

# Future of heavy-ion program at the LHC

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Wei Li (Rice University)

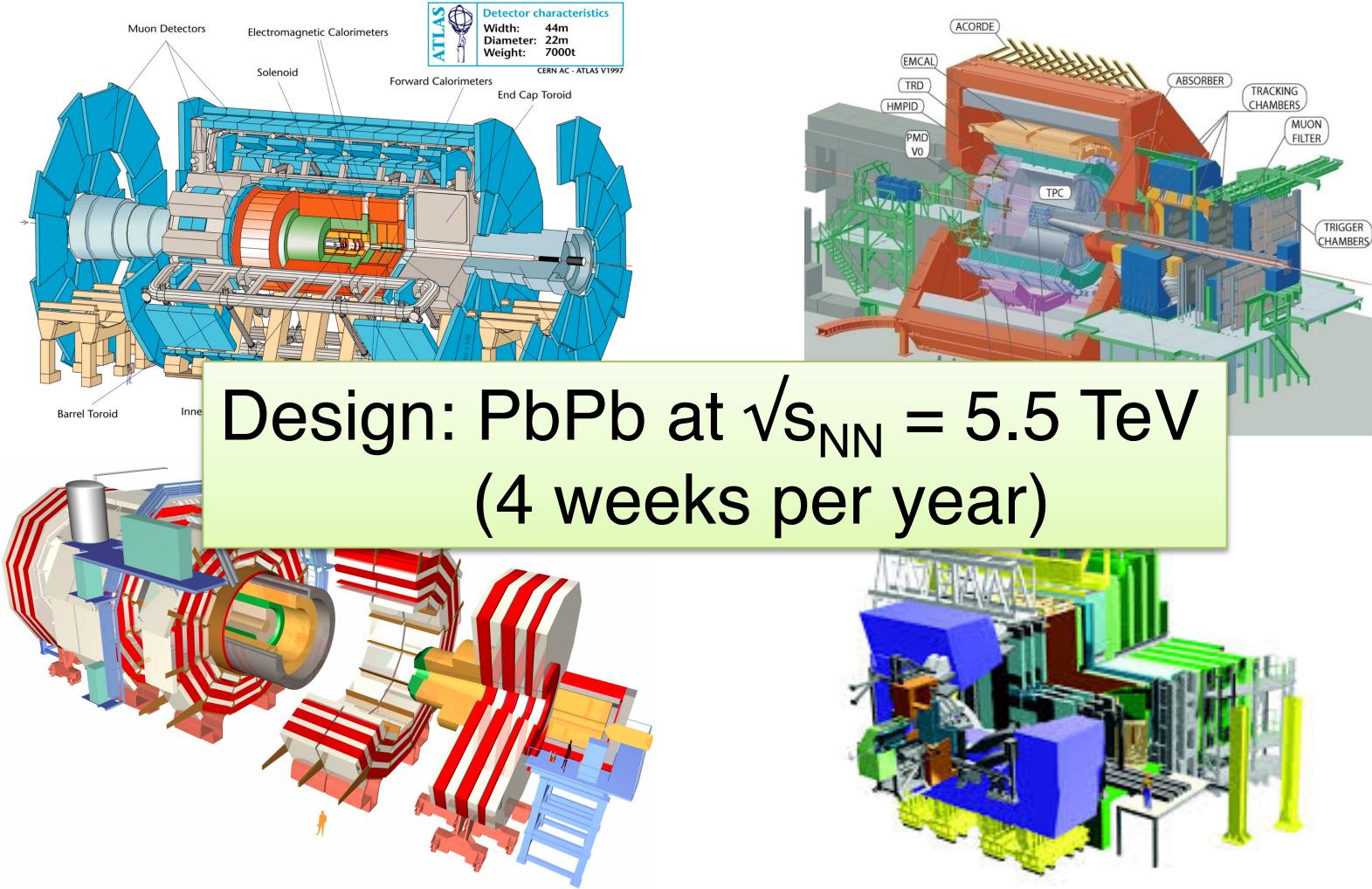
Many thanks to Pasquale Di Nezza, Laure Marie Massacrier



XII Quark Confinement and the Hadron Spectrum  
Aug. 29 – Sep. 3, 2016

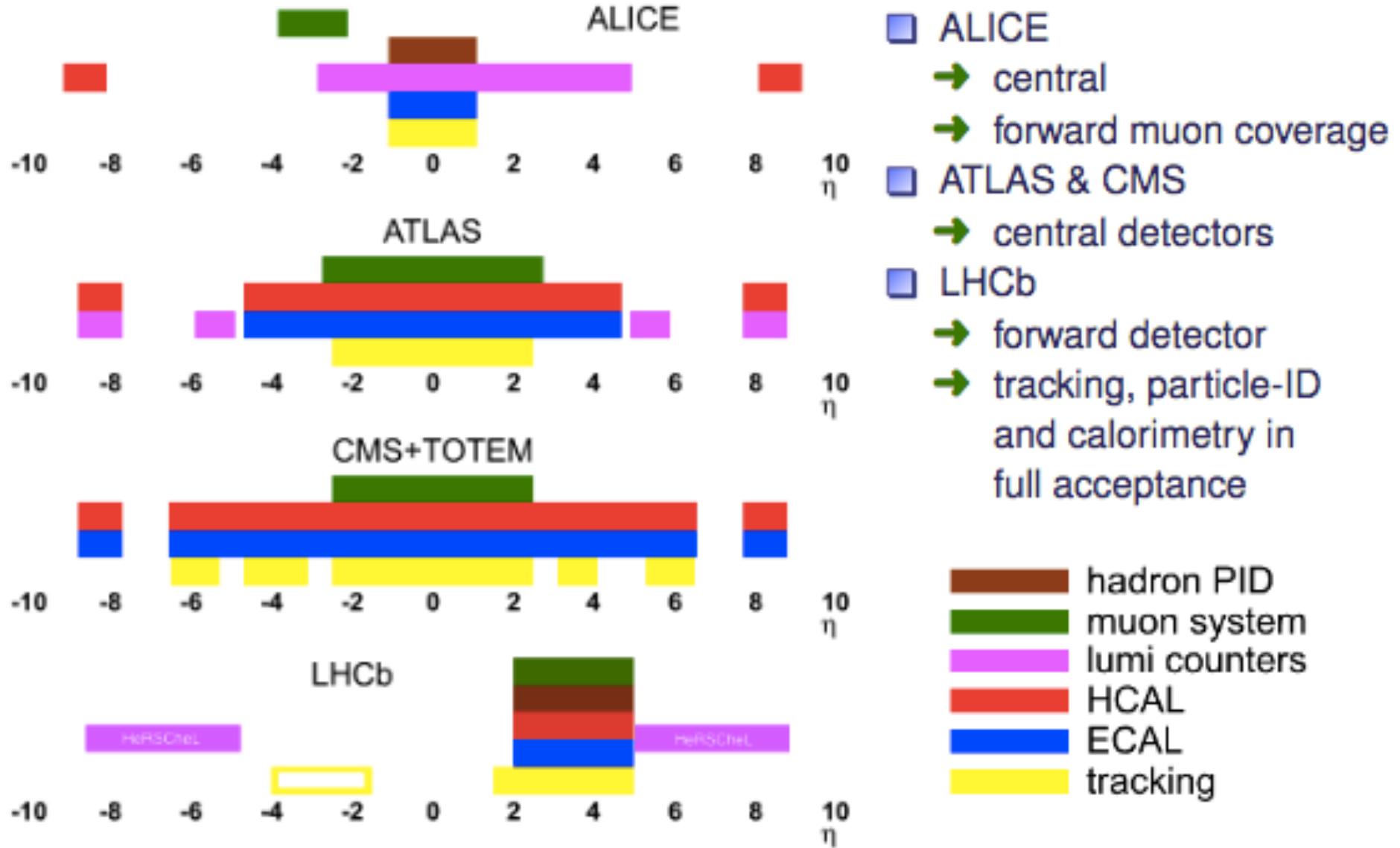


# Heavy-ion experiments at the LHC



HI program at the LHC expanded significantly beyond the originally planned scope of four experiments taking data and producing highly competitive results.

# Complementarity!



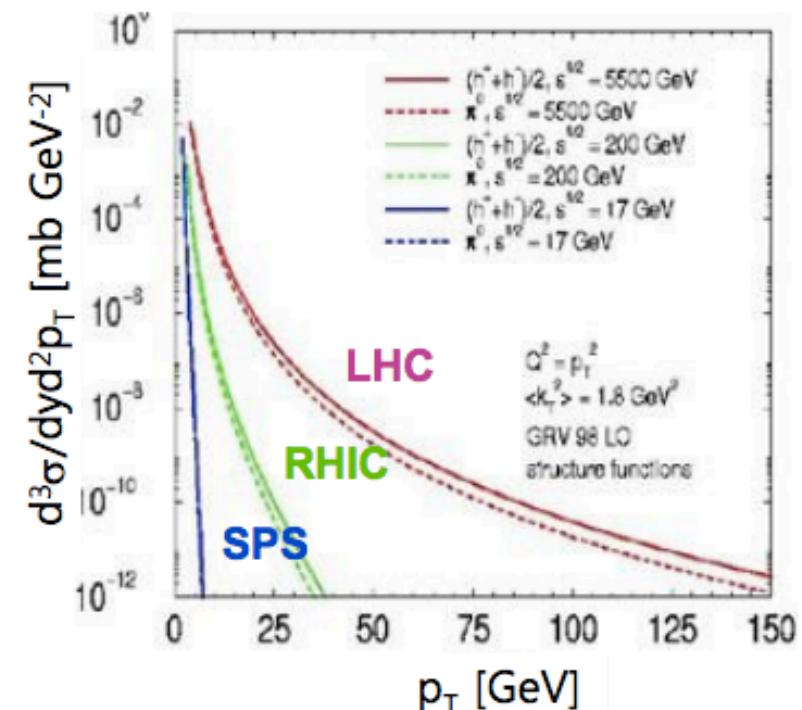
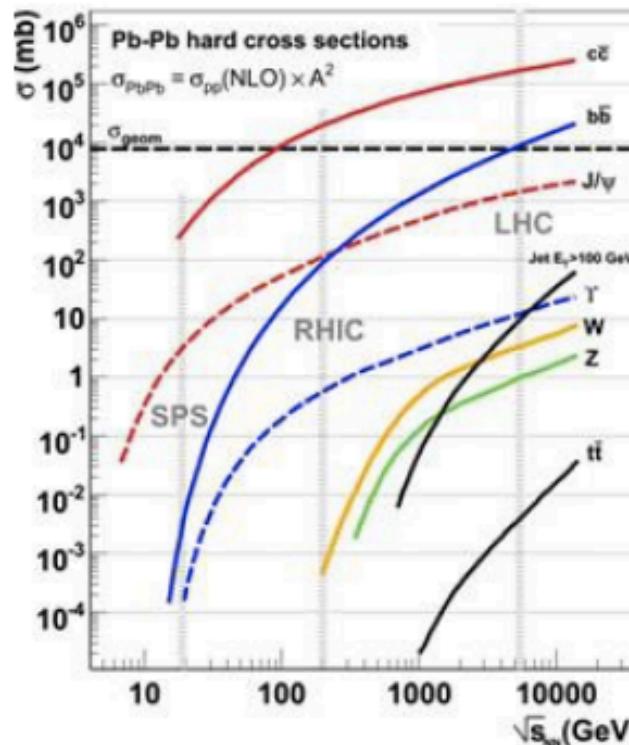
# Heavy-ion physics at the LHC

We have discovered a strongly-coupled QGP, which shows striking behavior as a nearly perfect fluid

But we still know little about:

