Hydrogen-like Atoms
from Ultrarelativistic Nuclear Collisions

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H-like Atoms

- Coulomb bound-sates: hadron π, K, p nucleus captured a lepton e, μ

- πμ observed in K_L decays at BNL 1976 and Fermilab 1982

M. Schwartz et al. PRL37(1976)249

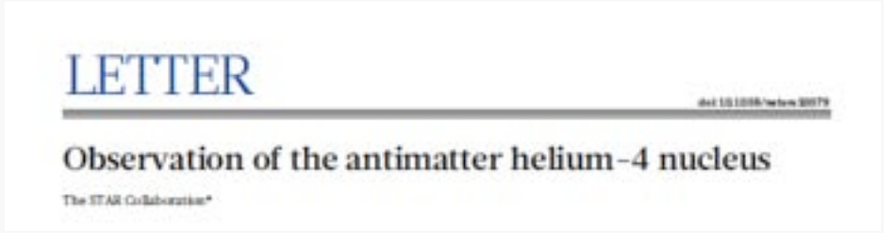
S.H. Aronson et al. PRL 48(1982)1078

- pμ used as precision tool for fundamental physics: proton size 2010

Pohl et al. Nature 466 (8 July 2010) 09250

H-like Atoms in HIC

Discovering Exotics: Antimatter Muonic Hydrogen ?!



LETTER

Observation of the antimatter helium-4 nucleus

The STAR Collaboration*

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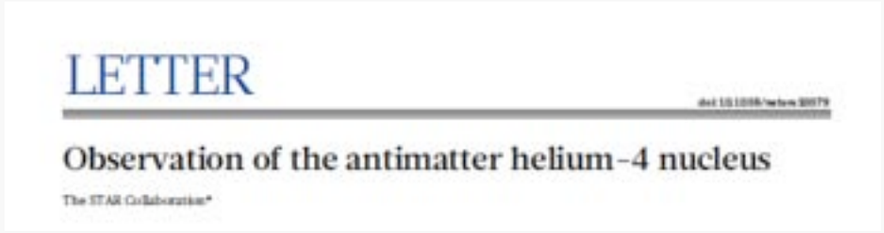
H-like Atoms in HIC

Discovering Exotics: Antimatter Muonic Hydrogen ?!



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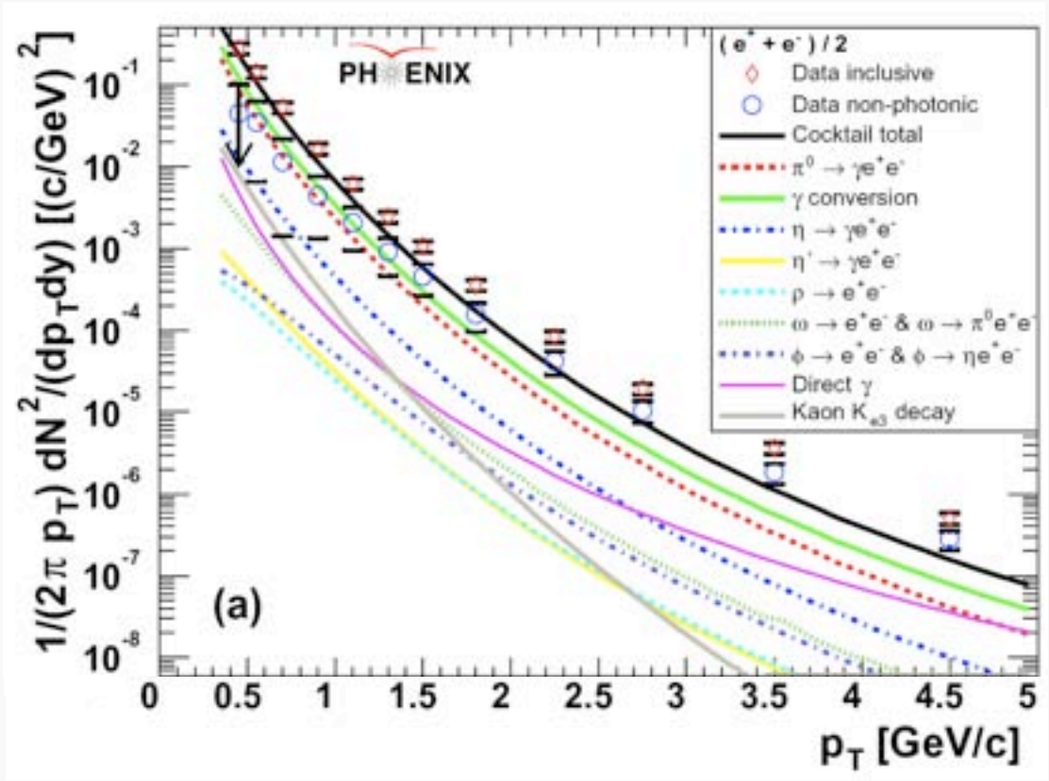
Direct Measurement of Single Lepton Spectrum



