Heavy flavour

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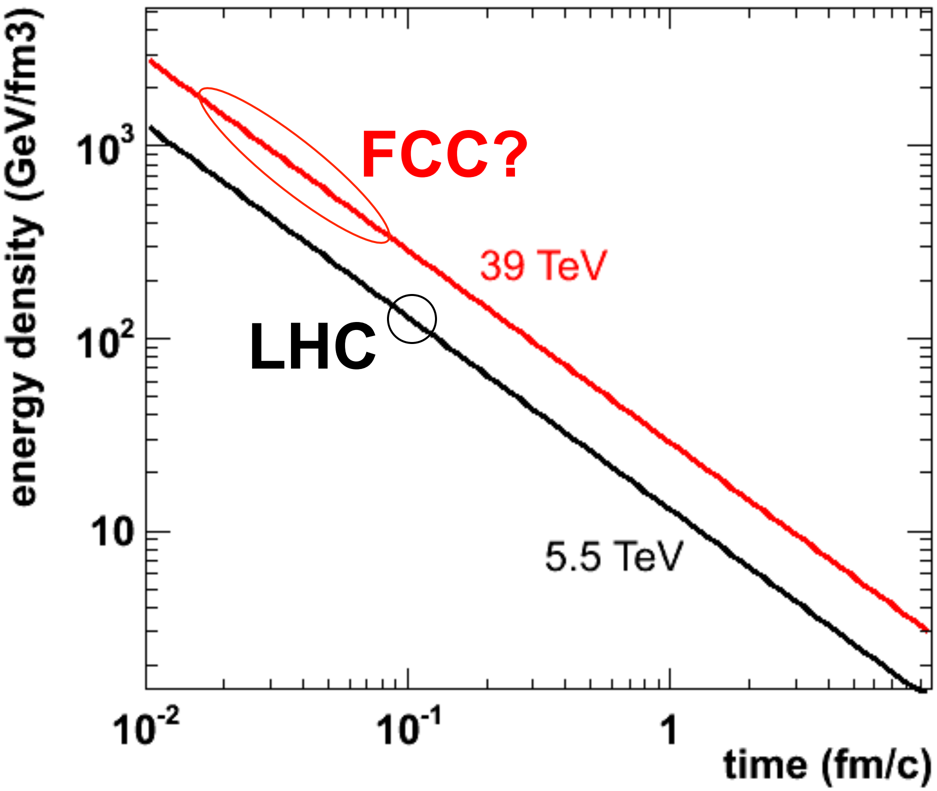
Outline

- Summary of available material
- Proposal for report

QGP studies at the FCC: energy density

- Energy density with Bjorken formula

$$\varepsilon(\tau) = \frac{E}{V(\tau)} = \frac{1}{c\tau\ \pi R_A^2}\frac{dE_T}{d\eta}$$

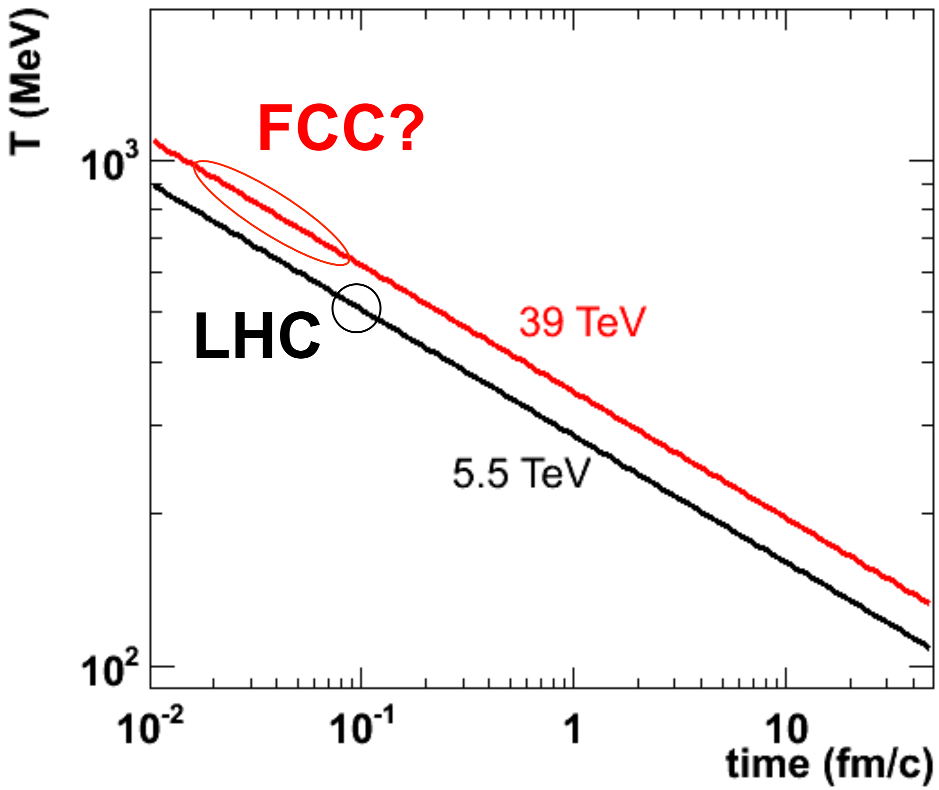


- x2.2 larger for the same time
  - e.g. 35 GeV/fm^3 at 1 fm/c
- Initial time (QGP formation time)?
  - Usually ~0.1 fm/c for LHC
  - Could be smaller at FCC
- Significantly larger initial energy density?

