XI CPAN Days - Oviedo - October 21-23, 2019

Fragmentation functions from e^+e^- annihilation at

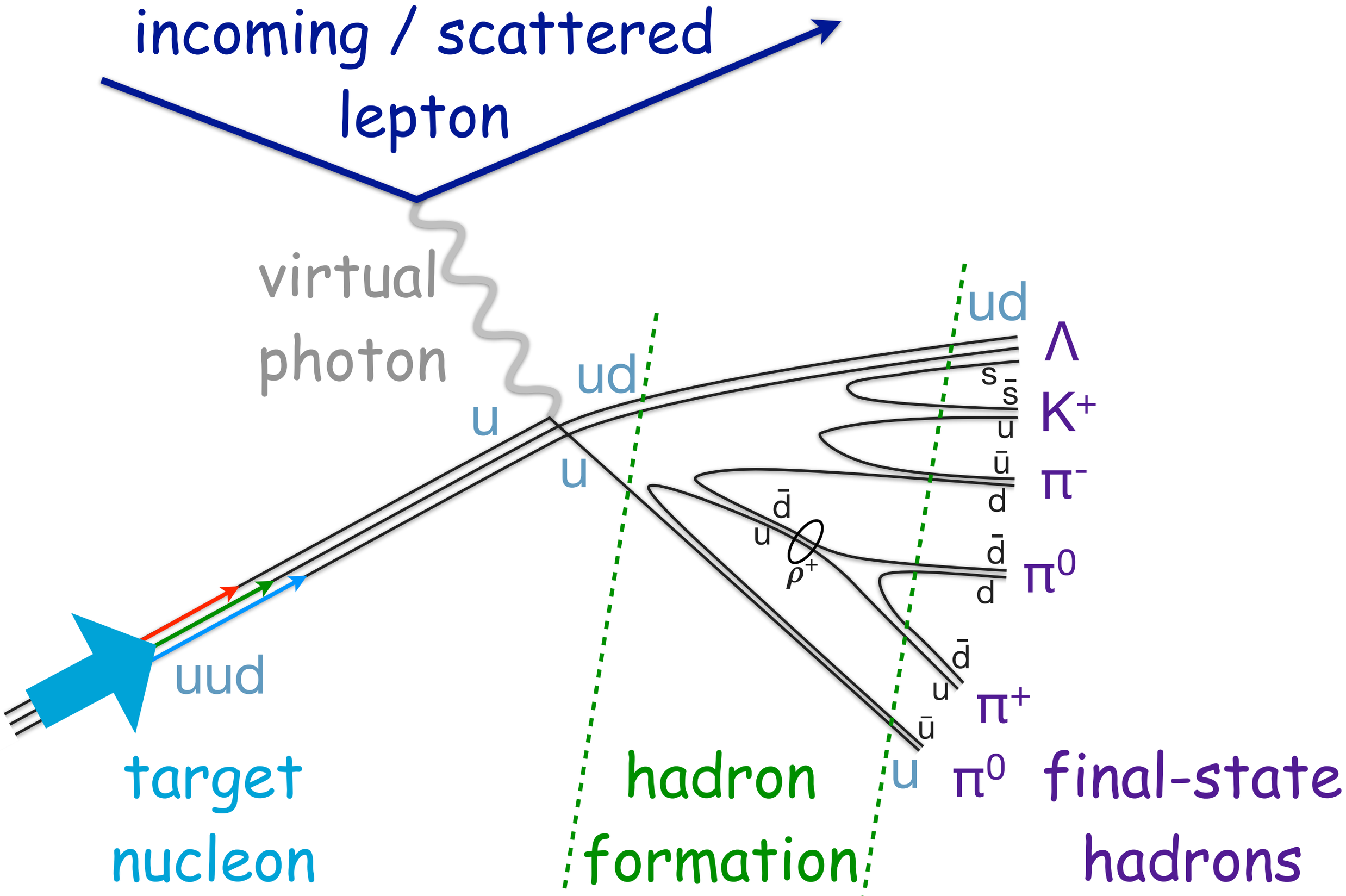
Gunar.Schnell @ desy.de

ikerbasque
Basque Foundation for Science

STRONG-2020

eman ta zabal zazu
Universidad del País Vasco
Euskal Herriko Unibertsitatea

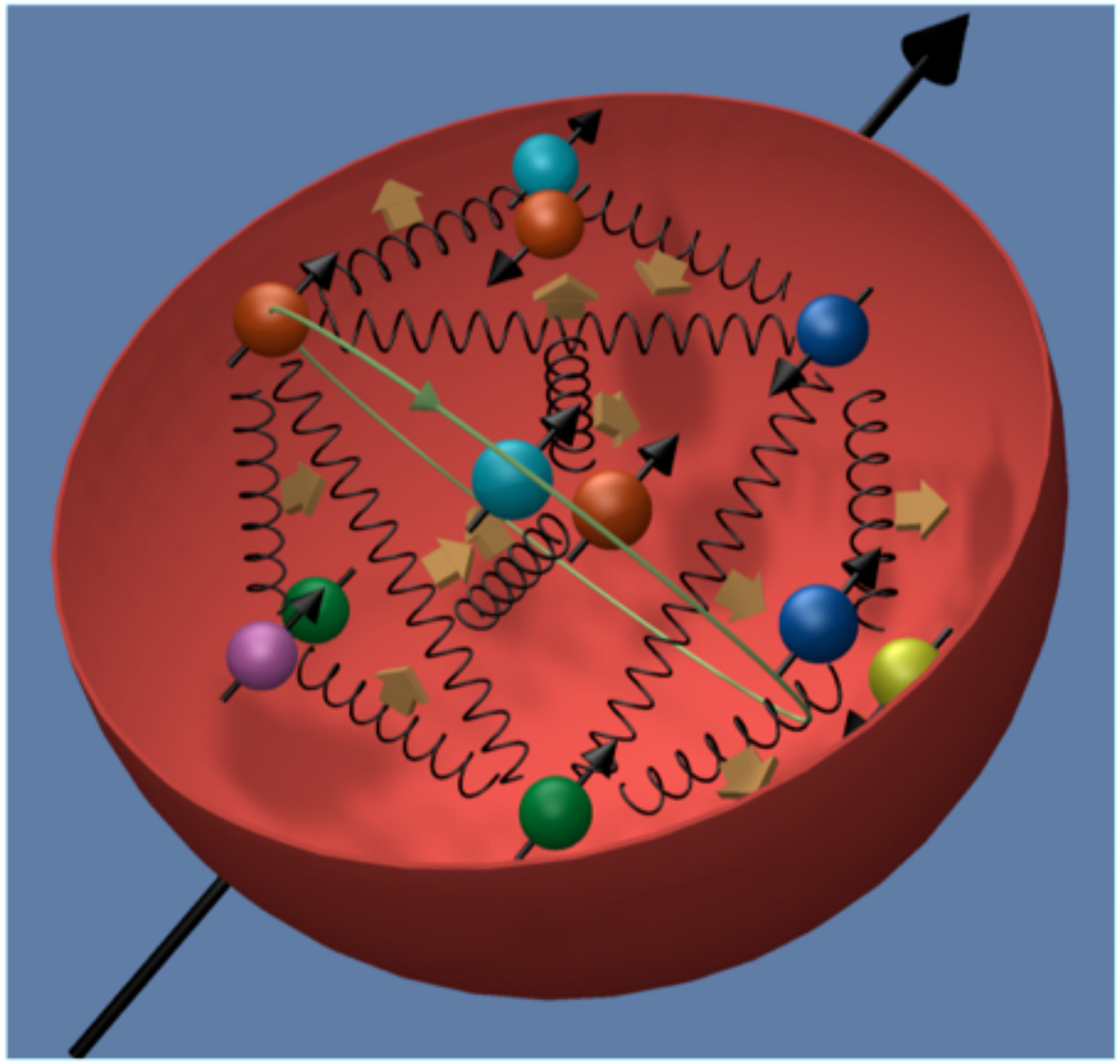
SIDIS: probing PDFs through fragmentation



SIDIS: probing PDFs through fragmentation

nucleon pol. \ quark pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

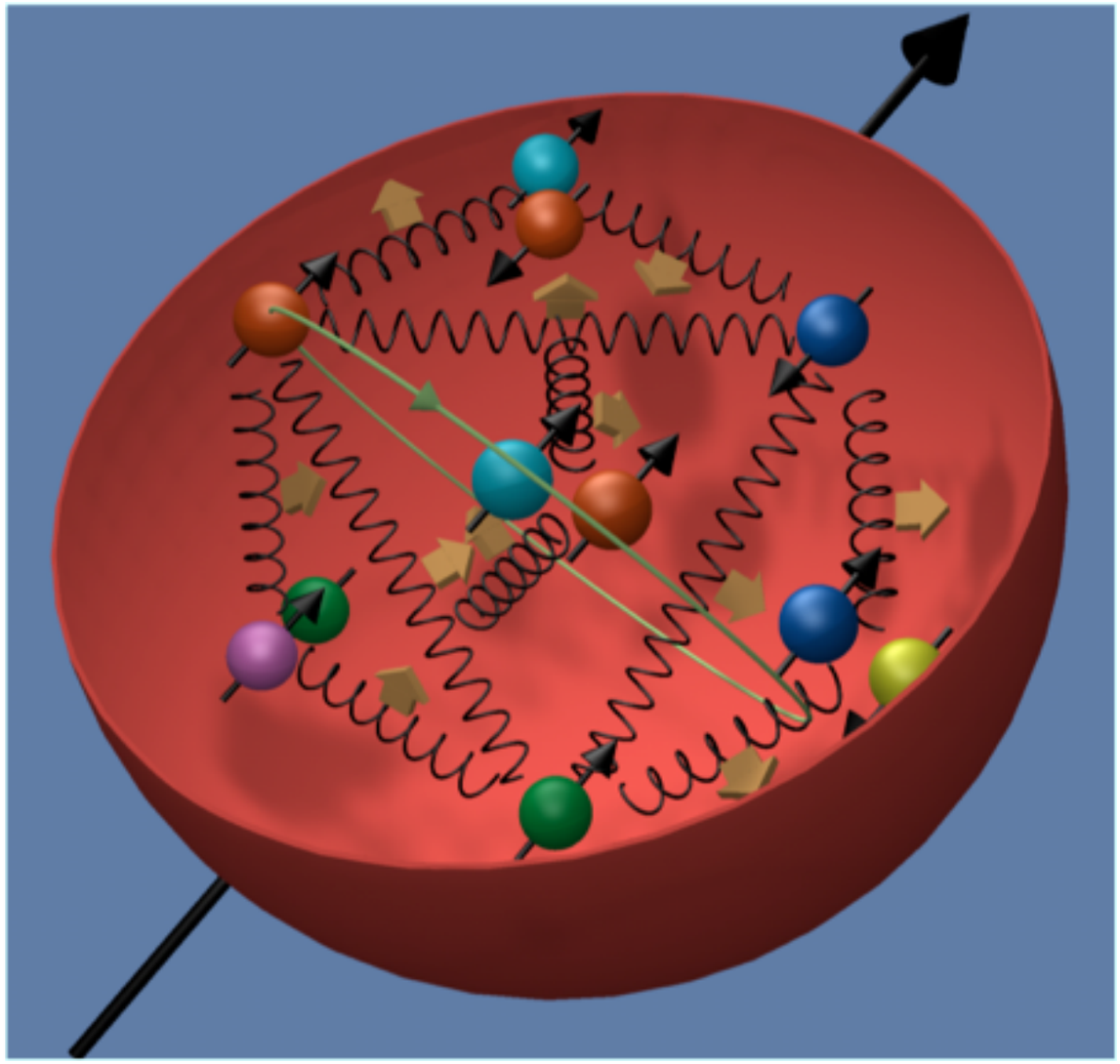
eight PDFs describing the spin-momentum correlations



SIDIS: probing PDFs through fragmentation

nucleon pol. \ quark pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

eight PDFs describing the spin-momentum correlations

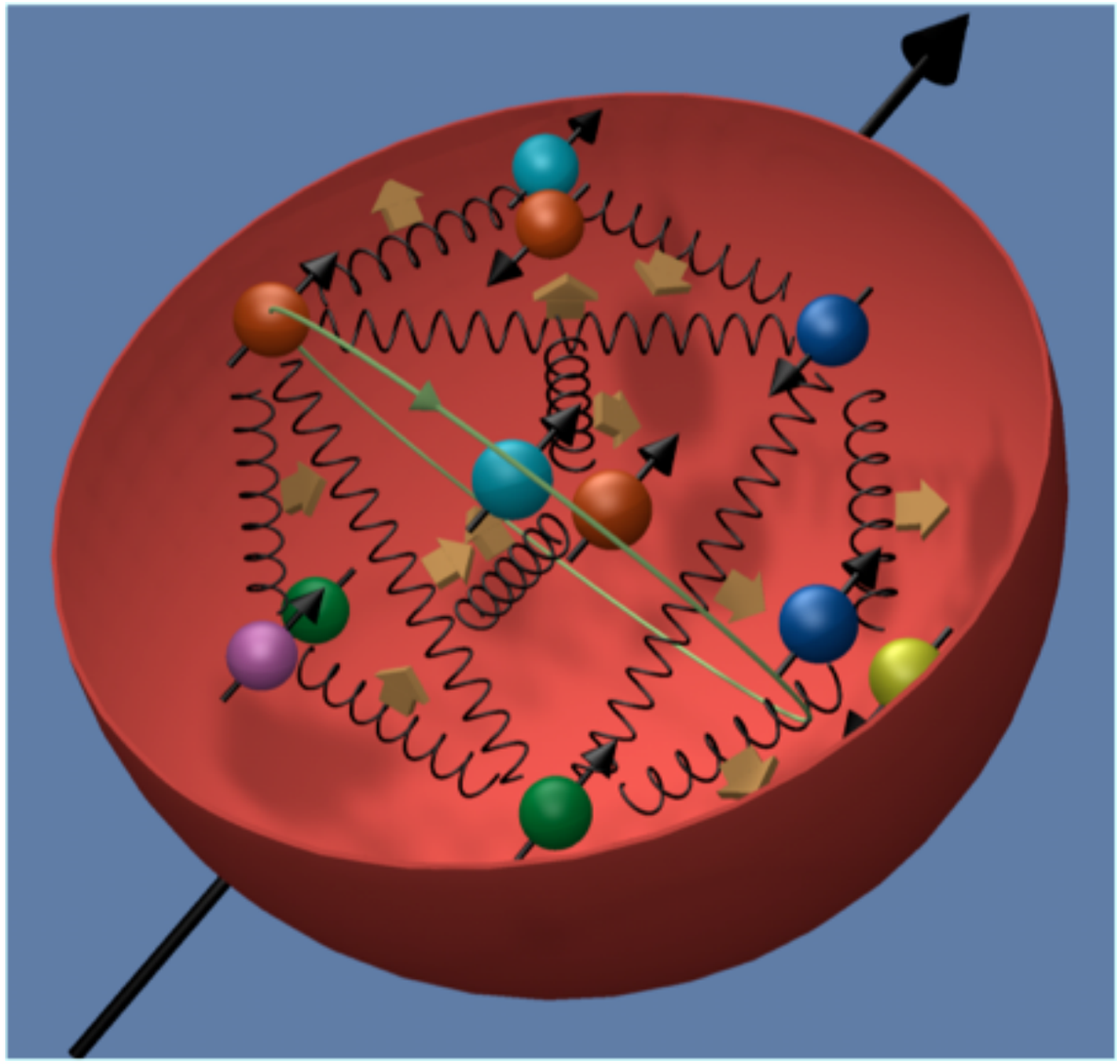


SIDIS: probing PDFs through fragmentation

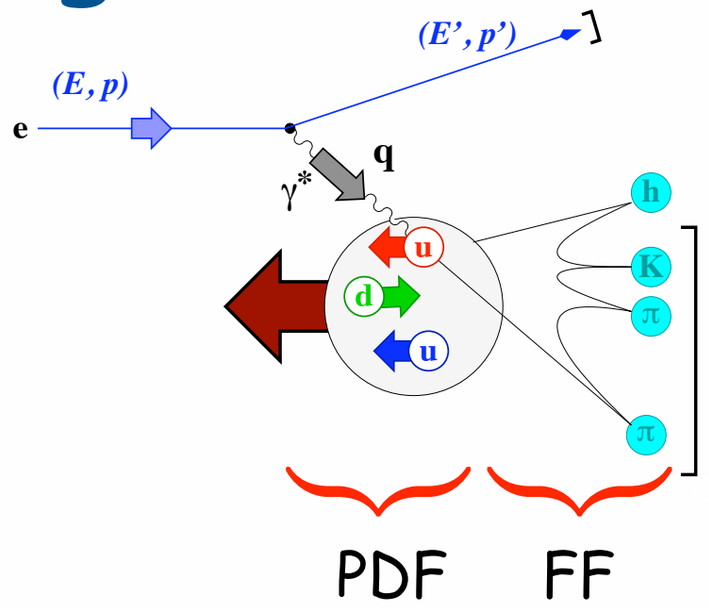
quark pol.

