The charming side of ALICE

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HELMHOLTZ GEMEINSCHAFT

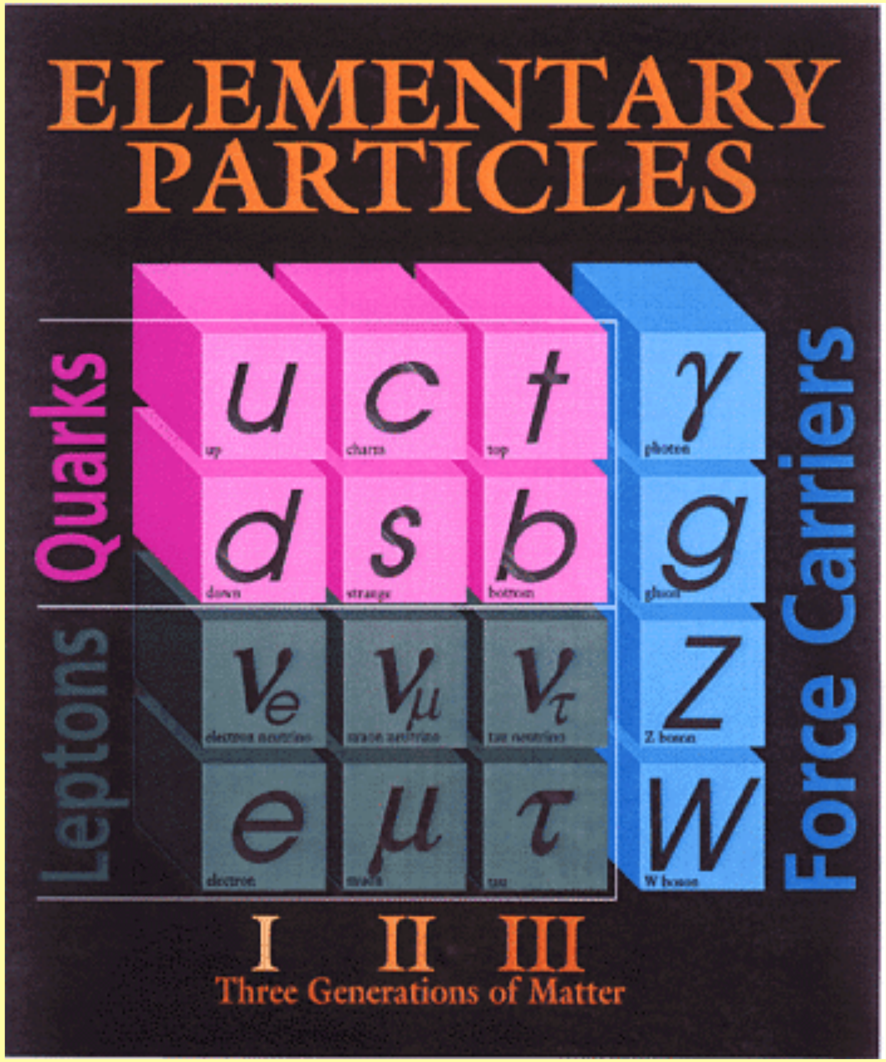
BMBF Forschungsschwerpunkt ALICE Experiment 201

ALICE

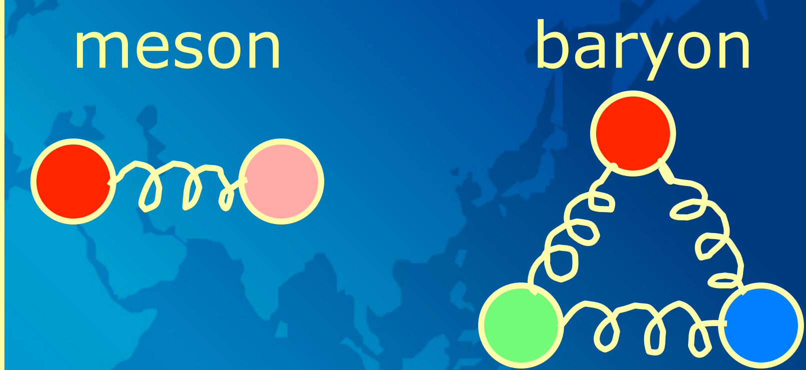
EMMI

GSI

Building Blocks of Matter



1) Quantum Chromodynamics (QCD) is the established theory of strongly interacting matter.
2) Gluons hold quarks together to from hadrons:

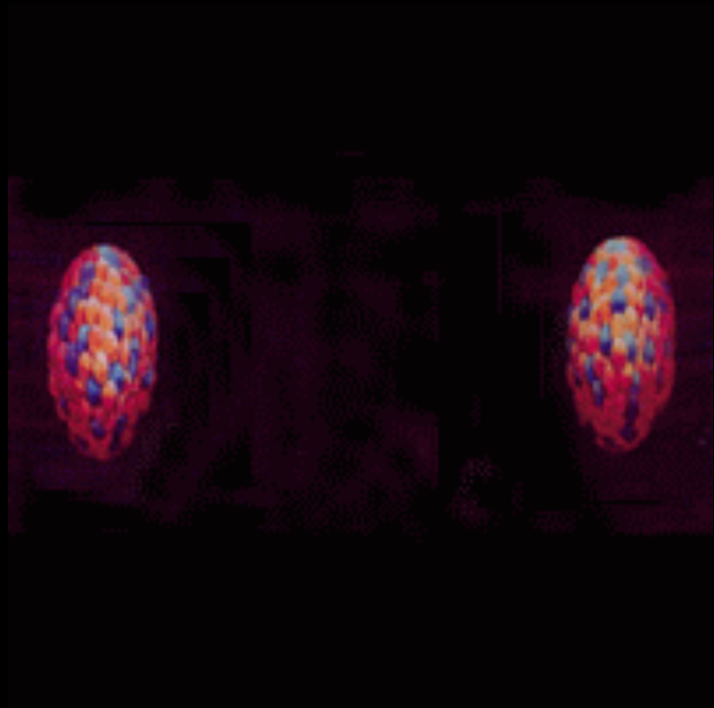


3) Gluons and quarks, or partons, typically exist in a color singlet state: confinement.

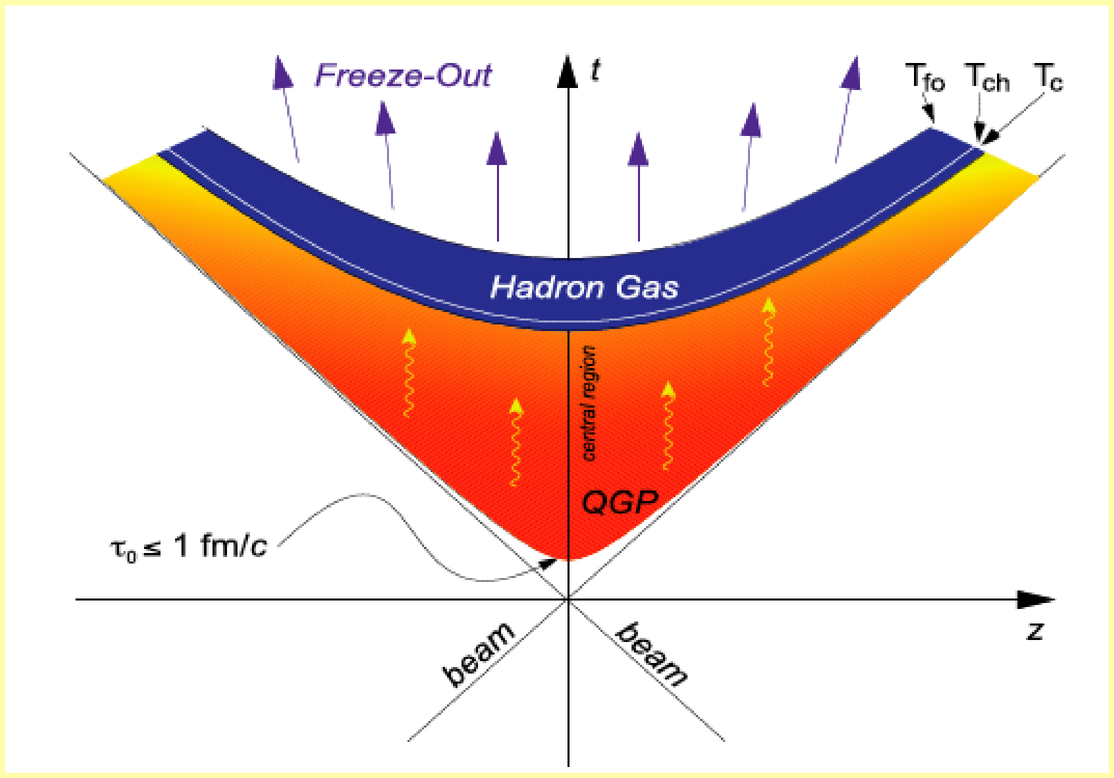
Quark Gluon Plasma

Source: Michael Turner, *National Geographic (1996)*

Collisions of atomic nuclei



Time Scales



Plot: courtesy of R. Stock.

- **QGP life time**
  10 fm/c ≈ $3 \cdot 10^{-23}$ s
- **thermalization time**
  0.2 fm/c ≈ $7 \cdot 10^{-25}$ s
- **formation time**
  (e.g. charm quark):
  $1/2m_c$ = 0.08 fm/c
  ≈ $3 \cdot 10^{-25}$ s
- **collision time**
  $2R/\gamma$ = 0.005 fm/c
  ≈ $2 \cdot 10^{-26}$ s

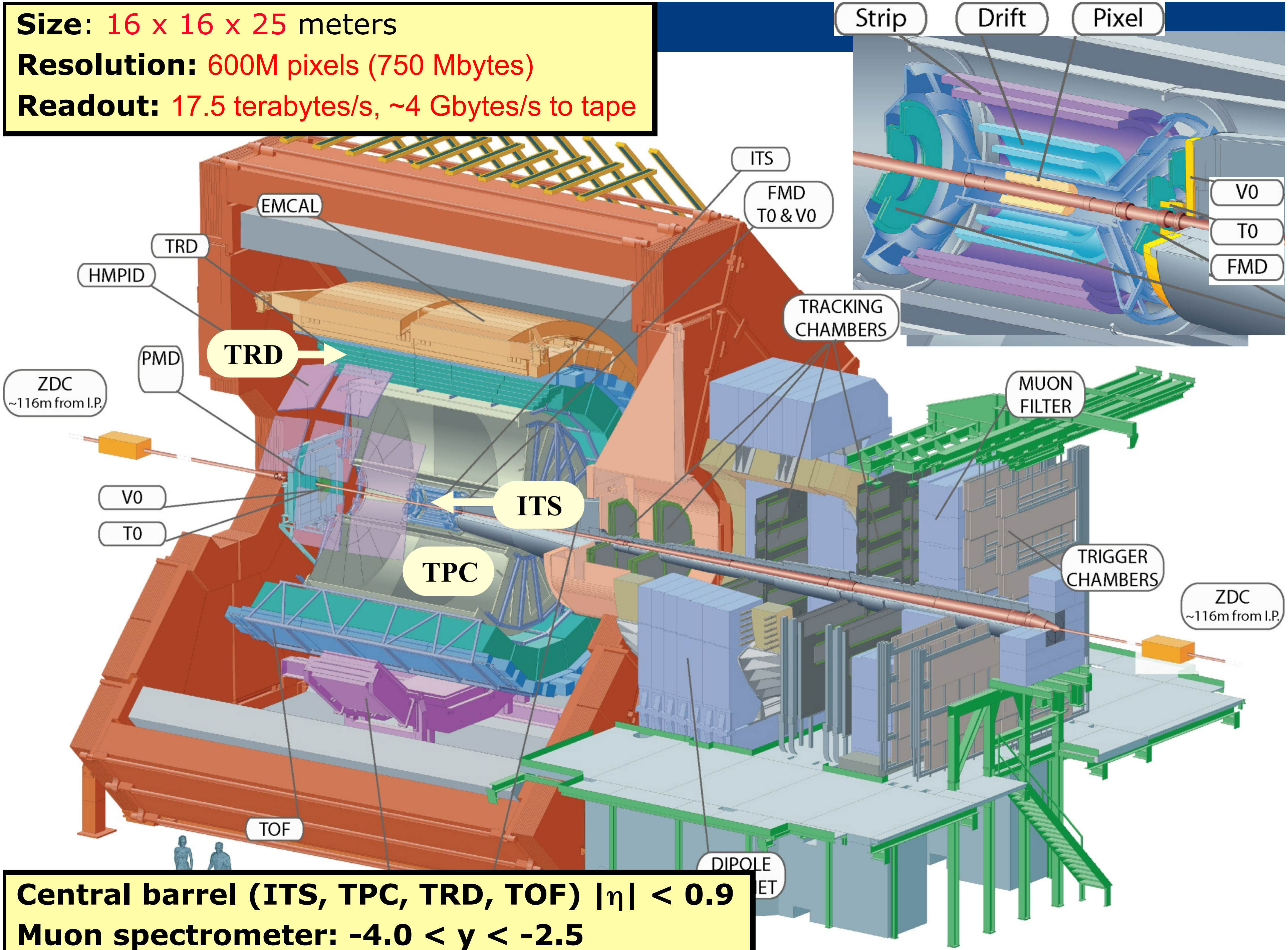
Outline

- Introduction
- LHC and ALICE
- Charm-quark production in pp
- Charm-quark production in Pb-Pb
- Summary / Outlook

