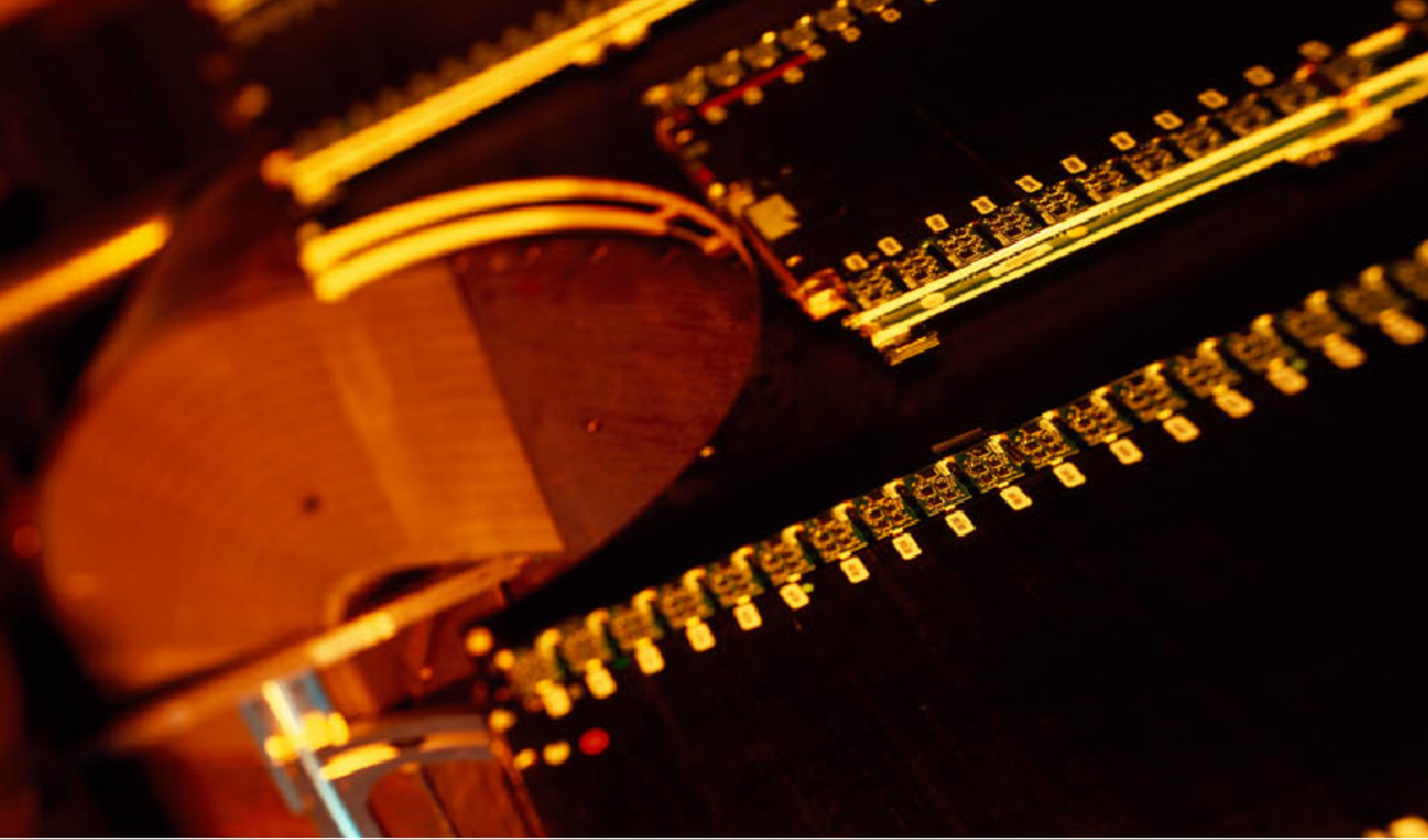


The ALICE MUON Arm

MFT Meeting @ Hiroshima (Japan)

October 5th 2015

A. Baldisseri

Irfu

Outlook

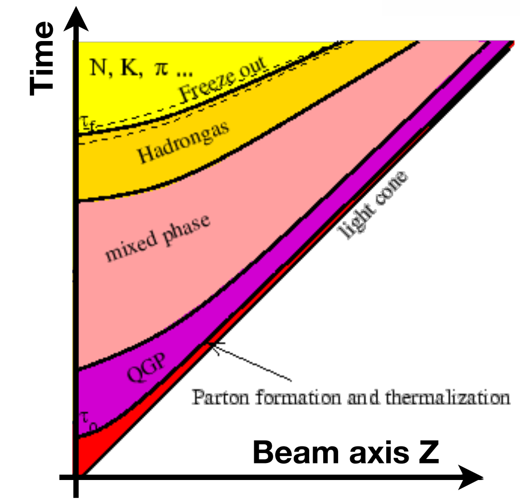
- The present ALICE Muon Spectrometer
  - Physics motivations
  - The setup
  - Physics highlights of Run 1 & Perspectives for Run 2
- The Upgrades
  - Limitations of the present Muon Arm
  - Running the spectrometer in Run 3/4
  - The upgrades of the Muon Arm
  - Physics perspectives for Run 3 (Ginés talk)

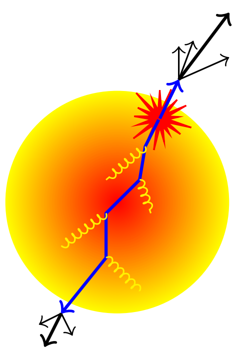
Muon Arm Institutes

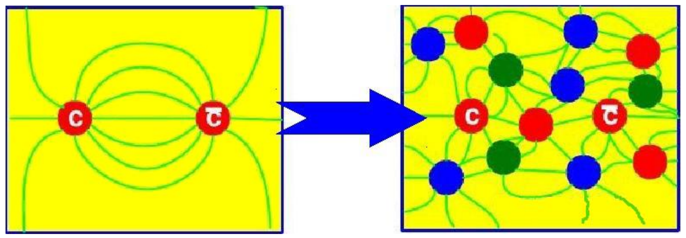
Armenia: Yerevan ANSL
Brazil: Campinas UNICAMP, Sao Paolo IFUSP, Sao Paolo EPUSP
France: Clermont-Fd, LPC/Univ. de Clermont-Ferrand, Lyon IPN,Nantes SUBATECH/Ecole des Mines/Univ. de Nantes, Orsay IPN, Saclay CEA-IRFU
Hungary: Budapest Institute for Particle Nuclear Physics,
India: Kolkata VECC, Kolkata SAHA, AMU, Mumbai Bhabha Atomic Research Centre, Kolkata Bose Institute
Italy: Cagliari INFN/Univ. di Cagliari, Torino INFN/Univ. di Torino, Alessandria INFN/Univ. del Piemonte Orientale
Korea: Seoul Konkuk University
Russia: Dubna JINR, Gatchina PNPI
South-Africa: Cape Town UCT, Cape Town iThemba

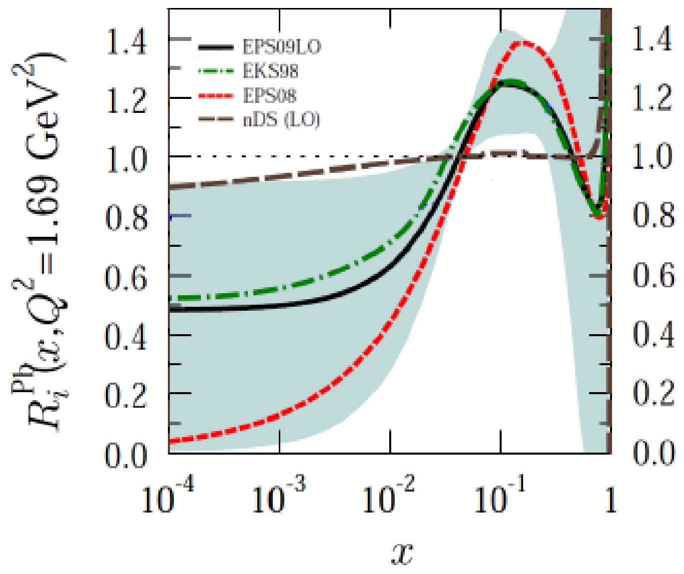
Physics motivations

- Why HF & Quarkonia are interesting probes?
  - Heavy quarks are produced in the early stage of the collision (hard scattering)
  - They are sensitive to the hot medium formed in the ultrarelativistic HI collision
- Open heavy flavors => Probing the medium by energy loss
  - Mass dependence ($\Delta E_c > \Delta E_b$) => comparison charm/beauty (only possible w/ MFT)
- Quarkonia => Probing the medium by color screening
  - Quarkonia should be suppressed by heavy quark potential screening
  - Recombination due to the high density heavy quarks could play a role
- Low mass => chiral symmetry restauration
  - in-medium modification => rho broadening
- Reference needed: pp collisions
  - Check production mechanisms (pQCD), A-A normalization
- Disentangle «hot effects» from «cold effects»: p-A collisions
  - Initial state effects: Modification of PDFs in nuclei (shadowing), gluon saturation

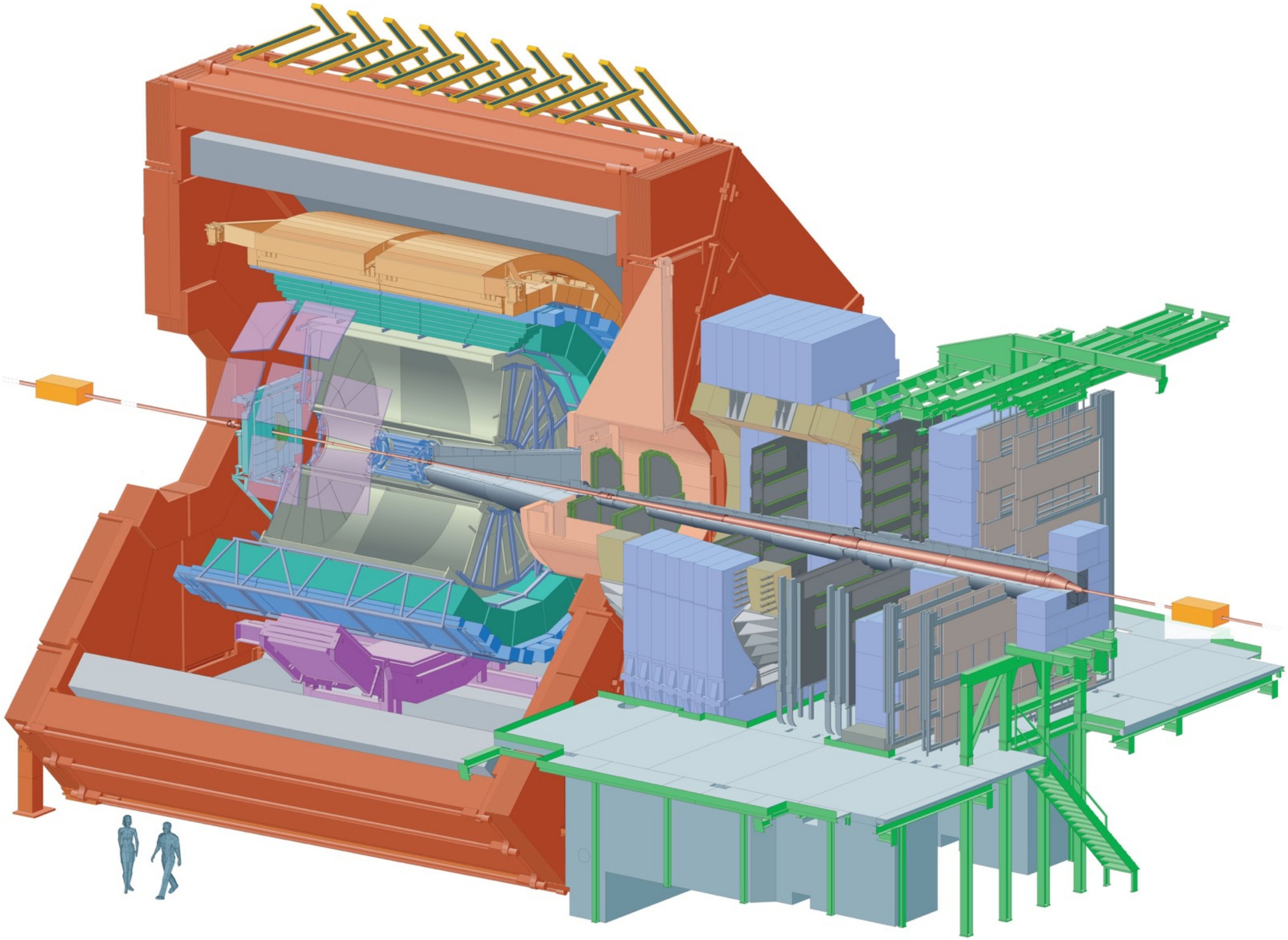




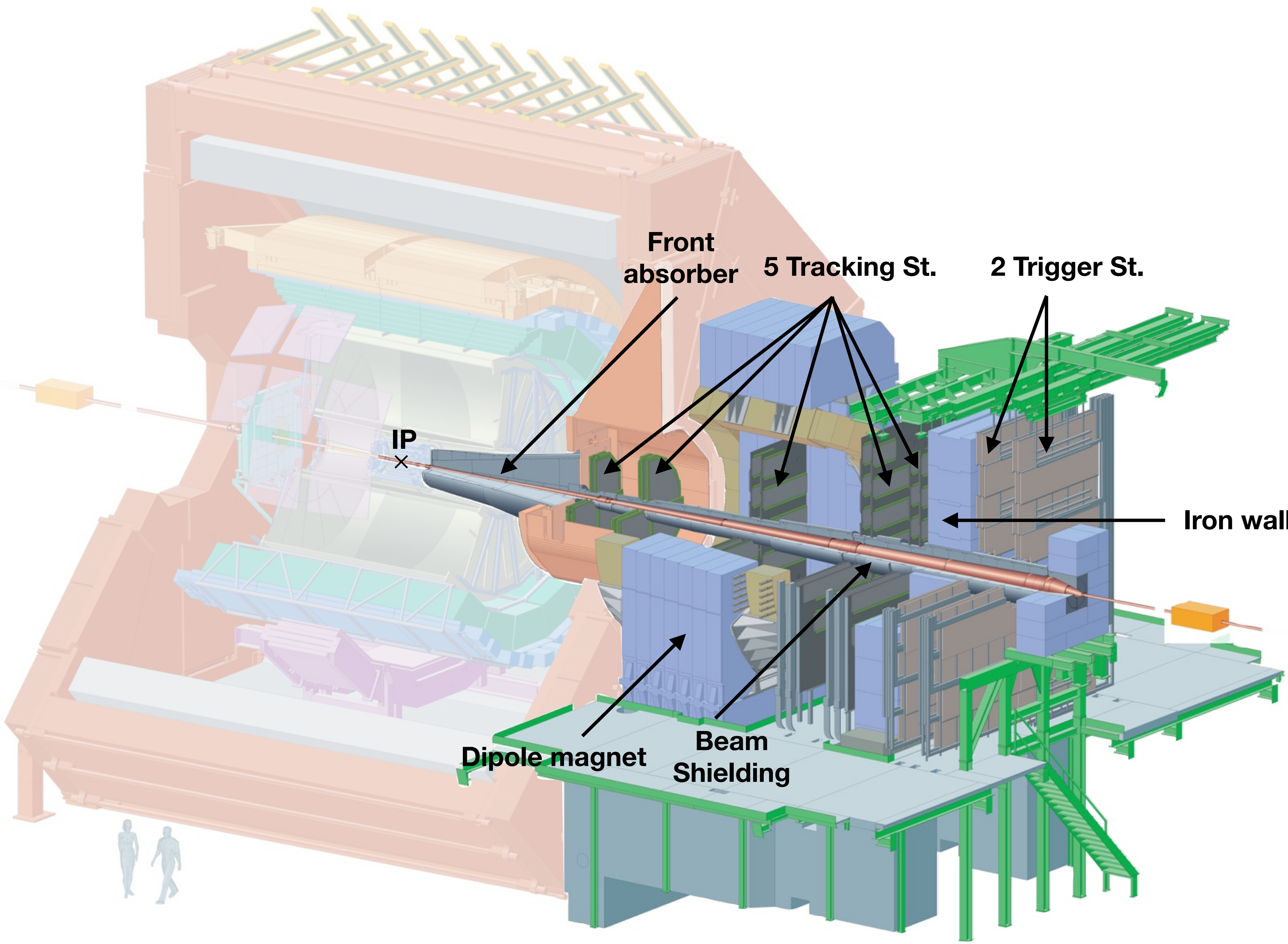




The ALICE Detector

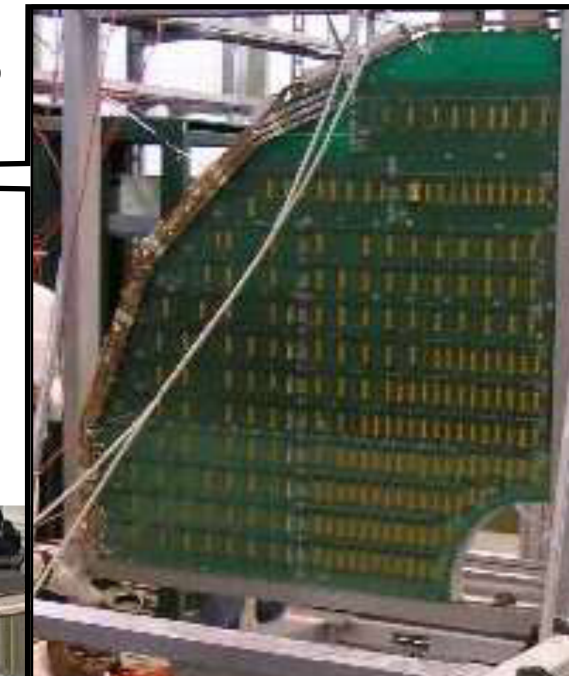


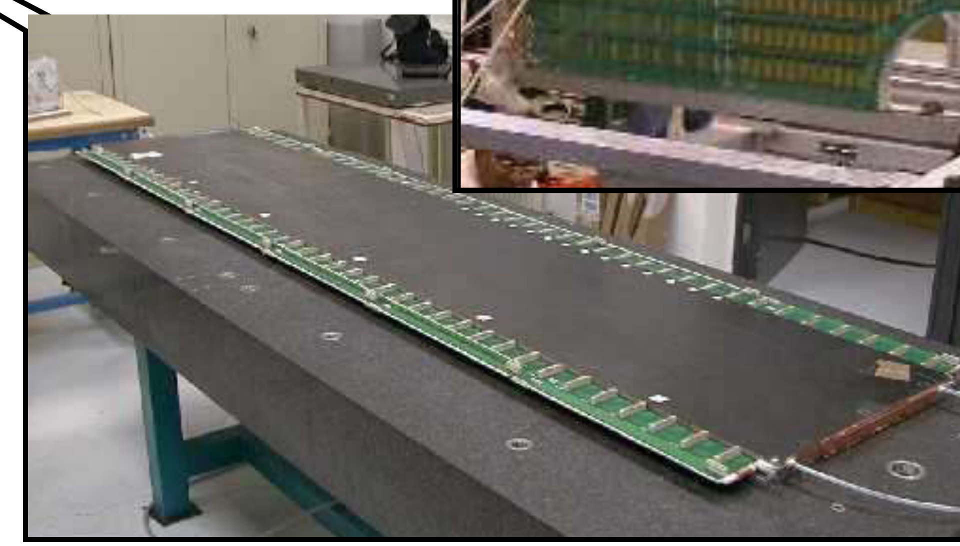
The ALICE Muon Spectrometer

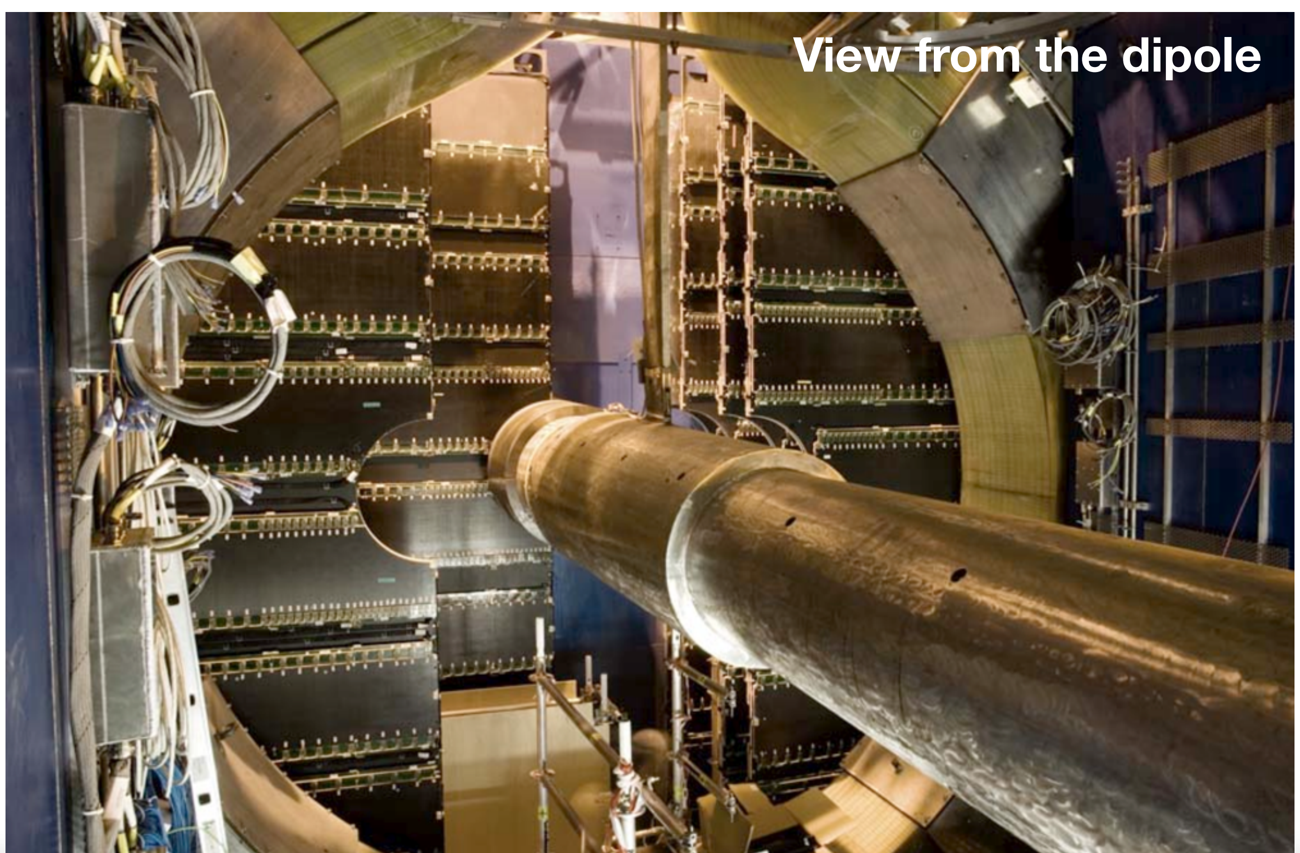


The Muon Tracking

- 10 planes of Cathode Pad Chambers (CPC) arranged in 5 stations
- Stations 1&2 quadrant type (3 pad segm.)
- Stations 3, 4, 5 slats type (3 pad segm.)
- 156 detection elements, 1.1 M channels
- CPC
  - Gas mixture Ar/CO_2 80:20, gap 5 mm (4.2 mm St. 1)
  - Gain of ~10^4, HV ~ 1650 V
  - Spatial resolution of ~100 μm and ε ~100%

