Soft-dielectron excess in pp collisions at $\sqrt{s}$=13 TeV

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36th Winter Workshop on Nuclear Dynamics
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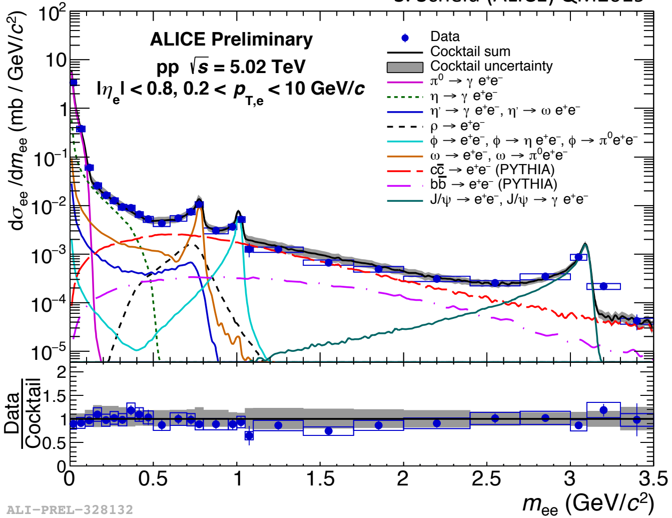
Dielectrons in pp – just a vacuum reference?

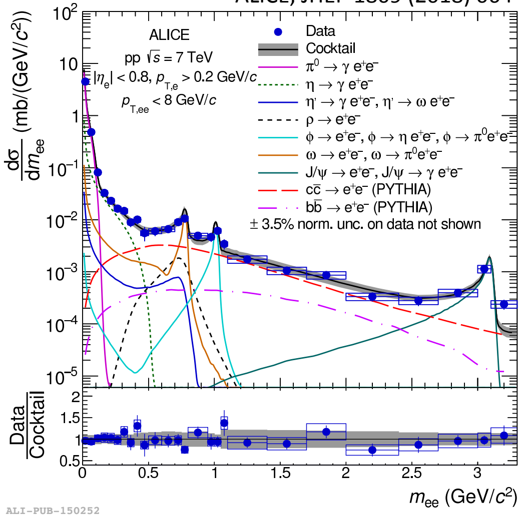
√s = 5 TeV

S. Scheid (ALICE) QM2019



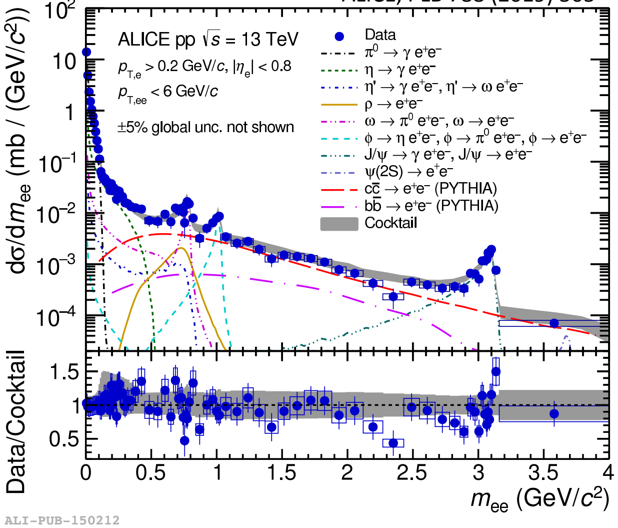
√s = 7 TeV

ALICE, JHEP 1809 (2018) 064



√s = 13 TeV

ALICE, PLB 788 (2019) 505



- Dielectron production ($p_{T,e} > 0.2$ GeV/c) in minimum bias pp is well described by hadron decays
- Given the indications for thermalization and collectivity in pp, this is a surprise
- Are we missing something?

Outline

Past: soft photon puzzle in hadronic collisions

Present: soft-dielectron production in pp collisions with ALICE

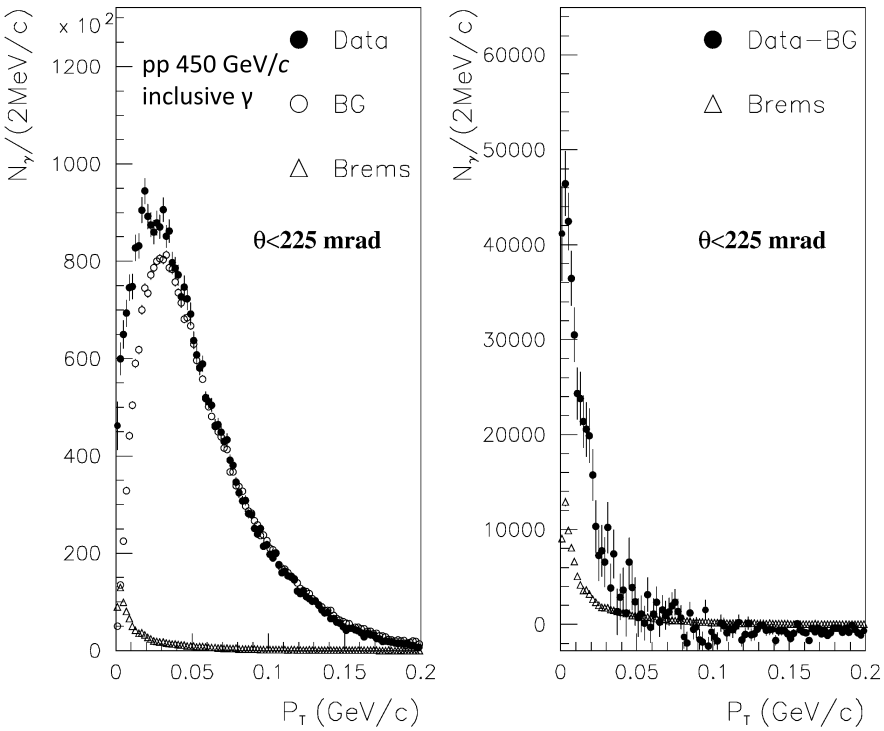
Future: perspectives for soft dielectron measurements with ALICE

‚Anomalous' radiation in small systems has a history

A. Belogianni et al., PLB 548 (2002) 129

Direct soft photon excess over hadronic decays observed in πp, Kp, μp, pp, p-Be at different energies and kinematic ranges

Hadronic Bremsstrahlung could not account for it



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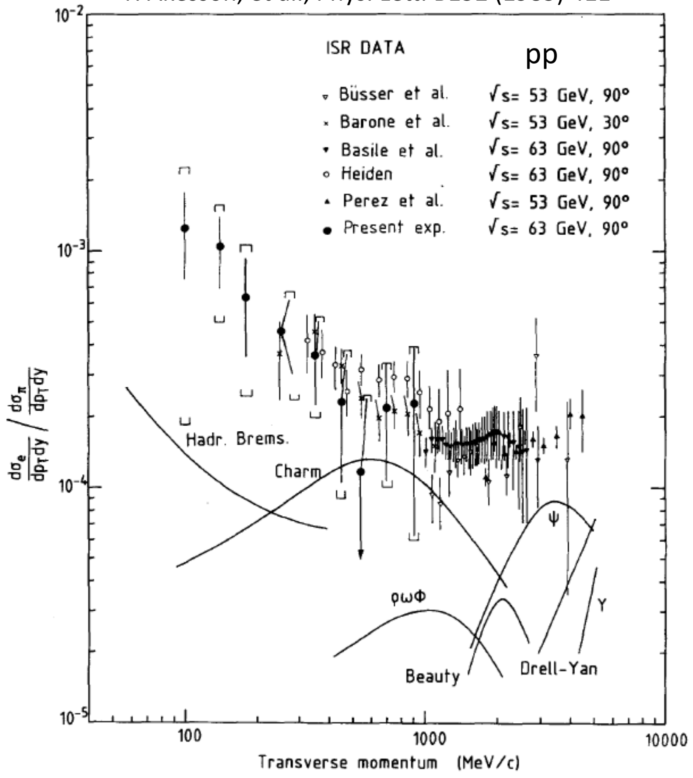
Indications of excess also observed in the virtual photon sector: e^{+}/π

T. Akesson, et al., Phys. Lett. B152 (1985) 411



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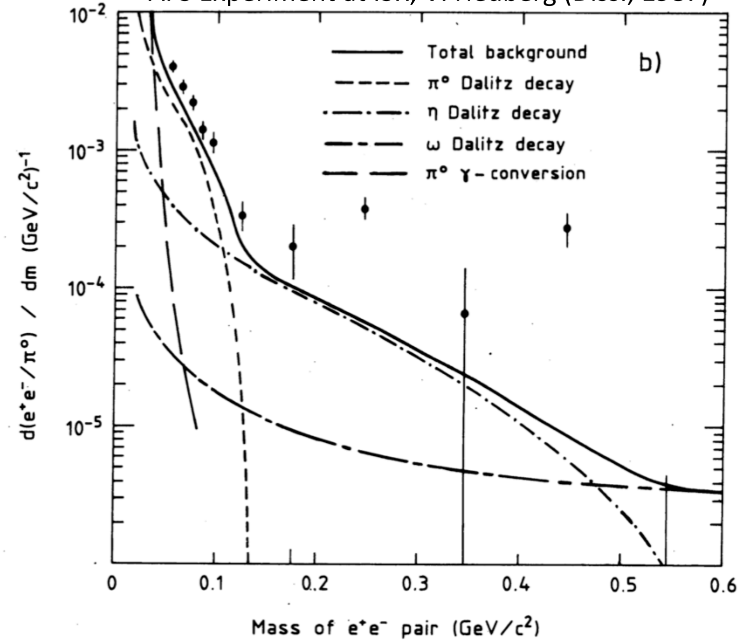
AFS Experiment at ISR, V. Hedberg (Diss., 1987)



Soft photon puzzle

The production of Bremsstrahlung is well constrained by the cross section for the radiation-less hadronic process (Low Theorem)

Below some characteristic energy scale E_0 , Bremsstrahlung from incoming and outgoing charged particles must dominate the contribution from an intermediate state for $E_\gamma \rightarrow 0$

The energy scale E_0 is given by the time and length scales of the intermediate state $E_0 = 1/\Delta t$

In pp collisions, Bremsstrahlung should dominate below ~200 MeV

BUT excess over Bremsstrahlung expectation extends down to much smaller E

Soft photon puzzle

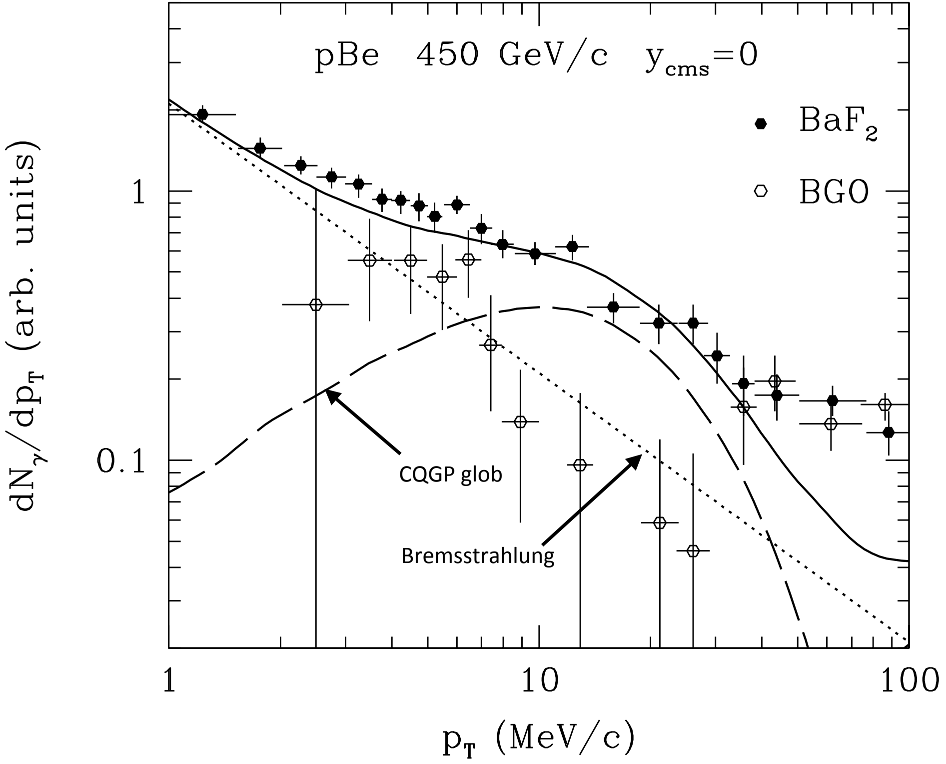
Proposed solutions:

- Soft parton annihilation
  V. Cerny, P. Lichard, J. Pisut, Z. Phys. C31 (1986) 163
- 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

...or combinations of them
P. Lichard, Phys. Rev. D50 (1994) 6824

→ exciting „new“ physics at work in pp!

