Systematics of reaction plane determination with the MPD experiment.

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Anisotropic transverse flow

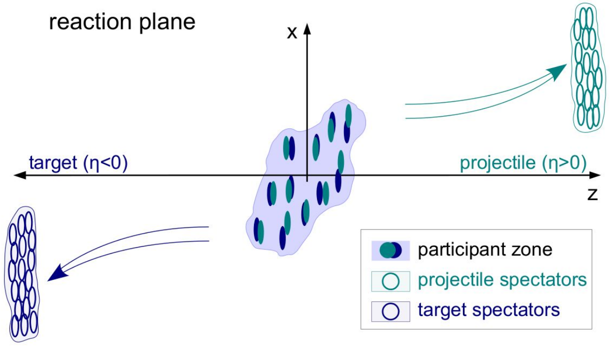
Spatial asymmetry of energy distribution at the initial state is transformed, through the strong interaction, into momentum anisotropy of the produced particles.

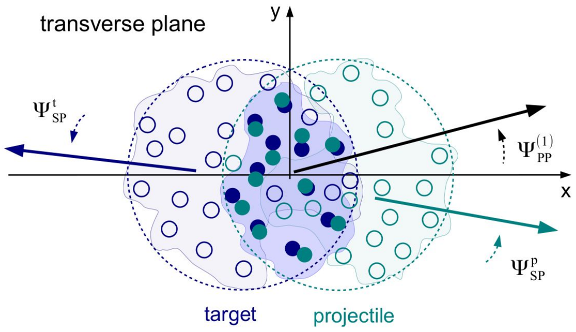
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_{RP}))\right)$$

$$\Downarrow$$

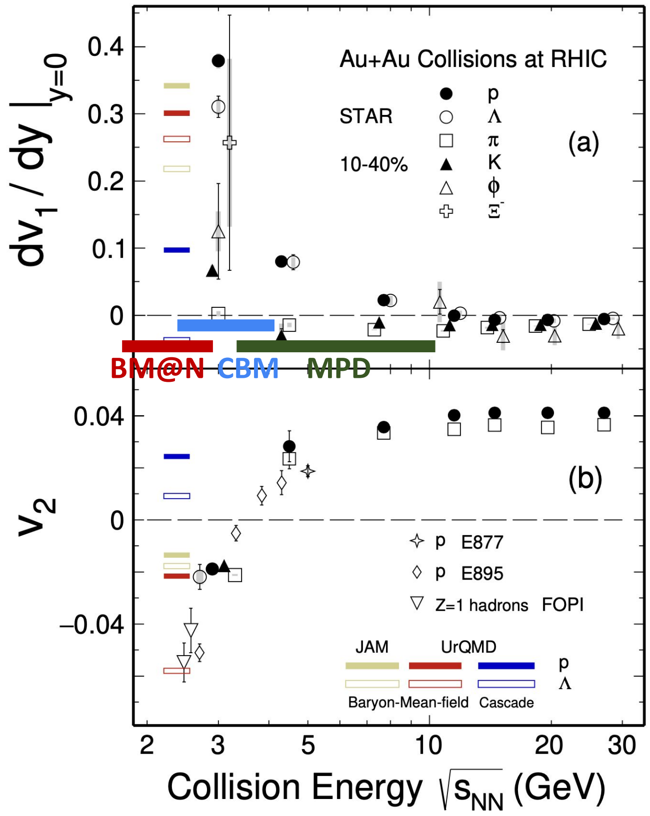
$$v_n = \langle \cos(n(\phi - \Psi_{RP})) \rangle$$

In the experiment reaction plane angle Ψ_{RP} can be approximated by participant Ψ_{PP} or spectator Ψ_{SP} symmetry planes.





Anisotropic transverse flow in heavy-ion collisions at Nuclotron-NICA energies



Strong energy dependence of dv_1/dy and v_2 at $\sqrt{s_{NN}}$ =4-11 GeV.

Anisotropic flow at FAIR/NICA energies is a delicate balance between:

- The ability of pressure developed early in the reaction zone and
- Long passage time (strong shadowing by spectators).

