



CMS Experiment at LHC, CERN
Data recorded: Mon Nov 8 11:30:53 2010 CEST
Run/Event: 150431 / 630470
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Collisions d'ions lourds dans l'expérience CMS au LHC

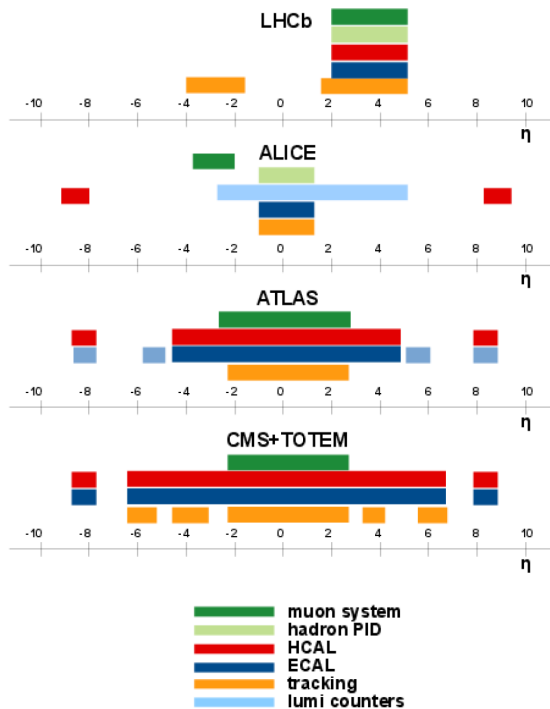
Matt Nguyen

Conseil Scientifique de l'IN2P3

February 8th, 2018

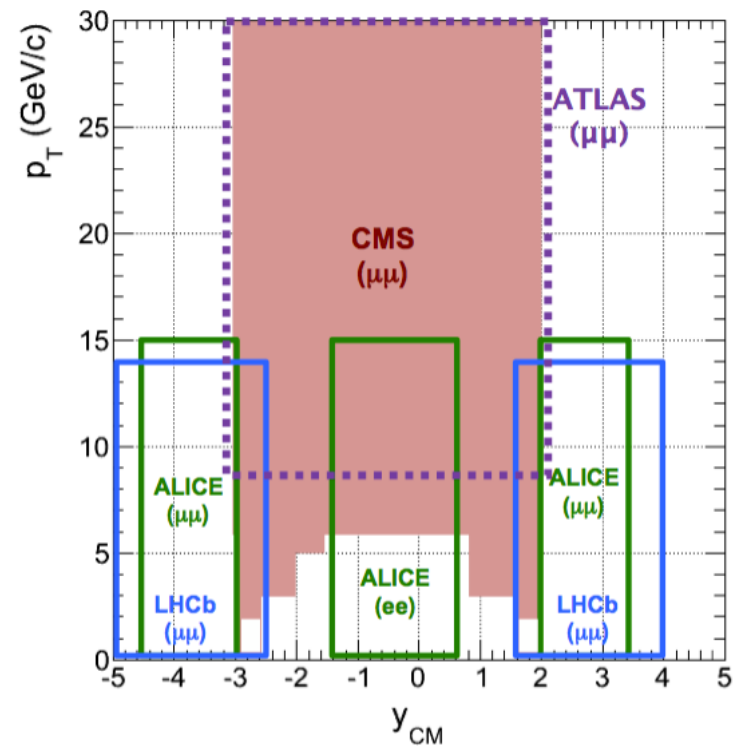
Why CMS?

Designed for rare probes



Jets, leptons, tracking/vertexing
High rate & large coverage

Complementary to other heavy-ion experiments



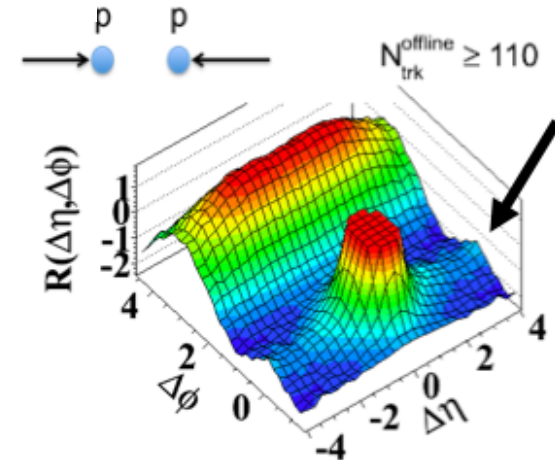
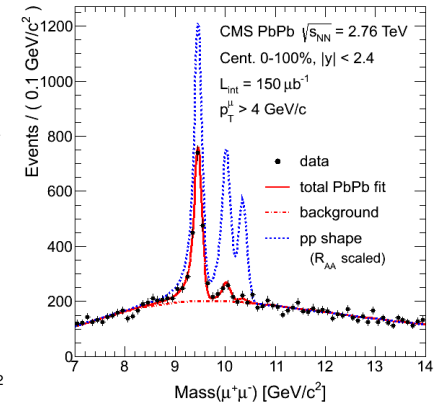
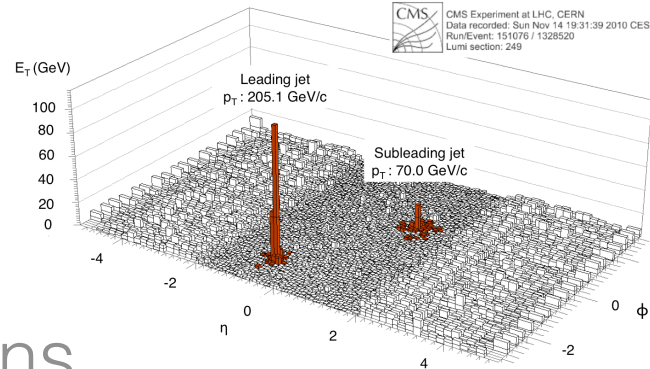
e.g., J/ψ coverage