The shine of the QGP is buried in the background

Measure the distribution of atoms formed by the binding of directly produced leptons to charged hadrons emerging from the final state of a nuclear collision

PHENIX.Phys. Rev. Lett. 96, 032301 (2006)

M. Schwartz (early 1990's, unpublished)

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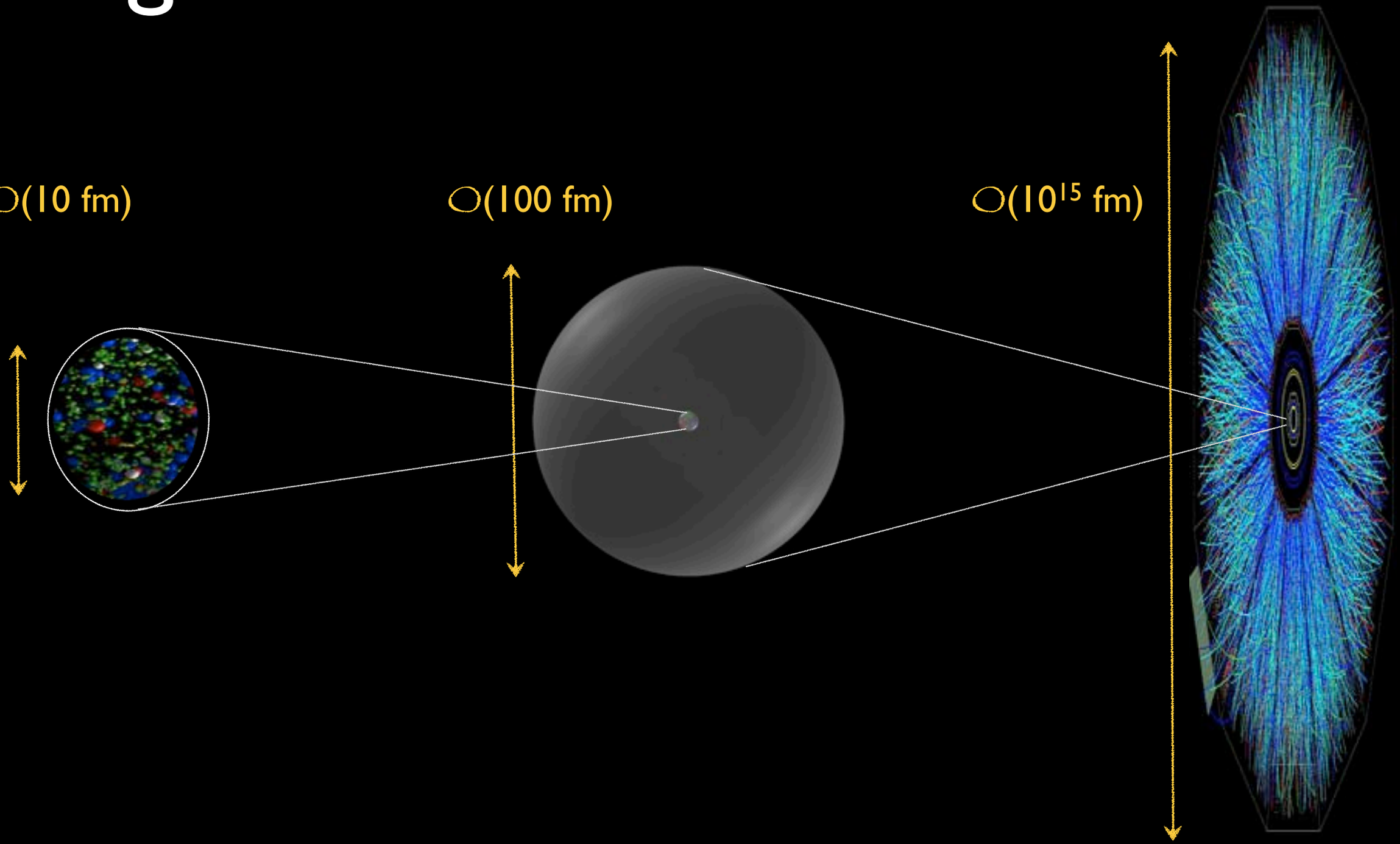
Ångstrom-Scale Muon Detectors