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



Soft photon puzzle

- Issue was not resolved, attention was drawn to heavy-ion collisions
- For coming 20 years, pp was considered a „vacuum reference“ without non-trivial physics
- Experiments could not access very soft photon and low-mass dilepton domain

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- Issue was not resolved, attention was drawn to heavy-ion collisions
- For coming 20 years, pp was considered a „vacuum reference“ without non-trivial physics
- Experiments could not access very soft photon and low-mass dilepton domain
- ALICE running strategy for Run 3 and 4 foresees extended campaigns at reduced solenoid field (0.5 T → 0.2 T) to enhance the sensitivity to soft (di-)electrons
- Dedicated campaigns in pp at B = 0.2 T taken by ALICE during Run 2 (2016-2018)

Dielectrons at low B-field with ALICE

Dedicated campaigns (550M MB pp collisions) during Run2 with reduced solenoid field (0.5 T → 0.2 T)

- Test case for Run3

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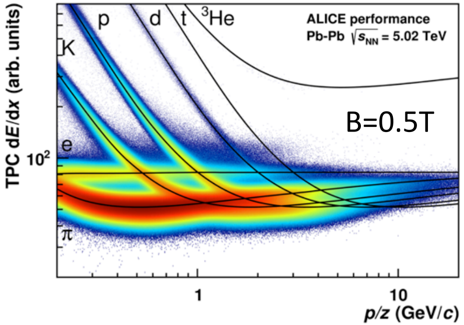
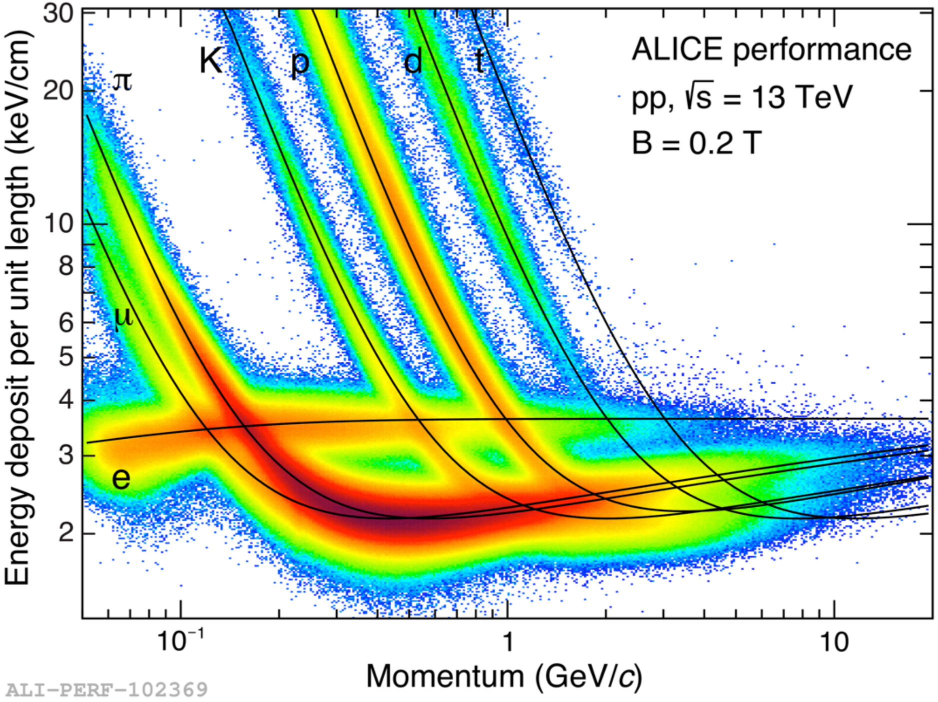


M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018)



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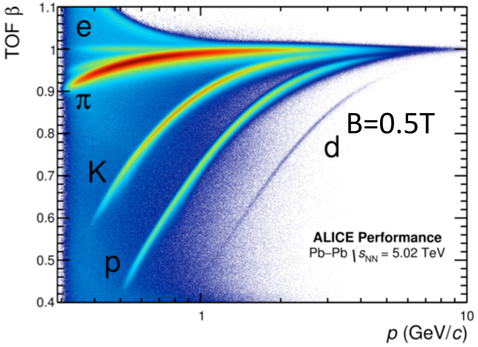
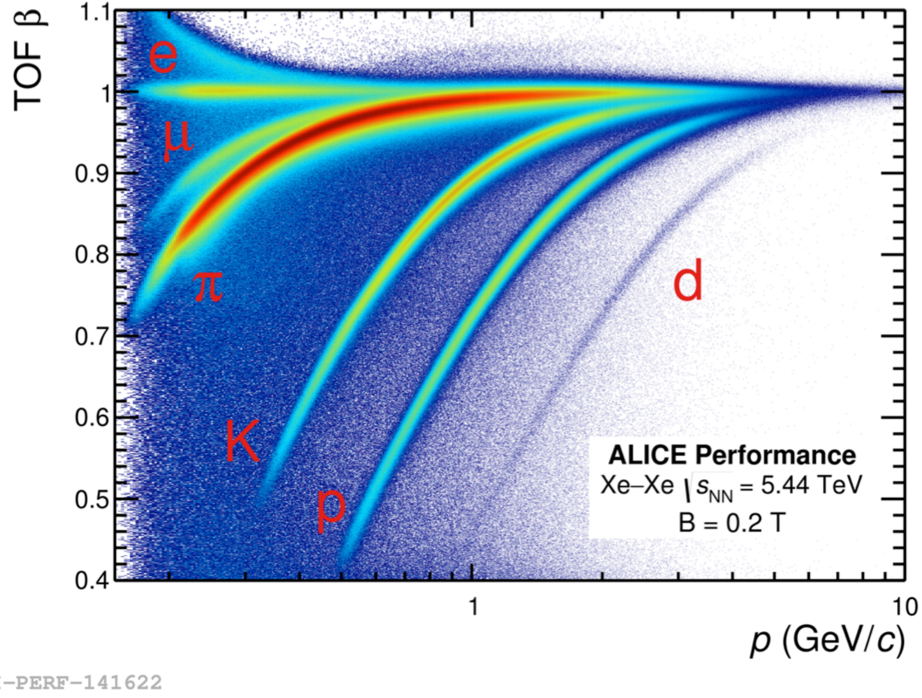
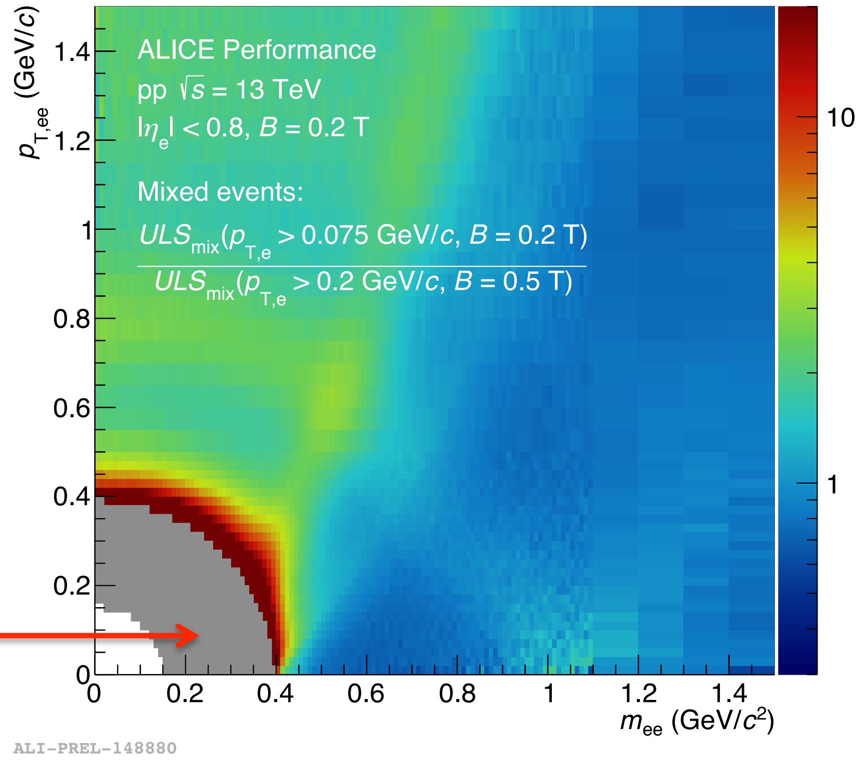




Dielectrons at low B-field with ALICE

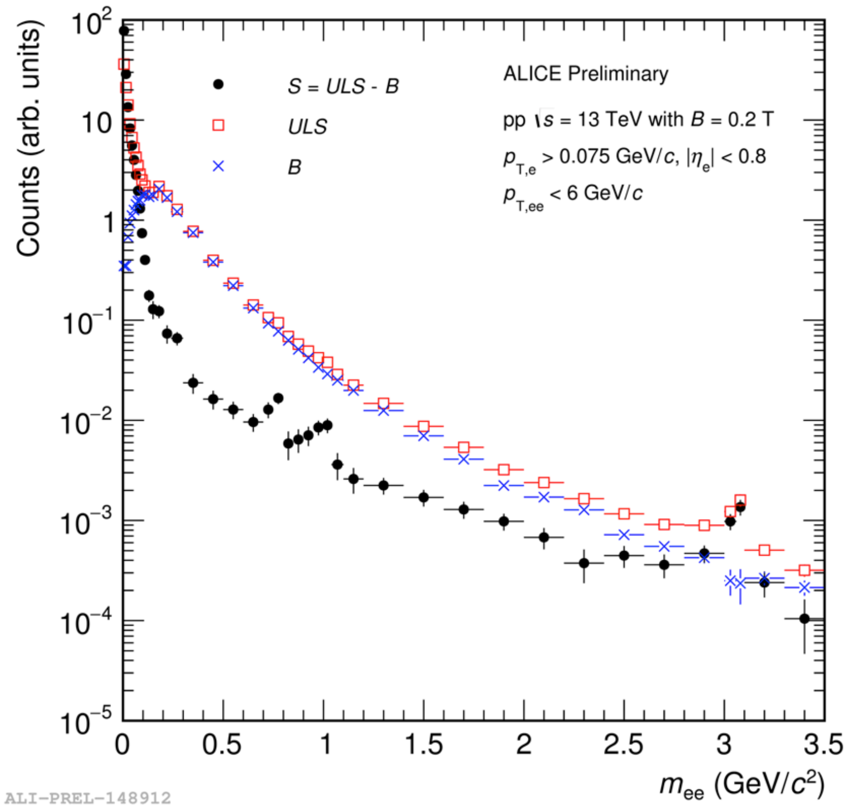
Dedicated campaigns (550M MB pp collisions) during Run2 with reduced solenoid field (0.5 T → 0.2 T)

- Test case for Run3
- Significantly improved acceptance for low p_T electrons
- Allows dedicated studies of very soft dileptons at low mass in pp
- Lowering $p_{T,e}$ cutoff from 0.2 to 0.075 GeV/c extends pair acceptance to $p_{T,ee} = 0$ for $m_{ee} > m_\pi$



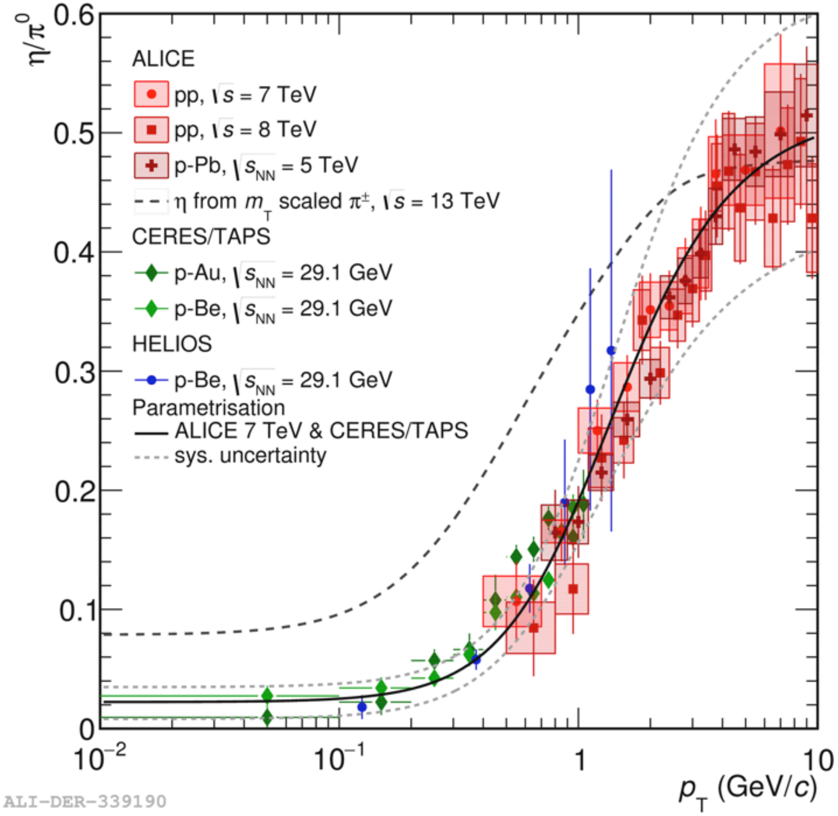
Signal extraction

- Statistical signal extraction
- Low-field running leads to sizable improvement of *S/B* and significance via Dalitz and conversion rejection as compared to standard field