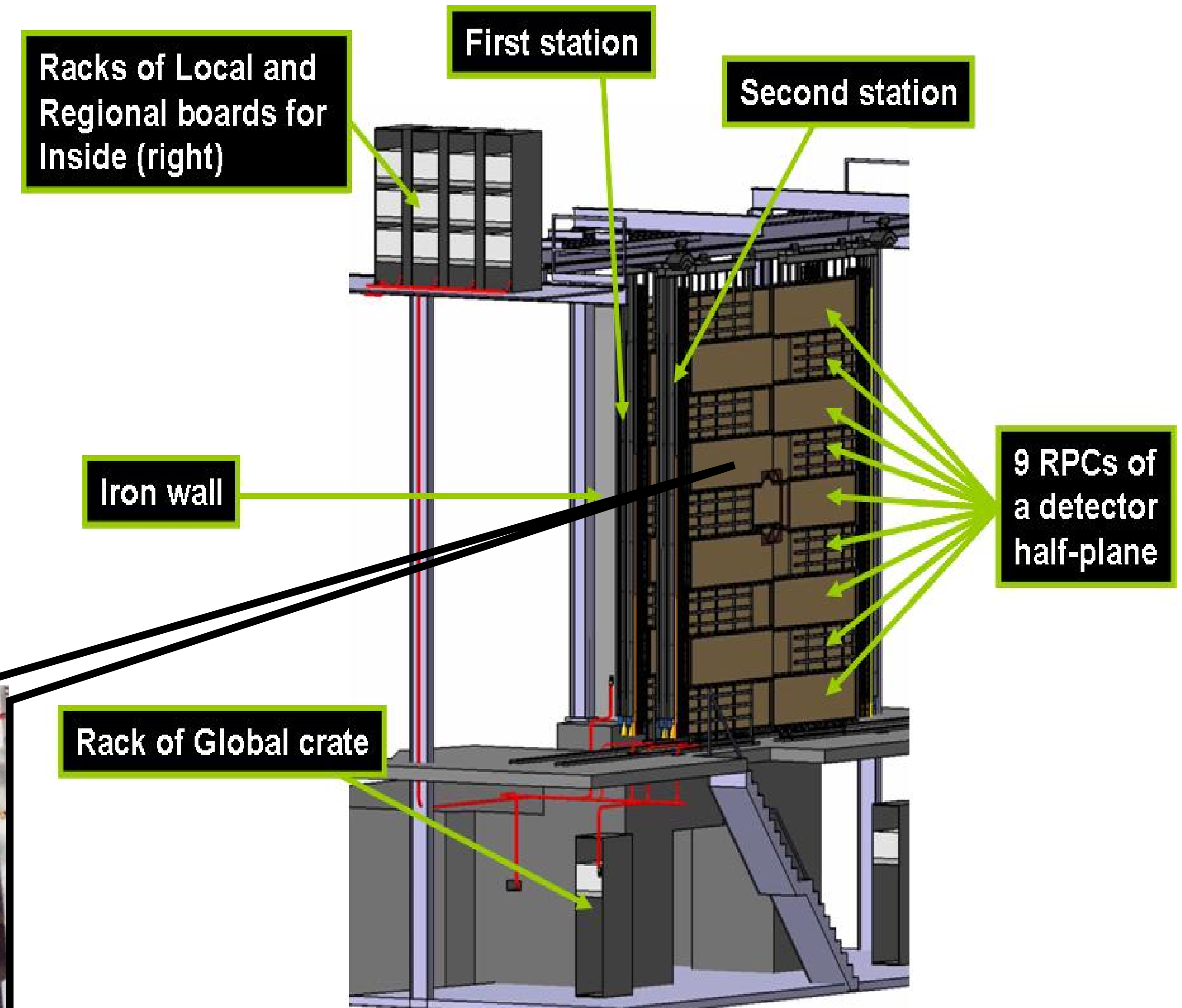


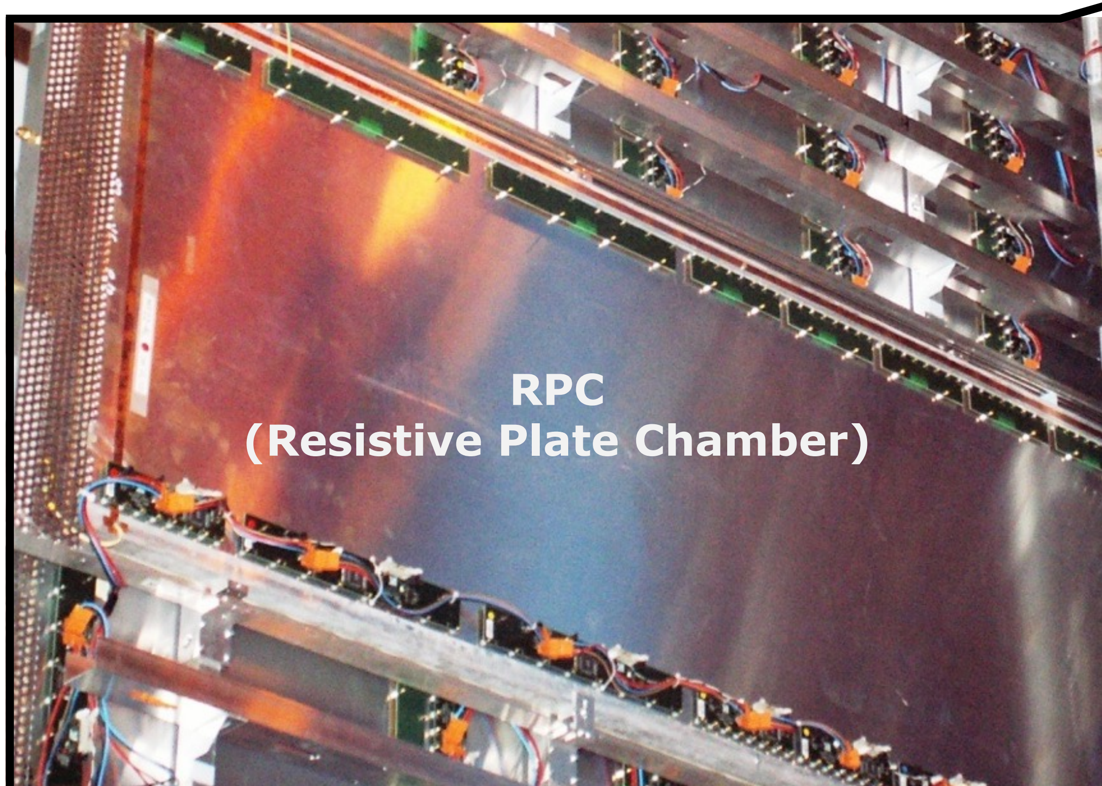




The Muon Trigger

- 4 planes of 18 single gap Resistive Plate Chambers (RPC) each,
- Arranged in 2 stations
- Total surface ~140 m^2
- Readout/FEE channels ~21000
- Trigger electronics: decision and readout
- Trigger decision
  - p_T-based muon selection
  - single muons, unlike-sign, and like-sign muon pairs





Physics highlights of Run 1
&
Perspectives for Run 2

(Today bias: Mostly Pb-Pb @ 2.76 TeV/nucleon, little p-Pb, almost no pp)

ALICE Data sets

- Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
  - **70 μb^{-1} in 2011** (20 times less in 2010)
- p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV
  - **11 nb^{-1} in 2013 (divided in p-Pb and Pb-p)**
- pp @ $\sqrt{s}$ = 7 TeV
  - **1.35 pb^{-1} in 2011**
- pp @ $\sqrt{s}$ = 2.76 TeV
  - **20 nb^{-1} in 2011**
- pp @ $\sqrt{s_{NN}}$ = 8 TeV
  - **1.3 pb^{-1} in 2012**

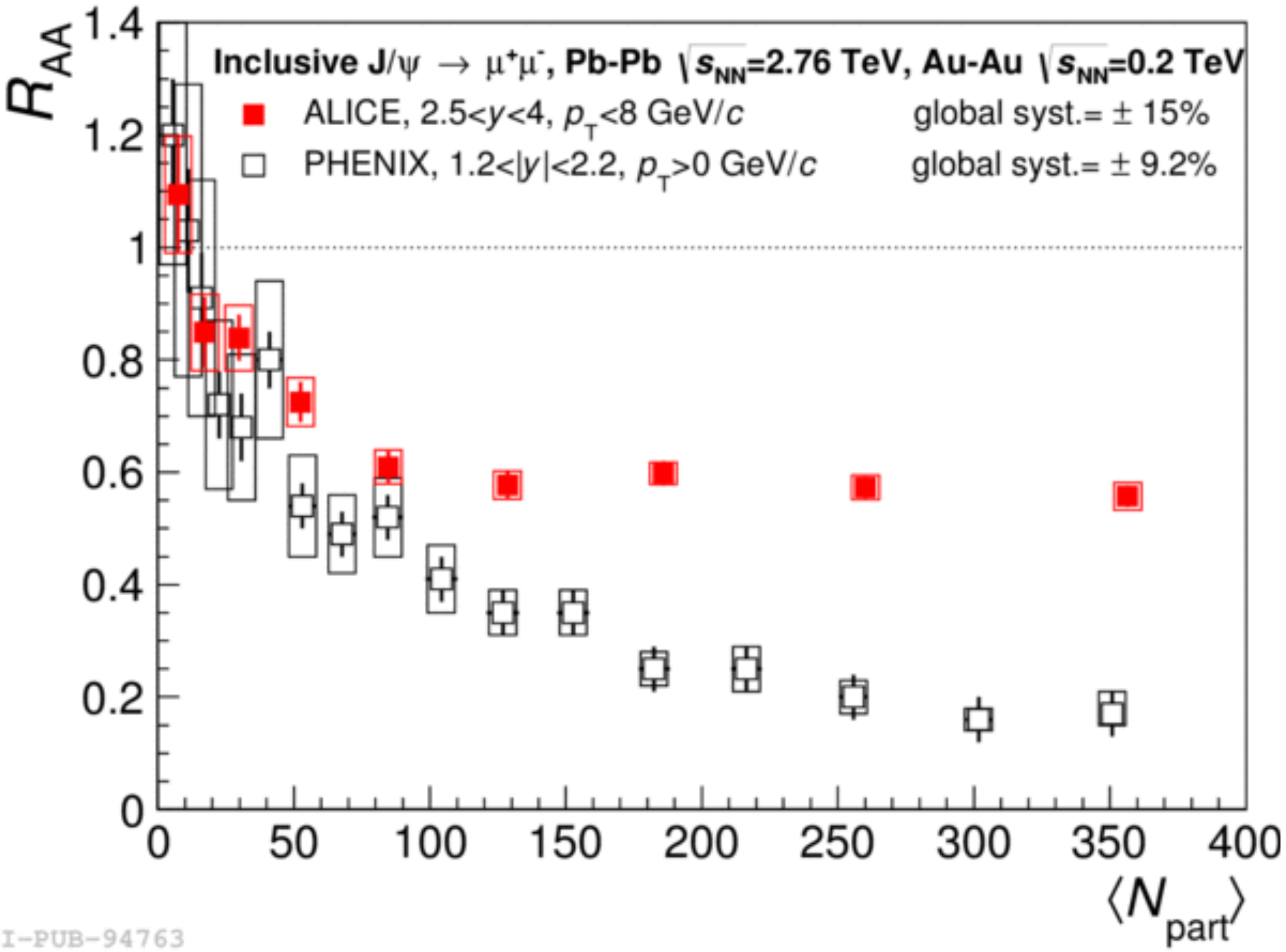
(Full luminosity seen by muon triggers)

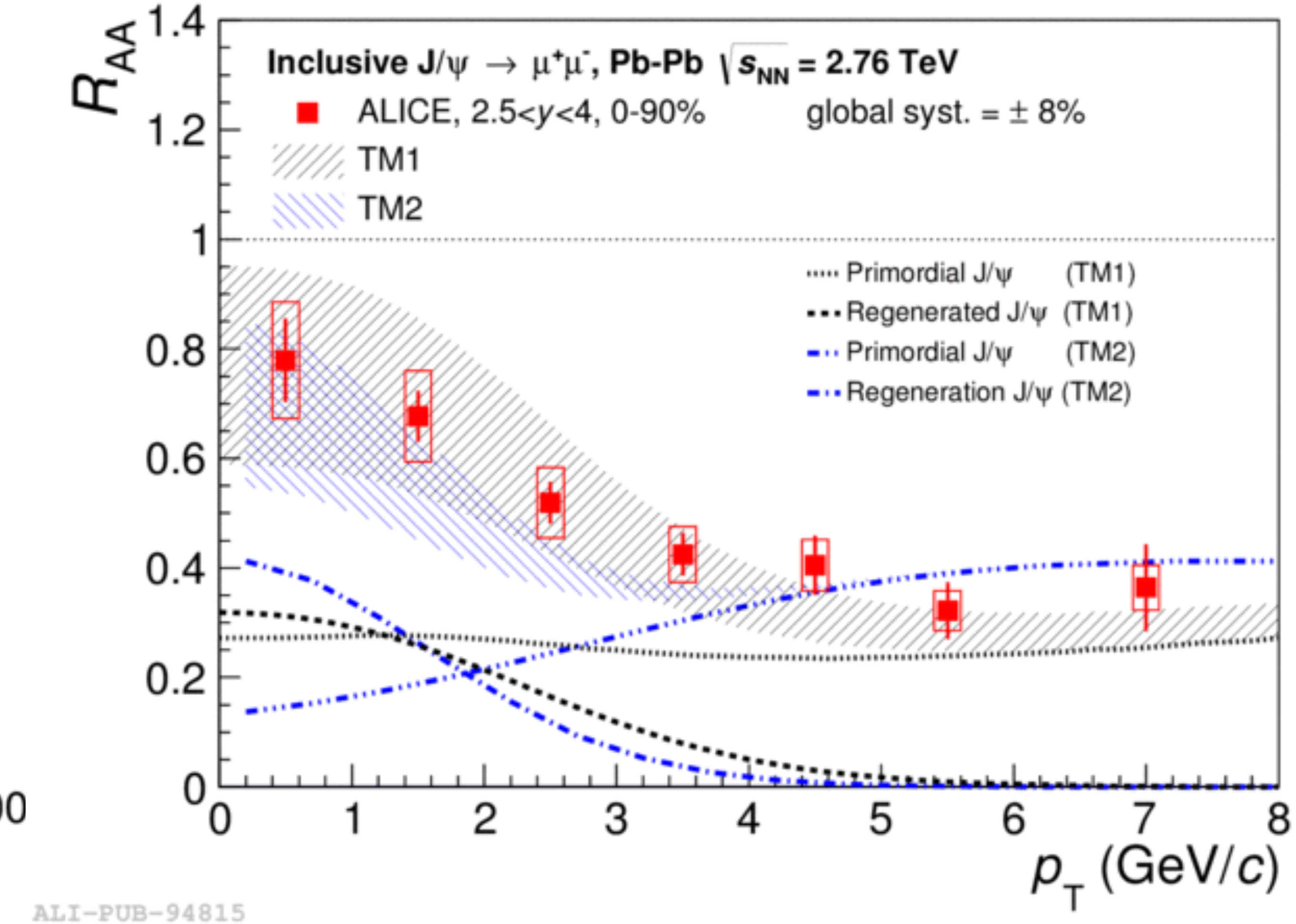
Run 2

➡Pb-Pb luminosity: 1 nb^{-1}
➡p-Pb: 30 nb^{-1}
➡p-p: ~50 pb^{-1}

J/ψ R_{AA} in Pb-Pb

Phys. Lett. B734 (2014) 314





TM1: Zhao et al. NPA 859 (2011) 114–125
TM2: Zhou et al. PRC 89 (2014) 054911

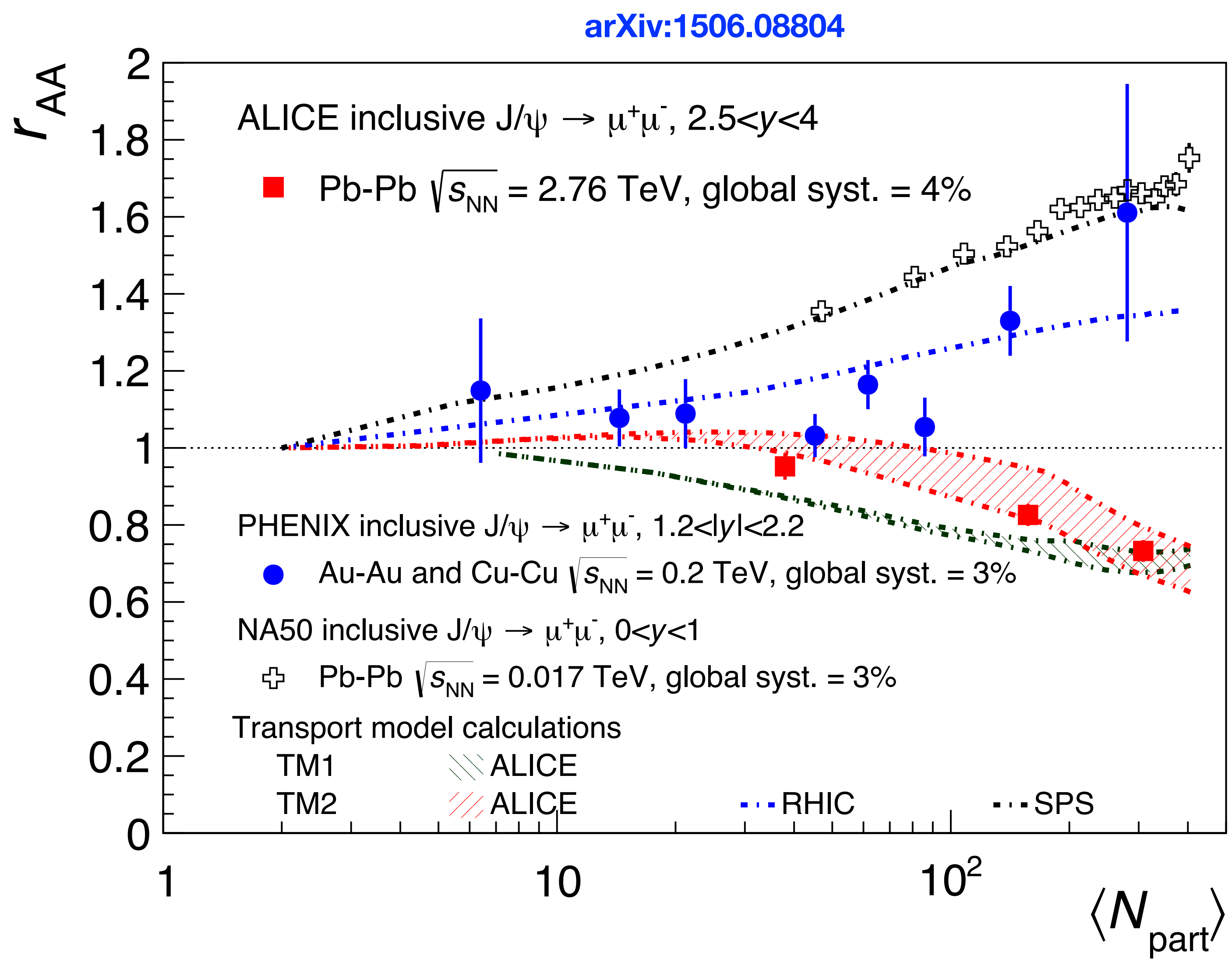
- Less suppression compared to RHIC (10 times lower energy)
- Less suppression at low p_T
- Recombination should play a role (~100 charm quark pairs in HI central)
- Models including regeneration give satisfactory agreement

Run 2

- ➡**Better multi-differential analysis (p_T, y)**
- ➡**Larger p_T range**
- ➡**Higher energy (more recombination ?)**

