Measurement of the open charm cross-section

in 200 GeV Cu+Cu collisions using STAR @ RHIC

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for the STAR collaboration

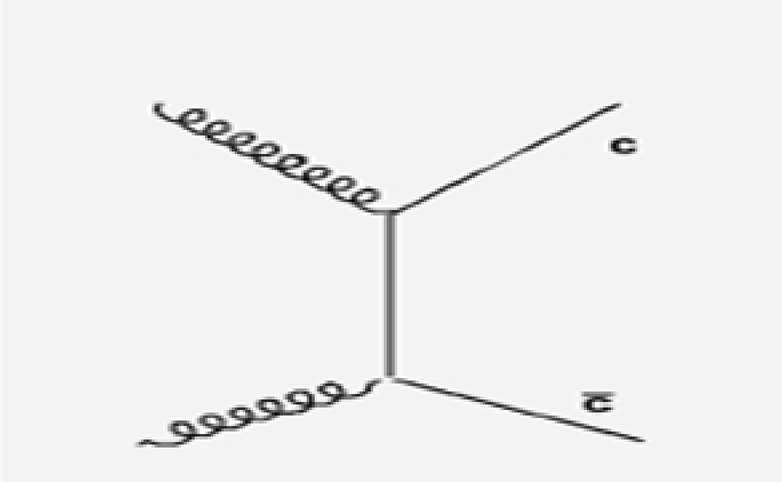
Physics motivations

Charm:

- is primarily produced by **gluon fusion**
  - little contribution from **gluon splitting** (see talk by A. Mischke and poster by X. Dong).
- **is sensitive to early stage of the collision** (quark produced at $\tau \sim \hbar / 2m_Q c^2 \sim 0.1\ fm/c$)
- has an **undisturbed mass**
- **large uncertainty** in pQCD
  - α_s large
  - **gluon PDF** undetermined

  for $P_T < M_c$

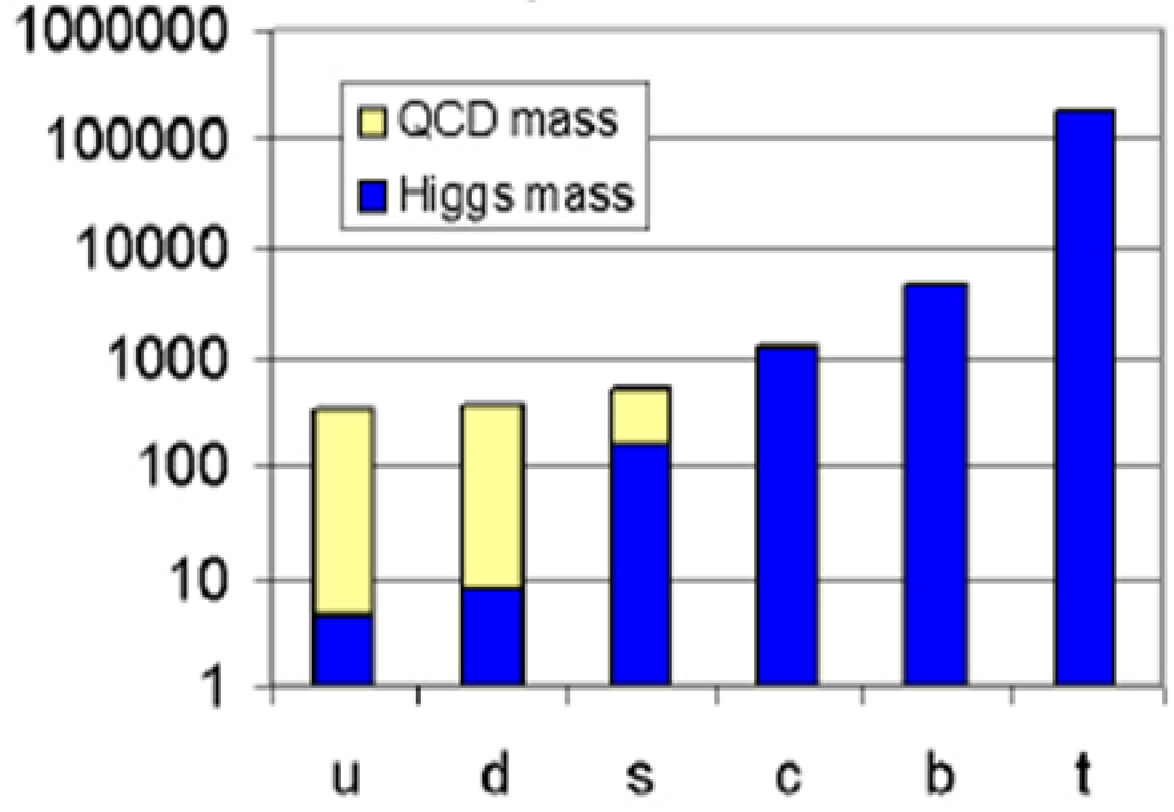
  → the cross-section is little constrained by theory

