Heavy flavour measurement in heavy-ion collisions

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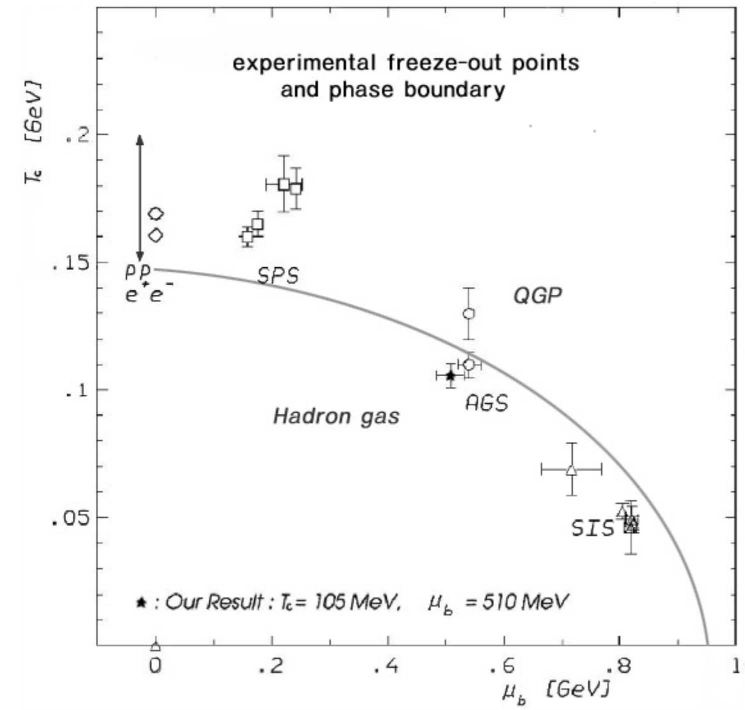
How was my research career started in this field?

- **M.S. in Experimental Nuclear Physics**

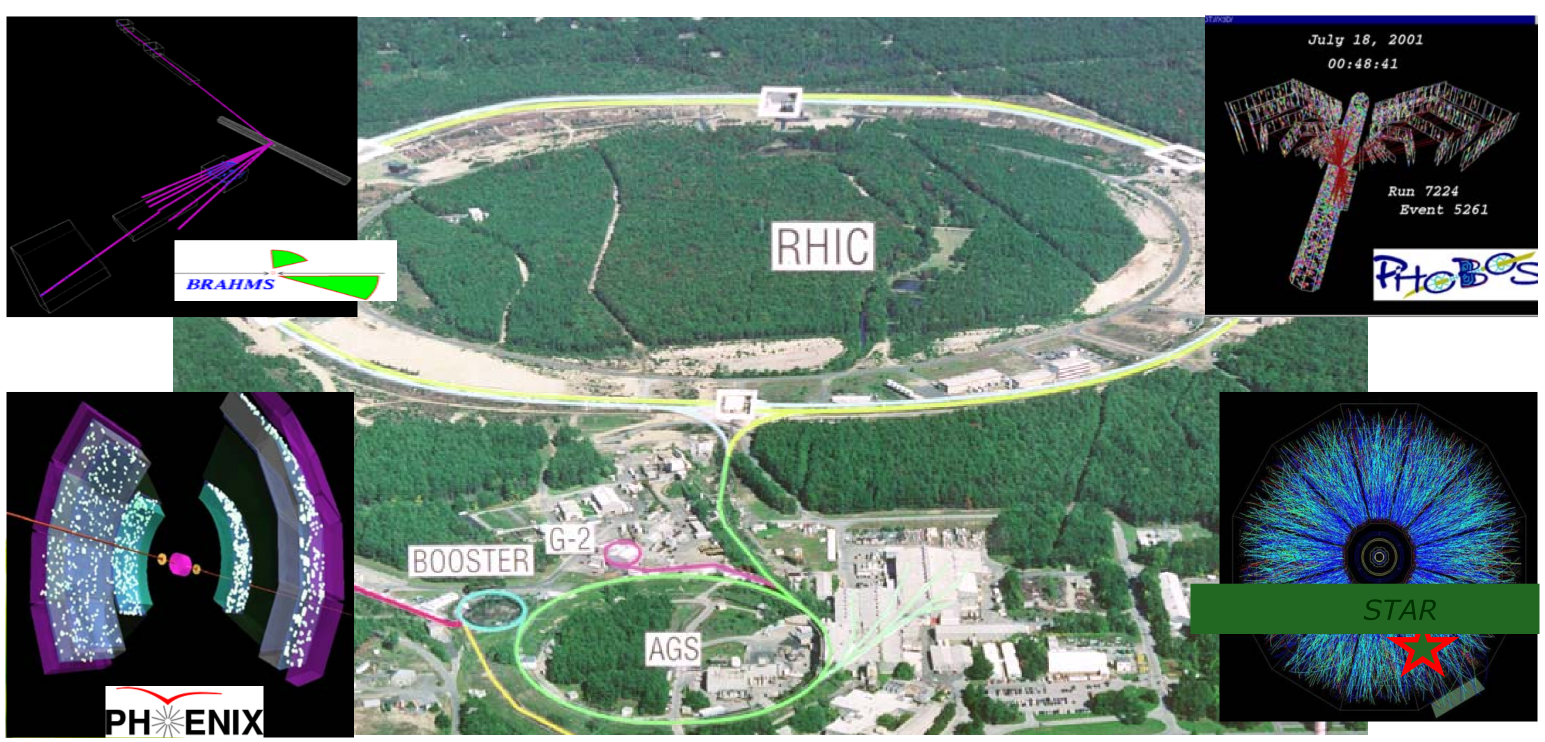
  March 1998 - February 2001.
  Thesis title: "Test of Thermal and Chemical Equilibrium at Freeze-out in Si+Au Collisions at 14.6 A·GeV"
  (Advisor: Prof. Byungsik Hong)

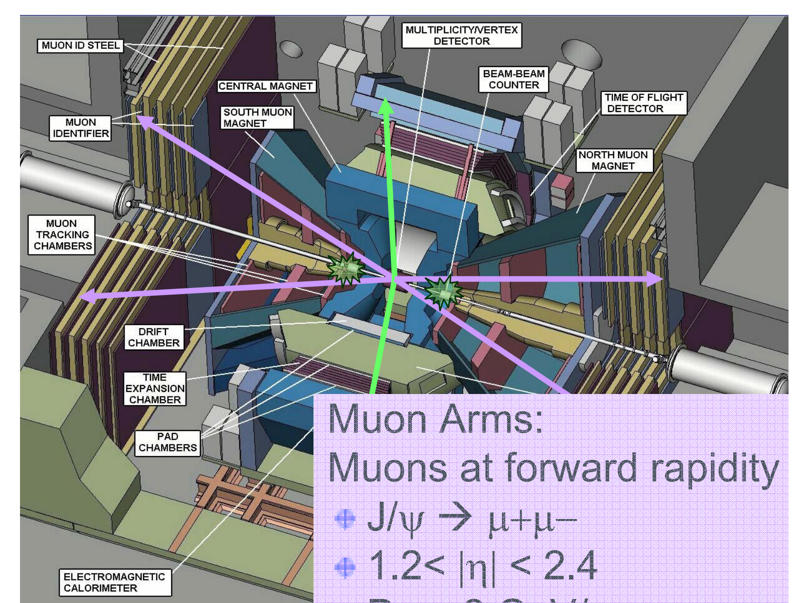


- **Ph. D. in Experimental Nuclear Physics**

  March 2001 - February 2006.
  Thesis title: "J/Ψ production at forward rapidity in $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions"

  (Advisor: Prof. Byungsik Hong)