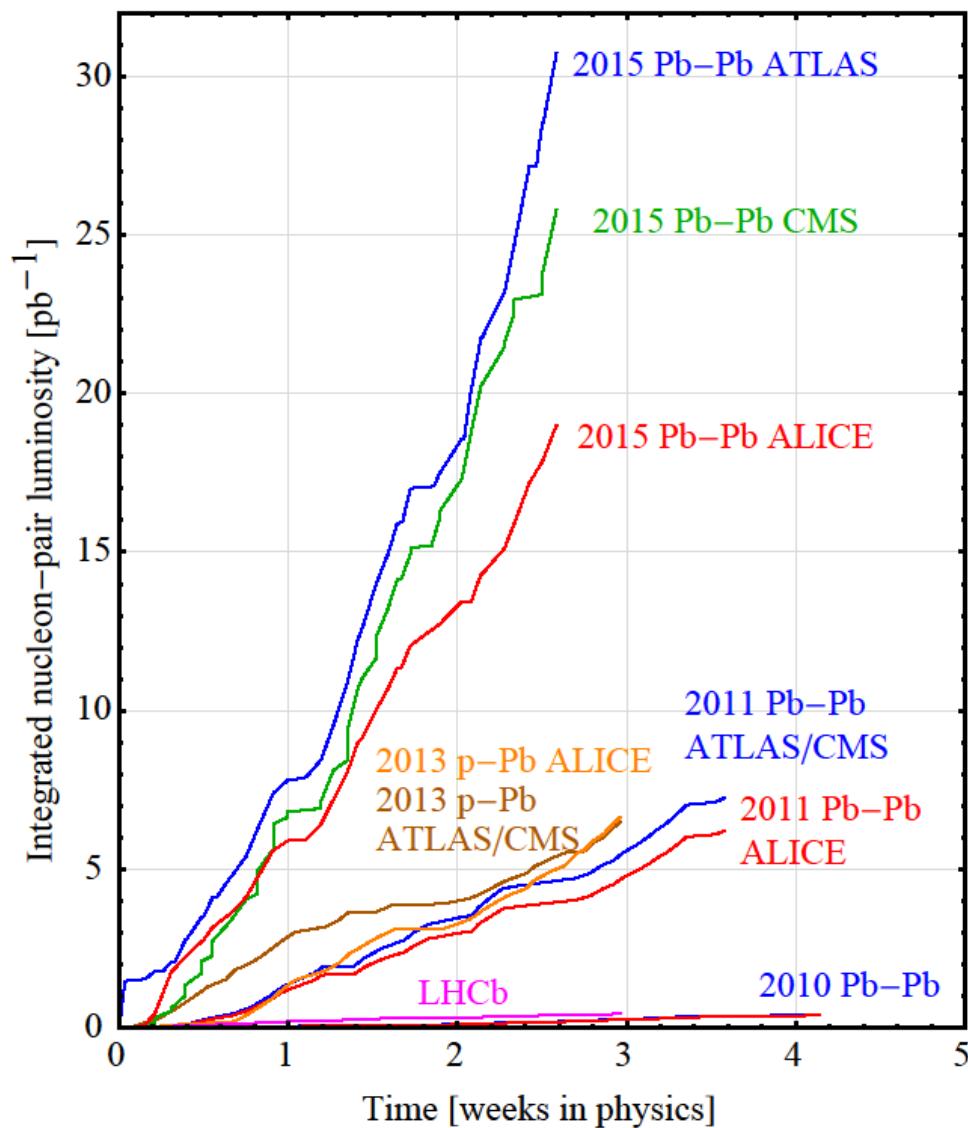
**why it flows and what is flowing?**

Approach: probing the QGP with multitude of probes at the LHC



# Heavy Ions at Run 1 + 2015

## Integrated NN luminosity

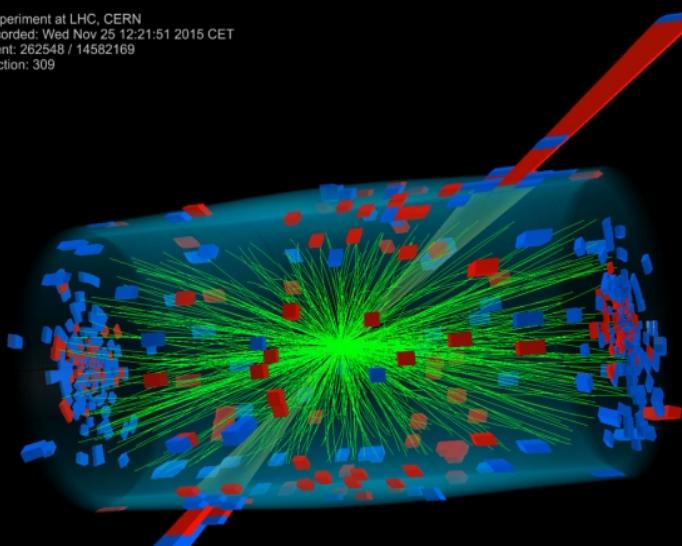


Year	System	$\sqrt{s_{\text{NN}}}$ (TeV)
2010	PbPb	2.76
2011	pp	2.76
2011	PbPb	2.76
2013	pPb	5.02
2013	pp	2.76
2015	PbPb	5.02
2015	pp	5.02

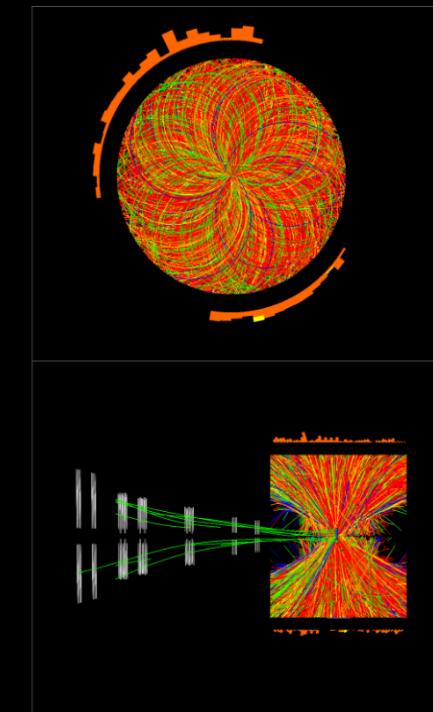
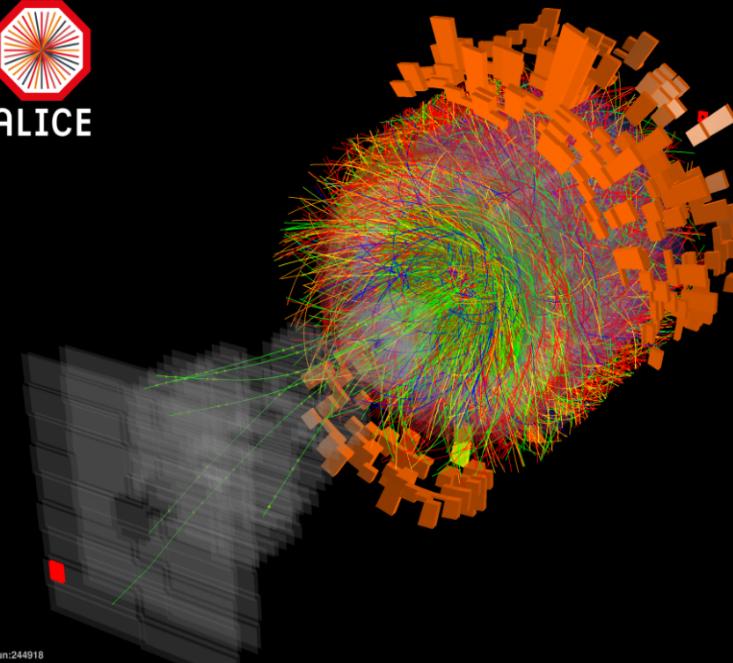
$\sim 0.7 \text{ nb}^{-1}$  for PbPb



CMS Experiment at LHC, CERN  
Data recorded: Wed Nov 25 12:21:51 2015 CET  
Run/Event: 262548 / 14582169  
Lumi section: 309



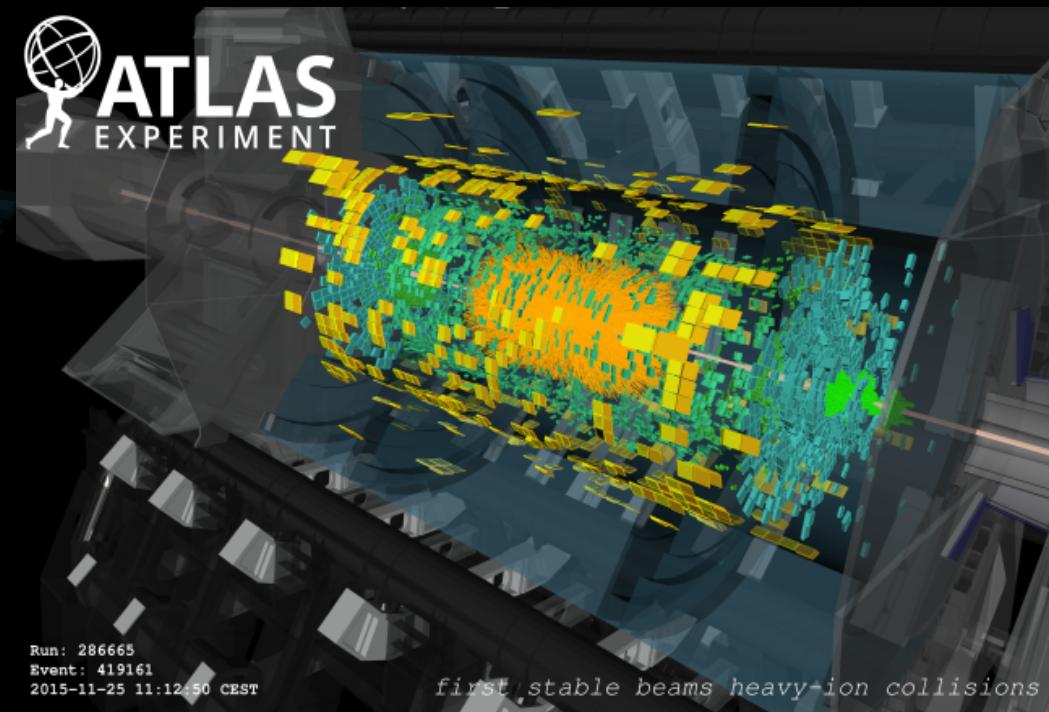
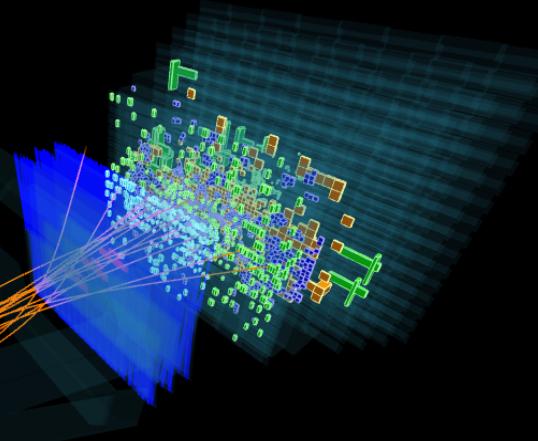
ALICE



