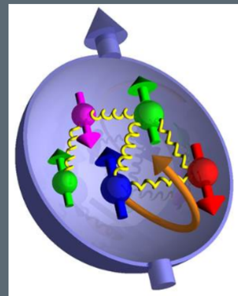
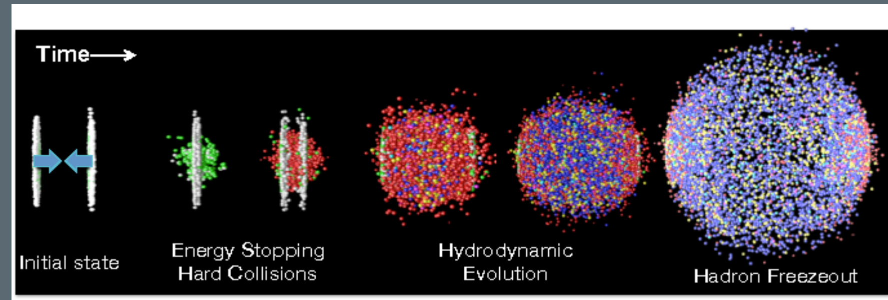
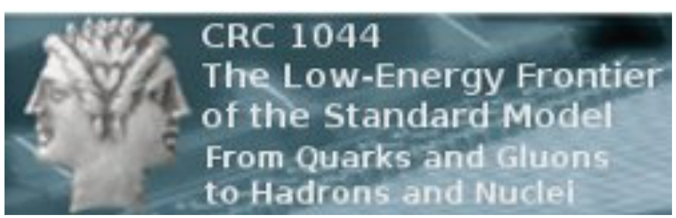
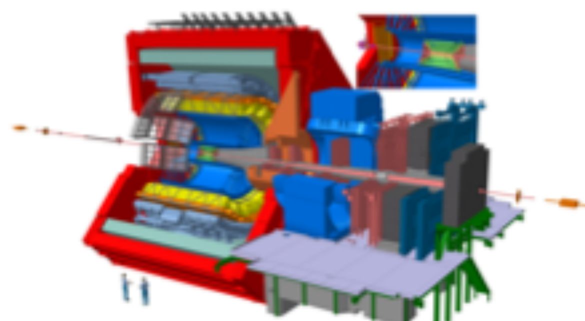




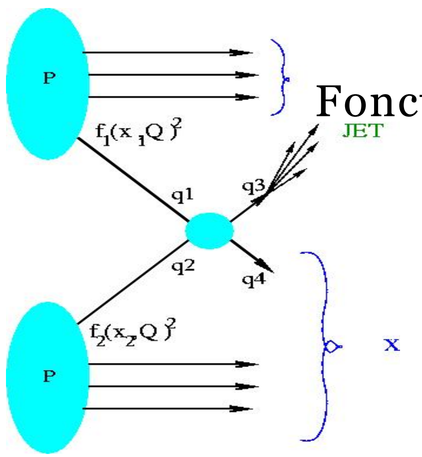
Physique hadronique

Prospectives LPC+
Marrand 11/07/2018





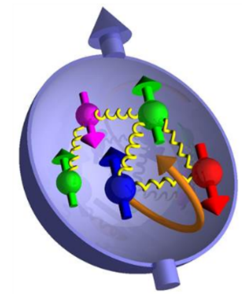
Panorama de la Physique des Interactions Fortes



pQCD

Fonction de Distribution Partonique

Structure du nucléon



Diffusion inélastique profonde

L-QCD

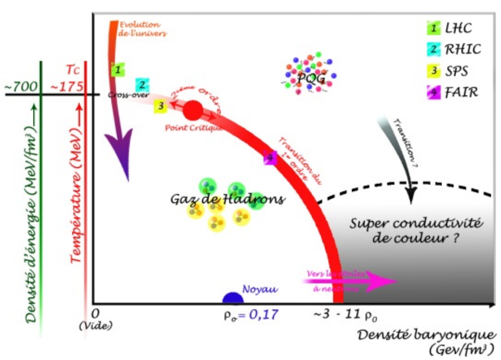
Physique des interactions fortes
QCD (ChromoDynamique Quantique)

Physique à grand xF

Physique de la saturation

Hadronisation

Physique du Spin



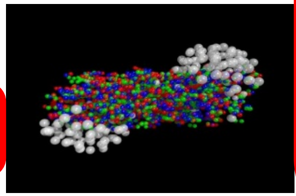
Exploration du diagramme des phases de la matière nucléaire

Quarkonia, Bottomonia, Saveurs lourdes ouvertes

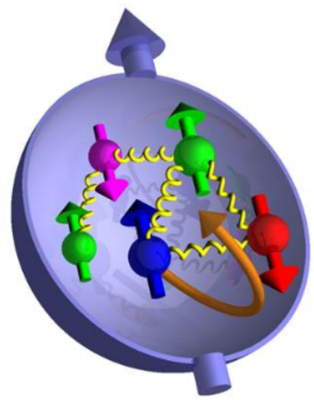
Sondes dures

Sondes globales

Plasma de Quarks et de Gluons



Structure du nucléon (proton/neutron)



La sonde électromagnétique à hautes énergies permet d'accéder aux :

- ✓ distributions de partons généralisées (GPD)
- ✓ distributions non-intégrées en impulsion transverse (TMD)
- ✓ amplitudes de distributions de transition (TDA)

⇨ Taille et structure longitudinale des hadrons

À basses énergies :

- ✓ distribution de quarks étranges dans le nucléon
- ✓ polarisabilité électrique et magnétique du proton

Au LPC depuis 2002 :

- ➢ Diffusion Compton Virtuelle et polarisabilité du nucléon (MAMI)
- ➢ 3 thèses et 5 stages M2 soutenus
- ➢ Co-porte parole Diffusion Compton Virtuelle , « associated PI » dans le CRC1044

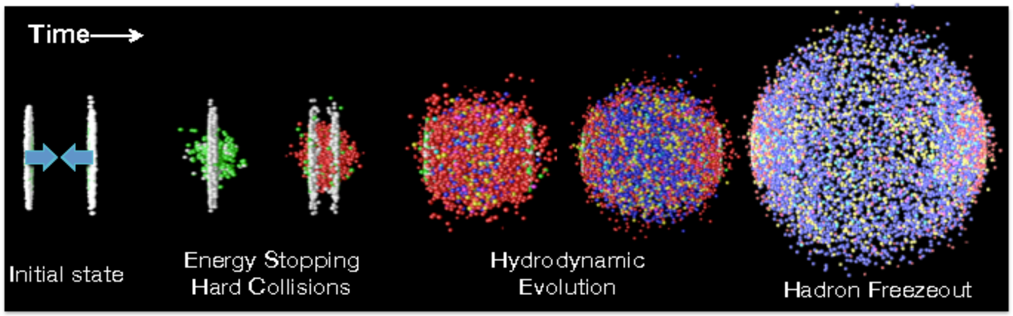
Enjeux de la communauté structure du nucléon basse énergie :

« The Low-Energy Frontier of the Standard Model ; from Quarks and Gluons to Hadrons and Nuclei »

Limites et perspectives au LPC : 1 permanent

- Horizon à court terme , 2018-2020, finalisation et publication des résultats préliminaires des 2 thèses récemment soutenues,
- implication dans les prospectives à long terme (expérience VCS future à Mainz et réanalyse des données pour la recherche de « dark photon »)

Pourquoi/comment étudier le Plasma de Quarks et de Gluons (QGP)?



Pour comprendre la matière nucléaire (diagramme des phases) dans des conditions extrêmes de température et de pression.

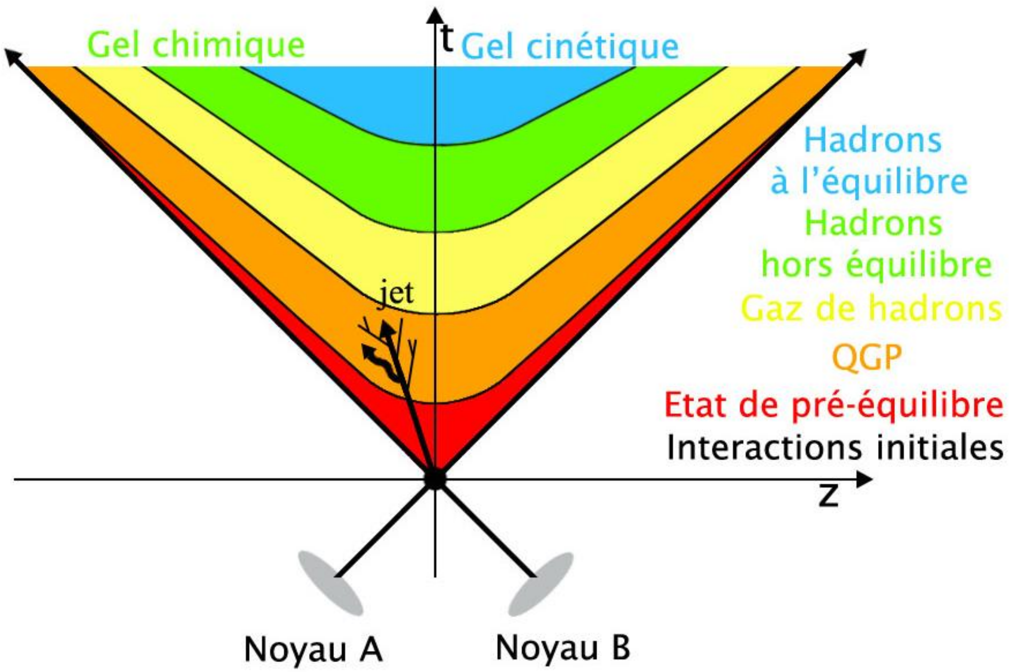
Étude du déconfinement

Dans les collisions d'ions lourds à haute énergie

SPS : indices de formation
RHIC : découverte du (s)QGP

Sondes globales : produites lors de l'hadronisation du QGP

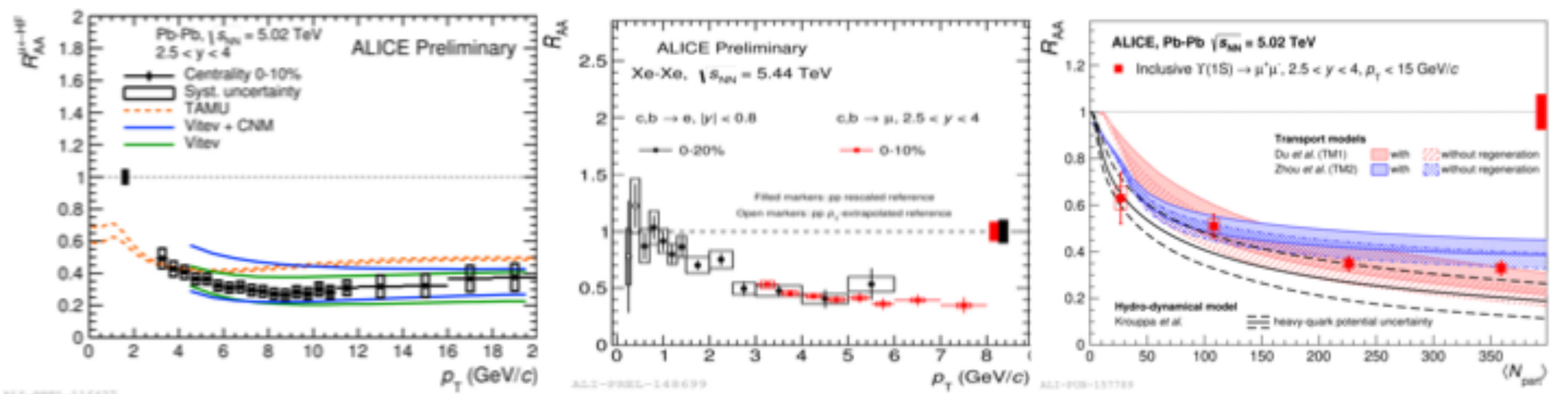
Sondes dures : produites lors de l'interaction initiale, traverse le QGP avant d'être détectées



Saveurs lourdes ouvertes et Quarkonia comme sondes du QGP

- Quarks lourds produits dans les premiers instants de la collision (processus durs gg)
  Permettent de caractériser le milieu produit

Facteur de modification nucléaire $R_{AA} = \frac{dN_{AA}/dp_T}{<N_{coll}> dN_{pp}/dp_T}$



Facteur de modification nucléaire < 1 interprété avec des effets de milieux chauds (QGP)
Effets froids (matière nucléaire) contrainte par R_{pA}
Section efficace inclusive pp bien décrite par les modèles

Très grande implication/expertise du LPC
(beaucoup d'autres analyses publiés et en cours : polarisation J/ψ, flow elliptique, Z)

Saveurs lourdes ouvertes et Quarkonia comme sondes du QGP

- Processus de production
  - impact des radiations de gluons
  - shadowing, corrélations d'état initial
  - production par fragmentation de gluons
  - Quarkonia : partie non perturbative de la production de l'état lié

- Propagation dans le QGP
  - perte d'énergie radiative et collisionelle
  - coefficients de transport