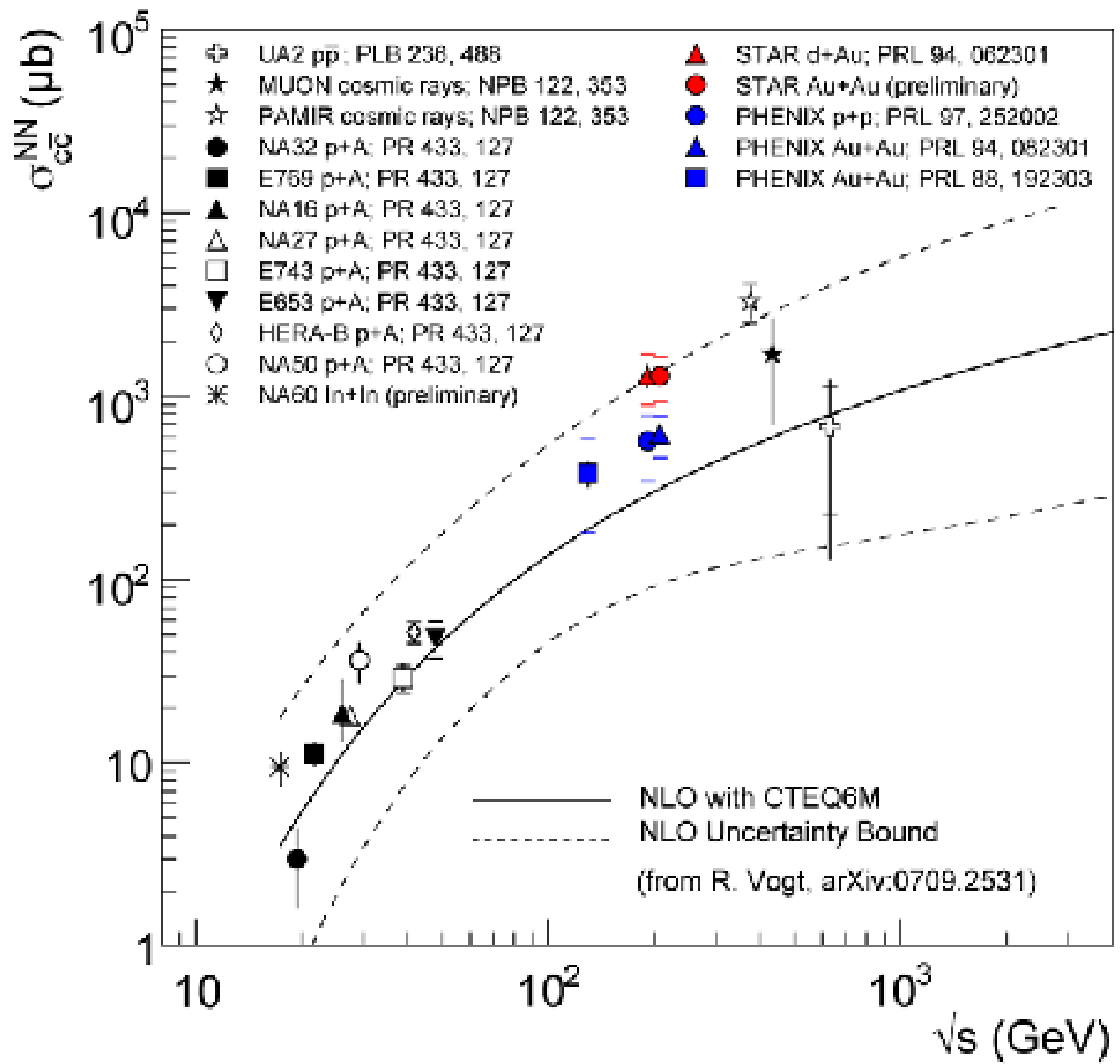


NLO: $301\ ^{+1000}_{-210}\ \mu b$

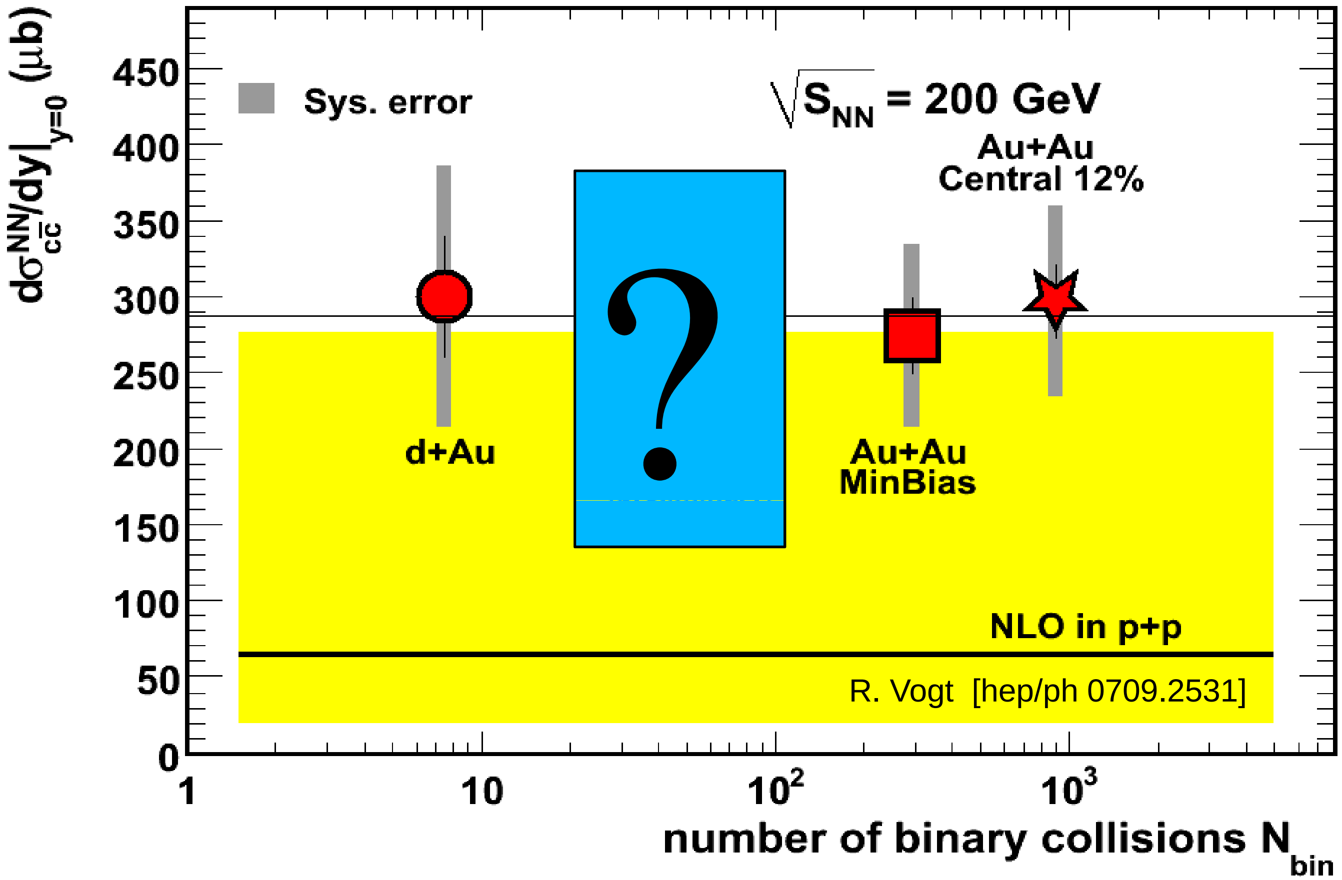
R. Vogt hep/ph 0709.2531

B. Müller, nucl-th/0404015





Binary scaling



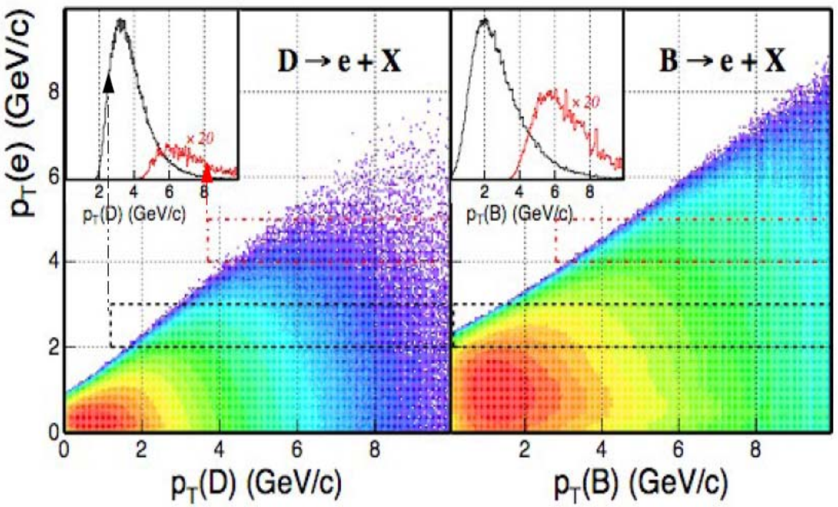
Charm production is a hard process: expect binary scaling.
Data so far supports this ⇒ d+Au to Au+Au.
What about Cu+Cu?

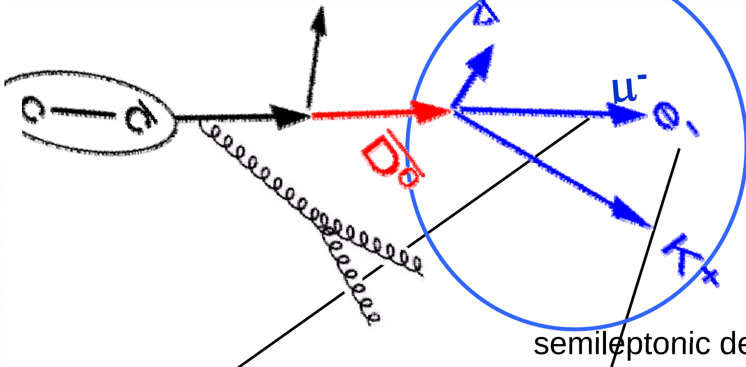
Open charm measurements

via semileptonic decays

Electrons and Muons….

Measured by STAR and PHENIX





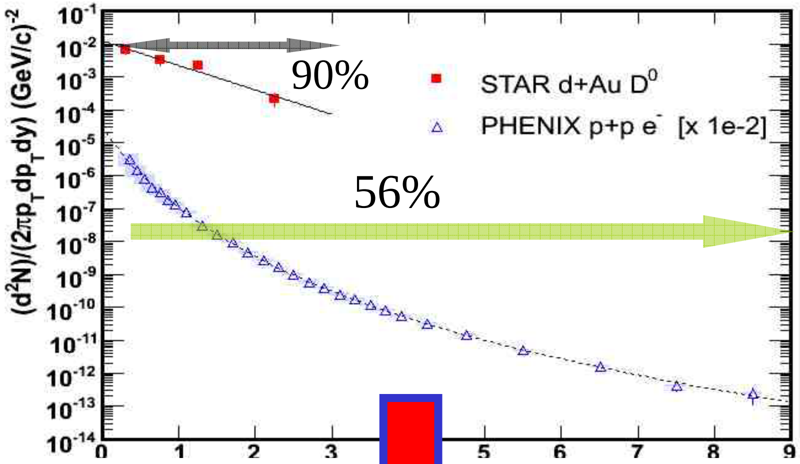
$c \to e^+ + X$
$c \to \mu^+ + X$
$D^0 \to e^+ + X$ (6.87 %)
$D^0 \to \mu^+ + X$

o **muon** from heavy quark semileptonic decay

o **electron** from heavy quark semileptonic decay

- Straightforward using detectors with **e^- PID** (TPC, EMC and TOF)
- Background is difficult to assess (photonic)
- Limited to higher **P_T**
- **e^-** does not reflect full **D** kinematics

