Bose-Einstein correlation measurements at CMS

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for the CMS Collaboration

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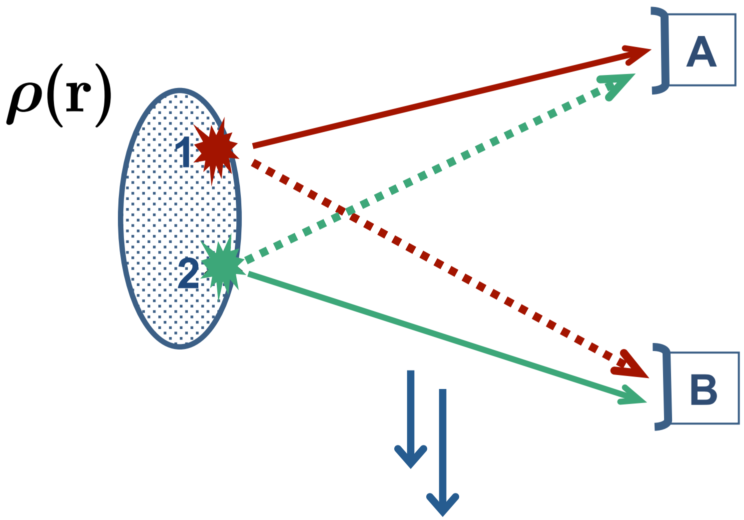
Bose-Einstein Correlations – Basics

- Detecting two identical Bosons emitted from sources 1 & 2 at A & B



- Two-Boson correlation function ⟶ reflects length of homogeneity

– Correlation function:

$$C_2(q_{inv}) = \frac{P_2(k_1,k_2)}{P_1(k_1)P_1(k_2)}$$

$$1+\lambda \left| \mathcal{F}[\tilde{\rho}(\mathrm{Q})] \right|^2$$

(ideal)

$$C_{BE}(q_{inv}) = c\ [\ 1+\lambda\ e^{-q_{inv}R_{inv}}\ ]$$

$$q_{inv}^2 = -(k_1-k_2)^2$$

Correlation Function – Fitting Parameterizations

- 1-D Correlation function (q_{inv})

$$C_{BE}(q_{\rm inv}) = 1 + \lambda \exp[-q_{\rm inv} R]$$

- 2-D Correlation function (q_l, q_t) (stretched exponential)

$$C_{BE}(q_l, q_t) = 1 + \lambda \exp[-\sqrt{(q_l R_l)^2 + (q_t R_t)^2}]$$

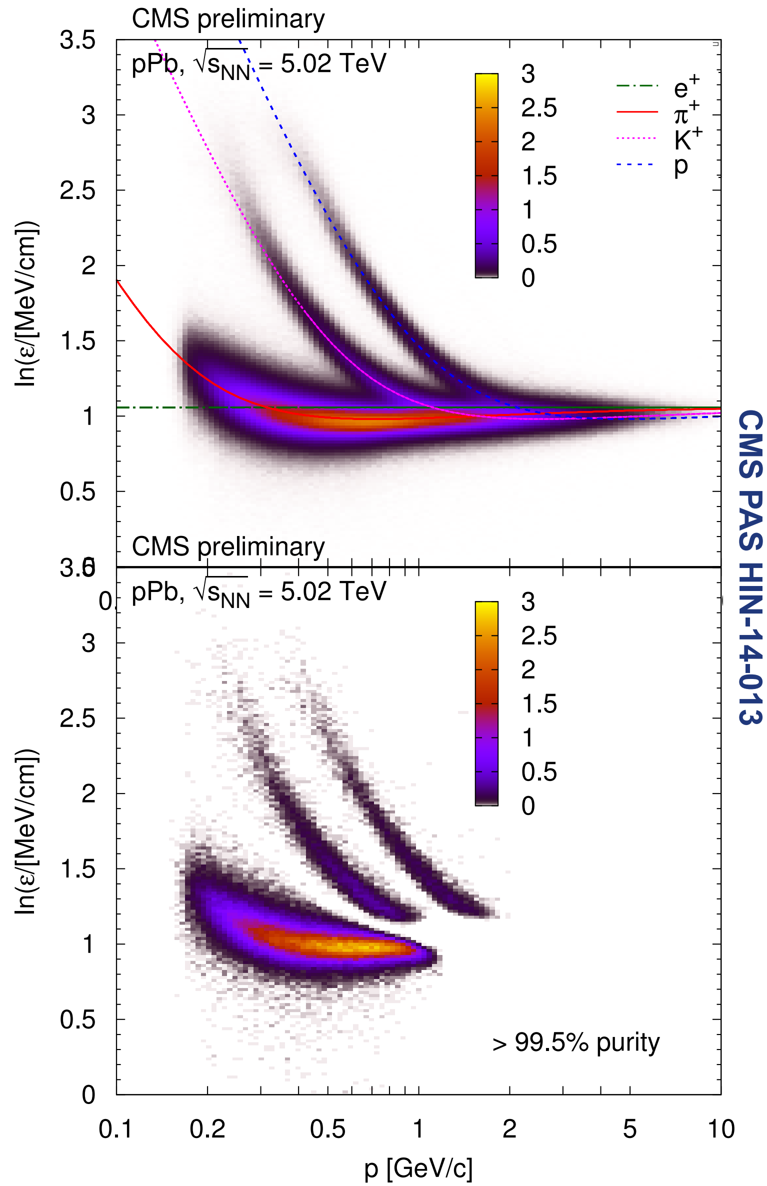
- 3-D Correlation function (q_l, q_s, q_o) (stretched exponential) (Bertsch-Pratt variables)

$$C_{BE}(q_l, q_s, q_o) = 1 + \lambda \exp[-\sqrt{(q_l R_l)^2 + (q_s R_s)^2 + (q_o R_o)^2}]$$

  - q_o → Component of $\mathbf{q_t}$ parallel to $\mathbf{k_T} = |\mathbf{p_{T1}} + \mathbf{p_{T2}}|/2$
  - q_s → Component of $\mathbf{q_t}$ orthogonal to $\mathbf{k_T}$