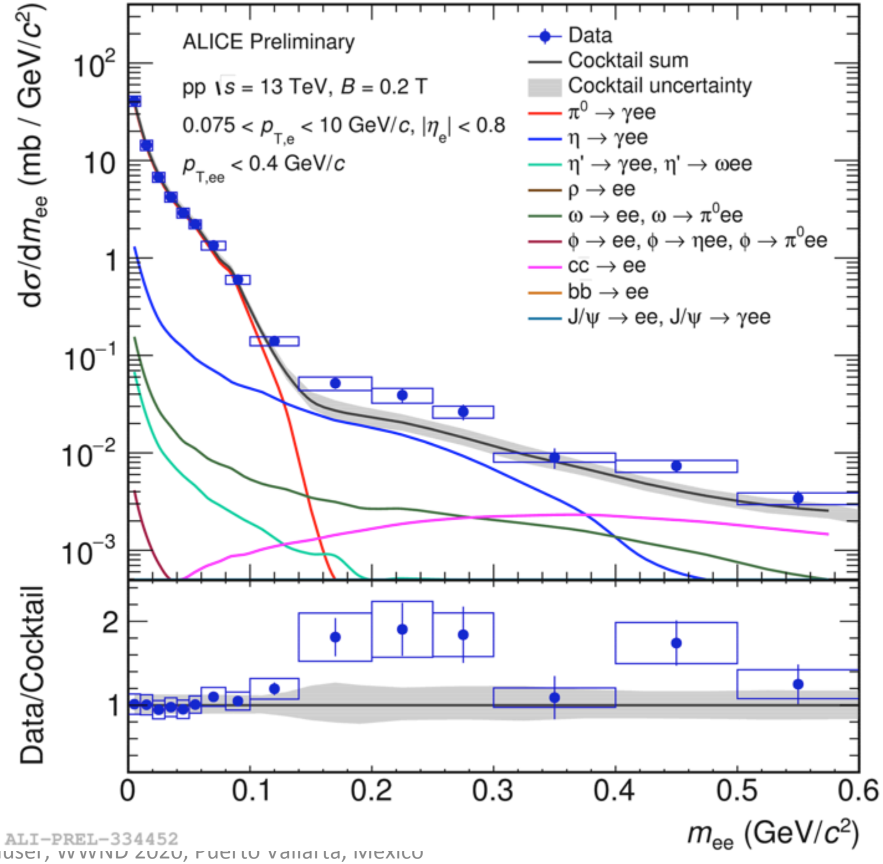
Hadronic cocktail – η/π

- Careful reassessment of existing η/π data
- m_T-scaling not compatible with data at low p_T
- Detailed low-p_T analysis of η in ALICE low-field data is ongoing



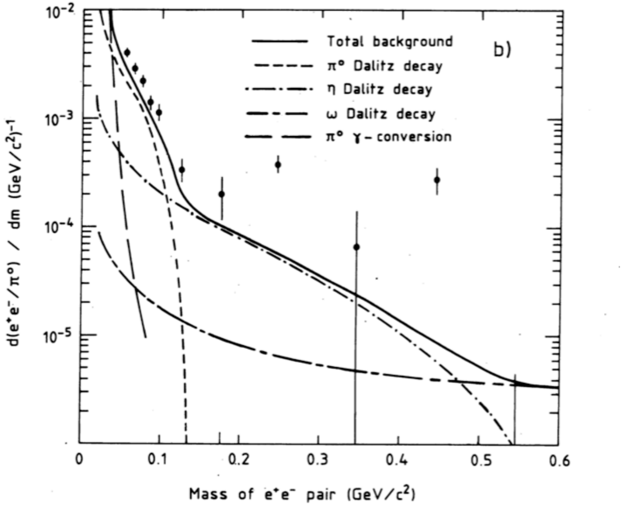
pp at 13 TeV with low B-field

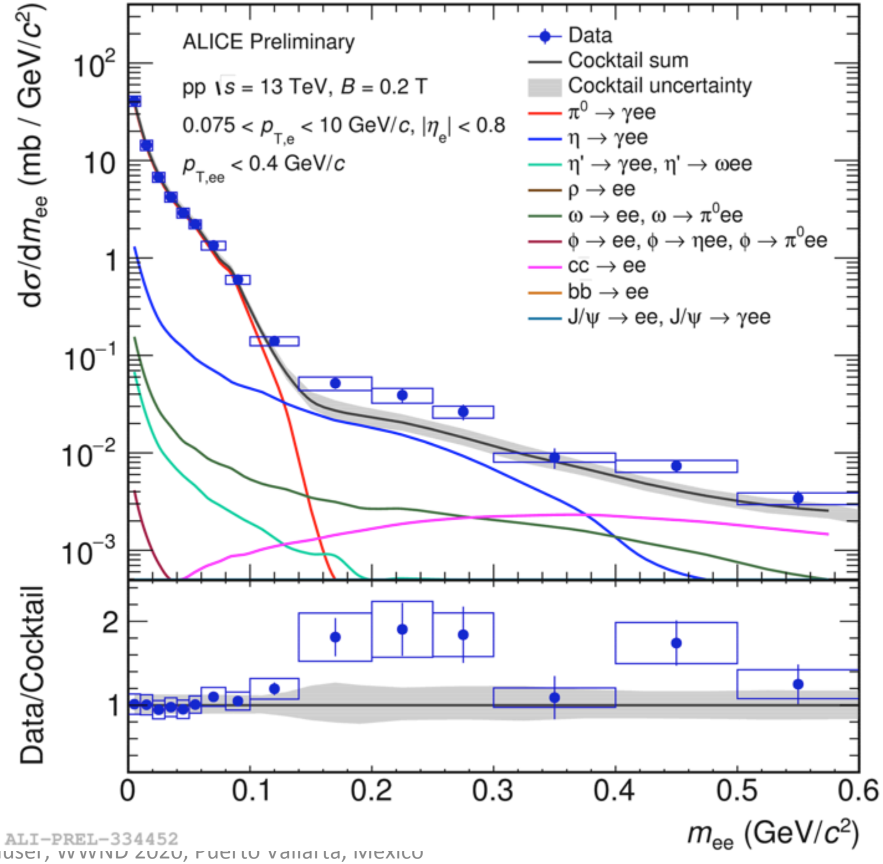
- Dielectron enhancement over hadronic cocktail observed in $m_{\pi} < m_{ee} < 0.6$ GeV/c^2



pp at 13 TeV with low B-field

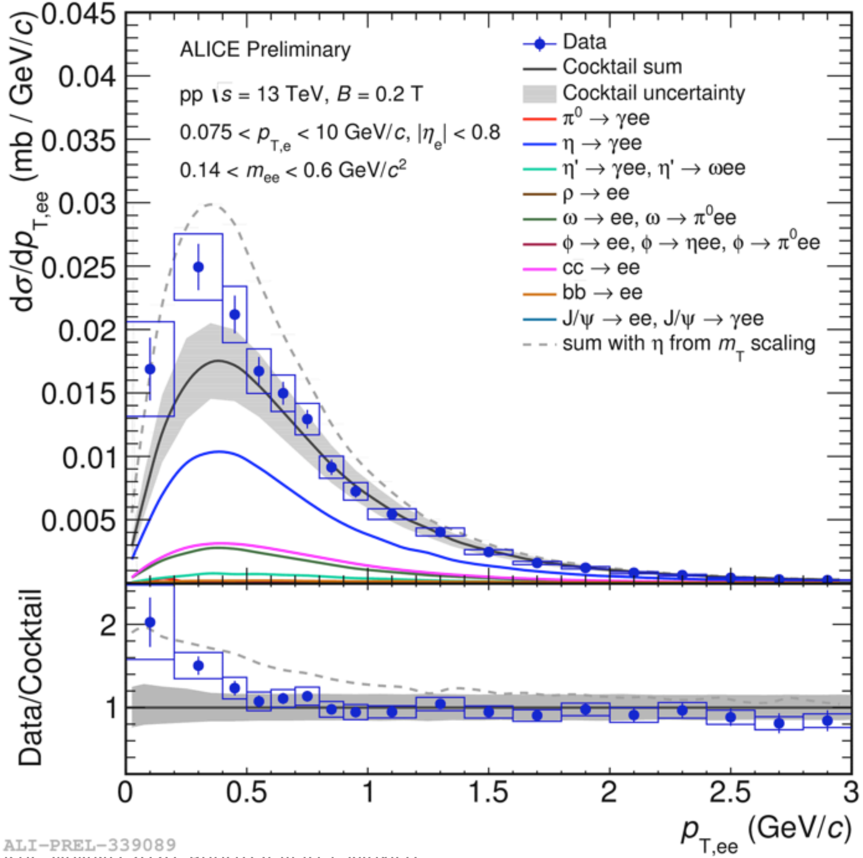
- Dielectron enhancement over hadronic cocktail observed in $m_{\pi} < m_{ee} < 0.6$ GeV/c^2
- Reminiscent of low-mass enhancement from AFS at ISR





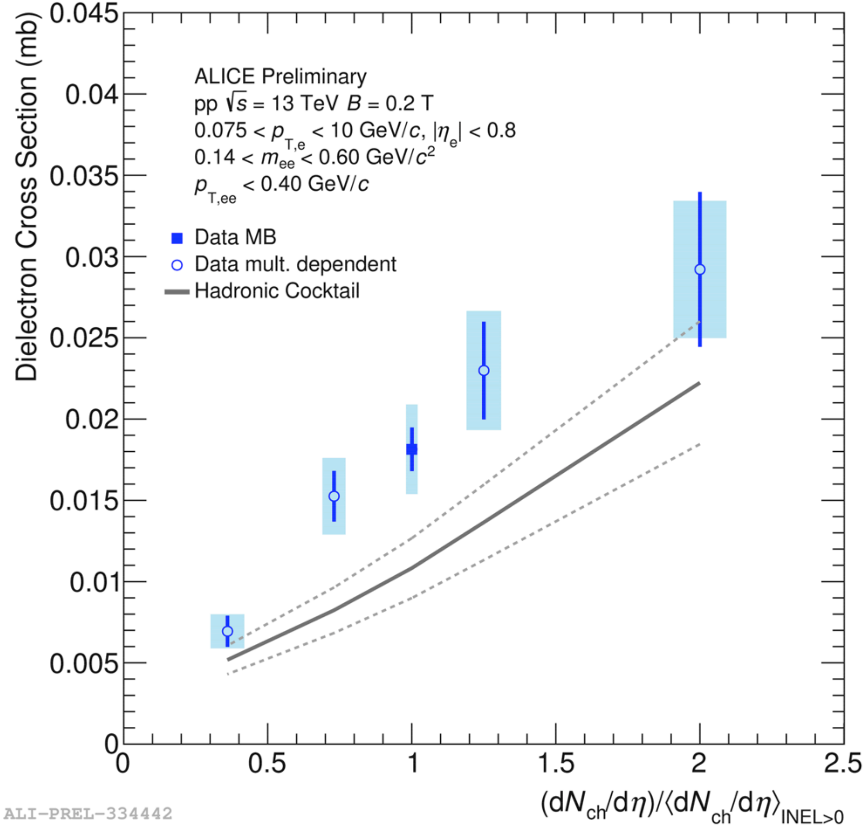
pp at 13 TeV with low B-field

- Dielectron enhancement over hadronic cocktail observed in $m_\pi < m_{ee} < 0.6$ GeV/c^2
- The enhancement is most pronounced at low p_T
- Possible relation to soft photon puzzle requires careful comparison to Bremsstrahlung calculations for dielectrons



