Prospects for heavy flavour measurements with the ALICE inner tracker upgrade

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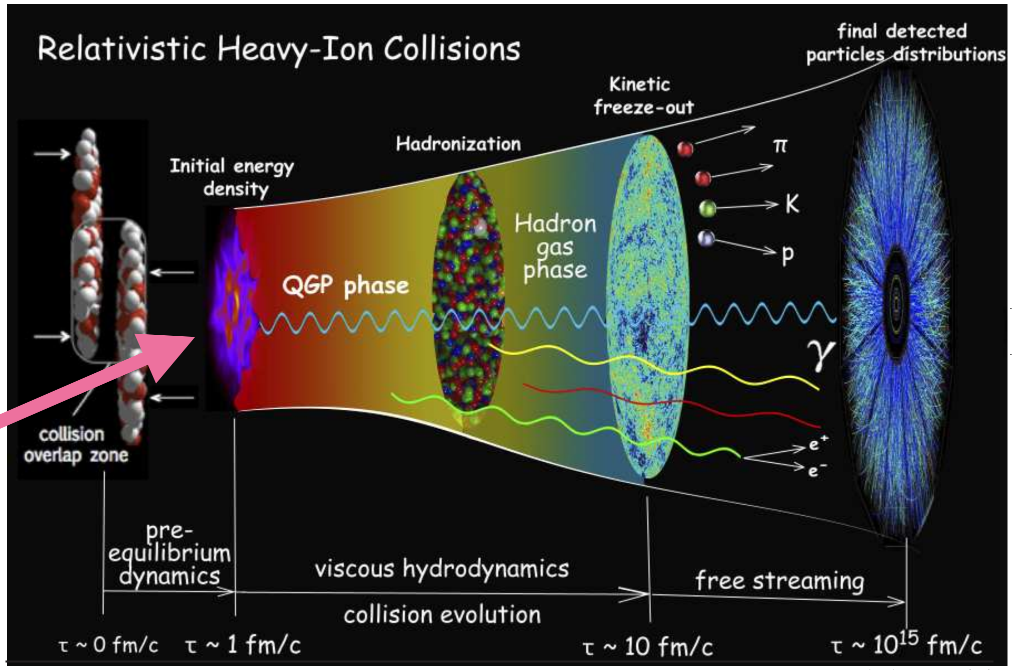
OUTLINE

- **Why Heavy-flavours in heavy-ion physics**
- **Overview of available ALICE measurements; where we are**
- **Heavy-ion program at LHC for Run2, Run3 and Run4**
- **ALICE upgrade strategy on heavy flavour sector**
- **Inner Tracking System upgrade design objectives**
- **Expected performance**
- **Summary**

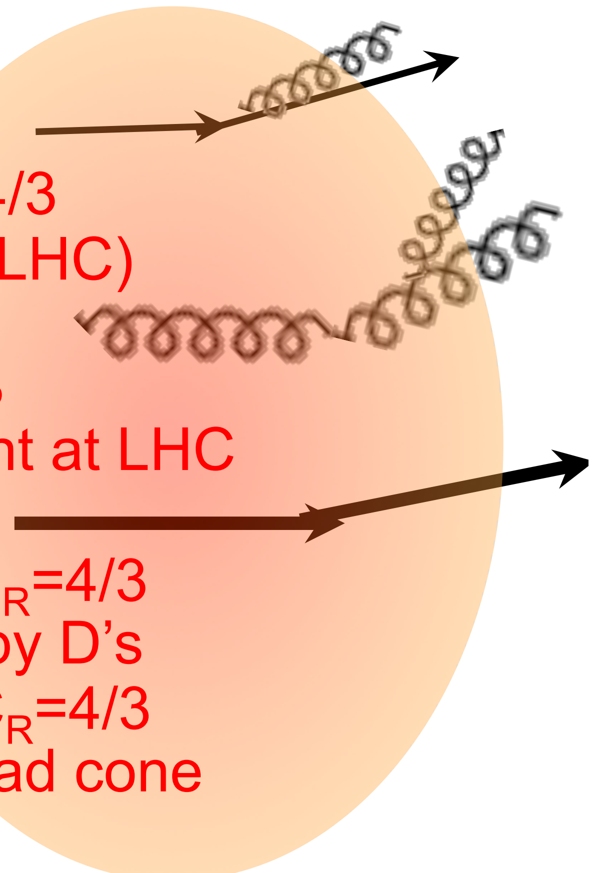
What's special about heavy quarks

- Heavy-ion (HI) collisions at LHC energies
  - QGP phase expected (lifetime ~ O(10 fm/c))
- Heavy quarks
  - Large mass ($m_q \gg \Lambda_{QCD}$) → produced in the early stages of the HI collision with short formation time($t_{charm} \sim 1/m_c \sim 0.1$ fm/c << $\tau_{QGP} \sim$ O(10 fm/c)), traverse the medium interacting with its constituents
  - Interactions with QGP don't change flavour identity
  - Cannot be destroyed/created in the medium
    - ➡ transported through the full system evolution → natural probe of the hot medium created in HI interactions

Hard processes:
- Charm, Beauty, W, Z, photons, Jets
- Probe the whole evolution of the collision



Heavy quarks as medium probes

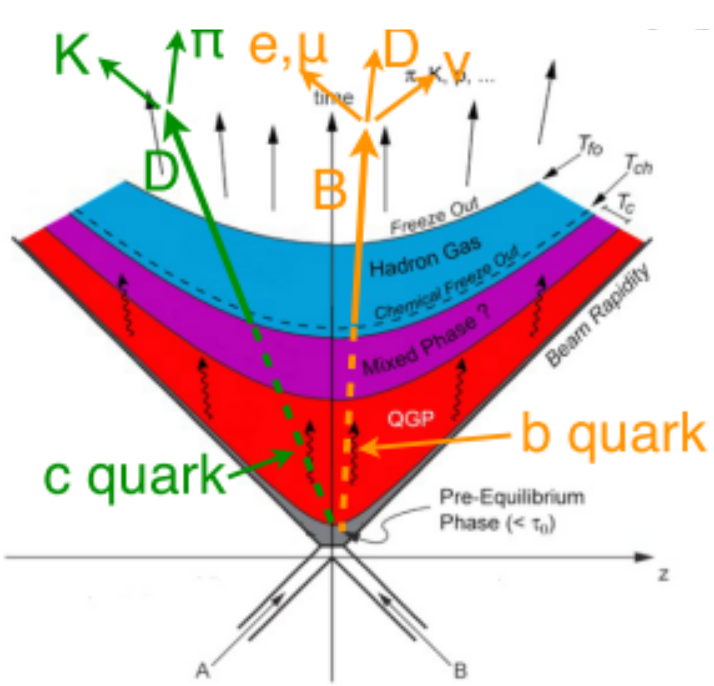


q: colour triplet
- **u,d,s:** m~0, C_R=4/3 (difficult to tag at LHC)

g: colour octet
- **g:** m=0, C_R=3 > E loss, dominant at LHC

Q: colour triplet
- **c:** m~1.5 GeV, C_R=4/3 small m, tagged by D's
- **b:** m~5 GeV, C_R=4/3 large mass → dead cone → < E loss

'Quark Matter'



Parton Energy Loss by
→ medium-induced gluon radiation
→ collisions with medium constituents

$$\Delta E(\varepsilon_{medium}; C_R, m, L)$$

Prediction: $\Delta E_g > \Delta E_{c \approx q} > \Delta E_b$

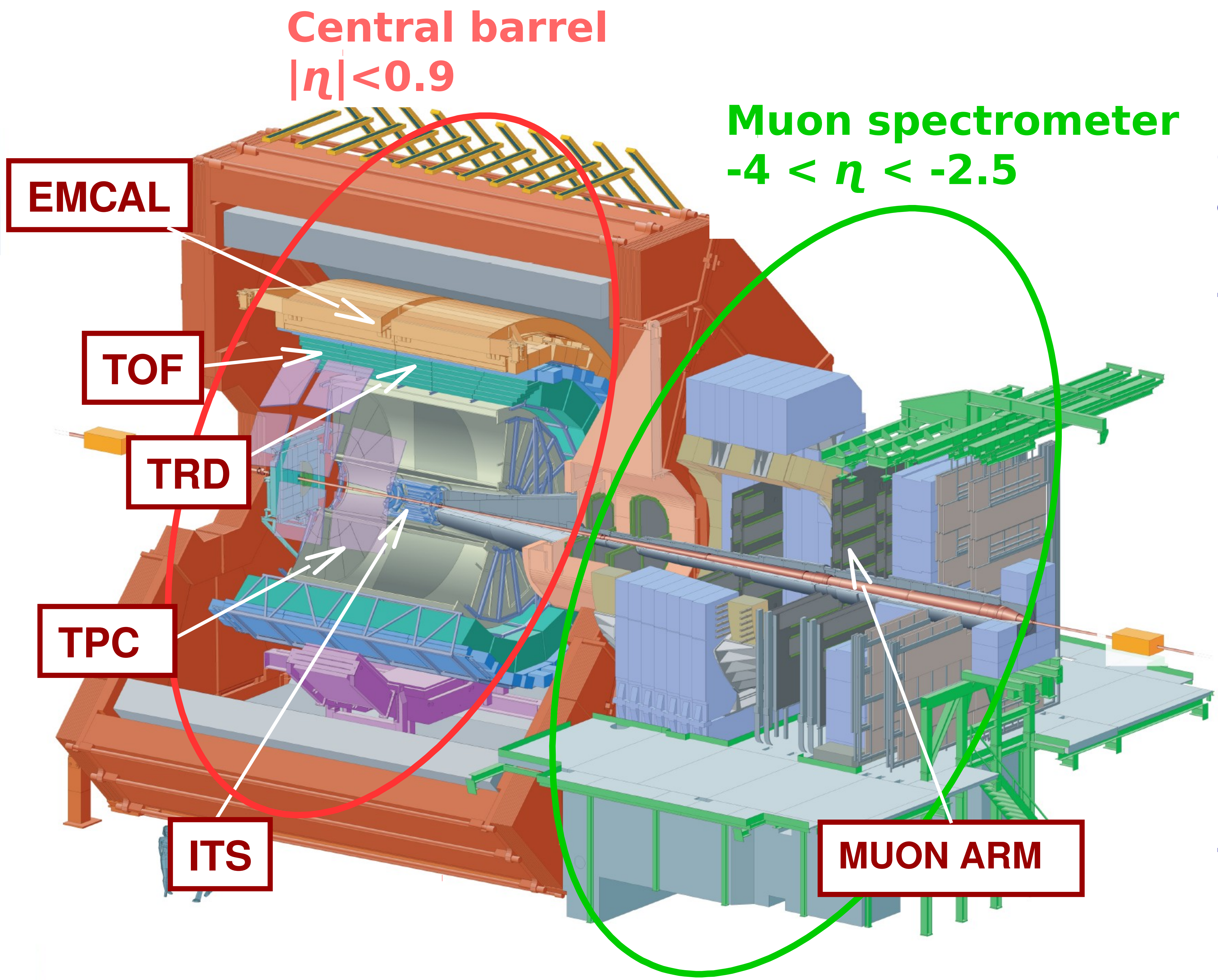
Might translate into a hierarchy of nuclear modification factors

$R_{AA}^{\pi} < R_{AA}^{D} < R_{AA}^{B}$?

Collectivity in the QGP
- Initial spatial asymmetry → azimuthal asymmetry of particle emission in momentum space

⇒ heavy quarks participate in collective expansion of the medium via sufficient re-scattering?

Heavy flavour measurements in ALICE



Heavy-flavour decay channels currently addressed in ALICE:

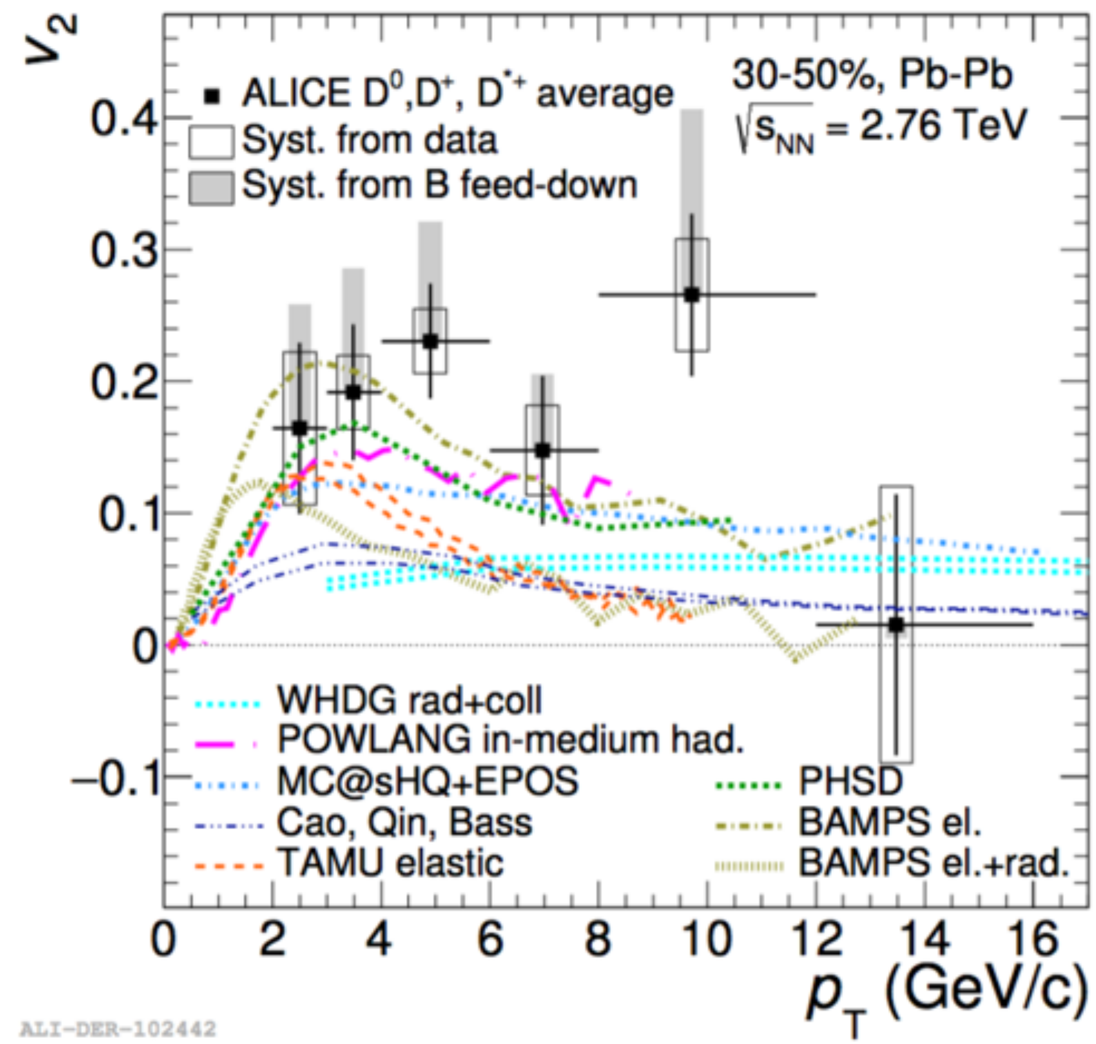
- **Central barrel:**
  - $D^0 \to K^-\pi^+$
  - $D^+ \to K^-\pi^+\pi^+$
  - $D_s^+ \to K^-K^+\pi^+$
  - $D^{*+} \to D^0\pi^+$
  - $\Lambda_c^+ \to pK^-\pi^+$ (pp,pPb only)
  - $\Lambda_c^+ \to p\,K_S^0$ (pp,pPb only)
  - $B \to J/\psi+X$
  - $D/B \to e+X$
  - $B \to e+X$
- **Muon spectrometer:**
  - $D/B \to \mu+X$

Where we are: heavy flavour measurement in ALICE

What we understood! Selective, representative results

- Open heavy flavor: excellent probes of the hot and dense medium
  - Heavy quarks take part in collective expansion
  - Still challenging to see expected hierarchy in energy losses
  - Distinguish between b/c energy losses is limited to high p_T
  - No access in Pb-Pb to charm (and beauty) baryons → baryon/meson ratio for light flavor only

PRC 90 034904 (2014) PRL 111 102301 (2013)



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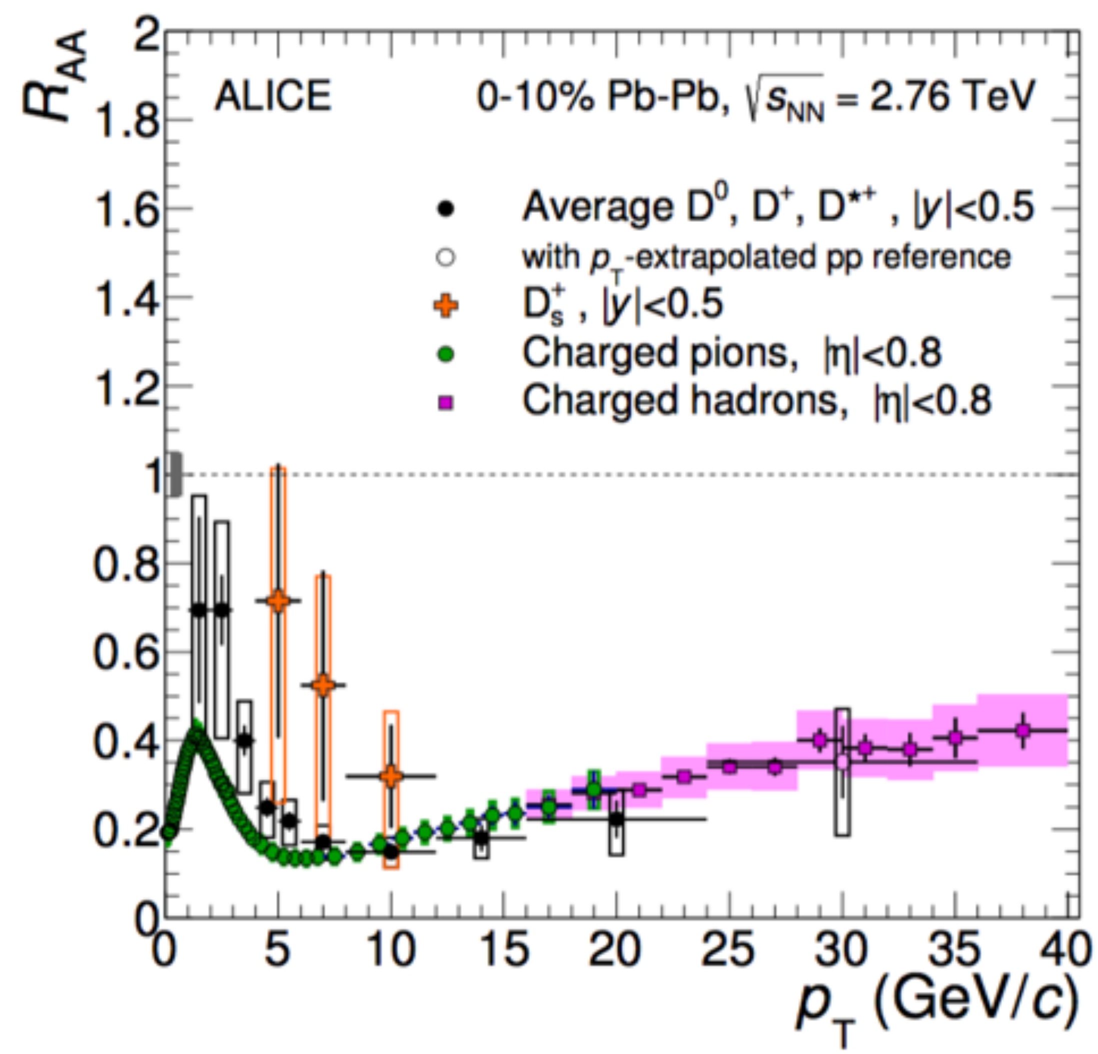
JHEP 03 (2016) 081 JHEP 03 (2016) 082



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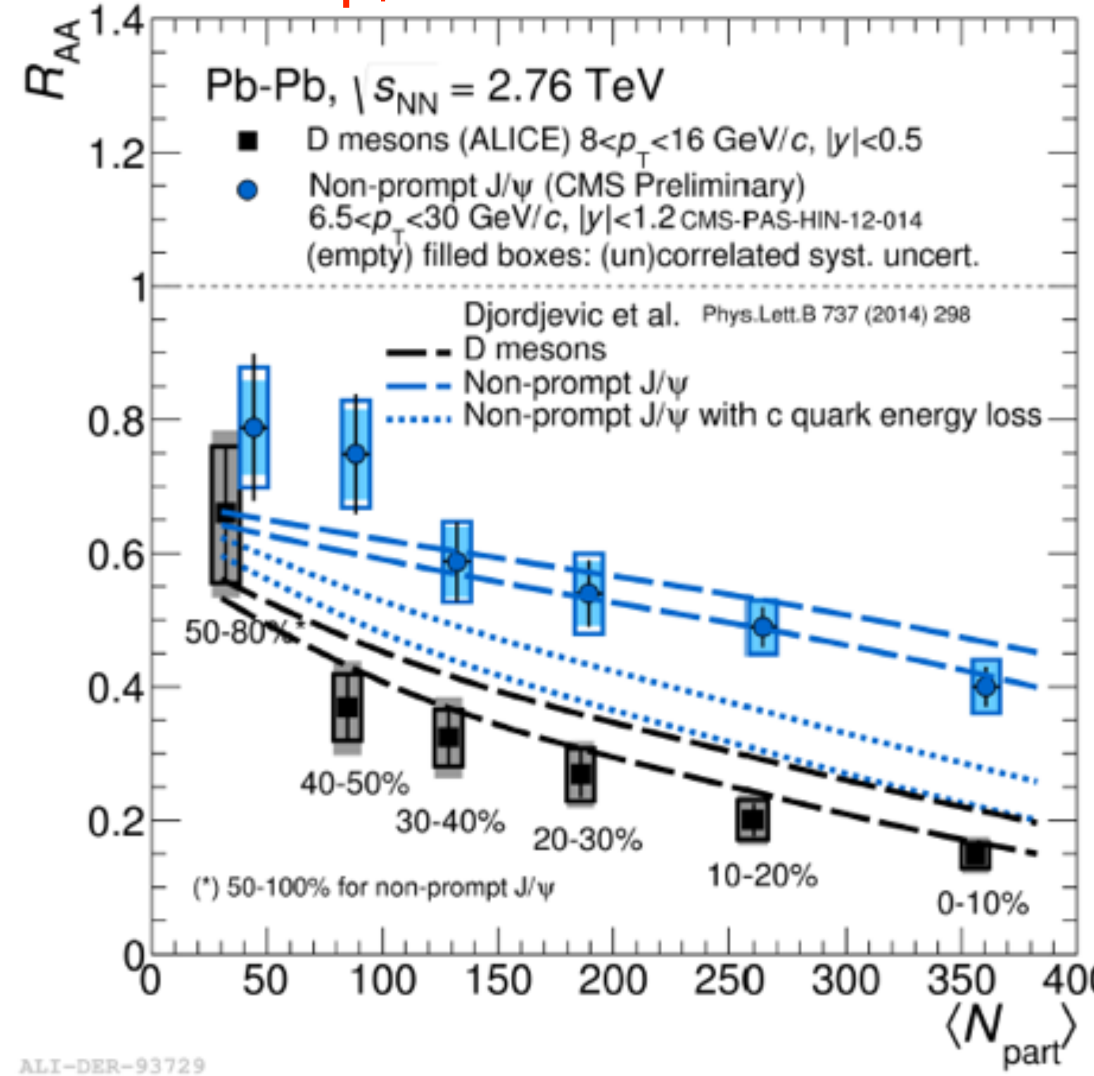
Meson p_T ~ 10 GeV/c JHEP 11 (2015) 205



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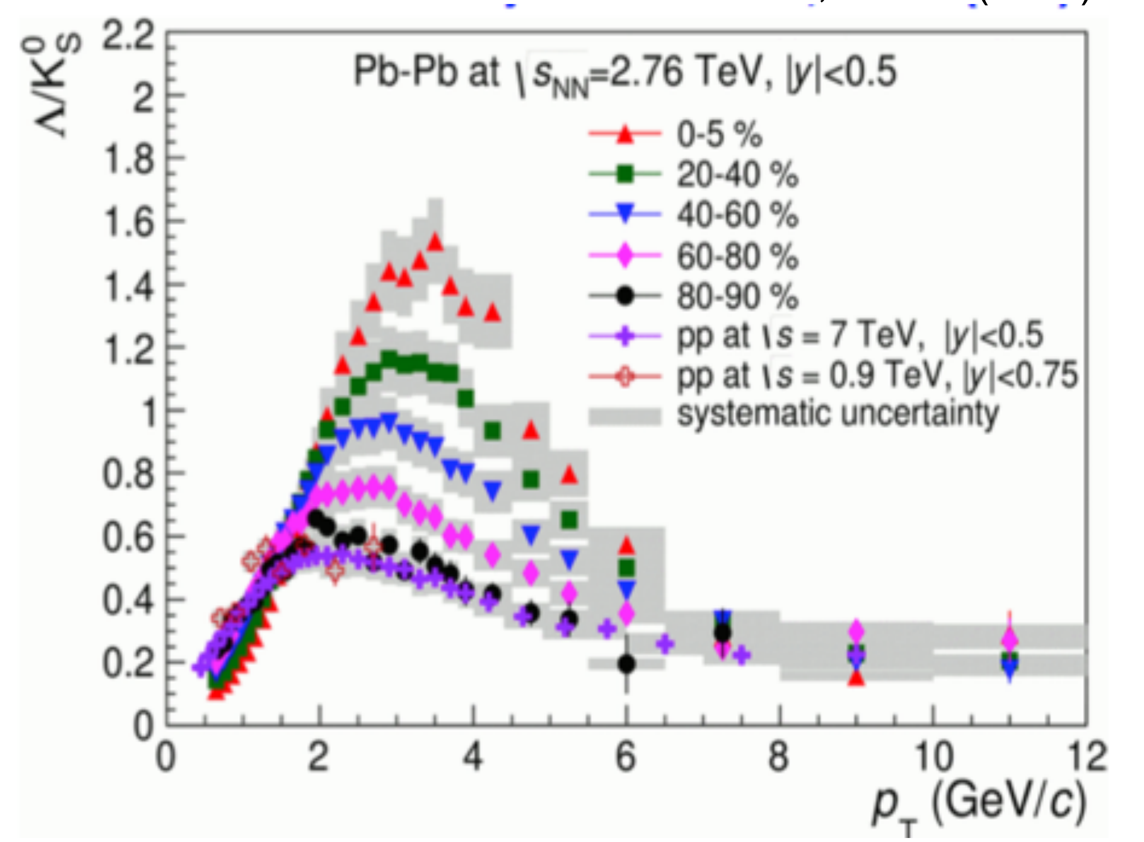
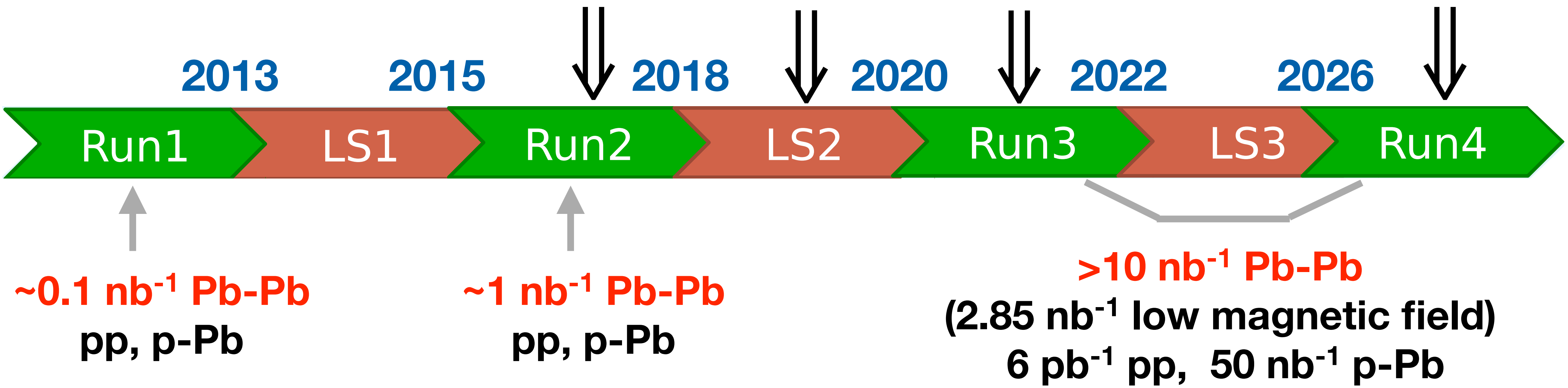
PRL 111, 222301(2013)