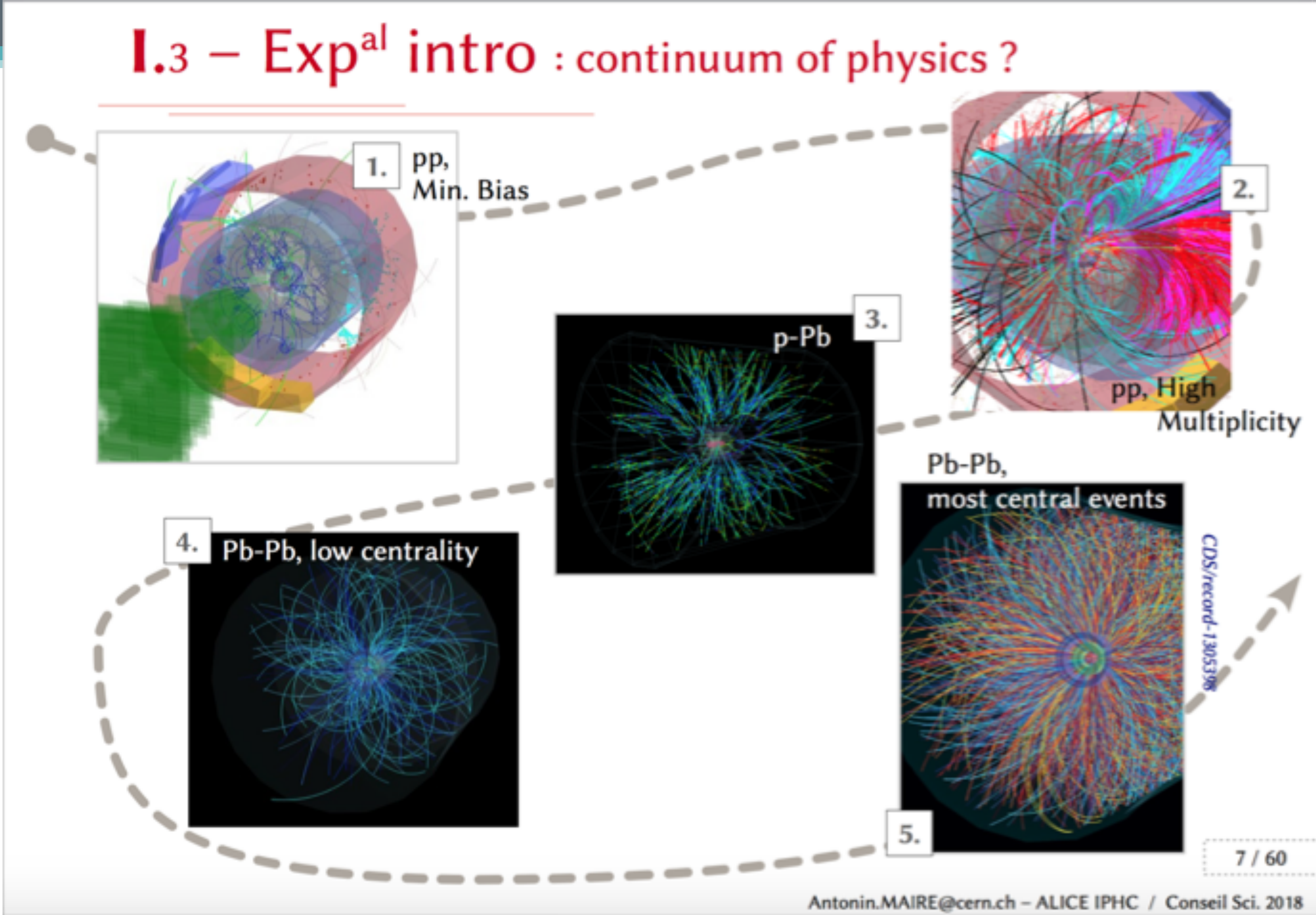
- Hadronization
  - Recombinaison
  - fragmentation

- Propagation dans un gaz hadronique
  - section efficace peu contrainte
  - Quarkonia : effet de dissociation par co-movers

Signes de QGP dans les petits systèmes au LHC ?

Table prepared by the WG small systems from the HL/E-LHC working group
See the yellow report, in preparation, for references (140)

Observable of effect	Pb-Pb	pPb (high mult)	pp (high mult)
SOFT Probes			
low p_T spectra ("radial flow")	yes	yes	yes
Intermediate p_T ("recombination")	yes	yes	yes
HBT radii	$R_{out}/R_{side} \sim 1$	$R_{out}/R_{side} \lesssim 1$	$R_{out}/R_{side} \lesssim 1$
Azimuthal anisotropy (v_n) (2 prt. correlations)	v_1-v_7	v_1-v_5	v_2-v_4
Characteristic mass dependence	v_2-v_5	v_2-v_3	v_2
Higher order cumulants	"4~6~8 " + higher harmonics	"4~6~8 " + higher harmonics	"4~6 "+ higher harmonics
Event by event v_n distributions	n=2-4	Not measured	Not measured
Event plane and v_n correlations	yes	yes	yes
HARD Probes			
Direct photons at low-p_T	yes	Not measured	yes
Jet Quenching	yes	Not observed	Not observed
Quarkonia	J/Ψ regeneration / Υ supression	suppressed	Not measured
Heavy-flavor anisotropy	yes	yes	Not measured



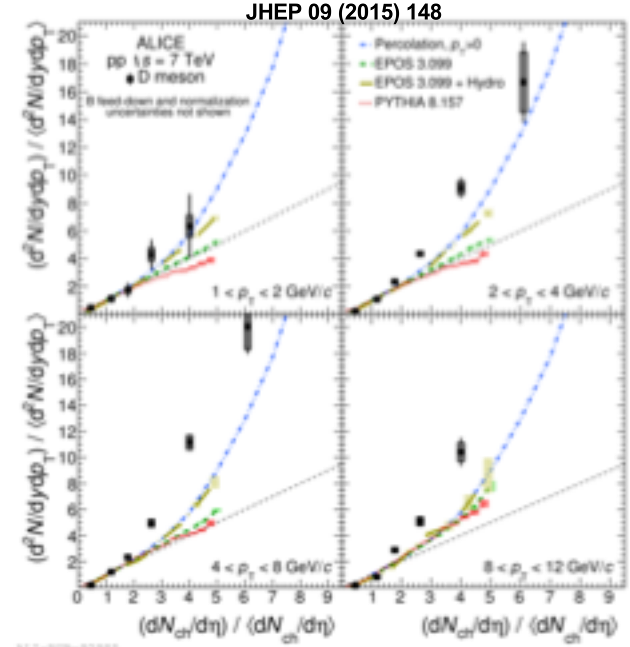
pp/pA/AA à la même multiplicité de particules chargées, est-ce le même comportement, rôle de la géométrie?

Comment est réalisée la transition de petit à grand système ?

QGP et collisions hadroniques

- Observe-t-on des gouttelettes de QGP dans les petits systèmes ? Collectivité vs. QGP
- Quid de l'interaction des sondes dures avec une gouttelette de QGP ?
- Quel mécanisme de l'état initial permettrait d'atteindre la densité d'énergie associée à la transition de phase dans les petits systèmes ? Est-ce le même
- Dans quelle mesure les collisions hadroniques à hautes énergies peuvent être décrites avec un seul formalisme ?

JHEP 09 (2015) 148



Au LPC : corrélation "hard-soft" via le charm et la beauté (J/ψ, D, Υ) en fonction de la multiplicité

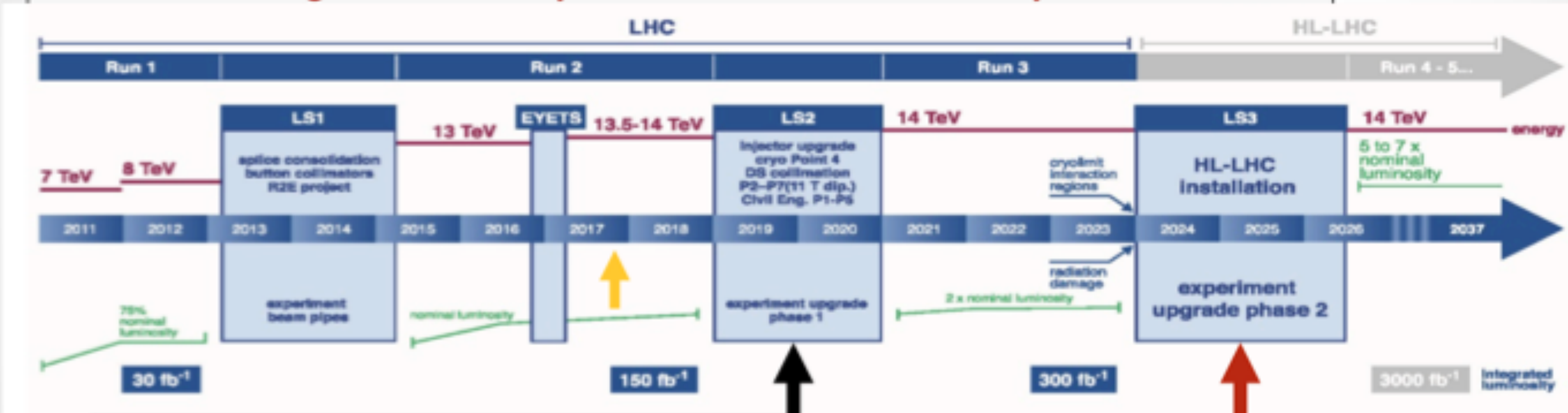
Flow elliptique des single muons et Upsilon dans différents systèmes

Run 3/4

LHC upgrades (LIU + HL-LHC): parameters and timeline

Nominal LHC: $\sqrt{s}$ = 14 TeV, L= 1×10^{34} $cm^{-2}s^{-1}$
Integrated luminosity to ATLAS and CMS: 300 fb^{-1} by 2023 (end of Run 3)

HL-LHC: $\sqrt{s}$ = 14 TeV, L= 5×10^{34} $cm^{-2}s^{-1}$ (levelled)
Integrated luminosity to ATLAS and CMS: 3000 fb^{-1} by ~ 2035



LS2 (2019-2020):
- ❑ LHC Injectors Upgrade (LIU)
- ❑ Civil engineering for HL-LHC equipment @ P1,P5
- ❑ 11 T dipoles P7
- ❑ Phase-1 upgrade of LHC experiments

LS3 (2024-2026):
- ❑ **HL-LHC installation**
- ❑ Phase-2 upgrade of ATLAS and CMS

13

ECFA meeting, CERN report, Fabiola Gianotti
https://indico.cern.ch/event/667672/contributions/2729660/attachments/1559939/2455491/PECFA-2017.pdf

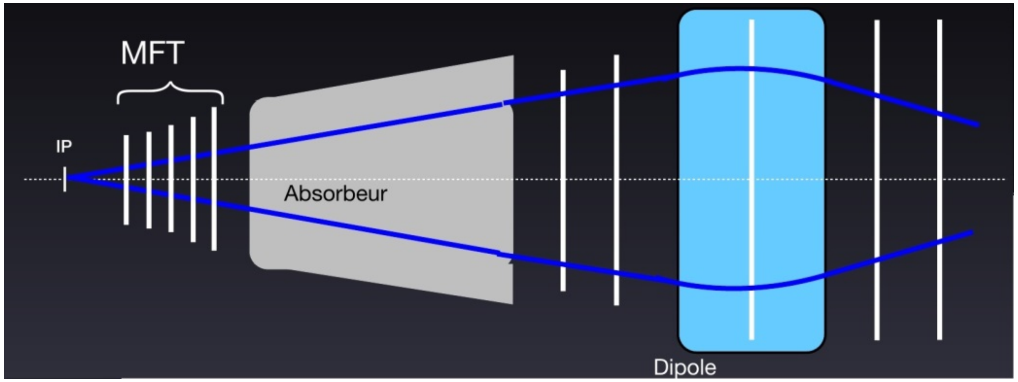
Run 3+4 (2019-2029)

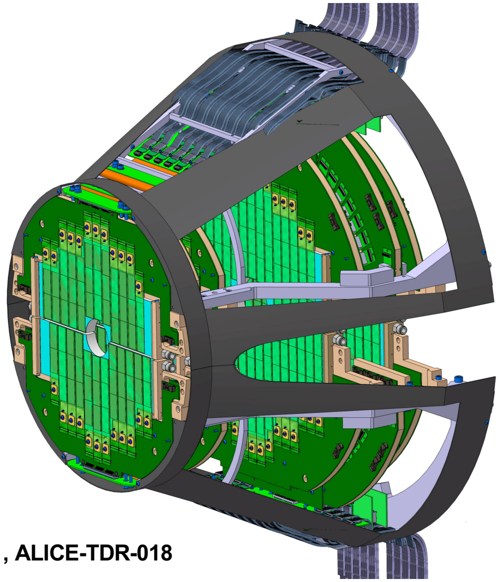
Pour utiliser pleinement les capacités de la machine après le LS2
upgrades ALICE

Lecture continue pour tous les systèmes (electronique), chambres TPC (GEM), ITS (CMOS), système de déclenchement (FIT), integrated Online/Offline (O2)

Contributions LPC

- Upgrade du spectromètre à muons: Muon ID (cartes FEERIC)
- Muon Forward Tracker, nouveau détecteur en amont du Muon ID
  Meilleur rejet du bruit de fond, séparation charm/beauté, vertex déplacé (J/ψ du B), amélioration de la résolution pour les basses masses
- Intégration dans O2



