QUARKONIA ET SAVEURS LOURDES

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pour le
Groupe Plasma Quarks-Gluons

Outline

- Physics motivations
  - Characterizing the QGP
  - Probes
- Proposed projects
  - Exploiting the present and near future
  - ALICE Upgrades
    - Muon Forward Tracker (MFT)
    - Forward Muon Spectrometer
    - VZERO
  - Emerging ideas
    - CHIC
    - AFTER

Characterizing the QGP

- Identify and study the properties of a new state of thermalized and deconfined nuclear matter, the QGP

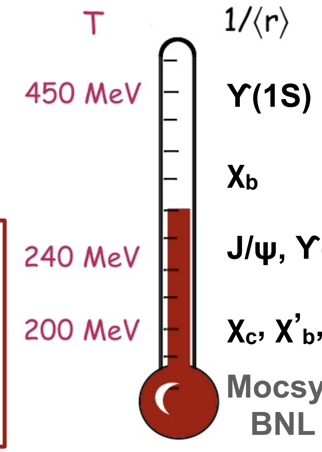
- QGP properties
  - Medium density
  - Medium viscosity
  - Temperature
  - Deconfinement

- In this presentation we will focus on Temperature and Deconfinement using the heavy quarks as our privileged probes
- Other points were or will be addressed by F. Gelis or M. Estienne

Probing the QGP Thermalization

- QGP Thermometers
  - Low mass dileptons (Chiral symmetry restoration temperature)
    - ALICE
    - MFT
  - Quarkonia (Initial temperature)
    - CMS, ALICE
    - MFT
    - CHIC
    - AFTER

Sequential quarkonia suppression by colour-screening could provide a measurement of the QGP initial temperature

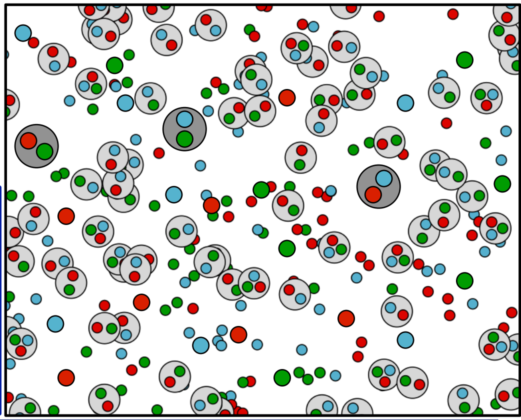


Matsui & Satz, PLB168 (1986) 415

Mocsy, EPJC61 (2009) 705
BNL workshop in June

- Recombination of deconfined quarks in the thermal medium
  - ALICE, CMS
  - MFT

If c-cbar pairs are abundantly produced and thermalize with the medium, recombination could compensate or exceed colour-screening suppression



LHC ANALYSES

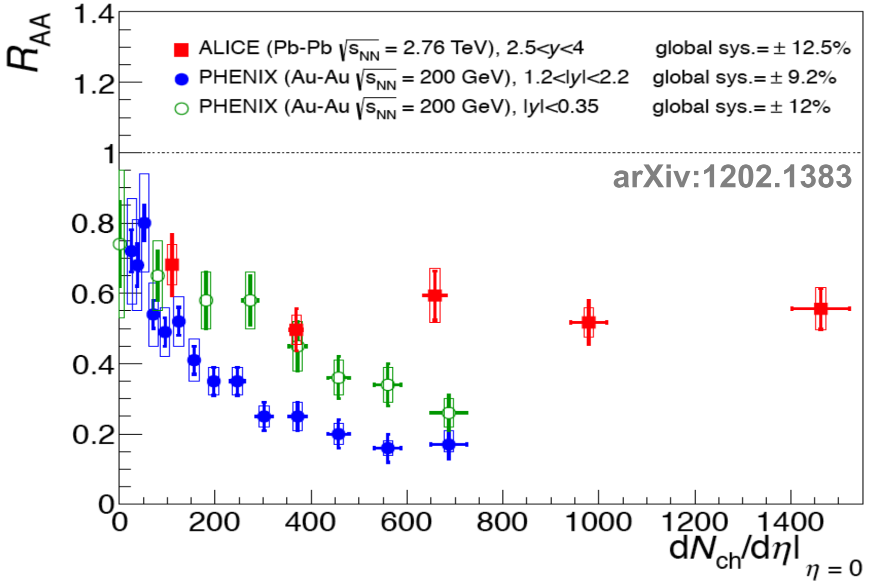
QGP THERMOMETER
QGP CONSTITUENT INTERACTIONS

2012 – 2018	2012 – 2018
IPNL, IPNO, IRFU, LPC, Subatech	LLR
33 physicists	6 physicists

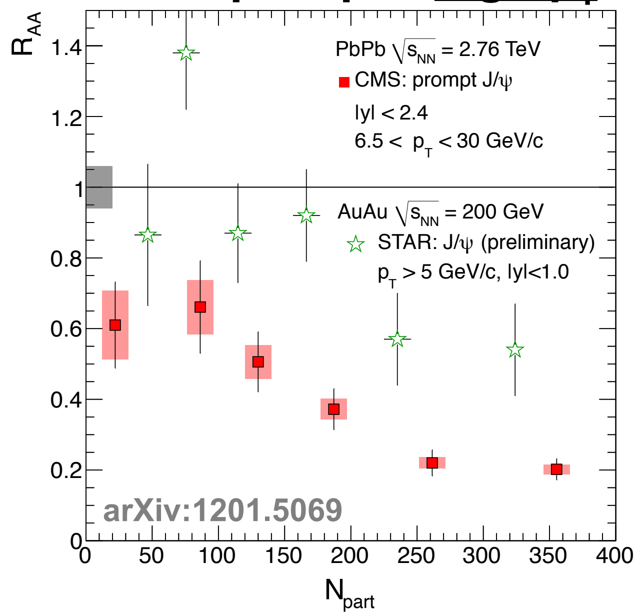
Already achieved – J/ψ

Nuclear modification factor R_{AA} compares Pb-Pb to p-p,
1 means no medium effect