Multiplicity dependence

- Multiplicity dependence of excess yield can shed light on production mechanism



Multiplicity dependence

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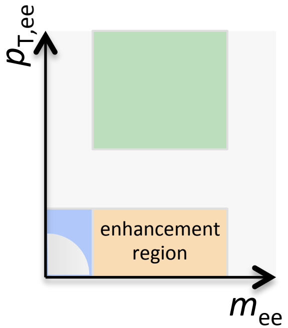
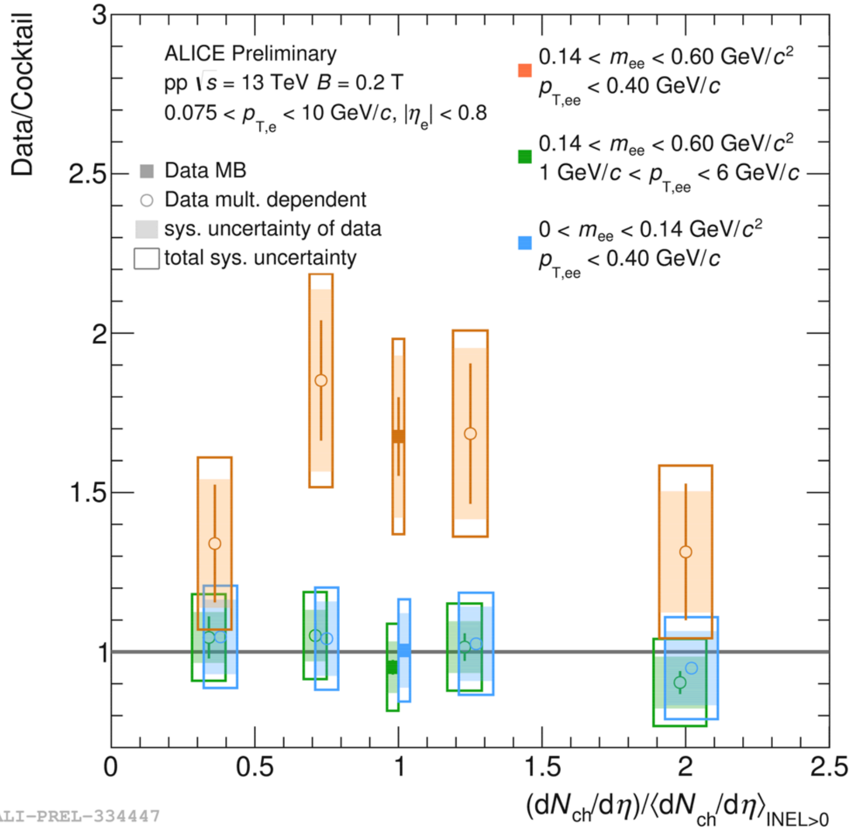
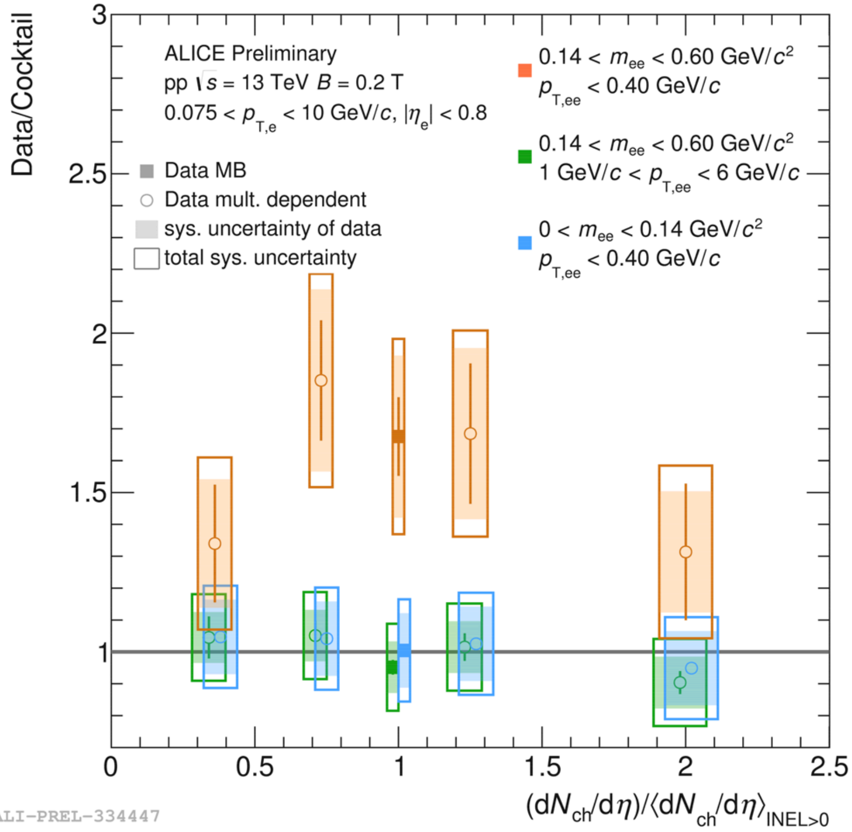
- Enhancement compatible with linear scaling with multiplicity
- Control regions are consistent with cocktail





Multiplicity dependence

- Multiplicity dependence of excess yield can shed light on production mechanism
- Enhancement compatible with linear scaling with multiplicity
- Control regions are consistent with cocktail
- More precise data are needed to settle the issue



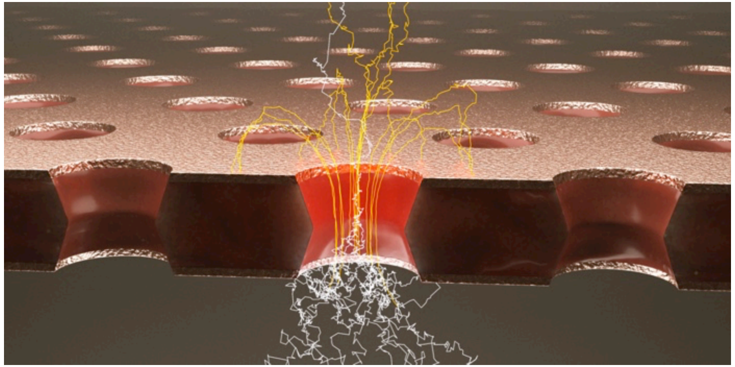
Future ALICE running at the LHC

Future ALICE running at the LHC

ALICE strategy for Run 3 + 4:

- 50 kHz Pb-Pb interaction rate (Run 2: < 10 kHz), continuous readout
- Collect $L_{Pb\text{-}Pb} = 13\ nb^{-1}$ (3 nb^{-1} at B = 0.2 T)
- Ongoing detector upgrades (LS2)

ALICE TPC Upgrade

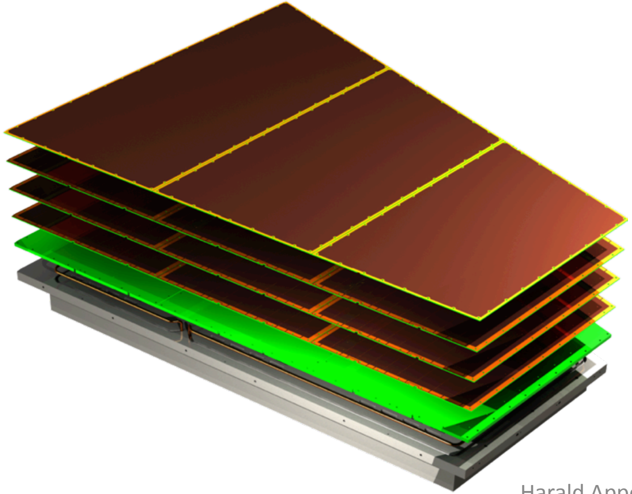


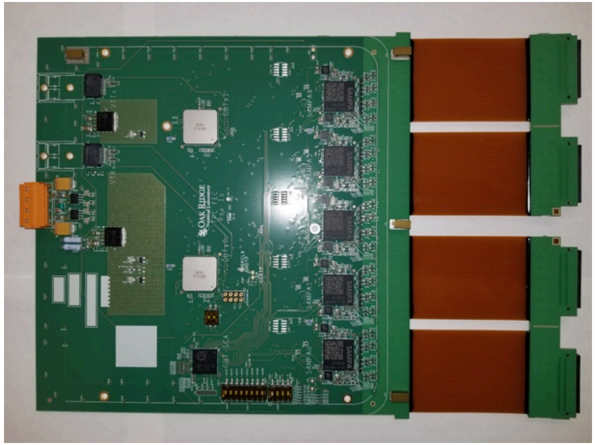
TPC Upgrade requirements

- Continuous readout at 50 kHz in Pb-Pb (was 0.5-1 kHz)
- Unprecedented challenges in terms of load and performance

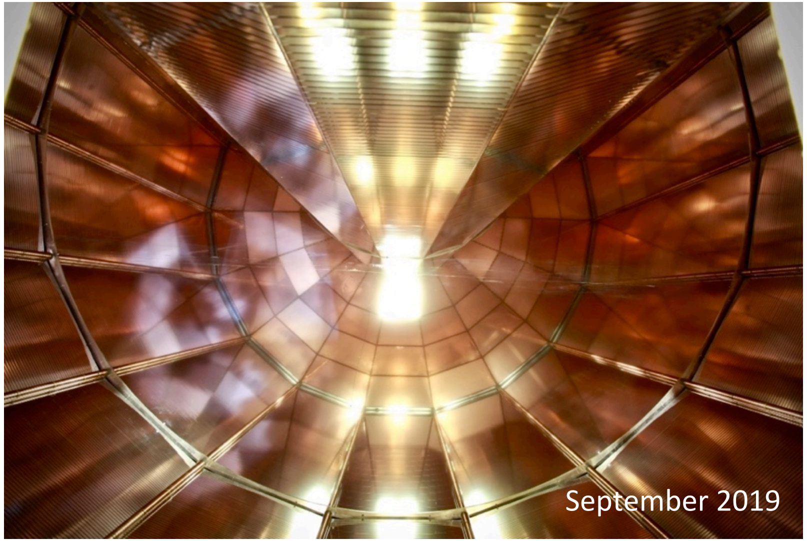
→ new Readout Chambers with GEMs

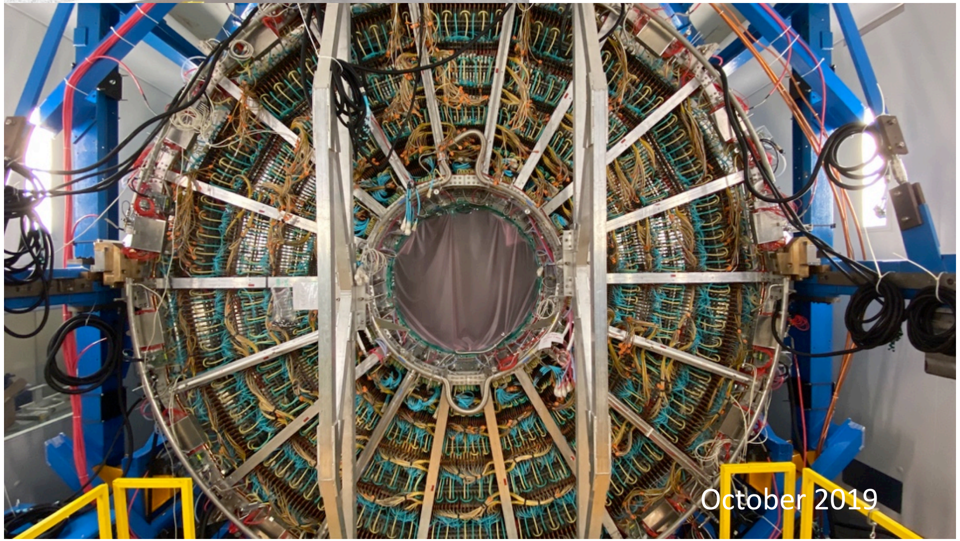
→ new Frontend Electronics





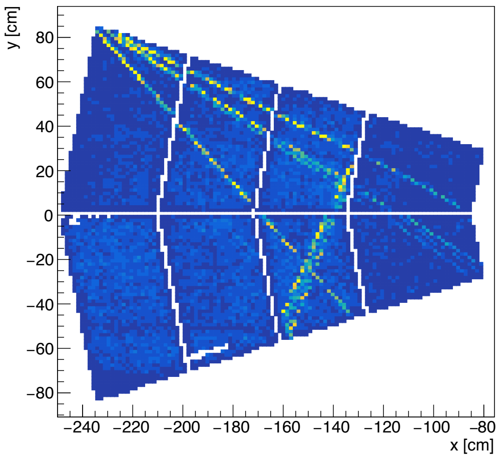
ALICE TPC upgrade

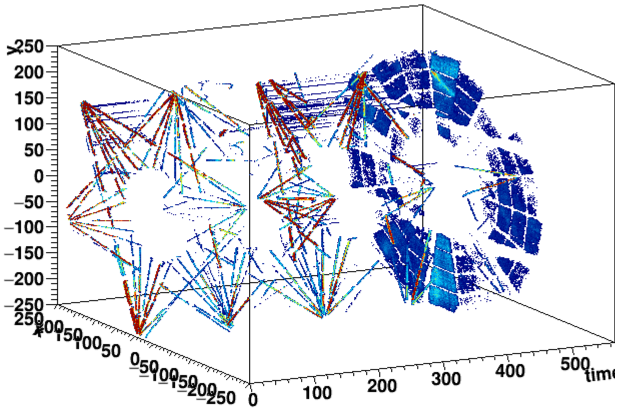




- MWPC-based readout chambers replaced by GEM detectors
- new Front-End Electronics and services installed

