A Large Ion Collider Experiment

Soft dilepton production in pp at 13 TeV with ALICE

BNL nuclear physics seminar

24.11.2020

Jerome Jung

Overview

Introduction and historic background:

- Anomalous Soft Photon (ASP) Puzzle
- AFS dielectron spectrum

ALICE & the low-magnetic field setup:

- Analysis techniques & low-field performance
- Soft dielectron production cross section

Outlook:

- ALICE low-field data taking in Run 3 & 4
- A next-generation LHC heavy-ion experiment: Run 5+

Motivation

Dilepton Production

Pb–Pb collisions:

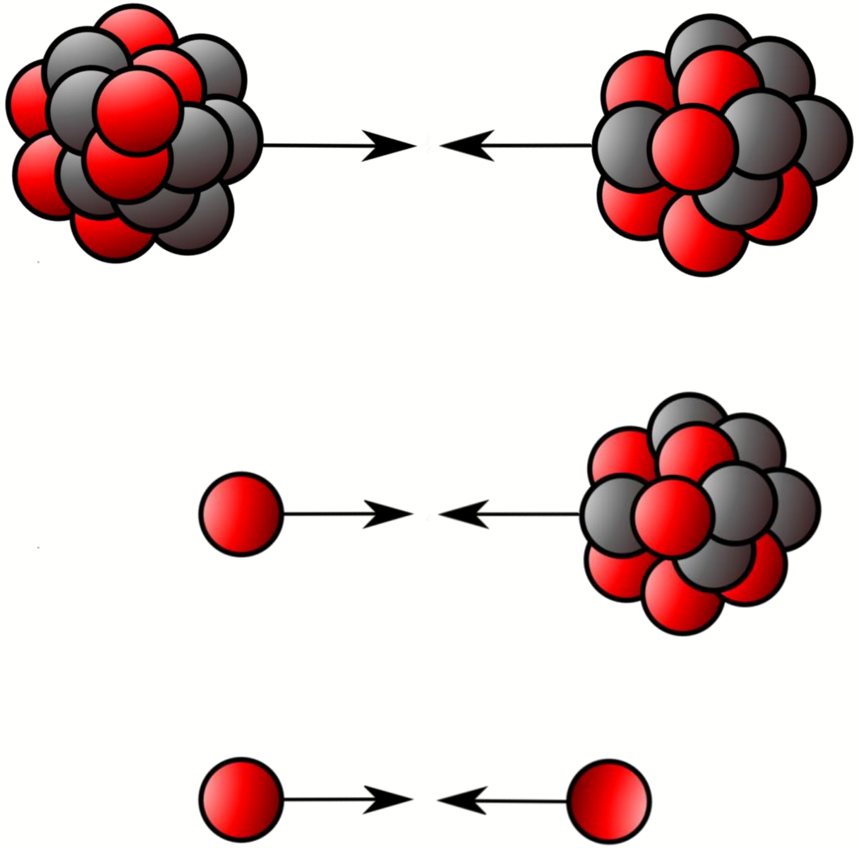
- Chiral-symmetry restoration: modification of vector mesons
- Thermal radiation throughout the medium evolution
- Decorrelation of heavy-flavor pairs in the medium
- Coherent photoproduction in peripheral collisions

p–Pb collisions:

- Study cold nuclear matter (CNM) effects (shadowing, energy loss)
- Onset of thermal radiation in high-multiplicity (HM) pA collisions

pp collisions:

- Vacuum baseline for p–Pb and Pb–Pb studies (heavy-flavor (HF), Drell-Yan, direct photons)
- Search for new phenomena in HM events



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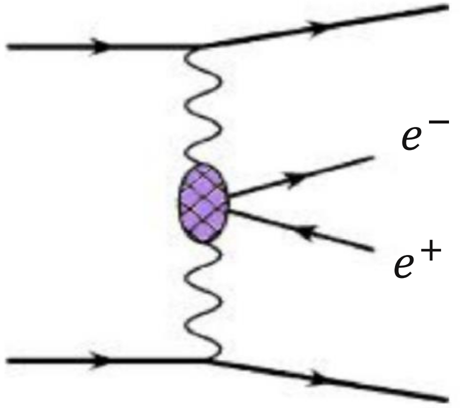
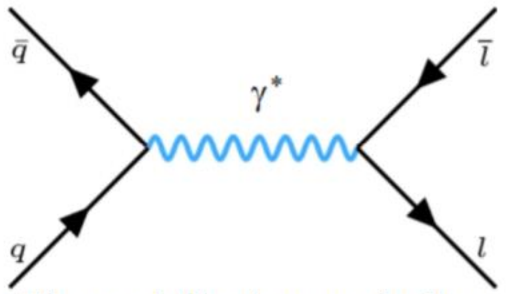
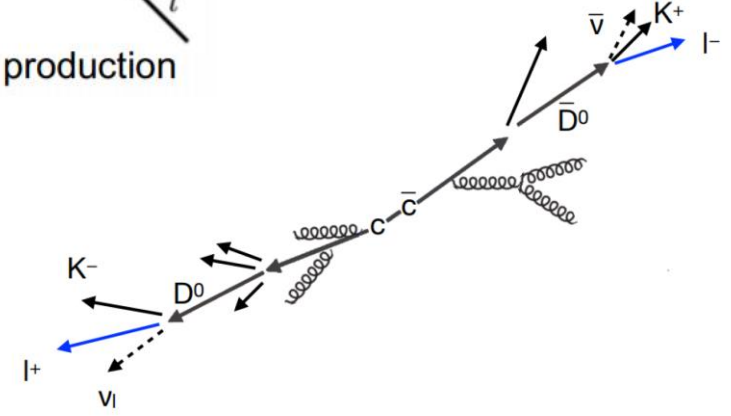


Coherent photoproduction



Thermal dilepton production



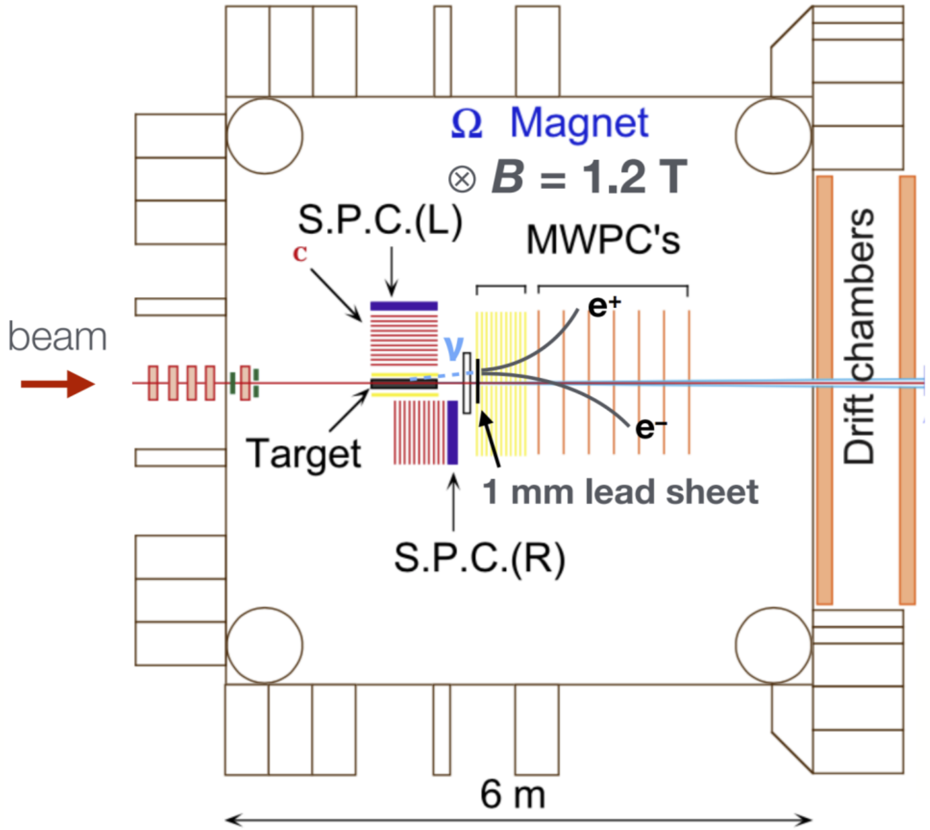
Correlated open-charm production

‘Anomalous’ radiation in small systems

The ‘Anomalous Soft Photon’ (ASP) puzzle

Several ‘fixed-target’ experiments observe the emission of soft photons in hadron-hadron collisions:

OMEGA spectrometer



Measurement via photon conversion method:

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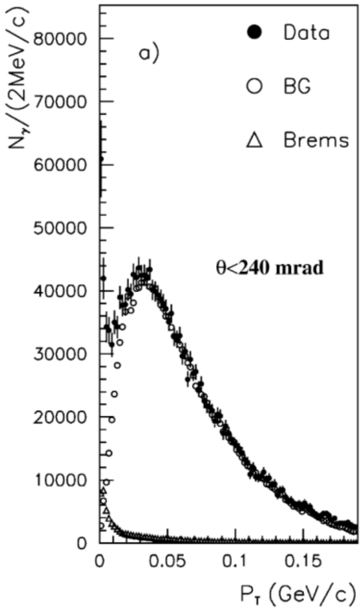
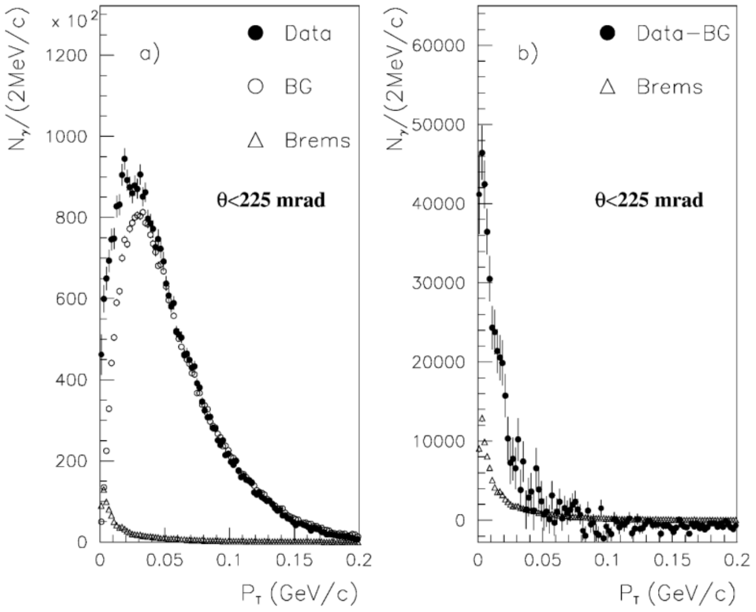
WA 91 πp

A. Belogianni et al. / Physics Letters B 548 (2002) 122–128



WA102 pp

A. Belogianni et al. / Physics Letters B 548 (2002) 129–139



Measurement via photon conversion method:

Significant excess of photons at low momenta compared to the expected contributions of hadronic decays

→ Exceeds even the expectations from hadronic bremsstrahlung

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Experiment	Year	Collision energy [GeV]	Photon pT [MeV/c]	Photon/Brems. ratio	Detection method	Reference
π^{+}p	1979	10.5	< 30	1.25 ± 0.25	bubble chamber	Phys. Rev. Lett. 43, 1065 (1979)
K^{+}p WA27, CERN	1984	70	< 60	4.0 ± 0.8	bubble chamber	Phys. Lett. B 141, 276 (1984)
π^{+}p CERN, EHS, NA22	1991	250	< 40	6.4 ± 1.6	bubble chamber	Z. Phys. C 51, 541 (1991)
K^{+}p CERN, EHS, NA22	1991	250	< 40	6.9 ± 1.3	calorimeter	Z. Phys. C 51, 541 (1991)
π^{-}p, CERN, WA83, OMEGA	1993	280	< 10 (0.2 < Eγ < 1 GeV)	7.9 ± 1.4	pair conversion, calorimeter	Phys. Lett. B 305, 182 (1993)
p-Be	1993	450	< 20	< 2	calorimeter	Z. Phys. C 59, 547 (1993)
p-Be, p-W	1996	18	< 50	< 2.65	pair conversion	Phys.Rev. C54 (1996) 1918
π^{-}p, CERN, WA91, OMEGA	1997	280	< 20 (0.2 < Eγ < 1 GeV)	7.8 ± 1.5	pair conversion	Phys. Lett. B 408, 487 (1997)
π^{-}p, CERN, WA91, OMEGA	2002	280	< 20 (0.2 < Eγ < 1 GeV)	5.3 ± 1.0	pair conversion	Phys. Lett. B 548, 122 (2002)
pp, CERN, WA102, OMEGA	2002	450	< 20 (0.2 < Eγ < 1 GeV)	4.1 ± 0.8	pair conversion	Phys. Lett. B 548, 129 (2002)
$e^{+}e^{-} \rightarrow$ 2 jets CERN, DELPHI	2006	91 (CM)	< 80 (0.2 < Eγ < 1 GeV)	4.0 ± 0.3 ± 1.0	pair conversion	Eur. Phys. J. C 47, 273 (2006)
$e^{+}e^{-} \rightarrow$ μ+μ– CERN, DELPHI	2008	91 (CM)	< 80	~ 1	pair conversion	Eur. Phys. J. C57, 499 (2008)

- Various collision systems (π^{+}p, K^{+}p, pp, p-A, $e^{+}e^{-}$)
- Large energy range (10.5 - 450 GeV/*c*)
- Different detection methods

→ Enhancement factors ranging between 3-8

‘Anomalous’ radiation in small systems

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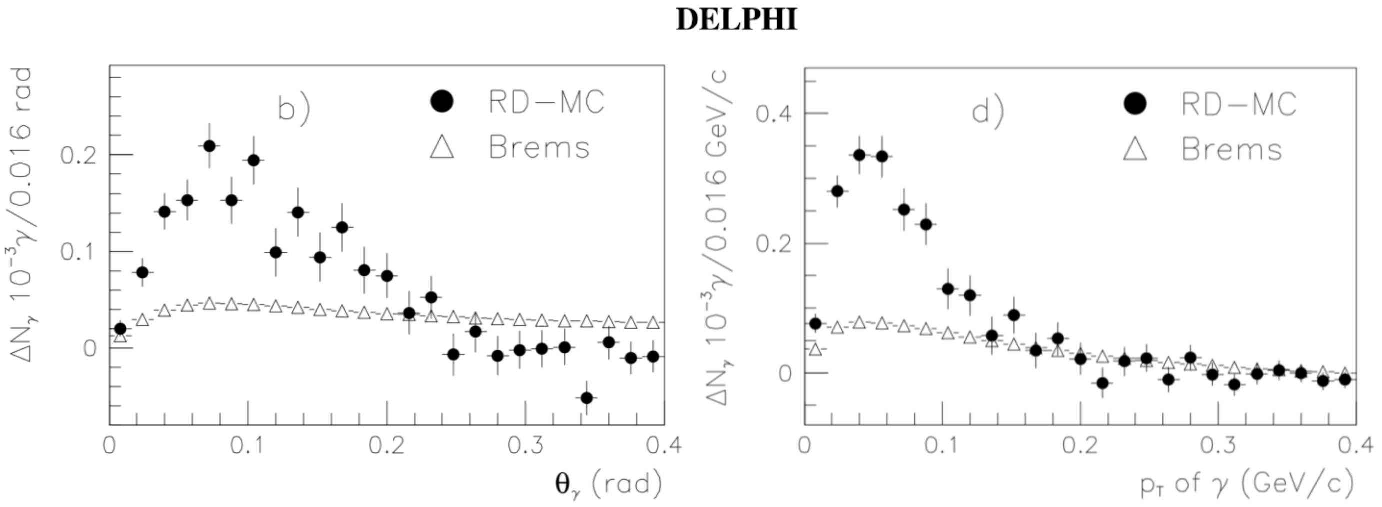

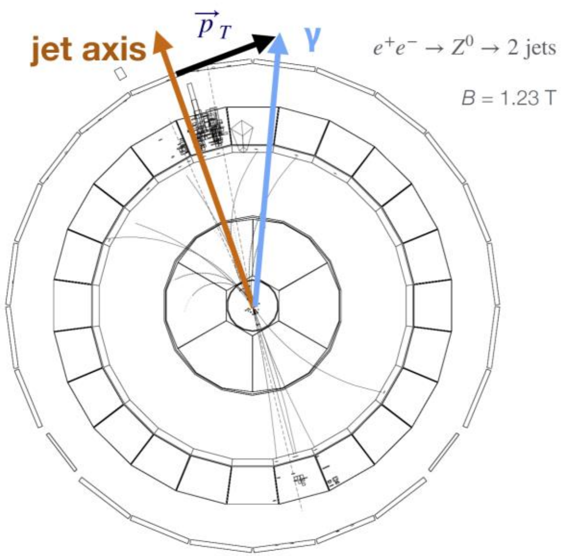

ASP also observed in ee collisions:

Hadronic ev.: $e^+ + e^- \to Z^0 \to \text{hadrons} + \gamma$

→ Excess of factor 4

<u>Conversion in front of TPC:</u>

Measured photon yield:
(69.1 ± 4.5 ± 15.7)×10^{-3} γ/jet

Expectation from bremsstrahlung:
(17.1 ± 0.01 ± 1.21)×10^{-3} γ/jet

Eur. Phys. J. C57, 499 (2008)

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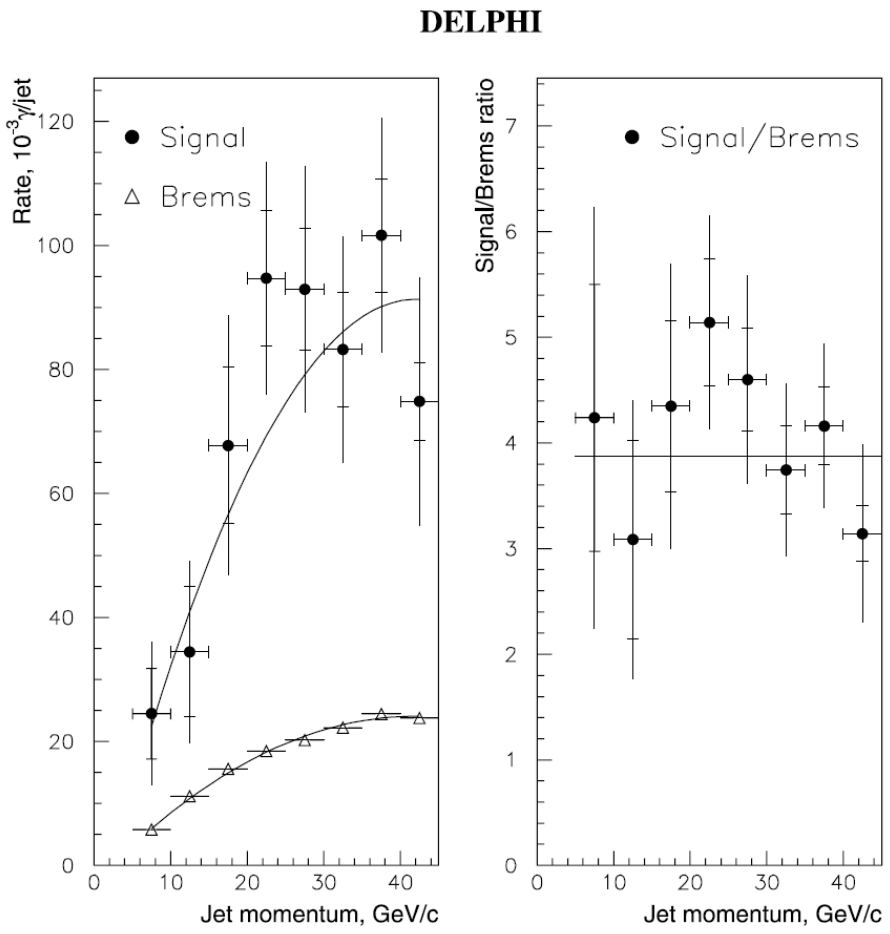
Eur. Phys. J. C **67,** 343–366 (2010)



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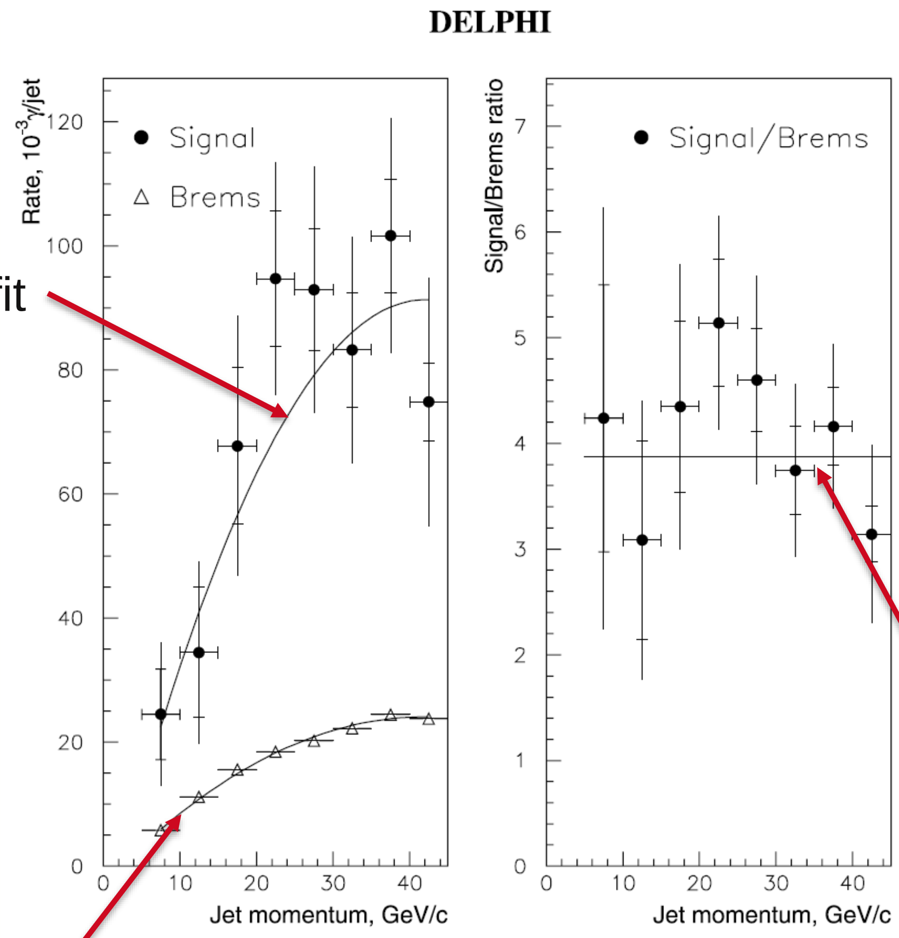

Scaled fit

Scaling factor

Hadr. bremsstrahlung fit

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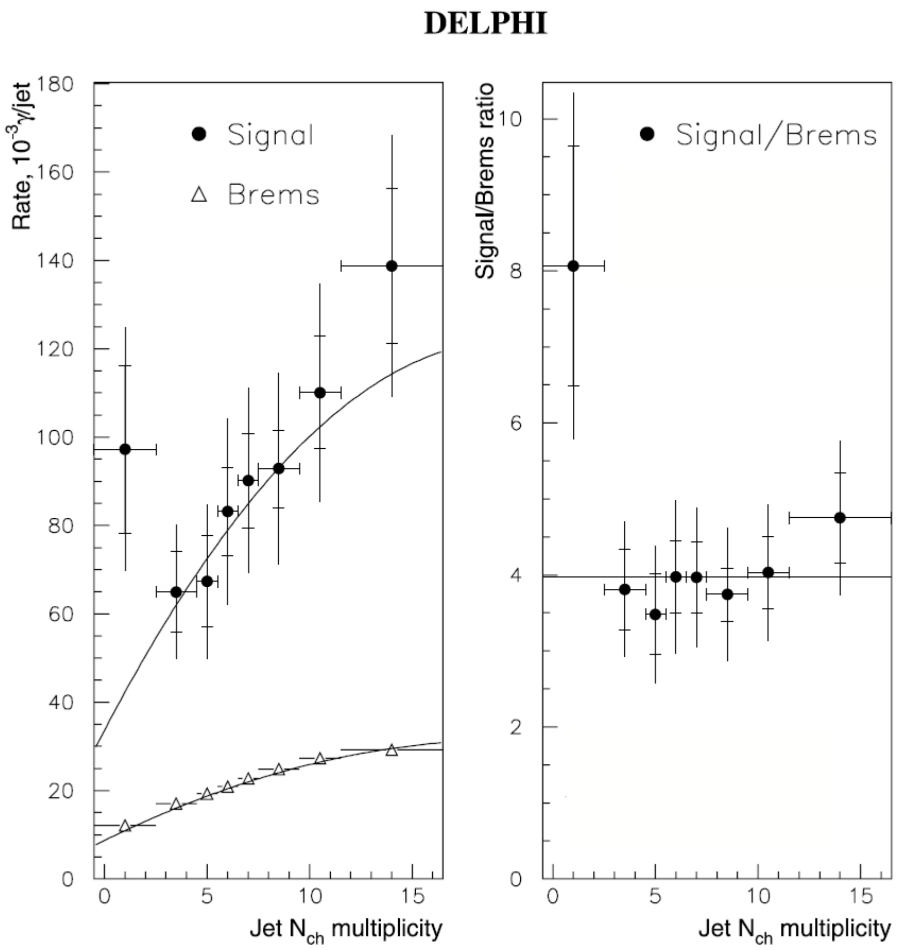

