Measurement of dielectrons in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

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Strangeness in Quark Matter 2016

Topical conference on Strangeness and Heavy Flavor production in Heavy-Ion Collisions

27 June - 1 July 2016
UC Berkeley

Outline

- Introduction & physics motivation

- Analysis strategy:
  - Track selection, electron ID & conversion rejection
  - Background description & signal extraction

- Dielectron measurements in pp, p-Pb & in **Pb-Pb collisions (NEW)**
  - Virtual photons in pp & in **Pb-Pb collisions (NEW)**

- Perspectives for dielectron measurements after the ALICE upgrade

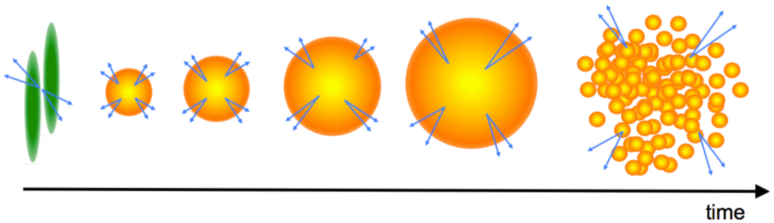
Dielectrons

Dielectrons:

- $\gamma^* \rightarrow e^+e^-$ (internal conversion)
- From interaction region & particle decays

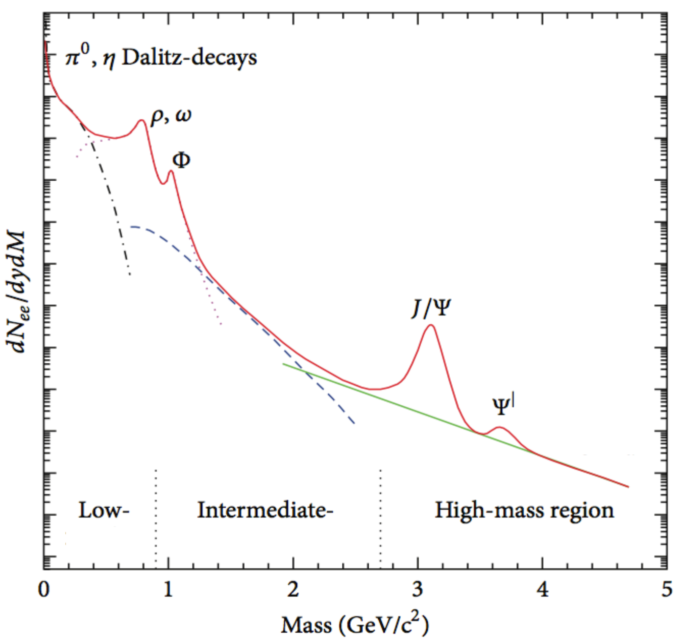
In Pb-Pb collisions:

- Emitted **continuously** during evolution of hot & dense system
- Negligible interaction with medium (**penetrating probes**)



Invariant mass spectrum:

- Different regions ⟷ different states & physical processes



Physics motivation

pp & p-Pb collisions:

- Study of virtual direct photons ($p_{\mathrm{T}}^{\mathrm{ee}} \gg m_{\mathrm{ee}}$):
  - ➢ complementary measurement of γ_{dir}
  - ➢ test of pQCD
- Heavy-flavor production (complementary to other HF analyses)
- Vacuum & cold nuclear matter baseline for Pb-Pb collisions

Pb-Pb collisions:

- Study of Electromagnetic (EM) radiation:
  - ➢ virtual direct photons (from low-mass region, as in pp & p-Pb collisions)
  - ➢ thermal radiation from QGP (from intermediate-mass region):

$$\frac{dn}{dm_{\mathrm{ee}}} \sim exp(-m_{\mathrm{ee}}/T) \quad \text{(no Doppler shift)}$$

- In-medium modification of low-mass vector mesons
  - ➢ connected to chiral symmetry restoration

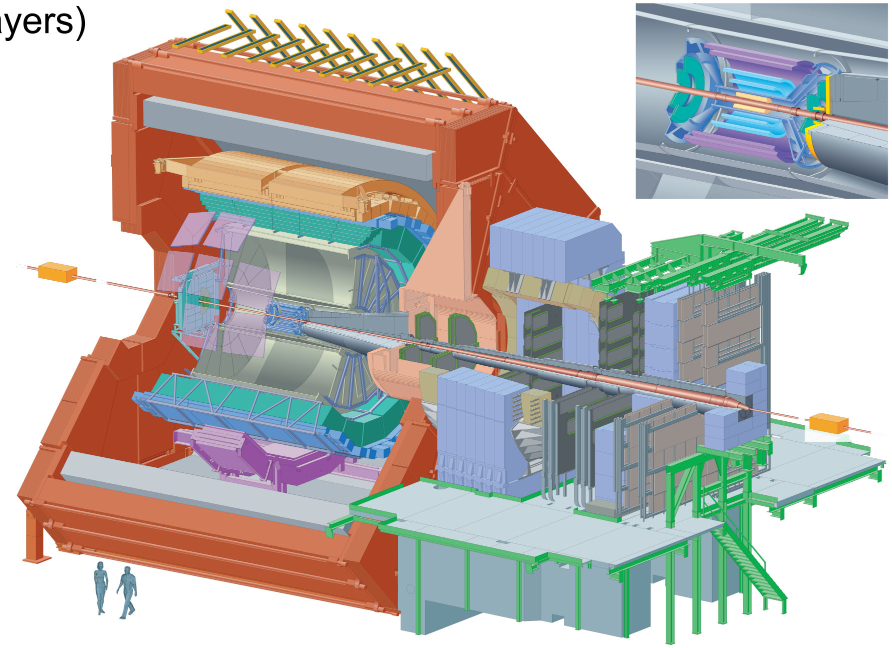
ALICE layout & datasets

ITS (Inner Tracking System)
- Tracking, vertexing & PID (via d*E*/dx in silicon layers)

TPC (Time Projection Chamber)
- Tracking & PID (via d*E*/dx in the gas)

TOF (Time Of Flight)
- PID (via TOF measurement)

V0
- Centrality estimator



Data sets used in these analyses:

Colliding system	Year	Number of events
pp at 7 TeV	2010	$\approx$ 350 M (min. bias)
p–Pb at 5.02 TeV	2013	$\approx$ 105 M (min. bias)
Pb–Pb at 2.76 TeV	2011	$\approx$ 20 M [0-10%], $\approx$ 17 M [10-50%]

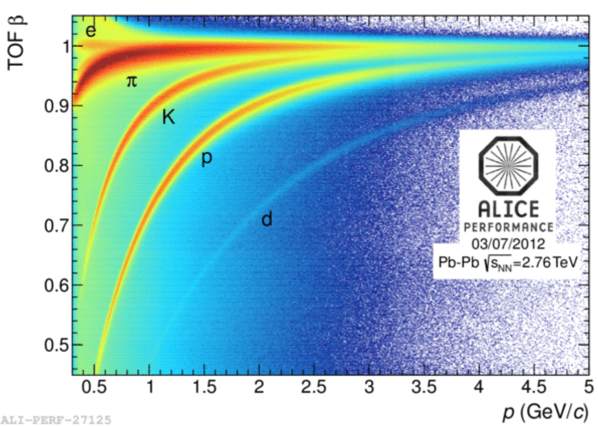
Track selection & PID

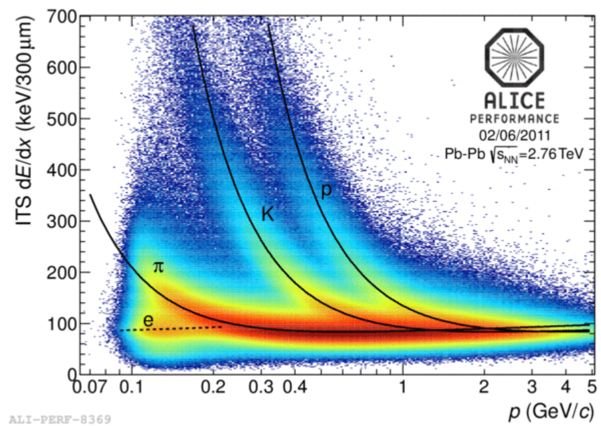
Selection of **primary tracks** (+ quality requirements)
Photon **conversion rejection** (single-track & pair rejection)

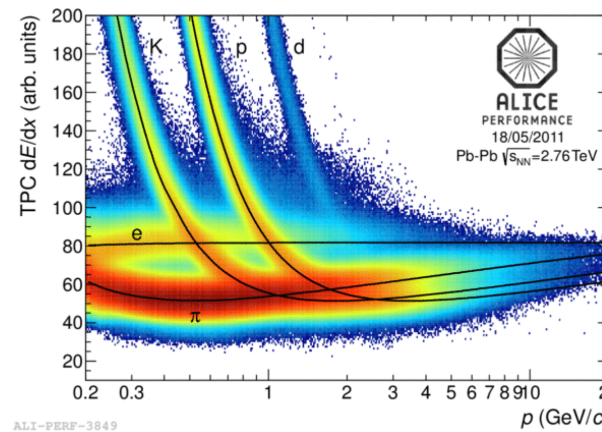
p_T-thresholds & acceptance:
$$\begin{cases} |\eta| < 0.8 \;\&\; p_{\mathrm{T}} \geq 0.2\ \mathrm{GeV}/c \text{ in pp \& p–Pb collision} \\ |\eta| < 0.8 \;\&\; p_{\mathrm{T}} \geq 0.4\ \mathrm{GeV}/c \text{ in Pb–Pb collisions (imposed by TOF)} \end{cases}$$

Electron ID based on:

- d*E*/d*x* measured by ITS & TPC
- time-of-flight measured by TOF







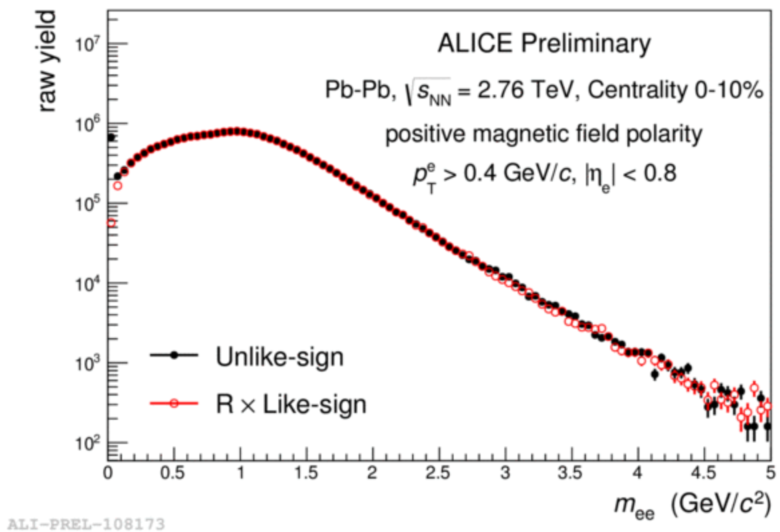
Hadron contamination < 1-10% (from pp to Pb-Pb collisions):

- effect on dielectron spectrum covered by uncertainties

Signal extraction

Background described by like-sign spectrum (**combinatorial** & **correlated** background):

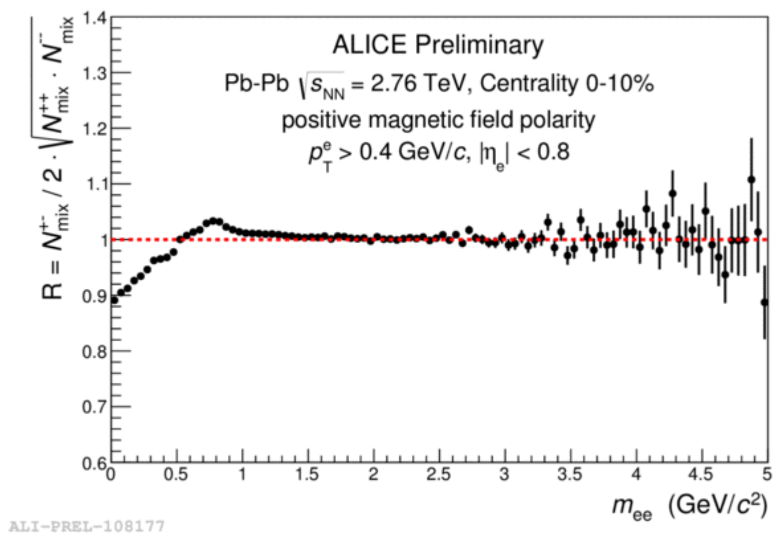
$$B = 2 \cdot R \cdot \sqrt{N_{++} \cdot N_{--}}$$



