

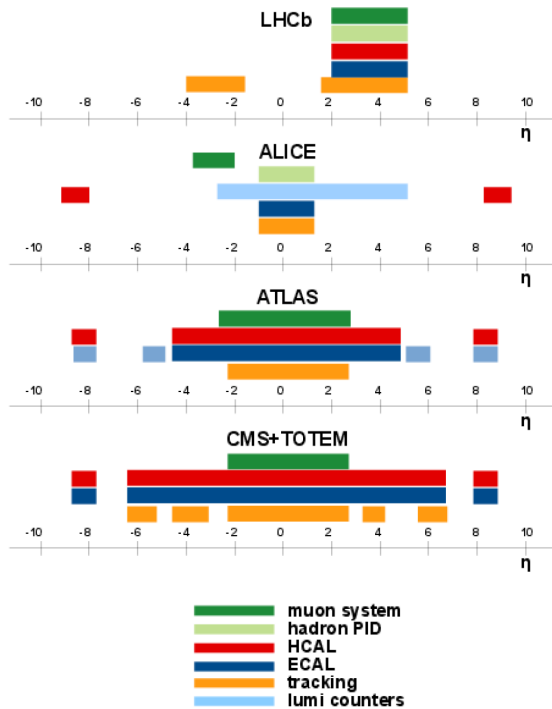


Collisions d'ions lourds dans l'expérience CMS au LHC

Matt Nouven
Raphaël Granier de Cassagnac
Conseil scientifique du LLR
Mardi 19 juin 2018
Conseil Scientifique de l'IN2P3
February 8th, 2018

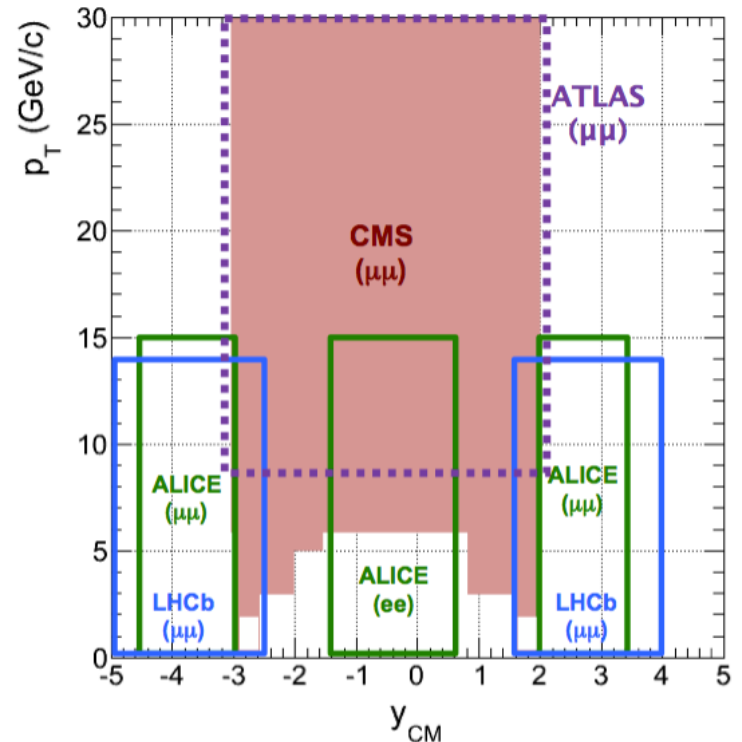
Why CMS?

Designed for rare probes



Jets, leptons, tracking / vertexing
High rate & large coverage up to
highest temperature (central PbPb)

Complementary to other
heavy-ion experiments

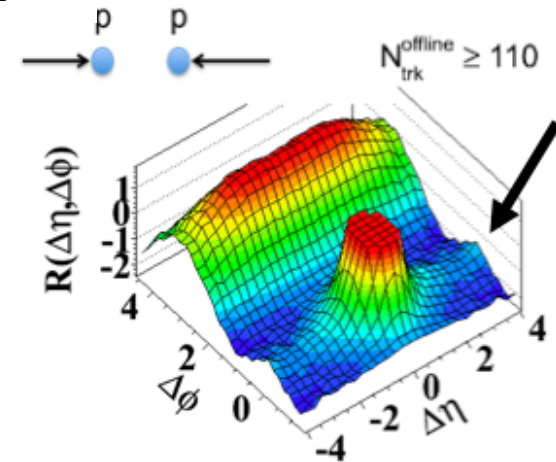
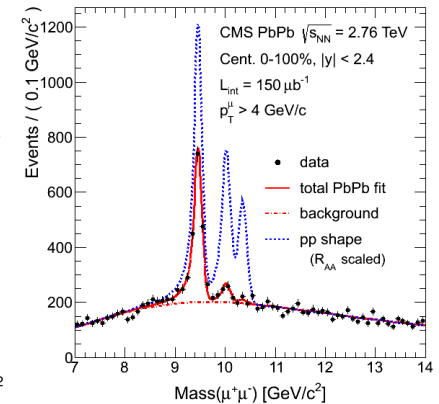
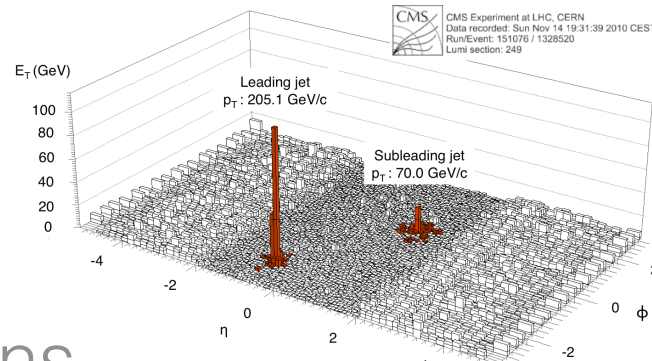