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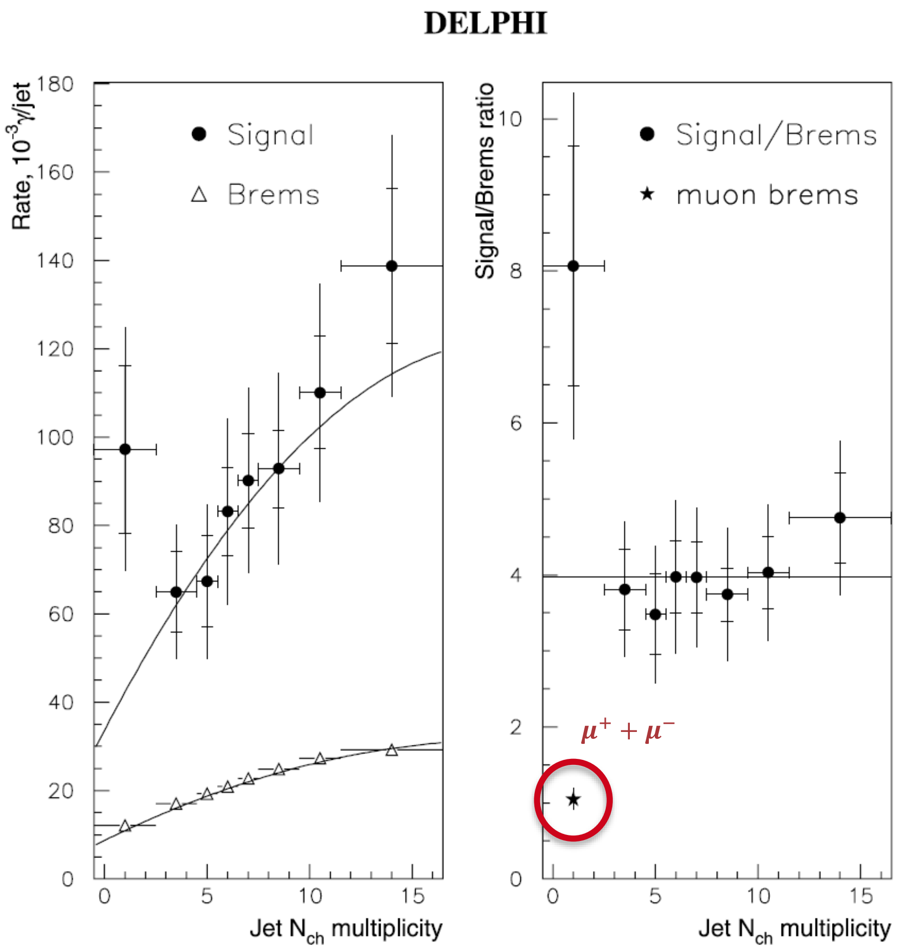

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Electromagnetic ev.: $e^+ + e^- \rightarrow Z^0 \rightarrow \mu^+ + \mu^- + \gamma$

- → No excess observed

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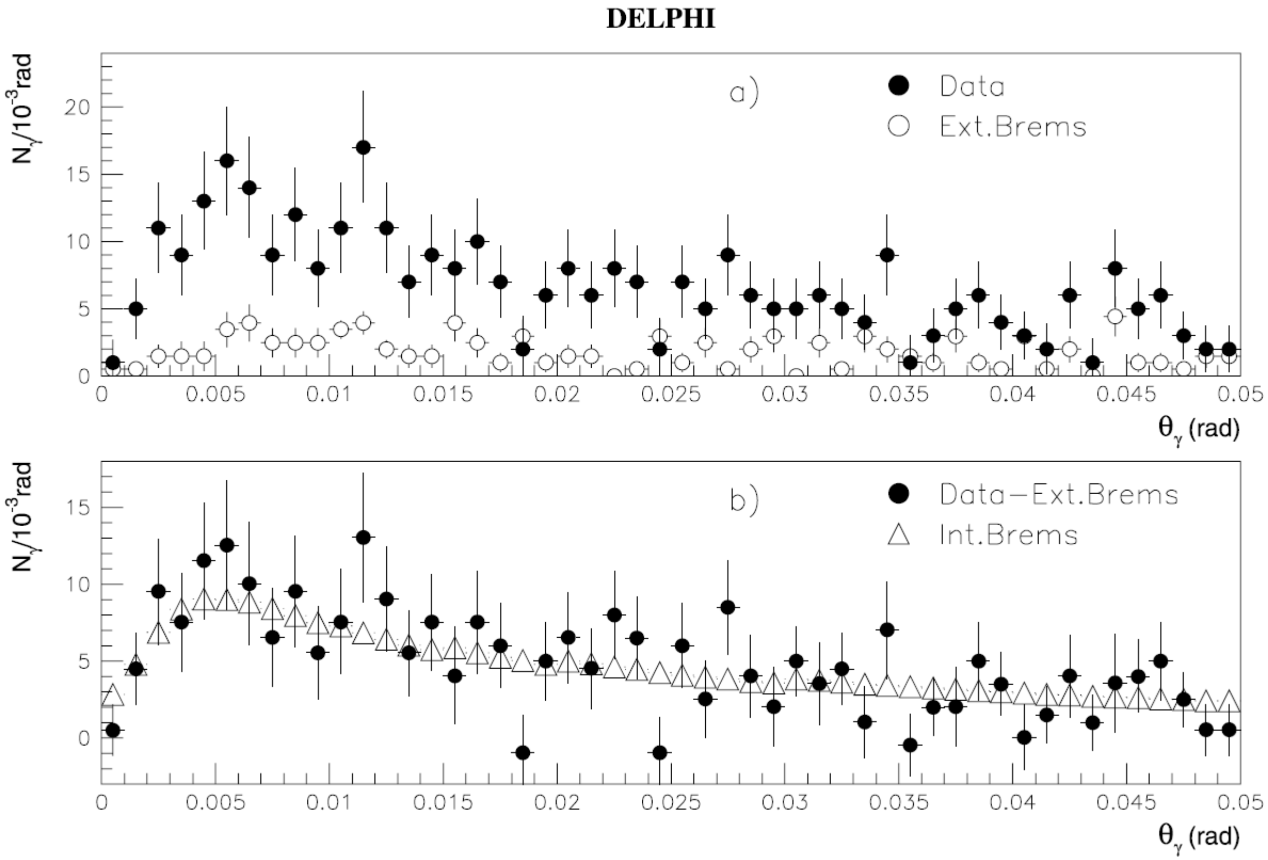

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ASP origin in the interaction of QCD ↔ QED ?

‘Anomalous’ radiation in small systems

The ‘Anomalous Soft Photon’ (ASP) puzzle

However, this additional contribution was not expected:

Low theorem: Direct correlation between the hadr. process and the corresponding hadr. Bremsstahlung (HB)

A + B → C + D known → A + B → C + D + γ precisely calculable

$$\frac{dN^{\gamma}}{d^3\vec{k}} = \frac{\alpha}{(2\pi)^2}\frac{-1}{E_{gamma}}\int \left(d^3\vec{p}_1 \ldots d^3\vec{p}_N\right)\left(\sum_{\text{Particle } i}\frac{\eta_i e_i \mathbf{P}_i}{\mathbf{P}_i\mathbf{K}}\right)^2 \frac{dN^{\mathrm{H}}}{d^3\vec{p}_1 \ldots d^3\vec{p}_N}$$

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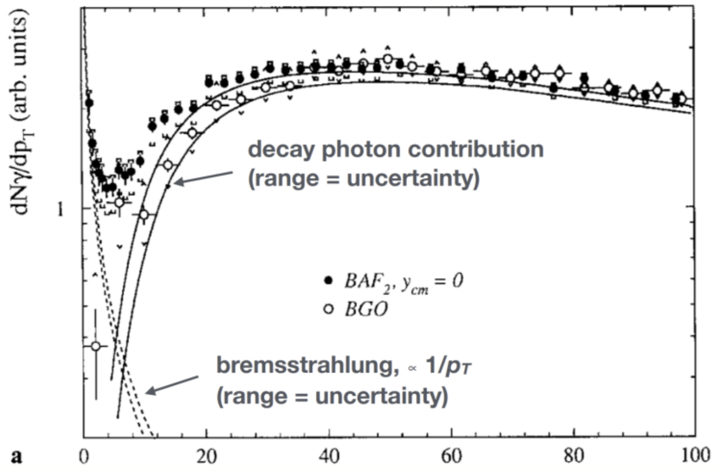
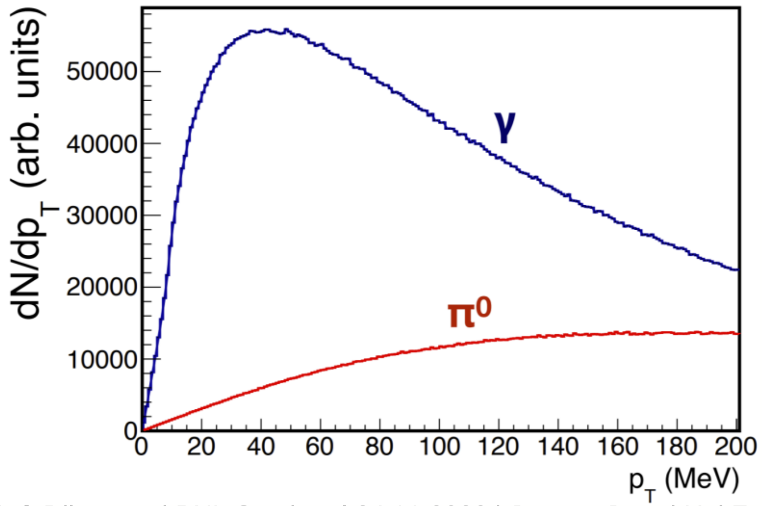
Characteristic $1/E_\gamma$ dependence



Contribution from decay photons



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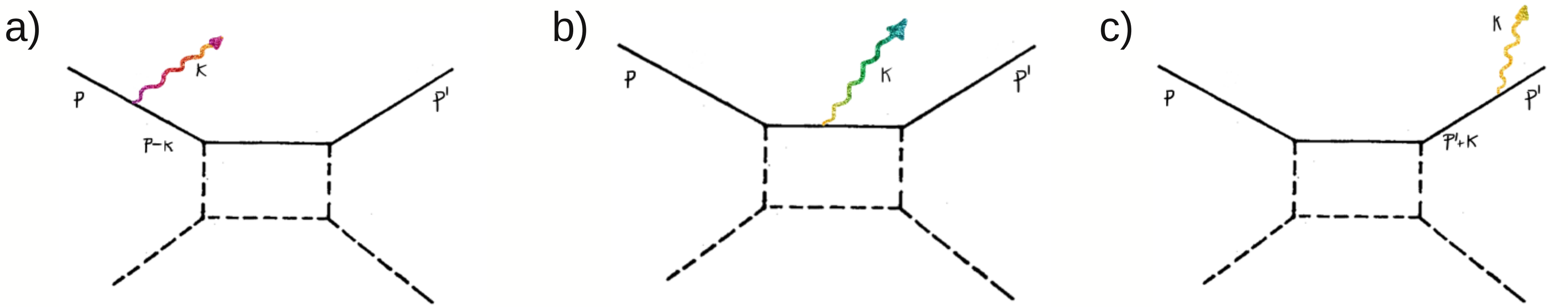
Landau-Pomeranchuk-Migdal (LPM) effect:



In the limit of vanishing photon energy k → 0:

Case a) & c): the emitting particle is real and the resulting bremsstrahlungs cross section diverges

Case b): the emitting particle is virtual and the resulting HB cross section is finite

→ HB dominates all other processes at sufficient low momenta

($\omega\, \Delta t \geq 1$, in pp: $p_{\mathrm{T}} < 0.2\ \mathrm{GeV}/c$)

‘Anomalous’ radiation in small systems

The ‘Anomalous Soft Photon’ (ASP) puzzle

However, this additional contribution was not expected:

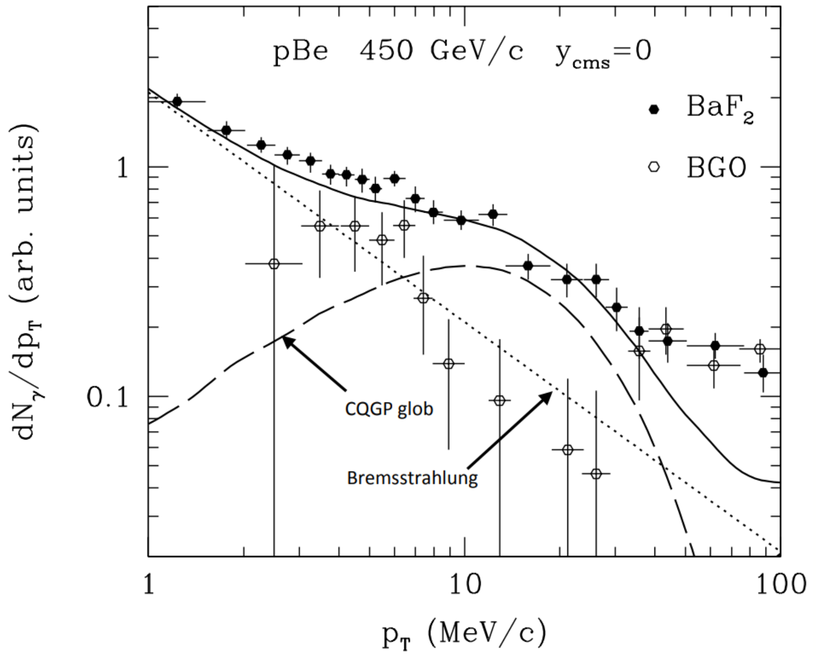
→ In contradiction with Low theorem and LPM effect:
- Suppression of the emission of soft photons from the intermediate state
- Hadr. bremsstrahlung should dominate at low momenta

Proposed solutions:

- Cold Quark-Gluon Plasma Glob
  L. van Hove, Annals Phys. 192 (1989) 66
- Pion Liquid
  E. Shuryak, PLB231 (1989) 175
- Quark Synchrotron Radiation
  G.W. Botz, P. Haberl, O. Nachtmann, Z. Phys. C67 (1995) 143
- (Modified) Soft Parton Annihilation
  V. Cerny, P. Lichard, J. Pisut, Z. Phys. C31 (1986) 163

→ Possibility for new and interesting physics!

P. Lichard, Phys. Rev. D50 (1994) 6824



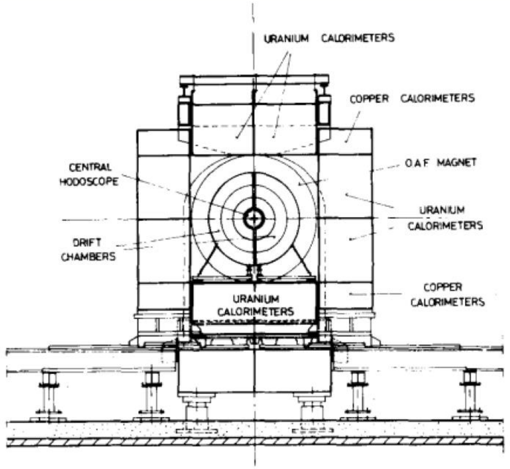
‘Anomalous’ radiation in small systems

The virtual-photon sector

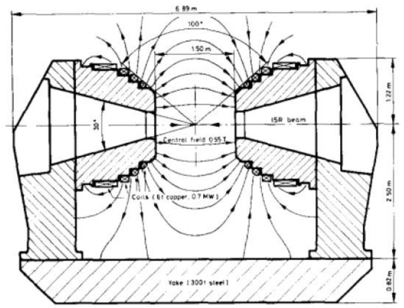
Unfortunately, the picture is not as clear:
→ Only a few measurements exist
→ Soft theorems in case of off-shell particles
not as well understood

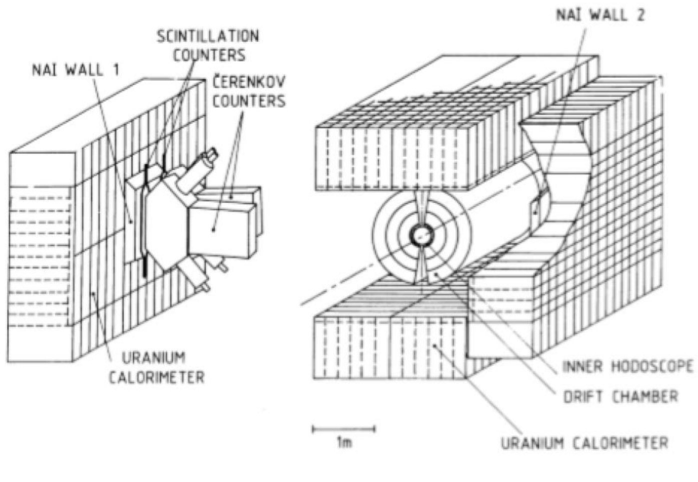
First hint for a possible excess based on the measurement of the e^+/π ratio by AFS at the ISR

Axial Field Spectrometer



(a) Frontal cross-section


(b) Vertical cross-section



(c) Cherenkov arm setup

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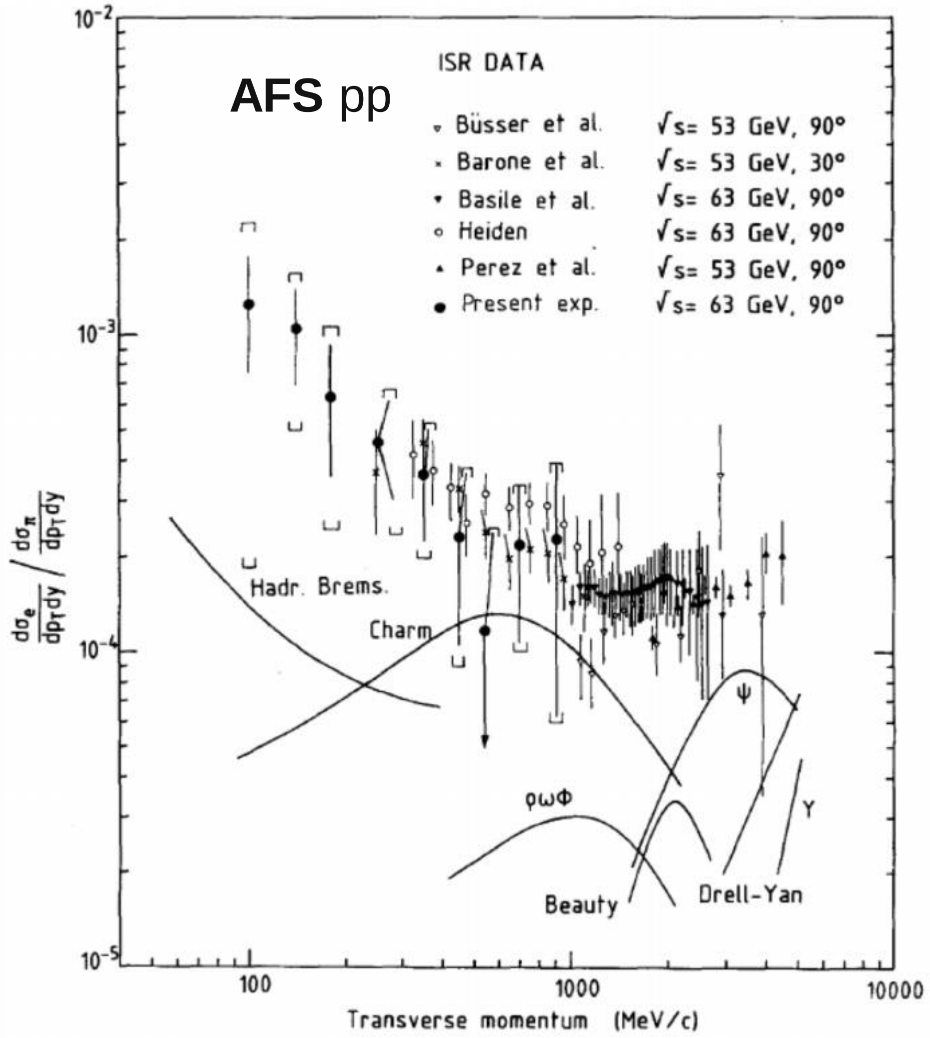
→ Clear surplus of positrons at low momenta compared to hadr. sources or bremsstrahlung



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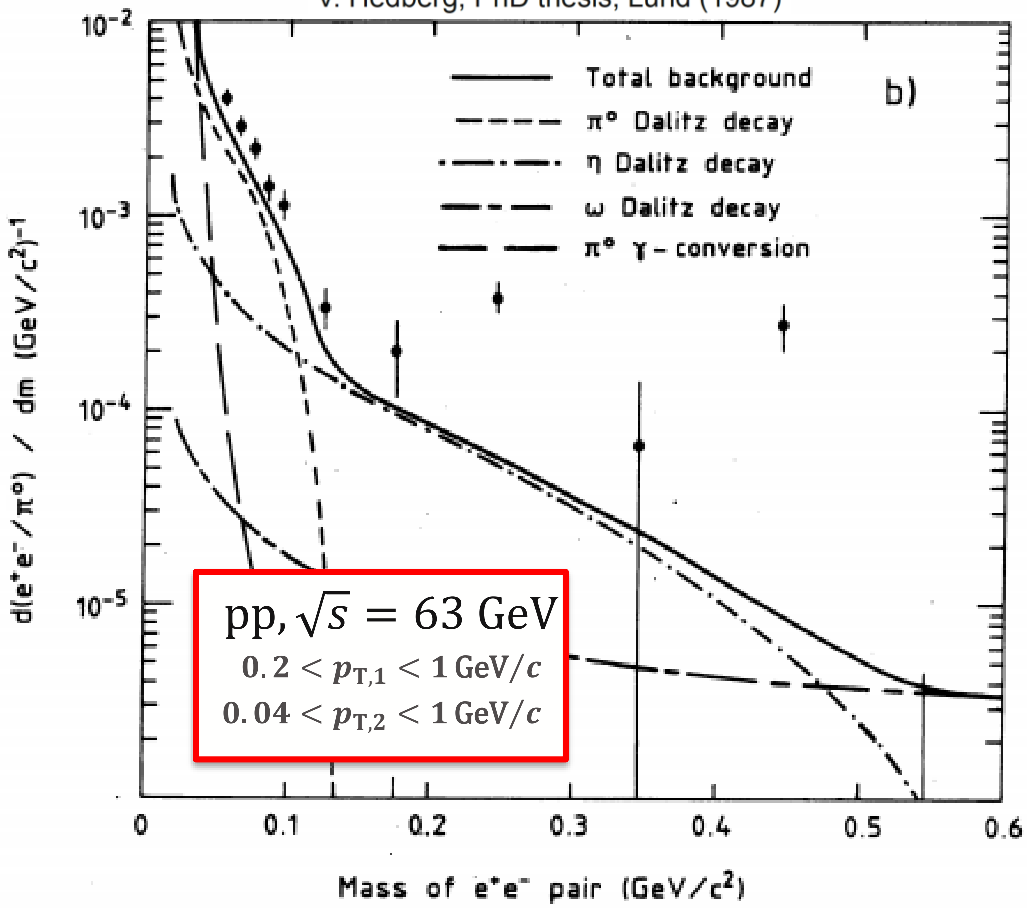
The corresponding dielectron spectrum also exceeds the expectation of hadr. decays in the LMR

→ However, this spectrum was never properly published

V. Hedberg, PhD thesis, Lund (1987)



Low-mass region (LMR) excess:
- $0.05\ GeV/c^2 < m_{ee} < 0.6\ GeV/c^2$
- $p_{T,ee} < 1\ GeV/c$

‘Anomalous’ radiation in small systems

The virtual-photon sector

No excess observed by other experiments:

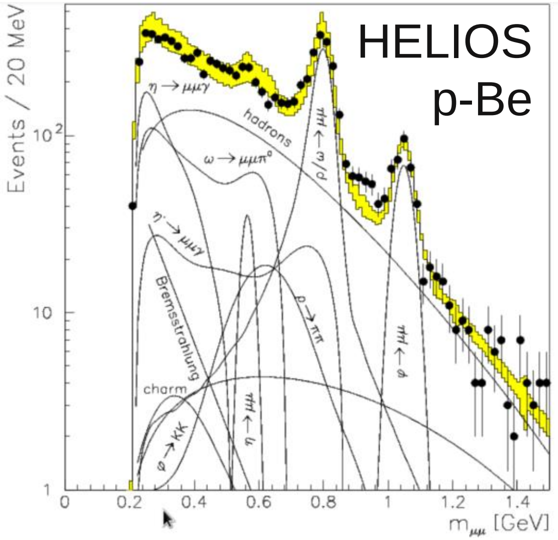
<u>HELIOS:</u>

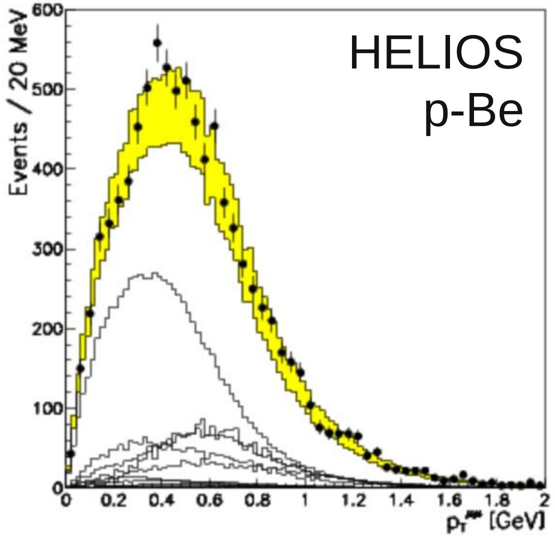
- Muon channel → higher momentum required
- Probes different phase space