Event 2598326  
Run 168486  
Wed, 25 Nov 2015 12:51:53

LHC

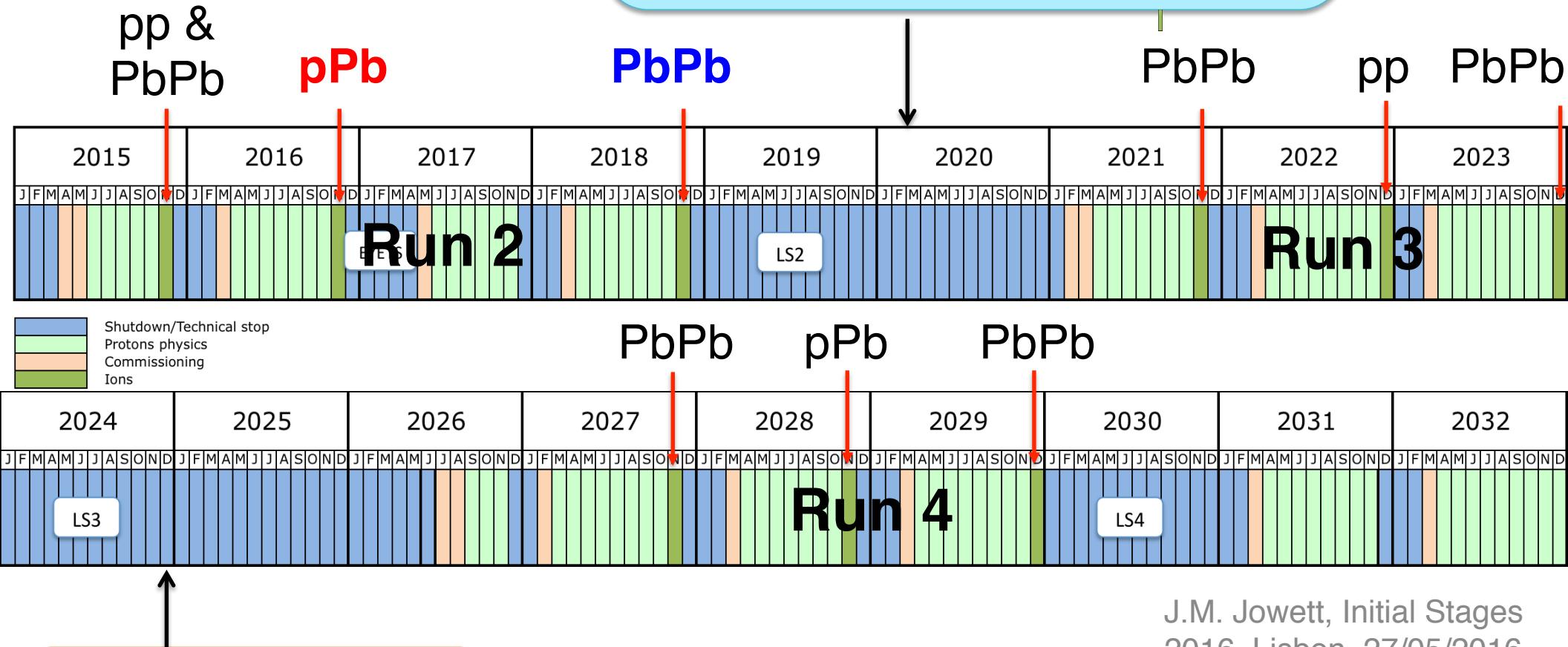
LHCb Experiment at CERN



# Future

LS2:

- ✧ ALICE major upgrades
- ✧ LHCb major upgrads
- ✧ CMS/ATLAS Phase 1 upgrade



LS3:

- ✧ CMS/ATLAS Phase 2 upgrade

Ultimate goal:

**PbPb  $L_{int} \sim 10 \text{ nb}^{-1}$**

Peak interaction rate:  $\sim 50 \text{ kHz}$

J.M. Jowett, Initial Stages  
2016, Lisbon, 27/05/2016

# ALICE future upgrade strategy

High precision measurements of rare probes from low to high  $p_T$  scale, with focus on heavy flavors

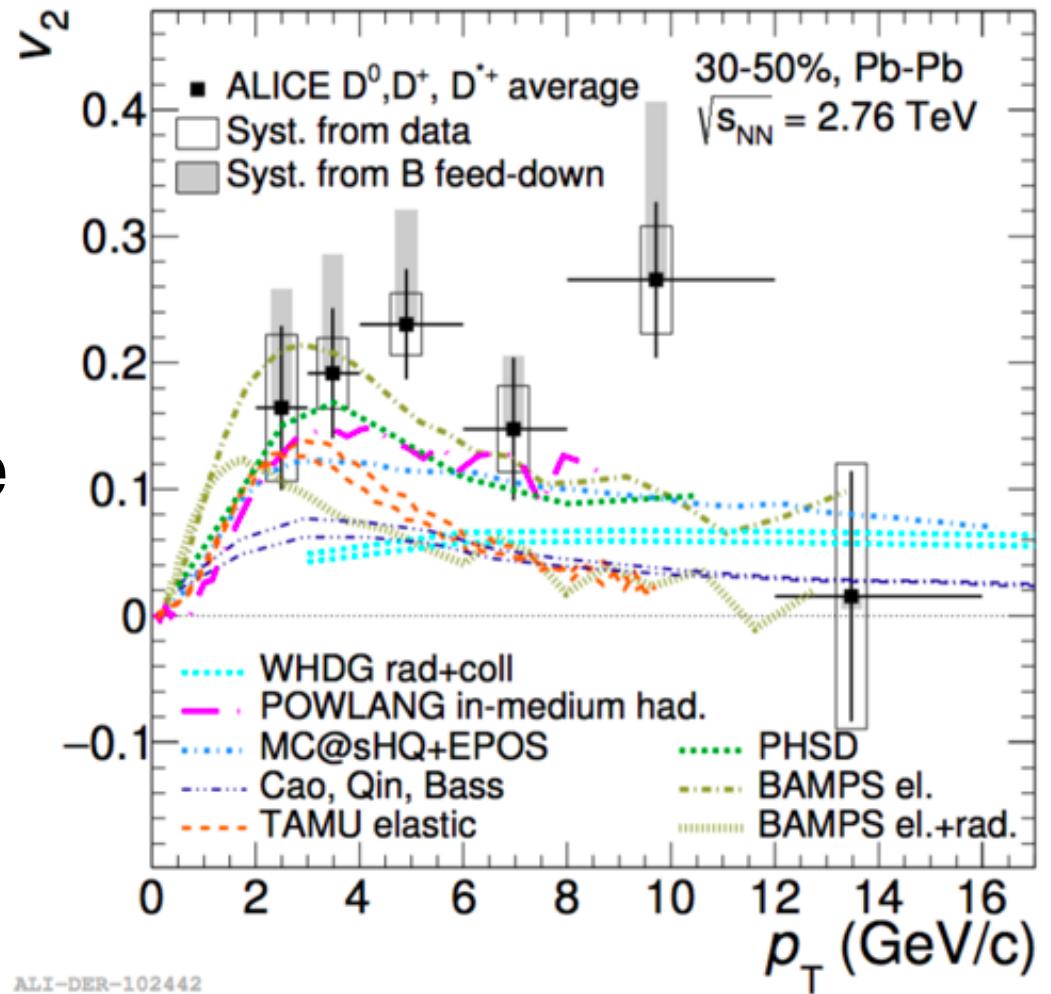
Detector capabilities requirements:

- Excellent tracking resolution at low  $p_T$
- High statistics → High readout rate
- Excellent PID capability

Major upgrades planned during LS2 (2019-2020)

# Quantifying the QGP – heavy flavor

Open heavy flavor:  
collective flow to probe  
early thermalization

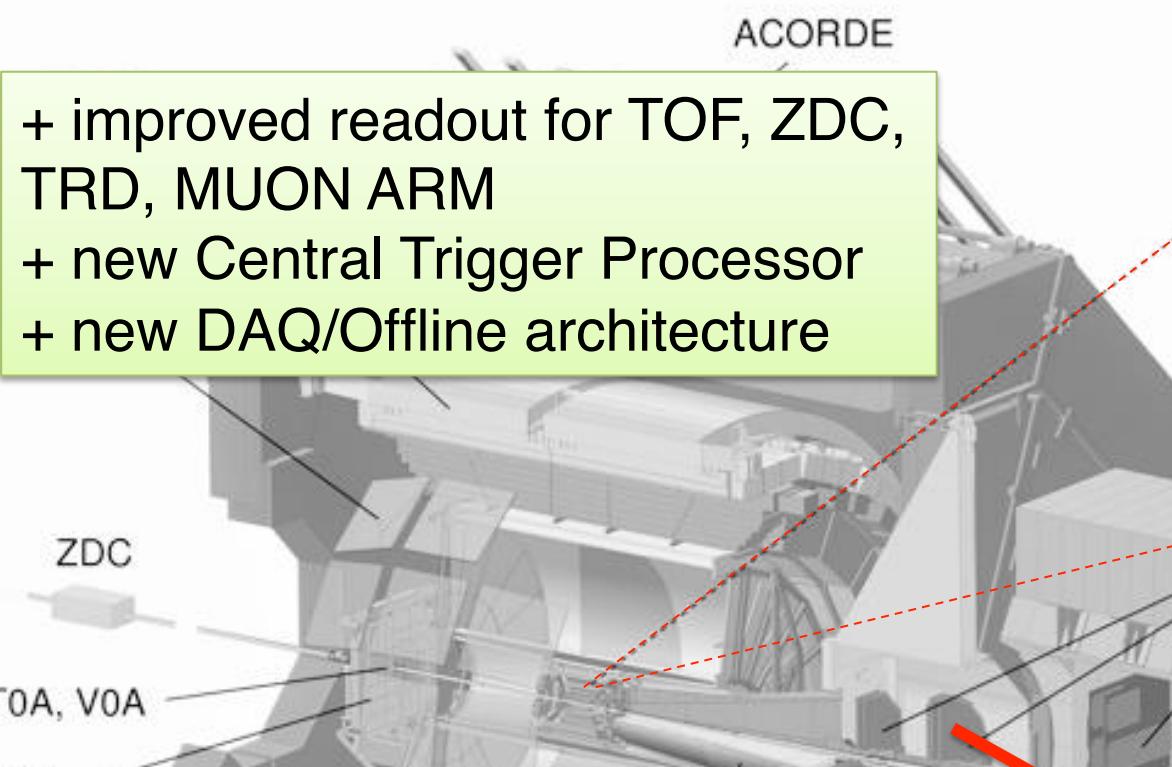


Not as easy to trigger on at low and intermediate p<sub>T</sub>

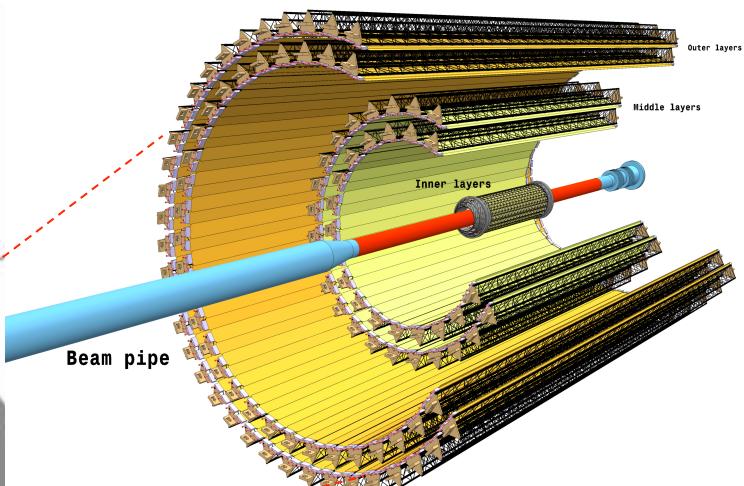
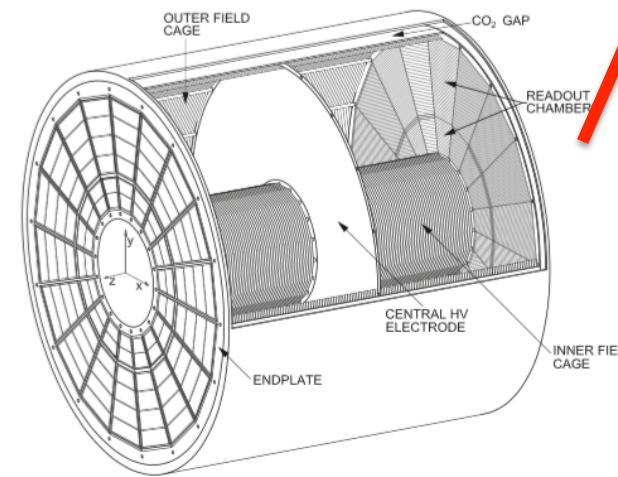
# ALICE upgrade

## New Inner Tracking System (ITS)

- + improved readout for TOF, ZDC, TRD, MUON ARM
- + new Central Trigger Processor
- + new DAQ/Offline architecture



