ALICE

HL-LHC WORKSHOP - WG5: HEAVY IONS EM RADIATION / LOW MASS DILEPTONS

Outline:

- Physics motivation
- Expected performance in Run3/4
  - Dielectrons
  - Dimuons
  - Dark photons
- Conclusion and ongoing work

Based (mainly) on:

ALICE Upgrade LoI:	*CERN-LHCC-2012-012*
	CERN-LHCC-2013-014
ITS TDR:	*CERN-LHCC-2013-024*
TPC TDR:	*CERN-LHCC-2013-020*
MFT TDR:	*CERN-LHCC-2015-001*

MICHAEL WEBER (SMI)
ON BEHALF OF THE ALICE COLLABORATION
31.10.2017

ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN
FTE NATIONALSTIFTUNG FORSCHUNG | TECHNOLOGIE | ENTWICKLUNG

ELECTROMAGNETIC PROBES OF THE QGP

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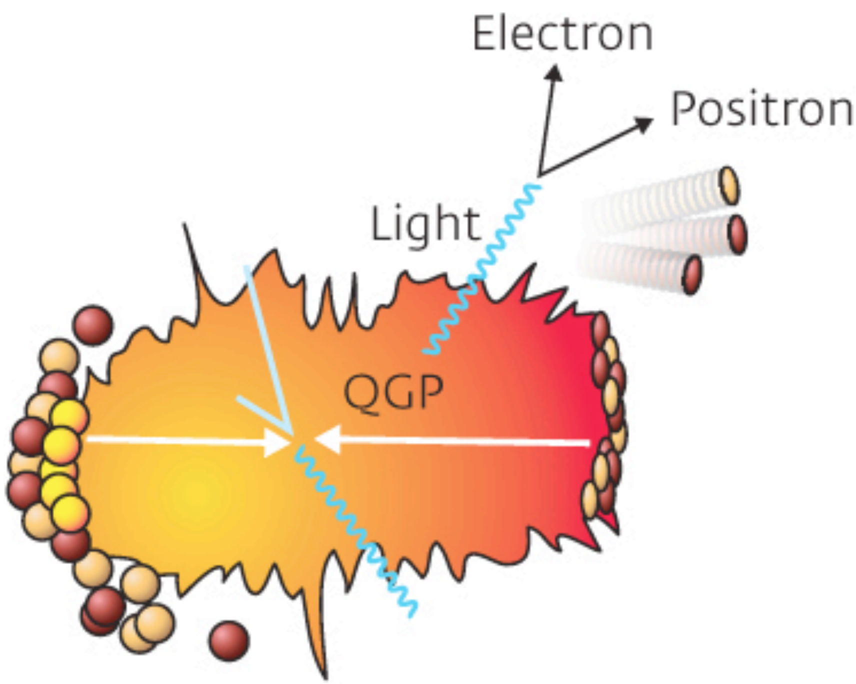


Photons: measure γ (Calo, PCM)
Dileptons: measure e^+e^- or $\mu^+\mu^-$ pairs

- Couple to **EM current**
- **very low interaction** with QCD medium (no strong interaction)

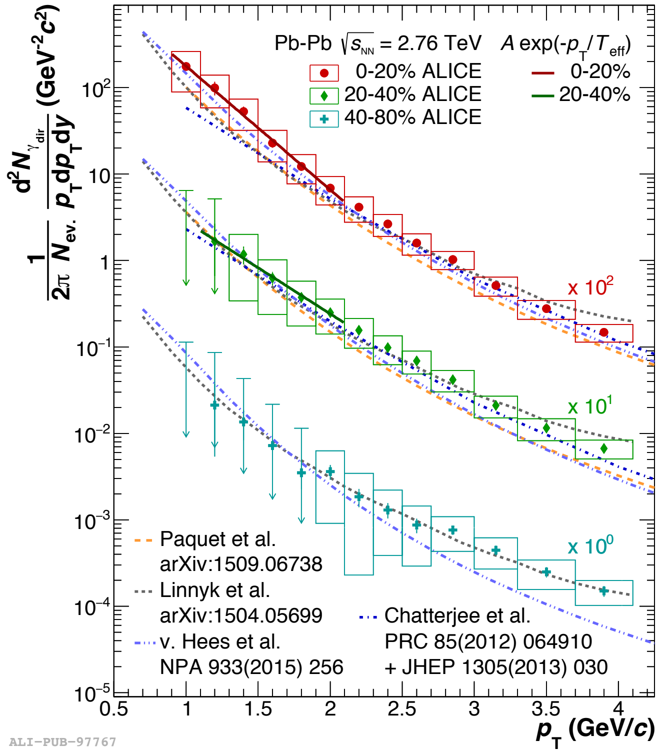
- **Sensitive to**
  Photons:
  - Thermal radiation

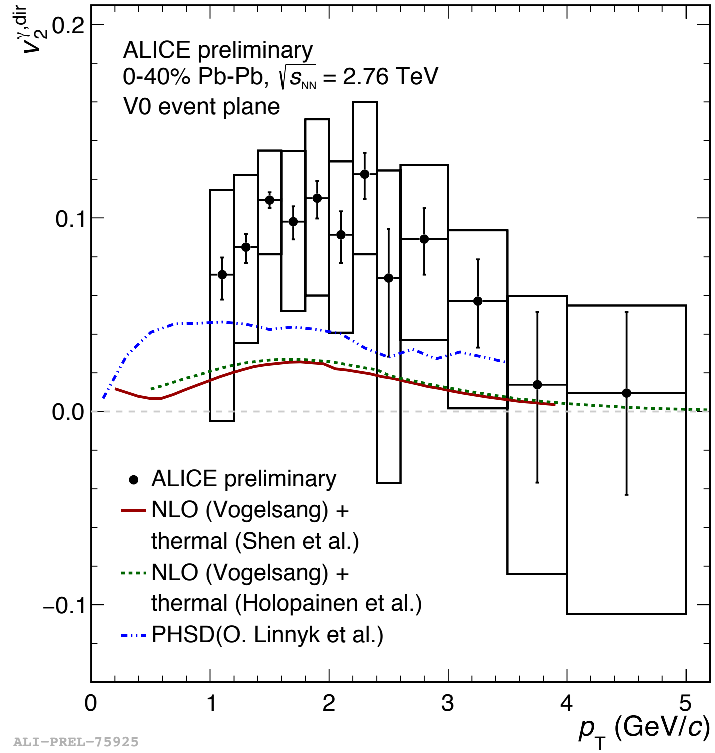
  Dileptons:
  - Thermal radiation
  - Vector meson spectral shape
  - Beyond SM particles with $J^{PC}=1^{--}$ (e.g. dark photons)

Dilepton emission rate in thermal equilibrium:

$$\frac{dN_{ll}}{d^4x d^4q} = -\frac{\alpha^2}{3\pi^3}\frac{L(M^2)}{M^2}\,\mathrm{Im}\,\Pi^{\mu}_{\mathrm{em},\mu}(M,q;\mu_B,T) \times f^B(q_0;T) \,,$$

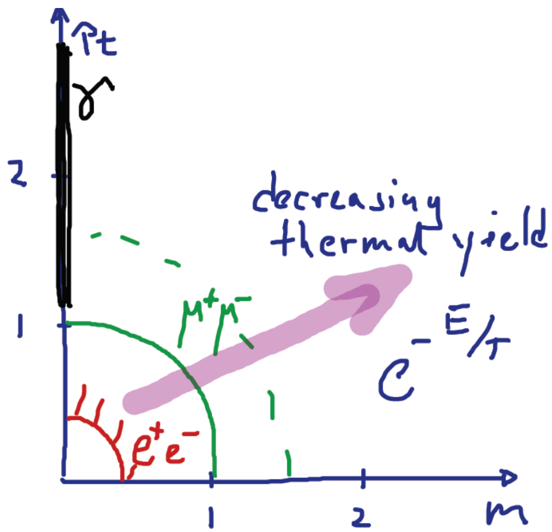
THERMAL RADIATION (PHOTONS)



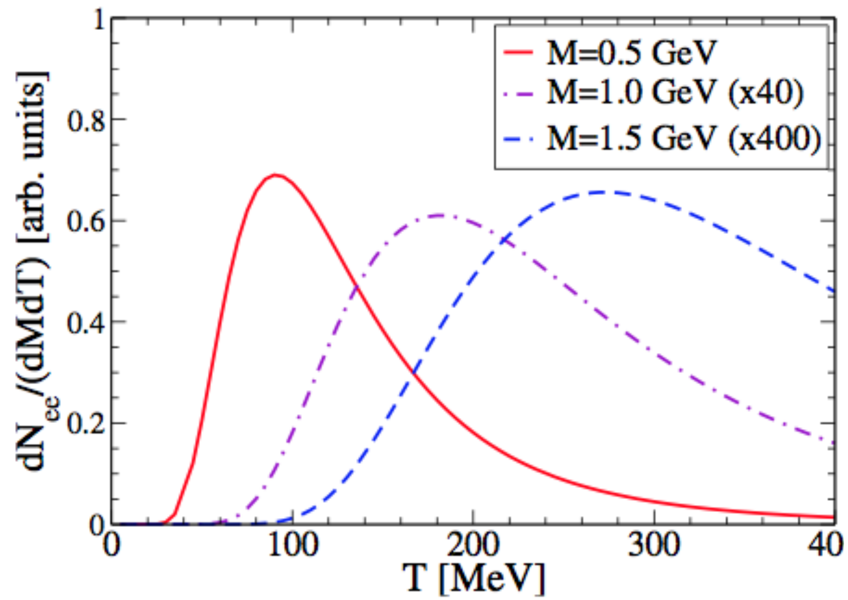


- **Measure thermal radiation** (black body photons)
- First measurement at LHC from soft exponential component of photon p_T spectrum (*ALICE, Phys.Lett. B754 (2016) 235*): ***T* ~ 300 MeV** (effective temperature averaged over system evolution)
- **Direct photon flow** larger than available theory predictions

THERMAL RADIATION (DILEPTONS)

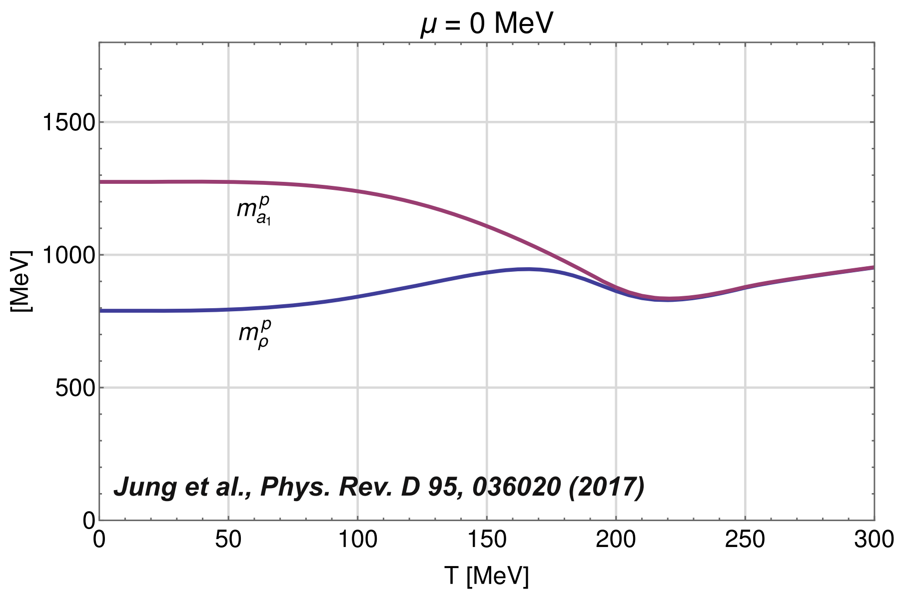


R. Rapp Acta Phys.Polon. B42 (2011)

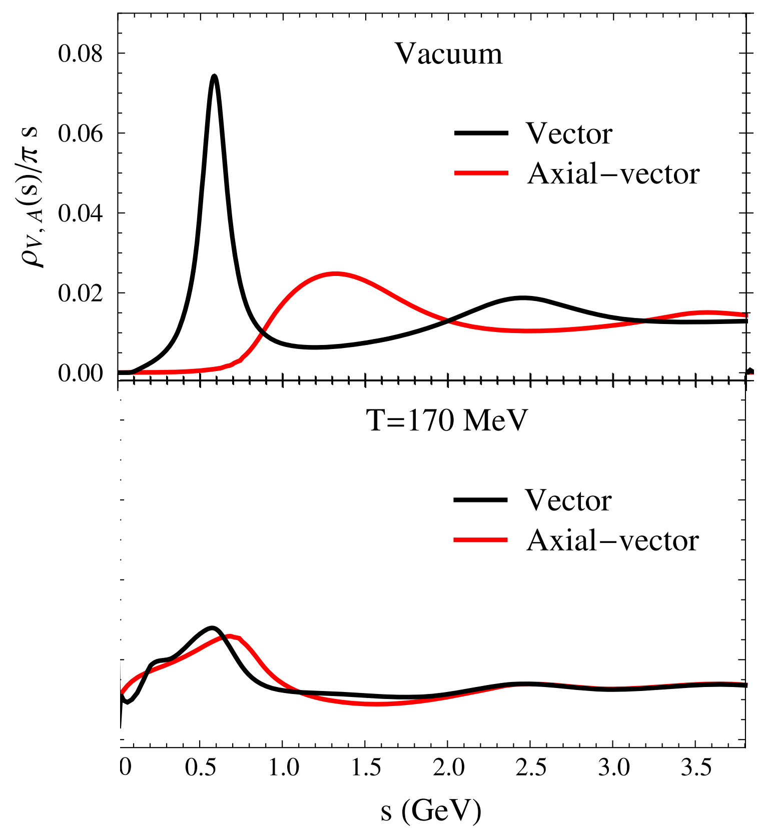


- **Measure thermal radiation** (black body photons)
- First measurement at LHC from soft exponential component of photon p_T spectrum (*ALICE, Phys.Lett. B754 (2016) 235*): ***T* ~ 300 MeV** (effective temperature averaged over system evolution)
- Dileptons:
  - **Map temperature during system evolution**
  - Invariant mass method **not sensitive to "blue-shift" from radial flow**