<u>CERES:</u>

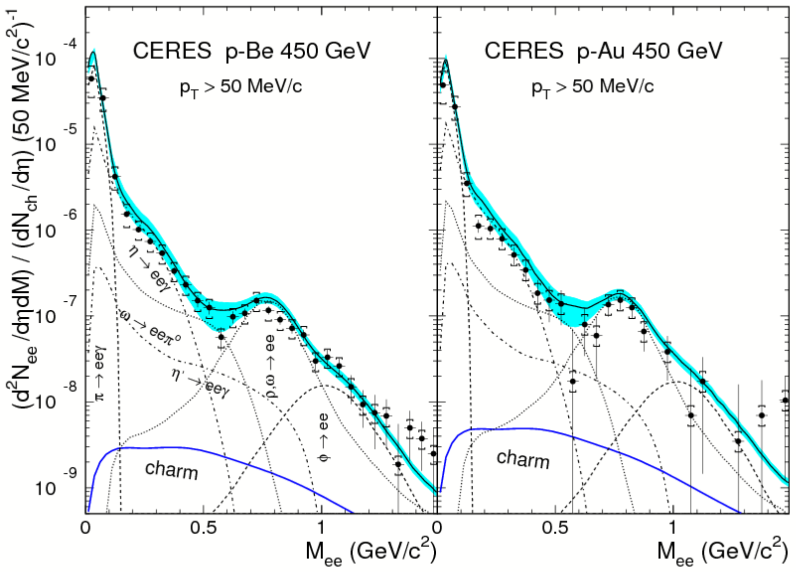
- Hadr. expectation mainly based on m_{T} scaling
  → Known to overestimate yield at low momenta

Since 20 years: pp considered only as a vacuum reference
→ Experiments could not access very soft regime





R. Veenhof, PhD Thesis



Phys.Rev.Lett. 75 (1995) 1272-1275

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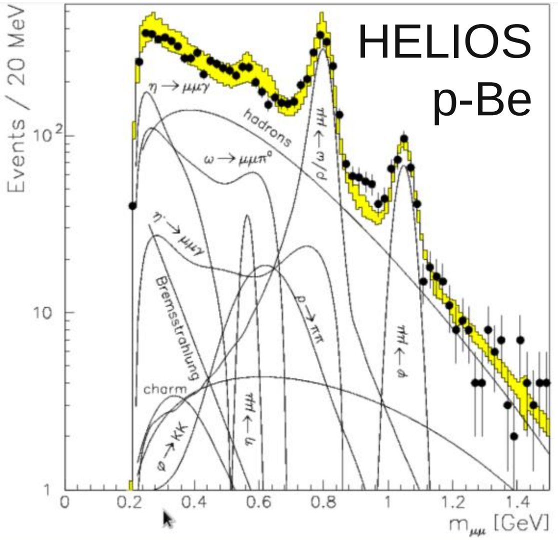
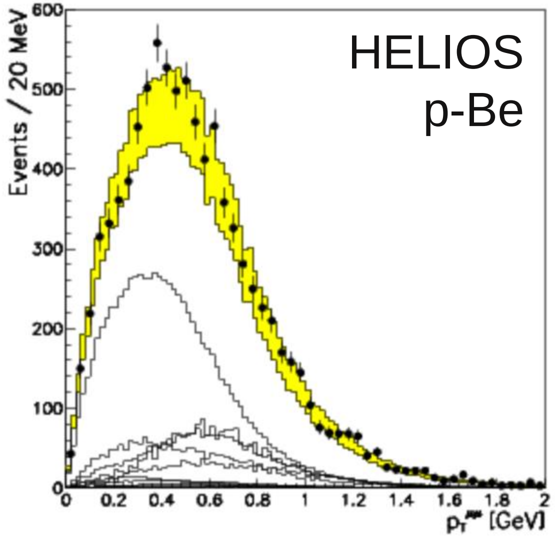
The question of anomalous soft-dilepton production remains unresolved for three decades
→ ALICE could shed new light on this puzzle





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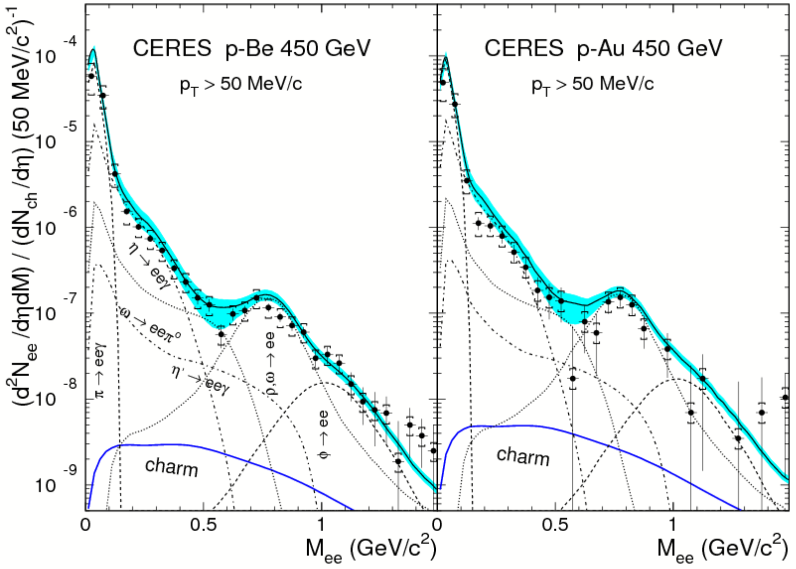

Phys.Rev.Lett. 75 (1995) 1272-1275

ALICE

Dedicated low-mass dielectron runs

Reduced field of the ALICE L3 solenoid magnet: (B = 0.5 T → 0.2 T)

→ Overall charged-particle acceptance increased

→ Bulk of the dielectron yield located at low momenta

→ Improve background rejection capabilities

→ Access to low-p_{T} particle production

Extending the single electron selection from
$p_{\mathrm{T}} \geq 0.2$ GeV/c down to $p_{\mathrm{T}} \geq 0.075$ GeV/c

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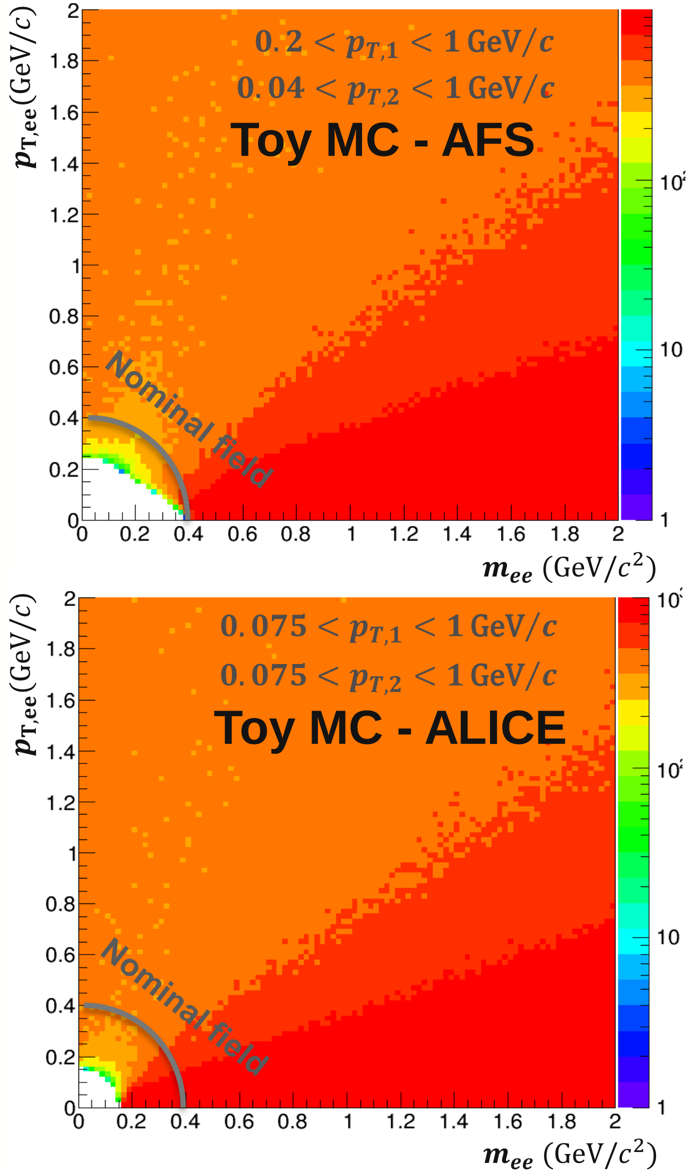
→ Allows to challenge the AFS measurement for the first time with even better acceptance

Dielectron acceptance:



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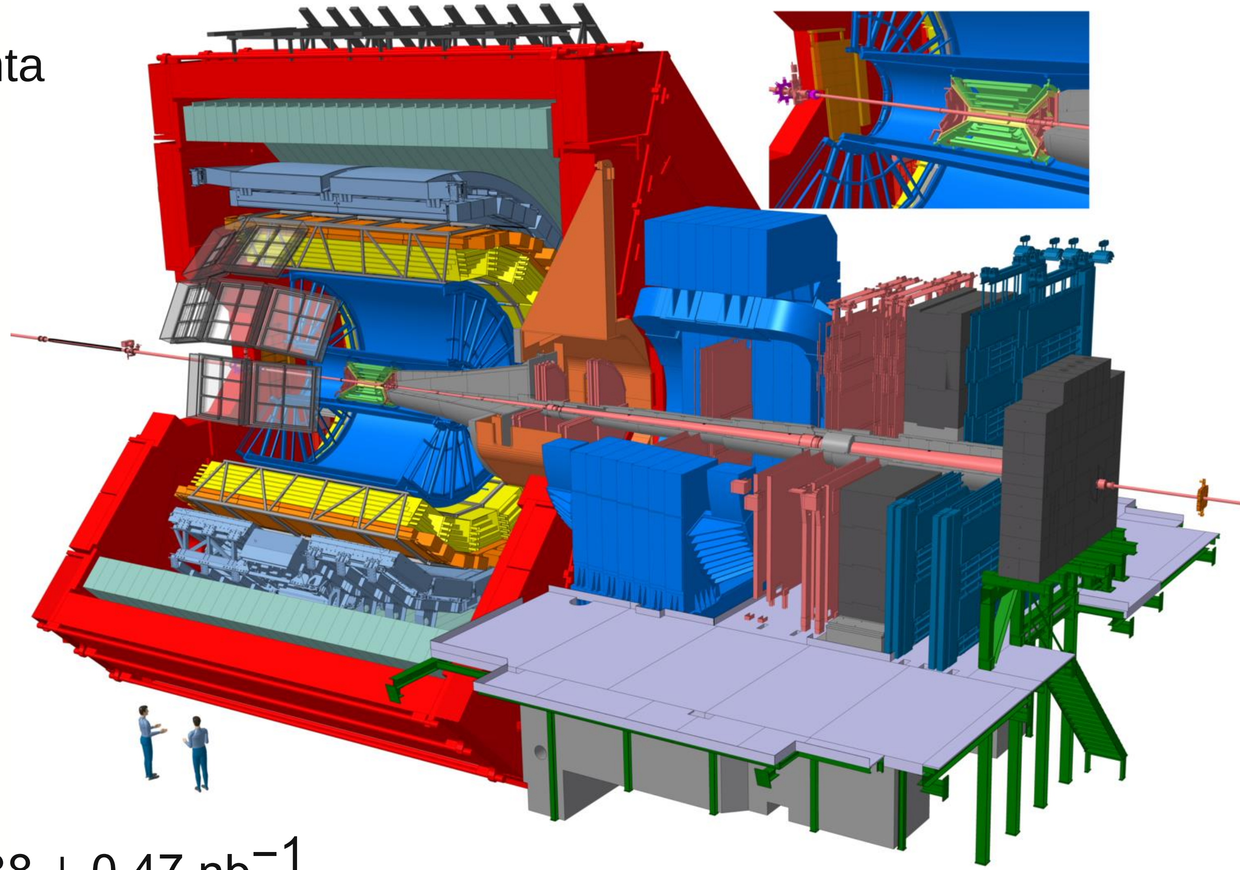
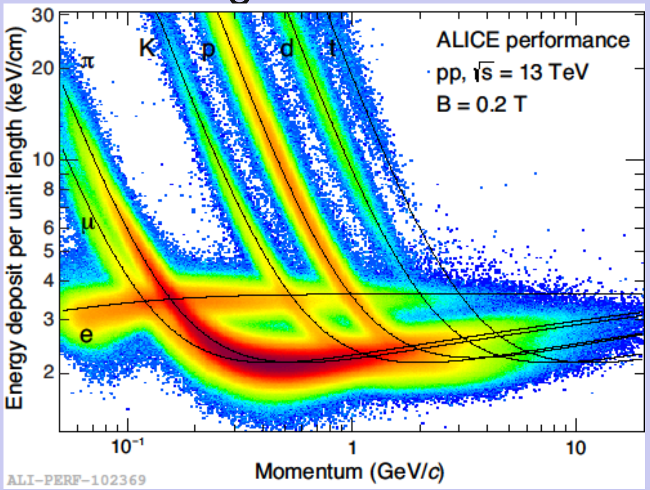
Data recorded 2016-2018 in pp collisions at 13 TeV

→ After physics selection a total of 542 × 10^6 MB events corresponding to an integrated luminosity of $\mathcal{L}_{\mathrm{int}} = 9.38 \pm 0.47\ \mathrm{nb}^{-1}$



ALICE apparatus

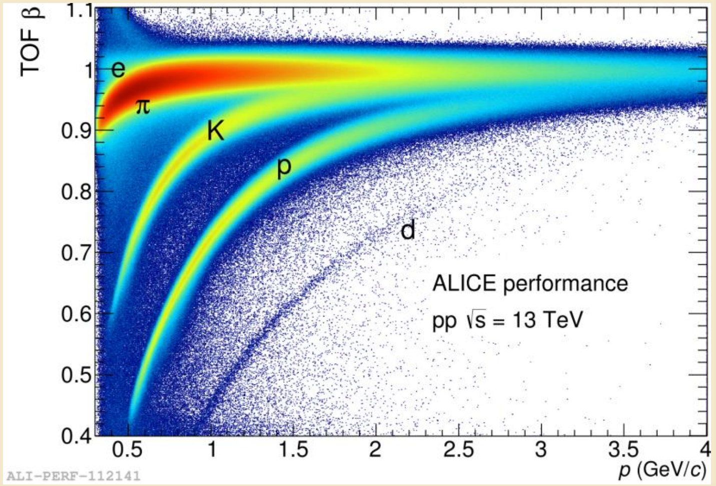
Time Projection Chamber
- Tracking & PID

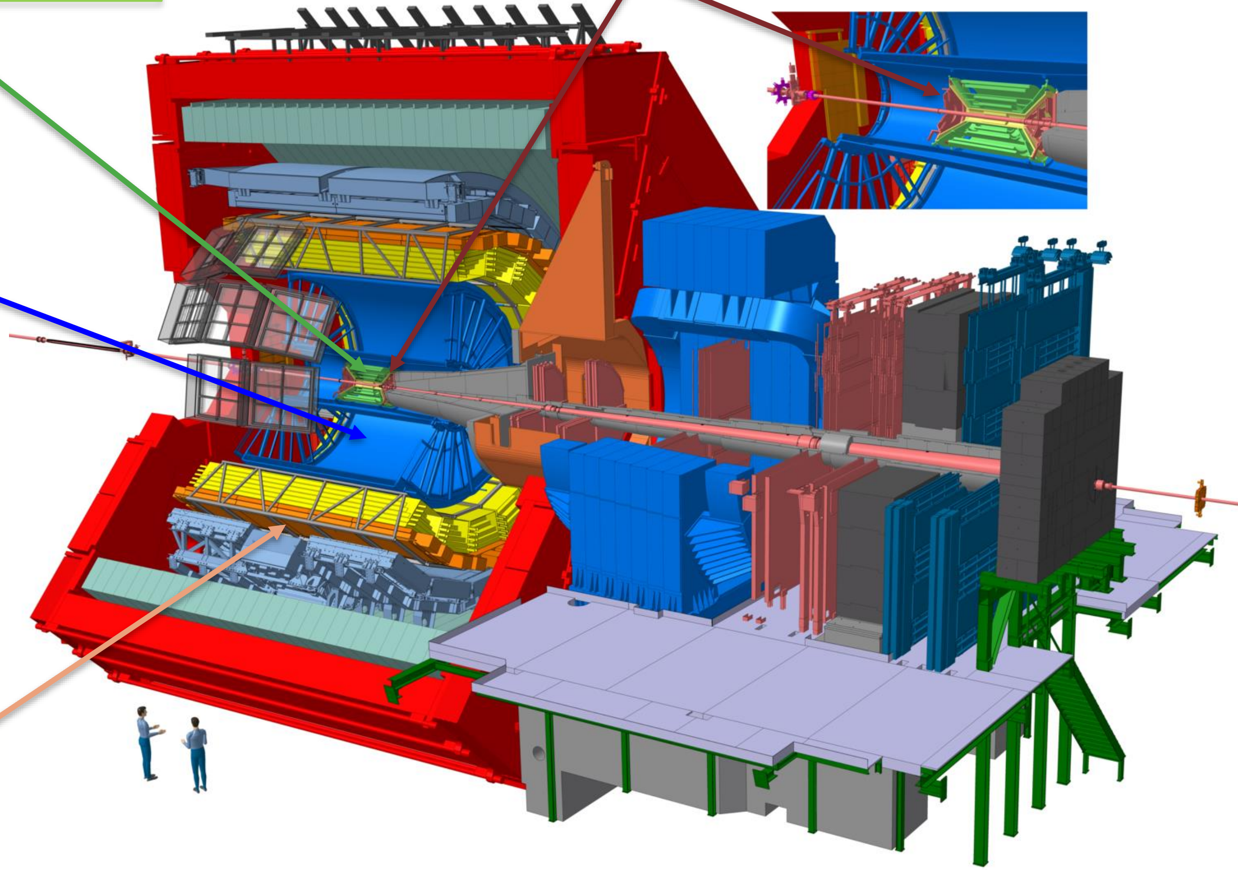


Inner Tracking System
- Vertexing & tracking
- Conversion rejection

V0 at forward rapidity
- MB & HM event triggering
- Multiplicity estimation

Time of Flight
- PID

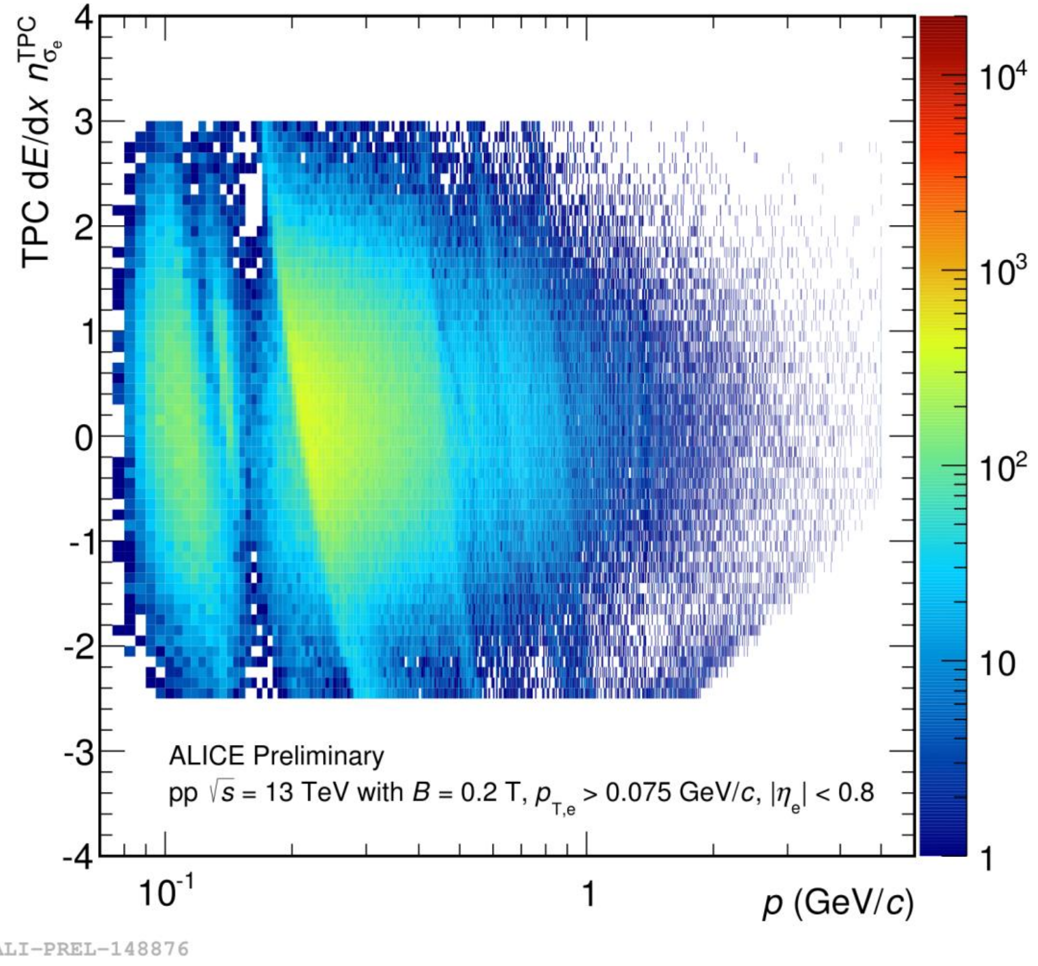




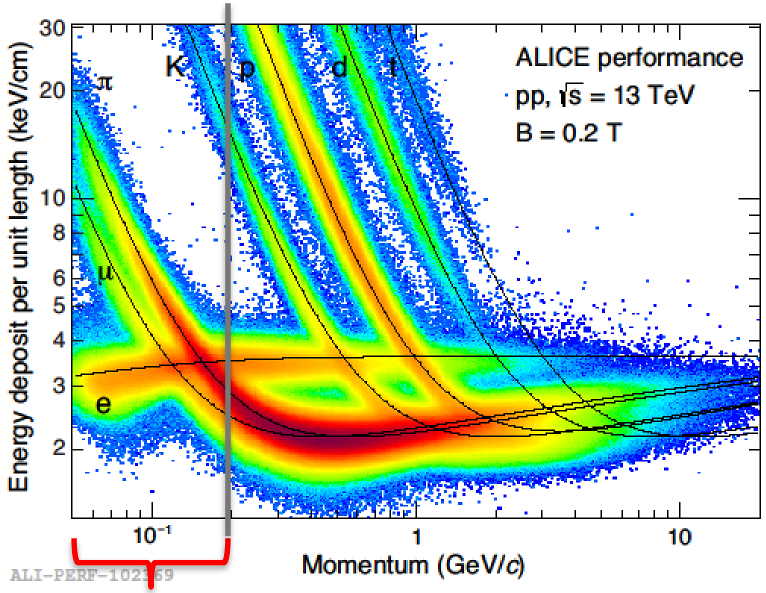
ALICE

Electron identification

$$n_{\sigma_e} = \frac{\left(\frac{dE}{dx}\right)_{\text{measured}} - \left(\frac{dE}{dx}\right)_{\text{expected}}}{\sigma}$$



