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INTERNATIONAL PHD PROJECTS IN APPLIED NUCLEAR PHYSICS AND INNOVATIVE TECHNOLOGIES
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φ meson production in proton-proton collisions at 158 GeV in the NA61/SHINE experiment at CERN SPS

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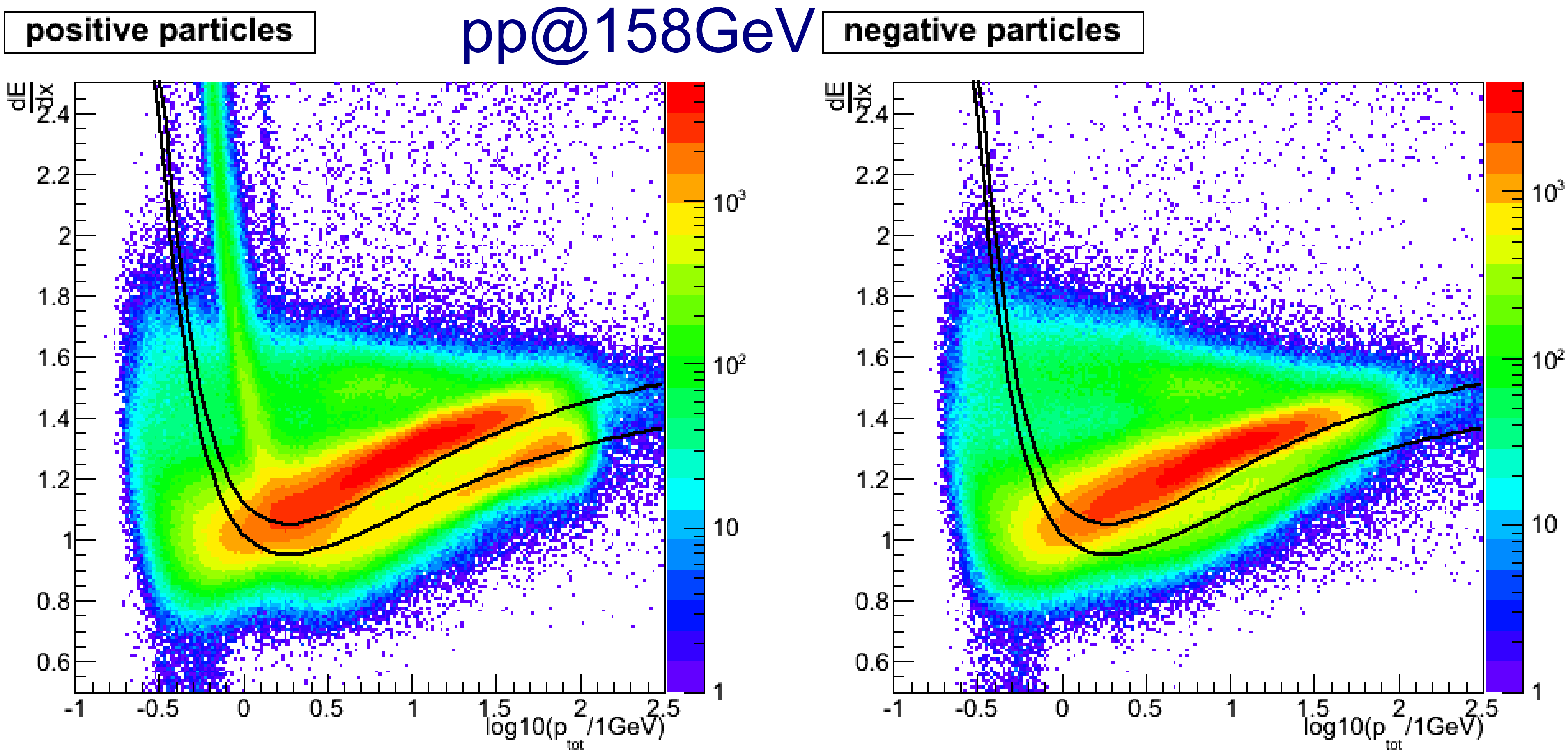
Introduction

- φ ($s\bar{s}$) meson according to PDG 2012:
  - Mass m = 1019.455 ± 0.020 MeV
  - Full width Γ = 4.26 ± 0.04 MeV
  - BR($\varphi \rightarrow K^+K^-$) = (48.9 ± 0.5) %
- The goal is to obtain φ multiplicities in pp collisions for 5 available energies
- Motivation: to constrain hadron production models – various types of models predict certain scaling properties for multiplicities of hadrons if we change energy or size of the colliding system. φ especially interesting due to its hidden strangeness ($s\bar{s}$) – should it be treated as a strangeness-neutral hadron which production is governed solely by the mass, or assuming that 2 strange quarks need to be produced and coalesced what might be influenced by strangeness suppression/enhancement, or … ?
- NA49 published results for pp,pPb @ 158 GeV, as well as PbPb at 20,30,40,80,158 GeV.
- First I will obtain results for pp@158GeV to cross check with NA49 – available only single differential spectra of p_T and y.
- Analysis by means of invariant mass spectra fits in the $\varphi \rightarrow K^+K^-$ decay channel. Available about 1.7M preselected pp@158GeV events.

Kaon candidate selection

- No PID selection for kaons – no φ peak in the spectrum
- accept tracks in +/- 5% band around Kaon Bethe-Bloch curve; area between black curves is accepted as Kaons



Signal extraction

- Background is parametrised using event mixing method:

  Kaon candidate taken from the current event is combined with candidates from previous 500 events to create phi candidates in the mixed events spectrum

- Signal is parametrised with Voigt function to take into account Lorentz shape of resonance and Gaussian broadening due to detector resolution:

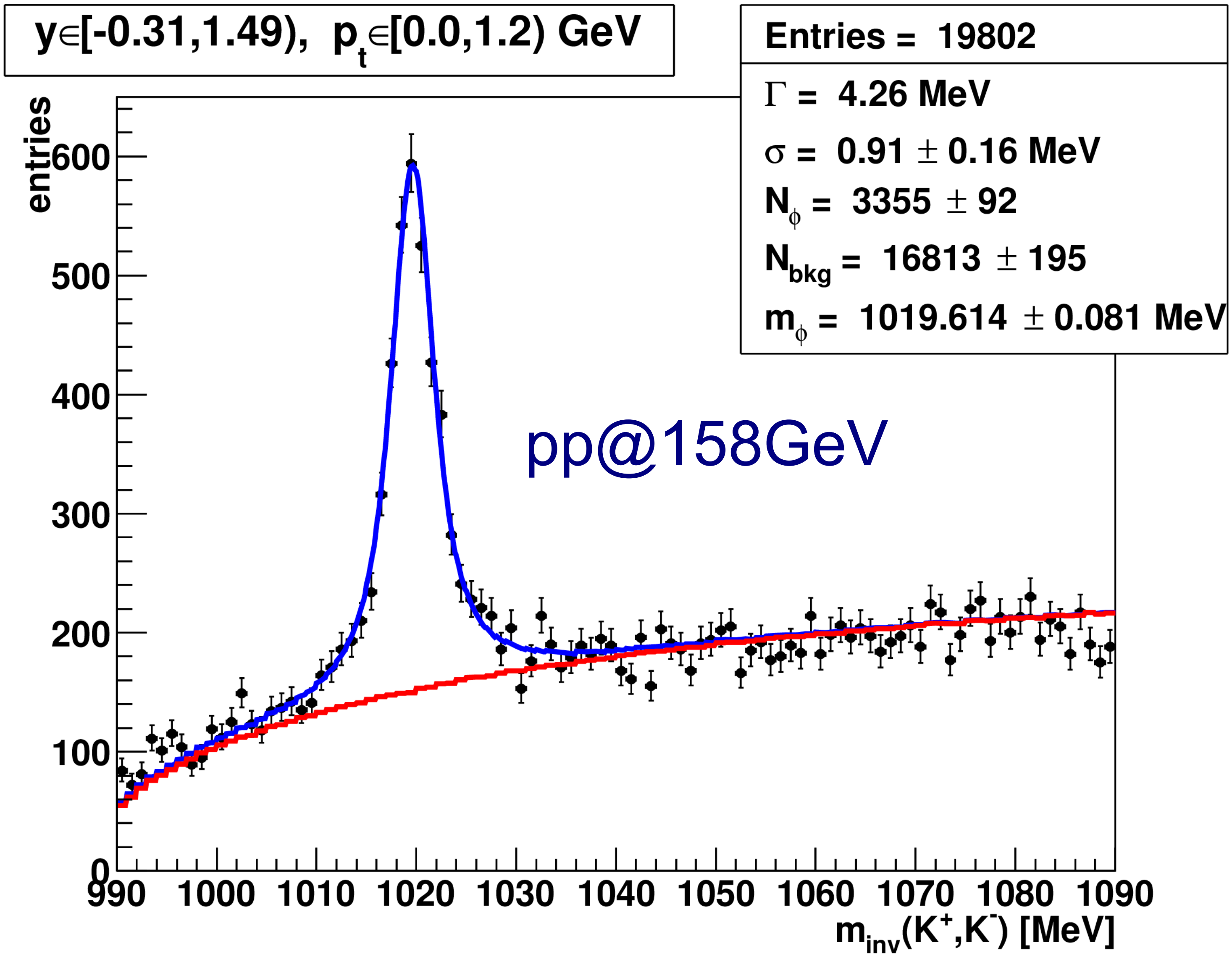
$$V(x;\sigma,\gamma) = \int_{-\infty}^{\infty} G(x';\sigma)L(x-x';\gamma)\,dx'$$

- Invariant mass spectrum is fitted with:

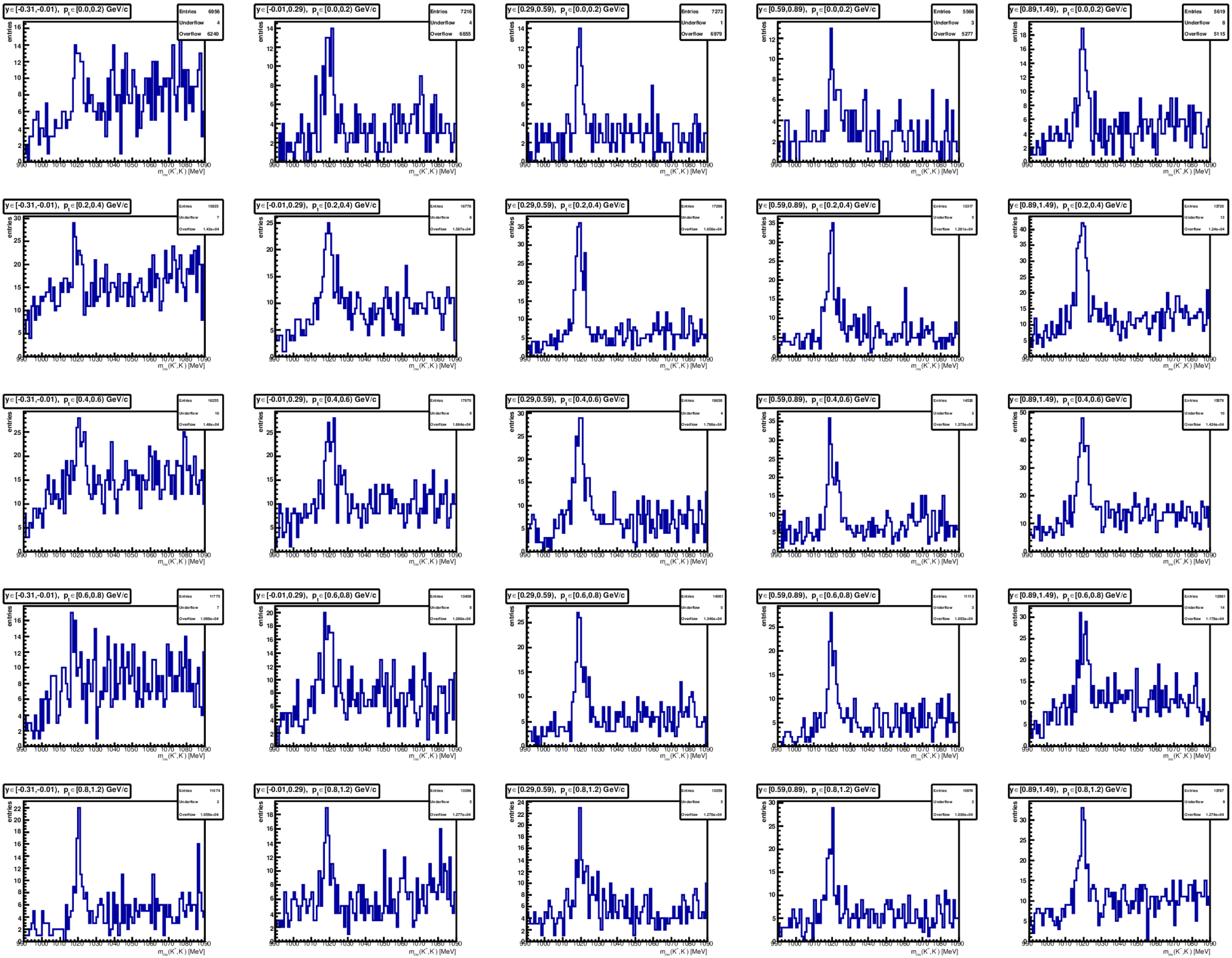
$$f(m) = N_\phi \cdot V(m - m_\phi; \sigma, \Gamma = 4.26\,\mathrm{MeV}) + \beta \cdot Mixed(m)$$

Unbinned phase space matching to NA49

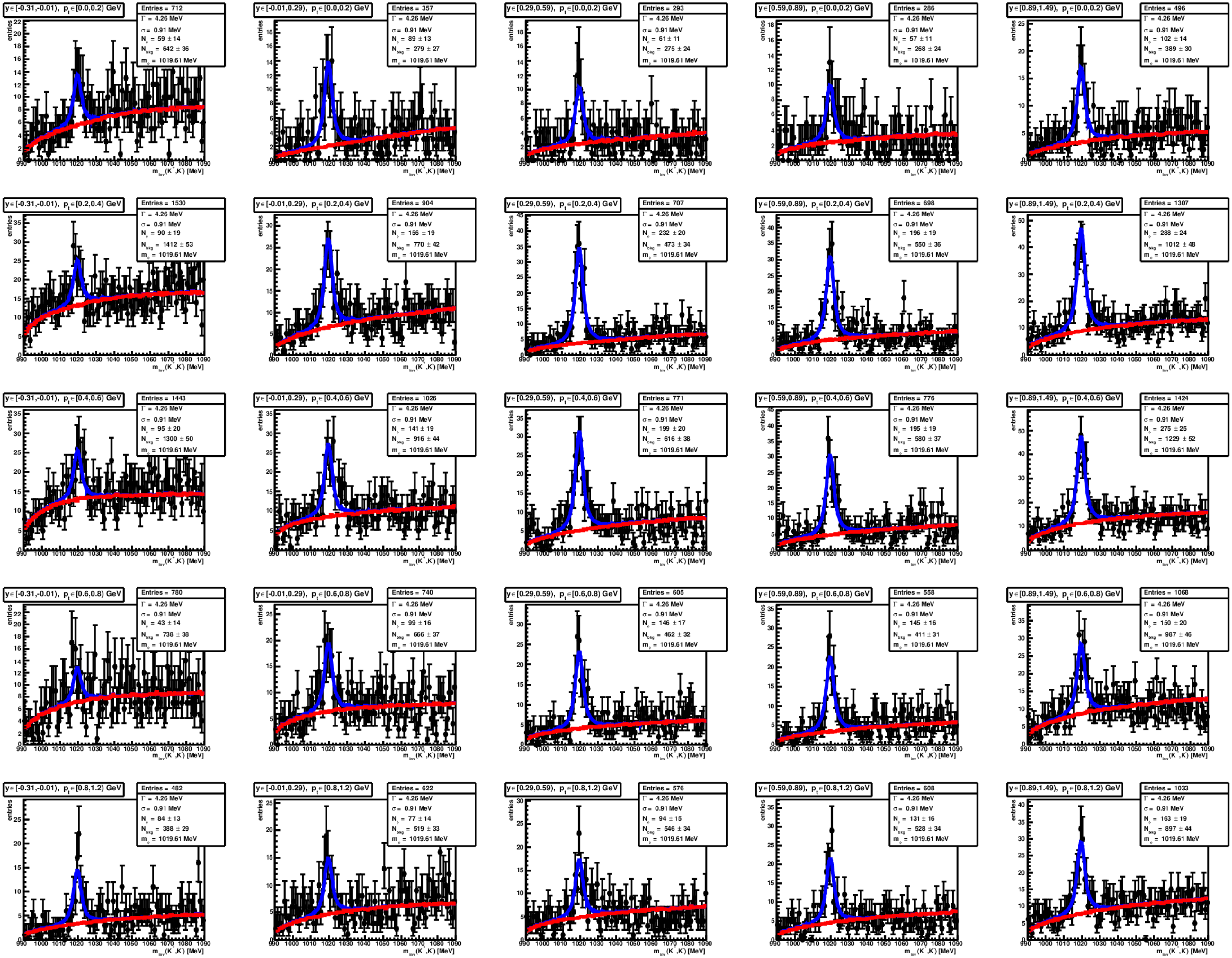
- Fit with Voigt + mixed event spectrum*β



Binning (2D based on NA49 2x1D binning) - pp@158GeV



Binning (2D based on NA49 2x1D binning) - pp@158GeV



Tag & Probe method

The method

- It is used by others (e.g. LHCb, ATLAS) to correct for number of resonances lost due to rejecting of daughter tracks by PID cut – PID cut efficiency
- One needs 2 data samples:
  - Probe

    Both kaon candidates need to pass PID cut for kaon (this was used up to now)
  - Tag

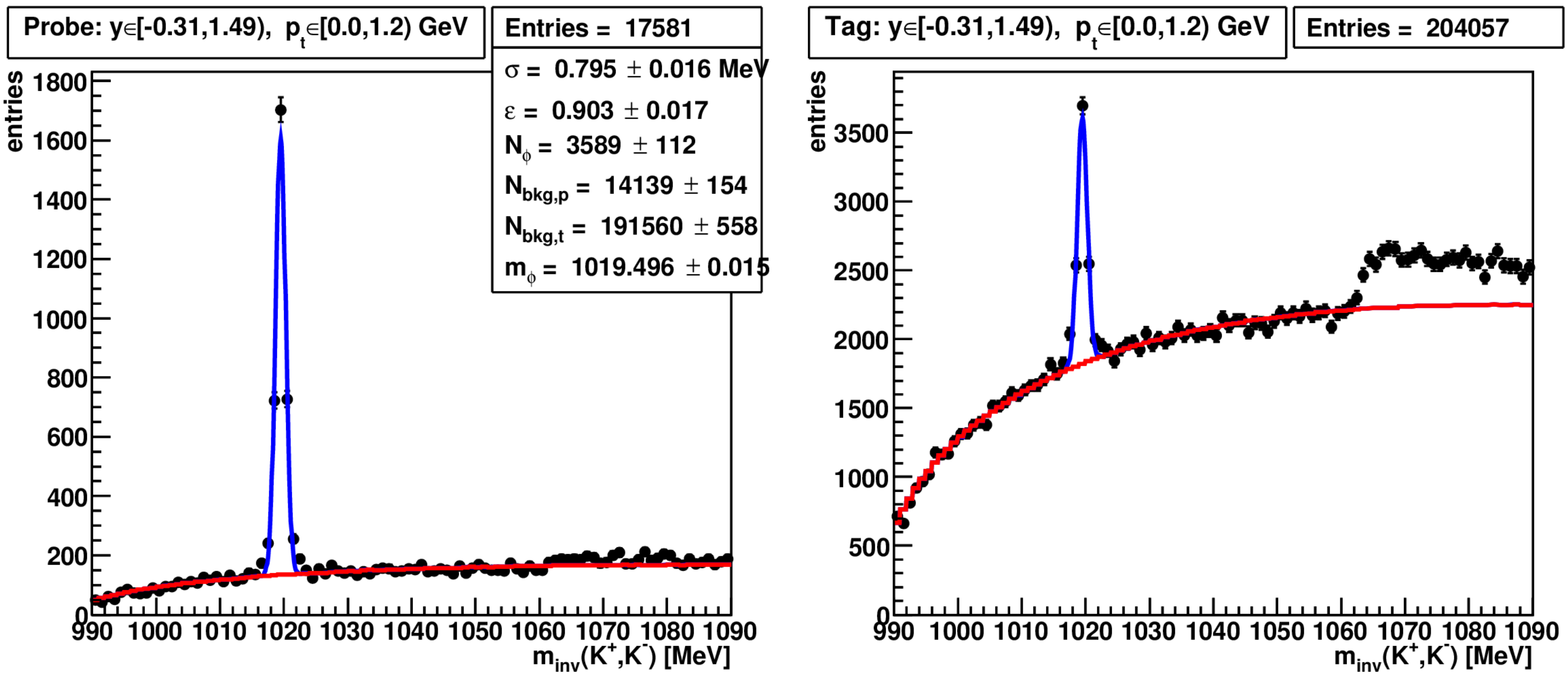
    At least one of kaon candidates need to pass PID cut for kaon
- Assuming true number of resonances in data is N_{φ} and PID cut efficiency is ε, numbers of observed resonances:

$$N_{tag} = 2N_{\phi}\epsilon(1-\epsilon) + N_{\phi}\epsilon^2$$
$$N_{probe} = N_{\phi}\epsilon^2$$