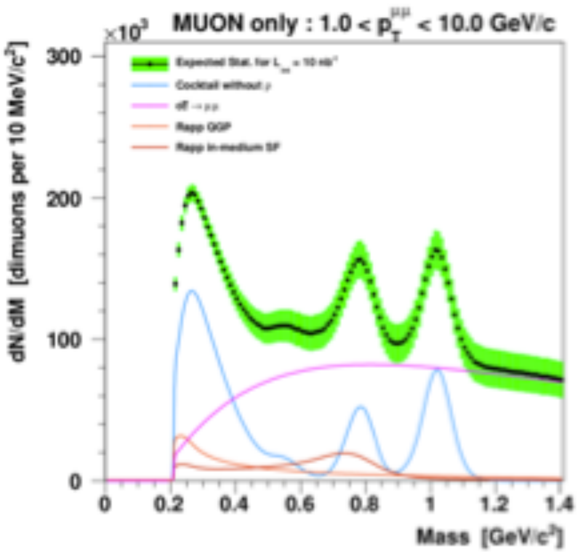


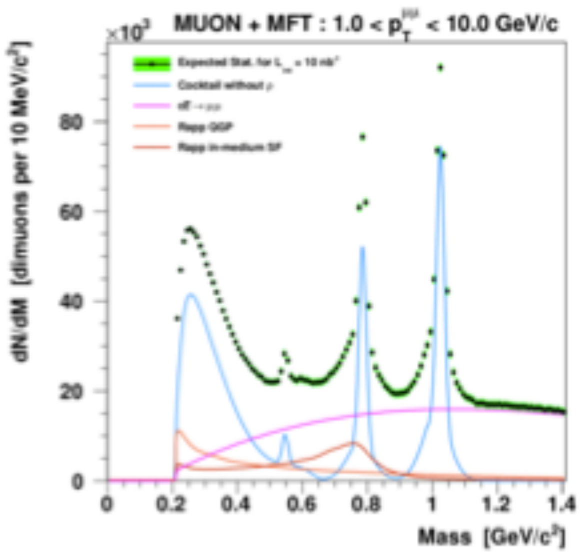
CERN-LHCC-2015-001, ALICE-TDR-018

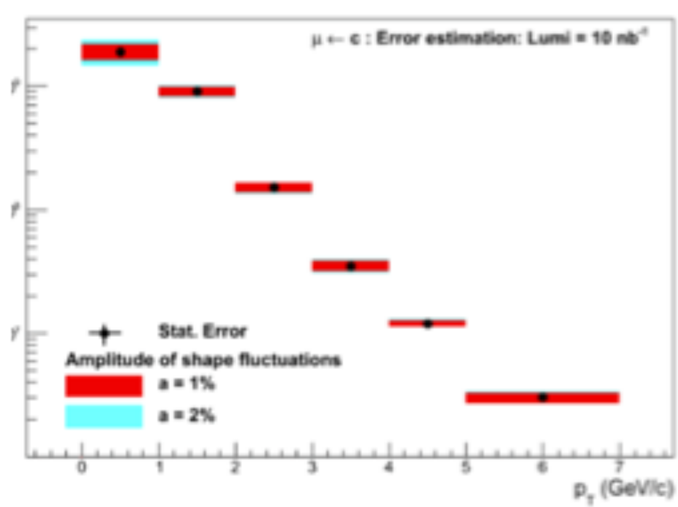
Run 3+4 (2019-2029)

- Programme de physique aux Runs 3+4 avec les upgrades ALICE particulièrement adapté pour les canaux rares / nouvelles observables demandant beaucoup de statistiques
  riche programme de physique attendu (ex : séparation charm/beauté, backup)

- Projet pour les 10 ans à venir :
  - Installation des upgrades
  - Exploitation des upgrades (Muon ID/ MFT) dans les conditions améliorées de la machine (luminosité/energie)
  - Analyses de physique plus complexes, limitées au run 2, ex. séparation charm/beauté, corrélation électron-muon, corrélation quarkonium-hadron, analyse multi-système pp, p-Pb et Pb-Pb, différentielle en multiplicité)







Et après?

- Ce qu'il manquera après les runs 3+4
  - Scan de systèmes, par exemple "ions lourds légers" comme O-O
  - Scan en énergie

- Où?
  - LHC run 5/6, jusqu'à l'horizon 2040
    projet pour une expérience dédiée ions lourds et/ou exploitation des upgrades des expériences de physique des particules avec runs dédiés
  - Cible fixe au LHC, Run 3+4, « parallèle » du mode collisionneur
    énergie < RHIC ($\sqrt{s}$=115 GeV) avec haute luminosité, déjà existant dans LHCb (SMOG)
    upgrade pour le Run 3, SMOG2, lumi x100
  - Electron Ion Collider, à partir de 2027
  - FAIR/CBM
  - HE-LHC/FCC, à l'horizon 2040/2050
    27 TeV/100 TeV

Contexte (inter)national

- Décembre 2018 : stat pour laquelle ALICE avait été approuvée 10 nb^{-1} en Pb-Pb
- Yellow report du CERN en préparation (performances attendues aux Runs 3+4)
- Rencontres QGP France 2-5 Juillet 2018
  https://indico.cern.ch/event/706294/

  Groupes de travail: Sondes molles
  Sondes dures - photons et jets
  Sondes dures - saveurs lourdes ouvertes et fermées
  Petits systèmes
  QCD froide

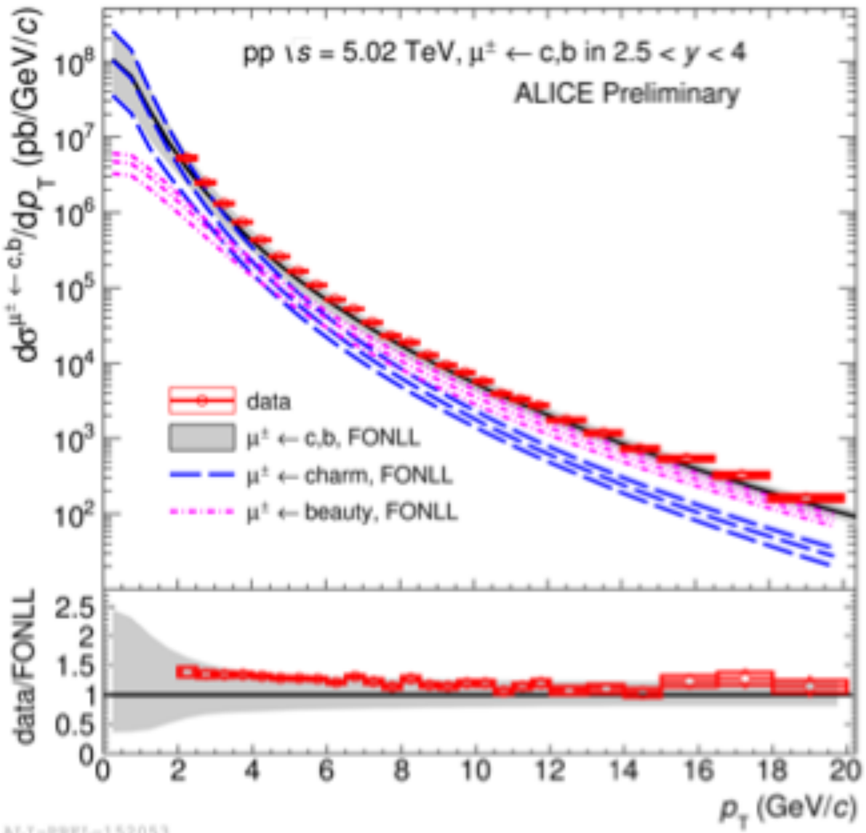
  - Première discussion sur l'avenir (après LHC Run 4) des collisions hadroniques à hautes énergies en France
  - Identification de 5 questions fondamentales de physique (à valider par la communauté)
  - Ce travail de prospectives continuera pour décliner ces questions en projets potentiels et leurs adéquations avec les forces/envies de la communauté
  - Prospectives pour améliorer les interactions avec les communautés connexes (structure du nucléon, équation d'état de la matière nucléaire, étoiles à neutron, lattice QCD)

Participation active des membres du LPC au travail de prospectives de la communauté QGP/ions lourds
Prémices de la réflexion, pas encore déclinée à l'échelle ALICE-LPC

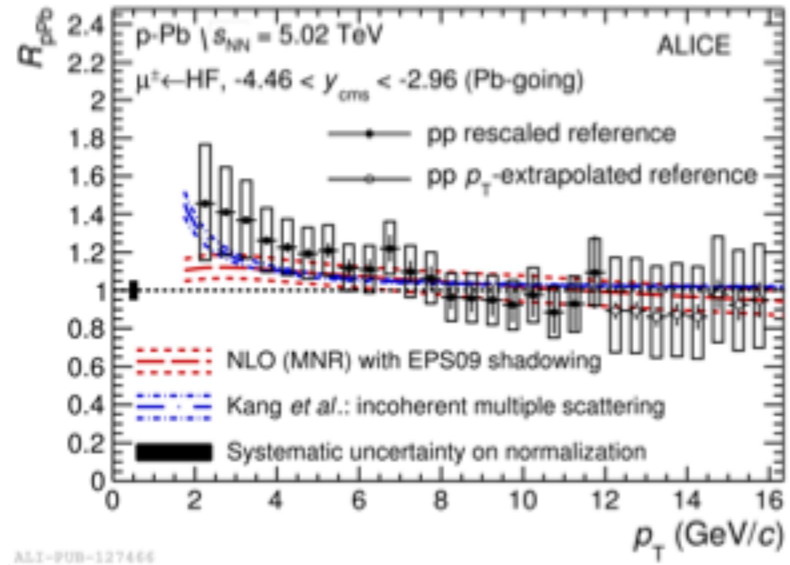
Conclusions

- Structure du nucléon
  - Finalisation des analyses en cours pour publication des résultats préliminaires
  - Participation à la prospectives à long terme du domaine

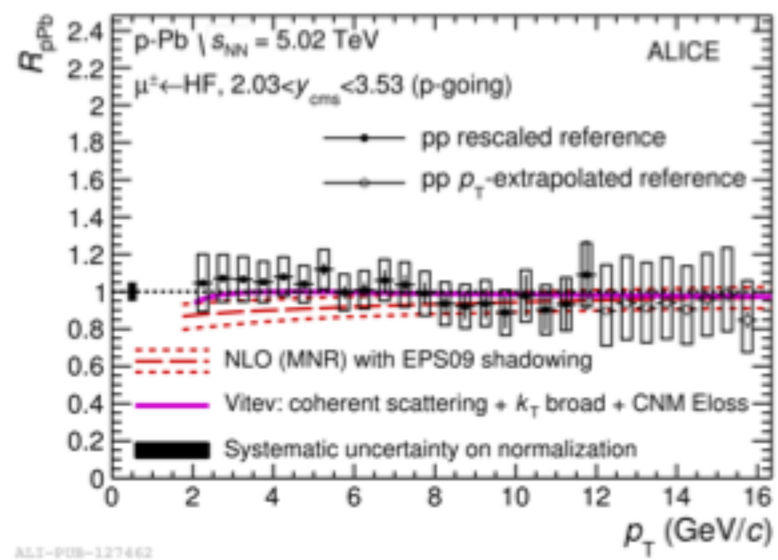
- Prospectives pour les collisions hadroniques à haute énergie / QGP
  - Installation des upgrades
  - Exploitation du riche programme de physique pour les Runs 3+4
    Bénéfices des upgrades (Muon ID + MFT)
    Bénéfices de l'augmentation de stat
  - Initiation d'une réflexion à plus long terme au niveau (inter)national
    Participation active du LPC



pp √s = 5.02 TeV, μ± ← c,b in 2.5 < y < 4
ALICE Preliminary
data
μ± ← c,b, FONLL
μ± ← charm, FONLL
μ± ← beauty, FONLL
dσ^{μ± ← c,b}/dp_T (pb/GeV/c)
data/FONLL
p_T (GeV/c)
ALI-PREL-152053

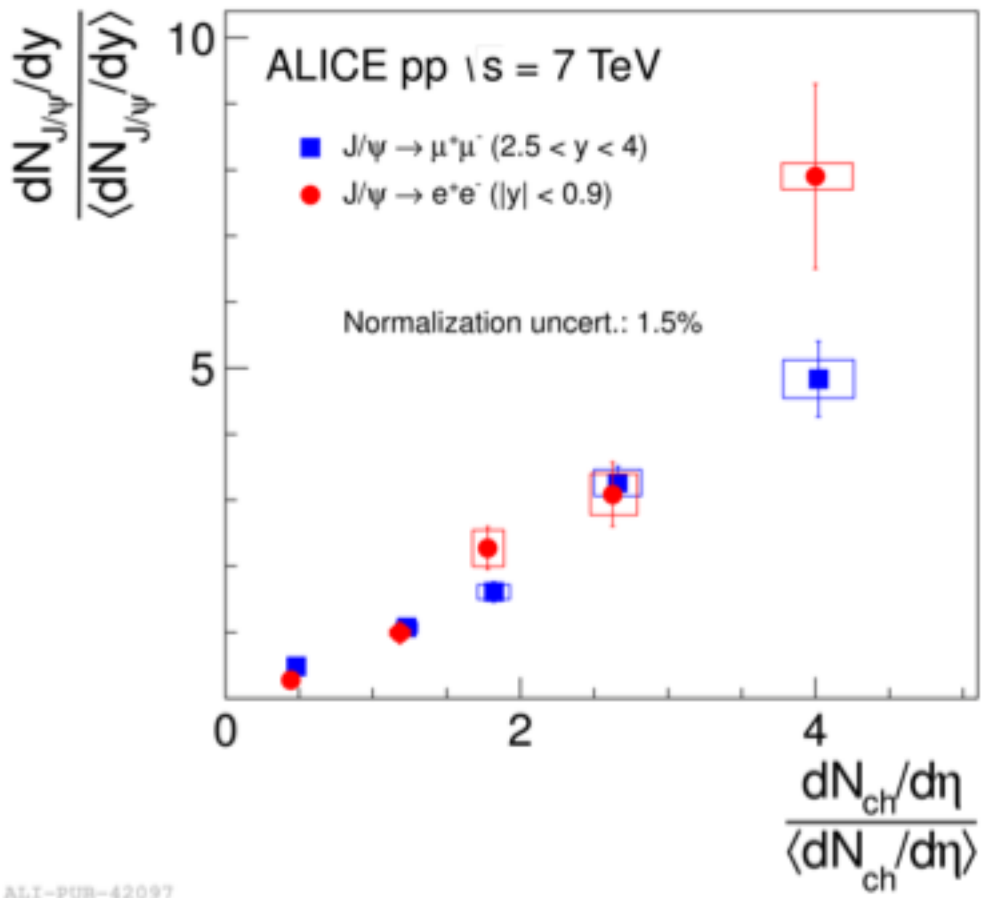


p-Pb √s_NN = 5.02 TeV
ALICE
μ±←HF, -4.46 < y_cms < -2.96 (Pb-going)
pp rescaled reference
pp p_T-extrapolated reference
NLO (MNR) with EPS09 shadowing
Kang et al.: incoherent multiple scattering
Systematic uncertainty on normalization
R_pPb
p_T (GeV/c)
ALI-PUB-127466