$\mathcal{O}(10\ \text{fm})$

$\mathcal{O}(100\ \text{fm})$

$\mathcal{O}(10^{15}\ \text{fm})$



Atoms form after freeze-out

Background produced
far from collision zone

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Production Rate

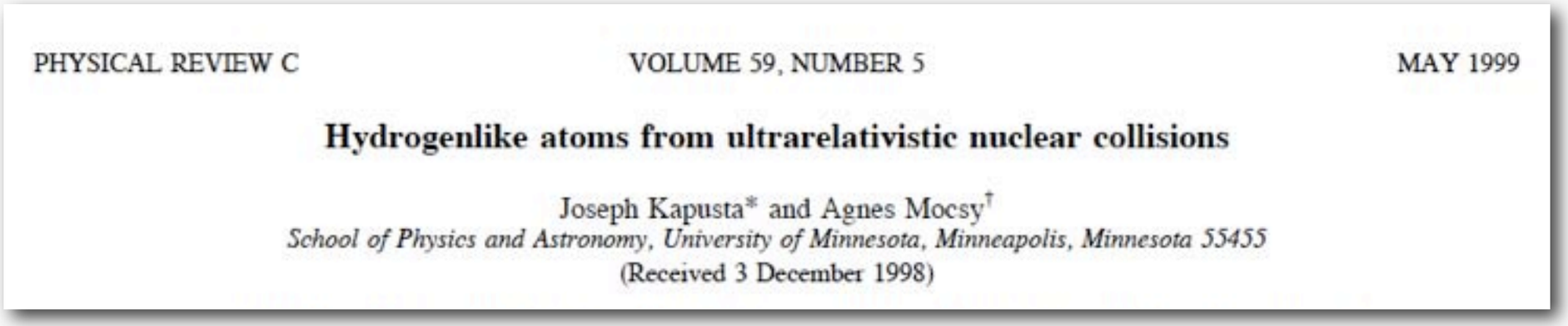
$$\frac{dN_{\rm atom}}{dyd^2p_{\perp,{\rm atom}}} = 8\pi^2\zeta(3)\alpha^3 m_{\rm red}^2 \frac{dN_h}{dyd^2p_{\perp,h}} \frac{dN_l}{dyd^2p_{\perp,l}}$$

G. Baym et al. PRD 48 (1993) R3957

- Atom yield depends strongly on the shape of lepton and hadron spectra
- Atoms form only if lepton and hadron are close in phase-space:

$$\frac{p_t^{atom}}{m_{atom}} = \frac{p_t^{lepton}}{m_{lepton}} = \frac{p_t^{hadron}}{m_{hadron}}$$