Der Large Hadron Collider am CERN

LHC	7	TeV	***c*** - 10 km/h
Tevatron	0.98	TeV	***c*** - 495 km/h
RHIC	250	GeV	***c*** - 7602 km/h
Geiger and Marsden	1	MeV	***c*** * 5%

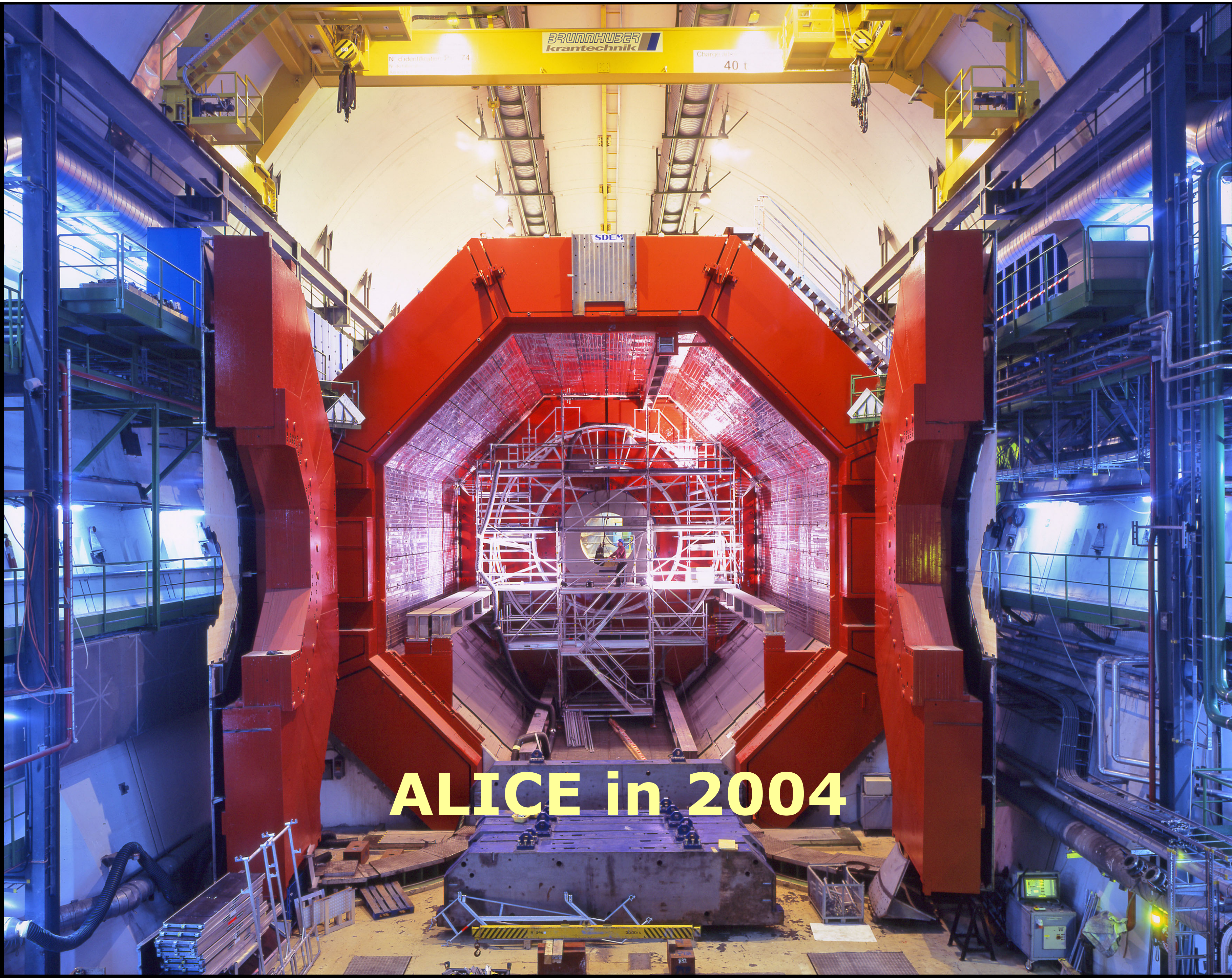
Size: 16 x 16 x 25 meters
Resolution: 600M pixels (750 Mbytes)
Readout: 17.5 terabytes/s, ~4 Gbytes/s to tape