CHIRAL SYMMETRY AND SPECTRAL FUNCTION



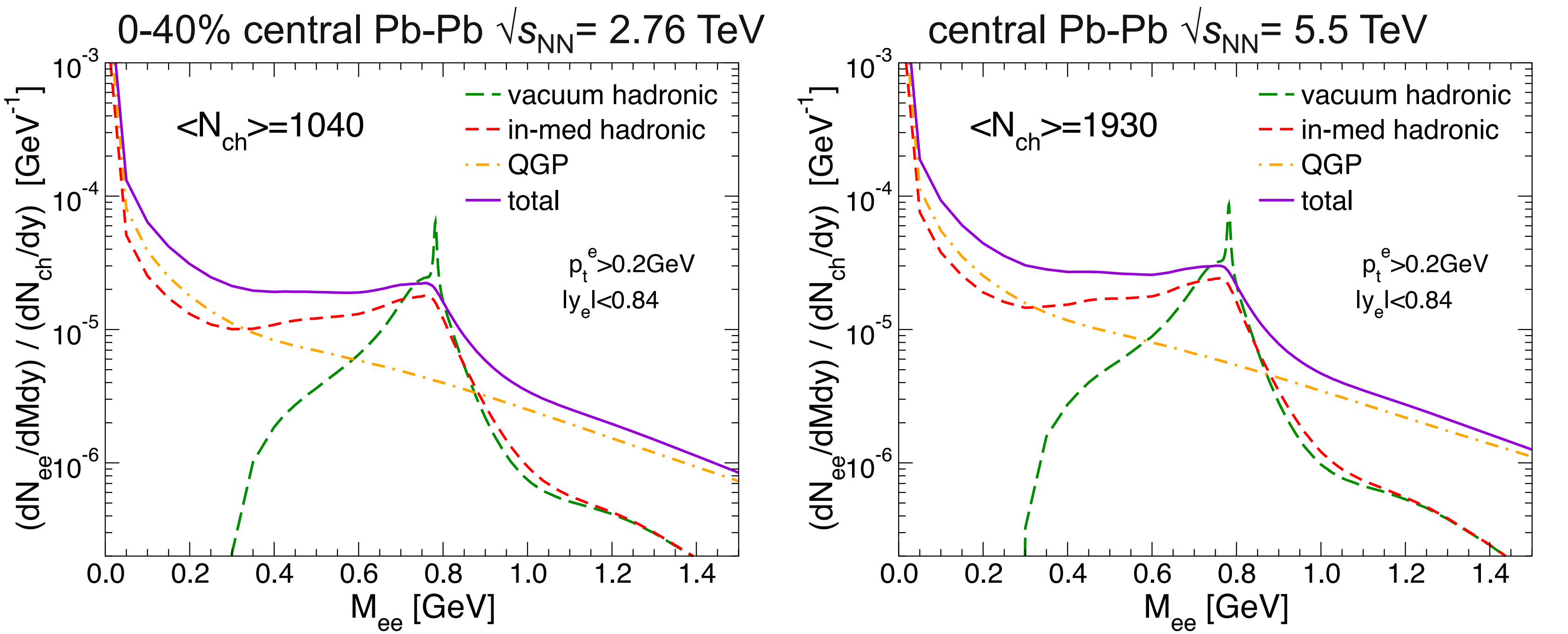
Hohler, Rapp, Physics Letters B 731 (2014) 103–109



symmetry	$SU_V(2)$	$SU_A(2)$
vacuum	unbroken	broken
high temperature	unbroken	unbroken
multiplets	$(n, p), \ldots$	$(\sigma, \pi), (\rho, a_1), \ldots$
order parameter	—	$\langle \bar{q}q \rangle$

“Isospin” “Parity”

INVARIANT MASS SPECTRA



At LHC energies:

- Vanishing μ_B: direct comparability to Lattice QCD
- Sizeable in-medium modification of ρ
- Large thermal radiation contribution above 1 GeV/c^2

R. Rapp, arXiv:1304.2309 [hep-ph]

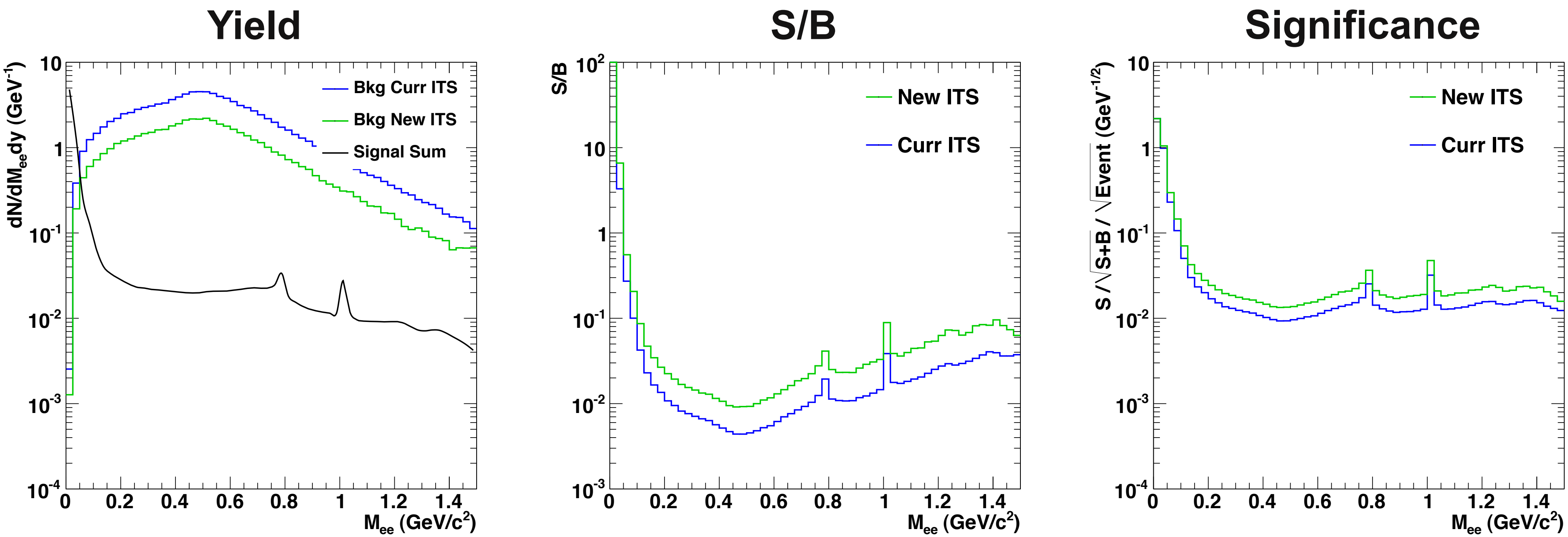
ALICE AFTER 2020

- Improved **vertex resolution**
  - Better separation of electrons from charm and bottom decays
- **Reduced material budget** and improved **low p_T efficiency**
  - Smaller background from conversion electrons
- Dedicated **low B field** run
  - Recover low p_T tracks
  - 3 nb^{-1} at B = 0.2 T
- **Higher rate** capability
  - 50 kHz Pb-Pb

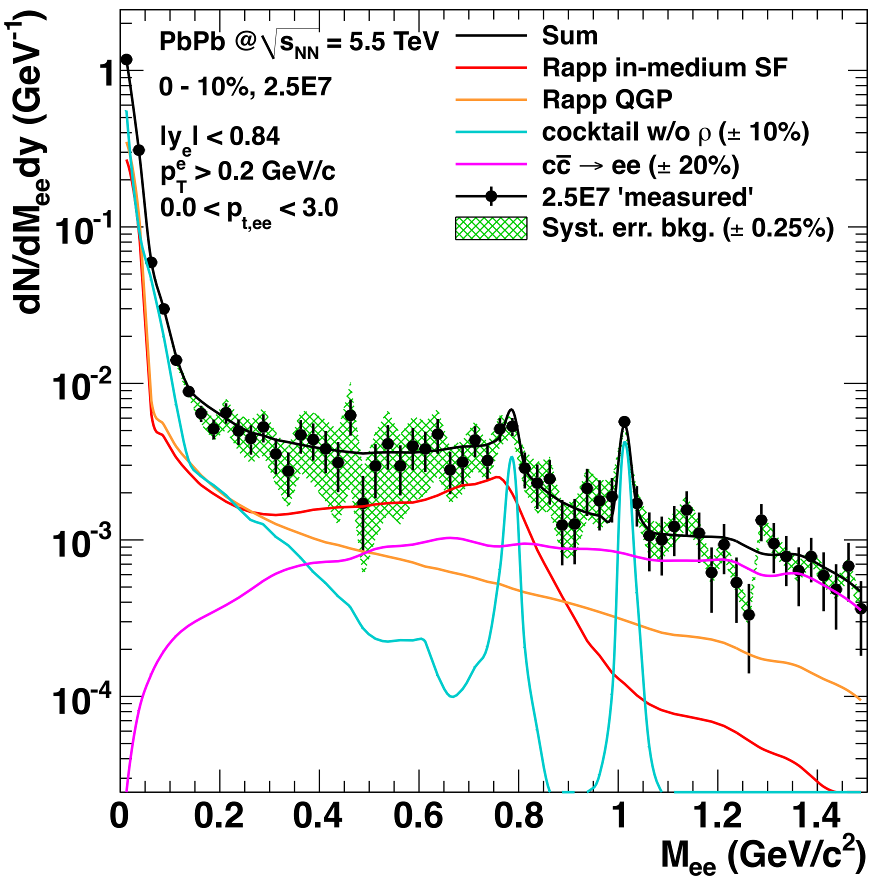
- Muon forward tracker (MFT) in addition to muon spectrometer
  - **Improved mass resolution**
  - **Reduced background**