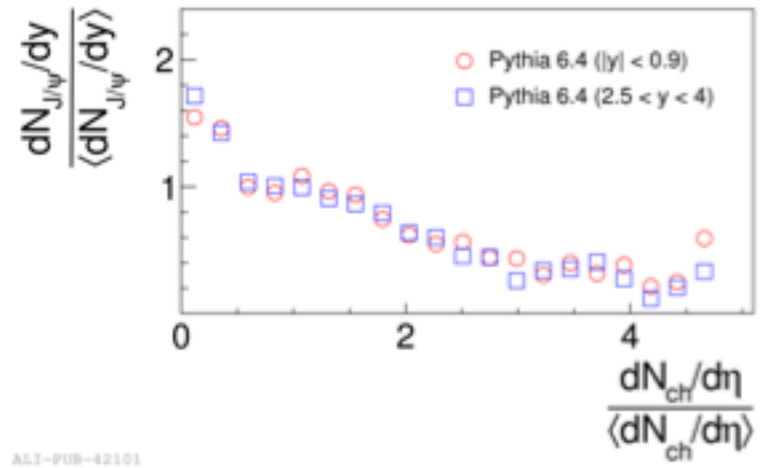


p-Pb √s_NN = 5.02 TeV
ALICE
μ±←HF, 2.03<y_cms<3.53 (p-going)
pp rescaled reference
pp p_T-extrapolated reference
NLO (MNR) with EPS09 shadowing
Vitev: coherent scattering + k_T broad + CNM Eloss
Systematic uncertainty on normalization
R_pPb
p_T (GeV/c)
ALI-PUB-127462

Phys. Lett. B 712 (2012) 3, 165–175



Phys. Lett. B 712 (2012) 3, 165–175



Motivation

- Heavy Flavors (HF), open and closed, as well as low- and intermediate-mass dileptons will allow to understand
  - chiral transition
  - deconfinement
  - properties of the QGP
  - hadronization

Motivation – Low- and Intermediate-Mass dileptons

- At the LHC energy: properties of the QGP medium (+ high-multiplicity small systems)
  - In-medium modified spectral function of ρ and ω to provide a reference for LQCD calculations and test predictions from phenomenological models
  - Fireball temperature (slope of the invariant mass spectrum for $M \approx 1.5$ GeV/c^2)

- At lower energies ($\sqrt{s} < 20$ GeV): properties of the deconfinement & chiral transitions
  - Evolution of the fireball temperature (slope of the invariant mass spectrum for $M \approx 1.5$ GeV/c^2) as a function of the energy density: measurement of the caloric curve of the QCD phase transition (never performed)
  - Measurement of the a_1-ρ chiral mixing through the identification of the $\pi a_1 \rightarrow \mu\mu$ structure in the invariant mass spectrum (never performed)

- Dileptons can also serve as
  - Clean decay channel for hadrons produced at the freeze-out
  - Complementary channel, although indirect and model-dependent, for the measurement of heavy-flavors at high energies
  - Drell-Yan
  - Bonus: search for dark photons and other beyond-standard-model light bosons

Motivation – Open Heavy Flavor

- In short, heavy quarks are produced early by hard collisions and traverse and probe the QGP, ok but …

- Production through
  - Hard parton-parton (mostly g-g) collisions but
    - gluon radiation
    - Shadowing
    - Initial state correlations
  - gluon fragmentation
- Propagation through the QGP
  - Collisional and radiative energy loss
  - Transport coefficients
    - Medium description
    - LQCD inputs/constrains
  - Could possibly lead to local thermal equilibrium
- Hadronization
  - Recombination
  - Fragmentation
- Propagation through a hadron gas
  - Hadronic cross sections are poorly know

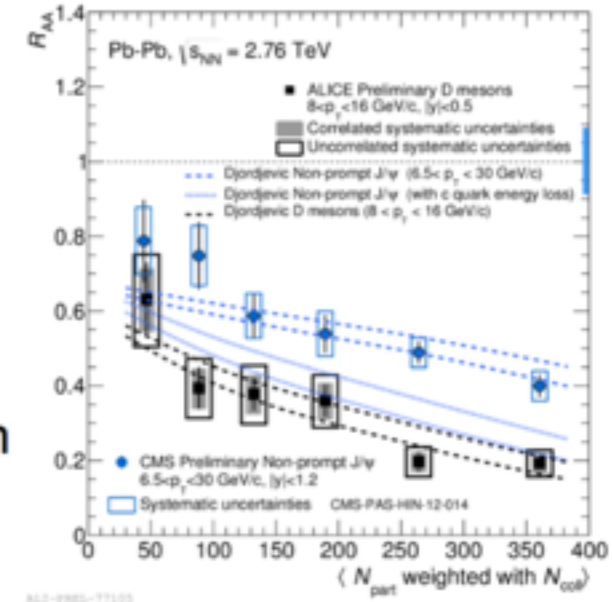
Motivation – Quarkonia

- In short, heavy quarks are produced early by hard collisions and traverse and probe the QGP, ok but …

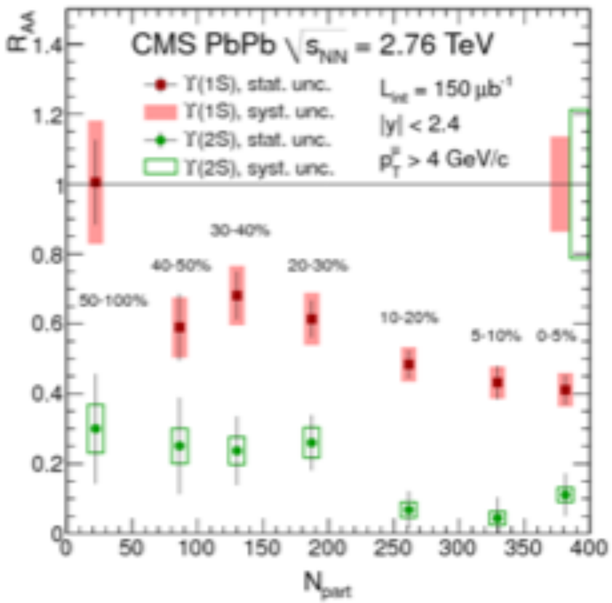
- Production
  - Perturbative: heavy-quark pair production
  - Non-Perturbative: binding of heavy-quark pair into a white quarkonium state
    - Not yet satisfactorily described
  - Fragmentation
- Propagation through the QGP
  - Probe of in-medium QCD force
    - Spectral functions
    - LQCD inputs/constrains
    - Medium description
    - Transport coefficients
- Hadronization
  - Recombination
  - Fragmentation
- Propagations through a hadron gas
  - Hadronic co-movers could play an important role, mostly for excited states

Run 1 & Run 2 in three figures

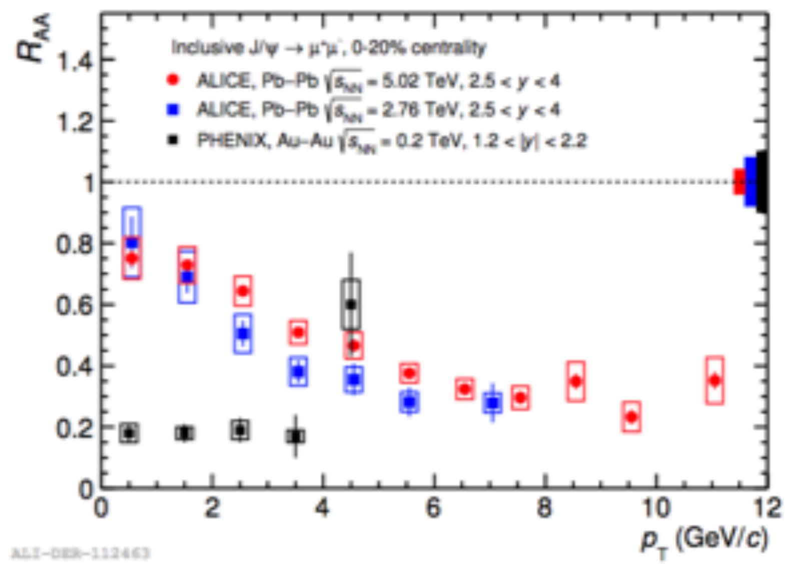
- R_{AA} of D mesons and non-prompt J/ψ
  - Flavour dependence of parton energy loss



- Υ(1S) and Υ(2S) R_{AA}
  - Stronger suppression of less bound quarkonium states

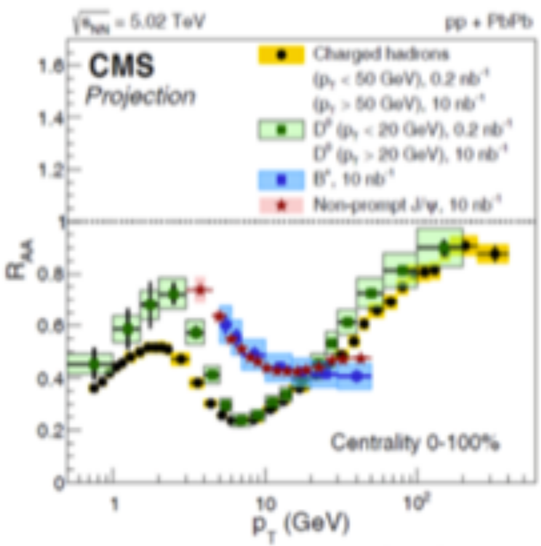


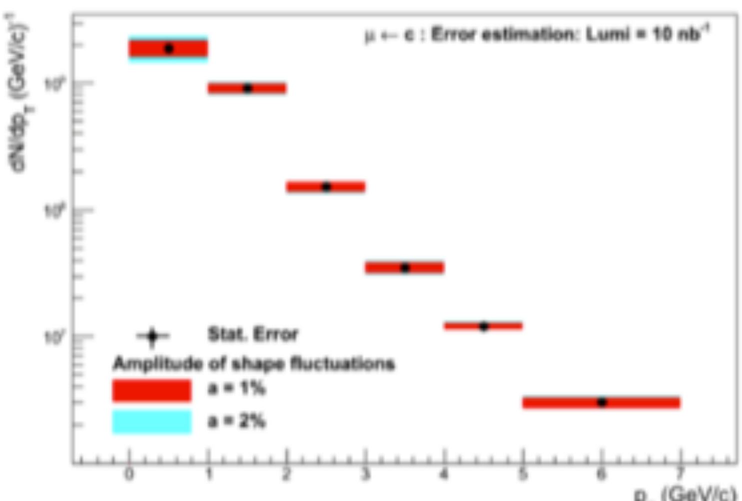
- J/ψ R_{AA}
  - Recombination of charm quarks

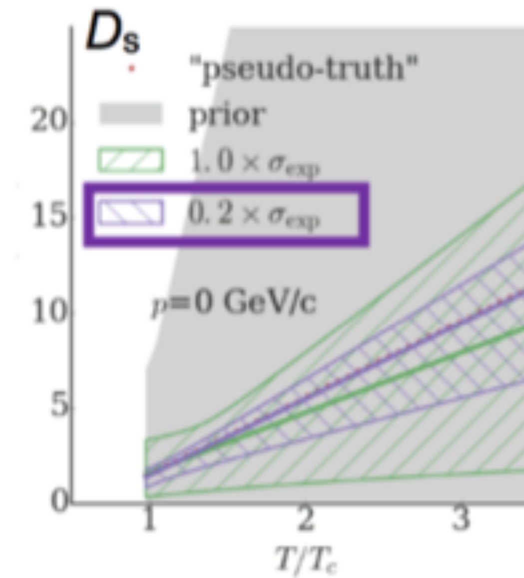


OHF – energy loss and collectivity

- Goal: address the transport properties of heavy quarks in the QGP
  - Transport coefficients, e.g. diffusion coefficient D_s
  - Transport parameter, q-hat
  - Collisional vs radiative energy loss
- Observables
  - R_{AA} and v_2 of D and B mesons
  - Separation of single muons from c and b decays (MFT)
  - Event-shape engineering for D mesons



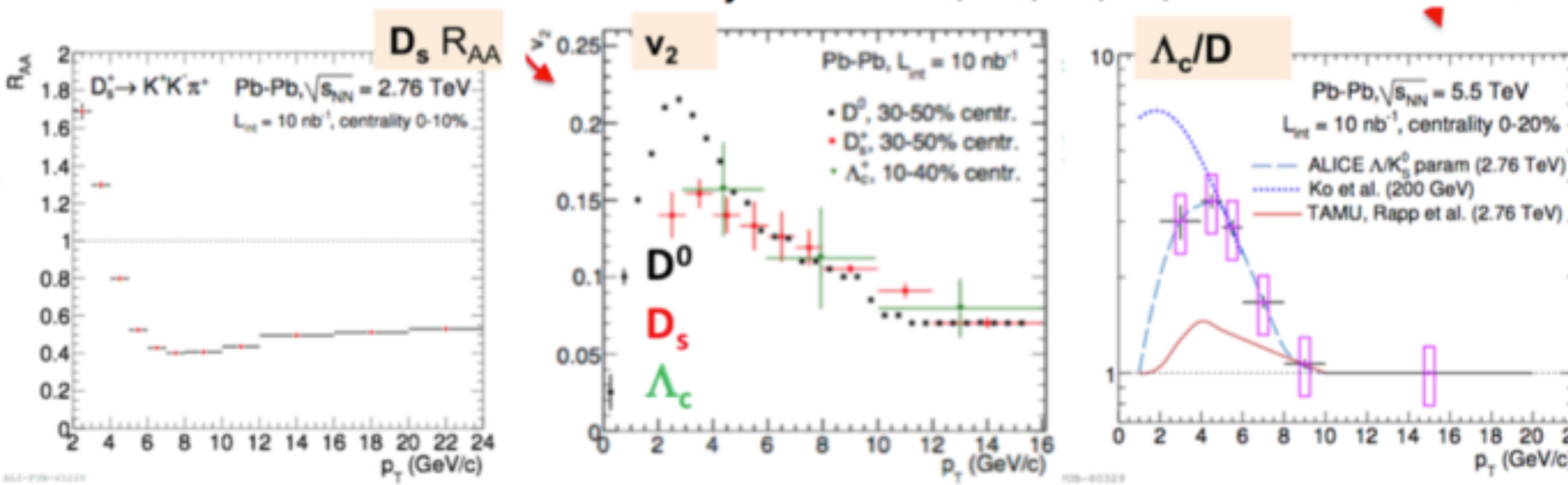




- Parallel development of theory is critical
  - Use of bayesian approach to extract model parameters from data should be extended

