Looking beyond LS4: new physics opportunities with a nearly massless collider detector

- a concept for a new, nearly massless collider detector
- general considerations on luminosity and physics opportunities
- selected remarks on physics topics

physics concepts developed with Federico Antinori, Stefan Floerchinger, Luciano Musa, Johanna Stachel, Krzysztof Redlich + feed-back from many ALICE colleagues

pbm

ECT* meeting
Electromagnetic Radiation from Hot and Dense Hadronic Matter
Villazano
Nov. 26-30, 2018

general remarks

- exceptional new opportunities arise with new technological developments and we (ALICE,...) should seize the moment
- new, ultra-thin (< 30 μm) Si pixels (MAPS), stitched together to large wafer-size area can be bent into cylindrical shape: possibility to realize a purely Si based collider detector for tracking and PID with a material budget of < 0.05 % X_0 per layer for the vertexer
- dE/dx measurements would be available for a few selected layers
- the excellent timing from MAPS (< 30 ps) combined with dE/dx measurements will provide PID information
- the whole detector could be less than 6 % X_0 in thickness (excluding the preshower part, of course)

- the Si is sufficiently fast and radiation-hard to allow an increase in luminosity by a factor of >> 10 compared to the upgraded ALICE apparatus in Run3/4
- except for end-cap specialized photon detectors and a pre-shower photon identifier beyond the outermost Si layer the detector would be a purely Si based collider detector
- any currently foreseen size fits well into the ALICE L3 solenoid
- with a focus on relatively low p_t phenomena, $0.01 < p_t < 10$ GeV, magnetic fields of < 0.5 T would be sufficient for momentum resolution of the order of a few %

Selected Physics Topics

needs very high luminosity

1. brief outline of detector concept – not a technical design (mostly by Luciano Musa, CERN)

Design guidelines

- Increase rate capabilities (factor 20 to 50 wrt to RUN4): $\langle L_{NN} \rangle$ ~ up to 10^{34} $cm^{-2}s^{-1}$
- Improve vertexing
  - Ultra-thin wafer-scale sensors with truly cylindrical shape, inside beampipe
  - spatial resolution ~ 1-3μm
  - material thickness < 0.05% X_0 /layer
- Improve tracking precision and efficiency
  - About 10 layers with a radial coverage of 1m
  - Spatial resolution of about 5μm up to 1m
  - whole tracker could be less than 6% X_0 in thickness (at mid-rapidity)
- Extended rapidity coverage (ideally up to 8 rapidity units)

Focus on relatively low p_T phenomena, $0.01 < p_T < 10$ GeV/*c*

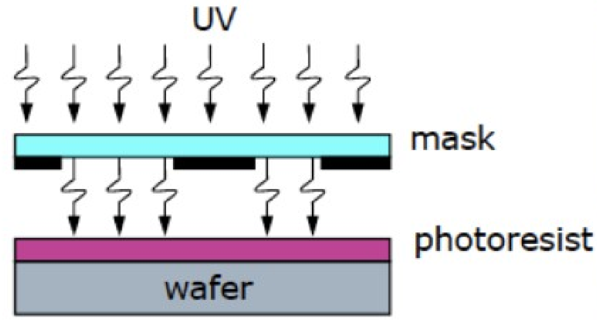
Magnetic fields of < 0.5T would be sufficient but 1T (or higher) is to be considered

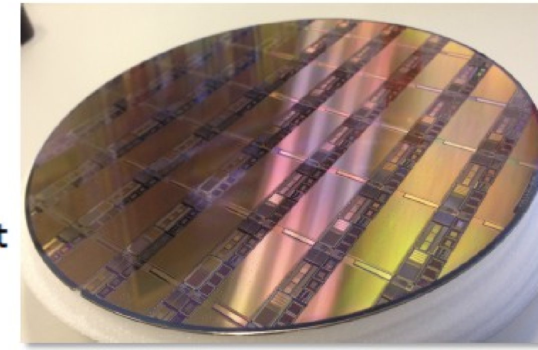
L. Musa (CERN) – ALICE Physics Week, 23 Oct 2018

CMOS photolithographic process defines wafer reticles size

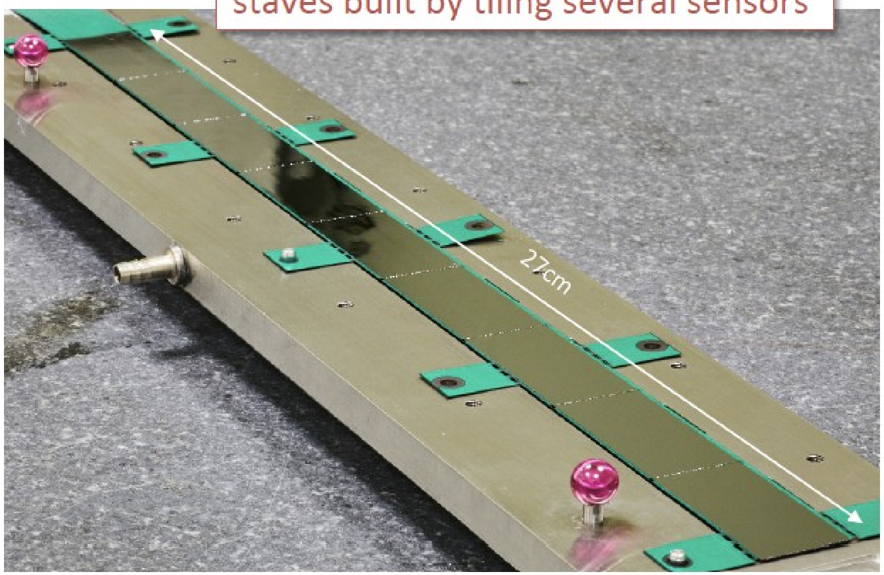
⇨ Typical field of view O(2 x 2 cm^2)

Reticle is stepped across the wafers to create multiple identical images of the circuit(s)

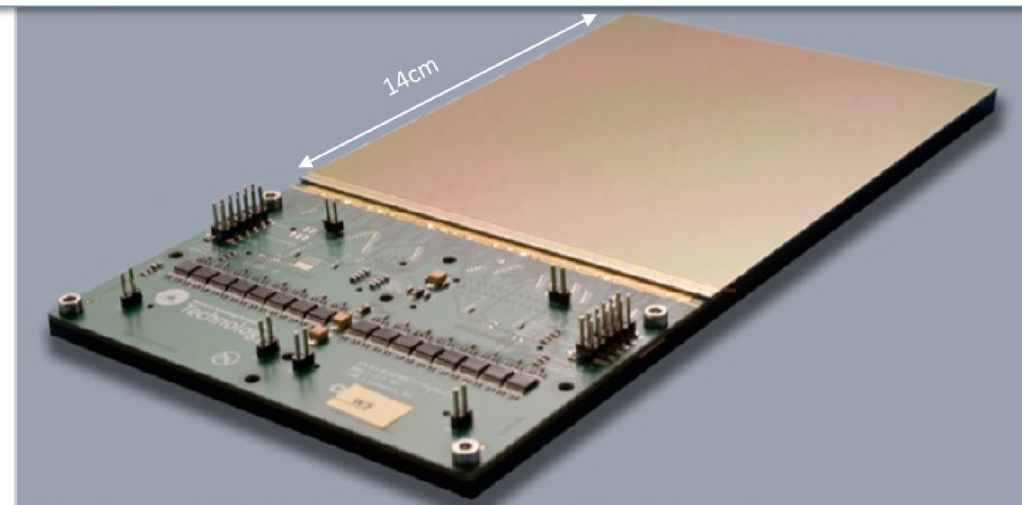




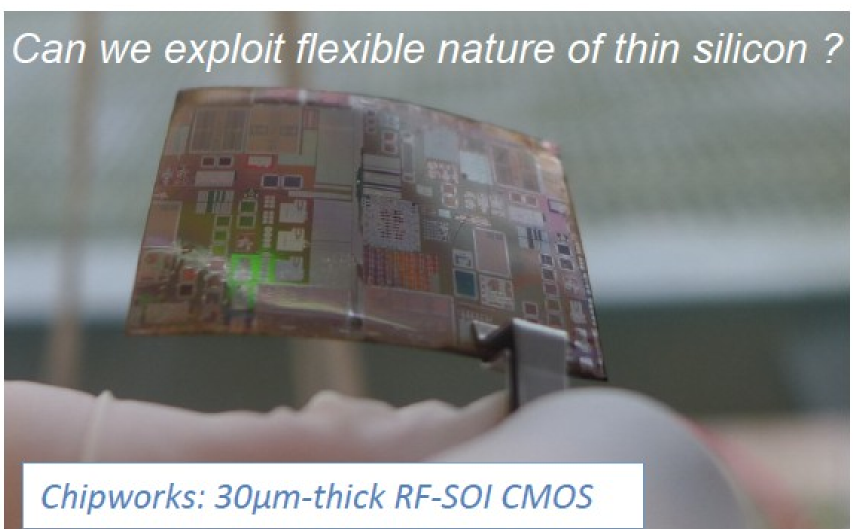
staves built by tiling several sensors



Stitching allows fabrication of sensors larger than the reticle size



Courtesy: R. Turchetta, Rutherford Appleton Laboratory



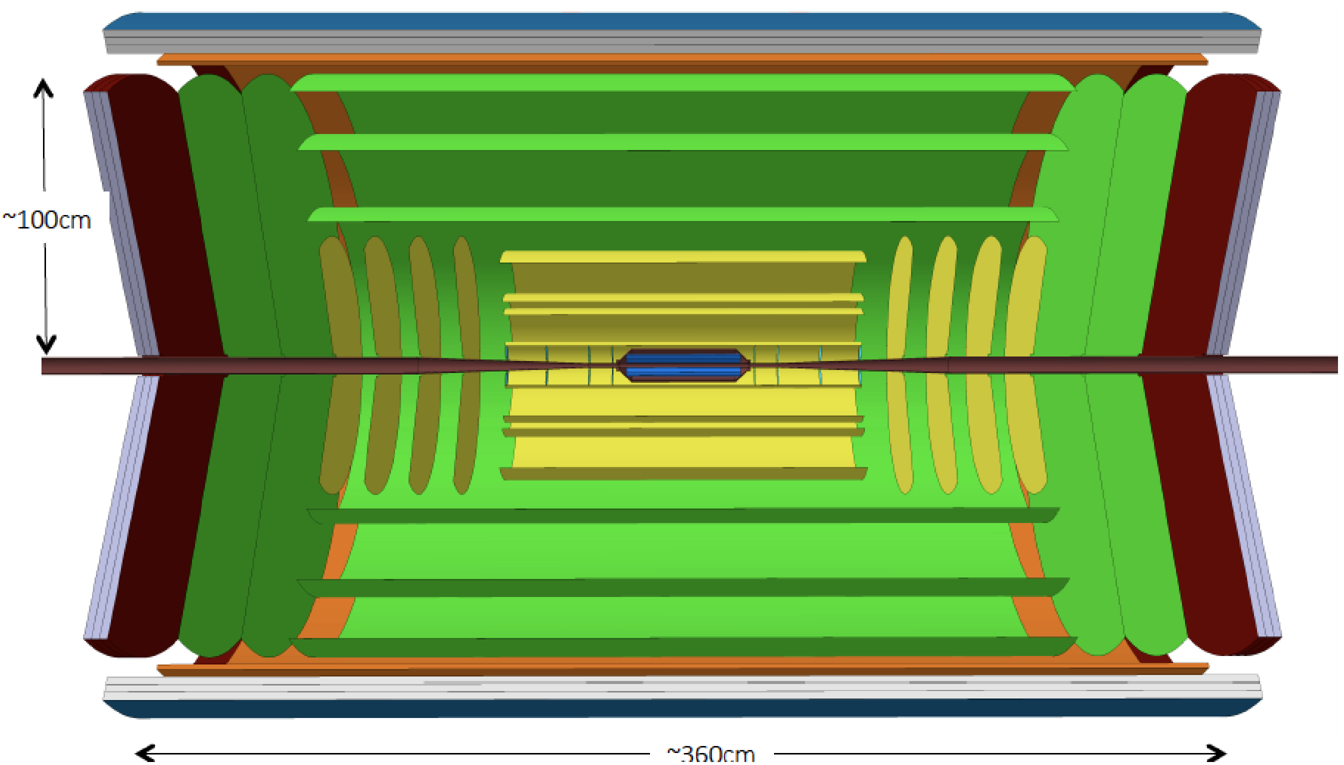
Ultra-thin chip (<50 um): flexible with good stability

Tracker: ~10 tracking barrel layers (blue, yellow and green) based on CMOS sensors

Hadron ID: TOF with outer silicon layers (orange)

Electron ID: pre-shower (outermost blue layer)

Extended rapidity coverage: **up to 8 rapidity units**
+ FoCal



Preliminary studies

Magnetic Field

- B = 0.5 or 1 T

Spatial resolution

- Innermost 3 layers: $\sigma \sim 1\mu m$
- Outer layers: $\sigma \sim 5\mu m$

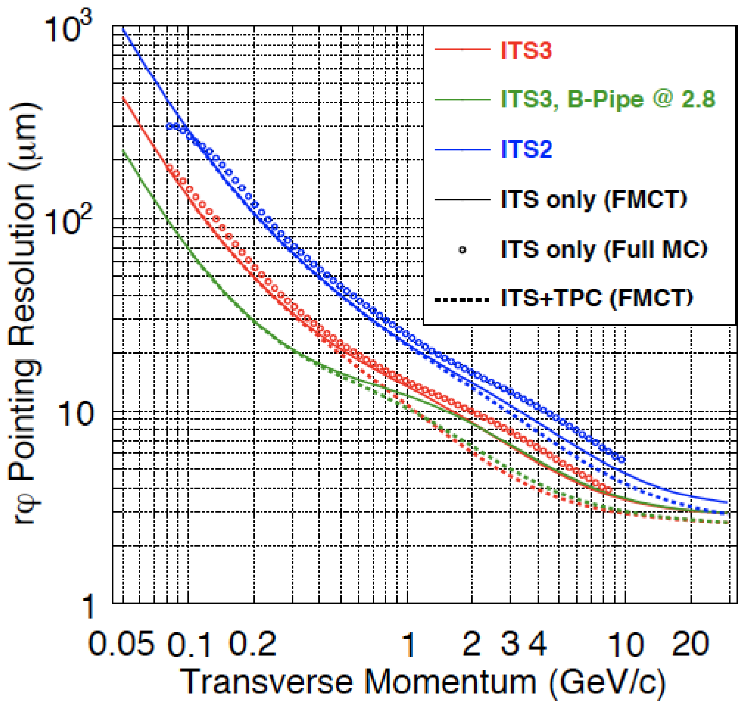
Time Measurement

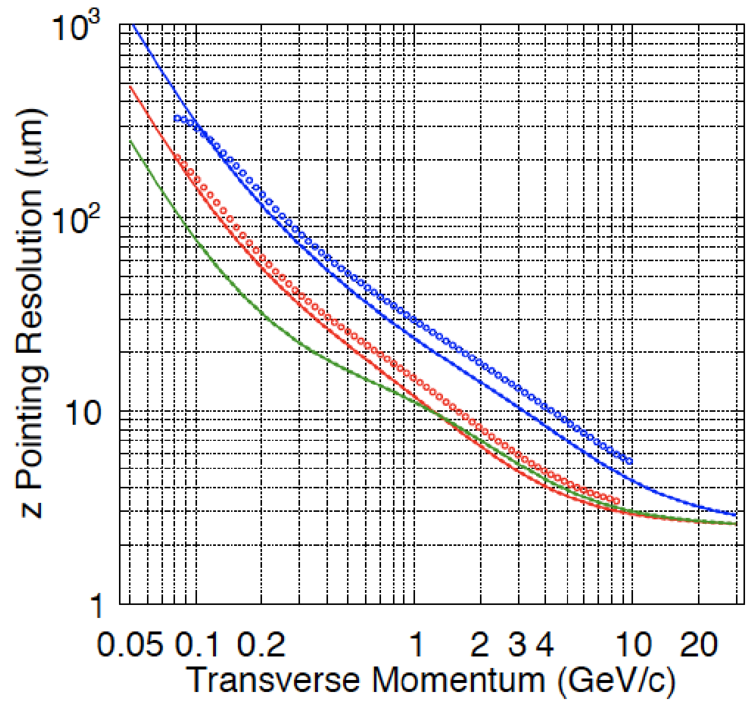
Outermost layer integrates high precision time measurement ($\sigma_t < 30ps$)

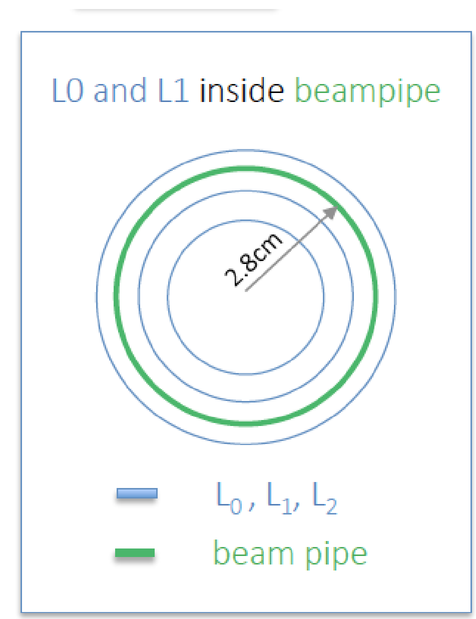
+ dedicated photon spectrometer at y = 4 for ultra-soft photons