Central barrel (ITS, TPC, TRD, TOF) |η| < 0.9
Muon spectrometer: -4.0 < y < -2.5

ALICE: >1300 members, 120 institutes, 35 countries

ALICE

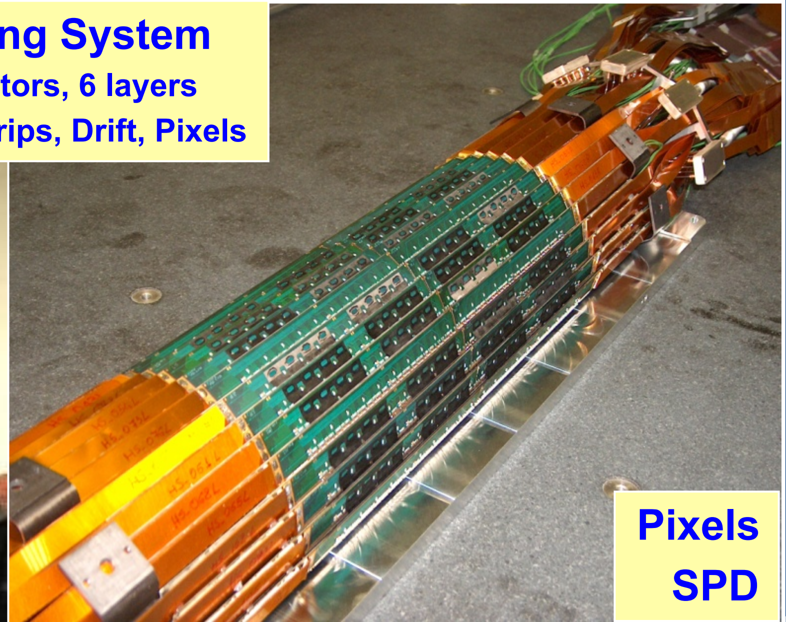

BRUNNHUBER
krantechnik
40 t
SDEM
ALICE in 2004

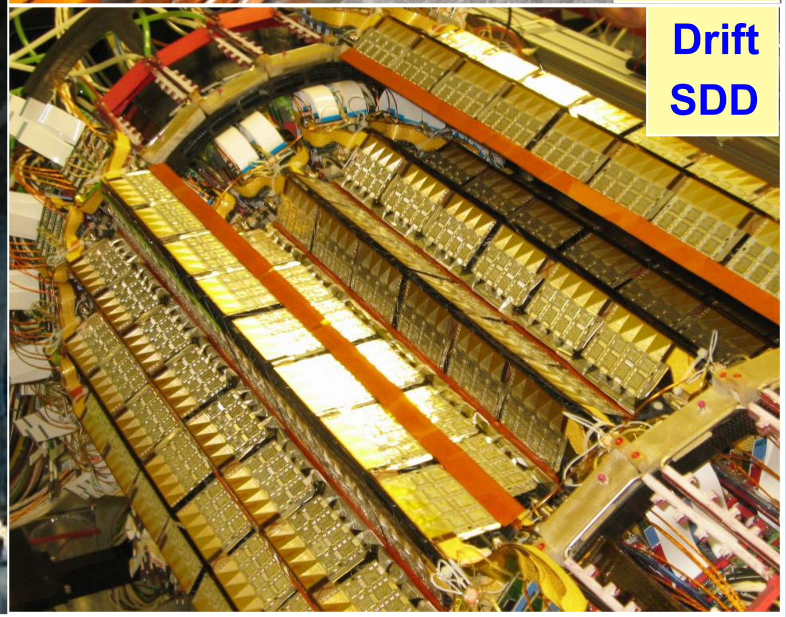
3 x 2 Layers Silicon Technology

Inner Tracking System

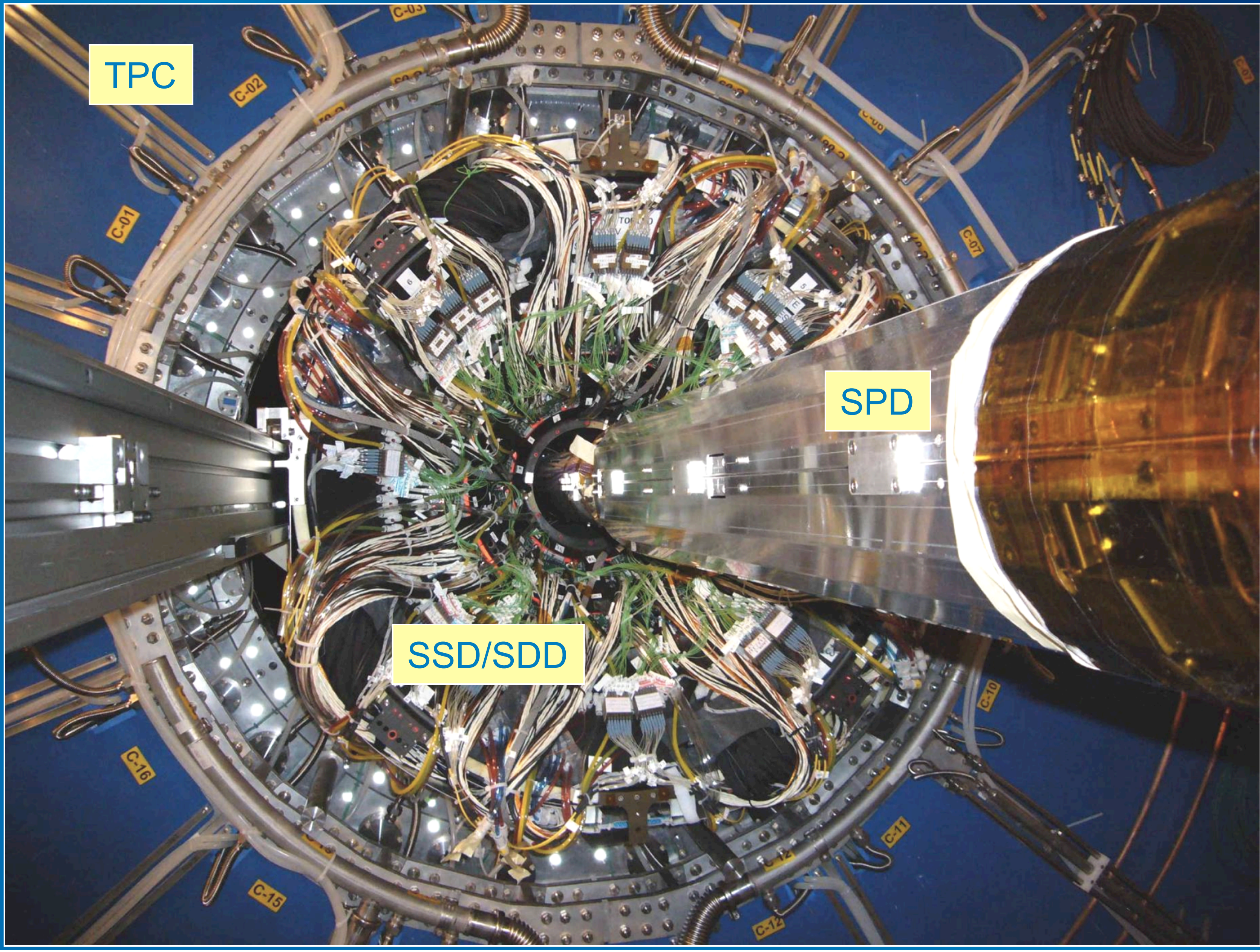
~ 10 m^2 Si detectors, 6 layers

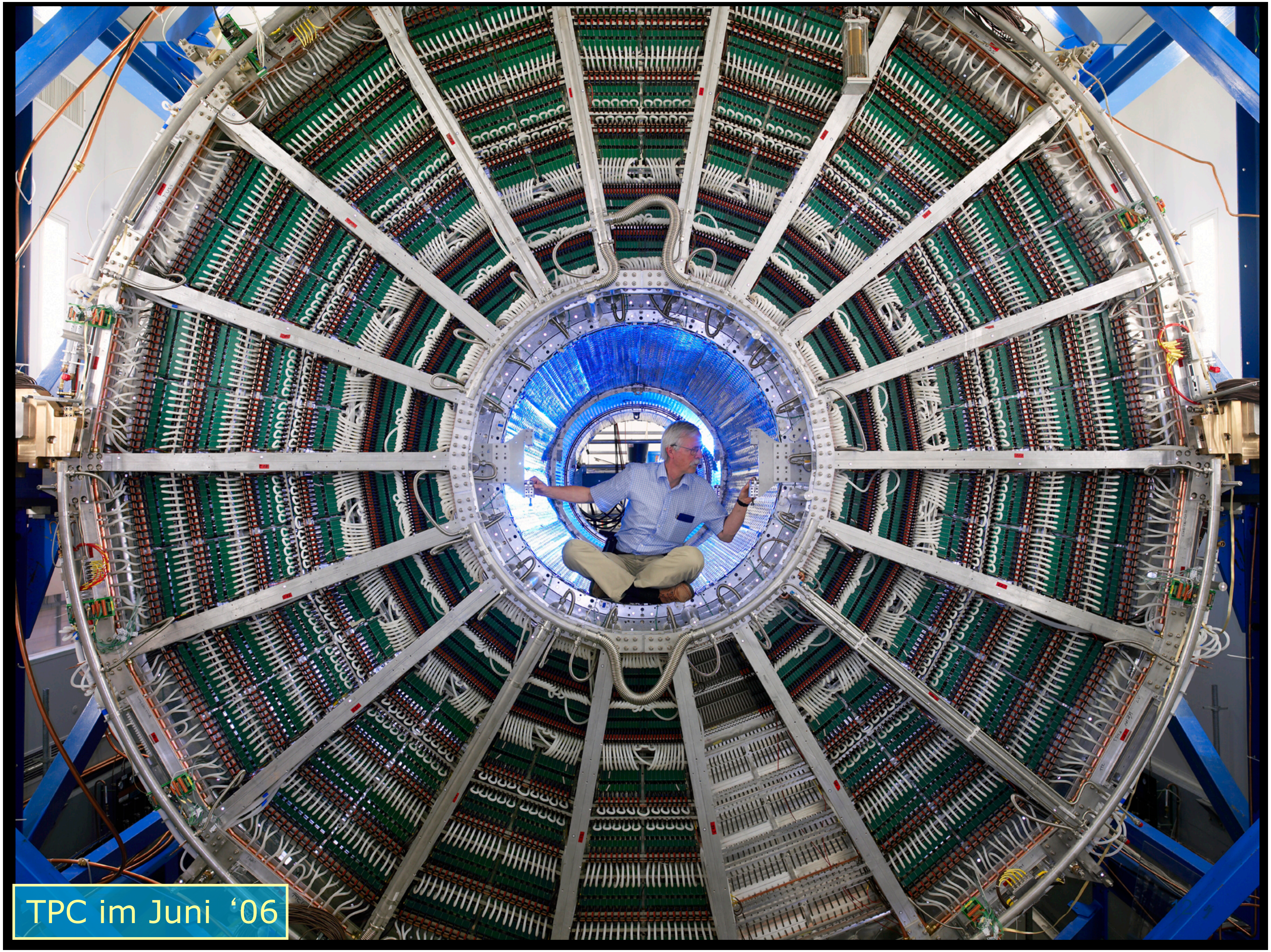
double sided Strips, Drift, Pixels



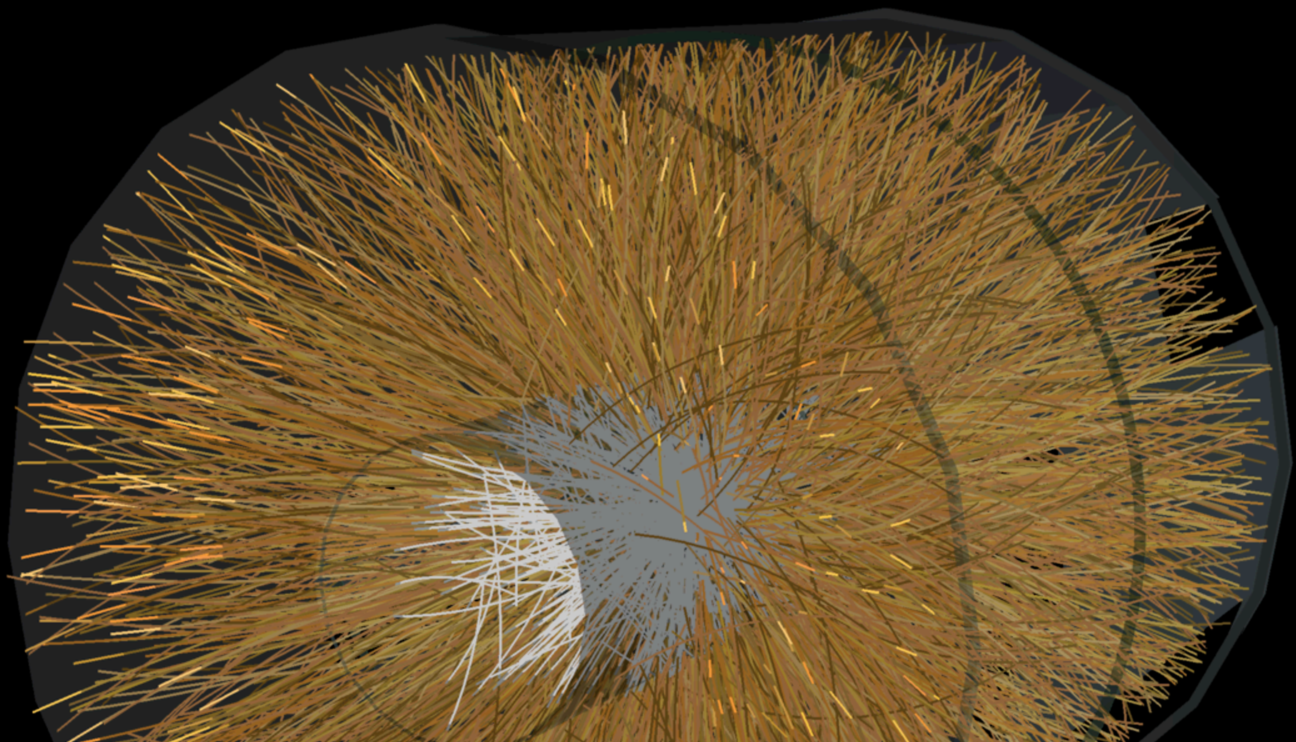


ITS Russian Dolls - Sliding the SSD/SDD over the SPD




TPC im Juni '06

Erste Bleikollisionen in ALICE !



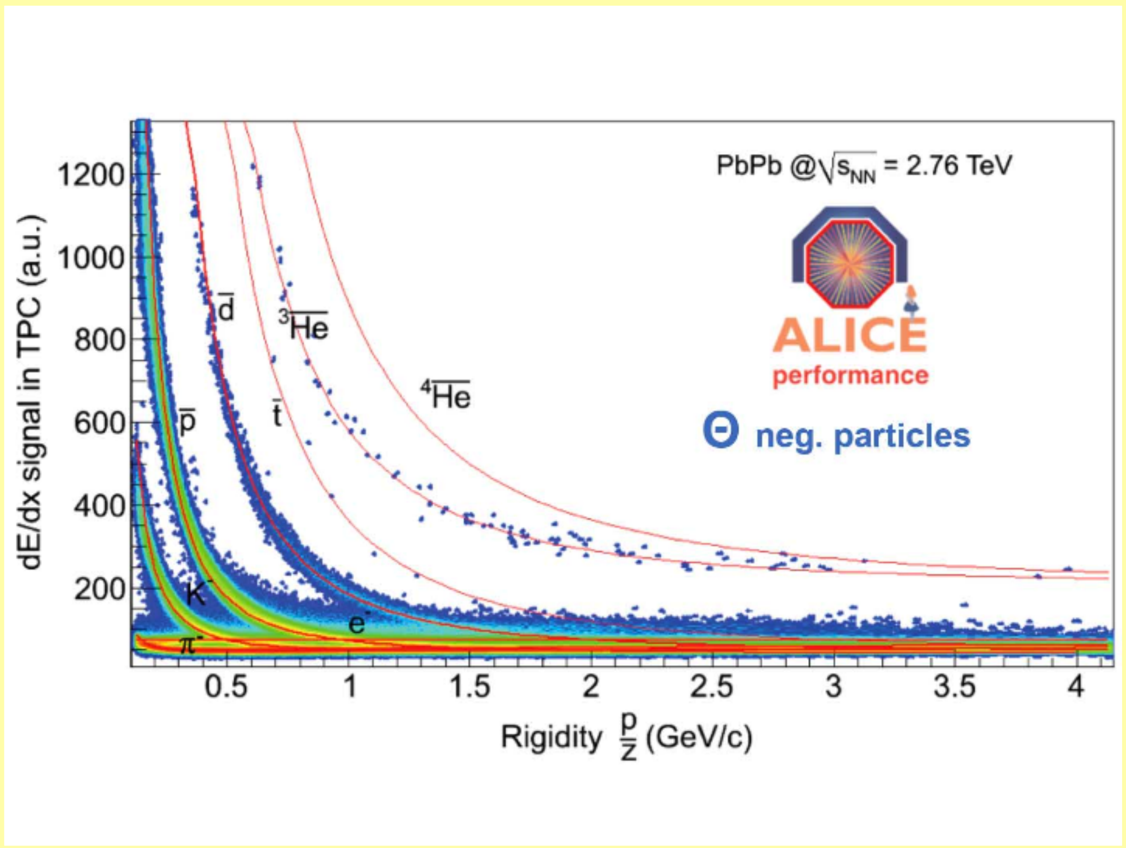
ALICE is designed for

- Highest multiplicities $dN/d\eta$ up to 6000
- Excellent tracking & particle identification
  down to lowest momentum ~ 100 MeV/c

6 ATeV

BBE693

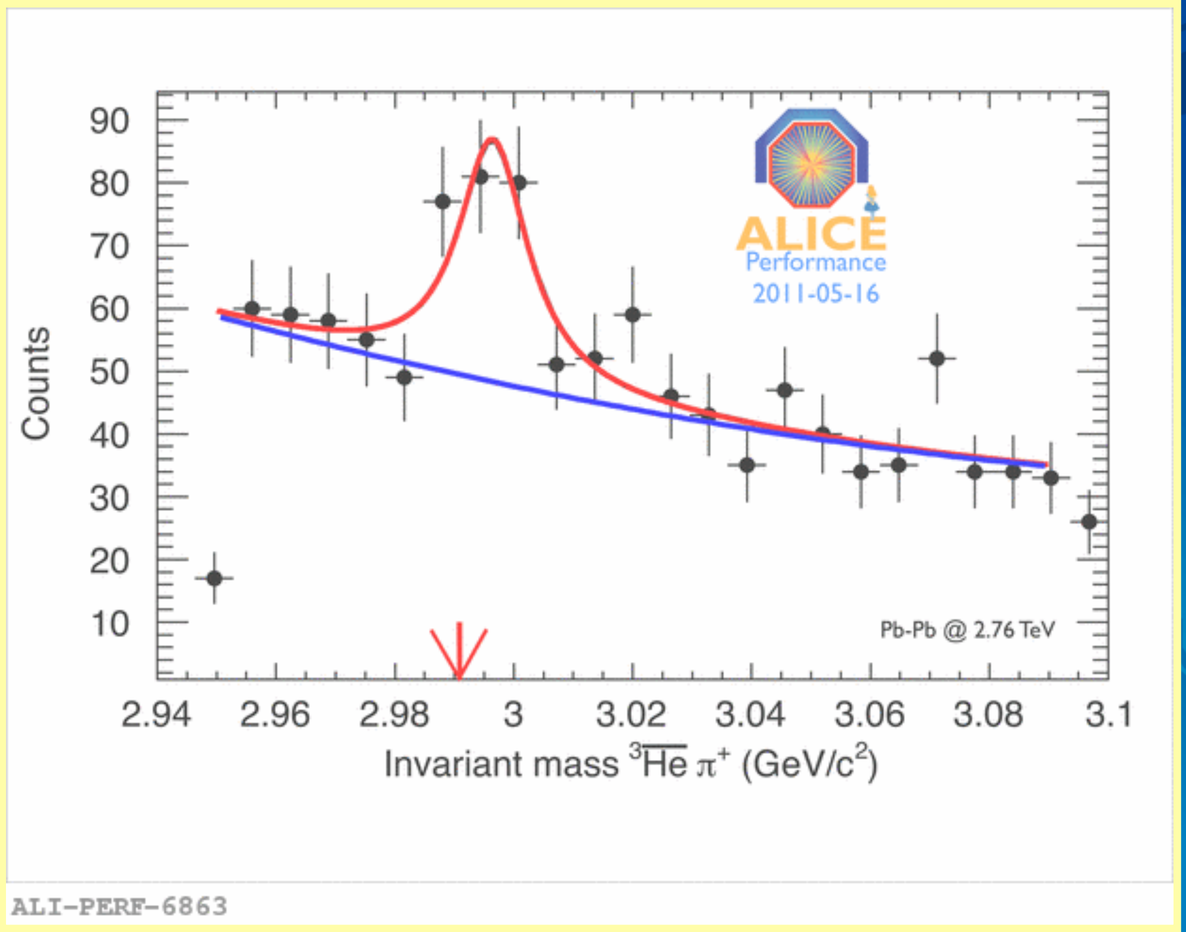
Particle Identification – dE/dx



- dE/dx:
  5% resolution
- Time-of-flight, resolution:
  120 ps (Pb-Pb)
  160 ps (p-p)