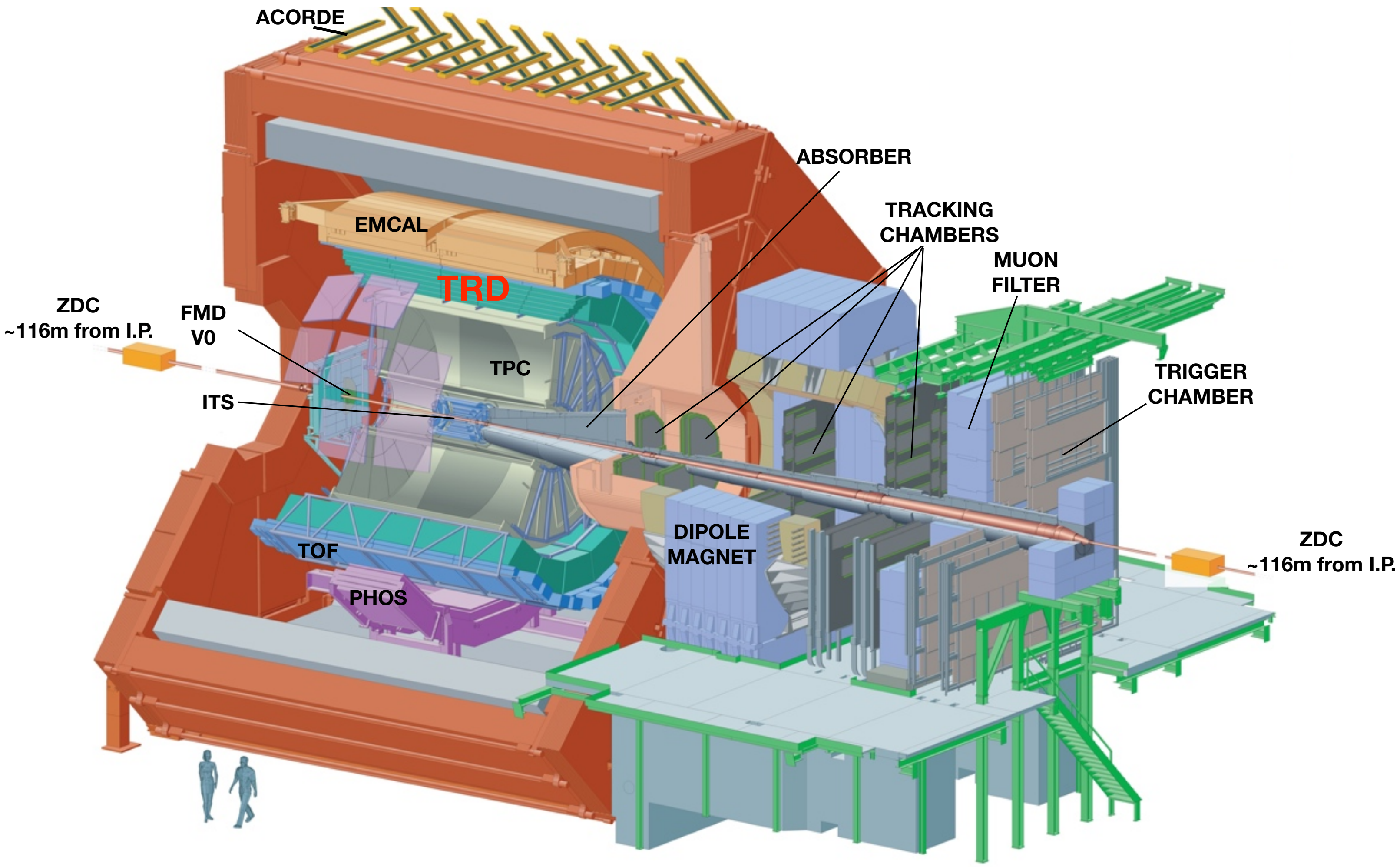




Muon Arms:
Muons at forward rapidity
- $J/\psi \rightarrow \mu^+\mu^-$
- $1.2 < |\eta| < 2.4$
- $P_\mu > 2$ GeV/c
- $\Delta\phi = 2\pi$

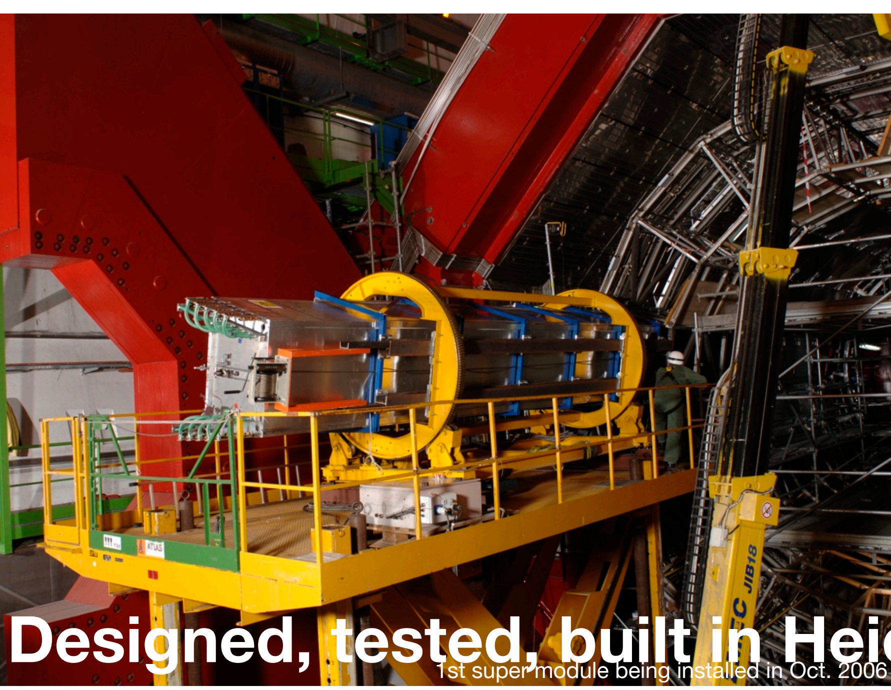
- **Also heavily participating muon detector construction**

Starting from RHIC, moving to LHC



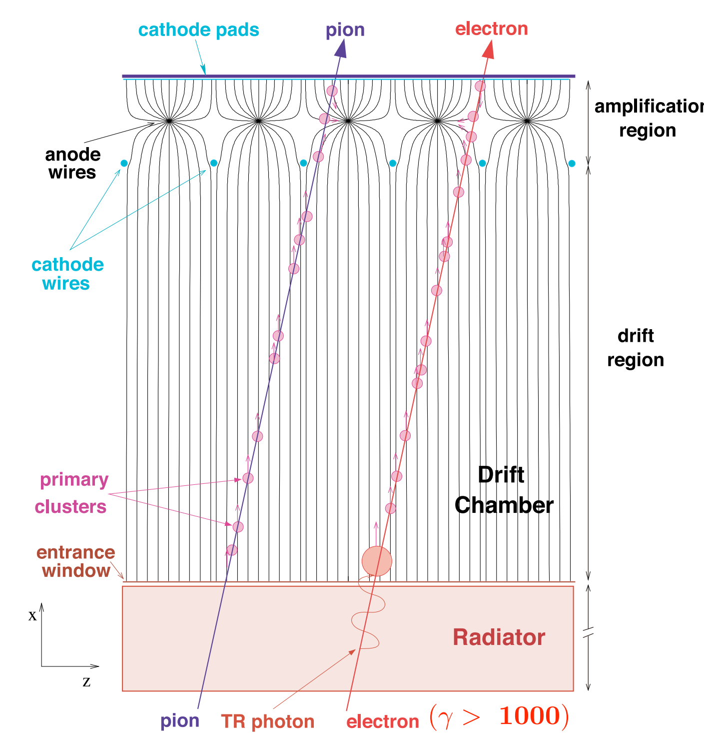
Collaboration: 31 countries, 109 institutes, > 1000 people

- Since 2006, my research career has been heavily engaged to the heavy-flavour measurement in heavy-ion collisions together with the relevant detector constructions
- ALICE heavy-flavour measurement, ALICE Transition Radiation Detector (TRD) construction, ALICE Inner Tracking System (ITS) upgrade



