Status and plans of the FCC heavy-ion physics studies

Andrea Dainese

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on behalf of the "FCC-ions" discussion group

contact persons:

N. Armesto, D. d'Enterria, S. Masciocchi, C. Roland, C. Salgado, M. van Leeuwen, U. Wiedemann

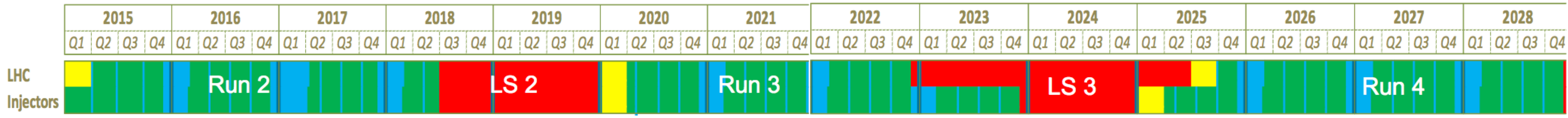
Outline

- Introduction, organization
- Future timeline with heavy ions at the LHC
- Ions at the FCC
- High-density QCD in the initial state: small-x and saturation
- High-density QCD in the final state: deconfinement and QGP
- High-multiplicity events in small systems (pp, pA)
- $\gamma\gamma$ collisions in a AA collider and connections to cosmic rays
- Summary

Introduction, organization

- A discussion group on "Ions at the FCC" started: coordinated by A.D., S. Masciocchi, U. Wiedemann
  - Sub-group of "FHC Physics, Experiments, Detectors"
- Two meetings up now, Dec 16-17 and Jan 29
  - https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=288576
  - https://indico.cern.ch/conferenceDisplay.py?confId=290413
- Particip. from CERN acc. team, theory, ALICE, ATLAS, CMS
- Goal: explore opportunities with HI at the FCC
  - Saturation (contacts: N. Armesto, M. van Leeuwen)
  - Soft physics (contact: U. Wiedemann)
  - Hard probes (contacts: A. Dainese, C. Roland, C. Salgado)
  - $\gamma\gamma$ / UPC (contact: D. d'Enterria)
- Work in progress! Just few initial ideas presented here

Timeline of future HI running at the LHC



~0.3-1.5 nb^{-1} PbPb LS2 ~2-4 nb^{-1} PbPb LS3 ~10 nb^{-1} PbPb

Experiments request/goal:

Also corresponding pp reference

PbPb 5.1TeV | PbPb 5.1TeV | pPb? 8.2TeV

Also corresponding pp reference

ArAr pPb PbPb 5-8 TeV

PbPb pp (?) 5.5 TeV

- Run 2 (LS1→LS2): Pb-Pb ~1/nb or more, at $\sqrt{s_{NN}}$ ~ 5.1 TeV
- LS2: major ALICE and LHCb upgrades, important upgrades for ATLAS and CMS, LHC collimator upgrades
- Run 3 + Run 4: Pb-Pb >10/nb, at $\sqrt{s_{NN}}$ ~ 5.5 TeV
- pp reference and p-Pb in both Runs 2 and 3-4

Ions at FCC: energies and luminosities

- Centre-of-mass energy per nucleon-nucleon collision:

$$\sqrt{s_{NN}} = \sqrt{\frac{Z_1 Z_2}{A_1 A_2}} \sqrt{s_{pp}} \quad \Rightarrow \quad \sqrt{s_{PbPb}} = 39\ TeV, \quad \sqrt{s_{pPb}} = 63\ TeV \quad \text{for } \sqrt{s_{pp}} = 100\ TeV$$

- First (conservative) estimates of luminosity (in comparison with LHC): x5 larger L_{int} per month of running

see talk by M. Schaumann

	LHC Run 2 [1]	LHC after LS2 [1]	FHC [2]
Pb–Pb peak $\mathcal{L}$ ($cm^{-2}s^{-1}$)	10^{27}	5×10^{27}	13×10^{27}
Pb–Pb L_{int} / month (nb^{-1})	0.8	1	5
p–Pb peak $\mathcal{L}$ ($cm^{-2}s^{-1}$)	10^{29}	t.b.d.	3.5×10^{30}
p–Pb L_{int} (nb^{-1})	80	t.b.d.	1000

- Possibility to increase L_{int} using nuclei with slightly smaller *Z*?
  - Some of the limiting factors (e.m. process) go with "large" powers of *Z*
- Could (optimistically) aim at a programme of 50-100/nb AA, i.e. LHC x5-10

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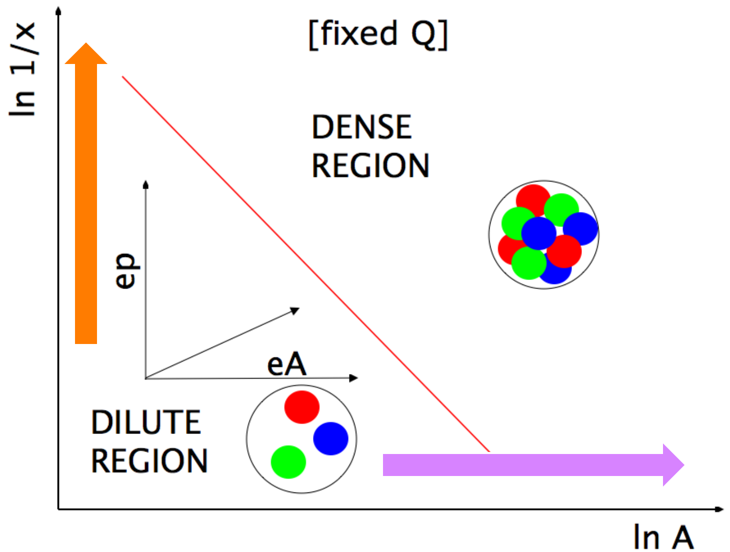
High-density QCD in the initial state: Saturation at low x

- Explore new unknown regime of QCD: when gluons are numerous enough (low-x) & extended enough (low-Q^2) to overlap → *Saturation, Non-linear PDF evolution*

Enhanced in nuclei: more gluons per unit transverse area

Saturation scale:

$$Q_S^2 \sim \frac{Ag(x,Q_S^2)}{\pi A^{2/3}} \sim A^{1/3} g(x,Q_S^2) \sim A^{1/3}\frac{1}{x^\lambda} \sim A^{1/3}\left(\sqrt{s}\ e^{y}\right)^\lambda$$



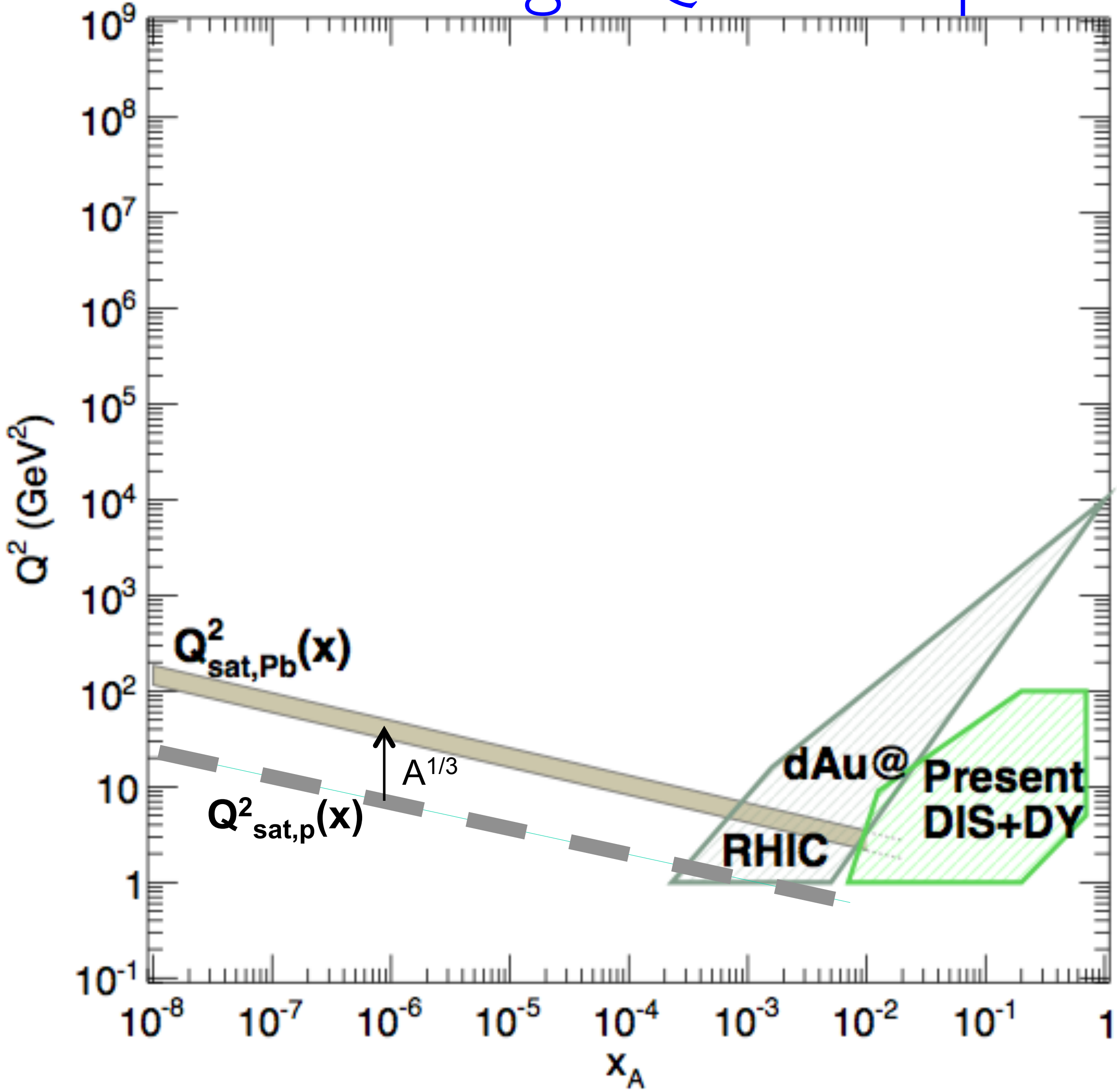
Saturation affects process with $Q^2 < Q_S^2$

Explore saturation region:

→ **decrease x (larger √s, larger y)**

→ **increase A**

Kinematic coverage Q^2 vs. x: pre-LHC



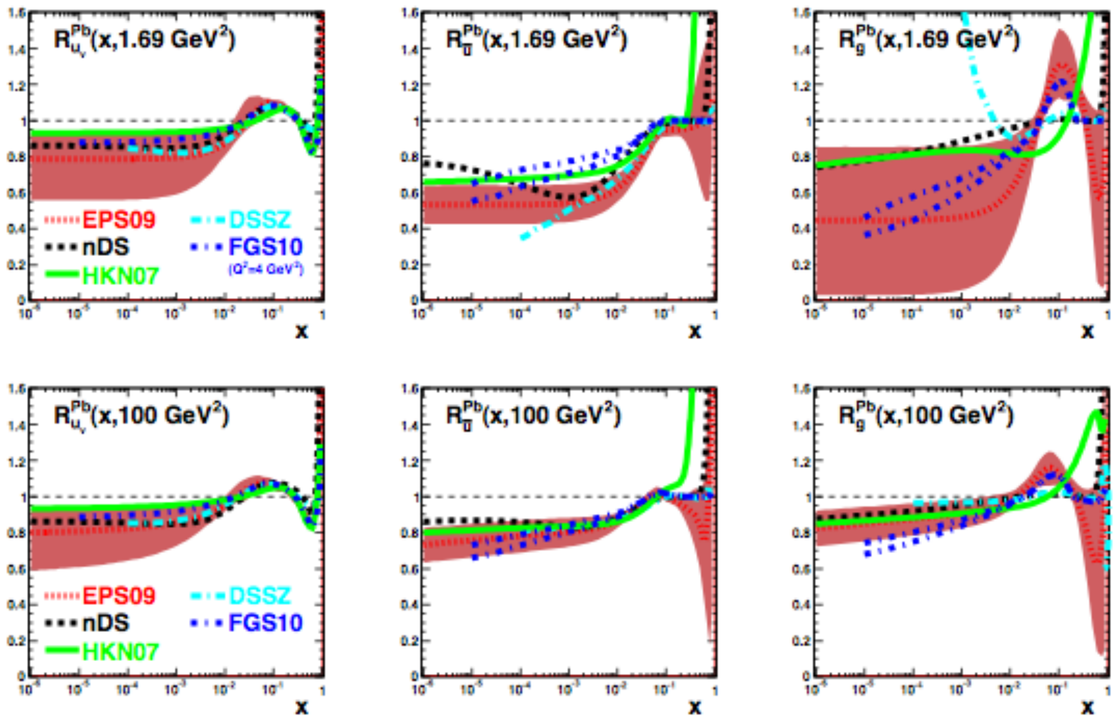
Nuclear modification of PDFs

- Lack of data at $x<10^{-3}$

→ large spread for nuclear modification of gluons at small scales and x

→ DGLAP analysis at NLO shows large uncertainties

$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$



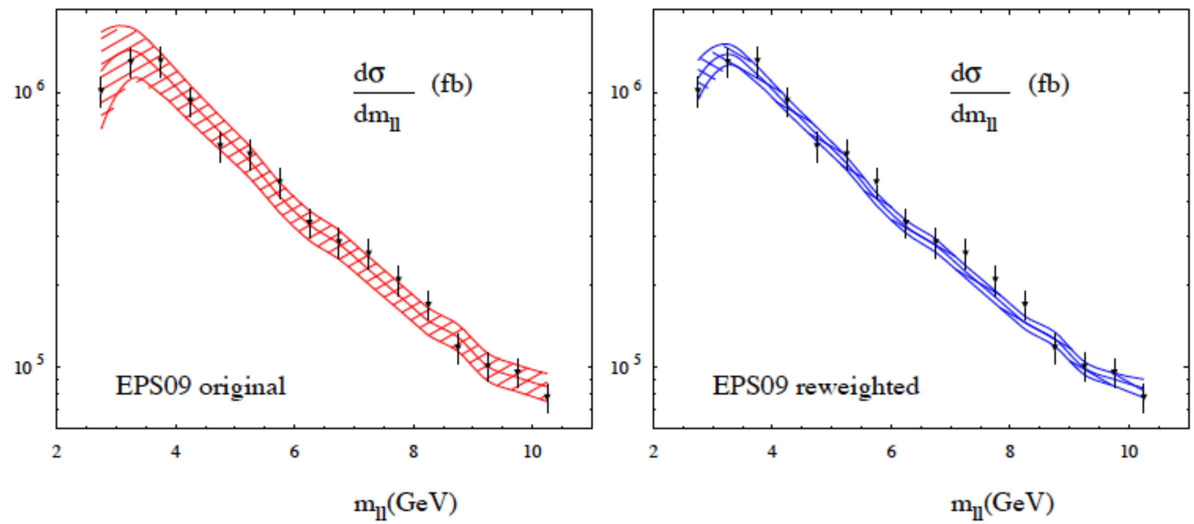
Testing non-linear evolution

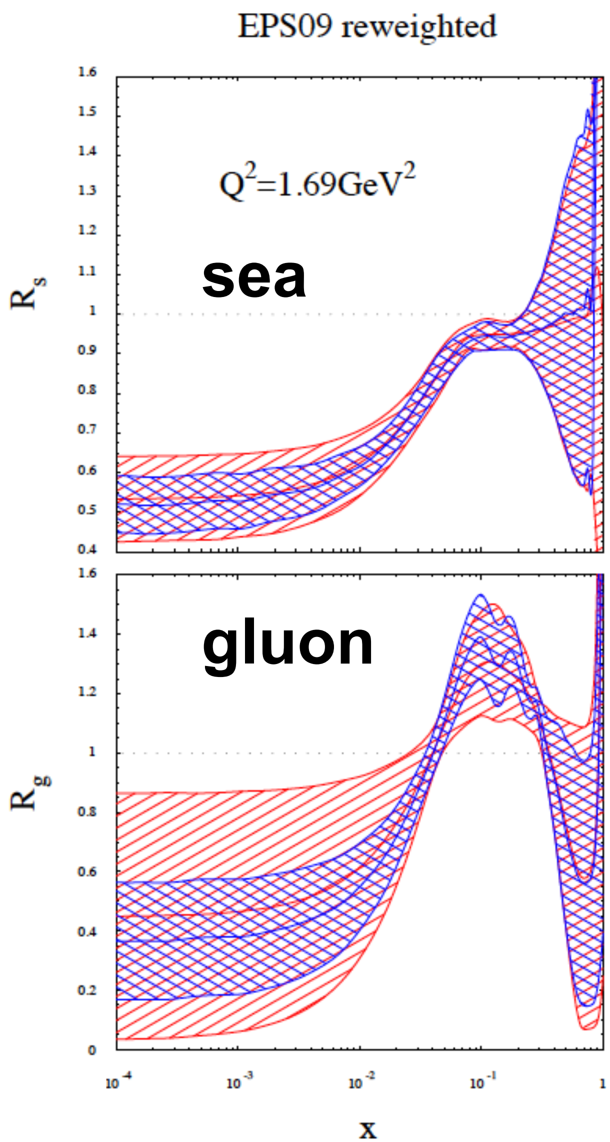
- Cover significant range in (x, Q^2) → next slides
- Multiple observables with sensitivity to quarks and gluons
  - At FCC expect significant charm contribution in sea (see J. Rojo)
- Kinematics is cleanest for partonic observables: photons, Drell-Yan, W/Z bosons
  - + no interactions in the final state
- Hadronic observables potentially very interesting (e.g. forward pion+jets)
  - Validation and sensitivity will come from LHC data (including possible impact of final-state effects in pA)

Plan: quantify impact of observables on nuclear PDF fits; expect constructive overlaps with ongoing LHC studies

For illustration: Drell-Yan in p-Pb at LHC

Pseudo-data (CMS acceptance)

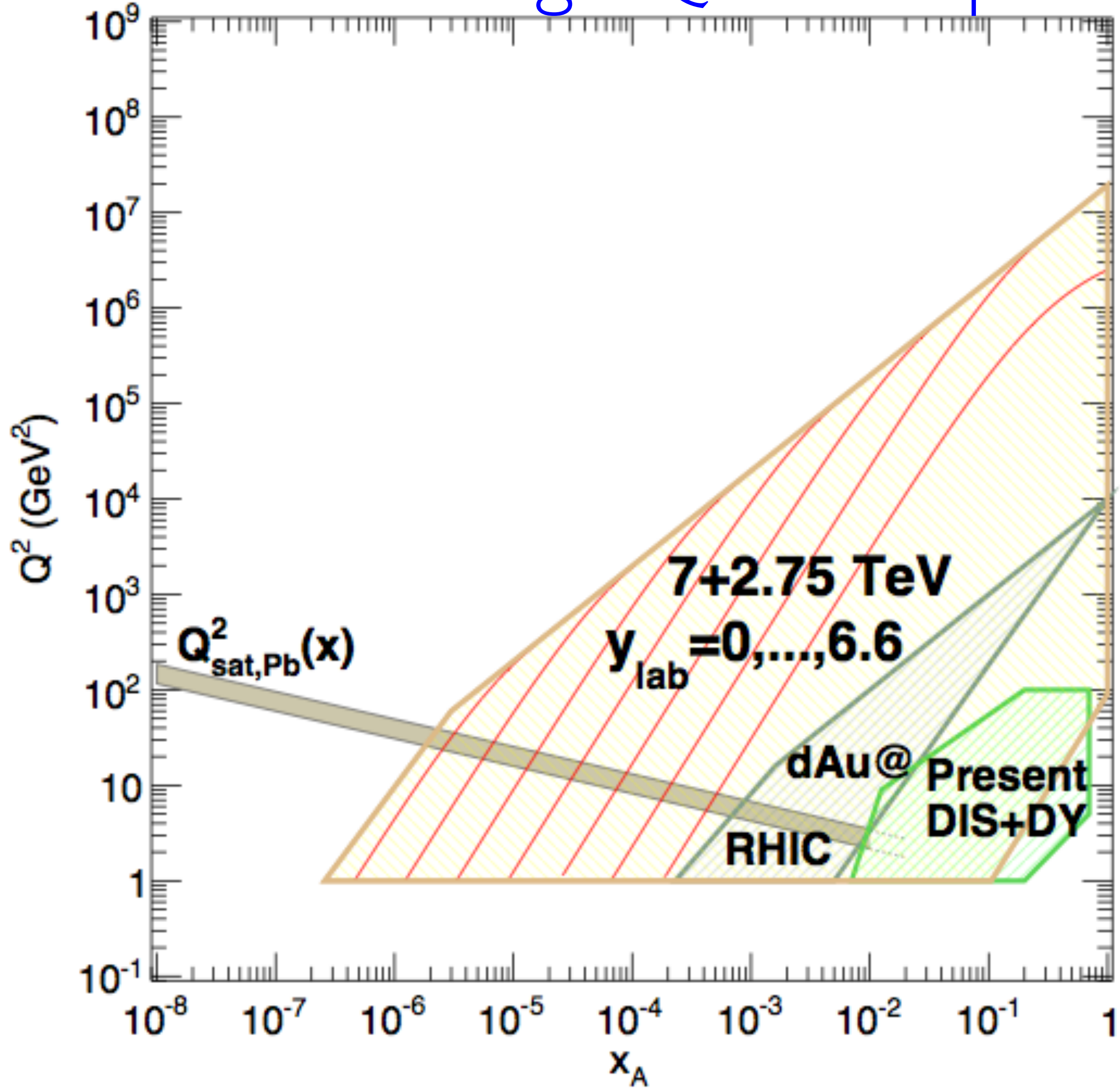




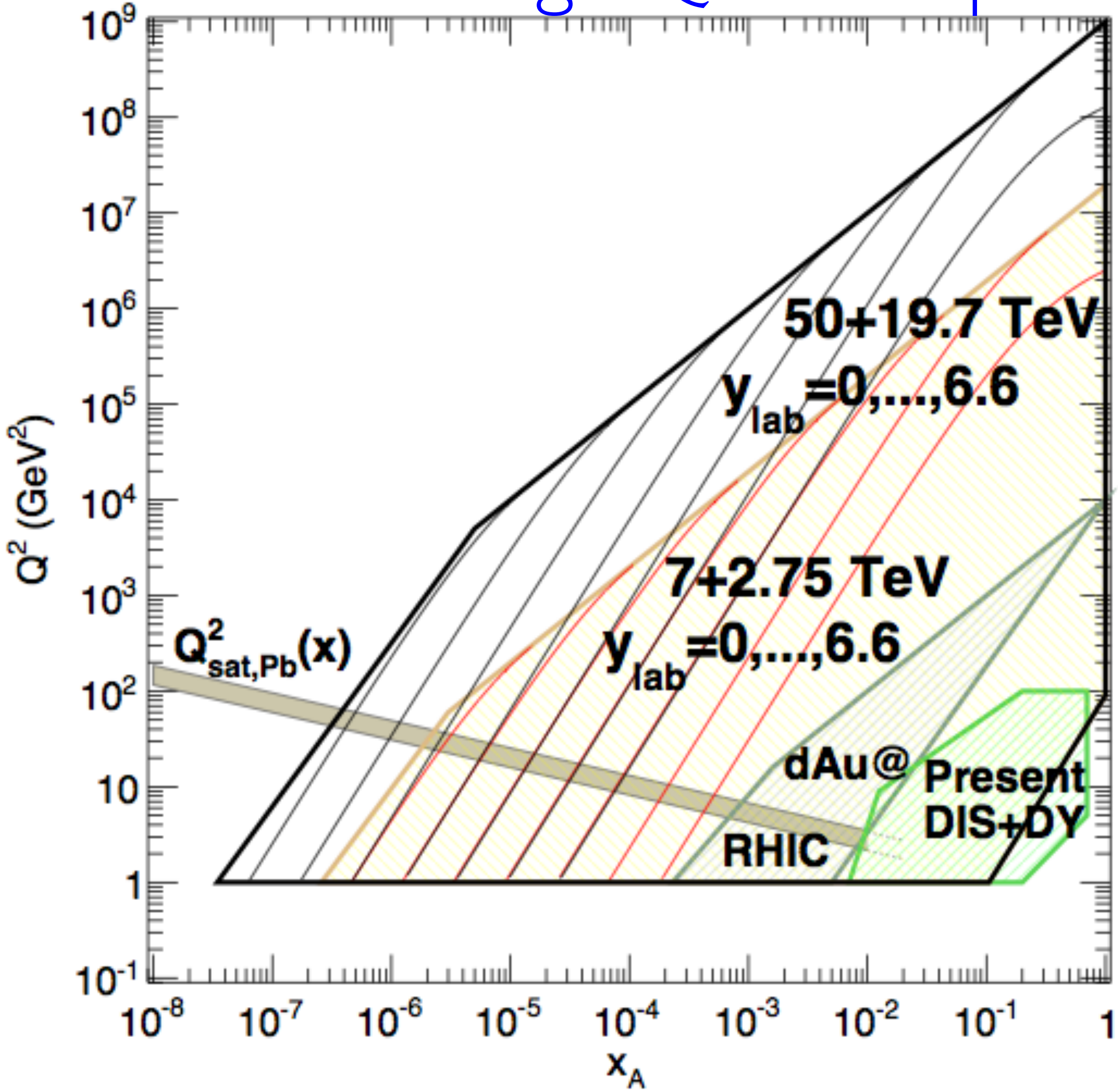
Plan: perform similar studies to assess sensitivity of FCC

Armesto et al., 1309.5371

Kinematic coverage Q^2 vs. x: pA LHC



Kinematic coverage Q^2 vs. x: pA FCC



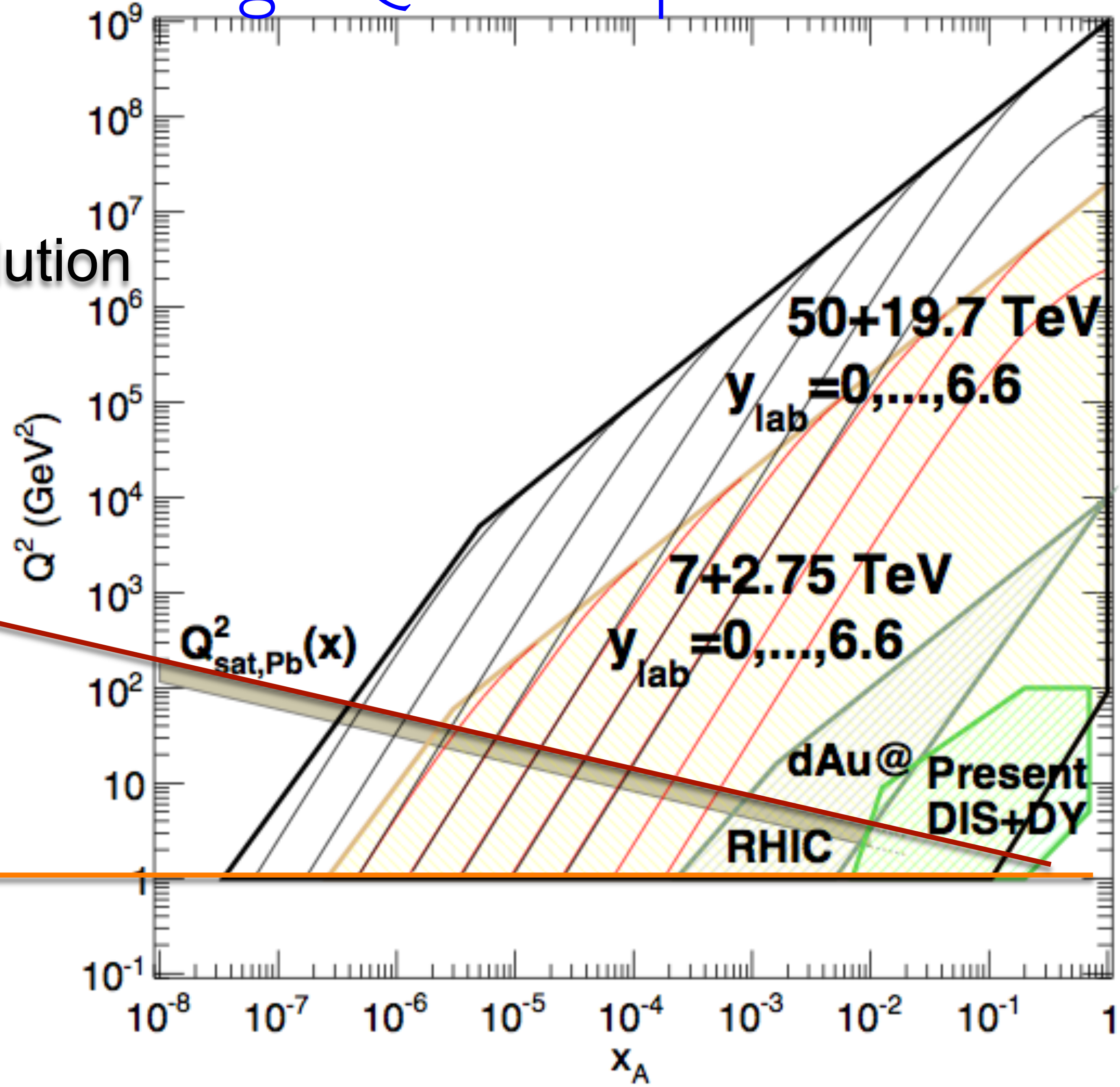
Kinematic coverage Q^2 vs. x: pA FCC

Goals:

- determine Q^2_{sat}
- test non-linear evolution

Non-Linear evolution for $Q^2 < Q^2_{sat}$

Low Q^2: initial conditions



Kinematic coverage Q^2 vs. x: pA FCC

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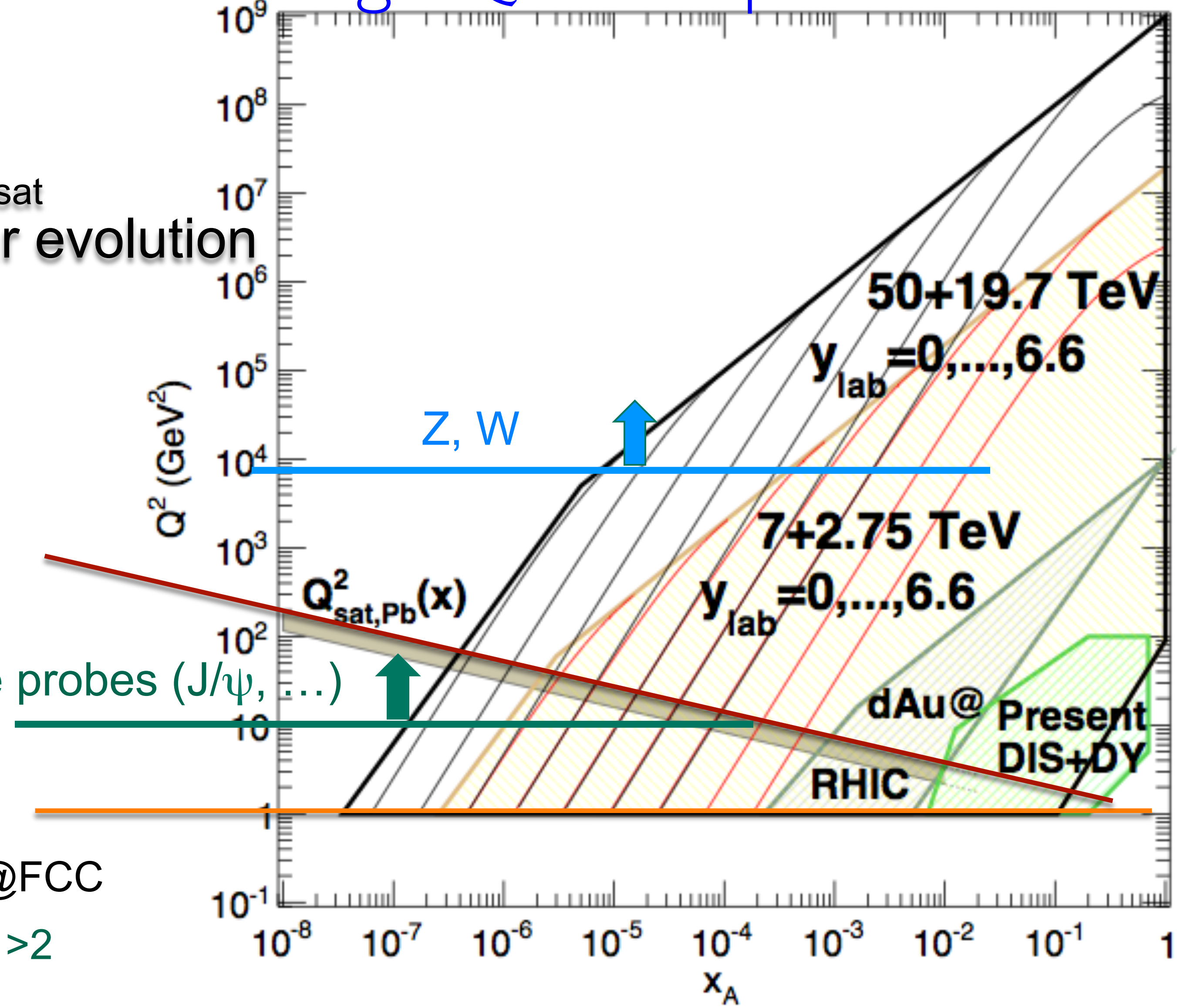
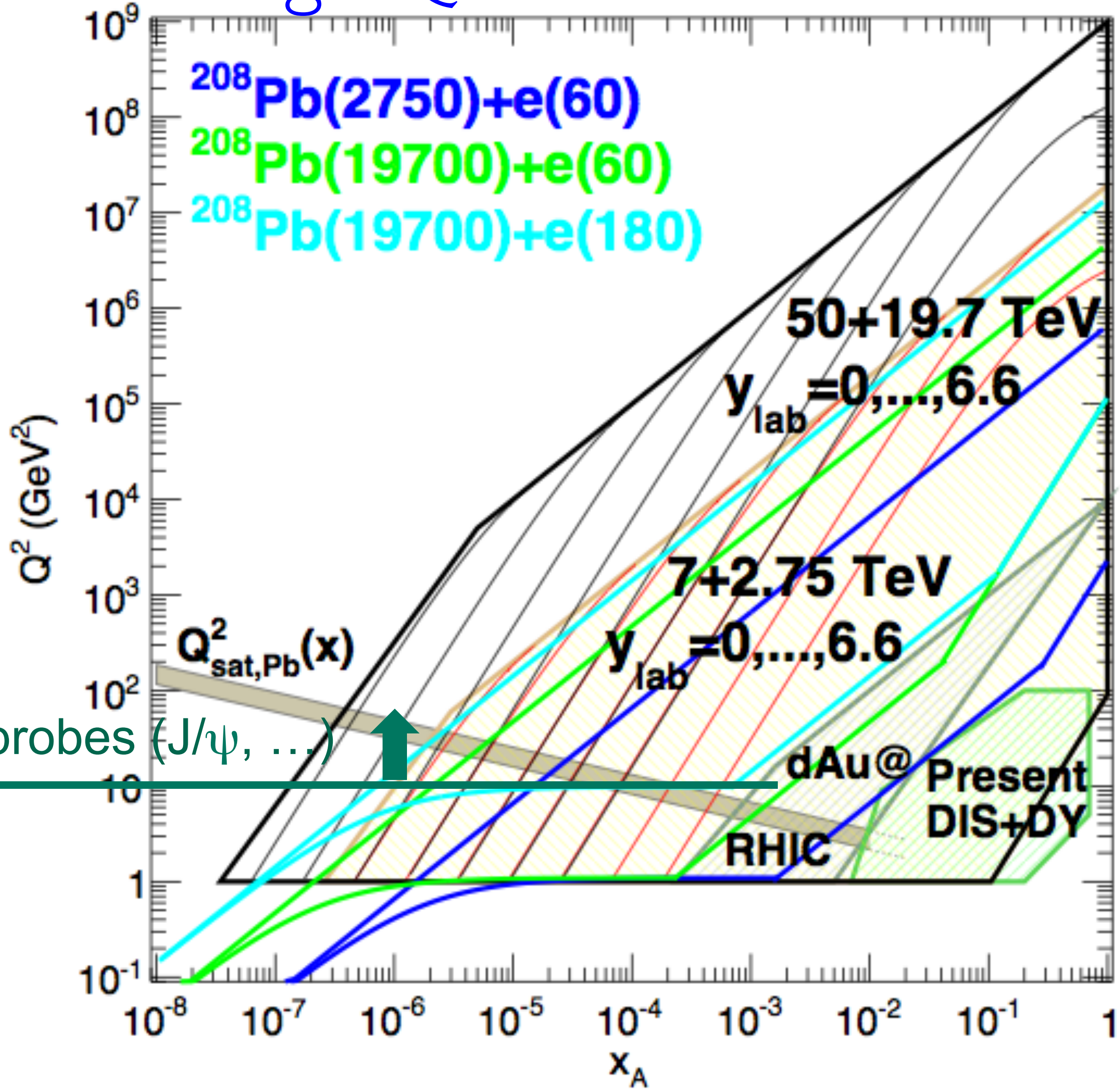


	y@LHC	y@FCC
Charm	>4	>2

Kinematic coverage Q^2 vs. x: eA FCC

pA at FCC:
unique access down to x~10^{-7} with perturbative probes

eA at FCC:
down to 10^{-6} with perturbative probes, but fully constrained parton kinematics



→ see also B. Cole in ep/eA session

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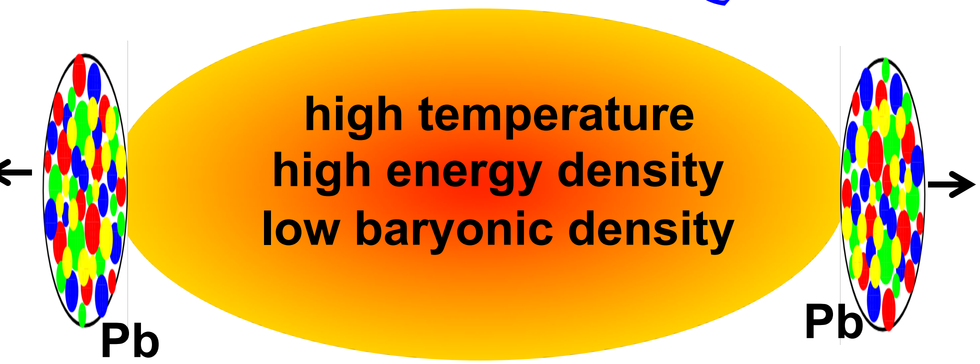
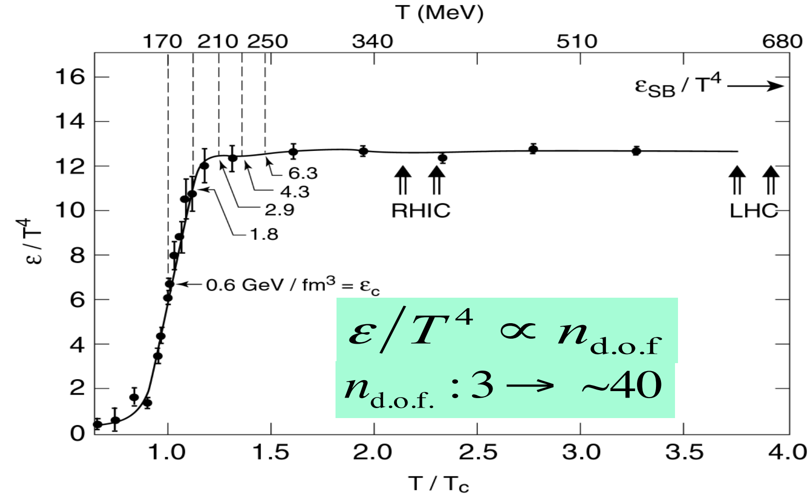
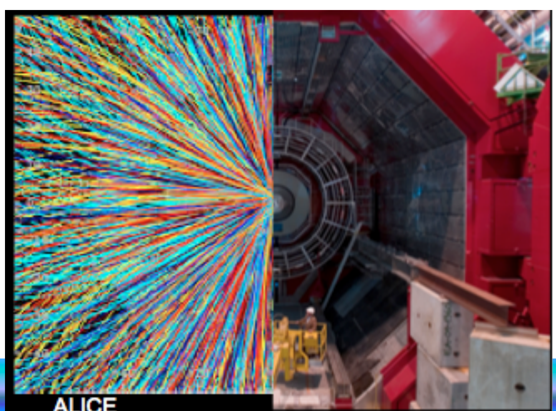
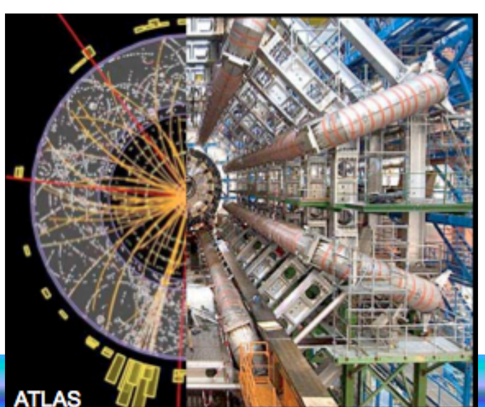
High-density QCD in the final state: the Quark Gluon Plasma

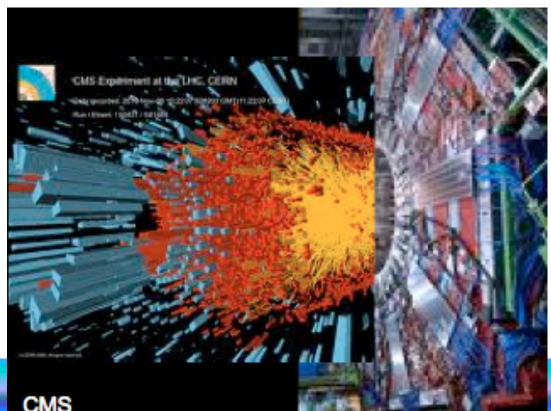




- Lattice QCD predicts phase transition at T_c~170 MeV
  → **Quark-Gluon Plasma**
- Confinement is removed
- Partonic degrees of freedom
- Unique opportunity to study in the laboratory spatially-extended multi-particle QCD system

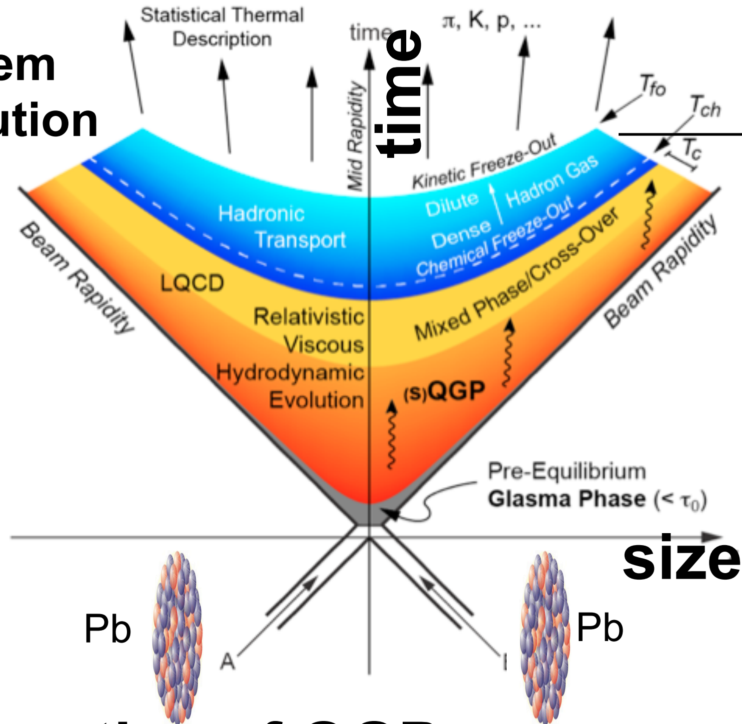


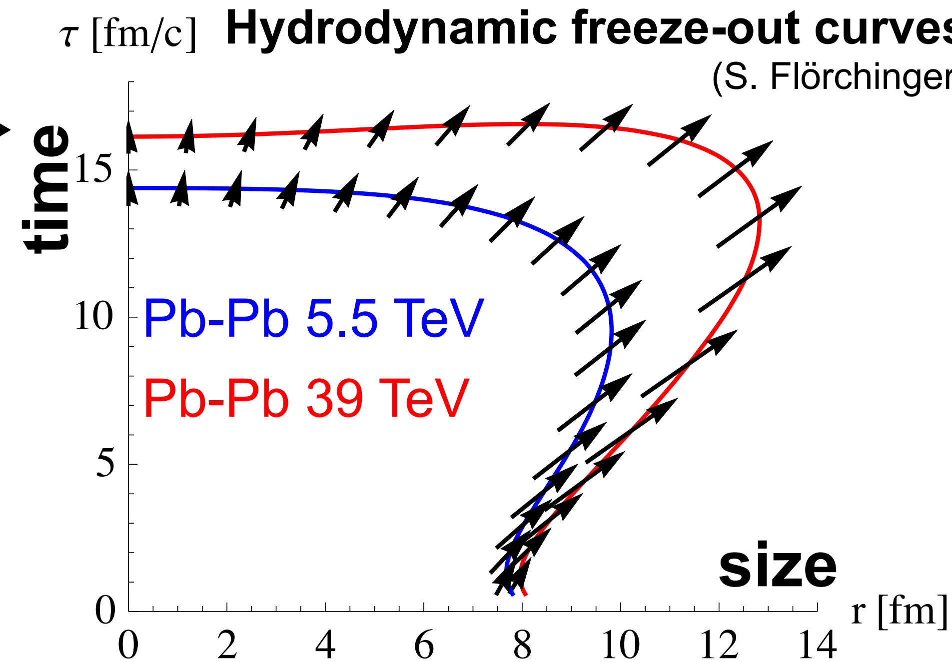




Quark-Gluon Plasma studies at FCC

System evolution





Properties of QGP:

- QGP volume increases strongly
- QGP lifetime increases
- Collective phenomena enhanced (better tests of QGP transport)
- Initial temperature higher
- Equilibration times reduced

Quark-Gluon Plasma studies at FCC

Questions to be addressed in future studies include:

Higher Temp.