OHF – hadronization mechanism

- Goal: understand HF hadronization
  - Heavy quark recombination at low p_T
  - Fragmentation at high p_T
  - A mix in the middle
- Observables
  - R_{AA} and v_2 of D and B mesons
  - More *exotic* charmed and beauty hadrons Λ_c, Λ_b, D_s, B_s, …

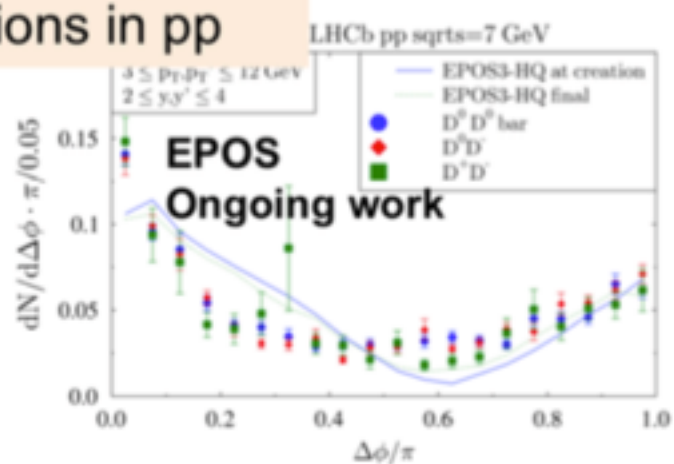


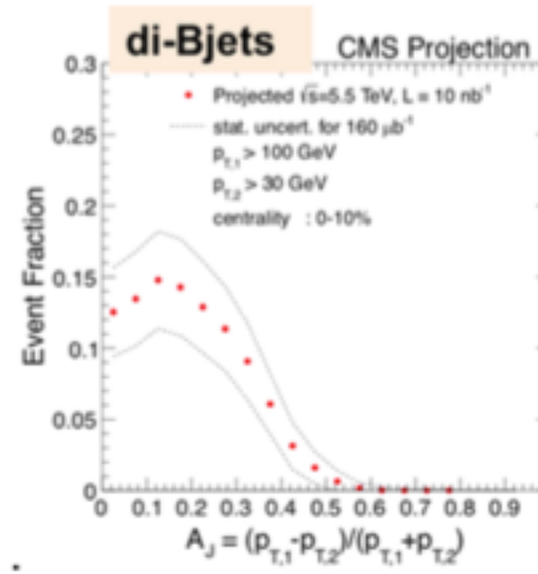
- Parallel development of theory is critical
  - Rigorous treatment of recombination is difficult (if any)

OHF – Correlations and jets

- Goal: understand energy loss
  - Radial distribution of lost energy
  - Mass and parton-type dependence of energy loss
- Observables
  - D-Dbar azimuthal correlations
  - HF-tagged jets
  - D-jet correlations
  - Di b jets

Theory: $\Delta\phi,\Delta y$ $D\overline{D}$ correlations in pp

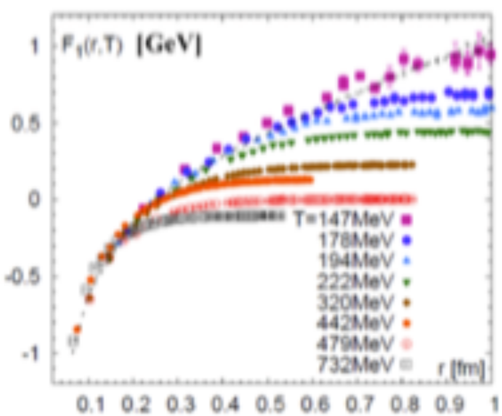


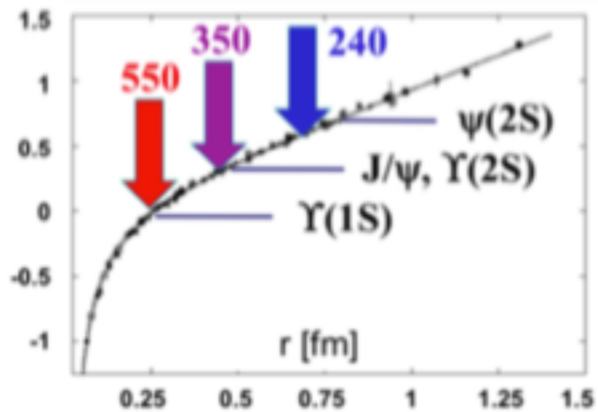


- Parallel development of theory is critical

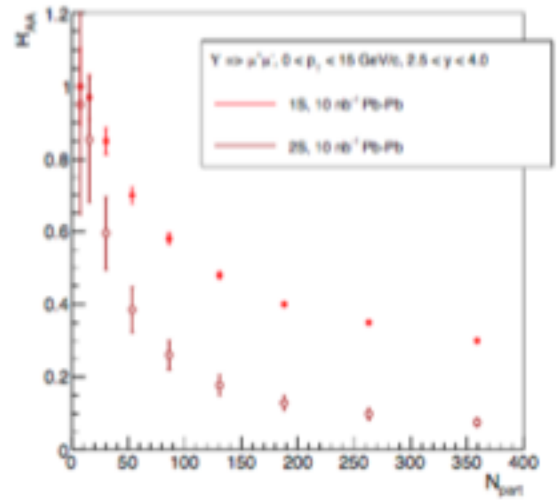
Quarkonia – deconfinement

- Goal: address the deconfinement mechanism
  - Study the in-medium QCD force
  - Access to different regions of the HQ potential
  - Study quarkonium spectral functions
- Observables
  - Suppression of different quarkonium states
    - Υ(1S): color-Coulomb
      J/ψ, Υ(2S,3S): confining force
    - ψ(2S): barely bound





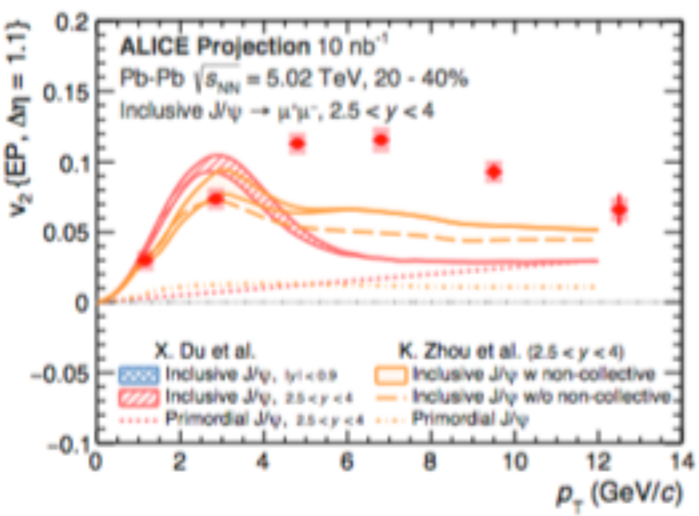
ALICE Projection

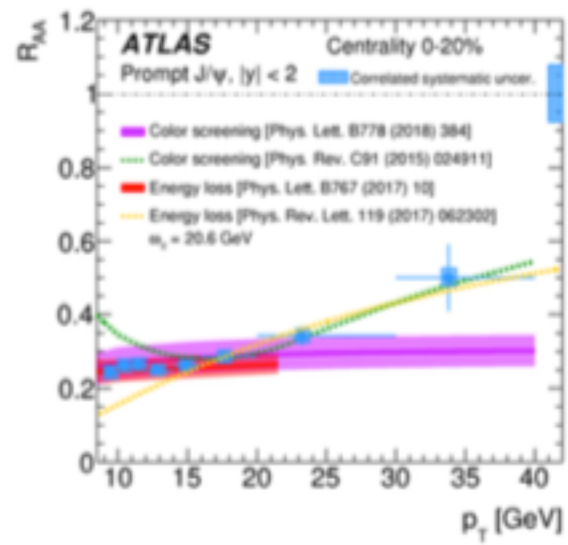


- Parallel development of theory is critical
  - Links and inputs to LQCD, e.g. spectral functions should be more systematic

Quarkonia – energy loss and collectivity

- Goal: address the transport properties of heavy quarks in the QGP
  - Transport coefficient, e.g. diffusion coefficient D_s
  - Collisional vs radiative energy loss
- Observables
  - R_{AA} and v_2 of J/ψ
  - High-p_T J/ψ, prompt and non-prompt



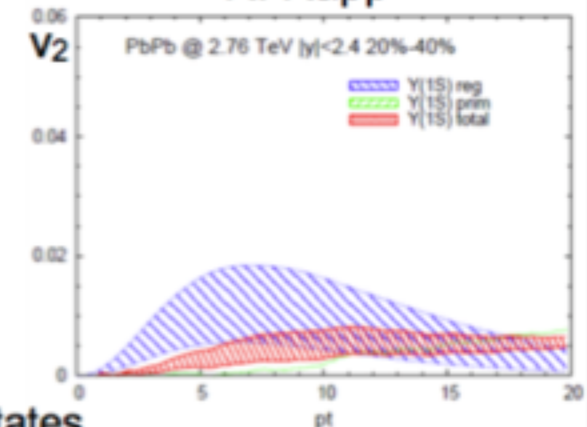


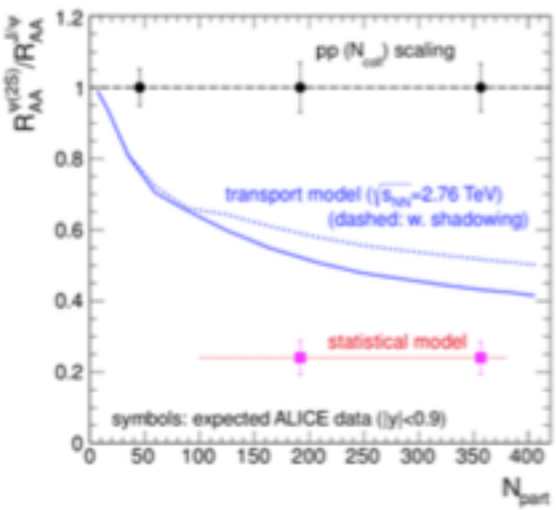
- Parallel development of theory is critical
  - Link between OHF and quarkonia theory is mandatory

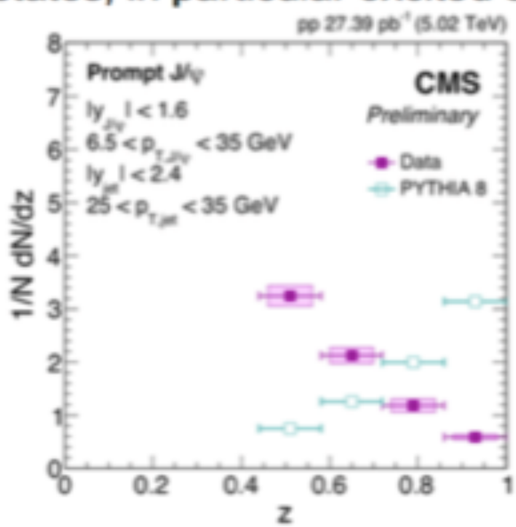
Quarkonia – hadronization mechanism

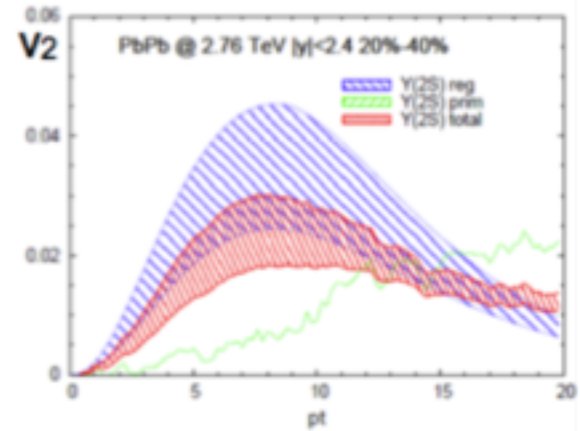
- Goal: understand quarkonium hadronization
  - Initial production
  - Heavy quark recombination / statistical hadronization
  - Fragmentation
  - Suppression and formation time
- Observables
  - R_{AA} and v_2 of charmonia
  - J/ψ in jets
  - p_T dependence of quarkonium states, in particular excited states

R. Rapp









- Parallel development of theory is critical
  - Rigorous treatment of recombination is difficult (if any)

What is a small system for QGP physics?

- The name « small systems » appeared at LHC Run I, it is now a session at Quark Matter, it is a recent aspect of heavy-ion physics

- It is a « fourre-tout » that sometimes refers to new phenomenon between RHIC and LHC connected to pp and p-A systems

- A nonofficial translation could be ”system *a priori too small* to show characteristics of heavy ion physics and however in which we observe them, at least some ”.

- Caveats « a priori too small » is not defined ...

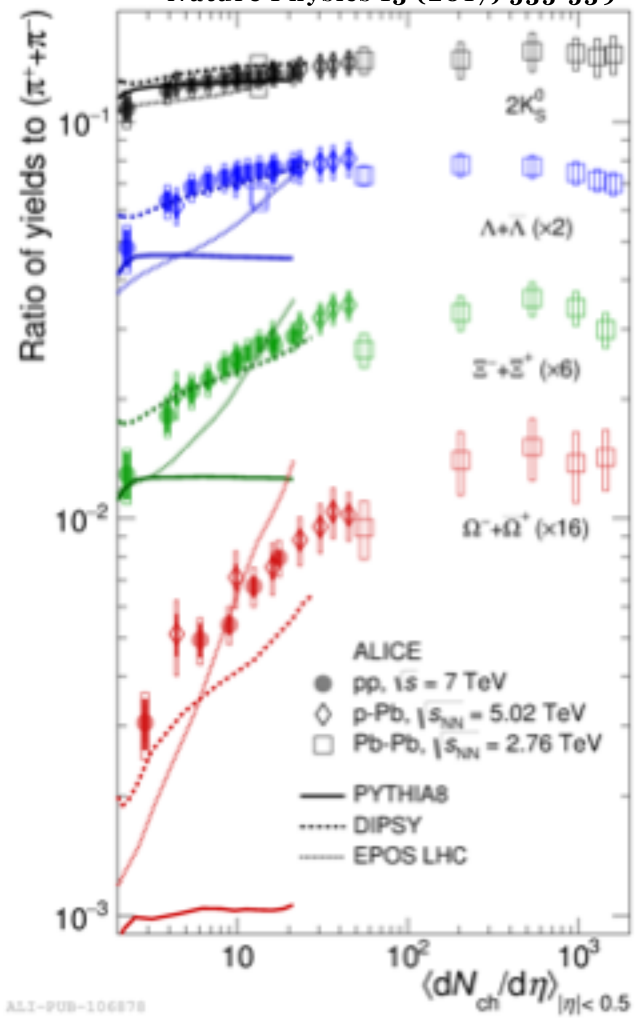
What is a small system for QGP physics?