Differential flow measurements $v_n(\sqrt{s_{NN}}$, centrality, pid, p_T, $y)$ will help to study:

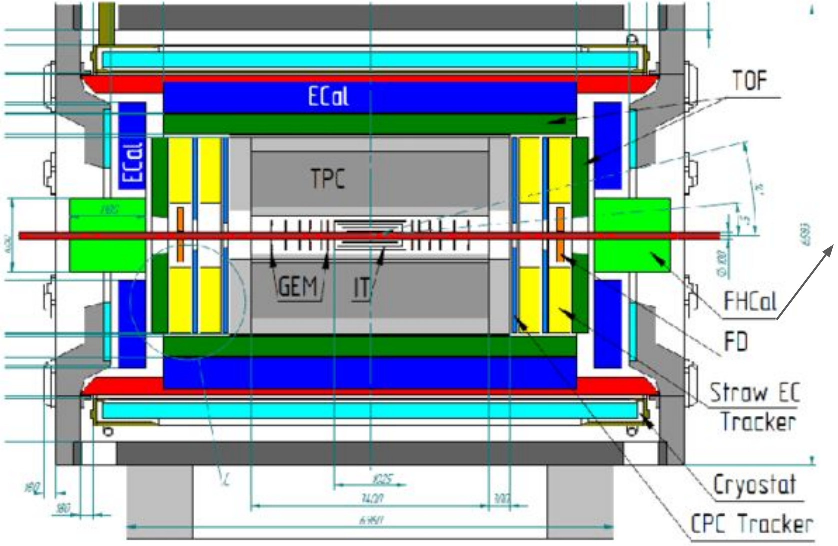
- effects of collective (radial) expansion on anisotropic flow
- interaction between collision spectators and produced matter
- baryon number transport

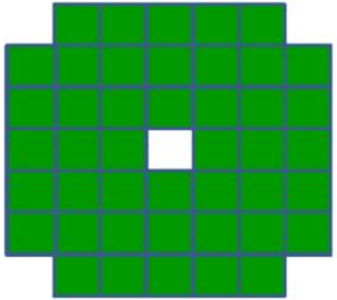
Several experiments (MPD, BM@N, STAR FXT, CBM, HADES, NA61/SHINE) aim to study properties of the strongly-interacted matter in this energy region.

M. Abdallah et al. [STAR Collaboration] 2108.00908 [nucl-ex]

MPD experiment

- 4π spectrometer designed to work at high luminosity in the energy range of the NICA collider (4-11 GeV)
- Capable of detecting of charged hadrons, electrons and photons.
- Precise 3-D tracking system and a high-performance particle identification system based on the time-of-flight measurements and calorimetry.
- Two hadron calorimeters (FHCal) allow for reconstruction of projectile and target spectator symmetry planes.





FHCal (transverse plane)

Dataset

- DCM-QGSM-SMM model (realistic yields of spectator fragments for symmetry plane reconstruction)
- Bi-Bi @ 9.2 GeV, 4M events
- Geant4 transport (important for proper simulation of hadronic showers)
- Simulation and reconstruction within MpdRoot environment

Analysis description

- Centrality based on multiplicity of reconstructed tracks
- Event selection
  - Successfully reconstructed primary vertex position
- Track selection
  - |DCA|<0.5
  - number of hits in TPC >16
  - track matched to TOF hit
- Particle identification
  - PDG of matched Monte Carlo track

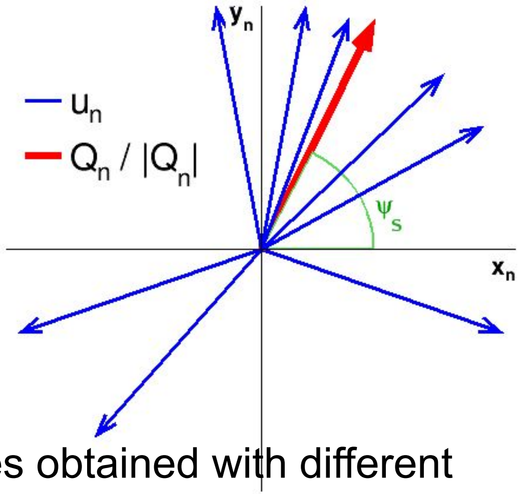
Scalar product method for v_n measurement

$\mathbf{u}$ and $\mathbf{Q}$-vectors:

$$\mathbf{u_n} = \{u_{n,x}, u_{n,y}\} = \{\cos n\phi, \sin n\phi\}$$

$$\mathbf{Q_n} = \{Q_{n,x}, Q_{n,y}\} = \frac{1}{\sum\limits_k w^k}\left\{\sum_k w^k u^k_{n,x}, \sum_k w^k u^k_{n,y}\right\}$$

Here w^k is energy in k-th module of FHCal.