nucleon pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

eight PDFs describing the spin-momentum correlations



SIDIS: probing PDFs through fragmentation



quark pol.

nucleon pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1,\ h_{1T}^\perp$

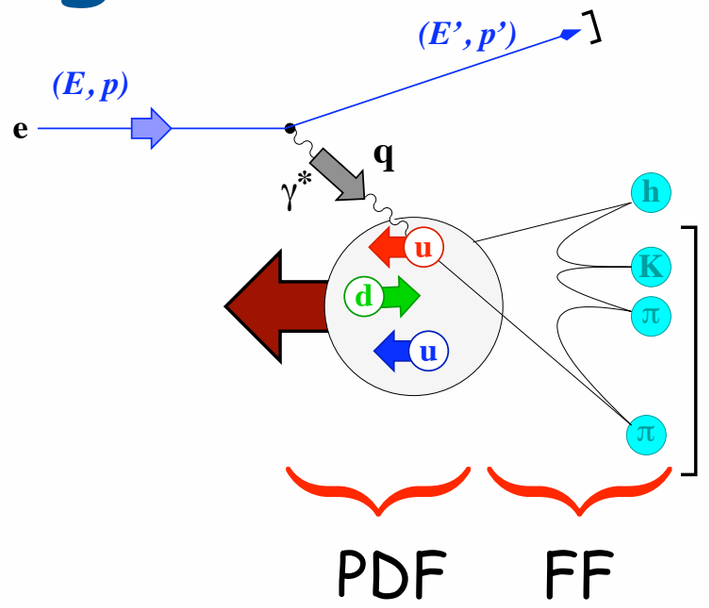
in SIDIS*) couple PDFs to:

Collins FF: $H_1^{\perp, q\to h}$

Dihadron FF: $H_1^{\angle, q\to h_1 h_2}$

*) semi-inclusive DIS with unpolarized final state

SIDIS: probing PDFs through fragmentation



quark pol.

nucleon pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

in SIDIS*) couple PDFs to:

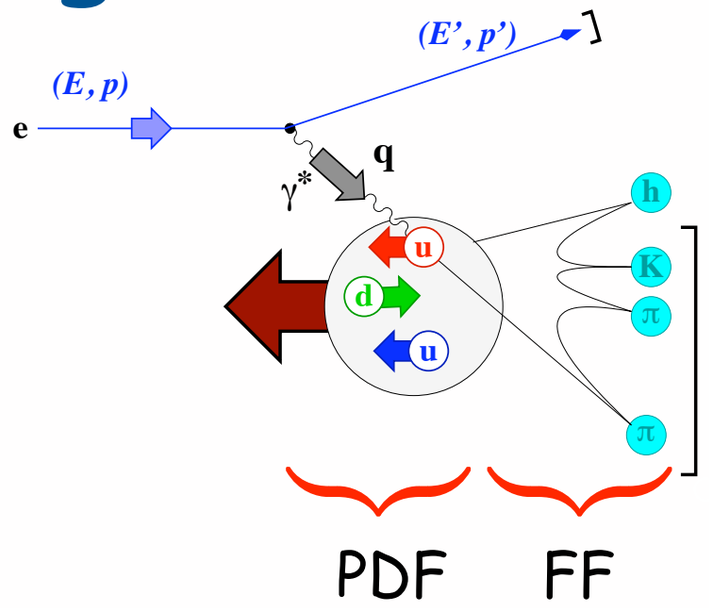
Collins FF: $H_1^{\perp, q\to h}$

Dihadron FF: $H_1^{\sphericalangle, q\to h_1 h_2}$

ordinary FF: $D_1^{q\to h}$

*) semi-inclusive DIS with unpolarized final state

SIDIS: probing PDFs through fragmentation



quark pol.

nucleon pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1, $h_{1T}^\perp$

in SIDIS*) couple PDFs to:

Collins FF: $H_1^{\perp, q\to h}$

Dihadron FF: $H_1^{\sphericalangle, q\to h_1 h_2}$

ordinary FF: $D_1^{q\to h}$

➟ FFs act as quark flavor-tagger and polarimeter

*) semi-inclusive DIS with unpolarized final state

fragmentation functions

- quarks not observed, only final-state hadrons (➠ confinement)

fragmentation functions

- quarks not observed, only final-state hadrons (➠ confinement)
- fragmentation fct's: non-perturbative but universal objects of QCD

fragmentation functions

- quarks not observed, only final-state hadrons (➠ confinement)
- fragmentation fct's: non-perturbative but universal objects of QCD
- (similar to PDFs) not calculable from first principle
  - parameterizations fitted to experimental data
  - probabilities that a parton fragments into a hadron carrying a momentum fraction (usually denoted z) of the parent parton
  - also depend on transverse momentum and parton/hadron polarization

fragmentation functions

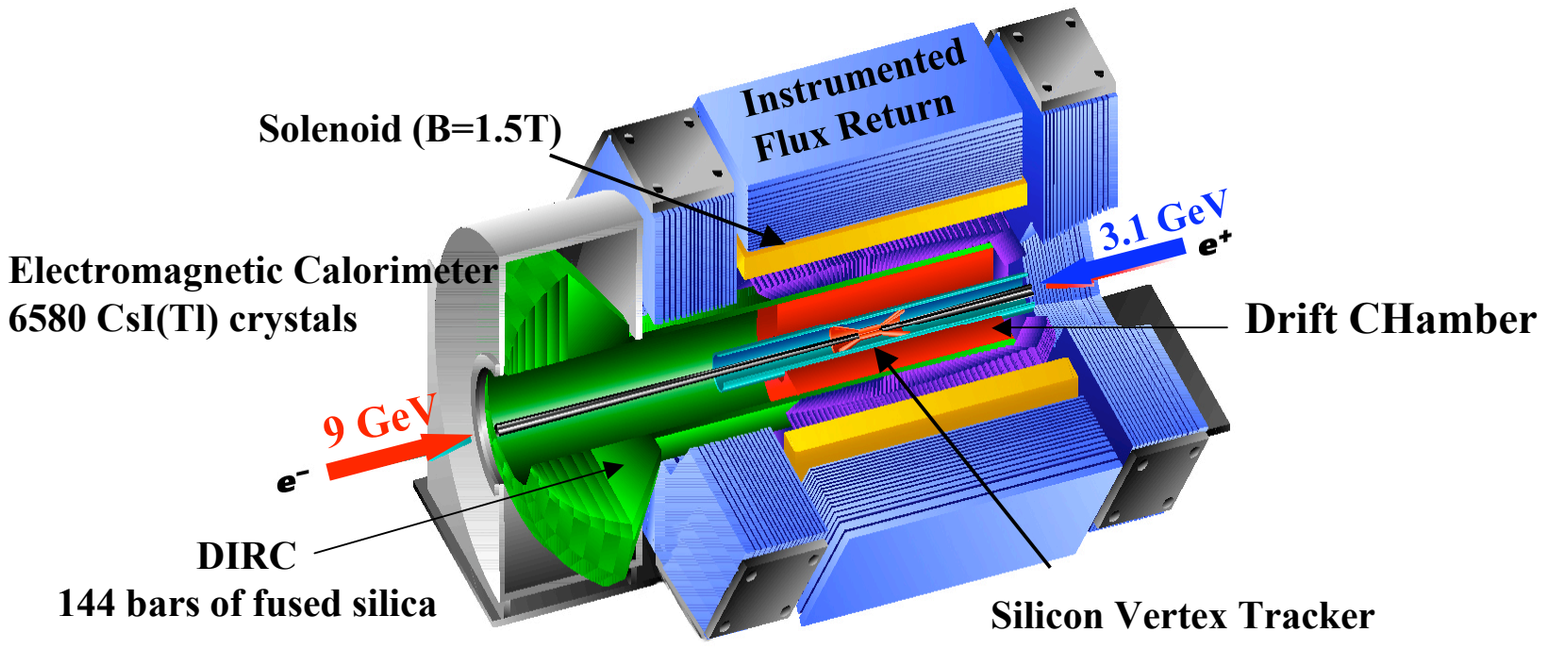
- quarks not observed, only final-state hadrons (➠ confinement)
- fragmentation fct's: non-perturbative but universal objects of QCD
- (similar to PDFs) not calculable from first principle
  - parameterizations fitted to experimental data
  - probabilities that a parton fragments into a hadron carrying a momentum fraction (usually denoted z) of the parent parton
  - also depend on transverse momentum and parton/hadron polarization
- currently much less constrained than, e.g., the proton PDFs

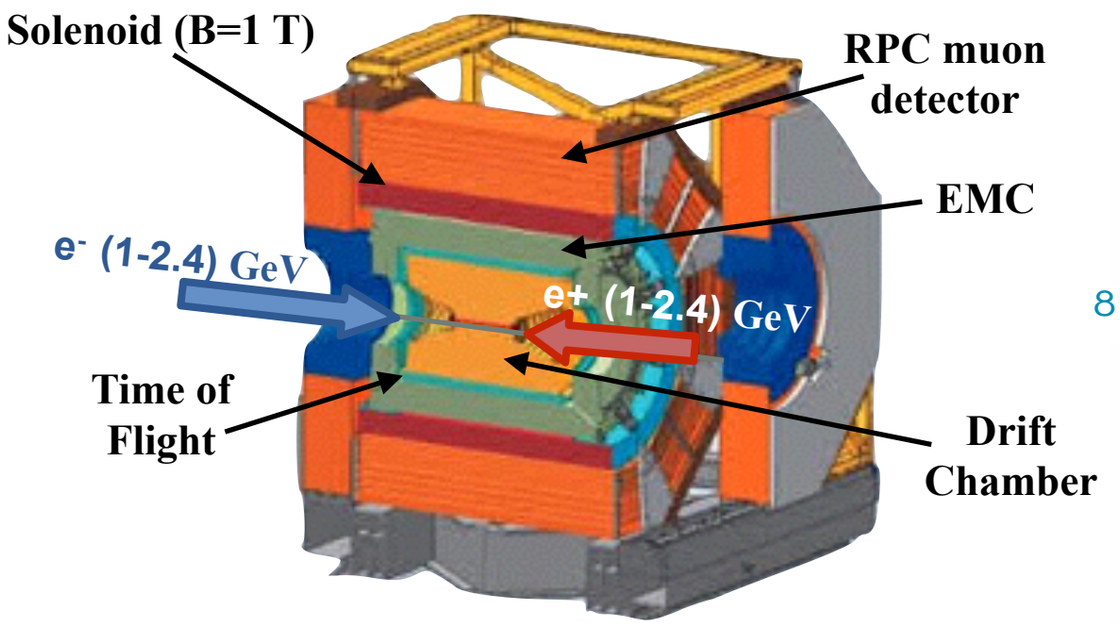
fragmentation functions

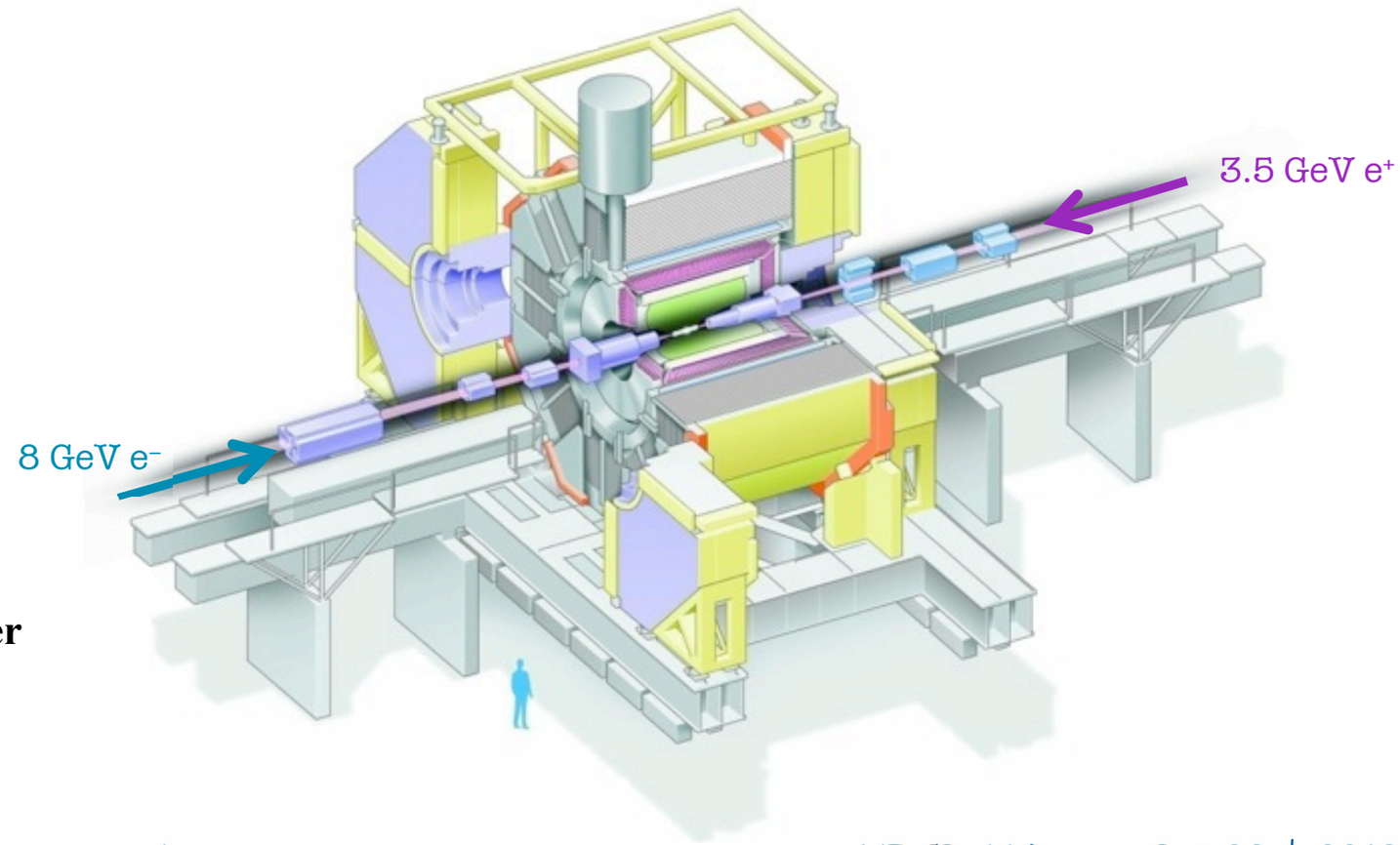
- quarks not observed, only final-state hadrons (➠ confinement)
- fragmentation fct's: non-perturbative but universal objects of QCD
- (similar to PDFs) not calculable from first principle
  - parameterizations fitted to experimental data
  - probabilities that a parton fragments into a hadron carrying a momentum fraction (usually denoted z) of the parent parton
  - also depend on transverse momentum and parton/hadron polarization
- currently much less constrained than, e.g., the proton PDFs
- "clean" laboratory: e^+e^- annihilation into quark-antiquark pairs