CMS heavy-ion physics program

3 large “physics interest groups”

- Dileptons
- High p_T
- Flow & correlations
- and two smaller ones
- Hadron spectra
- Forward physics

LLR

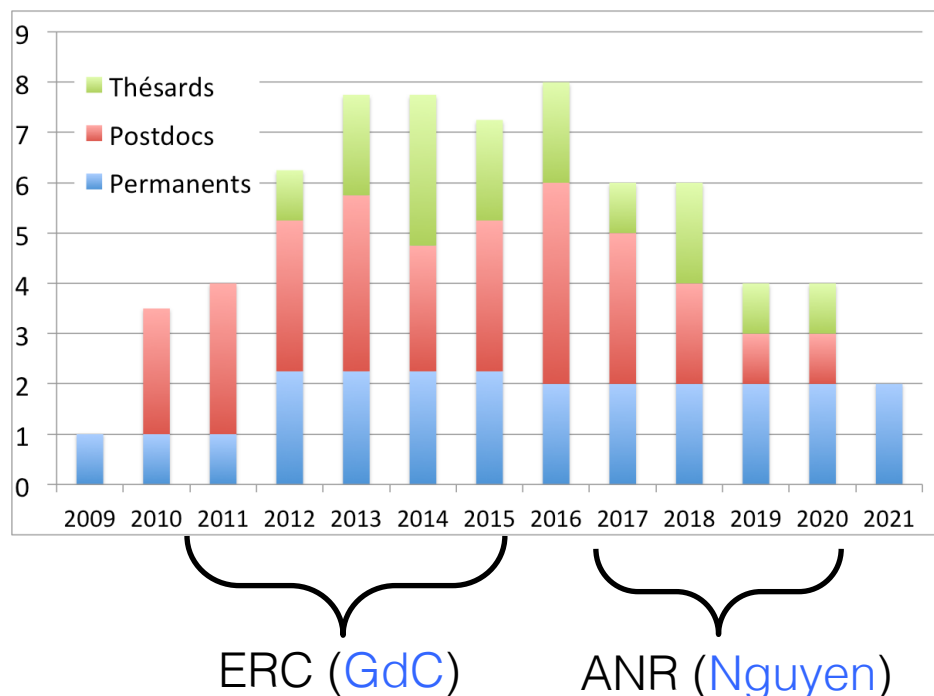


LLR is the leading group for dileptons in CMS-HI

Who are we?

- CMS-HI: O(100) participants
 - ~ Currently 75% in the U.S., increasingly moving to sPHENIX @ RHIC
- LLR unique CMS-HI group in France, almost unique in Europe embedded in larger CMS-LLR group (among strongest in the expt.)

LLR CMS-HI group composition by time:



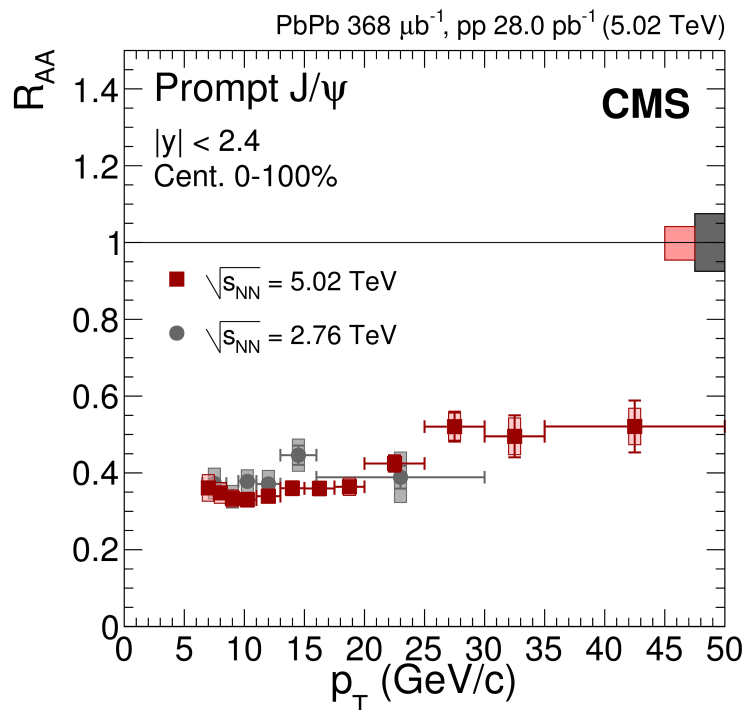
Permanent staff at LLR:

- Initiated by [Raphaël Granier de Cassagnac](#) via ERC starting grant (2010 – 2015)
- Reinforced by [Matthew Nguyen](#) (joined 2011), ANR JCJC (2016 – 2020)
- Joined by [François Arleo](#), as “associated theorist” (25%)

What have we done so far?

Charmonium dissociation

- Long history of charmonia studies at LLR (NA38/50, PHENIX) and also in France in general
- CMS strength: Separation of b-hadron feed-down component



Series of papers map dependence of R_{AA} on centrality, p_{T} and η for both J/ψ & ψ(2s)