Data Sample and Particle Identification

- **Data used** :
  - pp $\sqrt{s}$ = 0.9, 2.76, 7 TeV
  - pPb $\sqrt{s_{NN}}$ = 5.02 TeV
  - PbPb $\sqrt{s_{NN}}$ = 2.76 TeV (60-100%)
  - Used particles with $|\eta|$ <1
- **Tracking** : Excellent tracking performance, for pions down to p_T = 0.1 GeV/c
- **PID :** Ionization energy loss rate ($\ln\varepsilon$)
  - Momentum range p < 1.15 GeV/c (pions , kaons)
  - p < 2 GeV/c (protons)
- **High purity** identified particles (> 99.5%)



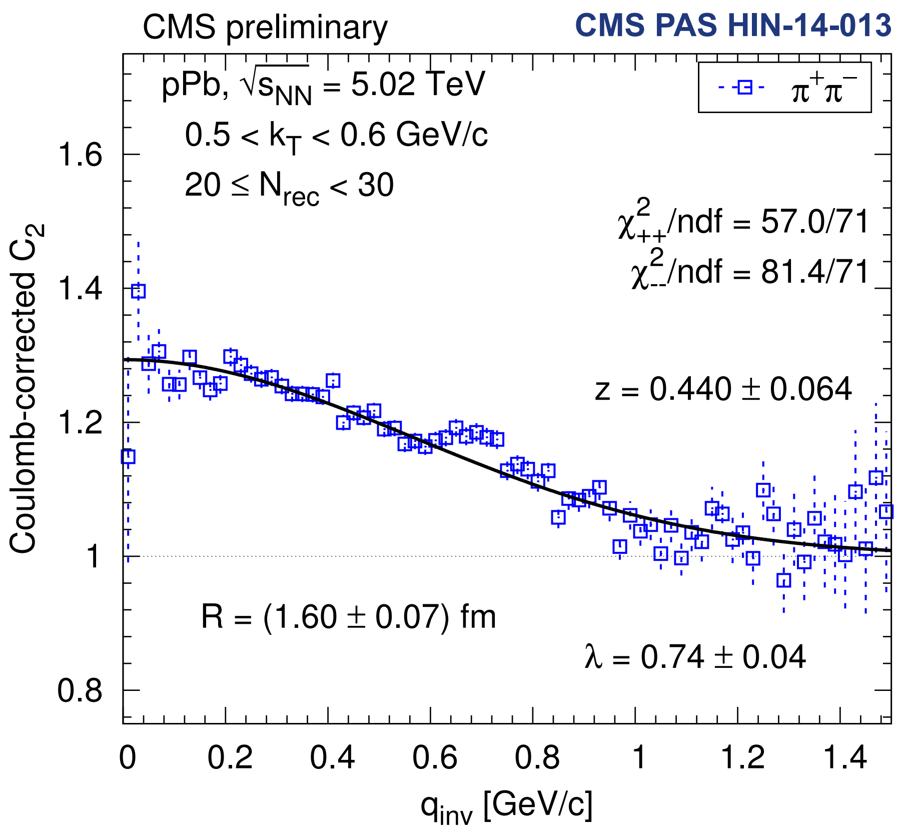
Method

- Experimentally→ Correlation function

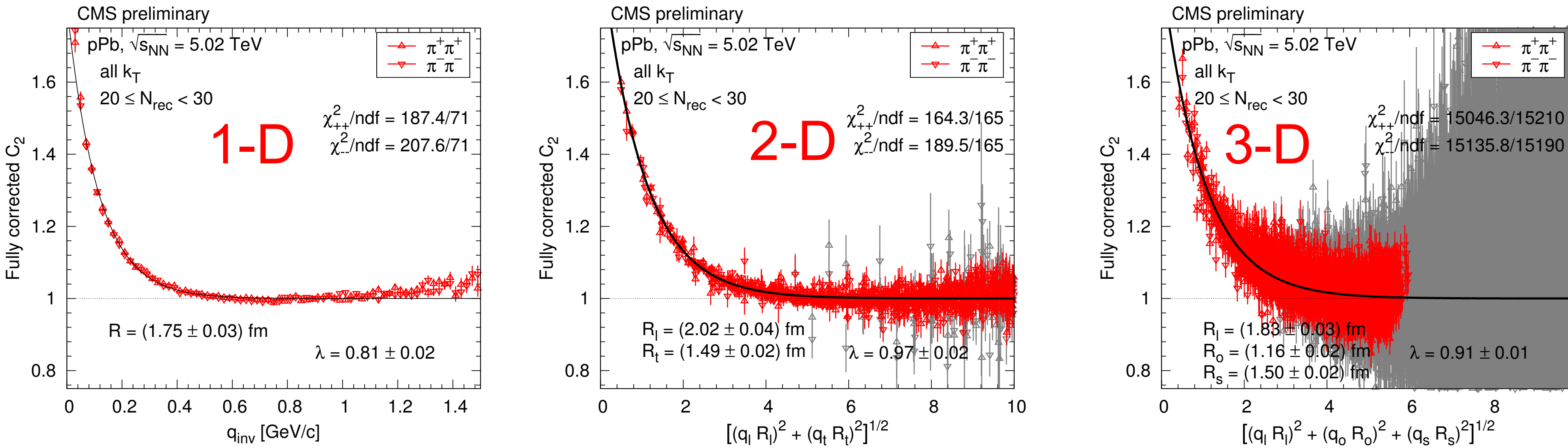
$$C_2(\mathbf{q}) = \frac{N_{\mathrm{signal}}}{N_{\mathrm{bckgnd}}}$$

N_{signal} → Identical particles from same event
N_{bckgnd} → Mixed events

- Coulomb: full formula
- Cluster contributions
  - Mini-jet,
  - Multi-body decay or resonances
- Unlike-sign (+−) pairs used to constrain the shape of the cluster contribution to like–sign (±±) pairs
- Systematics
  - Mixed Events
  - Cluster contributions
  - Fitting range