e^+e^- annihilation at BaBar, Belle, and BESIII

- BaBar/Belle: asymmetric beam-energy e^+e^- collider near/at $\Upsilon(4S)$ resonance (10.58 GeV)
- BESIII: symmetric collider with E_e=1...2.4 GeV







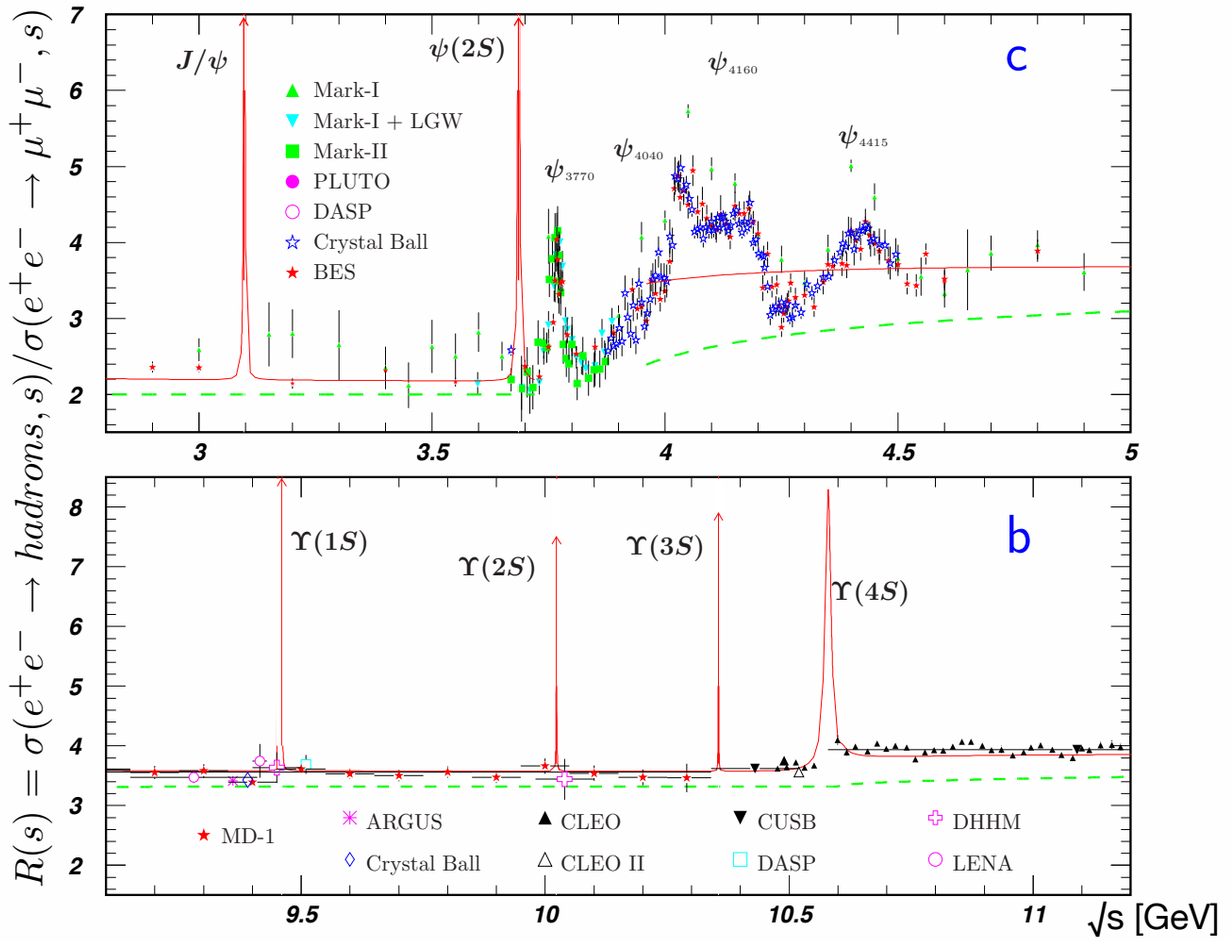
e^+e^- annihilation at BaBar, Belle, and BESIII

- BaBar/Belle: asymmetric beam-energy e^+e^- collider near/at $\Upsilon(4S)$ resonance

  (10.58 GeV)

- BESIII: symmetric collider with E_e=1...2.4 GeV

- integrated luminosities used for FF analyses:

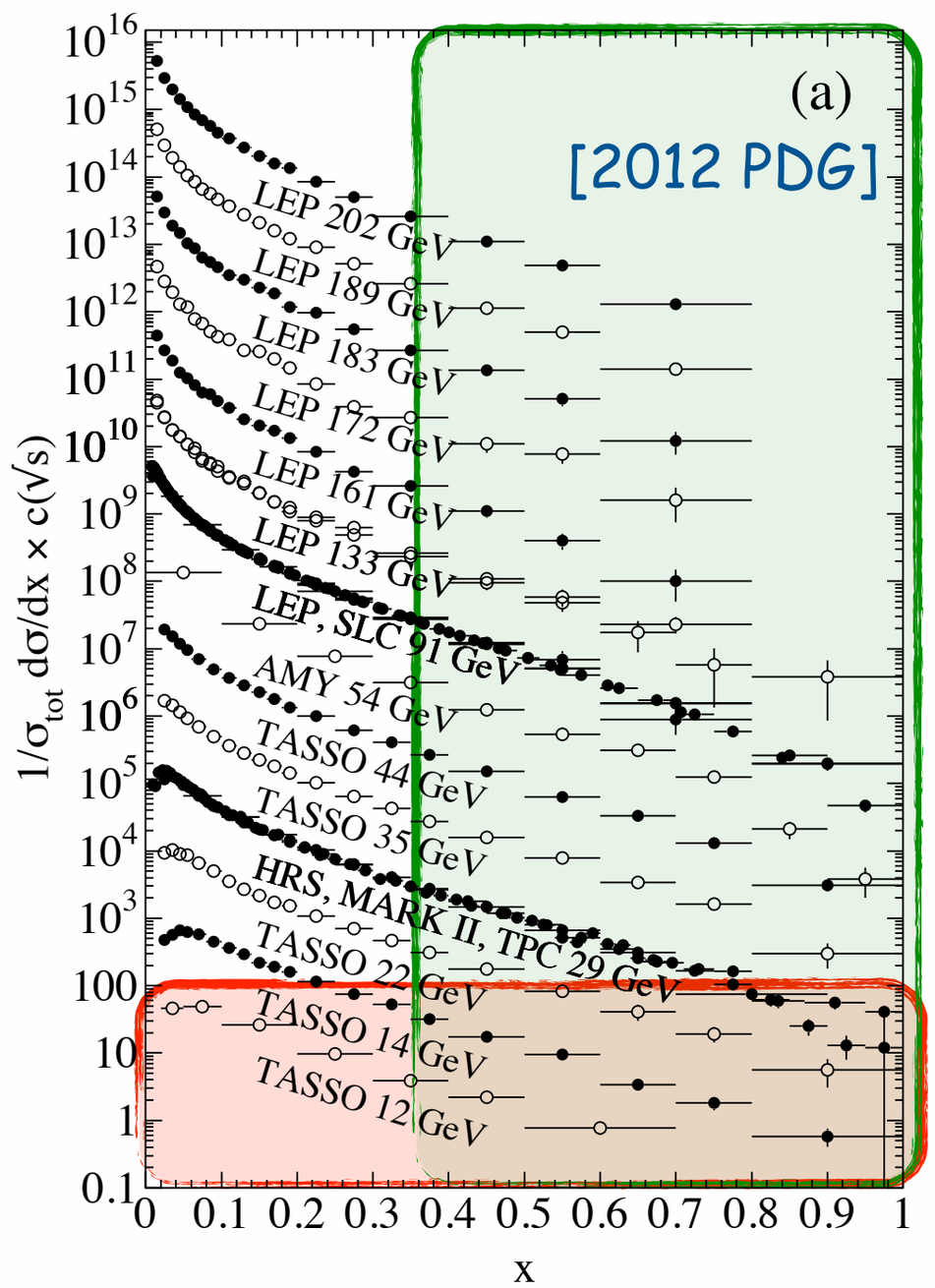


	$\Upsilon(4S)$ on resonance	$\Upsilon(4S)$ off resonance	other
BaBar	424.2 fb^{-1}	43.9 fb^{-1}	
Belle	(140+571) fb^{-1}	(15.6+73.8) fb^{-1}	~180 fb^{-1} @$\Upsilon(nS)$
BESIII			~62 pb^{-1} @3.65 GeV *)

*) used for the Collins analysis

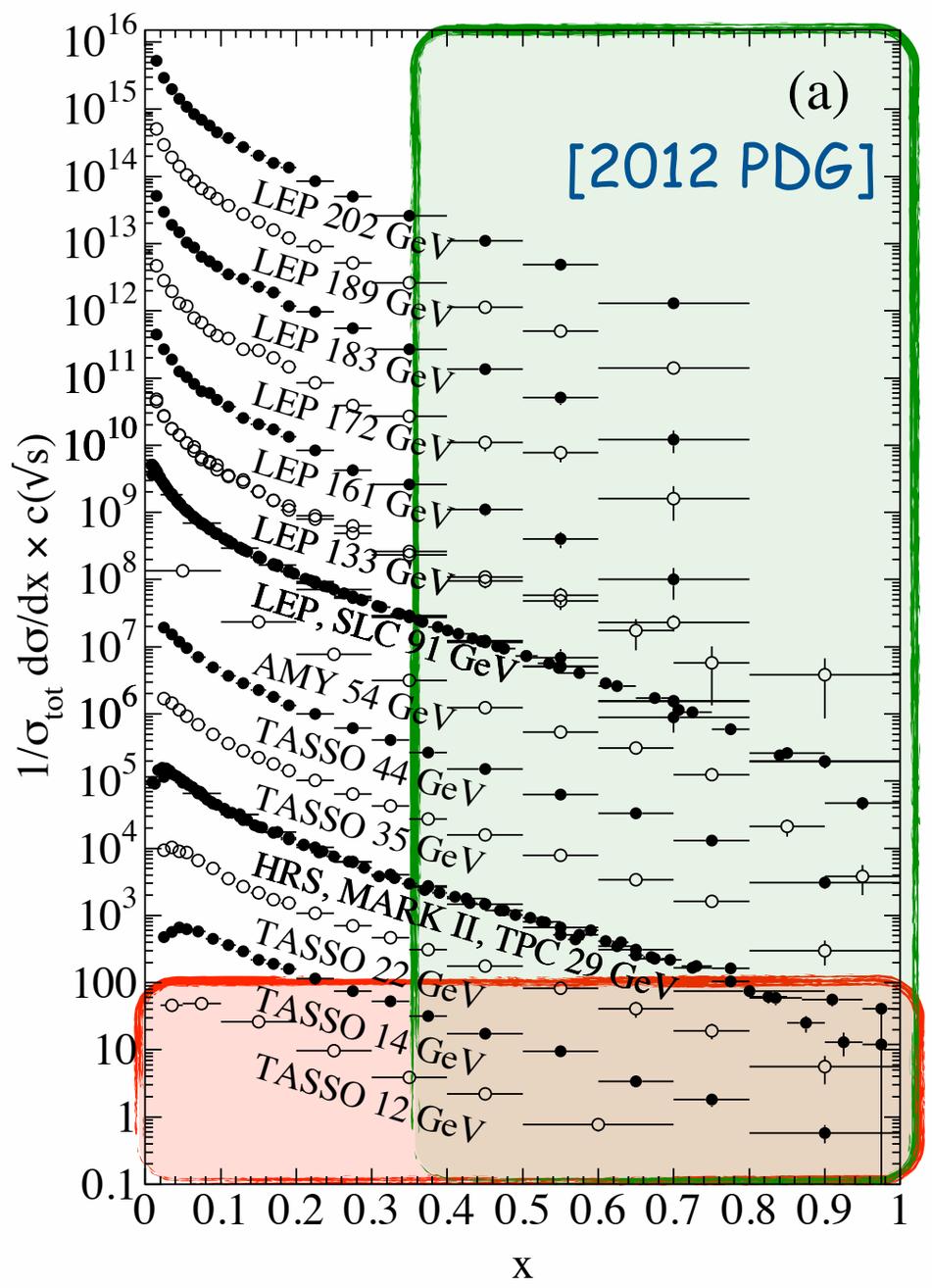
single-hadron production

- before 2013: lack of precision data at (moderately) high z and at low √s
  - limits analysis of evolution and gluon fragmentation
  - limited information in kinematic region often used in semi-inclusive DIS