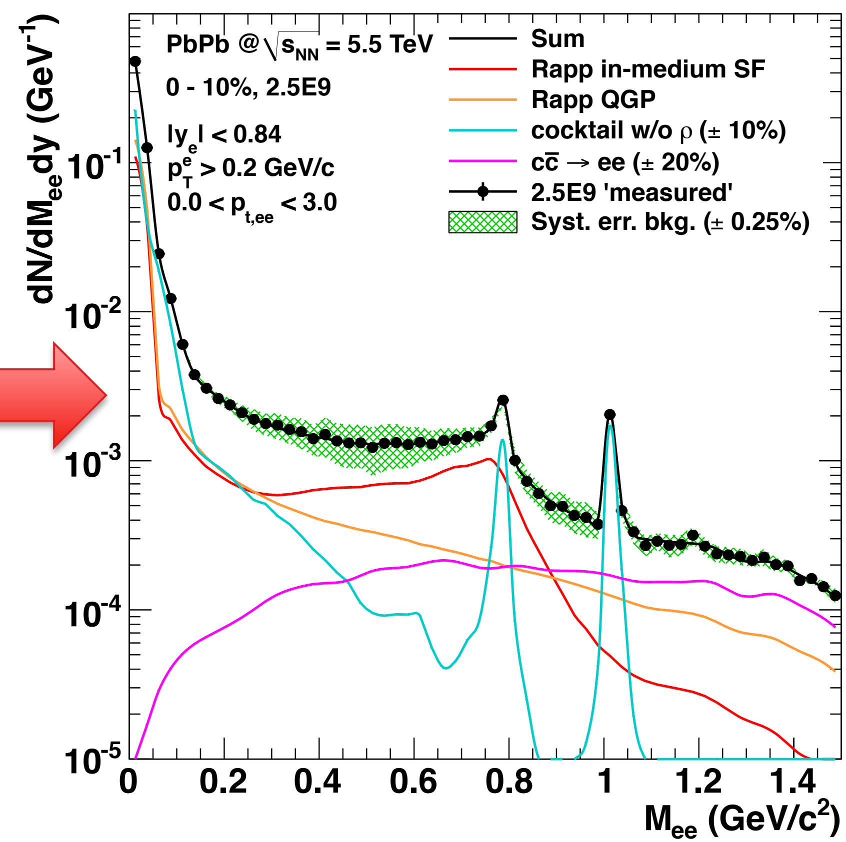
LOW MASS DIELECTRONS

UPGRADE IMPROVEMENT



UPGRADE IMPROVEMENT

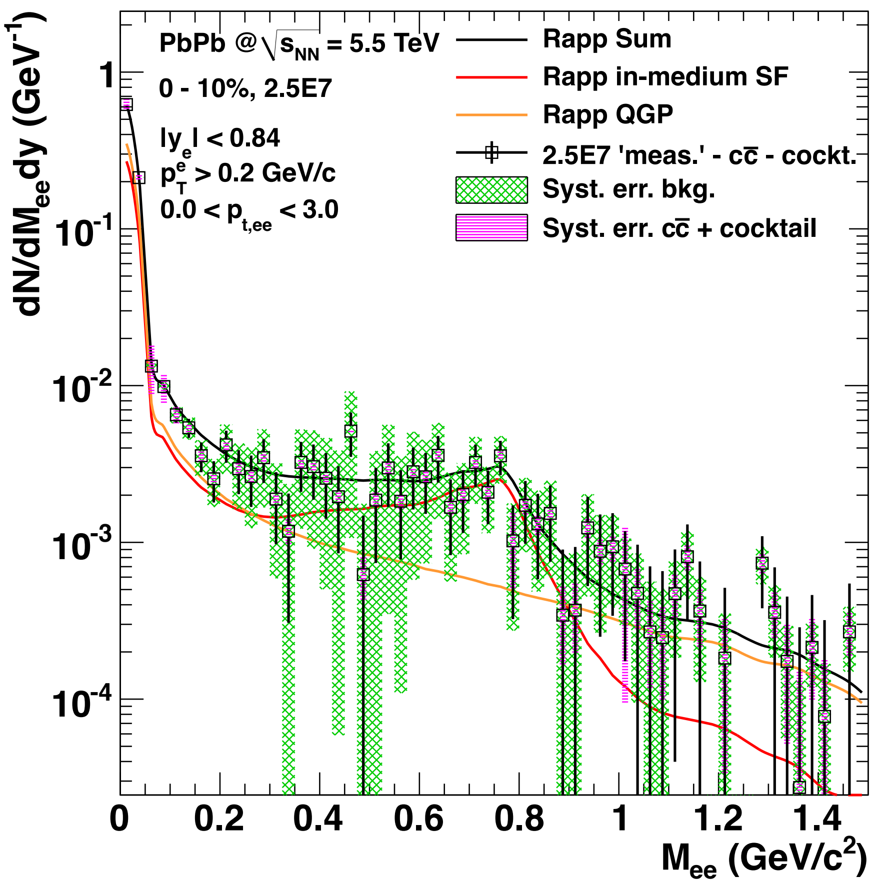


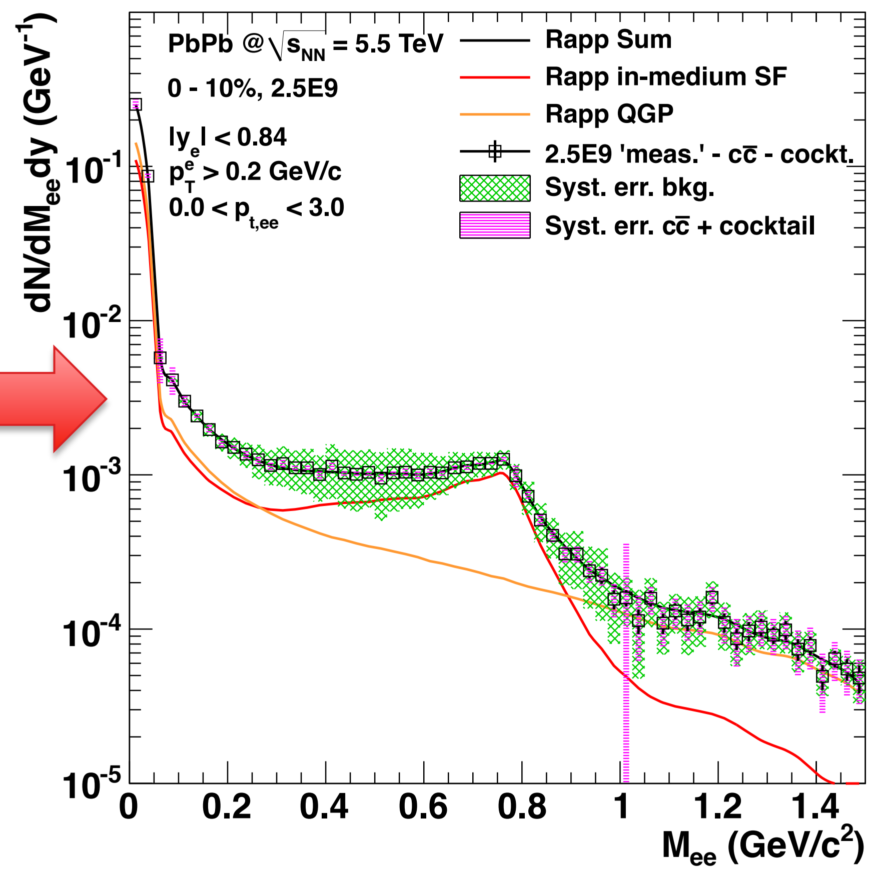


- Current ITS
- Current readout

- New ITS: less conversion, better DCA resolution
- New readout: x100 statistics

SPECTRAL FUNCTION

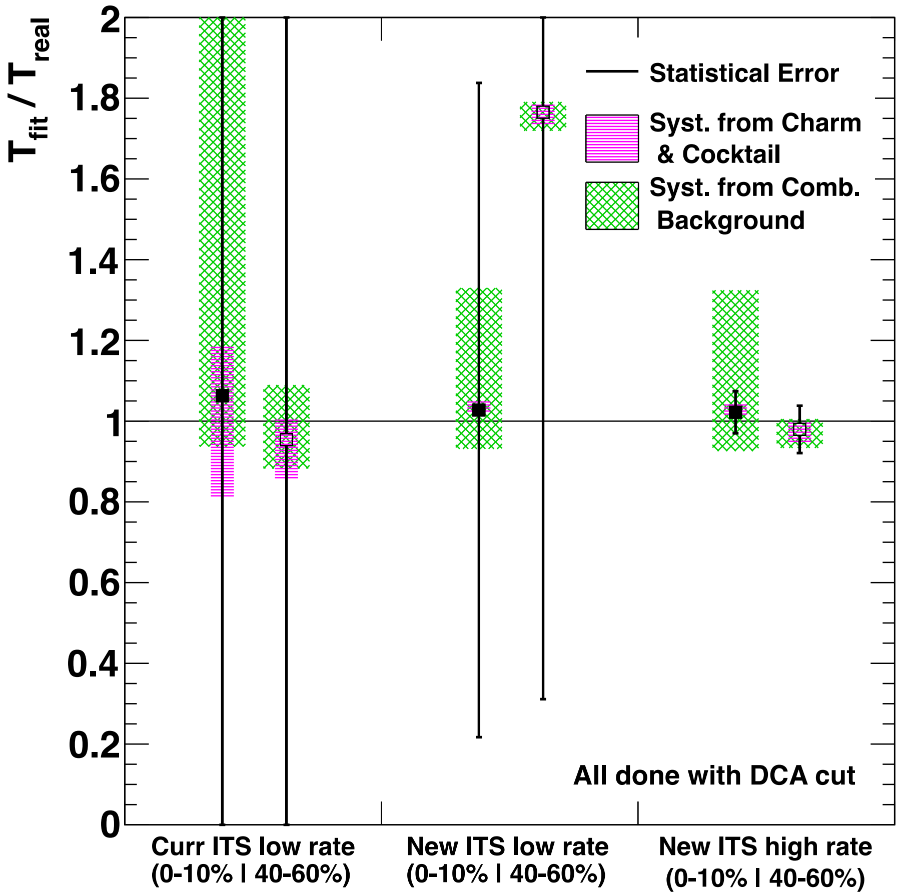




Low mass spectral function with ~20% uncertainty

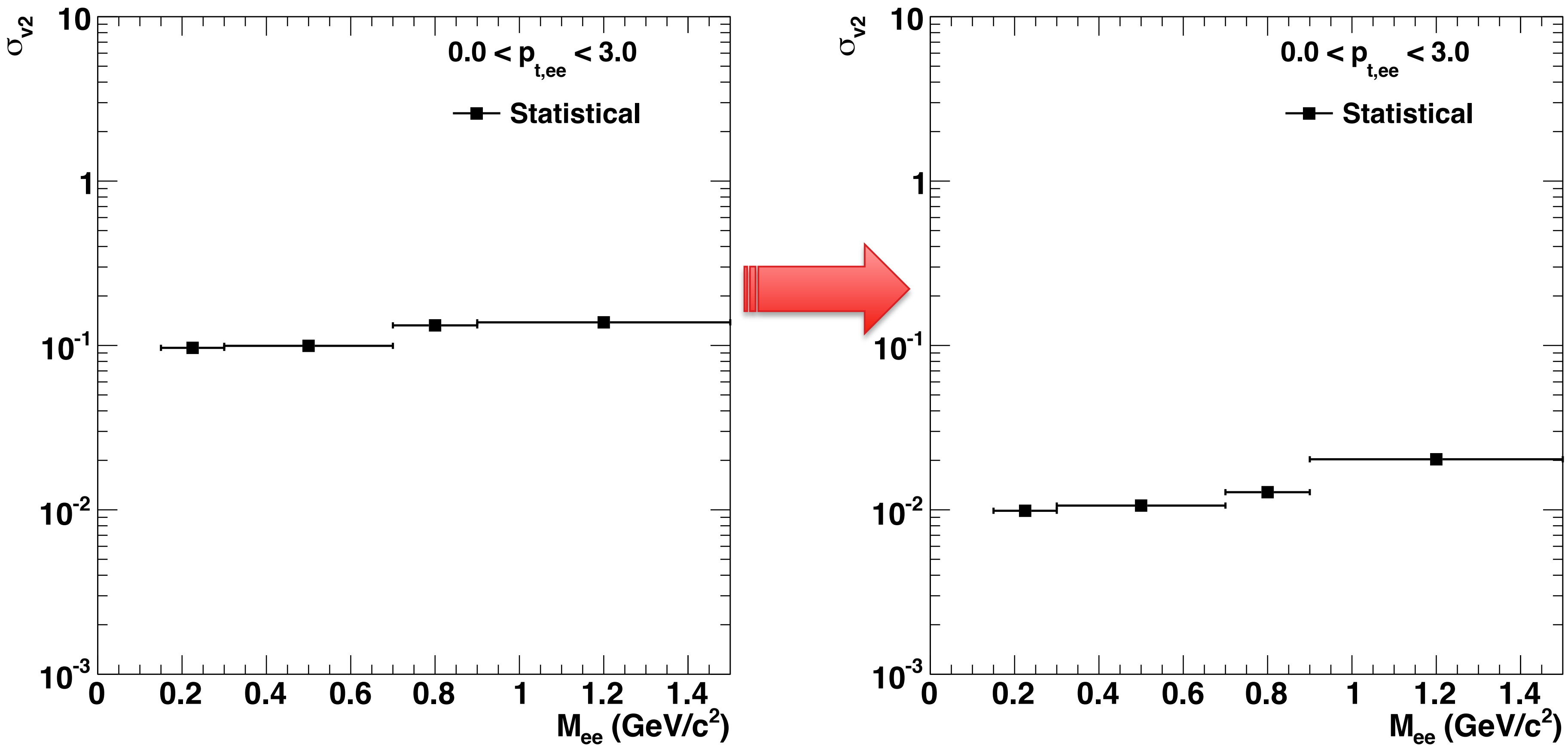
After **subtraction** of **long-lived light- and heavy-flavour sources**

TEMPERATURE EXTRACTION



From a fit to the invariant mass spectrum from 1.1 to 1.5 GeV/c^2

ELLIPTIC FLOW (20-40% CENTRALITY)



- Current ITS
- Current readout

- New ITS: less conversion, better DCA resolution
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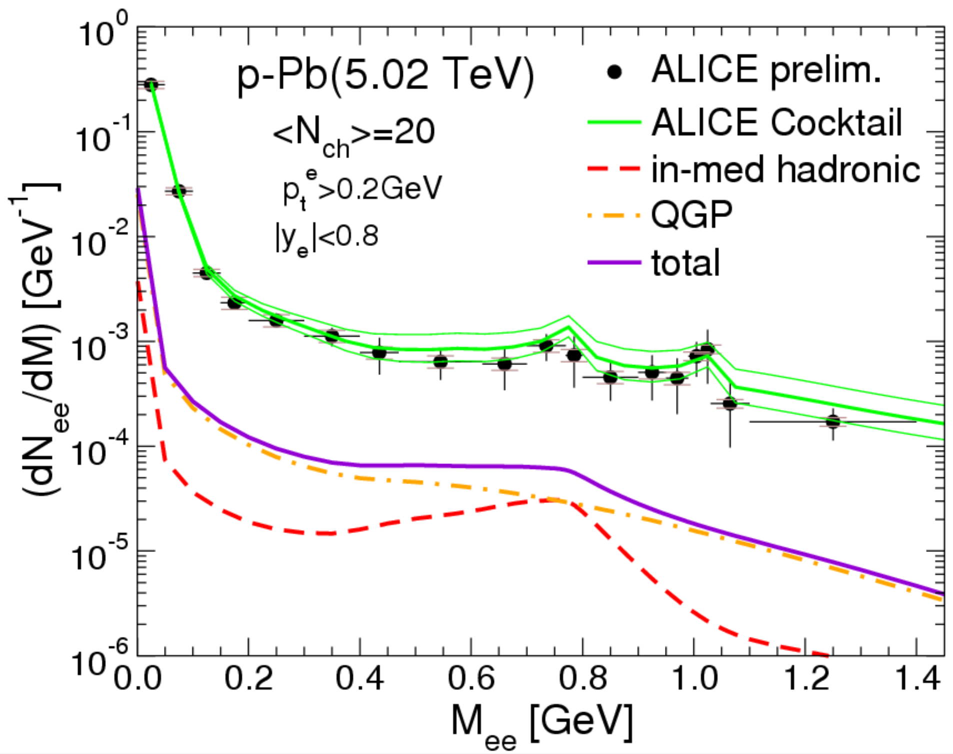
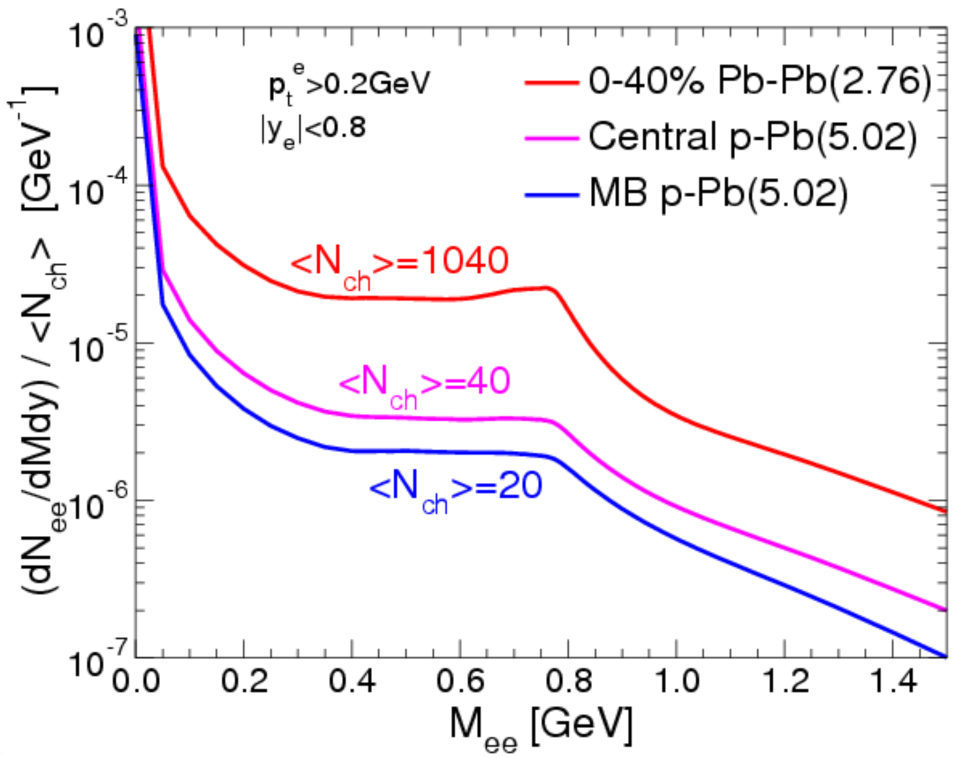
SMALL SYSTEMS