$0.01 < E_{photon} < 3$ GeV $0.37 < p_T < 110$ MeV

green lines: resolutions with 2 layers inside beam pipe







FMCT: semi-analytical, includes QED hits, but no energy loss fluctuations

Full MC: simplified ITS3 geometry, full MC simulation (GEANT3), Cellular Automaton ITS Tracker

2. soft electromagnetic radiation

direct and thermal photons in Pb-Pb collisions at LHC energy

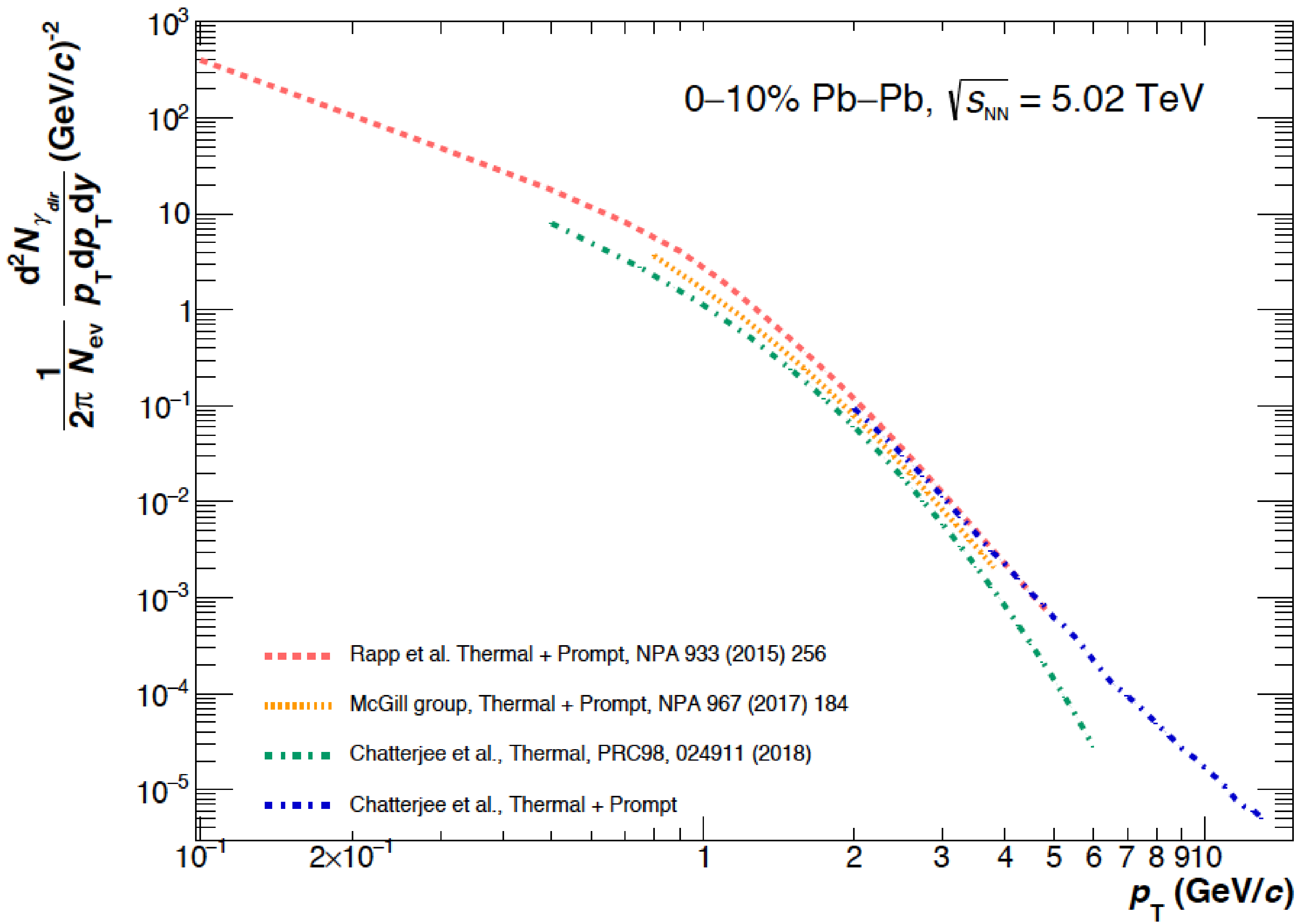


figure from CERN yellow report HL-LHC 2018

is the range below 2 GeV measurable? can one go further down in p_T?

physics considerations
real and virtual photon production at very low mass (<10 MeV) and very low p_T (< 20 MeV)

- low mass lepton and photon production are a consequence of the structure all gauge theories, see, in particular, [1, 3, 20, 23]. This realization has led to the development of 'soft theorems' a la Francis Low, [2]. According to these theorems the number of soft (real) photons and dileptons (virtual photons) actually diverges towards low p_T but *in a highly controlled manner that is central to the consistency of quantum field theory*, [23]. It would be of prime importance to reach the experimental sensitivity to test this prediction. This needs measurements at very low masses or p_T, probably below 10 MeV.
- it would be appropriate and important to measure dielectron mass distributions down to masses of the order of a few MeV and for p_T values of order 1/radius of the system under consideration. For r = 10 fm such as fireball size in Pb-Pb at LHC, this implies $p_T < 20$ MeV. Current measurements have typically $p_T \geq 200$ MeV, recent unpublished ALICE results at low B field go to 75 MeV for pp collisions.

physics considerations
real and virtual photon production at very low mass (<10 MeV) and very low p_T (< 20 MeV)

- soft photons can be measured with the conversion method, need to evaluate the p_T values possible. Note that photons from π^0 decay will be significantly suppressed below p_T = 30 MeV because of the decay Jacobian, see [13], where measurements with p + Be $\rightarrow \gamma + X$ at 450 GeV were made down to a few MeV with a BaF_2 crystal spectrometer. Some (tentative) indication of enhancement is observed over standard bremsstrahlung calculations. These results were analyzed by Nachtmann et al., [9, 15], in the framework quark synchrotron radiation. It would be very interesting to follow this up.
- an interesting area to pursue is the multiplicity dependence of photon and dielectron production. Bjorken and Weisberg, [4] and Rückl [5] and Pisut et al., [6, 7, 8, 10, 11, 12] predict a quadratic dependence ($q\bar{q}$ annihilation).

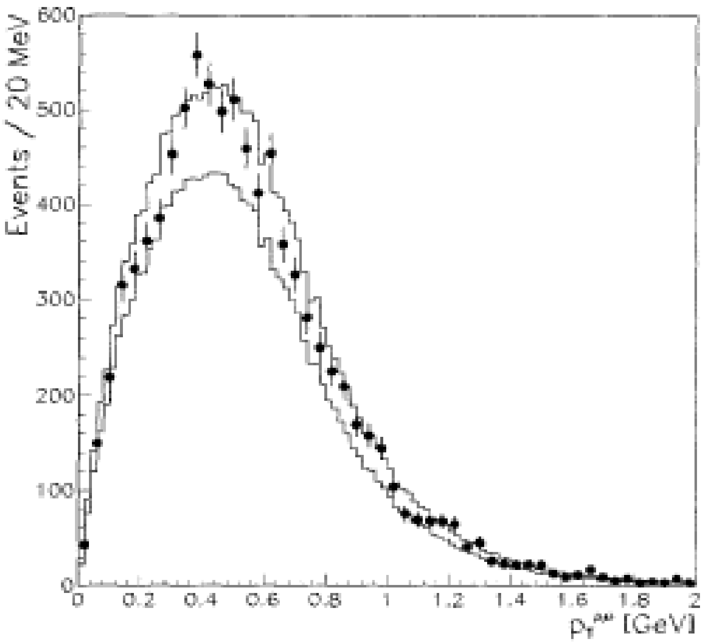
physics considerations
real and virtual photon production at very low mass (<10 MeV) and very low p_T (< 20 MeV) from pp to Pb-Pb collisions

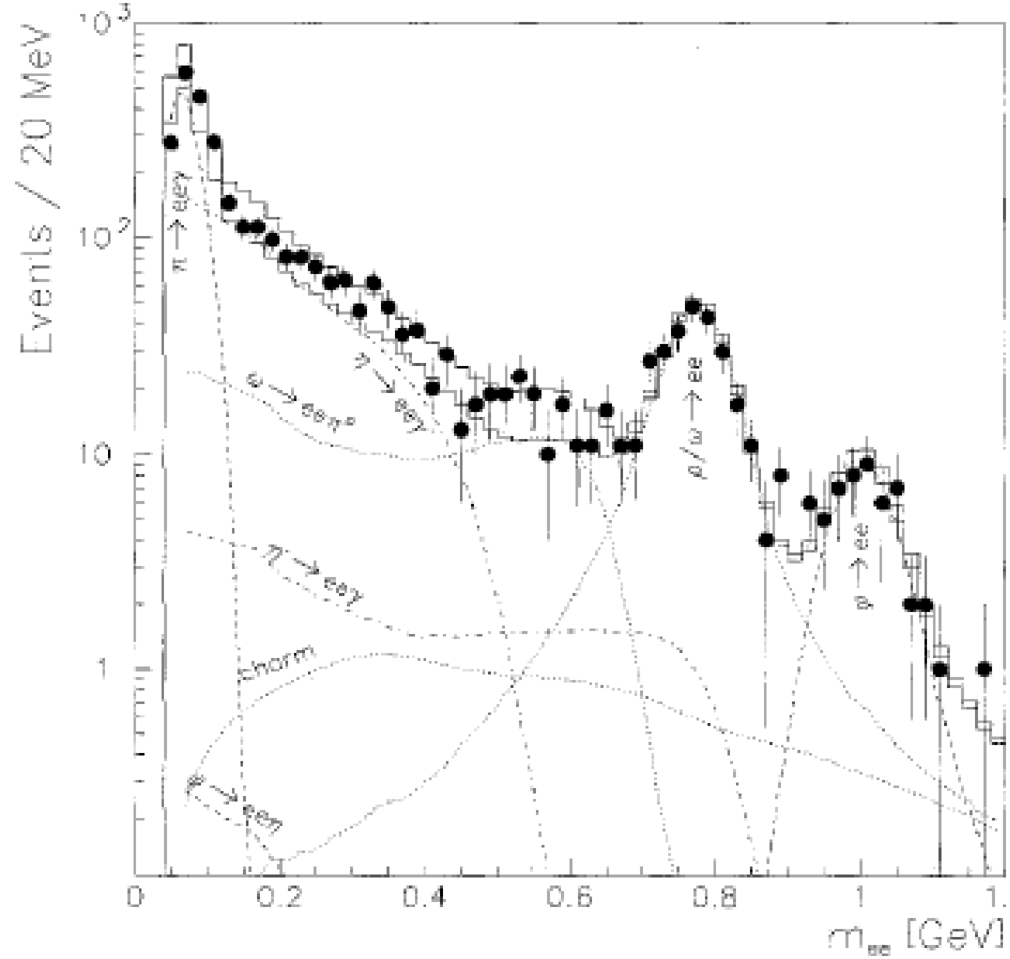
1. suppressing Dalitz decays of $\pi^0, \eta, \omega, \eta'$ as well decays from open charm and open beauty is key for a low mass dielectron measurement, see Fig. 11 of the ALICE pp paper, ref. 24. Note that the π^0 channel here is removed by a mass cut but we should aim for much lower mass cut. The main aim should be the measurement of 'primordial electromagnetic radiation' from the fireball formed ion the collision. Collision systems should range from pp to pPb to Pb-Pb, all studies as function of charged particle multiplicity. Conversions should be dramatically reduced by the layers inside the beam pipe and the generally low detector mass.

2. very low p_T photons could be measured with a special, small spectrometer at forward rapidity, say rapidity 2.5 - 5. A 5 MeV p_T photon would be boosted to energies of 60 - 740, respectively, maybe even 1 MeV p_T experiments could be done. The special spectrometer should have ultimate granularity, including charged particle veto. Since cross sections at very low p_T are large, large acceptance and hermeticity are not needed.
3. very important is efficient electron ID. Below p = 100 MeV this can be done well with dE/dx. Above that momentum some kind of pre-shower detector is needed.

Z. Phys. C 68, 47–64 (1995)

Low-mass lepton-pair production in p-Be collisions at 450 GeV/c

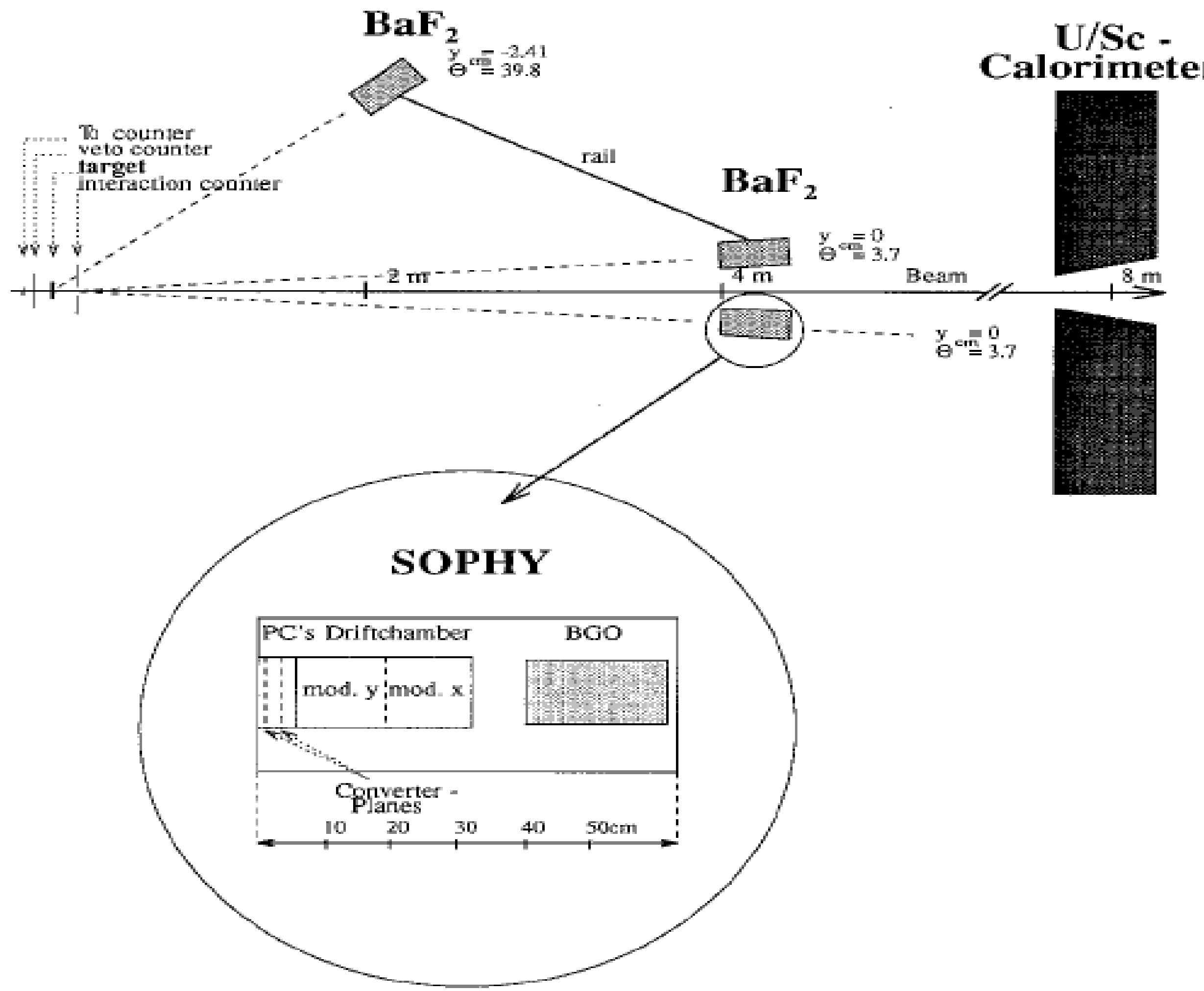


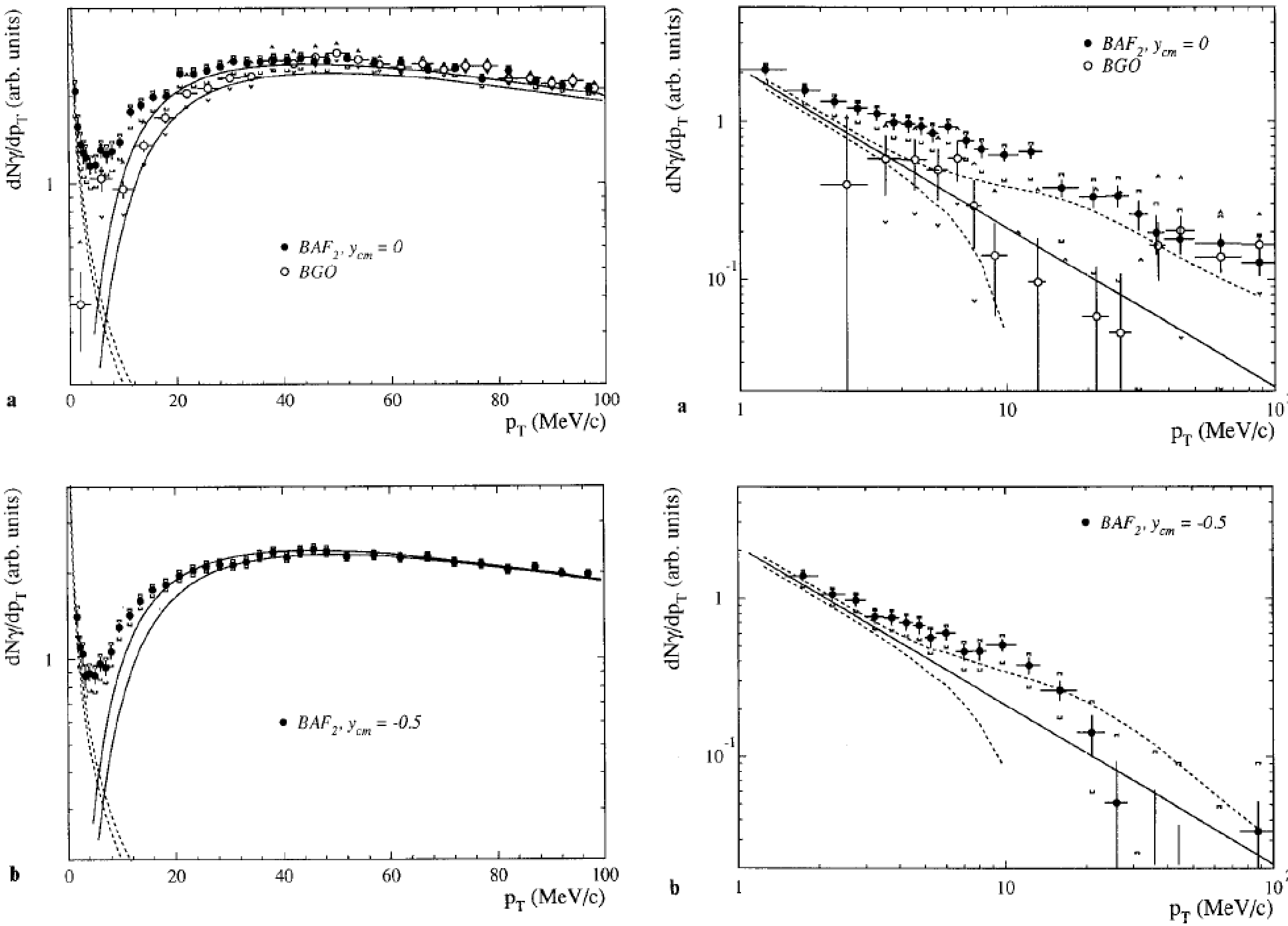


a few examples from the past, ...