single-hadron production

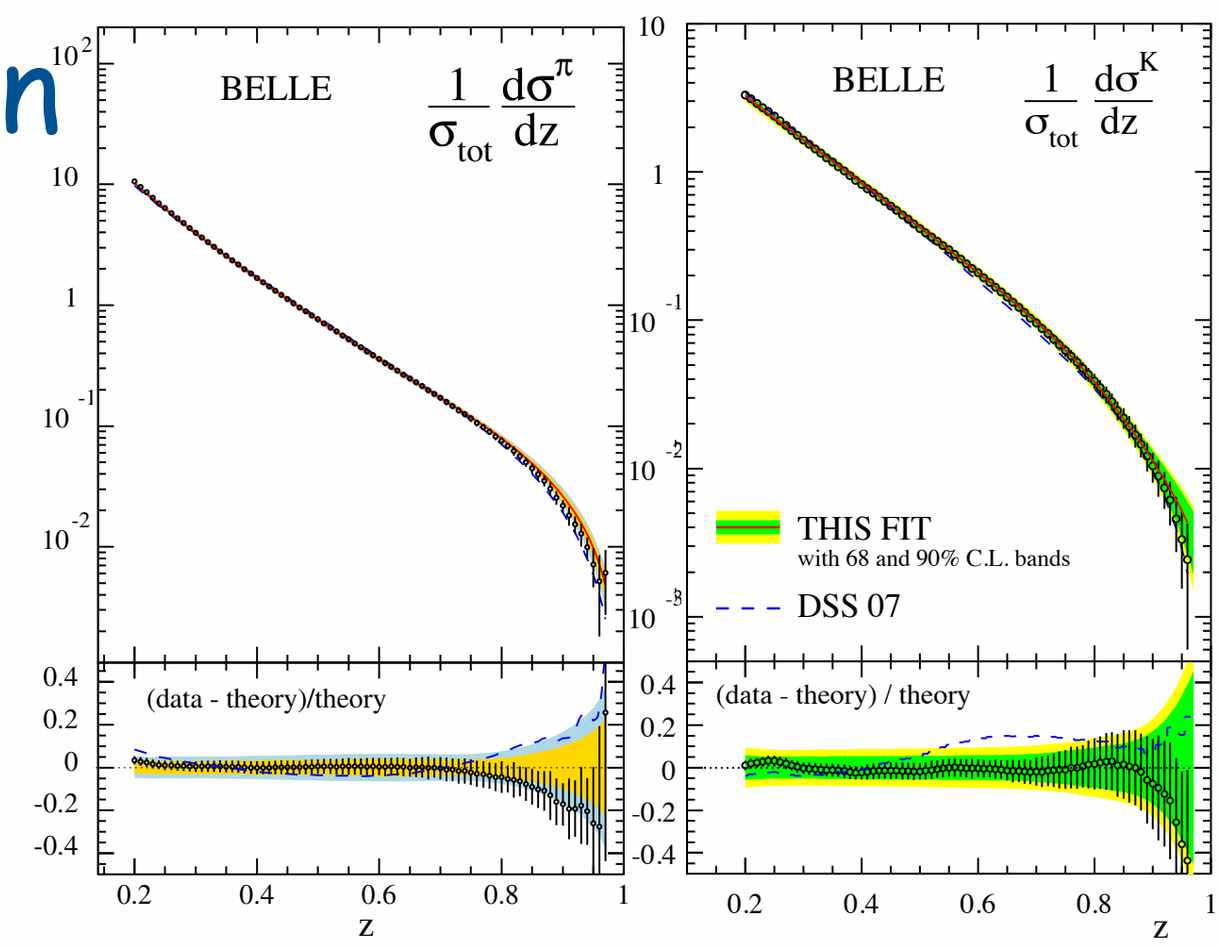
- before 2013: lack of precision data at (moderately) high z and at low √s
  - limits analysis of evolution and gluon fragmentation
  - limited information in kinematic region often used in semi-inclusive DIS



- by now also results from BaBar and Belle:
  - BaBar Collaboration, Phys. Rev. D88 (2013) 032011: **$\pi^{\pm}$, $K^{\pm}$, p+p**
  - Belle Collaboration, Phys. Rev. Lett. 111 (2013) 062002: **$\pi^{\pm}$, $K^{\pm}$**
  - Belle Collaboration, Phys. Rev. D92 (2015) 092007: **$\pi^{\pm}$, $K^{\pm}$, p+p**

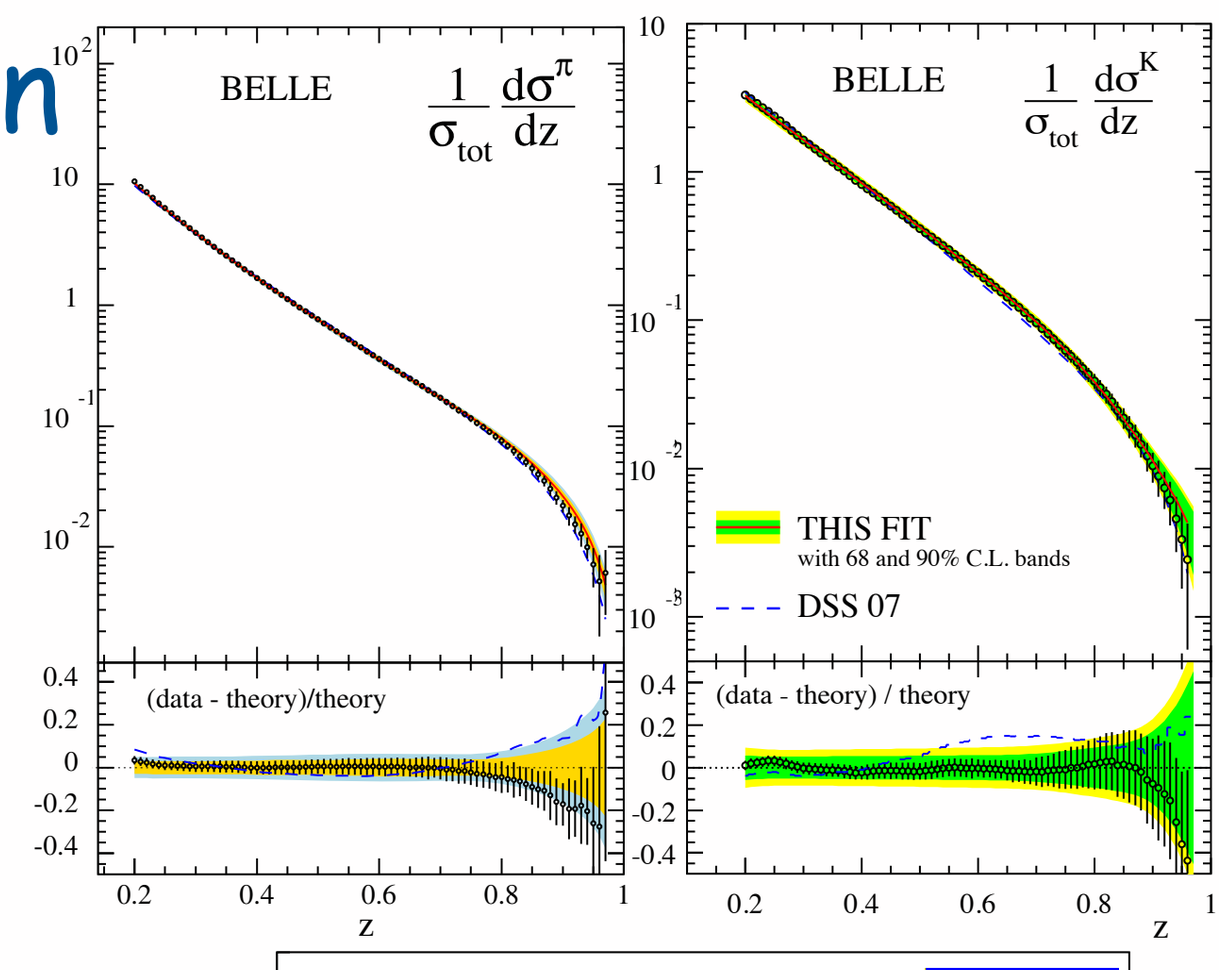
single-hadron production

- very precise data for charged pions and kaons
- Belle data available up to very large z (z<0.98)
- included in recent DEHSS FF fits [e.g. PRD 91, 014035 (2015)]

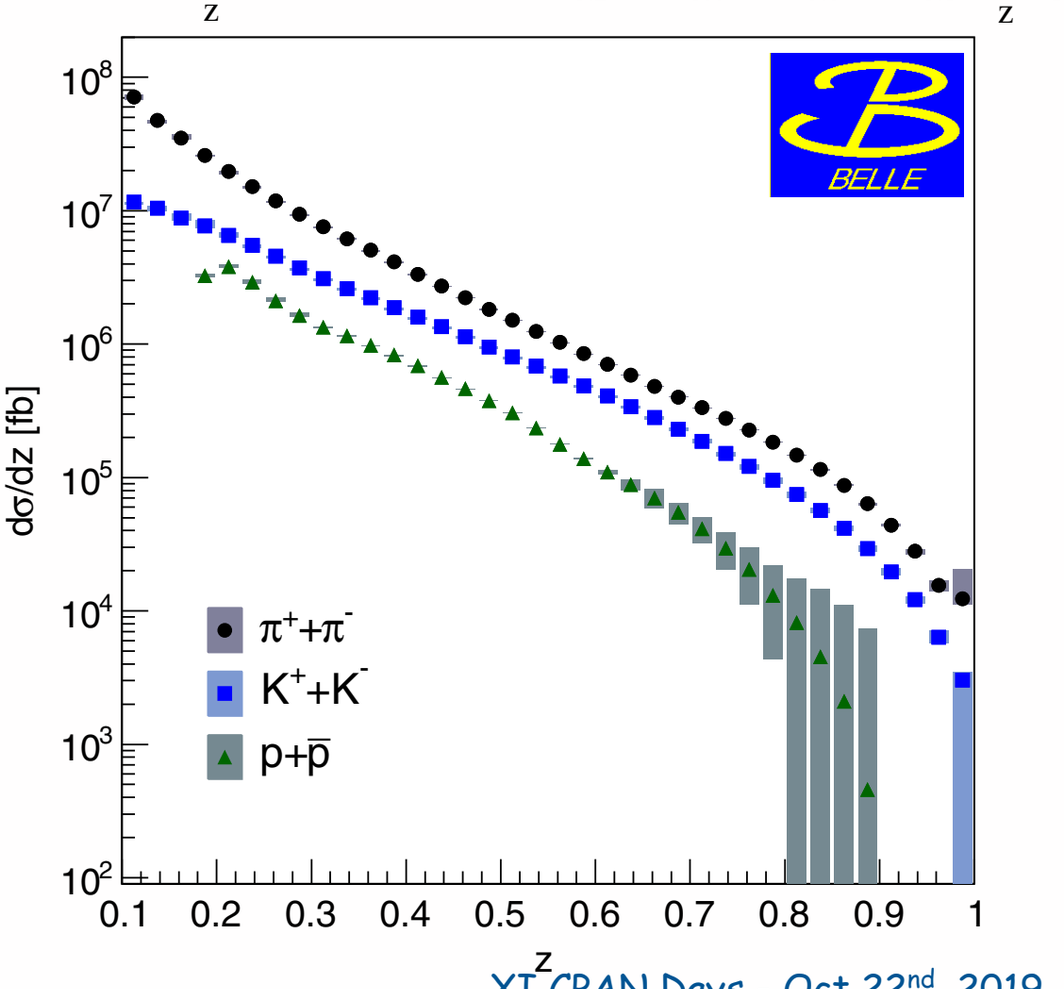


single-hadron production

- very precise data for charged pions and kaons
- Belle data available up to very large z (z<0.98)
- included in recent DEHSS FF fits [e.g. PRD 91, 014035 (2015)]

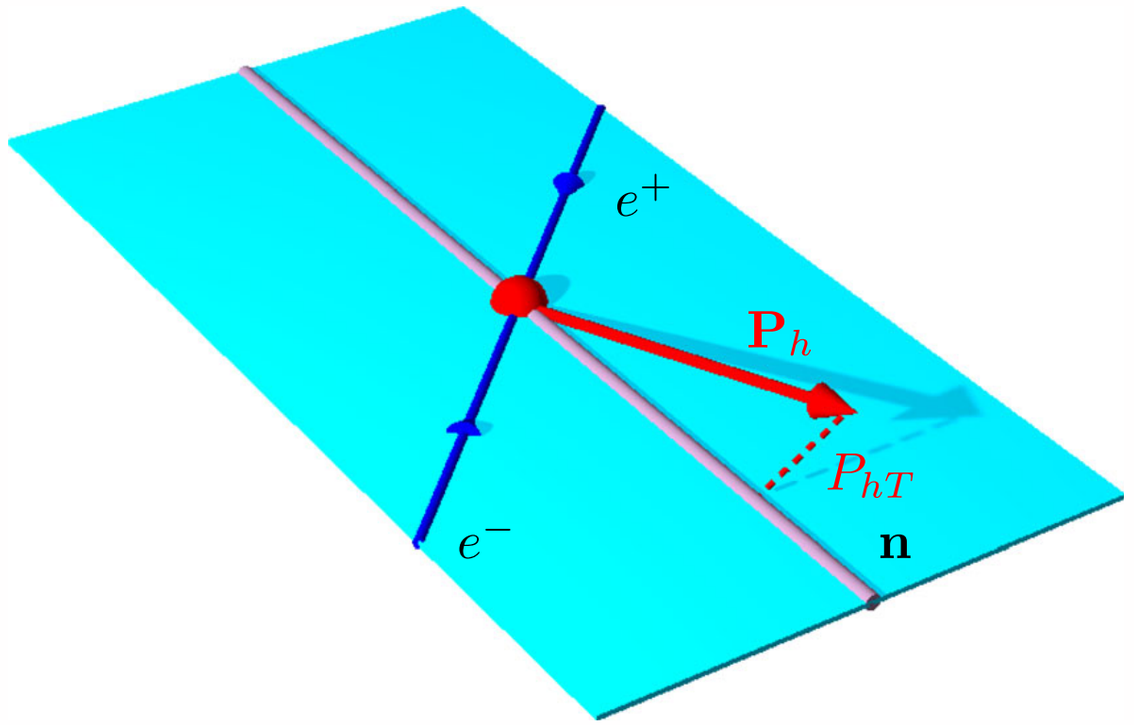


- **new** data for protons and anti-protons
  - not (yet) included in DEHSS, but in NNFF 1.0 [EPJC 77 (2017) 516]
  - similar z dependence as pions
  - about ~⅕ of pion cross sections