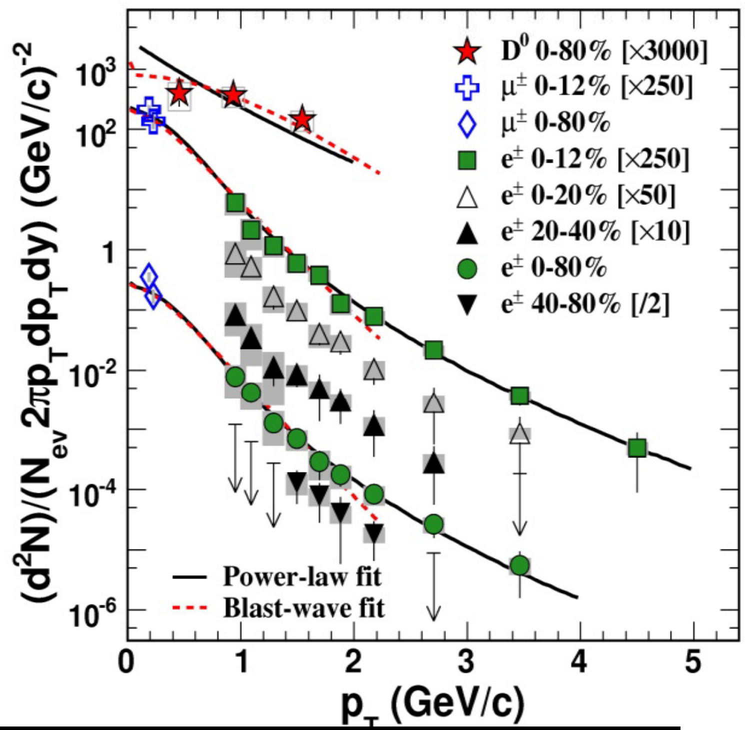
Charm Cross-Section to Date



- **Precise measurements at low P_T** are important
- **e^-** are weakly correlated to heavy quarks (fraction coming from both **D and B**)

→ **Need direct measurements**

Non photonic electrons, Muons and D mesons



Cross-section measurements so far:

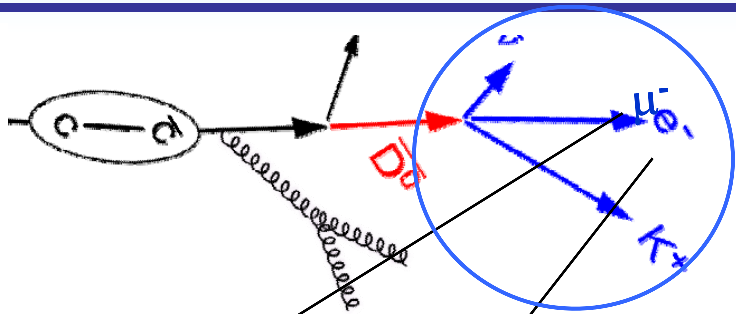
		p+p	Au+Au (MinBias)	d+Au
STAR	**driven by D mesons**		1.26 ± 0.09 ± 0.23	1.4 ± 0.2 ± 0.4
PHENIX	**from electrons**	0.567 ± 0.057 ± 0.224	0.622 ± 0.057 ± 0.160	

What about Cu+Cu?

Open charm measurements

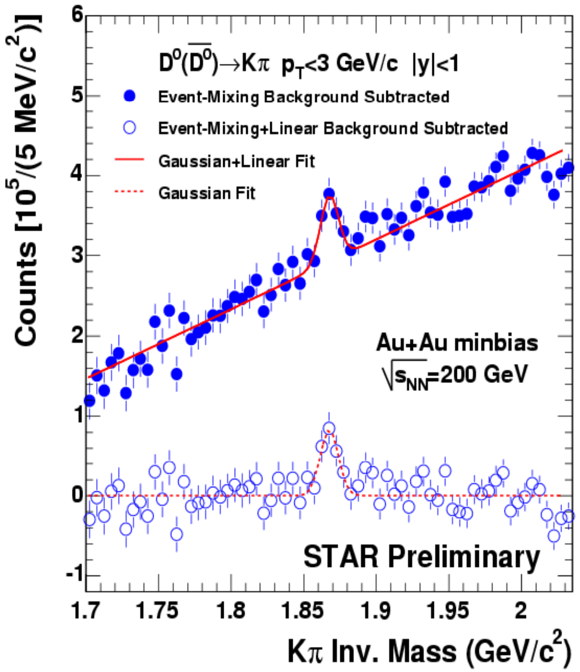
via hadronic decays

Direct reconstruction



semileptonic decay

$c \rightarrow e^+$ + anything
$c \rightarrow \mu^+$ + anything
$D^0 \rightarrow e^+$ + anything
$D^0 \rightarrow \mu^+$ + anything



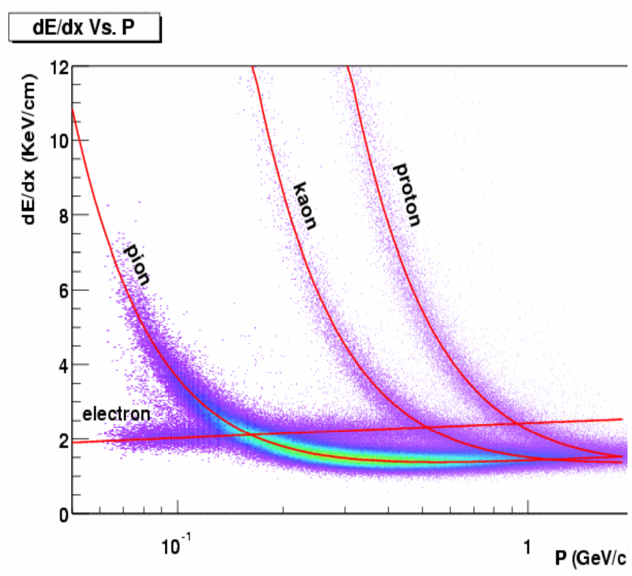
- o **muon** from heavy quark semileptonic decay
- o **electron** from heavy quark semileptonic decay
- o **hadronic** “Direct“ D^0 reconstruction
  (event. Mixing technique)

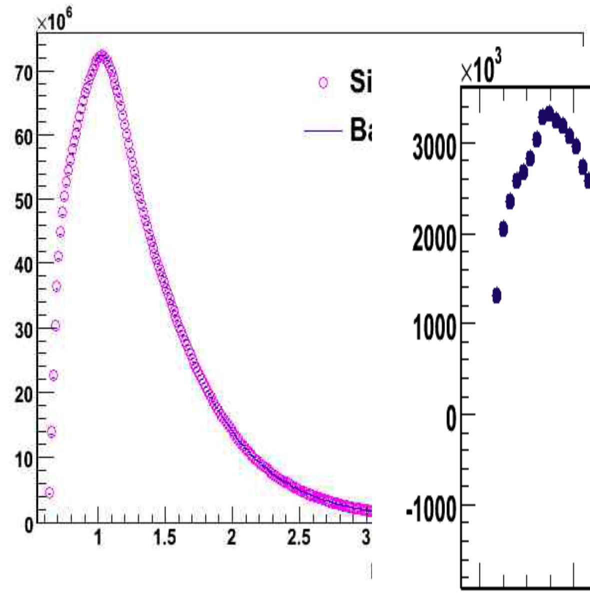
D^0 hadronic decay
reconstructed in minimum bias collision
(unique @ RHIC)