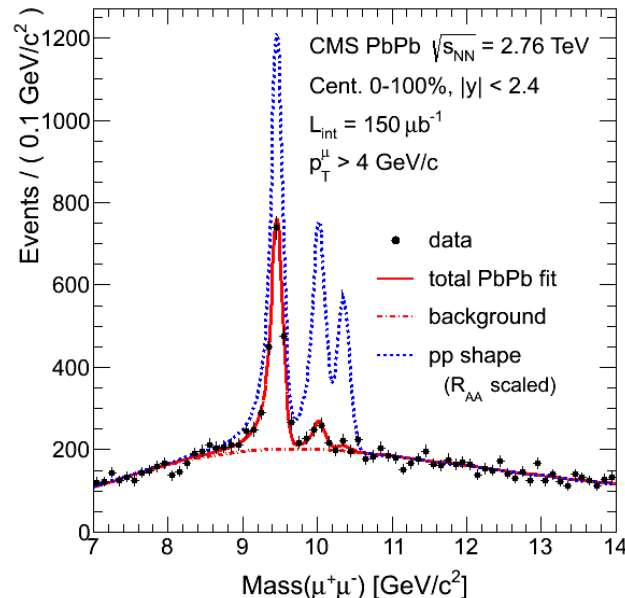
Topic	Paper reference	Contact
J/ψ	JHEP05 (2012) 063	Dahms
ψ(2s)	PRL113 (2014) 262301	Dahms
J/ψ (R_{AA} & v_2)	EPJC77 (2017) 252	Jo
ψ(2s)	PRL118 (2017) 162301	Chapon
J/ψ & ψ(2s)	arXiv:1712.08959	Blanco

New: Rise of J/ψ R_{AA} at large p_{T}

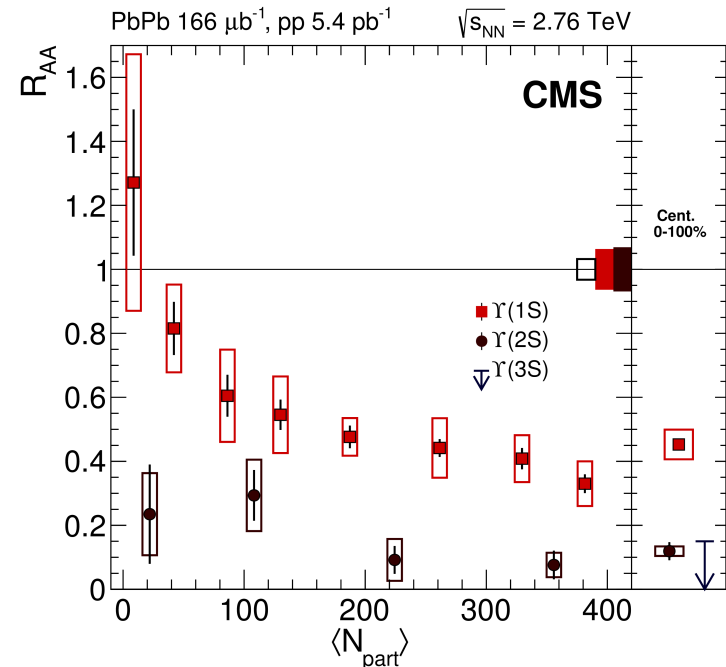
Pheno: energy loss as dominant J/ψ suppression mechanism at high p_{T}
[Arleo, PRL119 \(2017\) 062302](#)

Bottomonia

- All **3 states** well separated
- Coverage down to **$p_T = 0$**



1st Υ measurement (contact: [GdC](#)):
[PRL 107 \(2011\) 052302](#)
 Legacy Run 1 paper (thesis: [Filipovic](#))
[PLB770 \(2017\) 357](#)



- Free of competing effects in charmonia sector, e.g., regeneration
- Surprisingly rich “cold nuclear matter” effects in pA

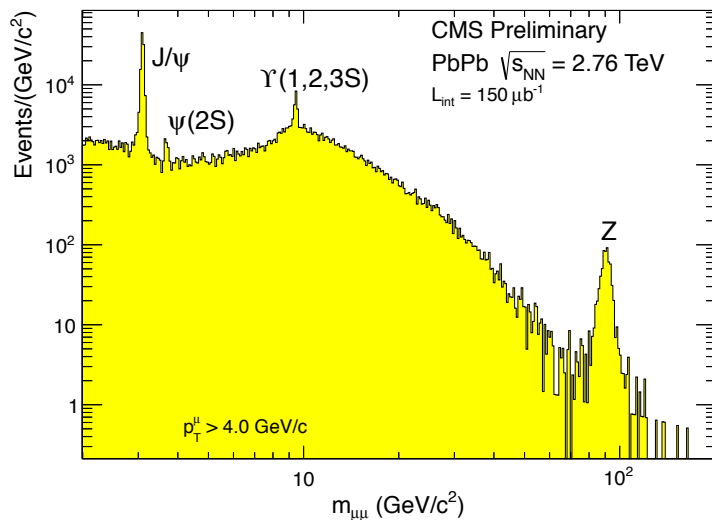
[JHEP04 \(2014\) 103](#), contact: [Mironov](#)

- Pheno: A new theory for onia in pA: “Energy loss via interference”

[JHEP03\(2013\)122](#), [Arleo](#) & [Peigne](#)

Weak bosons

AA: “standard candle”



- Initiated 1st measurements of W & Z bosons in heavy ions
- and led legacy Z (muon & electron): [JHEP 03 \(2015\) 022](#), contact: Benhabib