- Atom production estimated

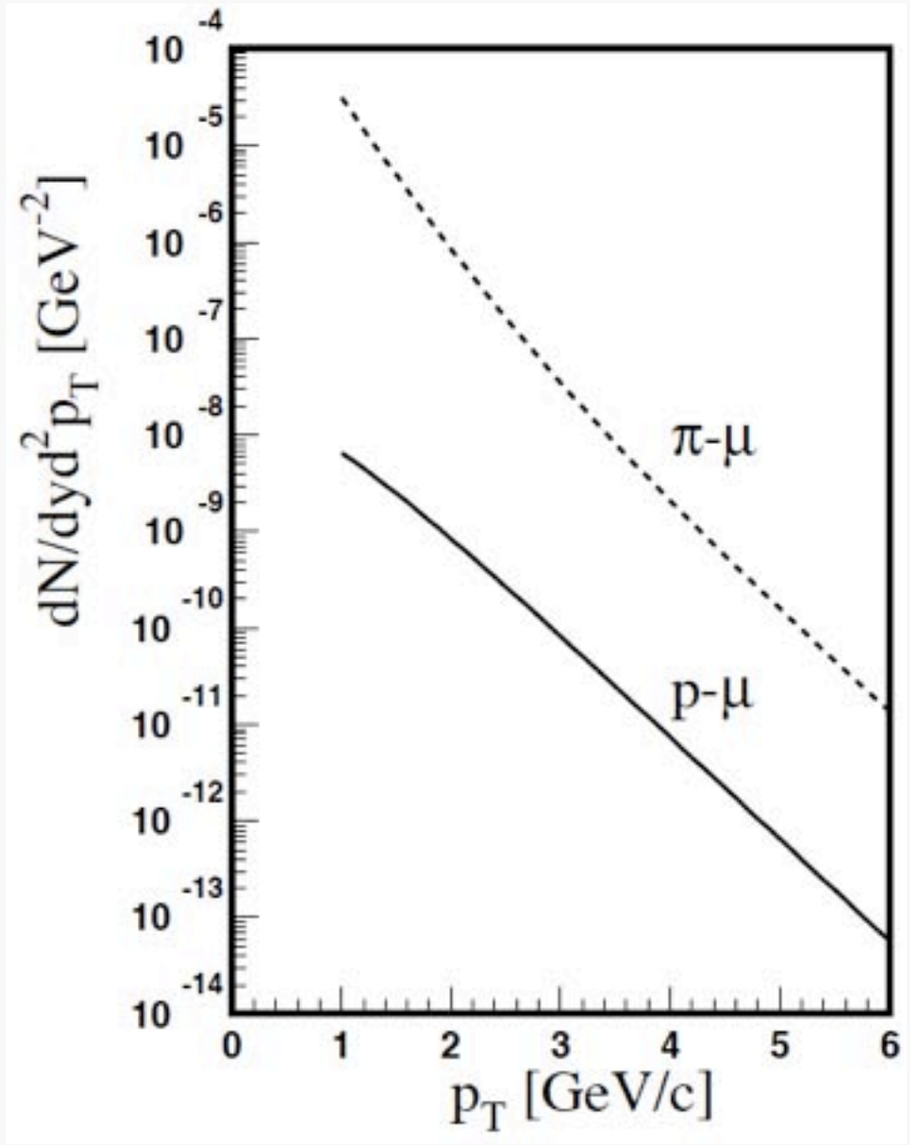


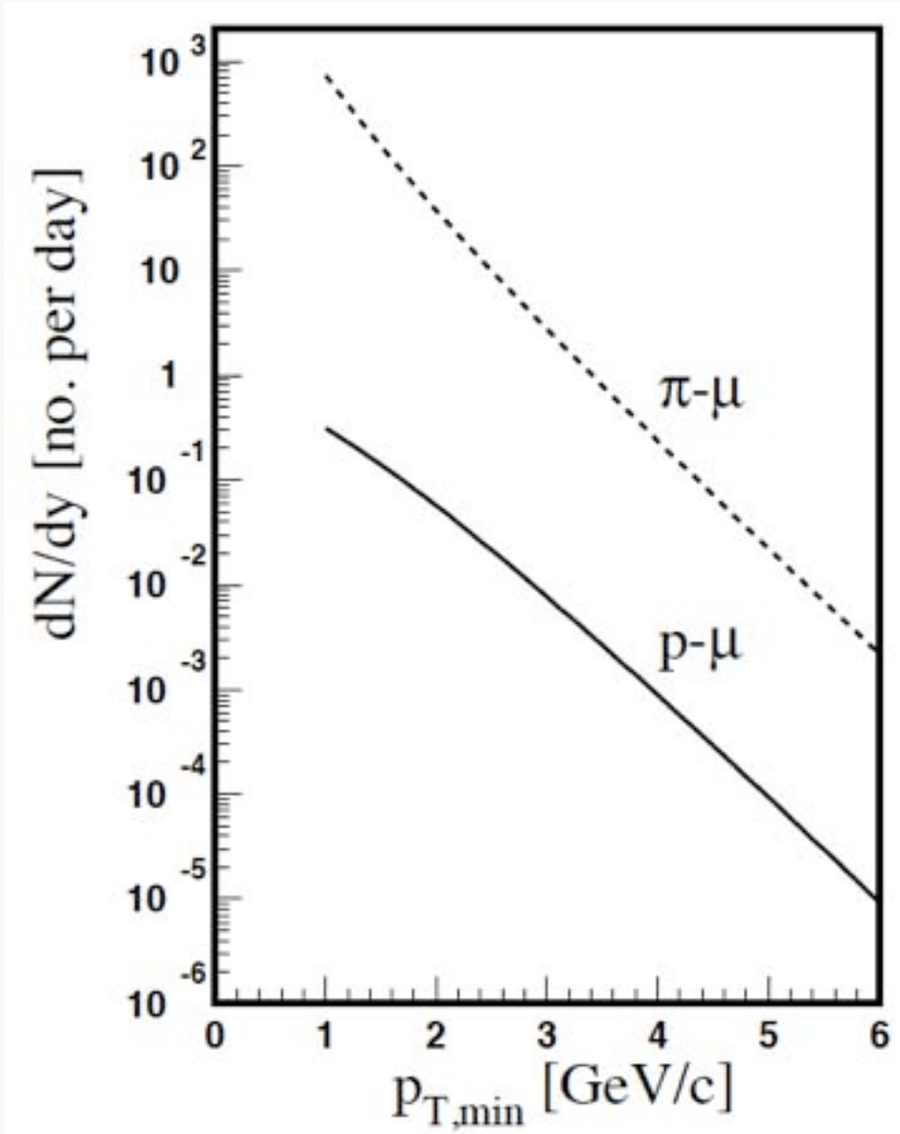
PHYSICAL REVIEW C VOLUME 59, NUMBER 5 MAY 1999