Fully Corrected Correlation



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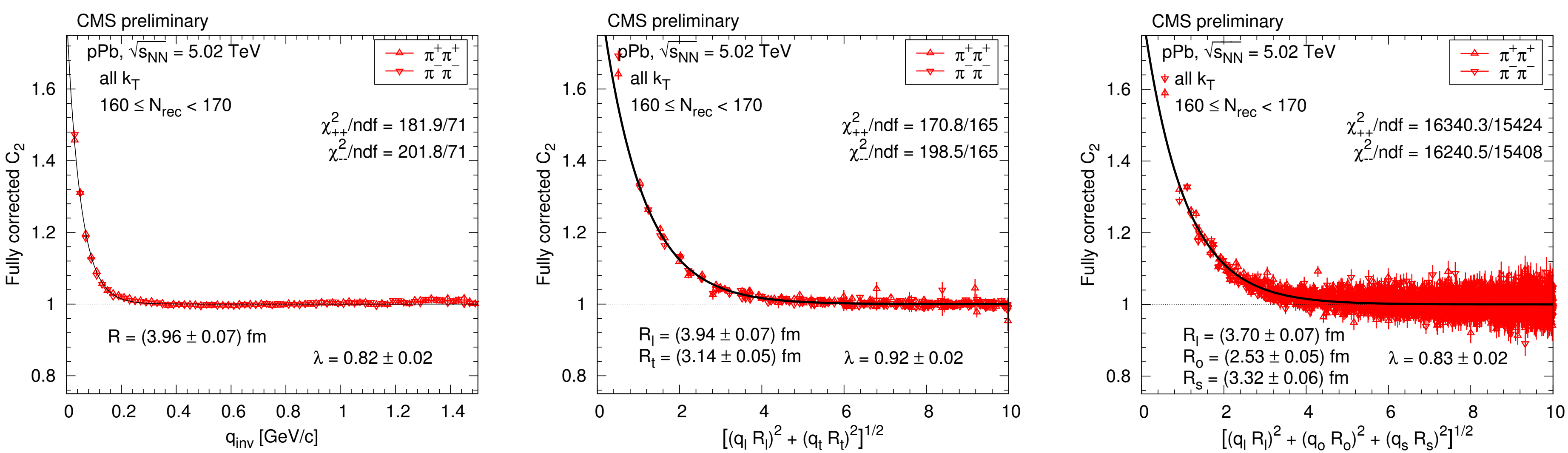
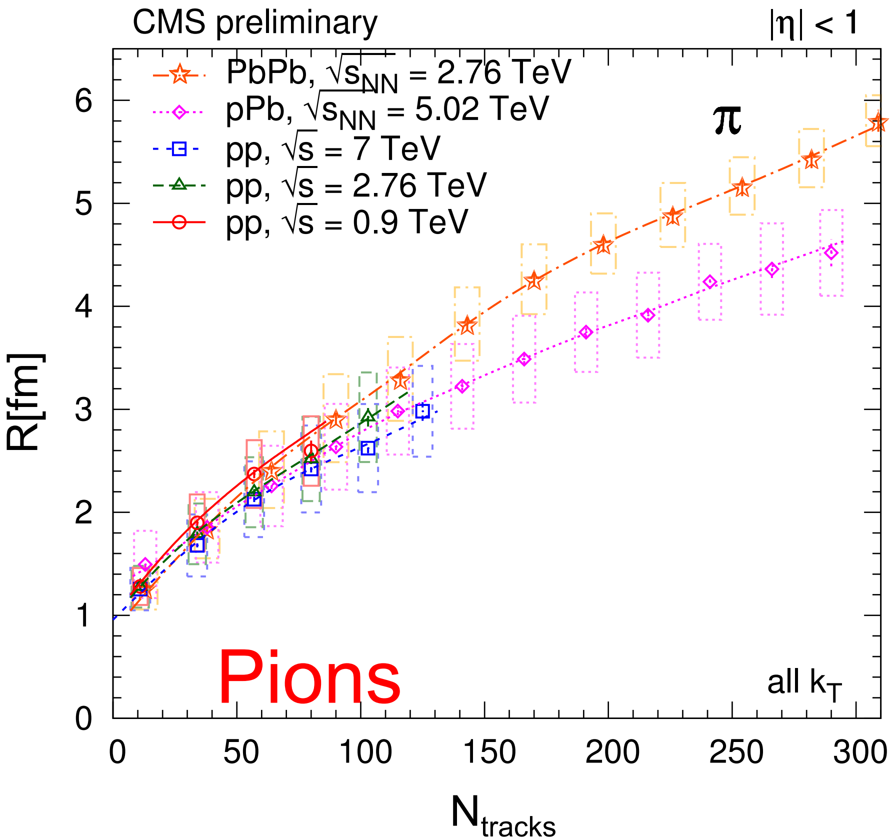
$$C_{BE}(q_{\rm inv}) = 1 + \lambda \exp[-q_{\rm inv} R]$$

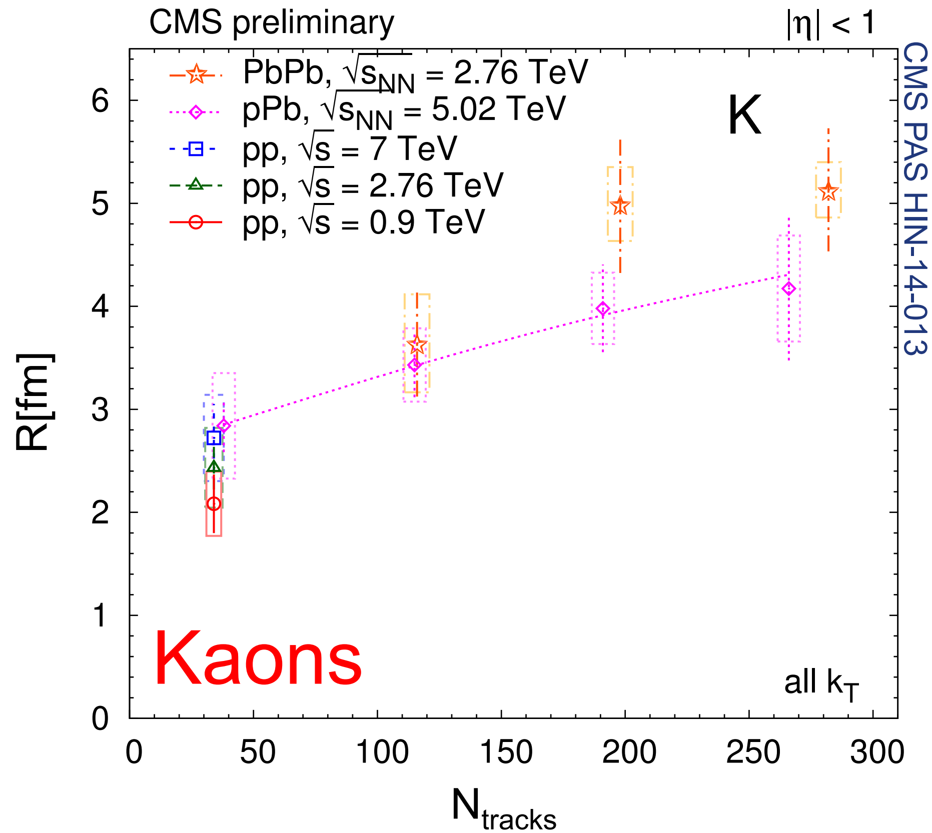
$$C_{BE}(q_l, q_t) = 1 + \lambda \exp[-\sqrt{(q_l R_l)^2 + (q_t R_t)^2}]$$