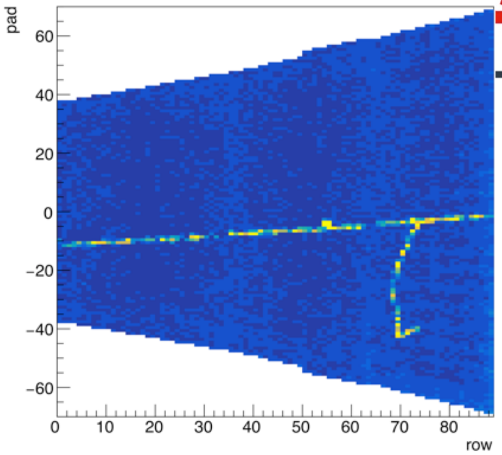
ALICE TPC pre-commissioning

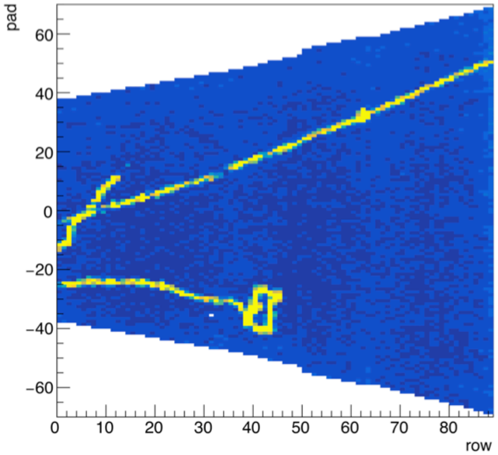




TPC pre-commissioning ongoing

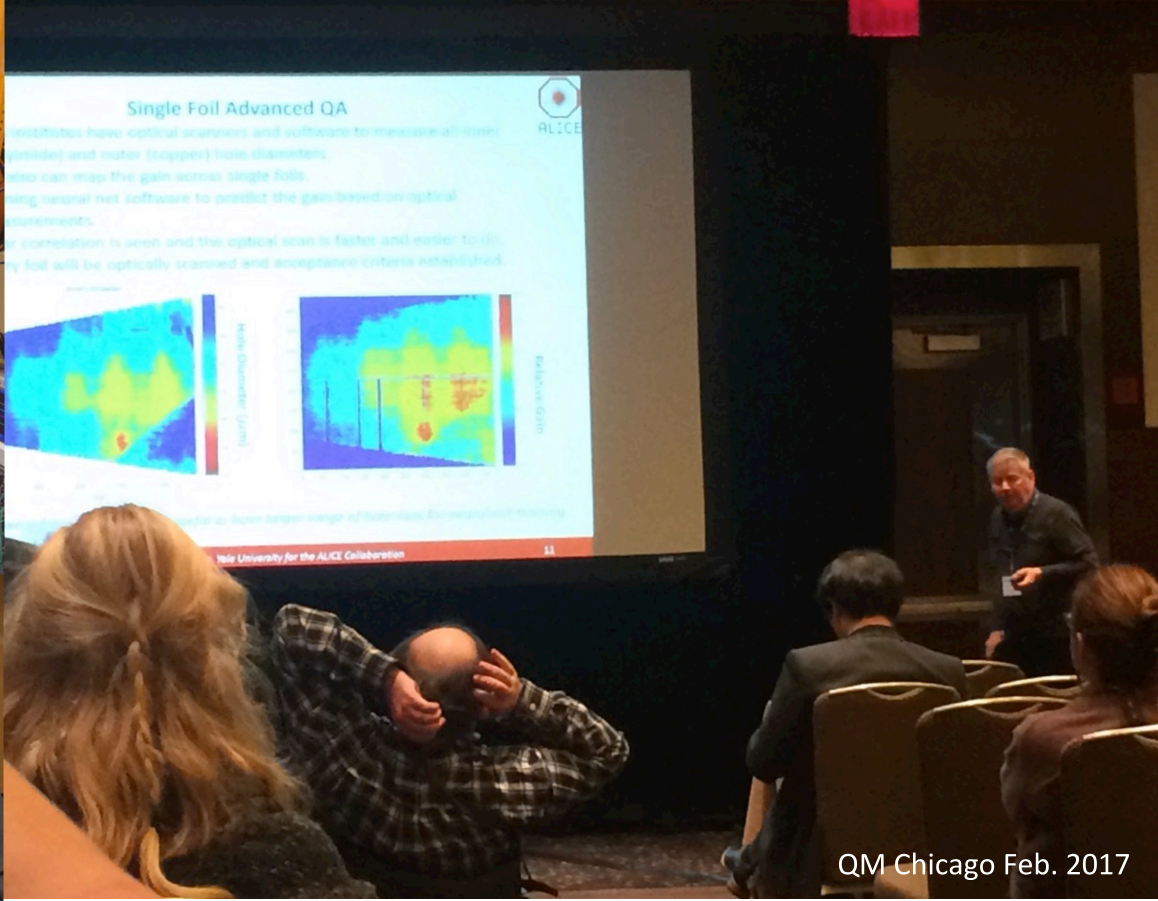
Full functionality validated with laser and cosmic tracks






Yale Oct. 2017


Detroit Oct. 2017



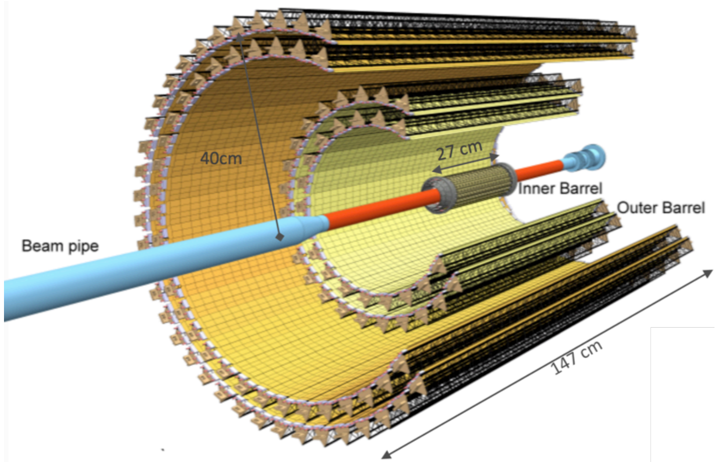
QM Chicago Feb. 2017

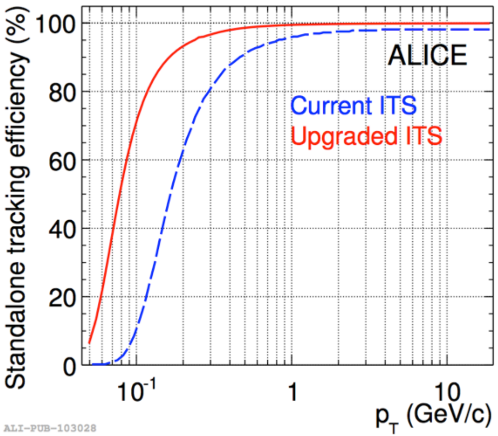
Thank you Dick Majka!

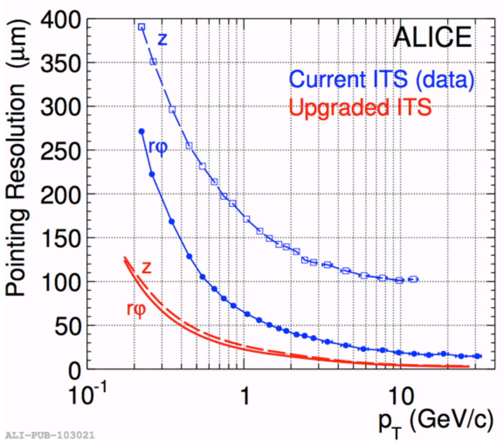
ITS 2

10 m^2 active silicon area, 12.5×10^9 pixels

- Closer to IP: 39 mm ⟶ **22 mm**
- Thinner (X_0 for innermost layers): ~1.14 % ⟶ **~0.30 %**
- Smaller pixels: 50 × 425 μm^2 ⟶ **27 × 29 μm^2**
- Granularity: 20 ch/cm^3 ⟶ **2000 pixels/cm^3**
- Readout rate: 1 kHz ⟶ **100 kHz**







ITS 2 performance

- Improved tracking efficiency
- Improved tracking resolution
- Pointing resolution ×3 better in transverse plane (×6 along beam)

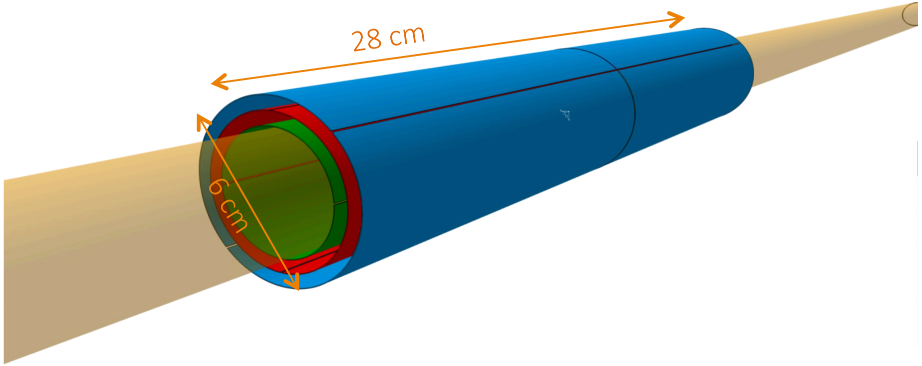
ITS 3 – a new ultra-light inner barrel in Run 4

3 truly cylindrical layers made of ~7x14 cm^2 sensors, thinned to 20-40 µm

- Readout circuitry outside acceptance
- No water cooling, minimal support structure in acceptance
- Total material at $R < 4$ cm: 1.3% ⟶ **0.3 %**

ITS 3 performance for dielectrons:

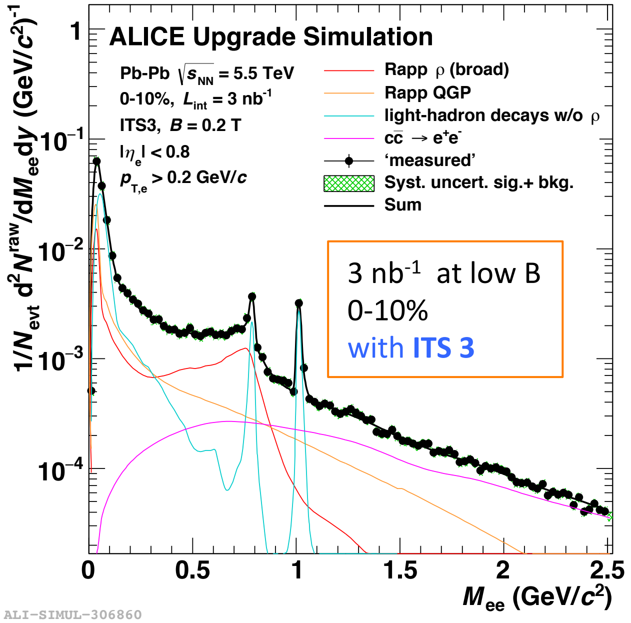
- 3x less conversions (main background)
- Better low-p_T standalone tracking efficiency
- Better precision to reject (non-prompt) heavy-flavor electrons