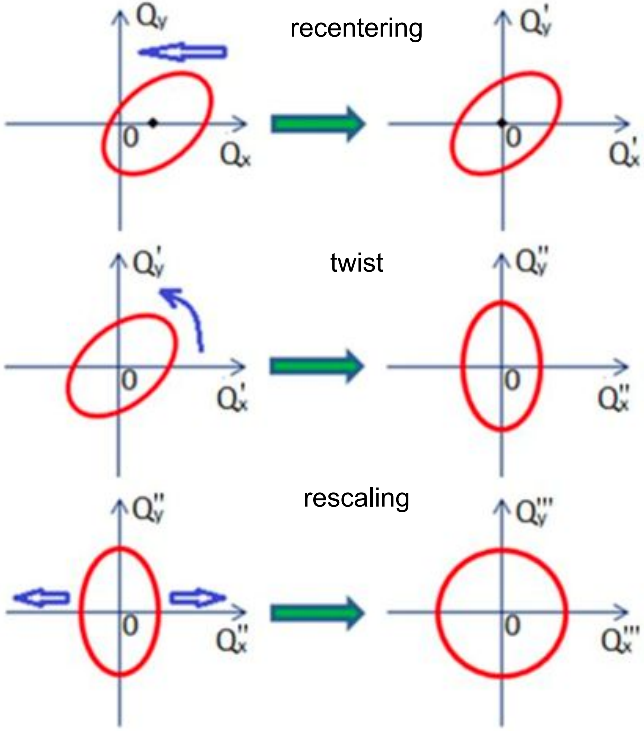
Scalar product method gives independent estimates for flow values obtained with different Q-vector components and symmetry plane sources.

v_1 with respect to symmetry plane Ψ_S is calculated using group of particles (modules) "*a*":

$$v^a_{1,i}(p_T, y) = \frac{2\langle u_{1,i}(p_T, y) Q^a_{1,i}\rangle}{R^a_{1,i}}, \ i = x, y.$$

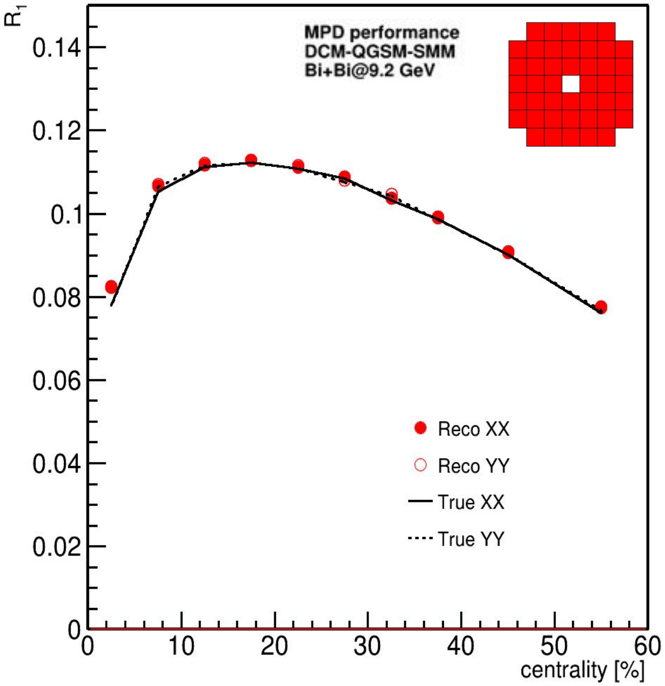
$R^a_{1,i}$ is a 1st order event plane resolution correction (details in the following slides)