– Electron 3σ selection using TPC d*E*/dx & TOF if available



Access only with low-B field

ALICE

Electron identification

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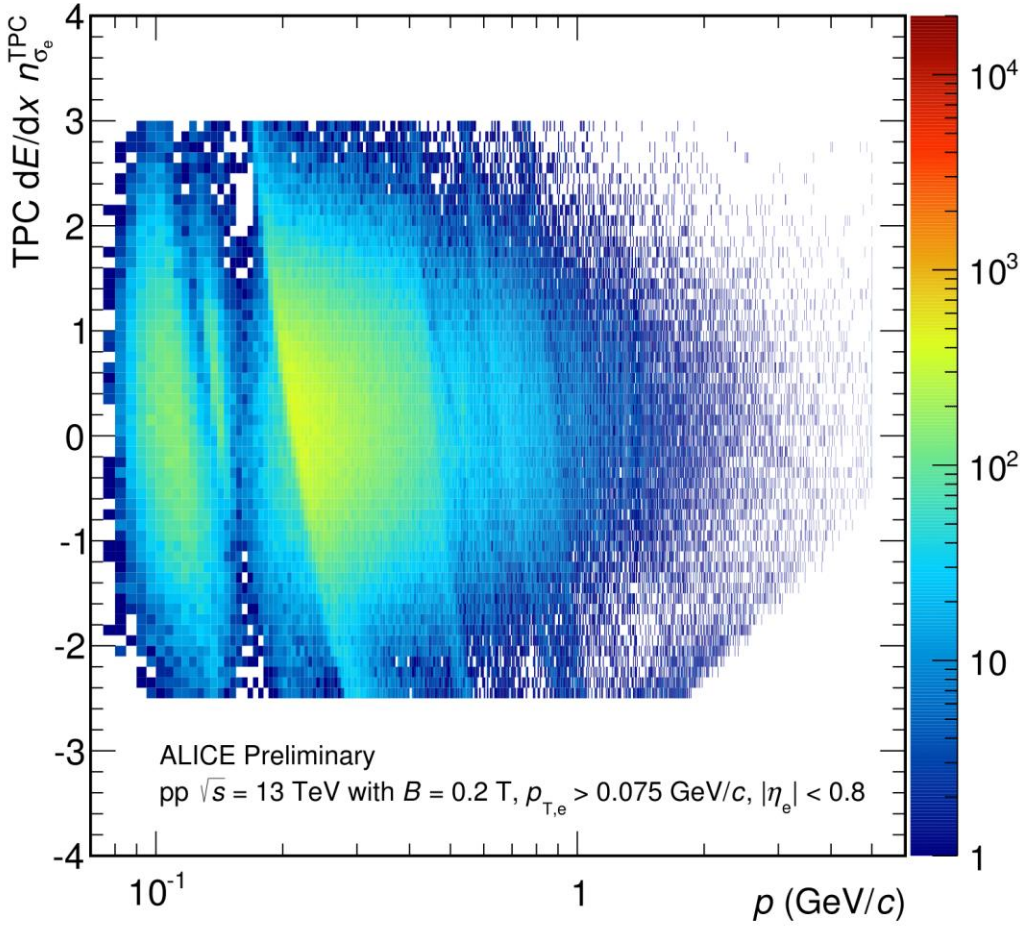
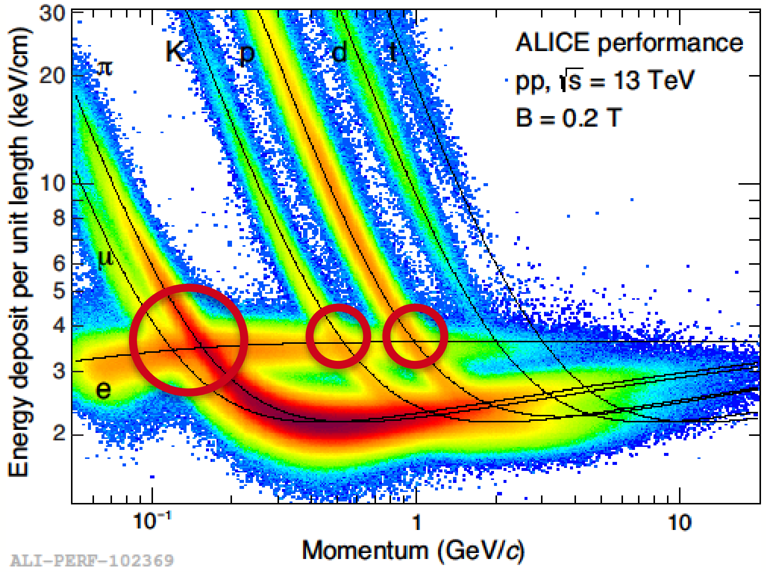


Hadron crossing regions

– Electron 3σ selection using TPC d*E*/dx & TOF if available

→ Residual hadron contamination



ALICE

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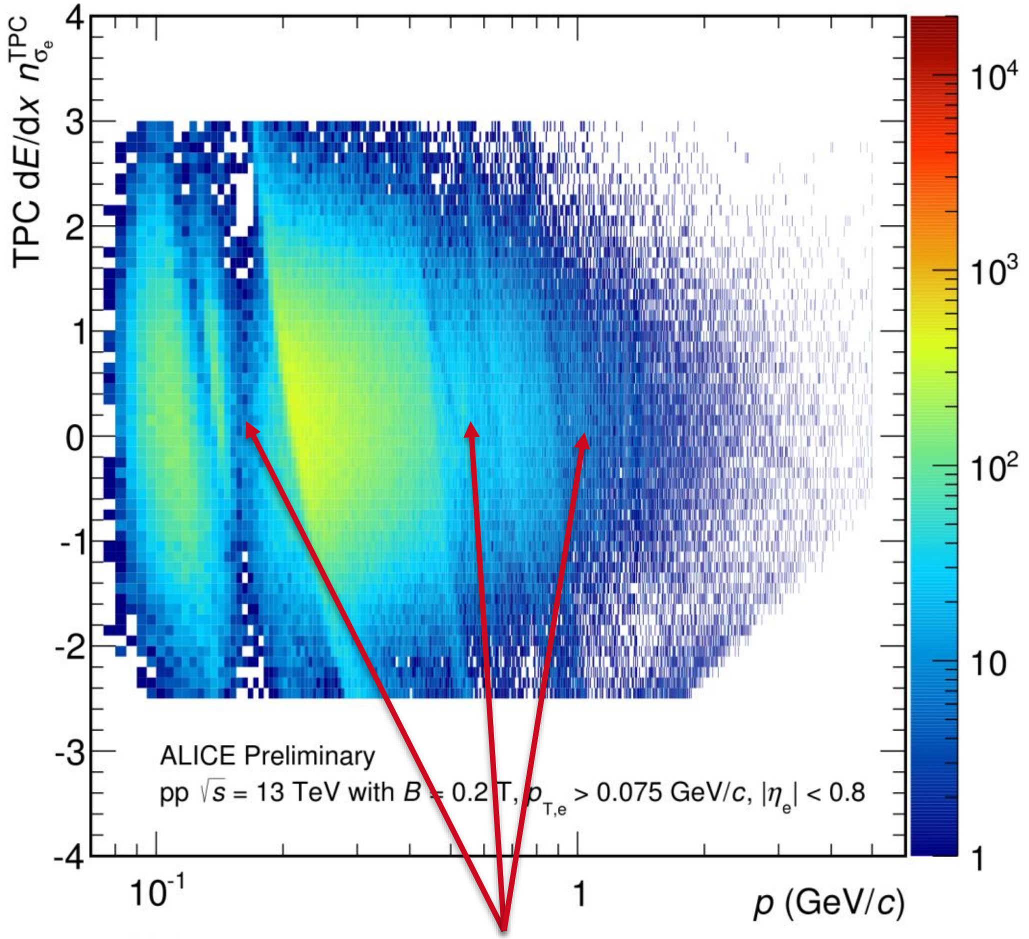
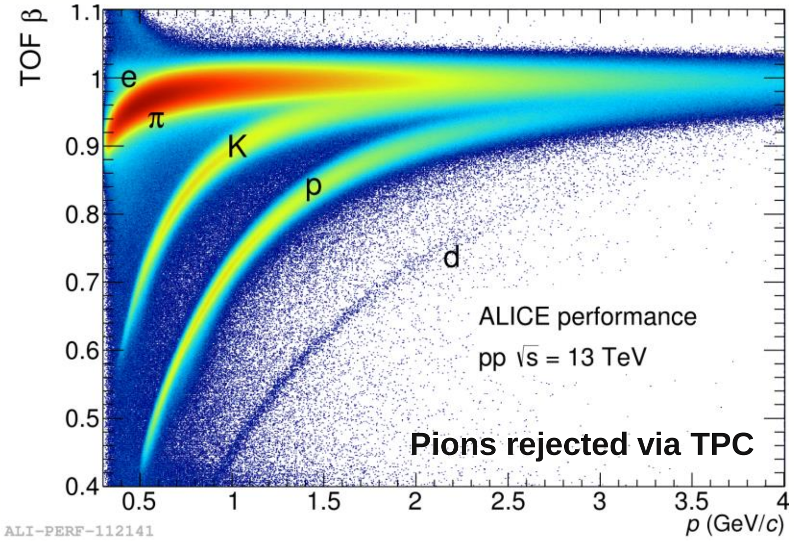


Hadron crossing regions:
only TOF efficiency

- Electron 3σ selection using TPC d*E*/dx & TOF if available
  → Residual hadron contamination
- 3σ hadron rejection in the TPC
- TOF info to recover electron

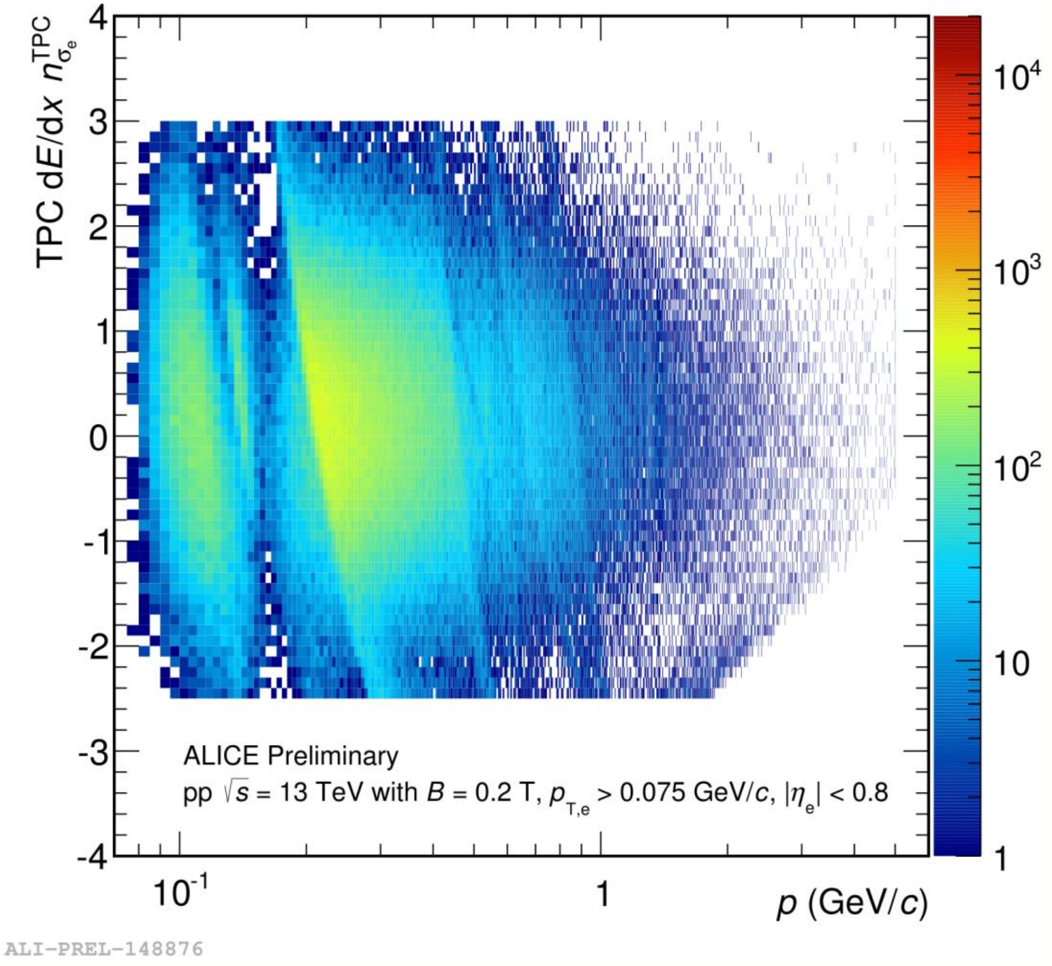


→ Clear rejection of K & p below p_{T} < 2 GeV/c

ALICE

Electron identification

$$n_{\sigma_e} = \frac{\left(\frac{dE}{dx}\right)_{\text{measured}} - \left(\frac{dE}{dx}\right)_{\text{expected}}}{\sigma}$$



- Electron 3σ selection using TPC d*E*/dx & TOF if available

  → Residual hadron contamination
- 3σ hadron rejection in the TPC
- TOF info to recover electron

→ No ITS PID required

→ Similar electron purity but higher electron selection efficiency compared to requiring TOF

→ Similar result to machine learning techniques

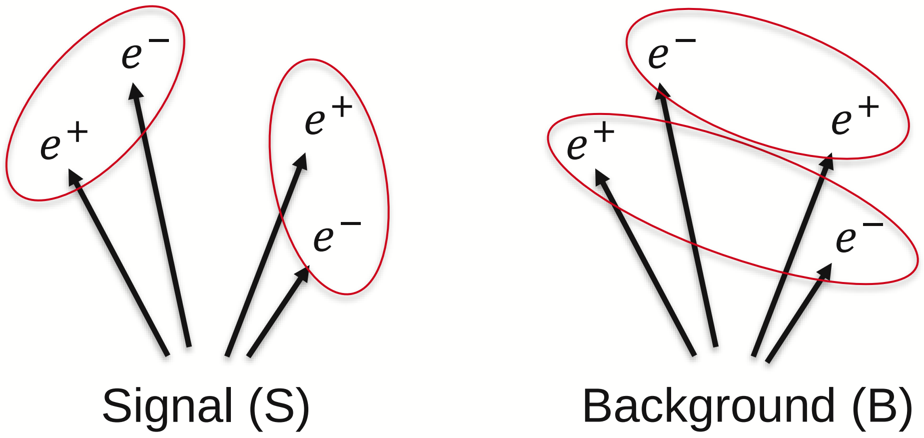
Analysis

Signal extraction

Combinatorial pairing of all electron and positron candidates:

- Unlike-sign (ULS) pairs:
  contain real signal, correlated & combinatorial background

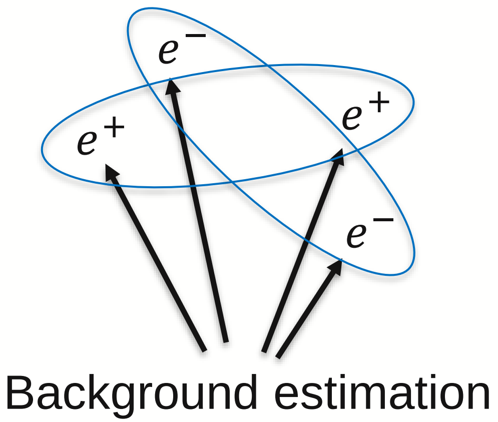
- Like-sign (LS) pairs:
  contain correlated & combinatorial background



Hybrid approach to background estimation:

- Arithmetic mean $\mathrm{B} = (\mathrm{LS}_{++} + \mathrm{LS}_{--})/2$ (low statistics)
- Geometric mean $\mathrm{B} = 2\sqrt{\mathrm{LS}_{++}\mathrm{LS}_{--}}$

→ Different bias due to charge asymmetry



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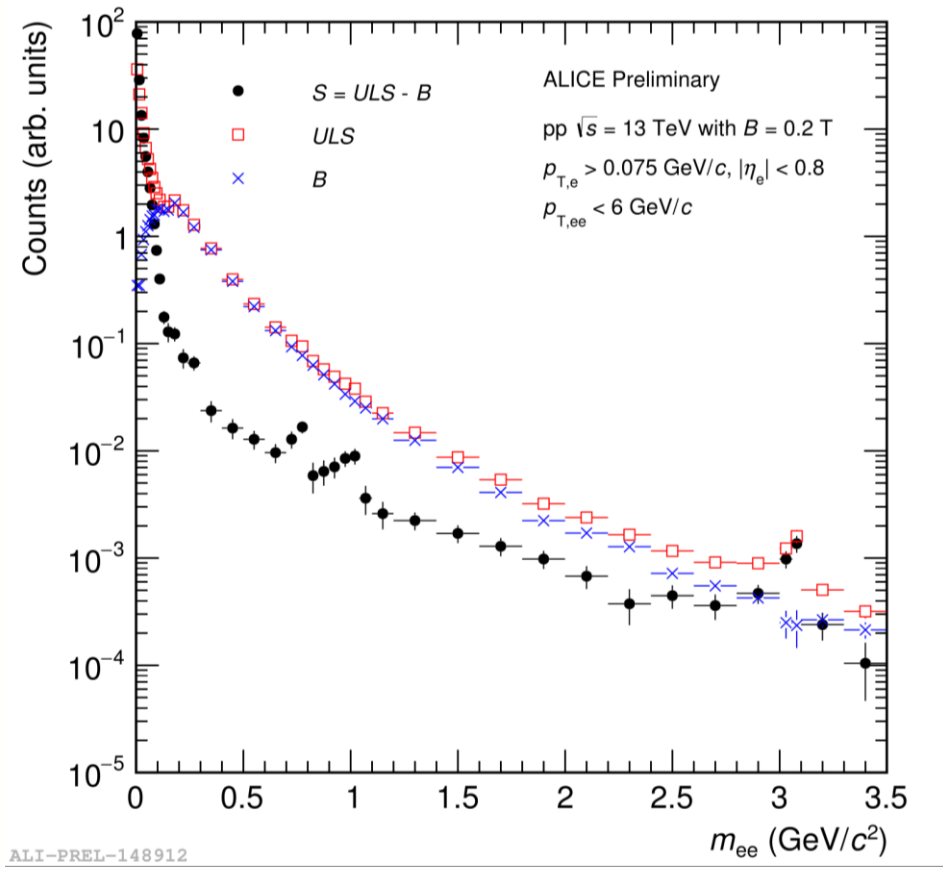
- Arithmetic mean $B = (LS_{++} + LS_{--})/2$ (low statistics)
- Geometric mean $B = 2\sqrt{LS_{++}LS_{--}}$

→ Signal **S** = ULS – B · R
R: rel. acceptance correction factor
$R = ULS_{mix}/(2\sqrt{LS_{mix,++}LS_{mix,--}})$



Low S/B: Reduction of combinatorial background key aspect of this analysis

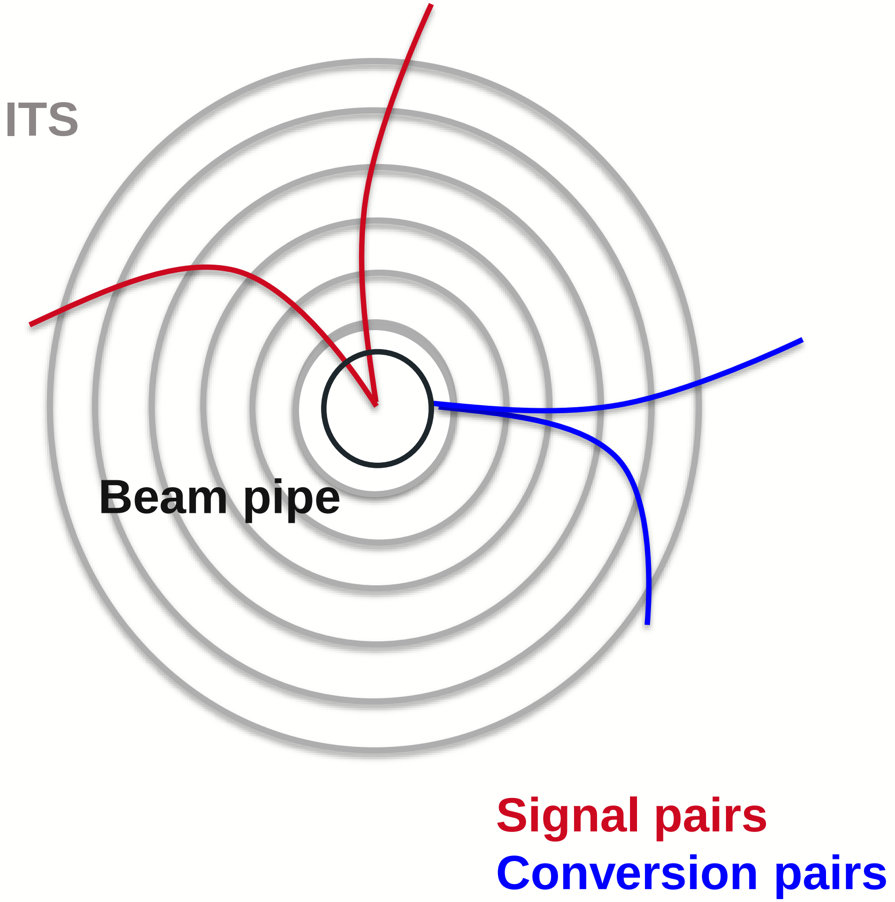
Analysis

Combinatorial background

Dominated by combinatorial pairs originating from

- π^0-Dalitz decays
- Conversions from beam pipe

Conversion pairs are “close” pairs
→ More likely to share an ITS cluster



Analysis

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Conversion pairs are "close" pairs

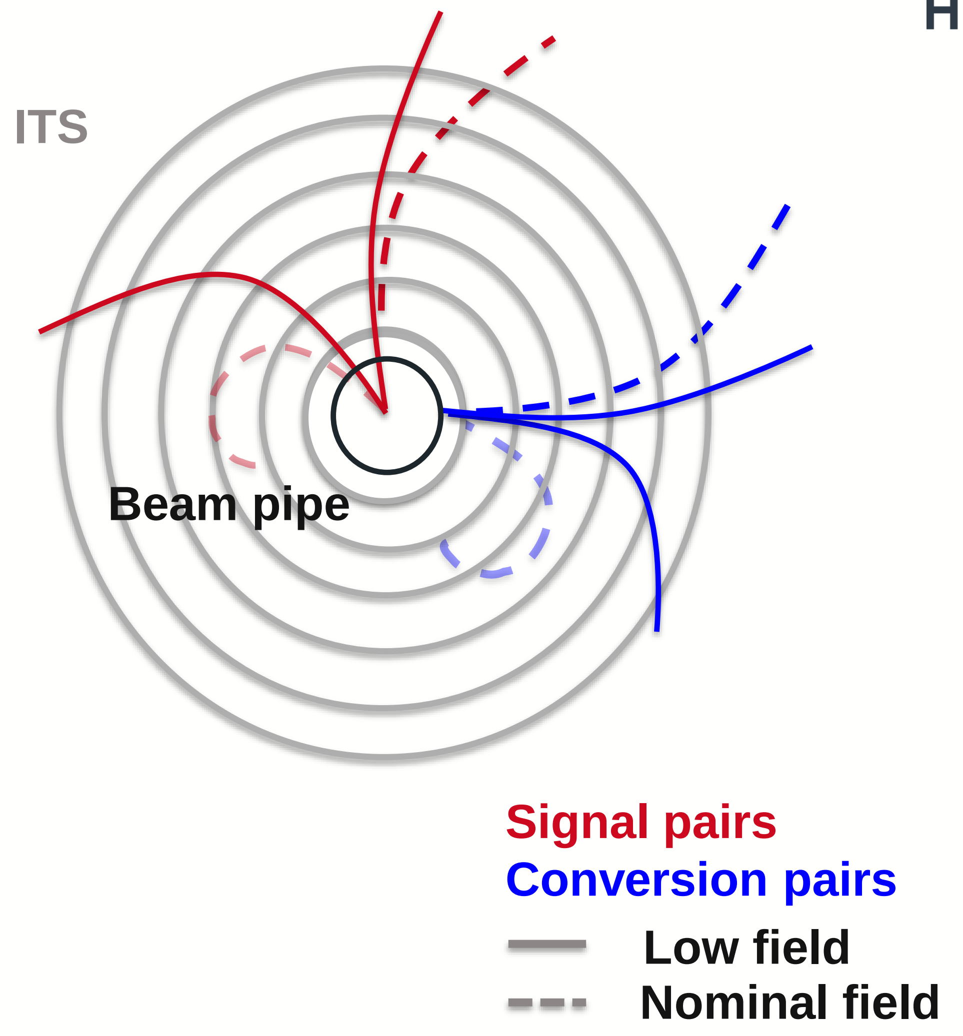
→ More likely to share an ITS cluster

<u>Low-field configuration</u>:

- More conversion pairs get reconstructed (especially asymmetric pairs)

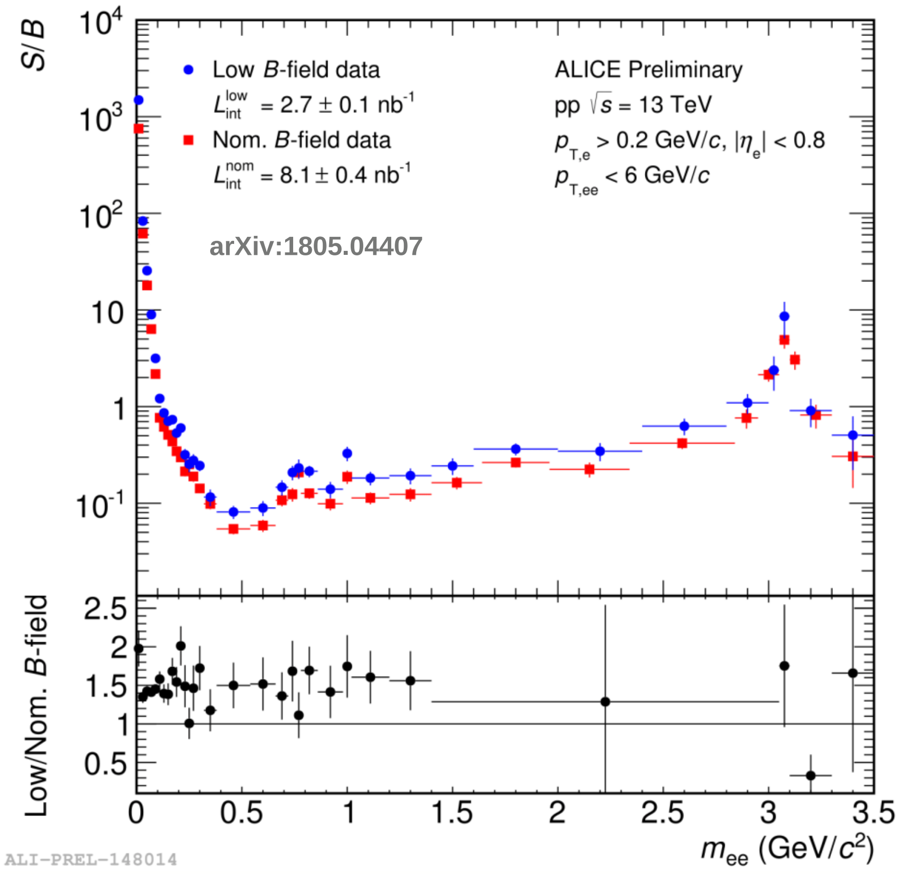
→ Higher conversion rejection efficiency via a veto on shared clusters in the ITS