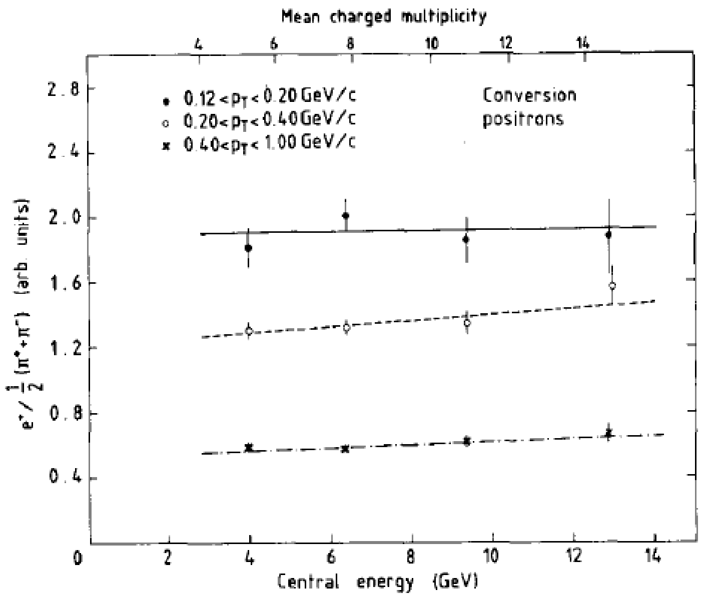
Z. Phys. C 59, 547–553 (1993)

Soft photon production in 450 GeV/c *p*-Be collisions

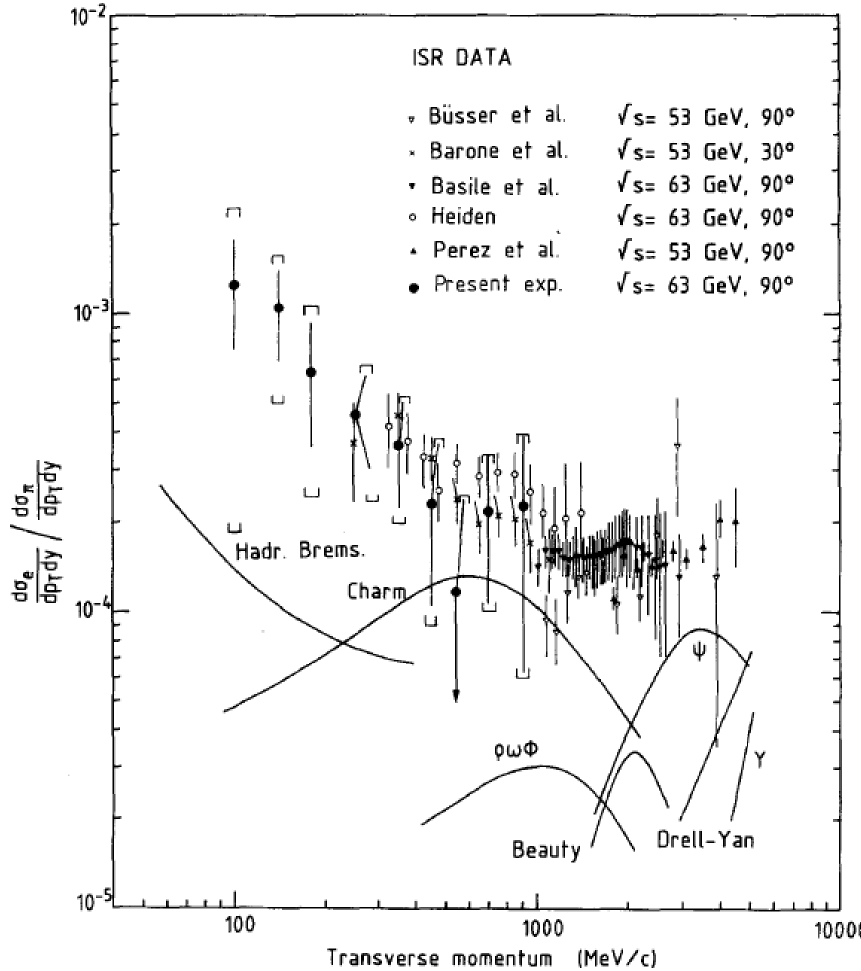




real photons down to the MeV scale, bremsstrahlung rise towards low p_T clearly observed, consistent with Low theorem



Volume 152B, number 5,6 PHYSICS LETTERS 14 March 1985

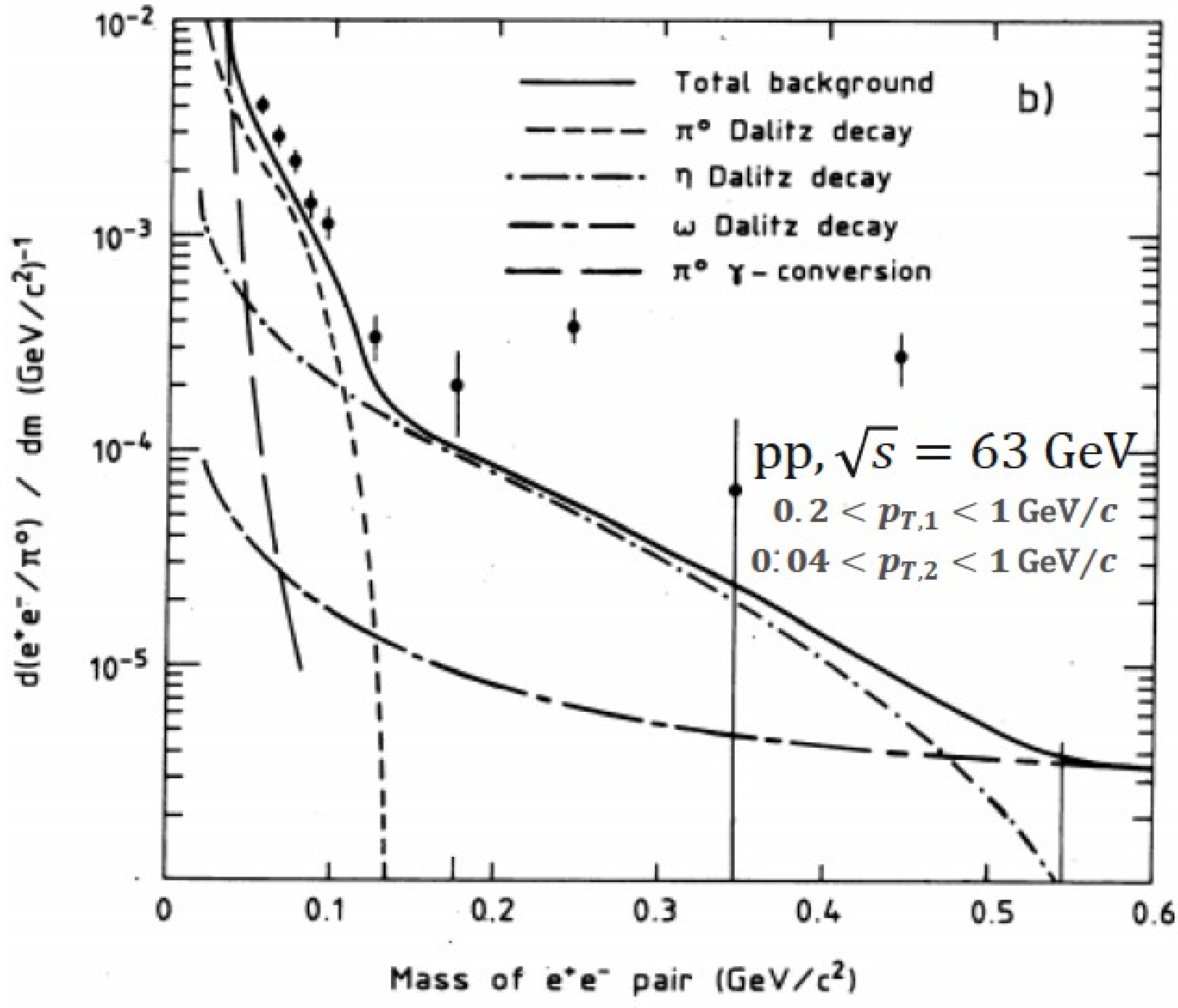


...the lonely anomaly left over from the ISR era

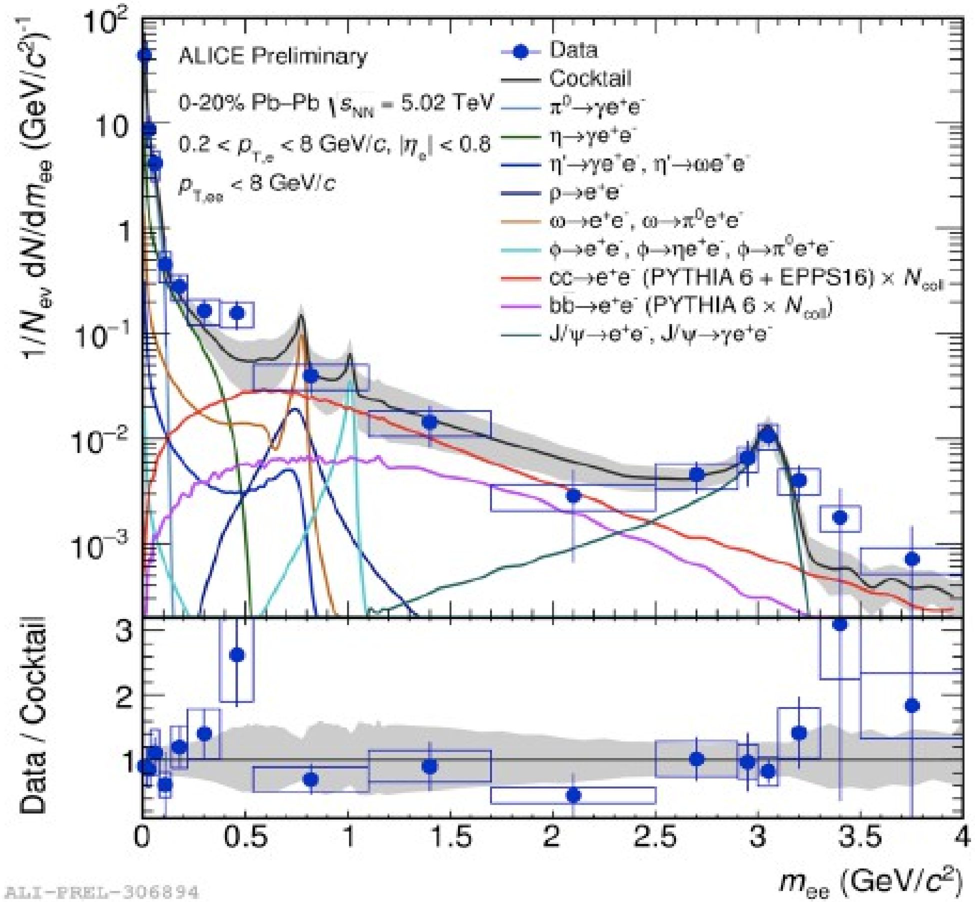
single positron measurements

ISR anomaly in di-electrons

'anomalous' dileptons in pp



first ALICE results at full LHC energy

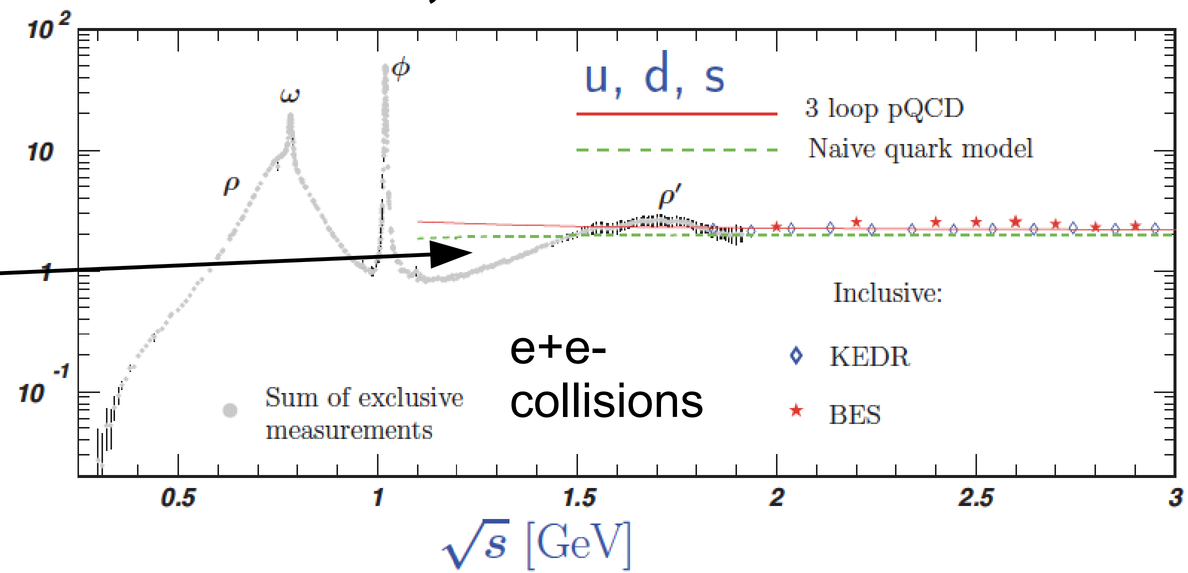


arXiv:1807.00923

chiral symmetry restoration and the rho-a1 region

vacuum masses: rho 770 MeV, a1 1230 MeV

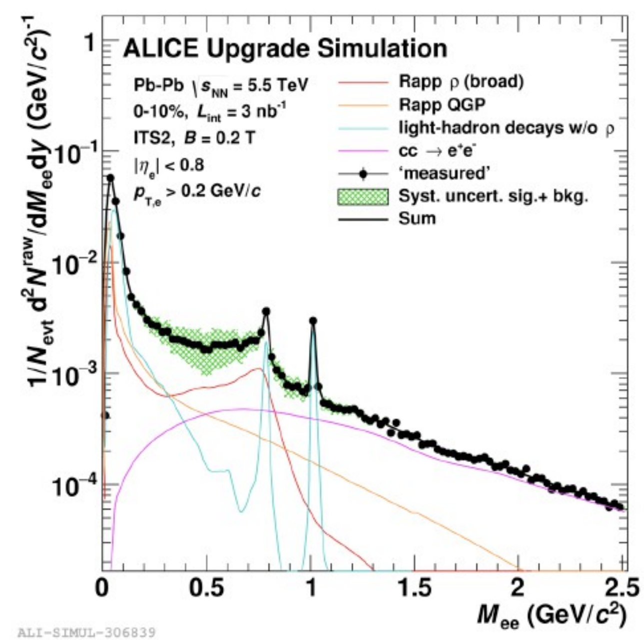
the idea: the rho and a1 mesons are chiral partners. In the vacuum, chiral symmetry is broken, the rho couples to e+e-, but not the a1.



in medium, chiral symmetry is restored, the chiral partners mix, and the hole in the spectral distribution should be filled.