QGP studies at the FCC: temperature

- Temperature from S-B relation

$$T(\tau) = \sqrt[4]{\varepsilon(\tau)\frac{30}{\pi^2 n_{d.o.f.}}}$$

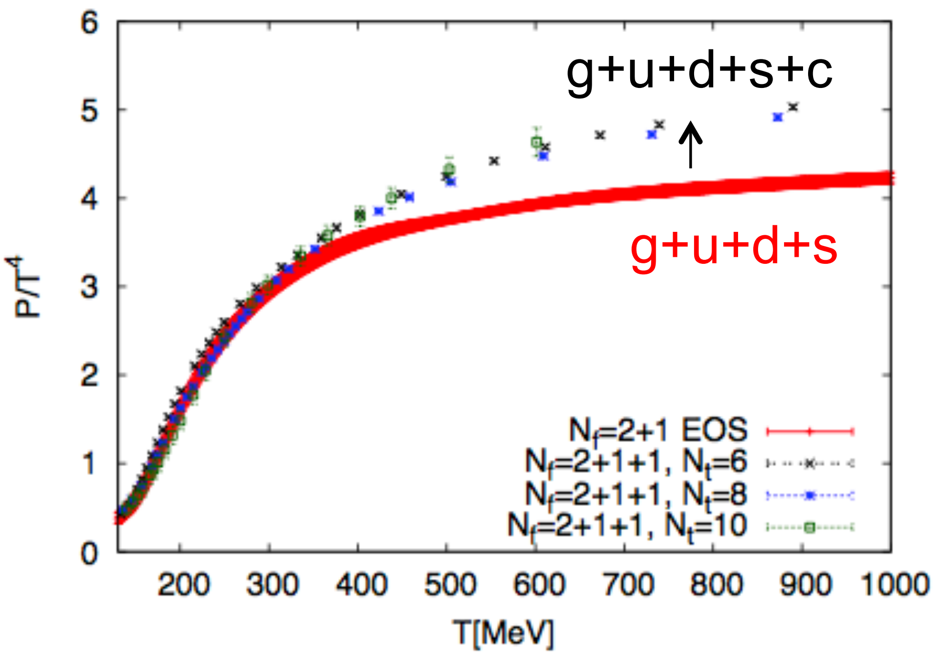


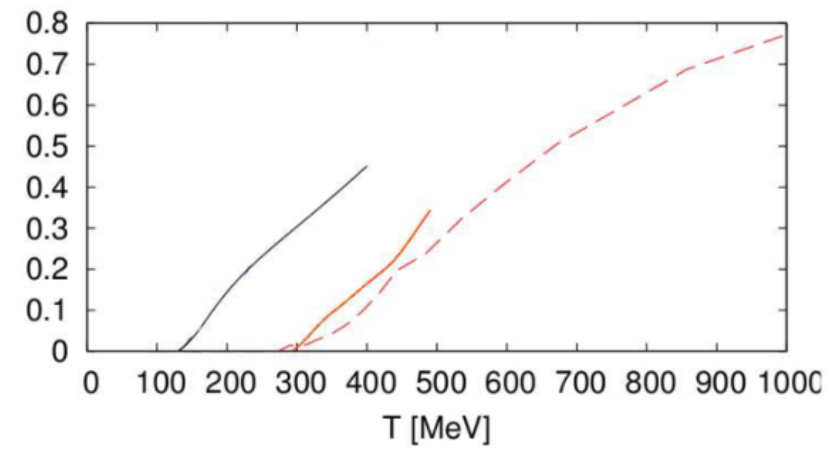
- 20% larger for the same time
  - e.g. 360 MeV at 1 fm/c
- Initial time (QGP formation time)?
  - Usually ~0.1 fm/c for LHC
  - Could be smaller at FCC
- Significantly larger initial temperature? Could reach close to 1 GeV?

Lattice QCD EoS with charm d.o.f.

- The large temperature reached at FCC may induce a difference in the EoS (from 3 to 4 quark flavours)
  - See Borsanyi, Lombardo, Ratti…

$$P/T^4 \sim \varepsilon/T^4 \propto n_{\mathrm{d.o.f}}$$



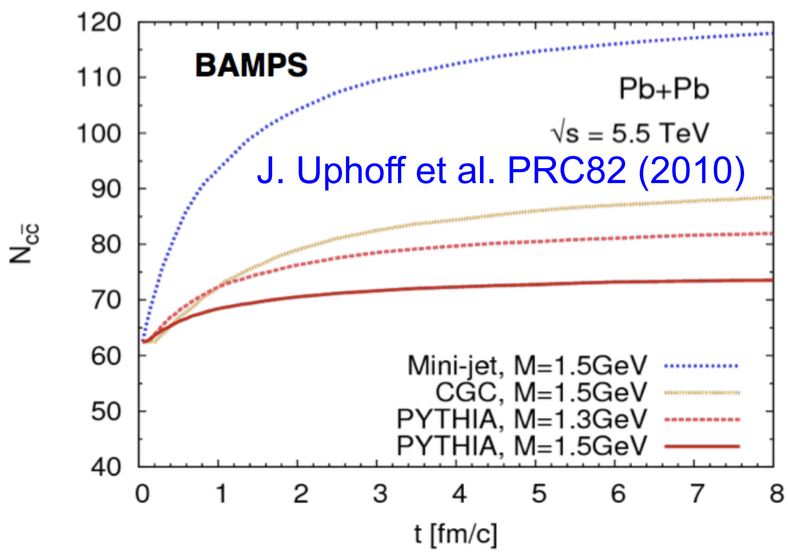


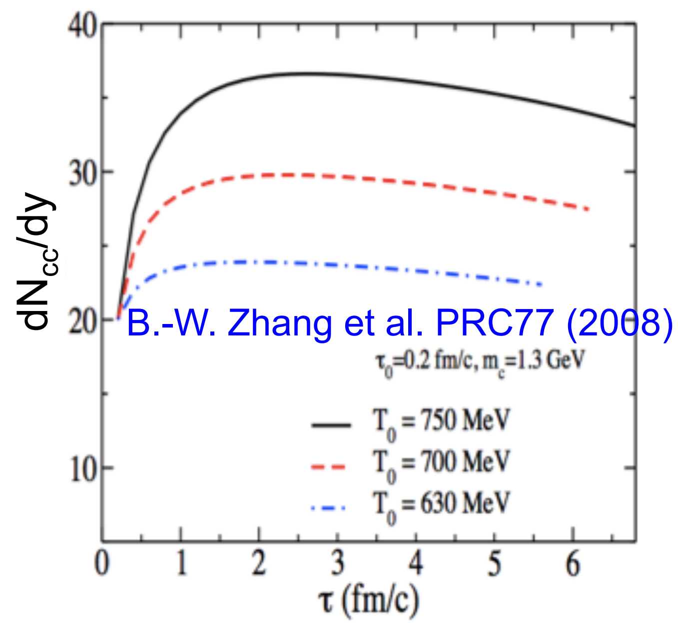
S. Borsanyi *et al*., arXiv:1204.0995

C. Ratti et al., NPA 904–905 (2013) 869c

Secondary/thermal charm? LHC

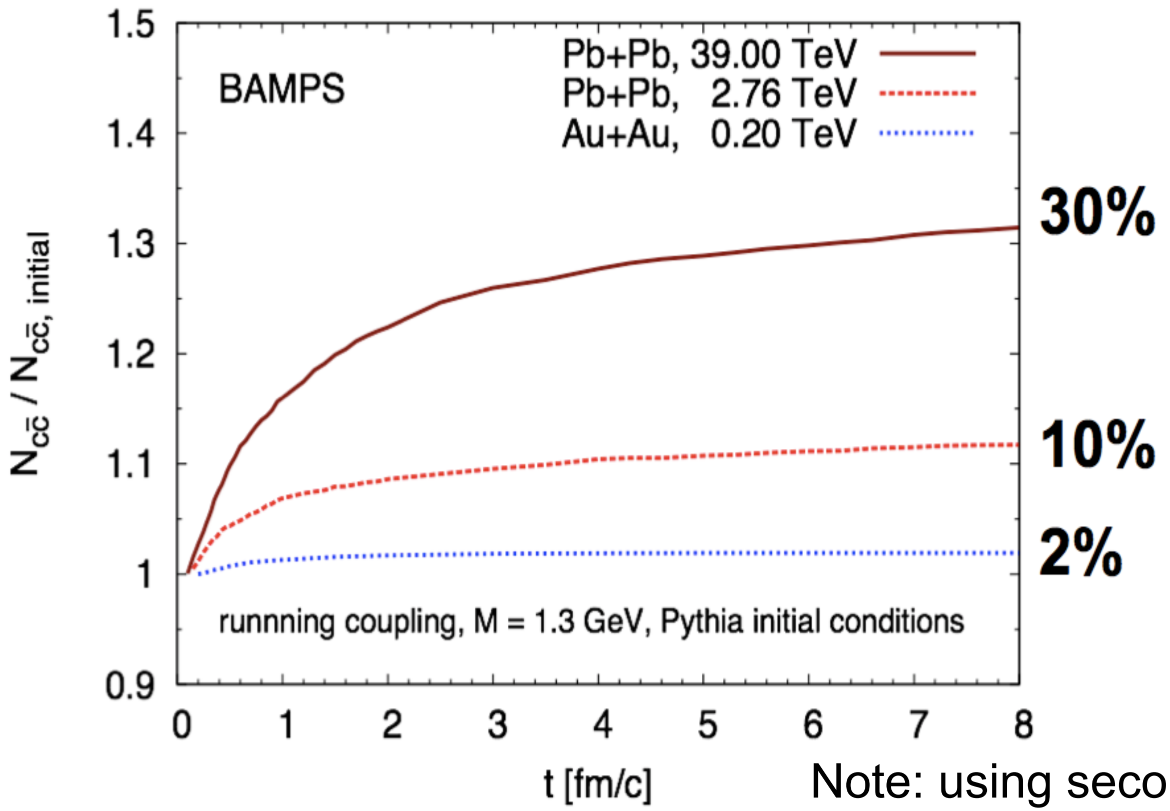
- Expect abundant production of c-cbar pairs in the medium
- Example: two “pre-LHC” calculations for 5.5TeV: + 15-45% wrt hard scattering
  - Strong dependence on initial conditions, initial temperature and formation time, c-quark mass