US & LS pairs have different acceptance (due to detector geometrical inhomogeneity)

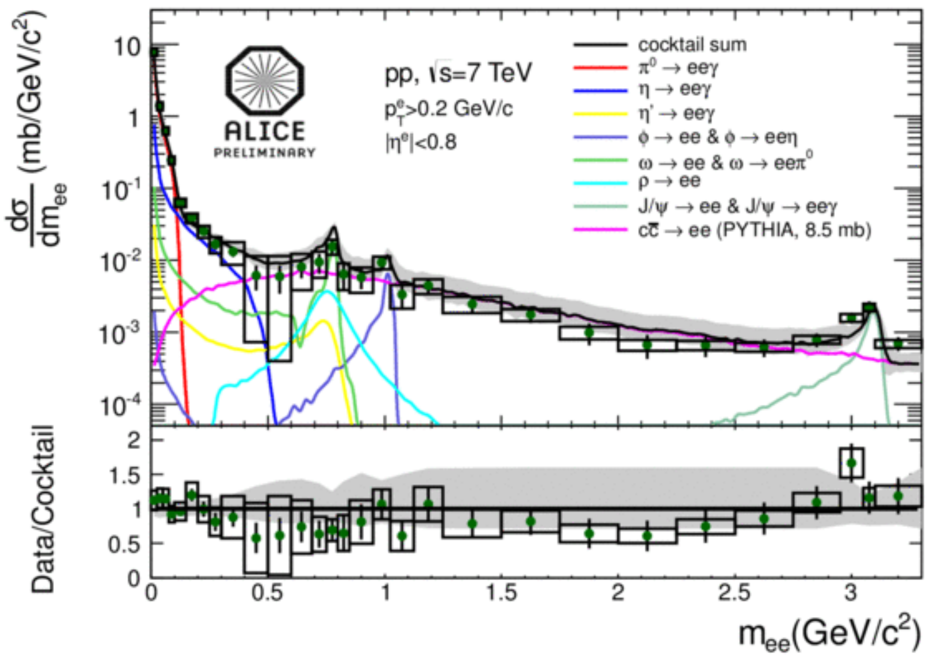
Acceptance correction from event-mixing:

$$R = \frac{N^{mix}_{+-}}{2 \cdot \sqrt{N^{mix}_{++} \cdot N^{mix}_{--}}}$$



$$\text{Raw Yield} = N_{+-} - 2 \cdot \text{R} \cdot \sqrt{N_{++} \cdot N_{--}}$$

Dielectrons in pp collisions



ALI-PREL-43484

Hadronic cocktail:

- $\pi^0, \eta, \omega, \phi, J/\Psi$: measured by ALICE
- other contributions: m_T scaling
- $c\bar{c}$: PYTHIA scaled to measured $\sigma_{c\bar{c}}$
- $b\bar{b}$ & Drell-Yan → work in progress

Hadronic cocktail consistent with data within uncertainties

Data might hint to a different mass shape of dielectrons from charm

➢ further studies using POWHEG & MC@NLO generators are ongoing

Virtual photons in pp collisions

Virtual photons extraction:

- Cocktail & virtual photons normalised to data at $m_{ee} = 0$
- Fit mass spectrum in kinematic region $p_T^{ee} \gg m_{ee}$ with:

$$f\ (m_{ee}) = r \cdot f_{dir}\ (m_{ee}) + (1- r) \cdot f_c\ (m_{ee})$$

Hadronic cocktail

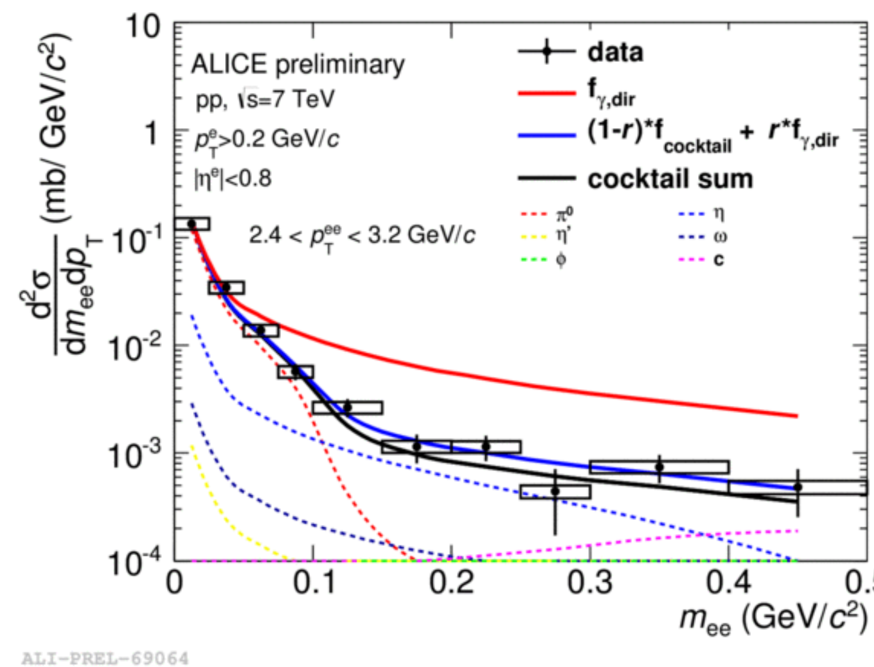
Direct photons described by Kroll-Wada equation:

$$\frac{d^2 n_{ee}}{dm_{ee}} = \frac{2\alpha}{3\pi}\frac{1}{m_{ee}}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)dn_\gamma$$

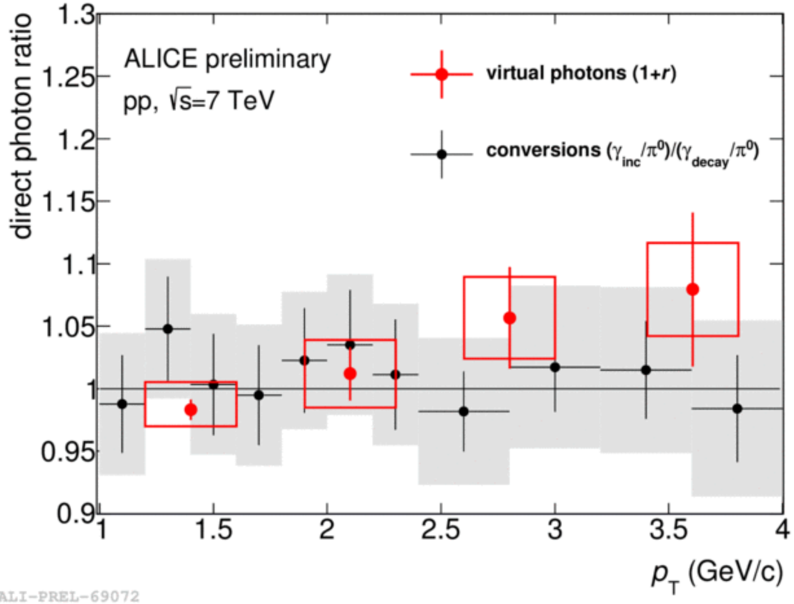
Fraction of virtual direct photons

- extracted from fit:

$$r = \frac{\gamma^*_{dir}}{\gamma^*_{incl}}$$



Direct photon spectrum in pp collisions



Fraction of direct photons consistent with the measurement from **Photon Conversion Method** (PCM):

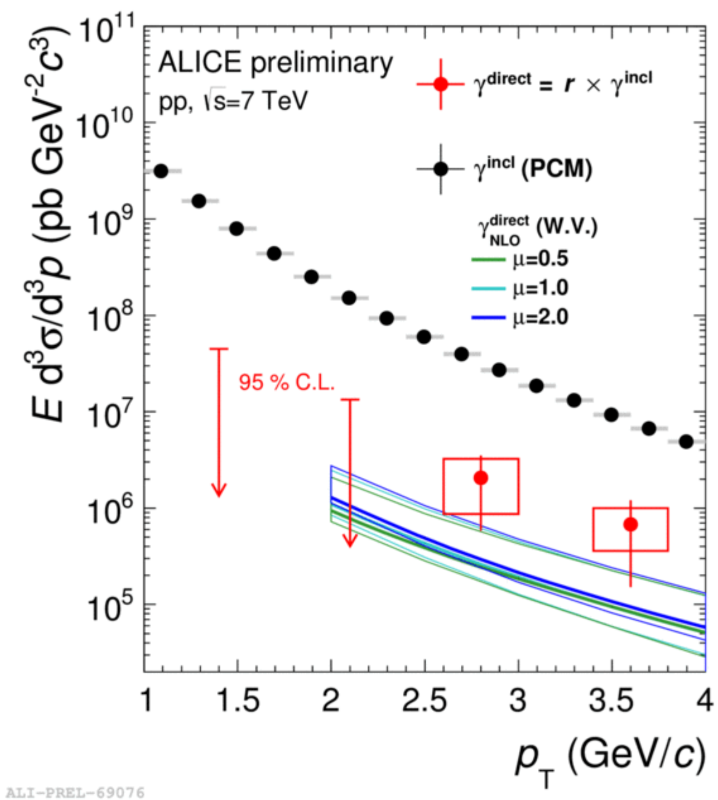
$$\rightarrow r = \frac{\gamma^*_{dir}}{\gamma^*_{incl}} = \frac{\gamma_{dir}}{\gamma_{incl}}$$

Direct photons yield:

$$\gamma^{dir}(p_{\mathrm{T}}) = r \cdot \gamma^{incl}(p_{\mathrm{T}})$$

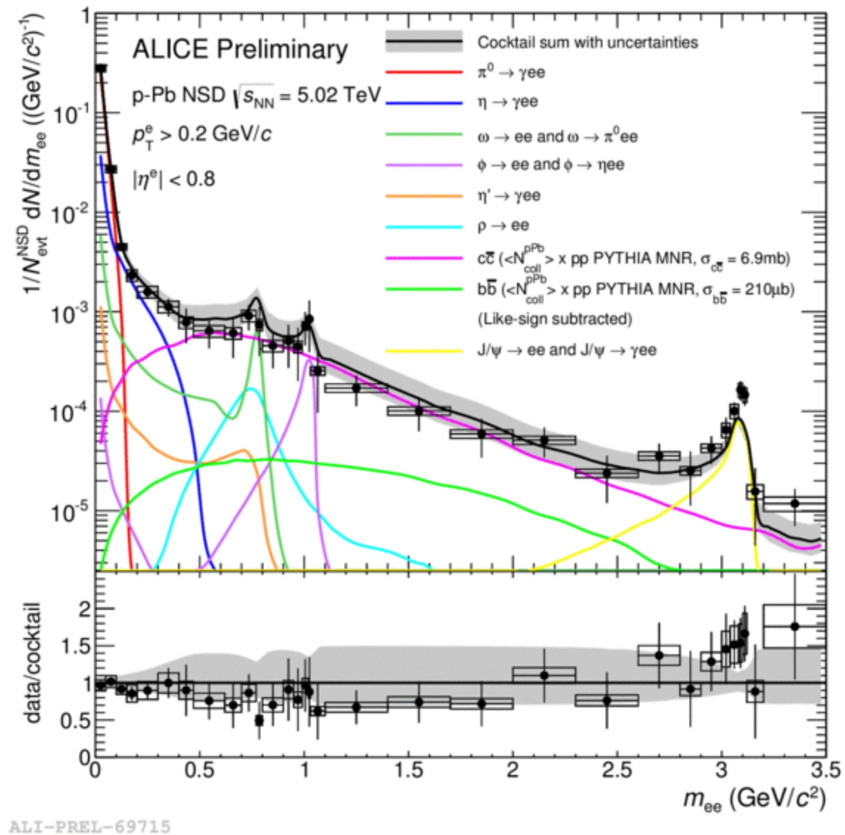
virtual photon fraction (for r)

from real photon measurement (for $\gamma^{incl}(p_{\mathrm{T}})$)



