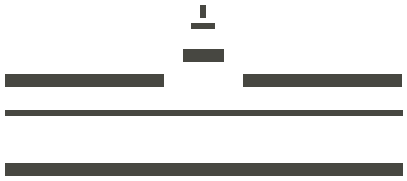

Westfälische
Wilhelms-Universität
Münster

Ultra-Relativistic Heavy Ion Collisions – Strong Interaction at High Temperature and Density

Christian Klein-Bösing / Johannes Wessels

RTG 2149 Retreat
Telgte 24.–26. November 2015

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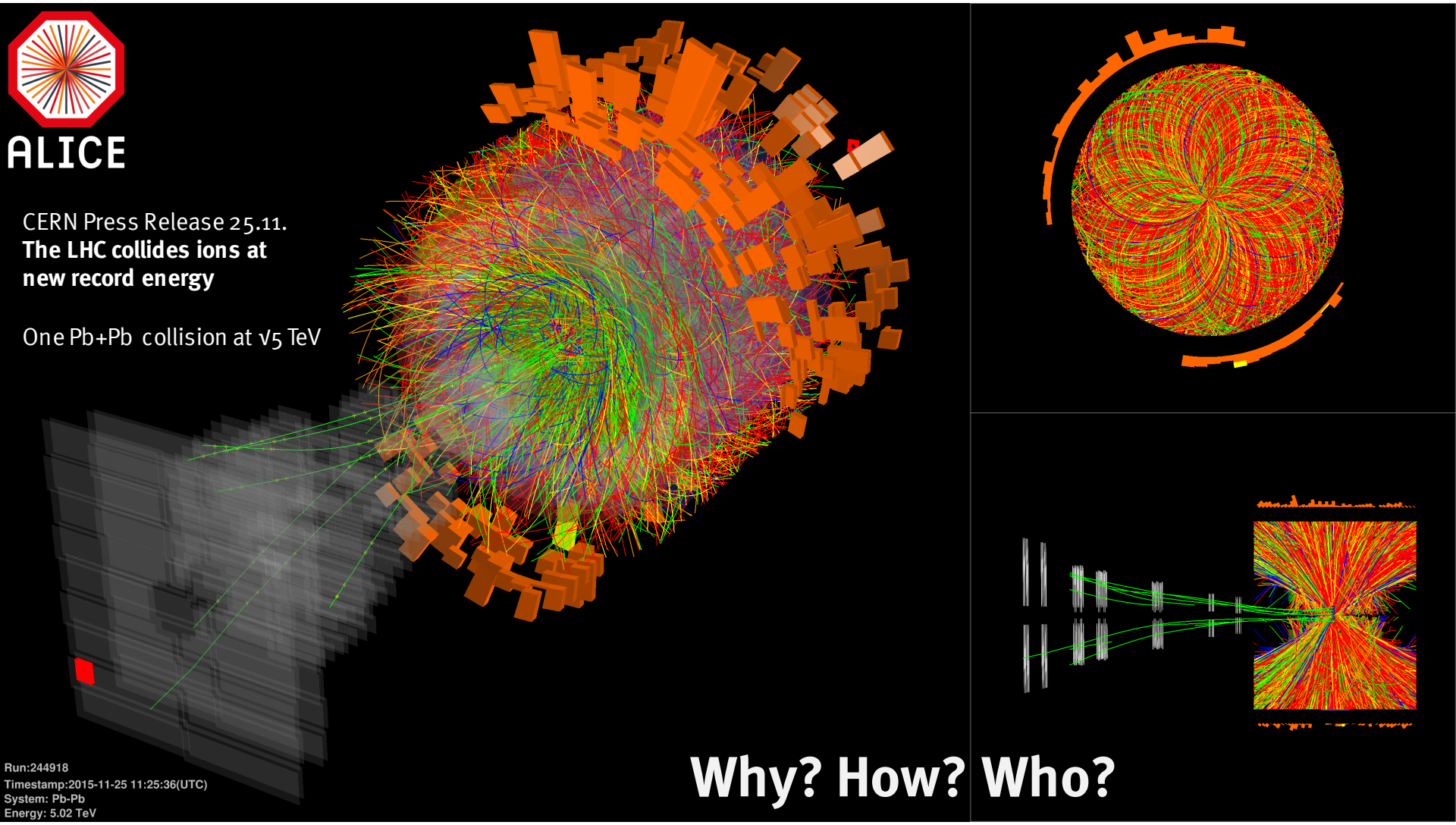
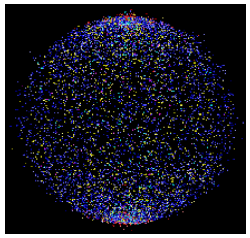
WWU Münster

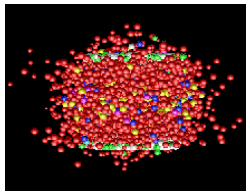
Graduiertenkolleg 2149
Research Training Group

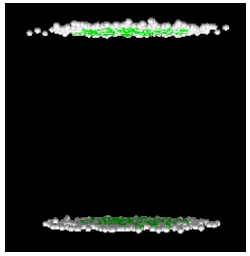

ALICE
CERN Press Release 25.11.
The LHC collides ions at new record energy
One Pb+Pb collision at √5 TeV
Run:244918
Timestamp:2015-11-25 11:25:36(UTC)
System: Pb-Pb
Energy: 5.02 TeV
Why? How? Who?