Secondary/thermal charm? BAMPS

- Calculation for FCC energy provided by J.Uphoff

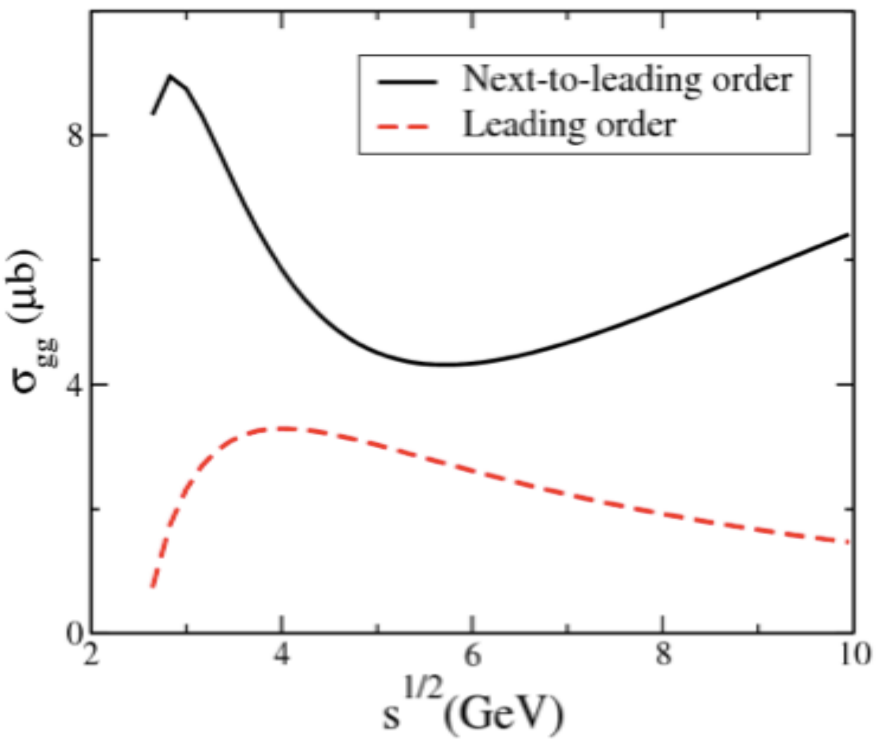


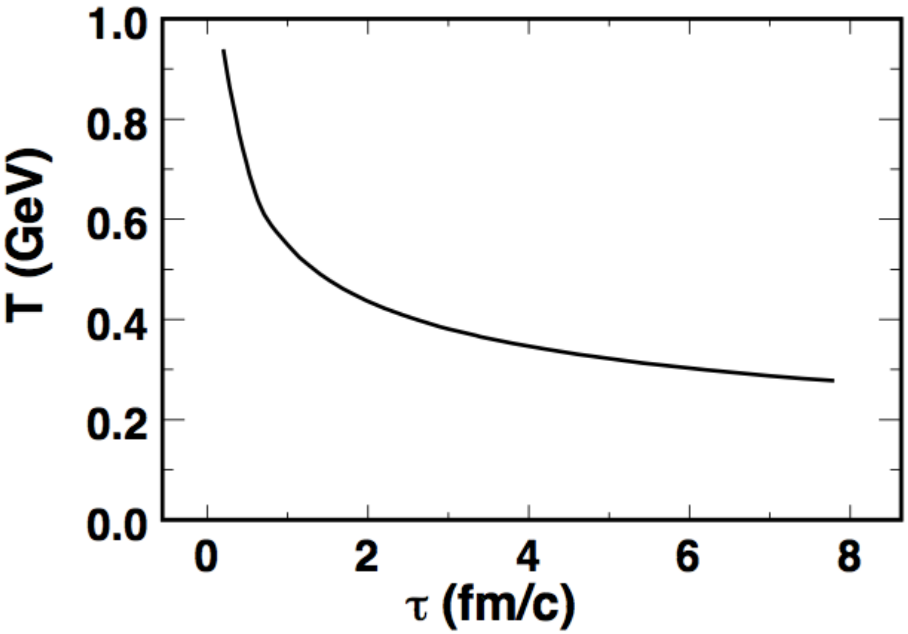
Note: using secondary production cross sections at LO (probably underestimated)

J. Uphoff, private communication, based on J. Uphoff et al. PRC82 (2010)

Secondary/thermal charm? Ko et al.

- Calculation for FCC energy provided by C.M.Ko
- Uses gg fusion process at LO and NLO (NLO dominant!)





C.M. Ko, Y. Liu, private communication,
based on B.-W. Zhang et al. PRC77 (2008)

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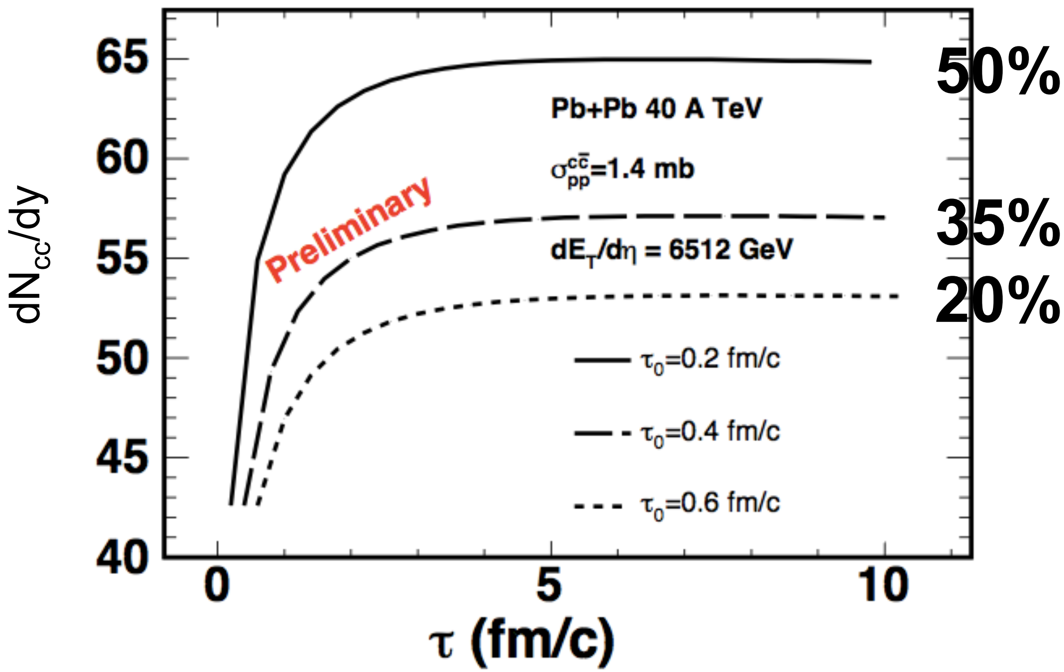