NLO pQCD calculations consistent with data within uncertainties

Dielectrons in p-Pb collisions



Data are consistent with cocktail within uncertainties

- Data might indicate lower charm production (compared to N_{coll} scaling) or different pair correlations from PYTHIA

Ongoing analyses:

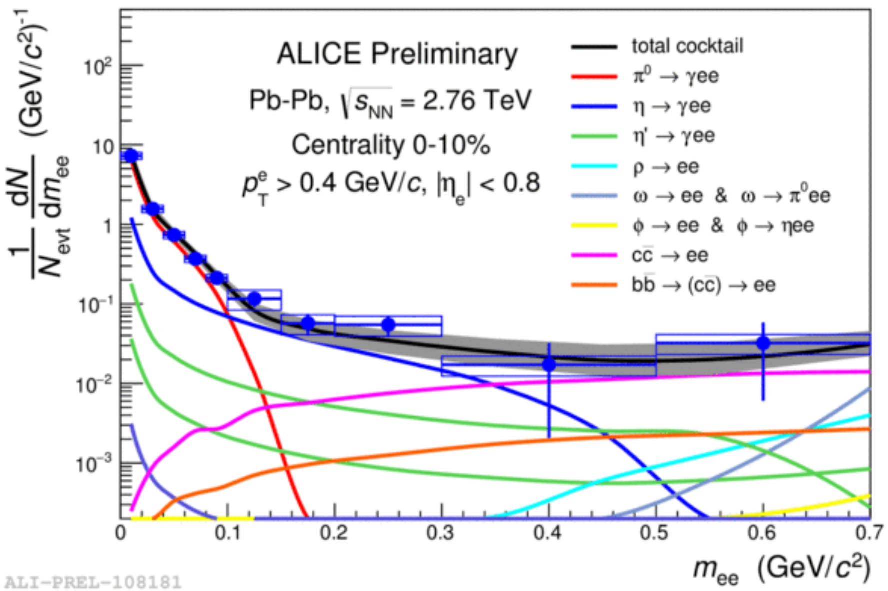
- virtual photons, open charm & beauty cross sections

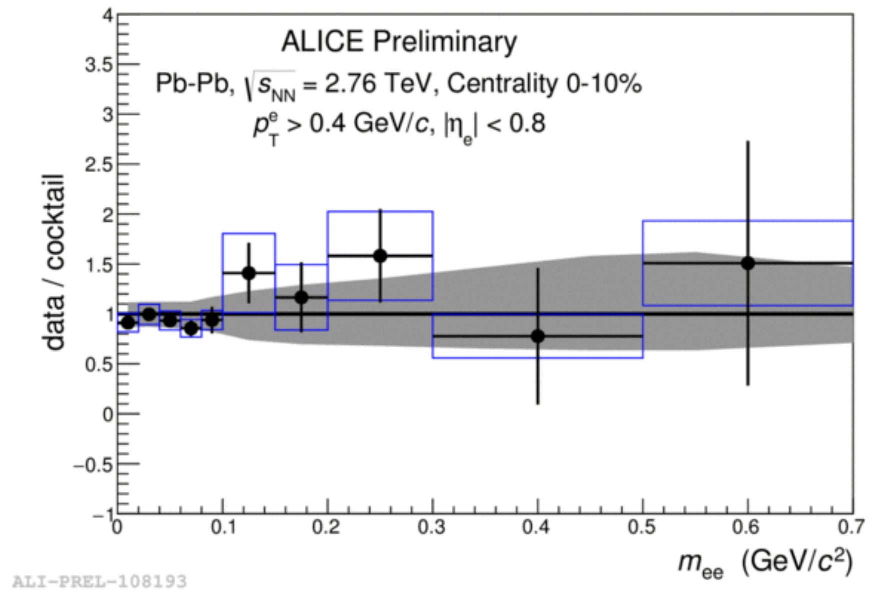
Dielectron measurements in Pb-Pb collisions at 2.76 TeV (NEW)

NEW

Dielectrons in central Pb-Pb collisions: 0-10% (I)

Focus on low-mass region ($m_{ee} \leq 700\ MeV/c^2$)





Hadronic cocktail:

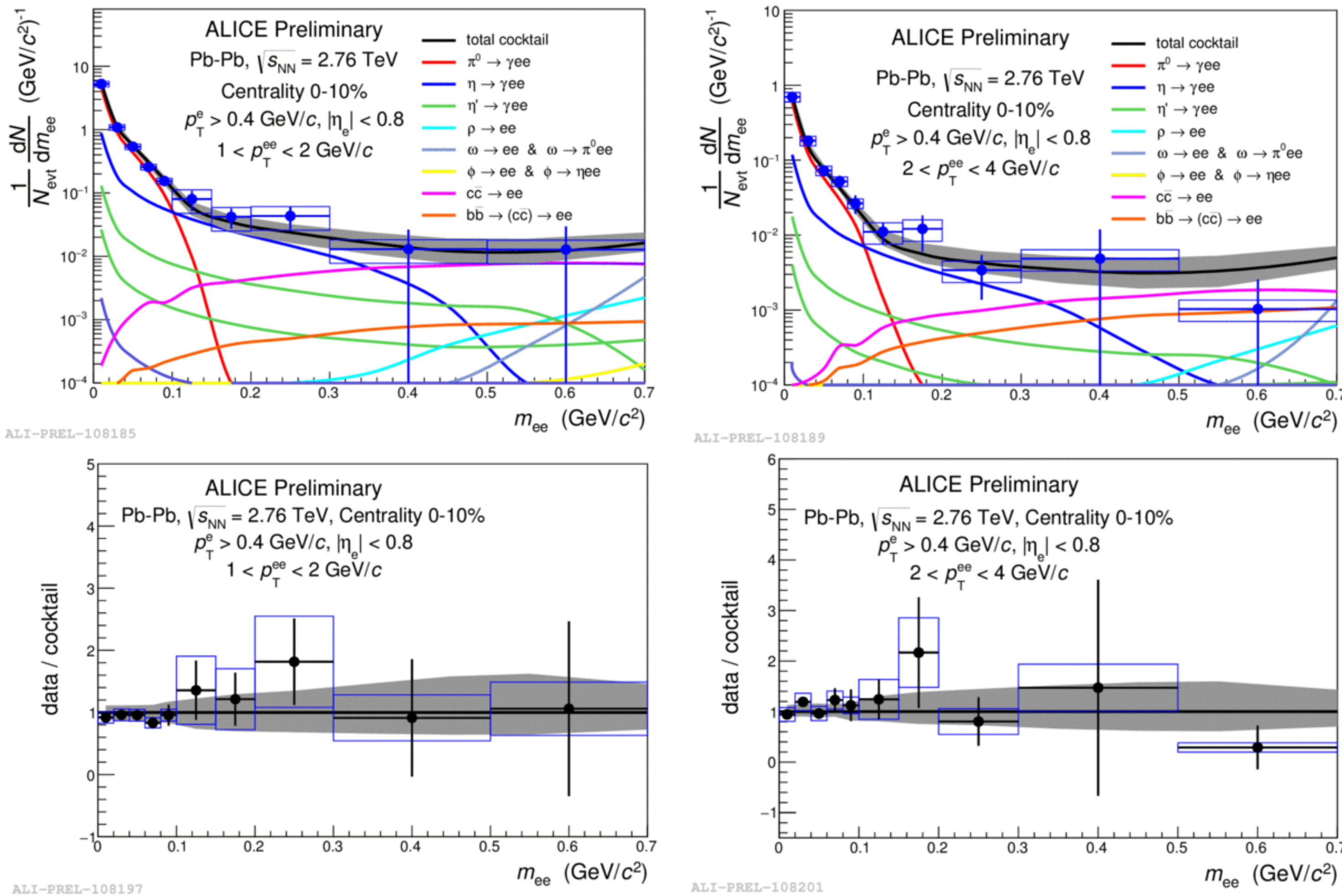
- π^0 measured by ALICE, other mesons via m_T scaling
- Heavy flavors: binary scaling of measurements in pp collisions

No enhanced dielectron production is observed in the low-mass region

➢ Reduced sensitivity due to low statistics & large uncertainties

Dielectrons in central Pb-Pb collisions: 0-10% (II)

NEW



Additional dielectron sources are not excluded:

- Contribution from virtual direct photons has been measured

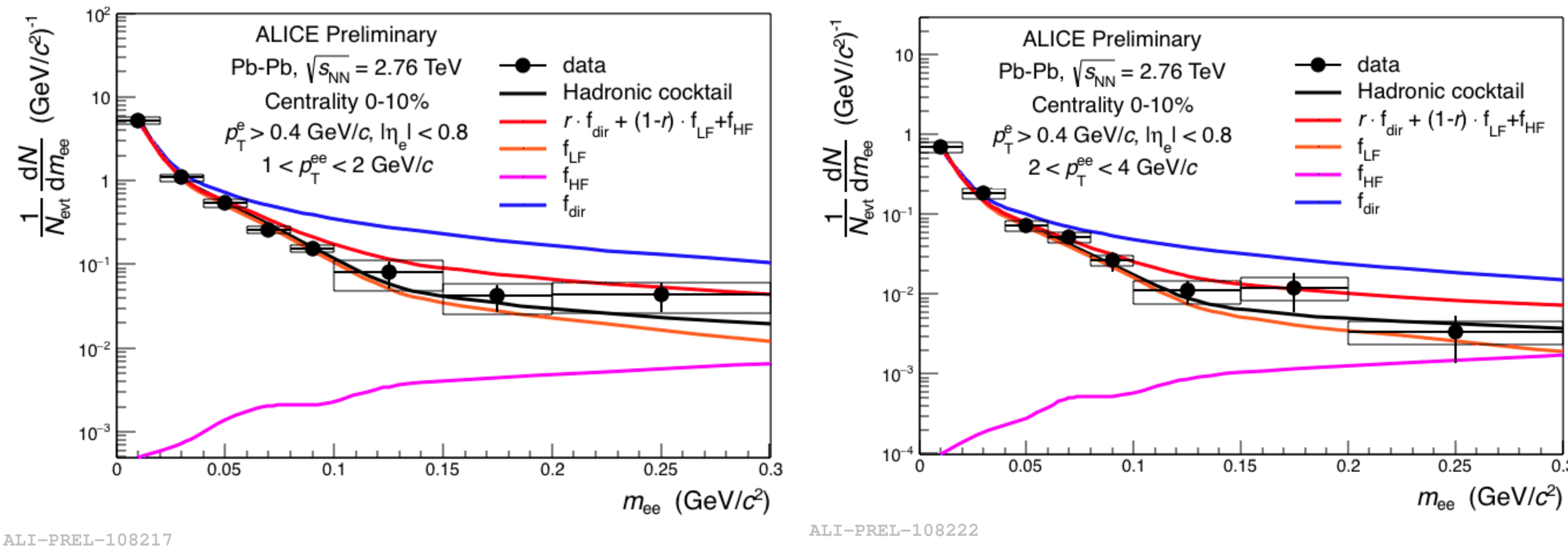
NEW

Virtual photon extraction

ALICE

Minimized χ^2 fit of data in the mass range [100,300] MeV/c^2:

$$f(m_{ee}) = r \cdot \underbrace{f_{dir}(m_{ee})}_{\text{Kroll-Wada}} + (1-r) \cdot \underbrace{f_{LF}(m_{ee})}_{\text{Light-flavor cocktail}} + \underbrace{f_{HF}(m_{ee})}_{\text{Heavy-flavor cocktail}}$$



Virtual photon fractions extracted from fit:

$$\begin{cases} r = 0.10 \pm 0.10 \text{ for } p_{\mathrm{T}}^{ee} \in [1,2] \text{ GeV}/c \\ r = 0.05 \pm 0.12 \text{ for } p_{\mathrm{T}}^{ee} \in [2,4] \text{ GeV}/c \end{cases}$$