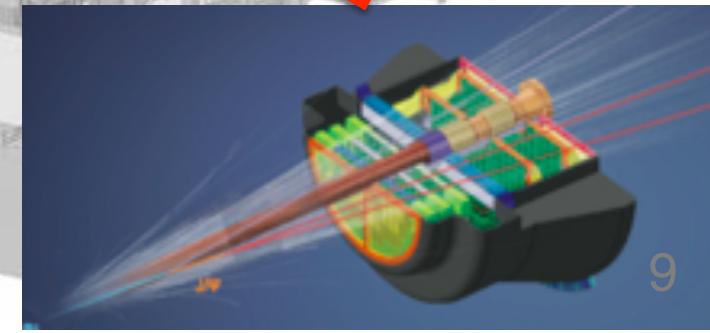
TPC with GEM based readout



MTR

ZDC

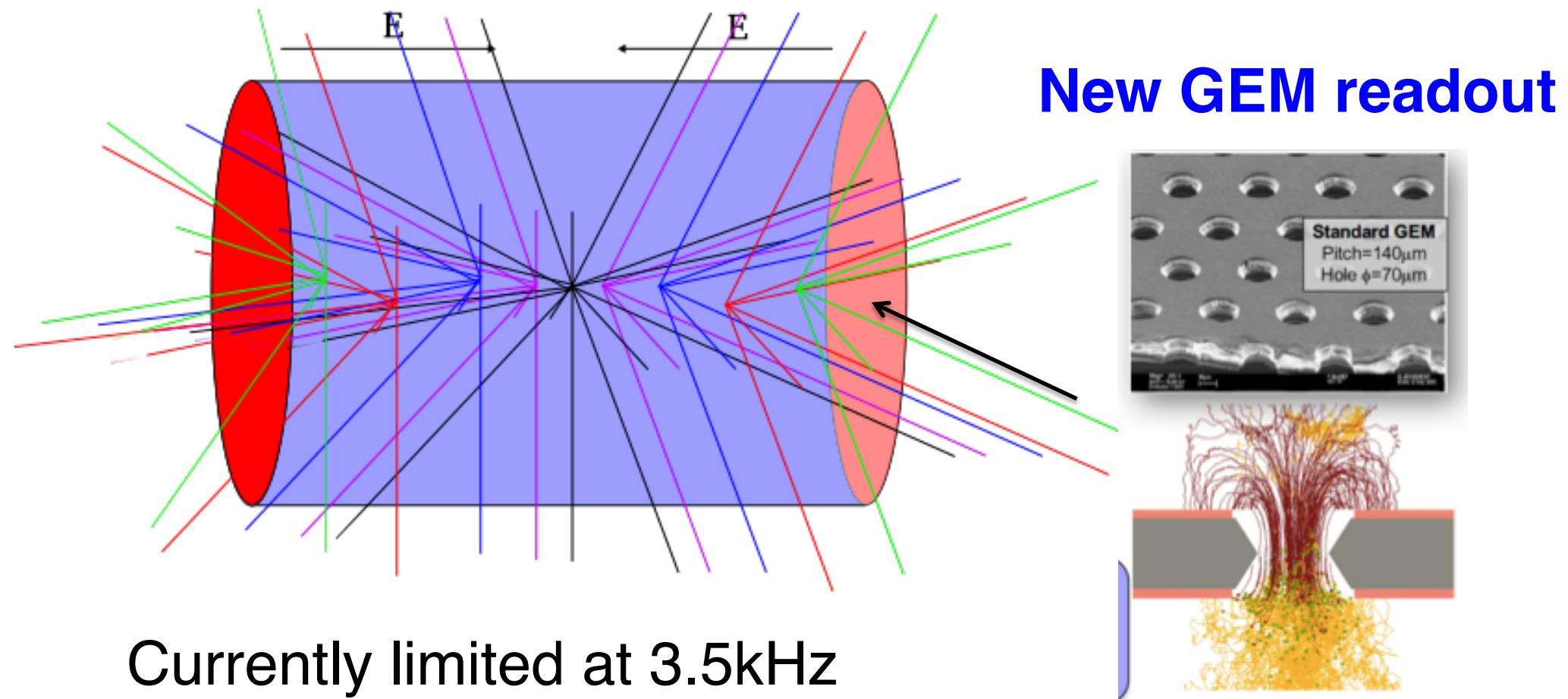
New Muon Forward Tracker (MFT)



# ALICE TPC upgrade

Upgrade objective:

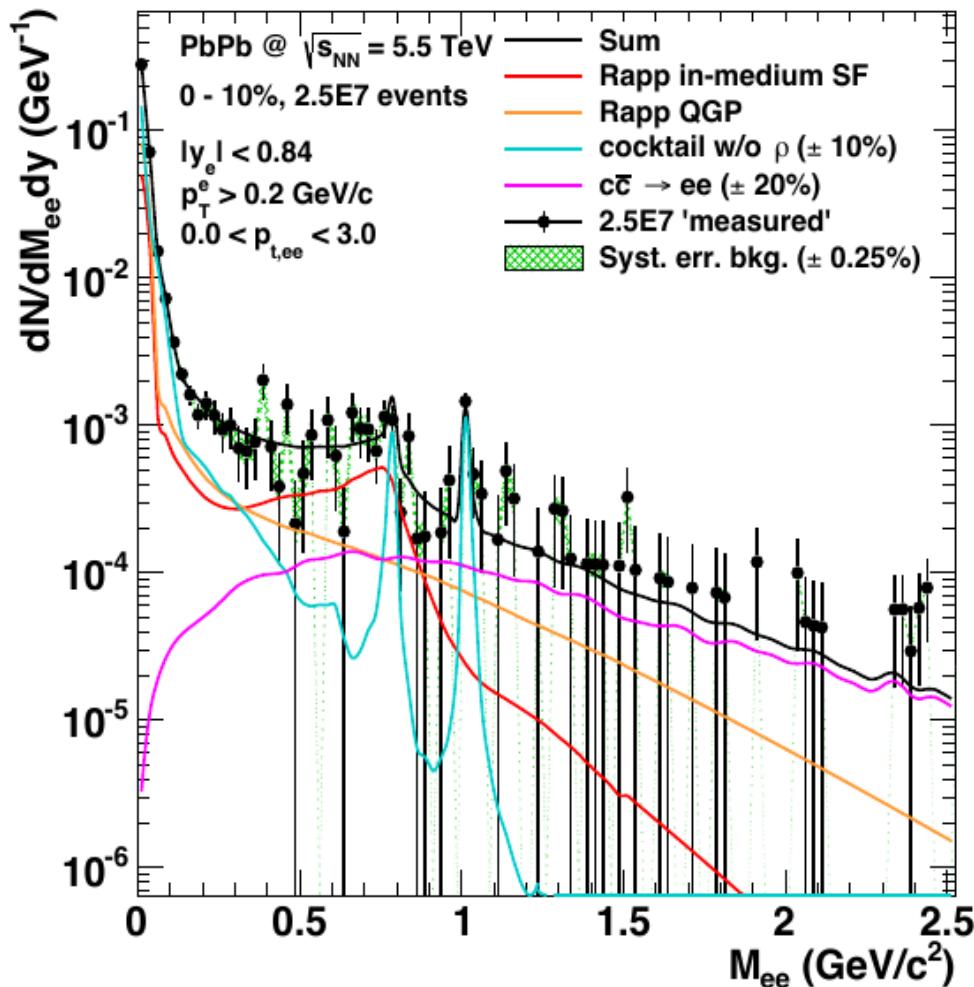
**Continuous readout of PbPb events at 50kHz**



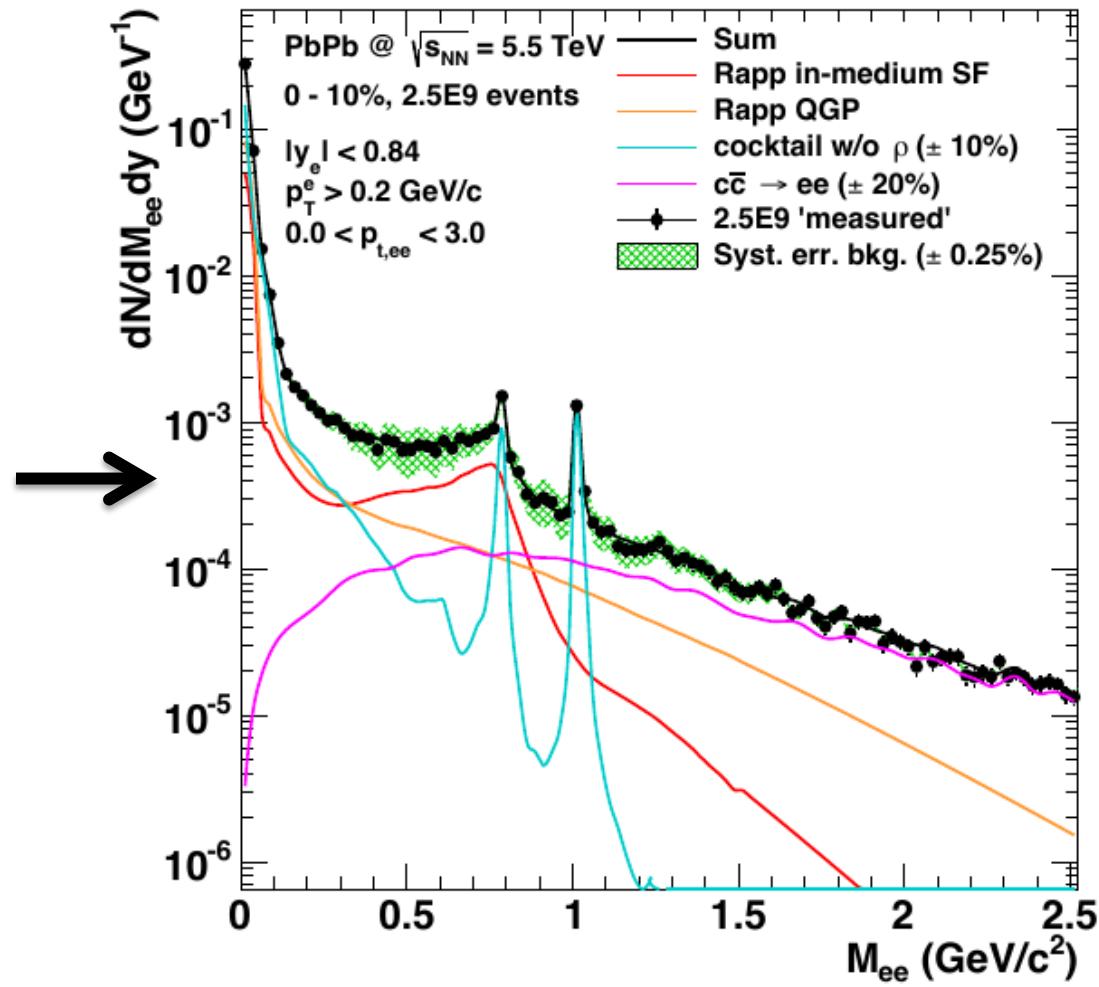
Currently limited at 3.5kHz  
mainly due to ion back flow (IBF)

