ASSCA2018 detector magnet homework and answer

1. Please list the basic configurations can be considered for detector magnets and their Attributes; the equation of the momentum resolution (δp/p) in one configuration.

Answer:

Basically three configurations can be considered for detector magnets, namely solenoids, toroids and dipoles.

1. *Solenoids*

Solenoids are conceptually simple, elegant and very effective. The vast majority of recent detectors at colliders have relied on solenoidal type magnets, producing a cylindrically symmetric field having the same axis as the colliding beams.

The length of the trajectory of a charged particle emanating at zenithal angle (i.e. the angle between the trajectory and the axis) θ from an interaction on the axis of a long solenoid of radius *R* producing a magnetic field *B,* is *.* The component of field perpendicular to the trajectory is *.* The change of angle*,* δθ*solenoid* , and the sagitta, *ssolenoid* of the trajectory are therefore

The “analyzing power” depends on the layout of the detector and is obtained by some combination of measurements of sagitta and changes in angle. In fact in a solenoid the momentum is usually analyzed by measuring tracks inside the magnet, and the momentum resolution (δp/p)solenoid scales as follows:

1. *Toroids*

In theory a toroidal magnetic field is ideal, both for a detector at a colliding beam facility and for forward and fixed target detectors. The field is symmetric and perpendicular to the particle motion. There is no field along the axis of the beams.

For an ideal toroid contained between current sheets at radii *Ri (inner)* and *Ro* (outer) and with field *Bi* at the inside radius, the deflection, and the sagittaof the trajectory within the field.

1. *Dipoles*

While dipoles are not appropriate for the central part of 4π detectors, they are the magnets of choice for dedicated “forward” detectors that concentrate on the cone of particles emanating in the forward direction, up to θ~300 mrad, as well as for fixed target detectors.

The momentum resolution of a dipole with field B and length L is of course simply

*(*δ*p/p)dipole ~ p/BL*

1. Please list technological aspects of detector magnet; write down the main problems that we have to consider for the boundary conditions.
2. *The requirement*

It is again stressed just how important it is to clearly establish what is required by the experiment. In order to iterate to a reliable magnet design that is matched to the rest of the experiment this can involve a lot of discussion. Cost and timescale must also be included right from the start.

1. *Operating conditions*

It is important to be fully aware of the conditions under which the magnet is expected to operate, as this can have a profound effect on how to go about its design. The vast majority of detector magnets operate in a quasi-DC fashion, for example, and their design can be simplified accordingly. Other important parameters are whether or not the field should be reversible, the expected length of runs, the expected number of hours of operation per year, and the expected lifetime of the magnet.

1. *Cooling supply*

What means are there available for cooling the magnet? Is there a refrigerator, and if so what capacity will be available for servicing the new magnet? Would it be expected to cool from dewars? Is a cryocooler an option to consider?

1. *Conductor*

Detector magnets rely on multifilamentary superconducting material that is in good electrical and thermal contact with a normal conductor of sufficient cross section to bypass the current due to a microscopic perturbation, to allow the affected superconductor to regain its superconducting state or to buy time for the quench protection circuitry to do its job. This stabilizing material is a pure metal with low electrical resistivity and high residual resistivity ratio (RRR). The magneto-resistance of the material must also be taken into account.

1. *Protection*

The cross-section of high purity aluminium required for quench protection is given by the adiabatic criterion

 *(13), where*

and *J* is the current density in the stabilizer, *I* is the operating current, *V* is the protection voltage, *E* is the stored energy, *Cp* is the specific heat of the conductor, ρ*(*Θ*)* is its resistivity and Θ*max* is the peak temperature during a quench. The adiabatic criterion assumes no heat conduction from the conductor hot spot and is therefore very conservative. The conductor typically works with a temperature margin of 1 - 3 degrees. The coils are secured against movement by impregnation. Quenches should not happen. If they do occur, due for example to energy release in cracking epoxy or a deficiency in the insulation creating a warm spot, then the design must be such as to quickly spread the heating by inducing a general quench and/or dump the stored energy in an external resistor. In this way the temperature rises uniformly throughout the coil, and the maximum temperature in the coil can be limited to less than 80 K, say, by a judicious combination of i) Extracting the stored energy. ii) Firing quench heaters. iii) Quench back. iv) Incorporating pure aluminium heat shunting sheets. The final choice of the conductor is made following detailed calculation of all possible scenarios in the environment of the magnet, including effects such as friction and work of fracture, which can lead to energy releases in the coil. To give an order of magnitude, in recent magnets the stability margin for a sudden release of energy is a few joules, down from about 10 J in the case of the LEP solenoids. The ratio of the stored energy, *E*, to the mass, *M*, of the winding, called the *E/M* ratio, is a convenient parameter for indicating the “safety” of the design and the attention which has to be paid to quench protection. Based on the results of refined calculation and validating testing, this ratio is being gradually pushed from the range 3 – 5 in past designs to around 10 and more in the most audacious designs today.

1. *Model and prototype work*

There is usually just one opportunity to build the complete magnet, and model and prototype work is limited to validation of choices of design concepts and components. It is vitally important to include this essential activity into the general plan. The well being of the whole experiment depends on the successful and timely completion of the magnet, so it is customary to request that the results of the model work be exposed to critical review.

1. *Reliability*

Because of the one-off nature of these magnets, large safety factors are usually applied and the construction is followed up with great attention. Any failure risks to be a catastrophic failure, and it will put in jeopardy the whole experiment. These superconducting magnets do however have a history of very good reliability.

1. *Size*

Bigger may be better for momentum resolution, but watch out for threshold sizes that lead to a jump in cost. An example of this is the supplementary civil engineering work that may be required to house the magnet. Another limitation is that imposed by transport. Beyond 6 - 7 m in diameter implies insitu winding.