Charmed meson and charmonium

~~Charmed meson~~ in nuclei

@ J-PARC

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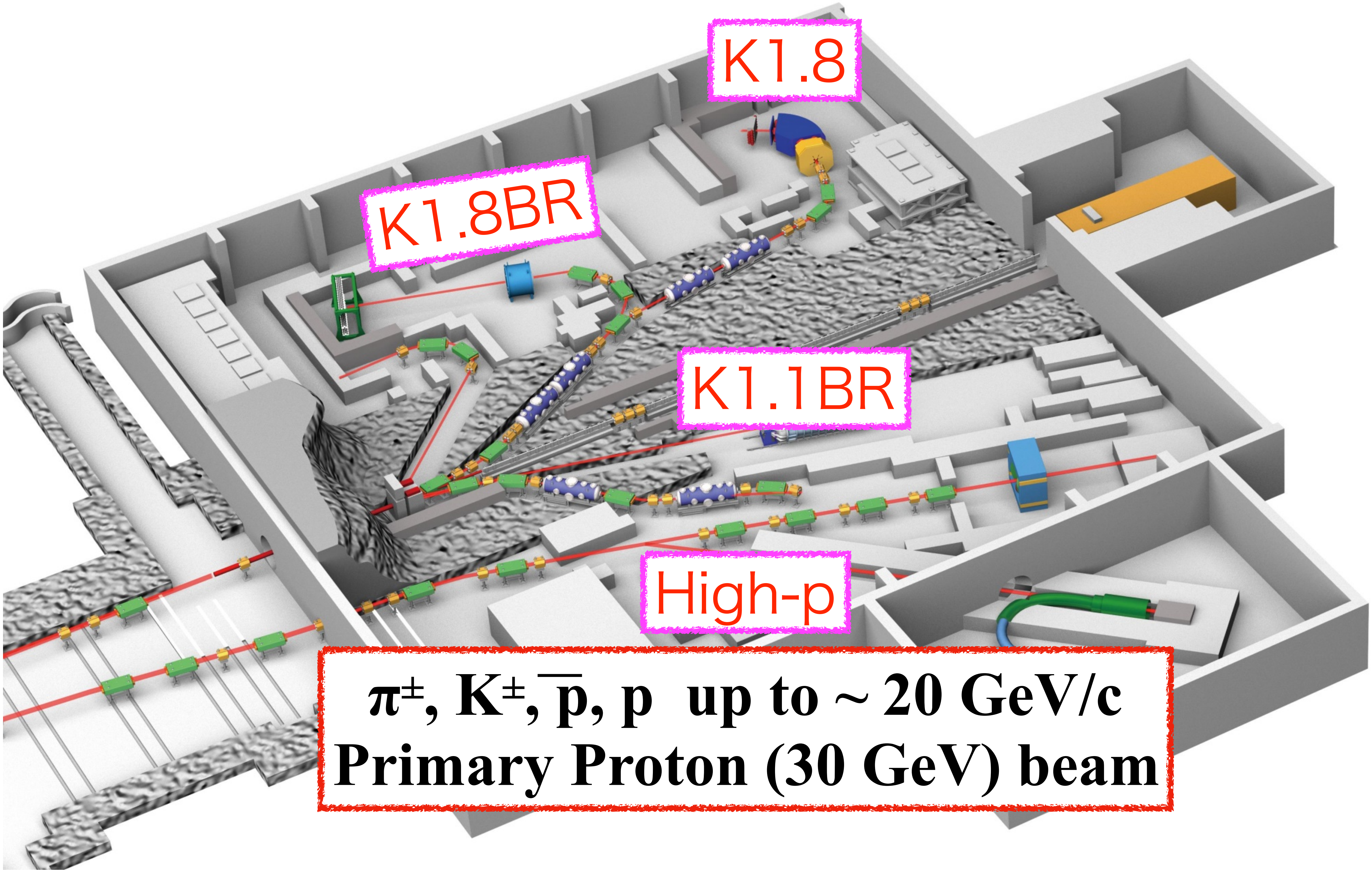
D and charmonium in nucleus

- Physics interest for this topics are already discussed in this workshop by many speakers
- So I am not repeating the reason why we need to measure it
- In this talk, I would like to introduce you the way "HOW" are we going to access those physics experimentally

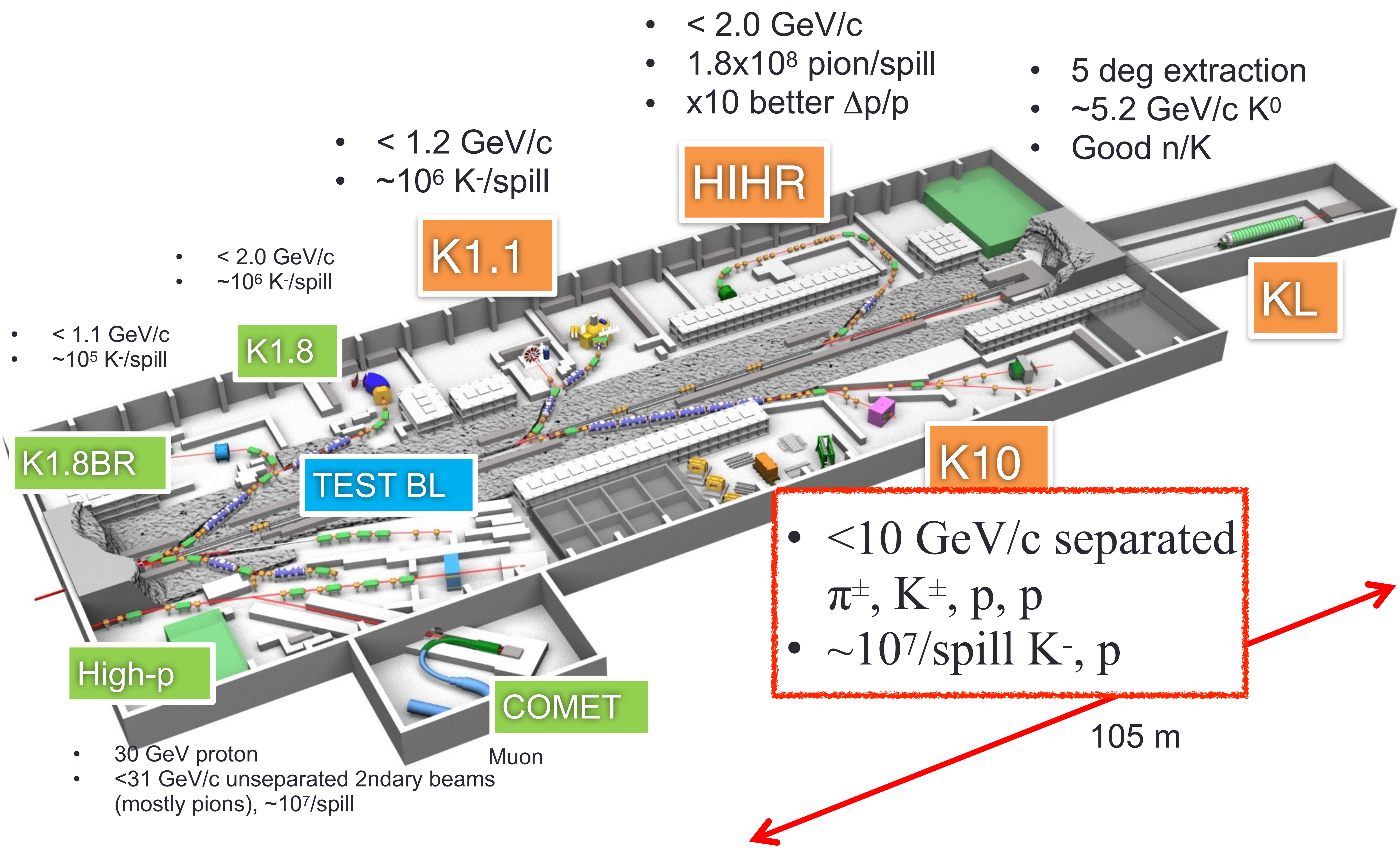
  ***i.e.* D and chairmanium meson in nucleus**
- However, it is not only the way. I believe, even more efficient way must be exist.

I definitely need to discuss with you!!!

J-PARC hadron hall



J-PARC Hadron hall extension



How to produce D meson? (or charmonium?)

- We are interested in the property of D meson (or charmonium) in nucleus

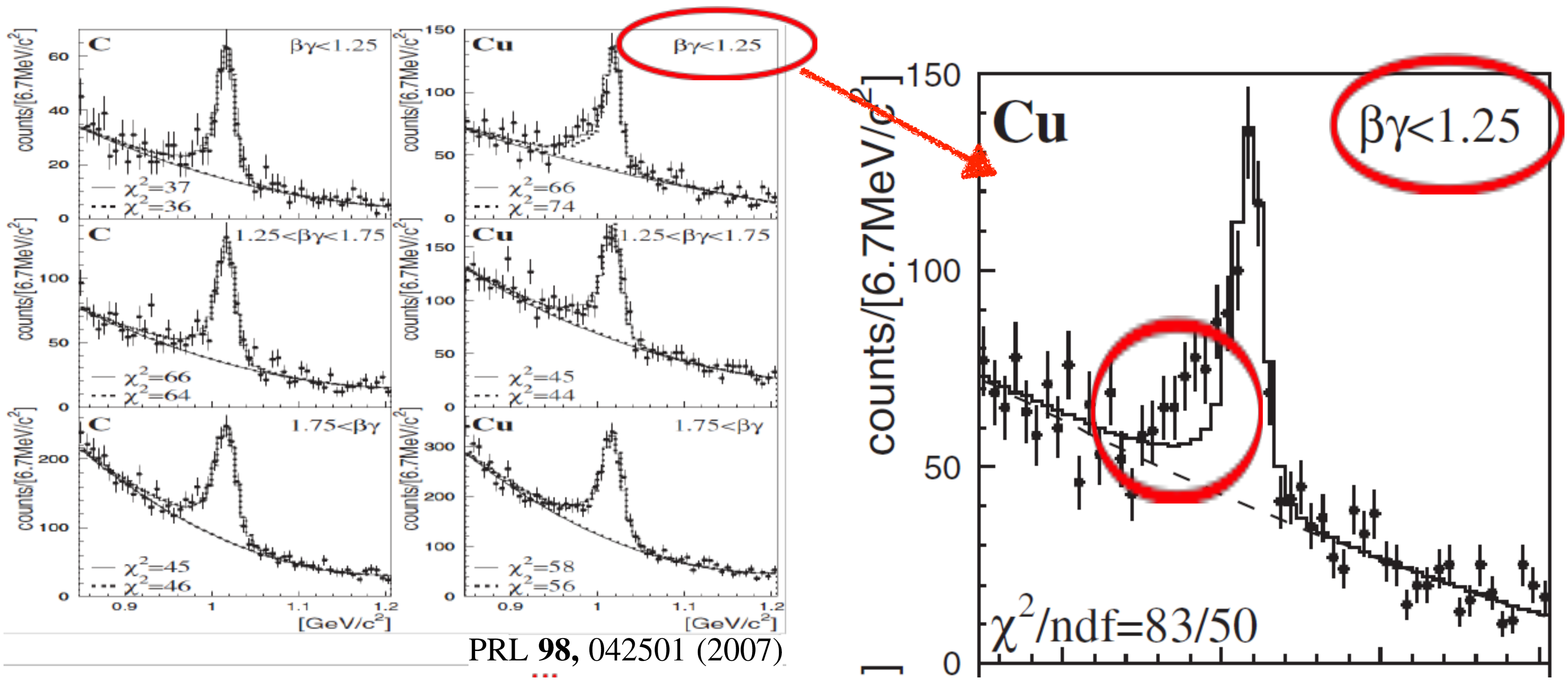
- What is need?

