

EF07 Highlights – SEC perspective

QCD and strong interactions: Heavy Ions

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Snowmass Day

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EF07: QCD and strong interactions: Heavy Ions¹

- New territories to explore for heavy ion physics
 - Small systems at LHC, e.g. pO / OO
 - New physics
 - EIC
- New detectors and facilities
 - Very soon: upgraded ALICE and LHCb, sPHENIX
 - Soon: Phase-2 (HL-LHC) ATLAS and CMS
 - EIC!
- Still a lot to learn about QGP, cold nuclear matter, nuclear PDF, ...

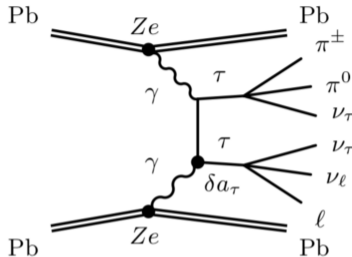
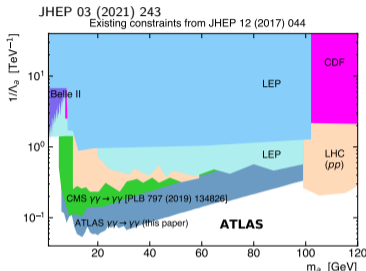
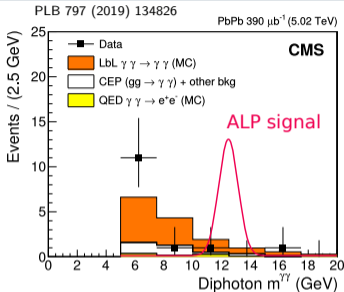
NB: this talk is on my behalf only. I will flash a few example studies but will surely miss many important works from EC physicists.

¹Conveners: Yen-Jie Lee (MIT), Swagato Mukherjee (BNL)



- Possibility to have Oxygen at the LHC during Run 3 (2024 ?)
- Details being discussed (e.g. collision energy)
- Interest for [cosmic ray physics](#) (especially pO), [small systems / QGP](#) (pPb < OO < XeXe)
- Workshop: [OppOrtunities at the LHC](#) (Feb 4–10 2021, see [summary](#) at EF workshop)





Heavy ion collisions are already used to search for new physics!

- Axion-like particle (ALP) search in $\gamma\gamma \rightarrow \gamma\gamma$ (ATLAS, CMS)
- Magnetic monopoles (MoEDAL)

Many more possibilities:

- $g - 2$ of the τ lepton: potential to improve constraints from LEP
- Sexaquark search
- ...

Workshop: [Heavy ions and new physics](#) (May 20–21, 2021, see [summary](#) at EF workshop)

See also [Snowmass Lol](#)



Workshops: Quarkonia as Tools ([2019](#), [2020](#), [2021](#))

See also writeup: *Perspectives for quarkonium studies at the high-luminosity LHC* ([arXiv:2012.14161](#))

Examples of [new experimental studies at the HL-LHC](#):

- Energy dependence using fixed-target collisions (LHCb)
- Excited and exotic charmonia: $\psi(2S)$, $\Upsilon(3S)$, $X(3872)$
- v_2 , polarisation

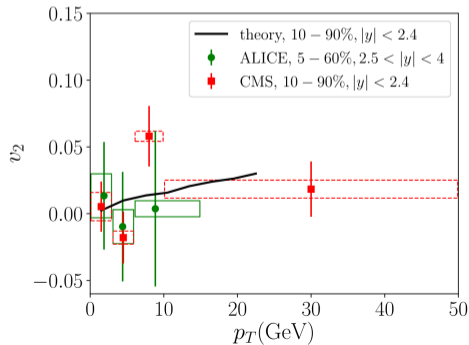
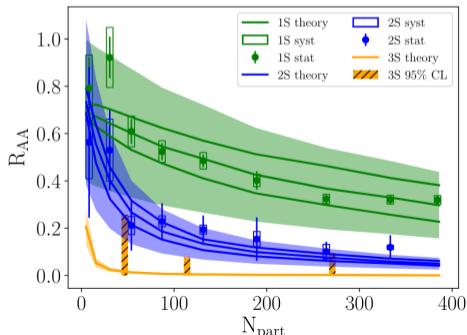
[Novel theory developments](#): e.g. EFT or open quantum system approaches

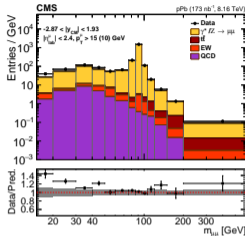
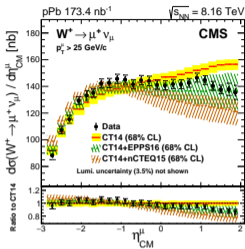


Quarkonium dynamics inside the QGP as an open quantum system

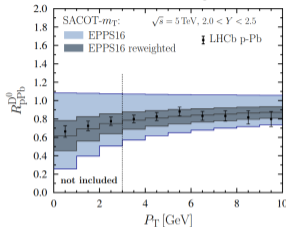
Xiaojun Yao et al, JHEP 01 (2021) 046

- Boltzmann equation for each quarkonium state
- Medium information \rightarrow gauge-invariant chromoelectric field correlators (generalizations of the heavy quark diffusion coefficient)
- Bottomonia: good agreement with LHC data (though nPDF uncertainty dominates)
- Plans:
 - Study charmonium production
 - Bayesian analysis to extract chromoelectric field correlators from data

