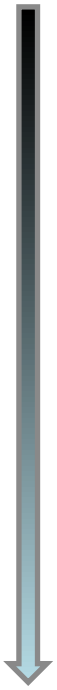
The SPSC has received an expression of interest to study charm production with proton and heavy ion beams. The SPSC recognizes the **strong physics motivation** of a study that addresses **central open questions** about the **color screening** of charmonium in heavy ion collisions and about **cold nuclear matter effects**. For a comprehensive investigation, an extension including open charm production would be desirable.

For further review, the SPSC would require a letter of intent with information about the experimental implementation and the **collaboration** pursuing it.

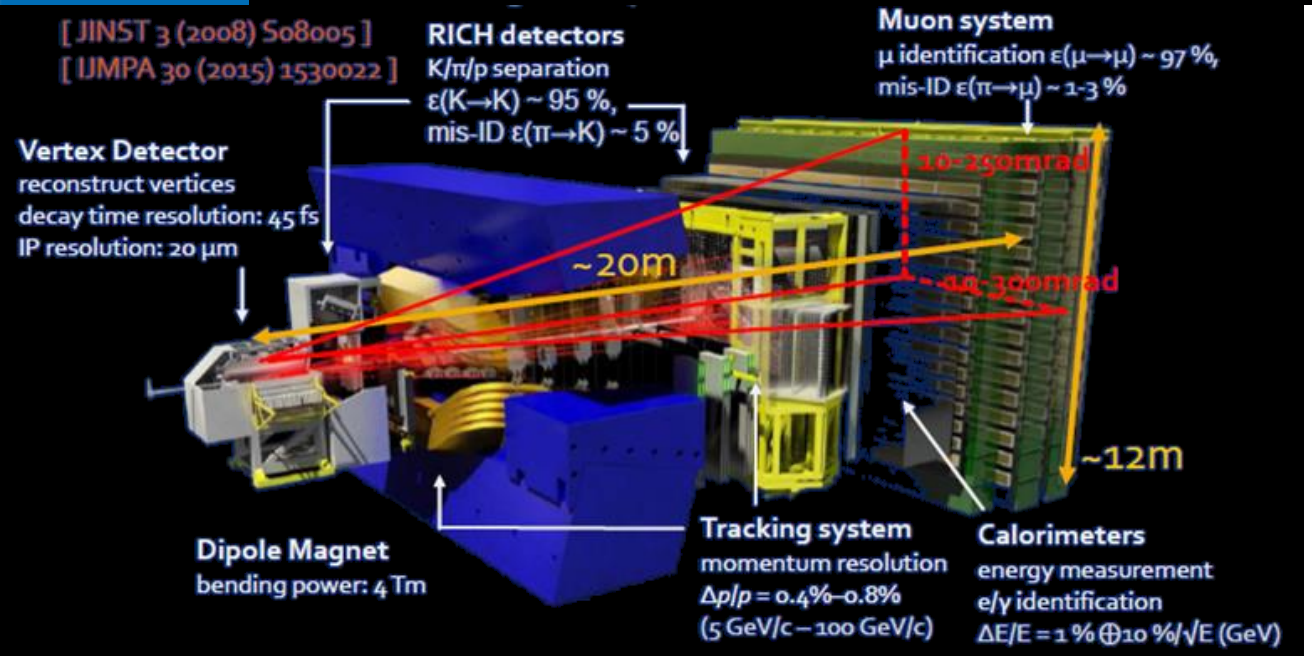
Chronologie

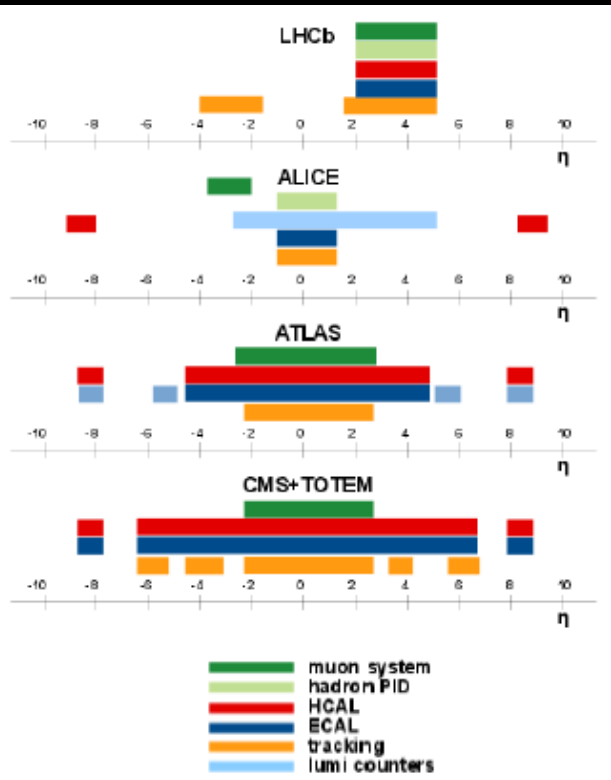
- ***2012***
  - ***Janvier*** **:** Présentation du projet CHIC au CS-LLR
    - mesure de la production du χ_c en collisions d'ions lourds au SPS-CERN
  - ***Juillet*** : town meeting « relativistic heavy ion » - CERN
  - ***Octobre :*** EoI soumise au SPSC (comité scientifique du SPS)
    - Minutes : *« The SPSC recognizes the strong physics motivation… a further review would require a LOI presented by a suitable collaboration…»*