  - The best : stopped D meson in nucleus
    like, pionic atom, Kaonic nucleus and hyper-nucleus
  - Or : producing slowly moving D meson

→ How slow D meson do we need?

Lesson from previous experiments (strangenss sector)

- KEK E325 experiment reported "*significant*" modification for spectral function of ϕ meson in nucleus, when they selected ϕ meson with $\beta\gamma < 1.25$.



PRL **98,** 042501 (2007)

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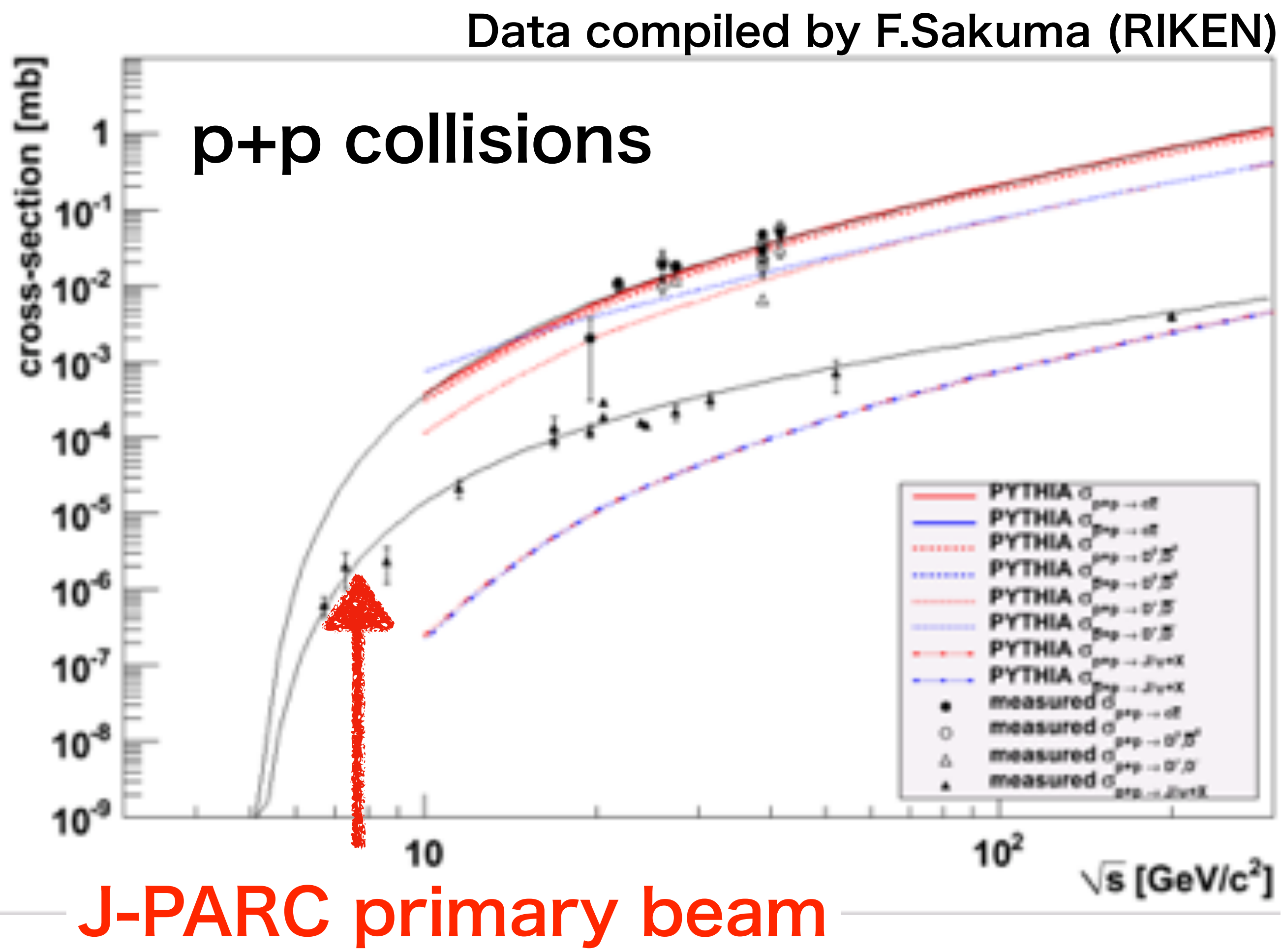
Probably $\beta\gamma \sim 1$ or less will be good.

D meson production with proton beam



Elementary reaction will be

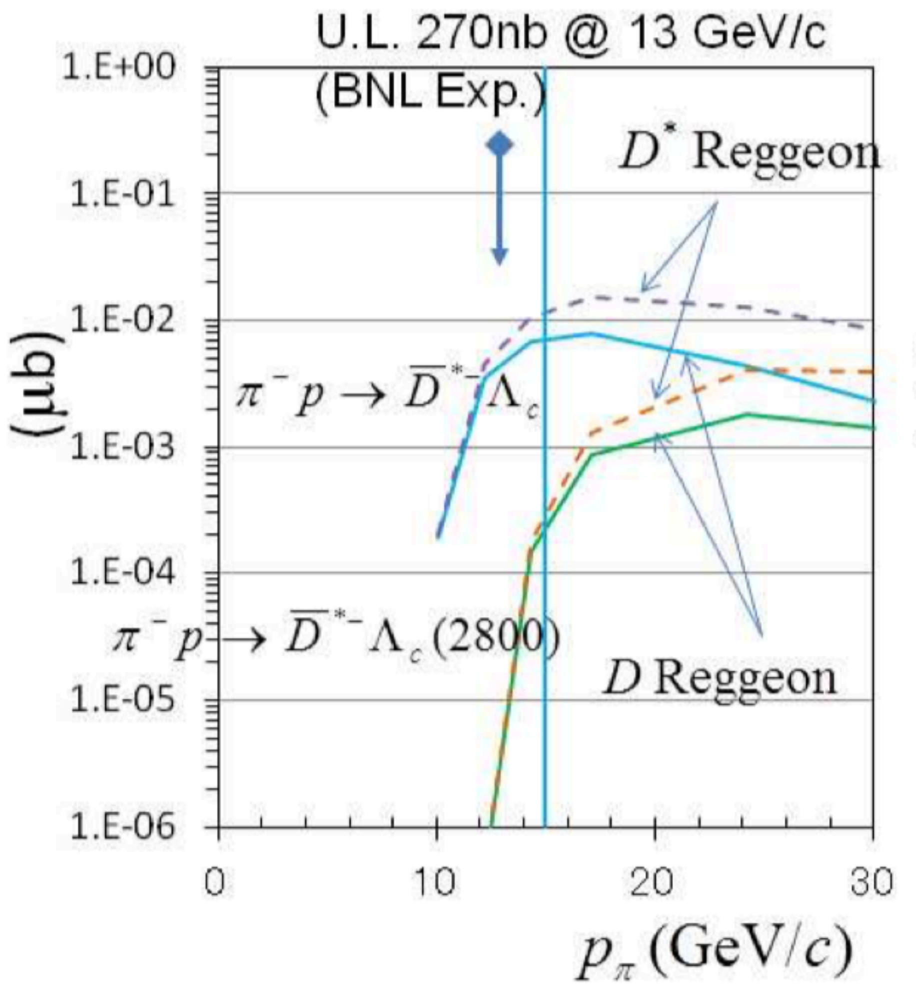
$$p + p \rightarrow D^- \Lambda_c p$$
$$p + p \rightarrow D^- D^+ pp$$

(1) production cross section near by threshold is not known well (~ 100 nb)

(2) typical momentum of D meson produced will be ~ 5-6 GeV/c ($\beta\gamma$ ~ 3) with p_{beam}=30 GeV

High intensity 30 GeV proton beam will be available at J-PARC on high-p beam line (~10^{10} ppp), but, momentum of produced D meson is too fast to use