Consistent with zero

- ➢ upper limit is estimated

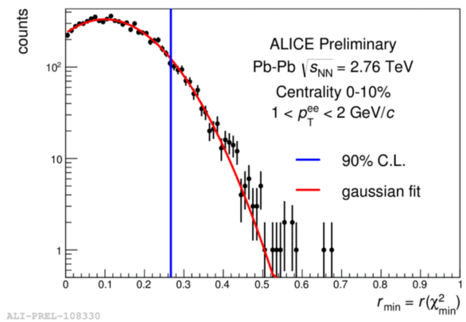
NEW

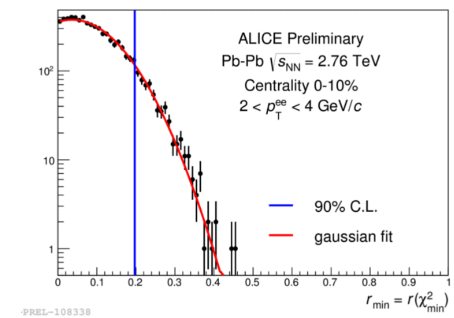
Upper limit extraction

ALICE

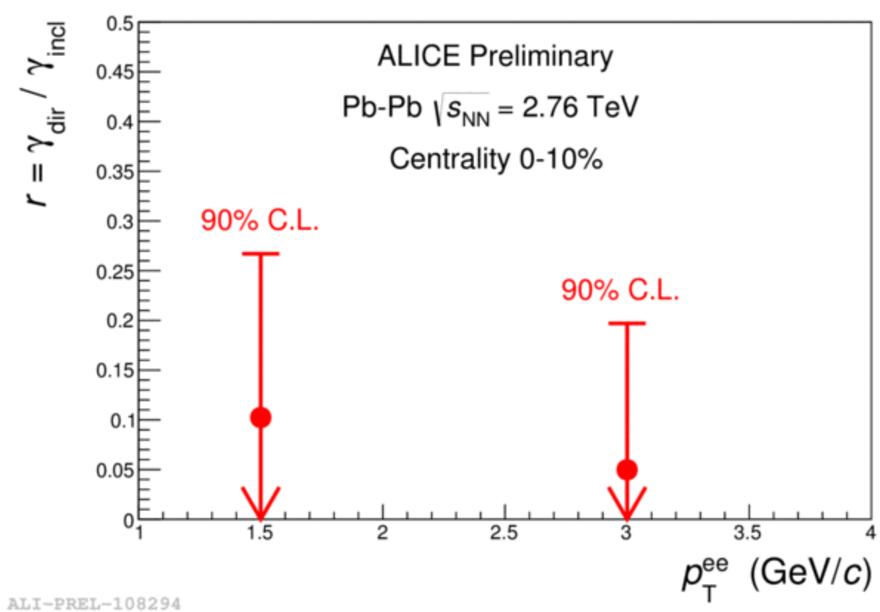
Upper limit estimation:

- Measure fraction of virtual photons in N (=10^4) simulated experiments:
  - ➢ random sampling of data around best fit curve and moving of data coherently by fraction of their systematic uncertainties





- Upper limit (90% CL) extracted from integration of obtained r distributions → $\int_0^r f(r)dr = 0.9 \cdot \int_0^1 f(r)dr$



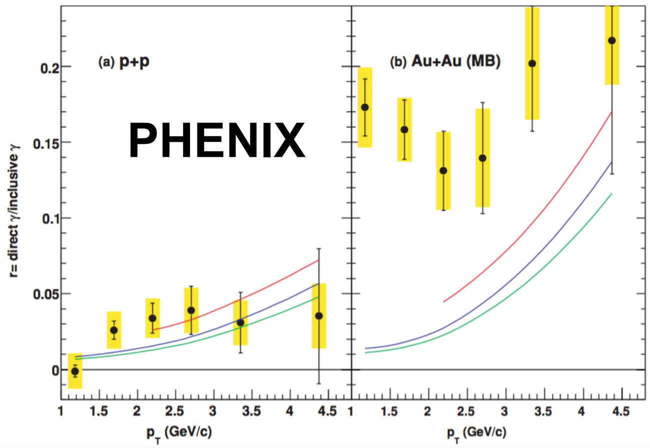
90% confidence limits:

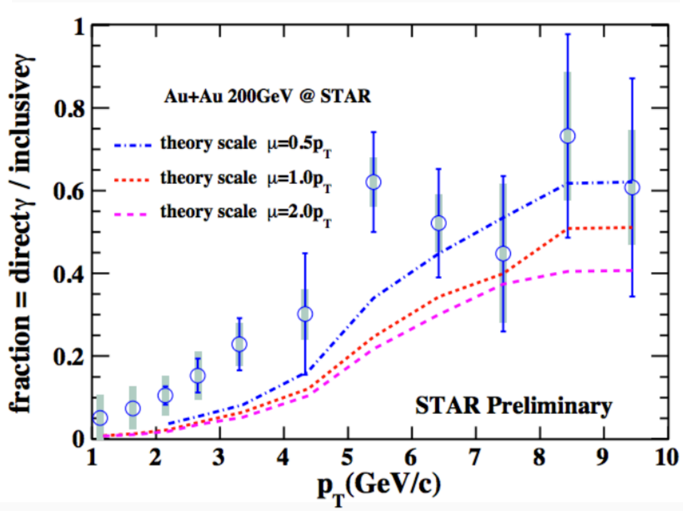
$$\begin{cases} r \leq 0.27 \text{ for } p_T^{ee} \in [1{,}2] \text{ GeV}/c \\ r \leq 0.20 \text{ for } p_T^{ee} \in [2{,}4] \text{ GeV}/c \end{cases}$$

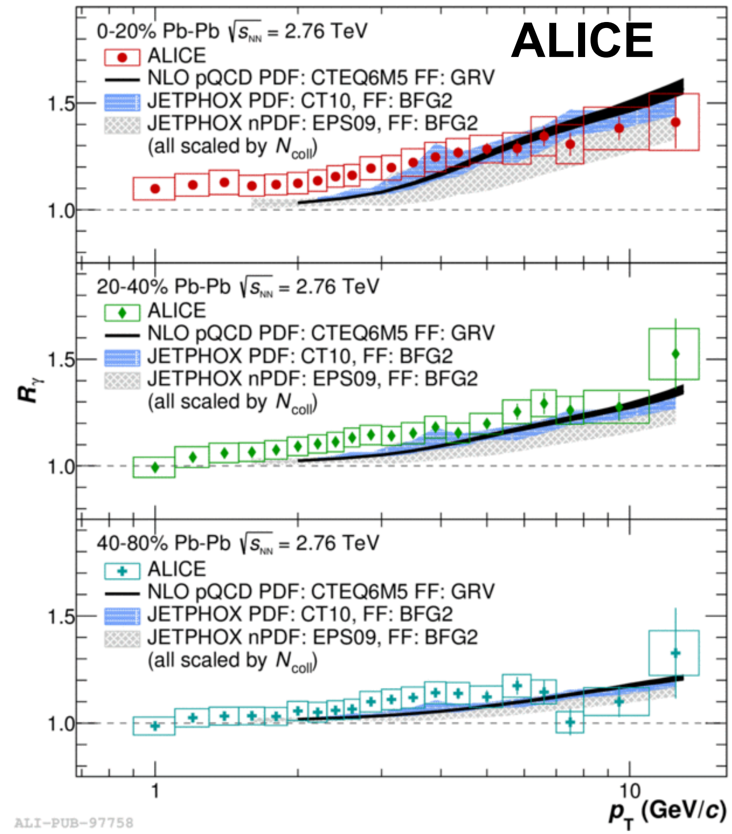
Comparison with other measurements

NEW

PHYSICAL REVIEW C **81**, 034911 (2010)







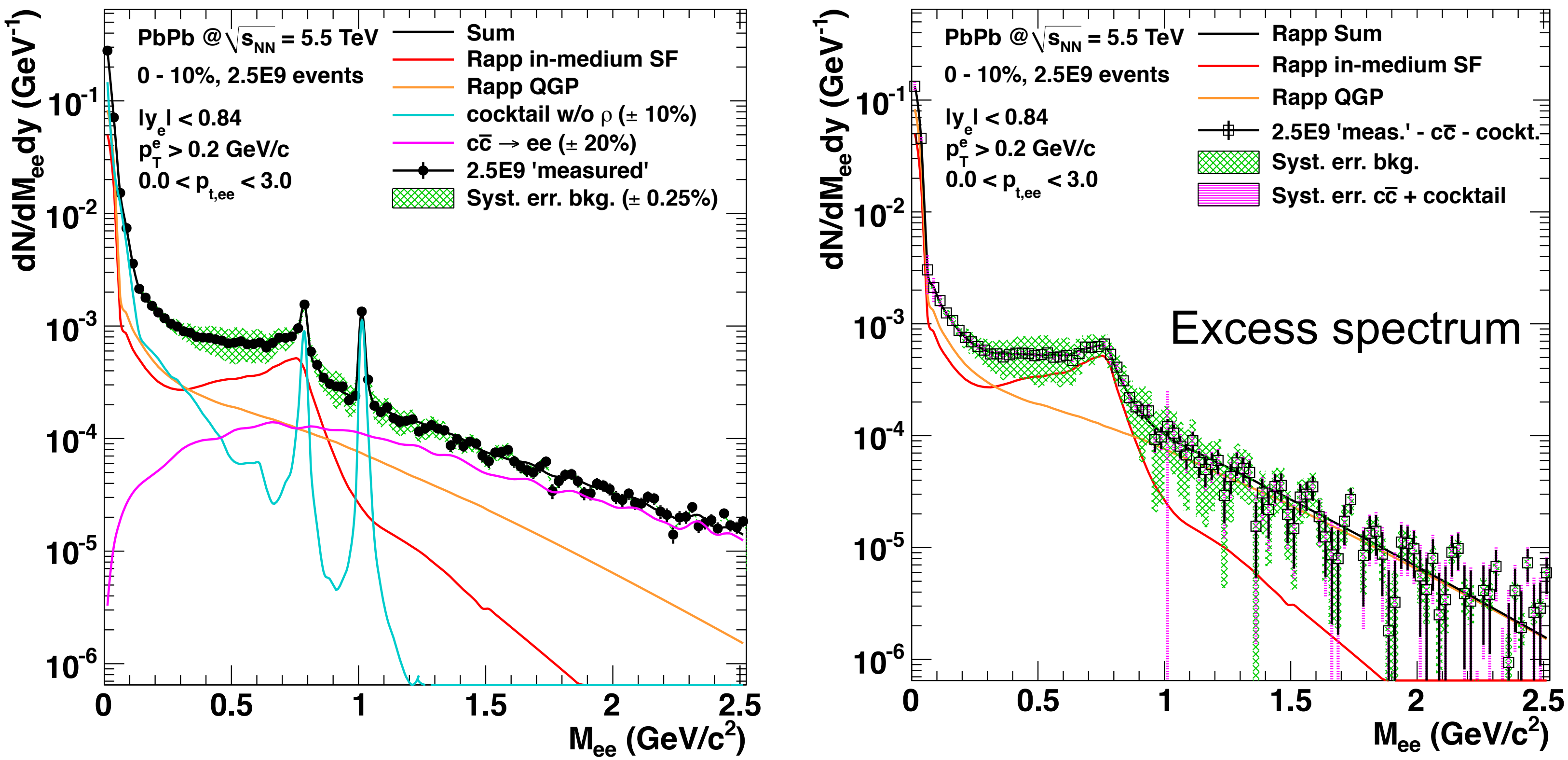
ALICE (PHOS+PCM): $r = 1 - \frac{1}{R_\gamma} \approx 0.1$

Extracted limits compatible with ALICE measurement from PCM+PHOS & previous results from PHENIX & STAR

Perspectives after ALICE upgrade

J. Phys. G 41 (2014) 087002

new ITS, 2.5×10^9 events with DCA cuts



- New ITS: suppression of main background sources (Dalitz, conversion & charm)
- Continuous TPC readout will increase event rate by a factor ~100
  - ➢ Detailed measurement of in-medium ρ modification & thermal radiation

Summary

Dielectron spectra measured in pp & p-Pb collisions:

- Consistent with hadronic cocktail
- NLO pQCD consistent with direct photons measured in pp collisions
- Further analyses ongoing

First dielectron measurement in Pb-Pb collisions at 2.76 TeV:

- Dielectron yield not significantly larger than hadronic cocktail
- Extracted upper limit at 90% C.L. on virtual photon production:
  - compatible with real photon measurement from ALICE and virtual photons from PHENIX & STAR

Expected scenario after ITS & TPC upgrade:

- Higher rate & improved background rejection power will allow us to precisely measure thermal radiation & in-medium effects of low-mass vector mesons