- Larger **number of degrees of freedom** in QGP at FCC energy? → g+u+d+s**+charm** ?
- Changes in the **quarkonium spectra**? does **Y(1S) melt** at FCC?

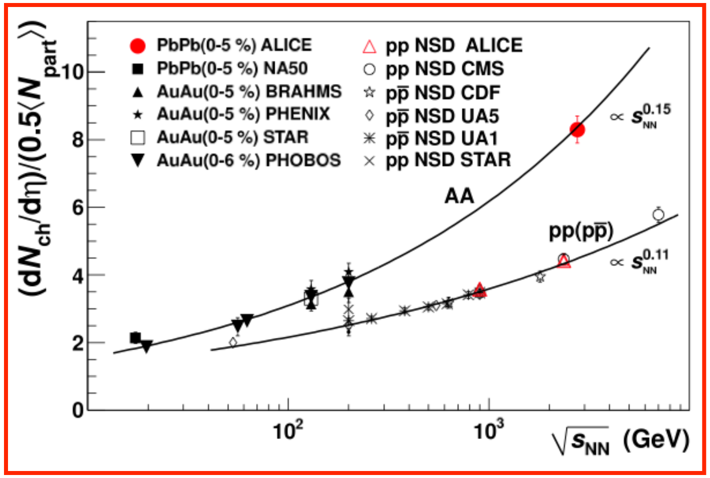
Higher energy

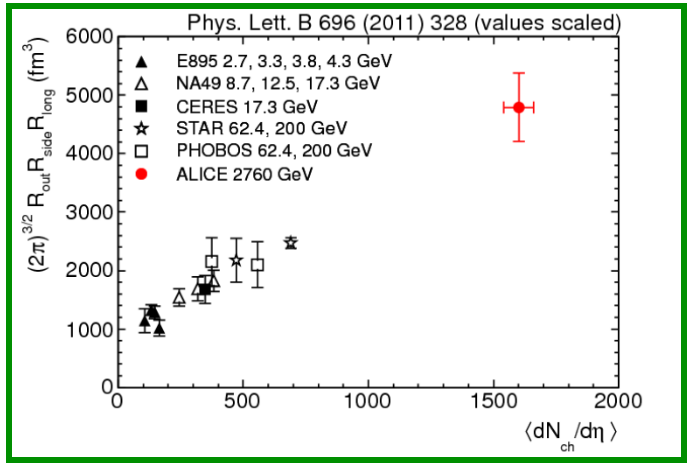
- How do studies of **collective flow** profit from **higher multiplicity and stronger expansion**? More stringent **constraints on transport properties** such as shear viscosity or other properties not accessible at the LHC
- **Hard probes** are sensitive to medium properties. At FCC, **longer in-medium path length and new, rarer probes** become accessible. How can both features be exploited?

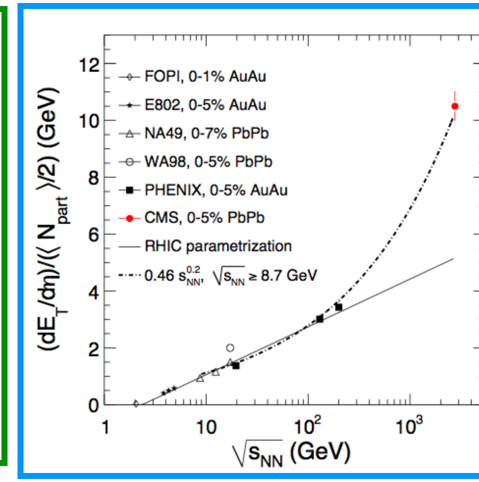
QGP studies at the FCC: global properties

- Extrapolation to 39 TeV: increase wrt LHC 5.5 TeV

$dN_{ch}/d\eta$ x 1.8 | **Volume x1.8** | **$dE_T/d\eta$ x2.2**





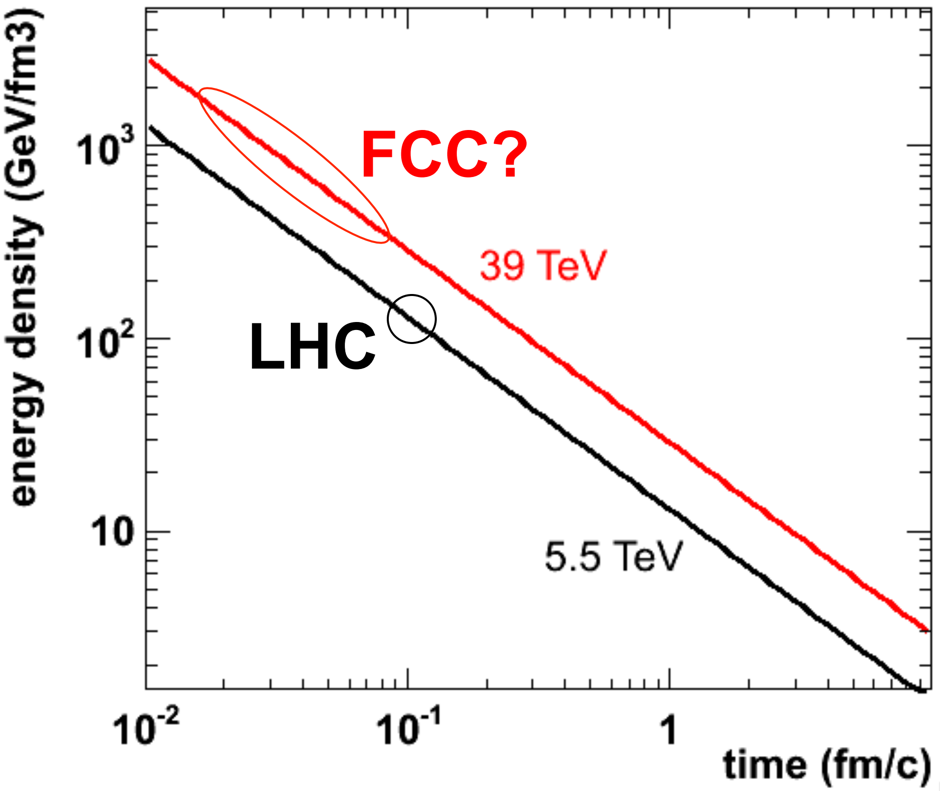


Quantity	Pb–Pb 2.76 TeV	Pb–Pb 5.5 TeV	Pb–Pb 39 TeV
$dN_{ch}/d\eta$ at $\eta = 0$	1600	2000	3600
Total N_{ch}	17000	23000	50000
$dE_T/d\eta$ at $\eta = 0$	2 TeV	2.6 TeV	5.8 TeV
BE homogeneity volume	5000 fm^3	6200 fm^3	11000 fm^3
BE decoupling time	10 fm/c	11 fm/c	13 fm/c

QGP studies at the FCC: energy density

- Energy density with Bjorken formula

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

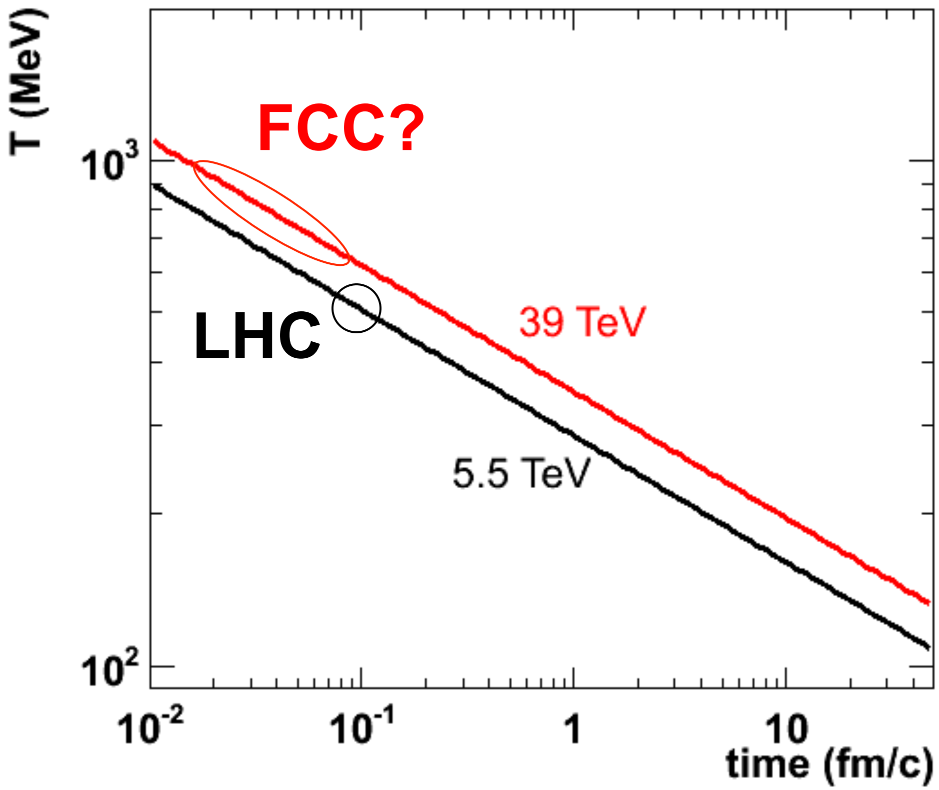


- x2.2 larger for the same time
  - E.g. 35 GeV/fm^3 at 1 fm/c
- Initial time (QGP formation time)?
  - Usually ~0.1 fm/c for LHC
  - Could be smaller at FCC
- Significantly larger initial energy density?

QGP studies at the FCC: temperature

- Temperature from S-B equation

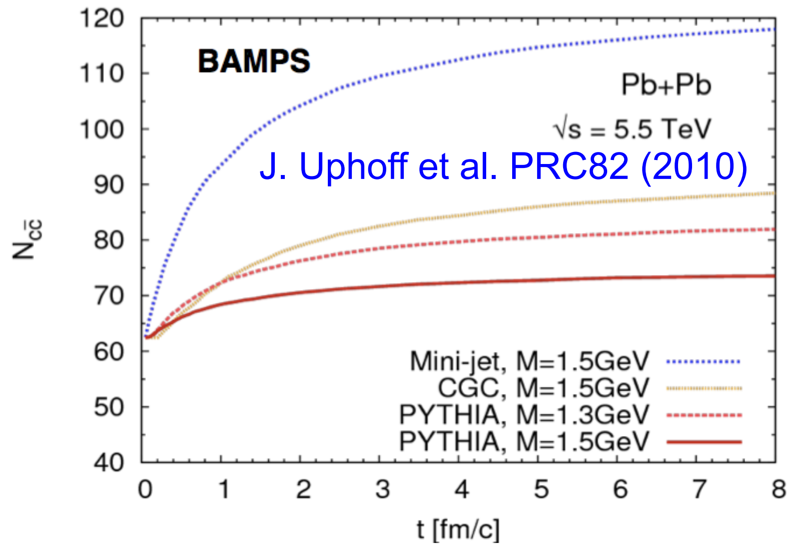
$$T(\tau) = \sqrt[4]{\varepsilon(\tau)\frac{30}{\pi^2 n_{d.o.f.}}}$$



- 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?

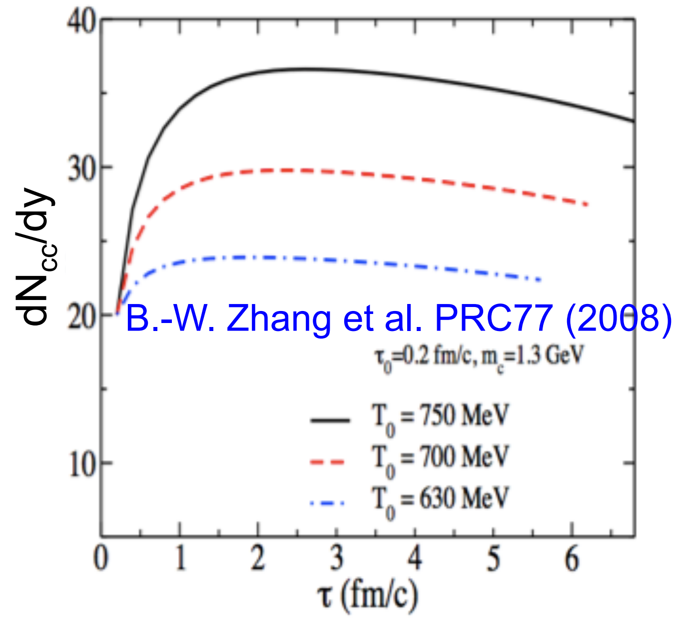
Charmed QGP? Secondary/thermal charm?