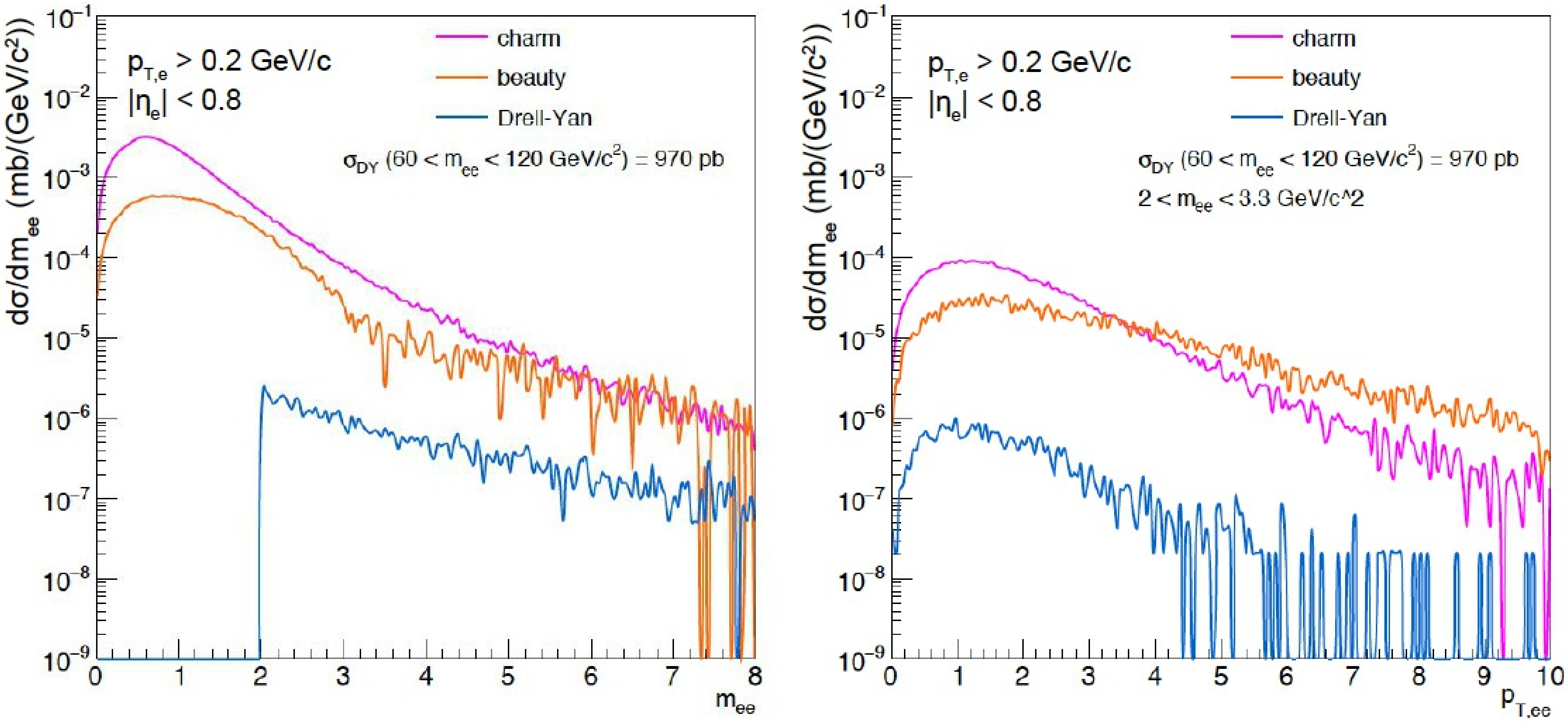
to detect this, measure dilepton mass distribution in the mass range 0.6 – 2.5 GeV region in Pb-Pb collisions with precision and at low transverse momentum, p_T < 50 MeV and compare with pp and e+e- results

the challenge: at LHC energies, the dominant dilepton decays from open charm and beauty need to be quantitatively removed new massless detector



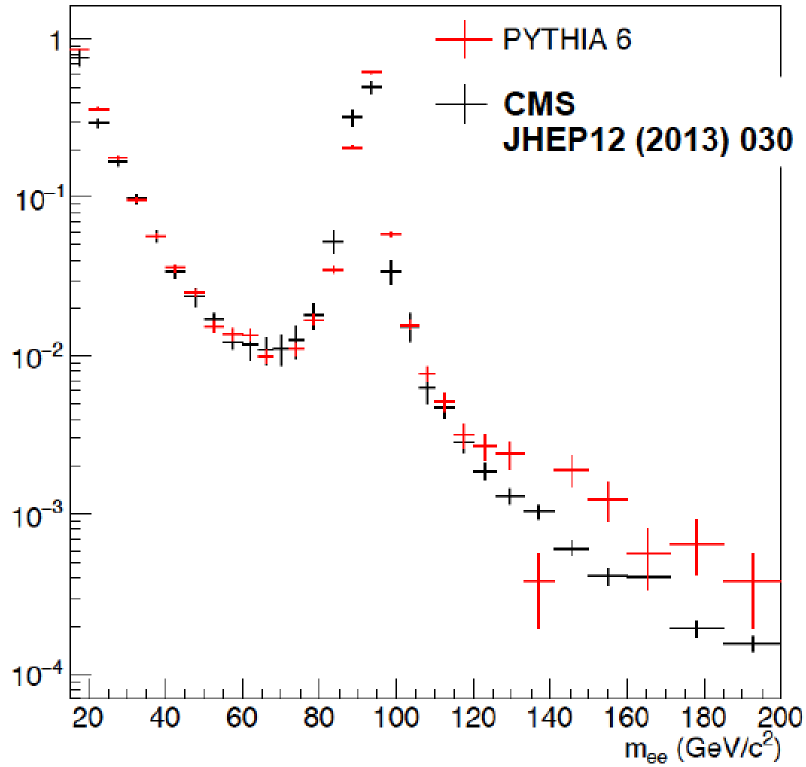
note: the background from Drell-Yan production is negligible at LHC energy

Drell-Yan distributions in the low mass region, extrapolated via Pythia6 from CMS measurements in the mass range 20 < m_ee < 120 GeV



Normalization of Pythia6 to Z and DY measurements by CMS

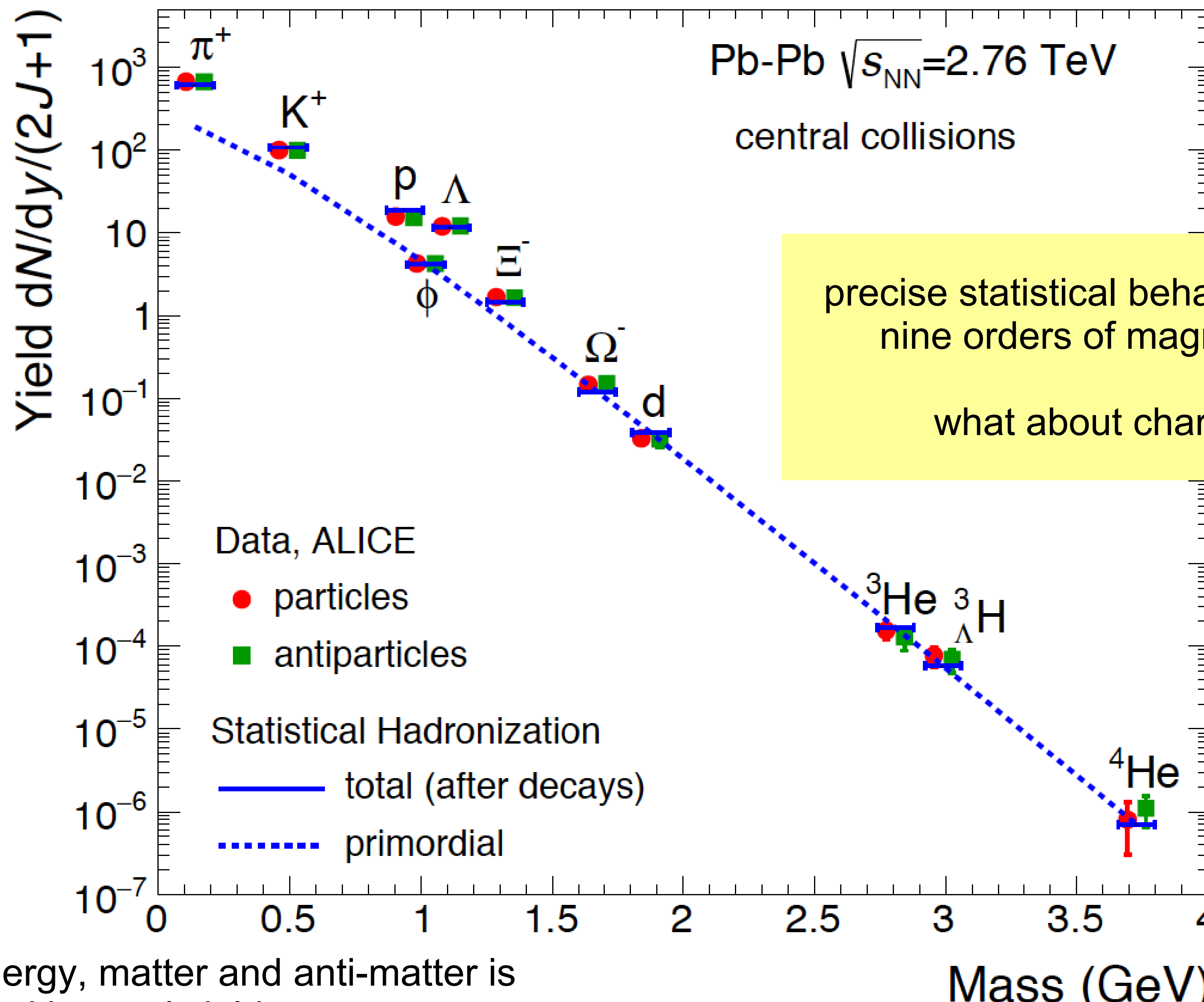
Arbitrary units



3. physics considerations
multi-charm and beauty states

Work in collaboration with Anton Andronic, Markus Koehler, Krzysztof Redlich, Johanna Stachel

at LHC energy, production of (u,d,s) hadrons is governed
by mass and quantum numbers only
quark content does not matter



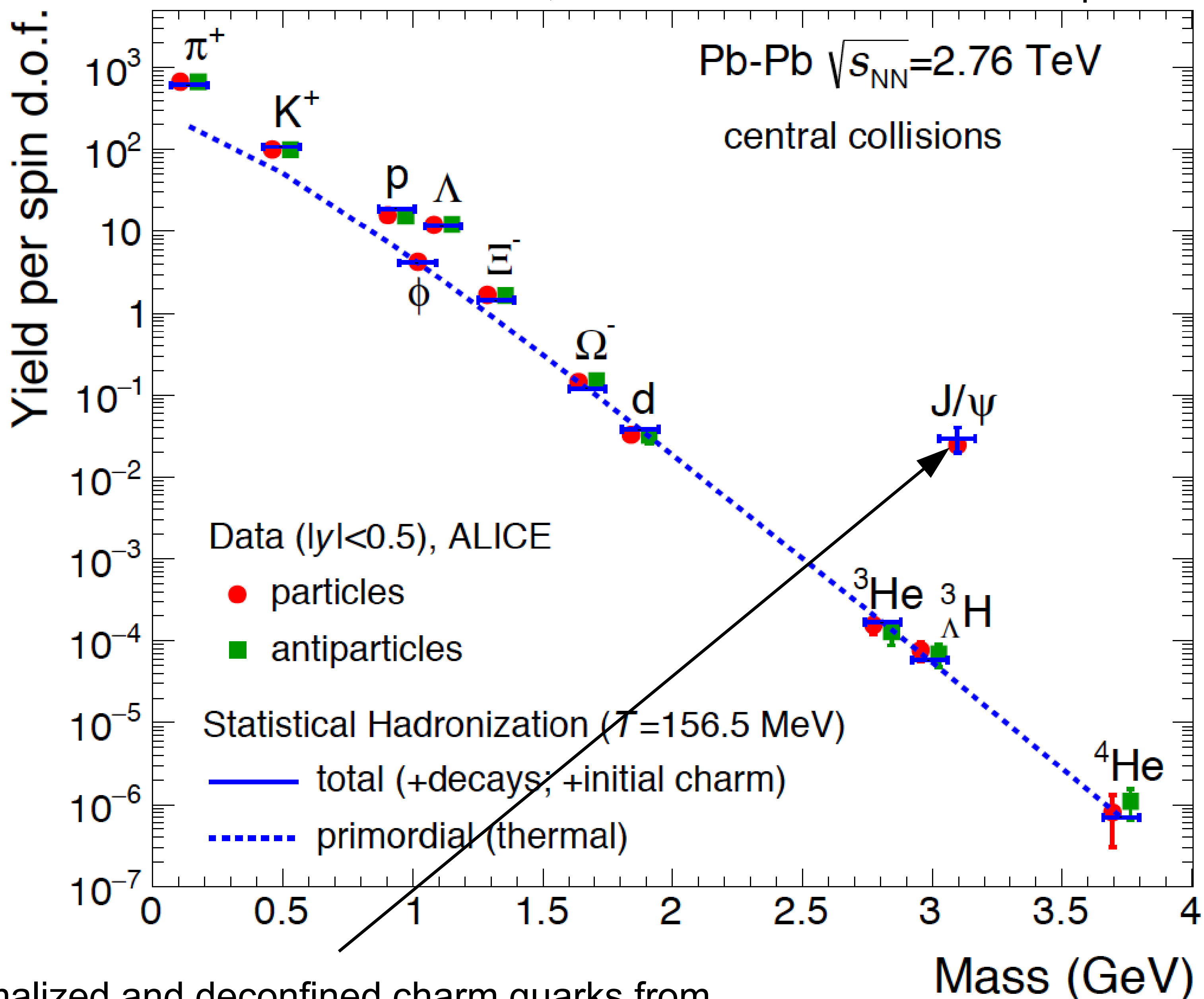
precise statistical behavior over
nine orders of magnitude!

what about charm?

at LHC energy, matter and anti-matter is
produced with equal yields

Andronic, pbm, Redlich, Stachel, arXiv:1710.09425, Nature 561 (2018) no.7723, 321-330

enhancement is precisely prediction by Statistical Hadronization Model
for quadratic scaling in number of charm quarks, they have to travel freely over the size of the fireball of 10 fm, about 10 times the radius of a proton



with thermalized and deconfined charm quarks from initial hard scattering

Andronic, pbm, Koehler,Redlich, Stachel, to appear

doorway state hypothesis:
all nuclei and hyper-nuclei, penta-quark and X,Y,Z states are formed as virtual, compact multi-quark states at the phase boundary. Then slow time evolution into hadronic representation. Excitation energy about 20 MeV, time evolution about 10 fm/c

Andronic, pbm, Redlich, Stachel, arXiv :1710.09425

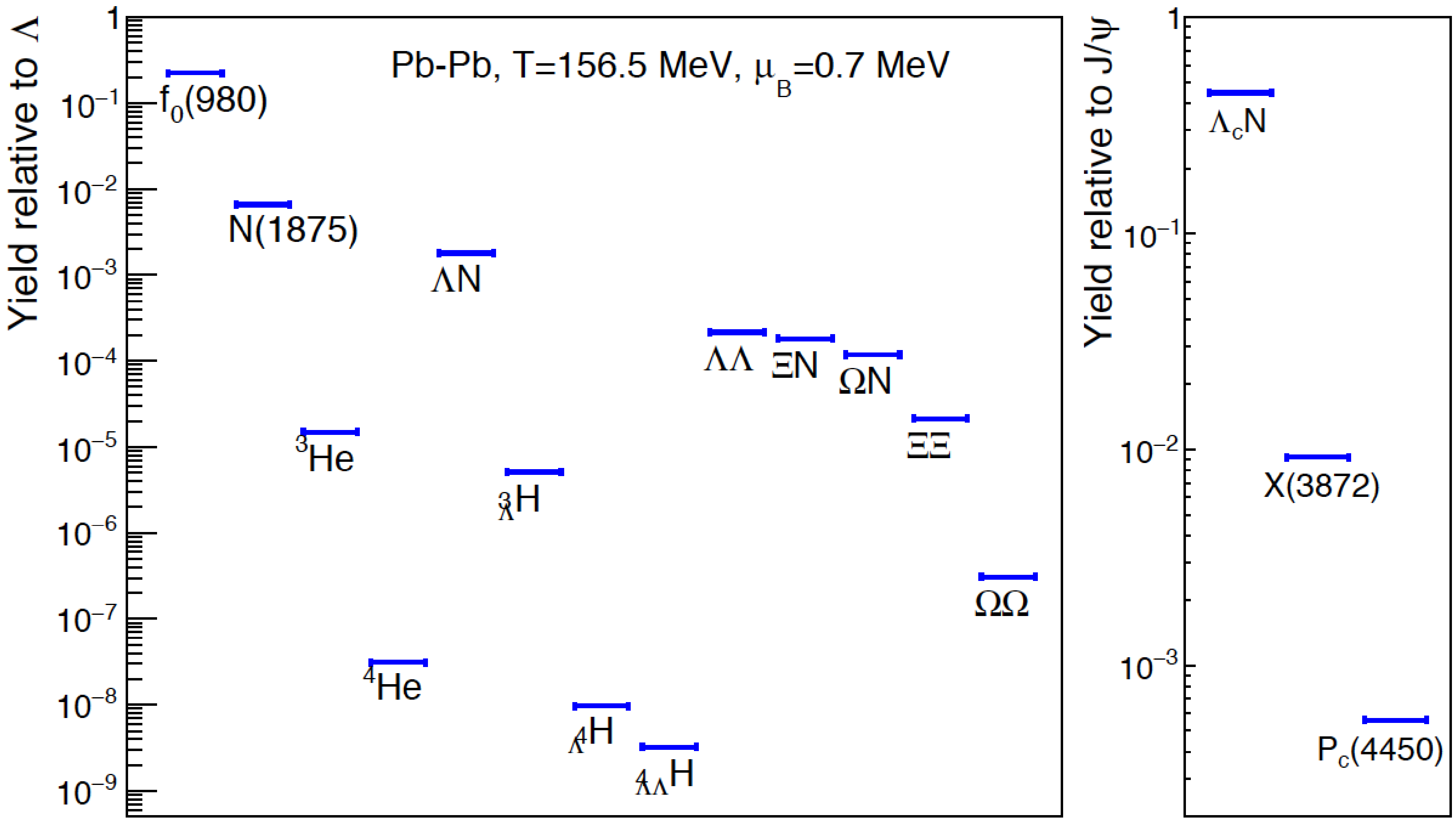
How can this be tested?