Heavy-ion program at LHC extended to Run2, Run3 and Run4



- Run2: ~1 nb^{-1} Pb-Pb at $\sqrt{s_{NN}}$ ~ 5.1 TeV, 1 p-Pb run
- LS2 (2018-2019)
  - Major ALICE and LHCb upgrades, important upgrades for ATLAS and CMS
  - LHC collimator upgrades: target luminosity 6 x 10^{27} $cm^{-2}s^{-1}$ → 50 kHz interaction rate
- Run3 + Run4 (“HL-LHC”, 2020-2028):
  - Experiments request: >10 nb^{-1} Pb-Pb (ALICE: 10 nb^{-1} at 0.5T + 3 nb^{-1} at 0.2T)
  - p-Pb high lumi, pp reference at 5.5 TeV, possibly light ions (e.g. Ar-Ar)

ALICE upgrade strategy: heavy flavour sector

- High precision measurements of rare probes at low p_T
  - **D mesons:** high-precision measurement down to zero p_T
  - Exclusive reconstruction of the **charm baryon Λ_c** ($c\tau$, only 60 μm)
  - Exclusive reconstruction of **beauty mesons (B) and baryons (Λ_B)**

➡ secondary vertices → improve inner tracker (improve spacial precision on track and vertex position)

➡ mostly "untirggerable" because of extremely low S/B

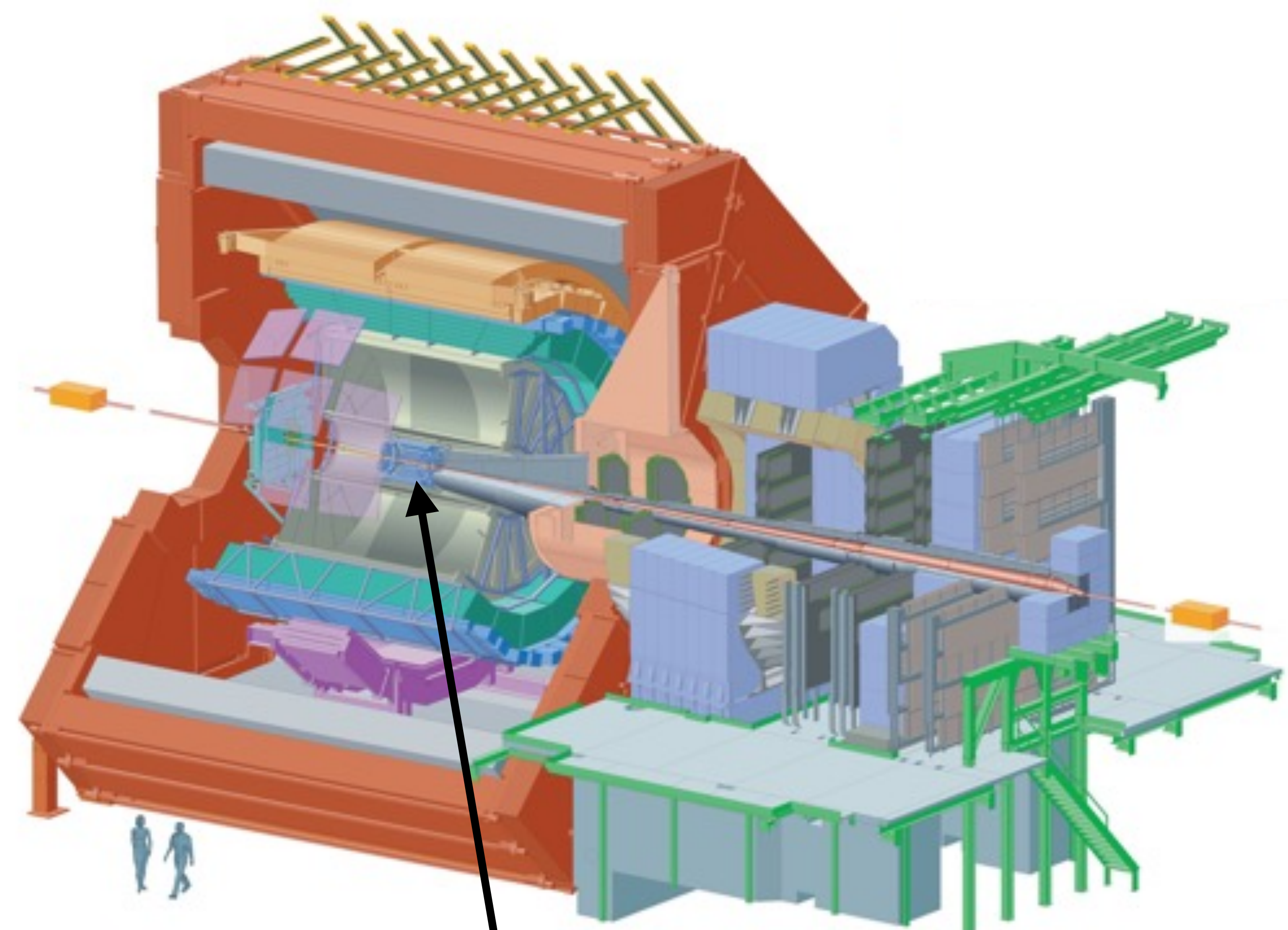
➡ Trigger approach: write all events at up to 50 kHz in Pb-Pb (currently 0.5 kHz)
~1 TB/s HLT/DAQ ~10 GB/s

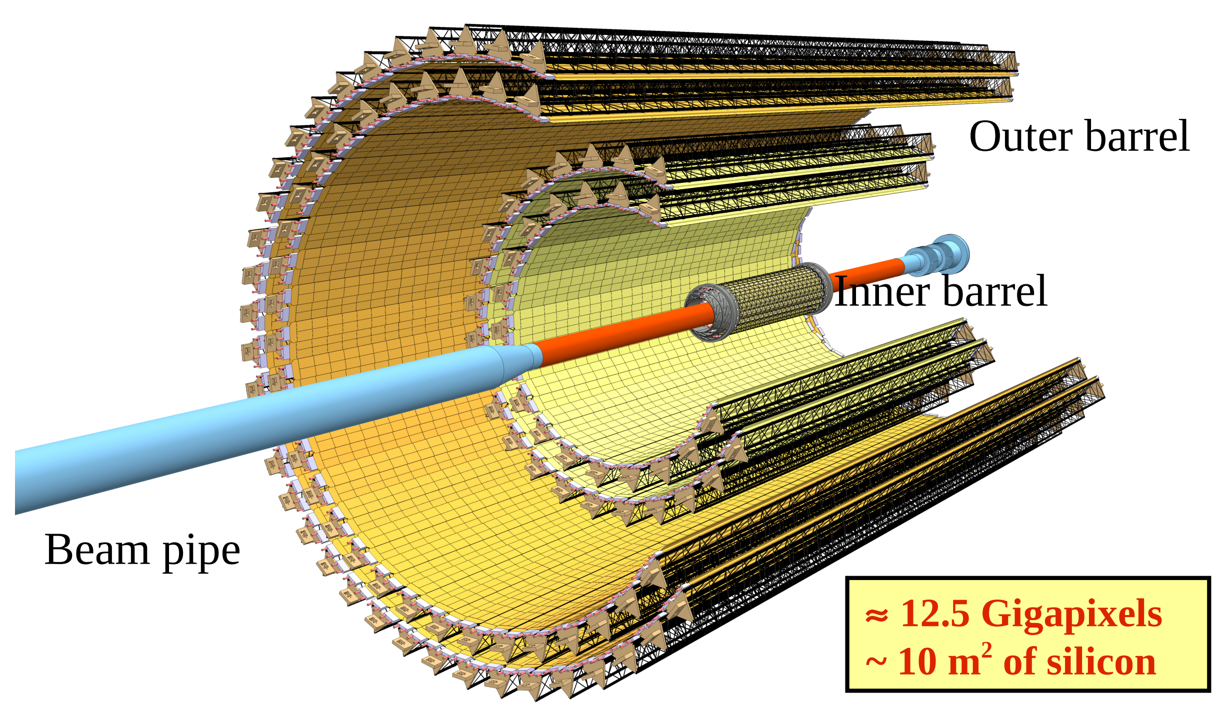
Upgrade of Inner Tracking System (ITS)

- **The new ITS design goals:**
  - Improve vertex resolution
  - High efficiency and p_T resolution
  - Fast readout: 50 kHz (Pb-Pb), 400 kHz (pp)
  - Fast insertion/removal

- **The new ITS features:**

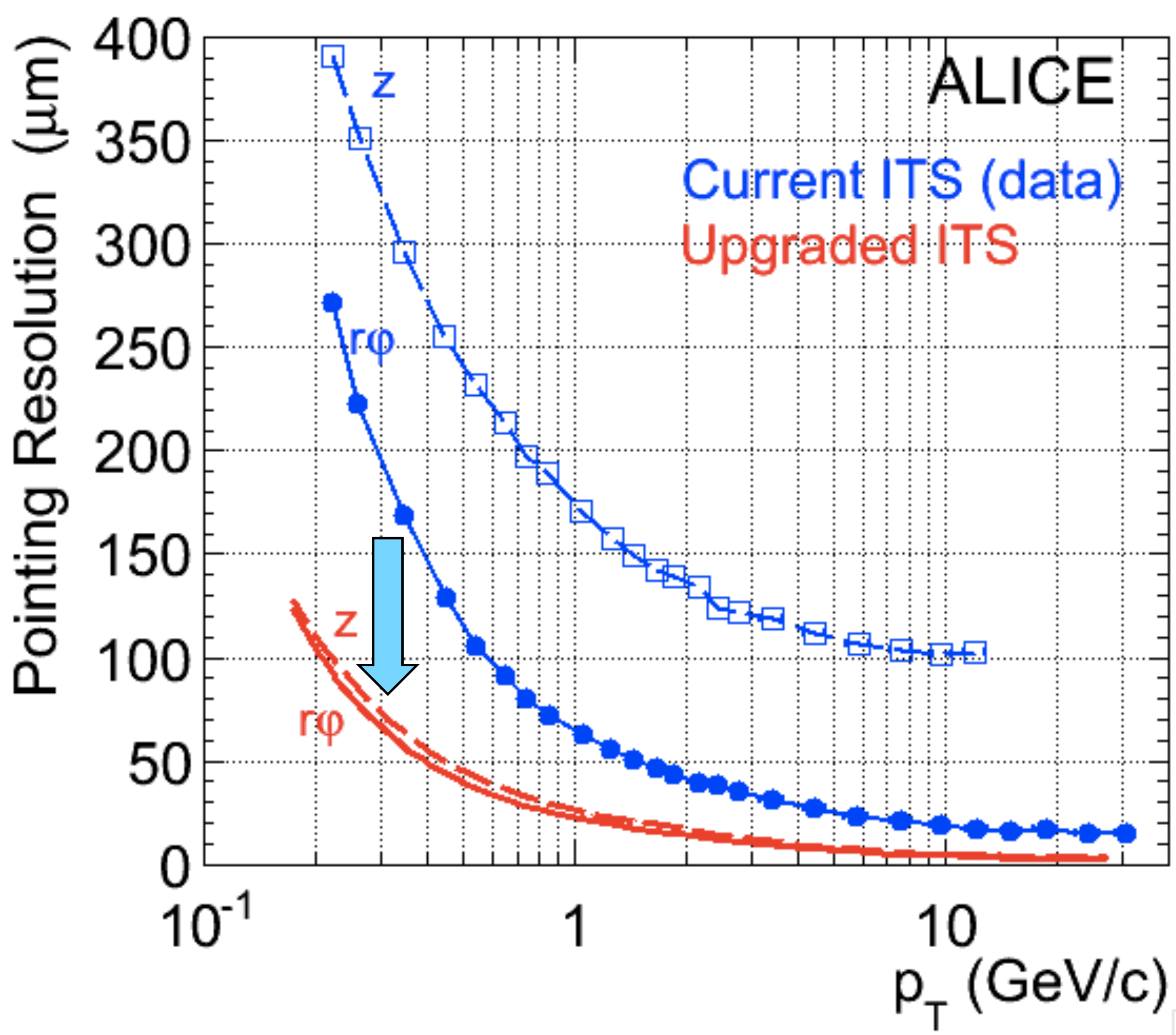
	Current ITS	New ITS
Layers	6	7
Inner radius	3.9 cm	2.3 cm
Pipe radius	2.9 cm	1.9 cm
Innermost layer thickness	1.14% X_0	0.3% X_0
Innermost layer pixel cize	50x425 μm^2	28x29 μm^2
Max. Pb-Pb readout	1 kHz	100 kHz

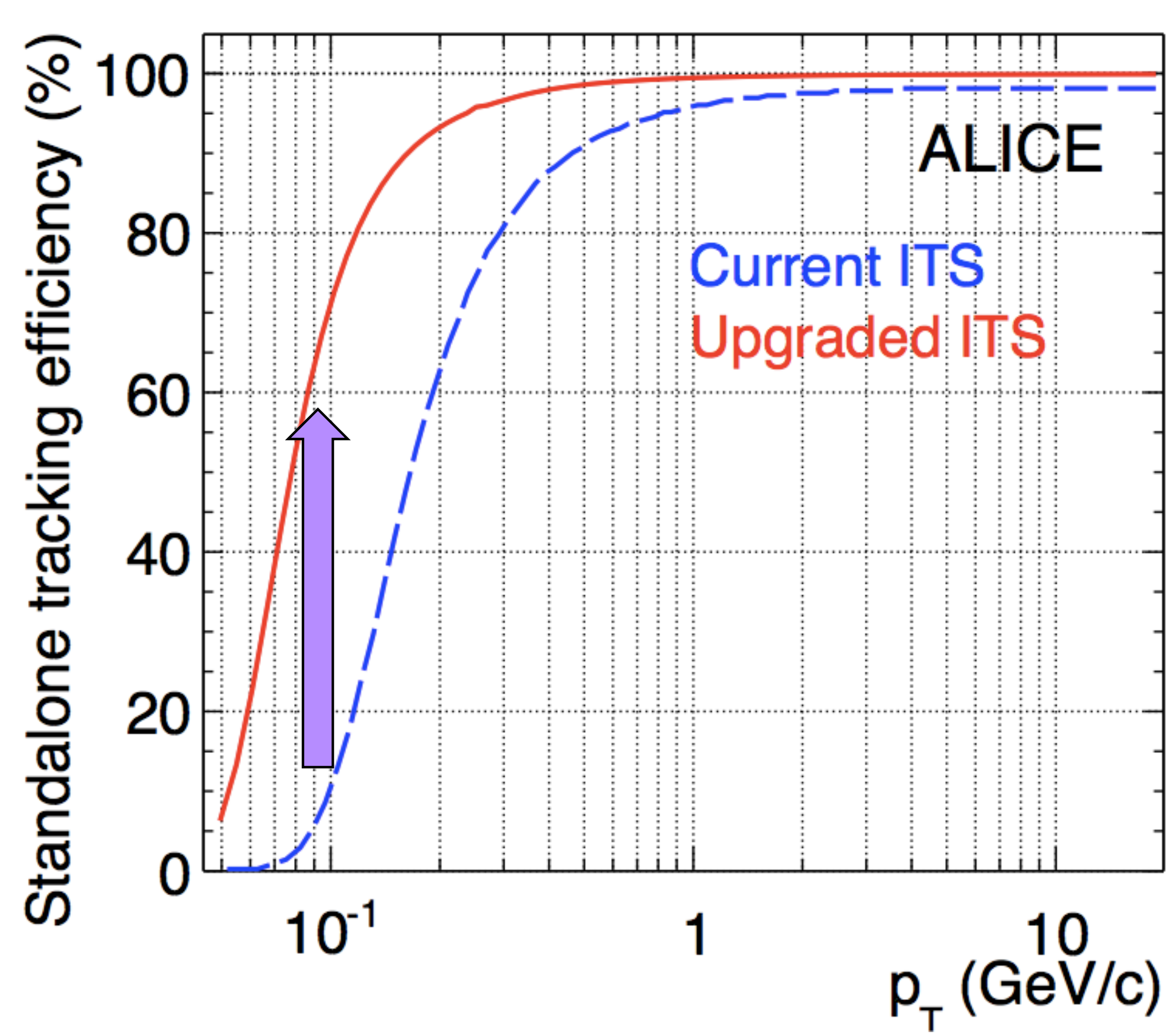




Improvement

- Pointing resolution x3 better in transverse plane (x6 along beam direction)
- Tracking efficiency x10 better at low p_T (~90% at p_T=0.1-0.2 GeV/c)





ALICE, CERN-LHCC-2013-024

ITS pixel chip - Monolithic Active Pixel Sensors (MAPS)

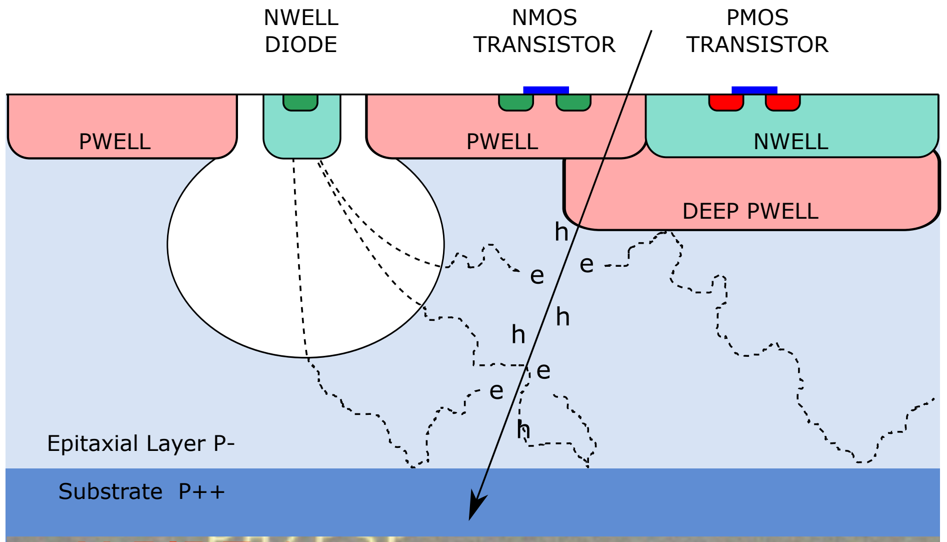
- MAPS attractive technology for ALICE due to:
  - Reduction of material budget (sensor&readout integrated) 350 μm→50-100 μm/layer
  - Radiation tolerance and moderate read-out time fitting ALICE needs
- ALICE baseline: MAPS using CMOS 0.18 μm technology (TowerJazz)
- Pixel pitch ~ 30 μm x 30 μm

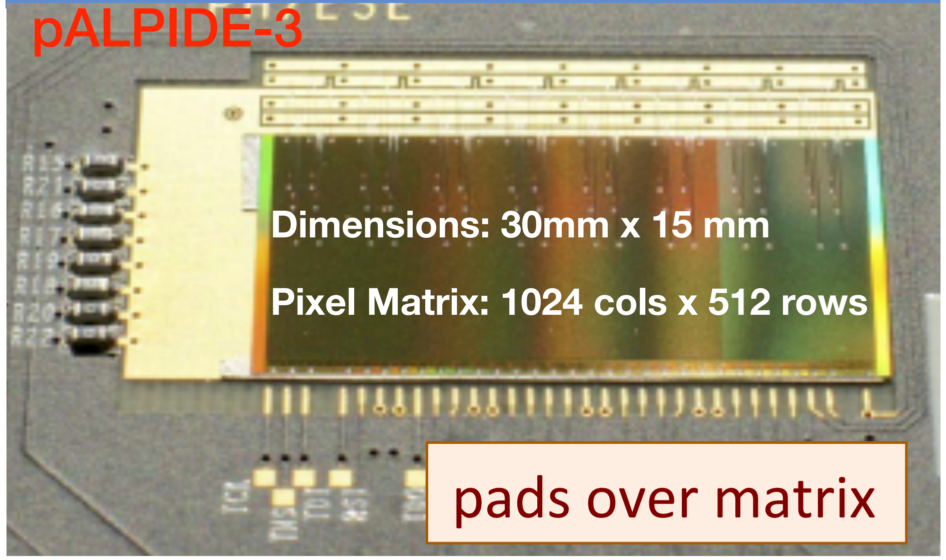
High-resistivity (1-8kΩ cm) p-type epitaxial layer (18μm - 40μm thick) on p-type substrate

Small n-well diode (2-3 μm diameter), ~100 times smaller than pixel → low capacitance

Application of (moderate) reverse bias voltage to substrate can be used to increase depletion zone around NWELL collection diode

Quadruple well process: deep PWELL shields NWELL of PMOS transistors, allowing for full CMOS circuitry within active area





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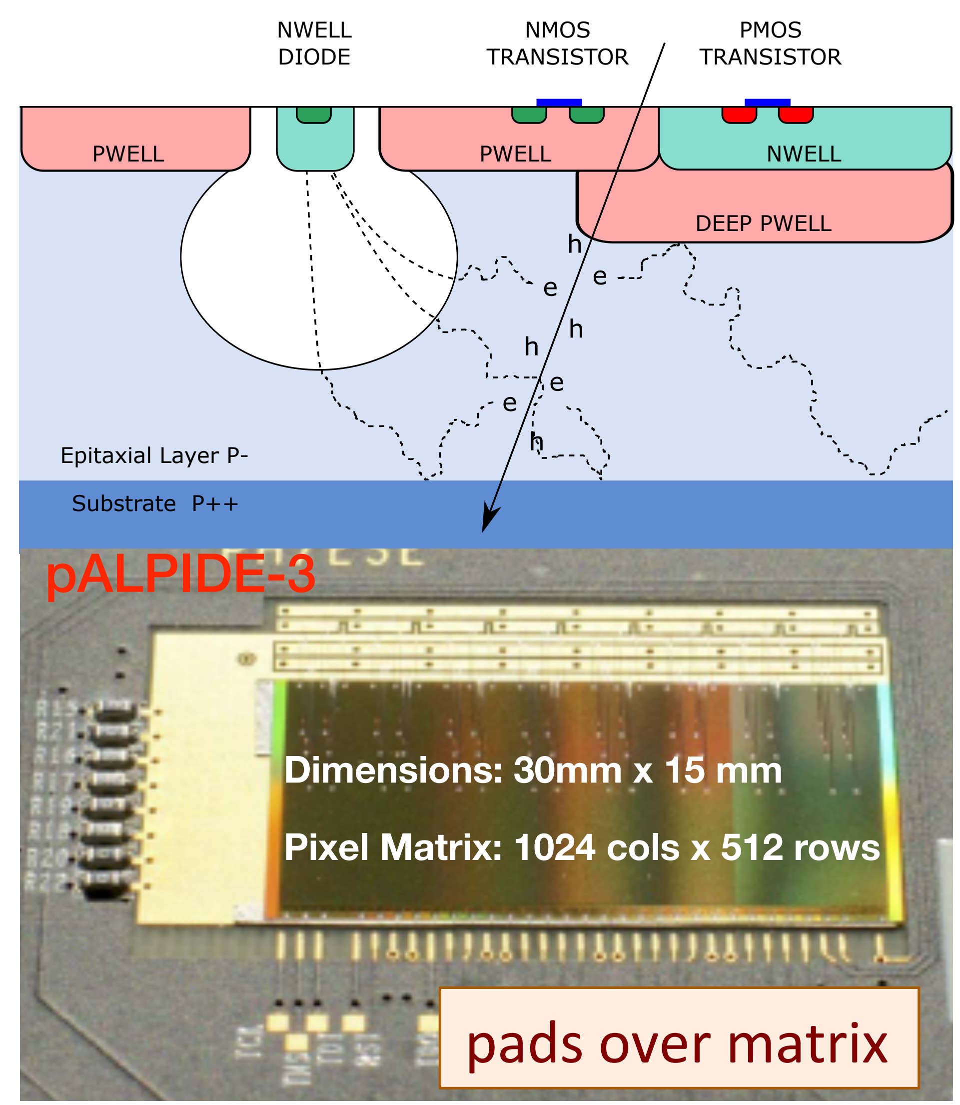
Final version of MAPS chip (ALPIDE = ALICE Pixel Detector) due August 2016 (after 3 prototype runs)
→ start production end of the year

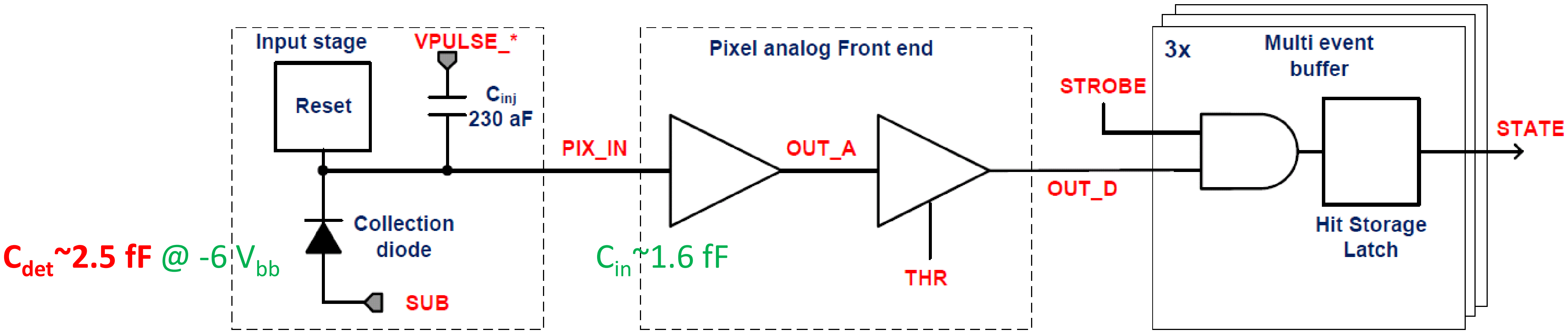
Power consumption: <100 mW/cm^2
Efficiency > 99%
Noise probability: < 10^{-6}