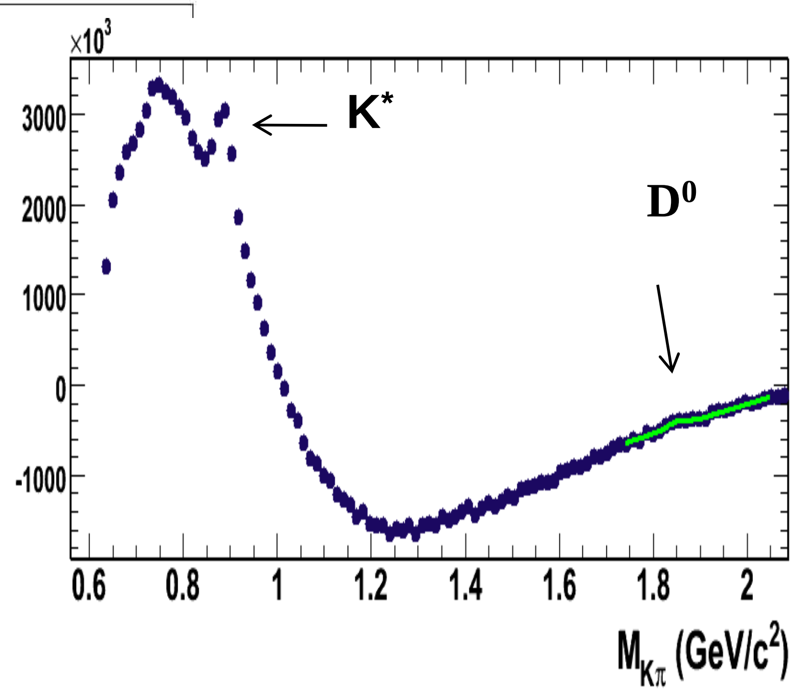
- ⬆ Direct measurement, covers **large fraction** of the **cross-section**
- ⬇ **Large** combinatorial background
- ⬇ High precision **vertexing** is needed

Direct D^0 reconstruction in STAR

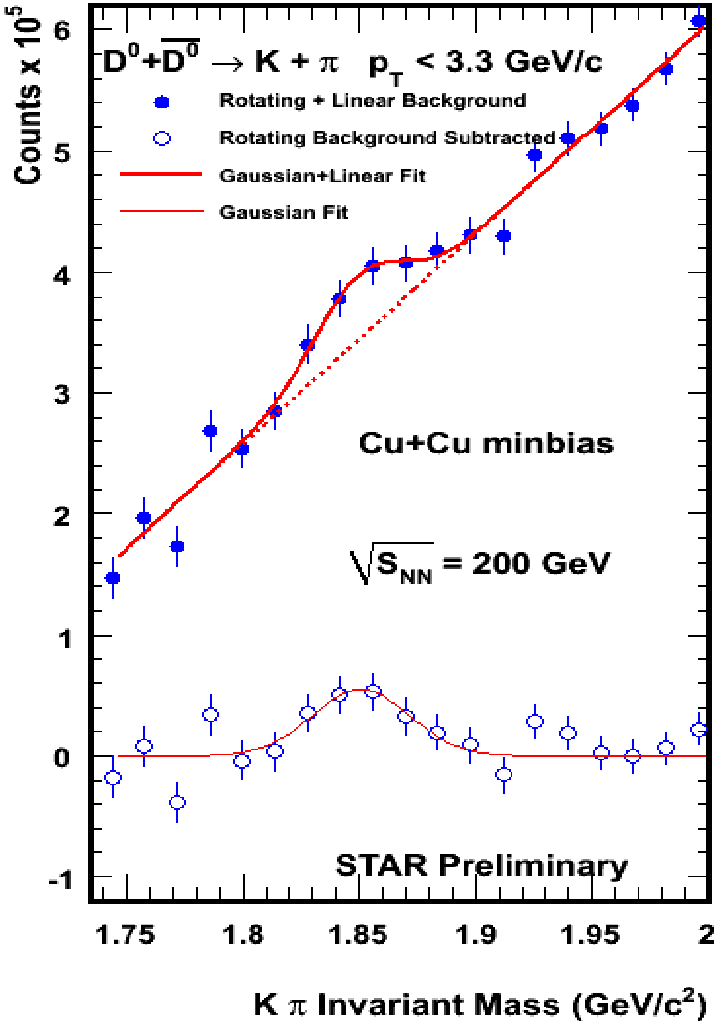
- Pions and Kaons are selected using the TPC
- Combine “same event” pairs $\Rightarrow$ signal+background
- Combine pairs coming from different events $\Rightarrow$ background
  (“mixed events” or “track rotating ”)
- After subtraction $\Rightarrow$ signal







Cu+Cu collisions @ 200 GeV



~ 28 Million events used

All the statistics available

Cu+Cu « minimum bias » (RHIC run V)

❖ After track rotating or mixed event subtraction: residual background

❖ Low S/B ratio:

$$\frac{S}{B} \approx \frac{1}{600}$$

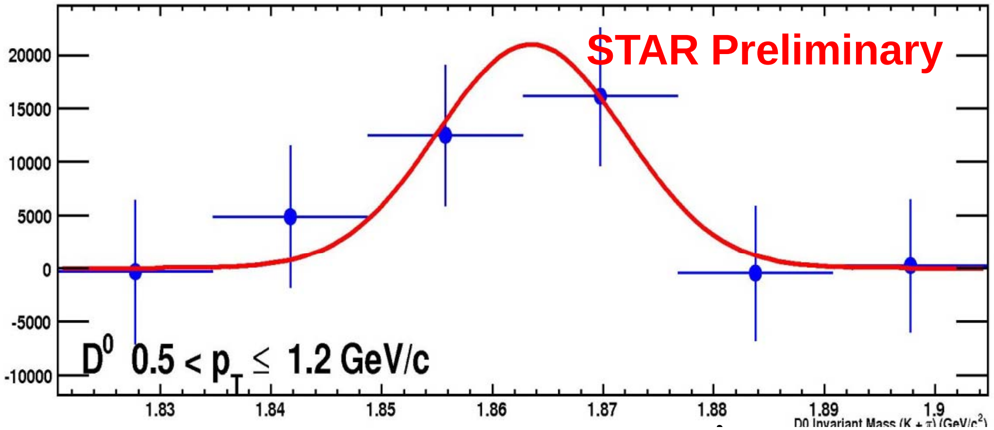
$$\frac{S}{\sqrt{S+B}} \approx 4$$

❖ Measurement only possible because of large S (~ 150 000)

❖ Large STAR acceptance !

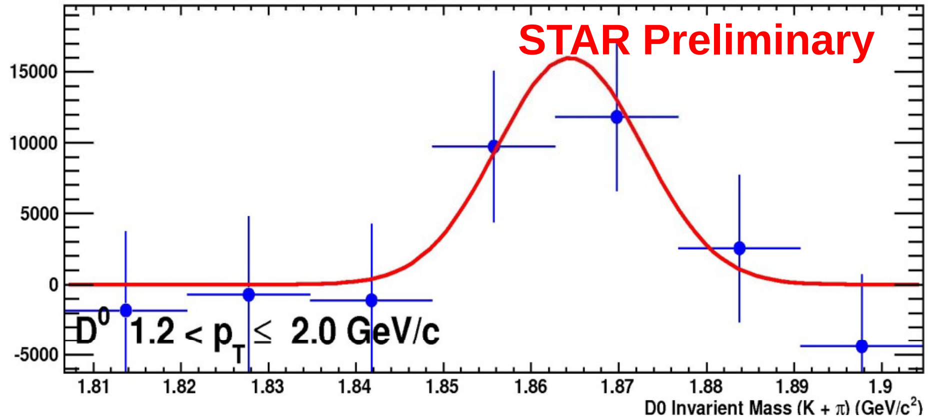
→ Challenging measurement

p_T bins

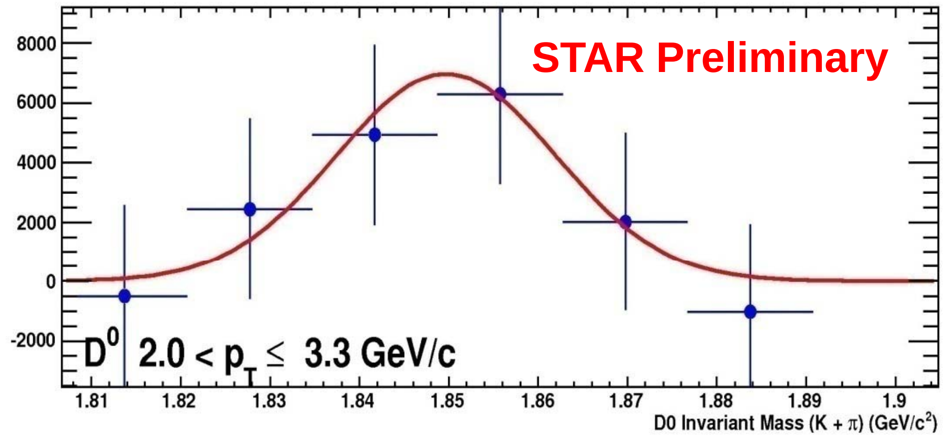


D^0 Mass in **agreement with the PDG**

(M_{D^0} =1864.84 ± 0.17 MeV/c^2)