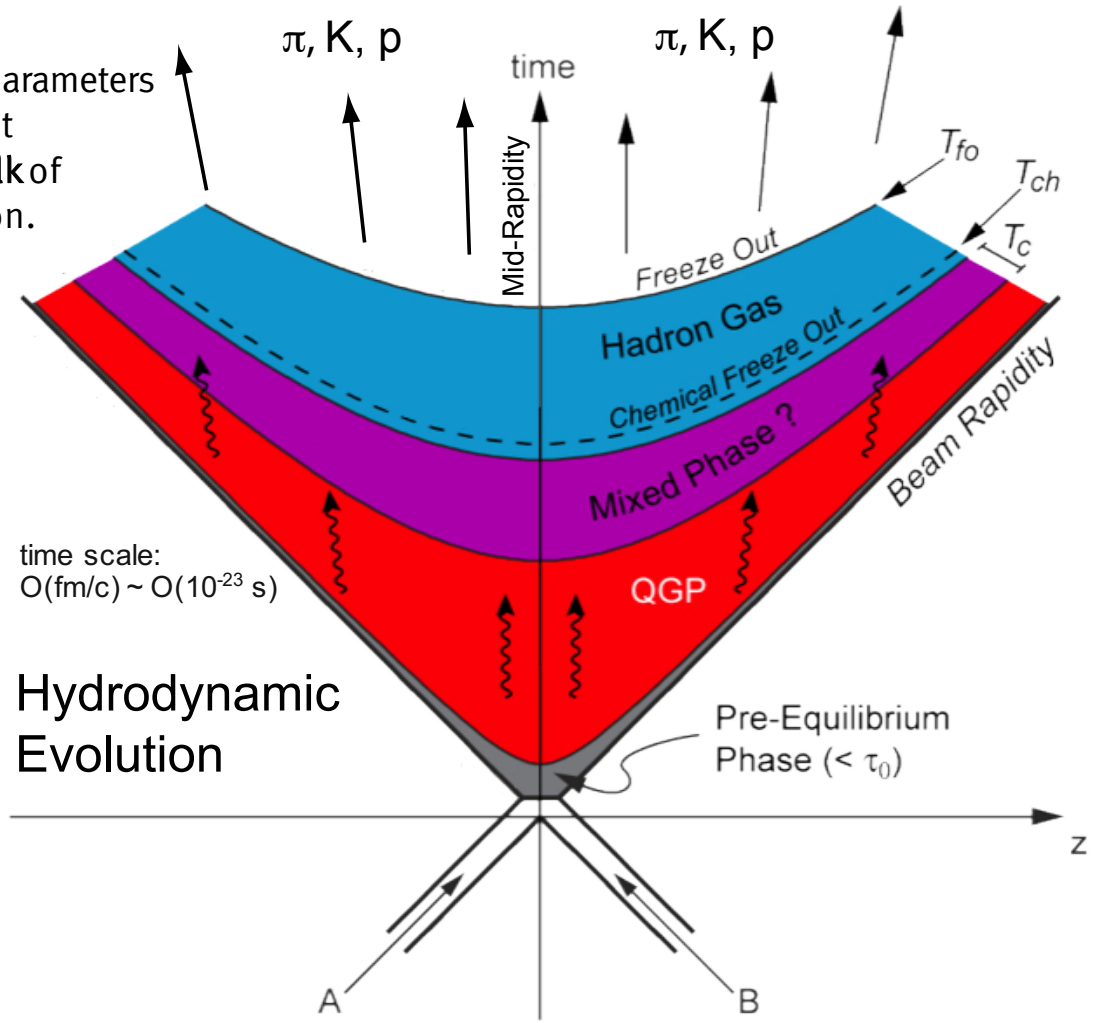
› Time Line of Heavy-Ion Collisions

Thermodynamic parameters (T,μ_B) at freeze-out determine the **bulk** of particle production.









time scale:
O(fm/c) ~ O(10^{-23} s)

Hydrodynamic Evolution

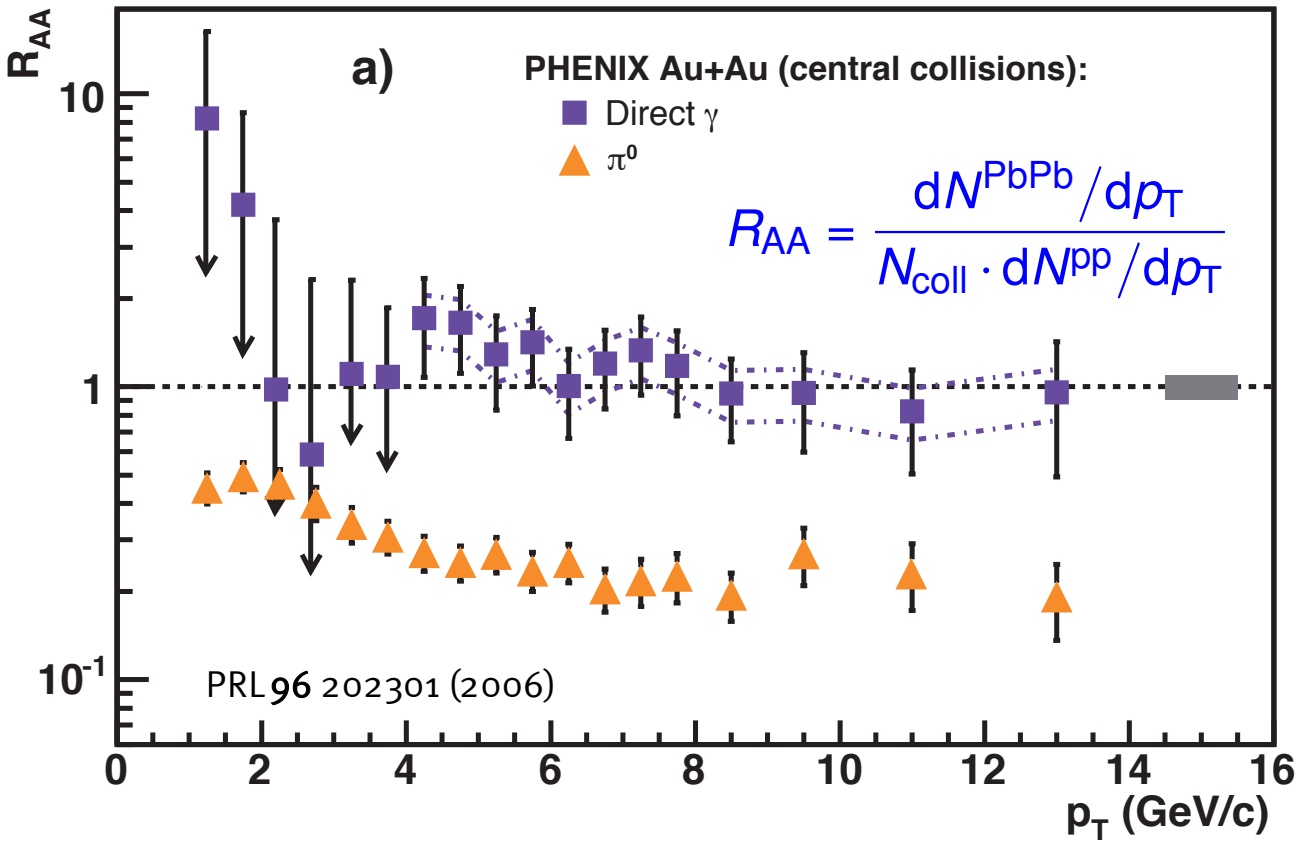
Particle production:

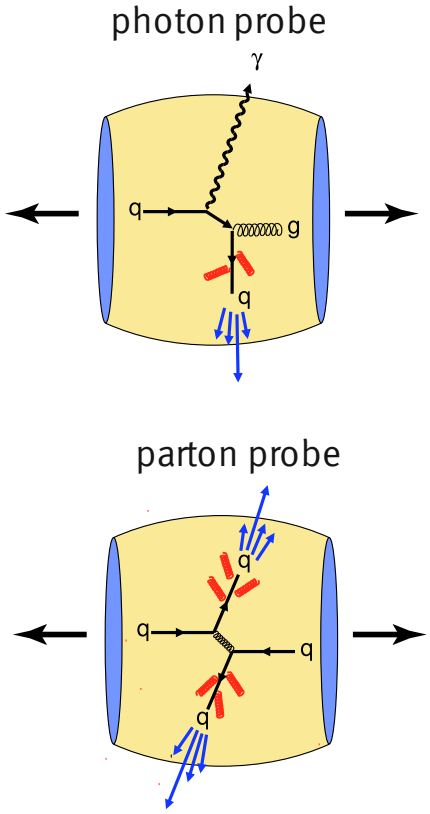
soft/low p_T (late) medium dominated, collective behavior

hard/high p_T (early), large Q^2 parton scattering/jets (N_{coll} scaling)

$$\frac{d\sigma}{dp_T} = \int \mathrm{PDF} \otimes \mathrm{pQCD} \otimes \mathrm{FF}$$

› Parton Energy Loss: A Clear Picture?





