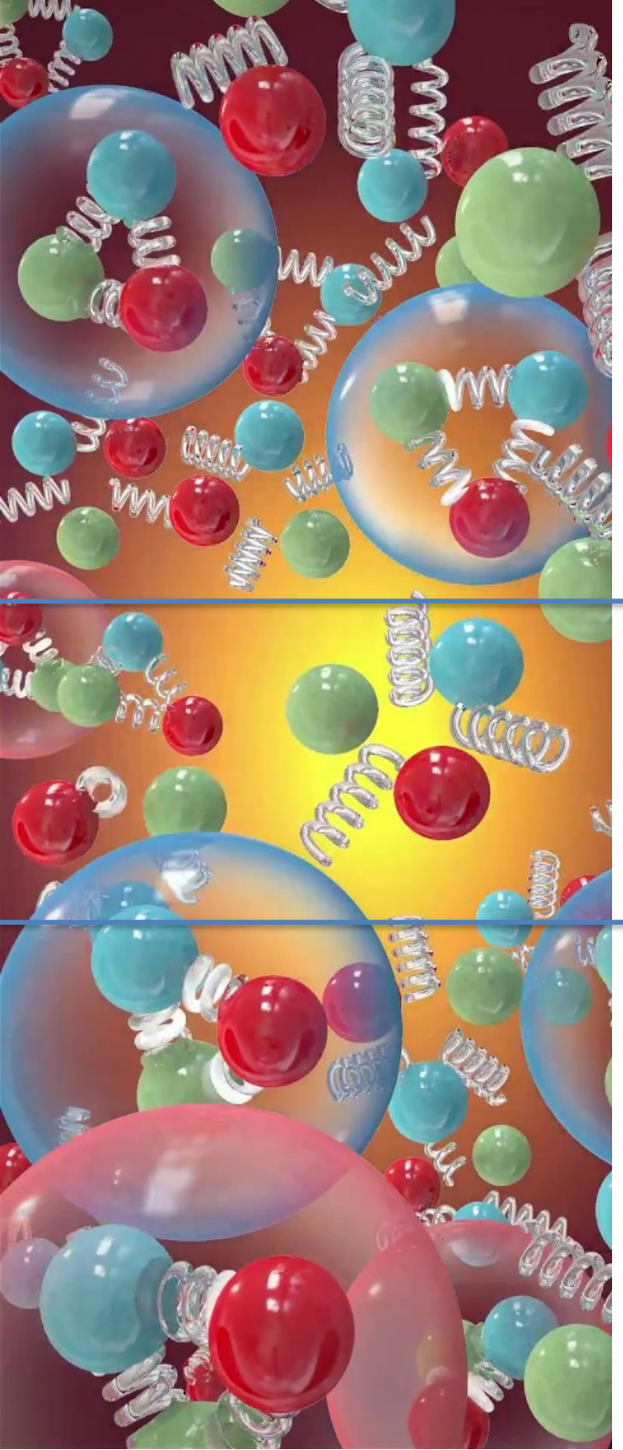


GDR QCD Workshop on
Dilepton Probes in Hadronic Physics

November 25, 2021, IJClab – Orsay

Low-Mass Dileptons with ALICE, and prospects for NA60+

Antonio Uras

IP2I - Lyon – CNRS/IN2P3

Outline

Low-mass dilepton measurements with ALICE

- Recent results from Run1+Run2
- Prospects for Run3+Run4

Low-mass dilepton measurements with NA60+

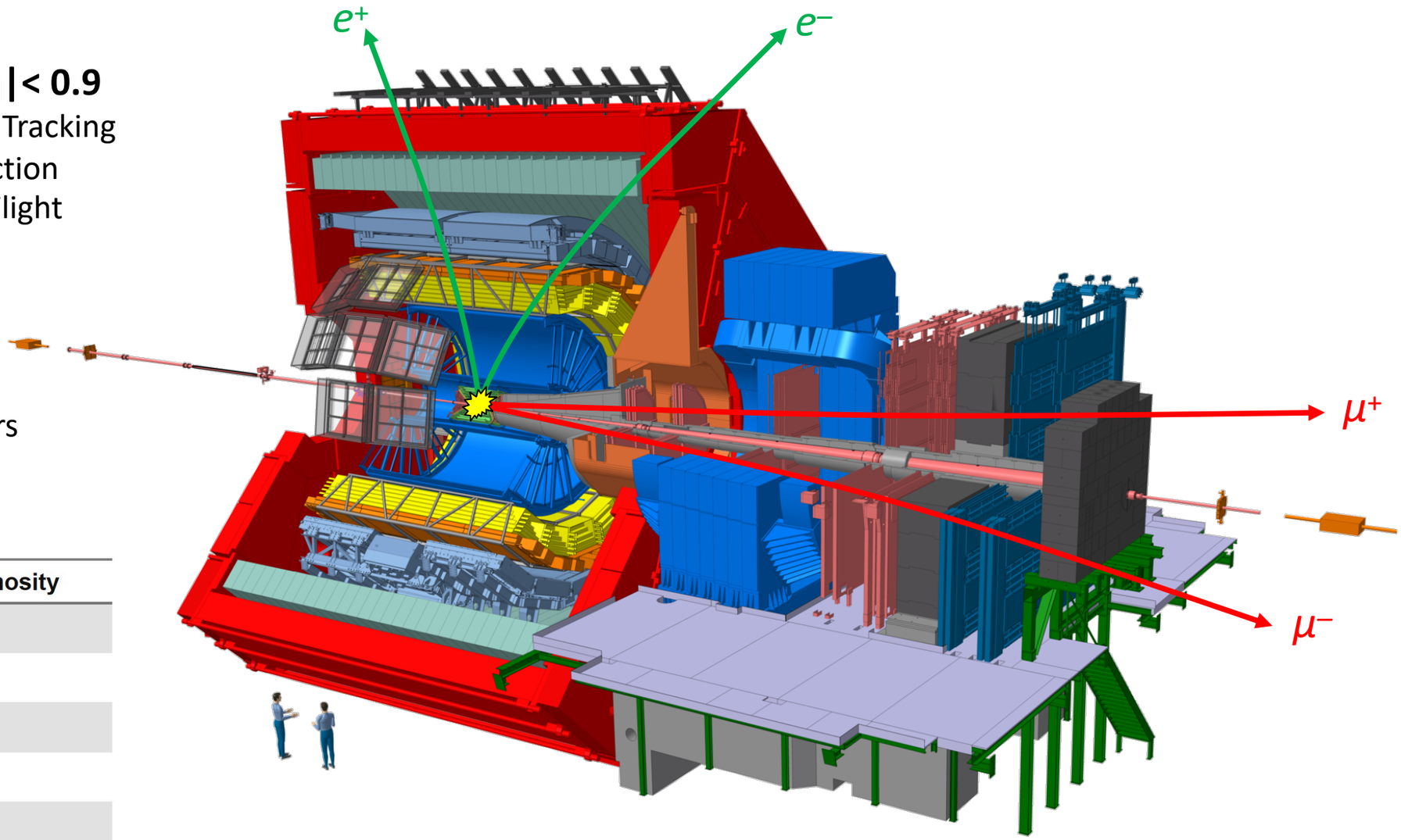
- The NA60+ project
- Expected performance for low-mass dimuon measurements

Dileptons with ALICE

Dilepton Measurement With ALICE in Run1+Run2

- **Dielectrons ⟶ |η|< 0.9**
  Central Barrel: Inner Tracking System + Time Projection Chamber + Time Of Flight

- **Dimuons ⟶ 2.5 < η < 4**
  Muon Arm: Tracking Chambers + Muon Trigger



System	Analysed luminosity
pp $\sqrt{s} = 5.02$ TeV	19.93 nb^{-1}
p-Pb $\sqrt{s_{NN}} = 5.02$ TeV	0.299 nb^{-1}
Pb-Pb $\sqrt{s_{NN}} = 5.02$ TeV	10 μb^{-1}
pp $\sqrt{s} = 13$ TeV (B=0.2T)	9.38 nb^{-1}
pp $\sqrt{s} = 13$ TeV (Muons)	36 pb^{-1}