Test with EPOS MC

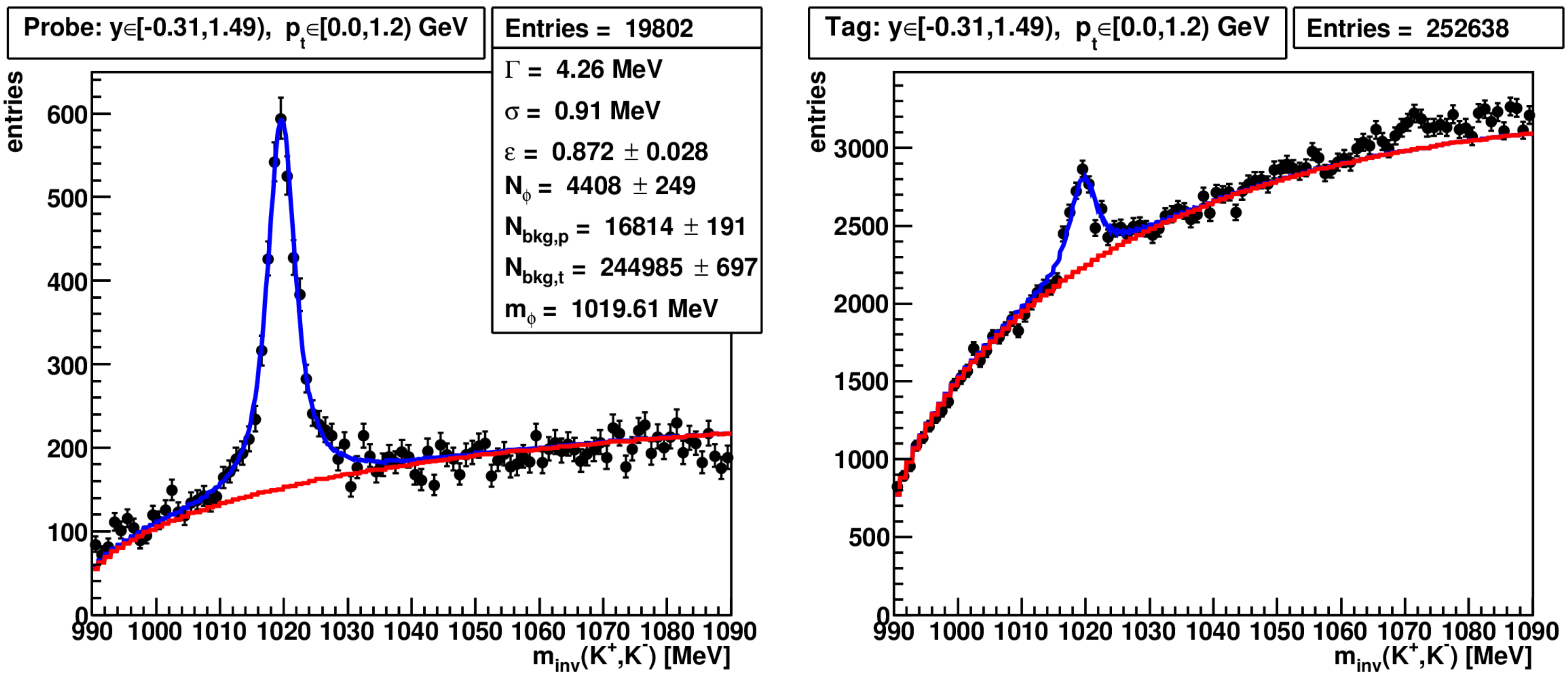
- To check whether my implementation of the method works, I implemented a PID cut in MC:
  - reconstructed VertexTrack is matched to MC track
  - PID cut passes in 90% times when matched MC track is kaon – this 90% should be returned by the method
  - To get some background from misidentification, PID cut passes also for 5% of pions or protons

Test with EPOS MC

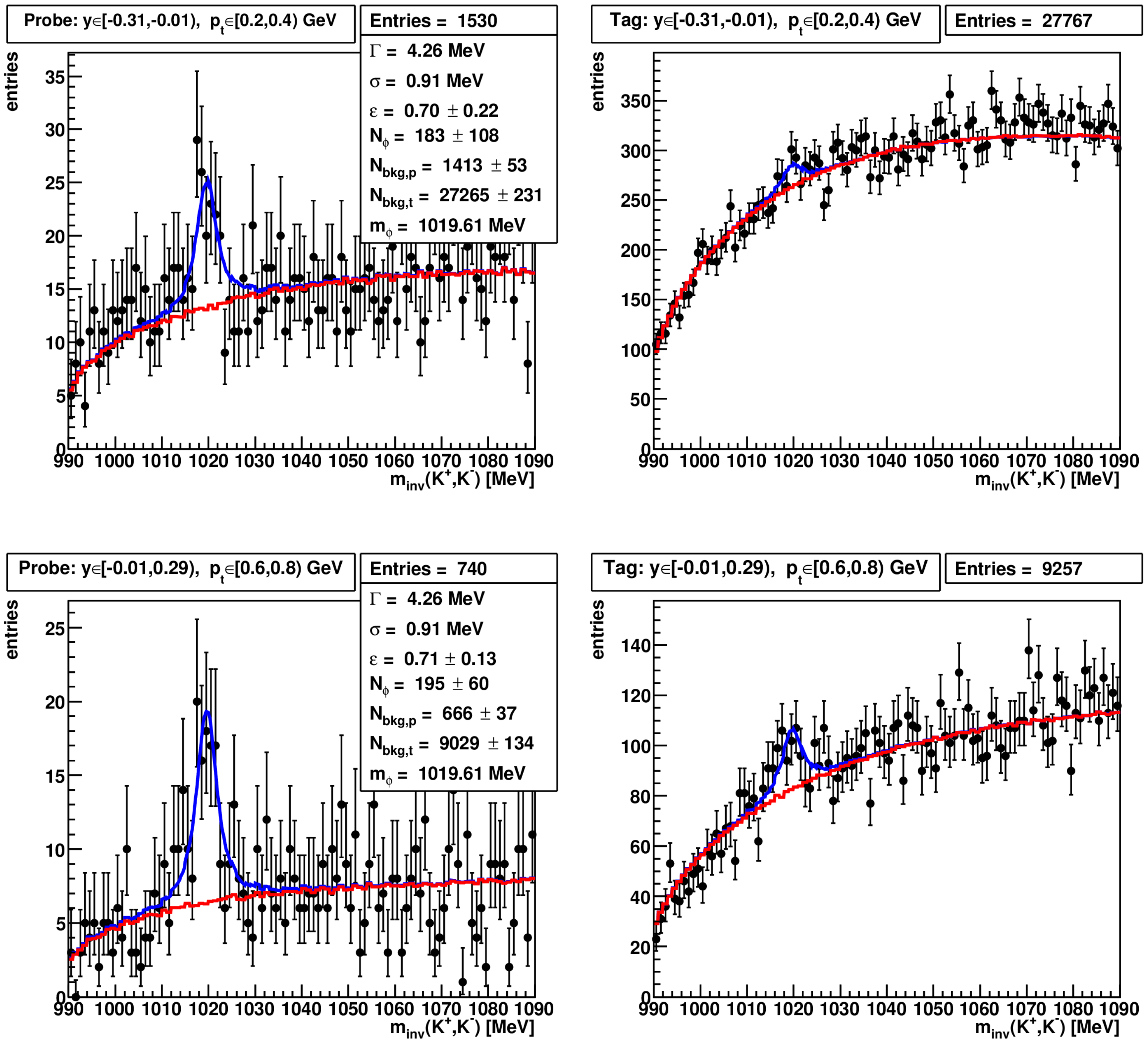


- Width of Lorentz is set to zero, because EPOS has no physical mass distribution
- Bump at m>1060MeV – probably misidentified K*→K,π
- Fit done in range 990-1060 MeV
- Obtained efficiency: 90.3% +/- 1.7%

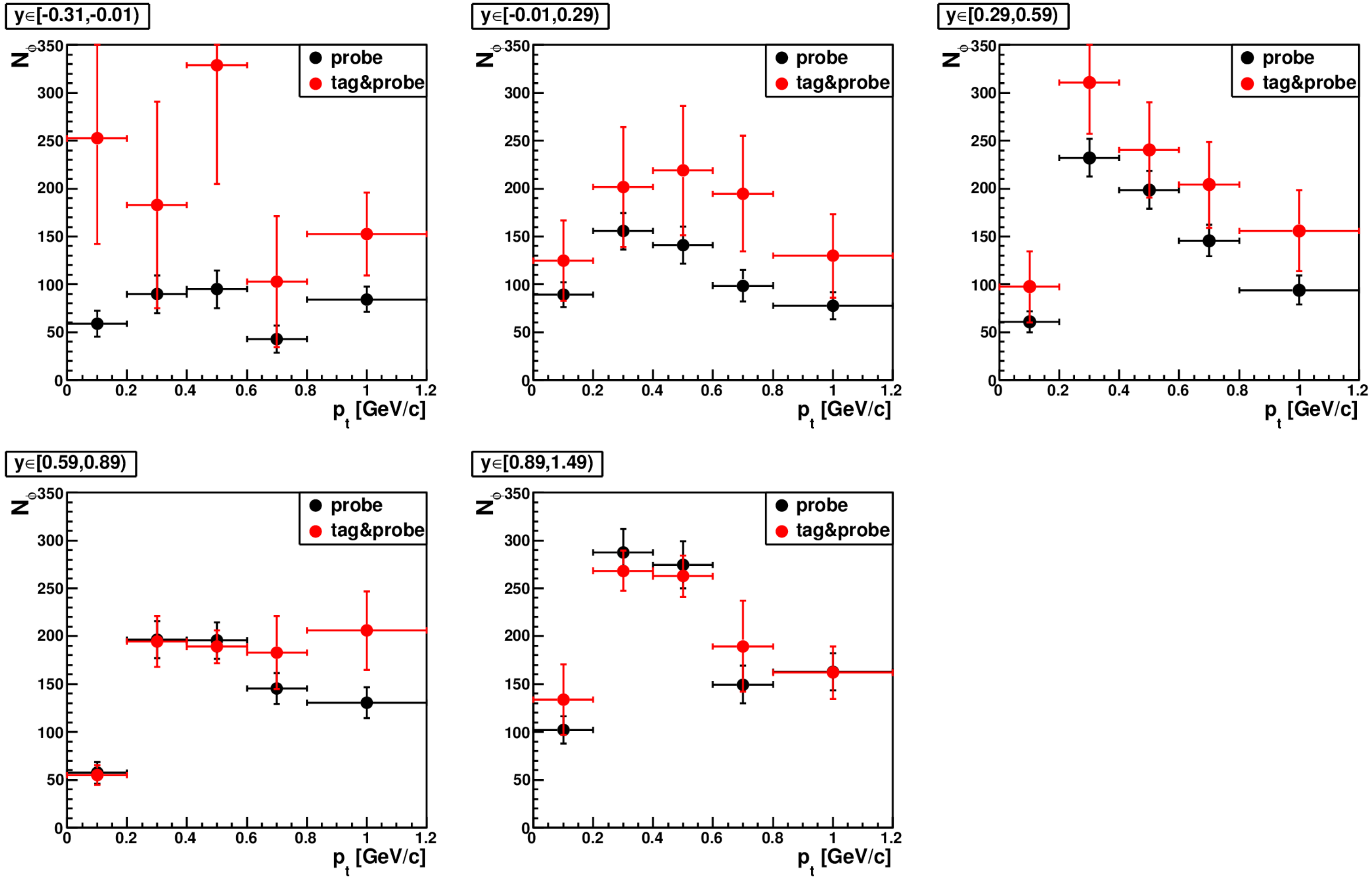
Data in unbinned phase space matching to NA49



