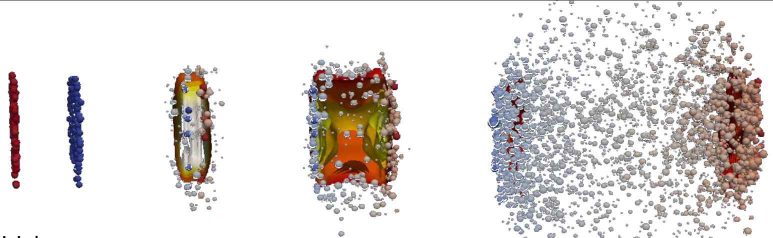
Long-range correlations in low-multiplicity pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ with ALICE

Jasper Parkkila (CERN)
for the ALICE Collaboration

Recontres de Blois
16 May 2023

Collectivity in large systems and hydrodynamic description



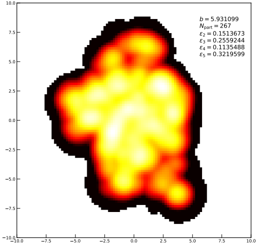
Initial-stage geometry

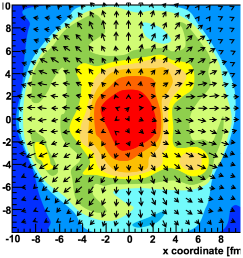
$$\varepsilon_n e^{in\Phi_n} \equiv -\frac{\langle r^n e^{in(\phi-\Phi_n)}\rangle}{\langle r^n\rangle}$$

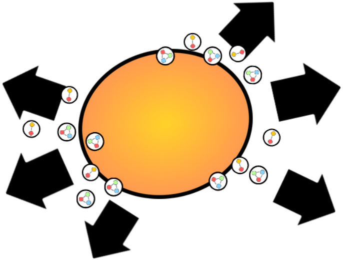
→ Transport

$$\delta_\mu T^{\mu\nu} = 0$$

→ Final-state momentum space anisotropy



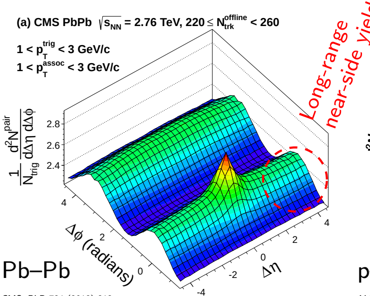




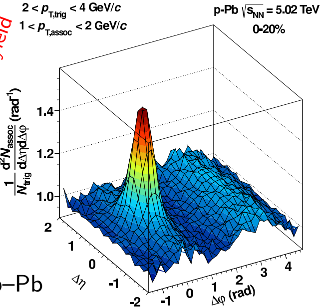
- Strong collectivity observed in heavy-ion collisions
- Collective motion a result of initial-state geometry and the fluid pressure gradients
- Well described by hydrodynamics

Collectivity in small systems

- Collectivity manifests in the form of long-range correlations, i.e. the ridge structure in two-particle correlation measurements

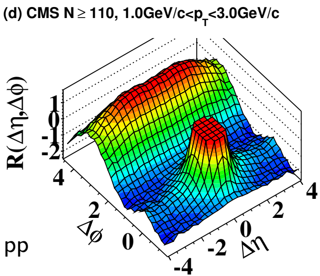


CMS, PLB 724 (2013) 213



ALICE, PLB 719 (2013) 29-41

CMS, JHEP 09 (2010) 091



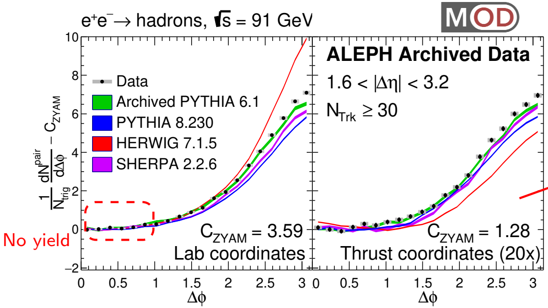
- pp, p–Pb: Non-zero long-range correlation at $\sim 1.4 < |\Delta\eta|$ (double-ridge $\langle\cos(2\Delta\varphi)\rangle \rightarrow$ collectivity signal)
- Long-range correlation emerges during the early stages. Pb–Pb: medium response to init. cond., pp: unclear
- Several theoretical approaches with/without medium: IC+hydro[1], hybrid corona[2], string interaction models[3]