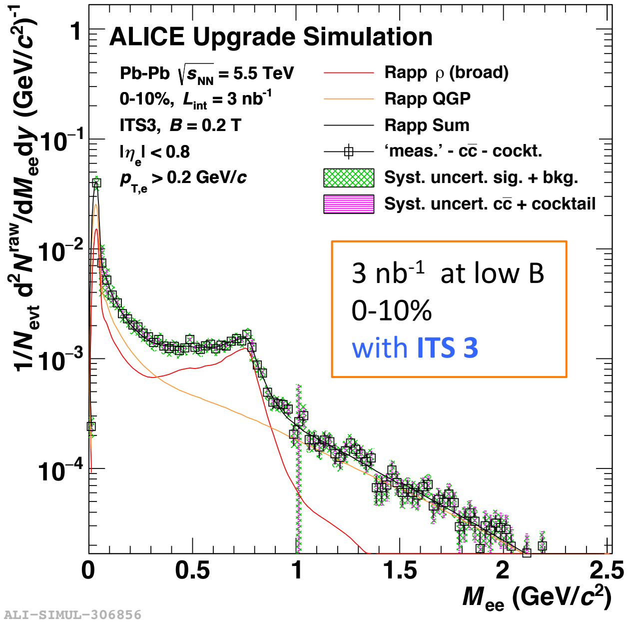


Significant improvement also for Λ_c, D_s

Dielectron mass spectrum in Run 4

Z. Citron et al., CERN Yellow Rep. Monogr. (2019) 1159





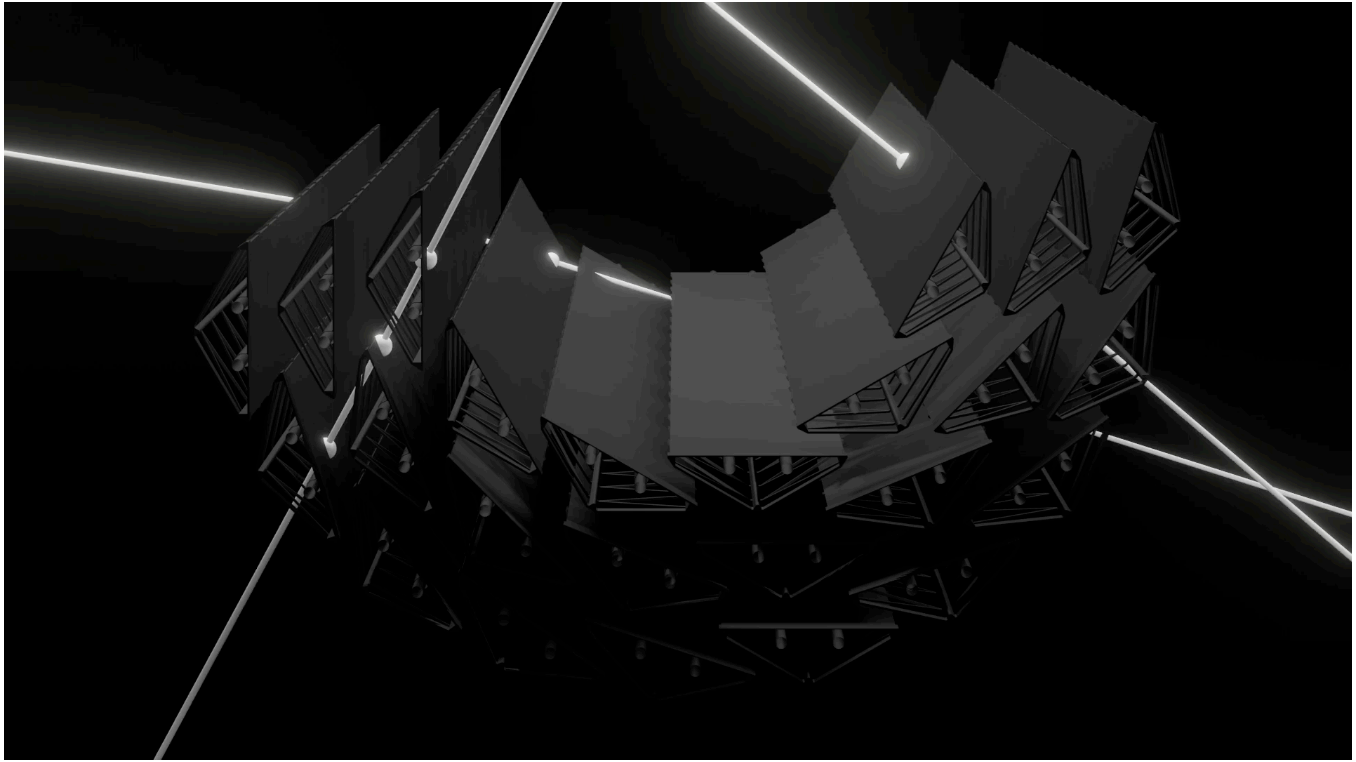
Detailed characterization of dielectron production:

- Pb-Pb: QGP temperature, ρ-broadening, chiral mixing
- pp: search for soft excess radiation
- Further suppression of charm contribution with ITS 3

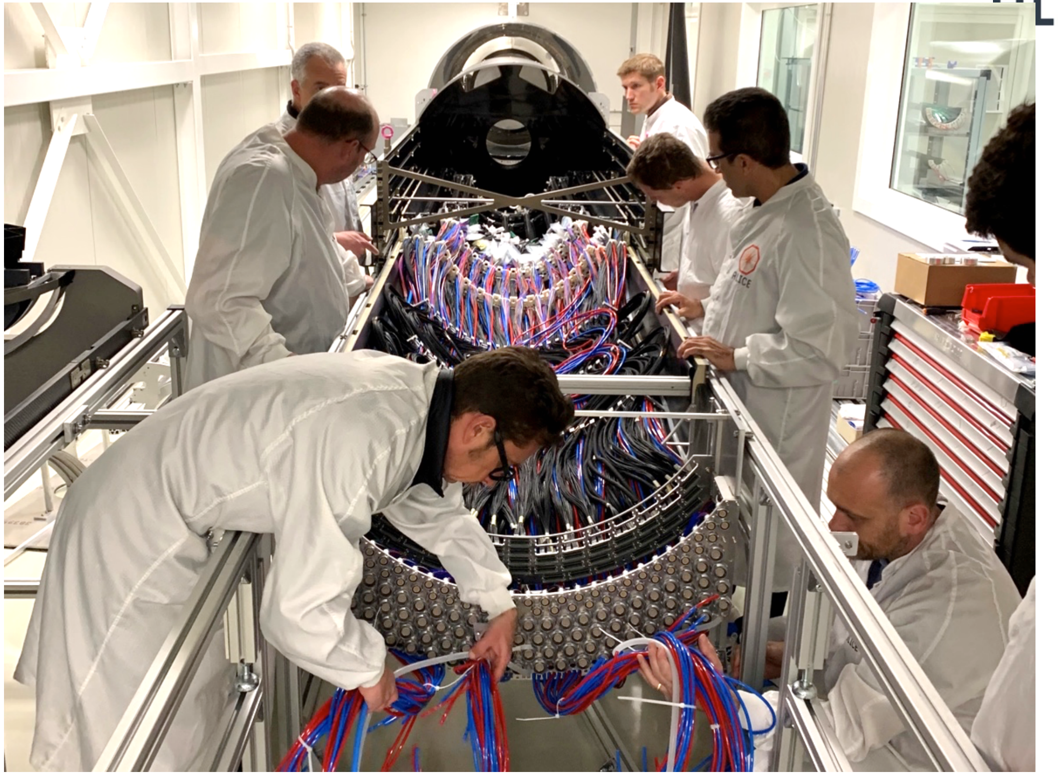
Summary

- ALICE observes an **excess of soft dielectrons** in pp at $\sqrt{s}$ = 13 TeV
- Possible relation to historical **soft-photon puzzle** needs to be worked out
- Excess radiation may help to characterize **early (pre-)equilibration mechanisms** in pp
- **Upgraded ALICE detector** in Run 3 and 4 (2021-2030) will have **special focus on soft dielectron production**

ITS Inner Barrel pre-commissioning



ITS 2 installation



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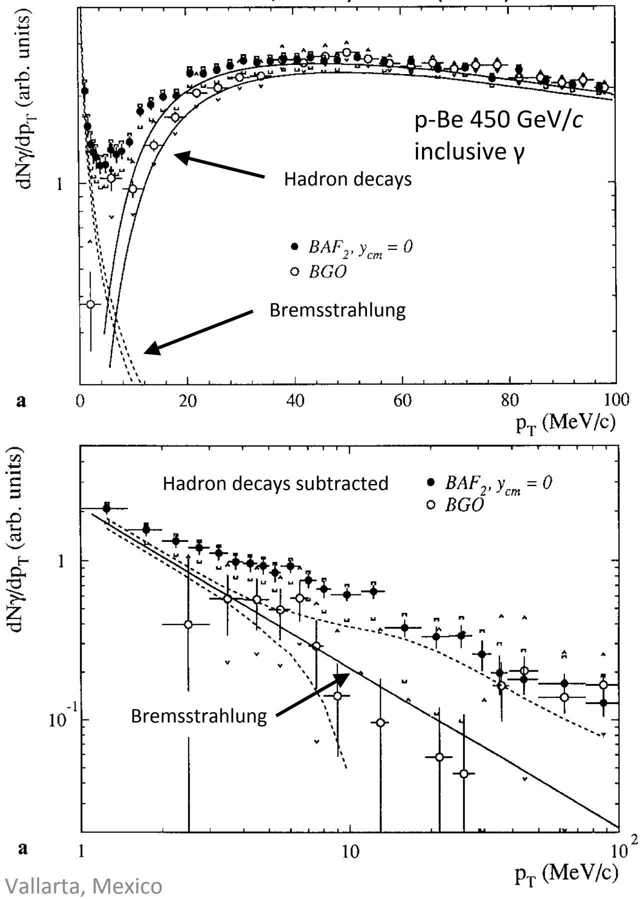
HELIOS Coll., Z. Phys. C59 (1993) 547



Hadronic Bremsstrahlung and the Low Theorem

PHYSICAL REVIEW VOLUME 110, NUMBER 4 MAY 15, 1958

Bremsstrahlung of Very Low-Energy Quanta in Elementary Particle Collisions

F. E. Low

Department of Physics and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts

(January 29, 1958)

It is shown that the first two terms in the series expansion of the differential bremsstrahlung cross section (in powers of the energy loss) may be calculated exactly in terms of the corresponding elastic amplitude and the electromagnetic constants of the participating particles.

If hadronic process A → B is known, then
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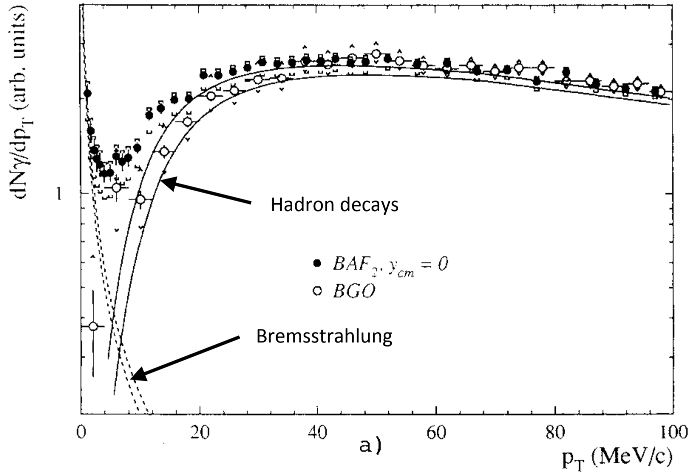
Hadronic decay contribution and Bremsstrahlung are directly related



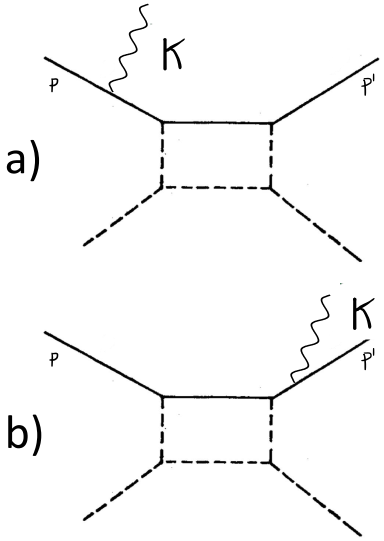
Hadronic Bremsstrahlung and the Low Theorem

- Scattering of a charged particle and a neutral one:

Cases a) and b): Emitting particle is on mass shell ($P^2 = m^2$)

→ cross section (k → 0) ~1/K

i.e. diverges



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→ cross section (k → 0) ~1/K

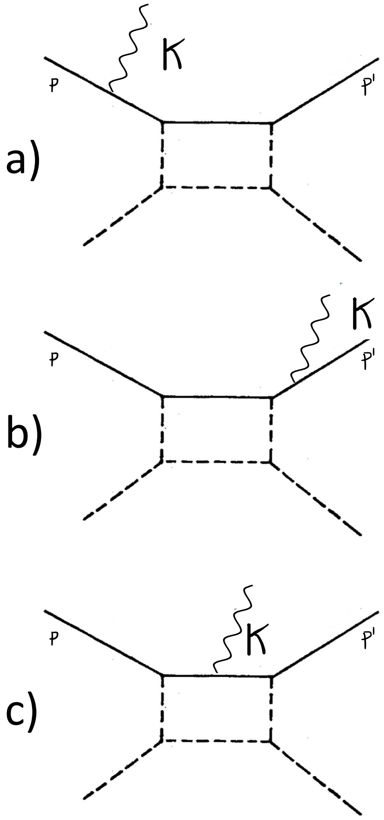
i.e. diverges

Case c): Emitting particle is not on mass shell ($P^2 \neq m^2$)

→ cross section (K → 0) const.