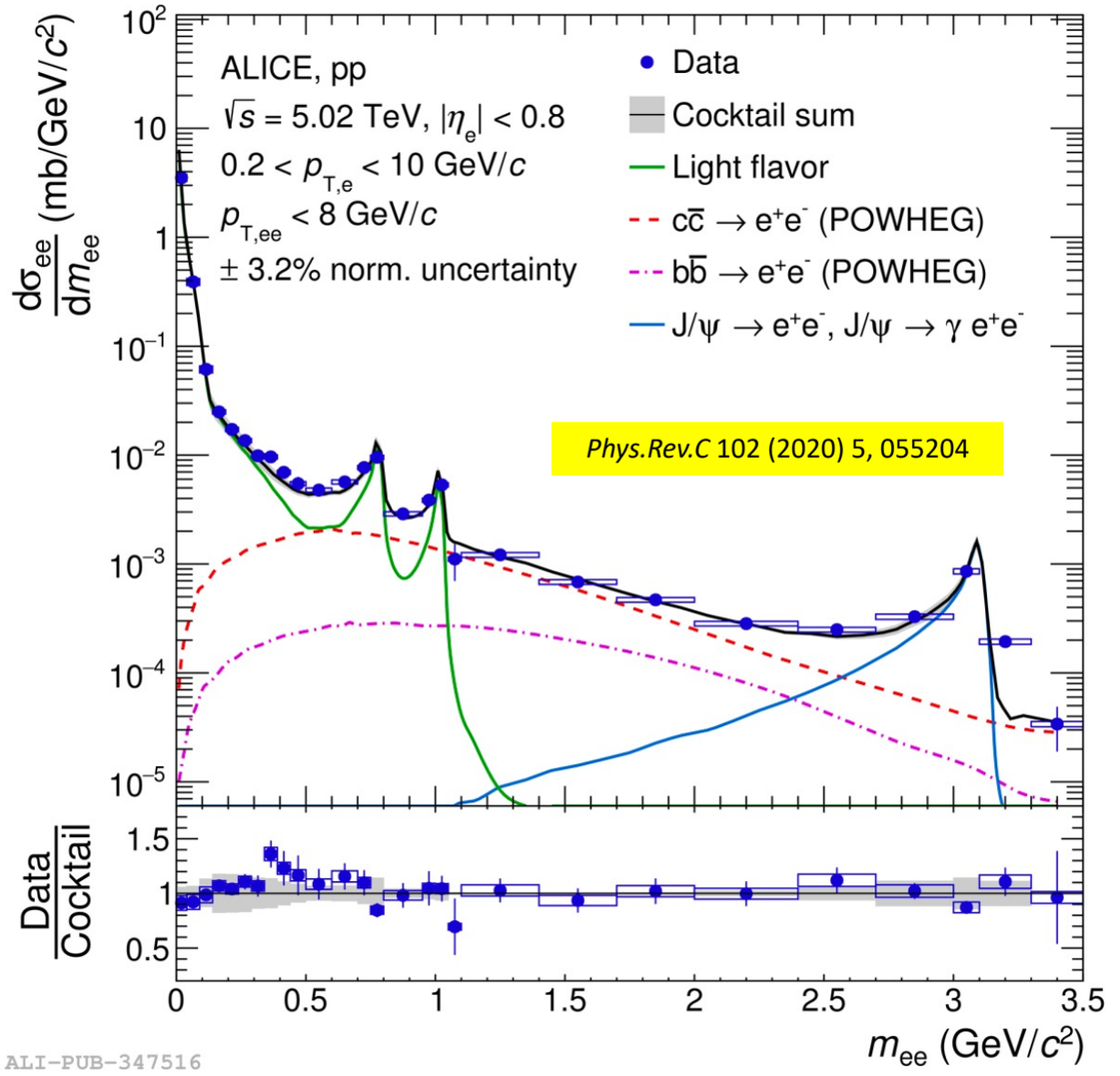
Dielectron Production in pp Collisions

Mass spectrum compared with cocktail of known hadronic sources

- **Data well described by cocktail within uncertainties**
- Similar results in pp collisions at 7 and 13 TeV
- Important baseline for p–Pb and Pb–Pb at 5.02 TeV

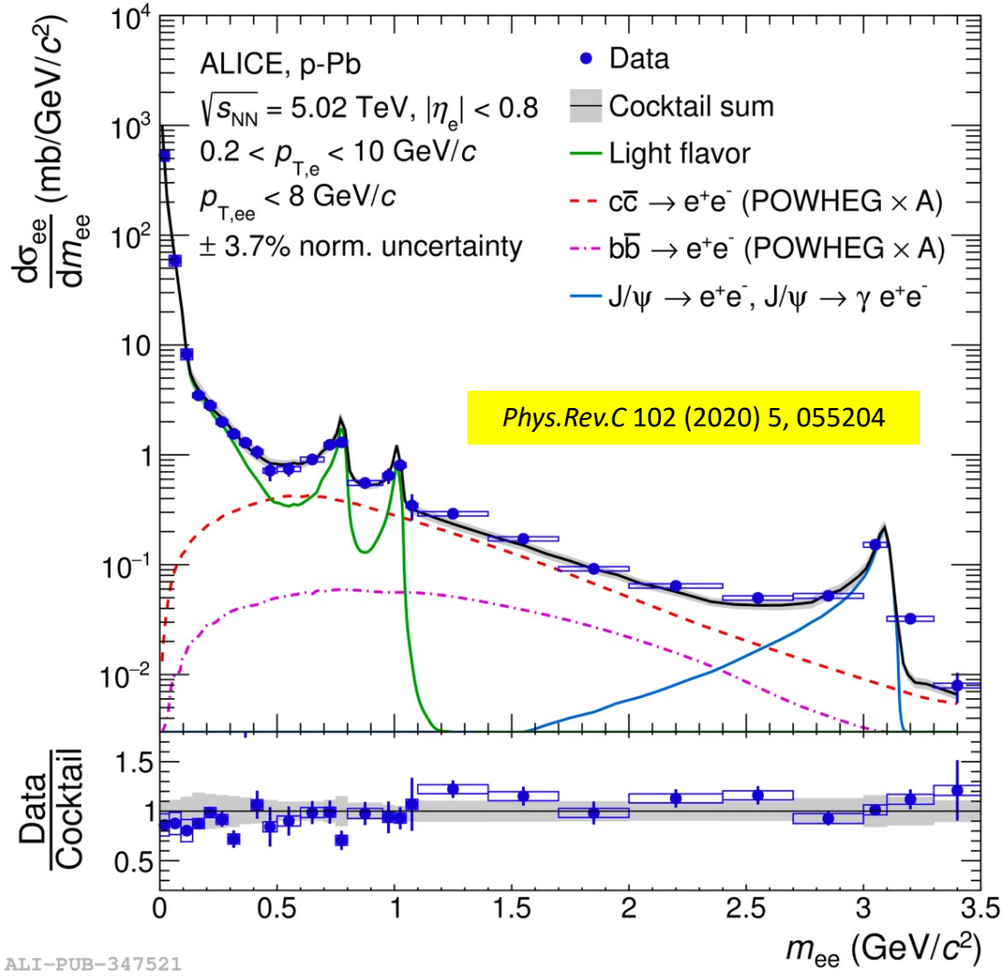
Heavy-flavour contributions dominate for $m_{ee} > 1.1$ GeV/c^2

- Complementary (w.r.t. heavy-flavour hadron measurements) σ_{bb} and σ_{cc} measurements



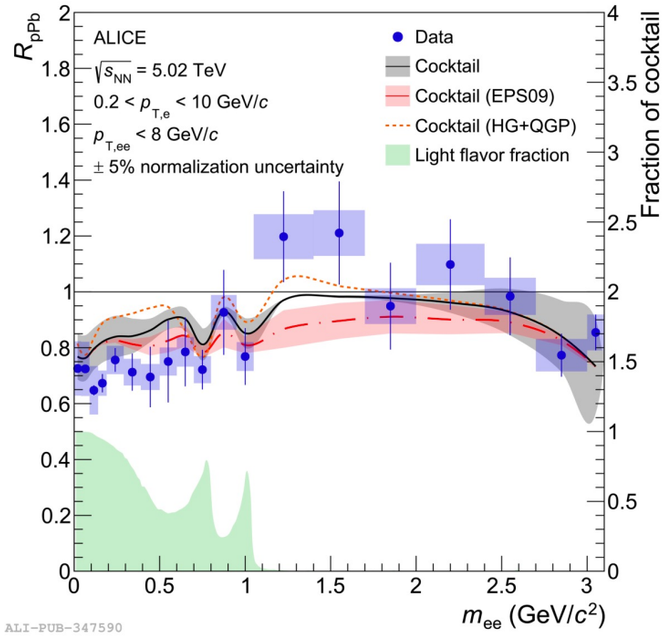
Dielectron Production in p-Pb Collisions

Spectrum in good agreement with cocktail of known hadronic sources



Phys.Rev.C 102 (2020) 5, 055204

- Heavy flavour from PYTHIA or POWHEG based on N_{coll} scaled measured σ_{bb} and σ_{cc} at 7 TeV. Current precision doesn't allow for conclusions on potential cold nuclear matter effects



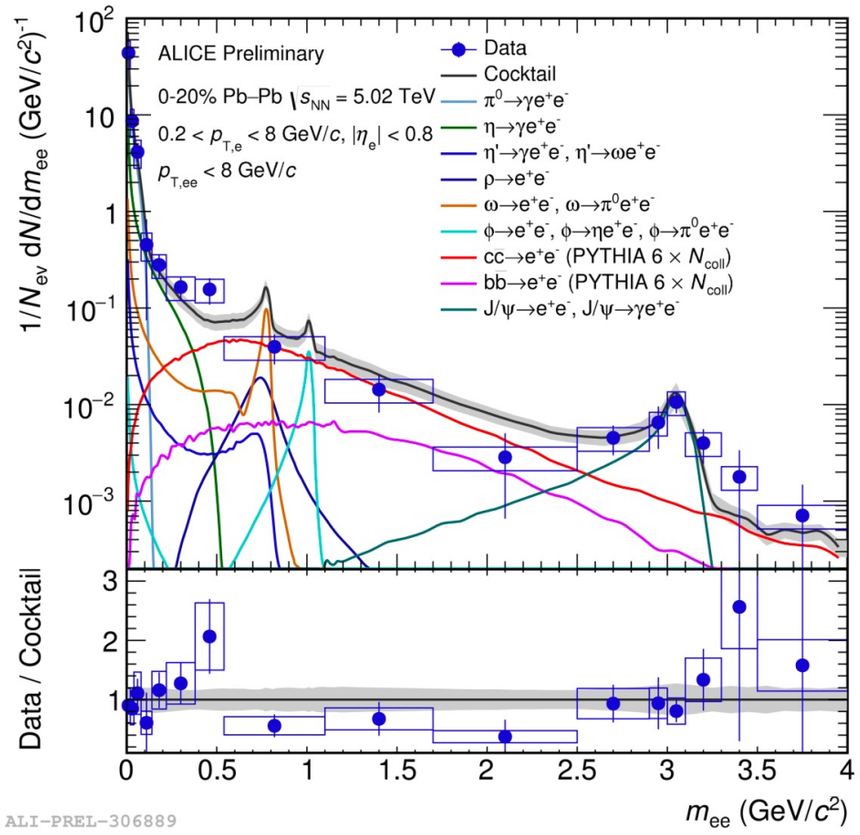
R_{pPb} vs m_{ee}:

- Deviation from unity for $m_{ee} < 1$ GeV/c^2 (expected since light flavor sources don't scale with N_{coll})
- Compatible with unity in the intermediate mass region