pA: nuclear parton distributions

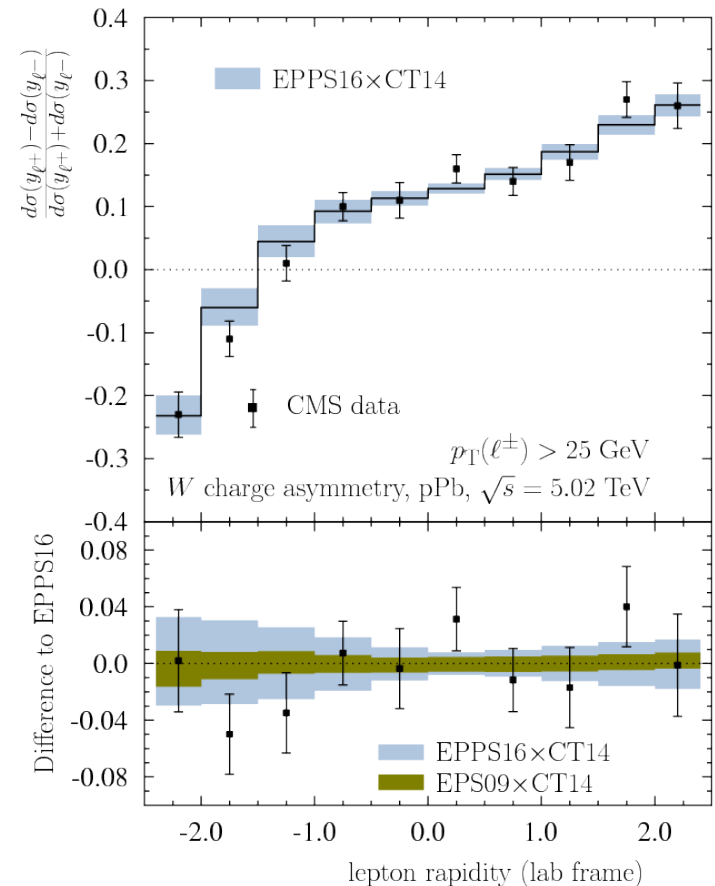


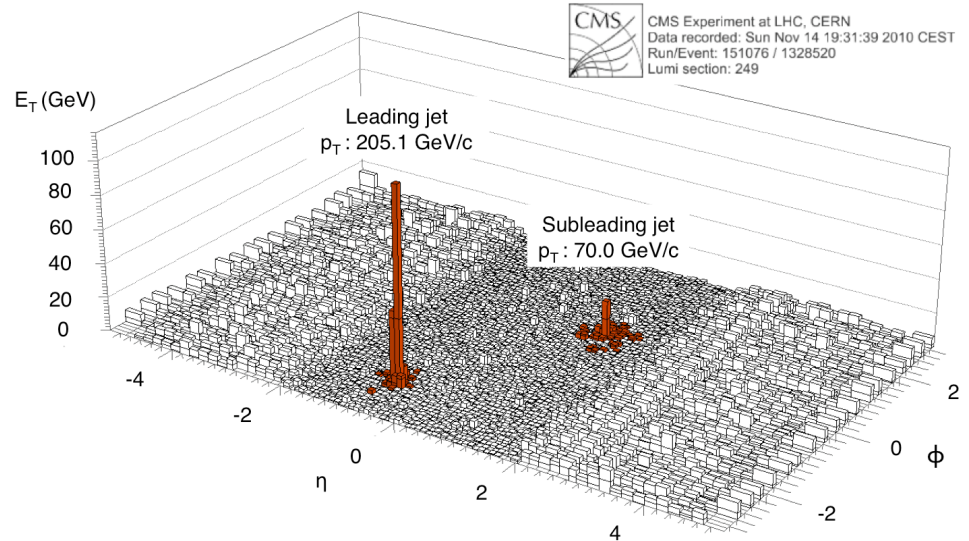
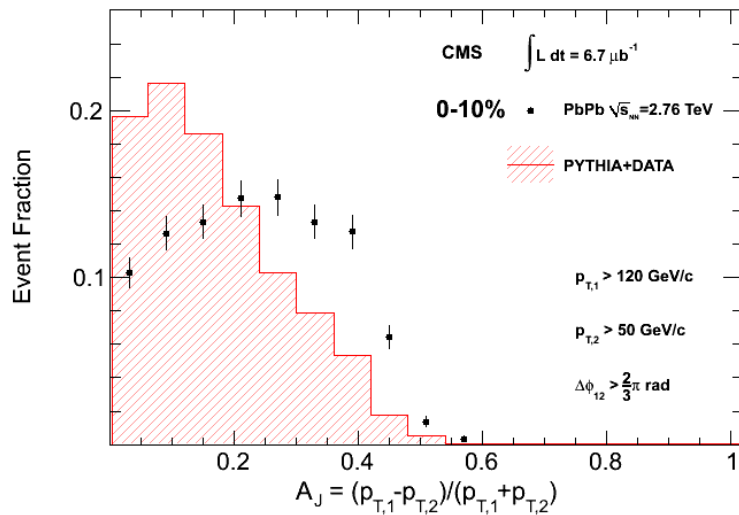
Figure courtesy EPPS

- W in pPb @ 5 TeV [PLB 750 \(2015\) 565](#), thesis: Florent
- Pheno: Arleo, Chapon, Paukkunen [EPJC 76 \(2016\) 214](#)