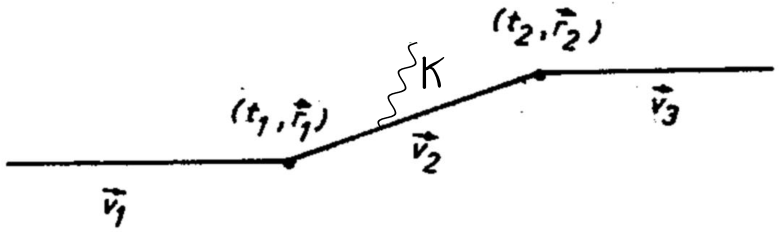
i.e. finite

→ Initial/final state Bremsstrahlung must dominate over radiation from intermediate stage below some characteristic K



Low Theorem and LPM effect

- Below which *K* does Bremsstrahlung take over?

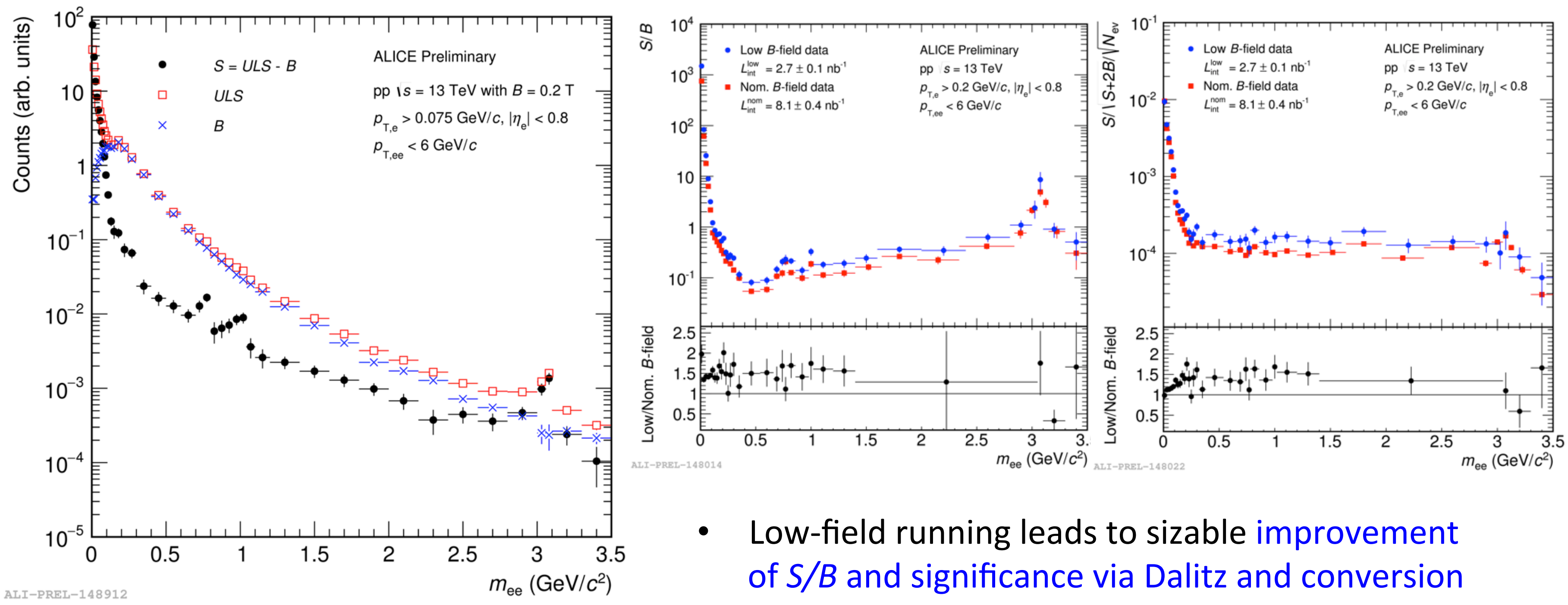


Radiation of photon with energy *K=(E,k)* from the intermediate stage is suppressed, if photon formation time exceeds time between scatterings, i.e.

$$\boxed{E\Delta t < 1}$$

→ in pp (time and length scales O(1 fm)), Bremsstrahlung should dominate below $p_T < 200$ MeV/c

Signal extraction, *S/B* and significance



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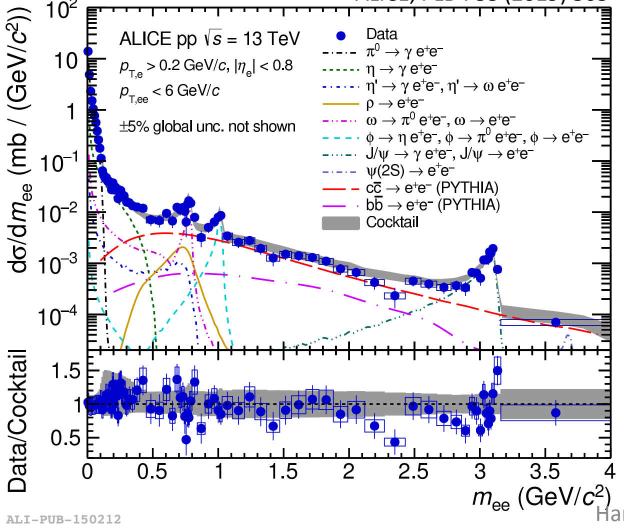
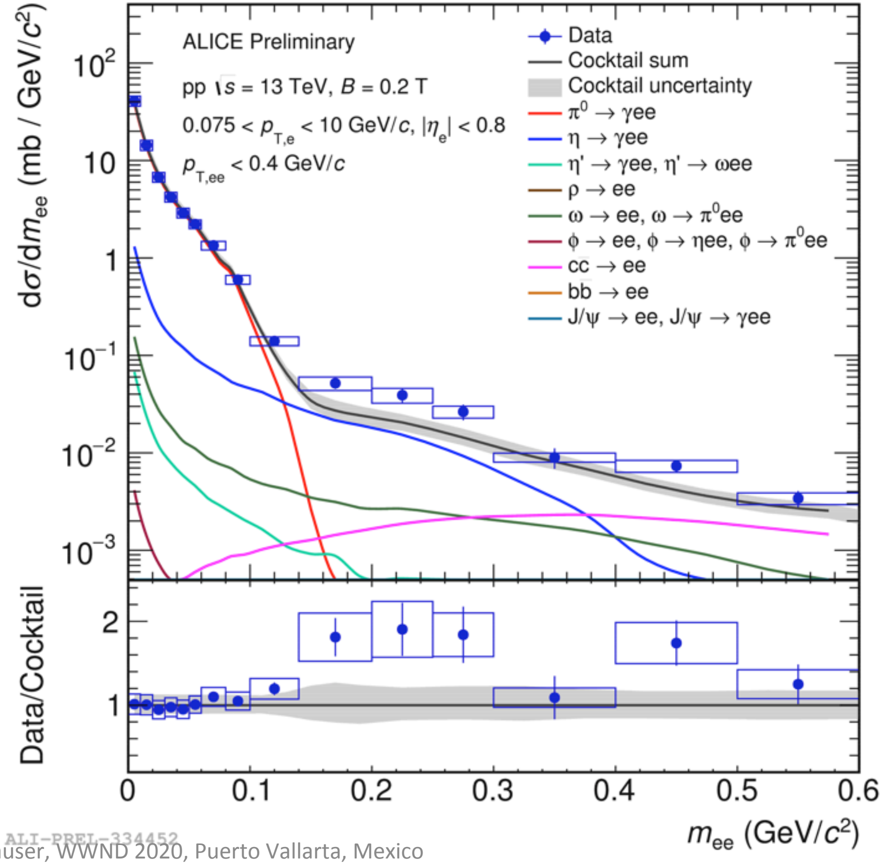
pp at 13 TeV with low B-field

- Dielectron enhancement over hadronic cocktail observed in $m_{\pi} < m_{ee} < 0.6$ GeV/c^2
- Not significant in previous analysis at nominal field

ALICE, PLB 788 (2019) 505





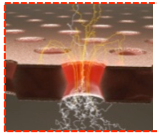
ALICE in Run 3 and 4

New Inner Tracking System (ITS 2 + ITS 3)

- Complementary Metal-Oxide-Semiconductor (CMOS) Monolithic Active Pixel Sensor (MAPS) technology
- Improved resolution, less material, faster readout

New Muon Forward Tracker (MFT)

- CMOS Pixels, MAPS technology
- Vertex tracker at forward rapidity



New TPC Readout System

- ROCs with Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout

New Fast Interaction Trigger (FIT) Detector

- Centrality, event plane

FoCal proposal (Run 4)