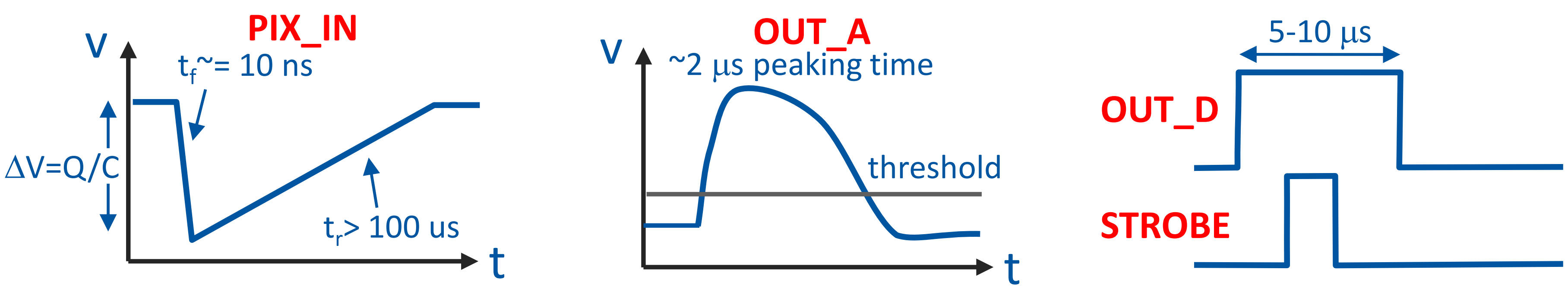
Non-Ionizing Energy Loss: 1.7×10^{13} 1 MeV n_{eq} /cm^2 (*)
Total Ionizing Dose: 2.7 Mrad for IB, 100 krad for OB (*)

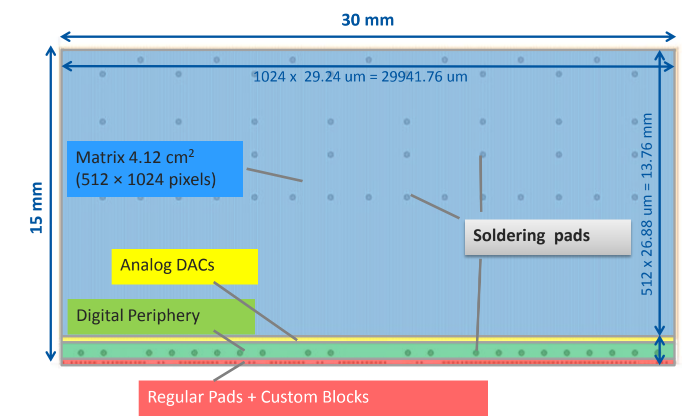


(*) 10 x radiation load integrated over approved programme (~ 6 years of operation)

In-pixel front-end circuitry of ALPIDE



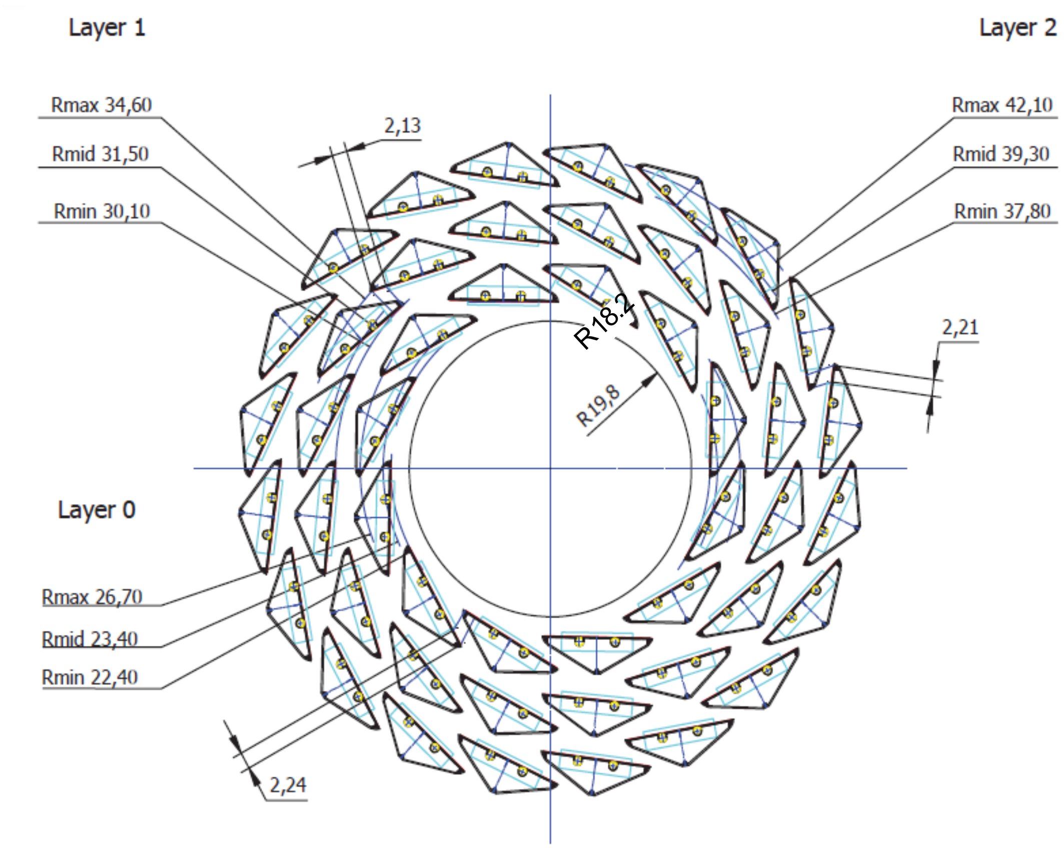




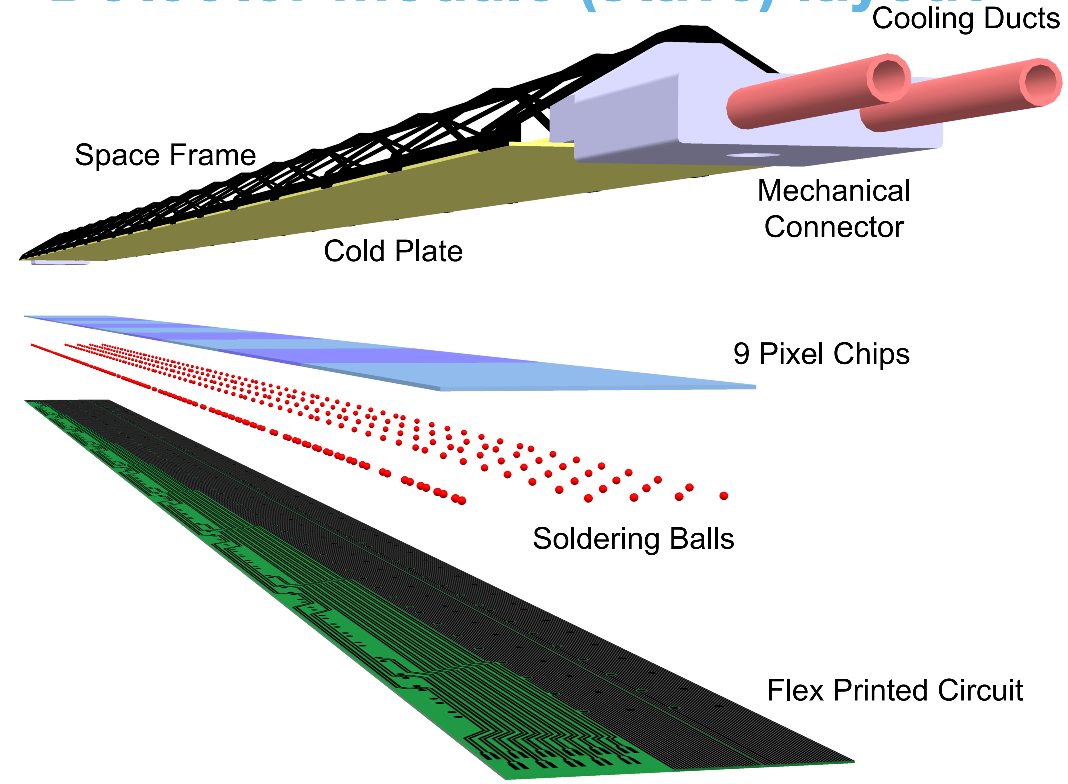
- Analog front-end and discriminator continuously active
  - Non-linear and operating in weak inversion. Low C:Ultra-low power: 40 nW/pixel
  - The front-end acts as analogue delay line
  - Test pulse charge injection circuitry
  - Global threshold for discrimination → binary pulse OUT_D
- Digital pixel circuitry with three hit storage registers (multi event buffer)
  - Global shutter (STROBE) latches the discriminated hits in next available register

Read out: The Priority Encoder sequentially provides the addresses of all hit pixels in a double column

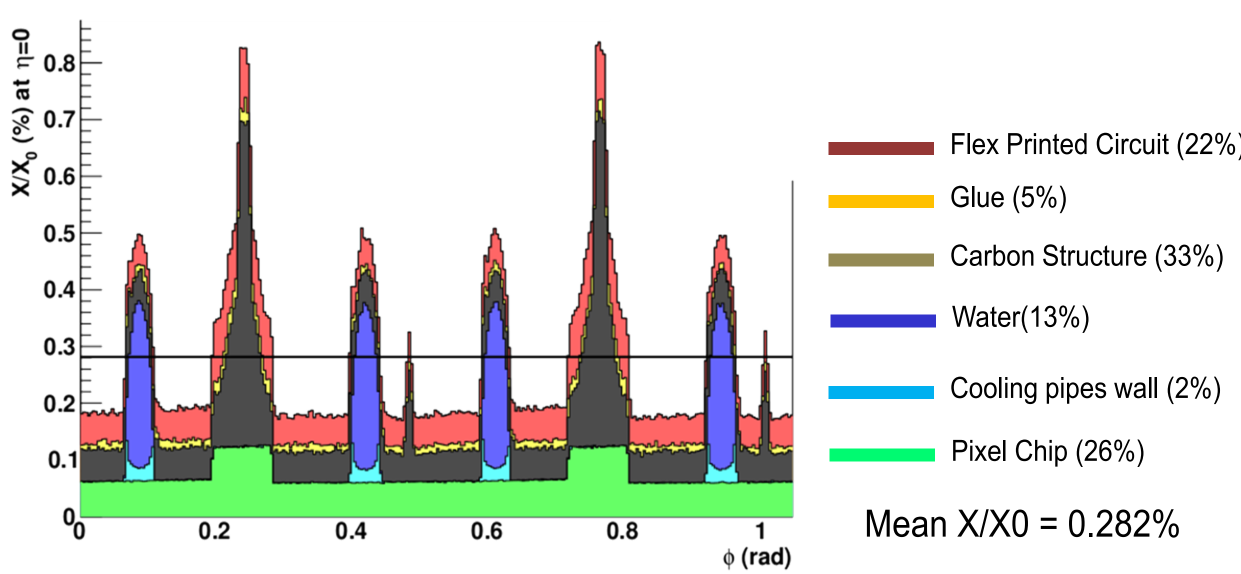
Detector modules



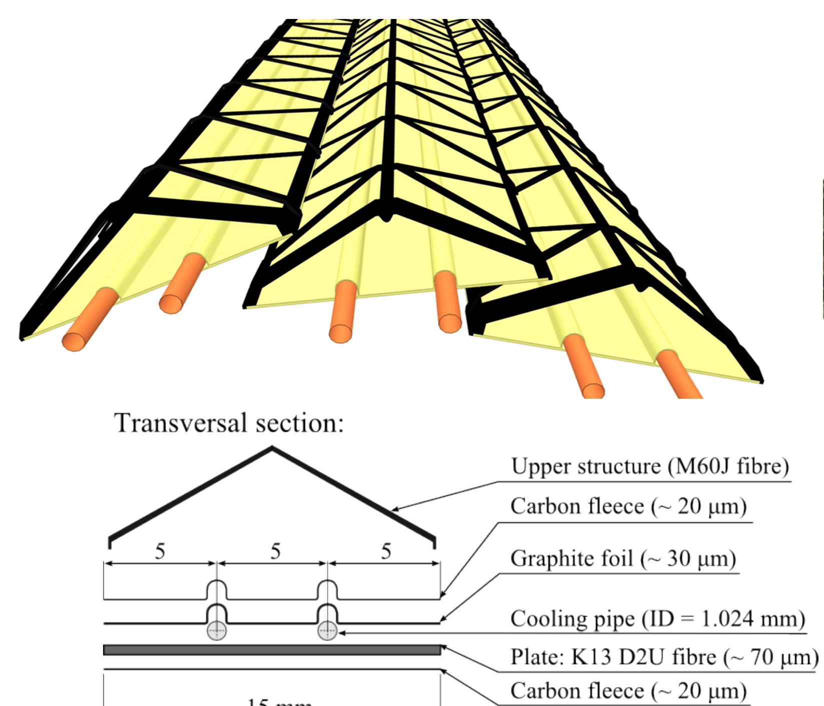
Detector module (stave) layout

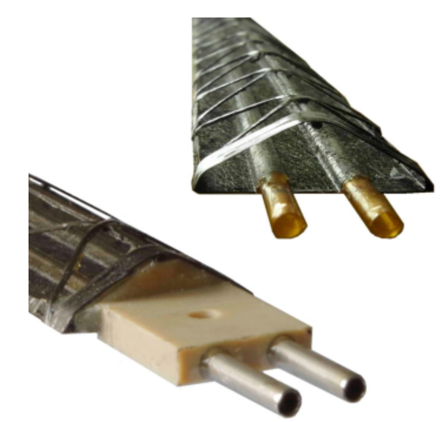


Material budget: ~ 0.3 % X_0 per layer



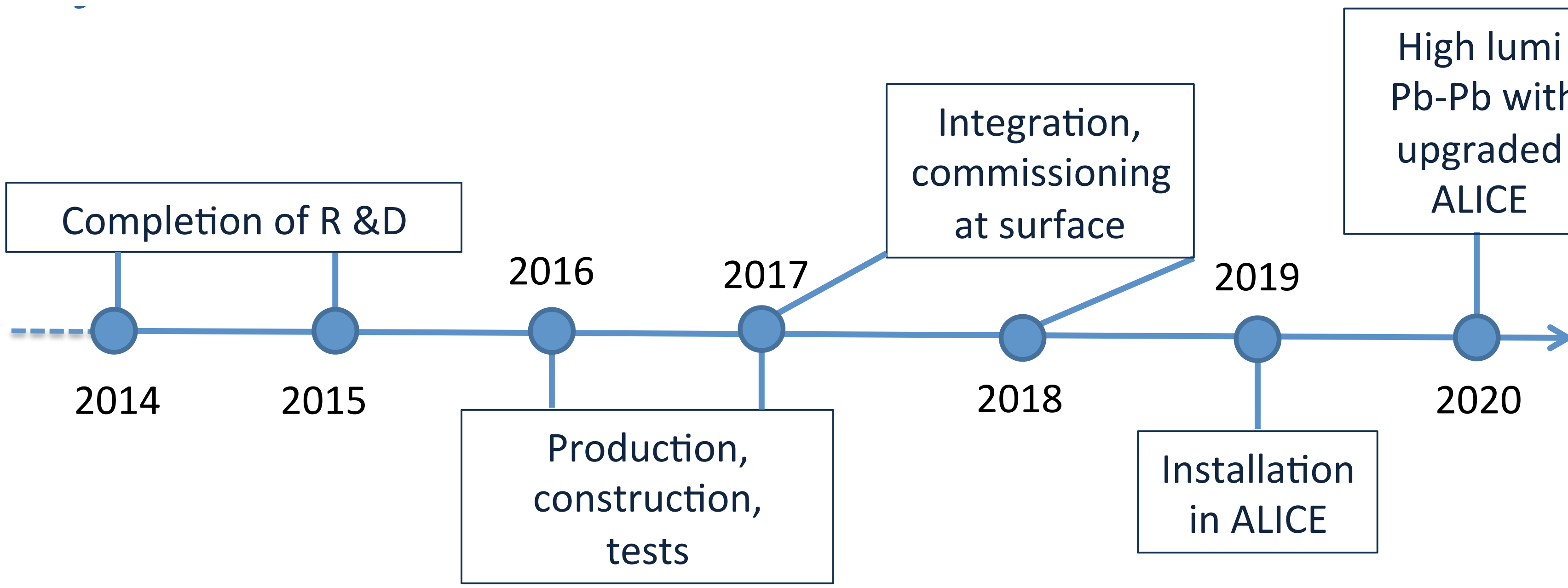
Inner Barrel Stave



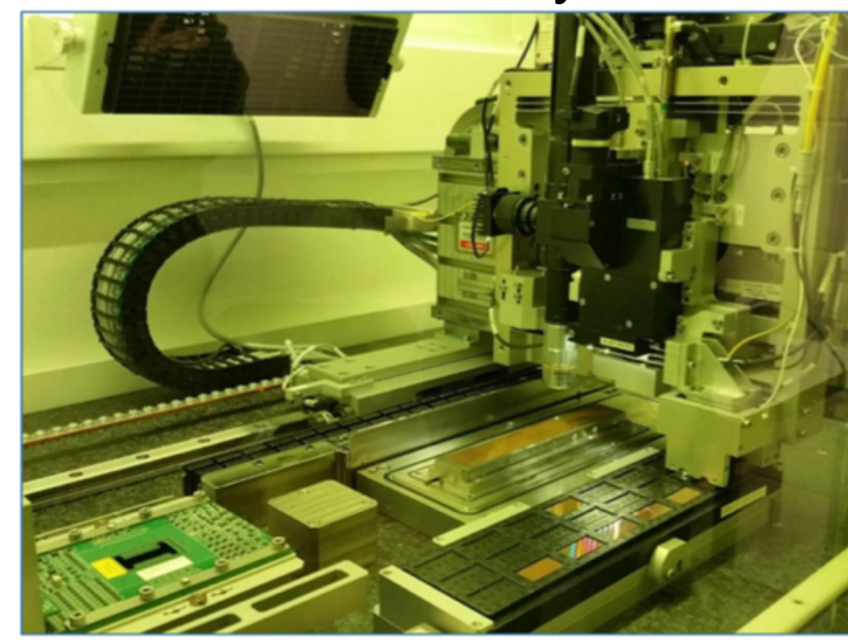


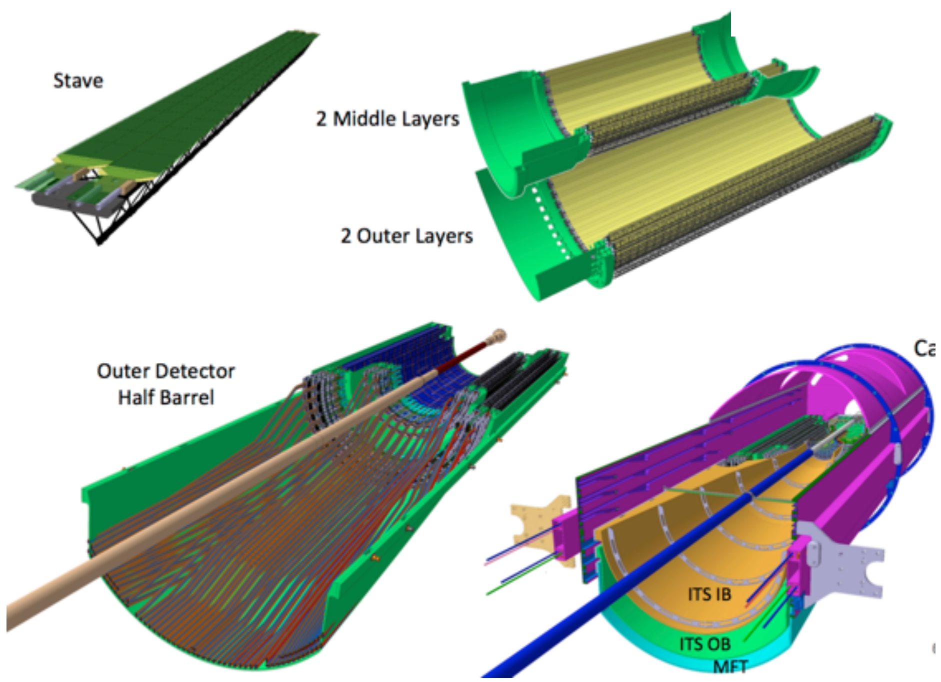
Total weight 1.5 gram

From plots & drawings to pictures



Module assembly machines

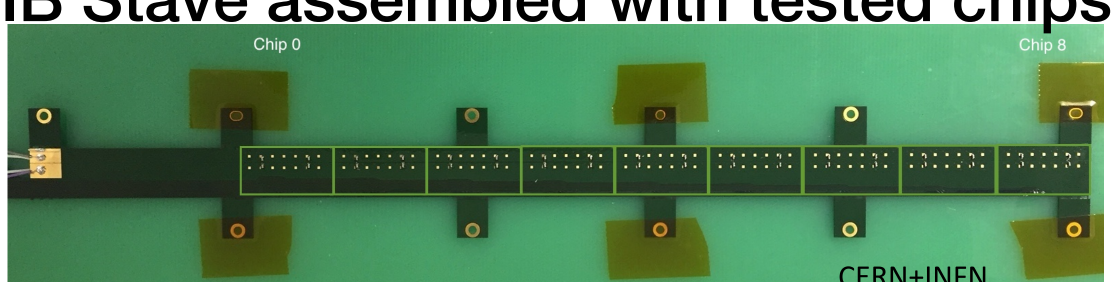




ITS IB staves

Production:
-n. 31 units produced

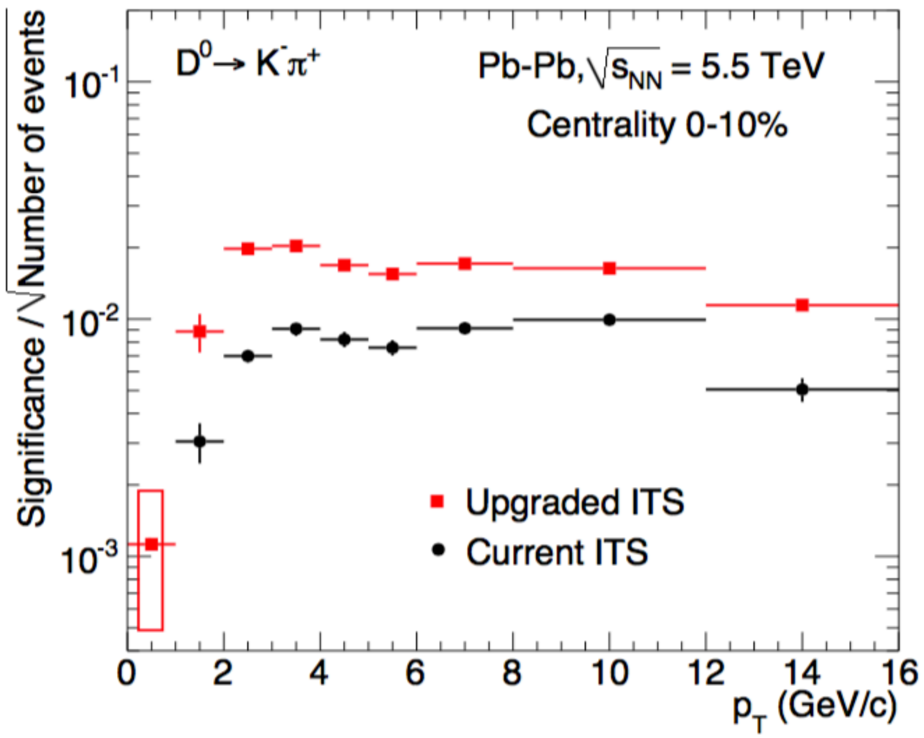
IB Stave assembled with tested chips

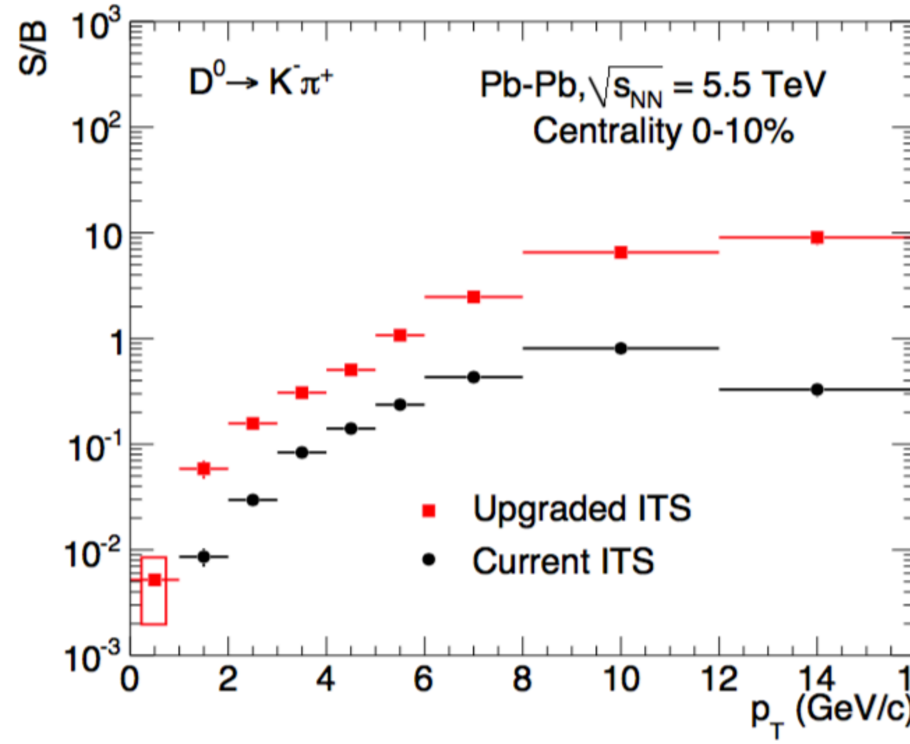


- Why Heavy-flavours in heavy-ion physics
- Overview of available ALICE measurements; where we are
- Heavy-ion program at LHC for Run2, Run3 and Run4
- ALICE upgrade strategy on heavy flavour sector
- Inner Tracking System upgrade design objectives
- **Expected performance**
- Summary

All results with L_{int}=10 nb^{-1}

D^0 as reference candle for charm



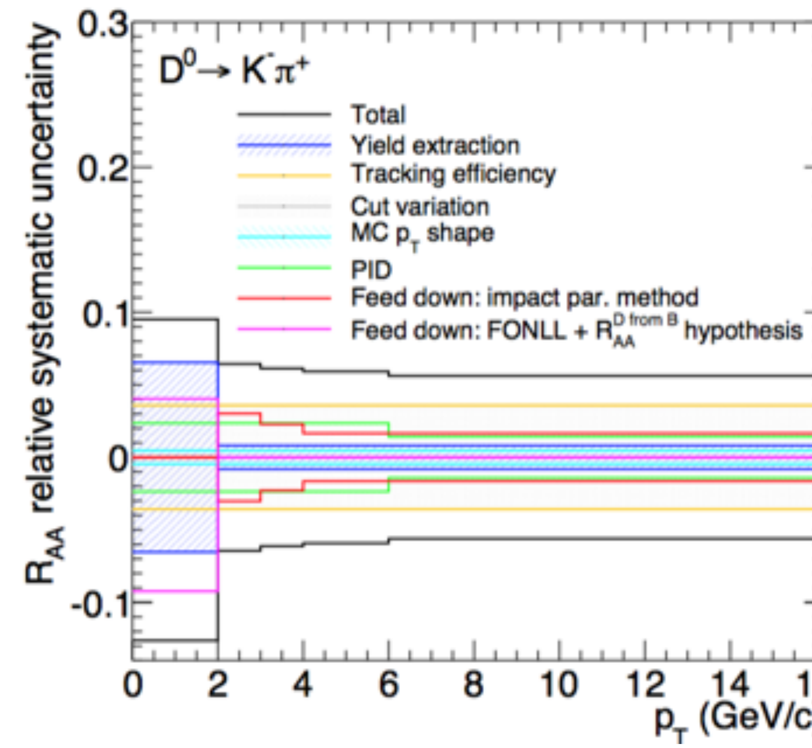


For L_{int}=10 nb^{-1} number of events 8×10^9

→ Significance 50 for p_T < 1GeV/c (and 1000 at high p_T)