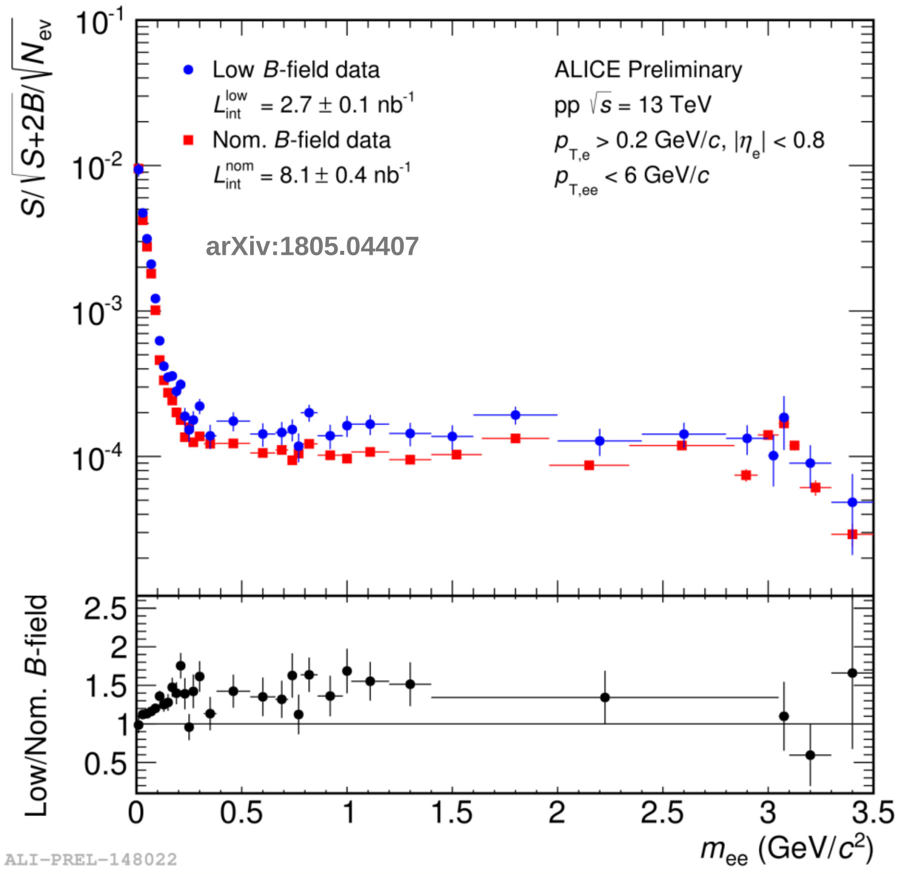
Additional photon conversion rejection based on their characteristic orientation relative to the magnetic field



Effects of low field

Comparison to nominal field setting in S/B and significance

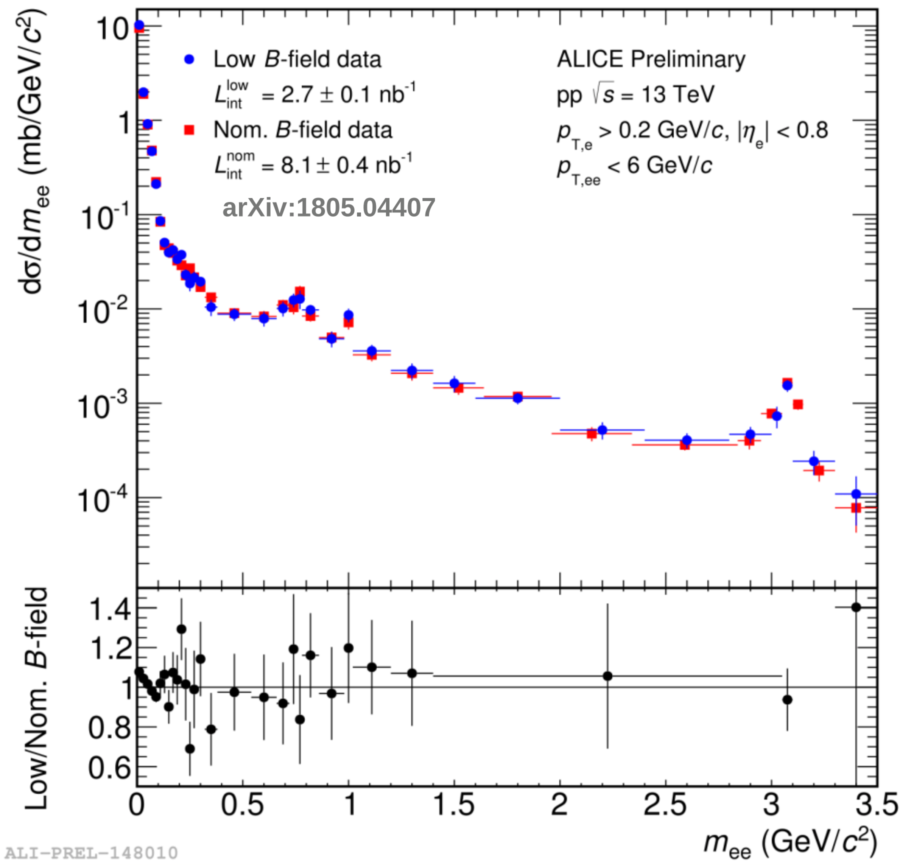




Higher tracking and PID efficiency in **low field**:
- Improvement in S/B especially for low invariant masses
- Clear boost in significance per event: reduction of stat. uncertainty

Corrected spectra

Comparison to nominal-field setting



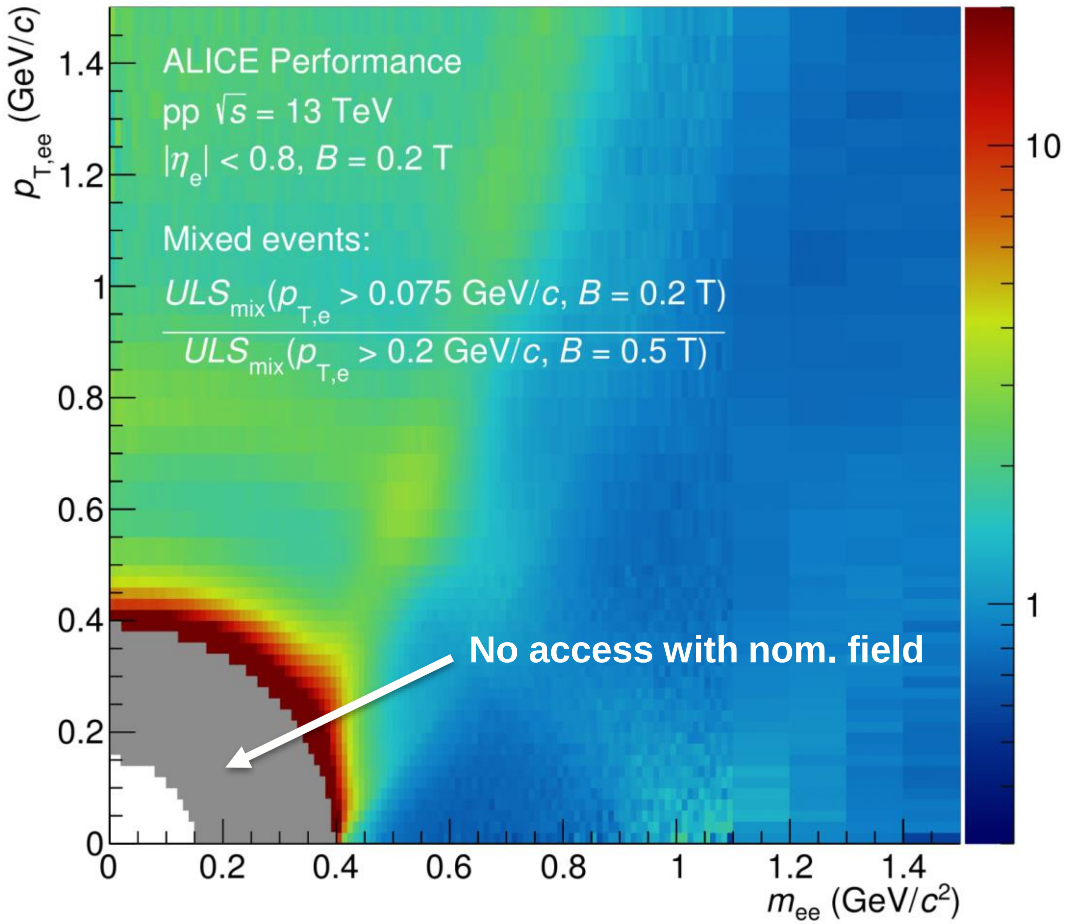
Comparison with published data within same kinematic region: ($p_T \geq 0.2$ GeV/c)

- Good agreement within statistical uncertainties
- Effect of low-field configuration on the resolution small within the given statistics
- Similar significance compared to measurement at nominal field ($\sim 440 \cdot 10^6$ vs. $\sim 150 \cdot 10^6$ events)

Low-B-Field Acceptance

Effects of the magnetic field

Mixed events: **Low Field** ($p_{\mathrm{T}} > 75\ \mathrm{MeV}/c$) / **Nom Field** ($p_{\mathrm{T}} > 200\ \mathrm{MeV}/c$)



ALI-PREL-148880

Gain in phase space with low field:

- Acceptance: lower single-leg p_{T}
- Efficiency: TOF

→ Increase sensitivity for soft virtual-photon production

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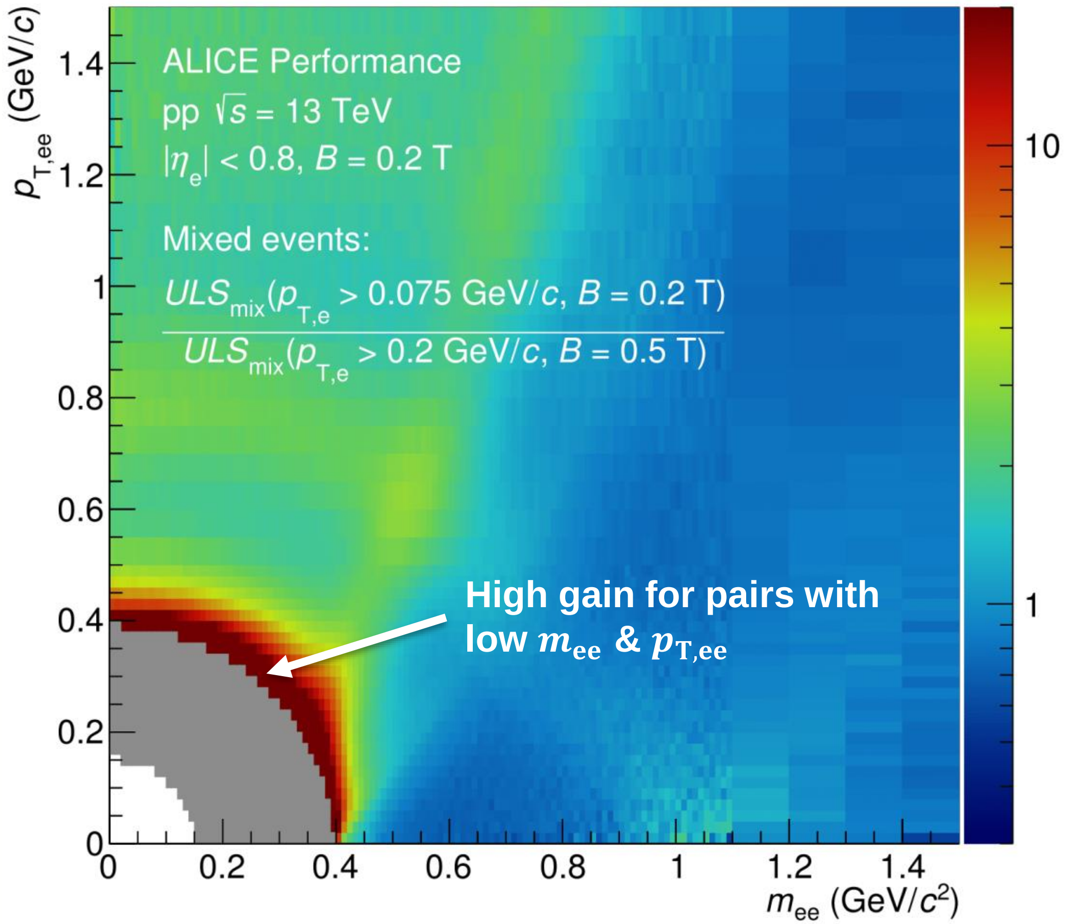

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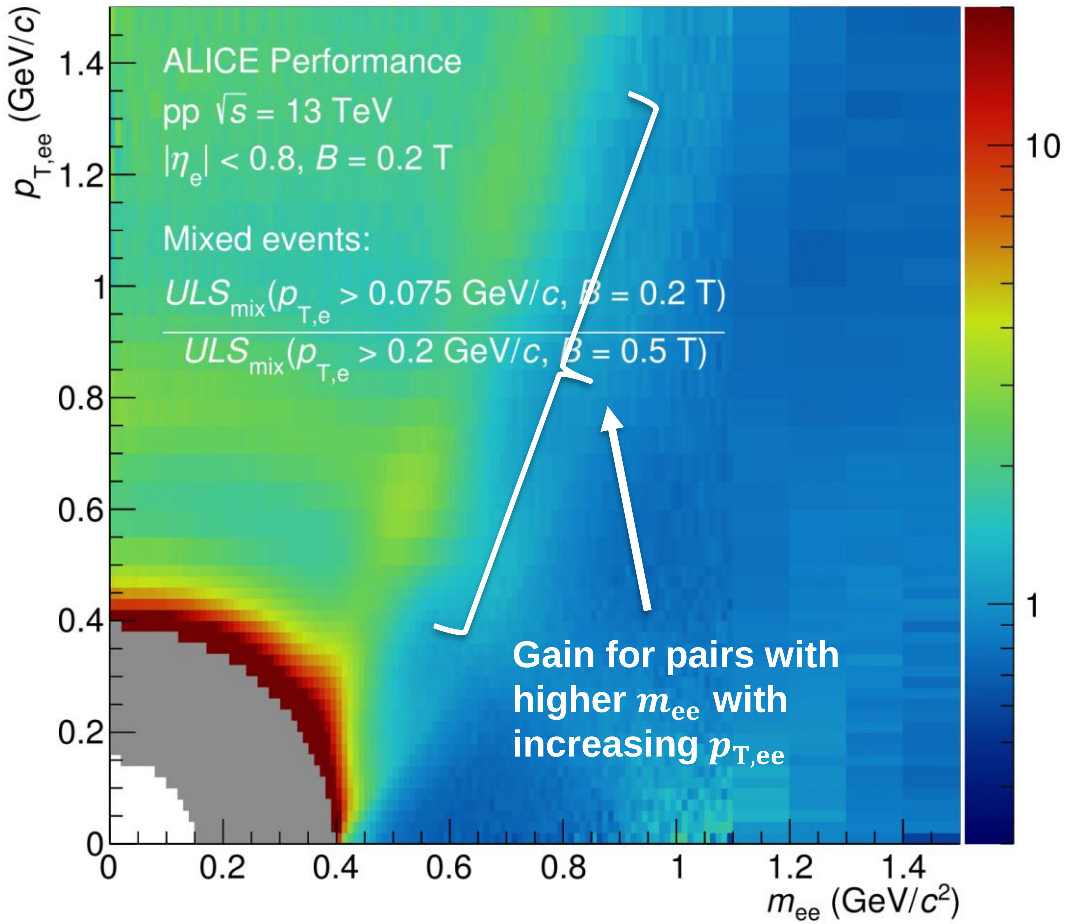

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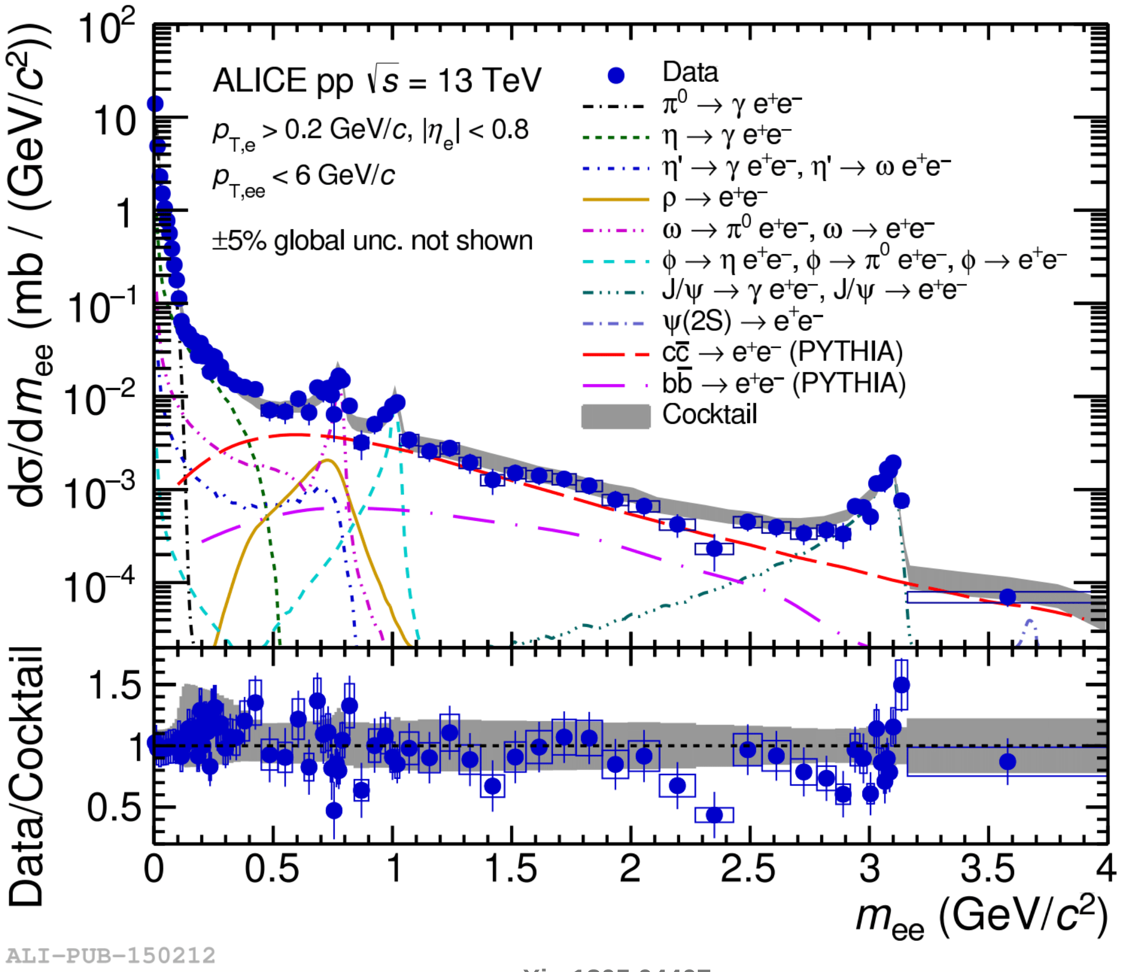
Dielectron production

Corrected spectra & hadronic cocktail

Published 13 TeV nominal Field



arXiv:1805.04407

Cocktail: (mainly analogous to nom.-field analysis)

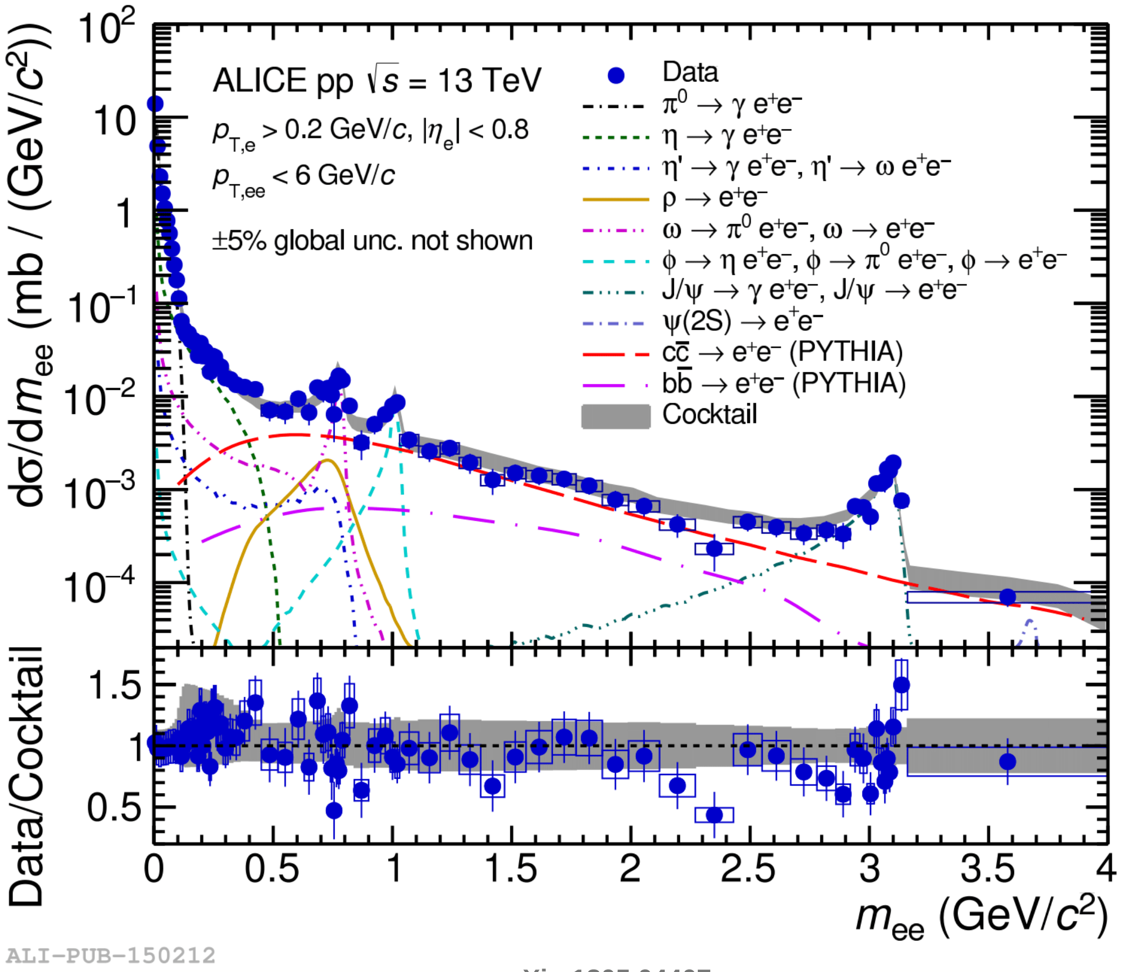
- π^0: parametrisation of p_T spectrum of $\pi^\pm$ in pp collisions at $\sqrt{s}$ = 13 TeV using a modified Hagedorn, $\pi^0/\pi^\pm$ estimated using an effective model that describes measured hadron spectra at low p_T
  → p_T-dependent scaling factor:
  upward shift by 18±6% for $p_T \to 0$
  drops monotonically to below 1% at p_T > 1 GeV/c
- LF: π^0 combined with particle ratios for η, ρ and ω, m_T scaling for remaining particles and cocktail unc.
- HF: Pythia6 scaled with FONLL cross sections to 13 TeV
- J/ψ: 7 TeV parametrisation scaled with FONLL to 13 TeV