e.g., J/ψ coverage

CMS heavy-ion physics program

3 large “physics interest groups”

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

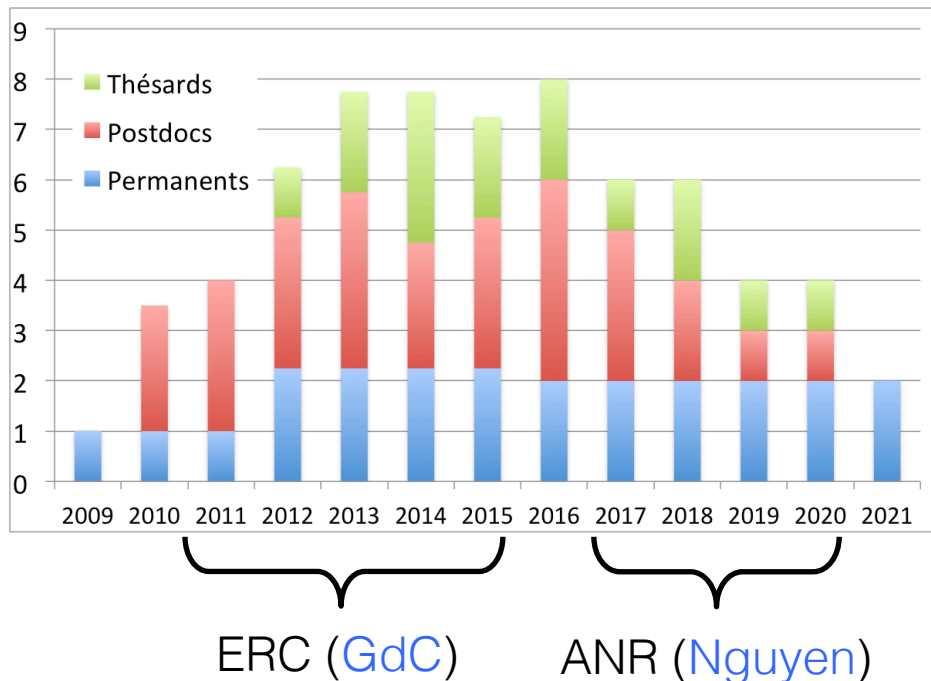


LLR is the leading group for dileptons in CMS-HI

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:



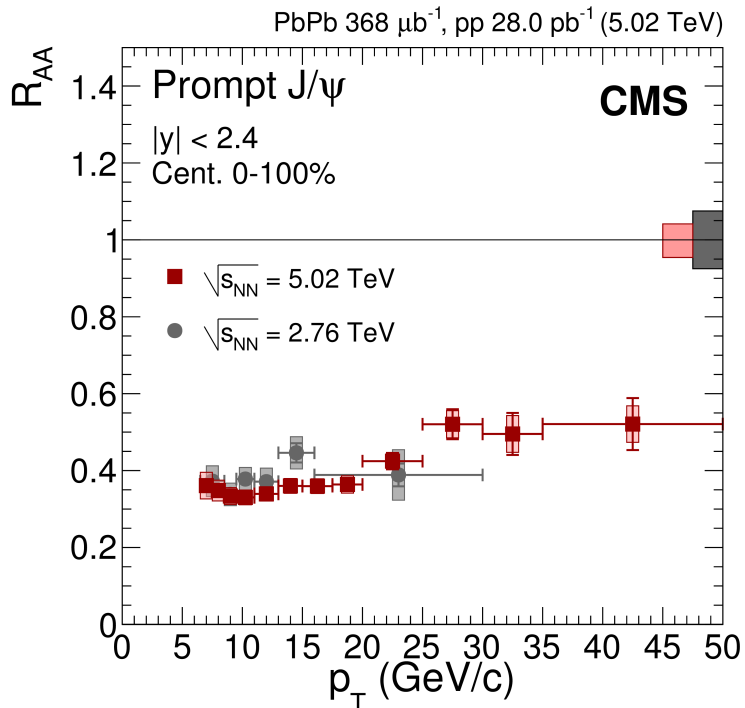
Permanent staff at LLR:

- 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 charmonium 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 & $\psi(2s)$

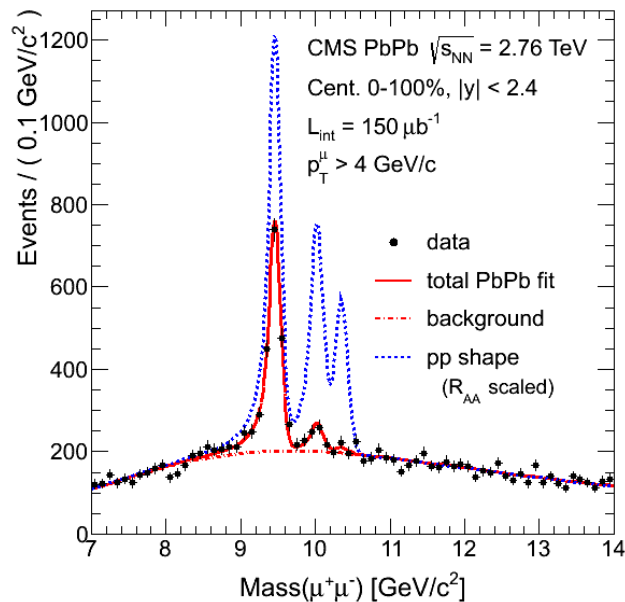
Topic	Paper reference	Contact
J/ψ	JHEP05 (2012) 063	Dahms
$\psi(2s)$	PRL113 (2014) 262301	Dahms
J/ψ (R_{AA} & v_2)	EPJC77 (2017) 252	Jo
$\psi(2s)$	PRL118 (2017) 162301	Chapon
J/ψ & $\psi(2s)$	arXiv:1712.08959	Blanco

↑
New: Rise of J/ψ R_{AA} at large p_T

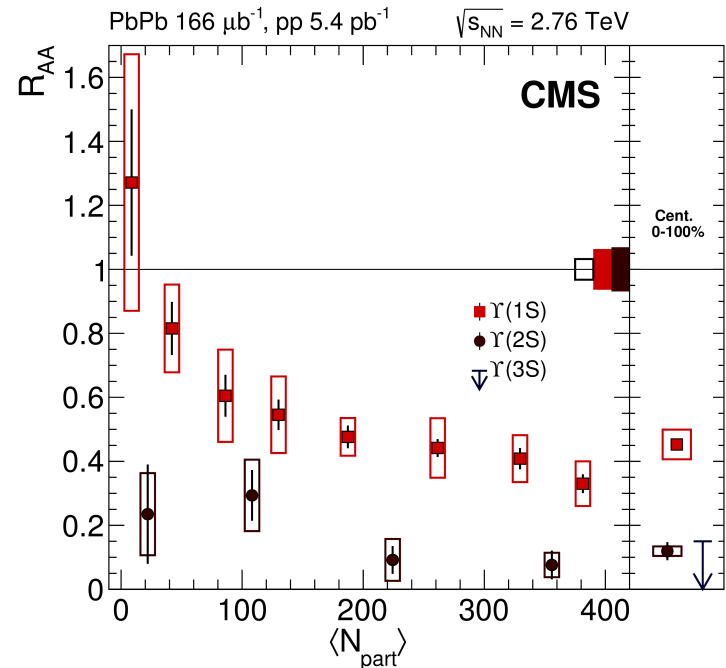
- Pheno: energy loss as dominant J/ψ suppression mechanism at high p_T
[Arleo, PRL119 \(2017\) 062302](#)

Bottomonia

- All **3 states** well separated
- Coverage down to $\mathbf{p_T = 0}$



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

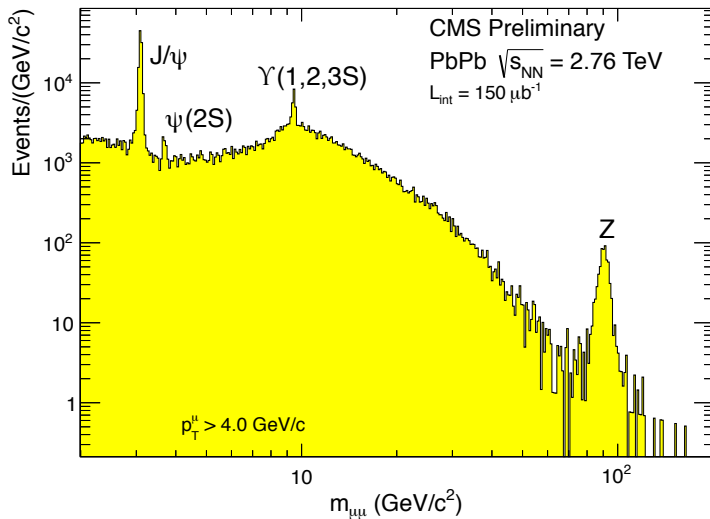
[JHEP04 \(2014\) 103](#), contact: [Mironov](#)