Jet quenching

LHC brought **jet reconstruction**
to heavy ions for **the 1st time**

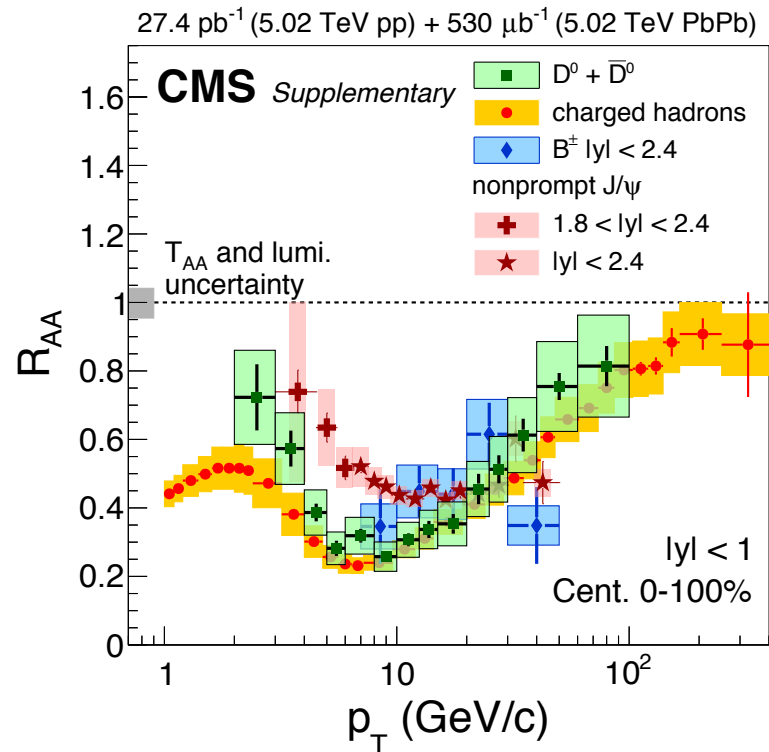
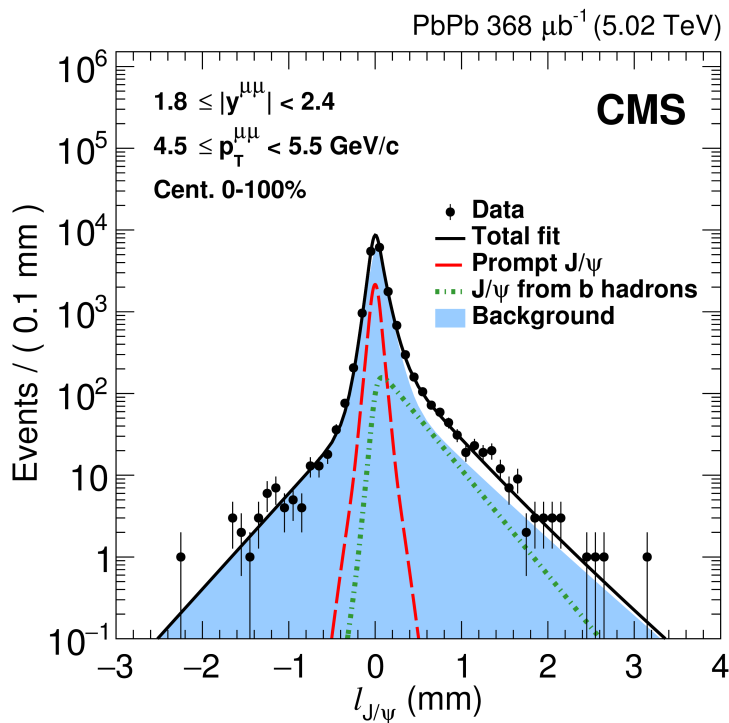
Dijet p_T imbalance in AA
[PRC 84 \(2011\) 024906](#),
contact: [Nguyen](#)



- CMS strength: combining jets w/ tracking
- Fragmentation functions & jet shapes
 - Jet-track correlations, e.g., missing p_T
 - Heavy-flavor tagging

Open heavy flavor

LLR lead the effort to measure **J/ψ from b-hadron decays** in AA for the **1st time** (same publications as prompt J/ψ)

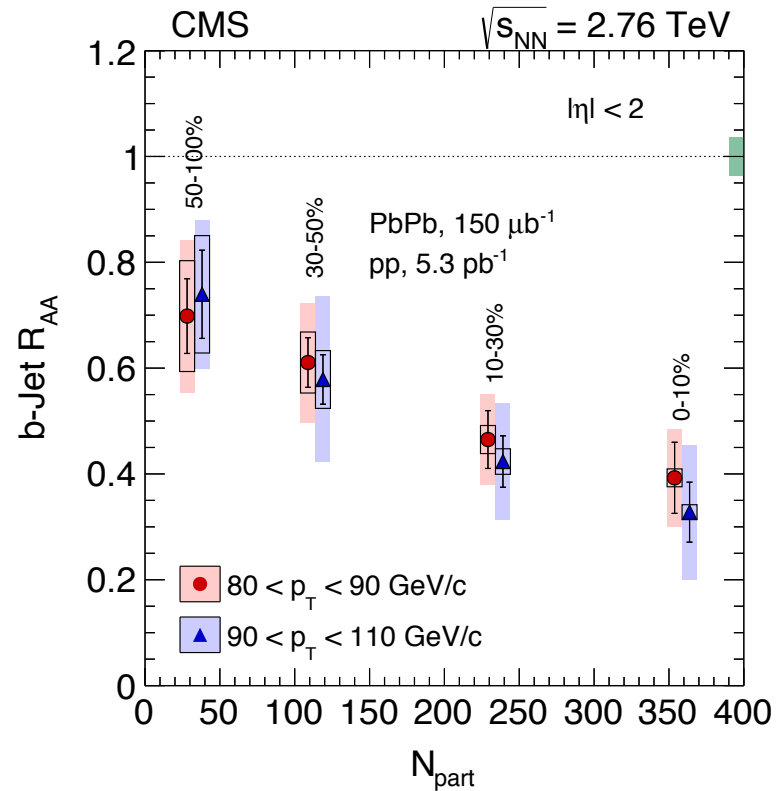
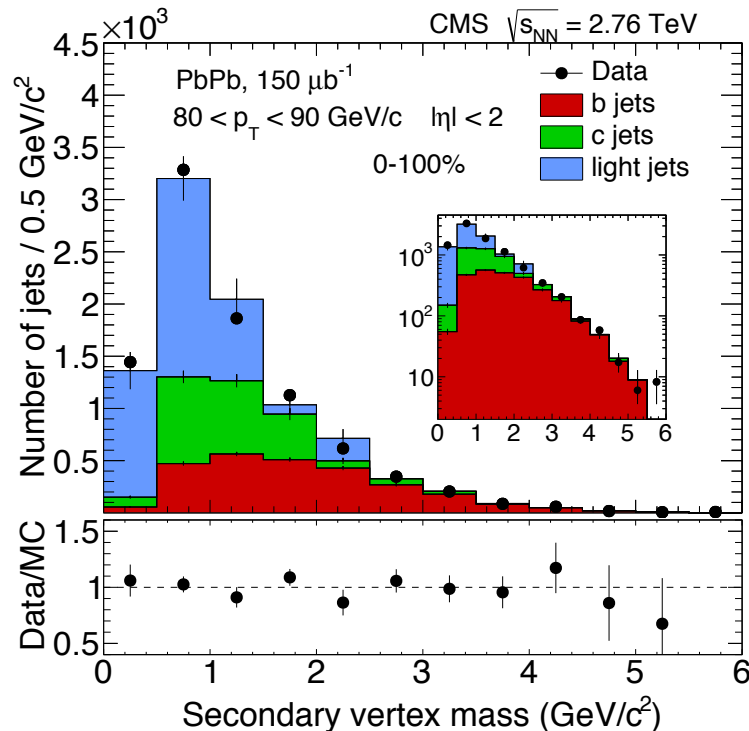