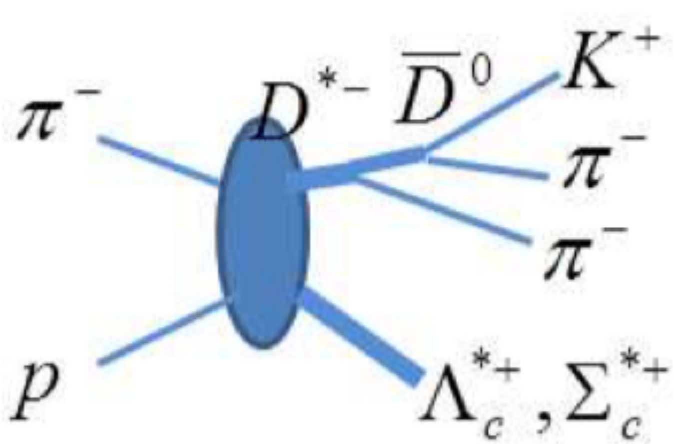
D meson production with pion beam



KEK/J-PARC-PAC 2012-19

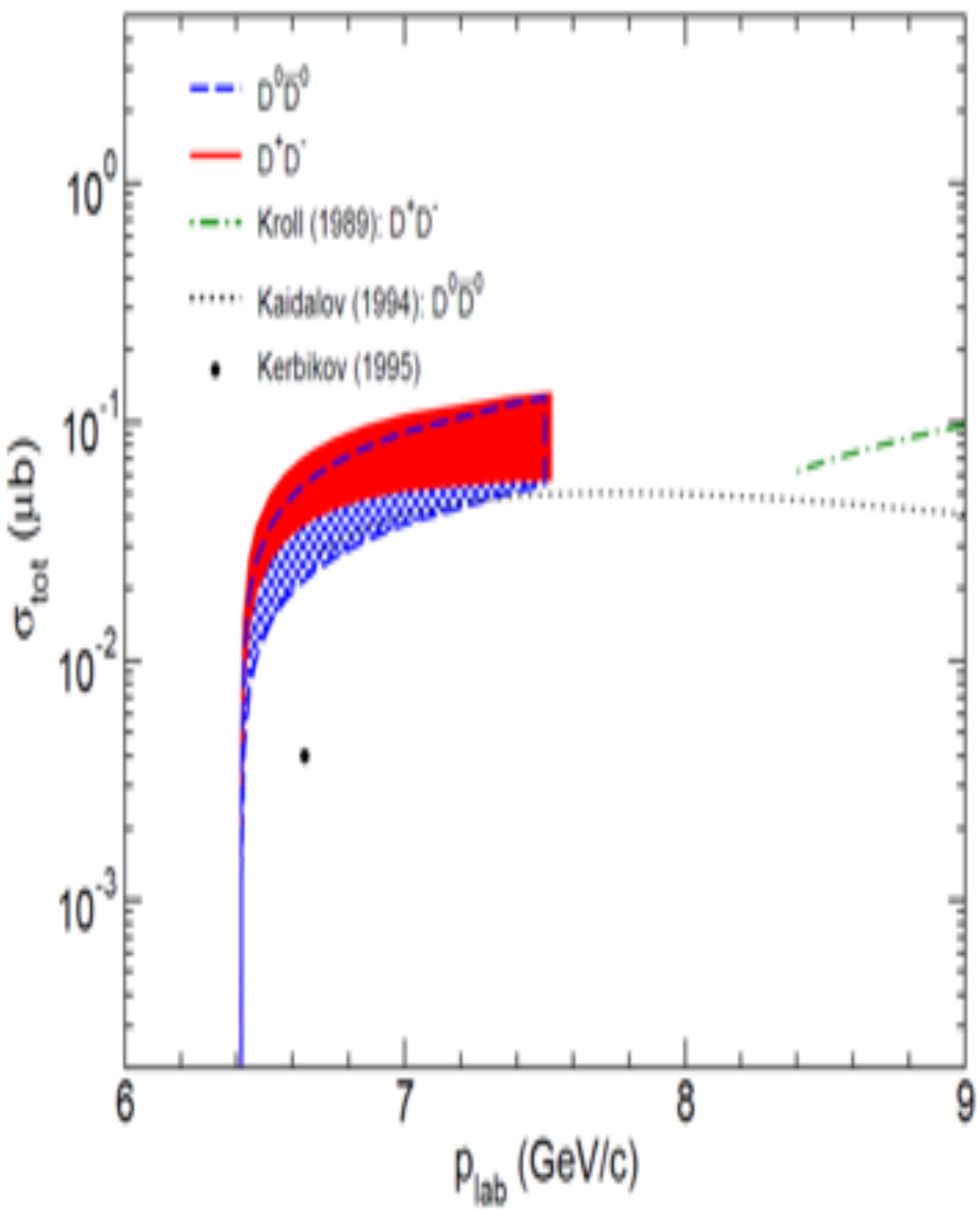
On high momentum beam line(High-p) high intensity π beam is available (up to 20 GeV/c).

However, production is expected to be "t-channel" process, i.e. produced D meson will be go forward with high momentum.



Thus it is not suitable to use this process to investigate medium effect with D meson

D meson production with p̄ beam



p̄p annihilation

Obviously baryon number on initial state is zero

All energy can be used for DD production $\bar{p}+p \rightarrow D^{-}D^{+}$

i.e. beam momentum of production threshold is going to be small (~ 6.4 GeV/c)

Produced D meson momentum with p_{beam}=7.0 GeV/c is ~ 2-4 GeV/c

Problem : nobody knows actual D meson production cross section on pp reaction around threshold

How to production D meson

- Using high energy proton;

  Momentum of produced D meson will be very large

- Using high energy pion: (t-channel production)

  Momentum of produced D meson will be very large

- Using anti-proton beam;

  Momentum of produced D meson may be usable??