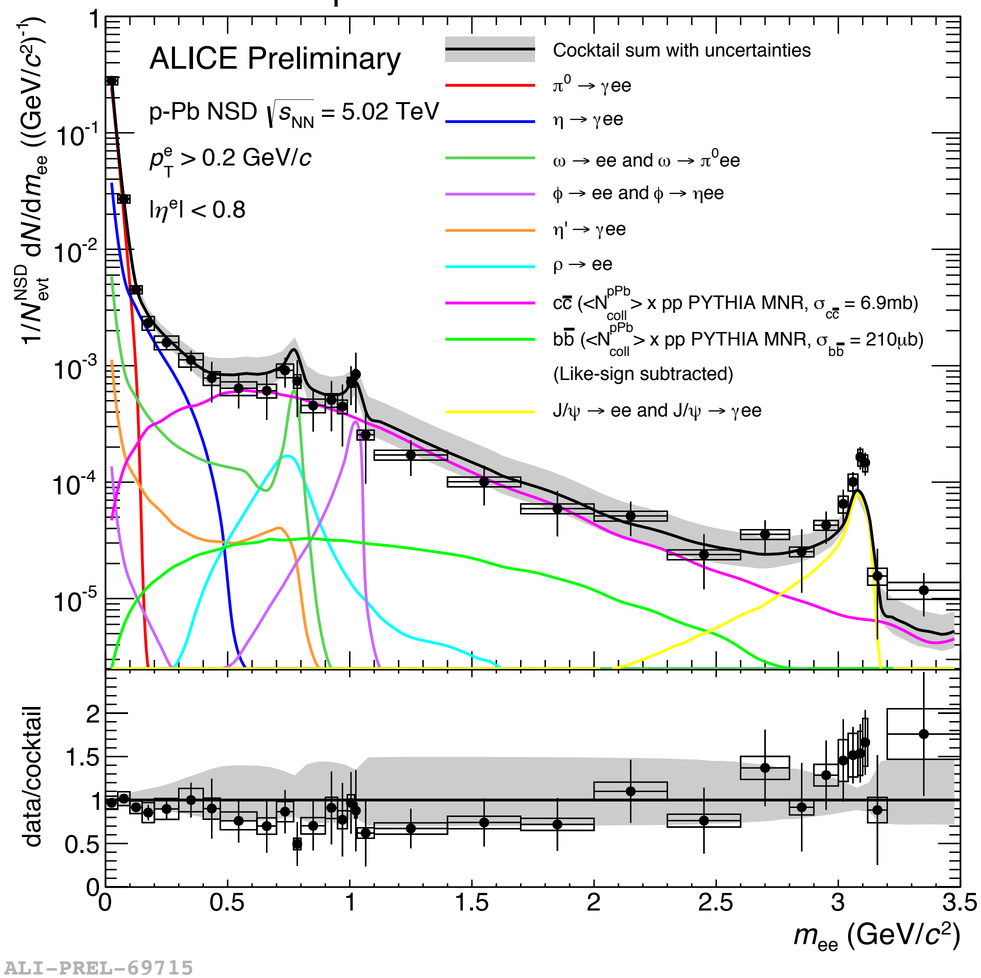




- Thermal radiation in small systems?
- R. Rapp, IS2014:
  - **10% thermal contribution in MB p-Pb collisions**

ESTIMATES FOR RUN 3/4 (p-Pb, 50 nb^{-1})

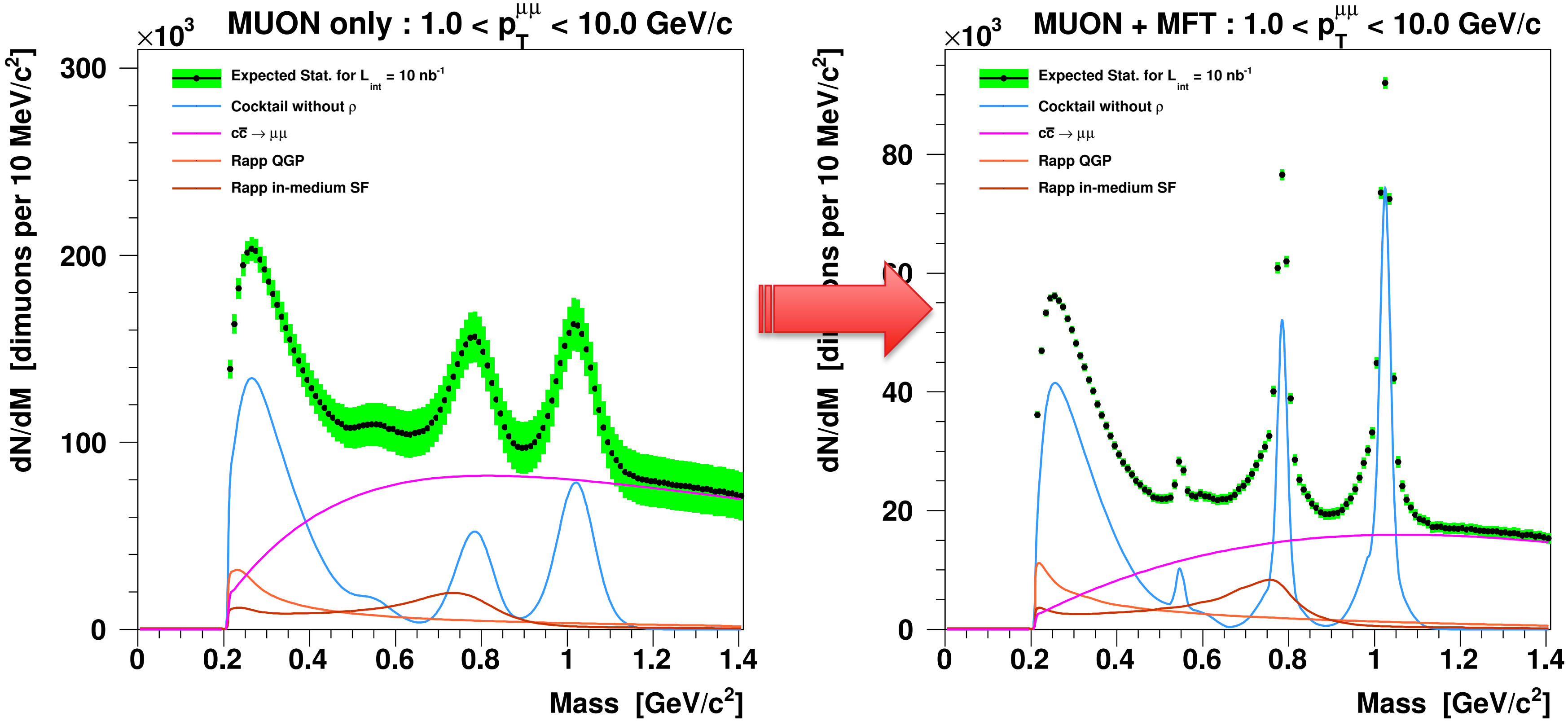
From Run 1 performance:



- Run 1 results based on L_{int} ~ 50 μb^{-1}.
- **Stat. uncertainties**
  - In the interesting mass regions (0.3<m_{ee}<0.7 GeV/c^2) and (1<m_{ee}<3 GeV/c^2):
  - **σ_{stat} ~ 20 - 50%**
- **For Run 3/4 (50 nb^{-1})**
  - **σ_{stat} ~ 1 - 2%**
- Measurement will not be limited by stat. uncertainties

LOW MASS DIMUONS

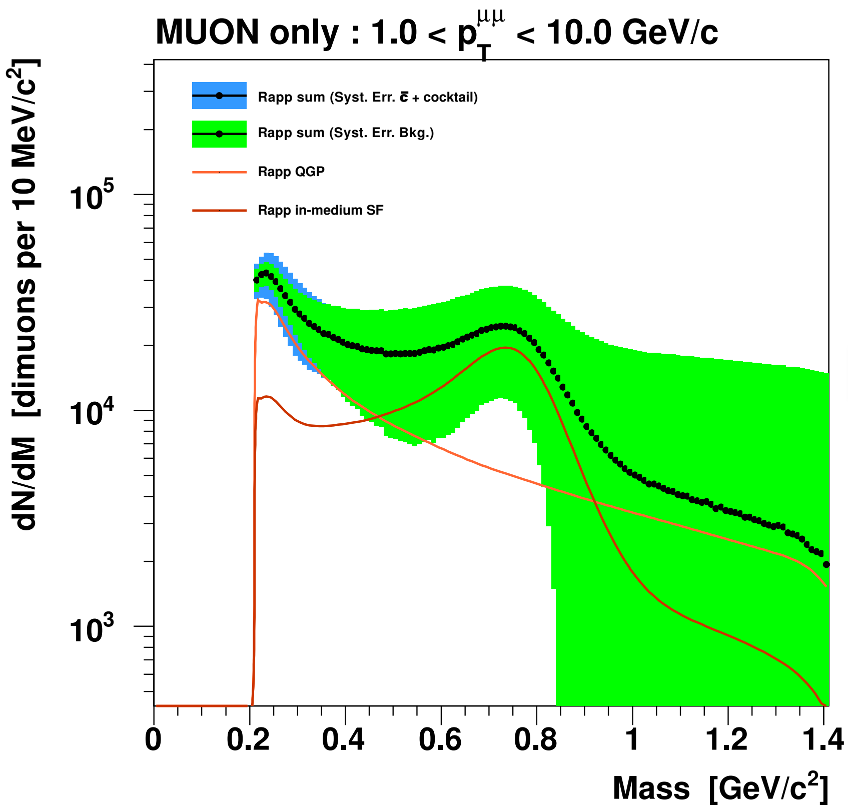
UPGRADE IMPROVEMENT (Pb-Pb)

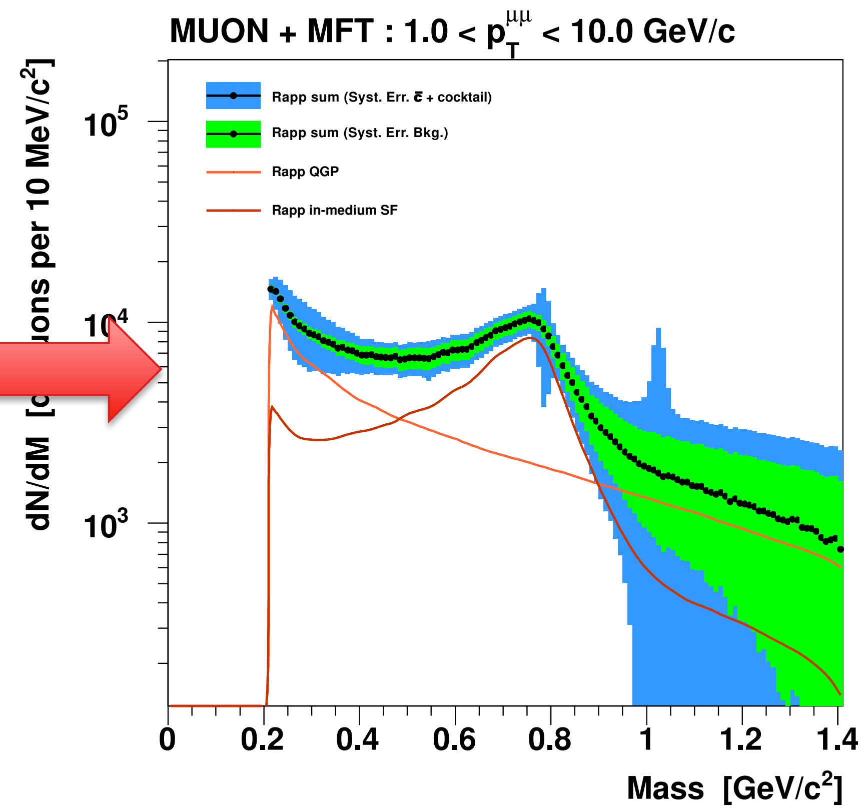


- MUON spectrometer only

- MUON+MFT: better mass resolution, less background

SPECTRAL FUNCTION



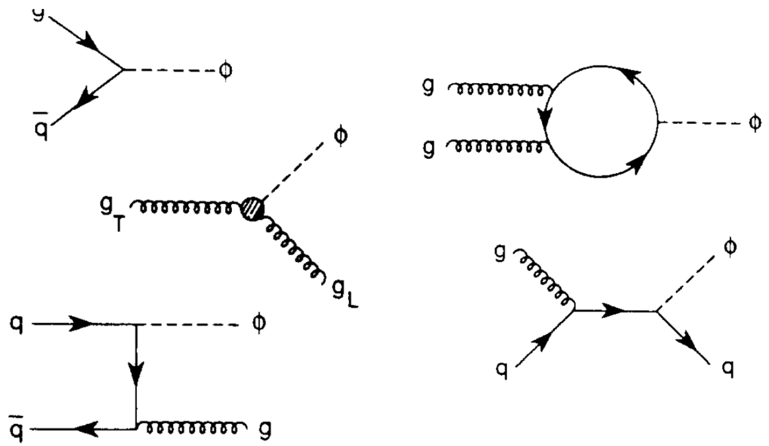


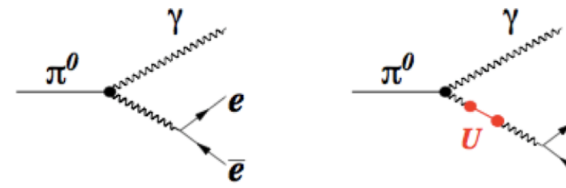
- Low mass spectral function with ~20% uncertainty
- Thermal radiation (M > 1GeV/c^2) difficult