- ***2013***
  - Contacts pris avec labos français/italiens/US
  - Présentations dans confs/workshops
- ***2014***
  - ***Janvier*** : 1er contact avec LHCb pour un possible programme « cible fixe »
  - ***Mars-novembre*** : Étude de faisabilité avec P. Robbe/LAL ➔ encourageants
  - ***Juillet*** : Projet ANR rejeté

    "In summary, the Committee considers that the proposal addresses very important questions in QCD... Unfortunately, in view of the large number of high quality projects submitted in this call, the Committee is not able to recommend the financing of this project."
- ***2015***
  - ***Janvier*** : présentation du physics case au groupe LHCb du LAL *(excellent accueil)*
  - ***Février*** : membre de la collaboration LHCb comme « membre associé LAL »
  - ***Avril*** : LHCb s'engage dans un programme « ions lourds » au LHC
  - ***Octobre*** : premières prises de données

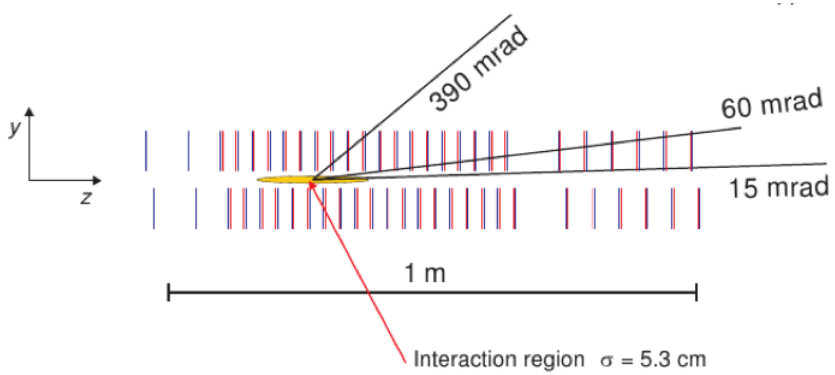


Le détecteur





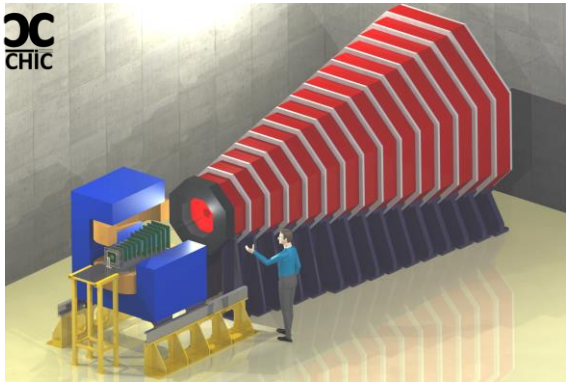
Le VELO (Vertex LOcator)