Inclusive J/ψ at low p_T



Prompt J/ψ at high p_T



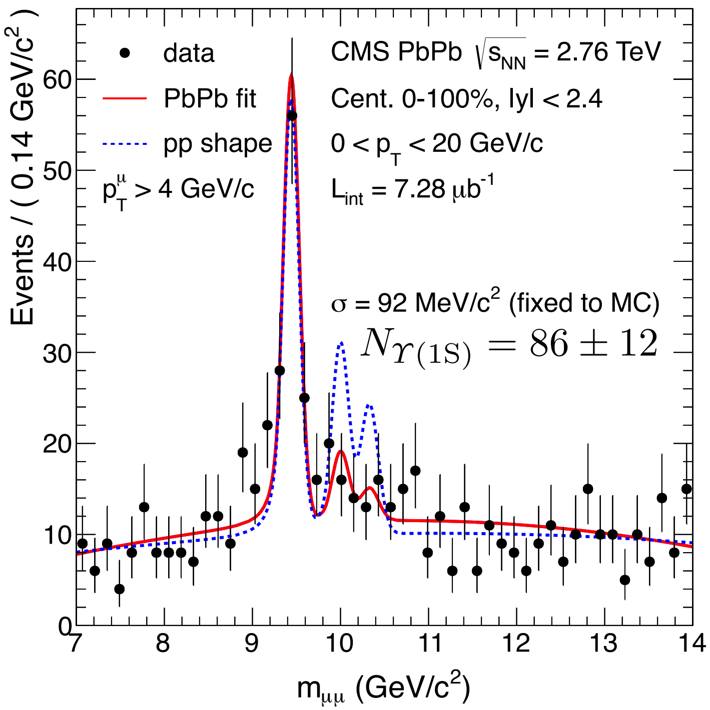
- Less suppression than at RHIC
  - – ALICE (forward) > PHENIX (forward)

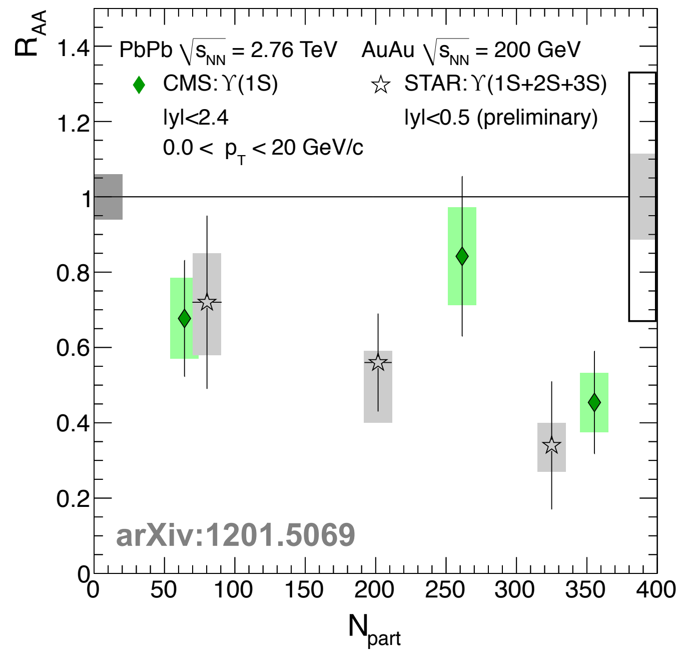
- More suppression than at RHIC
  - – CMS (p_T > 6.5 GeV/*c*) < STAR (p_T > 5 GeV/*c*)

- Recombination of charm quarks in the medium could be at play to produce low p_T J/ψ
  - – Would imply that deconfined heavy quarks do evolve with the medium