- Background down by factor 5
- Systematics improvement due to easier signal extraction & "direct" feed-down correction

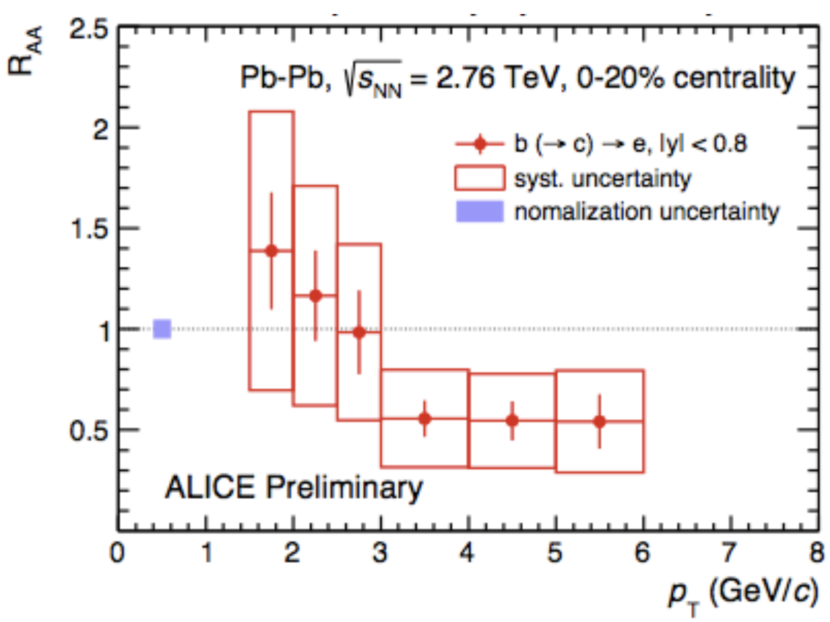
ALICE, CERN-LHCC-2013-024

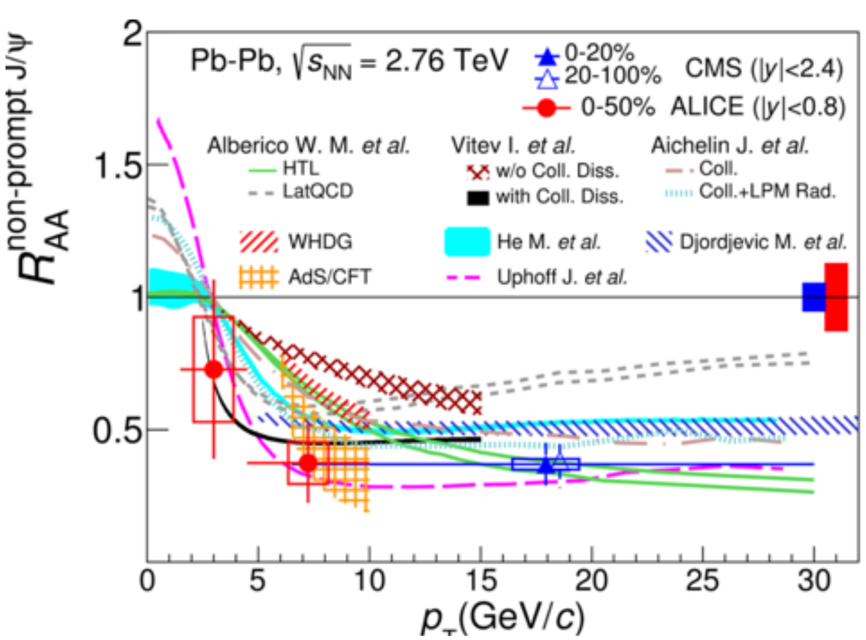


NOTE

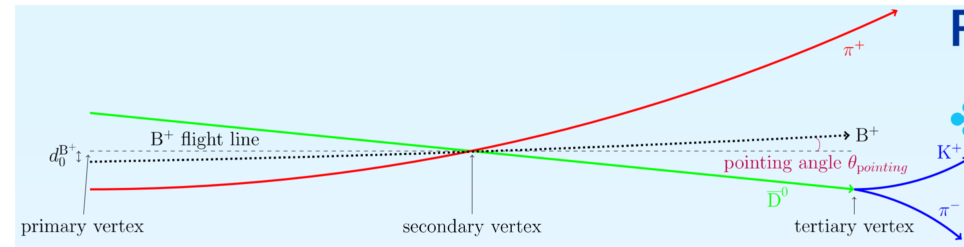
- Dominant charm uncertainties at low p_T:
  - Statistical → via larger readout rate
  - pp reference → via larger readout rate & a "short" pp run at Pb-Pb energy
  - Feed-down from B meson decays (now based on pQCD) → via measuring the prompt and non-prompt fractions

Low-p_T beauty



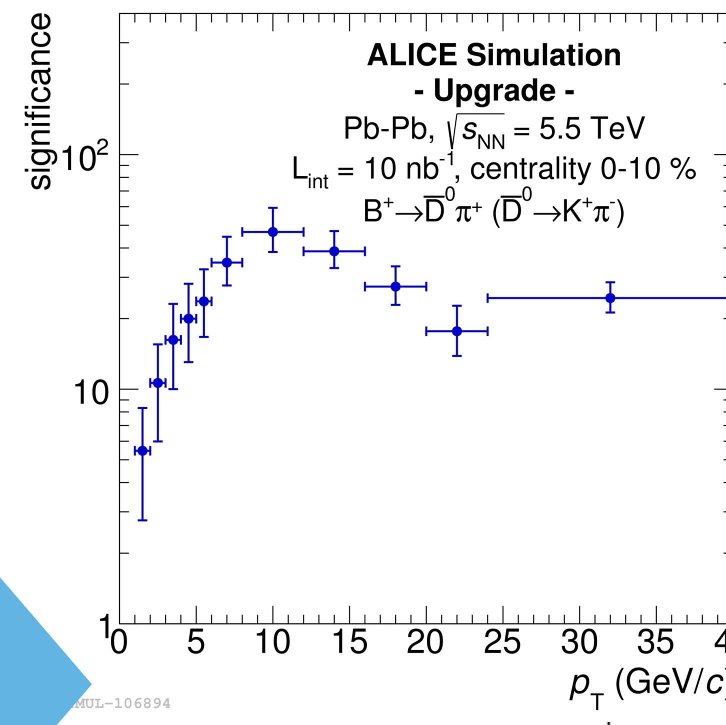


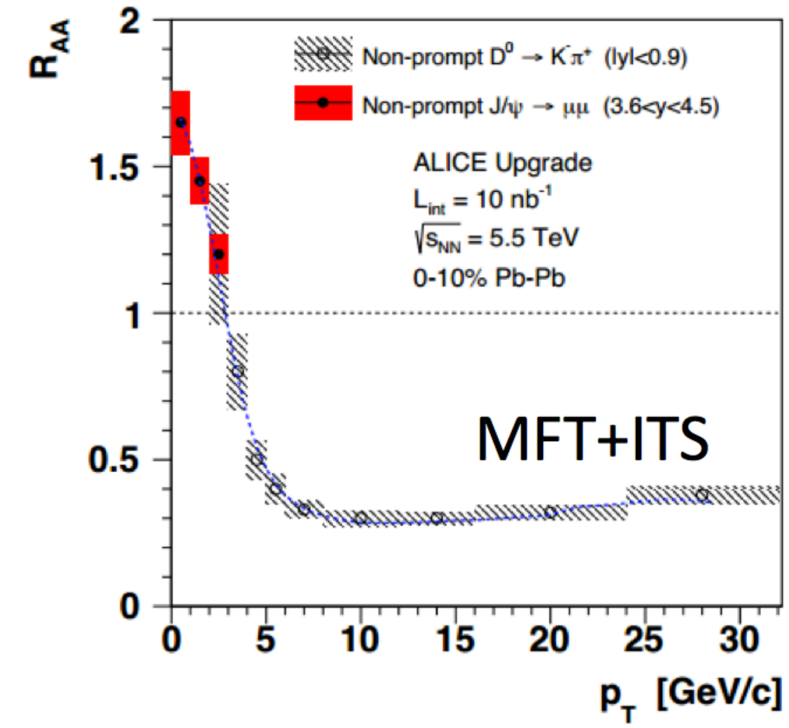
CMS-PAS-HIN-12-014

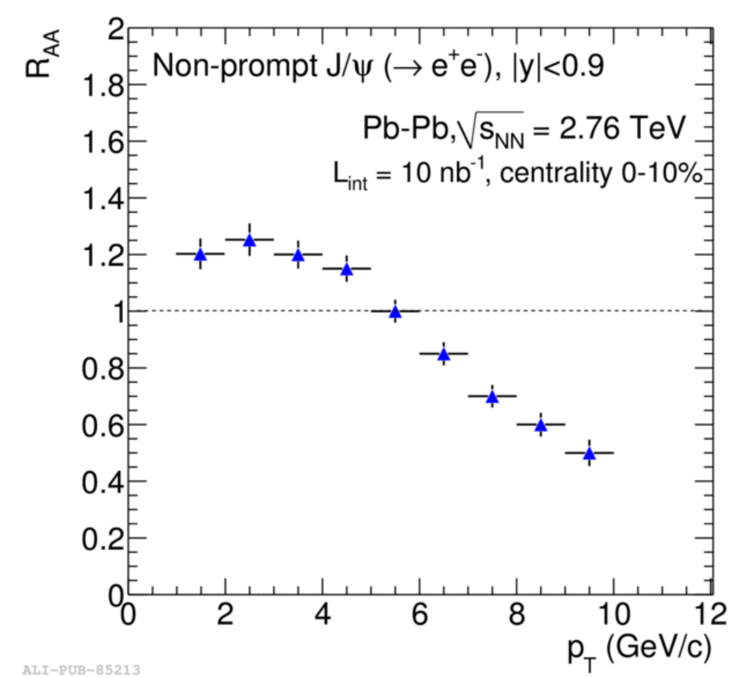


Rate limited probes!

- Combined branching ratio: (1.87 ± 0.06) · 10^{-4}







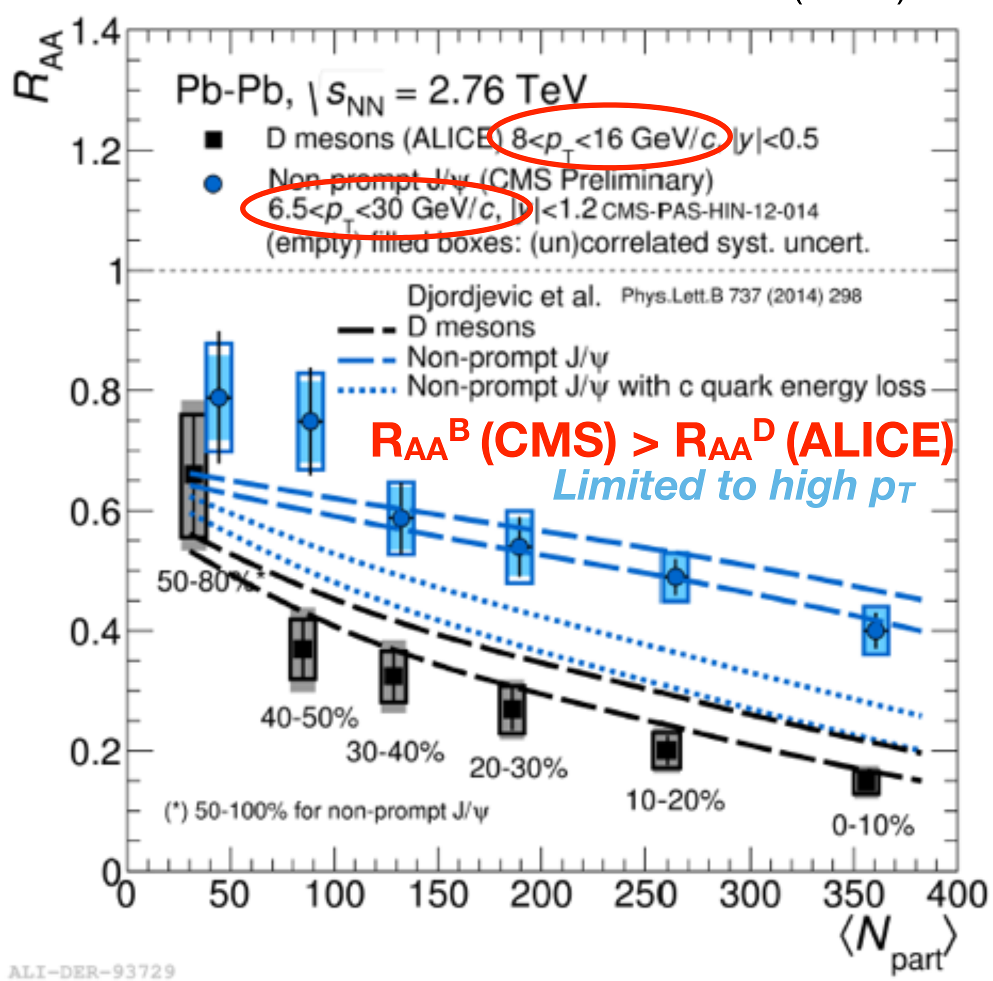
ALICE, CERN-LHCC-2013-024

- New channel opened (B) + much larger precision on R_{AA} (both via displaced J/ψ and non prompt D^0)
- The study of non prompt J/ψ in $\mu^+\mu^-$ channel key tool to measure B down to zero p_T

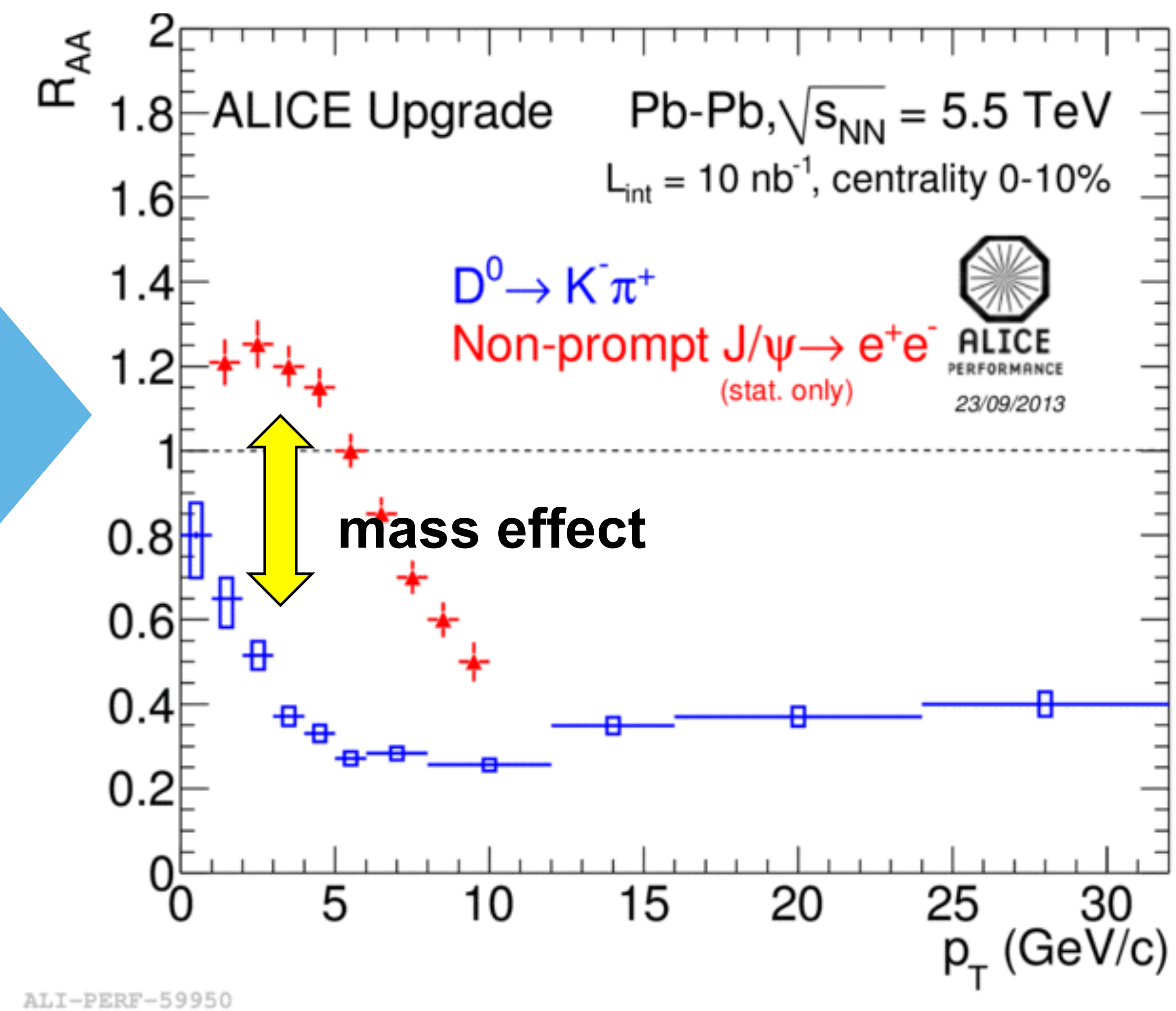
Beauty and charm energy loss

Present data at p_T ~ 10 GeV

JHEP 11 (2015) 205



Upgrade: Charm and beauty R_{AA} down to p_T ~ 0 using D^0 and B-decay J/ψ

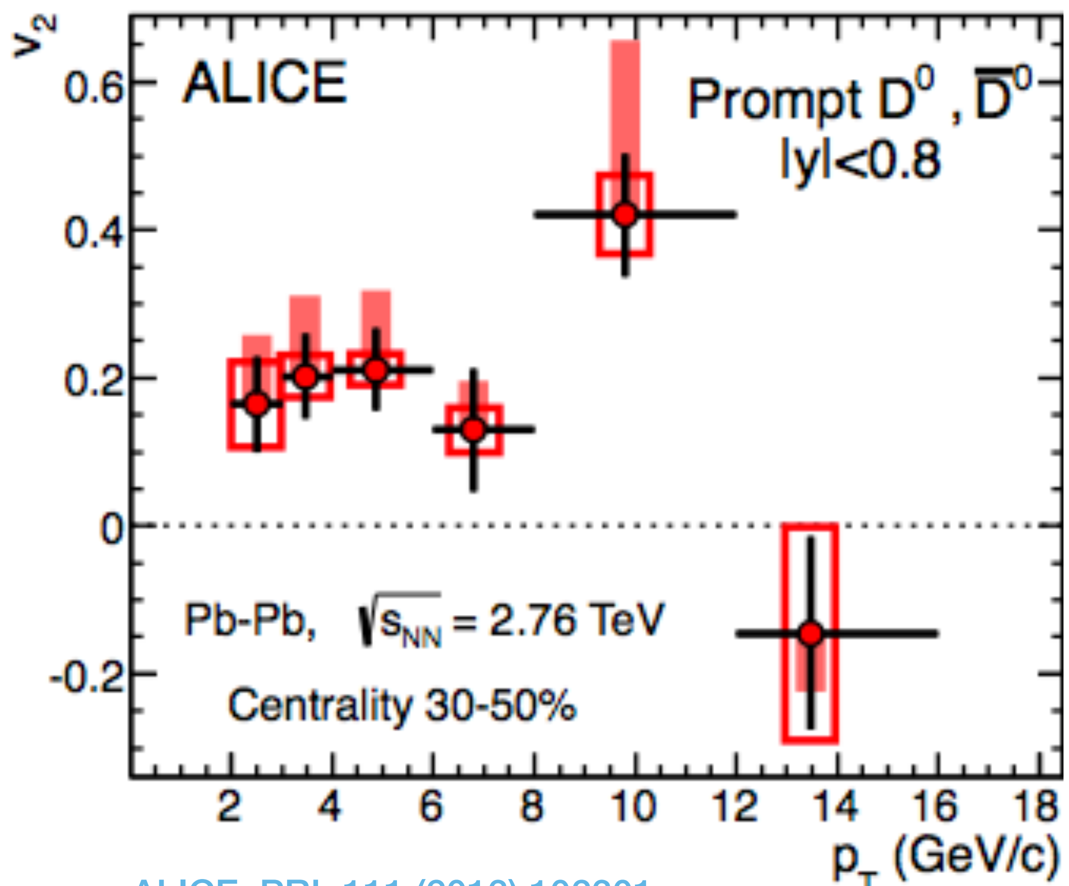


ALICE, CERN-LHCC-2013-024

Move from "first clear indication of $\Delta E_c > \Delta E_b$" to test quantitative description as a function of p_T

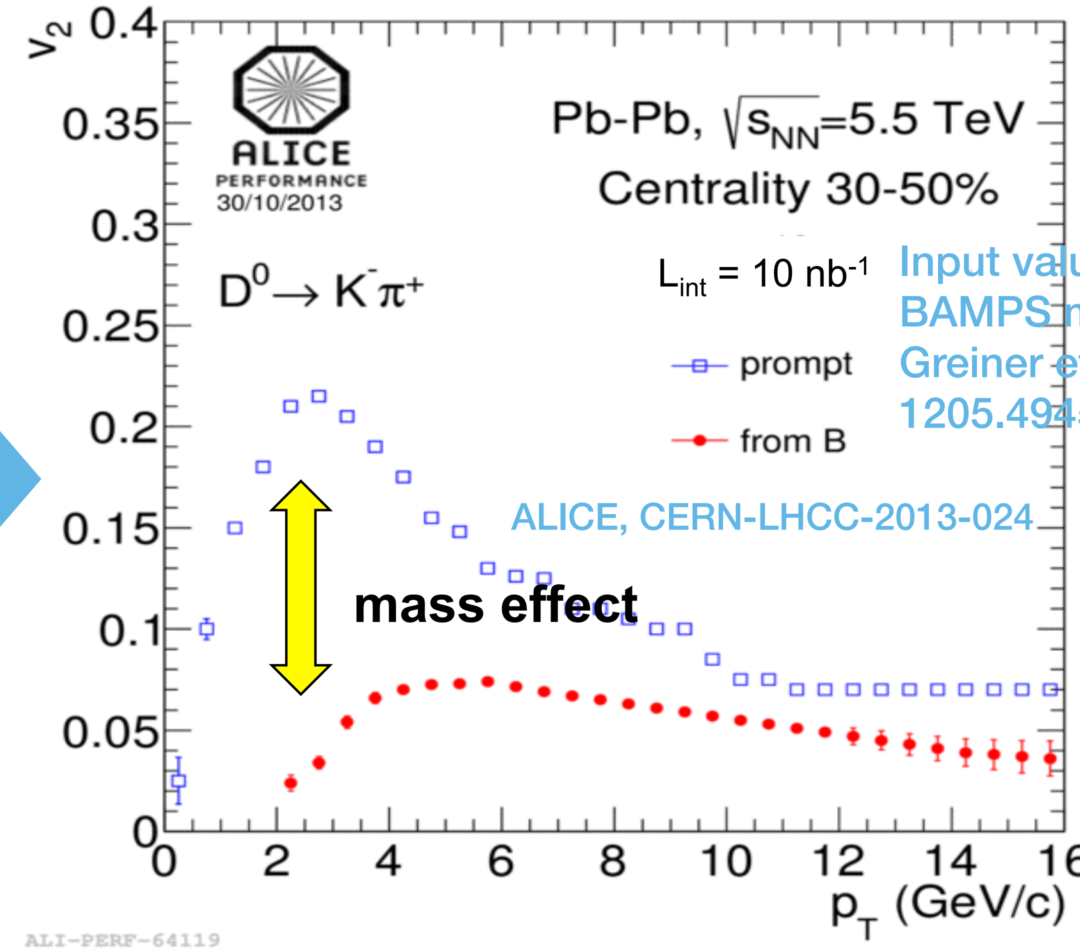
Heavy favour flow v_2

Present data: Charm v_2



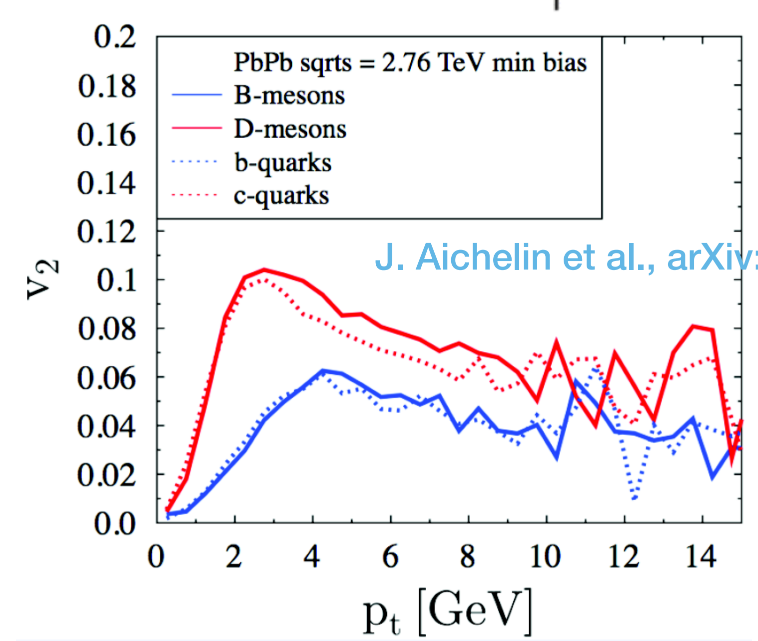
ALICE, PRL 111 (2013) 102301

Upgrade: Charm and beauty v_2 down to p_T ~ 0 using prompt and B-decay D^0



Input values from BAMPS model: C. Greiner et al. arXiv: 1205.4945

ALICE, CERN-LHCC-2013-024



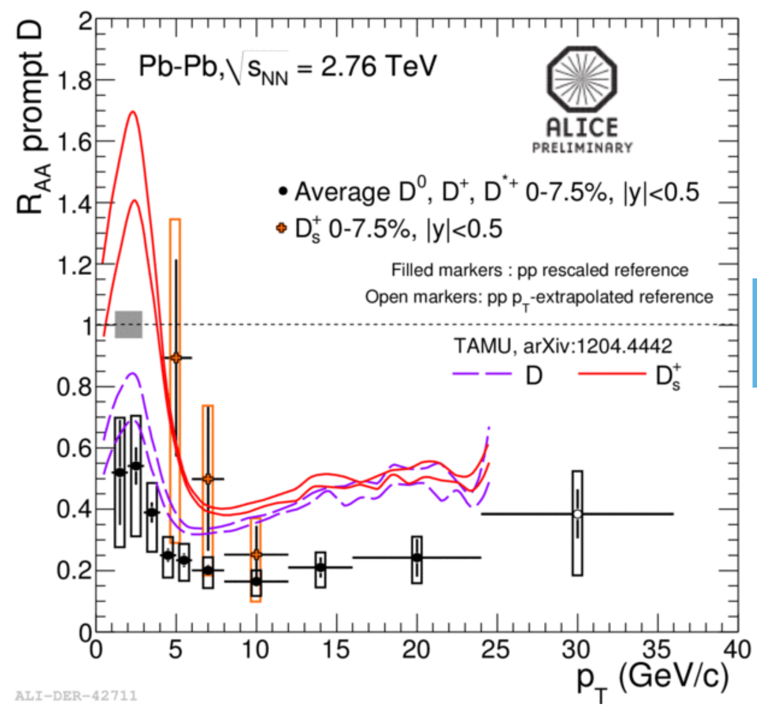
J. Aichelin et al., arXiv:1201.4192

- Larger uncertainties for charm and no measurement for beauty
- Models predict
  - Large v_2 for charm and significant mass effect in charm vs. beauty

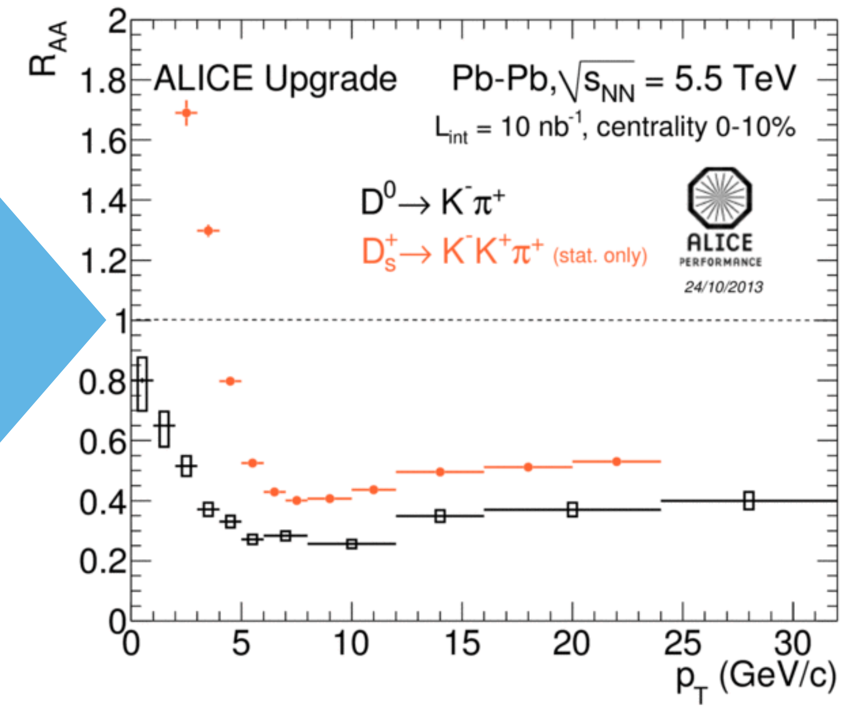
In-medium heavy flavour hadronization?