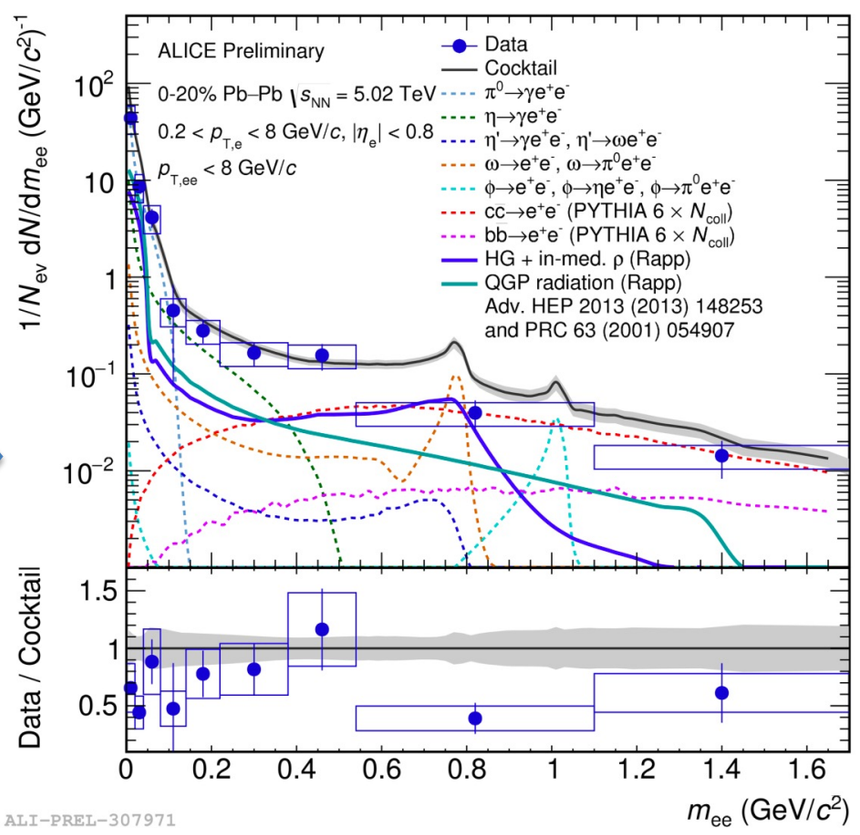
Dielectron Production in Central Pb-Pb

Most central Pb–Pb events (0-20%):

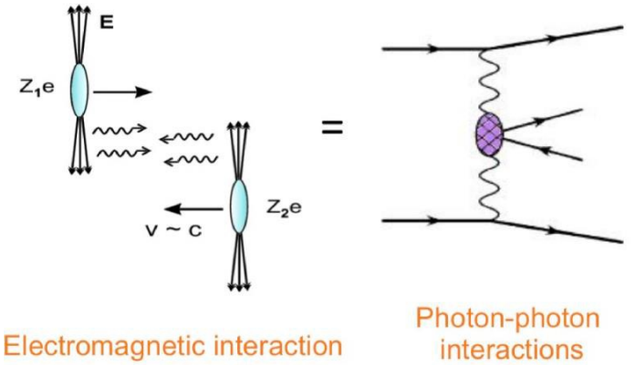
Hint of enhancement in the low mass region ($0.14 < m_{ee} < 0.54$ GeV/c^2). Consistent with the prediction for QGP radiation and in-medium effects by R. Rapp



ZOOM + QGP sources

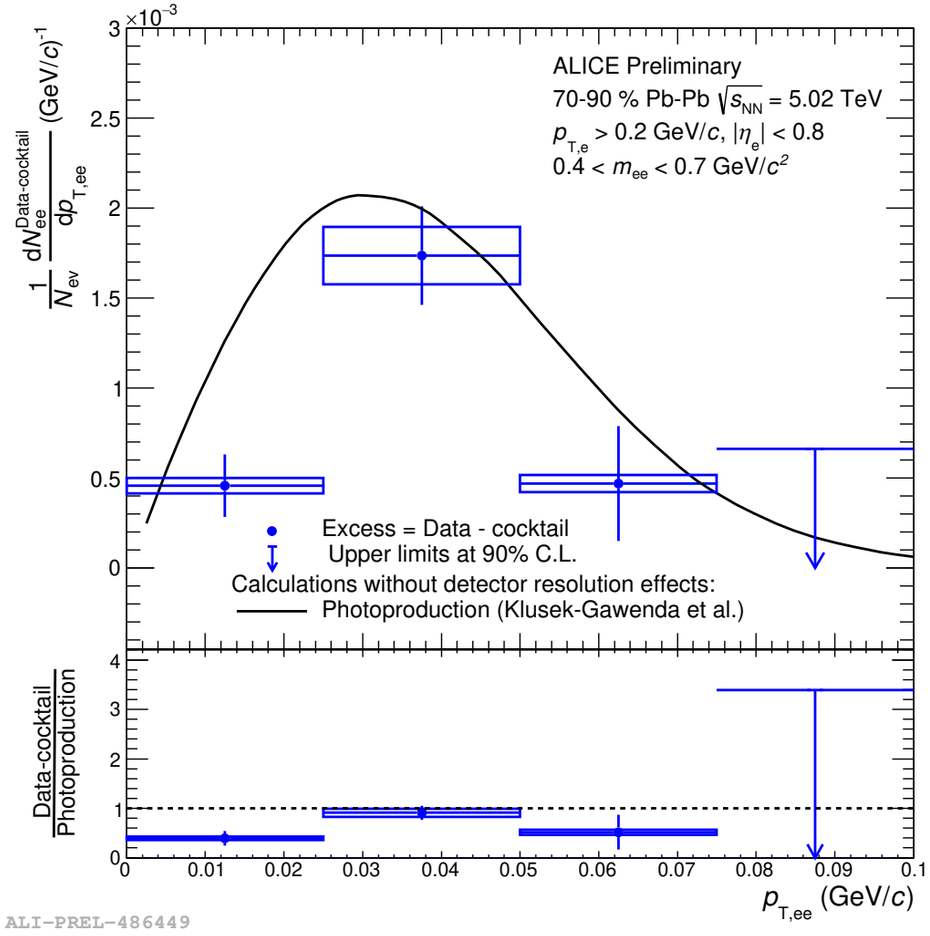


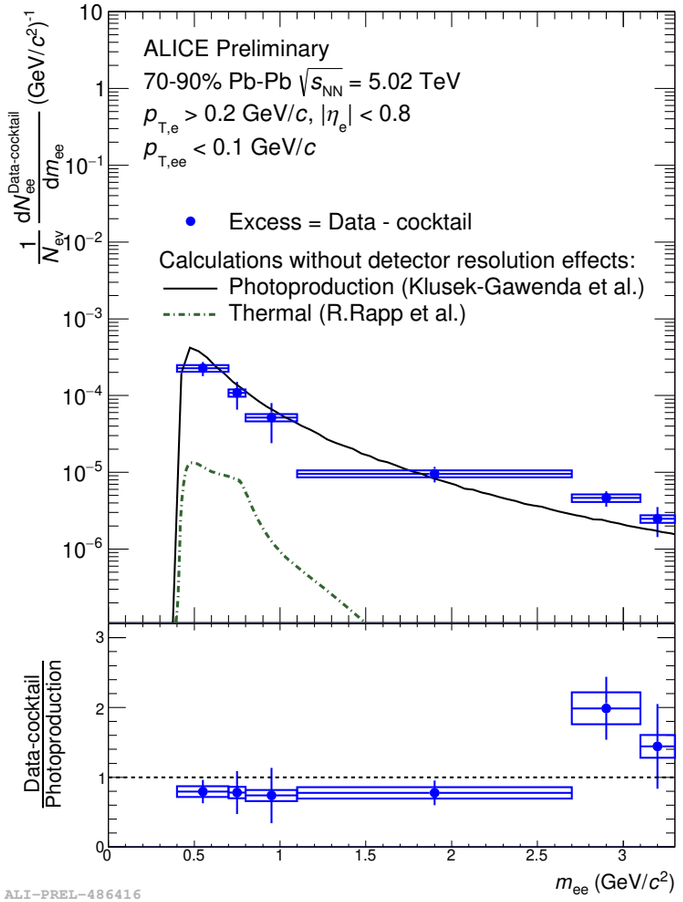
Soft Dielectron Production in Pb-Pb



Clear excess observed at low p_T in peripheral Pb–Pb:

- Consistent with coherent photoproduction, similar to the observation by STAR

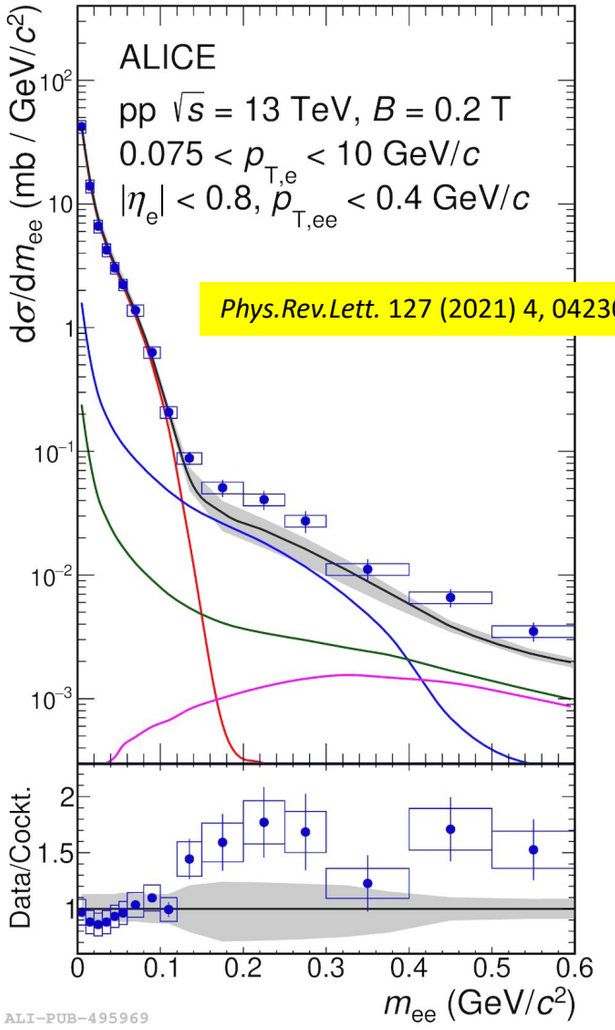




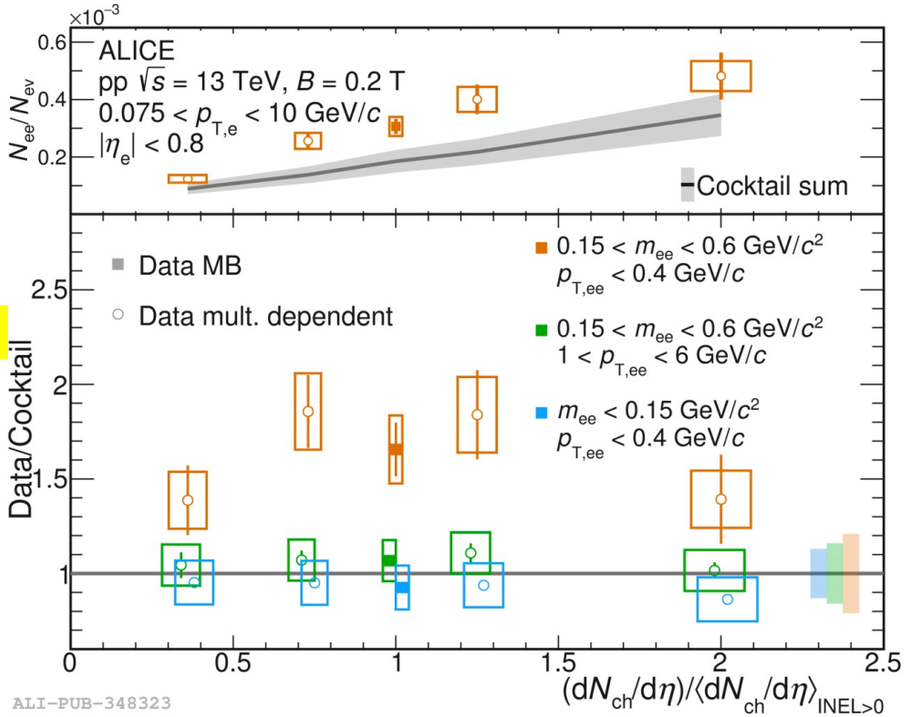
Soft Dielectrons in pp

CERN ISR – AFS (1987): Excess of dielectrons over expectation from known hadronic sources in an “elementary” collision system

- **1.6 σ excess** also observed by ALICE in a dedicated run with a reduced mag. field (to improve acceptance at low mass and low p_T)
- This excess cannot be explained with contributions from known hadronic decays



Phys.Rev.Lett. 127 (2021) 4, 042302

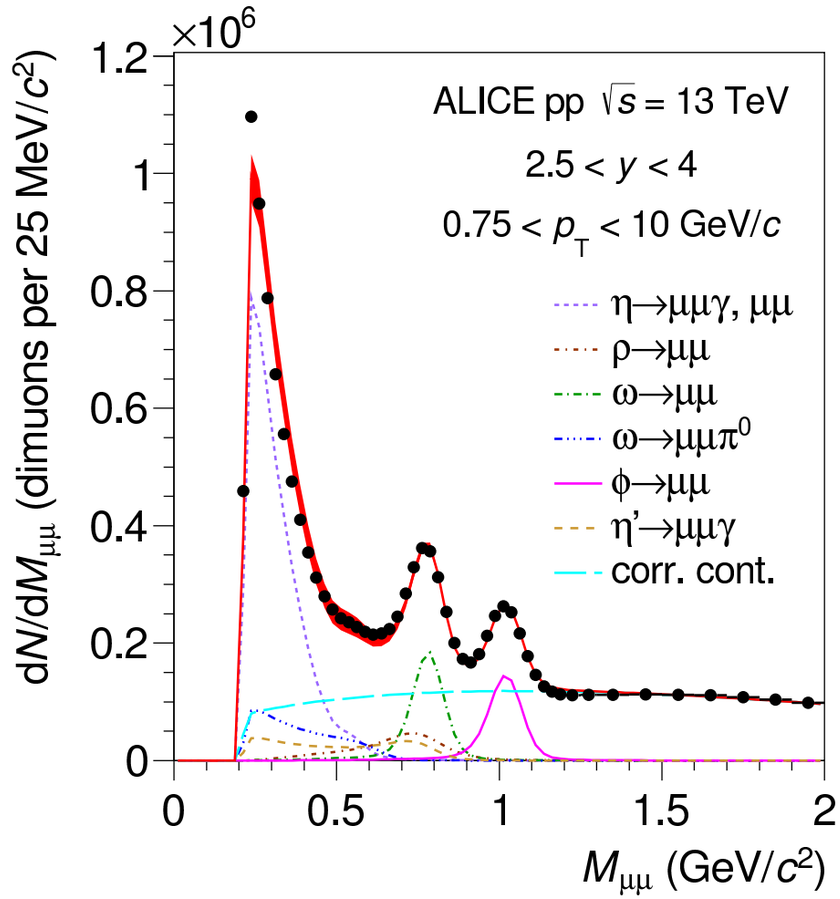


- No clear multiplicity dependence within uncertainties. Most consistent with linear scaling

Low-Mass Dimuon Production

Low-Mass Dimuon Spectrum: **good agreement between signal and MC**

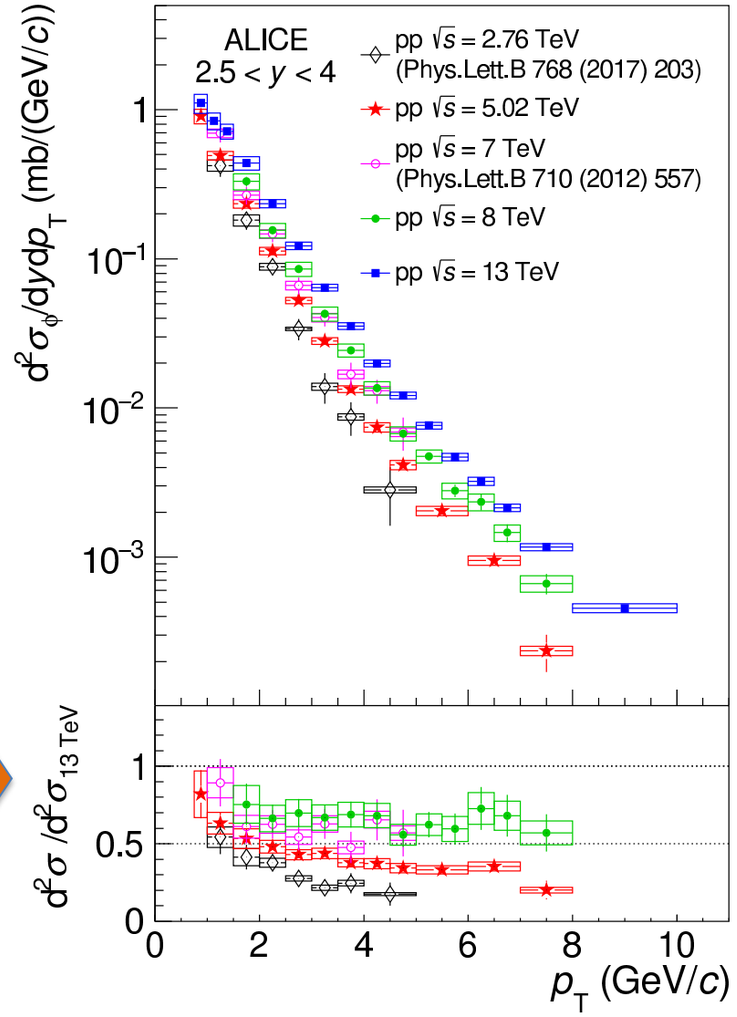
Eur.Phys.J.C 81 (2021) 8, 772



ALI-PUB-485951

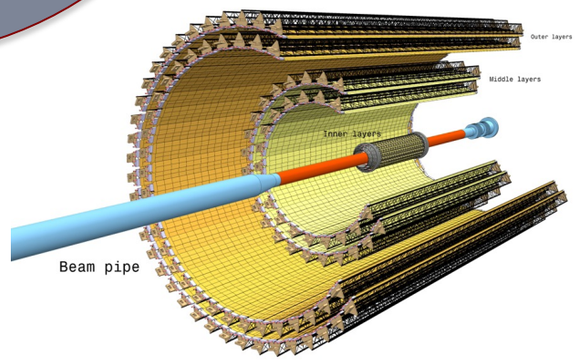
No dedicated vertex detector: limited knowledge on the continuum composition, limited control on the HF sources

Good signal/background + dedicated muon trigger: clean signal extraction for the 2-body decays of light vector mesons



ALI-PUB-485971

ALICE Upgrades for Run3+4



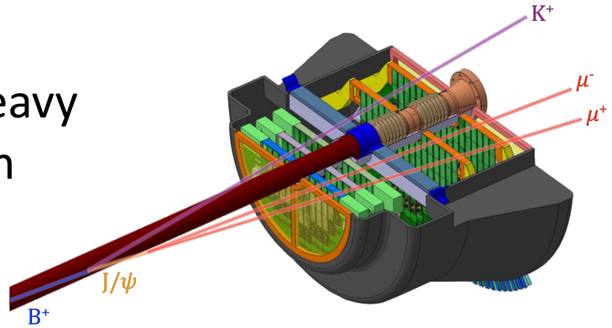
New Inner Tracking System (ITS)