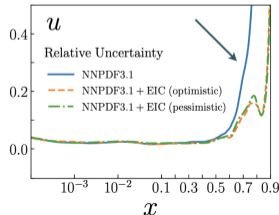
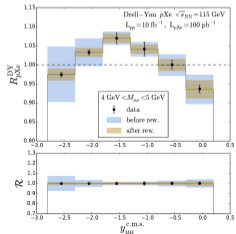
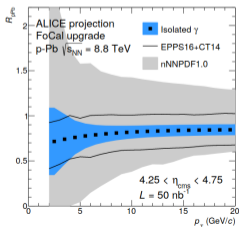
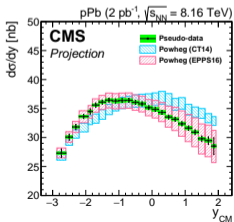




Snowmass Lol by G. Krintiras, EC, H. Paukkunen

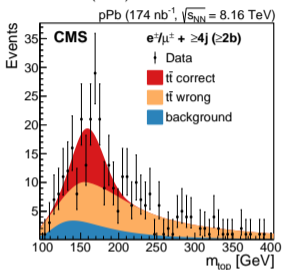


- LHC data provide new constraints: e.g. W bosons, Drell–Yan, heavy flavour
- Much more expected in the future: HL-LHC, FOCAL (ALICE), fixed-target (LHCb), EIC...

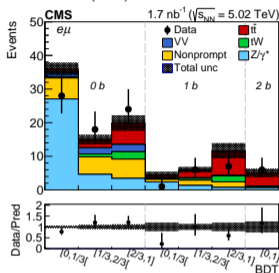




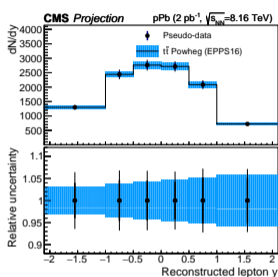
PRL 119 (2017) 242001



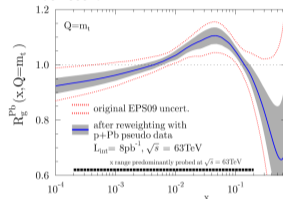
PRL 125 (2020) 222001



CMS-PAS-FTR-18-027



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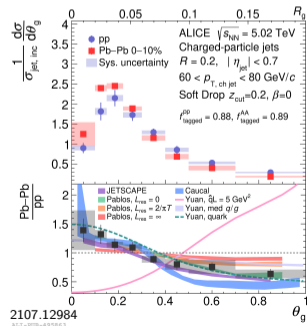
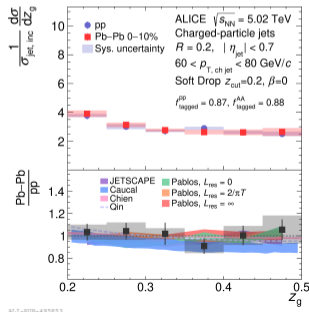
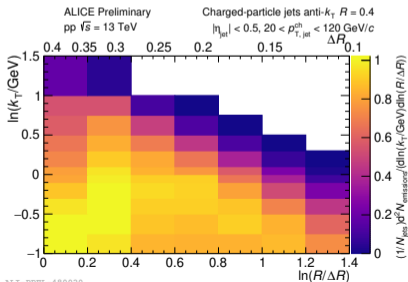


- Top quarks recently measured for the first time in heavy ion collisions (pPb, PbPb) by CMS
- Sensitive to nPDF
- New probe for jet quenching in AA
- HL-LHC: differential cross section in pPb, time-dependent quenching in ArAr?
- FCC: much more precise



Inputs from J. Mulligan

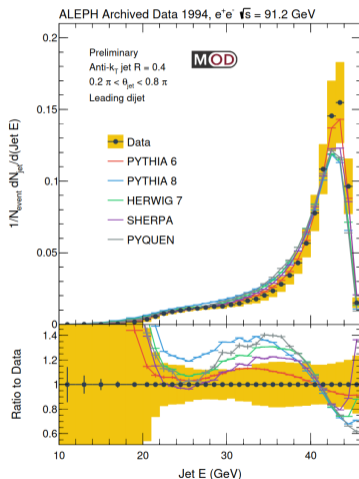
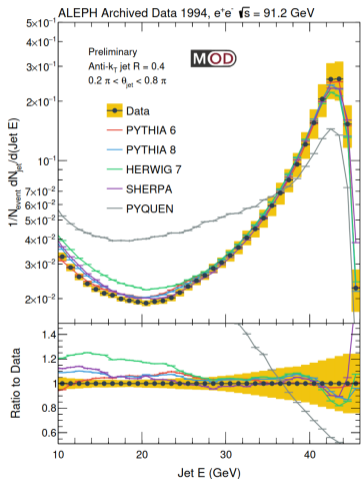
- More and more observables being measured in **pp** (Lund plane, dead cone...) and **AA** (groomed substructure z_g and θ_g , N -subjettiness τ_N , subjet fragmentation z_r ...)
- Complementarity between pp and AA to understand perturbative vs. nonperturbative physics
- "Hard" vs "soft" substructure
- Challenging background in AA – still room for improvement
- Global analysis will be key to uncovering the nature of deconfined QCD matter





Since the end of LEP operation, significant progress has been made in jet definition and jet algorithms:

- Jet substructure observables have been widely explored in pp and HI collisions
- Novel tools for jet flavor identification, EW boson & top tagging and studies of QGP
- However, those techniques are not yet used in $e^+ e^-$ annihilation data





- Lots of ideas about what future HI data can teach us
- Could not cover many topics, e.g. EIC, fixed target (including LHC), ...
- Early Career physicists playing an important role

For more information, see e.g. [Yen-Jie's slides](#) at the recent EF "restart" workshop and the corresponding [EF07 parallel session](#)