China-Italy cooperation and achievements

A. Rossi, INFN Padua

Thanks to F. Antinori, A. Dainese (INFN Padua), A. Fantoni (INFN Frascati), V. Manzari (INFN Bari)

CCNU and Padua charm and beautiful collaboration

Since 2006 a programme of student exchange between **Padua University and Wuhan CCNU** started

Shortly after a **cotutelle programme for PhD students** was established granting students a double degree.

Overall

- 7 short-term visits of master students and PhD
- 3 PhD students who completed the co-tutelle programme
- 1 cotutelle ongoing

Fruitful collaboration which further generated and expanded collaboration
- 1 PhD position at Padua University being started with a grant funded by CSC
- 2 postdocs in Padua ALICE team with INFN grants (one past, one to be started)

Collaboration extended to Wuhan **China University of Geoscience** and possibly to **Fudan University**

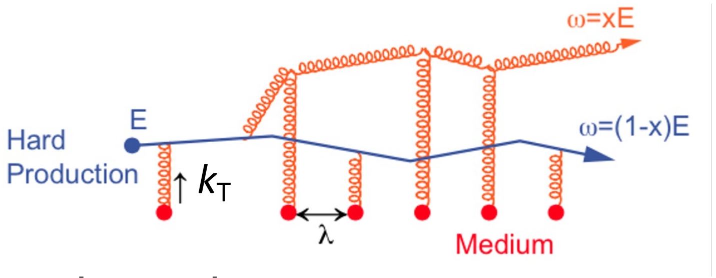
Physics topic: mainly heavy-flavour production
Very concrete outcome: several articles, many with “direct” contribution but many more originated from the work done together

Investigating the QGP with heavy quarks

→ see C. Terrevoli, F. Grosa, S. Cao, J. He,… talks

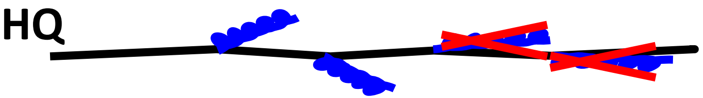
Ideal probes of final-state effects

- charm and beauty quarks produced only in hard-scattering
    - thermal production of charm [beauty] quarks expected very small [negligible]
- large Q^2 → pQCD calculation reliable



Initial goal: study partonic in-medium energy loss

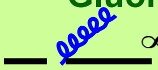
- heavy-quark → quark tagging → Casimir factor dependence
- heavy-quark → mass dependence



Dead-cone effect reduces in-medium energy loss
Expected hierarchy of radiative energy loss (dominating at high pt):

$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

Gluonsstrahlung probability



$$\propto \frac{1}{[\theta^2 + (m_Q / E_Q)^2]^2}$$

Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

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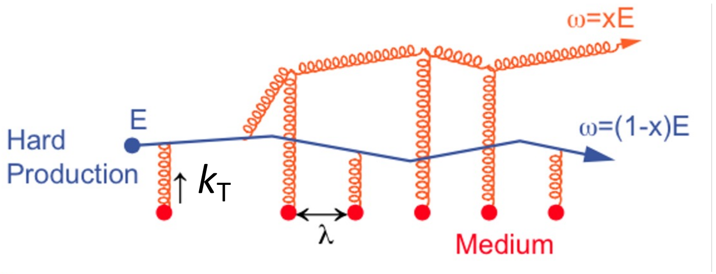


Initial goal: study partonic in-medium energy loss

- heavy-quark → quark tagging / mass dependence / **access to low pt**

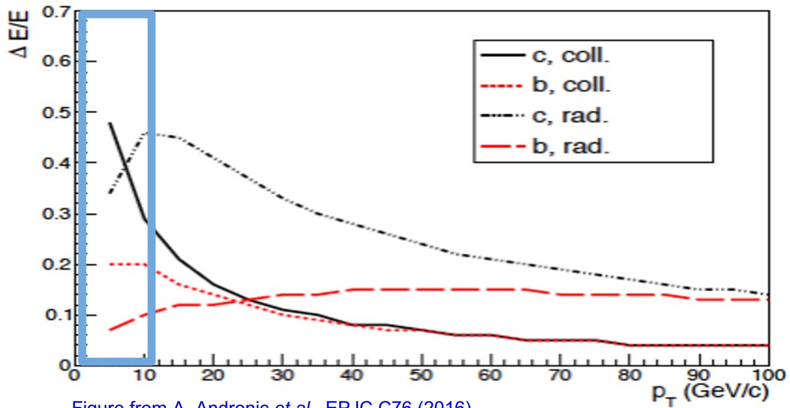


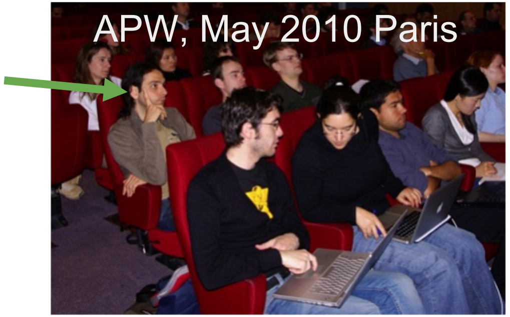
Figure from A. Andronic *et al.*, EPJC C76 (2016)
M. Djordjevic, Phys. Rev. C80 064909 (2009), Phys. Rev. C74 064907 (2006).

Different dynamics, different point of view:

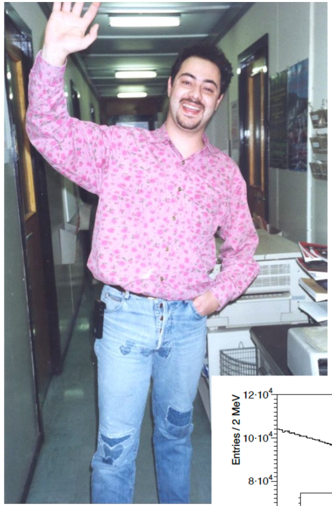
- collisional energy loss (elastic processes)
- transport and diffusion
  - HQ ~ “brownian-motion markers” of QGP

Why collaboration on heavy-flavour (HF) in Padua

Padua team involved since the beginning in the HF programme
Connected to proposal and involvement in ITS (SPD)



Federico at CERN in 1993 (LOI)

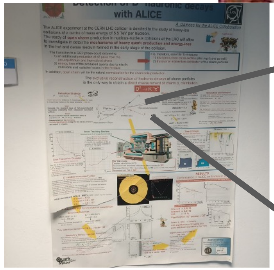


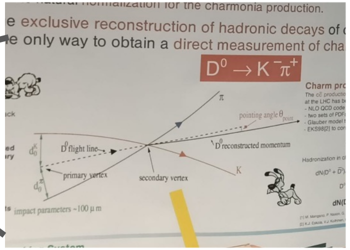
HEAVY FLAVOURS IN HEAVY-ION COLLISIONS AT THE LHC: ALICE PERFORMANCE

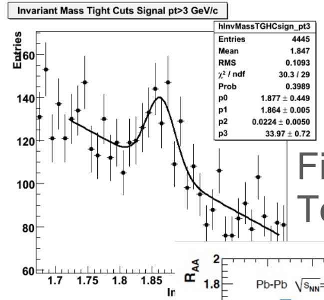
A. DAINESE
Università degli Studi di Padova and INFN, via Marzolo 8, 35131 Padova, Italy
e-mail: andrea.dainese@pd.infn.it
on behalf of the ALICE Collaboration[a]

nucl-ex/0405008

(2004)

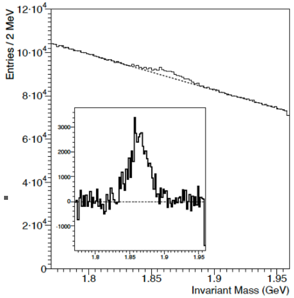


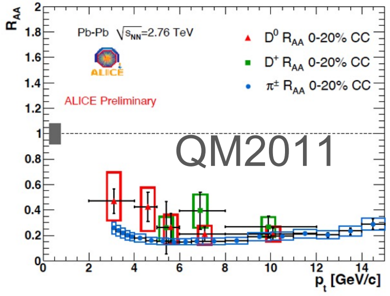




First D^0 in pp 7 TeV (my laptop)

$D^0 \to K^-\pi^+$ in tech. propos. (1995)





First outcome of Padua-Wuhan collaboration in pre-LHC era

Heng Tong Ding (pre-lattice career)

Effect of heavy-quark energy loss on the muon differential production cross section in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.5$ TeV

Z. Conesa del Valle [a,1], A. Dainese [b], H.-T. Ding [c], G. Martínez García [a], and D.C. Zhou [c]

[a] *Subatech (CNRS/IN2P3 - Ecole des Mines - Université de Nantes) Nantes, France*

[b] *INFN - Laboratori Nazionali di Legnaro, 35020 Legnaro (Padova), Italy*

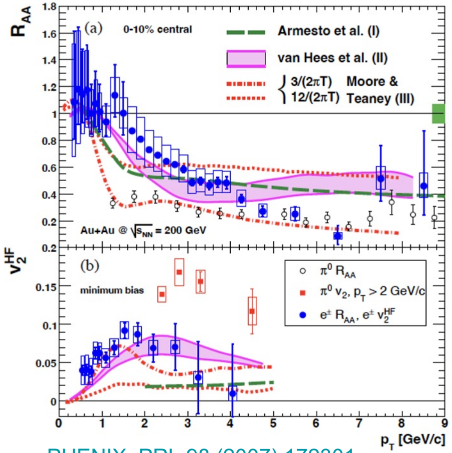
[c] *Institute of Particle Physics, Central China Normal University, Wuhan 430079, China*