After **subtraction** of **long-lived light- and heavy-flavour sources**

DARK PHOTONS

BEYOND STANDARD MODEL



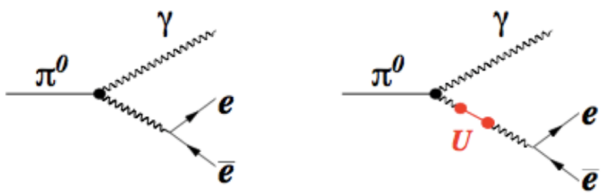


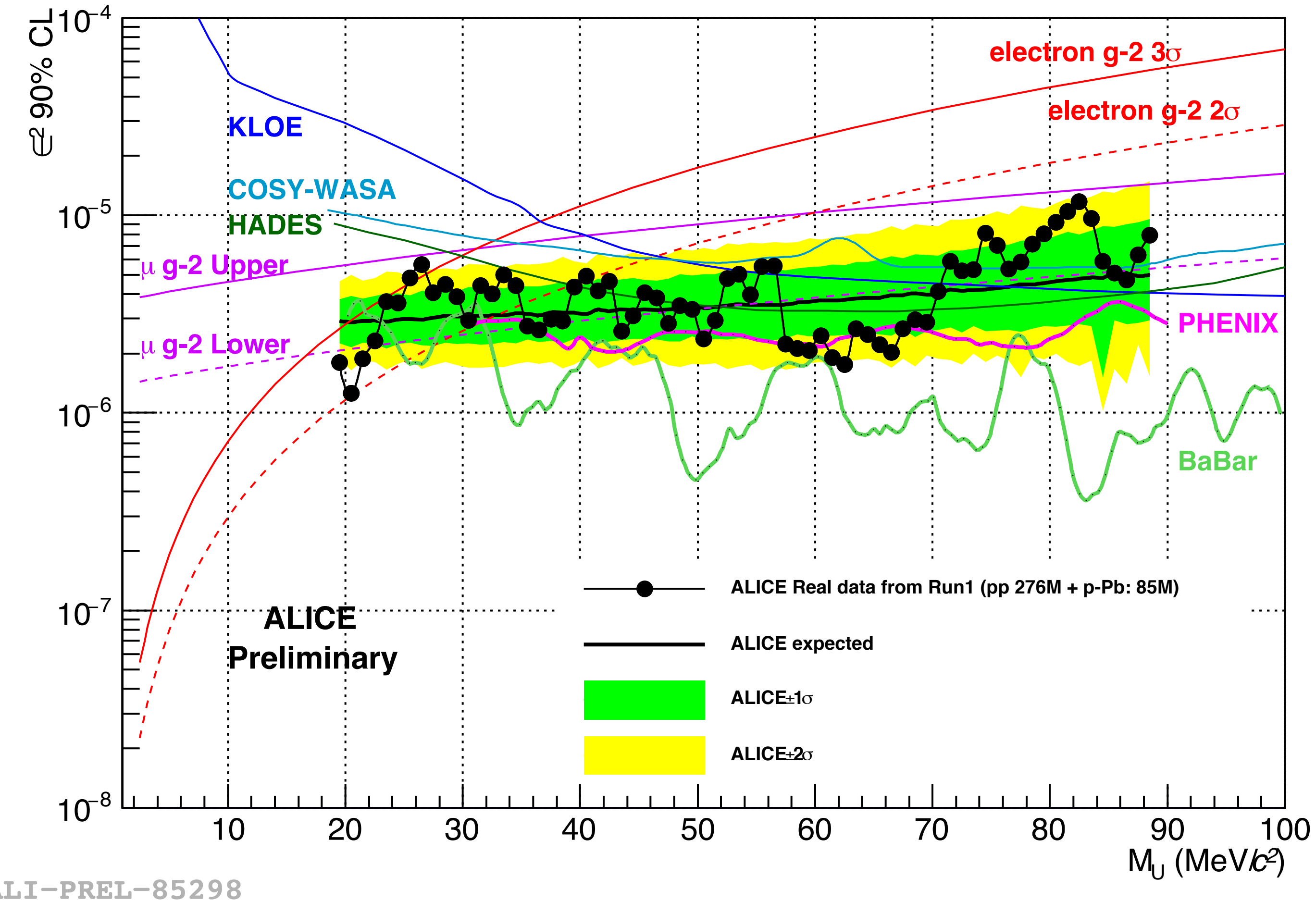
- **Light scalar or vector BSM bosons** could be observed in **high-energy (with large QGP volumes produced), high-luminosity nuclear collisions** *J. Ellis & P. Salati, Nuclear Physics B342 (1990) J. Davis & C. Böhm, arXiv:1306.3653*

- **Resonance in the thermal dilepton production from the QGP** for masses up to 3 GeV/c^2: dilepton measurements in ALICE could set limits on quark- and lepton-couplings of light BSM bosons

- **ALICE: feasibility studies on dark photons of mass < 100 MeV/c^2**

DARK PHOTONS (RUN1)





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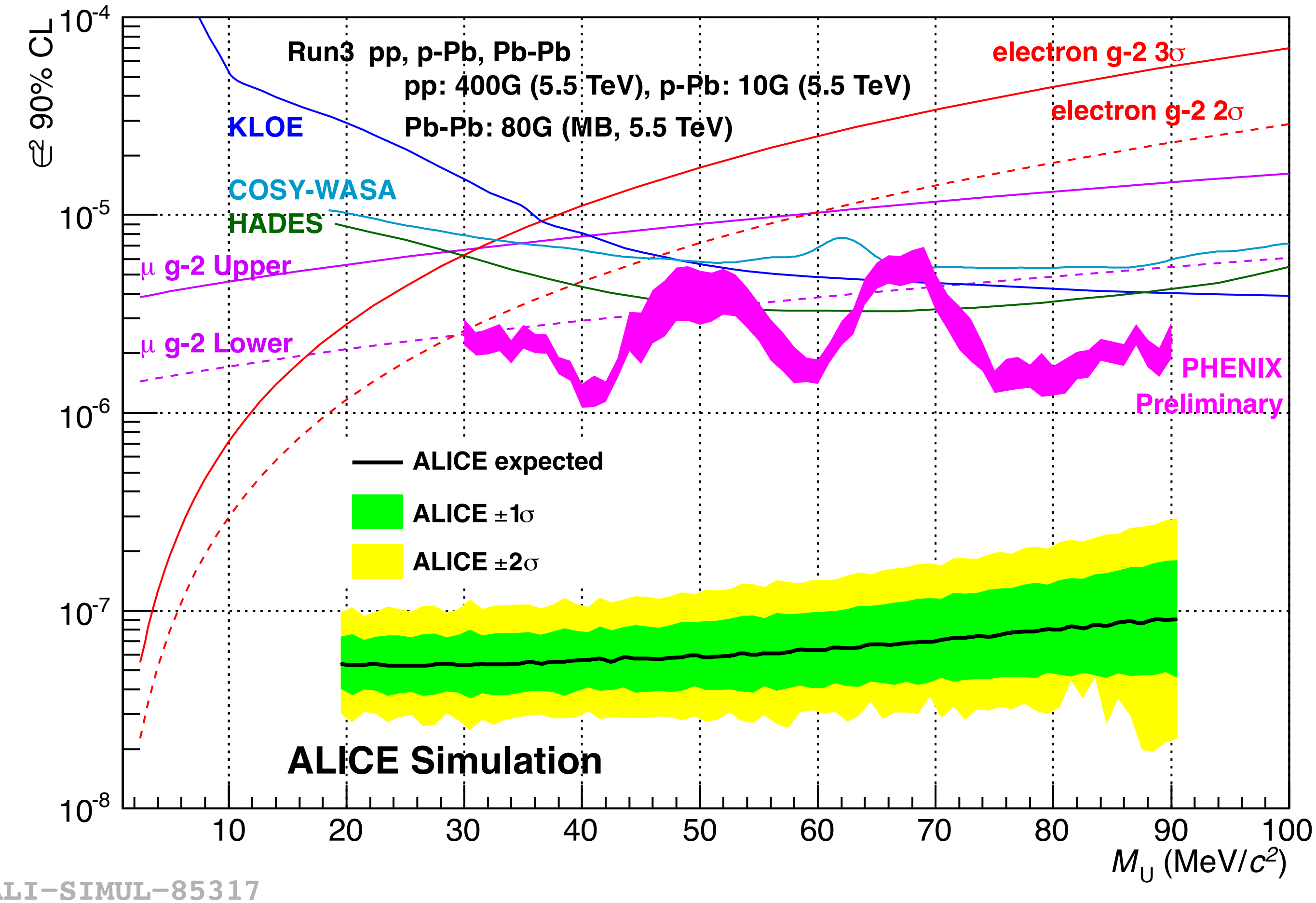
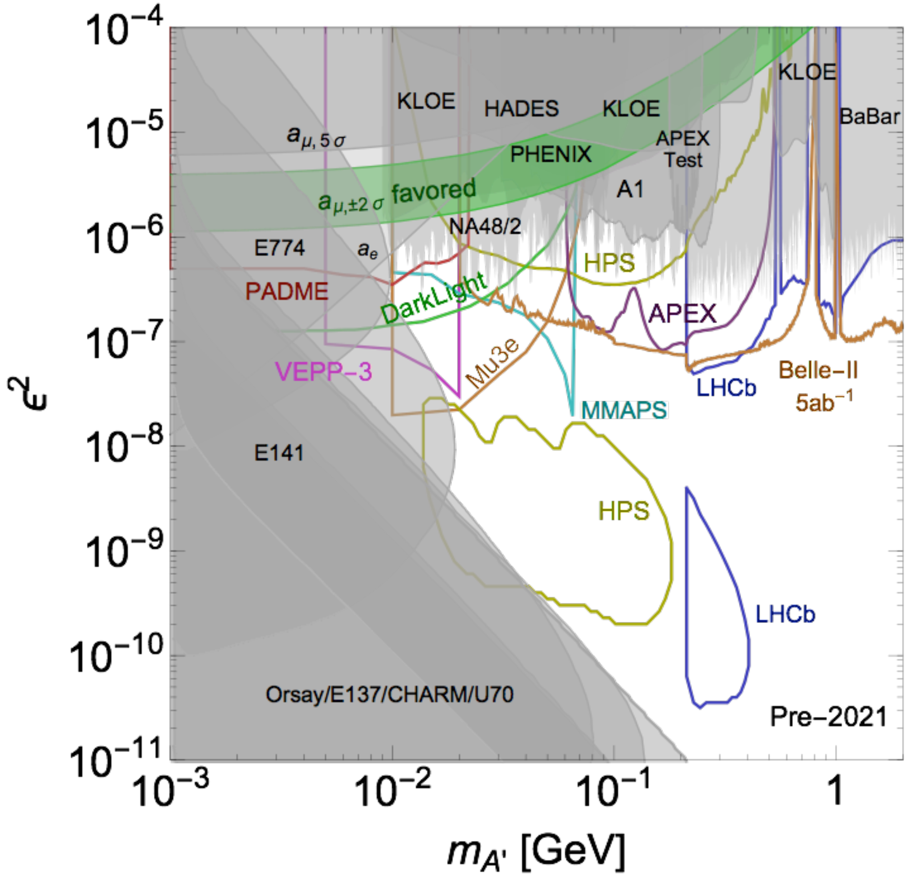
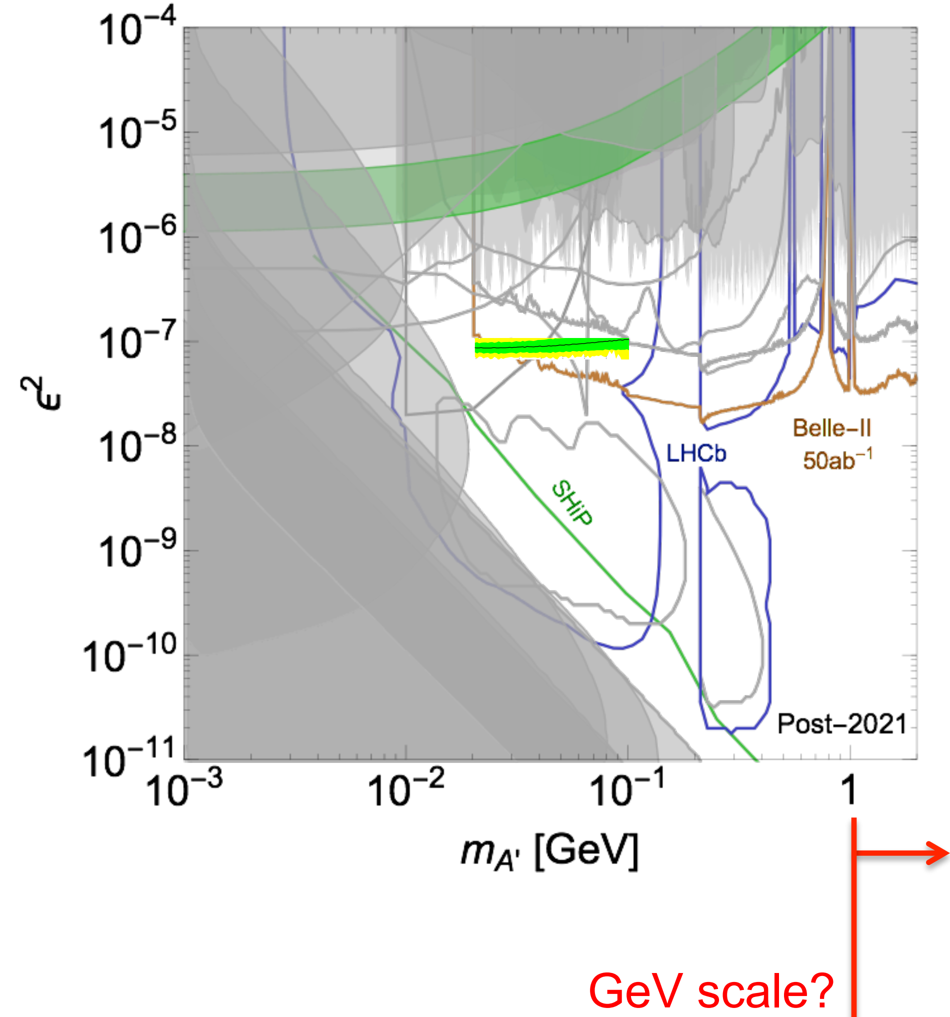
DARK PHOTONS (RUN3)