- Expect abundant production of c-cbar pairs in the medium
- Calculations for LHC 5.5TeV: + 15-45% wrt hard scattering
  - To be repeated for 39 TeV, could become comparable with initial production
- Should show up as "thermalized" component at 1-2 GeV
  - Need very precise reference in pp and pA collisions



- Secondary charm yield very sensitive to the initial temperature and to the temperature evolution
  - E.g. factor 2 difference between T_0 = 700 and 750 MeV

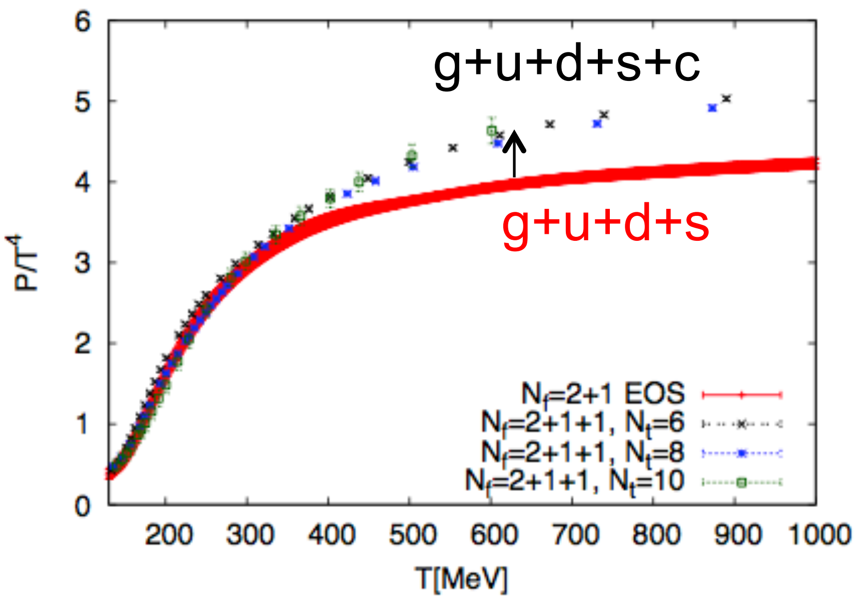
→ Unique opportunity at FCC



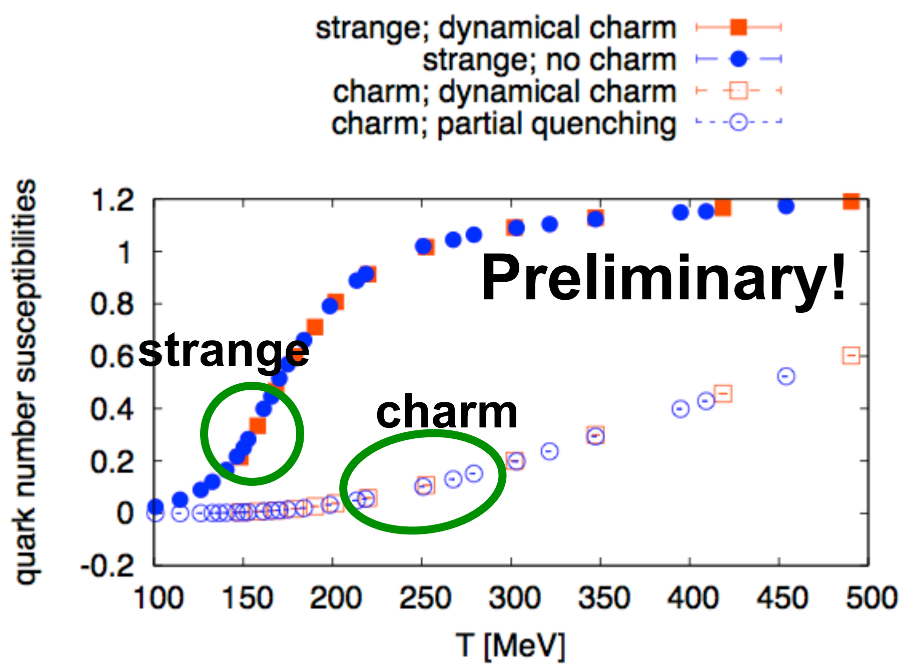
Charmed QGP?
Equation of state and charm deconfinement

- If charm is produced abundantly during the equilibration of the medium, this should show up in the equation of state

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



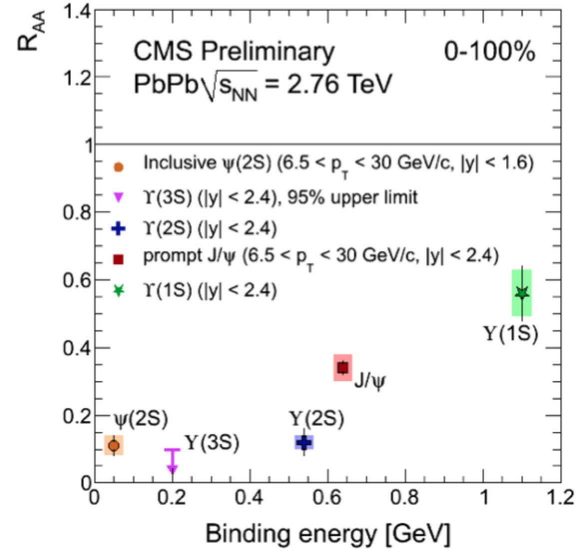
- Could verify the lattice QCD prediction that charm deconfinement occurs at ~1.5 T_C ~250 MeV, e.g. by fitting charm yields with resonance gas model



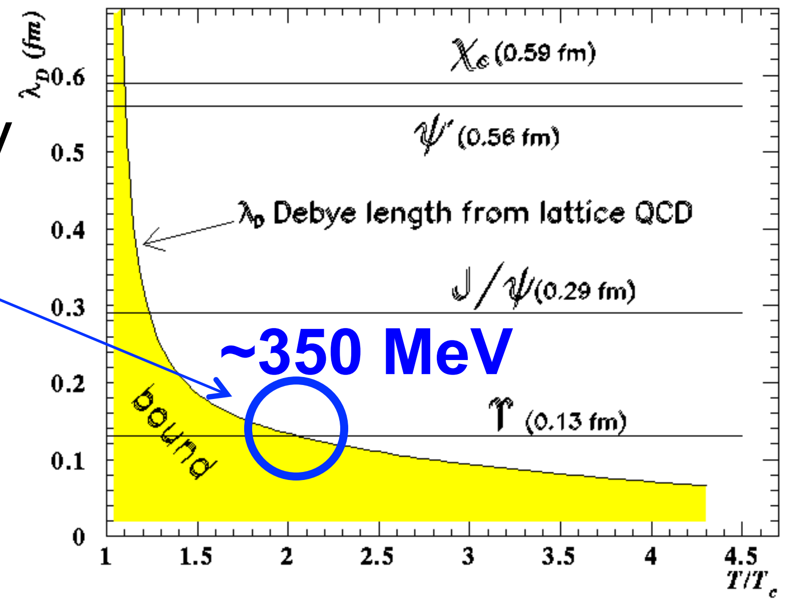
S. Borsanyi *et al*., arXiv:1204.0995

Υ(1S) melting at the FCC

- Sequential quarkonium melting (according to binding energy), one of the most direct probes of deconfinement
- Indication of sequential melting at LHC, but…
- Υ(1S) R_{AA}~0.5: consistent with suppression of higher states only
- Υ(1S) expected to melt at ~350 MeV



Digal,Petrecki,Satz PRD64(2001)
confirmed by recent calculations, e.g.
Miao, Mócsy, Petreczky, NPA (2011)



→ May not melt at LHC

→ Full quarkonium melting at FCC

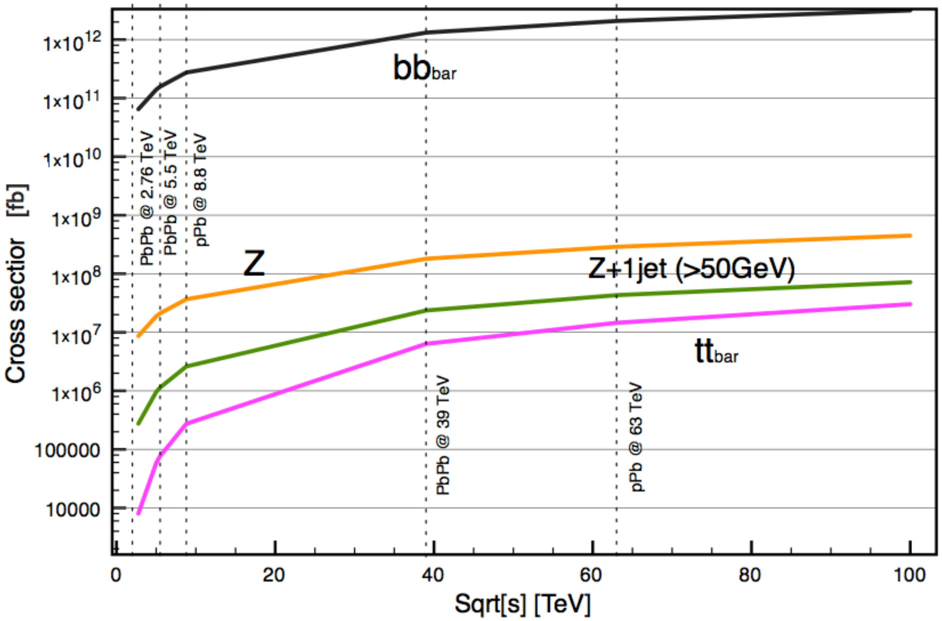
FCC: a new set of Hard Probes

- The current 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 …
    - HI performance in future detectors should reach the pp performance level of current LHC detectors
  - Final state distributions of based on these observables will be studied in depth in the HL-LHC
- The large cross section and luminosity of the FCC will allow tagging more complex decay topologies to isolate defined initial state parton configurations and their propagation in the medium
  - Probe the earliest phases of the collision
  - Defined parton configurations traversing the medium
    - e.g Z^0+n-jets, top quarks in $t\bar{t} \rightarrow \ell^+\ell^- + b\bar{b} + \not{E}_T$

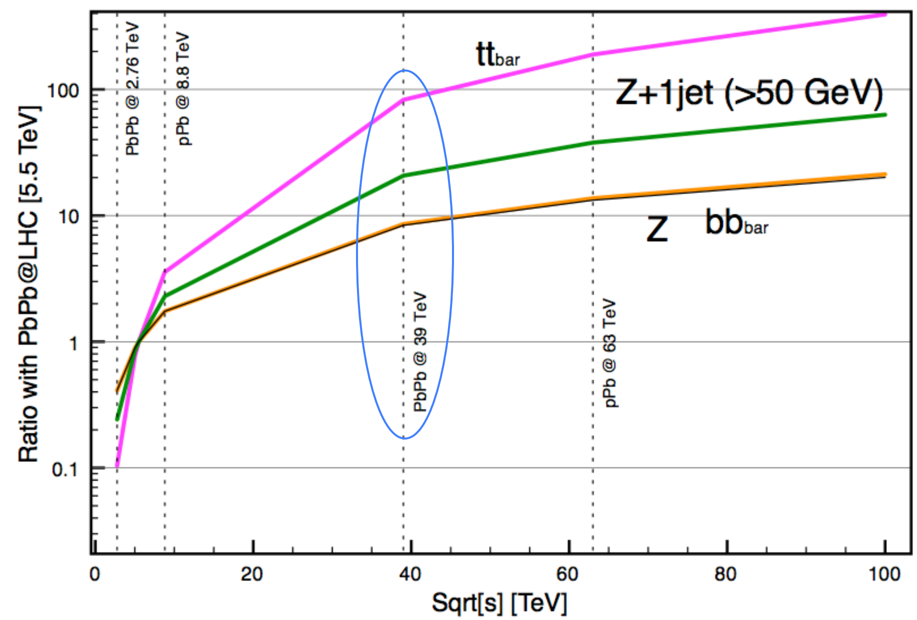
Hard probes cross sections: LHC→FCC

Computed for pp with MCFM (Campbell, Ellis, Williams, http://mcfm.fnal.gov)

$\sigma(\sqrt{s})$



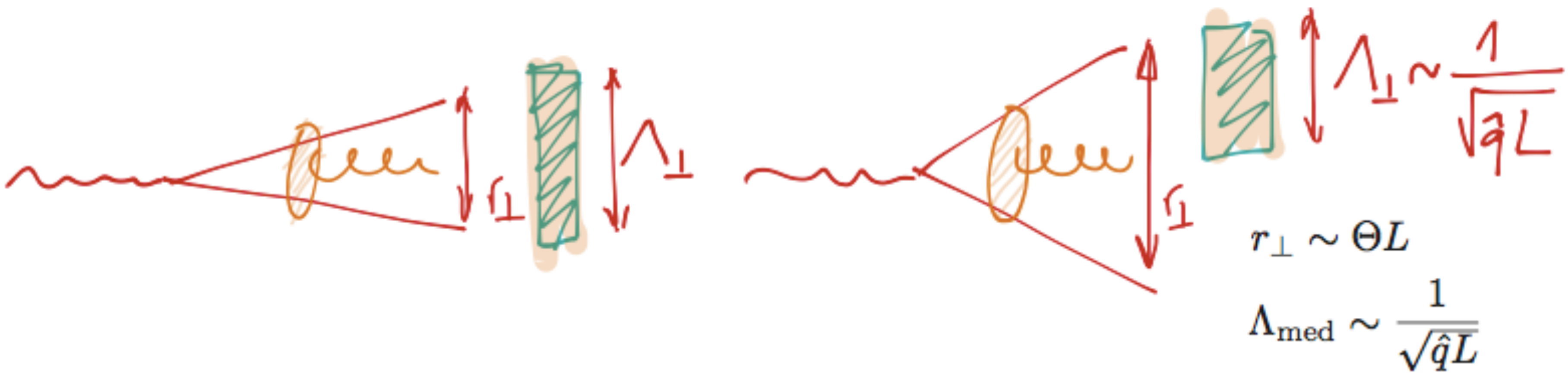
$\sigma(\sqrt{s}) / \sigma(5.5\ \text{TeV})$



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

An interesting physics case: boosted color singlets in the medium

Basic idea: the QCD medium does not affect colored objects smaller than its resolving power Λ



q-qbar with small opening angle; seen as color-singlet by the medium, no interaction expected

Medium induces decoherence, opening angle increases → energy loss of color-octet's in the medium

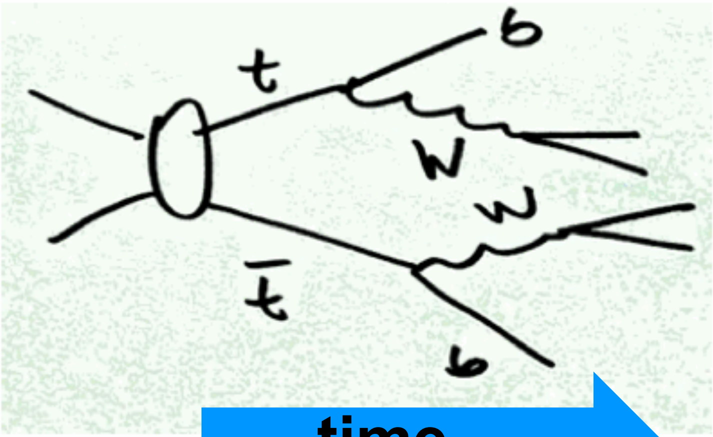
→ Boosted color singlet states can be used to probe the medium opacity / density at different time scales

Armesto, Casalderrey, Iancu, Ma, Mehtar-Tani, Salgado, Tywoniuk 2010-2014

An interesting physics case: boosted color singlets in the medium

First estimation of the timescales for boosted objects in the medium

$$t\bar{t} \rightarrow b\bar{b} + \ell + 2\,jets + \not{E}_T$$



time

	Pt=1 TeV	Pt=500 GeV
ttbat produced	0 fm/c	0 fm/c
top → W+b	1 fm/c	0.5 fm/c
W decay	1.6 fm/c	0.8 fm/c
qqbar in singlet	2.3 fm/c	1.3 fm/c

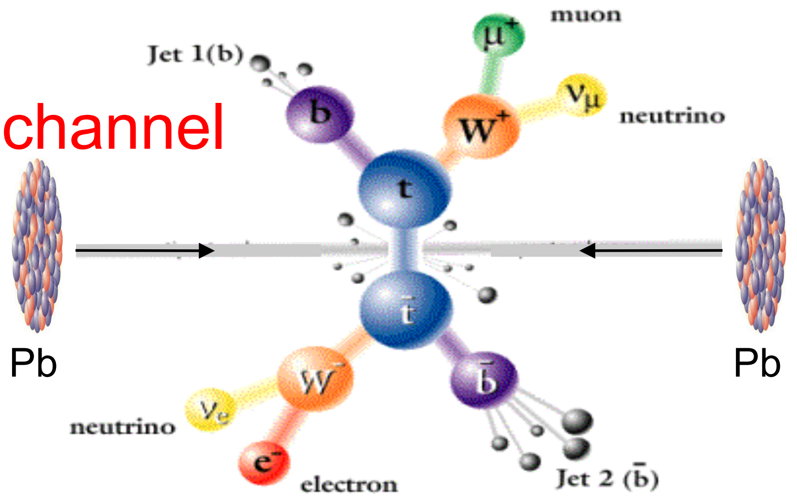
time

→ Interaction with the medium starts

A tool to probe timescale of medium evolution?