PLB 663 (2008) 202-208

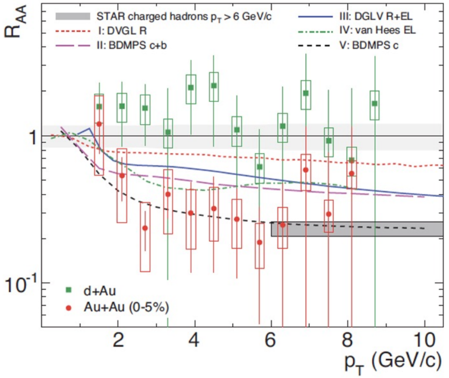
The heavy quark contributions (section 2.2) to the muon pt distribution are obtained from a NLO perturbative QCD(pQCD) calculation (MNR [11]) supplemented with the mass-dependent BDMPS quenching weights for radiative energy loss [12], quark fragmentation `a la Peterson [13] and semi-muonic decay with the spectator model [14]

Glory time of HF leptons at RHIC

… and of discovery of lower than expected charm R_{AA}



PHENIX, PRL 98 (2007) 172301



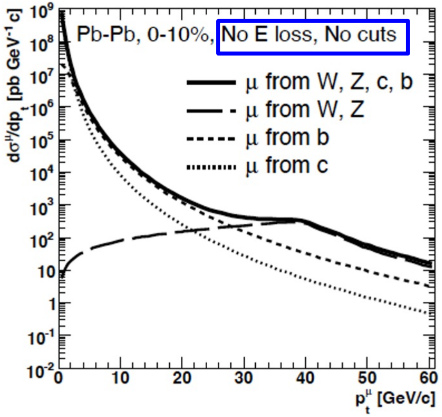
STAR: PRL 98 (2007) 192301, PRL 106 (2011) 159902 (erratum)

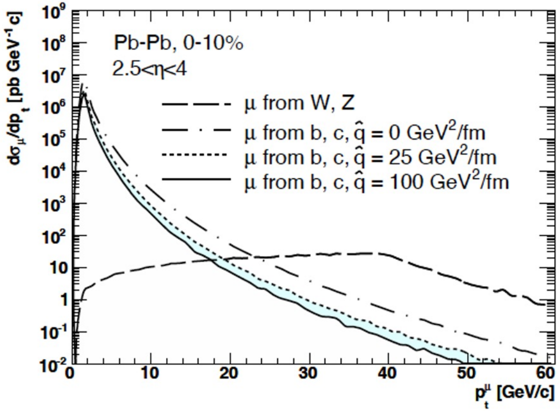
Heavy-Flavour electrons and muons were a major goal of ALICE programme at LHC

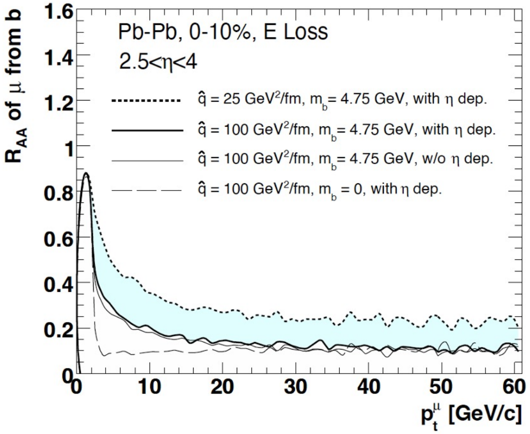
Where also W,Z muons could be measured

First outcome of Padua-Wuhan collaboration in pre-LHC era

Heng Tong Ding (pre-lattice career) PLB 663 (2008) 202-208







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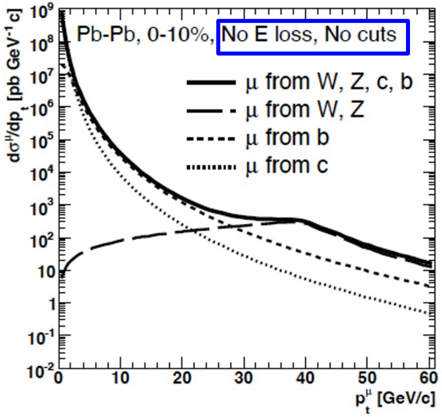
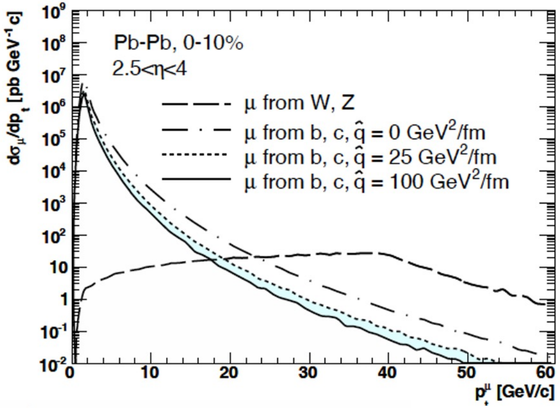
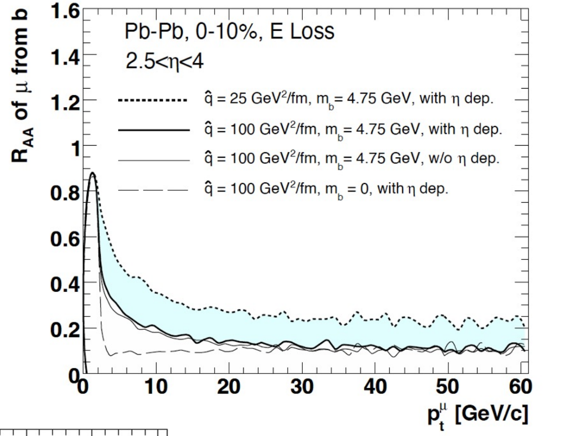
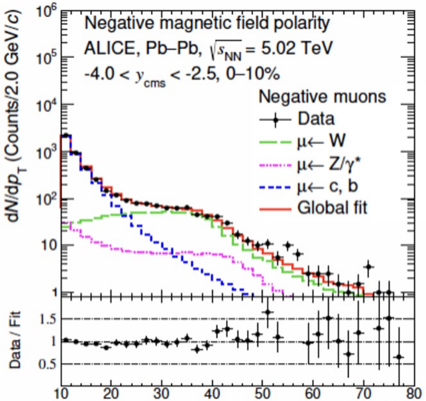


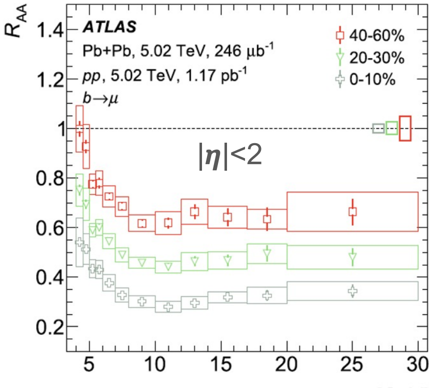




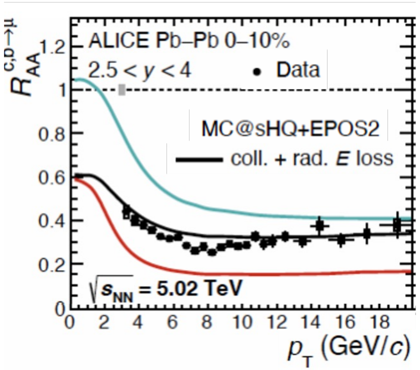
Nice to compare to what measured several years after!



ALICE, JHEP 05 (2022) 036 p_T (GeV/c)



ATLAS,PLB 829 (2022) 137077 p_T [GeV]



ALICE, PLB 820 (2021) 136558

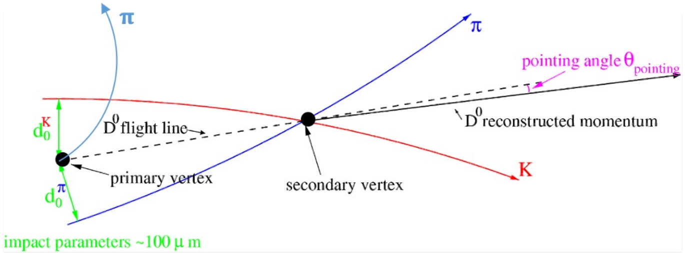
LHC era to start

LHC energies: charm and beauty quarks relatively abundant
ALICE: Inner Tracking System (ITS) with Pixel detector (SPD)

⇨ D-meson production via **exclusive reconstruction of D-meson decays**

Padova was one of the first institutes involved in the definition of the analysis strategy and development of the tools inside ALICE software for the reconstruction of D meson channels, focusing on the $D^0 \to K^-\pi^+$ channel.
Xiaoming Zhang spent few months in Padova implementing the code to reconstruct "**D cascades**", in particular for the analysis of $\mathbf{D^{*+} \to D^0(\to K^-\pi^+)\pi^+}$ channel.