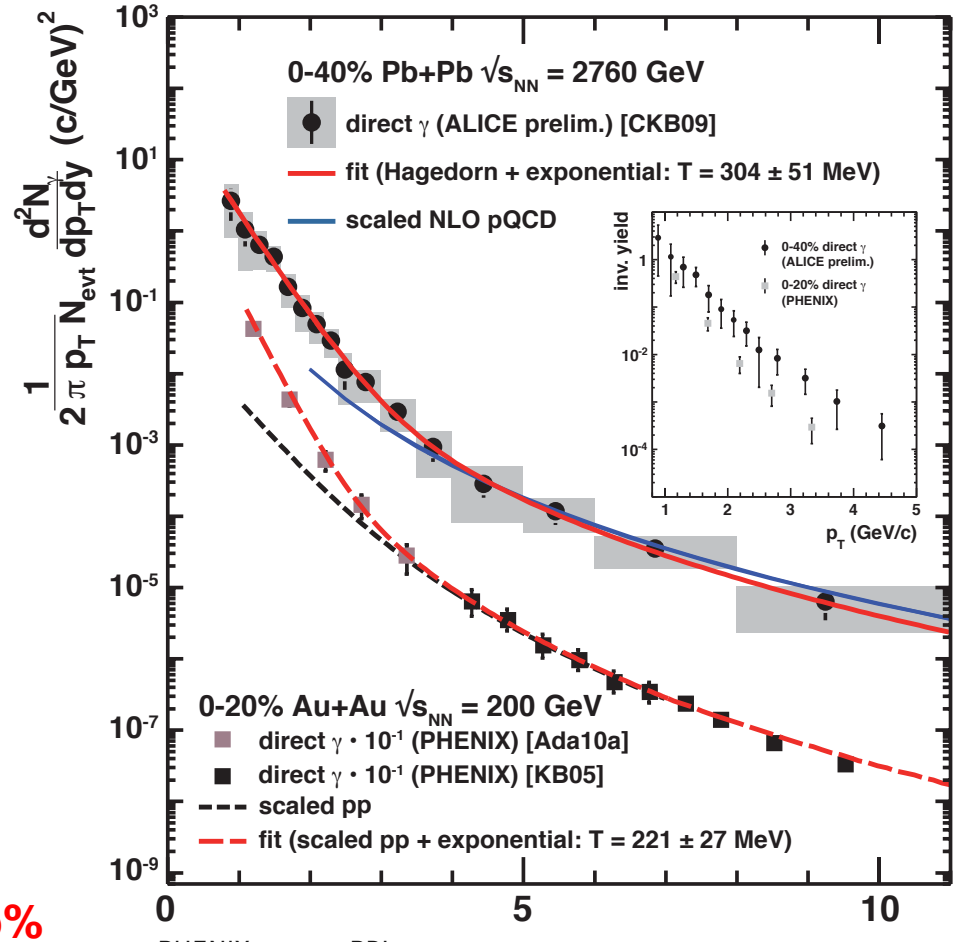
π⁰ as proxy for hard scattered partons strongly suppressed
Color neutral probes unaffected → **Strong final state effect**

› Direct Photons: A Closer Look

- At high p_T
  - Control for hard scattering rate
  - p_T › 4 GeV unaffected from the medium
- At low p_T
  - More than expected from p+p
  - Exponential behavior (thermal source?)

Effective slopes:
RHIC: T ≈ 220 MeV ($2.6 \cdot 10^{12}$K)
LHC: T ≈ 300 MeV ($3.5 \cdot 10^{12}$K)

Indication of thermal radiation at LHC.
Average slope/effective temperature ≈ 40% higher than at RHIC.



PHENIX: PRL 104:132301, 2010
ALICE: PhD M. Wilde (2015) arxiv:1509:07324

› How certain are we of direct photons in pp?

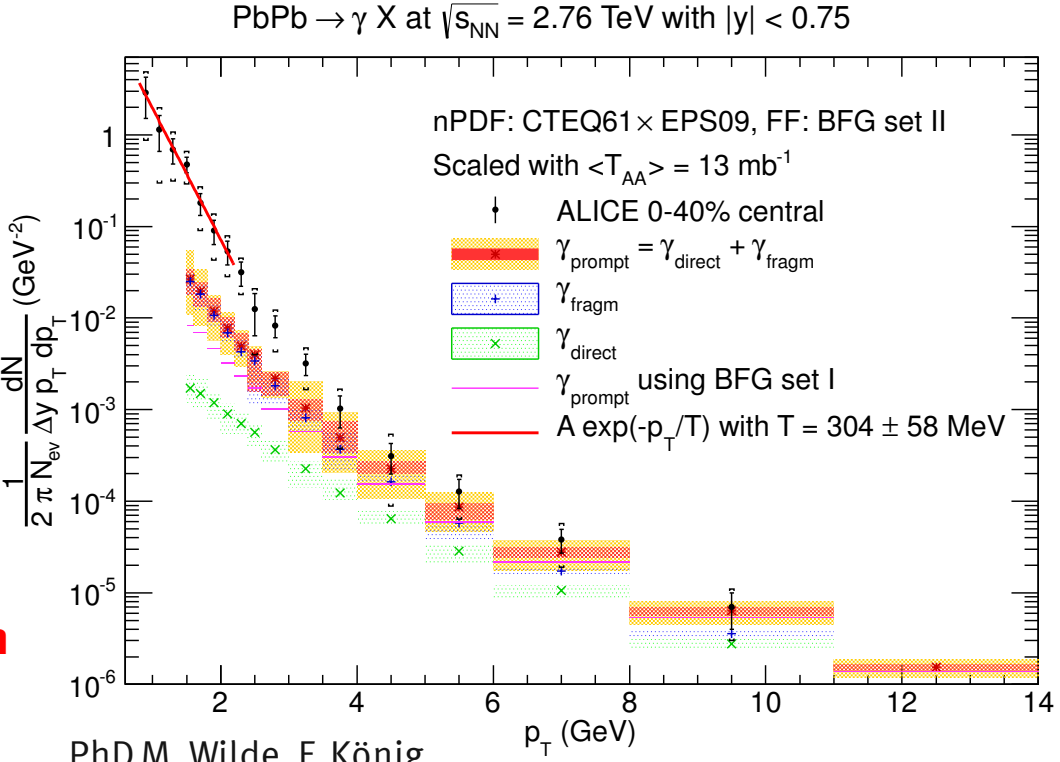
JHEP

Published for SISSA by Springer

Received: July 29, 2013

How robust is a thermal photon interpretation of the ALICE low-p_T data?

M. Klasen,[a] C. Klein-Bösing,[b,c] F. König[a] and J.P. Wessels[b]



NLO spectra down to 1.5 GeV, Including nuclear PDF, fragmentation contribution poorly constrained