WORLD DATA + ALICE

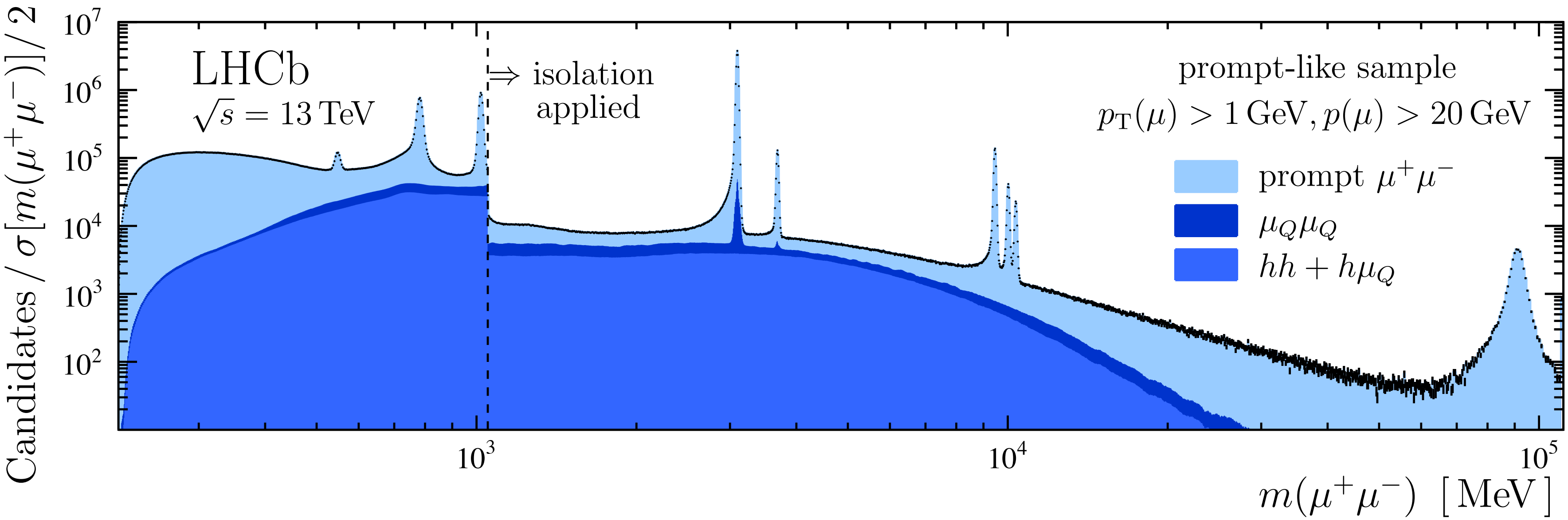




***J. Davis, C. Boehm**, arXiv:1306.3653*

Dark Sector Community Report 2016
arXiv: 1608.08632

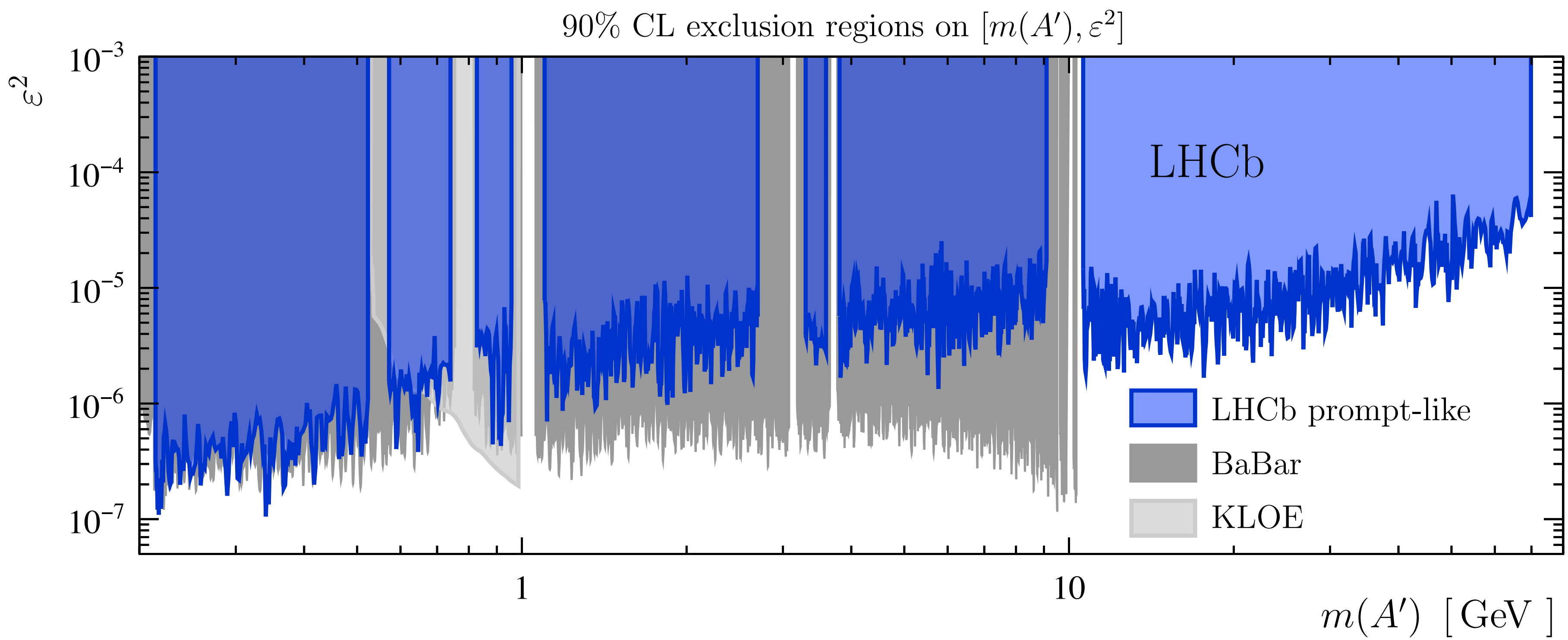
OTHER LHC EXPERIMENTS, e.g. LHCb



- intermediate-mass dileptons: precision temperature measurement above the φ mass via thermal radiation to be checked also in high-multiplicity p-Pb, pp
- masses below to be seen, current minimal p_μ with ID 3 GeV/*c*: p_T = 200, 400 MeV/*c* (η = 4.0, 2.5)

LHCb, arXiv:1710.02867 [hep-ex]

OTHER LHC EXPERIMENTS, e.g. LHCb



- Possibility to measure below 100 MeV?

LHCb, arXiv:1710.02867 [hep-ex]

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CONCLUSIONS

- Low mass dielectrons:

	Statistical uncertainty
Temperature (intermediate mass)	10 %
Elliptic flow ($v_2 = 0.1$) [4]	10 %
Low-mass spectral function [4]	20 %

- Low mass dimuons:
  - Higher statistics (10 nb^{-1}), but higher p_T cut and larger HF background than dielectrons
  - **prompt signals from QGP measurable within 20% uncertainty**
- Small systems:
  - Thermal radiation from high multiplicity pp and p-Pb collisions?
  - **Will not be limited by stat. uncertainties**
- Dark photons:
  - **Sensitivity $\varepsilon^2 \sim 10^{-7}$ for $20 < M_{ee} < 90$ MeV/c^2**

ONGOING WORK

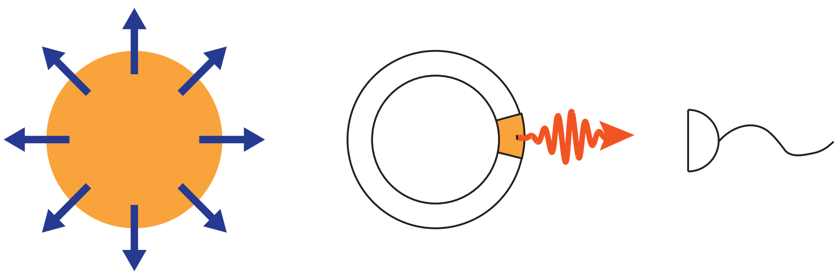
- **Dielectrons:**
  - **Improving simulations** with better understanding of combinatorial background and pointing resolution
  - **Improve understanding of systematic uncertainties**: HF (mass shape), background subtraction,…
  - Deduce **virtual photon method performance**

- **Dimuons:**
  - Tuning analysis cuts for **heavy-flavour reduction** above 1 GeV/c^2
  - **Improve understanding of systematic uncertainties**: HF (mass shape),…

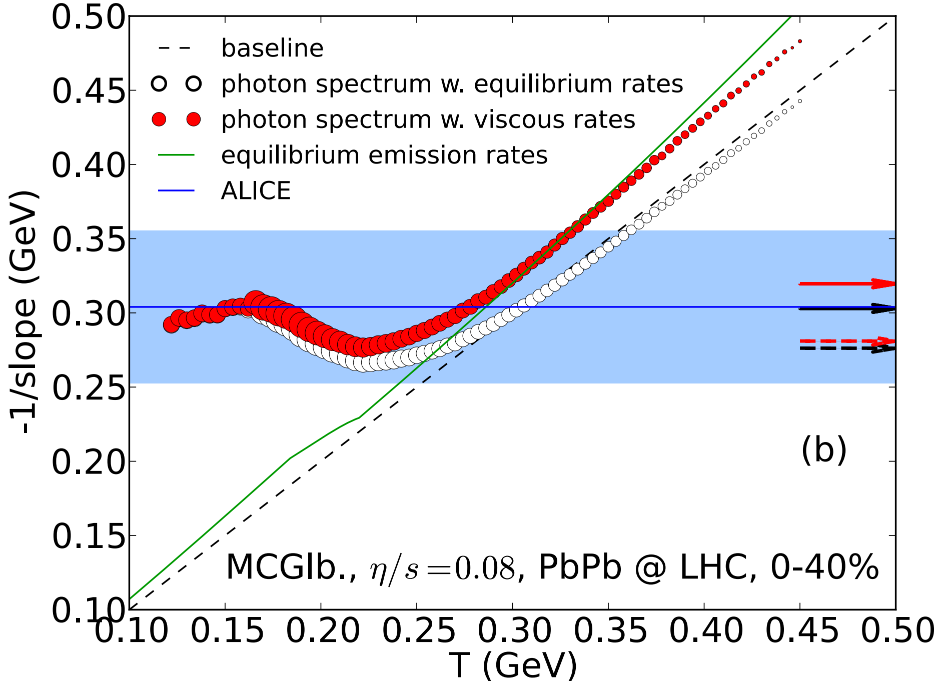
- **Photons:**
  - Higher precision and statistics needed
  - Better understanding of **material budget** (main source of systematic uncertainties), explore new observables with canceling systematics
  - Performance plots for physics cases (**thermal radiation, flow, interferometry,**…)

BACKUP

WHY NOT REAL PHOTONS?