- TPC dE/dx: separate p from K up to 1.1 GeV
- Time of flight: separate K from π up to ~ 1.5 GeV

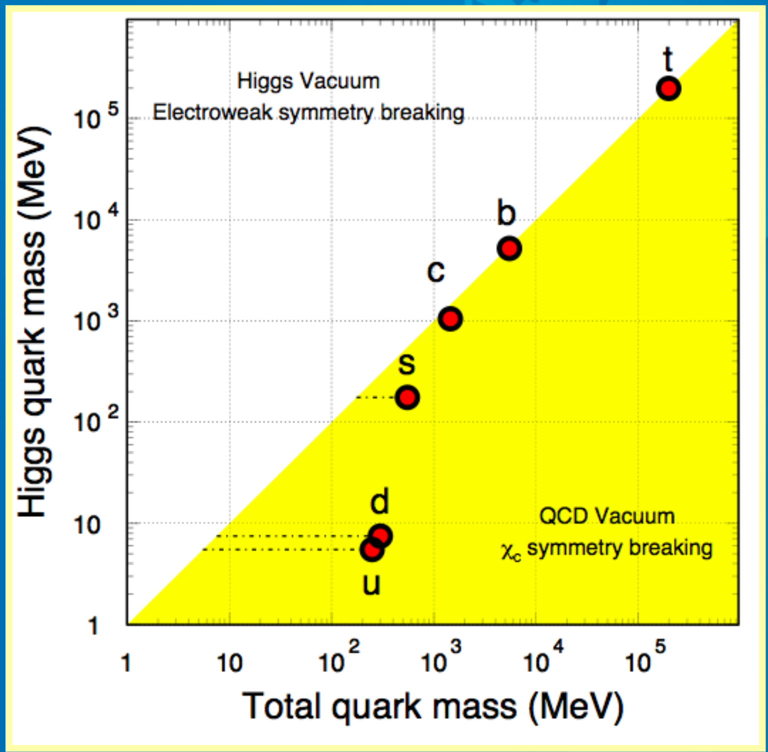
Exotica



- 4 anti-^{4}He candidates
- anti-$^{3}_{\Lambda}$H observed

(anti-)helium trigger:
J. Klein, PhD thesis;
F. Muecke, bachelor thesis,
Univ. Heidelberg, in preparation.

Heavy - flavor: a unique probe



X. Zhu, M. Bleicher, S.L. Huang, K.S., H. Stöcker, N. Xu, and P. Zhuang, PLB 647 (2007) 366.

$m_{c,b}$ » Λ_{QCD} : new scale

$m_{c,b}$ ≈ const., $m_{u,d,s}$ ≠ const.

initial conditions:

- $\sigma_{c\bar{c}}, \sigma_{b\bar{b}}$
- test pQCD, μ_R, μ_F
- probe gluon distribution

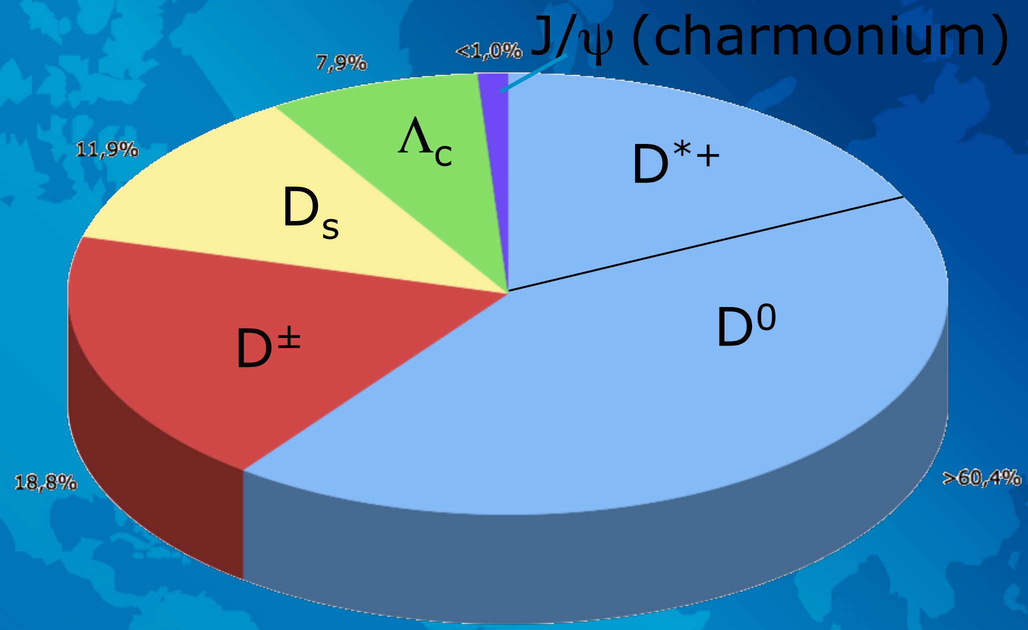
early partonic stage:

- diffusion (γ), drag (α)
- flow, jets, correlations
- probe thermalization

hadronization:

- chiral symmetry restoration
- confinement
- statistical coalescence
- J/ψ enhancement / suppression

Where does all the charm go ?



- **Total charm** cross section: **open-charmed** hadrons, e.g. **D^0, D^+, D^{*+},** Λ_c, … and **c,b → e(μ)** + X
- Quarkonia, e.g. **J/ψ** carries ≈**1%** of **total charm**

Heavy-quark detection

Open-charm reco. in ALICE

$D^0 \rightarrow K\pi$
$D^+ \rightarrow K\pi\pi$
$D^* \rightarrow D^0\pi$
$D_s \rightarrow KK\pi$

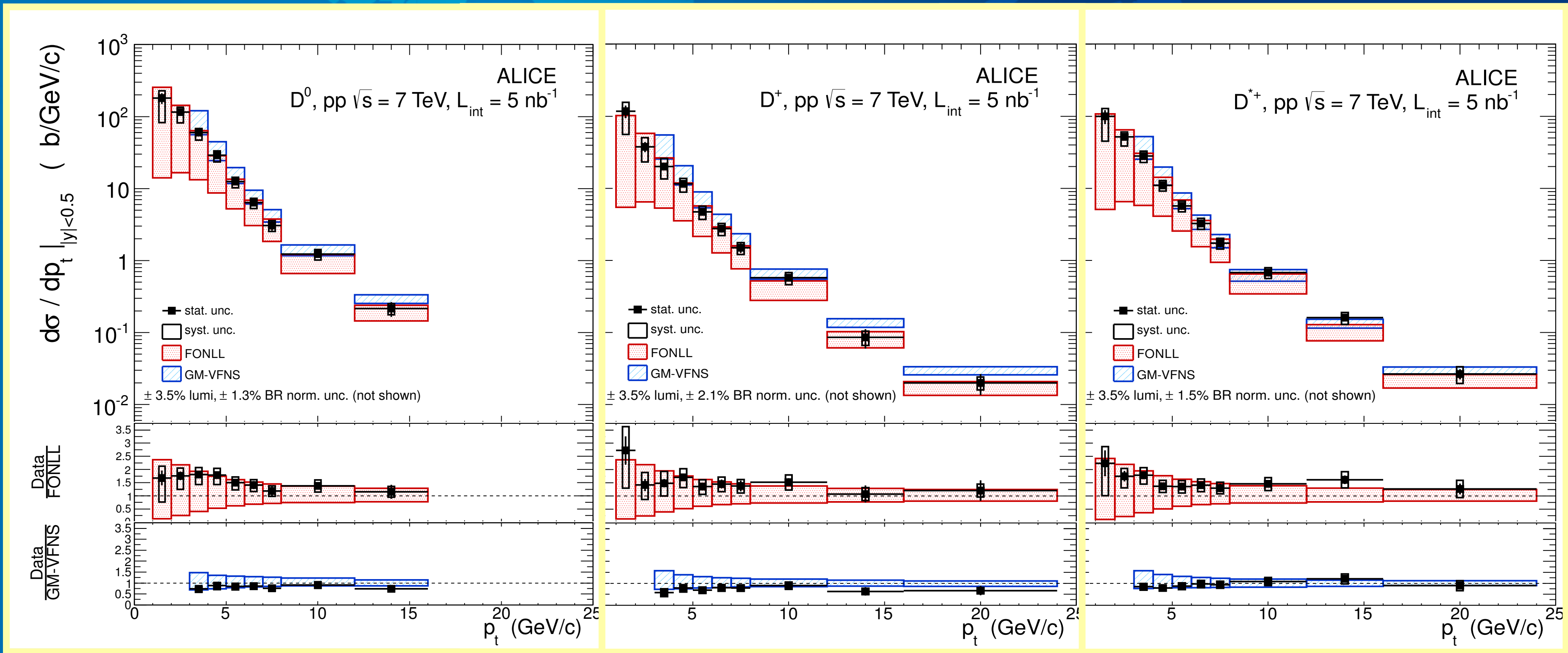
Under study:
$D^0 \rightarrow K\pi\rho$
$\Lambda_c \rightarrow pK\pi$
$\Lambda_c \rightarrow \Lambda\pi$
$\Lambda_c \rightarrow K^0{}_S\pi$

plot: courtesy of D. Tlusty.

- e.g., $D^0 \rightarrow K^- + \pi^+$, $c\tau = 123\ \mu m$
- **displaced** decay **vertex** is **signature** of **heavy-quark decay**

Open-charm spectra from pp @ 7 TeV

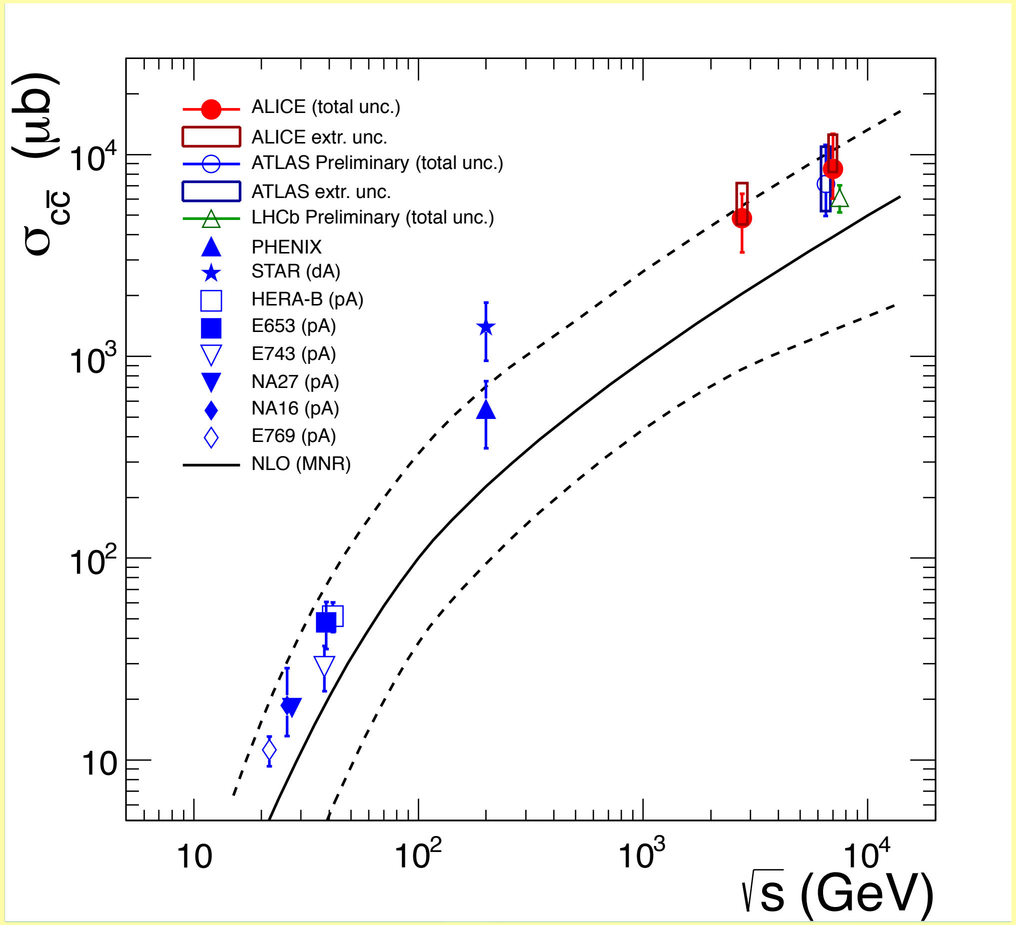
ALICE, JHEP 1201 (2012) 128; arXiv:1111.1553 [hep-ex];
D* analysis: Y. Wang, PhD thesis, Univ. Heidelberg, in preparation;
F. Schaefer, bachelor thesis, Univ. Heidelberg, in preparation.