# Low-mass dileptons with upgraded TPC

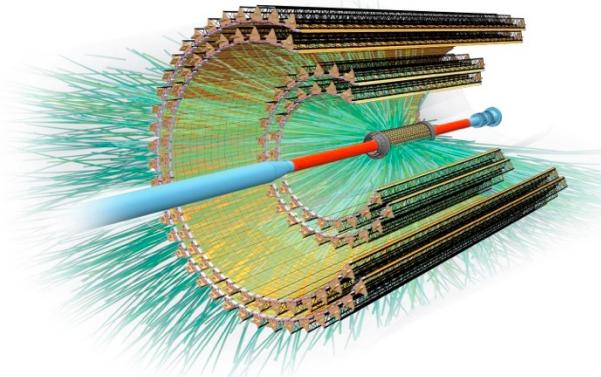
## Current rate capability



## Upgraded rate capability



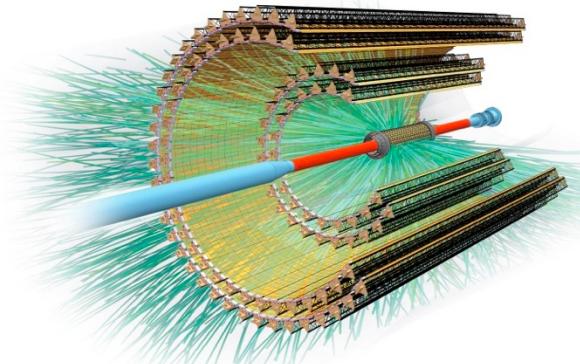
# ALICE ITS upgrade



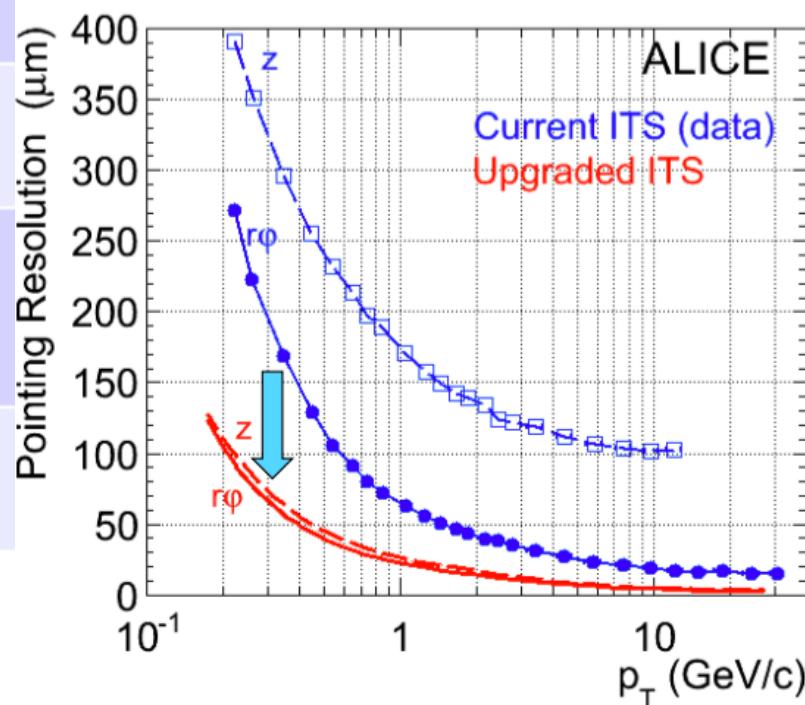
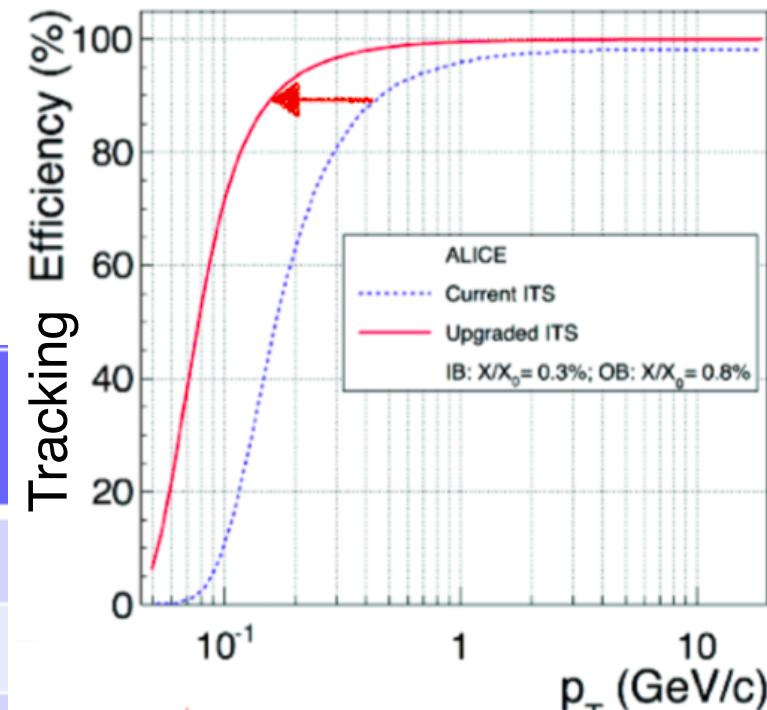
	ITS	ITS UPGRADE
# layers	6	7
Rapidity coverage	$ \eta  < 0.9$	$ \eta  < 1.5$
$r_{\min}$	3.9 cm	2.3 cm
Material budget per layer	$1.1\% X_0$	$0.3 - 1\% X_0$
Spatial resolution	$12 \times 100 \mu\text{m}^2$ $35 \times 20 \mu\text{m}^2$ $20 \times 830 \mu\text{m}^2$	$\sim 5 \times 5 \mu\text{m}^2$
Max Pb-Pb readout rate	1 kHz	100 kHz

Higher rate and resolution!

# ALICE ITS upgrade



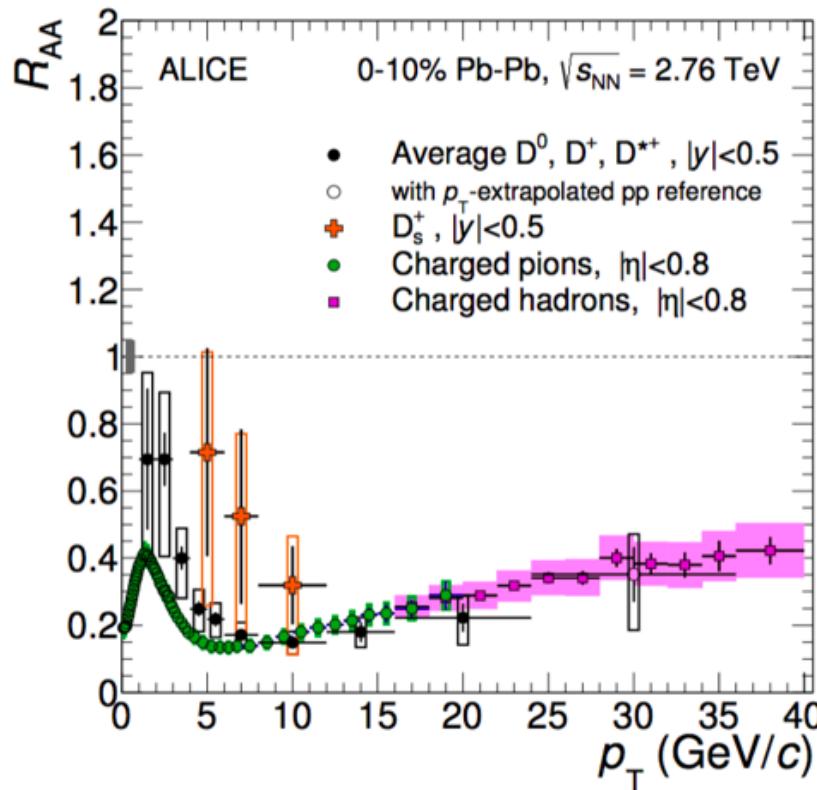
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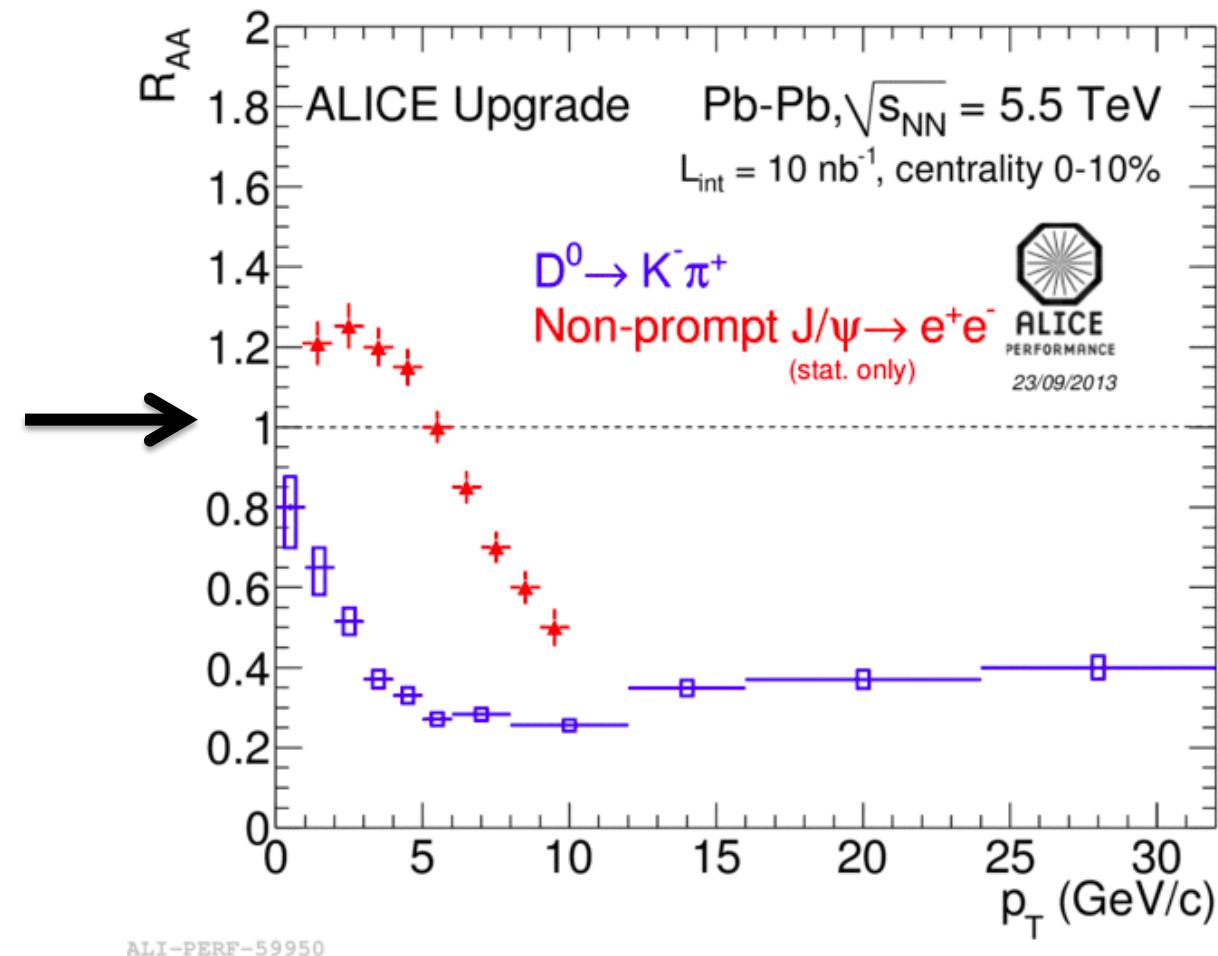
Higher rate and resolution!