- 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

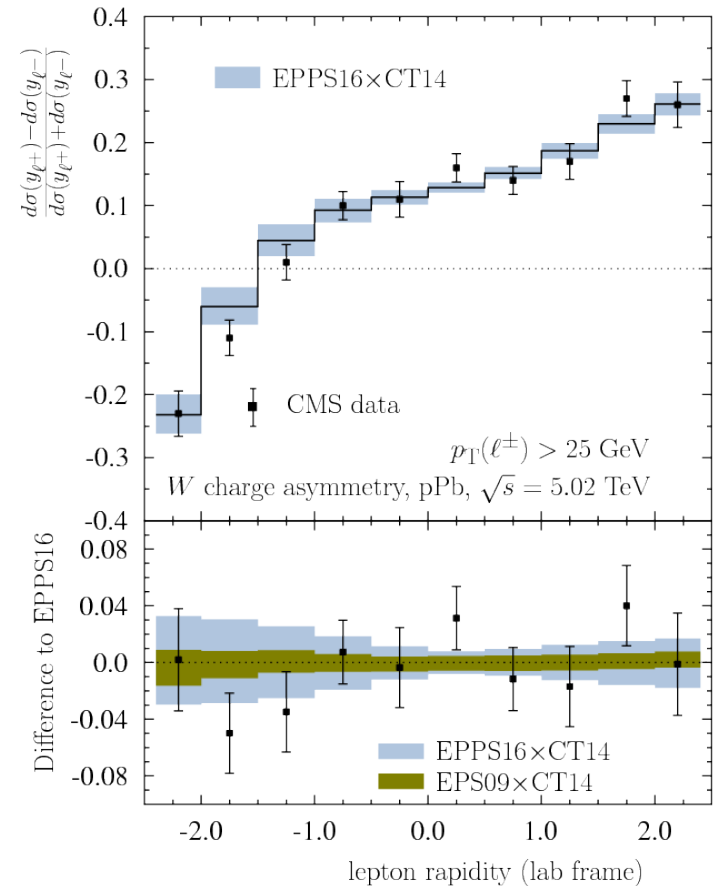


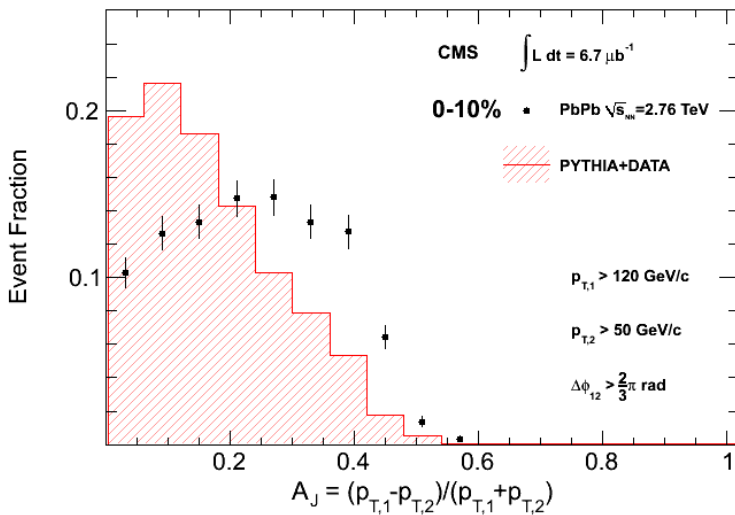
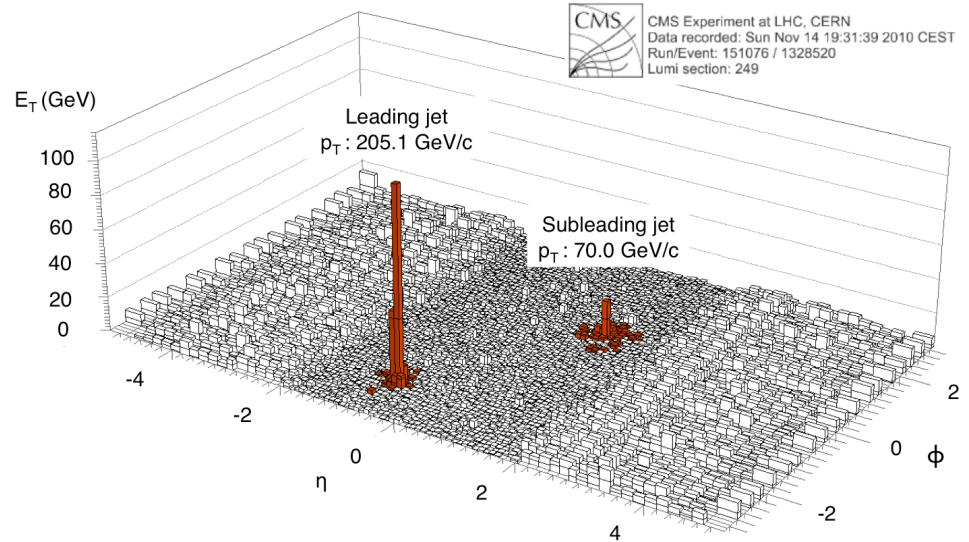
Figure courtesy EPPS