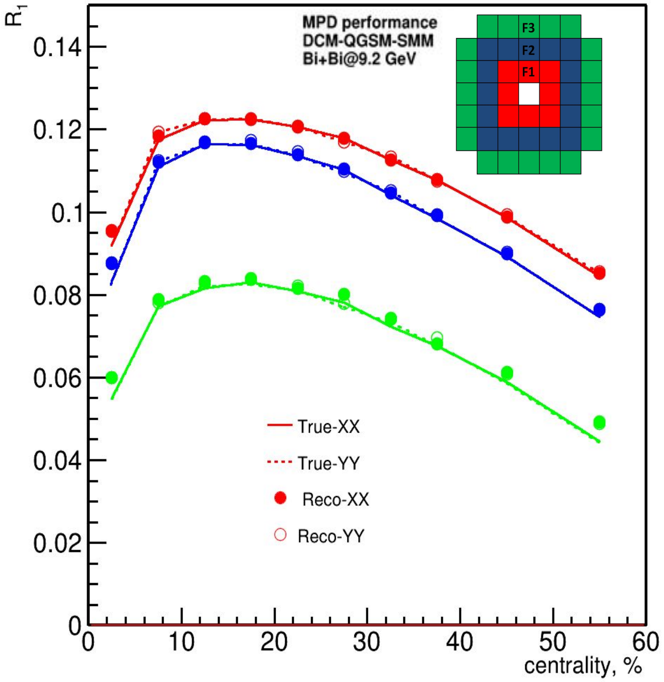
Corrections for azimuthal acceptance non-uniformity



- Non-uniformity of azimuthal acceptance may introduce substantial bias on the flow measurement results.
- Data-driven differential (centrality, primary vertex position, particle type or kinematics, etc.) corrections were applied for *u* and *Q*-vectors:
  - recentering
  - twist
  - rescaling.
- Implemented in QnTools framework (along with multidifferential Q-vector correlations and tools for correlation arithmetics and error propagation). https://github.com/HeavyIonAnalysis/QnTools

Reconstructed resolution correction (2-subevent method)