$D^{*+} \to \pi^+ D^0(\to K^-\pi^+)$



D^0-daughter tracks displaced from the primary vertex

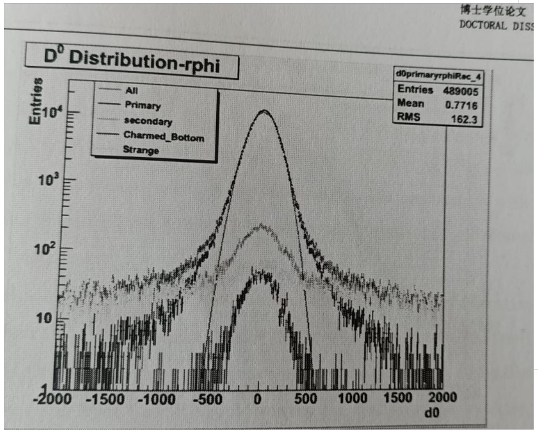
Scale of displacement set by D^0 $c\tau$ = 123 μm

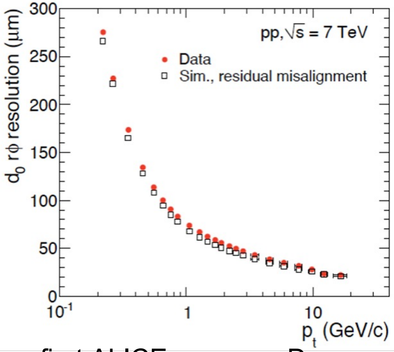
This determines the spatial resolution on track impact parameter require to distinguish real decay vertices from combinatorial background or tracks coming from primary vertex

ALICE ITS and SPD had been designed to meet this requirement
But one had to **measure the actual resolution values, verify that they were reproduced by simulations, and fix the latter if needed**

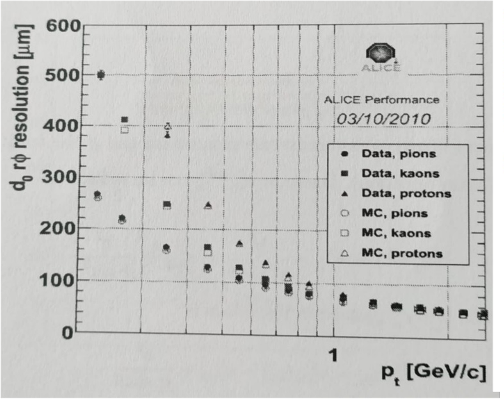
Monitor of track impact parameter resolution

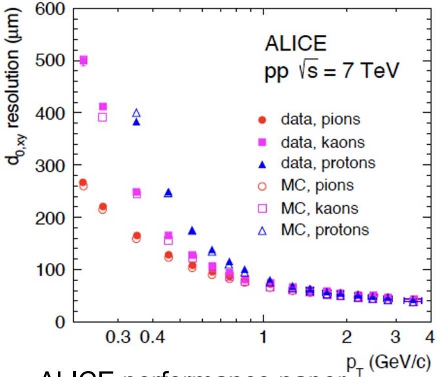
from Xianbao Yuan PhD thesis





first ALICE paper on D meson production, JHEP 01 (2012) 128





ALICE performance paper
Int.J.Mod.Phys.A 29 (2014) 1430044

Track resolution estimated from **fit to DCA distribution** of reconstructed tracks with dedicated procedure to **account for tails due to secondary particles**

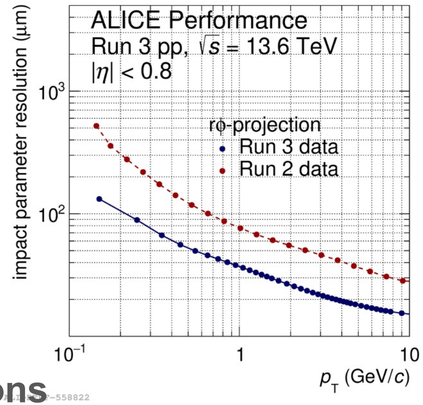
"Robust" procedure for reliable automatization

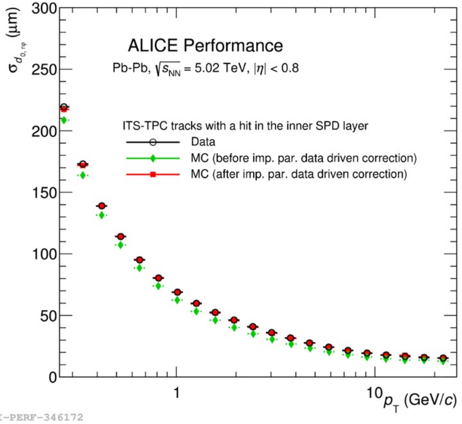
- extraction of Gaussian sigma, mean, pulls

Extensively used afterwards

Same approach in use **still today**

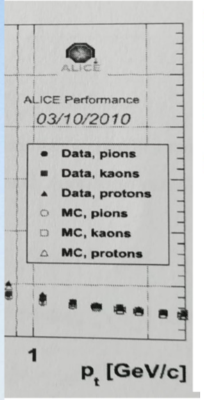
At the basis of our **data-driven calibration of MC simulations**

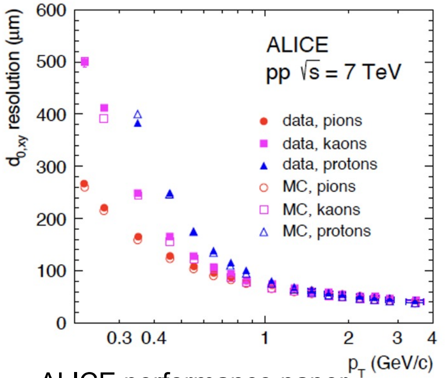




Monitor of track impact parameter resolution

Picture from Xianbao Yuan PhD thesis defense





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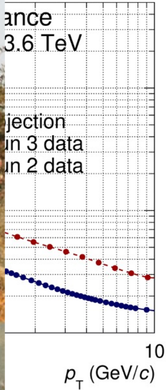

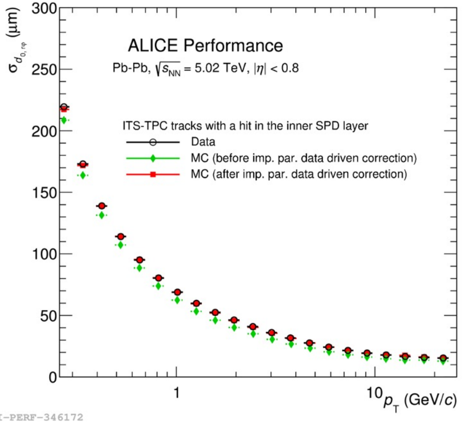

to **account for tails due to seconda**

“Robust” procedure for reliable autom

- extraction of Gaussian sigma, n

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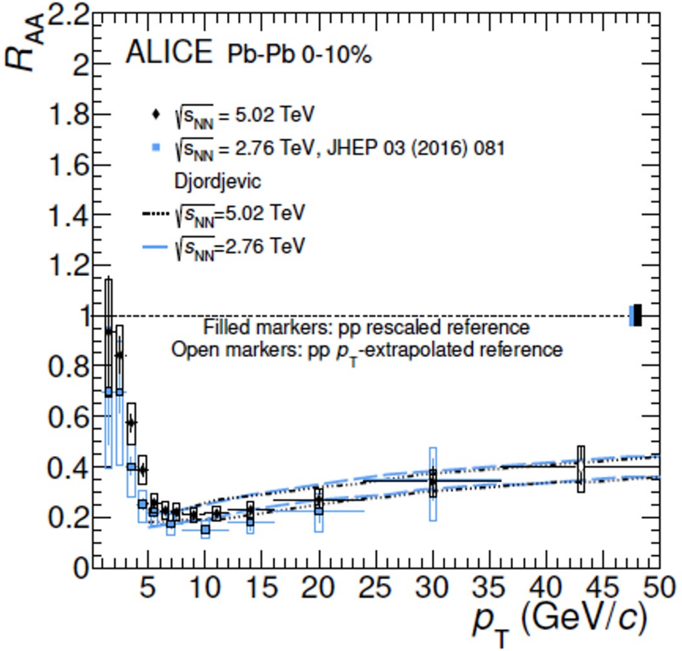
At the basis of our **data-driven calib**

D meson R_{AA} in Pb-Pb collisions… in the middle of Run 2

JHEP 1810 (2018) 174



Xinye Peng PhD work of thesis

First D⁰-meson measurement in Pb-Pb at 5.02 TeV

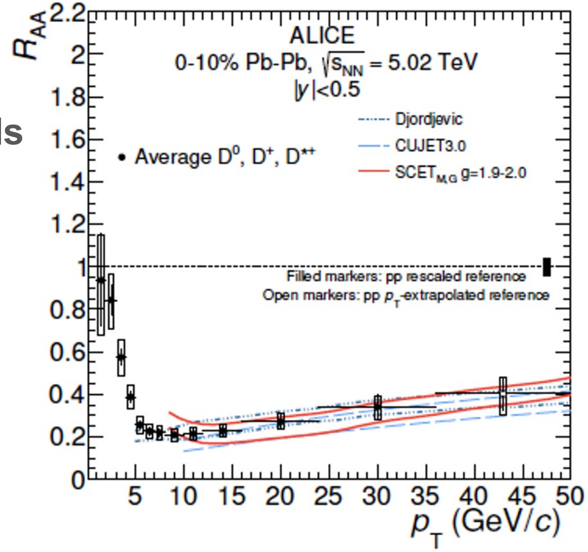
Improved precision and high-p_T reach w.r.t. 2.76 TeV measurement