Top quarks in Pb-Pb at HL-LHC and FCC

- $t\bar{t}$ decay channels:
  - 10% $b\bar{b} + \ell\ell + \not{E}_T$ observation channel
  - 44% $b\bar{b} + \ell + 2\,jets + \not{E}_T$
  - 46% $b\bar{b} + 4\,jets$



- Estimate for observation channel in CMS (CMS PAS-FTR-2013-025)

→ ~500 events for 10 nb^{-1} Pb-Pb 5.5 TeV ("HL-LHC")

- FCC: with 50-100 nb^{-1}, x400-800 more wrt HL-LHC

→ With CMS-like setup, ~2-4x10^5 for "observation channel"
  - could be 4-5x more in the other channels (but higher background)

→ few 10^3 with p_T > 0.5 TeV

→ few 10^2 with p_T > 1 TeV

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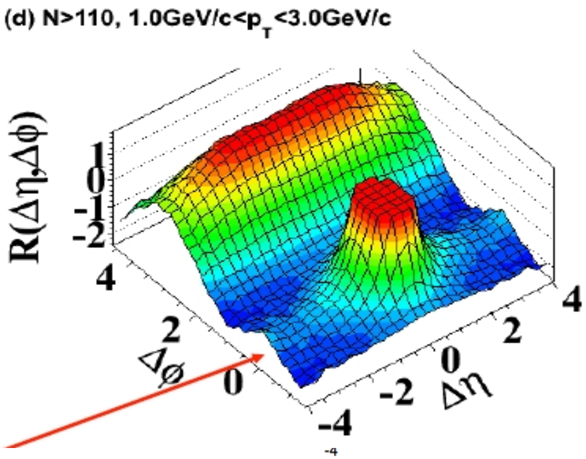
High-multiplicity events in small systems

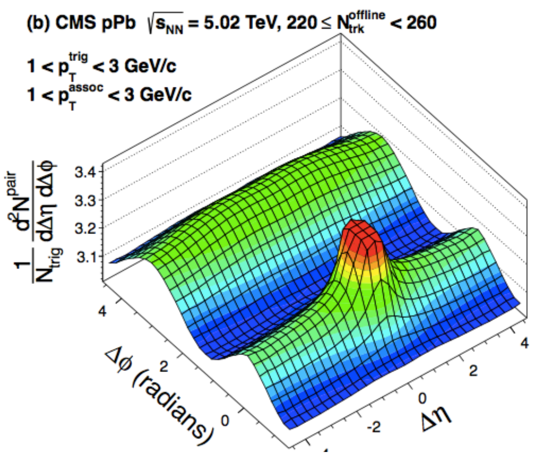
- One of the most interesting findings of the LHC HI programme: similarity of long-range correlations (ridge) in high-mult pp, pPb as in Pb-Pb collisions
- Similar mechanism? Collectivity in small high-density systems? Initial or final state collectivity?

pp, high mult



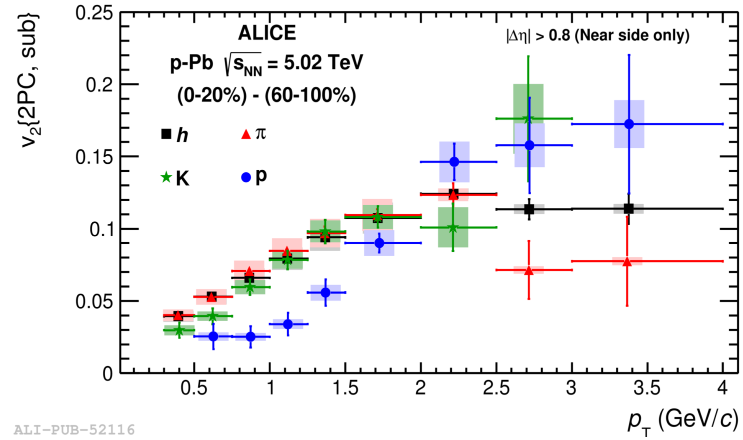
CMS, JHEP 1009 (2010) 091

pPb, high mult



CMS, PLB 724 (2013) 213

pPb, high mult



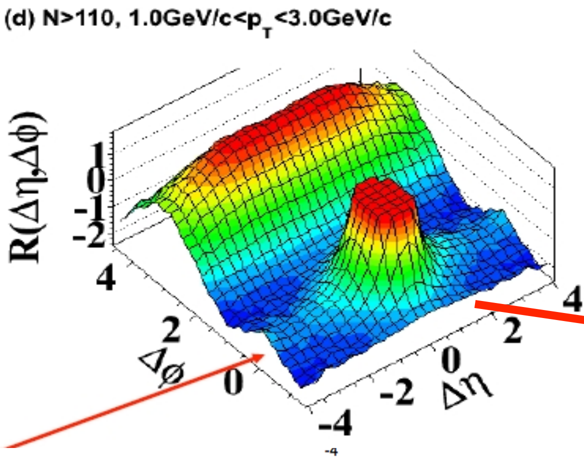
ALICE, PLB726 (2013) 164

- Increased energy of FCC could be a unique opportunity to explore more extreme multiplicities and study QCD mechanisms that lead to thermalization/collectivity

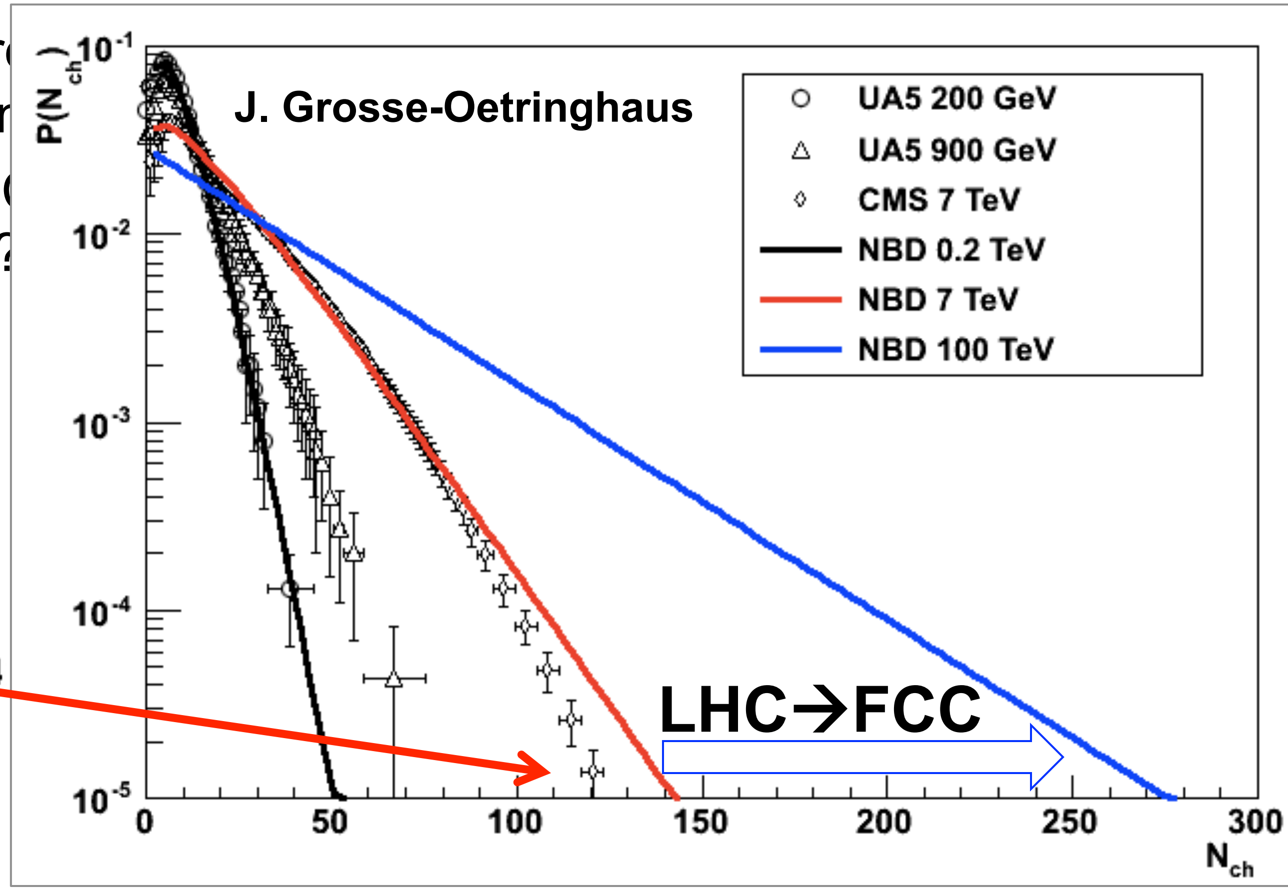
High-multiplicity events in small systems

- One of the most intere
long-range correlation
- Similar mechanism? (
final state collectivity?

pp, high mult



CMS, JHEP 1009 (2010) 091



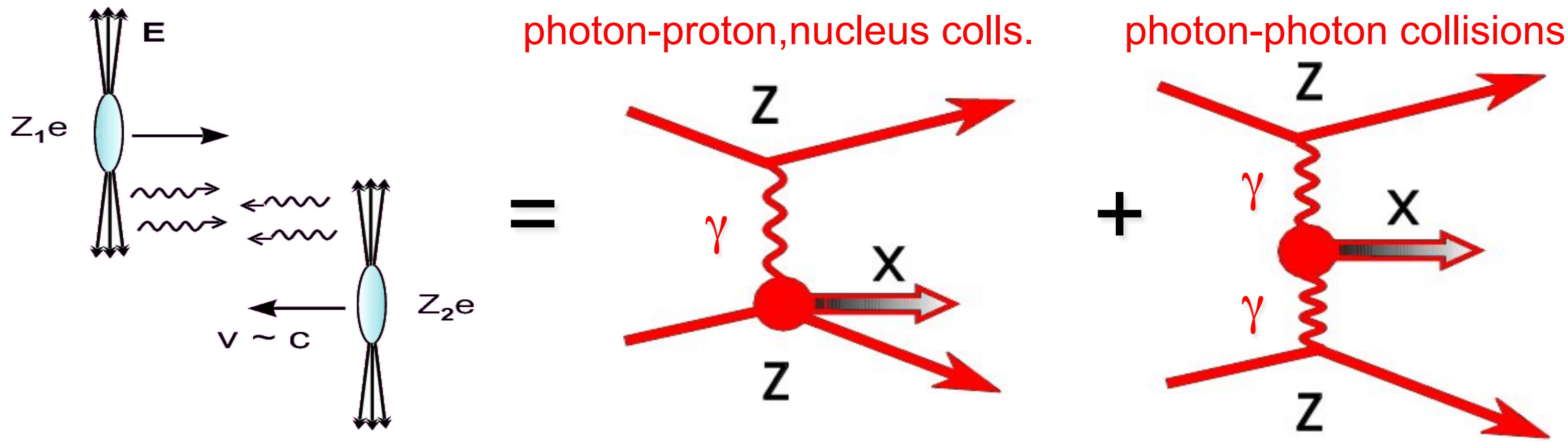
- Increased energy and luminosity of FCC could be a unique opportunity to explore more extreme multiplicities and study QCD mechanisms that lead to thermalization/collectivity

Outline

- Introduction, organization
- Future timeline with heavy ions at the LHC
- Ions at the FCC
- High-density QCD in the initial state: small-x and saturation
- High-density QCD in the final state: deconfinement and QGP
- High-multiplicity events in small systems (pp, pA)
- $\gamma\gamma$ collisions in a AA collider and connections to cosmic rays
- Summary

γ-induced collisions at FCC (Pb-Pb)

- Electromagnetic ultra-peripheral collisions (UPC): $b_{min} > R_A + R_B$
- HE ions generate strong EM fields from coherent emission of Z=82 p's:



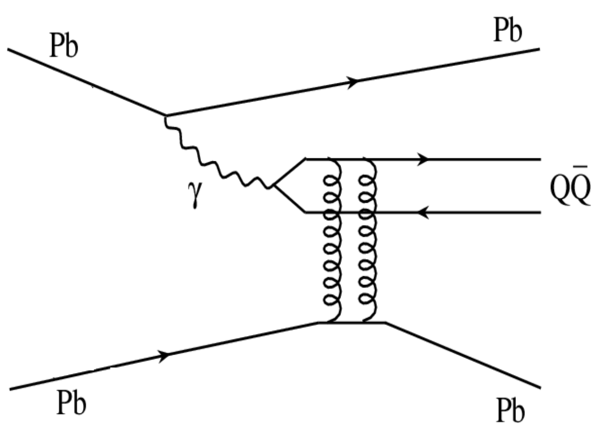
- Huge photon fluxes:
  - $\sigma(\gamma\text{-Pb}) \sim Z^2$ (~10^4 for Pb) larger than in pp
  - $\sigma(\gamma\text{-}\gamma) \sim Z^4$ (~$5 \cdot 10^7$ for PbPb) larger than in pp