Thank you for your attention

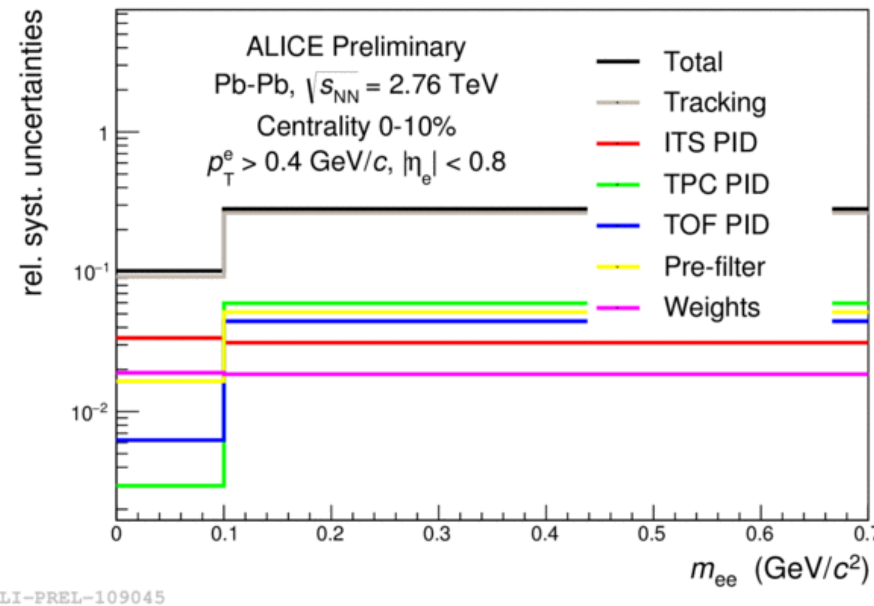
Backup Slides

Systematic uncertainties: Data

Sources of syst. uncertainties treated independently (syst. uncert = RMS*)

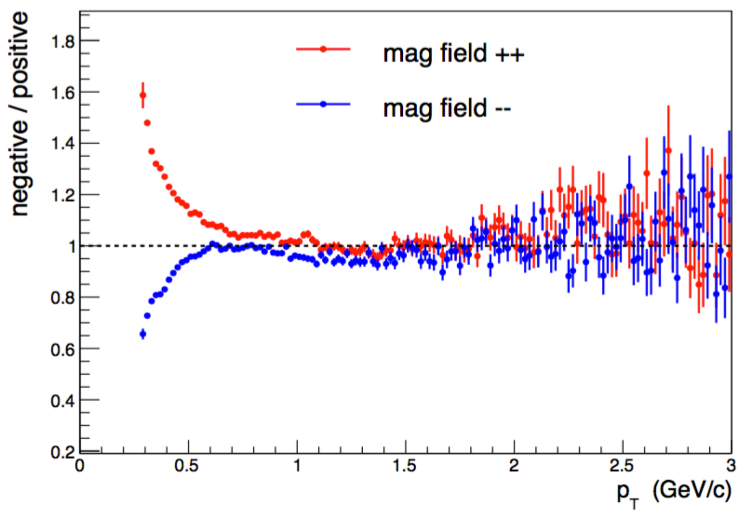
Total contribution: **sum in quadrature**

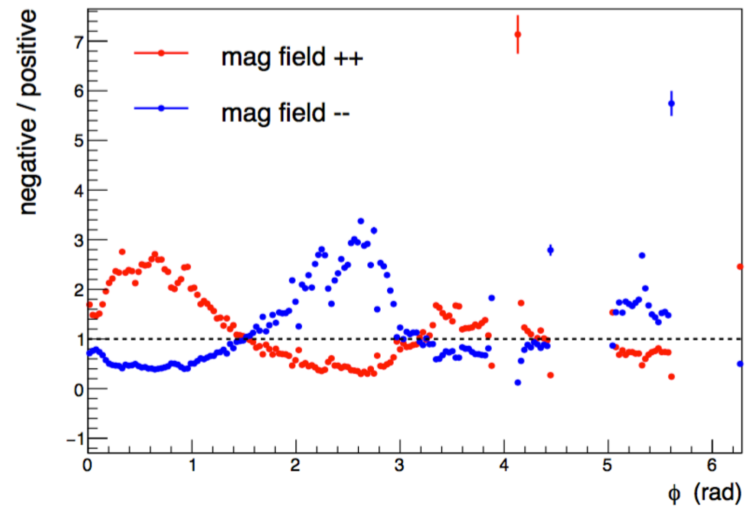
Source of uncertainty	**Relative uncertainty (low-mass)**	**Relative uncertainty (high-mass)**
Tracking	9.2 %	26.4 %
ITS PID	3.4 %	3.1 %
TPC PID	0.3 %	5.9 %
TOF PID	0.6 %	4.4 %
Pre-filter	1.6 %	5.1 %
Weights	1.9 %	1.8 %
Total systematic	**10.1 %**	**28.1 %**
Total statistical	**2 %**	**28 %**

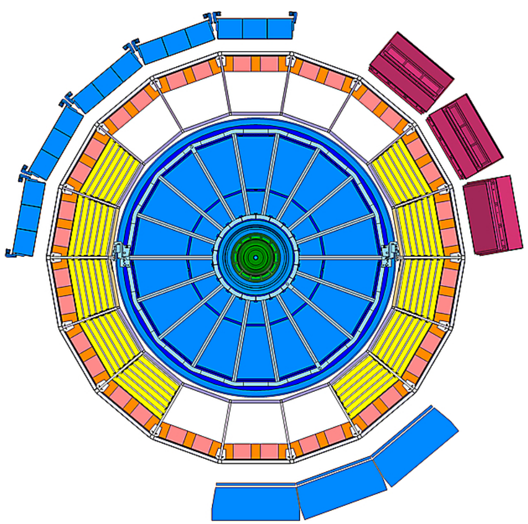


* For *weights* max. deviation is used

Charge asymmetry







ULS background & LS have same distributions but different acceptance:

- ULS bend in opposite directions
- LS bend in same direction

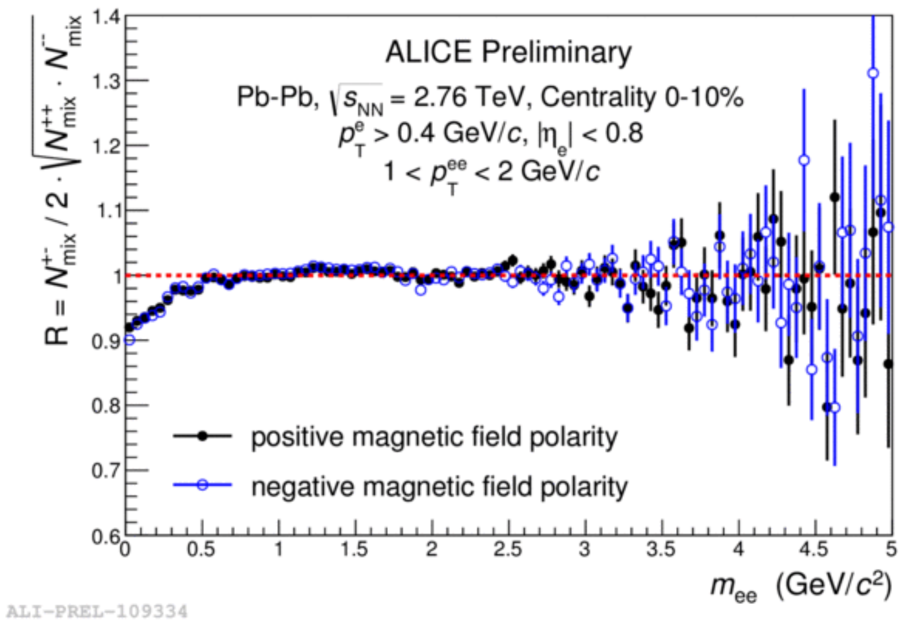
→ Distortions in LS distribution to be corrected

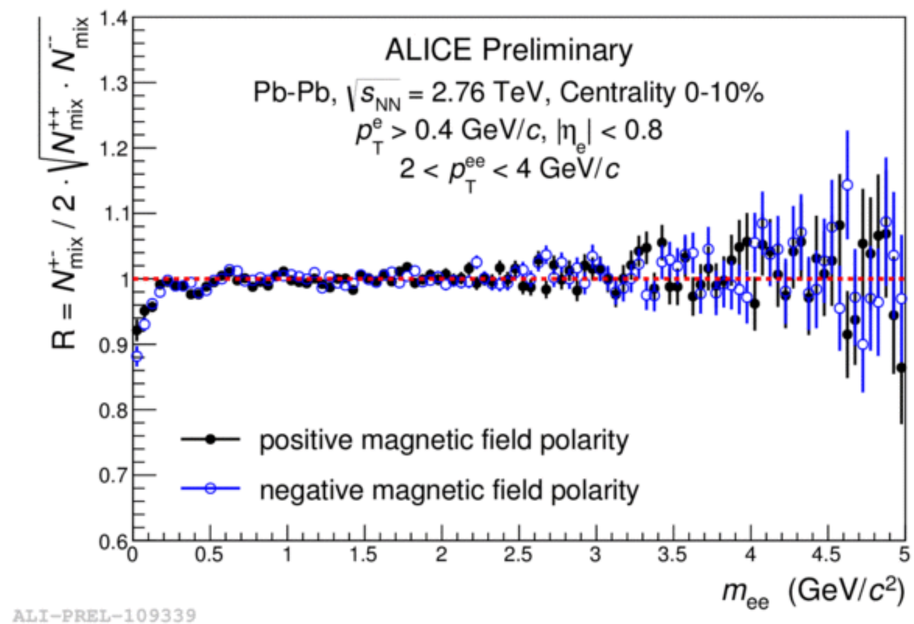
R-factor: opposite field polarities

Acceptance correction from event mixing:

$$R = \frac{N_{+-}^{mix}}{2 \cdot \sqrt{N_{++}^{mix} \cdot N_{--}^{mix}}}$$

Different shapes for opposite field polarities



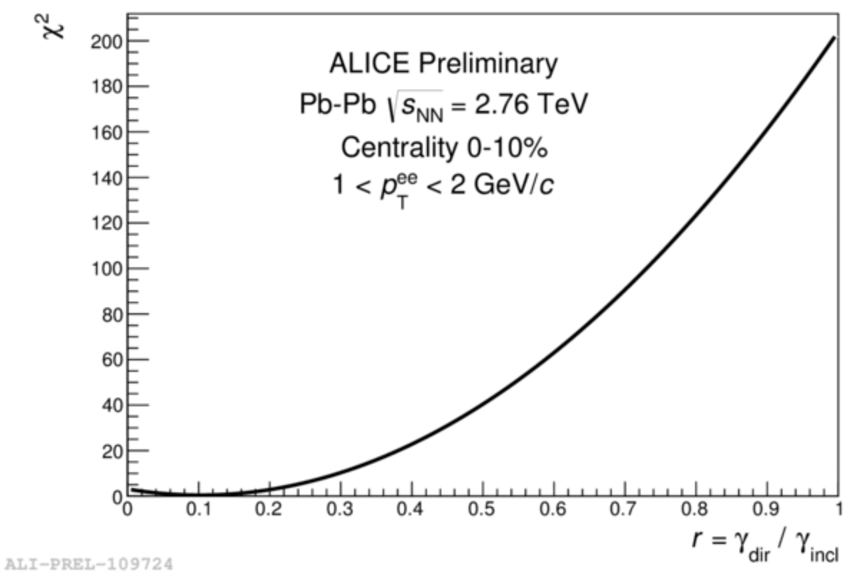


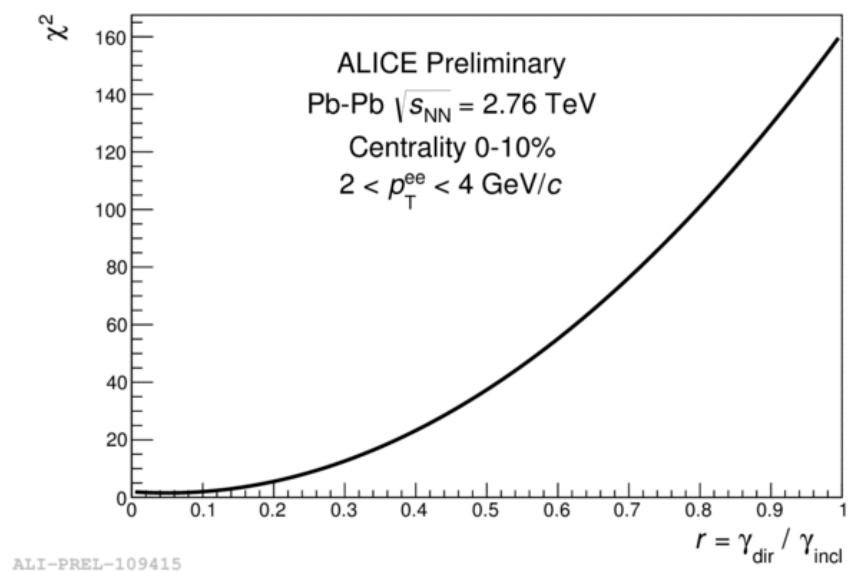
χ^2 minimization

- Fit parameter (r) is varied in the range [0,1]
- For each r the χ^2 is calculated:

$$\chi^2 = \sum_{i=1}^{n} \frac{(s_i - \mu_i)^2}{\sigma_i^2}$$

- $r_{min} \longleftrightarrow \chi^2_{min}$: best estimate of virtual direct photons fraction