# Heavy flavor physics with upgraded ALICE

Current

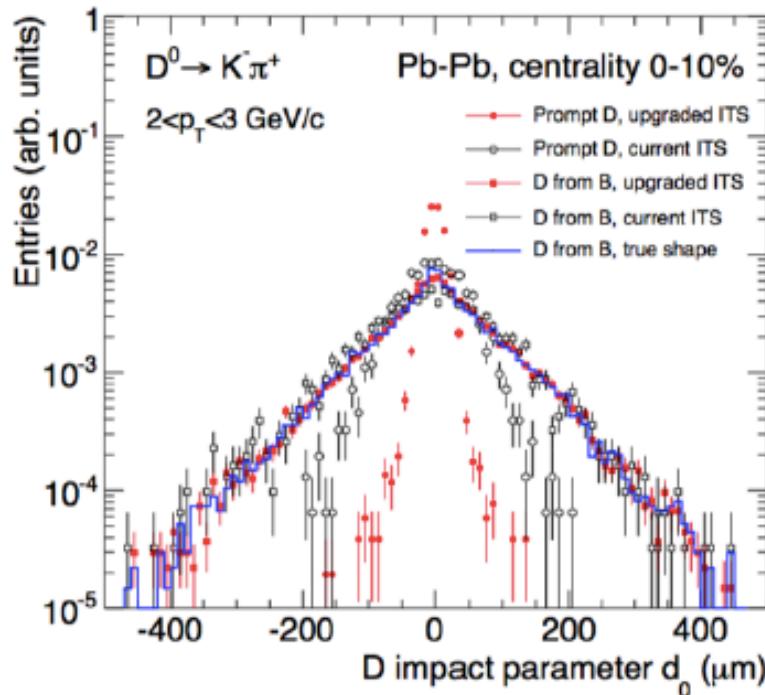


Upgraded



Precision studies of  $c$  and  $b$  down to  $p_T \sim 0$  GeV/c

# Heavy flavor physics with upgraded ALICE

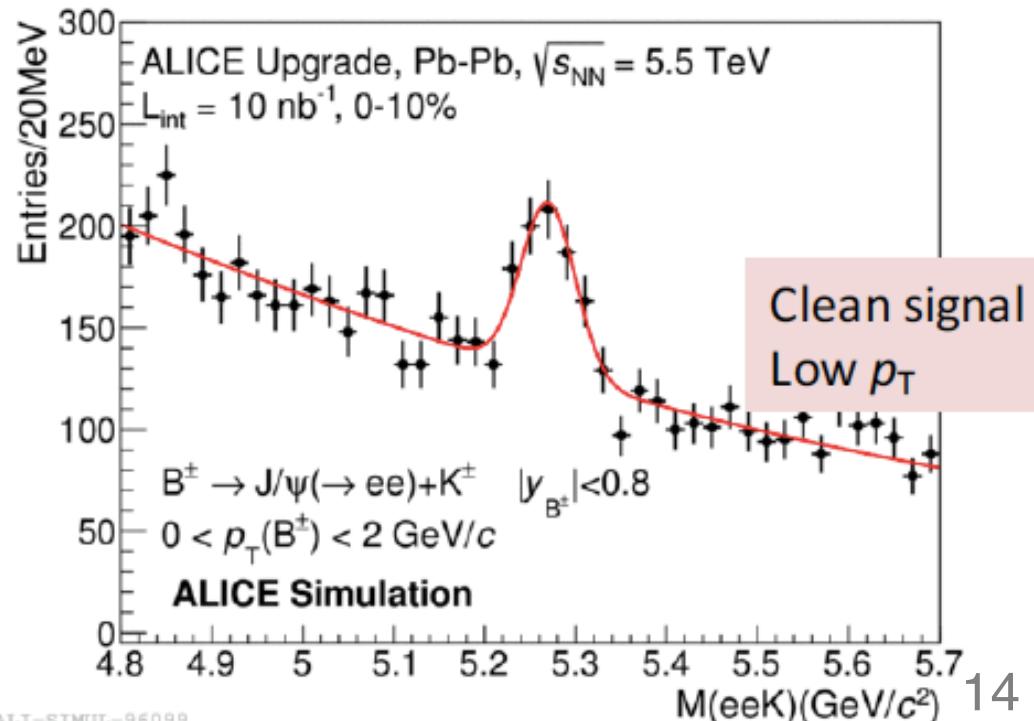


B.R.(B → D<sup>0</sup> + X) ~60%

B: cτ ~ 460-490 mm → exploit impact parameter shape

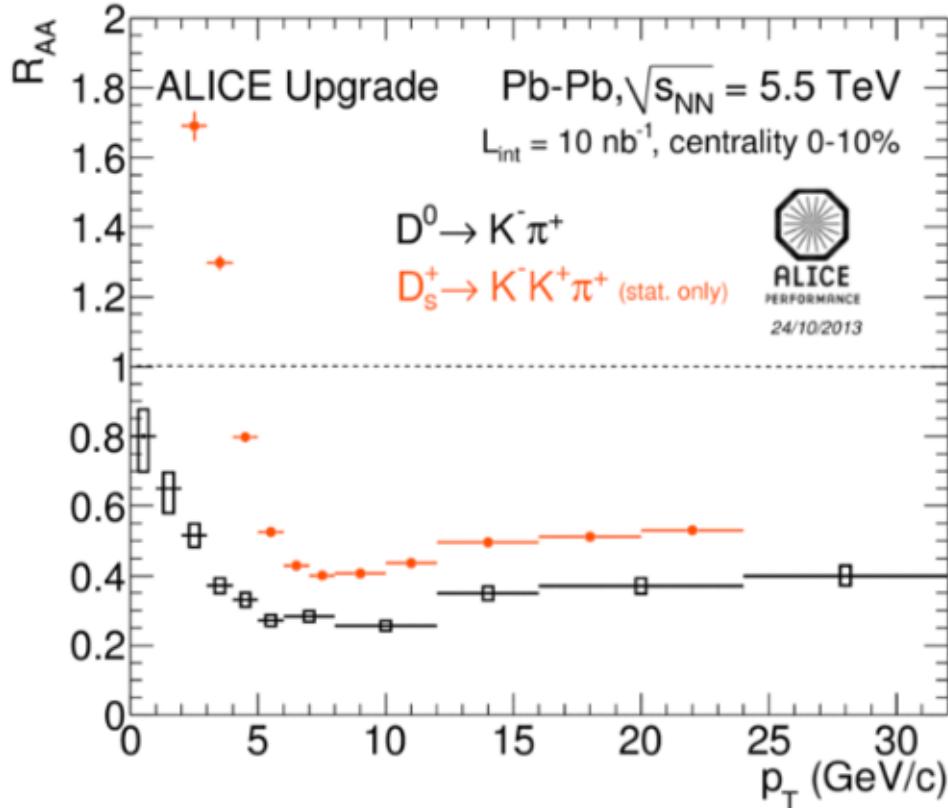
Data-driven separation of prompt vs non-prompt D<sup>0</sup>

Direct reconstruction of B with non-prompt J/ψ

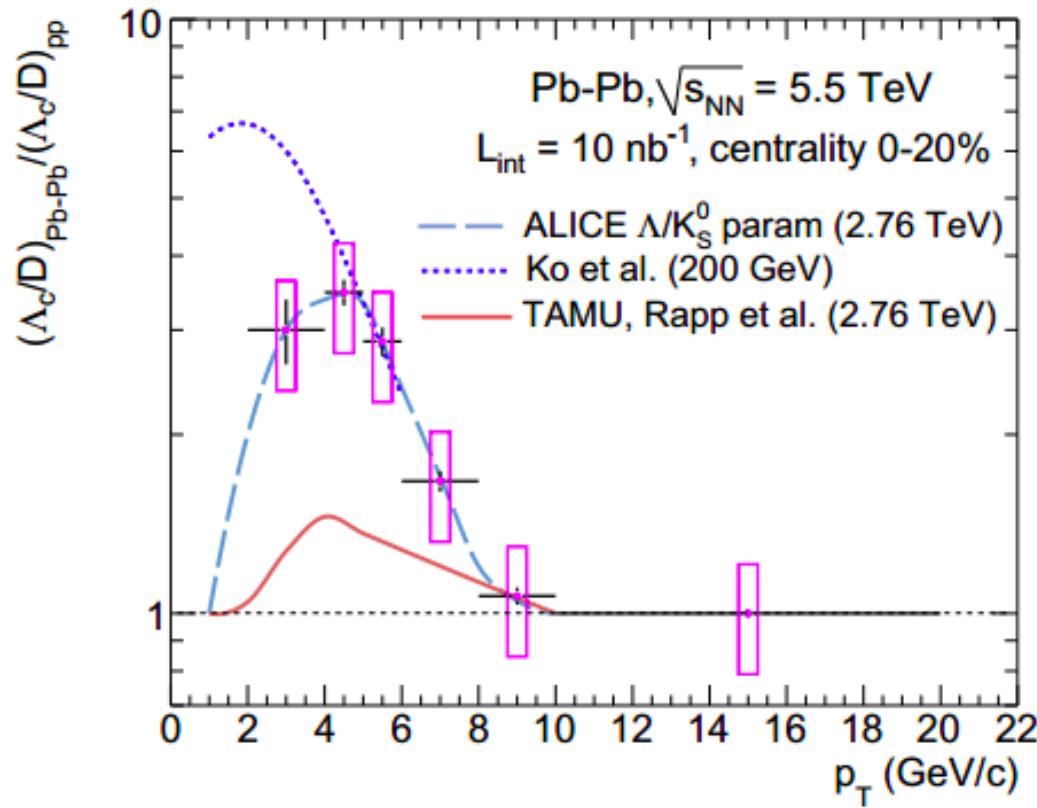


# Heavy flavor physics with upgraded ALICE

$D_s \rightarrow K\bar{K}\pi$  ( $\text{c}\tau$  150  $\mu\text{m}$ )



$\Lambda_c$  ( $\text{c}\tau$  60  $\mu\text{m}$ )  $\rightarrow p\bar{K}\pi$



Higher s abundance in QGP  
 $\rightarrow D_s$  enhanced if from in-medium hadronization

First time in PbPb!  
Hadronization via thermal vs coalescence?

# CMS/ATLAS strategy

## Focusing on

- ✧ high statistics, very high  $p_T$  hard probes
- ✧ Large acceptance → long-range correlations
- ✧ Flexible trigger capability → rare events