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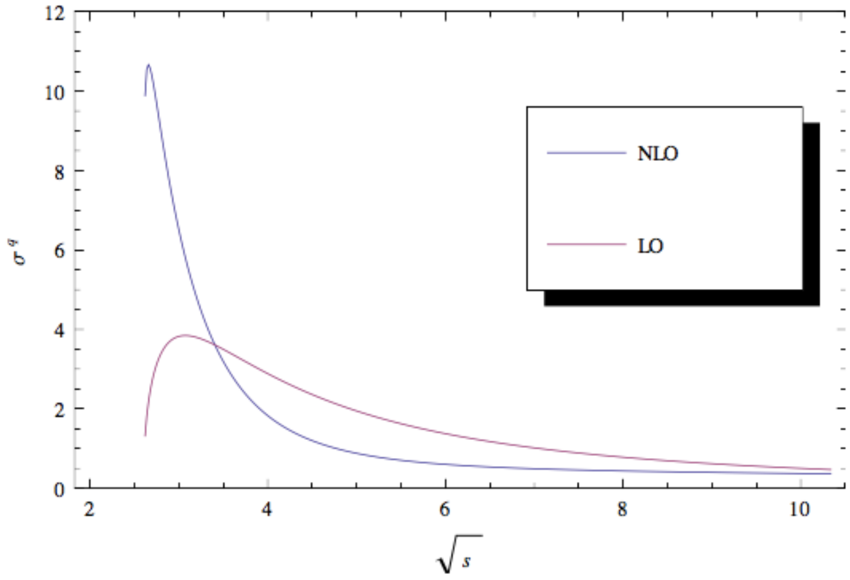
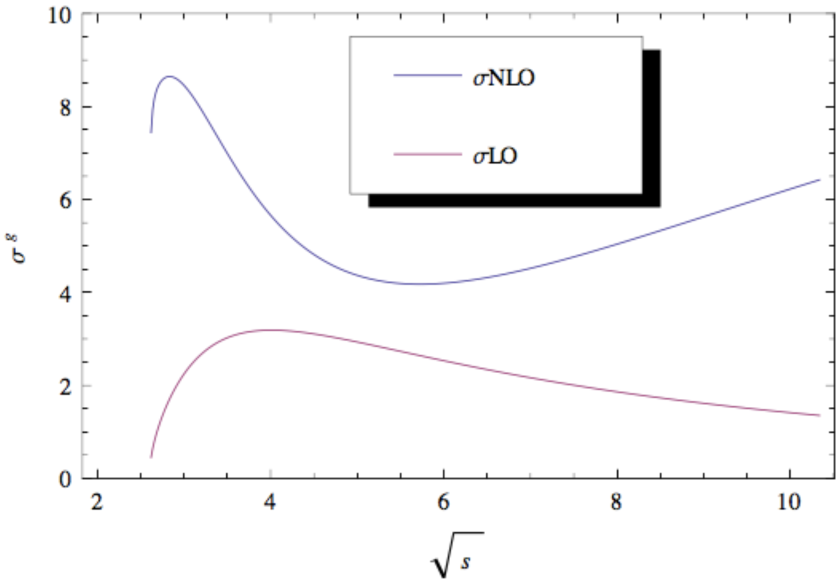
Potentially sensitive to medium properties (T_0, τ_0)

Secondary/thermal charm? Zhou et al.

- Uses gg and qqbar fusion process at LO and NLO
  - Leading Order: $g + g \to c + \bar{c}$ $\quad q + \bar{q} \to c + \bar{c}$
  - Next-Leading Order: $g + g \to c + \bar{c} + g$ $\quad q + \bar{q} \to c + \bar{c} + g$



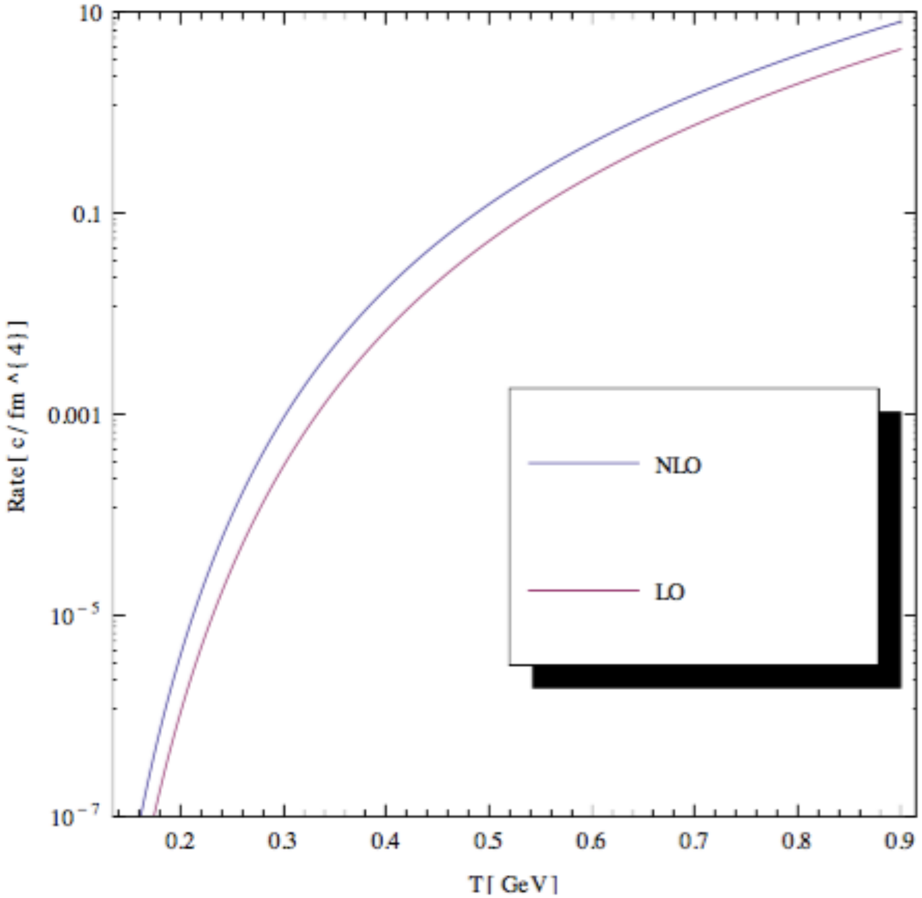


P. Nason, S. Dawson R.K. Ellis, NPB 303, 607 (1988)

K. Zhou, P. Zhuang, presented in Trento, March 2015

Secondary/thermal charm? Zhou et al.

- c-cbar production rate (per unit time and volume)



coll.energy	$\tau_0(fm/c)$	$T_{max}(MeV)$
2.76 TeV	0.6	484
5.5 TeV	0.6	580
39 TeV	0.3	860

K. Zhou, P. Zhuang, presented in Trento, March 2015

Secondary/thermal charm? Zhou et al.