J/ψ <p_T^2>

$$r_{AA} = \frac{\langle p_T^2 \rangle_{A-A}}{\langle p_T^2 \rangle_{pp}}$$



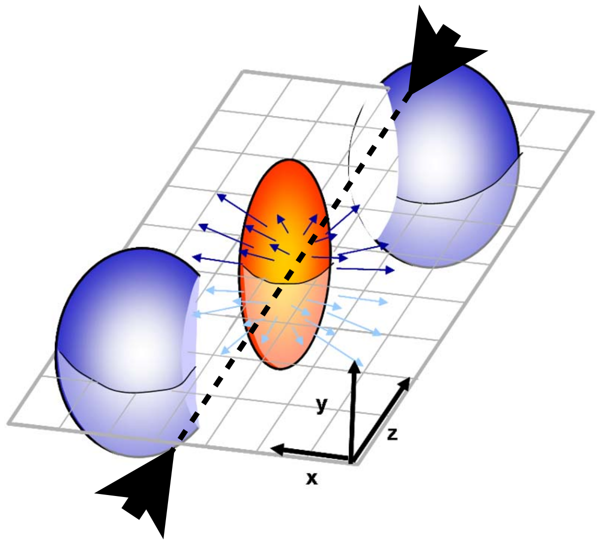
TM1: Zhao et al. arXiv:1102.2194

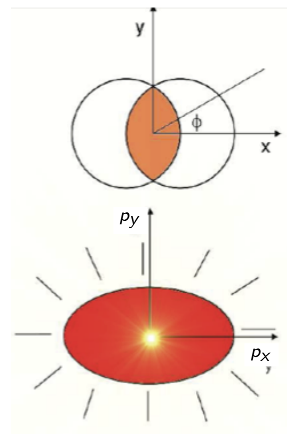
TM2: Zhou et al. arXiv:1401.5845

- Strong energy dependence of r_{AA}
- Transport models work reasonably well
- Considered as recombination signature

Run 2 **➡Higher statistics -> more centrality bins**

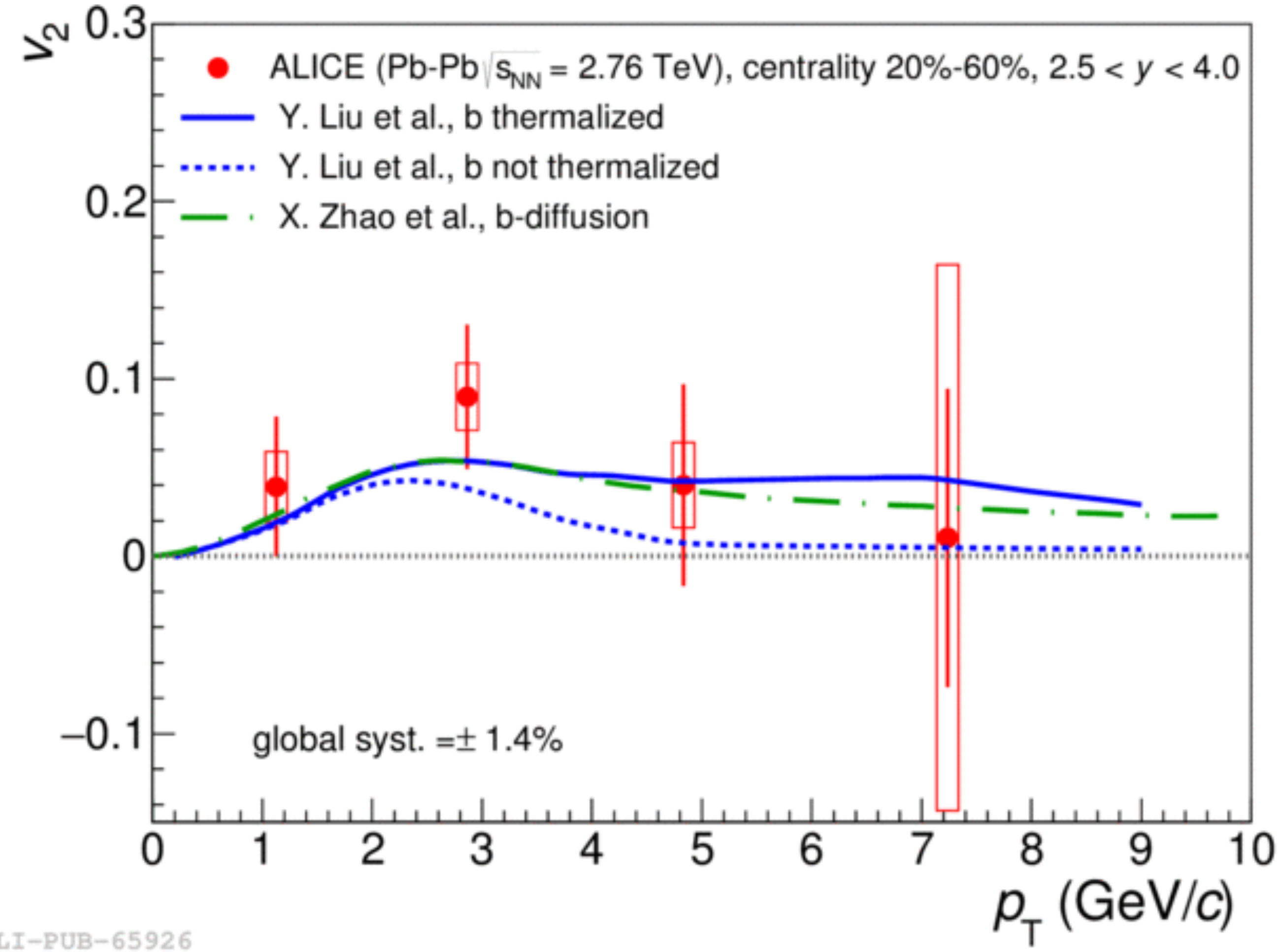
J/ψ flow in Pb-Pb





$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n(\phi - \Psi_{RP})\right)\right)$$

PRL 111 (2013) 162301



X. Zhao et al., Nucl. Phys. A904-A905, 611c (2013)
Y. Liu et al., Nucl. Phys. A834, 317c (2010)

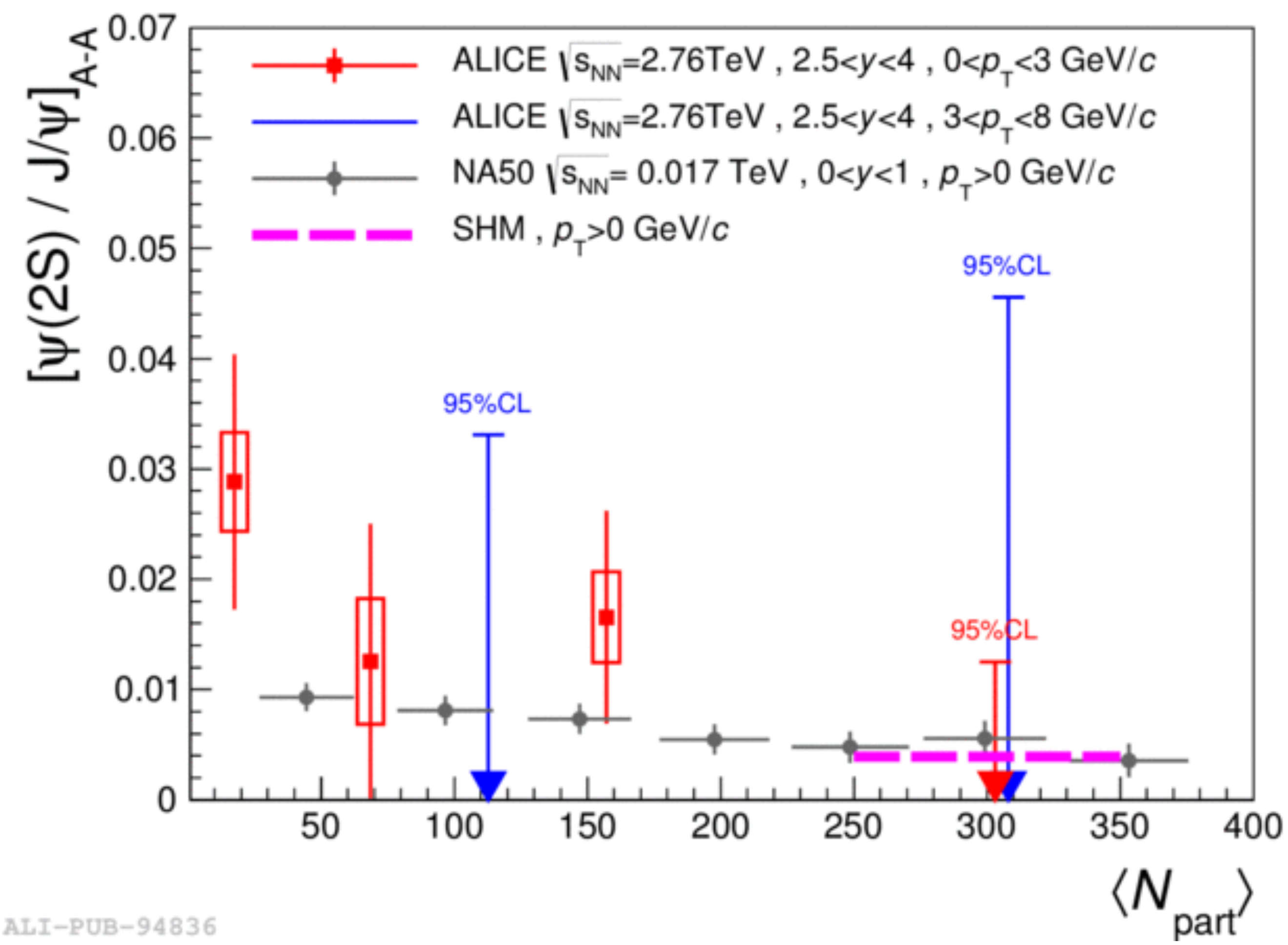
- Indication of a non-zero elliptic flow
- CO-onsidered at a signature of the recombination
- At RHIC J/ψ flow was compatible with zero

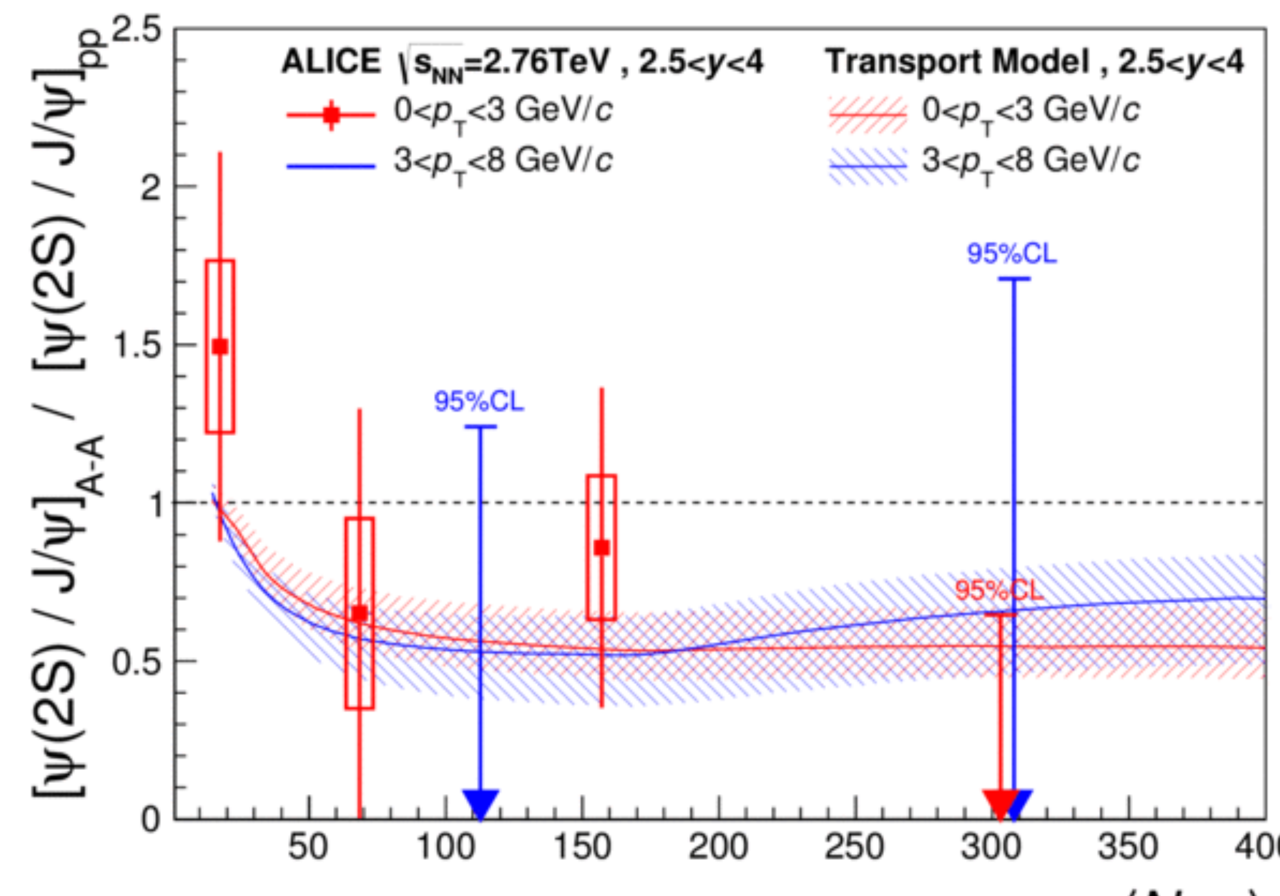
Run 2

➡Higher statistics
➡Conclusion on non zero flow (> 3 sigma)

ψ(2S) R_{AA} in Pb-Pb

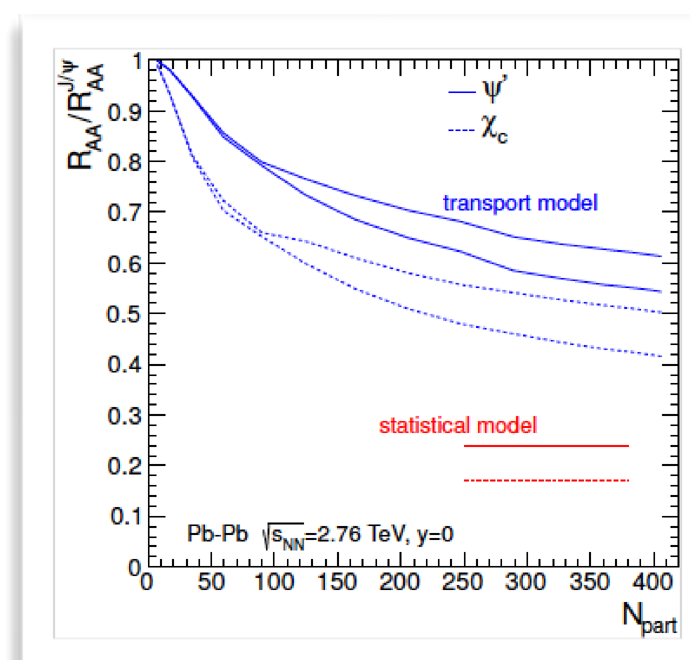
arXiv: 1506.08804





SHM: Andronic et. al., PLB678 (2009) 350-354
TM: Chen et. al., PLB276 (2013) 725-728

- Results are not inconsistent wrt models that describe J/ψ
- Discrimination between statistical and transports models