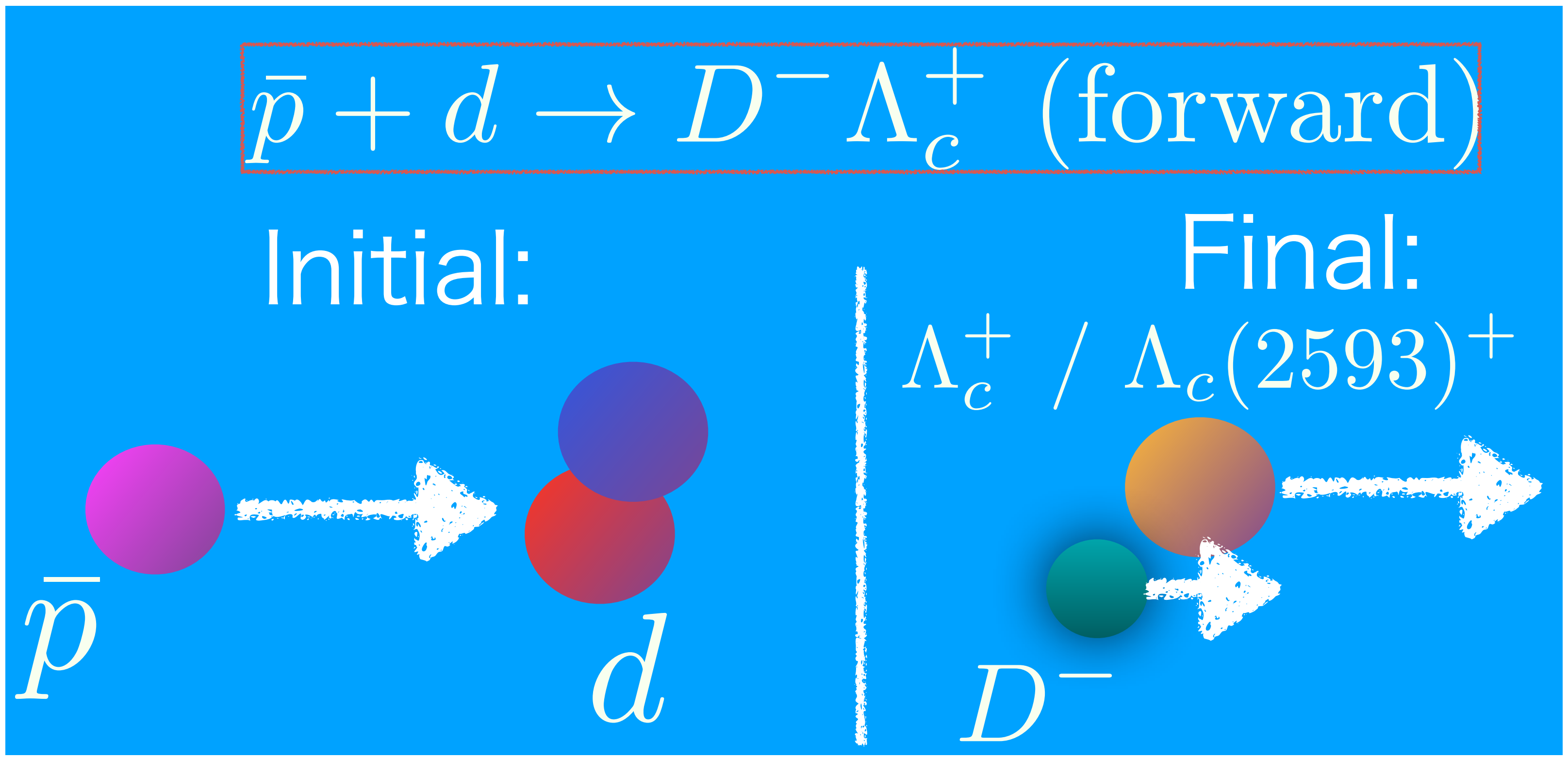
But

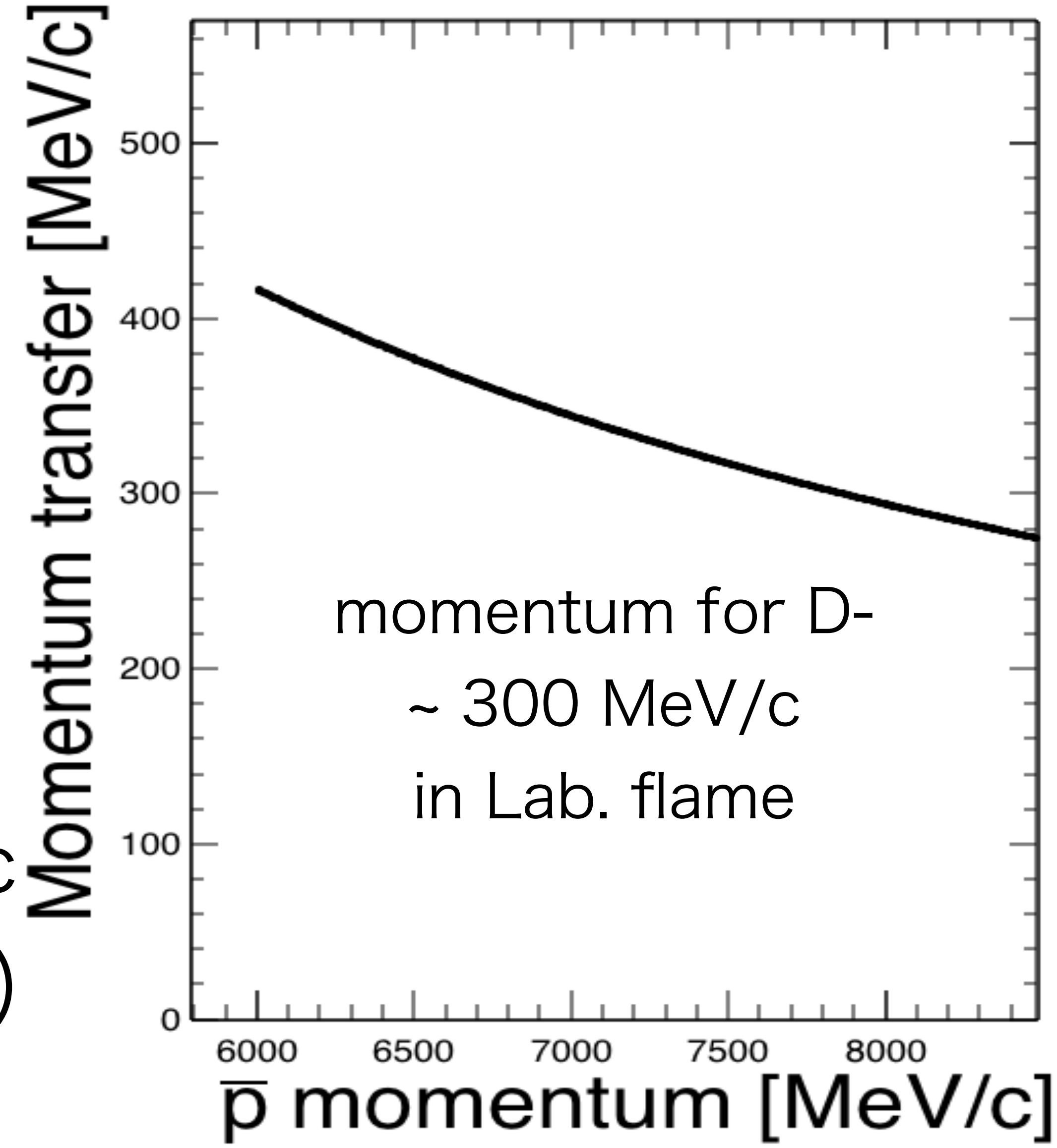
Maybe

still too big to be use for ordinary mesic nucleus production

Another way to produce slowly moving D meson

"two nucleon absorption process" may solve the problem ?





Momentum for produced D- ~ 300MeV/c
(same order with Fermi mom. in nucleus)

Only works for D^-, not for D^+

If D meson exiting to forward,
momentum for Λ_c will be ～700 MeV/c

The way to Λ_c Hyper nucleus ?

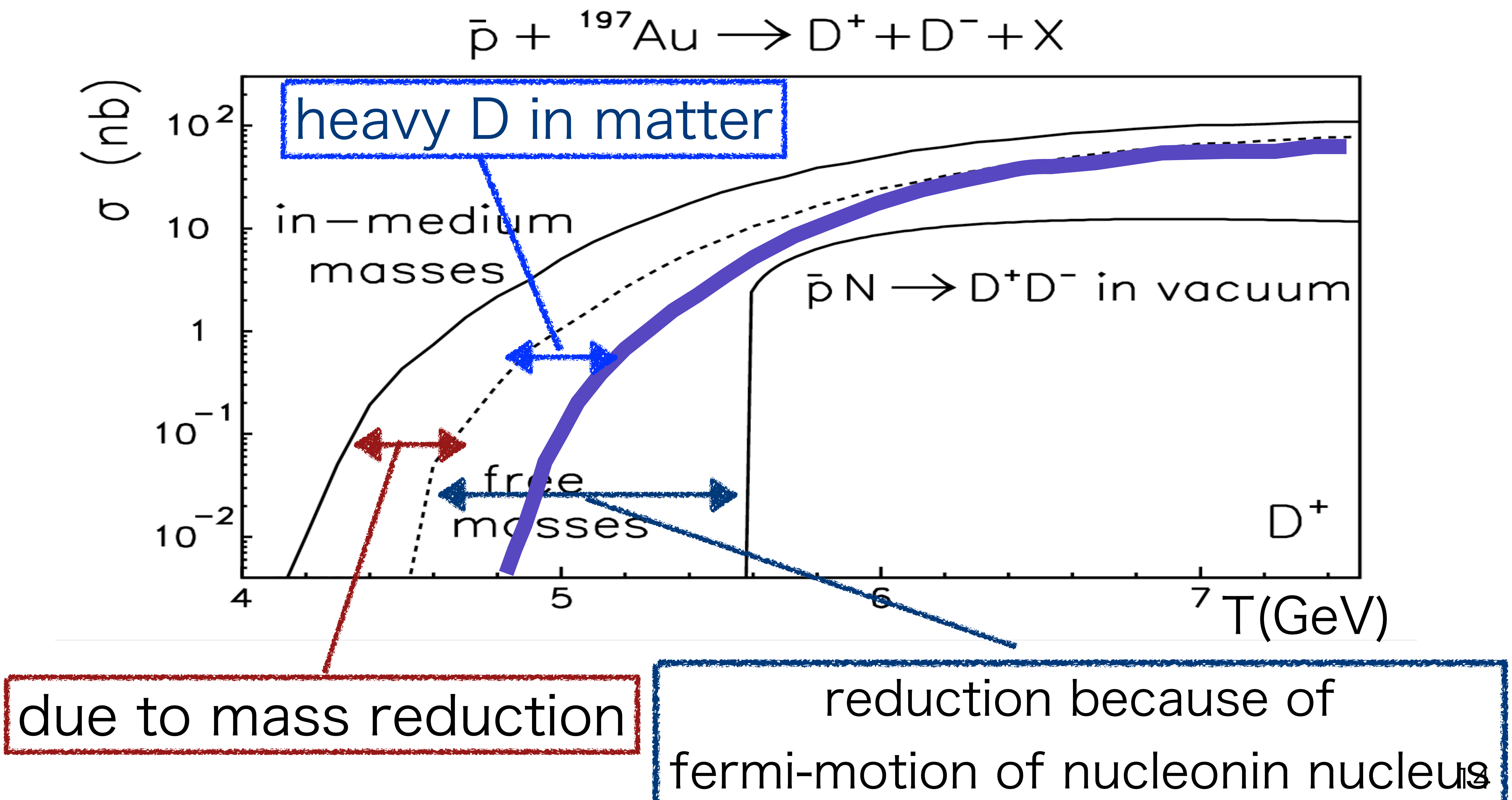
Again no experimental or theoretical estimation for the cross section is available…

Just concentrate on physics program with antiproton

Charm in nucleus
via anti-proton reaction on nucleus

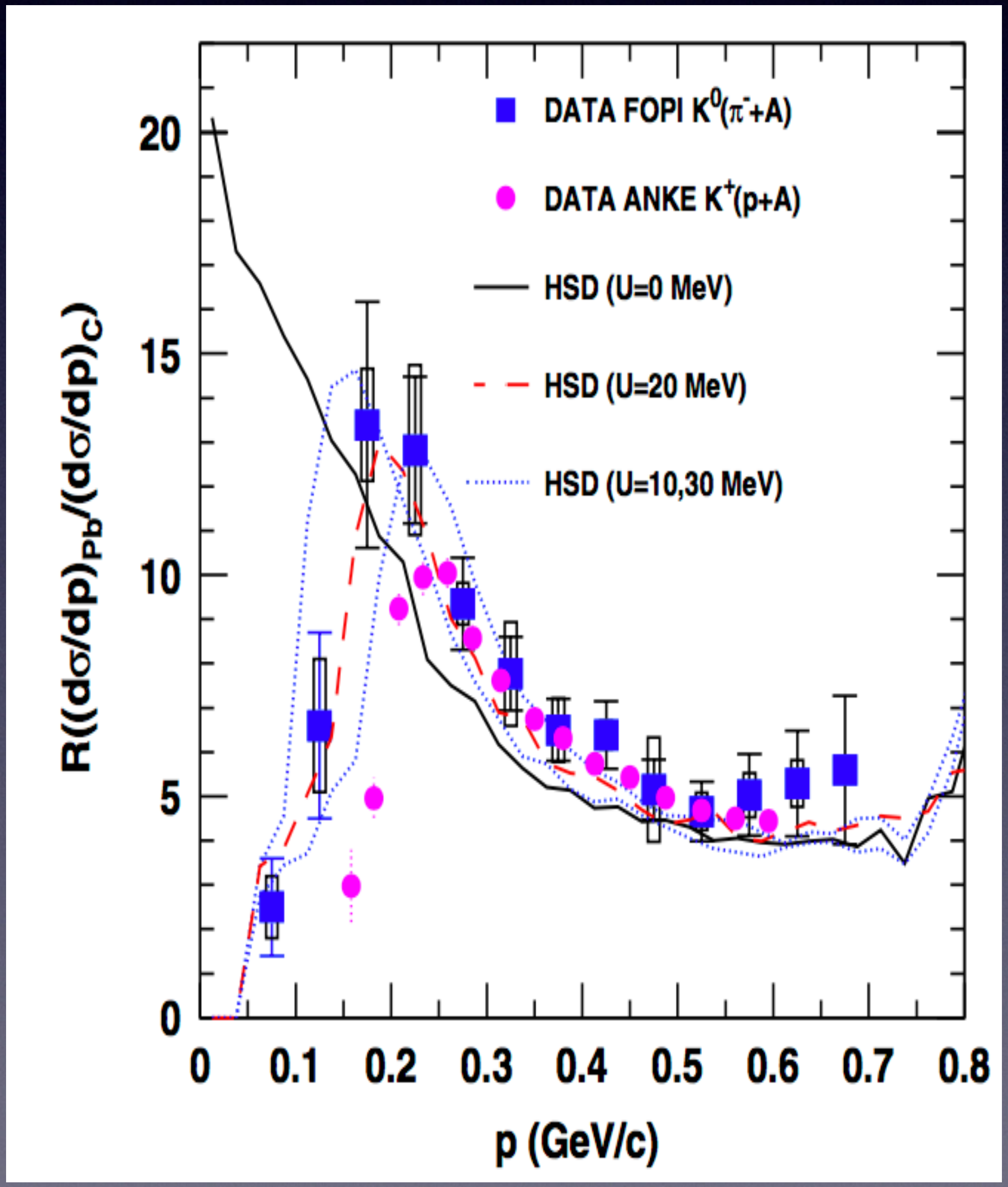
charmed meson in nuclear matter

- Sub-threshold enhancement of D+D- production on pbar-A interaction (Euro.Phys.J A,351)



Are there any way to measure DN interaction directory?