Strong suppression at high p_T

Described by pQCD-based models

Radiative processes dominant at high p_T

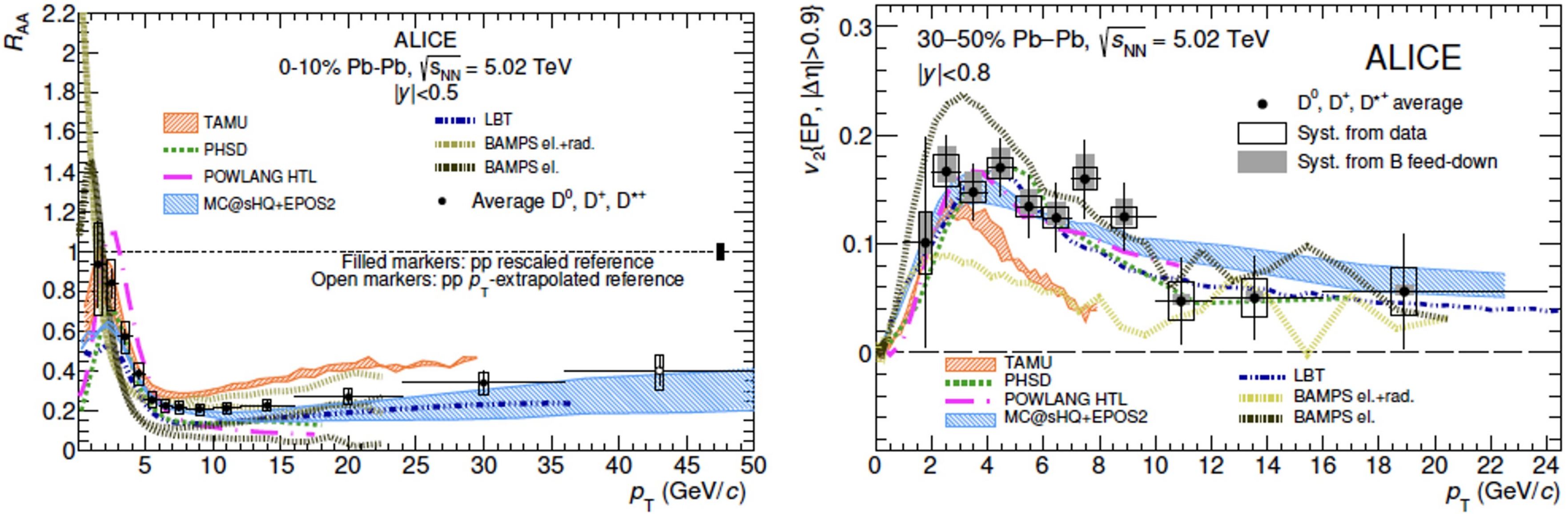
Not last word from run 2 but data uncertainties already comparable or smaller than theoretical ones



CUJET3.0 JHEP 02 (2016) 169, **Djordjevic** PRC 92 (2015) 024918, **SCET** JHEP 03 (2017) 146

D meson R_{AA} in Pb-Pb collisions… in the middle of Run 2

JHEP 1810 (2018) 174



"**Simultaneous description of R_{AA} and v_2 challenging for models**"

- comparison with transport models → constraints to **spatial diffusion coefficient D_s** and **charm relaxation time τ_{eq}** : $1.5 < 2\pi T D_s(T) < 7 \rightarrow 3 < \tau_{eq} = m_{charm} / T\, D_s(T) < 14$ fm/c at T_{PC}=155 MeV PRL 120 102301 (2018)
  - Further restricted by subsequent measurement
- **Importance of recombination** to describe both observables

Stimulated theoretical developments (e.g. space-momentum correlations in TAMU)

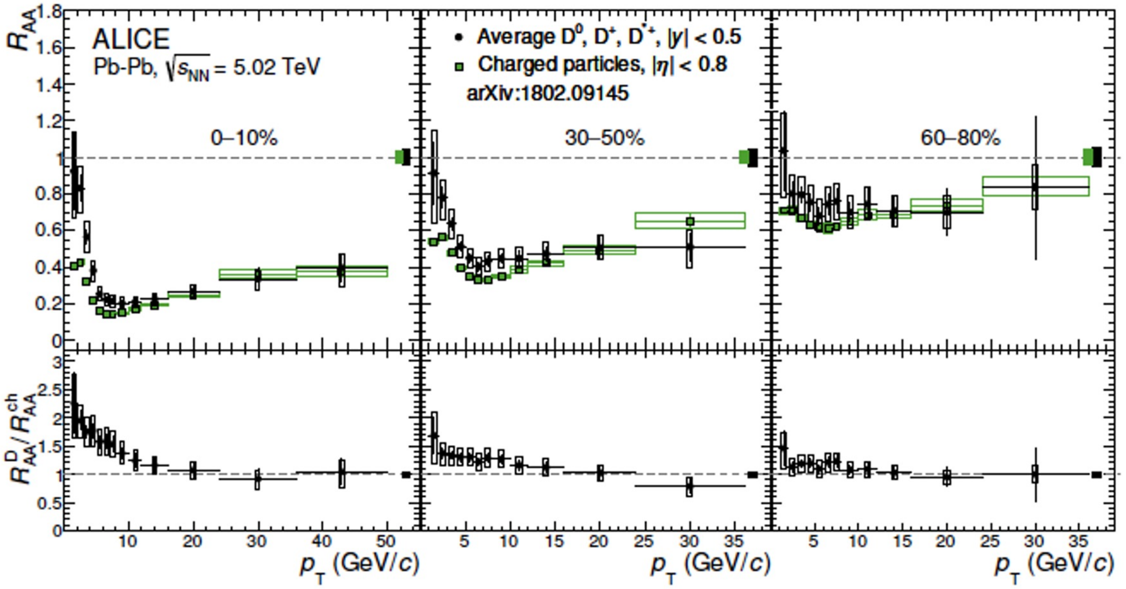
BAMPS J. Phys. G42 (2015) 115106, **LBT** PLB777 (2018) 255-259, **MC@sHQ+EPOS** PRC 89 (2014) 014905, **PHSD** PRC 93 (2016) 034906, **POWLANG** EPJC 75 (2015) 121, **TAMU** PLB 735 (2014) 445

D meson R_{AA} in Pb-Pb collisions… in the middle of Run 2

JHEP 1810 (2018) 174

D-meson and hadron/pion R_{AA}
- sizeable difference at low p_T
- similar at high p_T

… result of **combination of many effects** including energy loss dependence on **Casimir factor and quark mass**



D meson R_{AA} in Pb-Pb collisions… *at the end of Run 2*

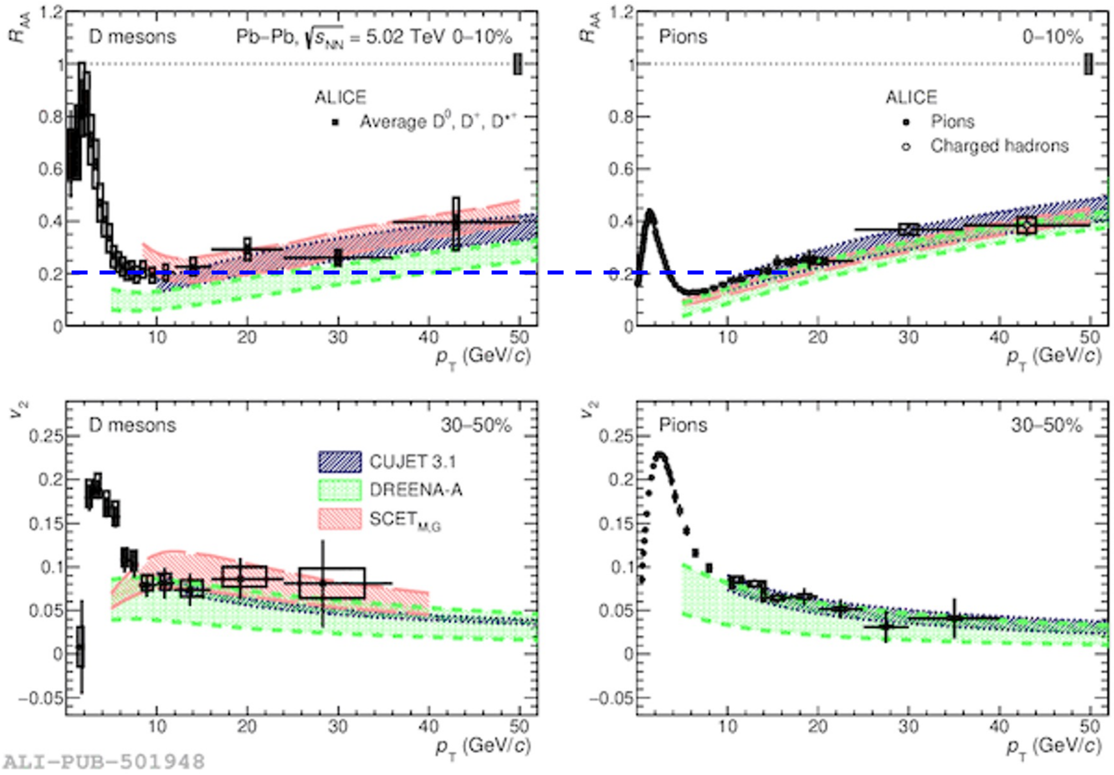
[JHEP 01 (2022) 174]

D-meson and hadron/pion R_{AA}
- sizeable difference at low p_T
- similar at high p_T

… result of **combination of many effects** including energy loss dependence on **Casimir factor and quark mass**

Reproduced by models accounting for different initial quark and gluon spectra, fragmentation, and energy loss
→ At high-p_T larger fraction of pions from light quarks than from gluons
→ Charm-mass effect not large at high p_T

$$\Delta E_g > \Delta E_{uds} \geq \Delta E_c$$



Similar v_2 at high p_T,
need to improve D-meson precision to further constrain models → **important goal of Run 3**

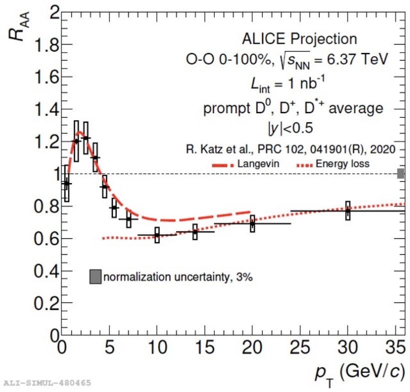
Prompt D: prospects for run 3 and O–O next year

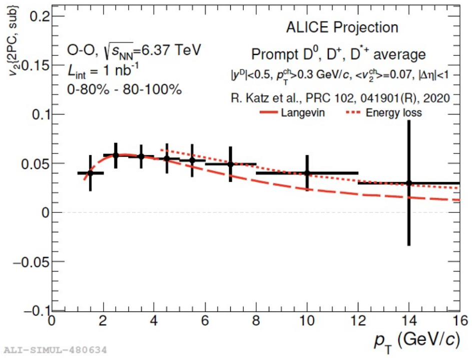
Room for improving precision in peripheral collisions (x100 more stat)