→ Good agreement within uncertainties

Dielectron production

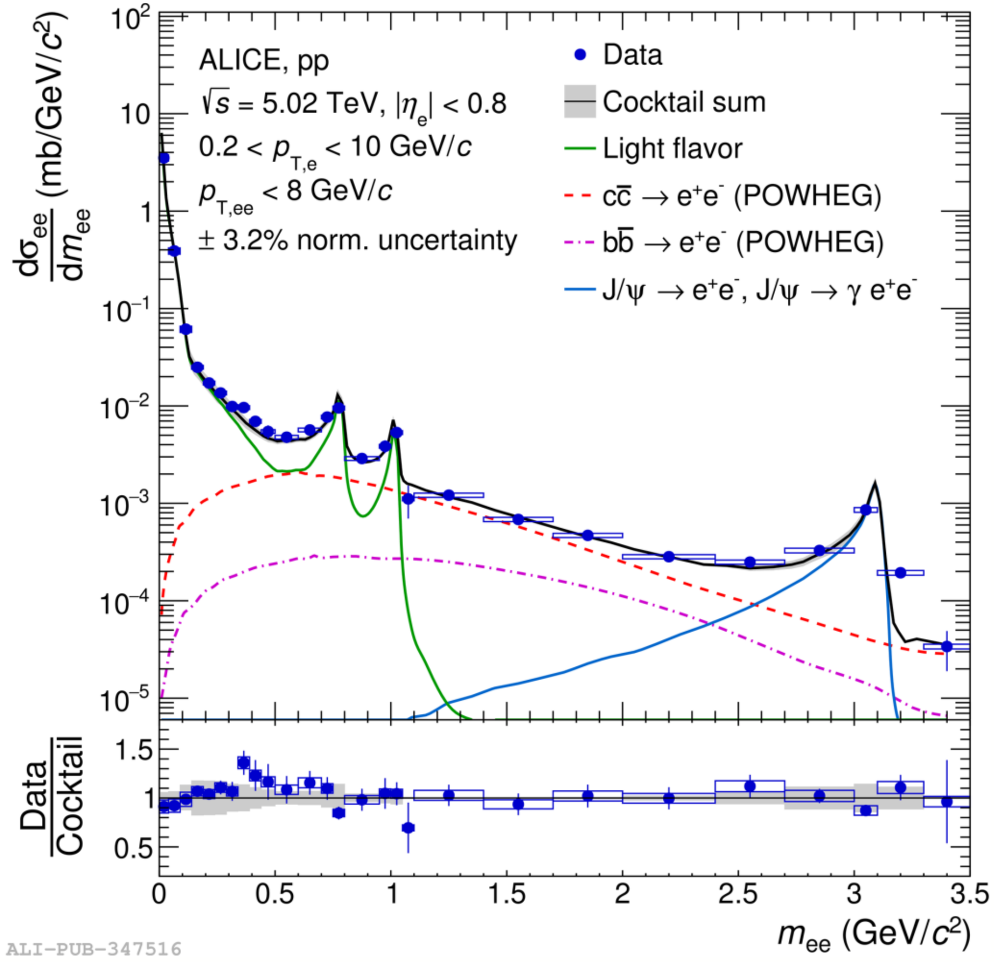
Corrected spectra & hadronic cocktail

Published 13 TeV nominal Field



arXiv:1805.04407

Published 5 TeV nominal Field

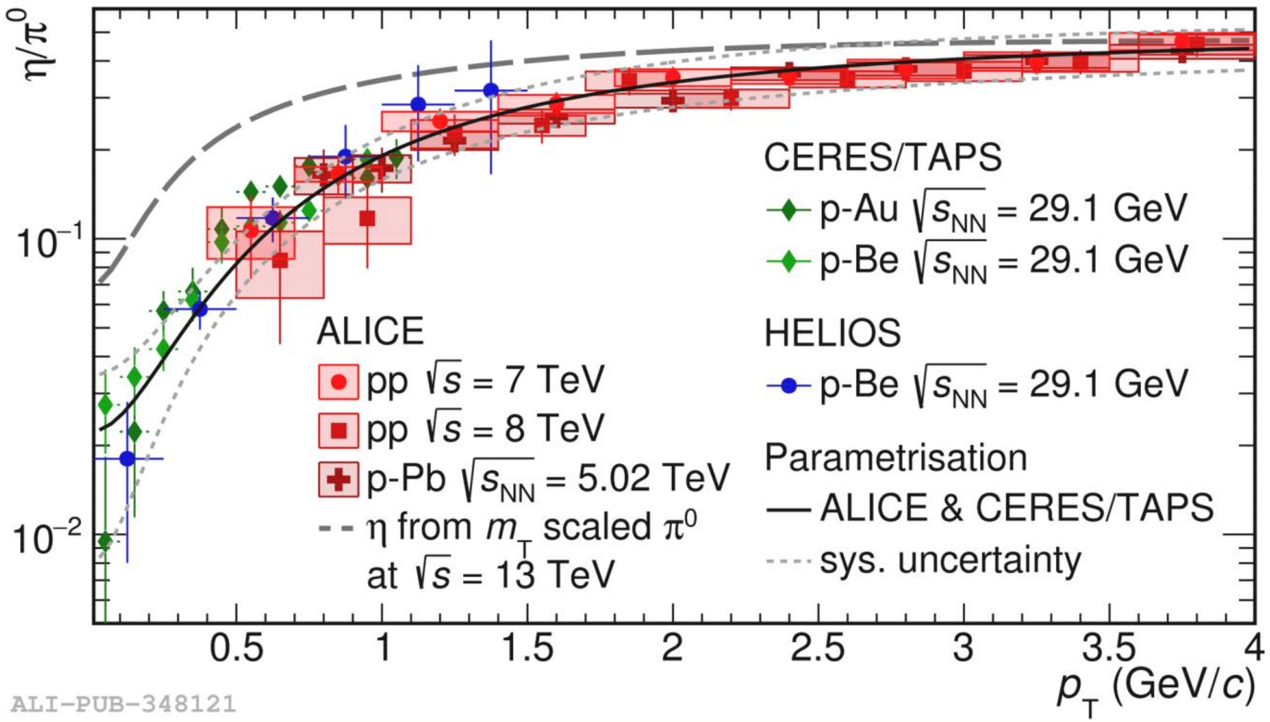


Hadronic Cocktail

arXiv:2005.14522

Low-p_{T} η parametrization

η contribution dominates the hadronic cocktail in the LMR:



ALI-PUB-348121

- ALICE measurement only down to $p_{\mathrm{T}} < 0.4\ \mathrm{GeV}/c$
- m_{T} scaling overshoots η at low p_T

New η-parametrisation required:

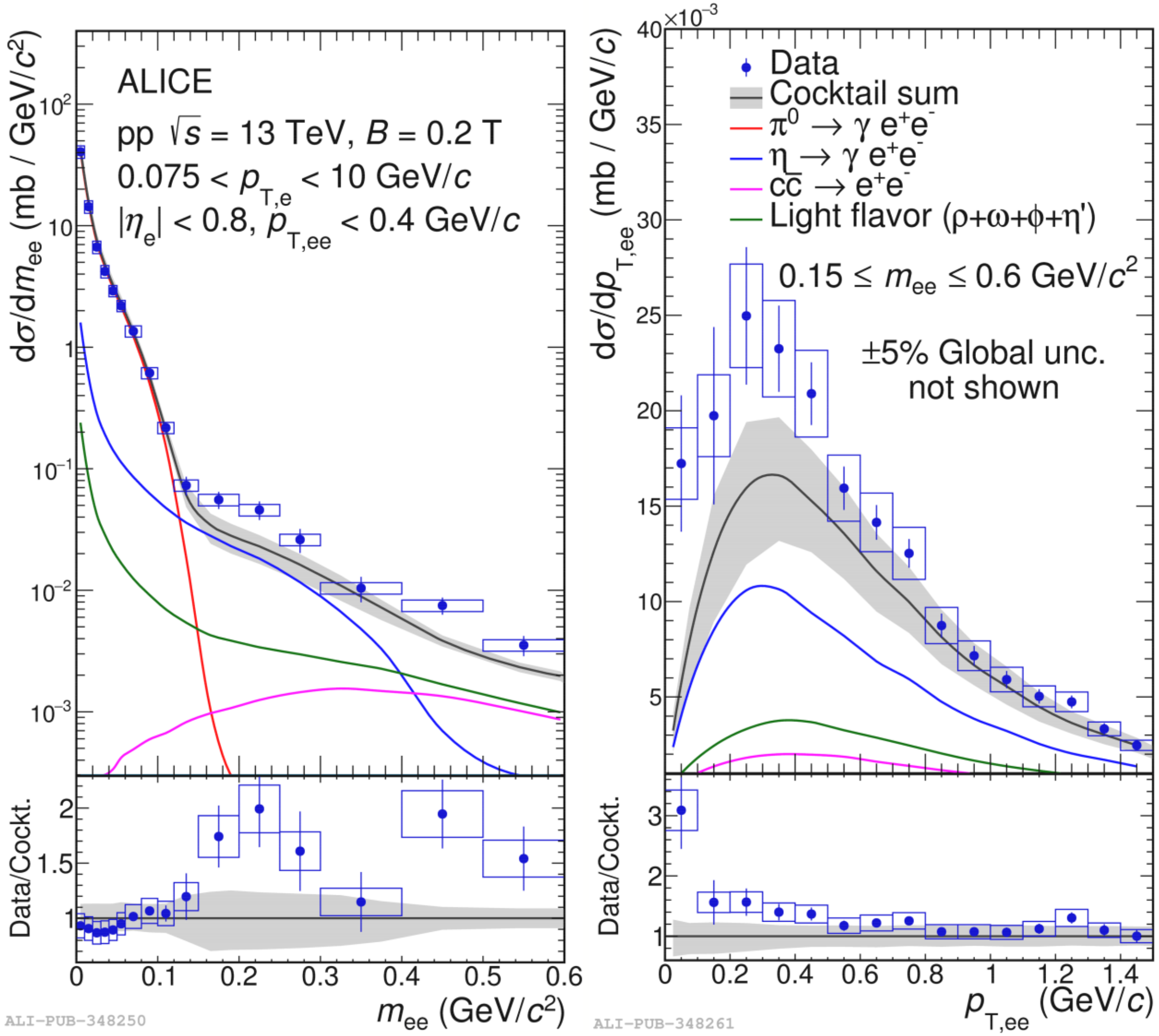
- Ceres/Taps data to constrain the cocktail at low p_{T}
  → Assumption: η/π^0 ratio independent of collision system and energy *Eur.Phys.J.C* 4 (1998) 249-257

Estimated uncertainty:
→ 15% at p_{T} > 0.5 GeV/*c* where data from LHC exist
→ 40% at smaller p_{T} covering the full spread of the data and a possible weak energy dependence

Dielectron production

Soft dielectrons in pp at 13 TeV

arXiv:2005.14522



Enhancement also observed at LHC energies

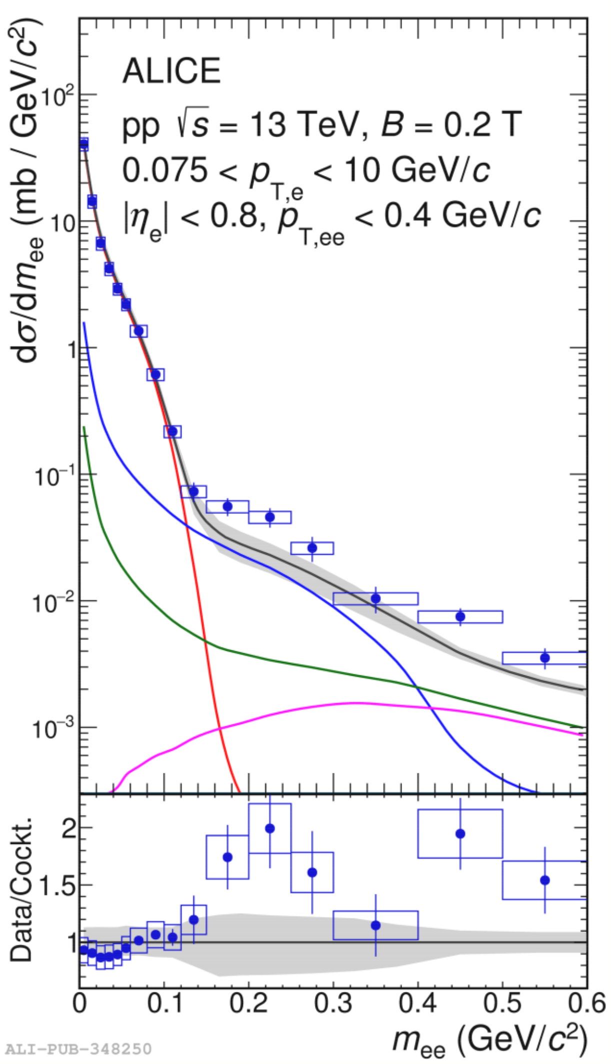
$0.14 < m_{ee} < 0.6\ \mathrm{GeV}/c^2$ & $p_{\mathrm{T,ee}} < 0.4\ \mathrm{GeV}/c$
→ 1.69 ± 0.14 (stat.) ± 0.18 (syst.) ± 0.36 (cocktail)

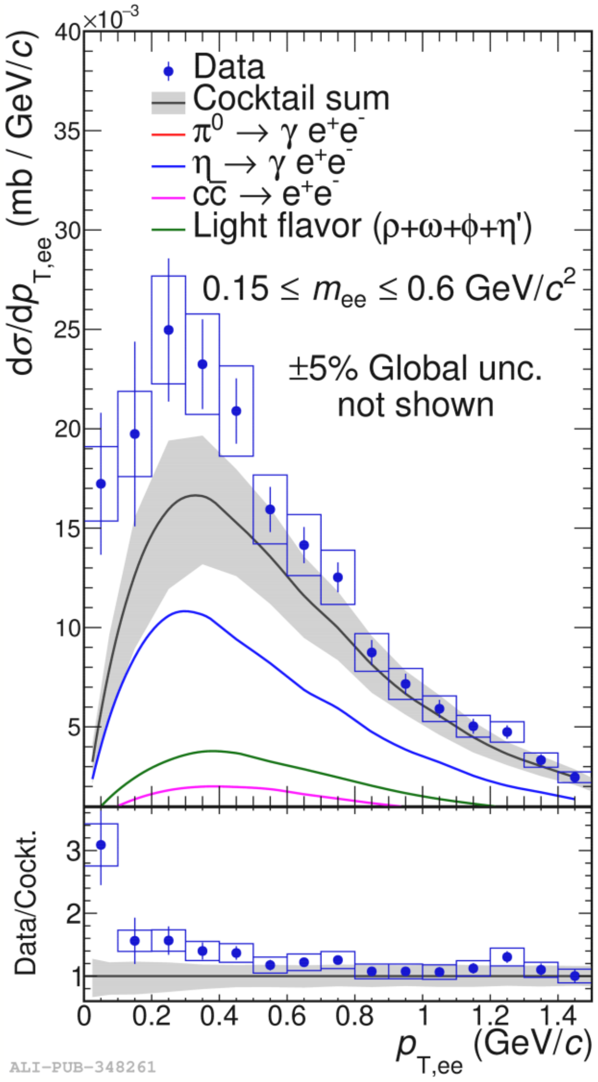
Significance mostly limited by hadr. cocktail uncertainty
→ Independent low-p_{T} π^0 & η measurement at LHC energies required

Dielectron production

arXiv:2005.14522

Soft dielectrons in pp at 13 TeV





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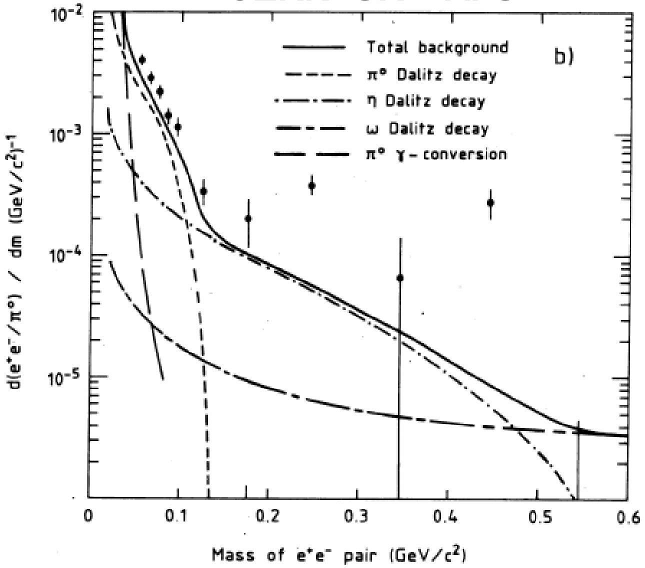
CERN ISR – AFS



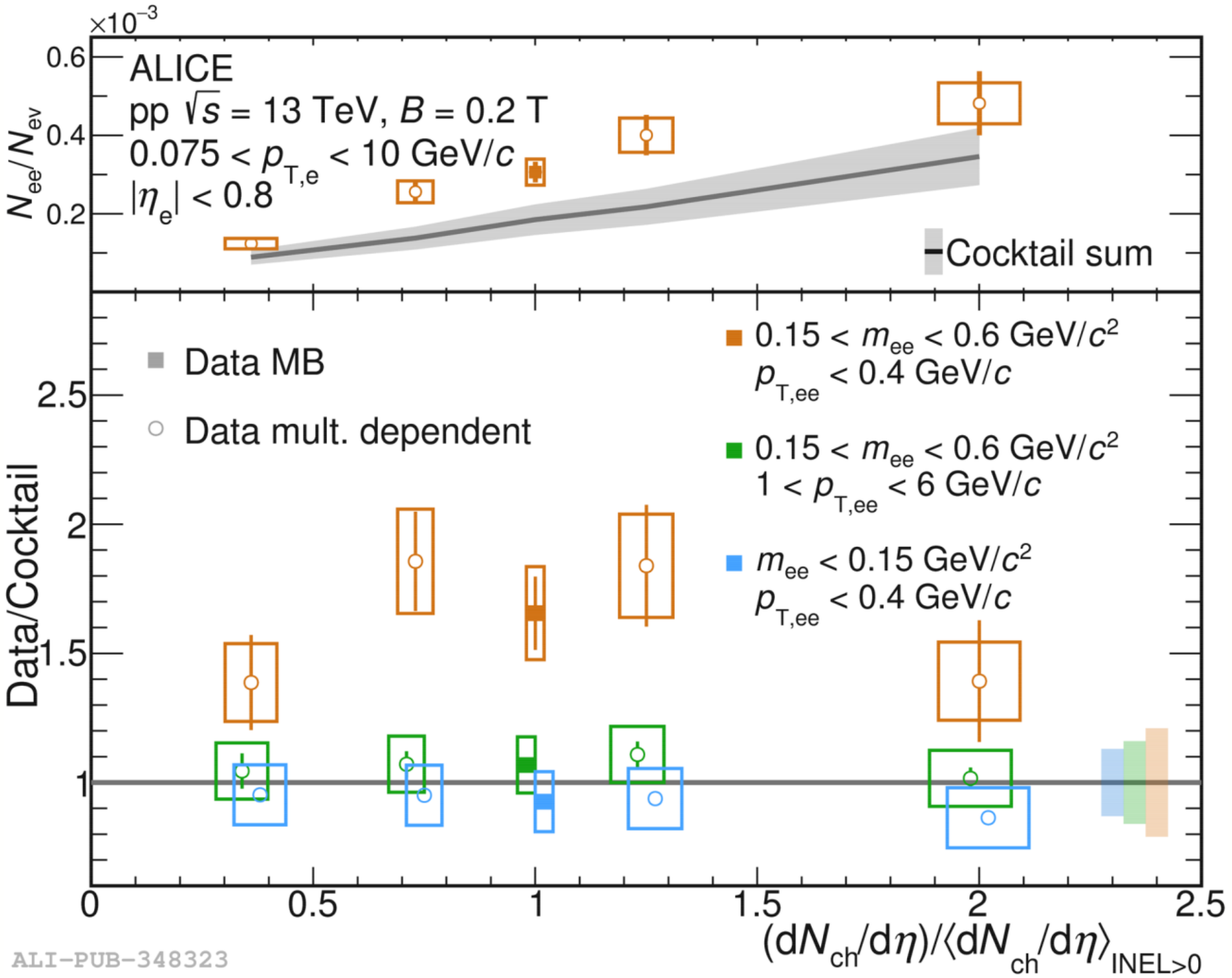
V. Hedberg, PhD thesis, Lund (1987)

→ Qualitatively similar picture compared to the ASF results

Dielectron production

Soft dielectrons in pp at 13 TeV

arXiv:2005.14522



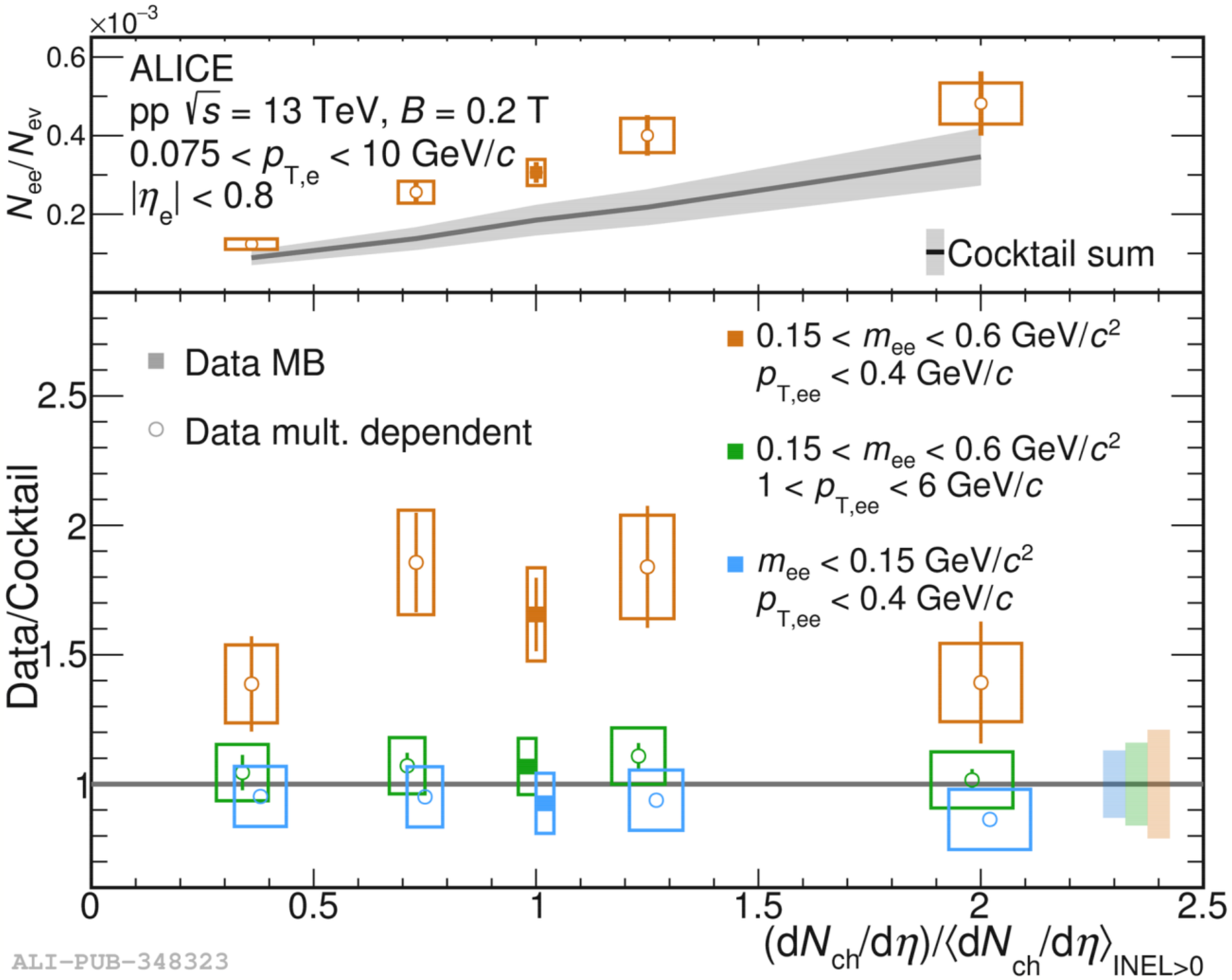
Multiplicity dependence may give insight about the underlying production mechanism:

- 4 intervals of the event multiplicity based on the V0 signal
- Subdivision into different regions of m_{ee} and $p_{\mathrm{T,ee}}$

Dielectron production

Soft dielectrons in pp at 13 TeV

arXiv:2005.14522



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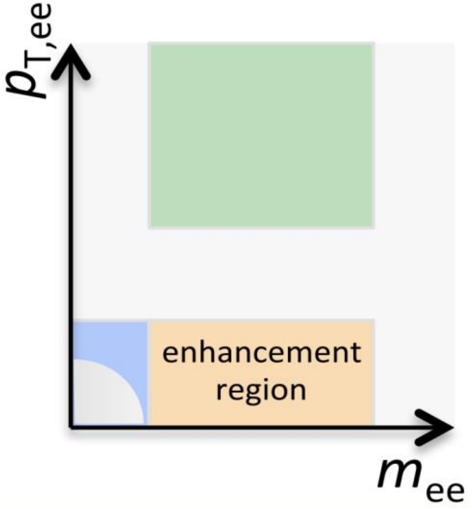


→ No excess at lower m_{ee} or higher $p_{T,ee}$

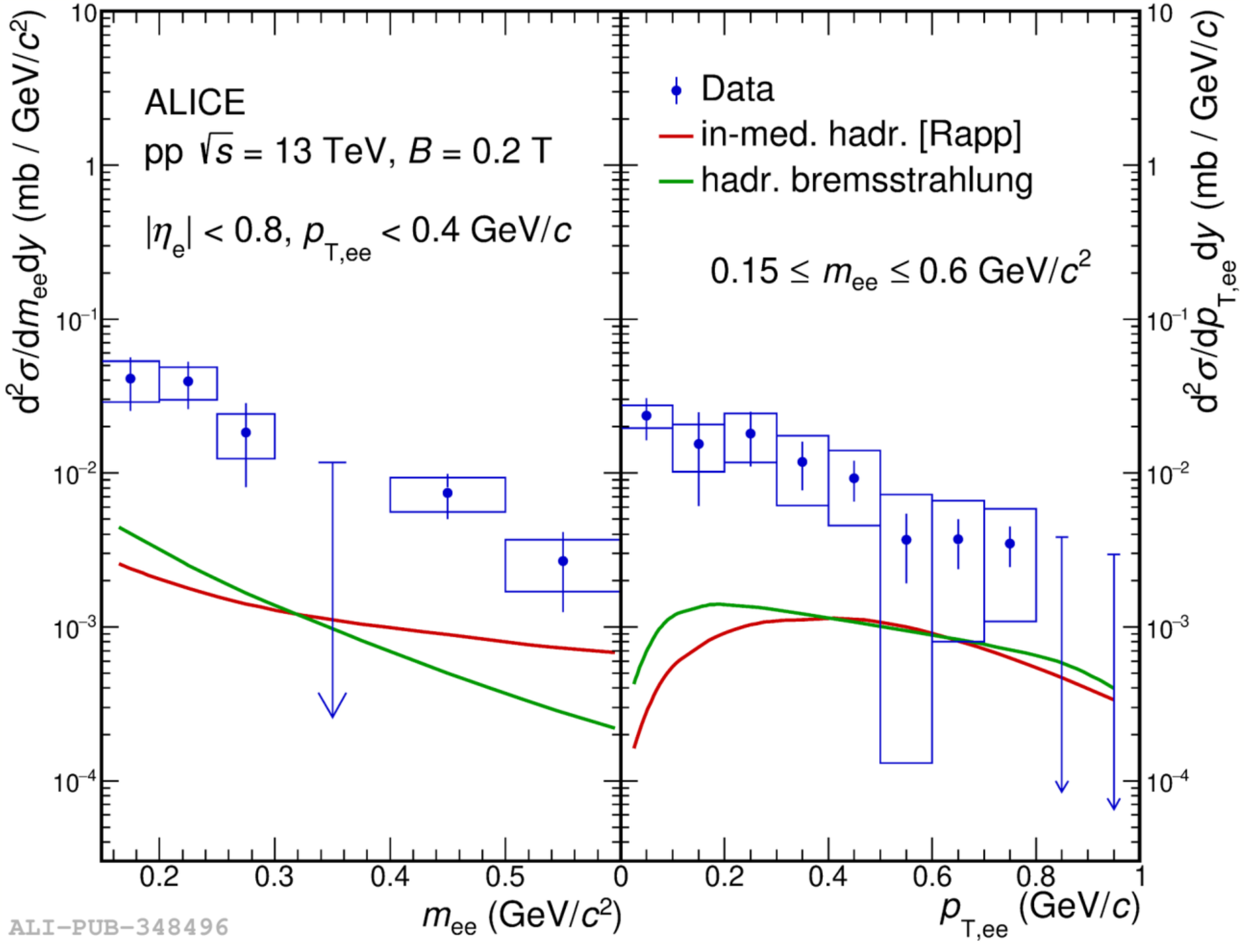
→ No clear multiplicity dependence within uncertainties
 - Most consistent with linear scaling