inclusive hadrons - transverse momentum

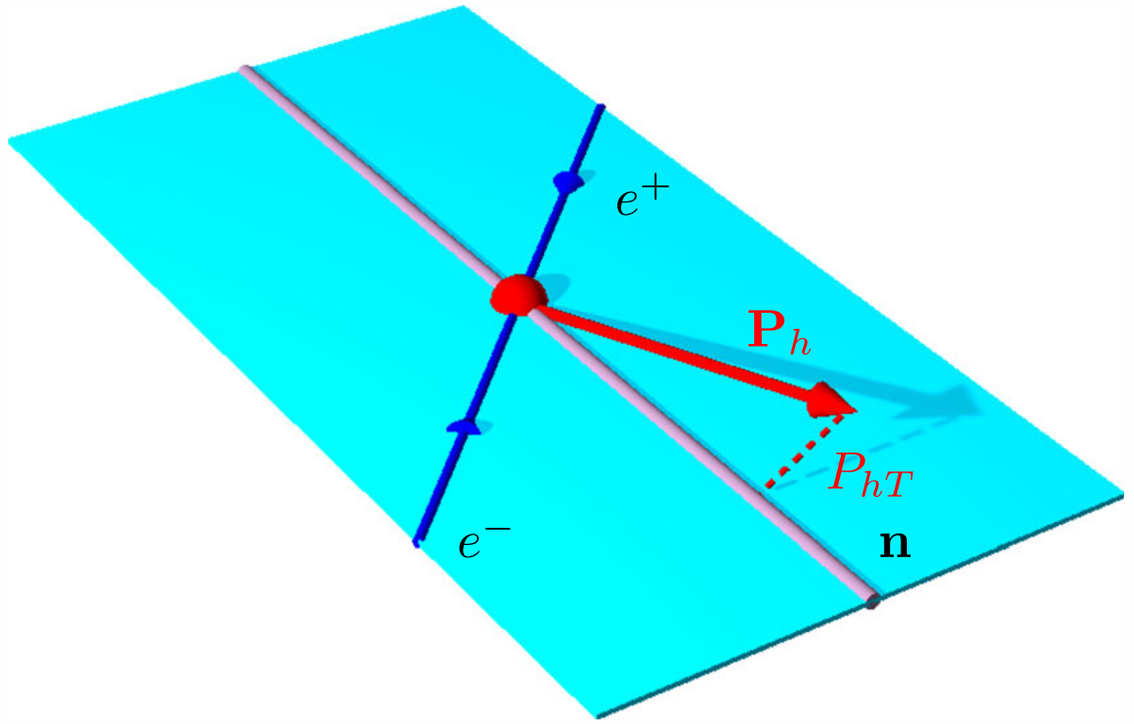
- quasi-inclusive hadron production gives access to transverse momentum in fragmentation
- transverse momentum measured with respect to thrust axis n
  - involves sum over all final-state particles in event
  - event selection and hadron distributions dependent on thrust value T required
    - low thrust -> more spherical
    - high thrust -> highly collimated



$$T \overset{\max}{=} \frac{\sum_h |\mathbf{P}_h^{\mathrm{CMS}} \cdot \hat{\mathbf{n}}|}{\sum_h |\mathbf{P}_h^{\mathrm{CMS}}|}$$

inclusive hadrons - transverse momentum

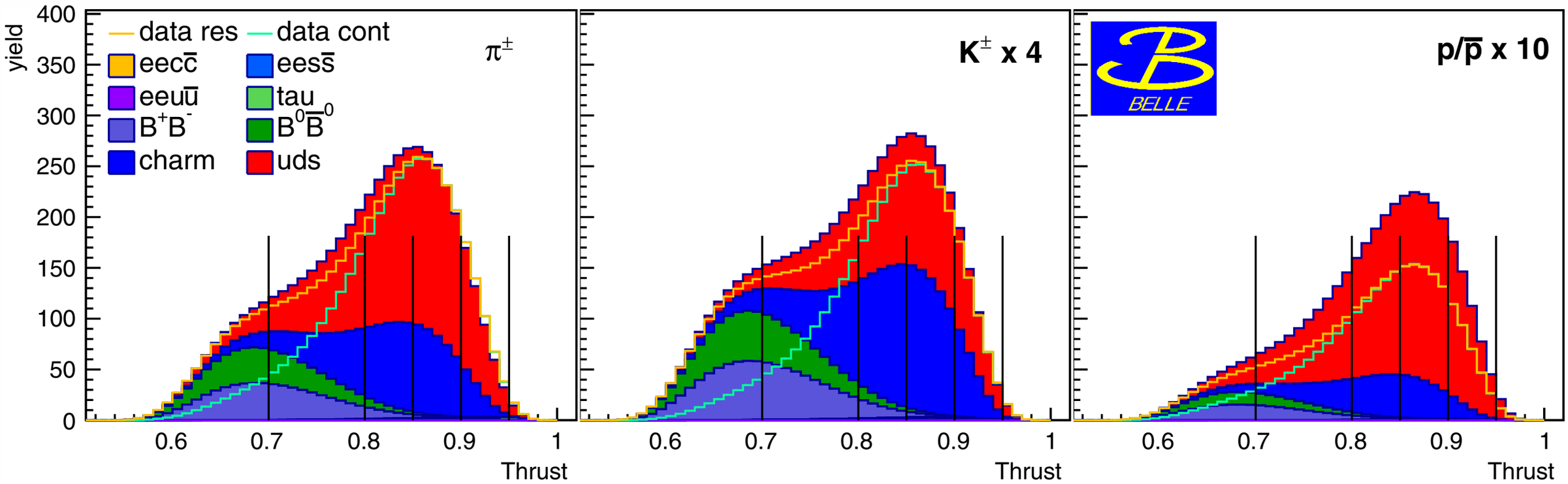
- quasi-inclusive hadron production gives access to transverse momentum in fragmentation
- transverse momentum measured with respect to thrust axis n
- analysis performed differential in z and P_{hT} in various slices in T (18x20x6 bins)
- correction steps similar as for P_{hT}-integrated cross sections
- Gaussian fits to transverse-momentum distribution provided for all hadrons in (z,T)-bins



$$T \overset{\max}{=} \frac{\sum_h |\mathbf{P}_h^{\mathrm{CMS}} \cdot \hat{\mathbf{n}}|}{\sum_h |\mathbf{P}_h^{\mathrm{CMS}}|}$$

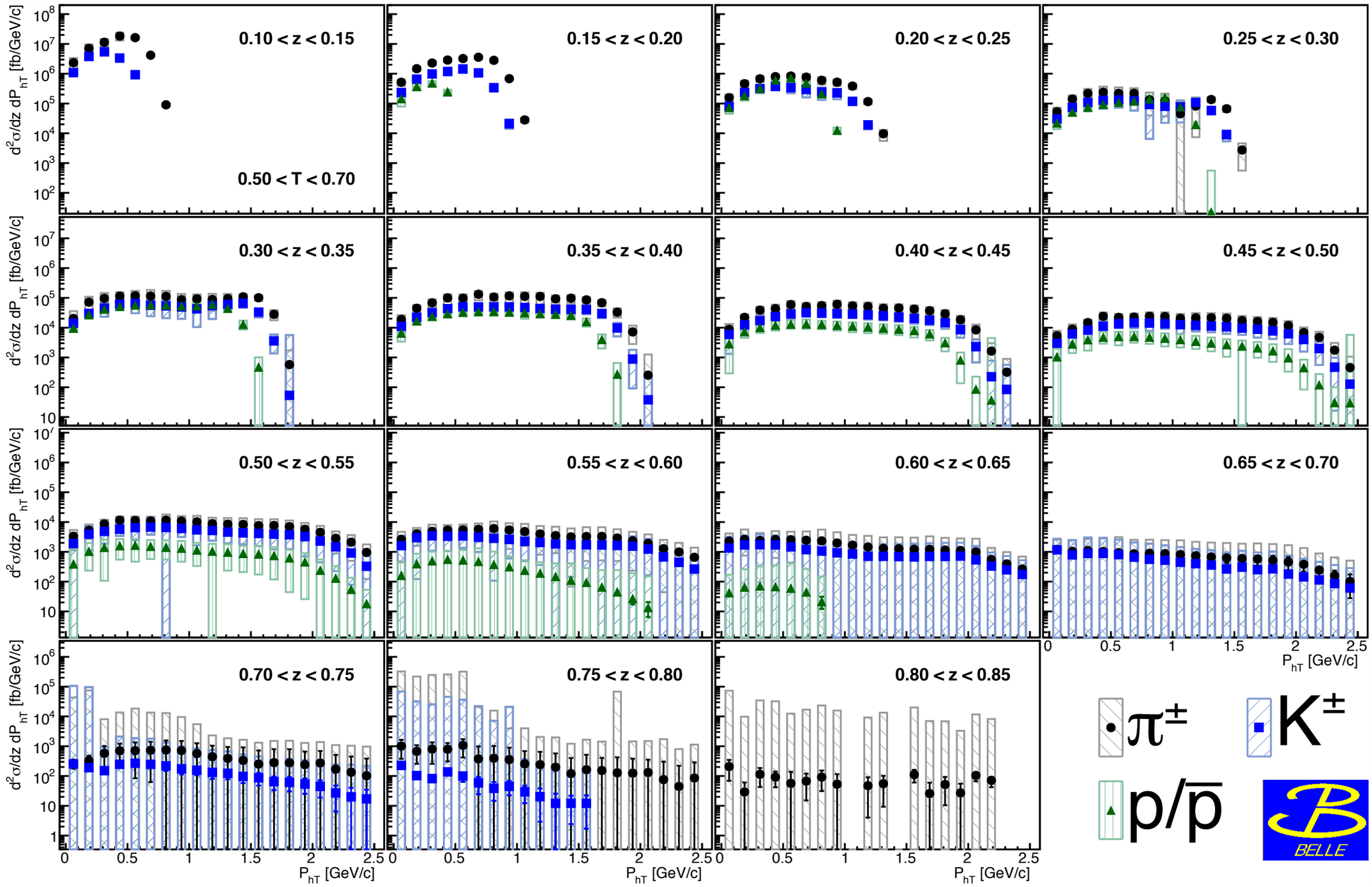
thrust distribution: process contributions

[Belle, PRD 99 (2019) 112006]



- large contribution from BB at lower thrust
- large thrust dominated by uds and charm fragmentation
  (at very large T significant τ contribution for pions, not visible here)
  - concentrate mainly on 0.85<T<0.9 bin, though others available as well

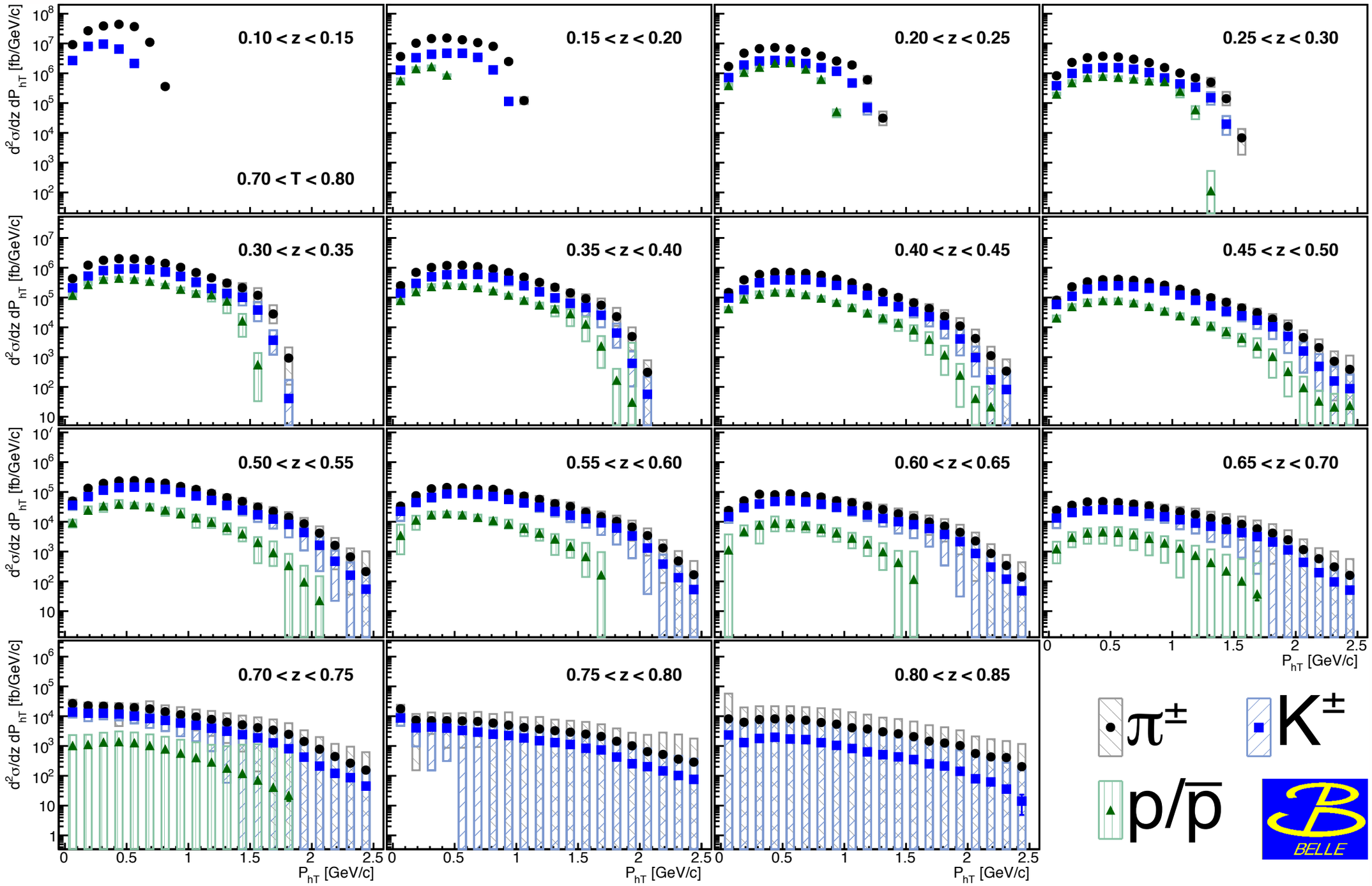
transverse-momentum distributions



[PRD 99 (2019) 112006]

- lowest T bin -> rather spherical events
  - transverse momenta almost uniformly distributed in medium-z bins
  - faster drop for heavier hadrons