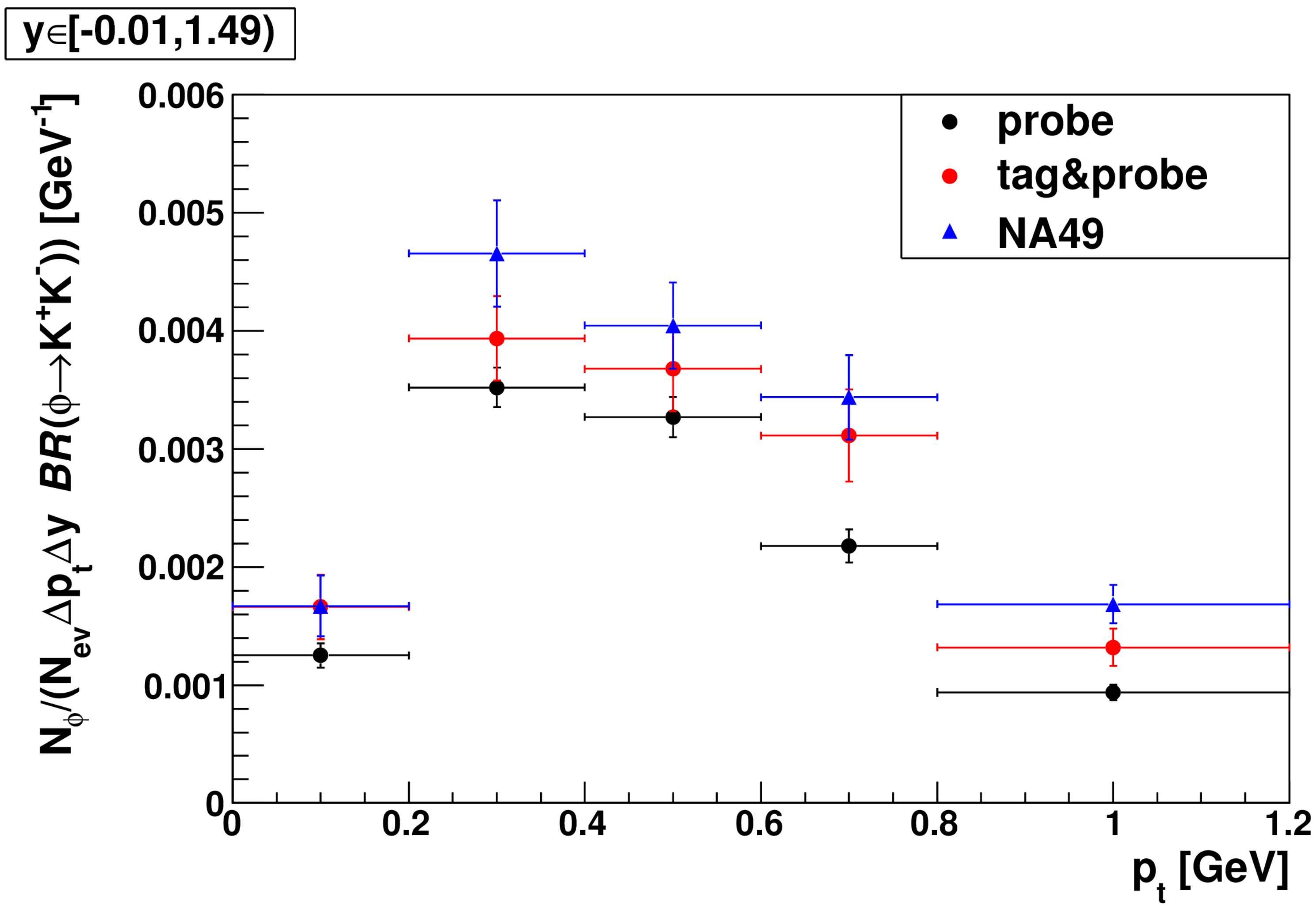
Examples of binned fits



Binned fit results



Comparison to NA49 – uncorrected spectrum



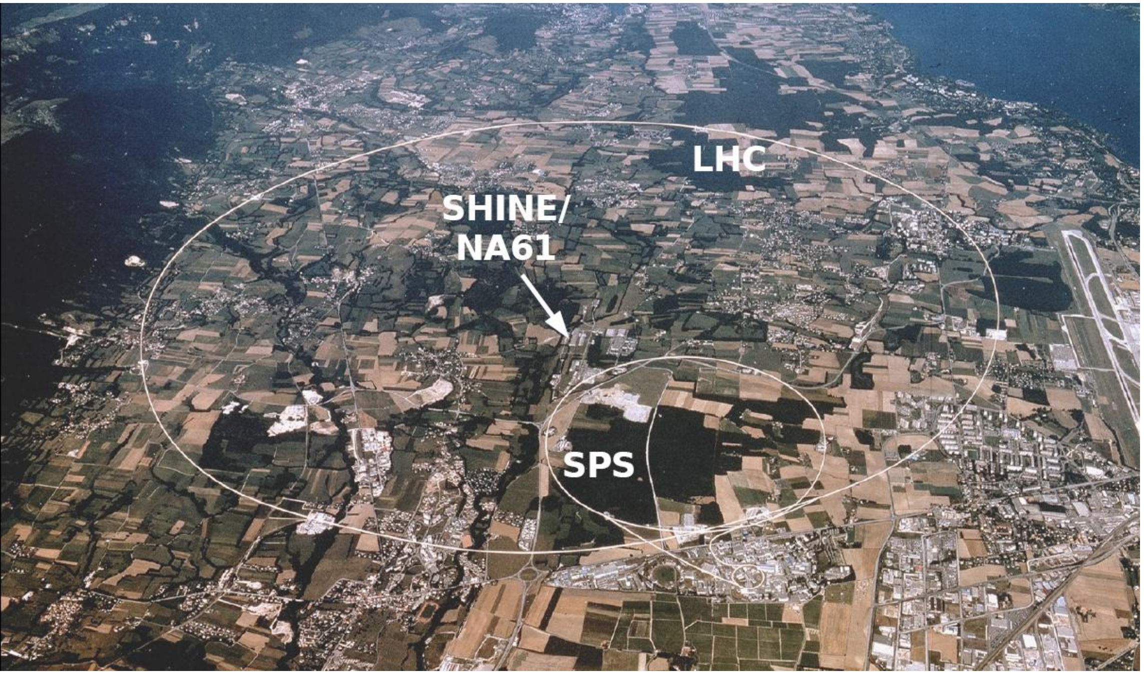
Conclusion

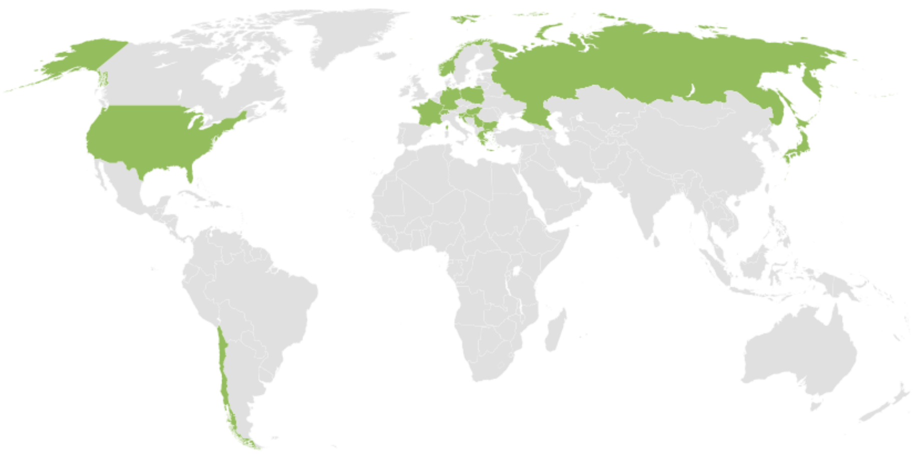
- Uncorrected spectrum looks reasonable.
- Analysis in progress, several corrections to be done.
- Need to move to newly reconstructed, better calibrated data and incorporate proper kaon candidate selection using fitted Bethe-Bloch.
- Check if it is possible to reduce tag&probe statistical uncertainty using a second band in the tag sample to remove pions/protons without changing efficiency for kaons.

BACKUP

General info

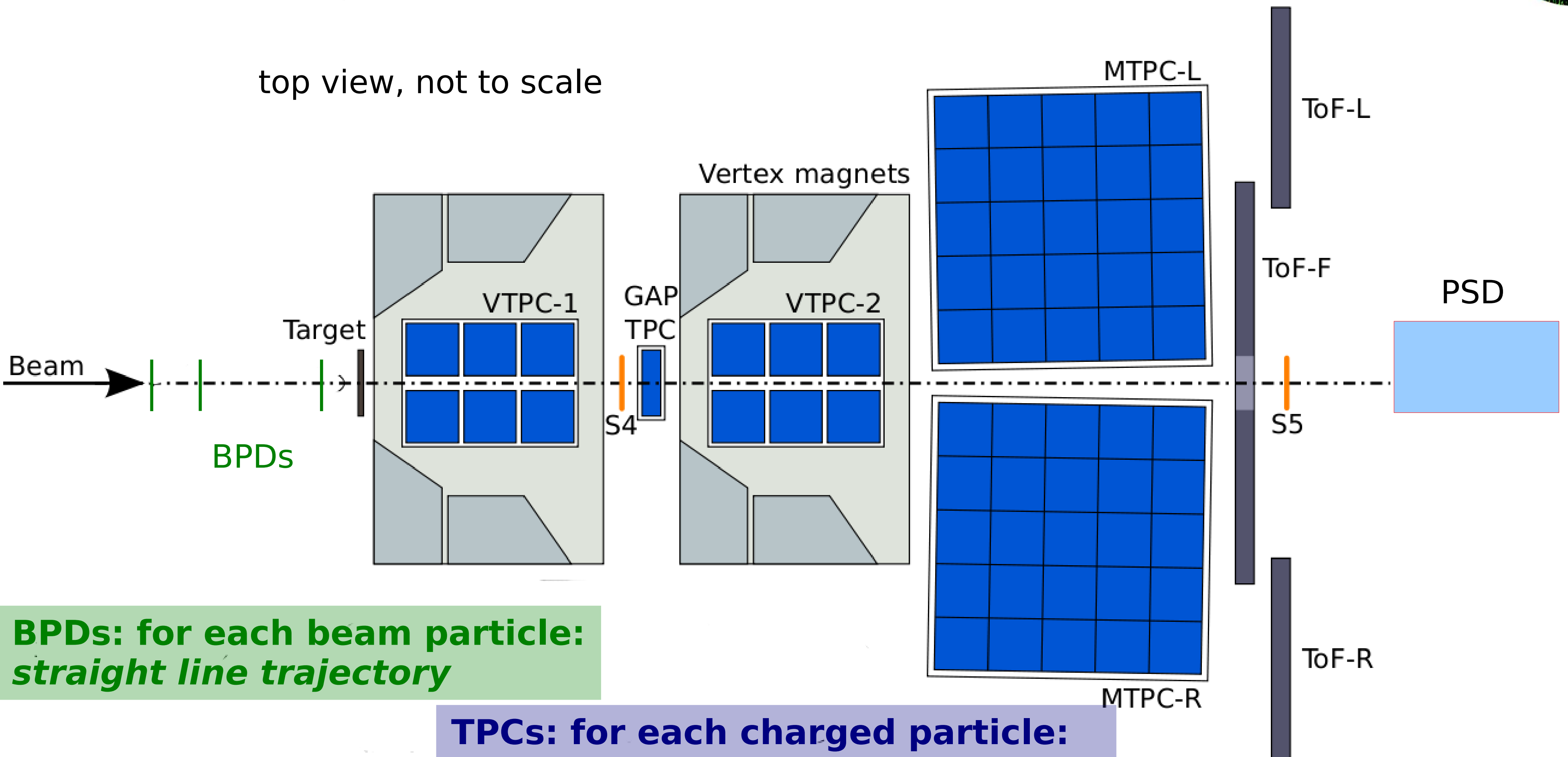
SHINE – SPS Heavy Ion and Neutrino Experiment