Lesson from K+ production experiment



Phys. Rev. Lett. 102 (2009) 182501

K^+ : repulsive force against to nucleon

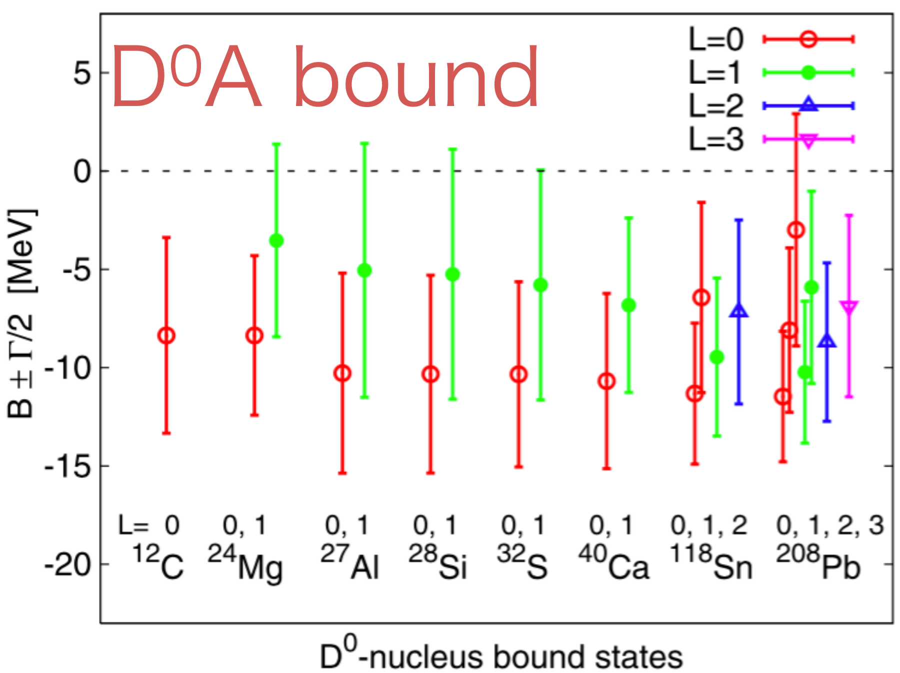
It will appear in nucleus dependence of K^+ mom. dist.

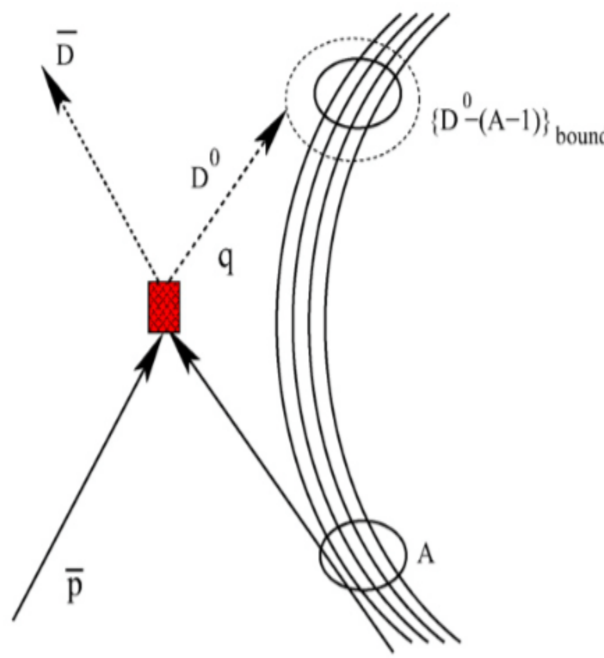
→ momentum of K+ will be pushed off to high momentum side due to repulsive force from nucleus

Can we expect same scenario with D mesons?

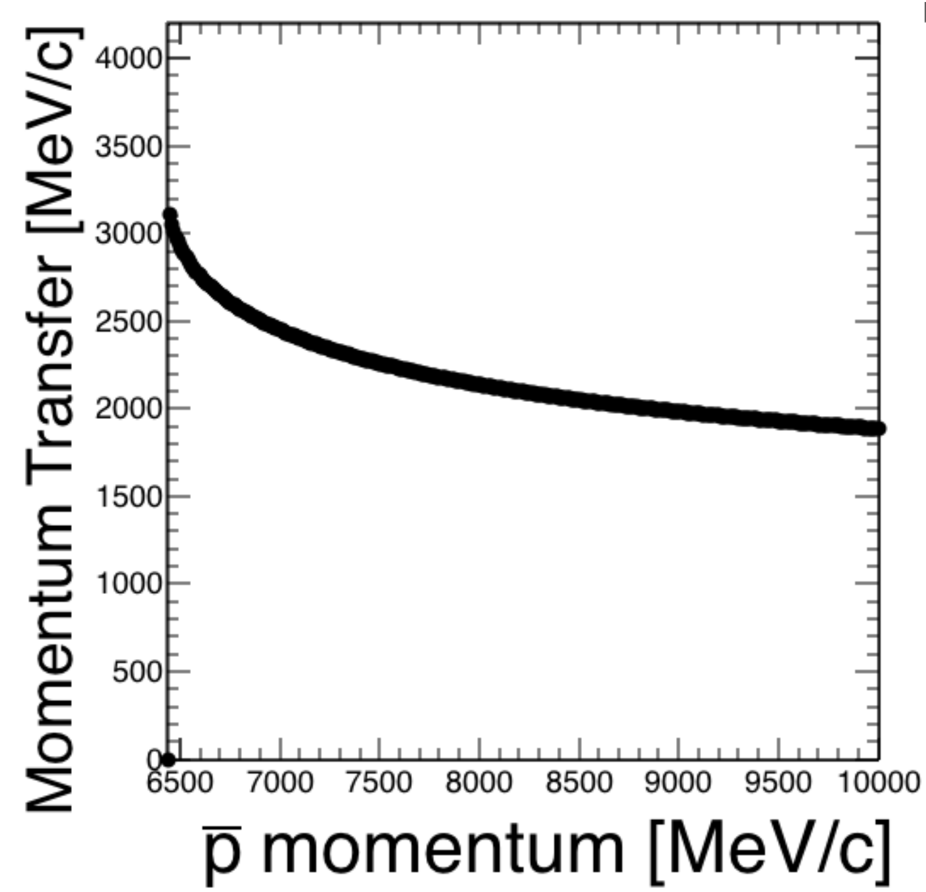
D meson nuclear bound state?

Theory tells us that $\bar{D}$ or D meson bound state might be exist





Phys. Lett. B690 (2010) 369–375,



- However, due to large momentum of D meson sticking probability of the meson on to nucleus will be small..

How about charmonium in nucleus?

Charmonium in unclear matter

George Wolf *et. al* , arXiv:1712.06537v1

Mass shift of charmonium states in $\bar{p}A$ collision

György Wolf,[1] Gábor Balassa,[1] Péter Kovács,[1,2,3] Miklós Zétényi,[1,3] and Su Houng Lee[4]

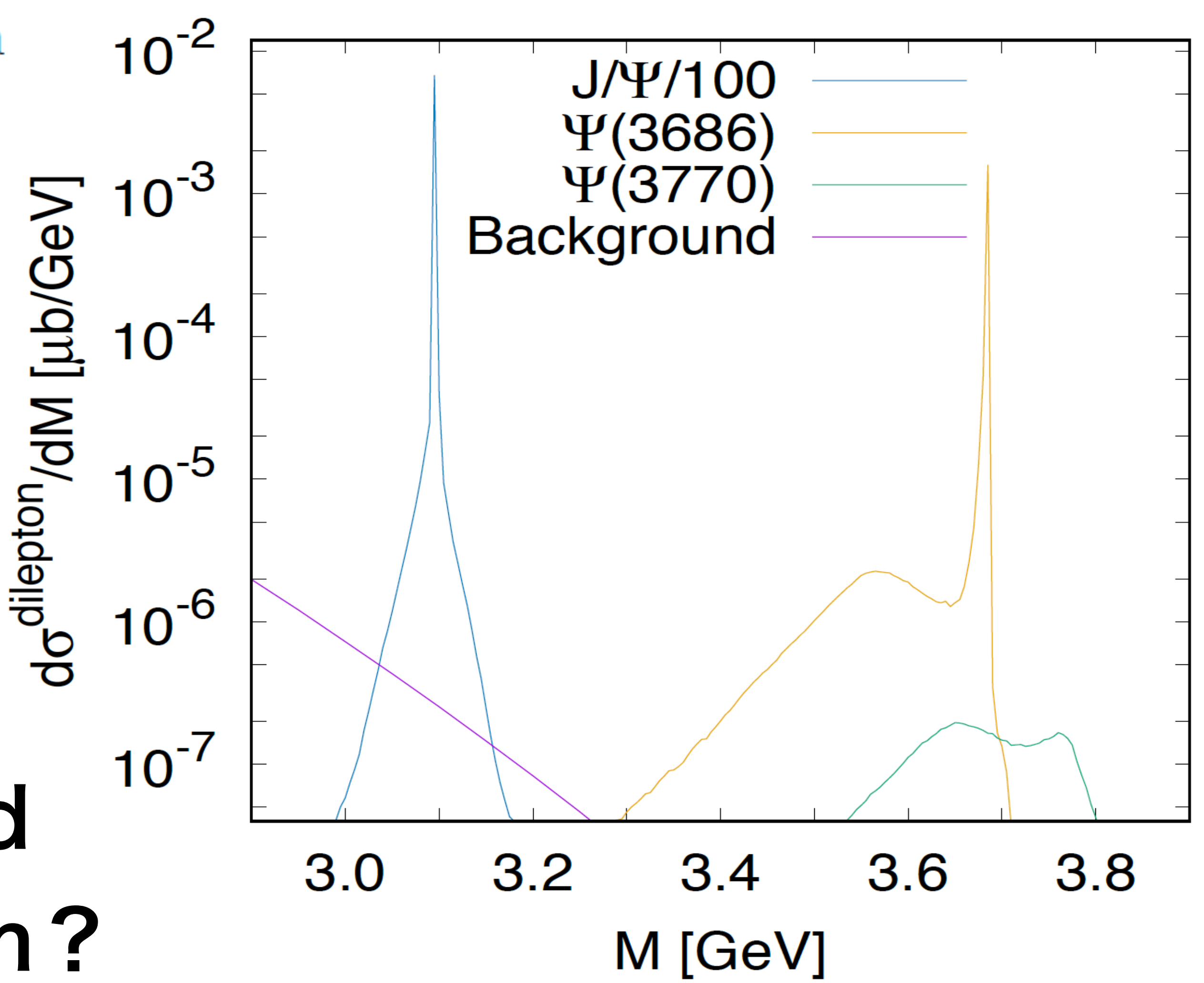
「those made of heavy quarks are sensitive mainly to the change of the non-perturbative gluon dynamics manifested through the changes in the gluon condensates. 」