Already achieved - Y

PRL 107 (2011) 052302

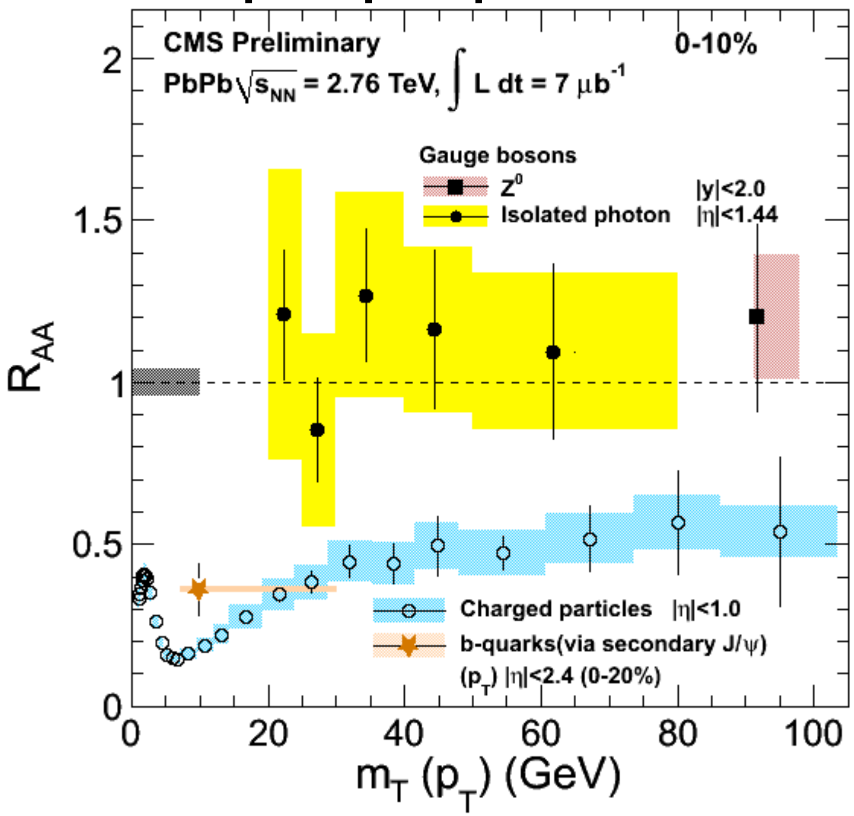




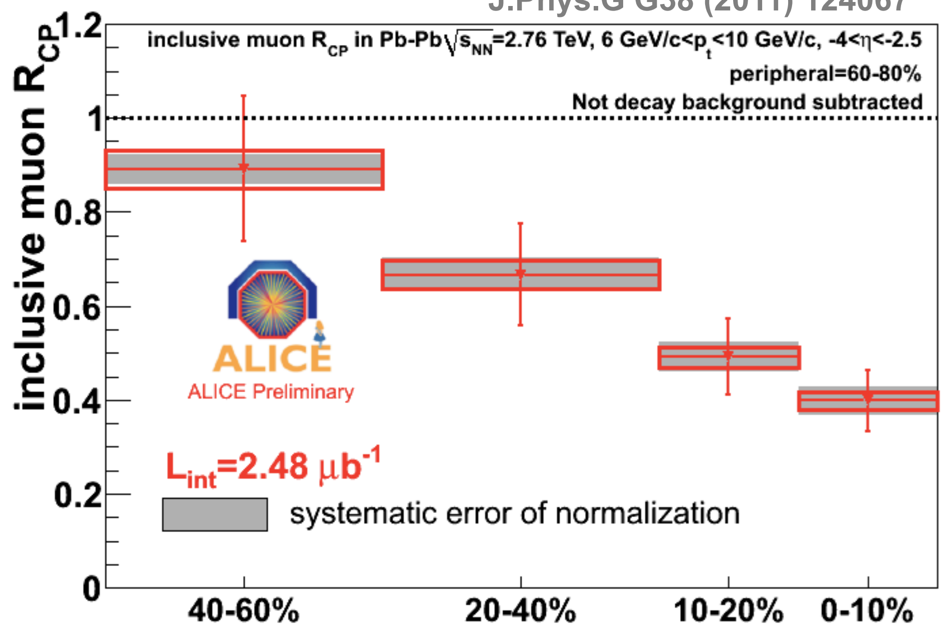
- First heavy ion measurement of Y excited states!
- Y excited states are suppressed
- Y ground state is suppressed by about 40%
  - Could be consistent with excited states suppression only.

Already achieved – open Heavy Flavor

Non-prompt J/ψ arXiv:1201.5069



J.Phys.G G38 (2011) 124067



- Inclusive muon spectra dominated by HF decays for p_T above 4 (>85%) - 6 (>90%) GeV/c

- Suppression of muons from c- and b-meson decays
- Suppression of non-prompt J/ψ
  - Indications of high-p_T b-quark quenching
- Flavour dependence of parton energy loss is at reach!

Quarkonia & HF: next steps

- J/ψ production from zero to high p_T
  - High statistics differential studies (centrality, p_T, y)
    - Confirmation of recombination interpretation and its characterization
  - Elliptic flow, new observable sensitive to regeneration models
- Initial state effects
  - Mandatory to quantify suppression from the QGP
  - p-Pb and Pb-p (2012)
- J/ψ, ψ', χ_c (?): suppression pattern
- Υ, Υ', Υ": suppression pattern, likely to be the right thermometer at LHC
- Open-charm and -beauty measurement
  - Open-charm: best reference for charmonium suppression
  - Open-beauty: non-prompt J/ψ
- Flavor dependence of parton energy loss