- 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

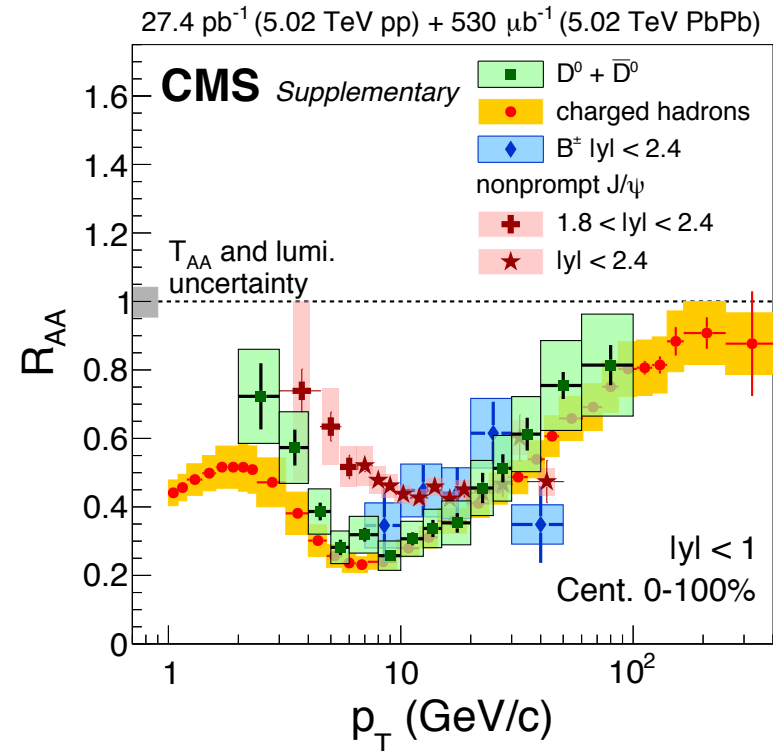
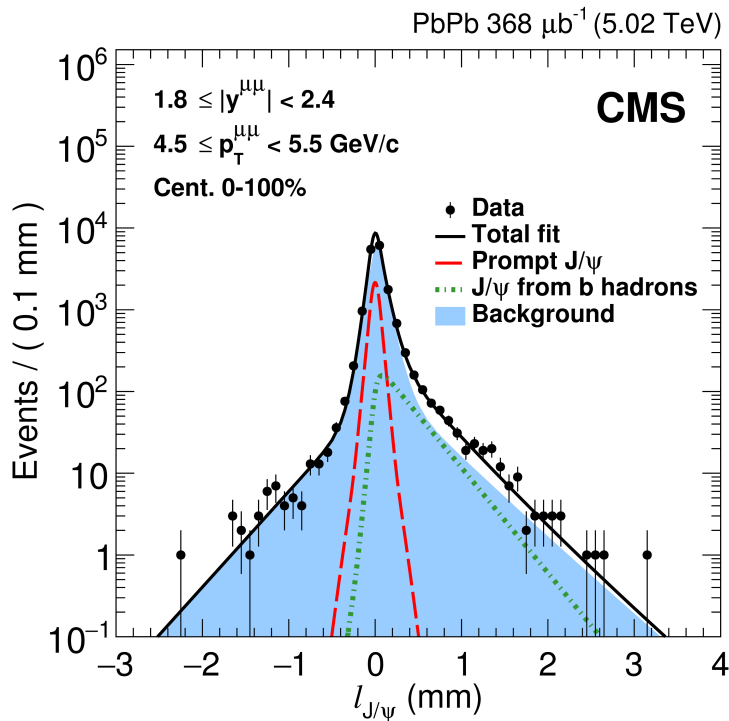
Dijet p_T imbalance in AA
[PRC 84 \(2011\) 024906](#),
 contact: [Nguyen](#)



- 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)