The masses of the low lying charmonium states, namely, the J/Ψ, $\Psi(3686)$, and $\Psi(3770)$ are shifted downwards due to the second order Stark effect. In $\bar{p}$ + Au collisions at $6-10$ GeV we study their in-medium propagation. The tim

Charmonium type (V)	Δm_V
J/Ψ	$-8+3$ MeV
$\Psi(3686)$	$-100-30$ MeV
$\Psi(3770)$	$-140+15$ MeV

J/ψ : very small change

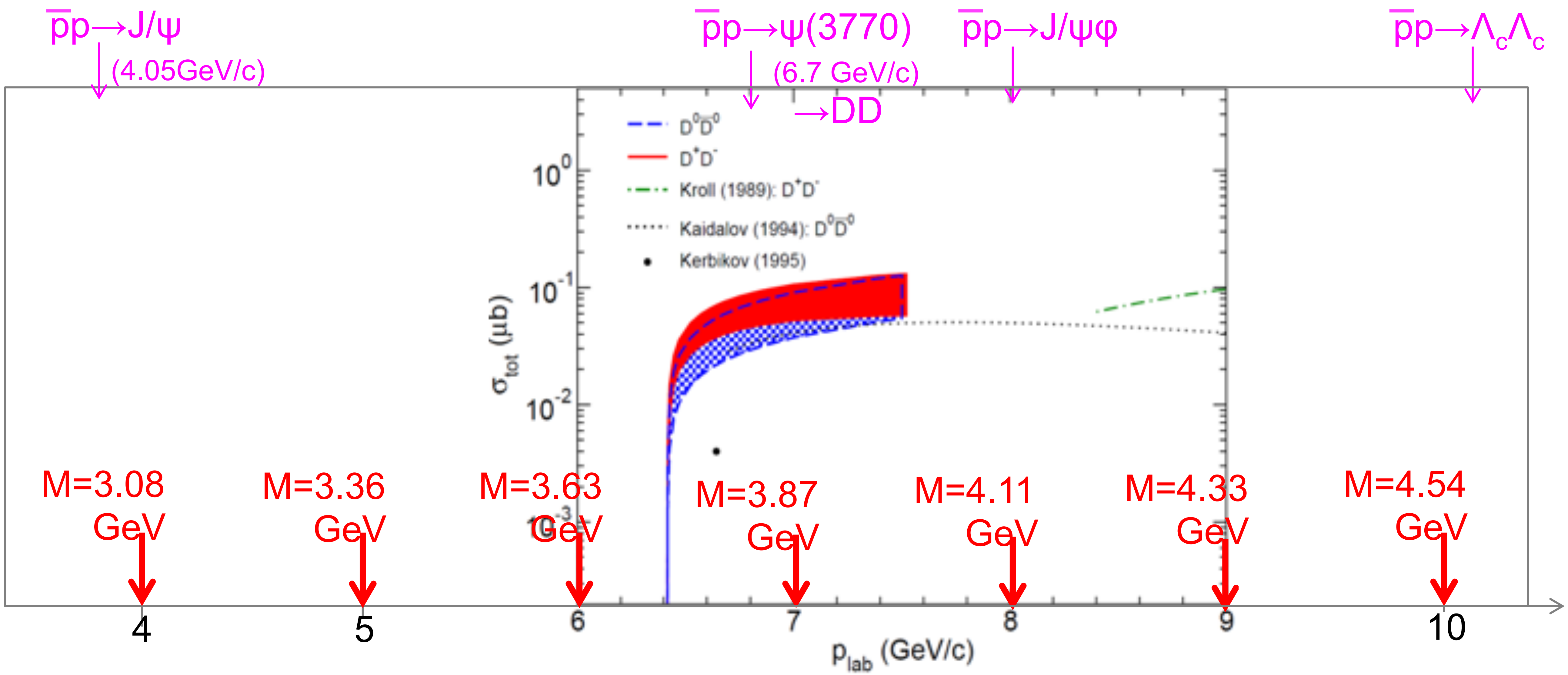
ψ' : large mass shift!



1) small background expected

2) large effect on ψ' spectrum?

How about charmonium?



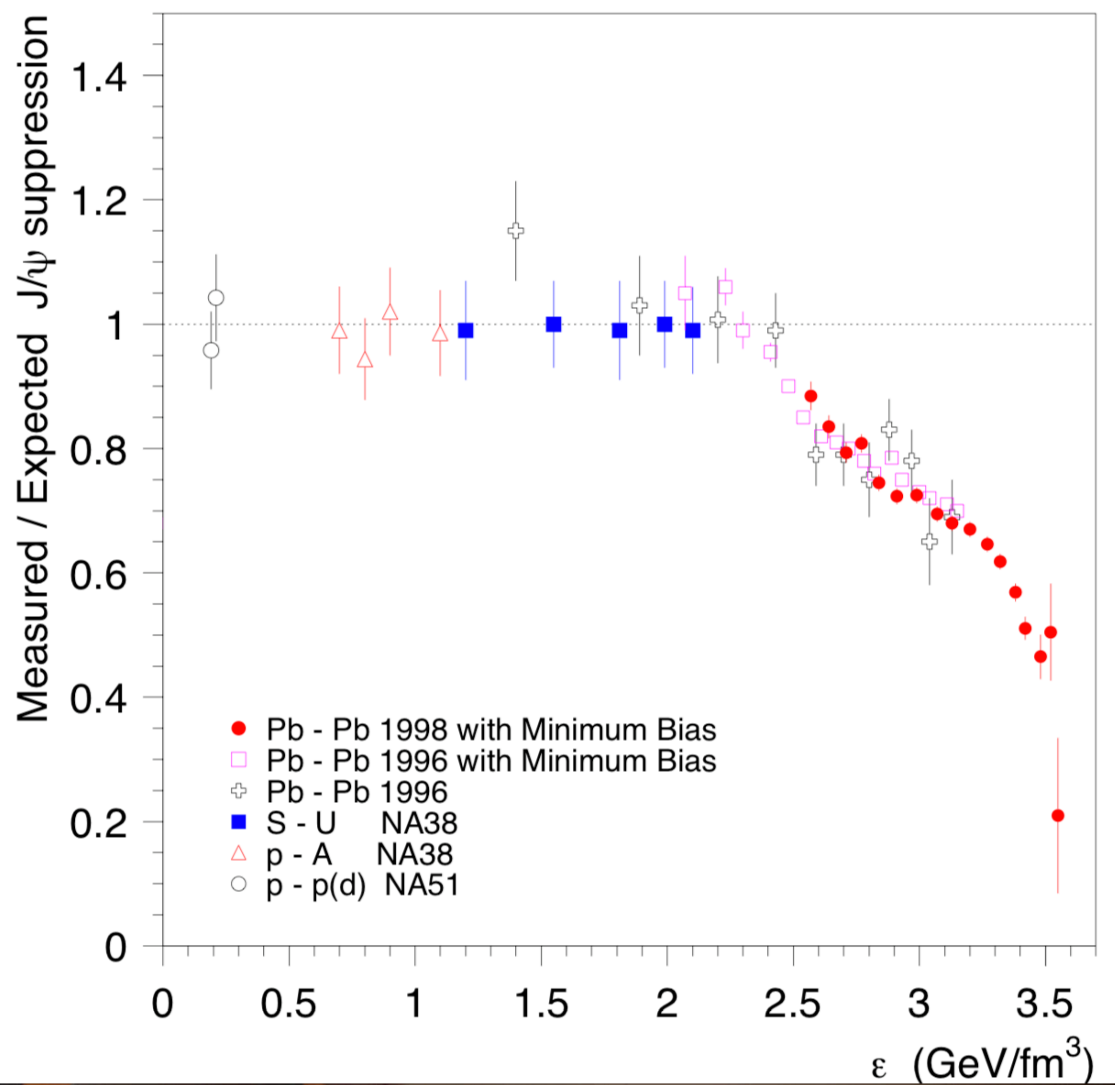
J/Ψ, Ψ', even Ψ(3770) may be in the range where we will able to investigate

First let's think about J/Ψ in nucleus

Charmonium-nucleon interaction

- In fact, J/ψ-N cross section is not known very well.
- Why we need to know?

  → to understand J/ψ suppression pattern observed in high energy heavy ion collisions



Effect of feed down to J/ψ (such as ψ', χ_c) is important

scenario we thought was

First, ψ', χ_c are melting and then J/ψ will be melt

We need to know J/ψ-N interaction, How strong?

J/ψ-N interaction

How to extract $\sigma_{J/\psi\text{-N}}$?

- From elastic photoproduction channel $\gamma p \to J/\psi p$

  ~ 1 mb (using vector meson dominance+optical theorem)

- The A dependence of J/ψ photoproduction (E=20 GeV)

  ~ 3.5 ± 0.8 mb (Phys.Rev.Lett.38(1977)263)

- From p-A collisions at high energy (NA60/CERN)

  (from A dependence of production X-section

  (J.Phys.G 38(2011)124143)

  ~7.6 ±0.7±0.6 mb (incident proton energy 158 GeV)

  ~4.3 ±0.8±0.6 mb (incident proton energy 400 GeV)

Consistent? Or not?