› Electrons as Proxy for Heavy Quarks

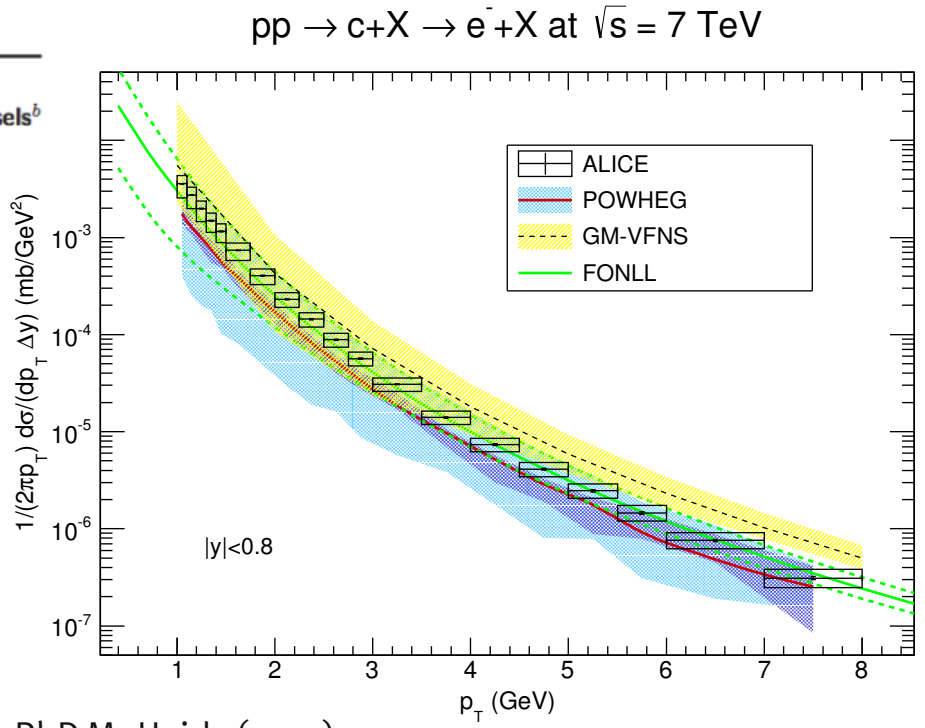
JHEP

Published for SISSA by Springer

Received: May 15, 2014

NLO Monte Carlo predictions for heavy-quark production at the LHC: pp collisions in ALICE

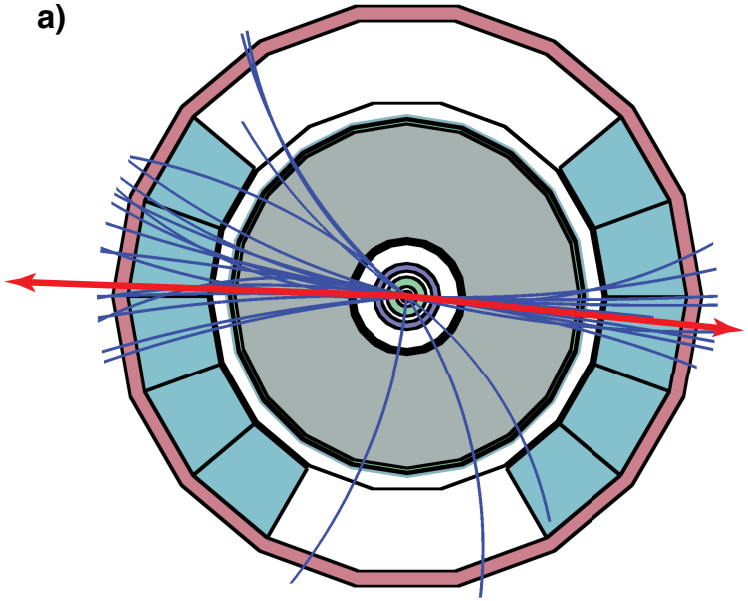
M. Klasen,[a] C. Klein-Bösing,[b,c] K. Kovarik,[a] G. Kramer,[d] M. Topp[a] and J.P. Wessels[b]

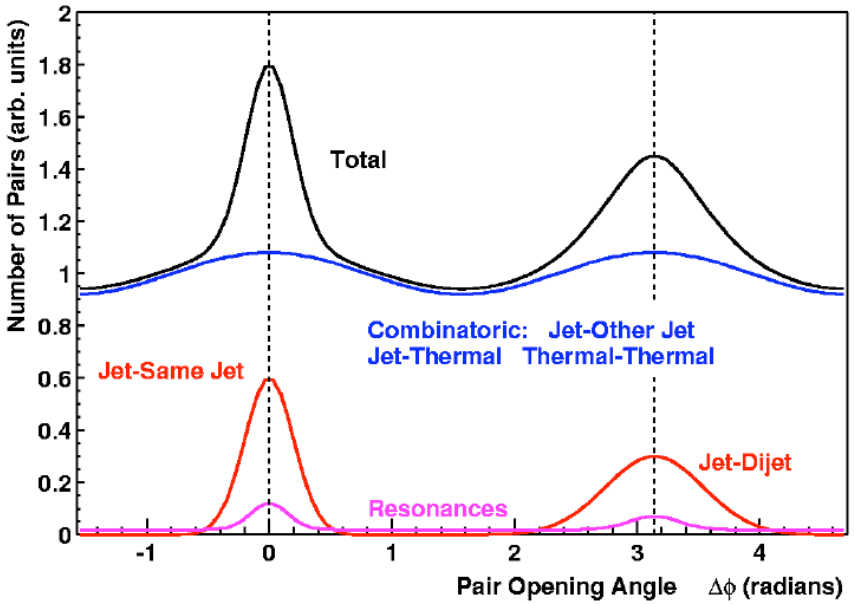


First heavy flavor electrons from NLO calculation + shower Monte Carlo

PhD M. Heide (2014)
Phys. Lett., B721:13–23, 2013.

› More Differential with Jets and Correlations





Reconstruct jets ….
….and decompose them again
(“Jet Fragmentation Function”)

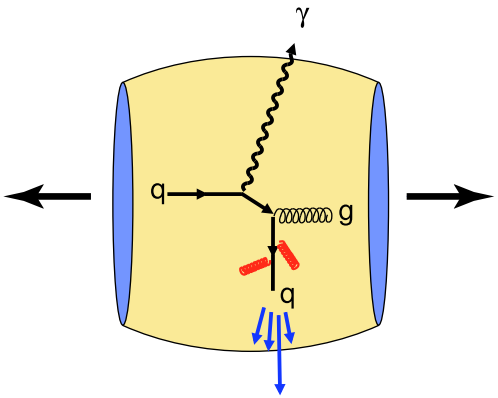
Correlate particles with a „trigger“.
Hadron → Light flavor
Electron → Heavy flavor
Photon → Light quark

› Sensitivity of Correlations

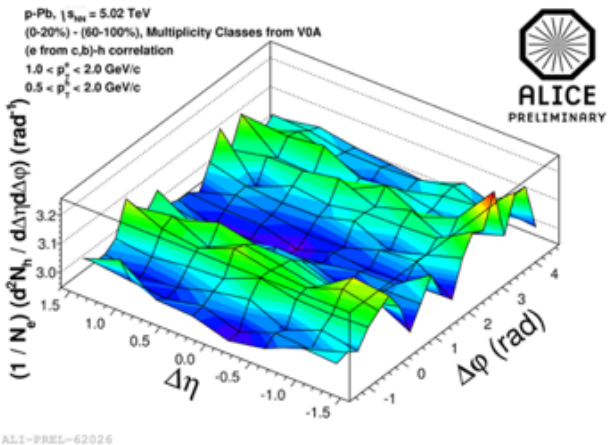
Full shower evolution: pp/pPb-reference → understand NLO effects
PbPb → medium modified fragmentation

Initial state: multiple parton interactions (Fedkevych)