Interesting for studying energy loss in small systems

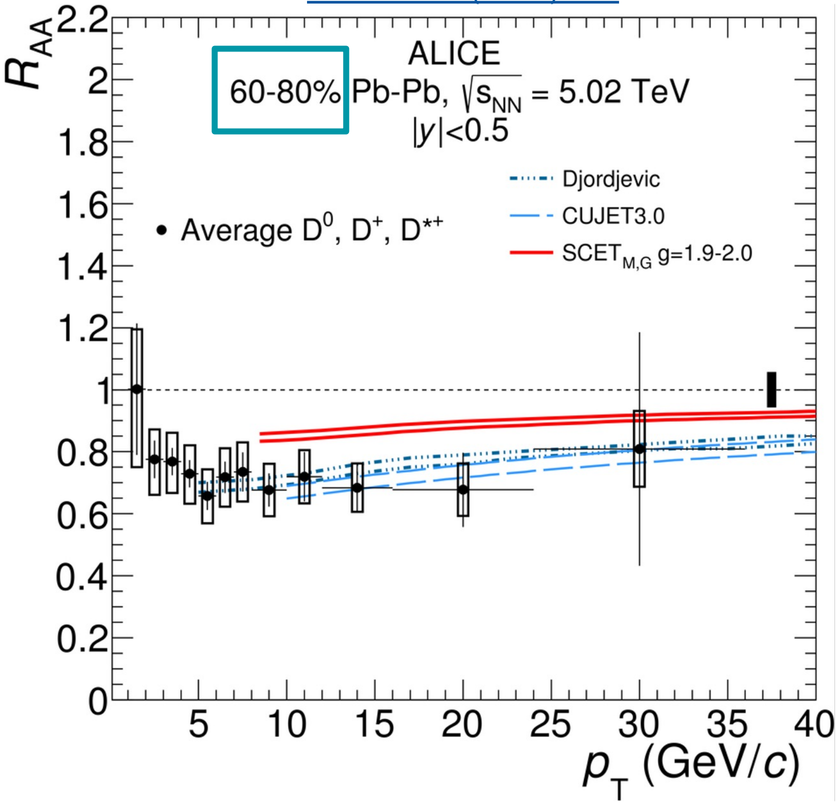
… “biases” in centrality determination

O–O and p-O runs in 2025!





JHEP 1810 (2018) 174



While celebrating in Wuhan and Padua

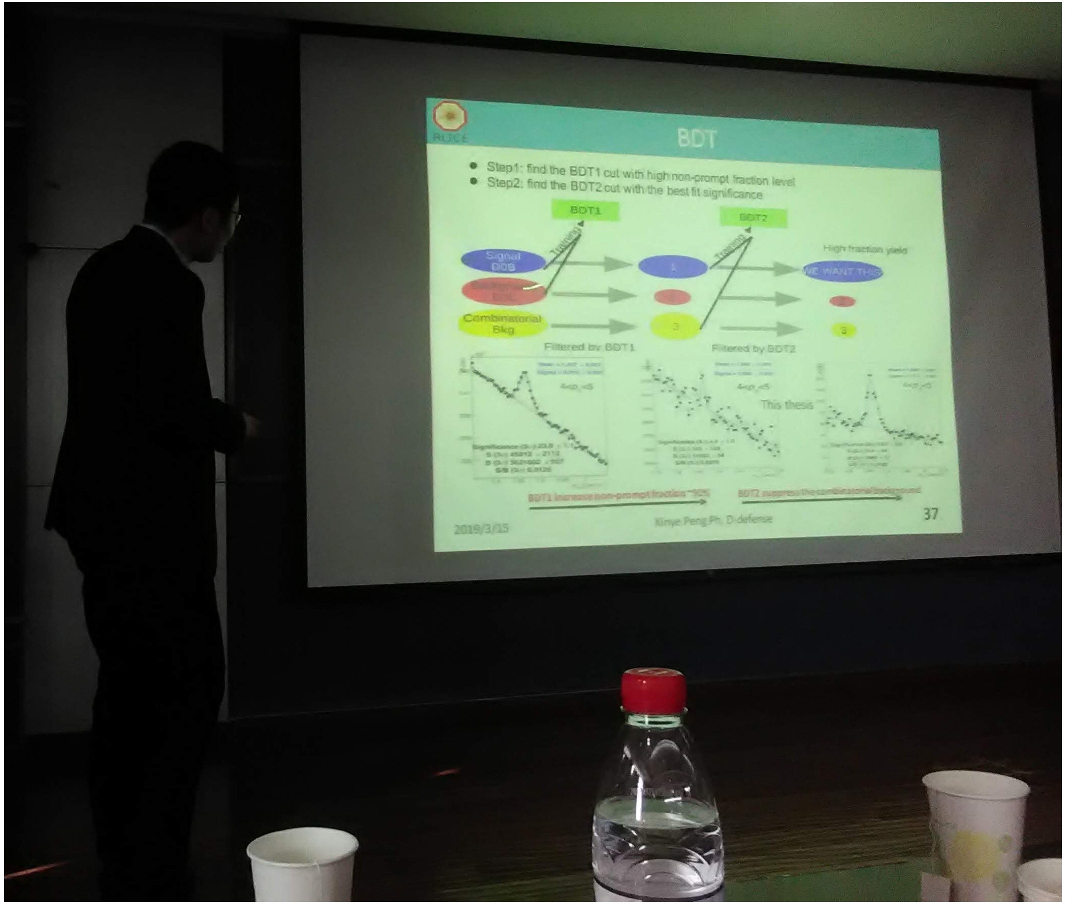
March 2019, after X. Peng PhD defense

While celebrating in Wuhan and Padua

March 2019, after X. Peng PhD defense

… we were working on beauty!

The beautiful power of machine learning



Measurement of beauty production via non-prompt D mesons

Using BDT from TMVA in 2 classification steps
1 - feed-down D^0 vs. prompt D^0
2 - feed-down D^0 vs. combinatorial background

Plus a very simple idea to quantify the fraction

Corrected yields (free parameters) Raw yield

$$(\mathrm{Acc}\times\varepsilon)_{\mathrm{i}}^{\mathrm{prompt}}\times N_{\mathrm{prompt}}+(\mathrm{Acc}\times\varepsilon)_{\mathrm{i}}^{\mathrm{non\text{-}prompt}}\times N_{\mathrm{non\text{-}prompt}}-Y_{\mathrm{i}}=\delta_{\mathrm{i}}.$$

Acceptance x efficiencies for given cut (i^{th}) on BDT response

→ **Profiling BDT response** (i = 1… n cuts)

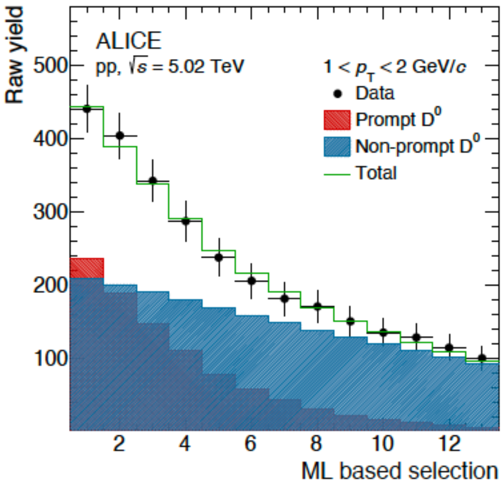
$$\begin{pmatrix}(\mathrm{Acc}\times\varepsilon)_1^{\mathrm{prompt}} & (\mathrm{Acc}\times\varepsilon)_1^{\mathrm{non\text{-}prompt}}\\ \vdots & \vdots \\ (\mathrm{Acc}\times\varepsilon)_n^{\mathrm{prompt}} & (\mathrm{Acc}\times\varepsilon)_n^{\mathrm{non\text{-}prompt}}\end{pmatrix}\times\begin{pmatrix}N_{\mathrm{prompt}}\\ N_{\mathrm{non\text{-}prompt}}\end{pmatrix}-\begin{pmatrix}Y_1\\ \vdots\\ Y_n\end{pmatrix}=\begin{pmatrix}\delta_1\\ \vdots\\ \delta_n\end{pmatrix}$$

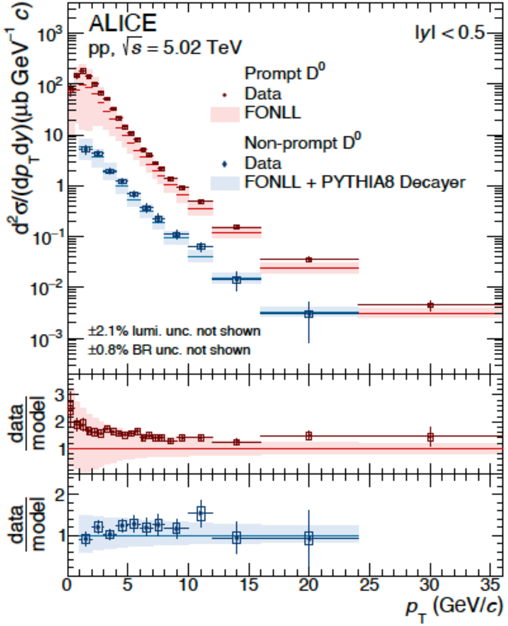
By minimizing $\chi^2=\boldsymbol{\delta}^{\boldsymbol{T}}\boldsymbol{C}^{-1}\boldsymbol{\delta}$ → N_{prompt} , $N_{\mathrm{non\text{-}prompt}}$

First attempt day after Xinye's defense!