- Fixed target experiment in the north area of the CERN SPS
- Beams:
  - Ions (secondary: Be, primary: Ar and Xe) at 13A - 158A GeV/c
  - Hadrons (secondary): p at 13 - 158 GeV/c, π^- at 158 and 350 GeV/c, K^- at 158 GeV/c
- Based on the upgraded NA49 detector
- Proposal November 2006, pilot run 2007, first physics run 2009, further runs in 2010-2013
- Collaboration of ~150 physicists, 28 institutes, 16 countries

Detector



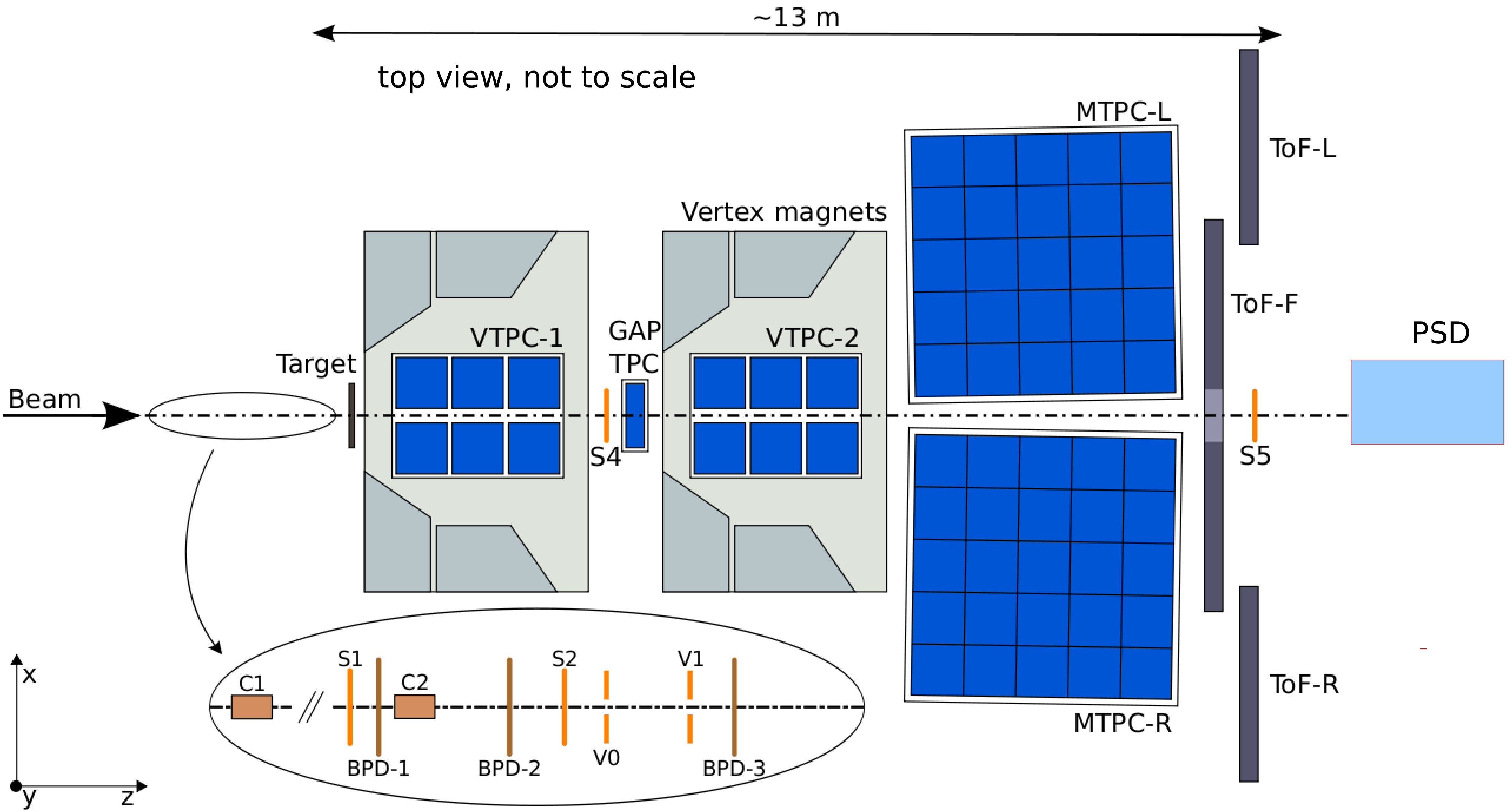
BPDs: for each beam particle:
straight line trajectory

TPCs: for each charged particle:
charge, momentum, mass (dE/dx)

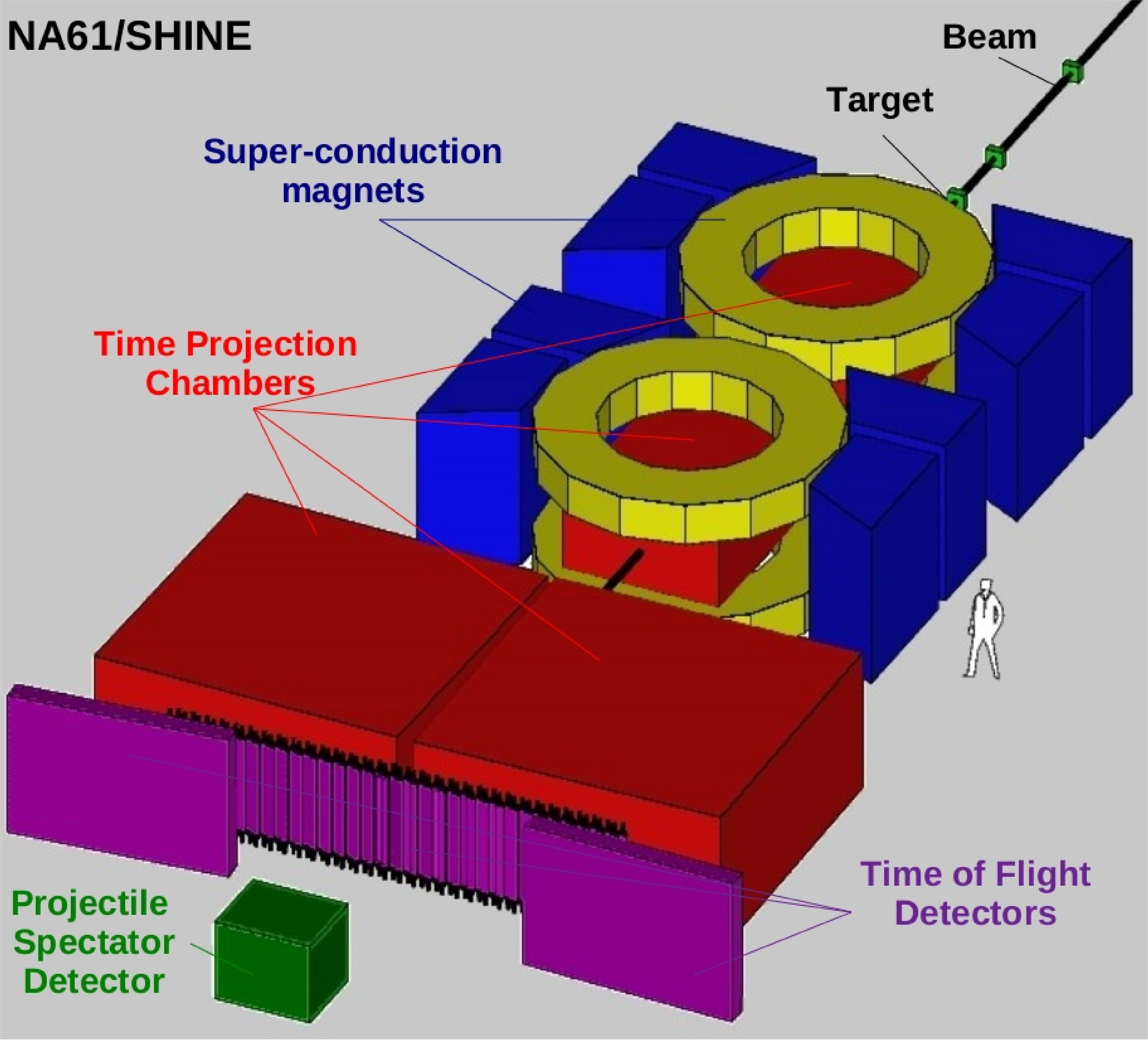
TOFs: for each charged particle:
mass (tof)

PSD: for all particles:
total energy

NA61/SHINE at CERN SPS



+Z detector, +A detector


NA61/SHINE
Beam
Target
Super-conduction
magnets
Time Projection
Chambers
Time of Flight
Detectors
Projectile
Spectator
Detector