Dielectron production

Soft dielectrons in pp at 13 TeV

arXiv:2005.14522

ALICE



Excess spectra after subtraction of the hadr. cocktail

Corrected for single-electron acceptance in $p_{\mathrm{T,e}}$ & η_{e}

→ Assuming iso. decay in the pair center-of-mass frame

→ Enables measurement of the excess cross section in $m_{\mathrm{ee}} > 0.15$ GeV/c^2 and $p_{\mathrm{T,ee}} > 0$ at midrapidity

Comparison to theory predictions:

→ Data exceeds description of thermal fireball model or hadronic bremsstrahlung

→ Coherent two-photon production of lepton pairs insufficient to describe the data due to its strong Z-dependence

Soft dielectrons in pp at 13 TeV

Summary

With the application of the low-field setup ALICE measured an excess of soft dielectrons over the expectation from hadron decays in pp collisions at $\sqrt{s} = 13$ TeV

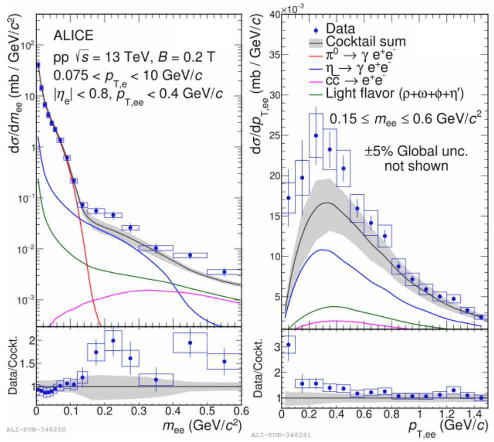
The enhancement factor estimated to be:
1.69 ± 0.14 (stat.) ± 0.18 (syst.) ± 0.36 (cocktail)

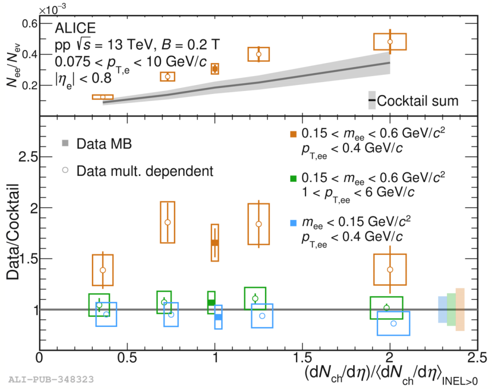
No clear dependence on the event multiplicity observed yet

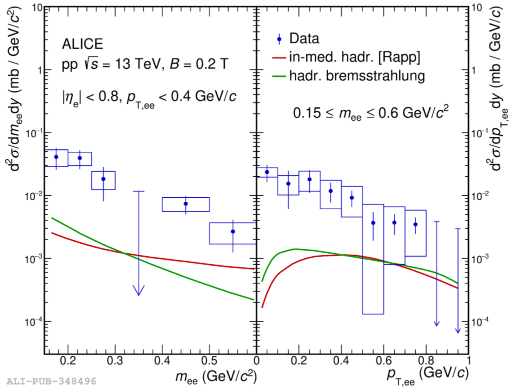
Acceptance-corrected excess yield cannot be explained by hadr. bremsstrahlung or by thermal dielectron production

The current measurement mostly limited by the uncertainty of the hadronic cocktail

Forthcoming precision measurements with the upgraded ALICE detector will help to further elucidate this finding







Dielectron production

Run 3 and 4

[CERN-LHCC-2013-020,CERN-LHCC-2013-024, CERN-LHCC-2015-001, ALICE-PUBLIC-2020-005]

<u>Detector upgrades:</u>

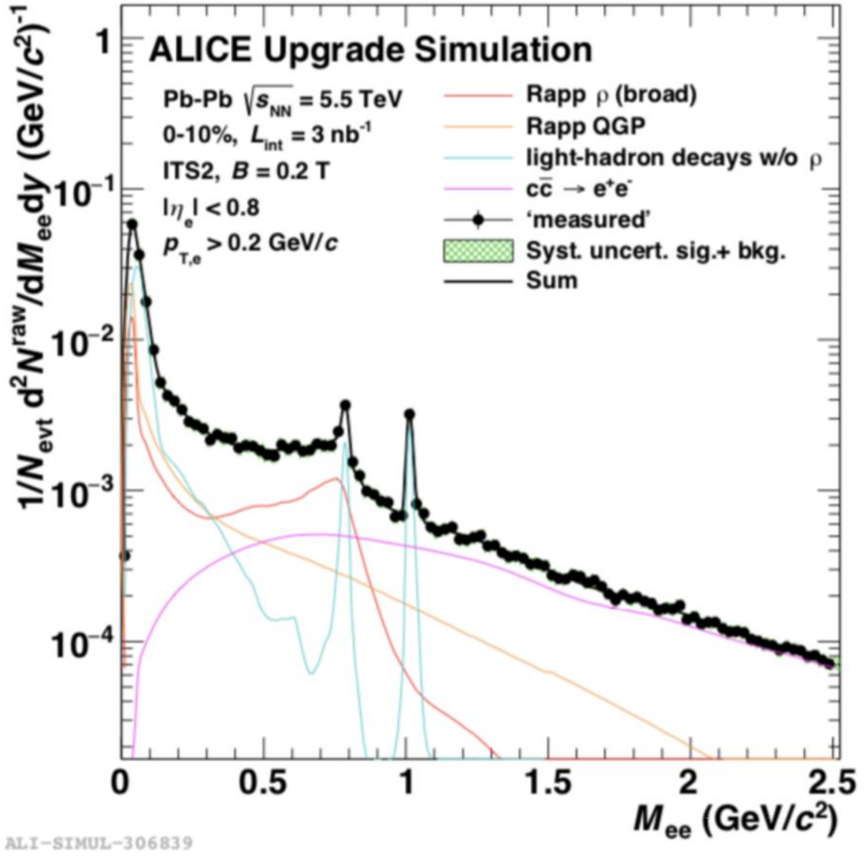
New ITS and upgrade of the TPC to a GEM based readout system:

- Improve the vertex pointing resolution by a factor 3-6
  - → Improves topological separation (DCA_{ee})
- Increase the readout rate in Pb–Pb by a factor 100
  - → 13 nb^{-1} MB Pb-Pb planned

<u>New low-field data taking campaign:</u>

Dedicated dielectron runs with low magnetic fields (B = 0.2 T):

- Increase statistics in pp collisions by a factor of 400
  - → Allows a precise multi-differential analysis
- First Pb-Pb runs (3 nb^{-1})
  - → Study of soft-dielectron production in medium



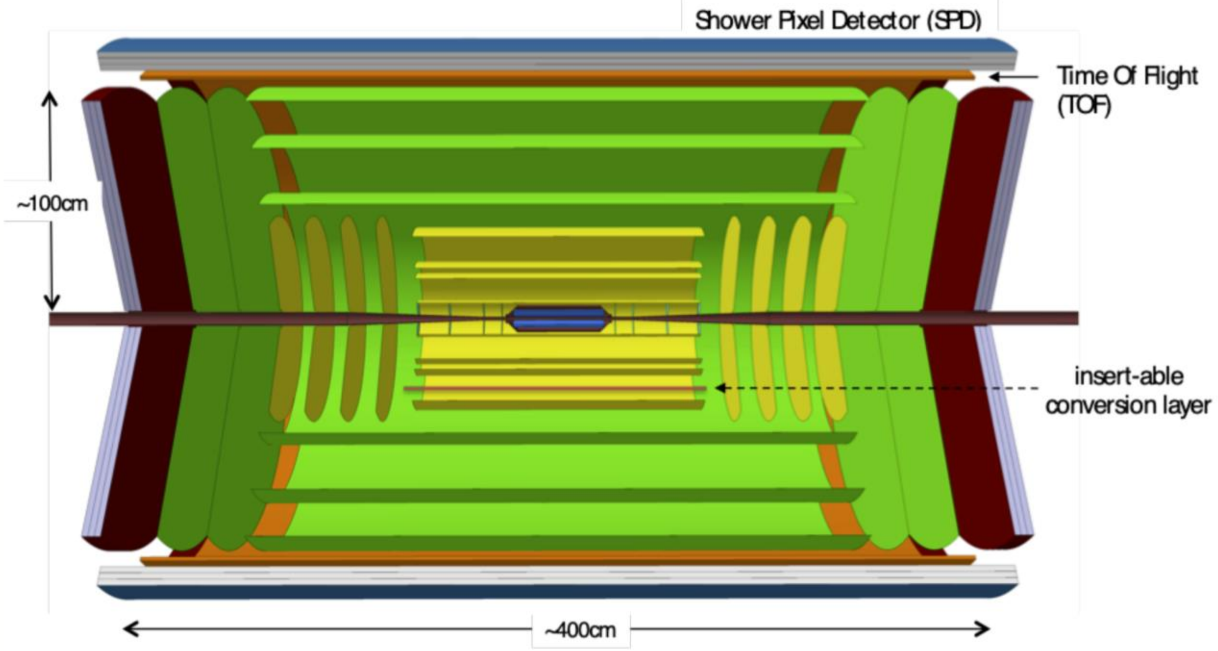
Citron, Z. et al, 1812.06772

Dielectron production

arXiv:1902.01211

Run 5+

A next-generation LHC heavy-ion experiment



Silicon based tacking:
- ~10 layers (blue, yellow, green) based on MAPS technology (p_T~$10\ \mathrm{MeV}/c$)

Particle ID:
- TOF with 3 outer silicon layers (red)

Electron ID:
- via TOF ($p_T < 0.5\ \mathrm{GeV}/c$) & pre-shower pixel detector (blue)

Photons:
- EMCal & conversion tracker/forward calorimeter

Key properties:

Ultra-low material budget for low pT tracking
- X/X0 ~ 0.05 % / layer

fast to sample large luminosity
- 50 - 100x Run 3/4

large acceptance
- $|\eta| < 4 \rightarrow \Delta\eta = 8$ (total)
- $|\eta| \approx 1.4$ (central barrel)

excellent spatial resolution for tracking and vertexing
- innermost layers: σ < 3 μm
- outer layers: σ ~ 5 μm

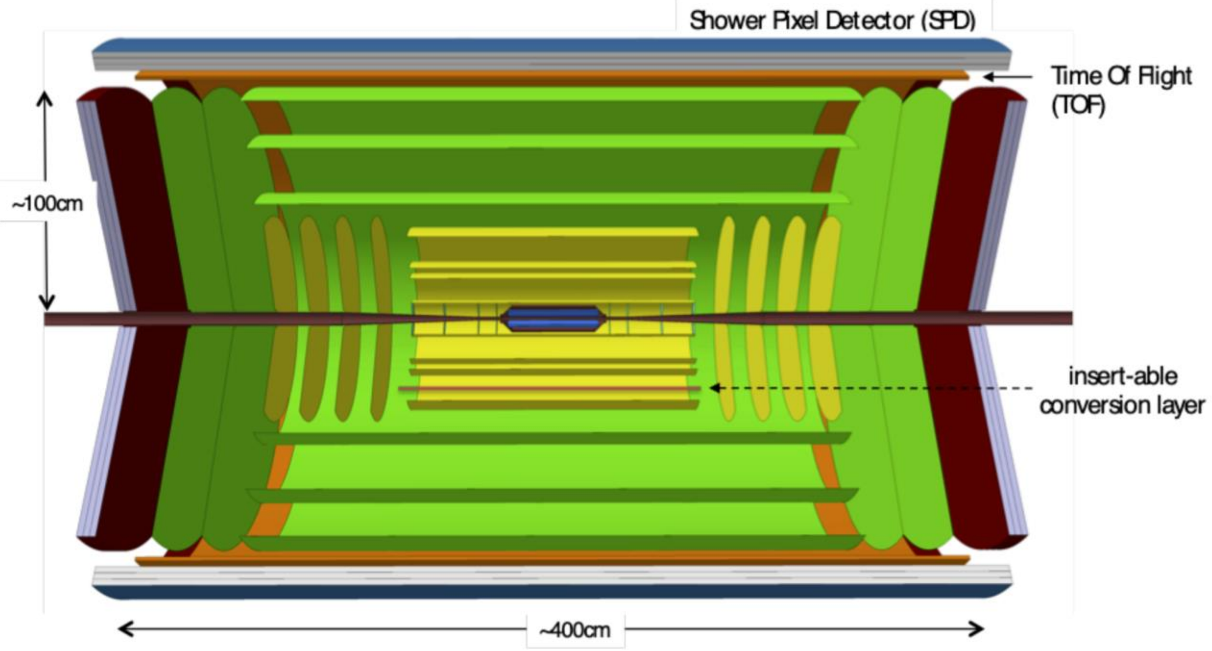
precise time measurement for particle identification
- σ ~ 20 ps

Dielectron production

Run 5+

arXiv:1902.01211

A next-generation LHC heavy-ion experiment



Letter of Intent to be prepared by the end of 2021!

Physics goals:

Heavy flavour
- Multiple-HF baryons: formation, coalescence etc.
- Heavy-flavor correlations, jets
- Quarkonia & Exotic states

Di-electrons:
- QGP temperature & flow measurement
- Chiral symmetry restoration
- Conductivity of the QGP

Low- p_T physics:
- Soft photon production ↔ Low's theorem
- Hadron production: condensates, low- p_T pion excess

Non-SM physics: dark photons, etc.

THANK YOU

Backup

‘Anomalous’ radiation in small systems

The ‘Anomalous Soft Photon’ (ASP) puzzle

p+Be measurement by Antos et al.

Z. Phys. C59 (1993) 547-554

ToF method

BaF$_2$ calorimeter

hadron rejection:
- charged: scintillator in front of BaF$_2$
- neutral (n, K_L^0): time-of-flight

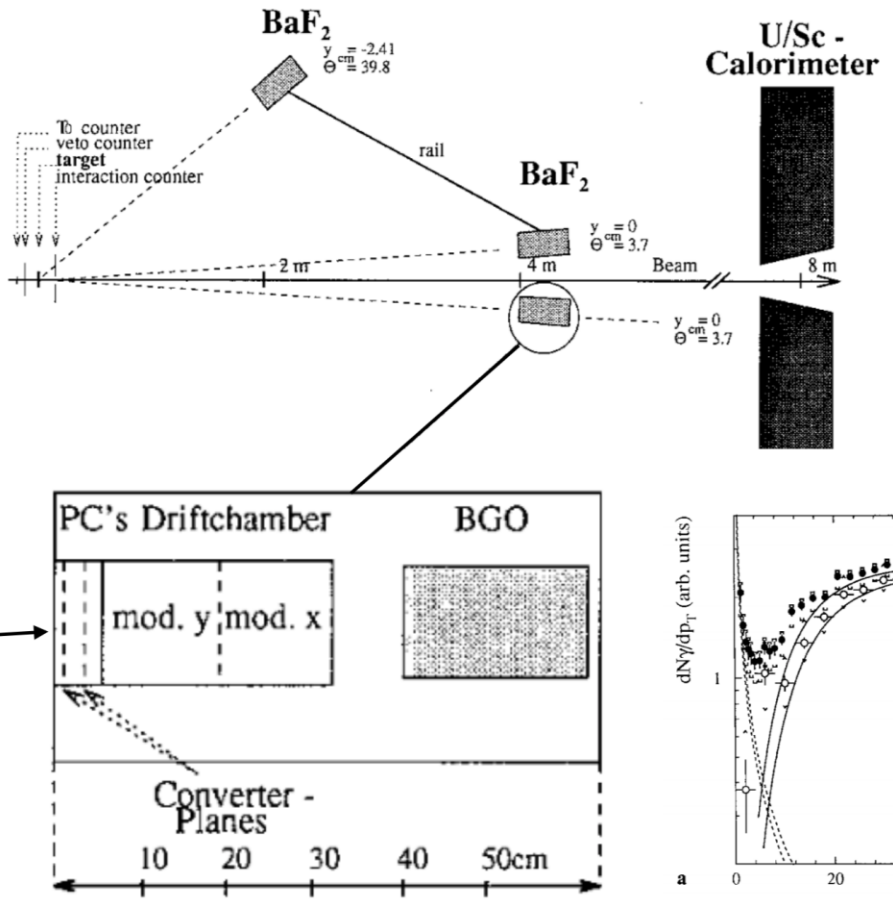
BGO conversion method

converters + tracking + BGO calorimeter

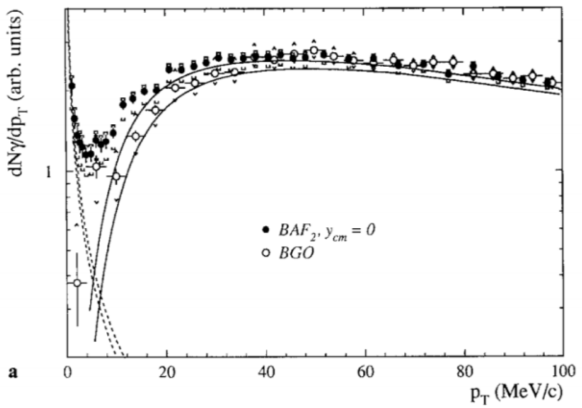
two iron converters (10% and 3% X_0)

BGO calorimeter:

$\sigma_E/E = 2.6\,\%/\sqrt{E/\mathrm{GeV}}$



"modified setup of the HELIOS experiment"



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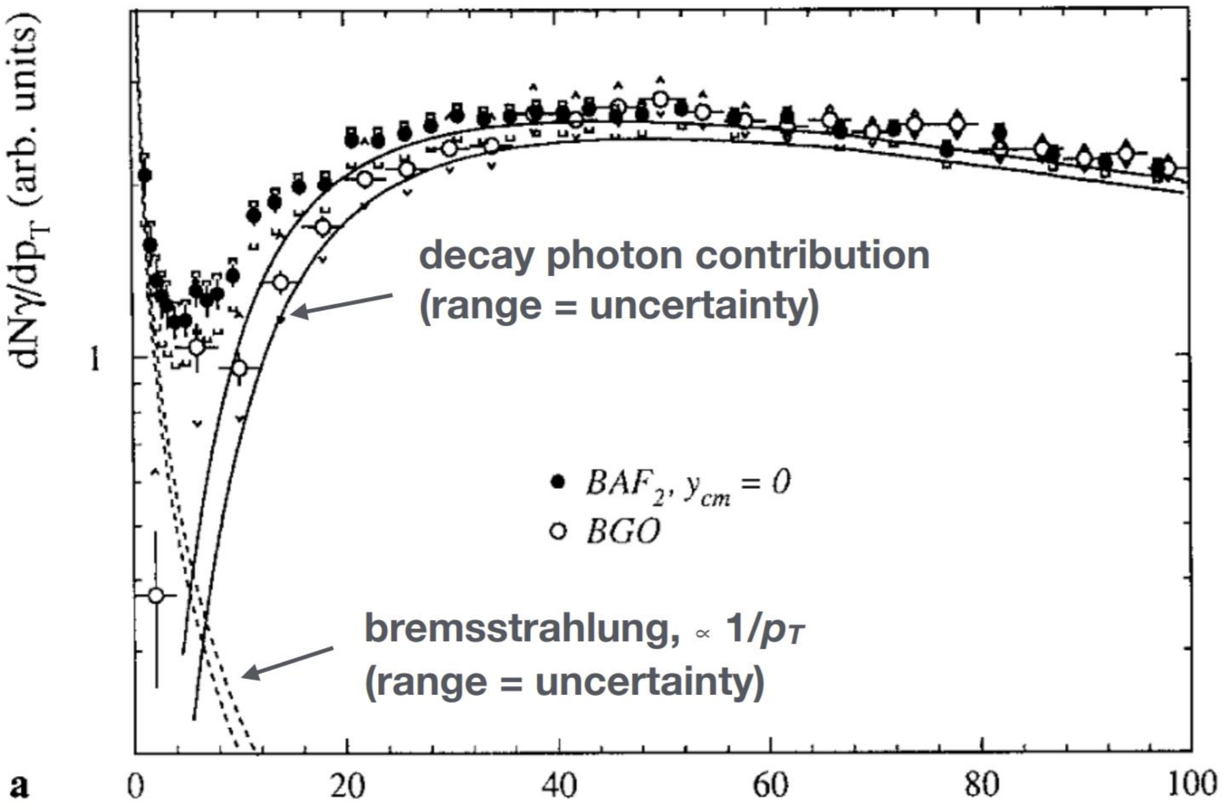


Two methods (BaF_2 and BGO)

Photons measured down to p_T = 1 MeV/c

No significant excess

Upper limit on additional 'anomalous' sources relative to bremsstrahlung: factor 2 at p_T = 10 MeV/c

Measurement at y_{CM} = 0

Hadronic Bremsstrahlung

Dielectons

Low theorem allows calculation based on hadr. cross section

Photons: diverge for k→0

$$\omega \frac{d^3\sigma}{dk^3} \simeq \frac{\alpha}{\pi^2 k_t^2}\left(\langle\Delta^2(0)\rangle + 0.35\rho_{ch}(0) + 0.05\rho_{ch}^2(0)\right)\sigma_{hadr}$$

(Rueckl approximation)

Dielectrons: no divergence due to mass term

(A search of a mechanism responsible for bremsstrahlung enhancement in hadronix reactions. III. Low mass dilepton production) Acta Physica Slovaca; 41 no. 4, (1991)

$$\left(\frac{d\sigma^{ee}}{dy\,dk_T\,dM}\right)_1 = \sigma_{hadr}^{inel}\,\frac{\alpha^2}{3\pi^2}\,\frac{k_T}{M}\,\frac{1}{k_T^2+M^2}\,4\langle\Delta Q(y_0)^2\rangle$$

$< \Delta Q^2 > \approx 1.32$ (extrapolation)

→ used as input in 2D toyMC to apply resolution

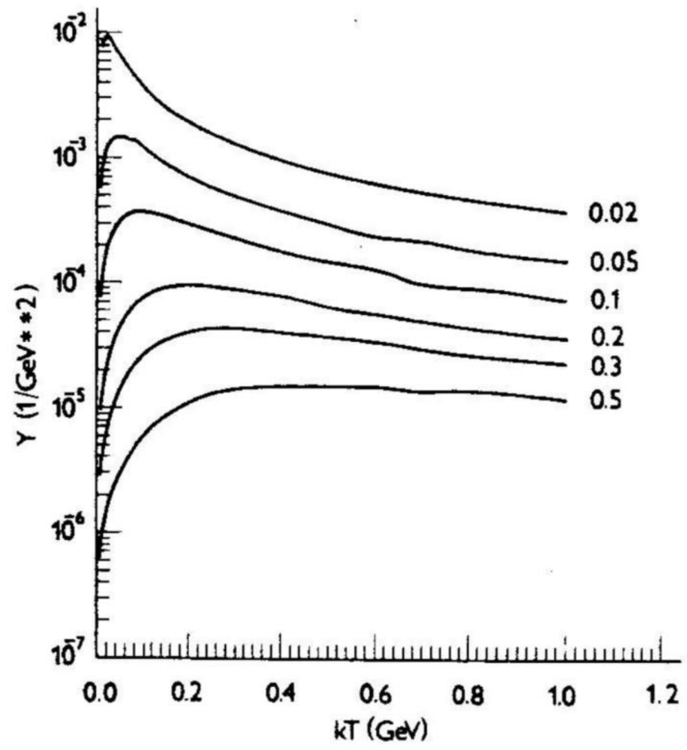


Fig. 2d. The sum of all contributions to the k_T-dependence of dilepton production at fixed dilepton mass M.