C. Shen, U. Heinz, J.-F. Paquet, C. Gale, PRC 89 (2014) 4, 044910



$$E_\gamma \frac{d^3 N_\gamma}{d^3 p_\gamma} \propto e^{-E_\gamma / T_{\mathrm{eff}}}$$

$$T_{\mathrm{eff}} = \underbrace{\sqrt{\frac{1+\beta_{\mathrm{flow}}}{1-\beta_{\mathrm{flow}}}}}_{2 \text{ for } \beta_{\mathrm{flow}}=0.6} \times T$$

- Large blueshift at late times when $T \approx$ 150 - 200 MeV
- Extraction of initial temperature from data requires comparison to (hydro) model

LOW B FIELD

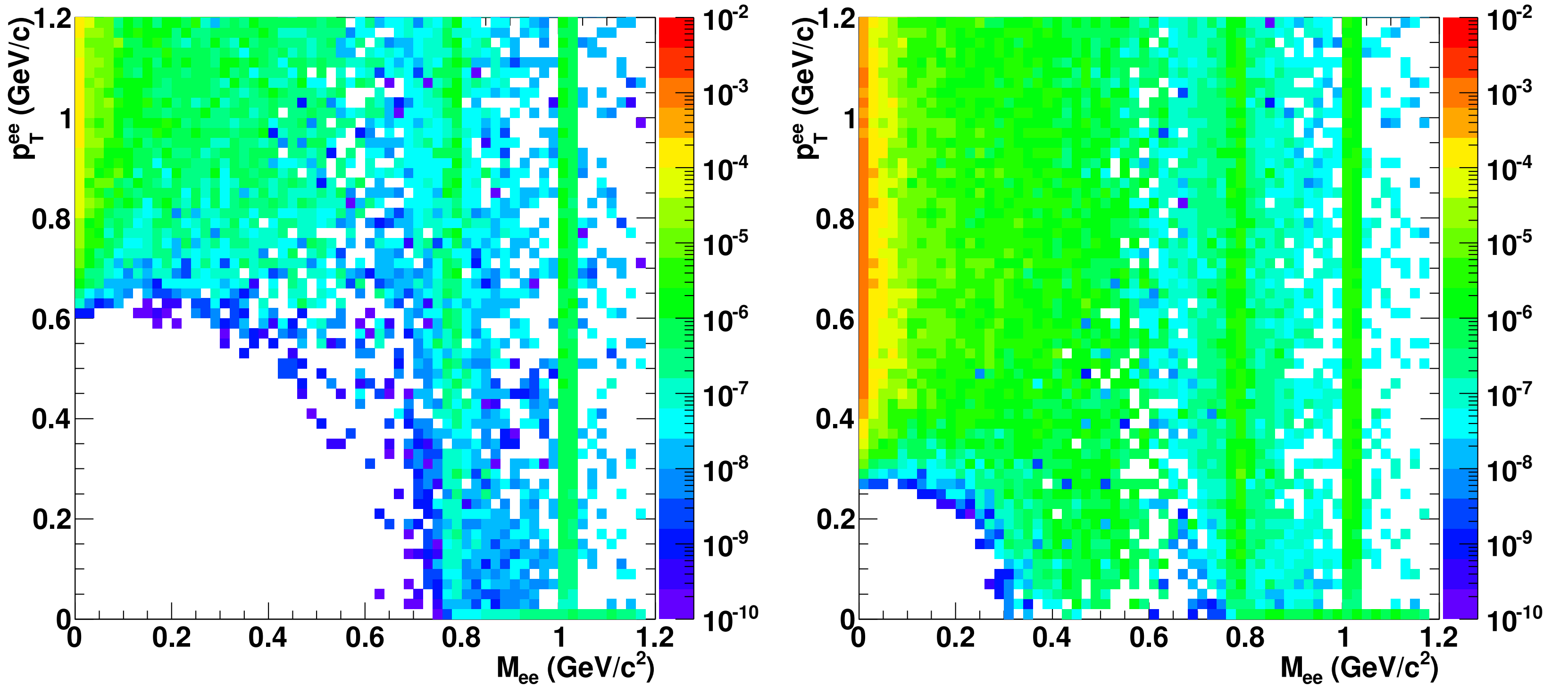


Figure 2.49: Acceptance for e^+e^--pairs from PYTHIA at $B = 0.5$ T (left) and $B = 0.2$ T (right).

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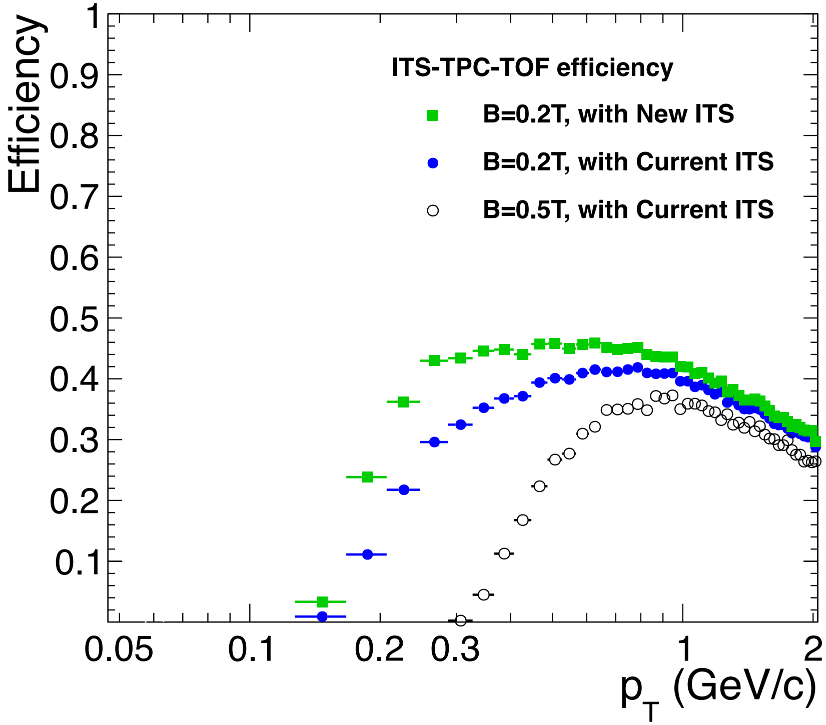
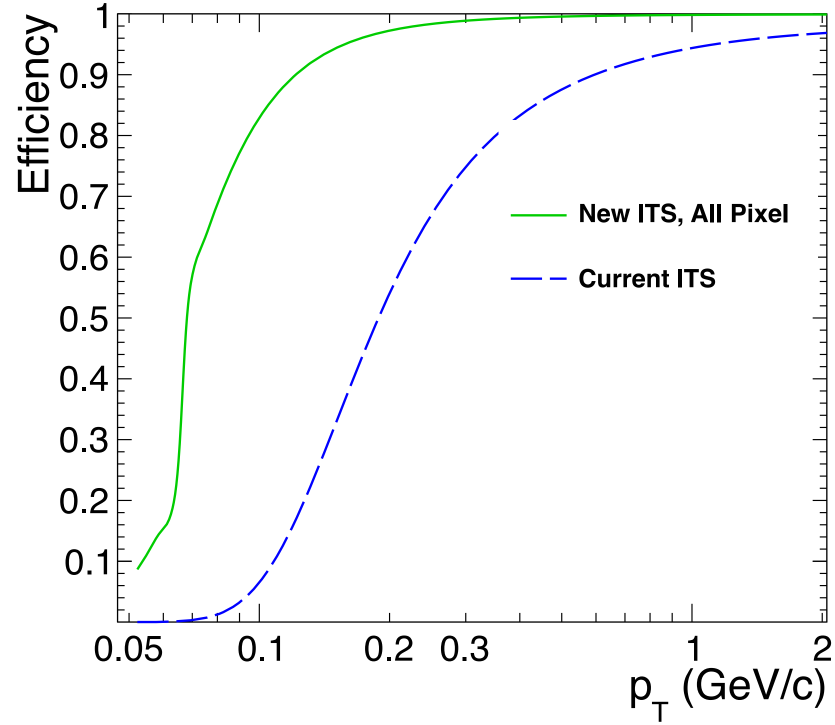
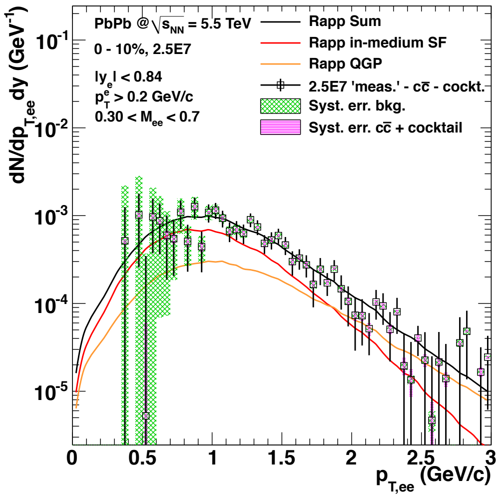
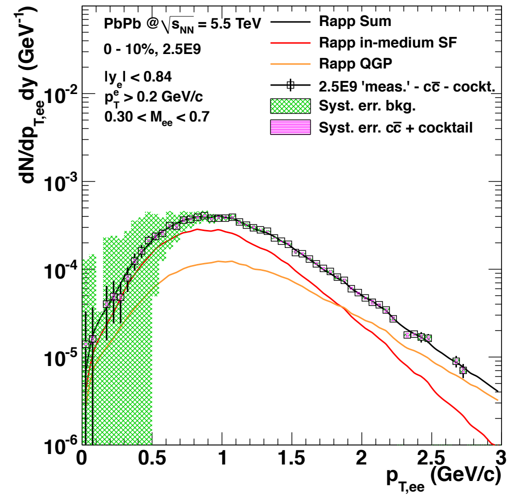
NEW INNER TRACKING SYSTEM

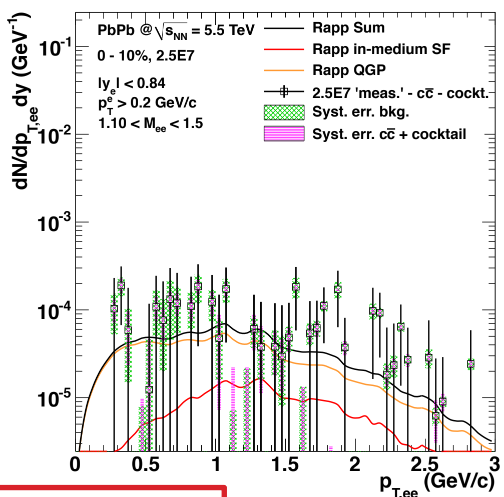


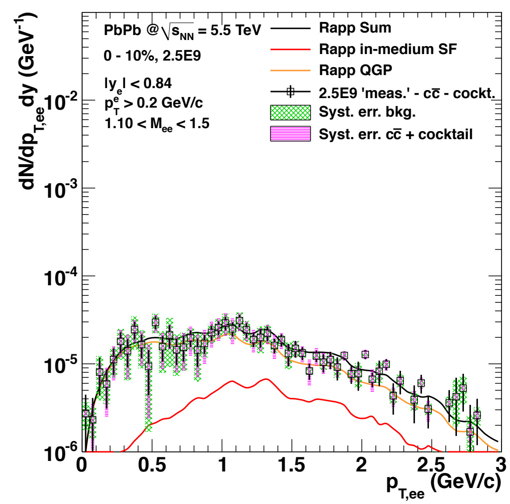


TRANSVERSE MOMENTUM DISTRIBUTIONS









- Current ITS
- Current readout

- New ITS
- New readout

VIRTUAL PHOTON MEASUREMENT (PB-PB,RUN 1)

Fit the following function to the data

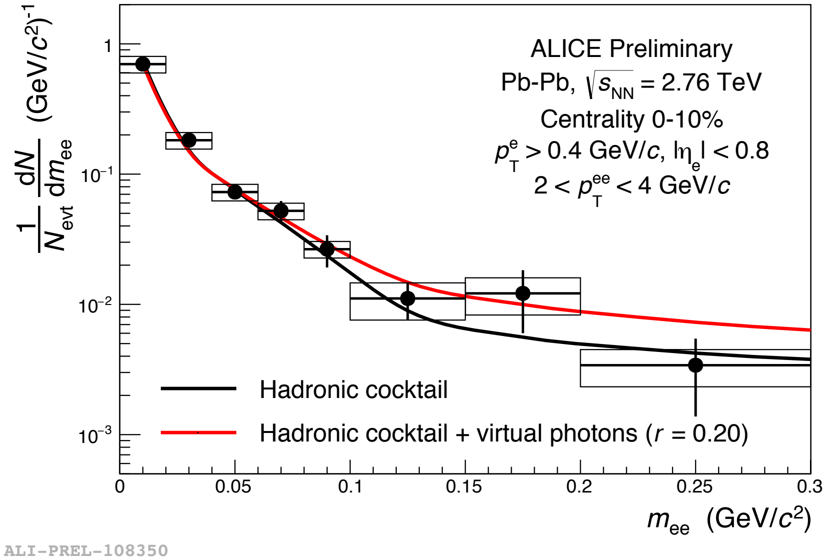
$$f(m_{ee}) = (1-r)\cdot f_{cocktail}(m_{ee}) + r\cdot f_{direct}(m_{ee})$$

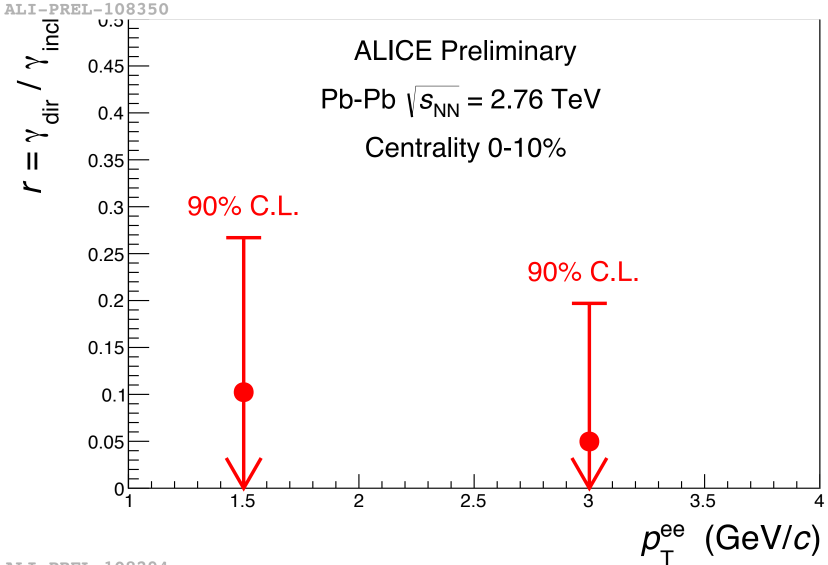
Cocktail contributions

Photon input from Kroll-Wada

- r is the ratio of direct to inclusive photons

Under the assumption that the ratio of direct to inclusive is the same as real to virtual
→ direct = r x inclusive (yields)