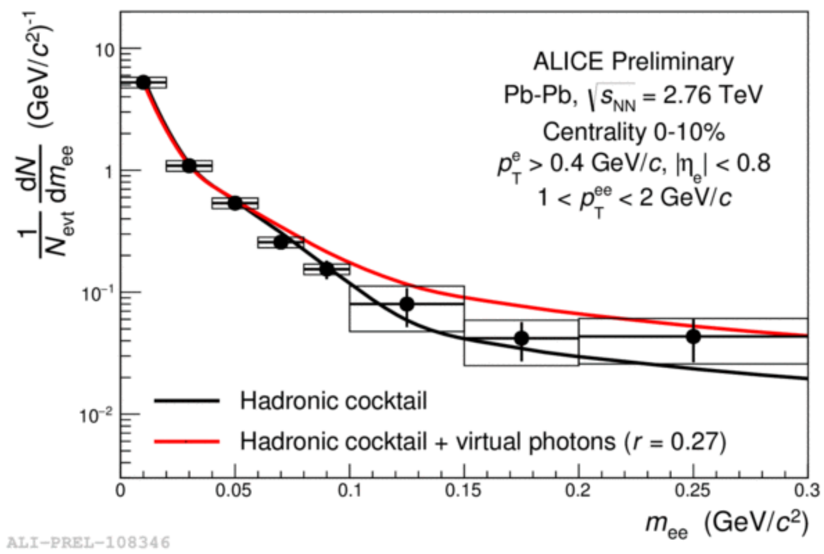


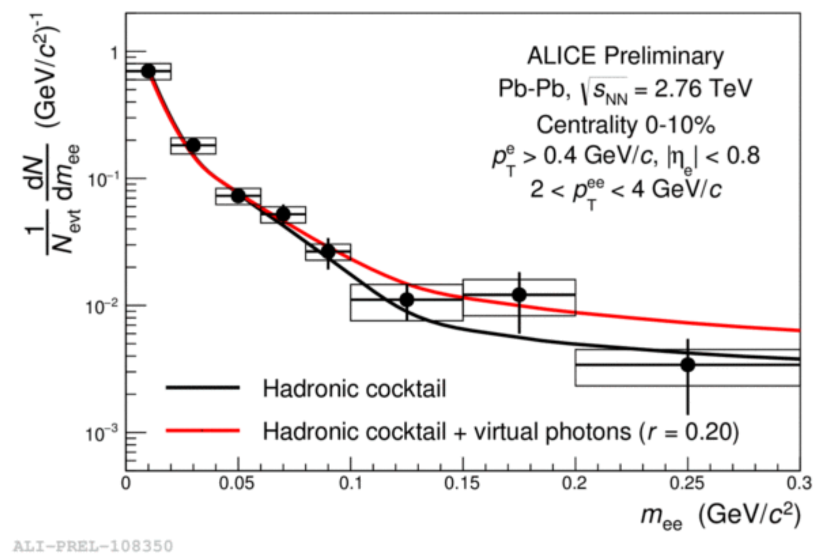


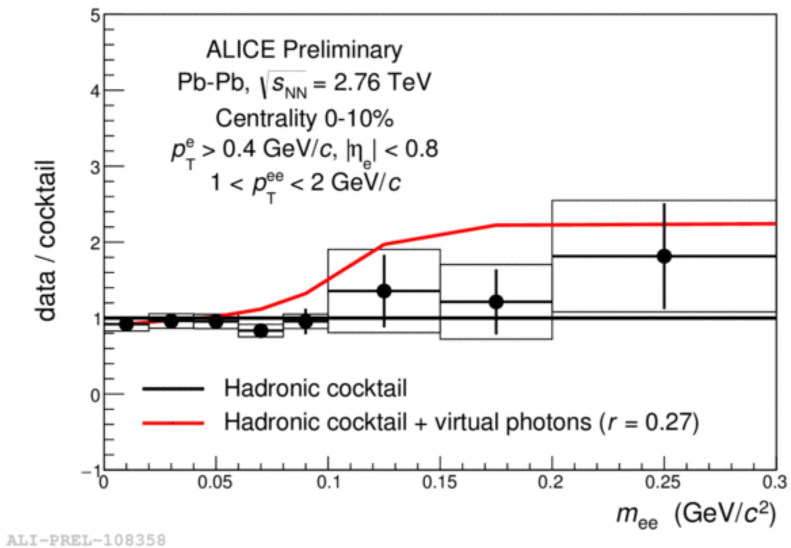
From PDG: $\Delta\chi^2$ = 2.71 for 1 parameter fit

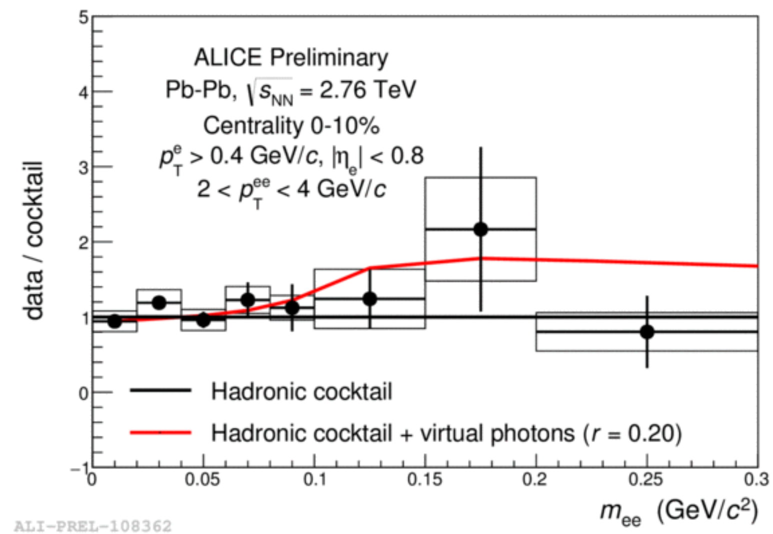
- Confidence range (1σ): [r_{min}- Δr_{min}, r_{min}+ Δr_{min}]
- Δr_{min} corresponds to $\chi^2 = \chi^2_{min}$ + 2.71

Upper limit on virtual direct photons



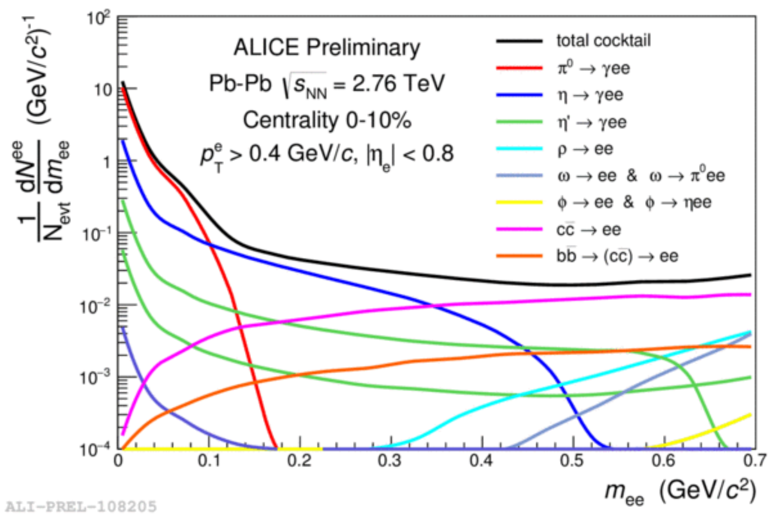


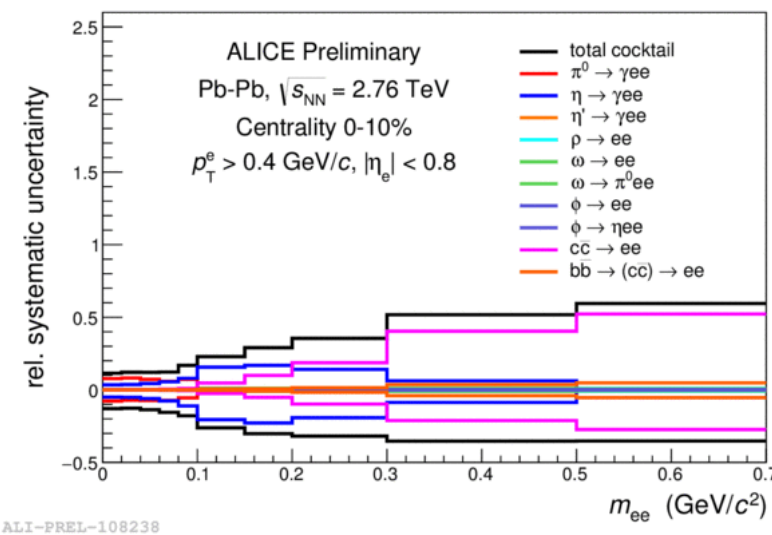




Hadronic cocktail

- Input parametrization from π^0 ($\pi^\pm$ only for [40-50%])
  - m_T-scaling for other LF mesons
- HF from PYTHIA in pp collisions at 7 TeV
  - scaled to 2.76 TeV (ratio of cross-sections)
  - scaled by N_{coll} (from MC Glauber)
- Syst. Uncertainties: from π^0 measurement, η/π, σ_{inel} in pp @ 7 TeV, $\sigma_{c\bar{c}}$ & $\sigma_{b\bar{b}}$