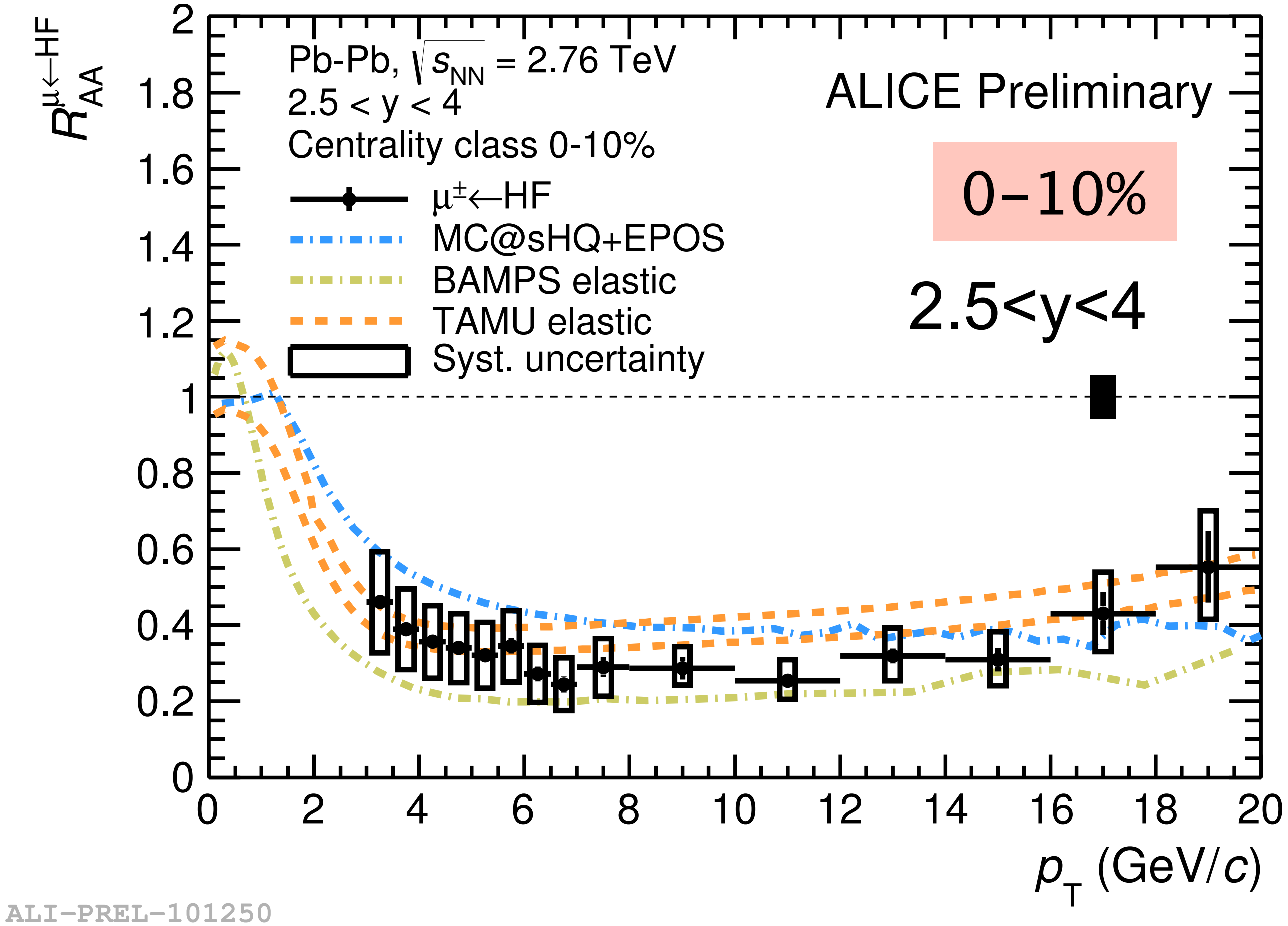


ALICE Upgrade LoI

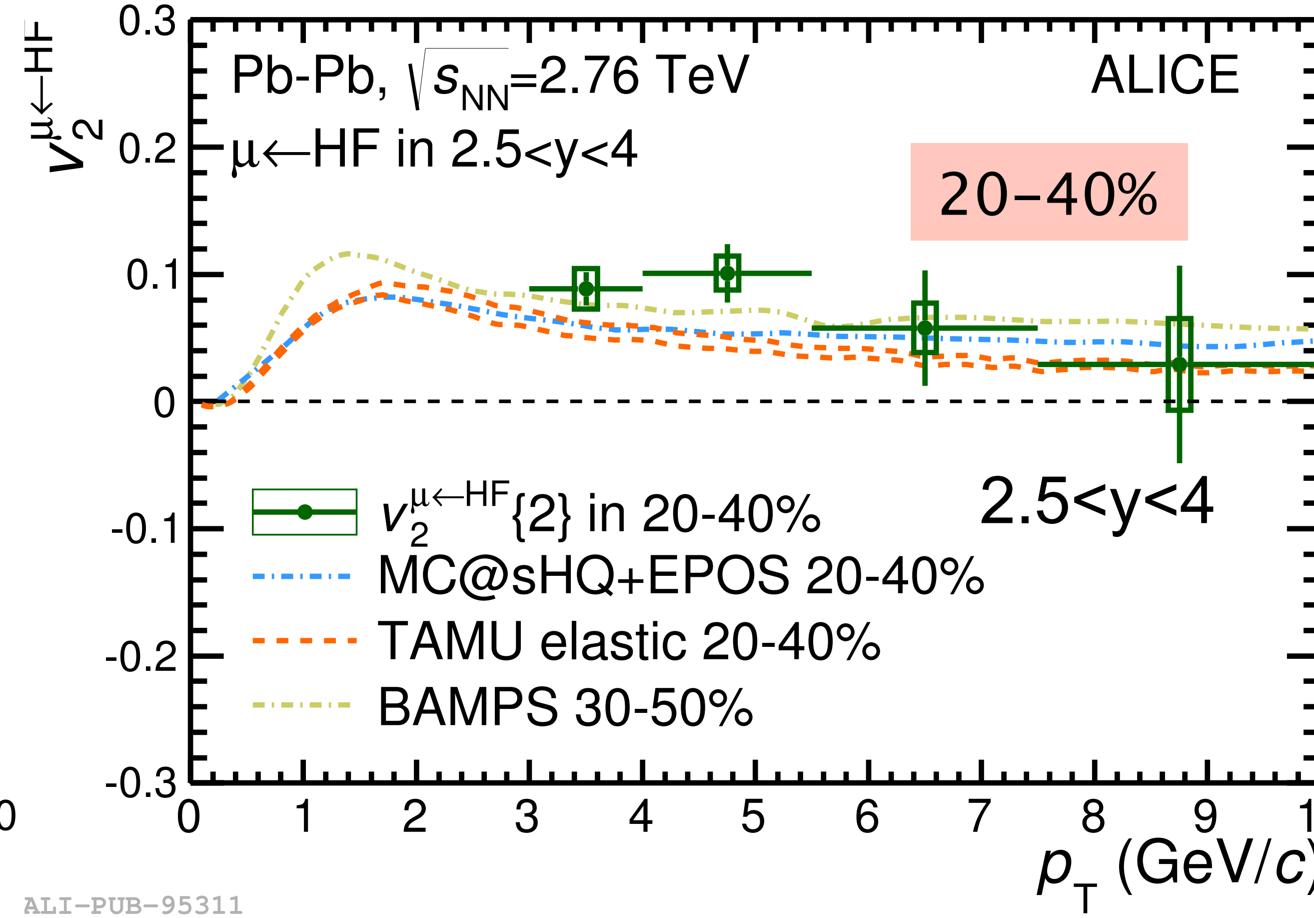
Run 2

- ➡ **Higher statistics**
- ➡ **Model test (Statistical vs Transport)**

Heavy flavor decays in muon



arXiv:1507.03134



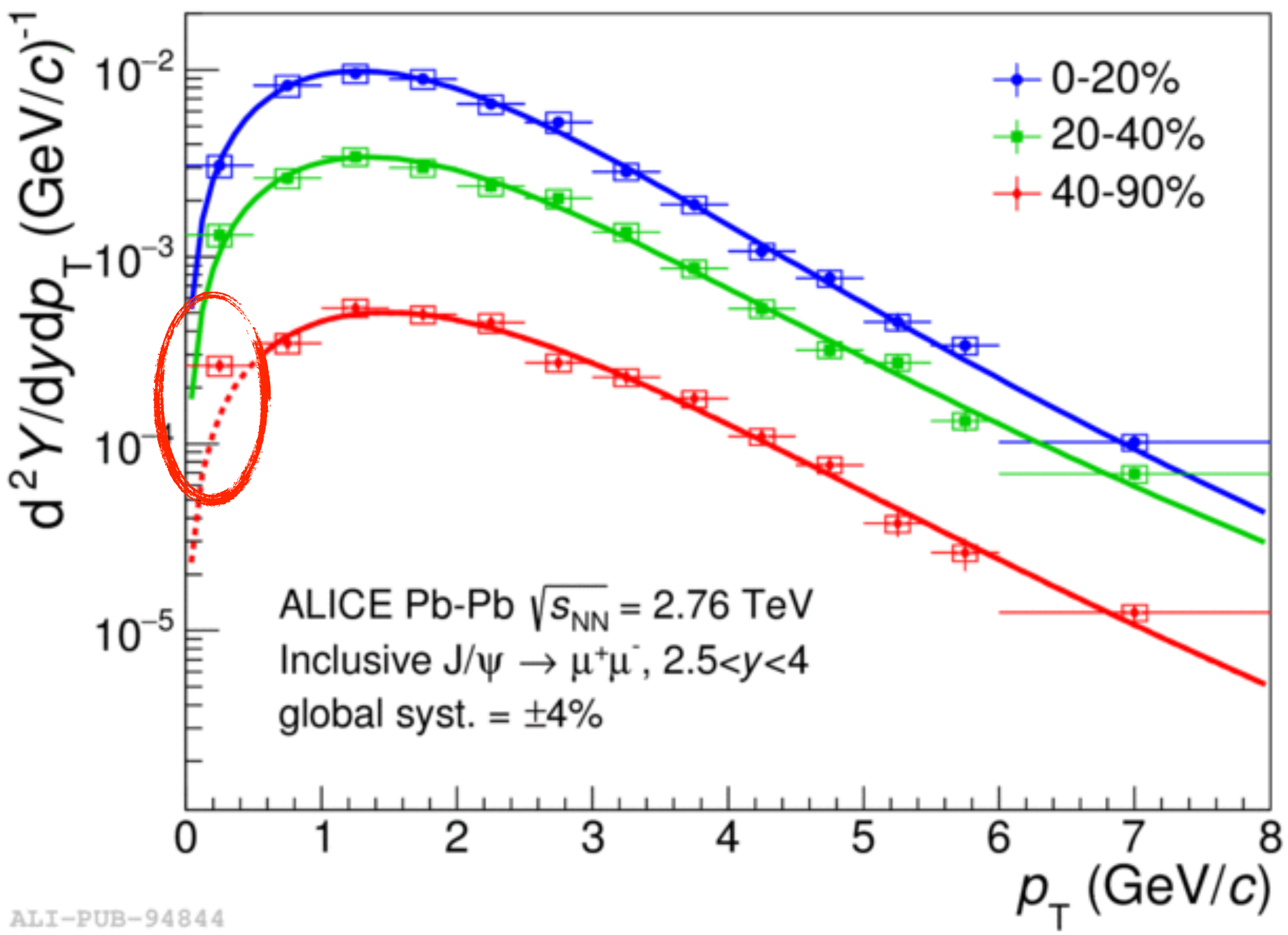
- Suppression observed for central collisions
- p_T > 3 GeV/c to control the background subtraction
- Models with in-medium energy loss gives the trend

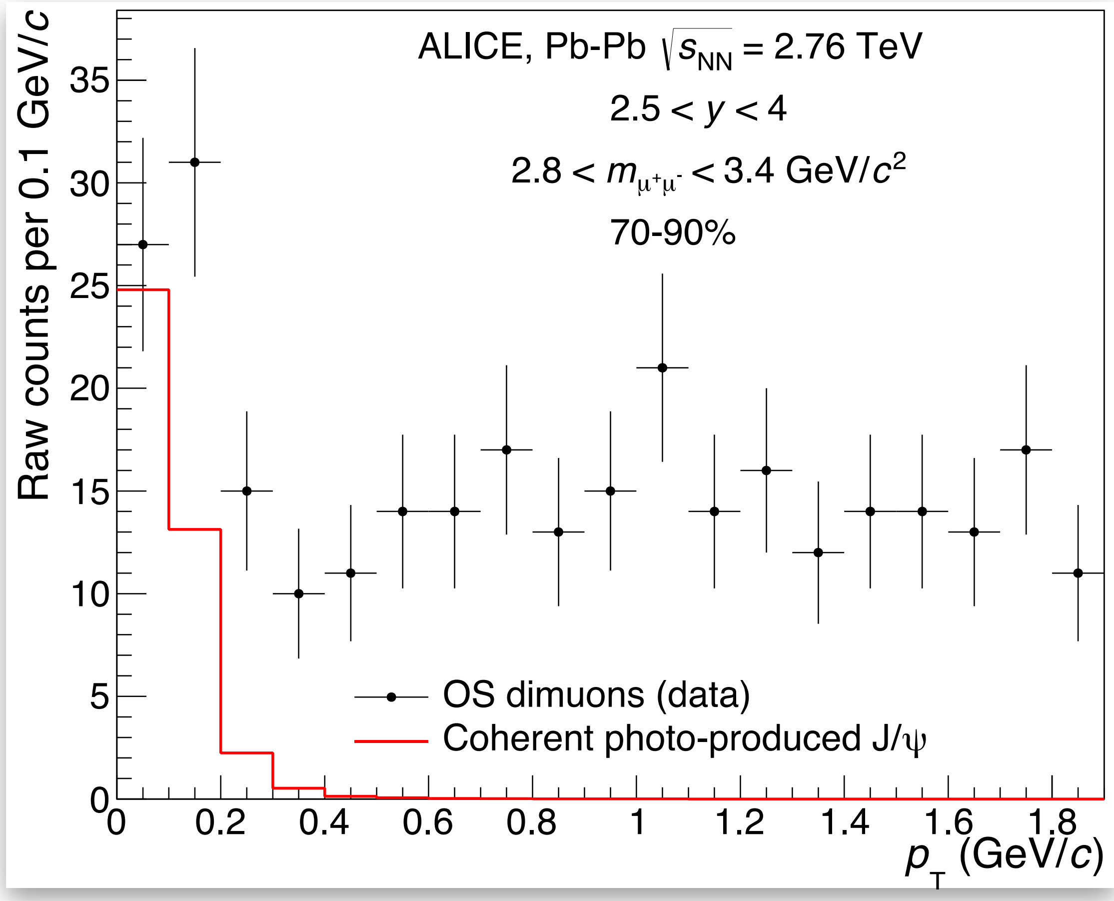
- Positive flow observed
- Models seems to underestimate the data

Run 2 **➡Higher p_T range**

J/ψ photoproduction in Pb-Pb (hadronic coll.)

arXiv:1506.08804



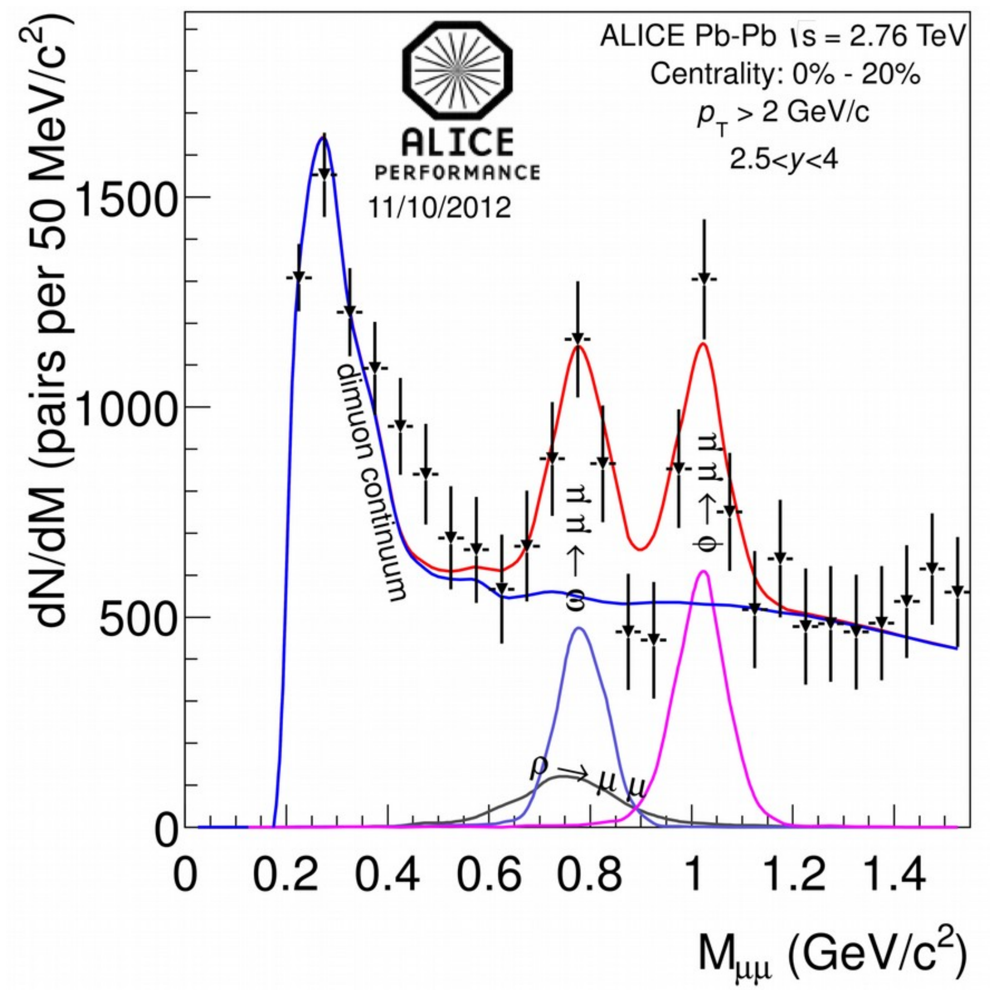


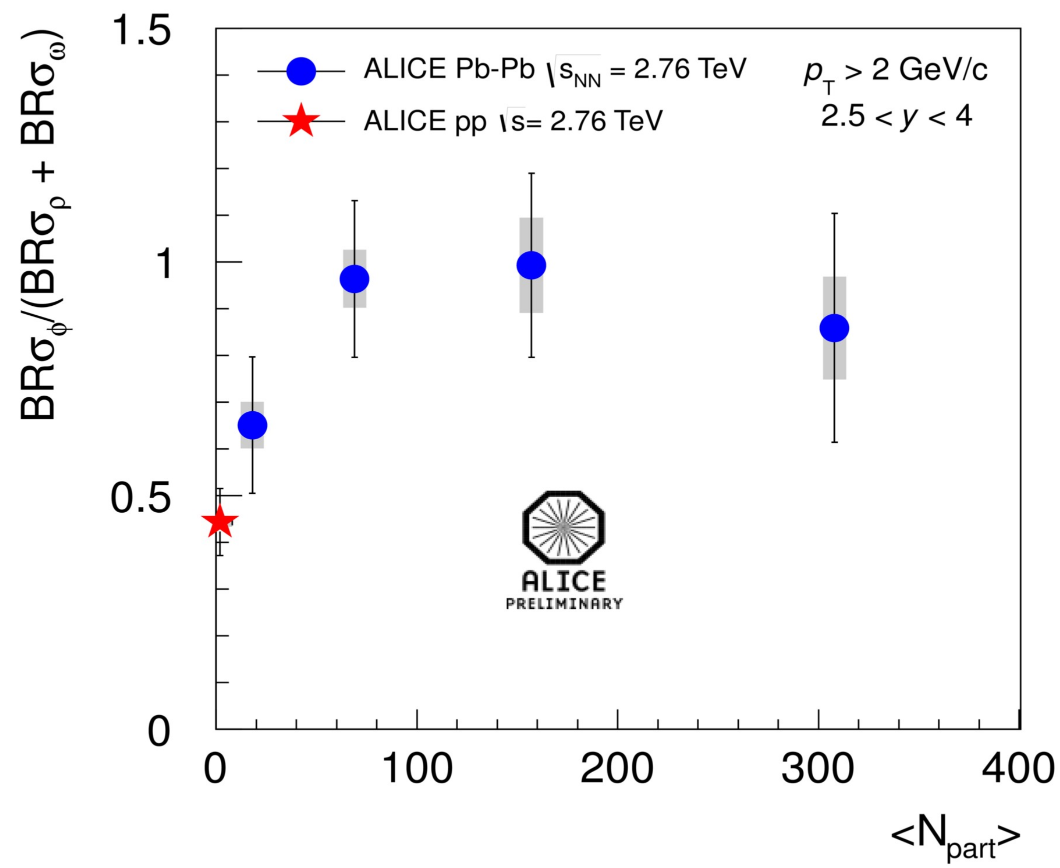
- Excess observed in peripheral collisions
- Could be from coherent J/ψ photoproduction (like in ultra peripheral collisions)

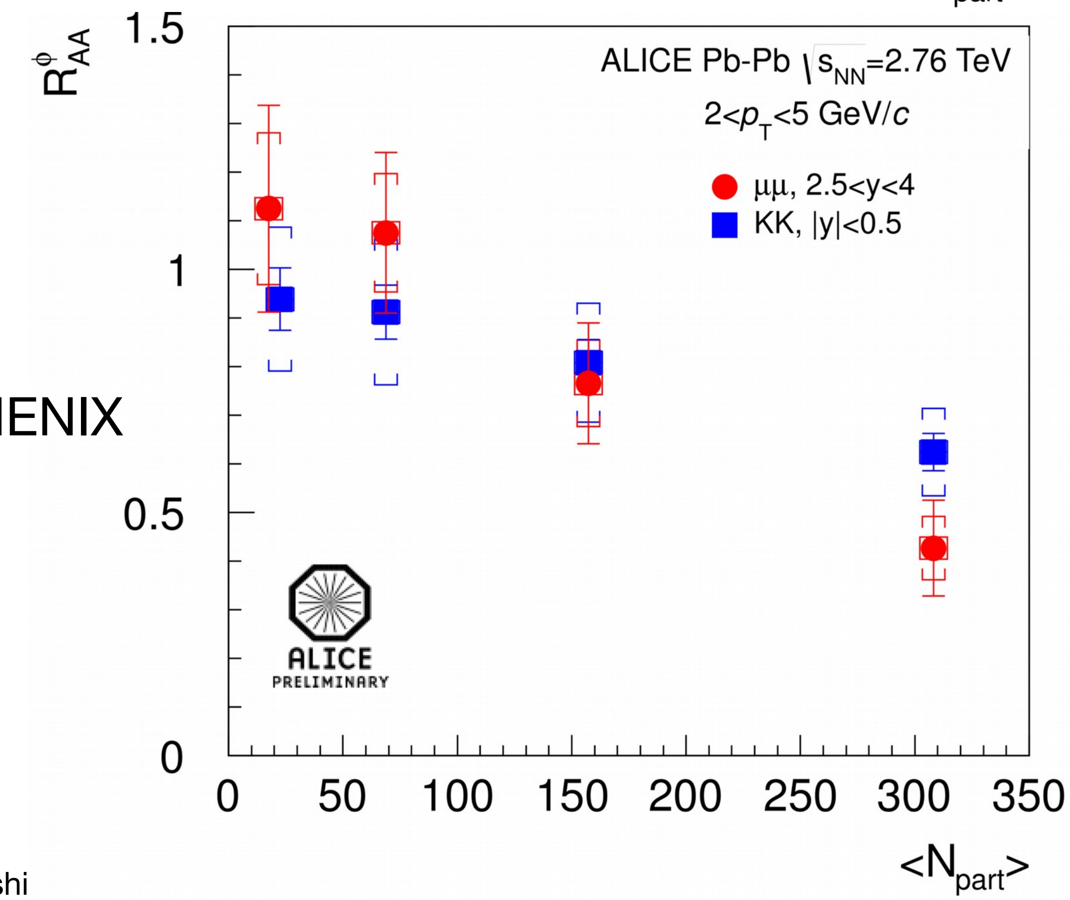
Run 2

➡Higher statistics
➡Photoproduced J/ψ used as probe?

