physics focus at LHC/ALICE

- dilepton and photon measurements at ALICE
- run 1 (2009–2013) dilepton results and status
- runs 2 (2015–2018) and 3 (2021–) strategies
- dielectrons versus dimuons
- Muon Forward Tracker upgrade for run 3
  - open heavy flavors and quarkonia
  - low mass, low $p_T$ physics
- summary and concluding remarks
Uniqueness of QCD Phase Transition

- only possible boundary to experimentally cross
  - lost phase within experimental reach
  - to prove (or disprove) paradigm of universe evolution
  - not just to catch residue

*K. Homma, 2008/09*
Looking into “Parallel World”

- phenomena with restored symmetry
- in case of chiral symmetry:
  - diminishing effective (light) quark masses
  - probably lower hadron masses
- e.g. light vector meson mass modification
  - leptonic decay channels with short life time
    - e.g. $\phi (s\bar{s}) \rightarrow e^+e^- (0.03\%)$
A Large Ion Collider Experiment

- the nucleus-nucleus collision experiment at LHC
- 37 countries; 151 institutes; ~1,550 members
5.02 TeV collisions right now (since 25 November)
- design energy at 5.5 TeV

2.76 TeV in 2010 and 2011
- already 14 times higher $\sqrt{s_{NN}}$ than at RHIC
Evaluated Initial Temperatures

- initial temperature > averaged photon slope
- 300–600 MeV at RHIC (slope ~ 220 MeV)
  - hydro-dynamic description w/ $\tau_0 = 0.15–0.6$ fm/c
- slope at ALICE: $297 \pm 12$ (stat.) $\pm 41$ (sys.) MeV

- cf. phase transition predicted at ~170 MeV

Across the Boundary and Beyond

F. Karsch,
Photon Measurement at ALICE

- EM calorimeter (+ dijet calorimeter)
  - large solid angle; connection with jet
- photon spectrometer (PHOS)
  - high spatial and energy resolutions
- photon conversion (dielectron) in TPC
  - high momentum resolution; powerful at low $p_T$
- *ref. K.Reygers, Tuesday next week*
Dielectron Measurement at ALICE

- **inner tracking system (ITS)**
  - tracking, vertex, PID via $dE/dx$

- **time projection chamber (TPC)**
  - tracking, PID via $dE/dx$

- **time of flight detector (TOF)**
  - hadron rejection
Dielectrons in Run 1 pp, p-Pb

- pp at 7 TeV: ~300 M minimum bias events
- p-Pb at 5.02 TeV: ~100 M minimum bias events

in agreement with expectations

ref. Alberto Caliva, Thursday this week
Dielectrons in Run 1 Pb-Pb

- at 2.76 TeV: 17 M central, 12 M semi-central
- feasibility in very low mass region
  - differential in pair $p_T$
  - central (0–10%) and semi-central (20–50%)
  - challenging S/B ratio
- analysis ongoing

ref. Alberto Caliva, Thursday this week
Virtual Photon Thermometers

- real photons
  - average over collision evolution
  - blue shift due to collective effects
- virtual photons ($\rightarrow$ dileptons)
  - invariant mass as extra dimension
  - selective in time
  - higher significance avoiding $\pi^0$
- low mass: extracted in pp, ongoing in p-Pb, Pb-Pb
- intermediate mass: future scope
  - no blue shift in invariant mass

R. Rapp,
-4 < \eta < -2.5

- data collected in run 1:
  - Pb-Pb at 2.76 TeV
  - p-Pb and “Pb-p” (muon arm on p going side) at 5.02 TeV
  - pp at 2.76, 7, 8 TeV
Low Mass Dimuons in Run 1 pp, p-Pb

- unlike sign muon pair analysis
  - matching between tracking and $\mu$ trigger
    - trigger threshold $p_{T\mu} \sim 0.5$ GeV/c
  - fiducial cuts on $\eta_{\mu}$ and $y_{\mu\mu}$

- combinatorial background via event mixing
same selections as in pp and p-Pb plus:
- sharp offline cut on $p_{T\mu} > 0.85$ GeV/c, $p_{T\mu\mu} > 2$ GeV/c
- empirical continuum background (blue lines)
\( R_{AA} \): A Run 1 Achievement

- comparison with mid-rapidity \( \phi \rightarrow K^+K^- \)

- in agreement point to point
- different slopes? different hydrodynamic push?
2015 Pb-Pb Strategy

- **300 µb$^{-1}$ in muon arm**
  - ~4 times run 1 integrated luminosity
- **150 M MB events (~19 µb$^{-1}$) in central barrel**
  - emphasis on peripheral to bridge pp, p-Pb and Pb-Pb
  - 00–10%: ~0.75 times run 1
  - 10–50%: ~2.5 times run 1
  - 50–90%: ~10 times run 1
- **pp reference at 5.02 TeV**
  - 0.15 pb$^{-1}$ in muon arm
  - 80 M MB events in central barrel
Low Mass Dielectron Goals