- ”A priori small” refers to system size: protons in initial stage

- But with sometimes a final state looking like a large system, at least for charged particle multiplicity

- For LHC RUN 1+2 energies, idea of reference system still valid for pp minimum bias. High multiplicity events represent a small contribution to the total cross section
 O(10^{-4}) in statistics

Nature Physics 13 (2017) 535-539



pp/pA/AA at the same multiplicity, is it the same behavior, role of geometry?

How is done the transition from small to large ?

Quark-Gluon Plasma

- Is the measurement the consequence of the evolution of a hydrodynamic fluid?
- Warning: hydro application do not necessarily imply QGP
- Hydro requires Re >> 1 => small $\frac{\eta}{s}$, with R_e the Reynolds number:

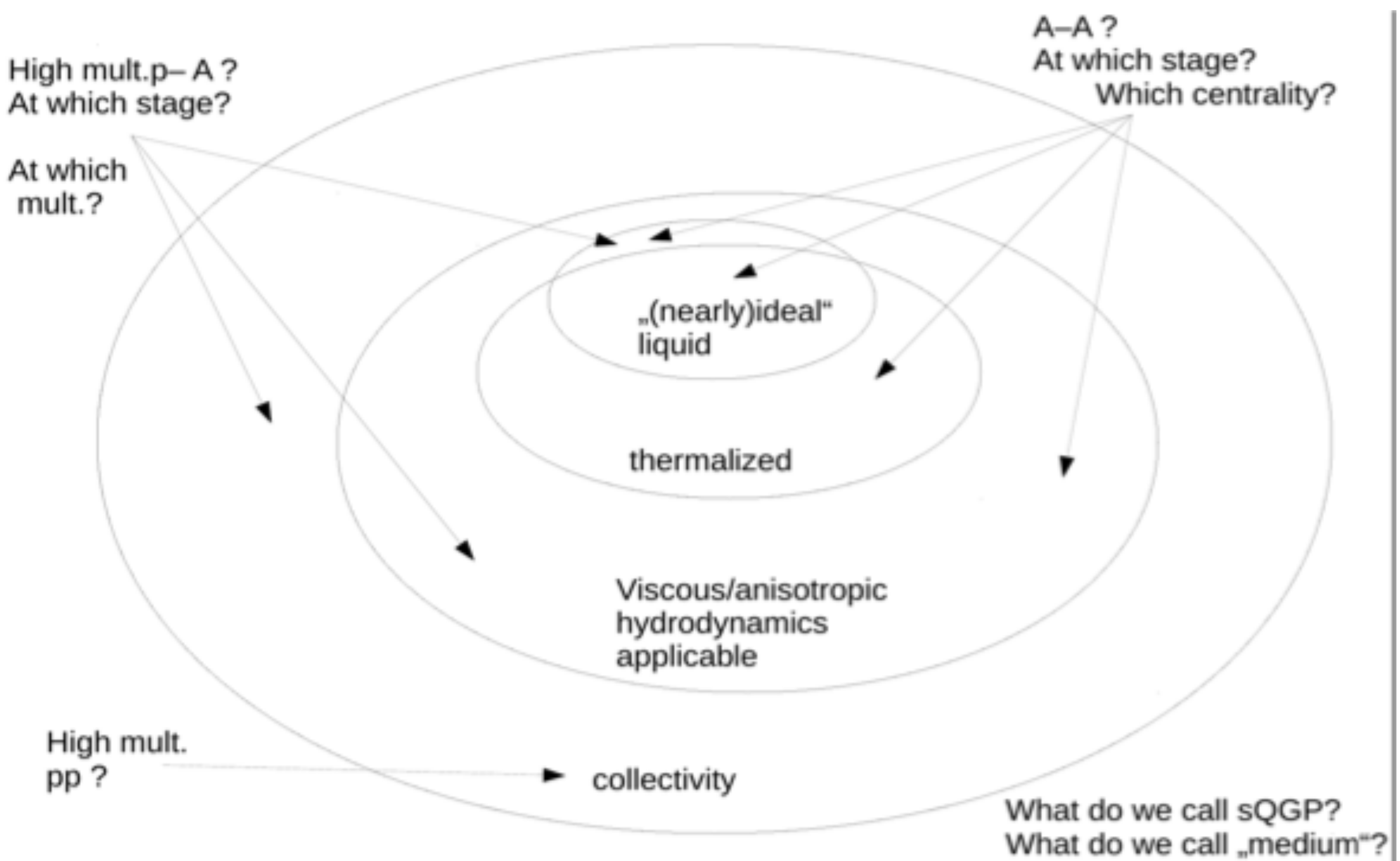
$$R_e = \frac{\mathrm{R}v}{\mathrm{v}} = \frac{\mathrm{R}v}{\eta/\rho} = \frac{\mathrm{R}vT}{\eta/s}$$

R: characteristic spatial dimens
v: characteristic velocity
$\mathrm{v} = \frac{\eta}{\rho}$: kinematic velocity
η: shear viscosity
s: entropy density

- Small η/s (<0.2) is a feature of observed QGP

Quark-Gluon Plasma

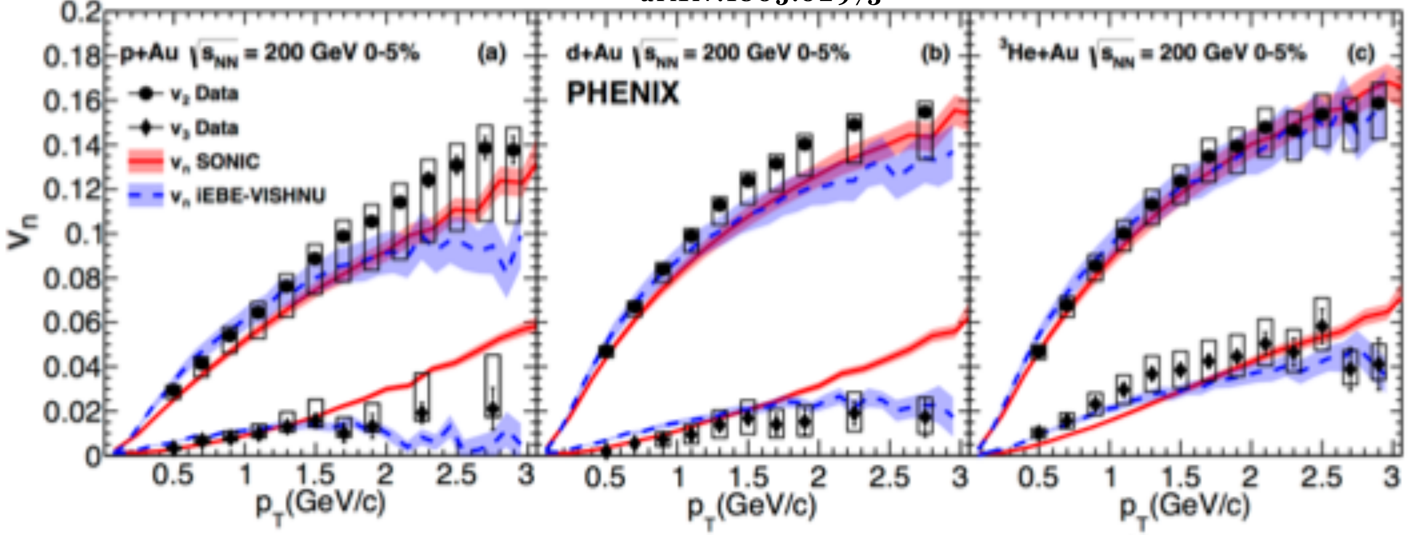
Which system is suited to test properties of thermal QCD as described by Lattice QCD ?



Courtesy of M. Winn

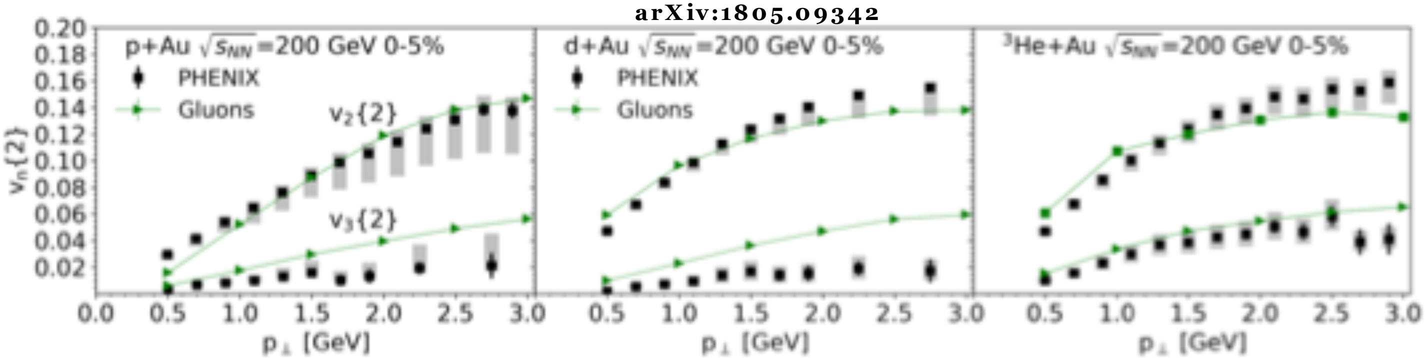
Signes de QGP dans les petits systèmes au RHIC ?

arXiv:1805.02973



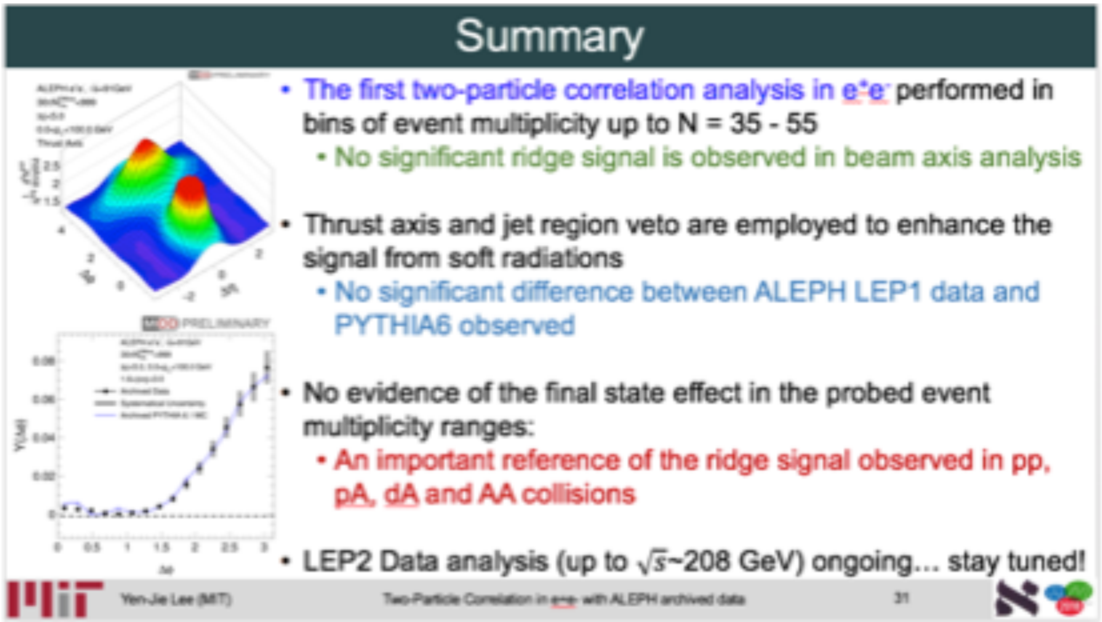
- PHENIX claim for QGP in small systems ...

arXiv:1805.09342



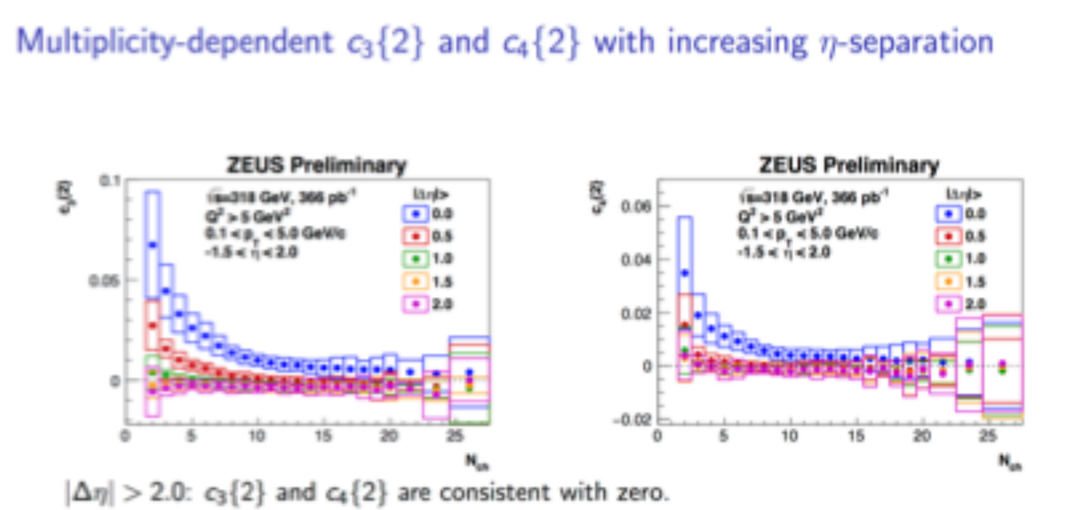
- ... also explained by CGC.