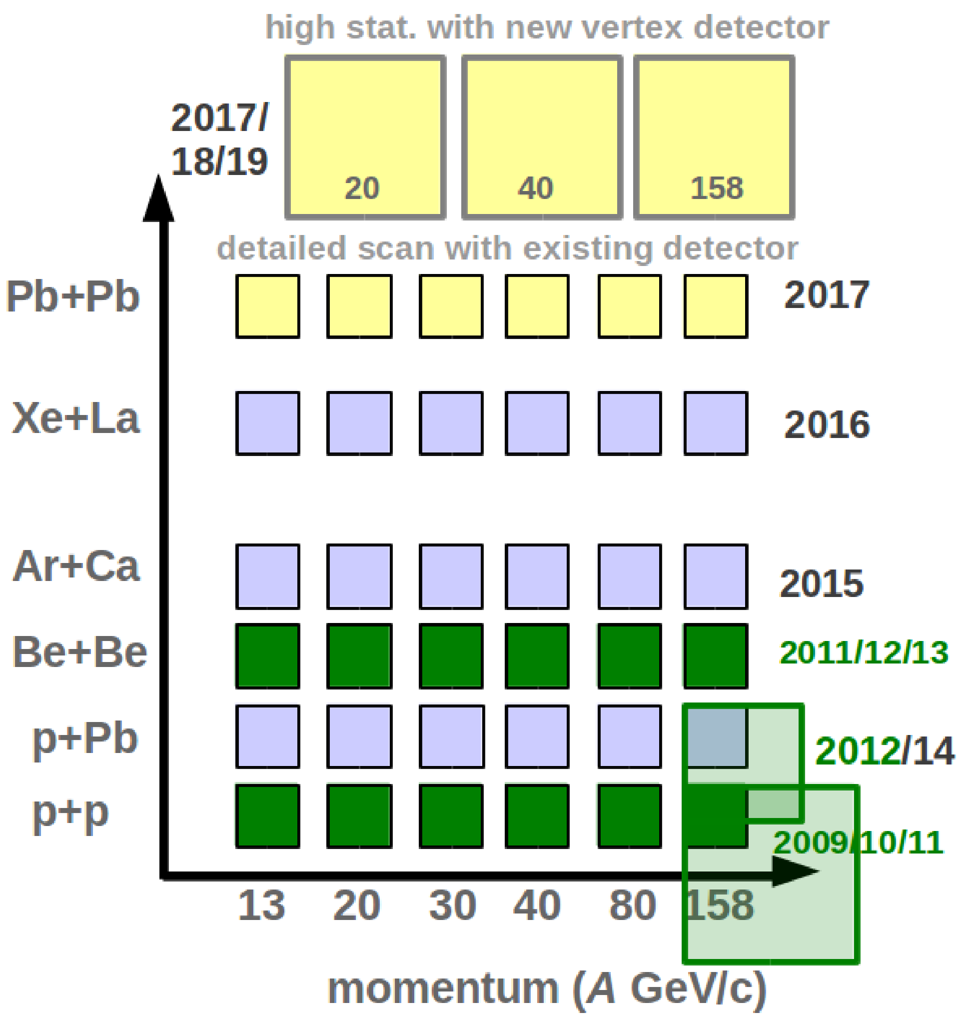
NA61/SHINE physics program

Hadron production in p+p, p+A, h+A, A+A at various energies

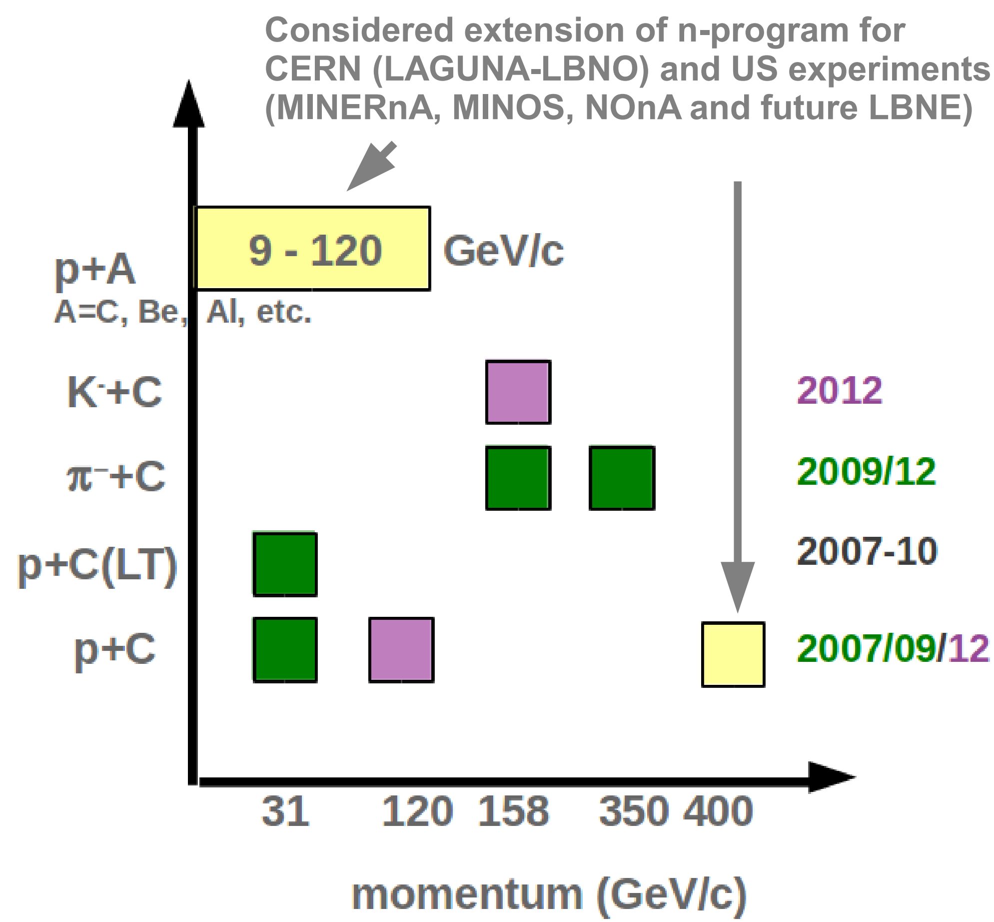
- **Heavy ion program - spectra, fluctuations, correlations**
  - search for the critical point of strongly interacting matter
  - study of the properties of the onset of deconfinement
  - study high p_T particles (energy dependence of nuclear modif. factor)
- **Neutrino and cosmic-ray physics programs - precision data on hadron production (spectra)**
  - reference measurements of p+C interactions for the T2K experiment for computing initial neutrino fluxes at J-PARC
  - reference measurements of p+C, p+p, p+C, and K+C interactions for cosmic-ray physics (Pierre-Auger and KASCADE experiments) for improving air shower simulations
- **Considered extensions beyond the approved program**
  - measurements of Pb+Pb collisions for the ion program

    (+ open charm and multi-strange particles, high pT spectra)
  - measurements for the Fermilab neutrino program
  - measurements for the CERN (LBNO) neutrino program

Status of the NA61 data taking within the heavy ion program



Status of the NA61 data taking within the neutrino and CR programs

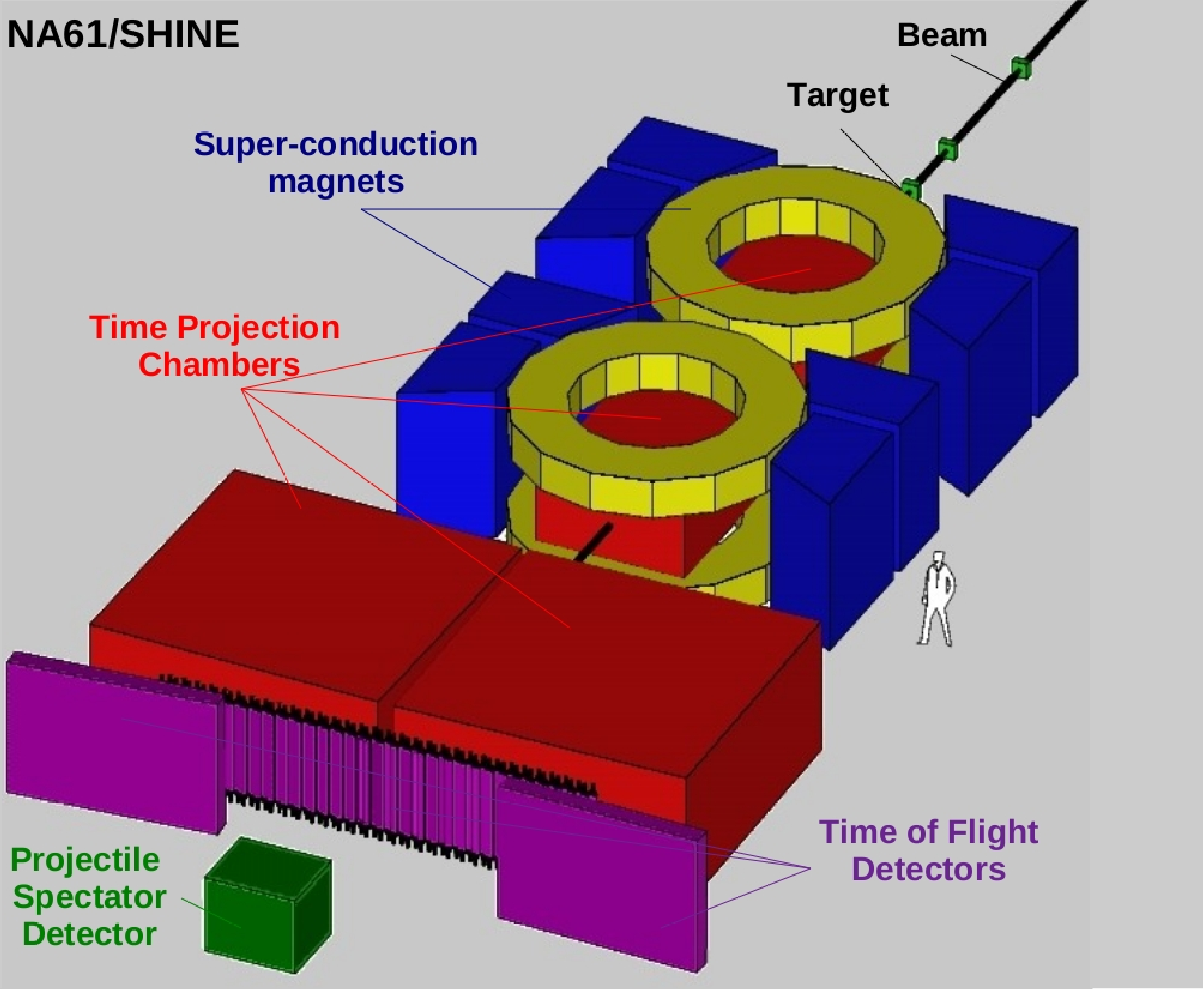


recorded data

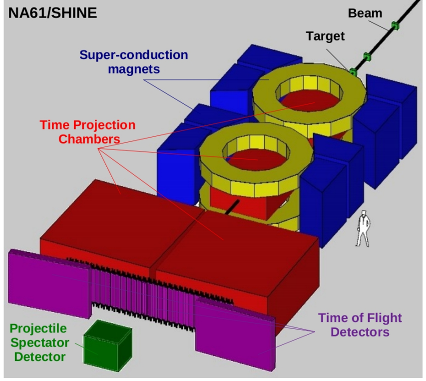
pilot (test) data

planned data (approved)

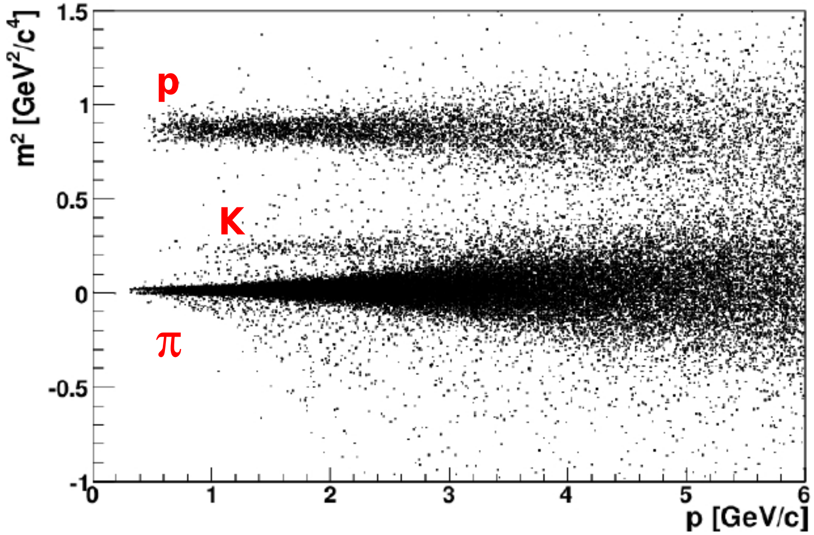
beyond the approved program


NA61/SHINE
Beam
Target
Super-conduction magnets
Time Projection Chambers
Time of Flight Detectors
Projectile Spectator Detector