precision measurement of spectra and flow pattern for light nuclei and hyper-nuclei, penta-quark and X,Y,Z states from pp via pPb to Pb-Pb

a major new opportunity for ALICE
beyond LS4 for X,Y,Z , multi-charm, charm-beauty and penta-quark states

thermal production yields of exotic states in central Pb-Pb collisions at 5 TeV/u

Andronic, pbm, Koehler, Redlich, Stachel preprint in preparation



example: X(3872)

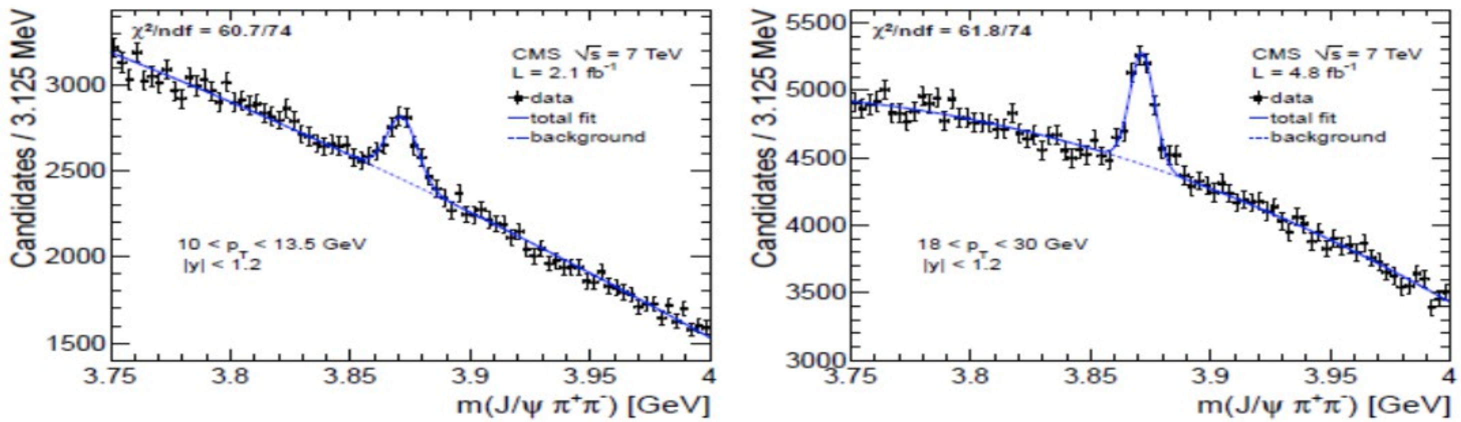
X(3872)

- 2003 -

$$B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$$

$$M = 3872.0 \pm 0.6 \pm 0.5\ \mathrm{MeV}$$

- 2013 -



X(3872)

$$I^G(J^{PC}) = 0^+(1^{++})$$

Mass $m = 3871.69 \pm 0.17$ MeV

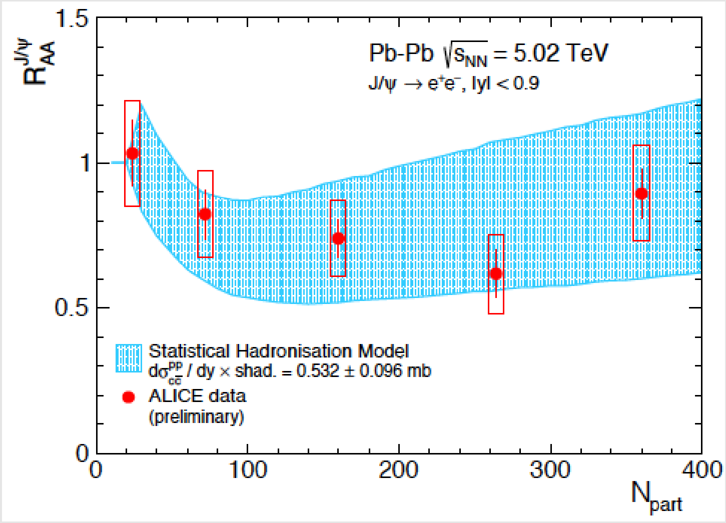
$m_{X(3872)} - m_{J/\psi} = 775 \pm 4$ MeV

$m_{X(3872)} - m_{\psi(2S)}$

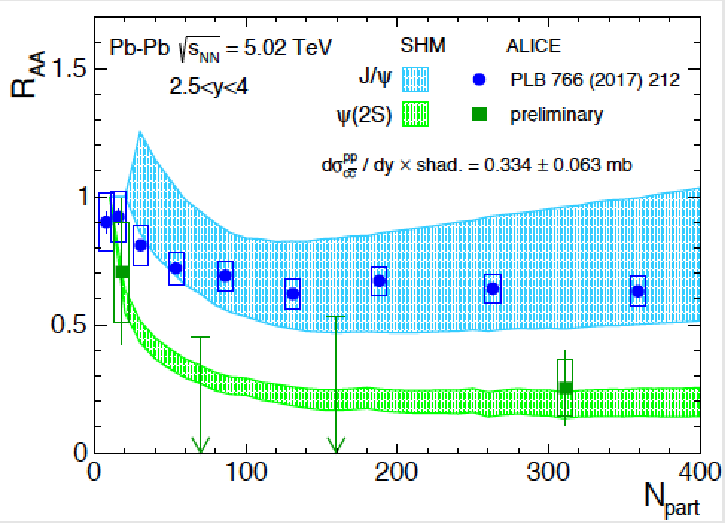
Full width $\Gamma < 1.2$ MeV, CL = 90%

physics considerations
quarkonia, chi states and deconfinement

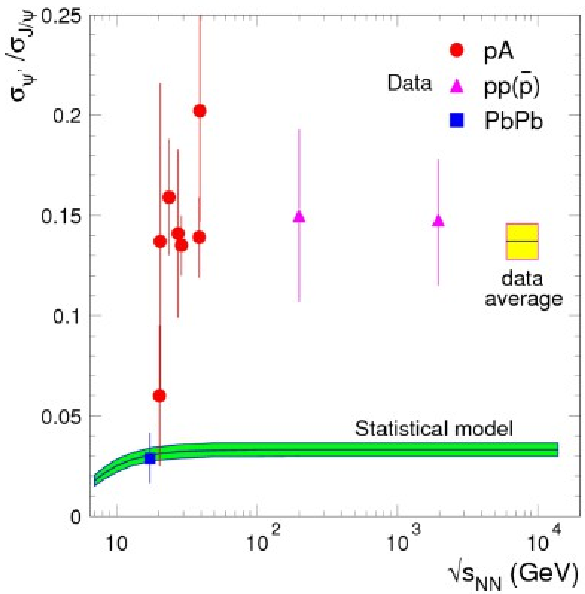
Mid-rapidity

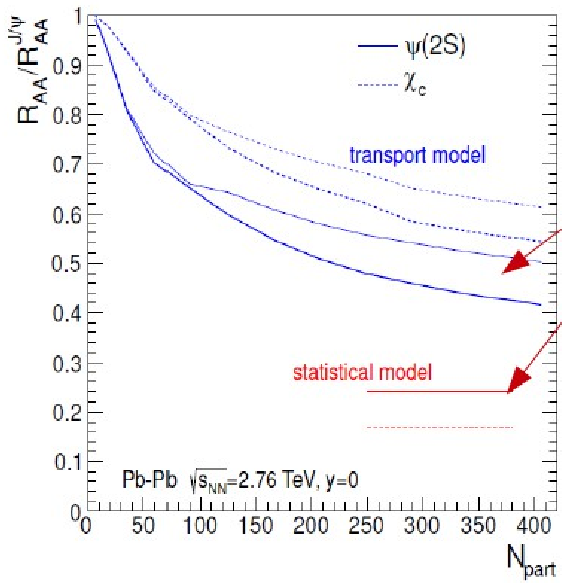


Forward rapidity



psi' and bound states in the QGP



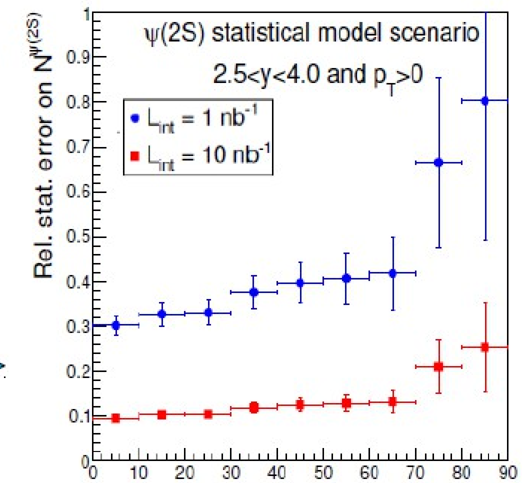


in fact, here one can distinguish between the transport models that form charmonia already in QGP and statistical hadronization at phase boundary!

for statistical hadronization need to see suppression by Boltzmann factor

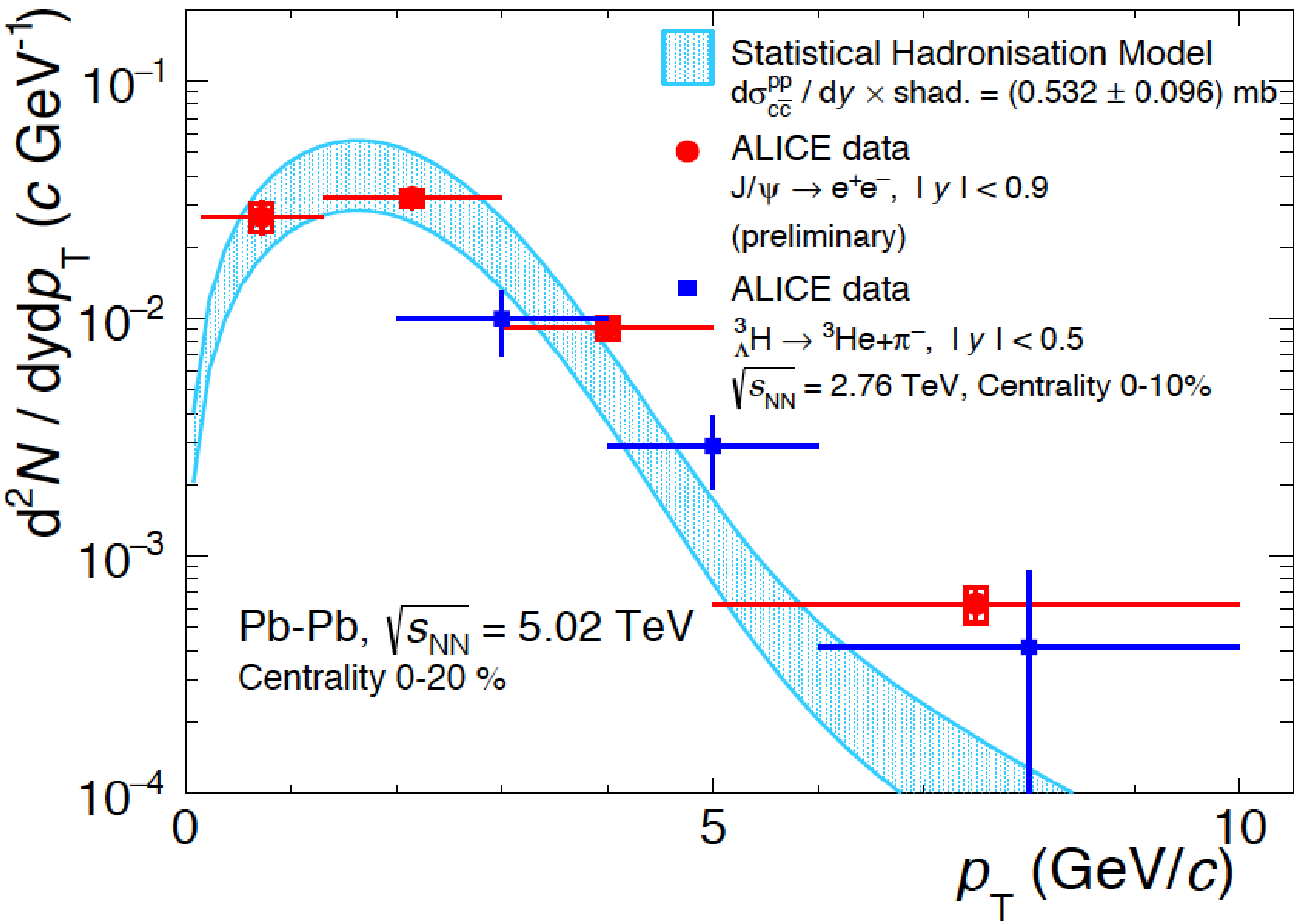
χ_c even bigger difference

expected ALICE performance muon arm run2 and run3



centrality

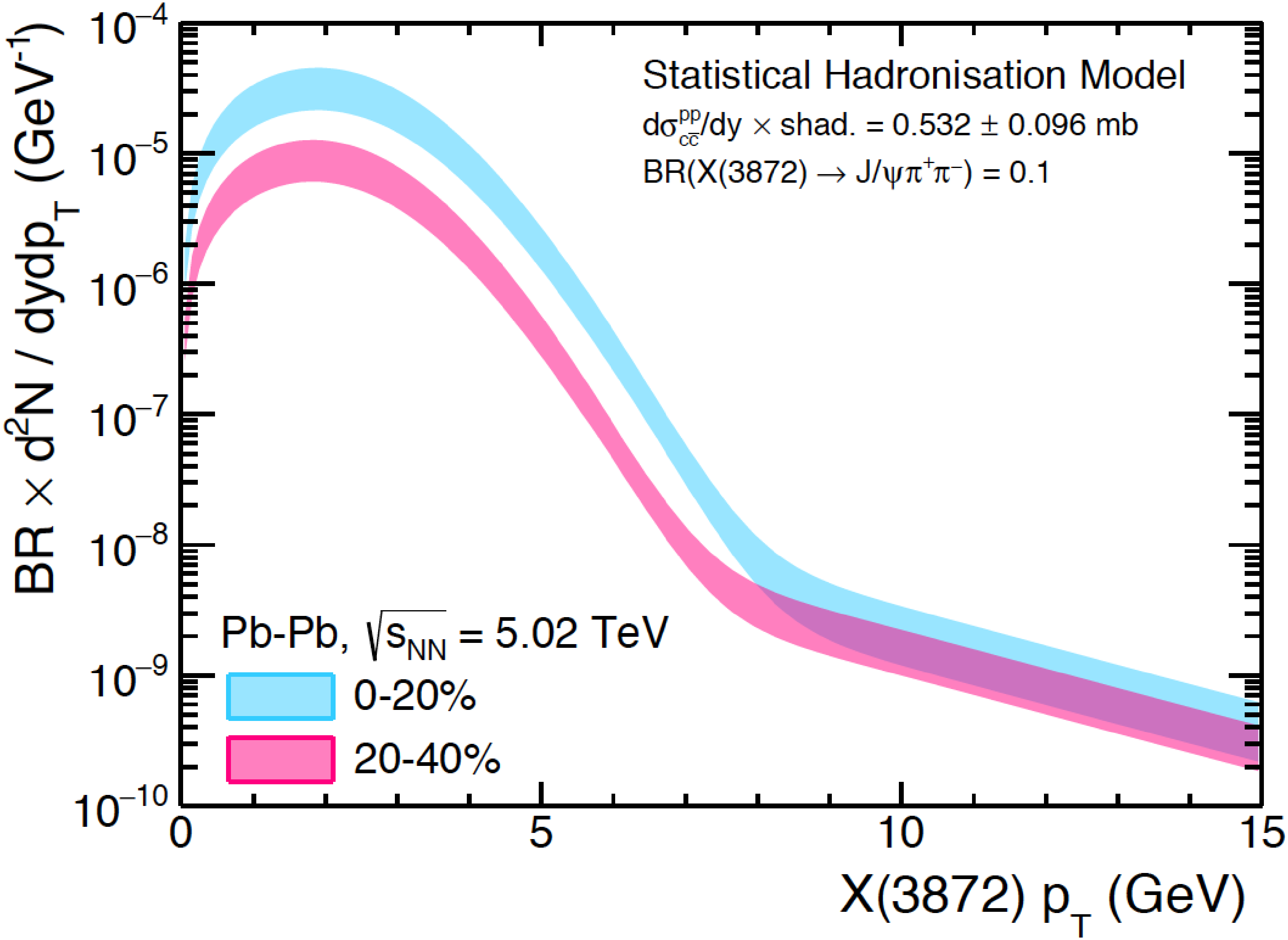
J/psi and hyper-triton described with the same flow parameters in the statistical hadronization model



binding energies:
J/psi 600 MeV
hypertriton 2.2 MeV
Lambda S.E. 0.2 MeV

from review: hypernuclei and other loosely bound objects produced in nuclear collisions at the LHC, pbm and Benjamin Doenigus, arXiv:1809.04681

transverse momentum spectrum for X(3872) in the statistical hadronization model Pb-Pb collisions at 5 TeV/u



new opportunity: deconfinement from quarkonium measurements

An essential ingredient of the statistical hadronization scenario for heavy quarks is that they can travel, in the QGP, significant distances to combine with other uncorrelated partons. The observed increase of the R_{AA} for J/ψ with increasing collision energy strongly supports the notion that the mobility of the heavy quarks is such that it allows travel distances exceeding that of the typical 1 fm hadronic confinement scale. In fact, for LHC energy, the volume of a slice of one unit of rapidity of the fireball exceeds 5000 fm^3, implying that charm quarks can travel distances of the order of 10 fm. This results in the possibility of bound state formation with all other appropriate partons in the medium with statistical weights quantified by the characteristics of the hadron (mass, quantum numbers) at the phase boundary. The results of the charmonium measurements thereby imply a direct connection to the deconfinement properties of the strongly interacting medium created in ultra-relativistic nuclear collisions.