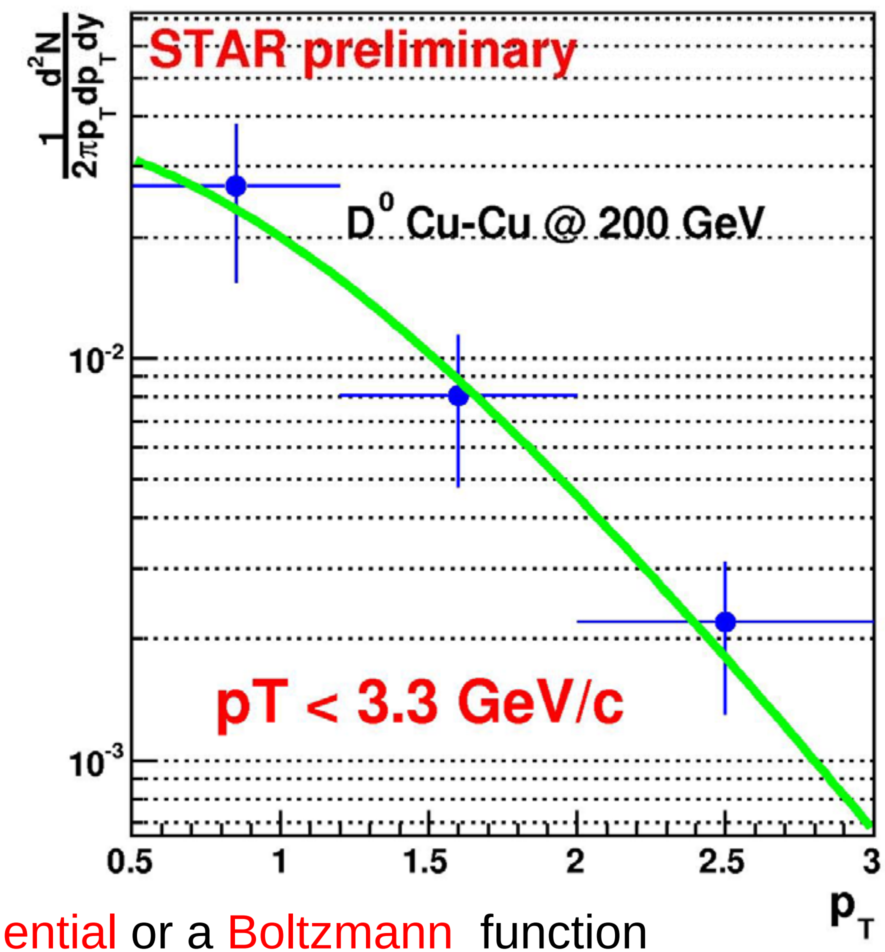


P_T (GeV/c)	**Mass** (GeV/c^2)	**Width** (MeV)
0.5-1.2	1.864 ± 0.005	8.4 ± 8.7
1.2-2.0	1.864 ± 0.005	8.3 ± 13
2.0-3.3	1.850 ± 0.015	12 ± 18



Spectra

After corrections:



$\frac{D^0 + \overline{D^0}}{2}$ Preliminary

dN/dy = 0.18 ± 0.035

Fit using an Exponential or a Boltzmann function

→ **same results** (within stat. errors).

Extraction of the cross-section

$$\sigma_{c\bar{c}}^{NN} = \frac{dN_{D^0}^{Cu+Cu}}{dy} \times \frac{\sigma_{inel}^{pp}}{N_{bin}^{Cu+Cu}} \times \frac{f}{R}$$

$$dN_{D^0}/dy = 0.18 +/- 0.035\ \text{(stat.)}$$

Number of binary collisions (Glauber)

$$N_{binary}^{Cu+Cu} = 51.5 + 1.0 - 2.9$$

Inelastic cross-section in p+p (UA5)

$$\sigma_{inel}^{pp} = 41.8 +/- 0.6\ \text{mb}$$

Conversion to full rapidity (Pythia)

$$f = 4.7 \pm 0.7$$

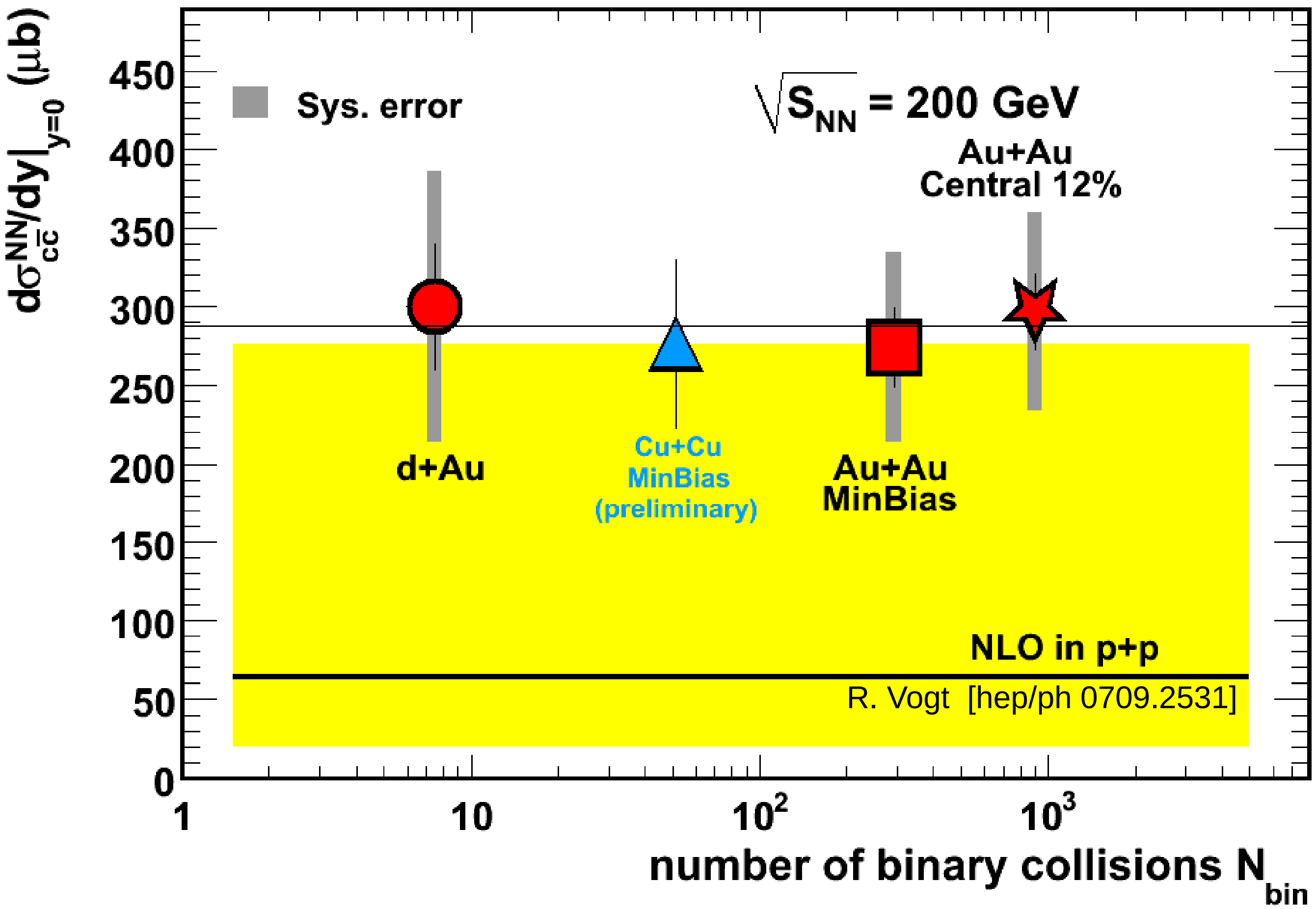
Ratio obtained from e^+e^- collisions

$$R = N_{D^0} / N_{c\bar{c}} = 0.54 \pm 0.05$$

STAR Preliminary:

$$\Rightarrow \sigma_{c\bar{c}}^{NN} = 1.30 \pm 0.25\ (stat.)\ mb$$

d σ/dy in STAR…



- Accurate background subtraction is crucial
- Systematic study is ongoing

Scaling with the number of binary collisions from d+Au to Au+Au **confirmed in Cu+Cu.**