1st super module being installed in Oct. 2006


2nd layer being tested in the super module



TRD construction, installation and commissioning

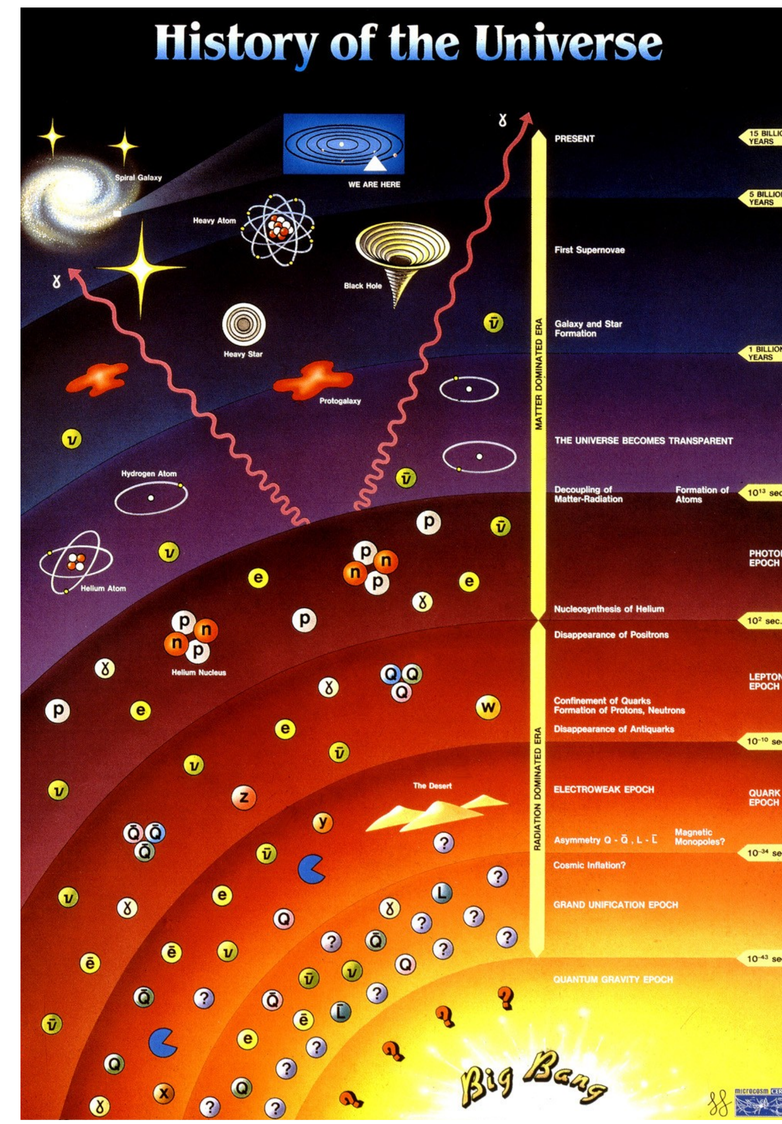
Introducing highlight of the research works

: dedicated to the heavy-flavour measurement and relevant detector construction

Why Heavy-Ion Collisions?

• Quantum Chromodynamics (QCD) works fine if you treat one particle at a time and when the ”scale” is high enough (above several GeV/c).

By colliding nuclei at enormous energies, two extraordinary accelerators — RHIC and now the LHC — are making little droplets of “big bang matter”: the same stuff that filled the whole universe for the first few microseconds after the big bang.



• We want to understand how QCD works for large systems, systems containing 1000’s of particles occupying ”large” volumes.

via heavy ion collision

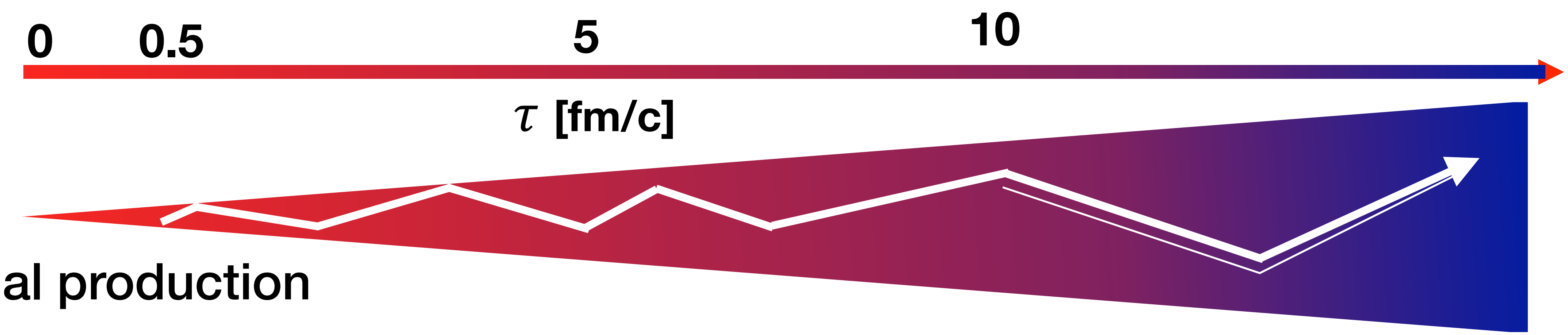
• We want to understand how (nuclear) matter behave under extreme conditions, under extreme temperatures and densities.

One goal of heavy-ion collisions is to understand what happened in the early universe.

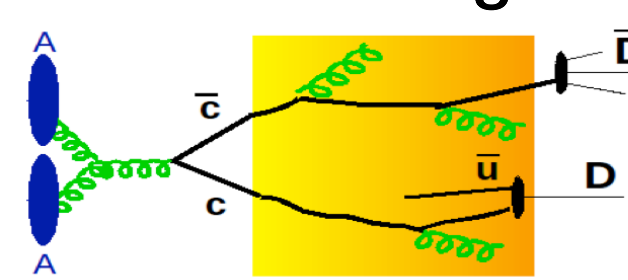
Why heavy flavour?

- $m_{c,b} \gg \Lambda_{QCD}$ **pQCD initial production**
- $m_{c,b} \gg T_{RHIC,LHC}$ **negligible thermal production**
- $\tau_0 \approx 1/2m_Q$ (<0.1 fm/c) $\ll \tau_{QGP}$ (O(10fm/c)) **witness of all the QGP**

⇨ **"Calibrated probes" of the medium**



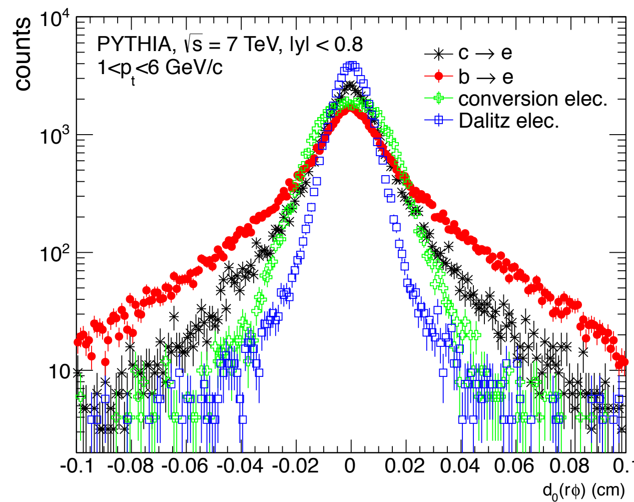
- Initial production
  - pQCD-NLO
  - MC-NLO
  - CNM effect
- Dynamics in QGP
  - energy loss via radiative ("gluon Bremsstrahlung") and collisional processes
    - color charge (Casimir factor)
    - quark mass (dead-cone effect)
    - path length and medium density
- Hadronization
  - via quark coalescence and/or fragm.
  - hadronic rescattering