Low masses in Pb-Pb



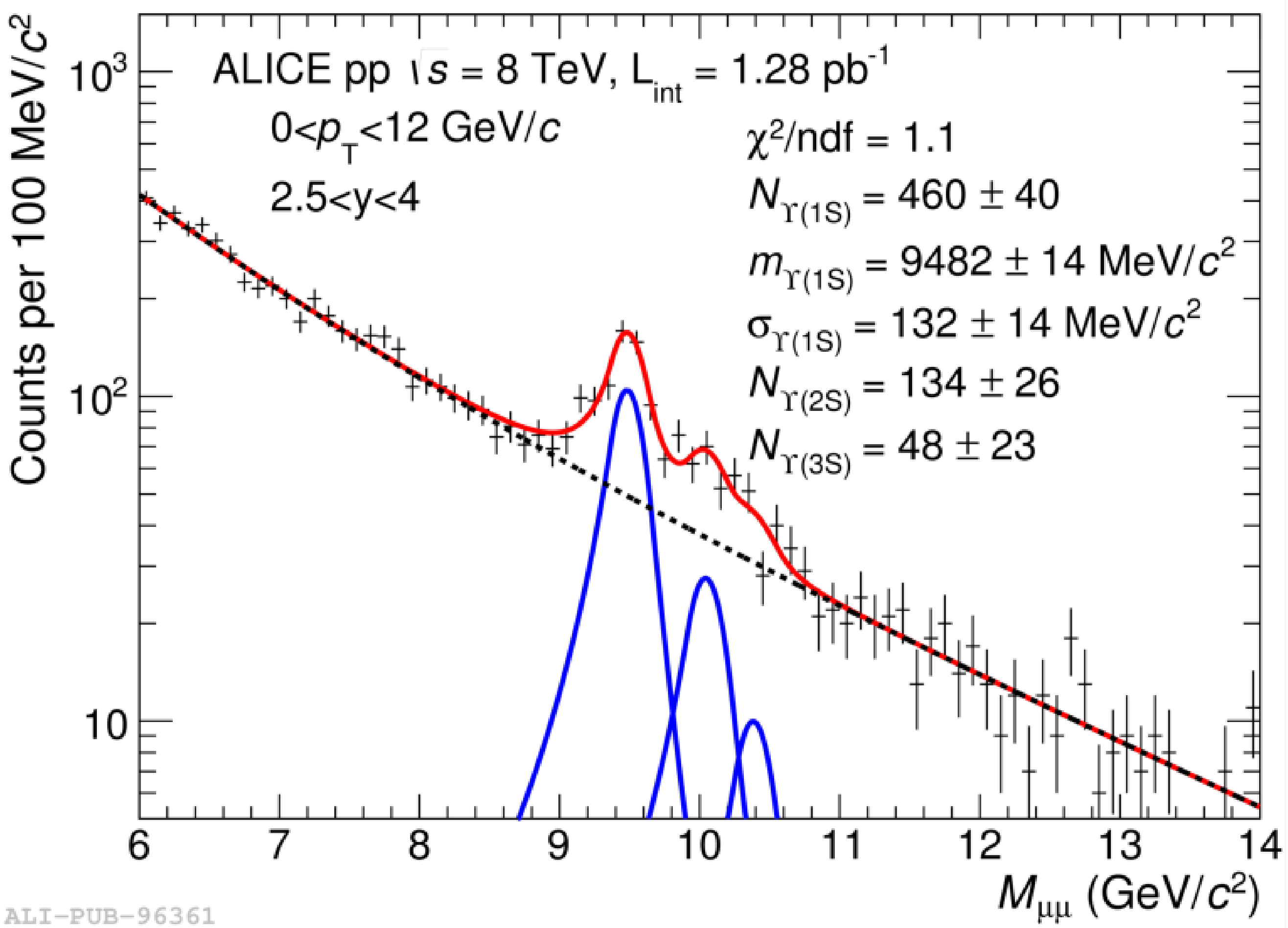


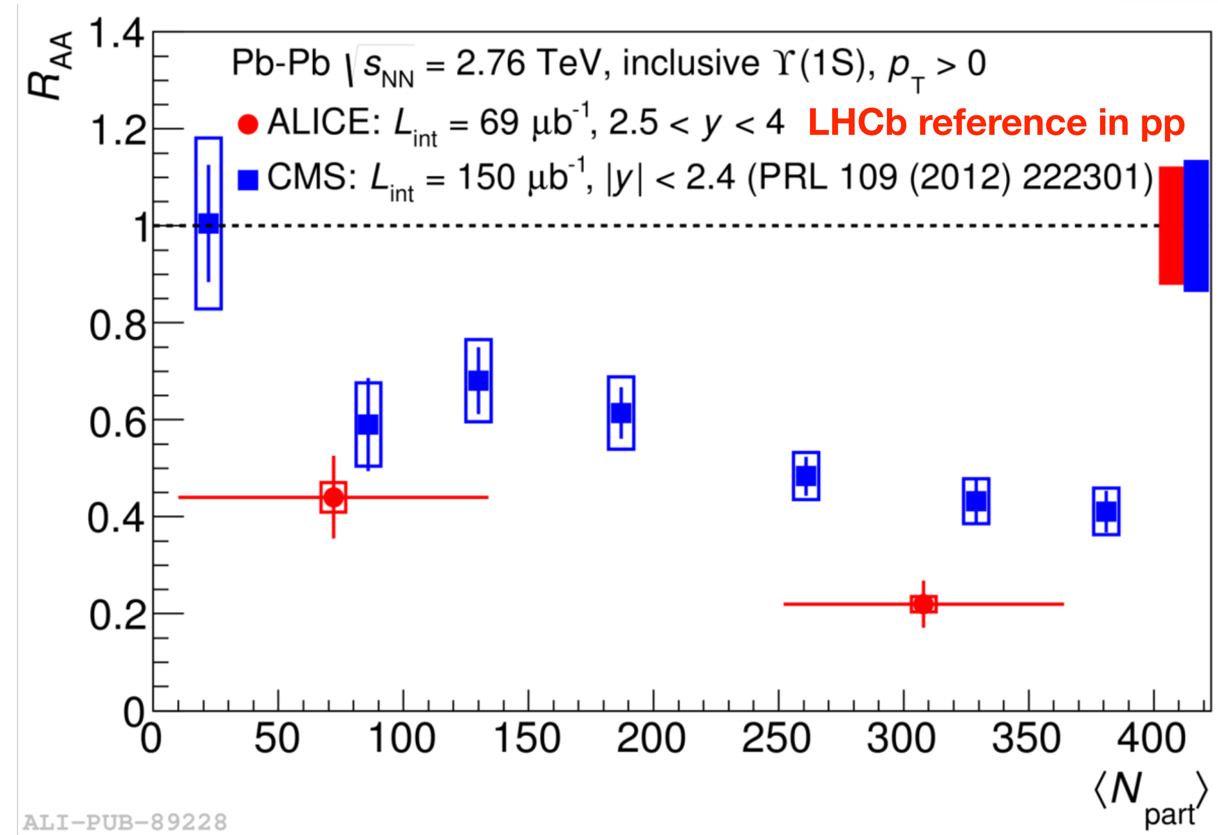


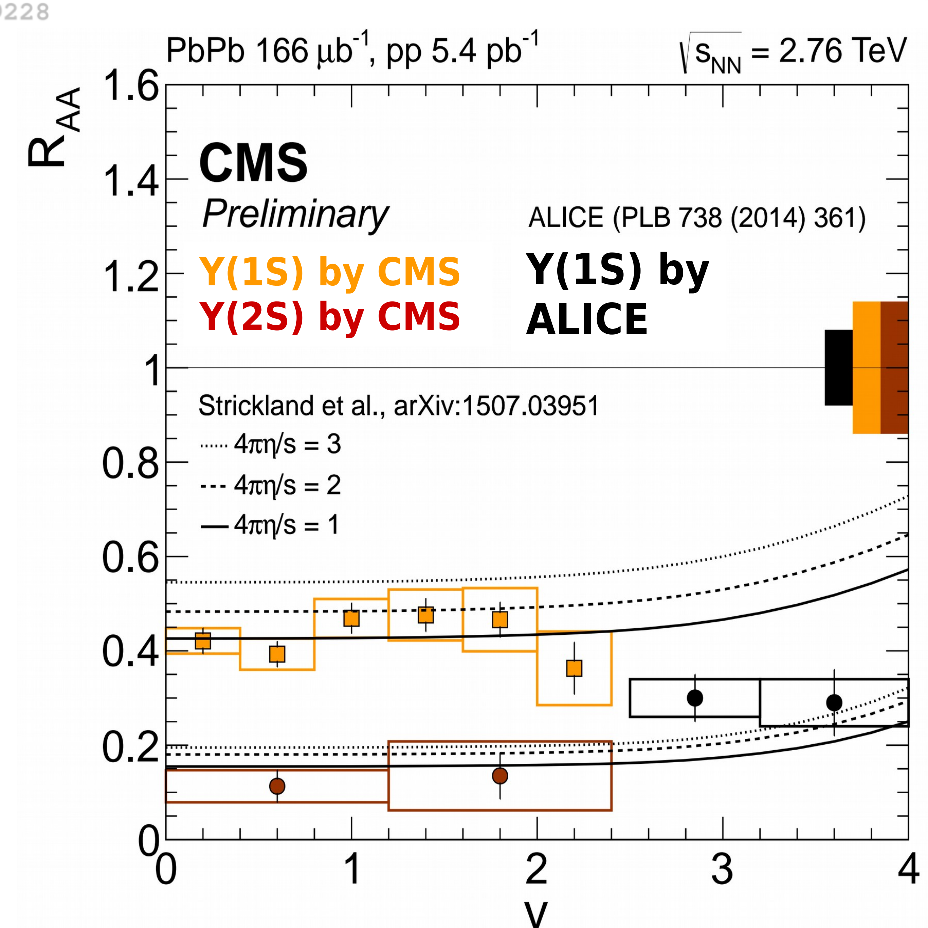
- $\phi/(\rho+\omega)$ increase from pp to Pb-Pb (saturation)
- R^ϕ_{AA} : Similar trend observed in Au-Au collisions @ PHENIX

Run 2
- ➡ **Higher statistics**
- ➡ **Improve systematics (?)**

Upsilon R_{AA} in Pb-Pb







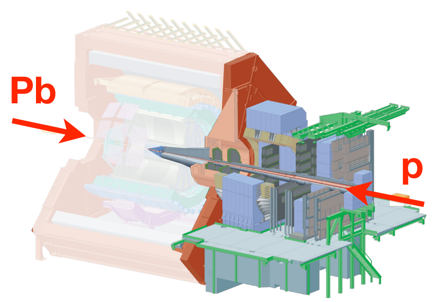
- Y Strongly suppressed (more wrt central rapidity)
- Y vs y: rather flat now with CMS new pp reference!

Run 2

- ➡**Higher statistics**
- ➡**Differential studies**

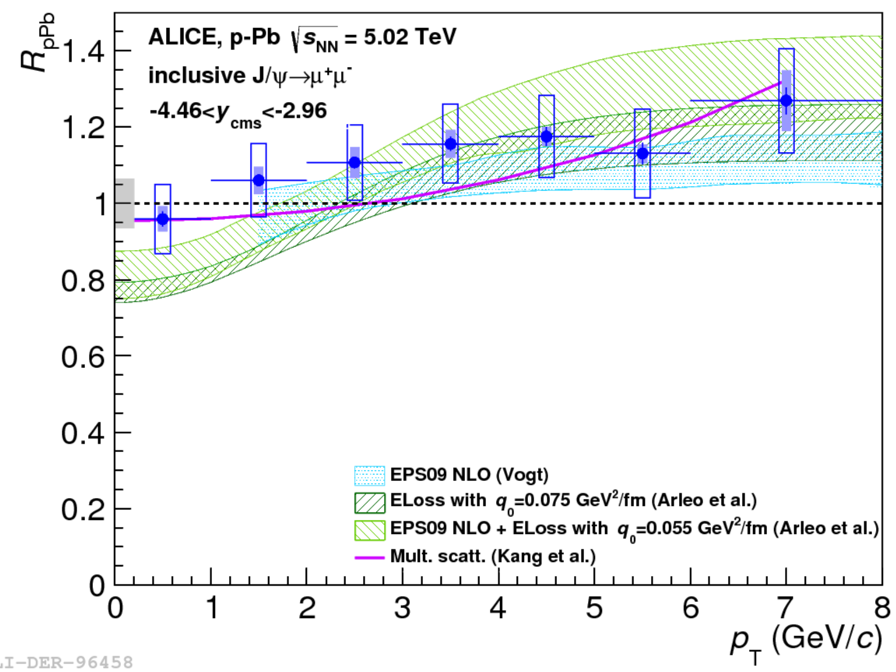
Quarkonia in p-Pb

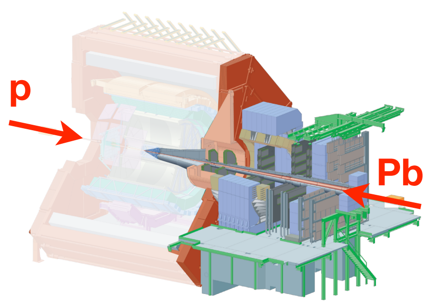
J/ψ vs p_T



x = 1-5 10^{-2}

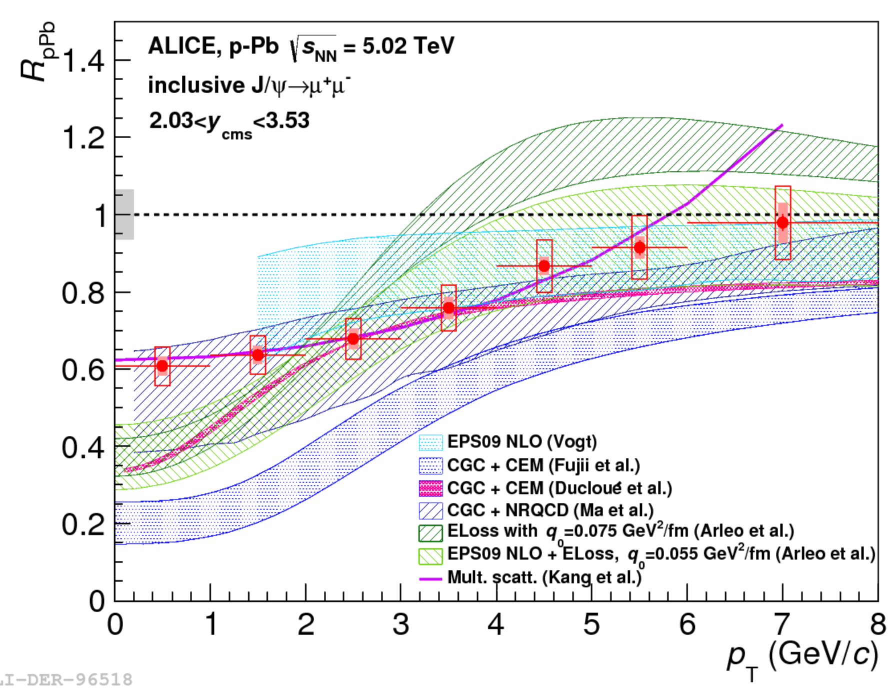
Backward y



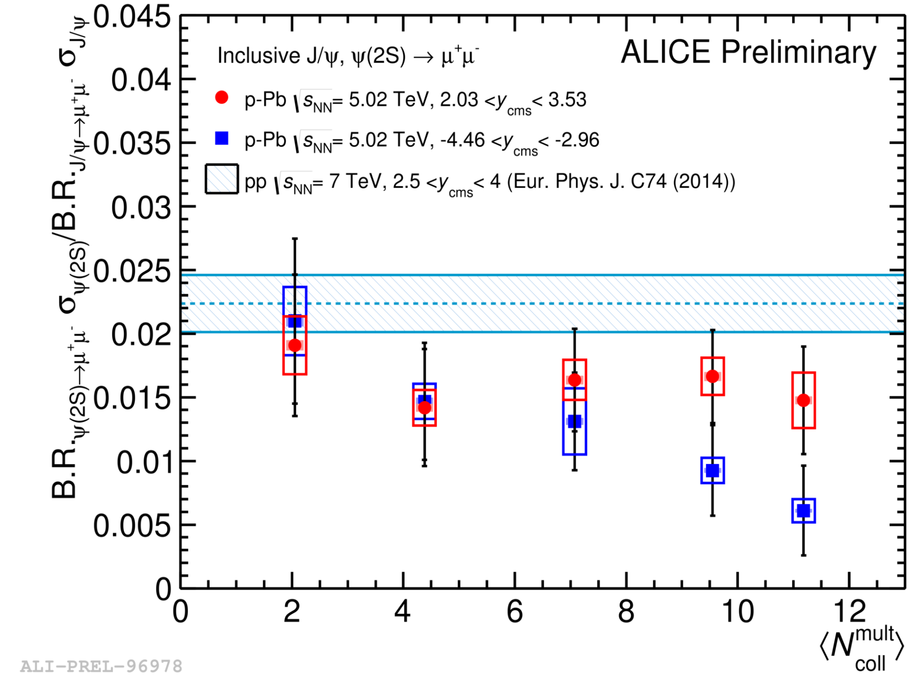


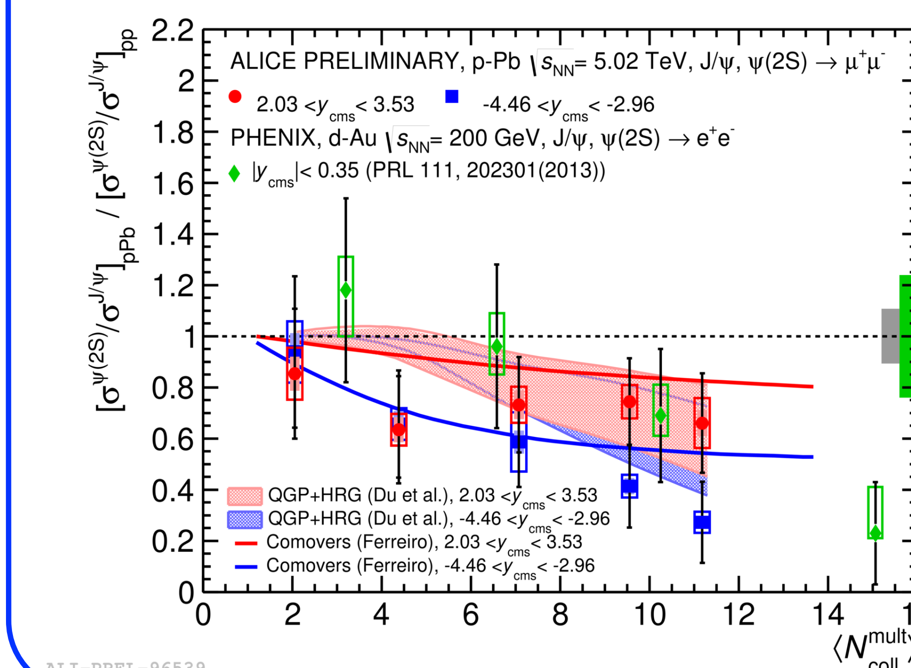
x = 2-8 10^{-5}

Forward y



ψ(2S) / J/ψ vs N_{coll}





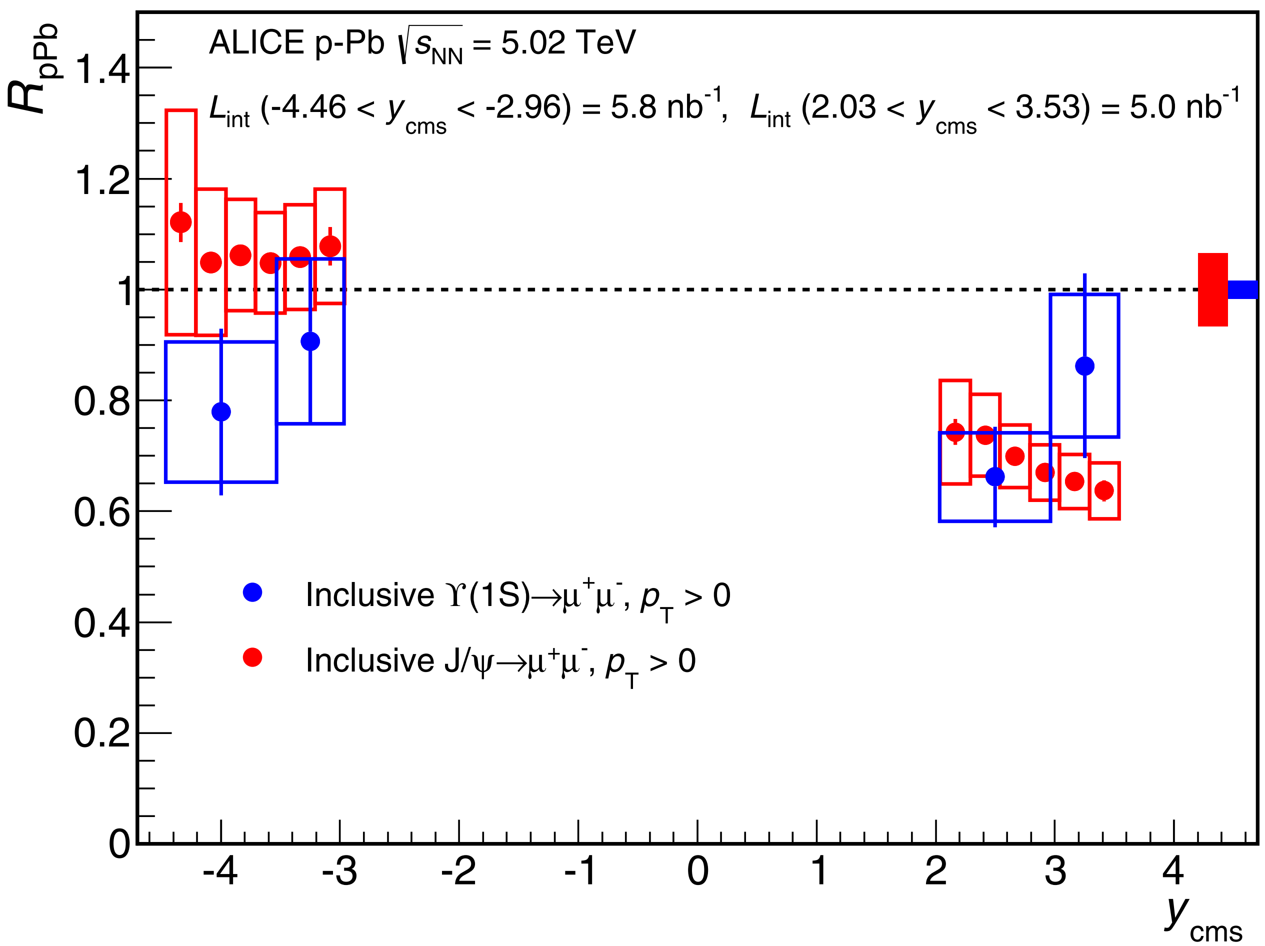
- J/ψ: Backward (almost) no nuclear effets, forward => suppression @ low p_T
- ψ(2S): More suppressed than J/ψ. Comover model gives the trend