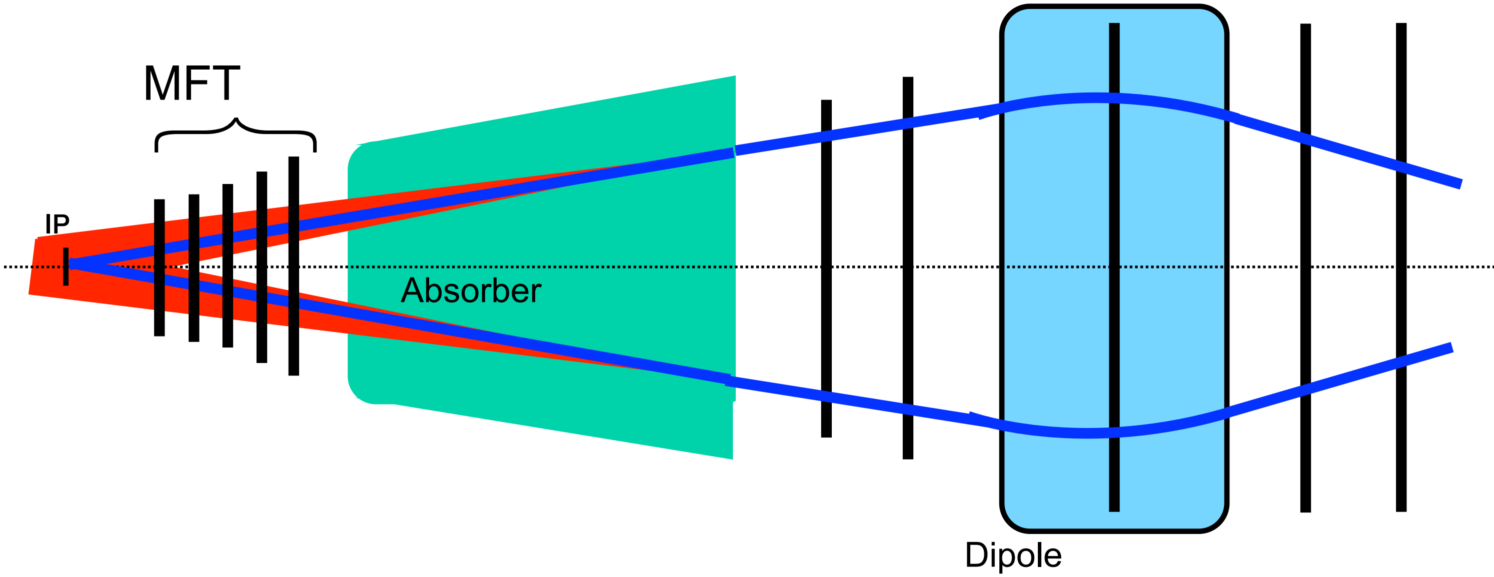
- ALICE and CMS perfectly complement each other
- To continue to take advantage of its particularities in the HL-LHC era, ALICE is proposing an important upgrade program
- CMS will continue to make the best usage of the existing detector with its good mass resolution, secondary vertex capabilities, and large bandwidth

ALICE MFT &
ALICE MUON UPGRADE

QGP THERMOMETER
QGP CONSTITUENTS INTERACTION

2012 – 2018
R&D
IPNL, IPNO, IRFU, LPC, Subatech
5.4 M€
33 physicists, 15 eng. & tech.

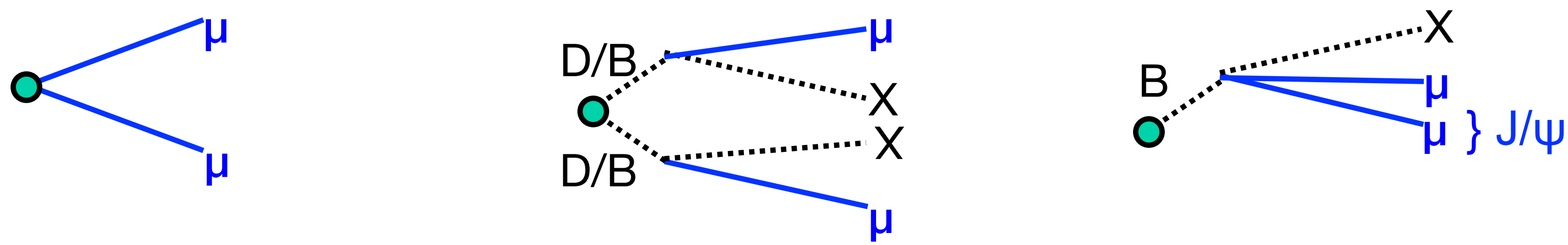
Why an MFT



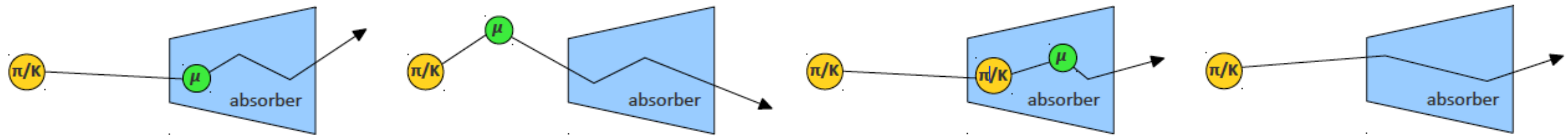
- Present Spectrometer
  - Uncertainty in track extrapolation to the primary vertex
- Spectrometer + MFT
  - Matching muon tracks with clusters in the MFT
  - Improvement of the pointing angle resolution ⇒ improvement of mass resolution

Key considerations for MFT design

- Good secondary vertex capabilities for separation of muons from D (cτ~150 μm) and B (cτ~500 μm) mesons decays