Rate equation for charm production

$$\partial_\mu(n_{c\bar{c}}^{LR}u^\mu) = R_{gain} - R_{loss} \quad (2)$$

$n_{c\bar{c}}^{LR}$: charm pair density in local rest frame
$u^\mu = \gamma(1, \vec{v})$: 4-velocity of fluid cell in Hydro medium
Considering boost invariant initial condition in mid-rapidity:

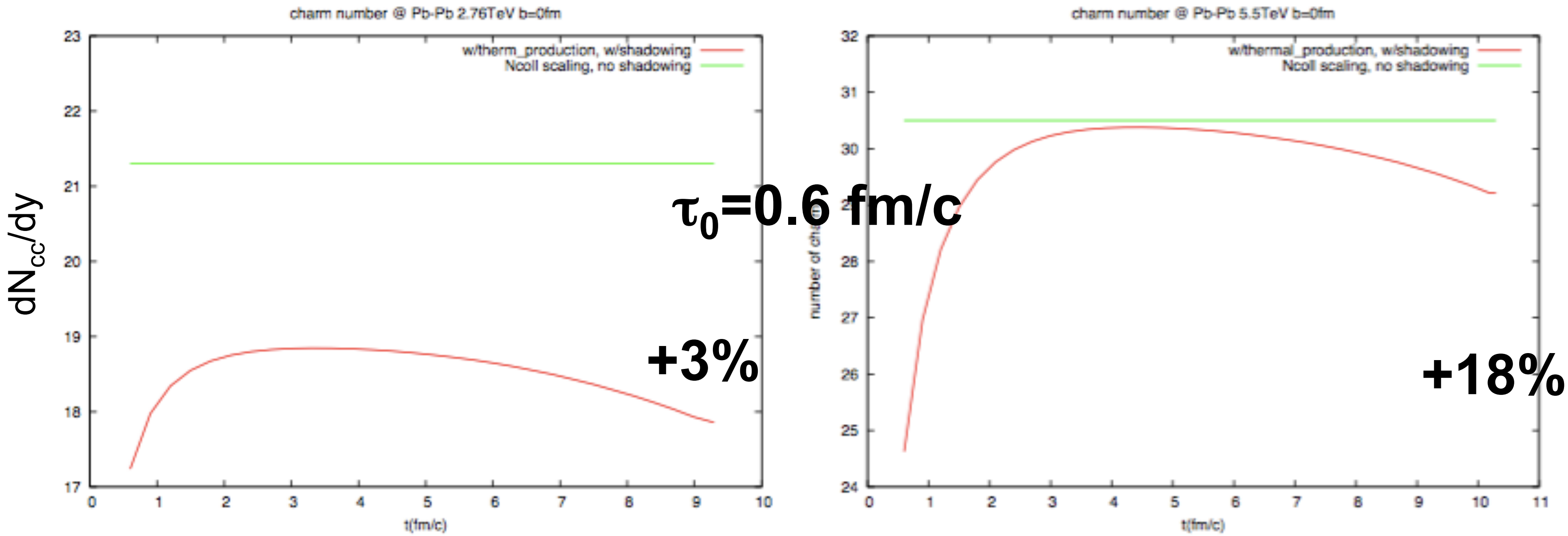
$$\partial_\tau(n_{c\bar{c}}) + \nabla_T(n_{c\bar{c}}\vec{v}_T) + \frac{n_{c\bar{c}}}{\tau} = R_{gain} - R_{loss} \quad (3)$$

$n_{c\bar{c}}$: charm pair density in lab frame
Initial condition: $n_{c\bar{c}}(\vec{x}_T, \tau_0) = \frac{1}{\tau_0}\frac{d\sigma_{c\bar{c}}^{pp}}{d\eta}|_{\eta=0} T_{AB}(\vec{x}_T)$
$\times[1 + A(R_g(\bar{x}, \bar{\mu}_F) - 1)\frac{T_A(\vec{x}_T)}{T_{AB}(\vec{0})}][1 + A(R_g(\bar{x}, \bar{\mu}_F) - 1)\frac{T_B(\vec{x}_T)}{T_{AB}(\vec{0})}]$

K. Zhou, P. Zhuang, presented in Trento, March 2015

Secondary/thermal charm? Zhou et al.

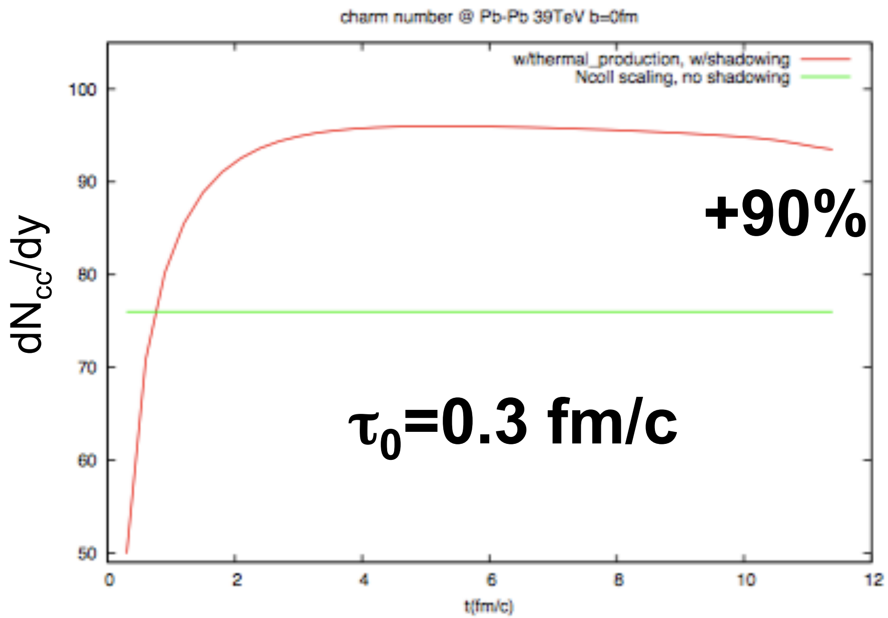
- Results for LHC energies
  - 2.76TeV, shadowing will reduce the charm production, thermal production is negligible
  - 5.5TeV, thermal production can just compensate the shadowing induced reduction

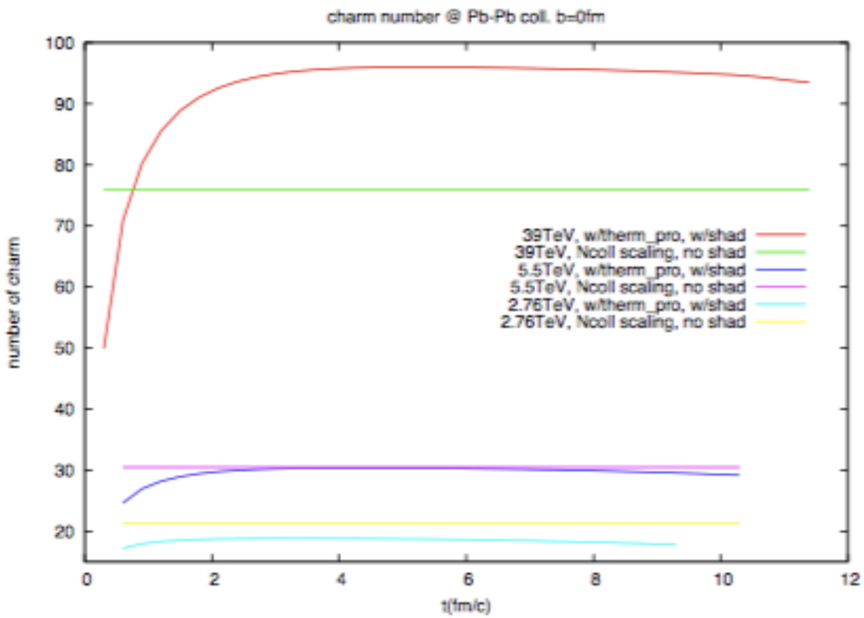


K. Zhou, P. Zhuang, presented in Trento, March 2015

Secondary/thermal charm? Zhou et al.