Run 2 ➡**statistics x 3**

Upsilon in p-Pb

Phys. Lett. B 740 (2015) 105

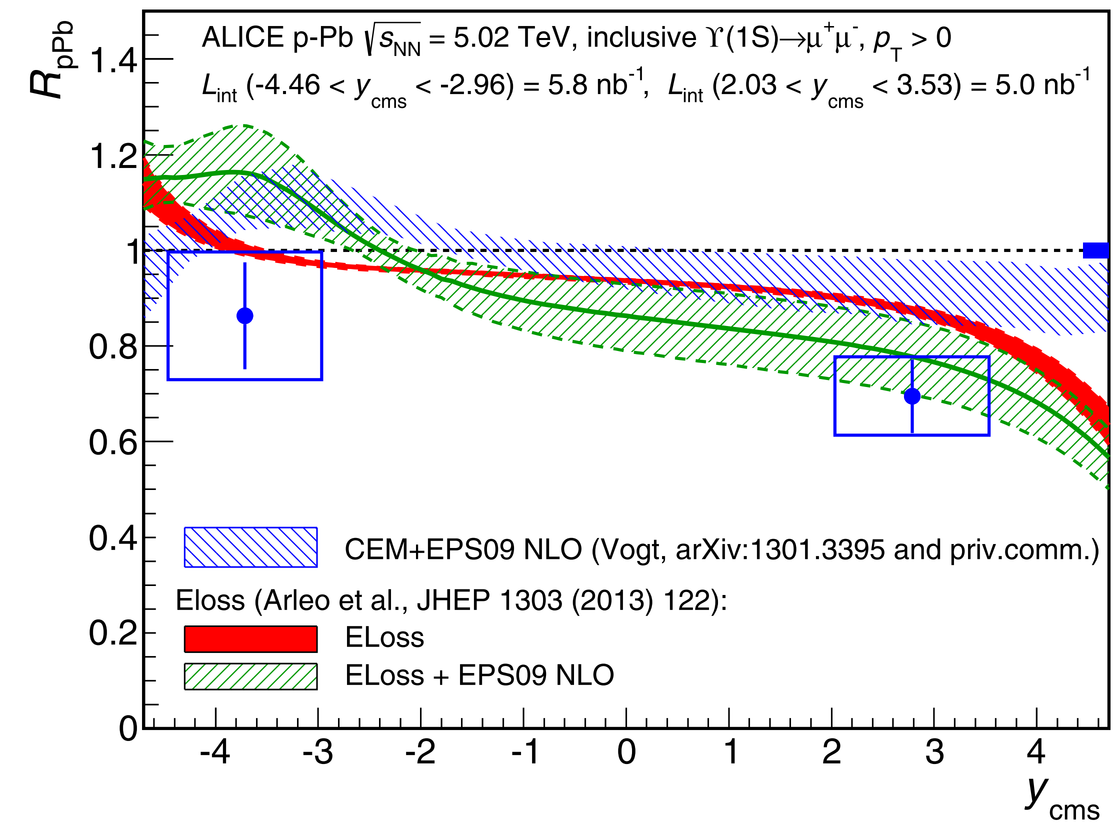
J/ψ vs Υ

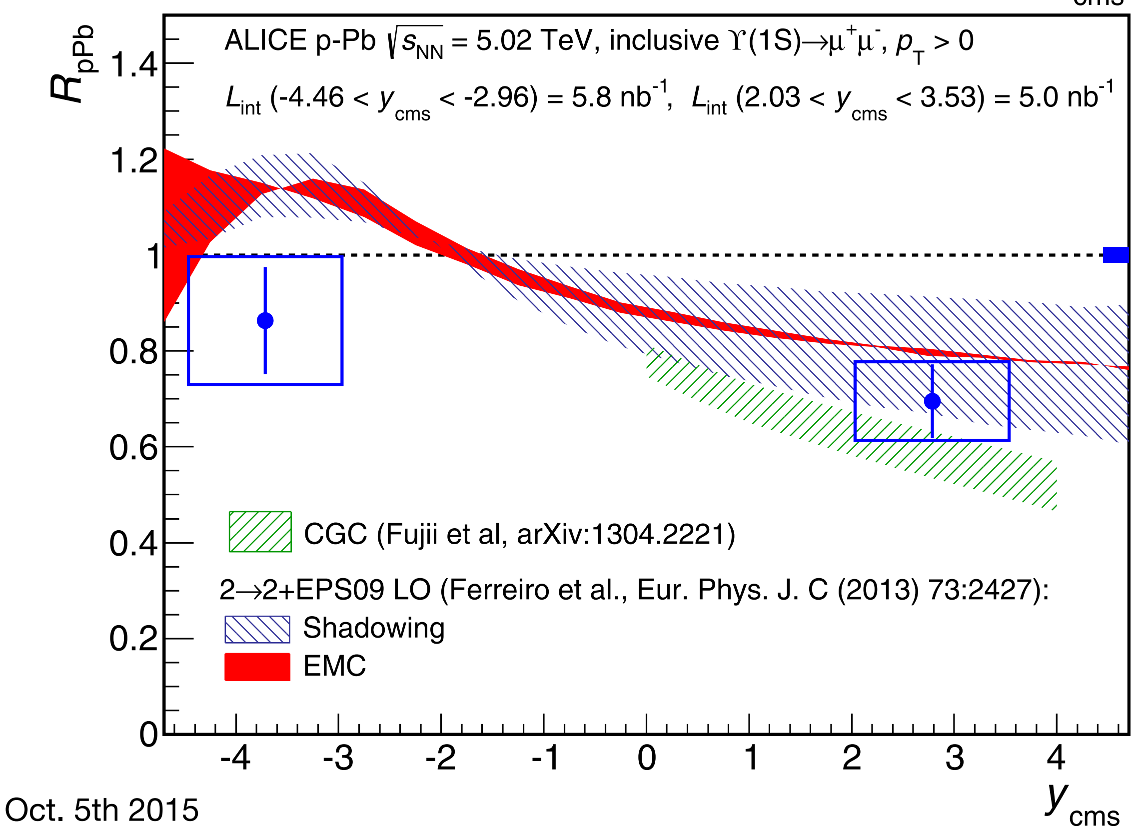


- J/ψ and Υ similar suppression (within errors bars!)
- Shadowing and/or (coherent) energy loss models overestimate the data

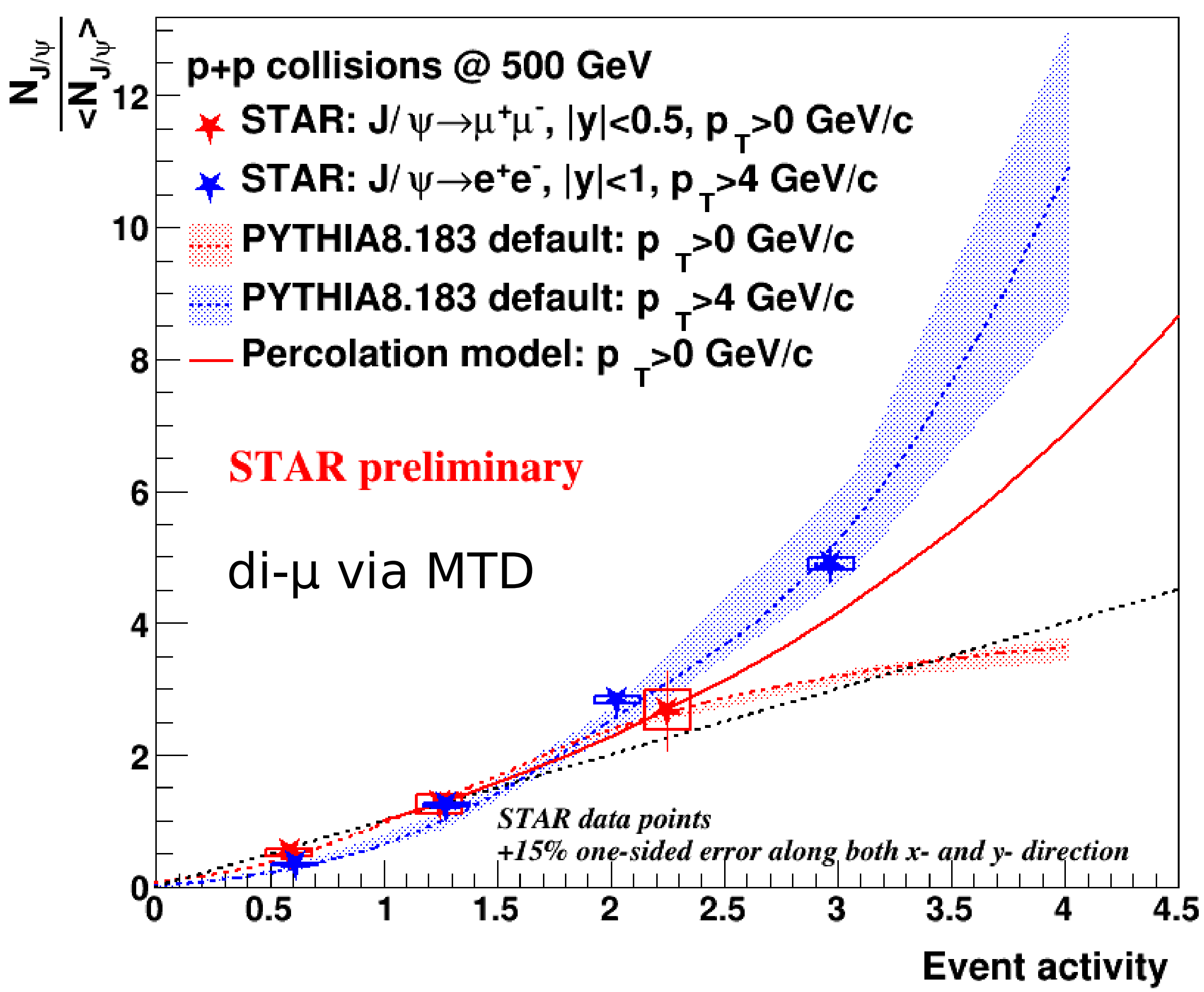
Run 2 **➡statistics x 3**

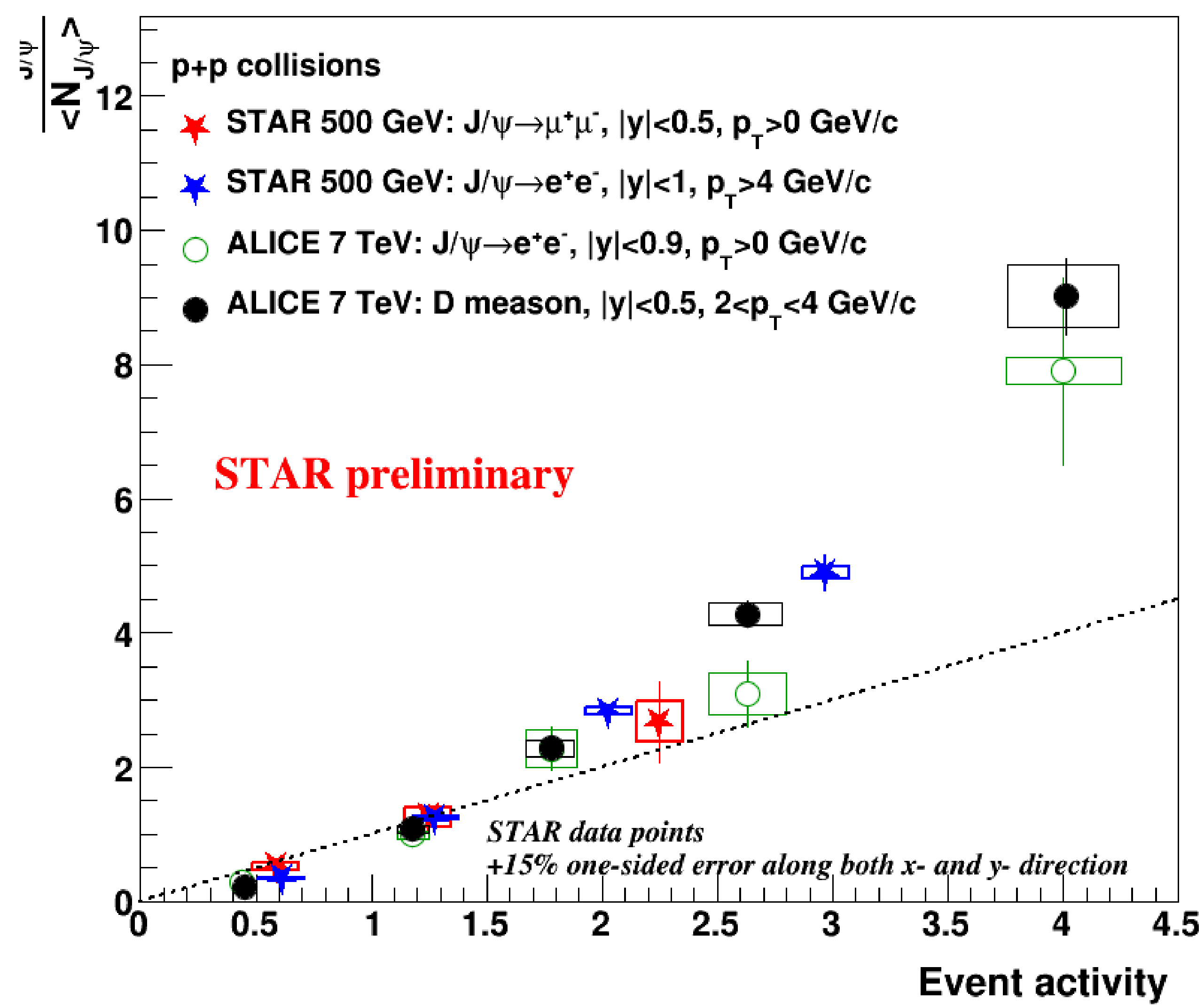
Υ vs models





J/ψ vs multiplicity in pp





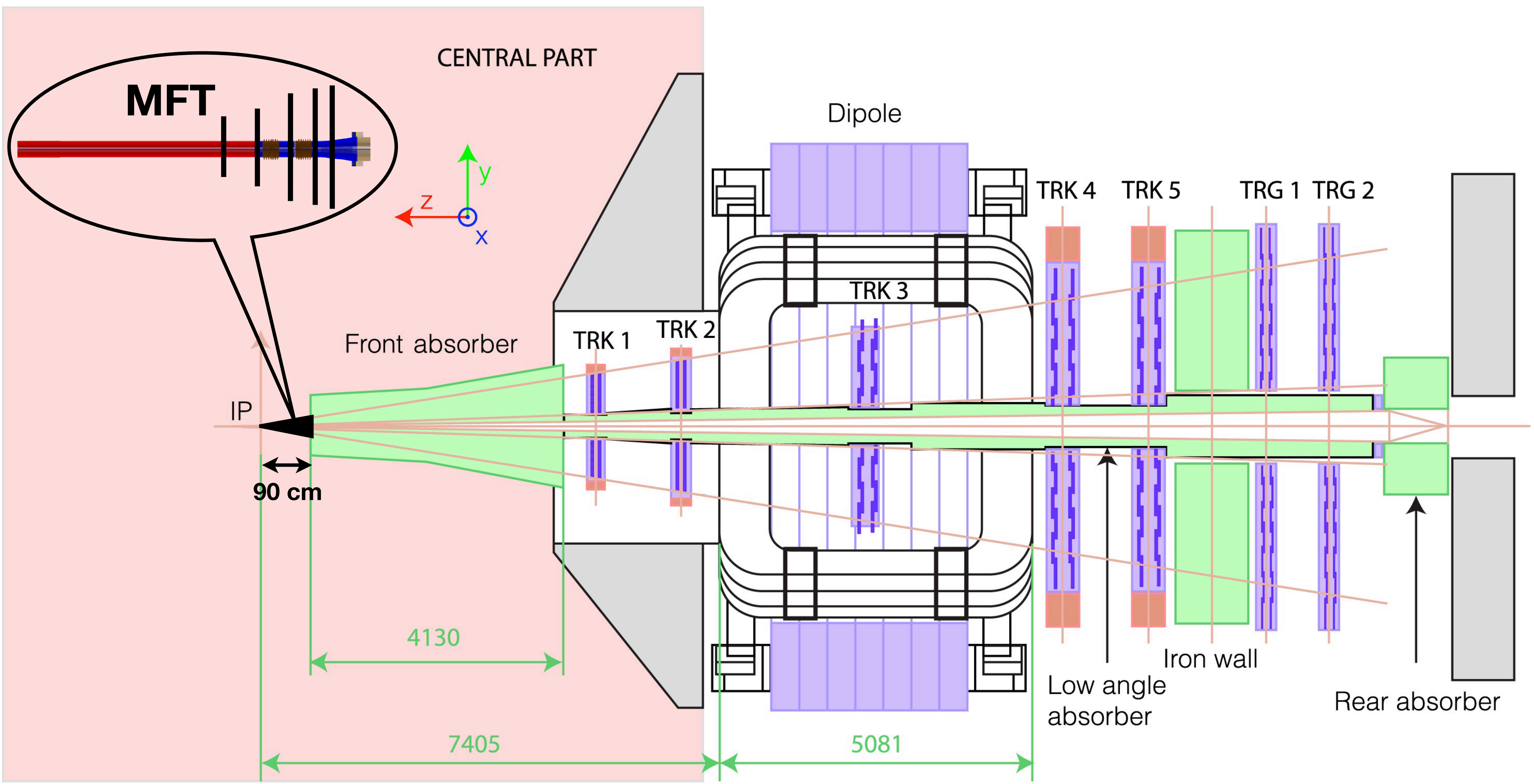
- PYTHIA 8 and Percolation (Ferreiro et. al. PRC 86 (2012) 034903) fairly reproduces the data
- Need higher event activity range to disentangle the models

Run 2 ➡**statistics x ~50**

Upgrades: MCH and MID

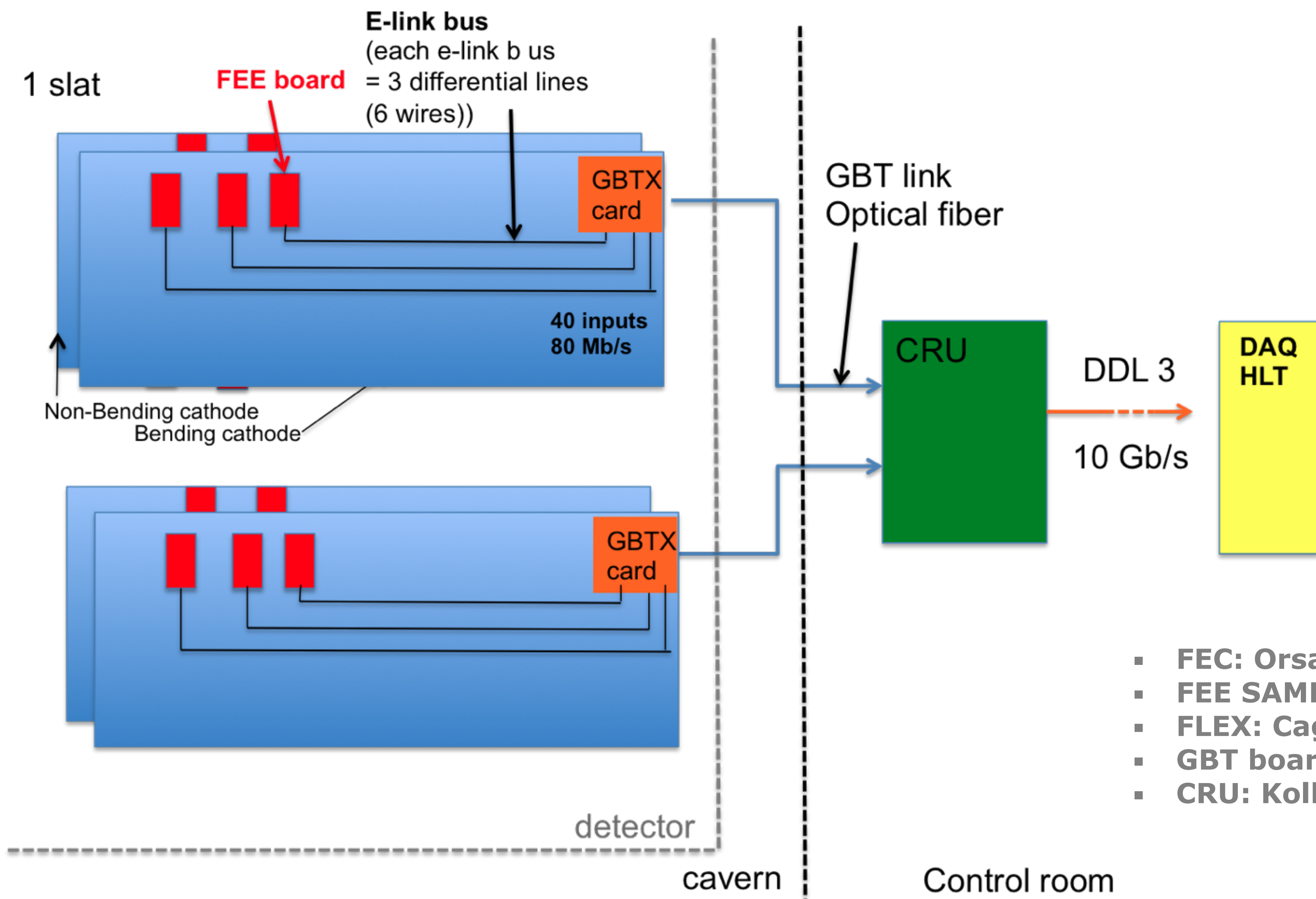
The Upgraded MUON Spectrometer

- HL-LHC start after the LS2 (mid 2018 to end of 2019)
  - Upgraded Pb-Pb luminosity: $L=6\ 10^{27}\ cm^{-2}s^{-1}$ (50 kHz of int. rate) => **DAQ @ 100 kHz**
  - Present nominal LHC luminosity in Pb-Pb: $L=10^{27}\ cm^{-2}s^{-1}$ (8 kHz of int. rate) => **DAQ @ 1 kHz**
- Need to upgrade the FEE & readout of MUON Trigger and Tracking
- Add the new Muon Forward Tracker (MFT)



MCH Electronics and readout scheme

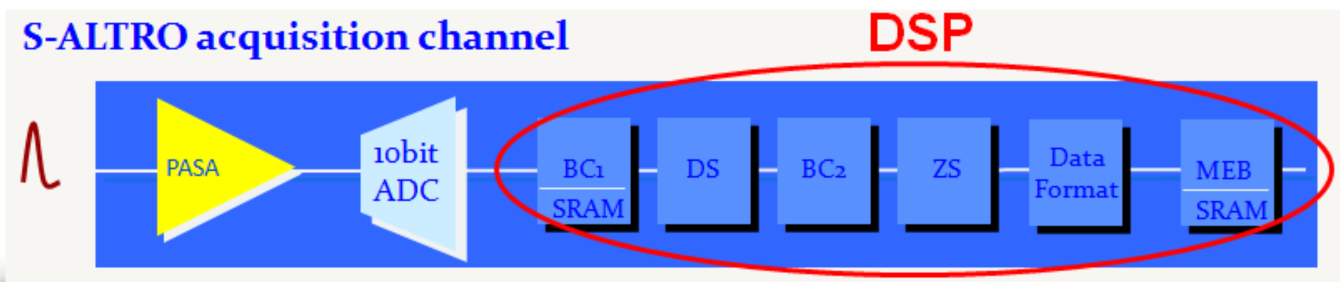
- New FEE based on SAMPA chip (1.1 M channels, ~18k boards of 64 ch)
- New e-link data buses (external to detectors for slats, new PCB for quadrants)
- GBT concentrator card (40 x 80 Mb/s inputs, 3.3 Gb/s fiber output): ~500 cards
- Common Readout Unit (CRU) interfaced to the DAQ: ~500 inputs, ~20 boards



- **FEC: Orsay**
- **FEE SAMPA: Sao Paolo**
- **FLEX: Cagliari**
- **GBT board: Saclay**
- **CRU: Kolkata / Aligarh**