Summary

Today:

- The charm cross-section was measured in Cu+Cu @ 200 GeV ; $\sigma_{c\bar{c}}^{NN} = 1.30 \pm 0.25\, mb$
- A direct measurement in Cu-Cu is **consistent with a scaling of the cross-section with N_{bin} (at low pT)**.
- Theory: **large uncertainty in pQCD calculations** and **data points are needed.**

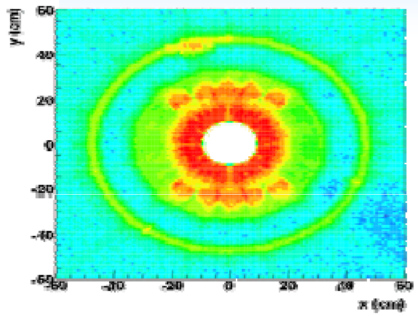
In the Future:

- STAR **low material runs**
- use of **SSD/SVT** and eventually the **HFT** upgrade (2010-2012)

will allow:

  - **precise measurements** of the charm cross-section
  - direct **topological** measurements of charm and of its **anisotropy parameter V_2,** R_{AA}, R_{CP}
  - isolation of the **bottom contributions**

Outlook



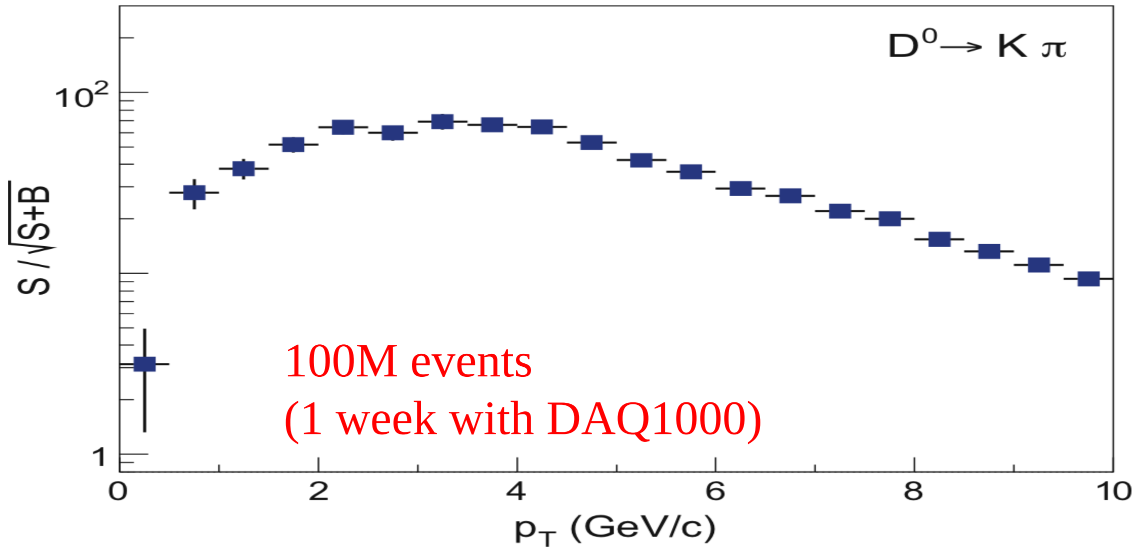
❖ Low material run (without the SVT/SSD)
→ low radiation length in run VIII
→ reduce the photonic background

❖ Reconstructing the secondary vertex with SVT/SSD in Au+Au (run VII)

❖ « Upgrade » for RHIC2

and especially

The future STAR ***Heavy Flavor Tracker***



→ Direct and topological measurements of charm and precise V_2

See the HFT poster
by Jan Kapitan
(for the STAR HFT collaboration)

Backup

The charm cross-section

$$\sigma_Q(S,m^2)=\sum_{i,j}\int dx_1 dx_2\, \hat{\sigma}_{ij}(x_1x_2S,m^2;\alpha_s(\mu_R^2),\mu_R^2,\mu_F^2)\,F_{i/A}(x_1,\mu_F)\,F_{i/B}(x_2,\mu_F)+O\left(\frac{\Lambda}{m}\right)^p$$

Hard scattering | Parton Distribution Functions **(PDF)** | Corrections

Calculation:

NLO QCD + resummations | minimal & properly extracted NP fragm. | **Simulation (MC) of decay**

$$pp \xrightarrow{pQCD} Q \xrightarrow{NP\,fragm.} H_Q \xrightarrow{decay} e$$

For predicting total cross sections one can stop here

NLO: 301^{+1000}_{-210} μb

R. Vogt hep/ph 0709.2531

FONLL: $256^{+400}_{-146}\,\mu b$

M. Cacciari *et al.*, *PRL 95 (2005) 122001*

Experiment :

pQCD + PDF **Fragmentation Functions**

$$\frac{d\sigma_H}{dp_T}=\frac{d\sigma_Q}{dp_T}\otimes D^{np}$$

Measured (differential) cross section

NLO (+NLL) calculation

non-perturbative fragmentation (usually extracted from e+e- data)

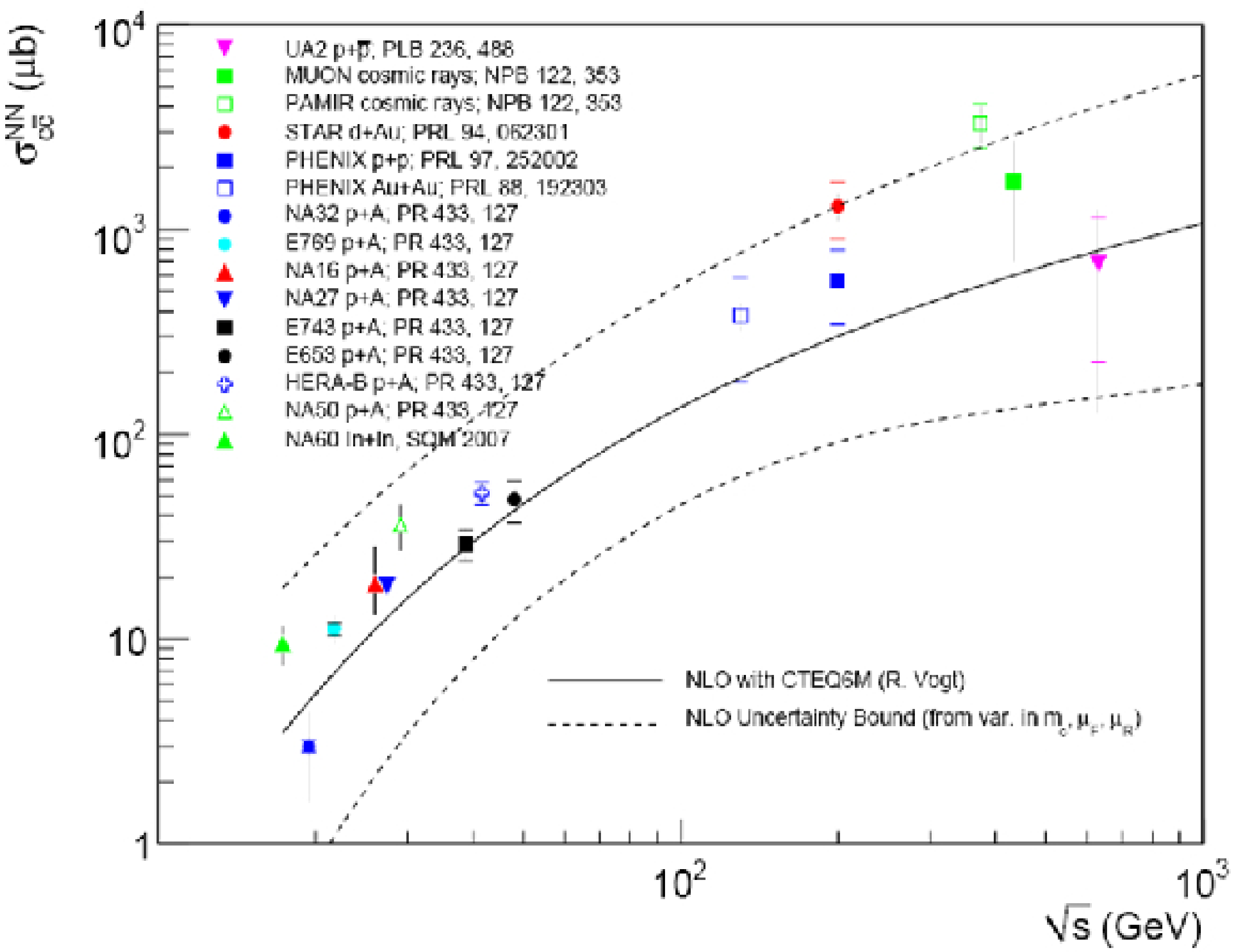
Cross-section – How well is the calculation constrained?