Signes de QGP dans les tous petits systèmes ?



QM2018, Yen-Jie Lee

- LEP e^+e^- $\sqrt{s}$=91 GeV
- High mult = 55 particles in $|\eta|<5$
- No ridge observed, compatible with PYTHIA



QM2018, Jacobus Onderwaater

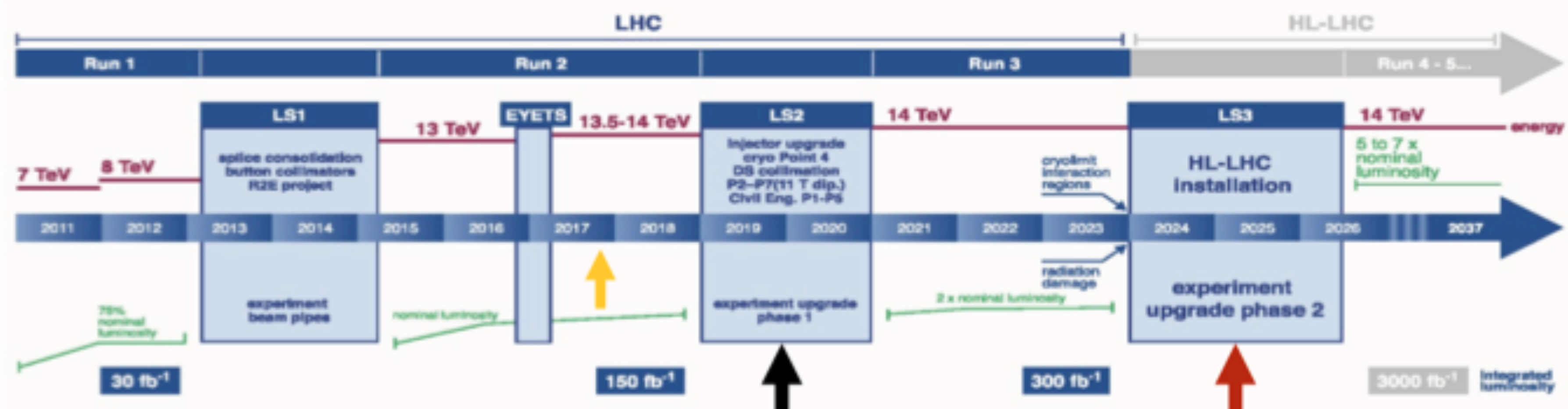
- HERA ep $\sqrt{s}$=318 GeV
- High mult = 35 particles in $-1.5<\eta<2$
- No observation of 2-particle correlations, compatible with Ariadne (dipole cascade model) and Lepto (Lund string)

After LS2: Run 3+4

LHC upgrades (LIU + HL-LHC): parameters and timeline

Nominal LHC: $\sqrt{s}$ = 14 TeV, L= 1×10^{34} cm^{-2} s^{-1}
Integrated luminosity to ATLAS and CMS: 300 fb^{-1} by 2023 (end of Run 3)

HL-LHC: $\sqrt{s}$ = 14 TeV, L= 5×10^{34} cm^{-2} s^{-1} (levelled)
Integrated luminosity to ATLAS and CMS: 3000 fb^{-1} by ~ 2035



LS2 (2019-2020):
- ❑ LHC Injectors Upgrade (LIU)
- ❑ Civil engineering for HL-LHC equipment @ P1,P5
- ❑ 11 T dipoles P7
- ❑ Phase-1 upgrade of LHC experiments

LS3 (2024-2026):
- ❑ **HL-LHC installation**
- ❑ Phase-2 upgrade of ATLAS and CMS

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ECFA meeting, CERN report, Fabiola Gianotti
https://indico.cern.ch/event/667672/contributions/2729660/attachments/1559939/2455491/PECFA-2017.pdf

Warning : heavy ions and particle physics timeline

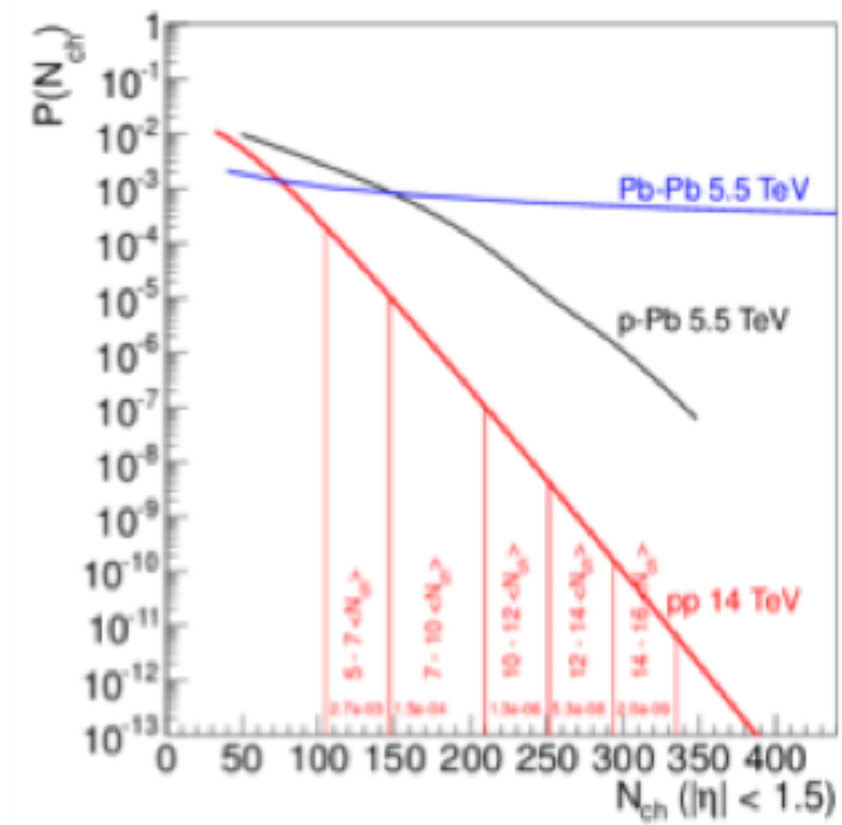
- For the heavy-ion community HL-LHC starts at RUN 3 (2021-2023)
- For the particle physics community HL-LHC starts at RUN 4 (2026-2028)

In the following, timeline with run number for clarity : 3+4 and 5+6

Simulations prepared for the Yellow report (HL-LHC working group) are based on RUN 3+4 estimates

Run 3+4

- Increase in energy, pp to 14 TeV, important for high mult in small systems
- Increase in luminosity, also important for high mult in small systems
- The yellow report will contain predicted number of events at a given multiplicity based on extrapolated multiplicity distribution
- Run 3+4 running conditions are favorable for small systems studies in high multiplicity environment (statistics hungry), be carefull of pile-up

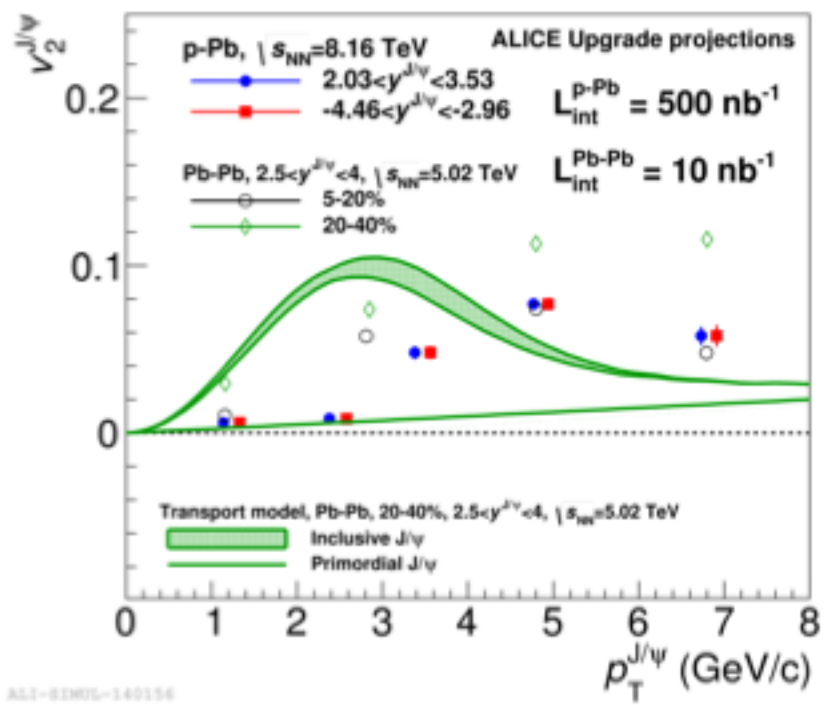


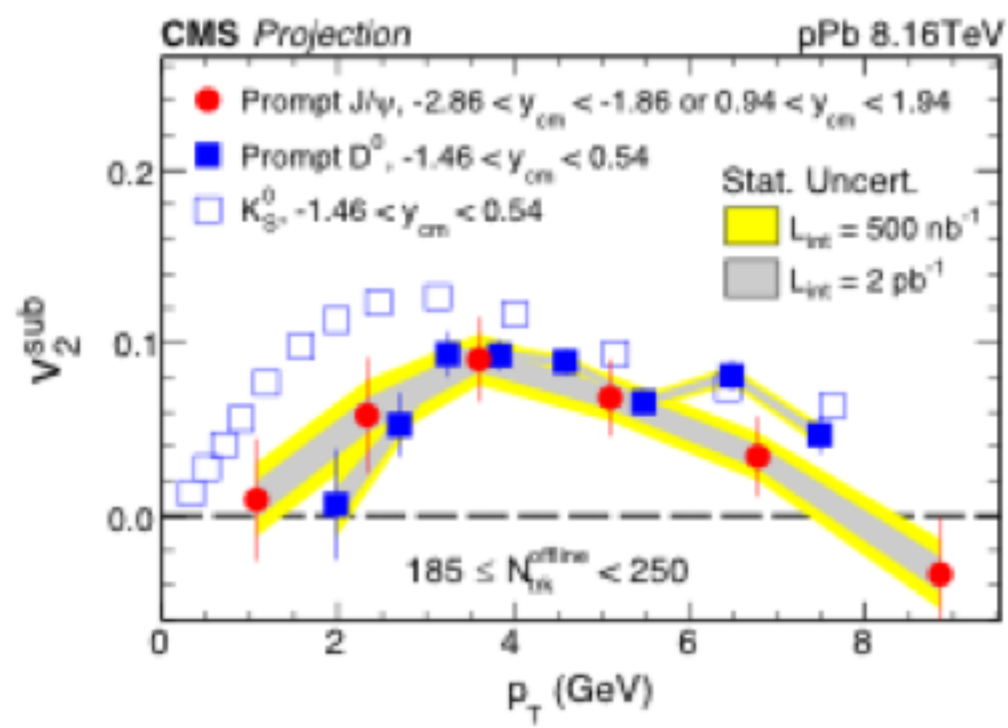
Run 3+4: Flow/Correlations

https://indico.cern.ch/event/686494/contributions/3034636/attachments/1670133/2678939/HEHLLHCWorkshop_v3.pdf

- Precise control over IS (geometry/fluctuations) and FS effects
- Onset of collectivity
- Test various description (hydro, CGC)

- Non-flow v_n measurements
- Symetric cumulants w and wo subevents
- ID v_n (light, strange, charm, beauty)