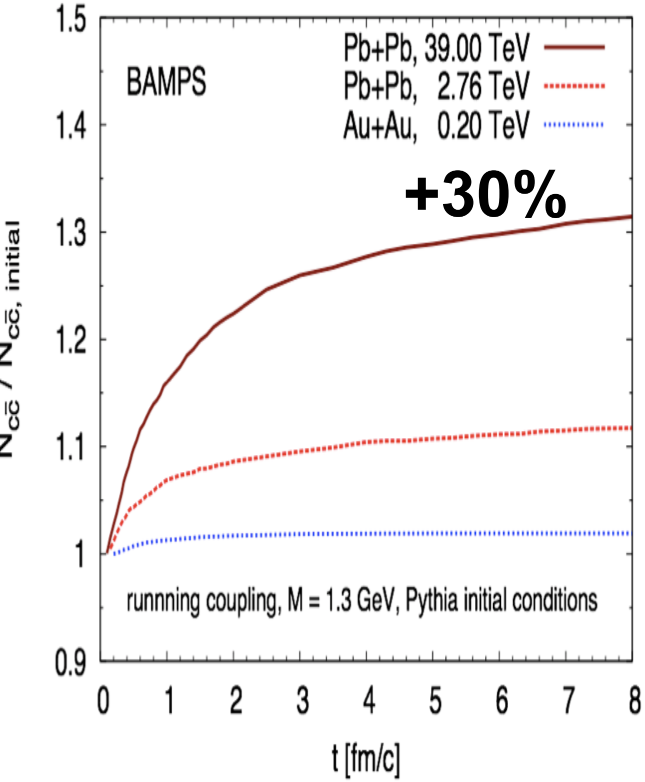
- Results for FCC energies
  - 39TeV, thermal production can overcome the shaodwong and finally leads to 22% enhancement
  - along with increasing coll.energy, thermal charm production becomes more important.



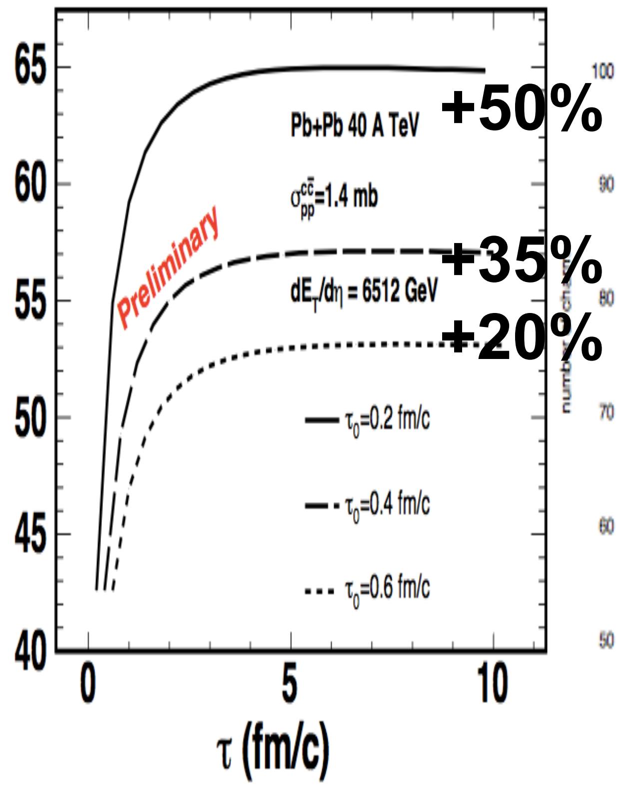


K. Zhou, P. Zhuang, presented in Trento, March 2015

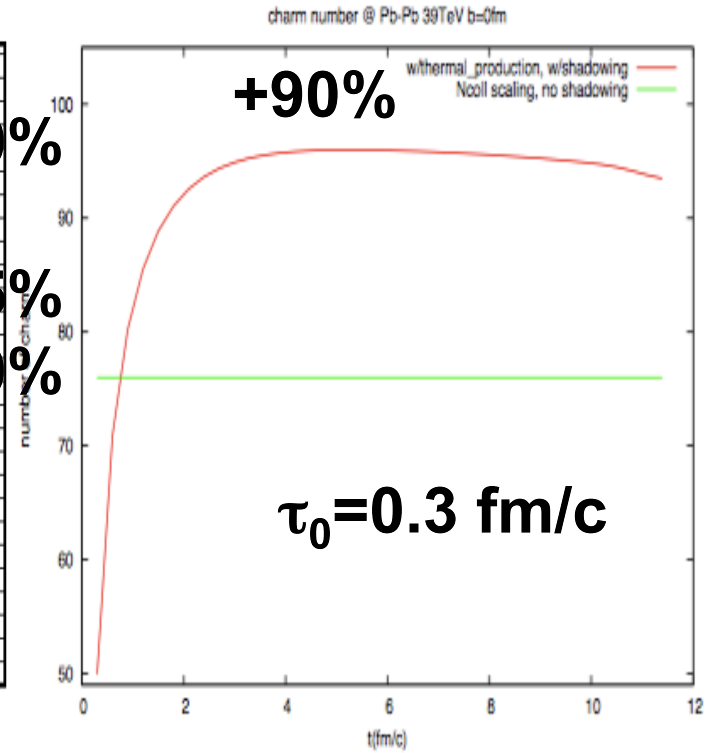
Secondary/thermal charm? Comparison



LO only



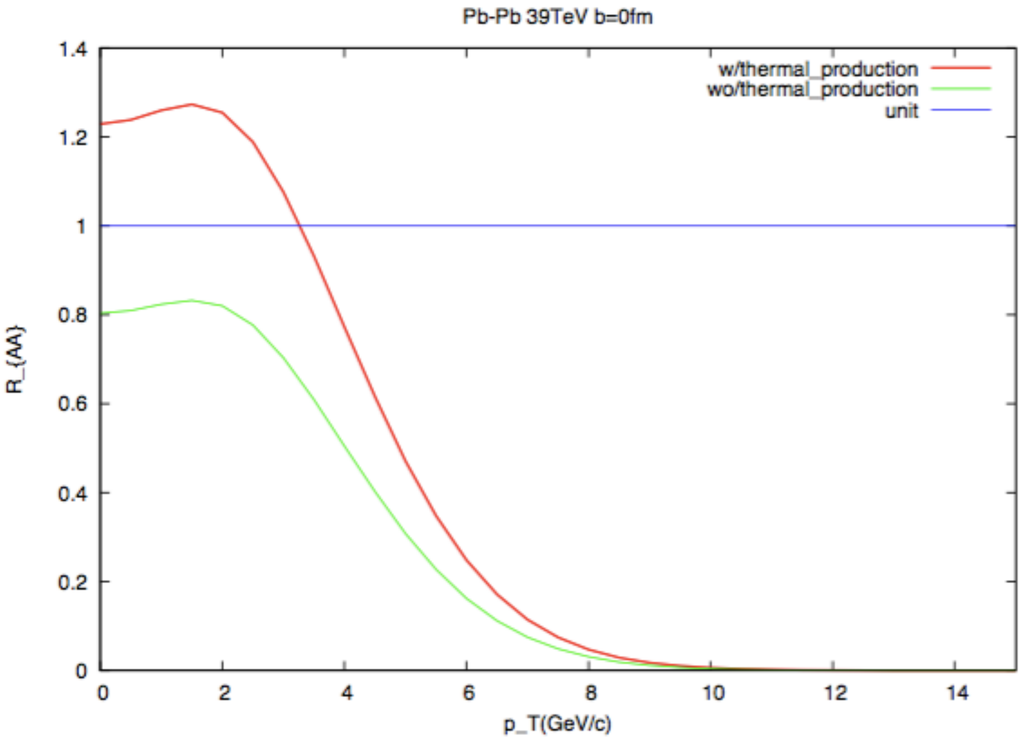
NLO gg only



NLO gg + q-qbar

J/psi production with (re)generation and thermal charm

- Effect on J/psi production via (re)generation
  - thermal charm production leads to $R_{AA}^{J/\Psi} > 1$ at low p_T.