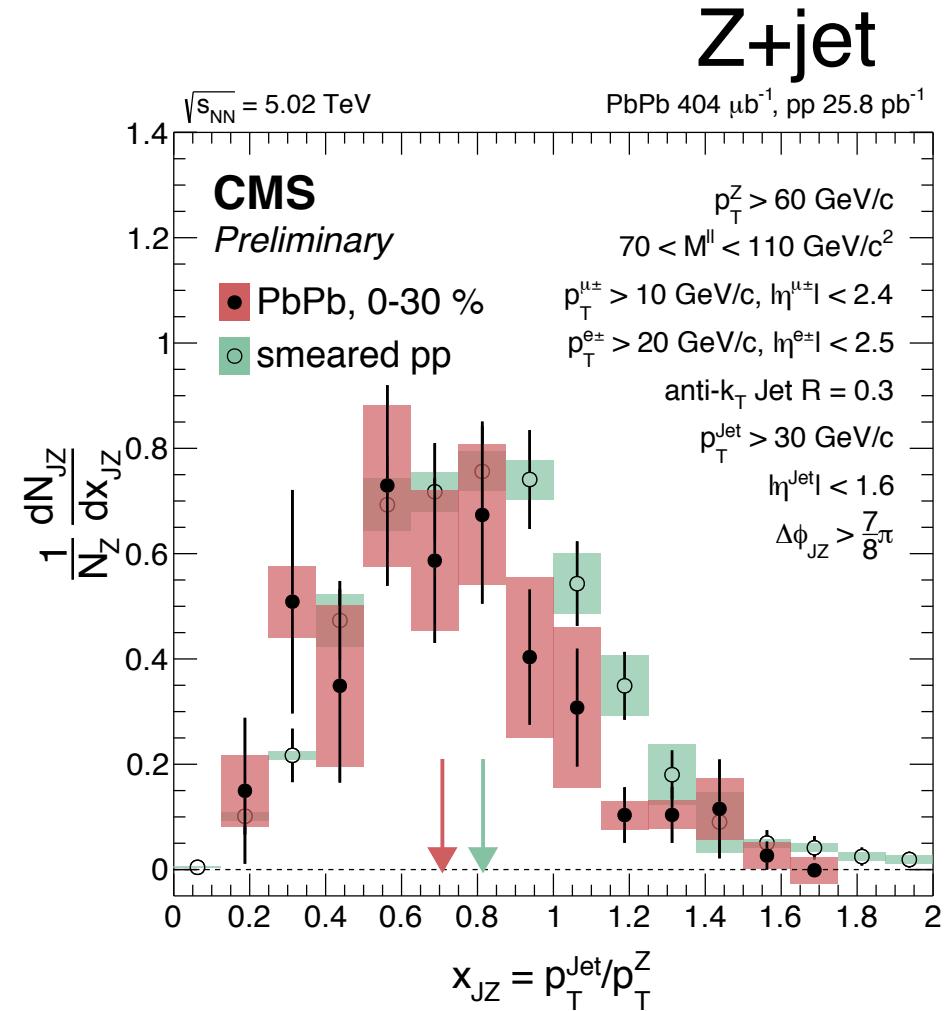
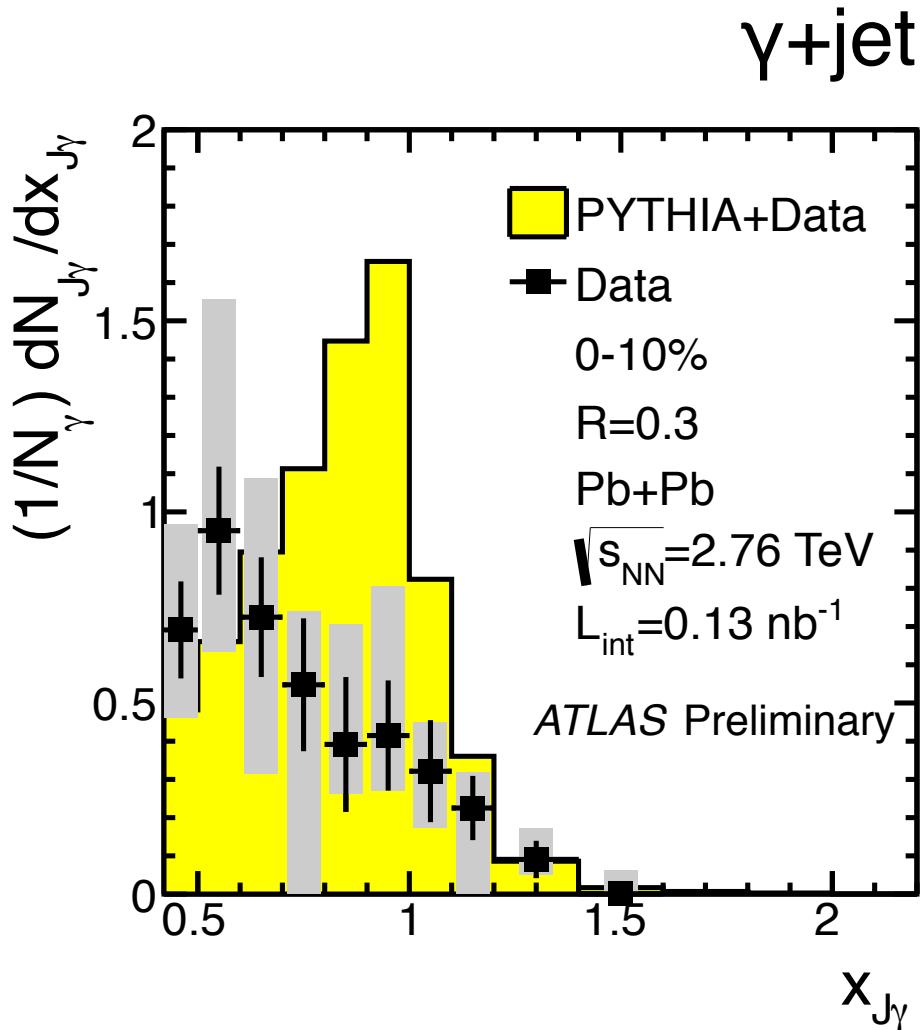
Run 1 → Run 3+4

	2010–2011 2.76 TeV 160 $\mu\text{b}^{-1}$	HL-LHC 5.5 TeV 10 $\text{nb}^{-1}$
Jet $p_T$ reach (GeV/c)	~ 300	~ 1000
Dijet ( $p_{T,1} > 120$ GeV/c)	50k	~ 10M
b-jet ( $p_T > 120$ GeV/c)	~ 500	~ 140k
Isolated $\gamma$ ( $p_T^\gamma > 60$ GeV/c)	~ 1.5k	~ 300k
Isolated $\gamma$ ( $p_T^\gamma > 120$ GeV/c)	—	~ 10k
W ( $p_T^W > 50$ GeV/c)	~ 350	~ 70k
Z ( $p_T^Z > 50$ GeV/c)	~ 35	~ 7k

x60  $L_{\text{int}}$  and x3 from  $\sqrt{s}$

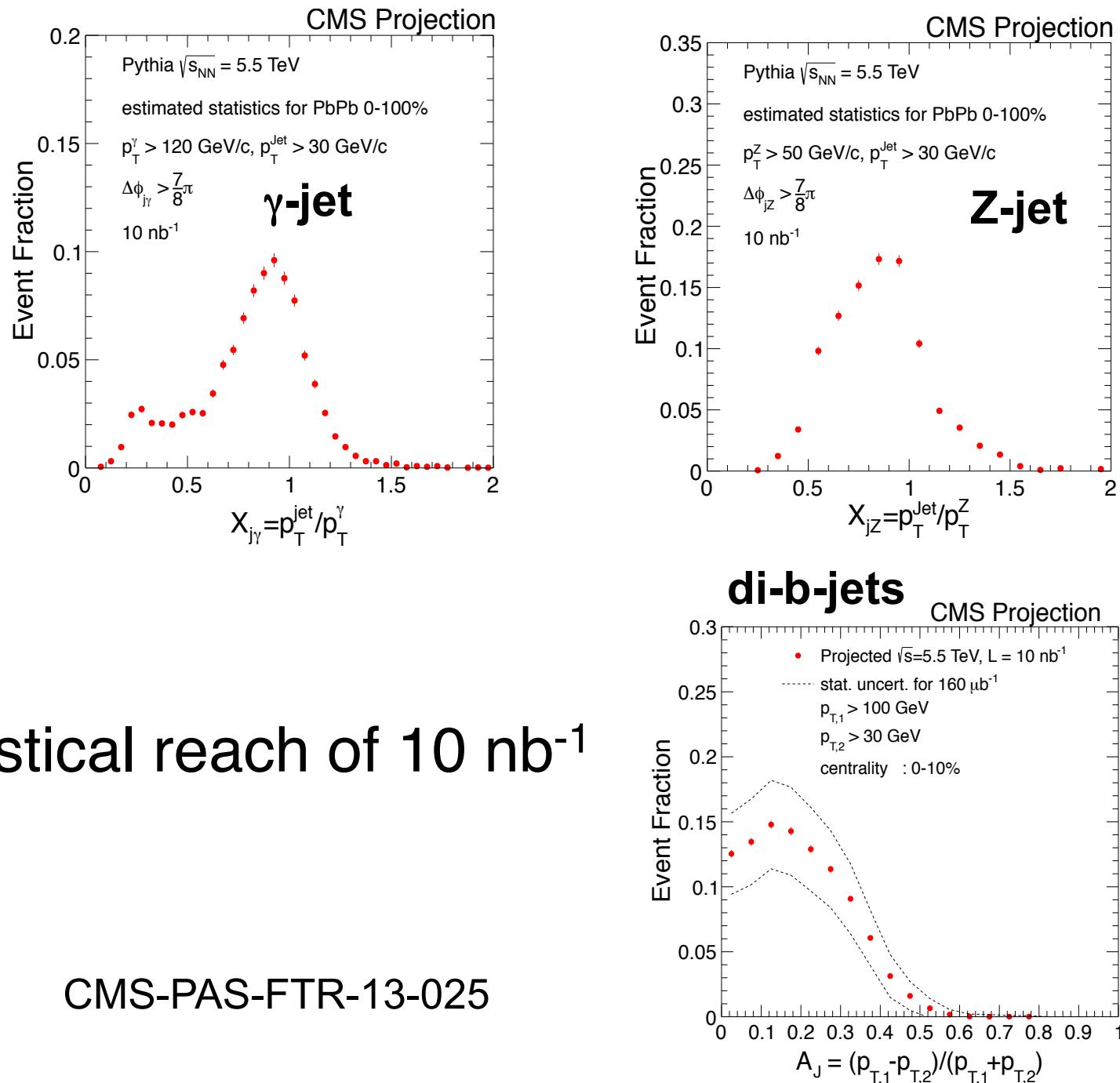
# Quantifying the QGP – high- $p_T$ hard probes

“Golden probes” of QGP



First look at run 1&2 for proof of principle

# Quantifying the QGP – high- $p_T$ hard probes



Statistical reach of  $10 \text{ nb}^{-1}$

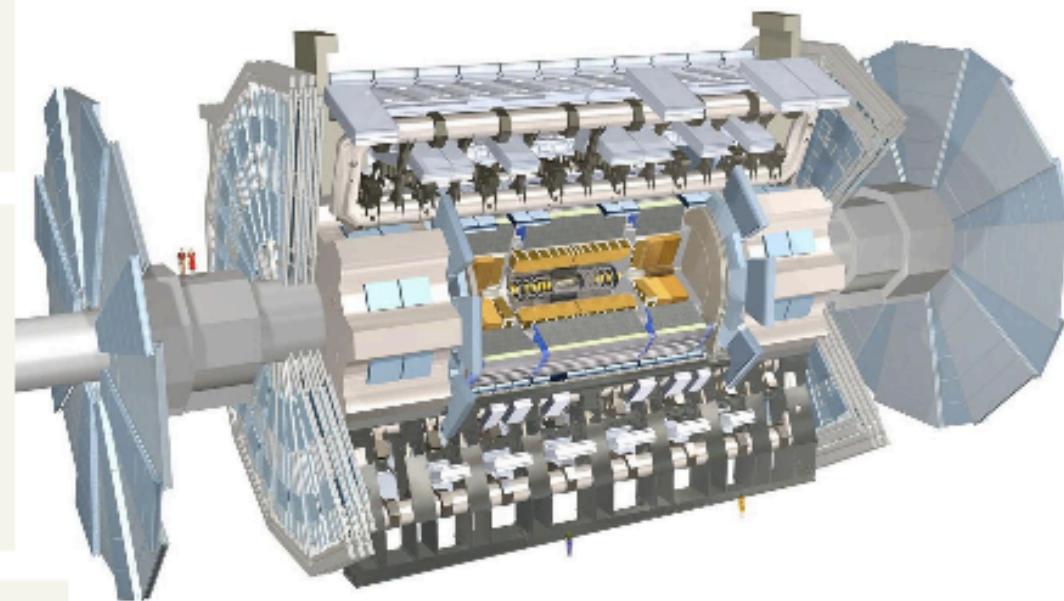
CMS-PAS-FTR-13-025

# Phase I upgrades for ATLAS/CMS

## **Pixel detectors : add 1 measurement point**

ATLAS: Insertable Barrel Layer - 2015 (LS1)

CMS: Full replacement - end 2016



## **Calorimeters: increase granularity for trigger**

ATLAS: new Front End in Liquid Argon (barrel & endcaps) - LS2 (2018)

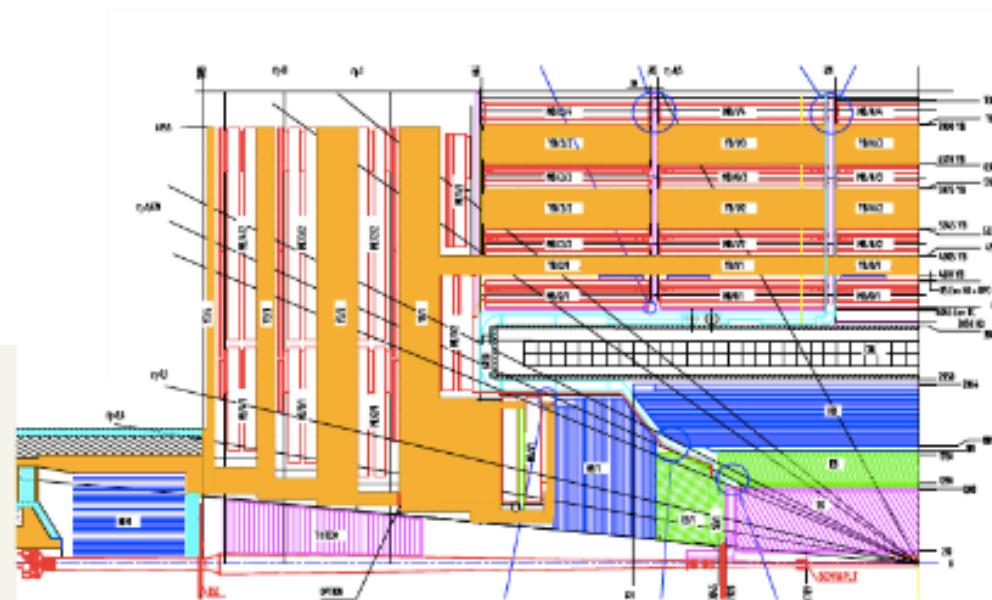
CMS: New photo-detectors for HF/HE/HB (also anomalous signal) - From 2015 to LS2