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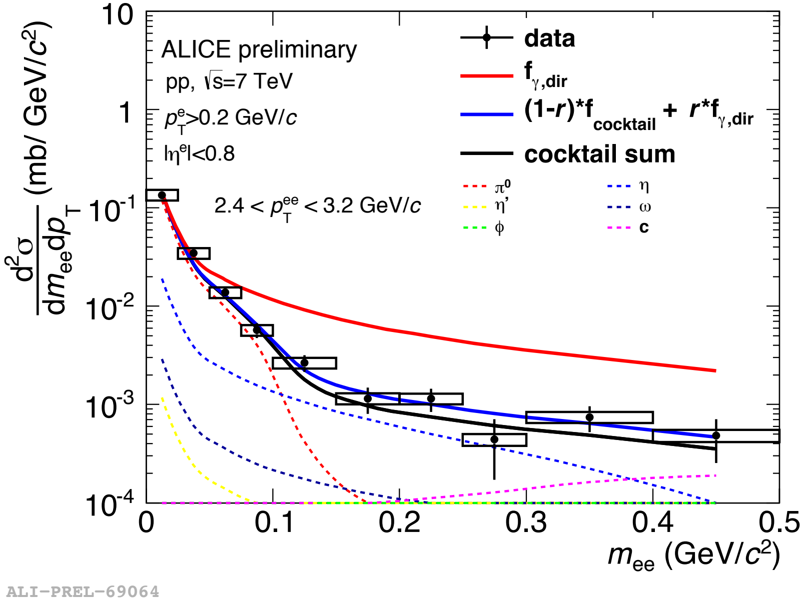
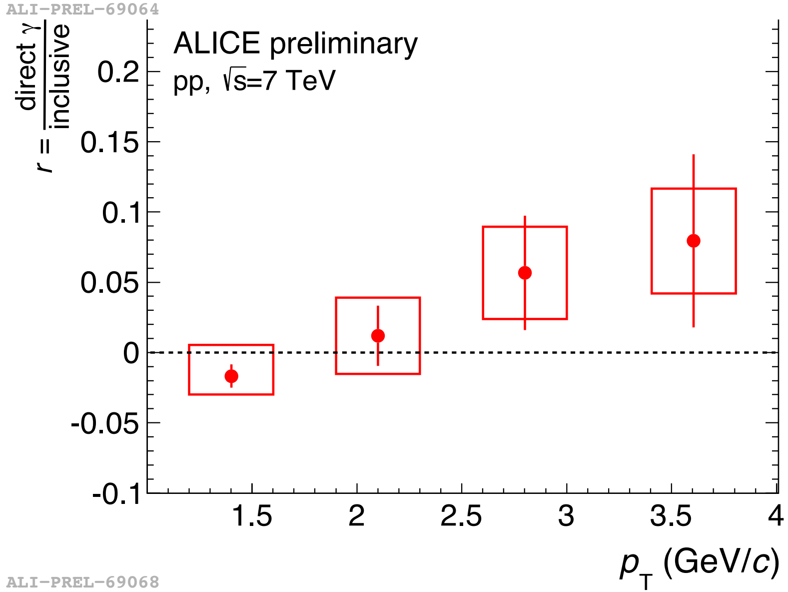
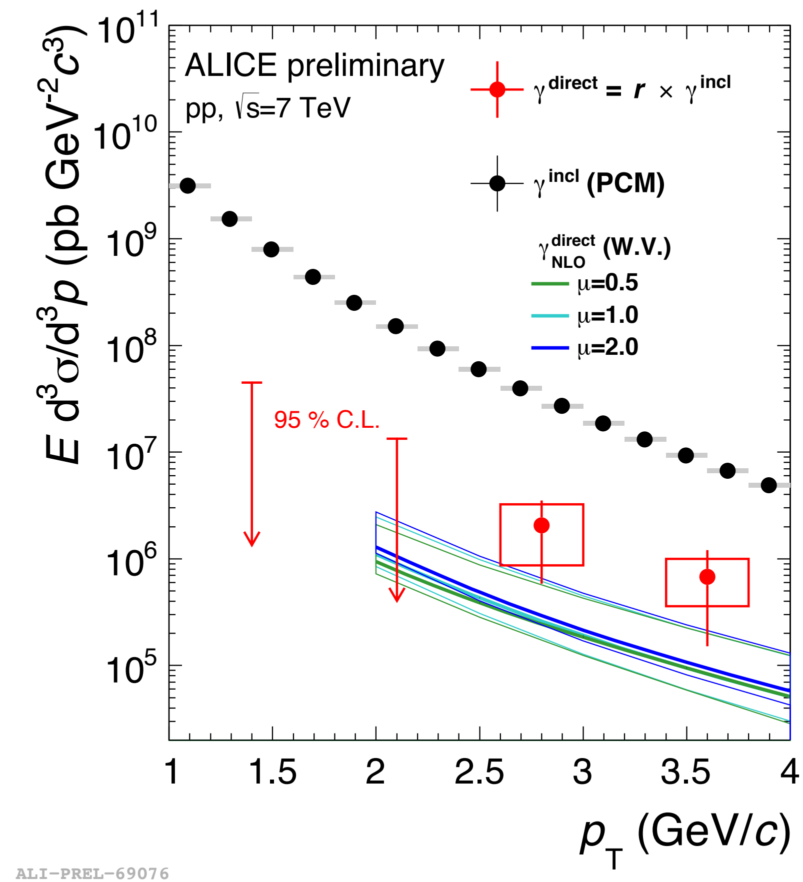
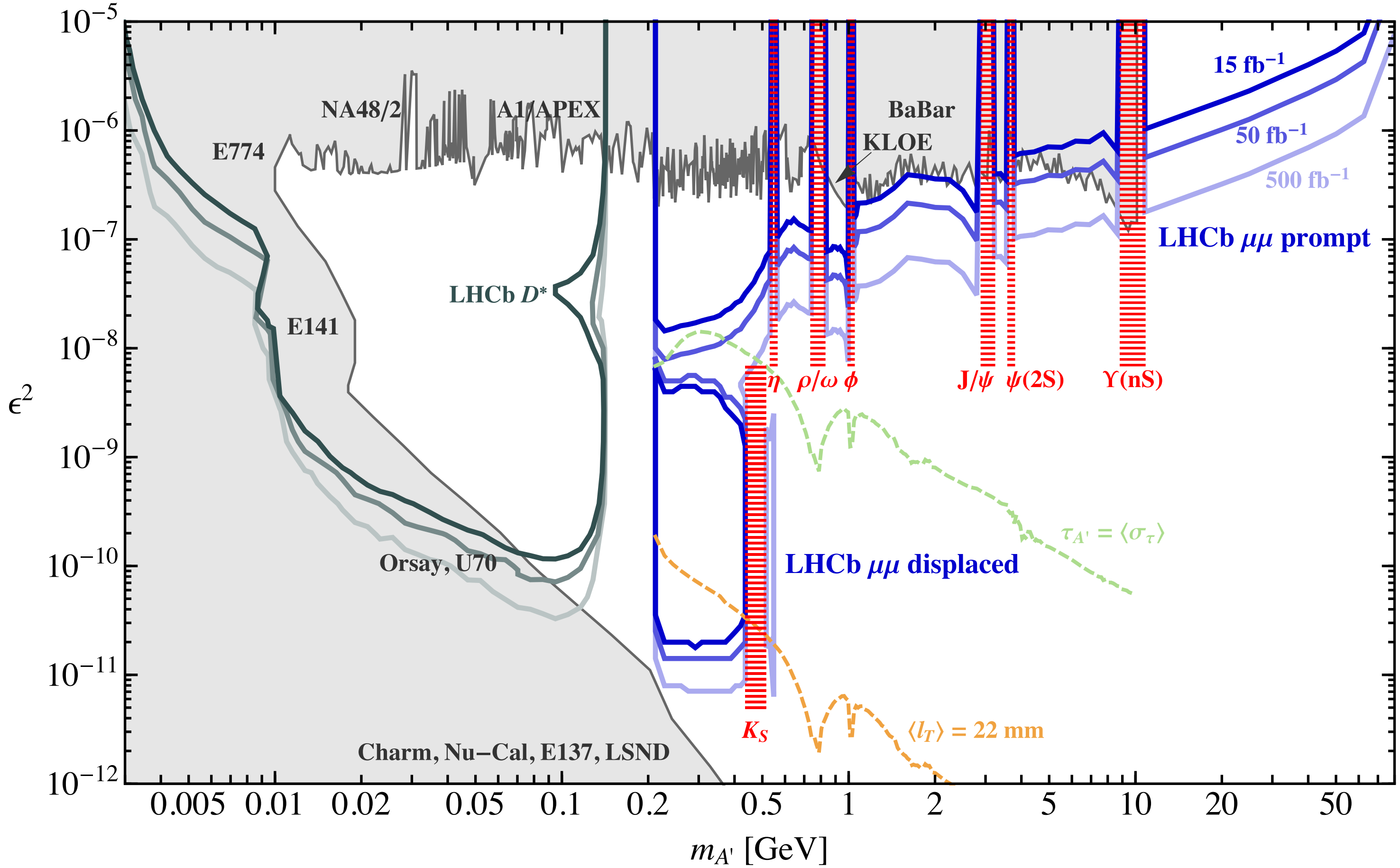
VIRTUAL PHOTON MEASUREMENT (PP,RUN 1)







DARK PHOTONS – LHC B



***LHCb**, Phys. Rev. Lett. 116, 251803 (2016)*

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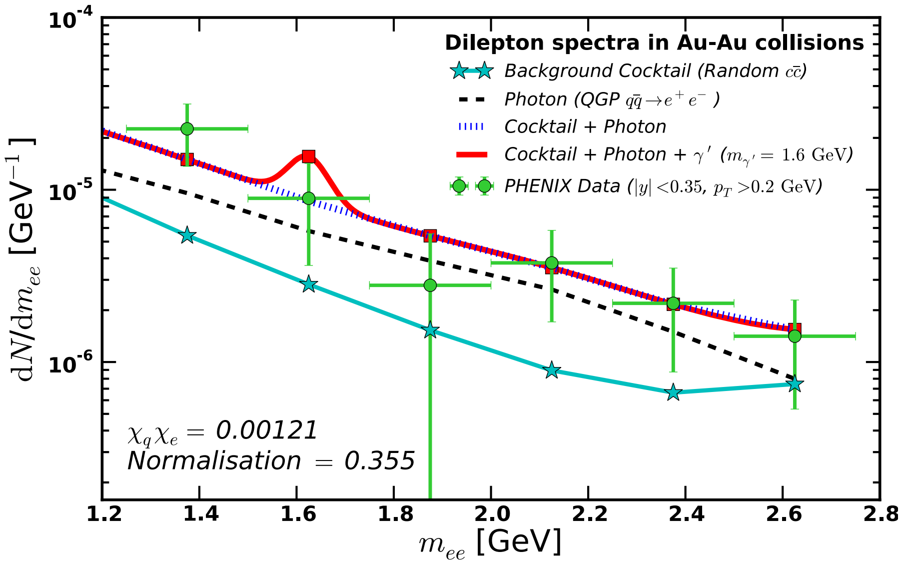
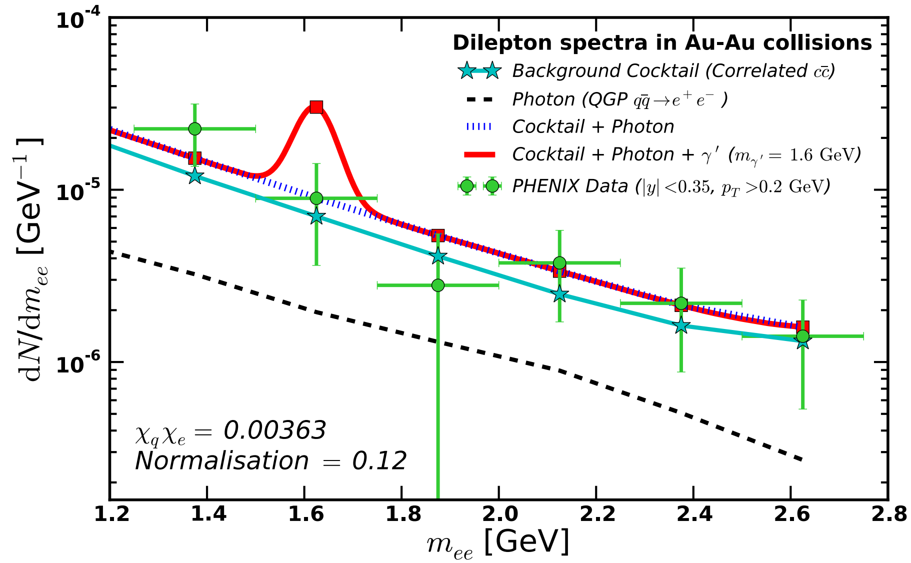
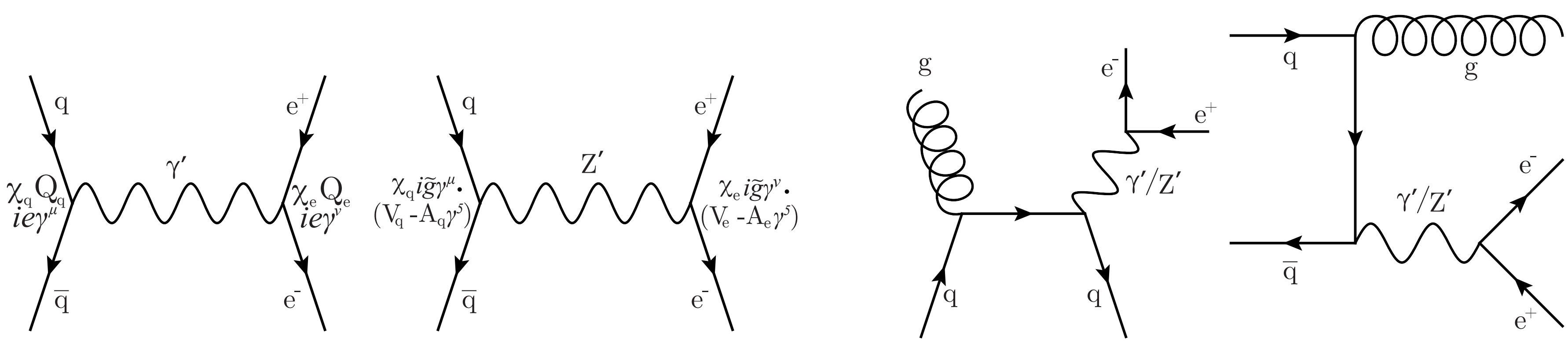
GEV-SCALE NEW GAUGE BOSONS







***J. Davis, C. Boehm**, arXiv:1306.3653*