Something may be still missing?

What do we need to taking into account?

- at high energy, feed down from higher charmonium states (ψ'/χ_c etc) need to be taking into account
- Can we really separate "J/ψ-N" – "J/ψ-co-mover" – others?
- do we see strong energy dependence?

Let's think about J/Ψ production with anti-proton at J-PARC

J/ψ production with anti-proton

- Just focus on J/ψ production using pbar-p →J/ψ channel (only J/ψ produced!) on J/Ψ threshold

  i.e. It is not necessary to taking into account feed down of chemed mesons

- Very well known production cross section

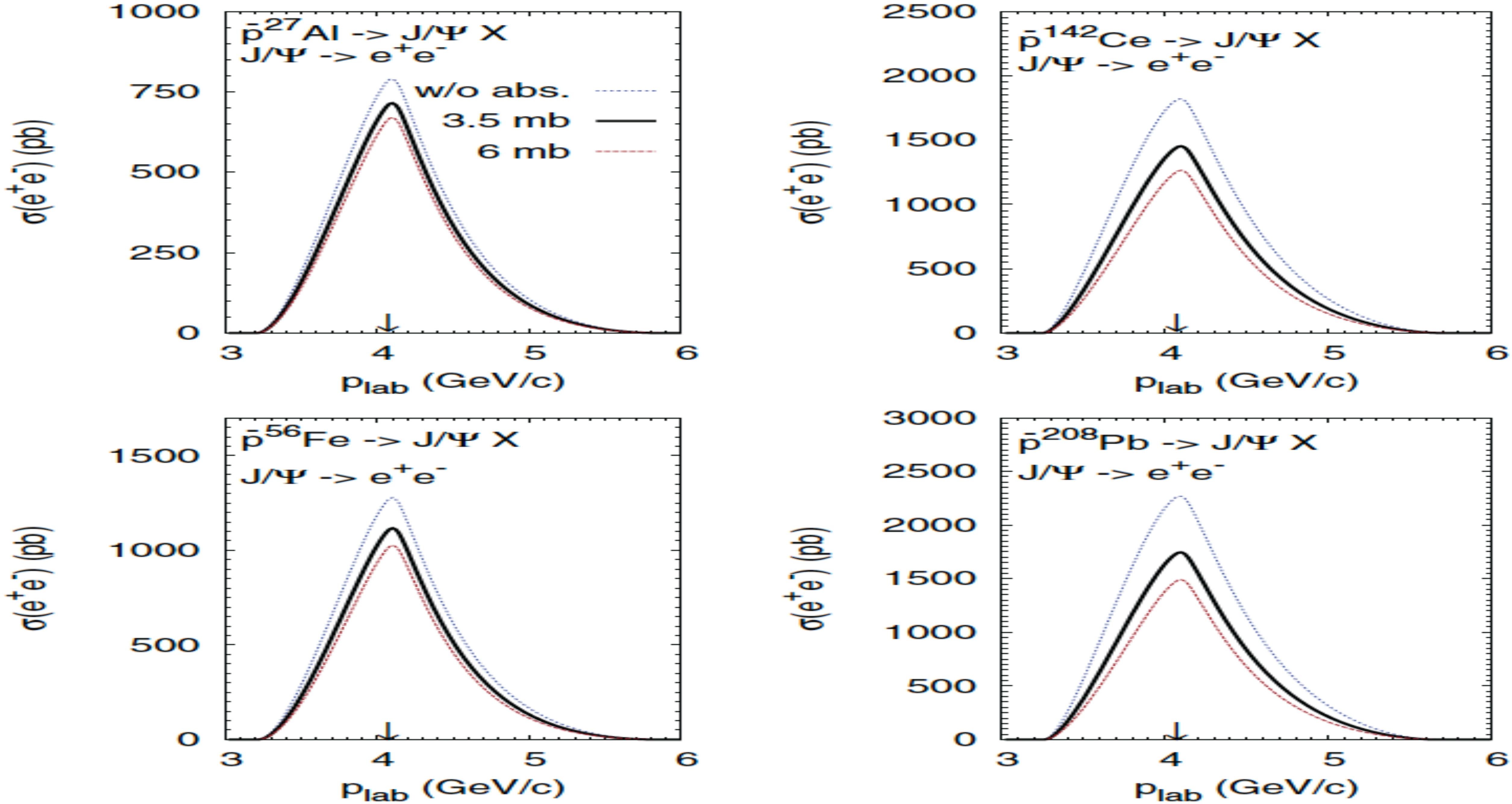
  (~ 311 nb for pbar-p →J/ψ→$\mu\mu$ on pole energy where beam momentum of anti-p is 4.07 GeV/c)

- Advantage (?) : Antiproton will absorbed on the surface of nucleus

  i.e. Produced J/ψ will penetrate through nucleus

Production cross section

In case of anti-proton-nucleus interaction



- PhysRevC(2013)054608

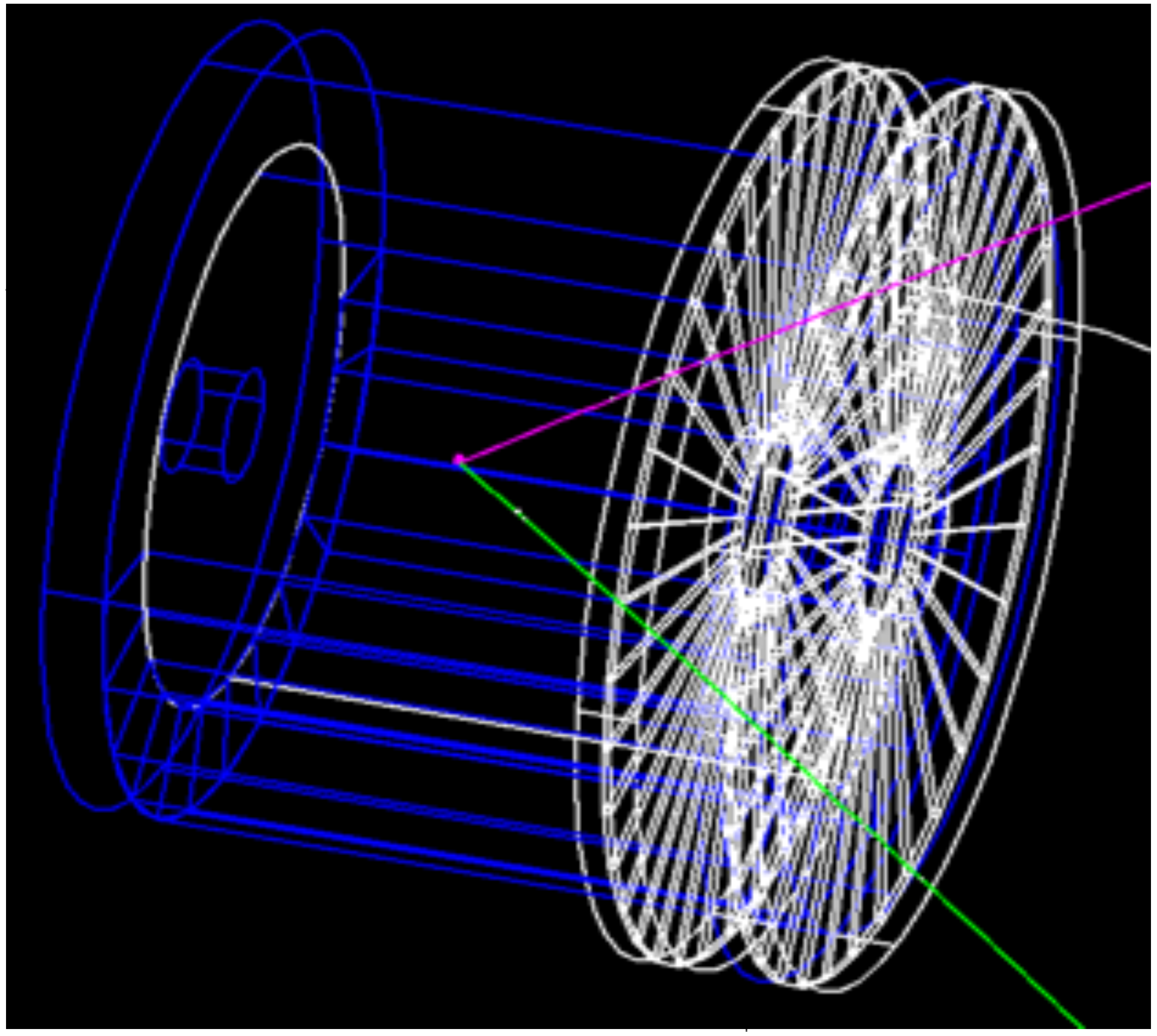
expected to be ~ nb

Detetor setup

- Purpose :

  A-dependence of J/ψ, ψ' production cross section using anti-proton proton annihilation