Hydrogenlike atoms from ultrarelativistic nuclear collisions

Joseph Kapusta* and Agnes Mocsy†
School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455
(Received 3 December 1998)

Spectra & Yield estimates from 1998



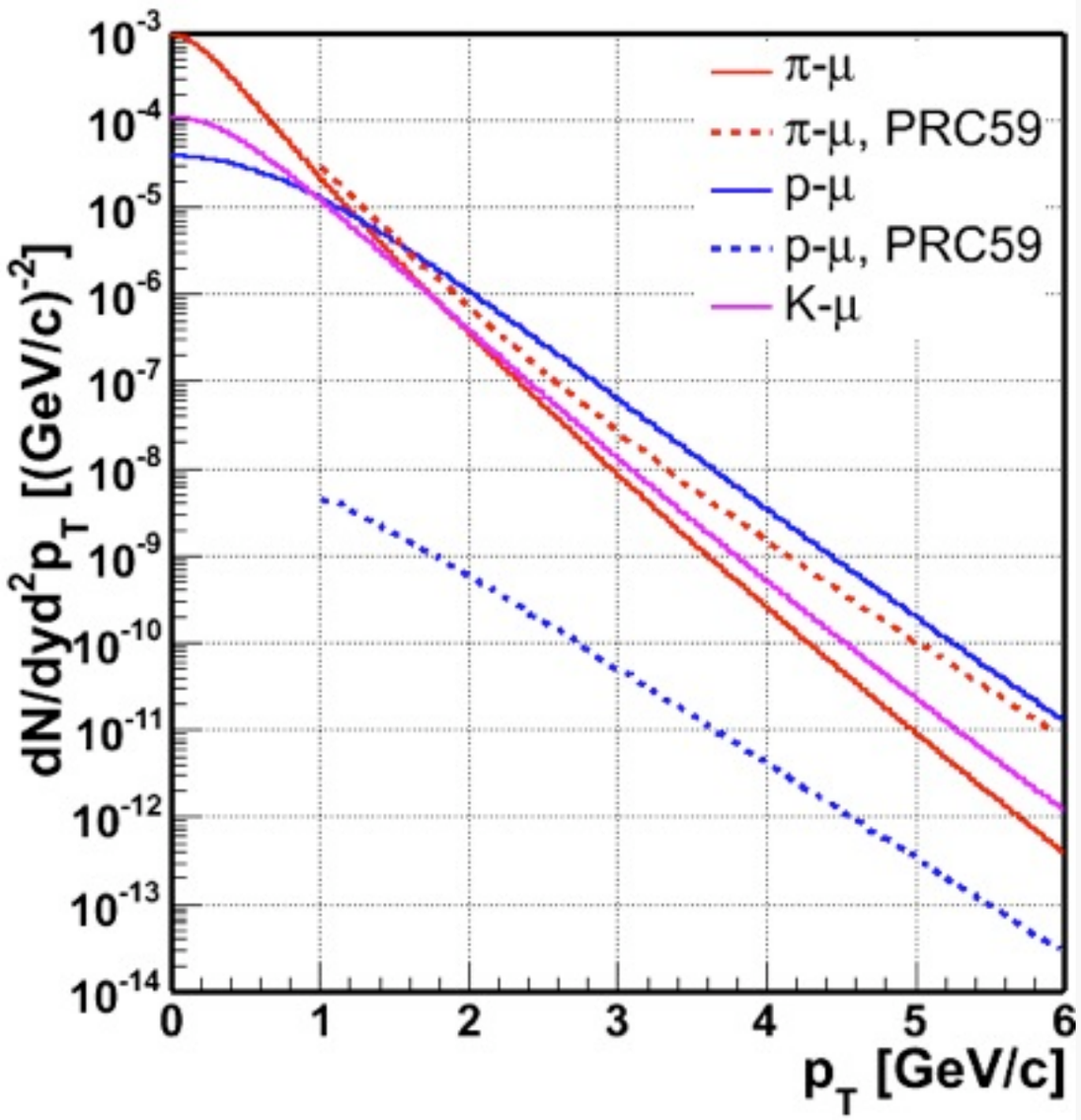


J.Kapusta, A.Mocsy PRC 59 (1998) 2937

Based on estimated luminosity of 2×10^{26} $cm^{-2}s^{-1}$

~ 1000 $\pi\mu$ per unit rapidity per day with $p_T > 1$GeV/c