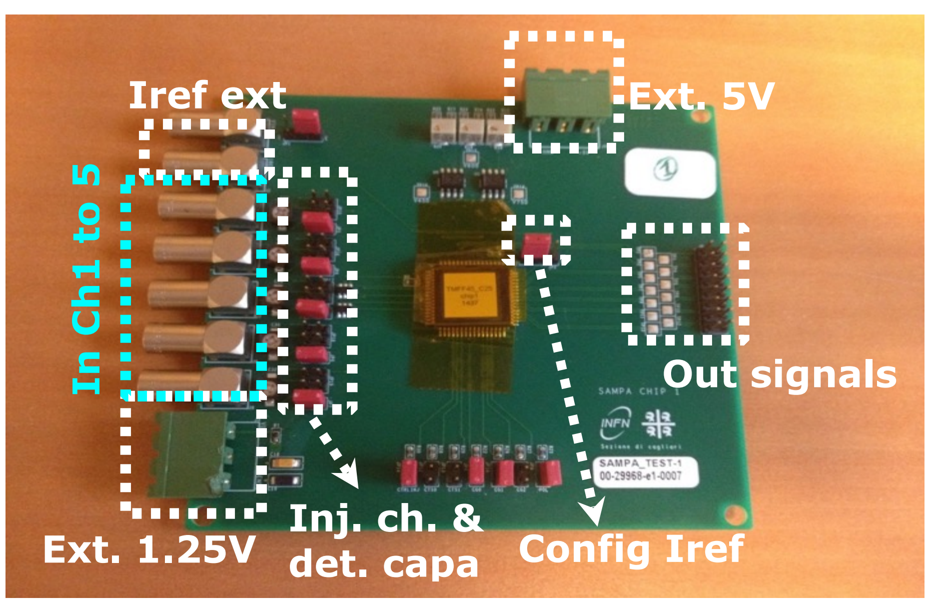
The SAMPA chip

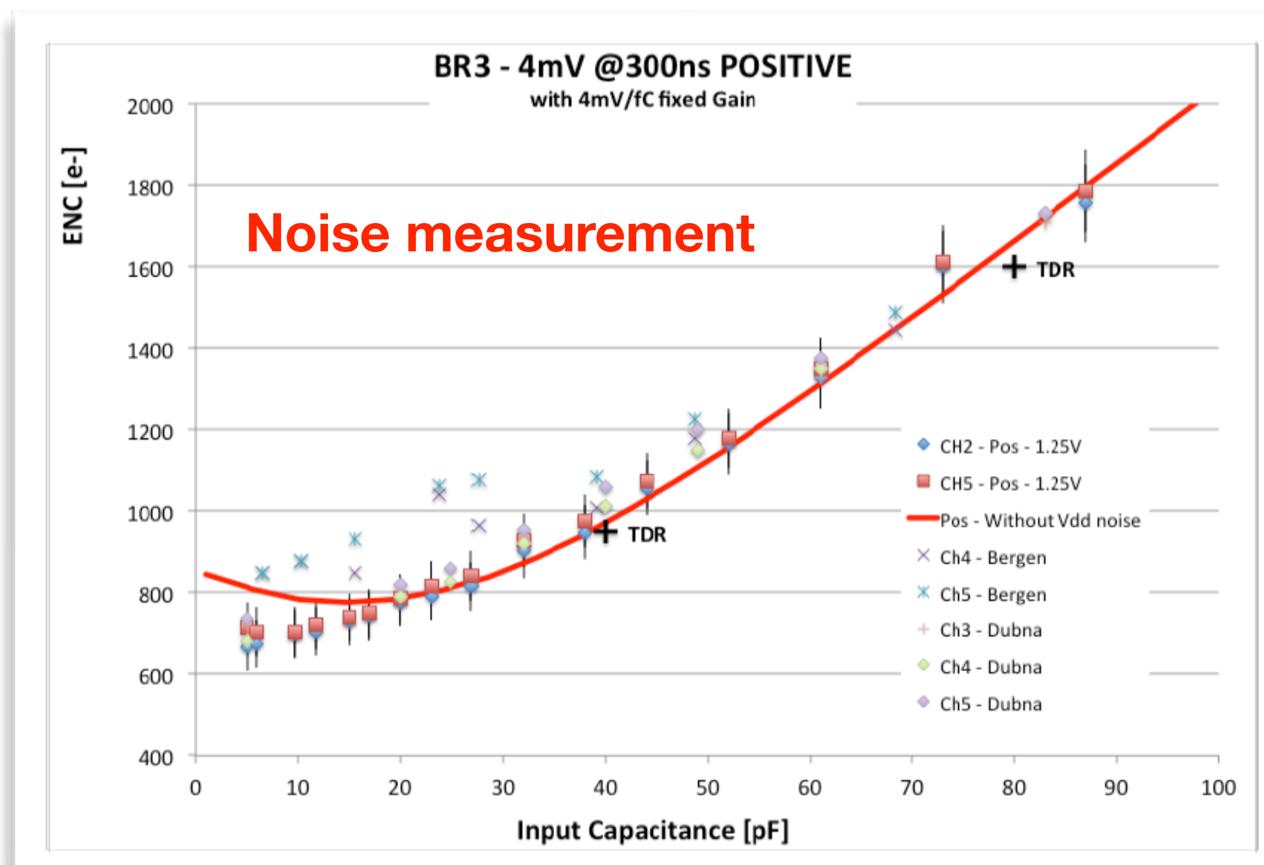
- « All-in-one » (analog & digital) 32 ch chip for MCH (38 k) and TPC
- Based on SALTRO architecture, designed in TSMC 130 nm



  - Analog (pre-amplifier + shaper), continuous sampling @ 10MHz, 10 bits ADC
  - Digital processing (DSP): baseline correction, zero suppression, multi-event buffers, …
  - **Continuous or triggered readout, sampling and readout running in parallel**

- First MPW1 prototype (~analog) tested

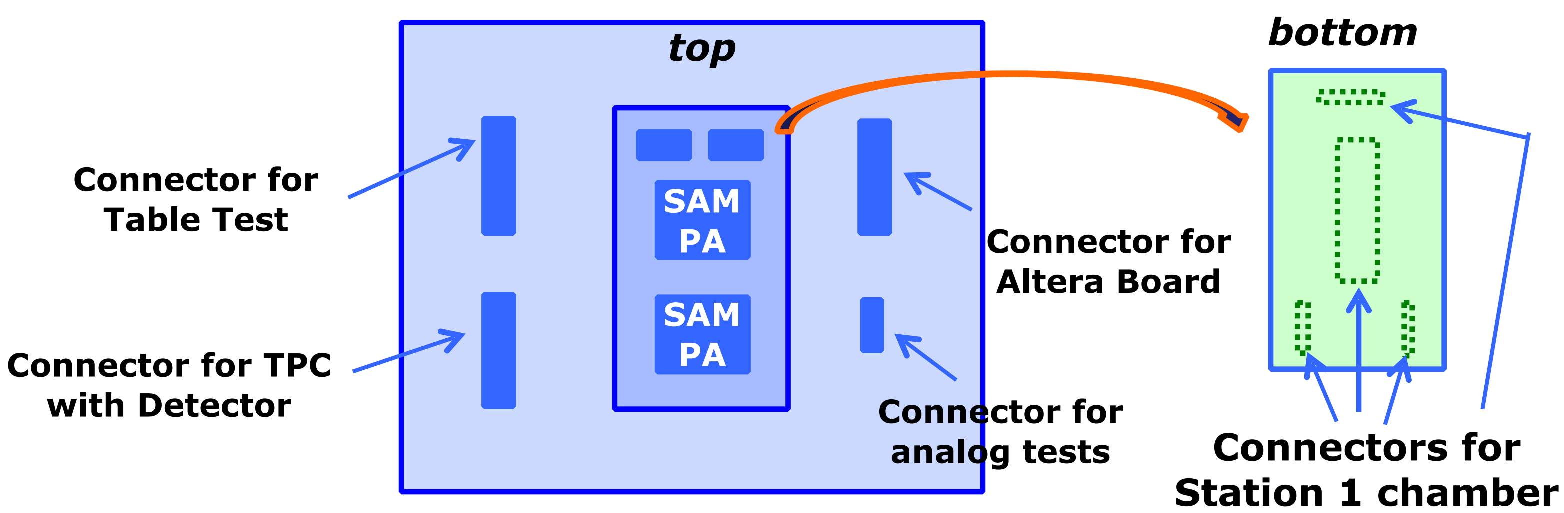


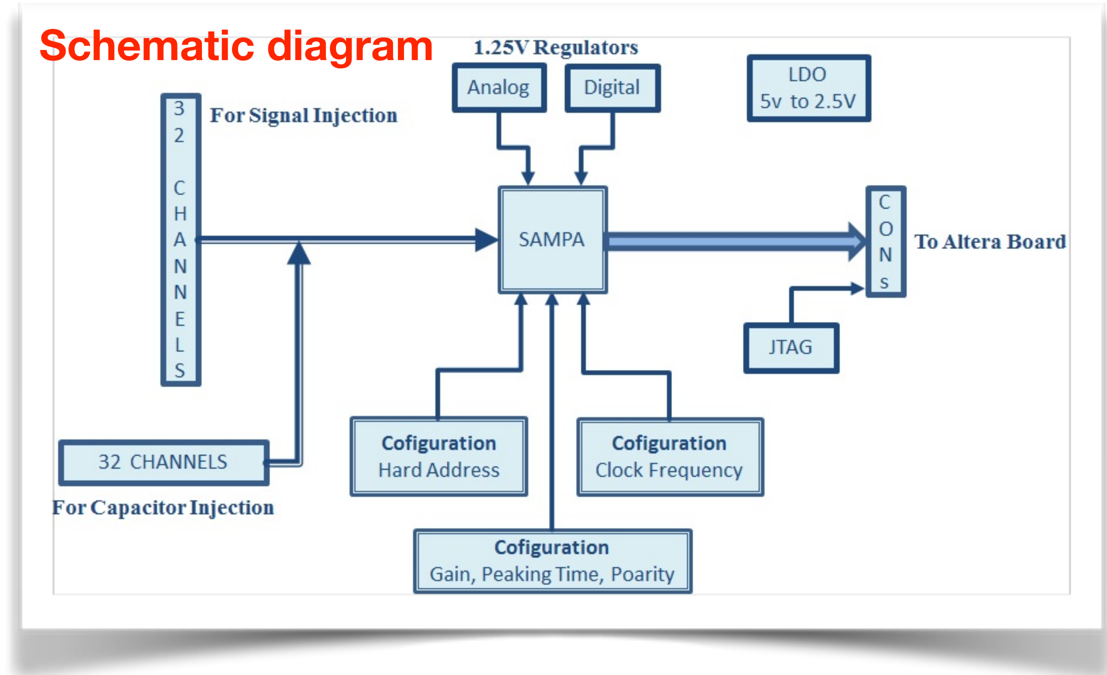


- Next step: Full chip MPW2 (sub. 11/15)

The DualSampa (FEC)

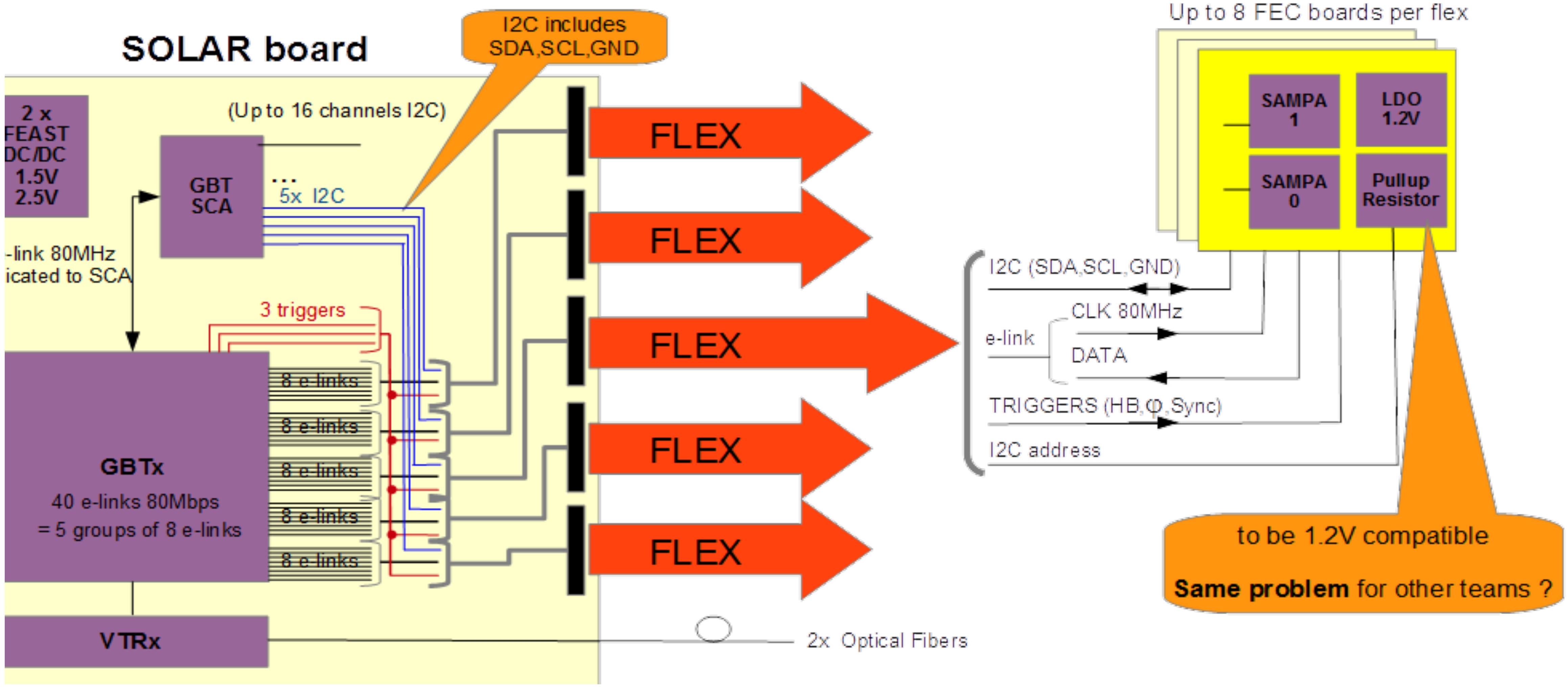
- SAMPA MPW2 (32 channels)
  - MWP2 submission 11/15 => delivery 02/16 (several months of delay wrt original planing)
  - Carrier board for qualification tests (w/ 2 SAMPAs), first schematic diagram done @ Orsay





- DualSampa (32 channels FEC)
  - Design started => we will take advantage of the implementation of MPW2 cards
  - 2 models due to different geometry of Stations 1 and 2 and Stations 3,4 and 5
  - Potential issues: power consumption ~20 mW/ch (1.2 V) wrt ~13 mW/ch presently
    - SAMPA optimisations under study
    - Cooling studies needed (air flow increase sufficient?)

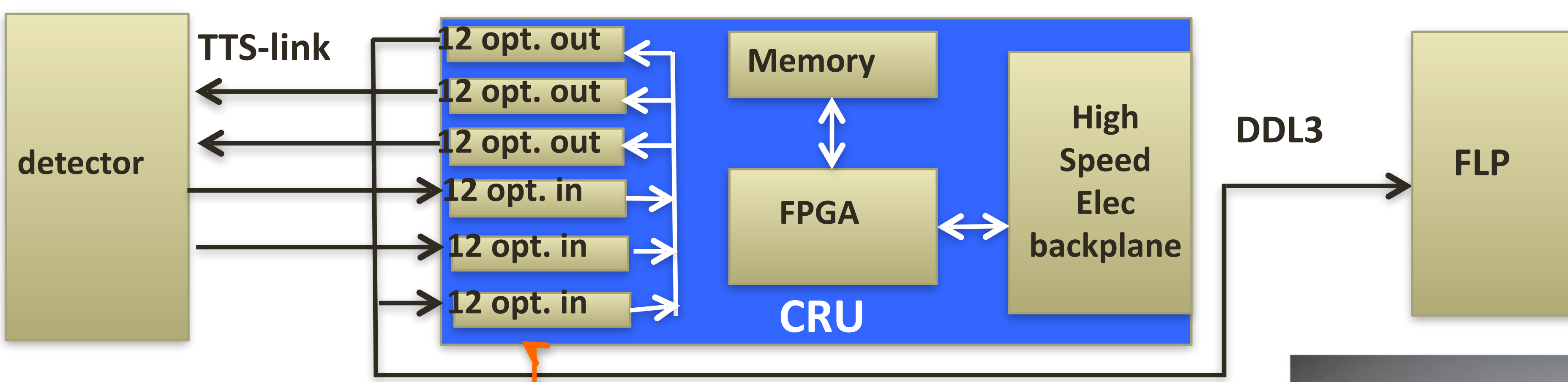
The SOLAR Concentrator Card

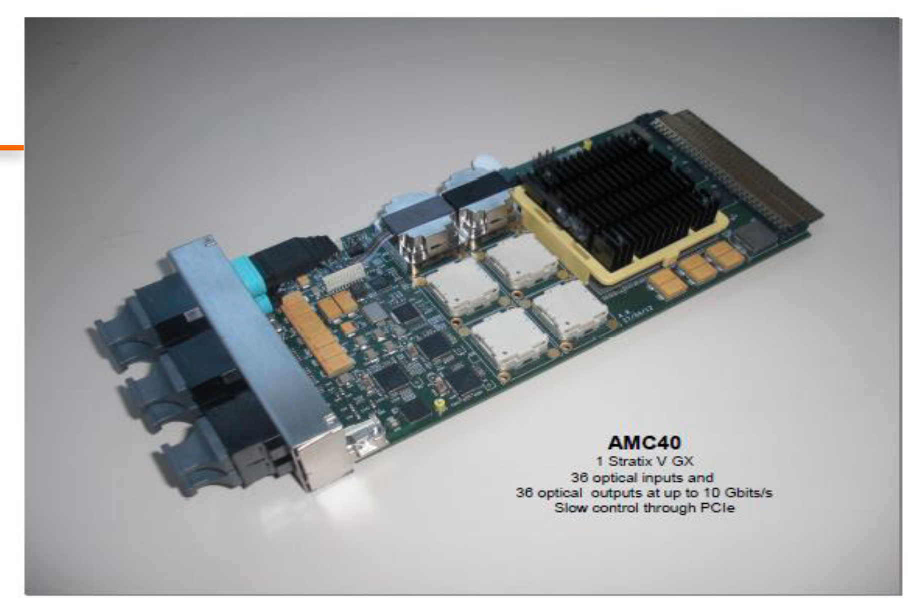


- SOLAR board
  - 1 GBTx, 1 VTRx, 1 SCA
  - Handle up to 40 DualSAMPA (5 FLEX)
  - Design started
  - First prototype in 2016
- FLEX
  - 41 lines per FLEX (reduced vs. TDR)
  - Design started
  - Prototype ordered @ CERN (Rui lab.)