4.
measure p_T spectra and v_n(p_T) for excited charmonia psi(2s), chi_c, Y(2s), Y(3s), chi_b

The detection and quantitative measurement of χ_c states involves the identification of a low energy (about 300 - 440 MeV near mid-rapidity) photon in addition to a J/ψ meson. To measure this we will pursue two options. In option 1 the low energy photon is measured with large efficiency and over the full solid angle in the pre-shower detector. To separate the χ_c states one needs a photon energy resolution of about 5% near 400 MeV corresponding to $\frac{\delta E_\gamma}{E\gamma} \approx 3\%/\sqrt{E_\gamma(GeV)}$ which should be achievable in the preshower detector. For the second option, with lower efficiency but excellent photon energy resolution we plan to introduce, very close to the beam pipe, a (removable) external converter of thickness of 5 - 10% of a radiation length. A photon can then be identified by the absence of tracks in the inner Si layers and by two tracks of opposite charge whose combined momentum precisely points to the primary interaction vertex.

Interesting new opportunities arose with recent findings by Belle2 and LHC$_b$ that the $\chi_c \to l^+l^-J/\psi$ is of order 10^{-4}. This would imply that the $\chi_c \to 4leptons$ becomes an attractive channel to study the production of χ states with very high resolution. Also it would be very interesting in this context to measure the production of B_c^+ in Pb–Pb collisions. Recent LHC$_b$ findings indicate substantial branching ratios into $J/\psi\pi^+$ which could be detected in the planned detector with good accuracy. Very large enhancements are predicted for B_c^+ production in the statistical hadronization model. A measurement in this channel would hence be very illuminating.

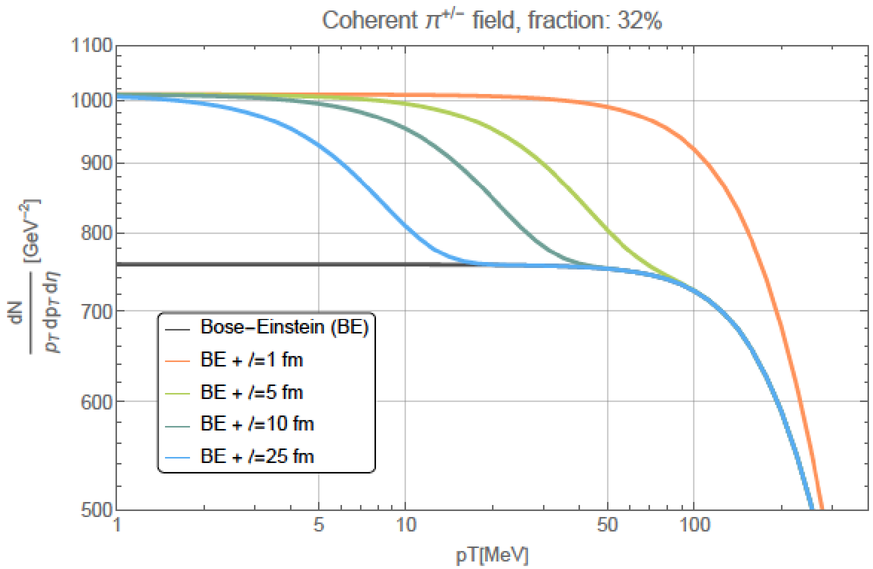
5. fluctuations of conserved charges

Locally conserved quantum number like net baryon number or electric charge undergo diffusive motion in a medium such as the quark-gluon plasma. The corresponding transport properties at first order in a fluid dynamic derivative expansion are the baryon diffusion constant, which is directly related to heat conductivity, and the electric conductivity. Correlation functions of net baryon number and net electric charge that are differential in azimuthal angle and in rapidity as well as transverse momentum contain in principle the corresponding information. With sufficient particle identification capabilities and additional theory developments one could access this highly interesting physics and attempt a determination of heat conductivity as well as electric conductivity in an expanding quark-gluon plasma.

The experimental coverage at very low transverse momenta will greatly facilitate the comparison of predictions from LQCD on chiral susceptibilities and transport coefficients with experimental measurements of higher moments of the distributions of net baryon number. Note that, in LQCD, no possibilities exist to introduce cuts in rapidity and transverse momentum, implying that measurements need to be performed over the widest phase space possible for meaningful results.

6. spectral distortions at very low transverse momentum for pions

- Is the spectrum of hadrons in the low-p_T regime a Bose-Einstein or Fermi-Dirac spectrum (depending on spin) governed by a common temperature T and fluid velocity u^μ on the freeze-out surface?
- Can deviations from ideal gas occupation numbers on the freeze-out surface due to dissipative terms and interactions be understood quantitatively in terms of dissipative fluid dynamics, kinetic theory or non-equilibrium quantum field theory?
- Are the effect of quantum statistics visible in spectra of light hadrons, in particular pions, at low transverse momentum?
- Is maybe even a condensate or coherent fraction of pions or kaons visible in the spectrum and correlation functions at low transverse momentum?



Spectrum of charged pions from a fluid dynamics calculation with an added component from a coherent component. The coherent field at freeze-out is assumed to be of the form $\pi^{\pm}(\tau, r, \phi, \eta) \sim e^{-r^2/2l^2}$ where l is a coherence length. In momentum space this leads to a Gaussian contribution from the coherent component $\sim e^{-l^2 p_T^2}$. The coherence length l is varied between 1 fm (orange curve) and 25 fm (blue curve). The black curve shows the spectrum without coherent fraction for comparison.

References

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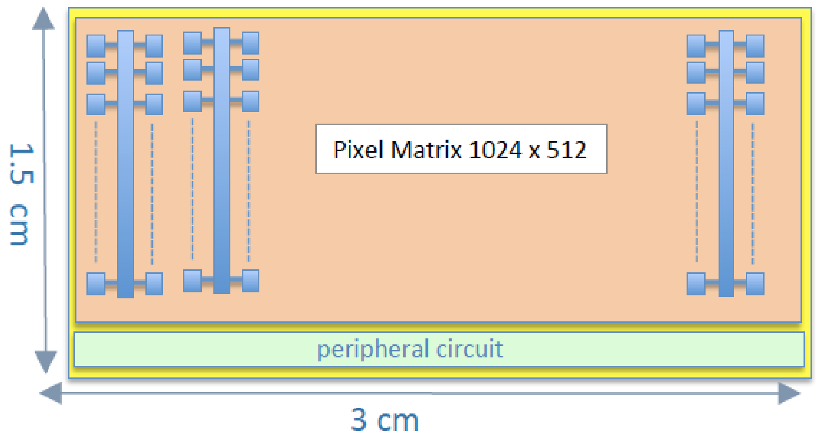
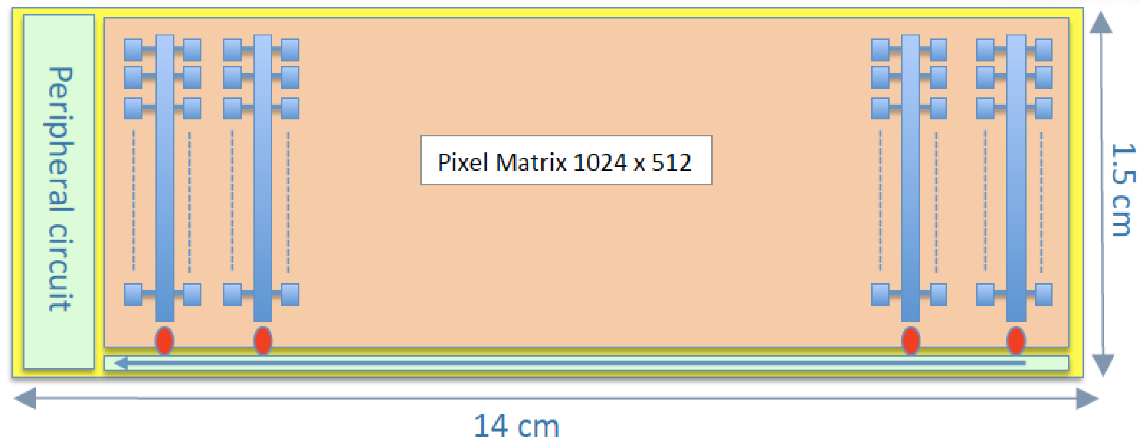
additional slides

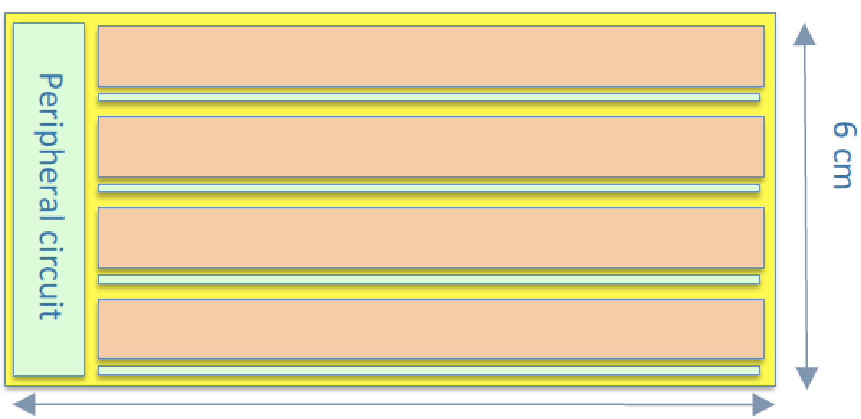
ALPIDE Chip



1D stitched sensor (z direction)



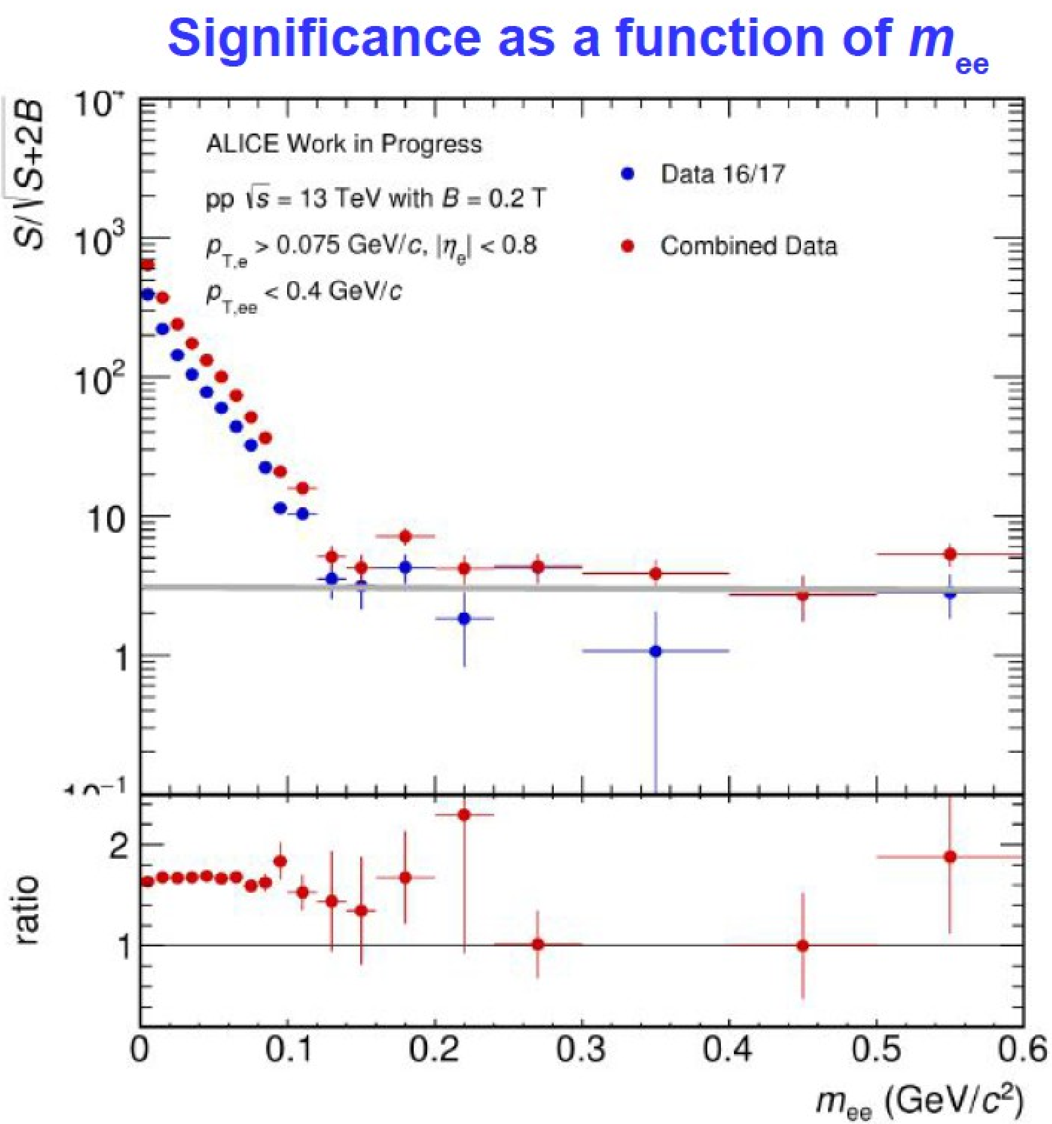
2D stitched sensor – wafer-scale



By instantiating multiple times the same circuits in the second dimension (ϕ) one can realize the sensors for the different layers. For example

- L0 = 14 cm x 6.0 cm
- L1 = 14 cm x 7.5 cm
- L2 = 14 cm x 9.0 cm

first attempt at low B field and for low transverse momenta, ALICE LMee PAG



ITS3 proposal – August 2018

Proposal for the construction of a novel vertex detector

- New beam pipe with IR = 16mm, ΔR = 0.5mm
- Three truly cylindrical layers based on curved ultra-thin sensors (⇨ $x/X_0 \approx 0.05\%$ per layer)
- The three layers differ only for their radii, with the innermost layer at 18mm radial distance from IP

The new vertex detector (ITS3) would be installed in LS3 to replace the innermost three layers of ITS2 (LS2)

The ITS3 will consist of two separate barrels: Inner Barrel and Outer Barrel

- The Outer Barrel (four outermost layers) will be that of ITS2
- The new Inner Barrel (three innermost layers) will instead replace the Inner Barrel of ITS2

The ITS3 will provide a large reduction of the material budget (close to IP) and an improvement of the tracking precision and efficiency at low p_T

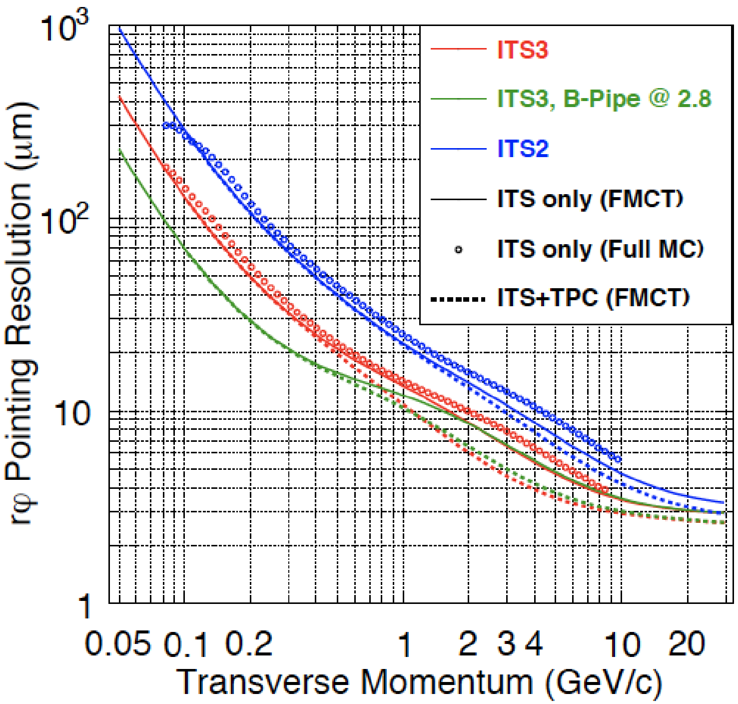
The combination of these two improvements will lead to a significant advancement in the measurement of low p_T charmed hadrons and low-mass dielectrons