- New pixel technology: improved granularity and resolution, reduced material budget

CERN-LHCC-2013-024, CERN-LHCC-2013-024

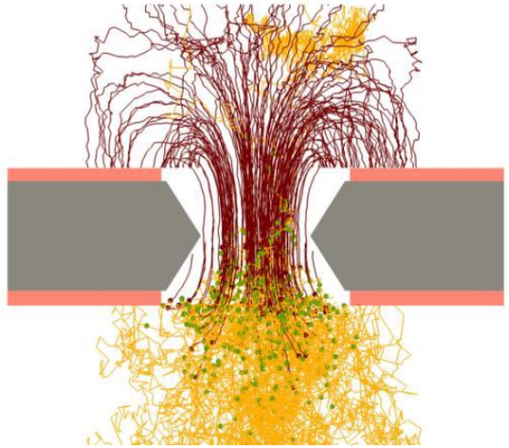
New Forward Muon Tracker (MFT)

- Vertex tracker for the forward muon spectrometer: heavy flavor vertices, prompt/displaced muon discrimination



TPC Upgrade:

- Replacement of the MWPC-based readout by detectors employing GEMs to allow TPC operation in continuous mode

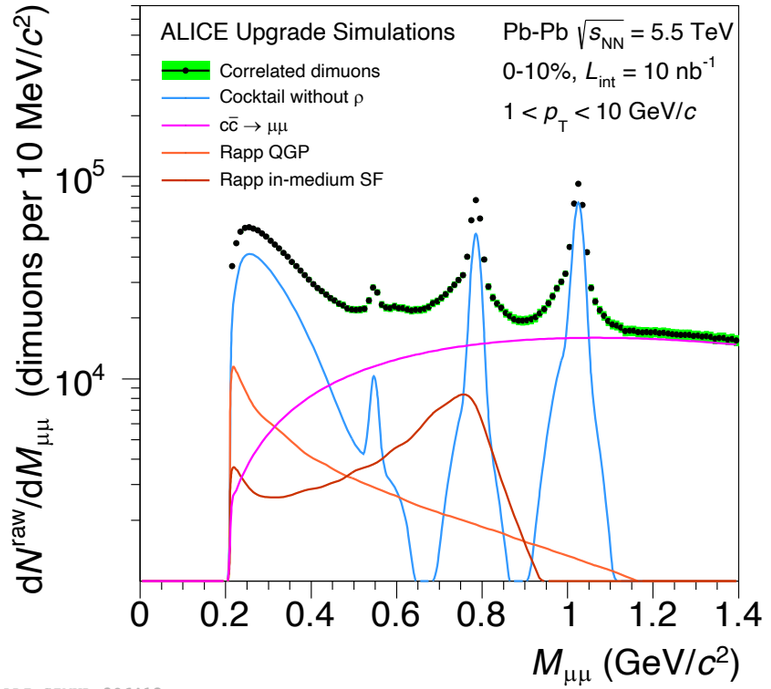


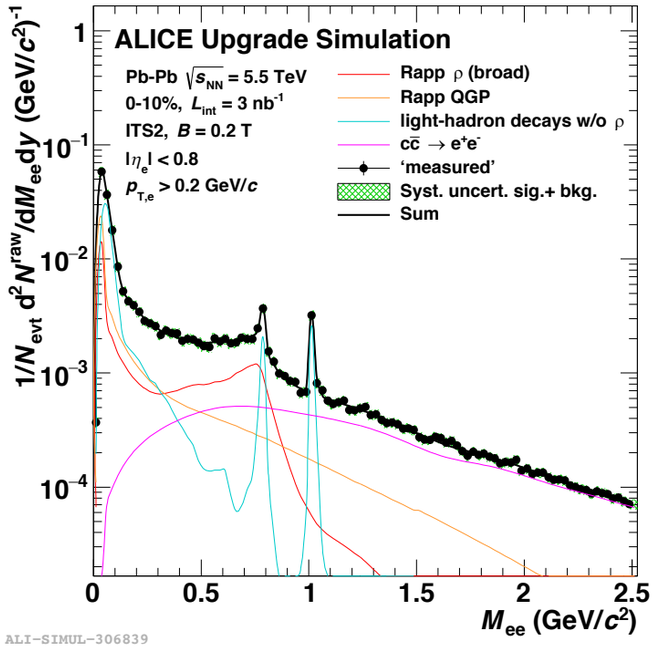
Upgraded read-out for many detectors, new integrated Online-Offline (O^2), new Fast Interaction Trigger detector

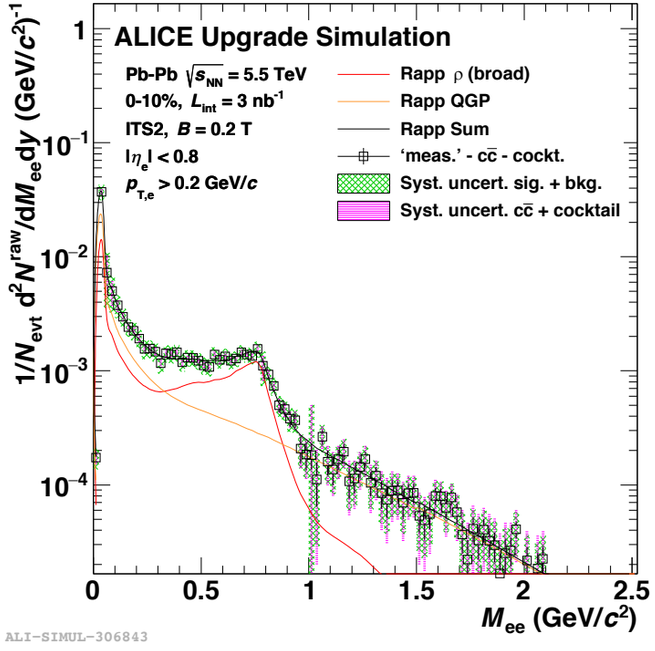
- Upgraded ALICE will record Pb-Pb data at 50 kHz (1 kHz in Run 2)

Low-Mass Dileptons with ALICE in Run3+4

- **Low and intermediate mass dileptons** both in the dielectron (mid rapidity) and dimuon (forward rapidity) channels: **isolation of medium-modified ρ; thermal radiation from QGP**
- Improved precision in the **measurement of dilepton offset, for the** isolation of prompt sources
- **Improvement of the mass resolution** for light resonances in the dimuon channel

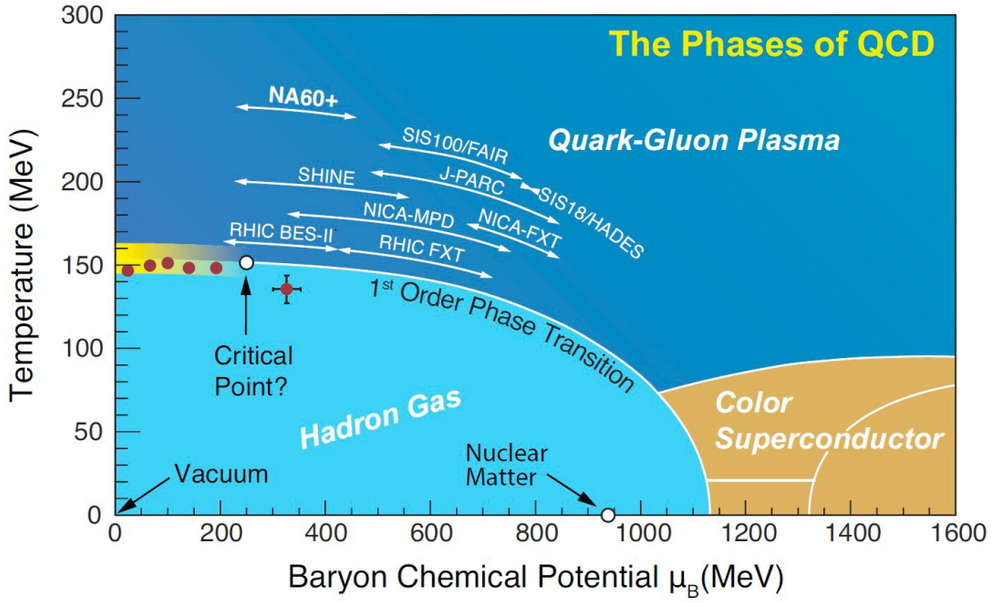






Dileptons with the NA60+ Projects

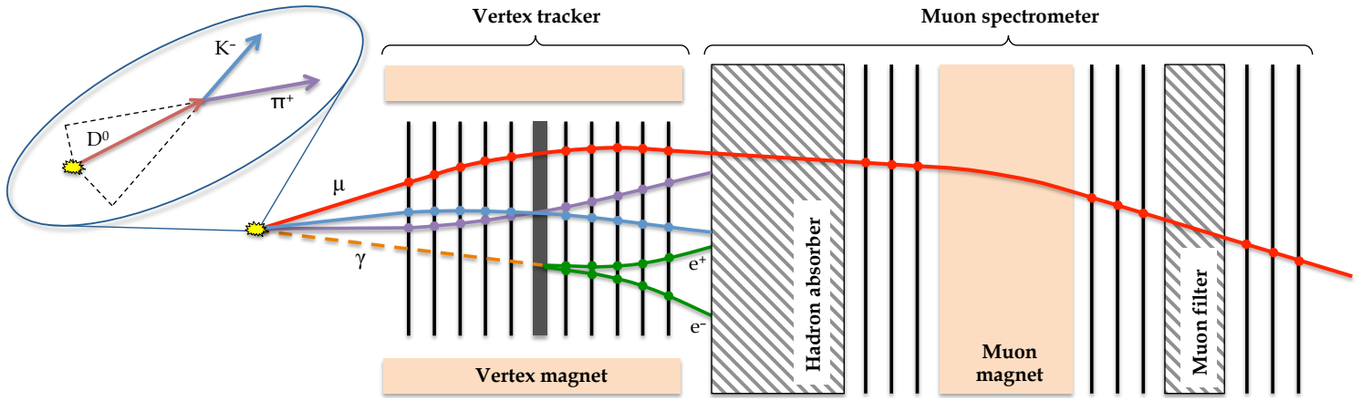
The NA60+ Project



Investigate the large μ_B region of the QCD phase diagram through the study of hard and electromagnetic probes at the CERN SPS