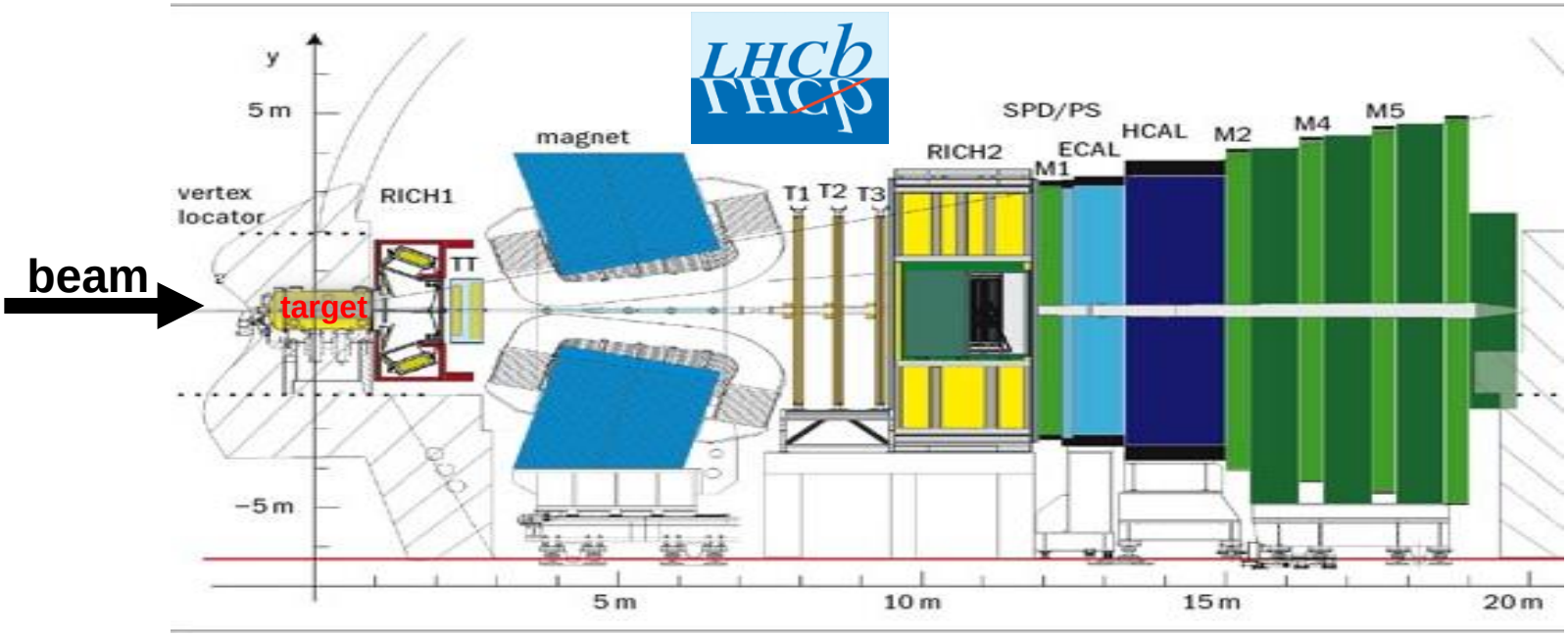


Cible fixe

SMOG (System for Measuring Overlap with Gas)

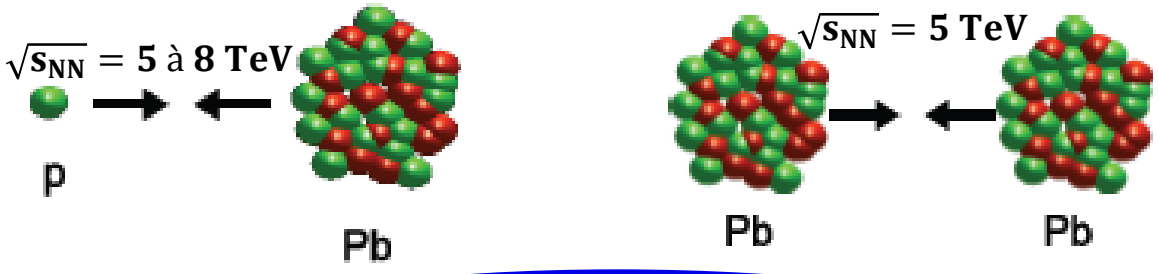
- **Injecting gas in LHCb Vertex Locator (VELO) region**
  - Primary role : luminosity measurement
  - Can be used as an internal gas target
  - Noble gas only : (very low chemical reactivity)
    - He (4), Ne (20), Ar (40), Kr (84), Xe (131)
    - Gaz pressure : 10^{-7} to 10^{-6} mbar