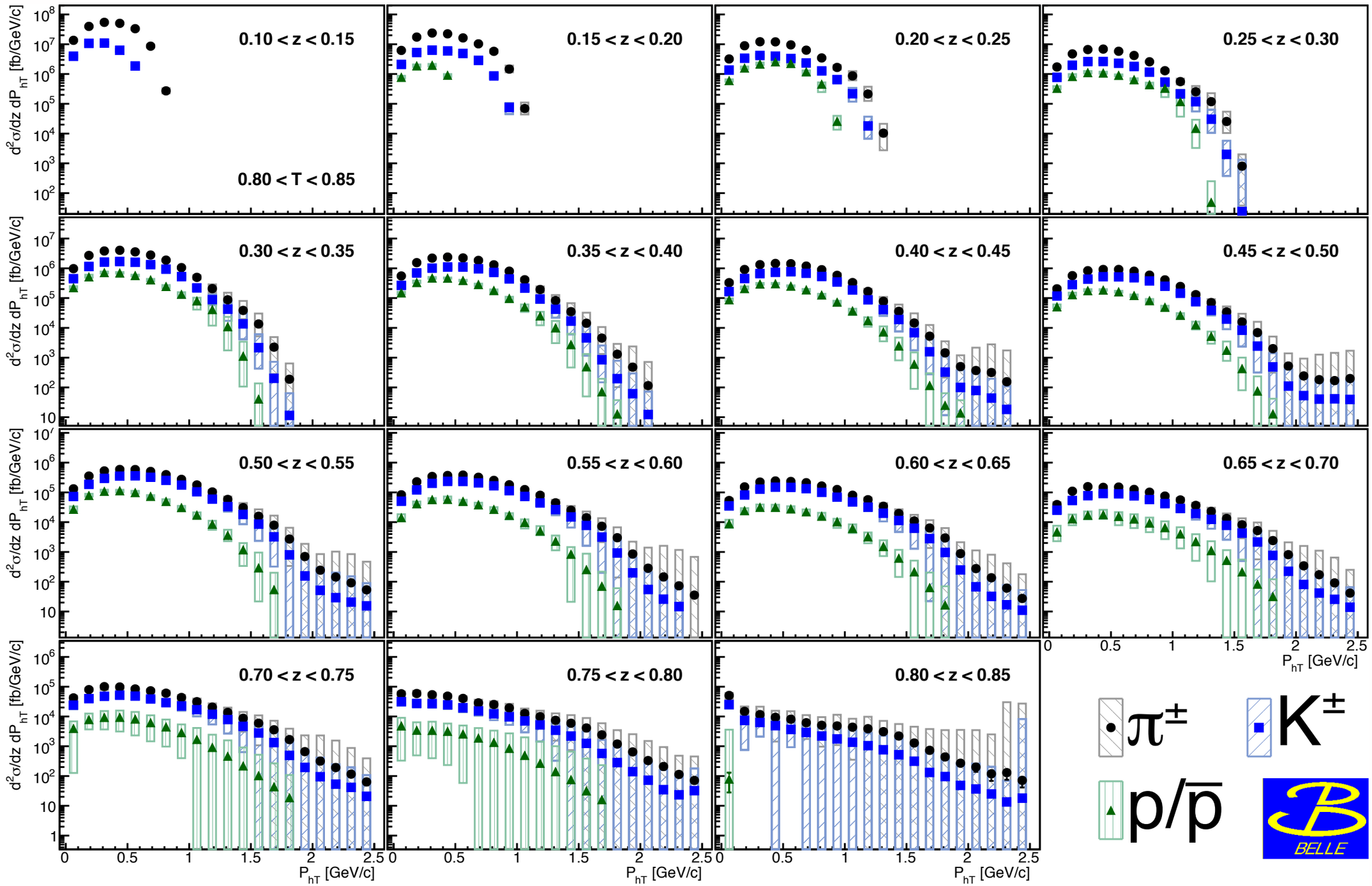
transverse-momentum distributions



[PRD 99 (2019) 112006]

- 0.7 < T < 0.8 -> particles already more collimated
  - transverse momenta already more Gaussian distributed
- large-z region with large uncertainties

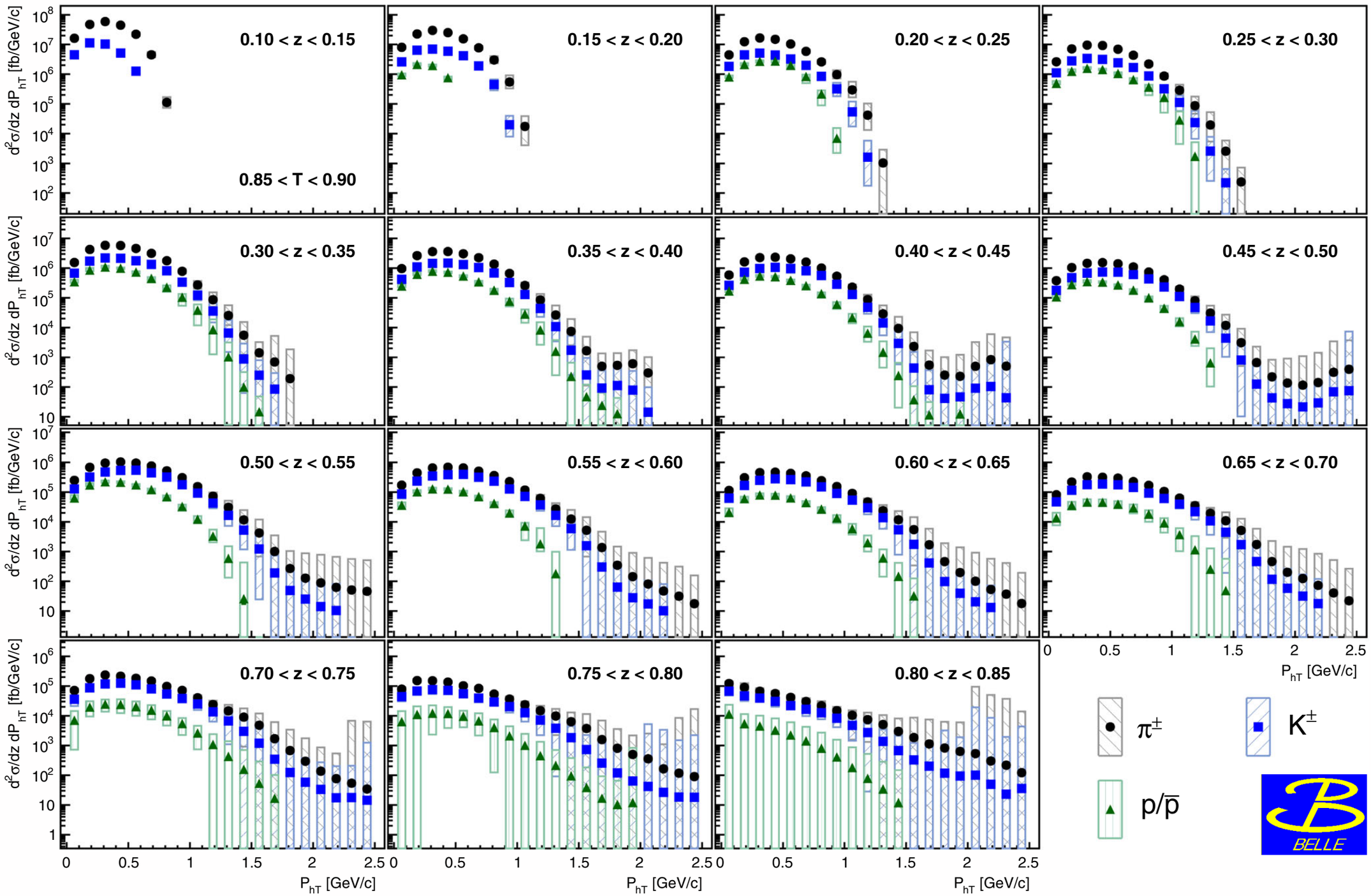
transverse-momentum distributions



[PRD 99 (2019) 112006]

- 0.8 < T < 0.85
  - transverse momenta mostly Gaussian distributed
  - possible deviations for large-P_{hT} tails [but also larger uncertainties]

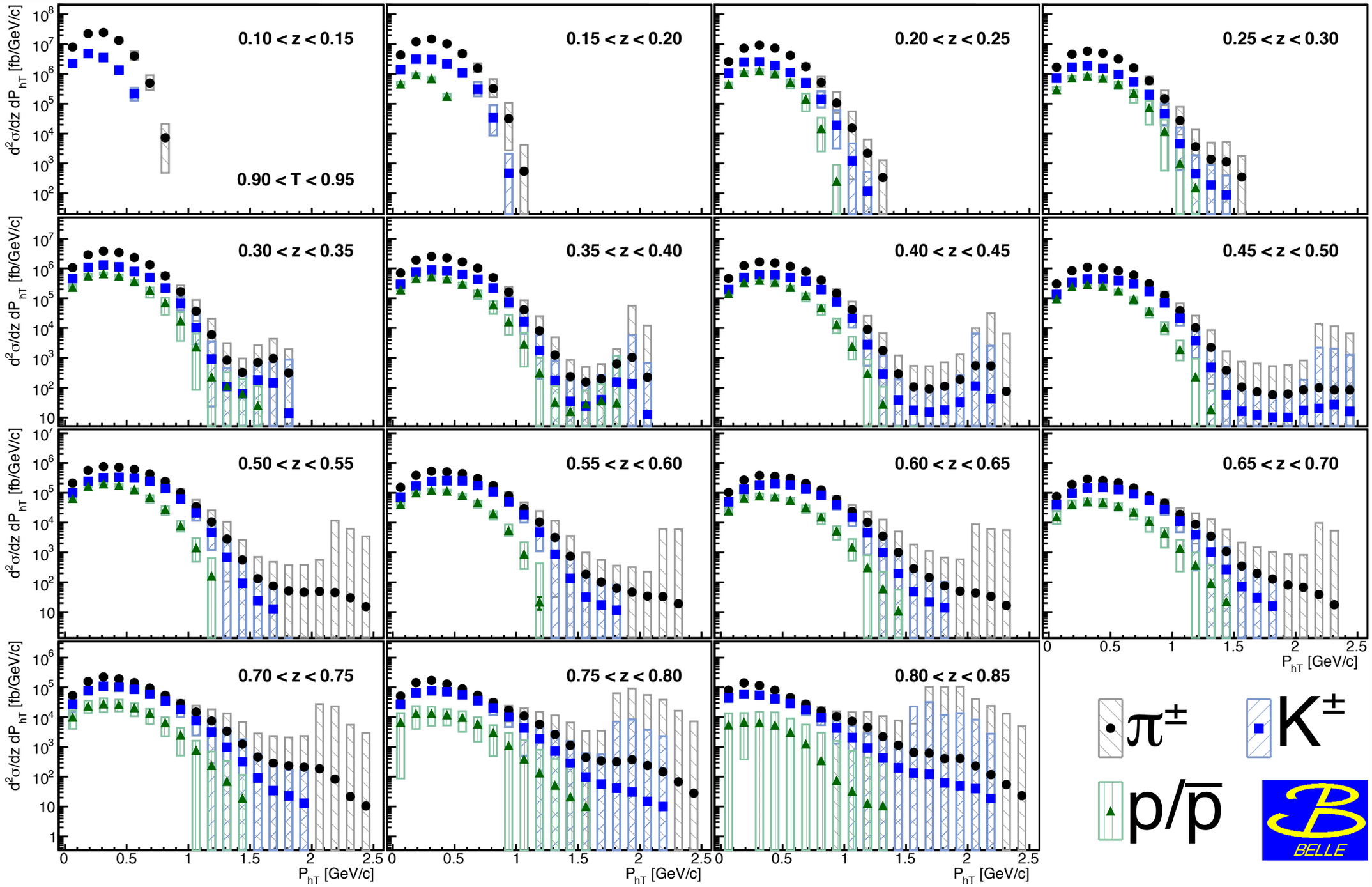
transverse-momentum distributions



[PRD 99 (2019) 112006]

- 0.85 < T < 0.9
  - transverse momenta mostly Gaussian distributed; widths narrowing
  - possible deviations for large-P_{hT} tails [but also larger uncertainties]

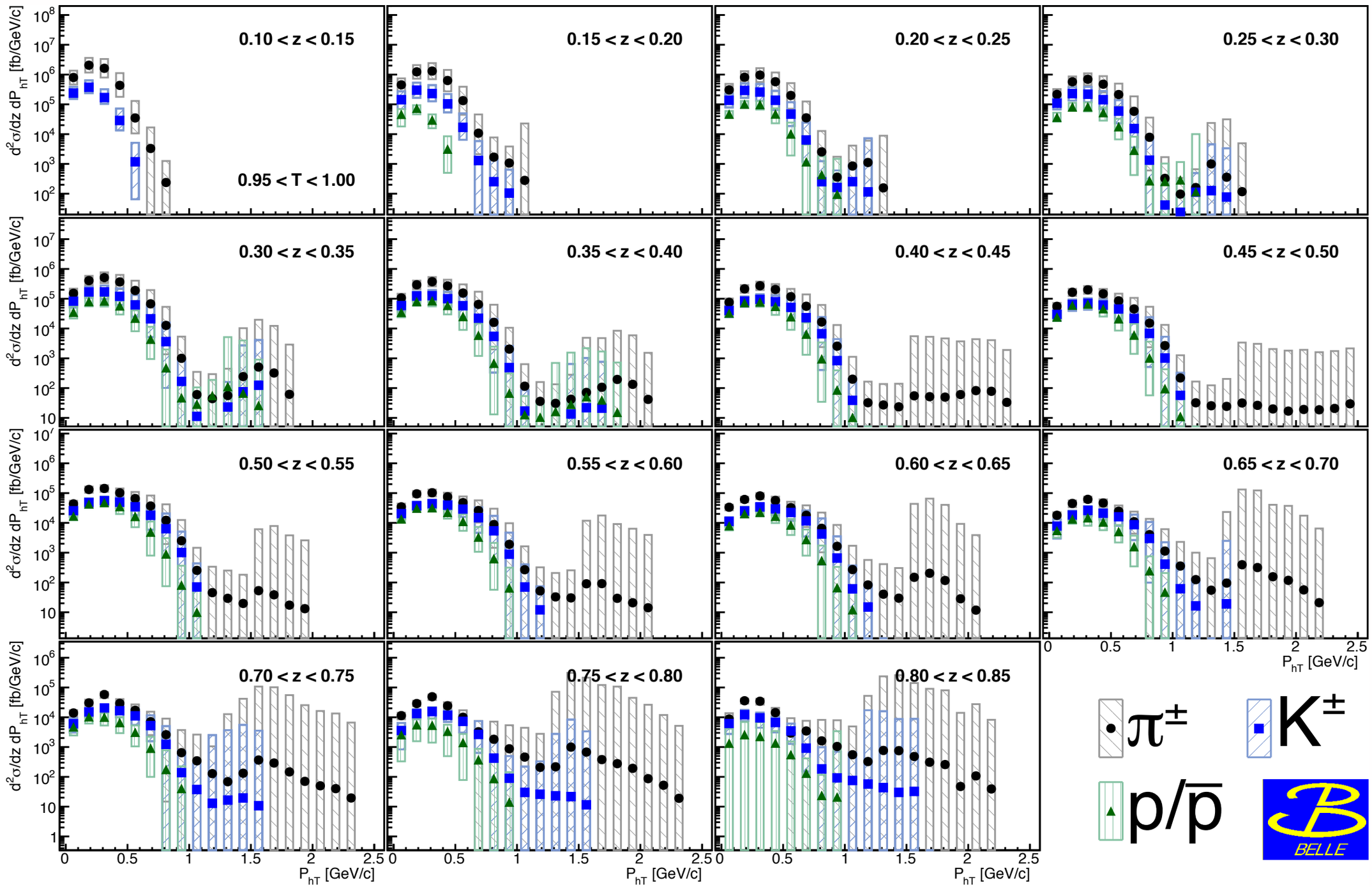
transverse-momentum distributions



[PRD 99 (2019) 112006]