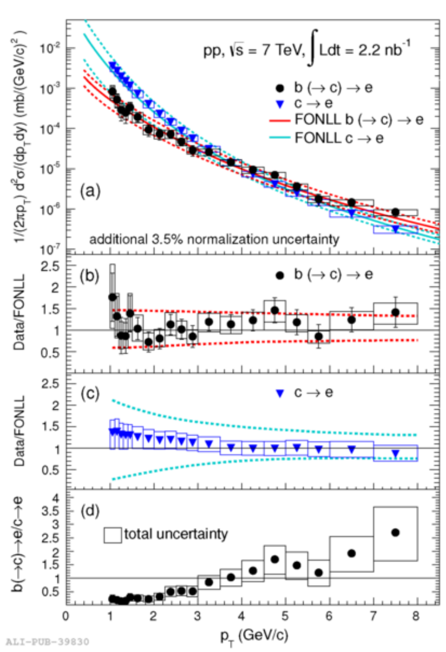
Measurement of beauty decay electrons

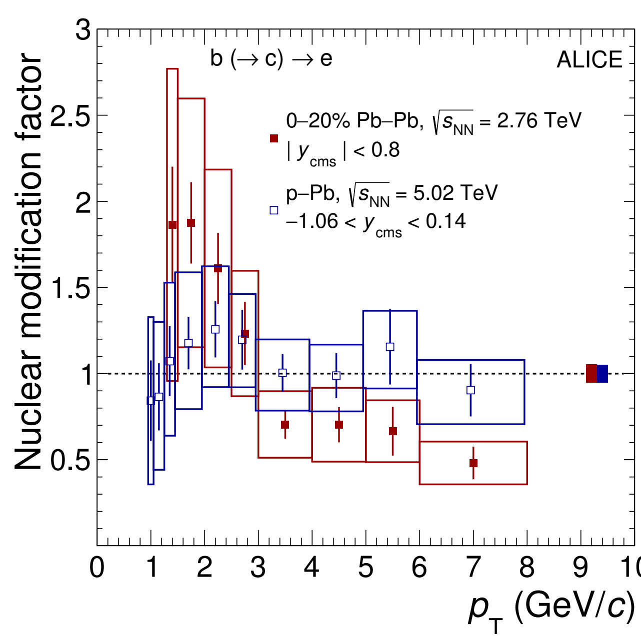
Beauty production is studied via the measurements of electrons from semi-leptonic decays of beauty hadron in pp, p-Pb and Pb-Pb collisions.

Separate B→e from D→e using impact parameter distributions



- Measured B→e production cross section in pp collisions at 7 TeV & 2.76 TeV, published in 2013, 2015





JHEP
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Measurement of electrons from beauty-hadron decays in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

ALICE
The ALICE collaboration
E-mail: ALICE-publications@cern.ch

Abstract: The production of beauty hadrons was measured via semi-leptonic decays at mid-rapidity with the ALICE detector at the LHC in the transverse momentum interval $1 < p_T < 8$ GeV/c in minimum-bias p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and in $1.3 < p_T < 8$ GeV/c in the 20% most central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The pp reference spectra at $\sqrt{s} = 5.02$ TeV and $\sqrt{s} = 2.76$ TeV, needed for the calculation of the nuclear modification factors R_{pPb} and R_{PbPb}, were obtained by a pQCD-driven scaling of the cross section of electrons from beauty-hadron decays measured at $\sqrt{s} = 7$ TeV. In the p_T interval $3 < p_T < 8$ GeV/c, a suppression of the yield of electrons from beauty-hadron decays is observed in Pb-Pb compared to pp collisions. Towards lower p_T, the R_{PbPb} values increase with large systematic uncertainties. The R_{pPb} is consistent with unity within systematic uncertainties and is well described by theoretical calculations that include cold nuclear matter effects in p-Pb collisions. The measured R_{pPb} and these calculations indicate that cold nuclear matter effects are small at high transverse momentum also in Pb-Pb collisions. Therefore, the observed reduction of R_{PbPb} below unity at high p_T may be ascribed to an effect of the hot and dense medium formed in Pb-Pb collisions.

Keywords: Heavy Ion Experiments
ArXiv ePrint: 1609.03898
JHEP07(2017)052

- Measured R_{pA} at 5 TeV and R_{AA} at 2.76 TeV: published in July 2017, JHEP 07 (2017) 052
- We are now working on R_{AA} at 5 TeV and cross section measurement at 13 TeV (close to final)
- Beauty electron elliptic flow analysis is ongoing

Measurement of b-tagged jets (FKPPL project)

FKPPL ALICE-b project started since 2017

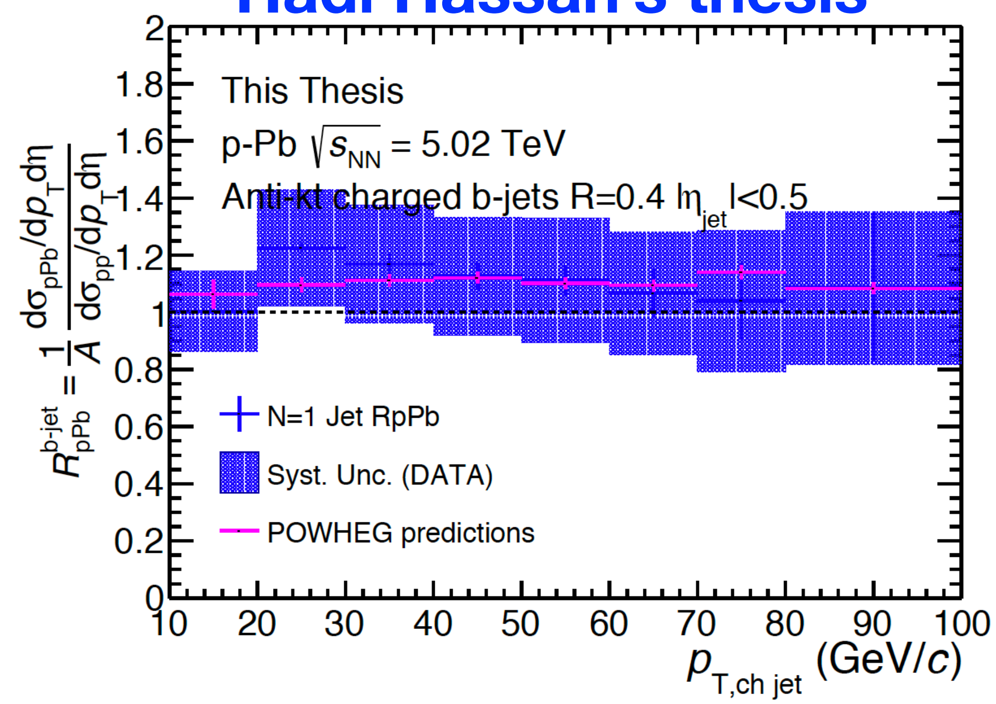
Main French and Koeran Institute: CNRS/IN2P3, Inha University

Project Leader on both sides: Rachid Guernane, MinJung Kweon

Separate b-tagged jets using track counting method based on the track impact parameter

- B-jet production in pp and p-Pb collisions measured
  - Consistent with NLO predictions
  - R_{pPb} consistent with unity
  - Plan to request propose paper in coming months