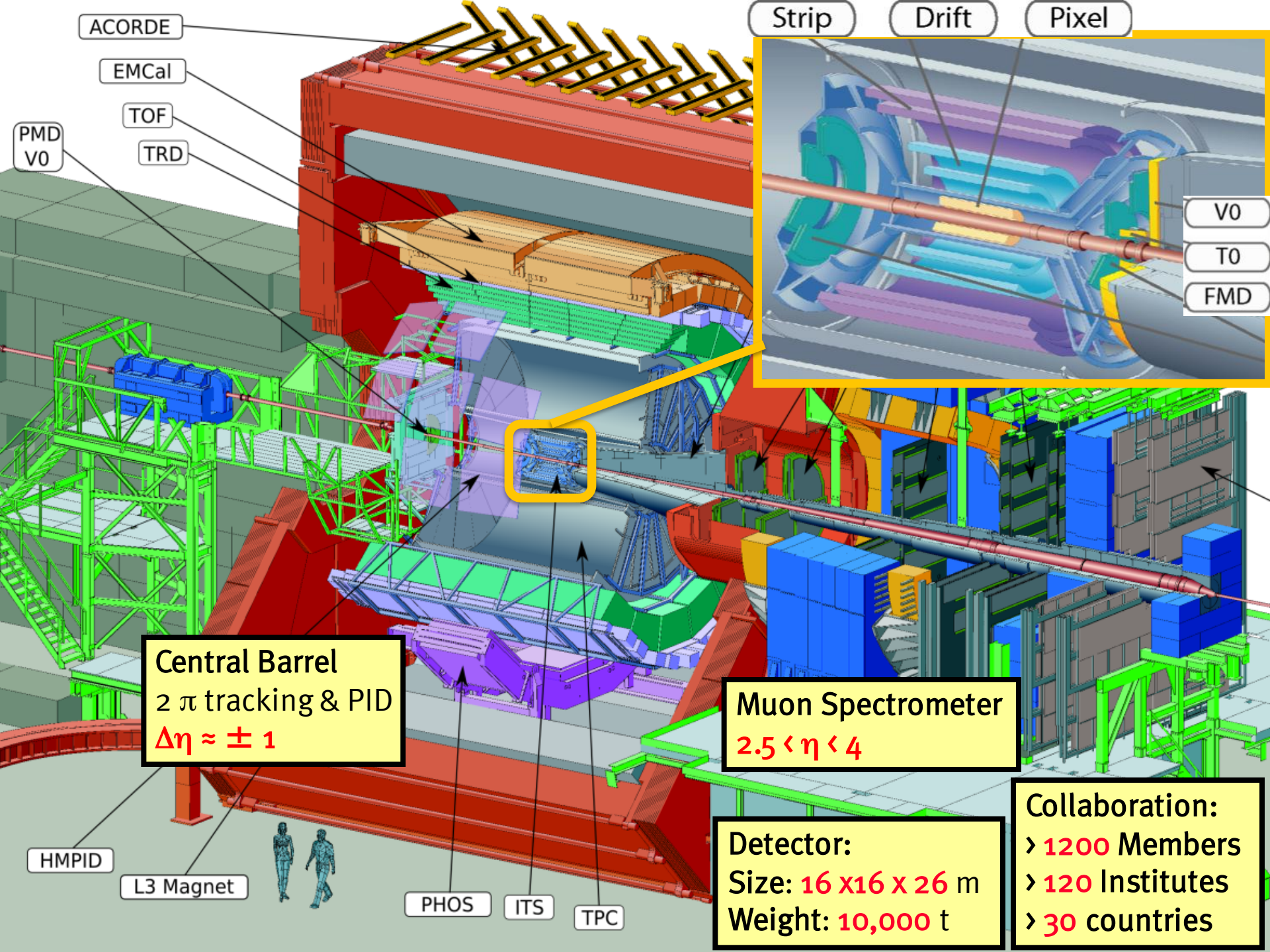
Photon-hadron (Poppenborg)
- At LO fixed recoil jet momentum
- NLO vs. isolated
- Constrain photon fragmentation



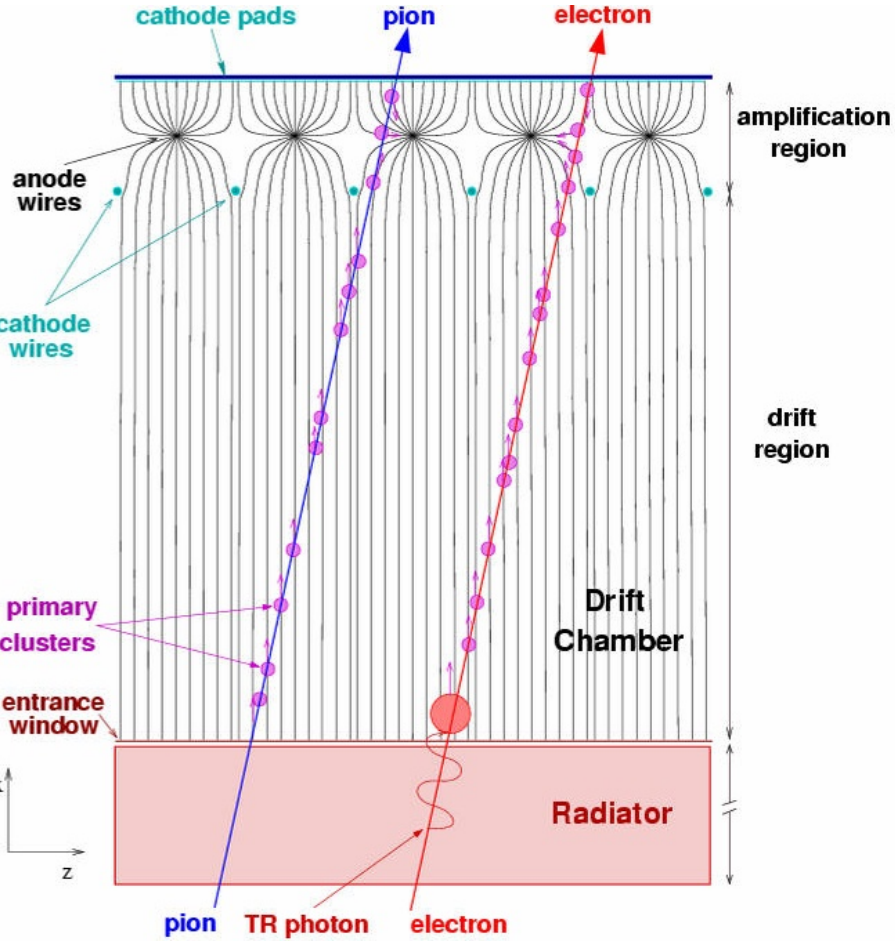
Electron-hadron (Herrmann)
- Surprising long range correlations in pPb
- Role of NLO (gluon splitting, flavor excitation