covers spectrum from 1 up to 24 GeV/c

Open-charm cross section

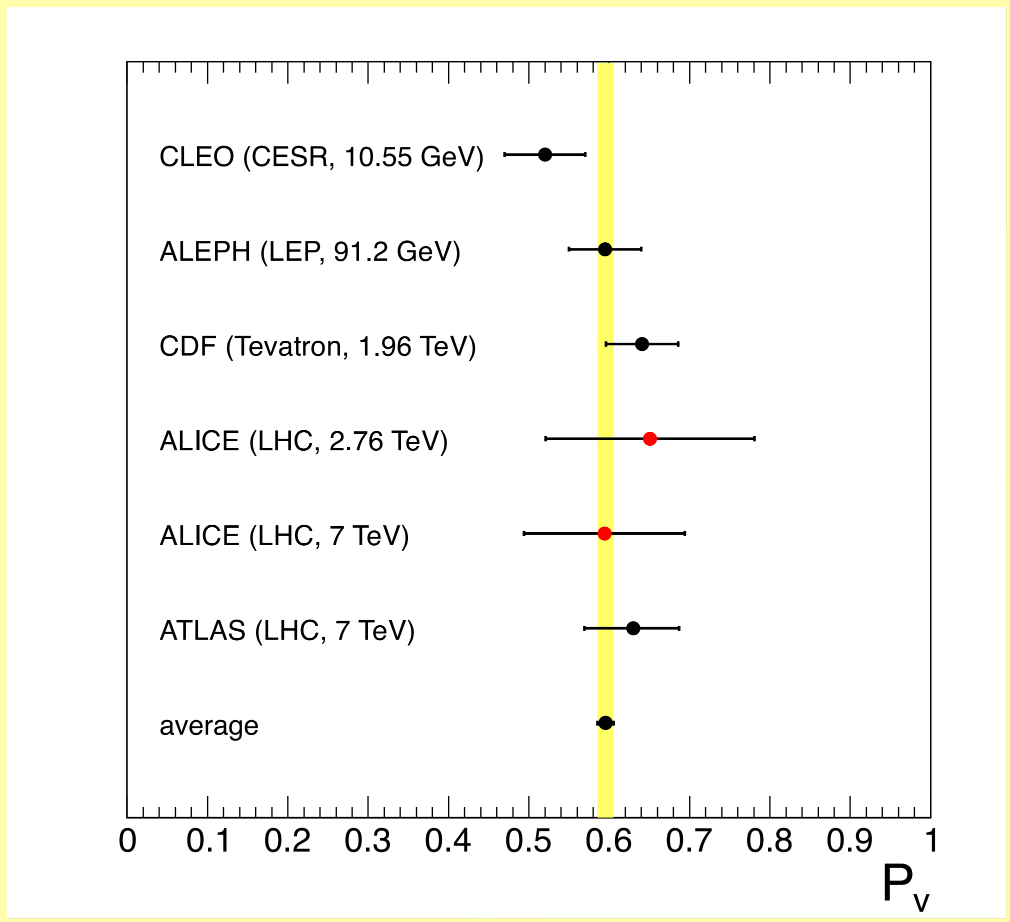
ALICE, arXiv:1205.4007 [hep-ex];
J. Wilkinson, bachelor thesis, Univ. Heidelberg (2011);
S. Stiefelmaier, bachelor thesis, Univ. Heidelberg, in preparation.



- LHC: First collider measurements at TeV scale
- ATLAS & LHCb agree with ALICE
- upper band of theory describes experimental data

Charm hadronization

ALICE, arXiv:1205.4007 [hep-ex];
J. Wilkinson, bachelor thesis, Univ. Heidelberg (2011);
S. Stiefelmaier, bachelor thesis, Univ. Heidelberg, in preparation.

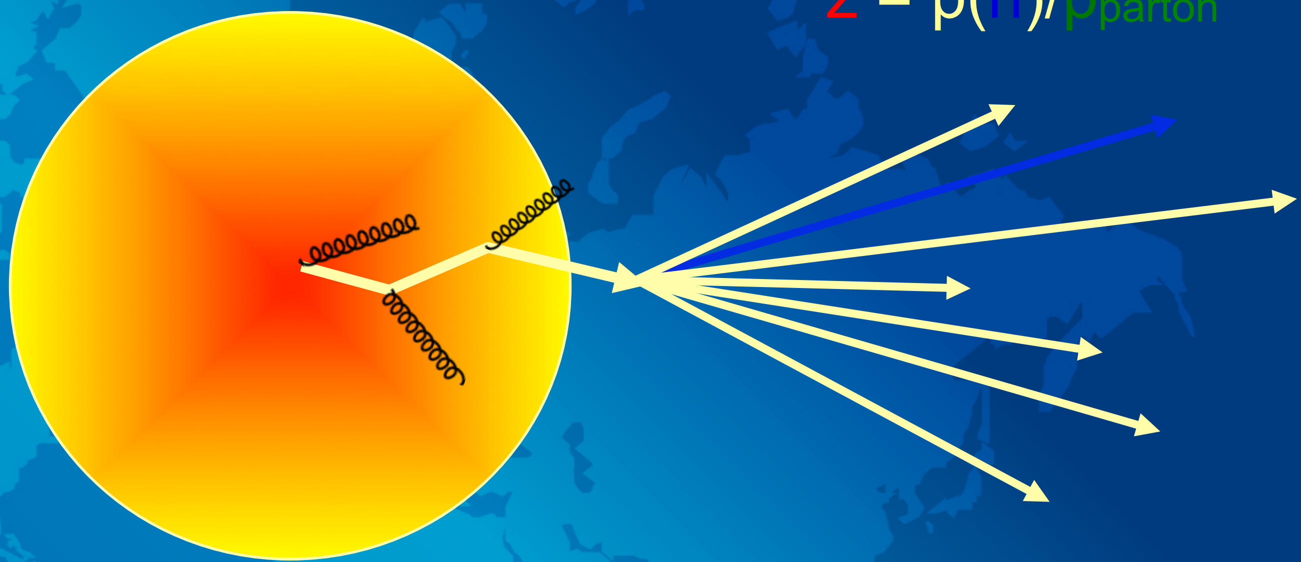


- P_v: fraction of D-mesons in vector state (V) to all mesons (V+S), $P_v = V / (V+S)$
- World average: $P_v = 0.60 \pm 0.01$
- Stat. model, T=164 ± 10 MeV: $P_v = 0.58 \pm 0.13$, agrees with data
- HQET predicts $P_v = 3/(3+1) = 0.75$

Energy loss in the medium

J.D. Bjorken, PRD 27 (1983) 140.

$z = p(h)/p_{parton}$



quark-gluon plasma

Fast parton (i.e. charm quark) propagates in the medium

Loses energy due to gluon bremsstrahlung + elastic collisions

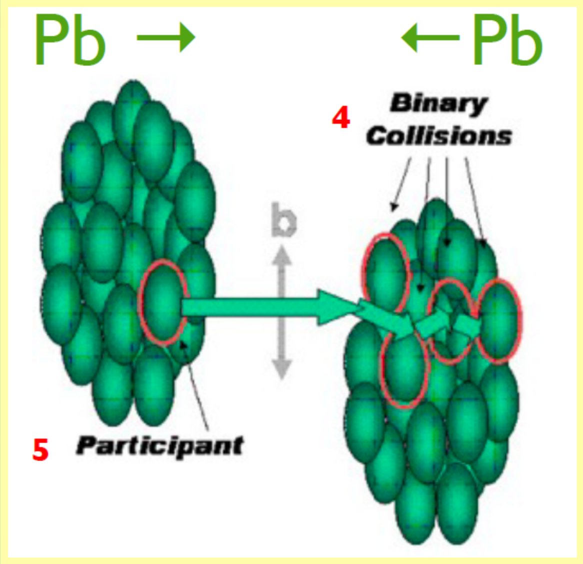
Appears as D-meson at lower momentum wrt pp collisions

→ probe QGP

Nuclear Modification Factor - R_{AA}

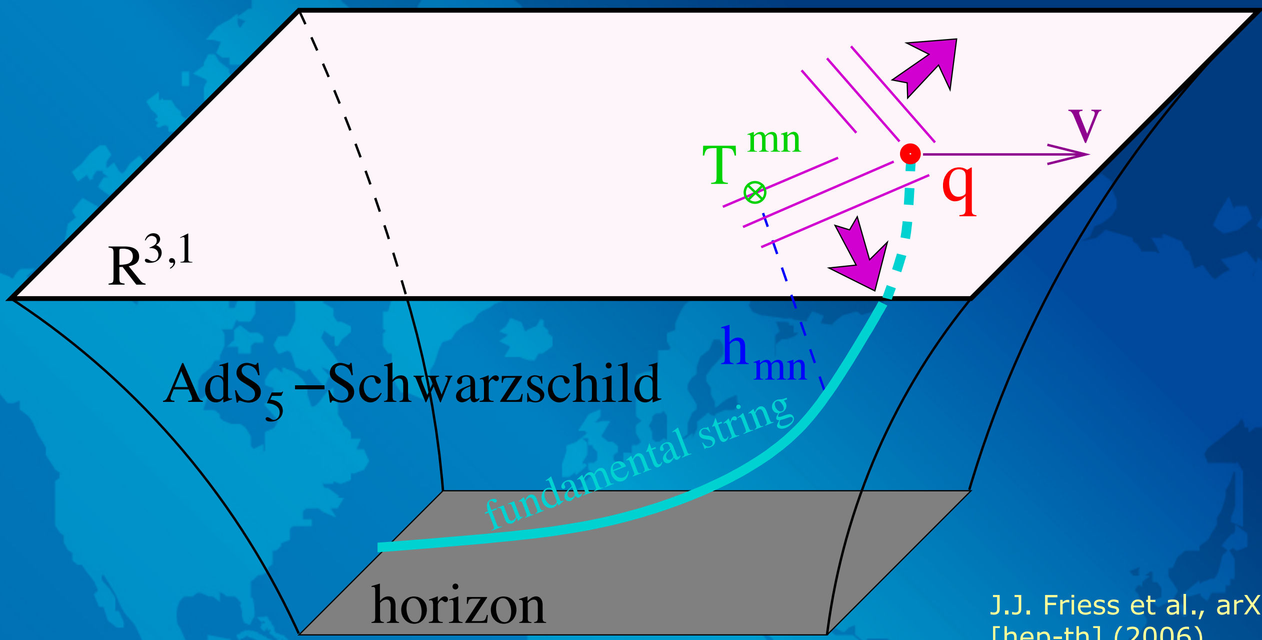
$$R_{AA}(p_T) = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \cdot \frac{\mathrm{d}N_{AA}/\mathrm{d}p_T}{\mathrm{d}N_{pp}/\mathrm{d}p_T}$$

- define R_{AA}, expect unity in the absence of nuclear effects (for hard processes)
- N_{coll} = number of binary nucleon-nucleon collisions



- at RHIC, suppression of factor ~5
- at LHC, suppression of factor ~6
- strong medium effects !