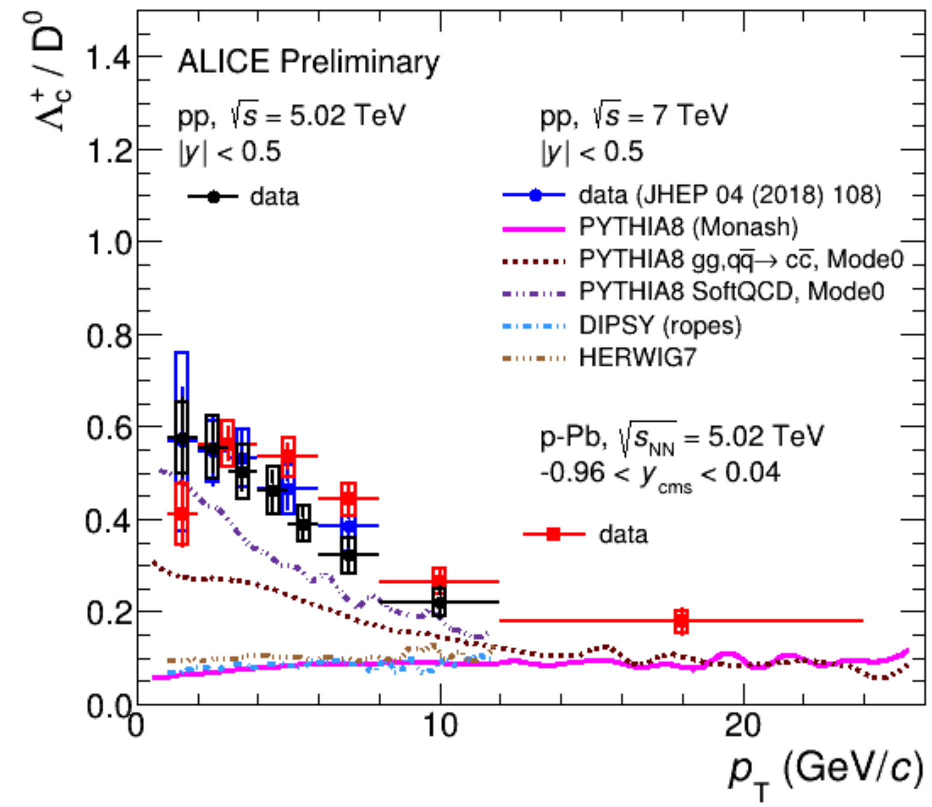
Hadi Hassan's thesis

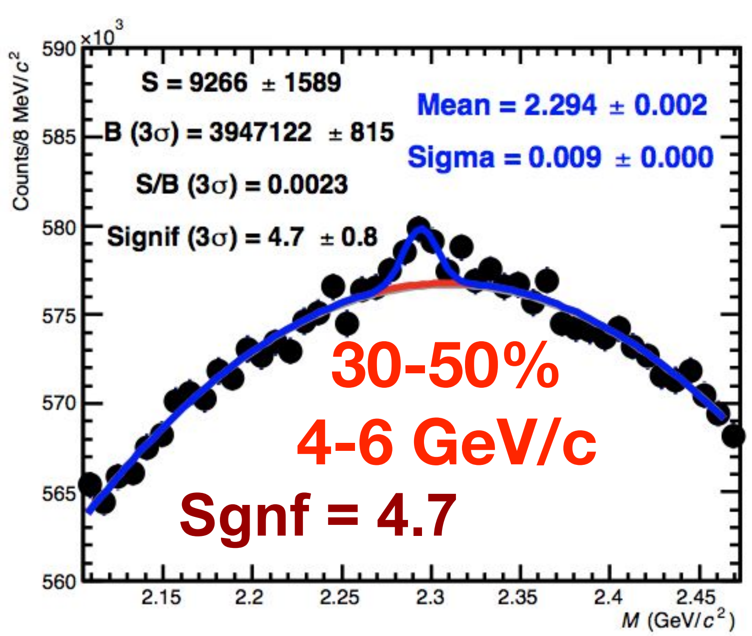


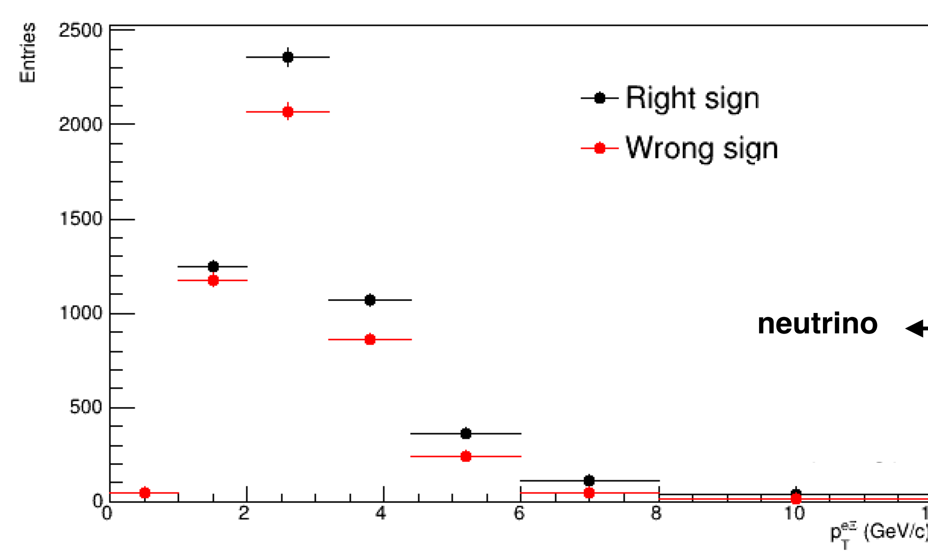
Outcome of FKPPL ALICE-b project to measure b-tagged jets

Charmed baryon measurement: Λ_c, Ξ_c production in pp, p-Pb, Pb-Pb collisions (FKPPL project)

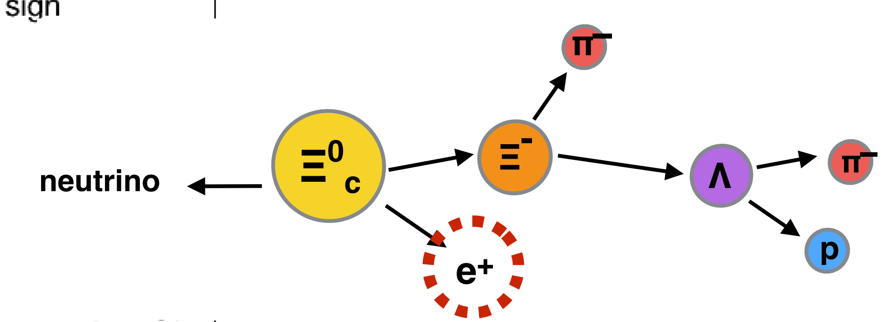
- **Charmed baryon-to-meson ratio** probes **hadronisation mechanisms**
- Baryon production measured to be **larger than expectations** from MC generators
  - Colour reconnection modes within PYTHIA aim to model hadronisation in multi-parton system
  - Colour reconnection modes qualitatively describe the data
- Analysis of Pb-Pb data to measure Λ_c to lower p_T region well underway