$$C_{BE}(q_l, q_s, q_o) = 1 + \lambda \exp[-\sqrt{(q_l R_l)^2 + (q_s R_s)^2 + (q_o R_o)^2}]$$



One Dimensional Results : Pions & Kaons

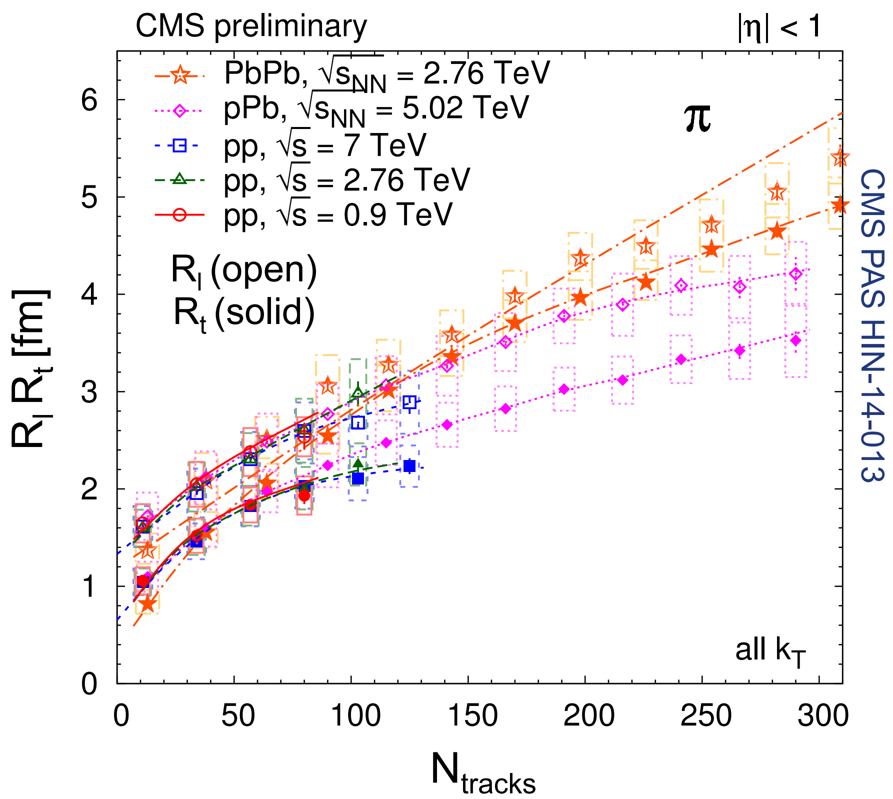




- One- dimension $C_{BE}(q_{inv})$ – exponential fit
  - R for pions and kaons → increase with N_{tracks} for all systems and center of mass energies
  - Small increase for kaons compared to pions: long lived resonances and re-scattering

See poster by Ferenc Sikler

Two Dimensional Results: Pions



- Two-dimensional $C_{BE}(R_l, R_t)$ (*stretched* exponential fit)
  - pp and pPb: $R_l > R_t$ → elongated source in the beam direction in pp and pPb collisions
  - For peripheral PbPb: $R_l \approx R_t$ → spherical source

Three Dimensional Results: Pions

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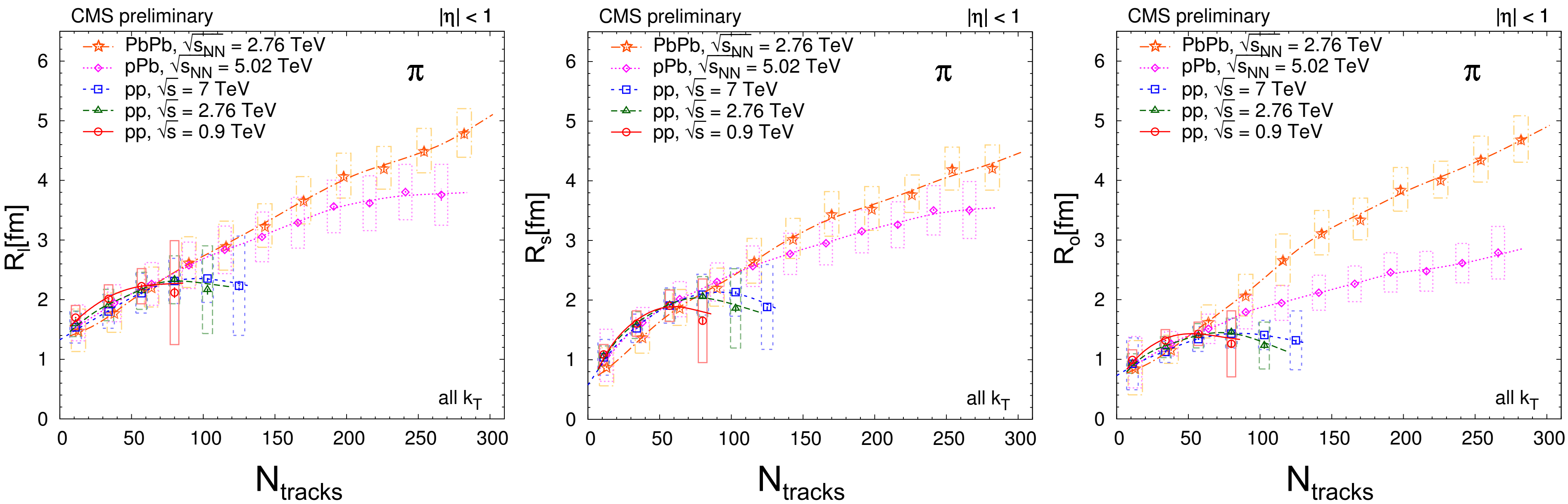