Hadronic Bremsstrahlung

Rapidly decreasing decay photon background

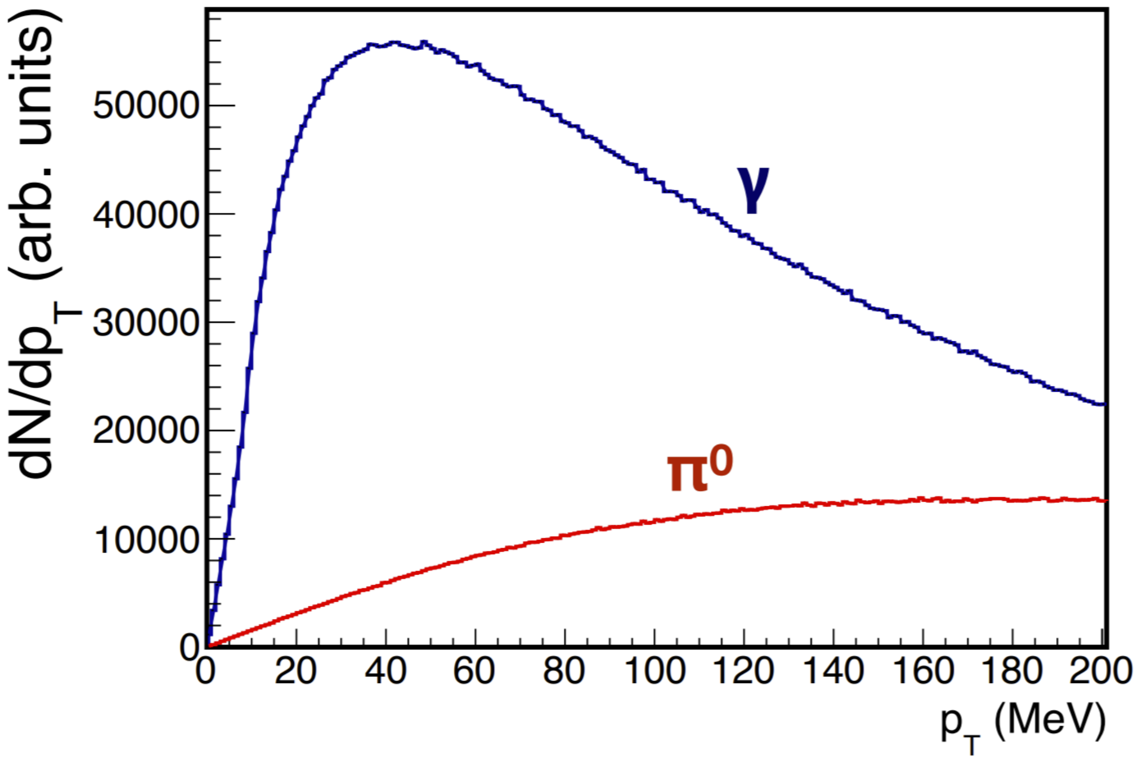
π^0 transverse momentum distribution:

$$\frac{dN_\pi}{dp_T} \propto \frac{p_T}{e^{m_T/T} - 1}, \quad T = 230\,\mathrm{MeV}$$

π^0 generated with flat dn/dy in $-5 < y < 5$

π^0 and γ with $-0.5 < y < 0.5$ counted in histogram

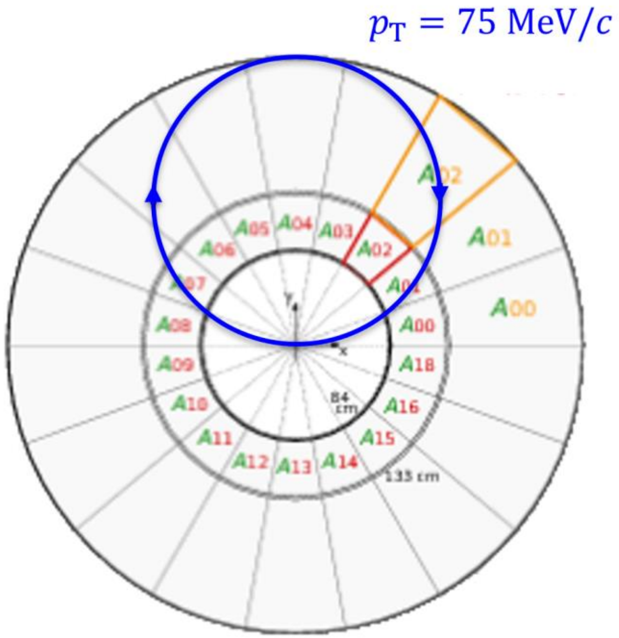
Due to the rest mass of the neutral pion the decay photon yield falls off rapidly for $p_T < 15$ MeV

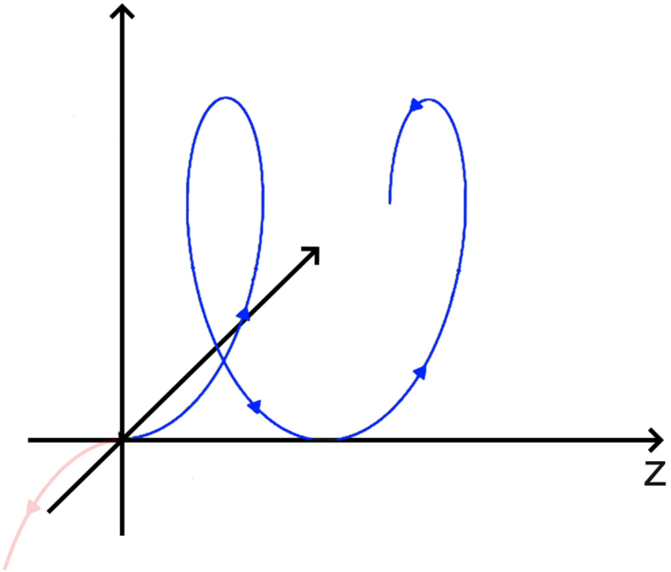


Low p_T dielectrons
Fake signal

A looping low-momentum track in the TPC with vanishing longitudinal momentum ($\eta = 0$) might hit the interaction point again

Such a looper might get incorrectly reconstructed by the tracking algorithm, a source of fake signal:





Low p_T dielectrons

Fake signal

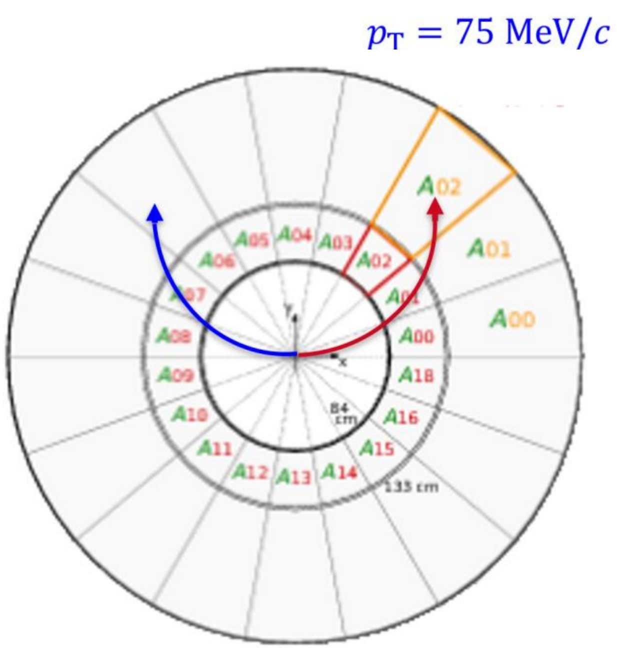
A looping low-momentum track in the TPC with vanishing longitudinal momentum ($\eta = 0$) might hit the interaction point again

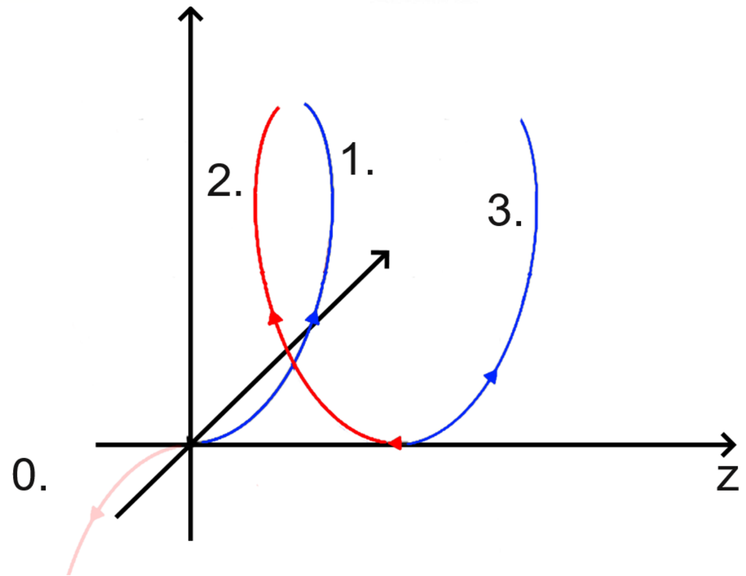
Such a looper might get incorrectly reconstructed by the tracking algorithm, a source of fake signal:

→ Accumulation of ULS pairs at $\eta = 0$ at low $p_{T,ee}$
Should scale linear with multiplicity

→ No contribution in the LS at at low $p_{T,ee}$

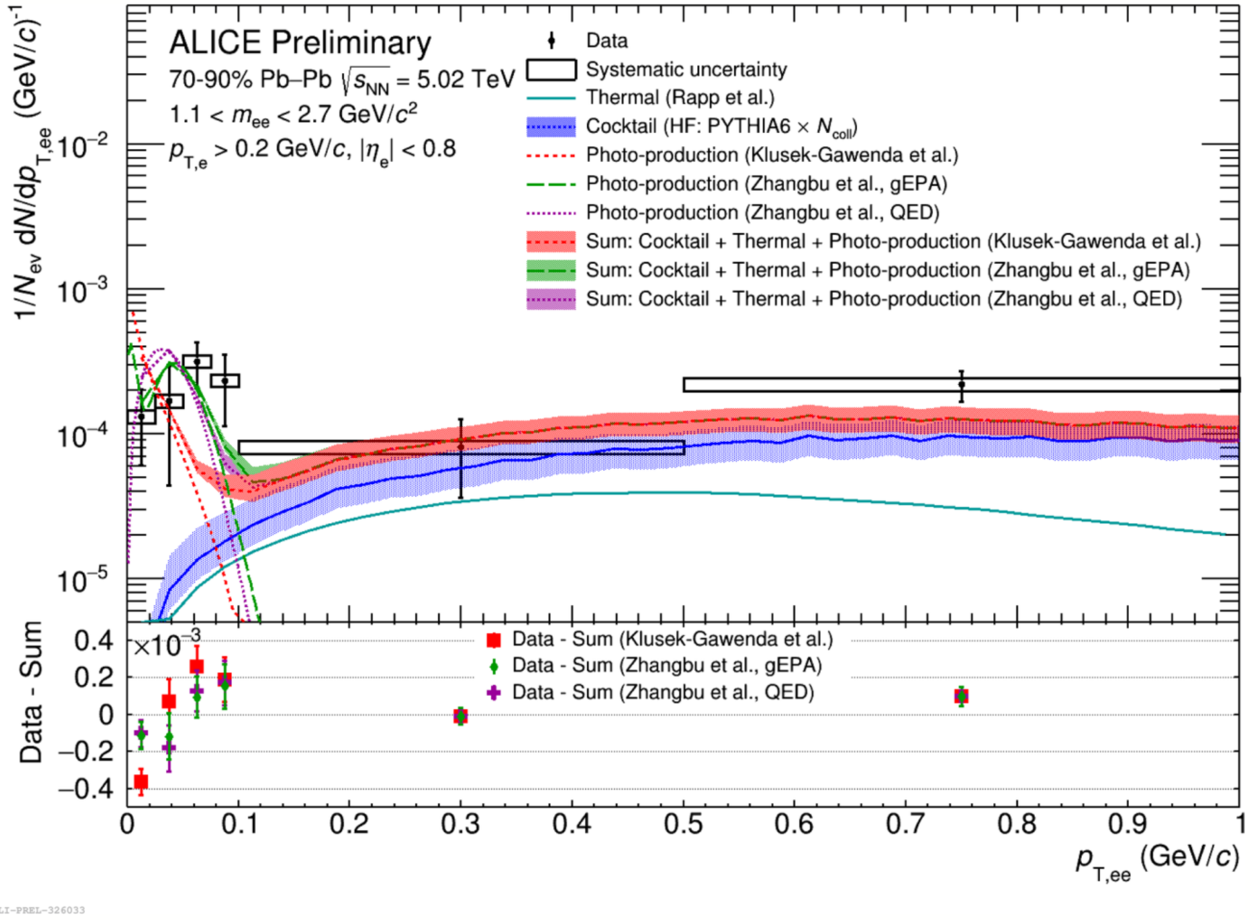
Rejection of these pairs based on a hard rejection of a displacement in z direction

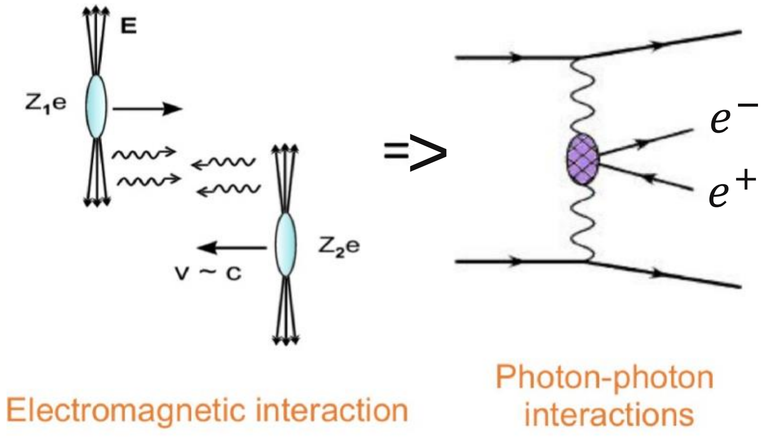




Dielectron production

Pb-Pb at 5 TeV





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

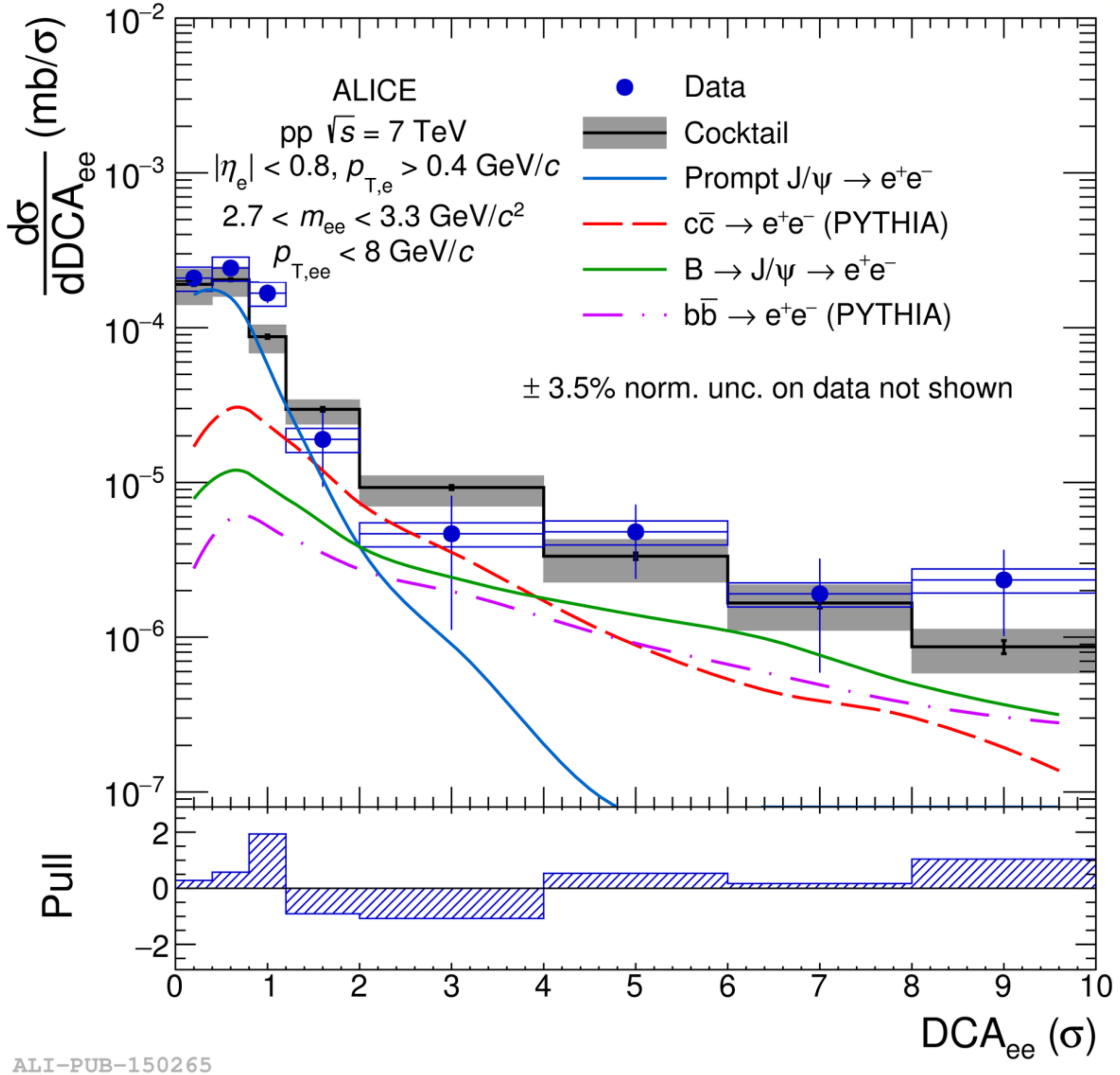
→ Consistent with coherent photoproduction
→ Similar to the observation by STAR
[Phys. Rev. Lett. 121.132301 (2018)]

More differential studies with 2018 data:

- Event plane angle
- Sensitivity to magnetic field

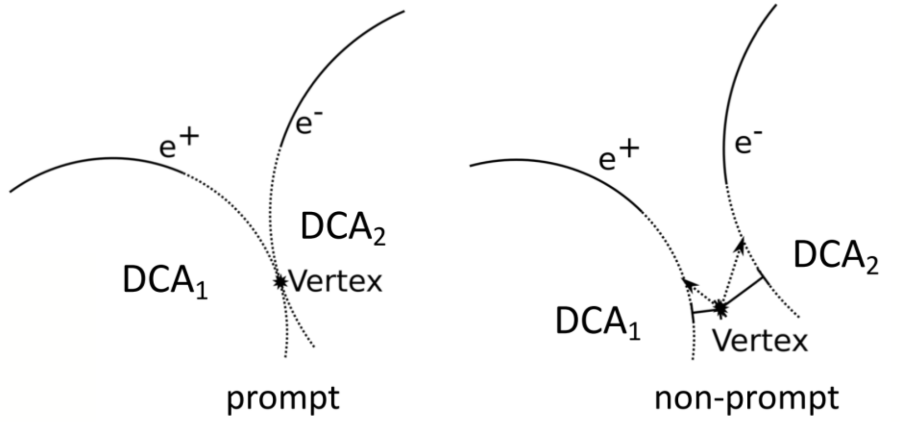
Dielectron production

Future DCA analysis



ALI-PUB-150265

Separation of prompt and non-prompt sources:



$$\rightarrow \mathrm{DCA_{ee}} = \sqrt{\frac{\mathrm{DCA}_1^2 + \mathrm{DCA}_2^2}{2}}$$

$$\rightarrow \mathrm{DCA_{ee}(thermal)} \gg \mathrm{DCA_{ee}(HF)}$$

Feasibility demonstrated in 7 TeV pp

→ To be applied in future dielectron analysis

→ Better resolution in Run 3

Background Estimation

Comparison of different Strategies

- $\mathrm{ULS_{BKG}} = M \cdot N - \min(M, N)$

  → $\mathrm{ULS_{BKG}} = \Omega \cdot \left(1 + \frac{AN}{\Omega}\right)$

- $\mathrm{LS_{Arith}} = \frac{M(M-1)+N(N-1)}{2}$

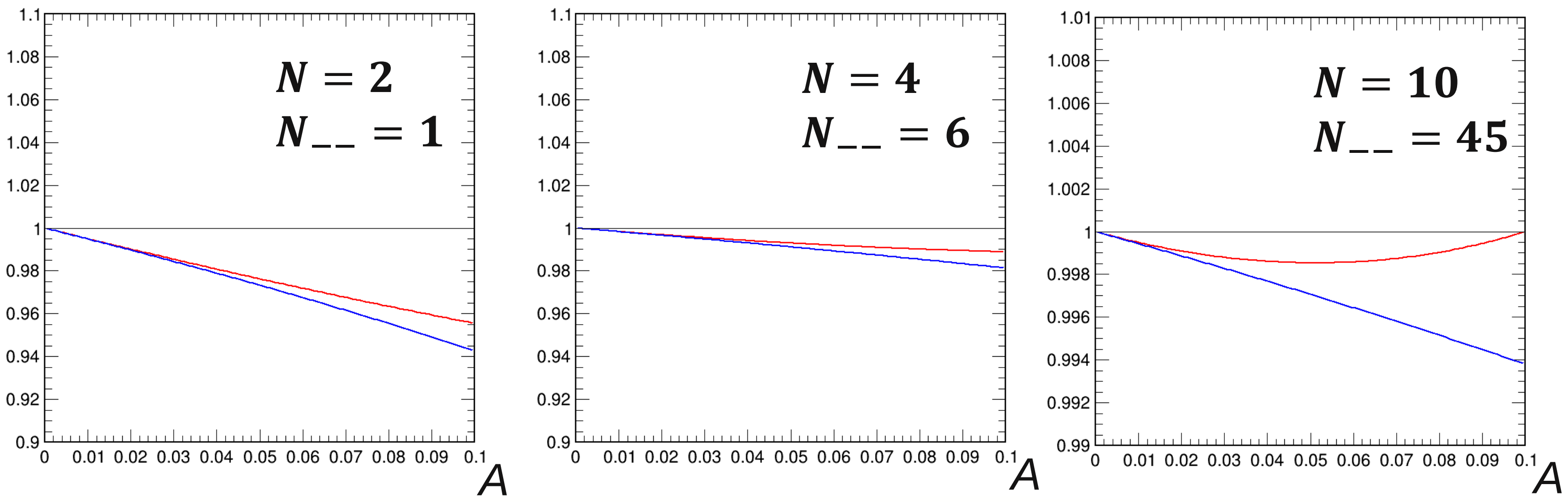
  → $\mathrm{LS_{Arith}} = \Omega \cdot \left(1 + \frac{AN+(AN)^2}{2\Omega}\right)$

- $\mathrm{LS_{Geom}} = \sqrt{\frac{M(M-1)\cdot N(N-1)}{4}}$

  → $\mathrm{LS_{Geom}} = \Omega \cdot \left(1 + \frac{AN}{\Omega}\right)^{1/2} /2$

$$N := \text{Number of } e^-$$
$$M := \text{Number of } e^+$$
$$A := 1 - \frac{M}{N} \text{ (Asymmetry)}$$
$$\rightarrow M = N(1-A)$$
$$\Omega := N(N(1-A)-1)$$

- Geometric Background always underestimates the background
- Arithmetic Background closer to ULS Background for low N



Precision of the background estimation depends on the asymmetry as well as the statistics

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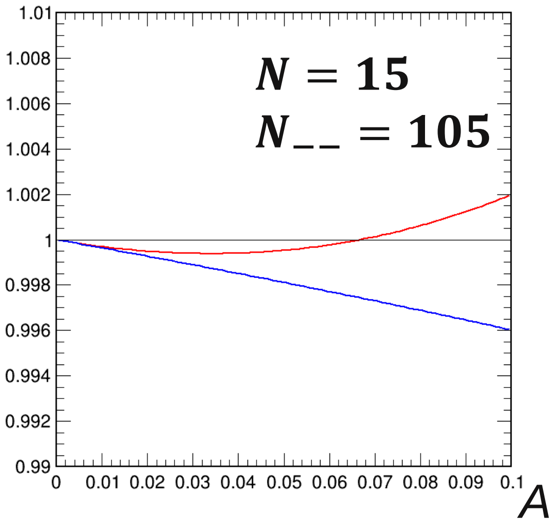

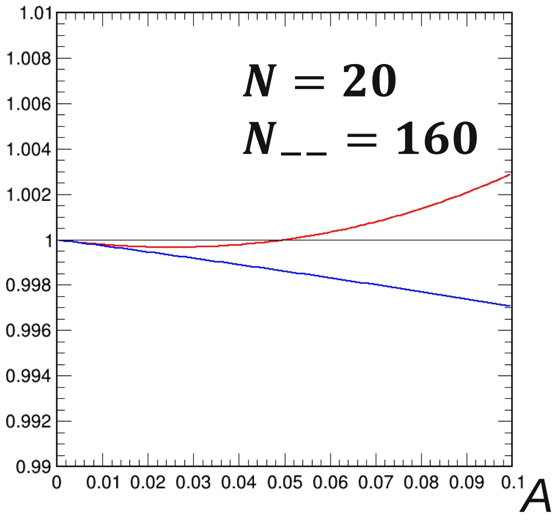

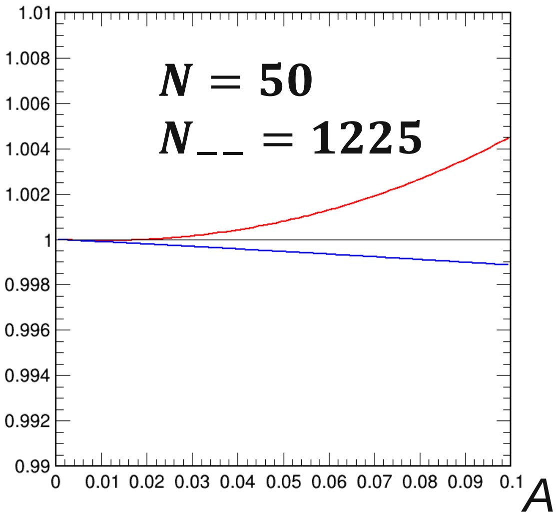

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