- From LHC Run 1 data, hints that charm could recombine in the QGP
  - J/ψ R_{AA} at low p_T
  - D_s R_{AA} larger than D R_{AA}?

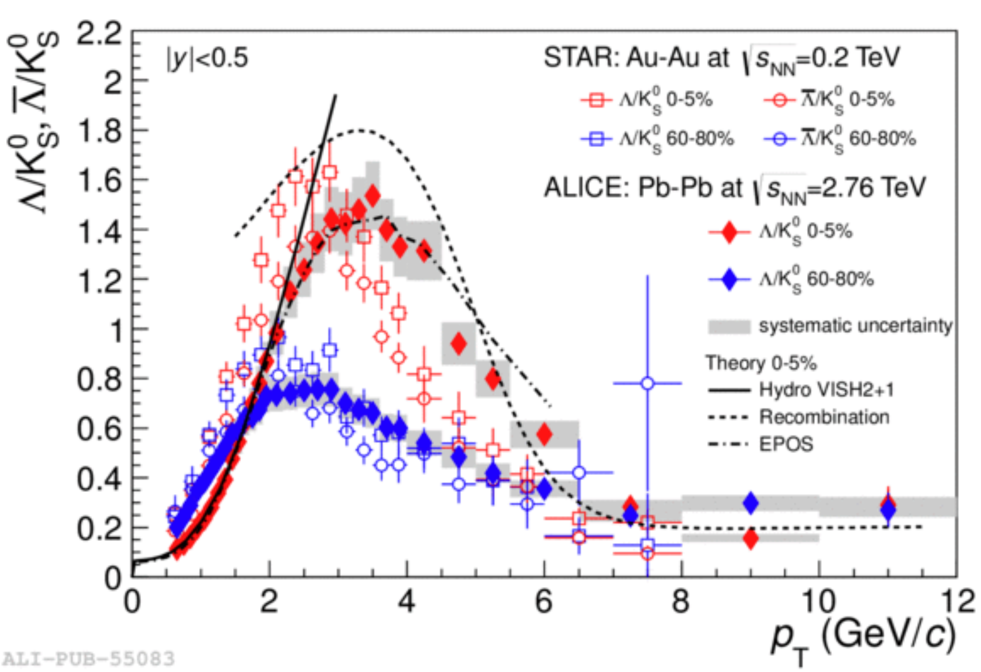
In QGP higher s abundance → D_s enhanced if charm hadronizes in the medium by recombination (Rafelski et al., Rapp et al.)



D⁰ and D_s R_{AA}

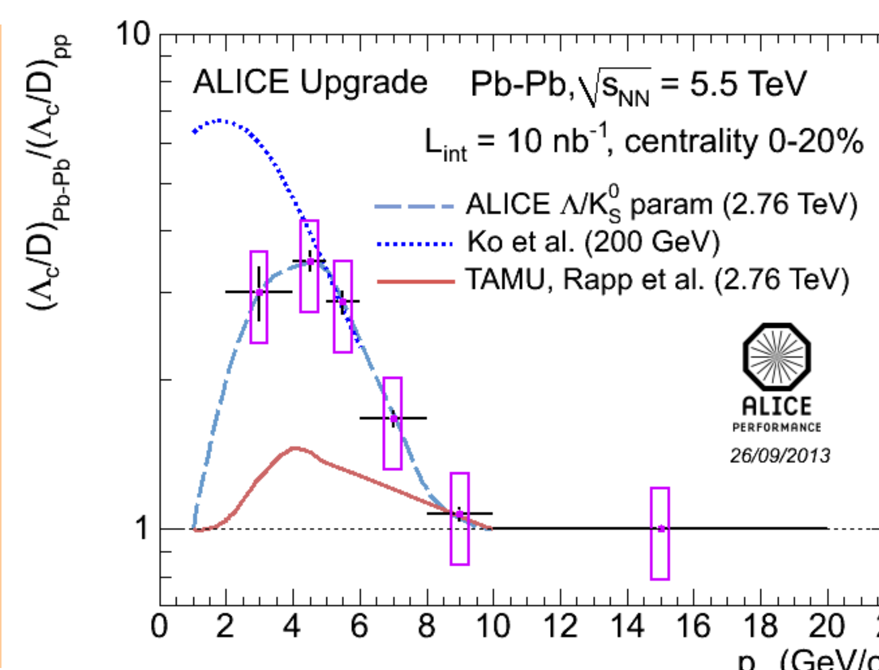


Λ_c/D "enhancement"



Λ/K described by hadronization via parton-recobination and radial flow.

Is baryon/meson enhanced at intermediate p_T also in the heavy flavor sector?



Λ_b also can be measured down to 4-7 GeV/c

Summary of physics reach on heavy flavour sectors

Observable	Current, $0.1\,\mathrm{nb}^{-1}$		Upgrade, $10\,\mathrm{nb}^{-1}$	
	$p_{\mathrm{T}}^{\mathrm{min}}$ (GeV/c)	statistical uncertainty	$p_{\mathrm{T}}^{\mathrm{min}}$ (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
$\mathrm{D_s}$ meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_{T}-int.)	1	5 %
B^{+} yield	not accessible		3	10 %
Λ_{c} R_{AA}	not accessible		2	15 %
$\Lambda_{\mathrm{c}}/\mathrm{D}^{0}$ ratio	not accessible		2	15 %
Λ_{b} yield	not accessible		7	20 %
D meson v_2 ($v_2 = 0.2$)	1	10 %	0	0.2 %
$\mathrm{D_s}$ meson v_2 ($v_2 = 0.2$)	not accessible		< 2	8 %
D from B v_2 ($v_2 = 0.05$)	not accessible		2	8 %
J/ψ from B v_2 ($v_2 = 0.05$)	not accessible		1	60 %
Λ_{c} v_2 ($v_2 = 0.15$)	not accessible		3	20 %

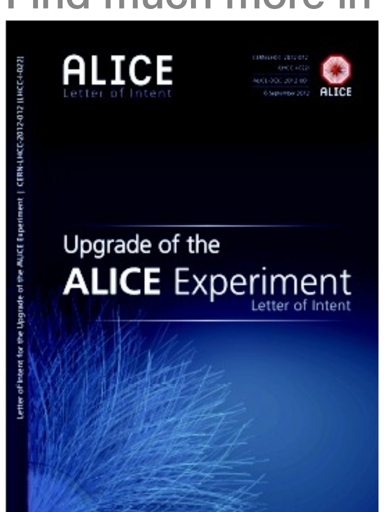
ALICE, CERN-LHCC-2013-024

Summary

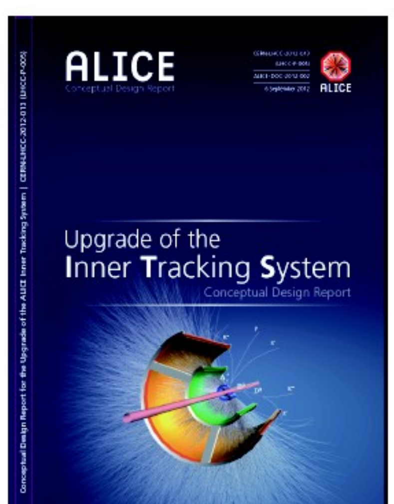
- New ITS detectors will be installed during the Long Shutdown 2 and will be ready for the Run3 of LHC foreseen from 2020
- The installation of the new silicon pixel detector, ITS, will significantly extend the ALICE physics reach in the HF sector:
  - Improved precision for existing measurements down to p_T=0
  - New and unique measurements in both charm and beauty sectors

> **We are approaching to precision era**
> **in the "heavy flavor sector"**
> **as we've done for the "light sector"**
> **and also for the "strange sector"**

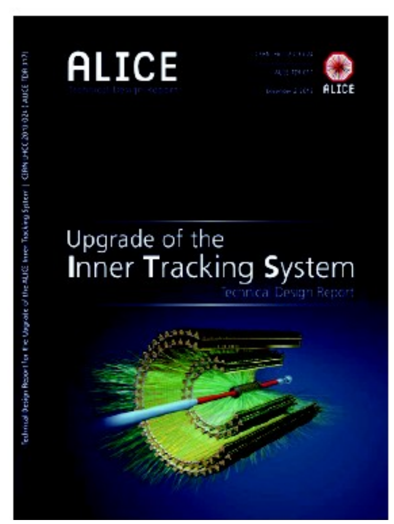
Find much more in



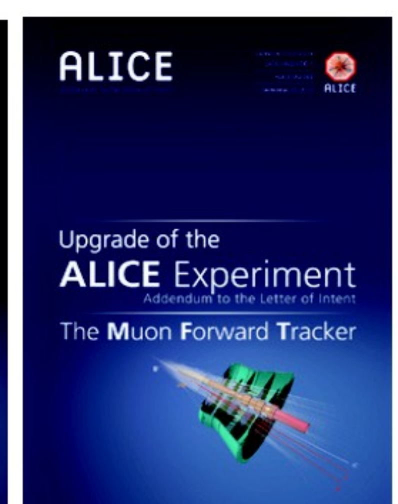
CERN-LHCC-2012-012
LHCC-I-022, 2012.



CERN-LHCC-2012-005
LHCC-G-159,2012.



CERN-LHCC-2013-024
ALICE-TDR-017



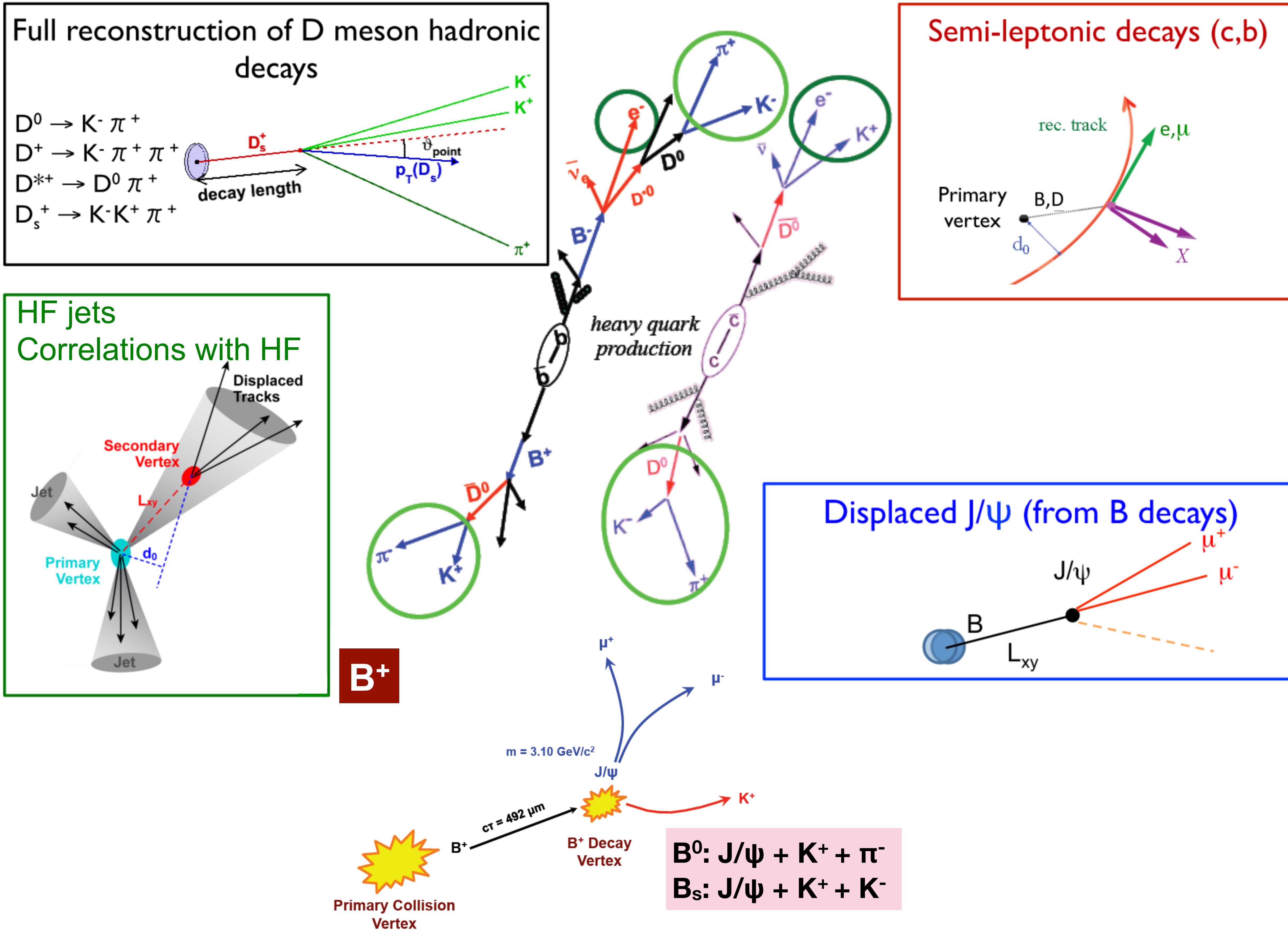
CERN-LHCC-2013-014
LHCC-I-022-ADD-1

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

Thank you for your attention!

Extra Slides

Heavy-flavour Observables: measure decay products



Summary of available measurements: AA

	PHENIX	STAR	ALICE	ATLAS	CMS
HF electrons	✓	✓	✓		
HF muons	✓		✓	✓	
D^0, D^+, D^{*+}		✓	✓		
D_s^+			✓		
$B \rightarrow J/\psi$					✓
B jets					✓
B electrons			✓		

Originally compiled by Z. Conesa dV and Andrea Dainese

For RHIC, different c.m.s energies and different collision species

Summary of available measurements: p(d)A

	PHENIX	STAR	ALICE	ATLAS	CMS	LHCb
HF electrons	✓		✓			
HF muons	✓		✓	✓		
D^0, D^+, D^{*+}		✓	✓			
D_s^+			✓			
$B \to J/\psi$						✓
B jets					✓	
B electrons			✓			
B					✓	

Originally compiled by Z. Conesa dV and Andrea Dainese

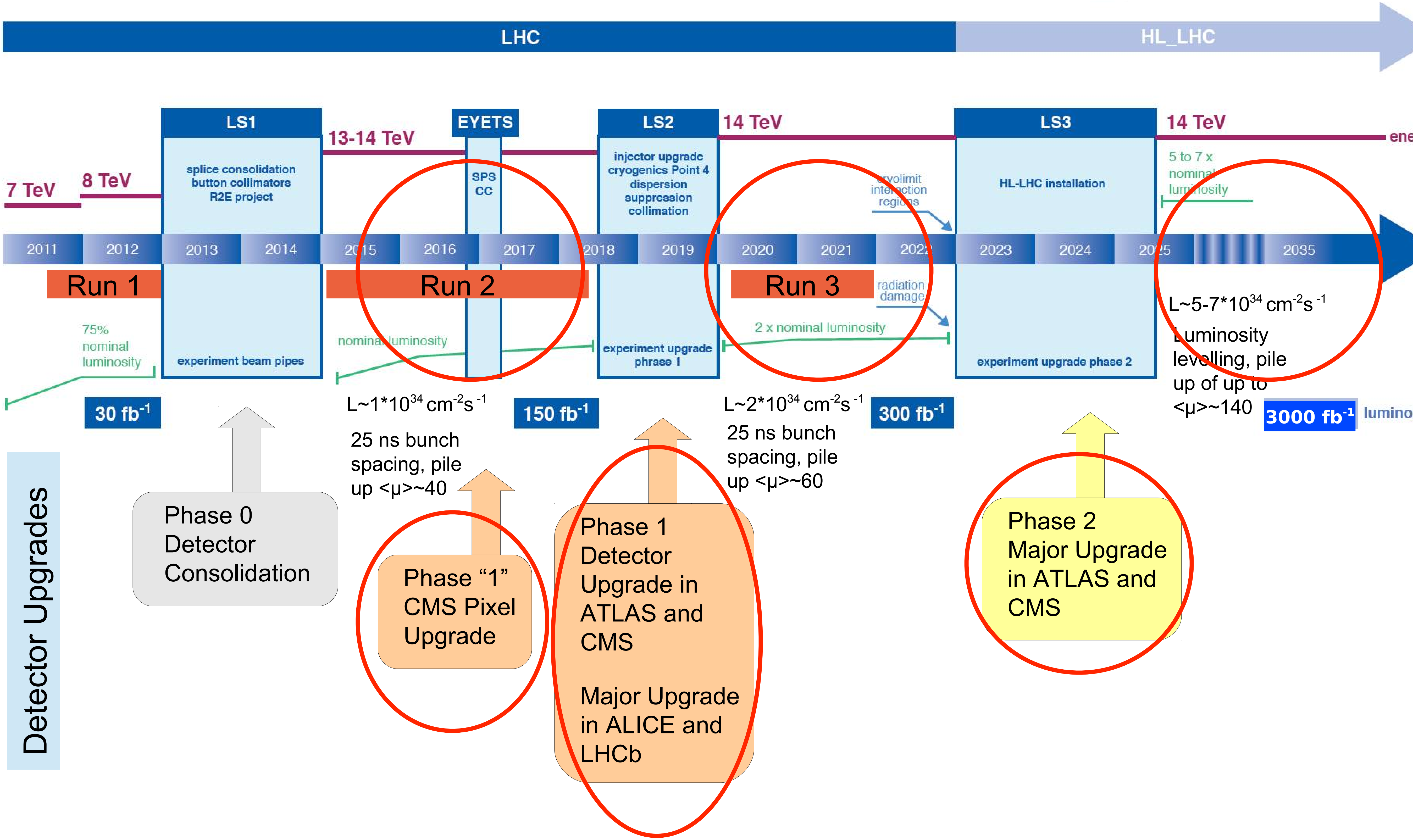
Heavy Ions at the LHC for Run1 (up to 2013)

year	system	$\sqrt{s_{NN}}$ (TeV)	L_{int}
2010	**Pb-Pb**	**2.76**	**~ 10 μb^{-1}**
2011	pp	2.76	~ 250 nb^{-1}
2011	**Pb-Pb**	**2.76**	**~ 150 μb^{-1}**
2013	**p-Pb**	**5.02**	**~ 30 nb^{-1}**
2013	pp	2.76	~ 5 pb^{-1}

Table by Andrea Dainese

- **2011 Pb-Pb run: 5×10^{26} $cm^{-2}s^{-1}$! already above nominal luminosity**
- **First, very successful, p-Pb run (with all four large experiments)**
- **Two short pp reference runs at $\sqrt{s}$ of Pb-Pb**

From LHC to HL-LHC



8th Annual Meeting of the Helmholtz,
Feb. 2014, Susanne Kuehn

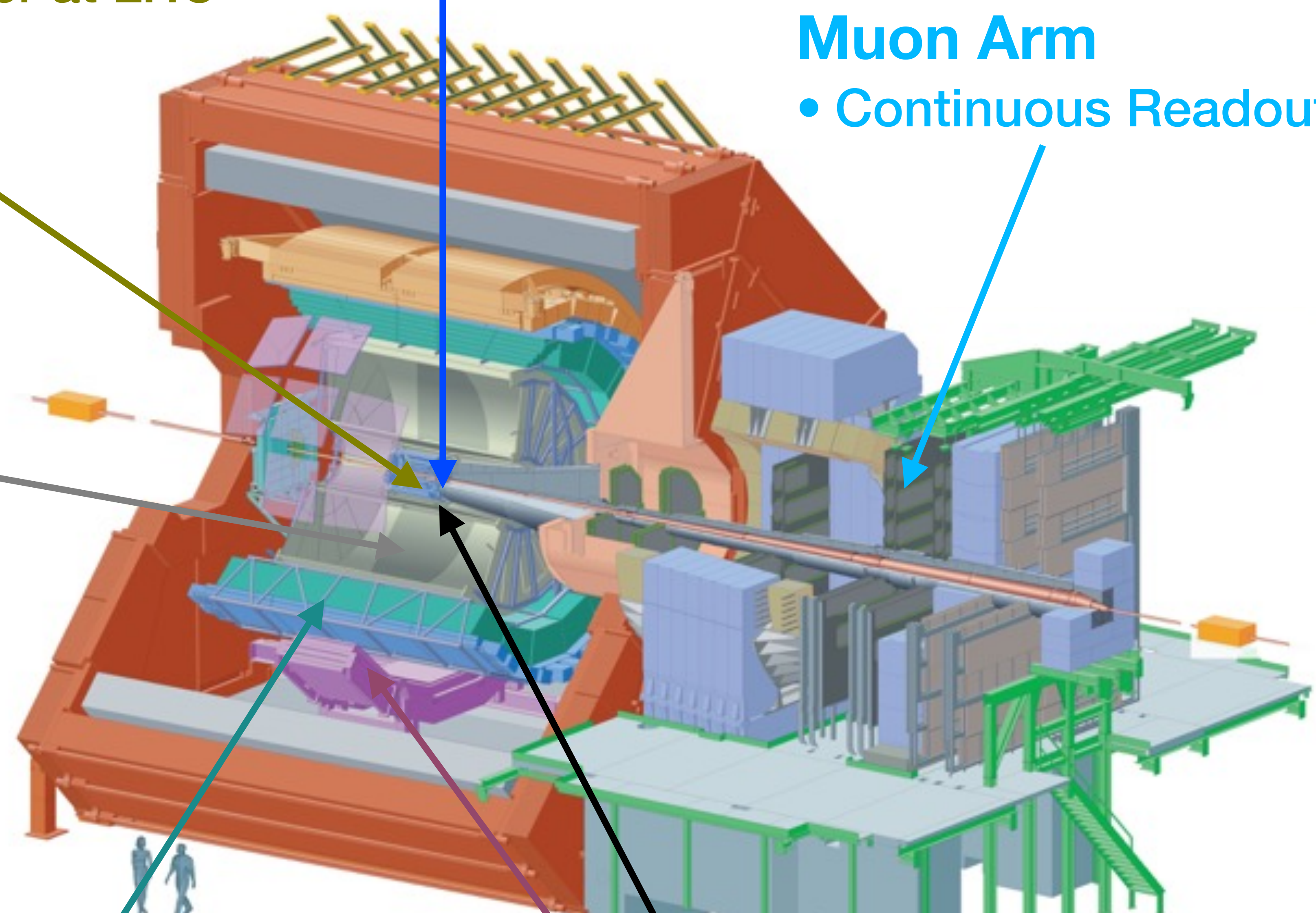
ALICE Upgrade for Run3 & Run4

New Inner Tracking System
- New pixel technology
- Less material → thinnest tracker at LHC

Muon Forward Tracker (MFT)
- New Silicon Tracker
- Improved Muon pointing resolution

Muon Arm
- Continuous Readout

Time Projection Chamber
- New GEM technology for readout chambers
- Continuous readout
- Faster readout electronics



Data Acquisition, High Level Trigger
- New architecture
- On-line tracking & data compression
- 50 kHz Pb-Pb event rate

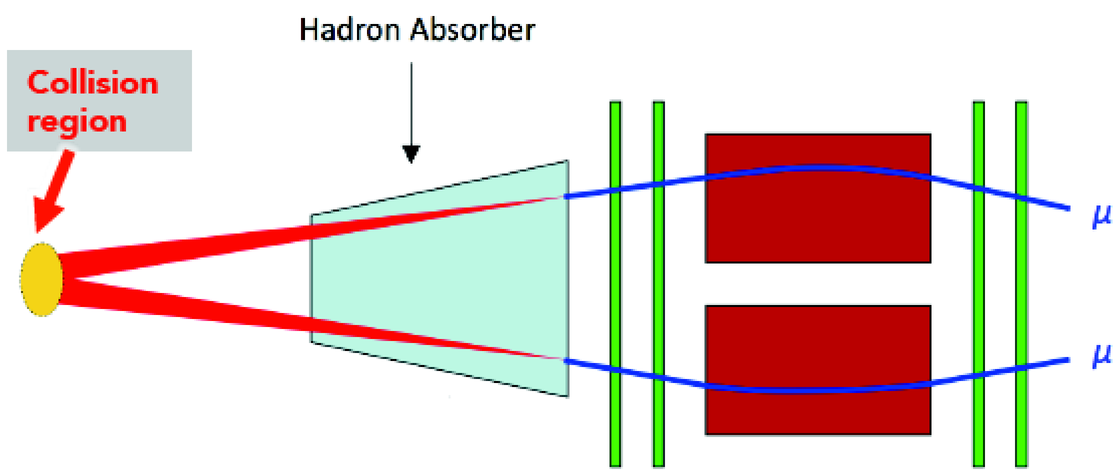
NewTriggerDetectors (FIT)