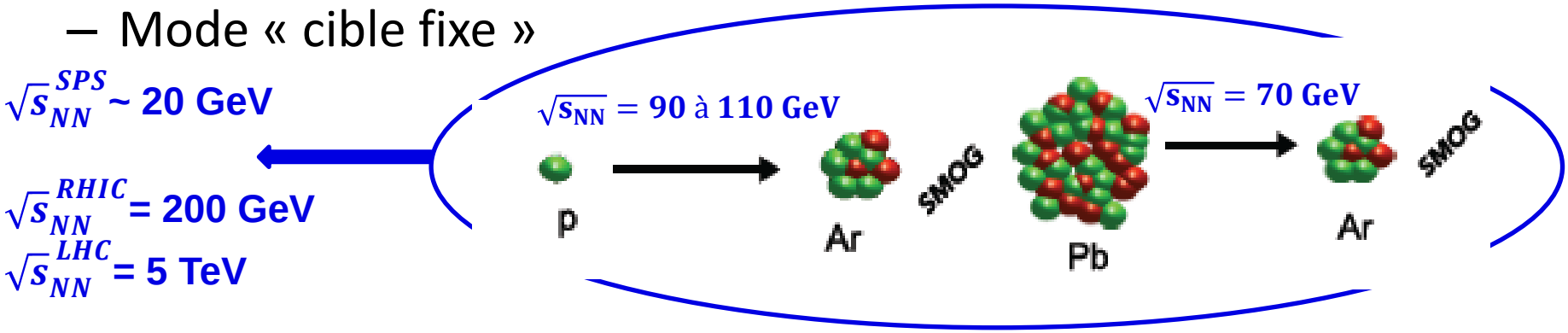


Programme ions lourds

- **LHCb fonctionnera en deux modes**
  - Mode collisionneur



  - Mode « cible fixe »



LHCb rapidity $2.5 < y_{LHCb} < 4.5 \Longrightarrow \begin{cases} \text{7 TeV beam:} & -2.3 < y^*_{LHCb} < -0.3 \\ \text{2.75 TeV beam:} & -1.8 < y^*_{LHCb} < 0.2 \end{cases}$

Running PbAr ?

- **PbAr@70 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**

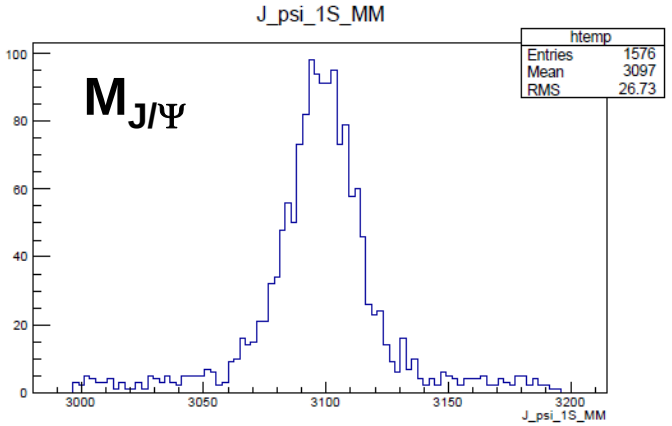
(based on EPOS-LHC-v3400)

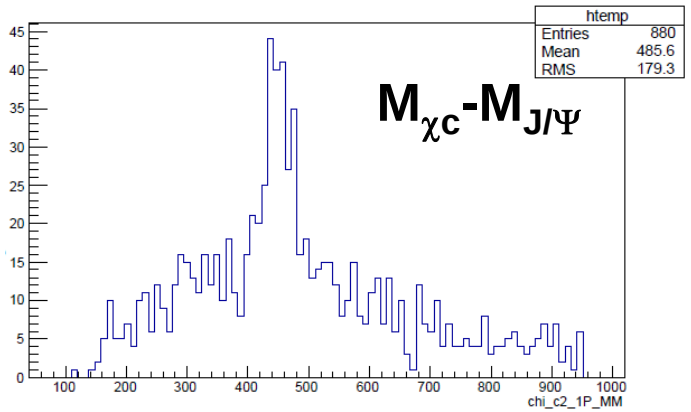
  - PbAr @ 71 GeV multiplicity ≡ PbPb@17 GeV multiplicity

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

Acceptance × efficiency
(PbAr full LHCb simulations)