The Common Readout Unit (CRU)

- Interface detectors data (GBT fibers) to the DAQ (DDL 3 optical link 10 Gb/s)
- Replace the CROCUS data readout concentrator in MCH
- Common to many detectors: MCH, MID, TPC, …
- Located in the counting rooms (no SEU issues)
- Present design
  - Based on AMC40 card from LHCb
  - Programmable FPGA (can eventually be used for data formatting/compression)

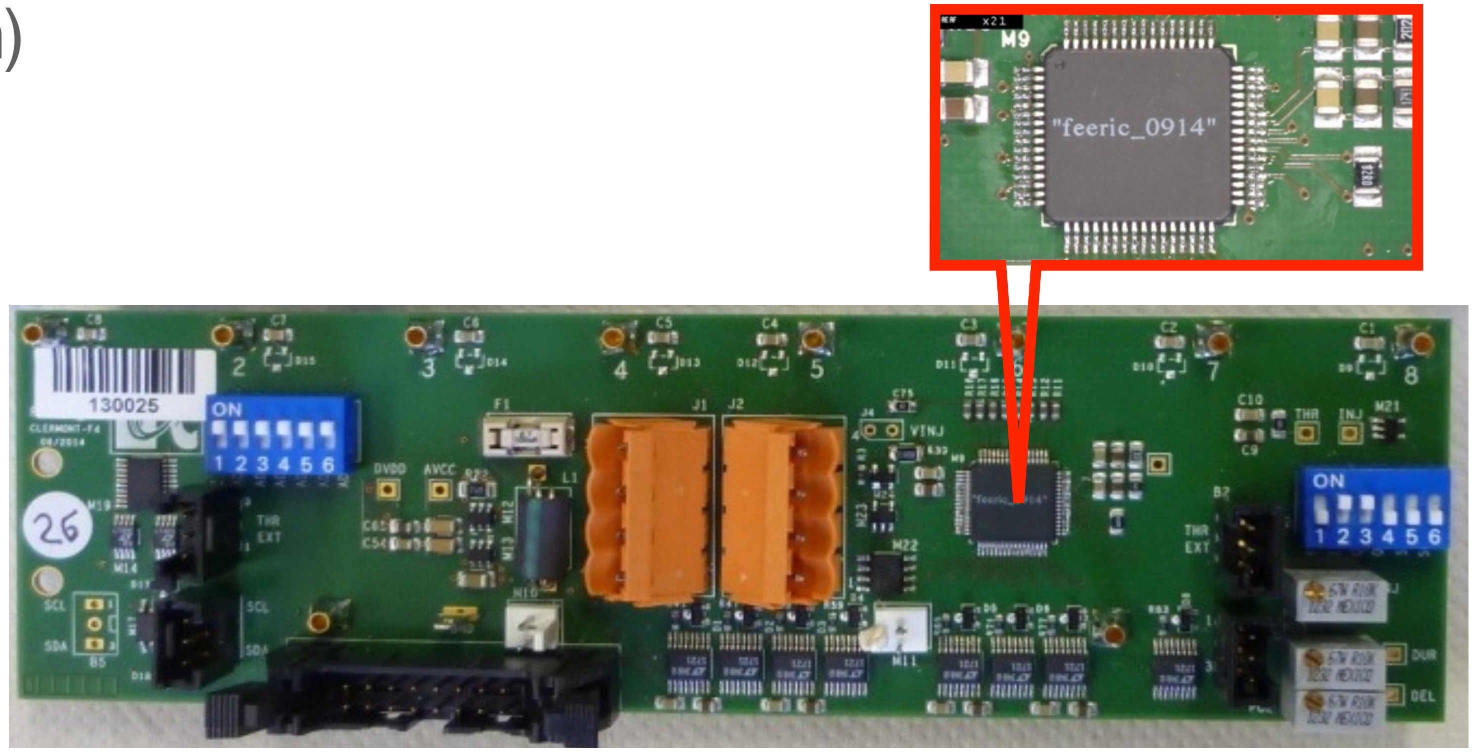




- Hungary / India collaboration: design & production

MID Front End Electronics

- Goal: Limit RPC ageing (× 3-5)
- Present FEE without amplification => upgrade with amplification
- Increase of the max. counting rate from ~50 Hz/cm^2 to ~200 Hz/cm^2
- 2384 FEE cards needed (20992 ch)
- R&D program started in 2012
- New ASIC (FEERIC) and FE card
  - ASIC 0.35 µm CMOS technology
  - 8 channels, bi-polarity input
  - Dynamic range from 20 fC < q < 3 pC
  - Resolution <500 ps for q > 100 fC

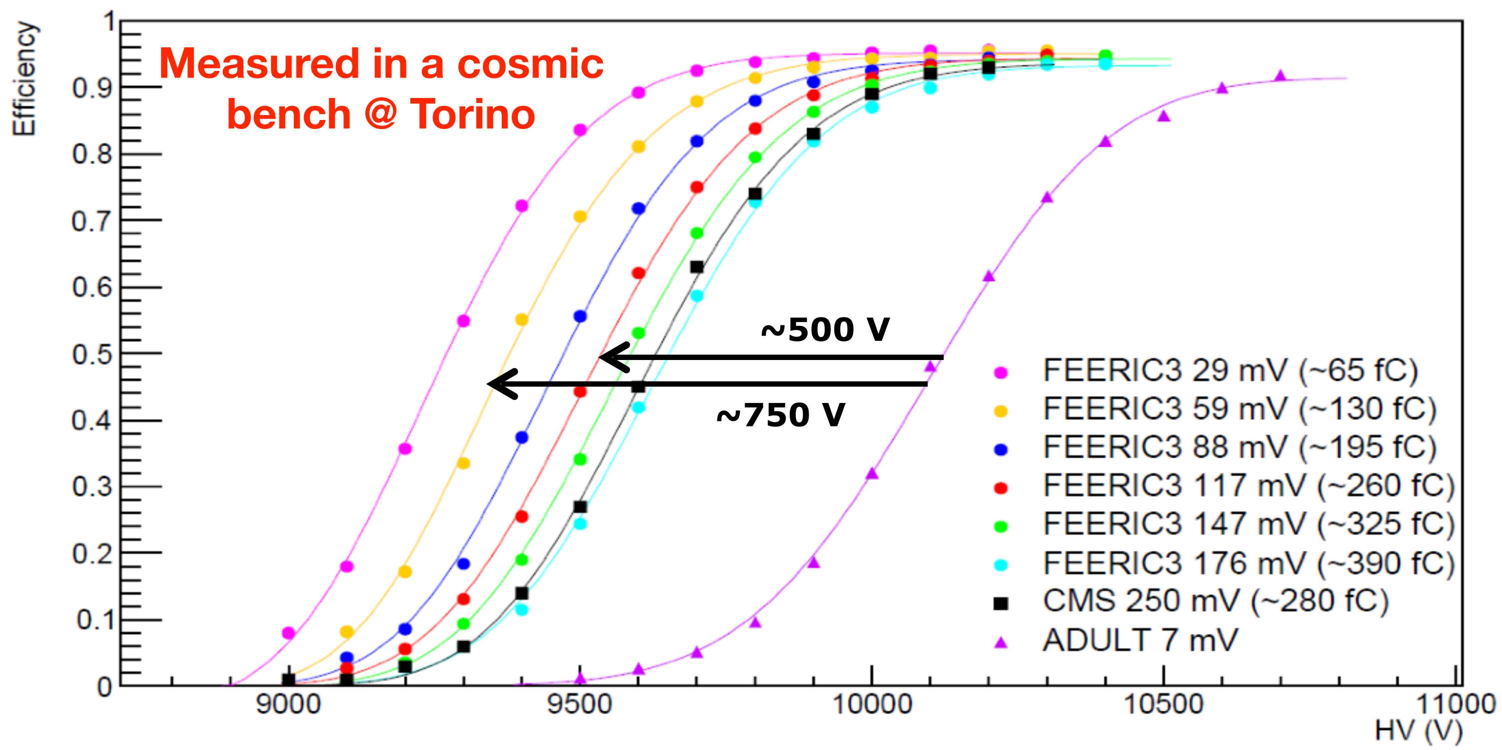


- Planning
  - LS1 (done) : Equip 1 RPC (/72) in the cavern with 40 FEERIC cards (w/ final ASIC)
  - Run2 : test in realistic conditions (under way) + production
  - LS2 : installation

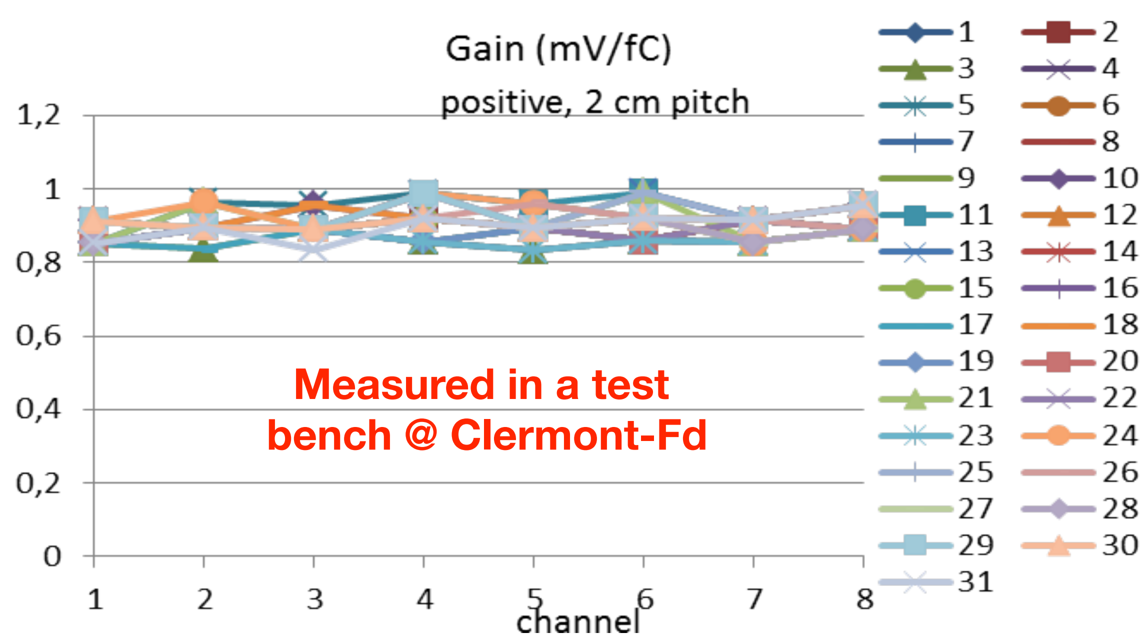
- **FEE: Clermont-Fd / Torino / Korea**
- **Readout cards: Clermont-Fd**
- **RPC & Gas system : Torino**

FEERIC results

- Efficiency
  - Shift by -550 V (thr=130 fC) to -750 V (thr=200 fC) wrt present operating conditions with ADULT 7mV
  - Final threshold will depends on background conditions

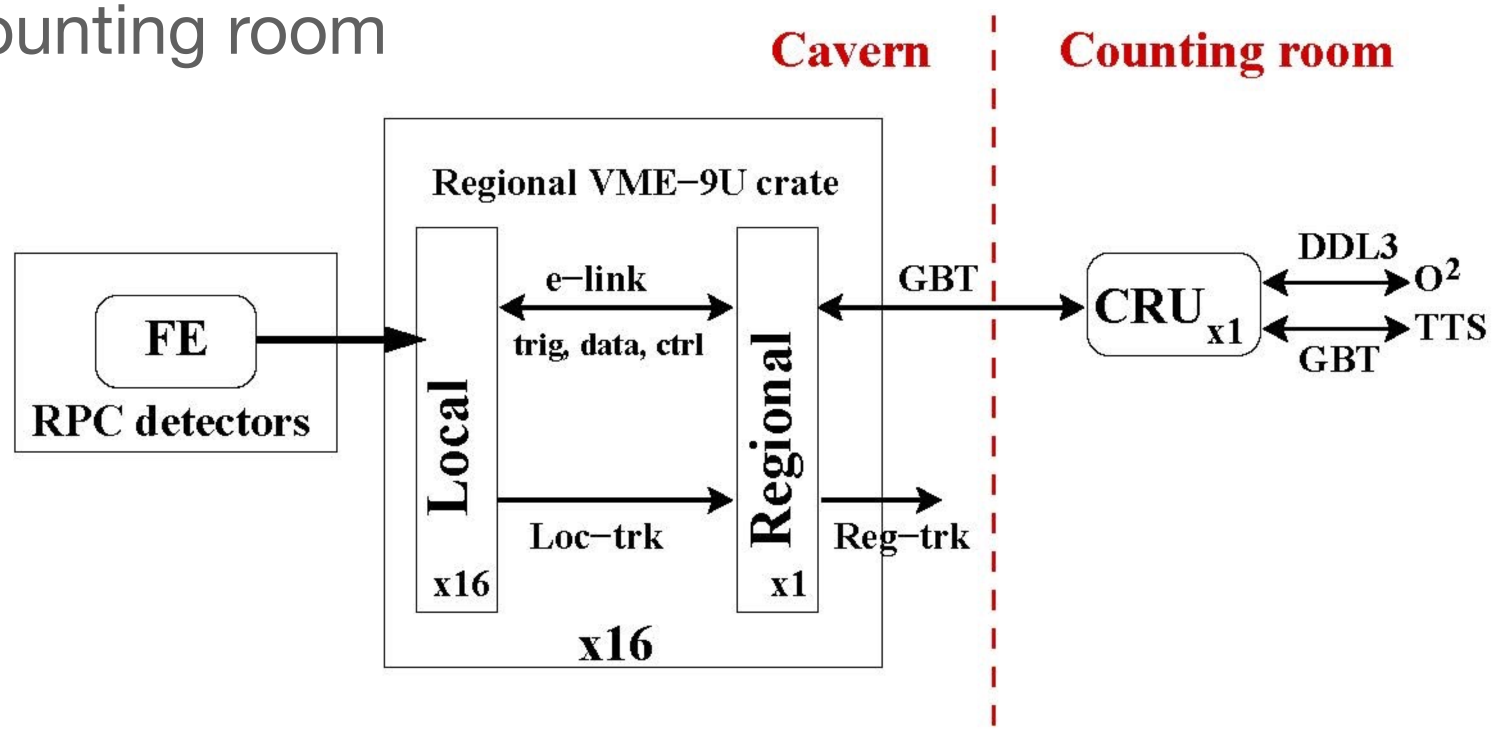


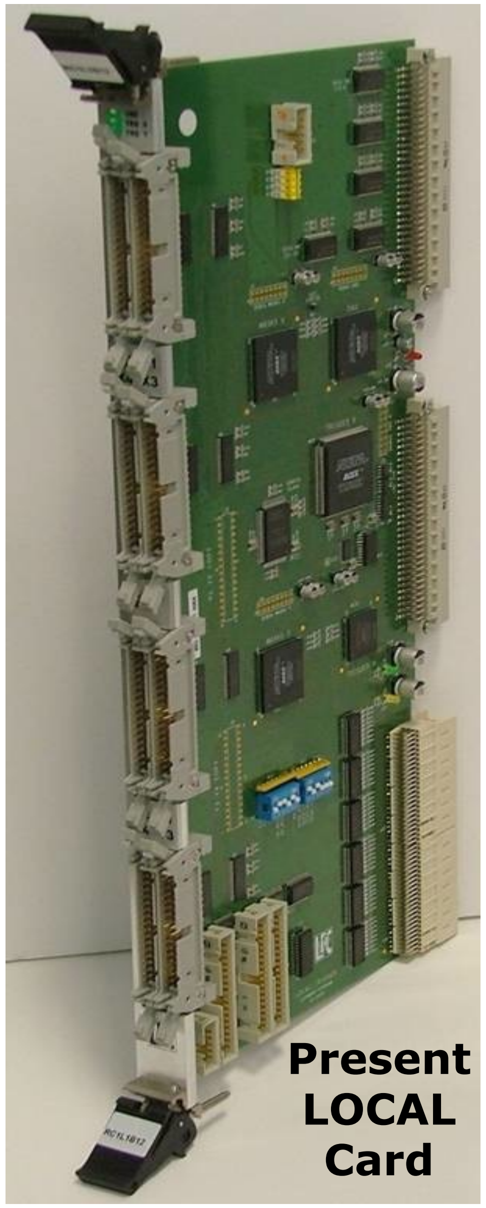
- Gain homogeneity
  - measured w/ pre-serie cards (31)
  - Low dispersion => OK



MID readout electronics

- Muon Trigger hw decision not needed anymore=> Muon Identifier (MID)
- Dead-time free readout up to 100 kHz MB in Pb-Pb
  - x100 above present design
  - Continous readout (improved wrt TDR)
  - Fast (~300 ns) simple (no anymore p_T based) muon trigger decision available
- Replacement of 234 LOCAL and 16 REGIONAL cards
- 1 CRU in counting room

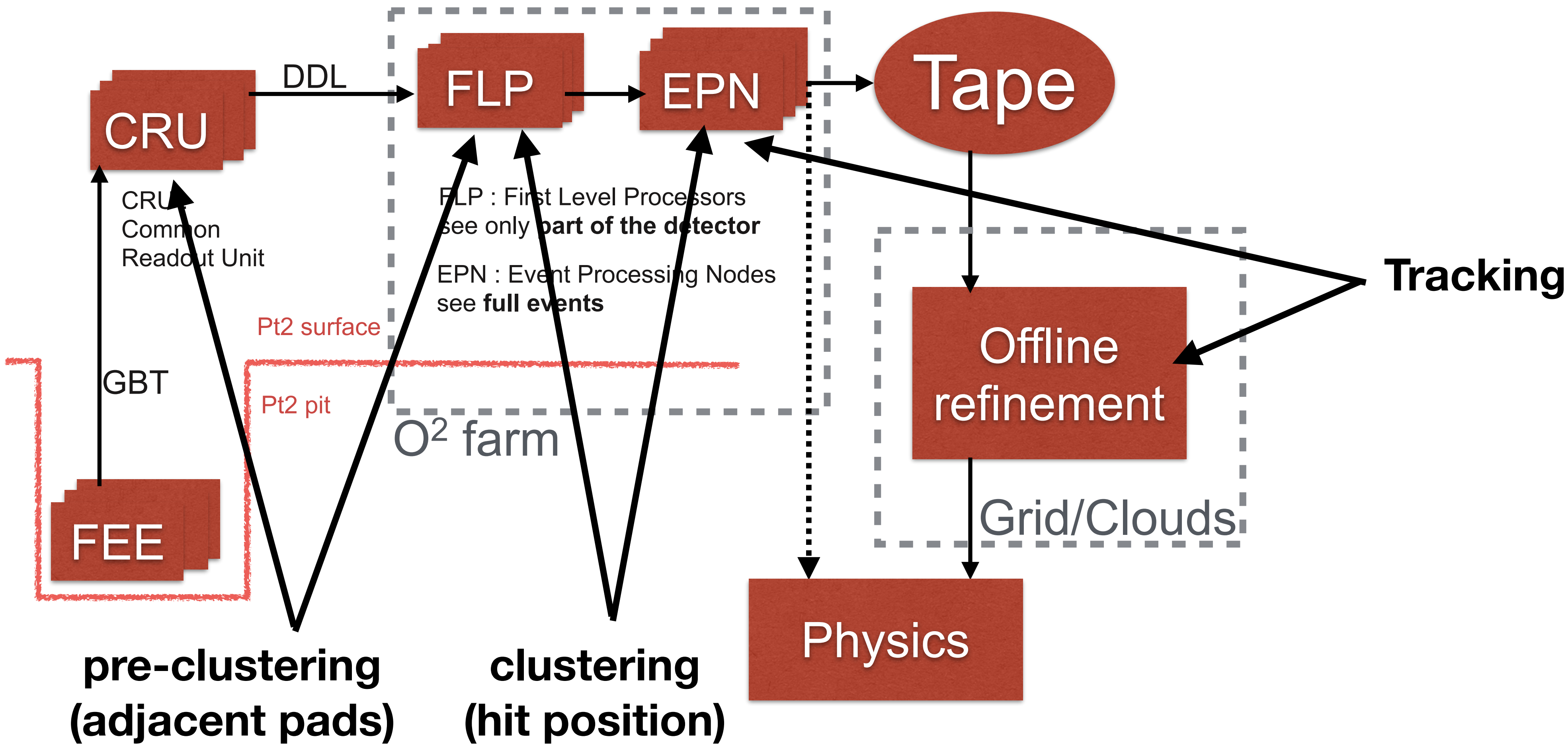




- Planning
  - 2014-2016 : LOCAL and REGIONAL prototypes
  - 2016-2017 : Production
  - LS2 : Installation

MUON Software Upgrade

- Discussion on Run 3 computing strategy started
  - Part of the ALICE « Conceptual Design Note about Calibration and Reconstruction »
  - Linked with O^2 working groups 6 & 7
- Basic question: Where do pre-clustering, clustering, tracking, …
  - In the present software: 80% of the time is devoted to clustering
  - Expected MUON data rate ~3 GB/s @ 100 kHz



- Task force created (~10 people, not all FTE)

Conclusion

- **Run 1**
  - **New phenomena: Charmonia recombination (R_{AA}, $\langle p_T^2 \rangle$, J/ψ flow)**
  - **First results on ψ(2S), Υ, Low masses, Open HF**
  - **Other topics: photoproduced J/ψ (UPC & hadronic), W, …**
- **Run 2**
  - **Improved statistics (1nb^{-1})**
  - **Conclude in many topics (J/ψ flow, J/ψ polarisation, ψ(2S), Υ, …)**
- **Run 3/4: Ambitious MUON Upgrade w/ MFT**
  - **Very high statistics for the present channels (10 nb^{-1}) -> very detailed studies**
  - **Open new physics channels -> Open HF separation, Prompt J/ψ, Low masses, …**
  - **Goal: Conclude on the properties of QGP @ LHC**

A very exiting program for Run 2 (while preparing the upgrades)
Participation in physics analysis are very welcome

Backup

Muon Spectrometer Characteristics

Muon detection	
Polar, azimuthal angle coverage Minimum muon momentum	$171^\circ \leq \theta \leq 178^\circ$, 360° $4\,\mathrm{GeV}/c$
Pseudo-rapidity coverage	$-4.0 < \eta < -2.5$
Front absorber	
Longitudinal position (from IP) Total thickness (materials)	$-5030\,\mathrm{mm} \leq z \leq -900\,\mathrm{mm}$ ($\sim$10 λ_{int}, $\sim$60 X_0) (carbon-concrete–steel)
Dipole magnet	
Nominal magnetic field, field integral Free gap between poles Overall magnet length Longitudinal position (from IP)	0.67 T, 3 T m 2.972–3.956 m 4.97 m $-z = 9.94$ m (centre of the dipole coils)
Tracking chambers	
No. of stations, no. of planes per station Longitudinal position of stations Anode-cathode gap (equal to wire pitch) Gas mixture Pad size st. 1 (bending plane) Pad size st. 2 (bending plane) Pad size st. 3, 4 and 5 (bending plane) Max. hit dens. st. 1–5 (central Pb-Pb $\times$ 2) Spatial resolution (bending plane)	5, 2 $-z = 5\,357, 6\,860, 9\,830, 12\,920, 14\,221$ mm 2.1 mm for st. 1; 2.5 mm for st. 2–5 80 %Ar/20 %CO_2 $4.2 \times 6.3,\ 4.2 \times 12.6,\ 4.2 \times 25.2\ \mathrm{mm}^2$ $5 \times 7.5,\ 5 \times 15,\ 5 \times 30\,\mathrm{mm}^2$ $5 \times 25,\ 5 \times 50,\ 5 \times 100\,\mathrm{mm}^2$ 5.0, 2.1, 0.7, 0.5, $0.6 \cdot 10^{-2}$ hits/cm^2 $\simeq 70\,\mu$m
Tracking electronics	
Total no. of FEE channels Shaping amplifier peaking time	1.08×10^6 $1.2\,\mu$s
Trigger chambers	
No. of stations, no. of planes per station Longitudinal position of stations Total no. of RPCs, total active surface Gas gap Electrode material and resistivity Gas mixture Pitch of readout strips (bending plane) Max. strip occupancy bend. (non bend.) plane Maximum hit rate on RPCs	2, 2 $-z = 16\,120, 17\,120$ mm 72, $\sim$ 140 m^2 single, 2 mm Bakelite$^{\mathrm{TM}}$, $\rho = 2$–$8 \times 10^9\,\Omega$cm Ar/$C_2H_2F_4$/i-buthane/SF_6 (50.5/41.3/7.2/1) 10.6, 21.2, 42.5 mm (for trigger st. 1) 3%(10%) in central Pb-Pb 3 (40) Hz/cm^2 in Pb-Pb (Ar-Ar)
Trigger electronics	
Total no. of FEE channels No. of local trigger cards	2.1×10^4 $234 + 8$