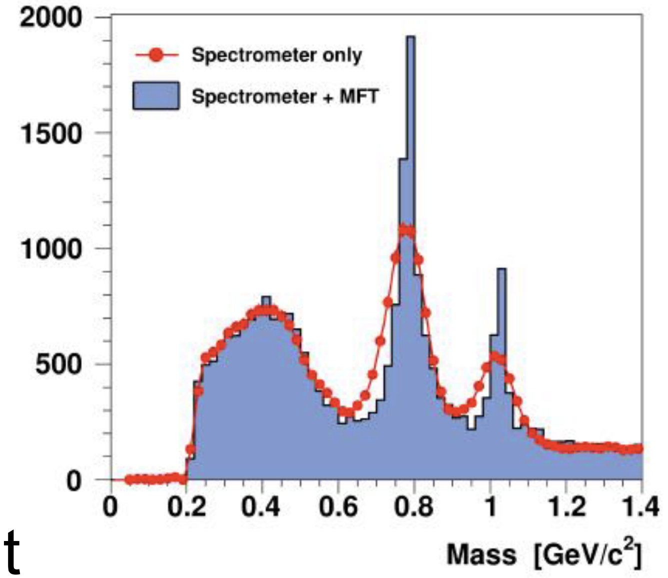
- Good background rejection



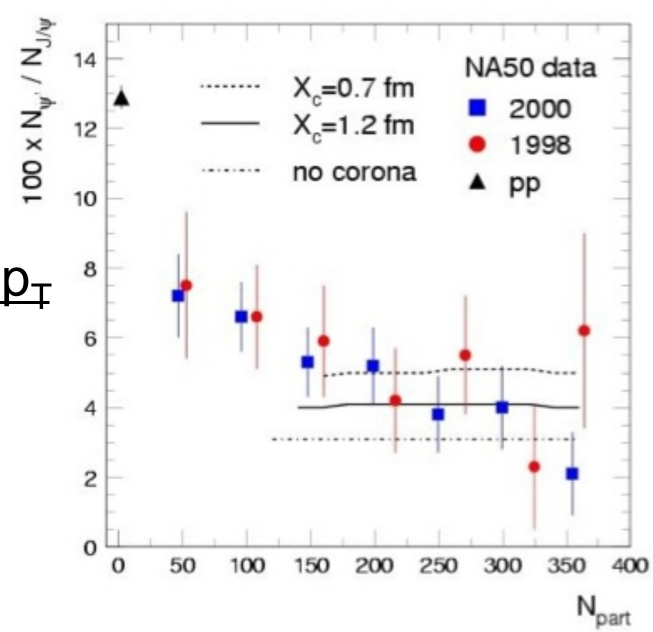
- High track matching rate with muon spectrometer

MFT physics case – I

- Medium effects: modification of the ρ spectral function
  - Improvement of invariant mass resolution
  - Better background rejection
  - Unique at LHC

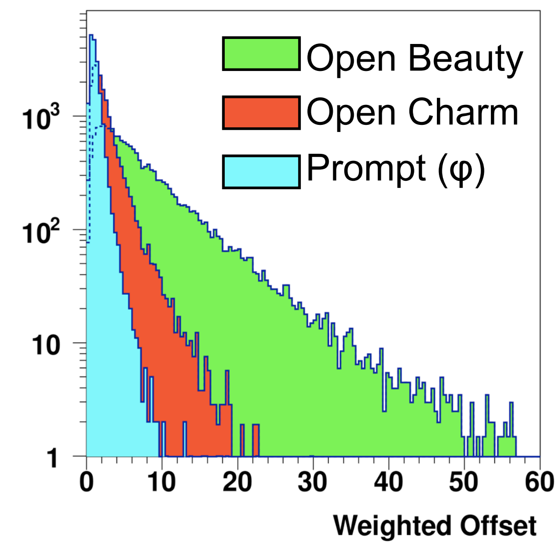


- Improving the quarkonia measurement
  - Better invariant mass resolution
  - Better background rejection
  - Particularly important for the ψ’
  - Keep charmonia acceptance down to zero p_T
  - Unique at the LHC



MFT physics case – II

- Flavor dependence of medium effects
  - Model independent charm and beauty separation using pointing angle
  - Charm and beauty flow
  - Full (p_T integrated) charm and beauty production cross-section
    - Important for quarkonium normalization

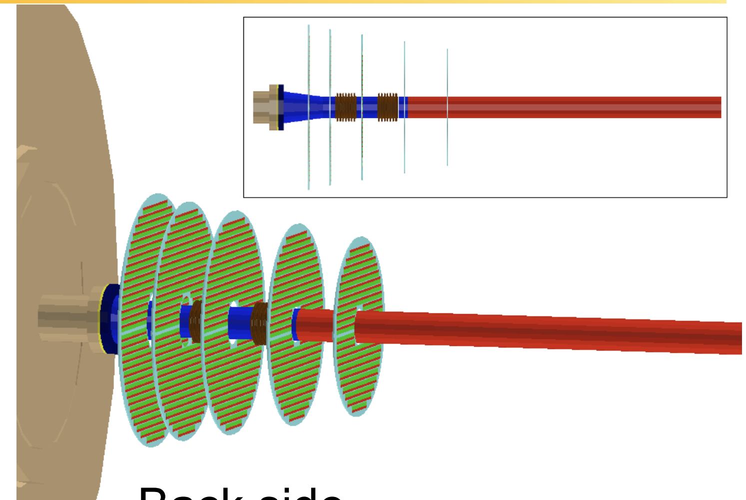


- Prompt J/ψ down to <u>zero p_T</u>
  - B-tagging using secondary vertex
  - Unique measurement of beauty production at LHC

- Exploring the measurement of B_c meson in A-A:
  - Challenging and interesting

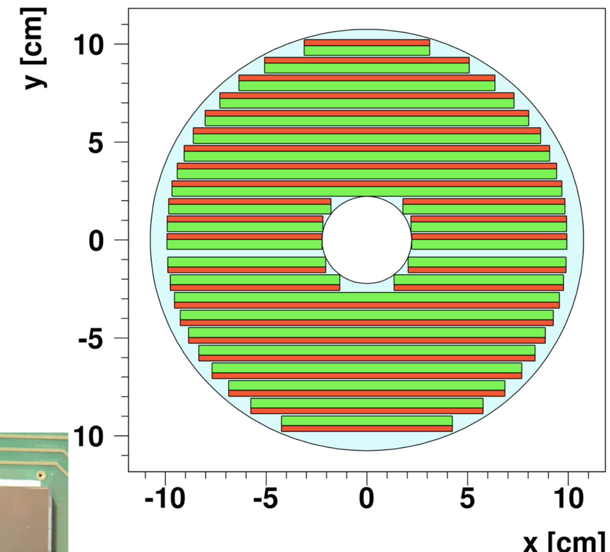
MFT working design

- 5 detection planes between the IP and the absorber
  - $-80 < Z < -50$ cm
  - $R_{min} \sim 2.5$ cm
  - $11 < R_{max} < 16$ cm
  - Surface ~ 2700 cm^2