Detector – particle identification



ToF – low momenta

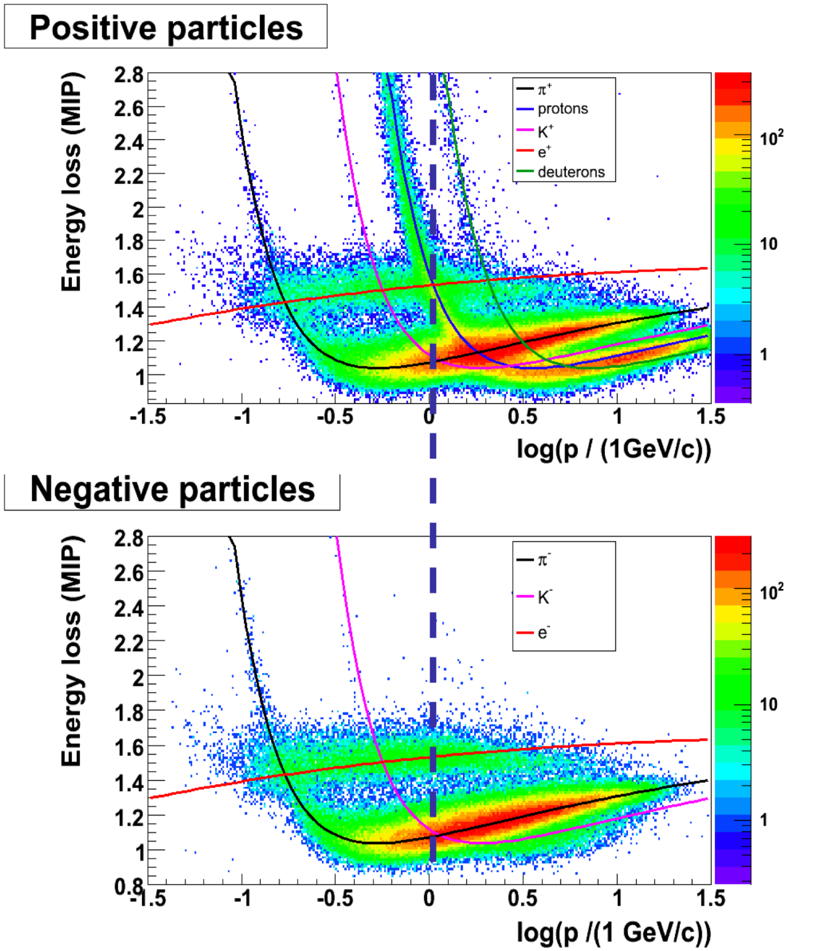


$\sigma(p)/p^2 \approx 10^{-4}$ (GeV/c)$^{-1}$

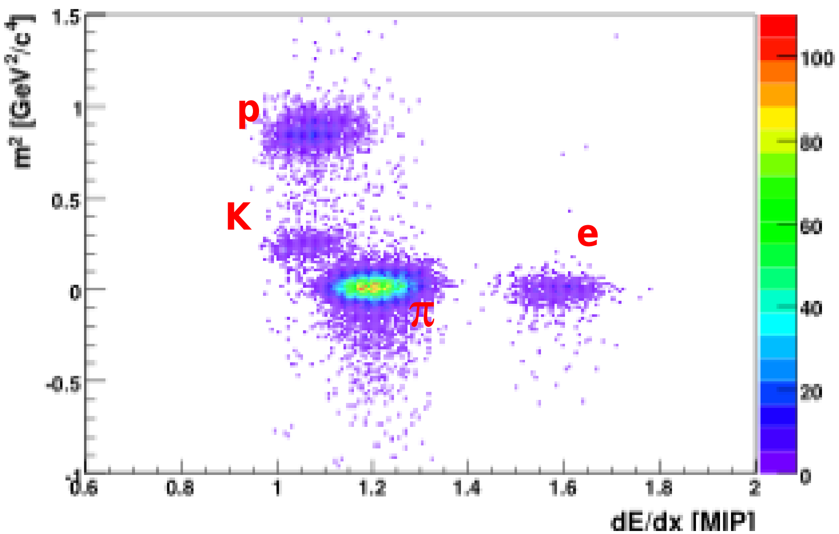
σ(ToF) ≈ 60-120 ps

$\sigma(dE/dx)/\langle dE/dx \rangle \approx 4\%$

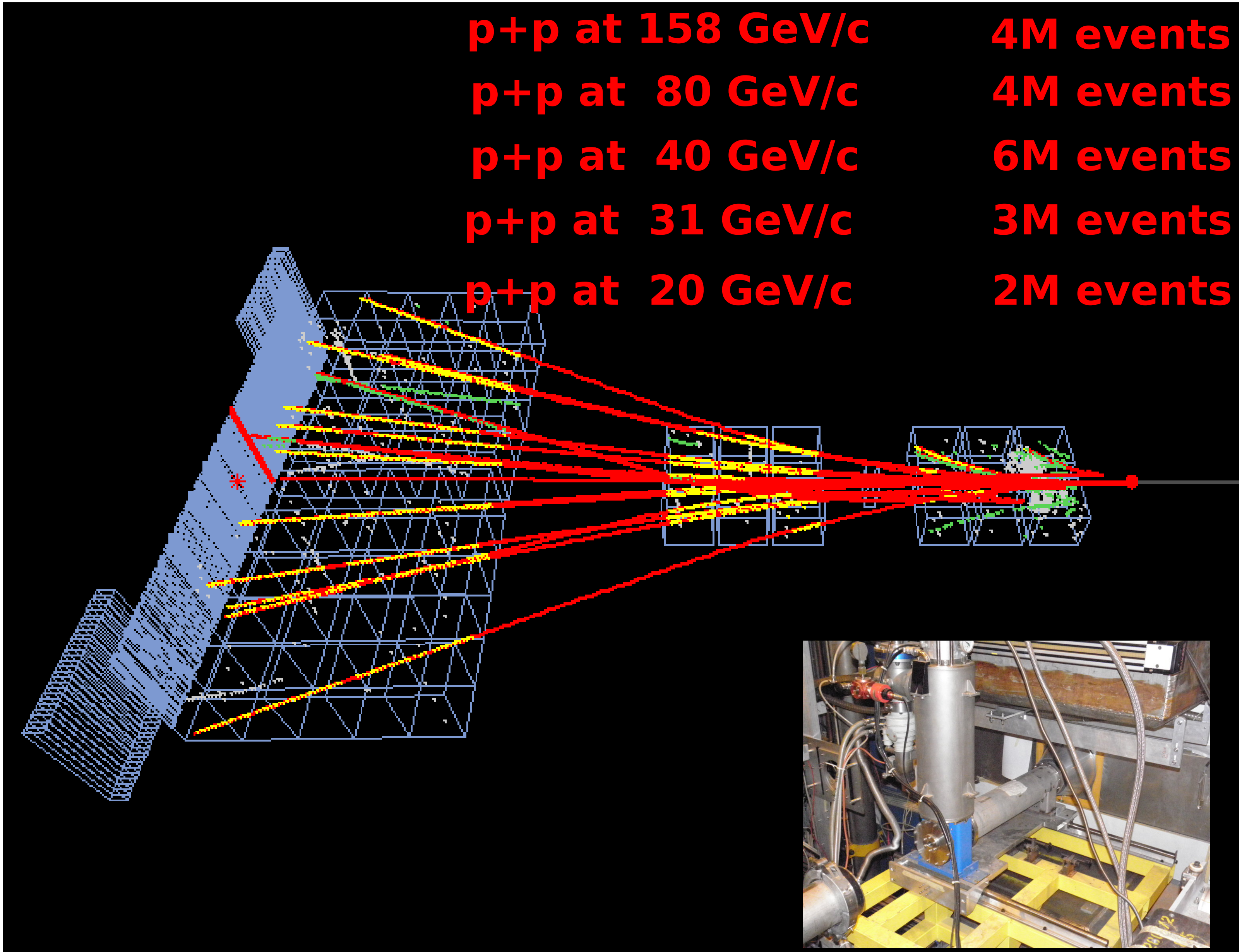
dE/dx – very low and high momenta



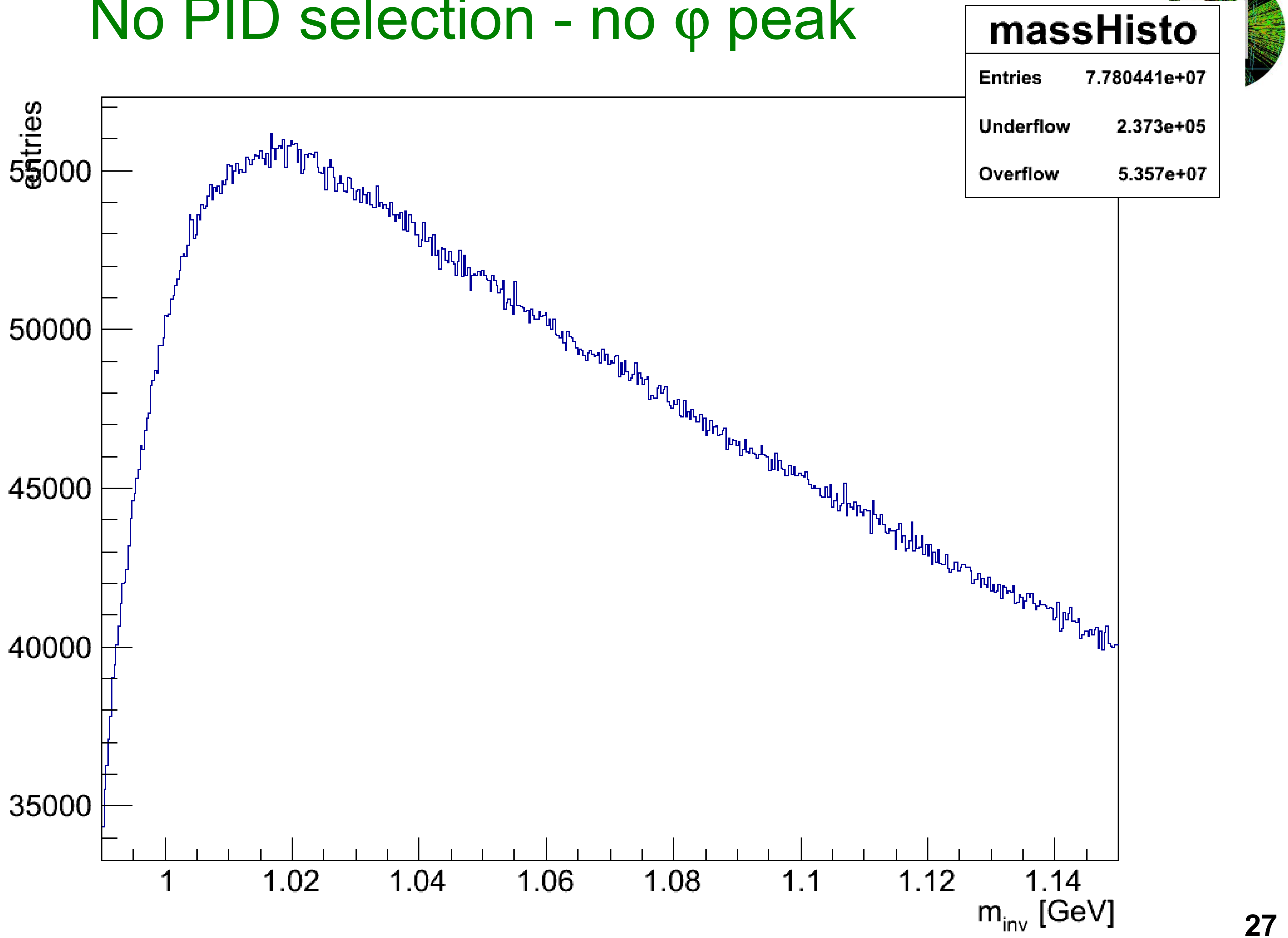
combined ToF and dE/dx – medium momenta



Data collected in 2009 for physics of strongly interacting matter



No PID selection - no φ peak



NA49 results

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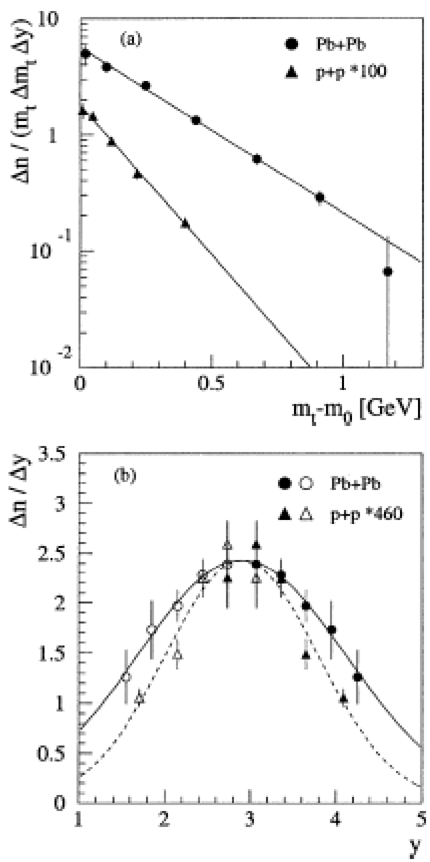

Fig. 2. (a) Transverse-mass distributions of ϕ-mesons (averaged over rapidity) for Pb + Pb ($3.0 < y < 3.8$) and p + p ($2.9 < y < 4.4$). (b) Rapidity distributions of ϕ-mesons for Pb + Pb and p + p. Full symbols represent measured points, open ones are reflected at midrapidity ($y_{cm} = 2.9$).

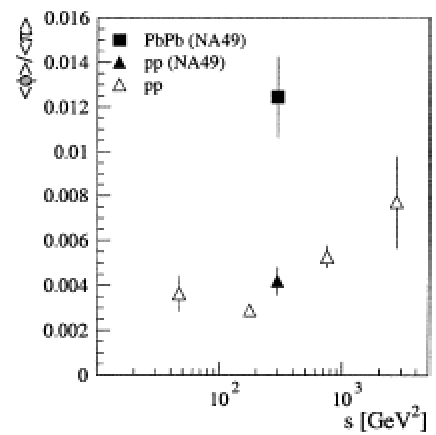

Fig. 3. ϕ/π ratio measured for Pb + Pb in comparison with p + p data (NA49 and previous work [18]) as a function of the square of the center-of-mass energy per nucleon pair. π yields in p + p were taken from [21].

duced particles, e.g., pions and kaons. From a fit with a Gaussian ($dn/dy \propto \exp(-(y - y_{cm})^2/2\sigma_y^2)$) one obtains for the widths $\sigma_y = 0.89 \pm 0.06$ (p + p) and 1.22 ± 0.16 (Pb + Pb). This difference is remarkable in view of the fact that the shape of the distributions of charged pions and kaons is very similar in both reactions (e.g., $\sigma_y(\pi) = 1.5$ [4]).

By integrating the fit functions discussed before over the whole kinematical range one obtains for the total average ϕ-multiplicities

– for p + p (inelastic): $\langle\phi\rangle = 0.012 \pm 0.0015$,
– for Pb + Pb (central): $\langle\phi\rangle = 7.6 \pm 1.1$.