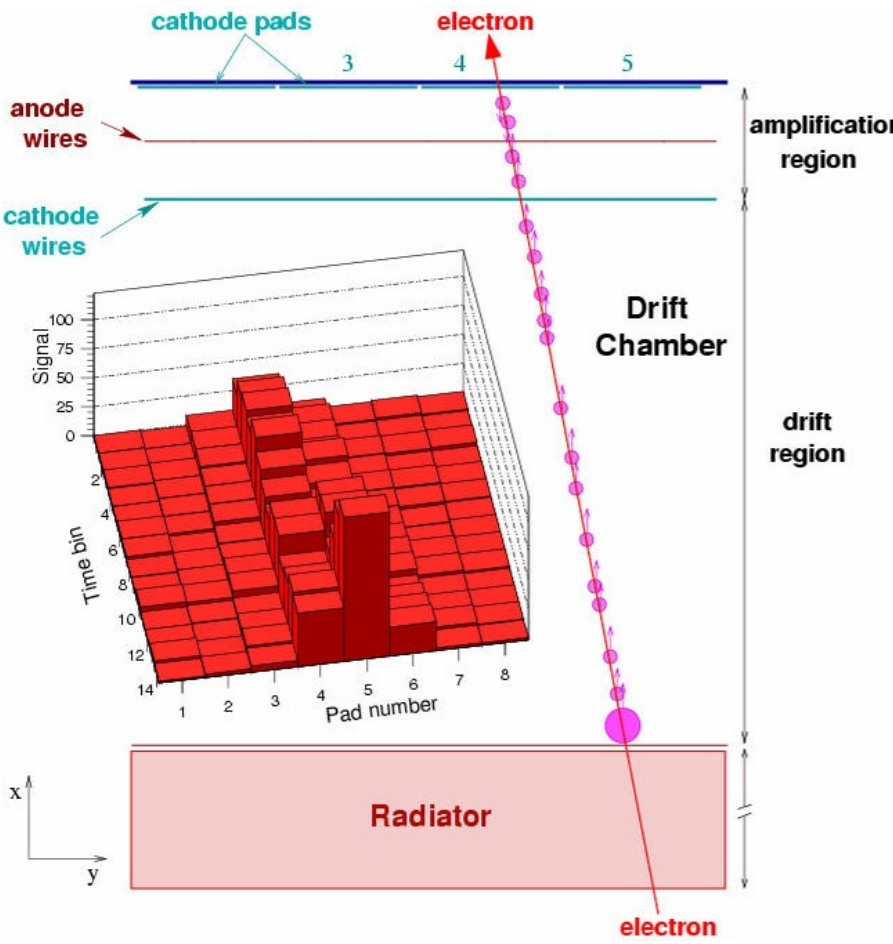


Event-by-event Monte-Carlo simulations will be indispensable tool:
POWHEG: NLO in pp PYTHIA: MPI JEWEL (Zapp): Medium modified parton shower

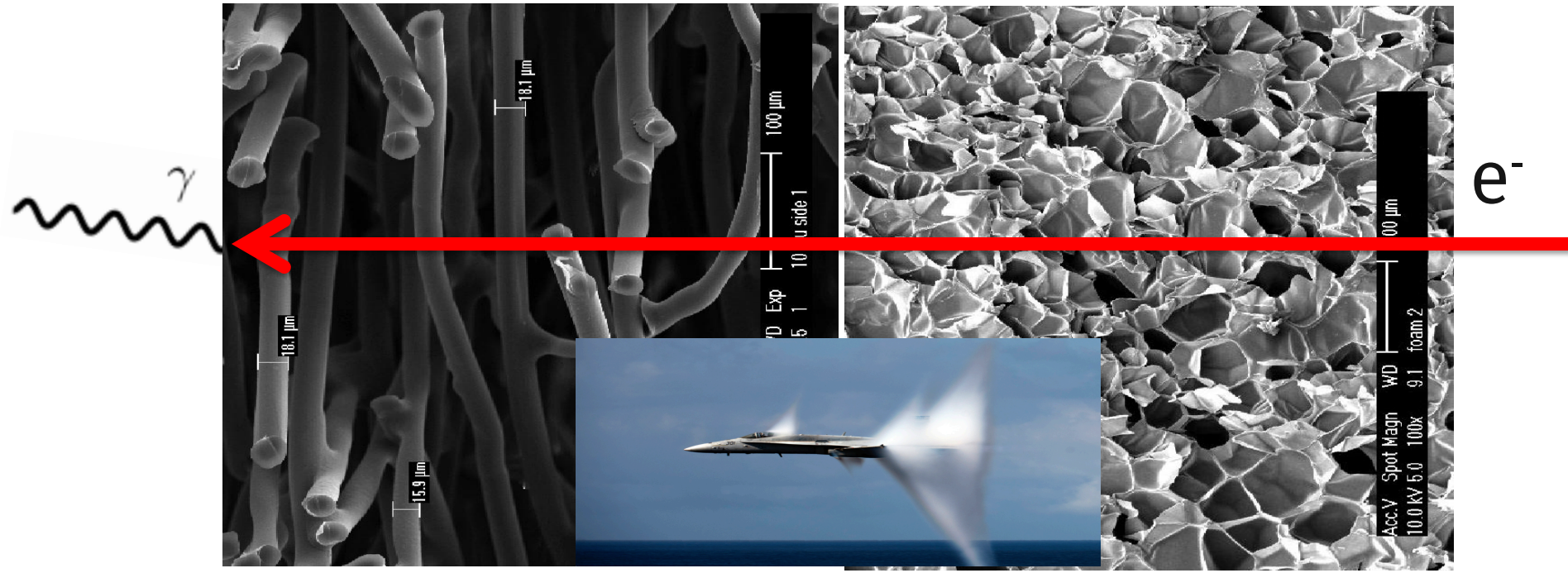

ACORDE
EMCal
TOF
TRD
PMD
V0
Strip
Drift
Pixel
V0
T0
FMD
HMPID
L3 Magnet
PHOS
ITS
TPC
Central Barrel
2 π tracking & PID
Δη ≈ ± 1
Muon Spectrometer
2.5 < η < 4
Detector:
Size: 16 x16 x 26 m
Weight: 10,000 t
Collaboration:
› 1200 Members
› 120 Institutes
› 30 countries