- **Hard probes:** onset of deconfinement, transport properties of the medium
- **E.M. probes:** insights on temperature of the system, chiral symmetry restoration, order of the phase transition

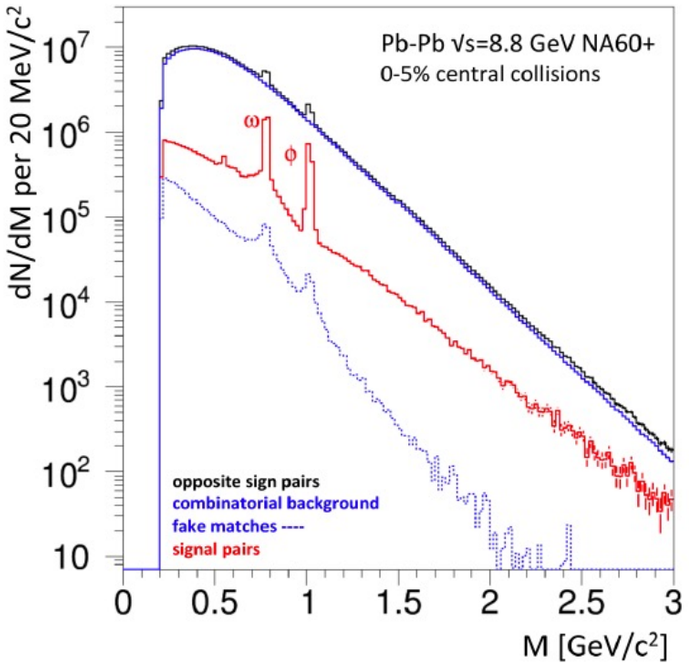
CERN SPSC 2019 017

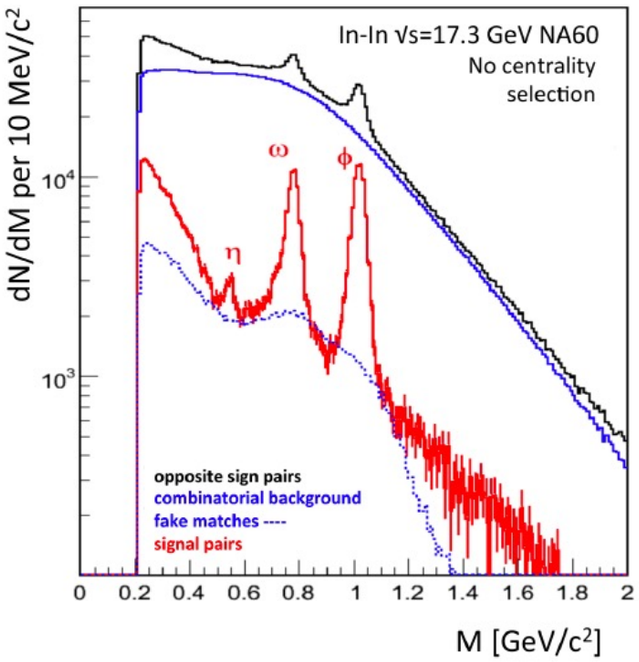


Detector concept: **muon spectrometer** → dimuon measurements + **vertex telescope** → reconstruct tracks close to the IP

Setup changes with beam energy to cover the region around midrapidity

Low-Mass Dimuons With NA60+



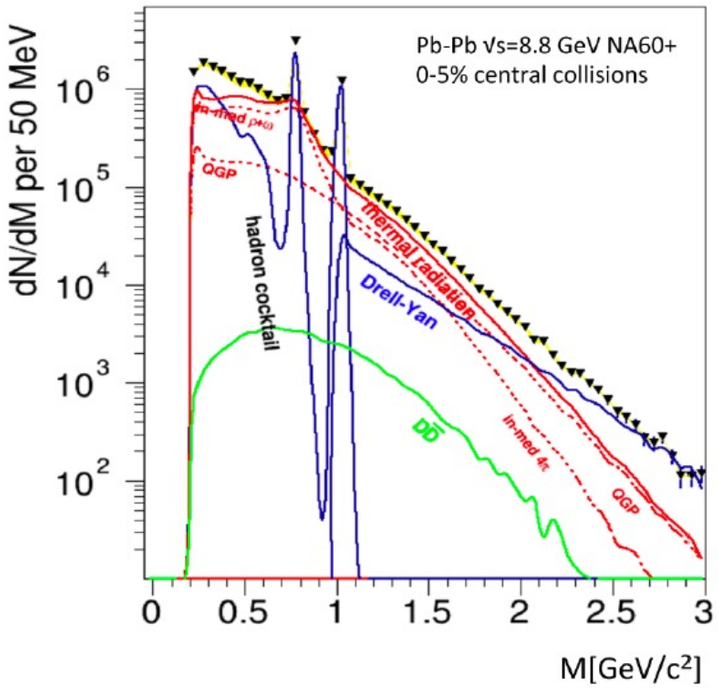


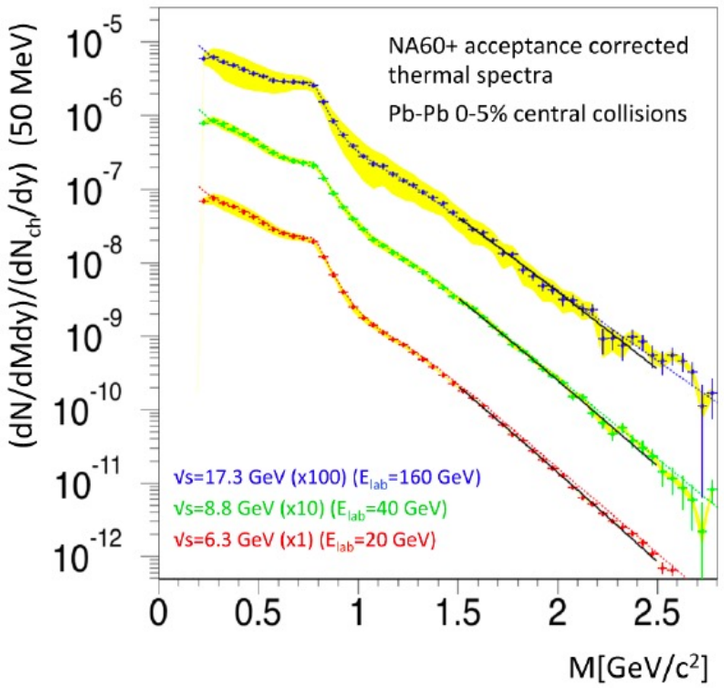
- Thermal dimuon distributions from R. Rapp et al., PLB753 (2016) 586
- Hadron cocktail from NA60 and statistical model (Becattini et al., PRC73 (2006) 044905)
- Drell-Yan and open charm from PYTHIA
- Combinatorial background: input spectra from NA49 measurements

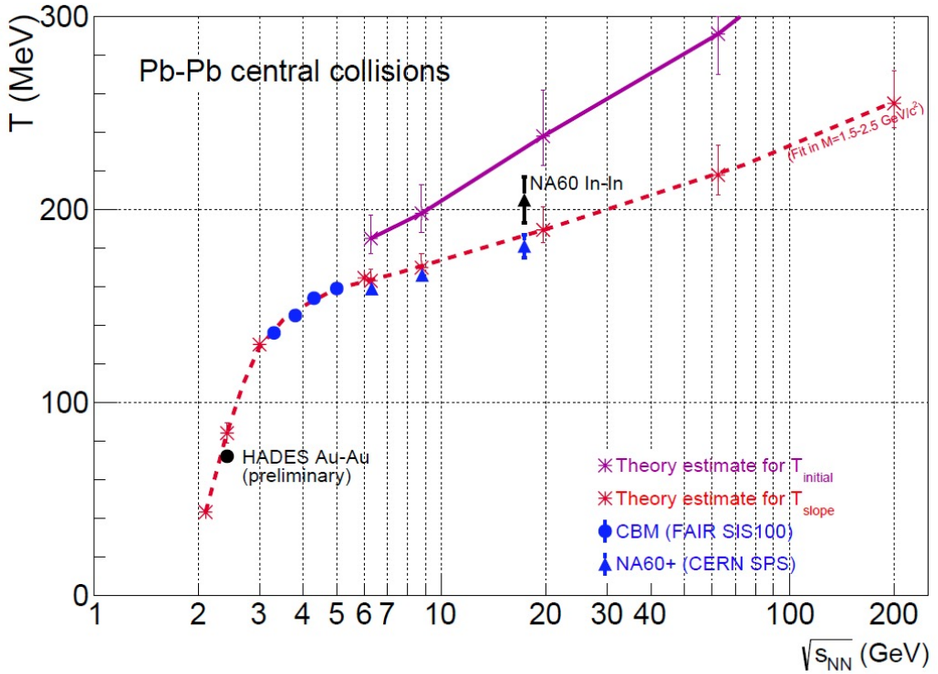
- 2×10^7 reconstructed central Pb-Pb (1 month data taking at interaction rate $\approx$ 1 MHz)
- S/B $\approx$ 1/18 at M = 0.6 GeV/c^2
- Combinatorial background subtracted with 0.5 % uncertainty
- Factor $\approx$ 100 improvement with respect to NA60