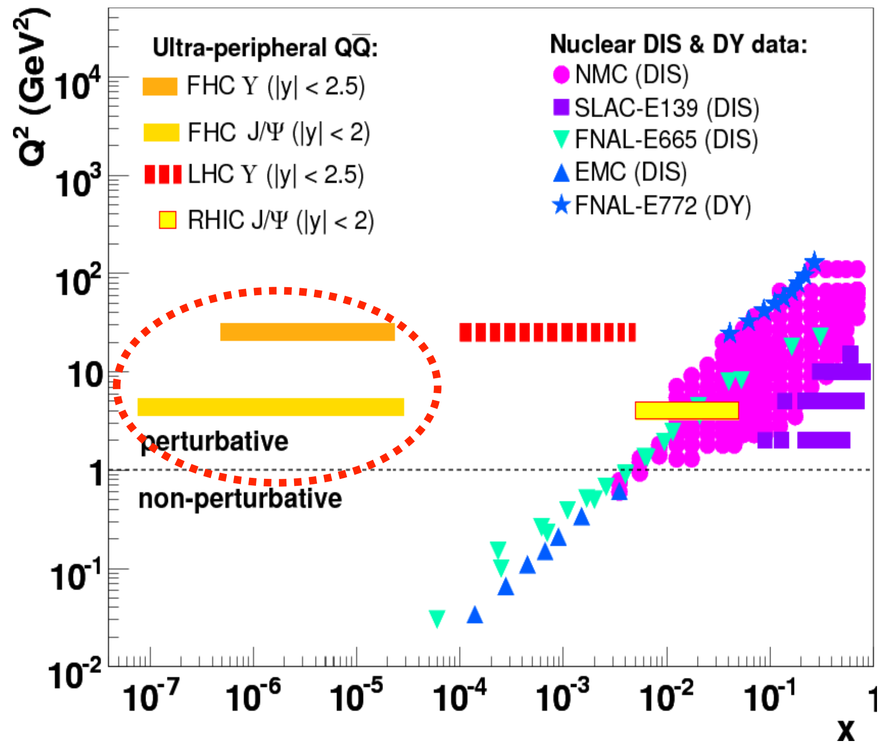
- Max. FCC γγ, γN √s energies:

PbPb: $\sqrt{s}_{\gamma\gamma} \sim$ 1.2 TeV $\sqrt{s}_{\gamma Pb} \sim$ 7 TeV
pPb: $\sqrt{s}_{\gamma\gamma} \sim$ 6 TeV $\sqrt{s}_{\gamma p} \sim$ 10 TeV

γ-Pb physics at FCC (Pb-Pb)

- Sensitive to <u>very</u> small *x* gluon density: powerful handle on saturation region with perturbative probes



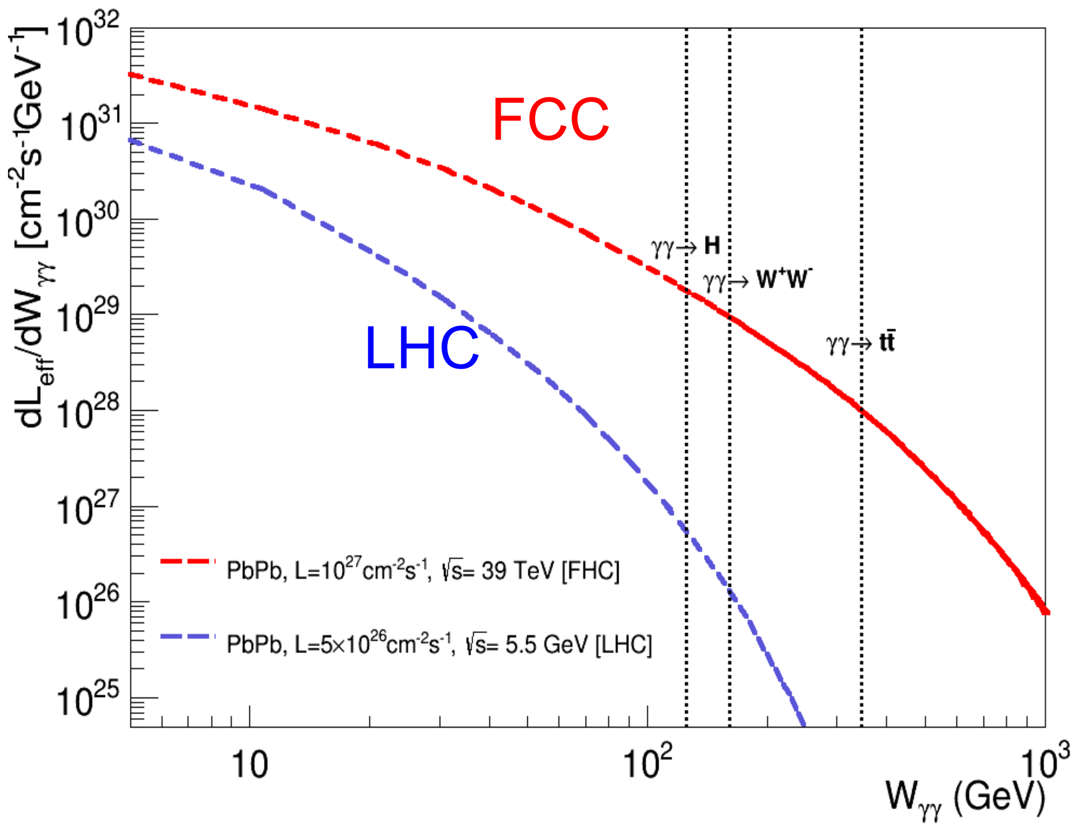


- Exclusive Q-Qbar: $x \sim m^2_{QQ}/s_{\gamma p,\gamma Pb} \sim 10^{-7}$
- Also: inclusive dijet, heavy-Q (also t-tbar)

~2 orders of magnitude below LHC!

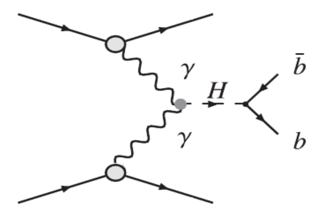
γγ physics at FCC (Pb-Pb)

- "Low masses": x4 higher effective lumi than at LHC-5.5 TeV
  Huge stats for: $\gamma\gamma \rightarrow \gamma\gamma$, double vector meson ($\gamma\gamma \rightarrow \rho\rho$, $J/\psi J/\psi$, $\Upsilon\Upsilon$),...
- High masses : x400 more lumi than LHC for Higgs
  x700 more lumi than LHC for W+W- (anomalous QGC)

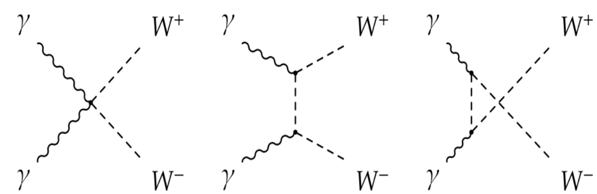


$$N_X = \int \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} W_{\gamma\gamma} \sigma_X^{\gamma\gamma}(W_{\gamma\gamma})$$

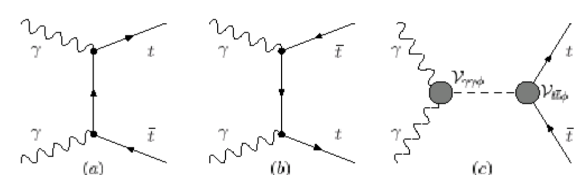
N_{Higgs} ~ 10 counts/month



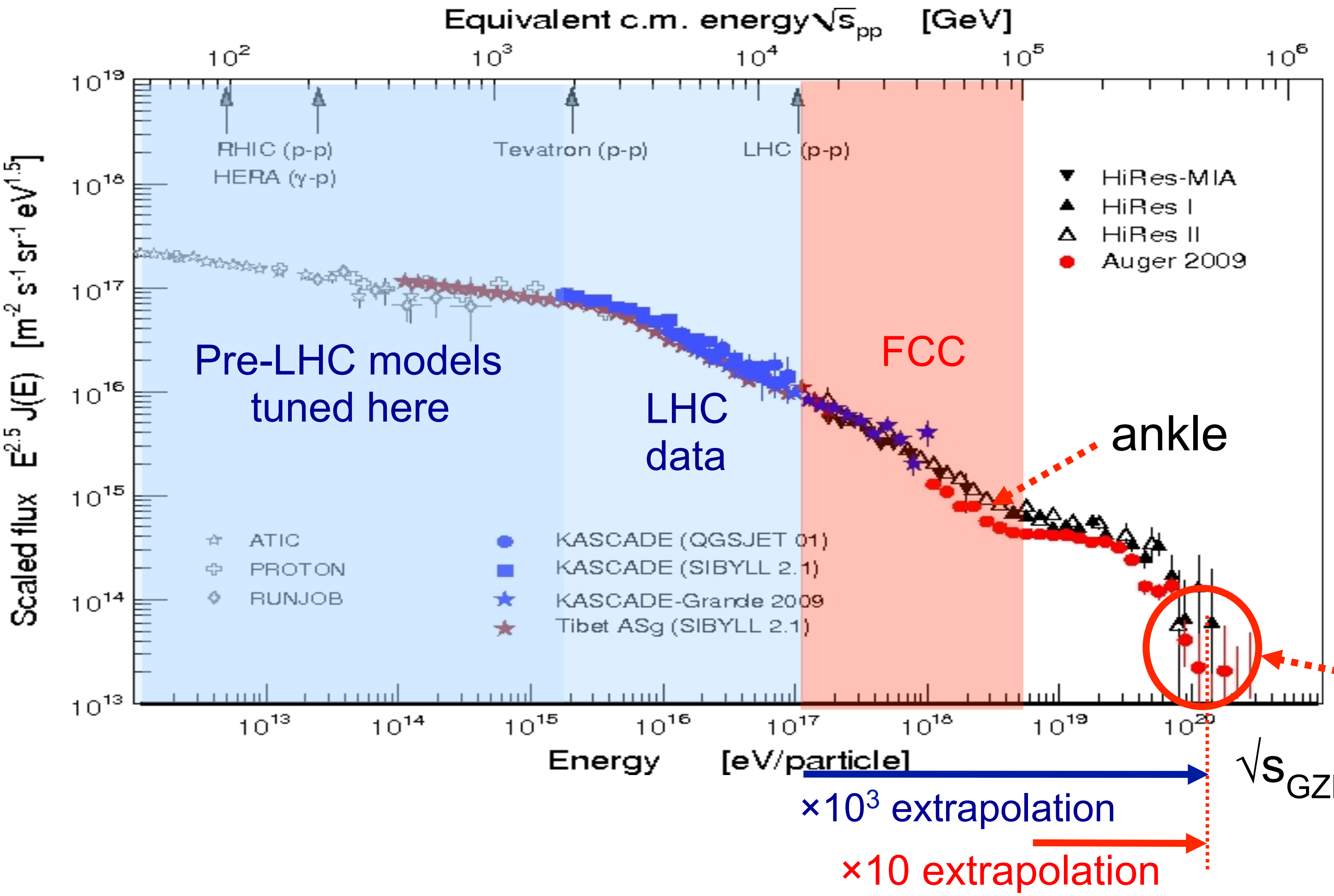
N_{W+W-}~ 1000 counts/month

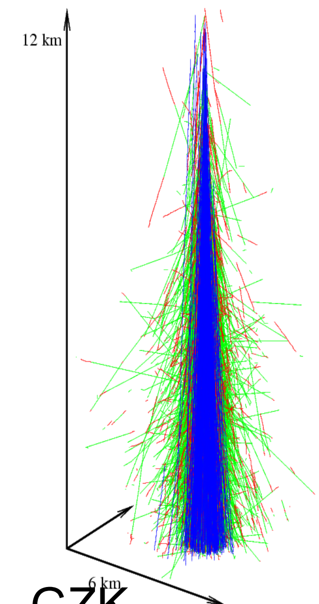


$N_{t\text{-}tbar}$~ few counts/month



Cosmic-rays MC tuning with FCC (Pb-Pb)





FCC pA and AA probe ankle-energy and provides strong constraints for hadronic Monte Carlos for UHECR (p,Fe+Air)

Summary and Outlook

- Group formed to discuss heavy ions at the FCC
  - Will be extended in the coming months
  - Could potentially become a work package within FCC-hh physics
- Saturation physics in pA, eA and γA
  - Higher energy and large nuclei provide unique access to the saturation region (down to $x \sim 10^{-7}$) with perturbative probes
- QGP physics
  - Much larger initial temperature and system volume entail potentially unique aspects
  - Higher energy and luminosity will be provide new, rarer, probes
- Plus: EW physics with $\gamma\gamma$ and benefit for UHECR studies

EXTRA SLIDES

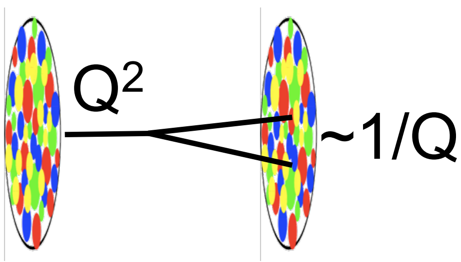
HI-HL-LHC Programme

(not exhaustive!)