› TRD – Principle of Operation

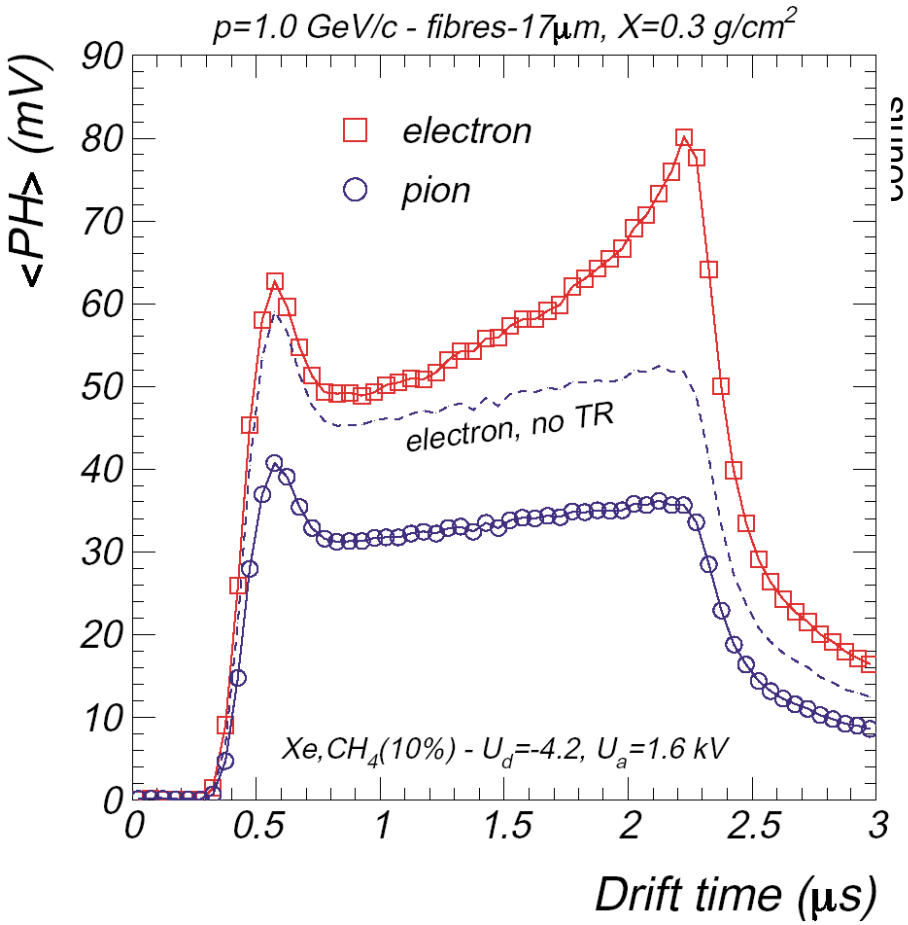


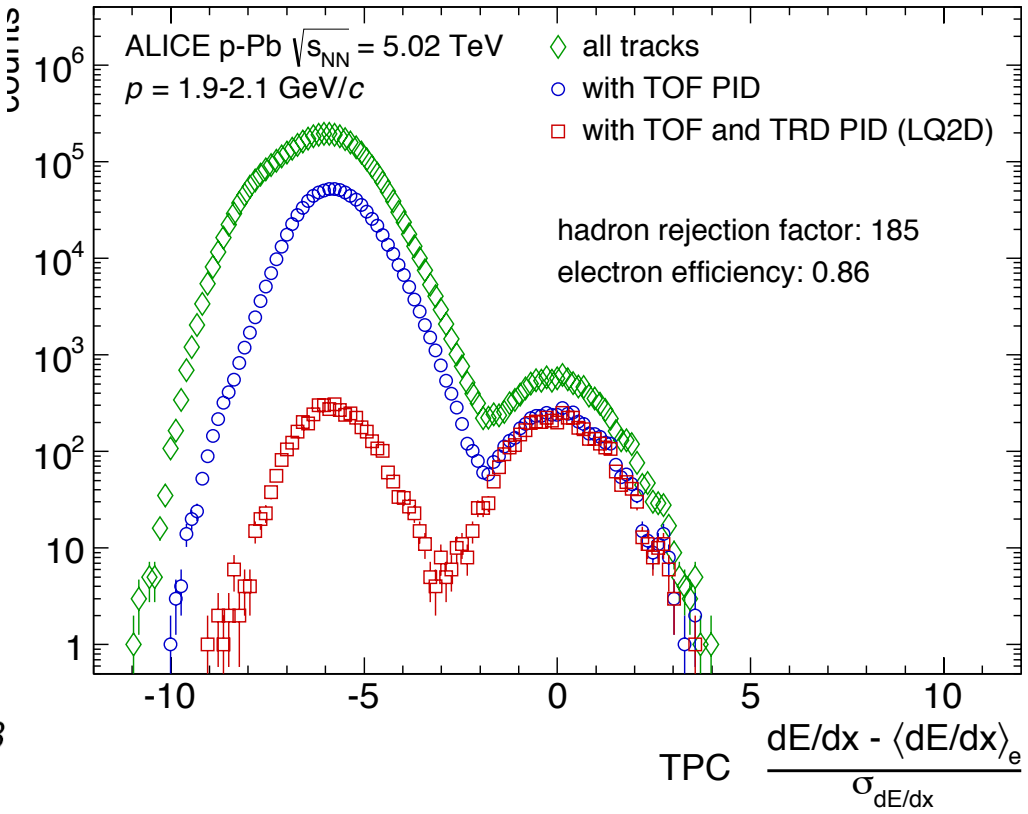


› Transition Radiation

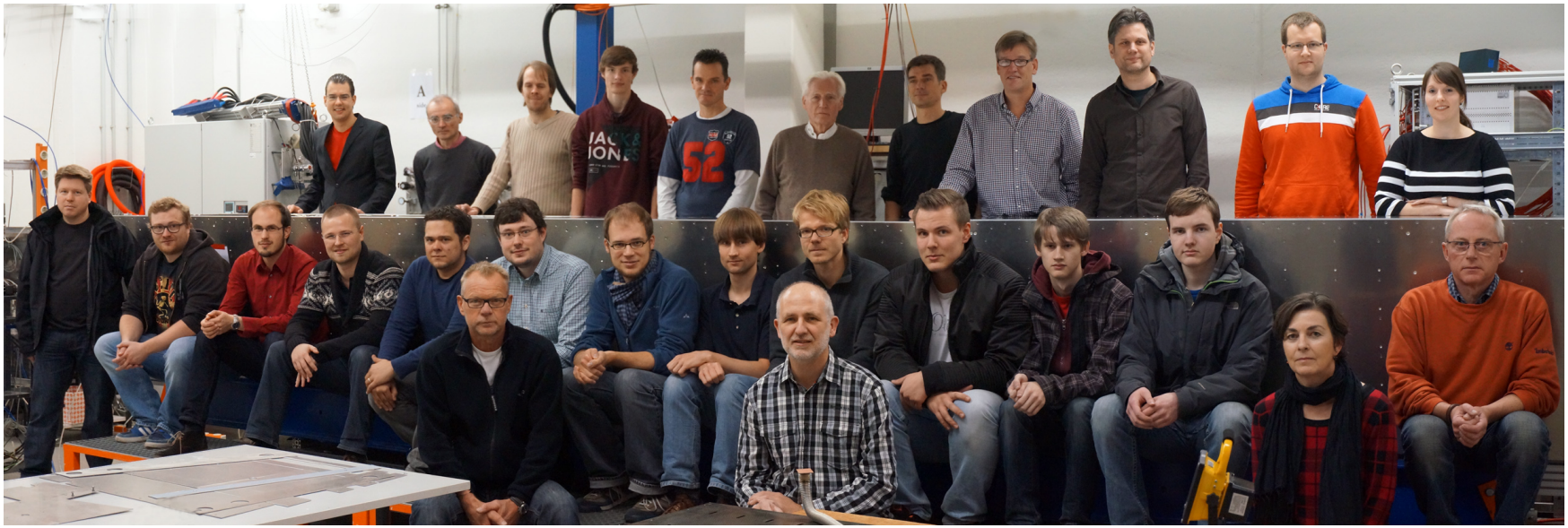


› Electrons and Pions





› AG Wessels and last TRD Module



plus





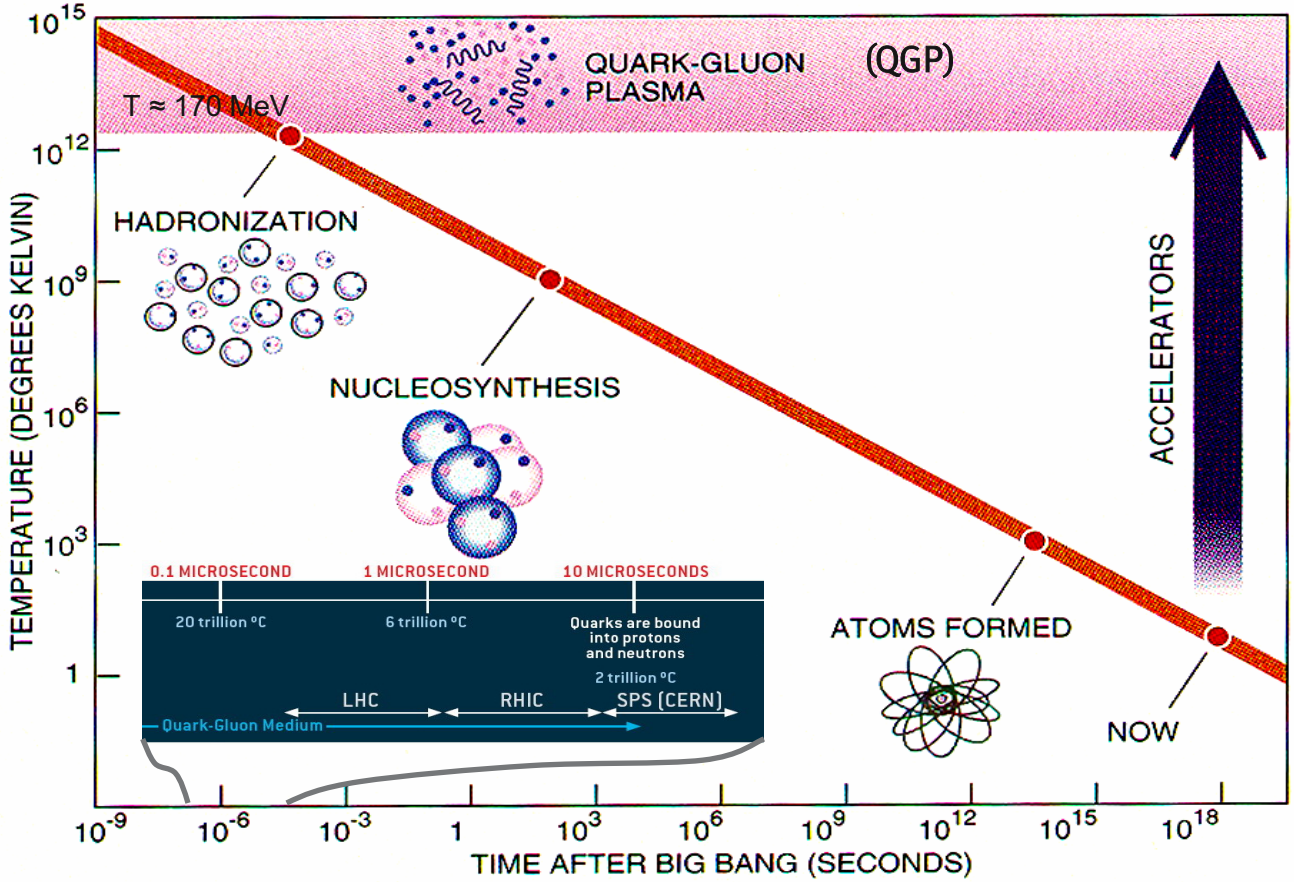

plus YOU?

plus CERNies




Backup

13.7 Billion Years Ago: The Quark-Gluon Plasma



Quarks and gluons are not confined into hadrons but can move freely

Recreated in the laboratory by colliding heavy ions (e.g. Au, Pb)

› Hard Probes / Parton Scattering

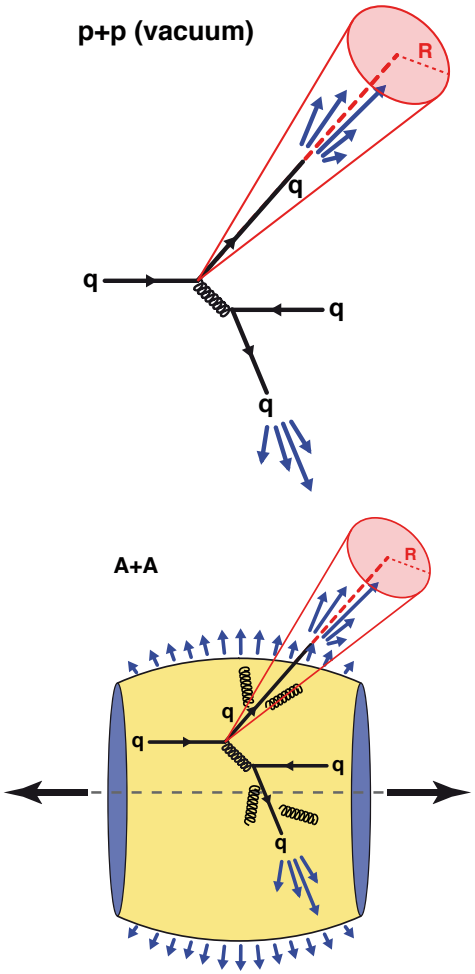
- Individual partons resolved at high Q^2
- $t \sim 1/Q \ll 1$ fm/c (early stage and rare)
- Partons fragment into "jets" of observable hadrons
  - Strong back-to-back correlation