$$R_{1,i} = \sqrt{\langle Q_{1,i}^{N} Q_{1,i}^{S} \rangle}, i = x, y$$

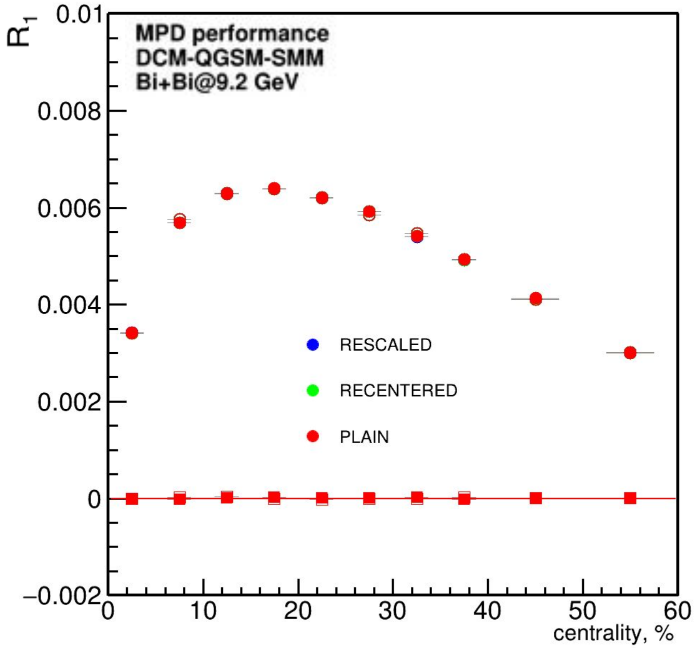
N - northern FHCal
S - southern FHCal

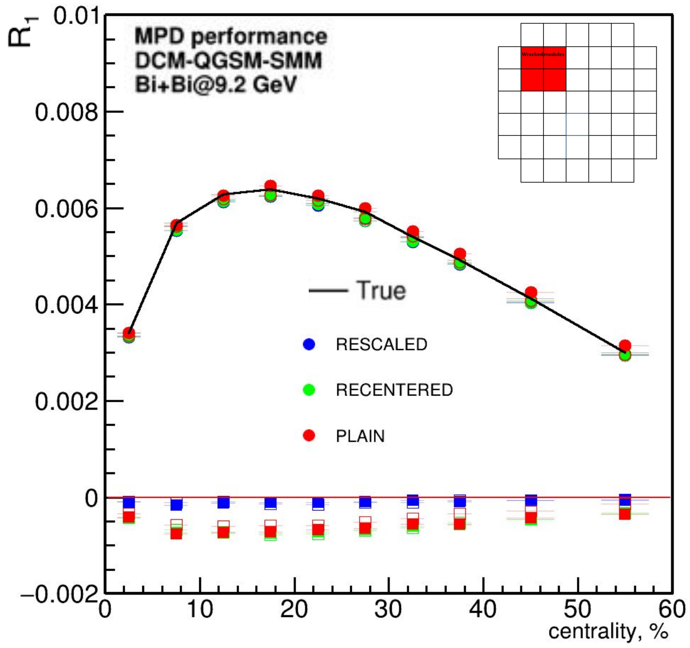
$$R_{1,x}^{True} = \langle Q_{1,x} \cos \Psi_{RP} \rangle$$

$$R_{1,y}^{True} = \langle Q_{1,y} \sin \Psi_{RP} \rangle$$

- Good agreement with true resolution for the full FHCal and separate module rings except for most central events (minimal anisotropy of nuclei overlap area).
- Consistent results for X and Y components - only combined values on further slides.

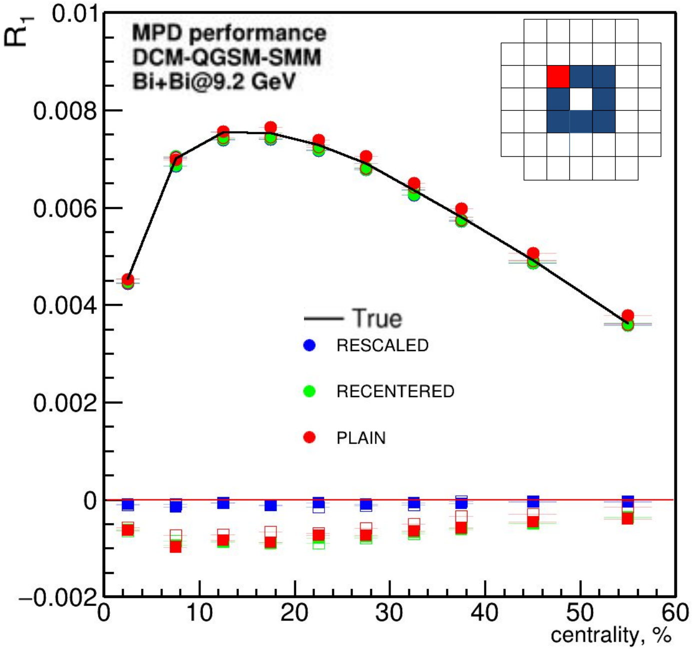
Effect of acceptance corrections on full FHCal resolution

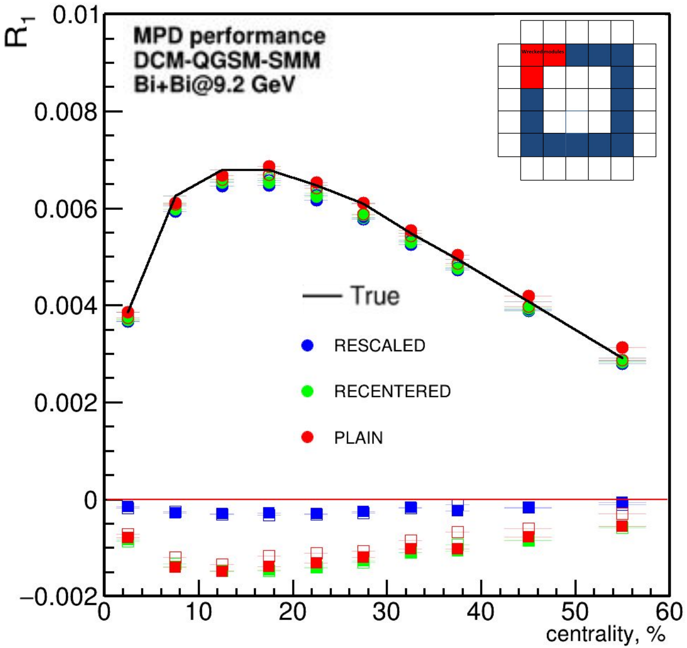




- No effect in case of fully functional detector
- Rescaling minimizes the effect of failing modules (marked red) on the symmetry plane estimate