K. Zhou, P. Zhuang, presented in Trento, March 2015

J/psi production within SHM

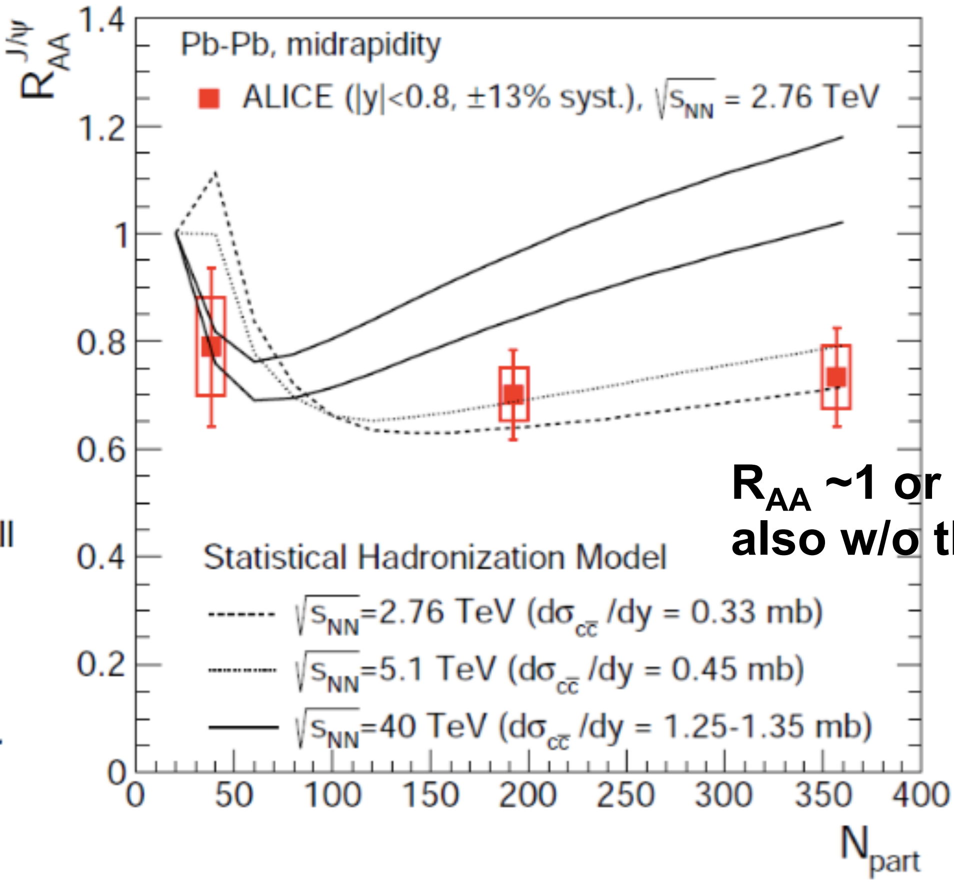
prediction of J/psi cross section at mid-rapidity for run2 and FCC

sqrt{s$_{NN}$} (TeV)	dN(c+c_bar)/dy Pb--Pb
0.2	3.4
2.76	12.5
5.5	17.5
40	51

uncertainty in energy dependence of open charm cross section and volume still large

new analysis based on all existing data to come soon.

Need also extrapolation for effects of shadowing .



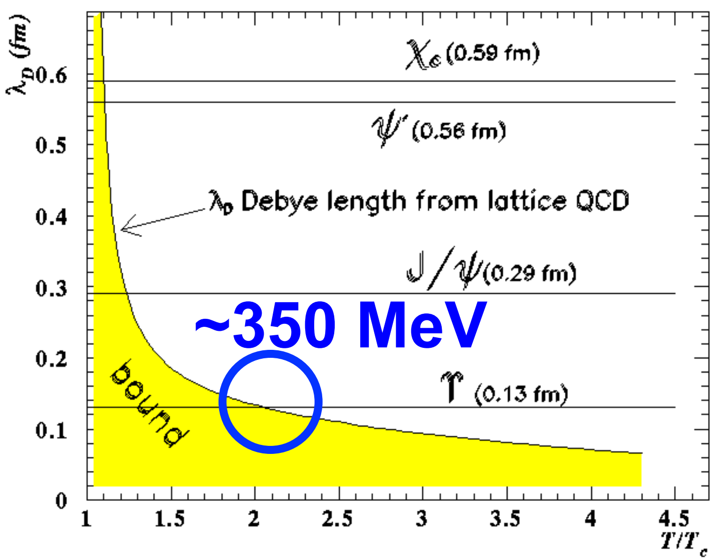
R_{AA} ~1 or >1, also w/o thermal charm

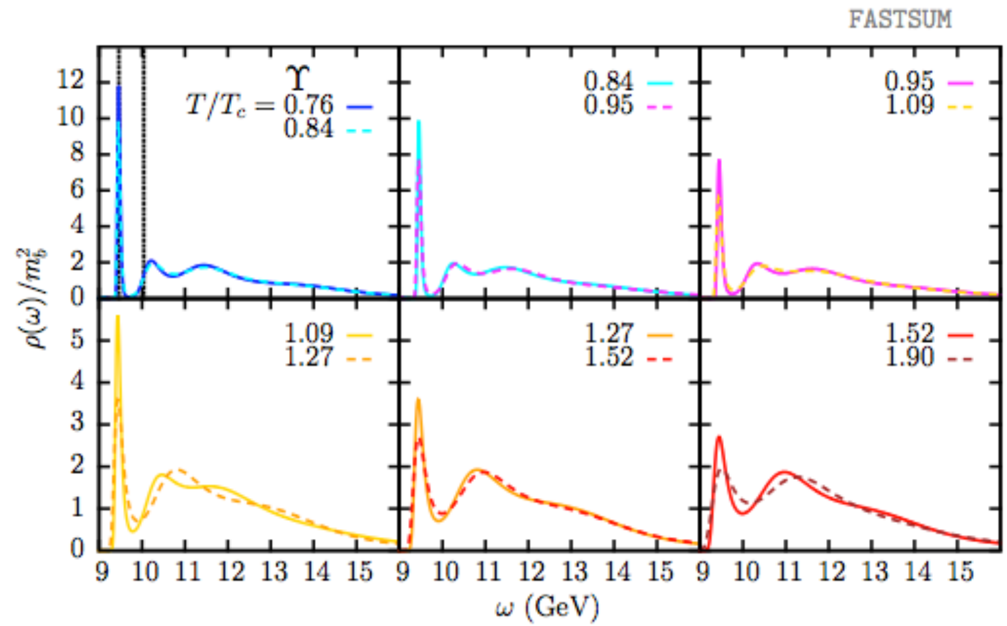
A. Andronic, P. Braun-Munzinger, J. Stachel, presented in Trento, March 2015

Y(1S) melting at the FCC?

- LHC: Y(1S) R_{AA}~0.5:
  - consistent with melting of higher states only?
  - or, in view of recent LHCb feed-down measurements, with "partial" Y(1S) melting
  - Y(1S) expected to melt at ~350 MeV

→ Full melting at FCC?





Digal,Petrecki,Satz PRD64(2001), confirmed by recent calculations, e.g. Aarts et al., JHEP, 07:097, 2014.