Flavor dependence a key constraint on energy loss models

b-quark jets

1st b-jet measurement in AA
[PRL113 \(2014\), 132301](#)
 contact: [Nguyen](#)

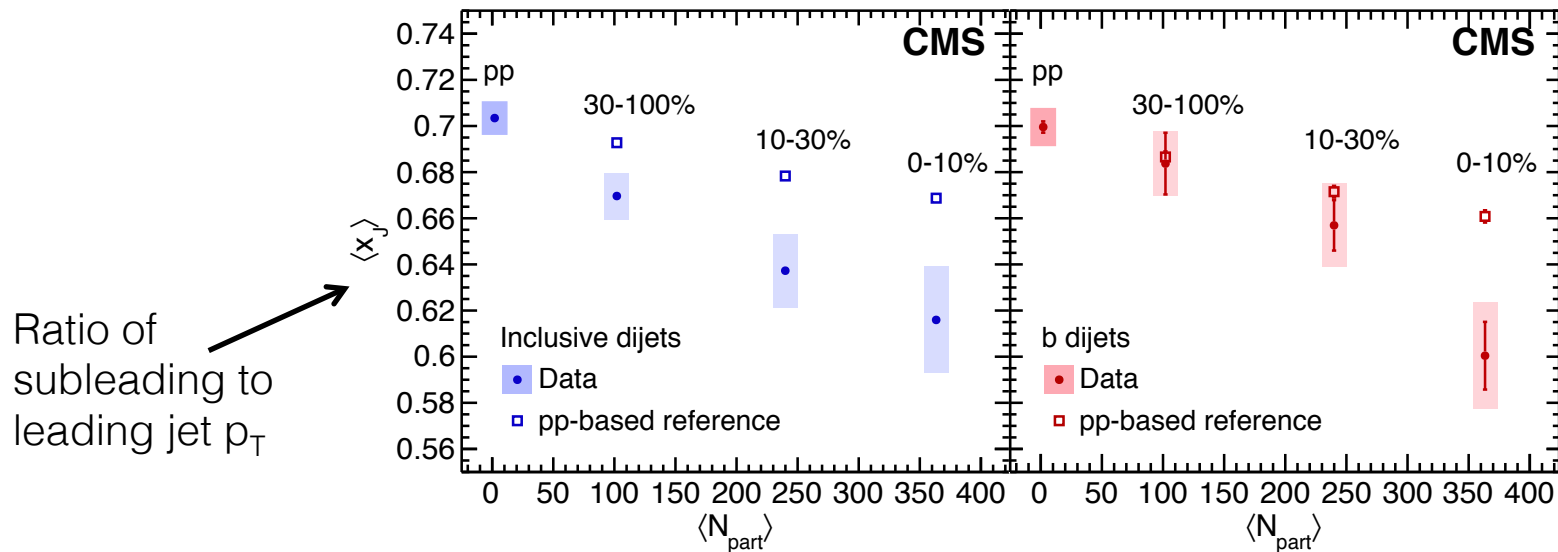
Jets tagged via displaced vertices from heavy hadron decays



- Comparable quenching to light jets, which are dominated by gluons
- Sets stage for more detailed measurements of identified jets

$b\bar{b}$ correlations

- Logical next step: correlations of heavy quark pairs
- Removes contribution of gluons fragmenting into heavy quarks



- No clear difference between p_T balance of inclusive and b-dijets
- Run 3 data will allow for a conclusive statement

[arXiv:1802.00707](https://arxiv.org/abs/1802.00707)
thesis: Lisniak

Scientific production

- 13 publications with LLR contact (74 total CMS-HI)
 - including some of the top-cited CMS papers
 - Many “firsts”: Nonprompt J/ψ, Y, W & Z, b-jets, etc.
 - + several closely related theory publications
- Scientific responsibilities within CMS
 - Heavy-ion convener: GdC ('10 – '11), Nguyen ('14 – '15)
 - Sub-conveners, dileptons: GdC, Dahms & high pT: Yilmaz
 - and other responsibilities in CMS:
 - Nguyen: Heavy-ion software coordination & computing responsibilities
 - GdC: Career, International & heavy-ion Publication committees
- Many major talks, conf. organization, etc. (see backup)

What have we learned?

- 1) Y states acting as a “thermometer” of QGP
- 2) W constraining nuclear parton distributions
- 3) Energy loss looking increasingly important for the description of J/ψ suppression
- 4) Energy loss of b-quarks in the QGP
 - a) Nonprompt: indication of flavor hierarchy
 - b) b-jets: no sign of quark/gluon difference yet

Still to come with Run 2

- W in pPb @ 8 TeV
→ Improved nPDF constraints
(thesis: [Ståhl, '18](#))
- Quark Matter 2018
-