The error estimates include contributions from statis-

NA49 results

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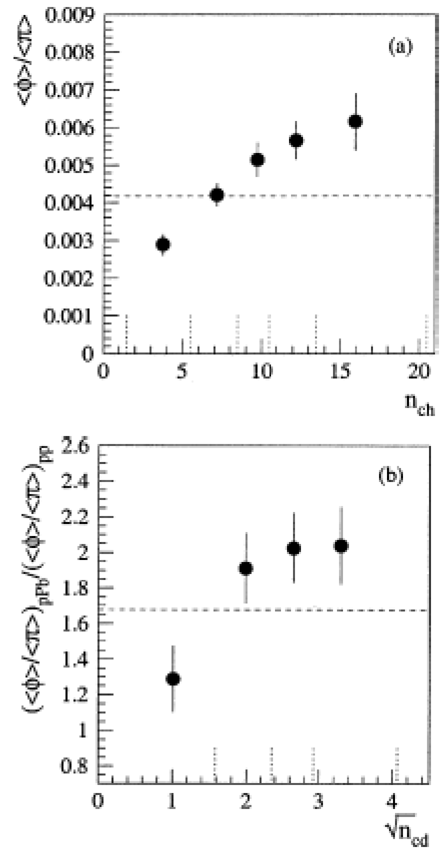

Fig. 4. (a) Multiplicity dependence of the ϕ/π ratio in p + p. The cross-section weighted average is indicated by the horizontal dashed line. (b) Centrality dependence of the ϕ/π ratio in the forward hemisphere in p + Pb normalized to the average p + p value. The minimum-bias value is indicated by the horizontal dashed line. Vertical dashed lines indicate bin sizes in the abscissa.

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Roadmap

1) Binned phase space – preliminary done using 2x1D NA49 binning
2) Event/track selection – preliminary
3) Signal extraction:

   signal & background parametrisation – done
4) correction for PID efficiency of kaons:

   based on knowledge of PID variables distributions or Tag&Probe method – possible innovation with respect to NA49 and current NA61 methods
5) correction for acceptance and decay of kaons:

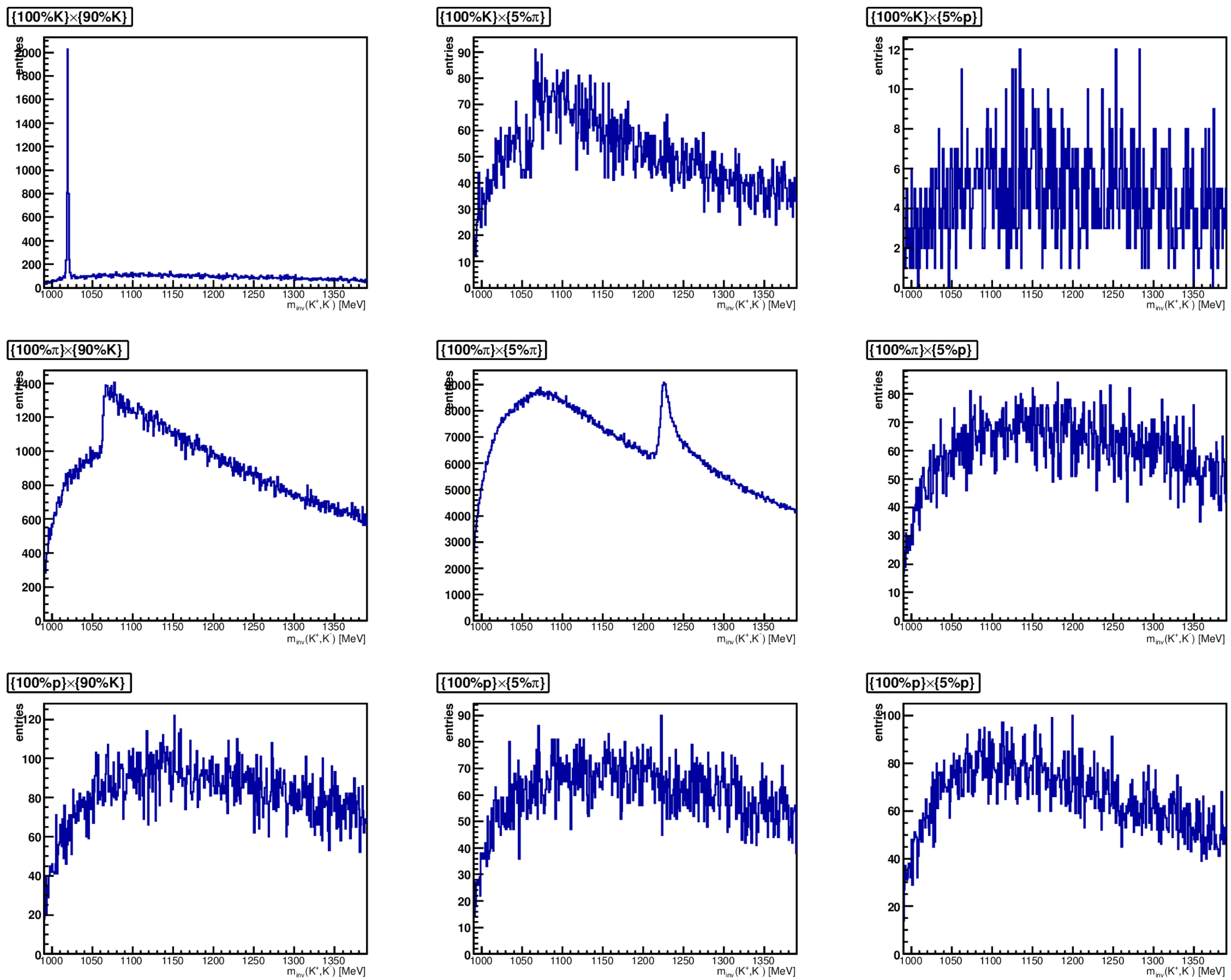
   on flat space MC
6) correction for reconstruction efficiency:

   MC model or embedding, but expected 100% based on NA49 experience
7) correction for EMPTY target contribution
8) correction for trigger bias due to S4 killing good events:

   MC model
9) systematic uncertainties studies
10) optimisations and reiteration

Possible sources of systematic uncertainty

- signal extractions ambiguities:
  - Lorentz: relativistic or not
  - detector resolution: gaus or e.g. crystal ball (probably irrelevant)
  - background: event mixing or analytical
  - fitting range, parameter constraints
- associated with corrections?
- ?


{100%K}×{90%K}
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entries
m_inv(K+,K-) [MeV]