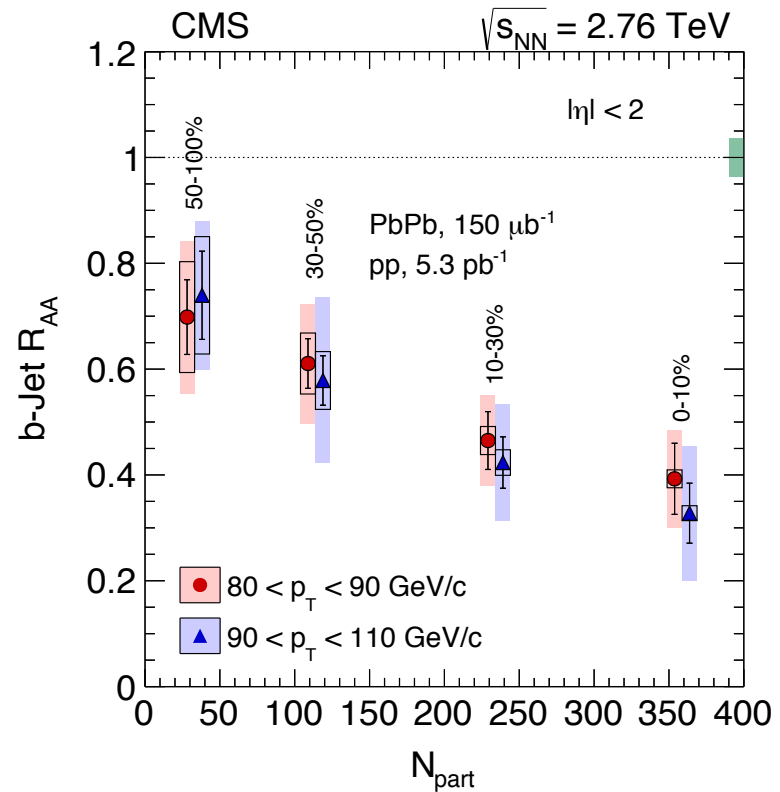
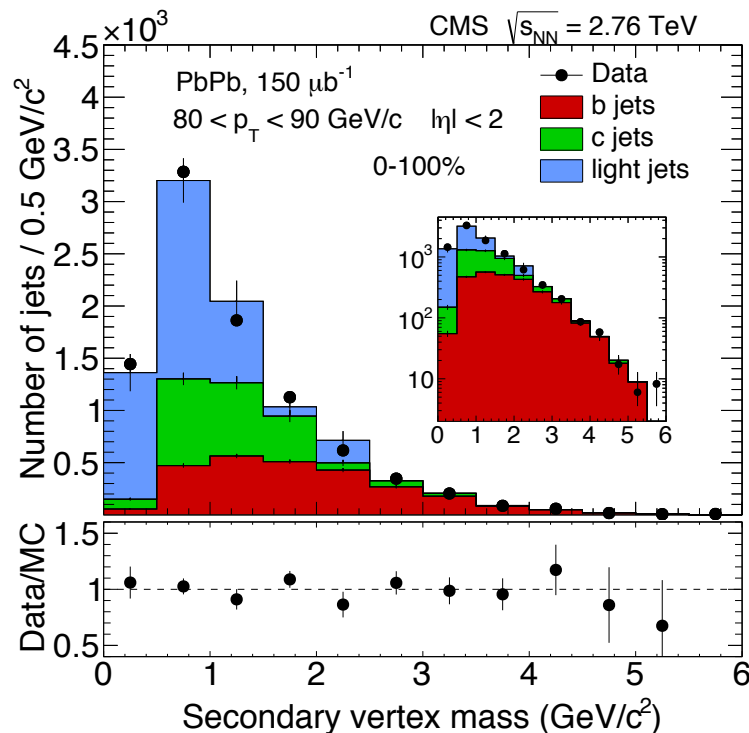


Flavor dependence a key constraint on energy loss models

b-quark jets

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

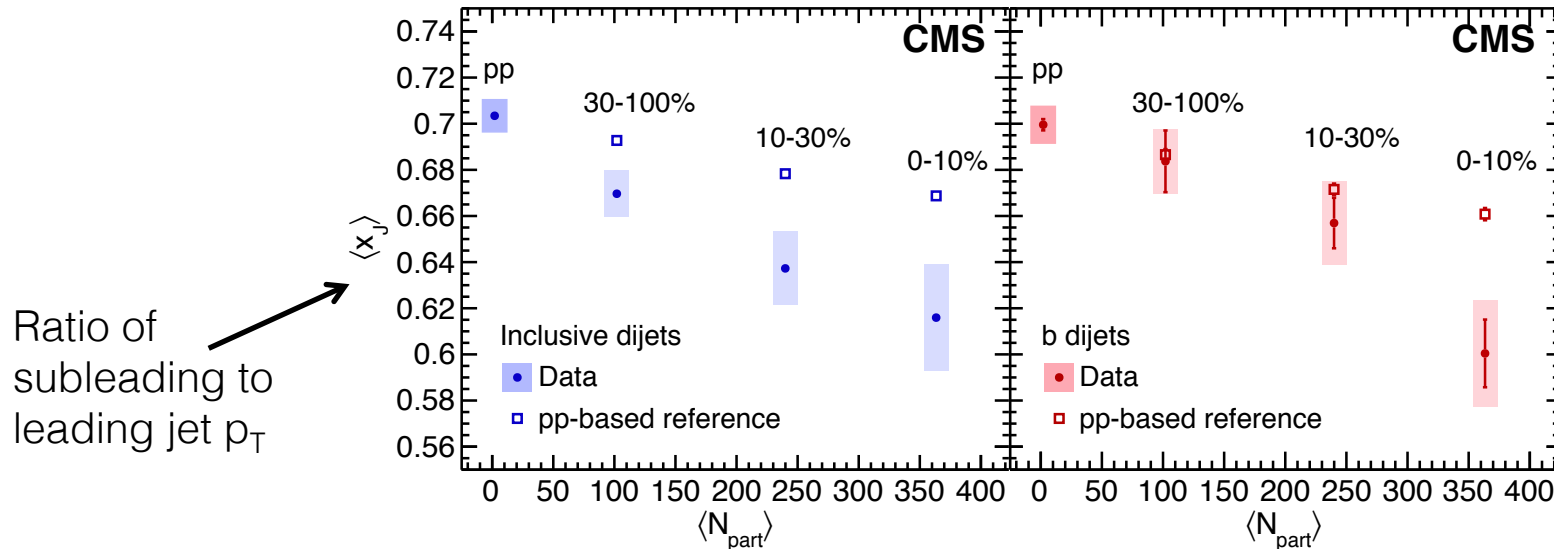
Jets tagged via displaced vertices from heavy hadron decays