[1] PRD 96 (2017) 9 [2] PRC 92 (2015) 3 [3] PLB 779 (2018)

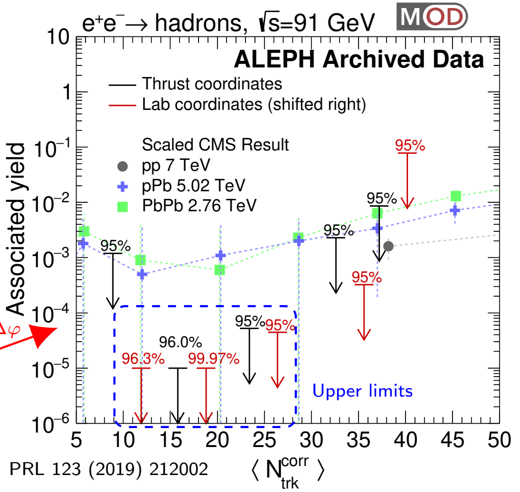
Interpretation by comparison to e^+e^-

Non-trivial interpretation of pp results due to intricate structure.

- Study the simpler processes involved in e^+e^- annihilations (point-like collision: no uncertainties on initial geometry or parton distribution function description)
- e^+e^- do not exhibit yield within the given confidence levels



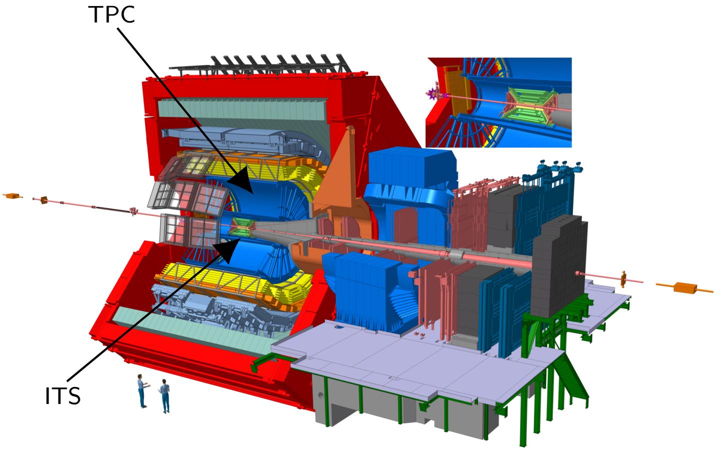
$\int_{|\Delta\varphi_{min}|} d\Delta\varphi$



PRL 123 (2019) 212002

- **Would we get similarly small values in pp as in e^+e^- or are the two systems intrinsically different?**

Analysis details and selection criteria



The ALICE detector in Run 2.

Events and detectors:

- pp $\sqrt{s} = 13\,\mathrm{TeV}$ recorded in 2017
- 558 million MB events
- TPC+ITS for tracking

Charged tracks and multiplicity:

- Multiplicity estimation: accepted tracks in $|\eta| < 1.0$, $p_\mathrm{T} > 0.2\,\mathrm{GeV}/c$
- Trigger and associated particles* $1.0 < p_\mathrm{T} < 2.0\,\mathrm{GeV}/c$, $|\eta| < 1.0$
- "Long-range" definition $1.4 < |\Delta\eta| < 1.8$

*In a two-particle correlation particle 1 "trigger" and particle 2 "associated".

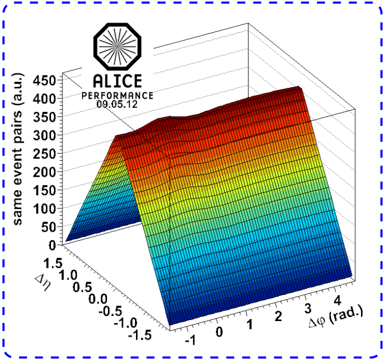
Analysis strategy for associated yield

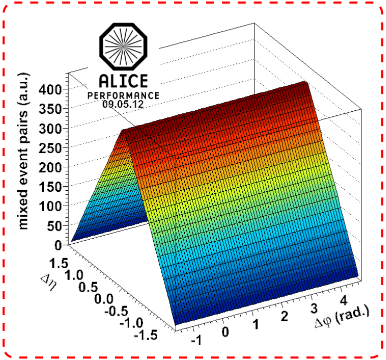
- **Two-particle correlation function** between trigger and associated particles ($p_{\mathrm{T,trig}} > p_{\mathrm{T,assoc}}$):