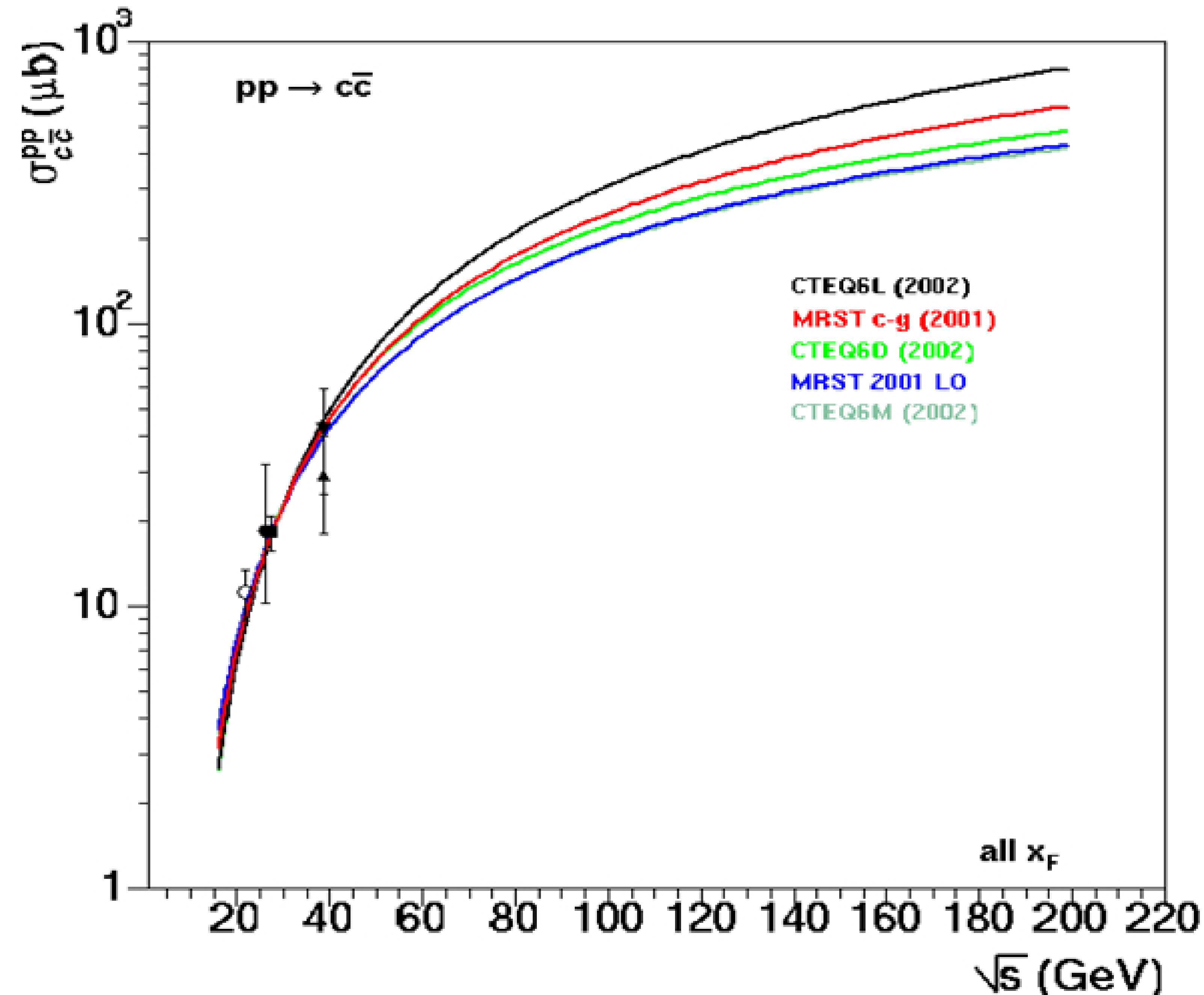
- Energy
- Charm quark mass (m_c)
- Scales
  - -m_R : fragmentation scale
  - -m_F : factorization scale
  - -a_s : strong coupling
- PDF used
- Fragmentation Functions (FF) non perturbative inserted in a perturbative calculation

Example:

FONLL:		$\mu_F = \mu_R = \mu = \sqrt{p_T^2 + m_c^2}, m_c = 1.2GeV/c^2$
PYTHIA:	CTEQ5M1, MSEL=1	
NLO:	MRST	$\mu = 2m_c, m_c = 1.2GeV/c^2$

H. Wöhri and C. Lourenço Jphys G Nucl Part Phys 30 (2004)315

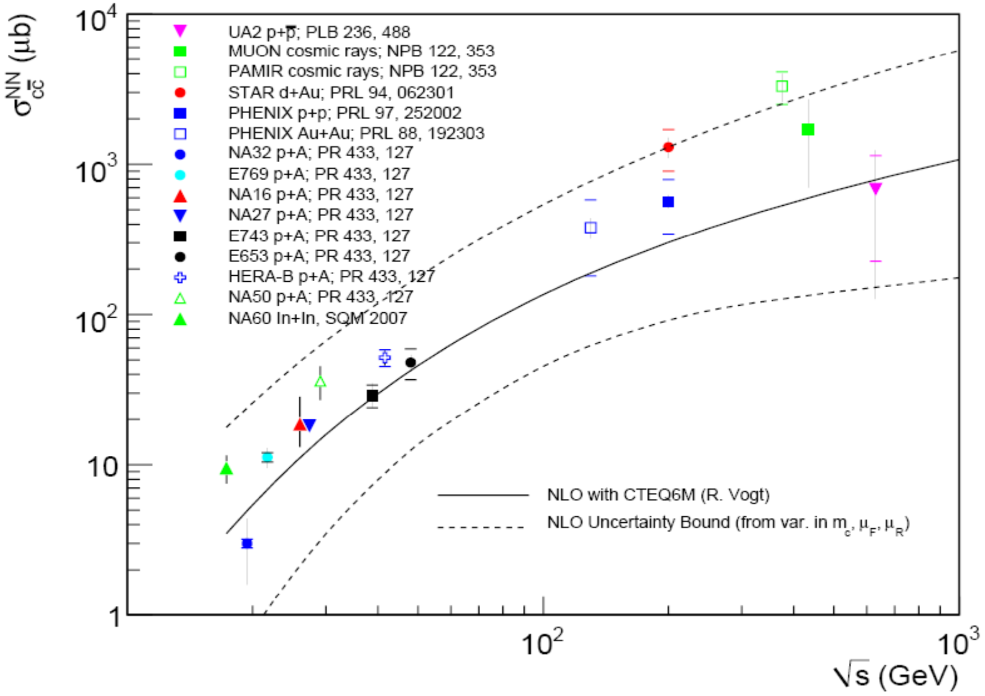




How to compare measurements to calculations ?