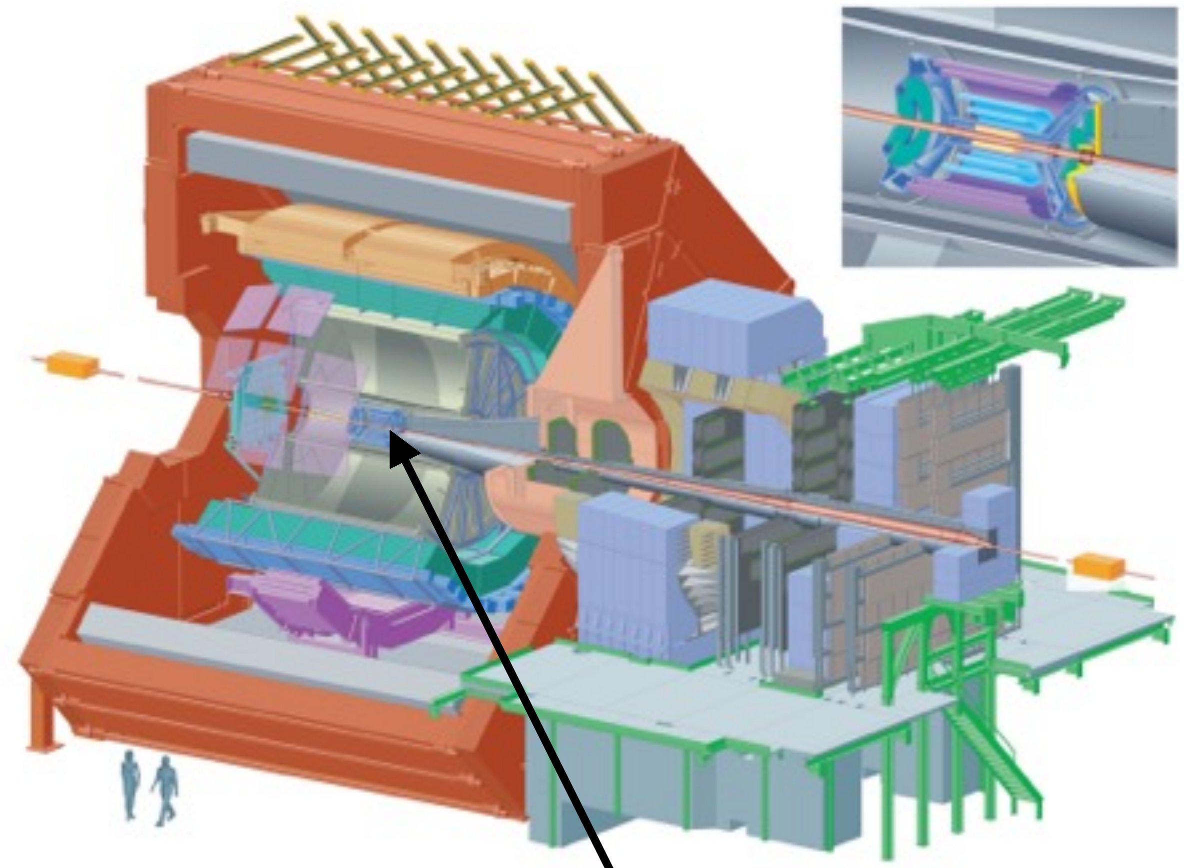
eΞ pair pt

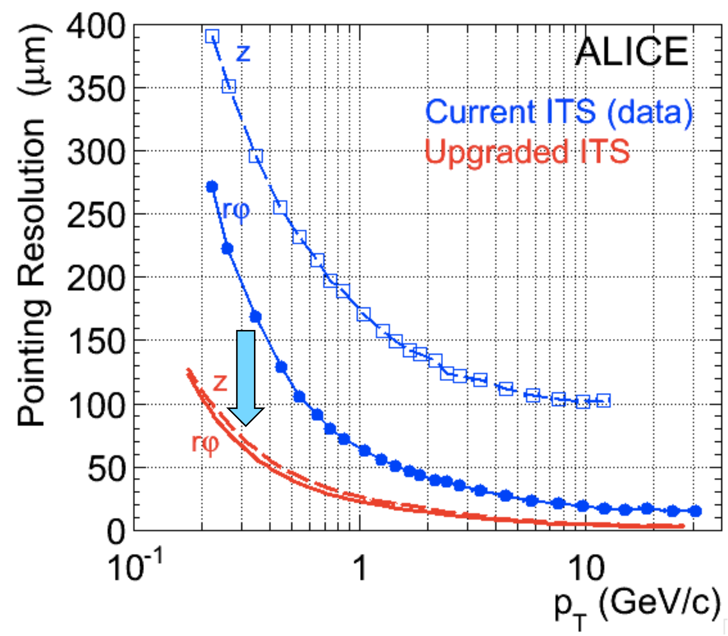


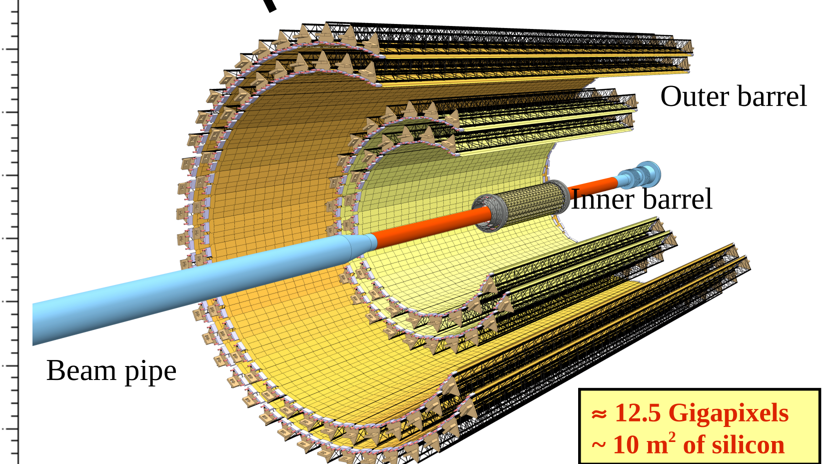
- Measure Ξ_c in pp collisions, extend to p-Pb collisions

ALICE Inner Tracking System upgrade for Run 3 & 4

- **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



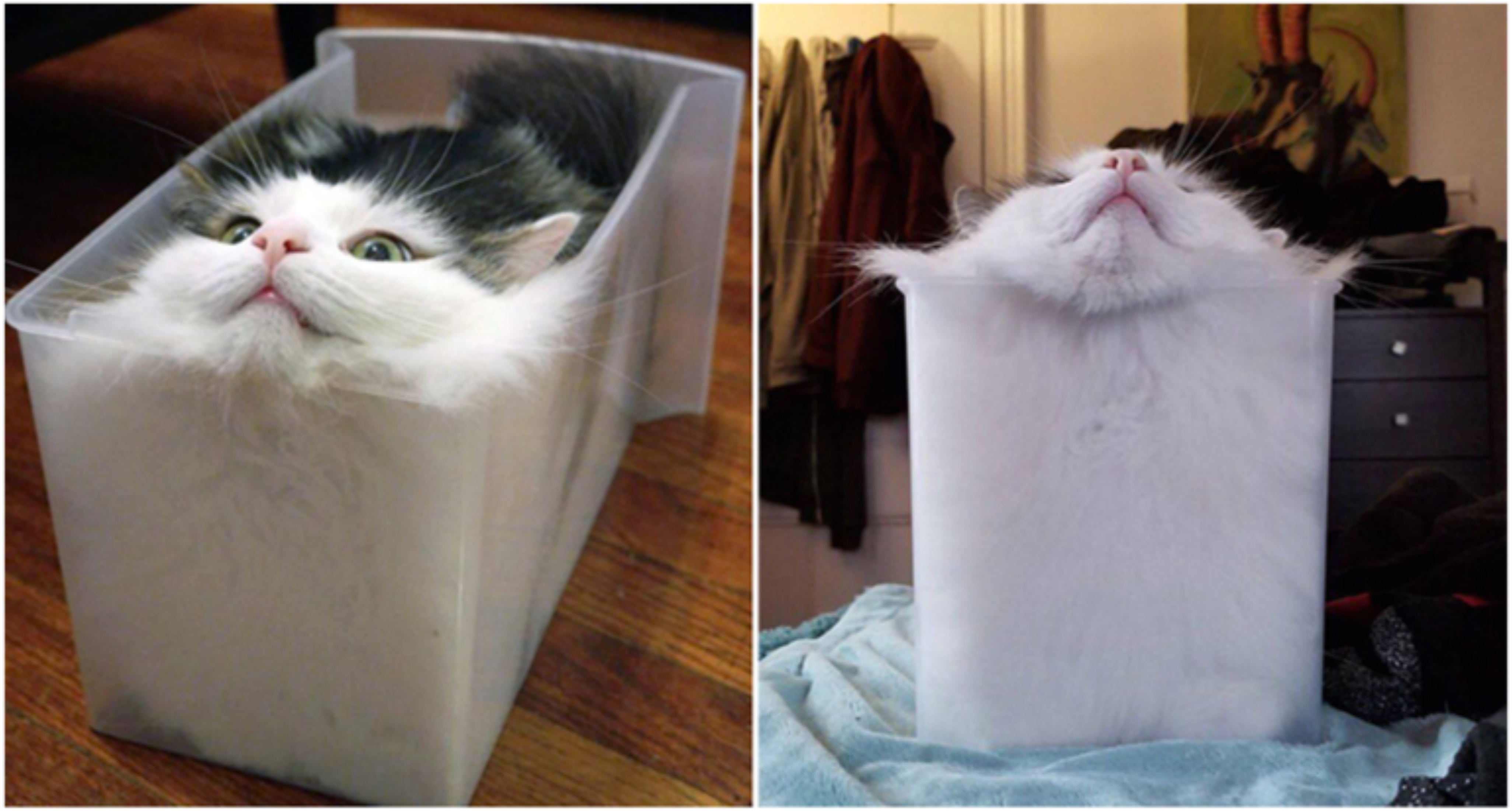




- **Inha university has been participated for chip R&D, massive chip test and HIC module assembly**