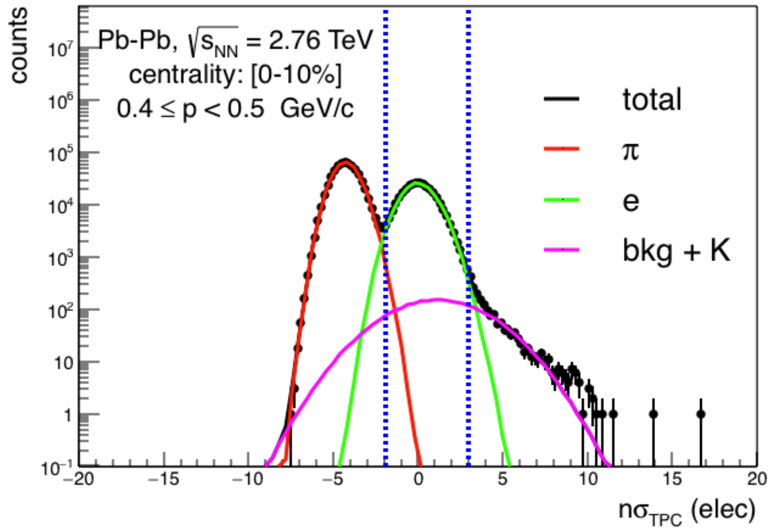


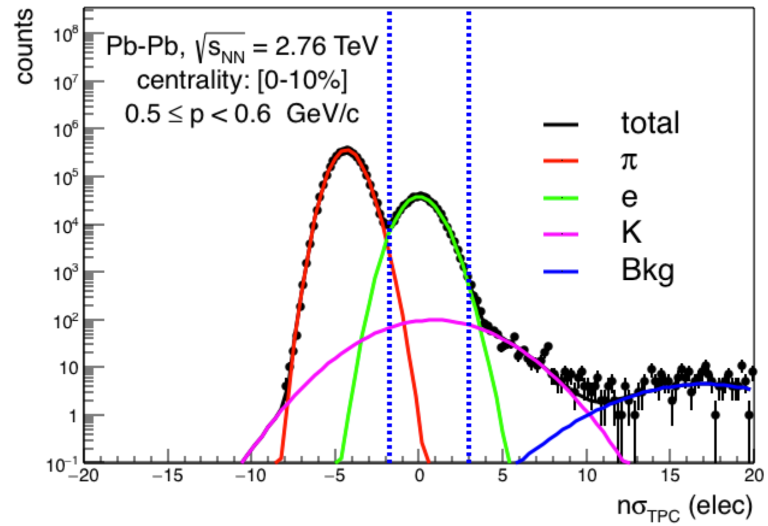


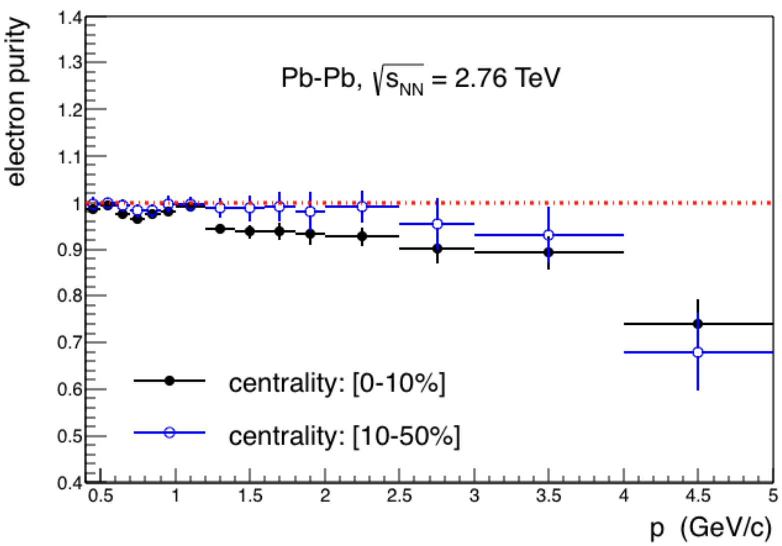
Momentum resolution & bremsstrahlung applied using same matrices used for the pair efficiency

Electron purity

Multiple Gaussian fit of $n\sigma_{TPC}^{elec}$ after inclusion cuts in TOF & ITS

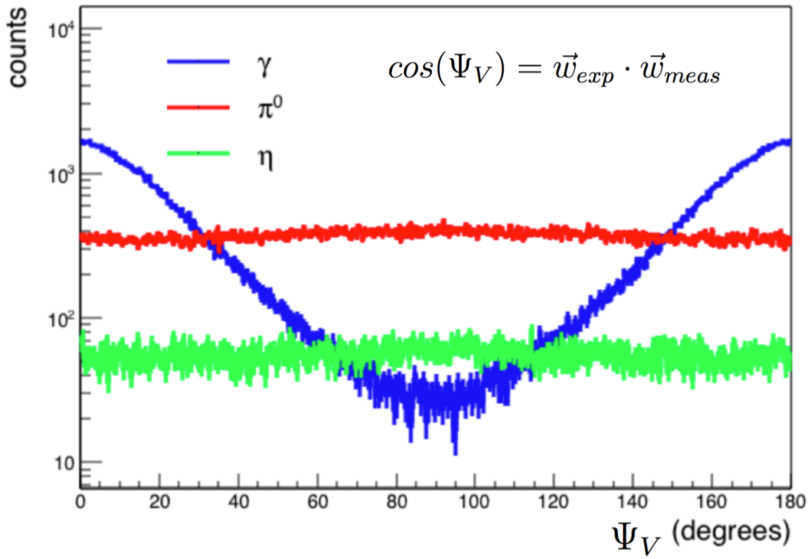


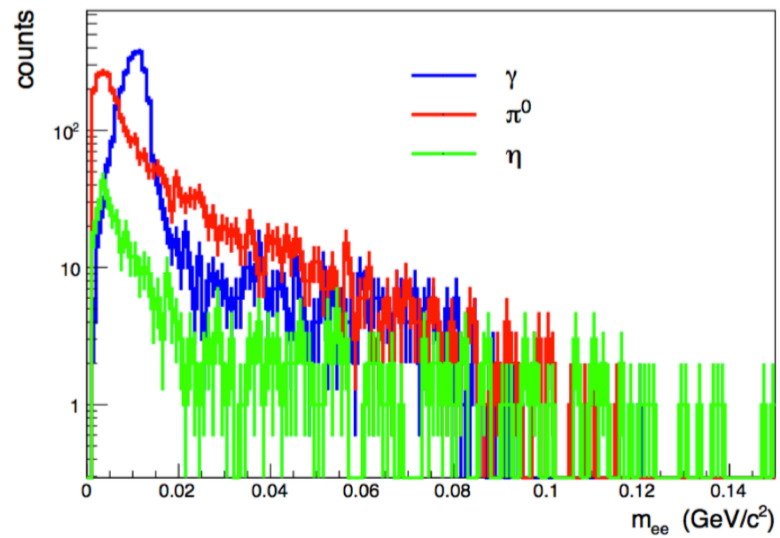


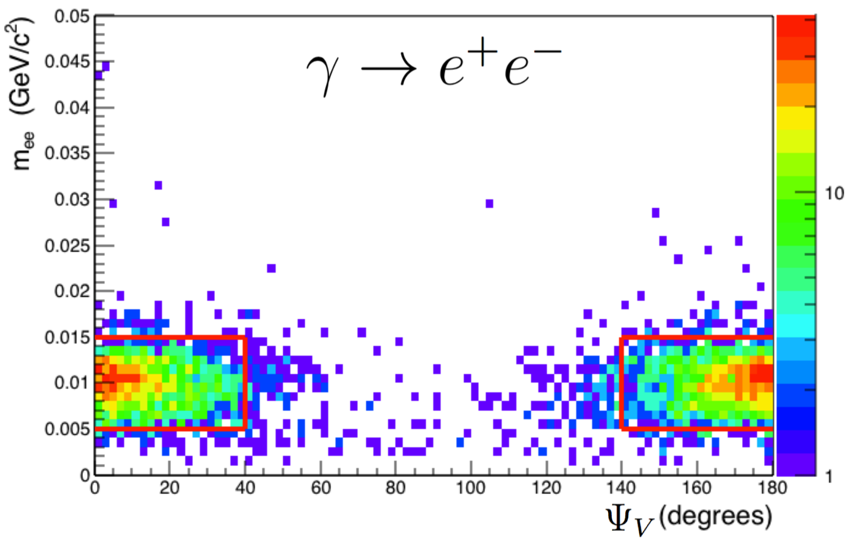


$$\text{e purity} = \frac{\text{electrons}}{\text{total}} > 90\ \%$$

Conversion rejection: pair cuts







Pair pre-filter: tag conversion candidates & reject from track sample

→ **Reduce combinatorial bkg**

Ψ_V calculation

$$\begin{cases} \vec{w}_{exp} = \vec{p} \times \vec{z} \\ \vec{w}_{meas} = \vec{p} \times \vec{u} \end{cases}$$

Expected orientation of opening angle

Actual orientation of opening angle

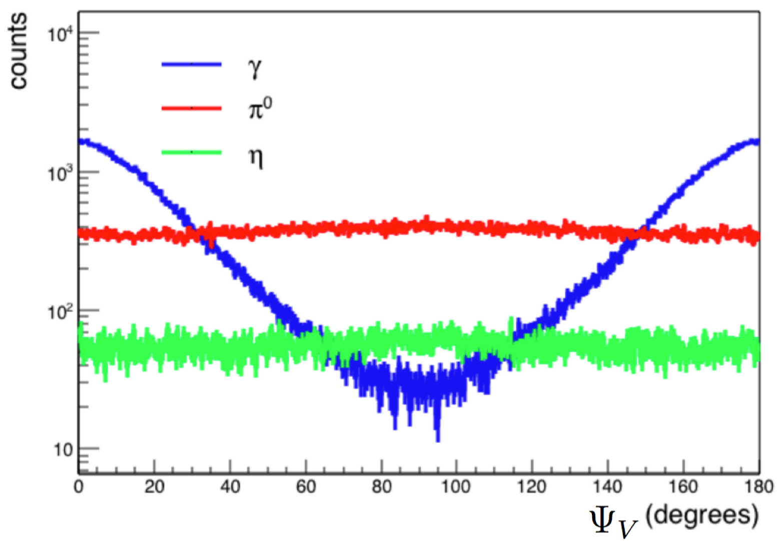
$\vec{p} = \vec{p}_1 + \vec{p}_2 \equiv$ Total pair momentum

$\vec{u} = \vec{p}_1 \times \vec{p}_2 \equiv$ Perpendicular to plane defined by the pair

$\vec{z} \equiv$ Orientation of mag. field

Ψ_V: angle between actual & expected orientation of opening angle

$$cos(\Psi_V) = \vec{w}_{exp} \cdot \vec{w}_{meas}$$

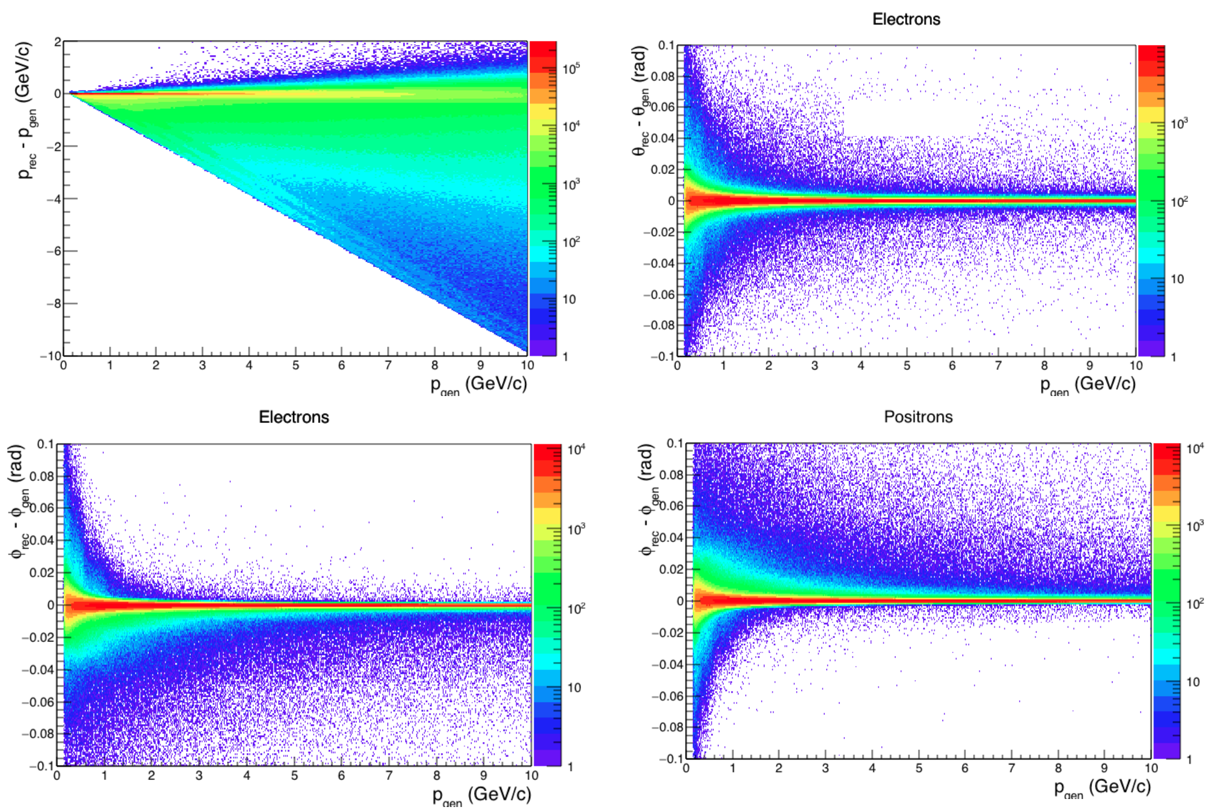


Pair efficiency calculation

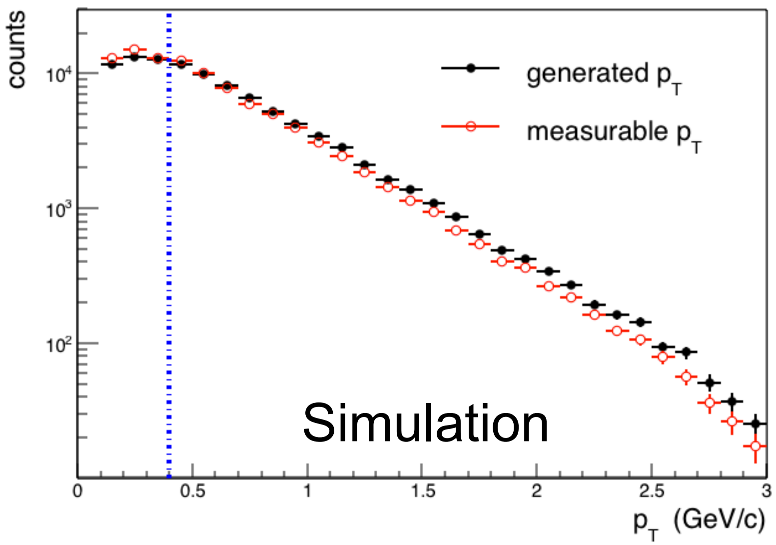
$$\epsilon_{pair} = \frac{\left[d^2n/dm^{meas}dp_T^{meas} \right]_{rec}}{\left[d^2n/dm^{meas}dp_T^{meas} \right]_{gen}}$$