- 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 [JHEP03 \(2018\) 181](#)
thesis: [Lisniak](#)

Scientific production

+2

- 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 p_T : 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

Quark Matter 2018

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



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

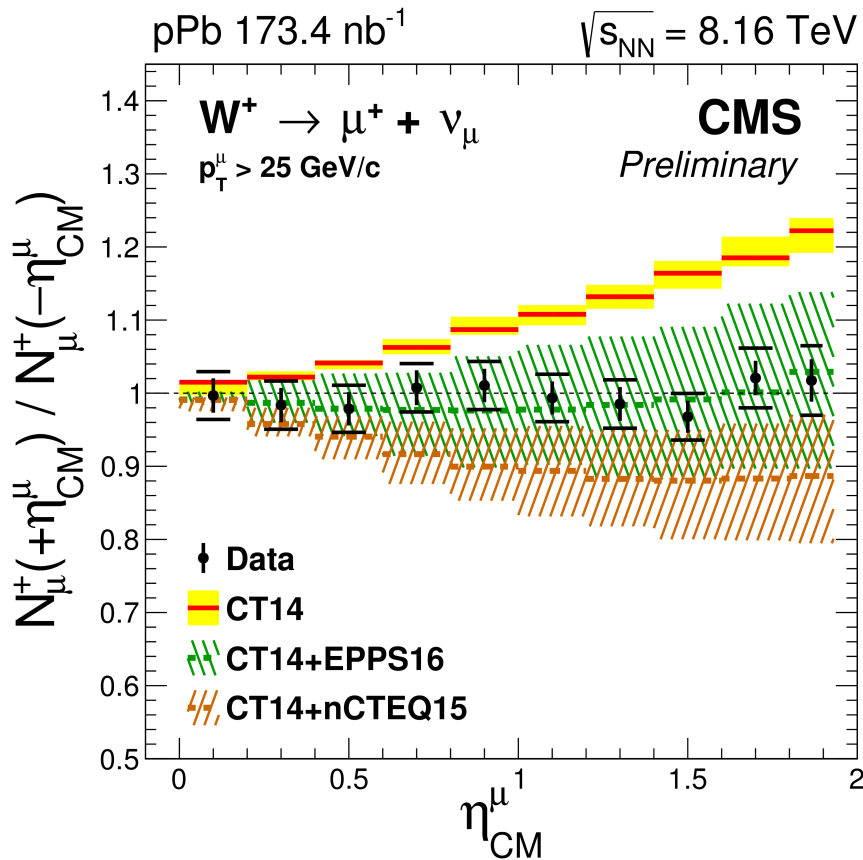
- J/ ψ fragmentation in jets in pp and PbPb
→ fragmentation modified by quenching?
(thesis: [Diab, '20](#))
- Jets containing two b quarks (“antenna”)
→ coherence effects between nearby
partons in shower?