Using QCD (and pQCD) :
- Heavy flavor cross-section can be correctly predicted
- Differential cross-section (as function of momentum, rapidity or energy…), requires « **adding a <u>minimal</u>, <u>self-consistent and universal</u> set of non perturbative input parameters »**

Matteo Cacciari
ISMD 2007



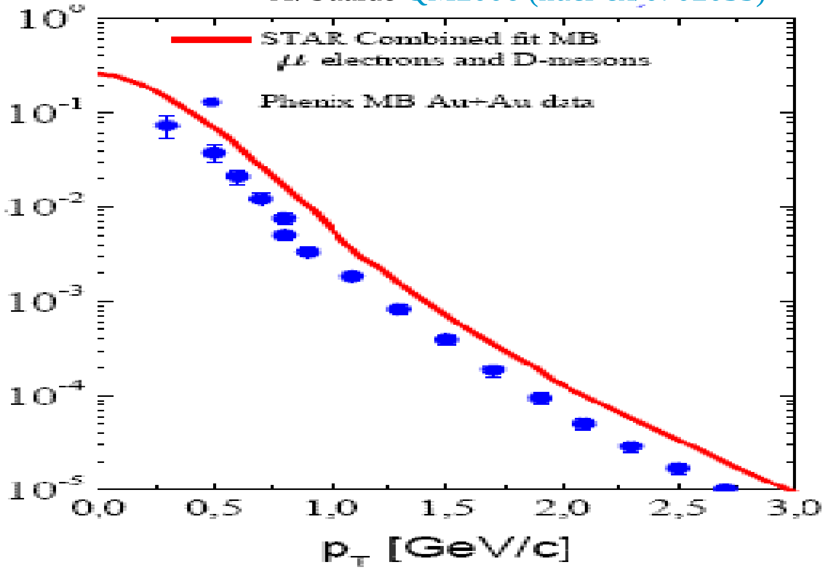
To make an accurate comparison, one should:
- Use **dedicated theoretical tools** (FONLL and now NNLO)
- Use **adequate parameters** (mass, renormalization and factorization scales, coupling), Partons Distribution Functions (PDF) and Fragmentation Functions (FF).
- **<u>Minimize extrapolations and deconvolutions</u>** <u>between measurements and theory</u>

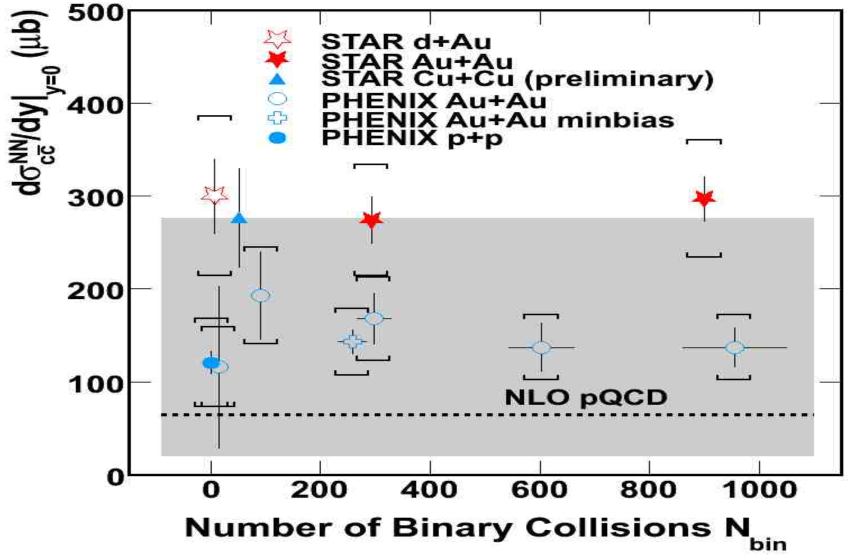
→ **If and only if** all those conditions are satisfied, **a good agreement between measurements and calculations can be reached**

→In real life, the error band is large and data points are needed...

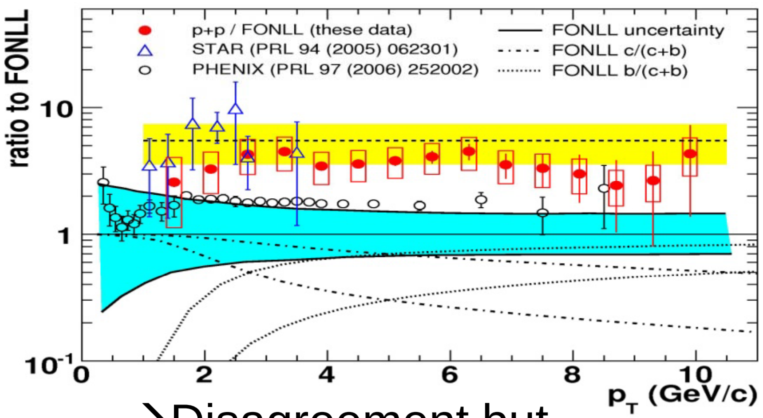
PHENIX vs. STAR

A. Suaide QM2006 (nucl-ex/0702035)





STAR PRL 98 (2007) 192301

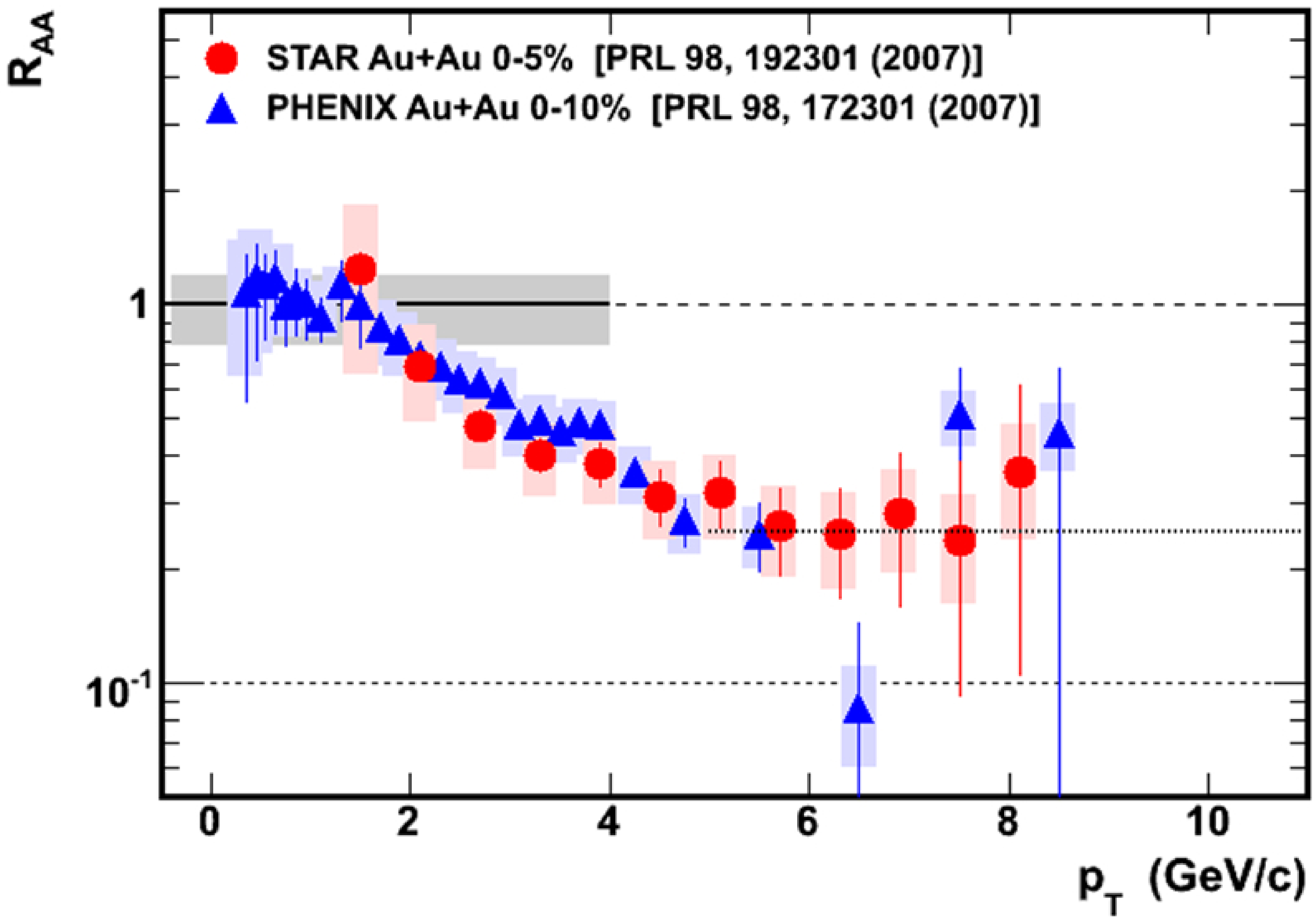


- Spectra shapes are the same.
STAR and PHENIX are seeing the same scaling with Nbin.

-The value of the cross-section is not the same (factor 2 to 3)
- STAR and PHENIX are both above FONLL predictions…

→Disagreement but let's look at the R_{AA} …

R_{AA}: (e^-) from d+Au to Au+Au central



Dead cone effect not observed …
(non photonic e^-)

R_{AA} in agreement between STAR and PHENIX
→Is there a normalization issue?