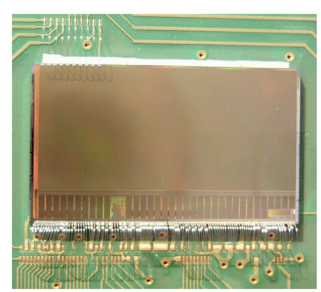


- Each MFT plane
  - consist of an assembly of ladders with a sensible layer and a read-out layer
  - $x/X_0 = 0.4\%$
  - double side to eliminate dead areas

Back side



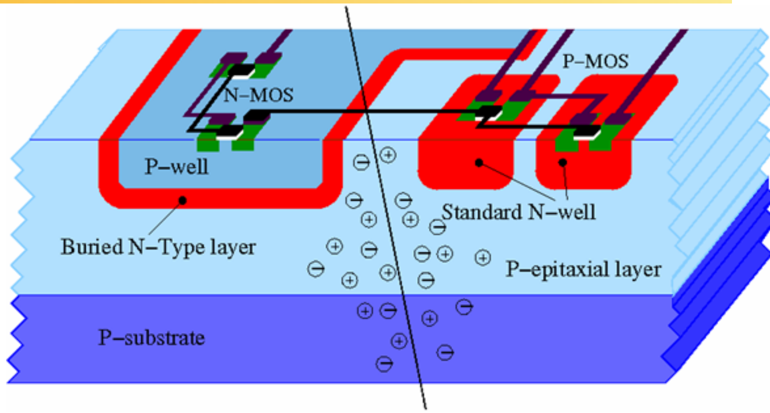
- Each ladder
  - A flex with bounded pixel sensors
  - pixel size 20x20 μm



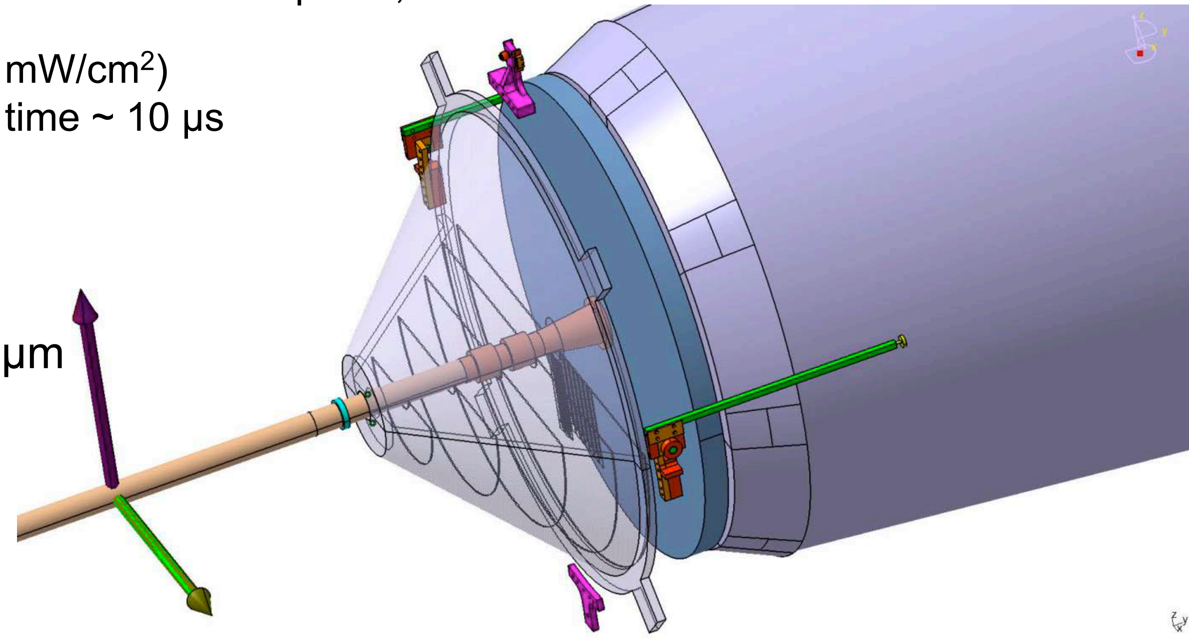
MIMOSA 26 (AMS 0.35mm)

R&D going on

- Detector technology: Monolithic Active Pixel Sensors (MAPS)
  - Benefit from large expertise of IPHC&IRFU
  - Common R&D with ALICE ITS Upgrade
  - Sensible area and read-out electronics in the same Si substrate .
  - Pixel size = 20 μm
  - Reduced thickness (50 μm) ⇒ low material budget (x/X_0 = 0.4% / layer)
  - Moving towards Tower Jazz 0.18 μm technology
    - Improvement of radiation tolerance: 10^{14} neq/cm^2 ; 5 MRad (?)
    - Reduced consumption (175 mW/cm^2)
    - Reduction of the integration time ~ 10 μs



- Mechanical constraints
  - Will hold the beam pipe
  - Planes positioning at ~ 10 μm
- Thermal studies
  - ~1 kW to dissipate



ALICE MFT &
ALICE MUON UPGRADE

GETTING READY FOR HIGH LUMINOSITY LHC

2012 – 2018
Feasibility studies
IPNL, IPNO, IRFU, LPC, Subatech,
1.5 M€
33 physicists, 7 eng. & tech.