W in pPb @ 8 TeV

New since February

- Près de 200 000 W



- Déviation significative vs PDF normales
- Pouvoir discriminant des PDF nucléaires
- Fortes contraintes
→ nouveaux fits
- HIN-17-007
- Contact: [Ståhl](#)
- Thesis: Oct, 8th 2018

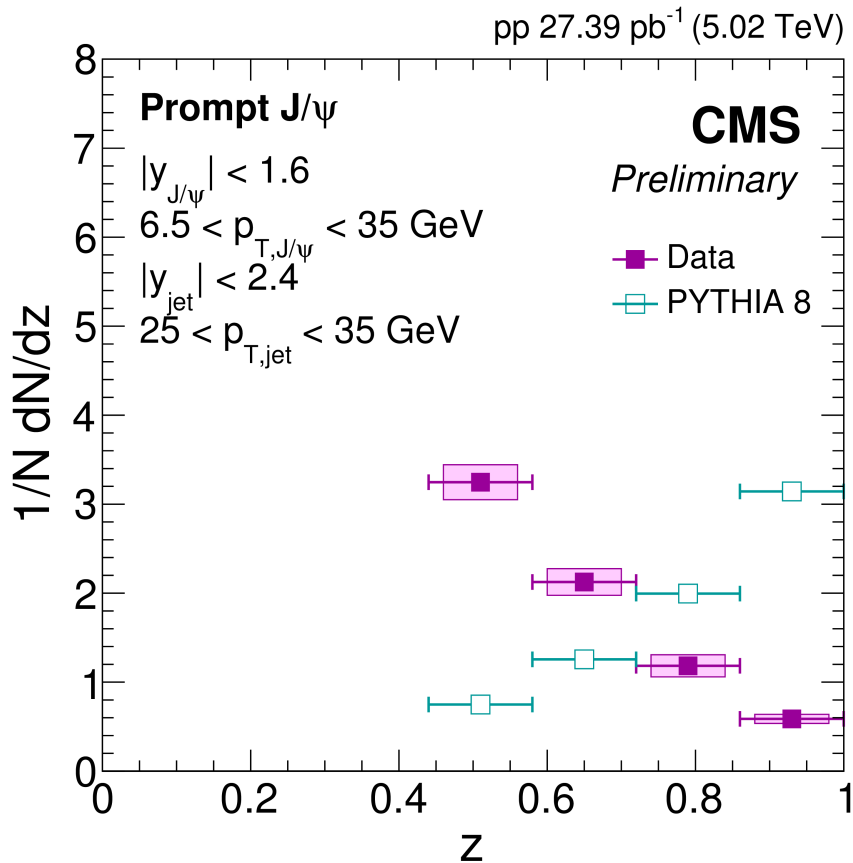
J/ ψ with jets

New since February

You mean like jet quenching?^[4]



Maybe! let's take a look together at their results.

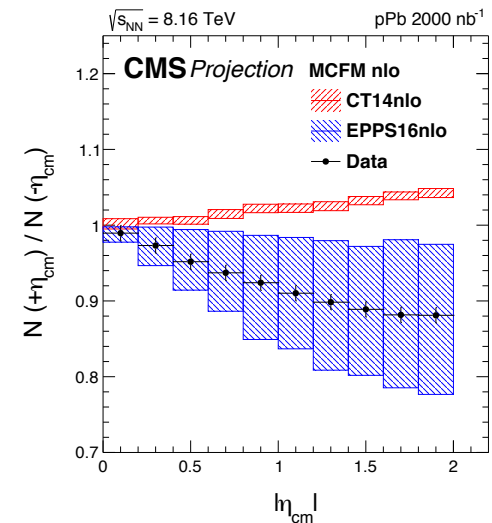
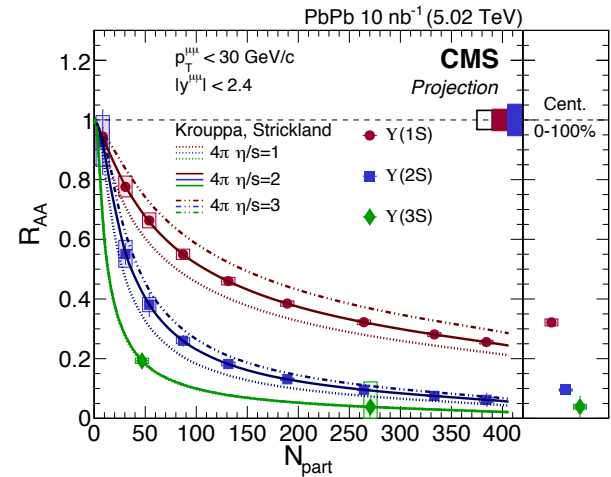


- Generators have the correlation of J/ ψ with jets totally wrong...
- (ok for nonprompt)
- HIN-18-012
- Contact: [Diab](#)
- Poster promoted to flash talk at QM'18

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) **funded**
 - 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} 18

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)

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

As a summary: self-evaluation

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Atouts (Strength)

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- Attractivité envers les étudiants et postdocs (Marie Curie...);
- Interface avec la théorie assurée d'un théoricien associé;

Faiblesses (Weakness)

- Rapport perméabilité / non-perméabilité
- Manque d'interaction dans les ungrados

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.

Malgré nos efforts, les expertises techniques sur les dileptons, quarkonia, bosons électrofaibles se perdent fin 2018... Gros potentiel avec les runs 3, 4 et sans doute au-delà ! Urgent de recruter quelqu'un pour reprendre ce flambeau... Pourquoi pas un maître de conférence à l'X ?

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 » (Bc, 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)