The beautiful power of machine learning

[JHEP 05 (2021) 220]





Mengke Cai work of thesis

Simple but very effective idea, **powerful for reaching low p_T** and better for syst. unc. w.r.t. other methods (e.g. DCA fits)

Further contribution by Turin group

- Ternary classification + easy and standardize use

Became a standard for D2H analyses (>8 papers)

Measurement of beauty production via non-prompt D mesons

Using BDT from TMVA in 2 classification steps

1 - feed-down D^0 vs. prompt D^0

2 - feed-down D^0 vs. combinatorial background

Plus a very simple idea to quantify the fraction

Corrected yields (free parameters) Raw yield

$$(\mathrm{Acc}\times\varepsilon)_i^{\mathrm{prompt}}\times N_{\mathrm{prompt}}+(\mathrm{Acc}\times\varepsilon)_i^{\mathrm{non\text{-}prompt}}\times N_{\mathrm{non\text{-}prompt}}-Y_i=\delta_i.$$

Acceptance x efficiencies for given cut (ith) on BDT response

→ **Profiling BDT response** (i = 1… n cuts)

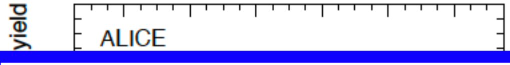
$$\begin{pmatrix}(\mathrm{Acc}\times\varepsilon)_1^{\mathrm{prompt}} & (\mathrm{Acc}\times\varepsilon)_1^{\mathrm{non\text{-}prompt}}\\ \vdots & \vdots\\ (\mathrm{Acc}\times\varepsilon)_n^{\mathrm{prompt}} & (\mathrm{Acc}\times\varepsilon)_n^{\mathrm{non\text{-}prompt}}\end{pmatrix}\times\begin{pmatrix}N_{\mathrm{prompt}}\\ N_{\mathrm{non\text{-}prompt}}\end{pmatrix}-\begin{pmatrix}Y_1\\ \vdots\\ Y_n\end{pmatrix}=\begin{pmatrix}\delta_1\\ \vdots\\ \delta_n\end{pmatrix}$$

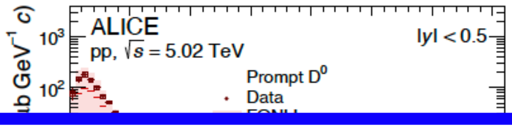
By minimizing $\chi^2=\boldsymbol{\delta}^T C^{-1}\boldsymbol{\delta}$ → N_{prompt} , $N_{non\text{-}prompt}$

First attempt day after Xinye's defense!

The beautiful power of machine learning

[JHEP 05 (2021) 220](#)





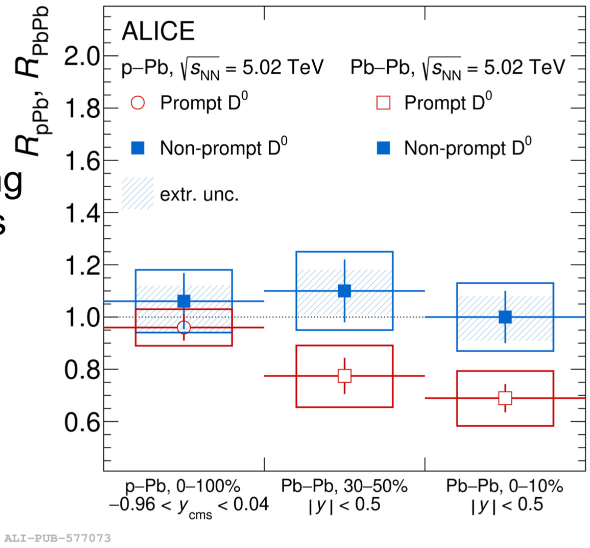
Measurement of beauty production via non-prompt D mesons

Mingyu Zhang
non-prompt D^0 in p-Pb
[arxiv 2407.10593](#)

Beauty: little room for shadowing or modified hadron abundances

Started before PhD
Visiting student in Padua

Now PhD student within Padua-Wuhan PhD cotutelle programme



g BDT from TMVA in 2 classification steps
ed-down D^0 vs. prompt D^0
ed-down D^0 vs. combinatorial background

a very simple idea to quantify the fraction

Corrected yields (free parameters) Raw yield

$$\times\varepsilon)_i^{\rm prompt} \times N_{\rm prompt} + (\mathrm{Acc}\times\varepsilon)_i^{\rm non\text{-}prompt} \times N_{\rm non\text{-}prompt} - Y_i = \delta_i .$$

eptance x efficiencies for given cut (i^{th}) on BDT response

Profiling BDT response (i = 1… n cuts)

$$\begin{pmatrix} \times\varepsilon)_1^{\rm prompt} & (\mathrm{Acc}\times\varepsilon)_1^{\rm non\text{-}prompt} \\ \vdots & \vdots \\ \times\varepsilon)_n^{\rm prompt} & (\mathrm{Acc}\times\varepsilon)_n^{\rm non\text{-}prompt} \end{pmatrix} \times \begin{pmatrix} N_{\rm prompt} \\ N_{\rm non\text{-}prompt} \end{pmatrix} - \begin{pmatrix} Y_1 \\ \vdots \\ Y_n \end{pmatrix} = \begin{pmatrix} \delta_1 \\ \vdots \\ \delta_n \end{pmatrix}$$

By minimizing $\chi^2 = \boldsymbol{\delta}^T C^{-1} \boldsymbol{\delta}$ → $N_{\rm prompt}$, $N_{\rm non\text{-}prompt}$

First attempt day after Xinye's defense!

Further contribution by Turin group
- Ternary classification + easy and standardize use

Became a standard for D2H analyses (>8 papers)

The beautiful power of machine learning

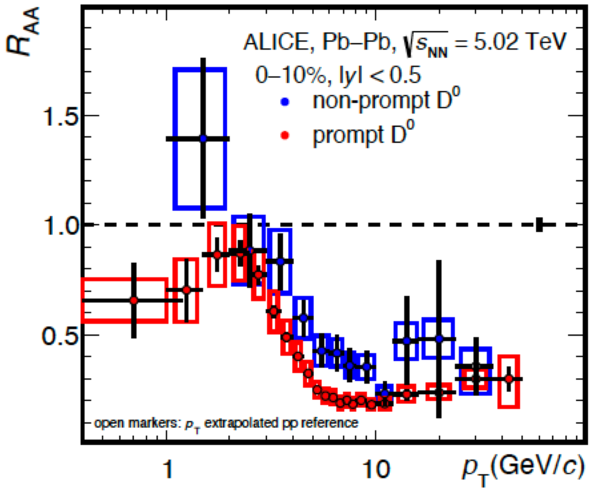
Mengke Cai work of thesis

Beauty vs. charm R_{AA} down to low p_T via separation of non-prompt and prompt D mesons

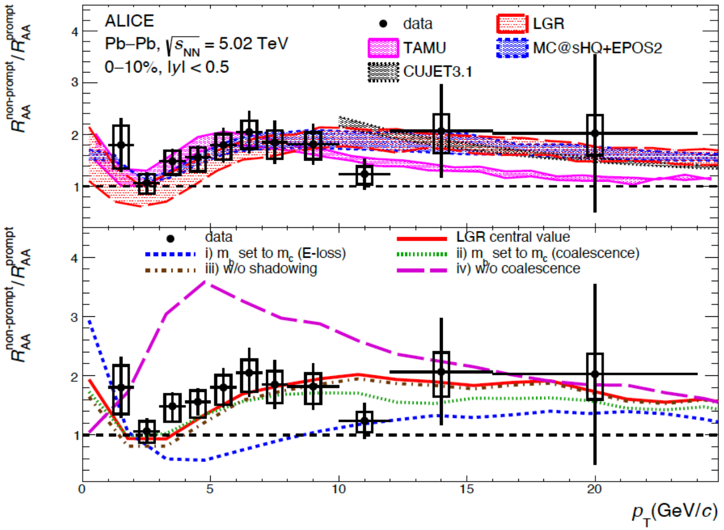
Fundamental for understanding quark diffusion and transport

R_{AA}(non-prompt)>R_{AA}(prompt)

(via models) $\Delta E_g > \Delta E_{uds} \geq \Delta E_c > \Delta E_b$



JHEP 12 (2022) 126



Also highlighted role of coalescence (for charm mainly!)
→ Necessity of constraining hadronization

TAMU: PLB 735 (2014) 445
MC@sHQ+EPOS2: PRC 89 (2014) 014905
LGR: EPJC 80, no.7, (2020) 671
CUJET3: CPC 43, no.4, (2019) 044101

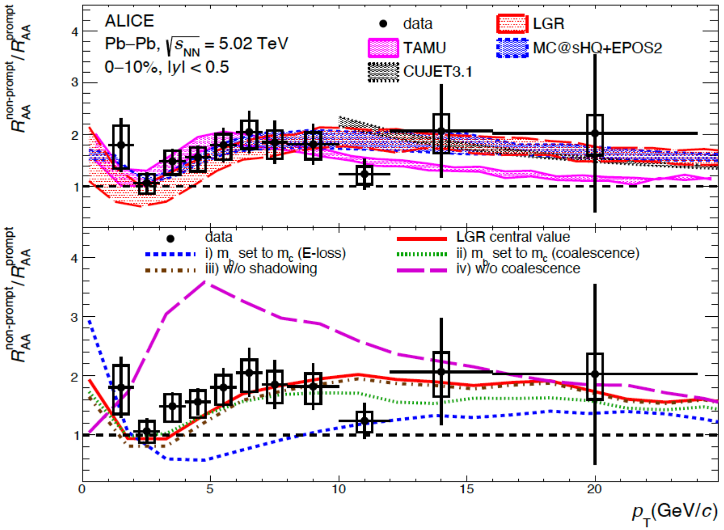
The beautiful power of machine learning

Beauty vs. charm R_{AA} down to low p_T via separation of non-prompt and prompt D mesons

Mengke Cai PhD defense (May 2023)

diffusion and transport

[JHEP 12 (2022) 126]



Also highlighted role of coalescence (for charm mainly!)
→ Necessity of constraining hadronization