ALICE MUON Upgrade

- High luminosity LHC:
  - Expected interaction rates: 50 kHz in Pb-Pb and 2 MHz in p-p
  - Major issue: **Readout speed for tracking chambers** (designed for 1kHz)
  - Major issue: **Trigger RPC aging**
  - Important issue: **Muon Trigger selectivity (trigger rates)**

- Tracking upgrade proposal
  - New read-out (CROCUS)
    - State of art FPGAs
    - Dead time < 100 μs
  - 20 CROCUS crates (7 boards per CROCUS)

- Trigger upgrade proposal
  - Replace the Front-End Electronics
    - New chip with an amplification stage to reduce RPC aging
    - R&D program needed (amplification => increased sensitivity to "noise")
  - Review trigger strategy

ALICE VZERO UPGRADE

GETTING READY FOR HIGH LUMINOSITY LHC

2012 – 2014

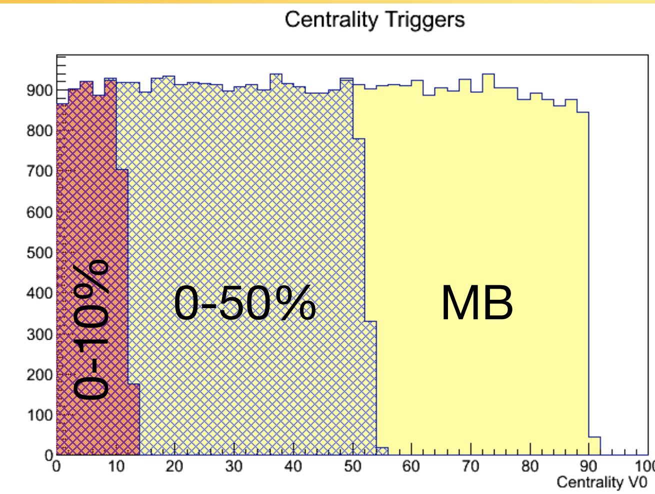
Feasibility studies

IPNL

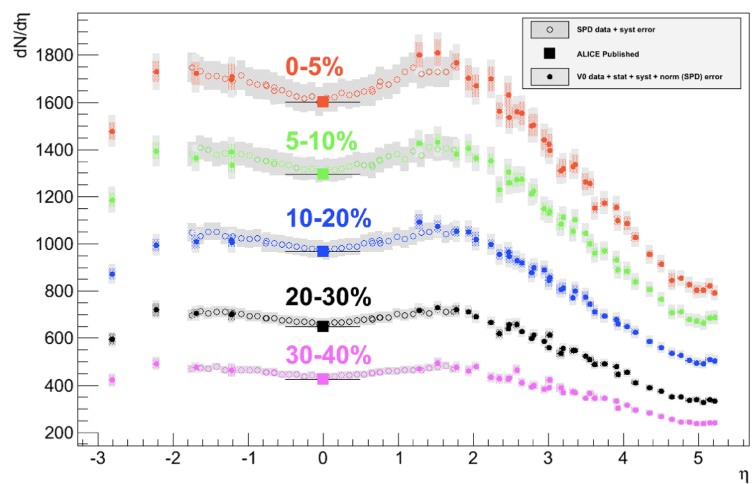
3 physicists, 1.5 eng. & tech.

The VZERO detector

- A fundamental detector for ALICE
  - Main trigger detector
  - Background events rejection
  - Luminosity measurements
  - Centrality determination
  - Event plane determination
  - Multiplicity measurement
- Need maintenance and improvement to keep providing it essential input
  - Replacement of the scintillators foreseen due to aging
  - Upgrade of electronics to adapt to new LHC running conditions