- Three-dimensional $C_{BE}(R_l, R_S, R_o)$ (*stretched* exponential fit)
  - For pp and pPb: $R_l > R_S > R_o$ → elongated source in the beam direction
  - For peripheral PbPb: $R_l \approx R_s \approx R_o$ → approximately spherical source
- Large difference observed between PbPb and pPb for R_o
  - Possible lifetime of the source

k_T Dependence

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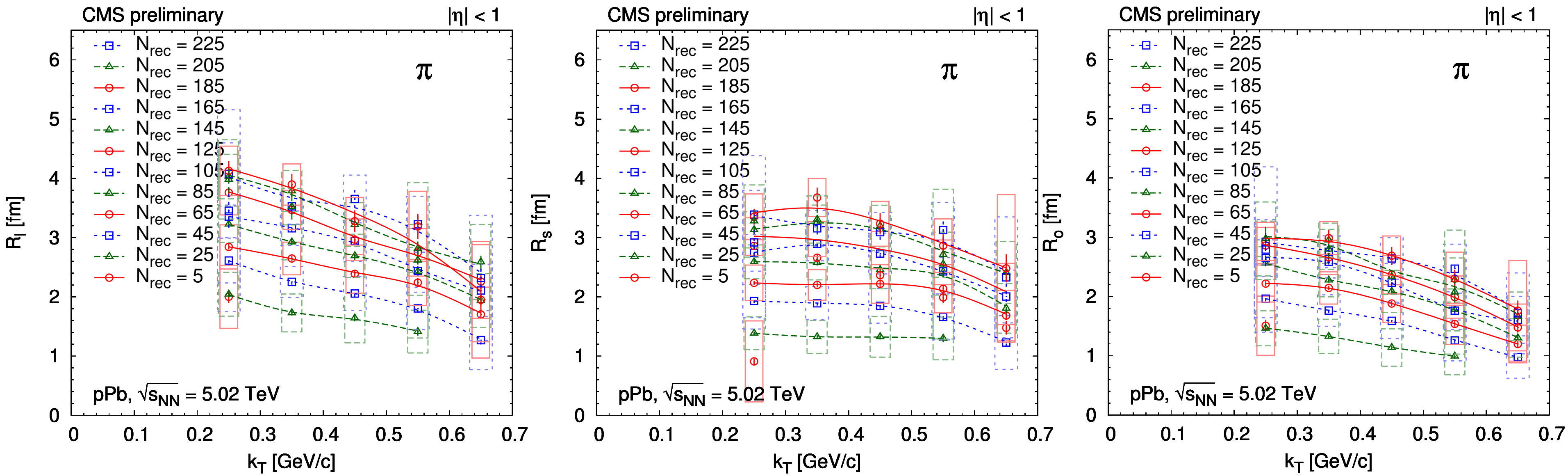


- Three-dimensional $C_{BE}(R_l,R_S,R_o)$ (*stretched* exponential fit)
  - R_l, R_s, R_o → decrease with increase in k_T
  - Similar behavior for all system and at all center of mass energies

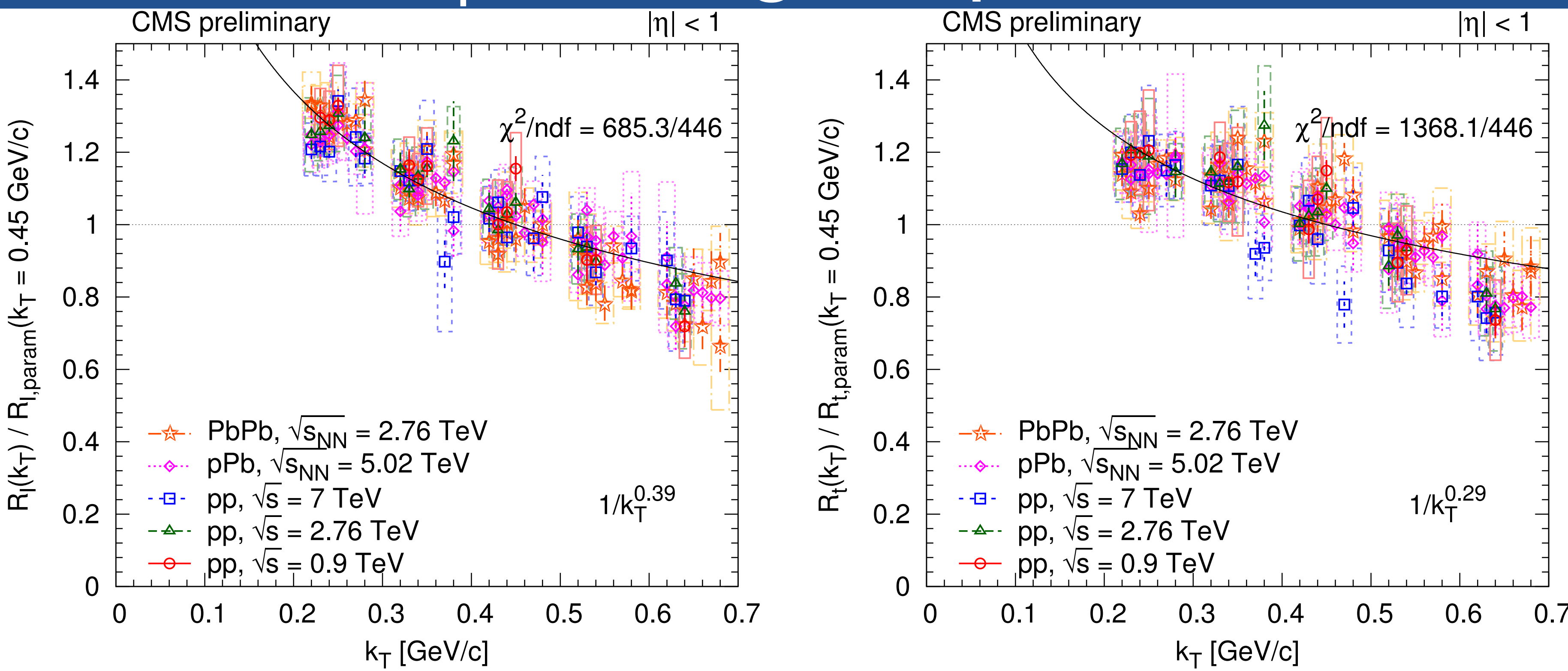
Scaling Properties in N_{tracks} and k_T