- 0.9 < T < 0.95
  - transverse momenta mostly Gaussian distributed; widths even narrower
  - possible deviations for large-P_{hT} tails [but also larger uncertainties]

transverse-momentum distributions

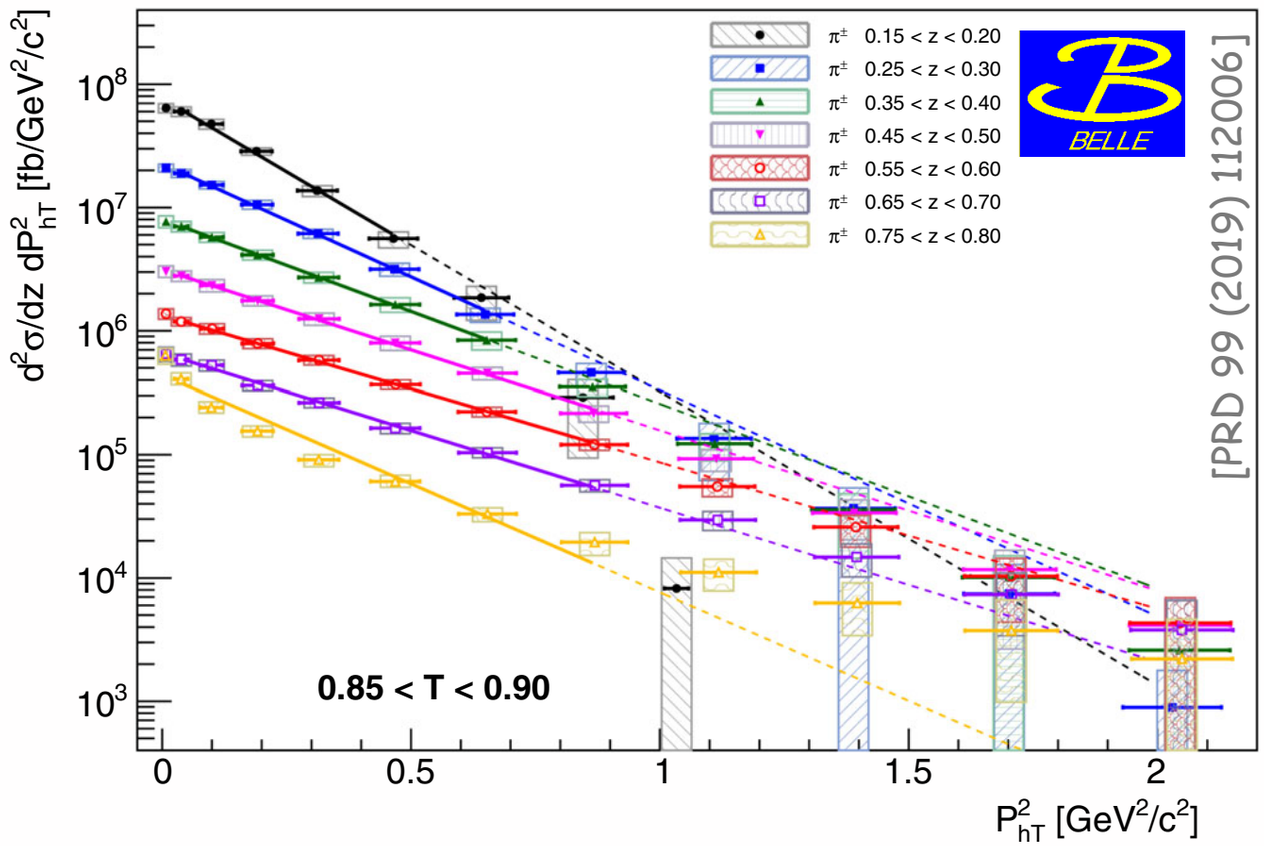


[PRD 99 (2019) 112006]

- 0.95 < T < 1.0
  - transverse momenta mostly Gaussian distributed
  - widths very narrow as particles very collimated

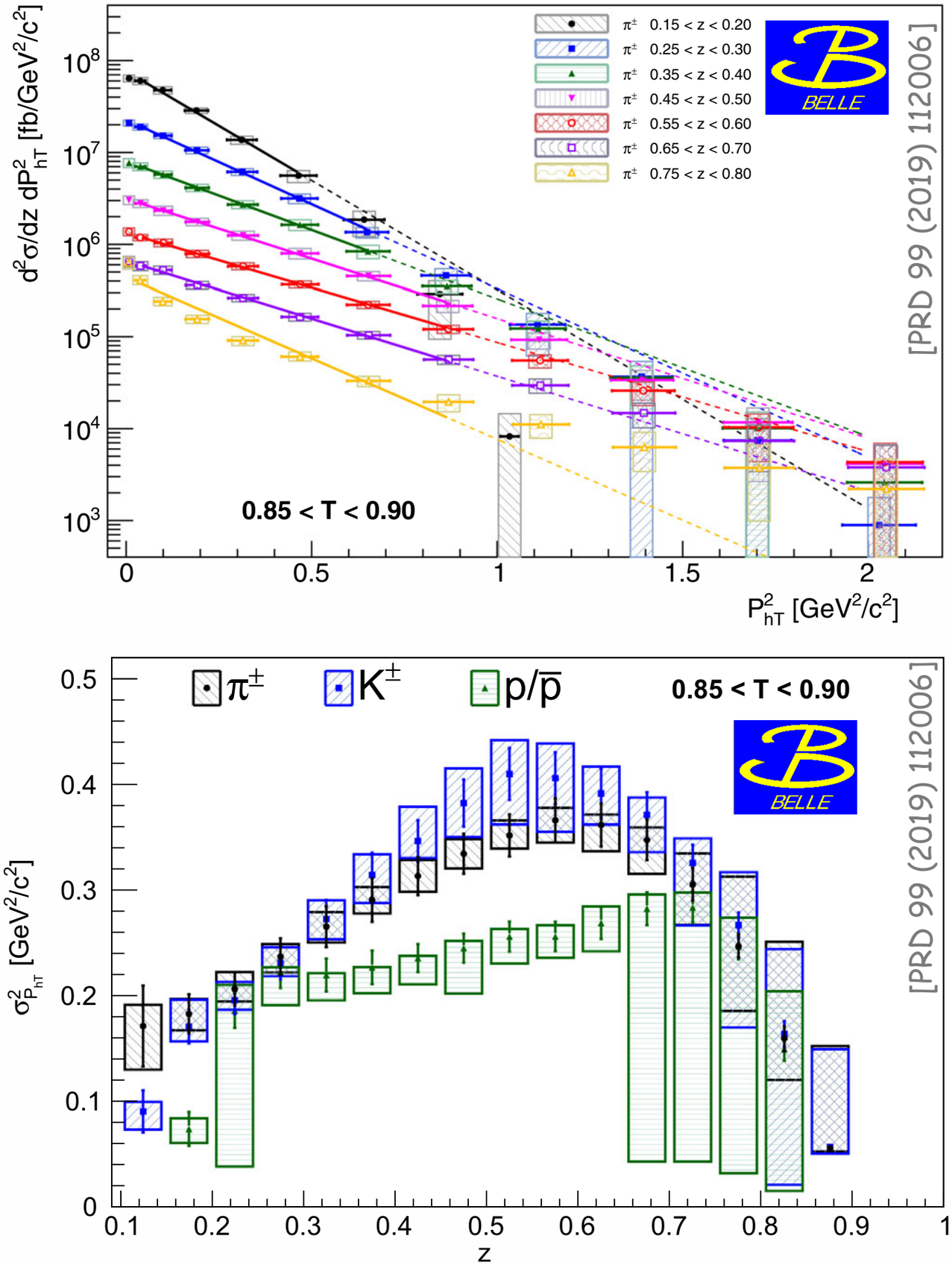
transverse-momentum: Gaussian widths

- 0.85 < T < 0.90
  - fit Gauss to low-P_{hT} data
  - mostly well described with possible exception at high z
  - deviation from Gauss at large P_{hT}
  - clear increase of width with z for low values of z



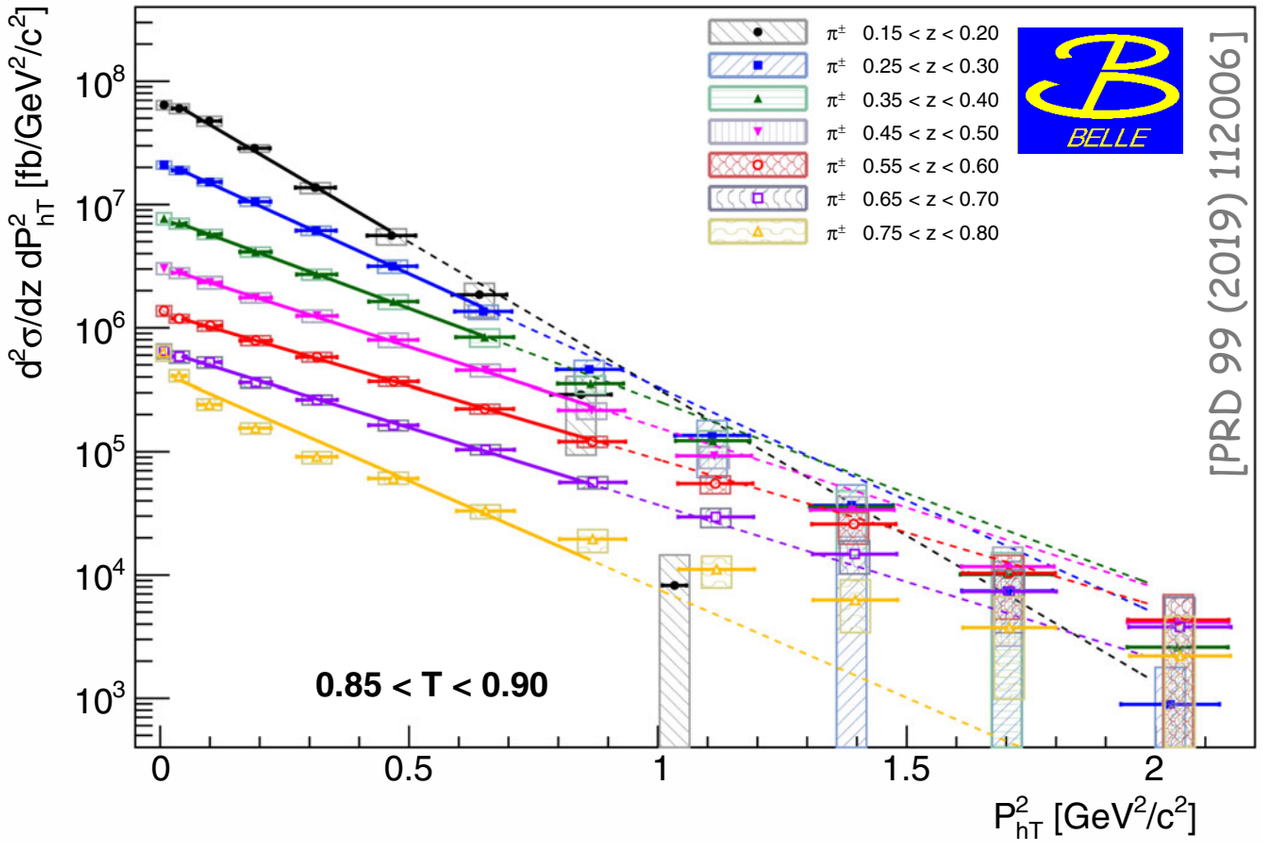
transverse-momentum: Gaussian widths

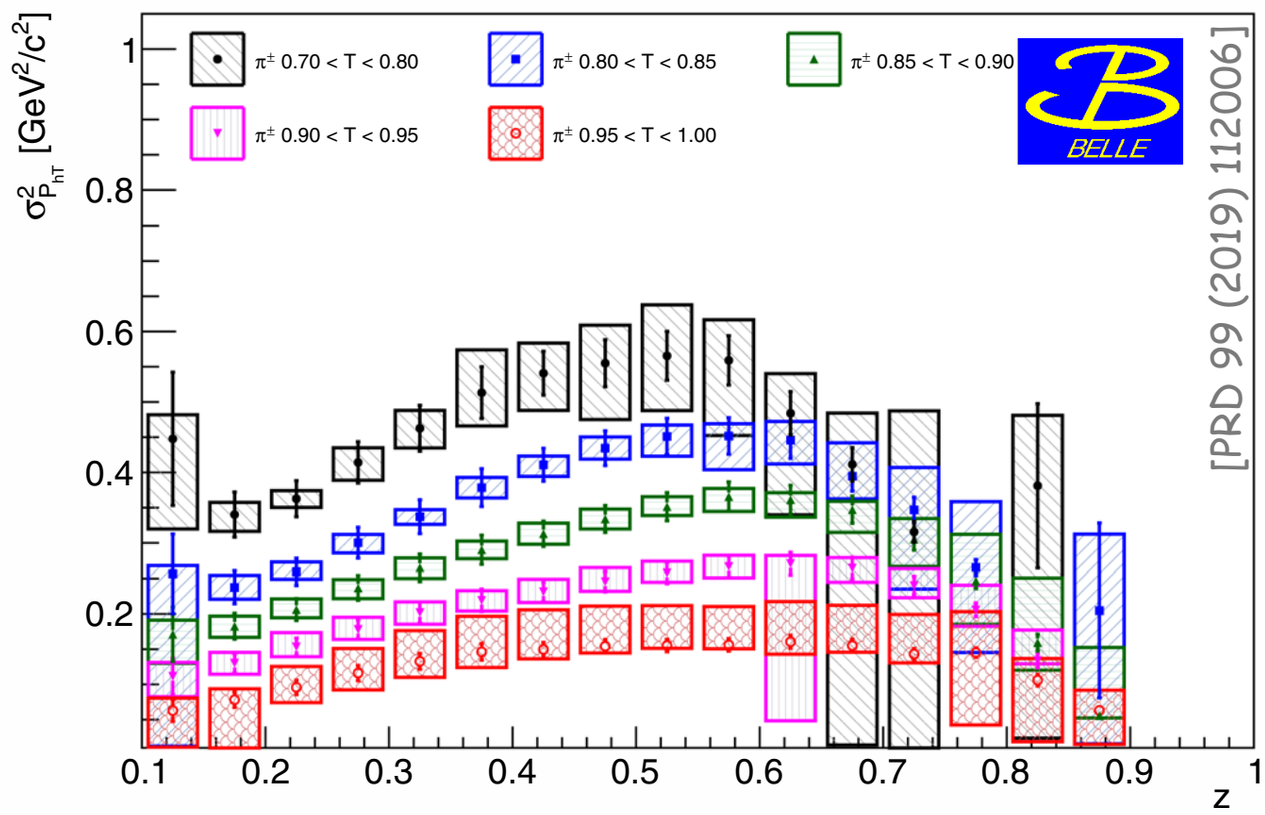
- 0.85 < T < 0.90
  - fit Gauss to low-P_{hT} data
  - mostly well described with possible exception at high z
  - deviation from Gauss at large P_{hT}
  - clear increase of width with z for low values of z
- Gaussian widths as function of z
  - general increase with z with turnover at larger values of z for mesons
  - protons with smaller width and more linear rise with z



transverse-momentum: Gaussian widths

- 0.85 < T < 0.90
  - fit Gauss to low-P_{hT} data
  - mostly well described with possible exception at high z
  - deviation from Gauss at large P_{hT}
  - clear increase of width with z for low values of z
- Gaussian widths depend on z and T
  - general increase with z with turnover at larger values of z
  - clear decrease of widths with increase of T
    - particles more and more collimated