AdS/CFT correspondence

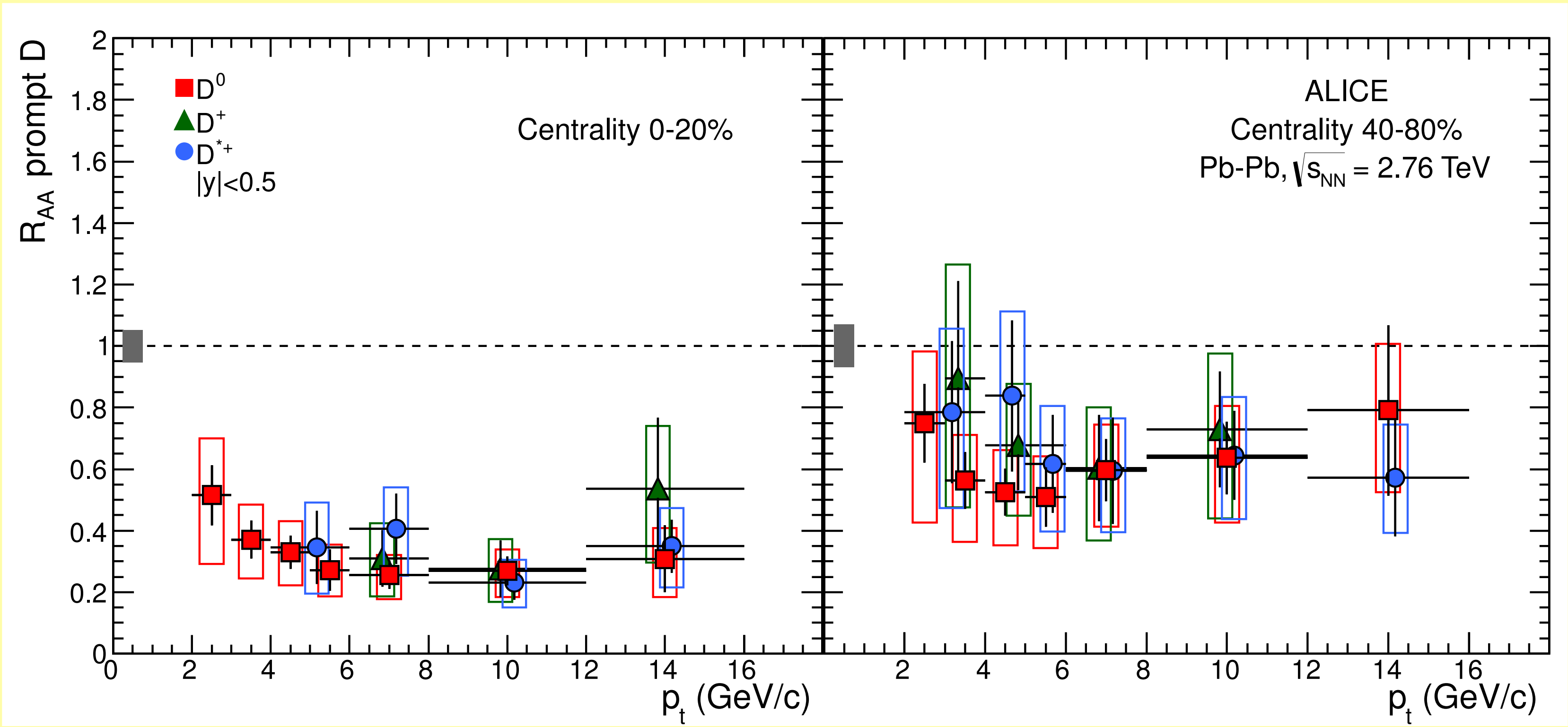


J.J. Friess et al., arXiv:0607022 [hep-th] (2006).

- Maldacena conjecture: string theory and conformal QFT mathematically equivalent
- heavy-quark energy loss modeled by embedding a string in AdS space
- Prediction: **strong suppression** for **charm, small** for **beauty**

Charm nuclear modification factor

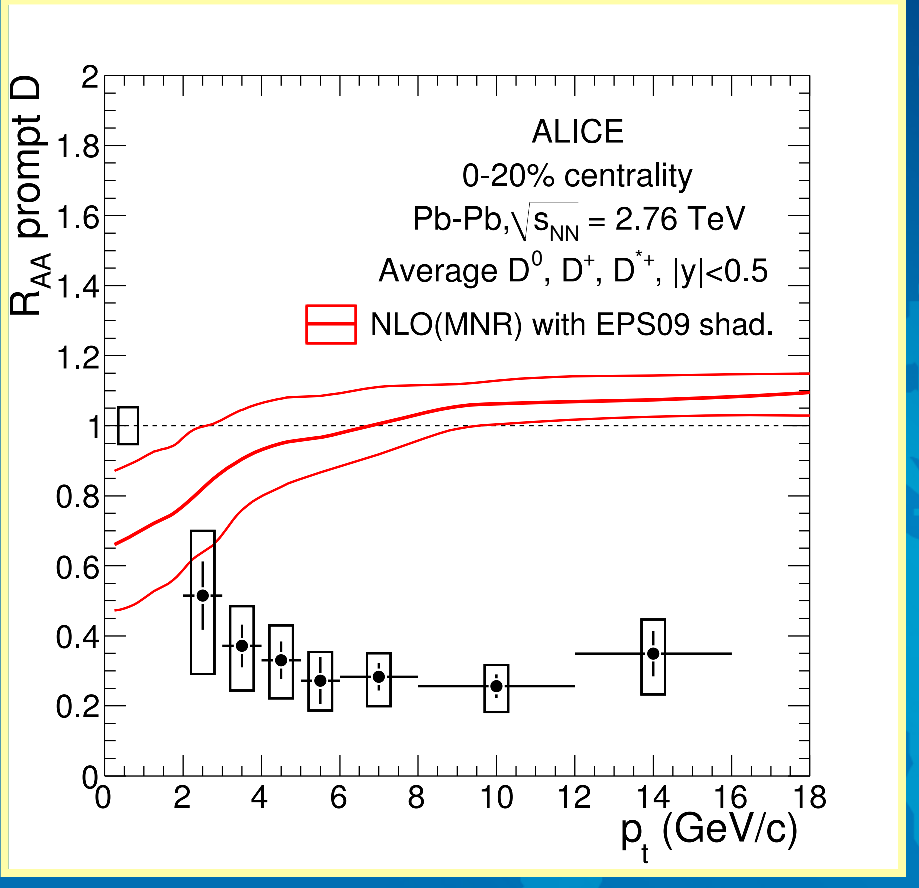
ALICE, arXiv:1203.2160 [nucl-ex].



- In Pb-Pb collisions: Charmed hadrons are suppressed by factor ~3-4 when compared to simple binary collision scaling from pp

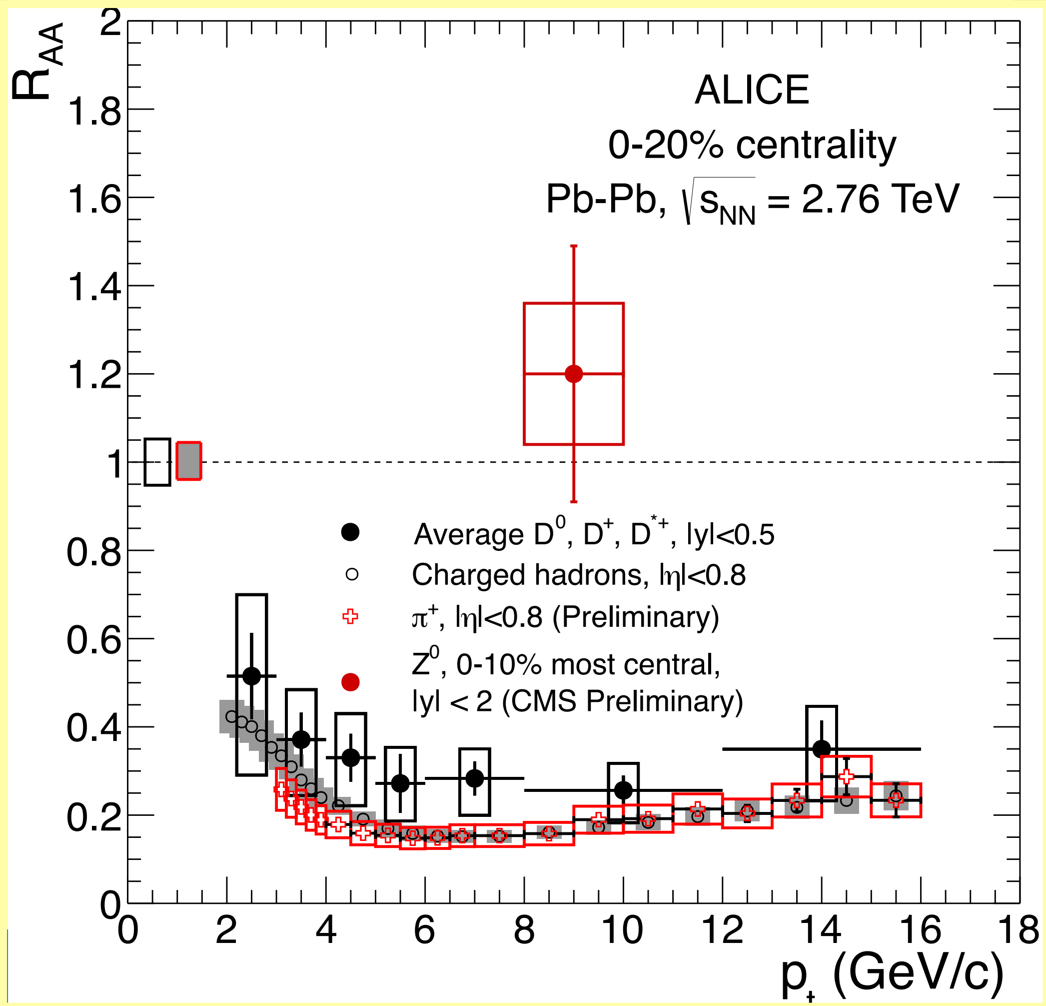
Shadowing, …

ALICE, arXiv:1203.2160 [nucl-ex].



- Initial state: gluon distribution in p different from Pb,
  e.g. shadowing, gluon saturation, … ?
- Observed suppression not an initial state effect
- **need p-Pb data to check !**

Comparison to other hadrons

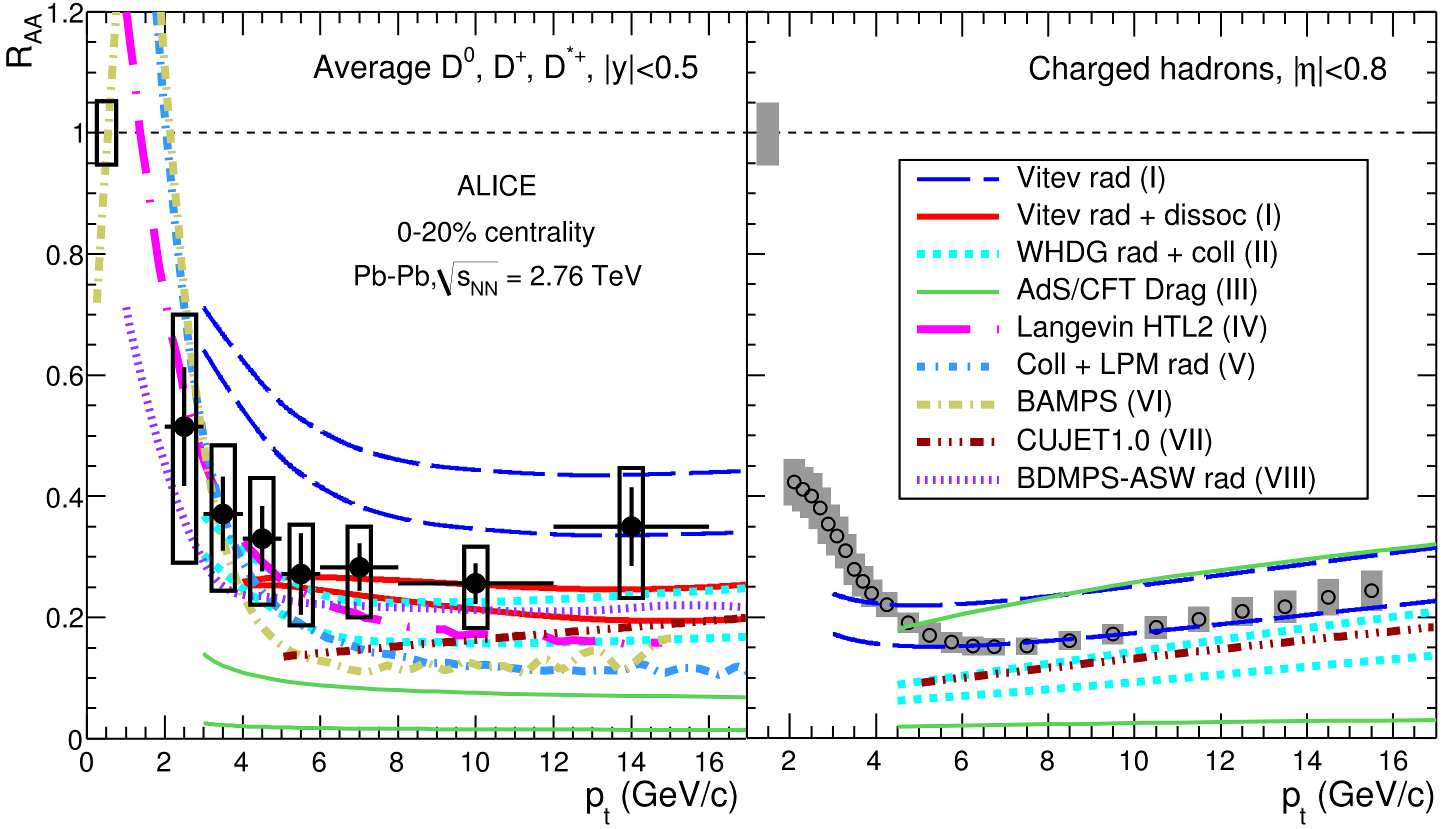


- Mass ordering in R_{AA}?
  J/ψ ← B (upper)
  D (middle)
  π (lower)
- Z-boson: R_{AA} ≈ 1 (!)