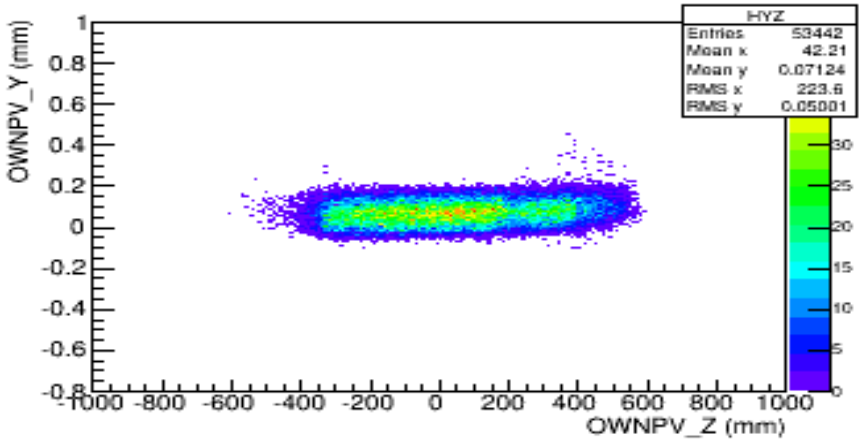
J/Ψ ~ 20%, χ_c (J/Ψ γ) ~ 5%

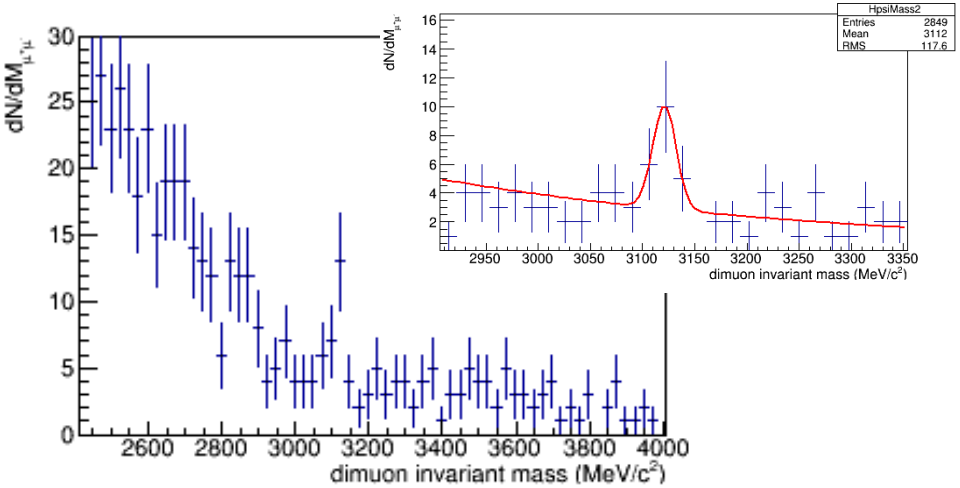




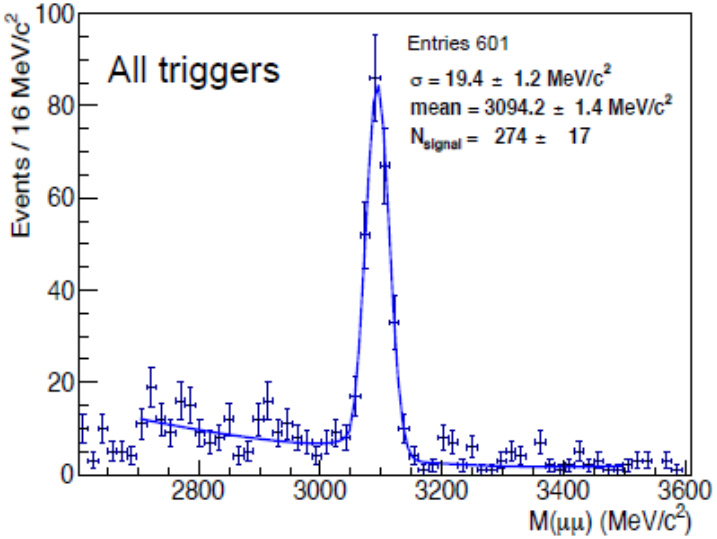
Real data

- **2013 : 27 minutes Pb+Ne @ 54 GeV**





- **Août 2015 : p-Ne @ ~110 GeV**
  - 12h de prise de données
    - 36 bunch protons



Conclusion

- **LHCb**
  - formidable opportunité de réaliser le programme de CHIC
  - Premières prises de données en 2015 !
    - Octobre 2015 : 3 jours de données pAr (~20000 J/ψ)
    - Novembre-décembre 2015 : 21 jours de données PbAr (~15000 J/ψ)

- **Partenariat avec LAL (forte synergie)**
  - LAL = expertise LHCb / LLR = expertise « ions lourds »
  - Physiciens « ions lourds » au LAL
    - Patrick Robbe : LHCb run coordinator
    - Giulia Manca: lauréate « ERC starting grant » au LAL
      - Étude des collisions PbPb à 5 TeV
      - Participation au programme SMOG

- **Stratégie LLR à court terme**
  - Recruter un postdoc expert LHCb (demande P2IO ; demande CNRS)
  - Proposer une thèse : **testing QGP color screening with SMOG-LHCb**
  - (thèse LAL : étude des collisions PbPb à 5 TeV)

- **Demande labo :**
  - Le cas échéant, un financement de thèse …