- continuum up to $J/\psi$ mass in minimum bias
- virtual photons in different centralities
  - low S/B ratio; ~0.25% in central, ~1% in semi-central

- dielectron elliptic flow
Low Mass Dimuon Goals

- $\phi$ and $\rho + \omega$ $R_{AA}$
  - $2 < p_T < 6$ GeV/c
- $\phi$ and $\rho + \omega$ elliptic flow
  - integrated over $p_T$

- low and intermediate mass spectrum
  - $2 < p_T < 6$ GeV/c
  - $\rightarrow$ hadronic cocktail + open heavy flavor
Other Dilepton Goals in Run 2

- $J/\psi$ $R_{AA}$ versus centrality, rapidity, $p_T$
- $J/\psi$ elliptic flow
- $J/\psi$ at very low $p_T$

Excited states: $\psi'$, $Y(1S)$, $Y(2S)$

Major Upgrades at Run 3 (2021–)

- **new ITS**
  - 7 layers of MAPS silicon pixel detectors
  - precise measurement of displaced vertices
    - to separate heavy flavor decays

- **new TPC readout chambers**
  - GEM technology with no gating grid
  - ~100 times higher data taking rate (50 kHz in Pb-Pb)
    - continuous readout

- **Muon Forward Tracker (MFT)**
Dielectron Goals and Plans in Run 3

- radiation in intermediate (> 1.1 GeV/c²) mass
  - precise measurement of early time temperature
    - average over early times, no blue shift
- expected precision: ±10% stat., ±10–20% sys.
  - 2.5 G minimum bias events assumed

- subtraction established for known sources

e± and μ±, Typical Brothers/Sisters

- basically equivalent; different only in masses
- unique in how to treat; especially in PID
- electron identification
  - charged hadron rejection via mass difference
    - cherenkov, dE/dx, momentum versus electro-magnetic energy
  - then Dalitz decay electrons from π0, η, ω, η’, φ, ...
- muon identification
  - charged hadron rejection via penetration
    - hadron absorber (1 GeV/c μ requiring 80 cm of iron to stop)
  - Dalitz only from η (→ γ μ+μ− BR ~ 0.03%) and heavier
  - π+ → μ+νμ, K+ → μ+νμ not from primary vertex
    (note: 5 years ago)
A Typical Electron Measurement

- **PHENIX at RHIC**

- precise tracking and electron identification
  - challenging background primarily from Dalitz decays
    - statistical subtraction
    - hadron blind detector
  - $\gamma$ conversion rejection
  - correlated background also evaluated
    - cross pairs
    - jet components
  - ref. Y. Watanabe, Monday this week
A Typical Muon Measurement

- **NA38/50/51 at SPS**
  - *ref.* H. Specht, Monday this week
- **µ± spectrometer w/ huge hadron absorber**
  - primarily for J/ψ physics
- **fast µ± trigger for high statistics**

- **low resolution:** $\sigma_z \sim 10$ cm, $\sigma_m \sim 80$ MeV at $\phi$
A Historical Muon Upgrade: NA60

- radiation hard Si telescope in front of absorber
  - high vertex and invariant mass resolutions
Excellent Vertex Resolution

- $\sigma_z \sim 200 \mu m$, $\sigma_{x,y} \sim 10–20 \mu m$
  - w/ $\geq 4$ tracks

indium target images in log scale
Evaluation of uncorrelated pairs

- checked with like sign (++, --) pairs
  - little cross pair contribution at SPS energy

~2% accuracy at NA60 over wide mass range
Excellent Low Mass Spectrum

- good statistics and invariant mass resolution
  - opening angle with silicon vertex tracker
  - momentum with $\mu^\pm$ spectrometer

- fake match evaluated with event mixing

02.Dec.2015  ECT* Workshop on Photons and Dileptons / Dileptons and MFT at ALICE / K.Shigaki
ρ Discussions Finally Allowed at SPS

- **Brown-Rho** (dropping mass)
- **Rapp-Wambach** (collision broadening)
two interesting regimes of quark-gluon droplets
- exploration on QCD phase diagram

virtues at LHC
- *not too forward* for “central” physics (2.5 < |\(\eta\) | < 3.6)
- *forward enough* for muon measurement
Forward Upgrade