$$\frac{1}{N_{\mathrm{trig}}{}^{*}}\frac{d^2N_{\mathrm{pair}}}{d\Delta\eta\Delta\varphi}(\Delta\eta,\Delta\varphi) = N^{*,\mathrm{mixed}}_{\mathrm{pair}}(0,0)\,\frac{N^{*,\mathrm{same}}_{\mathrm{pair}}(\Delta\eta,\Delta\varphi)}{N^{*,\mathrm{mixed}}_{\mathrm{pair}}(\Delta\eta,\Delta\varphi)},$$

same: correlations of particles from same event

Heavy-ion example

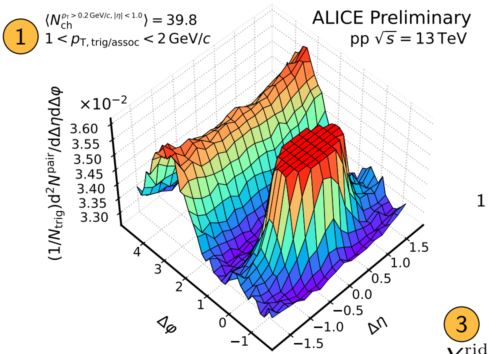




mixed: correlations of particles from different events

Long-range $\Delta\varphi$-correlations in low multiplicity

- Near-side ridge clearly visible in high-multiplicity events.



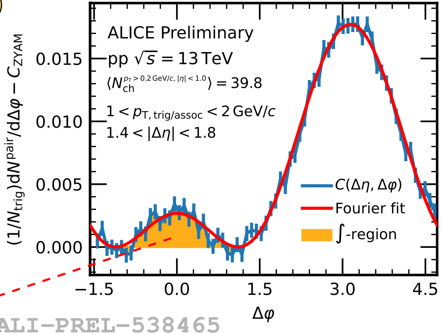
ALI-PREL-538420

2

$$\int {\rm d}\Delta\eta$$

$1.4 < |\Delta\eta| < 1.8$

$$\int \left(\frac{1}{N_{\rm trig}} \frac{{\rm d}^2 N_{\rm pair}}{{\rm d}\Delta\eta{\rm d}\Delta\varphi} \right) \frac{1}{\delta_{\Delta\eta}} {\rm d}\Delta\eta - C_{\rm ZYAM}$$



3

$$Y^{\rm ridge} = \int {\rm d}\Delta\varphi$$

ALI-PREL-538465

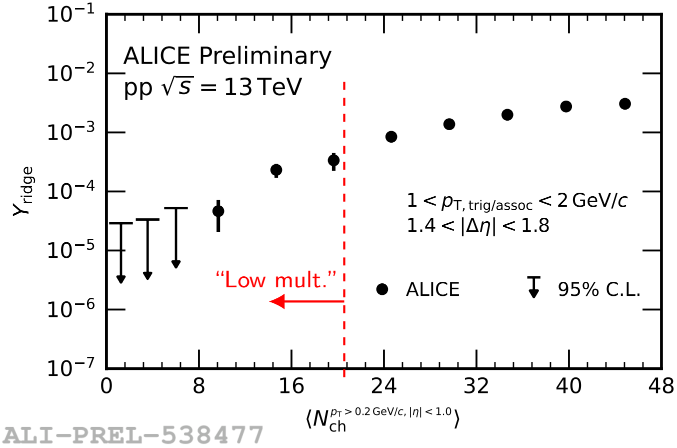
Find the ZYAM* and $|\Delta\varphi_{\rm min}|$ by fitting $F(\Delta\varphi) = A(1 + 2\sum_{n=1}^{3} v_n^{2,{\rm cent}} \cos(n\Delta\varphi)) + C_{\rm ZYAM}$ to the signal.