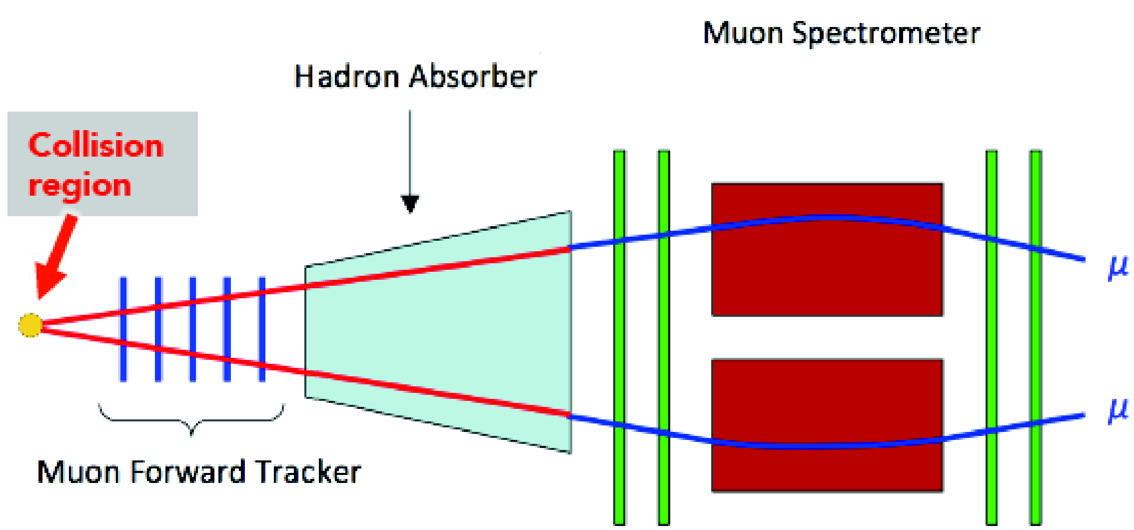
Time-Of-Flight Detector, Transition Radiation Detector
- Faster Readout

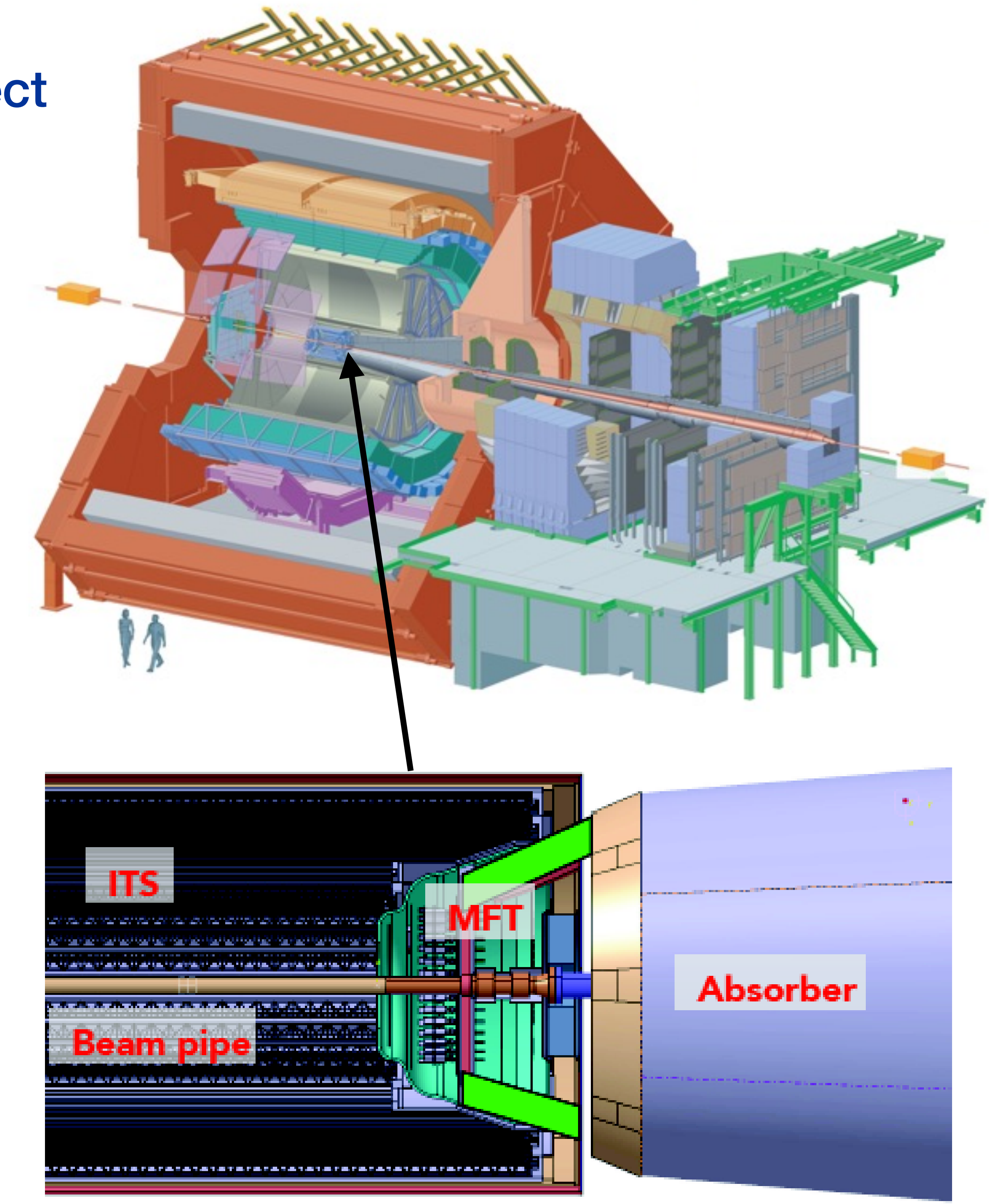
Calorimeters, HMPID
- Readout

ALICE Upgrade: Muon Forward Tracker

- 5 planes of silicon telescope
- Pixel chip: same as ITS upgrade project
- Track density
- Optimized for low-material thickness
  - 0.6% X_0 per detection plane



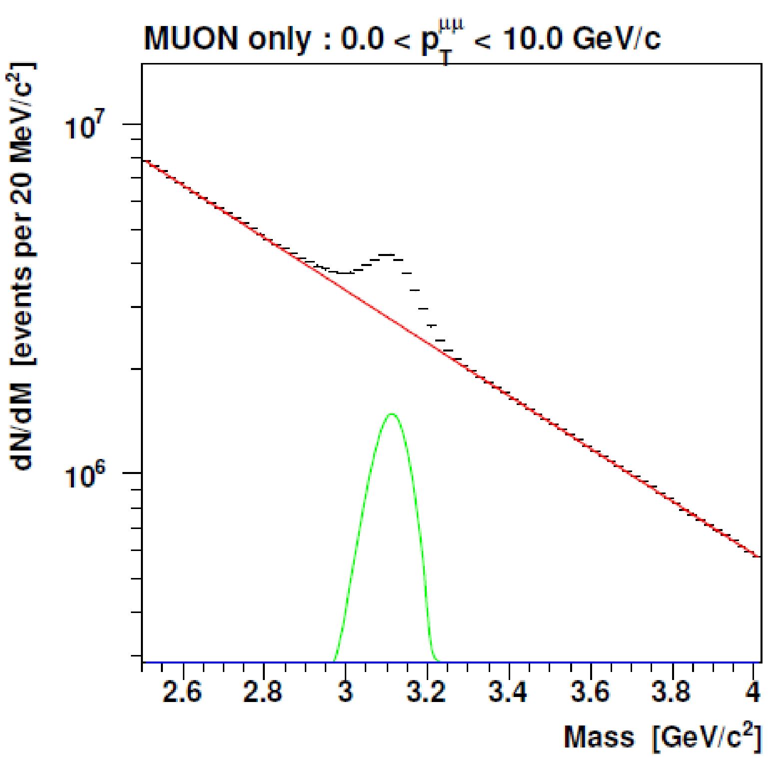


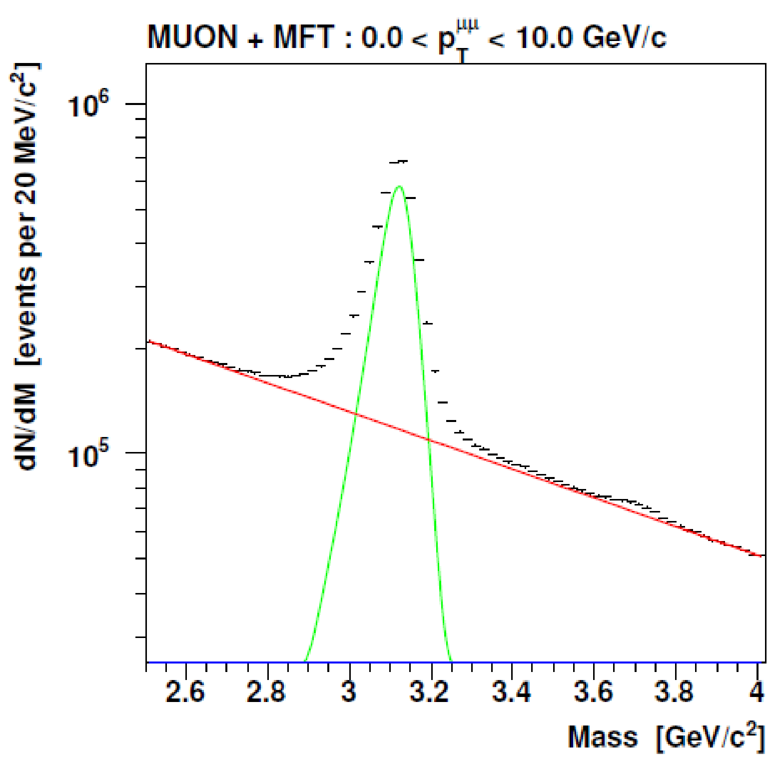


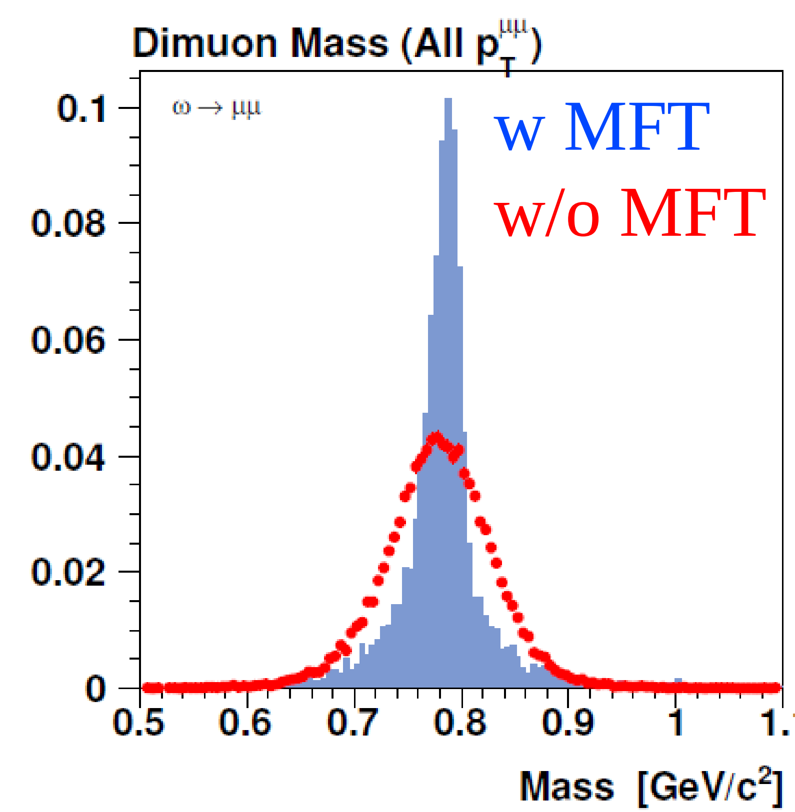
$2.5<\eta<3.6$

ALICE Upgrade: Muon Forward Tracker

- Separate prompt J/ψ and J/ψ from B decays
- Improve ψ(2s) detection (S/B ↗: systematics *1/3)
- Expected improvements also in Y mass region
- c/b separation down to p_T ~1 GeV/c (c,b without separation down to p_T > 2 GeV/c with current system)
- Low mass vector mesons accessible for p_T > 1-2 GeV/c







Heavy-flavour Program at LHC

- Complementary capabilities:
  - High p_T, high rate, jets: CMS & ATLAS
  - Low p_T coverage, low material budget, excellent PID: ALICE
  - LHCb providing excellent results in pp & p-Pb

- Heavy Flavour: a central topic for upgrades of all Heavy-Ion experiments. Characterization of mass dependence of energy loss, HQ in-medium thermalization and hadronization, as a probe of the medium transport properties
  - Low-p_T production and elliptic flow of several HF hadron species (focus of **ALICE**)
    - ➡ More statistics and precision at LHC energy → constrain energy loss (collisional vs. radiative) and hadronization (coalescence vs fragmentation) mechanisms
  - B and b-jets (focus of **ATLAS** and **CMS**)
    - ➡ Mass dependence of high p_T parton energy loss

Run2 Goal at LHC

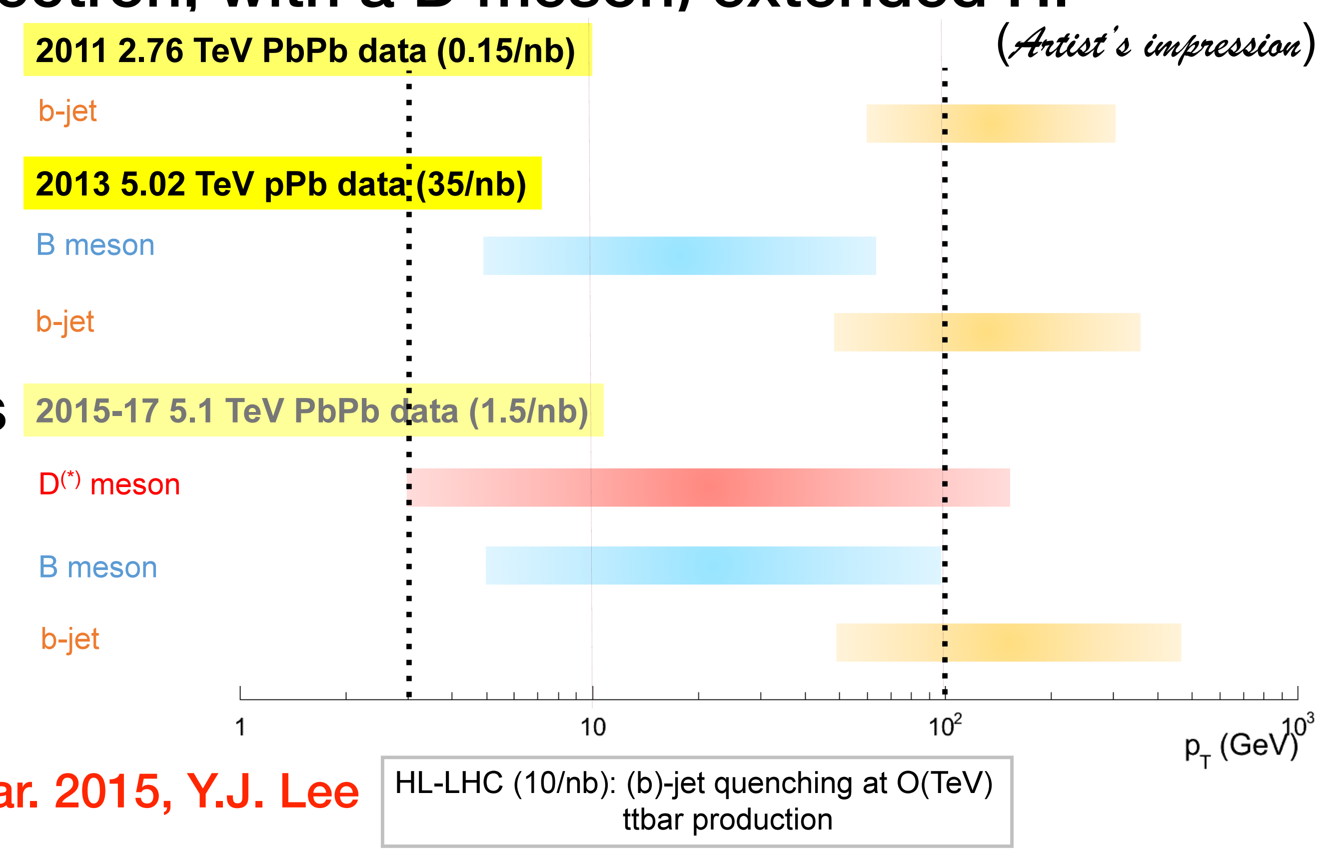
ALICE

- Measure heavy-flavour production cross sections, R_{AA}, v_2, I_{AA} at higher energy with improved precision and extended p_T reach (both at low & high p_T)
  - Many observables limited by statistics in Run-I
  - Some uncertainties can be reduced with larger statistics

- New observables:
  - v_2 of beauty-decay electrons, and HF v_3?
  - Other heavy-flavour hadrons (baryons?)
  - Beauty via 3-muon events
  - Heavy-flavour jets (b-tagged, with an electron, with a D meson) extended HF correlations (HFe-jet, HF-HF)

CMS

- Extended p_T reach
  - Extended p_T reach for b-jet & B mesons
- New observables:
  - b-jet p_T asymmetry
  - D meson and charm jet cross section



ECT, Mar. 2015, Y.J. Lee

Run3 & Run4 Focus on ALICE

- Main observables:
  - Low-p_T heavy flavour
  - Low-p_T charmonia
  - (Very) low-p_T and low-mass di-leptons
- Exploit detector specificities (strengthened with the upgrades):
  - Hadron and lepton ID
  - Light-weight and precise tracker
  - Low magnetic field
- Mostly "untriggerable" because of extremely low S/B

➡ Trigger approach: write all events at up to 50 kHz in Pb-Pb (currently 0.5 kHz)
~1 TB/s HLT/DAQ ~10 GB/s

➡ HL-LHC: increase of minimum-bias sample x100 wrt Run 2

Compiled by Andrea Dainese

Run3 & Run4 Focus on CMS & ATLAS

- Main observables:
  - Differential studies of jets at very high-p_T
  - b-jets
  - Multi-differential studies of Υ states

- Exploit detector specificities (strengthened with the upgrades):
  - muon ID
  - Precise tracker
  - Calorimetry

- Mostly based on muon, jet, displaced track triggers

➡ Trigger/DAQ approach: strong data reduction
(currently 0.5 kHz)
50 kHz, L1: ~ few kHz, HLT: ~ 100 Hz

➡ HL-LHC: increase of sample x10 wrt Run 2

Compiled by Andrea Dainese

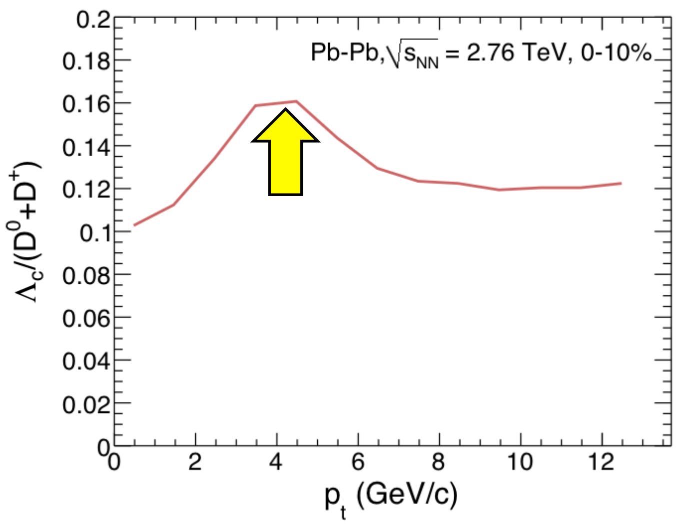
ATLAS, CMS, LHCb: Upgrades most relevant to HI

- **ATLAS**
  - Additional pixel layer (LS1), then new tracker (LS3): tracking and b-tag
  - Fast tracking trigger (LS2): high-multiplicity tracking
  - Calorimeter and muon upgrades (LS2): electron, γ, muon triggers
- **CMS**
  - Upgrade of trigger and DAQ, L1 calorimeter trigger (LS1): enables L1 rejection at 95%, e.g. (after LS2) from 50 kHz to <3 kHz (HLT input)
  - New pixel tracker (YES15-16), then new tracker (LS3): tracking and b- tag
  - Extension of forward muon system (LS2): muon acceptance
  - Upgrade forward calorimeter (LS3): forward jets in HI
- **LHCb (LS2)**
  - New trackers (pixel, strip, scintillating fiber)
  - Readout upgrade: up 40 MHz in pp → exploit full p-Pb luminosity

In-medium Heavy Flavour Hadronization?

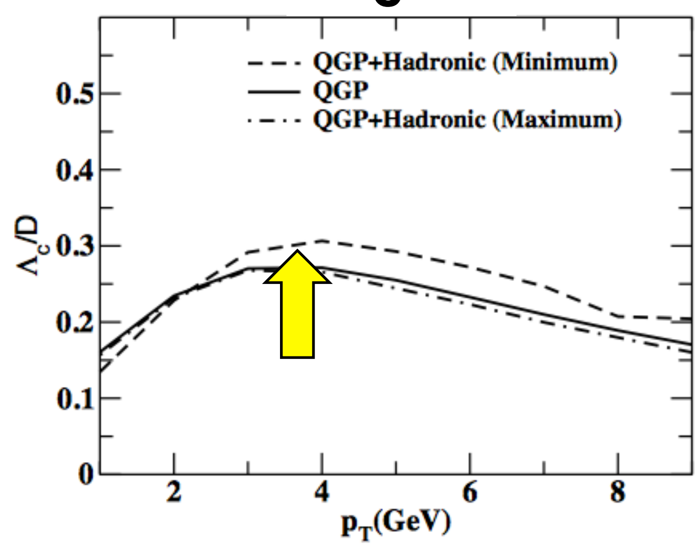
- From LHC Run 1 data, hints that charm could recombine in the QGP
  - Precise measurements of HF mesons (non-strange and strange) and baryons
  - Precise measurements of their v_2

Λ_c/D



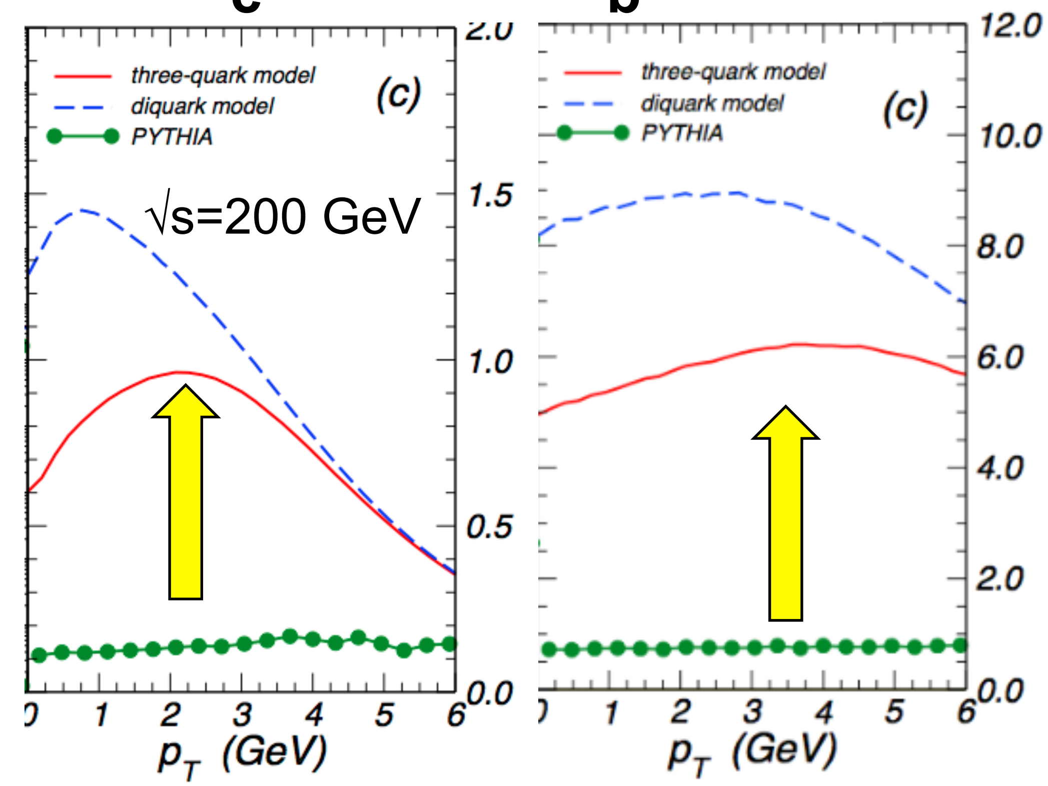
Rapp et al., based on PRL110 (2013)

Λ_c/D



Greco et al. PRD90 (2014)

Λ_c/D and Λ_b/B



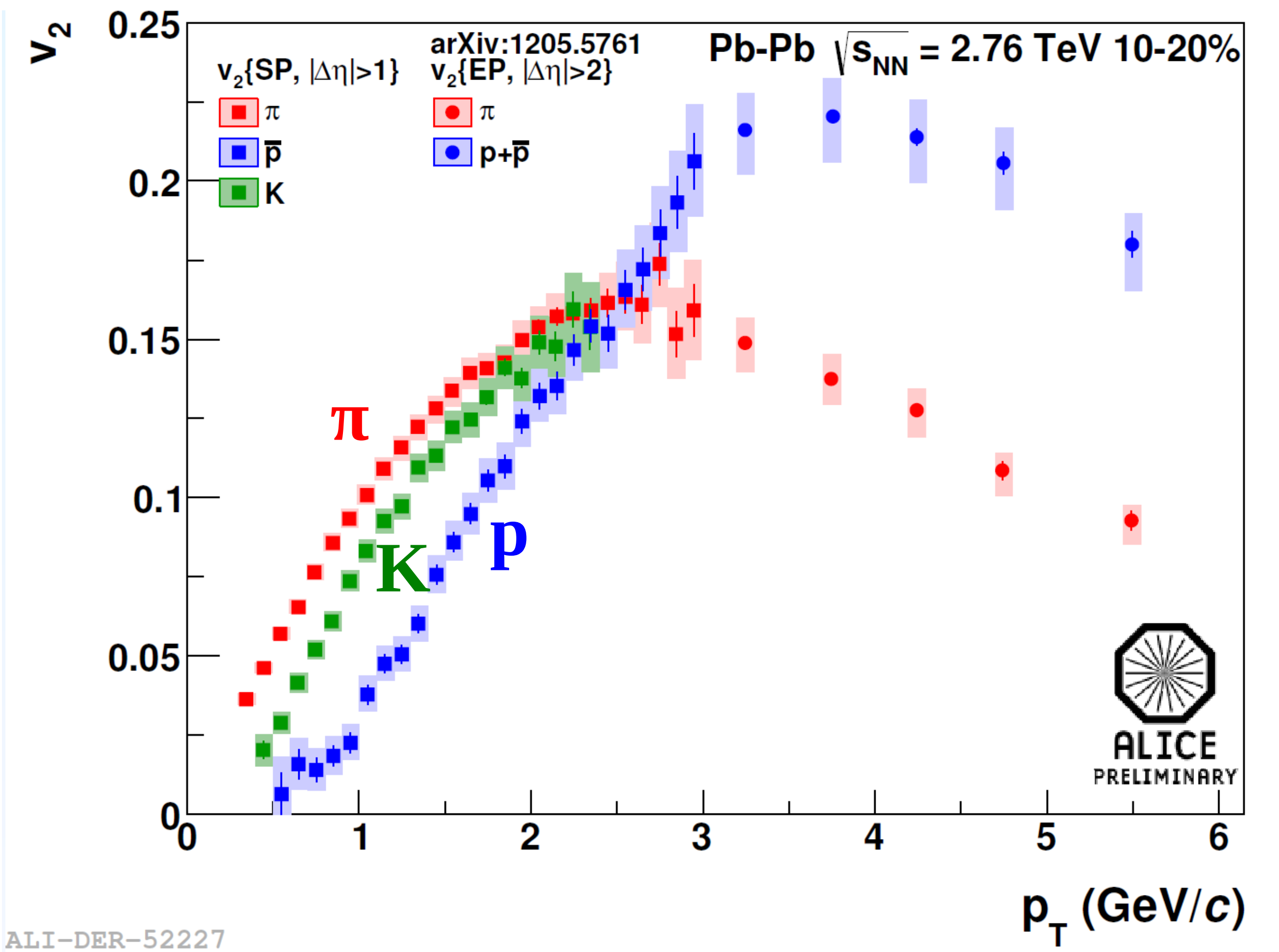
Ko et al. PRC79 (2008)