ALICE, arXiv:1203.2160 [nucl-ex],
CMS Z-boson: Phys. Rev. Lett. 106 (2011)212301.

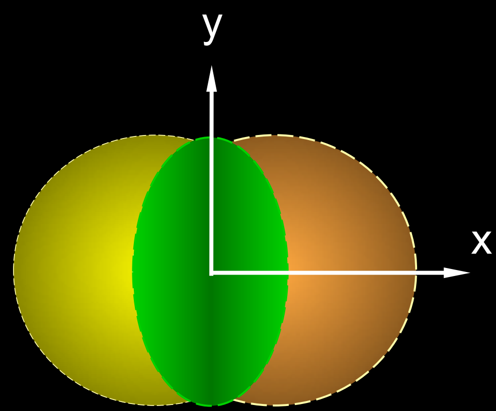
R_{AA} - model calculations

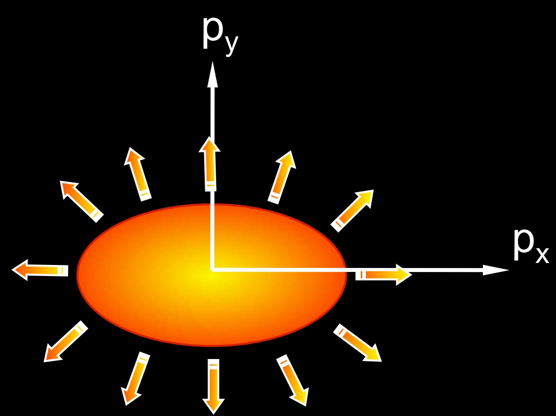
- D mesons charged hadrons



Anisotropy Parameter v_2

coordinate-space-anisotropy ⇔ momentum-space-anisotropy

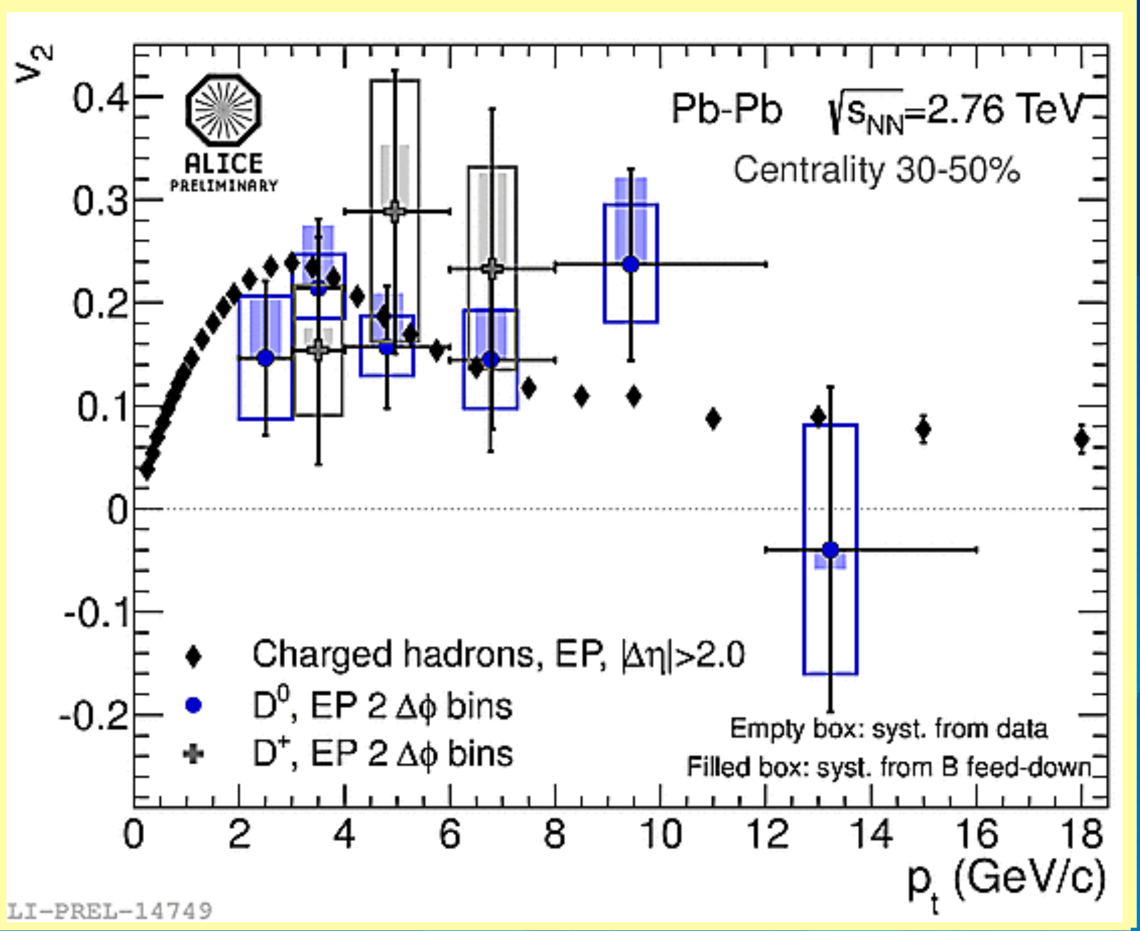




$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\varphi \rangle, \quad \varphi = \tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Initial/final conditions, EoS, degrees of freedom

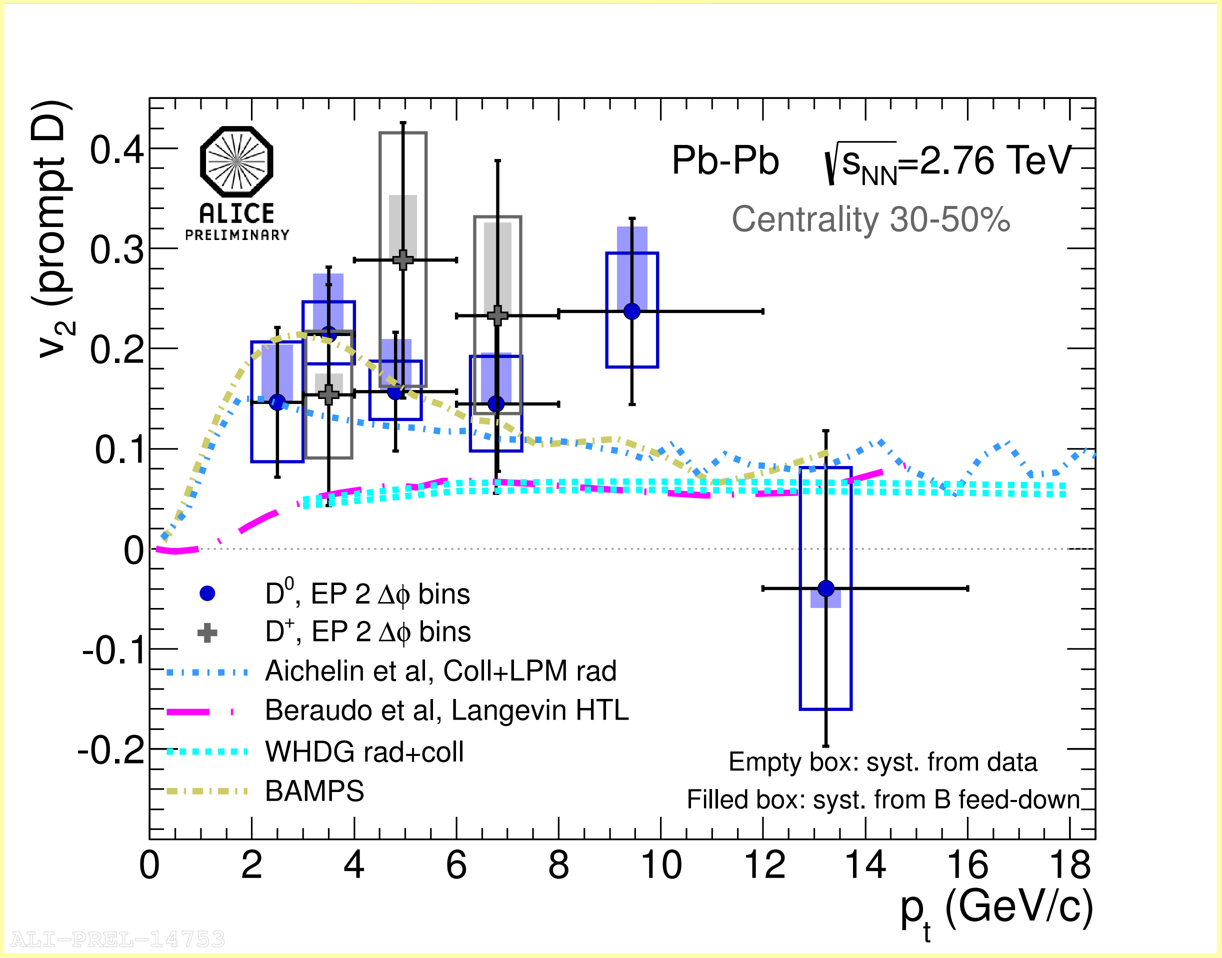
2nd Fourier Coefficient – v_2



D-meson v2 analysis:
R. Grajcarek, PhD thesis,
Univ. Heidelberg, in preparation.

- In Pb-Pb collisions: Charmed hadrons are suppressed by factor ~5 when compared to simple binary scaling

v_2 - Model calculations



Boltzmann approach (BAMPS):
C. Greiner, J. Uphoff et al.,
arXiv:1207.0755 [hep-ph];

See also: H. van Hees et al.,
arXiv:1102.1114 [hep-ph].

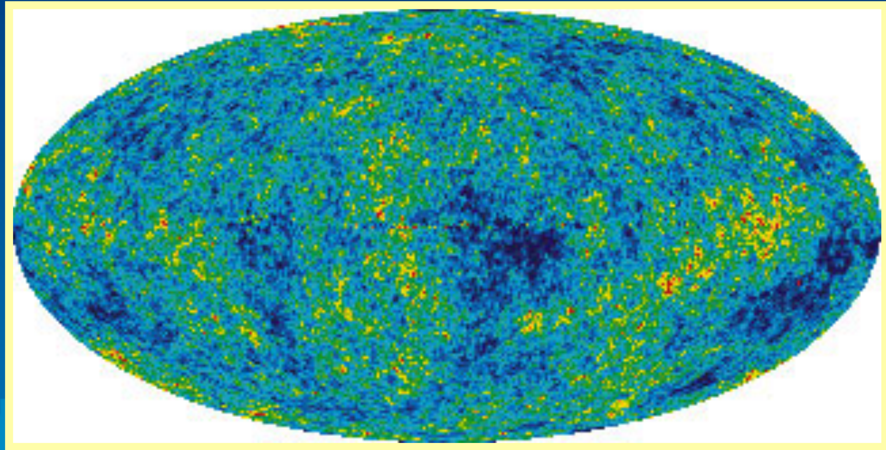
Need to scale collisional part up by factor of 4

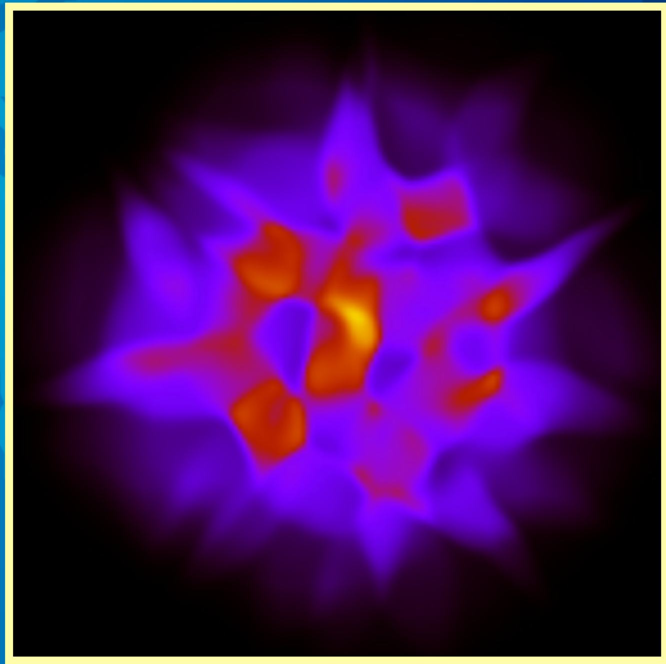
Indication for large radiative energy loss

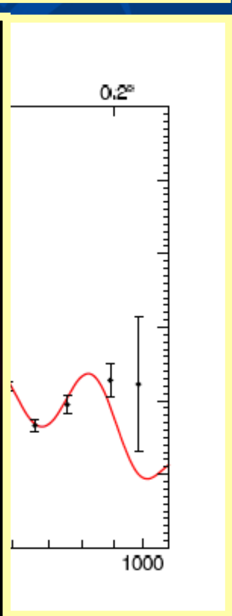
Dead cone dead ?