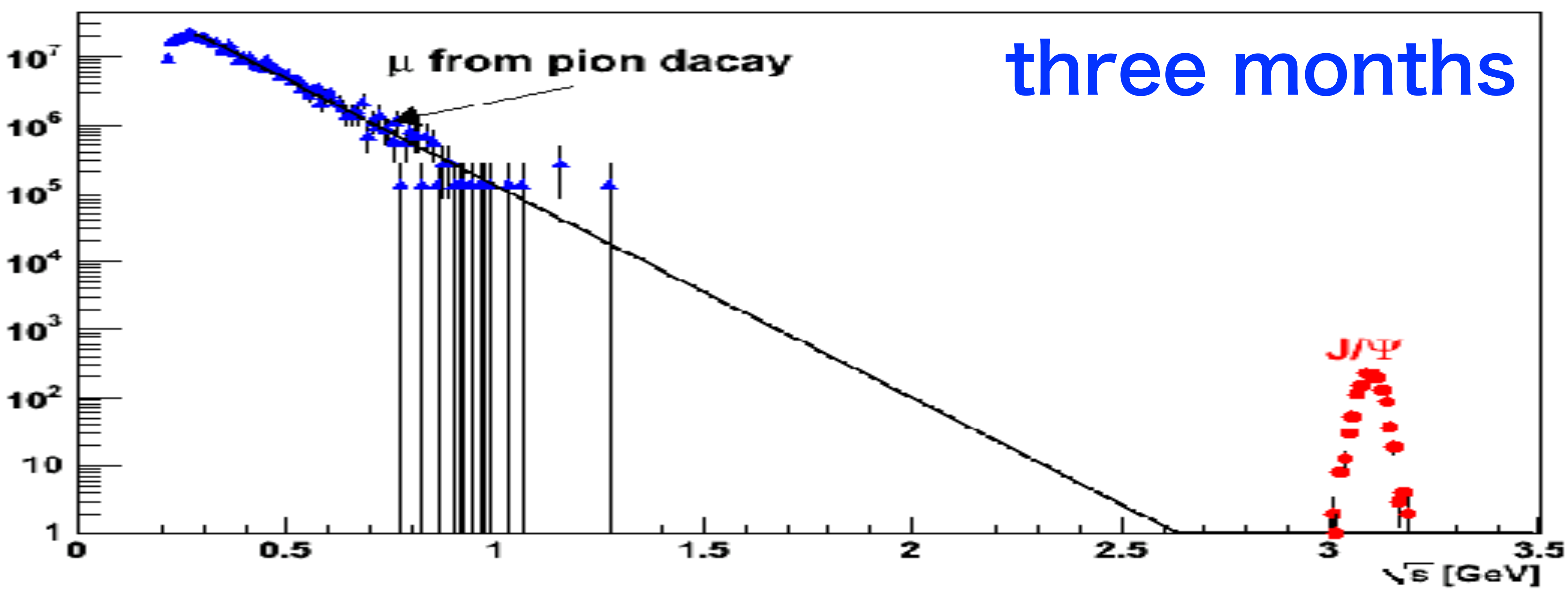
- Assuming :
  - Focusing on J/$\psi \rightarrow \mu\,\mu$
  - **7x10^6** anti-proton/spill at 4 GeV/c
  - Using 2.0g/cm^2 target



How the signal looks like?

- Fermi motion of nucleon in nucleus are taking into account for cross section evaluation
- Major background
  - Almost no "physical" background (low energy)
  - Muon from Pion decay will be major source

  but, the BG seems far away from signal.

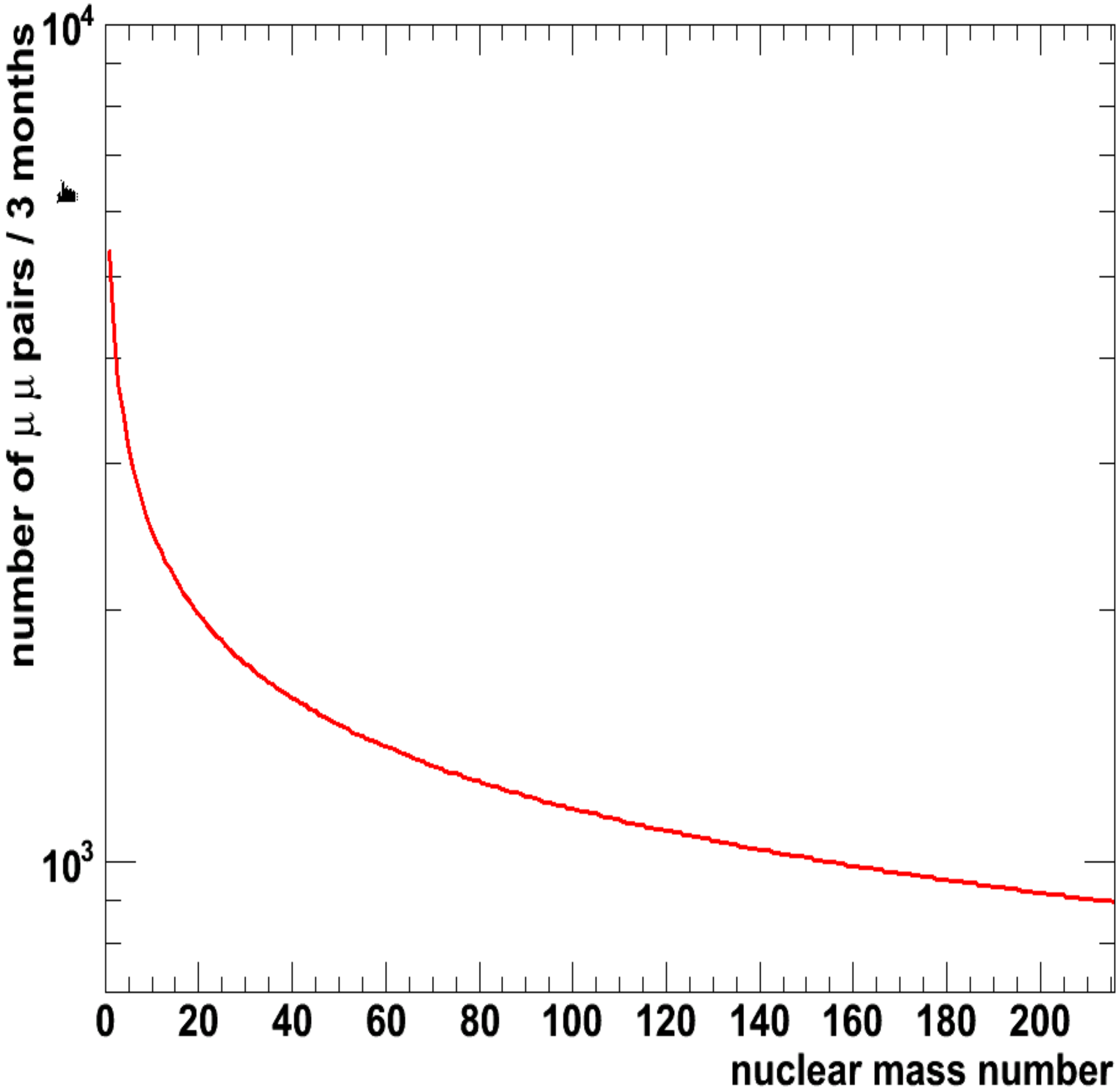


Number of signals (J/ψ) as a function of target nucleus mass number

~ $2x\ 10^3$ for A=30

~ 900 for A~208

Cross section for each nucleus can be determine with in 5% accuracy (stat.)



Summary

- Charmed hadron will be a good probe to investigate property of QCD vacuum

  (discussed intensively by previous speakers)

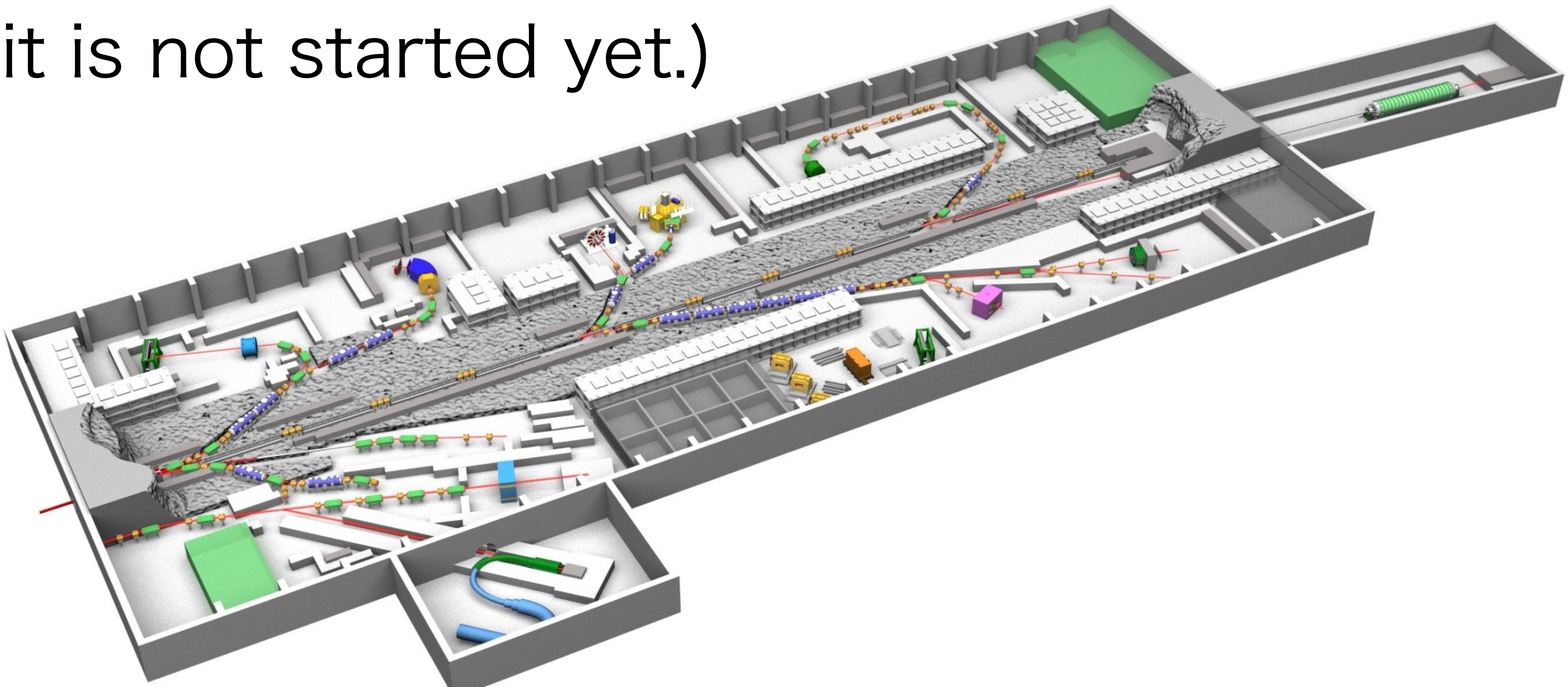
- Key issue will be to find the way how to produce slowly moving charmed hadron respect to nucleus

  - One of the best way to produce slowly moving charmed hadron might be the production via anti-proton

$$\bar{p} +^4 He \to J/\psi \ + t \qquad \bar{p} + \ d \ \to \Lambda_c + D^-$$

However

- To realize the physics program "charmonium or charmed meson in nucleus", we definitely need to construct new beam line which is planing on hadron hall extension project (it is not started yet.)



Your support is needed to go forward