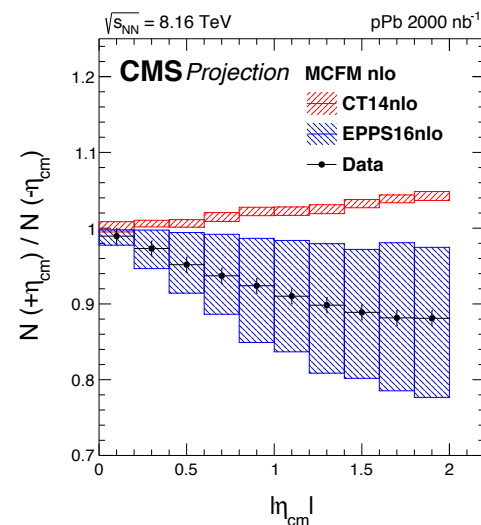
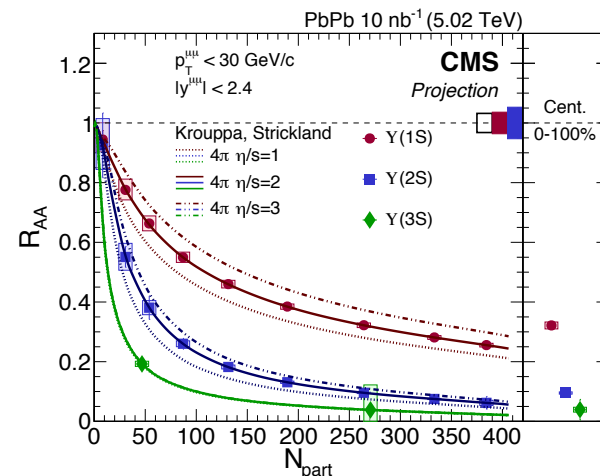
pp results for QM18,
PbPb w/ 2018 data
(2-3x 2015 PbPb)

- J/ ψ fragmentation in jets in pp and PbPb
→ fragmentation modified by quenching?
(thesis: [Diab, '20](#))
- Jets containing two b quarks (“antenna”)
→ coherence effects between nearby
partons in shower?

Longer term prospects

- $\geq 10 \text{ nb}^{-1}$ of PbPb in Run 3+4.
~ 10x more than Run 1+2!
- Unfinished business
 - Open Υ questions, e.g., Does it flow? Just how suppressed is the 3s?
 - Open b-jet questions: Will we see a difference between quark and gluon jets with higher stats?
- Exciting New Probes
 - Exotic heavy flavor: $X(3872)$, B_c , etc. Enhanced by recombination?
(thesis '21, pending funding)
 - γ +jet w/ heavy quarks: A heavy quark gun for the QGP.
Predictions: [Arleo et al](#), [JHEP02 \(2013\) 072](#)

Υ in PbPb w/ 10 nb^{-1} PbPb



W in pPb w/ 200 nb^{-1} 16

CMS upgrades

- “Phase 2”: major upgrade of CMS between Runs 3 & 4
 - Tracking out to $\eta = 4$ (currently 2.5) w/ reduced material budget
 - Muons with GEMs out to at least $\eta = 3$ (currently 2.5)
 - High granularity calorimeter (HGCAL) ($1.5 < \eta < 3$)
 - Not yet much reflection on impact for heavy ions, but e.g.,
 - Better dimuon mass resolution, e.g., better $\Upsilon(3s)$
 - Jet substructure and quark/gluon separation w/ HGCAL
 - Saturation physics in pA with forward hadrons or photons?
 - So far heavy-ion community not implicated in Phase 2
(NB: U.S. played strong role in Phase 1)
- Participation in HGCAL would solidify our perspectives, LLR HEP colleagues already play leading role

As a summary: self-evaluation

7. Auto-analyse SWOT / AFOM

(Excerpt from our document)

Atouts (Strength)

- Expertises internationalement reconnues (quarkonia, jets...);
- Attractivité envers les étudiants et postdocs (Marie Curie...);
- Interface avec la théorie, présence d'un théoricien associé;

Faiblesses (Weaknesses)

- Rapport permanents / non-permanents;
- Manque d'implication dans les *upgrades*;

Opportunités (Opportunities)

- Haute luminosité du run 3, et au-delà;
- Excellentes performances du détecteur CMS;
- Dynamisme d'une petite communauté (responsabilités...);

Menaces (Threats)

- Tarissement des sources de financement;
- Rapport de forces entre expériences.

Backup

Composition de l'équipe

Responsable scientifique local: Raphaël Granier de Cassagnac

Équipe démarrée en 2009, profitant énormément de l'implantation du LLR dans CMS et d'une ERC starting grant (2010-15)

Liste des chercheurs participants :

▪ 3 permanents :

- François Arleo, CRCN, HDR, 25%, théoricien associé à CMS (contributions exp. + expertise th.)
- Matthew Nguyen, CRCN, HDR, 100% (jets)
- Raphaël Granier de Cassagnac, DR2, HDR, 75% (quarkonia + electroweak)

▪ 2 post-doctorants :

- Inna Kucher, ANR, 100%, 2017-20 (jets)
 - Javier Martin Blanco, IN2P3, 100%, 2016-18 (quarkonia)
- (+ 8 postdocs depuis 2009 → 3 ≈permanent, 3 postdocs, 2 privés)*

▪ 2 doctorants :

- Batoul Diab, ANR, 100%, 2017-20 (jets)
 - André Ståhl, PHENIICS, 100%, 2015-18 (quarkonia)
- (+ 3 thèses soutenues → =1 postdoc CMS hors ions lourds, 2 privé)*

Évolution anticipée (3-5 ans)

- **Personnel...**

- Permanents : pas de retraite anticipée avant... presque 25 ans !
- Postdocs : 4 en 2016 – 1 = 3 en 2017, – 2 = 2 en 2018, – 1 = 1 en 2019
 - > tentative constante de renouvellement
 - (mais il paraît utopique de maintenir ce niveau, guichets épuisés...)
- Thésards : 2 c'est bien (sur cinq thèse, une seule ministérielle...)
 - > Projet de co-tutelle franco-coréenne (en lien avec FKPPL)

...en totale inadéquation avec nos...