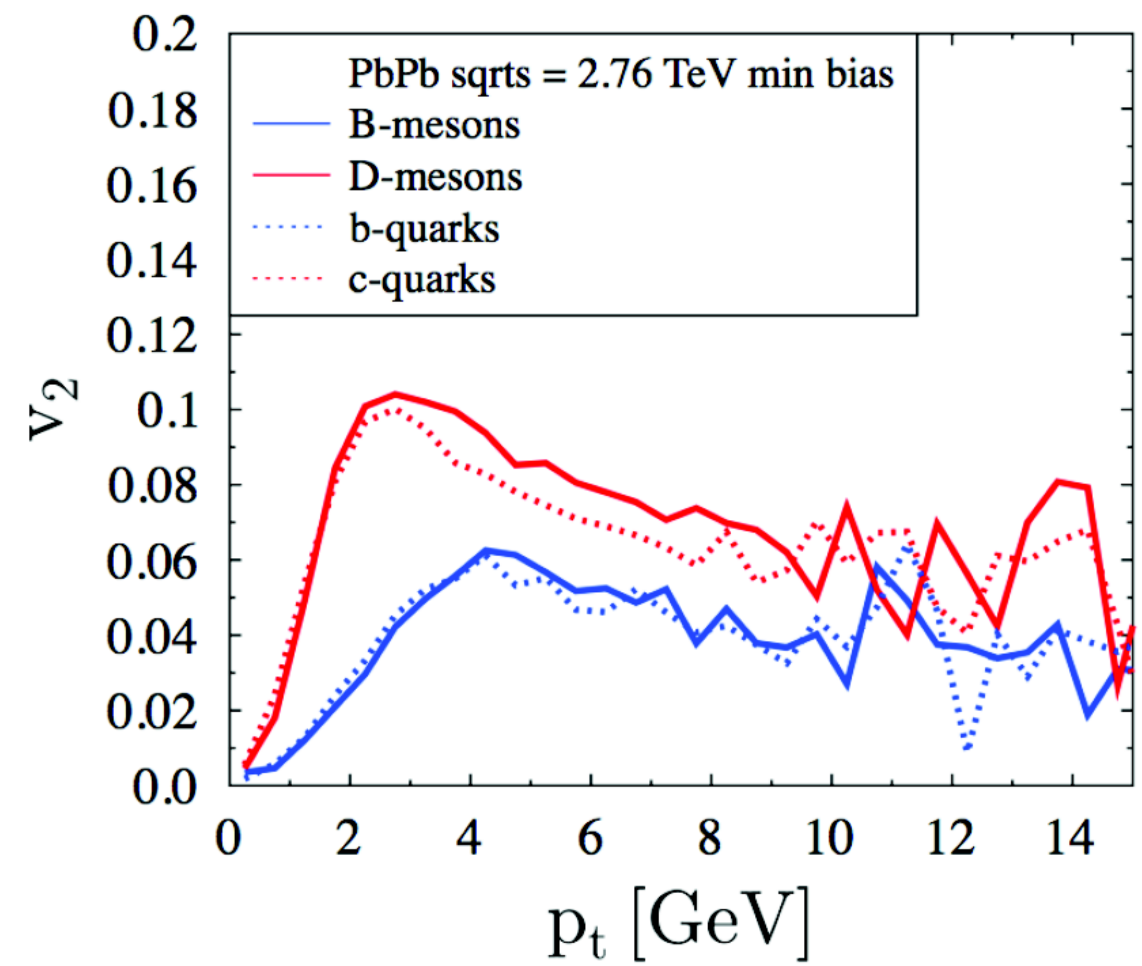
- If charm hadronizes in the medium by recombination, an enhancement of D_s production wrt non strange D meson would be expected at intermediate p_T

Kuznetsova, Rafelski, EPJ C 51 (2007) 113
He, Fries, Rapp, PRL 110 (2013) 112301

Heavy Favour Elliptic Flow v_2

- Heavy quark flow sensitive to
  - At low p_T: degree of thermalization of massive quarks in the medium
  - At high p_T: path-length dependence of energy loss
- Models predict
  - Large v_2 for charm and significant mass effect in charm vs. beauty

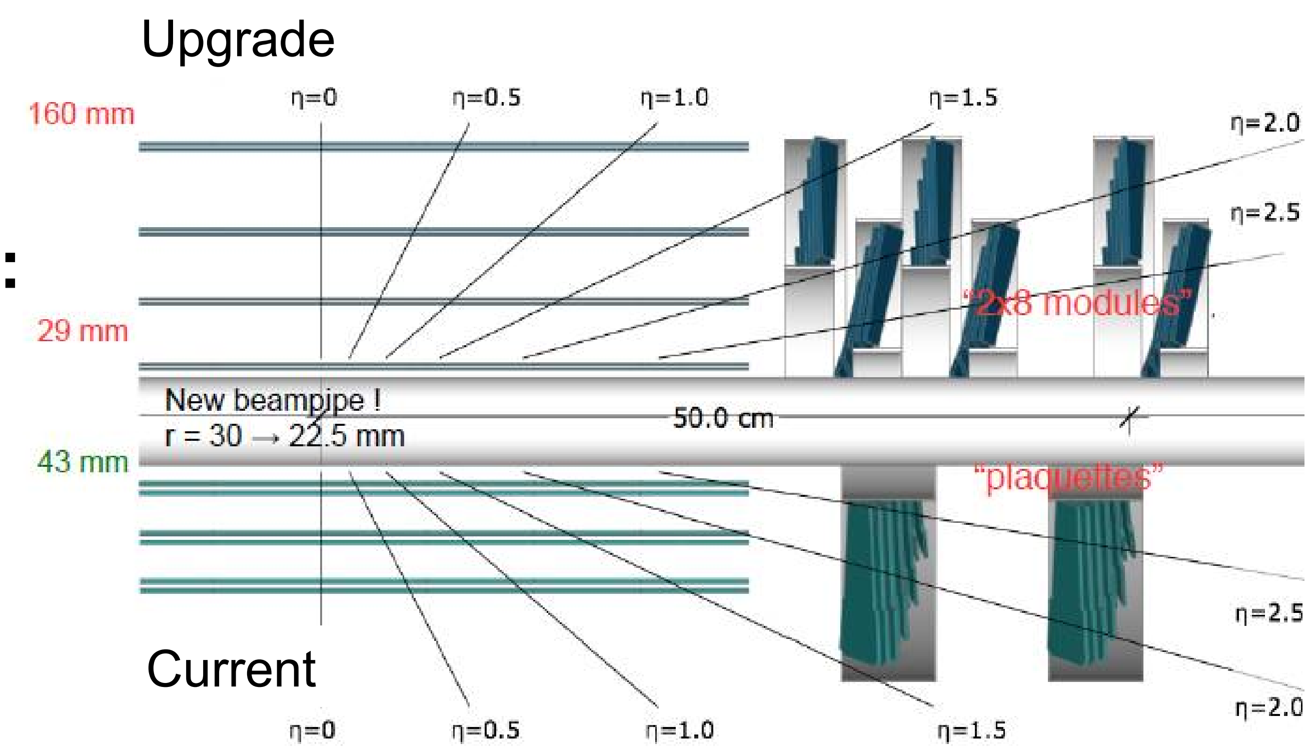


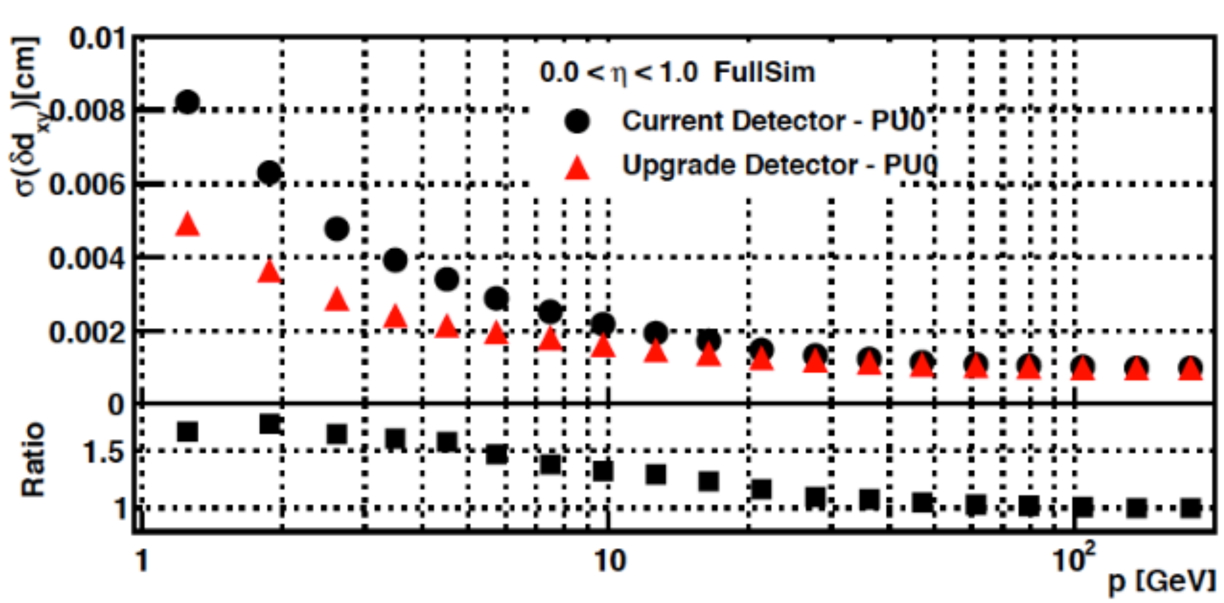


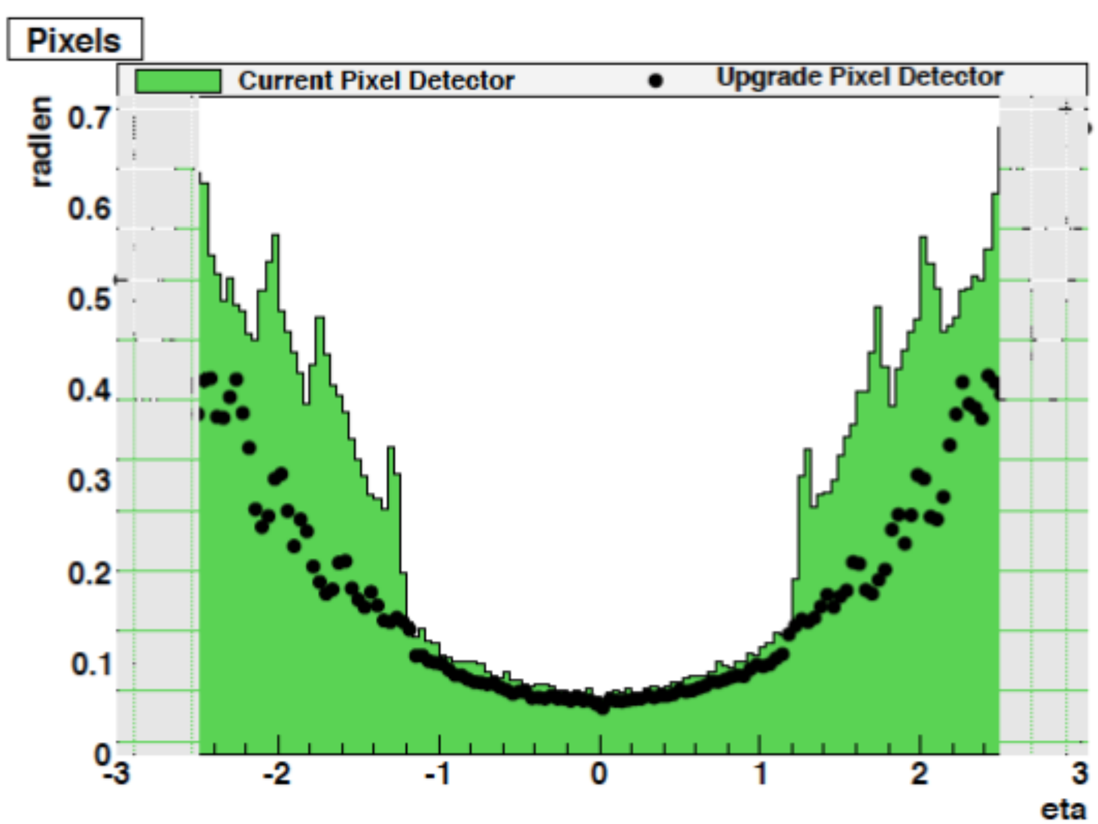
J. Aichelin et al., arXiv:1201.4192

CMS Upgrade: New CMS pixel tracker

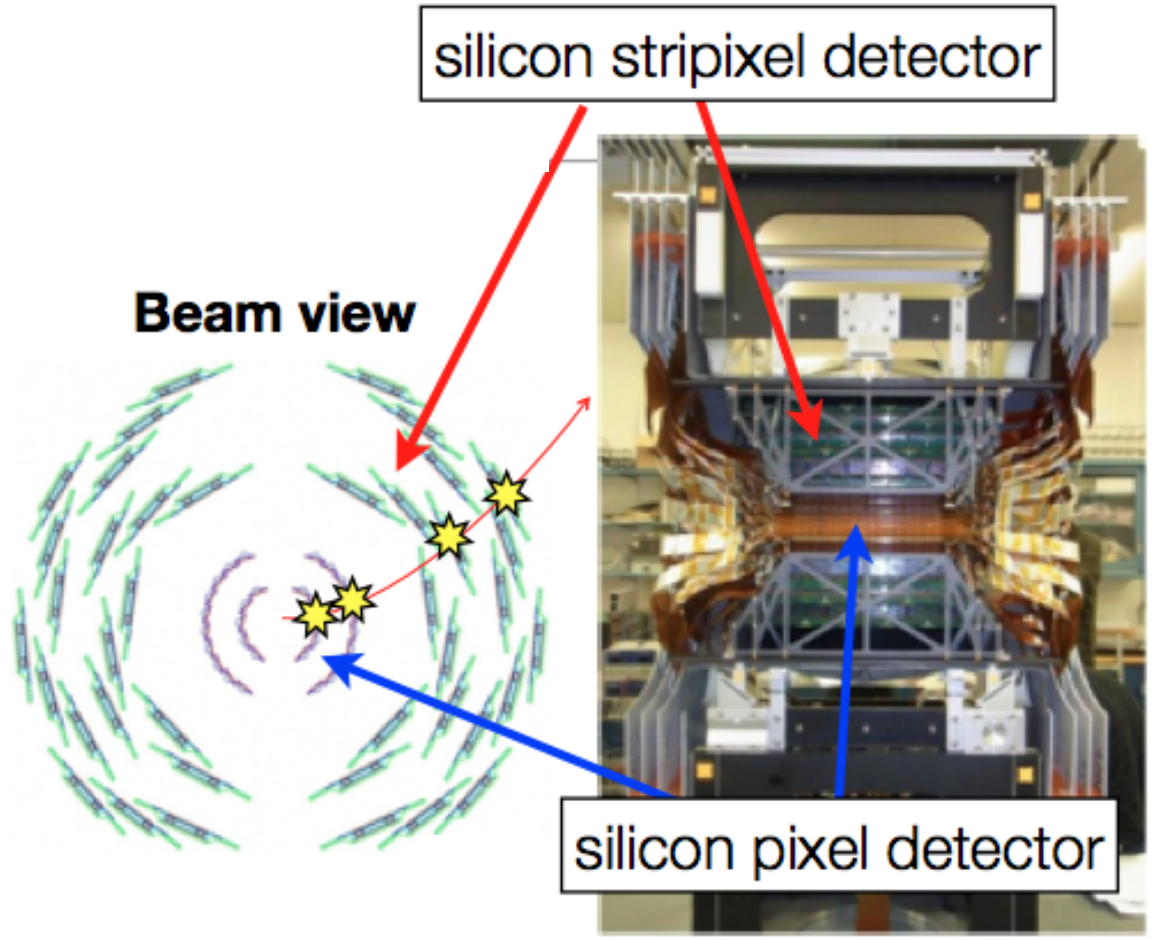
- To be installed during 2015-16 year-end technical stop
  - Reduced material budget
  - Improved IP resolution
- Will have strong impact, also in Pb-Pb:
  - Non-prompt J/ψ
  - b-tagged jets
  - Full reconstruction of HF decays



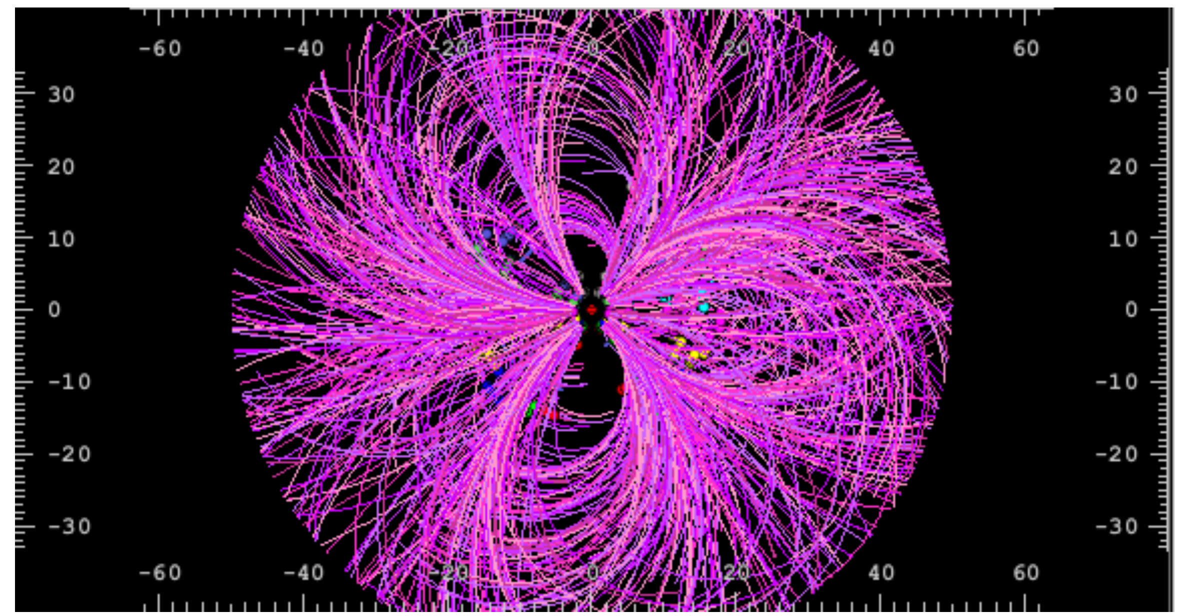




PHENIX VTX Upgrade (2011)

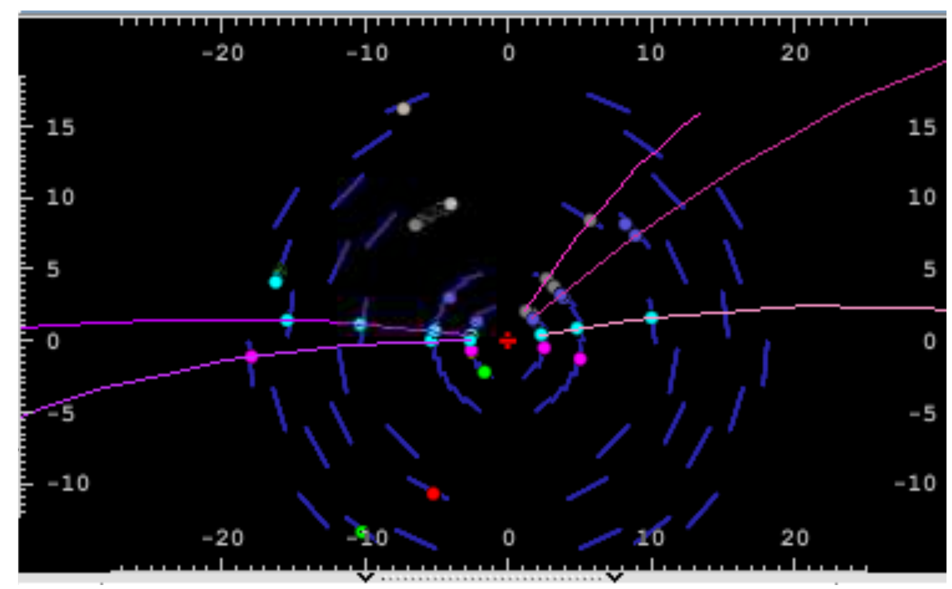


RUN2011: Au+Au at 200 GeV



M. Rosati, QM2012

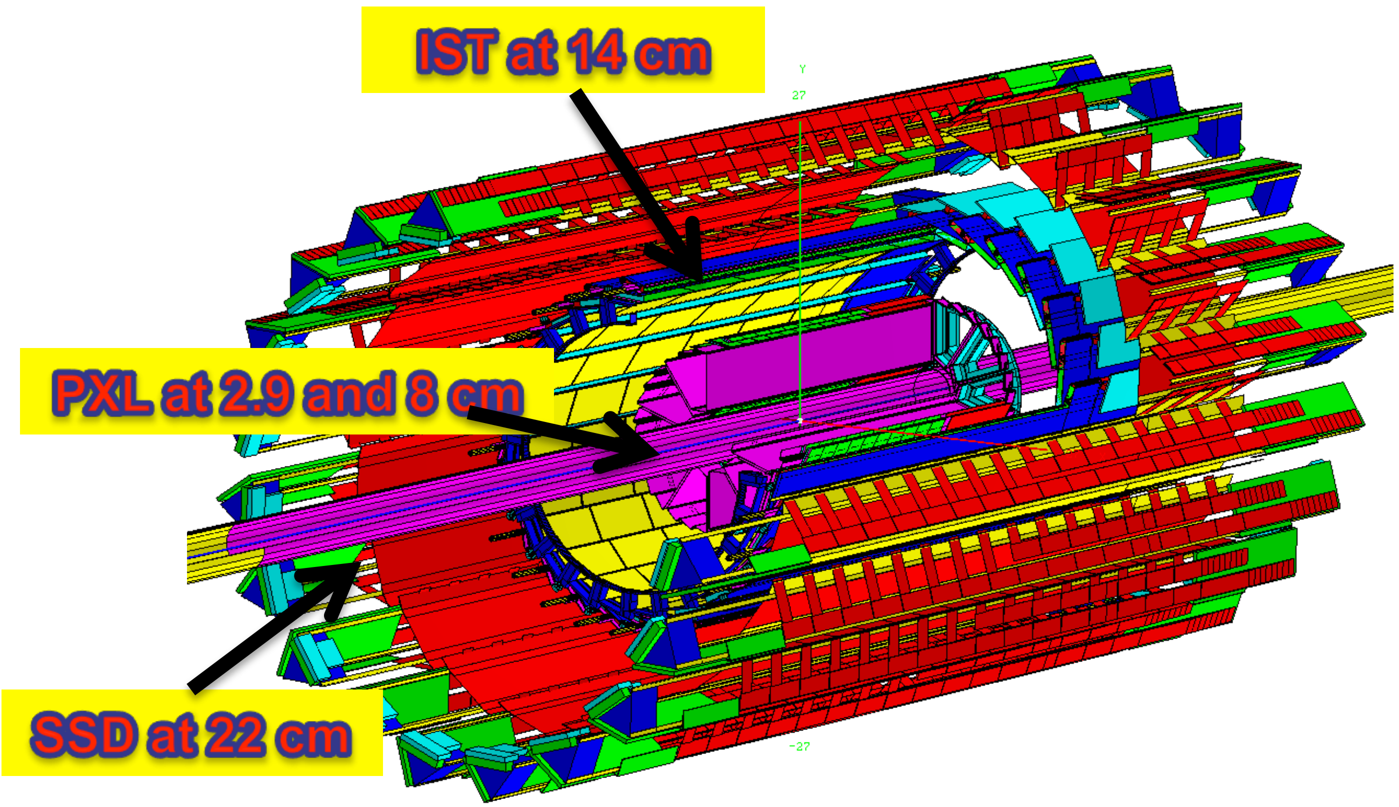
Run 2012: p+p at 200 GeV



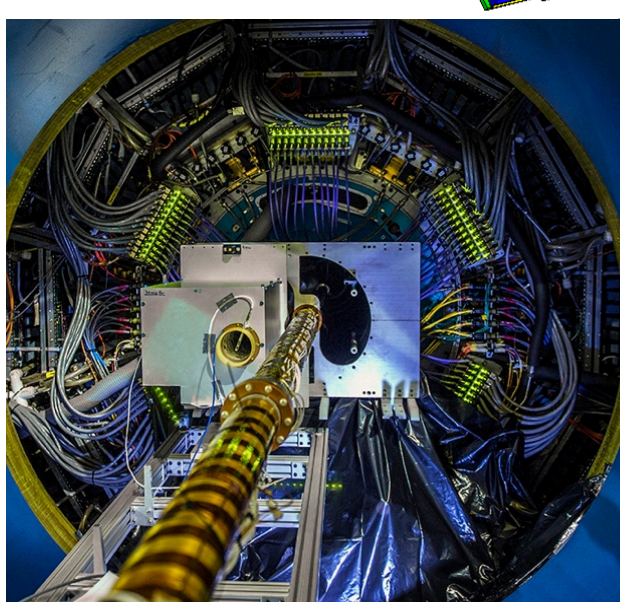
	PHENIX
Sensor tech.	Hybrid
Pitch size (μm^2)	50x425
Radius of first layer (cm)	2.5
Thickness of first layer	$1\%X_0$

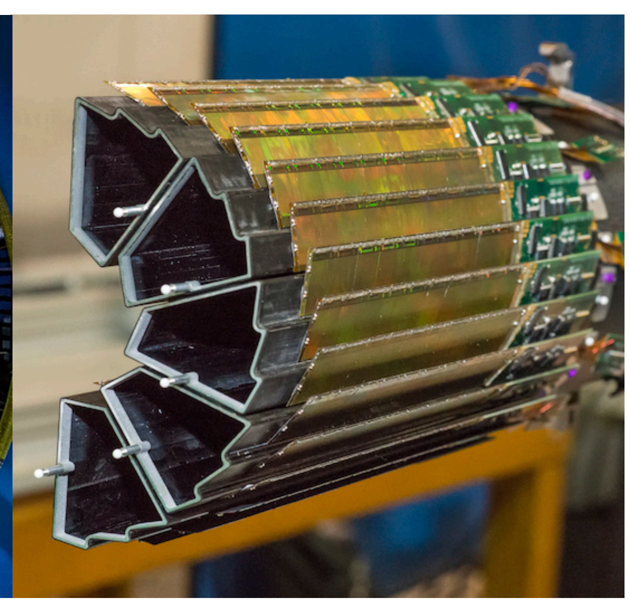
- From 2011 have VTX at midrapidity
- From 2013 have FVTX at forward/backward rapidity

STRA: Heavy Flavour Tracker (2014+)



- HFT = SSD (strip) + IST (pad) + PiXeL(MAPS)
  - Monotholic Active Pixel Sensor (MAPS) technology
  - Ultimate hit resolution (20.7x20.7 μm^2)
  - Thin material design (0.4%X_0) and air cooled – critical to reach low p_T
- Taking data since 2014:
  - Significant Au+Au, p+p and p+Au datasets have been collected with HFT