T_{slope} Measurement in NA60+

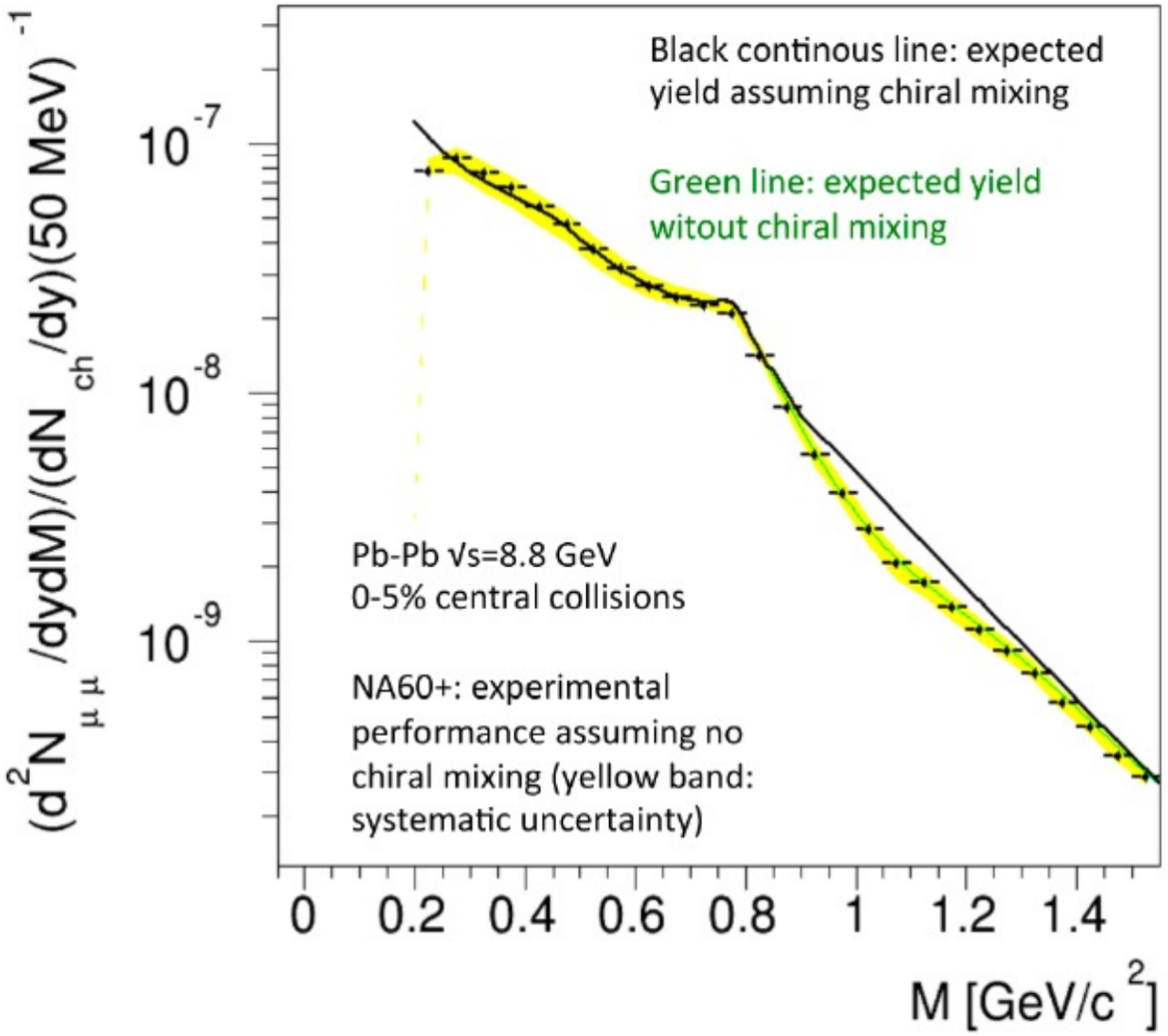
- **Thermal radiation:** dominated by ρ contribution at low mass; accessible up to M ≈ 2.5 - 3 GeV/c²
- **Drell-Yan contribution** to be estimated via p-A measurements
- **Acceptance-corrected spectra fitted with $dN/dM = M^{3/2} \exp(-M/T_s)$ in 1.5 < M < 2.5 GeV/c²**
- **Caloric curve:** accurate mapping of the region where the pseudocritical temperature is reached, sensitive to potential effects expected in case of 1st order phase transition!







Sensitivity to Chiral Symmetry Restoration



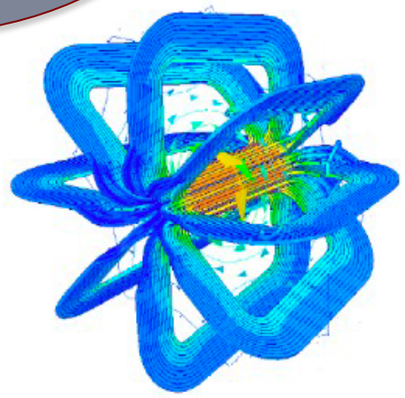
Simulations carried out by considering the alternative scenarios:

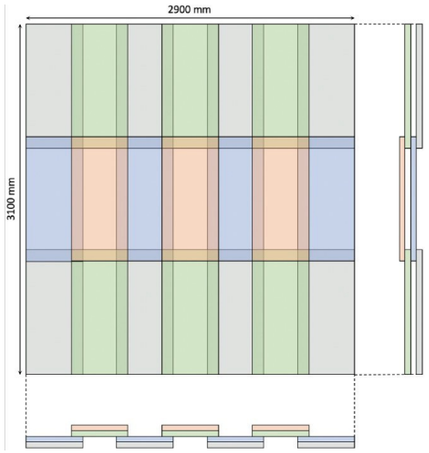
- No chiral mixing (dip in the region. $1 < M < 1.4$ GeV/c^2)
- Full ρ-a_1 chiral mixing

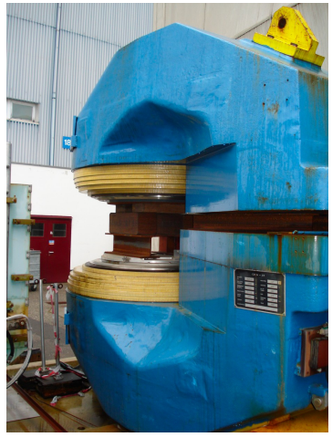
A 20-30% enhancement is expected in case of full mixing (modelled from R. Rapp, H. van Hees, PLB753 (2016) 586)

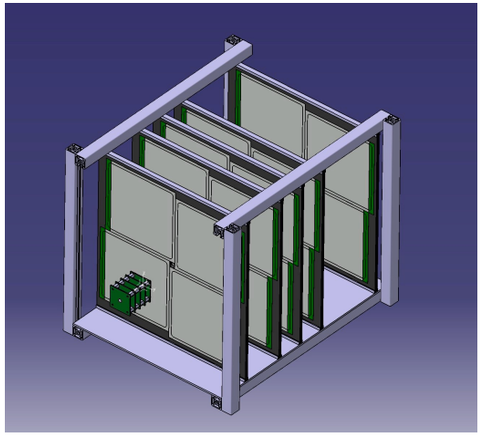
With the foreseen accuracy of the measurement, the effect can be clearly detected

NA60+ Project Status and Tentative Timescale









- **Toroid:** Completion of the prototype construction (scale 1:5), first tests carried out (low current)
- **Muon tracking stations** based on GEM modules: discussions ongoing with interested Institutes
- **Dipole:** CERN MEP48 dipole magnet (B ≈ 1.5 T at max current, up to 21° polar angle coverage)
- **Silicon vertex tracker:** 5 to 10 planes, large area MAPS with stitching technology (same as ITS3 - ALICE 3)
  - Thickness: *o*(20 µm)
  - Pixel size: *o*(15 × 15 µm^2)
  - No mechanical support/cooling in the sensitive area → material budget < 0.1% X_0
  - Spatial resolution: 5 µm or better

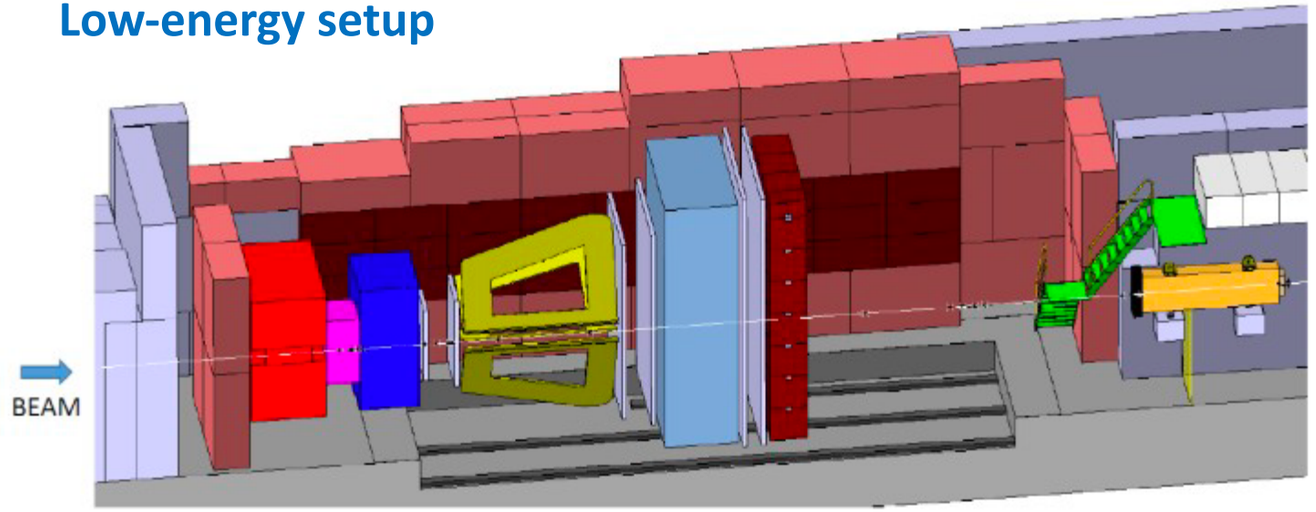
NA60+ Project Status and Tentative Timescale