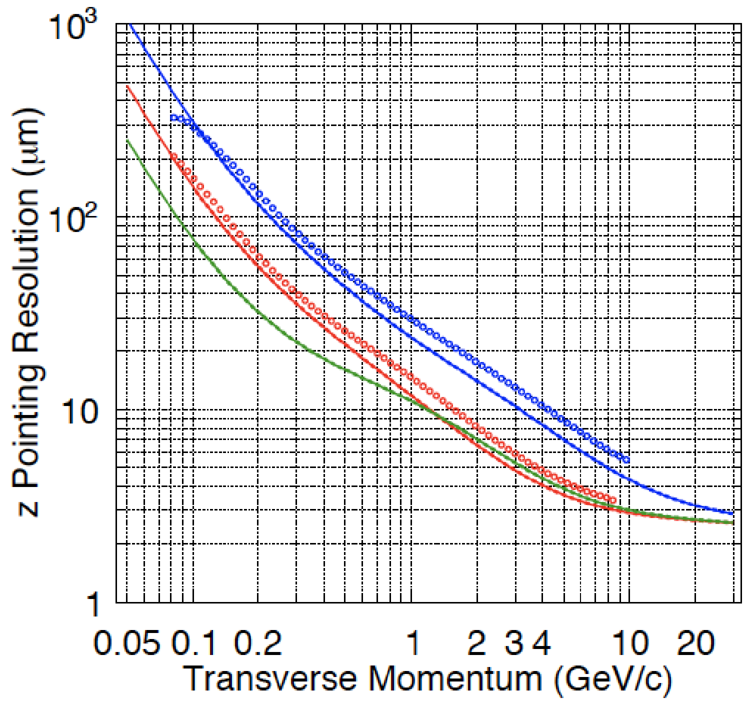
impact parameter resolution improved
by a factor of 3 compared to ITS2 for p_T < 0.5 GeV

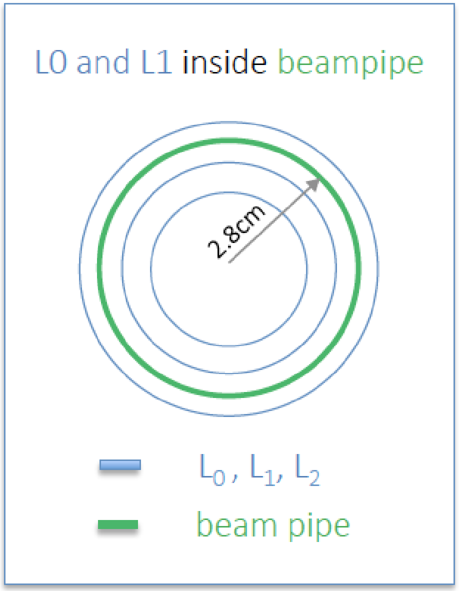
Impact parameter resolution (charged pions) for ITS2 and ITS3

EOI Sec. 4

ALICE

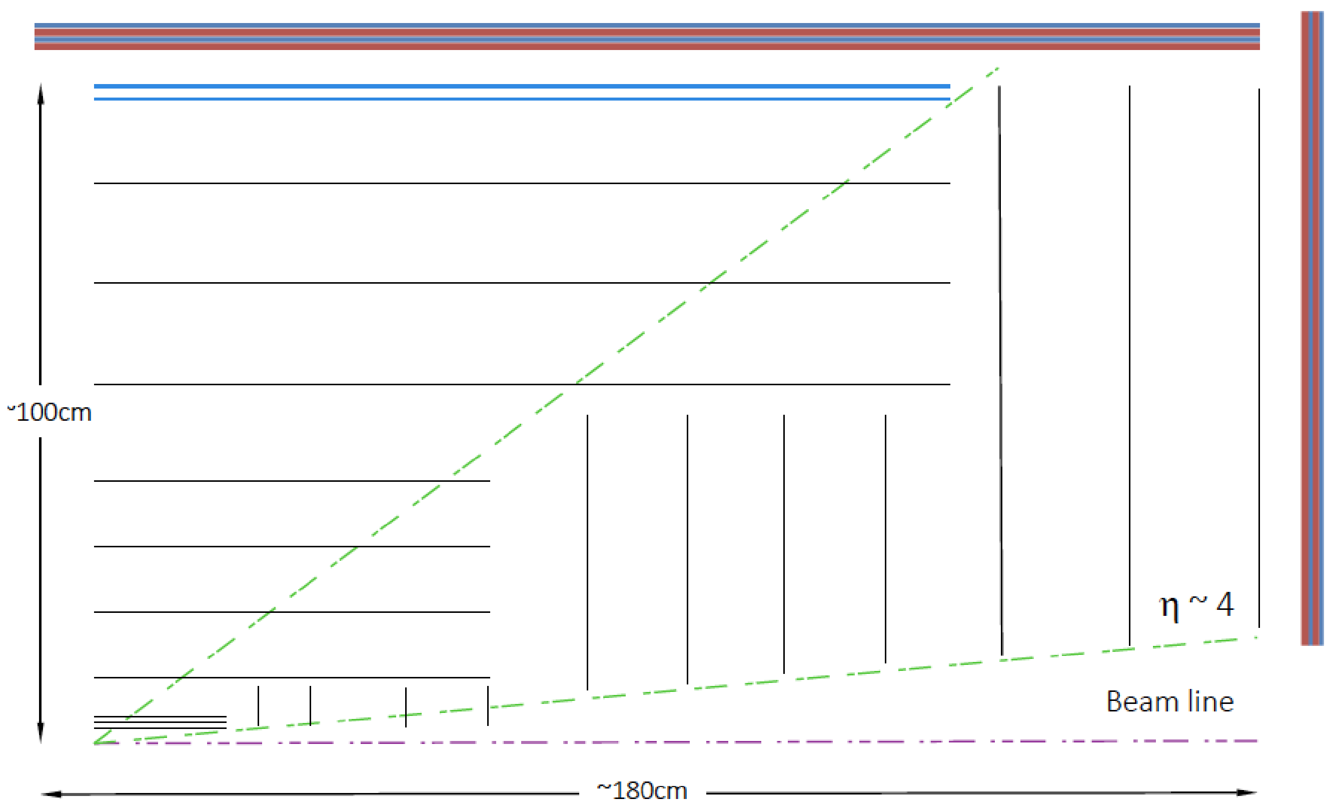






schematic detector setup

Tracker based on CMOS sensors: ~ 10 tracking barrel layers, ~ 7 endcap disks



Preshower
- 2-3 X_0 + silicon pixels

+ special photon calorimeter for photon p_T measurements at p_T ≈ 1 MeV

note: the two innermost layers could be inside the beam pipe, to avoid problems with conversions and dE/dx in the beam pipe

L. Musa – AGLCM Mar 2018 - CERN

Timing with silicon - CMOS MAPS

Two approaches

- Implement gain layer underneath the standard N-well collection electrode
- Optimize layout for timing measurement

First order approximation $\sigma_t = \frac{t_r}{SNR}$

In ultra-thin (O(10μm), fully depleted CMOS sensors (e.g. INVESTIGATOR or ALPIDE with CERN/TJ modified p

- Charge collection time < 1ns
- Noise ≈ few electrons
- Signal on seed pixel ≈ 1000 electrons

$t_r < 1ns$ $SNR > 100$ $\sigma_t < 10$

Time is ultimately limited by signal shape fluctuations inside the sensor

Use ultra-thin layers (e.g. 10μm and uniform depletion field)

note: TOF separation power scales ~ L/σ_{TOF}

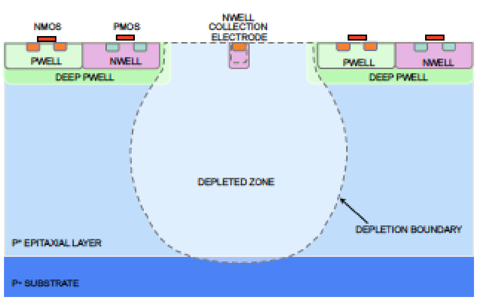
so: 80 ns and L = 4m (ALICE TOF) is equivalent to 20ps and L = 1 m

Novel fully depleted CMOS Pixel Sensors

In the framework of the R&D for the ALICE upgrade, CERN has developed in collaboration with Tower Semiconductor a process modification that allows full depletion of the high resistivity silicon layer

- Reduces charge collection time (<1ns)
- Enhances radiation hardness (~10^{15} n / cm^2)

The process modification requires a single additional process mask with no changes on the sensor and circuit layout



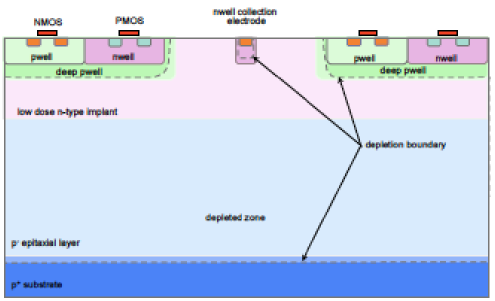
Vertical full depletion

Lateral partial depletion

Collection time < 30ns (V_{bb}=-3V)

Suitable for up to 10^{14} n/cm^2

Foundry Standard Process



Epi-layer fully depleted

Collection time < 1ns

Operational for up to 10^{15} n/cm^2

Modified process CERN/Tower

The ALICE test vehicle chip (investigator) and prototype ALPIDE chips exist with both flavors

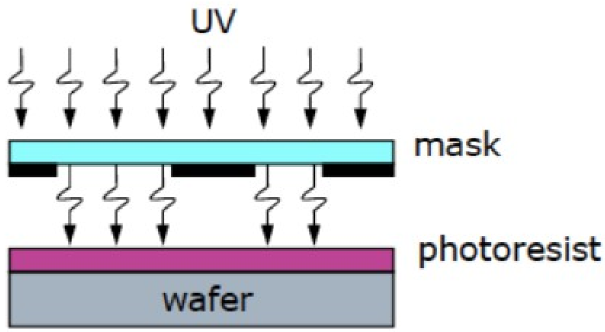
For details on process modification and experimental results see: NIM, A 871C (2017) pp. 90-96

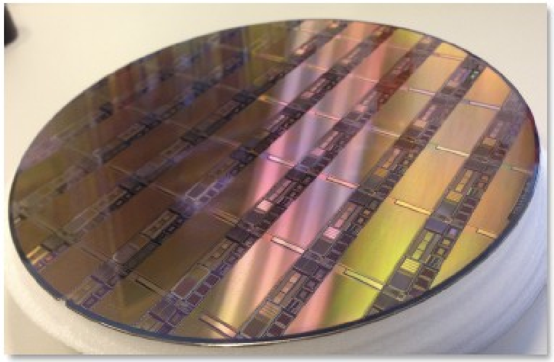
Stitching allows the fabrication of wafer scale sensors

CMOS photolithographic process defines wafer reticles size

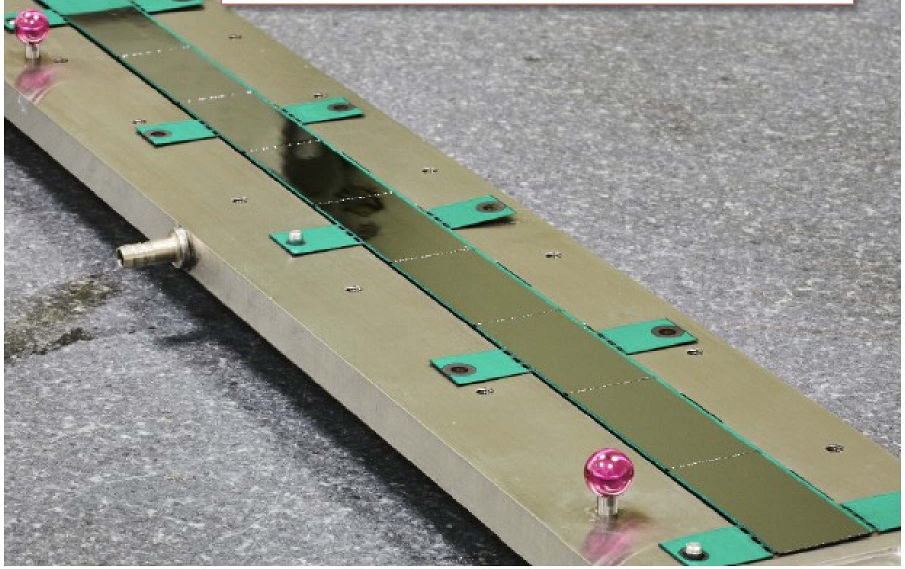
⇨ Typical field of view O(2 x 2 cm^2)

Reticle is stepped across the wafers to create multiple identical images of the circuit(s)

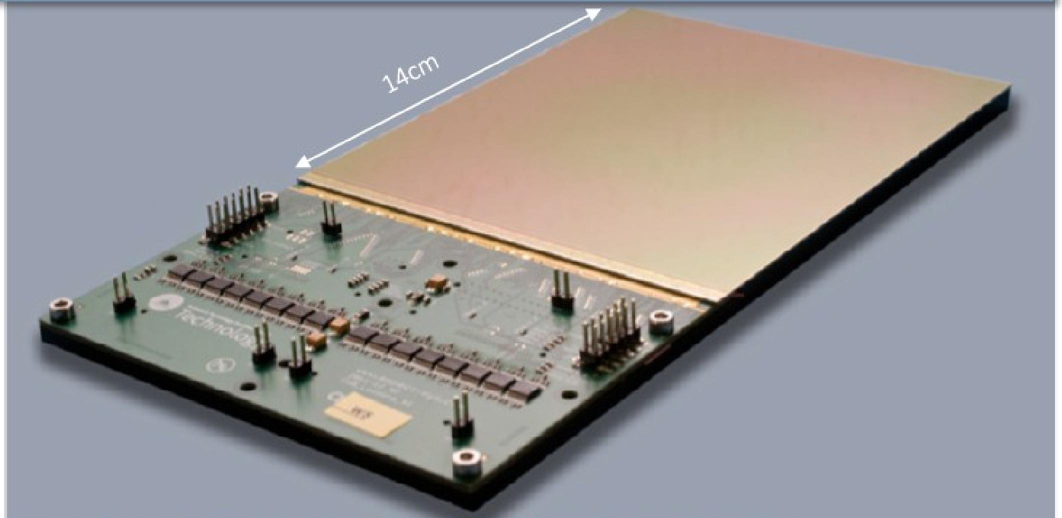




staves built by tiling several sensors

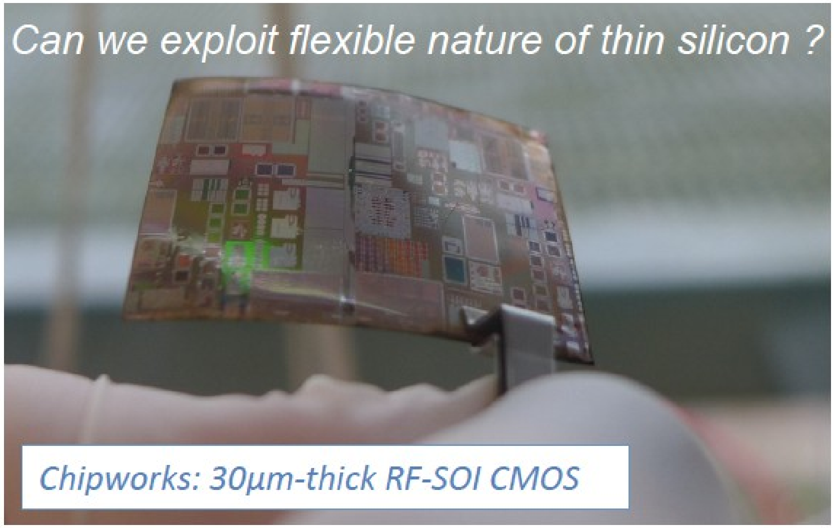


Stitching allows fabrication of sensors larger than the reticle size



Courtesy: R. Turchetta, Rutherford Appleton Laboratory

Ultra-thin curved silicon chips



Ultra-thin chip (<50 um): flexible with good stability

Die type	Front/back side	Ground/polished/plasma	Bumps	Die thickness (µm)	CDS (MPa)	Weibull modulus	MDS (MPa)	r_{min} (mm)
Blank	Front	Ground	No	15–20	1263	7.42	691	2.46
Blank	Back	Ground	No	15–20	575	5.48	221	7.72
IZM28	Front	Ground	Yes	15–20	1032	9.44	636	2.70
IZM28	Back	Ground	Yes	15–20	494	2.04	52	32.7
Blank	Back	Polished	No	25–35	1044	4.17	334	7.72
IZM28	Back	Polished	Yes	25–35	482	2.98	107	24.3
Blank	Back	Plasma	Yes	18–22	2340	12.6	679	2.50
IZM28	Front	Plasma	Yes	18–22	1207	2.64	833	2.05
IZM28	Back	Plasma	Yes	18–22	2139	3.74	362	4.72

van den Ende DA et al. *Mechanical and electrical properties of ultra-thin chips and flexible electronics assemblies during bending*. Mircoelectron reliab (2014), http://dx.doi.org/10.1016/j.microrel.2014.07.125