Updates estimates from 2011



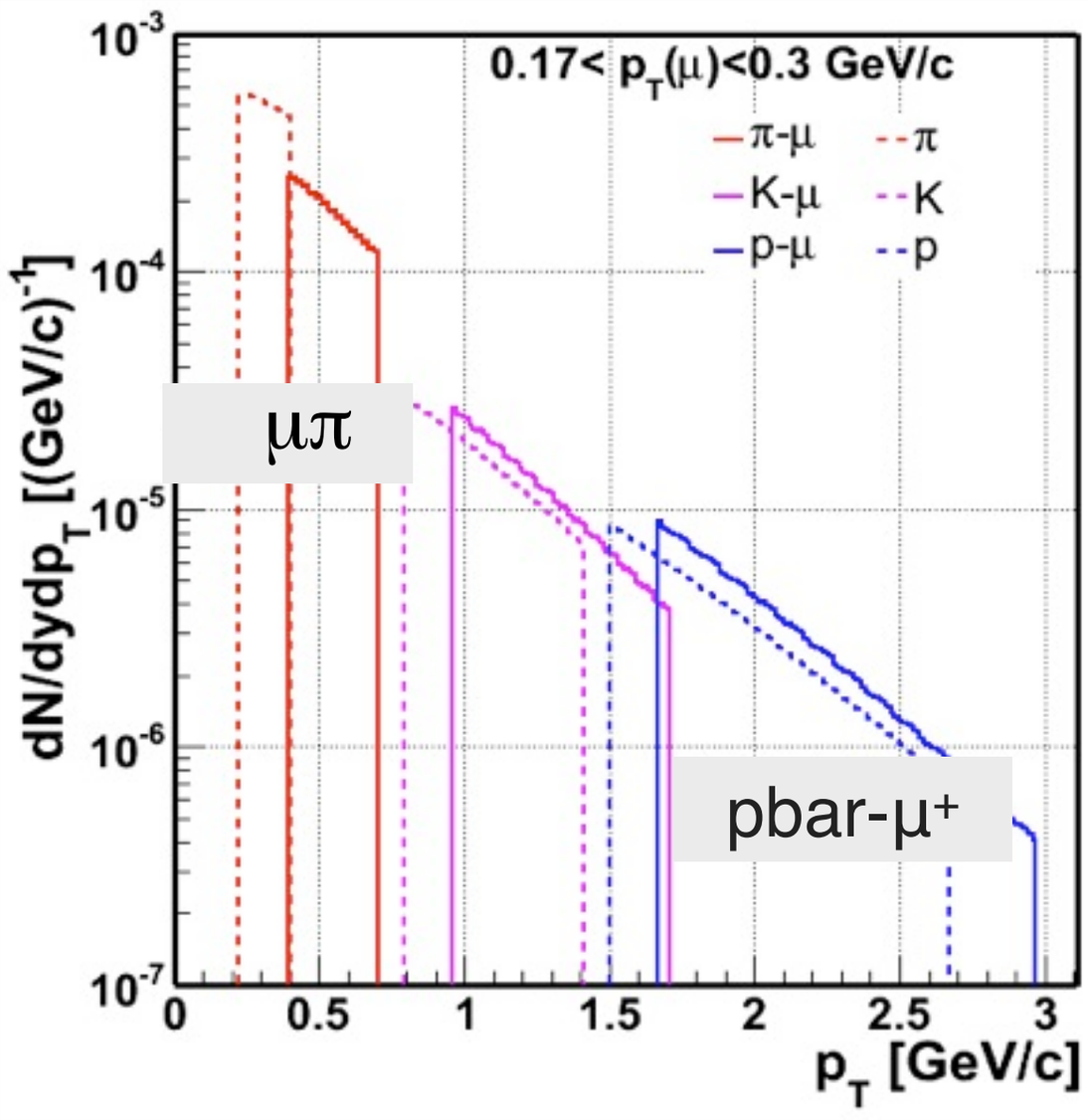
New estimates using
- measured hadron spectra
- μ spectra from π spectra scaled by $(\alpha/\alpha_s)^2$

$\pi\mu$ shows good agreement

Old $p\mu$ estimates are well below the new ones

Zhangbu Xu et al 2011

Feasibility in STAR



Muons can be identified at low p_T

$$0.17 < p_T < 0.3 \text{ GeV/c}$$

In 500M central events (one run):