## **Muon systems: complete coverage - improve forward resolution for trigger**

ATLAS: coverage - 2015 New forward disks - LS2

CMS: Complete coverage of CSCs and RPCs

Increase CSC read-out granularity - 2015



## **Trigger/DAQ: improve bandwidth & processing**

ATLAS: New Back-End electronics - LS2

and Fast Track Trigger (FTK) input at High Level Trigger - before LS2

CMS: New Back-End electronics - end 2015

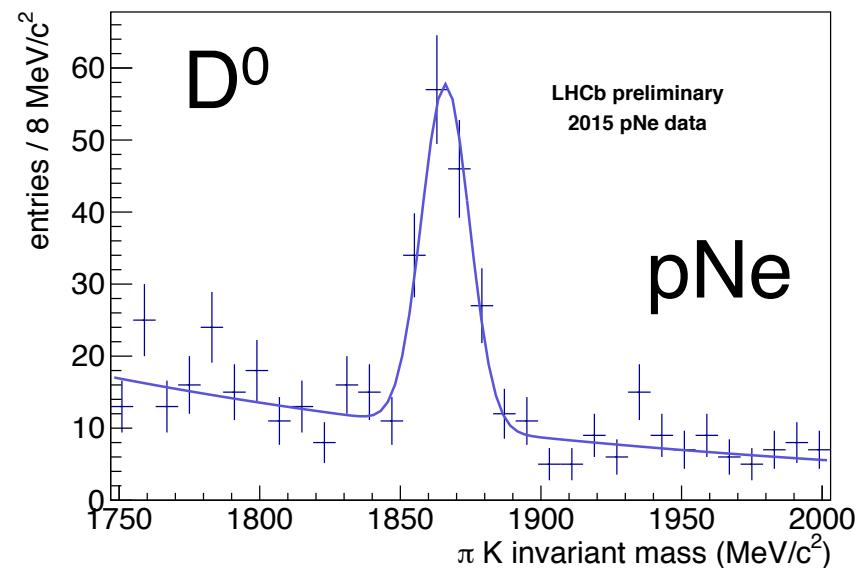
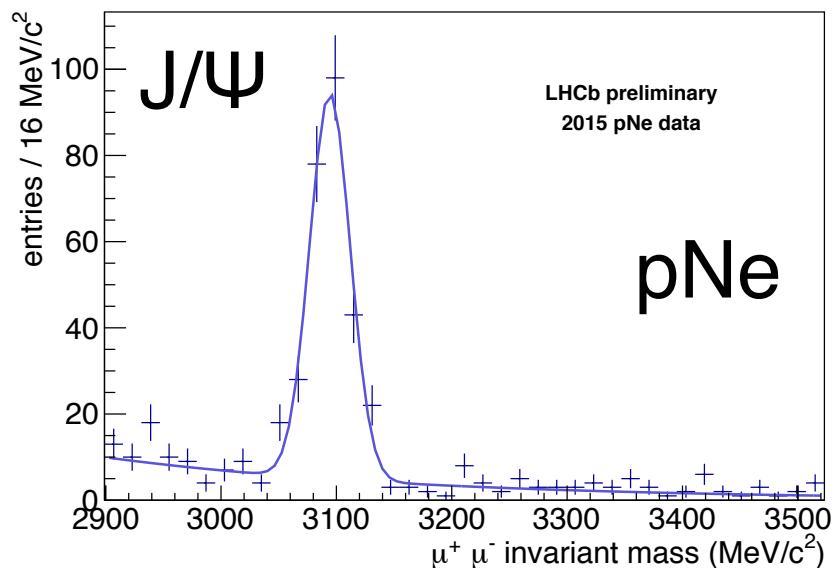
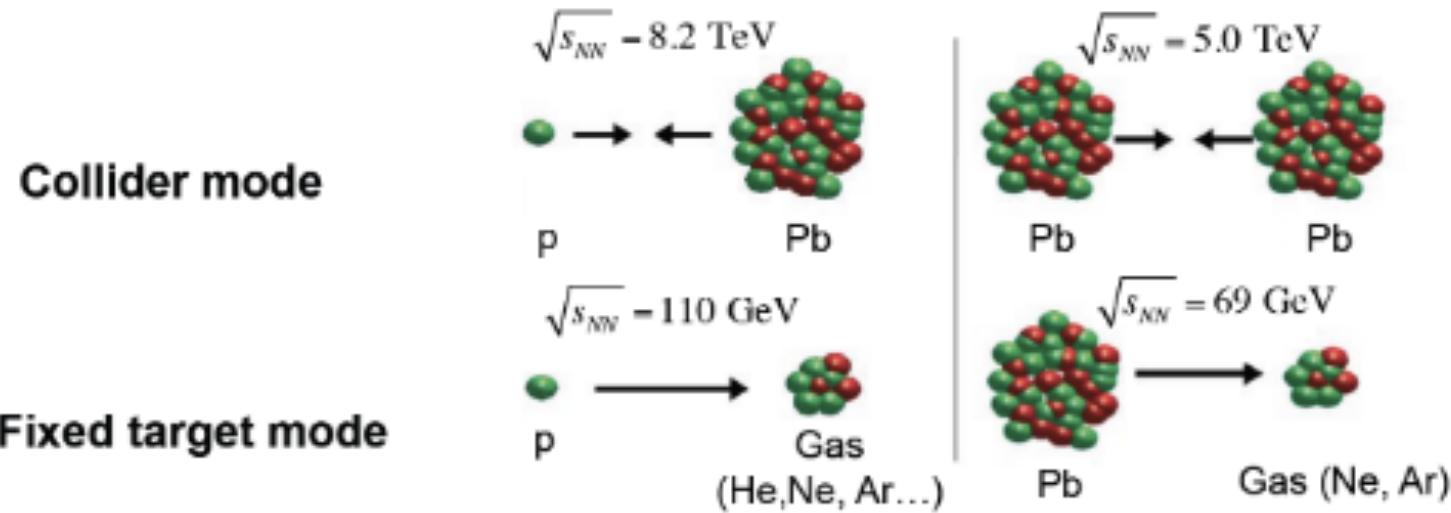
## Key Phase II Upgrades

Current at conceptual design and R&D level. Mainly driven by HL-LHC pp program.

- “Megahertz” DAQ
  - 1MHz readout rate for 150PU pp events
  - 100kHz readout rate for PbPb: entire event selection based on full reconstruction in the HLT
- Tracker Upgrade
  - 4 layer Pixel system, coverage:  $|\eta| < 2.4 \rightarrow |\eta| < 4$
  - New SiStriptracker: fast readout necessary for the MHz DAQ
- High Granularity Calorimetry
  - Better handle on jet constituents

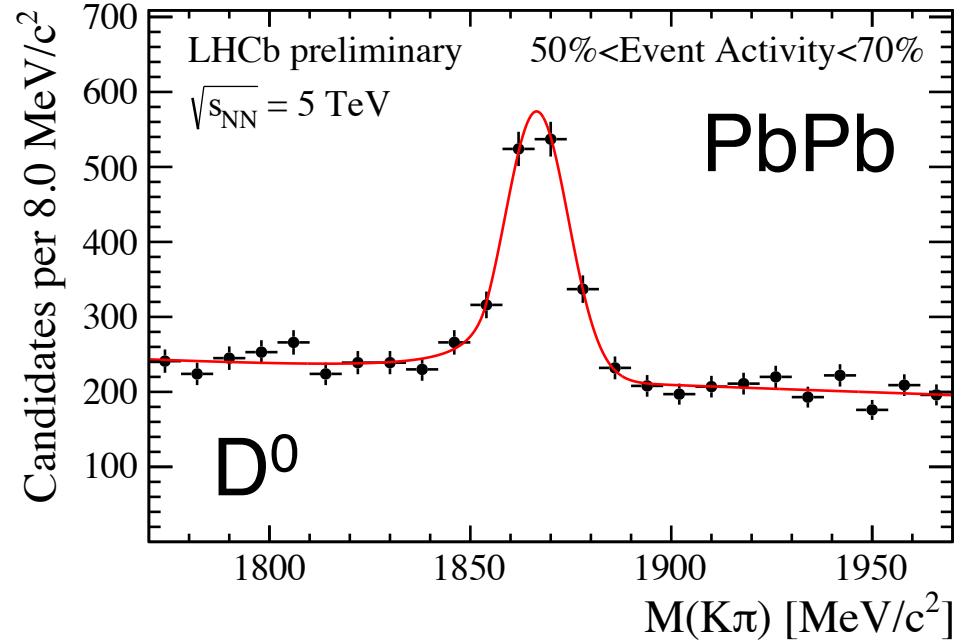
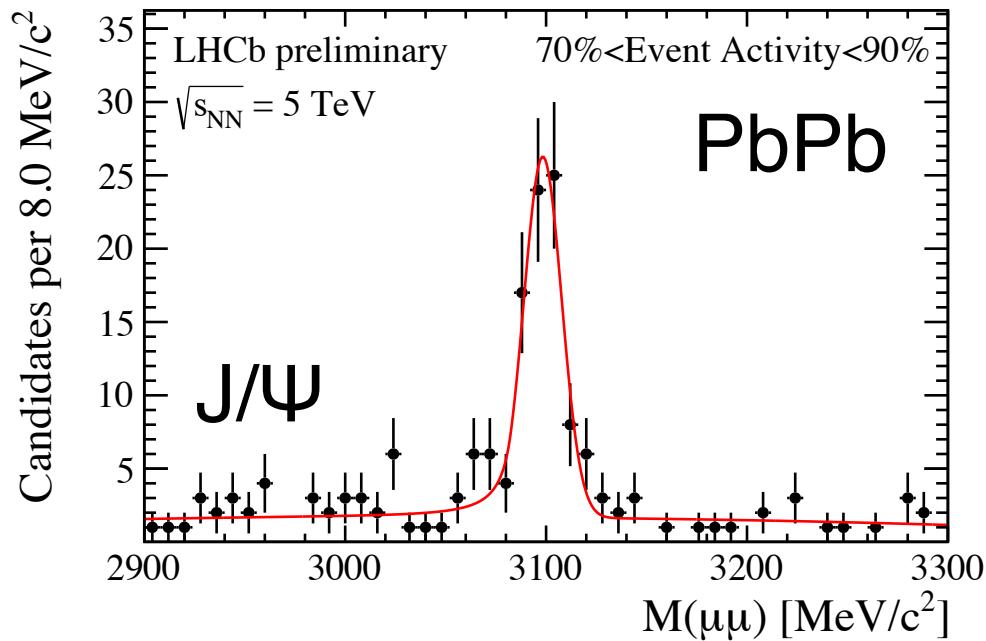
# Heavy ion program at LHCb

First heavy ion run in 2013:  $L_{\text{int}} \sim 1.6 \text{ nb}^{-1}$  for pPb



# Heavy ion program at LHCb

Participated in the PbPb run in 2015



Currently limited to peripheral (50-100%) events  
due to detector granularity

Plan to upgrade **V**Ertex **L**Ocator (silicon strips) at LS2 to  
improve granularity and reach full centrality for run 3-4

## Summary

Era of precisely quantifying the sQGP at the LHC  
heavy ion programs

Successful run 1+2 HI program for all 4 experiments

Future upgrades on the way to bring exciting new  
opportunities of heavy-ion physics in the coming  
decade

# Backup