- Measured in $1.4 < |\Delta\eta| < 1.8$ to suppress short-range nonflow correlations
- $p_{\rm T} > 1.0\,{\rm GeV}/c$ (*trig* and *assoc*) to avoid near-side jet broadening into $|\Delta\eta| > 1.4$

---

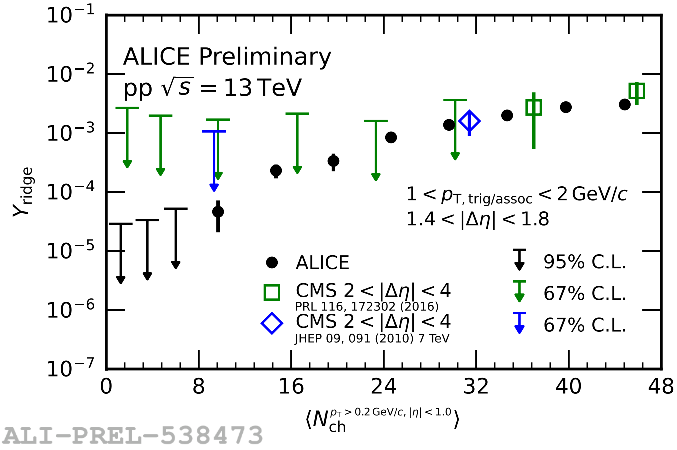
* Zero-Yield-At-Minimum

Ridge yield: precision measurement down to very low multiplicity in pp



- Non-zero yield even in very low multiplicity collisions
- The lowest bins are presented as 95% confidence limit
- Combined stat+syst uncertainty obtained using a bootstrapping method
  - $|z_{\mathrm{vtx}}| < 8 \to 10\,\mathrm{cm}$
  - $1.4 \to 1.5 < |\Delta\eta| < 1.8$
  - Long-range wing bias
  - Integration range
  - Tracking mode

Ridge yield: comparison with CMS results, PRL 116, 172302 (2016)



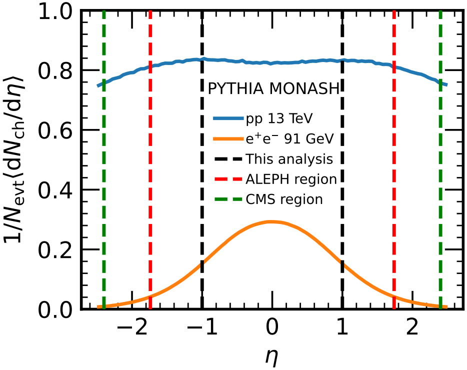
- Conversion of CMS multiplicity to ALICE using PYTHIA (factor = 0.59 × 1.15)
  - $p_{\mathrm{T,min}} \to 0.0\,\mathrm{GeV}/c$
  - $|\eta_{\mathrm{max}}| \to 4.0$
  - CMS efficiency
- CMS data points in agreement
- Improved uncertainty in the low multiplicity region: towards quantitative constraints!

Conversion of ALEPH multiplicity

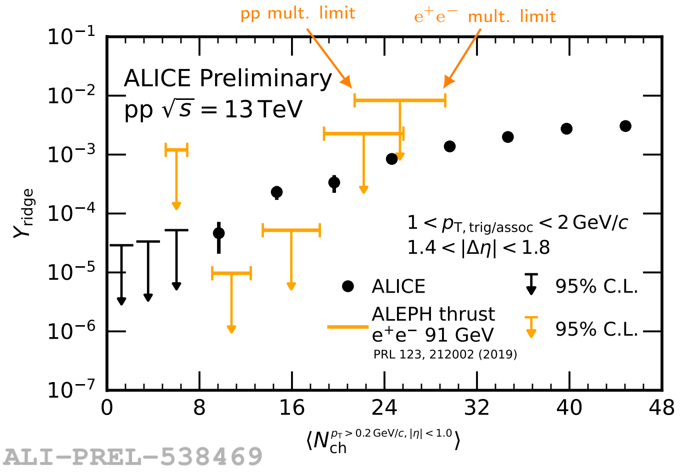
Experiment	$\lvert\eta_{\max}\rvert$	$p_{\mathrm{T},\min}$	$\sqrt{s}$
ALICE pp	1.0	0.2	13 TeV
ALEPH $\mathrm{e^+e^-}$	1.738	0.2	91 GeV