Still things are interesting…

Physicist Wins Ig Noble Prize For Study On Whether Cats Should Be Classified As Liquids Or Solids (Nov. 2018)



"If we take cats as our example, the fact is that they can adapt their shape to their container if we give them enough time. Cats are thus liquid if we give them the time to become liquid."

Calculated relaxation time, experimental time, the type of container, and the cat's degree of stress

The conclusion? Cats can be either liquid or solid, depending on the circumstances

Thank you very much!

First B Measurement via NEW METHODS

D,B → e + X

⇒ Measured inclusive electrons

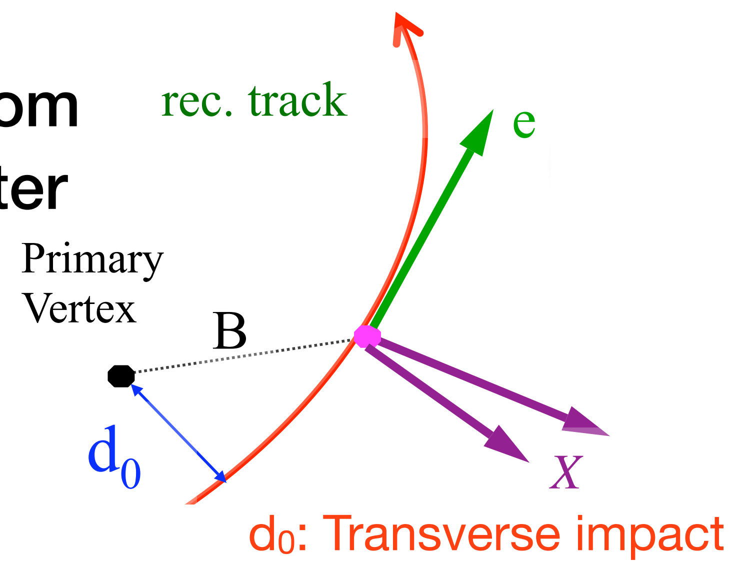
-

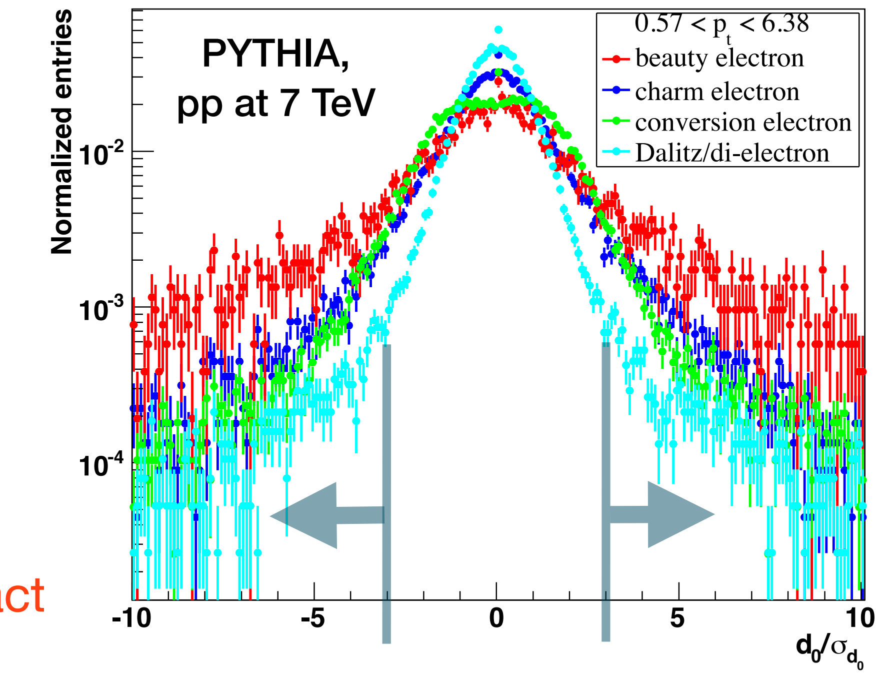
cocktail of background electrons based on data ⇨

- photonic, Dalitz/dielectron decays of mesons based on measured π^0,η spectrum and m_T scaled spectrum for heavier mesons(η',ρ,ω,ϕ)
- direct radiation based on NLO calculation
- J/Ψ and Υ based on measurement

B → e + X

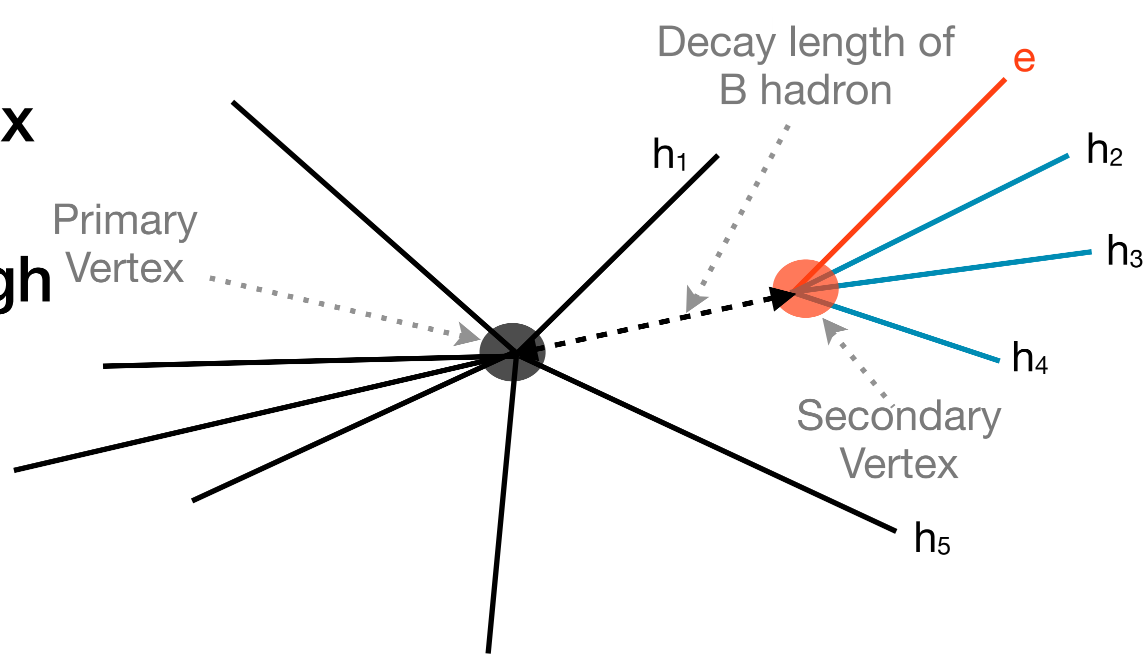
⇒ Preferential selection of electrons from B decay via their large impact parameter d_0 ($(c\tau)_B$ ~ 500 μm, B meson mass ~ 5 GeV/c^2)