Investigating the QGP with heavy quarks

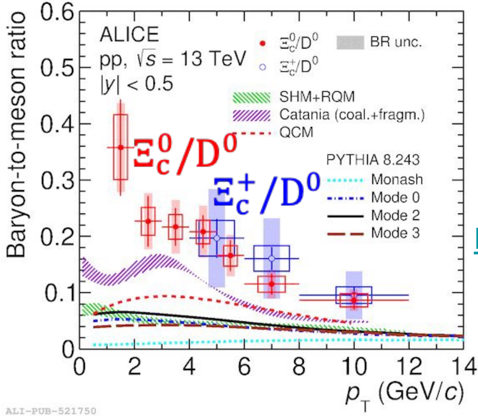
Ideal probes of final-state effects

- charm and beauty quarks produced only in hard-scattering
    - thermal production of charm [beauty] quarks expected very small [negligible]
- large Q^2 → pQCD calculation reliable

Hadronic interaction
Femtoscopy studies
(D-p,π,K correlations)

Hadronization: complication and opportunity

Coalescence of heavy quarks with surrounding light quarks expected to become important in a medium dense of colour charges
→ need to be understood and properly modelled in order to access earlier partonic dynamics



Jianhui Zhu
(at GSI)

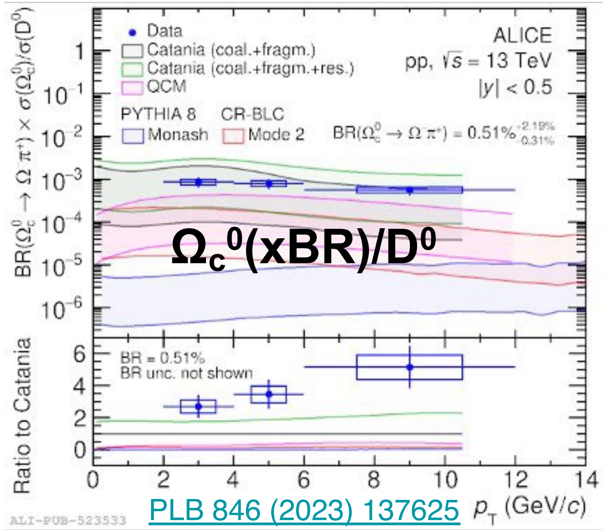
PRL. 127 (2021) 272001

pp: naive expectation of fragmentation dominance proved wrong by data!

Charm and beauty as probes of hadronization in all systems: new direction at the LHC!

Collaboration on hadronization studies

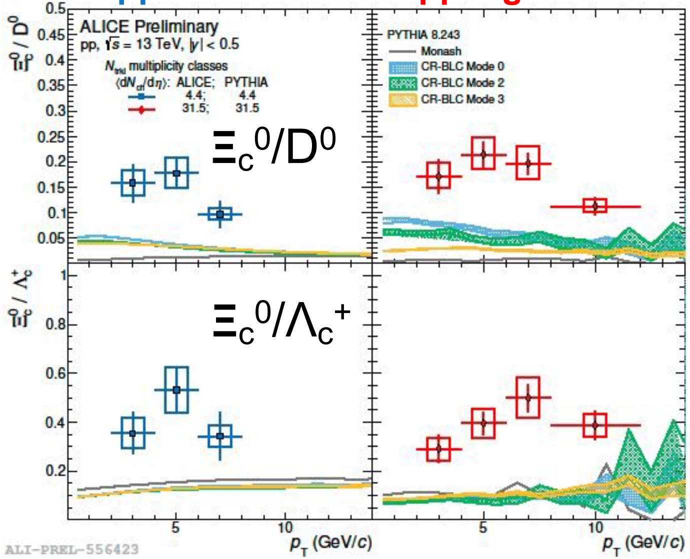
J. Zhu, GSI+Wuhan+Padua finalized in Padua



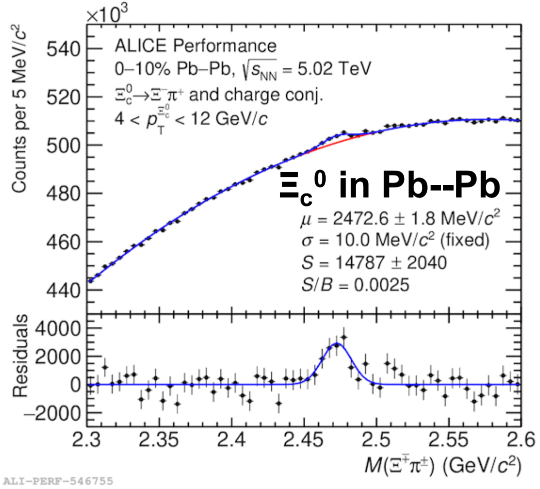
PLB 846 (2023) 137625

Work of **Tao Fang (student of Zhong-Bao Yin)** during 2 months visiting period in Padova + J. Zhang

pp low mult **pp high mult**



J. Zhu in Padua, now Fudan



J. Zhu came to Padova with an INFN post-doc but activity extended to collaboration with Wuhan CCNU and we wish to make concrete collaboration with Fudan

- First measurement of Ω_c^0 production (times BR) in pp collisions: possibly very large…
- Precision not enough to conclude about multiplicity trend of $\Xi_c^{0,+}/D^0$ in pp
- First observation of Ξ_c^0 **signal in Pb–Pb** collisions: ongoing work!

⇨ **Appetizers for Run 3!**

ITS2 upgrade for run 3

OB construction flow diagram

Pixel Chips
Test and Selection
(Yonsei)

Flexible Printed Circuits
Production and Test
(Trieste)

→ Module Construction Center
Assembly and Test
(Bari, Liverpool, Pusan, Strasbourg, Wuhan)

↓

Stave Production Center
Assembly and Test
(Daresburyl, LBNL, Turin and LNF, NIKHEF)

← Space frame & Cold Plate
Construction and Qualification
(CERN)

← Power Bus
Production and Test
(Tbd)

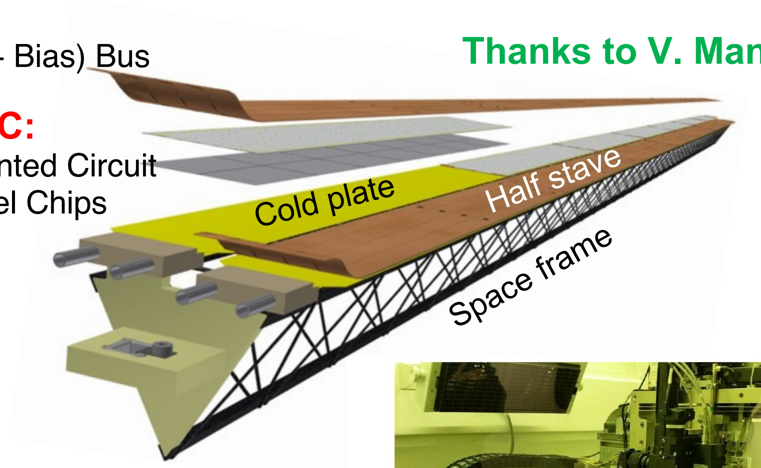
↓

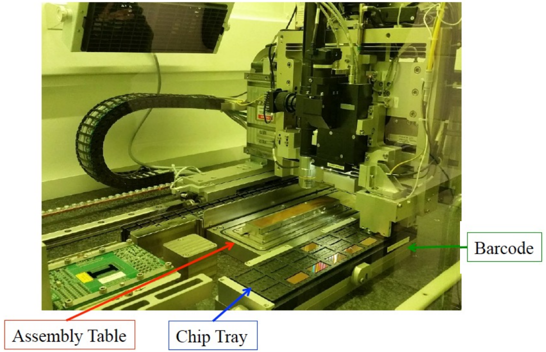
End-wheels
Production and Qualification
(Padova, LBNL)

Detector & Service Barrels
Production and Qualification
(CERN and LBNL)

→ Half-layer & Half-barrel
Integration and Commissioning
(CERN)

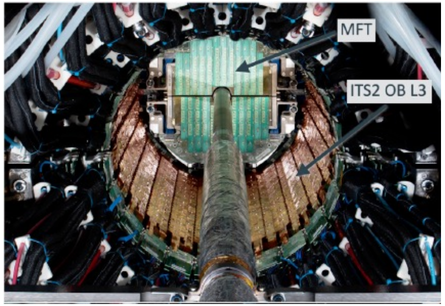
Thanks to V. Manzari

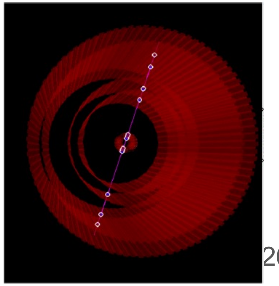




From **V. Manzari's report in Wuhan at June 2015**
5^{th} ALICE ITS Upgrade, MFT and O2 Asian Workshop

Total of 2550 OB-HIC needed (1692 + 20% spare, 80% yield)
Series production started in 2017-2018, splitted among 5 sites
Collaboration towards an important and successful project!