- Multiplicity defined by accepted particles within $|\eta| < 1.0$, $p_{\mathrm{T}} > 0.2\,\mathrm{GeV}/c$
- Conversion between different systems and experiments is done using PYTHIA
- ALEPH $\mathrm{e^+e^-}$ multiplicity cannot be directly converted to ALICE pp: evaluate limits in terms of both systems

Method	Experiment	Corr. factor
PYTHIA	ALEPH pp 13 TeV ALEPH $\mathrm{e^+e^-}$ 91 GeV	0.57 0.78
Flat $\mathrm{d}N/\mathrm{d}\eta$	ALEPH	0.63

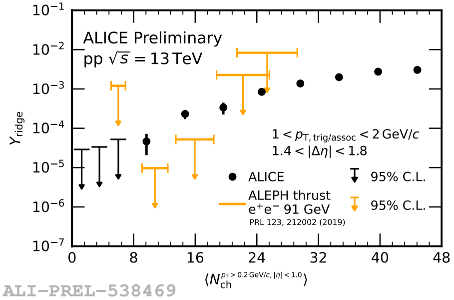


Ridge yield: comparison to ALEPH archived data e^+e^-, PRL 123, 212002 (2019)



- pp collision exhibits larger yield $Y^{pp}_{ridge} \gtrsim Y^{e^+e^-}_{ridge}$ within $\langle N_{ch} \rangle = 10 \sim 20$ ($\gtrsim 3.2\sigma$)
- A comparison to e^+e^- can provide insight to what processes might or do not contribute to the yield
- A reference point-like collision can also help understand the magnitude of initial stage effects

Summary



- Precise measurement of near-side ridge yield in 13 TeV pp collisions down to very low multiplicity
- Compatible with earlier CMS results (and significantly smaller uncertainties)
- pp Y^{ridge} larger than $\mathrm{e^+e^-}$ by $\gtrsim 3.2\sigma$ in $\langle N \rangle = 10 \sim 20$
- **First quantitative comparison between the near-side yield of $\mathrm{e^+e^-}$ and pp collisions**
- Identify the underlying mechanisms responsible for the emergence of near-side yield in pp

The findings can be used to constrain the origin of collective effects in small hadronic system collisions.

Backup

Thank you!

Analysis strategy for associated yield

- Two-particle correlation function between trigger and associated particles ($p_{\mathrm{T,trig}} > p_{\mathrm{T,assoc}}$).

$$\frac{1}{N_{\mathrm{trig}}{}^{*}(z)}\frac{d^2 N_{\mathrm{pair}}}{d\Delta\eta\Delta\varphi}(\Delta\eta,\Delta\varphi,z) = N^{*,\mathrm{mixed}}_{\mathrm{pair}}(0,0,z)\frac{N^{*,\mathrm{same}}_{\mathrm{pair}}(\Delta\eta,\Delta\varphi,z)}{N^{*,\mathrm{mixed}}_{\mathrm{pair}}(\Delta\eta,\Delta\varphi,z)},$$

$$\frac{1}{N_{\mathrm{trig}}}\frac{d^2 N_{\mathrm{pair}}}{d\Delta\eta\Delta\varphi} = \sum_z \dots$$

- Per-trigger yield. Measure over region $1.4 < |\Delta\eta| < 1.8$ at $p_{\mathrm{T}} > 1, \mathrm{GeV}/c$ i.e. outside the jet contributions:

$$Y(\Delta\varphi) = \frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N_{\mathrm{pair}}}{\mathrm{d}\Delta\varphi} = \int_{1.4<|\Delta\eta|<1.8}\left(\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2 N_{\mathrm{pair}}}{\mathrm{d}\Delta\eta\mathrm{d}\Delta\varphi}\right)\frac{1}{\delta_{\Delta\eta}}\mathrm{d}\Delta\eta - C_{\mathrm{ZYAM}}.$$

- Ridge-yield, obtained by integrating the near-side peak (main observable in this analysis):

$$Y^{\mathrm{ridge}} = \int_{|\Delta\varphi|<|\Delta\varphi_{\mathrm{min}}|}\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N_{\mathrm{pair}}}{\mathrm{d}\Delta\varphi}\mathrm{d}\Delta\varphi$$