- **... activités envisagées**

- Exploitation des collisions d'ions lourds pour le run 2, puis 3, puis 4
 - Raffinement des mesures passées : certains signaux manquants de stat (ψ' , Y''' , b-jets...), flot des Y, etc.
 - Plein d'idées nouvelles : Recherche de hadrons « exotiques » (B_c , $X(3872)$...) possiblement surgénérés, premiers tops en PbPb...
- Exploitation de HGCal pour les ions lourds
- Projet de valorisation financé : jeu vidéo sur la physique des particules (RGdC)

Prospectives ☹️

- **CMS = Chronique d'une Mort Signifiée ?**
- **Le groupe du LLR =**
 - Excellente production scientifique au run 1 ?
 - Elle est/sera bien inférieure au run 2 !
 - Elle sera quasi-nulle aux runs 3 et 4...
- **Les guichets sont épuisés (ERC, ANR...)**
- **Perspectives de recrutement très faibles (IN2P3, LLR...)**
- **La relève n'est pas assurée au niveau international**
 - Peu de « dileptoners » (3 petits groupes = coréen, indien, NSF)
 - Les Américains ont du mal à rester dans CMS (sPhenix...)
- ...

Composition de l'équipe (ex)

Liste des anciens chercheurs participants :

▪ 8 post-doctorants :

- Mihee Jo, FKPPL+Marie Curie, 100%, 2015-17 (**quarkonia**) → Privé (Samsung)
- Abdulla Abdulsalam, Polytechnique, 100%, 2016-17 (**quarkonia**) → Prof en Arabie Saoudite
- Yetkin Yilmaz, ANR+Marie Curie, 100%, 2013-16 (**jets**) → Postdoc LAL, machine learning
- Émilien Chapon, ERC+LLR, 100%, 2013-16 (**quarkonia** + **electroweak**) → CERN fellow
- Lamia Benhabib, IN2P3+ERC, 100%, 3,5 ans (**electroweak**) → Privé
- Camelia Mironov, Marie Curie+ERC, 100%, 4 ans (**quarkonia** + **electroweak**) → senior postdoc associate MIT, CMS, convener HIN
- Torsten Dahms, ERC, 100%, 3 ans (**quarkonia** + **electroweak**) → Postdoc d'excellence, Munich, Alice
- Sarah Porteboeuf, Europe, 100%, un an (**quarkonia**) → MdC Clermont Ferrand, Alice

▪ 3 doctorants :

- Stanislav Lisniak, Idex Paris-Saclay, 100%, 2016 (**jets**) → privé
- Alice Florent, ERC, 100%, 2014 (**electroweak**) → postdoc UCLA, CMS, exotica
- Nicolas Filipovic, ERC, 100%, 2015 (**quarkonia**) → postdoc Budapest, CMS → privé

Quelques talks en conférences... (1/2)

- ...
 - 07/17 : **SQM** (Martin-Blanco)
 - 07/17 : **EPS-HEP**, un plénier (Nguyen), un parallèle (Stahl) + **convener** (RGdC)
 - 07/17 : low-x (Nguyen)
 - 02/17 : **Quark Matter**, 1 parallèle (Martin-Blanco)
 - 09/16 : Hot quarks (Stahl)
 - 09/16 : **Hard probes**, un plénier (Arleo), 2 parallèles (Chapon, Jo)
 - 06/16 : Quarkonium workshop @ Washington, revue CMS ions lourds (Jo)
 - 03/16 : Quarkonium workshop @ Trento, summary (Arleo)
 - 01/16 : HEPinLHC @ Valparaiso, plénier (Arleo)
 - 12/15 : **Quark Matter**, 2 parallèles (Chapon, Jo) + un plénier (Nguyen)
 - 07/15 : **EPS-HEP**, un plénier (RGdC)
 - 07/15 : Intl conf on LHC @ Vietnam talk + **organisation** (Arleo)
 - 06/15 : **Hard Probes**, 2 parallèles (Filipovic, Arleo)
 - 06/15 : EDS, Jets in CMS (Yilmaz)
 - 06/15 : Blois, ATLAS+CMS ions lourds (Chapon)
 - 12/14 : Sapore Gravis workshop, 3 talks (GdC, Mironov, Nguyen)
 - 09/14 : @ Split, overview (Nguyen)
 - 09/14 : Hot quarks, 2 talks (Chapon, Filipovic) + **organisation** (RGdC)
 - ...
- (liste non exhaustive)

Quelques talks en conférences... (2/2)

- 09/14 : High pt workshop, 1 talk (Yilmaz)
 - 07/14 : Jet workshop, 1 talk (Nguyen)
 - 06/14 : Beauty, 1 talk (Nguyen)
 - 06/14 : LHCP (Florent)
 - 05/14 : **Quark Matter**, un poster (Lisniak) + un plénier (GdC)
 - 12/13 : Sapore Gravis workshop, 5 talks (Dahms, GdC, Filipovic, Mironov, Nguyen)
 - 11/13 : **Hard Probes**, 2 talks (Florent, Yilmaz) + 1 poster (Yilmaz)
 - 09/13 : High pt workshop, 1 talk (Nguyen)
 - 09/13 : IS2013, 1 talk (Mironov)
 - 07/13 : SQM'13, plénier (RGdC)
 - 07/13 : HEP, parallèle (Nguyen)
 - 07/13 : MIT-France workshop (Nguyen)
 - 05/13 : Blois (Nguyen)
 - ...
 - 04/13 : LHC France (Florent, Filipovic) + **organisation** (Nguyen)
 - ...
 - 10/12 : Hot quarks (Florent) + **organisation** (GdC)
 - 08/12 : **Quark Matter**, 2 par. (Benhabib, Nguyen) + 2 plén. (Mironov, GdC)
 - 05/12 : **Hard Probes**, 2 par. (Benhabib, Mironov) + 1 plén. (Dahms)
 - ...
- (liste encore moins exhaustive)