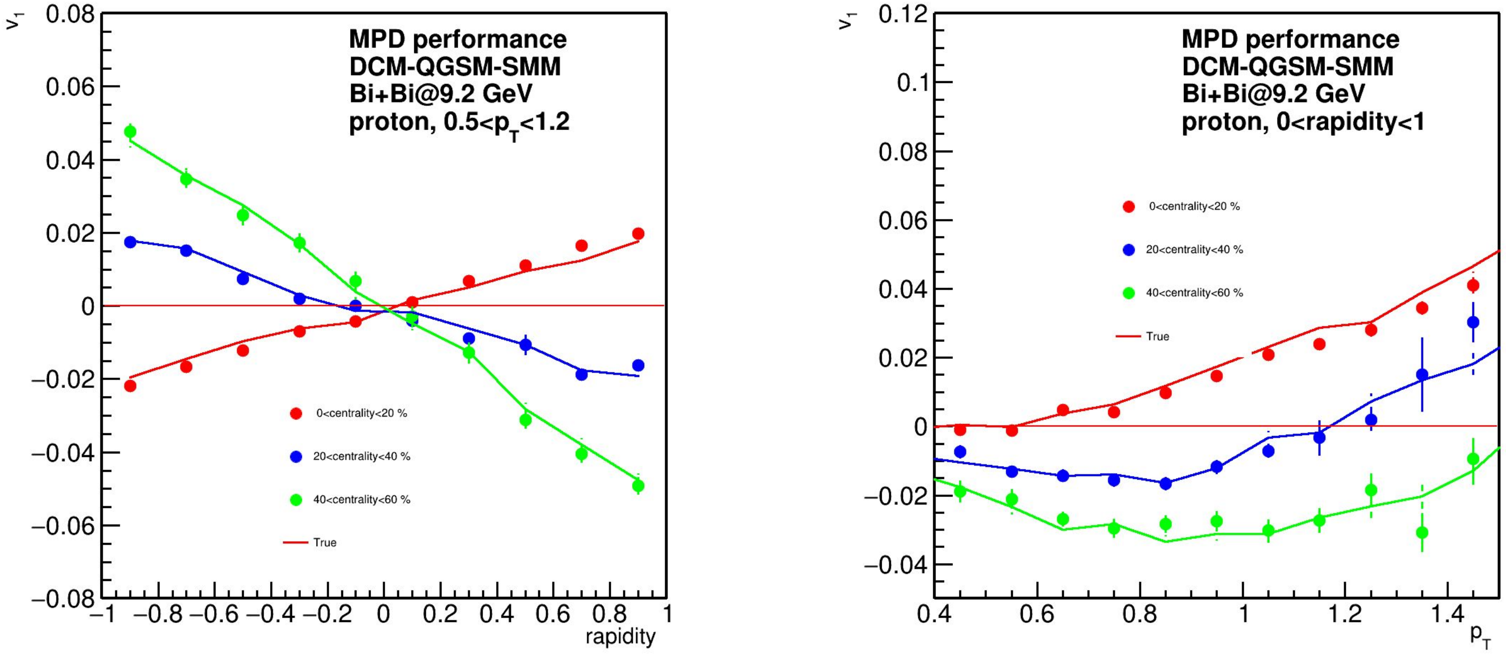
Effect of acceptance corrections on FHCal rings resolution





Rescaling minimizes the effect of failing modules (marked red)
on the symmetry plane estimates from module rings

Proton directed flow relative to spectator symmetry plane



v_1 dependences calculated relative to spectator symmetry plane are in good agreement with those from the event generator.

Summary

- Good agreement of reconstructed and true resolution for the full FHCal and separate module rings except for most central events with 2 subevent method.
- Consistent resolution values obtained with X and Y components of Q-vectors.
- Corrections for non-uniform acceptance can minimize the effect of failing FHCal modules.
- p_T and rapidity dependences of directed flow calculated relative to spectator symmetry plane are in good agreement with values from the event generator.

Outlook:

- Systematics of flow measurements relative to different spectator symmetry plane estimates (FHCal module groups) and participant plane