momentum resolution estimate for barrel
no multiple scattering

$B = 0.5\ \mathrm{T}$

$\delta p/p$ = 0.6 % @ 1 GeV
$\delta p/p$ = 0.8 % @ 10 GeV

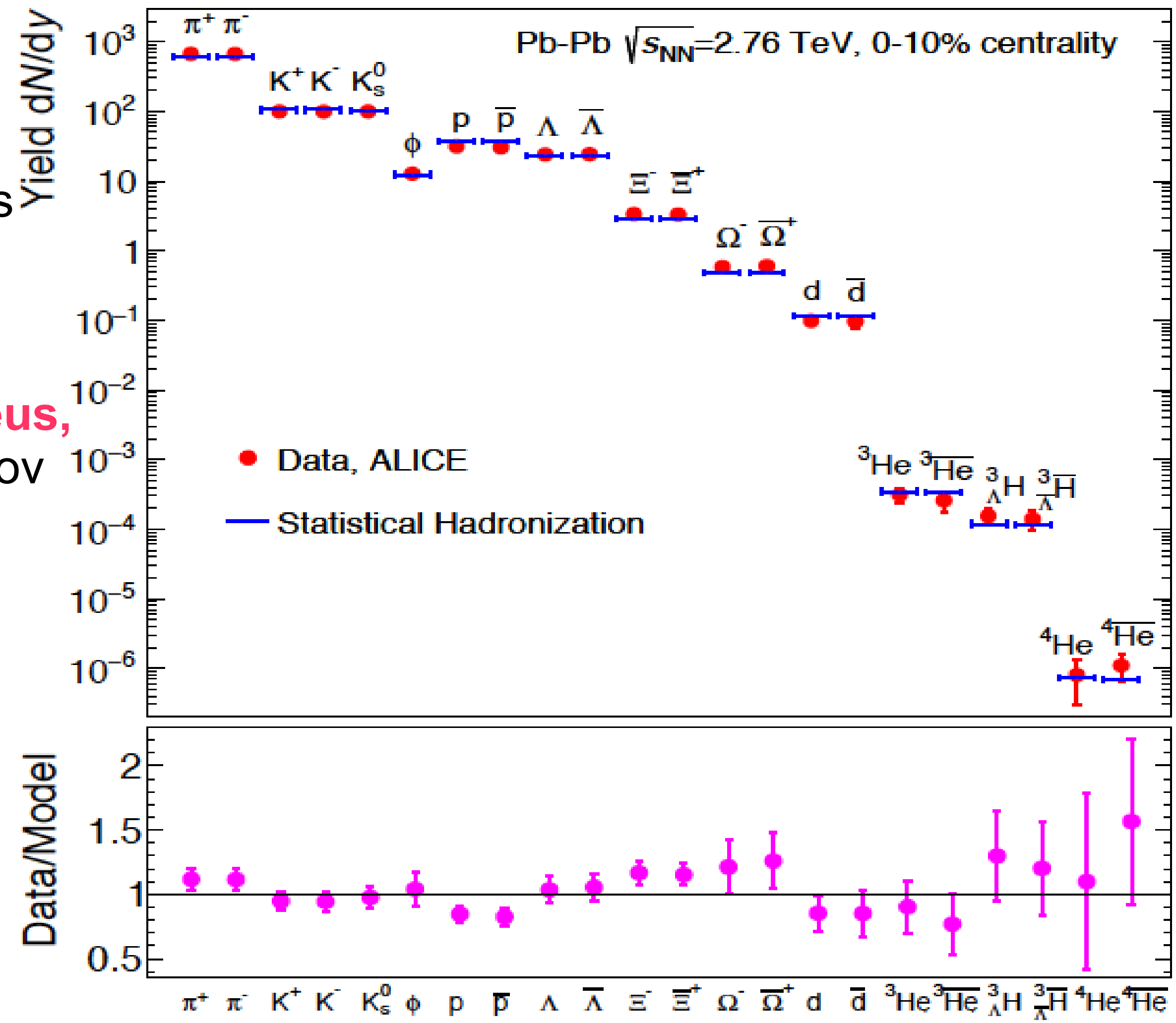
Spatial resolution
- Innermost 3 layers: $\sigma \sim 1\mu m$
- Outer layers: $\sigma \sim 5\mu m$

Time Measurement
Outermost layer integrates high precision time measurement ($\sigma_t < 30ps$)

Aug. 2018 update: excellent description of ALICE@LHC data

fit includes loosely bound systems such as deuteron and hypertriton
hypertriton is bound-state of (Λ,p,n), Λ separation energy about 130 keV
size about 10 fm, the **ultimate halo nucleus,** produced at T=156 MeV. close to an Efimov state

proton discrepancy of 2.8 sigma is now explained in arXiv:1808.03102
explicit phase shift description of baryon resonance region



Andronic, pbm, Redlich, Stachel, arXiv:1710.09425, Nature 561 (2018) no.7723, 321-330

Quark Model Spectroscopy

Why does the quark model work so well?

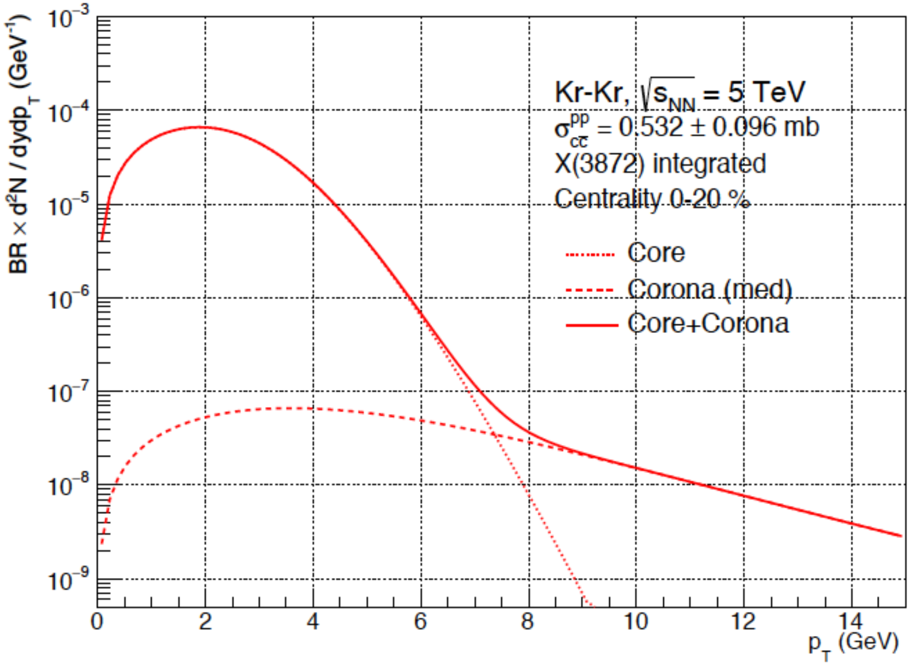
Why do M and B body plans dominate?

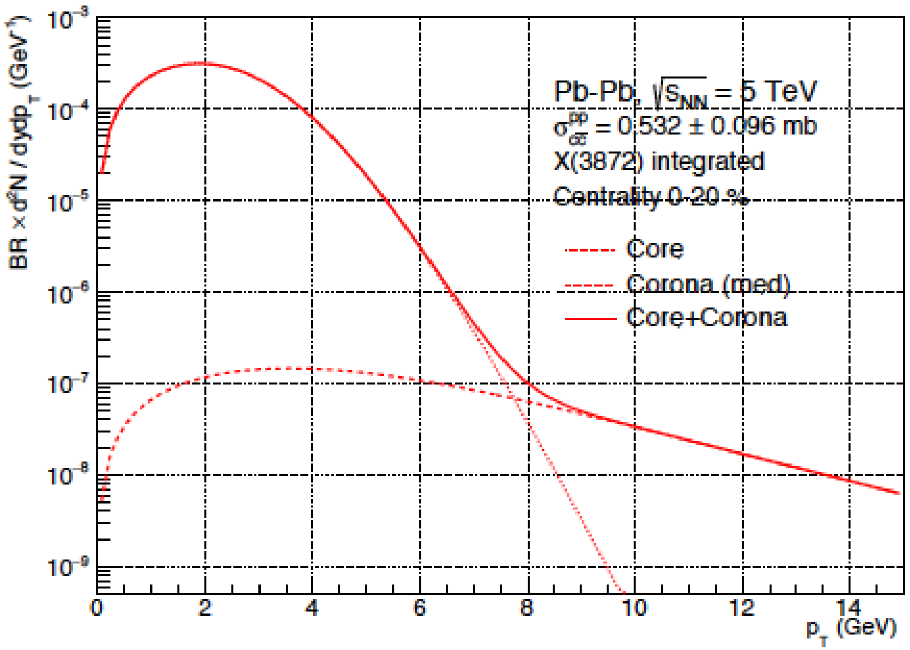
Why don't multibaryons make one big bag?

Frank Wilczek, QM2014 introductory talk

see also the recent review:
Marek Karliner, Jonathan L. Rosner, Tomasz Skwarnicki, arXiv:1711.10626

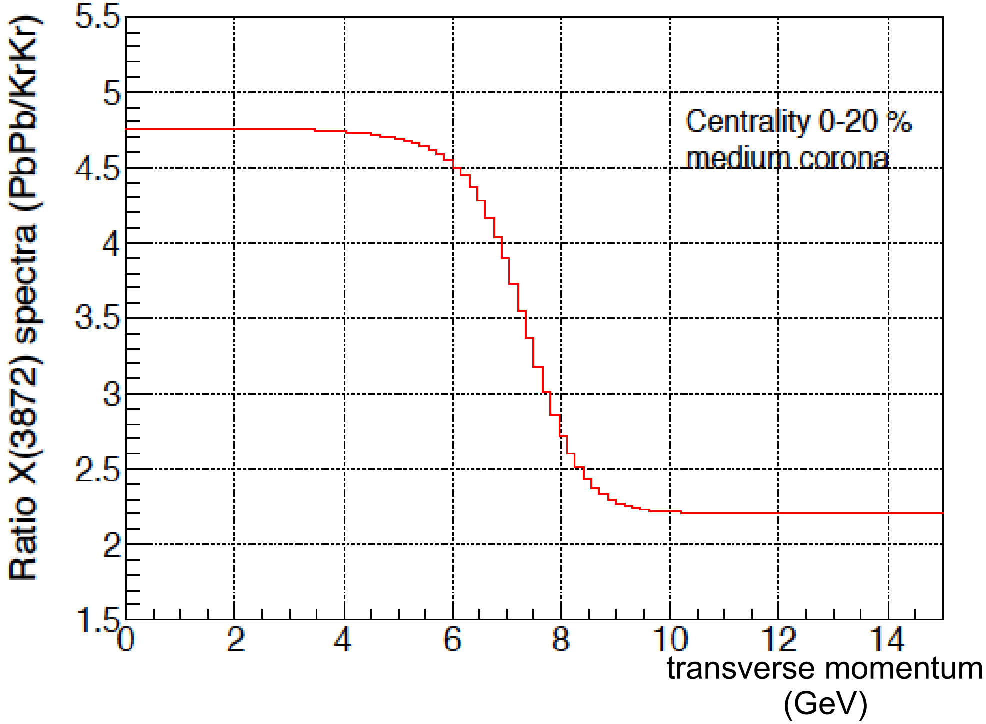
X(3872) transverse momentum spectrum for Kr+Kr and Pb+Pb at 5 TeV





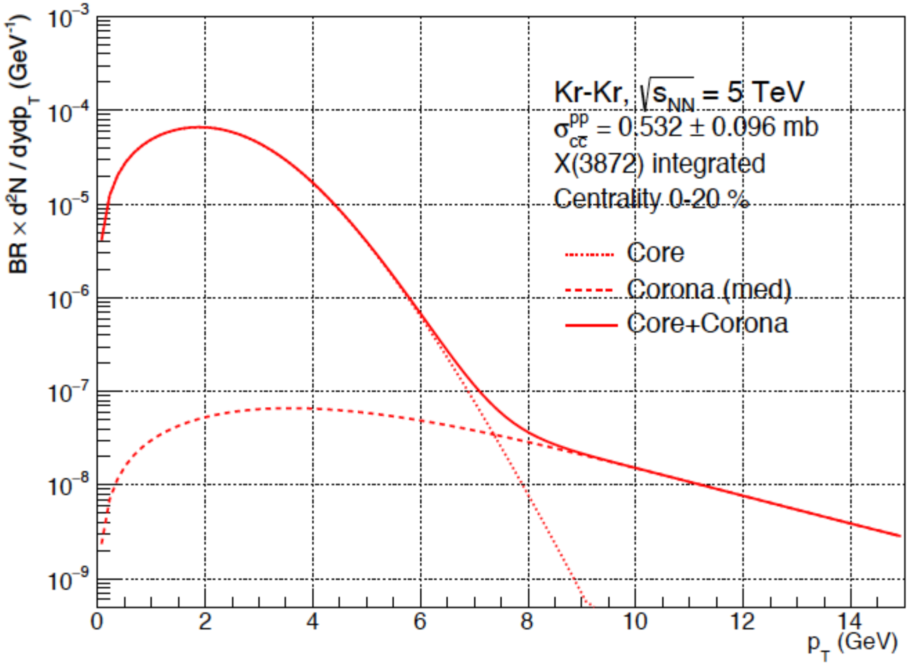
A. Andronic, pbm, M. Koehler, K. Redlich, J. Stachel, paper in preparation

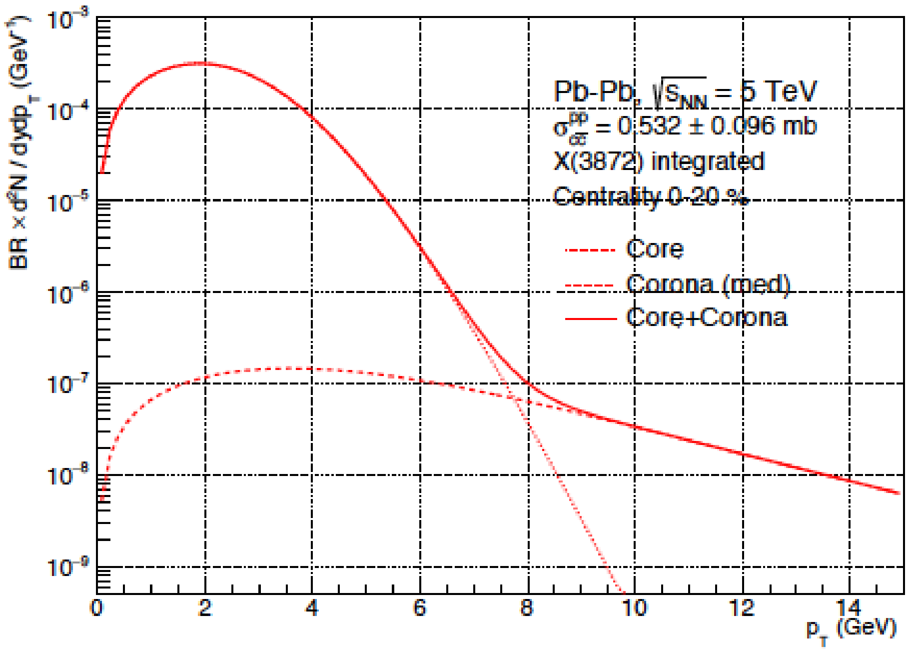
Pb/Kr ratio for X(3872)



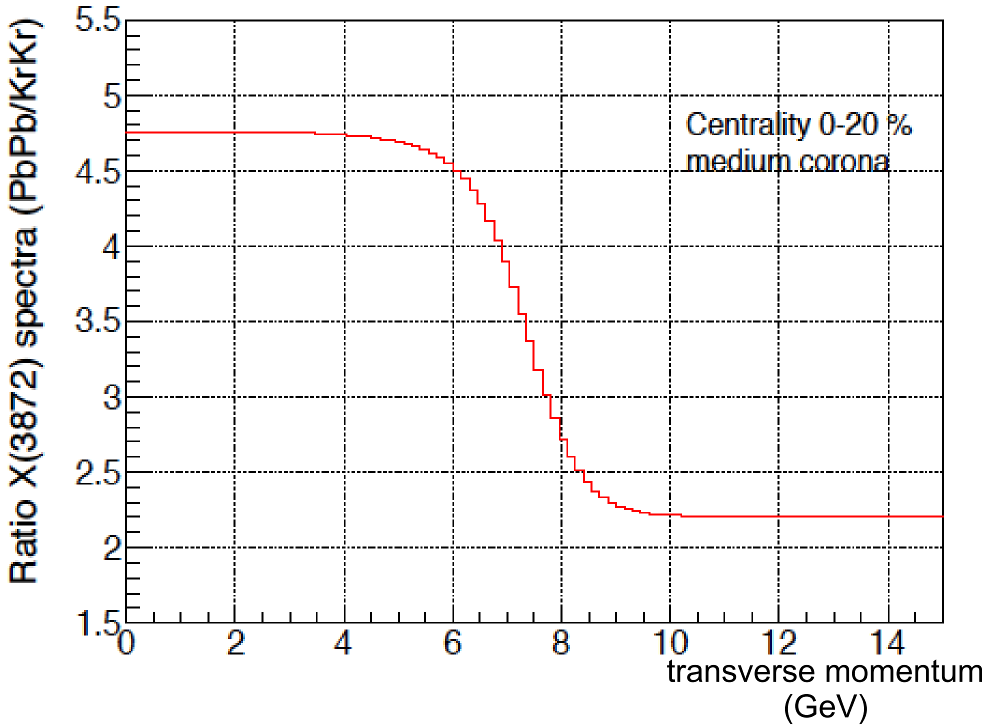
Pb/Kr ratio is of order 5
for transverse momenta < 5 GeV

X(3872) transverse momentum spectrum for Kr+Kr and Pb+Pb at 5 TeV





Pb/Kr ratio for X(3872)



Pb/Kr ratio is of order 5
for transverse momenta < 5 GeV