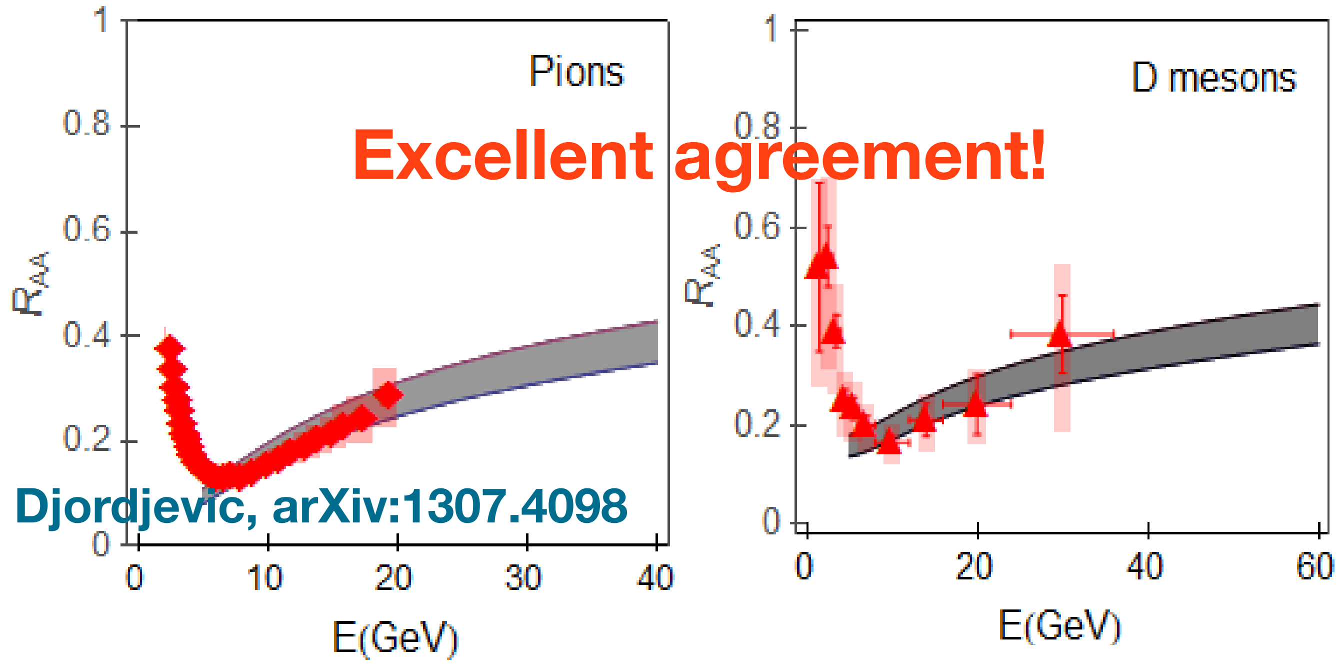




Detector	Radius (cm)	Hit Resolution R/φ - Z (μm)	Radiation length
SSD	22	20 / 740	1% X_0
IST	14	170 / 1800	<1.5 %X_0
PXL	8	12 / 12	~0.6 %X_0
	2.9	12 / 12	~0.4% X_0

Zhenyu Ye, ECT 2015 March, 2015

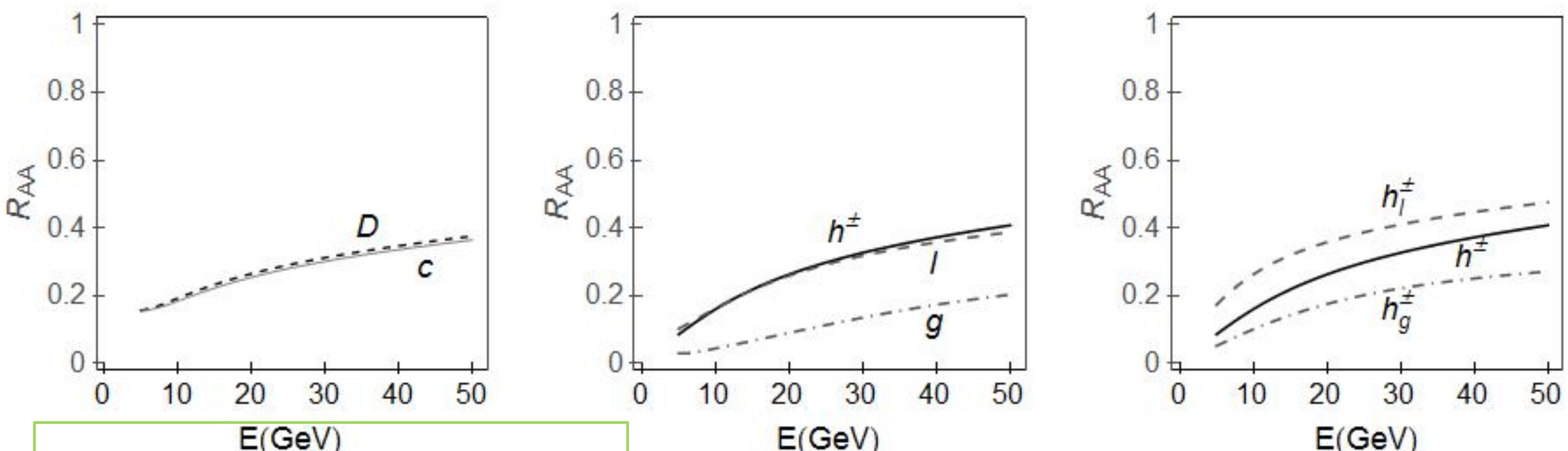
Color charge dependence?: D-meson R_{AA} vs. $\pi^{\pm}$



Excellent agreement!

Djordjevic, arXiv:1307.4098

Calculation by M. Djordjevic (rad+coll energy loss) can describe both R_{AA}



Shows strong colour charge effect in partonic R_{AA} (g vs. light and c)

R_{AA} (D) = R_{AA} (charm)

R_{AA} (light quarks) = R_{AA} (charm)

Distortion by fragmentation!

R_{AA} ($h^{\pm}$) = R_{AA} (D)

Colour charge effect plays!

ALICE O^2 project: Upgrade of the ALICE Online & Offline Computing

- 50k collisions per second, each ~20 MByte → ~1.1 TByte/s data input
- Detectors in continuous & triggered read-out mode
- Data reduction by on-line reconstruction and compression
- Storage of only reconstruction results, discard raw data
- Combined DAQ/HLT/off-line farm (O2)
- Subsequent reconstruction passes for physics on farm

Detectors	Input to On-line System (GBytes/s)	Peak Output to Computing Center (GByte/s)	Avg. Output to Computing Center (GByte/s)
TPC	1000	50	8
TRD	81.5	10	1.6
ITS	40	10	1.6
Others	25	12.5	2
Total	1146.5	82.5	13.2

ALICE Run2 goal in detail

- D mesons and Lc in hadronic decays
  - extension of cross section / yield measurements to higher and lower pT (down to pT = 0 for the D0 meson) with improved precision in all systems
    - constrain energy-loss models at high pT
    - address radial flow / recombination effects in Pb-Pb at low pT
    - measurement of total charm production cross section
  - extension of v2 measurements with improved precision
    - path-length dependence of energy loss at high pT
    - collectivity/thermalization at low pT
  - improved precision on rare hadrons (Ds+, Lc)
  - first look at heavy-flavor v3
  - D mesons in very high multiplicity pp collisions -> MPI at hard scale
- heavy-flavor decay electrons
  - extended RAA and v2 measurements for HF decay electrons
  - beauty-decay electrons (via impact parameter measurement)
    - RAA and v2 to address beauty quark energy loss and collectivity
  - beauty decays using (incomplete) displaced vertices including an electron

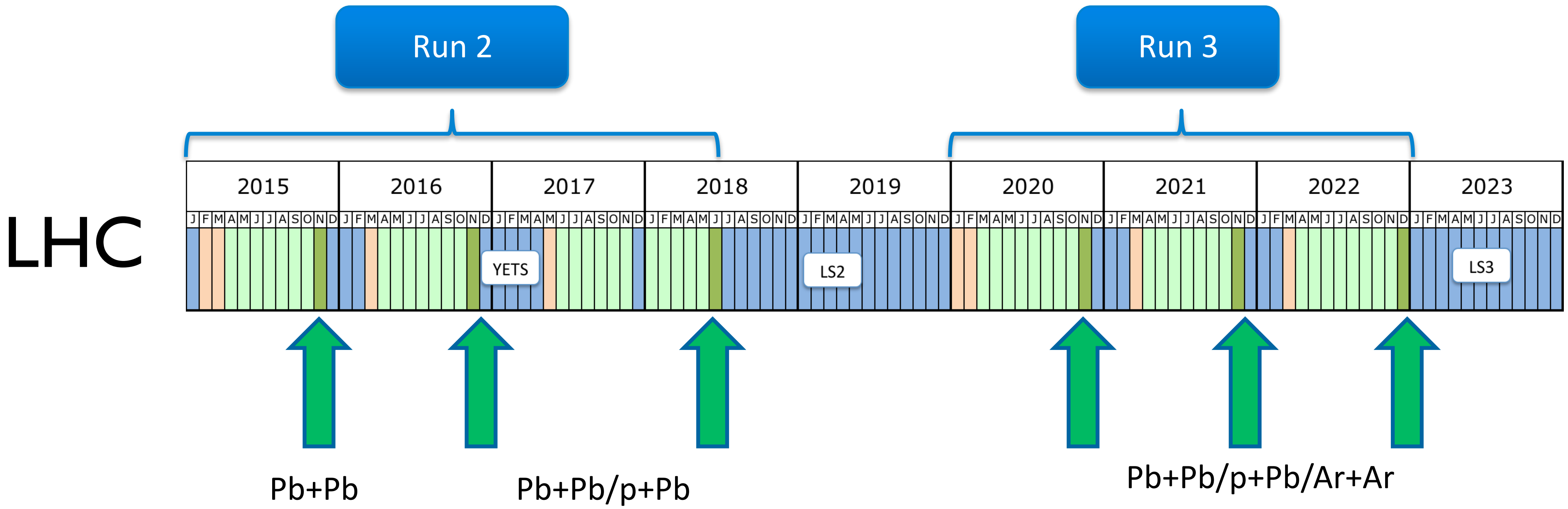
Specifications

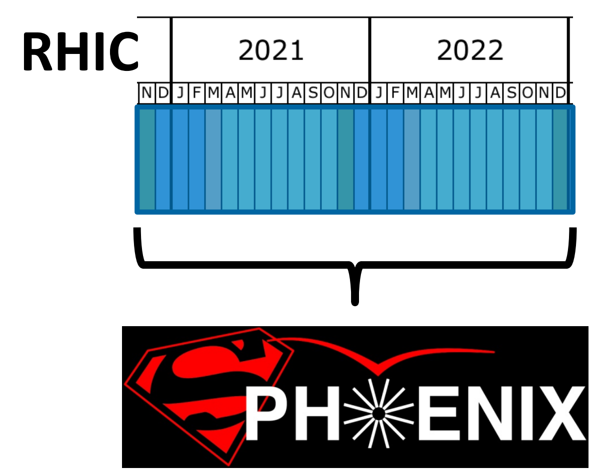
Pixel Silicon Detector at LHC/RHIC experiments

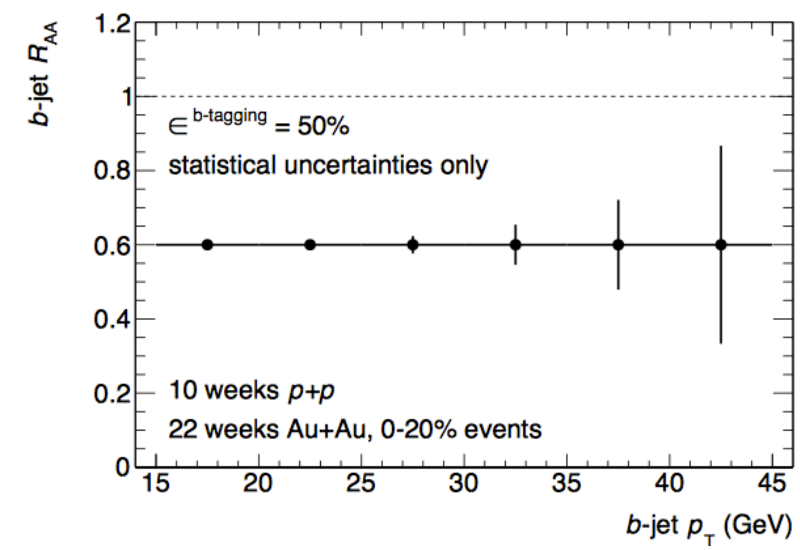
	ATLAS	CMS	ALICE	PHENIX	STAR
Sensor tech.	Hybrid	Hybrid	Hybrid	Hybrid	MAPS
Pitch size (μm^2)	50x400	100x150	50x425	50x425	20x20
Radius of first layer (cm)	5.1	4.4	3.9	2.5	2.8
Thickness of first layer	$\sim 1\%X_0$	$\sim 1\%X_0$	$1\%X_0$	$1\%X_0$	$0.4\%X_0$

* physics results from PHENIX/STAR discussed here don't include data from silicon pixel detectors

RHIC: BNL proposed schedule







Proposed sPHENIX run plan

p+p	10 weeks
Au+Au	22 weeks
p+Au	10 weeks

- After the 2016 run, the BNL plan has PHENIX being removed. In 2021 it will have been replaced by sPHENIX, a compact solenoidal detector that is optimized for **jet** and **Upsilon** measurements.
- sPHENIX will provide (unbiased) jet and Upsilon data that will complement the very precise data available from LHC by the end of Run 3 (~2023).

Pixel detector technologies

Several technologies have been considered

Hybrid pixel detectors

- Edgeless sensors (100μm) + front-end chip (50μm) in 130 nm CMOS

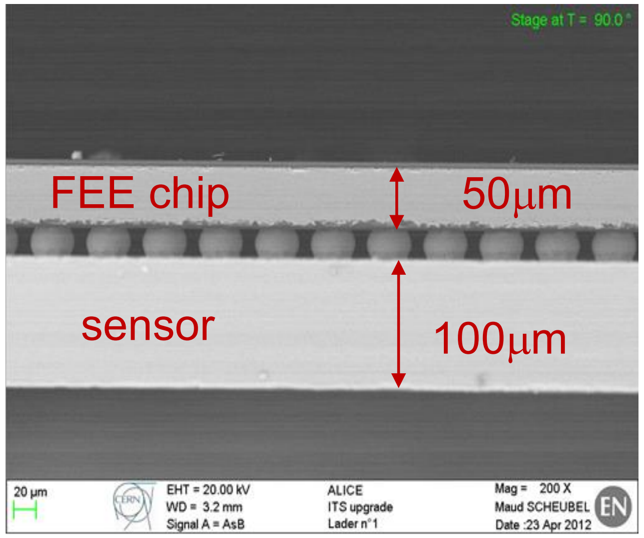
Monolithic pixel detectors

- MIMOSA like in 180 nm CMOS
- INMAPS in 180 nm CMOS
- LePix in 90nm CMOS

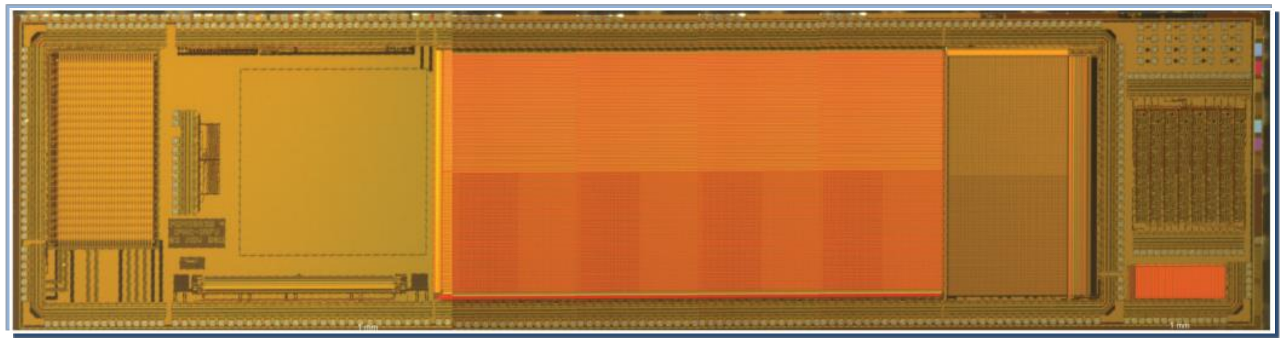
MIMOSA, INMAPS → Tower/Jazz

LePix → IBM

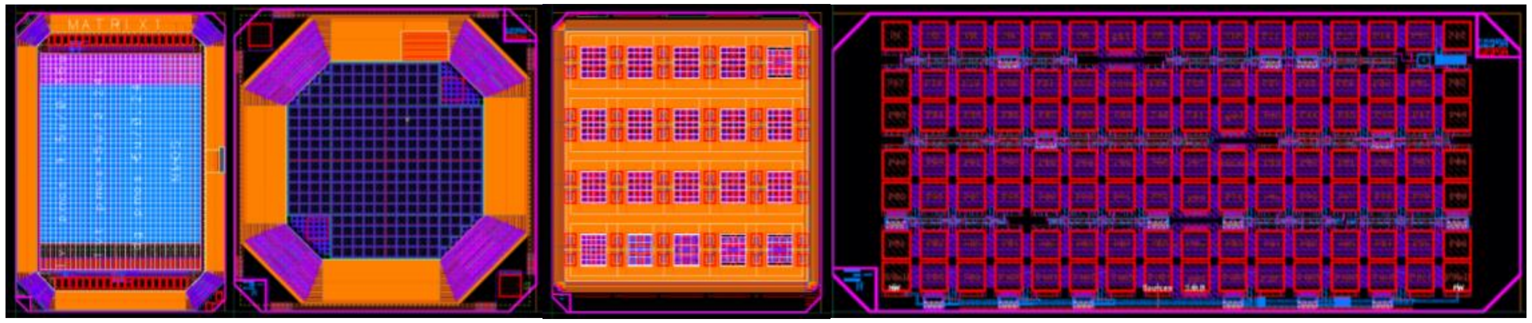
HYBRID (CERN)



MISTRAL prototype circuit (IPHC)

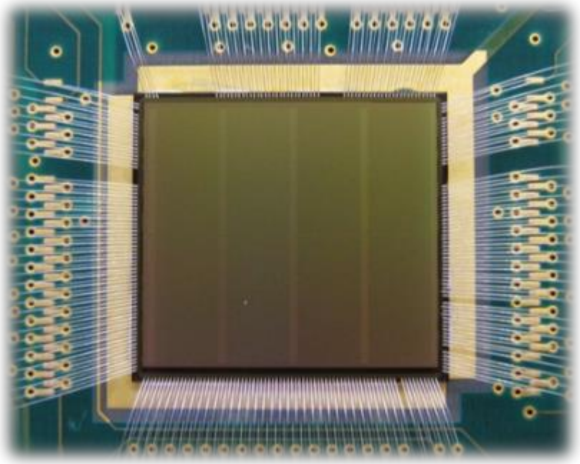


LePIX prototype circuit (CERN)



Matrix1 | Diode | Breakdown test | Transistor test

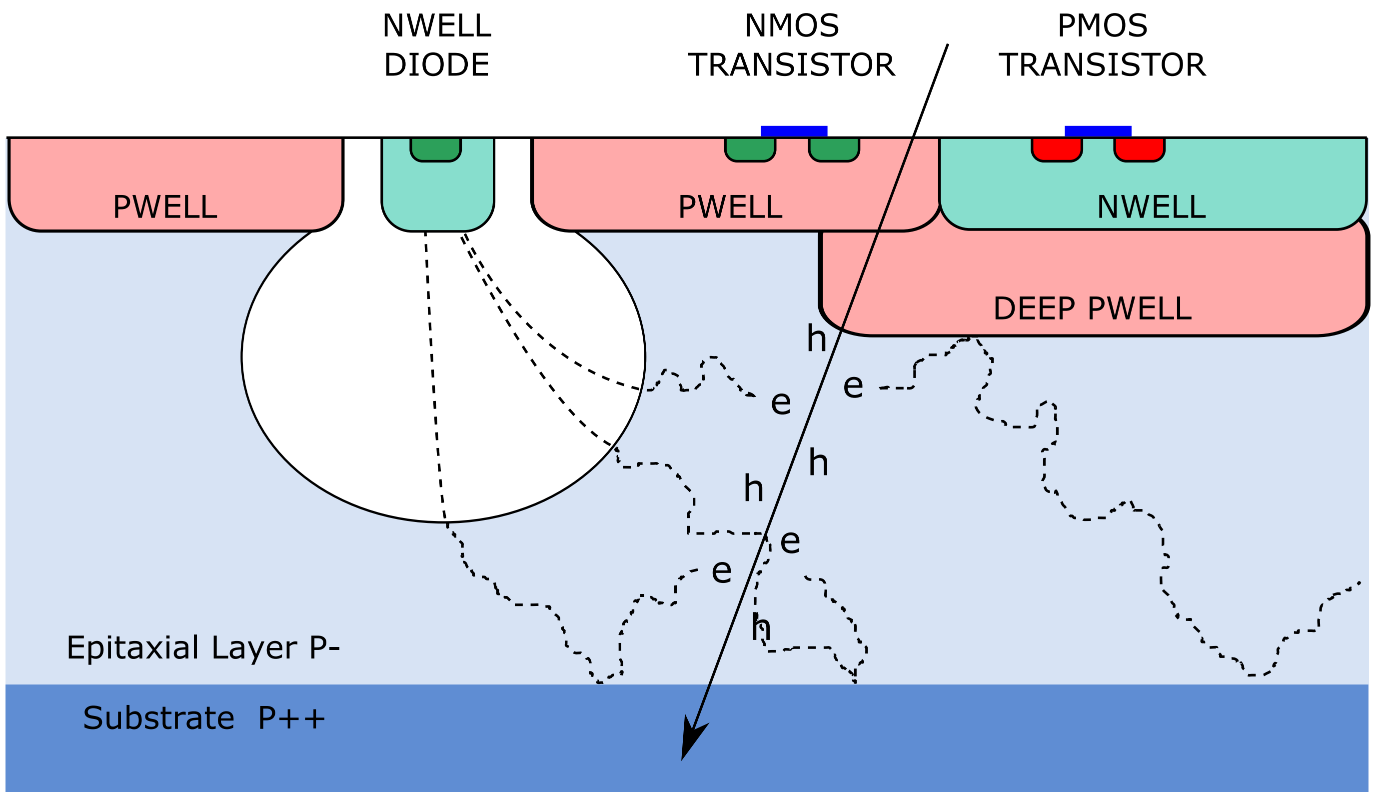
INMAPS (RAL)



TPAC prototype

50 μm pixel - over 150 CMOS transistors

CMOS Pixel Sensor using TowerJazz 0.18μm CMOS Imaging Process



Tower Jazz 0.18 μm CMOS

- feature size 180 nm
- metal layers 6

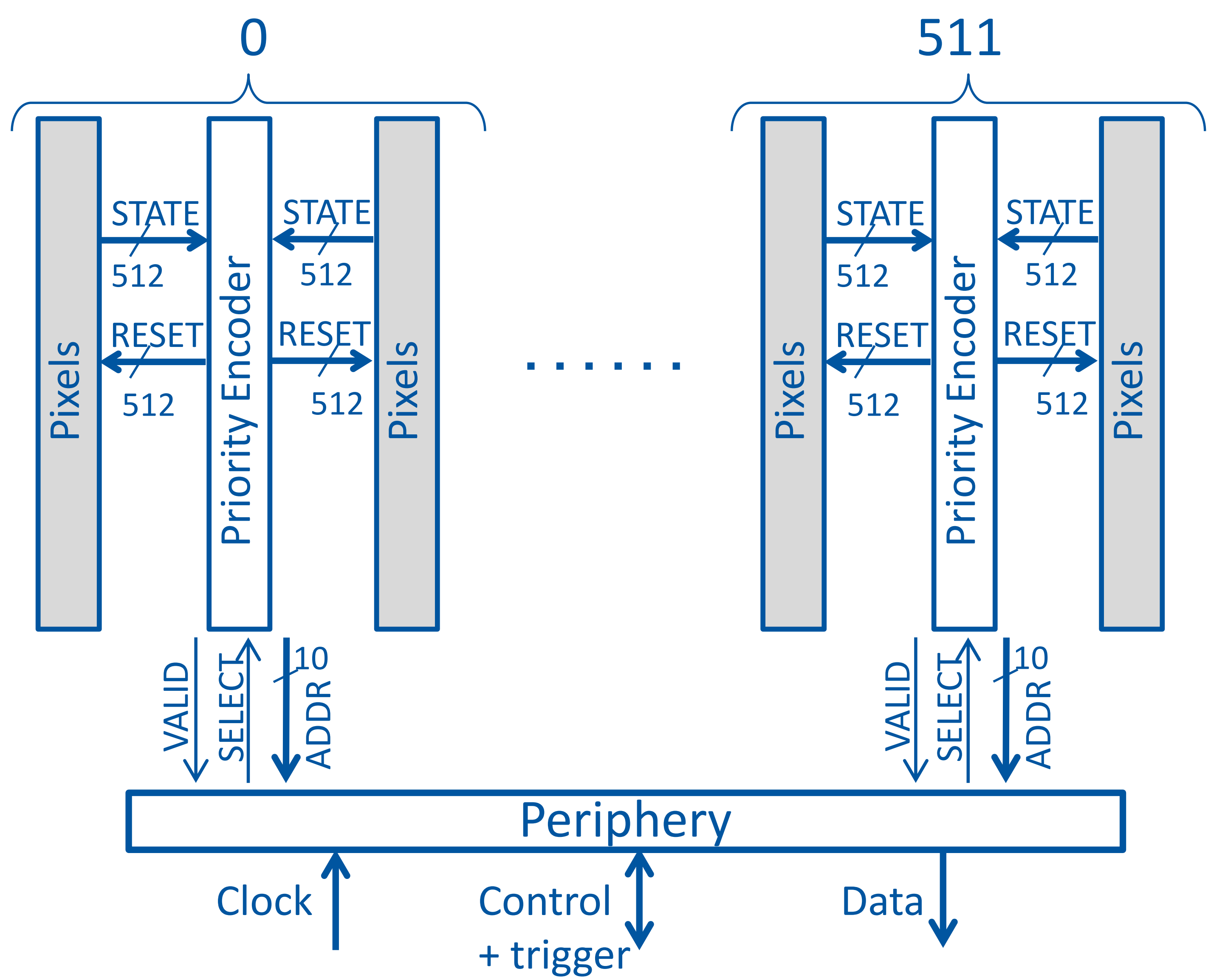
➔ Suited for high-density, low-power

- Gate oxide 3nm

➔ Circuit rad-tolerant

- High-resistivity (> 1kΩ cm) p-type epitaxial layer (20μm - 40μm thick) on p-type substrate
- Small n-well diode (2-3 μm diameter), ~100 times smaller than pixel => low capacitance
- Application of (moderate) reverse bias voltage to substrate can be used to increase depletion zone around NWELL collection diode
- Quadruple well process: deep PWELL shields NWELL of PMOS transistors, allowing for full CMOS circuitry within active area

Matrix Readout



The Priority Encoder sequentially provides the addresses of all hit pixels in a double column

- Combinatorial digital circuit steered by peripheral sequential circuits during readout of a frame
- No free running clock over matrix. No activity if there are no hits
- Energy per hit: E_h ~= 100 pJ -> ~3 mW for nominal occupancy and readout rate
- Buffering and distribution of global signals (STROBE, MEMSEL, PIXEL RESET)