- **Jets:** characterization of energy loss mechanism both as a testing ground for the multi-particle aspects of QCD and as a probe of the medium density
  - Differential studies of jets, b-jets, di-jets, γ/Z-jet at very high p_T (focus of **ATLAS** and **CMS**)
  - Flavour-dependent in-medium fragmentation functions (focus of **ALICE**)
- **Heavy flavour:** characterization of mass dependence of energy loss, HQ in-medium thermalization and hadronization, as a probe of the medium transport properties
  - Low-p_T production and elliptic flow of several HF hadron species (focus of **ALICE**)
  - B and b-jets (focus of **ATLAS** and **CMS**)
- **Quarkonium:** precision study of quarkonium dissociation pattern and regeneration, as probes of deconfinement and of the medium temperature
  - Low-p_T charmonia and elliptic flow (focus of **ALICE**)
  - Multi-differential studies of Υ states (focus of **ATLAS** and **CMS**)
- **Low-mass di-leptons:** thermal radiation γ ($\rightarrow$ e^+e^-) to map temperature during system evolution; modification of ρ meson spectral function as a probe of the chiral symmetry restoration
  - (Very) low-p_T and low-mass di-electrons and di-muons (**ALICE**)

Saturation scale

- Onset of non-linear QCD when gluons are numerous enough (low-x) & extended enough (low-Q^2) to overlap:



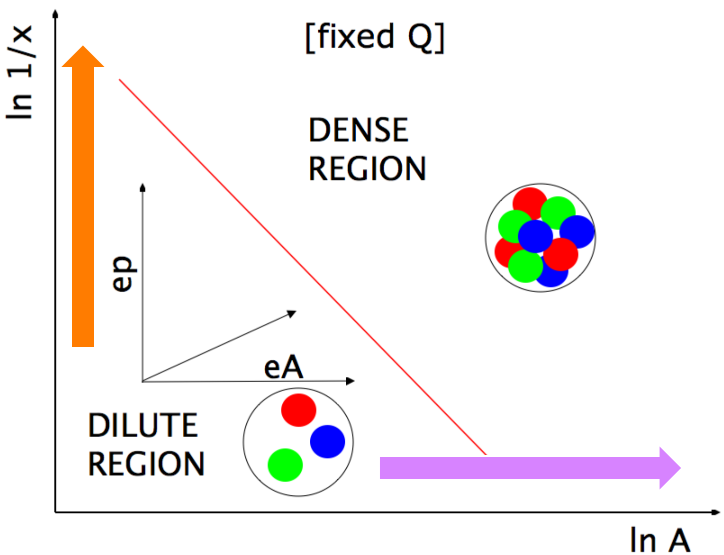
$$\frac{1}{Q^2} \cdot Ag(x,Q^2) \sim \pi R_A^2 \sim \pi A^{2/3}$$

gluon "area" — number of gluons — nuclear overlap

Saturation scale:

$$Q_S^2 \sim \frac{Ag(x,Q_S^2)}{\pi A^{2/3}} \sim A^{1/3} g(x,Q_S^2) \sim A^{1/3} \frac{1}{x^\lambda} \sim A^{1/3}\left(\sqrt{s}\, e^y\right)^\lambda$$

(λ~0.3)



Saturation affects process with $Q^2 < Q_S^2$

Explore saturation region:

→ **decrease *x* (larger √s, larger *y*)**

→ **increase A**

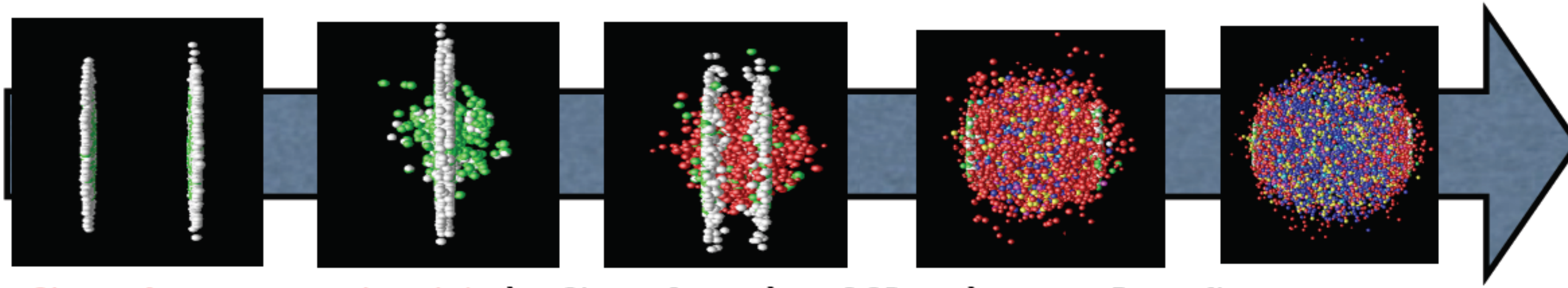
Some possibilities (not discussed in detail)

Observable	Sensitivity	
	Initial condition	Evolution
Charged single inclusive at fixed rapidity, HF: glue	yes	p_T dependence
DY, photons: sea and glue	yes	p_T dependence
Rapidity/energy evolution of single inclusive	yes	yes
Back-to-back correlations (charged, photons, jets,…): central-central, forward-forward	yes	p_T dependence
Back-to-back correlations: central-forward (charged, photons, jets,…)	yes	yes
Ridge	yes	???
…		

Plan: quantify impact of observables on nuclear PDF fits; expect constructive overlaps with ongoing LHC studies

REMOVE?

Relevance for the HI program



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

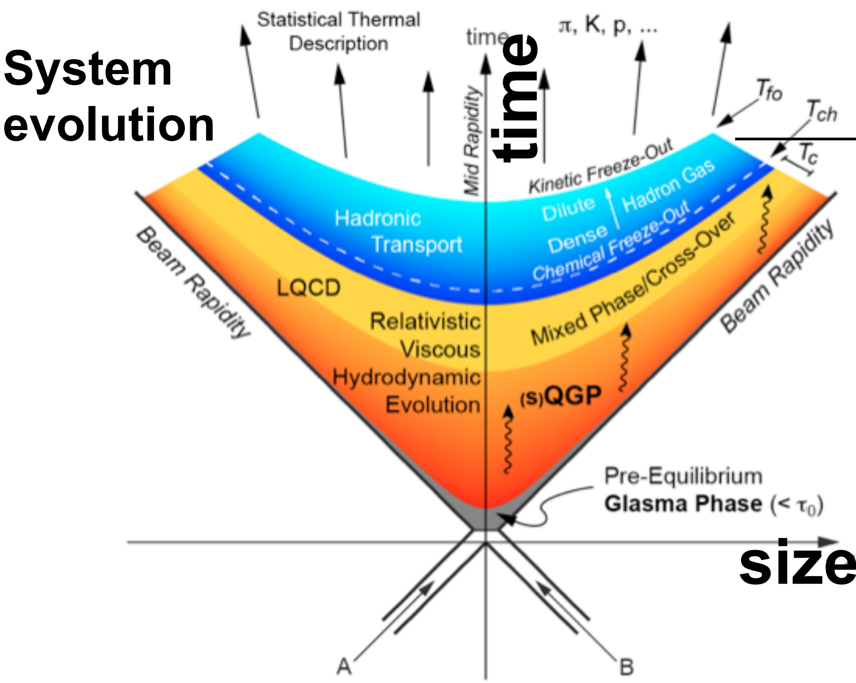
- Nuclear wave function at small x: nuclear structure functions.

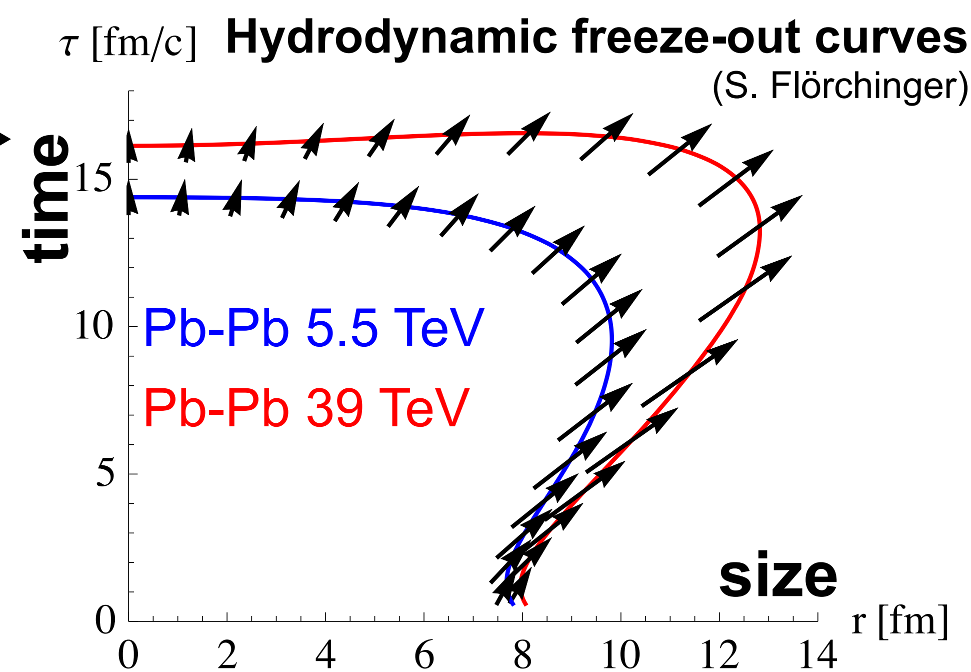
- Particle production at the very beginning: which factorisation in pA?

- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in pA.

- Probing the medium through energetic particles (jet quenching etc.): modification of QCD radiation and hadronisation in the nuclear medium.

Hydro simulation at FCC

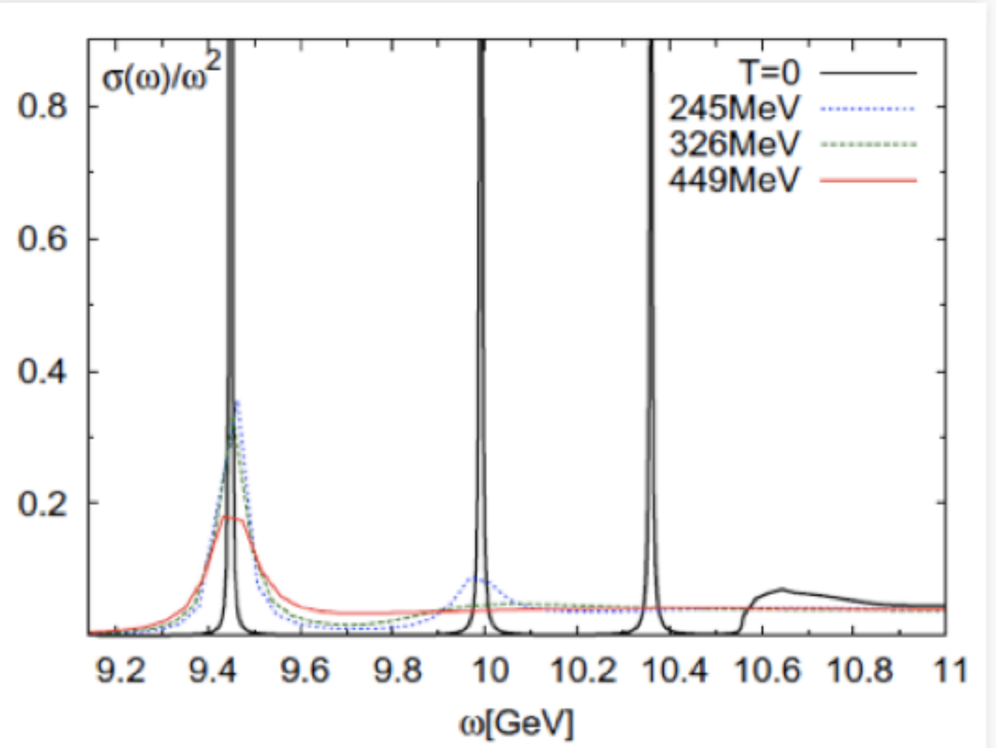




- Hydro-simulation (b=0, eta/s = 1/4pi, dN_{ch}/dy 3600 @ FCC) without
- initial fluctuations.
- In the simulation, the difference between FHC and LHC results from adjusting the initial temperature in the same geometry such that the final charged multiplicity increases to 3600 (instead of 1600 at LHC).
- The arrows along the curves indicate the direction and strength of flow

Υ(1S) melting at the FCC

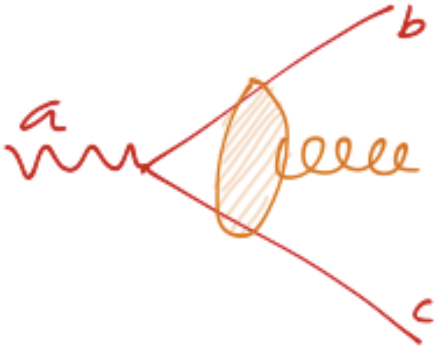
Miao, Mócsy, Petreczky, NPA (2011)



Υ(2S) and Υ (3S) melts by *T ~ 250* MeV and Υ(1S) melts by ~*350* MeV

Coherence and decoherence in the antenna

Antenna in the vacuum



$$r_\perp \sim \Theta\, t_{\rm form} \sim \frac{\Theta}{\theta^2 \omega}$$

$$\lambda_\perp \sim \frac{1}{k_\perp} \sim \frac{1}{\omega\theta}$$

$r_\perp > \lambda_\perp \iff \Theta > \theta$

Coherent emission

Antenna in the medium

- Decoherence parameter

$$\Delta_{\rm med} = 1 - \exp\left[-\frac{1}{12}\frac{r_\perp^2}{\Lambda_{\rm med}^2}\right]$$

$$r_\perp \sim \Theta L$$

$$\Lambda_{\rm med} \sim \frac{1}{\sqrt{\hat{q}L}}$$

- The medium color-rotates the antenna which eventually looses color coherence

Coherence for a singlet

- Decoherence parameter $$\Delta_{\rm med} = 1 - \exp\left[-\frac{1}{12}\frac{r_\perp^2}{\Lambda_{\rm med}^2}\right]$$

- For a given time t :::

$$r_\perp \sim \Theta t$$
$$\Lambda_{\rm med} \sim \frac{1}{\sqrt{\hat{q}t}}$$
$$\Delta_{\rm med} \sim 1 - \exp\left[-\frac{1}{12}\hat{q}\,\Theta^2\,t^3\right]$$

- So, the quark-antiquark pair remains in a color singlet during the time

$$t_{\rm sing} \sim \left[\frac{12}{\hat{q}\Theta^2}\right]^{1/3}$$

Top quark projection (FCC)

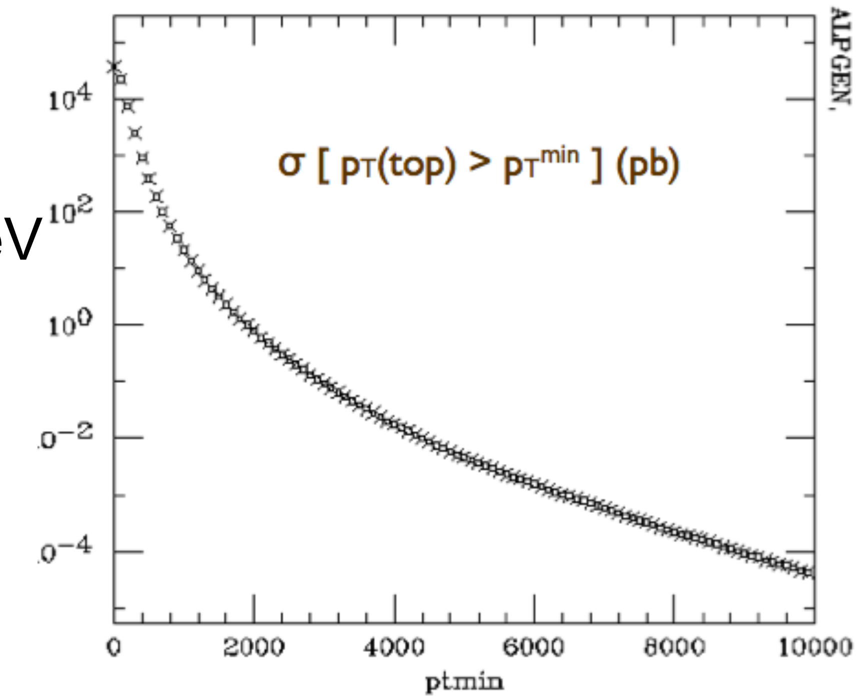
- ttbar cross section x80 from 5.5 to 39 TeV
- With L_{int}=50-100/nb, x400-800 top wrt 10/nb@LHC5.5

→ With a detector similar to CMS, we have ~2-4x10^5 in the "observation (cleanest) channel"; could be 4-5x more in the other channels

- Top cross section drops by 2 (3.5) orders of magnitude at p_T = 0.5 (1) TeV

→ few 10^3 with p_T > 0.5 TeV

→ few 10^2 with p_T > 1 TeV



M.Mangano, FHC informal meeting Nov 2013