- Pion radii
  - Increase with increasing N_{tracks}
  - Decrease with increasing k_T
  - Dependence on N_{tracks} and k_T factorizes:

$$R_{param}\ (N_{tracks},\ k_T) = [a^2 + (bN_{tracks}^{\beta})^2]^{1/2}\ .\ (0.2GeV/c/k_T)^{\gamma}$$

    - For a given R component → *a* (minimal radius) and γ are kept the same for all collision systems
    - Identical parameters used for the three proton-proton energies
    - All five systems are fit simultaneously
  - Plotting as a function of N_{tracks}
    - Radius is scaled to $R_{measured}$* $(1/0.45^{\gamma})$ / $(1/k_T^{\gamma})$
  - Plotting as a function of k_T
    - $R_{measured}$/(R_{param} at the same N_{tracks} but at k_T=0.45)

k_T Scaling Properties



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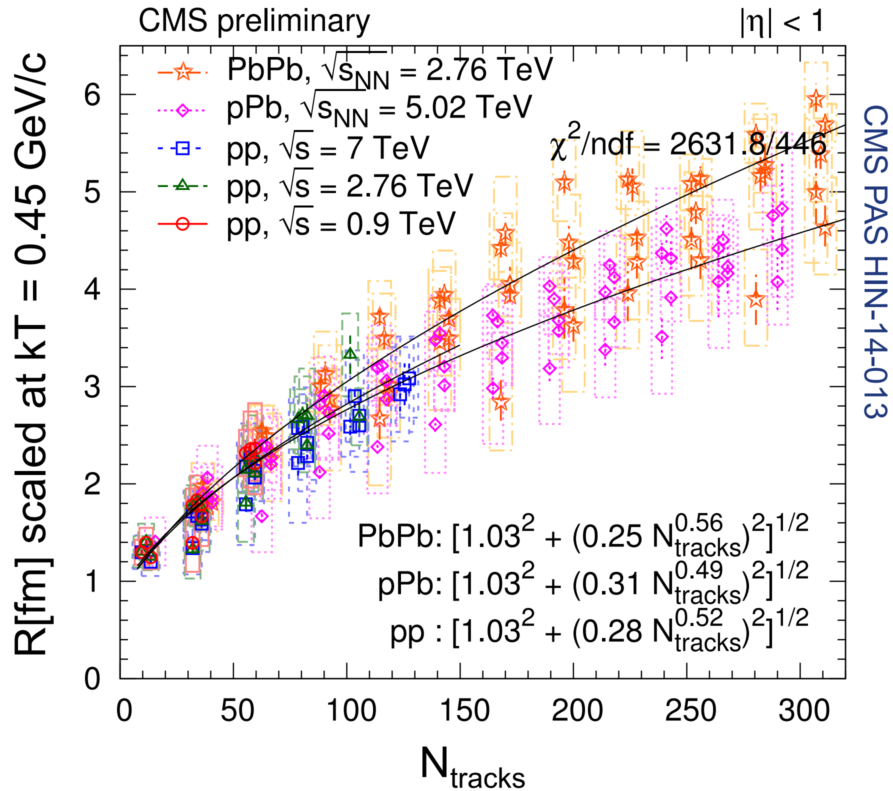
$$R_{param}\ (N_{tracks},\ k_T) = [a^2 + (bN_{tracks}^{\beta})^2]^{1/2}\ .\ (0.2GeV/c/k_T)^{\gamma}$$

- $R_{measured}$ (N_{tracks}, k_T) divided R_{param} (same multiplicity but k_T=0.45)
- All plots vs. k_T look similar but different slopes