Outline

- Summary of available material
- Proposal for report

HF section in the report

- Larger T(τ) and smaller τ_0 (→ larger T_0), possible effects:
  - Increase of QGP n(d.o.f.) → study of EoS with 4 flavours on the lattice
    - Ask one of the experts for a short paragraph
  - Thermal charm → predictions for c-cbar increase (only NLO ones? No BAMPS)
  - J/psi regeneration leads, possibly coupled to thermal charm, to R_{AA}>1
  - Y(1S) melting

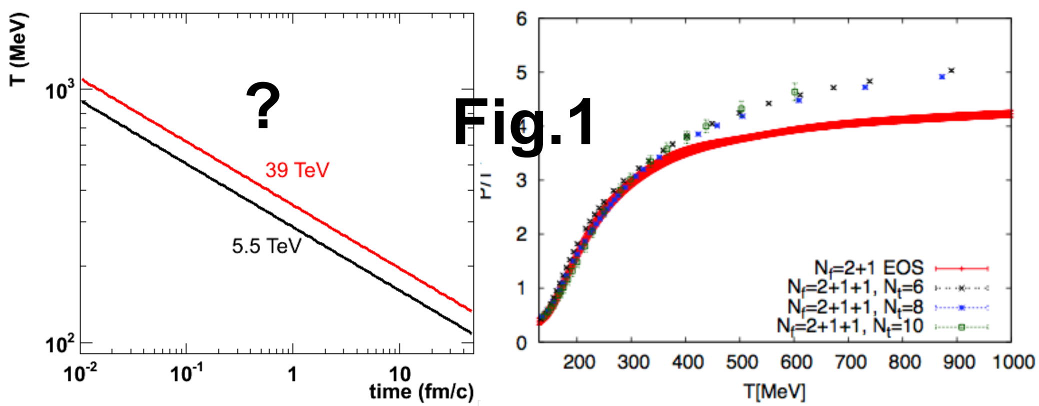


Fig.1

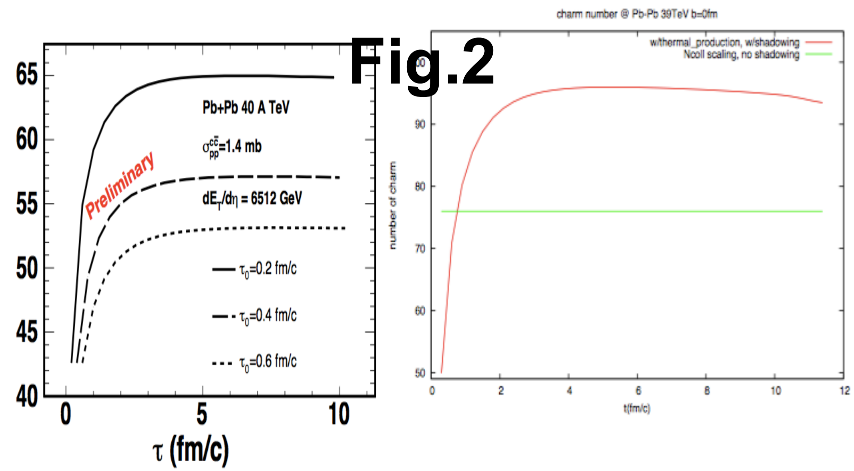


Fig.2

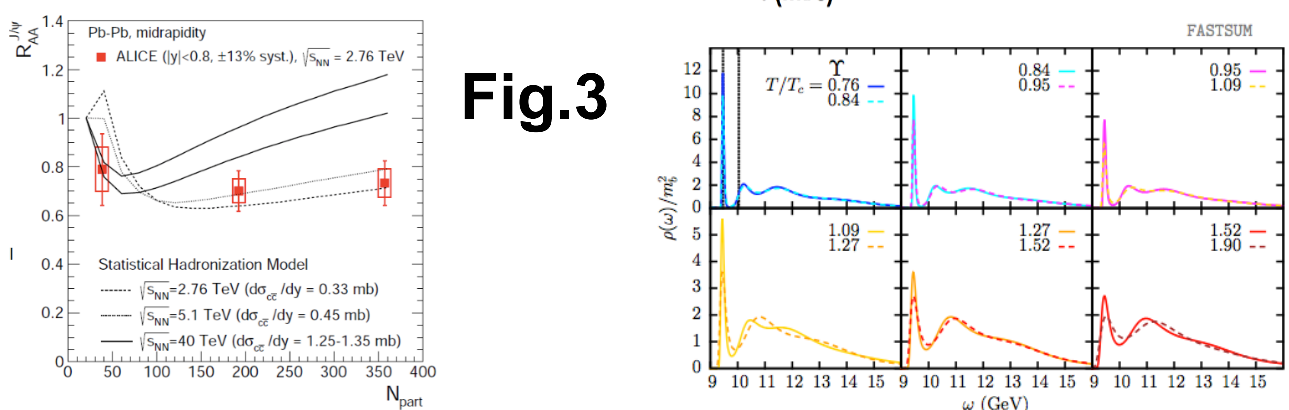
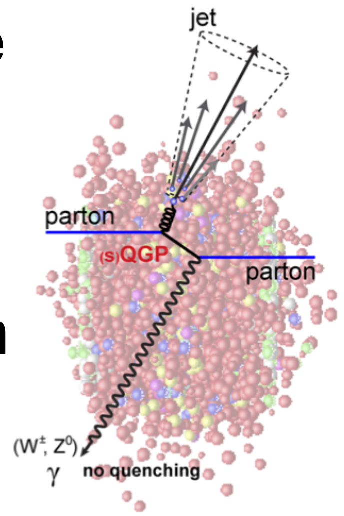


Fig.3

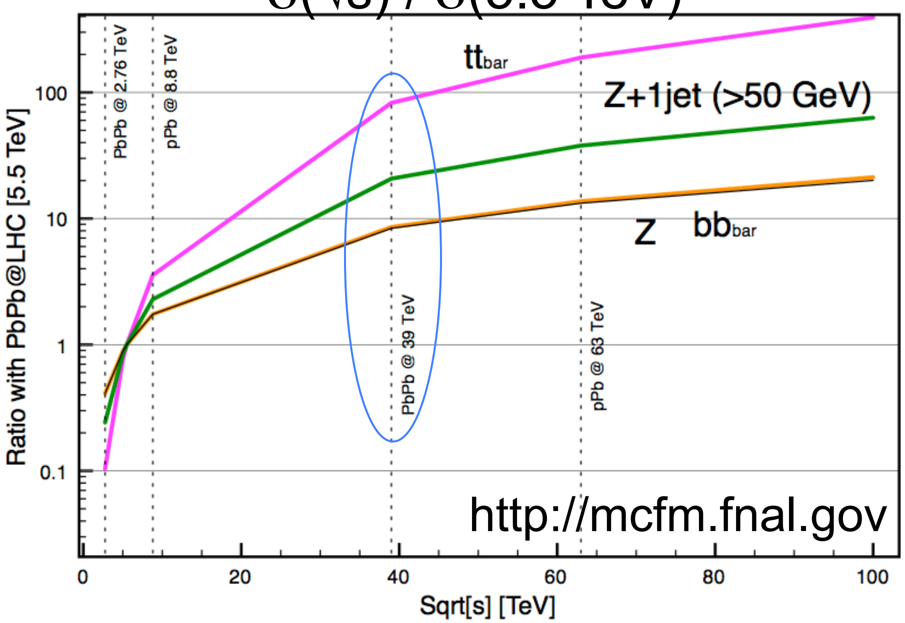
EXTRA SLIDES

FCC: a richer set of Hard Probes

- LHC heavy-ion programme shows that it is possible to reconstruct HEP-like observables in HI collisions
  - Jets, b-jets, Z^0, W, γ-jet correlations …
- Large $\sqrt{s}$ and $\mathscr{L}$ of the FCC will make new probes abundantly available, for the study of the interaction mechanisms, of the medium density and its time evolution



$\sigma(\sqrt{s})$ / σ(5.5 TeV)



- Larger increases for larger masses:
  - 80x for top
  - 20x for Z^0 + 1 Jet(p_T>50 GeV)
  - 8x for bottom or Z^0