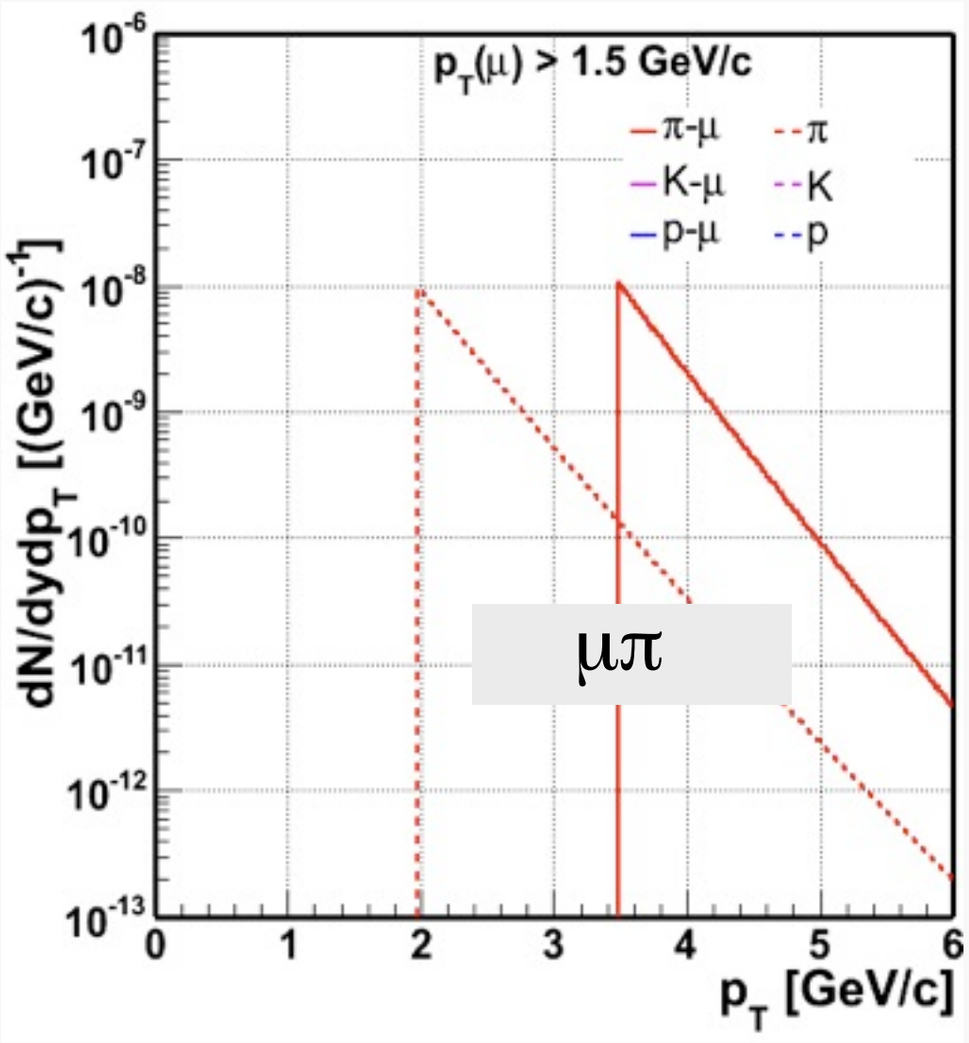
500 never before observed anti-muonic-hydrogen

22k $\pi\mu$ atoms

Zhangbu Xu et al 2011

$$\mathbf{p}_{\perp,\text{atom}}/m_{\text{atom}} = \mathbf{p}_{\perp,h}/m_h = \mathbf{p}_{\perp,l}/m_l$$