Discussions on the installation site recently converged: installation foreseen at the CERN-SPS, EHN1 hall, H8 beam line

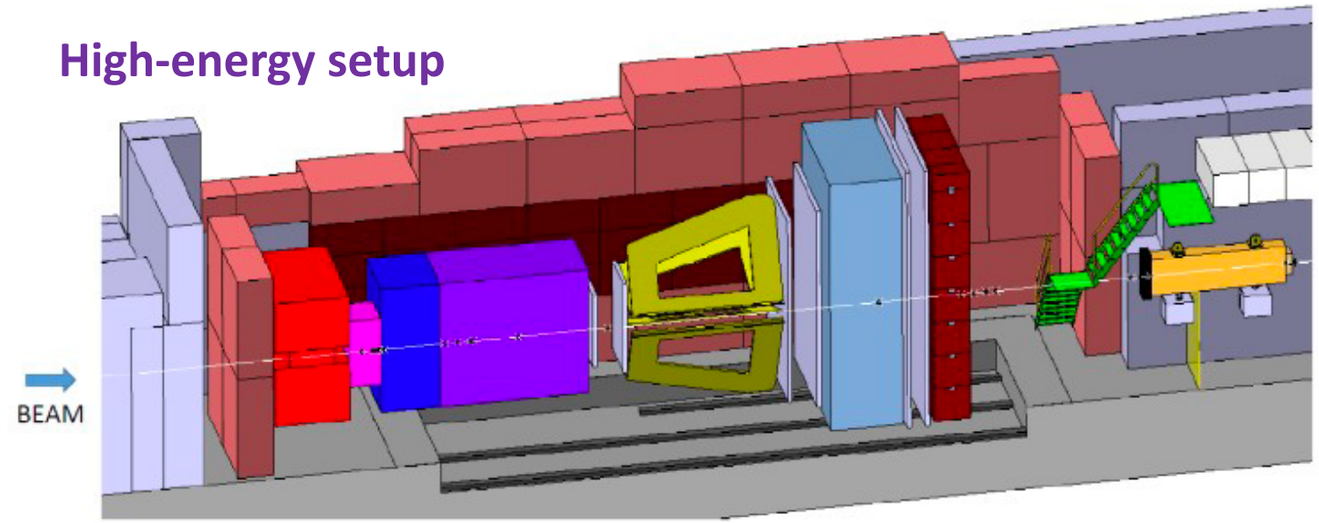
- Intensity: 10^7 Pb ions per 20 s spill (radioprotection studies ongoing)
- **The setup can be moved on rails along the beam axis. High energy setup:** muon spectrometer shifted forward by 3.3 m

Goal: start data taking with LHC run 4, around 2027

Low-energy setup

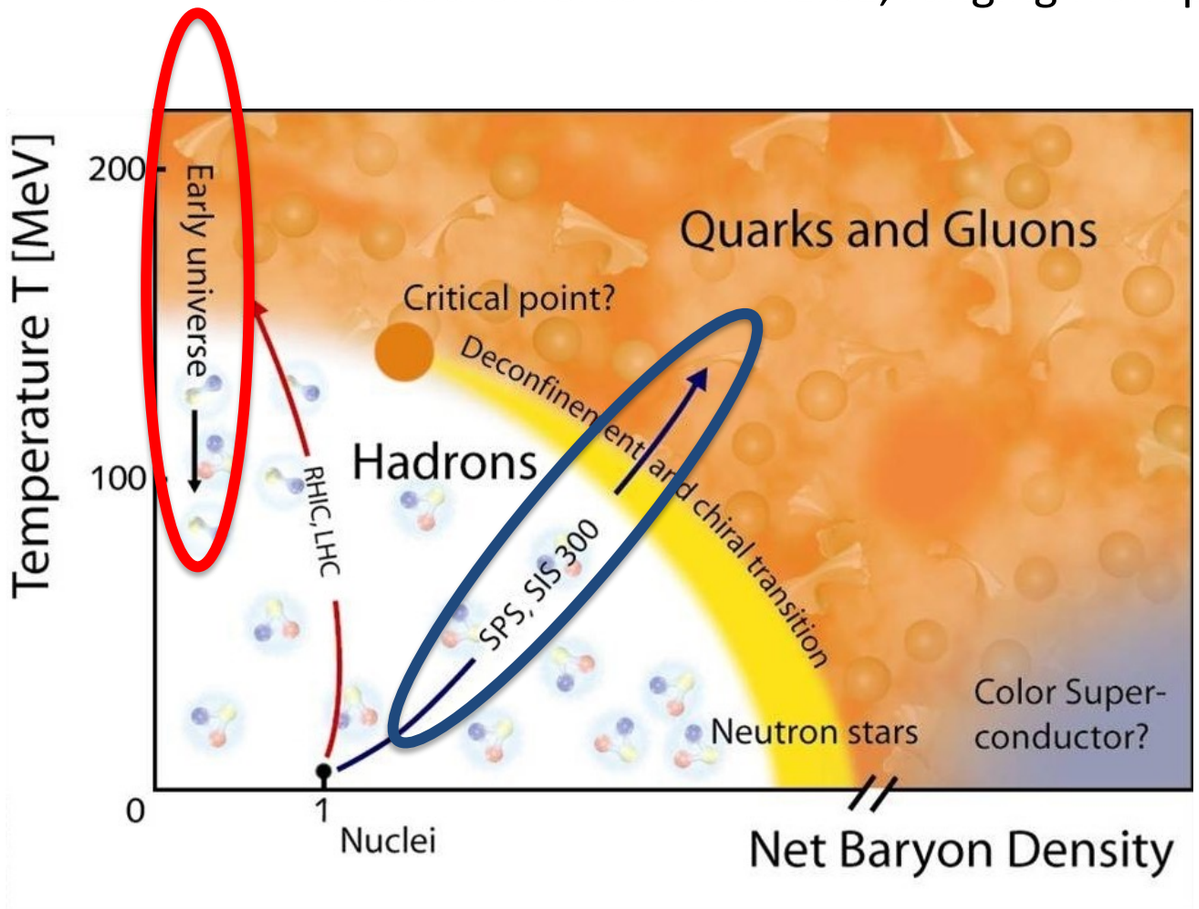


High-energy setup



Conclusions

Electromagnetic radiation in heavy-ion collisions, in the form of dilepton emission, continues to illuminate the properties of the formed medium: comprehensive set of measurements from ALICE, ranging from pp to central Pb-Pb events

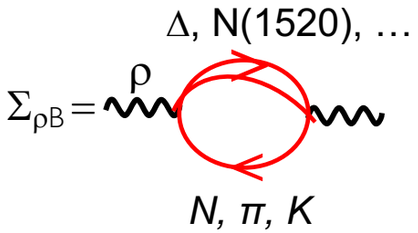


- Precision dilepton measurements are needed **both at the LHC and FAIR-SPS energies** to develop a consistent picture across the whole QCD phase diagram

- **Clear synergies between ALICE 2 and the ALICE 3 and NA60+ projects** both in terms of detector R&D, analysis tools, and interpretation of physics observations

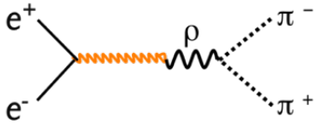
Backup Slides

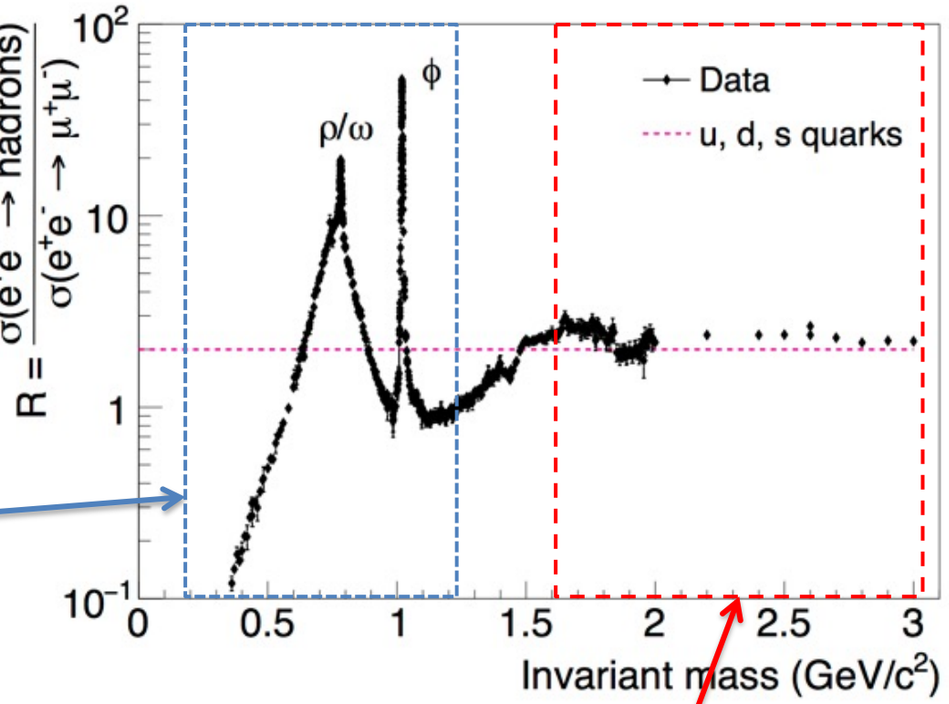
Dileptons: EM Emission Rate and Correlator



Chanfray, Rapp, Wambach,
Phys. Rev. Lett. 76 (1996) 368-371

Non-perturbative:
Vector Meson Dominance,
in-medium spectral functions





Perturbative: parton-hadron duality. Flat spectral function above 1.5 GeV → mass spectrum after integration over momenta and emission 4-volume:

$$\frac{\mathrm{d}N_{\ell\ell}}{\mathrm{d}M} \propto M^{3/2} \times \langle \exp(-M/T) \rangle$$