Bremsstrahlung, resolution & angular smearing applied to p_{gen} using detector **response matrices**:

$$\vec{p}_{true} \rightarrow \vec{p}_{meas}$$



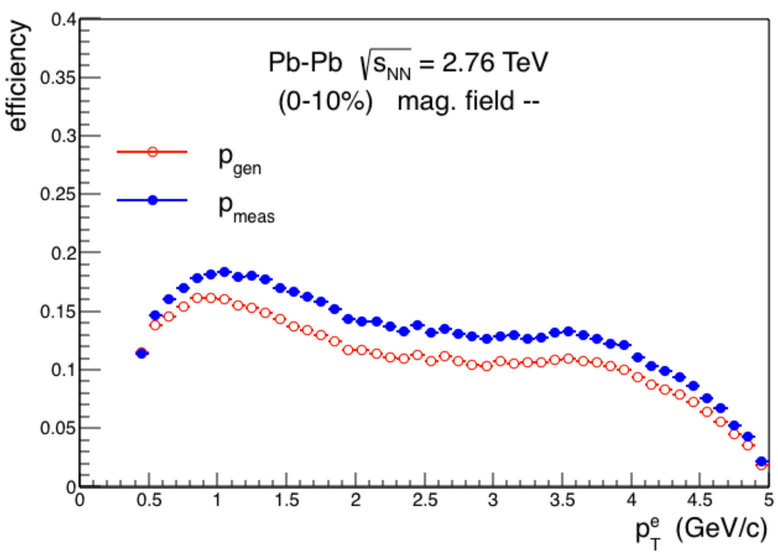
Efficiency: p_{gen} vs p_{meas}

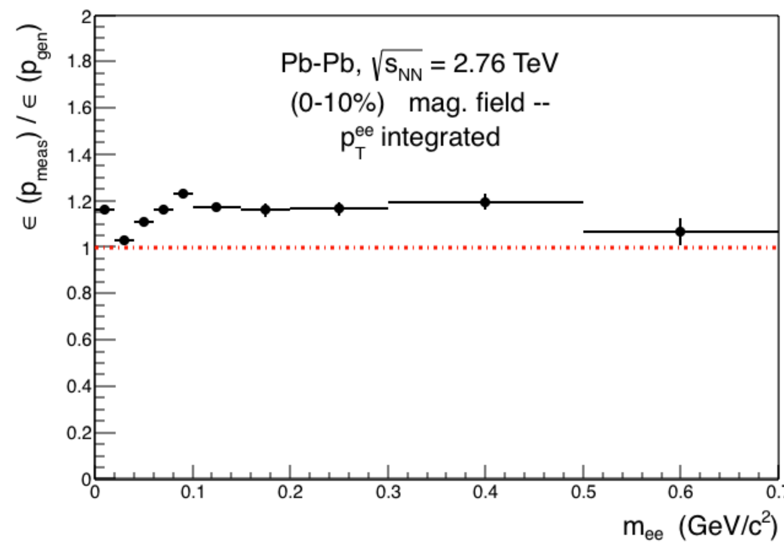


If p_{gen} is used in distribution of generated particles:

→ **Underestimation** of efficiency

$$\frac{\epsilon_{pair}(p_{meas})}{\epsilon_{pair}(p_{gen})} = \frac{rec/gen(p_{meas})}{rec/gen(p_{gen})} = \frac{gen(p_{gen})}{gen(p_{meas})}$$



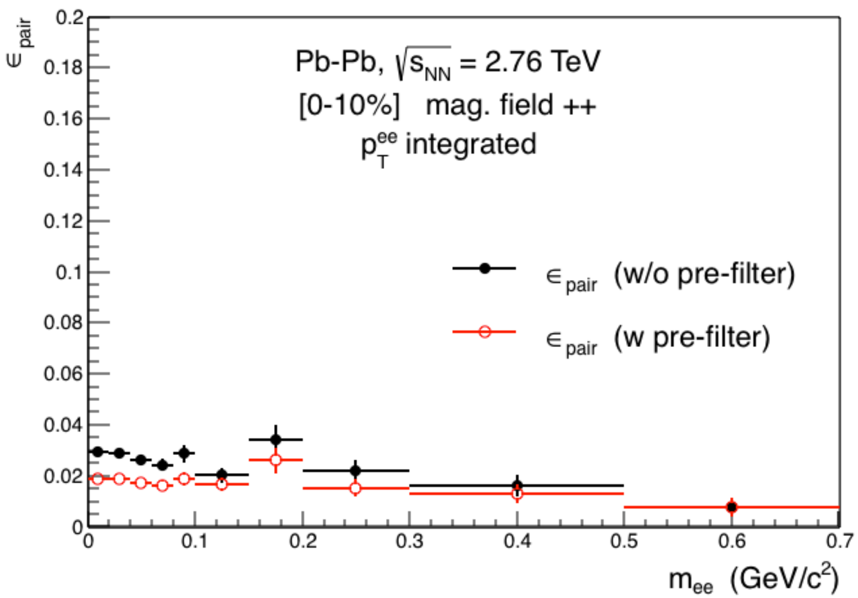


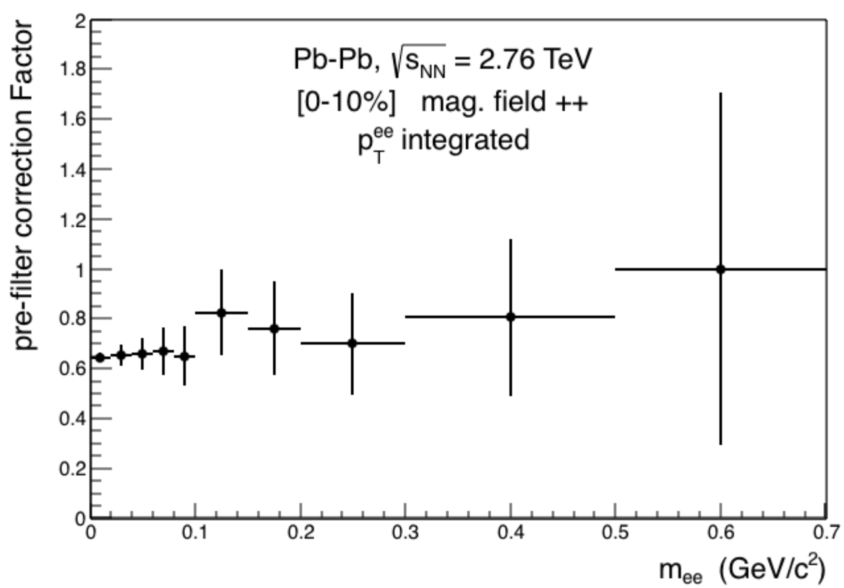
P_{meas} has to be used for efficiency calculation !!

Pair efficiency vs m_{ee}

$$\epsilon^{tot}_{pair} = \frac{rec}{gen} \cdot \frac{rec^{pref}}{rec}$$

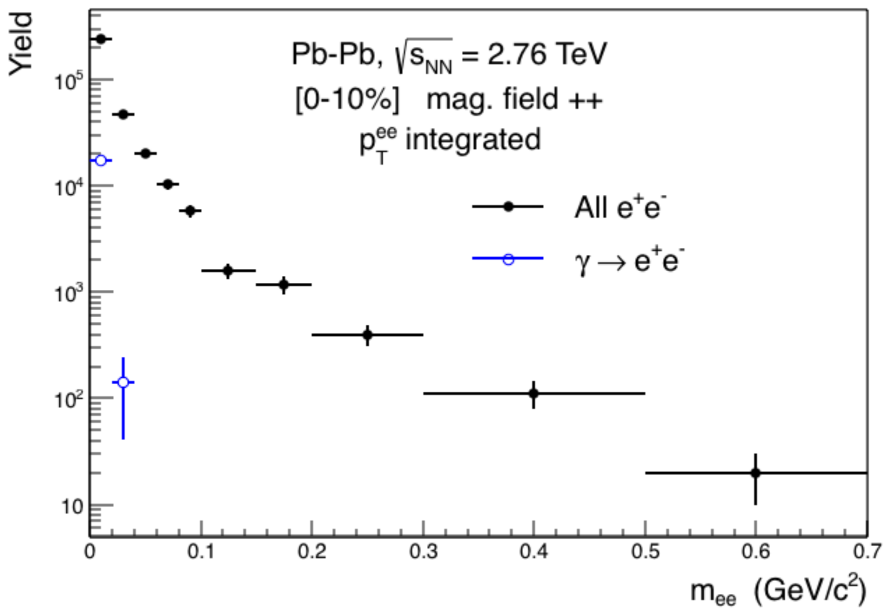
Pair Efficiency | Pre-filter Correction

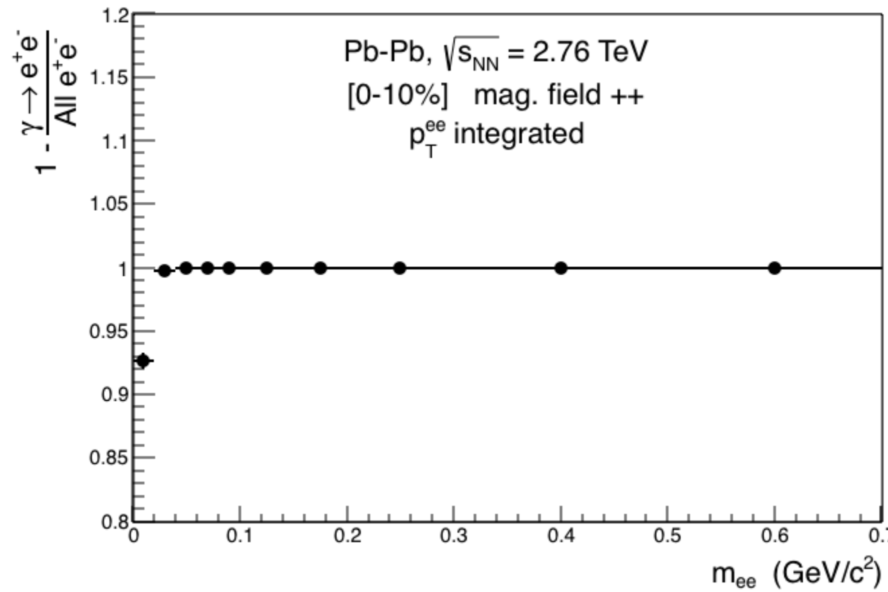




Correction for random signal rejection included in the efficiency

Residual conversion contribution





Correction factor estimated from MC
(using proper weights for γ mothers)

Applied on data before efficiency correction