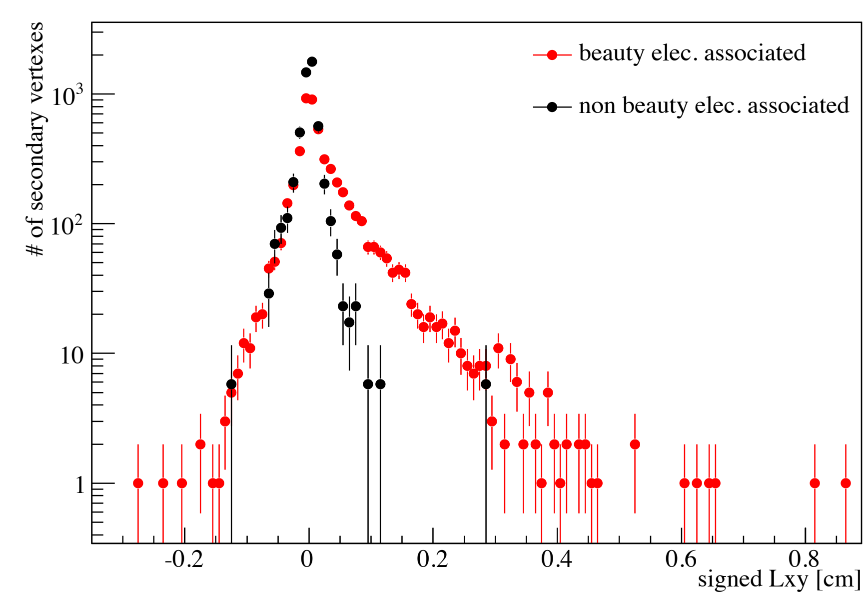




B tagged jet

⇒ Secondary vertex reconstruction of beauty decay through electron + hadrons



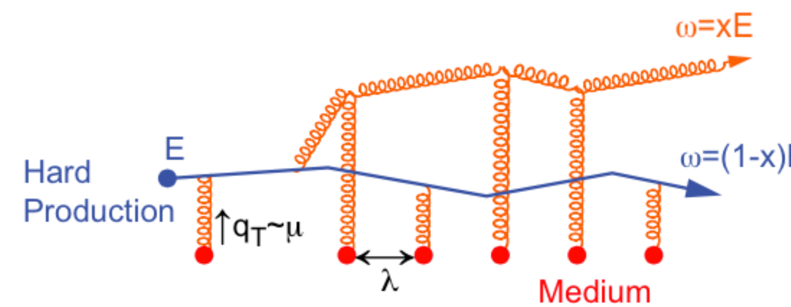


QGP tomography with heavy quarks (for large systems!)

- Early production in hard-scattering processes with high Q^2
- Production cross sections calculable with pQCD
- Strongly interacting with the medium
- Hard fragmentation ➜ measured meson properties closer to parton ones

at all p_T for charm and beauty (large masses >> Λ_{QCD})

⇨ **“Calibrated probes" of the medium**



Study parton interaction with the medium

→ via radiative (“gluon Bremsstrahlung”) and collisional processes

- color charge (Casimir factor)
- quark mass (dead-cone effect)
- path length and medium density

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

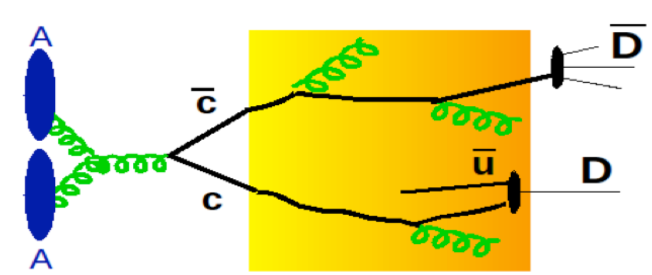
$$\Delta E_g > \Delta E_{c \approx q} > \Delta E_b$$

Might translate into a hierarchy of nuclear modification factors

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

→ medium modification to HF hadron formation

- hadronization via quark coalescence

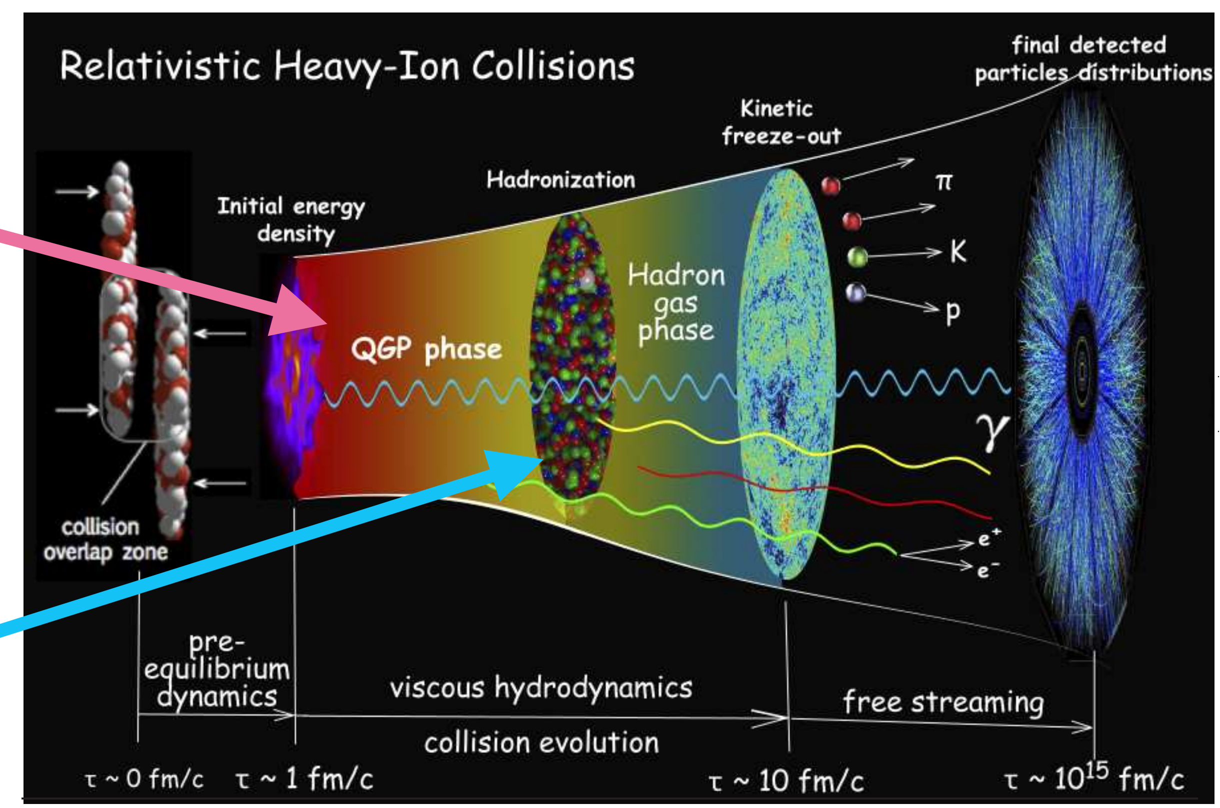


→ participation in collective motion

- arzimuthal anisotropy of produced particle

Hard probes: medium tomography

- Heavy-ion (HI) collisions at LHC energies
  - QGP phase expected (lifetime ~ O(10 fm/c))
- Hard probes: produced in the early stages of the HI collision, traverse the medium interacting with its constituents
  - ➡ Transported through the full system evolution
  - ➡ Efficient probes for understanding the transport properties of the medium
- Observables
  - High p_T particles, jets
  - Open heavy flavors
  - Quarkonia (J/ψ, ψ’, Υ, …)



NOTE: Hard probes not only give information about the QGP phase, but also about the hadronization phase (i.e. to study hadronization mechanisms like fragmentation vs recombination -D_s,…)