  - Main source of particle production at high p_T

$$\frac{d^2\sigma_h}{dp_T dy} = \int \mathrm{PDF} \times \mathrm{pQCD} \times \mathrm{FF}(q, g \rightarrow h)$$

  - In A+A: partons interact with QCD medium ("*jet tomography*"), leading parton "loses" energy:*

$$\Delta E \propto \alpha_s C_R \langle \hat{q} \rangle L^2 f(E, m_q)$$

Scattered parton properties (including medium effects) reflected in high p_T particles/jets.

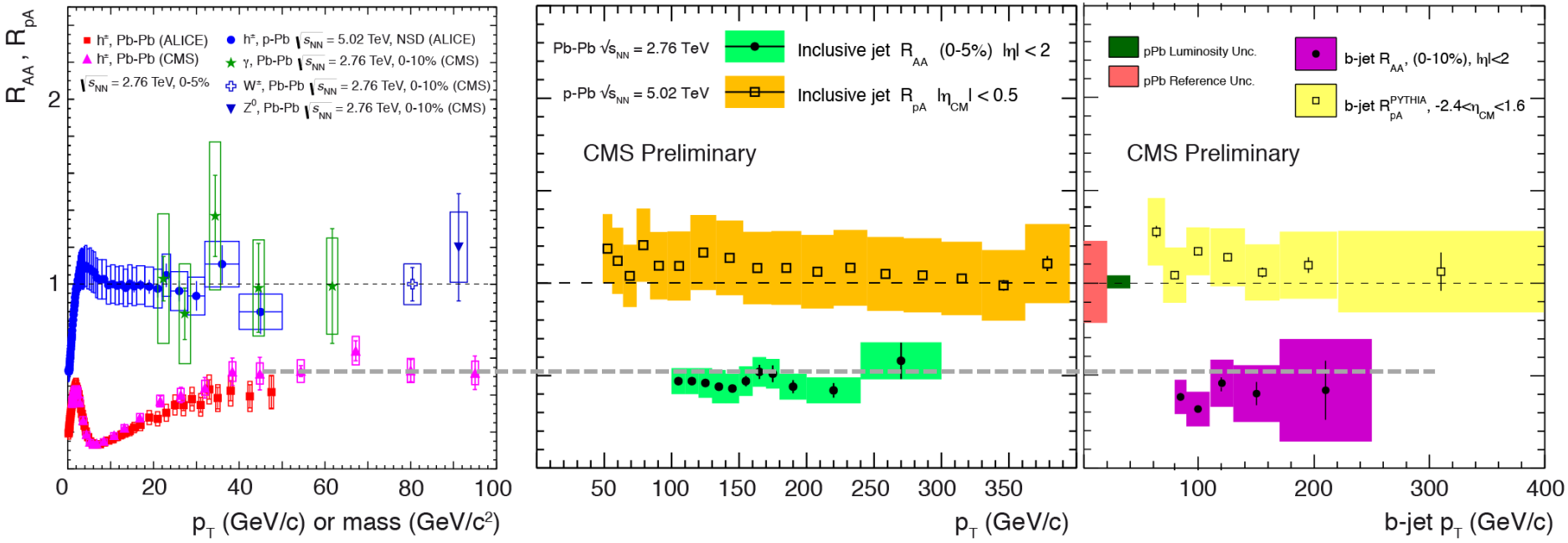


*E.g. Baier et. al NPB 484: 265 (1997)

› Hadrons, Jets, and b-Jets out to 500 GeV: Surprisingly Boring….

ALICE EPJ C74 3054 (2014)

CMS QM 2014 arxiv:1410.2576



No modification in pPb (cold nuclear matter) and for all color neutral probes in PbPb
Similar, limiting suppression for hadrons, light flavor and heavy quark jets.