Collaboration for DCAL (2010-2013)

Thanks to A. Fantoni

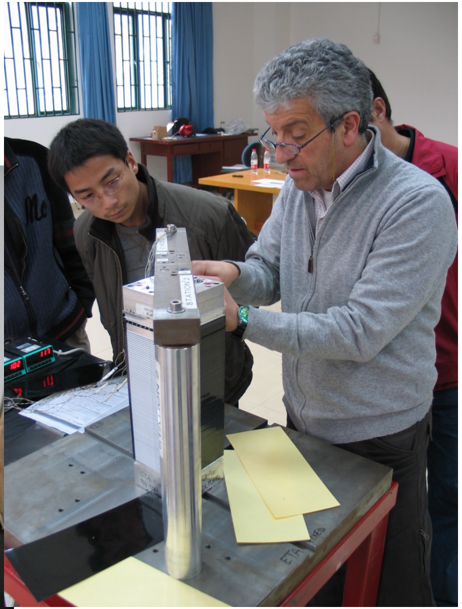
CHINA (Wuhan) provide **manpower for WLS fiber production for 3 Super Modules in INFN Frascati**
=> 1 engineer (Wanyan Qian) + 1 technician (Hanseng Dong) in Frascati for working on the WLS fibers and on the bundle preparation for 3 EMCAL SMs in May-July 2010
=> 1 engineer (Wanyan Qian) + 1 technician (Nonghao Li) for working on the WLS fibers and on the bundle preparation for 1.5 DCAL SM in February 2011 (1 month)

ITALY (INFN Frascati): provide module assembly tooling to Wuhan (two stations)
=> 2 assembly stations delivered to Wuhan in spring 2011

- provide facilities, expertise and manpower for WLS fiber bundle assembly for Europe and Asian module by INFN Frascati

=> 1 physicist (Alessandra Fantoni) + 2 technicians (Aldo Orlandi & Angelo Viticchié) in Wuhan (November 2011):

- check & validation: 2 LNF assembly stations
  + 1 chinese assembly station
- training module assembly to engineers & technicians
- assembly of few DCAL modules

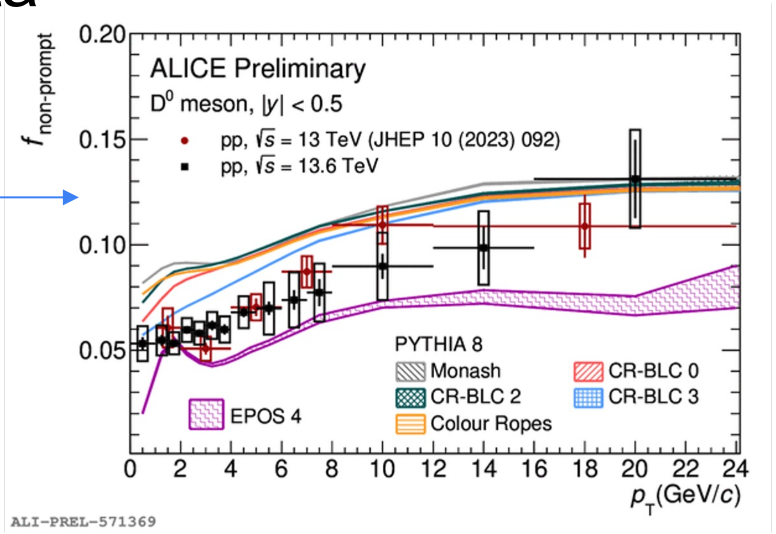


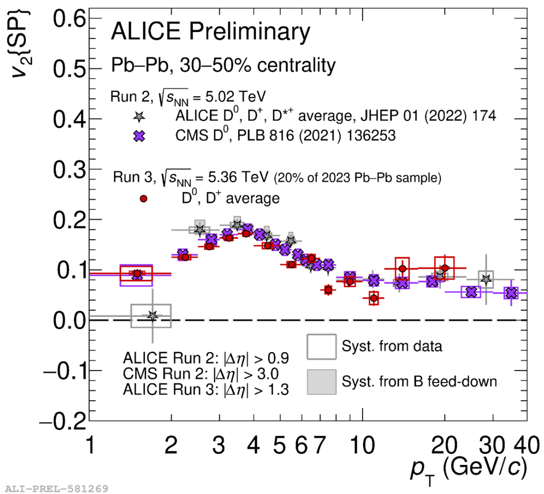
Ongoing collaboration on run 3 data

Mingyu Zhang, ongoing cotutelle PhD

Non-prompt/prompt D^0 fraction in pp@13.6 TeV →

Among first HF results with run 3 data approved as preliminary





Chuntai Wu (under X. Peng now at Wuhan GS supervision)
While starting **PhD in Padua funded by CSC**
D^0 v_2 in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV

Zheng Zhang, working on Λ_c^+ – hadron correlations
within **Wuhan CCNU – Bari University PhD cotutelle** programme

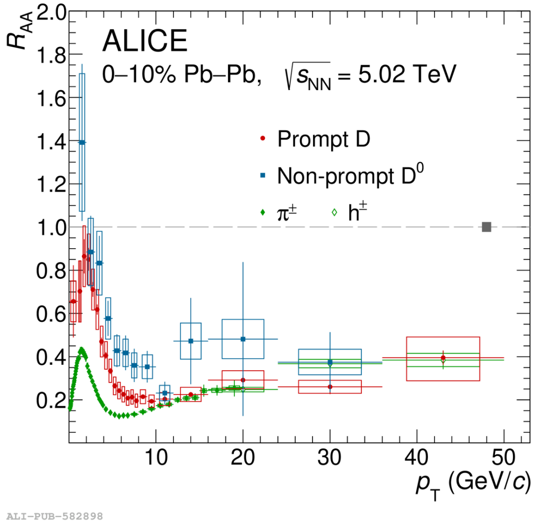
Final notes (not conclusion!)

China-Italy collaboration within ALICE has lasted for about 18 years
Expanding with time

Very fruitful collaboration

- Sharing of knowledge
- Development of new analyses and detectors
- Very concrete outcome: several papers, important results, working detectors

We are extremely greatful to prof. Daicui Zhou who started it



Scientific collaboration that profited from and triggered good human relationships and friendships

酒逢知己千杯少 (Jiǔ féng zhījǐ qiān bēi shǎo)
with a close friend, a thousand cups of wine is far too little

… I wish a thousand collaboration meeting to come

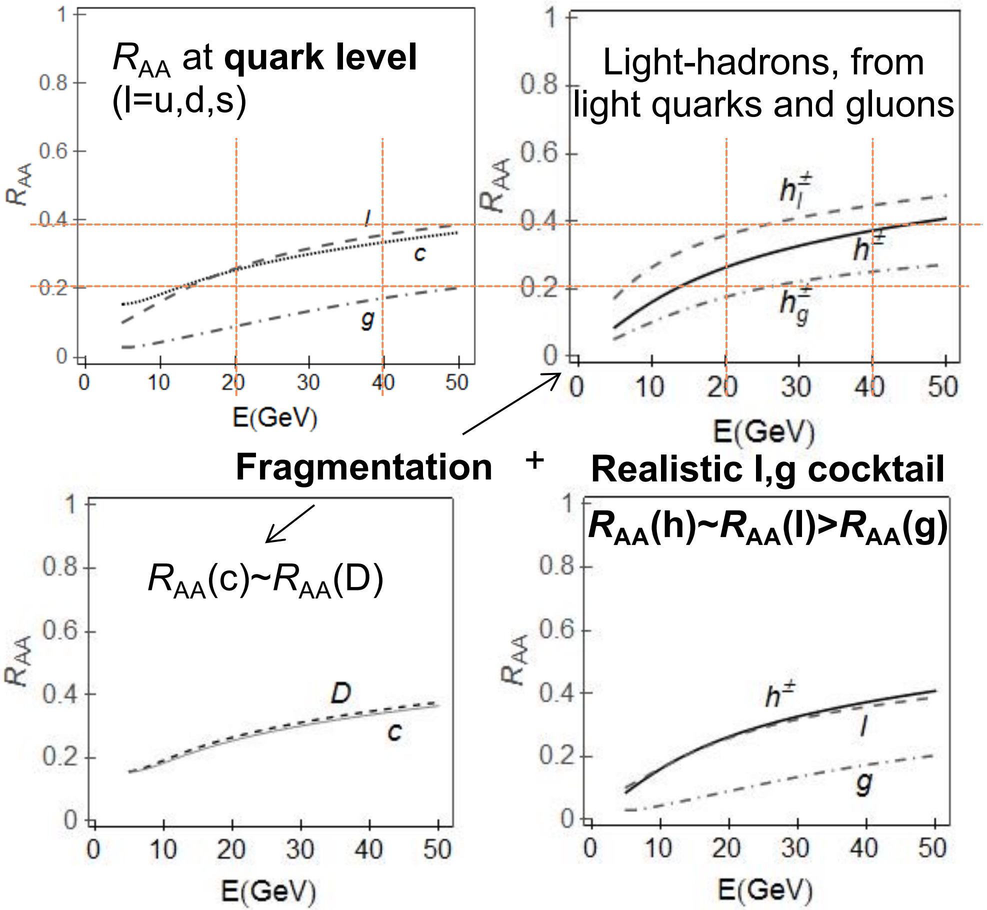
China-Italy… long standing collaboration

Venice is celebrating this year 700th hundreds year from the death of Marco Polo, a venetian merchant and explorer who spent 18 years in China getting close to the Khan
His experience (and book “Il Milione”) was such to foster relationships between Europe and China/Asia

Almost as old as Padua University (800 years) in 2022

Thanks!

D meson vs. pion R_{AA}, high p_T



M. Djordjevic, PRL112 (2014) 042302

Colour-charge dependence of energy loss and small charm-mass effects lead to:

$\Delta E_g > \Delta E_{uds} \geq \Delta E_c$

$R_{AA}(g) < R_{AA}(uds) \sim R_{AA}(c)$

(effect of different partonic spectra included)

R_{AA} of hadrons from light quarks, gluon strongly influenced by (soft) fragmentation

$R_{AA}(h_l) > R_{AA}(l)$

$R_{AA}(h_g) > R_{AA}(g)$

Expected hierarchy (at high p_T):

$\boldsymbol{R_{AA}(g) < R_{AA}(uds) \sim R_{AA}(h) \sim R_{AA}(D) \sim R_{AA}(c)}$

Investigating the QGP with heavy quarks

Large D-meson v_2

Close to pion for p_T>3 GeV/C
Confirmed also by ESE inspection
→ **charm quarks strongly coupled to the system**
→ small diffusion coefficient
$1.5 < 2\pi D_s T_c < 4.5$
(relaxation time $3 < \tau_{charm} \sim m_{charm}/T\ D_s < 9$ fm/c)

charm probes equilibration process
beauty likely to remain off equilibrium

EPJC 83 (2023) 1123