Feasibility in STAR



Zhangbu Xu et al 2011

Detector upgrades MTD will be used to trigger on high p_T muons

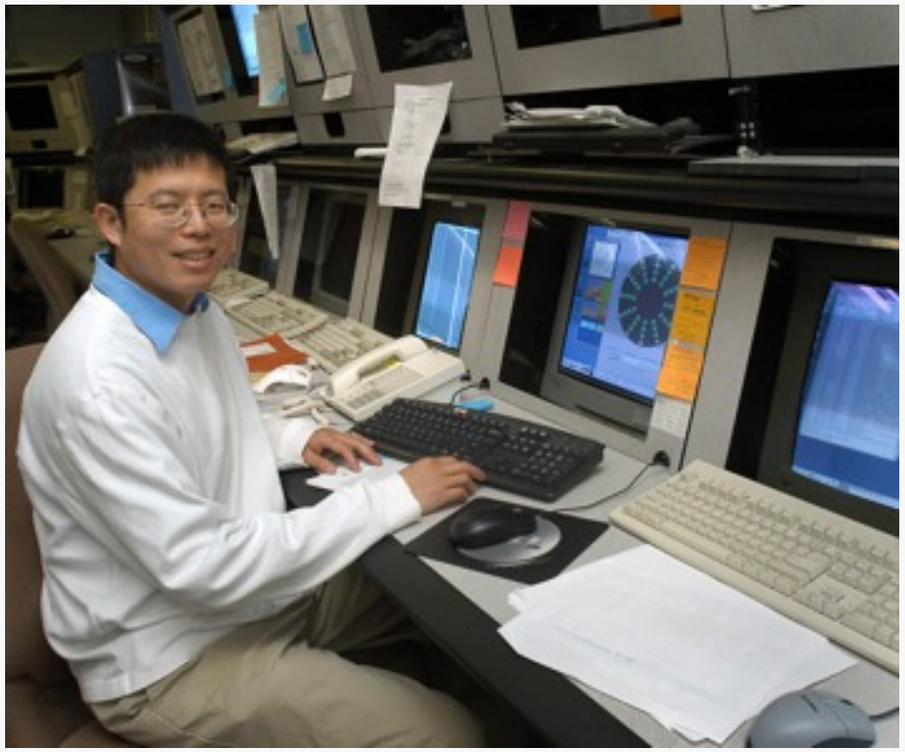
With RHICII Luminosity in a 12 week run:

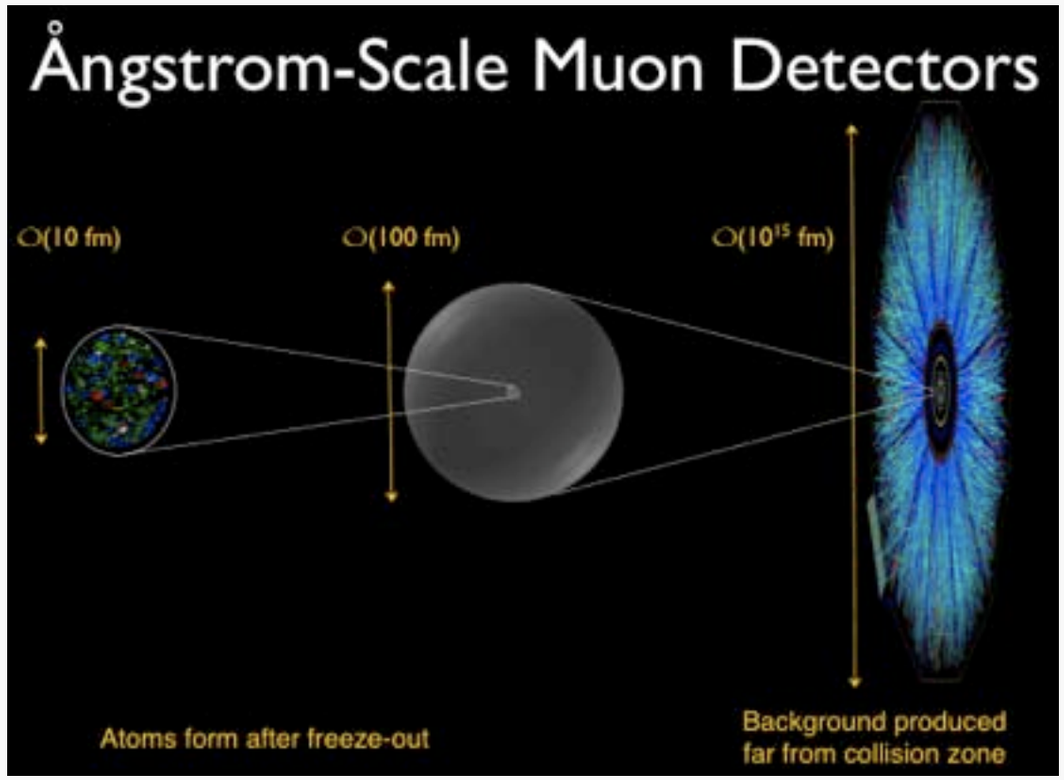
~200 $\pi\mu$ atoms w $p_{T,\mu} > 1.5$ GeV

Rates are accessible!

In conclusion, we have reinvestigated the rates for the production of hydrogenlike atoms at RHIC. The results are quite promising for their experimental detection. It remains to be seen whether an efficient detector can be designed to observe them.

J. Kapusta, A. Mocsy PRC 59 (1998) 2937





- STAR: they can be measured
  - provides information on the direct lepton spectrum
  - possible discovery of new particle: anti-matter muonic hydrogen!
- What about at the LHC?
- Theory revisited in collaboration with Mauricio Martinez & Liliana Apolinario (Santiago de Compostella)

The End

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