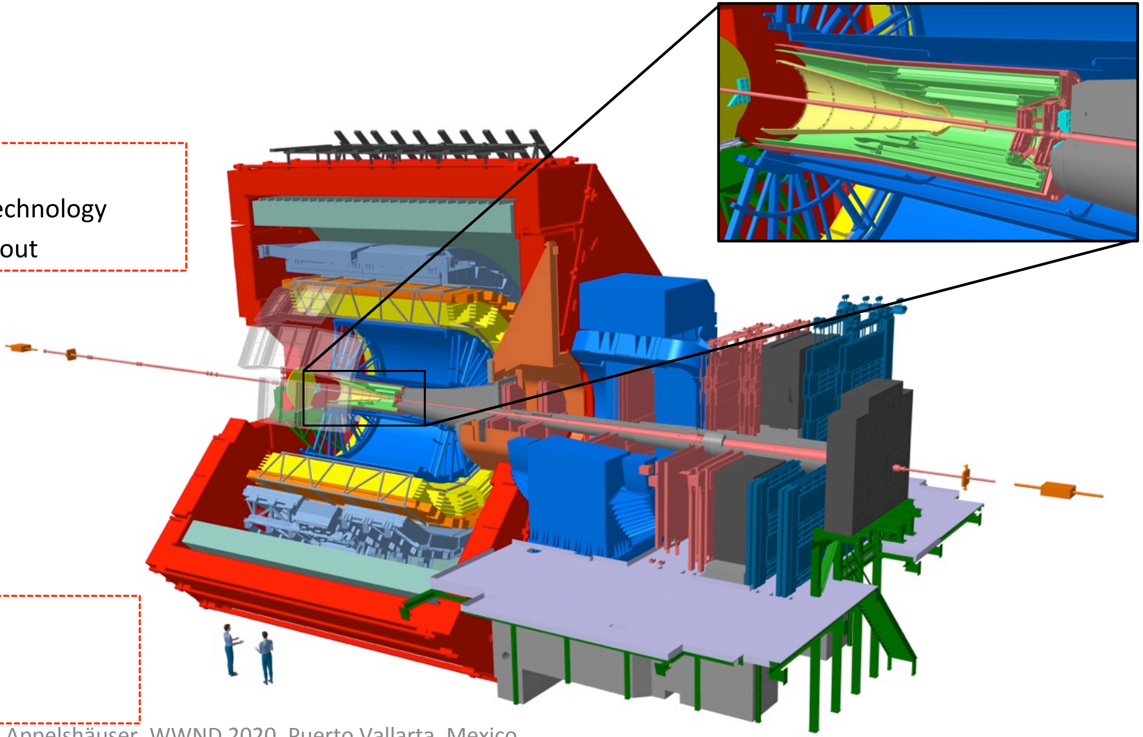
- Measure forward direct photons

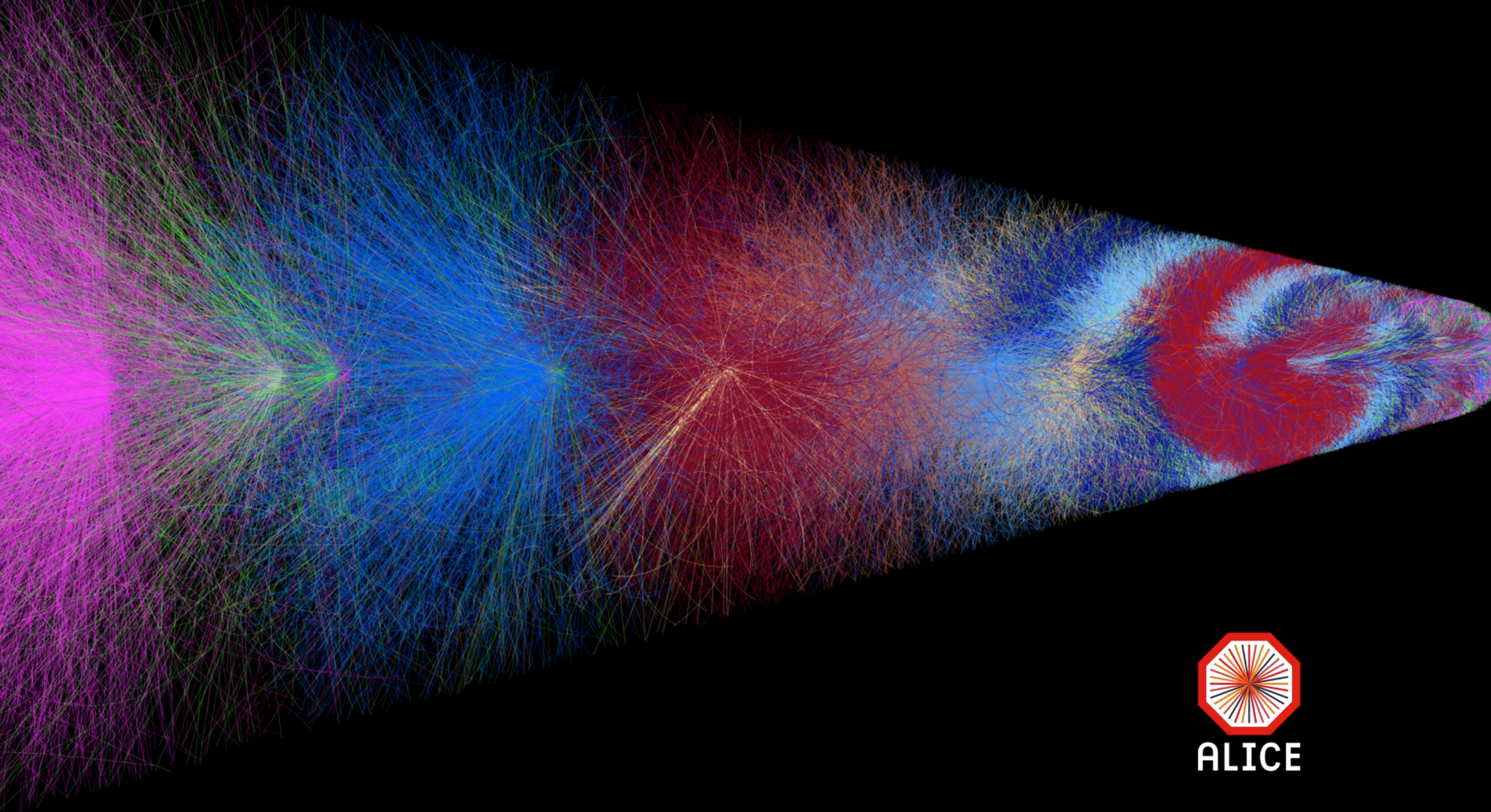
Readout upgrade

- TOF, TRD, MUON, ZDC, Calorimeters

Integrated Online-Offline system (O^2)

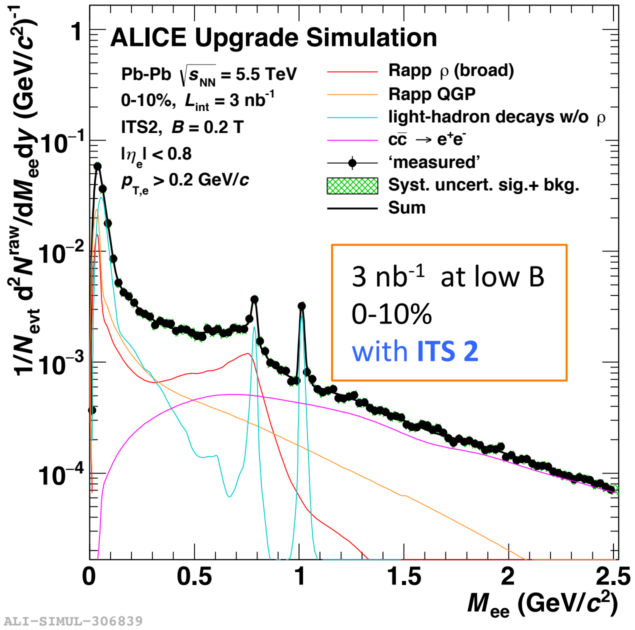
- Record MB Pb-Pb data at 50 kHz

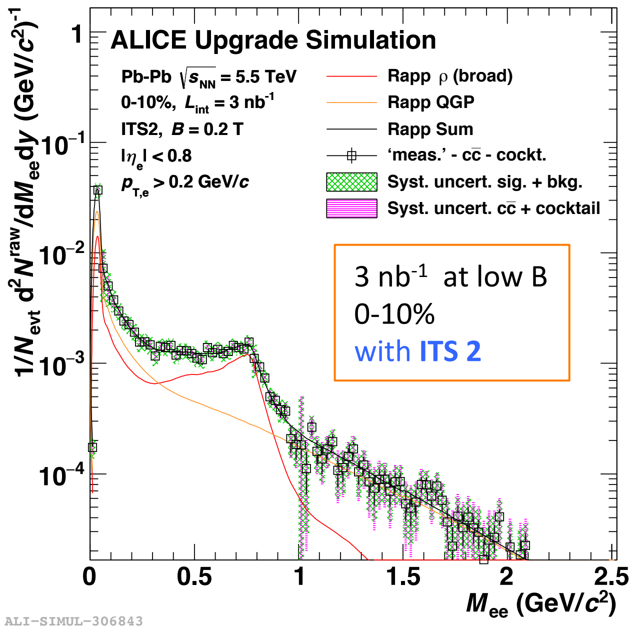



ALICE

Dielectron mass spectrum in Run 3

Z. Citron et al., CERN Yellow Rep. Monogr. (2019) 1159



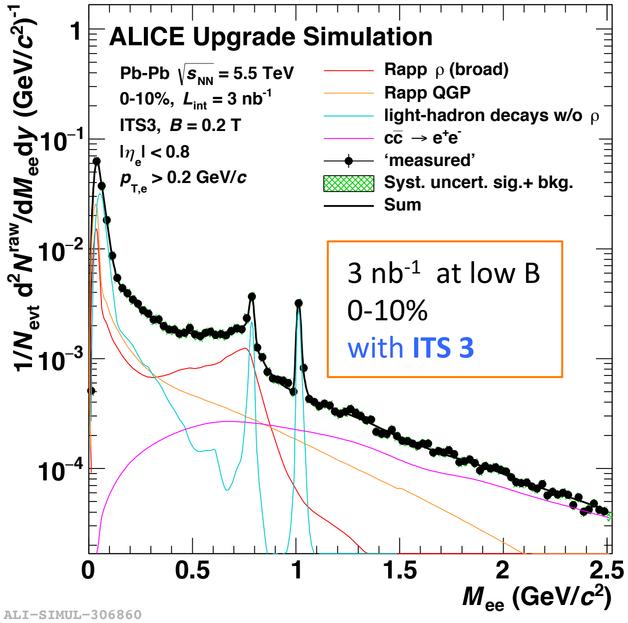


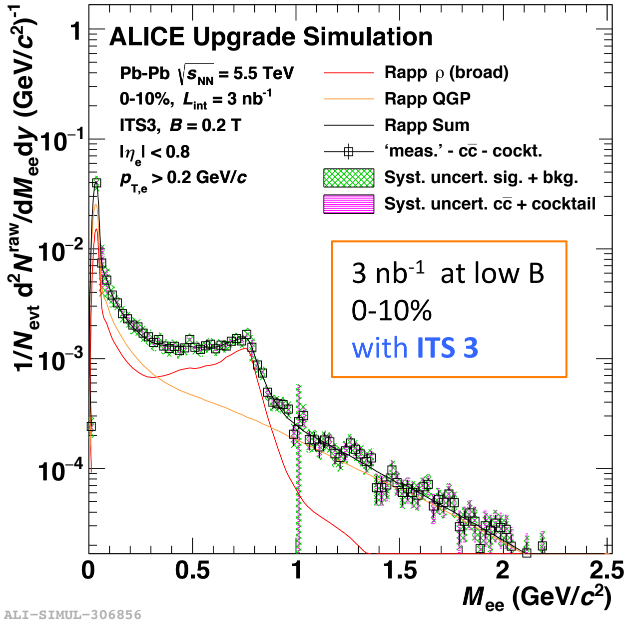
Detailed characterization of dielectron production:

- Pb-Pb: QGP temperature, ρ-broadening, chiral mixing
- pp: search for soft excess radiation

Dielectron mass spectrum in Run 4

Z. Citron et al., CERN Yellow Rep. Monogr. (2019) 1159





Detailed characterization of dielectron production:

- Pb-Pb: QGP temperature, ρ-broadening, chiral mixing
- pp: search for soft excess radiation
- Further suppression of charm contribution with ITS 3

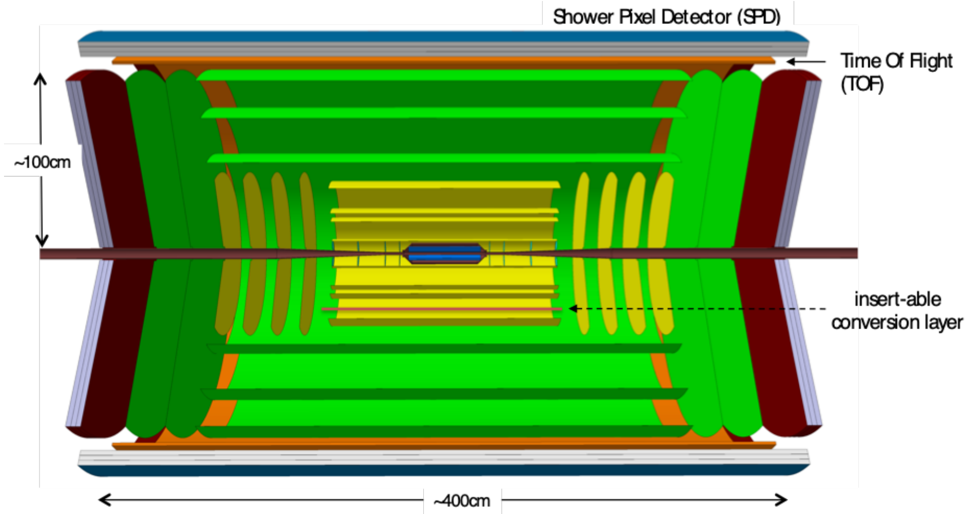
Future running at the LHC

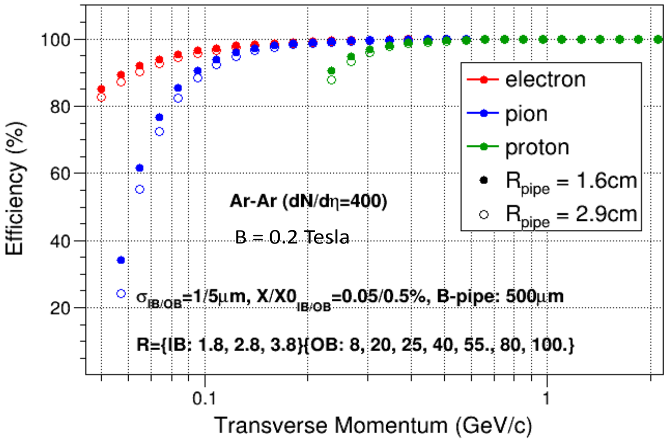
Run 5 and beyond:

- A next-generation heavy-ion experiment (ANGHIE)

A next-generation heavy-ion experiment

a thin, light, fast, all-silicon tracking and PID detector https://arxiv.org/abs/1902.01211





Heavy-flavor and quarkonia

- Multiply heavy-flavored hadrons: Ξ_{cc}, Ω_{cc}, Ω_{ccc}
- Ultimate precision on B-mesons at low p_T
- $X_{c1,2}$ states
- X,Y,Z charmonium-like states (e.g. X(3872))

Unique low material budget and low-p_T coverage

- Thermal radiation
- Chiral symmetry restoration
- Soft theorems