Next steps

- Extract power spectrum of v_n, like WMAP*
- Compare pp high multiplicity vs Pb+Pb
- Mach cone vs medium response for heavy-quarks (well defined probes)
- η/s

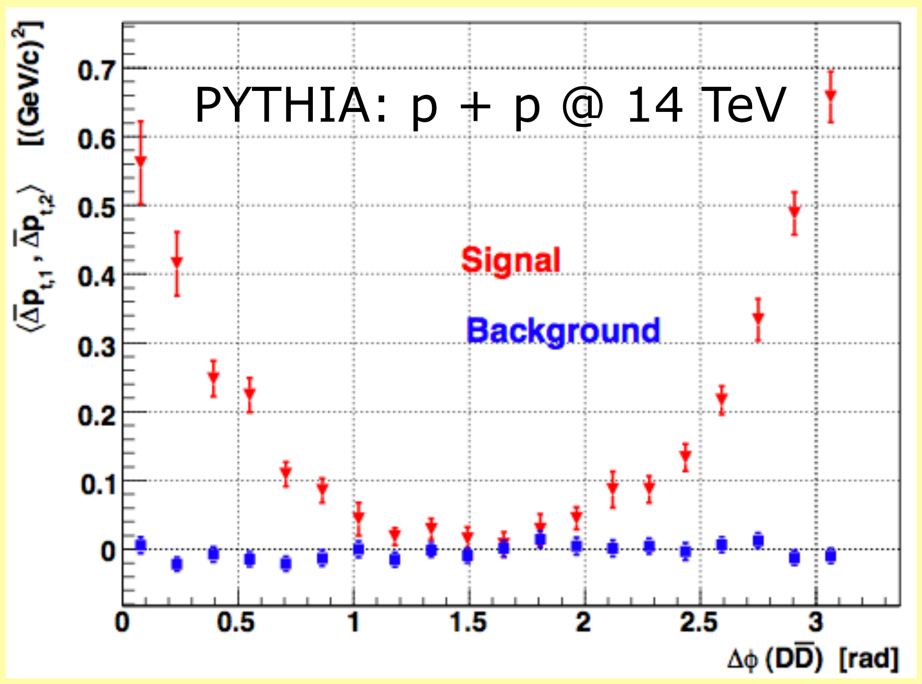


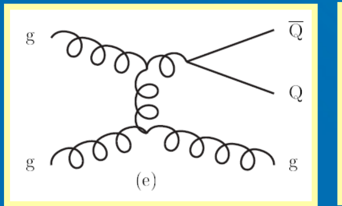


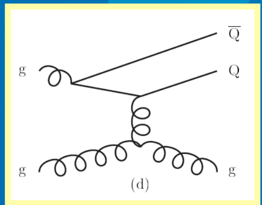


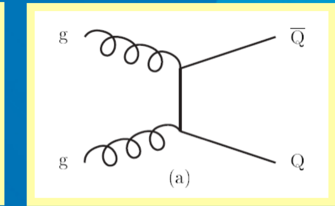
*WMAP data: The NASA/WMAP Science team; http://map.gsfc.nasa.gov/media/080997/index.html.
QGP plot: B. Schenke, S. Jeon, and C. Gale, arXiV:1109.6289.

Heavy – quark Correlations





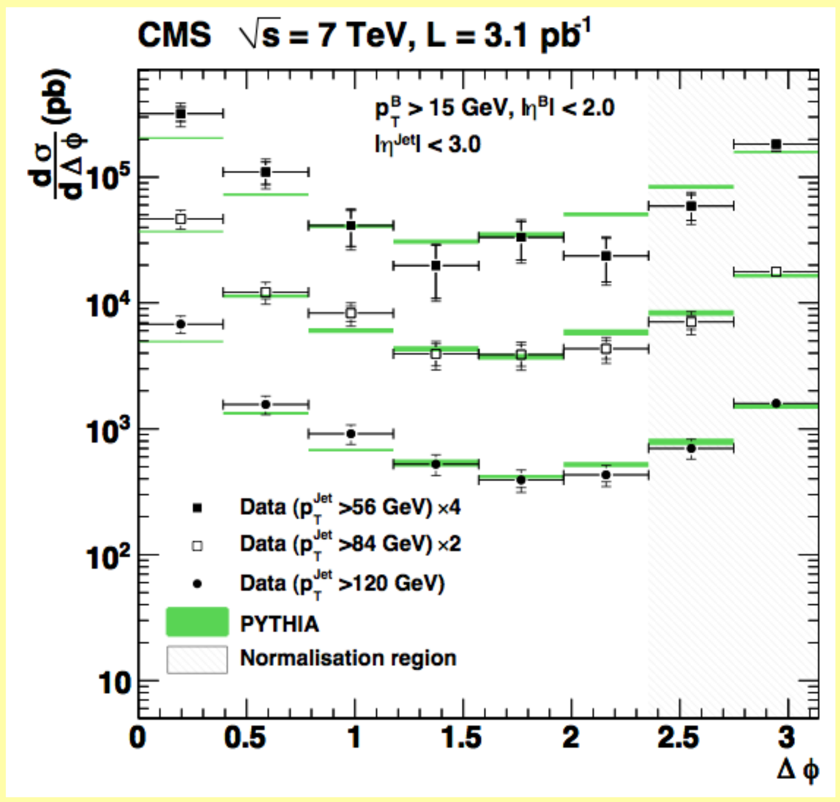


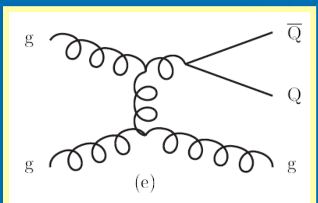


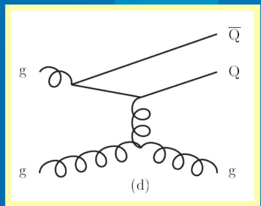
- Charm and anti-charm quarks created in pairs and thus correlated
- Look for modifications in Pb+Pb collisions
- Study transport properties / thermalization

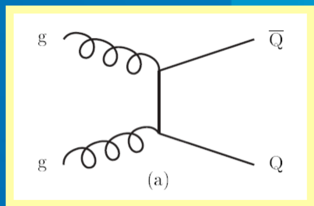
X. Zhu, M. Bleicher, S.L. Huang, K.S., H. Stöcker, N. Xu, and P. Zhuang, PLB 647 (2007) 366.
G. Tsildeakis, H. Appelshäuser, K.S., J. Stachel, NPA 858 (2011) 86; arXiv: 0908.0427 [nucl-ex].

Heavy – quark Correlations*





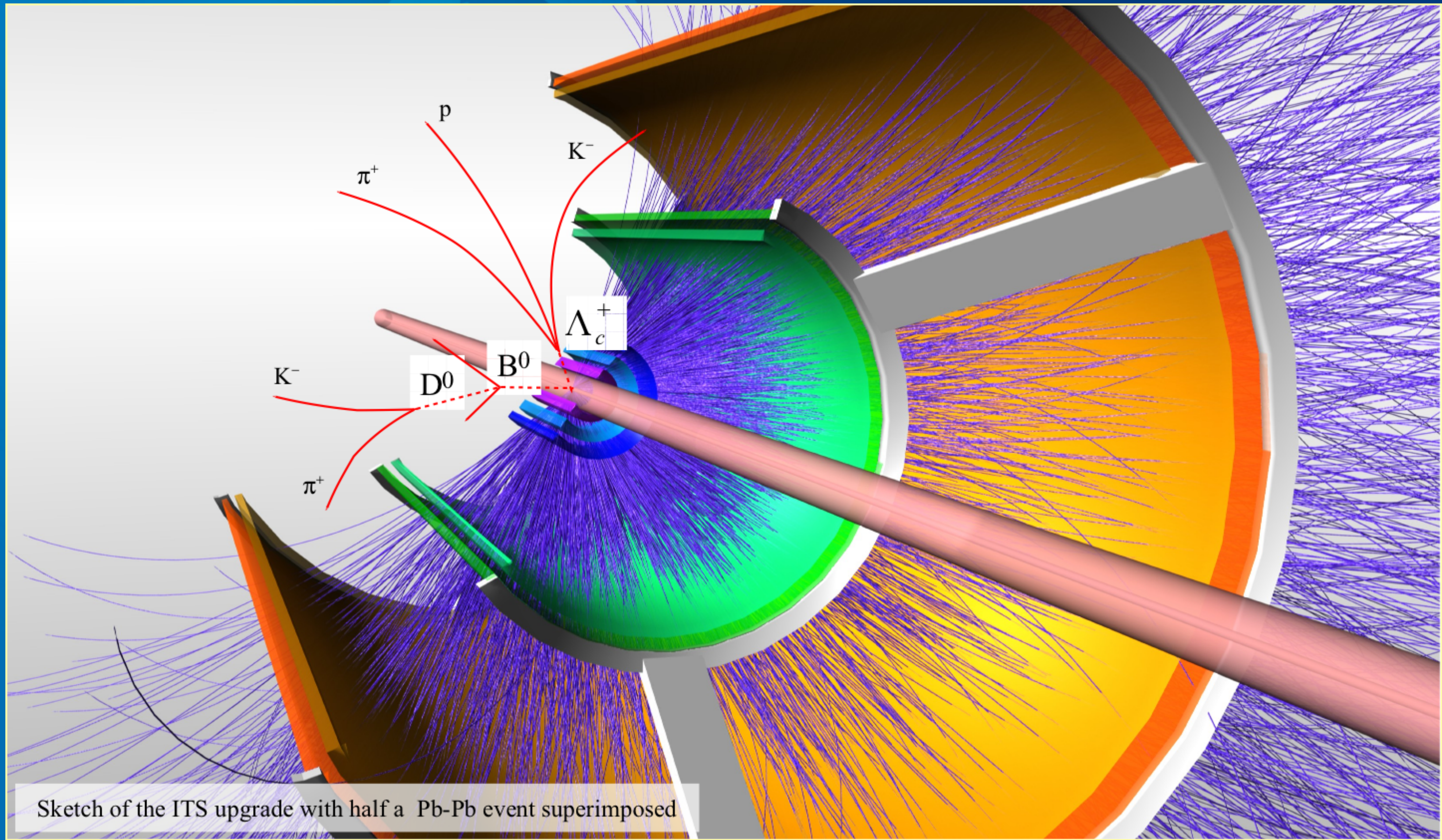




- CMS trigger: inspected 200 x 10^9 p+p collisions
- B–Bbar, establish correlations exist in p+p !
- Look out for modifications in Pb+Pb

*CMS collaboration:JHEP 1102 (2011) 136; arXiv:1192.3194v2 [hep-ex].

Upgrading the Inner Detector



- upgrade Concept recently approved by the ALICE Collaboration
- targeted for 2017-2018 LHC shutdown
- Conceptual Design Report CERN-LHCC-2012-005

LHC: Tentative Schedule

2010/11: **long run** with **pp** collisions at **7 TeV**

1 month of **Pb+Pb** collisions each year

2012: **long run** with **pp** at **8 TeV**

2013: **p+Pb control measurement**

2013/14: Machine consolidation and training

2014: **pp** and **Pb+Pb** at **full energy**

2017/18: long shutdown, luminosity + detector upgrades

2019: **pp** and **Pb+Pb** at high luminosity

ALICE - Jetzt geht's los !