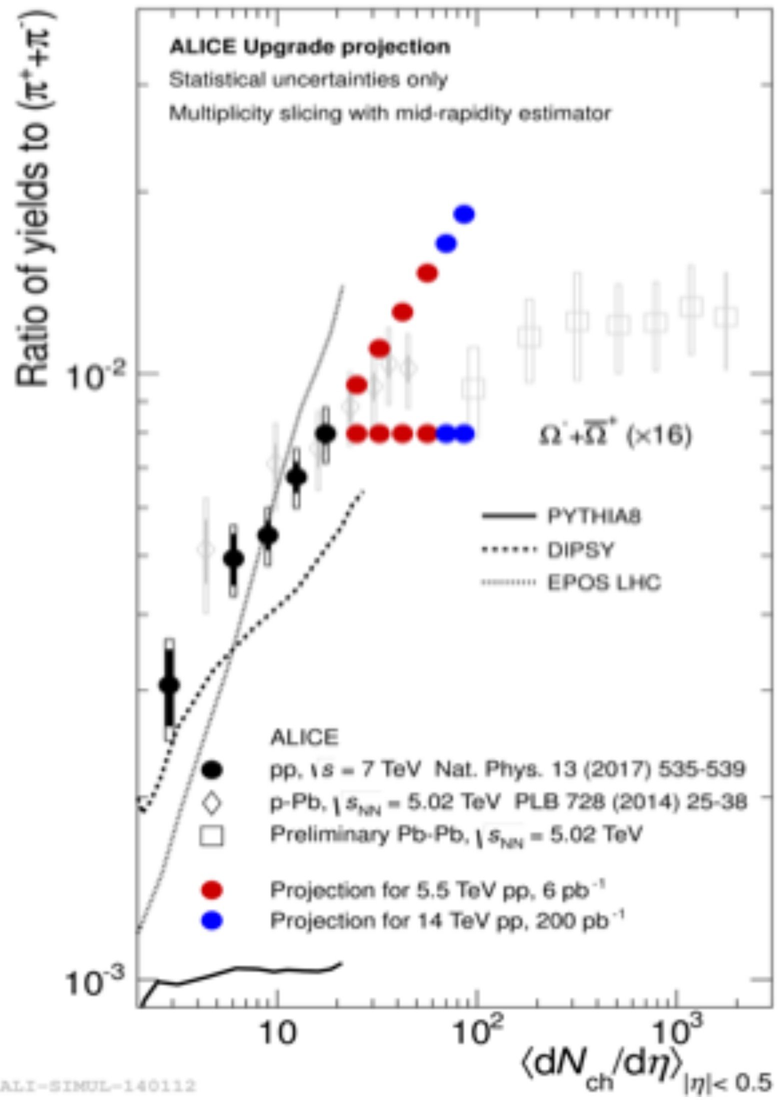




Run 3+4: Strangeness enhancement

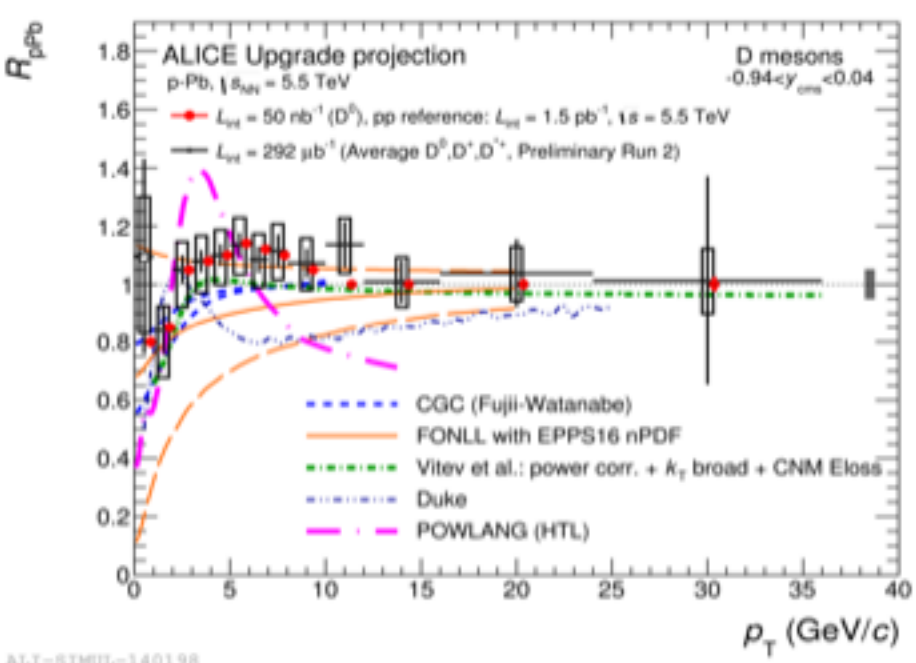
https://indico.cern.ch/event/686494/contributions/3034636/attachments/1670133/2678939/HEHLLHCWorkshop_v3.pdf

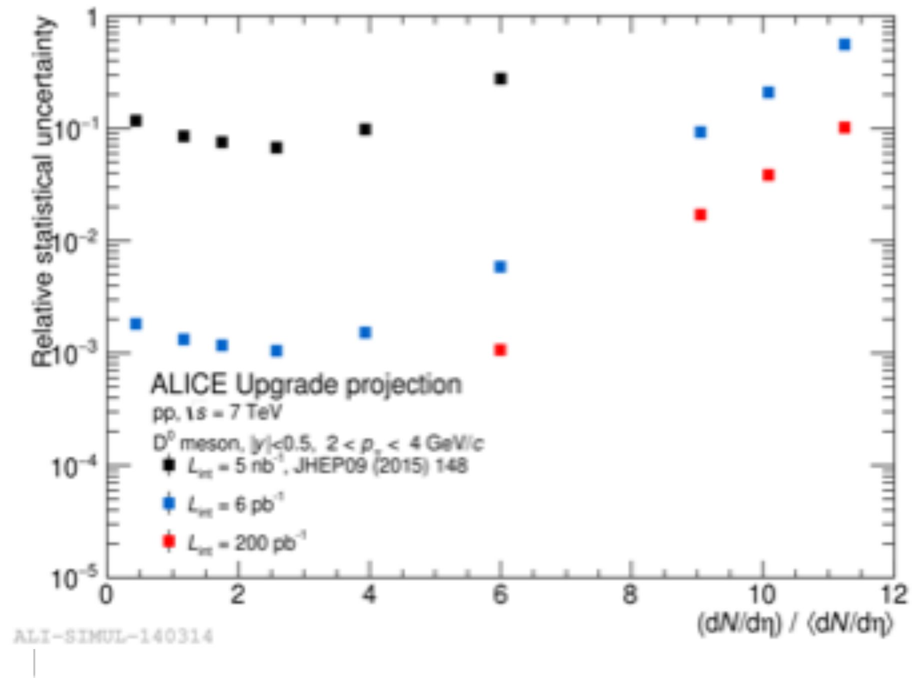
- Smooth transition between pp, pPb and PbPb
- Is the grand canonical limit reached?



Run 3+4: D measurements

- Large increase of precision help to reach high multiplicities and data/theory comparison





Run 3+4: Open questions

1) What is the best system size estimator?

- Multiplicity is the measured quantity (caveats: experimental estimator has to be well defined)

- Multiplicity is protected from theoretical biases (N_{part}, N_{coll} from Glauber models …)

- But hard to compare to formal calculation and first principle

- What about initial energy density or multiplicity per volume unit ?

Bjorken estimates

$$\varepsilon \sim \frac{n\pi}{\tau_0 A} \frac{3}{2} \frac{dN_{ch}}{d\eta}\bigg|_{\eta=0}$$

Multiplicity per volume unit

$$\frac{N_{ch}}{\pi R^3}$$

Problem of the definition of the normalization size in pp and p-Pb (A or R or ?)

Run 3+4: Open questions

2) Role of geometry / system size on hydro evolution in small system

pp high mult has a small size

Hydro can be applied out of equilibrium even if R_e do not satisfied the condition $R_e >> 1$

3) Energy loss definition

How to define jet-medium interaction in small systems

Energy loss proportional to system size => in small system, effect is small

How to define the reference ?

Ideas: jet asymmetry, jet substructure, Z-jet, photon-jet

4) Global interpretation and systematic data/theory comparison

Rivet, see for example the workshop Rivet for Heavy Ion (21-24 Aout)

https://indico.cern.ch/event/735911/

Run 3+4 physics program with planned detector upgrades
is very promising for small systems

What's next ?

Dreaming of an ideal physics program for small systems

To explore fundamental QCD questions raised by small systems:

- System scan

  Cover a wide range of systems (pp, pA and AA) with various nucleus
  O-O as a "light heavy-ion" a good candidate
- Energy scan
  Cover a wide range of energy with pp and pA at the same energy as AA

- Perform all measurements in multiplicity classes, multiplicity differential
  The highest multiplicity classes are the more interesting for small systems, analysis are statistic consuming => Dedicated triggers and high lumi
- Go toward more exclusive observables (soft-hard correlations) full tomography of the final state

- Systematic data/data and data/theory comparisons from all systems and all energies in similar multiplicity classes

What's next ?

Dreaming of the ideal detector for small systems: *ALICMSb*

1. Hermeticity = large η coverage

2. Tracking low p_T > 0 GeV/c
   = low B field
   = low material budget

3. PID over a large p_T range
   No TPC (slow), No Cerenkov (material budget)

4. Electromagnetic and hadronic calorimeter

5. Muon chambers 4π

6. Computing ressources

What's next ? LHC Run 5/6

ALICE upgrades ?

- Not yet an official proposal
- for a 4π compact silicium detector with very low momentum resolution ($p_T > 20$ MeV) with PID and TOF
- Ideal for charged tracks, photons and electrons

LHCb upgrades ?

- Not yet an official Expression of Interest,
- plan to run with the actual CMS/ATLAS lumi (10^{34} pile-up 30/40) with the HLT developed for Run 3/4 (very fine event topology selection)
- Providing reconstruction software development LHCb could be able to measure central heavy ion collisions at Run 5/6.

What's next ? LHC Run 5/6

CMS upgrades ?

- Hermeticity with low material budget.
- Potential for dedicated run at ”low” lumi and low B field (low p_T).
- Tagger = TOF PID at low pile-up ?
  Already planned for Run 4 p/K/π with 0.7 < p_T < 3-4 GeV/c

  https://indico.cern.ch/event/726024/

ATLAS upgrades ?

- Not evaluated

Can we develop a physics program for small systems (example of p-Xe, O-O, p-O) and energy scan at Run 5/6 ?

What's next ? Fixed target at LHC

- AFTER program

arXiv.org:1807.00603

- $\sqrt{s}$ = 115 GeV for pp, pd,pA and $\sqrt{s}$ = 72 GeV for Pbp, Pbd, PbA
- High luminosity => high stat
- 2 programs: LHCb (already existing with SMOG) and ALICE
- Multiplicity class reached with the available luminosity to be estimated

If high multiplicity reached at lower energy (below RHIC), interesting system scan to study the onset of collectivity

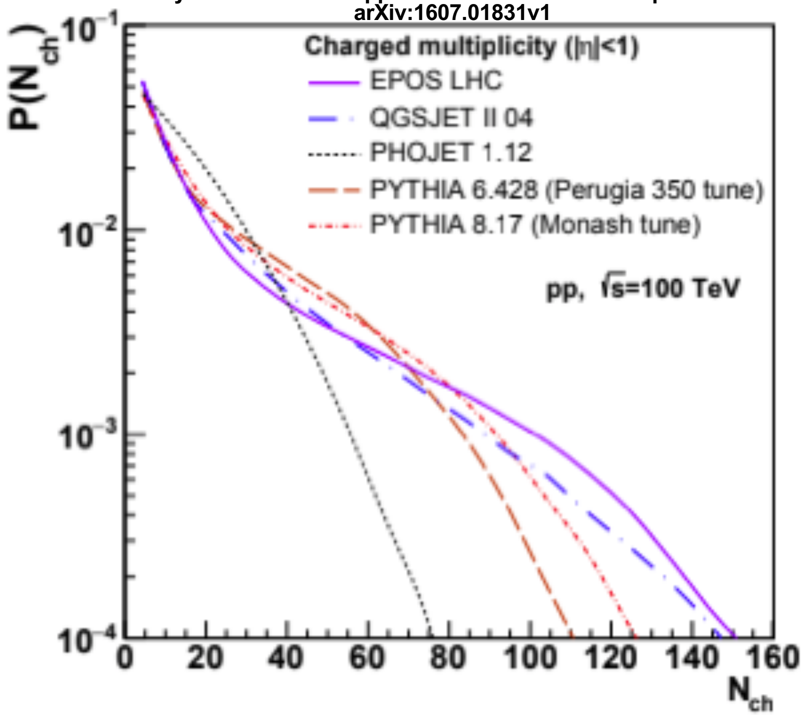
- LHCb in RUN 3+4: increase by a factor 100 with SMOG2 (see F. Fleuret talk on Monday)

What's next ? CERN HE-LHC/FCC/SPPS

- Essential for small system study: increase in multiplicity, increase in energy density
  => Increase in collision energy
- Future colliders at energies greater than LHC: natural continuation of small systems study

  - HE-LHC; upgrade LHC with FCC technology, 27 TeV, earliest possible physics starting date : 2040*
  - FCC-hh, **100 TeV**, earliest possible physics starting date : 2043*
  - SPPS, chinese project at **100 TeV**, FCC like

Physics at a 100 TeV pp collider: Standard Model processes
arXiv:1607.01831v1

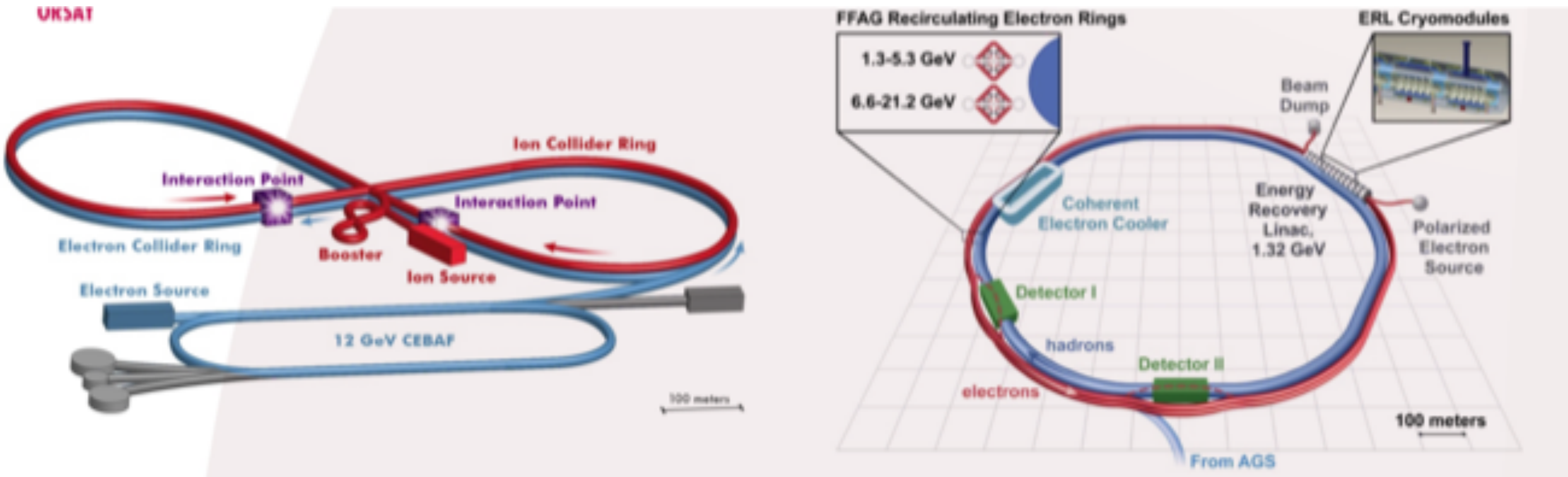


Starting physics in 20 to 30 years, but machine design, detector design is starting now!
Full simulation in preparation

* ECFA meeting, FCC report, Michael Benedikt
https://indico.cern.ch/event/667672/contributions/2730846/attachments/1560446/2456317/171117_FCC-Status_Berlin_ap.pdf

What’s next ? EIC

- Electron Ion Collider, first physics beam in 2027 (~10 years)



- Interest for small systems
    - Initial state (CGC, nPDF)
    - Hadronization
    - Centrality definition