dN/dη en PbPb



CHIC

QGP THERMOMETER

after 2015

Feasibility studies, simulations

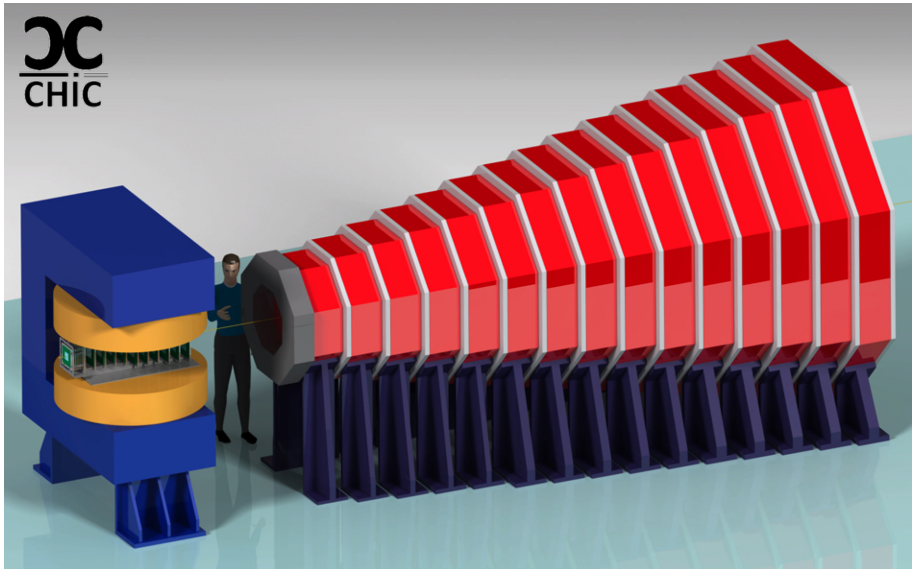
LLR

1 physicist

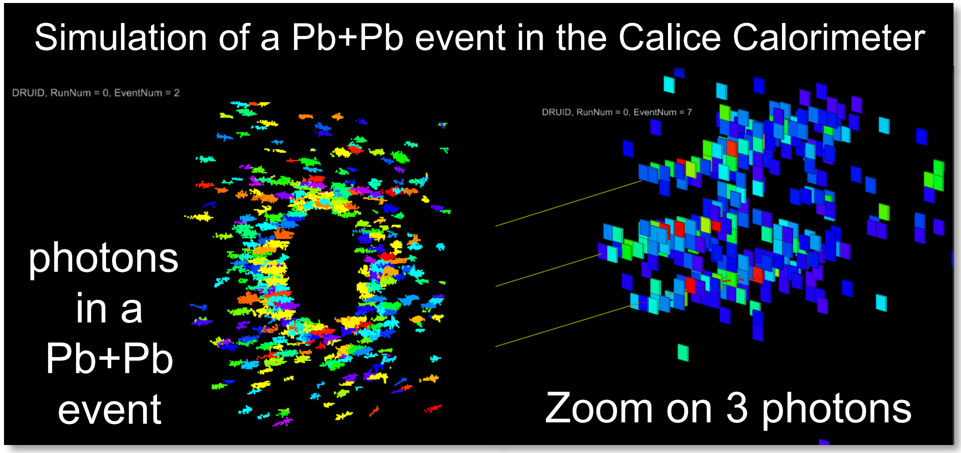
Charm in Heavy Ion Collisions @ SPS

- The J/ψ family could be the right thermometer at SPS energies
  - It is mandatory to measure all states (J/ψ, ψ', χ_c): sequential suppression
  - χ_c is the missing piece

    $\chi_c \rightarrow J/\psi + \gamma \rightarrow \mu^+ + \mu^- + \gamma$
- Measure charmonium states
  - in high luminosity p-A
  - in a wide (x_F) rapidity range $-0.5<y_{CMS}<2$
- Open charm, Drell-Yan for charmonium normalization



- Experimental apparatus
  - Fixed target experiment
  - Silicon pixel spectrometer
    - $\Delta p/p \sim 1\%$; $\Delta M_{J/\psi} \sim 20$ MeV
  - 2.5 T 1m long dipole magnet
  - Si+W ultra-granular calorimeter
    - $\Delta E/E \sim 20\%/\sqrt{E}$
  - Instrumented and magnetized Fe absorber



AFTER @ LHC

AFTER

TESTING QCD AT HIGH AND ULTRA-HIGH x_B

QGP THERMOMETER

~ 2025

Feasibility studies

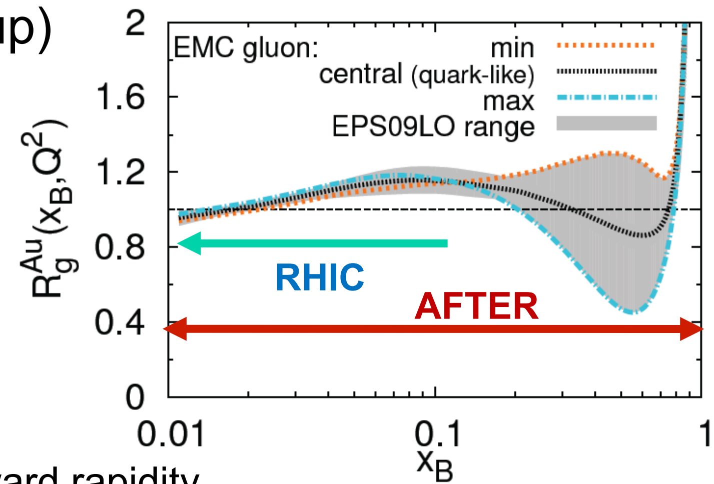
IPNO, IRFU, LLR

4 physicists

A Fixed Target ExpeRiment @ LHC

AFTER @ LHC

- Testing QCD at high and ultra-high x_B (QCD group)
- QGP related physics case:
  - high precision quarkonium studies
  - Constrain PDFs



- Use the 7 TeV LHC proton beam on fixed target
  - **√s~115 GeV** : charmonium and bottomonium states
  - Measure **high x_B gluon PDF in the nucleus**
    - mandatory to understand quarkonium production at forward rapidity
  - Easy to measure many p-A systems
    - with the highest yields ever (see table)
- Use the 2.76 TeV LHC Pb beam on fixed target
  - **√s~72 GeV**: intermediate energy between SPS and LHC
  - Can study any Pb-A system including Pb-p
  - Direct study of the QGP in the target rest frame

Yields in p-A for 1 rapidity unit at y=0

	Target	A	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
AFTER	1cm Be	9	0.62	1.1 10^8	2.2 10^5
AFTER	1cm Cu	64	0.42	5.3 10^8	1.1 10^6
AFTER	1cm W	185	0.31	1.1 10^9	2.3 10^6
AFTER	1cm Pb	207	0.16	6.7 10^8	1.3 10^6
	LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^7	7.5 10^4
	RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^6	5.9 10^3
	RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^4	18

- Experimental apparatus:
  - Silicon pixel spectrometer
  - Si+W EMCal
  - Fe magnetized muon ID detector
  - Hadronic calorimeter (to be defined)
  - PID detector (to be defined)

(Silicon pixel spectrometer, Si+W EMCal, Fe magnetized muon ID detector: Common with CHIC)

Summary

- The harvest of LHC results has just started, but exciting new results are already there!
- In the short and medium term, we will continue to exploit the particularities and capabilities of the two complementary LHC experiment, ALICE and CMS

- For the longer term, we plan to upgrade the existing ALICE muon spectrometer and complement it with a Muon Forward Tracker (MFT), to continue to benefit from the ALICE particularities in the HL-LHC era.
  - New insights into the thermal properties of the QGP will become available

- New ideas have recently emerged, CHIC could unveil QGP temperature at SPS, while AFTER could provide critical input for the QGP characterization at RHIC energies.