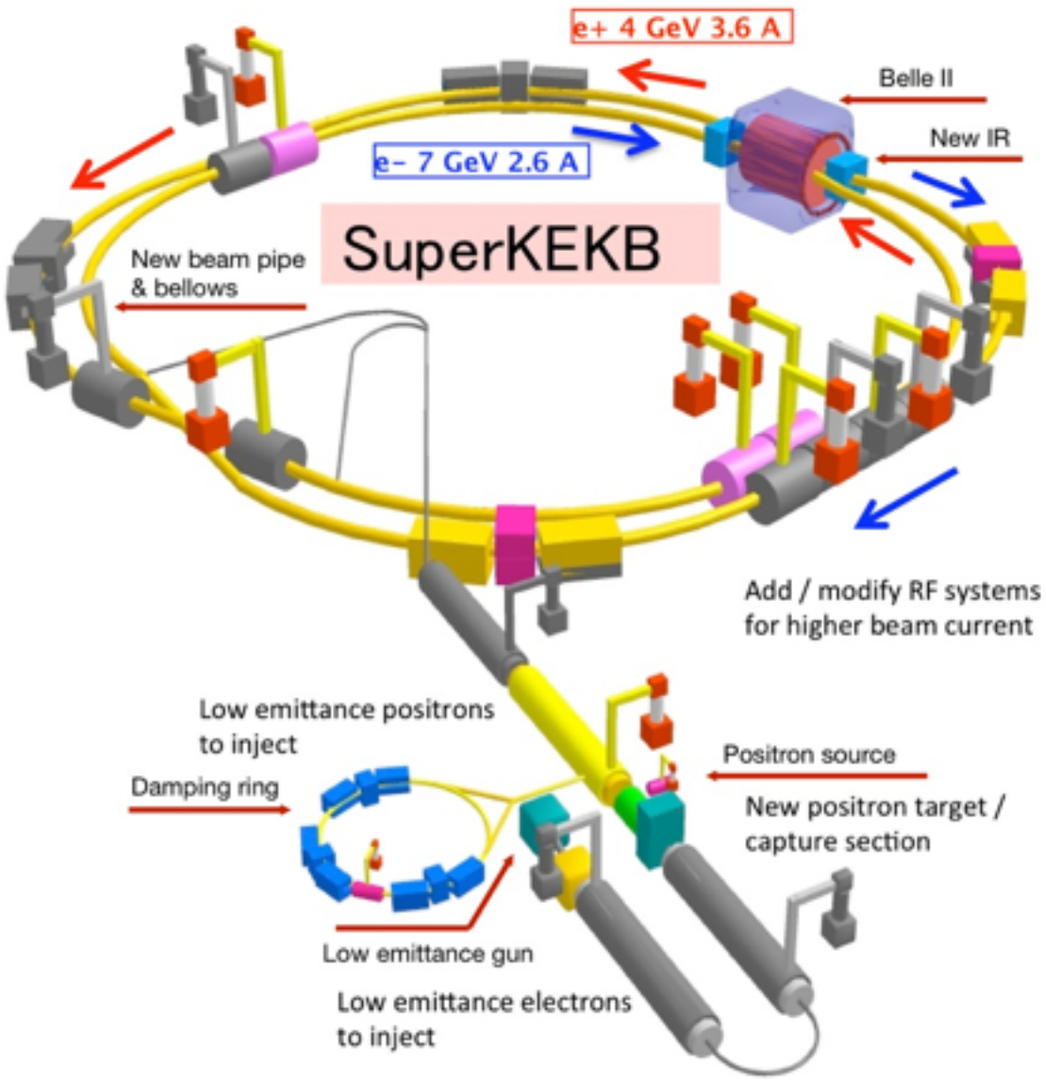


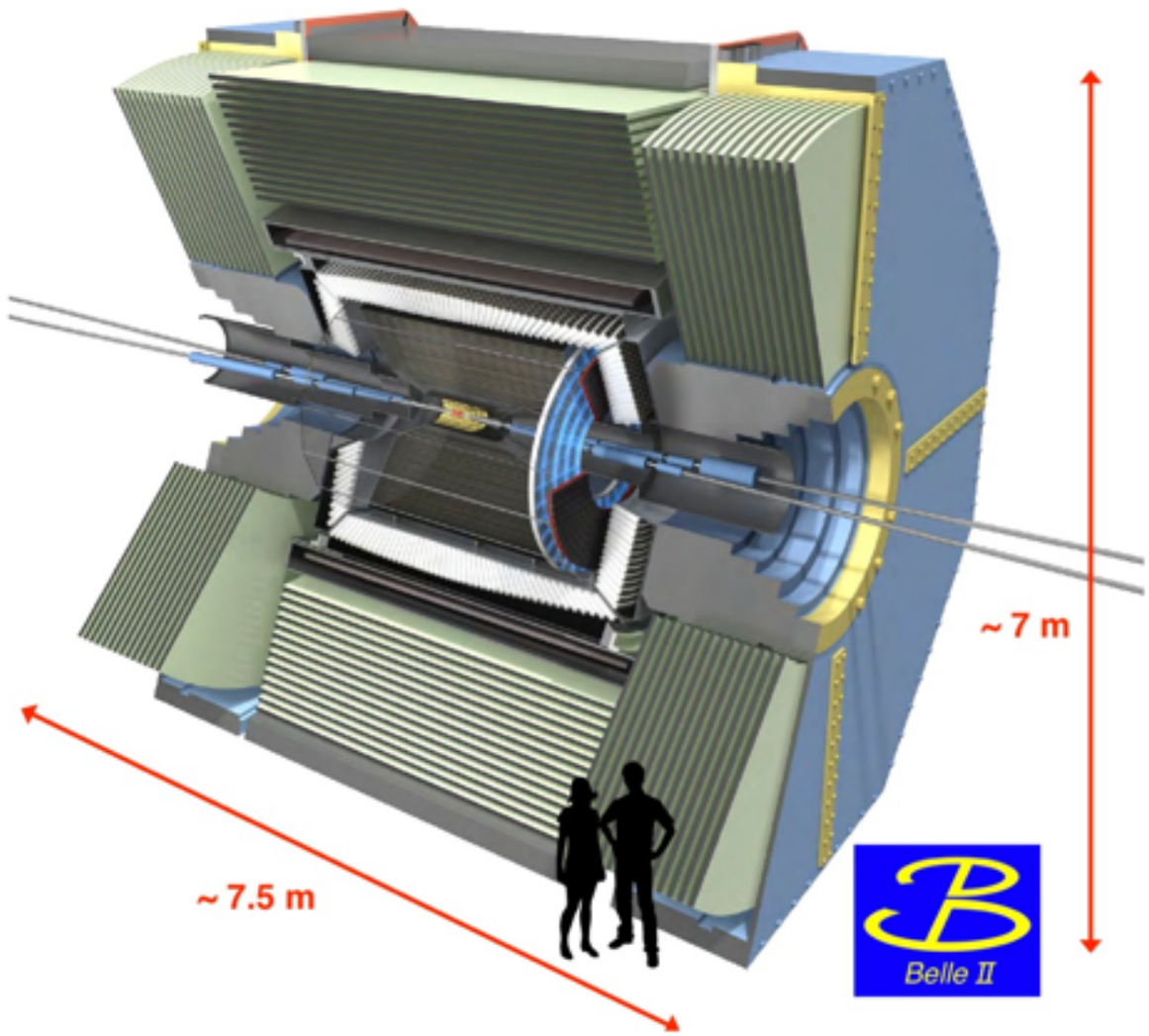


what else **available** or to expect (soon)

- single-hadron production
  - **hyperon cross sections** [PRD 97 (2018) 072005]
- k_T-dependent D_1 FFs
  - nearly back-to-back hadrons
- Collins asymmetries:
  - **charged pions and neutral meson (pion & eta) incl. k_T dependence** [PRL 96 (2006) 232002, PRD 78 (2008) 032011, PRD 86 (2012) 039905(E), arXiv:1909.01857]
  - kaon Collins FFs
- hyperon polarization
  - **transverse Lambda polarization** [Belle, PRL 122 (2019) 042001]
- di-hadron production
  - **unpolarized dihadron FFs** [PRD 92 (2015) 092007, PRD 96 (2017) 032005]
  - **chiral-odd interference fragmentation** [PRL 107 (2011) 072004]
  - helicity-dependent dihadron fragmentation function $G_1^\perp$ ("jet handedness")

the precision future starts now





backup

Belle II in Spain

M. Vos (IFIC)

C. Marinas (IFIC)

Belle II in Spain

M. Vos (IFIC)

- 'Advanced pixel detectors for future colliders', with emphasis in CMOS detector developments for Belle II VXD upgrade
- responsibilities in operation and management
- physics exploitation
  - lepton-flavor universality, e.g. $R(D^{(*)}, \pi, J/\Psi)$
  - fragmentation

C. Marinas (IFIC)

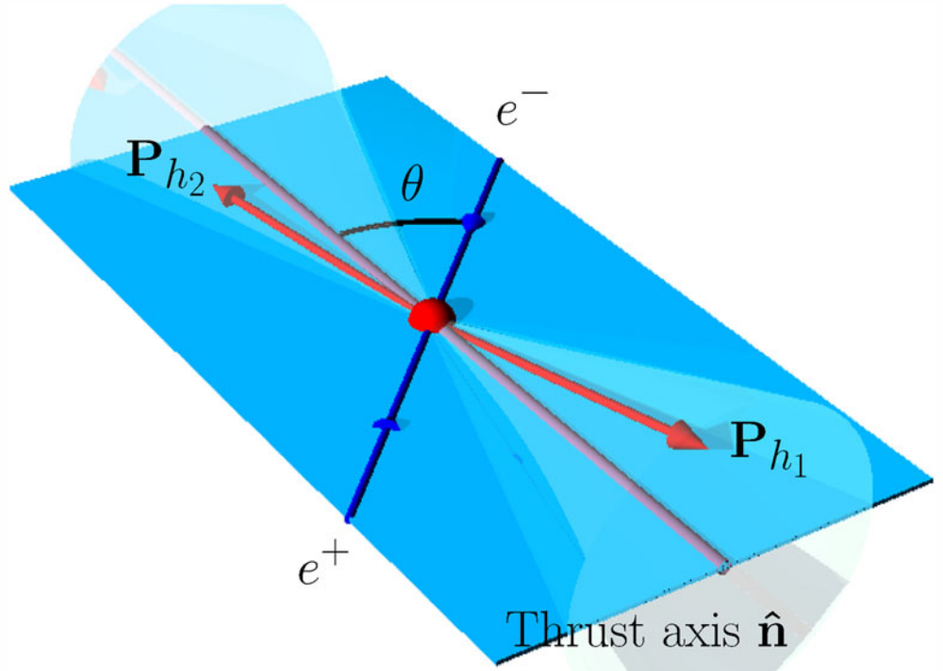
hadron-pair production

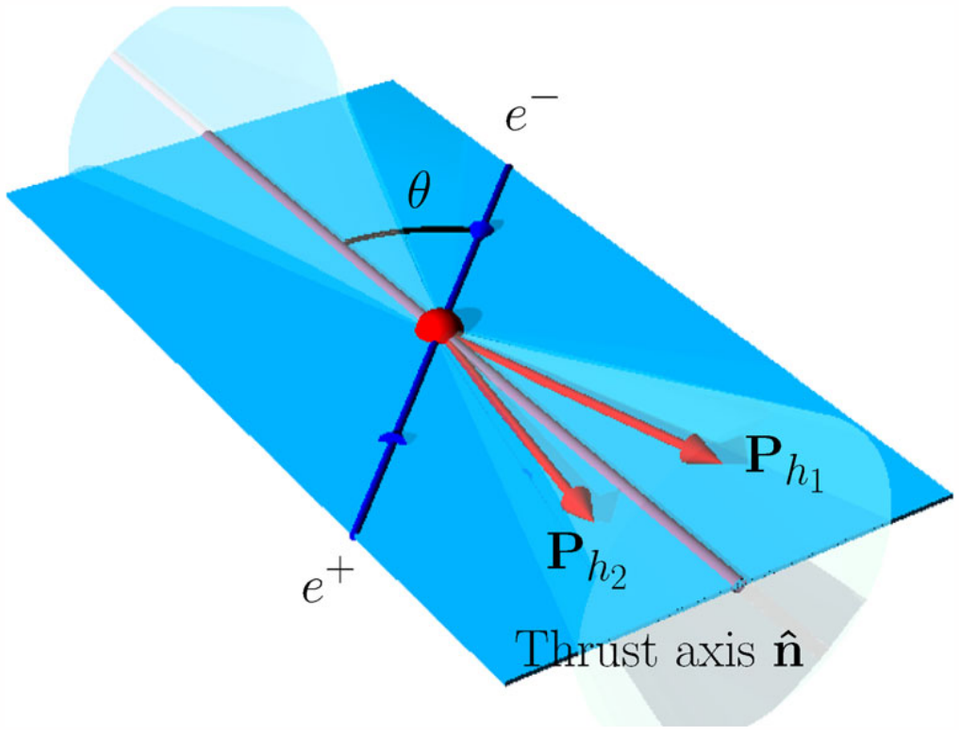
- single-hadron production has low discriminating power for parton flavor
- can use 2nd hadron in opposite hemisphere to "tag" flavor, transverse momentum, and polarization
  - mainly sensitive to product of single-hadron FFs
- if hadrons in same hemisphere:

dihadron fragmentation

- a la de Florian & Vanni [Phys. Lett. B 578 (2004) 139]
- a la Collins, Heppelmann & Ladinsky [Nucl. Phys. B 420 (1994) 565]; Boer, Jacobs & Radici [Phys. Rev. D 67 (2003) 094003]

- raises question of defining hemispheres





from hadron yields to cross sections

- hadron yields undergo series of corrections
  - particle (mis)identification [e.g., not every identified pion was a pion]
  - smearing unfolding [e.g., measured and true momentum might differ]
  - non-$q\bar{q}$ processes [e.g., two-photon processes, Υ -> BB, …]
  - "4π" correction [selection criteria and limited geometric acceptance]
  - QED radiation [initial-state radiation (ISR)]
  - optional: weak-decay removal (e.g., "prompt fragmentation")
- Collins asymmetries also corrected for false asymmetries and maybe for $q\bar{q}$-axis (mis)reconstruction
- partially different approaches in different experiments/analyses