See poster by Ferenc Sikler

Scaling Properties in 1D

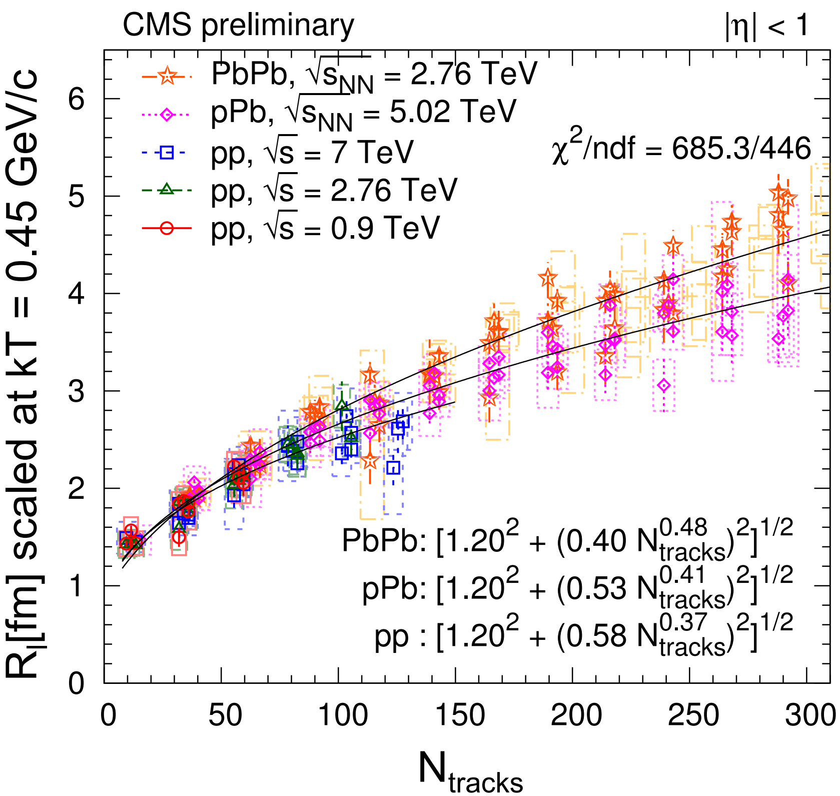


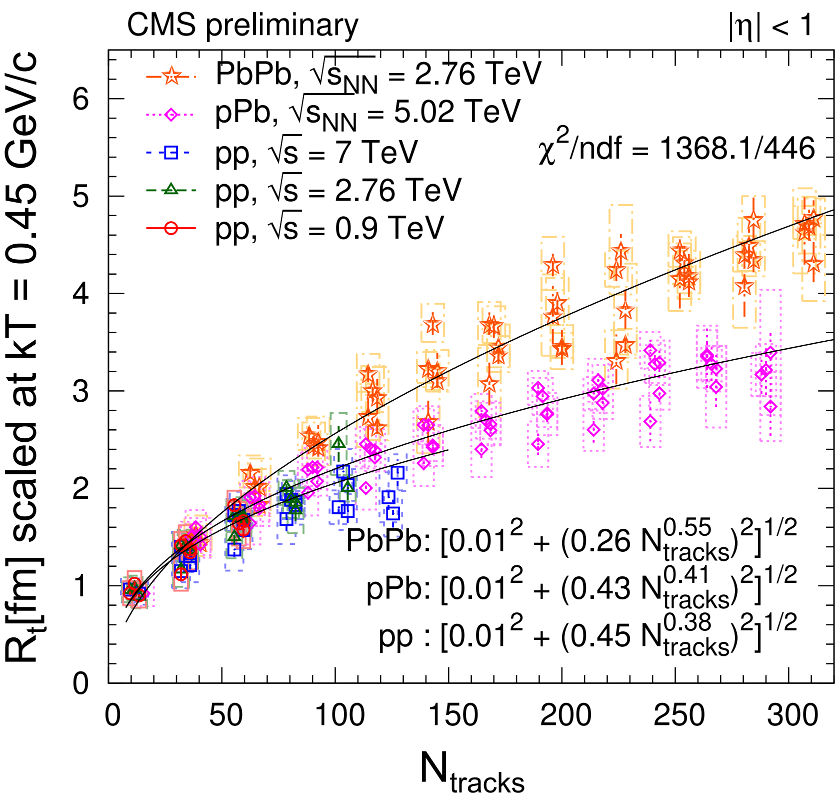
$$R_{param}\ (N_{tracks},\, k_T) = [a^2 + (bN^{\beta}_{tracks})^2]^{1/2}\ .\ (0.2GeV/c/k_T)^{\gamma}$$

- Radius is scaled to $R_{measured}$* $(1/0.45^{\gamma})$ / $(1/k_T^{\gamma})$

See poster by Ferenc Sikler

Scaling Properties in 2D





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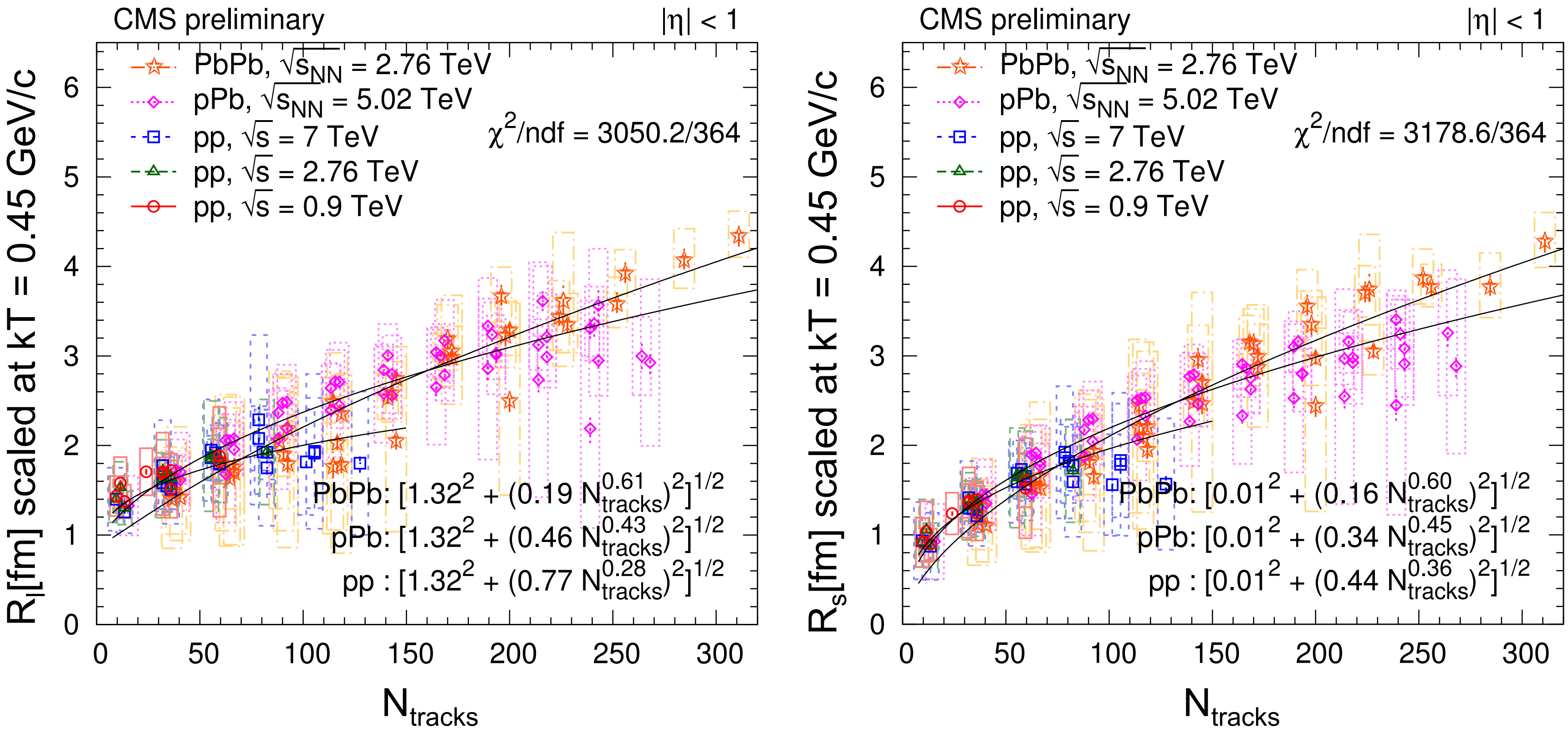
- In the low N_{tracks} limit → not sensitive to the type of system or to the colliding energy
- For all N_{tracks}, radii for pp and pPb are very similar