- high precision internal tracking
  - in association with existing forward muon spectrometer
- “classical” upgrade of muon experiments
  - e.g. NA60, PHENIX
  - CMS from the beginning
- challenges at ALICE:
  - only 40 cm left in $z$
  - momentum measurement not possible
    - tracks almost parallel to magnetic field
  - 60 $X_0$ frontal absorber in front of spectrometer
  - high multiplicity
2.5 (9.5°) < $-\eta$ < 4.0 (2°)
- (negative $\eta$ side in ALICE coordinates)
Muon Forward Tracker (2021–)

- eye glasses of muon spectrometer
6.6 Physics case review and update

ALICE ITS in the measurement of beauty via displaced $D_0$ are also shown, taken from the left plot of Figure 8.19 of [5]. As it can be clearly seen, the measurement of non-prompt $J/\psi$ in the dimuon channel at forward rapidity, considered in the present study, represents a key tool for the measurement of beauty down to zero $p_T$ in Pb-Pb collisions, in ALICE and more generally at the LHC.

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- $-3.6 < \eta < -2.45$
  - covering most of muon spectrometer acceptance

- 912 silicon pixel sensors (0.4 m$^2$)
- 5 disks (10 detection planes) at $z = 46–77$ cm
(Tight) MFT Environment
- Ladder assembly with active and readout zones
- Sensors on both sides staggered
  - No dead zone, 50% redundancy
CMOS Monolithic Active Pixel Sensor (MAPS)
- active and readout zones on same silicon substrate
- reduced cost compared to hybrid pixel technology
- 50 µm thickness → low material budget
- 28 × 28 µm² pixels
- 15 × 30 mm² sensor size
- ~700 kRad radiation tolerance

Alpide (ALICE pixel detector) readout architecture
- event timing resolution < 4 µs
- power consumption < 50 mW/cm²
< 0.6% $X_0$ per disk

1\textsuperscript{st}: flexible printed circuit

2\textsuperscript{nd}: water cooling structure

3\textsuperscript{rd}: silicon pixel sensor
Occupancy in Central Pb-Pb

- ~0.5 cluster/mm²/collision at most
- factor ~2 difference from 1\textsuperscript{st} to 5\textsuperscript{th} disk
Data Throughput

- estimation including Pb-Pb collisions, QED, noise
  - 100 kHz collision rate
  - 4 µs integration time
  - $10^{-5}$ fake hit rate
  - 35 bits average hit encoding

- max. ~250 Mb/s for inner sensors in 1st disk
  - high speed 1.2 Gb/s lines complying with requirements

- full data throughput ~57 Gb/s
Track Matching with Spectrometer

- high efficiency even in central Pb-Pb
  - ~90% at $p_T > 2$ GeV/c
  - ~60% at $p_T = 1$ GeV/c

- different methods under study
  - MFT cluster with spectrometer track (MFT Letter of Intent)
  - MFT track with spectrometer track (new)

![Graph showing correct matching rate versus transverse momentum $p_T$.]

- Correct Matching Rate
- $p_T$ (GeV/c)
significant improvement w/ MFT
- mass resolution by ~4
- LVM signal/background ratio by ~10
~20% uncertainty w/ MFT, ~70% w/o MFT
- at $m_{\mu\mu} \sim 0.5 \text{ GeV}/c^2$
- 10% hadron/charm subtraction uncertainties assumed
ALICE(Japan) Upgrade Strategies

- **1\textsuperscript{st}** – high $p_T$ phenomena (jets), heavy flavors
  - $\checkmark$ $\times$ 2–3 high speeding, new detectors; LS1 2013–2014
    - upgrade: TPC readout* (Tokyo), PHOS readout (Hiroshima)
    - new: di-jet calorimeter (Tsukuba)

- **2\textsuperscript{nd}** – low/mid $p_T$ phenomena
  - $\times$ 100 high speeding, new detectors; LS2 2019–2020
    - upgrade: TPC chamber (Tokyo), new vertex trackers
    - new: muon forward tracker (Hiroshima)

- **3\textsuperscript{rd}** – (further) forward physics
  - new detectors; LS3 2024 ?
    - new: forward calorimeter (Tsukuba)

* pending
Hiroshima on MFT Project

- focus on low mass physics
- in charge of detector control system
- ladder assembly and testing
  - expertise in laser soldering developed in ITS upgrade

- first hybrid integrated circuit assembly test satisfactory
Summary and Concluding Remarks

- confidence in looking into “parallel world”
  - chiral phenomena of most interest
    - further and updated theoretical(/experimental) inputs needed
- successful dilepton measurements at ALICE run 1
  - ref. Alberto Caliva, Thursday this week
- run 2 Pb-Pb ongoing for higher statistics
  - differential measurements, e.g. \( \phi, \rho + \omega, J/\psi \) elliptic flow
- major upgrades in run 3 (2021–)
- Muon Forward Tracker
  - unique tool also for low mass, low \( p_T \) physics