Scaling Properties in 3D



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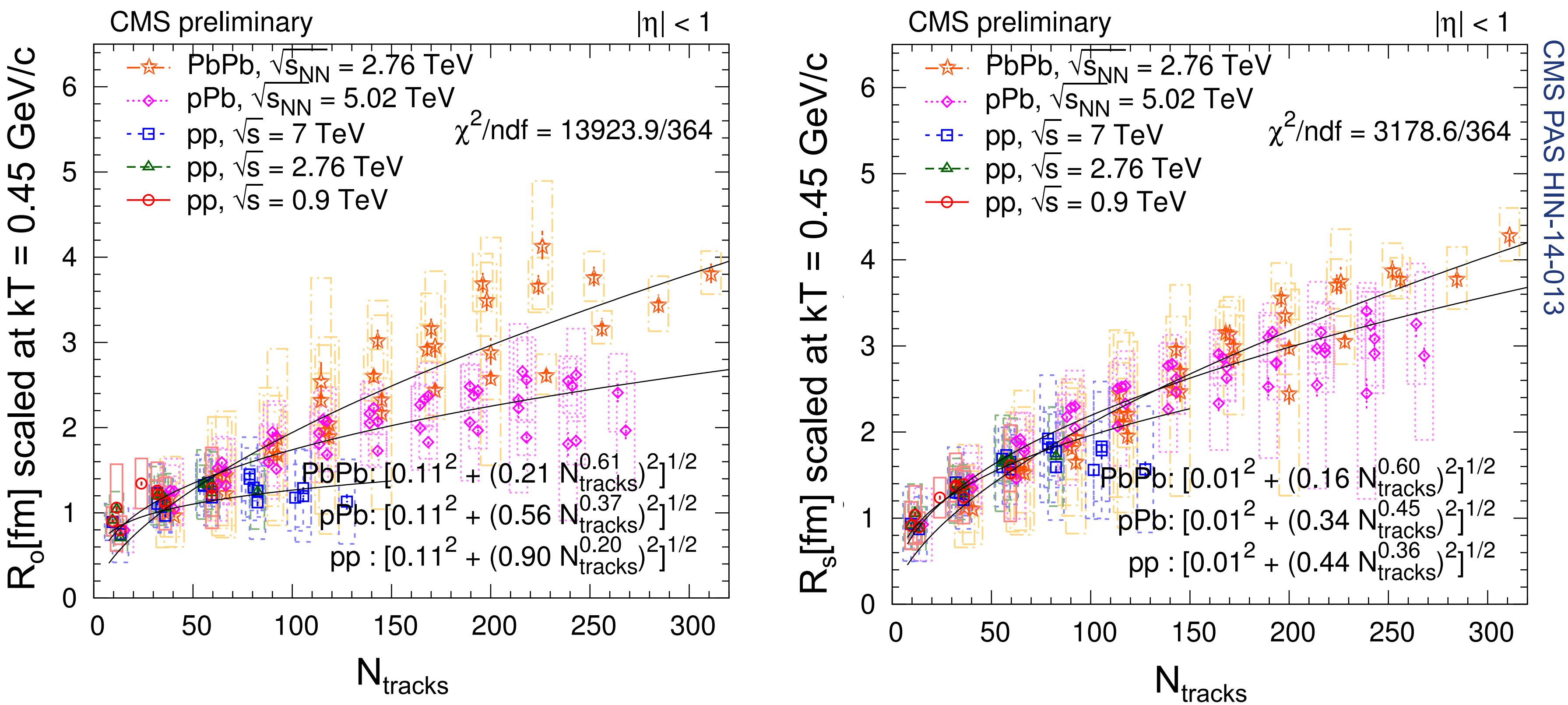
- R_l and R_s → very similar magnitudes and dependence on N_{tracks}

Scaling Properties in 3D



- R_o → some differences seen in the dependence on N_{tracks}

Summary

- ✓ Measured correlations → best described by stretched exponential function
- ✓ Radius parameters → from 1-5 fm
  - ✓ All the radii increase smoothly with N_{tracks}
  - ✓ Highest values for pPb and peripheral PbPb (large system)
  - ✓ Small increase for kaons compared to pions
  - ✓ Radius parameter decrease with increasing k_T
  - ✓ Radius parameters for pp and pPb are same for similar N_{tracks}
- ✓ For two- and three-dimensions in pp and pPb
  - ✓ $R_l > R_t$
  - ✓ $R_l > R_s > R_o$

  } source is elongated in the beam direction in pp and pPb collisions
- ✓ In peripheral PbPb collisions, R_o differs from that seen in pp, pPb, possibly indicating the different life time of the source created in such collisions

- Results Presented:
  - CMS PAS HIN-14-013
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN14013

- Poster: Ferenc Sikler

Thank you

Back Up

$$K(q_{\rm inv}) = G(\eta)\ [1 + \frac{\pi\eta q_{\rm inv} R}{1.26+q_{\rm inv}R}]$$

$$C_2^{+-}(q_{\rm inv}) = c\ K^{+-}(q_{\rm inv})\ [1 + \frac{b}{\sigma_b\sqrt{2\pi}}\ \exp(-\frac{q_{\rm inv}^2}{2\sigma^2})]$$

$$C_2^{\pm\pm}(q_{\rm inv}) = c\ K^{\pm\pm}(q_{\rm inv})\ [1 + z(N_{\rm rec})\ \frac{b}{\sigma_b\sqrt{\pi}}\ \exp(-\frac{q_{\rm inv}^2}{2\sigma^2})]\ C_{BE}(q_{\rm inv})$$